ECT*

Annual Report 2015

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

Edited by
Gian Maria Ziglio 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 arrange in-depth research at the forefront of contemporary developments in nuclear physics;
- to foster interdisciplinary contacts between nuclear physics and neighboring fields such as astrophysics, condensed matter physics, particle physics and the quantal physics of small systems;
- to encourage talented young physicists to participate in the activities of the ECT* and
- to strengthen the interaction between theoretical and experimental physics.

Altogether 710 scientists from 41 countries have visited the ECT* in 2015 and have participated in the activities of the Centre. As in previous years this demonstrates once again ECT*'s worldwide visibility and its key importance for the European and international physics communities.

In 2015 ECT* held:

- 18 Workshops and 2 Collaboration Meetings on new developments in nuclear and hadronic physics from the lowest to the highest energies, nuclear astrophysics, topics in QCD, many-body systems and related areas in condensed matter and atomic physics.

- a Doctoral Training Programme on “Computational Nuclear Physics - Hadrons, Nuclei and Dense Matter” that lasted six weeks and was attended by 17 students from 10 countries worldwide.

- a TALENT (Training in Advanced Low-Energy Nuclear Theory) course on “Few-Body Systems and Nuclear Reactions” that lasted three weeks and was attended by 28 students from 13 countries.

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

- basic research on nuclear structure and reactions, non-perturbative QCD and hadron physics, theory of hadronic and nuclear collisions at high energy, phases of strongly interacting 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 more than forty publications by the ECT* and ECT*-LISC researchers in refereed journals represent a substantial fraction of all publications produced in 2015 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 and NAOJ, the National Astronomical Observatory) and China (the ITP of the Chinese Academy of Sciences), ECT* signed in 2015 agreements with the Asian Pacific Centre for Theoretical Physics (APCTP) in Korea, the

Joint Institute for Nuclear Research (JINR) in Dubna and the Advanced Science Research Center (ASRC) of JAEA in Japan. These initiatives have already created joint activities in the workshop program of ECT* and contributed further to ECT*'s highly visible international profile.

The integration of LISC, the Interdisciplinary Laboratory for Computational Science of FBK, as an independent Research Unit ECT*- LISC has become fully effective in 2015. Furthermore, ECT* pursues a fruitful cooperation with TIFPA, the recently founded Trento Institute for Fundamental Physics and Applications funded by INFN.

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 2015 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 UK. ECT* also acknowledges additional partial support for its workshops from the ESF Network POLATOM, the Alexander von Humboldt Foundation, INFN-TIFPA, the Goethe University of Frankfurt/M., the BEC Centre Trento, APCTP, SISSA Trieste, Jefferson Lab, HIC-for-FAIR and IPN Orsay.

ECT* has been playing an important role as a Transnational Access (TNA) facility within European projects, and it will continue to do so in upcoming Horizon2020 activities.

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 2015 is also available on the ECT* web site (www.ectstar.eu).

Trento, March 2016

Wolfram Weise
*Director of ECT**
(Until Dec. 2015)

Jochen Wambach
*Director of ECT**
(From Jan. 2016)

Contents

2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Baha Balantekin (until Jan. 2015)	University of Wisconsin, Madison, USA
Angela Bracco	NuPECC/University of Milano, Italy
François Gélis (until Sept. 2015)	CEA Saclay, France
Maria-Paola Lombardo (until Sept. 2015)	INFN Frascati, Italy
Judith McGovern	University of Manchester, UK
Paul-Henri Heenen	Université Libre de Bruxelles, Belgium
Piet Mulders (Chair)	VU Amsterdam, Netherlands
Sanjay Reddy (from June 2015)	University of Washington, Seattle, USA
Johanna Stachel	University of Heidelberg, Germany
Ubirajara van Kolck	IPN Orsay, France

Honorary Member of the Board

Ben Mottelson — NORDITA, Copenhagen, Denmark

ECT* Director

Wolfram Weise — ECT*, Italy and TU München, Germany

2.2 ECT* Staff

Ines Campo (part time)	Technical Programme Co-ordinator
Serena degli Avancini	Technical Programme Co-ordinator
Barbara Curro' 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 and Senior Research Associates**

Guillaume Beuf, France (since Oct. 2015)
Daniele Binosi, Italy
Alexis Diaz-Torres, Germany
Daniel Gazda, Czech Republic (until Sept. 2015)
Maria Gomez Rocha, Spain (since Sept. 2015)
Philipp Gubler, Switzerland
David Ibañez Gil de Ramales, Spain (until Sept. 2015)
Chen Ji, China (since Sept. 2015)
Daisuke Sato, Japan
Dionysis Triantafyllopoulos, Greece

- **ECT*-LISC Researchers**

Maurizio Dapor (Head of ECT*-LISC Research Unit)
Silvio a Beccara
Lucia Calliari
Giovanni Garberoglio
Simone Taioli

- **PhD Students**

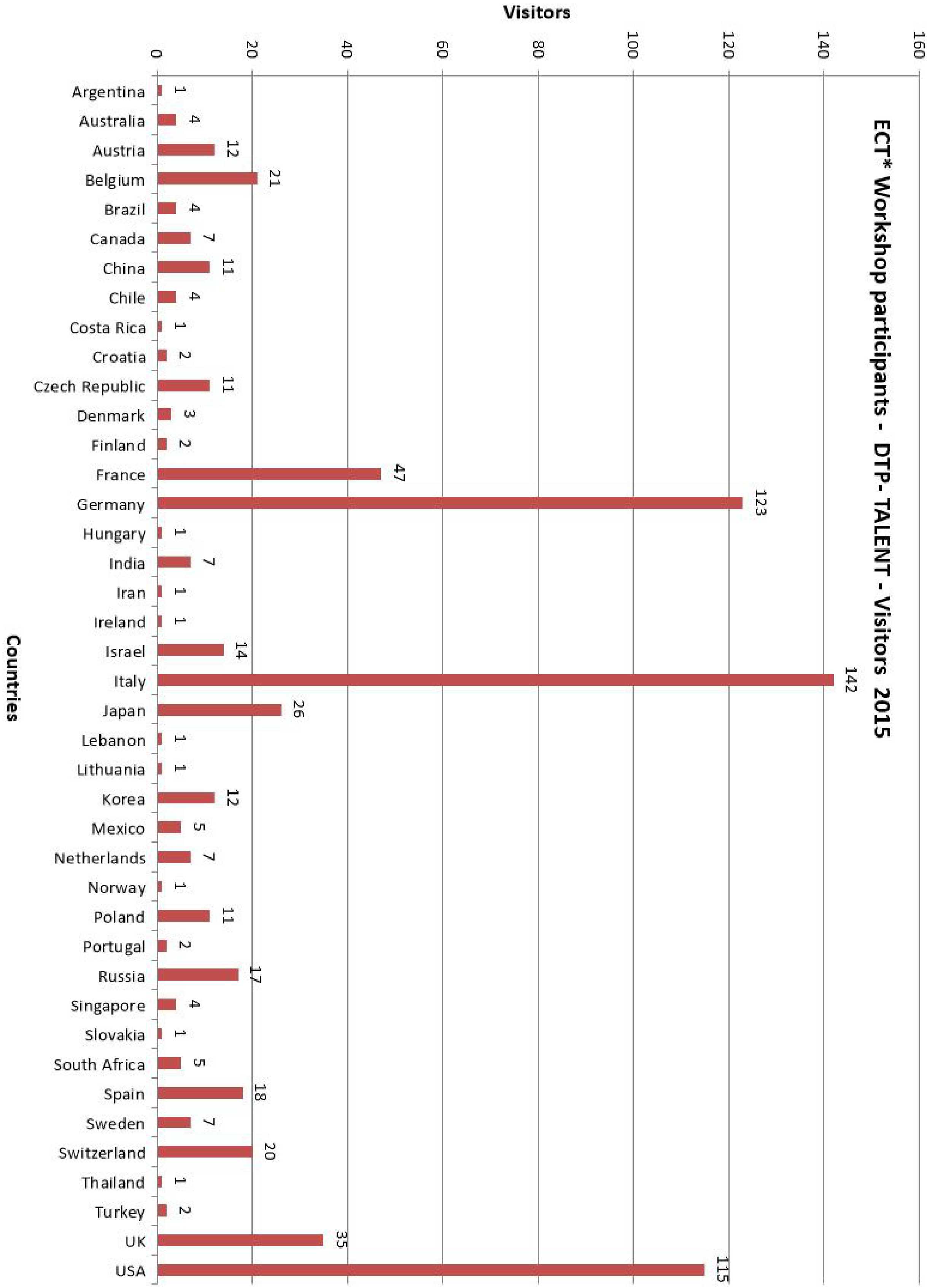
Maddalena Boselli, Italy
Robert Lang, Germany

2.4 Visitors in 2015

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

Faiza Akbar (12/04-22/05)	Aligarh Muslim University, India (DTP)
Michael Altenbuchinger (14/12)	TU München, Germany (VS)
Marcello Andolina (14/12)	University of Pisa, Italy (TS)
Alexander Arzhanov (12/04-23/05)	TU Darmstadt, Germany (DTP)
Nada Barakat (12/04-03/05)	LPE Beirut, Libanon (DTP)
Nir Barnea (20/07-07/08)	Hebrew University of Jerusalem, Israel (TS)
Jean-Paul Blaizot (17/04-03/05)	CEA Saclay, France (VS)
Davide de Boni (12/04-22/05)	Swansea University, UK (DTP)
Tamer Boz (12/04-23/05)	Maynooth University, Ireland (DTP)
Lorenzo Contessi (20/07-07/08)	University of Trento, Italy (TS)
Takahiro Doi (12/04-23/05)	Kyoto University, Japan (DTP)
Moti Elyahu (20/07-07/08)	Hebrew University of Jerusalem, Israel (TS)
Paolo Erdman (20/07-02/08)	University of Pisa, Italy (TS)
Fabrizio Ferrari Ruffino (20/07-07/08)	University of Trento, Italy (TS)
Graziano Fortuna (20/09-22/09)	LNL INFN, Italy (VS)
Mario Gattobigio (20/07-07/08)	CNRS, France (TS)
Arturo Gomez Camacho (06/06-20/06)	CEA Saclay, France (VS)
Mario Gomez Ramos (20/07-07/08)	Universidad de Sevilla, Spain (TS)
Giovanni de Gregorio (03/05-23/05)	University of Naples, Italy (DTP)
Dominique Guillemaud Mueller (20/09-22/09)	IN2P3, France (VS)
Tetsuo Hatsuda (17/04-27/04, 11/05-22/05)	RIKEN, Japan (DTP)
Oscar Javier Hernandez (20/07-07/08)	TRIUMF/ The University of Manitoba (TS)
Morton Hjorth-Jensen (05/05-24/05, 26/05-12/06)	Michigan State University, USA and University of Oslo, Norway (DTP)
Linda Hlophe (20/07-07/08)	Ohio University, USA (TS)
Dennis Hove (20/07-07/08)	Aarhus University, Denmark (TS)
Edmond Iancu (13/04-22/04)	CEA Saclay, France (VS)
Aurelian Isar (20/09-22/09)	NIPNE, Romania (VS)
Lei Jin (20/07-07/08)	University of Sevilla, Spain (TS)
Simon Kegel (20/07-07/08)	University of Mainz, Germany (TS)
Ghanshyambhai Khatri (20/07-07/08)	Jagiellonian University, Krakow, Poland (TS)
Alejandro Kievsky (20/07-07/08)	University of Pisa, Italy (TS)
Michal Kloc (11/04-23/05)	Charles University, Prague, Czech Republic (DTP)
Dmitry Kobyakov (12/04-18/04)	Institut für Kernphysik, Darmstadt, Germany (DTP)

Christopher Koerber (20/07-07/08)	FZ Jülich, Germany (TS)
Robert Lang (19/01-23/01, 19/04-22/04)	TU München, Germany (VS)
Rimantas Lazauskas (20/07-07/08)	CNRS, France (TS)
Maria Paola Lombardo (03/05-15/05)	INFN Frascati, Italy (DTP)
Amy Lovell (20/07-07/08)	Michigan State University, USA (TS)
Francesco Macheda (20/07-07/08)	University of Pisa, Italy (TS)
José Madrigal (13/04-22/04)	TU München, Germany (VS)
Tony Medland (20/09-22/09)	STFC, UK (VS)
Alfred Mueller (24/02-23/04)	Columbia University, NY, USA (VS)
Hajar Nematollahi (20/07-07/08)	Tehran University, Iran (TS)
Amy Nicholson (23/04-03/05, 12/05-22/05)	University of California, Berkeley, USA (DTP)
Andreas Nogga (20/07-05/08)	FZ Jülich, Germany (TS)
Jorge Nogueira (20/07-07/08)	ITA, Brazil (TS)
Shotaro Oka (12/04-26/04)	Rikkyo University, Tokyo, Japan (DTP)
Giuseppina Orlandini (04/05-17/05, 20/07-07/08)	University of Trento, Italy (DTP, TS)
Giuseppe Pastore (03/05-15/05)	University of Florence, Italy (DTP)
Francesco Pederiva (04/05-17/05)	University of Trento and TIFPA, Italy (DTP)
Stefan Petschauer (14/12)	TU München, Germany (VS)
Terri Poxon-Pearson (20/07-07/08)	Michigan State University, USA (TS)
Mannque Rho (13/09-19/09)	CEA Saclay, France (VS)
Achim Richter (27/09-09/10)	TU Darmstadt, Germany (VS)
Marco Rocchini (03/05-15/05)	University of Florence, Italy (DTP)
Alexander Rokash (20/07-07/08)	Ruhr University, Bochum, Germany (TS)
Patricia Roussel Chomaz (20/09-22/09)	CEA, France (VS)
Daniel Sääf (20/07-07/08)	Chalmers University of Technology, Sweden (TS)
Mario Sanchez (12/04-23/05)	Rikkyo University, Tokyo, Japan (DTP)
Francesca Sartori (20/07-07/08)	University of Trento, Italy (TS)
Thomas Schaefer (10/04-18/04, 26/05-05/06)	North Carolina State University, USA (DTP, VS)
Leandro Sottili (20/07-07/08)	University of Florence, Italy (TS)
Paul Springer (14/12)	TU München, Germany (VS)
Susanne Strohmeier (14/12)	TU München, Germany (VS)
Takuya Sugiura (12/04-02/05)	Osaka University, Japan (DTP)
Wasiu Tahya (12/04-23/05)	Stellenbosch University, South Africa (DTP)
Nikhil Vaidya (20/07-07/08)	FZ Jülich, Germany (TS)
Mateo Valdes (20/07-07/08)	IPHC Strasbourg, France (TS)
Deni Vale (20/07-07/08)	University of Zagreb, Croatia (TS)
Giorgio Valocchi (12/04-23/05)	Politecnico di Torino, Italy (DTP)
Yasunori Wada (20/07-07/08)	Tohoku University, Japan (TS)
Jochen Wambach (16/02-19/02, 20/04-23/04, 09/09-13/09)	TU Darmstadt, Germany (VS)
Ronen Weiss (20/07-07/08)	Hebrew University of Jerusalem, Israel (TS)
Corbinian Wellenhofer (14/12)	TU München, Germany (VS)
Sarah Wesolowski (20/07-07/08)	The Ohio State University, USA (TS)


ECT* Workshop participants - DTP- TALENT - Visitors 2015
Visitors
0
20
40
60
80
100
120
140
160
Countries
Argentina 1
Australia 4
Austria 12
Belgium 21
Brazil 4
Canada 7
China 11
Chile 4
Costa Rica 1
Croatia 2
Czech Republic 11
Denmark 3
Finland 2
France 47
Germany 123
Hungary 1
India 7
Iran 1
Ireland 1
Israel 14
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Japan 26
Lebanon 1
Lithuania 1
Korea 12
Mexico 5
Netherlands 7
Norway 1
Poland 11
Portugal 2
Russia 17
Singapore 4
Slovakia 1
South Africa 5
Spain 18
Sweden 7
Switzerland 20
Thailand 1
Turkey 2
UK 35
USA 115

3 Scientific Projects in 2015

3.1 Summary

Altogether 22 scientific projects have been run in 2015: 18 workshops, 2 collaboration meetings, a Doctoral Training Programme and the TALENT school. This chapter collects the scientific reports written by the workshop organizers. The report of the Doctoral Training Programme was prepared by Georges Ripka who coordinated this programme. The TALENT report was written by Giuseppina Orlandini and Alejandro Kievsky.

3.2 Workshops, Collaboration Meetings and Schools (Calendar)

Jan 12 – 23	**International Winter School and Workshop on "Strongly Correlated Fluids of Light and Matter"** Iacopo Carusotto (INO-CNR BEC Center) Cristiano Ciuti (Université Paris-Diderot) Rosario Fazio (SNS Pisa) Atac Imamoglu (ETH Zürich)
Jan 26 - 30	**Observations and Theory in the Dynamics of Neutron Stars** Nicolas Chamel (Université Libre de Bruxelles) Jeremy W. Holt (Texas A&M and University of Washington, Seattle) Arnau Rios Huguet (University of Surrey) Gang Shen (Technical University Darmstadt)
Mar 16 - 20	**Heavy Quark Physics in Heavy-Ion Collisions: Experiments, Phenomenology and Theory** Vincenzo Greco (University of Catania & INFN-LNS) Maria Paola Lombardo (INFN-LNF) André Mischke (Utrecht University) Nu Xu (LBL, Berkeley)
Mar 20	**Heavy Flavour in Heavy-Ion Collisions at the Future Circular Collider (FCC)** Andrea Dainese (INFN Padova)
Apr 13 - May 22	**Computational Nuclear Physics - Hadrons, Nuclei and Dense Matter** **(Doctoral Training Program)** Maria Paola Lombardo (INFN–LNF)
May 14 - 15	**Interplay of Structure and Dynamics in Heavy-Ion Collisions** Francesco Catara (University and INFN Catania) Maribel Gallardo (Departamento de Física Atómica Molecular y Nuclear, Sevilla) Edoardo Lanza (INFN Catania) Silvia Lenzi (University and INFN Padova) Andrea Vitturi (University and INFN Padova)

Jun 08 - 12	**New Directions in Nuclear Deep-Inelastic Scattering** Raphael Dupré (Institut de Physique Nucléaire, Orsay) Sergio Scopetta (Perugia University and INFN Perugia)
Jun 22 - 25	**Cold Atoms Meet High Energy Physics** Massimo Inguscio (LENS, Florence & INRIM, Torino) Guido Martinelli (SISSA) Sandro Stringari (University of Trento)
Jul 06 - 10	**Lattice Nuclei Nuclear Physics and QCD - Bridging the Gap** Johannes Kirscher (Hebrew University of Jerusalem) Francesco Pederiva (University of Trento) Martin Savage (University of Washington, Seattle)
Jul 20 – August 7	**Few-Body Methods and Nuclear Reactions (TALENT School)** Giuseppina Orlandini (University of Trento) Alejandro Kievsky (INFN Pisa)
Jul 22 - 24	**HASPECT Collaboration Meeting** Marco Battaglieri (INFN Genova)
Aug 24 - 27	**The Interplay Between Atomic and Nuclear Physics to Study Exotic Nuclei** Stephan Fritzsche (Helmholtz Institut Jena) Michel Godefroid (Université Libre de Bruxelles) Gerda Neyens (KU Leuven) Wilfried Nörtershäuser (Technische Universität Darmstadt)
Sep 01- 04	**Interfacing Structure and Reaction Dynamics in the Synthesis of the Heaviest Nuclei** Gurgen Adamian (JINR Dubna) Alexis Diaz-Torres (ECT*)
Sep 07 - 11	**LFC15: Physics Prospects for Linear and other Future Colliders after the Discovery of the Higgs** Gennaro Corcella (INFN Frascati) Stefania De Curtis (INFN Firenze) Frederic Kapusta (IPNHE-IN2P3) Stefano Moretti (University of Southampton) Giulia Pancheri (INFN Frascati) Francois Richard (LAL - IN2P3 Université de Paris Sud)
Sep 14 - 18	**ECT*-APCTP Joint Workshop: From Rare Isotopes to Neutron Stars** Francesca Gulminelli (LPC and University of Caen, France) Chang-Hwan Lee (Pusan National University, Busan, Korea) Yongseok Oh (Kyungpook National University, Daegu, Korea) Jürgen Schaffner-Bielich (Goethe University Frankfurt, Germany)
Sep 21 - 25	**Excited-State Quantum Phase Transitions** Tobias Brandes (TU Berlin) Pavel Cejnar (University of Prague)

Oct 05 - 09	**Recent Advances in Monte Carlo Methods** Shailesh Chandrasekharan (Duke University) Christof Gattringer (University of Graz) Ribhu Kaul (University of Kentucky) Dean Lee (North Carolina State University)
Oct 12 - 16	**Nucleon Resonances: From Photoproduction to High Photon Virtualities** Ralf W. Gothe (University of South Carolina) Viktor I. Mokeev (Jefferson Lab) Elena Santopinto (INFN Genova)
Oct 19 - 23	**Frontiers in Hadron and Nuclear Physics with Strangeness and Charm** Kai-Thomas Brinkmann (University of Giessen) Catalina Curceanu (LNF INFN Frascati) Johann Marton (SMI, Vienna) Ulf-G. Meissner (University of Bonn and FZ Jülich) Bing-Song Zou (ITP/CAS - Beijing)
Oct 26 - 30	**From 1D Fragmentation Towards 3D Correlated Fragmentation** Alessandro Bacchetta (INFN Pavia and Pavia University) Vincenzo Barone (Piemonte Orientale University, Alessandria) Rolf Ent (Jefferson Lab) Ted C. Rogers (Jefferson Lab and Old Dominion University)
Nov 16 - 20	**Information and Statistics in Nuclear Experiment and Theory ISNET-3** David Ireland (University of Glasgow) Witold Nazarewicz (FRIB/NSCL, Michigan State University) Bartlomiej Szpak (INP, Polish Academy of Sciences, Krakow)
Nov 30 – Dec 11	**New Perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC** Gordon Baym (University of Illinois at Urbana-Champaign) Axel Drees (Stony Brook University) Tetsuo Hatsuda (RIKEN Nishina Center) Kenta Shigaki (Hiroshima University)

3.3 Reports on Workshops and Collaboration Meetings

3.3.1 INTERNATIONAL WINTER SCHOOL AND WORKSHOP ON “STRONGLY CORRELATED FLUIDS OF LIGHT AND MATTER”

DATE: January 12 – 23, 2015

ORGANIZERS:

I. Carusotto (INO-CNR BEC Center, Trento, Italy)
C. Ciuti (Université Paris Diderot-Paris 7)
R. Fazio (SNS Pisa, Italy)
A. Imamoglu (ETH Zürich, Switzerland)

NUMBER OF PARTICIPANTS: 80

In total about 80 registered participants. Space restrictions at ECT* forced us to reject around 10 extra applicants. Participation was not limited to specialists on quantum fluids of light only, but an active interest came from a broader variety of physicists. This was very favourable to reinforce the scientific exchanges between neighboring communities. In addition to the officially registered participants there were:

- 3 post-docs from Paris 7 University that participated in the lectures and seminars as “uditori” at their own expenses.
- 2 Master students in Physics of the Trento University that spontaneously attended lectures and seminars on a regular basis. After attending the event, they are now very motivated to do their final “tesi di Laurea magistrale” on these subjects.
- more than 10 professors, researchers, post-docs and PhD students from Trento University and the BEC Center that quite regularly attended the lectures and seminars. Some of them also gave talks.

Remarkably, invited speakers accepted to travel from as far as Australia and Singapore to participate in the event. Some of these remote groups brought to Trento several PhD students at their own expenses: this emphasizes how this event was perceived as important and groundbreaking in the wide panorama of international events on quantum many-body physics.

Thanks to external funding from POLATOM-ESF and BEC, we have been able to partially cover the local expenses of several participants in addition to the invited speakers.

MAIN TOPICS:

As it was anticipated in the application, the general goal of the School and Workshop on “Strongly correlated fluids of light and matter” was to consolidate the international community working on the young field of Quantum Fluids of Light and to reinforce its interaction with more traditional fields of many-body physics such as ultracold atomic gases and strongly correlated electrons.
The original plan was to have a first week with a school-like character, with top-class scientists lecturing from basic concepts up to the most recent developments, and a second week with a

workshop-like character, with research seminars covering a broad selection of the hottest topics. Because of the limited availability of key lecturers and speakers, the distinction between the two weeks became less formal. Lectures and seminars turned out to be strongly mixed. This unexpected feature actually turned out to be a success, as it allowed to organize the sessions according to the subject, so as to give a more complete overview. Furthermore, while the lectures during the first week covered elementary concepts, the ones during the second week were far more advanced and brought the audience to the latest developments.

The main topics were:

- basics of the theory of dilute Bose gases of atoms and of photon/polaritons
- theory and experiments with polariton fluids in microcavity devices
- theory and experiments with fluids of light in cavityless propagating geometries
- strongly correlated photons in cavity arrays
- quantum hydrodynamics and artificial black holes
- non-equilibrium phase transitions
- topological effects in optics and photonics
- topological protection towards topological quantum computing
- numerical simulation of quantum many-body systems
- entanglement in strongly correlated many-body systems
- cavity-QED and quantum devices using superconducting quantum circuits in the microwave domain

LECTURERS:

F. Dalfovo (Trento University, Italy)
M. Devoret (Yale University, USA)
F. Verstraete (Vienna, Austria)
C. Kollath (Bonn, Germany)
A. Amo (LPN-CNRS Marcoussis, France)
A. Stern (Weizmann Institute, Israel)

SPEAKERS:

C. Ciuti (MPQ-Paris 7, France)
A. Imamoglu (ETH Zürich, Switzerland)
R. Fazio (SNS Pisa, Italy)
H. Tureci (Princeton, USA)
H. Price (BEC Trento, Italy)
T. Ozawa (BEC Trento, Italy)
M. Hafezi (JQI, USA)
P.-E. Larré (BEC Trento, Italy)
M. Rechtsman (Haifa, Israel)
M. Hartmann (Heriot-Watt, UK)
M. Weitz (Bonn, Germany)
J. Keeling (St. Andrews, UK)
F. R. Manzano (Trento University, Italy)
D. Rossini (SNS Pisa, Italy)
D. Angelakis (TU of Crete, Greece and CQT Singapore)
S. Diehl (Dresden, Germany)
K. Le Hur (Ec. Polytechnique, Paris, France)
E. Solano (Bilbao, Spain)
H.-S. Nguyen (LPN-CNRS Marcoussis, France)
D. Gerace (University of Pavia, Italy)
B. Deveaud (EPFL, Switzerland)
S. Bar-Ad (Tel Aviv, Israel)
D. Faccio (Heriot-Watt, UK)

T. Volz (Macquarie, Australia)

G. Molina-Terriza (Macquarie, Australia)

M. Wouters (Antwerp, Belgium)

S. Schmidt (ETH Zürich, Switzerland)

J. Simon (Chicago, USA)

M. Richard (Grenoble, France)

V. Savona (EPFL, Switzerland)

A. Bramati (LKB, Paris, France)

C. Conti (ISC-CNR, Roma, Italy)

L. Dominici (Lecce, Italy)

F. Piazza (TU Munich, Germany)

S. Koghee (Antwerp, Belgium)

G. Dagvadorj (Warwick, UK)

A. Chiocchetta (SISSA Trieste, Italy)

M. Bellec (Nice, France)

C. Bardyn (CalTech, USA)

L. Mazza (SNS Pisa, Italy)

J. Bloch (LPN-CNRS Marcoussis, France)

SCIENTIFIC REPORT:

Historically, most of the theoretical and experimental activities in the field of many-body physics addressed systems of matter particles such as atoms, electrons, nucleons, or quarks. In the last decades, a growing community of researchers has started exploring whether in suitable circumstances light can behave as a fluid composed of a large number of corpuscular photons with sizable photon-photon interactions. Even if this point of view is perfectly legitimate within the wave-particle duality in quantum mechanics, it is somehow at odds with our intuitive picture of light: the historical development of our understandings of matter and light have in fact followed very different paths.

The idea of matter being formed by a large number of elementary corpuscles that combine in different ways to form the variety of existing materials dates back to the ancient age with Demokritos' atomistic hypothesis, while the wavy nature of particles was put forward only in 1924 by de Broglie and experimentally demonstrated by Davisson and Germer in 1927. On the other hand, the long-standing debate between Newton's corpuscular and Huygens' undulatory theories of light appeared to be solved in the early 19th century with the observation of fringes in Young's double slit experiment and of the remarkable Arago's white spot in the shadow of a circular object. With the microscopic support of Maxwell's theory of electromagnetism, the undulatory theory was able to explain most experimental observations until the beginning of the 20th century when the corpuscular concept of a photon as a discrete quantum of light was revived by Einstein's theory of the photoelectric effect. Within the wave-particle duality, our standard interpretation of light then consists of a beam with a dual undulatory and corpuscular nature that is emitted by the source and then freely propagates through optical devices until it is absorbed.

Whereas this intuitive picture of light is perfectly sufficient to describe most cases of interest, it is still missing a crucial element, namely, the possibility of frequent collisions between photons that might lead to collective fluid-like behaviors in the many-photon system. While photon-photon interactions have been predicted to occur even in vacuum via virtual excitation of electron-positron pairs, the cross section for such a process in vacuum is so small that it does not play any significant role in realistic optical experiments. On the other hand, the nonlinear polarization of nonlinear optical media is able to mediate significant interactions between photons: Upon elimination of the matter degrees of freedom, third-order nonlinearities correspond, in the language of Feynman diagrams, to four-legged vertices describing, among others, binary collisions between a pair of photons. To create a stable luminous fluid, it is also crucial to give a finite effective mass to the photon. A simple strategy for this purpose involves a spatial confinement of the photon by metallic and/or dielectric planar mirrors. In a planar geometry with a pair of metallic mirrors separated by a distance l_z, the photon motion along the perpendicular z direction is quantized as $q_z = \pi M / l_z$, M being a

positive integer. For each longitudinal mode, the frequency dispersion as a function of the in-plane wave vector k has the relativistic form $\omega2(k) = c2[qz2+ k2]$ with a mass $mc2 = h\ c\ qz$.
Within recent years, this initially speculative idea has led to impressive experimental developments, which -among other- have demonstrated superfluidity in a fluid of light, Bose-Einstein condensation of photons and polaritons (a kind of dressed photons), controlled generation and manipulation of shock waves, soliton physics, an optical version of the Berezinski-Kosterlitz-Thouless superfluidity transition. While all these experiments were based on weakly nonlinear media where the dilute gas model based on a (generalized) Gross-Pitaevskii equation is accurate, the present challenge is to achieve a strong nonlinearity regime where strongly correlated states of the photon fluid can be generated and studied. First evidences of such a regime have been reported using single atoms in cavities, quantum dots in microcavities, and atomic gases in the Rydberg-EIT regime
As a result of these advances, the reseach on fluids of light is now beginning to require sophisticated many-body concepts and, in turn, to stimulate novel conceptual developments. As an example, a most remarkable novel aspect of fluids of light is that in many circumstances they are far from equilibrium and their state originates from a dynamical balance between pumping and dissipation, rather than from a thermodynamical equilibrium condition: novel states of matter might thus be found with unexpected properties and both theorists and experimentalists must be prepared to deal with the new challenges.
At the same time, this research is reaching a level of maturity that offers interesting insights into other fields of many-body physics, especially ultracold atomic gases. Most concepts and techniques are in fact shared by the two fields and some of the important present challenges of atomic physics might take advantage of the related success in optics. Concerning possible applications, one of the long-term goals of this research is to contribute to the development of integrated photonic platforms for communication and information processing using light: introducing many-body concepts in this effort is expected to open new possibilities to improve the flexibility and the robustness of such devices.
The School and Workshop on “Strongly correlated fluids of light and matter” has successfully covered all the main areas of research in the broad field of Quantum Fluids of Light, trying to emphasize the interdisciplinary relations with neighbouring fields such as, e.g., non-equilibrium statistical mechanics, strongly correlated electron gases, ultracold atom physics, and topological quantum mechanics. Participants who attended the whole event have obtained a complete overview of on-going work in this field and of the main open problems.

Results and Highlights

The main success of the School and Workshop was to contribute to establishing a world-wide community working on different aspects of the physics of Quantum Fluids of Light. So far, most of the advances in this research have in fact involved several distinct and independent communities of researchers working on specific aspects, while a general view was still lacking. Our goal was to put these sub-communities in contact and to reinforce their mutual interactions. As organizers, we feel that this objective was met: several participants have offered to give their contribution to the organization of events with a similar broad perspective in the next few years.
The main open problems that have been identified during the event and, in particular, during the final wrap-up sessions can be summarized as follows:

- Is it possible to observe new kinds of (quantum) phase transitions that are made possible by the non-equilibrium driven-dissipative nature of the fluid of light in a microcavity geometry?
- Renormalization-group calculations have anticipated that already the standard non-equilibrium BEC phase transition shows unexpected features, especially in the critical region and in 2D. Is it experimentally possible to measure them?
- What is the best platform (polaritons, circuit-QED, Rydberg atoms,...) to create a spatially extended array of cavities displaying strong photon-photon interactions?

- What is the most efficient scheme to pump photons into the device in order to generate a desired strongly correlated state of many-photons?
- What is the best optical platform (microcavity device, cavityless propagating geometry, or ...) to observe analog Hawking radiation from artificial black-hole configurations?
- What is the most efficient numerical technique to simulate the steady-state and dynamics of strongly interacting photons in driven-dissipative configurations?
- Is it possible to identify photonic configurations that support topologically protected quantum states?
- What are the advantages/disadvantages for quantum applications of working in the optical vs. microwave domain?

3.3.2 OBSERVATIONS AND THEORY IN THE DYNAMICS OF NEUTRON STARS

DATE: January 26 – 30, 2015

ORGANIZERS:

N. Chamel (Université Libre de Bruxelles, Belgium)
J. W. Holt (University of Washington, USA)
A. Rios (University of Surrey, UK)
G. Shen (TU Darmstadt, Germany)

NUMBER OF PARTICIPANTS: 37

MAIN TOPICS:

The workshop focused on recent observations and theoretical findings that challenge our understanding of neutron star dynamics. The goal was to bring together observers, theoretical astrophysicists and nuclear theorists to synthesize key developments in the field, build better models and map out future lines of research.

The main topics were:

- Equation of state of dense neutron-rich matter,
- Nuclear pastas in neutron-star crusts,
- Pulsar glitches and superfluidity,
- Quasi-periodic oscillations in the giant flares of soft gamma-ray repeaters and neutron star seismology.

SPEAKERS:

A. Alpar (Sabanci University)

N. Andersson (University of Southampton)

D. Antonopoulou (Anton Pannekoek Institute for Astronomy, University of Amsterdam)

H. Arellano (Universidad de Chile)

A. Bulgac (University of Washington)

M. Caplan (Indiana University)

A. Carbone (TU Darmstadt)

R. Ciolfi (University of Trento)

T. Delsate (University of Mons)

C. Drischler (TU Darmstadt)

A. Fantina (Université Libre de Bruxelles)

M. Forbes (Washington State University)

M. Gabler (Max Planck Institute for Astrophysics)

K. Glampedakis (University of Murcia)

V. Graber (University of Southampton)

K. Hebeler (TU Darmstadt)

C. Horowitz (Indiana University)

W. Kastaun (University of Trento)

D. Kobyakov (TU Darmstadt)

E. Kolomeitsev (Matej Bel University)

S. Lander (University of Southampton)

B. Link (Montana State University)
K. Palapanidis (University of Southampton)
C. Pethick (Niels Bohr International Academy and NORDITA)
P. Pizzochero (University of Milano)
P-G Reinhard (Institut für Theoretische Physik, Erlangen)
A. Rios Huguet (University of Surrey)
R. Sellahewa (University of Surrey)
J. Steinhoff (Albert Einstein Institute)
A. van Eysden (Montana State University)
C. Wellenhofer (TU Munich)

SCIENTIFIC REPORT:

Neutron stars are the most compact stellar objects in the universe and represent unique astrophysical laboratories for exploring matter under extreme densities, isospin asymmetries and magnetic fields. Most neutron stars are observed as radio pulsars with rotational periods ranging from milliseconds to seconds, but the development of space-based gamma-ray detectors and X-ray telescopes has led to the identification of new classes of neutron stars exhibiting novel phenomena not previously seen in radio pulsars. Neutron star mass and radius measurements are currently providing meaningful constraints on models of dense matter and the related equation of state. The goal of the workshop was to focus on complementary aspects related to new observations and theories in neutron star dynamics. Specifically the main topics that were addressed during the workshop can be summarized as follows.

- X-ray pulsars and nuclear pastas

Magnetic dipole radiation loss is the standard mechanism by which neutron stars lose rotational energy and spin down. From the observed periods of young isolated X-ray pulsars with large inferred magnetic fields, theoretical models predict the periods of old X-ray pulsars to lie in the range of 20-30 seconds. The fact that no isolated X-ray pulsars have been observed with rotational periods greater than 12 seconds has recently been conjectured as evidence for a highly resistive nuclear pasta layer in the densest region of the inner crust of neutron stars.

- Pulsar glitches and superfluidity

Pulsars are among the most accurate clocks in the universe with delays of a few milliseconds per year at most. Nonetheless numerous pulsars exhibit timing irregularities, the most spectacular of which are “glitches”: sudden increases in the rotational frequency and spin-down rate that gradually relax over time scales of days to years. The long-held consensus view is that these phenomena involve the catastrophic unpinning and migration of superfluid neutron vortices in the crust. But this picture has recently been challenged by observations and theoretical studies.

- Quasi-periodic oscillations in soft gamma-ray repeaters and neutron-star seismology

Quasi-periodic oscillations have recently been observed in the giant flares of a few soft gamma-ray repeaters, a class of highly magnetized neutron stars so called magnetars. Although the mechanism responsible for giant flares remains uncertain, it is expected to be accompanied by a reordering of the neutron star’s magnetic field and associated seismic activity in the crust. If this interpretation is correct, it may become possible to probe the interior of neutron stars and the presence of superfluids. These observations have triggered a renewed interest in the asteroseismology of neutron stars.
The following additional topics related to neutron star structure and dynamics were discussed during the workshop:

- the equation of state of dense matter,

- the existence of universal relations for neutron stars,
- binary neutron star mergers and short gamma-ray bursts.

Finally, a specific session was devoted to working group discussions in the framework of the Cooperation in Science and Technology (COST) action MP1304 NewCompStar

Results and Highlights

The workshop offered the opportunity to bring together observers, theoretical astrophysicists and nuclear physicists to assess theory needs, develop improved modelling, and plan future research directions in the field.

The formation of nuclear “pastas” in neutron-star crusts was discussed. In particular, semi classical molecular dynamics simulations predict the appearance of various nuclear pasta phases below normal nuclear densities. Nuclear pastas have been also recently studied with self-consistent mean field methods, though the number of nucleons that can be included in these calculations is considerably lower due to computing limitations. These pastas may impact various properties of neutron-star crusts like the shear and the bulk viscosities, the thermal conductivity, the electrical conductivity, the shear modulus and the breaking strain. Apart from the periods of isolated X-ray pulsars, other observable signatures of nuclear pastas were mentioned like crust cooling in transiently accreting neutron stars. Regarding the internal constitution of neutron-star crusts, it was also shown that the presence of unbound neutrons leads to an induced interaction between ions similar to the induced interaction in superconductors. As a result, the body-centered cubic lattice structure that has been usually assumed was found to be unstable.

Recent developments about pulsar glitches were presented by one of the leading experts in the field. Observations include the unusual glitch in PSR J1119-6127, as well as the discovery of a minimum glitch size in the Crab pulsar. On the theoretical side, it has been found that due to strong entrainment effects the neutron superfluid in the crust does not carry enough angular moment to explain large glitches like those observed in the emblematic Vela pulsar. Some interesting solutions were discussed involving vortex pinning to proton flux tubes in the outer core. Although pinning forces are essential ingredients to model glitches, their accurate computation by comparing different static vortex configurations is challenging. On the other hand, recent dynamical simulations of superfluid vortices can provide an alternative path to understanding the vortex-nucleus interaction. Experimental realizations using cold atoms were also discussed. Finally, the need of hydrodynamic equations at different scales was pointed out.

Several talks were devoted to quasiperiodic oscillations in magnetars. In particular, it was shown that the frequency detected in the giant flares from a few soft gamma-ray repeaters (SGRs) can be interpreted as the manifestation of magneto-elastic oscillations of the neutron star. However, many aspects of this phenomenon still remain very uncertain like superconductivity, entrainment, and the magnetic field evolution. For example, it was pointed out that shear waves associated with a tangled magnetic field in the neutron-star core could also explain quasiperiodic oscillations. Clearly, more work is needed to fully understand these observations.

3.3.3 HEAVY QUARK PHYSICS IN HEAVY-ION COLLISIONS: EXPERIMENTS, PHENOMENOLOGY AND THEORY

DATE: March 16 – 20, 2015

ORGANIZERS:

V. Greco (University of Catania, Italy)
M.P. Lombardo (INFN-LNF and Pisa, Italy)
A. Mischke (Utrecht University, Netherlands)
N. Xu (LBL – Berkeley, USA)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The general theme of the workshop concerned the dynamics of heavy quarks in the Quark-Gluon Plasma (QGP). To characterize this new phase of matter heavy quarks (HQ) play a crucial role as a probe thanks to their large mass with respect to the temperature T of the bulk as well as to ΛQCD.
The workshop aimed at bringing together experimentalists and theoreticians to discuss recent results from experiments and future experiments as well as theoretical developments regarding open and hidden heavy flavor dynamics in AA, pA and pp collisions in view of interesting heavy quark and quarkonia results coming from the heavy ion programs at LHC and RHIC. Both open and hidden heavy flavor physics is entering a new and exciting stage toward reaching a clear understanding of the experimental results with the possibility to link them directly to the advancement in lattice QCD.

The main topics were:
- Open heavy flavor production, suppression and collective flows
- Quarkonia suppression and regeneration
- Heavy flavor correlators and transport coefficients from Lattice QCD
- Cold nuclear matter effects in pA
- Future Experiments and upgrades.

The workshop included a discussion on new ideas from theory and future feasible measurements coming from the scheduled upgrades. The ECT* Colloquium was delivered by Helmut Satz.

SPEAKERS:

C. Greiner (Goethe University Frankfurt, Germany)
R. Rapp (Texas A&M University, USA)
P. Braun-Munzinger (GSI, Germany)
R. Vogt (UC Davis, USA)
G. M. Innocenti (MIT, USA)
P. Petreczky (BNL, USA)
G. Eugenio Bruno (Università di Bari, Italy)

A. Beraudo (INFN-TO, Italy)
Y.-J. Lee (MIT, USA)
C. Allton (Swansea University, UK)
E. Scomparin (INFN-TO, Italy)
A. Rothkopf (University of Heidelberg, Germany)
A. Dainese (INFN-PD, Italy)
R. Vertesi (Nuclear Physics Institute, Czech Republic)
M. Nardi (INFN-TO, Italy)
R. Maciula (Institute of Nuclear Physics, Poland)
W. Horowitz (University of Cape Town, South Africa)
P. Pagano (Università di Salerno, Italy)
S. Biondini (TU München, Germany)
A. Frawley (Florida State University, USA)
O. Kaczmarek (University of Bielefeld, Germany)
E. Bratkovskaya (FIAS, Germany)
J. Aichelin (Subatech, France)
H. Satz (University of Bielefeld, Germany)
M.Á.l Escobedo Espinosa (Institut de Physique Théorique, CEA Saclay)
R. Averbeck (GSI, Germany)
P. Gossiaux (Subatech, France)
A. Szczurek (Institute of Nuclear Physics, Poland)
M. Munhoz (Universidade de São Paulo, Brazil)
Z. Ye (University of Illinois at Chicago, USA)
K. Zhou (Goethe University Frankfurt, Germany)
S. Mukherjee (BNL, USA)
F. Scardina (Università di Catania, Italy)
S. Bass (Duke University, USA)
Santosh Kumar Das (Università di Catania, Italy)
H.Berrehrah (FIAS, Germany)
H. van Hees (Goethe University Frankfurt, Germany)

SCIENTIFIC REPORT:

Collider (RHIC) and the Large Hadron Collider (LHC) is to create a new state of matter where the bulk matter is constituted by a plasma of gluons and light quarks. HQ are quite ideal probes of the QGP because they are produced in the very early stage of the collision testifying the entire space-time evolution of the system. Furthermore, HQ thermalization time is likely to be larger than the lifetime of the QGP created in uRHIC's which offers the unique opportunity to have a non-fully thermalized probe that will carry more information on its dynamical interaction with the bulk medium. In addition from a theoretical point of view the large HQ mass is making feasible the evaluation of quarkonia correlators and transport coefficients directly from Lattice QCD calculations.
The experimental results at both RHIC and LHC energies have surprisingly shown a large suppression of pT spectra with respect to proton-proton collisions RAA (pT) as well as a large elliptic flow v2. This has challenged all theoretical approaches that are not able to predict correctly both RAA and v2.
The physics of quarkonia is historically one the main probes of QGP and has been studied for nearly thirty years. Moreover, new insights are coming from the recent development in lattice QCD from the evaluation of spectral functions and the possibility at LHC to reconstruct experimentally the presence of the single excited states in the QGP, especially for

bottomonia. This is opening up the possibility to have stringent constraints from both the theoretical and experimental sides for the understanding of in medium quarkonia physics.
Therefore both open and hidden heavy flavor physics is entering a new and exciting stage toward reaching a clear understanding of the experimental results linking them directly to the advancement in QCD. Furthermore, it is opening up also the perspective to link directly the dynamics of open and hidden heavy flavor. The multiple competing themes addressed in the workshop can be summarized as follows:

- What is the level of accuracy needed for the spectral functions in lQCD?
- Connection between open HF and quarkonia in HI collisions: can we progress?
- Is there a way to distinguish between statistical and dynamical quarkonia regeneration? Is there a real proof of charmonia regeneration at RHIC and LHC?
- It is important to see if the transport coefficients needed to explain the experimental results are those expected from QCD. Can we expect safe determination of the drag coefficient and its T dependence from lQCD and from the phenomenology?
- What are promising ways/techniques/observables to distinguish between radiative and collisional energy loss?
- Can we identify key observables to make a progress? Is there a puzzling relation between RAA and v2? Is it possible to access the vn physics as done in the light sector? Can the upgrade planned and the new RUN can hope to do it?

Results and Highlights

The topics enlisted above were addressed in more than thirty talks presented from Monday to Thursday. A short and lively Q&A session followed each talk, while Friday morning was reserved for a final discussion and assessment of the main results and open questions. The final Friday morning discussions were articulated in three segments - lattice, phenomenology, experiment - each lead by appointed convenors. The convenors introduced their sessions with the help of invited mini presentations, and a lively discussion followed. We list here some of the main conclusions and remaining outstating issues:

- Several difficulties in explaining the nuclear modification RAA and the elliptic flow can be traced back to the (weak) temperature dependence of the drag coefficient. While AdS/CFT and pQCD suggest aT2 dependence it seem that only a nearly constant drag can describe the experimental data. Such a behaviour — more typical of a liquid than of a gas — might be explained by the increasing strength of the in-medium interactions as T→ Tc. This interpretation is supported by scattering studies which use a realistic potential derived from the lattice QCD free-energy.
- Hadronization by recombination appears to play an important role. In fact, it has been observed that only the models including recombination describe the experimental data from RHIC and LHC. Recombination and diffusion have been discussed within a non-perturbative T-matrix approach with a driving term derived from lattice QCD potential.
- Charm does not have really a Brownian motion because its mass is not very large with respect to the momentum exchanged in the collisions. Different ways of implementing the fluctuation-dissipation theorem within a Langevin/Fokker-Planck approach lead to significant uncertainties. Because of this a pure Langevin dynamics is inaccurate for the Charm quark: a comparison with a Boltzmann approach that does not assume small momentum exchange in the collisions clearly exposes a non Brownian motion. Such non-Brownian dynamics can increase the efficiency of the build-up of the elliptic flow by about 30.
- It emerged a general consensus that at LHC Charmonia come abundantly from recombination. It emerged that a sequential recombination and dissociation can explain at least qualitatively the puzzling behavior of the double ratio Ψ/Ψ' vs the centrality of the collision observed by CMS.

- The calculation of transport coefficients in lattice QCD still suffers from large systematic uncertainties. These can be controlled by contrasting results from different analysis techniques, which have been discussed in detail. This program has started only recently and significant improvements with respect to the present status might be foreseen.
- The most reliable results for spectral functions have been obtained for the bottomonium in the S-wave channel (i.e. Upsilon). The data indicate that the first excited state melts around 2 Tc, consistently with the observations of CMS. The width of the state increases, and the phenomenological significance of this observation is still unclear.
- The relative weight of a radiative versus a collisional energy loss mechanism is still open and we have not been able to design a solid strategy that will allow to disentangle the two contributions. Some hope comes from the study of charm and anti-charm angular correlation that are however quite hard to measure experimentally even with the current update of the detectors.

3.3.4 INTERPLAY OF STRUCTURE AND DYNAMICS IN HEAVY-ION COLLISIONS

DATE: May 14 - 15, 2015

ORGANIZERS:

F. Catara (Dipartimento di Fisica e Astronomia and INFN, Catania)
M. Gallardo (Departamento de Fisica Atomica y Nucelar, Sevilla)
E. Lanza (Dipartimento di Fisica e Astronomia and INFN, Catania)
S. Lenzi (Dipartimento di Fisica e Astronomia and INFN, Padova)
A. Vitturi (Dipartimento di Fisica e Astronomia and INFN, Padova)

NUMBER OF PARTICIPANTS: 25

MAIN TOPICS:

The main aim of this meeting was to discuss the reaction mechanism for low-energy heavy-ion collisions, with specific focus on the connection with the nuclear structure aspects of the many-body colliding systems. In particular:

- Low-energy nuclear structure
- Collective modes
- Heavy-ion collisions
- Systems far from stability
- Many-body dynamics

SPEAKERS:

M. Saraceno (CNEA, Buenos Aires, Argentina)
H. Wolter (Munich)
A. Moro (Sevilla)
L. Corradi (INFN, Legnaro)
N. Lo Iudice (Napoli)
C.H. Dasso (Sevilla)
E. Vigezzi (Milano)
J. A. Lay (Sevilla/Padova)
A. Bonaccorso (Pisa)
L. Moschini (Padova/Sevilla)
A. Diaz Torres (ECT*)
A. Stefanini (INFN, Legnaro)
E.G. Lanza (Catania)

SCIENTIFIC REPORT:

In the two days the participants reported on different aspects of the nuclear systems (collective modes, pairing correlations, mean-field properties, clustering features) in connection with specific nuclear reactions. In particular Angela Bonaccorso reported on elastic, inelastic and break-up scattering, Laura Moschini on one-particle transfer, Lorenzo Corradi on pair transfer, multi-pair transfer, and charge-exchange reactions, Alberto Stefanini on sub-barrier fusion, Enrico Vigezzi and Jose' Antonio Lay on pairing correlations and two-particle transfer. Particular emphasis has been given to reactions involving systems far from stability (recently produced at the new facilities for radioactive beams) in connection with new structure phenomena (such as haloes, pygmy modes, exotic clustering), in the talks by Alexis Diaz-Torres, Edoardo Lanza and Antonio Moro. More specific points were discussed by Hermann Wolter, Nicola Lo Iudice and Carlos Dasso.

Results and Highlights

This workshop was a very useful opportunity to discuss the basic question on how to develop on the same footing structure and reaction models in low-energy heavy-ion collisions that allow to extract in a reliable way precise structure information from experimental reaction data. This is a lively problem in particular in connection with reaction processes that involve nuclear systems far from the stability line. We have to face, from one side, novel aspects and properties that involve the development of new structure models, and, on the other side, novel reaction mechanism that call for new reaction theories.

Different points of views have been presented in the workshop, ranging from those that tend to enphasize the need for “ab-initio” approaches to those that are more tight to many-body descriptions. Similarly traditional “semiclassical” formalisms have been confronted with fully quantal approaches. The particular problem of the treatment of continuum (via discretization procedures or alternative recipes) has raised intense discussions.

The reunion has also been an occasion to celebrate the 70th birthday of Carlos Dasso whose contribution in this field has been prolific and important.

3.3.5 NEW DIRECTIONS IN NUCLEAR DEEP-INELASTIC SCATTERING

DATE: June 08 - 12, 2015

ORGANIZERS:

R. Dupré (IPN Orsay, France)
S. Scopetta (Perugia University and INFN, Italy)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

Recent experimental and theoretical ideas, which are laying the ground for a new era in nuclear deep inelastic scattering, have been discussed at the Workshop. Novel coincidence measurements at high luminosity facilities, such as Jefferson Lab (JLab), have become possible, pointing out the nucleus as a laboratory for QCD studies. Issues like the extraction of the neutron information from light nuclei, the measurement of nuclear parton distributions, revealing unexpectedly large modifications compared to free partons, or the phenomenon of in-medium fragmentation, crucial to unveil the dynamics of hadronization, will be investigated with unprecedented accuracy. Moreover, the detection of multiple parton collisions in proton-nucleus scattering at the LHC could unveil the three-dimensional proton structure. The Workshop aimed at improving collaborations between theorists and experimentalists, working with electroweak and strong probes. Besides the presentation of recent results, an emphasis has been put on the preparation of experiments at JLab and at a future electron-ion collider.

The main topics were:

- EMC effect and short range correlations
- The 3D structure of bound nucleons: nuclear Generalized Parton Distributions and Multi-Parton Interactions
- In medium hadronization and color transparency
- Detecting slow nuclear recoil

SPEAKERS:

M. Alvioli (IRPI, Perugia, Italy)
W. Brooks (USM, Valparaiso, Chile)
G. Charles (IPN, Orsay, France)
E. Cisbani (ISSN and INFN, Rome, Italy)
R. Dupré (IPN, Orsay, France)
D. Dutta (MSU, USA)
L. Fanò (Perugia U. and INFN, Italy)
F. Fionda (Cagliari University and INFN, Italy)
S. Gilad (MIT, USA)
V. Guzey (PNPI, S. Petersburg, Russia)
M. Hattawy (IPN, Orsay, France)
L. Kaptari (JINR, Dubna, Russia)
S. Kuhn (ODU, Norfolk, USA)

S. Liuti (UVA, USA)
G. Miller (GW Univ., Seattle, USA)
U. Mosel (Giessen Univ., Germany)
M. Paolone (Temple University, Philadelphia, USA)
E. Piasetzky (Tel Aviv U., Israel)
M. Rinaldi (Perugia Univ. and INFN, Italy)
J. Ryckebusch (Ghent Univ., Belgium)
G. Salmè (INFN Rome, Italy)
M. Sargsian (Florida.I.U., USA)
I. Schienbein (LPSC Grenoble, France)
S. Scopetta (Perugia U. and INFN, Italy)
M. Strikman (PSU, USA)
D. Tapia Takaki (Kansas U., USA)
M.C. Traini (Trento University and INFN, Italy)
D. Treleani (Trieste University and INFN, Italy)
E. Voutier (IPN Orsay, France)
C. Weiss (Jlab, USA)
L. Zana (Edinburgh U., UK)

SCIENTIFIC REPORT:

The Workshop was organized around four interrelated topics. The problems with the theoretical explanation of inclusive deep inelastic scattering (DIS) represented the first one and two directions towards their solution, i.e., exclusive and semi-inclusive measurements, have been the second and third topics, respectively. These measurements often require the detection of recoiling nuclei, which has been the last main subject discussed in the workshop. The main motivation for the proposal of the Workshop had been the new experimental scenarii which will be able in the next years, mainly thanks to 12 GeV upgrade of JLab, to shed light on the nuclear parton structure, through dedicated experiment of unprecedented accuracy.

The first main topic of the Workshop, "EMC effect and SRCs", concerned both DIS processes, showing the EMC effect, i.e., the modification of parton distributions (PDFs) of bound nucleons in the valence region, and the observation of Short Range Correlations (SRC) between nucleon pairs in nuclei. The "Colloquium" was dedicated to review the status of the art and recent developments on the EMC effect. Then, the possibility to use new observables such as polarized targets and the link between the EMC effect and SRC have been discussed. Also presented were the results of preliminary analyses of existing data, performed within the data mining project at JLab and useful complementary information, provided by experiments with neutrino beams, have been examined. New theoretical developments have been presented, along light-front dynamics; nevertheless, present microscopic calculations, using conventional nucleon dynamics, cannot explain the EMC effect quantitatively. Exotic phenomena, such as medium modifications of the nucleon size and structure, are usually invoked. The present scenarii indicate clearly that DIS data only cannot answer the question of the origin of the EMC effect. In facts, different models with a few parameters can equally describe the data. To make progress, measurements beyond DIS are therefore needed: this introduces the following two topics. It was also interesting to see how SRC measurements, made at high energy in nuclear DIS, can impact on our vision of nuclear structure at low energy.

The section "The 3D structure of bound nucleons: nuclear GPDs and MPI", was dedicated to promising directions beyond DIS. First, the analysis of deeply virtual Compton scattering (DVCS), a hard-exclusive process where the non-perturbative QCD information is encoded in the generalized parton distributions (GPDs), which access the distribution of partons in the transverse plane (the so-called ``3d nucleon structure''). With precise measurements on nuclear targets, one should be able to compare these distributions for partons in bound nucleons to those in free ones, providing a pictorial view of the realization of the EMC effect. Preliminary calculations for light nuclei have been presented, as well as recent analyses of measurements at JLab, which have already run, showing very good prospects within this framework. Future plans for such experiments, involving also new facilities such as a positron beam, have been discussed. It has been also analyzed how information on the 3d structure of the proton, complementary to that encoded in GPDs, can be obtained from proton-nucleus scattering at the LHC, looking for multi parton interactions (MPI). This has been the subject of six talks and a discussion aimed at getting a common ground between communities working with electromagnetic and strong probes has taken place.

The third issue has been ”In-medium hadronization and color transparency”, dedicated to semi-inclusive DIS (SiDIS) reactions, another natural direction beyond DIS measurements. The study of hadronization in SiDIS off nuclei permits to investigate confinement and its dynamical origin. Comparing in-medium fragmentation for nuclei of different sizes allows to obtain information on the nature and life time of the hadronizing states and represents also a test of color transparency and nuclear filtering. There were five talks mainly related to this sublect. A careful study of final state interactions effects has arisen as an important theoretical tool to be considered. It has also been pointed out how these effects can hinder our observation of the relation between the EMC effect and SRC, pointing to the the importance to study these processes for a deeper understanding of the parton distributions in nuclei.

The last topic, “Detecting slow nuclear Recoil”, has to do with particularly interesting DVCS and SiDIS processes, which require the detection of recoiling nuclei. The theory and the possibilities offered by the so-called “spectator SiDIS” have been reviewed. The possibilities offered at JLab have been thoroughly discussed. Recent developments of nuclear recoil detectors for experiments at JLab, which seem to offer excellent perspectives for DVCS and “spectator SIDIS”, have been presented, also in connection with possible extensions of these programs at an Electron-Ion Collider.

Results and Highlights

The Workshop was a very useful opportunity to get together the experimentalists and theorists active in nuclear DIS, around a program much more focused on this subject than those offered in other events organized recently. This was in fact perceived by all the participants.
The Workshop has been the occasion to see, for the first time, results of preliminary analyses of experimental data and of preliminary calculations. While different opinions about issues like the origin of the EMC effect and the mechanism of in-medium hadronization are still present among the participants, there is a consensus on the novel possibilities offered by the new generation of experiments at JLab. The rather complete presentation of the forthcoming experiments and of the performances of the planned new detectors and beams will help the theorists to concentrate their efforts to calculations dedicated mainly to feasible measurements. This will have certainly an outcome in the next proposals for measurements at JLab.
An attempt to establish a common language between communities working with electromagnetic and strong probes, active in JLab and LHC Physics respectively, has also taken place. Despite of the clear difficulties of a similar task, a promising dialogue between some of the participants has started.
The activity has been carried out in a lively Workshop atmosphere, with detailed presentations (in particular, encouraging young people to give as many oral contributions as

possible) and enough time devoted to informal discussions. It has certainly provided a fruitful environment for young colleagues to get trained in these studies.

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3.3.6 COLD ATOMS MEET HIGH ENERGY PHYSICS

DATE: June 22 - 25, 2015

ORGANIZERS:

M. Inguscio (Inrim, Lens)
G. Martinelli (Sissa)
S. Stringari (University of Trento)

NUMBER OF PARTICIPANTS: 40

MAIN TOPICS:

The main goal was to favor joint collaborative discussions and exchange of strategies among physicists belonging to the communities of ultra cold atomic physics and high energy physics. The main focus was on theoretical issues of joint interest as well as on the experimental implementation in ultra cold atomic gases of basic concepts of elementary particle physics.

List of topics included:

- Spontanenously broken symmetries, abelian and non abelian gauge fields, supersymmetries
- Fulde-Ferrel-Larchin-Ochinokov phase
- Superfluidity in strongly interacting Fermi systems
- High density QCD and bosonic superfluidity
- Quantum hydrodynamics
- Kibble-Zurek mechanism
- SU(N) configurations
- Quantum simulation of quark confinement, magnetic monopoles
- Majorana Fermions
- Role of extra dimensions
- Lattice QCD
- Black holes
- Hawking radiation
- Higgs excitations in cold atoms
- Efimov states.

SPEAKERS:

F. Ferlaino (Innsbruck)
A. Cappelli (Florence)
A. Trombettoni (SISSA Trieste)
S. Tsuchiya (Tohoku University)
M. García Pérez (Madrid)
W. Zwerger (Munich)
G. Ferrari (INO-CNR Trento)
S. Peotta (Aalto)
P. Zoller (University of Innsbruck)
M. Dalmonte (University of Innsbruck)

L. Fallani (University of Florence)
L. Tagliacozzo (ICFO Barcelona)
K. Kasamatsu (Kinki University, Japan)
D. Sato (ECT* Trento),
M. Nitta (Keio University, Japan))
L. Pitaevskii (University of Trento)
M. Zwierlein (MIT Boston)
M. Endres (University of Harvard)
M. Baranov (University of Innsbruck)
K. Konishi (University of Pisa)
S. Pascazio (University of Bari)
E. Vicari (University of Pisa)
M. Eto (Yamagata University)
S. Montangero (University of Ulm)
E. Zohar (MPI Munich)
C. Salomon (ENS Paris)
R. Casalbuoni (University of Florence)
A. Smerzi (University of Florence)
B. Krippa (University of Nottingham),
A. Celi (ICFO Barcelona),
U. Fischer (University of Seoul)
I. Carusotto (Cnr-Ino Trento)

SCIENTIFIC REPORT:

During the workshop the speakers stimulated a significant number of discussions of joint interest for the communities of cold atoms and high energy physics. The contents of the talk and of the corresponding discussions are reported in the enclosed scientific programme of the workshop.

We expect that these themes will stimulate further scientific research activities in both fields of research. This is particularly relevant for the possibility of implementing fundamental concepts of high energy physics in experiments with cold atomic gases opening new perspectives in future research of high interdisciplinary interest.

3.3.7 LATTICE NUCLEI: NUCLEAR PHYSICS AND QCD - BRIDGING THE GAP

DATE: July 06 – 10, 2015

ORGANIZERS:

J. Kirscher (Hebrew University of Jerusalem, Israel)
F. Pederiva (University of Trento and INFN-TIFPA, Italy)
M. Savage (Institute for Nuclear Theory University of Washington, Seattle, USA)

NUMBER OF PARTICIPANTS: 23

MAIN TOPICS:

1. Lattice QCD calculations of nuclei with $A \leq 4$:
   - Energy spectra for 300 MeV $\leq m_\pi \leq$ 800 MeV.
   - Magnetic structure (moments and polarizabilities) at m_π = 800 MeV.
   - Derivation of the nuclear force.
   - The strange H-dibaryon.

2. Effective field theories for nuclear systems from the chiral to the heavy-pion-mass limit:
   - Pionless theory with and without electro-magnetic probes.
   - Electro-magnetic structure and scattering theorems from chrial perturbation theory.

3. Ab-initio methods for the nuclear few- and many-body problem
   - Quantum Monte Carlo calculations with chiral-effective interactions.
   - The diffusion Monte Carlo method with pionless interactions for $A \leq 16$.
   - Nuclear lattice techniques for 8-body scattering reactions.

SPEAKERS:

S. Aoki (Yukawa Institute, Kyoto, Japan)
N. Barnea (Hebrew Univ., Jerusalem, Israel)
L. Contessi (University of Trento and INFN-TIFPA, Italy)
A. Francis (York University, Canada)
D. Gazit (Hebrew Univ., Jerusalem, Israel)
A. Gezerlis (University of Guelph, Canada)
H. W. Griesshammer (G. Washington University, USA)
S. Elhatisari (Univ. of Bonn, Germany)
E. Epelbaum (Ruhr-Universität Bochum, Germany)
J. Kirscher (The Hebrew University of Jerusalem, Israel)
S. Koenig (Ohio State University, USA)
M.P. Lombardo (INFN-Pisa, Italy)
B. Long (Sichuan University, China)
A. Lovato (ANL, USA)
T. Luu (University of Bonn, Germany)

U. van Kolck (IPN, Orsay, France) T. Yamazaki (Univ. of Tsukuba, Japan)

SCIENTIFIC REPORT:

The increased ability to solve QCD on the lattice for the lightest nuclei suggests that the possibility of deriving the nuclear systematics from few fundamental constants is now closer. However, the possibility of performing calculations for more than a few bodies, even at unphysical pion masses is not foreseeable at the moment. Therefore it is necessary to establish a protocol allowing to extract information from lattice QCD (LQCD) calculation and extend it to the many-body sector.
To this end, effective field theories (EFT) provide a systematic framework. They connect the interaction between quarks and gluons to the appropriate force amongst neutrons and protons. With the latter, nuclear properties can be calculated using established few- and many-body techniques.
The aim of the workshop was to provide an exchange platform for experts from all three fields, LQCD, EFT, and few-/many-body physics, aiming to establish some common background, understand the reciprocal needs, and accelerate the bridging between particle and nuclear theories. This purpose was to be obtained not just by means of talks from the participants, but also with extensive discussions not just about general aspects, but also about those details that sometime make it difficult to have a useful reciprocal exchange of information.
The talks were organized in three main subgroups: LQCD (energy spectra, nuclear force matching, calculations for the strange sector); effective theories (fundamentals of pion-less theories and relation with strong and electromagnetic scattering observables), and ab-initio theoretical methods (various flavours of few-body and Quantum Monte Carlo calculations). A few talks had an introductory character, in order to establish some common grounds. In particular Martin Savage gave an initial overview of the state of the art of LQCD calculations meant also for the non-experts. Ubirajara van Kolck introduced pionless EFT at T=0 pointing out the range of applicability and the relationship with QCD when the pion mass is increased well beyond the physical value. Nir Barnea and Alessandro Lovato illustrated respectively the role of few-body and Quantum Monte Carlo calculations.
The topical LQCD talks showed the current situation in the determination of the spectrum of light nuclei, and the attempts of directly derive nuclear forces besides the possibility of providing electromagnetic observables. Some other interesting problems, such as the energy and structure of the H-dibaryon, were also addressed. On the other hand EFT experts showed how to compute observables related to weak processes, extensions of the pionless theory beyond LO, the scaling of scattering theorems to the case of a nuclear physics at unphysical pion mass. More specific applications of few- and many-body theories were also illustrated (in particular several applications of Quantum Monte Carlo methods).
As previously mentioned, an important role was played by the three discussion sessions centred on the workshop topics, but without rigid constraints.

Results and Highlights

The content of the talks, and even more the quality and extent of the scientific discussion showed that the workshop was timely. In particular, substantial progress should be expected in terms of what LQCD simulations can provide to nuclear physicists in terms of estimated observables. This was well illustrated by the talks of S. Aoki and M. Savage, and repeatedly stated during the afternoon discussions. This is of reciprocal interest for the high-energy and nuclear physics communities. It could in fact provide new arguments for submitting proposals to agencies funding the increasing computational needs of LQCD, and would give a new stimulus to the research in low energy nuclear physics. To this end, the proposal of working on a white paper describing an agenda for the next few years on this subject was launched, together with an expressed will of continuing on the line of involving the LQCD, EFT and ab-initio calculations communities in a more continuative way.

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3.3.8 HASPECT COLLABORATION MEETING

DATE: July 22 – 24, 2015

ORGANIZERS:

M. Battaglieri (INFN Genova, Italy)

NUMBER OF PARTICIPANTS: 22

MAIN TOPICS:

The workshop gathered together experimentalists and theoreticians working in hadron spectroscopy. Researchers from the main collaborations in the world (LHCb, BES-III, BELLE, CLAS, GLUEX) presented the latest results of their analysis and progresses in theory. A significant time has been devoted to general discussions to conceive strategies and plans to cope with the new and abundant data expected from the future and current experiments running in different laboratories. In particular the Joint Physics Analysis Center of JLab provided inputs for a thorough discussion about the necessary techniques in amplitude analysis. A recent claim about a possible evidence of a new state of matter made by a 5-quark configuration (pentaquark), has been discussed in a dedicated session.

The main topics were:

- Status of the experimental analysis of meson decay and production from CLAS, BES, BABAR and GLUEX collaborations;
- Progress in amplitude analyses;
- Tools and frameworks for future analysis.

SPEAKERS:

M. Battaglieri (INFN Genova)

L. Bibrzycki (Krakow University)

M. Camp (Ohio University)

R. De Vita (INFN Genova)

E. Fanchin (INFN Genova)

S. Fegan (Mainz University)

C. Fernandez-Ramirez (JLab) (remote)

B. Garillon (IN2P3-Orsay)

I. Garzia (INFN-Ferrara)

D. Glazier (Glasgow University)

S. Hughes (Edinburgh University)

B. Kubis (Bonn University)

L. Lanza (Roma TVU)

V. Mathieu (Indiana University)

P. Mattione (Carnegie Mellon Univ.) (remote)

J. Nys (Gant University)

A. Pilloni (Roma University)

A. Rizzo (INFN-RMTV)

E. Santopinto (INFN Genova) (remote)

A. Szczepaniak (Indiana University)

S. Wallner (TU Munich)

L. Zana (Edinburgh University) (remote)

SCIENTIFIC REPORT:

Fundamental interactions of components of matter are not yet fully understood. Some basic questions such as: how the mass of the visible world is generated? How do the quarks, light constituents of the proton and neutron (and the other hadrons) sum up to provide the mass of nucleons (and therefore the mass of the visible universe)? Why the mediator of the strong interaction (the gluon) does not show up in the spectrum of hadrons? Are the three quarks (that make baryons) and quark-antiquarks configurations (that make mesons) the only possible ones? The answer to these questions requires a sophisticated procedure that involves both experiments and theories necessary to interpret data.

To face the challenge presented by new experiments in which a huge amount of high-quality data will be produced, we need to develop a set of tools to optimize each step in the analysis. Data need to be collected, analyzed, transferred, accessed and stored in a convenient and accessible repository. Reconstructed four-momenta need to be fed into sophisticated partial-wave analyses that, making use of experimental and theoretical constraints, provide reliable results. Observables need to be compared to the best existing solution of the fundamental theory of the strong interaction provided by Lattice-QCD and interpreted by using effective models that pick out the underlying dominant mechanisms of the theory. This complex analysis chain requires that the different skills and competences that are present in the hadron physics community be shared among groups and collaborations. Parallel computing, algorithmic optimization, cloud technology, massive data management, together with a thorough and well-founded theoretical framework that can be used to analyze data require that experts share information and techniques to produce reliable results.
The goal of HASPECT networking is exactly to address this problem supporting exchanges and establishing links among these different communities, all involved in the same business: hadron physics laboratories in Europe (CERN, GSI, BONN, MAINZ) need to interact with their counterpart in US (JLab) and Asia (BESIII and Belle). The theoretical community needs to establish a contact with experimental collaborations that are performing the experiments and event-based analyses. Sophisticated computing techniques need to be merged with the specific requirements of a well-motivated and solid phenomenological scheme to perform high-level analysis necessary for physics interpretation. Senior scientists need to transfer their competences and their background to the new generation of researchers that will be the resource of the future.

Results and Highlights

During the workshop the different problems related to the meson spectroscopy data analysis and interpretation have been discussed resulting in a roadmap for the future that includes the following actions:

- Development of analysis tools that can be shared between different data set and experimental collaborations;
- Development of a web portal where the recent progress in amplitude analysis and the parametrization of the basic reaction mechanisms can be stored and made publicly available;
- Comparison of the experimental results to the latest Lattice QCD predictions and use of the phenomenological models to establish a link between theory and experiments;
- Development of statistical tools to insure the highest quality of the data analysis.

3.3.9 THE INTERPLAY BETWEEN ATOMIC AND NUCLEAR PHYSICS TO STUDY EXOTIC NUCLEI

DATE: August 24 - 27, 2015

ORGANIZERS:

M. Godefroid (Université libre de Bruxelles, Belgium)
S. Fritzsche (Helmholtz Institute Jena, Germany)
G. Neyens (Katholieke Universiteit Leuven, Belgium)
W. Nörtershäuser (TU Darmstadt, Germany)

NUMBER OF PARTICIPANTS: 43

MAIN TOPICS:

The main topics were:

- Ab initio calculations in light few-electron systems
- Laser spectroscopy of few-electron systems
- Ab initio calculations in many-body systems
- Quantum dynamics and dynamical processes
- Laser spectroscopy of complex systems

SPEAKERS:

J. Bieroń (Jagiellonian University, Krakow, Poland)
J. Billowes (Univ. Manchester, UK)
K. Blaum (MPIK Heidelberg, Germany)
C. Brandau (GSI Helmholtz Centre Darmstadt, Germany)
P. Campbell (Univ. Manchester, UK)
B. Cheal (Univ. Liverpool, UK)
G.W.F. Drake (Univ. Windsor, Canada)
J. Ekman (Malmö University, Sweden)
K. Flanagan (Univ. Manchester, UK)
P. Indelicato (Univ. Pierre et Marie Curie, Paris, France)
P. Jönsson (Malmö U., Sweden)
M. Kowalska (CERN/ISOLDE, Geneva, Switzerland)
Y.S. Kozhedub (St. Petersburg Univ., Russia)
M.G. Kozlov (Gatchina, Russia)
J. P. Marques (Univ. Nova de Lisboa, Portugal)
K. Minamisono (Michigan State University, USA)
P. Mueller (Argonne National Laboratory, USA)
K. Pachucki (Univ. of Warsaw, Poland)
A. Palffy (MPIK, Heidelberg, Germany)
R. Sánchez (GSI Helmholtz Centre Darmstadt, Germany)

B.K. Sahoo (Navrangpura, Ahmedabad, India)
V. Shabaev (St. Petersburg Univ., Russia)
P. Van Duppen (KU Leuven, Belgium)
M. Wada (RIKEN, Japan)
K. Wendt (Univ. Mainz, Germany)
Z.-C. Yan (Univ. New Brunswick, Canada)
D.T. Yordanov (Orsay, France)
A. Barzakh (B.P. Konstantinov Petersburg Nuclear Physics Inst., Gatchina, Russia)
R. Beerwerth (Univ. Jena, Germany)
R. De Groote (KU Leuven, Belgium)
R. Ferrer (KU Leuven, Belgium)
L. Filippin (Univ. libre de Bruxelles, Belgium)
J. Li (Beijing, China)
B. Maas (TU Darmstadt, Germany)
A. V. Malyshev (St. Petersburg University, Russia)

SCIENTIFIC REPORT:

Introduction

The number and quality of laser spectroscopy studies on short-lived nuclei to explore changes in the nuclear size, spin, and moments for isotopes far away from stability, has increased tremendously in the last decade. The analysis of measured optical hyperfine structures and isotope shifts of spectral lines of radioactive atoms or ions provides a very detailed picture of the nuclear ground state. A fundamental feature is the distribution of charge within the nucleus, revealing a variety of collective and single-particle phenomena. The differential changes in the nuclear mean-square charge radius measured for long isotope sequences, may be compared with the predictions from state-of-the-art nuclear models. The latter can be used to extract from the mean-square charge radii further observables such as the diffuseness of the nuclear surface, the quadrupole deformation, etc. Parity non-conservation and halo structure are other examples where the variation of the change in the mean-square radii plays a key role. The study of neutron-rich nuclei provides important insight into the nuclear forces that hold these loosely bound systems together. Until recently, there was no effective method to measure the nuclear charge radii for short-lived, light nuclei. Advances in both atomic structure theory and laser spectroscopy have now changed this situation, leading to their precision determination, independent of nuclear structure models. These results guide our understanding of the nuclear forces in the extremely neutron-rich environment.
The aim of the workshop is to gather experts in collinear and in-source laser spectroscopy, usually belonging to the radioactive ion beam spectroscopy communities with atomic physicists who develop theoretical approaches and computational strategies, to provide the required electronic parameters.

Ab initio calculations in light few-electron systems

The atomic physics of light, few-electron systems can best be addressed by the non-relativistic QED approach, which starts from very accurate wave functions that are solutions of the non-relativistic Schrödinger equation and add relativistic and quantum electrodynamical corrections by perturbation series expansion in the parameter α and $Z\alpha$. The high fidelity that can be reached in this field has been presented by the leading experts. Various applications have been discussed, reaching from high-precision mass-shift calculations for the extraction of nuclear charge radii of e.g. halo isotopes, experimental tests of the relativistic and QED contributions appearing in these calculations, the charge state and excitation distribution after β-decay processes. The proton-radius puzzle has been addressed by several speakers and other discrepancies between theoretical predictions and experimental results or inconsistencies in extracting nuclear parameters from different charge states or transitions were discussed. These discrepancies were identified as very important issues. Progress is expected towards reliable calculations of five-electron systems, which would support laser spectroscopy experiments on boron isotopes and calculations of mass-independent α^4 contributions to the total transition energies in two-electron systems that would allow the extraction of absolute charge radii solely from transition frequency measurements.

Laser spectroscopy of few-electron systems

This field was covered with contributions about light as well as heavy few-electron systems. A new experimental approach towards the measurement of the charge radius of the one-proton halo nucleus 8B was presented that will use a transition in He-like B3+. It turned out that the above mentioned calculations of five-electron systems could lead to a new route for such an experiment, strongly simplifying the preparation of the initial state of the ions. The current status of ion-trap spectroscopy of beryllium ions to extract the hyperfine structure anomaly of 11Be and the magnetisation distribution of this halo isotope was reported. This connected as well to a discussion on the role of hyperfine anomaly in the tests of strong-field QED by laser spectroscopy on hydrogenlike and lithiumlike bismuth ions, where the recent successful measurements performed at GSI were discussed.

Ab initio calculations in many-body systems

The state-of-the-art ab initio calculations of electronic parameters and their limitations have been illustrated by experts in atomic physics developing relativistic multiconfiguration methods, many-body perturbation approaches combining coupled-cluster and configuration interaction. The difficulty of capturing core-core correlation effects in multiconfiguration methods, and the need to understand the interplay between configuration state function expansions and orbital sets has been emphasized. In this line, the interest of the “Partitioned Correlation Function Interaction” approach was illustrated. Original methods based on the detailed interaction between the nuclear and electron charge distributions are proposed, together with a new formulation of the field shift implemented in the framework of the relativistic codes that should allow a refined extraction of the nuclear root mean-squares change values. For a few valence electrons, a package combining configuration interaction with many-body perturbation theory is now available in which effective operators are built for various observables including hyperfine constants, P-odd and P,T-odd interactions. Advantages of truncated coupled-cluster method over truncated CI methods have been discussed. The origin of EDMs at the elementary level was mentioned and motivations to investigate them in diamagnetic atoms were discussed. Different approaches to calculate atomic wave functions to understand the role of correlation and relativistic effects were highlighted.

Quantum dynamics and dynamical processes

Multiply and highly-charged ions have contributed as well to our understanding of the nuclear properties and, especially, of various radio-active isotopes. For example, these ions support dynamical tests on the coupling of matter to the radiation field, and as it has been explored in a great deal of laser-atom studies. As explicitly discussed in this workshop, resonant electron-ion collision with medium and high-Z ions allow, in particular, a very sensitive test on the shape and charge radii of various medium and high-Z isotopes, and with potential applications toward the systematic study of (such chains of) radioactive isotopes. In addition, electron-ion and ion-ion collision helped to explore the quantum dynamics in strong Coulomb field, including the elementary electron transfer and ionization processes. Sizeable modifications in the transfer cross sections can be attributed hereby to quantum electrodynamics, the theory of interaction of (real) electrons with (real and virtual) photons of the field. —- For the isomeric state of thorium-229 at about 7.8 eV (above of the nuclear ground state), moreover, it was explained how the tiny light-nucleus interaction might be enhanced experimentally by pulsed light fields of proper time structure. Indeed, the 'thorium-clock' (if it will be ever worked out in detail) may provide a new type of optical frequency standard, and if new schemes are to be developed to stabilize the clock cycle at sufficiently low temperatures.

Laser spectroscopy of complex systems

Several improved experimental techniques have been presented, in order to extend our studies to more exotic and heavier systems, up to the actinide and super-heavy regions. Especially for this last region, where no stable isotopes are available for reference measurements to find proper atomic and ionic excitation and ionisation schemes, input from atomic theory will be crucial. However, also in the intermediate mass range, the recently developed atomic theory models using large configuration spaces will help in extracting nuclear information from the measured hyperfine spectra.

Results and Highlights

Extracting charge radii from measured isotope shifts remains a long way, even for below medium mass nuclei. The current art still consists in determining the proportionality “atomic factors” with sufficient precision and accuracy to establish quantitative relations and in providing nuclear radii that make sense from the nuclear physics point of view. The method often relies on semi-empirical approaches and muonic data with large corrections calculated with limited computing power. While improving the reliability of their estimations, atomic physicists should accept the message that the resulting trend of radii is the ultimate assessment element to answer the question “which field and mass shift electronic parameters should be used in the process?” The resulting nuclear radii should indeed be consistent with the systematics of radii in neighboring chains and with nuclear structure known from other observables. As far as nuclear moments are concerned, one can certainly conclude that the interaction between the two communities should be strengthened, in particular for heavier and complex systems for which many observed lines should be assigned and therefore ab initio calculations of isotope shift and hyperfine structure parameters are relevant, perhaps even crucial for interpreting the spectroscopic data.

The experimental nuclear laser spectroscopy community has benefited enormously from this workshop, as they got into contact with several atomic theory groups from all over Europe and even outside. Contacts between both communities, learning each other’s potentials and limitations, is of highest importance to further strengthen the future nuclear structure research in very exotic isotopes, both light and heavy.

3.3.10 INTERFACING STRUCTURE AND REACTION DYNAMICS IN THE SYNTHESIS OF THE HEAVIEST NUCLEI

DATE: September 01 - 04, 2015

ORGANIZERS:

A. Diaz-Torres (ECT*, Italy)
G. G. Adamian (JINR Dubna, Russia)

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

This Humboldt Kolleg brought together key experimenters and theorists in the physics of low-energy nuclear science to debate recent achievements and discuss in depth new perspectives for further progress in the understanding of the properties and production mechanisms of the heaviest nuclei. Combining nuclear structure and reaction dynamics is the major issue for planning and interpreting measurements in the new generation of rare-isotope beam facilities, such as FRIB in USA, SPIRAL2 in France, FAIR in Germany and RIBF in Japan. These facilities have dedicated low-energy research programmes using re-accelerated exotic beams for understanding the physics of neutron-rich matter of importance for understanding galactic chemical evolution. The Kolleg addressed the latest progress in the experimental production of the heaviest isotopes and their theoretical descriptions.

SPEAKERS:

A. Diaz-Torres (ECT*, IT)
G.G. Adamian (JINR Dubna, Russia)
G. Muenzenberg (GSI, Germany)
(Colloquium speaker)
S. Hofmann (GSI, Germany)
J. A. Lay-Valera (INFN-Padova and Padova University, Italy)
E. Williams (ANU, Australia)
S. Heinz (GSI, Germany)
N. V. Antonenko (JINR Dubna, Russia)
V.V. Sargsyan (JINR Dubna, Russia)
Y. Tchuvil'sky (Moscow State University, Russia)
A. Nasirov (INP Tashkent, Uzbekistan)
G. De Angelis (INFN-Legnaro, Italy)
S.-G. Zhou (ITP Beijing, China)
J. Meng (Peking University, China)
N. Wang (Guangxi Normal University, China)
L. Guo (CAC Beijing, China)
P. Ring (TU Munich, Germany)
E. Litvinova (Western Michigan Univ., USA)
A. Afanasjev (Mississippi State U, USA)
A. Tumino (Kore University & INFN Catania, Italy)
J. Cseh (ATOMKI, Hungary)
B. B. Back (ANL, USA)

O. Tarasov (MSU, USA)

D. Seweryniak (ANL, USA)

Z. Podolyak (Surrey University, UK)

X. Roca-Maza (Milano University, Italy)

SCIENTIFIC REPORT:

The programme of the Humboldt Kolleg included talks of senior professors as well as young scientists. The Kolleg was opened with an interesting talk by Giacomo de Angelis about the programmes of the Alexander von Humboldt (AvH)-Foundation, especially in Italy. The scientific part of his talk was about the SPES project at Legnaro for the production of exotic neutron-rich nuclei. The latest progress in the experimental production of new superheavy nuclei and the extension of the periodic table of chemical elements were presented by Sigurd Hofmann and Gottfried Muenzenberg, who gave a Colloquium attended also by students from the University of Trento and ECT* researchers. Theoretical descriptions of the complete fusion reactions leading to the formation of heavy and superheavy nuclei were demonstrated in talks by Alexis Diaz-Torres and Gurgen Adamian. Comparisons between the predictions made with different diabatic and adiabatic fusion models were given. The role of the position of the next shell closure after the 208Pb in the production of the new superheavy nuclei was analysed in details. Jose Antonio Lay presented new results of theoretical studies of effects of octupole deformation on sub-barrier heavy-ion fusion. The talks by Birger Back, Elizabeth Williams, Avazbek Nasirov and Luo Guo were devoted to the perspectives of the study of the quasifission process, both experimentally and theoretically. These investigations are very important because quasifission is the main process which prohibits the complete fusion of heavy nuclei, decreasing the production cross section. Vazgen Sargsyan presented new results about theoretical studies on the population of the rotational bands built on the ground-state state of superheavy nuclei. Theoretical and experimental achievements as well as challenges in the field of the the nuclear structure of the heaviest elements were central themes in the talks by Anatoli Afanasjev, Nikolai Antonenko, Elena Litvinova, Peter Ring, Shan-Gui Zhou and Dariusz Seweryniak. New predictions of the quasiparticle and isomeric states, fission barriers, energies of the alpha-decays, position of the next magic nucleus after the lead, and ground state shell corrections of the heaviest nuclei within the macroscopic-microscopic two-center shell model and relativistic mean field model were presented in these interesting talks. In the talk by Ning Wang the new mass formula was suggested for the heavy and superheavy nuclei. Resonance and halo phenomena in the neutron-rich exotic nuclei were discussed in the talk by Jie Meng, while Xavier Roca-Maza spoke about the regularization of zero-range effective interactions in the finite nuclei. The electron shell impact on the alpha-decay of heavy nuclei was the subject of the talk by Yuri Tchuvil'sky. New experiments were suggested to study this interesting phenomenon. The important role of quarteting in atomic nuclei in the clusterization (for example, for the alpha-clusterization) process was demonstrated in the talk by Jozsef Cseh. He presented new achievements in the application of symmetry methods to nuclear physics. The new experimental possibilities for the production of exotic neutron-rich nuclei in multinucleon transfer and fragmentation reactions were discussed in the talks by Sophie Heinz, Oleg Tarasov and Zsolt Podolyak. Aurora Tumino discussed the latest developments in the field of carbon-burning at stellar energies as well as very recent experiments using the Trojan-Horse method. These investigations are very important for nuclear astrophysics. It is important to emphasize that the production and properties of superheavy and exotic nuclei as well as the interplay between nuclear structure and reaction dynamics are some of the frontier research areas in nuclear physics today.

Results and Highlights

Most participants expressed the view that the Humboldt Kolleg was fascinating, very well organized, with comprehensive and interesting talks, detailed and useful discussions and active exchange of comments, suggestions and ideas. New ideas were presented and unpublished new data were discussed. The workshop stimulated a lot of debate, and even more importantly, a number of new ideas and collaborations, since it brought together people from key theoretical and experimental groups. Everybody liked the long, interactive talks (one hour) as they facilitated extensive and fruitful discussions. It was made possible by a highly favourable number of participants. The Workshop Colloquium by Gottfried Muenzenberg (GSI, Germany) was excellent, attended also by several external people (mainly from the ECT* and the University of Trento). Of the 26 participants, 11 were Humboldtians and 4 German researchers. We are convinced that this Humboldt Kolleg has helped the participants (i) to establish closer international cooperation in the aforementioned areas of nuclear physics, (ii) to analyse the prospects for the coming years, and (iii) to develop new joint research programs with international research centers, especially in Germany. The Humboldtians gave talks which were very useful and attractive for graduate students and young researchers. During the Humboldt Kolleg we organized a presentation about the AvH-Foundation and provided informational material on the AvH-Foundation programmes, also promoting the AvH-Foundation programmes among graduate students and young researchers. We are very grateful to the AvH-Foundation for the financial support which allowed us to organize this meeting, which was the first ever Humboldt Kolleg to take place at the ECT*

3.3.11 LFC15: PHYSICS PROSPECTS FOR LINEAR AND OTHER FUTURE COLLIDERS AFTER THE DISCOVERY OF THE HIGGS

DATE: September 07 - 11, 2015

ORGANIZERS:

G. Corcella (INFN, Frascati National Laboratories, Italy)
S. De Curtis (INFN, Florence, Italy)
S. Moretti (University of Southampton, UK)
G. Pancheri (INFN Frascati National Laboratories, Italy)
F. Richard (Laboratoire de l'Accelerateur Lineaire d'Orsay, IN2P3, Orsay, France)

NUMBER OF PARTICIPANTS: 50

MAIN TOPICS:

This workshop was the 8th of a series on physics at future particle colliders. After the successful first run of the LHC, culminated in a Higgs boson discovery, a number of projects for future accelerators is now being actively discussed. Trailing on past experience of ours on Linear Colliders activities, the present workshop on Linear and other Future Colliders (LFC2015) aimed at generating fruitful discussions between theorist and experimentalists on the options open to the future of particle physics. The workshop in fact invited scientists from everywhere in the world, and specifically from areas where future facilities could be built, to discuss topical arguments related to the physics of such colliders.

This workshop explored in particular physics prospects herein in the light of the landscape emerged after LHC Run1 and the potential outcomes of Run 2.

The workshop was organised along the following main topics:

- Status of the Linear Collider project
- New projects and prospects in particle physics after the discovery of the Higgs boson in LHC Run I
- Review of experimental results from Run 1 and first Run 2 results
- Total and elastic proton-proton cross-section: LHC and cosmic ray results
- The astrophysics connection
- Status of the g-2 experiment and theoretical calculations
- Flavour physics,
- Top and Higgs physics measurements and uncertainties
- Beyond the Standard Model: new Higgs, exotics, SUSY
- Phenomenological aspects and tools in QCD

SPEAKERS:

A. Azatov, CERN (Geneva, Switzerland)
D. Barducci (LAPTH, Annecy, France)
M. Beneke, (TU Munich, Germany)
C. Bini (University of Rome `La Sapienza', Italy)
S. Biondini (TU Munich, Germany)
M. Bonesini (INFN, Milan Bicocca, Italy)
D. Buttazzo (TU Munich, Germany)
C. Carloni Calame (convener) (University of Pavia, Italy)
L. Cieri (University of Rome, Italy)
M. Cobal (Univer of Udine, Italy)
D. Comelli (convener) (INFN, Ferrara, Italy)
G. Corcella (INFN, Frascati National Laboratories, Italy)
D. d'Enterria (CERN, Geneva, Switzerland)
S. De Curtis (INFN Firenze, Italy)
B. Dev (TU Munich, Germany)
R. Ferrari (University of Milan, Italy)
G. Ferrera (convener) (University of Milan, Italy)
M. Gomez (Helva University, Spain)
D. Grasso (INFN, Pisa, Italy)
A. Guffanti (University of Copenhagen, Denmark)
F. Hautmann (University of Oxford, UK)
D. Hertzog (University of Washington, Seattle, USA)
E. Kou (LAL Orsay, France)
E. Laenen (Nikhef, Amsterdam, Netherlands)
R. Leonardi (University of Perugia, Italy)
L. Magnea (University of Turin, Italy)
B. Mele (INFN, Rome, Italy)
S. Moretti (University of Southampton, UK)
E. Morgante (University of Geneva, Switzerland)
G. Pancheri (INFN, Frascati National Laboratories, Italy)
O. Panella (convener) (INFN, Perugia, Italy)
G. Panico (IFAE, Barcelona, Spain)
P. Paradisi (University of Padua, Italy)
M. Passera (convener) (INFN, Padua, Italy)
F. Piccinini (convener) (INFN, Pavia, Italy)
R. Poeschl (LAL, Orsay, France)
G. Punzi (INFN, Pisa, Italy)
D. Racco (University of Geneva, Switzerland)
F. Richard (LAL, Orsay, France)
T. Robens (IKTP, Dresden, Germany)
A. Romanino (SISSA, Trieste, Italy)
C. Schwinn (University of Freiburg, Germany)
N. Srimanobhas (University of Chulalongkorn, Thailand)
F. Tramontano (convener) (University of Naples, Italy)
R. Turra (University of Milan, Italy)
V. Vagelli (INFN, Perugia, Italy)
G. Venanzoni (INFN, Frascati National Laboratories, Italy)
G. Villadoro (ICTP, Trieste, Italy)
K. Yokoya (KEK, Japan)
M. Zaro (LPTHE, Paris, France)

SCIENTIFIC REPORT:

This is a very important moment for particle physics. The success of the first run of the LHC (Run 1) has opened new horizons for the field while confirming the extraordinary construction of the Standard Model. It is now time to look at what has been done and plan once more for the future. The main activities of interest for particle physicists, whether experimentalists, theorists or phenomenologists, have been addressed as follows.

g-2 SESSION (convener: Carlo Carloni Calame)

The anomalous magnetic moment of the muon (g-2) is one of the best known quantities in particle physics, both from the experimental and the theoretical side. Intriguingly, it represents one of the few discrepancies between the current measurement and the theoretical prediction within the Standard Model, which at present differ by more than 3 standard deviations. It is thus a possible open window on New Physics effects beyond the Standard Model.

ASTROPARTICLE SESSION (convener: Denis Comelli)

AstroParticle physics is a discipline on its own right, which links theoretical issues in particle physics and experimental searches at colliders with space and cosmological observations. To plan for future machines, it is crucial to know the interplay between signals from the cosmo and those at particle colliders, as well as how far in energy the search can go. LHC has limits in energy, but present plans for upgrades in luminosity will allow tiny signals of Beyond the Standard Model physics to be revealed, if they exist.

TOP PHYSICS SESSION (convener: Francesco Tramontano)

The physics of the top quark will play a prevailing role in all the future experiments on particle physics at very high energies. The aim of the session was twofold, first we wanted to have the status of the art about the present knowledge of the top quark both from the experimental and the theoretical point of view. The second point has been to show the perspectives offered by the different options for the next future high energy collisions machines, namely lepton or hadron colliders at higher energies and higher luminosity with respect to the current ones.

BSM/HIGGS SESSION (conveners: Aldo Deandrea and Roberto Franceschini)

The search for new physics at the TeV scale is one of the two main pillars of the Large Hadron Collider physics programme, the other being the study of the Higgs boson properties. The Beyond the Standard Model Higgs session therefore attacked core questions for the physics of the Large Hadron Collider. This session aimed at investigating the prospects of learning with higher precision the properties of the discovered Higgs boson signals and of establishing the search for new processes of Higgs boson production and decay. Furthermore the session aimed at assessing the opportunities for the Large Hadron Collider and future colliders to detect the production of new scalar states that might be part of a set of Higgs bosons from the true fundamental theory of the TeV scale.

BSM/EXOTICA SESSION (convener Orlando Panella)

The purpose of this section was to highlight alternative scenarios of physics Beyond the Standard Model not covered by the other BSM sections. Such scenarios (composite models, majorana neutrinos, flavor violations, partial compositeness, etc.) need to be thoroughly investigated in order to assess the potential for LHC Run 2 and its future high luminosity phase, as well as of other future lepton colliders, with respect to the possibility to find a evidence for new physics signals.

QCD SESSION (conveners: Giancarlo Ferrera and Fulvio Piccinini)

The role of QCD for physics studies at future colliders is without any doubt of fundamental importance. In the case of both hadronic and leptonic high-energy machines, the interesting reactions at high transfer momentum either directly originate from a QCD hard scattering of partons in the colliding hadrons or include non-negligible QCD contributions through higher-order radiative corrections. For this reason it is necessary to have a precise knowledge of the QCD dynamics both at perturbative and non-perturbative level.

Results and Highlights

The workshop addressed the problems outlined in the Scientific Report above, by way of a panorama of present successes and future plans in particle physics. Plans for future colliders included a presentation and update of the Japanese effort for the construction of an international linear collider. The interest of such future machines for particle physics was highlighted by the Thursday Colloquium by Prof. François Richard from Orsay. A general overview was given both about plans for new accelerators and the outlook for future experiments. In each session, updates from LHC experiments and theoretical ideas or models contributed to a joint view of the status of the field in its different components.
For each of the sessions of the workshop, the following results were presented and discussed.

g-2 SESSION

The aim of the session was to present an overview of the past and future experiments (a new g-2 measurement is planned to start in 2017 at Fermilab) alongside a critical and comprehensive overview of the theoretical evaluations and possible ways to improve or to independently re-analyze corrections which give a large contribution to the theoretical error. The three speakers covered in depth all these aspects, sparking the interest of the workshop participants in the forthcoming results.

ASTROPARTICLE SESSION

The workshop interest has been on future avenues of searches both in the universe and at the sub-nuclear scale. This aspect was highlighted in the astrophysical session, in which the impact on the full cosmological history of the universe of an unstable Standard Model Higgs potential was discussed. We also had a report from the AMS-02 experiment on the International Space Station, which has collected important data on cosmic rays after 4 years in space. A theoretical analysis of the above data showed the interplay between Astro and Dark Matter signatures. It is also possible to set robust collider limits on heavy mediator Dark Matter. A discussion on modelling galactic cosmic ray origin and propagation examined recent successes and open issues. Finally, another problem to reckon with is that further understanding of the dynamics of particle collisions, namely the total pp cross-section which sheds light on the large distance behaviour of QCD, needs cosmic rays experiments to explore higher energies. Thus it is important to search for ways to extract more precise information from proton-air processes.

TOP PHYSICS SESSION

During the workshop there has been a good balance between the theoretical and experimental presentations, well-tuned to the composition of the audience. New results from the LHC experiments ATLAS and CMS have been presented. The same happened on the theory part where new higher precision computations were presented, including, respectively, new Electro-Weak and QCD corrections to leading processes involving the production of top quarks at future colliders.

BSM/HIGGS SESSION

Several results have been obtained in the BSM/Higgs session. The present status of the measurement of Higgs boson properties and the search of new scalar states has been reviewed. The impact of the measurement of the Higgs boson mass has been discussed and its consequences for the properties of the fundamental theory of TeV scale physics have been elucidated. Furthermore it has been presented the scope of detecting a new reaction for the production of a Higgs boson, in which two Higgs bosons are produced from the same hard scattering. The prospects of identifying traces of physics Beyond the Standard Model in the study of this reaction have been discussed in detail. Furthermore it has been presented the status and the prospects for the direct observation of new scalar states arising in different types of fundamental theories in association with the already observed Higgs boson. Additionally it has been discussed the effect of the Higgs boson and of new physics in the precision study of production and decay of top quarks at future leptonic colliders.

BSM/EXOTICA SESSION

There have been presentations about alternative models of electroweak interactions such as composite models, generic heavy neutrinos models and scenarios of flavor violations in supersymmetric theories. The presentations highlighted the prospects for studying experimentally the above scenarios both at the standard LHC in its high luminosity phase as well as at future leptonic colliders. The presentations have triggered interesting discussions between the participants to the workshop and at least one collaboration has started as a result of the session.

QCD SESSION

The main purpose of the session was to have an overview both on the status and prospect for QCD studies at present and future colliders. From the experimental side the results from the ATLAS and CMS collaborations at the LHC have been presented, including very recent highlights at the center-of-mass energy of 13 TeV. From the theory side we had several presentations and discussions on recent advances in QCD: in particular, on the determination of parton densities, on the treatment of pile-up effects and on the calculation of higher-order corrections both at fixed order and at all orders.

Conclusions

As in all previous versions of this series, all the participants expressed their appreciation of both the format and the content of the workshop. The interplay between future projects, present experimental results and updates on advances in phenomenology and theory are seen as a great strength of this series of workshops and contribute to make it a unique opportunity to capitalise on particle physics. Main actors in the field presented the European, Japanese and International programs. A Colloquium by Prof. Francois Richard from the Laboratoire de l'Accelerateur Lineaire d'Orsay, France, described the vision of the future from a particle physicist point of view. On the social activity side, a movie about the Austrian physicist Bruno Touschek was shown and a successful excursion to Altopiano del Renon in South Tyrol was graced by good weather and enjoyed by the participants.

The workshop proceedings in both electronic and paper format will contribute to the literature on present prospects in particle physics. For previous editions of this series, the Proceedings were published by Societa' Italiana di Fisica for LC09 and LC10, by INFN as VoL. LIII of the Frascati Physics Series, for LC11, and by Societa' Italiana di Fisica for LC13. For this edition of the Workshop, LFC15, they will be published by the INFN Frascati National Laboratories in the Frascati Physics Series.

3.3.12 ECT*-APCTP JOINT WORKSHOP: FROM RARE ISOTOPES TO NEUTRON STARS

DATE: September 14 - 18, 2015

ORGANIZERS:

F. Gulminelli (LPC and University of Caen, France)
C.H. Lee (Dept. of Physics, Pusan National University, Busan, Korea)
Y. Oh (Dept. of Physics, Kyungpook National University, Daegu, Korea)
J. Schaffner-Bielich (Institute for Theoretical Physics, Goethe University, Frankfurt, Germany)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

Various heavy ion accelerators are under construction, including SPIRAL2 at Caen, FAIR at GSI and RAON at IBS in Korea. A deep understanding of rare isotope physics is thus essential for microscopically founded modellings of astrophysical problems related to dense matter in the universe, as it can be found in neutron stars and possibly in the dynamical process of black hole formation. Progress in this subject is expected to shed light on our understanding of new isotopes and compact stars. In this workshop, we discussed the expected “QCD phase structure from the vacuum to nuclear matter to compact stars” and the future possibilities of joint multidisciplinary researches, in particular, among scientists from Asia Pacific Center for Theoretical Physics (APCTP) and ECT* member countries. The main topics of the workshop covered different current problems from rare isotope physics to the astrophysical problems related to compact stars.

The main subjects included:

- Neutron Rich Exotic Nuclei and Neutron Star Crust;
- r-process and Heavy Elements;
- Nuclear Data and Neutron Star Core Structure;
- Neutron Star Mergers and Gravitational Waves.

SPEAKERS:

M. Boselli (ECT*/Trento, Italy)
L. Coraggio (INFN, Italy)
F. Gulminelli (Caen, France)
S. Goriely (Bruxelles, Belgium)
E. Ja Ha (Soongsil Univ., Korea)
N. Itagaki (YITP, Kyoto, Japan)
M. Kim (Pusan National Univ., Korea)
Y. Kim (RISP, IBS, Korea)
Y. Kwon (Soongsil Univ., Korea)
K. Kwak (UNIST, Korea)
C.-H. Lee (Pusan National Univ., Korea)
Y. Lee (Pusan National Univ., Korea)
W. Hui Long (Lanzhou Univ. China)
J. Margueron (Lyon, France)
Y. Oh (Kyungpook National Univ., Korea)

P. Papakonstantinou (RISP, IBS, Korea; Greece)
F. Pederiva (Trento, Italy)
L. Rezzolla (Frankfurt, Germany)
M. Rho (Saclay, France)
S. Rosswog (Stockholm Univ., Sweden)
J. Schaffner-Bielich (Goethe Univ., Germany)
E. Shin (Kyungpook National Univ., Korea)
G. Verde (IPN Orsay, France)
W. Weise (ECT*, Italy)
U. Yakhshiev (Inha Univ., Korea; Uzbekistan)
G.-S. Yang (Soongsil Univ., Korea)
S. Zhang (Peking Univ., China)

SCIENTIFIC REPORT:

In this workshop, various aspects and current issues of both nuclear physics and astrophysics have been discussed.

Half of the talks, mainly in the first half of the workshop, were focused primarily on nuclear physics issues including hadronic dense matter, exotic nuclei, r-process nuclei and heavy elements. Exotic nuclei with extreme neutron-to-proton ratios could exhibit in general quite different shell structures compared to stable ones. While they are mostly not found on earth, core-collapse supernova and other stellar explosions are known to produce a substantial amount of such rare isotopes. These elements are also abundantly found in the crust of neutron stars. Reliable and predictable calculations of the structure of those exotic nuclei constitute today a great challenge for nuclear theorists. The origin of heavy elements is one of the primary scientific goals of rare isotope facilities. The rapid neutron capture process (r-process) synthesizes roughly half of the known heavy elements. Unlike the slow neutron capture process (s-process), the required physical environment and astrophysical sites for the r-process are not fully understood. Possible sites are expected to include type II supernova explosions and neutron star mergers. To achieve a full understanding of this process, it is essential to have a reliable nuclear theory for very neutron-rich exotic nuclei and new experimental measurements. New facilities such as RAON and SPIRAL2 will provide valuable information in this respect.

Another half of the talks, mainly in the second half of the workshop, were focused on the astrophysical subjects related to neutron stars and supernovae. In the core of neutron stars, the density is expected to reach several times the nuclear matter saturation density. However, the change of nuclear matter properties beyond the nuclear matter saturation density is still one of the key problems in both nuclear physics and neutron-star-related astrophysics. The main uncertainty beyond the saturation density comes from the lack of experimental data at high densities. New RIB facilities like FAIR and RAON will be able to provide valuable nuclear data which can be applied to various phenomena related to the neutron star core structure, e.g., simulations of core collapse (electron capture, thermal properties), accretion onto neutron stars in low-mass X-ray binaries, cooling of neutron stars with superfluidity in the core, and the hyperonic content in the core of neutron stars. Gravitational waves from neutron star binary mergers might be detected in a few years by ground based gravitational wave detectors such as advanced LIGO in the USA, Virgo in Europe and KAGRA in Japan. During the merger process, the neutron star is expected to break up and reveal the information on the inner structure via gravitational waves. Hence, gravitational wave observations will eventually be able to provide very important information on the neutron star structure. In addition, neutron star mergers are considered to be the most promising sites for producing nuclei via the r-process, and the origin of short-hard gamma-ray bursts.

Results and Highlights

The Workshop provided a good opportunity for participants from APCTP, especially from Korea, and ECT* member countries to present their own works and share common interests. There was no joint activities between APCTP and ECT* for more than 10 years as the last joint meeting was held at 2004. Therefore, this workshop provided a good chance to understand current research activities of both sides and it was very timely as new rare isotope facilities are under construction in both sides.

RAON at Institute for Basic Science (IBS) is a new facility that is under construction in Korea. Hence the talks by Korean participants have been focused on the theoretical works on various hadronic and astrophysical problems without experimental results on the rare isotope physics. On the other hand, talks by other member countries have been based more strongly on the experimental and numerical results related to the physics of rare isotopes.

Highlights of the meeting are the connection between astrophysical problems and rare isotope physics, including r-process, etc. as described above. There were exchanges of ideas on improving our understanding of various problems in nuclear physics and nuclear astrophysics.

During the workshop, we found many common interests and agreed that active collaborations among the physicists of both sides are very important to achieve the goals of new facilities. This workshop was very fruitful for both sides as it initiated the future possibilities for the collaboration between Europe and Asia and we hope that this activity be continued by various meetings and mutual visits.

3.3.13 EXCITED-STATE QUANTUM PHASE TRANSITIONS

DATE: September 21 – 25, 2015

ORGANIZERS:

Pavel Cejnar (Institute of Particle and Nuclear Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic)
T. Brandes (Institut für Theoretische Physik, TU Berlin, Germany)

NUMBER OF PARTICIPANTS: 35

MAIN TOPICS:

Excited-State Quantum Phase Transition (ESQPT) is a novel concept unifying various types of singularities present in discrete energy spectra of quantum systems with a limited number of effective degrees of freedom. The ESQPTs extend the ground-state quantum phase transitions in diverse many-body systems (like atomic nuclei, molecules, Bose-Einstein condensates), lattice system (e.g., graphene), and quantum-optical systems (cold atoms, systems with tuneable matter-field coupling). The ESQPT phenomena are rooted in some classical phase-space singularities and their key signatures are identified in nonanalytic density and flow properties of quantum spectra, and in some anomalous dynamical and thermodynamical features of the system. These signatures have a potential impact on complex processes involving many-body systems as well as on various quantum information techniques.

SPEAKERS:

P. Cejnar (Charles University Prague, Czech Republic)
T. Brandes (TU Berlin, Germany)
F. Iachello (Yale University, USA)
M. Kastner (National Institute for Theoretical Physics, Stellenbosch, South Africa)
A. Richter (U Darmstadt, Germany)
J. Hirsch (Universidad Nacional Autónoma de México, Mexico)
M. A. Bastarrachea-Magnani (Universidad Nacional Autónoma de México, Mexico)
A. Relaño (Universidad Complutense de Madrid, Spain)
A. Kolovsky (Kirensky Institute of Physics, Krasnoyarsk, Russia)
E.-M. Graefe (Imperial College London, UK)
V. Konotop (University of Lisbon, Portugal)
M.Kloc (Charles University Prague, Czech Republic)
P.Stránský (Charles University Prague, Czech Republic)

J. Dudek (Univerity of Strasbourg and IPHC/CNRS Strasbourg, France)
M. Macek (Yale University, USA)
P. Pérez Fernández (Universidad de Sevilla, Spain)
H. Waalkens (University of Groningen, The Netherlands)
F. Pérez-Bernal (Universidad de Huelva, Spain)
J. E. García Ramos (Universidad de Huelva, Spain)
M. Gessner (University of Freiburg, Germany)
M. Oberthaler (University of Heidelberg, Germany)
L. Santos (Yeshiva University, New York, USA)
W. Kopylov (Technische Universität Berlin, Germany)
R. Puebla (University of Ulm, Germany)
J. Dukelsky (Instituto de Estructura de la Materia CSIC Madrid, Spain)
D. Brody (Brunel University London, UK)
V. Manuel Bastidas Valencia (Technische Universität Berlin, Germany)
J. Chávez Carlos (Universidad Nacional Autónoma de México, Mexico)
N. Moiseyev (Technion - Israel Institute of Technology, Haifa, Israel)
T. Novotný (Charles University Prague, Czech Republic)
D. Heiss (University Stellenbosch, South Africa)
M. Dvořák (Charles University Prague, Czech Republic)

SCIENTIFIC REPORT:

This was the first workshop devoted to Excited-State Quantum Phase Transitions. The main goal was to establish a common language and a basis for an exchange of ideas for the interested experts from different fields of quantum many-body physics – like nuclear physics, molecular physics, physics of cold atoms and BECs, quantum optics etc. The common focus was put on various realizations of the ESQPT phenomenon in the spectra of diverse quantum many-body systems. Quantum spectral singularities known earlier in some specific systems (like van Hove singularities in lattice systems, quantum monodromy in molecular and related systems, effects of separatrix in systems with one degree of freedom etc.) were discussed under the unifying light of the ESQPT concept. The long-term aim of these efforts is to classify various types of ESQPTs, to describe the mechanisms of their occurrence, and to explore their dynamical and thermodynamical consequences.
The Workshop facilitated discussions between relevant experts and opened ways for progress in multiple directions. The main topics addressed in various talks can be summarized as follows:

- Specific signatures of ESQPTs in finite algebraic systems, like the vibron model of molecules, the interacting boson model of nuclear collective motions, Richardson-Gaudin models of fermionic or bosonic systems with pairing etc. Possibilities of finding some symmetry-dictated “order parameters” in the excited spectra of these models. These topics were addressed in the contributions of F. Iachello, J. Dukelsky, F. Pérez Bernal, J.E. García Ramos, M. Macek and others.

- Occurrence of ESQPTs of various types in atom-field systems that exhibit the Dicke superradiance. Quantum phase diagrams and defining properties of quantum phases in these models. These aspects were discussed in the talks by J. Hirsch, M.A. Bastarrachea-Magnani, P. Cejnar, A. Relaño, M. Kloc and J. Chávez.

- Characteristic features of ESQPTs in various lattice systems described by models of the Bose-Hubbard type. Relation between ESQPTs rooted in the phase-space description to those caused by anomalous dispersion relations in the momentum space. These topics were presented in the talks by F. Iachello, A. Richter, M. Macek, P. Pérez Fernández, A. Kolovsky, P. Stránský and others.

- Transition between collective spin models of the Lipkin type, with infinite-range interactions, and microscopic spin models of the Ising type, with only local interactions. To what extent the ESQPT structures survive? The question was addressed in talks of M. Gessner and M. Kastner.

- Other models and approaches that are of potential interest from the viewpoint of ESQPTs, like an atom-molecule conversion models, BECs in dissipative environments, some models of collective degrees of freedom in atomic nuclei, or an nonequilibrium heat-transport model, were discussed in talks of E.M. Graefe, V. Konotop, J. Dudek and T. Novotný. An overview of a closely related concept of monodromy was presented by H. Waalkens.

- General classification of various ESQPTs in terms of the Morse theory for non-degenerate stationary points of the Hamiltonian function for systems with arbitrary number of degrees of freedom. Specific examples of ESQPTs generated by degenerate (non-quadratic) stationary points. These topics were addressed in the contributions of M. Kastner, P. Cejnar and P. Stránský.

- The search for a relation between thermodynamic (canonical) phase transitions and the ESQPTs. There is no doubt that both these phenomena are tightly interconnected, but at the same time they seem to be complementary (the ESQPTs appear in the collective subspace, while the thermal phase transitions apply if the full space including all microscopic degrees of freedom is considered). This was discussed in the talks of M. Kastner, P. Cejnar and T. Brandes.

- Description of relevant dynamical consequences of ESQPTs of various types. For example, those appearing in the response to quantum quenches (sudden changes of the system's parameters) – slowdown or speedup of the initial state decay. Such consequences can establish an experimental protocol for the identification of ESQPTs and may play an important role in various quantum information techniques. These topics were described in the contributions of L. Santos, M. Oberthaler and A. Relaño.

- Consequences of ESQPT in driven systems. Adiabatic versus sudden driving. Analogues of ESQPTs in kicked systems. This wide and important field was outlined in the talks by T. Brandes, V. Bastidas, M. Oberthaler, V. Kopylov and R. Puebla.

- Relation of spectral singularities of the QPT and ESQPT type to non-Hermitian degeneracies (branch or exceptional points) of the Hamiltonian with complex-extended control parameters. The convergence of exceptional points to the physical (real) domain of control parameters represents the essential mechanism how the precursors of quantum critical behaviour for ground and excited states show up in finite systems.

The physics of exceptional points was discussed in talks by N. Moiseyev, D. Heiss, D. Brody and M. Dvořák.

- Possibilities for experimental detection of ESQPTs. Clearly measured examples of ESQPTs are known in highly excited molecules and in the artificial graphene, realized with the aid of so-called photonic crystals. It is desirable to manifest the ESQPT phenomena using the tools of cold-atom physics, where they can be also relevant from the viewpoint of quantum-information applications. The experimental aspects were discussed in the talks by A. Richter and M. Oberthaler.

Results and Highlights

The Workshop was successful in promoting the ESQPT concept as a subject of common interest for experts in different branches of quantum many-body physics. It created the synergy needed for the continuation and extension of the concept in various directions. There is now a good prospect for a rapid progress in all the areas discussed.
The prevailing discourse of the Workshop was oriented theoretically, but the participation of a few experimentalists gave the discussions some realistic backing. A very good feature of the Workshop was the presence and active participation of numerous PhD students and postdocs who focus their work on this subject. There is an intention to organize a similar workshop in 2 years or so, hopefully with an increased accent on fresh experimental results.

The directions of future research that resulted from the present Workshop can be summarized as follows:

- General classification of various types of ESQPT
- Link of ESQPTs to thermodynamical phase transitions
- General vs. model-specific description of quantum phases resulting from ESQPT phase diagrams
- Description and systematization of various dynamical signatures of ESQPTs
- Dynamical control of criticality in driven systems
- Experimental protocols to detect ESQPTs in synthetic quantum systems
- Role of ESQPTs in quantum information techniques

3.3.14 ADVANCES IN DIAGRAMMATIC MONTE CARLO METHODS FOR QUANTUM FIELD THEORY CALCULATIONS IN NUCLEAR, PARTICLE, AND CONDENSED MATTER PHYSICS

DATE: October 05 - 09, 2015

ORGANIZERS:

S. Chandrasekharan (Duke University, USA)
C. Gattringer (University of Graz, Austria)
R. Kaul (University of Kentucky, USA)
D. Lee (North Carolina State University, USA)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The goal of the workshop was to explore recent advances in Monte Carlo methods, especially those that use Monte Carlo sampling of diagrams. Some of the topics that were covered in the workshop include:

- World-line methods (Quantum Spins and Emergent Gauge Fields)
- Diagrammatic, Fermion Bag and Auxiliary Field Methods (Strongly Correlated Electrons, Nuclear EFT)
- Dual Variables (Lattice Gauge Theories)
- Tensor Networks

SPEAKERS:

F. Assaad (University of Würzburg,)
F. Bruckmann (University of Regensburg)
P. Buividovich (University of Regensburg)
S. Chandrasekharan (Duke University)
K. Damle (Tata Institute of Fundamental Research)
S. Elhatisari (University of Bonn)
H.-G. Evertz (TU of Graz)
C. Gattringer (University of Graz)
S. Gazit (University of California at Berkeley)
G. Mario (University of Graz)
E. Huffman (Duke University, USA)
R. Kaul (University of Kentucky at Lexington)
T. Lang (University of Innsbruck)
D. Lee (North Carolina State University)
O. Philipsen (Goethe University of Frankfurt)
L. Pollet (University of Munich)
A. Sandvik (Boston University)
T. Sulejmanpasic (North Carolina State University)
B. Svistunov (University of Amherst, USA)

H. Vairinhos (ETH Zürich)
L. Wang (ETH Zürich)
S. Wessel (University of Aachen)
U.-J. Wiese (University of Bern)
U. Wolff (Humboldt University)
M. Zaletel (Station Q (Microsoft Research)

SCIENTIFIC REPORT:

Diagrammatic perturbation theory can be constructed at both strong and weak couplings. Both these approaches have been used extensively in analytic calculations of various quantities. Partition functions can also be written as a sum of such diagrams. Monte Carlo algorithms can be used to sample these diagrams if all diagram weights are positive and if the series is convergent. Over the past decade it has become clear that this alternative approach can lead to very efficient Monte Carlo algorithms. The most famous example of this new Monte Carlo approach is the stochastic series expansion (which is basically a high temperature expansion) for quantum spin systems. In classical spin systems a similar expansion is easy to construct. These expansions lead to the world-line (or current-loop) representation of the models. Using worm or directed loop algorithms one can very efficiently update these world-line configurations. Many models have recently been solved within this approach and exotic phases and transitions are being explored.

In lattice gauge theories the high temperature expansion is referred to as the strong coupling expansion and leads to a theory of surfaces. In Abelian gauge theories the weights of these surfaces are positive and one can in principle design algorithms to sample them. One can also introduce bosonic matter fields that interact with the gauge fields without introducing sign problems. Recently some efficient algorithms have been developed to solve such Abelian- gauge-Higgs systems in some regions of parameter space. With non-Abelian gauge fields the strong coupling series contains negative weights. In this case re-summation techniques are being explored. New ideas of rewriting lattice gauge theories are also being developed. Applications to finite density QCD with heavy quarks have recently appeared.

With gapless (or light) fermions the diagrammatic series is no longer positive in the world-line formulation. However, a re-summation allows one to rewrite the series as a sum over determinants. These determinants can be positive whenever some pairing can be discovered. Such an approach has been used under different names: diagrammatic determinantal Monte Carlo (when weak coupling diagrams are used) and fermion bag Monte Carlo (when strong coupling diagrams are used). It was realized recently that there is a duality between them. They can also be formulated either in continuous time or discrete time. A variety of interesting new problems are now solvable in this approach. The method seems to be similar with the traditional auxiliary field methods. Advantages/disadvantages of one approach over the other are still unclear.

An advantage of the weak coupling diagrammatic approach is that disconnected diagrams in the partition function can be obtained as an exponential of connected diagrams. Further one can focus on vertex functions and skeleton diagrams that are simpler. One can also take into account renormalization (or “boldification”) if necessary. Finally, one may be able to work directly in the thermodynamic limit. However, the main disadvantages are that the series is not convergent in this approach and sign problems, although much milder up to some order of the expansion, can become severe. Despite these difficulties, results using this approach have begun to appear.

Clearly, solutions to sign problems are important for the success of the new diagrammatic methods and it is well known that frustrations cause sign problems. Interestingly frustrated systems are also highly entangled. So it is interesting to explore if quantum entanglement is related to sign problems and our ability to perform computations. Since quantum entanglement appears to be captured well through tensor networks, one wonders if the tensor approach can be combined with diagrammatic Monte Carlo methods for some class of models.

Results and Highlights

The workshop brought together experts on the various topics discussed above, some of whom gave pedagogical reviews of the field while others focused on recent results.
A variety of presentations focused on how the world-line (or current-loop) representations have allowed us to solve many new and exciting problems. This includes SU(N) anti-ferromagnets that display the phenomena of emergent gauge fields and spin-liquid phases. Extension to SO(N) quantum spin models with a new type of emergent spin liquid phase is being explored. Spin liquid phases are related to quantum field theories with topological terms of interest to particle physicists. We also learned how scattering properties can be extracted from the world-line approach.
In the context of fermion Monte Carlo methods, it has been shown that entanglement entropy can be measured using auxiliary field determinantal Monte Carlo. Spinless fermions can be tackled using the Majorana representation. Applications to the Kene-Mele Hamiltonian have emerged. Applications of the world-line method are also being explored in nuclear physics through a new idea called the "impurity lattice Monte Carlo."
Using the fermion bag approach a new mechanism of fermion mass generation has been observed. This occurs at an exotic second order critical point that separates two phases with the same symmetries. This transition was predicted both in lattice field theory studies and in a model of bilayer graphene simultaneously. In bosonic systems, exotic transitions between two phases with the same symmetries are referred to as spin protected topological (SPT) transitions. A simple current-loop model appears to show such a transition in a paired superfluid.
Applications to lattice gauge theories have emerged but remain in their infancy. Here the main difficulty seems to be that we do not yet have efficient algorithms, like the worm algorithm, to update closed surfaces. In the presence of matter fields, a variant of the worm that also updates plaquettes was used to solve the Abelian-gauge-Higgs model. However, regions of parameter space with large correlation lengths were not explored. Strong coupling diagrammatics have been explored and applications to heavy dense QCD seems to be emerging. Other representations of the path integral are also being explored to study compact QED.
We got a glimpse of both the success and challenges of the weak coupling diagrammatic Monte Carlo. It has been applied to a variety of models including impurity models, Hubbard models, resonant fermion models, frustrated magnets and even non-equilibrium dynamics etc. Some parts of the ground state phase diagram of the repulsive Hubbard model has been computed. The basic message is that fermionic problems are usually better behaved than bosonic models due "sign blessing." But still resummation is often necessary and large orders cannot be accessed at the moment. Since one truncates the approach at some finite order of the expansion, there may be uncontrolled systematic errors. Ideas of how to avoid the Dyson collapse arguments have emerged. While there are still challenges and a lack of manpower, the potential of the method remains exciting.
While the workshop did not focus on tensor networks (TN), there was one pedagogical review. In 1d things work quite well, but in 2d there are several challenges that still need to be settled. The three main problems are that: (1) It is unclear which phases of matter are described well by TN, (2) It is difficult to compute generic observables since sometimes the computations scale exponentially in system size, (3) There is no systematic way to construct the TN for a given Hamiltonian.
Finally, concerning sign problems, it is now clear that not all sign problems are equally difficult to solve and that by choosing an appropriate basis some sign problems may indeed be solvable. There is not yet a systematic method that guides us to the right basis. Finding solutions to sign problems is emerging as a new area of research. For example it was shown

that a quantum dimer basis was useful in solving a fully frustrated spin ladder problem. Similarly, sign problems in frustrated Ising models can be alleviated with cluster algorithms that consider larger spin clusters as the basic building block. We also learned that the Majorana representation of fermions was at the heart of the new solution to sign problems that emerged in 2014 for particle-hole symmetric spin-less fermion models. Combining bosonic world-lines with the concept of fermion bags one can also solve interacting fermion-boson models.

At the end many participants said they enjoyed the workshop, especially the ability to share ideas from different communities tackling similar challenges was refreshing and educational. More such workshops bringing together physicists working on diverse projects that share common challenges were strongly encouraged.

3.3.15 NUCLEON RESONANCE SPECTRUM AND STRUCTURE FROM EXCLUSIVE MESON PRODUCTION UP TO HIGH PHOTON VIRTUALITIES

DATE: October 12 – 16, 2015

ORGANIZERS:

R. W. Gothe (University of South Carolina, USA)
V. I. Mokeev (Jefferson Lab, USA)
E. Santopinto (INFN Genova, Italy)

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

The workshop focused on the study of the nucleon resonance (N*) spectrum and structure as it becomes accessible through the electromagnetic excitation of the nucleon (EmNN*) in exclusive meson production.

The main topics were:

- baryon spectrum in exclusive meson photoproduction,
- search for new baryon states in combined studies of exclusive photo- and electroproduction,
- electroexcitation of N* states and their structure at photon virtualities up to 5 GeV2,
- extension of these studies with CLAS12 to low (>0.01 GeV2) and highest (up to 12 GeV2) photon virtualities ever achieved in exclusive electroproduction,
- advances in the reaction models and amplitude analyses for the extraction of resonance parameters, and
- (progress of QCD-based approaches relating measured resonance electrocouplings to the non-perturbative strong interaction mechanisms that are behind the formation of nucleon resonances and elucidate their emergence from QCD.

Rapid growth of high-quality experimental results on exclusive meson photoproduction off nucleons from CLAS, ELSA, GRAAL, and MAMI gives us the unique opportunity to establish the baryon spectrum from experimental data with minimal model dependence. Resonance electrocouplings obtained in a wide area of photon virtualities, mostly from CLAS exclusive meson electroproduction off nucleons data, offer valuable information allowing us to explore the complex interplay between meson-baryon and quark degrees of freedom in the N* structure and provide unique access to many facets of the non-perturbative strong interaction as it generates excited nucleons with various quantum numbers. Future extension of these studies toward high photon virtualities will allow us to explore the transition from quark-gluon confinement to perturbative QCD as it is revealed in the structure of excited nucleons. The workshop focused particularly on new results and the development of future strategies, methods, and approaches to extract, predict, and understand the baryon spectrum and its photo- and electrocouplings ϒNN* based on Standard Model QCD. The workshop thus addressed challenging problems of contemporary hadron physics, namely the generation of hadron mass by strong interaction in the non-perturbative regime through dynamical chiral symmetry breaking and the nature of quark-gluon confinement, as they emerge from the studies of the light baryon structure. The workshop aimed to foster already initiated efforts and to create new opportunities to facilitate and stimulate further discussions and growth in this field.

SPEAKERS:

A. Bashir (Univ. of Michoacan, Mexico)
D. Binosi (ECT*, Italy)
V.M. Braun (Univ. of Regensburg, Germany)
R. Briceno (Jefferson Lab, USA)
V.D. Burkert (Jefferson Lab, USA)
D. Carman (Jefferson Lab, USA)
A. D'Angelo (Univ. of Roma and INFN Roma, Italy)
I. Danilkin (Univ. of Mainz, Germany)
G. de Teramond (Univ. of Costa Rica, Costa Rica)
G. Eichmann (Univ. of Giessen, Germany)
B. El-Bennich (Univ. Cruzeiro do Sul and Univ. Estadual Paulista, Brazil)
J. Ferretti (Univ. of Roma, Italy)
H. García Tecocoatzi (INFN Genova and UNAM, Italy)
M. Giannini (Genova Univ., Italy)
R.W. Gothe (Univ. of South Carolina, USA)
H. Haberzettl (George Washington Univ., USA)
K. Joo (Univ. of Connecticut, USA)
H. Kamano (RCNP Osaka Univ., Japan)
P. Kroll (Univ. of Wuppertal, Germany)
L. Lanza (Univ. of Roma, Italy)
T.-S.H. Lee (Argonne National Lab., USA)
R. Magana Vsevolodovna (INFN Genova, Italy)
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J. Nys (Ghent Univ., Belgium)
I. Obukhovsky (Moscow State Univ., Russia)
N. Offen (Univ. of Regensburg, Germany)
K. Park (Old Dominion University, USA)
S. Qin (Argonne National Lab., USA)
G. Ramalho (IIP Federal Univ. of Rio Grande do Norte, Brazil)
D. Richards (Jefferson Lab., USA)
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S. Strauch (Univ. of South Carolina, USA)
L. Tiator (Univ. of Mainz, Germany)
Y. Yamaguchi (INFN Genova, Italy)

SCIENTIFIC REPORT:

Substantial progress has been demonstrated during the workshop on the measurements of meson-photoproduction off nucleons and their amplitude analyses as well as on the extension of our knowledge of the excited nucleon state spectrum, photocouplings, and their partial hadronic decay widths by employing elaborated and in some cases even almost model-independent reaction model approaches. They are carried out by either analyzing the reaction amplitudes as constrained by the data or by employing reaction models to compute differential cross sections and polarization asymmetries. In the future, similar analyses of exclusive electroproduction at low Q2 will be important to cross-check the observation of the new N*-states that have been seen in photoproduction data, to enhance the capabilities for new state discovery in exclusive channels due to the improved resonance-to-background ratio at higher Q2, and to potentially provide compelling evidence for hybrid baryons through the specific Q2-evolution of their transition form factors. These studies will be further extended by new results on exclusive meson electroproduction off bound neutrons, offering new prospects to access the electrocouplings of resonances excited off neutrons.
The presented studies and results of exclusive meson electroproduction off protons provide for the first time a set of information on electrocouplings of low-lying N* states with masses less than 1.6 GeV at photon virtualities up to 5.0 GeV2 and preliminarily on electrocouplings of most N* states in mass range up to 1.8 GeV. The reliability of the YvNN* electrocoupling results of low-lying N*-states, that have been published in the 2014 edition of the PDG report, has been established through consistent results from independent analyses of the major exclusive meson electroproduction channels off the proton, namely Nπ and π+π-p. Physics analyses of these results revealed the N* structure as a complex interplay between the inner core of three dressed quarks and external meson-baryon cloud.
Furthermore, to investigate the nucleon resonance structure from partially explored – where meson-cloud degrees of freedom contribute substantially to the baryon structure – to still unexplored distance scales – where quark degrees of freedom dominate and the transition from dressed to current quarks occurs – we depend on experiments that allow us to measure observables that are probing this evolving non-perturbative QCD regime over its full distance range. Resonance transition form factors are uniquely suited to trace this evolution by measuring their Q2 dependence in a broad area of photon virtualities from 0.01 GeV2 up to 12 GeV2. Extending the information on the nucleon ground-state structure in terms of elastic form factors and various partonic structure functions by data on the excited nucleon structure based on the YvNN* electrocouplings is essential in order to explore the non-perturbative strong interaction mechanisms, which are responsible for generation of both the ground and excited nucleon states.
The extension of exclusive electroproduction measurements with the CLAS12 detector at Jefferson Lab by the approved experiments E-09-003 and E12-06-108A into the range of photon virtualities from 5 to 12 GeV2, where quark degrees of freedom are expected to dominate, was discussed. They will then cover continuously the interaction distance range that corresponds to the transition from the quark-gluon confinement towards the pQCD regimes of strong interaction. The current and upcoming experimental data in conjunction with advanced QCD-based approaches that relate the N*-resonance properties to QCD will allow us to systematically study:

- the N*-spectrum and its emergence from the underlying complex dynamics of the non-perturbative strong interaction in QCD,

- the manifestation of “missing” baryon and potentially other new states of hadron matter, the so-called hybrid-baryon states, in exclusive photo- and electroproduction,

- the complex interplay of quark-gluon and meson-baryon degrees of freedom in the N*-structure,

- the transition from fully dressed constituent to bare current quarks, elucidating the nature of quark-gluon confinement in baryons and the behavior of the universal QCD beta-function in the infrared regime, and
- the emergence of more than 98% of the baryon mass and of the dressed quark structure, both generated non-perturbatively through dynamical chiral symmetry breaking.

The close collaboration and open discussions of experimentalists and theorists, as we could experience at this ECT* workshop, is essential to provide the best high-precision data, high-quality analyses, and state-of-the-art QCD-based calculations on YNN* photo- and electrocouplings of the resonance spectrum.

Results and Highlights

The Workshop gave us a unique opportunity to merge expertise and knowledge of experimentalists with that of theorists from European, USA, and other international institutions on the nucleon resonance spectrum and structure as well as to develop and refine the best suited approaches for the reliable extraction of resonance parameters and their sound theoretical interpretation in a comprehensive QCD-based hadron structure theory.

We have developed the strategies for the extraction of the N*-spectrum from combined analyses of exclusive meson photo- and electroproduction data. In addition various approaches were discussed and refined to extract resonance photo- and electrocouplings, such as: dynamical coupled-channel models for global multi-channel analyses incorporating multi-meson-baryon states, reaction models for independent analyses of N π, N ππ, ηp, ωp, and KY exclusive channels, state-of-the-art methods for reaction amplitude extractions, and reaction models applicable at high photon virtualities. Analyses of CLAS data on exclusive N π and N ππ electroproduction provided consistent information on electrocouplings for most of the excited nucleon states in the mass range up to 1.8 GeV and at photon virtualities up to 5 GeV2. Furthermore, preliminary results on exclusive Nπ electroproduction off bound neutrons have become available. In combination with the advances in the reaction models by Argonne-Osaka and GWU groups for exclusive reactions inside the deuteron, these data open up prospects extracting electrocouplings of resonance states excited off neutrons. Finally, experimental efforts and signatures of hybrid-baryons in electroproduction were discussed.

QCD-based efforts were presented and fostered to describe and interpret resonance parameters within the framework of Lattice QCD and continuum strong QCD as well as by employing advanced quark models (like for example the Unquenched Quark Model that is a systematic coupled channels model, or the Interacting Quark Diquark Model that implements systematic use of the diquark effective degrees of freedom). Continuum strong QCD (DSEQCD) describes successfully the nucleon elastic form factors

as well as the N→Δ(1232)3/2+ and N→N(1440)1/2+ transition form factors with the same dressed quark mass function, demonstrating for the first time the ability to access this fundamental ingredient of the non-perturbative strong interaction with the help of data on elastic and transition form factors. These new results by the ANL theory group represent one of the most important continuum QCD results of the last decade that has been achieved in synergy of experimental and theoretical efforts with leading contribution from the CLAS experimental results on the N→ Δ(1232) and N→N(1440)1/2+ transition form factors.

Advances in the Light Cone Sum Rule approach reported at this workshop by the Regenburg-Dubna collaboration allow us now to probe quark distribution amplitudes (DA) of the N(1535)1/2- resonance based on the CLAS electrocouplings for this state. These quark DA's can thus be derived starting from the QCD Lagrangian within LQCD. This approach offers an alternative way of relating resonance electrocouplings to first principles of QCD. The JLab LQCD group keeps developing the only available LQCD approach capable to derive resonance electrocouplings from the QCD Lagrangian accounting for all relevant contributions to the resonance structure including their decays.

On another side, the recent development of the Unquenched Quark Model (UCQM) formalism, that makes up for various deficiencies of other three quark models, offers an alternative tool that can be used when LQCD or Chiral Effective Theory still cannot be applied to describe the N* spectrum and structure. UCQM takes into account in a systematic way the sea components and is a coupled channel quark model with continuum components. Recent systematic results regarding the calculation of the longitudinal and transverse electromagnetic NN* transition form factors, as well as their strong decays, have also been described within a collective hypercentral model. This is a simple model based on the three quark symmetry that describes the basic baryon features, so that it can be used as a first step or as guidance for observable without continuum components. Finally, it has been discussed, that the recent development of the Interacting Quark Diquark Model (IQDM), which is based on direct and exchange interactions using the effective quark-diquark degrees of freedom, is able to assess in a systematic way the baryon spectrum and structure. IQDM also predicts many missing resonances, although many less than the three quark model, and is able to describe the P13(1900).

All the presented and discussed advances will allow us to further explore the emergence of nucleon resonances from quarks and gluons and to address the most challenging open problems of the Standard Model on the origin of hadron masses and quark-gluon confinement in baryons within a QCD-based framework.

We fostered and broadened already initiated experimental and theoretical efforts, and created opportunities to facilitate and stimulated the needed growth in this field that tries to uncover the emergence of the non-perturbative regime from QCD.

This five-day workshop focused on current and future experimental data, phenomenological data analyses, and QCD-based interpretations of the baryon spectrum and the resonance electrocouplings, and in particular provided the opportunity to initiate international efforts to develop new approaches for the extraction of resonance photo- and electrocouplings from exclusive meson production induced by real to highly virtual photons. The workshop was an important step in the development of methods towards a QCD-based theoretical interpretation of the EmNN* couplings that will allow us to probe the strong interaction at continuously varying length scales, covering the transition from sizeable meson-baryon to the dominance of quark degrees of freedom in the N* structure at Q2 < 5 GeV2 with the currently available data and the gradual transition from dressed to pQCD quarks with the prospective data at Q2 > 5 GeV2.

3.3.16 FRONTIERS IN HADRON AND NUCLEAR PHYSICS WITH STRANGENESS AND CHARM

DATE: October 19 - 23, 2015

ORGANIZERS:

K.-T. Brinkmann (Univ. Giessen - Germany)
C. Curceanu (LNF–INFN, Frascati Italy)
J. Marton (SMI, Vienna Austria)
U.-G. Meißner (Univ. Bonn & FZ Jülich Germany)
B.-S. Zou (ITP/CAS China)

NUMBER OF PARTICIPANTS: 37

MAIN TOPICS:

The workshop was centred on the most recent developments in the strangeness and charm physics (hadronic and nuclear), both in theory and experiment. Combining the theoretical and experimental findings in these fields is allowing a better and more accurate understanding of the processes undergoing in the low-energy QCD sector, with implications from particle and nuclear physics to astrophysics.

The main topics of discussions were:

- Kaonic deuterium status and new ultra-high precision experiments (with TES detectors)
- Isospin-dependent antikaon-nucleon scattering length extraction
- The Lambda(1405) resonance updated status: experiments and theory
- Antikaonic Nuclei: status and new experimental results
- Pentaquark in the charm sector: theoretical and experimental studies
- XYZ mystery in charmonium-like spectra
- Strangeness and astrophysics – structure of neutron stars
- Further selected topics in theoretical and experimental studies on the strong interaction with charm
- Ab initio calculations of charmed hadrons

Experimental results:

- SIDDHARTA-2 and AMADEUS status and results at DAFNE
- E15 at J-PARC
- FOPI and HADES at GSI
- BES, BEPC exp. Result

Next-generation experiments

- AMADEUS at DAFNE
- TES based detector experiments at J-PARC and DAFNE

- New Experiments at J-PARC
- Experiments at CERN
- Experiments in China (BEPC (BES), Lanzhou ….)
- Experiments at JLAB, ELSA, MAMI

SPEAKERS:

Y. Jia (IHEP Beijing, China)
H. Martinez (TU München, Germany)
R. Williams (Univ. Giessen, Germany)
A. Filippi (INFN Torino, Italy)
T. Matulewicz (FUW, Warsaw, Poland)
J. Haas (Univ. Giessen, Germany)
D. Sirghi (LNF-INFN, Italy)
S. Ohnishi (Hokkaido Univ., Japan)
A. Cieply (Rez. Prague, Czech Republic)
P. Vesely (Rez. Prague, Czech Republic)
S. Petschauer (TU München, Germany)
A. Gal (The Hebrew Univ. Jerusalem, Israel)
H. Tamura (Tohoku Univ., Sendai, Japan)
R. Del Grande (LNF-INFN, Italy)
K. Piscicchia (LNF-INFN, Italy)
F. Pederiva (Trento Univ., Italy)
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J. Zeskal (SMI, Vienna, Austria)
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R. Muenzer (TU München, Germany)
J. Hrtankova (Rez. Prague, Czech Republic)
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Y. Ikeda (RIKEN, Japan)
Q. Zhao (ITP Beijing, China)
M. Barabanov (JINR, Russia)

SCIENTIFIC REPORT:

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

1) The strangeness sector:

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

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

- **Kaonic atoms, in partiular kaonic deuterium measurement**
  The experimental access to the isospin scattering lengths (a0 and a1) by the measurement of the K-lines of kaonic deuterium is still an open topic. With the combination of the results of kaonic hydrogen and deuterium the scattering lengths in both isospin channels I=0,1 can be pinned down. The experiment on kaonic deuterium involves severe challenges compared with kaonic hydrogen: anticipated lower yield of x-rays, larger width, need for efficient background reduction). Discussions about exotic atoms results and planned experiments were given.

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

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

B) The antikaon in the nuclear medium and the nature of sub-threshold resonances

For more than 50 years the Λ (1405) sub-threshold resonance has been studied because of its special nature – not fitting in the baryon scheme and connected with the predictions of quasi-bound kaonic nuclear clusters. An intensively discussed question is the pole structure of Λ (1405) being a one or two pole object. In recent chiral SU(3) studies a 2-pole structure is expected with one pole coupled to KbarN and the second coupled to $\pi\Sigma$.

We discussed:

- **New studies of the sub-threshold resonances**
  There are several experiments at different research infrastructures (GSI, LNF, J-PARC, JLAB…) devoted to the study of the s-wave resonance Λ (1405) and other resonances (e.g. Σ (1385)). The new data are extremely important to clarify the nature of sub-threshold resonances. We discussed the new results and future experiments, together with theoretical work.

- **New experiments on strangeness production: AMADEUS**

  The measurement of the antikaon absorption off different nuclear targets – AMADEUS step 0 and future dedicated AMADEUS measurement – can bring new light on many items still open in strangeness nuclear physics. Results of various analyses were discussed together with future plans.

C) Few-hadrons bound systems

- **New studies on kaonic nuclear quasi-bound systems in experiment and theory**
  New measurements are under way in experiments at J-PARC (E15, E27), searching for possible quasi-bound kaonic nuclear systems. The experiment E15 uses a newly available high intensity, high quality kaon beam at the K1.8BR beam-line of J-PARC. The new data and future plans on the kaonic cluster K-pp from J-PARC were presented and discussed.

2) The charm sector

A) Charm physics – pentaquark:

The following items were intensively discussed:
- The possible structure of the recently discovered charmed pentaquark
- The production mechanism of heavy pentaquark

B) Ab initio calculations of charmed hadrons

In the last few years, the calculation of properties of charmed mesons have become a major topic in lattice QCD. In combination with Lüscher type methods, the spectrum of excited and exotic charmonium states has been investigated by various groups. Also, combining EFT methods and lattice simulations, the nature of the charm-strange mesons has been investigated. Furthermore, the role of disconnected diagrams is being analyzed in EFTs, large-N_c and also using all-to-all propagators in various simulations. Items such as NNLO QCD corrections to quarkonium production and decay, phenomenology of the heavy quarkonium electric dipole transitions, heavy quarkonia from Dyson-Schwinger equations were extensively presented and discussed.

Results and Highlights

The progress in hadron and nuclear physics with strangeness and charm has a broad impact on contemporary physics, extending from nuclear and particle physics to astrophysics. The field is evolving very fast, with new data coming from numerous recent experiments (HADES, FOPI, SIDDHARTA, AMADEUS, E15, CLAS, BESIII, just to name a few); other experiments are planned (at DAFNE, BES or JPARC) and many others are in the proposal phase. On the theoretical side, refined calculations and methods (chiral perturbation theory, effective field theories, lattice calculations, few- and many-body approaches, etc.) are yielding results with steadily improving accuracy, which, combined with the experimental findings, are allowing to have a better and more accurate understanding of the processes undergoing in the low-energy QCD sector. There are, however, still many open problems. Among these, some play a key-role: the structure of Λ (1405), the possible existence of deeply bound kaonic nuclear states, the neutron-rich hypernuclei and their binding energies, the kaon-nucleon/nucleus and hyperon-nucleon/nucleus interactions, the structure of the heavy pentaquark. On the other side, a fast evolving field, based on more and more available experimental data in strangeness physics and advance in microscopic theories, together with new data coming from astronomy and astrophysics observations, is the study of the possible role of strangeness in astrophysics. Items such as the equation of state for neutron stars including strangeness (hyperons or kaons), are presently a flourishing field of research.

The successfully achieved aim of the workshop was to discuss the most recent achievements in the hadron and nuclear physics with strangeness and charm and the future perspectives in the by bringing together specialists in various sectors. The latest theoretical findings boosted by the experimental results were discussed in order to make a step forward in planning the future strategy aiming at deeper and more complex understanding of the underlying phenomena.

The workshop gathered together world-leading experimental and theoretical experts in the field and young scientists and students, providing a state-of-the-art overview of the field of low-energy QCD in the strangeness sector. The young participants' percentage was about 50%, many of them at ECT* for the first time, which is one of the successes of the workshop.

The organization of this Workshop in the ideal environment of ECT* contributes to the progress of the field.

Last but not least a note of merit: the organization of the workshop by ECT* (special thanks to Ines Campo, Barbara Curro' Dossi, Gian Maria Ziglio, and to the ECT* Director, Prof. W. Weise) was excellent.

3.3.17 FROM 1D FRAGMENTATION TOWARDS 3D CORRELATED FRAGMENTATION

DATE: October 26 – 30, 2015

ORGANIZERS:

A. Bacchetta *(Pavia University and INFN, Pavia, Italy)*
V. Barone *(Piemonte Orientale University and INFN, Torino, Italy)*
R. Ent *(Jefferson Lab, USA)*
T. C. Rogers *(Jefferson Lab and Old Dominion University, USA)*

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

The workshop focused on the extensions of the usual 1D approach to the hadron fragmentation processes, and discussed possible developments towards a 3D correlated fragmentation framework.

The main topics were:

- Basic questions about hadronization and fragmentation
- Physical interpretations, issues of factorization, and non-perturbative QCD
- The status of phenomenology with fragmentation functions, di-hadron fragmentation, and fracture functions
- Hadron multiplicities and Monte Carlo simulations
- Experimental status of fragmentation

SPEAKERS:

C. Aidala (Univ. Michigan, USA)
D. Anderle (Univ. Tübingen, Germany)
V. Barone (Piemonte Orientale Univ. and INFN Torino, Italy)
M. Boglione (Torino Univ., Italy)
W. Brooks (UTFSM, Chile)
F. Ceccopieri (Liege University, Belgium)
I. Cloet (Argonne National Lab, USA)
J. Collins (Penn State University, USA)
R. Ent (Jefferson Lab, USA)
C. Gagliardi (Texas A&M Univ., USA)
O. Gonzalez (Torino Univ., Italy)
M. Guzzi (Univ. Manchester, UK)
T. Kaufmann (Univ. Tübingen, Germany)
Y. Koike (Niigata Univ., Japan)
L. Lönnblad (Lund Univ., Sweden)
N. Makke (INFN & Univ. Trieste, Italy)
H. Matevosyan (Adelaide U, Australia)
S. Melis (Turin Univ., Italy)
P. Mulders (Vrije Universiteit Amsterdam/NIKHEF, Netherlands)
D. Neil (MIT, USA)
M. Radici (INFN Pavia, Italy)
G. Rodrigo (Univ. Valencia, Spain)

T. Rogers (Old Dominion Univ. and Jefferson Lab, USA)
A. Signori (Vrije Univ. Amsterdam/NIKHEF, Netherlands)
D. Sivers (Portland Physics Institute/Michigan, USA)
M. Stratmann (Univ. Tübingen, Germany)
A. Vladimirov (Univ. Regensburg, Germany)
A. Vossen (Indiana Univ., USA)

SCIENTIFIC REPORT :

The process of how colored quarks and gluons propagate through matter and bind themselves through interactions in patterns of massive hadrons, with different properties, is still largely unknown. As a consequence of confinement, any individual quark or gluon vigorously struck in a scattering process must convert itself to a family of (at minimum) quark-antiquark mesons or three-quark baryons. The properties of the mesons and baryons produced in this fragmentation process are related in a highly non-trivial way to those of the initiating parent quarks and gluons.

Hadron production from electron-quark scattering processes (or electron-positron collisions) is commonly described in terms of fragmentation functions, which reflect the probability that a quark transforms into a hadron. Since the exact mechanisms involved in fragmentation are poorly understood, these are merely parameterizations. Recently, various phenomenological analyses have shown that we need to go beyond the ordinary one-dimensional (1D or collinear) fragmentation functions. Our understanding of the process whereby massive and colorless hadrons emerge from near-massless and color-charged quarks and gluons, suffers from the same shortcomings as the 1D parton (spin and momentum) distributions in the description of nucleon structure. The partons exhibit three-dimensional (3D) confined motion inside nucleons, reflecting the 3D structure of the nucleon. Hadrons can emerge from electron-quark scattering process only by the struck quark binding with at least an additional antiquark to be picked up either from the QCD vacuum or from the remnant beam (target) fragments. The final hadron can accumulate a momentum transverse to the beam direction by a convolution of the transverse momentum of the struck quark and the transverse momentum of the additional antiquark. This then turns the understanding of the emergence of hadrons from color charge into a correlated 3D problem, for which the present fragmentation function descriptions are woefully insufficient.

On the other hand, extending the fragmentation framework towards inclusion of transverse momentum dependence likely suffers similar pitfalls in terms of factorization breaking as those of transverse-momentum dependent parton distributions. In these case in particular, accounting for the effects of a surrounding QCD medium may be necessary for achieving a fully satisfactory description of the fragmentation process.

Similarly, a well-developed framework, based on the concept of fracture functions, exists to describe what happens when the hadron emerges in the target fragmentation (i.e., forward) region. Even if these fracture functions follow nicely QCD-prescribed evolution equations, very little is known about them. A spin-based and 3D description is necessary as in the case of fragmentation functions.

The workshop has analyzed and discussed in detail the most urgent questions concerning spin and transverse momentum effects in fragmentation. In particular, the following topics have been addressed:

- Recent results on semi-inclusive DIS (hadron multiplicities, Collins and Sivers asymmetries) and hadroproduction, and their phenomenological interpretations, in terms of transverse-momentum dependent (TMD) functions or twist-3 contributions.

- Transverse-momentum dependent evolution of parton distributions and fragmentation functions: relevance of non-perturbative contributions and attempts at modelling them.

- Models of fragmentation: string model, Nambu-Jona-Lasinio model, Monte Carlo simulations.

- Spin-dependent and extended fracture functions as a new way to explore the quark (and diquark) structure of the nucleon and the basic mechanisms of QCD (confinement and chiral symmetry breaking).

- Effects within a nuclear medium in heavy-ion and semi-inclusive deep inelastic scattering reactions, and possible correlation of a quantum mechanical description of the final emerging hadron state with quantum entanglement in jet physics.

Results and Highlights

- A major theme (and consensus) of the workshop was that objects like correlation functions (fragmentation functions (TMD, collinear, dihadron, etc) need to be resolved and studied in terms of their underlying non-perturbative physics.

- Models used in Monte Carlo simulations, like the string model and the NLJ model, were discussed, and we began exploring how they might be related to general factorization schemes and ordinary fragmentation functions, and how one could disembroil the Lund string, or translate physical ideas in the Lund "black box" into a field theoretical model. The possible reciprocity of the transverse-momentum inducing effects of the Lund model and the transverse-momentum dependent parton distributions was noted.

- A survey of problems with current fits of fragmentation functions (and related objects) was presented, and provided further motivation to examine the physical foundations of various non-perturbative models.

- The implementation of TMD evolution in phenomenological analyses of SIDIS and Drell-Yan data was discussed. A particular attention was devoted to the non-perturbative aspects of this evolution, which are not fully constrained yet.

- The importance of fracture functions and dihadron fragmentation functions for understanding the hadron emergence in final states was pointed out. Thus far, there has been less phenomenological attention paid to these. The workshop discussed how they should be combined with the phenomenology of fragmentation functions in a single treatment of hadron emergence.

- Experimental approaches that could give most insight into the quantum field origin of hadron emergence were discussed. Measurements involving the target region of fragmentation could shed light on the transverse momentum or spin balanced or diffused by the QCD vacuum. Measurements of the Collins function seem especially of importance as the origin of the Collins effects is closely related to dynamical chiral symmetry breaking. Measurements of the environment around a self-polarized Lambda informs about the time scale of fragmentation and the absorbance, or more likely damping, of spin by the QCD vacuum. Finally, it was proposed to explore the emergence of polarization in the final state from an unpolarized electron-nucleon scattering process through a polarizing fracture function.

3.3.18 INFORMATION AND STATISTICS IN NUCLEAR EXPERIMENT AND THEORY (ISNET-3)

DATE: November 16 - 20, 2015

ORGANIZERS:

D. Ireland (University of Glasgow, UK)
W. Nazarewicz (Michigan State University, USA)
B. Szpak (Institute of Nuclear Physics PAN, Poland)

NUMBER OF PARTICIPANTS: 32

MAIN TOPICS:

In recent years a number of important results obtained by applying statistical tools to the analysis of nuclear structure models and nuclear data have been published. The topic is generally considered to be important, especially in the context of model extrapolations. However, the task of assigning statistical uncertainties to theoretical calculations in the domain of nuclear physics is challenging. The major source of uncertainty in estimation of model parameters and in calculated observables is the approximate character of physical models. Therefore it is by no means obvious, which of the available statistical methods are most suitable in the context of on-going research.
The aim of workshop at ECT* was to discuss the use of information theory in the analysis of experiments, and the use of applied mathematics and statistics within the context of theoretical models that are dealing with current and future experimental data.

Key questions addressed during the workshop

- How can we estimate statistical uncertainties of calculated quantities?
- How we can assess the systematic errors arising from physical approximations?
- How can model-based extrapolations be validated and verified?
- How can we improve the predictive power of theoretical models?
- When is the application of statistical methods justified, and can they give robust results?
- What experimental data are crucial for better constraining current nuclear models?
- How can the uniqueness and usefulness of an observable be assessed, i.e., its information content with respect to current theoretical models?
- How can statistical tools of nuclear theory help planning future experiments and experimental programs?
- How to quantitatively compare the predictive power of different theoretical models?

Methods discussed:

- Statistical methods and methods of statistical learning: parameter estimation, covariance analysis, robust techniques and least-squares alternatives, regression diagnostics
- Information theory

- Bayesian approaches and consistent inclusion of a priori expectations
- Uncertainty quantification and Monte-Carlo error propagation
- Computational techniques

SPEAKERS:

A. Afanasjev (Mississippi State Univ., USA)
E. Ruiz Arriola (Univ. of Granada, Spain)
J. Bliss (TU of Darmstadt, Germany)
R. Casten (Yale University, USA)
G. Colo (University of Milan and INFN, Italy)
A. Ekstrom (University of Tennessee, USA)
C. Forssen (Chalmers University of Technology, Sweden)
D. Furnstahl (Ohio State University, USA)
K. Graczyk (University of Wroclaw, Poland)
T. Haverinen (University of Jyväskylä, Finland)
D. Ireland (University of Glasgow, UK)
Y. Jaganathen (Michigan State University, USA)
M. Kortelainen (University of Jyväskylä and Helsinki Institute of Physics, Finland)
R. Navarro-Perez (Lawrence Livermore National Laboratory, USA)
W. Nazarewicz (Michigan State University, USA)
N. Paar (University of Zagreb, Croatia)
A. Pastore (University of York, UK)
J. Piekarewicz (Florida State University, USA)
S. Pratt (Michigan State University, USA)
X. Roca-Maza (University of Milan and INFN, Italy)
D. Regnier (CEA Bruyères, France)
P.-G. Reinhard (University of Erlangen, Germany)
J. Ryckebusch (Ghent University, Belgium)
N. Schunck (Lawrence Livermore National Laboratory, USA)
A. Schwenk (TU Darmstadt, Germany)
P. Stevenson (University of Surrey, UK)
R. Surman (University of Notre Dame, USA)
B. Szpak (IFJ PAN Krakow and University of Warsaw, Poland)
S. Wesolowski (Ohio State University, USA)
S. Wild (Argonne National Laboratory, USA)

SCIENTIFIC REPORT:

The scientific method uses experimentation to assess theoretical predictions. Based on experimental data, the theory is modified and can be used to guide future measurements. The process is then repeated, until the theory is able to explain observations, and experiment is consistent with theoretical predictions. The positive feedback in the loop "experiment-theory-experiment-" can be enhanced if statistical methods and scientific computing are applied to determine the independence of model parameters, parameter uncertainties, and the errors of calculated observables.

Nuclei communicate with us through a great variety of observables. Some are easy to measure; some take a considerable effort and experimental ingenuity. But not every observable has a potential to impact theoretical developments: some are more important than others. Nuclear theory is developing tools to deliver uncertainty quantification and error analysis for theoretical studies as well as for the assessment of new experimental data. Statistical tools can also be used to assess the information content of an observable with respect to current theoretical models, and evaluate the degree of correlation between different observables. Such technologies are essential for providing predictive capability, estimate uncertainties, and assess model-based extrapolations - as theoretical models are often applied to entirely new nuclear systems and conditions that are not accessible to experiment.
In recent years important progress has been achieved in the field. However, a rigorous statistical analysis of the obtained results is still rather the exception than the rule. This workshop provided the sharing of experience in using different statistical methods in strongly related areas. This will move us much further forward in answering the important questions presented in the workshop proposal.

Results and Highlights

The importance of the topics discussed during the workshop was very well recognized by all of the workshop participants which resulted in long and lively discussions. It is difficult to summarise in detail all of the novel developments presented during the workshop and the directions of future developments. We therefore only highlight here several selected topics.

One of the most important and current topics discussed during the workshop was the application of the Bayesian inference techniques to calibration and discrimination of the nuclear structure models. The advantages of the approach like the possibility to include a priori information directly in a fit or the straightforward calculation of statistical uncertainties were well taken by the participants.
The complete example of Bayesian analysis was presented by Dick Furnstahl and Sarah Wesolowski, both from Ohio State University. The approach was applied to quantify the truncation errors in nuclear Effective Field Theory example. The Bayesian framework allowed to include in an analysis the assumption about the naturalness of the coupling constants. Then the technique of Bayesian model selection, based on the calculation of evidence, was used to select the best maximum power of expansion in chiral EFT, based on the available data. It was shown that the result can be well understood when naturalness prior is being used and differs significantly from the case when uniform prior (least-squares case) is being used.
The applications of Bayesian approach were also presented by Scott Pratt (Michigan State University) for the analysis of heavy-ion models and data from the RHIC and the LHC and by the Jan Ryckebush (Ghent University) for the case of extracting the physics information from pseudoscalar-meson photonproduction. Again, they have shown that the method of Bayesian model selection is very useful in model discrimination. In contrary, the methods developed in frequentist approaches rarely give clear interpretation of the obtained results. Despite the obvious advantages of the Bayesian approaches the methods can be rarely applied in nuclear structure physics due to its high computational cost. This problem can be overcome with the application of emulators – a subject which is an example of another workshop highlight. The idea of this approach is very simple: to replace the full, computationally expensive model with the properly designed emulator and hence reduce the computational

cost to a level which would allow to apply the Bayesian inference or other uncertainty quantification method. This kind of an approach has been intensively developed in the recent years in the engineering and military applications of uncertainty quantification and effective methods of the construction of emulators based on e.g. Gaussian processes now exist.
Nicolas Schunck, from Lawrence Livermore National Laboratory, showed that such an emulator can be built for the Skyrme-Hartree-Fock model. The approach based on the emulation allowed his team to derive the full a posteriori distributions for the model parameters using the Bayesian framework. Finally, they were able to quantify the uncertainty for the prediction of the fission barrier height in 240Pu.
The sophisticated methods of statistical inference based on the Bayesian interpretation of probability can also be used in nuclear physics and the examples of such works has been presented during the workshop. Krzysztof Graczyk from the University of Wrocław has shown how to model the nucleon form factors with the methods of Bayesian Neural Networks.
Jorge Piekarewicz from the Florida State University presented the results of modelling the mass residues also with the help of Bayesian Neural Networks. He concluded that this approach allows to significantly reduce the difference in predictions of different models (reduce the systematic scattering of different predictions).
All of the workshop participants agreed that the application of the Bayesian methods in nuclear structure physics should be further explored in the forthcoming years.
Another important subject of the workshop was the role of optimization techniques. We have concluded that the technical stage of the optimization of a cost function should not be trivialized. Instead, one should carefully apply several different optimization algorithms, preferably including those recently developed, to make sure that optimal solution of a problem has been obtained.
Similarly, the role of simplifications in a fitting protocol (like keeping some of the parameters constant or dividing the optimization over all parameters into consecutive optimization of groups of parameters) should be carefully studied, as it may also lead to large systematic errors.
Among the most spectacular results were those shown by Christian Forssen from Chalmers University of Technology and Andreas Ekström from University of Tennessee, who presented a novel parameterization of the chiral EFT nucleon-nucleon interaction at NNLO. By merging the methods of the automatic differentiation (for accurate calculation of the Jacobian) with the consistent inclusion of all the models parameters in a fit, a new parameterization of the chiral force was obtained. This force possesses significantly improved extrapolation properties over the previously derived parameterizations. This allows to calculate finite nuclei using the ab-initio methods more precisely and including the corresponding statistical uncertainties.
An influence of an optimization algorithm choice on the results of the fit were presented in a talk given by Stefan Wild from Argonne National Laboratory. He described the novel algorithm called POUNDERs (Practical Optimization Using No DERivatives), which is particularly suitable for noisy least-square problems for which the calculations of derivatives is not possible (because of the computational cost or noise). Instead of directly calculating the Jacobian and/or Hessian matrices the algorithm tries to investigate the structure of the problem. The results obtained with this novel approach were presented by Markus Kortelainen from University of Jyväskylä, who applied the algorithm to derive new parameterizations of the Skyrme Energy Density Functional, now called UNEDF parameterizations. The very good convergence of the algorithm allowed to use a large set of experimental data in a fit which has resulted in an improved predictive power of the parameterizations.
Several other talks during the workshop were devoted to different aspects of the calibration of the Energy Density Functionals, both Skyrme-like and relativistic ones. The most interesting and important results included the use of correlations between the observables and model parameters which cannot be directly measured. As it was shown several times during the workshop, this kind of the approach can be used to infer about the important

parameters of nuclear matter, like the slope of the symmetry energy. It can be also used to indicate the most important observables that should be measured to effectively constrain these parameters.
The applications of uncertainty quantification methods to different subjects in nuclear astrophysics were covered by Rebecca Surman from University of Notre Dame, Julia Bliss from Technical University of Darmstadt and Amy Lovell from Michigan State University. Rebecca Surman have shown how the uncertainties of different mass models influence the r-process nucleosynthesis abundance pattern and concluded that significant improvement in theoretical models that provide estimates for masses out to the neutron drip line is needed before the abundance pattern details can be used to constrain the r-process scenarios.
The workshop highlighted particularly well the need for the uncertainty quantification arising from the systematic errors, which reflects the model inadequacy, and this subject has triggered a particularly lively discussions. Unfortunately, the subject is also the most difficult one from the computational and statistical perspective. The workshop participants agreed that the simplest method of choice for the quantification of systematic errors should be the cross-comparison of different theoretical models. However, to do so each of the compared models should come with the associated statistical uncertainties.

3.3.19 NEW PERSPECTIVES ON PHOTONS AND DILEPTONS IN ULTRARELATIVISTIC HEAVY-ION COLLISIONS AT RHIC AND LHC

DATE: November 30 – December 11, 2015

ORGANIZERS:

G. Baym *(University of Illinois at Urbana-Champaign, USA)*
A. Drees *(Stony Brook University, USA)*
T. Hatsuda *(RIKEN Nishina Center, Japan)*
K. Shigaki *(Hiroshima University, Japan)*

NUMBER OF PARTICIPANTS: 35

MAIN TOPICS:

This workshop brought together theorists and experimentalists working on direct photons and dileptons in ultrarelativistic heavy ion collisions to summarize the current status of the measurements in various facilities and, importantly, to discuss new theoretical ideas of future measurements to explore the state of matter at the initial stages of heavy ion collisions.

Thermal photons are a valuable probe of the state of the big-bang universe in cosmology as well as the state of the little-bang plasma in ultrarelativistic heavy-ion collisions. The cosmic microwave background (CMB) provides information on the temperature of the universe at the time of decoupling, while enhanced direct photons in heavy ion collisions provide valuable information on the initial temperature of the hot quark-gluon plasma (QGP) -- as experimentally shown e.g., by the PHENIX Collaboration at RHIC using conversion of virtual photons into dileptons.

The anisotropy of the photon spectrum provides further details of the initial states; similar to the way the detailed fluctuation spectrum of the CMB background measures the initial state anisotropy caused by the inflation of the Universe, the unpolarized photon spectrum is a potentially sensitive probe of the momentum anisotropy of quarks and gluons in the evolving quark-gluon plasma. Moreover measurement of the CMB polarization, particularly the odd parity B-mode, gives, after subtraction of other sources of polarization, critical evidence for gravitation waves created at the time of inflation; correspondingly, polarization of thermal photons in relativistic heavy ion collisions probes the initial properties of the QGP, such as the momentum-space anisotropy of quarks and gluons, initial state polarization of quarks, strong magnetic fields in non-central collisions, synchrotron radiation from quarks, etc.

Thermal dileptons, produced by off-shell thermal photons, are also a promising probe of the spectral properties of the QGP in the vector channel. The spectral shape of the dilepton-production rate below and above the omega and phi resonances can provide information on the chiral properties of the hot or dense QCD medium. Also, as mentioned above, the on-shell extrapolation of the dilepton yield is now established as a useful tool to study thermal photons: the generalization of the method for the dilepton angular distribution may provide a method to study the polarization of thermal photons.

SPEAKERS:

H. Specht (University of Heidelberg, Germany)
Y. Watanabe (University of Tokyo, Japan)
T. Hatsuda (RIKEN, Japan)
F. Geurts (Rice University, USA)
T. Galatyuk (GSI, Germany)
R. Ryblewski (Polish Academy of Sciences, Poland)
K. Shigaki (Hiroshima University, Japan)
D. Sato (ECT*, Italy)
T. Galatyuk (GSI, Germany)
K. Ozawa (KEK,Japan)
G. Usai (University and INFN Cagliari, Italy)
J. Ghiglieri (Bern, Switzerland)
A. Caliva (NIKHEF, Netherlands)
L. Oliva (University of Catania, Italy)
P. Gubler (ECT*, Italy)
K. Aoki (KEK, Japan)
N. Tanji (University of Heidelberg, Germany)
A. Drees (Stony Brook University, USA)
G. Baym (University of Illinois at Urbana Champaign, USA)
A. Ipp (TU Vienna, Austria)
M. Strickland (Kent State, USA)
K. Reygers (University of Heidelberg, Germany)
G. David (BNL, USA)
J. Wambach (TU Darmstadt, Germany)
K. Hattori (BNL, USA)
C. Shen (McGill Univ., Canada)
H.-U. Yee (University of Illinois at Chicago, USA)
T. Kim (Kyoto University, Japan)
M. Greif (Goethe University Frankfurt, Germany)
A. Rothkopf (University of Heidelberg, Germany)
M. Barabanov (JINR, Russia)

SCIENTIFIC REPORT:

The plan for the workshop was to maximize discussion between theorists and experimentalists on photons and dileptons in Heavy-Ion Collisions. The focus of the first week (20 Nov. – 4 Dec.) was the theories and experiments on dileptons, while the focus of the second week (7 Dec.-11 Dec.) was the theories and experiments on thermal photons. Each morning we had two one-hour talks. Each afternoon we had an extra one-hour talk or discussion session about specific topics. On 3 Dec. and 10 Dec. we also had student sessions where 30 min. talks by the graduate students were given.

Under the MoU exchanged between ECT* and the RIKEN Nishina Center (RNC), the RNC regarded this workshop as a joint research project and supported some of the travel and local expenses of theorists and experimentalists from Japan.

In the first week (the dilepton week), the following subjects were covered in the Workshop:

- Experiments on Lepton Pairs in the SPS Era
- Dielectron measurements by PHENIX

- Dilepton spectral function and chiral symmetry restoration
- Future Beam Energy Scan Measurements at RHIC
- Dileptons at HADES
- Dilepton production from a highly-anisotropic quark-gluon plasma
- Dilepton Measurement at ALICE - especially the Muon Forward Tracker Upgrade
- Chiral symmetry breaking and confinement effects on dilepton and photon productions
- Dileptons at CBM
- J-PARC Heavy ion program
- Fixed target experiments at CERN
- The NLO dilepton rate meets the lattice
- Dielectron measurements in pp,p--Pb and Pb--Pb collisions with ALICE at the LHC
- Modelling early time dynamics of relativistic heavy ion collisions
- The Experimental study of vector mesons in nuclear medium at J-PARC
- phi meson in nuclear matter - recent results from theory
- Nonequilibrium photon production by classical color fields

In the second week (the photon week), the following subjects were covered in the Workshop:

- The Direct Photon Puzzle: Observations of the PHENIX Experiment
- Polarization of Direct and Virtual Photons from Gluon Anisotropy in Ultrarelativistic Heavy Ion Collisions
- Photon HBT-Correlations from a QGP
- Photon production from a momentum-space anisotropic QGP
- Direct Photons with ALICE
- Direct photons - promises kept, broken - and open
- Nonlinear QED effects on photon and dilepton spectra in supercritical magnetic fields
- Direct photons: Messengers from relativistic heavy-ion collisions
- P-odd Spectral Density at Weak Coupling: Application to Spin Polarized Photon Emissions
- Gauge invariant non-perturbative analyses of photon and dilepton production rates above Tc
- Photons from partonic transport
- Towards realistic quarkonium phenomenology from first principles
- Perspective study of charmonium, exotics and baryons with charm and strangeness

Also, we had discussion sessions on the following subjects,

- Spectral sum rules and dilepton data
- Future dilepton experiments
- Thermal photon puzzle
- Photon polarization in heavy-ion collisions

Results and Highlights

The present two-week Workshop provided a very useful opportunity to have intensive discussions on the current status and future perspectives of photons and dileptons as penetrating probes for hot/dense QCD matter. The balance between theory talks and experimental talks was ideal to have intimate interactions among participants. The discussion sessions organized in the afternoon played a crucial role to ask detailed questions to the speakers, to summarize the current status of each subject, and to discuss future directions with relaxed atmosphere.

The importance of analysing the current and future dilepton data from the point of view of the spectral sum rules was well recognized by both theorists and experimentalists after intensive discussions. New developments on the rho-a1 chiral degeneracy as well as the spectral shift of the phi-meson were reported. Recent progress of the precision calculations of dilepton and photon production rates from the quark-gluon plasma, which is an essential input for comparing theories and experiments, was reported. Photon and dilepton productions from anisotropic plasma from different theoretical frameworks were discussed and compared. Polarized photons from quark-gluon plasma under various conditions (quark spin polarization, strong magnetic field, strong momentum anisotropy, etc) and possible experimental detection through real and virtual photons were also discussed intensively.

3.4 ECT* DOCTORAL TRAINING PROGRAM 2015

Computational Nuclear Physics Hadrons, Nuclei and Dense Matter

(Report written by Georges Ripka)

The 2015 ECT* Doctoral Training Program on Computational Nuclear Physics – Hadrons, nuclei and dense matter was held at ECT from April 13 to May 22 for a duration of 6 weeks. The program coordinator was Maria Paola Lombardo (INFN), 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 2015 Doctoral Training Program was attended by 10 full-time students and 7 part-time students. This is a smaller number of students than in the past Doctoral Training Programs, possibly because the subject was somewhat too heterogeneous. The students were all working on their PhD.

There were six lecturers, one each week. Two lectures were delivered each morning. The fact that the lecturers were present at ECT* in the afternoons allowed the students to discuss with them.

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

Most lecturers made slides, handwritten notes and other files available to the students. The files were placed in a new so-called Private Area of a FKB website, which could only be accessed using a password given 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 new website, giving practical information to the students, designed by Barbara Curro' Dossi, proved very useful to the students.

3.4.1 Lecture Programme

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

Week 1, April 13 -17

Thomas Schaefer *(North Carolina State University, USA)*
QCD and symmetries

The first three lectures of Schaefer were delivered on the board and the remainder, essentially qualitative albeit interesting, was composed of projected slides. Schaefer invited the students to download some notes and slides from his personal website https://sites.google.com/a/ncsu.edu/ect-2015. He spoke of QCD, the running coupling constant, gauge invariance, the Elitzur theorem, the breaking of chiral symmetry, phase diagrams plotted as functions of the temperature and of the chemical potential, Wilson loops and confinement, effective field theory, the color-flavor locked phase, and more. Much of this material, for example ghost fields, bag models, sigma models and AdS CFT, was mentioned.

Week 2, April 20 - 24

Tetsuo Hatsuda *(RIKEN, Japan)*
Lattice approach to nuclear physics

Hatsuda gave ten lectures on lattice QCD. They were detailed and written on the board. He left hand-written notes as well as a pdf folder of slides. He presented in detail the QCD lagrangian, gauge invariance, the Euclidean formulation of the partition function, continuum QCD with Wilson lines and then pursued with 4-dimensional QCD on the lattice, first with gluons, the Yang-Mill's action, plaquettes. He then pursued with fermions, the Wilson action, fermion propagators, the handling of doublets, the Haar measure, and the Elitzer theorem. He then explained the strong coupling limit, he calculated the Wilson loop with two fixed heavy quark sources separated by a given distance R and derived the R dependence of the Wilson loop to show confinement.

Week 3, April 27 - 30

Amy Nicholson *(University of California, Berkeley, USA)*
Lattice methods for many-body systems

For each of her lectures, Nicholson gave arxiv references. She also made available detailed handwritten notes and a pdf file of slides, showing results. Her lectures covered lattice calculations of many-body systems starting with a non-relativistic Hamiltonian. She discussed the Hubbard-Stratonovic transformation, the sign problem of fermions, how to truncate the interaction, hybrid Monte Carlo, improved effective actions, fermions in the limit of unitarity, the calculation of the Bertsch parameter, the pi-nucleon interaction and induced 3-body forces, the hypercubic group and its representations, and more.

Week 4, May 4 - 8
Week 5, May 11 - 15

Giuseppina Orlandini *(University of Trento and TIPFA)*
Ab initio many-body methods: from few to many nucleons

Orlandini lectured on Monte Carlo calculations of nucleons interacting with 2-body forces. She made several pdf extracts from papers available to the students. She discussed center-of-mass motion, the use of Jacobi coordinates, hyperspherical coordinates and the hyperspherical harmonics basis, the use of a harmonic oscillator hamiltonian for the center of mass of the system, the Lee-Suzuki similarity transformations of the nucleon-nucleon interaction (only mentioned), the antisymmetrization problem, structure functions related to inelastic crossections, moments and sum rules, and the Lorentz integral transform.

Francesco Pederiva *(University of Trento and TIPFA)*
Ab initio many-body methods: variational and diffusion Monte Carlo

Pederiva lectured on Monte-Carlo calculations of non-relativistic interacting particles and he organized some exercise sessions in which students ran illustrative numerical programs. He discussed calculations of boson and fermion systems (mostly bosons) interacting with two and three-body forces. He displayed the central limit theorem, the Metropolis algorithm and discussed optimum choices of random variables to either solve the Schrodinger equation or minimize the energy. He ended by evoking the fermion sign problem.

Week 6, May 18 - 22

Morten Hjorth-Jensen *(Michigan State University and University of Oslo)*
Ab initio many-body methods: configuration interaction theory, many-body perturbation theory and coupled cluster theory

In compliance to the subject of the Doctoral Training Program, Hjorth-Jensen explained - insisting on how to compute - various schemes, such as the Hartree-Fock approximation, the shell model (called FCI = full configuration interaction) and coupled cluster theory (CC) applied mostly to nuclei.

3.4.2 List of Participants

Full time students:

Faiza Akbar	Aligarh Muslim University, India
Alexander Arzhanov	Technische Universität Darmstadt, Germany
Tamer Boz	Maynooth University, Ireland
Davide De Boni	Swansea University, UK
Takahiro Doi	Kyoto University, Japan
Michal Kloc	Charles University, Prague, Czech Republic
Vikas Kumar	Indian Institute of Technology, Roorkee, India
Mario Sanchez	IPNO, Orsay, France
Giorgio Valocchi	Politecnico di Torino, Italy
Wasiu Yahya	Stellenbosch University, South Africa

Part time students:

Nada Barakat	LPE, Beirut, Lebanon
Giovanni De Gregorio	Università di Napoli "Federico II", Italy
Dmitry Kobyakov	Institut für Kernphysik, Darmstadt, Germany
Shotaro Oka	Rikkyo University, Tokyo, Japan
Giuseppe Pastore	Università di Firenze, Italy
Marco Rocchini	Università di Firenze, Italy
Takuya Sugiura	Osaka University, Japan

3.4.3 Seminars delivered by the students

Dimitry Kobyakov (Institut fur Kernphysik, Darmstadt, Germany): *Collective modes in the inner crust of neutron stars*

Michal Kloc (Charles University, Prague, Czech Republic): *Quantum phase transitions in systems with a finite number of degrees of freedom*

Davide De Boni (Swansea University, UK): *Heavy quark bound states in a quark-gluon plasma, dissociation and recombination*

Nada Barakat (Laboratoire de physique et d'electronique (LPE), Beirut, Lebanon): *Improvement of the topological isolation energy in the ATLAS experiment*

Takahiro Doi (Kyoto University, Japan): *An analytical expression of the Polyakov loop in terms of Dirac modes on a lattice*

Takuya Sugiura (Osaka University, Japan): *Derivative expansion of the wave function equivalent potential*

Faiza Akbar (Aligarh Muslim University, India): *Lepton mass effect in CCQE processes*

Vikas Kumar *(Indian Institute of Technology, Roorkee, India): High-spin structure of $^{124-127}Te$ isotopes in 50-80 shell model spaces*

Wasiu Yahya *(Stellenbosch University, South Africa): A microscopic study of scattering from unstable nuclei within a relativistic framework*
Giovanni De Gregorio *(Università di Napoli "Federico II", Italy): Self-consistent multiphonon approach to nuclei using realistic potentials*

Tamer Boz *(Maynooth University, Ireland): Two-color QCD at high density*

Alexander Arzhanov *(Technische Universitat, Darmstadt, Germany): Towards a better mass model for astrophysics*

Giuseppe Pastore *(Universita degli Studi di Firenze, Italy): Energy and time measurements with partially depleted silicon detectors*

Mario Sanchez *(IPNO, Orsay, France): The nucleon-nucleon $^{1}{}_{0}S$ channel in nuclear effective field theory*

Marco Rocchini *(Universita di Firenze, Italy): g-factor measurements for isometric levels in ^{172}W*

Giorgio Valocchi *(Politecnico di Torino, Italy): Autoresonance in single domain magnetic nanoparticles*

3.5 Training in Advanced Low Energy Nuclear Theory (TALENT):

Few-Body Systems and Nuclear Reactions

This report aims at giving a summary, including background information, of the Nuclear Talent course on Few-Body Systems and Nuclear Reactions. The course was held at the premises of the European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), Trento, Italy in the period July 20 to August 7, 2015. This report first contains a general introduction to the Nuclear Talent initiative, followed by a detailed description of the course.

3.5.1 Introduction to the TALENT courses

A recently established initiative, **TALENT: Training in Advanced Low Energy Nuclear Theory**, see www.nucleartalent.org, aims at providing an advanced and comprehensive training to graduate students and young researchers in low-energy nuclear theory. The initiative is a multinational network between several European and Northern American institutions and aims at developing a broad curriculum that will provide the platform for a cutting-edge theory of atomic nuclei and nuclear reactions. These objectives will be met by offering series of lectures, commissioned from experienced teachers in nuclear theory. The educational material generated under this program will be collected in the form of WEB-based courses, textbooks, and a variety of modern educational resources. No such all-encompassing material is available at present; its development will allow dispersed university groups to profit from the best expertise available.
The advanced training network in nuclear theory will provide students (theorists and experimentalists) with a broad background in methods and techniques that can be easily transposed to other domains of science and technology. The characteristic feature of this initiative is training in multi-scale nuclear physics. This knowledge is crucial, not only for a basic understanding of atomic nuclei, but also for further development of knowledge-oriented industry; from nanotechnology and material science to biological sciences, to high performance computing. As such, the proposed training aims at providing an inter-disciplinary education when it comes to theories and methods.
The ultimate goal of the proposal is to develop a graduate program of excellence in low-energy nuclear theory. The program will build strong connections between universities, research laboratories and institutes worldwide, and will provide a unique training ground for the future needs of nuclear physics.

3.5.2 Report: TALENT course on Few-Body Systems and Nuclear Reactions

Few-body theories give a fundamental contribution to understanding the underlying dynamics of physical systems. In nuclear physics characteristics and origin of nuclear forces have long be debated. At the end of the nineties a number of realistic potentials have appeared with the characteristic to describe the NN world data with a $\chi 2$ /per datum close to one. New ideas have also appeared using effective interactions based on the symmetries of QCD, and providing a link to the fundamental theory of the strong interaction in a systematic way. Great efforts are done by the few-body community to analyze the capability of all these interactions to describe the few-body nuclear dynamics, trying to minimize the error in the solution of the quantum mechanical problem, which could taint the comparison with experimental data and invalidate conclusions. The intention of the course is to discuss different methods used to describe few-nucleon systems. Even the case A = 2 is not trivial if one uses realistic forces where the tensor force couples two different orbital angular momentum states. Though during the course the theory of the NN interaction will not be discussed in detail, a brief introduction to this subject will be given. A characteristic of the nuclear systems is the presence of a three-body force, accordingly some attention will be given to this subject. This fact gives particular importance to the A = 3, 4 systems that will be discussed in detail. The ultimate motivation in a program devoted to solve a problem of interacting nucleons is to evaluate the capability of the underlying theory to describe observables. The ground state energy and the mean square radius are the first observables to be analyzed. Methods dealing with this kind of observables enter in the category of bound state methods. Very different techniques have to be applied to describe scattering observables as cross sections, symmetries, recombination rates, response functions, etc. Specific differences dealing with bound state or scattering state techniques will be discussed in detail during the course. Possibilities of extensions of the methods to larger systems and/or non-nuclear systems will be also discussed.

Motivations and goals

The interest in solving the few-nucleon problem started with the discovery of the nucleus and the first attempts to construct a Nucleon-Nucleon (NN) interaction. At that time Wigner derived the range of the NN force from estimates of the deuteron, triton and ^{4}He binding energies. Much work has been done in this direction in the last 80 years and, at present, sophisticated numerical methods exist to solve the few-nucleon system with high accuracy. However, transmission of this knowledge to the new generations could not be an easy task. Textbooks do not treat in details this kind of arguments and many times the new developments remain inside a small group of experts. On the other hand the few-nucleon problem has received a revival from the modern approach to nuclear forces based on chiral effective field theory and from the focus that the atomic and condensed matter physics community is recently devoting to few-body systems. Taking these considerations into account, the following items summarize the main characteristics of the course:

- The main topic for this TALENT/ECT* course was the solution of the few-nucleon problem. The discussion started introducing the NN interaction which plays a central role in this problem. Then numerical methods have been introduced with great details and the final point has been the construction of observables from the underlying theory. Comparisons of the results to the experimental data have been obtained and discussed.
- Our main goal was to give the students the tools to perform by themselves the three steps indicated above. To this aim the lectures were organized in the following way. Mornings were dedicated to detailed explanations using the blackboard and the afternoons numerical applications were done by the students closely followed by the lecturers.
- In order to make operative this procedure, some standardization was needed. It was decided from the beginning the use of FORTRAN90 as the language for the numerical applications. The students have been informed before the beginning of the course and some material has been sent to them. Moreover, for each exercise a script was prepared on the web site accessible to the students.
- Though the students had very different background and expertise, the use of scripts allowed most of them to arrive to the final answer of the problems. Moreover, they could communicate among themselves and discuss common errors and solutions. During the exercise time, division in groups followed by the lecturers were a common action.

Application process and selection procedure

A one-page flyer for the school was distributed during the winter and the beginning of the spring 2015 to different mailing lists. The same information was given at the ECT* web page, where the script TALENT appears explicitly after clicking in "TRAINING". The application required to fill a form, to send a Curriculum Vitae, a description of academic and scientific achievements and a short letter expressing the applicant's personal motivation for attending the course. Finally a letter of recommendation sent to the ECT* Director was required. A review of 52 applications received by the deadline was started at the beginning of May by the organizers and completed before the end of the month. Due to the large number of applications no deadline extension was necessary.
Distribution of the participants:
30 students were selected privileging the younger and more qualified ones;
28 students attended the course: 5 females, 23 males: 5 from USA, 1 from Brasil, 2 from Asia, 2 from Israel and 18 from Europe. The student background was mainly in nuclear structure, nuclear astrophysics, nuclear reactions and effective field theory.

Detailed Course Content

Each week of the course was organized with four lectures of 45 min. each during the mornings, with a coffee break in between. The afternoon sessions were devoted to the exercises with a coffee break at 16:30. On Thursday 30/07 and 6/08 the morning sessions were organized to discuss special topics. Friday 24/07 afternoon was reserved for a discussion session. On Friday 31/07 selected students gave short presentations of their research work.

Lectures on follow-up and in-depth analysis of some topics included the OBEP (A. Nogga), the Coulomb problem (A. Kievsky), resonances and virtual states (R. Lazauskas), and an introduction to the Efimov physics (M. Gattobigio).

Schedule of the 3 weeks:

First week

Monday: Introduction – The two-body problem - The NN system – Numerical methods – The NUMEROV algorithm I

Tuesday: Elements of scattering theory – Introduction to the NN force – The effective range expansion – The NUMEROV algorithm II

Wednesday: The one pion exch. potential – The tensor force – The two-nucleon system - Momentum space solutions – Configuration space solutions

Thursday: The NN coupled equations I - Systems with A>2 - Jacobi coordinates – Momentum space solutions – Configuration space solutions

Friday: Hyperspherical coordinates - Introduction to the 3N system - discussions

Second week

Monday: The Faddeev Eqs. in conf. space - The HH method – Configuration space problems – Momentum space problems

Tuesday: The Faddeev Eqs. in momentum space – The HH method

Wednesday: The variational principle – The Faddeev Eqs. in conf. space – The Faddeev Eqs. in momentum space – The HH method

Thursday: Special topic – Efimov physics - The Faddeev Eqs. in momentum space - The Faddeev Eqs. in conf. space

Friday: The Kohn var. principle – The transition matrix – Four-nucleon system - Presentations

Third week

Monday: Scattering and resonances – Basic expansion methods – Configuration space problems – Momentum space problems

Tuesday: Introduction to the RGM – Introduction to the SVM – Reactions with external probes – Faddeev Eqs. solutions – Project plan discussion

Wednesday: Electromagnetic reactions – Discretization of scat. states – Resonances and virtual states – Scatt. states from bound states

Thursday: Integral methods – Special topic – Deuteron photo-desintegration – sum rules

Friday: Summary - Discussions

Course material and website

During the course a dedicated website at the internal ECT* website has been used by lecturers and students. Each lecturer had a personal directory where the specific material has been located, this included the lectures as well as the exercises.

During the exercises it was possible to project the material allowing the lecturer to work on-line showing specific procedures to the students. This procedure was used several time to explain the scripts to the students.

After the course was completed, all the material were copied in a memory stick and distributed to students and lecturers before their leaving. In this way each participants has a copy of the complete material.

Exercises and final project

A main part of the course were devoted to allow the students to solve by themselves the Schrödinger equation for two nucleons, the Faddeev equation for three nucleon and even the

Faddeev-Yakubovsky equations for four nucleons. In order to achieve this goal a procedure in steps of increasing difficulty was prepared. All the exercises were organized in building blocks already used in the previous days. For matrix diagonalization standard programs were uploaded from the package LAPACK.
Scripts with interpolation, differentiation and integration were prepared and explained to the students the first day. The students who had no experience with this copied the scripts and were able to get familiar with them.
In the rest of the week students learned how to solve the Schrödinger equation in configuration and momentum space for coupled channels.
Trying to be as systematic as possible, the same techniques were extended in the second week to solve the Faddeev equations in configuration and momentum space. All the students were able to have operative programs using simple potentials. In the case of coupled channel the students where divided in two groups to work on the solution in configuration space and in momentum space.
In the second week also a simple implementation of the hyperspherical harmonics was proposed to the students.
The third week was devoted to finish exercises on the three-body problem as well to a simple implementation of the Faddeev-Yakubovsky equations.
A simple exercise on the deuteron photodisintegration was proposed.

Credit assignment
The University of Trento agreed to give official certificate of credit recognition after the evaluation procedure. To this aim the organizers assigned a final project to those students who required these CFU inside their educational portfolio. A total of 10 students decided to produce a final project which has to be presented in written format within the end of September.

ECT* support and budget

Logistic
The ECT* assigned Susan Driessen as the secretary of the course, with the help of Serena degli Avancini, who had already TALENT experience.
The students had personal space in two rooms in the Villa and one room in the “rustico”. The availability of a lecture room and a second room close to it was important when the students were divided in two groups.
The students and lecturers had identification badges that allowed to access ECT after hours.
All the students had a laptop, only in one case it was necessary to provide an ECT laptop.
Wireless connection and access to the internal ECT* website were provided.
The website was continuously updated by Dr. Barbara Curro’ Dossi. She provided an invaluable help and assistance in maintaining and constructing the website and in any sort of difficulty lecturers and students may have encountered. Barbara and Susan really helped to make the course a success.
Two rooms were assigned to the organizers and lecturers.
Coffee-breaks took place at "La Baracca", a bar located a two minutes walk from the ECT*. An open space with some tables and a nice view on the mountain and valley was reserved to this aim. Coffee, cappuccini, croissants as well as cold drinks and ice-creams were offered.

Housing and food
The students were housed in two places: the majority of them were in Agritur La Cascata in Povo (5’ by bus, 30’ on foot) and a few in Villazzano in Hotel La Canonica (10’ on foot) from the ECT*. Lunches were served in the ECT* cafeteria from Monday to Friday.

Student Feedback
At the beginning of September a letter was sent to the students asking to answer a few questions that reported here:

- Comment on the structure of having lectures in the morning and numerical exercises in the afternoon
- Comments on the pace of the course (too slow/fast, not enough/too many details vs. learning about more physics topics, etc)

- We chose to present most of the lectures by blackboard to reduce the pace and allow more interaction. Do you prefer **blackboard or slides for the lectures?**
- Comments on the usefulness of the exercises and what you would change. Do you think you will go back and work on problems you didn't have time for during the course?
- Would you have preferred more analytical problems vs. computational ones?
- How was the interaction with the lecturers? Has it been helpful?
- How was the interaction with the other students? Has it been helpful?
- How was the interaction with the secretary staff? Has it been helpful?
- Was the website useful? How would you improve it?
- Comments on lodging and food and coffee breaks?
- Comments on logistics at ECT*
- What was the best thing about the course?
- What would you change?
- Would you attend another TALENT course?
- Comparisons to other schools you have attended
- Other comments

At the time of this report the complete list of answers was not yet available.

Miscellaneous

The six lecturers were present for the whole duration of the course. One of them had to leave only two days earlier.
Two students had to leave four days earlier.
Only one social pizza dinner could be organized towards the end of the third week, when it was clear that the budget would have allowed it.

Participants and their home institution

The target audience for the Few-Body course included mainly theoreticians (85%) with a small component of experimentalists (15%). Taking into account the different educational systems in U.S., Japan and Europe, the background of the students spread among the last year of a Master degree and first years of a PhD program.

Name	**Institution**
Andolina Marcello	Università di Pisa, Italy
Contessi Lorenzo	Università degli Studi di Trento, Italy
Elyahu Moti	HUJI Jerusalem, Israel
Erdman Paolo	Università di Pisa, Italy
Ferrari Ruffino Fabrizio	Università degli Studi di Trento, Italy
Gomez Ramos Mario	Sevilla University, Spain
Hernandez Oscar Javier	TRIUMF, USA
Hlophe Linda	Ohio University, USA
Hove Dennis	Aarhus University, Denmark
Jin Lei	University of Seville, Spain
Kegel Simon	Universität Mainz, Germany
Khatri Ghanshyambhai	Jagiellonian University, Poland
Koerber Christopher	FZ Jülich, Germany
Lovell Amy	Michigan State University, USA
Macheda Francesco	Università di Pisa, Italy
Nematollahi Hajar	Tehran University, Iran
Nogueira Jorge	Technological Institute of Aeronautics, Brasil
Poxon-Pearson Terri	Michigan State University, USA
Rokash Alexander	Ruhr Universität Bochum, Germany
Sääf Daniel	Chalmers University Göteborg, Sweden
Sartori Francesca	Università degli Studi di Trento, Italy
Sottili Leandro	Università di Firenze, Italy
Vaidya Nikhil	FZ, Jülich, Germany
Valdez Mateo	IPHC Strasbourg, France
Vale Deni	University of Zagreb, Croatia

Wada Yasunori	Tohoku University, Japan
Weiss Ronen	Hebrew University Jerusalem, Israel
Wesolowski Sarah	Ohio State University, USA

3.5.3 Summary

We hope to have delivered a coherent, and to some reasonable extent, detailed information about the few-body methods for structure and reactions that are used nowadays in physical and astrophysical problems. The emphasis was on A=2-4. The students have confronted the challenge of both learning the fundaments of the different methods, and program, or use simplified scripts, to calculate observables by themselves, following the points of view of the different approaches.

Independently from the students' comments that are not yet available, here we list what in our opinion were the pluses and minuses of the experience:

On the plus side:

- The student participation in the exercises, and some of their smart questions.
- The lectures of our colleagues, the discussions about them and the nice atmosphere among us and with the students.
- The ECT* and its surroundings.
- The possibility to publish our lectures with Springer (open access online).

On the minus side:

- Students arriving late on Sundays had problems to reach the hotel due to the reduced bus schedule. Moreover, there were very few possibilities to have dinner in Povo on Sunday night. It is necessary to organize transportation for late arrivals.
- Too little "social program" due to budget restrictions. The students were active to organize themselves in groups for the weekend, but some remained isolated.
- The computational backgrounds of the students were very different and it was difficult to cope with this.
- Explicit assessment of student learning has been missing for those who have not asked for credits.

4 Research at ECT*

In this chapter the activities in 2015 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 of the researchers. Cooperations of the scientists within the Centre are as prominently visible as 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) parallel to his research in QCD. Alexis Diaz-Torres works on low-energy nuclear reaction dynamics relevant to astrophysical processes and acts at the same time as advisor of a PhD student at the University of Trento holding an FBK/ECT* fellowship. Dionysis Triantafyllopoulos directs his research primarily towards QCD at the highest energy densities and represents at the same time ECT* in the PhD Committee of the Physics Department of the University.

4.1 Projects of ECT* Researchers

Guillaume Beuf

Heavy quarks in proton-nucleus collisions – the hybrid formalism

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 of the Negev, Israel, and University of Connecticut, USA)

In the context of proton-nucleus collisions at high energy, the single inclusive production of hadrons in the forward direction can be conveniently calculated in the hybrid formalism [1], that is the collinear factorization on the proton side while high-density and high-energy effects are resummed on the side of the nucleus. Next-to-leading-order (NLO) corrections to that process have been first calculated Ref.[2]. Among these NLO corrections one has to isolate and resum the collinear and the high-energy leading logarithms, in order to get the genuine fixed order NLO correction. Numerical simulations [3] have uncovered severe pathologies in the results of Ref.[2]. In Ref.[4], we have already recalculated the NLO corrections to this observable, and pointed out several problems in the calculated of Ref.[2], in particular in the treatment of the high-energy leading logarithms. All the abovementionned calculations are considering quarks as massless for simplicity.
Finally, in Ref.[5], we have explored the quark mass effects within the hybrid formalism. We considered two processes. First, we computed the single inclusive cross-section for production of hadrons with open heavy flavour in the proton forward direction at leading order, which was out of reach without including quark masses. Next, in the same kinematics, we calculated the heavy-quark contribution to single inclusive production of light or unidentified hadrons at NLO. This contribution to the NLO correction is analog to the massless one except that, thanks to the quark mass, it cannot give rise to high-energy leading logs. Hence, the results of Ref.[5] will be helpful to further disentangle the issues encountered in Ref.[3], in addition to improve the accuracy of the hybrid formalism and extend its scope.

Diffractive dijet production in deep inelastic scattering and photon-hadron collision in the Color Glass Condensate

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

In Ref.[6], we studied diffractive dijet production in deep inelastic scattering and real (and virtual) photon-hadron collisions in the Color Glass Condensate formalism at leading order. We showed that the diffractive dijet cross section is sensitive to the color-dipole orientation in the transverse plane (by contrast to the other observables considered in the literature), and is a good probe of possible correlations between the dipole transverse separation vector r and the dipole impact parameter b.
We also investigated the diffractive dijet azimuthal angle correlations and t-distributions in photon-hadron collisions and showed that they are sensitive to gluon saturation effects in the small-x region. In particular, we showed that the t-distribution of diffractive dijet photoproduction off a proton target exhibits a dip-type structure in the saturation region. This effect is similar to diffractive vector meson production. Besides, at variance with the inclusive case, the effect of saturation leads to stronger azimuthal correlations between the jets.

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[2] G. A. Chirilli, Bo-Wen Xiao and Feng Yuan, Phys. Rev. D **86**, 054005 (2012).
[3] A. M. Stasto, Bo-Wen Xiao and D. Zaslavsky, Phys. Rev. Lett. **112**, 012302 (2014).
[4] T. Altinoluk, N. Armesto, G. Beuf, A. Kovner and M. Lublinsky, Phys. Rev. D **91**, no. 9, 094016 (2015).
[5] T. Altinoluk, N. Armesto, G. Beuf, A. Kovner and M. Lublinsky, arXiv:1511.09415 [hep-ph].
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Daniele Binosi

Yang-Mills two-point functions in linear covariant gauges

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

In this work we use two different but complementary approaches in order to study the ghost propagator of a pure SU(3) Yang-Mills theory quantized in the linear covariant gauges, focusing on its dependence on the gauge-fixing parameter ξ in the deep infrared. In particular, we first solve the Schwinger-Dyson equation that governs the dynamics of the ghost propagator, using a set of simplifying approximations, and under the crucial assumption that the gluon propagators for $\xi>0$ are infrared finite, as is the case in the Landau gauge ($\xi=0$). Then we appeal to the Nielsen identities, and express the derivative of the ghost propagator with respect to ξ in terms of certain auxiliary Green's functions, which are subsequently computed under the same assumptions as before. Within both formalisms we find that for $\xi>0$ the ghost dressing function approaches zero in the deep infrared, in sharp contrast to what happens in the Landau gauge, where it known to saturate at a finite (non-vanishing) value. The Nielsen identities are then extended to the case of the gluon propagator, and the ξ-dependence of the corresponding gluon masses is derived using as input the results obtained in the previous steps. The result turns out to be logarithmically divergent in the deep infrared; the compatibility of this behavior with the basic assumption of a finite gluon propagator is discussed, and a specific Ansatz is put forth, which readily reconciles both features.

The lattice gluon propagator in renormalizable ξ gauges

In collaboration with P. Bicudo (CFTP, Portugal), N. Cardoso (NCSA, USA), O. Oliveira (University of Coimbra, Portugal), P. J. Silva (University of Coimbra, Portugal)

In this work we study the SU(3) gluon propagator in renormalizable Rξ gauges implemented on a symmetric lattice with a total volume of $(3.25 \text{ fm})^4$ for values of the guage fixing parameter up to ξ=0.5. As expected, the longitudinal gluon dressing function stays constant at its tree-level value ξ. Similar to the Landau gauge, the transverse R_ξ gauge gluon propagator saturates at a non-vanishing value in the deep infrared for all values of ξ studied. We compare with very recent continuum studies and perform a simple analysis of the found saturation with a dynamically generated effective gluon mass.

The Cosmological Slavnov-Taylor Identity from BRST Symmetry in Single-Field Inflation

In collaboration with A. Quadri (University of Milan, Italy)

In this work we obtain the cosmological Slavnov-Taylor (ST) identity of the Einstein-Hilbert action coupled to a single inflaton field from the Becchi-Rouet-Stora-Tyutin (BRST) symmetry associated with diffeomorphism invariance in the Arnowitt-Deser-Misner (ADM) formalism. The consistency conditions between the correlators of the scalar and tensor modes in the squeezed limit are then derived from the ST identity, together with the softly broken conformal symmetry. Maldacena's original relations connecting the correlators of 2- and 3-point functions are also recovered. In this case, we point out a finite correction to the consistency conditions involving one soft graviton which depends on the angle between the soft and the hard momenta.

PARTONS: PARtonic Tomography of Nucleon Software: A computing platform for the phenomenology of Generalized Parton Distributions

In collaboration with B. Berthou (IRFU, France), N. Chouika (IRFU, France), M. Guidal (IPN Orsay, France), C. Mezrag (ANL, USA), H. Moutarde (IRFU, France), F. Sabatié (IRFU, France), P. Sznajder (IPN Orsay, France), J. Wagner (NCBJ, Poland)

In this work we describe the architecture and functionalities of a C++ software framework, coined PARTONS, dedicated to the phenomenology of Generalized Parton Distributions. PARTONS provides a necessary bridge between models of Generalized Parton Distributions and experimental data measured in various exclusive channels. We outline the specifications of the PARTONS project in terms of practical needs, physical content and numerical capacity. This framework will be useful not only for theorists to develop new models but also to interpret existing measurements and even design new experiments.

Proceedings

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A. C. Aguilar, D. Binosi and J. Papavassiliou, *The gluon mass generation mechanism: a concise primer*, arXiv:1511.08361 [hep-ph].

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D. Binosi, *The two-, three- and four-gluon sector of QCD in the Landau gauge*, J. Phys. Conf. Ser. **631**, no. 1, 012066 (2015)

Maddalena Boselli

Reaction dynamics of weakly bound nuclei at low-energy: development of a quantum mechanical toy model

In collaboration with Alexis Diaz-Torres (ECT, Italy)*

My PhD project consists in developing a quantum mechanical model to describe reaction dynamics involving weakly bound nuclei at low energies and in implementing it in a Fortran-90 code to calculate relevant observables for a given reaction of this type.
Due to a high probability for the projectile nucleus to break into its constituents, at a given incident energy several events can occur: no capture breakup, complete fusion and incomplete fusion. The first refers to the case when the projectile breaks but none of its constituents is captured by the target, the second refers to the opposite situation when all the constituents are captured and the latter to the case when only part of the constituents are fused with the target. The main goal is that to calculate the cross section as a function of the incident energy for each of these processes individually.
The approach to the problem consists in dealing with the simplest situation first, when a three-body scattering problem is considered. A one-dimensional toy model is built and the time-dependent Schrödinger equation is solved in order to obtain the wavefunction describing the system at a time t after the interaction occurred. This is then used to calculate the cross section for any of the possible reaction processes. Once every aspect of this toy model would be well understood, it would be possible to move on towards a more realistic situation adding complexity to the model.
The toy model 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 to the problem. During the last year, the work was focused on the 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. After having learnt a method [2] which computes the transmission coefficients through the Coulomb barrier as a function of the center of mass energy, time was given to implement it in the code. Some aspects, related to the connection between computational limitations and theoretical requirements, started to be further investigated in order to optimize the code and decrease the computing time. The theoretical approach on which the toy model is based is described in [1].
During this last year the work consisted in extending the toy model from one to three dimensions. 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: the distance R between the target and the center of mass of the projectile and the distance χ between the projectile constituents. In addition tho these, the total wave function depends on two other variables: the angle θ between χ and R, and the projection K onto the BF-z axis (R) of the total angular momentum of the system J. As J is conserved, the total wave function is expanded onto individual J-components which are obtained by solving the time dependent Schrödinger equation using the same method which was used in the one-dimensional case. Apart from taking care of the additional angular terms, no major conceptual changes needed to be done. At the present the three-dimensional version has been implemented in a Fortran-90 code based on the previous one-dimensional one and tests have been performed to check its reliability. Once this procedure will be completed, it will be possibile to compare the results with experimental data.

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Alexis Diaz-Torres

Low-energy reaction dynamics of weakly-bound nuclei

In collaboration with theorists and experimenters in Italy (INFN-Legnaro), France (IPHC-Strasbourg), Mexico (ININ), Brazil (Fluminense U), Poland (Warsaw University), Australia (ANU), Russia (JINR-Dubna) and China (ITP/CAS-Beijing)

In Refs. [1,2] a classical-trajectory Monte-Carlo model for treating low-energy reaction dynamics of weakly-bound nuclei was developed, which is implemented in an user-friendly code [3]. This is being exploited for planning, guiding and interpreting particle-gamma coincidence measurements, fusion measurements as well as breakup measurements in reactions induced by weakly-bound nuclei at energies near the Coulomb barrier [4,5]. The model has been developed further, which can now deal with both direct and inverse kinematics. Many calculations have recently been performed for planning experiments that exploit the incomplete fusion mechanism at various facilities [6]. 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 [7], where the role of the ^{6}Li resonant states in the elastic differential cross sections has particularly been studied. A unified quantum description of relevant reaction processes of weakly-bound nuclei (breakup, transfer, complete and incomplete fusion) is being pursued, which is the central aspect of the work carried out by my PhD student (Maddalena Boselli) at the ECT*. This PhD project is based on solving the time-dependent Schroedinger equation of a three-body scattering problem. The first results obtained within a simplified model have been published [8-10]; Ref. [10] being an Editor's suggestion paper. The model is being extended to three dimensions. In collaboration with theorist 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 [11].

Quantifying sub-Coulomb fusion of heavy ions using the time-dependent wave-packet method

In collaboration with M. Wiescher (JINA and Notre Dame University, USA)

A number of critical heavy-ion reactions for stellar burning have been investigated within the time-dependent wave-packet method [12]. This method might be a more suitable tool for expanding the cross-section predictions towards lower energies than the commonly used potential-model approximation, as preliminary results for ^{16}O + ^{16}O and ^{12}C + ^{12}C indicate [13,14]. The origin of resonance structures in the low-energy fusion excitation curve has be addressed. Calculations for the ^{12}C + ^{16}O heavy-ion fusion at sub-Coulomb energies is being pursued as well.

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

In collaboration with theorists from JINR-Dubna

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 [15,16]. It has been demonstrated that energy-shifting formulae yield reliable reaction and capture probabilities [17], 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 breakup probabilities of weakly bound nuclei from experimental elastic and quasi-elastic differential cross-sections [18].

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Daniel Gazda

Calculations of light hypernuclei from first principles

In collaboration with A. Gal (Racah Institute of Physics, HU Jerusalem, Israel), P. Navrátil (TRIUMF, Canada), J. Mareš (Nuclear Physics Institute, Czech Republic), R. Roth, and R. Wirth (TU Darmstadt, Germany)

Recent advances in *ab inito* computational nuclear many-body methods together with modern developments of hypeorn-nucleon forces based on chiral SU(3) chiral effective field theory pave way to understanding of properties hypernuclei and hyperons in nuclear matter based on the underlying theory of strong interactions. Existing measurements of hypernuclear spectra already provide wealt of indispensable information on the underlying hyperon-nucleon interactions and experimental efforts are now intensified in several present and future high-precision experiments at international facilities like J-PARC, JLab, and FAIR.

Recently we incorporated strangeness degrees of freedom into the no-core shell model methodology [1] and performed first *ab initio* calculations of Lambda hypernuclei, including heavier p-shell hypernuclei [2, 3]. In our calculations we employ realistic state-of-the-art nucleon-nucleon [4] and three-nucleon interactions [5] together with chiral as well as phenomenological hyperon-nucleon forces [6, 7]. Lately we focused in particular on charge symmetry breaking in the lightest mirror hypernuclei Lambda-H-4 and Lambda-He-4, representing a long-standing issue of hypernuclear spectroscopy. The unusually large value of the Lambda separation energy difference in the ground states of A=4 hypernuclei was reaffirmed in recent high-precision experiment [8] and negligible value for the excited states was reported lately in [9]. We performed calculations using leading-order chiral hyperon-nucleon potentials [6] together with charge symmetry breaking electromagnetic Lambda-Sigma^0 vertex [10]. We demonstrated for the first time that the observed charge symmetry breaking in A=4 hypernuclear ground states can be reproduced using realistic interaction models [11].

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Maria Gomez Rocha

Meson spectroscopy from a Bethe-Salpeter/Dyson-Schwinger approach

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

In Ref. [1,2], we investigated capabilities of the effective interaction in a rainbow-ladder truncated meson model of QCD within a covariant Landau-gauge Bethe–Salpeter-equation approach. Based upon past success for the light- as well as heavy-quark domains, we are starting now to investigate the applicability of the rainbow-lader truncation to the case of heavy-light mesons.

Following up on earlier work [3,4], we recently published an article in which we investigate possible effects of a dressed quark–gluon vertex in heavy–light mesons. We studied corrections to the rainbow-ladder truncation of the Dyson–Schwinger–Bethe–Salpeter equation system. Adopting a simple interaction kernel [5] the resulting set of coupled integral equations reduce to a set of coupled algebraic equations. At first, we concentrated on pseudoscalar mesons [6]; our current work is concerned with the extension to vector mesons.

Renormalization-group approach to Hamiltonian dynamics

In collaboration with S. D. Glazek (University of Warsaw)

In Ref. [7] we applied the reonomalization group procedure for effective particles [8] to Yang-Mills theory. Asymptotic freedom of gluons were described in terms of a family of scale-dependent renormalized Hamiltonian operators acting in the Fock space.
We are currently working on the extension of this procedure to quantum chromodynamics for the purpose of investigating relativistic properties of hadrons. To this goal we started considering simpler theories, like quantum electrodynamics or scalar theories.

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Philipp Gubler

Operator product expansion and sum rules: study of the single-particle spectral density of the unitary Fermi gas

In collaboration with N. Yamamoto (Keio University, Japan), T. Hatsuda (RIKEN, Japan) and Y. Nishida (Tokyo Institute of Technology, Japan)

The unitary Fermi gas has been studied intensively during the last decade and has attracted much interest partly because of the possibility of tuning the interaction between different fermionic species in ultracold atomic gases through a Feshbach resonance by varying an external magnetic field. In our work [1], which was published at the beginning of this year, we have developed a new method for studying this system, making use of the operator product expansion to derive a general class of sum rules on the imaginary part of the single-particle self-energy. These sum rules are furthermore analyzed by the maximum entropy method, which allows us to obtain the single-particle spectral density of the unitary Fermi gas.

The phi meson spectral function in nuclear matter from an effective field theory approach

In collaboration with W. Weise (ECT)*

The φ meson spectrum in cold nuclear matter has recently been studied experimentally at KEK [2] and will be further examined during the next few years at the E16 experiment in J-PARC. 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 understood to stem from interactions of kaons with the surrounding nuclear medium. As the strength of the effective kaon-nucleon interaction has during the last few years been newly constrained due the kaonic atom measurements, it is now possible to study the φ meson modification with much less systematic uncertainty and hence to gain a more accurate interpretation of the experimental results of KEK and J-PARC. A first letter about this topic was published this year [3].

Higher twist QCD effects in vector meson correlators

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

Vector mesons at finite density have been studied with the help of 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. A first step towards this goal has been achieved this year, as we were able to constrain a twist-3 operator from newly available experimental data. This work was published in [6].

D mesons in nuclear matter from QCD sum rules

In collaboration with K. Suzuki (RIKEN, Nishina Center, Japan) and M. Oka (Tokyo Institute of Technology, Japan)

In this work, we have 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 first preprint about this topic has recently been made publicly available [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 preprint of this study was recently accepted for publication in Physical Review D [8].

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 [9].

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Chen Ji

Nuclear structure effects in light muonic atoms

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

Stimulated by the proton 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 Ref. [1] we extended our previous work in μ^2H and μ^4He^+ 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 also plan to calculate nuclear structure effects on hyperfine splittings in muonic atoms, where the magnetic polarizability is important.

Effective field theory for halo nuclei

In collaboration with G. Orlandini, W. Leidemann, and F. Pederiva (University of Trento & INFN-TIFPA)

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 an effective field theory (EFT) a powerful tool to explore halo systems. Our work and also studies by groups on two-neutron halos in the EFT framework have been summarized in our recent commissioned review article [2]. 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 $\alpha(\alpha n,\gamma)^9$Be by studying the electromagnetic transitions in ^{9}Be.

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Daisuke Sato

Effects of confinement and chiral symmetry breaking on dilepton/photon production

In collaboration with W. Weise (ECT), Y. Hidaka (RIKEN, Japan), S. Lin, R. Pisarski (BNL, USA)*

According to first principle computations of quantum chromodynamics (QCD), it is necessary to consider the effect of (partial) confinement and chiral symmetry breaking when we focus on the temperature (T) realized in heavy-ion collision experiments, even when T is above the transition temperature. Motivated by this observation, we calculated [1] the photon and the dilepton production rate from QCD plasma at finite T, taking into account the effect of the confinement using a Polyakov loop model [2]. This calculation includes the effect of quantum interference between different collision processes, which was not included in the precious calculation [3]. We also calculated these production rates by taking into account the additional effect of the chiral symmetry breaking using a similar model [4]. The results in the both calculations suggest that the dilepton production rate is not suppressed while the photon production rate is significantly suppressed by the two effects. We also argued that the suppression of the photon production increases the elliptic flow, which is an important observable in heavy-ion collision experiment.

Fermionic zero mode in Bose-Fermi mixture in cold atom system

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 effects. The Nambu-Goldstone (NG) theorem then implies that a zero-energy fermionic excitation (goldstino) appears [5]. Such zero mode was analysed in relativistic system such as Wess-Zumino model [5] and QCD [6], which has approximate SUSY at high temperature. Recently, it was proposed to simulate the SUSY by using Bose-Fermi cold atom systems [7], and the goldstino was also suggested to appear there. We analysed the spectral properties of the goldstino in such system in the weak coupling region [8]. We obtained the analytic expressions for the dispersion relation and the strength of the goldstino at small momentum region, and showed that the spectral properties of the goldstino approaches those in the free limit at large momentum. We also derived the sum rule, in a model-independent way, which constrains the spectral function of the goldstino.

Exact sum rules for vector spectral functions at finite temperature

In collaboration with P. Gubler (ECT)*

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 requires assuming an ansatz for its functional form since it is a dynamical quantity. We derived several exact sum rules at zero and finite momentum that constrain this spectral function using a method developed recently [9], which combines operator product expansion and hydrodynamics. We gave a suggestion for improvement of the ansatz used in the lattice QCD based on these sum rules. A paper presenting these results is in preparation.

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Dionysios Triantafyllopoulos

Resumming double logarithms in the QCD evolution of color dipoles

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

The Color Glass Condensate is an effective theory for the soft, small-x, components of a fast moving hadron, and finds applications in the initial stages of ultra-relativistic heavy-ion collisions and in various semi-hard processes [1]. The most important element in this effective theory is the Balitsky-Kovhcegov equation which gives the evolution of the dipole-hadron scattering amplitude. The next-to-leading (NLO) version of such an equation was derived in [2], however it suffers from a severe lack-of-convergence problem, due to radiative corrections enhanced by collinear logarithms [3,4,5]. Through an explicit calculation of Feynman graphs in light cone (time-ordered) perturbation theory, it has been shown that the corrections enhanced by double collinear logarithms are associated with soft gluon emissions which are strictly ordered in lifetime [5,6]. We have resummed such corrections, both in the kernel and in the initial condition, and arrived at a local in rapidity evolution equation [6]. The numerical studies of this collinearly-improved BK equation demonstrated the essential role of the resummation in both stabilizing and slowing down the evolution.

Collinearly-improved BK evolution in the HERA data

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

Having established a collinearly-improved version of the Balitsky-Kovchegov (BK) equation, which resums to all orders the radiative corrections enhanced by large double transverse logarithms, we studied its relevance as a tool for phenomenology by confronting it to the DIS HERA data. Before doing that, we first improved the perturbative accuracy of our resummation by including two classes of single-logarithmic corrections: those generated by the first non-singular terms in the DGLAP splitting functions and those expressing the one-loop running of the QCD coupling. The equation thus obtained included all the next-to-leading order corrections to the BK equation which are enhanced by (single or double) collinear logarithms. Subsequently we used the numerical solutions to this equation to fit the HERA data for the electron–proton reduced cross-section at small Bjorken x [7] . We obtained good quality fits for physically acceptable initial conditions. Our best fit, which showed a good stability up to virtualities as large as Q=20 GeV for the exchanged photon, used as an initial condition the running-coupling version of the McLerran–Venugopalan model [8], with the QCD coupling running according to the smallest dipole prescription. Good fits had been also performed in previous works, e.g. in [9], where the only higher order corrections included were those out to the running coupling. One of the most important aspects of the fit in [7] was that it led to much more physical values of the fit parameters, due to the inclusion of logarithmically enhanced corrections.

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Wolfram Weise

The topics of my research in 2015 include:

- Studies in QCD and hadron physics
- Effective field theory approaches to nuclear matter and neutron stars
- Investigations of the phases of strongly interacting matter

These projects are pursued in cooperation with scientists from my home institution, Technische Universität München, and with colleagues in Japan, France and USA. Selected examples are reported in the following.

Structure and dynamics of hadronic systems with strange quarks

In collaboration with Y. Ikeda (RIKEN, Japan), S. Ohnishi (Hokkaido Univ., Japan), T. Hyodo (Yukawa Institute for Theoretical Physics, Kyoto, Japan), P. Gubler (ECT), S. Petschauer and N. Kaiser (TU Munich, Germany)*

Low-energy QCD in the sector of light (u, d and s) quarks is realized in the form of an effective field theory with spontaneously broken chiral symmetry. Hadrons with strangeness and theirs interactions are of special interest as they prominently involve the interplay of spontaneous and explicit chiral symmetry breaking, the latter induced by the strange quark mass which is intermediate between “light” and “heavy”. Systematic investigations have been focused on antikaon-nucleon interactions close to threshold and extrapolated into subthreshold regions, using the framework of chiral SU(3) effective field theory (EFT) combined with coupled-channels methods. Constraints from accurate measurements of kaonic hydrogen have been implemented and the physics of the Lambda(1405) baryon as an antikaon-nucleon quasibound state embedded in the strongly coupled pion-hyperon continuum has been further established [1,2].

A detailed investigation of such mechanisms in antikaon-deuteron reaction has been performed [3]. Progress has been made in the systematic approach to baryon-baryon interactions involving hyperons using the framework of chiral SU(3) EFT and its application to hypernuclear many-body systems [4,5]. Anti-kaon nucleon interactions also enter prominently in the construction of in-medium spectral functions of the phi meson. Moments of such spectral functions have been analysed using finite-energy QCD sum rules, establishing connections with the scalar strange-quark content of the nucleon and setting constraints on four-quark condensates involving strange quarks [6].

[1] Y. Ikeda, T. Hyodo, W. Weise, Few-Body Systems **54** (2013) 1113.
[2] W. Weise, Hyperfine Int. **233** (2015) 131.
[3] S. Ohnishi, Y. Ikeda, T. Hyodo, W. Weise, arXiv: 1512.05773, Phys. Rev. C (2016), in print.
[4] S. Petschauer, J. Haidenbauer, N. Kaiser, U.-G. Meissner, W. Weise, Phys. Rev. **C63** (2016) 014001.
[5] S. Petschauer, N. Kaiser, J. Haidenbauer, U.-G. Meissner, W. Weise, Eur. Phys. J. **A52** (2016)15
[6] P. Gubler, W. Weise, Phys. Lett. **B751** (2015) 396, and preprint (2016).

Chiral effective field theory approaches for nuclear and stellar matter

In collaboration with J.W. Holt (Univ. of Washington, Seattle, USA), M. Rho (IPhT, CEA Saclay, France), N. Kaiser and C. Wellenhofer (TU Munich, Germany)

This extensive research program applies in-medium chiral effective field theory (at the interface between low-energy QCD and nuclear physics) as a framework to treat the nuclear many-body problem. The investigations have resulted in a systematic approach to the thermodynamics of isospin-symmetric and asymmetric nuclear matter and the nuclear equation of state, including the liquid-gas phase transition. A series of currently important topics, including for example the construction of the second-order quasiparticle interaction in nuclear matter with chiral two- and three-nucleon forces, the derivation of the corresponding energy density functional, the Fermi liquid approach to neutron matter, are summarized in recent publications [7] and review articles [8,9].

[7] C. Wellenhofer, J.W. Holt, N. Kaiser, W. Weise, Phys. Rev. **C89** (2014) 064009.
[8] J.W. Holt, N. Kaiser, W. Weise, Prog. Part. Nucl. Phys. **73** (2013) 35.
[9] J.W. Holt, M. Rho, W. Weise, Physics Reports (2016), in print.

Phases of QCD: strongly interacting matter and the functional renormalisation group

In collaboration with M. Drews and R. Lang (TU Munich & ECT)*

Exploring the phase diagram of QCD with its variety of nuclear, hadronic and quark-gluon sectors is one of the fundamental themes of modern nuclear and particle physics. The nature of the chiral and deconfinement transitions, the transport properties of hot and dense matter produced in high-energy heavy-ion collisions, and the constraints on the equation-of-state of cold dense matter provided by observations of massive neutron stars – these are key issues of frontline research in this area. We have contributed to these topics along several lines of research: investigating transport properties (such as the shear viscosity) in the vicinity of the deconfinement transition [10, 11]; and constructing an equation of state for dense matter at low temperatures in a way consistent with empirical constraints both from nuclear physics and neutron stars [12]. Recent new developments include a non-perturbative chiral approach to dense nuclear and neutron matter using functional renormalisation group methods to treat important fluctuations beyond mean-field approximation [13,14].

[10] R. Lang, W. Weise, Eur. Phys. J. **A50** (2014) 63.

[11] R. Lang, N. Kaiser, W. Weise, Eur. Phys. J. A51 (2015) 127.
[12] T. Hell, W. Weise, Phys. Rev. **C90** (2014) 045801.
[13] M. Drews, W. Weise, Phys. Lett. **B738** (2014) 187.
[14] M. Drews, W. Weise, Phys. Rev. **C91** (2015) 035802.

4.2 Publications of ECT* Researchers in 2015

Daniele Binosi

D. Binosi
The two-, three- and four-gluon sector of QCD in the Landau gauge
J. Phys. Conf. Ser. 631 (2015), 012066

P. Bicudo, D. Binosi, N. Cardoso, O. Oliveira, P.J. Silva
Gauge fixing and the gluon propagator in renormalizable xi gauges
PoS Lattice (2015)

D. Binosi, L. Chang, J. Papavassiliou, C. D. Roberts
Bridging a gap between continuum-QCD and ab initio predictions of hadron observables
Phys.Lett. B742 (2015) 183

A. C. Aguilar, D. Binosi, J. Papavassiliou
Yang-Mills two-point functions in linear covariant gauges
Phys.Rev. D91 (2015) 085014

P. Bicudo D. Binosi N. Cardoso O. Oliveira P. J. Silva
The lattice gluon propagator in renormalizable ξ gauges
Phys.Rev. D92 (2015) 114514

Alexis Diaz-Torres

M. Boselli, A. Diaz-Torres
Reaction dynamics of weakly-bound few-body nuclei at energies around the Coulomb barrier
Few-Body Systems (2015) DOI: 10.1007/s00601-015-1028-2

M. Boselli, A. Diaz-Torres
Quantifying low-energy fusion dynamics of weakly bound nuclei from a time-dependent quantum perspective
Physical Review C 92 (2015) 044610

V. V. Sargsyan, G. G. Adamian, N. V. Antonenko, A. Diaz-Torres, P. R. S. Gomes, H. Lenske
Derivation of breakup probabilities of weakly bound nuclei from experimental elastic and quasi-elastic scattering angular distributions
Physical Review C 92 (2015) 054620

D. Torresi, M. Mazzocco, L. Acosta, A. Boiano, C. Boiano, A. Diaz-Torres et al.
Reaction dynamics studies for the system 7Be + 58Ni
Journal of Physics: Conference Series 590 (2015) 012057

A. Diaz-Torres, M. Wiescher
Relating molecular structure and low-energy fusion through time-dependent wave-packet dynamics: the 12C+12C collision
EPJ Web of Conferences 93 (2015) 02017

A. Gomez Camacho, A. Diaz-Torres, P.R.S. Gomes and J. Lubian
Effect of 6Li resonances on near-barrier elastic scattering involving 28Si and 58Ni target nuclei

Physical Review C 91 (2015) 014607

Daniel Gazda

J. Mareš, A. Cieplý, E. Friedman, A. Gal, D. Gazda
K^- and η nuclei
Hyperfine Int. 234 (2015) 49

Philipp Gubler

P. Gubler, N. Yamamoto, T. Hatsuda, Y. Nishida
Single-particle spectral density of the unitary Fermi gas: Novel approach based on the operator product expansion, sum rules and the maximum entropy method
Annals of Physics 356 (2015) 467–497

P. Gubler, K.S. Jeong, S.H. Lee
New determination of ST<N|qbar D_mu D_nu q|N> based on recent experimental constraints
Phys. Rev. D 92 (2015) 014010

P. Gubler, W. Weise
Moments of phi meson spectral functions in vacuum and nuclear matter
Physics Letters B 751 (2015) 396

Abhishek Mukherjee

Y. Alhassid, M. Bonett - Matiz, A. Mukherjee, H. Nakada, C. Özen
Recent advances in the application of the shell model Monte Carlo approach to nuclei
J. Phys. Conf. Ser. 580 (2015) 012009

Daisuke Sato

J.-P. Blaizot, Y. Hidaka, D. Satow
Spectral properties of the Goldstino in supersymmetric Bose-Fermi mixtures
Phys. Rev. A 92, 063629 (2015)

Y. Hidaka, S. Lin, R. Pisarski, D. Satow
Dilepton and photon production in the presence of a nontrivial Polyakov loop
JHEP 10, 005 (2015)

D. Satow, W. Weise
Chiral symmetry breaking and confinement effects on dilepton and photon production around Tc
Phys. Rev. D 92 (2015) 056001

Dionysis Triantafyllopoulos

E. Iancu, J.D. Madrigal, D.N. Triantafyllopoulos
Particle production with rapidity correlations in proton-nucleus collisions
AIP Conf. Proc. 1654 (2015) 080004

E. Iancu, J.D. Madrigal, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
Collinearly-improved BK evolution meets the HERA data
Phys. Lett. B750 (2015) 643

E. Iancu, J.D. Madrigal, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
Resummation of large logarithms in the rapidity evolution of color dipoles
PoS DIS (2015) 076

E. Iancu, J.D. Madrigal, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
Resumming double logarithms in the QCD evolution of color dipoles
Phys. Lett. B744 (2015) 293

Wolfram Weise

D. Satow, W. Weise
Chiral symmetry breaking and confinement effects on dilepton and photon production around Tc
Phys. Rev. D 92 (2015) 056001

R. Lang, N. Kaiser, W. Weise
Shear viscosities from Kubo formalism in a large-N_c Nambu & Jona-Lasinio model
Eur. Phys. J. A51 (2015) 127

W. Weise
Topics in low-energy QCD with strange quarks
Hyperfine Int. 233 (2015) 131

M. Drews, W. Weise
From asymmetric nuclear matter to neutron stars: a functional renormalization group study
Phys. Rev. C91 (2015) 035802

P. Gubler, W. Weise
Moments of phi meson spectral functions in vacuum and nuclear matter
Phys. Lett. B751 (2015) 396

4.3 Talks presented by ECT* Researchers

Daniele Binosi

From continuum QCD to hadron phenomena
Talk delivered at: Few Body 2015 (Chicago, USA, May 18-22, 2015); QCD-TNT IV (Ilha Belha, Brazil, Aug. 31 Sept. 4, 2015); Nucleon Resonances (Trento, Italy, Oct. 12-16, 2015); Second Sino-Americas workshop (Wuhan, China, Nov. 16-20, 2015)

Alexis Diaz Torres

Insights into the low-energy elastic scattering of halo nuclei
Invited talk at WONP-NURT 2015, Havana, Cuba
13 Feb 2015

Linking structure and reaction dynamics in the realm of nuclear astrophysics: The 12C+12C sub-Coulomb fusion
Invited seminar at CIRCE, Caserta, Italy
05 May 2015

Linking structure and reaction dynamics in the realm of nuclear astrophysics
Talk at the ECT* Workshop "Interplay of Structure and Dynamics of Heavy-Ion Collisions", Trento, Italy
15 May 2015

Linking structure and reaction dynamics in the realm of nuclear astrophysics: A time-dependent perspective
Invited seminar at the University of York, UK
18 May 2015

Quantifying low-energy reaction dynamics of weakly bound nuclei
Invited talk at the International Workshop "Weakly Bound Exotic Nuclei", Natal, Brazil
29 May 2015

Quantifying low-energy fusion dynamics of weakly bound nuclei
Invited plenary talk at the 12th International Conference Nucleus-Nucleus Collisions, Catania, Italy
25 Jun 2015

Predicting reaction observables from back-scattering measurements in low-energy heavy-ion collisions
Invited talk at the International Conference "Nuclear Structure and Related Topics", Dubna, Russia
16 Jul 2015

Role of diabaticity in reactions forming heavy elements
Talk at the Humboldt Kolleg "Interfacing Structure and Reaction Dynamics in the Synthesis of the Heaviest Nuclei", Trento, Italy
01 Sep 2015

Quantifying low-energy fusion dynamics of weakly bound nuclei
Invited seminar at the Guangxi Normal University, Guilin, China
27 Oct 2015

Linking structure and reaction dynamics in the realm of nuclear astrophysics: a time-dependent perspective
Invited talk at the International Workshop "Physics of Strong Interaction", Guilin, China
01 Nov 2015

Calculating observables from back-scattering measurements in low-energy heavy-ion collisions
Invited seminar at the China Institute of Atomic Energy, Beijing, China
04 Nov 2015

Quantifying low-energy fusion dynamics of weakly bound nuclei
Invited seminar at the ITP of the Chinese Academy of Sciences, Beijing, China
05 Nov 2015

Evolution of transfer-like reactions from Coulomb to Fermi energy
Invited talk at the International Workshop "HIB@LNS", Catania, Italy
15 Dec 2015

Daniel Gazda

Ab initio calculations of light hypernuclei
Talk at the "Strangeness in Nuclei and in Neutron Stars" workshop, Pisa, Italy.
21 May 2015

Maria Gomez Rocha

Asymptocic freedom of gluons in Hamiltonian dynamics
Light-Cone 2015 Conference, Frascati, Italy
22 Sep 2015

Philipp Gubler

Operator product expansion and sum rule approach to the unitary Fermi gas
Talk at Intersection between QCD and Condensed Matter, Schladming, Austria
05 Mar 2015

Flavor structure of lambda baryons from lattice QCD
1st Hadron Spanish Network Days and Spanish-Japanese JSPS Workshop, Valencia, Spain
15 Jun 2015

Moments of phi meson spectral functions in vacuum and nuclear matter
Seminar, Nuclear theory group, Tokyo Institute of Technology, Tokyo, Japan
25 Aug 2015

Moments of phi meson spectral functions in vacuum and nuclear matter
Seminar, Nucleon & Hadron Physics Group, Yonsei University, Seoul, South Korea
02 Sep 2015

The phi meson in nuclear matter - recent results from QCD sum rules and effective theories
Talk at the ACHT 2015 workshop, Leibnitz, Austria
08 Oct 2015

Sum rules for vector channel at finite temperature
Seminar, Nucleon & Hadron Physics Group, Yonsei University, Seoul, South Korea
25 Nov 2015

The phi meson in nuclear matter - recent result from theory
Talk at the ECT* workshop "New perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC"
04 Dec 2015

Chen Ji

Nuclear structure effects in exotic atoms
Seminar, Institute of Particle Physics, Central China Normal University
12 Oct 2015

Nuclear structure effects in exotic atoms
Seminar, Facility of Rare Isotope Beam (FRIB), Michigan State University
11 Nov 2015

Daisuke Sato

Photon and dilepton production in semi-QGP and its effect on elliptic flow
Invited talk at Frontiers of Hadronic Physics: Brains circulate Three, Brookhaven National Laboratory, USA
25 Feb 2015

Nambu-Goldstone fermion mode in quark-gluon plasma and Bose-Fermi cold atom system
Talk at Intersection between QCD and Condensed Matter, Schladming, Austria
05 Mar 2015

Fermionic Nambu-Goldstone mode and (quasi-) supersymmetry breaking at finite temperature in QCD and cold atoms
Cold Atoms Meet High Energy Physics, ECT*, Trento
23 Jun 2015

Chiral symmetry breaking and confinement effects on dilepton and photon production in heavy ion collision
Selected topics in the Physics of the Quark Gluon Plasma and Ultrarelativistic Heavy Ion Collisions, YITP, Kyoto, Japan
15 Sep 2015

New perturbative expansion at high temperature and investigation of ultrasoft fermion mode
Invited talk, JPS meeting, Osaka, Japan
26 Sep 2015

Chiral symmetry breaking and confinement effects on dilepton and photon production and their elliptic flow
ECT* Workshop on "New perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC"
02 Dec 2015

Chiral effective field theories and phases of QCD
Invited talk at the HHIQCD2015 Symposium, Yukawa Institute for Theoretical Physics, Kyoto, Japan
04 Mar 2015

Topics in QCD,
Three invited lectures at the International School Niccolo' Cabeo, Ferrara, Italy
25-26 May 2015

From kaonic hydrogen to strangeness in neutron stars
Invited talk Symposium “10 Years Stefan Meyer Institute”, Vienna, Austria
29 May 2015

Nuclear phases, neutron stars and the functional renormalisation group
Invited talk at the RIKEN - Nishina seminar, RIKEN, Japan
14 Jul 2015

Dense baryonic matter and the functional renormalisation group
Invited talk, Nuclear Theory seminar, Stony Brook University, NY, USA
06 Aug 2015

Baryonic matter and renormalisation group
Invited talk at the ECT*-APCTP Joint Workshop: From Rare Isotopes to Neutron Stars, Trento, Italy
15 Sep 2015

Phases of strongly interacting matter: from quarks to nuclei and neutron stars
Colloquium at Institut de Physique Nucléaire, Orsay, France
28 Sep 2015

Chiral dynamics and nuclear matter
Invited talk at the EMMI Workshop "Cold Dense Matter: from Short-Range Correlations to Neutron Stars", GSI, Darmstadt, Germany
15 Oct 2015

Phases of strongly interacting matter: from quarks to nuclei and neutron stars
Invited colloquium in the series "Coloquios Severo Ochoa" at IFIC, University of Valencia, Spain
04 Nov 2015

4.4 Courses taught by ECT* Researchers

Dionysis Triantafyllopoulos

Particle Physics

In the spring of 2015 I taught a 48-hour course on Particle Physics for the "Master of Science in Physics" (Laurea Magistrale in Fisica) program of the University of Trento. The objective was to introduce and discuss the basic aspects of the theories of fundamental interactions. It was a small class composed of six students and the prerequisites to attend the course were knowledge of Quantum Mechanics and Special Relativity. All lectures were done on the blackboard.

The syllabus was the following:

- Scalar fields, continuous symmetries and Noether's theorem, quantization.
- Quantum gauge fields in the Coulomb gauge.
- Representations of the Lorentz group, Weyl and Dirac fermions, chiral symmetry.
- Quantization of spin1/2 fields.
- Flavour SU(2) and SU(3) symmetries, charges as generators of symmetries.
- Linear σ-model with scalars and fermions.
- Spontaneous symmetry breaking in σ-model, Goldstone bosons, Nambu-Goldstone theorem.
- Masses of pseudo-Goldstone bosons.
- Quantum Electrodynamics, Feynman rules.
- Transition probabilities in scattering, cross sections, electron-positron to muons.
- Motivation for QCD, non-abelian gauge invariance.
- Path integrals in quantum mechanics.
- Path integrals for scalar and fermionic fields.
- Path integral in QCD, Faddeev-Popov ghosts, covariant and light-cone gauges.
- Renormalization, regularization, β-function in QCD.
- Electron-positron to hadrons at NLO, choice of scale in the running of the coupling.
- Higgs mechanism in scalar QED. Existence of massive gauge bosons, 4-Fermi theory.
- Spontaneous symmetry breaking in SU(2) x U(1), Higgs sector and massive gauge bosons.
- Optical theorem, unitarity, scattering of longitudinal gauge bosons.
- Leptons and their masses, quark sector, CKM matrix, top decay.

The students solved a total of 20 problems as a homework assignment and took an oral exam.

4.5 Seminars and colloquia at ECT*

Nonperturbative study of the four gluon vertex
ECT Seminar*
07 Jan 2015
Daniele Binosi (ECT*)

Running coupling effects in the evolution of jet quenching
ECT Seminar*
14 Jan 2015
Dionysis Triantafyllopoulos (ECT*)

Nambu-Goldstone fermion in QGP and Bose-Fermi cold atom system
ECT Seminar*
21 Jan 2015
Daisuke Sato (ECT*)

Application of the operator product expansion and sum rules to the study of the single-particle spectral density of the unitary Fermi gas
ECT Seminar*
27 Jan 2015
Philipp Gubler (ECT*)

Neutron stars as fundamental physics laboratories
ECT Colloquium*
28 Jan 2015
Nils Andersson (University of Southampton)

Hadronic properties in the nuclear medium
ECT Seminar*
17 Feb 2015
Jochen Wambach (Technical University of Darmstadt)

Quantum chromodynamics at high energy (part 1)
ECT Lecture Course*
18 Mar 2015
Alfred Muller (Columbia University)

The temperature of the quark-gluon plasma
ECT Colloquium*
18 Mar 2015
Helmut Satz (Universität Bielefeld)

Quantum chromodynamics at high energy (part 2)
ECT Lecture Course*
25 Mar 2015
Alfred Muller (Columbia University)

Quantum chromodynamics at high energy (part 3)
ECT Lecture Course*
01 Apr 2015
Alfred Muller (Columbia University)

Quantum chromodynamics at high energy (part 4)
ECT Lecture Course*
14 Apr 2015
Alfred Muller (Columbia University)

Quantum chromodynamics at high energy (part 5)
ECT Lecture Course*
16 Apr 2015
Alfred Muller (Columbia University)

Quantum chromodynamics at high energy (part 6)
ECT Lecture Course*
22 Apr 2015
Alfred Muller (Columbia University)

Jets in ultrarelativistic heavy ion collisions: a tale of two cascades
ECT Seminar*
29 Apr 2015
Jean-Paul Blaizot (CEA Saclay)

From continuum QCD to hadron observables
ECT Seminar*
13 May 2015
Daniele Binosi (ECT*)

Theoretical estimates of stellar e-captures from first-principles simulations
ECT- LISC Seminar*
04 Jun 2015
Simone Taioli (LISC)

Particle dynamics from meV to MeV
ECT- LISC Seminar*
04 Jun 2015
Giovanni Garberoglio (LISC)

Implications of the Nuclear EMC effect
ECT Colloquium*
08 Jun 2015
Gerald A. Miller (University of Washington, Seattle)

The breakup threshold anomaly for the weakly bound systems 9Be+208Pb and 9Be+209Bi at near Coulomb barrier energies
ECT seminar*
10 Jun 2015
Arturo Refugio Gomez-Camacho (ININ, Mexico)

Hyperon potentials in nuclear matter from SU(3) chiral effective field theory
ECT - TUM seminar*
17 Jun 2015
Stefan Petschauer (TU Munich)

QCD-inspired determination of four-quark couplings
ECT- TUM seminar*
17 Jun 2015
Paul Springer (TU Munich)

Quartic isospin asymmetry energy of nuclear matter from chiral pion-nucleon dynamics
ECT - TUM seminar*
17 Jun 2015
Norbert Kaiser (TU Munich)

Thermodynamics of isospin-asymmetric nuclear matter from chiral effective field theory
ECT - TUM seminar*
17 Jun 2015
Corbinian Wellenhofer (TU Munich)

Overview of the heavy-ion programme at LHC
ECT - TUM seminar*
17 Jun 2015
Robert Lang (TU Munich)

Predicting reaction observables from back-scattering measurements in low-energy heavy-ion collisions
ECT Seminar*
01 Jul 2015
Alexis Diaz-Torres (ECT*)

Moment analysis of the phi-meson spectral function in vacuum and nuclear matter
ECT Seminar*
08 Jul 2015
Philipp Gubler (ECT*)

Transport of energetic electrons in solids
ECT LISC Seminar*
23 Jul 2015
Maurizio Dapor (LISC)

Resummation of large higher order corrections in non-linear QCD evolution and its relevance for electron-proton DIS
ECT Seminar*
23 Jul 2015
Dionysis Triantafyllopoulos (ECT*)

Charge symmetry breaking in light hypernuclei
ECT Seminar*
26 Aug 2015
Daniel Gazda (ECT*)

Super Heavy Elements exploring the limits for the existence of elementary matter
ECT Colloquium*
01 Sep 2015
Gottfried Münzenberg (GSI, Darmstadt)

Nuclear structure effects in light muonic atoms and proton radius puzzle
ECT- TIFPA seminar*
08 Sep 2015
Chen Ji (ECT*-TIFPA)

Flavor structure of lambda baryons from lattice QCD
ECT Seminar*
09 Sep 2015
Philipp Gubler (ECT*)

The future of accelerator physics
ECT Colloquium*
10 Sep 2015
Francois Richard (Univ. Paris Sud)

Asymptotic freedom in the front-form Hamiltonian for quantum chromodynamics of gluons
ECT Seminar*
16 Sep 2015
Maria Gomez Rocha (ECT*)

High-energy QCD and gluon saturation: towards higher orders
ECT Seminar*
06 Oct 2015
Guillaume Clement Beuf (ECT*)

Understanding low-energy reaction dynamics of weakly bound nuclei
ECT Seminar*
07 Oct 2015
Maddalena Boselli (ECT*- Univ. of Trento))

The Perturbative and Nonperturbative Conformal Window
ECT Seminar*
13 Oct 2015
Thomas Ryttov (CP3 Origins, Univ. of Southern Denmark)

Baryons and the Borromeo
ECT Colloquium*
14 Oct 2015
Craig Roberts (Argonne National Lab)

Understanding neutron stars with terrestrial experiments
ECT Colloquium*
22 Oct 2015
Laura Fabbietti (TU Munich)

The many angles of hadron production
ECT Colloquium*
28 Oct 2015
Marco Stratmann (Univ. of Tuebingen)

Information and statistics: a new paradigm in Theoretical Nuclear Physics
ECT Colloquium*
16 Nov 2015
Jorge Piekarewicz (Florida State University)

Sum rules for vector channel at finite temperature
ECT Seminar*
17 Nov 2015
Daisuke Sato (ECT*)

Improving the kinematics for high-energy QCD evolution equations in coordinate space
ECT Seminar*
25 Nov 2015
Guillaume Clement Beuf (ECT*)

Baryonic matter and renormalisation group
ECT Seminar*
22 Dec 2015
Wolfram Weise (ECT* and TU Munich)

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 the just started H2020 (2014-2020) and ECT* have been a constant presence in QIPC consortia.
- This continues to be true at present, since during 2015 D. Binosi actively worked on the Coordination Action **QUTE-EUROPE** (Quantum Technologies for Europe) in which he contributes to Work-Package 2 (Coordination and Collaboration) and 3 (Dissemination). The funding for the ECT* node is 37,450.00€ for 3 years.
- In addition, D. Binosi has been actively contributing to the preparation of the Coordination Action “Quantum Emerging Technologies”, that has been submitted to the Horizon 2020 program of the European Commission (Call: H2020-FETOPEN-2015-CSA Topic: FETOPEN-CSA-FETEXCHANGE-2015 Type of action: CSA, Proposal number: 713288, Proposal acronym: QET). If accepted the funding of the ECT* node will be is 37,500.00€ for 3 years

6 ECT*-LISC 2015

6.1 Introduction and Summary

The current trend in materials science consists in the development of an interdisciplinary approach covering all the length scales from the nanometer (electronic structure) to mesoscopic (molecular and supramolecular) and continuum (mechanical and thermal properties). A joint theoretical and experimental approach has been proven to be very efficient in understanding the properties of modern materials, thus optimizing them for practical applications.

LISC hosts researchers with expertise in theoretical study of solid-state systems using a variety of computational approaches, 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 and optical properties of materials, electron spectroscopy, metal-organic frameworks, quantum statistical mechanics, and nuclear physics in a broad sense.

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 scientists in the Trento area.

6.2 ECT* - LISC 2015 Activities and Results

Fano's approach to discrete-continuum interaction

A theoretical study of a number of results in apparently conceptually distant research areas, ranging from core-electron spectroscopies to the description of universal properties in ultra-cold Fermi gases, and from the investigation of β-decay in heavy nuclei to the nucleosynthesis of the elements in stars, has been reached within a general framework based on the Fano's approach to discrete-continuum interaction [1,2].

This unified method is capable of analyzing the dynamics of atoms, molecules, and solids under the influence of incident radiation or electron beams and, simultaneously, to predict quantitatively the spectral line shapes correlating their features with the internal dynamic of the perturbed system.

On the computational side, we demonstrated by using the concept of the multichannel scattering T-matrix that our approach is amenable to efficient program implementations for determining numerically continuum wave functions including the main correlation effects. A variety of algorithms and computational procedures were used to implement our scattering approach for limiting the computational cost of the calculations.

In particular, we showed how our approach can be used to disentangle conformational changes and characterize folding of biological samples, complementing in this respect ultraviolet 2D spectroscopy and nuclear magnetic resonance (NMR) [3]. We simulated the 1s sulfur core levels for a number of configurations of a model tetrapeptide in solution. This biomolecule folds in solution from an open configuration where sulfur atoms are very far each other, to a T-stacked native state forming a disulfide bridge. By using our scattering approach we demonstrated that core-electron analysis is a valid alternative to 2D-UV and 2D-IR spectroscopies for disentangling conformational dynamics of proteins. Indeed, we were able to characterize, by using calculated core-level shifts, folded and unfolded configurations, finding sizably different signals (above 0.6 eV with respect to the folded reference state), which could be in principle detected by experimental measurements performed at synchrotron facilities.

Investigation of materials growth from first-principles

A second line of research has been pursued by investigating materials growth from first-principles [4]. In particular, we used high-kinetic energy impacts between inorganic surfaces and molecular beams seeded by organics to activate chemical-physical processes leading to nanocrystals growth. We focussed on single-layer graphene synthesis on copper by C_{60} supersonic molecular beam (SuMBE) epitaxy at low temperature. Using a variety of electron spectroscopy techniques and first-principles simulations, we demonstrated graphene growth by SuMBE describing the chemical-physical mechanisms occurring during the growth. In particular, we found a crucial role of high-kinetic energy deposition in enhancing the organic/inorganic interface interaction, to control the cage openings and to improve the growing film quality. These results, while discussed in the specific case of graphene on copper, are potentially extendable to different metallic or semiconductor substrates and where lower processing temperature is desirable.

Non-Euclidean crystallographic groups and mechanically stable molecular structures
In order to open-up new research territories, we presented a number of results on the realization in our Euclidean 3-space of the wonders of Lobachevsky non-Euclidean geometry [5]. In particular, we combined the theoretical approach (group-theory, geometry, topology), with extensive and innovative numerical simulations, implemented in tailored codes. This led us to the first mechanically stable molecular structure that is a manifestation of a specific non-Euclidean crystallographic group. We found such group, and show how it is related to a negative-curvature counterpart of a Platonic solid, in the case of the Beltrami pseudosphere. This method might be applied to other surfaces of constant negative Gaussian curvature (e.g., we present the case of the elliptic pseudospheres, applications to the hyperbolic pseudospheres are immediate, we envisage how to proceed with the Dini surface, etc.). Clearly, these results point to a general procedure to generate all such surfaces. Recall that surfaces of constant negative Gaussian curvature are in correspondence with the sin-Gordon equation for solitonic excitations. Graphene hexagonal topology was of great help in designing the Beltrami pseudosphere. Furthermore, the choice of graphene was dictated by theoretical results by one of us, where a correspondence was found between the physics of conductivity electrons of graphene membranes with 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 spacetimes, whose “Planck length” is the carbon-to-carbon bond-length of graphene. This work has thus far and wide implications ranging from non-Euclidean geometry, to certain black-hole scenarios; from the generalized Thomson problem, to material science. Finally, as is well known, graphene is an important material, for a plethora of applications in condensed matter physics and beyond.

Plasmonics and optical properties of materials
This work is a joint computational and experimental investigation on the optical properties of silver nanoparticles embedded in a SiO_2 anti-reflective-coating (ARC) located on top of a crystalline silicon wafer [6]. The effect of the particle size, particle position within the ARC layer, and surface coverage on the light transmitted into the silicon crystal are simulated by a finite-difference time-domain (FDTD) in-house software. On the experimental side, a composite anti-reflective structure, made of a silica layer with embedded silver nanoparticles, is deposited on top of silicon wafers. Samples differing in the size and position of the embedded metal particles are produced. For each configuration, the total reflectance is optically measured by means of a photo spectrometer coupled to an integrating sphere. We provide direct comparison of experimental and simulation results, along with an exhaustive discussion about the transmission efficiency of the investigated systems. We also discuss how our analysis might be extended to different configurations and cell design.

Electron energy loss and optical properties of materials
This work is part of a long term investigation aimed at deriving the optical properties of materials from electron energy loss measurements in the reflection geometry (REELS) [7-10]. In this regard, the fact is exploited that the cross section for electron inelastic scattering depends on the material dielectric function, from which, in turn, the optical properties can be calculated. Retrieving however the dielectric function from REELS measurements is not an easy task and it requires a detailed understanding of electron energy loss spectra. Over the last period, we focussed in particular on the role of the momentum transfer in determining the spectra.

Computational modeling of adsorption in condensed matter systems
We contributed to the characterization of the adsorption properties of hydrogen and methane in novel pillared graphene-oxide nanostructures, and contributed with a review chapter and a paper on the principal simulation methods used to study the adsorption of quantum particles (mostly hydrogen and its isotopologues) in Metal-Organic Frameworks [11,12].

Secondary electrons energy deposition produced by proton beams in PMMA
We have studied the radial dependence of the energy deposition of the secondary electron generated by swift proton beams incident with energies T=50keV–5MeV on polymethylmethacrylate (PMMA) [13]. Two different approaches have been used to model the electronic excitation spectrum of PMMA through its energy loss function (ELF), namely the extended-Drude ELF [14] and the Mermin ELF [15]. The average energy of the generated secondary electrons show sizeable differences when evaluated with these two ELF models.

Organic photovoltaic
With organic photovoltaic (OPV) technology moving towards commercialization, high-throughput analytical techniques are required to study the nanoscale morphology of OPV blends [16]. The possibility of separating the topographical and chemical information in a polymer nano-composite, using low-voltage SEM imaging, was calculated using a Monte Carlo simulation [17]. We have also shown that energy-selective secondary electron detection can be used to obtain high-contrast, material-specific images of an organic photovoltaic blend. [18].

Interdisciplinary research
A significant part of the activity has been devoted to interdisciplinary research: in particular we wrote parallel codes used in the investigation of electron scattering in solids, the calculation of virial coefficients of non-degenerate quantum gases, and contributed to the numerical solution of master equations describing the motion of heavy quarks in abelian quark-gluon plasmas.

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6.3 Publications of ECT* - LISC Researchers in 2015

Silvio a Beccara

S. a Beccara, L. Fant, P. Faccioli
Variational scheme to compute protein reaction pathways using atomistic force fields with explicit solvent
Phys. Rev. Lett. 114 (2015) 098103

Lucia Calliari

L. Calliari, M. Dapor, G. Garberoglio, S. Fanchenko
Reflection electron energy loss spectra beyond the optical limit

Nucl. Instr. Methods Phys. Res. B 352 (2015) 171

M. Dapor, G. Garberoglio, L. Calliari
Energy loss of electrons impinging upon glassy carbon, amorphous carbon, and diamond: Comparison between two different dispersion laws
Nucl. Instr. Methods Phys. Res. B 352 (2015) 181

Maurizio Dapor

M. Dapor
Mermin differential inverse inelastic mean free path of electrons in polymethylmethacrylate
Frontiers in Materials 2 (2015) 27

S. Taioli, M. Dapor, N. Pugno
Editorial: New frontiers in multiscale modelling of advanced materials
Frontiers in Materials 2 (2015) 71

R. C. Masters, A. J. Pearson, T.S. Glen, F.I Sasam, L. Li, M. Dapor, A. M. Donald, D. Lidzey, C. Rodenburg
Sub-nanometre resolution imaging of polymer– fullerene photovoltaic blends using energy-filtered scanning electron microscopy
Nature Communications 6 (2015) 6928

M. Dapor
Energy loss of fast electrons impinging upon polymethylmethacrylate
Nucl. Instr. Methods Phys. Res. B 352 (2015) 190

L. Calliari, M. Dapor, G. Garberoglio, S. Fanchenko
Reflection electron energy loss spectra beyond the optical limit
Nucl. Instr. Methods Phys. Res. B 352 (2015) 171

M. Dapor, G. Garberoglio, L. Calliari
Energy loss of electrons impinging upon glassy carbon, amorphous carbon, and diamond: Comparison between two different dispersion laws
Nucl. Instr. Methods Phys. Res. B 352 (2015) 181

M. Dapor, I. Abril, P. de Vera, R. Garcia-Molina
Simulation of the secondary electrons energy deposition produced by proton beams in PMMA: influence of the target electronic excitation description
Eur. Phys. J. D 69 (2015) 165

Q. Wan, R. A. Plenderleith, M. Dapor, S. Rimmer, F. Claeyssens, C. Rodenburg
Separating topographical and chemical analysis of nanostructure of polymer composite in low voltage SEM
Journal of Physics: Conference Series 644 (2015) 012018

R. C. Masters, Q. Wan, Y. Zhou, A. M. Sandu, M. Dapor, H. Zhang, D. G. Lidzey and C. Rodenburg
Application of low-voltage backscattered electron imaging to the mapping of organic photovoltaic blend morphologies
Journal of Physics: Conference Series 644 (2015) 012017

Giovanni Garberoglio

G. Garberoglio, N. Pugno, S. Taioli
Gas asorption and separation in realistic and idealized frameworks of organic pillared graphene: a comparative study
J. Phys. Chem. C, 2015, 119 (4), pp 1980–1987

G. Garberoglio
Modeling quantum effects on adsorption and diffusion of hydrogen in metal–organic frameworks
Metal-Organic Frameworks 6 (2015) 214

L. Calliari, M. Dapor, G. Garberoglio, S. Fanchenko
Reflection electron energy loss spectra beyond the optical limit
Nucl. Instr. Methods Phys. Res. B 352 (2015) 171

M. Dapor, G. Garberoglio, L. Calliari
Energy loss of electrons impinging upon glassy carbon, amorphous carbon, and diamond: Comparison between two different dispersion laws
Nucl. Instr. Methods Phys. Res. B 352 (2015) 181

Simone Taioli

G. Garberoglio, N. Pugno, S. Taioli
Gas adsorption and separation in realistic and idealized frameworks of organic pillared graphene: a comparative study
J. Phys. Chem. C, 2015, 119 (4), pp 1980–1987

S. Taioli, M. Dapor, N. Pugno
Editorial: new frontiers in multiscale modelling of advanced materials
Frontiers in Materials 2 (2015) 71

S. Taioli, S. Simonucci, S. a Beccara, M. Garavelli
Tetrapeptide unfolding dynamics followed with core-level spectroscopy: a first-principles approach
Phys. Chem. Chem. Phys. 17(2015) 11269

S. Taioli
A bird's eye view on the concept of multichannel scattering with applications to materials science, condensed matter, and nuclear astrophysics
Frontiers in Materials 2 (2015) 33

L. Aversa, S. Taioli, M.V. Nardi, R. Tatti, R. Verucchi, S. Iannotta
The interaction of C60 on Si(111) 7 × 7 studied by supersonic molecular beams: interplay between precursor kinetic energy and substrate temperature in surface activated processes
Frontiers in Materials

6.4 Talks presented by ECT* - LISC Researchers

Maurizio Dapor

Application of the Monte Carlo method to electron scattering problems

Seminar at Univ. of Sheffield, UK
12 Jan 2015

The Monte Carlo method. An Introduction.
Conference at University of Sheffield, UK
26 Nov 2015

Simone Taioli

Theoretical estimates of stellar e-captures from first-principles simulations
Invited lecture at 12th Russbach School on Nuclear Astrophysics, Rußbach, Austria
09 Mar 2015

The growth of carbon-based materials by supersonic beam epitaxy: experiments, theory and calculations
Graphene - the Bridge between Low- and High-Energy Physics, in Prague, Czech Republic
15 Sep 2015

From materials science to astrophysics with multichannel scattering theory
Invited plenary talk at the Nanoscience & Nanotechnology 2015 conference, Frascati – Rome
30 Sep 2015

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 8 laptops for the workshop partecipants:
Laptops DELL latitude E6510
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 to 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.