ECT*

Annual Report 2016

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

Institutional Member of the European Science Foundation Expert Committee NuPECC

FONDAZIONE BRUNO KESSLER

ECT*

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 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 physics.

Altogether 712 scientists from 38 countries have visited the ECT* in 2016 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 physics communities.

In 2016 ECT* held:

- 18 Workshops and 1 Collaboration Meeting 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 “Nuclear, neutrino and relativistic astrophysics” that lasted six weeks and was attended by 14 students from 8 countries worldwide.

In addition to these 20 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 6 of this Annual Report. Altogether, 59 publications by the ECT* and ECT*-LISC researchers in refereed journals represent a sizable fraction of all publications produced in 2016 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 2016 a formal agreement with EMMI, the ExtreMe Matter Institute at GSI, Germany.

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

In January 2016, FBK-ECT* and the Physics Department of the University of Trento signed the renewal of an agreement with ECT*-LISC. The ECT*-LISC researchers will participate in the teaching program of the Physics Department through lectures and the supervision of Master and PhD students, thus further strengthening the ties between ECT* and the University.

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 2016 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, the Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, and the United Kingdom. ECT* also acknowledges additional partial support for its workshops, received in 2016 from CNRS (France), the Heidelberg Graduate School of Fundamental Physics (Germany), Temple University (USA), Duke University (China), Jefferson Lab (USA), INFN-TIFPA Trento (Italy), BEC Trento (Italy), the University of Trento (Italy), INFN (Italy), CNR Firenze (Italy), the Max-Planck Institute of Quantum Optics (Germany), the PRISMA Cluster of Excellence at the Johannes Gutenberg University Mainz (Germany), Stony Brook University (USA), the Helmholtz Institute Mainz (Germany), EMMI (Germany), the University of Oslo (Norway), Queen's University Belfast (UK), IPN Orsay (France) and the Goethe University of Frankfurt (Germany).

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 the next four years. Its transnational access activities have partially supported 8 workshops 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 coordinator of the Doctoral Training Programme, Georges Ripka, 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 2016 is available on the ECT* web site (www.ectstar.eu).

Trento, February 2016

Jochen Wambach
*Director of ECT**

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2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Gert Aarts	Swansea University, UK
Omar Benhar	INFN/Università "La Sapienza", Rome, Italy
Angela Bracco	NuPECC/University of Milano, Italy
Nicole d'Hose (since June 2016)	CEA Saclay, France
Judith McGovern (until January 2016)	University of Manchester, UK
Paul-Henri Heenen	Université Libre de Bruxelles, Belgium
Piet Mulders	VU Amsterdam, Netherlands
Sanjay Reddy	University of Washington, Seattle, USA
Dirk Rischke (since June 2016)	Johann Wolfgang Goethe-Universität, Frankfurt, Germany
Johanna Stachel (until June 2016)	University of Heidelberg, Germany
Ubirajara van Kolck	IPN Orsay, France

Honorary Member of the Board

Ben Mottelson	NORDITA, Copenhagen, Denmark

ECT* Director

Jochen Wambach	ECT*, Italy and TU Darmstadt, Germany

2.2 ECT* Staff

Ines Campo (part time)	Technical Programme Co-ordinator
Serena degli Avancini	Technical Programme Co-ordinator
Barbara Currò Dossi	Systems Manager
Susan Driessen (part time)	Assistant to the Director
Tiziana Ingrassia (part time)	Accounting Assistant
Mauro Meneghini	Maintenance Support Manager
Gian Maria Ziglio	Technical Programme Co-ordinator and Web Manager

2.3 Resident Researchers

- **ECT* Postdocs**

Guillaume Beuf, France
Daniele Binosi, Italy
Jesus Casal Berbel, Spain (since October 01)
Alexis Diaz-Torres, Germany (until August 31)
Maria Gomez Rocha, Spain
Philipp Gubler, Switzerland (until May 31)
Chen Ji, China
Daisuke Sato, Japan (until February 29)
Dionysis Triantafyllopoulos, Greece
Arno Tripolt, Germany (since March 01)

- **ECT*-LISC Postdocs**

Martina Azzolini
Maurizio Dapor (Head of ECT*-LISC Research Unit),
Lucia Calliari (until June 2016)
Giovanni Garberoglio
Andrea Pedrielli
Tommaso Morresi
Simone Taioli

- **PhD Students**

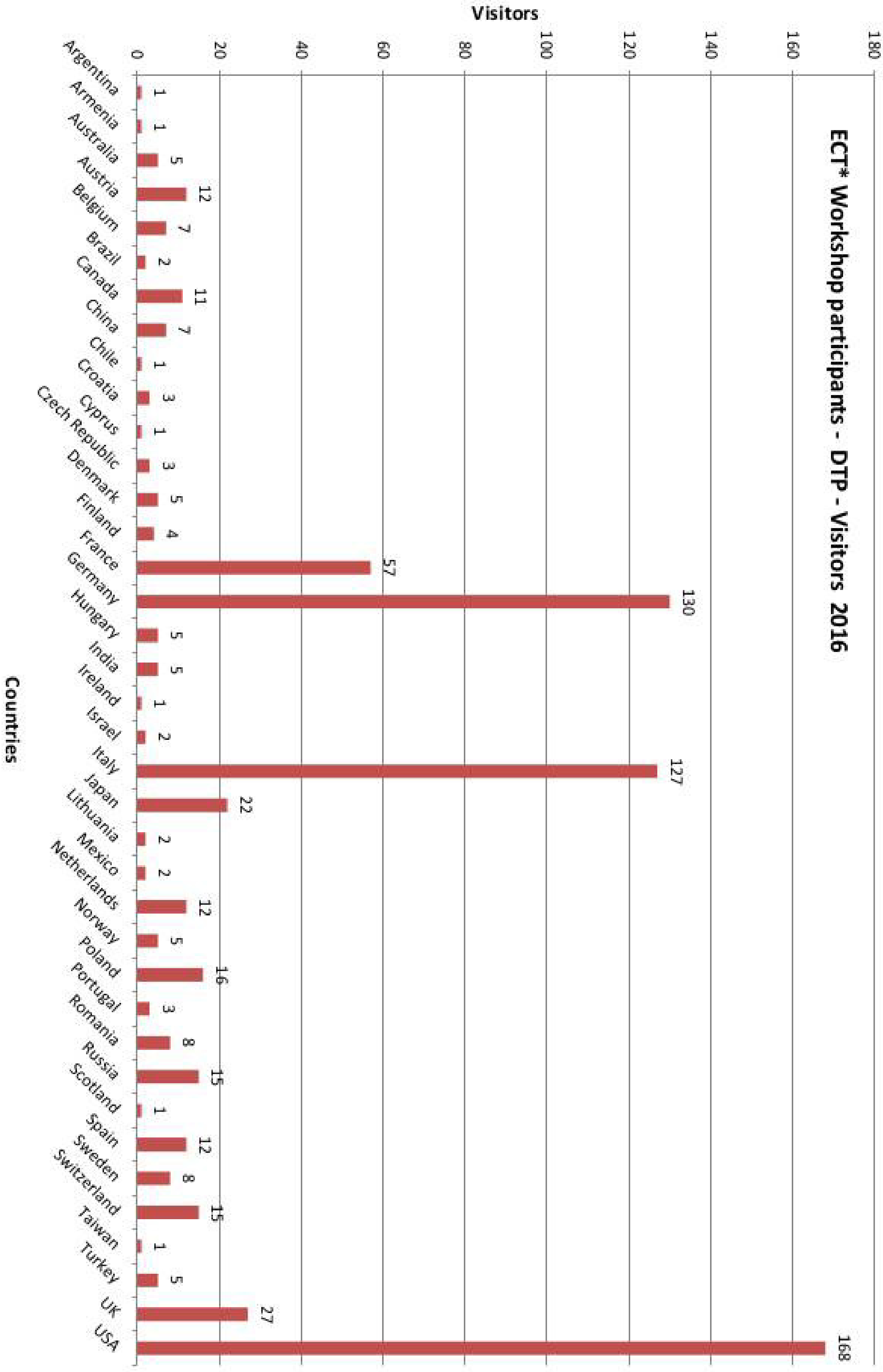
Maddalena Boselli, Italy (until April 30, 2016)

2.4 Visitors in 2016

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).

Syed Afsar Abbas (10-15/10)	JMI University, New Delhi, India (VS)
Tolga Altinoluk (03/06-10)	TU Darmstadt, Germany (VS)
Baha Balantekin (06-10/06)	University of Wisconsin-Madison, USA (DTP)
Jean-Paul Blaizot (10-18/04, 18/06-11/07)	CEA Saclay, France (VS)
Angela Bracco (19-20/05)	NuPECC/University of Milano, Italy (VS)
Peter Braun-Munzinger (14-15/03)	GSI Darmstadt, Germany (VS)
Ibrahim Ceyhun Andac (4/06-17/07)	Istanbul Technical University, Turkey (DTP)
Prasanta Char (04/06-16/07)	Saha Institute of Nuclear Physics, Kolkata, India (DTP)
Sercan Çıkıntoğlu (04/06-17/07)	Istanbul Technical University, Turkey (DTP)
Jozsef Cseh (20/09-22/09)	Hungarian Academy of Sciences, Hungary (VS)
Roie Dan (25/07-05/08)	The Hebrew University of Jerusalem, Israel (VS)
Victor Efros (23/04-06/05)	Kurchatov Institute, Moscow, Russia (VS)
Basak Ekinci (04/06-16/07)	Mimar Sinan Fine Arts University, Istanbul, Turkey (DTP)
Timon Emken (25/06-16/07)	University of Southern Denmark, Denmark (DTP)
Miguel Escobedo-Espinosa (22-25/06)	CEA Saclay, France (VS)
Bruno Giacomazzo (04-08/07)	University of Trento, Italy (DTP)
Alexander Heger (13-17/06)	Monash University, Australia (DTP)
Paul Hoyer (03-30/04)	University of Helsinki, Finland (VS)
Ernst-Michael Ilgenfritz (12-27/11)	Ruhr University, Bochum, Germany (VS)
Thomas Janka (20-24/06)	Max Planck Inst. für Astrophysik, Garching, Germany (DTP)
Matti Järvinen (17-24/04)	LPTENS, France (VS)
Chris Jung (28/03-01/04, 31/07-05/08)	Justus-Liebig-Universitaet, Giessen, Germany (VS)
Ronnie Kosslof (20/07-07/08)	The Hebrew University of Jerusalem, Israel (VS)
Maria-Paola Lombardo (12-24/11)	INFN Frascati, Italy (VS)
Konstantin Maslov (08/06-17/07)	Nat. Research Nucl.Univ. “MEPhI”, Moscow, Russia (DTP)
Paolo Mazzali (20-24/06)	Astrophysics Research Institute, Liverpool University, UK (DTP)
Nimrod Moiseyev (06/07-03-08)	University of Florence, Italy (VS)
Niklas Grønlund Nielsen (26/06-16/07)	University of Southern Denmark, Denmark (DTP)
Stéphane Peigné (20/07-07/08)	SUBATECH, France (VS)
Andrea Quadri (20-25/11)	University of Milano (VS)
Sanjay Reddy (27/06-01/07)	University of Washington, USA (DTP)
Jean-Marc Richard (04/09-03/10)	Institute de Physique Nucléaire, Lyon, France (VS)
Achim Richter (27/06-10/07, 16-21/07)	TU Darmstadt, Germany (VS)
Hirokazu Sasaki (04/06-16/07)	Univ. of Tokyo, NAOJ, Japan (DTP)

Daisuke Sato (26/06-02/07)	Goethe Universität, Frankfurt, Germany (VS)
Lorenz von Smekal (29/03-01/04)	Justus-Liebig-Universitaet, Giessen, Germany (VS)
Christian Stiegler (12-13/05)	Lund University, Sweden (VS)
Friedel Thielemann (11-15/07)	University of Basel, Switzerland (DTP)
Armin Vahdat Motlagh (11/06-17/07)	Istanbul Technical University, Turkey (DTP)
Nicole Suzanne Vassh (05-30/06)	University of Wisconsin, Madison, USA (DTP)
Sreekanth Villuvattah (27/09-04/10)	University of Florence, Italy (VS)
Eda Vurgun (04/06-17/07)	Istanbul Technical University, Turkey (DTP)
Wolfram Weise (22-26/02)	TU München, Germany (VS)
Hannah Yasin (05-30/06)	TU Darmstadt, Germany (DTP)
Anna Maria Zdeb (05/06-16/07)	University of Maris Curie-Sklodowska, Lublin, Poland (DTP)
Yonglin Zhu (04/06-17/07)	North Carolina State University, USA (DTP)


ECT* Workshop participants - DTP - Visitors 2016
Visitors
Countries
0
20
40
60
80
100
120
140
160
180
Argentina 1
Armenia 1
Australia 5
Austria 12
Belgium 7
Brazil 2
Canada 11
China 7
Chile 1
Croatia 3
Cyprus 1
Czech Republic 3
Denmark 5
Finland 4
France 57
Germany 130
Hungary 5
India 5
Ireland 1
Israel 2
Italy 127
Japan 22
Lithuania 2
Mexico 2
Netherlands 12
Norway 5
Poland 16
Portugal 3
Romania 8
Russia 15
Scotland 1
Spain 12
Sweden 8
Switzerland 15
Taiwan 1
Turkey 5
UK 27
USA 168

3 Scientific Projects in 2016

3.1 Summary

Altogether 20 scientific projects have been run in 2016: 18 workshops, 1 collaboration meeting and a Doctoral Training Programme. This chapter collects the scientific reports written by the workshop organizers. Georges Ripka who coordinated this programme prepared the report of the Doctoral Training Programme.

3.2 Workshops, Collaboration Meetings and School (Calendar)

Feb 08 – 12	**Spectroscopy of Resonances and QCD** Ulf-G. Meissner (Universität Bonn and FZ Jülich) Klaus Peters (GSI Darmstadt/GU Frankfurt) Ulrich Wiedner (Universität Bochum)
Feb 29 - Mar 04	**New Observables in Quarkonium Production (QUARKONIUM2016)** Torsten Dahms (Technische Universität München) Elena G. Ferreiro (Universidade de Santiago de Compostela) Jean-Philippe Lansberg (CNRS/IN2P3 IPNO Orsay) Cristian Pisano (Universiteit Antwerpen)
Apr 04 - 08	**Determination of the Absolute Electron (Anti)-neutrino Mass** Loredana Gastaldo (Universität Heidelberg) Kathrin Valerius (Karlsruhe Institute of Technology)
Apr 11 - 15	**Parton Transverse Momentum Distributions at Large X: a Window into Parton Dynamics in Nucleon Structure within QCD** Alessandro Bacchetta (INFN Pavia and Pavia University) Jian-Ping Chen (Jefferson Lab) Hayan Gao (Duke University) Zein-Eddine Meziani (Temple University) Paul Souder (Syracuse University)
Apr 18 - 22	**Probing Transverse Nucleon Structure at High Momentum Transfer** Evaristo Cisbani (INFN Rome) Ian Cloet (Argonne National Laboratory) David Hamilton (University of Glasgow) Seamus Riordan (Stony Brook University) Bogdan Wojtsekhowski (Jefferson Lab)
May 02 - 06	**Advances in Transport and Response Properties of Strongly Interacting Systems** Yannis Burnier (EPFL) Jeremy W. Holt (Texas A&M and University of Washington - Seattle) Alessandro Lovato (ANL) Alessandro Roggero (INT and Univ. of Washington)
May 30 - Jun 01	**Equations of State in Quantum Many-body Systems** Stefano Giorgini (BEC Center and University of Trento) Markus Holzmann (Université Grenoble) Francesco Pederiva (University of Trento) Giacomo Roati (INO-CNR and LENS Florence)

Jun 06 - 10	**Towards Consistent Approaches for Nuclear Structure and Reactions** Carlos Bertulani (Texas A&M University-Commerce) Guillaume Blanchon (CEA - DAM - DIF) Gregory Potel (Lawrence Livermore National Laboratory) Vittorio Somà (CEA Saclay)
Jun 06 – Jul 15	**Nuclear, Neutrino and Relativistic Astrophysics (Doctoral Training Program)** Sanjay Reddy (University of Washington)
Jun 20 - 24	**The Proton Radius Puzzle** Ronald Gilman (Rutgers University) Gerald A. Miller (University of Washington, Seattle) Randolf Pohl (Max-Planck-Institut für Quantenoptik)
Jul 11 - 15	**Statistical Properties of Nuclei** Yoram Alhassid (Yale University) Lee Bernstein (University of California, Berkeley) George Bertsch (University of Washington - Seattle) Ann-Cecilie Larsen (University of Oslo) Andreas Zilges (University of Cologne)
Jul 25 - 29	**Baryons over Antibaryons: the Nuclear Physics of Sakharov** Christopher Lee (Los Alamos National Laboratory) Rob G. E. Timmermans (University of Groningen) Ubirajara van Kolck (IPN Orsay)
Aug 01 - 05	**Physics Beyond the Standard Model and Precision Nucleon Structure Measurements** Krishna Kumar (Stony Brook University) Frank Maas (Mainz University) Paul Souder (Syracuse University) Marc Vanderhaeghen (Universität Mainz)
Sep 11 - 16	**Testing the Quantum Superposition Principle in Nuclear, Atomic and Optomechanical Systems** Angelo Bassi (Trieste University) Catalina Curceanu (LNF – INFN Frascati) Mauro Paternostro (Queen's University Belfast) Hendrik Ulbricht (University of Southampton)
Sep 19 - 23	**Proton-Neutron Pairing and Alpha-Like Quartet Correlations in Nuclei** Augusto Macchiavelli (Lawrence Berkeley National Laboratory) Michelangelo Sambataro (INFN Catania) Nicolae Sandulescu (NIPNE Bucharest)
Sep 26 - 30	**QCD at LHC: forward Physics and UPC Collisions of Heavy Ions** Nicolo' Cartiglia (INFN and University of Torino) Lucian Harland (UCL) Cyrille Marquet (CPhT - École Polytechnique) Christophe Royon (Kansas University USA/PAN Cracow) Gregory Soyez (CEA Saclay)

Oct 03 - 07	**Three-body Systems in Reactions with Rare Isotopes** Carlos Bertulani (Texas A&M University-Commerce) Renato Higa (Universidade de São Paulo) Alisher S. Kadyrov (Curtin University) Andreas T. Kruppa (Hungarian Academy of Sciences) Akram M. Mukhamedzhanov (Texas A&M University)
Oct 17 - 21	**Physics beyond the Limits of Stability: Exploring the Continuum** Angela Bonaccorso (INFN Pisa) Nigel Orr (LPC Caen)
Oct 24 - 28	**Nucleon and Nuclear Structure Through Di-Lepton Production** Alexandre Camsonne (Jefferson Lab) Lech Szymanowski (Poland National Center for Nuclear Research) Eric Voutier (CNRS/IN2P3/IPNO IPN Orsay)
Nov 07 - 11	**Gauge Topology: from Lattice to Colliders** Massimo D'Elia (University of Pisa) Edward Shuryak (Stony Brook University)

3.3 Reports on Workshops and Collaboration Meetings

3.3.1 SPECTROSCOPY OF RESONANCES AND QCD

DATE: February 8 - 12, 2016

ORGANIZERS:

U. Meißner (Univ. Bonn, Germany)
K. Peters (GSI, Germany)
U. Wiedner (Ruhr-University Bochum, Germany)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

Spectroscopic investigations of nature have been essential in establishing the quark model and subsequently QCD. With the “second charm revolution” happening right now with the discovery and establishment of unusual states called X, Y, Z in the charm mass region and similar states observed containing bottom quarks a new window for getting insights into the strong interaction has opened up. Searches for similar phenomena are intensified in the light-mass region. Identifying and classifying hadronic molecules, tetra-quark states and gluonic excitations like hybrids and glueballs will ultimately lead to a better understanding of the different facets of the strong interaction. The current workshop was planned to review the experimental situation and theoretical efforts, methods and models available and pursued in future to give future guidance to experimentalists and theorists.

The main topics were:

- Charmonium-like sector at electron positron colliders (Belle, BaBar, BES)
- Charmonium-like sector at hadron machines (LHC)
- Heavy-light systems
- Light-quark spectroscopy
- Photoproduction experiments
- Heavy-quark baryons
- Light-quark baryons
- Lattice results
- Molecular states
- Four-quark states
- The heavy-light spectrum
- Effective field theories

SPEAKERS:

G. Bali (Univ. of Regensburg, Germany)
D. Bettoni (Univ. of Ferrara, Italy)
R. Cardinale (Univ. of Genova, Italy)
J. T. Castella (TU München, Germany)
A. Celentano (Univ. of Genova, Italy)
U. Meißner (Univ. of Bonn, Germany)
R. Mitchell (Indiana Univ., USA)
F. Nerling (Frankfurt Univ., Germany)
A. Palano (Univ. of Bari, Italy)
J. Pelaez (Univ. Complutense Madrid, Spain)

V. Credé (Florida State Univ., USA)
S. Dürr (Univ. of Wuppertal, Germany)
M. Fritsch (Univ. of Mainz, Germany)
B. Grube (TU München, Germany)
E. Guido (Univ. of Torino, Italy)
T. Johansson (Univ. of Uppsala, Sweden)
B. Kopf (RUB Bochum, Germany)
C. B. Lang (Univ. of Graz, Austria)
V. Mathieu (Indiana Univ., USA)
K. Peters (GSI, Germany)
A. Pilloni (Jefferson Lab., USA)
A. Pompili (Univ. of Bari, Italy)
A. Rebhan (TU Wien, Austria)
D. Roenchen (Univ. of Bonn, Germany)
J. Stevens (Jefferson Lab., USA)
A. Szczepaniak (Indiana Univ. USA)
C. Urbach (Univ. of Bonn, Germany)
U. Wiedner (RUB Bochum, Germany)

SCIENTIFIC REPORT:

Spectroscopy experiments were at the heart of physics in the past century. However, if we could really understand the strong interaction by QCD, hadron spectroscopy nowadays would be a dull rather than a challenging enterprise. In fact, the contrary seems to be the case: as the work has gone to deeper levels, the open problems have increased. Even the heavy-quark states that were thought to be well understood have continued to produce many surprises. In this context, the charm quark plays a special role in that its bound states are characterised by the transition between perturbative and non-perturbative QCD.

Interest in charmonium physics got a big boost again in 2003, when the Belle collaboration found an unexpected, surprisingly narrow state in the $J/\psi\ \pi^+\pi^-$ invariant mass spectrum, called X(3872). For this narrow state, the Belle collaboration suggested a JPC assignment of 1^{++}, recently confirmed by the LHCb collaboration. This state is hard to reconcile with a conventional charmonium state. Its position within 0.5 MeV of the DD threshold is remarkable, as well as the fact that the state decays into $J/\psi\ \pi^+\pi^-$ and $J/\psi\ \pi^+\pi^-\pi^0$ with similar rates. The proximity to a threshold makes it a potential candidate for a hadronic DD molecule. The study of this object is a challenge for both theoretical and experimental groups.

Furthermore, the B-factory experiments Belle and BaBar then observed several unusual states containing charm quarks, often referred to as X, Y, Z states in the charmonium mass region. One of these states was the Y(4260), decaying into $J/\psi\ \pi^+\pi^-$. Exploring exactly this region is the aim of the BESIII experiment in Beijing, where positrons and electrons collide with the appropriate energy. By tuning the energy at which electrons and positrons annihilate at the Collider to 4260 MeV, the BESIII Collaboration has been able to directly produce and collect large samples of Y(4260) decays. Since the exact nature of the Y(4260) is unclear, it was uncertain what would be found in its decays. In the spring of 2013, the BESIII Collaboration reported the appearance of an electrically charged particle in these decays – called the $Z_c(3900)$ – decaying to a charged pion (consisting of up and down quarks/antiquarks) and a neutral J/ψ (consisting of a charm quark and an anti-charm quark). Because of its decay to the J/ψ, the $Z_c(3900)$ particle must contain at least a charm quark and an anti-charm quark, a combination which has no electric charge. But since the $Z_c(3900)$ has electric charge, it must also contain additional quarks. Hence, the $Z_c(3900)$ must be an object containing at least 4 quarks. A new type of hadron was thus established. Some of the newly discovered states are suspected to be 4-quark states, some behave more like molecules, and some might have a hybrid character. In the baryon sector LHCb recently reported an exotic signal decaying to $J/\psi p$, which could be the sign of a pentaquark state. So it seems that after the so-called “November revolution” in 1974 that brought the discovery of the charm quark, additional unexpected features continue to appear in this mass region.

Results and Highlights

The workshop was very useful because it showed on the theoretical side that different approaches (e.g. lattice calculations and effective field theories) are necessary to help to classify the new experimental results. Although it became obvious that the experimental approaches utilizing different accelerators and beams are mandatory to get better insights into the emerging QCD picture. The participants appreciated to get a broad overview of new QCD phenomena and their possible QCD-based explanations.

It is obvious that we are dealing with completely unexpected particles composed of quarks and gluons, in most cases involving charm quarks. These particles have shown up in high-precision spectroscopy experiments of the newest generations. Also the analysis methods in hadron spectroscopy were refined in the past decades, allowing to extract more detailed and precise information e.g. on quantum numbers. An experimentally open question is, if similar phenomena as observed with charm quarks exist as well involving only light quarks. It became also clear that an antiproton spectroscopy experiment like PANDA that has fewer limitations than other running experiments will be extremely useful to understand the new QCD phenomena in hadron physics.

Theory has started to give more precise guidance to entangle the nature of the new particles. E.g. could the triangle singularities help to classify penta-quark-like structures or precise predictions of mass hierarchies and decay patterns lead to an identification and distinction of four-quark states, molecular states and hybrids. Concerning glueballs "stringy-approaches" start to show interesting results and insights.

3.3.2 NEW OBSERVABLES IN QUARKONIUM PRODUCTION (QUARKONIUM2016)

DATE: February 29 – March 4, 2016

ORGANIZERS:

T. Dahms (Excellence Cluster Universe - TUM, Munich, Germany)
E.G. Ferreiro (IGFAE, University of Santiago de Compostela, Spain)
J.P. Lansberg (IPN Orsay, Université Paris-Sud, CNRS/IN2P3, France)
C. Pisano (University of Antwerp, Belgium and University of Pavia, Italy)

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

The great originality of this workshop resided in its aim of gathering experts from the so-called "spin physics" and "heavy-ion" communities who are interested by novel quarkonium related observables at colliders and fixed-target experiments.

The main topics covered were:

- Quarkonium production in pp, pA and AA collisions: where do we stand?
- TMD factorisation and associated quarkonium production at the LHC
- Excited-quarkonium production in pA and AA collisions
- Quarkonium-pair production: when TMD meets QGP
- Experimental requirements for forthcoming measurements

SPEAKERS:

M. Anselmino (Torino Univ. and INFN, Italy)

F. Arleo (Laboratoire Leprince-Ringuet, France)

R. Arnaldi (Torino Univ. and INFN, Italy)

I. C. Arsene (Univ. of Oslo, Norway)

D. Boer (Van Swinderen Institute, Univ. of Groningen, Netherlands)

R. Boussarie (LPT Orsay, Paris Sud Univ. / CNRS, France)

M. Calderon (Univ. of California Davis, USA)

I. Cherednikov (Universiteit Antwerpen, Belgium)

T. Dahms (Excellence Cluster Universe - TUM, Germany)

C. L. da Silva (LANL, USA)

D. d'Enterria (CERN, Switzerland)

A. Mukherjee (IIT Bombay, India)

F. Murgia (INFN Cagliari, Italy)

P. Petreczky (BNL, USA)

C. Pisano (Univ. of Antwerp, Belgium and Univ. of Pavia, Italy)

S. Porteboeuf (LPC, Clermont-Ferrand, France)

D. Price (Univ. of Manchester, UK)

J. Qiu (BNL, USA)

P. Robbe (Laboratoire de l'Accélérateur Linéaire, France)

L. M. Massacrier (LAL & IPNO, Paris Sud Univ./IN2P3-CNRS, France)

J. Matoušek (Charles Univ., Prague, Czech republic and INFN Trieste, Italy)

F. Scarpa (IPN Orsay, Paris-Sud Univ., CNRS/IN2P3, France)

B. Ducloue (Univ. of Jyväskylä, Finland)

M. Á. Escobedo Espinosa (Inst. de Physique Théorique, CEA, France)

E. Ferreiro (Univ. of Santiago de Compostela, Spain)

P. Gossiaux (SUBATECH, Nantes, France)

C. Hadjidakis (IPN Orsay, Univ. Paris Sud/ IN2P3-CNRS, France)

J. Kamin (Univ. of Illinois at Chicago, USA)

V. Kartvelishvili (Lancaster Univ., UK)

T. Kasemets (Nikhef/VU, Netherlands)

D. Kikola (Warsaw Univ. of Technology, Poland)

I. Kratschmer (Austrian Academy of Sciences, Austria)

J.-P. Lansberg (IPN Orsay Paris Sud U./IN2P3-CNRS, France)

Y. Li (LAL, Paris Sud U./IN2P3-CNRS, France)

Z.-E. Meziani (Temple Univ., Philadelphia, USA)

E. Scomparin (Torino Univ. and INFN, Italy)

H. Shao (CERN, Switzerland)

D. Souza Covacich (Univ. of Bristol, UK)

P. Taels (Univ. of Antwerp, Belgium and CEA Saclay, France)

Z. Tang (Univ. of Science and Technology of China, China)

B. Trzeciak (Utrecht Univ., Netherlands)

A. Vairo (TU Munich, Germany)

K. Watanabe (Central China Normal Univ., China)

M. A. Winn (Physikalisches Inst. Univ. of Heidelberg, Germany)

K. Zhou (FIAS/ITP, Goethe, Univ. Frankfurt am Main, Germany)

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:

- NRQCD non-perturbative matrix elements fits: impact of the excited states
- Cold nuclear matter effects: initial vs. final state effects & ground vs. excited states
- Hot nuclear matter effects: initial vs. final state efforts & ground vs. excited states
- TMD factorisation: constraints on the final-state colour, evolution, QCD corrections
- Extraction of linearly polarised gluon in unpolarised proton at the LHC: the case of associated quarkonium production

- Experimental status of associated quarkonium production studies at the LHC, Tevatron and RHIC
- Experimental status: LHC, RHIC and fixed-target data
- Theoretical status: explaining fixed-target, RHIC and LHC data coherently (nuclear absorption, colour screening, energy loss phenomena, low x effects, recombination effects)
- Relating pA and AA observations
- Quarkonium pair production and Double parton scattering
- Double Parton Scattering in proton-nucleus and nucleus-nucleus collisions
- Prospects for Quarkonium pair production studies in heavy-ion collisions at the LHC
- LHC & RHIC prospects
- Existing fixed-target facilities (COMPASS, Fermilab)
- Proposed facilities (EIC, LHeC, AFTER@LHC)
- How to bridge the gap between heavy-ion and spin theoretical tools
- How to bridge the gap between heavy-ion and spin experimental studies
-

Results and Highlights

The workshop allowed us to gather senior researchers who contributed to the early experimental and theoretical studies with younger colleagues. It was a privileged moment for experts from Europe, the US and Asia to meet, exchange their know-how and discuss the progress of their most recent works.

Here is a non-exhaustive itemised list of answers obtained during the workshop:

- the production of two hard probes in nucleus-nucleus collisions exhibit a specific nuclear scaling; this should be checked experimentally even if it appears as obvious;
- quarkonium production in proton-proton collisions is not yet understood. We eagerly wait for NNLO computations in the CSM, NRQCD predictions based on the fragmentation approach, predictions at one loop in the TMD factorisation approach;
- isolated quarkonium production as well as quarkonium+charged particle correlations should be measured and MC based predictions should be made available;
- the use of the so-called pocket formula for DPS is to be used with care;
- low pT J/psi produced in peripheral nucleus-nucleus collisions are likely from photon-induced reactions; more work needs to be done on the theory side to understand the photon flux and how this production mechanism contributes to more central collisions; new observables needs to be looked at to confirm this hypothesis (chi(c) production, polarisation, lower energy, …);
- the unexpectedly large difference in 2S and 1S suppression suggests significant final-state effects also in cold nuclear matter. At the LHC, time scales are too short for absorption to take place, do comovers play a significant role?;
- updated predictions, including the pT dependence, for excited states charmonium production from regeneration models need to be made and each ingredient used should be explained; In particular such models should be able to reproduce both the PbPb and pPb behavior;
- the gluon Sivers effect remains to be observed and quarkonium production is a good candidate to do so.

A special issue in Few Body Systems (Springer) in 2017 will be published on the topic of the workshop with contributions from the participants as well as contributions from colleagues who could not attend the meeting.

3.3.3 DETERMINATION OF THE ABSOLUTE ELECTRON (ANTI)-NEUTRINO MASS

DATE: April 4 - 8, 2016

ORGANIZERS:

L. Gastaldo (Kirchhoff Institute for Physics, Heidelberg University, Germany)
K. Valerius (Institute for Nuclear Physics, KIT, Germany)

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

The mass scale of neutrinos is one of the fundamental open questions in modern physics, with far-reaching implications from cosmology to particle physics. Precision measurements of the kinematics of weak interactions, notably of the ^{3}H β-decay spectrum and the ^{163}Ho electron capture spectrum, represent the only model independent approach to address this question in a laboratory experiment.

The next milestone is to reach sub-eV sensitivity with respect to the electron (anti-)neutrino mass. This goal can only be achieved by bringing together expertise from different fields such as nuclear and particle physics, atomic and molecular physics, theory and phenomenology.

The objective of this workshop was to foster the discussion between theorists and experimentalists involved in the different projects at a time when large experiments are approaching the starting phase. The workshop also addressed prospects of extending the physics reach of current and next-generation experiments beyond the quest for neutrino masses by probing for the existence of light and medium-mass sterile neutrinos or even attempting detection of relic neutrinos.

The main topics were:

- Role of massive neutrinos in Theory and Cosmology
- Role of sterile neutrinos in Theory and Cosmology
- Cosmic Neutrino background
- Neutrino oscillations
- ^{3}H-based experiments
- ^{163}Ho -based experiments
- Modelling and interpretation of the measured ^{3}H and ^{163}Ho spectra
- Challenges related to the ^{3}H and ^{163}Ho source
- Challenges for detector and read-out systems
- Sensitivity of ^{3}H- and ^{163}Ho -based experiments to sterile neutrinos
- Identification and suppression of background sources

SPEAKERS:

B. Bornschein (Inst. of Technical Physics, Karlsruhe Inst. for Technology, Germany)

M. Croce (Los Alamos National Laboratory, USA)

A. De Rujula (Departamento de Física

B. La Roque (Univ. of California, Santa Barbara, California, USA)

T. Lasserre (Inst. sur la recherche des loins fondamentales de l'Univers, Saclay, FR)

C. Lunardini (Arizona State Univ., Tempe,

Teórica, Facultad de Ciencias, Madrid, Spain and CERN, Switzerland)
M. Drewes (Physik Department T70, Technische Universität München, Germany)

G. Drexlin (Karlsruhe Inst. of Technology, Inst.e for Nuclear Physics, Germany)

C. Duellmann (Johannes Gutenberg-Universität Mainz, Inst. für Kernchemie, Germany)

S. Eliseev (Max-Planck Inst. for Nuclear Physics, Heidelberg, Germany)

C. Enss (Kirchhoff Inst. for Physics, Heidelberg Univ., Germany)

A. Faessler (Inst. for Theor. Physics, Univ. of Tübingen, Germany)

E. Ferri (Milano-Bicocca Univ., Italy)
M. Fertl (CENPA, Univ. of Washington, Seattle, USA)

J. Formaggio (Department of Physics, Massachusetts Inst. of Technology, Boston, USA)

F. Fränkle (Karlsruhe Inst. of Technology, Inst.e for Nuclear Physics, Germany)

C. Giunti (INFN Torino, Italy)

F. Glück (IEKP/IKP, Karlsruhe Inst. for Technology, Germany)

S. Hannestad (Department of Physics and Astronomy, Aarhus, Denmark)

C. Hassel (Kirchhoff Inst. for Physics, Heidelberg Univ., Germany)

J. Hays-Wehle (INFN - Milano Bicocca / NIST, Bouler, Colorado, USA)

S. Kempf (Kirchhoff Inst. for Physics, Heidelberg Univ., Germany)

M. Lusignoli (La Sapienza Univ., Rome, Italy)
Arizona, USA)

S. Mertens (Karlsruhe Inst. of Technology, Inst.e for Nuclear Physics, Germany)

E. Myers (Florida State Univ., Tallahassee, Florida, USA)

D. Parno (CENPA, Univ. of Washington, Seattle, USA)

P. C.-O. Ranitzsch (Münster Univ., Inst. for Nuclear Physics, Germany)

W. Rodejohann (Max-Planck Inst. for Nuclear Physics, Heidelberg, Germany)

A. Saenz (Humboldt-Universität Berlin, Inst. für Physik, Berlin, Germany)

S. Scholl (Physics Inst., Univ. of Tübingen, Germany)

T. Schwetz (Karlsruhe Inst. of Technology, Inst.e for Nuclear Physics, Germany)

H. Seitz-Moskaliuk (Karlsruhe Inst. of Technology, Inst. of Experimental Nuclear Physics, Germany)

T. Thümmler (Karlsruhe Inst. of Technology, Inst. for Nuclear Physics, Germany)

M. Totzauer (Theory Department, Max-Planck-Inst. für Physik, Munich, Germany)

C. Tully (Department of Physics, Princeton Univ., USA)

C. Weinheimer (Münster Univ., Inst. for Nuclear Physics, Germany)

K. Wendt (Physics Inst., Johannes Gutenberg-Universität, Mainz, Germany)

Z. Xing (Inst. of High Energy Physics, Chinese Academy of Sciences, China)

SCIENTIFIC REPORT:

Neutrinos, and in particular their tiny but non-vanishing masses, play a key role in the continuously growing research field of astroparticle physics. A finite neutrino mass is of fundamental relevance for our understanding of the universe at its largest (cosmological) scales, as well as at subatomic scales for the notion of mass generation mechanisms of elementary particles. Therefore, the determination of the as yet unknown absolute neutrino masses ranks among the most pressing quests of current astroparticle physics research.

Several paths can be pursued to investigate the absolute neutrino masses. In particular, direct kinematical methods allow performing a model-independent measurement of the electron neutrino and antineutrino mass with high sensitivity and low systematic uncertainties. In the past this approach was mainly driven by the investigation of the ^3H beta spectrum, and such experiments obtained the at present best upper limit on the electron antineutrino mass of about 2 eV.

At the beginning of the 2000s the activities were dominated by the development of the KATRIN experiment together with the interesting, but at the moment not competitive, ^{187}Re experiments. Nowadays, new approaches are investigated to develop experiments to investigate the ^3H β-spectrum and a new large community is growing to develop experiments to determine the electron neutrino mass analyzing the ^{163}Ho electron capture spectrum with a sensitivity that can be compared to the one achievable with ^3H based experiments. The experiments designed to reach sub-eV sensitivity on the electron antineutrino mass using ^3H are: KATRIN, Project8, and PTOLEMY. The experiments designed to reach sub-eV sensitivity on the electron neutrino mass using ^{163}Ho are: ECHo, HOLMES, and NuMECS. To make these experiments possible, researchers from different fields need to join efforts. Typically, internal meetings serve the purpose of gathering the subgroups of each individual experiment, but to achieve a fruitful exchange between all the subgroups of the different experiments (e.g., at an international conference) is very hard.

The aim of this workshop was therefore to bring together theorists and experimentalists involved in the above-mentioned experiments to discuss recent advances in the fields of neutrino mass phenomenology and direct neutrino mass measurements. The workshop took place at a time when new approaches have been demonstrated to be successful and new experiments have been funded. Our intention was thus to further sustain this momentum by sharing both innovative experimental approaches and improved theoretical descriptions of the ^3H and ^{163}Ho spectra.

The one-week workshop program was arranged along the following topical building blocks:

- Introductory presentations providing an overview of the status of the field both on the theoretical and experimental side.
- Experimental progress: In-depth discussion of challenges to be met by experimentalists regarding specific aspects of source preparation, background suppression, detector optimization and analysis methods.
- Impact of theory on experiment: Highlights of recent progress in the description of basic theoretical foundations such as the spectral shapes in ^{163}Ho electron capture and ^3H β-decay.
- Impact of experiment on theory: Prospects of broadening the physics reach of current and next-generation experiments beyond the neutrino mass determination and thus enabling to probe a larger scope of emerging theoretical concepts and ideas (e.g., searches for light and medium-mass sterile neutrinos, for Lorentz invariance violation in the neutrino sector, for contributions of right-handed weak interactions, constraints on the cosmic relic neutrino background, etc.).

The main objective of the workshop, viz., to bring together international experts and junior researchers & students, was fully reached. By choosing the interactive format of a workshop over the more informative one of a conference we succeeded in fostering lively exchange on in-depth matters of the field, both experimental and theoretical in nature, and in strengthening existing collaborative links. We believe that, thanks to this workshop, many new contacts within our research community have been established. The large quantity of unanimously positive feedback the organizers received during and after the workshop supports us in this view.

Results and Highlights

The workshop was conceived to enhance the discussion among researchers interested in the absolute value of the electron (anti-)neutrino mass both from the side of the implications of finite neutrino masses in the standard particle model as well as in cosmology and from the side of developing very precise and technologically challenging experiments. In this respect we can say that the workshop was a very useful opportunity to bring together leading experts and junior researchers and students. This was very much appreciated by all participants. Members of the three collaborations involved in ^{3}H -based experiments, KATRIN, Project8, and PTOLEMY, and of the three collaborations involved in ^{163}Ho -based experiments, ECHo, HOLMES, and NuMECS, attended the workshop as well as a large number of theorists. Among the participants there were sixteen PhD students. This large fraction of students, invited with the aim of bringing them in contact to recognized experts in the field, was one key element of the workshop which was realized thanks to the institutions supporting the students' participation. For the first time, both the experimental challenges related to the ^{3}H - and ^{163}Ho -based experiments as well as the theoretical aspects related to the finite electron neutrino mass have been discussed during a single workshop. Many participants expressed their appreciation of this particularly focused agenda, which clearly distinguishes the programme of the ECT* event from other workshops, towards the organizers.

The total number of presentations was 43. Among these, thirteen were 40-minutes talks related to theoretical aspects both regarding the description of the experimental data and examining the implications of neutrino masses in particle physics and cosmology. Two 40-minutes talks were focused on the measurements of the energy available to the decay for ^{3}H and ^{163}Ho, a very important parameter which is at the basis of the experimental determination of the electron neutrino mass. One 40-minutes talk addressed the future of ^{3}H-based experiments. Twenty-seven shorter talks were dedicated to the challenges in various complementing aspects of the experiments and proved very useful in illuminating the different approaches used by the individual collaborations, for example for the production/purification/handling of the radioactive ^{3}H and ^{163}Ho sources or for identifying and reducing background sources. On Wednesday the second part of the morning was reserved for the poster session. Twelve posters presented by PhD students and young researchers were lining the walls of the ECT* Conference Room. From Wednesday to Friday the posters were accessible and turned out to be a source of copious enriching discussions also outside the poster session.

While a complete and detailed list of the numerous and extensive discussions which were generated by the different talks would be too lengthy, we would like to mention at least two topics which have received great attention: the theoretical models to describe the measured ^{3}H and ^{163}Ho spectra and the role of the experiments designed for the determination of the (anti-)neutrino mass for the investigation of both eV and keV sterile neutrinos.

3.3.4 PARTON TRANSVERSE MOMENTUM DISTRIBUTIONS AT LARGE X: A WINDOW INTO PARTON DYNAMICS IN NUCLEON STRUCTURE WITHIN QCD

DATE: April 11-15, 2016

ORGANIZERS:

A. Bacchetta (INFN and University of Pavia)
J.-P. Chen (Jefferson Lab)
H. Gao (Duke University)
Z.-E. Meziani (Temple University)
P. Souder (Syracuse University)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The workshop focused on theoretical and experimental issues related to 3D imaging of nucleon structure in momentum space. The goal was to explore the present theoretical and experimental status in regard to the extraction of the transverse momentum dependent (TMD) distributions as well as the impact of future measurements planned at different facilities, in particular measurements of semi-inclusive deep inelastic scattering planned at the Jefferson Lab 12 GeV upgrade using the Solenoidal Large Intensity Device (SoLID). The workshop focused on a combined approach to achieve pristine extraction of the TMDs given the present and expected progress on the theoretical side and planned experimental measurements worldwide. To this end the program included discussions on factorization, evolution, universality, hadronization issues and interpretation of extracted TMDs including lattice QCD and phenomenological models.

With the imminent start of the Jefferson Lab 12 GeV experiments in Hall A (SBS and SoLID), Hall B (CLAS12) and Hall C (HMS-SHMS) and current measurements a closer look at the projected impact of these measurements was explored. Polarized Drell-Yan measurements from COMPASS at CERN and polarized SeaQuest at Fermilab, as well as polarized and unpolarized fragmentation functions from e^+e^- colliders (BESIII, Belle and BABAR) were also considered as critical to provide the needed data to perform universality tests of TMDs, in particular the change of sign of the Sivers function extracted from SIDIS and that measured in Drell-Yan.

The main topics were:

- Recent Progress in TMDs, theory and experiments
- Orbital momentum
- Lattice QCD calculations of TMDs
- Phenomenology/Models of TMDs
- Future Experimental programs of TMDs and their impact

SPEAKERS:

M. Anselmino (INFN and University of Torino, Italy)

A. Bacchetta (INFN and University of Pavia, Italy

S. Liuti (University of Virginia, USA)

W. Lorenzon (University of Michigan, USA)

N. Makke (University and INFN Trieste, Italy)

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

M. Chiosso (University of Torino, Italy)

E. Cisbani (INFN Roma, Italy)

I. Cloet (Argonne National Lab, USA)

M. Contalbrigo (INFN Ferrara, Italy)

M. Engelhardt (New Mexico State University, USA)

G. Ferrera (University of Milano, Italy)

L. Gamberg (Penn State University, Berks, USA)

H. Gao (Duke University & Duke Kunshan University, USA and China)

S. Joosten (Temple University, USA)

G. Koutsou (The Cyprus Institute, Cyprus)

H.-B. Li (Institute of High Energy Physics, Beijing, China)

L. Montovani (University of Pavia, Italy)

P.J.G. Mulders (VU and Nikhef, Netherlands)

C. Pisano (University of Pavia, Italy)

J. Qiu (Brookhaven National Lab, USA)

M. Radici (University of Pavia, Italy)

T. C. Rogers (Old Dominion University, USA)

N. Sato (Jefferson Lab, USA)

M. Schlegel (University of Tübingen, Germany)

P. Schweitzer (University of Connecticut, USA)

J. Soffer (Temple University, USA and France)

P. Souder (University of Syracuse, USA)

X. Xiong (University of Pavia, Italy)

SCIENTIFIC REPORT:

The field of research within QCD of 3D imaging of nucleon structure in momentum space has been very prolific in the last ten years and TMDs are at the heart of it. Experimental and theoretical work has been progressing at a healthy pace and has proven to be a fertile ground of both understanding QCD as well as providing for a richer insight on nucleon structure and the dynamics of the basic constituents of the nucleon. Together with Generalized Parton Distributions (GPDs), which provide for a 2D spatial and 1D momentum imaging, a full and complementary picture of the structure of the nucleon can be developed. Both TMDs and GPDs are offsprings of mother functions known as Wigner distributions.

The workshop was a very important opportunity to sharpen the physics case that demands a new large acceptance detector capable of handling the required luminosity for the measurement of asymmetries in SIDIS with high statistical precision. SoLID is the device in question and its physics capabilities and science impact in the case of measurements of TMDs was explored in relation to the existing and planned measurements worldwide and gauged with the present theoretical progress in the field of TMDs.

The multidimensional aspect of these measurements requires high luminosity for mapping critical observables with sufficient precision to provide complete information on the dynamics of the confined constituents of the nucleon. This dynamics is determined by taking advantage of couplings between the spin of the nucleon, the spin of its constituents and their orbital motion.

The workshop provided a nice summary of existing and planned measurements that are needed for complementing the SoLID TMD planned measurements at Jefferson Lab, in particular concerning the tensor charge, an intrinsic property of the nucleon. The present status of the tensor charge determination was described and the impact of a SoLID SIDIS measurement scrutinized. For example, lattice QCD calculations of the tensor charge were discussed with an eye on future improvements of its determination through understanding and reducing the systematic errors of these comparisons, especially when the future extractions are achieved with minimal uncertainties.

Access to the orbital angular momentum of the constituents is yet another avenue of research where both GPDs and TMDs could contribute and thus was explored at this workshop. It has long been recognized that the mere existence of the Sivers asymmetry implies the existence of orbital angular momentum, however, how to relate the Sivers function to the GPD E, which enters in the determination of the Ji's sum rule is not fully resolved. Models have provided guidance on a possible relation but it is clear that a good starting point calls for the concept of generalized TMDs (GTMDs). The latter are Fourier transforms of Wigner distributions. Reconstructing GTMDs with the help of GPDs and TMDs would be a great achievement in the field and it would call for precision data in both SIDIS measurements, as well as exclusive measurements like deep virtual Compton scattering (DVCS).

Our understanding of QCD using nucleon structure as a testing ground is displayed through the need of verifying the universality relation between the Sivers/Boer-Mulders function extracted from SIDIS and the one determined in Drell-Yan experiments. This test embodies the importance of carrying extractions in SIDIS with a reliable knowledge of the fragmentation functions determined in e^+e^- collisions. The two processes are critical for confirming our understanding and predictive power of seemingly different processes in QCD.

The variety of scales where the SIDIS, Drell-Yan and e^+e^- measurements are performed call for an understanding of the scale dependence and evolution. TMDs evolution is important to comprehend in order to make sense of measurements taken in a wide variety of scales. The theoretical basis of TMDs evolution and its implementation was discussed intensely at this workshop due to its importance in the global analysis and extractions of TMDs from the experimental data.

Results and Highlights

One of the strong impacts of the workshop was an atmosphere that promoted serious but cautious discussions of the present theory issues and a path to clean extractions of physics observables from the data. The impact of the proposed science program, using SoLID, emerged stronger than ever.

In fact, from the theory side, work has been performed diligently to address issues of universality of TMDs, TMDs evolution and their implementation in global analyses of the data, the missing part presently being precision data. SoLID measurements combined with SBS, CLAS12, polarized Drell-Yan and BESIII measurements will provide data with the needed precision to have a serious impact on the 3D momentum imaging of the nucleon constituents, tests of factorization, universality and TMDs evolution. Discussions of the path to calculating TMDs rather than moments of TMDs (like the tensor charge) using lattice QCD appeared still to be in their infancy but perhaps in the next five years breakthroughs may be possible. Although not accepted by everyone, new ideas on how to access GTMDs through measurements were proposed, the jury being still out on whether a direct access to GTMDs is possible.

It was clear from the workshop's experimental presentations that the SoLID detector through its approved physics program of SIDIS measurements will be able to significantly contribute to our knowledge of nucleon structure. This detector was highlighted in the long-range plan of nuclear physics in the US consistent with the excitement expressed in this workshop. It was also clear that one of the outcomes of this workshop is the need to keep a global perspective that will require increased precision in the combined measurements of polarized Drell-Yan, hadron production in e^+e^- and SIDIS for carrying the major objectives of the science program described in this workshop, namely testing factorization, TMDs evolution and universality before heading towards understanding the role of orbital angular momentum and providing for 3D momentum images of the nucleon constituents.

3.3.5 PROBING TRANSVERSE NUCLEON STRUCTURE AT HIGH MOMENTUM TRANSFER

DATE: April 18 - 22, 2016

ORGANIZERS:

E. Cisbani (INFN Rome, Italy)
I. Cloët (Argonne National Laboratory, USA)
D. Hamilton (University of Glasgow, UK)
S. Riordan (Stony Brook University, USA)
B. Wojtsekhowski (Jefferson Lab, USA)

NUMBER OF PARTICIPANTS: 34

MAIN TOPICS:

The main theme discussed in the workshop was the dynamics of strongly correlated systems. Particular attention was focused on the techniques used to extract information about the real-time dynamics from Euclidean-time correlations. This is of paramount interest for researchers in the cold atom physics, nuclear structure and nuclear astrophysics, neutrino physics and quark-gluon plasma communities.

Alternative approaches, such as real-time dependent methods have also been extensively discussed, in view of their interplay with "standard" imaginary-time techniques.

SPEAKERS:

J. Annand (University of Glasgow, UK)

E. Cisbani (INFN Rome, Italy)

I. Cloët (Argonne National Laboratory, USA)

V. Druzhinin (Novosibirsk State University/BINP, Russia)

G. Eichmann (University of Giessen, Germany)

G. Franklin (Carnegie Mellon University, USA)

G. Gilfoyle (University of Richmond, USA)

D. Hamilton (University of Glasgow, UK)

D. Keller (University of Virginia, USA)

N. Kivel (Johannes Gutenberg-Universität, Germany)

M. Kohl (Hampton University, USA)

P. Kroll (Universität Wuppertal, Germany)

K. Kumericki (University of Zagreb, Croatia)

C. Mezrag (Argonne National Laboratory, USA)

G. Miller (University of Washington, USA)

C. Morales (Helmholtz-Institut Mainz, Germany)

S. Pacetti (University of Perugia, Italy)

A. Puckett (University of Connecticut, USA)

S. Riordan (Stony Brook University, USA)

G. Salmè (Sapienza University of Rome/INFN Rome, Italy)

B. Sawatzky (Jefferson Lab, USA)

S. Syritsyn (Jefferson Lab, USA)

B. Wojtsekhowski (Jefferson Lab, USA)

R. Young (University of Adelaide, Australia)

I. Zimmermann (Helmholtz-Institute Mainz, Germany)

SCIENTIFIC REPORT:

Recent experimental measurements using electron- and photon-nucleon elastic scattering - the simplest exclusive processes - are revealing reaction mechanisms much more subtle than previously or naively assumed. For example, the two-photon exchange contribution appears to be essential for a robust description of electron-nucleon scattering at large momentum transfers and recent wide-angle Compton Scattering (WACS) results clearly confirm that non-perturbative effects are still dominant at the large (relative to Λ_{QCD}) Mandelstam variables explored so far. Moreover, recent Jefferson Lab data at relatively high momentum transfer has, for the first time, made possible a quark flavor decomposition of the nucleon elastic electromagnetic form factors in the space-like region, where the emerging theoretical framework hints at possible diquark correlations inside the nucleon. These efforts complement the significant experimental and theoretical progress that is beginning to provide insights into the multidimensional partonic structure of the nucleon.

In this exciting context, perturbative QCD has proven successful at describing certain reaction observables, however at current momentum transfers it is still unable to predict elastic scattering data. This may change however, with the forthcoming Jefferson Lab experiments at larger momentum transfers, which may observe the predicted transition to the perturbative scaling regime. New approaches based on the Dyson-Schwinger and Faddeev equations appear successful at describing form factors at high momentum transfer and are a promising tool with which to study WACS. The recent soft collinear effective theory, with the introduction of a new universal form factor, may also help develop a better understanding of WACS processes. Lattice QCD and Nambu-Jona-Lasinio effective theory offer further insights into the flavor dependence of these observables. The relationship between WACS form factors and elastic form factors, which can be explored using the DSE approach, are key issues in understanding the complementarity of the two processes and for the extraction of information on the transverse structure of the nucleon.

The needs of the hadron physics community in terms of theoretical approaches and experimental data to better understand, e.g., nucleon structure, nucleon form factors, exclusive electron and photon elastic scattering process and the underlying quark-gluon structure, must be explored.

Results and Highlights

Recent experimental measurements using electron- and photon-nucleon elastic scattering - the simplest exclusive processes - are revealing reaction mechanisms much more subtle than previously or naively assumed. For example, the two-photon exchange contribution appears to be essential for a robust description of electron-nucleon scattering at large momentum transfers and recent wide-angle Compton Scattering (WACS) results clearly confirm that non-perturbative effects are still dominant at the large (relative to ?QCD) Mandelstam variables so far explored. Moreover, recent Jefferson Lab data at relatively high momentum transfer has, for the first time, made possible a quark flavor decomposition of the nucleon elastic electromagnetic form factors in the space-like region, where the emerging theoretical framework hints at possible diquark correlations inside the nucleon. These efforts complement the significant experimental and theoretical progress that is beginning to provide insights into the multidimensional partonic structure of the nucleon.

In this exciting context, perturbative QCD has proven successful at describing certain reaction observables, however at current momentum transfers it is still unable to predict elastic scattering data. This may change, however, with the forthcoming Jefferson Lab experiments at larger momentum transfers, which may observe the predicted transition to the perturbative scaling regime. New approaches based on the Dyson-Schwinger and Faddeev equations appear successful at describing form factors at high momentum transfer and are a promising tool with which to study WACS. The recent soft collinear effective theory, with the introduction of a new universal form factor, may also help develop a better understanding of WACS processes. Lattice QCD and Nambu-Jona-Lasinio effective theory offer further insights into the flavor dependence of these observables. The relationship between WACS form factors and elastic form factors, which can be explored using the DSE approach, are key issues in understanding the complementarity of the two processes and for the extraction of information on the transverse structure of the nucleon.

The needs of the hadron physics community in terms of theoretical approaches and experimental data to better understand, e.g., nucleon structure, nucleon form factors, exclusive electron and photon elastic scattering process and the underlying quark-gluon structure, must be explored.

3.3.6 ADVANCES IN TRANSPORT AND RESPONSE PROPERTIES OF STRONGLY INTERACTING SYSTEMS

DATE: May 02 - 06, 2016

ORGANIZERS:

Y. Burnier (EPFL, Switzerland)
J. W. Holt (Texas A&M and Univ. of Washington, USA)
A. Lovato (ANL, USA)
A. Roggero (INT and Univ. of Washington, USA)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The focus of the workshop was nucleon structure, in particular, those aspects that can be measured using elastic scattering and wide angle Compton scattering (WACS). The forthcoming Jefferson Lab 12 GeV program was explored in detail, with special attention paid to the utility of the Super BigBite Spectrometer in Hall A. Key Jefferson Lab experiments were discussed as well as advances in theory, particularly from the Dyson-Schwinger equations, lattice QCD and soft collinear theory.

The main topics included:

- nucleon electromagnetic form factors
- time-like form factors
- wide-angle Compton scattering
- form factor experiments
- form factor interpretation
- Dyson-Schwinger equations
- Lattice QCD
- soft-collinear effective theory

SPEAKERS:

G. Aarts (Swansea University, UK)

C. Allton (Swansea University, UK)

M. Barabanov (JINR, Russia)

O. Benhar (INFN/Sapienza University, Italy)

G. Bertaina (Univ. of Milan, Italy)

Y. Burnier (EPFL, Switzerland)

G. Carleo (ETH Zurich, Institute for Theoretical Physics, Switzerland)

F. Ferrari (ULB, Belgium)

A. Gezerlis (Univ. of Guelph, Canada)

P. Gubler (ECT*, Italy)

A. Mecca (INFN Roma, Italy)

C. Mezrag (Argonne National Laboratory, USA)

H. Meyer (Mainz University, Germany)

H. Ohno (Center for Computational Sciences, University of Tsukuba, Japan)

G. Orlandini (Univ. of Trento, Italy)

A. Pastore (Univ. of York, UK)

F. Pederiva (Univ. of Trento, Italy)

A. Rios (Univ. of Surrey, UK)

L. Riz (Univ. of Trento, Italy)

R. Rota (Université Paris Diderot - Paris 7,

T. Harris (Helmholtz Institute Mainz, Germany)

C. Ji (ECT*/INFN-TIFPA, Italy)

O. Kaczmarek (Univ. of Bielefeld, Germany)

M. Laine (ITP - Univ. of Bern, Switzerland)

M. P. Lombardo (INFN Frascati, Italy)

A. Lovato (ANL, USA)

P. Magierski (Warsaw University of Technology, Poland)

A. Mecca (INFN Roma, Italy)

France)

A. Rothkopf (ITP - Heidelberg University, Germany)

S. Serafini (Univ. of Trento and INO-CNR BEC Center, Italy)

R. A. Tripolt (ECT*, Italy)

J. Weber (TU Munich, Germany)

G. Wlazlowski (Warsaw University of Technology, Poland)

R. Zillich (JKU Linz, Austria)

SCIENTIFIC REPORT:

A number of intriguing physics phenomena, ranging from the X-ray bursts in accreting binary systems to the neutrino scattering off nuclei and stellar matter, to the fate of the quark-gluon plasma, are intrinsically related to the dynamics of strongly correlated systems.

The steadily increasing availability of High Performance Computing, together with improvements in numerical algorithms, has enabled a microscopic description of the ground-state properties of many-body nuclear and atomic systems. At the same time, lattice QCD calculations are getting closer and closer to the physical pion mass while bigger and more refined lattices are progressively easier to manage.

An equally quantitative description of the dynamical properties of strongly coupled systems, earlier only accessible to more approximate mean-field schemes, appears now to be within reach. The main difficulty implied in this endeavor, shared by all projection Monte Carlo techniques, is extracting dynamical information from the Euclidean-time correlators, which is an active area of research in the fields of cold-atoms physics, nuclear structure and nuclear astrophysics, neutrino physics and quark-gluon plasma physics.

At the same time, fully time-dependent methods are required to study phenomena where the linear response theory is not applicable. Among those, time-dependent density functional theory, time-dependent variational Monte Carlo and time-dependent Hypernetted-Chain Euler-Lagrange methods play a prominent role. The latter especially are able to encompass the correlations of the strongly interacting system.

The multiple themes relevant for the dynamics of strongly correlated systems addressed in the workshop can be summarized as follows:

- What potential problems may arise from the "maximum entropy" technique, which is de facto the standard method used in Lattice QCD to extract information from Euclidean-time correlators? In particular, is the so-called "Bryan method" accurate enough to capture all the relevant physics of the problem?
- In condensed matter physics, alternative methods, such as "GIFT", are employed. In nuclear physics, on the other hand, the Lorentz kernel, which is better behaved than the Laplace kernel, has proven to be successful. Are these viable approaches for Lattice QCD problems?
- Integral-transform techniques are not the sole method used to obtain the response of strongly correlated systems. Many-body approaches, such as the correlated basis function theory, the Functional Renormalization Group, and real-time techniques, such as time-dependent Hartree-Fock and time-dependent variational Monte Carlo are valid alternatives. Is there a possible interplay with Euclidean-time methods?

In addition to these main themes, there were a number of other subjects covered in the workshop, represented by one or a few speakers each, including: Chen Ji: "Two-photon exchange contributions to muonic atoms" and Angela Mecca: "Transport properties of the Fermi hard-sphere system".

Results and Highlights

The workshop proved to be a useful arena for bringing together researchers of different fields, all actively working on the dynamics of strongly correlated quantum many-body systems. The workshop allowed for the discussion of both recent developments in computational techniques as well as new physics results. The speakers made a real effort in presenting their methods and results to the broad audience and many exchanges occurred between the different fields. The participants could not only learn about different physics questions, but also profit from other ideas and approaches to attack the numerical analytic continuation.

Within the maximum entropy technique, a potential flaw in the Bryan algorithm was extensively discussed. Notwithstanding the fact that in cases where the spectrum does not present multiple peaks Bryan's algorithm suffices, it is fair to say that for more complicated cases more advanced methods have to be considered. Other alternative non-Bayesian methods were also put forward. They could on one side complement and check the usual approaches, but also be used to improve the precision of the data, using the analyticity constraints.

Real-time variational Monte Carlo and time-dependent Hypernetted-Chain Euler-Lagrange techniques have acquired a degree of accuracy that allows for a fruitful interplay with the standard imaginary-time projection techniques. These methods shift the problem from the inversion of the Laplace transform to devising an accurate wave function for the excited states of the system. Somewhat along the same lines, a pioneering investigation of complex-time correlations for the study of the ground-state dynamic structure function has been presented.

For the description of the quark-gluon plasma, the Euclidean data generated in lattice QCD is less precise than in other fields and the physical results obtained by numerical analytic continuation can be strongly method dependent. With these caveats in mind, promising results were shown for the extraction of the transport coefficients of the quark-gluon plasma, such as its electric conductivity, the heavy quark diffusion and photon production. The properties of the quarkonium bound states embedded in the quark-gluon plasma were also extensively discussed, within different approaches, and a path towards resolving former discrepancies was drawn.

Significant advances in real-time dynamical simulations of nuclear systems and trapped cold atoms were reported in the framework of the superfluid local density approximation. In particular, the first dynamical simulations of the vortex-nucleus interaction, relevant for the physics of neutron star inner crusts, revealed a repulsive interaction that would give rise to anti-pinning in the density regime studied. Dynamical simulations of quantum turbulence through vortex breaking and recombination were studied for cold Fermi gases, and a comparison to recent experiments with oscillating vortex rings was presented.

3.3.7 EQUATIONS OF STATE IN QUANTUM MANY-BODY SYSTEMS

DATE: May 30 - June 01, 2016

ORGANIZERS:

S. Giorgini (BEC Center and University of Trento)
M. Holzmann (Université Grenoble)
F. Pederiva (University of Trento)
G. Roati (INO-CNR and LENS Florence)

NUMBER OF PARTICIPANTS: 50

MAIN TOPICS:

The workshop aimed to bring together researchers actively involved in the investigation of the equation of state in a variety of quantum many-body systems ranging from ultra-cold atoms, nuclear matter and high-pressure hydrogen. The goal of this interdisciplinary initiative was to focus on common threads and methodologies, both at the experimental and theoretical level, and to allow for a fruitful exchange of ideas and perspectives.

The main topics were:

- Cold atoms: Fermions, Bosons and mixtures
- QCD matter
- Neutron matter and neutron stars
- Magnetic properties of ultracold gases
- High pressure hydrogen
- Quantum Monte Carlo methods

SPEAKERS:

D. Ceperley (Univ. of Illinois, Urbana, USA)

A. Drago (Univ. of Ferrara, Italy)

L. Fabbietti (TU München, Germany)

G. Ferrari (CNR-INO BEC Center, Trento, Italy)

S. Gandolfi (Los Alamos Nat. Lab., USA)

C. Hofrichter (LMU, München, Germany)

S. Jochim (Univ. of Heidelberg, Germany)

M. Knudson (Washington State Univ., Pullman, USA)

B. Militzer (Univ. of California, Berkeley, USA)

C. Pierleoni (Univ. of L'Aquila, Italy)

A. Polls (Univ. of Barcelona, Spain)

L. Pricoupenko (Univ. Pierre et Marie Curie,

G. Prodi (Univ. of Trento, Italy)

N. Prokof'ev (Univ. of Massachusetts, Amherst, USA)

G. Pupillo (Univ. of Strasbourg, France)

C. Salomon (Ecole Normale Supérieure, Paris, France)

L. Sanchez-Palencia (Institut d'Optique, Paris, France)

K. Schmidt (Arizona State Univ., Tempe, USA)

S. Sorella (SISSA, Trieste, Italy)

J. Struck (MIT, Cambridge, USA)

J. Wambach (ECT*, Trento, Italy)

M. Zaccanti (CNR-INO & LENS, Firenze, Italy)

Paris, France)

SCIENTIFIC REPORT:

The study of the equation of state is a central topic in many different fields of physics. In particular, in quantum many-body physics many important features related to interactions and to the quantum nature of the system leave their signatures in the equation of state, which becomes a fundamental tool for both the experimental and the theoretical investigation.

In ultracold gases, the analysis of the equation of state has revealed fundamental properties of the superfluid transition, both for bosons and for interacting fermions, with special characteristics related to the spatial dimensionality. For bosons on a lattice, the superfluid to Mott-insulator transition is signalled by the compressibility of the gas and can be extracted from the equation of state. In Fermi superfluids, the crossover from the BCS to the BEC regime can be observed by measuring how the energy changes around the magnetic Feshbach resonance of the scattering amplitude. Also important information about Bose-Fermi superfluid mixtures and repulsive Fermi mixtures close to a ferromagnetic instability can be obtained from the study of the equation of state.

In astrophysics and in particular in neutron stars physics, the equation of state plays a crucial role. It determines completely the inner structure of the star and therefore its full behaviour as an astronomical object. A great challenge for theorists is to predict the equation of state from ab initio calculations of nuclear matter under extreme conditions of pressure using realistic model of inter-nuclear interactions. An equivalently challenging task for experimentalists is to understand which features of the equation of state of neutron stars can be inferred from experiments carried out on Earth and how one can test the validity of different theoretical models.

The same scenario also applies to the study of giant planets whose internal structure is essentially determined by the behaviour of hydrogen at very large pressures. Interesting questions arise having to do with the metallic or non-metallic behaviour of solid hydrogen and also with the possible superfluid nature of the liquid phase. In this case numerical simulations, in particular utilizing quantum Monte-Carlo methods, represent an essential theoretical tool whereas, on the experimental side, experiments can be carried out in laboratories by producing extremely high compressions both static and dynamic.

In this workshop we have brought together active and distinguished researchers from the field of ultracold atoms, neutron stars and nuclear matter and high-pressure hydrogen to discuss various aspects of the equation of state of these quantum many-body systems, emphasizing analogies and peculiarities between them. What potential problems may arise from the "maximum entropy" technique, which is de facto the standard method used in Lattice QCD to extract information from Euclidean-time correlators? In particular, is the so-called "Bryan method" accurate enough to capture all the relevant physics of the problem?

Results and Highlights

The main result of the workshop has been the shared knowledge of the similarities and common scientific threads of the three areas of research. In particular, the existence of a well-established theoretical tool capable to address the difficult questions raised by strong interactions and quantum behaviour in these three fields of physics. The tool is represented by quantum Monte-Carlo methods, both in the path-integral and in the variational and diffusion versions. Advances and further developments of the method would be of great benefit for the progress in each of these fields.

Particularly appreciated has been the contribution by C. Salomon on the first realization of superfluid mixtures of bosons and fermions where, in addition, the Fermi superfluid is strongly interacting due to the resonant coupling produced by a Feshbach resonance. In the same area of ultracold atoms, the seminar by M. Zaccanti has revealed the interesting prospects of observing clear signatures of itinerant ferromagnetism in a repulsive Fermi-Fermi mixture. The talk by L. Fabbietti provided instead a very clear and fascinating overview of all the possible experiments realized on the Earth's surface to detect structural features of neutron stars and what constraints they pose on the theoretical description of these astronomical objects. Finally, D. Ceperley gave a thorough and detailed overview of the various computational techniques available in the study of dense hydrogen and of their possible future developments.

3.3.8 TOWARDS CONSISTENT APPROACHES FOR NUCLEAR STRUCTURE AND REACTIONS

DATE: June 06-10, 2016

ORGANIZERS:

C. Bertulani (Texas A&M University-Commerce, USA)
G. Blanchon (CEA, DAM, DIF, France)
G. Potel (Lawrence Livermore National Laboratory, USA)
V. Somà (CEA Saclay, France)

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

Low-energy nuclear reactions are arguably the tool of choice to gain experimental insight on nuclear structure up to a few tens of MeV of excitation energy. The relationship between structure and reaction observables is nonetheless not so straightforward. On the one hand, several theoretical nuclear structure schemes are extending their reach to scattering observables and reaction theory for low-energy reactions. On the other, reaction practitioners are facing the challenge of reducing the model dependence and thus increasing their predictive power. This workshop has promoted cross-talks between these communities with the long-term aim of developing consistent approaches to structure and reactions. Special emphasis has been given to optical potentials derived with different degrees of phenomenology (ab initio, from effective interactions, data-driven) and to the necessity of working towards reaction cross sections devoid of model dependent quantities.

The main topics discussed in this workshop were:

- Strategies to systematically reduce the model dependence in cross section calculations
- Analysis of the status of microscopic optical potentials, with emphasis on advances in ab initio and effective interaction approaches
- Common bases for comparing data-driven, microscopic (from effective interactions) and ab initio optical potentials
- Possible feedback for structure models from reactions applications
- Viable strategies for introducing reaction constraints in the quest for effective interactions
- Analysis the endeavors of the ab initio nuclear structure community towards reaction calculations and the new paths opened by the availability of chiral and low-momentum interactions
- Address computational advances and challenges of the different approaches

SPEAKERS:

H. Arellano (Department of Physics, U Chile-FCFM, Chile)

C. Barbieri (University of Surrey, UK)

F. Barranco (Sevilla University, Spain)

A. Bonaccorso (INFN Pisa, Italy)

R. Broglia (Milano University, Italy and Niels

A. Idini (University of Surrey, UK)

M. Kohno (Research Center for Nuclear Physics, Osaka, Japan)

V. Lapoux (CEA Saclay, France)

J. Lay Valera (INFN Padova, Italy)

D. Lee (North Carolina State University, Bohr Institute, Denmark)

A. Bulgac (University of Washington, USA)

H. Crawford (Lawrence Berkeley National Laboratory, USA)

A. Deltuva (Vilnius University, Lithuania)

A. Diaz-Torres (ECT*, Italy)

V. Durant (TU Darmstadt, Germany)

Ch. Elster (Ohio University, USA)

T. Furumoto (Yokohama National University, Japan)

A. Gillibert (CEA Saclay, France)

J. W. Holt (University of Washington, USA)

G. Hupin (CEA, DAM, DIF, France)

USA)

B. Morillon (CEA, DAM, DIF, France)

T. Nakatsukasa (University of Tsukuba, Japan)

J. Rotureau (Michigan State University, USA)

C. Qi (Royal Institute of Technology, Sweden)

J. Tostevin (University of Surrey, UK)

E. Vigezzi (INFN Milano, Italy)

M. Vorabbi (University of Pavia, Italy)

F. Xu (Peking University, China)

S.-G. Zhou (Chinese Academy of Sciences, China)

SCIENTIFIC REPORT:

Much of the renewed interest in low-energy nuclear physics revolves around the extension of our knowledge towards neutron-rich, exotic nuclei. Experimentally, the steady availability of beams of unstable isotopes is providing information on previously unexplored regions of the nuclear chart.

These new data, which in certain cases defy the standard interpretation (e.g. with the appearance of new magic numbers), have critically challenged and triggered revisions/extensions of the various theoretical approaches to nuclear structure. In particular, considerable focus has moved towards internal consistency, predictive power and thorough estimation of theoretical uncertainties. This is in line with the increased popularity of ab initio calculations, which aim at connecting nuclear structure properties directly with the underlying interactions between nucleons. Structure theories that start from effective interactions, like energy density functionals (EDFs), are also undergoing a re-examination, introducing issues like error quantification, predictability and connection to ab-initio theories into the picture.

Nevertheless, this critical process has been less evident for the theoretical description of nuclear reactions. The extension of reaction models to neutron-rich nuclei is still largely based on phenomenology (biased towards stable nuclei). Most notably, a unified treatment of structure and reaction is often - if not always - approximate or missing. Lately we are witnessing a boost of interest in nuclear reactions, the fundaments of their theoretical description, the extraction of structure information and the importance of pursuing consistent schemes when doing so. This attention is largely motivated by the fact that state-of-the-art approaches are now ready to undertake the first concrete steps towards developing a common framework for structure and reaction.

Over the last decades nuclear ab initio approaches have undergone tremendous progress in computing structure observables and are progressively being extended to study reactions. While for light systems a good number of applications have appeared, reaction calculations in medium-mass nuclei are still very limited. A means of connecting reaction observables to the underlying nucleonic interactions is represented by optical potentials. Nuclear matter models can provide such connections, although existing schemes typically rely on a folding with an ad hoc matter density. Work towards a more consistent treatment is in progress and projects aiming at deriving optical potentials from a full-edged ab initio perspective have been announced.

Results and Highlights

The workshop provided an opportunity to confront and discuss complementary theoretical approaches to the study of low-energy structure and reactions, as well as to acknowledge the status of relatively recent lines of research, such as ab initio reaction theory. There were also very interesting experimental talks where the need for a consistent treatment of theory and reactions was explicitly stressed. It was showed how the simultaneous consideration of a complete set of experiments (elastic scattering + one-neutron transfer + two neutrons transfer) could shed light on the interplay between structure and reaction aspects. Within this context, it was also pointed out how different experiments seemed to lead to conflicting conclusions regarding the structure of the nuclei involved, calling for a revision of the theoretical description of both the structure and the reaction aspects of such experiments.

From the ab initio point of view, recent developments in few-body systems were presented, making use of different approaches: No-core shell model + RGM (Resonating Group Method), Faddeev equations, and EFT (Effective Field Theory) on the lattice. These approaches are restricted to a small number of nucleons (up to about 5-8), but all of them provide scattering observables obtained from fundamental nucleon-nucleon interactions in excellent agreement with experimental findings. For larger systems, ab initio efforts based on state-of-the art EFT nucleon-nucleon interactions were essentially devoted to the computation of optical potentials. It was particularly interesting to see how a variety of different approaches (coupled cluster, self-consistent Green's functions, local density approximation, t-matrix in the impulse approximation, folding and double folding models) provided very promising microscopic optical potentials. It was argued that time seems ripe for the inclusion of such optical potentials in more standard reaction theory formalisms, albeit overcoming technical issues such as non-locality.

NFT (Nuclear Field Theory) was presented as a complementary approach to ab initio. It was shown that, by empirically renormalizing its building blocks (single-particle levels, surface and gauge phonons), it was able to give a consistent and complete description of a variety of observables (parity inversion, one- and two-nucleon transfer cross sections, splitting of single-particle states, decay rates…) in stable as well as in exotic halo nuclei. An extension of its reach to scattering states has been proposed, and should be on its way.

Very interesting results were also presented in the context of time-dependent approaches (notably fission within a time-dependent energy functional theory), and the role of dynamic and static core excitations in scattering observables.

During the whole workshop, many healthy discussions arose, confronting microscopic or ab-initio approaches with more phenomenological ones. While the latter showed how a complete and consistent description of nuclei could be achieved in terms of few elementary modes of excitation, the former presented impressive progress in the microscopic evaluation of such building blocks. Perhaps most importantly, both presented decided efforts and big progress towards tackling structure and reactions under consistent formalism.

3.3.9 THE PROTON RADIUS PUZZLE

DATE: July 19 – 22, 2016

ORGANIZERS:

R. Gilman (Rutgers University, New Brunswick, NJ, USA)
G. A. Miller (University of Washington, Seattle, WA, USA)
R. Pohl (Max-Planck-Institute of Quantum Optics, Garching, Germany)

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

This workshop is the 2nd workshop on the "proton radius puzzle", i.e. the 7 standard deviations discrepancy between the proton radius from muonic hydrogen on the one hand, and the world averages of hydrogen spectroscopy and elastic electron scattering on the other. Experts from all relevant communities were present, and new projects presented in the 1st workshop in 2012 yielded first results.

The main topics were:

- New results from muonic deuterium and muonic helium
- A new measurement from atomic hydrogen
- A first glance on new electron scattering measurements at very low Q2
- Analysis of electron scattering data
- Polarizability of the proton, deuteron and helium nuclei
- Theory of muonic hydrogen energy levels
- Physics beyond the Standard Model
- New projects:
  i) Proton radius and Rydberg constant from hydrogen and H-like ions
  ii) Electron scattering at very-low Q2, new polarization transfer and structure function measurements
  iii) Elastic muon-proton scattering

Again, the workshop featured very lively discussions and produced many new insights.

SPEAKERS:

J. Bernauer (MIT, Cambridge, USA)

M. Birse (University of Manchester, UK)

E. Borie (KIT, Karlsruhe, Germany)

W. Briscoe (George Washington University, USA)

C. Carlson (College of William&Mary, Williamsburg, USA)

E. Cline (Rutgers University, New Brunswick, NJ, USA)

C. Collicott (George Washington University, USA, and Johannes Gutenberg Universität,

S. G. Karshenboim (MPQ, Garching, Germany and Pulkovo Observatory, Russia)

M. Kohl (Hampton University, Hampton, USA)

T. Kohlert (Max-Planck-Institute of Quantum Optics, Garching, Germany)

J. Krauth (Max-Planck-Institute of Quantum Optics, Garching, Germany)

B. Krusche (University of Basel, Switzerland)

I. Lavrukhin (George Washington University, USA)

Germany)

M. Dalton (Jefferson Lab, USA)

K. de Jager (University of Virginia, USA)

M. Diepold (Max-Planck-Institute of Quantum Optics, Garching, Germany)

E. Downie (George Washington University, USA)

J. Dreiling (National Institute of Standards and Technology, USA)

L. Dreissen (LaserLaB Amsterdam, Netherlands)

B. Duran (Temple University, USA)

M. Eides (University of Kentucky, Lexington, USA)

K. Eikema (LaserLaB Amsterdam, Netherlands)

A. Gasparian (NC A&T State University, North Carolina, USA)

R. Gilman (Rutgers University, New Jersey, USA)

F. Hagelstein (Johannes-Gutenberg Universität, Mainz, Germany)

E. Hessels (York University, Toronto, Canada)

D. Higinbotham (Jefferson Lab, USA)

M. Horbatsch (York University, Toronto, Canada)

C. Ji (ECT* Trento, Italy)

L. Maisenbacher (Max-Planck-Institute of Quantum Optics, Garching, Germany)

M. Mihovilovic (Johannes-Gutenberg Universität, Mainz, Germany)

J. McGovern (University of Manchester, UK)

G. A. Miller (University of Washington, Washington, USA)

K. Pachucki (University of Warsaw, Poland)

V. Pascalutsa (Johannes-Gutenberg Universität, Mainz, Germany)

G. Paz (Wayne State University, Detroit, USA)

A. Pineda (Universitat Autonoma de Barcelona, Spain)

R. Pohl (Max-Planck-Institute of Quantum Optics, Garching, Germany)

J. Ralston (University of Kansas, USA)

T. Rostomyan (Rutgers University, New Brunswick, NJ, USA)

I. Sick (University of Basel, Switzerland)

S. Strauch (University of South Carolina, USA)

T. Suda (Research Center for Electron-Photon Science, Japan)

S. Thomas (MINES ParisTech, Paris, France)

A. Vacchi (INFN Trieste, Italy)

V. Yerokhin (Peter the Great St. Petersburg Polytechnic University, Russia)

SCIENTIFIC REPORT:

The 2010 measurement of the Lamb shift (2S-2P energy difference) in the muonic hydrogen atom has created the "proton radius puzzle": The rms proton charge radius R_p determined from the muonic hydrogen Lamb shift differs by 4% or 7 standard deviations from the accepted CODATA value of R_p which has been obtained from elastic electron-proton scattering and spectroscopy of electronic hydrogen and deuterium. As of 2016, the "proton radius puzzle" is still unsolved. Moreover, also the deuteron rms charge radius from the Lamb shift in muonic deuterium is 7 standard deviations smaller than the CODATA value, amplifying the "proton radius puzzle".

The CODATA value originates from a least-squares adjustment including the world data on elastic electron-proton and electron-deuteron scattering as well as 24 transition frequencies in atomic hydrogen (H) and deuterium (D). The world data on spectroscopy on H and D is in good agreement with the recent results from MAMI at Mainz and Jefferson Lab.

Laser spectroscopy of the Lamb shift in light muonic atoms is extremely sensitive to the nuclear charge radius: The muon's mass is 200 times the electron mass, therefore the muonic Bohr radius is about 200 times smaller than the Bohr orbit in regular hydrogen and H-like ions. Hence the finite size effect on the S states in muonic atoms is $200^3 \approx 10$ million times larger than the finite size effect in regular hydrogen and light H-like ions. Hence, R_p and R_d can be determined from the 2S Lamb shift in μp and μd with unprecedented accuracy. Strikingly, the value of the proton charge radius from muonic hydrogen is 4% smaller than the CODATA value.

The workshop covered all facets of the proton radius puzzle: Review of experiments and data, methods of fitting electron scattering data, theory in muonic hydrogen, aspects of nuclear polarizability, and physics beyond the standard model explanations of the discrepancy. Results were presented on several projects that had been announced in the 2012 workshop. Other projects gave promising outlooks.

New results on muonic deuterium were announced in the opening session of the workshop. Interestingly, also the deuteron charge radius extracted from muonic deuterium shows a 7-sigma discrepancy to the CODATA value! However, the same value of the squared charge radius difference between the deuteron and proton is obtained from both muonic and electronic H and D. This means that the smaller deuteron radius from muonic deuterium is consistent with the smaller proton charge radius obtained from muonic hydrogen

Fitting the electron scattering data had been a source of intensive discussions in the previous workshop. New fit results were presented at this year's workshop, which yield the smaller proton radius, but do not suffer from the inferior chi-squared that previous such analyses showed. Many discussions ensued about the validity (or lack of it) of such fits. Fitting low-Q^2 data alone should take into account the correct curvature of the data, which, as several talks emphasized, should be determined from the data at higher Q^2. Alternatively, these higher moments can maybe be calculated from effective field theory or chiral perturbation theory. However, good arguments were presented against many of the fit procedures that yield smaller radii. Thus there are still the "2 camps" in the elastic electron scattering community that advocate either the large or the small radius.

New data is urgently needed to give a clearer picture. Especially data at very low momentum transfer may be able to give a reliable radius, without being affected by higher-Q^2 behaviour. Two such projects at lowest Q^2, at MAMI and at Jefferson Lab, that were motivated by the proton radius puzzle have taken data since the first workshop in 2012. Both presented a first glimpse at the data at the workshop. Data analysis is underway. A new experiment is being set up at Tohoku University in Japan that will measure absolute cross sections in electron-proton scattering down to $0.0003\ (\mathrm{GeV/c})^2$.

The MUSE experiment at PSI reported good progress at the workshop. MUSE will soon compare elastic electron-proton and muon-proton scattering at low Q^2 for the first time. It will be able to observe any difference between electron-proton and muon-proton interaction that is caused by effects other than the mass difference. By comparing positive and negative lepton scattering, MUSE will be able to study the two-photon effect (TPE) in electron-proton and muon-proton interaction. Since a few models of "soft protons" have been put forward that explains the radius puzzle by an unexpectedly large TPE in the muon-proton interaction, MUSE results are urgently needed. There was unanimous agreement among the workshop participants that MUSE has a very solid physics motivation that goes well beyond the proton radius puzzle. For example, any conceivable improvement in the muonic hydrogen spectroscopy (which could be accomplished by the CREMA collaboration who are currently building the required improved lasers) would need a matching improvement in the theoretical treatment of the TPE in muonic hydrogen. MUSE is going to be a key experiment for this. It was noted during the workshop that even the new data on muonic deuterium does not completely rule out the "soft proton" hypothesis.

Several talks were concerned with beyond Standard Model (BSM) solutions of the proton radius puzzle. A new electrophobic scalar boson could at the same time solve the long-standing g-2 discrepancy for the muon. Another prediction concerned a particle similar to a "dark photon". Again, muonic deuterium does not rule out such BSM solutions. Beam dump experiments could e.g. detect such a new boson, or rule it out. A new measurement at J-PARC is also expected to test lepton universality by high precision measurements with stopped kaons.

Large progress was presented on the theory of muonic atoms. In preparation of results from muonic deuterium and helium, the nuclear polarizability contributions have recently been calculated with excellent precision. For the deuteron, for example, four groups have calculated the TPE contributions with an accuracy of about 1%, corresponding to 0.020 meV. New insights into cancellations between elastic and inelastic contributions have been gained, which make such an accuracy possible. Very different approaches gave very similar results. Hence, the new value of the deuteron charge radius from muonic deuterium, R_d=2.1256(8) fm, seems to be very reliable. It is however 7 standard deviations smaller than the accepted CODATA-2010 value of R_d = 2.1424(21) fm. On the other hand, the smaller value from muonic deuterium can be well explained by a smaller proton inside the (otherwise unchanged) deuteron. This gives even more weight to the proton radius puzzle. An alternative way to interpret the muonic deuterium results is a threefold-improved value of the muonic deuterium TPE contributions, as compare to the current state-of-the-art theoretical determinations. This number from experiment may serve as a benchmark for future high-precision calculations of the deuteron polarizability.

The CREMA collaboration reported not only on muonic deuterium (recently published in Science), but also on preliminary new results on muonic helium ions. Here, again, the theory is making good progress, but a complete summary of all QED contributions to the Lamb shift in light muonic atoms (from Z=1 to A=4) would be very welcome. As it stands, the muonic helium-4 charge radius will be more than a factor of 5 more accurate than the only other value from elastic electron scattering.

On the atomic physics side, a number of talks were concerned with the theory and experiments in "simple" atomic systems, ranging from atomic hydrogen, deuterium, and helium ions, to hydrogen molecular ions and molecules. There is tremendous progress on the theory side, and a determination of the Rydberg constant, or even the charge radii, from simple molecules seems within reach. Experimentally, the classical Lamb shift in hydrogen is producing data that may soon yield an improved value for the proton charge radius from 2S-2P in hydrogen atoms. Also, the 1S-2S transition in H-like He^+ ions is soon going to be probed for the first time. This measurement will, when combined with a helium nuclear charge radius from muonic helium reported at this meeting, yield a new value for the Rydberg constant. Another promising path towards an improved Rydberg constant is in the measurement of optical transitions in highly excited circular Rydberg states in H-like ions like Ne^{9+}. These circular states are not affected by the nuclear size. An exciting new measurement on the Rydberg constant was first reported at this meeting: the new measurement of the 2S-4P transition in atomic hydrogen, performed at the MPQ in Garching, Germany, yielded a Rydberg constant that is as accurate as the current world average from atomic hydrogen, but significantly smaller. This measurement seems to support the smaller proton charge radius first observed in muonic hydrogen. This measurement, however, had to go through great lengths to evaluate all relevant systematics. The final result corresponds to an accuracy of 1:10'000 of the line width! It is also clear that a single measurement cannot invalidate the current set of 24 measurements in atomic H and D. More, and more accurate, results from atomic and simple molecular systems are therefore required to add more evidence against the current CODATA value of the Rydberg constant.

The workshop concluded with outlooks on several new projects, also with muonic atoms. Here, three experiments will measure the 1S hyperfine splitting in muonic hydrogen (CREMA has also proposed to measure the HFS in muonic helium-3). These measurements will yield vastly improved values for the so-called Zemach radius of the proton (and helion), which encodes the magnetic structure of the proton. Here, different electron scattering results have yielded differing values of the magnetic form factors, and a muonic determination may give new insights. The

CREMA collaboration is also considering laser spectroscopy of muonic Li, Be, and B, and X-ray spectroscopy of muonic nuclei in the medium-to-high-Z range, in particular including radioactive nuclei. Finally, an idea was presented to measure 1S-2S in regular tritium atoms, as a way to ultimately improve the triton charge radius by a factor of 400 or so.

Results and Highlights

The proposals and projects presented in the first workshop presented excellent progress. There is even an indication now that atomic hydrogen can eventually be reconciled with a smaller proton radius. Much more data is expected in the next few years.

3.3.10 STATISTICAL PROPERTIES OF NUCLEI

DATE: July 11-15, 2016

ORGANIZERS:

Y. Alhassid (Yale University., USA)
G.F. Bertsch (University of Washington, USA)
A. C. Larsen (University of Oslo, Norway)
A. Zilges (University of Cologne, Germany)

NUMBER OF PARTICIPANTS: 34

MAIN TOPICS:

The general theme of the workshop was to bring together theory and experiment with the goal of improving our understanding of the properties of nuclear excited states that are relevant to reactions in nucleosynthesis and element production in fission.

The main topics were:

- Level densities
- Gamma strength functions
- M1 modes
- Pygmy dipole mode
- Generalized Brink-Axel hypothesis
- (Porter-Thomas) fluctuations
- Recommended Input Parameter Library

SPEAKERS:

S. Åberg (Lund University, Sweden)

Y. Alhassid (Yale University, USA)

G.F. Bertsch (University of Washington, USA)

B.A. Brown (Michigan State University, USA)

Th. Døssing (Niels Bohr Inst., Denmark)

R. Firestone (University of California Berkeley, USA)

S. Frauendorf (Notre Dame University, USA)

S. Goriely (ULB, Belgium)

S. Grimes (Ohio University, USA)

M. Guttormsen (University of Oslo, Norway)

M. Horoi (Central Michigan University, USA)

C.W. Johnson (San Diego State University, USA)

T. Kawano (Los Alamos National Laboratory,

E. Litvinova (Western Michigan University, USA)

L. Moretto (University of California Berkeley, USA)

P. Ring (TU Munich, Germany)

A. Richter (TU Darmstadt, Germany)

R. Schwengner (Helmholtz-Zentrum, Germany)

K. Sieja (Institut Pluridisciplinaire Hubert Curien, France)

S. Siem (University of Oslo, Norway)

A. Voinov (Ohio University, USA)

P. von Neumann-Cosel (TU Darmstadt, Germany)

H.A. Weidenmüller (Max Planck Inst., Germany)

V. Zelevinsky (Michigan State University, USA)

M. Krtička (Charles University, Czech Republic)

A. C. Larsen (University of Oslo, Norway)

USA)

A. Zilges (University of Cologne, Germany)

SCIENTIFIC REPORT:

The theory of reactions in heavy nuclei relies largely on their statistical properties, most importantly the nuclear level density and the gamma-decay strength function. Often these properties cannot be measured directly and reliable theoretical input is needed. This is the situation for many unstable nuclides that are involved in stellar nucleosynthesis. Accurate reaction data are also needed for nuclear engineering of next generation nuclear reactors. Recent experiments have revealed new structures of the gamma strength function beyond the usual electric giant dipole resonance. The workshop's goal was to discuss and compare various theoretical approaches so that more reliable predictions of statistical properties can be made. For example, the Recommended Input Parameter Library (RIPL) is widely used in applications.

The workshop started on the first and second day with presentations of recent experimental advances. Later talks were mainly concerned with various theoretical methods to describe statistical nuclear properties. The format of the workshop, in which talks were limited to the morning sessions, left plenty of time for interactions among participants and discussion sessions in the afternoons.

In the following we describe the main themes discussed in the workshop under each of two main categories.

(i) Level densities. A number of experimental methods to determine level densities were presented, including the Oslo method, particle evaporation spectra and high-resolution proton scattering. However, each of the methods has its own limitations and reliable determination of level densities appears to require a combination of several methods.

There were many presentations on the theory side. The calculation of level densities in the presence of nuclear correlations is a challenging many-body problem and the presentations were focused on a number of promising microscopic methods: finite-temperature mean-field approximations, combinatorial methods, moment method and the auxiliary-field quantum Monte Carlo approach. The latter is a numerically exact method (up to statistical errors) that has been applied to nuclei as heavy as the lanthanides.

A number of points were made in the discussions. In order for the Oslo method to be better understood, the Oslo group is posting on their website their three-dimensional matrices of excitation-energy tagged gamma-ray spectra for other experimentalists to analyze independently. Among empirical parameterizations of level densities, it seems that the constant-temperature model is a better description between the broken-pair threshold and just below the neutron separation energy.
It was pointed out that there are significant deficiencies in the published level density parameterizations, including but not limited to the inconsistency of the widely used temperature expression derived from the Fermi-gas model. In general, the progress on improving phenomenological models has been slow. In particular, there remains a large gap between the phenomenological parameterizations by the Fermi gas model and what has been achieved by microscopic methods such as density functional theory. There is also much work to be done to validate different approximation methods by benchmarking their predictions in cases where numerically exact methods can also be applied.

Level densities are important input to the Hauser-Feshbach theory of statistical nuclear reactions. It appears that proton evaporation spectra are quite sensitive to the parameters of the level density formulas. Statistical reactions were also shown to be sensitive to rotational quantum numbers in deformed nuclei.

(ii) Gamma strength functions. There was much experimental and theoretical evidence for a low-energy enhancement ("upbend") in the M1 strength that competes in some nuclei with the E1 strength. Several theoretical studies based on the configuration-interaction shell model method were reported to have found enhanced M1 strength built on highly excited states decaying with low transition energy, and they were supported by qualitative arguments. More definitive experiments may be possible in the future using polarized photon sources and by measuring the final proton's spin in the (p,p') reaction, as well as Compton-polarization measurements of low-energy gamma rays following, e.g., a charged particle reaction. There is a clear need to understand the conditions under which the low-energy M1 enhancement is present and to determine its functional form. This will improve existing parameterizations of the gamma strength functions. So far, progress on improving phenomenological models for the radiative strength function has been slow.

Theoretical calculations of the low-energy M1 enhancement were limited mostly to mid-mass nuclei where the conventional configuration-interaction shell model can be applied. It would be interesting to apply methods such as the auxiliary-field Monte Carlo approach to determine whether such enhancement is also observed in heavy nuclei. In this method it is possible to calculate imaginary-time response functions, and the challenge is to invert them to determine the strength functions.

The Brink-Axel hypothesis states that the giant dipole resonance is independent of the initial state upon which it is built. An open question is whether this hypothesis holds more generally for the radiative strength function, and in particular at lower energies where it is dominated by other contributions such as M1. Recent experiments of the Oslo group indicate that the Brink-Axel hypothesis is satisfied more generally for gamma transitions between states in the continuum. Theoretical calculations in mid-mass nuclei based on the configuration-interaction shell model seem to support this for transitions between excited states. However, transitions to the ground state might be strongly influenced by its peculiar configuration. More experiments and theoretical calculations are needed before a firm conclusion can be drawn.

As a last theme of the meeting, the possible violation of one of the tenets of the statistical theory was discussed. Namely, the Porter-Thomas distribution of the neutron resonance widths, which is based on random-matrix theory, may be violated in certain heavy nuclei (e.g., platinum isotopes). A possible mechanism was proposed, based on the characteristics of the coupling to the neutron channel near the neutron separation energy and non-statistical gamma decays that violate the orthogonal invariance of random-matrix theory. In view of the dominance of M1 strength at lower transition energy, it would be interesting to determine whether the M1 transition intensities follow Porter-Thomas statistics, and preliminary results were discussed.

Results and Highlights

The workshop was very well received by the participants and in particular they liked the format, which left much time for discussions and interactions. Many theoretical questions were raised in the workshop and they will require further study. A website was therefore set up to post results of various methods for comparison purposes. It was also agreed in the workshop to focus collectively on specific nuclei for benchmarking the performance of various theories in a controlled setting, namely using the same model spaces and Hamiltonians. The nuclei selected for benchmarking are ^{56}Fe, ^{57}Fe and ^{58}Ni in the mid-mass region, and ^{162}Dy and ^{161}Dy as typical heavy deformed nuclei. Selected light nuclei, accessible to the conventional configuration-interaction shell model method, are ^{26}Al, ^{27}Al and ^{26}Mg.

An important conclusion was that a reliable experimental determination of statistical properties requires a combination of several methods and that these methods should eventually lead to consistent results. This holds for both the level density and the gamma strength function. On the theory side it is clear that various methods to calculate level densities should be benchmarked and compared with each other to better understand their limitations and how they might be improved. For the M1 strength function, most calculations to date have been limited to the configuration-interaction shell model approach. However, this approach is limited by the size of the model space, and it is imperative to explore other methods that are capable of treating heavy nuclei where much larger model spaces are required, such as the quasiparticle random-phase approximation and the auxiliary-field Monte Carlo method. In general, the urgent need for reliable, microscopic approaches both for level-density and gamma-strength calculations are strongly emphasized.

In addition to this report, the organizers are preparing a document for participants that will summarize the physics addressed in the workshop and the main issues that require further study. This document will also describe the tasks to be carried out in the benchmark comparison studies.

3.3.11 BARYONS OVER ANTIBARYONS: THE NUCLEAR PHYSICS OF SAKHAROV

DATE: July 25-29, 2016

ORGANIZERS:

C. Lee (LANL, USA)
R.G.E. Timmermans (Univ. of Groningen, Netherlands)
U. van Kolck (IPN Orsay, France)

NUMBER OF PARTICIPANTS: 27

MAIN TOPICS:

An explanation has long been sought for the apparent dominance of matter over antimatter in the universe. In a ground-breaking paper, Sakharov proposed that the asymmetry is due to particle physics in the early universe, and he characterized the ingredients required for successful baryogenesis: Not only must sufficient violation of baryon number and the product of charge conjugation and parity exist to make baryogenesis possible, but also departure from thermal equilibrium during a relevant period of the universe's history.

The goal of our workshop was to tie together the recent progress in and prospects for understanding in particular the nuclear aspects of the Sakharov criteria, which formed the main topics for our workshop:

<u>Baryon number (*B*) violation:</u>

In addition to the traditional search for proton decay in nuclei, the possibility of violation of *B* (and lepton number *L*) by two units has come to the forefront. Efforts in this direction come in the form of measurements on neutrinoless double beta decay and recent proposals for advances in neutron-antineutron oscillation experiments in vacuum and in nuclei.

<u>Charge-conjugation and parity *(CP)* and time-reversal (*T*) violation:</u>

Experiments at a number of facilities are significantly pushing the limits on neutron and atomic/molecular electric dipole moments (EDMs). Moreover, prospects are under scrutiny for the search of EDMs of charged particles, in particular the proton, the deuteron, and other light nuclei, in storage rings.

<u>Out-of-equilibrium processes:</u>

In recent years, numerous groups have made sophisticated studies of electroweak baryogenesis (EWB) using nonequilibrium quantum field theory to go beyond simple diffusion equations, and discovered new effects that could significantly change predictions of *CP* violation and the baryon asymmetry (BAU), in some cases by orders of magnitude.

The theoretical and experimental progress made it timely to re-examine the implications for models for baryogenesis. The nuclear physics community is increasingly gearing towards building the tools to calculate strong-interaction matrix elements relevant to low-energy tests with lattice QCD. In parallel, effective field theories (EFTs), for instance based on chiral perturbation theory, are being developed to relate these quantities to nuclear and atomic observables

SPEAKERS:

J. Bakker (Univ. of Groningen, Netherlands)

Z. Berezhiani (Univ. L'Aquila, INFN, Italy)

M. Buchoff* (LLNL, USA)

J. de Vries (Nikhef, Netherlands)

W. Dekens (LANL, USA)

B. Dev (MPI Heidelberg, Germany)

V. Flambaum (Univ. of New South Wales, Australia)

K. Fuyuto (Saga Univ., Japan)

B. Garbrecht (Technische Univ. München, Germany)

S. Gardner (Univ. of Kentucky, USA)

V. Gudkov (Univ. of South Carolina, USA)

S. Inoue (Univ. of South Carolina, USA)

T. Kuwahara (Nagoya Univ., Japan)

N. Mavromatos (King's College, UK)

U. Meißner (Univ. of Bonn, Germany)

E. Mereghetti (LANL, USA)

G. Nardini (Univ. of Bern, Switzerland)

J. Noordmans (Univ. do Algarve, Portugal)

F. Oosterhof (Univ. of Groningen, Netherlands)

M. Ramsey-Musolf* (Univ. of Massachusetts, Amherst, USA)

A. Ritz (Univ. of Victoria, Canada)

C. Schat (CONICET, Argentina)

E. Shintani (RIKEN, Japan)

R. Timmermans (Univ. of Groningen, Netherlands)

A. Tureanu (Univ. of Helsinki, Finland)

A. Wirzba (FZ Jülich, Germany)

N. Yamanaka (RIKEN, Japan)

*Remote talks

SCIENTIFIC REPORT:

We designed a "vertical" program to study the three Sakharov subareas at the nuclear scale and relate these to high-energy scales beyond the electroweak scale and, where needed, to the atomic and molecular scales below. The main issues that we addressed are:

1. Viable models beyond the electroweak scale provide various sources for *CP/T* and *B/L* violation. Traditionally, the implications to low-energy observables have been studied in a case-by-case basis. Yet, they can be encoded in operators of higher dimension involving Standard-Model particles, which can be propagated down to nuclear- and atomic-scale experiments using effective field theory. At low energies, such operators imply different relations among observables. The effects on baryogenesis of higher-dimensional operators and, more generally, new physics were discussed in the talks by Berezhiani, Ramsey-Musolf, Flambaum, Dev, Mavromatos, Fuyuto, and Garbrecht.

2. The interpretation of nuclear-scale experiments depends on strong-interaction matrix elements, often at the one-nucleon level. Lattice theorists are beginning to carry out significant simulations of symmetry-violating quantities, such as the neutron EDM and the amplitude for neutron-antineutron oscillation. The status of these calculations was reviewed from various angles in the talks given by Shintani, Meißner, Mereghetti, and Buchoff.

3. Crucial experiments involve nuclei, atoms, molecules, and now also gravitational waves. The first steps have been taken to disentangle *CP* violation due to the QCD vacuum angle from that due higher-dimensional operators in nuclei and diamagnetic atomic systems, which suggest richer low-energy dynamics than assumed so far as input to many-body calculations (often just *CP*-

violating pion-nucleon couplings). Similar issues affect *B* violation. Neutrinoless double beta decay is a unique probe of *L* violation, where the recent developments in the understanding of the many-body nuclear dynamics could have significant impact. Discovering the imprints of the electroweak phase transition on astrophysical process is a growing enterprise.

3a. The connection with *CP* violation at high-energy scales was discussed by de Vries, Ritz, and Dekens, while Gudkov, Wirzba, Yamanaka, Inoue, and Schat emphasized the link between hadronic EDMs and nuclear and atomic *CP*-violating observables.

3b. *B* violation by one unit is a well-established field, which was reviewed from the point of view of supersymmetry by Kuwahara. In contrast the possible implications of *B* violation by two units has been hotly debated in the literature, as reflected in the workshop in talks by Oosterhof, Gardner, and Tureanu.

3c. Signatures for the deviation from equilibrium via a phase transition or, as an alternative, *CPT* violation were discussed, respectively, by Nardini, and Mavromatos and Noordmans.

4. Recent studies have uncovered new mechanisms and explored regimes of parameter space in new models where enhanced, resonant generation of a *CP* (and thus *B*) asymmetry during the electroweak phase transition can occur. Reliable quantitative predictions for these processes are essential to establish the viability of these models for baryogenesis. Our workshop provided an environment to compare competing approaches to understanding resonant baryon generation, resolve outstanding issues/discrepancies, and provide guidance to particle theorists to build models that could achieve successful electroweak baryogenesis. Some of these approaches, issues, and phenomenological implications were addressed in the above-mentioned talks by Fuyuto, Garbrecht, and Ramsey-Musolf.

Results and Highlights

The workshop was unique in bringing together theorists who do not usually interact: particle and nuclear physicists working either on symmetry violation or baryogenesis. The format of relatively few talks, with ample time for discussions, led to much interaction among the participants. Many of them expressed their satisfaction with the high-level of interaction and the wide range of related topics.

By the end of the workshop, we formed a coherent picture of the latest status and most promising future directions of tools to probe *B* and *CP* violation. We made progress in discussing what kind of experiments are needed – and useful from a theoretical perspective – to pinpoint the dominant sources of these violations. We have also identified some of the most important calculations that are needed as input to nuclear effective field theory, which can then extend calculations to light nuclei. Unfortunately, no many-body theorist could attend the meeting, which prevented a full discussion of larger nuclei.

One of the highlights was the convergence of ideas regarding the implications of neutron-antineutron oscillation. Because of the already stringent bounds on the scale of baryon number violation by one unit (starting at dimension six in the Standard Model), much attention is currently devoted to violation by two units (dimension nine). Several high-energy models were presented. The period before the workshop had seen claims that their most important consequence, neutron-antineutron oscillation, implies *CPT* or *CP* violation. Although not all participants in this debate were present, among the workshop attendees a consensus seemed to have emerged that neither *CPT* nor *CP* are necessarily violated. Preliminary results were presented of both a chiral-perturbation-theory analysis of the quark-mass dependence of the oscillation and a lattice calculation of the relevant matrix elements. These efforts should assist the extraction of information about new physics from a possible measurement of the oscillation at the upcoming European

Spallation Source. The case was also made for the potential importance of neutron-mirror neutron oscillation.

Likewise, participants seemed to agree that one of the best opportunities for learning about new *CP* violation would be a program on light nuclear EDMs. As shown by various speakers, there is now a pretty complete link between high and low energies via EFT. New physics, including dark matter, has been parameterized in terms of operators of various dimensions in the Standard Model. The dimension-six operators and quark-gluon operators at the QCD scale have been connected through the renormalization group. There has been steady progress on obtaining nucleon EDMs from the vacuum angle with lattice QCD, and first steps are being taken to extend these calculations to other operators like quark EDMs. And several speakers demonstrated that nuclear EFTs (perhaps aided by the extra constraints coming from an expansion in a large number of colours) have control over the calculation of *CP*-violating effects in light nuclei, whose EDMs act as filters for the different sources of *CP* violation. This chain allows for an interplay between experimental constraints coming from colliders and from low-energy experiments. There is strong support among theorists for the incipient storage-ring EDM program being contemplated in Korea and Jülich. Moreover, it was argued that neutron scattering on nuclei is not far from producing complementary information. Lattice QCD calculations of *CP* violation from dimension-six sources was identified as the most important theoretical priority.

A viable, but more exotic alternative to the standard Sakharov scenario involves *CPT* violation, which together with *B* violation can result in baryogenesis in thermal equilibrium. Several theoretical scenarios were discussed. Here interesting connections are possible with many low-energy experiments that search for Lorentz and *CPT* violation with neutrons, nuclei, and atoms, which can be interpreted in the framework of the Standard Model Extension. An important recent development reported at the workshop was the exploration of chiral perturbation theory for Lorentz and *CPT* violation in hadronic and nuclear systems.

While the Sakharov criteria identify the symmetries of nature that must be broken in order to generate a baryon asymmetry at all, implementing such symmetry breaking in a specific model and computing the resultant quantitative prediction for the BAU is another challenge entirely. We had several talks consider some such specific scenarios, techniques to calculate the BAU, and prospects to test these models. EWB models were discussed, including supersymmetric extensions of the Standard Model and 2-Higgs doublet models that provide new sources of *CP* violation and extra scalar particles, which can enhance the strength of the first-order phase transition by appropriately changing the shape of the Higgs effective potential. The latest status of quantitative predictions for BAU through EWB in these models was reported as well as computations of EDMs induced by the same *CP*-violating phases leading to the BAU. The interplay with collider searches for the new particles was also highlighted. Leptogenesis scenarios, in which *CP* violation in the neutrino sector is communicated to baryons via electroweak sphaleron processes, offer another possibility to create an asymmetry. In addition to the traditional scenarios, where new heavy neutrinos at an energy scale much above the electroweak provide the new *CP* violation, newer scenarios have been proposed with GeV-scale right-handed neutrinos, which could generate signals in current collider experiments. Advanced theoretical techniques were illustrated for the treatment of quantum transport and derivation of kinetic equations for evolution of charge densities out of equilibrium. These techniques often reveal new phenomena, such as flavour oscillations and resonant enhancements of *CP*-violating charge densities, beyond what is revealed by simpler treatments (such as Higgs vev-insertion approximations), and significantly reduce theoretical uncertainty. It was shown that current and upcoming experiments have a rich potential to tightly constrain specific models and scenarios of baryogenesis, when combined with concomitant advances in theoretical computations of the BAU. In this vein, one speaker presented the fascinating potential of future satellite-based gravitational-wave experiments (eLISA) to detect signals coming from the electroweak phase transition, which would provide a truly dramatic signature for EWB.

3.3.12 PHYSICS BEYOND THE STANDARD MODEL AND PRECISION NUCLEON STRUCTURE MEASUREMENTS

DATE: August 1-5, 2016

ORGANIZERS:

Frank Maas - (Johannes Gutenberg University, Mainz, Germany)
Krishna Kumar - (Stony Brook University, USA)
Paul Souder - (Syracuse University, USA)
Marc Vanderhaeghen - (Johannes Gutenberg University, Mainz, Germany)

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

The main purpose of this workshop was to review and stimulate future directions in searches for physics beyond the Standard Model and novel probes of nucleon structure using parity-violating electron scattering.

The main topics were:

- Review of electroweak physics and physics beyond the standard model including synergies with collider and neutrino physics
- Semi-leptonic electroweak processes, background processes
- Interplay between beyond standard model physics and QCD in deep inelastic scattering
- Radiative Corrections; running of the weak mixing angle
- Box-graphs and two-loop effects
- Overview of the Experimental Program at Mainz and JLab and new ideas
- Polarized source and polarized beam monitoring, challenges and systematic
- Spectrometer and integrating detector designs and their technical challenges
- Summary discussion of theoretical challenges
- Summary discussion of experimental challenges and plans

SPEAKERS:

A. Aleksejevs (Memorial University of Newfoundland, Canada)

D. Armstrong (College of William and Mary, USA)

K. Aulenbacher (Johannes Gutenberg-Universität Mainz, Germany)

S. Barkanova (Acadia University, Canada)

S. Baunack (Johannes Gutenberg-Universität Mainz, Germany)

D. Becker (Johannes Gutenberg-Universität Mainz, Germany)

N. Berger (Johannes Gutenberg-Universität Mainz, Germany)

P. Blunden (University of Manitoba, Canada)

N. Liyanage (University of Virginia, USA)

F. Maas (Helmholtz-Institut Mainz, Germany)

W. Marciano (Brookhaven National Laboratory, USA)

J. Mammei (University of Manitoba, Canada)

Ch. Matejcek (Johannes Gutenberg-Universität Mainz, Germany)

D. McNulty (Idaho State University, USA)

W. Melnitchouk (Jefferson Lab, USA)

R. Michaels (Jefferson Lab, USA)

G. Miller (University of Washington, USA)

K. Mimouni (EPFL Lausanne, France)

O. Moreno Diaz (Universidad Complutense

L. Capozza (Helmholtz-Institut Mainz, Germany)

I. Cloet (Argonne National Laboratory, USA)

S. Covrig Dusa (Jefferson Lab, USA)

H. Davoudiasl (Brookhaven National Laboratory, USA)

J. Diefenbach (Johannes Gutenberg-Universität Mainz, Germany)

A. Esser (Johannes Gutenberg-Universität Mainz, Germany)

R. Ferro Hernández (Universidad Nacional Autónoma de México (UNAM), Mexico)

V. Flambaum (University of New South Wales, Australia)

A. Freyberger (Jefferson Lab, USA)

M. Gericke (University of Manitoba, Canada)

M. Gorshteyn (Johannes Gutenberg-Universität Mainz, Germany)

J. Green (Johannes Gutenberg-Universität Mainz, Germany)

K. Kumar (Stony Brook University, USA)

de Madrid, Spain)

C. Palatchi (University of Virginia, USA)

M. Petschlies (Bonn University, Germany)

M. Pitt (Virginia Tech, USA)

S. Riordan (Stony Brook University, USA)

J. Roca Maza (University of Milan, Italy)

K. Schier (Johannes Gutenberg-Universität Mainz, Germany)

M. Schott (Johannes Gutenberg-Universität Mainz, Germany)

Ch.-Y. Seng (University of Massachusetts Amherst, USA)

P. Souder (Syracuse University, USA)

Sh. Su (Arizona University, USA)

H. Spiesberger (Johannes Gutenberg-Universität Mainz, Germany)

M. Vanderhaeghen (Johannes Gutenberg-Universität Mainz, Germany)

Y. Zhao ((Stony Brook University, USA)

SCIENTIFIC REPORT:

There are new and vibrant experimental initiatives at Mainz and Jefferson Laboratory to measure neutral weak amplitudes and vector analysing powers in a range of kinematic configurations and with a wide variety of nuclear targets. The proposed measurements have been discussed and summarized. They require improved understanding of the electroweak and QCD theory for the interpretation of the experimental observables in terms of fundamental quantities. The workshop has brought together the world specialists to identify the most important challenges and synergies among the proposed initiatives.

One primary theme of the workshop was the future potential of parity-violating electron scattering to explore new physics manifestations that are difficult to access at existing high-energy colliders. The P2 experiment at Mainz and the MOLLER and SoLID experiments at JLab are being developed to make the next generation of ultraprecise weak neutral current amplitude measurements in elastic electron proton scattering, Moller scattering and deep inelastic electron deuteron scattering, allowing for an independent determination of the weak charges of the proton, the electron and the u-, and d-quarks respectively. This first part of the workshop was focusing on exchange between experiment and theory, like for example QED radiative corrections have been discusses. They need to be known to high precision in order to identify the kinematics. Electroweak quantum corrections modify the measured weak charges including possible effects from beyond standard model physics. The target precision of the experiments requires a full treatment up to two-loops including two boson exchange graphs like the gamma-Z-box graph. Several groups presented their strategy to go to higher precision concerning electroweak quantum corrections. While the P2-experiment and the Moeller experiment both deal with elastic scattering off a proton or electron target, the SoLID-experiment at JLab requires in addition the separation of higher twist QCD-effects from possible BSM-physics. This has been discussed in detail.

A separate set of measurements in parity violating electron scattering off heavy nuclei are being pursued to make precise measurements of the neutron skin of heavy nuclei via precise measurements of neutral weak amplitudes using 48Ca and/or 208Pb targets. This allows for a determination of the asymmetry energy in the Equation of State of Nuclear Matter and has direct impact on the dynamics of neutron stars. This method has been discussed in detail and compared to other methods. It is conceptually less dependent on difficult to control effects like final state interaction or collective nuclear effects as compared to other determinations of the neutron distribution like coherent pion production of measurement or Pygmy-resonances.

Finally, a synergistic set of measurements of the vector analysing powers with transversely polarised electron beam of a variety of low- and high-Z nuclei is being explored to enhance the physics program and reduce systematic errors in the primary measurements. The question of the two-photon-box graph which is one important QED-correction in parity violating scattering and which would be used here to study nuclear dynamics.

The interpretation of the results requires improved understanding of electroweak radiative corrections, nucleon structure and non-perturbative QCD dynamics. This has been reviewed in different talks. Two summary talks have made a thorough discussion of the week's program and has summarized possible future steps.

Results and Highlights

The exploration of Beyond Standard Model (BSM) Physics and the comparison of sensitivities of different low energy high precision experiments has been done. The exploration of presently known high precision experiments at low energies and their sensitivity has been explored in effective theories. So far a purely leptonic (four fermion) calculation renders it possible to compare sensitivities of different experiments. The workshop has triggered new semi-leptonic calculations to extend present work to elastics electron proton scattering.

The mass range for new particles from BSM can go up to 50 TeV for the present experiment proposals. It can also go down to several 50 MeV, which is by far complementary and unreachable by present day high energy colliders.

The present accuracy of electroweak radiative corrections has been discussed. There are several attempts to increase it to a full two-loop correction. The Canadian group as well as the Mexican group have started to work on it. The expected accuracy of such calculations meets the experimental requirements of the parity violation experiments. One important, sizeable part of the electroweak radiative corrections are the so called box diagrams. There have been several calculations in the past by different groups, which have employed vastly different error estimates. This has been discussed at the workshop. A common working group has pointed out the different approaches and is working on a common, unified error estimate approach.

A special emphasis has been on QED radiative corrections. They do not alter the value of the measured asymmetry (like for electroweak radiative corrections), but they can alter the four-momentum transfer Q2 at the interaction vertex and are therefore an important part of the experiment systematics. A new initiative is on the way to include a new event generator for experiment simulations including NNLO.

The interplay between BSM and QCD is of special importance for deep inelastic parity violating scattering of a deuteron target like for the SoLID experiment. This has been discussed at the workshop. A series of measurements combining low x and high x measurements can systematically study higher twist QCD effects where BSM-physics is supposed not to contribute and vice versa. This will need further improved QCD-calculations.

3.3.13 TESTING THE QUANTUM SUPERPOSITION PRINCIPLE IN NUCLEAR, ATOMIC AND OPTOMECHANICAL SYSTEMS

DATE: September 12-15, 2016

ORGANIZERS:

A. Bassi (University of Trieste, Italy)
C. Curceanu (INFN, Italy)
M. Paternostro (Queen's University Belfast, United Kingdom) (Chair and main organizer)
H. Ulbricht (University of Southampton, United Kingdom)

NUMBER OF PARTICIPANTS: 27

MAIN TOPICS:

The general theme of the workshop concerned the test of the quantum superposition principle and the emergence of quantum phenomena in mesoscopic and macroscopic systems open to environmental effects. The experimental platforms addressed by the talks presented at the workshop spanned a wide range of situations, from (ultra-)cold atomic systems to cavity optomechanics. This allowed the exploration of a broad range of physical effects, from standard decoherence mechanisms in complex systems (including some of biological inspiration) to exotic collapse models, whose test and validation is attracting increasing attention.

The main topics were:

- Tests on quantum foundations from matter-wave interferometry to atomic, nuclear and high-energy physics.
- Fundamental tests of quantum mechanics in linear/non-linear optics and in atomic and nuclear systems.
- Testing the limits of quantum theory through optomechanics.
- From quantum dynamics to quantum simulations through matter-light interactions.
- Quantumness in hostile environments: a route from particle and nuclear physics to quantum biology.

SPEAKERS:

A. Avella (INRIM Torino, Italy)

M. Barbieri (Università Roma Tre, Italy)

S. Bose (University College London, UK)

F. Caruso (Florence University, Italy)

I. Carusotto (BEC Center Trento, Italy)

C. Curceanu (INFN, Italy)

S. Donadi (University of Trieste, Italy)

M. Genoni (University of Milano, Italy)

D. Goldwater (University College London, UK)

O. Gühne (Universität Siegen, Germany)

D. Fausti (University of Trieste, Italy)

B. Hiesmayr (University of Vienna, Austria)

R. Kaltenbaek (University of Vienna, Austria)

N. Kiesel (University of Vienna, Austria)

M. Landini (ETH Zürich, Switzerland)

A. Mari (Scuola Normale Superiore Pisa, Italy)

S. McMillen (Queen's University Belfast, UK)

M. Mueller (Florence University, Italy)

L. Pezze' (Florence University, Italy)

M. Rashid (University of Southampton, UK)

A. Serafini (University College London, Italy)

A. Feix (University of Vienna, Austria)
B. Vacchini (University of Milano, Italy)
A. Vinante (University of Trento, Italy)

SCIENTIFIC REPORT:

Microscopic systems can be prepared in quantum configurations with no classical counterpart. Such a possibility seems precluded when the 'complexity' of the system grows towards the macroscopic domain: so far we have no evidence of non-classical behavior of the macroscopic world around us. Why is it so? How is quantumness lost as we abandon the microscopic domain? These questions, which remain to date largely unanswered, address one of the most interesting and challenging goals of modern research in physics, and served the primary goal of the workshop.

The speakers of the workshop have discussed the limitations in our understanding and formulation of quantum mechanics, reviewing the state of the art at both the theoretical and experimental level, and exploring the possibilities for factual progress in the area of fundamental quantum physics. The talks have covered a wide-range of platforms and theories, from standard approaches based on matter-wave interferometry to novel ones built around the possibilities offered by atomic/nuclear physics and the various incarnations of optomechanics. At the core of the work-programme of the workshop was the analysis of the effects of environmental and intrinsic decoherence.

Entanglement, decoherence, locality, quantum interference in complex systems (including biological ones) were at the core of the presentations. Such themes have been extended significantly to cover the description, and indeed the possibility to test, of non-standard decoherence models such as those embodied by collapse theories, including the spontaneous emission of radiation, and the assessment of deviations from the linearity of quantum mechanics. Such discrepancies could be tested from the sub-atomic and nuclear scale all the way up to more mesoscopic domains. Some of such theories are strongly linked to gravity, and part of the activities of the meeting has verged towards the further exploration of such connections and their testability in foreseeable experimental settings. The workshop has not neglected possible technological implications. In particular, the possibility to engineer sensing devices with unprecedented sensitivities has been discussed.

Results and Highlights

The workshop was a very successful opportunity to shape a community that is growing in size but that remains, to date, rather unstructured. Events such as this workshop are instrumental to define the boundaries of the topics discussed above, discuss the state of the art, and identify future directions of investigation. The workshop has clearly shown the need for a stronger interplay between the foundations of quantum mechanics and the information theoretical framework, which offers promising tools for the exploration of non-standard decoherence models and their ultra-efficient assessment. Moreover, the platforms for quantum simulation that are currently experimentally explored provide potentially fertile grounds for the emulation of complex systems and thus the exploration of the quantum-to-classical transition and possible deviations from its standard formulation.

3.3.14 PROTON-NEUTRON PAIRING AND ALPHA-LIKE QUARTET CORRELATIONS IN NUCLEI

DATE: September 19-23, 2016

ORGANIZERS:

A. O. Macchiavelli (LBNL, Berkeley, USA)
M. Sambataro (INFN, Catania, Italy)
N. Sandulescu (IFIN, Bucharest, Romania) (coordinator)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The main topics were:

- Proton-neutron pairing in various approximations
- Competition between T=1 and T=0 pairing in even-even and odd-odd nuclei
- Fingerprints of proton-neutron pairing in nuclear properties
- Relation between proton-neutron pairing and quartet correlations
- Alpha clustering in nuclei

SPEAKERS:

G. de Angelis (INFN, Padova, Italy)
M. Assié (IPN, Orsay, France)
V. V. Baran (IFIN, Bucharest, Romania)
R. Chasman (ANL, Argonne, USA)
J. Cseh (ATOMKI, Debrecen, Hungary)
J. Dukelsky (CSIC, Madrid, Spain)
S. Frauendorf (UND, Notre Dame, USA)
D. Gambacurta (ELI-NP, Bucharest, Romania)
A. Gezerlis (UG, Guelph, Canada)
P. van Isacker (GANIL, Caen, France)
C. W. Johnson (SDSU, San Diego, USA)
C. Qi (KTH, Stockholm, Sweden)
R. Lasseri (IPN, Orsay, France)
R.J. Liotta (KTH, Stockholm, Sweden)
A. O. Macchiavelli (LBNL, Berkeley, USA)
N. Manton (UC, Cambridge, UK)
T. Neff (GSI, Darmstadt, Germany)
S. Pittel (UD, Delaware, USA)
M. Sambataro (INFN, Catania, Italy)
N. Sandulescu (IFIN, Bucharest, Romania)
P. Schuck (IPN, Orsay, France)
Y. Taniguchi (NIMedS, Moroyama, Japan)
Y. Tanimura (IPN, Orsay, France)
A. Vitturi (INFN, Padova, Italy)
P. Vogel (Caltech, Pasadena, USA)
A. Volya (FSU, Tallahassee, USA)

SCIENTIFIC REPORT:

One of the most debated questions in nuclear structure is whether in nuclei the isoscalar proton-neutron pairs act coherently in the form of a condensate, as is the case for neutron or proton pairs. To elucidate this issue and, more generally, to understand the role played by the proton-neutron pairing correlations in nuclei, many efforts have been made recently. This research has been stimulated by the expanding capabilities of radioactive beam facilities around the world which can produce and study heavy nuclei close to the N=Z line. Proton-neutron correlations are expected to be particularly important in these nuclei.

Traditionally, the proton-neutron pairing correlations in nuclei are studied in the framework the of Hartree-Fock-Bogoliubov (HFB) approach. In HFB all types of pairing correlations, both isovector (T=1) and isoscalar (T=0), are treated simultaneously by employing a generalized Bogoliubov transformation which mixes the protons and neutrons in the same quasiparticle state. Recent HFB calculations, presented during the workshop, indicate that in some heavy nuclei close to the N=Z line a condensate of T=0 proton-neutron pairs might exist, alone or coexisting with the condensates of T=1 pairs. This interesting prediction should, however, be checked in other approaches because it is not clear yet how much it can be affected by the fact that in HFB calculations the particle number and the isospin are not exactly conserved.

An alternative approach to the HFB theory, discussed during the workshop, which conserves both the particle number and the isospin, is the quartet condensation model (QCM). In this approach, the ground states of T=1 and T=0 pairing Hamiltonians are described accurately in terms of a condensate of alpha-like quartets, instead of a condensate of Cooper pairs. During the workshop it was also shown that an extension of the QCM, in which the quartets are distinct from each other, can describe the correlations induced not only by pairing forces but also by general shell-model-like interactions with high precision. The proton-neutron pairing and the quartet degrees of freedom have been also discussed in a BCS-like formalism in which the quartets are considered together with the Cooper pairs.

An important subject discussed comprehensively during the workshop was the impact of proton-neutron pairing correlations on nuclear properties. Thus, various talks presented recent studies about the role played by the proton-neutron pairing on Wigner energy, high-spin states and neutrinoless double beta decay. A special session was dedicated to proton-neutron transfer reactions, performed recently in various laboratories, which are expected to provide valuable information on the competition between T=0 and T=1 pairing in N=Z nuclei.

Many studies, including the ones presented in this workshop, point to the fact that the proton-neutron correlations are intimately related to alpha-like quartet correlations. An interesting open question, addressed in this workshop, is the connection between alpha-like quartteting and alpha clustering. Related to this issue, in some talks it was shown that, on the one hand the shell model can provide accurate predictions for the alpha particle transfer reactions in N=Z sd-shell nuclei. On the other hand, the shell model fails to describe properly the alpha particle decay. During the workshop there have also been very interesting talks on alpha clustering in nuclei, obtained in various approaches based on symmetry groups, the Fermionic Quantum Molecular Dynamics, the Antisymmetrised Quasi-Cluster model, the THSR ansatz for alpha condensation and the Skyrme model.

Results and Highlights

The ECT* and the workshop schedule provided an excellent atmosphere for extensive discussions, both during the talks and in dedicated sessions, on the most important open issues related to proton-neutron (pn) pairing and alpha-type correlations in nuclei. The lively discussions and the diversity as well as the originality of the exchanged ideas were quite impressive; we consider that this was in fact a key element for the success of the workshop.

The discussions focused mainly on the following issues: 1) the influence of the spin-orbit interaction, deformation and symmetries conservation on the competition between T=0 and T=1 pn pairing; 2) the relation between the Wigner energy and pn pairing; 3) what we can learn about T=0 pn pairing from the low-lying states of odd-odd N=Z nuclei; 4) the role of spin-aligned pn pairs with J=9 in ^{92}Pd; 5) how to extract relevant information on pn pairing from deuteron transfer reactions; 6) how to identify two- and four-body collective correlations in shell model calculations; 7) what is the relation between quartteting and alpha clustering; and 8) the emergence of alpha-type correlations/clustering from various approaches.

During the discussions many suggestions were made on the directions to which further efforts should be focused. In conclusion, we would like to mention the general consensus on the fact that, in order to grasp the fingerprint of pn pairing and alpha-type correlations in nuclei, we need more specific experimental data, such as cross sections for deuteron and alpha transfer reactions in self-conjugate nuclei in the pf-shell region, and more accurate and transparent theoretical tools.

3.3.15 QCD AT LHC: FORWARD PHYSICS AND UPC COLLISIONS OF HEAVY IONS

DATE: September 26-30, 2016

ORGANIZERS:

Nicolo Cartiglia, Torino, Italy
Lucian Harland Lang, UCL, UK
Cyrille Marquet, CPhT, Ecole Polytechnique, France
Christophe Royon, University of Kansas, Lawrence, USA
Gregory Soyez, IPhT, Saclay, France

NUMBER OF PARTICIPANTS: 45

MAIN TOPICS:

The aim of the meeting was to present and discuss the new results from the LHC related to QCD, namely on forward physics and diffraction and the study of heavy ion runs (ion-ion and proton-ion) at the LHC. The relation with cosmic ray physics was be also developed. The timing of the workshop was particularly well suited with respect to the LHC schedule, since many results at the new energy of 13 TeV were public at the time of the workshop and were ready to be discussed.

The spirit of meeting was to favor fruitful and informal discussions between experimentalists and theorists. We dedicated lots of time to discussions on new results, hot topics and exciting open problems on low-x physics and QCD at the LHC (typically, there was one discussion session per day with appointed discussion leaders before the workshop).

The discussed subjects are the following:

- LHC results on QCD and diffraction
- QCD evolution equations: open problems
- The problem of saturation
- Low x and jet physics at the LHC
- Forward physics at the LHC
- diffractive events and the problem of the Pomeron
- diffraction at HERA vs. LHC
- exclusive diffraction at LHC
- investigation of hadronic final states
- vector-meson production
- diffraction and saturation at RHIC
- prospects in photon-photon physics
- Heavy ion reactions and hydrodynamics of the QGP
- AdS/CFT applications to QCD

We divided the meeting into 5 different sessions following the schedule of the workshop:

- Soft diffraction and total cross section
- Hard diffraction
- Low x and BFKL
- Exclusive diffraction
- Heavy ions

SPEAKERS:

H. Al Ghoul (University of Kansas, Lawrence, USA)

J. Baechler (CERN, Geneva, Switzerland)

C. Baldenegro (University of Kansas, Lawrence, USA)

J. Bartels (University of Hamburg, Germany)

L. Bonechi, University of Florence, Italy)

F. Ceccopieri (University di Perugia, Italy)

F. Celiberto (University of Calabria, Cosenza, Italy)

J. Chwastowski (PAN, Cracow, Poland)

D. Colferai (University of Florence, Italy)

T. Csorgo (University of Budapest/Gyongyos, Hungary)

F. Deganutti (University of Florence, Italy)

P. Erland (PAN, Cracow, Poland)

L. Forthomme (University of Kansas, Lawrence, USA)

P. Grafstrom (CERN Switzerland, and University of Bologna, Italy)

J. Kaspar (University of Pisa, Italy)

P. Lebiedowicz (PAN, Cracow, Poland)

C. Lindsey (University of Kansas, Lawrence, USA)

D. Lucsanyi (University of Budapest and Gyongyos, Hungary)

M. Luszczak (University of Reszow, Poland)

R. Maciula (University of Reszow, Poland)

R. Mc Nulty (University of Dublin, Ireland)

K. Osterberg (University of Helsinki, Finland)

G. Pancheri (INFN, Italy)

R. Pasechnik (Lund University, Sweden)

T. Peltzmann (Nikhef, Netherlands)

M. Praszalowicz (Jagellonian University, Cracow, Poland)

F. Ravera (University of Torino, Italy)

P. Rodriguez (University of Granada, Spain)

C. Royon (University of Kansas, Lawrence, USA)

R. Staszewski (PAN, Cracow, Poland)

M. Trzebinski (PAN, Cracow, Poland)

J. Williams (University of Kansas, Lawrence, USA)

SCIENTIFIC REPORT:

Many data have been accumulated at the LHC related to forward physics at a center-of-mass of7, 8 and now 13 TeV by the different experiments (Alice, ATLAS, CMS, LHCb, LHCf, TOTEM). They correspond to different acceptances related to the detectors and allow (ATLAS, CMS, TOTEM) proton tagging or not. In addition to a review of the present results, it was important to discuss the future plans at the LHC, especially for the low luminosity runs to be taken at 13 and 14 TeV or even at lower energies (2 TeV) in order to compare with Tevatron results.

The main topics discussed during the workshop were the following:

- Soft diffraction: the measurement of total and elastic cross sections as performed in ATLAS (ALFA) and TOTEM. It was stressed that it is important to perform these measurements at 14 TeV when available and also at Tevatron energies in order to measure the rho parameter
- Hard diffraction at the LHC: it can lead to a better understanding of the Pomeron structure and to study if the phenomenon of diffraction is the same at hadronic or electron-proton colliders such as HERA
- Low x and BFKL, saturation: It is important to identify new observables that can be measured at the LHC in order to see first the BFKL regime and then the saturation effects. Very forward jet measurements in pp and ep seem to be a good candidate.
- Exclusive diffraction: it might lead to important discoveries in QCD (glueballs) or beyond standard model physics (anomalous couplings)

- Heavy ion runs at the LHC: the importance of seeing Color Glass Condensate effects was discussed
- Detectors: some more experimental aspects such as the roman pots, Si and timing detectors and recent technologies were described.

Results and Highlights

Let us first mention that all talks were uploaded on indico so that they can be easily accessed: https://indico.cern.ch/event/568781/timetable/#all

1) Total and elastic cross sections

Both TOTEM and ATLAS can measure elastic scattering at very small t-values. Such small t-values allow a measurement of the rho-parameter i.e. the real to imaginary part of the elastic scattering amplitude in the forward direction. We discussed at the workshop the possibilities of performing this at the LHC. For the first time, we stressed the interest of going to lower energies for this measurement.

The energy of 2 TeV (or lower) would have a special interest related to the fact that measurements exist at 2 TeV from the Tevatron but in this case for anti-proton proton scattering. Proton-proton scattering and anti-proton scattering have not been measured at the same energy since ISR -times where a measurement of anti-proton proton scattering was performed at 52 GeV. Comparison of anti-proton scattering with proton scattering might give information on the up to now elusive C=-1 partner of the Pomeron i.e. the Odderon.

There is in addition a clear motivation to measure again soft diffraction at 14 TeV if the machine can deliver such an energy.

2) Hard diffraction and the Pomeron structure

We discussed the measurements in CMS-TOTEM/ATLAS that can constrain the Pomeron structure. The existence of diffractive events where protons are intact in the final state is explained by the exchange of a colorless object called the Pomeron. In hard perturbative QCD, the Pomeron can be assumed of being made of quarks and gluons (at lowest order, it can be two gluons in order not to have any color exchange). The idea is to define new observables at the LHC that are sensitive to the Pomeron structure.

The Pomeron structure in terms of quarks and gluons has been derived from QCD fits at HERA and at the Tevatron and it is possible to probe this structure and the QCD evolution at the LHC in a completely new kinematical domain at the LHC. In addition, we discussed the possibility to test if diffraction is due to the same processes at hadron or electron-proton colliders since soft rescattering effects can have a leading role at hadron colliders.

New observables such as dijets, gamma+jets, W asymmetries, etc., were discussed at the workshop. Many data have already been accumulated and new results are expected soon.

3) BFKL resummation and saturation

The difficult part of this topic is to find dedicated observables that are sensitive to BFKL resummation and saturation. We had some theoretical talks which aim at describing complex measurements such as 3 or 4 jets in pp collisions that should be sensitive to BFKL resummation effects. The measurements of jet gap jet events with two proton tagged is also quite interesting since it leads to a large fraction of gap between jets with respect to standard dijets (of the order of 15-20%).

Another interesting measurement that was presented is the very forward jet cross section in pp and pA runs. The suppression effects due to saturation can be as large as 80% for low pT jets and is strongly dependent on the difference in azimuthal angles between the two jets.

Data have already accumulated this autumn and the measurement should be performed soon.

4) Exclusive diffraction and beyond standard model

The advantage of the exclusive diffractive and photon exchange processes is that all particles can be measured in the final state. Both protons can be measured in CMS-TOTEM/CT-PPS/ATLAS and the produced particles (jets, vector mesons, Z boson, etc.) in CMS/ATLAS, and there is no energy loss such as in the pomeron remnants. It is thus possible to reconstruct the properties of the object produced exclusively (via photon and gluon exchanges) from the tagged proton since the system is kinematically constrained. It is worth mentioning that it is also possible to constrain the background by requesting the matching between the information of the two protons and the produced object, and thus, central exclusive production is a potential channel for beyond standard model searches at high masses.

This is indeed the case for di-photon, WW, ZZ productions that were discussed at the workshop. In all these cases, the observation of exclusive events at high masses would be the sign of new physics since background is found to be negligible for 300 fb-1 after selection. It leads to the best sensitivity at the LHC on anomalous couplings.

The low mass cases were also discussed, such as the exclusive production of two pions. The measurement has already been done by ATLAS and represents a test of QCD. TOTEM is also looking for the exclusive production of glueballs, which is a fundamental topic in QCD.

3.3.16 THREE-BODY SYSTEMS IN REACTIONS WITH RARE ISOTOPES

DATE: October 03-07, 2016

ORGANIZERS:

C. Bertulani (Texas A&M University-Commerce, USA)
R. Higa (University of Sao Paulo, Brazil)
A. Kadyrov (Curtin University, Australia)
A. Kruppa (Hungarian Academy of Sciences, Hungary)
A. Mukhamedzhanov (Texas A&M University, USA)

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

The development of the so-called Effective Field Theories (EFT) has provided a new path to account for three-body processes in nuclear reactions with applications to nuclear astrophysics. A challenge remains on how to proceed further with this method in studies of reactions at radioactive beam facilities. This requires a firm theoretical knowledge of three-body reactions, such as (d,p) reactions, at low energies. Theoretically, such processes are better studied by means of the generalized Faddeev equations in the Alt-Grassberger-Sandhas (AGS) form. Despite intense theoretical efforts, these reactions still lack a precise account, in particular because of the difficulty to handle the Coulomb interaction. This meeting has focused on the synergies among several theoretical and experimental methods that have been developed over the last few years. These include extensions of EFT for halo nuclei, three- and four-body systems, (d,p) reactions, and advanced multi-channel methods with focus on the underlying three-body mechanisms. The meeting has engendered a fruitful discussion of nuclear decays and nuclear reactions based on the most accurate knowledge of the nuclear interaction, the most reliable theoretical and experimental approaches, and the use of fast computers.

The main topics discussed in this workshop were:

- on the theory side we have concentrated on few-body aspects, i.e. those trying to link QCD to inter-nucleon interactions that can be used as input in ab-initio calculations (three-body, four-body) of low energy reactions. We have invited theorists who work on nuclear EFTs, renormalization group theory and nuclear reaction theories using few-body techniques;

- on the experimental side, we have focused on experiments aiming at researching indirect techniques linked to few-body problems, such as transfer and breakup reactions. In particular, the measurements related to applications to nuclear astrophysics has been highly emphasized. We had the presence of experimentalists who work on surrogate techniques for fusion reactions, halo nuclei, direct reactions, and decay processes.

SPEAKERS:

M. Avrigeanu (Horia Hulubei National Institute for Physics and Nuclear Engineering, Romania)

A. Bonaccorso (INFN, Italy)

K. Ogata Research Center for Nuclear Physics, Osaka University, Japan)

G. Orlandini (University of Trento, Italy)

D. Pang (Beihang University, China)

L. Canton (INFN Padova, Italy)

P. Capel (Université libre de Bruxelles (ULB), Belgium)

J. Casal (Universidad de Sevilla, Spain)

A. Deltuva (Vilnius University, Lithuania)

P. Descouvemont (ULB, Belgium)

H.-W. Hammer (TU Darmstadt, Institut für Kernphysik, Germany)

K. Hebeler (TU Darmstadt, Germany)

K. Jones (University of Tennessee, USA)

B. Jurado (CENBG, France)

N. Kalantar-Nayestanaki (KVI-CART, The Netherlands)

A. Kievsky (INFN, Italy)

M. La Cognata (INFN LNS, Italy)

A. M. Moro (Universidad de Sevilla, Spain)

M. Pato (University of São Paulo, Brazil)

D. Phillips (Ohio University, USA)

O. Rubtsova (Skobeltsyn Institute of Nuclear Physics, Moscow State University, Russia)

FNU Shubhchintak (Texas A & M University Commerce, United States)

Y. Suzuki (Niigata University, Japan)

N. Timofeyuk (University of Surrey, United Kingdom)

L. Trache (IFIN-HH, Romania)

H. Viet Nhan Tran (Texas A&M University-Commerce, United States)

A. Tumino (Università degli Studi di Enna "Kore", Italy)

T. Uesaka (RIKEN Nishina Center for Accelerator-Based Science, Japan)

F. Xu (Peking University, China)

SCIENTIFIC REPORT:

To make reliable predictions for the synthesis of chemical elements and the evolution of stars and galaxies, we need several types of data, including nuclear reaction rates that lead to nucleosynthesis. Stellar nucleosynthesis processes typically involve unstable nuclei with limited or no knowledge about the corresponding reaction rates. Direct measurements relevant for nuclear astrophysics involving unstable nuclei are difficult for two reasons: a) targets (or projectiles at appropriate energies for inverse kinematics) of unstable nuclei are not easily available, and b) charged-particle reactions at very low energies are difficult to measure due to Coulomb repulsion. This problem has led to the development and use of indirect methods. The list of indirect techniques that are used today includes Coulomb dissociation, transfer reactions (the ANC method), breakup at intermediate energies, the Trojan horse method, and spectroscopic studies, in particular the location of resonance states and the determination of resonance parameters. This meeting was focused on the synergies among several theoretical and experimental methods that have been developed over the last few years.

Results and Highlights

Our workshop has provided an opportunity to confront and discuss complementary theoretical approaches to the study of low-energy structure and reactions, as well as to acknowledge the status of relatively recent lines of research, such as ab initio reaction theory. There were also very interesting theoretical and experimental talks, where the need for a consistent treatment of theory and reactions was explicitly stressed. It was showed how the simultaneous consideration of a complete set of experiments such as elastic scattering, breakup reactions and transfer, could shed light on the interplay between structure and reaction aspects. One important conclusion was that different experiments seem to lead to conflicting conclusions regarding the structure of the nuclei involved, calling for a revision of the theoretical description of both the structure and the reaction aspects of such experiments.

This workshop has fostered new collaborations to solve the generalized three-body Faddeev equations (in the form of the AGS equations) taking into account explicitly both excitations of the target and Coulomb interaction. Very interesting results on the importance of multiple continuum-continuum transitions where shown and how a special treatment of the matrix elements have to be introduced to circumvent divergences. One of the main results has been the opportunity to shed some light on the specific role that three-body mechanisms play in both reactions with rare nuclear isotopes and in nuclear astrophysics, and to identify mechanisms and reasons for the appearance of such a generalized three-body imprints. The meeting emphasized the interplay between nuclear reaction techniques including, e.g., effective field theory methods, and how they fare when compared with data.

During the workshop, many healthy discussions arose, confronting microscopic or macroscopic (phenomenological) methods in reaction theory and their interface with nuclear structure. Most importantly, our workshop gathered the major experts in the field of nuclear reactions from around the world. As an outcome, lively and vivid discussions arose, pointing out the major reasons for the weakness of some theories and experimental analysis. Judging by the several positive comments send to the organizing committee by participants, this workshop is considered a full success within its range of scope.

3.3.17 PHYSICS BEYOND THE LIMITS OF STABILITY: EXPLORING THE CONTINUUM

DATE: October 17-21, 2016

ORGANIZERS:

A. Bonaccorso (INFN Pisa)
N. Orr (LPC-Caen, France)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The focus of the workshop was on the understanding the physics of systems lying beyond the limits of stability - that is, states residing in the continuum - with emphasis on the light (A<40) neutron rich nuclei. Apart from the extreme tests that their structure provide for models, owing to their large N to Z ratios, and the influence of the continuum, together with the increasing importance of the effects of 3 nucleon force, such systems are now, with the advent of facilities such as the RIBF-RIKEN, accessible experimentally. Beyond their spectroscopy and the influence of the manner by which they are formed, new phenomena are expected to occur, including correlations (such as di-neutron-like configurations) between the unbound valence neutrons. In addition, as recent studies have suggested, the possibility of multi-nucleon correlations, in particular, those involving 4 neutrons have resurfaced.
The workshop was organized around the following principal themes each of which was assigned, as best as possible, a full day. Each day, except Friday concluded with a general discussion session lead by one of the senior participants.

The main topics were:

- Structure models (Monday, Tuesday, Thursday)
- Reaction models (Monday, Tuesday)
- The 4-neutron and related very light systems (Wednesday)
- Reaction and other probes and extracting structural information from the observed spectra (Monday, Tuesday)
- New experimental data (Monday, Thursday)
- Neutron-neutron correlations (Thursday, Friday).

SPEAKERS:

G. Blanchon (CEA, Arpajon, France)
J. Carbonell (IPN-Orsay, France)
M. Cavallaro (LNS Catania, Italy)
J. Dohet-Eraly (INFN Pisa, Italy)
T. Fukui (INFN Naples, Italy)
L. Grigorenko (FLNR JINR, Dubna, Russia)
K. Hagino (University of Tohoku, Japan)
E. Hiyama (RIKEN, Japan)
G. Hupin (CEA, Arpajon, France)
F.M. Marqués (LPC-Caen, France)
T. Nakamura (Tokyo Institute of Technology, Japan)
N. Orr (LPC-Caen, France)
M. Ploszajczak (GANIL, France)
K. Riisager (Aarhus University, Denmark)
G. Rogachev (Texas A&M University, USA)
P. Sharov (FLNR JINR, Dubna, Russia)
S. Shimoura (CNS-Tokyo, Japan)
A. Shirokov (Moscow State University,

R. Kanungo (St Mary's University, Canada)
Y. Kikuchi (RIKEN, Japan)
Y. Kobayashi (University of Niigata, Japan)
H. Lenske (University of Giessen, Germany)
A. Lovell (NSCL-MSU, USA)

Russia)
E. Vigezzi (INFN Milan, Italy)
A. Volya (FSU, USA)
F. Wamers (GSI, Germany)
A. Wuosmma (University of Connecticut, USA)

SCIENTIFIC REPORT:

The study of nuclei far from stability is one of the most active domains in nuclear physics today as evidenced by the intense activity around recently commissioned facilities, such as the RIBF-RIKEN, and the construction and planning of new installations (e.g., SPES, Italy and the RISP, South Korea). In parallel, advances in theoretical approaches – in particular those of an "ab initio" character – coupled with dramatically increasing computational capabilities are providing for even more sophisticated and realistic modelling of light (A<40) nuclei away from stability.

The workshop was devoted, as indicated earlier, to exploring those systems lying beyond the limits of stability with emphasis on the light, very neutron rich systems. In addition to providing for extreme tests for structure models, they provide a window on the role of the continuum and the effects of three-nucleon forces. Beyond issues related to their spectroscopy, new phenomena are predicted to occur, including correlations between the unbound valence nucleons. Moreover, while two-proton radioactivity is now reasonably well established and studied, two-neutron radioactivity remains an open issue. Finally, the possibility of multi-nucleon correlations, in particular, those involving 4 neutrons – either within the continuum states of ^{7}H, ^{19}B and ^{28}O, for example – or as a tetra-neutron resonance, remain to be seriously investigated.

The workshop assembled some of the leading players along with a selection of younger up and coming physicists within the field, and allowed for the exchange of the latest results and developments, as well as looking forward to the next steps – both theoretically and experimentally. The following key questions were addressed:

- Unbound states can be accessed by a number of different reaction probes and techniques: nucleon transfer and missing mass spectroscopy, breakup/"knockout" and invariant mass spectroscopy, and resonant elastic scattering. Are the different techniques and theoretical approaches employed equally accurate and reliable?
- How can we best model reactions (transfer, "knockout"/breakup) leading to continuum states? How well can we describe the population of the non-resonant continuum?
- Can we determine the structure of a continuum state independently from the reaction mechanism, which produced it? What are the most appropriate observables?
- What are the limitations of the various structure models and how can they be overcome?
- What is the role of 3N (and potentially 4N) forces in the structure of the most exotic systems?
- How should/can we couple (sophisticated) structure calculations with reaction models?

What is the best means to probe and to model realistically neutron correlations? What lessons can we learn from two-proton radioactivity?

Results and Highlights

The workshop was an unqualified success and, quite apart from generating a great deal of debate, it shed light on a number of the issues mentioned above.

In a first instance the significant advances in "ab-initio" type approaches for describing continuum states in light nuclei and their reactions were discussed, as were their limitations and avenues for further developments. One clear message was the ability to now treat in a unified manner the bound and continuum states. An important feature of present-day calculations is their capability to compute the phase shifts of resonant states from which the resonance energies and widths can be estimated.

Improved modelling of low-energy nucleon transfer to continuum states using refinements of existing techniques generated considerable interest. Its significance in terms of interpreting experiments, which are now becoming more frequent with the advent of ISAC2-TRIUMF and HIE-ISOLDE-CERN, was underlined by a vigorous discussion of attempts to model very recently acquired data (presented at the workshop) for the d(^{9}Li,p)^{10}Li reaction. An often neglected, but important feature of such reactions populating broad resonances, was also brought to the attention of the workshop through the example of the d(^{6}He,^{3}He)^{5}H reaction – namely the variation in Q-value across the resonance.

The importance of the manner by which continuum states (especially those which are broad) are populated – including via beta-decay – was also discussed and the need to take such effects into account to extract structural information was a clear conclusion. This was detailed in particular by the case of recent studies of ^{10}He. It is clear, however, that the present tools being employed in this direction need to be improved (for the most part a "source" approach has been employed). This issue links back to the attempts to improve the modelling of transfer reactions to continuum states and the need to develop further the methods to model high-energy knockout. In this context, the transfer to the continuum approach, as discussed, has shown the way.

Considerable attention was payed, both experimentally and theoretically, to the issues surrounding correlations in the decay (typically in-flight) of unbound systems and continuum states. While the general principles are recognized – realistic structure models followed by a proper evolution of the decaying particles including the final-state interactions – detailed and rigorous calculations are not simple. The need to incorporate the experimental setups' response and acceptance effects were agreed to be of importance in the testing of predications against theory.

The character of multi-neutron systems stimulated a great deal of attention and discussion. Preliminary NCSM (No core shell model) in the continuum calculations as well as N-body ab-initio type calculations employing explicitly 3N forces suggest that, at best, the 4n system exists as an extremely broad structure at relative high energy in the continuum. In stark contrast, NSCM calculations employing a new NN interaction (JISP16) point to a possible near threshold resonance of relatively narrow width, in surprisingly good agreement with the recent results from RIKEN (presented in detail at the workshop). At present it is not clear if the latter also reproduce neighboring systems such as ^{4}H. An important outcome of the discussions is that the RIKEN-French collaboration performing the N-body calculations will attempt to employ the JISP16 interaction without an explicit 3N force. Importantly, the first attempts to see whether the reaction used to populate the 4n system can produce a low-lying effect were discussed. Finally, the somewhat surprising links between the properties of systems such as ^{5}H and those of hypernuclei, as seen in recent studies, were pointed out.

Finally, from an experimental point of view a number of new experimental results were presented during the workshop, including new direct reaction studies of ^{5}H, ^{10,11}Li, the first spectroscopy of ^{21}C and high precision results for ^{26}O. As noted earlier, some of these provided the focus for discussions of various theoretical developments. Important theoretical feedback was provided during the discussions for a proposal being prepared for RIKEN to measure the n-n correlations in the decay of ^{26}O.

3.3.18 NUCLEON AND NUCLEI STRUCTURE THROUGH DILEPTON PRODUCTION

DATE: October 24-28, 2016

ORGANIZERS:

A. Camsonne (Jefferson Laboratory, USA)
L. Szymanowski (National Centre for Nuclear Research - NCBJ, Warsaw)
E. Voutier (Institut de Physique Nucléaire d'Orsay, France)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The workshop focused on the study on the nucleon structure through dilepton production. Higher luminosities together with improved detector technologies open access to dilepton measurements that can give new information on Generalized Partons Distributions (GPDs).

The main topics were:

- Generalized Parton Distributions
- Double Deeply Virtual Compton Scattering
- Timelike Compton Scattering
- Meson Production
- Drell Yann
- Fitting of GPDs

SPEAKERS:

I. Anikin (JINR, Russia)

N. Baltzell (JLAB, USA)

M. Boer (LANL, USA)

R. Boussarie (INP Krakow, Poland)

V. Braun (Regensburg University, Germany)

S. Brodsky (SLAC, USA)

A. Camsonne (JLAB, USA)

W.-C. Chang (Institute of Physics Academia Sinica, Taiwan)

L. Colaneri (IPNO, Orsay)

S. Dobbs (Northwestern University, USA)

A. Efremov (JINR, Russia)

K. Gnanvo (University of Virginia, USA)

O. Gryniuk (Mainz University, Germany)

M. Guidal (IPN Orsay, France)

V. Guzey (Petersburg Nuclear Physics Institute, Russia)

C. Hyde (Old Dominion University, USA)

Y. Ilieva (University of South Carolina, USA)

P. Kroll (University of Wuppertal, Germany)

K. Kumericki (University of Zagreb, Croatia)

S. Liuti (University of Virginia, USA)

Z.-E. Meziani (Temple University, USA)

K. Semenov-Tian-Shansky (Petersburg Nuclear Physics Institute, Russia)

S. Stepanyan (Jefferson Lab, USA)

Y. Szymanowski (NCBJ, Warsaw, Poland)

V. Tadevosyan (A.I.Alikhanian National Science Lab., Armenia)

O. Teryaev (JINR, Dubna, Russia)

E. Voutier (IPN Orsay, France)

J. Wagner (NCBJ, Warsaw, Poland)

C. Weiss (Jefferson Lab., USA)

Z. Zhiwen (Duke University, USA)

SCIENTIFIC REPORT:

Many experiments are dedicated to exclusive reaction measurements, particularly Deeply Virtual Compton Scattering (DVCS), in order to extract Generalized Parton Distributions. Other processes with a lepton pair in the final state can also allow access to GPDs assuming their universality. The goal of the workshop was to summarize properties of GPDs and address questions relevant to those processes:

- Double Deeply Virtual Compton Scattering (DDVCS)
    - Are the kinematical region $Q'^2>Q^2$ and $Q'^2<Q^2$ equivalent?
    - Does the process need finite t correction to be taken into account?
    - What observables are the most interesting?
    - What is the effect of the antisymmetrisation for DDVCS in the e^+e^-?
- Timelike Compton Scattering (TCS)
    - What does Timelike Compton Scattering brings to the GPD program?
    - Which measurements can be carried out and which ones are the most interesting to be done in a short time scale?
- Deeply virtual meson production (DVMP)
    - What can be extracted from the DVMP program?
    - What can we learn from J/psi at threshold production?
- Drell Yan (DY) process
    - Complementarity of the pp Drell Yan program with the GPD program for nucleon structure
    - Pion Drell Yan for GPD measurement
- GPD fits
    - Do we have ways to extract GPDs from the DVCS data?

What would other processes such as DDVCS, TCS and DVMP bring to the GPD extraction?

Results and Highlights

The workshop was very well received and allowed to bring together experimentalists from several different facilities with theory experts of the field.

A summary of GPD models, properties and representations laid requirements ground for a complete determination of GPDs. Models are successful to describe the data in limited kinematical ranges which can already help to extract information and predict rates for other processes. More complex models will be needed to fully describe the GPDs over the full kinematical range.

A roadmap for possible measurements and the incorporation of this process in the global GPD analysis was discussed. Particularly, the scientific benefits of such measurements were clearly established. Several issues were discussed and specific work was initiated. In the case of DDVCS a consensus emerged that the full kinematical range of the dilepton mass (Q'^2) is equally scientifically valuable on both side of the initial virtual photon line (Q^2). This allows focusing on a kinematical range, easier reachable in experiment. The relevant scaling variable Q^2-Q'^2 defines different regions of applicability of factorization models.

The discussion among the participants allowed defining an experimental strategy. The consensus was to focus on a small scale experiment which could run early and demonstrate the sign change of the asymmetry at fixed Q^2 varying Q'^2 for DDVCS with dimuons in the final state. This would also confirm GPDs universality, and would consequently comfort the notion of global GPD fits using other processes as TCS for example. A quick study of the e^+e^- case was also presented, but the required accuracy in the treatment of the anti-symmetrisation process might lead to larger uncertainties than in the dimuons case. Sample of those DDVCS events in e^+e^- channel will be available from parasitic CLAS12 electro-production data but it was decided to first focus on the muon measurement.

Similar to DDVCS, TCS could also provide measurements complementary to DVCS. Such an experiment allows access to the real part of the DVCS amplitude and is also sensitive to the E GPDs. Experimentally, a photon source on a transversally polarized target is easier to achieve than in the electro-production channel. This option is expected to be studied in details in a near future with a possible new high intensity photon source.

The Deeply Virtual Meson production (DVMP) and exclusive photo-production of the ρ-meson seem to be a good handle to access transversity GPDs. J/Ψ production gives information about the gluon distribution of the nucleon even in JLab kinematics. The Drell-Yan process probes the sea structure of the nucleon and is linked with TMDs. A large amount of data is available from Fermilab, BNL, CERN and KEK. Several measurements are also planned at those facilities and at the new NICA facility under construction in Dubna. Pion Drell-Yan measurements can complement the kinematical coverage of electron machines for DVMP and would allow hadron machines to contribute to the GPD program.

Fit techniques are in an advanced stage and are already able to extract, in a model dependent way, interesting GPDs allowing the reconstruction of the nucleon structure. Future additional high quality data will allow removing the model dependence of fitting procedures. Methods based on the VGG model allow already global fitting of GPDs using DVCS and TCS data. Including DDVCS data in this process would require a year-scale work. As discussed during the meeting, the D-term is largely unconstrained by current data. This motivates further DDVCS measurements but this needs to be supported by extensive pseudo-data. The PARTON framework allows fast computation of observables from different GPD models, and provides a modular environment especially suited for an easy implementation of different models.

To summarize, the community was encouraging all dilepton measurements, particularly the sign change of the DDVCS asymmetry, which would yield an unambiguous signature of GPDs universality. Preliminary fitting results showed the benefits of the different processes for GPDs extraction, and work towards determining the achievable accuracy with future data has been initiated at the workshop.

3.3.19 GAUGE TOPOLOGY: FROM LATTICE TO COLLIDERS

DATE: November 7-11, 2016

ORGANIZERS:

M. D'Elia (University of Pisa, Italy)
E. Shuryak (Stony Brook University, USA)

NUMBER OF PARTICIPANTS: 35

MAIN TOPICS:

The main topics were:

- Topological susceptibility, instantons and $U_A(1)$ effects at high temperatures
- Confinement: electric flux tubes and vortices
- Confinement: lattice monopoles
- Instanton-dyons and deconfinement transition
- Mechanism of chiral symmetry breaking and restoration
- Deformations of QCD: extra operators with Polyakov line, adjoint color, imaginary chemical potentials, flavor-dependent holonomies

SPEAKERS:

C. Bonati (Dipartimento di Fisica e Astronomia & INFN, Florence, Italy)

P. Buividovich (University of Regensburg, Germany)

M. Catillo (University of Graz, Austria)

L. Cosmai (INFN Bari, Italy)

M. D'Elia (University of Pisa, Italy)

A. Di Giacomo (University of Pisa, Italy)

A. Dromard (University of Regensburg, Germany)

M. Faber (TU Wien, Austria)

P. Faccioli (University of Trento, Italy)

Z. Fodor (Wuppertal University, Germany)

K. Fukushima (University of Tokyo, Japan)

M. Garcia Perez (University of Madrid, Spain)

C. Gattringer (University of Graz, Austria)

L. Glozman (University of Graz, Austria)

J. Greensite (University of California at San Francisco, USA)

M. Ilgenfritz (JINR, Dubna, Russia)

R. Larsen (Stony Brook University, USA)

T. Iritani (University of Tokyo, Japan)

M. Lombardo (INFN, Frascati, Italy)

M.A. Lopez-Ruiz (University of Indiana at Bloomington, USA)

B. Martemyanov (ITEP Moscow, Russia)

M. Puhr (University of Regensburg, Germany)

E. Shuryak (Stony Brook University, USA)

T. Sulejmanpasic (Ecole Normale Supérieure, Paris, France)

A. Turbiner (University of Mexico, Mexico)

S. Valgushev (University of Graz, Austria)

A. Zhitnitsky (University of British Columbia, Canada)

SCIENTIFIC REPORT:

The workshop attracted leading experts on gauge topology from Europe, the USA and Japan. Although the organizers adopted relatively lengthy lecture-style time slots for each talk, there were 27 of them, packed into 4.5 days. It was the second workshop on this topic, the first being held at Stony Brook in August 2015. This time it had naturally a much larger European participation, but followed the first in style and subject.

The overall vitality of the community is seen from the significant scientific progress achieved over just one year's time since the first workshop. Therefore, it has been decided to continue the series, with "Gauge topology III", tentatively planned for the spring of 2018. The excellent organization of the workshop on the part of ECT* has prompted our decision to apply to ECT* again for that time slot.

The two main pillars of the workshop were: i) new lattice data on gauge topology observables; ii) progress in modeling the QCD phase transitions using topological solitons, monopoles, instantons and – most represented this time – instanton-dyons. We will discuss those subsequently below.

Regarding lattice results, one of the main topics concerned calculations of the global parameters of the topology, topological susceptibility χ and interaction parameter b2, as a function of the temperature, especially in view of providing information relevant to axion physics. Z. Fodor reported on the recent achievements of his group, based on numerical simulations with dynamical fermions and physical quark masses, ranging from T = 100 MeV to about 2000 MeV, which concluded that the region above Tc is well described by an ideal gas of instantons. C. Bonati and M. Lombardo presented a different set of lattice measurements of the topological susceptibility, which has a smaller T range, but display a much weaker T-dependence. The methology and the approximations involved in each of these works and the possible reasons for the disagreement have been extensively discussed during the Thursday session. One of the problems in the measurement of topological quantities is related to the critical slowing down of topological modes towards the continuum. In this respect, an interesting possible new approach has been discussed by A. Dromard. M. Ilgenfritz and B. Martemyanov discussed a direct localization of the instanton-dyons in lattice configurations. Ilgenfritz also discussed results related with complex chemical potentials. More possibilities for future lattice studies related with complex chemical potentials and external fields have been outlined in the final talk by M. D'Elia. L. Glozman described several papers by the Graz group and by others, to separate the effects of the quasi-zero-mode-zone in the Dirac eigenvalue spectra – leading to SU(Nf) and U(1) chiral symmetries breakings – from the effect of all other modes, which seem to show a much higher degree of symmetry. An interesting talk along this direction was presented also by M. Catillo.

P. Buividovich, K. Fukushima and M. Puhr discussed effects of magnetic fields, related with chiral magnetic effect. C. Gattringer described ongoing attempts to reformulate lattice gauge theories in terms of dual variables, something, which could be a solution to the sign problem in lattice simulations at finite baryon density.

Regarding topological solitons and their role in confinement/deconfinement, the workshop started with a concise lecture by A. Di Giacomo, devoted to lattice monopoles and their role in the confinement phenomenon. Other aspects of confinement have been discussed by J. Greensite, M. Faber and L. Cosmai, regarding respectively the static potential, the role of center vortices in the problem of confinement and the structure of the color flux tube at zero and finite temperature. A. Zhitinitsky presented and discussed an intriguing analogy between topological excitations in QCD and in superfluid systems. Instanton-dyon ensemble studies have been discussed by E. Shuryak, E. Larsen and M. Lopez-Ruiz. It was shown that deconfinement and chiral transitions, in pure gauge and 2-flavor QCD are reproduced in this approach. Furthermore, dramatic changes in both transitions are seen for the so-called ZN QCD, consistent with recent lattice data reported at the workshop by Iritani. The connection of these results with those on complex chemical potentials still needs to be studied. S. Valgushev discussed the role of complex instantons in two-dimensional gauge theories. Other topics included the talks by M. García Pérez and T. Sulejmanpasic on "volume independence", the setting in which no phase transitions happen when a gauge theory is compactified on a circle. A. Turbiner instead summarized new developments in the semiclassical theory of quantum mechanics. We also had an exciting talk by P. Faccioli, on the usage of instanton-like tools in the physics of protein folding.

The overall success of the workshop is to a large extent due to its relatively small size of about 30 participants, that fostered scientific discussion, and to the decision of having all lunches and dinners together. The quality of those significantly improved compared to our former experiences: we congratulate the ECT* staff for this and for the overall smooth organization.

Results and Highlights

In general, the field of gauge topology clearly finds its revival, attracting new attention both from the lattice community and from theorists working on semiclassical description of topological solitons.

Significant progress in lattice studies of the gauge topology is measurement of the topological susceptibility as a function of the temperature for the full QCD theory, i.e. in the presence of light dynamical quarks. This is important by itself, but also in connection to possible axion phenomenology. Present lattice studies are trying to deal with algorithmic sampling difficulties in the region of high temperature, which is the most relevant for axion cosmology. Various new strategies have been proposed in the last few months; some differences between various methods of calculation remain and are yet to be resolved.

Semiclassical theories, based on instanton-dyons, have used a number of many-body methods to describe the topology of the gauge fields. This approach has reproduced lattice data for the deconfinement transition, in pure gauge and in QCD-like theories. The same was shown for the chiral symmetry restoration transition.

Imaginary chemical potentials, or flavor-dependent holonomy phases as they are also called, provide a large variety of QCD-like theories in which the deconfinement and chiral symmetry restoration transitions are significantly modified. These phenomena were shown to be related with fermionic zero modes of the instanton-dyons.

3.4 ECT* DOCTORAL TRAINING PROGRAM 2016

Nuclear, neutrino and relativistic astrophysics

(Report by G. Ripka)

The 2016 ECT* Doctoral Training Program (DTP) on ***Nuclear, neutrino and relativistic astrophysics*** was held at ECT* from June 6 to July 15 for a duration of 6 weeks. The program coordinator was Sanjay Reddy (University of Washington), 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 2016 DTP was attended by 11 full-time students and 3 part-time students. All students were working on their PhD.

There were 7 lecturers, one each week, except for the 3rd week, during which there were 2 lecturers. In addition, Jochen Wambach, the director of ECT*, held a t*utorial on General Relativity and gravitation*.

Two lectures were delivered each morning. The fact that the lecturers were present at ECT* in the afternoons allowed the students to closely interact with them.

Each student was asked to give a half-hour seminar on her/his present research, or, in case s/he had just started the PhD work, on her/his previous research. The seminars were held in the afternoon and were announced on the ECT* Web page, in the DTP Weekly Program section. The student seminars are listed below.

Most lecturers prepared slides, handwritten notes and other material available to the students. The material was placed in a new so-called Private Area of an FBK website, which could only be accessed from ECT*, using a password provided to each student by ECT*. It was decided that the files in the Private Area would be deleted at the end of the Doctoral Training Program. The website, designed by Barbara Curro' Dossi, with practical information for the students, proved very useful and was well received.

At the end of the DTP, each student was given a USB key containing the lecture notes, student seminars, photographs and the list of lectures for each week.

At the end of the program, the students were asked to provide an informal (anonymous) report, with a personal assessment of the 2016 DTP programme. The reports were handed over to the ECT* director.

3.4.1 Lecture Programme

The lecturers were asked to use the blackboard rather than deliver power-point-like presentations and they partly did so. Plots of results were, of course, projected on a screen.

Week 1, June 6-10

Baha Balantekin *(University of Wisconsin-Madison, USA)*
Neutrinos in astrophysics and cosmology

The lectures of Balantekin started with the essentials of neutrino physics. He described Majorana fields and their charge conjugates and introduced the interaction terms of the

Standard Model Lagrangian for electrons and neutrinos. He discussed charge-conjugate fields, mass matrices of neutrinos, neutrino oscillations, effective interactions obtained in mean-field approximations, particle distribution functions, and rates of particle production. He gave a qualitative description of nuclear synthesis, neutrino heating, and the proton loss rate. He discussed the conditions of hydrostatic stellar equilibrium. He concluded his lectures with the cosmological expansion and issues related to Big Bang nucleosynthesis.

Week 2, June 13-17

Alexander Heger *(Monash University, Australia)*
Stellar evolution and explosions

The lectures of Heger dealt with the theory of stellar evolution and pre-supernova conditions. He discussed the equation of state (EOS) of a star and the relevant thermodynamic variables, such as pressure and energy density, the mean molecular weight, and the total gas pressure. For the description of stellar evolution he introduced the concepts of degenerate electrons, adiabatic exponents, crystallization, Coulomb parameters, energy conservation and transport, the mean free path of a photon, and the diffusive flux. He also discussed conditions for crystallization, energy transport, thermodynamic reactions and others. He ended by showing a variety of Kippenhahn diagrams.

Week 3 (June 20-24, 2016)

Jochen Wambach *(Director of ECT*, Trento)*

To put some of the DTP lectures in a more general context Wambach gave a tutorial on General Relativity and gravitation. The geometry of a curved space was introduced on a 2-dimensional surface. The motion of a point particle and the geodesics on this surface were described using the Lagrange equations. Covariant and contravariant vectors and tensors were introduced as well as the Riemann tensor, parallel transport, and tangent planes. These geometrical concepts were taken over to 4-D space-time to yield the Einstein equations. Examples such as spherical mass distributions and the Schwarzschild metric were presented as well as gravitational waves.

Thomas Janka *(Max Planck Institut für Astrophysik, Garching, Germany)*
Supernova theory

Janka discussed the roughly 1-10 stellar explosions per second in the universe (2 every 100 years in the Milky Way). He introduced the phenomenology of stellar explosions, including neutrino bursts, the supernova classification scheme, and the cosmic cycle of matter, the adiabatic index, thermonuclear supernovae, and other phenomena. He discussed in detail the numerical simulations of core-collapse supernovae for stars with masses between 8 and 100 solar masses, including the role of neutrino heating and showed a variety of numerical result for the core-collapse dynamics.

Paolo Mazzali *(Astrophysics Research Institute, Liverpool University, UK)*
Observations of core-collapse supernovae

Mazzali lectured on how to understand and classify data obtained by the observation of supernova explosions. He explained how to interpret the spectral lines of H, He, C, … so as to distinguish different types of supernovae. He discussed conditions for the formation of shock waves. He described qualitatively various stellar processes and discussed the conditions for when and how they occur during the evolution.

Week 4: June 27-July 1

Sanjay Reddy *(University of Washington, USA)*
Neutron stars and dense matter

Reddy started with how to estimate orders of magnitudes for the equilibrium conditions of compact stellar objects such as white dwarfs and neutron stars, including requirements from General Relativity. He continued with thermodynamics, introducing the Helmholtz and Gibbs free energy, non-interacting Fermi gases, the liquid drop model, and the neutron and proton chemical potentials. He discussed different regions in the crust of neutron stars as well as the Gibbs conditions for phase transitions at high densities. He discussed the role of hyperons, weakly interacting quark matter, high-density phase transitions, as well as pairing and its influence on the specific heat. He ended by discussing the birth and evolution of an isolated neutron star.

Week 5: July 4-8, 2016

Bruno Giacomazzo *(University of Trento, Italy)*
Neutron star mergers and gravitational waves

Giacomazzo started by discussing Schwarzschild black holes, point particles orbiting around black holes, minimal radii, innermost stable circular orbits, Kerr spinning black holes, ergospheres and jets emerging from black holes. He then went on to explain the theory of gravitational waves, with an example of two particles. He introduced classifications of gravitational waves, which depend on the mass ratio of a compact binary system, on the black hole spin and on the neutron star's compactness. He ended by discussing electromagnetic emission and jets from binary neutron star mergers.

Week 6: July 11-15, 2016

Friedel Thielemann *(University of Basel, Switzerland)*
Nucleosynthesis

Thielemann discussed the ejecta from various stars and how they are generated. He explained the basic physics incrediences for nuclear reaction rates in stars. He then proceeded to describe stellar burning stages, conditions for electron capture, how neutron capture is required to form nuclei heavier than ^{56}Fe, the formation of heavy elements, the r-process, explosive nucleosynthesis in core-collapse supernovae, mass transfer from companion stars, and super-bursts from carbon burning. He explained how Coulomb barriers increase the cross-sections for protons but decreases them for neutrons and how gravitational contraction raises the temperature.

3.4.2 List of Participants

Full time students:

Ibrahim Ceyhun Andac	Istanbul Technical University, Turkey
Prasanta Char	Saha Institute of Nuclear Physics, Kolkata, India
Sercan Cikintoglu	Istanbul Technical University, Turkey
Basak Ekinci	Mimar Sinan Fine Arts University, Istanbul, Turkey
Konstantin Maslov	National Research Nuclear University "MEPhI", Moscow, Russia
Hirokazu Sasaki	University of Tokyo, National Astronomical Observatory, Japan
Armin Vahdat Motlagh	Istanbul Technical University, Turkey
Nicole Suzanne Vassh	University of Wisconsin, Madison, USA
Eda Vurgun	Istanbul Technical University, Turkey

Anna Maria Zdeb — University of Maras Curie-Sklodowska, Lublin, Poland
Yonglin Zhu — North Carolina State University, USA

Part time students:

Timon Emken — University of Southern, Denmark
Niklas Gronlund Nielsen — University of Southern, Denmark
Hannah Yasin — TU Darmstadt, Germany

3.4.3 Seminars delivered by the students

Hannah Yasin *(TU Darmstadt, Germany)*
Gamma ray bursts triggered by neutrino-antineutrino annihilation

Prasanta Char *(Saha Institute of Nuclear Physics, Kolkata, India)*
Role of hyperon matter in core collapse supernova

Basak Ekinci *(Mimar Sinan Fine Arts University, Istanbul, Turkey)*
Modelling the circumnuclear disc and the young stellar discs at the galactic center

Nicole Suzanne Vassh *(University of Wisconsin, Madison, USA)*
Neutrino magnetic moment in the laboratory, astrophysics and cosmology

Konstantin Maslov *(National Research Nuclear University "MEPhI", Moscow, Russia)*
A method of stiffening the relativistic mean field (RMF) equation of state and its application to the hyperon puzzle

Eda Vurgun *(Istanbul University, Turkey)*
Spectral evolution of an anomalous X-ray pulsar

Anna Maria Zdeb *(University of Maris Curie-Sklodowska, Lublin, Poland)*
Spontaneous fission mass distribution

Yonglin Zhu *(North Carolina State University, USA)*
Neutrino oscillations above a numerically computed disk from a merging compact object

Hirokazu Sasaki *(University of Tokyo, National Astronomical Observatory, Japan)*
Collective neutrino oscillations and application to nucleosynthesis in core-collapse supernovae

Armin Vahdat Motlagh *(Istanbul Technical University, Turkey)*
Observational properties in low mass X-ray binaries

Ibrahim Ceyhun Andac *(Istanbul Technical University, Turkey)*
The inclination angle and evolution of the braking index of pulsars with plasma filled magnetosphere

Sercan Cikintoglu *(Istanbul Technical University, Turkey)*
Relativistic stars in the Starobinsky Model with matched asymptotic expansions

Timon Emken *(University of Southern Denmark)*
Simulating dark matter trajectories for direct detection experiments

Niklas Gronlund Nielsen *(University of Southern Denmark)*
Dark matter bound states in the sun

4 Research at ECT*

In this chapter the 2016 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. Among the ECT* Senior Scientists, Daniele Binosi continued his efforts in coordinating a European project in the field of quantum information (Qute-Europe) in parallel to his research in QCD. Alexis Diaz-Torres, who moved to the University of Surrey as a Senior Lecturer in Theoretical Nuclear Physics in September 2016, works on low-energy nuclear reaction dynamics relevant to astrophysical processes and has acted as advisor of a PhD student at the University of Trento. Dionysis 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 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 prediction 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. The final result for the full NLO corrections to DIS in the dipole picture, combining both types of contributions, will follow soon [4].

Heavy quark contributions to forward particle production in high-energy proton-nucleus collisions

In collaboration with T. Altinoluk, N. Armesto (University of Santiago de Compostela, Spain), A. Kovner (University of Connecticut, USA) and M. Lublinsky (Ben Gurion University, Israel)

The single-inclusive hadron production at forward rapidity is the simplest observable which can be used to study the onset of non-linear gluon saturation effects in high-energy hadronic collisions, such as proton-nucleus collisions at the LHC. As such, it is one of the first processes to be studied beyond leading order in this context. In Ref. [5] we cross-checked the earlier results [6] for the next-to-leading order (NLO) correction to that observables, where only massless quarks and gluons were considered. In a follow-up paper [7], we calculated the heavy quark contribution, so that now the full NLO correction to that observable is known analytically.

Exclusive diffractive dijet production in Deep Inelastic Scattering at low Bjorken x

In collaboration with T. Altinoluk, N. Armesto (University of Santiago de Compostela, Spain) and A. H. Rezaeian (Federico Santa Maria Technical University, Chile)

In Ref.[8], we studied exclusive dijet production in diffractive DIS at low Bjorken x, in the dipole picture. As other diffractive observables, that process is sensitive to the impact parameter profile of the dipole-target amplitude, which is not accessible through inclusive DIS. But in addition, we found this observable to be also sensitive on the dependence of the dipole-target amplitude on the angle between the dipole vector and the impact parameter vector. That angular dependence is neglected in all available phenomenological models. Hence, exclusive dijet production in diffractive DIS is an important process to consider in order to improve the theoretical description of high-energy scattering with gluon saturation.

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Daniele Binosi

Symmetry preserving truncations of the gap and Bethe-Salpeter equations

In collaboration with L. Chang (University of Nankai, China), J. Papavassiliou (University of Valencia, Spain), S.-X. Qin (Argonne NL, US), C. D. Roberts (Argonne NL, US)

Ward-Green-Takahashi (WGT) identities play a crucial role in hadron physics, e.g. imposing stringent relationships between the kernels of the one- and two-body problems, which must be preserved in any veracious treatment of mesons as bound-states. In this connection, one may view the dressed gluon-quark vertex, Γ^a_μ, as fundamental. In this work we use a novel representation of Γ^a_μ, in terms of the gluon-quark scattering matrix, to develop a method capable of elucidating the unique quark-antiquark Bethe-Salpeter kernel, K, that is symmetry-consistent with a given quark gap equation. A strength of the scheme is its ability to expose and capitalise on graphic symmetries within the kernels. This is displayed in an analysis that reveals the origin of H-diagrams in K, which are two-particle-irreducible contributions, generated as two-loop diagrams involving the three-gluon vertex, that cannot be absorbed as a dressing of Γ^a_μ in a Bethe-Salpeter kernel nor expressed as a member of the class of crossed-box diagrams. Thus, there are no general circumstances under which the WGT identities essential for a valid description of mesons can be preserved by a Bethe-Salpeter kernel obtained simply by dressing both gluon-quark vertices in a ladder-like truncation; and, moreover, adding any number of similarly-dressed crossed-box diagrams cannot improve the situation.

Unified description of seagull cancellations and infrared finiteness of gluon propagators

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

In this work we present a generalized theoretical framework for dealing with the important issue of dynamical mass generation in Yang-Mills theories, and, in particular, with the infrared finiteness of the gluon propagators, observed in a multitude of recent lattice simulations. Our analysis is manifestly gauge invariant, in the sense that it preserves the transversality of the gluon self-energy, and gauge independent, given that the conclusions do not depend on the choice of the gauge-fixing parameter within the linear covariant gauges. The central construction relies crucially on the subtle interplay between the Abelian Ward identities satisfied by the nonperturbative vertices and a special integral identity that enforces a vast number of "seagull cancellations" among the one- and two-loop dressed diagrams of the gluon Schwinger-Dyson equation. The key result of these considerations is that the gluon propagator remains rigorously massless, provided that the vertices do not contain (dynamical) massless poles. When such poles are incorporated into the vertices, under the pivotal requirement of respecting the gauge symmetry of the theory, the terms comprising the Ward identities conspire in such a way as to still enforce the total annihilation of all quadratic divergences, inducing, at the same time, residual contributions that account for the saturation of gluon propagators in the deep infrared.

On the zero crossing of the three-gluon vertex

In collaboration with A. Athenodorou (University of Cyprus), Ph. Boucaud (LPT Orsay, France), F. De Soto (University Pablo de Olavide, Seville, Spain), J. Papavassiliou (University of Valencia, Spain), J. Rodriguez-Quintero (University of Huelva, Spain), S. Zafeiropoulos (University of Frankfurt, Spain)

In this work we report on new results on the infrared behavior of the three-gluon vertex in quenched Quantum Chromodynamics, obtained from large-volume lattice simulations. The main focus of our study is the appearance of the characteristic infrared feature known as 'zero crossing', the origin of which is intimately connected with the nonperturbative masslessness of the Faddeev–Popov ghost. The appearance of this effect is clearly visible in one of the two kinematic configurations analyzed, and its theoretical origin is discussed in the framework of Schwinger–Dyson equations. The effective coupling in the momentum subtraction scheme that corresponds to the three-gluon vertex is constructed, revealing the vanishing of the effective interaction at the exact location of the zero crossing.

Natural constraints on the gluon-quark vertex

In collaboration with L. Chang (University of Nankai, China), J. Papavassiliou (University of Valencia, Spain), S.-X. Qin (Argonne NL, US), C. D. Roberts (Argonne NL, US)

In principle, the strong-interaction sector of the Standard Model is characterised by a unique renormalisation-group-invariant (RGI) running interaction and a unique form for the dressed--gluon-quark vertex, Γ_μ; but, whilst much has been learnt about the former, the latter is still obscure. In order to improve this situation, in this work we use a RGI running-interaction that reconciles both top-down and bottom-up analyses of the gauge sector in quantum chromodynamics (QCD) to compute dressed-quark gap equation solutions with 1,660,000 distinct Ansätze for Γ_μ. Each one of the solutions is then tested for compatibility with three physical criteria and, remarkably, we find that merely 0.55% of the solutions survive the test. Plainly, therefore, even a small selection of observables places extremely tight bounds on the domain of realistic vertex Ansätze. This analysis and its results should prove useful in constraining insightful contemporary studies of QCD and hadronic phenomena.

Schwinger mechanism in linear covariant gauges

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

In this work we explore the applicability of a special gluon mass generating mechanism in the context of the linear covariant gauges. In particular, the implementation of the Schwinger mechanism in pure Yang-Mills theories hinges crucially on the inclusion of massless bound-state excitations in the fundamental nonperturbative vertices of the theory. The dynamical formation of such excitations is controlled by a homogeneous linear Bethe-Salpeter equation, whose nontrivial solutions have been studied only in the Landau gauge. Here, the form of this integral equation is derived for general values of the gauge-fixing parameter, under a number of simplifying assumptions that reduce the degree of technical complexity. The kernel of this equation consists of fully-dressed gluon propagators, for which recent lattice data are used as input, and of three-gluon vertices dressed by a single form factor, which is modelled by means of certain physically motivated Ansätze. The gauge-dependent terms contributing to this kernel impose considerable restrictions on the infrared behavior of the vertex form factor; specifically, only infrared finite Ansätze are compatible with the existence of nontrivial solutions. When such Ansätze are employed, the numerical study of the integral equation reveals a continuity in the type of solutions as one varies the gauge-fixing parameter, indicating a smooth departure from the Landau gauge. Instead, the logarithmically divergent form factor displaying the characteristic "zero crossing", while perfectly consistent in the Landau gauge, has to undergo a dramatic qualitative transformation away from it, in order to yield acceptable solutions. The possible implications of these results are briefly discussed.

Scale-setting, flavour dependence and chiral symmetry restoration

In collaboration with C. D. Roberts (Argonne NL, US), J. Rodriguez-Quintero (University of Huelva, Spain)

In this work we determine the flavour dependence of the renormalisation-group-invariant running interaction through judicious use of both unquenched Dyson-Schwinger equation and lattice results for QCD's gauge-sector two-point functions. An important step is the introduction of a physical scale setting procedure that enables a realistic expression of the effect of different numbers of active quark flavours on the interaction. Using this running interaction in concert with a well constrained class of dressed--gluon-quark vertices, we estimate the critical number of active lighter-quarks above which dynamical chiral symmetry breaking becomes impossible: $n^{cr}_f \approx 9$; and hence in whose neighbourhood QCD is plausibly a conformal theory.

Process-independent strong running coupling

In collaboration with C. Mezrag (Argonne NL, US), J. Papavassiliou (University of Valencia, Spain), C. D. Roberts (Argonne NL, US), J. Rodriguez-Quintero (University of Huelva, Spain)

In this work we unify two widely different approaches to understanding the infrared behaviour of quantum chromodynamics (QCD), one essentially phenomenological, based on data, and the other computational, realised via quantum field equations in the continuum theory. Using the latter, we explain and calculate a process-independent running-coupling for QCD, a new type of effective charge that is an analogue of the Gell-Mann--Low effective coupling in quantum electrodynamics. The result is almost identical to the process-dependent effective charge defined via the Bjorken sum rule, which provides one of the most basic constraints on our knowledge of nucleon spin structure. This reveals the Bjorken sum to be a near direct means by which to gain empirical insight into QCD's Gell-Mann--Low effective charge.

Maddalena Boselli

Fusion processes in low-energy collisions of weakly-bound nuclei

In collaboration with A. Diaz-Torres (University of Surrey, UK)

My PhD project consists in developing and implementing in a Fortran-90 code a quantum mechanical model to describe the reaction dynamics of a low energy collision between a few-body weakly bound projectile and a stable target.
The approach to the problem consisted in dealing with the simplest situation first and a one-dimensional toy model was initially built during the first two years of the PhD.
It was implemented in a Fortran-90 code and its reliability was tested checking intermediate results against the outcome of other theories based on a different approach.

During the last year, the work was focused on the implementation of the three-dimensional version of the model. A specific reference frame, the so called "body-fixed reference frame (BF)" was chosen to describe the system. With respect to it, the spacial degrees of freedom are still two as it was in the case of the one-dimensional model. In addition to these, the total wave function depends on angular variables as well. I learnt different techniques to deal with angles, such as basis expansion methods as well as their explicit treatment through the Discrete Variable Representation method. Due to the peculiarity of the BF reference frame, I dedicated some time in studying the connection between the Hamiltonian in the laboratory frame with that in the BF frame. I established a collaboration with Professor Brian Sutcliffe of the Université Libre de Bruxelles, Department of Quantum Chemistry, trying to adapt the general formalism he developed to construct the three-dimensional Hamiltonian of a molecular system in the BF frame, to my nuclear system. I chose him because in my view his work looked the most accurate in the derivation of the three-dimensional Hamiltonian and I was interested in this, in particular in understanding the origin and effect of the Coriolis couplings that appear in the BF Hamiltonian.
On the practical side, I readapted some parts of the one-dimensional code. In particular I extended the window operator method which is a procedure to extract the energy-dependence of the fusion cross sections. This is a crucial step in order to compare the results with experimental data. In addition to this, some aspects related to the connection between computational limitations and theoretical requirements, have been further investigated in order to optimize the code and decrease the computing time.

Towards the end of this last year of PhD I started to write the thesis and doing this I searched the literature to get a better knowledge of the other existing approaches to the study of reaction dynamics involving weakly bound projectile as well as of the importance of investigating the structure and reaction mechanism of weakly bound halo nuclei in connection to some of the open questions in nuclear astrophysics.

Jesús Casal Berbel

Quasifree scattering and transfer reactions induced by three-body nuclei

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

The current advances in radioactive beam physics have enabled the study of quasifree scattering and transfer reactions induced by exotic nuclei in inverse kinematics. These reactions provide a powerful tool to extract spectroscopic information, 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 break up. 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. The aim of this collaboration is to establish a solid theoretical framework to describe these reactions, using a proper three-body structure model [1] and reliable reaction formalisms: the DWBA approach for transfer reactions of the form (p,d), and the Transfer to Continuum (TC) formalism [2] for quasifree (p,pN) processes. In our prescription, all the structure information is contained in the overlaps between the three-body ground-state wave function and the two-body continuum states after one nucleon removal. We have explored the effect of the structure properties in the computed cross sections and compared with the available experimental data for the ^{11}Li(p,d)^{10}Li transfer [3] and ^{11}Li(p,pn)^{10}Li quasifree [4] reactions. We are now on the process of extending the method in order to include core excitation effects, as well as to apply the formalism to other exotic systems (e.g., ^{6}He, ^{12}Be, ^{14}Be).

Two-proton capture reaction on 15O to produce 17Ne

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

In Refs. [1,5] we developed a three-body model to compute radiative capture reaction rates of astrophysical interest [6], showing the relevance of the direct or three-body capture at low temperatures compared to sequential estimations. We applied the method to the formation of ^{6}He (^{4}He + n + n) and ^{9}Be (^{4}He + ^{4}He + n), which could play a role in neutron-rich environments for the r-process. On the proton-deficient side of the nuclear chart, the two-proton capture reaction on ^{15}O to produce ^{17}Ne has been proposed as a key ingredient for the rp-process controlling the trigger conditions of type I x-ray bursts. We computed the reaction rate for ^{17}Ne formation within a full three-body model, considering sequential and direct, resonant and non-resonant contributions on an equal footing. The outcome of these calculations was published recently [7]. Our results provide rates several orders of magnitude larger than previous estimations in the low-temperature regime, which could have important implications for rp-process simulations. We recently proposed an alternative method to estimate these three-body reaction rates from inclusive breakup measurements at low energies [8], which could help in understanding these differences.

Low-energy breakup induced by three-body nuclei

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

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. [9], we applied the Continuum-Discretized Coupled-Channels (CDCC) method using three-body pseudostates [3] to describe the elastic scattering and breakup of ^{9}Be on ^{208}Pb and ^{27}Al 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. As the next step, the case of ^{9}Be + ^{120}Sn is especially interesting since, due to the small excitation energy of the first excited state of the target, the full description of the quasielastic scattering is a motivating challenge [10]. We are now working on the low-energy breakup of ^{17}Ne, which could help in understanding its exotic structure, and to extend the formalism to include structure and dynamic core excitations.

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Alexis Diaz-Torres

Low-energy reaction dynamics of weakly-bound nuclei

In collaboration with theorists and experimenters in China (ITP/CAS-Beijing) and Mexico (ININ)

A systematic study of near-barrier elastic scattering of the ^{6}Li projectile on a number of targets have been performed within the continuum-discretized coupled-channel (CDCC) framework [1], where the role of the ^{6}Li resonant states in the elastic differential cross sections has particularly been studied. In collaboration with theorists from the ITP/CAS in Beijing, I have carried out a systematic study of complete fusion suppression in reactions involving weakly bound nuclei at energies above the Coulomb barrier [2]. A quantum description of fusion processes of weakly-bound nuclei (complete and incomplete fusion) has been pursued, which was the central aspect of the PhD work carried out by Maddalena Boselli at the ECT*. She successfully defended her PhD thesis in October 2016. This work is based on solving the time-dependent Schrödinger equation of a three-body scattering problem. The first results obtained within a simplified model were published [3-6]; Ref. [4] being an Editor's suggestion paper. The model was extended to three dimensions, and some publications are currently in preparation.

Interlacing theory and experiment in low-energy heavy-ion reaction dynamics

In collaboration with theorists and experimenters in Russia (JINR-Dubna), Brazil (Fluminense U) and Germany (JLU Giessen)

Based on reaction theory, we have suggested new methods to extract elastic (quasi-elastic) scattering angular distribution and reaction (capture) cross sections from the experimental elastic (quasi-elastic) back-scattering excitation function taken at a single angle. These have been justified by a number of coupled-reaction-channel calculations [7-9]. It has been demonstrated that energy-shifting formulae yield reliable reaction and capture probabilities [10,11], which are useful for simplifying (or circumventing impracticable) calculations of heavy-ion reaction observables at low energies. The method has been extended to the derivation of both breakup and transfer probabilities from experimental elastic and quasi-elastic differential cross-sections [12,13].

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María Gómez Rocha

Binding force in heavy quarkonium

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

In Ref. [1,2] we applied the renormalization group procedure for effective particles (RGPEP) to SU(3) quantum Yang-Mills theory. The RGPEP is a Hamiltonian approach to QCD that uses the concept of effective particles. Such effective particles are different from the bare or canonical ones in that they have a finite *size s*. The concept of *size* (or equivalently, scale $\lambda=1/s$) is used to explain the different behaviour of interacting particles at different energy scales. We derived an effective Hamiltonian and calculated the corresponding running coupling in the three-gluon vertex. We are currently applying the procedure used in [1,2] to QCD. This is, we have added the interaction with quarks, and now we are deriving an effective Hamiltonian for heavy quarkonia [3]. We are studying the features of the binding force, including the confinement problem.

Effects of a dressed quark-gluon vertex in vector heavy-light mesons and theory average of $B_c{}^*$ meson mass

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

We extended our earlier investigations [4] of heavy-light pseudoscalar mesons to the vector case, using a simple model [5] in the context of the Dyson-Schwinger-Bethe-Salpeter approach. We investigated the effects of a dressed-quark-gluon vertex in a systematic fashion and illustrated and attempted to quantify corrections beyond the phenomenologically very useful and successful rainbow-ladder truncation. In particular, we investigated the dressed quark-photon vertex in such a setup and made a prediction for the experimentally as yet unknown mass of the B_c^*, which we obtained at 6.334 GeV well in line with predictions from other approaches. Furthermore, we combined a comprehensive set of results from the theory literature. The theory average for the mass of the B_c^* meson is 6.336 ± 0.002 GeV. We published our results in [6].

Aspects of open-flavour mesons in a comprehensive Dyson-Schwinger-Bethe-Salpeter study

In collaboration with T. Hilger, A. Krassnigg (University of Graz, Austria) and W. Lucha (Institute of High Energy Physics, Vienna, Austria)

In this project we extend our studies of quarkonia [7] in the Dyson-Schwinger-Bethe-Salpeter-equation approach to explore their results for all possible flavour combinations. Within the limitations of the setup previously used we obtain results for masses and leptonic decay constants and put them in perspective with respect to experiment and other approaches [8].

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Philipp Gubler

QCD condensates and the φ meson spectral function in nuclear matter

In collaboration with W. Weise (TUM, Germany)

The φ meson spectrum in cold nuclear matter has recently been studied experimentally at KEK [1] and will be further examined during the next few years at the E16 experiment in J-PARC [2]. For interpreting these experimental results, it is important to understand the modification of the φ meson spectral function from a theoretical perspective. If the φ meson is considered from the point of view of an effective field theory with hadronic degrees of freedom, its modification can be understood to stem from interactions of kaons with the surrounding nuclear medium. From the point of view of QCD, it is still challenging to have direct access to the spectral function. With the help of QCD sum rules, it is however possible to relate moments of the spectral function to certain combinations of QCD condensates, which allow us to constrain the behaviour of these condensates in nuclear matter from measurements of the φ meson spectral function. A second paper in this line of work was published this year [3].

Higher twist effects in vector meson correlators in QCD

In collaboration with S.H. Lee (Yonsei University, Korea) and Hyung Joo Kim (Yonsei University, Korea)

Vector mesons at finite density have been studied with the help of the QCD sum rule method already for quite some time [4,5]. In these studies, higher twist operators have been taken into account to some degree, but a complete computation of all the relevant Wilson-coefficients and estimates of the respective operator expectation values are still missing. Our goal is to close this gap and to compute all the missing higher twist contributions to the vector meson correlators from QCD up to operators of mass dimension 6. It is expected that these so far ignored terms will especially be important for the momentum dependence of the φ meson meson spectral function at finite density.

Behaviour of D mesons in nuclear matter from QCD sum rules and a simple quark model

In collaboration with K. Suzuki (RIKEN, Nishina Center, Japan), M. Oka (Tokyo Institute of Technology, Japan), A. Park (Yonsei University, South Korea), M. Harada (Nagoya University, Japan), S. H. Lee (Yonsei University, South Korea), C. Nonaka (Nagoya University, Japan) and W. Park (Yonsei University, South Korea)

In this work, we have first analyzed spectral functions of pseudoscalar D mesons in nuclear matter using QCD sum rules and the maximum entropy method. This approach enables us to extract the spectral functions without any phenomenological assumption, and thus to visualize in-medium modification of the spectral functions directly. Doing this, we have found that the reduction of the chiral condensates of dimension 3 and 5 causes the masses of both D^+ and D^- mesons to grow gradually at finite density. Additionally, we find a D^+-D^- mass splitting of about −15 MeV at nuclear saturation density. A paper about this topic was published this year [6].
We have furthermore attempted to give a simple physical explanation for the above result with the help of a simple quark model picture. In this model, the increase of the D meson mass at finite density can be explained by the interplay between the decreasing quark mass due to the partial resoration of chiral symmetry, the resulting broadening of the quark wave function and the linear confining potential. A paper discussing the above picture was published in Physical Review D [7].

D mesons in a magnetic field

In collaboration with K. Hattori (RIKEN-BNL, USA), S.H. Lee (Yonsei University, Korea), S. Ozaki (KEK, Japan), K. Suzuki (RIKEN, Nishina Center, Japan) and M. Oka (Tokyo Institute of Technology, Japan)

The mass spectra of open heavy flavor mesons in an external constant magnetic field are studied within QCD sum rules. Spectral Ansätze on the phenomenological side are proposed in order to properly take into account mixing effects between the pseudoscalar and vector channels, and the Landau levels of charged mesons. As a result, it is found for neutral D mesons a significant positive mass shift that goes beyond simple mixing effects. In contrast, charged D mesons are further subject to Landau level effects, which together with the mixing effects almost completely saturate the mass shifts obtained in the sum rule analysis. A paper about this study was published this year in Physical Review D [8].

Exact sum rules in the vector channel and their applications to lattice QCD

In collaboration with D. Satow (ECT, Italy)*

In this work, three exact sum rules for the spectral function of the electromagnetic current with zero spatial momentum at finite temperature are derived, two of them for the first time. We explicitly check that these sum rules are satisfied in the weak coupling regime and examine which sum rule is sensitive to the transport peak in the spectral function at low energy or the continuum at high energy. Possible applications of the three sum rules to lattice computations of the spectral function and transport coefficients are also discussed: We propose an ansatz for the spectral function that can be applied to all three sum rules and fit it to available lattice data of the Euclidean vector correlator above the critical temperature. As a result, we obtain estimates for both the electrical conductivity σ and the second order transport coefficient τ_J. A paper related to this project was published this year in Physical Review D [9].

Lattice QCD study of Λ and Λ_c ground and excited states

In collaboration with T.T. Takahashi (Gunma National College of Technology, Japan) and M. Oka (Tokyo Institute of Technology, Japan)

In this study we utilize lattice QCD to study the spectrum of both positive and negative parity Λ-baryons containing two light quarks and either a strange or charm quark (the latter is usually referred to as Λ_c). The goal of this study is to understand the effect of the heavy charm quark on the structure and flavor content of the Λ_c-baryons in comparison with the ordinary Λ-baryon with a strange quark. In this context we are particularly interested in examining the charmed counterpart of the negative parity Λ(1405) state, which is believed to be rather a meson-baryon molecule state than a genuine three quark state. Indeed, we found in our work that while Λ(1405) shows indications for being a molecular state, the lowest charmed negative parity state exhibits the properties of a quark-model type three quark state. A paper about this topic was recently published in Physical Review D [10].

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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 radius puzzle, 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. [1-2] we extended our previous work in μ^2H and μ^4He^+ [3-5] and calculated the nuclear structure effects in μ^3H and

μ^3He^+. Combining effective interaction hyperspherical harmonics techniques with state-of-the-art nuclear potentials (AV18/UIX and chiral EFT), we improved the uncertainty in the predicted structure effects. This allows significant improvements in determining charge radii from the Lamb shift measurements, and may help unveil possible exotic hadronic structures. We are currently performing the calculation of nuclear structure effects on hyperfine splittings in muonic atoms, in which the magnetic polarizability is important.

Effective field theory for halo nuclei and alpha clustering

In collaboration with G. Orlandini, W. Leidemann, F. Pederiva (University of Trento & INFN-TIFPA), H.-W. Hammer (Technische Universität Darmstadt, Germany), A. Thapaliya, and D. 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. We are currently working on combining cluster EFT potentials with many-body techniques, including quantum Monte Carlo and effective interaction hyperspherical harmonics methods. We plan to 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. I have recently summarized EFT studies on structure observables in two-neutron halos in a commissioned review article [6]. In collaboration with Hans-Werner Hammer and Daniel R. Phillips, I am writing a more complete and detailed review article for J. Phys. G to cover most of the relevant formalisms in calculating both structure and electromagnetic reaction observables of halo nuclei in the framework of EFT.

Effective field theory studies of Efimov physics in cold atoms

In collaboration with D. R. Phillips (Ohio University, USA), E. Braaten (Ohio State University, USA), B. Acharya, and L. Platter (University of Tennessee, USA)

Efimov physics has been observed by an explosion of experiments assessing recombination in ultracold atomic gases. These discoveries triggered microscopic studies of the Efimov features. The EFT implements a systematic expansion in the ratio of low and high momentum scales to describe the few-body universal physics. Using EFT, we investigated the finite-range effects to three-body recombination features in ultracold atoms and to bound and scattering properties of the ^4He atomic trimer [7-9]. The short-range effects are encoded by EFT contact interactions and evaluated perturbatively in systematic EFT expansions. In our recent work, the range effects to Efimov features, which break discrete scale invariance, are connected with anomalous dimensions entering the renormalization group limit cycle [10]. This year, the EFT analysis is further extended by our collaboration to atomic systems with heteronuclear mixtures [11].

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Daisuke Sato

Novel QCD sum rules in vector channel at finite temperature and its application to lattice QCD

In collaboration with P. Gubler (ECT, Italy)*

The vector spectral function at finite temperature is an important quantity because it contains all the information on the vector meson spectrum, electrical conductivity, and the dilepton/photon production rate. Despite its importance, the first-principle computation of this quantity by lattice QCD calculation requires to assume an ansatz for its functional form as the energy, since it is a dynamical quantity. We derived three sum rules at zero momentum that constrain this spectral function by using a method developed recently [1], which uses operator product expansion and hydrodynamics. We gave a suggestion for improvement of the ansatz used in the lattice QCD by using these sum rules. These results were published in Ref. [2]. We are now writing a paper that contains a generalization of the results above for the finite momentum case.

Goldstino in supersymmetric Bose-Fermi cold atom system in BEC phase

In collaboration with J. P. Blaizot (CEA-Saclay, France) and Y. Hidaka (RIKEN, Japan)

It was suggested that supersymmetry (SUSY) is broken at finite temperature/density due to medium effect, and due to the Nambu-Goldstone (NG) theorem, a zero-energy fermionic excitation (goldstino) appears [3]. Such zero mode was analyzed in relativistic system such as Wess-Zumino model [3] and QCD [4], which has approximate SUSY at high temperature. Recently, it was proposed to simulate the SUSY by using Bose-Fermi cold atom system [5], and the goldstino was also suggested to appear there. We analyzed the spectral properties of the goldstino in such system, at weak coupling region [6], and as a result, we obtained the analytic expressions for the dispersion relation and the strength of the goldstino at small momentum region. At Bose-Einstein Condensate (BEC) phase, we expect that the three-point coupling induced by the BEC generates the mixing process between the fermion and the goldstino propagators, so that the fermion spectrum with small momentum/energy is largely modified due to the goldstino excitation. This effect may be observable in experiment. We are now writing a paper that presents the results above.

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Dionysios Triantafyllopoulos

Factorization for forward particle production in proton-nucleus collisions

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

Within the Color Glass Condensate effective theory [1], we reconsidered the calculation of the single inclusive particle production at forward rapidities in proton-nucleus collisions at high energy and at next-to-leading order (NLO) [2]. We established a new factorization scheme, perturbatively correct through NLO, in which there is no rapidity subtraction as was usually done in earlier studies [3,4]. That is, the NLO correction to the impact factor (i.e. the parton-nucleus cross section in the absence of any evolution) is not explicitly separated from the high-energy evolution. We singled out the first step of the evolution and the NLO impact factor was included by computing this first emission with the exact kinematics for the emitted gluon, rather than by using the eikonal approximation. This calculation had already been presented in the literature [3,4], but the reorganization of the perturbation theory that we proposed is new. The advantage of our proposal, as compared to the earlier approaches, is that our scheme is free of the fine-tuning inherent in the rapidity subtraction, which we suspect to be the origin of the negativity of the NLO cross-section observed in previous studies [5,6].

Single logarithms in the evolution of color dipoles

In collaboration with E. Iancu, G. Soyez (IPhT, Saclay, France) and A.H. Mueller (Columbia University, USA)

In an earlier work [7] we established the correct version of the Balitsky-Kovchegov (BK) equation in the collinear limit, which resumes to all orders the radiative corrections enhanced by large double transverse logarithms and which are associated with the kinematics (see also [8]). Here [9] we improved the accuracy of our resummation by including two classes of single-logarithmic corrections: those generated by QCD dynamics, and in particular by the first non-singular terms in the DGLAP splitting functions and those expressing the one-loop running of the QCD coupling. Thus the resulting equation included all the next-to-leading order corrections to the BK equation, which are enhanced by (single or double) collinear logarithms. It has a stable positive numerical solution, in contrast to the NLO BK equation [10], whose solution exhibits a severe unphysical instability [8,11]. Given the recent interest for higher order corrections to the BK equation in maximally supersymmetric theories [12], we reflected on the similarities and differences between the respective equations and their resummed versions in the two theories.

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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 (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.

The resonances Via Padé (RVP) method

In collaboration with I. Haritan, N. Moiseyev (Technion, Israel) and J. Wambach (ECT, Italy)*

In Ref. [2] we showed how complex resonance poles and threshold energies for systems in hadron physics can be accurately obtained by using a method based on the Padé-approximant which was recently developed for the calculation of resonance poles for atomic and molecular auto-ionization systems. The main advantage of this method is the ability to calculate the resonance poles and threshold energies from real spectral data. In order to demonstrate the capabilities of this method we applied it to an analytical model as well as to experimental data for the squared modulus of the vector pion form factor and the S0 partial wave amplitude for $\pi\pi$ scattering. The extracted values for the resonance poles of the $\rho(770)$ and the $f0(500)$ or σ meson are in very good agreement with the literature. In future applications we will further explore its potential and intend to use it, for example, to determine the temperature dependence of resonance poles for hadrons in a hot and dense medium or to obtain real-time correlation functions from their imaginary-time counterparts.

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Jochen Wambach

My research in 2016 included the following topics:

- Nuclear structure and nuclear astrophysics
- Equilibrium properties of hot and dense strong-interaction matter
- Medium modifications of the spectral properties of hadrons.

The projects in these areas have been pursued in collaboration with researchers from my home institution, TU Darmstadt, and with collaborators from Bulgaria, Germany, Japan, Russia and the United States. In the following selected examples are summarized.

Spin-flip transitions in nuclei and in core-collapse supernovae

In collaboration with J. Birkhan, P. von Neumann-Cosel, G. Martinez-Pinedo, V. Yu. Ponomarev, A. Richter (TU Darmstadt), A.A. Dzhioev and A.I. Vdovin (Joint Institute for Nuclear Research, Dubna, Russia), H. Matsubara and A. Tamii (Research Center for Nuclear Physics, Osaka University, Japan) and Ch. Stoyanov, (Institute for Nuclear Research, Sofia, Bulgaria)

The work in Ref. [2] continues a long-standing collaboration with my experimental colleagues at TU Darmstadt on the spectral properties of stable nuclei, excited by photons, electrons and hadronic probes. The main characteristic of these studies is the high energy resolution of the probes which, in particular, reveals the fine structure of collective modes and hence the complexity and the stochastic features of nuclear motion [1]. Based on inelastic proton-scattering measurements at incident energies close to 300 MeV and extreme forward-angles, a new method for extracting the electromagnetic isovector M1 spin-flip strength was proposed in Ref. [2] and applied to ^{48}Ca and ^{208}Pb. Consistency with earlier (e,e') and (n,γ) measurements was found, suggesting the possibility to extract systematic information on the isovector M1-strength in heavy nuclei.

The significant role played by neutrinos in core-collapse supernovae is well known [3]. Inelastic neutrino scattering from nuclei contributes significantly to establishing thermal equilibrium between neutrinos and matter. For a quantitative description of the scattering rates it is necessary to consider thermal ensembles of nuclei and develop a theory that is thermodynamically consistent. Based on the method of Thermo-Field-Dynamics [4] - an alternative to the Matsubara formalism - we have developed a scattering theory, which properly includes transitions from thermally excited states [5]. In Rev. [6] it has been applied in selfconsistent calculations of neutral-current neutrino-nucleus reactions and neutrino pair emission using various Skyrme interactions. Two representative nuclei along the collapse path, ^{56}Fe and ^{82}Ge, have been considered [7]. Comparisons with earlier hybrid approaches show significant differences in the energy dependence of the thermal rates, especially in the low-energy region. The influence on the dynamics of the core-collapse is yet to be investigated.

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The phase structure of QCD matter at high chemical potential

In collaboration with B.-J. Schaefer and L. von Smekal (University of Gießen, Germany), N. Strodthoff (Lawrence Berkeley Laboratory, Berkeley, USA) and R.-A. Tripolt (ECT, Italy)*

A major challenge in Quantum Chromodynamics (QCD) is the exploration of the phase structure of strong- interaction matter, including possible phase transitions and the existence and location of a critical endpoint for the quark-hadron transition. Employing the Functional Renormalization Group (FRG) as a powerful method to describe phase transitions, we have studied the phase diagram for many years within effective low-energy realizations of QCD, such as the quark-meson model [8]. In Ref. [8] it was found that, in contrast to a mean-field evaluation of the grand potential, the first-order transition to the “Lee-Wick state” of nearly massless quarks is avoided and the sigma field expectation value remains finite across the phase boundary. On the other hand, the phase boundary bends the “wrong way” in the sense of the Clausius-Clapeyron relation and results in a degreasing pressure with increasing temperature. We have recently revisited this finding [9] by performing a detailed stability analysis in the pion direction. The results indicate a rich phase structure involving p-wave pion condensation induced by coupling to low-frequency particle-hole excitations.

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Spectral functions in hot and dense hadronic matter

In collaboration with C. Jung, L. von Smekal and F. Rennecke (University of Gießen) and R.-A. Tripolt (ECT)*

Spectral functions of QCD matter encode information on the particle spectrum as well as collective excitations and serve as input for the calculation of transport coefficients such as viscosities, conductivities and diffusion constants. However, the calculation of such real-time observables at finite temperature and density represents an inherently difficult problem. Usually they involve analytic continuations of pertinent Euclidean correlation functions. Within the framework of the FRG we have recently succeeded in formulating an approximation scheme, which is both thermodynamically consistent and symmetry conserving, i.e. yields the correct Goldstone modes [10]. In Refs. [10,11] the effects of chiral symmetry restoration at high temperature and large chemical potentials on the pion- and sigma-meson spectral functions where studied in the quark-meson model and the expected degeneracy of the parity partners in the restored phase was found for the first time. Because of the importance of vector mesons for the low-invariant-mass emission spectrum of real photons and dileptons in heavy-ion collisions, we have recently started studying the evolution of vector- and axial-vector spectral functions with temperature and chemical potential, using a gauged quark-meson model within the FRG framework. The first results [12], albeit neglecting vector-meson loops, are very encouraging in that they again yield degeneracy in the restored phase. Thus a stringent connection between chiral symmetry restoration and observable real- and virtual-photon rates in heavy-ion collisions are possible.

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Other scientific activities

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

1. Arbeitstreffen “Kernphysik” Schleching
   (Heavy Ions, Cosmic Rays, Neutrinos)
   Schleching, Germany, Feb. 18 - 25, 2016

2. International School of Nuclear Physics, 38th Course:
   Nuclear Matter under extreme conditions – Relativistic heavy-ion collisions
   Erice, Italy, Sept. 16 – 24, 2016

3. 626. WE-Heraeus-Seminar:
   Neutron Stars: A Cosmic Laboratory for Matter under Extreme Conditions
   Bad Honnef, Germany, Oct. 26 -29, 2016

4.2 Publications of ECT* Researchers in 2016

Guillaume Clement Beuf

T. Altinoluk, N. Armesto, G. Beuf, A. Rezaeian
Diffractive dijet production in deep inelastic scattering and photon-hadron collisions in the color glass condensate
*Phys. Lett. **B758** (2016) 373-383*

T. Altinoluk, N. Armesto, G. Beuf, A. Kovner, M. Lublinsky
Heavy quarks in proton-nucleus collisions - the hybrid formalism
*Phys. Rev. **D93**, 054049 (2016)*

G. Beuf
Dipole factorization for DIS at NLO I: Loop correction to the photon to quark-antiquark light-front wave-functions
*Phys. Rev. **D94**, 054016 (2016)*

T. Altinoluk, N. Armesto, G. Beuf, A. Moscoso
CGC beyond eikonal accuracy: finite width target effects
EPJ Web Conf. 112 (2016) 02001

T. Altinoluk, N. Armesto, G. Beuf, A. Kovner, M. Lublinsky

Initial State Correlations and the Ridge
Acta Phys. Polon. Supp. 9 (2016) 479

Daniele Binosi

A. Athenodorou, D. Binosi, Ph. Boucaud, F. De Soto, J. Papavassiliou, J. Rodriguez-Quintero, S. Zafeiropoulos
On the zero crossing of the three-gluon vertex
Phys. Lett. ***B761*** *(2016) 444-449; arXiv:1607.01278 [hep-ph]*

A. C. Aguilar, D. Binosi, C. T. Figueiredo, J. Papavassiliou
Unified description of seagull cancellations and infrared finiteness of gluon propagators
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Maddalena Boselli

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Low-energy fusion dynamics of weakly-bound nuclei: a time dependent perspective
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M. Gomez-Rocha, T. Hilger, A. Krassnigg
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*Nucl. Phys. **A954**, 125 (2016)*

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Relating the strangeness content of the nucleon with the mass shift of the phi meson in nuclear matter
AIP Conf. Proc. 1701 (2016) 080004

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Effective-field-theory analysis of Efimov physics in heteronuclear mixtures of ultracold atomic gases
*Phys. Rev. **A94** (2016) 032702*

N. Nevo Dinur, C. Ji, S. Bacca, N. Barnea
Nuclear structure corrections to the Lamb shift in μ^3H e+ and μ^3H
*Phys. Lett. **B755** (2016) 380-386*

C. Ji
Three-body systems in physics of cold atoms and halo nuclei
*Int. J. Mod. Phys. **E25** (2016) 1641003*

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Update on nuclear structure effects in light muonic atoms
Hyperfine Interact. 237 (2016) 158

A. Thapaliya, C. Ji, D. Phillips
Halo Effective Field Theory of 6He
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Understanding the proton radius puzzle: Nuclear structure effects in light muonic atoms
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Daisuke Sato

P. Gubler, D. Satow
Exact vector channel sum rules at finite temperature and their applications to lattice QCD
*Phys. Rev. **D94**, 094042 (2016)*

Dionysios Triantafyllopoulos

E. Iancu, J.D. Madrigal, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
Resumming large higher-order corrections in non-linear QCD evolution
Nucl. and Part. Phys. Proc. 276-278 (2016) 209

E. Iancu, J.D. Madrigal, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
The collinearly-improved Balitsky-Kovchegov equation
*Nucl. Phys. **A956**, 557 (2016)*

E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos
CGC factorization for forward particle production in proton-nucleus collisions at next-to-leading order
JHEP 1612 (2016) 041

Ralf-Arno Tripolt

C. 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
*arXiv: 1610.08754 [hep-ph], submitted to Phys. Rev. **D***

R.-A. Tripolt, I. Haritan, J. Wambach, N. Moiseyev

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Jochen Wambach

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J. Birkhan, H. Matsubara, P. von Neumann-Cosel, N. Pietralla, V. Yu. Ponomarev, A. Richter, A. Tamii, J. Wambach
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Phys. Rev. ***C93****, 041302(R) (2016)*

Wolfram Weise

S. Petschauer, N. Kaiser, J. Haidenbauer, U.-G. Meissner, W. Weise
Leading three-baryon forces from SU(3) chiral effective field theory
Physical Review ***C93*** *(2016) 014001*

S. Ohnishi, Y. Ikeda, T. Hyodo, W. Weise
Structure of the Λ(1405) and the K^- d -> πΣn reaction
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Resonances in QCD
Nucl. Phys. ***A948*** *(2016) 93*

M. Drews, W. Weise
Functional renormalization group study of nuclear and neutron matter
AIP Conf. Proc. 1701 (2016) 080002

J. W. Holt, M. Rho, W. Weise
Chiral symmetry and effective field theories for hadronic, nuclear and stellar matter
Physics Reports 621 (2016) 2-75

S. Petschauer, J. Haidenbauer, N. Kaiser, U.-G. Meissner, W. Weise
Hyperons in nuclear matter from SU(3) chiral effective field theory
Eur. Phys. J. ***A52*** *(2016)*

4.3 Talks presented by ECT* Researchers

Guillaume Clement Beuf

Full NLO corrections for DIS structure functions in the dipole factorization formalism
Talk at the 3rd International Conference on the Initial Stages in High-Energy Nuclear Collisions (InitialStages2016);
May 2016, Lisbon, Portugal

Evolution equations and factorization in pA collisions
Plenary talk at the 8th International Conference on Hard and Electromagnetic Probes of High-energy Nuclear Collisions (Hard Probes 2016);
Sep 2016, Wuhan, China

Daniele Binosi

Somewhere over the rainbow
Invited talk at the workshop "Nonperturbative aspects of QCD and Hadro-Particle Physics";
October 2016, Sevilla, Spain

Maddalena Boselli

Understanding reaction processes in low-energy collisions of weakly bound nuclei
Talk given at the Third Topical Workshop on Modern Aspect in Nuclear Structure;
February 2016, Bormio, Italy

Jesús Casal Berbel

Quasifree (p,pn) and transfer (p,d) reactions induced by three-body nuclei
Talk given at the workshop "Three-body systems in reactions with rare isotopes";
October 2016, ECT (Trento), Italy*

Alexis Diaz-Torres

Modelling low-energy reaction dynamics of complex atomic nuclei from a time-dependent quantum perspective
Colloquium at the Heidelberg Center for Quantum Dynamics;
20 Jan 2016, Heidelberg, Germany

Linking structure and reaction dynamics in the formation and decay of new elements
Invited Talk at the Third Topical Workshop on Modern Aspects in Nuclear Structure;
27 Feb 2016, Bormio, Italy

Molecular structures in slow nuclear collisions
Invited Talk at the ECT* Workshop "Towards Consistent Approaches for Nuclear Structure and Reactions";
08 Jun 2016, Trento, Italy

Selected topics in the physics of low-energy nuclear reactions
Invited Seminar at the University of Surrey;
23 Jun 2016, Guildford, UK

Maria Gomez Rocha

Asymptotic freedom in the Hamiltonian approach to binding of colour
Talk given at the XIIth Quark Confinement and the Hadron Spectrum.
August 2016, Thessaloniki, Greece

From asymptotic freedom toward heavy quarkonia using RGPEP
Talk given at the Light Cone 2016 Conference.
September 2016, Lisbon, Portugal

Philipp Gubler

Spectral functions of mesons at finite temperature/density
Talk at the 31st Reimei Workshop on Hadron Physics in Extreme Conditions at J-PARC;
January 2016, Tokai, Japan

Phi meson in nuclear matter and the strangeness content of the nucleon
Seminar;
April 2016, TUM, Munich, Germany

Exact vector channel sum rules at finite temperature
Talk at the ECT* workshop "Advances in transport and response properties of strongly interacting systems";
May 2016, Trento, Italy

Chen Ji

Regularization and renormalization in halo effective field theory
Invited talk at EMMI RRTF Workshop
January 2016, GSI Helmholtzzentrum für Schwerionenforschung, Germany

Nuclear structure effects in light muonic atoms
Presentation at ECT* Board Meeting
January 2016, Trento, Italy

Effective field theory description of clustering in halo nuclei
Invited talk at KITPC conference on “Clustering effects of nucleons in nuclei and quarks in multi-quark states"
April 2016, Beijing, China

Nuclear polarization effects in light muonic atoms
Invited seminar talk at Institute of High Energy Physics
April 2016, Beijing, China

Two-photon contributions to Lamb shift in muonic atoms
Talk at ECT* workshop on “Advances in transport and response properties of strongly interacting systems”
May 2016, Trento, Italy

Monte Carlo methods and alpha clustering
Invited Talk at TRIUMF Theory Department
May 2016, Vancouver, Canada

Range effects to Efimov physics in identical bosons and heteronuclear mixtures
Invited talk at EMMI RRTF Workshop
June 2016, GSI Helmholtzzentrum für Schwerionenforschung, Germany

Nuclear structure contributions to Lamb shift in light muonic atoms
Invited plenatary talk at The 23rd European Conference on Few-Body Problems in Physics
August 2016, Aarhus, Denmark

Dionysios Triantafyllopoulos

Resummation of large transverse logarithms in the high energy evolution of color dipoles
Talk at the workshop “QCD at Cosmic Energies VII";
May 2016, Chalkida, Greece

Progress in higher order CGC computations
Plenary talk at the conference "Initial Stages in High Energy Nuclear Collisions";
May 2016, Lisbon, Portugal

Resummation of large higher order corrections in non-linear QCD evolution
Talk at the conference "XIIth Quark Confinement and the Hadron Spectrum";
August 2016, Thessaloniki, Greece

Collinear resummations in non-linear QCD evolution
Talk at the workshop "QCD at LHC: forward physics and UPC collisions of heavy ions";
30 Sep 2016, Trento, Italy

Ralf-Arno Tripolt

Spectral functions and transport coefficients from the Functional Renormalization Group
Talk given at the ECT* workshop “Advances in transport and response properties of strongly interacting systems”;
May 2016, Trento, Italy

In-medium spectral functions and transport coefficients of hadrons
Talk at the International School of Nuclear Physics – Nuclear matter under extreme conditions – Relativistic heavy-ion collisions;
September 2016, Erice, Sicily, Italy

The “resonances Via Padé” method
Seminar talk given at TIFPA;
October, 2016, Trento, Italy

The “resonances Via Padé” method
Seminar talk given at TU Darmstadt;
December, 2016, Darmstadt, Germany

The “resonances Via Padé” method
Seminar talk given at Gießen University;
December, 2016, Gießen, Germany

The “resonances Via Padé” method
Seminar talk given at Heidelberg University;
December, 2016, Heidelberg, Germany

Jochen Wambach

The equation of state and spectral properties of QCD matter
Talk at the ECT* workshop “Equation of State in Quantum Many-Body Systems”.
June 1, 2016, Trento, Italy

Opening address and scientific scope of the 38th Erice School
Talk at the International School of Nuclear Physics “Nuclear Matter under extreme conditions – Relativistic heavy-ion collisions”.
Sept. 17, 2016, Erice, Italy

Neutron stars: theory and observation
Talk at the 626. WE-Heraeus Seminar “Neutron Stars: A Cosmic Laboratory for Matter under Extreme Conditions”.
Oct. 26, 2016, Bad Honnef, Germany

4.4 Seminars and colloquia at ECT*

Spectral functions from the functional renormalization group
ECT Seminar*
30 Mar 2016
Christopher Jung (Justus-Liebig-Univ. Giessen, Germany)

Bound states in perturbation theory
ECT seminar*
27 Apr 2016
Paul Hoyer (Univ. of Helsinki, Finland)

Real-time phenomena in QCD at non-zero temperature
ECT Colloquium*
04 May 2016
Harvey Meyer (Johannes Gutenberg Univ. Mainz, Germany)

Relation between electronuclear sum rules in clusterized nuclei and alpha-particle
Cluster model and experiment
ECT seminar*
18 May 2016
Victor D. Efros (Kurchatov Institute, Russia)

Towards consistent approaches for nuclear structure and reactions
ECT colloquium*
08 Jun 2016
Ricardo Americo Broglia (Univ. of Milan, Italy and The Niels Bohr Institute, Denmark)

Nuclear physics
Dep. Phys TN - ECT seminar*
14 Jun 2016
Winfried Leidemann (Univ. of Trento, Italy)

Numerical gravitation
Dep. Phys TN - ECT seminar*
14 Jun 2016
Bruno Giacomazzo (Univ. of Trento, Italy)

Quantum gravity and cosmology
Dep. Phys TN - ECT seminar*
14 Jun 2016
Sergio Zerbini (Univ. of Trento, Italy)

Cold atoms and quantum optics
Dep. Phys TN - ECT seminar*
14 Jun 2016
Iacopo Carusotto (Univ. of Trento, Italy)

Cold atoms and theory of Bose Einstein condensates
Dep. Phys TN - ECT seminar*
14 Jun 2016
Franco Dalfovo (Univ. of Trento, Italy)

Theoretical physics of biological matter
Dep. Phys TN - ECT seminar*
14 Jun 2016
Pietro Faccioli (Univ. of Trento, Italy)

Overview of ECT*
Dep. Phys TN - ECT seminar*
14 Jun 2016
Jochen Wambach (ECT*)

Nonperturbative methods in quantum field theories
Dep. Phys TN - ECT seminar*
14 Jun 2016
Daniele Binosi (ECT*)

The structure of the hadron at high-energy
Dep. Phys TN - ECT seminar*
14 Jun 2016
Dionysios Triantafyllopoulos (ECT*)

Overview of the research in condensed matter at ECT*-LISC
Dep. Phys TN - ECT seminar*
14 Jun 2016
Francesco Pederiva (Univ. of Trento, Italy)

Toward heavy-light mesons from a Dyson-Schwinger-Bethe-Salpeter approach
ECT seminar*
24 Jun 2016
Maria Gomez Rocha (ECT*)

Thermodynamic limits from excited quantum phase transitions via exceptional point trajectory calculations
ECT seminar*
21 Jul 2016
Nimrod Moiseyev (Technion - Israel Institute of Technology, Israel)

Low energy tests of the standard model using parity violation electron scattering
ECT Colloquium*
03 Aug 2016
Frank Maas (Helmholtz-Institute Mainz, Germany)

Exotic baryons: past and future
ECT seminar*
14 Sep 2016
Jean-Marc Richard (Institut de Physique Nucléaire de Lyon, France)

Chemical non-equilibrium and viscosity at the early stages of heavy ion collisions
ECT seminar*
28 Sep 2016
Sreekanth Villuvattath (Center for High Energy Physics, Indian Institute of Science, Bangalore, India)

Variational description of continuum states
ECT Colloquium*
05 Oct 2016
Alejandro Kievsky (INFN-Pisa, Italy)

The quantized charge standard model, the eightfold way model, and the topological Skyrme model
ECT Seminar*
12 Oct 2016
Syed Afsar Abbas (Centre for Theoretical Physics, JMI Univ., New Delhi, India)

Reactions induced by weakly bound three-body nuclei
ECT seminar*
16 Nov 2016
Casal Berbel Jesus (ECT*)

Higgs potential from derivative interactions
ECT seminar*
23 Nov 2016
Andrea Quadri (Univ. of Milan, Italy)

First forays in the qubit arena
ECT Seminar*
07 Dec 2016
Garberoglio Giovanni (ECT*-LISC)

5 Quantum Information Processing and Communication activities at ECT*

- ECT* has been involved in the field of Quantum Information Processing and Communication (QIPC) over the last decade. Specifically, the QIPC field has been a so-called Proactive Initiative of the Future and Emerging Technologies Unit in DG Information Society and Media of the European Commission in the Framework Programme FP5 (1999-2002), FP6 (2003- 2006), FP7 (2007-2013) and, finally, H2020 (2014-2020) and ECT* have been a constant presence in QIPC consortia.
- This tradition has continued during 2016, with D. Binosi actively working on the Coordination Action **QUTE-EUROPE** (Quantum Technologies for Europe) in which he contributed to Work-Package 2 (Coordination and Collaboration) and 3 (Dissemination). The initiative (which had a funding for the ECT* node of 37,450.00€ for 3 years.) ended in February, with the final review of the project successfully passed in May. It should be noticed that, as a result of the coordination work done over the past ten years, the European Commission announced on the 19th of April 2016 the launch a Flagship initiative in the field of Quantum Technologies, with an estimated budget of 1 billion € over 10 years.

6 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.

6.1 Projects of ECT*-LISC Researchers

Martina Azzolini

Monte Carlo simulation of electron transport in diamond and graphite crystals

*In collaboration with M. Dapor, S. Taioli, T. Morresi (ECT *)*

The first year of PhD was dedicated to the study and the application of a Monte Carlo model for the treatment of the electron transport in materials. In the model a mono energetic electron beam, that impinges on a target material, is considered. The primary electrons interact elastically and inelastically with the target, producing secondary electrons. By collecting the electrons that escape from the target surface, as a function of their kinetic energy, it is possible to determine fundamental properties of the target material. The elastic scattering was treated by considering the Mott cross section [1]. With the aim to compute the value of the energy loss at each inelastic interaction, the Ritchie dielectric theory was applied [2]. The Ritchie theory was applied considering the dielectric function obtained by the Drude – Lorentz theory [4], starting with experimental optical data or ab initio calculation, or by a full ab initio calculation. This approach was applied to diamond and graphite crystals in order to reproduce the primary electron spectrum and the secondary electron yield [5]. The simulated results were compared to the available experimental data.

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Maurizio Dapor

Influence of secondary electron energy and angular distributions on swift proton radial doses in PMMA

In collaboration with I. Abril (Universitat d'Alacant), P. de Vera (Queen's University Belfast), R. Garcia-Molina (Universidad de Murcia)

The high energy deposition rates characteristic of accelerated ion beams find plenty of applications in industry and medicine, such as in ion beam nanolithography and ion beam cancer therapy. Such applications exploit the pattern of energy distribution at the nanoscale, where intense radial doses arise around ion tracks, being exhausted in just a few nanometres. This allows, on the one hand, the production of nanometric structures with high precision (for nanofabrication) and, on the other hand, the clustering of damage in biomolecules such as DNA (which justifies the increased biological efficiency of ion beams over conventional radiotherapy). It is, then, important to know precisely how these radial doses build up in materials of interest, such as the polymer polymethyl methacrylate (PMMA). This material is widely used as a resist in nanolithography [1] and as a water equivalent material in dosimetric studies.The way in which the energy lost by an ion is distributed around its path is mainly determined by the number of ejected secondary electrons, and by their energy and angular spectra [2]. All these characteristics can be accurately determined for organic materials within a semiempirical method based on the dielectric formalism. This formalism also permits to obtain the energy loss characteristics of both ion and electron beams in condensed materials, accounting for all the electronic excitations and ionisations. Once all these data are known, they can be used as input in Monte Carlo track structure codes to follow the complete slowdown of the secondary electron cascade. In this work, the cross sections calculated within the dielectric formalism are used within the Monte Carlo code SEED (Secondary Electron Energy Deposition), which also includes other relevant interaction phenomena between the electrons and the condensed target, namely multiple elastic scattering and excitation of phonons and polarons [3].

Comparison between experimental measurement and Monte Carlo simulation of the secondary electron energy spectrum of low order Poly(3-hexylthiophene-2,5-diyl)

In collaboration with R. C. Masters, I. Ross, D. Lidzey, A. Pearson, I. Abril, R. Garcia-Molina, J. Sharp, M. Unčovský, T. Vystavel, C. Rodenburg

The characterization of polymers is a very complex problem due, in particular, to beam induced radiation damage and charging phenomena [4,5]. Poly(3-hexylthiophene-2,5-diyl), commonly known as P3HT, is a polymer widely used in organic electronics. A Monte Carlo simulation [3] is compared with experimental data about the secondary electron energy distribution of the low order semi crystalline polymer regioregular P3HT. Our comparison of simulated and experimental secondary electron spectrum shows an excellent agreement, revealing a peak followed by a broad shoulder, a shape that we attribute to the combined effect of the band-gap and of a filtering effect. We determined both the filtering effect, related to the working distance, and the band gap. The Monte Carlo simulation allowed us evaluating the minimum depth of provenience of the emitted secondary electrons in the experiment, which is about 2.5nm for low order P3HT.

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Giovanni Garberoglio

Ab-initio calculation of virial coefficients of non-degenerate quantum gases

In collaboration with A. H. Harvey (NIST, USA) and K. Szalewicz (University of Delaware, USA)

This is the continuation of a long-standing collaboration with NIST and the University of Delaware aimed at checking the accuracy of fully ab-initio calculations of virial coefficients. In our breakthrough paper [1] we showed that this approach resulted in values of the third virial coefficient of helium with a much better accuracy than the best experimental data available. Subsequent extensions to rigid and flexible linear molecules enabled the calculation of the second virial coefficient of hydrogen isotopologues [2,3] and their mixtures.
We are presently extending this work to the calculation of the second and third virial coefficient of water, using state-of-the-art pair and three-body potentials.

Mechanical and adsorptive properties of carbon-based materials

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

In the framework of the Graphene Flagship we are working on the design of novel carbon based materials, mostly made by graphene sheets.
In Ref. [4] we assessed the performance of a three-dimensional structure made by graphene-oxide layers connected by organic pillars in the adsorption of various gases and their selective separation. This approach is being extended to novel structures such as nanoscrolls of graphene.
Additionally, we have recently modelled and characterized a series of graphene-based nanofoams whose structure mimicks truss networks [5] and that showed interesting energy-adsorbing properties which are currently being investigated in more details.

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Tommaso Morresi

Ab initio study of the dielectric response function of Carbon-based and related materials

In collaboration with M. Azzolini (ECT), S. Taioli (ECT*), M. Dapor (ECT*)*

The study of the slowing down mechanisms of electrons (and more generally of charged particles) in condensed matter systems is very important in radiation science. The key quantity for describing the electronic response of a material under external perturbation is the dielectric function.
My research deals with the computation of these functions using ab-initio methods such as Density Functional Theory (DFT) and Time Dependent DFT (TDDFT). In particular, in [1] we performed a Monte Carlo simulation of electron back-scattering in diamond and graphite and we assessed the effect of using ab-initio calculated dielectric functions with respect to the semi-classical models. We have shown that for insulators and semiconductors first principles calculations of the dielectric response display better agreement with the experimental data. We explain this behaviour by the fact that ab-initio methods are able to accurately describe the plasmon resonance dispersion, by taking into account the decay of many-body charge density oscillations into single particle excitations, which is out of reach for semi-classical models, such as the Drude-Lorentz approach. On the other hand, we have shown that for metallic and semi-metallic systems, where excitonic effects are less important due to a more effective charge screening, ab-initio methods and semi-classical models give comparable results.

References

[1] M. Azzolini, T. Morresi, G. Garberoglio, L. Calliari, N. M. Pugno, S. Taioli, M. Dapor, ArXiV:1612.01898 [cond-mat]

Andrea Pedrielli

Numerical simulations on energy storage and deformation of “3D” graphene and related materials

Supervised by N. M. Pugno (UniTn-FBK) and G. Garberoglio (FBK-ECT)*
In collaboration with S. Taioli (FBK-ECT)*

Graphene has attracted much attention due to its 2D nature and to unsurpassed electronic, optical and mechanical characteristics. In particular, from a mechanical point of view, the high performances presented at nano-scale have to be transferred effectively from nano- to macro-scale and, desirably, to the third dimension. Successfull use of graphene in this regard depends critically on three factors: first, the design of proper architectures that preserve graphene's intrinsic mechanical properties, such as the large ultimate strength and the ability to retain its initial size after strain; second, a better understanding of the properties of 3D carbon-based materials upon compressive and tensile loads; third, the possibility of synthesising these materials by scalable and cost effective practices. We performed a computational investigation of the mechanical properties of novel graphene-based 3D architectures from atomistic simulations. In particular, we suggest a specific set of mechanically stable nanotruss networks using graphene sheets connected by nanotubular pillars forming nanoporous structures with octet-truss geometry. To investigate these issues and help our understanding of the critical factors affecting the production of high-performance carbon-based foams, such as behavior under tension and compression as a function of nanotube/sphere diameters' ratio, anisotropy of samples, and lattice defects, we

perform computational simulations with reactive potential on realistic carbon-based nanotruss structures.
The outcome of this work is consituted by the paper [1], published on the journal Carbon (Elsevier), with title “Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression”. The major achievements of this study are three: first, we devise a new way to design novel graphene-based architectures with different intrinsic features; second, we calculate a number of mechanical observables of these nano-foams, such as stress-strain curves, Young modulus, Poisson ratio, density scaling relation, instabilities under compression load and energy absorption characteristics upon impact; third, we show how the mechanical properties of these foams are propagated from nano- to macro-scale. While the mechanical properties turned out to be almost isotropic under tensile load, 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. The performance of these nanotruss networks is analyzed with regards to their use as impact energy absorbers, finding properties outperforming materials traditionally used in these applications. Finally, the study of instability, touched upon in contribution, has a very high importance in the field of mechanical metamaterials.

We also are working on gas absorption and dynamics in pillared graphene frameworks that are promising structures to overcome the current limitations in gas storage and gas filtration.

Numerical simulation on the response of electron holography in graphene structures

Supervised by C. Degli Esposti Boschi (IMM-CNR)
In collaboration with L. Ortolani (IMM-CNR), V. Morandi (IMM-CNR) N. M. Pugno (UniTn-FBK) and G. Garberoglio (FBK-ECT), S. Taioli (FBK-ECT*)*

Electron holography is a high resolution microscopy technique that presents results with a non-trivial interpretation. We performed numerical simulation [2] on the response of electron holography in flat graphene and single layer folded sheets, using a Density Functional Theory approach. We compute the phase shifts of the electron beam due to the inner potential integrated across the sample thickness to have a better understanding of experimental data.

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Francesco Segatta

Modelling Photoinduced Events and Non-Linear Spectroscopy in Complex Multi-Chromophoric Systems

In collaboration with M. Garavelli (University of Bologna), S. Jurinovich, L. Cupellini, B. Mennucci (University of Pisa) and S. Taioli (FBK-ECT)*

Light-Harvesting (LH) Pigment-Protein Complexes (PPC) in plants and photosynthetic bacteria, constitute the fundamental units through which sunlight is collected, harvested and converted in chemical energy. In these complexes, the close proximity (high coupling) of the light-absorbing molecules, strongly affects the static and dynamic spectral properties of the whole system. To tackle such complexity, we have worked with our collaborators of the University of Pisa to develop a multi-scale approach[1,2] to the problem: 1) we compute the local excitation properties of each single chromophore with very accurate Quantum Chemistry calculations, also including molecular vibrations and environmental fluctuations; 2) we compute the couplings between the chromophores (at an higher level with respect to the commonly used Point Dipole Approximation); 3) we combine these local informations via a Frenkel Exciton Hamiltonian Model, which returns the properties of the whole molecular aggregate. Our study is characterized by an ab-initio approach in computing the parameters of the Frenkel Exciton Model, relying on experiments (X-ray data) only for the LH structure, and its level of sophistication allows to reproduce and interpret linear and non-linear spectroscopy (e.g. Two Dimensional Electronic Spectra)[3] of these systems.

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Simone Taioli

Scattering methods for electron spectroscopy of materials and beyond

In collaboration with S. Simonucci (University of Camerino)

We developed a unified framework based on the scattering theory formalism, which is capable of describing a variety of physical processes ranging from core-electron spectroscopies of solids [1,2,3] to the description of the universal properties in ultra-cold Fermi gases [4,5,6], to the investigation of β-decay and e-capture in astrophysical scenarios [7] to unravelling the folding paths of proteins [8,9]. This method relies on a generalisation of Fano's approach to discrete-continuum interaction and, in particular, on the calculation of the multichannel *T*-matrix for determining accurately the continuum wave functions of particles emitted/captured from/in system's excited states, including the main correlation effects. The theory has been implemented into an *ab-initio* code suite called SURPRISES [10].

Epitaxy of carbon-based materials

In collaboration with R. Verucchi, L. Aversa, R. Tatti, M.V. Nardi, S. Iannotta (IMEM, CNR Trento), D. Alfè (University College London), G. Speranza (Center for Materials and Microsystems, FBK Trento), E. Cavaliere (Università Cattolica del Sacro Cuore)

A second line of research concerned the first-principles simulation of the out-of-equilibrium chemical-physical processes leading to crystal growth by supersonic molecular beam epitaxy (SuMBE). In particular, we demonstrated that high-kinetic energy fullerene beams impinging on semiconductor (silicon) or metallic (copper) targets can synthesise both 3D structures, such as silicon carbide nanocrystals [11,12,13], and prototype 2D materials, such as graphene [14,15], obtaining a significant reduction of the processing temperature with respect to existing growth techniques.

Imaginary crystals made real

In collaboration with S. Simonucci (University of Camerino), N. Pugno (University of Trento)

In this research activity, we combined theoretical approaches based on non-Euclidean group theory with numerical simulations to obtain the first energetically stable graphene-based molecular structure, which is a manifestation of a specific non-Euclidean crystallographic group [16]. We showed that this group is related to the negative-curvature counterpart of a Platonic solid, and identified this structure as a Beltrami pseudosphere. While this method points to a general procedure to generate all such surfaces, we used graphene hexagonal topology to design the Beltrami pseudosphere. The choice of graphene was dictated by a correspondence between the physics of low-energy electrons in graphene arranged in these geometries, and quantum field theory in the presence of non-trivial curved spacetimes, e.g., 2+1-dimensional black holes. Therefore, from this latter perspective, our work is a solid first step towards a laboratory realization of condensed-matter structures corresponding to discrete space-times, whose “Planck length” is the carbon-to-carbon bond-length of graphene. This work has far and wide implications ranging from non-Euclidean geometry, to certain black-hole scenarios, to the solution of the generalized Thomson problem, and to material science.

First-principles simulation electronic, mechanical and optical properties of materials (Graphene flagship)

In collaboration with A. Paris (Center for Materials and Microsystems, FBK Trento), G. Garberoglio, L. Calliari (European Center for Theoretical Studies in Nuclear Physics and Related Areas, FBK Trento), P. Umari (University of Padua), N.M. Pugno (University of Trento)

In this respect, we proposed a number of novel developments of graphene’s use by simulating from first-principles (many-body perturbation theory) and classical (molecular dynamics and path integral) methods: i) gas adsorption, energy storage and sieving properties in realistic models of organic-pillared reduced-graphene-oxide sheets in comparison to metal organic frameworks [17,18,19]; ii) mechanical properties of graphene foams and of bio-inspired materials [20,21]; iii) multiscale memristive behavior in TiO_2 crystals as alternative to graphene’s photo-controllable and photoswitchable characteristics [22]; iv) the excited state properties, notably band gap, of carbon nanotubes [23,24,25].

Transport of electrons in solids

In collaboration with M. Dapor, M. Azzolini, T. Morresi (European Center for Theoretical Studies in Nuclear Physics and Related Areas, FBK Trento)

The last research area is devoted to the study of the electron transport in solid targets. In particular we compared, using a Monte Carlo approach [26] the electron transport properties with reflection electron energy loss measurements in diamond and graphite films. We assessed the impact of different approximations of the dielectric response on the observables of interest for the characterization of carbon-based materials. We calculated the frequency-dependent dielectric response and energy loss function 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 a better agreement with electron energy loss measured spectra with respect the widely used Drude-Lorentz model. This discrepancy is particularly evident for insulators and semiconductors beyond the optical limit ($q \rightarrow 0$), where single particle excitations become relevant. Furthermore, we showed that the behaviour of the energy loss function 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 regime (<100 eV) and thus on the accuracy of MC simulations.

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6.2 Publications of ECT*-LISC Researchers in 2016

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
arXiv:1612.01898v1 [cond-mat.mtrl-sci]

Maurizio Dapor

Y. Zhou, D. S. Fox, P. Maguire, R. O'Connell, R. Masters, C. Rodenburg, H. Wu, M. Dapor, Y. Chen, H. Zhang
Quantitative secondary electron imaging for work function extraction at atomic level and layer identification of graphene
Scientific Reports 6, 21045 (2016)

Q. Wan, R. C. Masters, D. Lidzey, K. J. Abrams, M. Dapor, R. A. Plenderleith, S. Rimmer, F. Claeyssens, C. Rodenburg
Angle selective backscattered electron contrast in the low-voltage scanning electron microscope: Simulation and experiment for polymers
Ultramicroscopy 171, 126 (2016)

M. Dapor, I Abril, P. de Vera, R. Garcia Molina
Energy deposited by secondary electrons generated by swift proton beams through polymethylmethacrylate
International Journal of Chemical, Molecular, Nuclear, Materials and Metallurgical Engineering 10, 965 (2016)

M. Dapor
Spectra of electrons emerging from PMMA
GIT Imaging & Microscopy 18, 38 (2016)

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
arXiv:1612.01898v1 [cond-mat.mtrl-sci]

Giovanni Garberoglio

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). arXiv:1606.05494*

R. Tatti, L. Aversa, R. Verucchi, E. Cavaliere, G. Garberoglio, N. M. Pugno, G. Speranza, S. Taioli
Synthesis of single layer graphene on Cu (111) by C_{60} supersonic molecular beam epitaxy
*RSC Advances **6**, 37982 (2016)*

J.-P. Blaizot, D. De Boni, P. Faccioli, G. Garberoglio
Heavy quark bound states in a quark–gluon plasma: Dissociation and recombination
*Nuclear Physics A **946**, 49 (2016)*

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
Submitted to Carbon. arXiv:1612.01898

Andrea Pedrielli

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). arXiv:1606.05494*

Simone Taioli

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
arXiv: 1612.01898, submitted to Carbon [cond-mat]

A. Paris, S. Taioli
Multiscale Investigation of Oxygen Vacancies in TiO2 Anatase and Their Role in Memristor's Behavior
*The Journal of Physical Chemistry C **120** (38), 22045 (2016)*

S. Taioli, A. Paris, L. Calliari
Characterization of Pristine and Functionalized Graphene on Metal Surfaces by Electron Spectroscopy
*Graphene Science Handbook: Size-Dependent Properties **5**, 269 (2016)*
CRC Press Taylor & Francis Group
ISBN-9781466591356

S. Taioli, R. Gabbrielli, S. Simonucci, N.M. Pugno, A. Iorio
Lobachevsky crystallography made real through carbon pseudospheres
*Journal of Physics: Condensed Matter **28** (13), 13LT01 (2016)*

R. Tatti, L. Aversa, R. Verucchi, E. Cavaliere, G. Garberoglio, N.M. Pugno, G. Speranza, S. Taioli
Synthesis of single layer graphene on Cu (111) by C_{60} supersonic molecular beam epitaxy
*RSC Advances **6** (44), 37982 (2016)*

S. Palmerini, M. Busso, S. Simonucci, S. Taioli
Lithium abundances in AGB stars and a new estimate for the 7Be life-time
*Journal of Physics: Conference Series **665** (1), 012014 (2016)*

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 (2016), arXiv: 1606.05494 [cond-mat]*

6.3 Talks presented by ECT*-LISC Researchers in 2016

Martina Azzolini

Transport of Fast electron in Diamond
Talk given at the ECOSS32 European Conference on Surface Science
August 2016, Grenoble, France

Transport of Fast electron in Diamond
Invited talk at the conference "Nanoscience and Nanotechnology 2016"
September 2016, Frascati, Italy

Maurizio Dapor

Modeling electron materials interactions by Monte Carlo method
Departamento de Física Aplicada, Universidad de Alicante
May 2016, Alacant, Spain

Comparison between experimental measurement and Monte Carlo simulation of the secondary electron energy spectrum of low order Poly(3-hexylthiophene-2,5-diyl)
VIII Taller de colisiones inelásticas en la materia
December 2016, Quintana Roo, México

Giovanni Garberoglio

Quantum mechanical effects in small molecules
Invited talk given at the National Institute of Standards and Technology.
August 2016, Boulder (CO), USA

Quantum mechanical effects in small molecules
Talk given at the Department of Chemical and Petroleum Engineering of the University of Pittsburgh.
September 2016, Pittsburgh (PA), USA

Computational Materials Science: from meV to (several) MeV
Talk given at the National Energy and Technology Laboratory
October 2016, Pittsburgh (PA), USA

Tommaso Morresi

Monte Carlo simulation of electron transport in diamond and graphite
Poster presentation at the ECOSS32 conference
August-September 2016, Grenoble, France

Inelastic scattering of electrons in carbon-based materials: ab-initio dielctric theory approach
Poster presentation at the Nanoscience & Nanotechnologies conference
September 2016, Frascati, Italy

Andrea Pedrielli

Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression
Invited talk at the Conference “Nanoscience and Nanotechnology”.
September 2016, Roma, Italy

Designing graphene based nanofoams with nonlinear auxetic and anisotropic mechanical properties under tension or compression
Invited talk at the Conference “Materials .it 2016”.
December 2016, Catania, Italy

Simone Taioli

Graphene trumpets, foams, pillared networks, carbon materials growth, and all that from first-principles
Invited talk given at the “EMN Meeting on Computation and Theory”
Oct 2016, Las Vegas, USA

Theoretical estimates of e- captures and beta-decay from first-principles simulations
Talk given at the “28th Indian-Summer School on Ab Initio Methods in Nuclear Physics”
August 2016, Prague, Czech Republic

The growth of carbon-based materials by Supersonic Molecular Beam Epitaxy: experiments, theory and calculations
Invited talk given at the Department of Condensed Matter Physics, Charles University in Prague
April 2016, Prague, Czech Republic

Scattering methods applied to condensed matter and nuclear research
Lecturer at the Faculty of Mathematics and Physics, Charles University
February - April 2016, Prague, Czech Republic

7 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 optical 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 network (GARR and Trentino Network s.r.l.). The connection speed is up to 1 Gps (100 Mbps guaranteed) through the GARR network plus 1 Gbps (100 Mbps guaranteed) through the Trentino Network.

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

25 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 10.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 FBK and through the Google service.
The following useful Google services they 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 Hangouts
5. Google Classroom

HIGH PERFORMANCE COMPUTING

The ECT* researchers can access KORE, a High Performance Computer of FBK. KORE is made of about 1100 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.