ECT*

Annual Report 2017

European Centre for Theoretical Studies in Nuclear Physics and Related Areas
Trento

Institutional Member of the European Science Foundation Expert Committee NuPECC

Edited by
Barbara Currò Dossi and Susan Driessen

1 Preface

The European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) is one of the Research Centres of the Fondazione Bruno Kessler (FBK) and an Institutional Member of the European Expert Committee NuPECC (Nuclear Physics European Collaboration Committee). Its objectives – as stipulated in its statutes – are:

- to provide for in-depth research at the forefront of contemporary developments in nuclear physics;
- to foster interdisciplinary contacts between nuclear physics and neighbouring fields such as computational physics, astrophysics, condensed matter physics, particle physics and the quantum physics of small systems;
- to encourage talented young physicists to participate in the activities of the ECT*;
- to strengthen the interaction between theoretical and experimental nuclear physics and related areas.

Altogether 674 scientists from 38 countries have visited the ECT* in 2017 and have participated in the activities of the Centre. As in previous years this reconfirms ECT*'s worldwide visibility and its key importance for the European and international nuclear physics communities.

In 2017 ECT* held:

- 20 Workshops on recent developments in nuclear- and hadronic physics from the lowest to the highest energies, nuclear astrophysics, topics in QCD, quantum many-body systems and related areas in condensed matter and atomic physics.

- a Doctoral Training Programme on "Microscopic Theories of Nuclear Structure, Dynamics and Electroweak Currents" that lasted three weeks and was attended by 25 students from 11 countries worldwide.

- a Training in Advanced Low Energy Nuclear Theory (TALENT) on "Theory for Exploring Nuclear Structure Experiments" that lasted three weeks and was attended by 31 students from 14 countries worldwide.

In addition to these 22 scientific events, ECT* supported:

- basic research on nuclear structure and reactions, non-perturbative QCD and hadron physics, the theory of hadronic and nuclear collisions at high energy, phases of strong- interaction matter, nuclear astrophysics and neutron stars, many-body theory and computational physics. This research was performed by the in-house group of Junior Postdoctoral Fellows and Senior Research Associates in close interaction with each other, with the Director of the Centre, and with scientific visitors and collaborating physicists elsewhere. The research activities of the Centre are documented in detail in Chapters 4 and 5 of this Annual Report. Altogether, 49 publications by the ECT* and ECT*-LISC researchers in refereed journals represent a sizable fraction of all publications produced in 2017 within the Fondazione Bruno Kessler in the same year.
- In addition to the previously established international cooperation agreements with major research institutions in Japan (RIKEN Nishina Centre, the Advanced Science Research Center ASRC of JAEA and NAOJ, the National Astronomical Observatory), Korea (the Asian Pacific Centre for Theoretical Physics, APCTP), China (the ITP of the Chinese Academy of Sciences), and Russia (JINR in Dubna, the Joint Institute for

Nuclear Research), ECT* signed in 2017 a protocol of agreement with JINR, Dubna for a financial contribution towards ECT*.

These initiatives have created joint activities in the workshop program of ECT* and have contributed further to the highly visible international profile of the Centre.

The existence and the continuing success of ECT* rests upon the “bottom-up” initiatives, pursued by the physics communities in Europe and worldwide. Maintaining ECT*´s high level of scientific activity and visibility in 2017 has only been possible through a stable operating budget in recent years. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research institutions in Belgium, Finland, France, Germany, Hungary, Italy, the Netherlands, Romania, Russia and the United Kingdom. ECT* also acknowledges additional partial support for its workshops, received in 2017 from EMMI (Germany), Temple University (USA), JLAB (USA), CEA Saclay (France), HITS-Heidelberg Institute for Theoretical Studies (Germany), Cardiff University (UK), George Washington University (USA), Chalmers University of Technology (Sweden), Justus-Liebig-Universität Gießen (Germany), Goethe Universität Frankfurt (Germany), INFN LNF (Italy), University of Illinois (USA), Brookhaven National Laboratory (USA), University of York (UK), and INFN (Italy). To ensure access to High-Performance-Computing resources for the ECT* researchers the Forschungszentrum Jülich (Germany) has granted funds for a sizable amount of time on the JUQUEEN supercomputer. The allocated computer time will be available until the end of March 2018.

As for the European projects within the new Framework Programme Horizon 2020, the ENSAR2 project has started on March 1, 2016 and will run for four years. Its transnational access activities have partially supported 8 workshops in 2017 that were selected by the Director in accordance with the International Scientific Committee.

Finally, it is a great pleasure to thank the members of the Scientific Board, the organizer of the Doctoral Training Programme Omar Benhar and the coordinator Georges Ripka, the organizers of the TALENT School, Alex Brown and Morten Hjorth-Jensen, the scientific staff and – last but not least – the highly competent administrative and technical staff of the ECT* for their dedicated cooperation.

As its predecessors the Annual Report of 2017 is available on the ECT* website (www.ectstar.eu).

Trento, March 2018

Jochen Wambach
*Director of ECT**

Contents

2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Scientific Board

Gert Aarts	Swansea University, UK
Omar Benhar	INFN/Università "La Sapienza", Rome, Italy
Angela Bracco	NuPECC/University of Milano, Italy
Nicole d'Hose	CEA Saclay, France
Paul-Henri Heenen (until June)	Université Libre de Bruxelles, Belgium
Morton Hjorth-Jensen (from October)	Michigan State Univ., USA and Univ. of Oslo, Norway
Piet Mulders (until June)	VU Amsterdam, Netherlands
Sanjay Reddy	University of Washington, Seattle, USA
Dirk Rischke	Johann Wolfgang Goethe-Universität, Frankfurt, Germany
Marc Vanderhaeghen	University of Mainz, Germany
Ubirajara van Kolck	IPN Orsay, France
Marc Vanderhaeghen (from October)	University of Mainz, Germany

Honorary Member of the Board

Ben Mottelson — NORDITA, Copenhagen, Denmark

ECT* Director

Jochen Wambach — ECT*, Italy and TU Darmstadt, Germany

2.2 ECT* Staff

Serena degli Avancini	Technical Programme Co-ordinator
Ines Campo (part time)	Technical Programme Co-ordinator
Barbara Curro' Dossi	Systems Manager
Susan Driessen (part time)	Assistant to the Director
Christian Fossi (from June)	Technical Programme Co-ordinator and Web Manager
Gian Maria Ziglio (until April)	Technical Programme Co-ordinator and Web Manager

2.3 Resident Researchers

- **ECT* Junior Postdocs and Senior Researchers**

Guillaume Beuf, France (until September)
Daniele Binosi, Italy
Arianna Carbone, Italy (from October)
Jesus Casal Berbel, Spain
Maria Gomez Rocha, Spain
Chen Ji, China
Naoto Tanji, Japan (from September)
Ralf-Arno Tripolt, Austria
Dionysis Triantafyllopoulos, Greece

- **ECT*/LISC PhD Students and Senior Researchers**

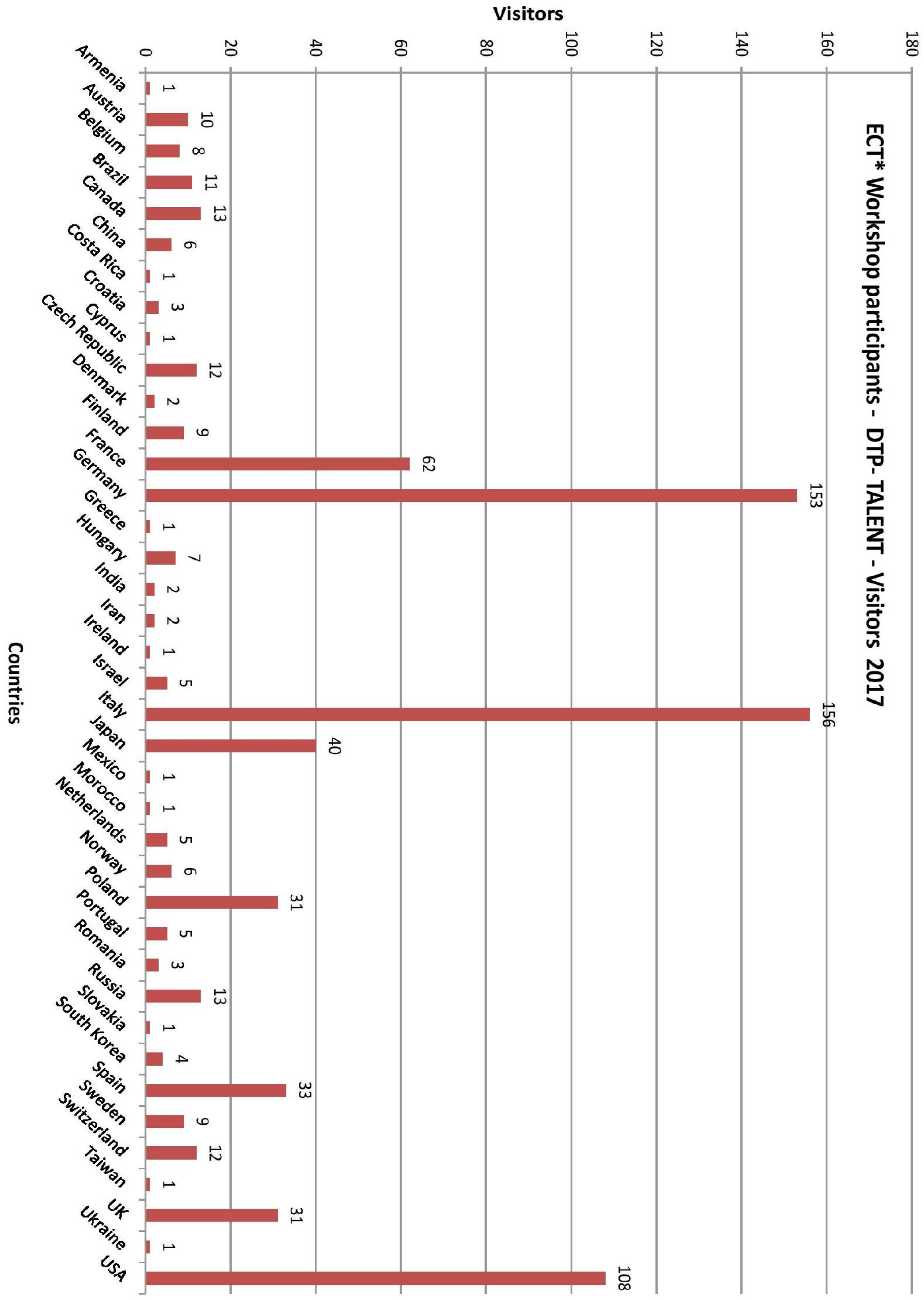
Martina Azzolini
Maurizio Dapor (Head of ECT*-LISC Research Unit),
Giovanni Garberoglio
Andrea Pedrielli
Tommaso Morresi
Simone Taioli

2.4 Visitors in 2017

This list includes Visiting Scientists (VS) who typically spent from a few days up to several weeks at the Centre, as well as participants and lecturers of the Doctoral Training Programme (DTP) and the TALENT School (TS).

Isabel Abril Sanchez (27/05-13/06) Universitat d'Alacant, Spain (VS)
Gilho Ahn (02-22/07) National and Kapodistrian University of Athens, Greece (TS)
Karl Martin Albertsson (11/06-22/07) Lund University, Sweden (DTP/TS)
Paolo Andreatta (03-21/07) Università degli Studi di Trento, Italy (TS)
Artur Marek Ankowski (19-30/06) Virginia Tech, USA (DTP)
Pierre Noel Arthuis (11/06-01/07) CEA Saclay, France (DTP)
Pawel Baczyk (11/06-01/07) University of Warsaw, Poland (DTP)
Carlo Barbieri (21/06-01/07) University of Surrey, UK (DTP)
Tobias Beck (01-22/07) TU Darmstadt, Germany (TS)
Stefano Bellucci (28/07-11/08) INFN-LNF, Italy (VS)
Omar Benhar Noccioli (11-30/06) INFN Roma, Italy (DTP)
Ina Kristine Berentsen Kullmann (02-23/07) University of Oslo, Norway (TS)
Jean-Paul Blaizot (22/06-08/07) CEA Saclay, France (VS)
Antoine Maurice André Boulet (11-30/06) IPN Orsay, France (DTP)
Alexander Brown (03-21/07) Michigan State University, USA (TS)
Gianluca Colo' (19-25/02) Universty and INFN Milano, Italy (VS)
Lorenzo Contessi (12-30/06) Università degli Studi di Trento, Italy (DTP)
Lucia Crespo Campo (02-23/07) University of Oslo, Norway (TS)
Tor Djärv (02-22/07) Chalmers University of Technology, Sweden (TS)
Mehdi Yoan Ismael Drissi (11/06-01/07) CEA Saclay, France (DTP)
Monia El Barbari (11/06-01/07) University Abdelmalek Essaadi, Morocco (DTP)
Evgeny Valer'evic Epelbaum (14-17/06) Ruhr-Universität Bochum, Germany (DTP)
Dag Isak August Fahlin Stromberg (11/06-01/07) TU Darmstadt, Germany (DTP)
Patrick Fasano (02-22/07) University of Notre Dame, USA (TS)
Anne Forney (02-22/07) University of Maryland College Park, USA (TS)
Alexandra Gade (09-15/07) Michigan State University, USA (TS)
Stefano Gandolfi (18-30/06) Los Alamos national Laboratory, USA (TS)
Fei Gao (11/09-10/10) Peking University, Cina (VS)
Rafael Garcia-Molina (27/05-13/06) Murcia University, Spain (VS)
Noam Gavrielov (02-22/07) The Hebrew University, Israel (TS)
Udo Gayer (02-21/07) TU Darmstadt, Germany (TS)
Rosa-Belle Gerst (01-22/07) Universität zu Köln, Germany (TS)
Luca Girlanda (11-15/06) Università del Salento, Lecce, Italy (DTP)
Stanislaw Glazek (26/02-04/03) University of Warsaw, Poland (VS)
Alex Gnech (11-30/06) Gran Sasso Science Institute, Italy (DTP)
Erin Good (02-23/07) Louisiana State University, USA (TS)
Robert Grzywacz (09-16/07) Univ. of Tennessee and Oak Ridge Nat. Laboratory, USA (TS)
Guillaume Häfner (02-22/07) Universität zu Köln, Germany (TS)
Tiia Kristiina Haverinen (11/06-22/07) University of Jyväskylä, Finland (DTP/TS)
Morten Hjorth-Jensen (03-21/07) Univ. of Oslo, Norway and Michigan State Univ. USA (TS)
Ashley Hood (02-23/07) Louisiana State University, USA (TS)
Paul Hoyer (08-15/04, 10-18/11) University of Helsinki, Finland (VS)
Thomas Huether (11/06-01/07) TU Darmstadt, Germany (DTP)
Gustav Ragnar Jansen (04-14/07) Oak Ridge National Laboratory, USA (TS)
Christopher Jung (24-29/09) Justus-Liebig-Universitaet, Giessen, Germany (VS)
Maciej Konieczka (11/06-01/07) University of Warsaw, Poland (DTP)
Agota Koszorus (02-22/07) Inst. for Nuclear and Radiation Physics, KU Leuven, Belgium (TS)
Alessandro Lovato (19-23/06) TIFPA INFN Trento, Italy (DTP)
Antonio Márquez Romero (02-21/07) University of York, UK (TS)
Christopher Stuart Mcilroy (10/06-01/07) University of Surrey, UK (DTP)
Laura Kristina Mertes (11/06-01/07) TU Darmstadt, Germany (DTP)

Sean Miller (02-23/07)	University of Oslo, Norway (TS)
David Miur (02-22/07)	University of York, UK (TS)
Xavier Mougeot (19-21/07)	CEA Saclay, France (VS)
Ovidiu Vasile Nițescu (02-22/07)	Horia Hulubei National Institute, Romania (TS)
Takaharu Otsuka (09-13/07)	University of Tokyo, Japan (TS)
Vishvas Pandey (10/06-02/07)	Virginia Tech, USA (DTP)
Giovanni Pederiva (03-21/07)	University of Oslo, Norway (TS)
Liqiang Qi (02-22/07)	IPN Orsay, France (TS)
Andrea Quadri (28/05-01/06)	University of Milano (VS)
Vahedeh Razazi (03-22/07)	Urmia University of Technology, Iran (TS)
Achim Richter (15/07-04/08)	TU Darmstadt, Germany (VS)
Georges Ripka (19-25/02)	CEA Saclay, France (VS)
Julien Ripoche (11-30/06)	CEA/DAM Ile-de-France, France (DTP)
Luca Riz (12/06-21/07)	Università degli Studi di Trento, Italy (DTP/TS)
Noemi Rocco (12-30/06)	University of Surrey, UK (DTP)
Robert Heinz Roth (18-23/06)	TU Darmstadt, Germany (DTP)
Hideyuki Sakai (19-25/02)	RIKEN, Japan (VS)
Alessandro Saltarelli (19-21/07)	University of Camerino, Italy (VS)
Gianluca Salvioni (02-22/07)	University of Jyväskylä, Finland (TS)
Masaki Sasano (19-25/02)	RIKEN, Japan (VS)
Archana Saxena (10/06-01/07)	Indian Institute of Technology Roorkee, India (DTP)
Rodric Bernard J. Seutin (11/06-01/07)	TU Darmstadt, Germany (DTP)
Matthew Shelley (02-22/07)	University of York, UK (TS)
Stefano Simonucci (17-21/07)	University of Camerino, Italy (VS)
Joanna Ewa Sobczyk (10/06-01/07)	University of Wroclaw, Poland (DTP)
Enrico Speranza (26/06-01/07)	GSI and TU Darmstadt, Germany (DTP)
Hans Spielvogel (11-30/06)	TU Darmstadt, Germany (DTP)
Azar Tafrihi (11/06-02/07)	Isfahan University of Technology, Iran (DTP)
Masaaki Tokieda (02-21/07)	Tohoku University, Japan (TS)
Oliver Vasseur (02-23/07)	IPN Orsay, France (TS)
Mathias Mamen Vege (02-22/07)	University of Oslo, Norway (TS)
Michele Viviani (11-16/06)	INFN Pisa, Italy (DTP)
Lorenz von Smekal (24-29/09)	Justus-Liebig-Universitaet, Giessen, Germany (VS)
Shane Wilkins (02-22/07)	University of Manchester, UK (TS)
Anna Maria Zdeb (11/06-01/07)	Maria Curie-Skłodowska University, Poland (DTP)


ECT* Workshop participants - DTP- TALENT - Visitors 2017
Visitors
Countries
0
20
40
60
80
100
120
140
160
180
Armenia 1
Austria 10
Belgium 8
Brazil 11
Canada 13
China 6
Costa Rica 1
Croatia 3
Cyprus 1
Czech Republic 12
Denmark 2
Finland 9
France 62
Germany 153
Greece 1
Hungary 7
India 2
Iran 2
Ireland 1
Israel 5
Italy 156
Japan 40
Mexico 1
Morocco 1
Netherlands 5
Norway 6
Poland 31
Portugal 5
Romania 3
Russia 13
Slovakia 1
South Korea 4
Spain 33
Sweden 9
Switzerland 12
Taiwan 1
UK 31
Ukraine 1
USA 108

3 Scientific Projects in 2017

3.1 Summary

Altogether 22 scientific projects have been run in 2017: 20 workshops, a Doctoral Training Programme and a TALENT school. This chapter collects the scientific reports written by the workshop organizers, by Georges Ripka who coordinated the Doctoral Training Programme and by the coordinators of the TALENT school.

3.2 Workshops and Schools (Calendar)

Feb 06 – 10	**Unraveling the Complexity of Nuclear Systems: Single-Particle and Collective Aspects Through the Looking Glass** Pierre Capel (University of Bruxelles) Gianluca Colò (University of Milano) Maria Colonna (LNS Catania) Marcella Grasso (IPN Orsay) Denis Lacroix (IPN Orsay) Antonio M. Moro (University of Sevilla)
Feb 27 - Mar 03	**QCD Challenges in pp, pA and AA Collisions at High Energies** Guillermo Contreras Nuno (Czech Technical University) Victor Goncalves (Universidade Federal de Pelotas) Rainer Schicker (University of Heidelberg) Antoni Szczurek (Institute of Nuclear Physics Krakow)
Mar 20 - 24	**Superfluidity and Pairing Phenomena: from Cold Atomic Gases to Neutron Stars** John W. Clark (Washington University St. Louis) Eckhard Krotschek (University at Buffalo SUNY) Armen Sedrakian (Frankfurt University)
Apr 03 - 07	**The Proton Mass: At the Heart of Most Visible Matter** Zein-Eddine Meziani (Temple University) Barbara Pasquini (University of Pavia) Jianwei Qiu (Brookhaven National Laboratory) Marc Vanderhaeghen (University of Mainz)
Apr 10 - 14	**Walk on the Neutron-Rich Side** Stefano Gandolfi (Los Alamos National Laboratory) Vittorio Soma (CEA Saclay)
May 08 - 12	**Space-Like and Time-Like Electromagnetic Baryonic Transitions** Philip Cole (Idaho State University) Beatrice Ramstein (IPN Orsay) Andrey Sarantsev (University of Bonn and Gatchina)
May 22 - 26	**Landau Fermi Liquid Theory in Nuclear and Many-Body Systems** Dany Davesne (University/IPN Lyon) Alessandro Pastore (University of York) Arnau Rios Huguet (University of Surrey)

Jun 05 - 09	**Bridging Nuclear and Gravitational Physics: the Dense Matter Equation of State** Andreas Bauswein (Heidelberger Institut für Theoretische Studien) Arianna Carbone (TU Darmstadt) James A. Clark (Georgia Institute of Technology) James M. Lattimer (Stony Brook University)
Jun 12 - 16	**Nuclear Astrophysics in the Gravitational Wave Astronomy Era** Randolf Pohl (Max-Planck-Institut für Quantenoptik Garching) Gerald A. Miller (University of Washington) Ron Gilman (Rutgers University)
Jun 12 – 30	**Microscopic Theories of Nuclear Structure, Dynamics and Electroweak Currents (Doctoral Training Program)** Omar Benhar (INFN/Università “La Sapienza” Rome)
Jun 28 - 30	**Simulating QCD on Lefschetz Thimbles** Andrei Alexandru (George Washington University) Paulo Bedaque (University of Maryland) Christian Schmidt (University of Bielefeld)
Jul 03 – 21	**Theory for Exploring Nuclear Structure Experiments (TALENT)** Alex Brown (Michigan State University) Morten Hjorth-Jensen (Michigan State University and University of Oslo)
Jul 10 - 14	**Open Quantum Systems: From Atomic Nuclei to Ultracold Atoms and Quantum Optics** Maxim Efremov (University of Ulm) Christian Forssen (Chalmers University of Technology) Mario Gattobigio (Université de Nice-Sophia Antipolis) Hans-Werner Hammer (TU Darmstadt)
Jul 17 - 28	**The Charm and Beauty of Strong Interactions** Adnan Bashir (Universidad Michoacana de San Nicolás de Hidalgo) Kai-Thomas Brinkmann (Justig-Liebig-Universität Giessen) Bruno El-Bennich (Universidade Cruzeiro do Sul) Gastao Krein (Universidade Estadual Paulista) Juan Nieves (Instituto de Fisica Corpuscular IFIC, CSIC & University of Valencia) Makoto Oka (Tokio Tech & ASRC, JAEA) Laura Tolos (ICE, CSIC-IEEC) Ulrich Wiedner (Ruhr-Universität Bochum)
Aug 21 - 25	**Functional Methods in Hadron and Nuclear Physics** Jan M. Pawlowski (University of Heidelberg) Dirk Rischke (Johann Wolfgang Goethe-Universität Frankfurt) Bernd-Jochen Schaefer (Justig-Liebig-Universität Giessen)
Sep 11 - 15	**LFC17: Old and New Strong Interactions from LHC to Future Colliders** Gennaro Corcella (INFN Frascati) Stefania De Curtis (INFN Firenze) Stefano Moretti (University of Southampton) Giulia Pancheri (INFN Frascati) Roberto Tenchini (INFN Pisa) Marcel Vos (Universidad de Valencia)

Sep 25 - 29	**Prospects on the Microscopic Description of Odd Mass Nuclei and other Multi-Quasiparticle Excitations with Beyond-Mean-Field and Related Methods** Michael Bender (IPNL) Luis Robledo (Universidad Autonoma de Madrid) Tomas R. Rodriguez (Universidad Autonoma de Madrid)
Oct 09 - 13	**New Perspectives on Neutron Star Interiors** Gergely Gábor Barnafoldi (Wigner Research Centre for Physics Budapest) Gordon Baym (University of Illinois at Urbana-Champaign) Laura Tolos (Institute of Space Sciences ICE, CSIC - IEEC)
Oct 23 - 27	**ASTRA: Advances and Open Problems in Low-Energy Nuclear and Hadronic STRAngeness Physics** Catalina Curceanu (LNF-INFN) Emiko Hiyama (RIKEN Nishina Center) Johann Marton (SMI-Vienna) Josef Pochodzalla (University of Mainz) Isaac Vidana (University of Coimbra)
Nov 06 - 10	**Dilepton Productions with Meson and Antiproton Beams** Wen-Chen Chang (Academia Sinica, Taipei) Jen-Chieh Peng (University of Illinois at Urbana-Champaign) Stephane Platchkov (IRFU, CEA Saclay) Oleg Teryaev (Bogoliubov Laboratory of Theoretical Physics)
Nov 20 - 24	**Axions at the Crossroads: QCD, Dark Matter, Astrophysics** Maria Paola Lombardo (INFN-LNF) Alessandro Mirizzi (University of Bari)
Nov 27 - Dec 01	**Phase Diagram of Strongly Interacting Matter: From Lattice QCD to Heavy-Ion Collision Experiments** Alexei Bazavov (Michigan State University) Massimo D'Elia (University of Pisa) Marlene Nahrgang (Subatech & École des Mines Nantes)

3.3 Workshop reports

3.3.1 UNRAVELLING THE COMPLEXITY OF NUCLEAR SYSTEMS: SINGLE-PARTICLE AND COLLECTIVE ASPECTS THROUGH THE LOOKING GLASS

DATE: February 06 – 10, 2017

ORGANIZERS:

Pierre Capel (Univ. Bruxelles, Belgium)
Gianluca Colò (Univ. Milano, Italy),
Maria Colonna (LNS-Catania, Italy)
Marcella Grasso (IPN Orsay, France)
Denis Lacroix (IPN Orsay, France)
Antonio M. Moro (Univ. Sevilla, Spain)

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

The aim of the workshop was to discuss the interplay between single-particle and collective effects in the description of the most relevant phenomena in nuclear structure and nuclear reactions physics, which are presently debated within the low-energy nuclear physics community. The workshop was framed within the activities, pursued by the organizers, inside TheoS, the theoretical Joint Research Activity of ENSAR2.
We have gathered experts in structure and reaction theories to discuss the state-of-the-art of nuclear models and to foresee possible improvements and extensions. In addition, several key representatives from leading experimental facilities have provided an overview of the ongoing and planned activities being carried out.

The main topics were:

- Ground-state properties within EDF-based and ab initio models
- Shell effects, shape coexistence, spontaneous symmetry breaking and restoration
- Low-lying excitations and giant resonances: onset of collectivity
- Spectroscopic tools: what experimentalists need from theorists and what theorists can provide to experimentalists
- Recent progress in nuclear direct reaction theory
- Interface between nuclear structure and reaction models

SPEAKERS:

P. Arthuis (CEA-Saclay, France)

B. Bally (CEA-Saclay, France)

F. Barranco (Univ. of Seville, Spain)

A. Bonaccorso (INFN-Pisa, Italy)

J. Bonnard (IPN Orsay, France)

S. Burrello (INFN-LNS, Catania, Italy)

J. Casal (ECT*, Trento, Italy)

E. Litvinova (Wheaten Michigan University, USA)

F. Nunes (Michigan State University, USA)

A. Obertelli (CEA-Saclay, France)

N. Orr (LPC-Caen, France)

A. Pastore (University of York, England)

L. Robledo (Univ. Autónoma de Madrid, Spain)

M. Cavallaro (INFN-LNS, Catania, Italy)
F. Crespi (Univ. of Milano, Italy)
L. Fortunato (Univ. Padova, Italy)
D. Gambacurta (ELI-NP, Bucarest, Romania)
C. Hebborn (ULB, Bruxelles, Belgium)
E. G. Lanza (INFN Catania, Italy)
J. A. Lay Valera (Univ. de Sevilla, Spain)
H. Liang (RIKEN Nishina Center, Japan)
J. Roca Maza (Univ. Milano, Italy)
T. Rodríguez (Univ. Autónoma de Madrid, Spain)
M. Sasano (RIKEN Nishina Center, Japan)
V. Soma (CEA-Saclay, France)
O. Sorlin (GANIL, Caen, France)
E. Vigezzi (INFN, Milano, Italy)
A. Vitturi (Univ. Padova, Italy)
C.Y. Yang (IPN Orsay, France)

SCIENTIFIC REPORT:

Nuclear physics has strongly progressed during the last years with significant achievements in the understanding of the nucleon-nucleon interaction and in the development of sophisticated many-body models. To describe nuclear phenomena and to interpret observations one should properly combine (i) our current knowledge of the nuclear interaction in different spin-isospin channels with (ii) theories for the treatment of the stationary solution of the nuclear many-body problem, and with (iii) the most recent advances for describing nuclear reactions. Below, we provide the scientific context for each of these ingredients:

- Nuclear interactions: the interaction between nucleons is one of the building blocks of nuclear physics. In recent years, with important advances in effective field theories, especially in the low-energy QCD non-perturbative sector, new interactions have been designed that are appropriate for solving the nuclear many-body problem. In particular, this has opened new opportunities to link QCD to low-energy nuclear physics and to perform so-called ab initio calculations. In parallel, enormous efforts have been made to better understand effective interactions and their possible use in mean-field and beyond-mean-field theories.
- Nuclear structure: a variety of nuclear theories are now available with different levels of sophistication. These models allow us to describe the properties of the ground state and excited states of nuclei. Among the most developed and used models are the ab initio theories based on bare interactions, configuration-interaction and/or energy-density-functional (EDF) theories (the latest two being based on effective interactions). These approaches provide complementary tools to interpret experimental observations on nuclear masses, excited states, density profiles, nuclear shapes and possible shape coexistence. Efforts have been made in recent years to bridge these theories and render some of them less empirical.
-Nuclear reaction models: Nuclear reactions are tools for extracting information on nuclear structure and for better understanding the properties of the nuclear interaction in the medium. There are experiments that provide direct evidence of nuclear properties, as for instance those based on gamma-ray and mass measurements. Most often, only a complete treatment of both the reaction and the nuclear-structure facets leads to a successful interpretation of experimental observations and a reliable extraction of the underlying structure properties. Various reaction models, incorporating nuclear structure descriptions, have been developed: coupled-channel models, which include the continuum when necessary, precise DWBA calculations, eikonal and Glauber approximations, microscopic time-dependent approaches. While the strategy is rather well established, it appears that very often the interface between nuclear structure and nuclear reactions is unsatisfactory.

Results and Highlights

One of the goals of the workshop was to stimulate exchanges between different communities of low-energy nuclear physics covering nuclear reaction theories, nuclear structure theories and experimental expertise related to different facilities worldwide such as GANIL, RIKEN, MSU, LNL, LNS. In this respect, the workshop was very successful, with many fruitful discussions between experts from these communities during the oral presentations and the discussion sessions. During the workshop, we organized three discussion sessions respectively on (a) the link between nuclear structure and nuclear reactions, (b) the interaction to be used in mean-field and beyond mean-field approaches and on (c) the connection between experiments and theory.

The physics of nuclei ranging from very small systems to medium-mass and heavy nuclei was discussed during the workshop. In particular, the possibility to probe aspects related to internal correlations was debated. Beside standard experimental techniques like transfer reactions, γ-ray spectroscopy or knock-out reactions, new probes have been introduced such as, for instance, multi-nucleon removal, viz. (p,2p) and (p,3p) reactions, the possibility to use antiprotons and their decay to probe densities at the surface of nuclei, and double-charge exchange reactions. For all these reactions and processes, extensive discussions have been made to figure out how existing tools can be improved and if new specific tools should be developed. The important role of continuum and correlations in exotic nuclei have been discussed both on static properties and dynamical effects. Advantages and drawbacks of time-dependent (TDHF) and time-independent methods (RPA) were carefully analyzed. Current and future avenues were suggested.

The workshop was oriented to clarify the interplay between single-particle and collective effects and their role on experimental probes. Many oral contributions have discussed the recent progress in the description of low-lying and high-lying (viz. giant resonances) states in nuclei, including odd-even and odd-odd nuclei. The description and the observation of intriguing excitation modes like pygmy dipole modes, Gamow-Teller excitations, or isoscalar dipole modes (IS-GDR) were extensively discussed together with the correct interfacing between RPA/QRPA models and DWBA reaction models. Differences between TDHF and RPA in the IS-GDR are observed. It was concluded that this aspect should be clarified.

A significant part of the discussion was devoted to the progress achieved within the EDF framework, especially in its beyond-mean-field (BMF) level. Several methods ranging from perturbation many-body theories, extensions of RPA, and configuration mixing methods have been presented as well as specific applications. Advantages, drawbacks and technical difficulties were illustrated. In spite of the differences between the various theories, a common key ingredient is the effective interaction used at the mean-field and beyond-mean-field levels. The specific treatment of ultraviolet divergences with the use of some subtraction procedures was for instance clarified. The necessity to optimize the effective interaction at the BMF level was debated. New functionals bridging empirical parameters with low-energy constants related to the bare interaction were introduced. Moreover, it was discussed that a deeper connection between the bare interaction used in ab initio methods and more phenomenological EDF functionals is desirable. It was also concluded that EDF could benefit from tools developed in Effective Field Theories, such as for instance regularization techniques.

A session was devoted to discuss the necessity of improving the structure models currently employed in reaction calculations. Two strategies were delineated. On the one hand, the direct use of *ab initio* calculations (transition densities, overlap functions, etc.) into the existing reaction frameworks. On the other hand, extensions of more phenomenological models (such as the particle-rotor and particle-vibrator models) to overcome their limitations (such as the correct treatment of Pauli blocking or the explicit inclusion of antisymmetrisation) and the inclusion of possible extensions.

A final discussion on the connection between experiment and theory was made. It was for example mentioned, in order to improve the experiment/theory collaborations, that theorists should be integrated at the early stage of any experiment. The need to provide uncertainties in theoretical predictions, like energy levels, densities or reaction cross-sections, was also emphasized. In addition, the necessity to work on defining specific physics cases and/or priorities has been underlined.

Overall the workshop was very successful with extensive discussions on current subjects of interest in nuclear physics. One of its specificities was to bring together people from different communities in nuclear theory and from the experimental field. The lively exchanges that were fostered during this meeting have enabled everyone to develop a broader picture of the state of the art in nuclear theory and the current challenges the various communities face nowadays.

3.3.2 QCD CHALLENGES IN pp, pA AND AA COLLISIONS AT HIGH ENERGIES

DATE: February 27 – March 03, 2017

ORGANIZERS:

G. Contreras Nuno (Czech Technical University, Prague, Czech Republique)
V. Goncalves (Universidade Federal de Pelotas, Brazil)
R. Schicker (Phys. Inst., Heidelberg University, Germany)
A. Szczurek (Institute of Nuclear Physics PAN Cracow, Poland)

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

The focus of this workshop was the discussion of QCD processes for which data have recently become available at the on-going RHIC and LHC programmes, or are expected in the near future. Whereas inclusive processes with a hard scale can be calculated within pQCD in LO and NLO, calculations of exclusive processes are relatively new. They are presently being developed by formulating effective models consistent with QCD, such as for example for the spin structure of the pomeron. The linear description of QCD dynamics based on DGLAP and BFKL evolution equation can be tested by particle production data in pp, pA and AA collisions. At low values of Bjorken-x, the transition to a nonlinear behaviour of QCD dynamics as expressed in gluon saturation effects is expected. Moreover, particle production in pA and AA collisions is modified by shadowing effects and propagation in the medium, and a formulation of a unified approach to incorporate these effects remains a challenge.

The main topics were:

- Particle and multi-particle production in pp, pA and AA collisions
- Ultra-peripheral physics in pA and AA collisions
- Signals of gluon shadowing at low-x
- Central exclusive production in pp collisions

SPEAKERS:

I. Babiarz (Univ. of Rzeszow, Poland)

H. Beck (Univ. of Heidelberg, Germany)

F. Bellini (Univ. of Bologna and INFN, Italy)

C. Bierlich (Lund University, Sweden)

A. Borissov (Pusan National University, Korea)

R. Boussarie (PAN Cracow, Poland)

M. Broz (Czech Technical University, Prague, Czech Rep.)

E. Bruna (INFN Torino, Italy)

A. Bursche (Univ. of Cagliari, Italy)

R. Kycia (Cracow University of Technology, Poland)

P. Lebiedowicz (PAN Cracow, Poland)

M. Luszczak (Univ. of Rzeszow, Poland)

M. Machado (UFRGS, Porto Alegre, Brazil)

R. Maciula (PAN Cracow, Poland)

C. Marquet (Ecole Polytechnique Palaiseau, France)

B. Moreira (Universidade de São Paulo, Brazil)

F. Navarra (Universidade de São Paulo, Brazil)

V. Cairo (CERN, Switzerland)

J. Cepila (Czech Technical University, Prague, Czech Rep.)

P. Chaloubka (Czech Technical University, Prague, Czech Rep.)

P. Christiansen (Lund University, Sweden)

S.U. Chung (Brookhaven Nat. Lab., USA)

A. Cisek (Univ. of Rzeszow, Poland)

G. Contreras Nuno (Czech Technical University, Prague, Czech Rep.)

C. Ewerz (Univ. Heidelberg & EMMI/GSI Darmstadt, Germany)

S. Glazek (Univ. Warsaw, Poland)

V. Gonçalves (Federal University of Pelotas, Brazil)

L. Jenkovszky (Bogolyubov ITP, Nat. Acad. of Science, Ukraine)

A. Ontoso (Frankfurt Institute for Advanced Studies, Germany)

M. Rangel (Universidade Federal do Rio de Janeiro, Brazil)

W. Schäfer (PAN Cracow, Poland)

R. Schicker (Univ. Heidelberg, Germany)

P. Silva (State University of Campinas, Brazil)

D. Spiering (Universidade de São Paulo, Brazil)

R. Staszewski (PAN Cracow, Poland)

M. Sumbera (Nucl. Phys. Inst. ASCR, Czech Rep.)

A. Szczurek (PAN Cracow, Poland)

M. Trzebinski (PAN Cracow, Poland)

K. Werner (Univ. of Nantes, France)

SCIENTIFIC REPORT:

During the workshop, more than 40 talks of 20 minutes were delivered. We also had 3 round tables of nearly 2 hours each. On Friday afternoon we also organised a working session on the quarkonium-physics opportunities with a fixed-target experiment using the LHC beams. We have addressed issues related to the production of excited quarkonia, the associated production of quarkonia as well as polarisation and other correlation observables in quarkonium production. Both aspects related to polarised nucleon-nucleon collisions as well as heavy-ion collisions were considered.

Excited quarkonium states show an unexpected behaviour in nuclear matter whereas the understanding of their production in pp collisions requires more observables to constrain the theory and feed-down effects. We had two round tables on these matters following dedicated talks. We also devoted significant time for discussing a particular class of new observables, which is that of associated-quarkonium production. It is particularly relevant since it can provide extremely important information on the gluon TMDs as well as on the physics underlying double-parton scatterings both in nucleon-nucleon and heavy-ion collisions.

More specifically the following topics were addressed:

The study of particle and multi-particle production in pp, pA and AA collisions at high energies reveals a number of issues, which require an improved QCD-based understanding. In many cases, when talking about hard processes, i.e. production of jets with large transverse momenta or heavy objects (gauge bosons, Higgs boson, heavy quarks, quarkonia, etc.) the method of perturbative QCD can be applied. In this case, state of the art calculations include next-to-leading order corrections. An alternative method is the kt-factorization. The methods for inclusive processes are well understood. In contrast, methods for exclusive processes are relatively new, and are being developed at present.
One application example of pQCD is hard single-diffractive production of different objects, such as gauge bosons, charmed quarks (or mesons), dijets, dileptons, etc. So far these processes have been calculated only in leading-order collinear approach. Now they can be calculated next-to-leading order. Recently, the kt-factorization has been applied to those processes for the first time. However, more advanced methods have to be developed for several processes measurable at the LHC.

In some exclusive hard diffractive processes, the methods proposed by Khoze, Martin and Ryskin can be used. In some exclusive soft processes, effective models consistent with QCD can be applied. This includes recent developments on spin structure of the pomeron -- a basic object for this kind of processes. In central exclusive processes, new objects such as glueballs and hybrids can be produced. The existence and properties of such objects can be addressed in lattice QCD and in effective models.

The hadronic structure at high energies is characterized by a large density of gluons. As gluons are coloured particles, they are expected to recombine in the new kinematical range probed at LHC energies, modifying the linear description of QCD dynamics. In particular, these non-linear effects are predicted to modify the standard collinear factorization description, which is used to calculate cross sections. The magnitude of these modifications is enhanced at forward-rapidities and in nuclear reactions. These aspects have motivated the development of new theoretical approaches that take into account gluon shadowing (saturation) effects at low-x and large nuclei. The analysis of the exclusive photoproduction process of vector mesons is of particular interest since it allows studying the gluon distribution in proton and nucleus at low values of Bjorken-x. Such analyses require, however, the correct understanding of photon fluxes carried by the beam particle as well as the internal spectrum of the target species.

Additionally, pp elastic scattering data from the TOTEM experiment were discussed, and the deviation of the differential cross section from a single exponential behaviour at low t-values was scrutinized. Regge approaches were presented in this context. The spin structure of the pomeron was analysed, and it was shown that recent RHIC data on polarized proton scattering can only be understood by the tensor pomeron model. The study of particle and multi-particle production in pp, pA and AA collisions at high energies reveals a number of issues, which require an improved QCD-based understanding. In many cases, when talking about hard processes, i.e. production of jets with large transverse momenta or heavy objects (gauge bosons, Higgs boson, heavy quarks, quarkonia, etc.) the method of perturbative QCD can be applied. In this case, state of the art calculations include next-to-leading order corrections. An alternative method is the kt-factorization. The methods for inclusive processes are well understood. In contrast, methods for exclusive processes are relatively new, and are being developed at present.

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Results and Highlights

The results of the main topics of this workshop can be summarized as follows:

- *Particle and multi-particle production in pp, pA and AA collisions*

The production of one and two J/Ψ mesons was discussed. The kt-factorization approach was used in the context of single J/Ψ meson production. Several new (higher-order) processes were discussed in the context of double J/Ψ production. The results were compared to new ATLAS data and a reasonable description was achieved. Both exclusive and semi-exclusive production of vector mesons was discussed. The kt-factorization and the dipole approach were used in this context. Both of these approaches included so-called gluon saturation effects. Some evidence for the saturation effects was presented in the context of exclusive J/Ψ production. It was shown that electromagnetic excitation leads to larger contributions than diffractive excitation, in contrast to naive expectations. Several mechanisms and a new formalism were discussed. The dependence of the gap survival factor as a function of several kinematical variables was discussed in a model with multi-parton-interactions as implemented to PYTHIA. The production of one and two jets associated with cc and D-meson production was studied in the framework of kt-factorization. Several differential distributions were discussed. Predictions for the LHC were shown. Also hard diffractive processes were discussed. This includes single-diffractive production of cc-pairs and dijets. For the first time the kt-factorization was used for calculating differential cross sections for the diffractive processes.

- *Ultra-peripheral physics in pA and AA collisions*

The talks on experimental results covered the photoproduction of vector mesons in pp collisions measured by LHCb, and all available results from photoproduction processes in p-Pb and Pb-Pb collisions by ALICE. In both these talks, the recently acquired data from the 2016 Run of p-Pb collisions at a record centre-of-mass energy of 8.16 TeV were discussed. The presentations on theory and phenomenology discussed the improved understanding of proton dissociation in vector meson photoproduction processes, the use of geometrical fluctuations in the transverse plane to search for saturation effects, the description and uncertainties of ultra-peripheral collisions in a colour-dipole formalism including saturation, a novel method to extract shadowing from J/Ψ coherent photonuclear production, and the creation of two vector mesons in a photoproduction process. Moreover, an in-depth discussion took place on exotic charmonium production in photon-photon collisions at the LHC.

- *Signals of gluon shadowing at low-x*

The analysis of new observables has been proposed to probe and constrain the magnitude of gluon saturation at low-x and in large nuclei. Both topics have been extensively discussed at the workshop. In particular, a recent proposition for the nonlinear factorization of the cross section has been presented, including its implications for dijet production. On the phenomenological side, several speakers emphasised the importance of studying exclusive processes as a source of information on the QCD dynamics. The implications on different final states have been presented. Finally, possible spatial correlations inside the proton have been discussed as well as its implications in the initial conditions of the hadronic and nuclear collisions.

- *Central exclusive production in pp collisions*

Models for soft mesonic excitations in pomeron-pomeron fusion were presented, including both the production of resonances as well as the non-resonant pion-pair continuum. Moreover, purely exclusive processes were discussed. An example is the production of $\pi^+\pi^-$ and $\pi^+\pi^-$ $\pi^+\pi^-$ (2 —> 6 process), discussed for the first time. The presentation of $\pi^+\pi^-$ production was devoted both to continuum and resonance mechanisms. The presentation on four-pion production concentrated on processes with three pomerons, never discussed quantitatively before. Production and decay amplitudes of 2 —> 3 body processes were discussed for double pomeron as well as for photon-pomeron processes.

3.3.3 SUPERFLUIDITY AND PAIRING PHENOMENA: FROM COLD ATOMIC GASES TO NEUTRON STARS

DATE: March 20 – 24, 2017

ORGANIZERS:

J. W. Clark (Washington University St. Louis, USA)
E. Krotschek (University at Buffalo SUNY, USA)
A. Sedrakian (Frankfurt University, Germany)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The central theme of the workshop was the ongoing quest for the underlying microscopic physics of superfluidity and pairing phenomena in diverse fermion systems, especially nuclear matter, ultracold atomic gases, and liquid 3He phases. Theoretical techniques for exploring superfluid systems were discussed in depth; these included commonly practiced methods involving correlated basis functions, density functionals, and Green functions. An important sub-theme of the workshop focused on the remarkable variety of unconventional phases that may arise in the diverse systems of interest, notably the emergence of imbalanced superfluids and lattice systems featuring flat bands.

The main topics were:

- Computation of pairing gaps in nuclear matter including short- and long-range correlations, as well as the effects of three-body forces
- Flat bands in periodic systems as a potential source of high-temperature superconductivity in classes of doped strongly-correlated materials including heavy-fermion metals and ultra-cold superfluids more generally
- Unconventional pairing in systems with spin polarization or flavor or other population imbalance
- Clustering in nuclear matter, most notably alpha clustering and Bose condensation of alpha particles
- Diverse properties of pairing in neutron stars, with implications for astrophysical observations, especially for their thermal evolution

SPEAKERS:

G. Astrakharchik (Universitat Politecnica de Catalunya, Barcelona, Spain)

O. Benhar (INFN and Univ. of Roma, Italy)

A. Bulgac (Univ. of Washington, Seattle, USA)

M. Baldo (INFN Catania, Italy)

A. Gezerlis (Guelph University, Guelph, Canada)

N. Chamel (ULB, Bruxelles, Belgium)

J. W. Clark (Washington University in St.

T. Ohishi (Univ. and INFN Padova, Italy)

A. Recati (LMU, Munich, Germany)

A. Rios (University of Surrey, Surrey, UK)

G. Röpke (Rostock University, Germany)

P. Schuck (IPNO, Orsay, France)

H.-J. Schulze (INFN Catania, Italy)

A. Sedrakian (FIAS, Goethe University, Frankfurt am Main, Germany)

V. Shaginyan (Petersburg Nuclear Physics Institute, NRC Kurchatov Institute, Russia)

Louis, St. Louis, USA)

P. Magierski (Warsaw University of Technology, Warsaw, Poland)

G. Matrone (IPNO, Orsay, France)

E. Krostchek (SUNY Buffalo, Buffalo, USA)

P. Papakonstantiou (Institute of Basic Science, Daejeon, South Korea)

A. Pastore (University of York, York, UK)

S. Peotta (Aalto University School of Science, Aalto, Finland)

C. Pethick (Niels Bohr Academy, Copenhagen, Denmark)

P. Törmä (Aalto University School of Science, Aalto, Finland)

L.Tolos (IEEC/CSIC, Bellaterra, Spain)

M. Urban (IPNO, Orsay, France)

G. Wlaslowski (Warsaw University of Technology, Warsaw, Poland)

E. Vitali (William and Mary University, Williamsburg, USA)

G. Volovik (Aalto University School of Science, Aalto, Finland))

SCIENTIFIC REPORT:

Proof of the Cooper theorem some sixty years ago provided the key to understanding pairing phenomenon in interacting many-fermion systems, triggering creation of the Bardeen-Cooper- Schrieffer (BCS) microscopic theory of electronic superconductivity. Since that landmark development, the basic paradigm of BCS theory has been extended to diverse fermionic systems, with remarkable successes. Exploration of its broader application, modification, and implementation is currently as lively as ever, even more so. Indeed, this last decade has witnessed striking progress in our understanding of fermionic pairing across an array of systems characterized by vastly different energy scales. In parallel with the ongoing effort to uncover the mechanism responsible for high-temperature electronic superconductivity in solids as studied in traditional condensed-matter laboratories, there has been intense activity in the exploration of pairing phenomena in novel systems such as magnetically or laser trapped ultra- cold atomic vapors and in complex many-body systems including liquid 3He, finite nuclei, nucleonic matter existing in neuron stars, and quantum chromodynamics.

The workshop addressed the following broad topics:

1) From the methodological perspective, the participants made a collective critical assessment of progress toward the development of realistic and reliable microscopic models of pair-correlated fermionic systems. The strengths and weaknesses of various *ab initio* computational approaches to pairing problems were examined and discussed. These included, among others, quantum Monte-Carlo, cluster-expansion and hypernetted chain, correlated basis function (CBF), and self-consistent Green function methods. These approaches spanned essentially the entire range of many-body methods in play, notably involving (i) continuum Green's functions evaluated through physically motivated approximation schemes and (ii) correlated basis functions together with Fermi hypernetted-chain cluster re-summations and Euler-Lagrange optimization, as well as computationally-oriented procedures, most notably (iii) Monte-Carlo-based wave-function approaches and (iv) density-functional treatments requiring large-scale supercomputer simulations.

2) A secondary theme of the workshop involved the exploration of conceptually novel aspects of pairing expressed in non-BCS situations. Chief among these were asymmetrical pairing, phase-separated pairing states, Cooper pairs with non-zero total momentum, gapless superconductivity, and fat-band superconductivity in various compounds exhibiting heavy-fermion and strange-metal behavior. The status of microscopic theoretical description of these aspects in concrete physical examples was evaluated and essentially confirmed in some important cases. In particular, the BCS-BEC crossover, which is of great interest in experiments on ultra-cold atoms, was studied in considerable detail.

3) Clustering phenomena beyond dimerization also received attention. Of special interest was incipient Bose condensation in alpha-clustered matter in finite nuclear systems (especially certain light “alpha-particle'' nuclei such as 8Be, 12C, and 160) and infinite nuclear matter. The effects of clustering in nuclear systems were considered in the context of a number of observables, notably symmetry energies, lifetimes, and level spectra.

4) Rather unexpectedly, there was deep and extensive examination of the (sometimes profound) influence on pairing properties of band structure of periodical lattices. On the one hand, the band structure/pairing relationship was aired in the context of the inner crust of a neutron star. In this setting, simple estimates indicate that pairing is suppressed by the band structure, but this finding is not confirmed in more elaborate calculations. On the other hand, the emergence of flat bands in electron systems of novel materials were considered as a possible avenue to high-temperature superconductivity.

This workshop featured a high degree of spontaneity. There were a number of relevant presentations and discussions on topics not initially planned. These included some aspects of low-temperature and low-dimensional boson and fermion systems, discussion of topological defects (vortices) and forces acting on them (for example, the Iordanski and Kopnin forces on a vortex), and properties of systems exhibiting flat bands of either geometric or dynamic origin.

Results and Highlights

The overall goal of this workshop on the ubiquitous role of pairing in fermionic media was to bring together colleagues who (i) have shown constructive interest in interdisciplinary communication and (ii) are positioned to contribute significantly to a richer fundamental understanding of pairing phenomena through integration of concepts and techniques drawn from nuclear physics, quantum fluids, and cold atomic gases. In this sense, the workshop was most definitely a success. Enthusiastic responses have been received from the participants of the workshop with regard to both its format and content. The varied themes that have been addressed in this meeting and the ensuing results will be reflected in refereed contributions to a special volume of the *Journal of Low Temperature Physics*. Collection of the papers for this volume from interested workshop participants is projected for May 2017. Additionally, it is likely that slides of the talks themselves will be made available online.

The scientific highlights of the workshop can be summarized as follows:

1. The nuclear pairing problem was addressed extensively from the standpoint of microscopic quantum many-body theory. The different many-body formalisms applied by the workshop participants include self-consistent Green functions methods, correlated-basis methods, and Monte-Carlo techniques. In different ways, all of these approaches aim toward quantitative determination of corrections of self-energies and effective interactions beyond mean-field approximations. The quantitative role of fundamental three-body forces has also been highlighted in some contributions. Importantly, the nature of pairing in finite nuclei as derived from the Kohn-Sham density functional has been explored in the context of nuclear fission. Another computational highlight of the workshop was the progress made on the interplay between band structure and pairing in neutron star crusts, which reveals the tension between simple semi-analytical estimates and full band structure calculations.
2. Progress in the physics of polarized (asymmetrical or imbalanced) systems that exhibit pairing was another salient highlight of the workshop. A number of key issues have been addressed at considerable depth, most notably the BCS-BEC crossover, formation of inhomogeneous phases, and use of T-matrix theory in the spirit of the Nozieres-Schmitt-Rink model to include the effects of fluctuations.
3. An especially interesting highlight of the workshop was the lively discussion of flat bands and the associated phenomenon of fermion condensation in diverse quantum

many-body systems, especially in the context of condensed matter physics. It has been proposed that such phenomena may open a path to room temperature superconductivity. Comparisons of theory with experiment that offer support for this possibility were described by some participants.

4. An important development that was prominent at the workshop is the extensive and intensive exploitation of major computational resources in current research that focuses on dynamical properties of many-fermion systems with pairing. The results from numerical simulations of fission, vortex-nucleus interactions, etc. presented in the three talks by the members of the group of A. Bulgac highlight the challenges confronted and overcome at the limits of current numerical capabilities for direct head-on treatment of superfluid systems within density functional theory.

Given the special environment of ECT* that fosters free interchange of ideas among physicists from different backgrounds, this workshop was remarkably successful in drawing on the diversity of experience and the analytical and computational strengths of its participants to make tangible progress toward deeper understanding of pairing phenomena in nuclear and cold-atom systems, as well as in related pairing problems in condensed matter. It is anticipated that this event will provide a sound platform for future cross-disciplinary and cross- community collaborations between its participants.

3.3.4 THE PROTON MASS: AT THE HEART OF MOST VISIBLE MATTER

DATE: April 03 – 07, 2017

ORGANIZERS:

Z.E. Meziani (Temple University, USA)
B. Pasquini (University of Pavia, Italy)
J. Qiu (Jefferson Lab, USA)
M. Vanderhaeghen (Mainz University, Germany)

NUMBER OF PARTICIPANTS: 34

MAIN TOPICS:

The subject of understanding the proton mass in terms of its constituents, as naive as it may sound, is of paramount importance to the field of Hadronic/Nuclear physics. The emergence of hadron masses from quarks and gluons is one of the most fascinating subjects in coherence physics and a cornerstone of QCD. In a tour de force, calculations of the baryon mass spectrum in lattice QCD have been successfully carried out, however developing the intuition of how the mass of each hadron emerges, finds many pathways as noticed in the workshop held at Temple University in March of 2016. How the mass of the proton emerges from its constituents is a natural and familiar question shared by many colleagues from other areas of physics where the mass of key systems is commonly described in terms of the mass of their constituents.
While the mass of a hadron in QCD is an emergent phenomenon, it is nevertheless important to cast our answer in terms of the energy/mass of the constituents in order to facilitate communication with the public in a familiar way. This is now crucial as the nuclear physics community in the U.S. and elsewhere embarks on the justification of building even larger experimental facilities in the quest of understanding QCD and the structure of hadronic/nuclear matter from basic principles. In the U.S. such a facility is the electron ion collider (EIC) project that has been endorsed by the US nuclear physics community as the next construction project after the completion of FRIB. The science justification of this project is undergoing an evaluation by a committee from the US National Academy of Science to cement its raison d'être. The quality and importance of the problems addressed by Nuclear physics, especially those involving a true understanding of the inner workings of QCD need to identify connections and pathways to others area of physics. The "mass of the proton" is one theme amenable to emphasize what remains to be understood in QCD as a worthwhile goal that can be appreciated by the wider physics community not just the practitioners of hadronic/nuclear physics.
The workshop supported a three-pronged theoretical approach to the subject of the origin of hadron masses with an added value on defining possible measurements that would make whole the investigation of the origin of the proton mass. This theoretical approach combined with experimental measurements should in principle allow for a deeper understanding of this complex subject. Direct lattice QCD calculations of hadron masses, mass decompositions, where the role of the constituents are explored, as well as phenomenological and approximated analytical approaches formed the three legs supporting the theory base of this workshop. Experiments aimed at some specific pieces of this puzzle, for example the individual terms in a decomposition of the mass in terms of the constituents, could form a platform for experimental measurements that will be pursued if at all possible.
1- How can lattice QCD help us explore the role of "individual" constituents in making up the hadron masses? For example, we explored the role of quark masses, in particular how much strange and heavy quark masses contribute to the proton mass, as well as how much gluon contribute to the proton's energy-momentum.

2- What can the decomposition in terms of constituents teach us? Can we take advantage of the non-uniqueness of the decomposition to cast it in terms of intuitive physical and independently measurable quantities?
3- In the approximated analytical, phenomenological or model approaches, how well can we control the approximations? Examples are the proton wave function, or the pi-N sigma term, how to quantify or improve the approximations made and how do different approaches compare with each other?
4- Identify new measurements that could be pursued at existing or future facilities and which would measure relevant observables closely linked to a given decomposition and could effectively test our assumptions. Examples are measurements of the J/Psi electro- and photo-production at threshold at Jefferson Lab and the measurement of Upsilon electro- and photo-production at threshold at a future Electron Ion Collider.

The main topics were:

- Covariant decomposition
    - Light quark mass contributions
        - π-N σ term
    - Heavy quarks mass contributions
        - Lattice QCD evaluations
    - Trace Anomaly
        - Lattice QCD evaluations

- Rest Frame Decomposition
    - Ji's decomposition
    - Lorcé's decomposition
    - Lattice QCD evaluations

- Non-Perturbative Interpretations
    - Dyson Schwinger approach
    - Holographic Approach

- Connections to experiments
    - Threshold production of heavy quarkonia at threshold
    - Pentaquarks with ccbar and bbar

- Quarkonium bound states in nuclei

SPEAKERS:

J. M. Alarcon (Jefferson Lab, USA)

C. Alexandrou (University of Cyprus and the C. Institute, Cyprus)

D. Binosi (ECT*, Italy)

M. Burkardt (New Mexico State University, USA)

S. Brodsky (SLAC, USA)

J.-P. Chen (Jefferson Lab, USA)

E. Chudakov (Jefferson Lab, USA)

I. Cloët (ANL, USA)

S. Cotogno (Nikhef/VU, Amsterdam, Netherlands)

C. Hoelbling (Wuppertal University, Germany)

P. Hoyer (Univ. of Helsinki, Finland)

X. Ji (University of Maryland, USA)

D. Kharzeev (Stony Brook University & BNL, USA)

H.-W. Lin (Michigan State University, USA)

K.-F. Liu (Univ. of Kentucky, USA)

C. Lorcé (École Polytechnique, Paris, France)

L. Mantovani (Univ. of Pavia, Italy)

P. J. G. Mulders (Nikhef/VU, Amsterdam, Netherlands)

J. de Elvira (Univ. of Bern, Switzerland)

G. de Teramond (Univ. of Costa Rica, Costa Rica)

A. Deshpande (Stony Brook University)

G. Eichmann (Univ. of Giessen, Germany)

P. Faccioli (Univ. of Trento, Italy)

O. Gryniuk (Johannes Gutenberg University, Mainz, Germany)

K. Hafidi (ANL, USA)

J. Papavassiliou (Univ. of Valencia, Spain)

V. Pascalutsa (Johannes Gutenberg University, Mainz, Germany)

C. Roberts (ANL, USA)

D. Richards (Jefferson Lab, USA)

K. Slifer (Univ. of New Hampshire, USA)

Y.-B. Yang (Univ. of Kentucky, USA)

SCIENTIFIC REPORT:

During the workshop, we had presentations that focused on the covariant decomposition and the rest frame decomposition of the proton mass as well as the link to observables that are either calculated using lattice QCD or calculated through models. Specific talks addressed the light quark mass contributions using lattice QCD calculations as well as the extractions of the π-N σ term from experimental data. Lattice calculations of the heavy quarks mass contributions and their relation to the trace anomaly were presented. Since there has been no direct evaluation of the trace anomaly using lattice QCD, discussions on the difficulties and requirement for such calculations were held with experts of lattice QCD.

In the case of non-perturbative approaches, namely the Dyson-Schwinger or holographic calculations, the mass decomposition is casted in different components compared to Ji's decomposition for example, and thus further discussions were held to understand their interpretation in the frame of the previous decomposition. In these models, the proponents promoted among others the concept of having a binding energy term in the hadron mass energy budget, while using effective degrees of freedom akin to atomic or nuclear systems.

Discussions about how to use other components of the energy momentum tensor to gain more information on Ji's decomposition or provide a new decomposition were considered.

The threshold photo-production of heavy quarks (charm and bottom) at JLab and at an EIC was considered. The potential of such experiments to shed light on the trace anomaly size was discussed. Among the results from existing experiments was the determination of the scattering length and binding energy of the J/Psi-nucleon system. Measurements of possible of J/Psi-nucleus bound states were also discussed.

Results and Highlights

Among the results of this workshop, there was the clear need of using lattice QCD to evaluate with precision the contribution of the heavy-mass quarks contribution and try to deduce the trace anomaly. Also another opportunity that emerged was the need to show simultaneously that, in the chiral limit, lattice QCD can prove that the mass of the proton is finite, whereas that of the pion is zero.

A highlight was a new decomposition offered by Cedric Lorcé "at the end of the workshop and later appeared on the Arxiv as a paper titled "the hadron mass decomposition, and submitted as arXiv:1706.05853 [hep-ph].

From this workshop, it was clear that a direct connection of the threshold J/Psi or Upsilon production cross section and the matrix element of the trace anomaly of the energy momentum tensor is still missing and further exploration of this link is crucial to a full program of mass decomposition. For example, in Ji's decomposition, each component in the mass decomposition can be connected to an identifiable measurement, except for the trace anomaly that is crucial for understanding the role of gluonic or color fields in providing the mass of the nucleon.

Also it was agreed that this meeting would result in a White Paper summarizing the main conclusions reached in this and the previous workshop on the mass of the proton held at Temple. Therefore, this report will be complemented by a more thorough white paper on the highlights and results of this workshop, as well as prospects and guidance for future research on this subject.

3.3.5 WALK ON THE NEUTRON-RICH SIDE

DATE: April 10 – 13, 2017

ORGANIZERS:

S. Gandolfi (Los Alamos National Laboratory, USA)
V. Somà (CEA Saclay, France)

NUMBER OF PARTICIPANTS: 29

MAIN TOPICS:

The workshop focused on recent advances in the study of neutron-rich nucleonic systems, from few-neutron resonances to neutron stars. It intended to bring together theorists working on few- and many-body systems, as well as experimentalists, with the goal of identifying future theory and experiment needs towards a better understanding of exotic nuclear phenomena and predictive theoretical tools.

The main topics were:

- Few-neutron resonances, with particular focus on the tetraneutron
- Properties of medium-mass nuclei towards the neutron drip line
- Equation of state of neutron-rich nuclear matter and application to neutron stars
- Limits of validity and/or approximations of current many-body techniques, in particular when dealing with weakly bound systems
- Models of the nuclear Hamiltonian, with particular focus on the isospin-3/2 part of three body forces

SPEAKERS:

C. Barbieri (Univ. of Surrey, UK)
A. Carbone (TU Darmstadt, Germany)
J. Carbonell (IPN Orsay, France)
M. Drissi (CEA Saclay, France)
T. Duguet (CEA Saclay, France)
R. Garcia Ruiz (Univ. of Manchester, UK)
E. Gebrerufael (TU Darmstadt, Germany)
J. Gibelin (LPC Caen, France)
C. Greene (Purdue University, USA)
G. Hagen (Oak Ridge, USA)
E. Hiyama (RIKEN, Japan)
J. D. Holt (TRIUMF, Canada)
C. Ji (ECT*, Italy)
R. Kanungo (Saint Mary's University, Canada)
M. La Cognata (LNS Catania, Italy)
R. Lasauskas (Univ. of Strasbourg, France)
D. Logoteta (Univ. of Pisa, Italy)
D. Lonardoni (Michigan State Univ., USA)
J. Lynn (TU Darmstadt, Germany)
M. Marqués (LPC Caen, France)
P. Navrátil (TRIUMF, Canada)
F. Pederiva (Univ. of Trento, Italy)
L. Riz (Univ. of Trento, Italy)
T. Suda (Tohuku Univ., Japan)
I. Tews (INT Seattle, USA)
T. Uesaka (RIKEN, Japan)
E. Vigezzi (INFN Milano, Italy)

SCIENTIFIC REPORT:

A very fluent research is carried out to understand the properties of neutron-rich systems. Considerable progress has been made in recent years in studying properties of nuclei far from stability, in particular towards the neutron drip-line, in investigating the possible existence of many-neutron resonances, the alteration of expected nuclear magic numbers, and the properties of neutron stars. Understanding such exotic systems challenges our knowledge built on stable nuclei, demanding a deeper insight in nuclear interactions and many-body theories as well as novel experimental developments.

A major theoretical challenge that reveals in all these systems is the current poor knowledge of many-neutron interactions. Several microscopic nuclear Hamiltonians, including the phenomenological ones like Argonne-families and those obtained within the framework of chiral effective field theory (EFT), naturally need or predict three- and many-neutron forces. These interactions contain parameters that, at present, need to be fixed by reproducing nuclear observables. The main problem is that the isospin T=1/2 part of the three-body interaction totally dominates the T=3/2 part in nuclei, leaving three-neutron forces (pure T=3/2) poorly constrained when nuclei close the stability are considered. In the future, lattice QCD calculations might help in this direction e.g. by providing three-neutron scattering simulations, although it will presumably take several years before the needed level of accuracy can be reached. Similar issues also affect more effective approaches like energy density functionals, where extrapolations to neutron-rich systems are often characterised by strong model dependence. Interplay with ab initio theories on the neutron-rich side (e.g. the use of pseudo-data) is being explored and could be highly beneficial.

The evolution of large supercomputers generated significant advances in developing numerical tools to calculate properties of medium-mass nuclei and infinite nuclear matter. These methods include Quantum Monte Carlo methods, Coupled Cluster, In-medium SRG, Self-Consistent Green's Function, Lattice EFT and variants of ab initio shell model. With the benchmarks between different approaches becoming more and more solid, we are now at the point where the limitations and range of validity of nuclear Hamiltonians can be quantitatively discussed. From this point of view, neutron-rich systems offer unique opportunities to challenge our knowledge built over the years on nucleon-nucleon/few-body scattering and stable nuclei.

The importance of three-body forces to qualitatively describe the nuclear drip line in oxygen and others isotopic chains has been recently highlighted. Radii, excitation spectra and several other low-energy observables are poorly reproduced when three-nucleon forces are not incorporated. Moreover, there is strong theoretical evidence of the crucial role played by the three-neutron interaction in neutron stars. The three-neutron force is now clearly the bridge between symmetry energy and radii of neutron stars, with future measurements/observations adding strong constraints to its form.

Recently, claims on the possible observation of a low-lying four-neutron resonance in Japan have revived the attention on (quasi-)bound few-neutron systems. Few other experiments are planned with increased statistic in different labs worldwide, with the aim of shedding light on the tetra- neutron. Such a system presents a challenge for theory, with difficulties related to the treatment of continuum and the scarce knowledge of three- and four-neutron forces. Several calculations are underway and more are to be expected. The combination of both experimental and theoretical studies will definitely provide precious information on interactions between neutrons.

In future years a substantial part of the experimental effort will be devoted to extend our knowledge on the neutron-rich side of the Segrè chart, with major large-scale facilities either concluding their upgrades (GANIL, RIKEN, ISOLDE, SPES) or in completion process (FRIB, FAIR). In this evolving scenario, it is important to understand which experiment and/or system, among all possibilities, can most help our theoretical description and thrive a consistent understanding of neutron-rich systems.

In view of this growing attention, the workshop addressed the following themes:

- Theoretical and experimental efforts and prospects in determining the drip-line of medium-mass nuclei
- Which systems are more suited to probe/explain the appearance or disappearance of magic numbers?
- Limits of validity and/or approximations of current many-body techniques
- What we can say about the T=3/2 part of three-body forces based on actual experimental results, and how this propagates to the neutron matter equation of state and neutron stars?
- What are the experimental needs from theory in the neutron-rich sector, and vice versa?

Results and Highlights

The workshop offered the opportunity, for researchers working on the physics of neutron-rich systems, to confront and discuss complementary and overlapping approaches, theoretical tools and experimental programs. A lively and constructive debate took place over several days on the possible existence of a (bound or resonant) state of 4 neutrons, the tetraneutron. Past, present and future experimental efforts towards its detection were discussed (Marqués, Uesaka). Discordant theoretical calculations were reviewed (Carbonell, Greene, Lasauskas, Lynn). One the most critical points was identified in the mathematical tools used to identify the (position of the) resonance in approaches that are typically built to address bound states. Extensions to other very light and neutron-rich systems were also reviewed (Hiyama).

Recent experimental advances in measuring properties of medium-mass nuclei towards the drip-line were presented by several speakers (Garcia Ruiz, Gibelin, Kanungo, La Cognata, Suda). In different regions of the nuclear chart, namely for light systems, around Z=20 and around Z=28, there is a fruitful interplay between such forefront experimental programs and theoretical, especially ab initio efforts. This provides a superb testing ground for the development of new-generation nuclear interactions and the refinement of many-body methods, as outlined in a few excellent theoretical presentations (Barbieri, Duguet, Gebrerufael, Hagen, Holt, Lonardoni, Navrátil, Vigezzi). Such systems offer the possibility to test particular applications of effective field theory (EFT) as well as to revisit the very bases of EFT for low-energy nuclear physics (Drissi, Ji, Pederiva).

Last but not least, recent progress on the determination of the nuclear equation of state was reviewed, with particular focus on neutron matter and implications for the neutron-star equation of state (Carbone, Riz, Tews). In that respect, a useful insight is provided by calculations with explicit Delta degrees of freedom (Logoteta).

3.3.6 SPACE-LIKE AND TIME-LIKE ELECTROMAGNETIC BARYONIC TRANSITIONS

DATE: May 08 - 12, 2017

ORGANIZERS:

P. Cole (Lamar University, USA)
B. Ramstein (IPNO, France)
A. Sarantsev (Univ. of Bonn, Germany and PNPI Gatchina, Russia)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The general theme of the workshop concerned the study of electromagnetic baryon transitions. Extracting these transition amplitudes over a broad range of q^2, gives keen insight into the evolution of meson-cloud effects and how dynamically generated masses emerge from the asymptotically-free, nearly massless quarks of perturbative QCD. The internal structure of the baryons is encoded within electromagnetic transition form factors, which are analytic functions of the four-momentum transfer squared q^2. The space-like region ($q^2<0$) is explored using meson electroproduction experiments, while the time-like region ($q^2>0$) can be accessed at low q^2 via the Dalitz decays of the baryonic resonances and at large q^2 in e^+e^- annihilation reactions. At the $q^2=0$ point, photoproduction measurements anchor the connection between the space-like (SL) and time-like (TL) regions. In addition, the photoproduction experiments coupled with the complementary pion-beam data provide the requisite knowledge on baryon properties thereby allowing for the extraction for full information on electromagnetic structure of the baryon transitions. In the time-like region, the Dalitz decays of baryons provide the elementary background for the search of medium modifications of baryons in strongly interacting matter via e^+e^- emission. The area of research afforded by studying excited baryons and extracting the transition form factors (TFFs) sets the common ground for the time-like and space-like communities to collaborate. Up until now, these two communities have not coordinated efforts nor have had a common workshop. This ECT* workshop marks the first such collaborative effort in sharing the disparate information across the space-like and time-like divide. The goal of the meeting was to bring together experts from these two different communities with the aim to build bridges and enhance cross-fertilization so as to increase overall knowledge on the nature of baryons by making full use of the suite of data from the time-like and space-like regimes.

The main topics were:

- Proton and neutron transitions in the space-like region
- Studies of time-like electromagnetic transitions
- Vector mesons in medium and the connection with electromagnetic structure of time-like electromagnetic baryon transitions
- Baryon spectroscopy from photoproduction and meson beam experiments
- Unified description of space-like and time-like transitions
- Prospects for future studies

SPEAKERS:

D. Binosi (ECT* Trento, Italy)

V. M. Braun (Univ. of Regensburg, Germany)

W. Briscoe (George Washington University, USA)

P. Cole (Idaho State University, USA)

S. Costanza (University of Pavia, Italy)

A. D'Angelo (INFN and University of Rome Tor Vergata, Italy)

M. Döring (George Washington University, USA)

C. S. Fischer (Univ. of Giessen, Germany)

B. Friman (GSI Darmstadt, Germany)

T. Galatyuk (TU-Darmstadt, Germany)

L. Ya. Glozman (University of Graz, Austria)

R. W. Gothe (Univ. of South Carolina, USA)

H. Haberzettl (George Washington University, USA)

K. Joo (Univ. of Connecticut, USA)

H. Kamano (KEK, Japan)

E. Klempt (Univ. of Bonn, Germany)

S. Leupold (Uppsala University, Sweden)

M. Niiyama (Kyoto University, Japan)

V. A. Nikonov (University of Bonn, Germany)

M. T. Peña (IST Lisbon, Portugal)

R. Rapp (Texas A&M University, USA)

J. Ritman (FZ Jülich, Germany)

H. Sako (JAEA, Tokyo, Japan)

P. Salabura (UJ Cracow, Poland)

B. Sarantsev (PNPI Gatchina, Russia and Univ. of Bonn, Germany)

H. Schmieden (Univ. of Bonn, Germany)

K. Schönning (Uppsala University, Sweden)

F. Scozzi (IPN Orsay, France and TU Darmstadt, Germany)

K. Semenov (PNPI Gatchina, Russia)

I. Strakovsky (George Washington University, USA)

J. Stroth (Univ. of Frankfurt, Germany)

A. Thiel (Univ. of Bonn, Germany)

L. Tiator (Univ. of Mainz, Germany)

R.-A. Tripolt (ECT* Trento, Italy)

J. Wambach (ECT*, Italy and TU Darmstadt, Germany)

M. Zétényi (WRCP Budapest and EMMI Darmstadt, Germany)

SCIENTIFIC REPORT:

Electromagnetic transitions in the space-like region ($q^2<0$) have been intensively explored using meson electroproduction experiments for q^2 up to ~5 GeV^2 with the CLAS detector at JLab (R. Gothe, K. Joo). Helicity amplitudes have been measured for many baryon resonances (up to N → N(1720) and Δ(1700)). The extraction of the same helicity amplitudes in different meson production channels (1π, 2π, η) and using different analysis techniques, such as dispersion relations and isobar models, have provided invaluable checks of the robustness of the results. Insight into the light-quark-flavor separated electrocouplings can be expected from the ongoing studies of neutron transitions. JLab has recently been upgraded to 12 GeV and the new CLAS12 detector will soon extend these form-factor measurements up to ~10 GeV^2. The availability of precise measurements over a large range in q^2 has already allowed for the extraction of meson cloud and quark core contributions to the helicity amplitudes of each transition. As expected, the meson cloud shrinks as q^2 increases, giving way to the quark core part, from which the evolution of the constituent quark mass can then be inferred. The differences between the relative weights of the meson-cloud and quark-core contributions for the different transitions are very spectacular and reflect the sensitivity of the helicity amplitudes on the baryon quantum numbers. Although admittedly not unambiguous, the distinction between meson cloud and quark core is effective and relevant degrees of freedom in ascertaining how baryon electromagnetic structure evolves with distance and thereby allows us to ascertain how dynamically-generated masses emerge from the asymptotically-free, nearly massless quarks of perturbative QCD.

The asymptotic behavior of the helicity amplitudes was further discussed in the meeting. Although in many baryon resonance cases there appears to be a scaling of the helicity amplitudes with increasing q^2, which is consistent with perturbative QCD, the CLAS12 data at larger q^2 are needed to confirm this scaling behavior.

The case of the Roper N(1440) was discussed in great detail. Up until very recently the structure and mass of the Roper was a mystery. Thanks to the huge improvement afforded by the accuracy and precision of electroproduction experiments, the matter of the structure of the N(1440) has been resolved. The possibility of a hybrid structure of the N(1440) resonance is now excluded and the helicity amplitudes at large q^2 are fully consistent with radial excitation of the 3-quark core. Further, the q^2 dependence of form factors will soon be investigated in the upcoming CLAS12 experiments in the search for hybrid baryons in the $\pi\pi$ and KY channels (A. D'Angelo).

The study of excited baryons in the time-like region are still in its infancy but promising results in the low q^2 region using the Dalitz decay of baryonic resonances have been provided by the HADES collaboration (P. Salabura, F. Scozzi). The first measurement of the Dalitz decay of the Δ(1232) baryonic resonance in the pp reaction at 1.25 GeV has been recently published. The study of higher-lying resonances is informative about the role Vector Dominance plays in time-like form factors but clear and decisive interpretation is hindered by the model dependence due to the unavoidable overlap between the broad states in the pp reaction. The π^-p reaction offers a more direct way to probe time-like electromagnetic form factors. This motivated new HADES experiments with the GSI pion beam and the results of a pioneering experiment have been reported.

Only a few theoretical attempts have been made to calculate electromagnetic form factors in the time-like region. Such models should reproduce existing data in the space-like region and provide an extension to the time-like region, consistent with the known particle production channels (e.g. vector meson at low q^2). A constituent quark+meson cloud model (T. Peña) has been developed along this line for the transitions to Δ(1232) and N(1520). A two-component VDM model reproducing the couplings at the photon point was also presented (M. Zetenyi). Moreover, A. Sarantsev proposed a model-independent and combined analysis of pion-, photo-, and electroproduction based on a partial-wave-analysis solution, which can be used as a predictive tool for the e^+e^- production in π^-p reaction. In addition to the e^+e^- invariant mass, the distributions of two other interesting observables are the virtual photon angle, which is sensitive to the spin and parity of the baryonic transition and the helicity angle, which gives additional information on the electromagnetic structure of the transition. A preliminary analysis of the HADES data in pion-induced reactions allowed to extract a parameterization of the angular distributions based on the spin density matrix formalism showing sensitivity to the virtual photon polarization for the first time. Such analysis will be continued in future at GSI in the second resonance region.

At large q^2, time-like electromagnetic transitions can be studied in e^+e^- annihilation reactions. The present analysis of BESIII data with $\sqrt{s}$ between 2 and 5 GeV is focused on nucleon or hyperon elastic form factors (K. Schönning). In the near future, hyperon Dalitz decays will also be studied at HADES (J. Ritman). Hyperons present the advantage of being narrow and likely to be identified by means of invariant masses in pp or even pA reactions, where high rates are available. The production of double strange hyperons (like Ξ^{--}(1321)) will also be investigated with the aim at understanding the origin of the very large cross sections measured in nuclear reactions far below threshold. The physics program devoted to hyperons will be extended at PANDA in antiproton-proton reactions. PANDA can indeed play a significant role for the hyperon spectroscopy, with a particular interest to the search for missing Ξ and Ω states. New theoretical works are developed for electromagnetic transitions of hyperons, as the one presented by S. Leupold, which is based on chiral perturbation theory.

The highlights of the experimental investigation of the QCD diagram are the search for new exotic phases, the transition to deconfined phases, the critical point, the equation of state of hot and dense QCD matter and chiral symmetry restoration. This quest requires the measurement of excitation functions of many observables (excess and flow of dileptons, strange and multi strange particle production, as well as fluctuations). This is an ongoing task of collaborations studying heavy-ion collisions from LHC and RHIC energies down to GSI/SIS18 (1-2 GeV/nucleon) (J. Stroth, T. Galatyuk). The talks at our workshop presented details about the results and perspectives of the HADES and STAR collaborations as well as the new CBM project at FAIR.

After 30 years of investigations of dilepton production in heavy-ion collisions, there is now a robust understanding across the QCD diagram in terms of quark-gluon plasma and hadronic radiation with melting ρ resonance. A great step has been taken recently towards this global description thanks to the availability of new coarse-grained transport approach. They combine the properties of hydrodynamics and transport calculations and allow for a calculation of emission rates taking into account the evolution of the bulk properties (densities, temperatures) during collision. The ρ melting arises as a result of the interaction with hadrons or with the in-medium pion cloud (J. Wambach, R. Rapp), an effect which depends on temperature but even more strongly on baryon density. A consistent ρ melting is also observed in gauged linear sigma models within the functional renormalization group (R-A. Tripolt). Another interesting effect is the disappearance of chiral mass splitting (a1-ρ, N-N1535) observed in various approaches (chiral Lagrangians, QCD sum rules, and lattice QCD calculations). The simultaneous reduction of the order parameters of the chiral symmetry restoration (pion decay constant and scalar condensate) when temperature increases is scrutinized as a way to understand the mechanisms in chiral symmetry restoration. The inputs of the hadronic models are consistent with $\pi N \rightarrow \rho N$ and nuclear photo-absorption data, but the necessity to have more constraining experimental data from baryon spectroscopy was discussed. The question of polarization of the ρ in a thermal medium was also addressed (B. Friman).

A huge quantity of information of interest for baryon spectroscopy studies was provided in the last decade by meson photoproduction reactions. Single- and double-polarization observables in π° and η production are particularly useful for separating the helicity amplitudes. Measurements on the neutron, moreover, give supplementary information on the different isospin combinations. The activities at MAMI with the A2 detector (S. Constanza) and at ELSA with CBELSA/TAPS (Annika Thiel) were presented. Recently, the measurement of multi-meson final states (π° π° or π° η) was used to investigate cascade decays. Their interpretation attracts considerable interest since a natural explanation for some missing states could be that they cannot be excited directly from the nucleon, but only to other excited baryons. Much emphasis has recently been put on the charm sector. The discovery of the X,Y,Z states triggered various hypotheses on their nature; the interpretation of the two structures observed at LHCb around 4.4 GeV/c^2 as pentaquarks is controversial. The observations could be simply related to threshold effects as well documented in the strange sector. The BGO-OD experiment has recently started to take data at ELSA. The open-dipole arrangement in the forward direction is optimized for the low-*t* meson photoproduction, coupled with the high neutral detection to gammas in the central region and the high linearly polarized photon beam, the BGO-OD experiment will provide new data for hyperon production (H. Schmieden).

Several theoretical and phenomenological talks at the workshop offered a complete review of the existing tools (PWA, coupled-channel technique,…) for the extraction of information on baryon spectroscopy. I. Strakovsky presented a review of results provided by the SAID analysis of meson photoproduction with emphasis on the impact on the most recent data on the sensitivity of PWA. H. Kamano discussed applications of the ANL-Osaka dynamical coupled-channel approach for electromagnetic transition form factors, ηN scattering parameters, ν induced reactions and hyperon spectroscopy. New precise estimates of branching ratios for the decays of baryonic resonances to vector meson nucleon and KΛ channels have been deduced from CLAS and CB-Elsa data using the Bonn-Gatchina analysis (V. Nikonov). MAID is a collection of online programs for pseudoscalar meson-, photo-, and electroproduction (L. Tiator). One of the outcomes is an empirical parameterization of transition form factors, which can be extrapolated to low q^2 in the time-like region. The Siegert theorem gives in addition useful constraints for the longitudinal form factor at q^2=0. There was also a talk on the importance of consistently implementing gauge invariance locally for the description of electroproduction experiments (H. Haberzettl). The LASSO technique (M. Döring) offers a way to scan large classes of models, selecting the simplest model with minimum number of parameters and prediction error.

The validity of the quark model was addressed in particular by E. Klempt. Although recent studies have allowed the identification of new resonances predicted by the quark model, up to now many resonances still remain unobserved and are thus termed *missing resonances*. Dyson-Schwinger equation approaches offer a very promising and fruitful tool to make *ab initio* QCD calculations, as discussed by C. Fischer and D. Binosi. This approach has been applied to calculations of the baryon spectrum and transition form factors and allows investigations of the origin of properties like Vector Dominance in electromagnetic form factors or chiral symmetry breaking. Concerning baryon transition form factors, good agreement with the data at large q^2 is obtained, while the description at lower q^2 is limited due to meson-cloud effects which cannot be taken into account at the moment by such approaches. We also learnt about theoretical studies to investigate the relation between chiral symmetry and confinement in QCD (L. Glozman).

The lack of precise data from pion-induced experiments was stressed by many speakers. In particular our knowledge of πN, ρN and other quasi-body $\pi\pi$N final states comes mainly from isobar-model analyses of $\pi N \rightarrow \pi\pi N$ data. A larger experimental database is needed to determine precisely the partial wave amplitudes, including polarization measurements. Many amplitudes are indeed required to describe 3-body final states. This motivates projects of future meson beams (W. Briscoe). In the meantime, the GSI pion beam can be used. Two-pion production in $\pi^- p$ reaction was already measured by HADES (P. Salabura) in the N(1520) region and there is a plan for measurements in the second resonance region. Similar measurements are also in preparation at JPARC (H. Sako). N. Niiyama presented data on photoproduction of the ϕ vector meson at LEPS and of pseudoscalar η meson at LEPS2, as well as strange and charmed baryon production at BELLE.

Two talks were devoted to QCD studies not directly connected to baryonic transitions: the talk of V. Braun on nucleon axial form factor and the one by K. Semenov-Tian-Shansky on baryon to meson transition distribution amplitudes.

The summary of the workshop (P. Cole) clearly emphasized the variety of the results presented and the connections that exist. He listed the open issues that ought to be addressed in future joint activities and proposed the writing of a white paper on the subjects of the workshop.

Results and Highlights

It is always a pleasure to organize a meeting in ECT* Trento where very efficient support and good working conditions are available. We were also especially proud and happy to trigger scientific interest from the ECT* staff and to count among our speakers the director and two other members of the ECT*.

Our workshop had a challenging goal. We sought to bring together experimentalists, theorists, and phenomenologists from the disparate communities working on different aspects of electromagnetic baryon transitions and find common goals, interests and establish possible collaborations. This was the first time such a group has met at such a workshop. The workshop was a success offering a satisfactory balance among physicists of the different topics and also between experts and younger scientists. If it had not been already clear to the attendees before the workshop, the strong links between and among the different topics in the time-like and space-like regimes became abundantly clear towards the end of the workshop.

We had a complete review on the current state of knowledge on baryon spectroscopy, with the requisite theoretical tools. Unfortunately, due to travel problems two of the Lattice QCD speakers could not attend. They would have certainly added to the meeting.

The contrast between the knowledge in the space-like region, where very precise data are available, and the pioneering studies in the time-like region were striking at the workshop. The expertise acquired in the space-like region will assist in developing the needed tools for extracting the baryon transition form factor information in the time-like region. How to reach a global understanding of space-like and time-like form factors is an ambitious goal, but the meeting allowed to tackle the problem on sound scientific facts and to trigger interest on this topics.

Our four discussion sessions were very lively and fruitful. They addressed open questions which were strongly discussed, as the pertinence of the concept itself of baryon resonances, the quark-hadron duality, the types of new experimental results needed, the ambiguity of the meson cloud/constituent quark pictures, the interpretation of time-like form factors. The development of new theoretical tools and perspectives of new experiments also triggered vivid discussions.

A point of convergence of outmost importance has been the acknowledgement that progress in baryon spectroscopy needed to provide the base for studying vacuum and in-medium baryon transitions is currently hindered by the lack of data from meson-beam facilities. This should guarantee the support from the different communities represented in our meeting for the construction of such facilities in the next decade.

In summary, the key word to describe our meeting was cross-fertilization. It definitely helped reinforce existing joint works, but it is also very satisfactory and gratifying that new initiatives originated directly from discussions at the workshop.

First P. Cole proposed in the summary talk of the workshop to coordinate a white paper on SL TL form factors, which attracts enthusiasm and needs now to come to reality.

Three months later a session (chaired and organized by Philip Cole) entitled “Baryon structure through meson electroproduction, transition form factors, and time-like form factors” was set up at the NSTAR workshop on the physics of excited nucleons in August 2017 in Columbia, South Carolina. This was the first time that such a session has convened at NSTAR. This parallel session was well attended.

It is also worth to note that, following discussions at the workshop, a new collaboration started between the Bonn-Gatchina PWA and the Giessen coupled-channel groups.

Finally, a Letter of Intent for a Joint Research Activity in the framework of H2020 European Integrating Initiative in Hadron Physics has been prepared by a group of attendees of the workshop.

3.3.7 LANDAU FERMI LIQUID THEORY IN NUCLEAR AND MANY BODY SYSTEMS

DATE: May 22 – 26, 2017

ORGANIZERS:

D. Davesne (Université de Lyon, IPN Lyon, France)
A- Pastore (University of York, United Kingdom)
A. Rios Huguet (University of Surrey, United Kingdom)

NUMBER OF PARTICIPANTS: 18

MAIN TOPICS:

The workshop aimed at bringing together the scientific community to discuss Landau Fermi liquid theory (FLT) to improve the nuclear many-body problem. FLT is a cornerstone of quantum many-body systems with a universal character that can be successfully applied to a variety of fermionic systems, including nuclei and nuclear matter. The workshop brought together quantum many-body practitioners, both within and outside the nuclear domain, as well as nuclear density functional experts, to review past achievements and recent advances in nuclear FLT.

The main topics were:

- FLT & energy density functional techniques: infinite & finite size instabilities
- FLT & energy density functional techniques: the tensor channel
- FLT & nuclear observables: connection between infinite matter and nuclear experiments
- FLT parameters from microscopic ab initio calculations
- FLT in condensed matter (helical FLT)

SPEAKERS:

M. Anguiano (Univ. of Granada, Spain)

M. Baldo (INFN Catania, Italy)

M. Bender (IPN Lyon, France)

K. Bennaceur (IPN Lyon, France)

O. Benhar (Univ. la Sapienza, Rome, Italy)

M. Grasso (IPN Orsay, France)

J. W. Holt (Texas A&M, USA)

A. Idini (University of Surrey, UK)

E. Kolomeitsev (Matej Bel University, Slovakia)

J. Maciejko (Alberta, Canada)

A. Polls (Univ. of Barcelona, Spain)

X. Roca-Maza (INFN Milano, Italy)

I. Vidaña (Coimbra, Portugal)

C. Yang (IPN Orsay, France)

F. Pederiva (Univ. of Trento, Italy)

SCIENTIFIC REPORT:

FLT provides a basic understanding of interacting fermionic systems from very generic principles. The existence of fermionic quasi-particles is a basic building block for this low-energy theory that describes strongly interacting many-body systems in terms of weakly coupled excitations around the Fermi surface. The connection between thermodynamical properties and weak quasiparticle interactions is established by means of the so-called Landau parameters, which describe the particle-hole interaction around the Fermi surface.

Since its inception in the 1950s, this fundamental theory has found applications in a variety of systems and fields. In this workshop, we explored applications in nuclear systems and topological insulators; the synergies between FLT and density functional theory; and microscopic aspects of Landau parameter calculations.

Given the small number of participants (17 in total), each speaker was given a 50+25 minutes slot to discuss in detail research questions, their fit within FLT, and technical aspects. The format was successful and allowed for frequent and direct speaker-audience interactions. The long format of the talks also facilitated the interaction between scientists working on many-body problems in very different domains, ranging from transport properties of neutron stars to topological insulators.

At the end of each day, 45-minute discussion sessions were focused around different aspects of FLT. The main goal was to clarify important aspects of the model trying to reach a consensus on how this theory could be used to guide other phenomenological many-body methods as for example Nuclear Energy Density Functional theory.

2 of the 4 workshop deliverables were of a scientific reporting nature:

1. *To review past achievements and discuss recent progress on nuclear FLT.*

   Several speakers discussed recent applications of FLT in a variety of nuclear systems, particularly in aspects of nuclear response (Kolomeitsev, Baldo) and neutrino propagation (Benhar, Pederiva).

2. *To explore applications of FLT and exploit new developments in other fields that can be of use in low-energy nuclear physics.*

The implications of FLT for astrophysics were highlighted in several talks (Holt, Benhar, Vidaña). Non-nuclear quantum many-body systems were discussed as well, with focused talks on hard spheres (Polls) and helical Fermi liquids (Maciejko).

Results and Highlights

Because of the very intensive discussions at the workshop, the following 2 deliverables were considered:

1. *The set-up of a task force of different ab initio practitioners that will compute Landau parameters with specific interactions to quantify many-body uncertainties.*

   A comparison of Landau parameters, obtained with CBF (Benhar) and chiral-based many-body perturbation theory (Holt) showed that there were significant differences in the Landau parameters of neutron matter. A first step towards pinning down the origin of these differences (by removing the dependence on the NN force) will be addressed by this task force. Landau parameters can nowadays be computed in these two approaches (CBF, Benhar/Lovato and MBPT, Holt) as well as Brueckner Hartree Fock (Vidana) and Self-Consistent Green's functions (Rios). These non-perturbative calculations also have the potential to bridge the gap between recent EDF efforts (Grasso) and effective field theory approaches at low densities can for unitary gases (Yang) and low-density hard-sphere systems (Polls).

2. *The tensor terms of the effective interaction should be globally fit and the FLT-based instability analysis should be a minimum requirements.*

Gogny (Angiano), Skyrme (Bender, Bennaceur) and pseudopotential (Idini) practitioners are now introducing tensor terms in the nuclear EDF. These terms matter for specific combinations of single-particle energies, although the comparison with EDF eigenstates is not free of systematics. Global refits including the tensor term are difficult (only achieved so far in Skyrme EDFs), particularly because the observables that have been used to fit these are so far of a single-particle nature. An instability analysis based on FLT can provide indications of unphysical regions in parameter space, and thus help constrain the parameter space of the fit.

3. *There are sensitive spin-dependent and tensor observables that could be used in EDF fits beyond single-particle structure information.*

   Much as Skyrme RPA calculations can be used to devise new EDF parametrizations that reproduce isospin-dependent resonances (Roca-Maza), nuclear spin resonances (e.g. 0-) might be amenable a similar procedure. This would help pin down spin-dependent tensor terms in the EDF. The phenomenological description of these resonances has been often based on FLT. New RPA calculations (Roca-Maza) and/or new approaches to address the nuclear response (Pederiva, Baldo) would provide a more systematic setting to fit the tensor term in the EDF.

During the meeting, a very preliminary set of results concerning properties of Landau parameters at lowest order in many-body perturbation was achieved. These will be extended to higher orders of many-body perturbation theory in further meetings. All participants agreed that FLT is a useful tool in nuclear physics that could be developed further. The organisers will seek for further opportunities (EMMI Rapid Task Force, one-day workshops) to establish a series of future meetings that can help cement the status of FLT as a key many-body approach in nuclear structure, dynamics and nuclear astrophysics.

3.3.8 BRIDGING NUCLEAR AND GRAVITATIONAL PHYSICS: THE DENSE MATTER EQUATION OF STATE

DATE: June 05 – 09, 2017

ORGANIZERS:

A. Bauswein (Heidelberg Institute for Theoretical Studies, Germany)
A. Carbone (TU Darmstadt, Germany)
J. A. Clark (Georgia Tech, USA)
J. M. Lattimer (Stony Brook NY, USA)

NUMBER OF PARTICIPANTS: 41

MAIN TOPICS:

The workshop aimed at stimulating collaborations and fertilizing the dialog between the nuclear physics, astrophysics and gravitational-wave communities in the quest to determine the properties of the dense matter equation of state (EoS). On the one hand, efforts in the microscopic description of neutron-rich matter can help to constrain and to validate the large number of EoSs employed in astrophysical numerical simulations. On the other hand, neutron-star oscillations produced in astrophysical events such as core-collapse supernovae or neutron-star mergers represent a unique probe for high-density matter. The characteristic oscillations are visible in the gravitational-wave signal and may be measurable as the sensitivity of the current instruments increases. Hence, an interplay between gravitational-wave astronomy, together with astrophysical simulations and input from nuclear physics, has been the objective of the workshop, in the pursuit to finally help pin down the dense matter EoS.

The main topics were:

- Nuclear matter, symmetry energy and constraints on the neutron-star matter EoS
- EoS of hot and dense matter: ab initio, mean-field and beyond
- EoSs for astrophysical simulations: nuclear energy density functionals
- Gravitational-wave imprint on the dense matter EoS: neutron-star mergers and black holes-neutron stars binary systems
- Gravitational-wave detection and data analysis

SPEAKERS:

A. Carbone (TU Darmstadt, Germany)

N. Chamel (ULB, Belgium)

K. Chatziioannou (Canadian Institute for Theoretical Astrophysics, Canada)

J. Clark (Georgia Tech, USA)

A. Da Silva Schneider (Caltech, USA)

R. De Pietri (Univ. of Parma, Italy)

W. Del Pozzo (Univ. of Pisa, Italy)

A. Endrizzi (Univ. of Trento, Italy)

B. Lackey (AEI Potsdam-Golm, Germany)

J. Lattimer (Stony Brook, USA)

C. Lazzaro (INFN Padova, Italy)

A. Maselli (Univ. of Tübingen, Germany)

A. Perego (TU Darmstadt, Germany)

D. Radice (Princeton University, USA)

L. Ravera (Politecnico di Torino, Italy)

S. Reddy (INT Seattle, USA)

L. Rezzolla (Goethe University of Frankfurt,

F. M. Fabbri (Univ. of Trieste, Italy)

A. Fantina (GANIL, France)

B. Giacomazzo (Univ. of Trento, Italy)

S. Greif (TU Darmstadt, Germany)

C. Gonzalez-Boquera (Univ. of Barcelona, Spain)

F. Guercilena (Goethe University of Frankfurt, Germany)

T. Hinderer (AEI Potsdam-Golm, Germany)

C. J. Horowitz (Indiana University, USA)

H.-T. Janka (MPA Garching, Germany)

Germany)

A. Rios (Univ. of Surrey, UK)

L. Riz (Univ. of Trento, Italy)

A. Schwenk (TU Darmstadt, Germany)

M. Shibata (YITP Kyoto, Japan)

I. Tews (INT Seattle, USA)

S. Traversi (Univ. of Ferrara, Italy)

M. Tringali (Univ. of Trento, Italy)

I. Vidaña (Univ. of Coimbra, Portugal)

K. Yagi (Princeton University, USA)

SCIENTIFIC REPORT:

The equation of state (EoS) of neutron-rich matter at sub- and supranuclear densities poses important challenges due to the uncertainties related to the symmetry energy and its density dependence. The form of the EoS strongly affects the dynamics of heavy-ion collisions, as well as the stellar properties of neutron stars, the core-collapse supernova mechanism or the nucleosynthesis path in neutron star mergers. Hence, its detailed knowledge can unravel novel aspects of physical phenomena that range from nuclear structure to astrophysics. Recently, the mutual combination of theoretical nuclear physics and astrophysical observations has provided constraints on the cold neutron star matter EoS and the mass-radii relation. Nonetheless, these measurements and calculations are still compatible with a variety of different candidate EoSs, and tighter constraints on the properties of high-density matter are highly desirable, from both a nuclear and an astrophysical point of view. Moreover, certain astrophysical events like core-collapse supernovae and neutron-star mergers are additionally affected by the finite-temperature behavior of the dense matter EoS. Recently, the first detection of gravitational waves from a black hole merger by Advanced LIGO has triggered a lot of interest in the modelling of neutron-star mergers and in investigating the EoS dependence of these events. On the one hand these simulations rely crucially on the interaction of astrophysicists with the nuclear physics community providing the microphysics input. On the other hand the modelling of compact object mergers can be employed to interpret future gravitational-wave detections, which may then in turn provide deeper insights into the properties of cold and hot dense matter.

Set up in a time when gravitational-wave emission has been for the first time detected by Advanced LIGO, we brought together within this workshop at ECT* experts involved in the microscopic description of nuclear matter, specialists in the simulations of the gravitational-wave emission from merger events, and researchers devoted to gravitational-wave data analysis. Each of these three communities was represented by one/third of the participants. The main themes covered can be summarized within the following three bullets, pertaining to the objectives of each community:

- From the point of view of nuclear physics, speakers have presented recent advances in the description of infinite nuclear matter both from an ab-initio and a density functional theory perspective. The properties of cold and hot matter were discussed within several different nuclear many-body methods, of a variational, diagrammatic or Monte Carlo kind, with the use of realistic interactions. The use of chiral nuclear forces has been particularly stressed, to link with the underlying quantum theory, QCD. Nuclear physics constraints have been examined, highlighting the importance of reasonable neutron-star matter equations of state in accordance with the nuclear physics. All-purpose unified equations of state for astrophysical simulations have been discussed from an energy density functional point of view, debating the importance of providing a unique equation of state valid for a range of temperatures, densities and proton fractions.

- From the point of view of astrophysical simulations, the properties of the high-density matter EoS have been discussed via the imprint it leaves on the gravitational-wave signal from neutron-star mergers. Talks have debated how the stiffness of the EoS affects the dynamics of the postmerger phase and, in particular, the frequencies of the excited oscillations modes. Furthermore, emphasis has been put in examining the tidal deformability in the late inspiral phase of a neutron star-black hole or double neutron star binary merger, which encodes information on the EoS. Attention has been given to (quasi-)universal relations in the gravitational-wave emission as a way to understand the properties of neutron-star merger physics.

From the point of view of the gravitational-wave data analysis, speakers have explained the techniques used to analyze the signals received by the detector via use of modeled vs. unmodeled characterizations of the wave-forms. Furthermore, advances in the modelling of waveforms for binary neutron stars have been presented, setting the status and the remaining challenges for gravitational-wave astronomy.

Results and Highlights

The workshop was well balanced in participation between speakers belonging to the three main areas of research highlighted in the previous section. This has helped bridging between the different fields, nourishing discussions and debates not only between people pertaining to the same community, but encouraging crossroad-science. The connection between the different research areas has been successfully achieved through the different talks presented.

A fruitful balance has moreover been sought in merging participants of different level of experience: the workshop was formed by 17 seniors, 15 postdocs and 9 students. This has helped alternating the program between longer and shorter talks, and most of all gave the chance to younger people to get into contact with the more experienced researchers.

During the five days, a total of 34 talks, of which 5 from PhD students, were presented, giving 30'+5' to advanced and 15'+5' to students. Consequently the program has been in general well received both in terms of distribution of topics, timing, organization and speakers diversity background.

A concluding discussion session on the Thursday afternoon was organized. This was also in view of the inclusion of the workshop in a working group meeting event of the NewCompstar COST Action MP1304, whose objective is exploring fundamental physics via compact stars. Topics of the discussion session ranged from understanding the impact of dynamical/non-linear tides on the EoS extraction, to examining challenges in modelling the inspiral vs./with the post-merger phase of the gravitational-wave signal, all the way to debating the importance of viscous dissipation both in the inspiral and post-merger phases.

3.3.9 NUCLEAR ASTROPHYSICS IN THE GRAVITATIONAL WAVE ASTRONOMY ERA

DATE: June 12 – 16, 2017

ORGANIZERS:

O. Benhar (INFN and Sapienza Università, Roma, Italy)
B. Giacomazzo (Università di Trento and INFN-TIFPA, Italy)
F. Pannarale (Cardiff University, UK)

NUMBER OF PARTICIPANTS: 37

MAIN TOPICS:

Following the first direct detection of gravitational waves on September 14, 2015, the workshop addressed the general theme of probing matter at supranuclear densities via gravitational-wave and electromagnetic (i.e., multimessenger) observations of high-energy astrophysical phenomena, such as neutron star binary mergers, gamma-ray bursts, and supernova explosions. The main goal of the workshop was to bring together nuclear physicists, astrophysicists, and astronomers to examine open issues and to establish strategic synergies, needed to pave the way for an improved understanding of nuclear physics as we approached the era of multimessenger astronomy with gravitational waves.

The main topics were:

- Equation of state of neutron stars
- Gravitational wave searches
- Isolated neutron stars
- Neutron star binary mergers
- Neutron star crust physics
- r-processes
- Supernovae
- Electromagnetic observations (in the context of the topics listed above)

SPEAKERS:

S. Bernuzzi (Univ. of Parma, Italy)

M. Branchesi (Univ. of Urbino, Italy)

F. Burgio (INFN Catania, Italy)

C. Chirenti (Universidade Federal do ABC, Brazil)

A. Cumming (McGill University, Canada)

E. Endeve (University of Tennessee Knoxville, USA)

R. Fernandez (University of Alberta, Canada)

C. Fryer (Los Alamos National Laboratories, USA)

P. Mösta (Univ. of California Berkeley, USA)

F. Pederiva (Univ. of Trento and INFN-TIFPA, Italy)

A. Perego (TU Darmstadt, Germany)

J. Powell (Univ. of Glasgow, UK)

D. Radice (Princeton University, USA)

S. Reddy (Univ. of Washington, USA)

S. Rosswog (Stockholm Univ., Sweden)

B. Sathyaprahash (PennState University, USA)

D. Siegel (Columbia University, USA)

W. Ho (Univ. of Southampton, UK)

C. Horowitz (Indiana University, USA)

I. Jones (Univ. of Southampton, UK)

K. Kiuchi (Yukawa Institute for Theoretical Physics, Japan)

A. Lovato (INFN-TIFPA, Italy)

J. McEnery (NASA Goddard Space Flight Center, USA)

C. Miller (Univ. of Maryland, USA)

L. Stella (INAF – Osservatorio Astronomico di Roma, Italy)

F. Thielemann (Univ. of Basel, Switzerland)

E. Troja (NASA Goddard Space Flight Center, USA)

J. Veitch (Univ. of Glasgow, UK)

SCIENTIFIC REPORT:

On September 14, 2015, the two instruments of the Laser Interferometer Gravitational-Wave Observatory (LIGO) simultaneously detected a gravitational wave (GW) for the first time. This ground-breaking result marks the beginning of the era of GW astronomy. GWs have remarkably small amplitudes, but carry precious and otherwise inaccessible information about the emitting source, providing scientists with a new mean to learn about the cosmos which complements electromagnetic (EM) and neutrino observations.

At the time of the workshop, the next major milestone to achieve in GW astronomy was the coincident detection of GW and EM and/or neutrino radiation emitted by the same source/event, which would open the era of multimessenger astronomy incorporating GWs. Multimessenger observations can probe the heart of high-energy astrophysical phenomena – such as neutron star binary mergers, gamma-ray bursts, and supernova explosions – which drive physics to its extremes. The GW and nuclear astrophysics communities therefore faced the challenge of having to swiftly and readily progress to a stage in which instruments could be used in synergy to perform cutting edge discoveries in fundamental physics, astrophysics, astronomy, and cosmology. The first multimessenger observation occurred two months after the end of the workshop, on August 17, 2017!

The workshop brought together world experts in nuclear physics, astrophysics, and GW and EM observations. It covered several topics from a theoretical, phenomenological, and observational point of view. In order to stimulate cross-disciplinary interactions, topics were spread across the week and specific themes were not confined to a single day. The main conclusions we reached and guidelines we established with regards to the multiple themes addressed in the workshop can be summarized as follows.

- X-ray information (in 1-2 years) and GW information (in 5-10 years) on NSs will be independent enough to provide complementary tests of the NS equation of state. In this context, detailed gravitational waveform models of the inspiral, merger and post-merger from analytical/numerical relativity are of paramount importance. Awareness about systematics and biases should be raised in the context of using statistical fits to interpret X-ray or GW data.
- Dynamical ejecta from NS mergers makes the strong r-process. While there is qualitative agreement among different groups about the ejecta properties and the kilonova/macronova emission, uncomfortably large quantitative disagreements need to be addressed. Including weak interactions in the modelling of NS mergers is essential to determine the properties of the ejecta and the observables of such mergers. We need to better understand the impact of nuclear physics inputs on the r-process heating rate, as well as the composition of the dynamical ejecta. Magneto-turbulence is yet to be investigated and there is a need to better understand the relation between gamma-ray bursts and kilonovae.
- There is a need to continue an open dialog on code comparisons to help disentangle differences in the quantitative predictions made by different groups in the context of supernovae and NS mergers. Further, numerical simulations of these events should directly use inputs coming from microscopic theories of nuclear matter.

- We need to think about mechanisms for building mountains on NSs, as opposed to just working out the maximum sizes of the mountains. More observations targeted at seeing stellar oscillations in NSs (e.g., in low-mass X-ray binaries) would be great.

Results and Highlights

The workshop was a success in terms of number and diversity of the participants, and the intense cross-disciplinary discussion sessions. Among the topics we debated upon, three are well worth singling out:

- NS binary mergers as possible short gamma-ray burst progenitors. We highlighted the importance of joint GW and short gamma-ray burst observations to firmly connect the two, and to pave the way for the future of GW astronomy and gamma-ray astronomy in the post Swift/Fermi era.
- The origin of heavy elements via r-processes in NS binary mergers and the kilonova/macronova emission that accompanies them. We discussed in detail the modelling shortcomings that may be yielding quantitative discrepancies among different codes/groups and stressed the importance of firmly connecting short gamma-ray bursts and kilonovae.
- Constraining the NS equation of state will be a concrete possibility with GW observations, and multimessenger observations, but the data analysis and the modelling that will necessarily feed in to it will both have to be carried out extremely carefully.

Two months after the end of the workshop, on August 17, 2017, the first multimessenger observation of two NS merging was accomplished. This was a great success: it was the first GW observation of a binary NS system and the GW data has provided direct constraints to the NS equation of state; the short-gamma ray burst that followed allowed to confirm that NS mergers are indeed progenitors of such; a kilonova was also observed and NS binaries are now known to be sites for the formation of heavy elements via r-processes. All these achievements were central topics of discussion during the workshop. Several of the participants were directly involved in the scientific output that followed from the August 17, 2017 multimessenger observation; collaborations and dialogs opened during the workshop facilitated parts of the analyses carried out in connection with the observation.

All the talks have been collected and uploaded online on the workshop webpage (https://sites.google.com/g.unitn.it/nagw2017/home) which is directly linked from the ECT* workshop webpage (http://www.ectstar.eu/node/2223).

3.3.10 SIMULATING QCD ON LEFSCHETZ THIMBLES

DATE: June 28 – 30, 2017

ORGANIZERS:

A. Alexandru (George Washington University, USA)
P. Bedaque (University of Maryland, USA)
C. Schmidt (University of Bielefeld, Germany)

NUMBER OF PARTICIPANTS: 21

MAIN TOPICS:

Non-perturbative lattice QCD calculations at non-vanishing baryon number density are hampered by the QCD sign problem. The path integral, that in lattice QCD is calculated numerically, becomes highly oscillating. One possible solution is the Lefschetz thimble approach. It requires a deformation of the original integration domain into a manifold embedded in complex space. For properly chosen integration manifolds ("thimbles") the sign problem is drastically alleviated. For small bosonic and fermionic models this approach has been shown to work. With this workshop we explored the prospect of the Lefschetz thimble approach to get extended to full QCD and discussed current numerical and theoretical limitations.

The main topics were:

- Finding the relevant thimbles
- Sampling on the thimble
- Numerical costs and approximations
- Applications to models

SPEAKERS:

G. Aarts (Univ. of Swansea, UK)
Y. Abe (Univ. of Tokyo, Japan)
H. Fujii (Univ. of Tokyo, Japan)
S. Kamata (Keio Univ., Japan)
J. Rantaharju (Duke University, USA)
G. Ridgway (Univ. of Maryland, USA)
J. Stryker (Univ. of Washington, USA)
Y. Tanizaki (BNL, USA)
W. Unger (Bielefeld Univ., Germany)
S. Valgushev (Regensburg Univ., Germany)
N. Warrington (Univ. of Maryland, USA)
F. Ziesché (Bielefeld Univ., Germany)

SCIENTIFIC REPORT:

Since the formulation of QCD in the 1960s and 1970s, people have speculated on the QCD phase diagram. Model calculations based on the symmetries of the QCD Lagrangian suggest a surprisingly rich and complex phase structure of QCD at nonzero baryon number density. At low temperatures but high baryon number densities, various (color) super-conducting, super-fluid or even super-solid phases have been proposed, which can be homogeneous or inhomogeneous in space. One of the most prominent features of the phase diagram is the possible critical point of the chiral phase transition at intermediate densities, which is expected to be realized as a critical endpoint of a line of first order phase transitions between the chirally broken hadronic phase and the chirally symmetric quark gluon plasma phase. Using heavy ion collisions, huge efforts are made to find the critical end point and even map out the first order phase transition line. The Beam Energy Scan program II (BES II) at RHIC is scheduled to start in 2019, facilities that are supposed to work in this density regime (FAIR and NICA) are currently under construction. At the high density, low temperature region of the phase diagram, relevant to neutron star physics, the fundamental questions are to locate the density where the transition from nuclear to quark matter occurs, determine the fate of the strange degrees of freedom and determine which particular superfluid/superconducting phase is actually realized in Nature. These questions are particularly important now that the detection of neutron star mergers through gravitational waves is imminent.

Perturbation theory is applicable to QCD only at asymptotically high temperatures and densities. The picture improves slightly, using re-summed versions thereof. However, a non-perturbative first principle QCD calculation of the phase diagram is still lacking. Lattice QCD, which has proven to be extremely successful at zero baryon number density, is hampered by the infamous sign problem once a nonzero baryon chemical potential (μ_B) is introduced. The reason lies in the complex phase that is acquired by the fermion determinant at $\mu_B > 0$. The fermion determinant, which is obtained after integrating out the Grassmann valued fermion fields from the QCD partition function, is part of the weight in lattice QCD calculations. It is subject to importance sampling during a Monte Carlo integration of the grand canonical partition function. As soon as the determinant is not a real and positive function anymore, standard MC methods break down. The so-called “sign problem” arises from the fluctuating sign of the determinant that leads to extreme cancelations and an exponentially suppressed signal-to-noise ratio.

In the past, many attempts have been made to circumvent this problem, including reweighting, Taylor expansion on the chemical potential, analytic continuation from purely imaginary chemical potentials, canonical partition functions and strong coupling methods. However, they all have certain limitations. The most recent strategy is based on a complexification of the integration variables, in the same way as it is used in the Complex Langevin (CL) approach. However, the basis of the Lefschetz Thimble (LT) approach is the deformation of the original domain of integration to a manifold embedded into the complex space. Picard-Lefschetz theory tells us that associated with each complex saddle point of the effective action, there exists a manifold (”thimble”) such that the path integral can be expressed as a linear combination of Integrals over the thimbles. On each thimble the complex phase of the determinant (effective action) is constant. As this idea is rather new, its prospects for applications in full QCD are not clear at all.

The workshop gathered researchers that gained some experiences with the LT approach in model calculations, as well as some that gained experiences in related approaches such as CL simulations. The general scheme of the workshop covered the foundations of the LT approach, as well as some practical and numerical aspects. For each presented model calculation the participants discussed the number of relevant thimbles, strategies to find the thimbles, and strategies to sample on the relevant thimbles. Here the most pressing question discussed was in which way the present methods can be generalized to be more efficient in order to be applicable to higher dimensional models and/or full QCD calculations.

A further important emphasis of the workshop has been laid on the relation between the LT and CL approaches. A deeper understanding of how and why the generated distribution of the CL sampling method approaches the Lefschetz thimbles might help to improve on the current problems with the CL approach. It is known - but not fully understood why – in some cases the CL algorithm converges towards wrong results.

In addition to these main themes there were a number of other subjects covered in the workshop, including: other approaches to the sign problem like the re-weighting from complex ensembles and the strong coupling formulation of QCD. Also the application of the LT approach to real time dynamics was discussed. The related topic of resurgence theory was briefly touched.

Results and Highlights

The workshop was a very useful opportunity for all thimble practitioners to share their latest results and insights and foster collaborations between different groups in long and lively discussions. The overall workshop atmosphere was very positive. Although it became clear that most of the current methods can't be applied directly to full QCD and/or are computationally much too expensive for a realistic setting, the LT approach remains to be promising. Concerning the application in full QCD many things remain to be clarified. Some of them are related to the number of relevant thimbles in full QCD that need to be considered, others concern the gauge degrees of freedom. Also the fact that in QCD the original domain of integration is a compact manifold (integration variables are SU(3)-valued), is an aspect that most of the model calculations do not cover yet. However, some progress was achieved in terms of possible new numerical estimators of the Hessian. The Hessian matrix of the effective action needs to be computed frequently by some of the LT algorithms, which is by far the most costly part of the algorithm. Further algorithmic improvements have been discussed.

It was once more demonstrated that the CL and LT approaches are closely related, in the sense that the probability distribution generated by the CL algorithm seems to track one or even more thimbles. The reason was discussed in detail, in terms of the corresponding flow equations used in the two different algorithms. A further discussion of the re-weighting procedure from CL distributions complemented the picture. Unfortunately, a deeper under-standing of the breakdown of the CL method that goes beyond the current explanations in terms of shape parameter of the CL distribution could not be obtained. It remains to be seen whether a connection to the number phases or topology of the thimbles can be made.

In many of the presented model calculations the LT approach provided indeed a solution to the notorious sign problem. Especially, for the application to real-time dynamics of the scalar ϕ^4-model, the LT approach is currently the only ab-initio method capable of providing an answer (at least in the small time regime). Further talks and discussions on alternative approaches to the sign problem helped judge the severity of the sign problem and to classify the successes and failures of the LT method. The workshop will certainly trigger further interesting applications of the LT method. Some suggestions have been made during the discussions.

3.3.11 OPEN QUANTUM SYSTEMS: FROM ATOMIC NUCLEI TO ULTRACOLD ATOMS AND QUANTUM OPTICS

DATE: July 10 – 14, 2017

ORGANIZERS:

M. Efremov (Ulm University, Germany)
C. Forssén (Chalmers University of Technology, Sweden)
M. Gattobigio (Université de Nice, France)
H.-W. Hammer (TU Darmstadt, Germany)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

Small open quantum systems are intensely studied in various fields of physics (nuclear, atomic, and molecular physics; mesoscopic physics; quantum optics, etc.). The properties of such systems are profoundly affected by their environment, and in particular, by the continuum of their decay and inelastic scattering channels. In spite of their specific features, they also display generic properties that are common to all weakly bound/unbound systems close to threshold. The objective of this workshop, the fifth in a series, was to bring together various physics communities, which are addressing similar universal few- and many-body phenomena and using common concepts and methodologies.

The main topics were:

- Driven open quantum systems
- Dynamical phase transitions and quantum phase transitions
- Weakly bound and unbound nuclei; dripline physics
- Quantum and classical chaos
- Modern computational approaches and coupling to the continuum
- Open effective field theory and nonhermitian Hamiltonians

SPEAKERS:

P. Capel (ULB, Belgium)
R. Dörner (Frankfurt University, Germany)
L. Fortunato (University of Padova, Italy)
A. Gade (NSCL, USA)
M. Gianfreda (Centro Fermi and CNR, Italy)
G. Jansen (ORNL, USA)
A. Kievsky (INFN Pisa, Italy)
M. Lebenthal (ENS of Cachan, France)
S. Montangero (University of Padua, Italy)
G. Morigi (Saarland University, Germany)
P. Navratil (TRIUMF, Canada)
W. Nazarewicz (NSCL, USA)
T. Oishi (University of Padua, Italy)
D. Phillips (Ohio University, USA)
L. Platter (University of Tennessee, USA)
M. Ploszajczak (GANIL, France)
A. Richter (TU Darmstadt, Germany)
W. Schleich (Ulm, Germany)
C. Schmickler (TU Darmstadt, Germany)
A. Tumino (Univ. Kore and INFN-LNS, Italy)
A. Vairo (TUM, Germany)
A. Volya (Florida State University, USA)
M. Weitz (Bonn University, Germany)
M. Zimmermann (Ulm University, Germany)
N. Zinner (Aarhus University, Denmark)

SCIENTIFIC REPORT:

The framework of quantum mechanics has been set almost 100 years ago using e.g. a Hamiltonian description of the system and its evolution. The range of use of this approach covers many fields of research, from nuclear and particle physics to atomic physics, quantum chemistry and nowadays even reaching into more complex biological systems. For open systems in nuclear physics, various approaches including continuum states have been used to describe a large variety of experimental situations. Alternatively, an effective Hamiltonian approach can be used to describe the finite lifetimes of resonance states. In this workshop, we have focused on the physics of open quantum systems and gathered experts from particle and nuclear physics to atomic physics and quantum optics covering both theory and experiment.

The workshop has provided a unique opportunity to deepen our understanding of quantum mechanics in open systems as provided by recent advances in theory and experiments with trapped ultracold atomic gases. Modern experimental setups offer an incredible amount of control: the number of particles can be varied (from many to few); the geometry of the trap can be changed (effectively tuning the dimensionality from quasi 1d to 2d and 3d); and even the strength of the interaction between the species can be varied (from strongly to weakly interacting through the use of Feshbach resonances). Modern tunnelling experiments provide access to tuneable, decaying few-body systems, and the associated capability to engineer the dissipation basically allows to control the non-Hermitian part of the Hamiltonian. Different aspects of open quantum systems in connection with few- and many-body physics were discussed at the workshop.

In low-energy atomic physics, the use of effective Hamiltonians has attracted a lot of recent attention, with the advent of experimental possibilities using ultracold atoms and well-controlled light-matter interactions. We have focused on driven, open quantum systems where cooperative effects such as (i) Dicke super- and subradiance, (ii) Anderson localization, (iii) BEC of photons, and (iv) Ionization and tunnelling in systems of few electrons are studied. These research fields share many features with the studies of mesoscopic physics where transport properties are at the center of interest. Dynamical phase transitions and quantum phase transitions, as well as non-equilibrium statistics, are currently investigated in many experiments.

In low-energy nuclear physics, the growing interest in open quantum systems is largely associated with experimental achievements in producing weakly bound and unbound nuclei in the vicinity of the particle drip-lines, and efforts in studying structures and reactions with those nuclei. Unfortunately, on the theory side there is an artificial separation between nuclear structure and nuclear reactions that sometimes hinders a deeper understanding of the underlying physics. This separation can partly be explained by the huge success of the phenomenological nuclear shell model, which employs the idea of a strongly renormalized bare nuclear interaction between nucleons while it completely ignores couplings to the continuum. The time is now ripe to combine developments in the theory of open quantum systems, from different fields of research, with modern computational approaches into a unified framework for nuclear structure and reactions. A whole session on Friday was devoted to including modern effective field theories and ab initio nuclear structure input in reaction calculations. This will allow studying nuclear resonance phenomena from an ab initio perspective and will offer insights into the physics that is being explored with radioactive beam experiments. Another specific component of the nuclear many-body problem discussed in several talks at the workshop, are the strong particle correlations, which impose the need for a simultaneous description of the configuration mixing and the coupling to open decay channels.

A new theoretical development is the establishment of so-called ``open effective field theories'' whose density matrices satisfy the Lindblad equation. The theories are designed to describe multi-particle systems with deeply inelastic reactions that produce particles with large momenta outside the domain of validity of the effective theory. The term open effective field theory has initially been coined in the context of primordial quantum fluctuations in the early universe. Further potential applications range from non-relativistic QED to effective theories for heavy quarks, nuclear effective field theories and ultracold atoms. One of the workshop talks focused on the production of Quarkonia in a Quark Gluon Plasma using an open EFT.

Results and Highlights

This workshop, with dedicated free time for discussions, has provided a great opportunity for exchange of ideas, and to come up with relevant research projects that of are general interest. This workshop has been very fruitful in several ways. First it has allowed learning about the latest development in the field of open quantum system, in cold atom physics as well as nuclear and particle physics. The overview speakers allowed the participants less familiar with one of these fields of research to have an introduction into the open questions, which then have been presented in more detail by specialized talks. Questions raised by experts from one field of research for the speakers of the other field have shown that common questions and techniques exist and allowed to see which part of one's research can be useful to a larger community of researcher.

One important aspect has been the time taken for coffee and lunch breaks, which are essential to allow all the participants to meet each other and continue in the discussions and at some occasion engage in new collaborations. Also, the time after the afternoon sessions as well as the free Wednesday afternoon have been used by many participants meeting at this workshop to work together on precise aspects of their research. One example was the possible occurrence of Efimov-type Triple alpha resonances in 6Li-6Li scattering discussed by Tumino. Her talk lead to intensive discussions among nuclear and atomic physicists about possible improvements of the analysis and started a new collaboration.

We have received very positive feedback from the participants of the workshop by email, referring to the workshop as “very lively and intense”, “stimulating and exciting”, and providing “brand new perspectives”. Thus we are considering organizing a follow-up meeting in 2 or 3 years from now.

The workshop was organized with generous support from: The European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) and the ENSAR2 project within the Transnational Access Activity for its workshop activities (an integrating activity of the HORIZON2020 Programme of EU). In addition, the Swedish Foundation for International Cooperation in Research and Higher Education (STINT), the Institute for Integrated Quantum Science and Technology (IQST) of Ulm University, the Institute of Nuclear Physics of TU Darmstadt, and the Collaborative Research Center 1245 “Nuclei: From Fundamental Interactions to Structure and Stars” of the Deutsche Forschungsgemeinschaft provided additional funds that allowed generous support for all invited participants.

3.3.12 THE CHARM AND BEAUTY OF STRONG INTERACTIONS

DATE: July 17 – 28, 2017

ORGANIZERS:

A. Bashir (Universidad Michoacana de San Nicolás de Hidalgo, Mexico)
K.-T. Brinkmann (Universität Giessen, Germany)
B. El-Bennich (Universidade Cruzeiro do Sul, Brasil)
G. Krein (Universidade Estadual Paulista, Brasil)
J. Nieves (Instituto de Fisica Corpuscular - CSIC & U. Valencia, Spain)
M. Oka (Tokio Tech & ASRC - JAEA, Japan)
L. Tolos (Institute of Space Sciences ICE - IEEC & CSIC, Spain)
U. Wiedner (Universität Bochum, Germany)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The general theme of the workshop concerned the spectrum, decays, form factors and weak interactions of heavy hadrons and their properties in hot and dense matter. Over the past years, several experiments have been designed in order to extract information on heavy hadrons, such as BESIII, BelleII, ALICE, LHCb, JLab, amongst others, whereas future facilities are being planned, e.g. FAIR, NICA and the J-PARC upgrade. Moreover, various theoretical approaches have emerged as a complementary tool to study the heavy (flavored) meson and baryon spectrum, their strong, electric and weak interactions and decays. In view of the present state of theory and experiment, the proposed workshop was aimed at fostering active discussions and building up networks between theorists and experimentalists working on the physics of heavy hadrons.

The main topics were:

- Heavy Hadrons on the Lattice
- Nonperturbative Continuum QCD Approaches
- Spectrum of Heavy Hadrons
- Heavy Hadron Production and Decays
- Effective Theories in Heavy Quarkonia
- Interactions of Charmed Mesons with Nuclear Matter
- Heavy Hadrons in Hot-Dense Matter, Transition Form Factors and
- Neutral Meson Oscillations and CP violation

SPEAKERS:

M. Albaladejos (Univ. of Murcia, Spain)

M. Barabanovs (JINR, Russia)

A. Bashirs (Univ. of Michocan, Mexico)

N. Brambillas (TU Munich, Germany)

M. Albaladejos (Univ. of Murcia, Spain)

M. Barabanovs (JINR, Russia)

A. Bashirs (Univ. of Michocan, Mexico)

R. Mitchell (Indiana University, USA)

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M. Oka (Tokyo Institute of Technology, Japan)

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S. Collins (Univ. of Regensburg, Germany)

T. Doi (RIKEN, Japan)

B. El-Bennich (Cruzeiro do Sul University, Brazil)

M. Gómez-Rocha (ECT*, Italy)

P. Gubler (Keio University, Japan)

F.-K. Guo (Institute of Theoretical Physics, Chinese Academy of Sciences, China)

J. Haidenbauer (FZ Jülich, Germany)

E. Hiyama (RIKEN, Japan)

T. Johansson (Uppsala University, Sweden)

G. Krein (Instituto de Fisica Teorica - Universidade Estadual Paulista, Brazil)

X. Liu (Jülich Research Centre, Germany)

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V. Magas (Univ. of Barcelona, Spain)

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A. Ramos (Univ. of Barcelona, Spain)

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D. Rodriguez Entem (Univ. of Salamanca, Spain)

S. Ryan (Trinity College Dublin, Ireland)

T. Sekihara (Japan Atomic Energy Agency, Japan)

K. Serafin (Univ. of Warsaw, Poland)

J. Soto (Universitat de Barcelona, Catalonia)

K. Tanida (Japan Atomic Energy Agency, Japan)

L. Tolos (Institute of Space Sciences, Spain)

U. Wiedner (Ruhr-University Bochum, Germany)

R. Williams (Univ. of Giessen, Germany)

S. Yasui (Tokyo Institute of Technology, Japan)

SCIENTIFIC REPORT:

One of the primary theoretical efforts in Hadron Physics is to understand the nature of hadrons and a great deal of the research activity revolves around two fundamental questions: what constituents are the hadrons made of and how does Quantum Chromodynamics (QCD), the strong interaction component of the Standard Model, produce them? These are simple questions which, however, may not entail simple answers. To understand the measurable content of QCD, spectroscopy is a valuable and time-honored tool. Nonetheless, for many hadrons the picture of multi-quark states may not be sufficient and they may better qualify as dynamically generated (molecular) states or both, a superposition of a constituent quark core dressed by meson-baryon clouds. Experimental investigations of the hadron structure and spectrum via hadron-hadron scattering processes, photon-, meson- and electro-production from nucleons at world-wide accelerator facilities in the past decade has produced an enormous growth of available data. That data has vastly improved our knowledge of the baryon and meson spectrum, establishing the existence of new states, and enabled empirical determination of the resonance electrocouplings of most nucleons with mass less than 2 GeV. On the other hand, the structure of hadrons and their formation implies the even deeper question of how confinement is realized in QCD. From a different viewpoint, one may likewise ask under which conditions hadrons can be deconfined using temperature and density as parameters. To this end, heavy-ion colliders have been the primary source to shed light on the phase diagram and deconfinement.

At the same time, there has been a growing interest in heavy flavored hadrons in connection with many on-going experiments, such as BES III, Belle II, ALICE, LHC*b*, amongst others, as well as with planned facilities, e.g. FAIR, NICA and the J-PARC upgrade. Charm and beauty mesons are ubiquitous in many fields of particle and nuclear physics which are seemingly disconnected yet share the same theoretical difficulties: the computations of static and dynamic bound-state observables at zero and finite temperature and/or density are arduous due to their nonperturbative nature and often based on model-dependent assumptions. The charm quark, in particular, sits in an uncomfortable mass region as it is neither a light quark for which a flavor symmetry extension is justified, nor is it heavy enough to allow for a reliable heavy-quark expansion and associated factorization theorems as for the beauty quark. Various complementary theoretical tools have emerged to determine the heavy hadron spectrum, their decays, oscillations and multiple form factors, amongst which heavy quark effective theory, lattice QCD, nonperturbative continuum approaches such as Dyson-Schwinger and Bethe-Salpeter equations and Nambu–Jona-Lasinio models, effective Lagrangians and coupled-channel models.

The topics discussed during the two-week workshop have covered the following areas:

Heavy Hadrons in the Lattice
Lattice QCD plays a central role in the study of hadron spectroscopy. Masses of the light mesons and baryons are reproduced within the 5% error at the physical quark mass point Simulations of heavy quarks on the lattice require new formulations so that the continuum limit is properly taken. After recent technical developments, the present calculations show that lattice QCD works well for heavy hadrons. Indeed, a new method of lattice QCD can analyze the hadron-hadron interactions and their resonances. Such analyses may shed a light to exotic structures of hadrons.

Spectrum of Heavy Hadrons
Hadrons with one or more heavy quark(s) provide us with new opportunities to study the dynamics of QCD in hadron spectrum. As the heavy quark is subject to the (approximate) heavy-quark spin symmetry, heavy-light hadrons will allow us to extract information on color-non-singlet light quark clusters and the effect of the color confinement. Some recent results on the extensive quark model calculations of excited heavy-light hadron systems have revealed specific excitation modes.

Study of newly observed exotic resonances requires complex coupled channel approaches as multiple hadronic scattering states give significant effects on their structure. The quark model is regarded as setting the standard and the “exotic” hadrons are the ones that cannot be represented by the quark model. They include multi (4 or more)-quark states, hadron molecules, hybrid hadrons. This is the case, for example, of X(3872), first observed in B decays by Belle. It appears to be a $J^{PC} = 1^{++}$ state and its mass, $M_X = 3871.69 \pm 0.12$ MeV/c^2, coincides with the Dbar D^{*0} threshold. Its composition is controversial and numerous theoretical descriptions have been proposed, such as mixtures of pure charmonium and molecular bound states, pure molecular bound states or tetraquarks. Furthermore, to make a solid foundation for the results, comparisons of the model calculations to the lattice QCD simulations are critically important.

Heavy Hadron Production and Decays
Production and decay processes of heavy hadrons reveal their structures, wave functions and components, and thus provide additional information to the spectra of hadrons. Recent developments include the use of charm/bottom baryon decays producing heavy hadrons, and the study of pionic-decay patterns of heavy baryons, which are useful for analyzing the heavy hadron structure. Moreover, it is also crucial to analyze the exclusive production processes consistently with various hadron thresholds.

Effective Theories on Heavy Quarkonium
Since the discovery of the X(3872) at Belle, a plethora of systems made of two heavy quarks near and/or above the open flavor threshold, the so-called heavy quarkonium, have been

discovered. Heavy quarkonium have been mostly found as charmonium states but also in bottomonium. Among them, recent discoveries in the bottomonium sector, such as charged bottomonium states Z(10610) and Z(10650) or pentaquarks at LHCb, certify the existence of exotic states, which challenge traditional models. Thus, the existence of heavy quarkonium calls for a QCD-based rigorous interpretation based on EFTs.

Interactions of Charmed Mesons with Nuclear Matter
The study of interactions between charmed mesons and nuclear matter are a major piece of the proposed activities of the PANDA Collaboration. It could also conceivably be pursued at the upgraded Jefferson Laboratory (JLab). More precisely, low-momentum charmonia and D mesons can be produced by annihilation of antiprotons on nuclei at FAIR and in electroproduction from nuclei owing to enhancements of hadronic interactions at threshold at JLab. Since charmonia do not share valence-quarks in common with the surrounding nuclear medium, the influence of that medium on their propagation has been described by, e.g., QCD van der Waals forces and intermediate charmed hadron states.

Heavy Hadrons in Hot-Dense Matter
The properties of matter created in heavy-ion collisions (HiCs) have been a subject of interest over the past decades. Most of the studies have been focused in the deconfined phase, the quark-gluon plasma (QGP), its chiral restoration phase and associated order parameters. The study of the properties of QGP is the main goal of several present and future heavy-ion experiments at SPS, RHIC LHC, ALICE, CBM and NICA. For the characterization of this phase, hadrons with heavy flavor (charm or bottom) play a fundamental role. Whilst an enhancement of charm and strangeness in the QGP phase is predicted to lead to the copious production of D(s) mesons at the LHC, J/ψ suppression has long been suggested as an unambiguous signature for QGP formation. Indeed, heavy quarks, produced in the early stage of the collision, can probe the formed medium during its entire evolution. When the medium cools down, the hadronization takes place and, after freeze-out, heavy-flavored hadrons are finally detected. Therefore, heavy hadrons are considered to be an efficient and unique probe for testing the QGP and hadronic phases.

Transition Form Factors
A test of the transition region from nonperturbative to perturbative dynamics in hadrons is provided by charmed transition form factors. The γγ* → ηc transition form factor was measured by the BaBar Collaboration and has not been the object of controversy as the γγ* → π0 transition. In particular, the measured form factor obeys the 1/Q2 behavior of asymptotic QCD and its perturbative calculation describes the data rather well and remains almost indistinguishable from nonperturbative approaches down to lower momentum transfer. The question arises where and how much earlier than in the pion transition form factor the perturbative limit sets in.

Neutral Meson Oscillations
After the discovery of neutral B and B_s oscillations, experimental searches for $D^0\bar{D}^0$ oscillations have successfully proven existence. These oscillation processes, followed by weak decays, may produce indirect signals of physics beyond the current Standard Model via possible contributions from new particles in the associated box diagrams that describe the oscillations. First evidence came from both the BaBar and Belle Collaborations in 2007, with further proof reported by the CDF Collaboration shortly afterwards. A global combination of the collected data established the existence of these oscillations while recently, LHC*b* presented the first compelling observation based on a single measurement. The theoretical description of neutral heavy meson oscillations and their weak decays is theoretically challenging. Besides a perturbative factorization of the decay amplitudes (which is not always allowed) it involves nonperturbative QCD effects, such as long-distance contributions due to intermediate meson states. Moreover, factorization ansätze even beyond the leading logarithms are not valid for weak decay amplitudes of D and D_s mesons and one ought to seek alternative approaches that consistently and simultaneously incorporate short- and long-distance physics rather than a perturbative expansion.

Results and Highlights

The workshop was a very useful opportunity to discuss about the aforementioned topics. In particular the seminar-style talks and long discussion intervals promoted intense exchanges and debates. The good mix of topics and theoretical approaches was appreciated by the participants. The second week saw also a more balanced mix of experimental and theoretical talks. During the workshop, the following questions were brought to discussion:

- *Triangular singularity*

  In decays of hadron resonances to three (or more) hadrons, there come cases with a triangular singularity, where the pairs of hadrons become close to on-mass-shell and the triangle diagram is enhanced. There were suggestions that some of the peaks in the decay processes are produced by this singularity. We had discussions on how such peaks are modified and become less sharp because of the resonance widths of the intermediate states.

- *How to distinguish between a molecular state and a pure quark state experimentally?*

  Newly discovered exotic charmonium-like hadrons have properties that cannot be explained as a charm-anti-charm system, but require more complicated structures, such as tetra-quarks, hadronic molecules, or threshold effects. We have had an intense discussion on how we can distinguish compact multi-quark states from loosely-bound hadron-hadron molecules. There are ideas of quantifying "compositeness" of the exotic resonances by using the renormalization of the pole residue, but this quantity is model dependent. There was a suggestion that the polarization of the final state may make the distinction of a compact quark state from a composite state, because in a composite state certain spin configurations are more preferred than the others.

- *Lattice results on hadron resonances*

  Lattice QCD was very successful in describing the spectrum of the ground state hadrons to a few-percent accuracy, but its ability in reproducing excited resonance hadrons is so far limited. A few recent approaches to above-threshold hadrons on lattice have been reported. One is an approach, which employs variational method with multiple operators with diagonalization. Multi-quark operators can be applied to extract exotic hadron spectrum including hybrid mesons. The other is an approach to derive potentials between hadrons and apply them to scattering states as well as resonances. It can be also applied to coupled channel systems. Its application to Z(3900) has been discussed in detail.

  Besides, Lattice QCD provides information about the dependence of the hadron resonance properties on the quark masses. Such information could be also employed to learn details on the structure of the resonances, and it can be also used to distinguish between molecular and pure quark states.

- *Experimental signatures of medium effects at PANDA*

  The possibility to use different nuclear targets opens the window for charm physics with nuclei or for color transparency studies, as well as for an intensive hypernuclear physics program. Although in-medium mass modifications are not easily accessible, the possibility exists to study charmed meson interaction with nucleons inside nuclear matter. This could be achieved by tuning the antiproton energy to one charmonium or charmonium-like states and study their decays. The experimental difficulties of producing charmed nuclei with *D* mesons were also expounded which leads to the conclusion that charmonia may be better candidates.

- *Poincaré invariant Bethe-Salpeter amplitudes beyond leading truncation*

  In several talks that dealt with continuum approaches to QCD, as an alternative to lattice QCD calculations, the conclusion was that the spectrum of light hadrons below 1.5 GeV as well as ground-state charmonia and bottomonia are rather well described in the chiral-symmetry preserving "rainbow-ladder" truncation of associated Dyson-Schwinger and Bethe-Salpeter equations. However, in the charm and beauty physics important case of heavy-light mesons as well as radially excited states, parity partners and exotic states are not well reproduced by this common approximation, even in numerically more advanced calculations. The case for systematic step-by-step increments based on either symmetries or diagrammatic corrections to the rainbow-ladder truncation was made.

- *Experimental status of heavy hadrons*

  In several presentations about XYZ states the production mechanism was stressed, as only the *X*(3872) has been so far produced in different reactions. To access the content and properties of these new states more production mechanisms and decay channels must be studied at BES, LHC*b* and possibly in the future at FAIR and at JINR.

- *Progress of Lattice QCD at finite temperature and/or density*

  Progress in the extension of the equation of state towards high temperatures and finite densities with lattice QCD were presented. The QCD topological susceptibility at high temperatures and its relevance for dark matter search was highlighted.

- *Evidence for strong SU(4) breaking?*

  The strong breaking of SU(4) symmetry in the mass sector of the QCD Lagrangian is evident. However, theoretical approaches based on Dyson-Schwinger equations, quark models, QCD sum rules or AdS/QCD do not agree on the magnitude of SU(4) breaking in charmed couplings between charm mesons/charmonia and nuclear matter and which enter effective Lagrangian models. Some approaches hint at a breaking similar to that of SU(3) in which case the formation of charmed nuclei is rather unlikely if these charmed nuclei bound states are predominantly formed via meson exchange.

3.3.13 FUNCTIONAL METHODS IN HADRON AND NUCLEAR PHYSICS

DATE: August 21 – 25, 2017

ORGANIZERS:

J. M. Pawlowski (University of Heidelberg, Germany)
D. H. Rischke (Goethe University, Frankfurt, Germany)
B.-J. Schaefer (JLU Giessen, Germany)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

In the past two decades non-perturbative functional methods in hadron and nuclear physics have made rapid progress and now allow for a quantitative comparison to experimental data. They are applied to understand low-energy properties of QCD such as the hadron mass spectrum, and in particular higher-lying resonances, and they give access to the phase structure of QCD, not only at finite temperature, but also at finite density. Moreover, also real-time properties of strongly interacting matter, such as spectral densities and fluid-dynamical transport coefficients can be addressed. The objective of this workshop was to bring together various physics communities, to focus on aspects of low-energy QCD that can be addressed by functional methods, and to make progress where these methods are particularly well-suited.

The main topics were:

- Excited states in the QCD mass spectrum
- Phase structure of QCD at finite density and fluctuations
- Real-time properties of QCD and transport coefficients

SPEAKERS:

R. Alkofer (Univ. of Graz, Austria)

J. Berges (Heidelberg University, Germany)

O. Bär (Humboldt University Berlin, Germany)

M. Barabanov (JINR Dubna, Russia)

J. Bartels (Univ. of Hamburg, Germany)

M. Birse (Univ. of Manchester, UK)

J. Braun (TU Darmstadt, Germany)

M. Buballa (TU Darmstadt, Germany)

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S. Flörchinger (Heidelberg Univ., Germany)

M. Huber (Univ. of Graz, Austria)

K. Kondo (Chiba University, Japan)

D. F. Litim (University of Sussex, UK)

M. P. Lombardo (INFN, Pisa, Italy)

M. Mitter (University of Graz, Austria)

J. Papavassiliou (Univ. of Valencia, Spain)

F. Rennecke (Heidelberg University, Germany)

L. von Smekal (Justus-Liebig University, Giessen, Germany)

G. P. Vacca (INFN, Bologna, Italy)

M. Wagner (Goethe University, Frankfurt, Germany)

T. Yokota (Kyoto University, Japan)

O. Zanusso (Univ. of Jena, Germany)

SCIENTIFIC REPORT:

Quantum field theory allows for a deeper understanding of phenomena in many different areas of physics, such as statistical physics, non-equilibrium phenomena, universal aspects of phase transitions, hadron and nuclear physics, as well as quantum gravity. The emergence of collective phenomena in complex many-body systems is related to quantum fluctuations over several length or time scales, which must be treated in a non-perturbative manner. Functional methods, like Dyson-Schwinger equations (DSE), the functional renormalization group (FRG) approach, or nPI-methods are non-perturbative by construction and are best suited to address this problem.

Due to a variety of successful implementations of these functional techniques a broad range of applications is possible. Although the explicit formulation of the corresponding mathematical equations differs, these various functional methods are all connected by a common idea. For example, the pioneering formulation of the renormalization group (RG) from the mid 1950's looks at first glance very different from Wilson's approach from the early 1970's. Moreover, depending on the particular problem at hand many different ways are possible to implement Wilson's RG idea since there is no canonical procedure to formulate the RG method for a given physical problem. For newcomers, this variety is usually hard to disentangle. One of the key ideas of this workshop was to provide an overview over many different fields of applications of these functional techniques, such that similarities and differences of the various approaches are comprehensible also for young researchers and students.

With the advent of sophisticated experiments to verify theoretical predictions, the use of the FRG has attracted a lot of recent attention in QCD at finite temperature and density. One question concerns the existence and precise location of a possible critical endpoint (CEP) in the QCD phase diagram, which is the endpoint of a first-order phase transition line separating a hadronic phase with dynamical broken chiral symmetry from a quark-gluon plasma phase, where chiral symmetry is (approximately) restored. Various truncations of functional approaches applied to models of low-energy QCD that share the same global symmetries with QCD were discussed at the workshop.

Thanks to comprehensive *ab initio* lattice-QCD simulations, which are complementary to functional methods, the properties of strong-interaction matter at finite temperatures and vanishing density are quite well understood. However, there is no consensus on the QCD phase structure at finite chemical potential, since in this region no *ab initio* simulations are possible and most of our understanding arises from applications of functional methods within certain truncations. In addition, the usual assumption is that the corresponding chiral order parameter is spatially homogeneous. If this assumption is relaxed, an inhomogeneous phase with spatially modulated chiral condensates appears in the phase diagram, which completely covers the first-order phase boundary of the homogeneous analysis. As a consequence, the CEP is replaced by a Lifshitz point, at which the inhomogeneous phase and two homogeneous phases with broken and restored chiral symmetry meet. As reported at this workshop, a further indication of the existence of an inhomogeneous phase may be the occurrence of a tachyonic instability and a negative entropy-density phase on the high-density side of the chiral phase transition line at low temperatures and finite chemical potential, if one does not allow for an inhomogeneous order parameter.

Transport coefficients are important input for modelling the dynamics of strong-interaction matter in heavy-ion collisions and neutron stars. The transport coefficients can be extracted from the low-frequency limit of spectral functions via Kubo relations. In order to determine spectral functions, one needs to compute real-time correlation functions. In this respect, major breakthroughs have been accomplished by several groups in the recent past, and progress in this field has been reported at the workshop.

Properties of low-energy QCD can be addressed via DSE's, the FRG, or lattice QCD. The workshop featured talks by key speakers addressing all of these methods. A very recent question concerns the possible existence of so-called tetraquark states, which consist of two quarks and two antiquarks. As reported at this workshop, such states are most likely not true bound states if their constituents are exclusively light quark flavors, but a tetraquark consisting of at least two charm or two bottom quarks may form a stable bound state.

The basis for these bound-state investigations is a quantitative access and understanding of the fundamental quark-gluon correlation functions in low-energy QCD. Several key talks have been concerned with the progress in this area, and in particular the status of the description of dynamical chiral symmetry breaking.

In the past decade the tunability of ultracold atomic system via Feshbach resonances has led to an impressive wealth of results. These results concern e.g. the phase structure of ultracold systems and in particular the BEC-BCS crossover, the hydrodynamics of systems with shear viscosities close to the quantum bound and the physics of three-body (Efimov trimers) and four-body bound states. The variability of the scales involved makes this a case study for functional and in particular RG methods. While being interesting in its own right, ultracold atomic systems are also used as quantum simulators for other quantum systems. In our workshop the physics of four-body bound states was governed by an excellent overview talk.

Far-from-equilibrium properties of strongly correlated gauge theories can be described with classical-statistical methods, including the dynamics of quantized fermions. Interestingly, these systems may be realized with ultracold atoms in table-top experiments, offering access to exciting phenomena such as string breaking and Schwinger pair production. The status in this rapidly progressing field has been reported at the workshop.

Results and Highlights

The workshop provided a great opportunity to connect experts in functional methods working in different physics communities. The workshop offered an excellent portal to exchange new ideas and to establish research projects that are of relevance and interest in this field. The workshop has been very fruitful in several ways:

Firstly, it allowed to discuss and learn about the latest developments and applications of non-perturbative functional techniques in the field of low-energy QCD such as the hadron mass spectrum and higher-lying resonances, the phase structure of QCD under extreme conditions, as well as the real-time properties of strongly interacting matter such as spectral densities and fluid-dynamical transport coefficients. The keynote speakers gave an excellent introduction and overview of their corresponding field, allowing participants less familiar with the research subject to understand and follow up-to-date research, which was then presented in more detail by specialized talks. Each morning and afternoon session was concluded by short flash talks given by young researchers or students, who thus had an opportunity to introduce themselves and their work to the participants.

Another important aspect was the extended time slots for coffee and lunch breaks, which were essential to allow all participants to come together and continue the discussions that had been started in the sessions. In this manner, new collaborations could be started in some occasions. These breaks were of special significance, since no free afternoon could be arranged due to the multitude of talks.

In total we have received a very positive feedback from the participants of the workshop by email and in particular directly at the end of the workshop. Usually, every session of the day was closed by a discussion that was perceived to be quite productive. The short flash talks were also received very positively by the participants. This positive resonance motivates us to consider the organization of a follow-up meeting in two or three years.

The workshop could be organized with generous support from The European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Italy, and the ExtreMe Matter Institute (EMMI) at GSI, Germany. In addition, the Collaborative Research Centre 211 “Strong-interaction matter under extreme conditions” of the Deutsche Forschungsgemeinschaft provided funds that allowed for full support of all invited participants.

3.3.14 LFC17: OLD AND NEW STRONG INTERACTIONS FROM LHC TO FUTURE COLLIDERS

DATE: September 11 – 15, 2017

ORGANIZERS:

G. Corcella (INFN, LNF, Italy)
S. De Curtis (INFN, Florence, Italy)
S. Moretti (University of Southampton, UK)
G. Pancheri (INFN, LNF, Italy)
R. Tenchini (INFN, Pisa, Italy)
M. Vos (IFIC and University of Valencia, Spain)

NUMBER OF PARTICIPANTS: 46

MAIN TOPICS:

The LFC17 workshop highlighted current problems posed by strong interactions in perturbative and non-perturbative regimes and discussed how future colliders beyond the LHC can shed light on them. In particular, our meeting dealt with the following issues: state of the art of perturbative and non-perturbative QCD, non-perturbative uncertainties and interpretation of the top-quark mass, strong interactions as the binding force of new fermions in composite-Higgs models, role played by QCD in new physics searches at the LHC, hadronic contribution to the leptonic gyromagnetic moment. The workshop was organized according to an opening session introducing strong interactions at present and future colliders and topical working groups chaired by our conveners.

Conveners:

- *Perturbative QCD:* Giancarlo Ferrera (University of Milan, Italy)
- *Non-perturbative QCD:* Andrea Beraudo (INFN, Turin, Italy)
- *Top-quark Physics:* Francesco Tramontano (University of Naples, Italy)
- *g – 2:* Carlo Michel Carloni Calame (INFN, Pavia, Italy)
- *BSM and Higgs Physics:* Aldo Deandrea (University of Lyon I, France) and Roberto Franceschini (University of Rome 3, Italy)
- *BSM and Exotics:* Orlando Panella (INFN, Perugia, Italy) and Alfredo Leonardo Urbano (CERN, Geneva, Switzerland)

SPEAKERS:

A. Auerbach (Technion, Israel)

D. Barducci (SISSA, Italy)

A. Beraudo (INFN, Italy)

G. Beuf (ECT*, Italy)

U. Blumenschein (QMUL, UK)

R. Bonciani (La Sapienza Università di Roma, Italy)

P. Bozek (AGH University of Science and Technology, Poland)

G. Cacciapaglia (CNRS/IPNL, France)

M. Narain (Brown University, USA)

P. Nason (INFN, Milano Bicocca, Italy)

P. Paakkinen (University of Jyväskylä, Finland)

G. Pancheri (INFN Frascati, Italy)

M. Passera (INFN Padova, Italy)

A. Pomarol (Universitat Autonoma de Barcelona, Spain)

M. Redi (INFN, Italy)

E. Rinaldi (RIKEN BNL Research Center, USA)

J. Cline (McGill University, Canada)

R. Contino (Scuola Normale Superiore, Pisa, Italy)

A. Driutti (INFN Trieste, Italy)

B. Foster (DESY, Germany)

E. Furlan (ETH Zurich, Switzerland)

M. Grazzini (Univ. of Zurich, Switzerland)

A. O. M. Iorio (Università degli Studi di Napoli Federico II, Italy)

Y. Kats (CERN, Switzerland)

A. Keshavarzi (University of Liverpool, UK)

R. Leonardi (INFN, Italy)

P. Monni (CERN, Switzerland)

A. Rizzi (Università di Pisa, Italy)

G. Roland (MIT, USA)

G. Sborlini (Università degli Studi di Milano, Italy)

F. Simon (Max-Planck-Institute for Physics, Germany)

G. Somogyi (Univ. of Debrecen, Hungary)

A. L. Urbano (CERN, Switzerland)

P. Uwer (Humboldt-Universität zu Berlin, Germany)

M. Vos (IFIC, UVEG/CSIC, Spain)

U. A. Wiedemann (CERN, Switzerland)

SCIENTIFIC REPORT:

This workshop aimed at fostering physics knowledge on strong interactions and assessing expectations at future colliders, making use of the latest results from LHC and other experimental facilities. It was an international meeting and followed a well-established and renowned series of similar workshops, which have been held over the last few years in Florence, Frascati (twice), Perugia and the ECT∗ itself (2011, 2013 and 2015). The workshop reviewed our understanding of many related phenomena, where QCD represents a natural 'trait-d'union': the present experimental data guided us to discuss on which future accelerator facilities are best suited to answer the questions which, in the strong-interaction domain, may possibly remain open even after the LHC era.

In fact, at the LHC the Higgs boson is mostly produced through strong interactions (gluon fusion and associated production with top quarks), and therefore perturbative QCD calculations require ever increasing sophistication. In addition, of all interactions undergone by the Higgs, the fermionic ones are the least known, thus being the focal point of attention at the LHC Run 2 at 13 TeV.

Moreover, Higgs inflation scenarios and the stability of the electroweak (EW) vacuum depend on the value of Higgs and top-quark masses. The uncertainty on the measured top mass, once it is interpreted in terms of well-defined field-theory quantities, such as the pole mass, is in fact currently under debate, with perturbative and non-perturbative QCD playing a fundamental role. The most precise techniques, i.e. the so-called template and matrix-element methods, rely on Monte Carlo generators, which are based on a re-summation of perturbative QCD and contain non-perturbative phenomenological models for hadronization. On the other hand, strategies extracting the top mass from the direct comparison of measured observables with exact QCD calculations, such as the total top-antitop production cross section, do allow a straightforward extraction of the pole mass, but are still affected by non-perturbative uncertainties, such as colour reconnection, and, above all, they yield errors which are too large to be competitive with the other methods.

Indeed, strongly-interacting models are among the candidates to solve some of the theoretical flaws of the SM: the hierarchy problem, for instance, finds a natural solution in the hypothesis that the Higgs is a composite object, hence a sort of new pion, made up of new fermions carrying colour charge. Such fermions can mix with the top quark, indirectly affect Higgs observables and can even be produced directly as real objects at the LHC and future colliders.

Moving the focus to low-energy experiments, the lepton gyromagnetic factor, the so-called g − 2, gets relevant corrections from hadron physics and the present discrepancy in the muon sector, about three standard deviations, calls for a more refined estimation of non-perturbative effects.

Finally, in the ultimate attempt to understand strong interactions, a key role is ought to be played by theories that can replace phenomenological approaches in describing their hadronic dynamics, namely lattice or colour string/cluster methods of hadronization, which are typically implemented in Monte Carlo simulation programs. Promising alternative candidates are holographic models of QCD and strong interactions, which have lately been able to predict the spectra of various mesonic states.

The program was structured along the traditional subjects of inquiry of particle physics, i.e., Standard Model (SM) tests and Beyond the SM (BSM) searches, taking particular care about the interconnection between LHC, astrophysics, low-energy experiments, as well as future colliders. As discussed above, a significant thread of the 2017 edition was represented by strong interactions, in both QCD or EW frameworks, high- and low-energy regimes.

Results and Highlights

Hereafter, we shall discuss the main results presented in the introductive talks and in the topical sessions.
The introductive session dealt with general topics on strong interactions at present and future colliders. In particular, the main experimental projects at the future energy frontier, from both viewpoints of physics and accelerators, were reviewed. Moreover, we had an overview of LHC QCD results, from both experimental and theoretical perspectives, as well as of heavy-ion phenomenology at LHC, RHIC and future colliders.
The prospects for strongly-interacting physics at future accelerators were presented as well; furthermore, regarding physics beyond the Standard Model, we focused on models based on strong dynamics and their predictions for the LHC and experiments at higher energy and luminosity, in both pp and e^+e^- regimes.
The main results, presented in the perturbative QCD session, concerned recent experimental measurements and novel theoretical developments on hard QCD processes at present and future colliders. Results on high-p_T reactions at the Large Hadron Collider were highlighted, showing, in particular, recent measurements on vector-boson production in association with QCD jets, diboson production, single and double Higgs-boson production. It was reviewed the status of general algorithms for calculating jet cross sections up to next-to-next-to-leading order (NNLO) QCD in lepton and hadron collisions, presenting new quantitative results based on the colorful subtraction method at NNLO.
A novel technique for higher-order calculations was discussed: such a method is based on the duality relation between loops and phase-space integrals and an explicit calculation of the total Higgs boson decay rate at NLO was presented. New results on azimuthal correlations among particles in hard QCD scattering were shown, underlying that fixed-order computations can lead to divergences which can be removed by means of a proper all-order resummation procedure of the perturbative contributions. An infrared QCD model can also describe the energy dependence of the total cross section at very high energies and the non-diffractive soft and semi-hard collisions in hadronic processes.
The heavy-ion session was introduced by a general talk, giving a broad overview of the main items touched more deeply in the specific contributions. A talk was devoted to nuclear parton distribution functions (nPDF's), showing how a wide set of observables in eA, νA and pA collisions can be accommodated within a picture based on collinear factorization: universal PDF's are supplemented by nuclear corrections, which are the same in all processes. The new EPPS16 nPDF's set was obtained, including recent data on di-jets in pA collisions measured by CMS and neutrino DIS data. Initial-state effects were also addressed, paying special attention to gluon saturation. The picture, initially developed to describe the low-x evolution of the gluon density and to provide an interpretation of peculiar features of HERA DIS data, was later employed to get a first-principle description of the initial state in high-energy pA and AA collisions. Such initial conditions can be eventually evolved via

hydrodynamic equations. Relativistic hydrodynamics was addressed as well: the major surprise in the field came from the recent discovery of collective effects, suggesting a hydrodynamic interpretation, in small systems, like the ones produced in high-multiplicity pp and pA collisions. It was also conveyed the message that the same physics is at work in producing the quenching of jets in AA collisions and in making the initial system thermalize. One of the most important issues to understand in the forthcoming heavy-ion runs of the LHC is the absence of jet quenching in small systems (pA collisions), which, on the other hand, display signatures of collective flow. One can thus wonder: what is the benchmark to infer that azimuthal anisotropies of particle distributions entail a strong re-interaction of the system? Finally, heavy-flavour observables were debated too, given the fact that one has the potential to get access, in particular through beauty-quark measurements, to the transport coefficients of the plasma (friction and momentum broadening).
The anomalous magnetic moment of the muon, namely $a_\mu = (g_\mu - 2)/2$ is one of the best known quantities in particle physics, from both experimental and theoretical sides: intriguingly, there is a long-standing discrepancy between the current experimental measurements and the best theoretical predictions within the Standard Model, of the order of 3 – 4 standard deviations. The session was articulated in three talks. In the first one, we had an overview of the experimental techniques and results from past experiments, as well as updates on the status of the future Fermilab (USA) and J-PARC (KEK, Japan) experiments. The theory status of the a_μ calculation was briefly summarized. We also focused on a new proposed experiment to measure the hadronic contribution to the running of the electromagnetic coupling constant in the space-like region, via the scattering process $\mu e \rightarrow \mu e$. This high-precision measurement will allow estimating the leading-order hadronic contribution to a_μ (a^{HLO}_μ), which currently is giving the largest theoretical error on a_μ. Finally, we discussed the standard evaluations of a^{HLO}_μ, which can be calculated through dispersion relations and the optical theorem, by integrating the cross sections for the annihilation process $e^+e^- \rightarrow$ hadrons. An improved analysis of the available data was then presented: the current theoretical error on a_μ may be reduced by 30% and thus induce a discrepancy of 3.9σ between the Standard Model prediction and the current experimental value.
The ‘Higgs and BSM’ session aimed at exploring the role played by strong interactions in physics at the TeV scale and above, in particular, in the breaking of the electroweak symmetry. The topics covered were the following: strongly-interacting theories of the Higgs boson and their short-distance realization; strongly-interacting Dark Matter; signals at colliders from composite states emerging as bound states of the new-physics strong interactions; relations between strongly-coupled theories of electroweak symmetry breaking, their apparent fine tuning in parameters space and symmetry-breaking patterns observed in real-world condensed matter systems. The numerical calculations allowing to obtain non-perturbative results in the spectrum and phase diagram of these models were also presented, following an approach similar to the one developed for the treatment of strong interactions in QCD.

The top-quark session was opened by an overview on top-quark phenomenology at the LHC, and concluded by a companion presentation debating the perspectives for the physics of the heaviest currently known elementary particle at future lepton and hadron colliders. Furthermore, recent progresses in the POWHEG program was explored: the latest version of this NLO Monte Carlo generator contains NLO corrections to top decays, width effects, interference between production and decay phases, as well as non-resonant contributions. Interfacing POWHEG to HERWIG and PYTHIA showers yields some discrepancies in the top-mass reconstruction, which are currently under investigation. The top-quark mass extraction was also debated, taking particular care about the relation between the reconstructed mass and the pole mass; recent NNLO computations of the total $t\bar{t}$ cross section were presented, paying attention to the comparison of analytical and numerical approaches.

The ‘Exotics and Dark Matter’ session was opened by a presentation on exotic quarks of charge 5/3, predicted in composite models with higher-isospin multiplets: recasting the present experimental analyses, it is possible to set exclusion bounds on the exotic-quark masses. Moreover, we discussed Dark Matter searches at the LHC, with most of the attention devoted to weakly-interacting models, since they are within the experimental reach.

In particular, we emphasized the importance of the so-called ‘Simplified Models’ that are characterized only by the presence of a Dark Matter candidate and a mediator with the Standard Model sector: the presence of a momentum-dependent interaction causes a different sensitivity of the LHC searches, together at being subject to weaker constraints from direct detection experiments.
Searches for vector-like top-quark partners at the LHC were motivated end explored: direct searches and indirect constraints from electroweak precision data can play a complementary role in probing the existence of new vector-like quarks. The main conclusion is that the phase space of the discussed models is unlikely to be probed by direct production at the LHC, while it will be feasible at lepton or hadron colliders running at higher energies. From the experimental viewpoint, we had a summary of the present status of vector-like top-partner searches at the LHC, namely single and double vector-like quark production, and vector-like quark decays. In the next 6 months, the LHC will have the potentials to probe vectorial top partners up to masses of about 1 – 1.2 TeV.
We also had a presentation discussing the relation between B-decay anomalies and Dark Matter in strong-dynamics scenarios. In fact, the recent B-decay anomalies observed by LHCb could be explained in the context of a simple model with strong dynamics, containing a vector-like quark partner, a right-handed neutrino partner, and an inert Higgs doublet. The main conclusion is that the model can account for the observed anomalies and contains new states with TeV-scale mass that could be accessible at the LHC.

Besides, within Dark Matter searches at the LHC, we focused on a class of theories in which dark matter is a pseudo Nambu–Goldstone boson arising from a strongly-interacting sector. In these models a formulation of LHC searches in terms of effective operators is possible and well suited; also, the experimental results can be re-interpreted in terms of effective field theory approaches.

3.3.15 PROSPECTS ON THE MICROSCOPIC DESCRIPTION OF ODD MASS NUCLEI AND OTHER MULTI-QUASIPARTICLE EXCITATIONS WITH BEYOND-MEAN-FIELD AND RELATED METHODS

DATE: September 25 – 29, 2017

ORGANIZERS:

M. Bender (IPNL, France)
L. Robledo (Universidad Autónoma de Madrid, Spain)
T. R. Rodríguez (Universidad Autónoma de Madrid, Spain)

NUMBER OF PARTICIPANTS: 20

MAIN TOPICS:

The topic of the workshop is the analysis of the present status in the description of nuclear excitations where time reversal invariance is not preserved. There is a wide range of possibilities embracing this definition: nuclei with an odd number of protons or neutrons (or both), two (four, etc.) quasiparticle excitations built on top of the ground state and collective excitations, intrinsic states in rotating nuclei, etc. The purpose of the workshop is to gather together nuclear theorists actively working on the development of models, methods and applications related to this kind of situations.

The main topics were:

- Self-consistent mean-field description of odd-A and multi-quasiparticle excitations
- Self-consistent cranked mean fields
- Random phase approximation and particle-vibration coupling
- Symmetry restoration and generator coordinate method techniques
- Collective Hamiltonians for odd nuclei
- Mapping on the Interacting Boson-Fermion Model
- Interpretation of experimental data

SPEAKERS:

D. Ackermann (GANIL, France)

A. Afanasjev (Mississippi State University, USA)

B. Bally (Universidad Autónoma de Madrid, Spain)

M. Bender (IPNL, France)

R. Bernard (CEA DAM DIF Bruyères-le-Châtel, France)

S. Bottoni (Università di Milano, Italy)

J. Dobaczewski (University of York, UK)

T. Duguet (CEA Saclay, France)

T. Marketin (Univ. of Zagreb, Croatia)

A. Marquez-Romero (Univ. of York, UK)

K. Nomura (Univ. of Zagreb, Croatia)

N. Pillet (CEA DAM DIF Bruyères-le-Châtel, France)

F. Raimondy (Univ. of Surrey, UK)

L. M. Robledo (Universidad Autónoma de Madrid, Spain)

T. R. Rodriguez (Universidad Autónoma de Madrid, Spain)

W. Ryssens (IPNL, France)

P.-H. Heenen (ULB, Belgium)

D. Vretenar (University of Zagreb, Croatia)

E. Litvinova (Western Michigan University, USA)

C. Yannouleas (Georgia Tech, US)

SCIENTIFIC REPORT:

Most of the attention in nuclear physics is focused on the description of collective states in even-even nuclei. This seems paradoxical as three quarters of all possible nuclei have an odd number of either protons or neutrons (or both) and the number of non-collective excitations like two-quasiparticle excitations, high K isomers, etc. exceeds by far the number of purely collective excitations. One reason for this bias is the nuclear pairing interaction that couples two protons or two neutrons to spin J=0 as to form a Cooper pair. This property brings an enormous simplification when constructing phenomenological and microscopic models for even-even nuclei, for which often time-reversal invariance can be evoked. By contrast, for odd nuclei, there is always (at least) one nucleon that remains unpaired, which breaks the time-reversal symmetry, leads to open spin and also to states with a finite angular momentum, whose value is determined by the way how the unpaired nucleon is coupled to the paired ones. In one way or the other, there are always several competing possibilities for such coupling, which enormously complicates the modeling. The loss of time-reversal invariance gives rise to so-called time-odd fields, whose precise parameterization turns out to be a highly non-trivial task. Similar complications also arise when modeling certain excitation modes of even-even nuclei that involve non-collective degrees of freedom.

The aim of the workshop was to discuss the different models and techniques used to describe the above mentioned systems and phenomena and to identify common technical difficulties in their implementation. Special focus was on odd-A nuclei, high spin states, two and four quasiparticle excitations, both at the mean field level and beyond, including configuration mixing and symmetry restoration.

Results and Highlights

It was clear to all of the participants of the workshop that deepening our present understanding of how to implement time-odd fields in all kind of approaches and models is a crucial task for our field. Those time-odd fields have a non-negligible impact in many physical scenarios including apparently distant physical situations like the spectroscopy of nuclei, low-energy nucleus-nucleus collisions, and nuclear fission, the latter of which is strongly influenced by the quenching of pairing correlations associated to those time-odd fields and the corresponding impact on the dynamical inertias governing the scission mechanism.

The present state-of-the-art of large-scale applications of mean-field-based methods to the description of odd nuclei has been addressed in several talks (Afanasjev, Heenen, Marketin).

Several talks (Bender, Dobaczewski, Ryssens) addressed the impact of choices for intrinsic symmetries commonly made in many of these calculations on the results obtained. Not only energy spectra, but also magnetic moments can be significantly impacted. Lifting these standard symmetry constraints, however, introduces several new practical and conceptual problems whose implications have been the subject of debate during the discussion sessions.

Among the major technical difficulties encountered at the mean-field level, is the question how to fix a unique blocked configuration during the iterative non-linear procedure used to solve the HFB equations. Several alternatives have been presented (Robledo, Ryssens) and results obtained with them compared. While they lead to the same result when applicable, none of the presently devised schemes can converge to all configurations of interest. Possible workarounds to this problem have been discussed.

3.3.16 NEW PERSPECTIVES ON NEUTRON STAR INTERIORS

DATE: October 09 – 13, 2017

ORGANIZERS:

G. G. Barnaföldi (Wigner RCP of the Hungarian Academy of Sciences, Hungary)
G. Baym (University of Illinois at Urbana-Champaign, IL, USA)
L. Tolós (ICE, CSIC-IEEC, Spain, on leave to ITP, Frankfurt, Germany)

NUMBER OF PARTICIPANTS: 41

MAIN TOPICS:

This workshop brought together high-energy and nuclear theorists, observational astronomers and gravitational physicists. Our aim was to overview new theoretical ideas and proposed or soon-to-be launched future experimental facilities, bringing together results from ongoing electromagnetic and gravitational observations and related theoretical neutron star equations of state.

The main topics were:

- Investigation on the inner structure of neutron stars, existence of quark, hybrid and strange stars
- Tests of extreme dense QCD phase diagram at finite temperature
- Crust+core models and pulsar models, strong magnetic field in neutron stars, cooling of neutron stars, glitches
- New observables from X-ray and gamma satellites (NICER, LOFT, ATHENA, eROSITA)
- Gravitational wave detection and signals from isolated neutron stars or merging neutron star binaries
- Future experimental facilities for neutron star observables
- NewCompStar Working Group 1-2-3 meeting for the future perspectives

SPEAKERS:

D. Alvarez Castillo (JINR, Dubna, Russia)

G. G. Barnaföldi (MTA Wigner RCP, Hungary)

M. Bauböck (Max Planck Institut für Extraterrestial Physik ,Germany)

G. Baym (Univ. of Urbana Champaign, IL, USA)

W. Becker (Max-Planck Institut für Extraterrestial Physik, Germany)

M. Bejger (N. Copernicus Astronomical Center, Warsaw, Poland)

D. Blaschke (Univ. of Wroclaw, Poland)

S. Borsányi (Univ. of Wuppertal, Germany)

M. Caplan (McGill University, Canada)

A. Haber (TU Wien, Institute for Theoretical Physics, Austria)

P. Haensel (N. Copernicus Astronomical Center, Warsaw, Poland)

B. Haskell (N. Copernicus Astronomical Center, Warsaw, Poland)

T. Hinderer (Radboud University Nijmegen, Netherlands)

P. Kovács (MTA Wigner RCP, Hungary)

M. Limongi (INAF - Osservatorio Astronomico di Roma, Italy)

C. Pankow (CIERA/Northwestern, IL, USA)

P. Pizzochero (Univ. of Milano, Italy)

G. Prodi (Univ. of Trento, Italy)

P. Cerda-Duran (Univ. of Valencia, Spain)

M. Csanád (Eötvös University, Hungary)

A. Cumming (McGill University, Canada)

S. Furusawa (RIKEN, Japan)

U. R. M. E. Geppert (Univ. of Zielona Gora, Poland)

R. Gold (Goethe-Universität Frankfurt am Main, Germany)

V. Graber (McGill University, Canada)

H. Grigorian (Yerevan State University, Armenia & JINR, Dubna, Russia)

A. Raduta (IFIN-HH Bucharest, Romania)

S. Schmalzbauer (Goethe-Universität Frankfurt am Main, Germany)

A. Sedrakian (Frankfurt Institute for Advanced Studies)

L. A. Somlai (MTA Wigner RCP, Hungary)

H. Togashi (RIKEN, Japan)

L. Tolos (ICE, CSIC-IEEC, Spain on leave to ITP Frankfurt, Germany)

S. Typel (TU Darmstadt and GSI, Germany)

J. Wagg (Jodrell Bank Observatory, UK)

F. Weber (San Diego State University))

SCIENTIFIC REPORT:

Compact stars are the endpoints of the stellar evolution. Depending on their initial mass they can form white dwarfs, neutron-, and possibly hybrid- or quark stars and black holes as final states. Neutron stars have the most extreme dense matter of the Universe inside, especially at their core. However, this cannot be probed directly, only by solving a full model for the neutron star's equation of state and compare the obtained maximal mass and radius with the available measurements. In certain neutron stars one is able to measure precisely their mass with high accuracy using the gravitational effect, the Shapiro delay. Further mass-radius constraints can be deduced from light-curves of neutron stars, burst observations, and analysis of gravitational wave ringdowns. However, there remain many open theoretical questions in this field, which require further observational and phenomenological input. Investigations of the inner structure of neutron stars, the existence of quark, hybrid or strange stars, the test of extreme dense QCD phase diagram at finite temperature, the crust+core models and pulsar models, the strong magnetic field, and the cooling of neutron stars are ongoing. Furthermore, the forefront problem of understanding gravitational wave signals originating from isolated neutron stars or merging neutron star binaries will require improved understanding of neutron star interiors.

In this workshop, we successfully brought together about 40 theorists and astronomers working on the modelling and observation of neutron stars. Our aim was to summarize the current status of the observations by electromagnetic and gravitational measurements by various facilities in order to provide constraints for the equation of state of the compact star interiors. Besides the latest mass-and-radius measurements we also discussed neutron star interior models in the light of the forthcoming results from the NICER (Neutron Star Interior Composition Explorer) experiment recently mounted on the International Space Station. From the ESA side, eROSITA and ATHENA are the dedicated satellites for a similar purpose, planned for launch in this decade, especially the latter was selected as a second L-class mission in the ESA's Cosmic Vision 2015-2025 plan. We also discussed the next generation of the gravitation wave detections by adLIGO/VIRGO and the proposed Einstein Telescope. The future perspectives after the upgrades of the SKA (Square Kilometer Array) were also touched upon. The workshop was just days before the "Big News" of our field, the first gravitational wave detection of NSNS mergers, GW170817.

Results and Highlights

The plan for the workshop was to maximize discussion, centered primarily on the above questions, between high-energy nuclear theorists, gravitational physicists, and observational astrophysicists. Successfully we were able to ignite 'theory *vs.* observation' discussions. The two daily overview talks in the morning were followed by shorter related topics. The morning talks were related to the experimental facilities and observations from electromagnetic, X-ray to radio regimes and gravitational wave detectors. These talks were followed by overviews of related theoretical questions and models. Late afternoons were dedicated to dedicated panel discussion. We also gave the stage for young scientists, who could share their ideas and present latest results for a many-interest audience.

The aim of the workshop included the Working Group meeting of the NewCompStar COST action MP1304, where two of the organizers (G.G. Barnaföldi and L. Tolós) act as the QCD Topic Leader and Working Group Leader, respectively, in the "Working Group 2 – Physics of strong interaction theory and experiment".

We investigated the future experimental devices and their possible impact of the theoretical models and developments. We identified the key future prospects both on theoretical and observation/experimental side, which can provide input for the EoS database, CompOSE:

Running observations or experimental perspectives are based on three pillars: (i) gravitational wave detectors, the existing LIGO/VIRGO, (ii) electromagnetic messengers of the sky: NICER, FERMI, NEWTON XMM, and many radio telescopes, (iii) high-energy heavy-ion collisions experiments: RHIC BES, CERN SPS NA61, CERN LHC ALICE.

Future observations would be based on the upgrade of the running experimental facilities and building or launching new proposed ones. Gravitational wave observations were announced just three days after the Workshop finished, with the first observation GW originating NS-NS mergers in coincidence with electromagnetic counterparts. Planned detector constructions will further improve our knowledge by extended statistics and wider range of measurements: GW: ad LIGO/VIRGO (2017-), Einstein Telescope (2025?), EM: eROSITA (2020), SKA (2025) Heavy-ion Experiments: NICA (2018), RHIC sPHENIX/STAR, FAIR/GSI (2020).

Recent theoretical developments: Cooling of NS are defined more precisely by nuclear models especially after NS formation in supernova explosions. The phases and EoS have been further improved with electromagnetic interactions. At present lattice QCD results are limited by the sign-problem, but Functional Renormalization Group methods work well in the low-temperature and high-density regime. Numerical gravitational models today include rotation and magnetic field. Alternative gravitational models were extended due to constraints from the recent data. This information led us to start building the equation of state database, CompOSE.

Future theoretical directions: Future IT developments and computational numerical techniques will provide solid basis for improved calculation, including rotation and magnetic fields. Future lattice calculations hopefully reach the low-temperature and high-density limit of the phase diagram by resolving the (various) sign problems. Observations and experimental measurements will constrain theories more strictly, which results the Grand Unified EoS "GuEoS" including low- and high temperature and electromagnetic fields. Our plan is to provide a unified database of EoS and observation data in a novel and searchable database.

3.3.17 ASTRA: ADVANCES AND OPEN PROBLEMS IN LOW-ENERGY NUCLEAR AND HADRONIC STRANGENESS PHYSICS

DATE: October 23 – 27, 2017

ORGANIZERS:

C. O. Curceanu (LNF-INFN, Frascati, Italy)
E. Hiyama (Kyushu Univ./RIKEN, Japan)
J. Marton (SMI, Vienna, Austria)
J. Pochodzalla (Univ. Mainz and HIM, Germany)
I. Vidaña (INFN Catania, Italy)

NUMBER OF PARTICIPANTS: 41

MAIN TOPICS:

The workshop, "ASTRA: Advances and open problems in low-energy nuclear and hadronic STRAngeness physics" was dedicated to the discussion of the most recent achievements in nuclear and hadron physics with strangeness, both in theory and experiment, investigating also the implications in and from astrophysics and cosmology. Open problems (including hot puzzles, such as the structure of the $\Lambda(1405)$; the hypertriton lifetime and the hyperon puzzle in neutron stars), were discussed. The current understanding was thoroughly discussed by participants coming from various sectors, theoretical and experimental ones, since strangeness physics is of big interest for a large community of scientists, going from particle and nuclear physicists to researchers involved in astronomy, astrophysics and cosmology.

The main topics were:

- Kaonic deuterium and other kaonic atoms measurements and theoretical tools
- Hypernuclear Spectroscopy
- Hypertriton lifetime puzzle
- Neutron-star EOS and Strangeness in the neutron stars
- Strangeness production at LHC
- Theoretical models related to strangeness production in various mechanisms
- Experimental results (SIDDHARTA-2 and AMADEUS status and results at DAFNE; E15 and other experiments at J-PARC; ALICE at LHC; J-Lab experiments related to strangeness studies)
- Next generation experiments (AMADEUS at DAFNE; VOXES based detector experiments at DAFNE; Future experiments at J-PARC; Experiments at CERN; Experiments at JLAB, ELSA, MAMI)

SPEAKERS:

P. Achenbach (Johannes Gutenberg-University, Germany)

M. Barabanov (JINR, Russia)

O. Benhar (INFN and University of Rome, Italy)

P. Bydzovsky (Nuclear Physics Institute of

S. Nagao (Tohoku University, Japan)

F. Pederiva (University of Trento, Italy)

S. Piano (INFN Trieste, Italy)

K. Piscicchia (Centro Fermi, LNF - INFN, Italy)

J. Pokorny (Nuclear Physics Institute of the

the CAS, Czech Republic)

A. Cieply (Nuclear Physics Institute of the CAS, Czech Republic)

R. Del Grande (LNF - INFN, Italy)

B. Doenigus (Goethe-University Frankfurt, Germany)

A. Feliciello (INFN Torino, Italy)

E. Friedman (Hebrew Univ. of Jerusalem, Israel)

A. Gal (Hebrew Univ. of Jerusalem, Israel)

T. Gogami (Tohoku University, Japan)

B. Hohlweger (TU Munich, Germany)

J. Hrtankova (Nuclear Physics Institute of the CAS, Czech Republic)

H. Lenske (JLU Giessen, Germany)

S. Maurus (TU Munich, Germany)

CAS, Czech Republic)

F. Sakuma (RIKEN, Japan)

M. Schaefer (Nuclear Physics Institute of the CAS, Czech Republic)

H.-J. Schulze (INFN Catania, Italy)

A. Scordo (LNF - INFN, Italy)

D. Sirghi (LNF - INFN, Italy)

H. Tamura (Tohoku University, Japan)

H. Togashi (RIKEN, Japan)

Y. Toyama (Tohoku University, Japan)

C. Trippl (Stefan Meyer Institute, Austria)

P. Vesely (Nuclear Physics Institute of the CAS, Czech Republic)

I. Vidana (INFN Catania, Italy)

W. Weise (TU Munich, Germany)

SCIENTIFIC REPORT:

The main topics, which were discussed during the workshop, together with a short description, were:

a) *Theoretical and experimental studies on the strong interaction with strangeness in various processes – recent progress:*

A very active field in low-energy hadron physics with strangeness is the antikaon-nucleon/fee nucleons interaction studies. The threshold data on the low-energy interaction with strangeness provide unique information for the theory. On the basis of the successful x-ray measurements of the strong interaction observables of kaonic hydrogen by the SIDDHARTA Collaboration significant progress in the theoretical description was achieved. The SU(3) chiral approach turned out to describe the data in a consistent way. We discussed the following topics:

- *Kaonic deuterium measurement and other kaonic atoms*

The experimental access to the isospin scattering lengths (a_0 and a_1) by the measurement of the K-lines of kaonic deuterium is still an open topic. With the combination of the results of kaonic hydrogen and deuterium the scattering lengths in both isospin channels I=0,1 can be pinned down. The experiment on kaonic deuterium involves severe challenges compared with kaonic hydrogen: anticipated lower yield of x-rays, larger width, need for efficient background reduction). Discussions about exotic atoms results and planned experiments at DAFNE and J-PARC were held.

- *New measurements with ultrahigh-energy resolution detectors*

Advances in cryogenic detectors providing ultrahigh energy resolution, which may open the way to new studies of the strong interaction on the kaonic helium 2p state by measuring the transition 3d→ 2p were discussed. The strong interaction on the 2p state is very small according to recent results from the SIDDHARTA Collaboration and no significant isotopic difference between kaonic helium-3 and helium-4 was found in contrast to theoretical studies connected with kaonic nuclear bound states. The feasibility of new precision experiments has to be worked out. An interesting idea is the study of 2 transitions (involving so-called lower and upper level) in the same kaonic atom for separating one-nucleon absorption from multi-nucleon processes having a strong impact on the understanding of the antikaon-nucleon interaction in the nuclear medium.

- *Hyperon interactions*

Another important issue in strangeness nuclear physics is the description of the hyperon interactions, modelled after the successful approach to two- and three-nucleon forces derived from the symmetries of QCD. Here, few-body bound states play an important role in the determination of the corresponding low-energy constants and more work in this direction is required to pin down these forces with the required accuracy. Further, little is known about three-body forces involving hyperons, a gap that has to be closed if one wants to makes real progress in e.g. astrophysical applications. All these items were discussed in detail, including recent results from AMADEUS.

- *Hypernuclear Spectroscopy and hyperatoms with a focus on hypertriton lifetime puzzle*

The recent experimental results and future plans were revised and theoretical calculations presented.

- *Kaonic nuclei status*

New studies on kaonic nuclear quasi-bound systems in experiment and theory
New measurements performed in experiments at J-PARC (E15), which are searching for possible quasi-bound kaonic nuclear systems, were discussed, together with Sigma-proton AMADEUS result.

- *Various theoretical tools to understand strangeness production and strangeness interaction in nuclear medium*

b) The equation of state of neutron stars

The presence of strangeness, both in a confined (hyperons, kaons) or deconfined (strange quark matter) form, in the inner core of neutron stars is expected to have significant consequences for the equation of state (EoS), composition, structure and evolution of these objects. It is well known, however, that any additional degree of freedom, other than nucleons, appearing in the neutron star interior leads to the softening of its EoS and to the consequent reduction of its maximum mass M_{max}. The recent discovery of the two millisecond pulsars PSR J1614-2230 and PSR J0348+0432 with masses of the order of about 2Msun imposes a new severe observational constraint on any model for the EoS implying that any reliable one should predict $M_{max} > 2M_{sun}$. Also, the recent measurement of gravitational waves coming from the merger of two neutron stars set constrains on the EOS of neutron stars. In view of this, a natural question arises: can hyperons, or strangeness in general, still be present in the neutron star interior if M_{max} is reduced to values smaller than $2M_{sun}$, although their presence is energetically favourable? This question is at the origin of the so-called “hyperon puzzle”, whose solution is not easy and is nowadays a subject of very active research. Several solutions to tackle this problem have been proposed, although, in the absence of more restrictive experimental and observational constraints this problem remains still unsolved. Better information on the hyperon-nucleon (YN) and hyperon-hyperon (YY) interactions strengths is a crucial ingredient for the solution of this problem, but unfortunately it is still missed. The YN and YY interactions were studied in the framework of few-body calculations and shell model calculations. Recently, by the development of Lattice QCD calculation and Chiral perturbation theory etc., a deeper understanding was achieved, especially for the YN interaction, spin-dependent term. The study of YY interaction and hyperonic three-body force are presently very important issues. Examples of questions needing answers are: (1) How much repulsion is needed for YNN, YYN or YYY three-body forces to reproduce twice of solar mass neutron stars? (2) What is the strength of the Λ Λ-Ξ N and Ξ N interactions etc.?
A refined input from strangeness nuclear physics is therefore crucial for the solution of this puzzle. The implications that the discovery of massive neutron stars has on our present knowledge of hypernuclear physics were discussed during the workshop. In

addition to the maximum mass, the measurement of neutron star radii as well as the analysis of the thermal evolution of these objects can also serve to constraint the EoS and estimate the strangeness content of neutron stars and was discussed at the workshop.

Results and Highlights

The "ASTRA: Advances and open problems in low-energy nuclear and hadronic STRAngeness physics" workshop focused on the most recent achievements and open problems in nuclear and hadron physics with strangeness, both in theory and experiment, investigating also the implications in and from astrophysics and cosmology, in particular the equation of state for neutron stars. Future perspectives and possible solutions to puzzles as the hypertriton lifetime, the hyperon puzzle in neutron stars or the still-unknown structure of the Λ(1405) were thoroughly discussed, together with the possible relation between strangeness in binaries of neutron stars and their emission of gravitational waves, recently observed by LIGO and VIRGO. It was the right time for the various communities working in this field to come together, discuss their findings and plan future activities towards an even deeper understanding of the role of strangeness in the Universe.

The workshop brought together world-leading experimental and theoretical experts in the field and young scientists and students, providing a state-of-the-art overview of the field of low-energy nuclear and hadronic strangeness physics. The young participant's percentage was more than 50%, which is one of the successes of the workshop.

The organization of this workshop in the ideal environment of ECT* contributed to the progress of the field.

3.3.18 DILEPTON PRODUCTIONS WITH MESON AND ANTIPROTON BEAMS

DATE: November 06-10, 2017

ORGANIZERS:

W. C. Chang (Institute of Physics, Academia Sinica, Taiwan)
J.-C. Peng (Physics Department - University of Illinois, USA)
S. Platchkov (Nuclear Physics Division - IRFU - CEA Saclay, France)
O. Teryaev (Joint Institutes for Nuclear Research, Russia)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

This workshop explores the theoretical and experimental aspects of high-mass dilepton production with meson and antiproton beams. Opportunities to carry out new measurements on high-mass lepton pairs productions using meson and antiproton beams can provide unique information on the partonic structures of pion, kaon, and nucleons. A proposal to construct the RF-separated beams at CERN would produce high-intensity kaon and antiproton beams. A high-momentum secondary beam line being constructed at the J-PARC facility will also offer the possibility to measure exclusive Drell-Yan reactions for the first time to access Generalized Parton Distributions in a time-like process. The goal of this Workshop is to discuss in depth the physics opportunities and experimental feasibilities to investigate hadron structures using the Drell-Yan process with high-intensity meson and antiproton beams.

The main topics were:

- Physics of partonic structures of pion and kaon
- Probing meson structure with the Drell-Yan and J/ψ production with meson beams
- Exclusive Drell-Yan process with meson beams
- Opportunities for future dilepton production experiments with intense meson and antiproton beams

SPEAKERS:

V. Andrieux (Univ. of Illinois, USA)
M. Anselmino (Univ. of Turin, Italy)
J. Bernhard (CERN, Switzerland)
D. Boer (Univ. of Groningen, Netherlands)
F. Bradamante (INFN Trieste, Italy)
W.-C. Chang (Institute of Physics, Academia Sinica, Taiwan)
J. Chen (Jefferson Lab, USA)
A. Dbeyssi (Helmholtz, Mainz, Germany)
I. Denisenko (JINR, Dubna, Russia)
O. Denisov (INFN Torino, Italy)
S. Kumano (KEK, Japan)
H. Noumi (Osaka Univ., Japan)
B. Parsamian (Univ. Turin, Italy)
J.-C. Peng (University of Illinois, USA)
S. Platchkov (Nuclear Physics Division - IRFU - CEA Saclay, France)
B. Povh (Univ. of Heidelberg, Germany)
C. Marques Quintans (LIP, Lisbon, Portugal)
P. Reimer (ANL, USA)
C. Roberts (ANL, USA)

B. Grube (TU Munich, Germany)

A. Guskov (JINR, Dubna, Russia)

P. Hoyer (Helsinki Univ., Finland)

A. Kotzinian (INFN, Torino, Italy)

C.-J. Naim (CEA/Saclay, France)

P. Kroll (Univ. of Wuppertal, Germany)

T. Sawada (Univ. of Michigan, USA)

S. Sawada (KEK, Japan)

O. Teryaev (Joint Institutes for Nuclear Research, Russia)

J. Wambach (ECT*, Italy)

R. Yoshida (JLab, USA)

SCIENTIFIC REPORT:

The Drell-Yan (D-Y) process, together with Deep-Inelastic Scattering (DIS), has been the primary experimental tool for probing the partonic substructures in hadrons. While complementary to the DIS, the D-Y has unique advantages in extracting antiquark distributions in nucleons and in probing parton distributions in mesons and antiprotons. The DIS and D-Y also provide important results on QCD-evolution, factorization, universality, and more recently, the novel transverse momentum dependent parton distributions (TMDs).

A strong interest in D-Y process is evidenced by several experimental programs pursued at several laboratories. The fixed-target experiment E906 at Fermilab recently measured the sea-quark flavor structure at large values of x. In addition, the COMPASS experiment at CERN has completed the first measurement of polarized D-Y using pion beam to test the sign-change prediction of the Sivers function. Drell-Yan data have also been collected at collider energies by experiments at RHIC and at LHC. First result on the transverse single-spin asymmetry of W-production was recently reported by the STAR Collaboration. At LHC, high statistics measurements of Drell-Yan and W/Z production are also becoming available.

In spite of numerous DIS and D-Y measurements, many important topics on the structures of mesons and nucleons remain to be explored. New measurements on the valence-quark distributions in pion and kaon are of great interest to test many theoretical calculations on meson structure. For example, new calculations, based on chiral quark model, light-front constituent model, or the Dyson-Schwinger equation are available for the simplest hadrons, the pion and the kaon. However, only the pion number density distribution is relatively well measured. The kaon distribution is essentially unknown, as are the Boer-Mulders distributions for both mesons.

Recent theoretical developments have demonstrated a strong interest in pion-induced exclusive Drell-Yan process. If the final state is known, the process is described in terms of pion distribution amplitude (DA), nucleon Generalized Parton Distributions (GPD), and pion time-like form factor. Measurements of the pion DA thus provide a major new tool for accessing the momentum sharing between the two-pion valence quarks. An intense antiproton beam would also allow other exclusive D-Y processes to be explored.

Attractive new opportunities for progress in these directions exist at CERN and at J-PARC. The M2 beamline at CERN delivers high-energy hadron beams (composed mainly of pions) for a variety of experiments using the versatile COMPASS detector equipped with polarized targets. Initial studies show that a dedicated RF-separated beamline section could lead to an increase of number of kaons and antiprotons in the beam by a factor of 20 to 50, opening a whole new area of research. An intense meson and antiproton beam line, together with a dedicated spectrometer, is also being built at J-PARC. Its lower energies offer unique opportunities for pion DA measurements, as well as for pion and kaon distribution function measurements.

Results and Highlights

The talks presented at the Workshop were of excellent quality, reflecting significant efforts by the Workshop participants in preparing and delivering their talks. Many of these presentations were greeted with enthusiastic and interesting discussions afterwards. While it is impossible to summarize all these interesting results and discussions at this Workshop, we list below some highlights.

- Recent theoretical work predicts very different parton distributions in kaon and pion. In particular, the gluon content of kaon is expected to be significantly smaller than that of pion. This prediction provides a strong motivation for future experiments aiming at first measurements of the gluon content in kaon. Possible experiments include direct photon, J/ψ, and open charm production with kaon beam.
- An interesting alternative method to probe the meson structures is to use the so-called "tagged DIS" process, in which a forward-going nucleon is measured in coincidence with the lepton-induced DIS. The underlying mechanism for the tagged DIS is the scattering of lepton off the meson cloud of the nucleon. Earlier measurements at HERA suggested the feasibility of this method for extracting pion's sea-quark content. Future experiments at Jefferson Lab and at the Electron-Ion Collider could extend such measurement to different kinematic regions.
- The existing data on pion and kaon induced Drell-Yan, J/ψ, and direct photon production have been discussed extensively at the Workshop. The potential for extracting new information on the meson parton distributions using the existing J/ψ has also been pursued in some recent studies. The unpolarized dimuon production data with pion beam from COMPASS on various targets would likely provide interesting data before the RF-separated beam becomes available at CERN.
- The transition from the inclusive D-Y to exclusive D-Y is analogous to the transition from DIS to resonance production in electron scattering. The Bloom-Gilman duality, which has been tested in the DIS, might also lead to other theoretical and experimental investigation in the exclusive or semi-exclusive D-Y process.
- The conceptual design of the RF-separated beam at CERN was presented. A rich research field including the meson PDFs, TMDs of nucleon and meson, hadron spectroscopy with diffractive production of kaon beam, has been discussed extensively at this Workshop. A proposal containing many of the ideas presented at this Workshop will be submitted to CERN within one year from now.
- The status of the high-momentum beam at J-PARC, together with the physics reach using the E50 spectrometer for the exclusive Drell-Yan measurement, have been discussed. The physics interest for measuring exclusive J/ψ production is also mentioned. A Letter-of-Intent is expected to be submitted to J-PARC in the near future for such measurements.

At the conclusion of this Workshop, the participants were encouraged to send their thoughts on the following two questions: "What are the important unresolved theoretical issues?" and "What are the important measurements to be performed"? Below we list some of the comments sent by the participants:

- Important unresolved theoretical issues include "Origin of duality", "Hadron wavefunction at the x→ 1 limit", and "J/ψ production dynamics". Important future measurements include "Kaon's PDF", "Transition from inclusive to semi-exclusive to exclusive for the Drell-Yan process", and "Comparison between space-like and time-like exclusive reactions".
- Theoretical issues: "Can LQCD contribute further in the near future, *e.g.* validating other predictions of continuum QCD and generating novel predictions?"; "The continuum-QCD prediction of the gluon distribution within hadrons and valence-quark distributions within the nucleon should be given the highest possible priority"; "High-priority should be given to the computation of the Sivers and Collins functions in approaches with a mathematically sound connection to QCD." "Placing constraints upon, or preferably computation of, sea-quark distributions within the nucleon using QCD-connected theory should be given the highest possible priority." Experimental issues: "Accurate measurements of the valence-quark and sea-quark distributions within hadrons".
- Measurement of the sign of the Sivers function in Drell-Yan to test the current interpretation of the Sivers effect. The crucial measurements include the Drell-Yan, W-

production, and J/ψ production (which has large contribution for quark-antiquark annihilation when pion beam is used).

- "Origin of the nucleon spin, the origin of hadron masses, and internal structure of exotic hadron candidates by hadron tomography." "Exclusive processes using the pion, antiproton, as well as the virtual photons at KEKB".
- "In my opinion the comparison of internal quark and gluon content in kaon and pion is one of the most interesting topic of low-energy QCD". "Possibility to use at COMPASS pion and kaon beams of both polarities and possibility to study in parallel the Drell-Yan, J/psi and prompt photon production processes looks extremely promising."

In summary, we believe this workshop is very successful. We expect many follow-up activities in future theoretical and experimental work inspired by the presentations and discussions during this workshop.

3.3.19 AXIONS AT THE CROSSROADS: QCD, DARK MATTER, ASTROPHYSICS

DATE: November 20 – 24, 2017

ORGANIZERS:

M. P. Lombardo (LNF, Italy)
A. Mirizzi (Bari University and INFN, Italy)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The aim of the workshop has been to review and discuss the recent advances in the study of axions and future perspectives, ranging from their theoretical underpinning, over their indirect observational consequences in astrophysics, to their direct detection in laboratory experiments. Searches for axions are strongly motivated by our attempts to understand one remaining mystery in the physics of strong interactions, the strong CP problem: in a nutshell, the very low neutron EDM constrains the CP violation to be unnaturally small. Axions might explain this and, at the same time, they will help to understand the nature of dark matter, and to explain puzzling astrophysical and particle physics observations. A rich, diverse, and low-cost experimental program is already underway that has the potential for one or more game-changing discoveries. The workshop has been structured to address these issues in a synergic way and to stimulate discussions and collaborations among scientists working on axions from different perspectives.

The main topics were:

- Theoretical models
- Axion dark matter
- Astrophysical hints and bounds
- Experimental searches

SPEAKERS:

E. Berkowitz (FZ Jülich, Germany)

C. Bonati (Univ. Pisa & INFN, Italy)

M. Cicoli (Univ. Bologna & INFN, Italy)

N. Crescini (Univ. Padova & Lab. Nazionali Legnaro, Italy)

S. Davidson (IPN Lyon, France)

F. Della Valle (Trieste Univ. & INFN, Italy)

I. Dominguez (Granada Univ., Spain)

A. Ernst (Hamburg Univ., Germany)

H. Fischer (Freiburg Univ., Germany)

Z. Fodor (Wuppertal Univ., Germany)

N. Fonseca (Hamburg Univ., Germany)

J. Jeong (KAIST, South Corea)

R. Laha (JGU Mainz, Germany)

C. Ligi (LNF, Italy)

A. Lindner (DESY, Hamburg, Germany)

D. Montanino (Univ. of Lecce & INFN, Italy)

J. Redondo (Univ. of Zaragoza, Spain)

A. Ringwald (DESY Hamburg, Italy)

G. Rybka (Univ. of Washington, USA)

M. Roncadelli (INFN Pavia, Italy)

S. Sharma (BNL, USA)

G. Sigl (Hamburg Univ. Germany)

F. Steffen (MPI, Munich, Germany)

C. Gatti (LNF, Italy)

M. Giannotti (Barry Univ., USA)

M. Gorghetto (SISSA, Trieste, Italy)

W. Hollik (Hamburg Univ., Germany)

V. Klaer (TU Darmstadt, Germany)

O. Straniero (INAF, Astronomical Obs. Teramo, Italy)

Y. SungWoo (KAIST, South Corea)

G. Villadoro (ICTP Trieste, Italy)

H. Vogel (Stanford, USA)

A. Wickenbrock (JGU Mainz, Germany)

SCIENTIFIC REPORT:

The Standard Model (SM) of particle physics is an extremely successful theory, explaining all interactions between the known elementary particles as observed in the laboratory to a very high accuracy. However, from astrophysics and cosmology we know that there must be physics beyond the SM. In fact, most matter in the universe appears to be composed of non-relativistic dark matter (DM) particles with at most feeble interactions with SM particles.
In this context, the discovery of the Higgs boson provides strong evidence that fundamental scalar bosons exist in nature. It is thus a timely and well-motivated task to search for further light scalar or pseudoscalar particles. The prime example of such a very light pseudo-Goldstone boson is the axion, introduced to solve the strong CP problem in QCD. Beyond the axion there exists a wide range of interesting (pseudo) scalar particles which typically feature very similar interactions as the axion, but which may have different masses. These emerge in many theoretically appealing ultraviolet completions of the SM and are generically called axion-like particles or ALPs. These offer a convincing physics case in connection to the puzzle of DM, and provide a variety of opportunities for experimental and observational searches.

All these topics have been addressed in the workshop as summarized in the following:

- *Axion theory:* Which is the status of axion model building? How to connect axions and ALPs to BSM physics? Which is the preferred parameter space for QCD axions?
- *Axion Dark Matter:* Which are the production mechanisms for axion DM? How to get reliable predictions for axion dark matter mass? What lattice gauge theories can do for axion dark matter searches? How to distinguish axion DM from WIMPs? Which is the status of direct searches of axion DM? Which parameter space is accessible by current and future experiments?
- *Astrophysical bounds and hints on axions and ALPs:* Which is the status and the perspectives for axion and ALPs bounds from energy loss in stars? How reliable are current bounds with respect to astrophysical (and nuclear physics) uncertainties (e.g. in the SN 1987A)? Which improvement is possible with future data? Which is the status of ALPs constraints from VHE gamma-ray observations? Which parameter space will be probed by future experiments (e.g. CTA)?
- *Direct axion and ALP searches:* Which is the current status for axion searches? How to improve the current sensitivity? Which are the novel experimental approaches?

These topics were treated during the talks of the workshop and during the discussion sessions organized in the evenings.

Results and Highlights

The workshop has been extremely useful to address the previous questions in a synergic way, gathering together scientists from different communities. This choice has been successful as certified by the lively atmosphere during the talks and especially during the long discussion sessions, where people from different communities actively interacted stimulating new ideas and strategies. All participants expressed enthusiasm for the outcome of the workshop, especially for the opportunity of learning complementary approaches to axion physics.

The main results and highlights can be summarized as follows:

- *Axion theory:* It has been shown how several properties of the QCD axion can be extracted at high precision using only first principle QCD computations. Concerning model building an ideal framework for axions is offered by string theory. Indeed, the 4D low-energy theory of a generic string compactification features several ALPs, which can give rise to the astrophysical and particle physics applications. There have been presented scenarios where one of these ALPs is the QCD axion in intersecting brane models. Axions predictions in Grand Unified Theories have also been shown. The strong CP problem from a flavour perspective has been discussed.

- *Axion Dark Matter:* The mechanisms of production of axion DM (misalignment, string decay) have been revised. It has been shown how the evolution of axion number density in the early universe can be determined by calculating the topological susceptibility of QCD as a function of the temperature. In this context Lattice QCD provides an ab initio technique to carry out such a calculation. Results from different groups using different schemes have been compared. State-of-art calculations predict a range m=50-1500 μeV in the post-inflation scenarios. It has been pointed out that in this scenario, axion would possibly form "miniclusters" in our galaxy. From the lensing through these objects, a signature of axion DM could be obtained. Other possible astrophysical signatures would be associated to the flux of radio photons from conversion of axion-like particle dark matter in cosmic magnetic fields. Concerning the direct searches of axion DM, results and perspectives from different experiments have been compared. The ADMX experiment, based on resonant cavity, is currently exploring the axion mass range in the pre-inflation scenario, being sensitive up to m=40 μeV. High sensitivity to higher axion masses in the post-inflation scenario is expected from the MADMAX proposal, based on axion-photon conversions at the transition between different dielectric media. Dedicated studies for axion dark matter will be pursued at the CAPP Center in South Korea. New ideas for axion dark matter searches, like KLASH, QUAX, GNOME and CASPEr have been presented.

- *Astrophysical bounds and hints on axions and ALPs:* It has been discussed how puzzling results from astrophysics provide exciting phenomenological motivations for axions and ALPs. Indeed, ALPs (with m < 1 keV) can be produced in stars due to the coupling with SM particles (photons, electrons, nucleons) and would therefore alter the stellar evolution. Recently, it has been realized that observations of different stellar systems (e.g., white dwarfs, globular clusters, neutron stars) indicate an over-efficient cooling with respect to expectations. Intriguingly this effect can be associated to the emission of axions or ALPs. In terms of QCD axion models, data seem to suggest an axion with a mass m~10 meV. These hints need further data to be confirmed. In this context, the final data release of the astrometric satellite GAIA, foreseen in 2020, will produce a big impact and will allow to probe the electron-axion coupling or put stringent limits on it. The two-photon coupling also allows for photon-axion mixing in external magnetic fields. At this regard, a particularly intriguing hint for ALPs has been recently suggested by Very High-Energy gamma-ray experiments. Indeed, photon-axion conversions in large-scale cosmic magnetic fields would reduce the opacity of the universe to TeV photons, explaining the anomalous spectral hardening found in the Very-High-Energy gamma-ray spectra. The phenomenology associated with this effect has been discussed in different talks, as well as the discovery potential of the future Cherenkov Telescope Array.

- *Direct axion and ALP searches:* A rich, diverse, and low-cost experimental program searching for axions and ALPs is carried on through different experimental techniques. Of particular relevance are the recent bounds on axion-photon coupling, from the CAST experiment at CERN, searching for solar axions. Proposal for future generation solar axion experiments, like TASTE and IAXO have been presented. Their aim of these projects would be to probe the astrophysical hints discussed above. These will be also on the reach of the ALPS-II regeneration experiment at DESY, which will start collecting data in 2020. Results from the ALPs searches with PVLAS experiment have been also presented. New ideas, e.g. studying axions through spin-dependent forces, have been discussed.

3.3.20 PHASE DIAGRAM OF STRONGLY INTERACTING MATTER: FROM LATTICE QCD TO HEAVY-ION COLLISION EXPERIMENTS

DATE: November 27 – December 01, 2017

ORGANIZERS:

A. Bazavov (Michigan State University, USA)
M. D'Elia (University of Pisa, Italy)
M. Nahrgang (Subatech and École des Mines Nantes, France)

NUMBER OF PARTICIPANTS: 38

MAIN TOPICS:

This workshop focused on the physics of heavy-ion collisions, in particular, exploration of the QCD phase diagram, both in theory and experiment. In this workshop we connected the experts in ab initio theoretical calculations in lattice QCD with heavy-ion phenomenologists and experimentalists. The overarching themes were how the regions of high baryo-chemical potential can be approached experimentally, what are the signs of criticality and what theoretical predictions are available for them.

The main topics were:

- Fluctuations and higher-order cumulants of conserved charges
- Construction of effective models to study the regions of the QCD phase diagram where lattice calculations are not possible
- Complementary theoretical approaches, such as the functional renormalization group and real-time simulations in the frequency space
- Statistical models and extraction of freeze-out parameters
- Expectations for modeling of heavy-ion collisions at low beam energies (RHIC BES 2, CERN NA61, FAIR, NICA)

SPEAKERS:

J. Aichelin (Subatech, France)

A. Andronic (GSI, Germany)

F. Becattini (University of Florence, Italy)

D. Blaschke (University of Wroclaw, Poland)

M. Bluhms (University of Wroclaw, Poland)

C. Bonati (University of Pisa, Italy)

E. Bratkovskaya (GSI, Germany)

S. Chaterjee (AGH University Krakow, Poland)

R. Contant (University of Graz, Austria)

Z. Fodorn (Wuppertal University, Germany)

V. Koch (LBNL, USA)

M. Kuich (University of Warsaw, Poland)

M. P. Lombardo (INFN Frascati, Italy)

Y.-L. Ma (Jilin University, China)

A. Monnai (CNRS/CEA Saclay, France)

J. Pawlowski (Heidelberg Univ., Germany)

P. Petreczky (BNL, USA)

B.-J. Schaefer (Giessen Univ., Germany)

S. Sharma (BNL, USA)

A. Snoch (Goethe Univ. Frankfurt, Germany)

M. Stephanov (University of Illinois at

P. de Forcrand (ETH Zurich, Switzerland)

V. Friese (GSI, Germany)

A. Friesen (JINR, Russia)

T. Galatyuk (TU Darmstadt, Germany)

M. Gazdzicki (Jan Kochanowski University, Poland/Goethe University Frankfurt, Germany)

N. Haque (Giessen University, Germany)

S. Harabasz (TU Darmstadt, Germany)

P. Huovinen (Univ. of Wroclaw, Poland)

Chicago, USA)

J. Stroth (GSI, Germany)

R.-A. Tripolt (ECT*, Italy)

J. Weber (TU Munich, Germany)

N. Wink (Heidelberg University, Germany)

N. Xu (LBNL, Germany)

F. Ziegler (Heidelberg University, Germany)

SCIENTIFIC REPORT:

The investigation of the phase diagram of Quantum Chromodynamics (QCD) is the main goal of ultrarelativistic heavy-ion collision experiments and the related theoretical efforts. Strongly interacting matter can be present in the form of a hadron gas, a plasma of deconfined quarks and gluons (quark-gluon plasma, QGP) and many other fascinating and more exotic phases. The transition between these phases falls into the non-perturbative regime of QCD. The necessity to solve a strongly coupled non-perturbative quantum gauge theory at finite temperature and density is therefore a difficult theoretical challenge. Experimentally, the phase diagram of QCD can be probed in ultrarelativistic heavy-ion collision experiments, currently in operation at the Large Hadron Collider (LHC) and the Super Proton Synchrotron (SPS) at CERN, the Relativistic Heavy-Ion Collider (RHIC) at BNL and at the SIS18 at GSI/Helmholtz Center. Two future facilities are already in the stage of construction: Facility for Antiproton and Ion Research (FAIR) at GSI and Nuclotron-based Ion Collider Facility (NICA) at JINR.

In order to advance progress on the understanding of the QCD phase diagram we have invited not only first-class theorists and experimentalists to our workshop, but also focused on the importance of the bridging between these two areas by phenomenological approaches. These approaches typically use first-principle theoretical calculations and apply modeling, in particular dynamical modeling, to connect to experimental observables.

First-principle theoretical calculations in the non-perturbative regime are performed within the framework of lattice QCD. This numerical technique has provided quantitative results on QCD thermodynamics with an increasing precision over the last two decades. It is now able to locate the deconfinement transition, the restoration of chiral symmetry at high temperature and the QCD equation of state. Due to the sign problem, however, these calculations are limited to the small $\mu/T \sim O(1)$ region of the phase diagram, where these same methods have excluded a second-order phase transition. The question about the existence and location of the QCD critical point, as well as further conjectured phases at the high-density domain remain out of reach for the numerical techniques currently applied for lattice QCD calculations.

On the experimental side, enormous effort goes into the execution of current beam and system size scans and their analyses as well as into the planning of future programs. At the CERN-SPS the NA61/SHINE experiments run collisions of various species of ions at a number of different beam energies in order to create a two dimensional map of possible critical fluctuations and to study the onset of deconfinement both as a function of system size as well as beam energy. The RHIC beam energy scan phase I has yielded intriguing results for a number of observables related to the QCD phase transition, in particular the higher-order moments of net-proton fluctuations and the v1 signal of (anti-)proton flow. The analysis of these observables is still under scrutiny and evolves further in order to be prepared for the upcoming BES II.

In order to understand high- and lower beam energy heavy-ion collisions, dynamical modeling from the initial state to the final hadronic interactions is indispensable. One of the great successes of heavy-ion collision phenomenology is the fluid dynamical description of the expansion of the low-mu QGP including the lattice QCD equation of state. It demonstrates not only that systems created in heavy-ion collisions can be associated meaningfully to the thermodynamics of QCD, but also how theoretical calculations can be used to obtain reliable predictions for experimental observables.

During our workshop we discussed a number of challenges that emerge in the comparison between theory and experiment and possible tools and approaches to solve these issues.

Results and Highlights

The workshop schedule, which is reported below, was organized so as to have, each day, an optimal mixing of experimental and theory talks, followed by a common discussion. It was appreciated by the participants that every two-three talks were followed by a coffee break in order to avoid over-saturation and instead stimulate discussion immediately.

As intended in our proposal, the common theme of the majority of talks was fluctuations and their relation to the QCD phase diagram. The various contributions discussed fluctuations in one way or another as signals for the phase transition or of distinctive phases of QCD. This central theme was addressed from the experimental, the theoretical and the phenomenological side.

Every major collaboration measuring fluctuation observables at lower beam energies was represented during our workshop by at least one representative: Marek Gazdzicki (NA61/SHINE), Nu Xu (STAR), Tetyana Galatyuk and Joachim Stroth (HADES), Volker Friese (CBM) and David Blaschke (NICA). There was a lively discussion about the various methods of correcting for efficiencies and volume fluctuations. While STAR corrects according to formulae by V. Koch and A. Bzdak, which requires the underlying efficiency fluctuations to be binomial, HADES simulates the detector response and constructs the inverse matrix with these information. NA61/SHINE focuses in particular on measuring strongly intensive quantities, which are fluctuation observables that in the case of an ideal Boltzmann limit do not depend on the volume fluctuations. It was debated if these strongly intensive quantities can be calculated on the lattice. Since they involve extensive quantities in their construction, this could be difficult. Unfortunately, we had a last-minute cancellation from the ALICE participant. It would have been very interesting to also learn about their recent fluctuation analysis at highest beam energies.

On the theory side, we had excellent reviews about the latest results from most lattice collaborations working on the properties of QCD phase diagram. Zoltan Fodor reported on the latest results on QCD thermodynamics from the Wuppertal-Budapest Collaboration. Claudio Bonati presented a review of recent results on the curvature of the pseudo critical line for small mu/T, Maria Paola Lombardo reported on the latest results for QCD at finite T obtained with twisted mass Wilson fermions; Sayantan Sharma presented results regarding the QCD equation of state at finite baryo-chemical potential and the constraints on the location of the critical endpoint.

A systematic investigation of the critical endpoint by lattice QCD simulations is still hindered by the sign problem. As stressed in the talk by Philippe de Forcrand, even present expectations about the critical behavior coming from effective models might face surprises when confronted with the results of numerical simulations. Some steady progress has been reported for results obtained by functional renormalization group techniques, e.g., by Jan Pawlowski and Bernd Jochen Schaefer. It was discussed where one can generally place the region of reliability of various refinements of QCD-inspired models, and the conclusion was that they are mostly limited to regions, where they do not find a critical end point.

Between the theory and the experimental part we had many talks dedicated to the phenomenological parts connecting QCD thermodynamics with experimental observables. There was Misha Stephanov's talk on Hydro++, which includes the order parameter as an additional hydrodynamical variable near the critical point and instead of solving fluctuating hydrodynamics, equations for higher-order correlation functions are derived. This series needs to be truncated. Substantial progress to including critical fluctuations directly into the hydrodynamical equations has been presented by Marcus Bluhm. Here, numerical simulations on the net-baryon number fluctuations were performed with a free energy density functional from the 3D Ising model universality class. The equilibration in this approach was thoroughly scrutinized, before applying it to dynamical cooling scenarios. Although nonequilibrium effects like memory effects and critical slowing down were seen, the criticality was still observed. In Akihiko Monnai's talk emphasis was put on the divergence of the bulk viscosity near the critical point in one-dimensional hydrodynamical simulations.
It was pointed out, however, that most of our current understanding and most of the current approaches to treat critical fluctuations dynamically are based on hydrodynamics, although it might be estimated that the hydrodynamical phase, at least the hydrodynamical QGP phase, is rather short at lower beam energies. Therefore, we were happy to have contributions from further transport approaches, like the talks by Elena Bratkovskaya on phase transitions in PHSD and by Joerg Aichelin on PHQMD, which is a new transport approach applicable to FAIR and NICA energies reaching further into the possible line of first-order phase transitions.

Many models for the QCD phase transition rely on information of the phenomenological freeze-out curves obtained from heavy-ion experiments in combination with statistical hadronization models. This could be for locating simulations at a given sqrt(s) in the phase diagram or using the freeze-out conditions as input to calculate fluctuation observables at chemical freeze-out. A status of this field has been reported by Anton Andronic and Francesco Becattini.

We would like to highlight as well that we had talks of excellent quality from our young participants, in particular the master and PhD students, Aleksandra Snoch and Magdalena Kuich, from the NA61/SHINE experiment, as well as the PhD students, Nicolas Wink and Felix Ziegler from Heidelberg University applying FRG methods to calculate thermal and real-time correlation functions for QCD-inspired models.

Last, but not least, apart from utilizing the ECT* funds, we secured $2000 from the Beam Energy Scan Theory (BEST) collaboration, which we thank wholeheartedly, intended specifically to support junior researchers.

3.4 ECT* DOCTORAL TRAINING PROGRAM 2017

Microscopic Theories of Nuclear Structure, Dynamics and Electroweak Currents

ECT, June 12-30, 2017*

(Report by G. Ripka)

The 2017 ECT* Doctoral Training Program (DTP) on *Microscopic Theories of Nuclear Structure, Dynamics and Electroweak Currents* was held at ECT* from June 12 to June 30, 2017 for a duration of 3 weeks. The program coordinator was Omar Benhar (INFN and Università La Sapienza), the local coordinator, in charge of the finance, lodging and other administrative tasks of the students and lecturers was Serena Degli Avancini, and Georges Ripka (*IPhT, Saclay and ECT**) attended as student coordinator. The 2017 DTP was held back to back with the TALENT@ECT* - course on Advanced Low-Energy Nuclear Theory - "*Theory for Exploring Nuclear Structure Experiments"* (3-21 July, 2017).

The 2017 Doctoral Training Program was attended by 25 PhD students, who are listed at the end of this report. There were altogether 10 lecturers, on average 3 lecturers per week, which were scheduled both in the mornings and in most of the afternoons. Several students were asked to give 45-minute seminar presentations on their current research projects. Altogether 16 out of the 25 students gave seminars (listed below).

Most lecturers prepared slides, handwritten notes and other material to be made available to the students. The relevant files were placed in a password-protected area of a FBK website, which could only be accessed from ECT*. It was decided that the files would be deleted after the termination of the DTP. At the end of the DTP, each student was provided with a USB key containing the lecture notes, student seminars, and some photographs. The ECT* website, giving practical information, was designed by Barbara Curro' Dossi and proved very useful to the students. This year, most of the students were housed in shared rooms in Agritur, at Ponte Alto in the outskirts of Trento. Some were housed in the neighboring village of Villazzano. At the end of the program, the students were asked to write an informal (and not necessarily signed) report to be made available to the ECT* Director. They were encouraged to state difficulties they were confronted with and what could possibly be improved.

3.4.1 Lectures

The lecturers were encouraged to use the blackboard rather than power-point-like presentations and many did so. Plots of pertinent results were projected on a screen. The program coordinator, Omar Benhar, was present during the entire programme.

Week 1 (June 12-16, 2017)

Michele Viviani (INFN and University of Pisa)
Phenomenological nuclear interactions and currents
The lectures of Viviani discussed the pion-nucleon interaction, the T-matrix for pion-nucleon scattering, the nucleon-nucleon interaction resulting from various meson exchanges, the Argonne AV18 interaction and the need of three-body interactions.

Luca Girlanda (Università del Salento)
Nuclear electroweak currents within chiral EFT

Girlanda discussed the notion of chiral symmetry, conserved charges, field-theoretical Lagrangians, the pion as a Goldstone mode, $SU_L(2)$ and $SU_R(2)$ transformations and how to treat nucleons as well as their 2- and 3-body interactions.

Evgeny Epelbaum (Ruhr- Universität, Bochum)
Nuclear dynamics from chiral EFT
Epelbaum introduced the effective-range expansion, the relevant scales in terms of the meson- and nucleon masses, the occurrence of bound states and the corresponding effective ranges. He discussed the effect of integrating out pions and the resulting nucleon Lagrangian of 'pionless' EFT (effective field theory) as well as Feynman rules and dimensional regularization.

Weeks 2 and 3 (June 19-23 and June 26-30, 2017)

Stefano Gandolfi (Los Alamos National Laboratory)
Quantum Monte Carlo Approach
Gandolfi started by presenting simple examples of how to evaluate high-dimensional integrals numerically. He discussed the central limit theorem and Jastrow-correlated wavefunctions in position-space. He introduced Hubbard-Stratonovich transformations and the resulting auxiliary-field-diffusion Monte Carlo method. He finally presented several applications such as linear-response functions, nuclear charge form factors, the structure of the neutron star crust, the BCS-BEC crossover.

Robert Roth (Technische Universität, Darmstadt)
No-core shell model approach
Starting with the nuclear two-body problem, Roth discussed unitary transformations of the interaction using the renormalization group, and the corresponding transformation of the Hamiltonian. He addressed the decoupling of particle-hole excitations, normal ordering of the Hamiltonian (without 3-body interactions) with respect to a reference state, coupled-cluster theory and the decoupling in A-body space.

Alessandro Lovato (Argonne National Laboratory)
Correlated basis function approach
All lectures of Lovato were presented on the blackboard. He discussed Jastrow-like correlation factors, one- and two-body correlation functions and diagrammatic expansions. He introduced reducible and irreducible diagrams, diagram rules for vertex corrections, exponentiation, composite and bimodal diagrams, and the hypernetted-chain equations with their iterative solutions.

Carlo Barbieri (University of Surrey)
Self-consistent Green's functions approach
Barbieri presented a Hamiltonian with 2 and 3-body interactions as well as formal properties of the one-body and 2-body propagators (Green functions) and the Koltun sum rule. He then presented the self-consistent Green function approach to nuclear many-body theory and discussed various state-of-the-art results.

Benhar Omar (INFN and Sapienza University)
The lepton nucleus cross-section within nuclear many-body theory
Benhar discussed the non-relativistic pion-exchange interaction, the bound state in the S=1, T=0 channel and the pion-nucleon interaction. He explained electron scattering from the nucleon, as a composite particle, Gordon's identity and the corresponding form factors. He then introduced electron scattering as a precision tool for the study of nuclei and their internal structure.

Artur Ankowski (Virginia Tech)
Application of the spectral function formalism to electron and neutrino-nucleus scattering
The lectures of Ankowski presented the physics of neutrino oscillations, the matter-antimatter asymmetry and the detection of neutrinos produced in accelerators. He discussed what could

be deduced from such experiments, focusing in particular on the finite energy spread of the neutrino beams, and the problem of reconstructing the neutrino energy from the produced particles in the final state.

3.4.2 List of students

Albertsson Karl Martin	Lund University, Sweden
Arthuis Pierre Noel	CEA Saclay, France
Baczyk Pawel	University of Warsaw, Poland
Boulet Antoine Maurice André	IPN Orsay, France
Contessi Lorenzo	Università degli Studi di Trento, Italy
Drissi Mehdi Yoan Ismael	CEA Saclay, France
El Barbari Monia	University Abdelmalek Essaadi, Morocco
Fahlin Stromberg Dag Isak August	TU Darmstadt, Germany
Gnech Alex	GSSI (Gran Sasso Science Institute), Italy
Haverinen Tiia Kristiina	University of Jyväskylä, Finland
Huether Thomas	TU Darmstadt, Germany
Konieczka Maciej	University of Warsaw, Poland
Mcilroy Christopher Stuart	University of Surrey, UK
Mertes Laura Kristina	TU Darmstadt, Germany
Pandey Vishvas	Virginia Tech, US
Ripoche Julien	CEA/DAM Ile-de-France, France
Riz Luca	Università degli Studi di Trento, Italy
Rocco Noemi	University of Surrey, UK
Saxena Archana	Indian Institute of Technology Roorkee, India
Seutin Rodric Bernard J	TU Darmstadt, Germany
Sobczyk Joanna Ewa	University of Wroclaw, Poland
Speranza Enrico	GSI and TU Darmstadt, Germany
Spielvogel Hans	TU Darmstadt, Germany
Tafrihi Azar	Isfahan University of Technology, Iran
Zdeb Anna Maria	Maria Curie-Skłodowska University, Poland

3.4.3 Student seminars

The students gave the following seminars:

P. Baczyk (University of Warsaw)
Mirror and triplet energy differences with density functional theory

A. Boulet (IPN, Orsay)
Density functional theory based on bare interactions

T. Huther (TU, Darmstadt)
Chiral EFT expansion in light nuclei

A. Gnech (Gran Sasso Science Institute)
Time reversal violation in two-nucleon systems

M. Drissi (CEA, Saclay)
Interacting many-body methods and EFT interactions

L. Mertes (TU, Darmstadt)
Precision calculation of electromagnetic observables of light nuclei

M. El Barbari (University Abdelmarek Essaadi, Morocco)
Calculating S(d,β) for graphite using ab initio programs

A. Tafrihi (Isfahan University of Technology)
Nucleon-nucleon correlation and distribution functions in the LOCV approximation

T. Haverinen (University of Jyväskylä)
From the era of the standard Skyrme EDF's to novel approaches

H. Spiegelvogel (TU Darmstadt)
The Berggren basis for the no-core shell model

P. Arthuis (CEA, Saclay)
Recent developments in Bogoliubov many-body theory

E. Speranza (GSI and TU, Darmstadt)
Virtual photon polarization and dilepton anisotropy in pion-nucleon and heavy-ion collisions

A. Zdeb (Marie Curie Sklodowka University)
Microscopic description of fission mass yields

V. Pandey (Virginia Tech)
The impact of nuclear effects on accelerator-based neutrino oscillation physics

J. Sobczyk (University of Wroclaw)
Nuclear effects in neutrino studies

L. Riz (Università degli Studi di Trento)
QMC methods in dense neutron matter

3.5 ECT* Nuclear Talent Course 2017

Nuclear Theory for Nuclear Structure Experiments

ECT, July 3-21, 2017*

The twelfth Nuclear Talent course, 'Nuclear Theory for Nuclear Structure Experiments' was held at ECT* during the period from July 3 to July 21, 2017. It was the fourth course at ECT*, the first one in 2012, then in 2014 and in 2015 and finally in 2017. The support from ECT* has been crucial for the successful arrangement and running of these courses. For the 2017 course in total 52 applications were received and a final of 31 participants were selected.

3.5.1 Scope and goals

The nuclear shell model plays a central role in guiding the analysis of the wealth of nuclear structure experimental data. It provides an excellent link to the underlying nuclear forces and the pertinent laws of motion, allowing nuclear physicists to interpret complicated experiments in terms of various components of the nuclear Hamiltonian. Large-scale shell-model calculations represent challenging computational and theoretical topics, spanning from efficient usage of high-performance computing facilities to consistent theories for deriving effective Hamiltonians and operators. The goal and motivation of this course was to introduce and develop the nuclear structure tools needed to carry out forefront research using the shell model as the central tool. The various course activities focused on the development of a shell-model code for sd-shell nuclei, giving the participants the essential ideas of configuration interaction methods. During the first two weeks the students were supposed to develop such a shell-model code. With these insights, they could divert into several directions the last week, from the usage of the NushellX suite of nuclear structure programs to further developing their own shell-model program.

3.5.2 Teachers and organizers

The organizers were:

1. Alex Brown, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
2. Morten Hjorth-Jensen, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA and Department of Physics, University of Oslo, N-0316 Oslo, Norway

Morten Hjorth-Jensen will also function as student advisor and coordinator.

The teachers were:

1. Alex Brown, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
2. Alexandra Gade, National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA
3. Robert Grzywacz, at Oak Ridge National Laboratory, Oak Ridge, TN 37831 and Department of Physics and Astronomy, University of Tennessee, Knoxville, TN 37996-1200, USA
4. Morten Hjorth-Jensen, at National Superconducting Cyclotron Laboratory and Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA and Department of Physics, University of Oslo, N-0316 Oslo, Norway
5. Gustav Jansen, at Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA

3.5.3 Course Schedule

Lectures were approximately 45 min each with a small break between each lecture. The lecturers with their acronyms were:

- AG: Alexandra Gade
- BAB: Alex Brown
- GJ: Gustav Jansen
- MHJ: Morten Hjorth-Jensen
- RG: Robert Grzywacz

Schedule of the 3 weeks:

Week 1, July 3-7

Monday 3 July

09:00-09:30	Registration at the ECT*
09:30-10:00	Introduction and welcome (BAB, MHJ and GJ)
10:00-12:30	Survey of data (BAB)
12:30-14:30	Lunch + own activities
14:30-18:00	More survey of data (BAB)

Tuesday 4 July

09:30-11:30	Mean-field and shell-model basics (MHJ)
11:30-12:30	Single-particle potentials and shell-model basics (BAB)
12:30-14:30	Lunch + own activities
14:30-18:00	Single-particle potentials

Wednesday 5 July

09:30-11:30	Welcome by ECT* director Jochen Wambach and Shell-model basics (MHJ)
11:30-12:30	Shell-model dimensionalities (BAB)
12:30-14:30	Lunch + own activities
14:30-18:00	Work on shell-model project and NushellX

Thursday 6 July

09:30-11:30	Shell-model basics (MHJ)
11:30-12:30	Proton-neutron formalism and isospin (BAB)
12:30-14:30	Lunch + own activities
14:30-18:00	Work on shell-model project and NushellX

Friday 7 July

09:30-12:30	Effective interactions for shell model (GJ)
12:30-14:30	Lunch + own activities
14:30-17:00	Group presentations

Week 2, July 10-14

Monday 10 July

09:30-10:30	Masses from experiment (AG)
10:30-12:30	Effective Hamiltonians (BAB and GJ)
12:30-14:30	Lunch + own activities
14:30-18:00	Work on shell-model project and NushellX

Tuesday 11 July

09:30-10:30	Spectroscopic factors from experiment (AG)
10:30-12:30	Spectroscopic factors from theory (BAB)

12:30-14:30	Lunch + own activities
14:30-15:30	Monte Carlo Shell-model seminar by Takaharu Otsuka
15:30-18:00	Work on shell-model project and NushellX

Wednesday 12 July

09:30-11:30	Introduction to β-decay, experiment (RG)
11:30-12:30	β-decay and sum rules from theory (BAB)
12:30-14:30	Lunch + own activities
14:30-18:00	Discussion of IBM and shell-model by Noam, Tobias and Takaharu

Thursday 13 July

09:30-10:30	Electromagnetic decays from experiment (AG)
10:30-12:30	Shell-model transition probabilities (BAB)
12:30-14:30	Lunch + own activities
14:30-15:30	Presentation by Guillaume
15:30-18:00	Work on shell-model project and NushellX

Friday 14 July

09:30-11:00	Advanced aspects of β-decay, experiment (RG)
11:00-12:30	Summary of first two weeks (MHJ)
12:30-14:30	Lunch + own activities
14:30-17:00	Group presentations

Week 3, July 17-21

Monday 17 July

09:30-12:00	Building a shell-model code (MHJ)
12:00-13:00	More on β-decay and γ-decay (BAB)
13:00-14:30	Lunch + own activities
14:30-18:00	Discussions

Tuesday 18 July

09:30-12:00	Building a shell-model code, Lanczos' algorithm and Hartree-Fock theory (MHJ)
12:00-12:30	γ-decay (BAB)
12:30-13:00	Lunch + own activities
14:30-15:30	Laser spectroscopy talk by Agi and Shane
15:30-18:00	Discussions

Wednesday 19 July

09:30-11:30	From Hartree-Fock theory to the shell-model, analyzing the results (MHJ)
11:30-12:30	γ-decay Two-body transition operators and double-beta decay (BAB)
12:30-14:30	Lunch + own activities
14:30-15:30	No-core shell-model talk by Patrick and Nuclear interactions by Tor
15:30-18:00	Discussions

Thursday 20 July

09:30-12:30	From Hartree-Fock theory to the shell model, discussion of final project and summary of course (BAB and MHJ)
12:30-14:30	Lunch + own activities
14:30-17:00	Discussions

Friday 21 July

09:30-12:30	Project work and own activities (no lectures)
12:30-14:30	Lunch + own activities
14:30-18:00	Own activities

3.5.4 Activities and Outcomes

Approximately forty-five hours of lectures were held over three weeks and a comparable amount of practical computer and exercise sessions, including the setting of individual problems and the organization of exercises and projects. The mornings consisted of lectures and the afternoons were devoted to exercises and project work meant to shed light on the exposed theory, the computational project and eventual individual student projects. The total load was approximately 170 hours, corresponding to 7 ECTS in Europe. Professor Takaharu Otsuka gave a special lecture on Shell-Model Monte Carlo methods in the second week and in addition, five students gave presentations of their own research. These lectures were closely related to the topics of the present Talent Course. All learning material, with preparatory material on second quantization plus Alex Brown's lecture notes were provided well in advance before the school (three weeks) and were available via the Github link.
The students were divided into nine groups from the very first day of the school. These groups remained stable throughout the whole duration of the course. The basic set up consisted in having at least one experimentalist and one theorist in every group. Three groups had four members while the remaining six groups consisted of three members only.

The activities can be summarized as follows:

- Work in groups was used to carry out the tasks.
- The weekly results and progress of every group was presented at the end of week (Friday afternoons) in a conference-like setting to create accountability.
- Several social events were organized where individuals and groups could exchange their experiences, difficulties and successes to foster interaction.
- On-line and lecture-based training tailored to technical issues was provided. The lectures were aligned with the practical computational projects and exercises and the lecturers were available to help students and work with them during the project and exercise sessions.
- During the second week, after having introduced the basic theory needed to understand full configuration interaction theory, the theoretical interpretations were accompanied by talks on how to perform nuclear structure experiments. These lectures were given by Alexandra Gade and Robert Grzywacz and illustrated how nuclear structure theory can be used to interpret data. Several of the experimental students gave additional lectures the same week on additional experimental techniques.
- Each group of students maintained an online logbook of their activities and results using Github. This allowed the teaching team to monitor the weekly progress of each group. The weekly presentations were also stored at the Github address of each group.
- Training modules, codes, lectures, practical exercise instructions, online logbooks, instructions and information created by participants are stored into a comprehensive website that is available to the community and the public for self-guided training or for use in various educational settings.

Based on the feedback from the student reports that were asked for in a questionnaire at the end of the course, it can be concluded that the learning outcomes were achieved to a large extent. All groups developed their own shell-model code and benchmarked it with results from NushellX for sd-shell nuclei. Furthermore, NushellX was used to perform advanced interpretations of experimental data, allowing the participants to both understand the basic theory and to relate theory to experimental data from various decay modes.

3.5.5 Participants

The target group for the Nuclear Talent Courses was Master of Science students, PhD students and early post-doctoral fellows. In the selection of the participants priority was given to Master of Science students and early PhD students.
The students were expected to have operating programming skills in Fortran/C++/Python and knowledge of quantum mechanics at an intermediate level, with basic knowledge of

many-body physics. Of the 31 students, eight were Master of Science students and all, if possible, expressed they would like to continue with a PhD in nuclear physics. Of the PhD students, the majority were in their first two years. Sixteen nationalities (from three continents) and 20 different institutions/affiliations were represented. Twelve out of the 31 students were experimentalists and nine were female students. The students and their respective institutions are listed in the table below.

Name	Level	Institution	Nationality	Theory/ Expt
Ashley Hood(F)	PhD	Louisiana State University, USA	USA	Expt
Erin Good(F)	PhD	University of Maryland, USA	USA	Expt
Anne Marie Forney(F)	PhD	University of Maryland, USA	USA	Expt
Patrick Fasano(M)	PhD	Notre Dame University, USA	USA	Theory
Guillaume Häfner(M)	MSc	University of Cologne, Germany	Germany	Expt
Udo Gayer(M)	PhD	TU Darmstadt, Germany	Germany	Expt
Rosa-Belle Gerst(F)	PhD	University of Cologne, Germany	Germany	Expt
Tobias Beck(M)	PhD	TU Darmstadt, Germany	Germany	Expt
Paolo Andreatta(M)	PhD	University of Trento, Italy	Italy	Theory
Luca Riz(M)	PhD	University of Trento, Italy	Italy	Theory
Giovanni Pederiva(M)	MSc	University of Oslo, Norway	Italy	Theory
Gianluca Salvioni(M)	PhD	University of Jyväskylä, Finland	Italy	Theory
David Miur(M)	PhD	University of York, UK	UK	Theory
Matthew Shelley(M)	MSc	University of York, UK	UK	Theory
Shane Wilkins(M)	PhD	University of Manchester, UK	UK	Expt
Ina Berentsen(F)	MSc	MSc University of Oslo, Norway	Norway	Expt
Mathias Vege(M)	MSc	MSc University of Oslo, Norway	Norway	Theory
Sean Miller(M)	MSc	MSc University of Oslo, Norway	Norway	Theory
Tor Djärv(M)	PhD	Chalmers	Sweden	Theory
Martin Albertsson(M)	PhD	Lund University, Sweden	Sweden	Theory
Lucia Campo Crespo(F)	PhD	University of Oslo, Norway	Spain	Expt
Antonio Marquez Romero(M)	PhD	University of York, UK	Spain	Theory
Gilho Ahn(M)	MSc	University of Athens, Greece	Greece	Theory
Ovidiu Nitescu(M)	MSc	University of Bucarest, Romania	Romania	Theory
Noam Gavrielov(M)	PhD	The Hebrew University, Jerusalem, Israel	Israel	Theory
Olvier Vasseur(M)	PhD	IPN Orsay, Paris, France	France	Theory
Liqiang Qi(M)	PhD	IPN Orsay, Paris, France	France	Expt
Mahsa Razazi(F)	PhD	Islamic Azad University, Urmia, Iran	Iran	Theory
Masaaki Tokiada(M)	PhD	University of, Japan	Japan	Theory
Agota Kozsorus(F)	PhD	PhD University of Leuven, Belgium	Hungary	Expt
Tiia Haaverinen(F)	PhD	University of Jyväskylä, Finland	Finland	Theory

On average, the students performed very well. Seven students handed in the final report and will receive a credit transfer of the seven ECTS from the University of Trento.

3.5.6 Concluding remarks

As a recommendation to new teaching teams, setting student groups from day one is essential. Groups of 3-4 students were optimal and students with complementary and/or different skills interest did benefit from each other. This group of students was particularly well functioning and setting up working groups from the very beginning helped in developing new friendships and perhaps even new collaborations. The feedback from the students testifies to this. Having proper projects and exercises, which are coordinated with the lectures is essential. The learning outcomes and the satisfaction of having written one's own shell-model code cannot be underestimated. With several teachers it is also difficult to achieve a uniform teaching style. Some of the lectures were best suited in terms of slides. Other teachers used a mix of slides and blackboard, or just the blackboard. The latter slows down the pace and many of the respondents seemed to prefer that teaching modus. But with several teachers, it is also important that each teacher feels comfortable with her/his way of teaching, especially since this was an intensive three weeks course.

The support from the ECT*, and its yearlong experiences with running doctoral training programs and Talent courses, was central to the success of the course. Of utmost importance was Serena degli Avancini's help with all administrative matters, from housing to minor practicalities. Without her help and the other staff of the ECT*, and the director's (Prof. Jochen Wambach) enthusiastic support, it is unlikely that this course would have run as smoothly as it did.

4 Research at ECT*

In this chapter the 2017 activities of the scientific researchers at ECT*, i.e. of the Postdoctoral Fellows and Senior Research Associates, the Director, the long-term Visitors and their collaborators are briefly summarized. The contributions are listed in alphabetical order. Cooperations of the scientists within the Centre are most often joint projects with colleagues at institutions elsewhere. Pursuing such collaborations, with ECT* as a "brain-storming" focal point, is an essential element of the scientific life at the Centre and of the activities conducted by the in-house research group. In parallel to their research, the Director and Daniele Binosi have been involved in the planning and organization of the Q@Tn – Quantum Science and Technology, a Trento Initiative of the Bruno Kessler Foundation, the Institute for Photonics and Nanotechnology (CNR) and the University of Trento. Dionysios Triantafyllopoulos conducts research primarily focusing on QCD at the highest energy densities. At the same time he continues to represent ECT* in the PhD Committee of the Physics Department of the University of Trento.

4.1 Projects of ECT* Researchers

Guillaume Clement Beuf

Next-to-leading order corrections to Deep Inelastic Scattering structure functions in the dipole picture

Deep Inelastic Scattering (DIS) is the cleanest process to gain knowledge on the partonic content of a proton or nucleus. Even in the regime of low Bjorken x, where the parton picture breaks down due to the onset of gluon saturation, DIS keeps its role as reference process, provided the collinear factorization is replaced by the dipole factorization. The dipole amplitude can indeed be obtained by fits on DIS data at low x, and then be used to make predictions on other processes sensitive to gluon saturation. Hence, next-to-leading (NLO) corrections to DIS structure functions in the dipole factorization formalism are a required ingredient to reach precision in that approach.

Earlier calculations [1,2] focused only on the quark-antiquark-gluon part of these NLO corrections. In Ref. [3], I calculated instead the loop correction to the quark-antiquark contribution to DIS in the dipole picture. At this occasion, I had to develop new techniques to perform such NLO calculations in Light-Front perturbation theory, in dimensional regularization. In Ref. [4], I found a consistent method to combine the quark-antiquark and the quark-antiquark-gluon contributions, which are each UV divergent whereas their sum is finite. Hence, the final result for DIS structure function at NLO in the dipole picture is provided in Ref. [4], including the discussion of low x leading log resummation. A preliminary numerical study of that result has appeared in Ref. [5], and then the NLO result was later confirmed by the independent calculation in Ref. [6].

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Daniele Binosi

Evidence of ghost suppression in gluon mass dynamics

In collaboration with A. C. Aguilar and C. T. Figueiredo (University of Campinas, Brazil), J. Papavassiliou (University of Valencia, Spain)

In this work we study the impact that the ghost sector of pure Yang-Mills theories may have on the generation of a dynamical gauge boson mass, which hinges on the appearance of massless poles in the fundamental vertices of the theory, and the subsequent realization of the well-known Schwinger mechanism. The process responsible for the formation of such structures is itself dynamical in nature, and is governed by a set of Bethe-Salpeter type of integral equations. While in previous studies the presence of massless poles was assumed to be exclusively associated with the background-gauge three-gluon vertex, in the present analysis we allow them to appear also in the corresponding ghost-gluon vertex. The full analysis of the resulting Bethe-Salpeter system reveals that the contribution of the poles associated with the ghost-gluon vertex are particularly suppressed, their sole discernible effect being a slight modification in the running of the gluon mass, for momenta larger than a few GeV. In addition, we examine the behavior of the (background-gauge) ghost-gluon vertex in the limit of vanishing ghost momentum, and derive the corresponding version of Taylor's theorem. These considerations, together with a suitable Ansatz, permit us the full reconstruction of the pole sector of the two vertices involved.

Off-shell renormalization of dimension 6 operators in Higgs effective field theories

In collaboration with A. Quadri (Milan University, USA)

In this work we study the off-shell one-loop renormalization of a Higgs effective field theory with a sextic scalar potential is presented. This is achieved by renormalizing the theory once reformulated in terms of two auxiliary fields $X_{1,2}$, which, due to the invariance under an extended Becchi-Rouet-Stora-Tyutin symmetry, are tightly constrained by functional identities. The latter allow in turn the explicit derivation of the mapping onto the original theory. We elaborate on some phenomenological consequences of our results, as well as provide the generalization of the method to potentials involving operators of arbitrary higher powers in the scalar field.

Coupled dynamics in gluon mass generation and the impact of the three-gluon vertex

In collaboration with J. Papavassiliou (University of Valencia, Spain)

In this work we present a detailed study of the subtle interplay transpiring at the level of two integral equations that are instrumental for the dynamical generation of a gluon mass in pure Yang-Mills theories. The main novelty is the joint treatment of the Schwinger-Dyson equation governing the infrared behaviour of the gluon propagator and of the integral equation that controls the formation of massless bound-state excitations, whose inclusion is instrumental for obtaining massive solutions from the former equation. The self-consistency of the entire approach imposes the requirement of using a single value for the gauge coupling entering in the two key equations; its fulfillment depends crucially on the details of the three-gluon vertex, which contributes to both of them, but with different weight. In particular, the characteristic suppression of this vertex at intermediate and low energies enables the convergence of the iteration procedure to a single gauge coupling, whose value is reasonably close to that extracted from related lattice simulations.

Arianna Carbone

The liquid-gas phase transition in nuclear matter

In collaboration with A. Polls (Univ. Barcelona) and A. Rios (Univ. Surrey)

Following the extension of the self-consistent Green's function method to consistently include three-body nuclear forces developed in Ref. [1], we are at the moment able to calculate the finite-temperature properties of infinite nuclear matter using full chiral potentials. Up to now we have studied the zero-temperature behaviour of the energy of both symmetric nuclear and pure neutron matter, see Ref. [2] and Ref. [3], using different many-body methods and Hamiltonians.

We are now exploring a number of different chiral Hamiltonians to understand the finite-temperature properties of symmetric nuclear matter, and in particular to analyse the liquid-gas phase transition. This is motivated by multifragmentation and fission data experiments, which provide estimates of the liquid-gas phase transition critical temperature in nuclear matter. With our theoretical calculations performed at finite-temperatures, we want to predict this quantity providing a reliable theoretical error based both on the many-body approximation and the nuclear Hamiltonian in use.

The nuclear equation of state thermal index from ab initio calculations

In collaboration with A. Schwenk (Univ. Darmstadt)

In Ref. [4] we have studied the zero-temperature energy per nucleon of pure neutron matter, analysing both the many-body method truncation convergence and the chiral Hamiltonian order convergence. We are now interested in performing these results at finite-temperature, for symmetric, pure and asymmetric matter, to calculate the thermal index often used to simulate the temperature dependence of equations of state for astrophysical simulations, as explained in Ref. [5].

We are performing calculations exploiting the self-consistent Green's function method which is directly implemented at finite-temperature. The thermal index is usually considered as a constant value in equations of state used to simulate neutron-star binary merger or core-collapse supernovae events. Our first-principle calculations are indicating that the thermal index is both density and temperature dependent, and should then be included in the equation of state as a varying variable, to provide reliable predictions of, for example, the gravitational-wave spectrum from these massive events.

Ab initio equation of state for astrophysical simulations

In collaboration with A. Lovato and B. Giacomazzo (Univ. Trento)

Given the number of different models of nuclear equations of state used in supernovae and compact stars simulations, see Ref. [6], we want to provide a reliable equation of state based on nuclear ab initio calculations. Putting together the quantum Monte Carlo [7] and self-consistent Green's function many-body methods, and employing newly developed local chiral forces, see Ref. [8], we are constructing an equation of state which covers the necessary ranges of temperatures, densities and proton fractions needed to simulate such astrophysical events. We are taking particular attention in describing the high-density behaviour, in order to keep the equation of state causal and able to reach the two-solar mass neutron star.

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Jesús Casal Berbel

Description of (p,pN) reactions induced by three-body nuclei

In collaboration with M. Gómez-Ramos and A. M. Moro (University of Seville, Spain)

One-nucleon removal (p,pN) reactions in inverse kinematics provide a powerful tool to extract spectroscopic information of exotic nuclei, such as separation energies, spin-parity assignments, and occupation probabilities. In the case of three-body Borromean projectiles, the reaction products after one nucleon removal are unbound systems, which will automatically decay. Therefore, the study of these processes allows us to extract spectroscopic information on exotic three-body projectiles, by probing the continuum wave function of the unbound binary fragments. Recently [1], we have developed a novel method to study (p,pN) reactions induced by systems comprising a compact core and two valence nucleons, such as two-neutron halo nuclei. The theoretical framework incorporates a proper three-body structure model for the projectile [2] and a reliable reaction formalism: the Transfer to the Continuum method [3], here extended for core+N+N systems. In our prescription, all the structure information is contained in the overlaps between the three-body ground-state wave function of the projectile and the two-body continuum states after one nucleon removal. We have explored the effect of these structure properties on the computed cross sections and compared with the available experimental data for the 11Li(p,pn)10Li reaction at 280 MeV/u [1]. The 11Li model providing the best agreement with (p,pn) data is found to be the same describing satisfactorily the 11Li(p,d)10Li transfer reaction at 5.7 MeV/u [4]. We are now working on other reactions induced by Borromean projectiles, such as 8He(p,pn)7He, 22C(p,pn)21C or 17Ne(p,2p)16F. Of particular interest are the cases of 14Be(p,pn)13Be [5] and 14B(p,2p)13Be, in which gamma coincidences from the decay of the 12Be core in 13Be (12Be+n) were experimentally observed. To describe this feature, we are now considering the inclusion of core excitations in the structure description (e.g., as in Ref. [6]). This will provide a robust framework to support the increasing amounts of data being collected at GSI, RIKEN and MSU.

Four-body effects in the low-energy scattering of exotic nuclei

In collaboration with M. Rodríguez-Gallardo, J. M. Arias, J. Gómez-Camacho (University of Seville), and A. Arazi (TANDAR Laboratory, Argentina) et al.

The description of reaction induced by Borromean nuclei can be performed in a four-body framework, considering three-body projectiles impinging on a structureless target. In Ref. [7], we applied the Continuum-Discretized Coupled-Channels (CDCC) method using three-body pseudostates [2] to describe the elastic scattering and breakup of 9Be on 208Pb and 27Al at energies around the Coulomb barrier. The agreement with the available experimental data supported the reliability of the method to describe reactions induced by Borromean projectiles. More recently, we have applied the formalism to the case of 9Be + 120Sn, for which excited states of the target were experimentally populated [8]. Within the four-body CDCC, this excitations are implicitly contained in the absorption produced by the projectile-target optical potentials. However, a fully consistent and explicit description of the elastic scattering, breakup and target excitation for three-body projectiles is still to be done. We are also working on the low-energy breakup of 17Ne, which could help in understanding its exotic structure, and to extend the formalism to include structure and dynamic core excitations.

Three-body radiative capture reactions

In collaboration with E. Garrido (IEM-CSIC, Spain), R. De Diego (University of Lisbon, Portugal), J. M. Arias, M. Rodríguez-Gallardo, and J. Gómez-Camacho (University of Seville)

In Refs. [2], we developed a three-body model to compute radiative capture reaction rates of astrophysical interest. We applied the method to the 4He(2n,g)6He [2] and 4He(4He n, g)9Be [9] reactions at astrophysical conditions, which could play a role in neutron-rich environments for the r-process [10,11]. We showed the relevance of the direct or three-body capture at low temperatures compared to sequential estimations. More recently, we applied the same method to the 15O(2p,g)17Ne [12] capture, which has been proposed as a key ingredient for the rp-process controlling the trigger conditions of type I x-ray bursts. However, theoretical estimations of these rates are subject to large uncertainties. For this reason, we proposed a novel theoretical procedure to estimate the rate from inclusive breakup measurements at low energies [13]. In this line, we have participated in Letter of Intent recently presented at GANIL to measure 6He breakup below the Coulomb barrier at very forward angles and with high precision. These measurements are expected to provide solid constraints on the 4He(2n,g)6He reaction and to open new possibilities for more exotic systems of astrophysical interest. A summary of these topics has been recently presented [14].

Two-nucleon correlations in light exotic nuclei

Exotic nuclei far from stability give rise to unusual properties and decay modes [15]. Large efforts have been devoted to understanding the properties of two-neutron halo nuclei, for which theoretical investigations in core + n + n models indicate that the correlations between the valence neutrons play a fundamental role in shaping their properties [16]. The evolution of these correlations beyond the driplines has implications for two-nucleon radioactivity [17,18]. I have been recently working on the description of unbound three-body (core + N + N) systems, using a pseudostate method [2] in hyperspherical coordinates, to analyze their structure in terms of nucleon-nucleon correlations. The application to 16Be (14Be+n+n) and 6Be (4He+p+p) [19] has confirmed the strong dineutron and diproton configurations observed experimentally in the decay of these systems [20,21]. Interestingly, the pseudostate method, although being less demanding computationally, provides similar results compared to the calculation of actual three-body scattering states [17]. In addition, this method can be applied in general to three-body systems comprising several charged particles, for which the scattering asymptotic behavior is not known in general. This opens the possibility to perform a systematic study of two-nucleon emitters, such as the exotic oxygen isotopes 24O, 26O, 11O. The decay from excited states of dripline nuclei, e.g., the resonances in 6He or 17Ne, could also be studied. Work along these lines is ongoing.

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María Gómez Rocha

Effective-particle approach to bound states of quarks and gluons in heavy-flavor QCD

In collaboration with S. D. Glazek (University of Warsaw, Poland and Yale University, USA), J. More (Indian Institute of Technology, India) and K. Serafin (University of Warsaw)

A general approach to the construction of bound states in quantum field theory, called the renormalization group procedure for effective particles (RGPEP), was applied recently to single heavy-flavor QCD in order to study its utility beyond illustration of its general features [1,2]. This heavy-flavor QCD is chosen as the simplest available context in which the dynamics of quark and gluon bound states can be studied with the required rigor using Minkowski-space Hamiltonian operators in the Fock space, taking the advantage of asymptotic freedom [2]. The effective quarks and gluons differ from the point-like canonical ones by having a finite size *s*. Their size plays the role of renormalization group parameter. However, instead of integrating out high-energy degrees of freedom, our RGPEP procedure is based on a transformation of the front-form QCD Hamiltonian from its canonical form with counterterms to the renormalized, scale-dependent operator that acts in the Fock space of effective quanta of quark and gluon fields, keeping all degrees of freedom intact but accounting for them in a transformed form. After observing that the QCD effective Hamiltonian satisfies the requirement of producing asymptotic freedom [2], we derived the leading effective interaction between quarks in heavy-flavor QCD [3]. An effective confining effect is derived as a result of assuming that the non-Abelian and non-perturbative dynamics causes effective gluons to have mass. The obtained effective potential has the form of a Coulomb potential corrected by a harmonic oscillator potential. Our recent studies indicate the same force –modulus a factor--is obtained in baryons between heavy quarks.

Aspects of open-flavour mesons in a comprehensive DSBSE study

In collaboration with A. Krassnig and T. Hilger (University of Graz, Austria)

Open-flavour meson studies are the necessary completion of any comprehensive investigation of quarkonia. In this project, we extend recent studies of quarkonia in the Dyson-Schwinger-Bethe-Salpeter equation approach to explore their results for all possible flavour combinations. Within the inherent limitations of the setup, we obtained the most comprehensive results for meson masses and leptonic decay constants currently available and put them in perspective with respect to experiment and other approaches. Particular aspects of interest are the appearance and correspondence of so-called quasi-exotic quark bilinear meson states as recently discussed in [4, 5]. Furthermore, we obtained values for masses, leptonic decay constants, and in-hadron condensates due to the relevance of the topic for in-medium QCD [6, 7], and discussed the results in comparison to experimental data as well as estimating systematic uncertainties in our numbers. Our results were published in Ref. [8].

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Chen Ji

Nuclear structure effects in light muonic atoms

In collaboration with S. Bacca, O. J. Hernandez, N. Nevo Dinur (TRIUMF, Canada), and N. Barnea (The Hebrew University of Jerusalem, Israel)

Stimulated by the proton radius puzzle [1-2], measurements of Lamb shifts in muonic atoms other than the muonic hydrogen, such as μ^2H, μ^3H, μ^3He^+, and μ^4He^+, were performed at PSI. These experiments intend to extract nuclear charge radii with a high accuracy, but are crucially limited by the uncertainty in nuclear structure corrections. In Refs. [3-5] we studied the nuclear structure effects in those muonic atoms mentioned above. Combining effective interaction hyperspherical harmonics techniques with state-of-the-art nuclear potentials (AV18/UIX and chiral EFT), we provided accurate predictions to the structure effects. This allows significant improvements in determining charge radii from the Lamb shift measurements, and helped to unveil the deuteron radius puzzle found in the very recent μ^2H experiment [6]. To further constrain uncertainties in the nuclear-structure contributions to Lamb shifts, we recently performed a full analysis of both statistical and systematic uncertainties using the state-of-the-art chiral effective field theory nuclear potentials at various chiral orders [7]. We are currently studying nuclear structure effects on hyperfine splittings in muonic atoms, where the two-photon exchange contributions from the coupling between electric and magnetic photon currents are essential.

Effective field theory for halo nuclei and alpha clustering

In collaboration with G. Orlandini, W. Leidemann, F. Pederiva (University of Trento & INFN-TIFPA), Hans-Werner Hammer (Technische Universität Darmstadt, Germany), and Daniel R. Phillips (Ohio University, USA)

Developments at rare-isotope facilities have promoted the studies of exotic nuclei near the edge of stability, including halo nuclei. The energy-scale separation between the core excitation and the valence-nucleon separation makes effective field theory (EFT) a powerful tool to explore halo systems. In collaboration with Hans-Werner Hammer and Daniel R. Phillips, I wrote a detailed and pedagogical review article for J. Phys. G to explain the calculations of structure and electromagnetic reaction observables of halo nuclei in the framework of EFT [8]. I am currently working on combining cluster EFT potentials with many-body techniques, including quantum Monte Carlo and effective interaction hyperspherical harmonics methods. With these numerical tools, we investigate alpha-clustering structures in medium-mass nuclei, and calculate the astrophysical reaction rate $\alpha(\alpha n,\gamma)^9Be$ by studying the electromagnetic transitions in ^9Be.

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Naoto Tanji

Real-time lattice simulations of quark production in expanding QCD plasma

In collaboration with J. Berges (Heidelberg University, Germany)

In the high-energy limit of heavy-ion collisions, the system right after a collision is described as an over-occupied gluon plasma expanding in the beam direction. Its space-time evolution can be studied by means of real-time classical-statistical simulations of Yang-Mills equation. To find observable consequences of such nonequilibrium evolution, the understanding of quark dynamics is crucial since quarks couple to electromagnetic probes. In Ref. [1], we have investigated the quark production in the expanding over-occupied gluon plasma by using the real-time lattice simulation technique for quantum fermion fields and classical-statistical gauge fields. We observed that the total quark number shows after an initial rapid increase an almost linear growth in time. This growth rate was found to be consistent with a simple kinetic theory estimate demonstrating the effectiveness of kinetic theory descriptions. By investigating the quark production for different quark masses, we also found that the quark momentum distribution functions satisfy a nonequilibrium scaling law.
As an extension of this study, I am working on the real-time dynamics of the chiral charge production and the chiral magnetic effect at the early stage of heavy-ion collisions.

Functional renormalization group study of photon and dilepton production at finite temperature and chemical potential

In collaboration with C. Jung, L. von Smekal (Giessen University, Germany), R.-A. Tripolt and J. Wambach (ECT, Italy)*

Photons and dileptons are useful probes for the space-time history of heavy-ion collisions since they can escape from strongly-interacting matter almost unaffected. To find possible experimental probes for the chiral symmetry restoration, we study the photon and dilepton production at finite temperature and chemical potential within low-energy effective model for QCD. As a nonperturbative method that can describe critical phenomena correctly and is free from the sign problem at finite chemical potential, we employ the analytically-continued functional renormalization group (FRG) method [2]. By introducing photon fields to the extended quark-meson model that was previously studied in Ref. [3], we have formulated a FRG method to compute dilepton production rates. In addition to the radiation from charged pions and quarks, virtual photons are produced by conversion from rho mesons since they have the same quantum numbers. Numerical analysis of the FRG flow equations are now ongoing.

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Dionysios Triantafyllopoulos

Double non-global logarithms in the evolution of a jet and their resummation

In collaboration with Y. Hatta (Kyoto University, Japan), E. Iancu (IPhT, Saclay, France) and A.H. Mueller (Columbia University, USA)

The Banfi-Marchesini-Smye (BMS) equation [1] resums non-global energy logarithms in the QCD evolution of the energy lost by a pair of jets via soft radiation at large angles. In [2] we identified a new physical regime where, besides the energy logarithms, one has to also resum anti-collinear logarithms. Such a regime occurs when the jets are highly collimated (boosted) and the relative angles between successive soft gluon emissions are strongly increasing. These anti-collinear emissions can violate the correct time-ordering for time-like cascades and result in large radiative corrections enhanced by double collinear logs, making the BMS evolution unstable beyond leading order. We isolated the first such a correction in a recent calculation of the BMS equation to next-to-leading order by Caron-Huot [3]. To overcome this difficulty, we constructed a collinearly-improved version of the leading-order BMS equation which resums the double collinear logarithms to all orders [2]. Our construction was inspired by a recent treatment of the Balitsky-Kovchegov (BK) equation [4,5] for the high-energy evolution of a space-like wavefunction, where similar time-ordering issues occur [6,7]. We showed that the conformal mapping relating the leading-order BMS and BK equations correctly predicts the physical time-ordering, but it fails to predict the detailed structure of the collinear improvement.

The running coupling in the NLO calculation of forward hadron production

In collaboration with B. Ducloué, E. Iancu, G. Soyez (IPhT, Saclay, France), T. Lappi (University of Jyväskylä, Finland), A.H. Mueller (Columbia University, USA) and Y. Zhu (Technische Universität München)

In [8] we addressed and solved a puzzle raised by a recent calculation [9] of the cross-section for particle production in proton-nucleus collisions to next-to-leading order [10,11]: the numerical results showed an un-reasonably large dependence upon the choice of a prescription for the QCD running coupling, which spoiled the predictive power of the calculation. Specifically, the results obtained with a prescription formulated in the transverse coordinate space differed by one to two orders of magnitude from those obtained with a prescription in momentum space. We showed that this discrepancy is an artefact of the interplay between the asymptotic freedom of QCD and the Fourier transform from coordinate space to momentum space. When used in coordinate space, the running coupling can act as a fictitious potential which mimics hard scattering and thus introduces a spurious contribution to the cross-section. We identified [8] a new coordinate-space prescription which avoided this problem and led to results consistent with those obtained with the momentum-space prescription.

Non-Abelian colour charges, the BFKL equation and the dipole picture

We study the soft part (in terms of longitudinal moment) of the QCD wave-function of a “small” projectile in terms of non-abelian colour charges. We identify appropriate correlators of such charges and discuss their high-energy evolution. In a purely algebraic way in [12], we show how to obtain: a) the BFKL equation in coordinate space [13,14] with a finite number of colours and b) the equation of the dipole-pair density in the multicolour limit [15,16,17].

References

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Ralf-Arno Tripolt

In-medium spectral Functions of Vector- and Axial-Vector Mesons from the Functional Renormalization Group

In collaboration with Ch. Jung, L. von Smekal (Giessen University, Germany), F. Rennecke (BNL, USA and Heidelberg University, Germany) and J. Wambach (ECT, Italy)*

In Ref. [1] we presented first results on vector and axial-vector meson spectral functions as obtained by applying the non-perturbative functional renormalization group approach to an effective low-energy theory motivated by the gauged linear sigma model. By using a recently proposed analytic continuation method, we studied the in-medium behavior of the spectral functions of the rho and a1 mesons in different regimes of the phase diagram. In particular, we demonstrated explicitly how these spectral functions degenerate at high temperatures as well as at large chemical potentials, as a consequence of the restoration of chiral symmetry. In addition, we also computed the momentum dependence of the rho and a1 spectral functions and discussed the various time-like and space-like processes that can occur. We are working on improving the underlying model and making the connection to experimental data.

Numerical analytic continuation of Euclidean data

In collaboration with P. Gubler (Keio University, Japan), M. Ulybyshev (Regensburg University, Germany) and L. von Smekal (Giessen University, Germany)

In Ref. [2] we showed how complex resonance poles and threshold energies for systems in hadron physics can be accurately obtained by using the Resonances Via Padé method. Also the possibility to use this method to obtain real-time correlation functions from their imaginary-time counterparts was mentioned. We are currently working on a direct comparison of three different numerical analytic continuation methods: the Maximum Entropy Method, the Backus-Gilbert method and the Resonances Via Padé method. First, we will perform a benchmark test based on a model spectral function and study the regime of applicability of these methods depending on the number of input points and their statistical error. We will then apply these methods to more realistic examples, namely to numerical data on Euclidean propagators obtained from a Functional Renormalization Group calculation, to data from a Lattice Quantum Chromodynamics simulation and to data obtained from a tight-binding model for graphene in order to extract the electrical conductivity.

Fermionic spectral functions with the Functional Renormalization Group

In collaboration with J. Weyrich and L. von Smekal (Giessen University, Germany) and J. Wambach (ECT, Italy)*

We are working on the calculation of fermionic spectral functions with the Functional Renormalization Group approach. Our method is based on a well-defined analytic continuation procedure from imaginary to real energies that was developed recently for bosonic spectral functions [3]. In order to demonstrate the applicability of the method also for fermions we apply it to the quark-meson model and calculate the real-time quark propagator as well as the quark spectral function in the vacuum.

The low-temperature behavior of the quark-meson model

In collaboration with B.-J. Schaefer and L. von Smekal (Giessen University, Germany) and J. Wambach (ECT, Italy)*

We revisit the phase diagram of strong-interaction matter for the two-flavor quark-meson model using the Functional Renormalization Group [4]. In contrast to standard mean-field calculations, an unusual phase structure is encountered at low temperatures and large quark chemical potentials. In particular, we identify a regime where the pressure decreases with increasing temperature and discuss possible reasons for this unphysical behavior. We are working on identifying the source of this anomalous behavior.

Color superconductivity from the chiral quark-meson model

In collaboration with J. Weyrich and L. von Smekal (Giessen University, Germany) and J. Wambach (ECT, Italy)*

We study the two-flavor color superconductivity of low-temperature quark matter in the vicinity of chiral phase transition within the quark-meson model where the interactions between quarks are generated by pion and sigma exchanges [5]. Starting from the Nambu-Gor'kov propagator in real-time formulation we obtain finite temperature (real axis) Eliashberg-type gap equations for the quark self-energies (gap functions) in terms of in-medium spectral function of mesons. Exact numerical solutions of the coupled nonlinear integral equations for the real and imaginary parts of the gap function are obtained in the zero temperature limit using a model input spectral function. Future extensions of this approach may involve the evaluation of the components of the 2SC gap function using spectral functions of quark-meson model directly for specific values of density and temperature of quark matter.

References

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[4] R.-A. Tripolt, B.-J. Schaefer, L. von Smekal, J. Wambach, arXiv:1709.05991

[5] A. Sedrakian, R.-A. Tripolt, J. Wambach, arXiv:1711.04269

Jochen Wambach

My research in 2017 included the following topics:

- Extraction of resonance poles via Padé methods
- Equilibrium properties of hot and dense strong-interaction matter
- Medium modification of the spectral properties of hadrons

The projects have been pursued in collaboration with researchers from Germany, Israel, the United States as well as local researchers from ECT*. In the following selected examples are summarized.

Resonance poles from a model-independent algorithm

In collaboration with I. Haritan, and N. Moiseyev (Israel Institute of Technology, Haifa, Israel) and R.-A. Tripolt (ECT, Italy)*

The determination of resonance poles, uniquely defined as poles of the S -matrix in the complex energy plane, is a longstanding problem and particularly difficult for broad resonances or if decay channels open up in their vicinity. In these cases, simple approaches like a standard Breit-Wigner parameterizations fail and more involved theoretical tools are called for. We have introduced a Padé-approximant method that was originally developed for the calculation of auto-ionization resonances in quantum chemistry to the field. In contrast to other methods it only requires a set of real data points as input from which information on the complex plane can be extracted by performing an analytic continuation. In Ref. [1] we have shown how complex resonance poles and threshold energies for systems in hadron physics can be accurately obtained by using this method. The main advantage is the ability to calculate the resonance poles and threshold energies from real spectral data. In order to demonstrate the capabilities we have applied the method to analytical models as well as to experimental data such the vector pion form factor, the S0 partial wave amplitude for $\pi\pi$ scattering and the cross section ratio R(s) for $e+e-$ collisions. The extracted values for the resonance poles of the $\rho(770)$ and the $f_0(500)$ are in very good agreement with the literature. When the data are noisy the prediction of decay thresholds proves to be less accurate but still feasible.

[1] R.-A. Tripolt, I. Haritan, J. Wambach, N. Moiseyev, Phys. Lett. **B774** (2017) 411-416

In-medium spectral Functions of Vector- and Axial-Vector Mesons from the Functional Renormalization Group

In collaboration with Ch. Jung, L. von Smekal (Giessen University, Germany), F. Rennecke (BNL, USA and Heidelberg University, Germany) and R.-A. Tripolt (ECT, Italy)*

To get insights into the entire space-time history of ultrarelativistic heavy-ion collision, real photons and dileptons are particularly useful probes, since they have negligible interaction with the hadronic fireball. In this context the decay of vector mesons, located in the low invariant-mass regime, and here especially the ρ meson, is interesting, since the quantum numbers of vector mesons allow them to directly decay into dileptons. For this reason the in-medium properties of the ρ meson have received considerable attention. By analyzing dilepton spectra at low invariant masses one tries to find evidence for chiral symmetry restoration or the existence of a critical endpoint in the phase diagram of strong-interaction matter. Stringent conclusions require a treatment of the equilibrium and spectral properties on the same footing. In Refs. [2,3,4] we have presented first results on vector and axial-vector meson spectral functions as obtained by applying the non-perturbative Functional Renormalization Group (FRG) approach to an effective low-energy theory motivated by the gauged linear sigma model. By using a thermodynamically consistent and symmetry preserving analytic continuation method [5], we have studied the in-medium behavior of the spectral functions of the ρ and a_1 mesons in different regimes of the phase diagram. In particular, we have demonstrated explicitly how these spectral functions degenerate at high temperatures as well as at large chemical potentials, as a consequence of the restoration of chiral symmetry. In addition, we have also computed the momentum dependence of the ρ and a_1 spectral functions and discussed the various time-like and space-like processes that can occur. At present we are working on the resulting photon polarization tensor to infer real and virtual photon rates to be compared to experimental data.

[2] Ch. Jung, F. Rennecke, R.-A. Tripolt, L. von Smekal, J. Wambach, Phys. Rev. **D95**, 036020 (2017)

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Fermionic spectral functions from the Functional Renormalization Group

In collaboration with J. Weyrich, L. von Smekal (Giessen University, Germany) and R.-A. Tripolt (ECT, Italy)*

Having explored the spectral properties of mesonic fluctuations within the Functional Renormalization Group approach in the past [5,6] we are now working on the calculation of fermionic spectral functions. One of the aims is to explore the interplay between chiral dynamics and Fermi-liquid behavior of collective modes in the vicinity of the Fermi edge in high-chemical potential, low-temperature regions of the strong-interaction phase diagram. Our method is based on a well-defined analytic continuation procedure from imaginary to real energies that was developed for bosonic spectral functions in Refs. [5,6]. In order to demonstrate the applicability of the method for fermions we are currently applying it to the Quark-Meson (QM) model and calculate in a first step the real-time quark propagator as well as the quark spectral function in the vacuum [7].

[6] R.-A, Tripolt, L. von Smekal, J. Wambach, Phys. Rev. **D90**, 074031 (2014)

[7] R.-A, Tripolt, J. Weyrich, L. von Smekal, J. Wambach, work in progress

The low-temperature behavior of the quark-meson model

In collaboration with B.-J. Schaefer and L. von Smekal (Giessen University, Germany) and R.-A. Tripolt (ECT, Italy)*

As an effective low-energy description of QCD the QM model is widely used to compute the phase diagram of strong-interaction matter. When imposing spatial homogeneity, a first-order chiral transition at low temperature is found in the mean-field (MF) approximation, which ends in a critical point. In this point the phase transition is of second order and lies in the same universality class as the liquid-gas transition. Standard MF calculations in the QM model lead to a first-order phase transition line that is consistent with the Clausius-Clapeyron relation. The phase diagram of the QM model has also been calculated using the FRG approach in Ref. [8], which is much more powerful than MF theory in describing phase transitions. There it was found that at low temperatures, the curvature of the phase boundary bends the `wrong way' in the sense of the Clausius-Clapeyron relation. We have revisited this problem in Ref. [9] and have identified a region of negative entropy density, driven by fermionic fluctuations. We have also discussed possible reasons for this unphysical behavior.

[8] B.-J. Schaefer and J. Wambach, Nucl. Phys. **A757**, 479 (2005)

[9] R.-A. Tripolt, B.-J. Schaefer, L. von Smekal, J. Wambach, arXiv:1709.05991, submitted to PRD

Color superconductivity from the chiral quark-meson model

In collaboration with A. Sedrakian (Frankfurt University, Germany) and R.-A. Tripolt (ECT, Italy)*

One possible source of the region of negative entropy density in the FRG treatment of the QM phase diagram may be a Cooper instability of the Fermi surface to 2SC color superconductivity. It is easy to show that the interactions between quarks that are generated by pion and sigma exchanges are attractive. Starting from the Nambu-Gor'kov propagator in a real-time formulation we have derived in Ref. [10] a set of finite temperature Eliashberg-type gap equations for the quark gap functions in terms of in-medium spectral functions pions and sigma mesons. Exact numerical solutions of the coupled nonlinear integral equations for the real and imaginary parts of the gap function were obtained in the zero-temperature limit, using a model input spectral function. Future extensions of this approach may involve the evaluation of the components of the 2SC gap function using spectral functions of the QM model directly for specific values of density and temperature of quark matter.

[10] A. Sedrakian, R.-A. Tripolt, J. Wambach, arXiv:1711.04269, submitted to PLB

Other scientific activities

Besides the research described above, I have co-organized two major meetings in Nuclear Physics:

1. Arbeitstreffen “Kernphysik” Schleching
   (Nuclear Astrophysics, Functional Renormalization Group, Accelerator Physics)
   Schleching, Germany, March 2 - 9, 2017

2. International School of Nuclear Physics, 39th Course:
   Neutrinos in Cosmology, in Astro, Particle and Nuclear Physics
   Erice, Italy, Sept. 16 – 24, 2017

4.2 Publications of ECT* Researchers in 2017

Guillaume Clement Beuf

G. Beuf
Dipole factorization for DIS at NLO: Combining the quark-antiquark and quark-antiquark-gluon contributions
*Phys. Rev. **D96**, 074033 (2017), arXiv: 1708.06557 [hep-ph]*

T. Altinoluk, N. Armesto, G. Beuf, A. Kovner and M. Lublinsky
Quark correlations in the Color Glass Condensate: Pauli blocking and the ridge
*Phys. Rev. **D95**, 034025 (2017), arXiv: 1610.03020 [hep-ph]*

A. Kovner, T. Altinoluk, N. Armesto, G. Beuf and M. Lublinsky
Initial state correlations
*PoS **QCDEV2016**, 010 (2017)*
Proceedings of the conference "QCD Evolution Workshop (QCD 2016)" (May-June 2016, Amsterdam, Netherlands)

Daniele Binosi

J. Papavassiliou, A.C. Aguilar, D. Binosi, C.T. Figueiredo
Mass generation in Yang-Mills theories
*EPJ Web Conf. **164** (2017) 03005*

J. Rodríguez-Quintero, A. Athenodorou, D. Binosi, Ph. Boucaud, F. de Soto, J. Papavassiliou, S. Zafeiropoulos
Three-gluon Green functions: low-momentum instanton dominance and zero-crossing
*EPJ Web Conf. **137** (2017) 03018*

D. Binosi, C. Mezrag, J. Papavassiliou, C. D. Roberts, J. Rodriguez-Quintero
Process-independent strong running coupling
*Phys.Rev. **D96** (2017) no.5, 054026, arXiv:1612.04835 [nucl-th]*

D. Binosi, C. D. Roberts, J. Rodriguez-Quintero
Scale-setting, flavor dependence, and chiral symmetry restoration
*Phys.Rev. **D95** (2017) no.11, 114009, arXiv:1611.03523 [nucl-th]*

A.C. Aguilar, D. Binosi, J. Papavassiliou
Schwinger mechanism in linear covariant gauges
*Phys.Rev. **D95** (2017) no.3, 034017, arXiv:1611.02096 [hep-ph]*

D. Binosi, L. Chang, J. Papavassiliou, S.-X. Qin, C. D. Roberts.
Natural constraints on the gluon-quark vertex
*Phys.Rev. **D95** (2017) no.3, 031501, arXiv:1609.02568 [nucl-th]*

A.C. Aguilar, D. Binosi, C.T. Figueiredo, J. Papavassiliou
Evidence of ghost suppression in gluon mass dynamics
Submitted to EPJD, arXiv:1712.06926 [hep-ph]

D. Binosi, A. Quadri
Off-shell renormalization of dimension 6 operators in Higgs effective field theories
Submitted to JHEP, arXiv:1709.09937 [hep-th]

D. Binosi, J. Papavassiliou
Coupled dynamics in gluon mass generation and the impact of the three-gluon vertex
Submitted to Phys. Rev. D, arXiv:1709.09964 [hep-ph]

Jesús Casal Berbel

J. Casal
Two-nucleon emitters within a pseudostate method: The case of 6Be and 16Be
arXiv:1801.01280 [nucl-th], to be submitted

J. Casal, M. Rodríguez-Gallardo, J. M. Arias and J. Gómez-Camacho
Three-body radiative capture reactions
arXiv:1801.01272 [nucl-th], to appear in EPJ Web of Conferences
Proceedings of the conference "Nuclear Physics in Astrophysics VIII" (June 2017, Catania, Italy)

M. Gómez-Ramos, J. Casal and A. M. Moro
Linking structure and dynamics in (p,pn) reactions with Borromean nuclei: the 11Li(p,pn)10Li case
Phys. Lett. ***B772*** *(2017) 11, arXiv:1703.08320 [nucl-th]*

J. Casal, M. Gómez-Ramos and A. M. Moro
Description of the 11Li(p,d)10Li transfer reaction using structure overlaps from a full three-body model
Phys. Lett. ***B767*** *(2017) 307, arXiv:1611.06000 [nucl-th]*

Maria Gomez Rocha

S. D. Glazek, M. Gómez-Rocha, J. More, K. Serafin
Renormalized quark-antiquark Hamiltonian induced by a gluon mass ansatz in heavy-flavor QCD
Phys. Lett. ***B773*** *(2017) 172-178*

T. Hilger, M. Gómez-Rocha, A. Krassnigg.
Light-quarkonium spectra and orbital-angular-momentum decomposition in a Bethe-Salpeter-equation approach
Eur. Phys. J. ***C77*** *(2017) no.9, 625*

T. Hilger, M. Gómez-Rocha, A. Krassnigg, W. Lucha.
Aspects of open-flavour mesons in a comprehensive DSBSE study
Eur. Phys. J. ***A53*** *(2017) no.10, 213*

M. Gómez-Rocha.
From asymptotic freedom toward heavy quarkonia within the renormalization group procedure for effective particles
Few Body Syst. ***58*** *(2017) no.2, 65*

M. Gómez-Rocha.
Asymptotic freedom in the Hamiltonian approach to binding of color
EPJ Web Conf. 137 (2017) 03020

M. Gómez-Rocha, K. Serafin.
Effective-particle approach to bound states of quarks and gluons in QCD
e-Print: arXiv:1712.08100

Chen Ji

H. -W. Hammer, C. Ji, D.R. Phillips
Effective field theory description of halo nuclei
J. Phys. ***G44*** *(2017) 103002, arXiv:1702.08605 [nucl-th]*

O. J. Hernandez, A. Ekström, N. Nevo Dinur, C. Ji, S. Bacca, N. Barnea
A systematic study of nuclear structure uncertainties in muonic deuterium
arXiv:1711.01199 [nucl-th], submitted to Phys. Lett. B

Naoto Tanji

N. Tanji and J. Berges
Nonequilibrium quark production in the expanding QCD plasma
arXiv: 1711.03445 [hep-ph], submitted to Phys. Rev. D

Dionysios Triantafyllopoulos

E. Iancu, A.H. Mueller and D.N. Triantafyllopoulos
Particle Production in pA Collisions beyond Leading Order
Nucl. Phys. ***A967****, 297 (2017), arXiv:1705.10128 [hep-ph]*

Y. Hatta, E. Iancu, A.H. Mueller and D.N. Triantafyllopoulos
Resumming Double Non-Global Logarithms in the Evolution of a Jet
arXiv:1710.06722 [hep-ph], to appear in JHEP

B. Ducloué, E. Iancu, T. Lappi, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos and Y. Zhu
On the Use of a Running Coupling in the NLO Calculation of Forward Hadron Production
arXiv:1712.07480 [hep-ph], submitted to Phys. Rev. ***D***

Ralf-Arno Tripolt

Ch. Jung, F. Rennecke, R.-A. Tripolt, L. von Smekal, J. Wambach,
In-Medium Spectral Functions of Vector- and Axial-Vector Mesons from the Functional Renormalization Group
Phys. Rev. ***D95****, 036020 (2017), arXiv:1610.08754*

R.-A. Tripolt, I. Haritan, J. Wambach, N. Moiseyev,
Threshold energies and poles for hadron physical problems by a model-independent universal algorithm
Phys. Lett. ***B774*** *(2017) 411-416, arXiv:1610.03252*

J. Wambach, Ch. Jung, F. Rennecke, R.-A. Tripolt, L. von Smekal,
Spectral Functions from the Functional Renormalization Group
PoS(CPOD2017)077, arXiv:1712.02093

A. Sedrakian, R.-A. Tripolt, J. Wambach,
Color superconductivity from the chiral quark-meson model
arXiv:1711.04269, submitted to PLB

R.-A. Tripolt, B.-J. Schaefer, L. von Smekal, J. Wambach,
The low-temperature behavior of the quark-meson model
arXiv:1709.05991, submitted to PRD

R.-A. Tripolt, L. von Smekal, J. Wambach,
Spectral functions and in-medium properties of hadrons
World Scientific and Int.J.Mod.Phys. ***E26*** *(2017) no.01n02, 1740028, arXiv:1605.00771*

Jochen Wambach

Ch. Jung, F. Rennecke, R.-A. Tripolt, L. von Smekal, J. Wambach,
In-Medium Spectral Functions of Vector- and Axial-Vector Mesons from the Functional Renormalization Group
Phys. Rev. ***D95****, 036020 (2017), arXiv:1610.08754*

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A. Sedrakian, R.-A. Tripolt, J. Wambach,
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R.-A. Tripolt, B.-J. Schaefer, L. von Smekal, J. Wambach,
The low-temperature behavior of the quark-meson model
arXiv:1709.05991, submitted to PRD

R.-A. Tripolt, L. von Smekal, J. Wambach,
Spectral functions and in-medium properties of hadrons
World Scientific and IJMP ***E26*** *(2017) no.01n02, 1740028, arXiv:1605.00771*

D. Mueller, M. Buballa, J. Wambach
Dyson-Schwinger Approach to Color-Superconductivity: Effects of Selfconsistent Gluon Dressing
arXiv:1603.02865

4.3 Publications of ECT* long term Visitors in 2017

Achim Richter

L.M. Donaldson, C.A. Bertulani, J. Carter, V.O. Nesterenko, P. von Neumann-Cosel, R. Neveling, V. Yu. Ponomarev, P.-G. Reinhard, I.T. Usman, P. Adsley, J.W. Brummer, E.Z. Buthelezi, G.R.J. Cooper, R.W. Fearick, S.V. Förtsch, H. Fujita, Y. Fujita, M. Jingo, W. Kleinig, C.O. Kureba, J. Kvasil, M. Latif, K.C.W. Li, J.P. Mira, F. Nemulodi, P. Papka, L. Pellegri, N. Pietralla, A. Richter, E. Sideras-Haddad, F.D. Smit, G.F. Steyn, J.A. Swartz, A. Tamii
Deformation dependence of the isovector giant dipole resonance: the neodymium isotopic chain revised
Physics Letters ***B 776*** *(2018) 133-138*

4.4 Talks presented by ECT* Researchers

Guillaume Clement Beuf

Full NLO corrections for DIS structure functions in the dipole factorization formalism
Invited seminar at the CPHT, École Polytechnique
February 2017, Palaiseau, France

Full NLO corrections for DIS structure functions in the dipole factorization formalism
Talk at the 25th International workshop on "Deep Inelastic Scattering and related topics" (DIS 2017)
April 2017, Birmingham, United Kingdom

Full NLO corrections for DIS structure functions in the dipole factorization formalism
Invited talk at the workshop on "Saturation: Recent Developments, New Ideas and Measurements"
April 2017, Brookhaven Nat. Lab., NY, USA

Initial state and gluon saturation
Invited talk at the ECT* workshop on "Old and New Strong Interactions from LHC to Future Colliders" (LFC17)
September 2017, Trento, Italy

Daniele Binosi

The gap equation interaction kernel and the QCD effective charge
Invited talk at the workshop "The Proton Mass: At the Hearth of Most Visible Matter",
*3-7 April 2017, ECT**

Imaging dynamical chiral symmetry breaking through Schwinger-Dyson equations
Invited talk at the workshop "Space-like and time-like electromagnetic baryonic transitions",
*8-12 May 2017, ECT**

Jesús Casal Berbel

Structure properties of 10,11Li from (p,pn) and (p,d) reactions
Talk given at the Workshop "Unraveling the complexity of nuclear systems: single-particle and collective aspects through the looking glass".
February 2017, ECT (Trento), Italy*

Three-body radiative capture reactions
Talk given at the VIII International Conference "Nuclear Physics in Astrophysics (NPA8)".
June 2017, Catania, Italy

Linking structure and reaction dynamics of Borromean nuclei
Seminar at Padova University – Dipartimento di Fisica e Astronomia "Galileo Galilei".
June 2017, Padova, Italy

Linking structure and dynamics in (p,pn) reactions with Borromean nuclei

Talk given at the III International workshop on "Quasi-free Scattering with Radioactive-Ion Beams (QFS-RB17)".
July 2017, York, United Kingdom

Linking structure and dynamics in (p,pn) reactions with two-neutron halo nuclei
Seminar at ECT* Board Meeting.
October 2017, Trento, Italy

Description of (p,pN) reactions induced by Borromean nuclei
Invited talk at the XVI Meeting on "Selected Topics in Nuclear and Atomic Physics".
October 2017, Fiera di Primiero (TN), Italy

Two-nucleon correlations in light exotic nuclei: The 11O case
Seminar at Sevilla University – Departamento de Física Atómica, Molecular y Nuclear.
November 2017, Sevilla, Spain

María Gómez Rocha

Binding force in heavy quarkonium.
Talk given at the "Bound states in QCD and beyond II"
February 2017, Schlosshotel Rheinfels, Germany

Effective-particle approach to heavy flavor QCD.
Invited talk given at "The charm and Beauty of strong interactions"
July 2017, ECT*, Trento, Italy

Effective-particle approach to bound states of quarks and gluons in QCD.
Talk given at the "XVII International Conference on Hadron Spectroscopy and Structure"
September 2017, Salamanca, Spain

Chen Ji

Effective field theory for halo nuclei
Invited talk given at the ENST workshop "The tower of the effective field theories and the emergence of the nuclear phenomena".
January 2017, Saclay, France

From cluster model, ab-initio theory to halo effective field theory
Contributed talk given at the INT program "Toward predictive theories of nuclear reactions across the isotopic chart".
February-March 2017, Seattle, USA

What can halo EFT describe?
Invited talk given at the theory seminar at TRIUMF.
March 2017, Vancouver, Canada

Effective field theory description of halo nuclei
Invited talk given at the ECT* workshop "Walk on the neutron-rich side".
April, 2017, Trento, Italy

Few-Body Physics in Effective Field Theory
Invited talk given at the theory seminar at Huzhou University.
June 2017, Huzhou, China

Naoto Tanji

Nonequilibrium quark production in the expanding QCD plasma
Seminar talk at Giessen University;
December 2017, Giessen, Germany

Ralf-Arno Tripolt

The "Resonances Via Padé" Method
Invited talk given at a group meeting at LNF-INFN
February 2017, Frascati, Italy

The "Resonances Via Padé" Method
Invited talk given at a group meeting at the University of Graz
March 2017, Graz, Austria

In-Medium Vector-Meson Spectral functions with the Functional Renormalization Group
Invited talk given at the ECT* workshop "Space-like and time-like electromagnetic baryonic transitions"
May 2017, Trento, Italy

In-Medium Spectral functions with the Functional Renormalization Group
Talk given at the ECT* workshop "Functional Methods in Hadron and Nuclear Physics".
August 2017, Trento, Italy

Numerical analytic continuation of Euclidean data
Invited talk at COST-THOR Workshop
September 2017, Swansea, UK

In-Medium Spectral functions with the Functional Renormalization Group
Talk given at the ECT* workshop "Phase diagram of strongly interacting matter: From Lattice QCD to Heavy-Ion Collision Experiments"
November 2017, Trento, Italy

The "Resonances Via Padé" Method
Invited talk given at the Reimei 2017 workshop
December 2017, Tokai, Japan

Jochen Wambach

Meson Propagation in Nuclear Matter
Lectures in the GGI School on "Frontiers in Nuclear and Hadronic Physics"
February 2017, Florence, Italy

Hadron in Extreme QCD Matter
Talk at the ECT* workshop "Space-like and time-like electromagnetic baryonic transitions"
May 2017, Trento, Italy

Spectral functions from the Functional Renormalization Group
Talk presented at International Conference "CPOD 2017: Critical Point and Onset of Deconfinement"
August 2017, Stony Brook, USA

Matter under Extreme Conditions
Distinguished Lecture at the Instituto Superior Técnico, Universidade de Lisboa
November 2017, Lisbon, Portugal

Spectral functions from the Functional Renormalization Group
Talk at Centro de Física Teórica das Partículas, Instituto Superior Técnico, Universidade de Lisboa
November 2017, Lisbon, Portugal

4.5 Seminars and colloquia at ECT*

Revisiting the 3n system and possible new measurements
ECT seminar*
22 Feb 2017
Hideyuki Sakai (RIKEN Nishina Center for Accelerator-Based Science, Japan)

Effective particle approach to theory and phenomenology of strong interactions
ECT seminar*
01 Mar 2017
Stanislaw D. Glazek (University of Warsaw, Poland, and Yale University, USA)

Superfluidity and rotation of a superfluid spin-orbit coupled Bose-Einstein condensate
ECT seminar*
03 May 2017
Sandro Stringari (University of Trento, Italy)

Interaction of swift charged particles with condensed media: A short review and recent simulations
ECT seminar*
07 Jun 2017
Rafael Garcia-Molina (Departamento de Física, Universidad de Murcia, Spain)

Heavy quark bound states in a quark-gluon plasma
ECT seminar*
27 Jun 2017
Jean-Paul Blaizot (Institut de Physique Théorique, CEA, Saclay, France)

How the current high-precision experiments challenge the usual beta decay and electron capture models
ECT seminar*
07 Jul 2017
Xavier Mougeot (CEA, LIST, Laboratoire National Henri Becquerel, F-91191 Gif-sur-Yvette, France)

How the current high-precision experiments challenge the usual beta decay and electron capture models
20 Jul 2017
Xavier Mougeot (CEA, LIST, Laboratoire National Henri Becquerel, F-91191 Gif-sur-Yvette, France)

Monte Carlo simulation for nuclear alpha-clustering states
ECT seminar*
23 Aug 2017
Chen Ji (ECT*, Trento)

Light front QCD via Dyson-Schwinger equations
29 Sep 2017
Fei Gao (Beijing University, China)

Real-time lattice simulations of quark production in heavy-ion collisions
ECT seminar*
18 Oct 2017
Naoto Tanji (ECT*, Trento)

The quest for the axion
ECT Colloquium*
22 Nov 2017
Andreas Ringwald (DESY, Germany)

Ab initio studies of nucleonic matter from a Green's function approach
ECT seminar*
06 Dec 2017
Arianna Carbone (ECT*, Italy)

5 Research at ECT*-LISC

The current trend in condensed matter and materials science consists in the development of an interdisciplinary approach covering all the length scales from nanometer (electronic structure) to mesoscopic (molecular and supramolecular) and to continuum (mechanical and thermal properties). This approach is particularly suitable for computer simulations, which represent an effective alternative way to theoretical and experimental research.
In this regard, LISC hosts scientists with expertise in a variety of computational methods to study systems at any level of aggregation, ranging from ab-initio methods for electronic structure calculations, to Monte Carlo for electron-transport simulations, and, finally, to molecular dynamics both in the classical and ab-initio frameworks. LISC focuses on fundamental problems in materials science, covering both inorganic and organic materials. The main research areas are the following: electronic structure, dynamics on both ground and excited states, transport, multi-scale modeling in materials science, quantum non-degenerate gases, nuclear astrophysics, subatomic physics, degenerate Fermi gases, superconductivity, bio- and carbon-based materials, proton diffusion and energy deposition in polymers, secondary electron emission, scattering theory.
In this regard, LISC scientists are positioned at the forefront of current international research in the area of carbon-based materials (nanotubes, fullerenes, and graphene) and silicon-based materials. Besides carrying out world-class computational research, LISC provides a reference point for computational science in the Trento area.

5.1 Projects of ECT*-LISC Researchers

Martina Azzolini

Electron transport in Highly Oriented Pyrolytic Graphite: the role of the anisotropic structure in plasmon excitations. Calculation of secondary electron emission spectrum.

In collaboration with T. Morresi, S. Taioli, M. Dapor (ECT, Italy), N. M. Pugno (University of Trento, Italy & Ket-Lab, ASI, Rome, Italy & Queen Mary University of London, United Kingdom) and C. Rodenburg (University of Sheffield, United Kindom)*

In Ref. [1] we applied the Monte Carlo method to calculate reflection electron energy loss spectra of Highly Oriented Pyrolytic Graphite by considering only in-plane inelastic interactions. The comparison with experimental data demonstrated the need to include also intra-planar inelastic interactions. Thus the Monte Carlo code was modified to consider both the interaction directions. Moreover, the secondary electron emission spectrum was calculated by using this new model and compared with experimental data provided by Prof. C. Rodenburg.

Monte Carlo simulation of high-energy electron transport in SiO_2 target

In collaboration with S. Taioli and M. Dapor (ECT, Italy), N. M. Pugno (University of Trento, Italy & Ket-Lab, ASI, Rome, Italy & Queen Mary University of London, United Kingdom), and P. de Vera (University of Alicante, Spain)*

It was found experimentally that by irradiating with a high energy electron beam a layer of $W(CO)_6$ deposited on SiO_2, the growth of nanostructure is produced.

To model this phenomenon a couple of Monte Carlo simulation and Molecular Dynamic simulation is needed. With the Monte Carlo method, we simulated the propagation of primary electrons and the emission of backscattered and secondary electrons. Emitted electrons were recorded accordingly to the distance between the center of the beam and the emission position. The electron fluences are then used as input for molecular dynamics simulation of the second part of the process that will be performed by P. de Vera.

Calculation of secondary electron emission yield of Copper, Silver and Gold

In collaboration with S. Taioli and M. Dapor (ECT, Italy), N. M. Pugno (University of Trento, Italy & Ket-Lab, ASI, Rome, Italy & Queen Mary University of London, United Kingdom), R. Cimino and R. Larciprete (INFN, Italy)*

Monte Carlo simulations were performed to calculate the secondary electron emission yield curves of Copper, Silver and Gold. To obtain a good agreement with experimental data provided by INFN Laboratories [2] we found that Energy Loss Function (ELF) has to be considered as an effective ELF, which also includes surface excitations [3]. The effective ELF should be determined according to the initial energy of the beam.

Calculation of reflection electron energy loss spectra with Monte Carlo simulation and Numerical Solution method

In collaboration with S. Taioli and M. Dapor (ECT, Italy), N. M. Pugno (University of Trento, Italy & Ket-Lab, ASI, Rome, Italy & Queen Mary University of London, United Kingdom), O. Y. Ridzel (University of Wien, Austria & Moscow Power Engineering Institute, Russia) and P. S. Kaplya (Moscow Power Engineering Institute, Russia)*

In Ref. [4] a method to directly compute the Reflection Electron Energy Loss (REEL) spectrum without the calculation of the electron trajectories is presented. It consists in the Numerical Solution of the Ambartsumian-Chandrasekhar equations, obtained by the application of the invariant embedding method. The Monte Carlo simulation and the numerical solution methods were applied to the calculation of REEL spectra of three materials (Copper, Silver Gold). The comparison between the spectra shows the equivalence of these models in the REEL spectra calculation. The Numerical Solution method can be employed to quickly test the dielectric description of the target material. Once the Energy Loss function is tested the complete Monte Carlo simulation can be performed to calculate the secondary electron emission spectrum and the secondary electron emission yield.

References

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[2] L. A. Gonzalez et al., AIP Advances **7**, 115203 (2017).

[3] T. Nagatomi et al., Surd. Interface Anal **35**, 174 (2003).

Maurizio Dapor

Energy deposition around swift proton tracks in polymethylmethacrylate

In collaboration with I. Abril (University of Alacant, Spain), R. Garcia Molina (University of Murcia, Spain), and P. de Vera (University of Murcia, Spain)

The use of proton beams in several modern technologies to probe or modify the properties of materials, such as proton beam lithography or ion beam cancer therapy, requires us to accurately know the extent to which the energy lost by the swift projectiles in the medium is redistributed radially around their tracks, since this determines several endpoints, such as the resolution of imaging or manufacturing techniques, or even the biological outcomes of radiotherapy. In this project, the radial distribution of the energy deposited around swift-proton tracks in polymethylmethacrylate (PMMA) by the transport of secondary electrons is obtained by means of a detailed Monte Carlo simulation. The initial energy and angular distributions of the secondary electrons generated by proton impact, as well as the electronic cross sections for the ejection of these electrons, are reliably calculated in the framework of the dielectric formalism, where a realistic electronic excitation spectrum of PMMA is accounted for. The cascade of all secondary electrons generated in PMMA is simulated taking into account the main interactions that occur between these electrons and the condensed phase target. After analysing the influence that several angular distributions of the electrons generated by the proton beam have on the resulting radial profiles of deposited energy, we conclude that the widely used Rudd and Kim formula should be replaced by the simpler isotropic angular distribution, which leads to radial energy distributions comparable to the ones obtained from more realistic angular distributions. By studying the dependence of the radial dose on the proton energy we recommend lower proton energies than previously published for reducing proximity effects around a proton track. The obtained results are of relevance for assessing the resolution limits of proton beam based imaging and manufacturing techniques.

A rapid, 3-dimensional morphology analysis using backscattered electron imaging

In collaboration with C. Rodenburg (University of Sheffield, UK) and R. C. Masters (University of Sheffield, UK)

Finding the optimal morphology of novel organic photovoltaic (OPV) polymer blends is a major obstacle slowing the development of more efficient OPV devices. With a focus on accelerating the systematic morphology optimisation process, we demonstrate a technique offering rapid high-resolution, 3-dimensional blend morphology analysis in the scanning electron microscope. This backscattered electron imaging technique is used to investigate the morphological features and length-scales defining the promising PffBT4T-2OD:PC70BM blend system and show how its photovoltaic performance is related to the nature of its phase separation. Low voltage backscattered electron imaging can be used to probe for structure and domain stacking through the thickness of the film, as well as imaging surface morphology with highly competitive spatial resolution. For reference, we compare our results with equivalent images of the widely studied P3HT:PC60BM blend system. Our results also demonstrate that backscattered electron imaging offers significant advantages over conventional cross-sectional imaging techniques, and show that it enables a fast, systematic approach to control 3- dimensional active layer morphology in polymer: fullerene blends.

Electron energy-loss spectra of diamond and graphite

In collaboration with N. M. Pugno (University of Trento, Italy)

In this work we compare Monte Carlo (MC) simulations of electron-transport properties with reflection electron energy-loss measurements in diamond and graphite films. We assess the impact of different approximations of the dielectric response on the observables of interest for the characterization of carbon-based materials. We calculate the frequency-dependent dielectric response and energy-loss functions of these materials in two ways: a full ab initio approach, in which we carry out time dependent density functional simulations in linear response for different momentum transfers, and a semi-classical model, based on the DrudeeLorentz extension to finite momenta of the optical dielectric function. Ab initio calculated dielectric functions lead to better agreement with measured energy-loss spectra compared to the widely used DrudeeLorentz model. This discrepancy is particularly evident for insulators and semiconductors beyond the optical limit, where single-particle excitations become relevant. Furthermore, we show that the behaviour of the energy-loss function obtained at different accuracy levels has a dramatic effect on other physical observables, such as the inelastic mean free path and the stopping power in the low energy (<100 eV) regime and thus on the accuracy of MC simulations.

References

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Giovanni Garberoglio

Ab-initio calculation of virial coefficients for molecular gases

In collaboration with A.H. Harvey (NIST, USA), K. Szalewicz (University of Delaware, USA), P. Jankowski (Torun University, Poland)

We continued the on-going collaboration for the ab-initio calculation of virial coefficients of molecular gases. In Ref. [1] we validated state-of-the-art potentials for the interaction of molecular hydrogen with carbon monoxide, a mixture of interest in astrophysical research.
We are currently working with the extension of the same methodology to more complicated molecules, with particular attention to water and its isotopologues.

Mechanical and electronic properties of carbon based materials

In collaboration with N.M. Pugno (University of Trento, Italy)

In Ref. [2] we proposed a novel structure of carbon-based nanofoams, inspired by carbon-fullerene nanotruss networks. Our foams are generated in-silico using an experimentally driven procedure, namely the coating of metal nanoparticles with graphene. The resulting frameworks show very similar properties under traction, but under compressive regimes peculiar instabilities are found, leading to negative values of the Poisson ratios. In Ref. [3] we reported on the comparison between calculated and measured electron energy-lorem spectra in diamond and graphite. We compared various models including a fully ab-initio calculation using time-dependent density functional theory. The results show the sizable effect that some approximation can have on the final result.

Bio-inspired materials

In collaboration with N.M. Pugno (University of Trento, Italy)

In Ref. [4] we report an experimental/numerical investigation on the effect of graphene and carbon-nanotube doping on the tensile properties of spider silk. Experiments seem to indicate an increment of the mechanical properties of doped silk with respect to the pristine one. However, the actual reason for this increase is not fully understood from the theoretical point of view.

References

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Tommaso Morresi

Graphene on a Beltrami pseudosphere

In collaboration with S. Taioli, D. Binosi, N. M. Pugno (University of Trento), S. Roche (Institut Català de Nanociència i Nanotecnologia, Barcelona)

The goal of this work is to model a structure made of 3-coordinated carbon atoms on the surface of a Beltrami pseudosphere and to calculate the electronic properties of this system. Indeed, in Ref. [1] a theoretical proof that graphene can be used as a realization of the Hawking-Unruh effect is given. This is due to the particular properties of electrons in graphene [2]. We want to study and demonstrate this effect using computational methods. In the first part of the project, we have obtained the geometry of the system for a different number of atoms. At least 10^6 particles are needed to demonstrate the hypothesis devised in Ref. [1]. In order to reach such a big number of atoms, we developed a method that increases particles with a dualization algorithm up to ~10^6 starting from a small configuration, in reasonable computational time. Next step, in collaboration with Prof. Stephan Roche, will be the calculation of the Local Density of States (LDOS) of the optimized structures. This observable will give information on the behaviour of quantum fields in a curved spacetime with a horizon.

Modeling and simulations of SiC/SiOx core/shell nanowires

In collaboration with A. Pedrielli, S. Taioli, G. Garberoglio, N. M. Pugno (University of Trento), M.V. Nardi (CNR, Trento), M. Tiempel (CNR, Trento) and R. Tatti (CNR, Trento)

In this work we want to reproduce the experimental measurements performed by the group led by M. V. Nardi of XANES spectra in SiC/SiOx core/shell nanowires. These systems are interesting in cancer treatment because the 3C-SiC green emission can be used to activate the singlet oxygen production by porphyrins, the dominant cytotoxic agent produced during photodynamic therapy [3]. We developed a realistic model of a single SiC/SiOx core/shell nanowire and we characterized this structure both geometrically and electronically comparing our results with the literature. We calculated XANES spectra and we were able to reproduce rather accurately the experimental spectra. These results will be soon submitted to Nanoscale.

Study of the interaction between X-ray and a target of amorphous SiO2

In collaboration with S. Taioli, G. Monaco (University of Trento), N. M. Pugno (University of Trento)

The aim of this work is to simulate the interaction of 8 keV X-rays with a sample of amorphous silicon dioxide to reproduce experimental measurements obtained by prof. Monaco's group. We tackled the problem by performing non-adiabatic molecular dynamics simulations, which means that the potential giving rise to the motion of nuclei takes into account the excited states of the electrons [4]. We have shown that the inclusion of the excited state dynamics in non-adiabatic simulations, at variance with the Born-Oppenheimer approximation, is visible in physical measurable quantities, such as the intermediate scattering function F(q,t) or the mean square displacement, calculated from the trajectories of the particles. Although our simulations currently are at the stage of a proof-of-concept, we demonstrated that electronic excited states are fundamental to describe accurately the structural relaxation dynamics of irradiated systems.

References

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Andrea Pedrielli

Gas adsorption and dynamics in Pillared Graphene Frameworks

Supervised by N. M. Pugno (UniTn-FBK) and G. Garberoglio (FBK-ECT)*

In collaboration with S.Taioli (FBK-ECT)*

In Ref. [1] we presented and discussed the results of extensive simulations of gas adsorption and dynamics in Pillared Graphene Frameworks (PGFs), performed by means of Grand Canonical Monte Carlo method and Molecular Dynamics. PGFs are composed by graphene layers intercalated by organic molecules that act as spacers. The high surface-to-volume ratio of graphene layers can be exploit tuning the spacers dimension. We explored the influence on gas adsorption and dynamics of the pillar density and type for a narrow class of nitrogen-containing PGFs. The gases tested for adsorption were CH_4, CO_2, H_2, N_2 and O_2, and separation was assessed for some mixture thereof. The results shown a higher influence of the pillar density with respect to the pillar type, and good performances for gas separation, comparable to those of Metal Organic Frameworks (MOFs). An evaluation of the difference in using two different force fields to describe the gas-frameworks interaction, Universal Force Field or DREIDING, was also presented.

References

[1] A. Pedrielli, S. Taioli and G. Garberoglio, N. M. Pugno Microporous Mesoporous Mater. Vol. **257**, 222 (2018)

Francesco Segatta

Ab-initio description of nonlinear spectroscopy of Light Harvesting complexes

In collaboration with B. Mennucci and the Molecolab group (University of Pisa, Italy)

In Ref. [1] we employed highly accurate quantum chemistry approaches to simulate and interpret linear and nonlinear spectroscopy of complex multichromophoric architectures of known structure. The proposed scheme relies on a QM/MM multi-scale approach [2], able to link single chromophore units with the entire molecular aggregate via a so called Frenkel Exciton Hamiltonian. This includes molecular vibrations and environmental fluctuations, eventually delivering the system's manifold of states and their relaxation pathways with very high accuracy. Application to the LH2 test case, employed here as a challenging playground, gives an unprecedented insight into the interpretation of the spectral signatures of the measured 2DES signals.

Accurate semiclassical path integral computation of nonlinear spectroscopic techniques

In collaboration with D. F. Coker and J. Provazza (Boston University, MA, USA)

During the visiting period to the research group of Prof. David F. Coker at the Boston University, we started a collaboration aimed at developing accurate methods for the computation of nonlinear spectroscopy in natural and artificial photosynthetic complexes. In particular, we exploited the accuracy of the *partial linearized density matrix* dynamics methodology [3], formulated by Prof. Coker himself, to describe the system evolution occurring after light induced perturbations. This was combined to the *response function* formalism of optical spectroscopy [4,5], obtaining a promising approach for the computation of general nonlinear spectroscopic techniques, e.g., two-dimensional electronic spectroscopy. The outline of this newly developed method has been recently published in Ref. [6].

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Simone Taioli

2D Material Armors Showing Superior Impact Strength of Few Layers

In collaboration with N. Pugno and S. Signetti (University of Trento, Italy)

The research activity of this year was focussed along five different lines. First, we study the ballistic properties of two-dimensional materials upon the hypervelocity impacts of C_{60} fullerene molecules combining ab initio density functional tight binding and finite element simulations. The critical penetration energy of monolayer membranes is determined using graphene and the 2D allotrope of boron nitride as case studies. Furthermore, the energy absorption scaling laws with a variable number of layers and interlayer spacing are investigated, for homogeneous or hybrid configurations (alternated stacking of graphene and boron nitride). At the nano-level, a synergistic interaction between the layers emerges, not observed at the micro- and macro-scale for graphene armors. This size-scale transition in the impact behavior toward higher dimensional scales is rationalized in terms of scaling of the damaged volume and material strength. An optimal number of layers, between 5 and 10, emerges demonstrating that few-layered 2D material armors possess impact strength even higher than their monolayer counterparts. These results provide fundamental understanding for the design of ultra-lightweight multilayer armors using enhanced 2D material based nanocomposites (see Ref. [1]).

Gas adsorption and dynamics in Pillared Graphene Frameworks

In collaboration with A. Pedrielli, G. Garberoglio (ECT, Italy) and N. Pugno (University of Trento, Italy)*

Second, in Ref. [2] we study Pillared Graphene Frameworks, which are a novel class of microporous materials made by graphene sheets separated by organic spacers. One of their main features is that the pillar type and density can be chosen to tune the material properties. In this work, we present a computer simulation study of adsorption and dynamics of H_2, CH_4, CO_2, N_2 and O_2 and binary mixtures thereof, in Pillared Graphene Frameworks with nitrogen-containing organic spacers. In general, we find that pillar density plays the most important role in determining gas adsorption. In the low-pressure regime (< 10 bar) the amount of gas adsorbed is an increasing function of pillar density. At higher pressure the opposite trend is observed. Diffusion coefficients were computed for representative structures taking into account the framework flexibility that is essential for assessing the dynamical properties of the adsorbed gases. Good performance for the gas separation in CH_4/H_2, CO_2/H_2 and CO_2/N_2 mixtures was found, with values comparable to those of metal-organic frameworks and zeolites.

Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: role of dielectric-response models

In collaboration with M. Azzolini, T. Morresi, G. Garberoglio, M. Dapor (ECT, Italy) and N. Pugno (University of Trento, Italy)*

Third, in Ref. [3] we compare Monte Carlo (MC) simulations of electron-transport properties with reflection electron energy-loss measurements in diamond and graphite films. We assess the impact of different approximations of the dielectric response on the observables of interest for the characterization of carbon-based materials. We calculate the frequency-dependent dielectric response and energy-loss functions of these materials in two ways: a full ab initio approach, in which we carry out time-dependent density functional simulations in linear response for different momentum transfers, and a semi-classical model, based on the Drude-Lorentz extension to finite momenta of the optical dielectric function. Ab initio calculated dielectric functions lead to better agreement with measured energy-loss spectra compared to the widely used Drude-Lorentz model. This discrepancy is particularly evident for insulators and semiconductors beyond the optical limit ($q \neq 0$), where single-particle excitations become relevant. Furthermore, we show that the behaviour of the energy-loss function obtained at different accuracy levels has a dramatic effect on other physical observables, such as the inelastic mean free path and the stopping power in the low energy (< 100 eV) regime and thus on the accuracy of MC simulations.

A quantum chemical interpretation of two-dimensional electronic spectroscopy of Light-Harvesting complexes

In collaboration with F. Segatta, M. Garavelli (University of Bologna, Italy), B. Mennucci (University of Pisa, Italy), S. Mukamel (University of California, Irvine, USA) and M. Dapor (ECT, Italy)*

Fourth, in Ref. [4] nonlinear electronic spectroscopies represent one of the most powerful techniques to study complex multi-chromophoric architectures. For these systems, in fact, linear spectra are too congested to be used to disentangle the many coupled vibro-electronic processes that are activated. By using a 2D approach, instead, a clear picture can be achieved, but only when the recorded spectra are combined with a proper interpretative model. So far, this has been almost always achieved through parametrized exciton Hamiltonians that necessarily introduce biases and/or arbitrary assumptions. In this study, a first-principles approach is presented that combines accurate quantum chemical descriptions with state-of-the-art models for the environment through the use of atomistic and polarizable embeddings. Slow and fast bath dynamics, along with exciton transport between the pigments, are included. This approach is applied to the 2DES spectroscopy of the Light-Harvesting 2 (LH2) complex of purple bacteria. Simulations are extended over the entire visible-near-infrared spectral region to cover both carotenoid and bacteriochlorophyll signals. Our results provide an accurate description of excitonic properties and relaxation pathways, and give an unprecedented insight into the interpretation of the spectral signatures of the measured 2D signals.

Spider silk reinforced by graphene or carbon nanotubes

In collaboration with G. Garberoglio (ECT, Italy), N. Pugno (University of Trento, IT), A. C. Ferrari (University of Cambridge, UK), and F. Bonaccorso (Italian Institute of Technology, IT)*

Spider silk has promising mechanical properties, since it conjugates high strength (~1.5 GPa) and toughness (~150 J/g). In Ref. [5], we report the production of silk incorporating graphene and carbon nanotubes by spider spinning, after feeding spiders with the corresponding aqueous dispersions. We observe an increment of the mechanical properties with respect to pristine silk, up to a fracture strength ~5.4 GPa and a toughness modulus ~1570 J/g. This approach could be extended to other biological systems and lead to a new class of artificially modified biological, or “bionic”, materials.

Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression

In collaboration with A. Pedrielli, G. Garberoglio (ECT, Italy) and N. Pugno (University of Trento, Italy)*

Finally, in Ref. [6] the analysis of the mechanical response of realistic fullerene-nanotube nanotruss networks with face-centered cubic geometry is performed by using molecular dynamics with reactive potentials. In particular, the mechanical properties of these novel architectures are investigated in both compressive and tensile regimes, a number of truss geometries by straining along different directions. Our atomistic simulations reveal a similar behavior under tensile stress for all the samples. Conversely, under compressive regimes the emergence of a response that depends on the orientation of load is observed together with a peculiar local instability. Due to this instability, some of these nanotruss networks present a negative Poisson ratio in compression, like re-entrant foams. Finally, the performance of these nanotruss networks is analyzed with regards to their use as impact energy absorbers, displaying properties that outperform materials traditionally used in these applications.

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[2] A. Pedrielli, S. Taioli, G. Garberoglio and N. Pugno, Microporous and Mesoporous Materials **257**, 222-231 (2018)

[3] M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N. Pugno, S. Taioli and M. Dapor, Carbon **118**, 299-309 (2017)

[4] F. Segatta, L. Cupellini, S. Jurinovich, S. Mukamel, M. Dapor, S. Taioli, M. Garavelli and B. Mennucci, Journal of the American Chemical Society **139** (22), 7558-7567 (2017)

[5] E. Lepore, F. Bosia, F. Bonaccorso, M. Bruna, S. Taioli, G. Garberoglio, A. C. Ferrari and N. Pugno, 2D Materials **4** (3), 031013 (2017)

[6] A. Pedrielli, S. Taioli, G. Garberoglio and N. Pugno, Carbon **111**, 796-806 (2017)

5.2 Publications of ECT*-LISC Researchers in 2017

Martina Azzolini

M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N. M. Pugno, S. Taioli, M. Dapor
Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: Role of dielectric -response models
*Carbon **118**, 299 (2017), arXiv: 1612.01898 [hep-ph]*

Maurizio Dapor

[1] M. Dapor, R. C. Masters, I. Ross, D. G. Lidzey, A. Pearson, I. Abril, R. Garcia-Molina, J. Sharp, M. Unčovský, T. Vystavel, F. Mika, C. Rodenburg
Secondary electron spectra of semi-crystalline polymers – A novelpolymer characterisation tool?
*Journal of Electron Spectroscopy and Related Phenomena **222** (2018) 95*

[2] R. Garcia-Molina, M. Dapor, P. de Vera, I. Abril
Energy deposition around swift proton and carbon ion tracks in biomaterials
*IOP Conf. Series: Journal of Physics: Conf. Series **875** (2017) 112006*

[3] M. Dapor, I. Abril, P. de Vera, R. Garcia-Molina
Energy deposition around swift proton tracks in polymethylmethacrylate: How much and how far
*Physical Review **B96** (2017) 064113*

[4] M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N. M. Pugno, S. Taioli, M. Dapor
Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: Role of dielectric-response models
*Carbon **118** (2017) 299*

[5] F. Segatta, L. Cupellini, S. Jurinovich, S. Mukamel, M. Dapor, S. Taioli, M. Garavelli, B. Mennucci
A quantum chemical interpretation of two-dimensional electronic spectroscopy of light-harvesting complexes
*J. Am. Chem. Soc. **139** (2017) 7558*

[6] M. Dapor
Transport of energetic electrons in solids. Computer simulation with applications to materials analysis and characterization. Second Edition.
*Springer Tracts in Modern Physics, Volume **257**, Springer, Berlin, 2017*

[7] R. C. Masters, Q. Wan, Y. Zhang, M. Dapor, A. M. Sandu, C. Jiao, Y. Zhou, H. Zhang, D. G. Lidzey, C. Rodenburg
Novel organic photovoltaic polymer blends: A rapid, 3-dimensional morphology analysis using backscattered electron imaging in the scanning electron microscope
*Solar Energy Materials & Solar Cells **160** (2017) 182*

[8] M. Dapor
Role of the tail of high-energy secondary electrons in the Monte Carlo evaluation of the fraction of electrons backscattered from polymethylmethacrylate
*Applied Surface Science **391** (2017) 3–11*

Giovanni Garberoglio

G. Garberoglio, P. Jankowski, K. Szalewicz, A.H. Harvey
All-dimensional H_2–CO potential: Validation with fully quantum second virial coefficients
*J. Chem. Phys. **146**, 054304 (2017)*

A. Pedrielli, S. Taioli, G. Garberoglio, N.M. Pugno
Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression
*Carbon **111**, 796 (2017)*

M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N.M. Pugno, S. Taioli, M. Dapor
Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: Role of dielectric-response models
*Carbon **118**, 299 (2017)*

E. Lepore, F. Bosia, F. Bonaccorso, M. Bruna, S. Taioli, G. Garberoglio, A.C. Ferrari, N.M. Pugno
Spider silk reinforced by graphene or carbon nanotubes
*arXiv: 1504.06751 2D Materials **4**, 031013 (2017)*

Tommaso Morresi

M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N.M. Pugno, S. Taioli, M. Dapor
Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: Role of dielectric-response models
*Elsevier, Carbon **118** (2017) 299-309*
http://dx.doi.org/10.1016/j.carbon.2017.03.041

Andrea Pedrielli

A. Pedrielli, S. Taioli, G. Garberoglio, N. M. Pugno
Gas adsorption and dynamics in Pillared Graphene Frameworks
Microrporous and mesoporous materials, February 2018
ISSN 1387-1811

Simone Taioli

A. Pedrielli, S. Taioli, G. Garberoglio, N. Pugno
Gas adsorption and dynamics in Pillared Graphene Frameworks
*Microporous and Mesoporous Materials **257**, 222-231 (2018)*

S. Signetti, S. Taioli, N. Pugno
2D Material Armors Showing Superior Impact Strength of Few Layers
*ACS Applied Materials & Interfaces **9** (46), 40820–40830 (2017)*

E. Lepore, F. Bosia, F. Bonaccorso, M. Bruna, S. Taioli, G. Garberoglio, A. C. Ferrari, N. Pugno
Spider silk reinforced by graphene or carbon nanotubes
*2D Materials **4** (3), 031013 (2017)*

M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N. Pugno, S. Taioli, M. Dapor
Monte Carlo simulations of measured electron energy-loss spectra of diamond and graphite: role of dielectric-response models
*Carbon **118**, 299-309 (2017)*

F. Segatta, L. Cupellini, S. Jurinovich, S. Mukamel, M. Dapor, S. Taioli, M. Garavelli, B. Mennucci
A quantum chemical interpretation of two-dimensional electronic spectroscopy of Light-Harvesting complexes
*Journal of the American Chemical Society **139** (22), 7558-7567 (2017)*

A. Pedrielli, S. Taioli, G. Garberoglio, N. Pugno
Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression
*Carbon **111**, 796-806 (2017)*

5.3 Talks presented by ECT*-LISC Researchers in 2017

Martina Azzolini

Reflection electron energy loss spectra of highly oriented pyrolitic graphite: role of anisotropic structure in plasmon excitations
Talk given at the Conference “Sources, Interaction with Matter, Detection and Analysis of Low Energy Electrons 2017”.
September 2017, Pula, Italy

Maurizio Dapor

M. Dapor
Role of the electron cloud polarization on the radial dose along proton tracks in poly (methyl methacrylate) (PMMA)
20th International Conference on Surface Modification of Materials by Ion Beams (SMMIB 2017)
11 July 2017, Lisbon, Portugal

Giovanni Garberoglio

High-accuracy calculations of density virials
Talk given during a workshop organized to prepare an international partnership for the EMPIR call Fundamental 2017. Invited by the Principal Investigator.
June 2017, Prague, Czech Republic

Tommaso Morresi

Non adiabatic molecular dynamics: application to graphene synthesis and silica structural relaxation dynamics
Presentation of poster at the 'Workshop on Spectroscopy and Dynamics of Photoinduced Electronic Excitations'
May 2017, Trieste, Italy

Simone Taioli

Graphene synthesis, carbon foams, pillared graphene, pseudospheres and all that from first-principles, multiscale simulations and experiments
Talk given at the workshop “Synthetic methods across the flagship”
February 2017, Puerto de La Cruz, Tenerife

Graphene synthesis and the physics of carbon from ab-initio simulations and experiments
Talk given at the conference “1st European Conference on Chemistry of Two-Dimensional Materials (Chem2DMat)”
August 2017, Strasbourg, France

Graphene synthesis, carbon foams, pillared graphene, pseudospheres and all that from first-principles, multiscale simulations and experiments
Talk given at the conference “Recent Progress in Graphene & 2D Materials Research”
September 2017, Singapore, Singapore

6 ECT* Computing Facilities

CONNECTIVITY

- The core of the computational infrastructure at ECT* has recently been improved.
- The main network infrastructure is connected by 3 switches PoE - Power over Ethernet- (DELL Power Connect 5548P).
- 7 switches Dell Power Connect 5548 will be installed in order to improve the connectivity in the Villa Tambosi.
- The Rustico and the Villa at ECT* are connected by two multi-mode optical fibers.
- Between ECT* and FBK the connection is also provided by fiber (1Gbps).

ECT* access to the Internet is transmitted through the FBK. FBK is a BGP Autonomous System; The Internet connection is provided by Trentino Network s.r.l. (bidirectional 1 Gbit/s full speed) and GARR as back-up connection (100Mbit/s); if there are network problems, the connection trough the GARR is automatically activated.

HARDWARE

PC clients:
10 PCs for the local research:
Workstation DELL Precision T1500
Workstation DELL Precision T1600
Apple iMac 27"

8 PCs/laptops for the staff:
Workstation DELL Precision T1500
Workstation DELL Precision T1600
Laptops DELL latitude E5440

26 PCs for the participants of the schools and visiting scientists:
Workstation DELL Precision T1500
Workstation DELL Optiplex 755

A pool of 9 laptops for the workshop participants:
Laptops DELL latitude E6510
Laptop DELL latitude E6220
Laptops DELL latitude E4310
Laptops DELL latitude E4300

IMPORTANT SOFTWARE: Mathematica version 11.X: 1 network license server + 7 concurrent processes + 7 "Home Use" licenses.

SERVICES

All services are running on the hardware of the FBK datacenter. All users can access all services offered by the FBK and through the Google service.
The following useful Google services can be accessed through login on the "ectstar.eu" domain:

1. Google mail (using the "ectstar.eu" e-mail domain)
2. Google Cloud Print
3. Google Drive

4. Google Team Drive (since 22/11/17)
5. Google Hangouts
6. Google Classroom

HIGH PERFORMANCE COMPUTING

The ECT* researchers can access KORE, a High Performance Computer of the FBK. KORE is made of about 1120 cores and 300 TB of distributed storage, interconnected by a high speed network ranging from 1 Gbit/s to 10Gbit/10 with branches running on InfiniBand, a low latency network featuring very high throughput.

To ensure very much needed access to further HPC resources for the ECT* researchers - upon an initiative by the Director - the Forschungszentrum Jülich (Germany) has granted funds for 10M core hours on the JUQUEEN supercomputer. The allocated computer time under project number 12787 has been made available from Sept. 1, 2017 and will expire on March 31, 2018.