ECT*

Annual Report 2014

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

Institutional Member of the European Science Foundation Expert Committee NuPECC

FONDAZIONE
BRUNO KESSLER

ECT*

Edited by
Susan Driessen and Gian Maria Ziglio

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 762 scientists from 39 countries have visited the ECT* in 2014 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 communities.

In 2014 ECT* held:

- 17 Workshops and 4 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 "Heavy-ion collisions: exploring matter under extreme conditions" that lasted 6 weeks and was attended by 35 students from 16 countries worldwide.

- a TALENT (Training in Advanced Low-Energy Nuclear Theory) course on "Density functional theory and self-consistent methods" that lasted 3 weeks and was attended by 25 students from 12 countries.

In addition to these 23 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 Chapter 4 of this Annual Report. More than thirty publications by the ECT* researchers in refereed (impact factor) journals in 2014 represent a substantial fraction of all publications produced within the Fondazione Bruno Kessler in the same year.

ECT*'s international cooperation agreements with RIKEN and the National Astronomical Observatory of Japan, initiated in 2013, have already seen a welcome development in terms of workshop activities and scientific exchange in 2014. A new cooperation agreement, signed in 2014, with the Institute of Theoretical Physics of the Chinese Academy of Sciences in Beijing will further enhance ECT*'s international scientific profile.

Preparations for the integration of LISC, the Interdisciplinary Laboratory for Computational Science of FBK, as a research unit of ECT* have been progressing steadily. ECT*- LISC will be fully effective in 2015. Furthermore, ECT* has started a fruitful cooperation with TIFPA, the new 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 2014 has only been possible through a stable operating budget. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research centres in Belgium, the Czech Republic, Denmark, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, and the UK, and funds provided through the European FP7 projects Hadron Physics3, ENSAR, QUIE2T and Qute-Europe. Within FP7 ECT* has played an important role as a Trans-National Access (TNA) facility. ECT* also acknowledges partial support for its workshops from the ExtreMe Matter Institute EMMI, the Helmholtz International Center (HIC for FAIR), and the Goethe University of Frankfurt/Main.

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 2014 is also available on the ECT* web site (www.ectstar.eu).

Trento, March 2015

Wolfram Weise
*Director of ECT**

Contents

2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Baha Balantekin	University of Wisconsin, Madison, USA
Angela Bracco	NuPECC/University of Milano, Italy
François Gélis	CEA Saclay, France
Maria-Paola Lombardo	INFN Frascati, Italy
Judith McGovern	University of Manchester, UK
Paul-Henri Heenen	Université Libre de Bruxelles, Belgium
Piet Mulders	VU Amsterdam, Netherlands
Arturo Polls (until June 2014)	University of Barcelona, Spain
Johanna Stachel	University of Heidelberg, Germany
Ubirajara van Kolck (from September 2014)	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**

Daniele Binosi, Italy
Marco Cristoforetti, Italy (until 30/11/14)
Alexis Diaz-Torres, Germany
Daniel Gazda, Czech Republic
Philipp Gubler, Switzerland (from 01/11/14)
David Ibañez Gil de Ramales, Spain
Abhishek Mukherjee, India (until 31/08/14)
Daisuke Sato, Japan (from 01/10/14)
Dionysis Triantafyllopoulos, Greece

- **PhD Students**

Maddalena Boselli, Italy
Matthias Drews, Germany
Robert Lang, Germany

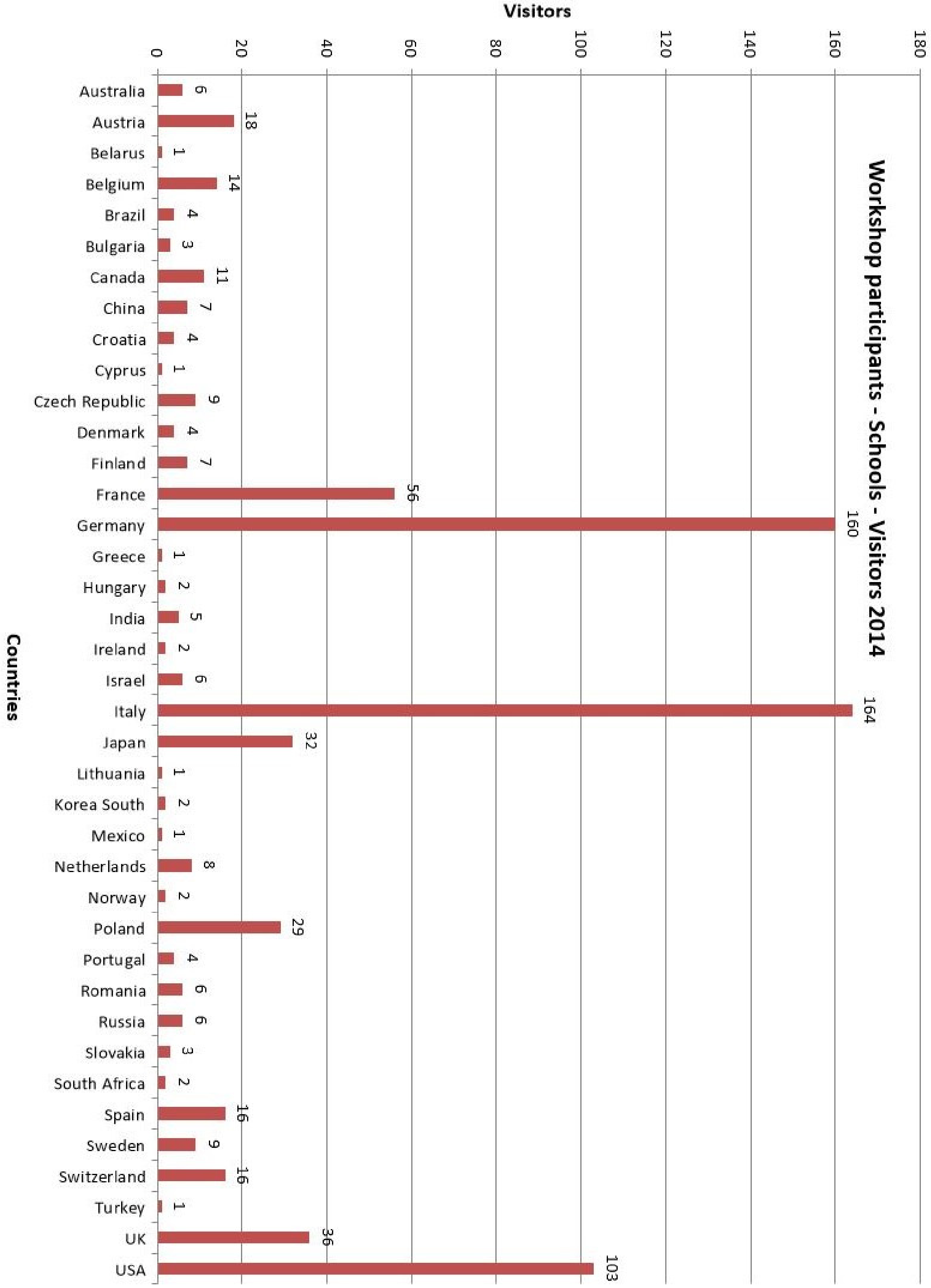
2.4 Visitors in 2014

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).

Paolo Giuseppe Alba (06/04-18/04, 25/04-13/05)	University of Torino, Italy (TS)
Michael Altenbuchinger (18/02-19/02)	TU München, Germany (VS)
Pieter Arnold (11/05-17/05)	University of Virginia, USA (DTP)
Alexander Arzhanov (13/07 -02/08)	TU Darmstadt, Germany (TS)
Jonah Bernhard (05/04-17/05)	Duke University, Durham, USA (TS)
Grahame Blair (02/10-04/10)	STFC, UK (VS)
Scott Bogner (13/07-26/07)	Michigan State University, USA (TS)
Juan Pablo Carlomagno (06/04-18/05)	UNLP, Buenos Aires, Argentina (DTP)
Nuria Carrasco Vela (19/05-23/05)	University of Roma, Italy (VS)
Wei-Chia Chen (13/07 -02/08)	Florida State University, USA (TS)
Camille Colle (13/07 -02/08)	Ghent University, Belgium (TS)
Lorenzo Contessi (14/07-01/08)	University of Trento, Italy (TS)
Pedro De Almeida Bicudo (23/11-29/11)	CFTP, Lisboa, Portugal (VS)
Jan Dobes (02/10-04/10)	ASCR, Czech Republic (VS)
Matthias Drews (17/02-21/02, 14/04-18/04, 01/09-04/09)	TU München, Germany (VS)
Alexander Dyhdalo (13/07 -02/08)	Ohio State University, USA (TS)
Thomas Epelbaum (06/04-16/05)	IPhT, CEA Saclay, France (DTP)
Laura Fabbietti (27/04-28/04)	TU München, Germany (VS)
Francesco Fambri (07/04-11/04)	University of Trento, Italy (DTP)
Zuzana Fekova (06/04-17/05)	Pavol Jozef Safarik University, Kosice, Slovakia (DTP)
Fabrizio Ferrari Ruffino (14/07-01/08)	University of Trento, Italy (TS)
Harald Fritzsch (14/04-18/04)	Ludwig Maximilians University, München, Germany (VS)
John Fuini (05/04-17/05)	University of Washington, USA (DTP)
Yuan Gao (13/07 -02/08)	University of Jyväskylä, Finland (TS)
François Gélis (06/05-10/05)	CEA Saclay, France (DTP)
Mattia Giardini (01/08-31/08)	Ulm University, Germany (VS)
Samuel Andrea Giuliani (13/07 -02/08)	TU Darmstadt, Germany (TS)
Carlo Guaraldo (09/07-10/07)	INFN LNF, Italy (VS)
Dominique Guillemaud-Mueller (02/10-04/10)	CNRS/IN2P3, France (VS)
Morten Hjorth-Jensen (13/07-26/07)	Mich. State Univ., USA and Univ. of Oslo, Norway (TS)
Jeremy Holt (06/07-11/07)	University of Washington, Seattle, USA (VS)
Masaru Hongo (06/04-17/05)	RIKEN and University of Tokyo, Japan (DTP)
Edmond Iancu (07/04-11/04)	CEA Saclay, France (VS)
Aurelian Isar (02/10-04/10)	NIPNE, Bucarest, Romania (VS)
Adam Jones (13/07 -02/08)	Michigan State University, USA (TS)
Norbert Kaiser (18/02-19/02)	TU München, Germany (VS)
Konstantinos Karakatsanis (13/07 -02/08)	University of Thessaloniki, Greece (TS)
Maciej Konieczka (13/07 -02/08)	University of Warsaw, Poland (TS)
Vladimir Kovalenko (07/04-17/05)	St. Petersburg State University, Russia (DTP)
Gwendolyn Lacroix (05/01-18/01)	University of Mons, Belgium (VS)

Mikko Laine (27/04-03/05)	University of Bern, Switzerland (DTP)
Robert Lang (06/04-17/05, 09/09-12/09, 19/10-23/10)	TU München, Germany (DTP, VS)
Justin Lietz (13/07 -02/08)	Michigan State University, USA (TS)
Zhe Liu (09/04-19/05)	Columbia University, New York, USA (DTP)
Mariapaola Lombardo (01/09-04/09)	INFN Frascati, Italy (VS)
Kliminad Mamo (06/04-18/05)	University of Illinois, Chicago, USA (DTP)
Vincent Mathieu (05/01-18/01, 14/04-19/04, 23/06-30/06)	Indiana University, USA (VS)
Surasree Mazumber (07/04-17/05)	Variable Energy Cyclotron Centre, Kolkata, India (DTP)
Angela Mecca (13/07 -02/08)	University of Roma, Italy (TS)
Ben Meiring (06/04-17/05)	University of Cape Town, South Africa (DTP)
Jan Mierzejewski (09/03-22/03)	University of Warsaw, Poland (VS)
Guilherme Milhano (13/04-19/04)	CENTRA, Lisbon and CERN, Switzerland (DTP)
Vincenzo Minissale (05/04-19/04)	University Catania, Italy (DTP)
Sukanya Mitra (07/04-18/05)	Variable Energy Cyclotron Centre, Kolkata, India (DTP)
Pablo Morales (06/04-18/05)	University of Tokyo, Japan (DTP)
J. Scott Moreland (05/04-17/05)	Duke University, Durham, USA (DTP)
Titus Morris (13/07 -02/08)	Michigan State University, USA (TS)
Eugenio Nappi (02/10-04/10)	INFN Bari, Italy (VS)
Daniel Ciprian Negrea (13/07 -02/08)	NIPNE, Bucarest, Romania (TS)
Saehanseul Oh (06/04-16/05)	Yale University, USA (DTP)
Kazuhisa Okamoto (06/04-17/05)	Nagoya Univesity, Japan (DTP)
Dmytro Oliinychenko (06/04-17/05)	FIAS, Frankfurt, Germany (DTP)
Lucia Oliva (06/04-12/04, 27/04-02/05)	University of Catania, Italy (DTP)
Simone Orioli (14/07-01/08)	University of Trento, Italy (TS)
Giuseppina Orlandini (28/07-01/08)	University of Trento, Italy (TS)
Daniel Pablos (06/04-17/05)	Universitat de Barcelona, Spain (DTP)
Jean-François Paquet (05/04-17/05)	McGill University, Montréal, Canada (DTP)
Nathan Parzuchowski (13/07 -02/08)	Michigan State University, USA (TS)
Stefan Petschauer (18/02-19/02)	TU München, Germany (VS)
Semyon Pozdnykov (06/04-18/05)	Saint-Petersburg State University, Russia (DTP)
Armando Puglisi (04/04-16/05)	University Catania, Italy (DTP)
David Regnier (13/07 -02/08)	Lawrence Livermore National Laboratory, USA (TS)
Anton Repko (13/07 -02/08)	Charles University of Prague, Czech Republic (TS)
Achim Richter (02/06-13/06, 18/11-21/11)	TU Darmstadt, Germany (VS)
Peter Ring (13/07-02/08)	TU München, Germany (TS)
Georges Ripka (01/04-19/05)	CEA Saclay, France (DTP)
Dirk Rischke (02/10-04/10)	University of Frankfurt, Germany (VS)
Fernando Roca (13/07 -02/08)	Universidad Autónoma de Madrid, Spain (TS)
Noemi Rocco (13/07 -02/08)	University of Roma, Italy (TS)
Jean-Bernard Rose (05/04-18/05)	McGill University, Montréal, Canada (DTP)
Patricia Roussel-Chomaz (02/10-04/10)	CEA Saclay, France (VS)
Andrey Sadofyev (04/04-16/05)	Massachusetts Institute of Technology, USA (DTP)
Vazgen Sargsyan (31/05-14/06)	JINR, Dubna, Russia (VS)
Nicolas Schunck (13/07-31/07)	Lawrence Livermore National Laboratory, USA (TS)
Gregory Soyez (13/04-18/04)	CEA Saclay, France (DTP)
Enrico Speranza (05/04-17/05)	GSI, Darmstadt, Germany (DTP)
Paul Springer (18/02-19/02)	TU München, Germany (VS)
Iwona Sputowska (05/04-18/05)	Polish Academy of Sciences, Krakow, Poland (DTP)
Sam Stevens (13/07 -02/08)	Ghent University, Belgium (TS)
Pieter Taels (06/04-16/05)	Universiteit Antwerpen, Belgium (DTP)
Derek Teaney (05/04-12/04)	Stony Brook University, USA (DTP)
Lauro Tomio (08/07-12/07)	Università di Sao Paolo, Brazil (VS)
Deni Vale (13/07 -02/08)	University of Zagreb, Croatia (TS)
Marco Van Leeuwen (21/04-26/04)	Universiteit Utrecht, Netherlands (DTP)

Oton Vazquez Doce (27/04-28/04)	TU München, Germany (VS)
Dario Vretenar (13/07-02/08)	University of Zagreb, Croatia (TS)
Jochen Wambach (05/09-14/09)	TU Darmstadt, Germany (VS)
Fan Wang (30/08-06/09)	Nanjing University, China (VS)
Daniel Ward (13/07 -02/08)	Lund University, Sweden (TS)
Corbinian Wellenhofer (18/02-19/02)	TU München, Germany (VS)
Douglas Wertepny (05/04-18/05)	The Ohio State University, USA (DTP)
Mohammed Younus (07/04-17/05)	Bose Insitute, Kolkata, India (DTP)
Olindo Zanotti (07/04-11/04, 21/04-02/05)	University of Trento, Italy (DTP)
Chunli Zhang (13/07 -02/08)	University of Tennessee, USA (TS)
Anna J. Zsigmond (06/04-17/05)	Wigner Centre, Budapest, Hungary (DTP)



Workshop participants - Schools - Visitors 2014
Visitors
0
20
40
60
80
100
120
140
160
180
Countries
Australia 6
Austria 18
Belarus 1
Belgium 14
Brazil 4
Bulgaria 3
Canada 11
China 7
Croatia 4
Cyprus 1
Czech Republic 9
Denmark 4
Finland 7
France 56
Germany 160
Greece 1
Hungary 2
India 5
Ireland 2
Israel 6
Italy 164
Japan 32
Lithuania 1
Korea South 2
Mexico 1
Netherlands 8
Norway 2
Poland 29
Portugal 4
Romania 6
Russia 6
Slovakia 3
South Africa 2
Spain 16
Sweden 9
Switzerland 16
Turkey 1
UK 36
USA 103

3 Scientific Projects in 2014

3.1 Summary

Altogether 23 scientific projects have been run in 2014: 17 workshops, 4 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 extended programme.

3.2 Workshops, Collaboration Meetings and Schools (Calendar)

Jan 14 – 16	**Lattice QCD and Hadron Physics** Elena Santopinto *(INFN-Genova)* Maria Paola Lombardo *(INFN – LNF/Frascati)* Pietro Colangelo *(INFN-Bari)* Marco Battaglieri *(INFN- Genova)*
Feb 24 - 28	**Quantum Mechanics Tests in Particle, Atomic, Nuclear and Complex Systems: 50 Years after Bell's Renowned Theorem** Beatrix Hiesmayr *(University of Vienna)* Catalina Curceanu *(LNF – INFN Frascati)* Andreas Buchleitner *(University of Freiburg)*
Apr 07 - 11	**Simulating the Supernova Neutrinosphere with Heavy Ion Collisions** Charles Horowitz *(Indiana University)* Joe Natowitz *(Texas A&M University)* Luke Roberts *(Caltech)* Hermann Wolter *(University of Munich)*
Apr 07 – May 16	**Heavy Ion Collisions: exploring nuclear matter under extreme conditions** **(Doctoral Training Programme)** François Gélis *(CEA Saclay)* Jean-Yves Ollitrault *(CEA Saclay)*
Apr 14 - 18	**QCD and Forward Physics at the LHC** Christophe Royon *(CEA Saclay)* Gregory Soyez *(CEA Saclay)* Antoni Szczurek *(Institute of Nuclear Physics PAN, Krakow)*
May 05 - 09	**Three-Body Forces: from Matter to Nuclei** Alexandros Gezerlis *(University of Guelph)* Kai Hebeler *(TU Darmstadt and EMMI)* Heiko Hergert *(Ohio State University)* Vittorio Soma *(CEA Saclay)*
May 12 - 16	**Hydrodynamics for Strongly Coupled Fluids** Thomas Schäfer *(North Carolina State University)*

	Jeon Sangyong *(McGill University)* Paul Romatschke *(University of Colorado)*
May 21 - 23	**Future Directions in the Physics of Nuclei at Low Energies** Ubirajara van Kolck *(IPN Orsay)* Faical Azaiez *(IPN Orsay)* Klaus Blaum *(MPI für Kernphysik Heidelberg)* Achim Schwenk *(TU Darmstadt)*
May 26 - 30	**Low-Energy Reaction Dynamics of Heavy-Ions and Exotic Nuclei** Alexis Diaz-Torres *(ECT*)* Nikolai Antonenko *(Bogoliubov Laboratory of Theoretical Physics)* Paulo Gomes *(Universidade Federal Fluminense)*
Jun 17 - 20	**New Frontiers in Multiscale Modelling of Advanced Materials** Simone Taioli *(FBK and University of Trento)* Nicola Pugno *(Unitn - FBK and Queen Mary University of London)* Maurizio Dapor *(FBK Trento)*
Jun 23 - 27	**Resonances and Non-Hermitian Quantum Mechanics in Nuclear and Atomic Physics** Christian Forssén *(Chalmers University of Technology Göteborg)* Nikolaj Zinner *(Aarhus University)* Robin Kaiser *(INLN Nice)*
Jun 30 - Jul 04	**Exciting Baryons: Design and Analysis of Complete Experiments for Meson Photoproduction** Lotar Tiator *(University of Mainz)* Jan Ryckebusch *(University of Ghent)* Annalisa D'Angelo *(University of Rome)*
Jul 14 – Aug 01	**Density Functional Theory and Self-Consistent Methods (TALENT)** Morten Hjorth-Jensen *(Michigan State University and University of Oslo)* Giuseppina Orlandini *(University of Trento)*
Jul 16 – 18	**Breakup Reactions of Exotic Nuclei and Related Topics** Paul-Henri Heenen *(Université Libre de Bruxelles)* Jacek Dobaczewski *(Warsaw University)* Helmut Leeb *(University of Wien)* Friedrich-Karl Thielemann *(University of Basel)*
Aug 25 - 29	**Spin and Orbital Angular Momentum of Quarks and Gluons in the Nucleon** Mauro Anselmino *(University of Turin)* Elliot Leader *(Imperial College, London)* Cédric Lorcé *(IPN Orsay and University of Liège)*
Sep 08 - 12	**Nuclear Physics and Astrophysics of Neutron-Star Mergers and Supernovae, and the Origin of R-Process Elements** Toshitaka Kajino *(National Astronomical Observatory of Japan and University of Tokyo)*

	Wako Aoki *(National Astronomical Observatory of Japan)* Akif Baha Balantekin *(University of Wisconsin-Madison, USA)* Masaomi Tanaka *(National Astronomical Observatory of Japan)*
Sep 22 - 26	**Dyson-Schwinger Equations in Modern Mathematics & Physics** Mario Pitschmann *(TU Vienna)* Wolfgang Lucha *(IHEP Vienna)* Craig D. Roberts *(Argonne National Laboratory)*
Sep 30	**BEC and Ultracold Gases Collaboration Meeting** Sandro Stringari (*University of Trento*) Rudolf Grimm (*University of Innsbruck*)
Oct 06 – 10	**QCD Hadronization and the Statistical Model** Reinhard Stock *(FIAS Frankfurt)* Francesco Becattini *(University and INFN Florence)* Marcus Bleicher *(FIAS Frankfurt)*
Oct 27 - 31	**Achievements and Perspectives in Low-Energy QCD with Strangeness** Catalina Curceanu *(LNF – INFN Frascati)* Laura Fabbietti *(Technische Universität München)* Carlo Guaraldo *(LNF – INFN)* Jiri Mares *(Nuclear Physics Institute ASCR)* Johann Marton *(SMI-Vienna)* Ulf-G. Meissner *(Universität Bonn and FZ Jülich)*
Nov 03 - 05	**Interdisciplinary Workshop on Statistical and Analysis Methods in Nuclear, Particle and Astrophysics** Andreas Müller *(Excellence Cluster Universe Munich), et al.*
Nov 10 - 14	**From Nuclear Structure to Particle-Transfer Reactions and Back** Marek Ploszajczak *(GANIL)* Jacek Dobaczewski *(Warsaw University)*
Nov 19 - 20	**3rd ADAMAS Collaboration Meeting: Advanced Diamond Assemblies at ECT*** Elèni Berdermann *(GSI)* Mladen Kiš *(GSI)* Christian Schmidt *(GSI)* Michael Traeger *(GSI)*

3.3 Reports on Workshops and Collaboration Meetings

3.3.1 LATTICE QCD AND HADRON PHYSICS

DATE: January 14 – 16, 2014

ORGANIZERS:

E. Santopinto *(INFN-Genova, Italy)*
M. P. Lombardo *(INFN- LNF Frascati, Italy)*
P. Colangelo *(INFN Bari, Italy)*
M. Battaglieri *(INFN Genova, Italy)*

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

- light and heavy flavour meson spectroscopy: experimental and theoretical results
- lattice results: hadron in spectroscopy and structure
- nucleon structure and three-dimensional picture
- amplitude analysis tools
- tools for cooperative development and computing infrastructure
- perspectives at CERN (COMPASS, LHC_b), PANDA (FAIR), CLAS12

SPEAKERS:

M. Battaglieri (INFN-Genova, Italy)
M. Peardon (Trinity College Dublin, Ireland)
E. Santopinto (INFN-Genova, Italy)
M. P. Lombardo (INFN-LNF, Italy)
P. Gianotti (INFN-LNF, Italy)
G. Salmè (INFN-Roma1, Italy)
M. Bochicchio (INFN-Roma1, Italy)
M. Radici (INFN-Pavia, Italy)
M. Papinutto (INFN-Roma1, Italy)
C. Ratti (Università di Torino, Italy)
F. Piccinini (INFN-Pavia, Italy)
M. Contalbrigo (INFN-Ferrara, Italy)
M. Caselle (Università di Torino, Italy)
A. Vladikas (Università di Roma2, Italy)
A. Martin (Università di Trieste, Italy)
P. Colangelo (INFN-Bari, Italy)
A. Pilloni (Università di Roma1, Italy)
C. Davies (Glasgow University, UK)
C. Patrignani (Università di Genova, Italy)
V. Mathieu (Indiana University, USA)
C. Claudio (CINECA, Italy)
E. Boglione (Università di Torino, Italy)

SCIENTIFIC REPORT:

Information about the meson spectrum and structure of the nucleon were collected in many different experiments over the last three decades using different probes and targets. Many leading laboratories in the world (BES, CERN, JLab, SLAC, Belle) and the new experimental facilities that will be built or upgraded in a near future (FAIR, JLAB12, JPARC) devote an important part of their physics program to understand the light quark spectroscopy and the internal structure of the nucleon. These new experiments with unprecedented statistics, with excellent resolution and with polarization observables measured, demand an unrivaled degree of detail in modeling the dynamics of strong interaction processes if new discoveries and insights into the hadron spectrum are to result. Thus the success of the new generation of experiments studying the fundamental spectroscopy of hadrons and the internal structure of the nucleon depends critically on the robust information that can be extracted about the scattering matrix elements for spectroscopy, and the novel parton distribution functions (GPD, TMD, ...) for the nucleon structure, parameterizing the non-perturbative hadron dynamics. During the workshop the key discussion points included: presentation of the experimental data, analysis collected by previous or running experiments (COMPASS and CLAS) and projected results expected from the future facilities (JLAB12 and PANDA); presentation of progress in developing tools to make the theoretical and phenomenological efforts applicable to experiments progress in QCD predictions of resonance parameters and feasibility of accurate non-perturbative QCD studies in the resonance region; presentation of the recent results. Regarding the nucleon structure the key talks discussed the amount of data already obtained and the new huge amount of data planned to be obtained in the future experiments. In particular a lot of phenomenological work has already been done on the study and extraction of TMDs: as far as TMD evolution is concerned, we have recently come a long way; there are now evolution schemes and some first attempts to the phenomenological study of the unpolarized distribution and fragmentation TMDs, on the TMD transversity and of the Sivers functions. These are very preliminary studies, which need to be refined. Anyway it was clear that structure and spectroscopy have to be studied together to obtain a deeper knowledge of the strong interaction.

LQCD results were presented regarding the hadron spectrum and the nucleon structure. In particular it has been discussed: i) the study of the elastic scattering using Luescher formalism and it has been shown that it works well; ii) the approaching the physical point where there is the opening of more thresholds and the difficulties to treat it. The next challenge will be what to do above the inelastic thresholds.

In particular a significant fraction of the workshop discussed the special needs of the new experiments where the High Performance Computing techniques will be required to deal with the huge expected statistics. Synergies between LQCD community, that routinely uses huge data samples and fast computing, and the tools required for future analysis were discussed finding a common ground for proposals and strategies.

Results and Highlights

The aim of the workshop was to bring together theoreticians from LQCD and Hadron Physics communities and experimentalists working on hadron spectroscopy and structure of the nucleon in leading laboratories in the world: JLab, GSI-FAIR, CERN. Open problems have been discussed triggering new common collaborative efforts in the field, both from the theoretical and experimental sides and moreover the spectroscopy community, the structure community and the lattice community agree that a more effective collaboration between the various theoretical communities can be beneficial for each of them, as well as a strong collaboration with the experimentalists. For this reason this hadron physics community has decided to meet again in one year. Finally, two dedicated working packages in the upcoming EU-funding program Horizon2020, called respectively “Hadron physics from lattice quantum field theory” and “HadronS: study of the spectrum of hadrons made by light and charm quarks” have been discussed and submitted.

3.3.2 QUANTUM MECHANICS TESTS IN PARTICLE, ATOMIC, NUCLEAR AND COMPLEX SYSTEMS: 50 YEARS AFTER BELL'S RENOWNED THEOREM

DATE: February 24 – 28, 2014

ORGANIZERS:

B.C. Hiesmayr *(University of Vienna, Austria)*
C. Curceanu *(LNF-INFN Frascati, Italy)*
A. Buchleitner *(University of Freiburg, Germany)*

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

This workshop was devoted to the heritage of John St. Bell and brought theoreticians and experimenters from many different fields together.

The main topics were:

- Quantum tests in Particle Physics
- neutral K-meson system, B-meson system, neutrinos, neutrons
- Quantum tests in condensed matter systems
- Quantum tests in Nuclear Physics
- Quantum tests in biological systems
- Quantum tests with ordinary matter and light-including molecules
- Relativistic entanglement

SPEAKERS:

A. Bassi (University of Trieste, Italy)
R. Bernabei (University of Roma Tor Vergata, Italy)
R. Bertlmann (University of Wien, Austria)
T. Brandes (TU Berlin, Germany)
A. Buchleitner (Albert-Ludwigs-University Freiburg, Germany)
I. Burghardt (Goethe University Frankfurt, Germany)
S. Campbell (Queen's University Belfast, United Kingdom)
E. Collini (University of Padova, Italia)
C. Curceanu (LNF-INFN, Italy)
A. Di Domenico (Sapienza University of Rome, Italy)
A. Diaz-Torres (ECT*, Italy)
S. Donadi (University of Trieste, Italy)
T. Durt (Institut Fresnel, France)
S. Filipp (ETH Zurich, Switzerland)
N. Friis (Austrian Academy of Sciences, Austria)
M. Genovese (INRIM, ITALY)

G. Ghirardi (ICTP, Italy)
S. Giampaolo (University of Wien, Austria)
A. Großardt (University of Trieste, Italy)
P. Haslinger (University of Wien, Austria)
B. Hiesmayr (University of Wien, Austria)
M. Huber (Universitat Autonoma de Barcelona, Spain)
F. Illuminati (University of Salerno, Italy)
G. Krizek (University of Wien, Austria)
A. Kupsc (Uppsala University, Sweden)
W. Löffler (Leiden University, The Netherlands)
J. Marton (Austrian Academy of Sciences, Austria)
E. Milotti (University of Trieste, Italy)
I. Pikovski (University of Wien, Austria)
E. Schneider (University of Trento, Italy)
F. Sciarrino (Sapienza University of Rome, Italy)
M. Tichy (University of Aarhus, Denmark)
M. Tiersch (University of Innsbruck, Austria)
H. Ulbricht (University of Southampton, UK)
J. Vaccaro (Griffith University, Australia)
M. Weitz (University of Bonn, Germany)

SCIENTIFIC REPORT:

Exactly 50 years ago John Steward Bell, a worldwide recognised theoretician at CERN, published a paper on a field he considered his hobby: foundations of quantum mechanics. He came up with an experimentally testable theorem that has to be fulfilled for any local realistic theory, but is in contradiction with the predictions of quantum theory. This seminal work initiated a new research line, far beyond the expected scope, and lead to new possible applications such as quantum cryptography or a formidable quantum computer.
In different words, Bell theorem gives a device-independent toolbox to prove when quantum systems outperform systems that can be described with classical theories. This workshop was devoted to the heritage of John St. Bell and brought theoreticians and experimenters from many different fields together.
Superposition and entanglement are basic ingredients for the explanation of various quantum phenomena for physical systems at different energy scales and of different complexity.
There have been talks dealing with neutral K-mesons which are entangled in their strangeness property. This system that oscillates between the particle and antiparticle state has been shown to be a unique laboratory for fundamental studies. In particular, Bell's theorem is violated due to a tiny violation of the matter-antimatter symmetry, experimentally found in the same year in which John Bell published his seminal paper. It was shown that since the generator of time evolution (Hamiltonian) is not symmetric with respect to the violation of the time-reversal symmetry, for a certain toy model of the universe, that this tiny difference measured in meson systems has a huge impact on cosmological scales.
There have been talks dealing with biological systems, such as the light harvesting complexes (photosynthesis) or the radical pair creation for the navigation of birds, or charge separation in organic solar cells, discussing whether genuine quantum effects could be responsible for a high efficiency.
Taking into account that all experiments are so far in agreement with the predictions of (standard) quantum theory, one is tempted to think that this theory is the fundamental one. Then immediately one runs into the problem of how one should explain the absence of superpositions in the macroscopic world. Collapse models provide a mathematical framework that explains the transition from a quantum to a classical world and provide new

predictions for the regime in-between. Some talks dealt with these predictions for different physical systems; it was noted that not only massive interfering systems may provide new experimental results in the near future. On the theoretical perspective, discussions focused on whether dark matter could provide an explanation.
Several talks referred to condensed matter systems, showing that genuine multipartite entanglement plays an important role in order to understand the physical properties of these systems. The orbital angular momenta of entangled photons provide us with a controllable system, allowing to reveal the power of entanglement in multipartite and multidimensional space.

Results and Highlights

The researchers participating in this workshop succeeded in finding a common language to address fundamental problems concerning the foundations of quantum theory, working out the respective advantages and disadvantages of distinct physical systems and developing approaches aiming to bring us to a unified picture.
On Tuesday, 25th February, there was a panel discussion about “the role of superposition or entanglement in our universe”. The panel and the active participants came up with different views, and the only agreement was that we still do not know enough about quantum theory to grab the underlying picture.
Last but not least, there were two talks by Reinhold A. Bertlmann and Giancarlo Ghirardi on their personal encounters with John St. Bell. The particle physicist Bertlmann told the story of how “Bertlmann’s socks” became subject of physics and how this brought him into the very foundations of quantum mechanics. Giancarlo Ghirardi, one of the three founders of the collapse models, emphasised how John St. Bell understood from the very beginning his exceptional contribution to the foundations, currently under extensive investigations. The workshop certainly benefited from the presence of these two researchers who experienced the exciting half century since Bell’s seminal paper.

3.3.3 SIMULATING THE SUPERNOVA NEUTRINOSPHERE WITH HEAVY ION COLLISIONS

DATE: April 7 – 11, 2014

ORGANIZERS:

C. Horowitz *(Indiana University, USA)*
J. Natowitz *(Texas A&M University, USA)*
L. Roberts *(Caltech, USA)*
H. Wolter *(Munich, Germany)*

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

The idea of this workshop was to explore the feasibility of reproducing supernova neutrinosphere conditions in the laboratory using heavy ion collisions with both stable and radioactive beams. Thus the workshop discussed the following main topics:

1) The equation of state and neutrino opacities of low-density neutron rich matter.
2) Using heavy ions to probe conditions in the supernova neutrino emission region.
3) Light cluster formation in heavy ion collisions and in the supernova neutrino sphere.
4) Neutrino emission and nucleosynthesis in core collapse supernovae.

A special aspect of this workshop was to bring together different communities in nuclear and astrophysics to discuss these questions: heavy ion experimentalists and theorists, many-body theorists, astrophysicists, and neutrino physicists. We succeeded in attracting representatives from most of the important groups currently working in these fields. A list of speakers and the program are provided as an attachment to this report. The intention of the workshop was to initiate a longer-term joint effort on this topic within the communities represented.

SPEAKERS:

M. Barbui (Texas A&M, USA)
D. Blaschke (Wroclav, Poland)
A. Bonasera (Texas A&M, USA)
E. Bonnet (GANIL, France)
A. Chbihi (GANIL, France)
T. Fischer (Wroclav, Poland)
C. Froehlich (N. Carolina State, USA)
T. Gaitanos (Giessen, Germany)
K. Hagel (Texas A&M, USA)
M. Hempel (Basel, Switzerland)
E. Lentz (Tennessee, USA)
W. Lynch (MSU, USA)
G. Martinez-Pinedo (TU Darmstadt, Germany)
G. McLaughlin (N. Carolina State, USA)
B. Mueller (Garching, Germany)

A. Mukherjee (ECT*, Italy)
J. Natowitz (Texas A&M, USA)
P. Napolitani (Orsay, France)
E. O'Connor (Toronto, Canada)
A. Ono (Tohoku, Japan)
A. Raduta (Bukarest, Romania)
S. Reddy (INT Seattle, USA)
G. Roepke (Rostock, Germany)
G. Shen (TU Darmstadt, China)
S. Shlomo (Texas A&M, USA)
W. Trautmann (GSI, Germany)
S. Typel (GSI, Germany)
G. Verde (Catania, Italy)
S. Wanajo (NAO, Japan)
A. Wuosmaa (Univ. of Connecticut, USA)
S. Yennello (Texas A&M, USA)

SCIENTIFIC REPORT:

Core collapse supernovae (SN) are giant explosions of massive stars that are dominated by neutrino emission. Much of the "action" in these SN occurs at sub-saturation densities near the neutrinosphere. The neutrinosphere is the surface of last scattering for the neutrinos and occurs at densities of 1/1000 to 1/10 of nuclear density and at temperatures near 4-5 MeV. The thermodynamical properties of this medium, in particular the composition, are important for the neutrino opacities, which in turn help determine the spectrum of emitted neutrinos, the composition of the neutrino driven wind, and the resulting nucleosynthesis. In the workshop we discussed how these conditions can be produced in low to intermediate energy heavy ion collisions (HIC), since in the expansion phase of a HIC the composition freezes out at similar densities and temperatures to those of the neutrinosphere, and light clusters such as deuterons, tritons, or alpha particles are formed.
The workshop discussed the validity of a statistical treatment of this freeze-out approximation, ways to measure temperatures and densities in this phase, and how to infer the symmetry energy. Predictions from many-body approaches for the equation of state of warm low-density matter including clusters were critically discussed. In addition we talked about improving procedures to include light cluster formation in transport models used to simulate heavy ion collisions. Astrophysical simulations of core collapse supernovae were reviewed emphasising the important role of neutrinos, and neutrino interactions and the need for inclusion of the effects of the symmetry energy and of light clusters in modelling neutrino interactions.

Results and Highlights

Neutrino interactions were shown to depend significantly on the symmetry energy of low-density matter and to modify the energy difference between emitted electron neutrinos and antineutrinos. This energy difference in turn helps determine the composition of the neutrino driven wind and is very important for nucleosynthesis. A tremendous amount of very careful work has been performed to extract the conditions of the freeze-out configuration in HIC. However, this analysis has to be done self-consistently using binding energies and volumes of medium modified clusters. Methods using a coalescence approach and correlation functions should be compared. For the treatment of cluster production in transport models different approaches exist which should be compared and checked against each other. Also a direct interface between HIC and supernova simulations is the neutrino response function, which could be directly obtained from appropriate transport models.
Based upon these considerations the workshop suggested a number of action items for future work.

1) Use transport models, that are calibrated to HIC data, to simulate the low density warm matter present in supernovae and calculate the dynamical response functions S(q,w). These describe how a neutrino scatters from the medium while transferring momentum q and energy w.
2) Explore how the composition of light clusters depends on the N/Z ratio of colliding nuclei using both stable and radioactive beams. This will help with informed extrapolations to the very neutron rich conditions of the neutrino-sphere.
3) Check the extraction of freeze out volumes and densities from the two methods used in the interpretation of HIC: correlation functions of various light particle pairs and coalescence methods.
4) Work on the improvement of the description of light clusters in transport models and codes.
5) (Re)analyze additional existing HIC data sets to determine light cluster compositions.
6) Develop a website and WIKI to foster communication among heavy ion and astrophysical communities.
7) Provide a short white paper on the HIC/supernova neutrinosphere physics for the low energy community meeting in Texas in August 2014 and for the next US Long Range Plan for nuclear physics.
8) We should hold a follow up workshop to maintain momentum in about two years, perhaps at the Institute for Nuclear Theory in Seattle or again at the ECT*, which provided a very agreeable atmosphere for this workshop. Such a workshop could be called “Femtonova II” (a Femtonova is a very small new star).

3.3.4 QCD AND FORWARD PHYSICS AT THE LHC

DATE: April 14 - 18, 2014

ORGANIZERS:

C. Royon *(IRFU-SPP, CEA Saclay, France)*
G. Soyez *(IPhT, CEA Saclay, France)*
A. Szczurek *(PAN, Krakow, Poland)*

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

The general scientific goal of this workshop is related to QCD and forward physics at the LHC, and especially the new detectors which will be added by the CMS and ATLAS collaborations to detect intact protons in the final state, and the additional physics topics that can be added using these new detectors.
The first item deals with QCD studies in diffraction at the LHC at previous accelerators. After discussing present results coming from the Tevatron and HERA experiments, the aim will be to present and discuss new results on diffraction at the LHC. The recent measurements performed by the Totem, ATLAS, LHCB and CMS experiments such as the total cross sections, soft and hard diffraction results using the rapidity gap methods or proton tagging will be discussed in detail, as well as the detectors used for these measurements. New potential measurements using present forward detectors (TOTEM and ALFA) will also be presented, for instance the exclusive production of pions, dimuons, kaons and production of charm.
The second item deals with new physics potentials allowed by additional proton detectors to be installed in the ATLAS and CMS experiments. New proton detectors will allow us to detect intact protons in a completely new kinematical domain compared to previous experiments, extending the previous measurements to much higher energies. The main aim of the meeting will be to enhance the synergy between theorists and experimentalists in order to enhance the physics capabilities and results of these new detectors to be installed in 2014-2015. QCD and diffractive studies in a wide kinematical region will allow us to understand better the Pomeron structure in terms of quarks and gluons by studying Double Pomeron Exchange and Single Diffractive events as an example. We can quote the constraints on the Pomeron structure using W/Z or photon+jet events as an example. Special attention will also be put on the determination of survival probabilities.
In addition, the production of exclusive events in QCD (jets, photons…) will also be discussed in detail. In jet events for instance, exclusive diffractive events lead to the presence of two jets and the two intact protons in the final state. Such events will be measured at the LHC, and the potential measurements of such events will be presented and analysed during the workshop.
Related to this second item is the study of precise tests of the standard model of particle physics, and specially the production of photon, W or Z pairs in photon exchange processes. In these events, the final state at the LHC shows two intact protons and the W or Z bosons decaying in the central LHC detector. The production cross section of such events is modified substantially by the possible new anomalous couplings between photons and W/Z bosons which could be a sign of new physics such as the existence of extra-dimensions in

the universe predicted by string theory. The observation of such new couplings at the LHC would be a major discovery. An additional topic which is also fundamental after the discovery of the Higgs boson at the LHC is the possibility of measuring the properties of the Higgs boson (mass, spin…) using exclusive diffractive events at the LHC. In addition, other exploratory physics topics using diffractive exclusive events such as the production of SUSY, Kaluza-Klein, magnetic monopoles events were discussed together with their implementation in Monte Carlo generators.
Much time was reserved for discussions between theorists and experimentalists during the workshop, and discussion leaders will be appointed among the key participants at the workshop.

SPEAKERS:

L. Apolinario (Santiago de Compostela, Spain)
J. Baechler (CERN, Geneva, Switzerland)
J. Bartels (Hamburg, Germany)
M. Berretti (CERN, Geneva, Switzerland)
M. Bruschi (Bologna, Italy)
N. Cartiglia (Torino, Italy)
G. Contreras (Czech Technical University, Prague, Czech Republic)
M. Dyndal (AGH, Cracow, Poland)
T. Epelbaum (IPhT, CEA Saclay, France)
L. Harland-Lang (Durham, UK)
G. H. Corral (Mexico, Mexique)
I. Katkov (KIT, Karlsruhe, Germany)
P. Lebiedowicz (PAN, Cracow, Poland)
M. Luszczak (University of Rzeszow, Poland)
T. Martin (University of Warwick, UK)
R.I. Maciula (PAN, Cracow, Poland)
T. Martin (Warwick University, UK)
G. Milhano (Lisboa, Portugal)
C. Marquet (Ecole Polytechnique, Palaiseau, France)
B. Murdaca (Cosenza, Italy)
R. McNulty (Dublin, Ireland)
P. Newman (Birmingham, UK)
R. Orava (Helsinki, Finland)
K. Osterberg (University of Helsinki, Finland)
R. Pasechnik (University of Lund, Sweden)
R. Peschanski (IPhT, CEA Saclay, France)
T. Pierog (KIT, Karlsruhe, Germany)
J. Pinfold (Alberta, Canada)
C. Royon (CEA Saclay, France)
M. Ruspa (Florence, Italy)
A. Sabio Vera (Madrid, Spain)
M. Saimpert (IRFU-SPP, CEA Saclay, France)
T. Sako (Nagoya, Japan)
A. Sbrizzi (Alberta, Canada)
R. Schicker (University of Heidelberg, Germany)
G. Soyez (IPhT, CEA Saclay, France)
A. Szczurek (PAN, Cracow, Poland)
M. Trzebinski (PAN, Cracow, Poland)
D. Volyanskyy (Heidelberg, Germany)

SCIENTIFIC REPORT:

The program of the workshop dealt with presentations and discussions of forward physics at the LHC

Present results on forward physics

TOTEM is an experiment at the LHC dedicated to the measurement of the total and elastic cross-sections and studies diffractive processes. TOTEM has measured the luminosity-independent total, elastic and inelastic proton-proton cross-sections at $\sqrt{s}$ = 7 TeV and 8 TeV using dedicated β^* = 90 m optics runs. At $\sqrt{s}$ = 7 TeV, the cross-sections were also determined using the CMS luminosity with results that are in excellent agreement with the luminosity-independent measurements, despite having very different systematic dependencies. At 8 TeV, data recorded at special β^* = 90 m and 1 km optics runs allowed for precise studies of the elastic cross-section and to probe the Coulomb-hadronic interference. This allows to test models of Coulomb-hadronic interference as well as to obtain a better determination of ρ, i.e. the ratio of the real and imaginary part of the hadronic elastic amplitude at t = 0.

TOTEM also performed together with CMS a charged particle psuedorapity density measurement at $\sqrt{s}$ = 8 TeV in three different event samples: an inclusive, a non-single diffractive enhanced and a single-diffractive enhanced sample, from data collected with a common trigger in a dedicated run. The data is compared to high-energy hadronic interaction models and none of the models considered provide a consistent description of all measured distributions. TOTEM also studied soft single- and double-diffractive processes at $\sqrt{s}$ = 7 TeV and the results seem to indicate a breaking of the factorization in diffractive processes at LHC.

In the reported studies the background rates expected in the horizontal and vertical RPs of the TOTEM experiment is estimated, respectively for running scenarios with beta*= 0.5m and beta* = 90m optics. The background was studied on two data samples recorded at a center of mass energy of 8 TeV with μ =8 (beta* =0.6m) and μ =0.05 (beta* =90m). At beta* = 0.6m it has been found that most of the reconstructed tracks are due to the background. The occupancy and the inefficiency due to multiple hits in the same cell of the timing detector were then studied assuming runs at 13 TeV, μ =50 and RPs inserted at 13_. Primary protons have been generated according to the elastic, diffractive and non-diffractive cross sections measured by TOTEM and then propagated with the proper optical functions. The background was linearly extrapolated from μ =8 to μ =50. An optimized readout geometry with 16 channels has been found, where the number of Central Diffractive (CD) events lost due to double hits is minimised. A trigger strategy to select the soft CD events at low-beta* was also implemented assuming a detector with 25 ps time resolution. The study is important in order to estimate the probability that the RP trigger is generated on background process (physics+beam related) once the central process is identified by the CMS trigger. The background has been also estimated for the running scenario at beta* = 90m and μ = 0.5. Here the signal in the detector is mainly due to primary protons generated in the elastic and in the single diffractive interactions. An optimized detector geometry with only 10 channels has been studied. Despite the low pile-up probability, timing detectors in the vertical RPs has been demonstrated to significantly improve the selection of CD events with low mass increasing both the purity and the efficiency of the CD trigger selection. Due to its forward coverage and the possibility of extending measurements to low transverse momenta, the LHCb detector provides important input to the understanding of particle production in a unique kinematic range where models have large uncertainties. It also allows exploration of cold nuclear matter effects and offers a unique opportunity to carry out fixed target physics studies. Using large data samples accumulated in the years 2010-2013, the LHCb collaboration has conducted a series of measurements providing important input to the knowledge of the parton density functions, underlying event activity, low Bjorken-x QCD dynamics, double parton scattering and cold nuclear matter effects. Future studies of inclusive particle production and nuclear matter effects require low pile-up samples of at least $10~{\rm nb}^{-1}$ minimum-bias proton-proton and $20~{\rm nb}^{-1}$ proton-lead data, respectively.

Future upgrades at the LHC

The TOTEM experiment is presently working on the consolidation and upgrade project with the aim to complete all related activities within the LS1 shutdown period. The consolidation project is a TOTEM stand alone activity while the upgrade project is an effort carried by the CMS and TOTEM collaborations. An official agreement between CERN, TOTEM and CMS was signed on January 2014. The consolidation project comprises the service work on the Roman Pot stations at 220/147 m and the relocation of the Roman Pots from 147m to the 210 m region. Within the upgrade project the integration of new RF shields in the horizontal Roman Pots in the 210 m region and the construction two new cylindrical Roman Pots, to be located downstream of the 220 m near station on each side of ip5, is foreseen. The newly developed RF shield and RP cylinder in combination with theÂ circular ferrites, integrated in the flanges of the Roman Pot bellow system, reduce significantly the radiofrequency impact of the LHC beam on the RP system and v.v.. In detailed RF simulations the optimal RP geometry in combination with the ferrite location was determined. The simulations were later compared with RF wire measurementsÂ performed on a Roman Pot test station in combination with the Roman Pot prototype RF shield and new RP cylinder. These newly developed cylindrical Roman Pots are furthermore optimized in respect to material budget and the expected particle spectrum. A thin window with a length of 12 cm on the bottom of the Roman Pot is separating the LHC vacuum fromÂ atmosphere. Pressure-, deformation and He leak tests have been performed on the prototype Roman Pot and demonstrated the compliance of this prototype with the LHC requirements. The details of the consolidation and upgrade projects in view of their integration in the LHC tunnel are described in the engineering change requested, documented in the CERN EDMS document system. The installation of the collimators (TCL4 and TCL6) are as well documented in related EDMS documents.

Progress has been done on both, the consolidation and the upgrade project. However the upcoming months are very critical in view of the successful installation of all RP components within the LHC LS1 schedule. Within the upgrade project a timing detector test beam line at SPS H8 is built up to study timing detector in combination with Roman Pot carriers allowing to reproduce the situation in the LHC. First tests with the SAMPIC chip in combination with a diamond detector have successfully started in a dedicated test lab.

The Totem and CMS experiments have officially agreed to write a joint Technical Design Report for the construction of a forward proton Tagger, called "CMS-TOTEM Precise Proton spectrometer", in short CT-PPS. The project consists in a combination of tracking and timing detectors, positioned along the beam line 220 meters downstream the interaction. The tracking system is made of silicon pixel detectors, placed inside the roman pots used by TOTEM in a previous project. The sensors will be read-out by the same front-end chip used in the CMS central tracking system. The sensors are made following the "3D" design, and they are specially tailored to have very small edges, to be able to go as close as possible to the beam line. The timing detectors are made by L-shaped quartz bars (the so called "QUARTIC" detectors), which have a timing resolution of 30 ps. QUARTIC will be housed in a specially designed cylindrical roman pot. The installation of the tracking and timing systems will take place during 2016-2017, depending on the shutdown schedule of the LHC accelerator complex.

The collaboration CMS-TOTEM will start before the installation of this new hardware: common data taking of the two experiments, using a combined data acquisition system, is planned to start already in 2015.

A talk was presented about the ATLAS Forward Physics Project (AFP) status. The ATLAS physics review outcome is that the measurements program at low and intermediate luminosity taken in special runs represents a physics case of interest for the experiment. The technical review panel did not identify any substantial problem and therefore encourage the ATLAS Collaboration to approve the AFP project and go to the next stage with the submission of the TDR. The main points to be improved before asking for the ATLAS approval, namely the compatibility with ALFA and TOTEM runs and the strategy to improve the collaboration strength, have been presented and discussed. The talk also presents the first layout of the TDR and the milestones for 2014. The main goal is to submit the TDR to LHCC in November and in parallel to perform at CERN SPS a joint test beam with ALFA on a roman pot equipped with one station of the tracker and one of the timing system.

New Hardware at the LHC

The main purpose of the CASTOR detector installed in the CMS collaboration is to contribute to the forward physics program of CMS in pp-collisions and perform measurements in ion collisions (Pb-Pb, p-Pb, p-O, p-N). In particular interesting is the interplay with cosmic ray physics. Such an interplay requires extension of the energy reach as close as possible to the energies of the cosmic ray primaries. Hence data taking in the conditions of LHC Run 2 (13 or 14 TeV center of mass energy) is of critical importance. Castor can stay in CMS during low luminosity runs. The installation/de-installation of Castor in CMS can be done during technical stops. So far several results using CMS/Castor calorimeter have been published indicating also potential for running at higher energies. They include underlying event studies at there different centre of mass energies in pp-collisions (running at different energies is always an interesting option), energy flow measurement in lead-lead ion collisions, discrimination of different diffractive topologies in a study of inclusive diffraction in pp-collisions at 7 TeV. Also good performance of the calorimeter is shown in year 2013 in proton - lead ion collisions where running with a common trigger, combining CMS and TOTEM information, is established and is very desirable also for future. The performance results include forward-central and forward-forward correlations, indication of topologies with gaps, transverse momentum spectrum of isolated forward electrons. Ongoing studies on forward jets with Castor are promising. Castor groups aims at implementing jet, rapidity gap, isolated electron and muon triggers to ensure effective data taking assuming low lumi and low to medium pile-up. Performance of such triggers needs to be assessed using simulations. Results of studies are shown at hadron level using several generators EPOS, QGSJet, Pythia, Sibyll keeping in mind a range of scenarios from pile-up of 0.1 and instantaneous luminosity of 1.1e30/cm2/s to pile-up of 1 and luminosity of 1.1e32/cm2/s. For event topologies with at least two reconstructed jets, with one of them being in Castor acceptance, the rapidity separation between the jets shows a very good model discrimination power. The study reveals no strong sensitivity to pile-up for this observable. Typical predicted cross section values for rapidity separations larger than 8 units are around several millibarns.

The latest technical developments of the AFP projects have been also presented focussing on the aspect related to the integration of the tracking and timing systems in the same roman pot.

AFP roman pots are the same as the TOTEM roman pots, except from small modifications (support table, the floor plate, etc...). To minimize the distance of closest approach to the tracking stations, the floor of the thin window is flat in the insed part, while in TOTEM is flat on the outside part. All the material for the manifacturing of the first prototypes which will be tested on the beam in November have been ordered. Detailed simulation studies done by the TOTEM collaboration have shown that RF losses will not be an issue for the current design.

An additional collimator in front of the Q6 magnet (TCL6), upstream of the ALFA roman pots detecting elastic scattered protons, is needed to run AFP at high luminosity to compensate for the increasing aperture of the TCL4 and TCL5 collimator which would otherwise strongly suppress the physics signal in AFP. The installation of TCL6 in LS1 is currently under approval at CERN and will be fundamental to study the near-beam environment already in run2. Monte Carlo simulation have shown that AFP horizontal roman pots will allow to study diffractive physics in ATLAS much better than with the vertical ALFA stations.

A compact timing detector, suitable for an integration in a roman pot together with a tracking detector, has been developed using L-shaped Cerenkov quartz bars. By smoothing the 90 degree angle of the light guide with a parallel cut, the light yield is even larger than with a straight bar. For running at high luminosity, the number of channels will be doubled in order to approach the needed time resolution of 10 ps. For running at high luminosity, AFP has developed in collboration with Photonis special photomultiplier tubes with increased lifetime which will survive up to 200 inverse fb. The AFP traking system is made of 5 layers of 3D silicon pixel sensors attached to FE-14 readout chips, the same technology used for the ATLAS innermost pixel detector (IBL), which will allow to reach 10 micrometer spatial resolution in track reconstruction.
Test beam studies show that the efficiency is close to 100% if one tilts the layers of about 15 degrees. The detector is expected to survive the in the high radiation environment at 2-3 mm from the beam. In order to cool down the silicon detector to around -10 celsius degrees, we consider to use a cheap air-cooling system based on Vortex tubes in which the heat is removed by PGS foils attached to a heat exchanger located in the housing of the roman pot. The total cooling power is less than 100 W. Thanks to the huge effort of the AFP collaboration in the last years, the AFP low luminosity physics program was recently approved by the ATLAS collaboration which is now reviewing the technical aspects of the AFP project. SAMPIC (SAMpler for PICosecond time pick-off) is a very fast read-out chip, designed for the timing detectors in the forward region. It is an Application-Specific Integrated Circuit (ASIC) for picosecond timing measurement, acquiring the all waveform shape of a detector signal. The discriminator is used only for triggering, not for timing (contrary to standard TDC) which avoids a jitter. All the information is kept, so it keeps the possibility to implement signal processing algorithms. The drawback is an important deadtime per channel due to the Analog-to-Digital Convertion (ADC). Each channel has an embedded ADC, so only triggered channels are in dead time for a given event, it is a tunable tradeoff between resolution and digitisation of the ADC. The possibility to use more than 1 SAMPIC channel to digitize a single detector channel will be available in the next version. 3 working identical prototypes are available now, 1 lent to CMS/TOTEM, 2 in Saclay/Orsay. The chip works and is usable now to perform timing measurement with detectors. It has a sampling speed from 1.6 to 10.26 GSPS, comes with an acquisition software and an analysis code in ROOT/C++. It has been tested with signals from pulse generators and show very promising results (2-4 ps RMS reached). It will be tested next week with real detector signals (Silicon and Diamond) from a laser. Beam tests are planned for the end of the year.

New aspects in theory

Mueller Navelet jets

A fundamental problem in high energy QCD is to find out the region of applicability of the perturbative Regge limit. Being a calculation at the corner of phase space it is crucial to identify the correct observables where the so-called multi-Regge kinematics dominates. In traditional observables such as structure functions in deep inelastic scattering it was difficult to disentangle the Regge dynamics since the investigated observables are too inclusive. It is only with the arrival of the Large Hadron Collider in the low luminosity runs with large number of events and very large center-of-mass energy that more exclusive distributions can be used to test the multi-Regge limit. A successful observable where the NLO BFKL formalism fits well the data is the ratio of azimuthal angle correlations as proposed by Schwennsen/Sabio-Vera in 2006 for which collinear contributions and the effect of the parton distribution functions are suppressed. In the present talk we discus the advantage of using Monte Carlo integration techniques in order to create new observables to generate distinct predictions of the BFKL resummation which can lead to a rich search of these effects at the LHC.
The production of Mueller Navelet jets was studied in proton-proton collisions, i.e. two jets characterized by high transverse momenta and large separation in rapidity. Using the BFKL approach with next-to-leading order jet vertices in the small-cone approximation and following the experimental cuts on the tagged jets at the Large Hadron Collider, several

observables related with this process have been calculated. In order to gauge the theoretical uncertainty, different representations for the amplitude, equivalent in the next-to-leading approximation, were used. Moreover, several methods of optimization of the perturbative series were adopted: principle of minimal sensitivity, fast apparent convergence and Brodsky-LePage-McKenzie (BLM) method. A particular attention was given to the BLM method, which we implemented in a way to some extent different from another collaboration (Duclou\'e et al), finding a very good agreement with CMS data.

Exclusive jet production at the LHC
We consider the CEP of dijets (qqbar and gg) and trijets (gqqbar and ggg) in hadron-hadron collisions, calculated within the Durham pQCD framework. I discuss the interesting features that these processes possess (such as the suppression of quark vs. gluon jets and the differing angular distributions in the trijet case). These features are not predicted in standard inclusive production, and indeed exclusive jet production presents the possibility to study isolated (dominantly) gluon jets in a particularly clean environment, at a hadron-hadron collider. I present a new Monte Carlo implementation for exclusive two and three jet production, within the pQCD approach, and present a range of phenomenological predictions using this.

Exclusive production of charmonia
We discussed about exclusive production of charmonia and the amplitude for gamma p to J/Psi p (gamma p to Psi' p) which was calculated in a pQCD kT-factorization approach. The total cross section for this process was calculated for different unintegrated gluon distributions and compared with the HERA data and the data extracted recently by the LHCb collaboration. The amplitude for gamma p to J/Psi p (gamma p to Psi' p) was used to predict the cross section for exclusive photoproduction of J/Psi (Psi') meson in proton-proton collisions. Compared to earlier calculations they (A. Cisek + W. Schafer + A. Szczurek) included both Dirac and Pauli electromagnetic form factors for the coupling of photons to protons. The effect of Pauli form factor was quantified. Absorption effects were taken into account and their role was discussed in detail. Different differential distributions e.g. in J/Psi (Psi') rapidity and transverse momentum were presented and compared with existing experimental data. In general, the UGDF with nonlinear effects built in better describe recent experimental data of the LHCb collaboration but no definite conclusion can be drawn.

Central exclusive production of mesons
We discuss exclusive central diffractive production of scalar (f0(980), f0(1370), f0(1500)), pseudoscalar (eta, eta'(958)), and vector (rho) mesons in proton-proton collisions. The amplitudes are formulated in terms of effective vertices required to respect standard rules of Quantum Field Theory and propagators for the exchanged pomeron and reggeons. In most cases two lowest orbital angular momentum - spin couplings are necessary to describe experimental differential distributions. We discuss differences between results of the “tensorial pomeron" and “vectorial pomeron" models. The theoretical results are compared with the WA102 experimental data, in order to determine the model parameters. Correlations in azimuthal angle between outgoing protons, distributions in rapidities and transverse momenta of outgoing protons and mesons in a special “glueball filter variable", as well as some two-dimensional distributions are presented. The tensorial pomeron ansatz can equally well describe existing experimental data on the exclusive meson production as the less theoretically justified vectorial pomeron ansatz. We show that high-energy central production, in particular of pseudoscalar mesons, could provide crucial information on the spin structure of the soft pomeron. Our study certainly shows the potential of $pp \to pMp$ reactions for testing the nature of the soft pomeron. For the rho production the photon-pomeron and pomeron-photon exchanges are considered. The coupling parameters of tensor pomeron and/or reggeon are fixed from the H1 and ZEUS experimental data of the gamma p to rho p reaction. We present first predictions of this mechanism for pp to pp rho to pi+ pi- reaction

being studied at COMPASS, RHIC, Tevatron, and LHC. The measurement of forward/backward protons is crucial in better understanding of the mechanism of pp to pp pi+ pi- reaction.

Jet quenching

Jet quenching, the generic name given to a collection of energy loss processes that a high energy particle experience when traversing a coloured and dense medium, is an important tool to assess the properties of the hot matter that is created in a heavy-ion collision. Current experimental data seems to indicate that the mechanism of energy loss should be able to suppress the jet yield and the jet energy, at the same time that the azimuthal direction of a jet is not much modified with respect to what is known from proton-proton collisions. Moreover, the lost energy is only recovered when going to very large angles (radial distances larger than 0.8 in (\eta, \phi) from the core of the leading jet). In order to describe these characteristics, several theoretical improvements were addressed in these last years. Among them: coherence effects between different emitters (in-medium QCD antenna) to investigate the property of (anti)angular ordering between successive emissions, finite energy corrections to account for the total energy loss, and computation of the medium-induced gluon radiation spectrum beyond the eikonal approximation to allow the individual broadening of the two outgoing partons. Putting all results together, it seems that a medium-modified jet is governed by two regimes depending on the characteristic scale of the medium and the transverse distance of two coloured correlated particles inside the medium: a coherent regime, where the particles are little affect by the medium interactions, and an independent propagation that will result in an enhancement of the loss of energy with respect to vacuum propagation.

Vetos in dijet production

We have concentrated on a specific process: the production of a dijet system imposing a veto on additional jets in the rapidity interval between those two jets. Compared to the pure diffractive dijet production, colour singlet exchanges dominate this process and large logarithms of pt/Q0, with pt the average transverse momentum of the two hard jets and Q0, the veto scale, have to be resummed at all orders. Besides the standard Sudakov exponent one also gets a contribution from so-called non-global logs arising from the fact that the veto is only applied in part of the total phase space. We have shown in arXiv:1301.1910 that the QCD resummed results (obtained solving the Banfi-Marchesini-Smye equation) provide a good description of the ATLAS measurements. We have also outlined the possible improvements in our prediction.

Saturation effects

We described a study of saturation effects in the production of forward di-jets in proton-lead collisions compared to proton-proton collisions at the Large Hadron Collider. The calculations were done using the framework of High Energy Factorization, and published in a paper written in collaboration with A. van Hameren, P. Kotko, K. Kutak and S. Sapeta. Such configurations with both jets produced in the forward direction probe the gluon density of the lead nucleus at small longitudinal momentum fraction, and also limit the phase space for emissions of additional jets. We find a significant suppression of the forward dijet azimuthal correlations in proton-lead versus proton-proton collisions, which we attribute to stronger saturation of the gluon density in the nucleus than in the proton. In order to minimize model dependence of our predictions, we use two different extensions of the Balitsky-Kovchegov equation for evolution of the gluon density with sub-leading corrections.

WW production at the LHC

The standard NLO calculations underpredict the measured rates of W+W production compared to recent ATLAS and CMS experimental data. We discuss new subleading processes for inclusive production of W+W pairs. We focus on photon-photon induced processes. We include elastic-elastic, elastic-inelastic, inelastic-elastic and inelastic-inelastic contributions. The inelastic photon distributions in the proton are calculated in two different ways: naive approach used already in the literature and using photon distributions by solving special evolution equation with photon being a parton in the proton. The results strongly depend on the approach used. We calculate also contributions with resolved photons. The diffractive components have similar characteristics as %the photon-photon elastic-inelastic and inelastic-elastic mechanisms. The subleading contributions are compared with the well known qq and gg as well as with double-parton scattering contributions. Predictions for the total cross section and differential distributions in W- boson rapidity and transverse momentum as well as WW invariant mass are presented. The gamma gamma components constitute only about 1-2 % of the inclusive W+W cross section but about 10 \% at large W transverse momenta. We calculate also cross section for single-diffractive production of W+W pairs including pomeron and subleading reggeon exchanges in the Ingelman-Schlein model. The H1 diffractive parton distributions are used in the calculations. The results are compared to the results of elastic-inelastic (inelastic-elastic) gamma gamma processes.

Quartic anomalous couplings

Forward proton tagging at the LHC seems promising to probe anomalous Quartic Gauge Couplings:

- proton tagging associated by high energy object detections in the central EM calorimeter allow to completely suppress the background

-WW gamma gamma and ZZ gamma gamma couplings already studied with positive outputs (improvement by a factor > 100)

- gamma gamma gamma gamma coupling: sensitivities around 10^{-13} to 10^{-14} GeV^4, down to $7 \cdot 10^{-15}$ GeV^4 at the HL-LHC, which allows to probe directly a large panel of new physics models. This anomalous coupling has no previous constraints from collider experiment and benefits from the fact that the standard model production happens only at low mass for the outgoing system.

A full amplitude calculation probing generic exotic heavy charged vectors/fermions (even scalars, sensitivity is smaller) loop contributions to the 4 gamma coupling has also been performed in a model-independant way. We are sensitive to vectors (fermions) up to 1400 (920) GeV.

New physics topics at the LHC and simulation studies

The LHCb experiment provides an excellent environment for the investigation of central exclusive production (CEP) on account of its large acceptance in rapidity (about 7 units in the forward and backward regions), its ability to trigger on low transverse momentum objects, and the low pile-up conditions in which it operates at the LHC (typically 1.5 interactions per beam-crossing). Measurements of CEP of J/ψ and $\psi(2s)$ have been published, while preliminary results are available on the CEP of χ_c mesons and the production of di-muons in photon-photon fusion. The largest systematic uncertainty in these measurements comes from inelastic events where the protons breaks up but the remnants remain unobserved. During the current shutdown, LHCb intends to install a system of scintillators in the far forward region, up to 114m from the interaction point. Simulation studies indicate that these will increase the rapidity coverage by over 4 units and extend the sensitivity down to $y=8$. Tests of detector prototypes with cosmic rays demonstrate that about 150 photoelectrons are produced per 20mm thick scintillator. These new detectors will allow a significant improvement to the physics output of LHCb, both for CEP and for measurements of single-diffractive processes. CEP results are expected in the leptonic modes for other vector mesons (Υ, Φ), in the hadronic modes for χ_c as well as pairs of mesons such as $\pi\pi. KK, D^+D^-$ etc. Apart from being sensitive tests of QCD, these modes are sensitive to saturation effects as well as the presence of odderons or glueballs.

Update on Monte Carlo predictions for high cross section "minimum bias" observables at sqrt s = 14 TeV where exactly one forward proton tag is required in either AFP or ALFA, using precalculate acceptance maps. Approximately 1 -- 3\% of events in simulation satisfy this requirement and between 0.2 -- 1.0 / nb of integrated luminosity would be required to study this in data. This corresponds to between 3 and 15 hours of dedicated minimum bias data taking with forward detectors included. Predictions were presented for the EPOS, Herwig++ and Pythia 8 generators with suitable choices of tune. Rapidity gap [arXiv:1201.2808], energy flow [arXiv:1208.6256] and charged particle multiplicity [arXiv:1012.5104] analysis variables were taken, all of which have published data from different LHC experiments at sqrt s = 7 TeV.

For the majority of the distribution considered, the requirement of a forward proton tag was shown to greatly enhance the diffractive component of the inelastic cross section in the central detector. This will allow for future probes of the Pomeron-proton interaction and for tests if the fragmentation of such systems is quantitatively different from proton-proton interactions. The MC predictions for such a selection were observed to differ more greatly than for an inclusive event selection.

The different mechanisms of forward proton production in these MC models was discussed and the possibility of correlating large rapidity gaps in ATLAS with a forward proton tag to select a pure sample of double-dissociative diffractive events was explored.

The TOTEM run scenario and physics for the upcoming LHC runs at $\sqrt{s}$ = 13 TeV in 2015-17 was presented. The physics output would be maximized with three run scenarios: one high β^* and low luminosity (μ ~0.05-0.1, Nb $\geq$ 156) for total cross-section, soft diffraction and charged multiplicity studies, one high β^* and medium luminosity (μ ~0.5, Nb ~ 1k) for pb-range cross-sections including studies with central diffraction and hard single diffraction, and one low β^* and high luminosity (μ ~30-50, Nb ~ 2.5-2.8k) for studies of high mass objects in central diffraction with fb-range cross-sections. The focus of the talk was on the physics of the high β^* and medium luminosity scenario that was not covered by other talks.

By combining the CMS and TOTEM apparatus, unique studies of central diffractive events pp $\rightarrow$ p + X + p is possible since both initial (from the protons) and final state (from the central system) is determined. This allows precise studies of low mass resonances and determination of their quantum numbers and gluon-richness, studies of the partonic structure of the hard "Pomeron" and of very pure gluon jet samples as well as searches for high missing mass events indicating possible new physics that might have escaped the standard LHC searches. Single diffractive events with jets or heavy quark mesons allow rapidity gap survival probability determinations. All of the above studies require pb–1 range integrated luminosities with high β^* optics that is only achievable in special runs with maximal number of bunches and protons per bunch.

The size of the LHC beam at the AFP stations for various optics modes was calculated. These numbers were crucial for the performed geometric acceptance studies. These, in turn, were performed for three different LHC optics: collision (beta* = 0.5$ m) and high beta (beta* = 90 and 1000 m). Next, the shape of these acceptances was explained on a basis of proton trajectories. The second part of the talk was devoted to soft diffraction. At the beginning the large differences between various Monte Carlo generators and their tunes were discussed. Next, the amount of single and double tagged events visible in the AFP detectors as a function of their distance from the beam was discussed. Finally, the origin of these protons was shown.

The possibility to measure single diffractive jet production was discussed. Studies of this process will lead to the measurement of the cross section as well as the gap survival probability. In order to distinguish between signal and background (recognised in this talk as non-diffractive jet production overlaid with soft pile-up protons), two requirements (proton tag in the AFP and one vertex reconstructed in ATLAS central detector) were introduced. Finally, predictions about the possible results with 100 h of collected data were presented.

The aim of the AFP detectors design is to measure the kinematics of the intact proton, that to say their position, their trajectory, their time of flight and their momentum fraction loss. The AFP detectors use the LHC magnet optics as a giant spectrometer since magnetic fields deflect particles according to their energy. A fast timing system that can measure precisely the time difference between outgoing scattered protons is a key component of the AFP detector for high luminosity runs since it can be used to reject overlap background. The final timing system must reach a resolution of 10 ps or better in order to distringuish between the different vertices, have a high efficiency and a high rate capability to handle the LHC collision frequency and present a level-1 trigger capability. In order to achieve this last point, it has to have a sufficient segmentation for multi-proton timing. MC simulations show that forward protons comes mainly from non-diffractive, soft single diffractive and soft double diffractive events additionnally to hard diffractive interactions. Significant discrepancies exist among the different generators (Pythia6, Pythia8, Phojet). Other protons coming from non physics background (beam halo, collision debris, ...) are not considered here. Protons were generated using Pythia8 and transported to the AFP detector at 206 m with FPTracker/MadX. Pile-up is simulated using combinatorics. The study shows that bars of less than 2 mm are required for the timing detectors segmentation, even if the bar closest to the detector will be hit at each bunch crossing at high pile-up (one can take it out from the trigger system for instance). However, the beam induced background might dominate in this region and a pixel detector would allow to handle this much more efficiently.

To interpret data of ultra-high energy cosmic ray measurement, the simulation of air shower is a must. The main source of uncertainty of this simulation is the hadronic interactions which are feeding the electromagnetic cascade and the muons observed by the experiments. Early LHC data were used to constrain high energy hadronic interaction models used for air shower simulations. In particular the inelastic cross-section and the multiplicity measurements were used to fix the parameters which are important for the extrapolation to higher energy. As a result the difference between the two most recent models, QGSJETII and EPOS, has been changed by about a factor of two for the main air shower observable the mean position of the shower development maximum, reaching the level of experimental systematic errors. To further reduce the remaining uncertainties, new forward measurements and correlations between different phase space and higher collision energy at LHC will be useful, but simulations show that the main source of difference between the models is now the extrapolation from proton-proton to proton-air interactions where very few data are available, in particular for light systems. It was then shown than if proton-oxygen collisions could be performed at LHC another factor of two could be gained, reducing the theoretical uncertainty to a level well below the experimental uncertainties. This will be a major step forward for the interpretation of cosmic-ray mass composition.

3.3.5 THREE-BODY FORCES: FROM MATTER TO NUCLEI

DATE: May 05 - 09, 2014

ORGANIZERS:

A. Gezerlis (*University of Guelph, Canada)*
K. Hebeler *(TU Darmstadt, Germany)*
H. Hergert *(The Ohio State University, USA)*
V. Somà *(CEA Saclay, France)*

NUMBER OF PARTICIPANTS: 37

MAIN TOPICS:

This workshop addressed the development of next-generation chiral effective field theory interactions, as well as their implementation in many-body frameworks for finite nuclei and infinite matter. Of particular interest was the discussion of recent high-quality refits of chiral forces, the development of local forces which are also suitable for Quantum Monte Carlo methods, as well as the incorporation of the next-generation three-nucleon interactions at N3LO and their impact on properties of matter, finite nuclei, and reactions.

Specifically, the main topics were:

- the current status and future directions of nuclear interactions derived within chiral EFT
- new approaches for systematically optimizing interactions and devising fit protocols
- paths for generating and distributing matrix elements of three-nucleon forces in a format suitable for all few- and many-body communities
- computational challenges related to the incorporation of three-nucleon interactions in ab initio many-body frameworks
- signatures of three-nucleon force effects in experimental observables.

SPEAKERS:

S. Binder (TU Darmstadt, Germany)
C. Barbieri (University of Surrey, UK)
A. Calci (TU Darmstadt, Germany)
A. Carbone (TU Darmstadt, Germany)
J. Carlson (Los Alamos National Laboratory, USA)
A. Cipollone (University of Surrey, UK)
T. Duguet (CEA Saclay, France)
E. Epelbaum (RU Bochum, Germany)
S. Ettenauer (Harvard University, USA)
R. Furnstahl (The Ohio State University, USA)
S. Gandolfi (Los Alamos National Laboratory, USA)
D. Gazit (The Hebrew University of Jerusalem, Israel)
H. Hergert (The Ohio State University, USA)

N. Kaiser (TU München, Germany)
N. Kalantar-Nayestanaki (University of Groningen, Netherlands)
H. Krebs (RU Bochum, Germany)
T. Krüger (TU Darmstadt, Germany)
D. Lee (North Carolina State University, USA)
D. Lonardoni (Argonne National Laboratory, USA)
J. Lynn (Los Alamos National Laboratory, USA)
J. Menendez (TU Darmstadt, Germany)
A. Mukherjee (Trento University, Italy)
G. Papadimitriou (Iowa State University, USA)
T. Papenbrock (University of Tennessee, USA)
F. Pederiva (University of Trento, Italy)
M. Petri (TU Darmstadt, Germany)
A. Rios Huguet (University of Surrey, UK)
A. Roggero (University of Trento, Italy)
J. Simonis (TU Darmstadt, Germany)
A. Spyrou (National Superconducting Cyclotron Laboratory, USA)
A. Steiner (Institute for Nuclear Theory, USA)
I. Tews (TU Darmstadt, Germany)
J. Vary (Iowa State University, USA)
C. Wellenhofer (TU München, Germany)

SCIENTIFIC REPORT:

Three-body forces are a key ingredient of all modern approaches to low-energy nuclear physics. Their impact ranges from subtle effects on the structure and limits of stability of finite nuclei, to sizeable contributions in neutron (star) matter, and the saturation of nuclear matter. Novel three-nucleon interactions are being currently developed and implemented in modern few- and many-body approaches. The most notable examples are the recent POUNDerS refitting of chiral forces and the local reformulation of chiral Effective Field Theory (EFT), as well as the incorporation of the completed N3LO three-nucleon interactions in nuclear matter and structure calculations. Considerable effort is being dedicated to addressing the conceptual and technical challenges associated with these tasks.

Three-nucleon forces derived within chiral EFT have recently been used to study pure neutron matter in the framework of Many-Body Perturbation Theory, lattice EFT, Coupled Cluster theory, self-consistent Green's functions, and Quantum Monte Carlo. The ability to use the same systematic input in a variety of state-of-the-art many-body schemes offers the previously unavailable option of carefully benchmarking properties of a simple (but still highly non-trivial) nuclear system. The next natural step is the theoretical understanding of nuclear saturation of matter, which has been elusive within a fully non-perturbative setting thus far. Three-body forces will be critical for this and will also impact our understanding of neutron stars as well as supernova environments. For this it will be crucial to have a firm grasp on the theoretical uncertainties of the forces, as well as the propagation of these uncertainties within many-body calculations. Experimental input will be key for obtaining a unified description of infinite matter and finite nuclei.

In nuclear structure, microscopic approaches have made remarkable progress over the last decade, extending their reach beyond light nuclei, addressing open-shell systems and bridging to reaction studies. Three-body forces play a central role in such advances, making a quantitative description of nuclei with mass number $A < 30$ possible. Pushing this frontier to larger particle numbers presents considerable challenges. The growth of the associated model spaces calls for new ways of computing and dealing with three-body potentials. In addition, further work at the level of the interaction, e.g. by including diagrams of higher order in the chiral expansion or by explicitly including Δ degrees of freedom is needed. Different Renormalization Group (RG) schemes are also being developed and will provide new perspectives on three-body forces and their utilization in ab initio calculations.

Results and Highlights

This workshop included six overview talks by established experts and shorter presentations targeted on more specific topics, which resulted in a well-balanced setting for structured and informal community-wide discussions. Since every speaker was asked to present explicitly the current status and future needs regarding three-nucleon forces in a dedicated slide, the workshop's specific theme was appropriately focused on. Key questions and projects arisen during the talks were then collected and re-examined in the moderated discussion session.

In the talks some completely new developments were presented for the first time. This includes first Quantum Monte Carlo calculations for nucleonic matter at finite proton fractions, which will allow novel studies and benchmarks of the nuclear equation of state (S. Gandolfi). Furthermore, an improved and more systematic way of regularizing the short- and long-distance physics in chiral EFT interactions was presented (E. Epelbaum & H. Krebs). This strategy was shown to lead to significantly smaller uncertainty bands for the nucleon-nucleon scattering phase shifts. Finally, a generalized coupled cluster approach based on a Bogoliubov reference state was presented, which will enable novel calculations of open-shell nuclei in the near future that are complementary to existing methods (T. Duguet).

One of the main points of debate concerned the need of benchmarks between different many-body methods and most importantly in different physical systems, namely light nuclei vs. medium/heavy nuclei vs. nuclear/neutron matter. While, on the one hand, ab initio calculations have made tremendous progress in the last few years, on the other hand the accumulated results point towards deficiencies in the currently available chiral two- and three-nucleon interactions. In particular, state-of-the-art calculations systematically overbind medium-mass and heavy nuclei and underestimate radii; it is also unclear whether the correct saturation properties of nuclear matter can be reproduced. However, the use of different techniques and conventions in the derivation of nuclear forces hinders a clean analysis of the problem. Cross-checks between different approaches and different systems starting with the same two- plus three-body potential would therefore be highly beneficial and help the construction of next-generation chiral interactions. Specifically, it was proposed to use light nuclei in an external harmonic trap as a benchmark system – this would be a more demanding test than neutron drops, which have been studied in the recent past. By adjusting the properties of the trap it could be possible to study more systematically the sensitivity of observables to high-momentum components of the wave function.

This closely relates to another much debated point, namely the possible set up of open-access websites as an efficient and novel way to distribute matrix elements across the different many-body groups. Remarkably, despite the great advances in the derivation of nuclear interactions from chiral EFT and in the development of ab initio approaches, an efficient interface between the two communities exists only in isolated cases.

An extended availability of different nuclear potentials would play a beneficial role in the issue of estimating theoretical uncertainties, which constitutes another highlight of the workshop. Always advocated by ab initio practitioners, a thorough analysis of theoretical errors and their propagation in the different steps of many-body calculations is often problematic in practice.

This is particularly important in view of a constructive interplay with current and forthcoming experiments. In this respect, results and exciting new directions were presented, e.g., in precision mass measurements and the spectroscopy of neutron-rich exotic nuclei, confirming the overlap between experimental and theoretical endeavours in low-energy nuclear physics.

3.3.6 HYDRODYNAMICS OF STRONGLY COUPLED FLUIDS

DATE: May 12 - 16, 2014

ORGANIZERS:

S. Jeon *(McGill University, Canada)*
P. Romatschke *(University of Colorado, USA)*
T. Schäfer *(North Carolina State University, USA)*

NUMBER OF PARTICIPANTS: 34

MAIN TOPICS:

Experiments have shown that both the Quark-Gluon Plasma as well as ultra-cold Fermi gases near unitarity are nearly perfect fluids. This means that the ratio of shear viscosity to entropy density is very small, and that kinetic theory and quasi-particle descriptions are not expected to be reliable. In order to fully quantify these statements we need to understand hydrodynamic models in a new physical regime of large velocity gradients, large fluctuations, and small physical volumes. The workshop brought together experts from high energy nuclear physics, string theory and atomic physics to advance our understanding of strongly coupled fluids, and to address such issues as the role of fluctuations, pre-equilibrium matching, the applicability of hydrodynamics in very small systems like pp and pA collisions, and the applicability of the AdS/CFT correspondence. We also addressed the possibility of observing new hydrodynamic effects related to anomalies.

The main topics were:

- Higher harmonics of flow and event-by-event hydrodynamics
- Energy and system size dependence of flow
- Equilibration and Matching
- Anomalous hydrodynamics
- Transport coefficients and quasi-particle models
- Strongly correlated non-relativistic fluids

SPEAKERS:

F. Becattini (INFN, University of Florence, Italy)
W. Broniowski (Polish Academy of Sciences, Poland)
G. Denicol (McGill University, Canada)
C. Gale (McGill University, Canada)
S. Gubser (Princeton University)
K. Hazzard (JILA and University of Colorado, USA)
U. Heinz (Ohio State University, USA)
T. Hirano (Tokyo University, Japan)
P. Huovinen (ITP, Frankfurt, Germany)
D. Kharzeev (Brookhaven National Laboratory)
P. Kovtun (University of Victoria)

J. Jia (Stony Brook)

M. Mendoza Jiminez (ETH)

G. Moore (McGill University)

T. Schäfer (North Carolina State University)

M. Stephanov (University of Illinois, Chicago)

D. Teaney (Stony Brook)

T. Yefsah (MIT)

SCIENTIFIC REPORT:

Over the last dozen years there has been a renewed interest in fluid dynamics of strongly correlated quantum systems. In 2001, experiments at RHIC discovered nearly ideal fluid behavior in the expansion of the fireball created in collisions of relativistic heavy ions. Shortly thereafter nearly ideal flow was also discovered in a very different system, ultracold Fermi gases in the vicinity of a Feshbach resonance. For nearly ideal fluid dynamics to be applicable the viscosity of the fluid must be very small, especially in systems that evolve on very short length and time scales. Recent analyses imply that the shear viscosity to entropy density ratio of the quark gluon plasma created at RHIC is extremely small, $\eta/s = (0.10\text{-}0.25)$.

Weak coupling calculations indicate that viscosity scales inversely with the coupling constant. A nearly ideal fluid characterized by $\eta/s \sim 1$ must therefore be strongly coupled, and cannot be described using kinetic theory and weak coupling methods. Shortly after the discovery of nearly perfect fluidity at RHIC a theoretically controlled realization of a strongly coupled gauge theory fluid was discovered based on the AdS/CFT correspondence. The AdS/CFT correspondence implies that for a large class of fluids there is a lower bound on the shear viscosity to entropy density ratio, $\eta/s \geq 1/(4\pi)$. The quark gluon plasma at RHIC/LHC and ultracold Fermi gases near a Feshbach resonance are the two fluids in nature that come closest to this theoretical bound. While separated by many orders of magnitude in temperature and density the quark gluon plasma and ultracold Fermi gases exhibit very similar transport properties.

RHIC is now in the precision measurement stage, and experiments at the LHC are providing a large amount of very accurate data. Fluid dynamics is an indispensable tool for understanding the system created at RHIC and the LHC, ranging from bulk properties to subtle many-particle correlations. Improving the hydrodynamic description in order to take full advantage of the precision of the data is not simply a matter of solving classical equations to higher accuracy, but it also raises interesting conceptual questions. These questions have to do with the interface between fluid dynamics and far-from-equilibrium quantum field theory in the initial state and kinetic theory in the final state. They also involve the role of fluctuations, gradient corrections, anomalies, the interaction with perturbative probes, etc. These problems are addressed using a variety of tools, like the AdS/CFT correspondence, effective field theory, and quantum kinetics.

The first goal of the workshop was to understand what tools are needed to analyse the experimental data from RHIC and the LHC, and what we can hope to learn in the next few years. The larger aim of this effort is to determine transport properties of the QGP with controlled uncertainties. This includes the temperature dependence of η/s, as well as signatures of the phase boundary or the QCD critical point. In order to achieve these goals we need reliable and well controlled theoretical tools. Current analyses are based on initial state models, event-by-event hydrodynamics, and kinetic afterburners. Questions we addressed include:

- Can pre-equilibrium calculations based on strong coupling AdS/CFT or weak coupling classical field evolution smoothly interface with the hydrodynamic stage?
- Do we need to improve the matching between the hydrodynamic stage and the initial and final stages? Do we need hydrodynamic descriptions that can handle large

inhomogeneities, or smoothly interpolate to free streaming boundary conditions? Do we need to go beyond the current second-order hydrodynamic description to understand the heavy ion collisions, for example by including hydrodynamic fluctuations?
- Can we extrapolate the hydrodynamic description to very small systems, like pA and pp collisions?

The second goal of the workshop was to advance new theoretical ideas that are emerging from thinking about fluids in terms of holographic dualities or effective theories. The AdS/CFT correspondence was used to determine the hydrodynamic equations for a conformal fluid at second order in the gradient expansion, and it has furnished theoretical models of the approach to equilibrium at strong coupling. AdS/CFT has also inspired a great deal of work on anomalous effects in hydrodynamics, like the chiral magnetic effect or the chiral vortical effect. Recently, numerical simulations of strong-coupling dynamics of gauge theories far from equilibrium have become feasible. Questions we discussed are:
- Can we use strong coupling methods to provide realistic initial conditions, and can we distinguish weak and strong coupling mechanisms for equilibration?
- Is complete equilibration necessary for the success of the hydrodynamic description?
- Can we construct a complete hydrodynamic framework for studying anomalous effects, and what are the most sensitive observables?

Results and Highlights:
We had productive discussions on a number of issues:
- Hydrodynamics in pA collisions: the evidence for hydrodynamic behavior in pA collisions appears to be compelling (the mass ordering of radial and elliptic flow, the agreement of v2 extracted via 2,..,8 particle correlation functions, etc.). The experimental situation was discussed by Jia. A simple scaling relation between pA and AA collisions was discussed by Teaney, and more detailed hydrodynamic fits were presented by Broniowski. Important questions remain regarding a suitable initial state model for pA collisions. Do quantum mechanical fluctuations of the shape of the proton play a role?
- New hydrodynamic solutions and longitudinal flow: Gubser discussed the late time behavior of hydrodynamic solutions obtained from colliding shock waves in AdS. These solutions are not Bjorken-like, but they can be described in terms of "complexified" Bjorken flow. Stephanov discussed the possibility of reconstructing the longitudinal flow profile from final state observables.
- New methods for simulating relativistic hydrodynamics: we had interesting discussion about the lattice Boltzmann method (Miller), and fluctuating hydrodynamics (Hirano).
- Role of bulk viscosity: a number of talks (Beccattini, Denicol) and a discussion session focused on the role of bulk viscosity. Effects of bulk viscosity are potentially significant, and it is not clear what the best observables are that constrain ζ.
- Role of fluctuations: a number of participants is working on fluctuating hydrodynamics. We had talks on the subject by Hirano, Moore, and Kovtun. From the point of view of phenomenology the question is what parameter governs the relative role of initial state and hydrodynamic fluctuations.
- Anomalies, magnetic fields, and vorticity in heavy ion collisions: Kharzeev provided an overview of anomalous effects in hydrodynamics. During one of the discussion sessions we focused on the current experimental situation regrading charge dependent flow effects, and about estimates of the amount vorticity present in a heavy ion collision.
- Experimental puzzles: Gale talked about theoretical studies devoted to understanding the large observed photon v2. Heinz emphasized the problem posed by the observed, approximate, equality of v2 and v3 in extremely central collisions.
- Nonrelativistic fluids: Yefsah talked about spin diffusion in strongly correlated Fermi gases, and about interesting solitons observed in the superfluid phase. Hazzard discussed the approach to equilibrium in strongly correlated Bose gases.

- Participants of the workshop finalized two papers during the meeting:
- P. Kovtun, G.D. Moore and P. Romatschke, Towards an effective action for relativistic dissipative hydrodynamics, arXiv:1405.3967 [hep-ph].
- Kozlov, M. Luzum, G. Denicol, S. Jeon and C. Gale, Transverse momentum structure of pair correlations as a signature of collective behavior in small collision systems, arXiv:1405.3976 [nucl-th].

3.3.7 FUTURE DIRECTIONS IN THE PHYSICS OF NUCLEI AT LOW ENERGIES

DATE: May 21 – 23, 2014

ORGANIZERS:

F. Azaiez *(Institut de Physique Nucleaire CNRS/IN2P3, France)*
K. Blaum *(Max-Planck-Institut für Kernphysik, Germany)*
A. Schwenk *(Institut für Kernphysik, Universität Darmstadt, Germany)*
U. van Kolck *(Institut de Physique Nucleaire CNRS/IN2P3, France)*

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

The workshop was meant to stimulate a brainstorm activity about future opportunities in the field of low-energy nuclear physics. We reviewed current ideas in the three main topics:

- nuclear structure and reactions
- nuclear astrophysics
- fundamental symmetries and neutrinos

involving hadronic systems and nuclei (from light to heavy). On the basis of this review, intense discussions scrutinized which of these ideas could serve as seeds for future experimental programs in Europe..

SPEAKERS:

T. Aumann (University of Darmstadt)
J. Dobaczewski (University of Warsaw and Jyväskylä)
S. Eliseev (University of Heidelberg)
S. Goriely (University of Brussels)
T. Janka (University of Garching)
N. Kalantar (University of Groningen)
E. Khan (University of Orsay)
Y. Litvinov (University of Darmstadt)
L. Marcucci (University of Pisa)
J. Menendez (University of Darmstadt)
F. de Oliveira (University of Caen)
J. Suhonen (University of Jyväskylä)
P. Woods (University of Edinburgh)

SCIENTIFIC REPORT:

The study of nuclear structure and reactions forms the core of nuclear physics, and its importance is widely recognized in understanding the production of elements in the universe and in testing rare or forbidden processes in the Standard Model of particle physics. At low energies QCD is a theory of hadrons, and properties of nuclei arise from inter-nucleon

interactions known to have a rich structure, including three-body components. Explaining and predicting properties of nuclei as a many-nucleon problem remains one of the most fundamental problems of nuclear physics.
Structure and reactions of nuclei have been an active field in Europe since its inception. A major theme of contemporary research is the study of the evolution of shell structure, and more generally of nuclear dynamics, towards the driplines, where important astrophysical processes take place. Large facilities such as GANIL, GSI and ISOLDE have provided the backbone of the experimental effort, supplemented by very active programs at ALTO (Orsay), LNL (Legnaro), 3 JYFL (Jyväskylä), and others. The vigorous effort dedicated to the construction of FAIR and the trio of next-generation ISOL facilities (HIE-ISOLDE, SPES, and SPIRAL2) ensures that significant progress will be achieved through 2025.
Yet, it is timely to make an assessment of the longer-term prospects for the field. What are the emerging trends and open questions in the structure of systems with two or more nucleons and their low-energy reactions? How should they shape the next-generation of radioactive beam facilities? Which of them can be turned into a subsequent experimental nuclear program for Europe?

Results and Highlights
Answering such multi-faceted questions is clearly a many step process. Our goal was to provide a venue where, as a first step, a focused discussion could be initiated. To accomplish this goal we planned a relatively small and short meeting with ample time for discussions. Each day was dedicated to a main topic consisting of 4-5 talks in the morning and open discussions in the afternoon. The talks by leading theorists and experimentalists reviewed most of the leadingedge issues in their topic, and were followed by short discussions to clarify specific points. The discussions in the afternoon involved all participants and dealt both with the ideas raised in the morning talks and with the points raised by the audience, under the leadership of 3-4 theorists and experimentalists. Participants, coming from a large number of European countries, were stakeholders in the future of the field, with a number of distinguished senior colleagues bringing their wisdom about what can, and cannot, be realistically accomplished. The final program of the workshop can be found at the end of this document.
The crisp views espoused by most participants led to very lively arguments. We summarize them separately for each topic, although of course there was a lot of overlap in the discussions.
Nuclear structure/reactions (based on a summary provided by T. Duguet, C. Forssén, and K. Hebeler):
The discussion started with general issues related to the justification, interest, visibility, and organization of the field. It was agreed that justification and visibility are needed in healthy balance, first and foremost for, and by, the field itself: key questions should always be (re)phrased.
Interdisciplinary features further strengthen the field, potentially injecting new ideas. “New” degrees of freedom could be a way forward, e.g. should this be the strangeness/hyper-nuclei era? A sense emerged that while new thinking comes from extremes, true understanding comes from systematics. One should not trust either experiment or theory without uncertainty quantification.
Next some general goals of nuclear structure and reaction theory were discussed, in particular, what do we want to achieve with QCD-based approaches? Most people expressed the opinion that we want to achieve a unified view of structure and reactions through progress from few- to many-body physics with controlled approximations, addressing i) the emergence of magic numbers, collective and individual excitations at the same energy scale; ii) the limits of nuclear stability as a function of nucleon number, energy, spin, isospin, strangeness; and iii) phenomena such as superfluidity, exotic collective excitations, one-nucleon dynamics, halo, etc. Precise/systematic/controlled account of rich phenomenology at play in stable and unstable systems requires uncertainty quantification and error propagation.

A general question that emerged was, “Can we understand the 4 nuclear landscape with effective field theories (EFTs)?”
Going towards very neutron-rich nuclei and other extremes, the question was raised whether there is an innovative production mechanism on the table. No clear answer seemed available.
On the theoretical front, we need predictive theories with as large a reach as possible, e.g. innovative ab initio many-body methods together with ab initio-rooted energy density functionals (EDFs) and configuration-interaction (CI) methods. We should strive for an era of theoretical uncertainty evaluation, but we are not there yet despite impressive phenomenological successes.
An obstacle on this road is the scale- and scheme-dependence of analysis and interpretations of data. The point was made that one should always split true observables from scale-dependent, interpretation-related ingredients, e.g. wavefunctions, correlations, few-body-force components, spectroscopic factors, single-particle shell structure, etc. This point needs to be fully integrated in our “mental algorithm” and to be seriously communicated in theoretical modeling and “extraction” of parameters. In particular, reaction theory needs to revisit various factorization schemes as a function of scale. In other words, the issue is how to translate advances in EFTs and ab initio methods to reaction theory.
To help with this task, we may hope to take true advantage of massively parallel computing in the years to come. This is an arena for collaboration between nuclear theorists, applied mathematicians, and computer scientists. One should further investigate how this can be best promoted in Europe (an initiative like SciDAC-DOE in the US?) and what is feasible within the next five/ten/fifteen years.
A few of the more specific directions that were suggested included the following:
- few-nucleon forces: the situation in the three- and four-nucleon systems is not settled but the problem seems to be mostly the lack of a systematic theoretical analysis, rather than of experimental data; a new, large experimental program was not deemed necessary, although existing efforts should of course be supported; exploitation of emerging calculational methods interfacing structure and reactions seems to be the best direction for the coming years.
- ab initio methods: precise and extensive calculations (NCSM, SCGF, CC, IMSRG) of light- and medium-mass nuclei to test few-body forces; calculations based on chiral effective field theory (EFT) that cover the nuclear chart (CI, EDF); uncertainties associated with input fewbody forces and many-body methods must be systematically assessed; improved forces based on chiral EFT (and lattice QCD?); an experimental push towards the neutron drip-line and beyond, e.g. light unbound nuclei.
- EDFs: theoretical uncertainty estimate and propagation, since the family of Skyrme EDF parametrizations reflect large intrinsic error bars and the fitting procedures strongly impact performance; improvement on performance of current EDF parametrizations — even though one should be impressed by the achievements of current EDF calculations, Skyrme, Gogny, and relativistic families of EDF parametrizations are insufficient; change in paradigm to reach spectroscopic quality, with new analytical form(s) incorporating enriched physics based on a systematic approach; more professional fitting strategies including uncertainty evaluation and propagation.
- phenomenology: converging mass predictions for exotic nuclei; deep understanding of clusterization in nuclei; unification of structure and reaction with accurate reaction models based on time-dependent EDF; determination of equation-of-state (EoS) quantities (such as the symmetry energy); measurement of soft and exotic modes in exotic (deformed) nuclei; neutron skins (direct measurement); giant monopole resonances (GMRs) in extended isotopic chains including exotic 5 nuclei; search for clusterization signals in the ground state of light nuclei.
Nuclear astrophysics (based on a summary provided by A. Tumino):
The astrophysics discussion mainly focused on explosive nucleosynthesis. It started with an in-depth analysis of the plenary talks of the morning session. It was emphasized in the talks that r-process nucleosynthesis has been confirmed in neutron star mergers, but no firm

conclusions about the equation of state (EoS) can be reached from supernovae yet. Several reactions needed for various stages of star evolution were listed.
Many of the nuclides generated in the huge explosion triggered by the final burning in a massive star are unstable. It was stressed that the physics of radioactive beams should be explored in order to understand supernovae explosions, gamma-ray bursts, and novae. However, much work is being done to fix a number of astrophysical constraints. Advances in supercomputing allow theorists to model stars and stellar explosions more realistically and to explore the close links between the properties of unstable nuclei and explosive nuclear astrophysics. Many groups have taken the opportunities offered by the world-wide developments of radioactive ion beams facilities to start to investigate such environments.
For charged-particle reactions in explosive scenarios, the Coulomb barrier is not a big issue because of the higher temperatures involved. Moreover, cross sections are higher than in the case of hydrostatic burning. However, intensities are lower and innovative methods to investigate such reactions are foreseen. In this field, weak-interaction processes play a role and in some cases, such as type-II supernovae, they are dominant.
Electron screening was another discussion topic. While it is negligible at the stellar temperatures relevant for charged-particle reactions involving radioactive species, its effect on cross sections cannot be neglected in laboratory reactions at the energies of hydrostatic burning. However, to assess reaction rates correctly, the screening effect has to be removed from experimental data. Alternatively, different experimental techniques, such as indirect methods, are needed to determine the so-called bare nucleus cross section. From a theoretical point of view, atomic models needed to predict electron screening are lacking in several aspects and are being revised. A recent description of electron screening in stars points out that electron screening in stellar plasmas plays a small role.
Symmetries and neutrinos (based on a summary provided by D. Gazit, N. Severijns, and C. Volpe):
The nucleus can act as both a detector and a laboratory for the study of symmetries and neutrinos. The traditionally strong correlation between theory and experiment is especially well developed in this field and should be maintained. Starting from questions such as "Which accuracy is needed in theory, and what limits the theoretical calculations?", "Which processes should be measured?", and "What can change in the next 10 years?", we discussed:
- Discrete symmetries. Here the main foci are the T, P, CP, and CPT symmetries, with experiments using antimatter, electric dipole moment searches in different types of systems (including proposed experiments on light nuclei), precision measurements of atomic parity violation, and neutrinos. In these searches, an experimental signal will positively indicate a symmetry violation.
However, in order to pinpoint the fundamental origin, signals from different systems are needed. In addition, constraining fundamental constants can be done only by theoretical calculations of these symmetry breaking effects.
- Fundamental constants (e.g. the exact value of the neutron lifetime and of the axial vector 6 coupling constant gA, time-dependence of the fine structure constant, etc.). For the exact determination of the neutron lifetime and gA especially, systematic effects need to be addressed in great detail in the upcoming experiments. Precision QED tests show nuclear structure effects at a significant level (10–11). This means that good theoretical control over systematic nuclear effects is needed in order to allow these precision tests. Today this can be done only for the lightest nuclei. This can be done by either showing an effect on a few nuclei, or by studying only these nuclei that can be calculated accurately enough.
- Beta decays. Important topics here are further increasing the precision of the Vud quark mixing-matrix element, correlation measurements searching for non-standard-model weak interactions, and bound beta-decay studies. Vud is a main topic in which theory has to show accurate calculations mainly of isospin symmetry breaking effects and nucleus-independent radiative corrections to further increase precision of the CKM unitarity test. Measurement accuracy is steadily increasing by the use of advanced experimental techniques, but further

collaboration with theory is needed to set up experimental tests to verify and validate the calculations of isospin-breaking effects. Correlations in beta decays might prove as a nuclear physics hatch to higher energy, better than direct high-energy studies, as was recently shown in the framework of an EFT approach allowing to directly compare results from low and high energies. These studies should therefore aim at the per mil level (factor of 5 to 10 improvement). Theory must follow, and specify the size of corrections, due to recoil (induced matrix elements), radiative processes, etc.

- Lorentz violation. Topics of interest here are measurements involving neutrinos and Lorentz violation tests in beta decay where data are historically scarce. Recently a theoretical framework has been published showing which are the most interesting observables in beta decay to test Lorentz violation and how such measurements can be interpreted.
- Neutrinos. The main topics for future searches are the search for leptonic CP violation, the determination of the neutrino absolute mass and mass ordering, of the neutrino nature (Dirac versus Majorana), and the search for additional, sterile neutrinos. These crucial open issues will be the object of a number of experiments in the coming decade. In addition, a few anomalies cannot be interpreted within the standard framework of three active neutrino oscillations and need reconciliation. These comprise the MiniBOONE, the "Gallium" as well as the "reactor neutrino" anomalies. Recent works have shown that the MiniBOONE anomaly could be due to nuclear effects in the cross sections (in particular 2p-2h) not taken into account properly so far. For the Gallium and the reactor anomalies the hypothesis of the existence of a sterile neutrino will soon be tested by using intense static radioactive sources. The clarification of the latter anomalies will strongly benefit from an improved knowledge of the beta decays of the fission products in the reactors (e.g. weak magnetism, forbidden transitions). Neutrino-nucleus interaction studies need more experimental measurements with low-energy neutrino beams, since data are still scarce. In this context calculations employing novel approaches currently developed would be of great interest.

These investigations are important both for astrophysical applications (supernova neutrino detection, nucleosynthesis processes) and for better constraining the nuclear spin-isospin response that is central in neutrinoless double-beta decay searches.

- Rare decays and processes. Particularly important are searches for neutrinoless double beta and muon (like the mu-e-gamma (MEG) experiment) decays and for dark matter. In the case of neutrinoless double beta decay and direct detection of dark matter searches, nuclear theory has a prominent role providing matrix elements and cross sections. However, the nuclei used in these experiments demand approximate methods. Here, we have laid out a minimal list of theoretical 7 tests, which can be used to validate a calculational method for the rare process. This list includes: two-neutrino double beta decays, Gamow-Teller and forbidden strengths, the spectrum of the mother and daughter nuclei. In addition, it will be important for theory to prove accurate in processes such as muon capture, "occupancies", and electromagnetic transitions. It was generally accepted that only calculations based on approaches capable of giving accurate results for this minimal list should be considered as being on a firm ground. We hope that follow-up meetings will sharpen these discussions to a point such that they would be useful input to broader assessments of the future of the field, such as the next long-range plan under the auspices of NuPECC.

Acknowledgements.
We would like to thank the ECT* for providing the funding (with EMMI) and the infrastructure, in particular the efficient work of Gian Maria Ziglio, for this workshop.

3.3.8 LOW-ENERGY REACTION DYNAMICS OF HEAVY-IONS AND EXOTIC NUCLEI

DATE: May 26 – 30, 2014

ORGANIZERS:

A. Diaz-Torres *(ECT*, Italy)*
N. V. Antonenko *(JINR Dubna, Russia)*
P. R. S. Gomes *(Federal Fluminense U, Brazil)*

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

In-depth discussions of selected, important recent experimental and theoretical developments in the field of low-energy nuclear reaction physics among the world's leading scientists has been the central objective of this workshop.

The main topics were:

- Breakup, transfer, fusion, elastic scattering and core-excitation effects in reactions involving halo and weakly bound nuclei
- Effect of pairing and core ground-state correlations on few-nucleon transfer reactions
- Multi-nucleon transfer reactions
- Effect of transfer on sub-Coulomb fusion and the fusion hindrance phenomenon
- Fusion and quasi-elastic barrier distributions
- Reaction forming heavy elements: quasi-fission, fission, super-heavy elements and role of structure of heaviest nuclei in their production
- Nuclear structure studies with heavy-ion transfer reactions
- Structure of light exotic nuclei

SPEAKERS:

M. Dasgupta (ANU, Australia)

P. Figuera (INFN-LNS Catania, Italy)

A. Lepine-Szily (USP, Brazil)

M. Mazzocco (INFN-Padova, Italy)

A. Diaz-Torres (ECT*, Italy) *

A. Gomez-Camacho (ININ, Mexico)

P. R. S. Gomes (Federal Fluminense U, Brazil)

P. Descouvemont (ULB, Belgium)

S. Hofmann (GSI, Germany)

A. M. Moro (Sevilla U, Spain)

J. A. Lay-Valera (INFN-Padova, Italy)

H. Lenske (JLU Giessen, Germany) *

A. Vitturi (INFN-Padova and Univ. Of Padova, Italy)

R. A. Broglia (Milan U, Italy)

E. Vigezzi (INFN-Milan, Italy)

F. Barranco (Sevilla U, Spain)

G. Scamps (GANIL, France)

D. J. Hinde (ANU, Australia)
K. Nishio (JAEA, Japan)
S. Heinz (GSI, Germany)
N. V. Antonenko (JINR Dubna, Russia)
G.G. Adamian (JINR Dubna, Russia)
V.V. Sargsyan (JINR Dubna, Russia)
G. Montagnoli (INFN-Padova and Univ. of Padova, Italy)
A. Stefanini (INFN-Legnaro, Italy)
S.G. Zhou (ITP Beijing, China)
E. Piasecki (University of Warsaw, Poland)
L. Fortunato (INFN-Padova, Italy)
S. Bottoni (INFN-Milan, Italy)
L. Corradi (INFN-Legnaro, Italy)

SCIENTIFIC REPORT:

The understanding of the physics of low-energy nuclear reaction is crucial for explaining the chemical evolution of the Universe. Nuclear-reaction physics research has entered a new era with developments of rare-isotope beam facilities, at which nuclear reactions are the primary probe of the new physics, such as novel structural changes. Innovative detection systems are allowing measurements of unprecedented selectivity and precision, including those using intense stable beams. These require new theoretical investigations in the nuclear structure and reaction dynamics. Properly combining many-body nuclear-structure information and reaction dynamics is a major outstanding problem. The evolution of the nuclear shells toward the proton and neutron drip-lines is of great interest. The expansion of the nuclide chart to unknown isotopes and elements is one of the fundamental problems. The production of new nuclei with Z=120 in fusion reactions would be a challenge to check the shell model predictions of the proton shell closures beyond Z=82.

Results and Highlights

Most participants expressed the view the meeting was outstanding, presenting the latest results on the topics outlined above. New ideas were presented and unpublished new data were discussed. The results of the quantum diffusion approach were suggested to be compared with the coupled channel calculations. The barrier distribution requires more precise measurements with smaller energy step. There was a fruitful discussion of the reasons for suppression and enhancement of the sub-barrier fusion. The neutron transfer could cause the change of the deformations of the approaching nuclei. New models on halo breakup and transfer reactions were shown and discussed. In these models the continuum states can play the role of a bath for the open quantum system and the corresponding theory can be applied. The production of nuclei near the drip-lines in transfer reactions requires larger intensities of radioactive beams. 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. As pointed out, different predictions of the position of the proton shell closure in the region of heaviest nuclei result from the uncertainties in the parameters used. Most delegates support the experimental activities for producing new elements and exotic nuclei. Everybody liked the long, interactive talks (one hour) as it facilitated extensive and fruitful discussions. It was made possible by a highly favourable number of participants. The Workshop Colloquium by Prof. Sigurd Hofmann (GSI, Germany) was excellent, attended by several external people (mainly from the University of Trento and FBK). A large number of participants were from INFN

3.3.9 NEW FRONTIERS IN MULTISCALE MODELLING OF ADVANCED MATERIALS

DATE: June 17- 20, 2014

ORGANIZERS:

S. Taioli *(FBK)*
M. Dapor *(FBK)*
N. Pugno *(University of Trento and Queen Mary University of London)*

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

- Atomistic, semi-empirical and continuum approaches to materials science
- Electronic, optical, thermodynamical and mechanical properties of materials
- Theoretical and Experimental Spectroscopy
- Large-scale calculations with HPC

SPEAKERS:

D. Alfè (University College London, UK)
A. De Vita (King's College London, UK)
M. Garavelli (Ecole Normale Superieure de Lyon, France)
G. Cerullo (Politecnico di Milano, Italy)
F. Mauri (IMPMC, France)
P. Umari (University of Padua, Italy)
F. Pederiva (University of Trento, Italy)
J K. Johnson (University of Pittsburgh, USA)
S. Sorella (SISSA, Italy)
I. Tavernelli (EPFL, Switzerland)
B. Aradi (University of Bremen, Germany)
A. Iorio (Charles University in Prague, Czech Republic)
P. Faccioli (University of Trento, Italy)
M. Casula (IMPMC, France)
M. Calandra (IMPMC, France)
L. Kover (Institute for Nuclear Research, H. Academy of Sciences, Hungary)
E. Barbieri (Queen Mary University of London, UK)
M. Orsi (Queen Mary University of London, UK)
N. Doltsinis (University of Münster, Germany)
F. Zerbetto (University of Bologna, Italy)
C. Creatore (University of Cambridge)
M. Paggi (Institute for Advanced Studies Lucca, Italy)
D. Bigoni (University of Trento, Italy)
P. Scardi (University of Trento, Italy)
G. Garberoglio (FBK, Trento, Italy)
R. Verucchi (CNR-Trento, Italy)
V. Tozzini (CNR-Pisa, Italy)

F. Bosia (University of Torino, Italy)

S. Ryu (Korea Advanced Institute of Science and Technology, Korea)

S. Signetti (University of Trento, Italy)

SCIENTIFIC REPORT:

In the last ten years we have seen remarkable developments in two branches of condensed-matter physics. One is the study of the laws governing strongly correlated systems, with the growing realisation that electronic states other than simple Fermi liquids occur in several materials families. This area has been fuelled by the potential applications of materials, such as high-Tc superconductors, low-dimensional carbon-based materials, notably graphene and bio-inspired nano-structures, to electronics as well as by a fundamental desire to understand the ground and excited states of interacting many-fermion systems. The other is the rapidly growing field of computational science, dealing with numerical techniques for the solution of mathematical equations arising in all areas of physics. Improved algorithms and increased computational power indeed widened the areas of application of computational methods, particularly allowing unprecedented access to the investigation of electronic, thermodynamical and mechanical properties of materials where experiments are difficult to perform due to ambient conditions (high temperature and pressure) or simply cost. In this respect, atomistic simulations, based on ab-initio approaches, are nowadays widespread in many areas of physics, chemistry and, more recently, biology. However, the computational scaling of these methods with the system size is rather unfavourable, normally increasing exponentially with the number of particles. Most importantly, many phenomena, such as protein folding or rare events, occur in a time scale which is normally out of reach of present simulations. This space-time dimensionality bottleneck is usually bypassed adopting approximations on the type of interaction potential among constituents, or using lower-level electronic structure methods via empirical or semi-empirical approaches paying a price in terms of accuracy of the results. Multi-scale approaches try to combine different scale algorithms along with matching procedure in order to bridge the gap between first-principles and continuum-level simulations without loss of accuracy. The final goal of any of these approaches in materials modelling would actually be taking most advantage of both the smooth electronic fast dynamics while integrating the equation of motion on the long time scale given by nuclei. However, due to a strong interplay among these two scales this is not always possible. This workshop was aimed to lie at the intersection between these two emerging fields dealing with the modelling of nano-materials properties at different level of aggregation and chemical complexity from synthesis to the characterization of the ground and excited-state properties. World-renowned experts in this field gathered together to discuss this topic and deliver a number of talks on a variety of novel and state-of-the-art theoretical and computational methods in electronic structure theory, ab-initio and classical molecular dynamics in both adiabatic and non-adiabatic flavour, tight-binding and embedded-atom methods, density functional theory, quantum Monte Carlo, to interpret a specific set of physical and mechanical problems mainly related to materials science and solid-state physics. In this respect, contributions from speakers were devoted to quantum, classical and statistical mechanical studies, such as semi-empirical, first-principle calculations; density-functional theory; atomic and molecular-scale simulations, e.g. MC and MD techniques; other modelling techniques using macroscopic input, e.g. FE-methods, elasticity. Many were the contributions on the above-mentioned properties of materials underlying the real need of input by more sophisticated smaller-scale approaches. The keynote lecture, delivered by prof. Dario Alfè (University College London, UK), concerned several aspects of this specific topic of multi-scale techniques as applied to the study of the Earth. In particular, this ECT* colloquium was focused on the first principles and multi-scale computer simulations of the electrical and thermal conductivity of core material. Indeed, knowledge of these two parameters is essential to build a thermal model of the Earth and its magnetic field and to understand Earth's dynamics on both long (4.5 billion years) and short (thousands of years) time scales. A second, while foremost goal of the present workshop along with the presentation of the basic theory, was to show the application of these advanced methods to the description of a number of properties and their comparison with experimental measurements, such as, but not limited to: electronic, dynamical, transport, mechanical, growth and thermodynamical properties of materials, notably metals and alloys, graphene and nanotubes, biological and bio-inspired materials (e.g. retinal proteins and spider silk), semiconductors, insulators, superconductors, biomaterials, polymers, ceramics and composites in liquid, crystal, amorphous and cluster-like states. In this respect, in order to enhance the communication between experimental materials researchers, computational workers and theoreticians on both existing and novel materials and their applications, this workshop hosted quite a few experimental talks. Finally, the original approach on which this workshop was grounded was to cross the borders between several computational, theoretical and experimental techniques, and its successful accomplishment was testified by the attendance of a broad community of scientists coming from different backgrounds in physics, chemistry and engineering. Indeed, workshop participation included experimental and theoretical physicists, chemists and engineers interested in materials research, solid-state physicists, ground and excited state electronic structure calculations experts, and computational modellers in a broad sense. These disciplines are usually not interacting due to different approaches and technical jargon normally adopted in their daily work. This workshop successfully reached the initial goal of intersecting these research areas through the establishment of new collaborations among participants. The activity of this workshop will be collected into a special issue, edited by the three organizers of this event, in Frontiers in Materials, section Mechanics of Materials (http://www.frontiersin.org/events/New_Frontiers_in_Multiscale_Modelling_of_Advanced_Materials/2431). Note that Frontiers has signed an agreement with Nature Publishing Group and that our special issue will be the first appearing in this journal.

Results and Highlights

Concerning the aforementioned points, the workshop talks and discussion clearly outlined that material properties emerge from phenomena on scales ranging from angstroms to millimeters, and from picoseconds to seconds. Incorporating continuum mechanics, quantum mechanics, statistical mechanics, atomistic simulations via multiscale hierarchical (such as molecular mechanics, DFTB, GW, finite elements and continuum theory) and concurrent (such as QM/MM) techniques to cite those tackled in this workshop is essential if one desires a thorough and deep understanding of materials. In this sense, the take-home message of this workshop is that only a treatment intertwining different space and time scales provides a correct conceptual and computational framework for calculating materials properties.

This workshop thus dealt with many of the key theoretical ideas behind multiscale modeling and confirmed the recent trend that materials researchers must understand fundamental concepts and techniques from different fields, not limited to the use of ab-initio or continuum mechanics techniques intended as mutually exclusive research areas. Classical topics were blended with new techniques to demonstrate the connections between different fields and highlight current research trends. Example applications drawn from modern research on the electronic, optical and thermo-mechanical properties of solids were used as a unifying focus throughout the workshop.

3.3.10 RESONANCES AND NON-HERMITIAN QUANTUM MECHANICS IN NUCLEAR AND ATOMIC PHYSICS

DATE: June 23 - 27, 2014

ORGANIZERS:

C. Forssén *(Göteborg, Sweden)*
R. Kaiser *(Nice, France)*
N. Zinner *(Aarhus, Denmark)*

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

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

The main topics were:

- Quantum optics with nuclei
- Continuum aspects of Experimental Nuclear Physics
- Efimov physics from cold atoms to nuclei
- Strong interactions and dissipation in low-dimensional systems
- Weakly bound systems: clustering and correlations
- Ab initio nuclear theory including the continuum
- Quantum Amplification by Superradiant Emission

SPEAKERS:

C. Adams (Durham, UK)
A. Browaeys (Institut d'Optique, France)
L. Celardo (Catholic University, Italy)
A. Diaz-Torres (ECT*, Italy)
M. Efremov (Ulm, Germany)
J. Evers (MPI Heidelberg, Germany)
H. Fynbo (Aarhus University, Denmark)
M. Gattobigio (INLN, Nice, France)
H.-W. Hammer (TU Darmstadt, Germany)
B. Huang (University of Innsbruck, Austria)
I. Lesanovsky (University of Nottingham)
M. Madurga (University of Tennessee, USA)
N. Michel (Ganil, France)

M. Ploszajczak (Ganil, France)
S. Quaglioni (LLNL, USA)
R. Roehlsberger (DESY, Germany)
M. Rontani (CNR, Italy)
J. Rotureau (Chalmers, Sweden)
M. Rudner (Niels Bohr Institute, Denmark)
W. Schleich (Ulm University, Germany)
M. Scully (Texas A&M, USA)
G. Zürn (Heidelberg, Germany)

SCIENTIFIC REPORT:

The framework of quantum mechanics has been set almost 100 years ago using e.g. a Hamiltonian description of the system and its evolution. The range of use of this approach covers many fields of research, from nuclear physics to atomic physics, from quantum chemistry and nowadays even reaching into more complex biological systems. For open systems, scattering approaches have been used to describe a large variety of experimental situations. Alternatively, an effective Hamiltonian approach can be used to describe the finite lifetimes of resonance states. In this workshop, the focus has been on the physics of open quantum systems with experts from nuclear and atomic physics, from theory and experiments. This workshop has provided a unique opportunity to deepen our understanding of quantum mechanics in open systems through the presentation of recent advances in both theory and experiments with radioactive ion beams and with trapped ultracold atomic gases. Modern experimental setups in atomic physics offer an incredible amount of control: the number of particles can be varied (from many to few); the geometry of the trap can be changed (effectively tuning the dimensionality from quasi 1d to 2d and 3d); and even the strength of the interaction between the species can be varied (from strongly to weakly interacting through the use of Feshbach resonances). Modern tunneling experiments provide access to tunable, decaying few-body systems, and the associated capability to engineer the dissipation basically allows controlling the non-Hermitian part of the Hamiltonian. This workshop, with dedicated free time for discussions, has been a great opportunity for exchange of ideas, and to come up with relevant research projects that of are general interest. In low-energy atomic physics, the use of effective Hamiltonians has attracted a lot of recent attention, with the advent of experimental possibilities using ultracold atoms and well-controlled light-matter interactions. Several speakers have spoken on driven, open quantum systems where cooperative effects such as Dicke super- and subradiance and photon blockade are studied. This research field shares many features with the studies of mesoscopic physics where transport properties are at the center of interest. Dynamical phase transitions and quantum phase transitions, as well as non-equilibrium statistics, are currently investigated in many experiments and will benefit from the presentations and discussions which have occurred during this workshop, where different aspects of open quantum systems in connection with few- and many-body physics have been addressed. In low-energy nuclear physics, the growing interest in open quantum systems is largely associated with experimental achievements in producing weakly bound and unbound nuclei in the vicinity of the particle drip-lines, and efforts in studying structures and reactions with those nuclei. Unfortunately, on the theory side there is an artificial separation between nuclear structure and nuclear reactions that sometimes hinders a deeper understanding of the underlying physics. This separation can partly be explained by the huge success of the phenomenological nuclear shell model that employs the idea of a strongly renormalized bare nuclear interaction between nucleons while it completely ignores couplings to the continuum. The presentations and discussions during this workshop will allow combining developments in the theory of open quantum systems, from different fields of research, with modern computational approaches into a unified framework for nuclear structure and reactions. This will allow studying nuclear resonance phenomena from an ab-initio perspective, and will offer insights into the physics that is being explored with radioactive beam experiments. A very specific component of the nuclear many-body problem, that has been an important theme of the workshop, are the strong particle correlations, which impose the need for a simultaneous description of the configuration mixing and the coupling to open decay channels.

Results and Highlights

This workshop has been very fruitful in several ways. First it has allowed learning about the latest development in the field of open quantum system, both in cold atom physics as in nuclear physics. The overview speakers allowed the participants less familiar with one of these fields of research to have an introduction into the open questions, which then have been presented in more detail by specialized talks. Questions raised by experts from one field of research for the speakers of the other field have shown that common questions and techniques exist and allowed to see which part of one's research can be useful to a larger community of researcher. One important aspect has been the time taken for coffee and lunch breaks, which are essential to allow all the participants to meet each other and continue in the discussions and at some occasion engage in new collaborations. Also, the time after the afternoon sessions as well as the free Wednesday afternoon have been used by many participants meeting at this workshop to work together on detailed aspects of their research.
In order to obtain feedback from the participants on the relevance and utility of such an interdisciplinary workshop, we have polled them anonymously and the results of this poll can be found at the following url:
https://docs.google.com/forms/d/1VibE_E1w7JCW0ahcPZlxmavRiSjDwUdhh8WPEyBj2_A/viewanalytics In summary, 80% of the respondents mention that they have received some inspiration from OTHER areas of research that they believe will be useful for future projects, and 25% claim that they learned new concepts and/or techniques that they will use immediately in their own research. Everyone answered that they would be interested in attending another workshop in this series (potentially in two years), or would strongly recommend a close colleague to attend. The participants also gave some detailed recommendations to further improve such an interdisciplinary meeting, comments which will be very useful for future organizers. In addition, we asked the participants about their thoughts about the final stages of the world cup, and six participants correctly predicted that Germany would become World Champions.

Support

The workshop was organized with generous support from: The European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*), and the HadronPhysics3 project (an integrating activity of the Seventh Framework Programme of EU). In addition, the Swedish Foundation for International Cooperation in Research and Higher Education (STINT) provided additional funds that allowed generous support for all invited participants.

3.3.11 EXCITING BARYONS: DESIGN AND ANALYSIS OF COMPLETE EXPERIMENTS FOR MESON PHOTOPRODUCTION

DATE: June 30 – July 4, 2014

ORGANIZERS:

L. Tiator *(Institut für Kernphysik, Universität Mainz, Germany)*
A. D'Angelo *(INFN and Department of Physics, University of Rome Tor Vergata, Italy)*
J. Ryckebusch *(Department of Physics and Astronomy, Ghent University, Belgium)*

NUMBER OF PARTICIPANTS: 38

MAIN TOPICS:

- Status of meson photo-production experiments with all possible degrees of polarization
- Complete experiments in pseudoscalar-meson photoproduction
- Model independent determination of reaction amplitudes
- Partial wave analyses (SAID, MAID, Bonn-Gatchina, ANL-Osaka)
- Effective field theories and chiral corrections to nucleon resonance masses and amplitudes
- Nucleon resonances and partial waves in lattice QCD

SPEAKERS:

R. Beck (University of Bonn, Germany)
V. Burkert (JLab, USA)
D. Carman (JLab, USA)
V. Crede (FSU, USA)
A. D'Angelo (University of Rome, Italy)
R. Di Salvo (University of Rome, Italy)
R. Edwards (JLab, USA)
R. Gothe (USC, USA)
H. Haberzettl (GWU, USA)
D. Ireland (University of Glasgow, UK)
H. Kamano (University of Osaka, Japan)
G. Mandaglio (University of Catania, Italy)
V. Mathieu (JLab, USA)
L. Markou (University of Nikosia, Greece)
K. Nakayama (UGA, USA)
K. Nikonov (University of Mainz, Germany)
M. Ostrick (University of Mainz, Germany)
E. Pasyuk (JLab, USA)
D. Rönchen (University of Jülich, Germany)
J. Ryckebusch (University of Ghent, Belgium)
A. Sandorfi (JLab, USA)
A. Sarantsev (University of Bonn, Germany)
T. Sato (University of Osaka, Japan)
S. Schumann (University of Mainz, Germany)

V. Shklyar (University of Giessen, Germany)
I. Strakovsky (GWU, USA)
A. Svarc (University of Zagreb, Croatia)
A. Szczepaniak (University of Indiana, USA)
L. Tiator (University of Mainz, Germany)
M. Vanderhaeghen (University of Mainz, Germany)
D. Watts (University of Edinburgh, UK)
R. Workman (GWU, USA)
Y. Wunderlich (University of Bonn, Germany)
R. Young (University of Adelaide, Australia)

SCIENTIFIC REPORT:

The aim of the workshop was threefold:

- First, we wished to gather the scientific community involved in the analysis of Complete Experiments of pseudoscalar-meson photoproduction and to discuss the possibilities to turn these experiments into a novel tool to improve the knowledge of baryon resonances.
- Second, we wanted to build bridges between theorists and experimentalists. This involves presentation of the preliminary results of the ongoing efforts at Jefferson Lab, Mainz and Bonn, to measure a sufficiently large amount of single and double polarization observables. Furthermore, the synergy between experimental and theoretical advances is expected to result in a number of guidelines for the next round of experimental proposals.
- Third, we wanted to discuss recent developments in Effective Field Theory (EFT) and Lattice QCD to describe the structure and decay of nucleon resonances. An interesting subject is the new development in lattice QCD with finite volume, where instead of stable nucleon resonances, phases or partial wave amplitudes are calculated on the lattice, following the method developed by Lüscher (M. Lüscher, Nucl. Phys. B354, 531 (1991).).

The purpose of this Workshop was to discuss the opportunities and challenges which are created by the advent of a large amount of polarization observables in meson photoproduction. We wished to give the scientific community interested in the study of excited baryons a forum to discuss and debate how these so-called complete measurements can help in forming a more coherent picture of excited baryons and in establishing links with lattice QCD.

Results and Highlights

One of the major challenges in the study of excited baryons is to bridge the gap between the predictions of Quantum Chromo Dynamics (QCD) and the results of precise measurements of pseudoscalar meson photoproduction. At the workshop, new and exciting developments in Lattice QCD (LQCD) calculations were presented (Edwards, Young). These efforts dramatically increase the ab-initio information about N* and Δ* properties. To date, LQCD cannot compute dynamic properties, like cross sections and polarization observables for pseudoscalar meson photoproduction. Sophisticated reaction theories, dispersion theories and amplitude analyses of the data are necessary to extract the information about N* and Δ* properties from the measurements. Various speakers have given a survey of the available expertise in amplitude analysis, dispersion and reaction theory at the workshop. One of the major evolutionary trends in the resonance-analysis community is the increasing level of complexity of the frameworks which are used to extract the physical information from the data. This is in particular the situation for the multi-channel analysis tools (Kamano, Rönchen, Sarantsev, Sato, Shklyar). This trend has some disadvantages in that it complicates the reproducibility of the results given the available amount of manpower. At the workshop, some speakers presented novel schemes which aim at extracting the physical information from the data in a scheme-independent way (Haberzettl, Svarc, Markou). Also the techniques which can be used to separate the resonant and non-resonant parts of the studied reactions, received quite some attention at the workshop (Szczepaniak, Mathieu).

By means of detailed examples in pion, eta and kaon photoproductions, many experts (Crede) stressed that very often measurements of angular cross sections do not suffice to unambiguously extract the resonance information from the data. At the workshop, we have seen many examples of ongoing analyses illustrating the potential of data for the polarization observables to constrain the partial waves and the underlying resonance content of a certain reaction. In selected talks (Beck, Burkert, Mandaglio, Ostrick, D'Angelo), a status update was given of the ongoing efforts at Bonn, GRAAL, Mainz and Jefferson Lab to measure polarization observables in pseudoscalar meson photoproduction. These efforts include building new experimental equipment (Di Salvo, Watts) that involves the development of polarized proton targets, polarized photon beams and techniques for measuring the recoil-nucleon polarizations. All participants of the workshop got a very good feeling of the new experimental information which will be provided in the next coming years.

A central point of discussion in the debate of determining the resonance content of reaction is the potential of so-called "complete experiments". At the end of the nineties it was suggested that at a well-selected amount of experiments (eight in total) at a particular kinematics could allow one to determine the reaction amplitudes in a model-independent way. Various speakers stressed that "mathematical completeness" does not imply practical completeness and that extracting the amplitudes from data with finite error bars are not necessarily straightforward. Several ongoing studies of extracting the amplitudes (Ryckebusch) and partial waves (Nikonov, Sandorfi, Schumann, Tiator, Wunderlich) from data involving single- and double-polarization observables, were presented at the workshop. Thereby, use is made of real data, pseudo data or a combination of both. The issue of how much information is contained in the data has been addressed (Ireland). It became obvious (Pasyuk) that in $K^+\Lambda$ photoproduction the ongoing analyses of the measurements is approaching the situation that the largest set of single- and double-polarization observables in an extended energy range will become available.

Whereas most talks concentrated on reactions with real photons on the proton, attention was also paid to reactions involving "neutron" targets (Strakovsky) and virtual photons. The last couple of years have seen an enormous increase in our knowledge of how electromagnetic couplings ("transition form factors") run with distance scales. These experimental results provide a window on the dynamics of baryons at various distance scales (Vanderhaeghen). Most of this knowledge is extracted from single-pion, double-pion and eta electroproduction studies. Several speakers (Carman, Gothe) stressed the importance of cross checking the results and setting up a program to measure the (transition) form factors in several alternate reactions.

Conclusions

Our immediate goals were met. A status update of the current research activities in pseudoscalar-meson photoproduction was presented. We succeeded to gather the experts and to discuss the steps to be taken in the near future. The presentations were followed by lively, self-critical and open discussions in which the majority of the participants got involved. The meeting was attended by senior and junior researchers in an open atmosphere. A lot of participants expressed their appreciation for the smooth organization of the workshop and their enthusiasm for the timeliness and focus of the workshop.

3.3.12 BREAKUP REACTIONS OF EXOTIC NUCLEI AND RELATED TOPICS

DATE: July 16 - 18, 2014

ORGANIZERS:

J. Dobaczewski *(Univ. Warsaw, Poland)*
P.-H. Heenen *(Univ. Brussels, Belgium)*
H. Leeb *(TU Wien, Austria)*
F. Thielemann *(Univ. Basel, Switzerland)*

NUMBER OF PARTICIPANTS: 15

MAIN TOPICS:

The workshop aimed at a discussion of recent advances in nuclear theory related to the nuclear research at present and future radioactive ion beam facilities. In this workshop emphasis was given to the status and recent developments of breakup reactions.

The main topics were:

- Continuum discretised coupled-channel method
- Eikonal description of breakup reactions
- Experimental studies of breakup reactions
- Gamov shell model and the coupling to the continuum
- Nuclear structure information for reaction calculations

SPEAKERS:

D. Baye (Free University Brussels, Belgium)
H. Chau (CEA-DAM, France)
P.-H. Heenen (Free University Brussels, Belgium)
M. Hjorth-Jensen (University Oslo, Norway)
J.A. Lay Valera (INFN, Univ. of Padova, Italy)
H. Leeb (TU Wien, Austria)
T. Matsumoto (Kyushu University, Japan)
T. Nakamura (Tokyo Inst. of Technology, Japan)
V. Pesudo-Fortes (CSIC, Madrid, Spain)
M. Ploszajczak (GANIL, France)
C. Qi (KTH Stockholm, Germany)
K. Spasova (University of Sofia, Bulgaria)
T. Srdinko (TU Wien, Austria)
D. Tarpanov (University of Warsaw, Poland)
J. Tostevin (University of Surrey, France)

SCIENTIFIC REPORT:

The 4th Collaboration Meeting of the JRA THEXO took place at ECT*, Trento, Italy in the period July 16-18, 2014. It was organized as a mini-workshop with the title BREAKUP REACTIONS AND RELATED TOPICS. The meeting was focused on the specific topic of breakup reactions and relevant nuclear structure input. In order to identify the current and future needs of novel developments experimentalists have been invited to present currently available and envisaged experiments on breakup-related observables at available and planned experimental facilities. The workshop was organized as follows: the first day was mainly focused on the current status of the various methods either to calculate breakup or to account for breakup. The presentations on the second day dealt with an overview on modern nuclear structure tools, which could become ingredients in reaction calculations. The third day was mainly devoted to identify the open problems and to discuss the next steps for further progress. The program of the collaboration meeting is attached in Appendix A. The given presentations are accessible on the Website www.ectstar.eu/meetings/. In the following a summary of the various topics is given.

MODELLING BREAKUP PROCESSES:
The modelling of breakup processes was considered in four seminal and four specialized presentations which gave an excellent overview on the most promising procedures and their current status. In an excellent introduction Baye presented the basis of the most prominent methods to deal with breakup processes, discussed the underlying basic approximations and their mutual relationships. In a more specialized presentation Tostevin discussed the current status of the eikonal approximation. Especially, he focussed on the description of fast one-nucleon and two-nucleon removal reactions and the impact of the continuum. Despite its semi-classical nature it provides a promising tool for nuclear structure studies of exotic nuclei with beams at higher energies, e.g. at SPIRAL2. The more basic, but numerically involved Continuum Discretized Coupled-Channel (CDCC) technique was subject of the presentations of Matsumoto and Huu-Tai-Chau. The former presented besides the standard CDCC approach also a promising extension to systems involving a three-body breakup of the projectile nucleus. A more pragmatic view was taken by Huu-Tai-Chau looking for an optimization between accuracy of the CDCC-calculation and computing effort. CDCC calculations including static and dynamic core polarization effects in reactions were presented by Lay. Results of a more traditional description of breakup processes of 11Li and 11Be were shown by Spasova.
Two presentations on the experimentally studies related to breakup processes completed this topic. Pesudo-Fortes reported on experiments at TRIUMF with 9Be and 11Be beams and their interpretation by means of CDCC calculations. Nakamura reported on the impressive Japanese program on the study of breakup related processes and provided an overview of the corresponding experimentally accessible observables.

NUCLEAR STRUCTURE TOOLS:
The status and developments of modern nuclear structure tools were covered in three seminal and two specialized presentations. Horth-Jensen presented the coupled-cluster theory and its application to weakly bound system, which was best demonstrated by the example of simple quantum dots. Using chiral interactions a consistent treatment of 2- and 3-body forces and correlations could be achieved. Chong-Qi considered simple correlations between the pairing gap and alpha-clustering and corresponding indications in two-nucleon transfer reactions. Heenen revisited the up-to-date status of mean-field calculations and beyond for low-energy nuclear spectroscopy in an ECT*-colloquium. The general talk was followed by a more detailed one by Tarpanov who focussed on the spectroscopic properties of the energy functional.

DISCUSSION OF OPEN PROBLEMS:
An important part of the workshop was the final discussion on the open problems in the study of breakup reactions. What concerns required experimental developments was already stated by several speakers in their presentations. It can be simply summarized by two statements: more exclusively (angular correlations, momentum correlations, ..) and more exotic (towards the drip-line and beyond). During the discussion it was clearly pointed out that it is frequently difficult to compare theoretical calculations with experiments in this field.
The open problems in theory was the main issue in the discussion which showed that two major topics must be distinguished, i.e. (1) Elastic Breakup and (2) Inelastic Breakup.

Ad (1) ELASTIC BREAKUP: Here, different models with different ranges of validity are available. There has been significant progress for what concerns accuracy, microscopic description of nuclei and the inclusion of core excitations. However, there is need for a benchmark to compare the different methods (Faddeev-based approach, CDCC, eikonal approach, semiclassical approach …) and to assess their validity.

Ad (2) INELASTIC BREAKUP: Experimental information is mainly limited to momentum distributions. Here, the modelling situation is not well established. It addresses mainly the high-energy picture and there arises the question - how we can get beyond. There exist conceptual differences between experimental data and theoretical calculations, shown by Tostevin, the origin of which is not clear.

Results and Highlights
The workshop gave an excellent overview on the current status of the modelling of breakup reactions. Recent developments have been reported in the presentations. Especially for elastic breakup significant progress has been achieved e.g. inclusion of core excitation into CDCC as well as the extension of CDCC to three-body particles. The concept of the meeting allowed ample discussion of the various topics. This opportunity has been extensively used by the participants and was essential for the very positive and collaborative atmosphere. Especially the final discussion on open problems gave a clear view on problems and challenges. It must be remarked that the positive atmosphere was an important aspect of the meeting because it has intensified the contacts with experimentalists and external experts.

3.3.13 SPIN AND ORBITAL ANGULAR MOMENTUM OF QUARKS AND GLUONS IN THE NUCLEON

DATE: August 25 – 29, 2014

ORGANIZERS:

M. Anselmino *(Torino University & INFN, Italy)*
E. Leader *(Imperial College, London, UK)*
C. Lorcé *(University of Liège, Belgium)*

NUMBER OF PARTICIPANTS: 27

MAIN TOPICS:

The main topics were:

The general theme of the workshop was focused on the splitting of the total angular momentum of a nucleon into separate quark and gluon components; an issue of importance for understanding the internal structure of the nucleon. Deep questions have arisen as to how precisely define these components and as to their measurability. Underlying this are issues about the role of gauge invariance and the validity of the age old textbook claim that it is impossible to separate the photon (gluon) angular momentum into a spin part and an orbital part in a gauge-invariant way. This is a matter of concern to the many experimentalists who believe they are measuring the polarization of the gluon in a polarized nucleon. There have been a host of papers on this subject in the last few years. Controversial arguments have been given as to whether a physically measurable quantity really needs to correspond to a gauge-invariant operator. New sum rules have been derived and novel suggestions have been made for measuring some of the terms in them, either experimentally or on a lattice. And it has turned out that orbital angular momentum is now recognized as a key concept in hadron structure and in the theory of high momentum transfer polarized reactions.

The main topics were:

- Quark and gluon angular momentum
- The various spin decompositions and sum rules
- Test of gauge independence of matrix elements
- Angular momentum and Generalized Partonic Distributions (GPDs)
- Overview of measurements of GPDs
- Angular momentum and Transverse Momentum Dependent distributions (TMDs)
- Spin angular momentum via TMD measurements in DIS and SIDIS
- Angular momentum in phenomenological models
- Angular momentum on the lattice
- Orbital angular momentum via TMD measurements in hadronic collisions

SPEAKERS:

A. Bacchetta (University of Pavia & INFN, Italy)
B. Bakker (Vrije University Amsterdam, The Netherlands)
L. Bland (Brookhaven National Laboratory, USA)
K. Bliockh (CEMS, RIKEN, Japan)
D. Boer (University of Groningen, The Netherlands)
M. Burkhardt (New Mexico State University, USA)
X.-S. Chen (Huazhong University of Science & Technology, China)
A. Courtoy (University of Liège, Belgium)
L. Gamberg (Penn State University Berks, USA)
G. Goldstein (Tufts University, USA)
C. Hyde (Old Dominion University, USA)
P. Kroll (University of Wuppertal, Germany)
E. Leader (Imperial College London, UK)
K.-F. Liu (University of Kentucky, USA)
S. Liuti (University of Virginia, USA)
C. Lorcé (University of Liège, Belgium)
B.-Q. Ma (Peking University, China)
A. Mukherjee (IIT Bombay, India)
B. Pasquini (University of Pavia & INFN, Italy)
M. Schlegel (University of Tübingen, Germany)
G. Schnell (University of the Basque Country UPV/EHU, Spain)
D. Sivers (Portland Physics Institute, USA)
M. Wakamatsu (Osaka University, Japan)
F. Wang (Nanjing University, China)
J. Zhou (Regensburg University, Germany)

SCIENTIFIC REPORT:

A major controversy arose a few years ago in QCD as to how to split the total angular momentum into separate quark and gluon components. The idea of identifying separate quark and gluon angular momentum operators is attractive, since these operators may be measurable in certain physical processes and there may be sum rules relating the spin of a nucleon to the angular momentum carried by its constituents. The operators for the total angular momentum, obtained via Noether's theorem from the QCD Lagrangian, consist of separate terms which seem to represent a natural division into quark and gluon angular momentum (AM) and with both quark and gluon AM split into a spin part and an orbital part. However such terms are not individually gauge invariant, which suggested one should use the Ji version of these operators, which has the nice property that they are gauge invariant, but in which the gluon AM is not separated into spin and orbital parts. This is in accord with the long held belief, expressed for the photon case in innumerable textbooks on QED, that such a splitting cannot be done in a gauge-invariant way. The controversy was ignited by a paper of Chen, Lu, Sun, Wang and Goldman in 2008 which claimed that such a splitting was indeed possible in a gauge-invariant way. The publication aroused an aggressive response with papers flying back and forth, leading to the organization of a workshop at the INT, in Seattle, in 2012, whose aim was to settle, once and for all, the controversy. In the event the net result was the opening up of a Pandora's box, with even greater controversy and many further papers.

The present workshop at the ECT*, Trento, has, at last, produced a consensus that fundamentally there are two physically interesting versions of AM, the canonical and the kinetic. The myriad of other versions all boil down to the gauge non-invariant canonical version viewed in a particular gauge.
A further achievement of the workshop was the clarification of the much debated issue as to whether a measurable observable must correspond to a gauge-invariant operator. Crucial to this was the invitation to the workshop of a member of the Quantum Optics community, K. Bliokh, who demonstrated that the spin and orbital angular momentum of photons have been routinely measured in paraxial laser beams for more than a decade. What in fact is measured is the value of these canonical quantities in a particular gauge, the Coulomb gauge. Thus it can be physically meaningful, and interesting, to measure a gauge non-invariant quantity in some particular gauge.
There was much discussion as how this could be done in the QCD case, i.e. how one might measure, for example, the quark canonical and kinetic total and orbital angular momentum inside a nucleon.
For the total quark kinetic angular momentum, there exists a beautiful connection to generalized parton distributions (GPDs), which can be measured in deeply virtual Compton scattering and in deeply virtual meson production and which are also related to electromagnetic form factors. The extraction of the GPDs from experiment is, however, not straightforward. Interesting results for GPDs were presented by P. Kroll, based on an analysis which put great emphasis on the electromagnetic form factor data. This means that what can be extracted reliably are only the valence part of the GPDs. Nonetheless this leads to values for (Ju-Jubar) and (Jd-Jdbar), which can be compared with lattice calculations of these quantities.
One of the highlights of the workshop was the presentation by K.-F. Liu of results from a lattice study of quark and gluon kinetic angular momentum in which, while still in the quenched approximation, both connected and disconnected insertions were taken into account, and in which, for the first time, results for the gluon angular momentum were given.

One challenging question, discussed by X.-S. Chen in a Skype presentation from China, is how one can test whether the matrix elements of an operator are or are not gauge invariant. The problem here is that in field theory one applies only classical gauge transformations to the quantum fields, whereas to transform the operator from one gauge to another may require an operator-valued gauge transformation. This has led to contradictory results in some cases and the issue remains unresolved.
The workshop also stressed the importance of the orbital angular momentum (OAM). Current estimates from phenomenology and lattice investigations indicate that the OAM likely accounts for about half the proton spin, which emphasizes the relativistic nature of the system. While there is basically no ambiguity about the total OAM, there is some unavoidable freedom in its decomposition into quark and gluon contributions. This workshop has demonstrated that different decompositions are equally interesting and reflect different aspects of the intricate quark-gluon interaction.
Traditionally, the OAM is obtained indirectly by first measuring the total AM and then subtracting the spin contribution. This contribution can however be accessed directly using e.g. twist-3 GPDs. Some encouraging, though preliminary, results have been presented by S. Liuti and collaborators. Another option is via the so-called Wigner or phase-space distributions, which offer a nice intuitive picture as illustrated in many model calculations.
Another important highlight of this workshop is that a consensus has been reached concerning the status of a particular Wigner distribution and its relation to OAM. The key question now is whether this kind of distribution can be accessed in experiments. Interestingly, G. Goldstein proposed a new exclusive process which might be sensitive to these Wigner distributions. Further dedicated investigations are therefore needed. Lattice QCD will also certainly help in this matter thanks to new strategies recently proposed by X. Ji and collaborators.

Phenomenological models are perfect laboratories for testing various propositions and checking sum rules. Even though they often drastically simplify the physics, they allow us to work out explicit examples and illustrations of the intricacies associated with AM decomposition, as shown by B. Pasquini, A. Bacchetta and M. Burkardt. Moreover, these models provide extremely useful Ansätze for the phenomenology.

Finally, this Workshop clearly showed how rich and how important the proton spin structure is for understanding the amazingly large asymmetries in polarized scatterings involving hadrons. The origin of many of the controversies is related to the fact that a decomposition is not unique. Deciding what is THE proton spin decomposition is essentially a matter of taste and convenience. The usefulness of a particular decomposition is ultimately dictated by its relation to experiments.

3.3.14 NUCLEAR PHYSICS AND ASTROPHYSICS OF NEUTRON-STAR MERGERS AND SUPERNOVAE, AND THE ORIGIN OF R-PROCESS ELEMENTS

DATE: September 08 - 12, 2013

ORGANIZERS:

T. Kajino *(National Astronomical Observatory of Japan and University of Tokyo, Japan)*
A. Baha Balantekin *(University of Wisconsin-Madison, USA)*
M. Tanaka *(National Astronomical Observatory of Japan)*
W. Aoki *(National Astronomical Observatory of Japan)*

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

Understanding the r-process requires a significant amount of nuclear physics input, both experimentally and theoretically, and astronomy input, too. Already many rare ion beam facilities, either currently operating or under construction, and astronomical observatories devote significant amount of resources to investigate this topic. This workshop was aimed to bring nuclear theorists, experimentalists and astronomers together for discussing open questions on the r-process.

The main themes were:

- calculating the binding energies and reaction rates in the r-process path,
- spin-isospin response in a broad range of nuclei from stable isotopes to rare ions,
- many-body techniques required to solve the neutrino transport and flavor evolution,
- spectroscopic data on neutron-capture elements in various supernova environments (i.e. near the proto-neutron star or in the outer shells) or merging neutron star binaries.

SPEAKERS:

B. Balantekin (University of Wisconsin-Madison, USA)
R. Diehl (Max Planck Institute for Extraterrestrial Physics, Germany)
M. Eichler (University of Basel, Switzerland)
C. Hansen (University of Copenhagen, Denmark)
T. Hayakawa (JAEA, Japan)
K. Hotokezaka (Hebrew University of Jerusalem, Israel)
Y. Ishimaru (International Christian University, Japan)
T. Kajino (National Astronomical Observatory of Japan)
O. Korobkin (Stockholm University, Sweden)
K. Kotake (Fukuoka University, Japan)

J. Lawler (University of Wisconsin-Madison, USA)
G. Lorusso (RIKEN, Japan)
Myung-Ki Cheoun (Soongsil University, Korea)
S. Nagataki (RIKEN, Japan)
N. Nishimura (Keele University, UK)
N. Paar (University of Zagreb, Croatia)
Y. Pehlivan Deliduman (Mimar Sinan University, Turkey)
O. Sorlin (GANIL, France)
J. Suhonen (University of Jyväskylä, Finland)
K. Sumiyoshi (Numazu College of Technology, Japan)
R. Surman (University of Notre Dame, USA)
T. Suzuki (Nihon University, Japan)
T. Takiwaki (RIKEN, Japan)
M. Tanaka (National Astronomical Observatory of Japan)
L. Trache (IFIN ‐ HH Bucharest, Romania)
J. Wambach (TU-Darmstadt, Germany)
S. Wanajo (RIKEN, Japan)
B. Wehmeyer (University of Basel, Switzerland)

SCIENTIFIC REPORT:

The origin of r-process elements is one of the most important questions in modern astronomy. Supernova explosions (the final fate of massive stars with masses larger than 10 solar masses) has been thought to be the most promising sites for r-process nucleosynthesis. In addition, there is a growing interest in neutron star mergers as the origin of r-process elements. To address this long-lasting question, knowledge from different fields is necessary, namely (1) astronomical observations of metal-poor stars, (2) numerical simulations of supernovae, (3) numerical simulations of neutron star mergers, (4) nuclear data including reaction rates and decay rates, and (5) neutrino physics.

This workshop has been opened by the review of recent astronomical observations of metal poor stars in our Galaxy (Lawler, Hansen). This was useful for all the participants to understand our “goal”. Especially, the participants shared the idea of “universality” in r-process abundance ratios in different stars. In addition, recent observations show the presence of “weak” r-process or lighter element primary process, which is also a key to understand the sites or r-process nucleosynthesis.

On supernova scenarios, we have learned the current status of numerical simulations (Kotake, Sumiyoshi, Takiwaki). Several speakers have addressed nucleosynthesis calculations in supernovae and supernova jet (or gamma-ray burst jet), role of neutrino, and importance of nuclear data in supernova nucleosynthesis (Balantekin, Kajino, Nagataki, Nishimura, Surman, Hayakawa, Suhonen, Pehlivan). They all emphasized the importance of precision nuclear data. Sometimes the uncertainty in the reaction rates is as influential as the uncertainty in the physical condition (temperature and electron fraction in supernova matter).

Various topics on nentron star mergers have been presented: numerical relativity (Hotokezaka), nucleosynthesis (Wanajo, Korobkin, Eichler) and electromagnetic emission (Tanaka). The effects of neutrinos (as in supernovae), reaction rate, and fission pattern are important for providing realistic predictions. Especially, heating by neutrino can reduce electron fraction and this effect is important to reproduce the entire pattern of r-process abundance ratio.

A possible way to distinguish these scenarios is chemical evolution of galaxies as the history of r-process nucleosynthesis is imprinted in our Galaxy and metal-poor stars. Recent progress in chemical evolution models was reported (Ishimaru, Wehmeyer).

For both scenarios (supernovae and neutron star mergers), input from nuclear physics is crucial. In the workshop, we have learned about new experiments as well as future plans (Lorusso, Sorlin, Trache), which will be essential for developing improved nuclear models. In fact, several speakers (Cheoun, Suzuki, Paar) addressed new theoretical approaches to take into account the results of recent experiments.

In summary, the workshop covers all the important topics (as listed above) to understand the origin of r-process elements. Some highlights are listed below.

Results and Highlights

The workshop covered all the important topics to understand the origin of r-process elements. To tackle this problem, interdisciplinary studies involving wide and different research fields are necessary. In this aspect, what was noteworthy for this workshop is the interactive atmosphere. Thanks to the pleasant environment and relaxed atmosphere of ECT*, all the participants had a chance for optimal scientific communication. In fact, most of the participants did not know each other before the workshop since they are working in different fields and usually there is only little opportunity to interact with one another. The organizers had positive feedback from many participants on this point. Examples of such interaction are following.

- Rebecca Surman and Marius Eichler demonstrated the strong impact caused by uncertainty in nuclear data to the final r-process abundance pattern. Since this was directly demonstrated to researchers working in nuclear physics, it turned out extremely useful to point out how important the interdisciplinary approach is.
- Kei Kotake, Tomoya Takiwaki, and Kohsuke Sumiyoshi showed the cutting-edge supernova simulations. But they also showed current limitations and possible future directions. This was helpful for other people (especially in different fields) to know that there is room for substantial improvements of supernova theory.
- A scenario of binary neutron star mergers was a new subject to many nuclear physicists since this is a rapidly growing field. The talks by Kenta Hotokezaka, Oleg Koroblin, and Shinya Wanajo gave not only an overall picture of neutron star mergers but also the cutting-edge status of this field.
- Giuseppe Lorusso presented most recent results from RIBF and suggested astronomers to observe elemental abundances of some specific isotopes more carefully. James Lawler immediately responded which elements can be observed easily.

Such interactions between participants are not expected in a typical workshop or conference in well-established science fields. The organizers appreciate that such discussions in our interdisciplinary workshop were carried out everywhere during the workshop. We believe that this is just a beginning of a continuing activity. To keep such momentum and promote more frequent interactions, many participants expressed their strong wish to continue this kind of workshop in the future. This ECT* workshop was the 1st event after the MOU had been signed between ECT* and the National Astronomical Observatory of Japan (NAOJ). Leveraging this close relationship, the organizers plan to have another workshop in the near future.

3.3.15 DYSON-SCHWINGER EQUATIONS IN MODERN MATHEMATICS AND PHYSICS

DATE: September 22 – 26, 2014

ORGANIZERS:

M. Pitschmann *(Institute of Atomic and Subatomic Physics, Austria)*
C. D. Roberts *(Physics Division, Argonne National Laboratory, USA)*
W. Lucha *(Institute for High Energy Physics, Austrian Academy of Sciences, Austria)*

NUMBER OF PARTICIPANTS: 20

MAIN TOPICS:

The general themes of this workshop concerned the appearance of Dyson-Schwinger equations in modern mathematics and physics. In mathematics, this relates to Hopf algebra structures of Dyson-Schwinger equations (DSEs) and renormalisation in quantum field theory. This shall bridge the gap between perturbative- and nonperturbative-QCD. The application of DSEs in strong interaction and beyond Standard Model physics. The immediate goal was to open a dialogue between mathematicians and physicists, so that each can come to appreciate the challenges and needs of the other.

The main topics were:

- Hopf algebra structure of renormalisation in quantum field theory and its correlation to Dyson-Schwinger equations
- QCD's β-function and its computation via the Hopf algebra representation of renormalisation in quantum field theory
- Constraining truncation schemes for the Dyson-Schwinger equations
- Predictions for hadron physics based on systematic truncations of Dyson-Schwinger equations

SPEAKERS:

S. Aagawala (Univ. Oxford, England)
K. Ayse (Univ. Adelaide, Australia)
M. Bellon (CNRS, Paris 6, France)
M. Borinsky (Humboldt-University, Germany)
P. Clavier (CNRS, France)
K. Ebrahimi-FARD (ICMAT, Madrid, Spain)
T. Klahn (Univ. Wroclaw, Poland)
J. Kock (Univ. Barcelona, Spain)
T. Krajewski (Centre de Physique Théorique, Marseille, France)
J. Papavassiliou (Univ. Valencia, Spain)
F. Patras (CNRS, Nice, France)
M. R. Pennington (Jefferson Lab, USA)
D. H. Rischke (Univ. Frankfurt, Germany)
C. D. Roberts (ANL, USA)

J. Rodriguez Quintero (Huelva, Spain)
F. Sannino (CP3-Origins, Denmark)
H.Sazdjian (University Paris-Sud, France)
S. Weinzierl (Johannes Gutenberg-Universität Mainz, Germany)

SCIENTIFIC REPORT:

Dyson-Schwinger equations (DSEs) are omnipresent in physics. In local relativistic quantum gauge field theories this tower of equations serves, at the simplest level, as a generating tool for perturbation theory being a crucial ingredient in the proof of perturbative renormalisability. In condensed matter physics, the gap equation is playing an important role in elucidating the properties of graphene, one of the most topical problems in physics today, while in particle physics, the DSEs are being used to explore strong-interaction alternatives to string-theory as a basis for extending the Standard Model. It is in these latter contexts that DSEs are today enjoying the most rewarding applications in the identification and explanation of nonperturbative phenomena.

Of primary importance amongst such problems is quantum chromodynamics (QCD), presenting a fundamental problem that is unique in the history of science. The elementary excitations in this theory, being confined, are not those degrees-of-freedom readily accessible via experiment. Moreover, there are numerous reasons to believe that QCD generates forces which are so strong that less-than 2% of a nucleon's mass can be attributed to the so-called current-quark masses that appear in QCD's Lagrangian; viz., forces capable of generating mass from nothing, a phenomenon known as dynamical chiral symmetry breaking (DCSB).

Using perturbation theory, it is impossible to elucidate the origin of these phenomena. Contributions are being made using the methods of lattice-regularised QCD. However, despite its promise, that approach has numerous limitations. An alternative is provided by QCD's Dyson-Schwinger equations (DSEs). There is a model-dependent element in the application of this method to the computation of real-world observables but that has been turned to advantage, so that now real predictions are being made and a feedback between experiment and theory is providing constraints on the infrared behavior of QCD's β-function.

On the other hand, unknown to the bulk of physicists, there is progress in mathematics. This began roughly fifteen years ago with a realization that the process of renormalisation in quantum field theory is naturally expressed via a Hopf algebra structure. Indeed, the Hopf algebra approach allows for a comprehensive description of the algebraic and combinatorial structures underpinning renormalisation. This enables a mathematically sound approach to the problem of computing the β-function that is based on two elements: the existence of quantum equations of motion, which are the Dyson-Schwinger equations, and the consequences of the renormalisation group for local field theories. One needs DSE in order to guarantee sufficient recursive structure in the theory such that a non-perturbative approach becomes feasible. The Hopf algebraic foundations of these phenomena make the approach possible. In addition, the Hopf algebra description permits mathematicians to comprehend and explore basic ideas of renormalisation, driving new applications of those ideas in the context of pure and applied mathematics. The progressive mathematical reformulation of the well-established physical procedure of renormalisation motivated mathematicians to imagine that this framework has the power to provide deeper insights into fundamental problems in quantum field theory. However, the majority lack an appreciation of just what those problems are, and of the physical connections between their formalism and phenomena. In the bulk, the framework is formally exact but practically inapplicable to the computation of a hadronic observable. Notwithstanding this, attempts have been made to compute the QCD β-function in the infrared.

This workshop gathered experts in: the Hopf algebra structure of Dyson-Schwinger equations and renormalisation in quantum field theory; perturbative- and nonperturbative-QCD; and the application of DSEs to phenomena in hadro-nuclear and -particle physics. The immediate goal was to open a dialogue between mathematicians and physicists, so that each can come to appreciate the challenges and needs of the other.

The discussions focused on the following questions:

1. What is the Hopf algebra structure of renormalisation and how is it related to the Dyson-Schwinger equations?
2. How does the Hopf algebra structure of renormalisation enable the computation of a theory's β-function, and what mathematical assumptions are necessary in order to provide relevant, falsifiable constraints on its real-world behavior?
3. Can the practical demands of perturbation theory in QCD be expressed in mathematical constraints within the Hopf algebra structure of renormalisation? For example, can one formulate the selective resummation of a subclass of diagrams?
4. Can the need for truncations in the practical application of DSEs to the prediction of hadron phenomena be formulated mathematically within the Hopf algebra structure? For example, does the algebraic structure provide insight into the nonperturbative construction of a fermion-antifermion scattering kernel; and what is the Hopf algebra anatomy of rainbow-ladder truncation, which is the most widely used approximation in DSE studies of QCD?
5. Can empirical observations in the four-dimensional real-world inform the analysis and thinking of mathematicians focused on abstract and lower-dimensional theories?

Results and Highlights

In 18 talks many aspects related to DSE have been addressed, ranging from PreLie algebras, singularities in the Borel plane and Hopf algebras on the mathematical side to mass generation, hadrons in the vacuum and at finite temperature and density as well as cold, dense quark matter at the physical side. This broad spectrum gave the participants insight into the manifold applications around this technique. More specific, progress has been achieved within the groups of physicists and mathematicians and new projects of research devised. In the respective talks and following discussions much was made of the opportunity for the Hopf algebra developments in mathematics to be communicated to practicing physicists, and for mathematicians to be "grounded" in the realities of contemporary QCD physics. All participants agreed that there is significant potential for further positive feedback in identifying how these new tools and modern practice can be used to improve each another. In order to enhance communication between physicist and mathematicians several participants agreed to compose written lecture notes around their respective talks emphasizing the pedagogical point of view. The article will:

- introduce Hopf algebra concepts for physicists;
- show that the graphs of rainbow-ladder-truncation form a Hopf algebra, Hgrl;
- explain under which circumstances Hgrl is a subalgebra of the Hopf algebra of QCD;
- detail the significance of these results for mathematics, the physics of hadrons and the study of hadronic phenomena using DSEs.

3.3.16 QCD HADRONIZATION AND THE STATISTICAL MODEL

DATE: October 06 - 10, 2014

ORGANIZERS:

R. Stock *(University of Frankfurt and FIAS, Germany)*
F. Becattini *(University of Florence and INFN, Italy)*
M. Bleicher *(University of Frankfurt and FIAS, Germany)*

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

The position and the nature of the QCD confinement transition line in the (T,mu(B)) QCD phase diagram remains as an open topic of the Standard Model. More generally, in fact, the entire phase diagram is not known with certainty. It has been addressed in Lattice QCD and Chiral Restoration models. On the other hand, there is semiempirical information: the limit of hadronic phase space (Hagedorn) is now seen as the location of the hadron to parton QCD boundary. The Statistical Hadronization Model (SHM) is applied to the multiplicity distributions over hadronic species, observed in elementary and in Heavy Ion collisions at very high energies. This procedure gives the “hadronic freeze-out” curve in the (T,mu(B)) plane. The first main topic of the workshop is the question of whether this curve is approximately, or even exactly equal to the QCD phase boundary line, at least at the low values of baryochemical potential mu(B) that are involved from CERN SPS up to LHC energies. The second aspect of main interest is the direct elaboration of the phase boundary by considering higher susceptibilities which would identify its (T,mu(B)) location by matching of lattice QCD with Hadron Gas Model susceptibilities. Initial experimental data are also available. Can we, thus, arrive at a clear prediction?

The main topics were:

- Statistical behaviour in strongly interacting field theories
- Lattice QCD confinement and chiral restoration
- Hadronization in QCD
- Hadronization in microscopic transport models
- Hadronic freeze-out
- The Statistical Model and its intrinsic approximations
- Data analysis from SPS via RHIC to LHC
- Higher susceptibilities from lattice QCD
- Matching with Hadron Gas predictions: the phase boundary?

SPEAKERS:

R. Bellwied (Univ. of Houston, USA)
H. Huang (UCLA Los Angeles, USA)
V. Mantovani-Sarti (INFN Torino, Italy)
C. Markert (U. of Texas, Austin, USA)

B. Mohanty (NISR, India)
F. Becattini (Università di Firenze and INFN, Italy)
P. Castorina (Univ. di Catania, Italy)
M. D'Elia (Univ. of Pisa and INFN, Italy)
V. Koch (LBL Berkeley, USA)
S. Pratt (Michigan State University, USA)
C. Ratti (Torino University, Italy)
M. Rigol (Pennsylvania State University, USA)
J. Aichelin (Subatech Nantes, France)
A. Andronic (GSI Darmstadt, Germany)
A. Bialas (Jagellonian University, Cracow, Poland)
D. Blaschke (U. of Wroclaw, Poland)
M. Bleicher (FIAS, Univ. Frankfurt, Germany)
C. Blume (University Frankfurt, Germany)
E. Bratkovskaya (FIAS, Frankfurt, Germany)
P. Braun-Munzinger (GSI Darmstadt, Germany)
S. Floerchinger (CERN, Switzerland)
M. Floris (CERN, Switzerland)
W. Florkowski (Jan Kochanowski University, Poland)
M. Gazdzicki (Univ. of Frankfurt, Germany)
C. Greiner (Univ. of Frankfurt, Germany)
F. Karsch (Bielefeld University, Germany)
H. Oeschler (University of Heidelberg, Germany)
K. Redlich (University of Wroclaw, Poland)
H. Satz (University Bielefeld, Germany)
M. Srednicki (Univ. of California, Santa Barbara, USA)
J. Stachel (University of Heidelberg, Germany)
J. Steinheimer-Froschauer (FIAS, Frankfurt, Germany)
R. Stock (FIAS Frankfurt, Germany)
H. Stoecker (GSI Darmstadt, Germany)
J. Stroth (University Frankfurt, Germany)

SCIENTIFIC REPORT:

Hadronization via QCD confinement and/or chiral symmetry breaking remains one of the open topics of QCD, in its non-perturbative sector. There are semi-phenomenological models for the mechanism, in particular the "colour pre-confinement" idea of Amati and Veneziano which was widely applied to e(+)-e(-) annihilation to hadrons in the "HERWIG" model(s) by B. Webber et al.. This model follows DGLAP shower evolution down to a cutoff energy where colour neutralizing momentum space arrangements of partons are forming, the so-called clusters arising with the invariant mass of the comprised partons. Their subsequent quantum mechanical decay to on-shell hadrons is dominated by the phase space available to each species, and by quantum number conservation. Ellis and Geiger have cast this overall model into a microscopic dynamical model in configuration space, which describes the hadronic multiplicities in elementary annihilation. The resulting quasi-classical equilibrium distribution of the hadronic yields has been the matter of endless controversy and bewilderment, in particular because R. Hagedorn had already described a classical equilibrium situation in his microcanonical Gibbs ensemble approach. The resemblance of this model (the so-called "Statistical Hadronization Model" SHM) to the Veneziano-Webber-Geiger model has for a long time been speculatively assumed, but recently shown in fact to hold, by F. Becattini. The essential ingredient is phase space dominance below the critical temperature of QCD. This

statement is apparently too simple to be accepted by a good half of the theoretical and experimental community, and a number of microscopic parton and hadron transport models have been formulated. In the course of this effort it became clear that simple “2 to 2” collisions at the microscopic level could neither create nor sustain the chemical equilibrium of species that was observed universally, from elementary to relativistic nucleus-nucleus collisions. The inferred parton/hadron densities in the vicinity of the phase transition are too small. However, introducing simultaneous multibody collisions, via cluster intermediate states formed from, and decaying to about 6-10 hadrons or resonances, did answer the equilibrium problem, tentatively. One of the topics of heated debate: both views introduce “clusters” which are, strictly speaking, not all too well characterized QCD objects. A rigorous QCD dynamical model still remains unattainable.
On the other hand there are theoretical predictions for the QCD parton-hadron phase boundary line, from baryochemical potential mu(B) = 0 onwards to quite substantial mu(B): first attempts toward a QCD phase diagram. These advances stem from Lattice QCD. On the other hand, the Statistical Hadronization Model has been widely employed to the hadron multiplicity data from relativistic heavy ion collisions, from SPS via RHIC to LHC energies. The SHM model is a grandcanonical one, and thus it shares its principal parameters, T and mu(B), with Lattice QCD. The SHM analysis, in its summary, gives a “freeze-out curve” in the (T,mu(B)) plane, where, at the same time, lattice QCD enters its tentative phase diagram of QCD matter. The first key question of the field: to which extent are these curves identical? More precisely: are they identical in the (T, mu(B)) domain where they COULD be identical. Namely in the domain of accelerator energies where the collisional dynamics of colliding heavy nuclei carries the system above the phase boundary, so that its hadronization can be observed, at all. This seems to be the domain from SPS energies onward, and, in fact, the SHM analysis yields a “freeze-out” temperature of about 160 MeV, identical to the lattice result for the position of the parton-hadron coexistence line. The central question: did we thus locate the transition line, and substantiate the QCD results?
The topic has gained a second main aspect over the last three years. In the process of trying to expand the lattice calculations from their starting point at mu(B) = 0, by means of e.g. Taylor expansion in terms of higher lattice derivatives of the partition function, the so-called susceptibilities, it became of interest to see whether these lattice susceptibilities did match smoothly with the corresponding Hadron Gas Model results. The idea: Lattice covers partons from T(c) upwards, but it also covers hadrons, from T(c) downwards. Does it overlap with a grand canonical hadron/resonance susceptibility model? And, in particular: where in (T,mu(B)) does it overlap? Here we are at the acute state of the art, and several international Lattice groups have presented first results. These are not yet straightforward, because it appears that the conventional models (both!) do not really come to a consistent single overlap. The causes are debated intensely. However, it is clear already now that the first result will indicate a phase transition temperature of about T = 150 MeV (although for today we would have to add: T = 150 +/-15 MeV), which immediately causes much “tension” with the higher SHM result from freeze-out.

Results and Highlights

The workshop was a very useful opportunity to balance the aforementioned competing views, and this was in fact perceived by all the participants. However, no final consensus could be found concerning the value, and virtue, of the SHM freeze-out results at zero to intermediate baryochemical potential. The fundamental, recent observation is the SHM result at the LHC energy of 2.76TeV, where the standard analysis yields a temperature of about 150MeV, contrary to the T = 164MeV results (both have error bars of about +/- 5 MeV) obtained at the lower RHIC and top SPS energies. Certainly the QCD parton hadron boundary line makes no final downward kink at mu(b) = 0. Thus a multitude of explanations arose in the community, such as second order corrections to the ideal freeze-out picture employed in the SHM: the idea of a sequential freeze-out in QCD (!) sees strange hadrons hadronize before nonstrange ones; the UrQMD study of annihilation/regeneration effects during the course of the final hadron/gas expansion phase sees deviations from the initial equilibrium implanted at hadronization which reduces the derived temperature; finally the set of high lying hadronic

resonance populations, as given in the Particle Data Book, may not be exhaustive and one thus proposes to introduce substantial additions of unknown strange resonances above 2 GeV. Add to this the remaining question: why does this occur at LHC but is apparently not visible at RHIC energy, which, of course, also refers to very well known (but never really confronted) differences in the basics of data analysis at LHC, and at RHIC. To say it somehow provocatively: all these different ideas were vigorously proposed or discarded by the gathered experts, without much sense of compromise. This situation had been the chief motivation of the workshop. But in the end it has to be admitted that clearly most of these remedial ideas must be premature or wrong but it is, eventually, the younger generation which will carry home a conclusion—and that was most certainly the case in this workshop.
The second main topic was the Lattice communities recent progress in an alternative approach to confront the parton-hadron coexistence line (or at least the hadronization temperature). One matches higher susceptibilities computed in two grandcanonical ensembles: Lattice at T above T(c), and the Hadron Gas model at T below T(c). The merging point would imply a determination of T(c), or even of (T(c),mu(B,c)). This way, an entirely theoretical analysis (the HRG of course enters data, too), but there are also initial experimental data available for the susceptibilities. This part of the course topics was characterized by a general learning effort, the two ideas concerning hadronization had not been presented and discussed before, in a common forum, and with plenty of time. The topic is presently in an exploratory stage, but extremely promising. Also it opens up new aspects of future run planning at RHIC, because it is at the lower energies of the RHIC Beam Energy Scan(BES) that the most crucially required susceptibilities must be measured which, uncomfortably, requires huge data statistics.

3.3.17 ACHIEVEMENTS AND PERSPECTIVES IN LOW-ENERGY QCD WITH STRANGENESS

DATE: October 27 – 31, 2014

ORGANIZERS:

C. Curceanu *(LNF-INFN, Italy)*
L. Fabbietti *(TUM, Excellence Cluster, München, Germany)*
C. Guaraldo *(LNF-INFN, Italy)*
J. Mares *(Nuclear Physics Institute, Rez Prague, Czech Republic)*
J. Marton *(SMI-Vienna, Austria)*
U.-G. Meißner *(University of Bonn, Germany)*

NUMBER OF PARTICIPANTS: 43

MAIN TOPICS:

The workshop focussed on the most recent achievements and perspectives, both from theoretical and experimental points of view, in low-energy QCD with strangeness and its possible implications in astrophysics. Present and future opportunities in this frontier field of research were discussed, together with the latest experimental results, methods and techniques, paralleled by theoretical progress.

Main topics of discussions were:

- Antikaon—nucleon and –nucleus interaction at low energy
- Kaonic atoms physics
- Antikaonic nuclei
- The structure of the Λ (1405)
- Hypernuclear spectroscopy
- Strangeness on a lattice - progress
- Excited hyperons and their interactions with nuclei
- Equation of state for neutron stars – possible role of strangeness
- Experimental results:

- SIDDHARTA, SIDDHARTA-2, AMADEUS and FINUDA at DAFNE
- FOPI and HADES at GSI
- E15 at J-PARC
- BESIII
- CLAS
- ALICE at LHC

Next-generation experiments

- AMADEUS at DAFNE
- SIDDHARTA-2 at DAFNE
- E15 at J-PARC
- BES
- ALICE

- Experiments at FAIR
- Other proposals

Within the framework of the workshop a LEANNIS meeting (WP9 in the framework of HadronPhysics3 project) was organized.

SPEAKERS:

O. Arnold (TUM, München Germany)
I. Bombarci (Univ. and INFN Pisa, Italy)
A. Cieply (NPI Rez, Czech Republic)
A. Drago (Uni. and INFN Ferrara, Italy)
L. Fabbietti (TUM, München, Germany)
A. Filippi (Univ. and INFN Torino, Italy)
E. Friedman (Racah Institute of Physics, Jerusalem, Israel)
A. Gal (Hebrew Univ. Jerusalem, Israel)
D. Gazda (ECT*, Italy)
C. Guaraldo (LNF-INFN, Italy)
J. Haidenbauer (FZ Jülich, Germany)
F. Hauenstein (FZ Jülich, Germany)
E. Hiyama (RIKEN, Japan)
J. Hrtankova (REZ Prague, Czech Republic)
C. Lagana (CERN)
R. Lalik (TUM, München, Germany)
R. Lea (Uni. And INFN Trieste)
M. Mai (Univ. Bonn, Germany)
M. Maggiora (Univ Torino and INFN, Italy)
J. Marton (SMI Vienna, Austria)
T. Matulewicz (Warsaw Poland)
D. Mihaylov (TUM, München, Germany)
R. Munzer (TUM, München, Germany)
U.-G. Meißner (Uni. Bonn, Germany)
F. Pederiva (Trento, Italy)
S. Petschauer (TUM, Germany)
S. Piano (Sez. Trieste, INFN, Italy)
M. Poli Lener (LNF-INFN, Italy)
F. Sakuma (RIKEN, Japan)
K. Sasaki (Univ. Tsukuba Japan)
A. Schmitt (Technical Univ. of Vienna, Austria)
N. Shevcenko (Rez Prague, Czech Republic)
M. Silarski (Jagellonian University, Krakow, Poland)
D. Sirghi (LNF-INFN, Italy)
O. Vazquez Doce (TUM, München, Germany)
P. Vesely (Rez Prague, Czech Republic)
W. Weise (ECT* and TUM, Germany)
S. Wycech (Prague, Poland)
J. Zmeskal (SMI Vienna, Austria)

SCIENTIFIC REPORT :

Within the framework of this workshop we focussed on the following main themes: kaonic atoms studies; antikaon-nucleon and -nucleus interactions at low energies; search for antikaonic nuclei; the structure of $\Lambda(1405)$; hyperon-nucleon and -nucleus interactions, hypernuclear spectroscopy; strangeness in heavy-ion collisions; equation of state for neutron stars including strangeness; new ideas for future experiments and new ideas for theory.
A general talk related to pending issues in low-energy strong interactions with strangeness was given by W. Weise.

Kaonic Atoms Physics:

Kaonic atoms are fundamental tools for understanding low-energy QCD in the strangeness sector. The SIDDHARTA experiment has provided the most precise results on kaonic hydrogen transitions to the 1s level, the first exploratory measurement of kaonic deuterium, and precision measurements of kaonic helium 3 and 4 transitions to 2p level. Yields for various kaonic atoms transitions were extracted, providing important information for cascade calculations. These results, discussed during the workshop, are presently being considered by the theoreticians working in the field in order to obtain information in low-energy QCD with strangeness. The SIDDHARTA-2 experiment at DAFNE is going to take data in the next years and to perform precision measurements on other types of kaonic atoms, starting with kaonic deuterium. Theoretical calculations as well as plans to perform this measurement were discussed during the workshop.

Antikaon-Nucleon and –Nucleus Interactions at Low Energy

The low energy antikaon-nucleon interaction is governed by the presence of resonances near threshold which lead to interesting phenomena in antikaonic nuclear systems. Many experimental results are emerging in this sector, for example the analysis of E15 data taken at J-PARC, the analysis of the 2002-2005 KLOE data or the dedicated AMADEUS 2012 carbon target data taking, which were discussed during the workshop. In the future, further opportunities will be exploited to study the low energy antikaon–nucleon and -nucleus interactions at J-PARC or using advanced 4π-tracking detectors techniques for gaining precision data with the AMADEUS set up at DAΦNE. Experimental results were discussed together with theoretical findings and future opportunities.

The Lambda(1405) resonance

The nature of the Lambda(1405) is still not yet well-known; it is currently described as a molecular states of an antikaon-proton quasibound state embedded in and strongly coupled to the pion-sigma-hyperon continuum. This item is of fundamental importance since it is connected with the strength of antikaon-proton interaction and, consequently, with the possibility to have deep or shallow bound kaonic nuclei. The latest experimental results from CLAS, FOPI, HADES and AMADEUS data were presented and discussed, together with theoretical results.

Single and double strangeness nuclei

A strong interest for the role of K- mesons in nuclei arrived since Akaishi and Yamazaki proposed in 2002 the debated super-strong binding effect mediated by antikaons in a nuclear medium. There are intensive ongoing searches for such bound systems with various reactions using stopped and in-flight K- beams, as well as proton and heavy ion induced reactions at various laboratories, such as at DAΦNE in Frascati using KLOE-data analyses, by AMADEUS, J-PARC with E15, and GSI using FOPI and HADES. Debated indications of the existence of deeply bound ppK- and ppnK- systems have been found in stopped K- reactions with FINUDA at DAΦNE, E549 at KEK and proton induced reactions in the analysis of DISTO data from SATURNE and OBELIX at CERN, which however were not confirmed up to now. The most recent results together with future plans (AMADEUS and E15 for example) were shown and discussed, from experimental and theoretical points of view. The annihilation of stopped antiprotons in nuclei is considered to be a powerful method for the production of quasi-bound double strangeness systems as ppK-K- and pnK-K-. Missing mass spectroscopy in the annihilation of stopped antiprotons in 3He using the produced K+K0 and K+K+ pairs, respectively, including a strangeness tracking of the ΛΛ decay products in the case of ppK-K- in an appropriate 4π-detector system is proposed to give unique evidence of the existence of such elementary double strangeness nuclear systems. Plans to propose experiments in this directions (at GSI, J-PARC or CERN) were presented and discussed.

Hypernuclear Spectroscopy

Many new results are emerging in the hypernuclear physics area; new experimental data and even more importantly, new theoretical ideas, are nowadays available and thus exerting pressure on existing and future experiments. The importance of hypernuclear physics is extending, in parallel with new accelerator and detector techniques, from strangeness -1 hypernuclei to strangeness -2 systems and to high precision experiments. A special role is played by the so-called neutron-rich hypernuclei which were intensively discussed. Results of the existent experiments were discussed together with theoretical studies and future experiment proposals.

Neutron Star Equation of State

Possible theoretical scenarios for the structure of neutron stars, based on the recent discovery of 2-solar-mass neutron stars and on our current knowledge of hadron interactions and low-energy strangeness physics were discussed in several talks.
A special session was dedicated to the LEANNIS – HP3 meeting in the afternoon of 29 October.

Results and Highlights

The progress in the low-energy QCD with strangeness 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, KLOE, E15, CLAS, BESIII, ALICE, just to name few); other experiments are planned (at DAFNE, GSI, FAIR or JPARC) and many others are in the proposal phase. On the theoretical side, refined calculations and methods (chiral 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 $\Lambda(1405)$, 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, just to name a few. 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 compact objects, 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 low-energy QCD with strangeness and the future perspectives in the field 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 provided an excellent opportunity to trigger future collaborations which might then put forward new projects in the framework of the upcoming EU - Horizon2020 program.

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 percentage of young participants was about 50%, which is one of the successes of the workshop.

The future of the field looks bright and promising – in good health, with an optimal mixing of experts and young researchers, theoreticians and experimentalists, understood items and problems to be solved.

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.

3.3.18 INTERDISCIPLINARY WORKSHOP ON STATISTICAL AND ANALYSIS METHODS IN NUCLEAR, PARTICLE AND ASTROPHYSICS

DATE: November 03 - 05, 2014

ORGANIZERS:

A. Müller *(Technische Universität München, TUM, Germany)*
F. Beaujean *(Ludwig-Maximilians Universität, LMU, München, Germany)*
H. Böhringer *(Max-Planck-Institut für extraterrestrische Physik, MPE, Germany)*
A. Caldwell *(Max-Planck-Institut für Physik, MPP, München, Germany)*
T. Ensslin *(Max-Planck-Institut für Astrophysik, MPA, Garching, Germany)*
B. Grube *(Technische Universität München, TUM, Germany)*
F. Guglielmetti *(Max-Planck-Institut für extraterrestrische Physik, Garching, Germany)*

NUMBER OF PARTICIPANTS: 29

MAIN TOPICS:

The goal of the meeting on "Statistical and Analysis Methods in Nuclear, Particle and Astrophysics" was to bring together experts on these methods from different communities, fostering new cooperations and projects. The three-day workshop involved an introductory session for students at the beginning, followed by three topical presentation sessions on astronomy & cosmology, particle physics and astroparticle physics. Each topical session was followed by students' sessions and a discussion session.

The main topics were:

- Bayesian and frequentist methods: introductory lectures and various applications
- Imaging techniques in astronomy
- Statistical methods in cosmology and particle physics (e.g. at LHC)
- Multivariate analysis methods
- Confidence interval constructions
- Variational Bayes techniques
- Analysis techniques for direct dark matter searches (e.g. in CRESST)

SPEAKERS:

C. Arina (IAP, France)
F. Beaujean (Ludwig-Maximilians Universität, LMU, München, Germany)
M. Betancourt (University of Warwick, United Kingdom)
S. Biller (University of Oxford, United Kingdom)
K. Cranmer (New York University, USA)
F. Guglielmetti (Max-Planck-Institut für extraterrestrische Physik, Germany)

J. Jasche (Technische Universität München, TUM, Germany)
B. Kegl (LAL Orsay, France)
F. Proebst (Max-Planck-Institut für Physik, MPP, München, Germany)
B. Wandelt (Institute Lagrange de Paris, France)

SCIENTIFIC REPORT:

Statistical and analysis techniques are widely applied in the fields of astronomy, cosmology, particle and nuclear physics. The aim of the meeting on "Statistical and Analysis Methods in Nuclear, Particle and Astrophysics" which was held from 3-5 November 2014 at ECT* was to bring together experts on these methods from different communities. Indeed this was the case because about 50 % came from the astronomy/cosmology side whereas the other 50 % were particle physicists or mathematicians. In this way, one could foster exchange of knowledge among the participants from different communities as well as initiate new co-operations and projects. The three-day workshop also involved an introductory session for students at the beginning followed by three topical presentation sessions on astronomy & cosmology, particle physics, and astroparticle physics. Each topical session was followed by students' sessions and a discussion session. Students were educated in these special techniques as well.
On the first day Fabrizia Guglielmetti gave an introductory lecture on probability theory. She explained the difference between Bayesian and Frequentist's methods and showed many instructive examples. This was greatly appreciated by the students.
On the second day in the morning, Fabrizia Guglielmetti and Torsten Ensslin presented the Bayesian method and how it can be applied in the field of cosmology. Ensslin and his PhD student developed a numerical information field theory package in python: the D3PO algorithm (arxiv:1311.1888). Jens Jasche presented a Hamiltonian Monte Carlo algorithm which was applied to a 4D analysis of the SDSS data.
In the afternoon session on the second day dealing with particle physics, Kyle Cranmer showed how to apply frequentist vs. Bayesian methods to experimental particle physics, in particular to Higgs physics at the LHC (CERN). Michael Betancourt presented the Stan package (http://mc-stan.org), a code which was written in C++. In his talk he presented Markov-Chain Monte-Carlo methods, Gibbs sampling and Hamilton Monte Carlo. Balazs Kegl presented the Higgs Machine Learning challenge and talked about deep learning. Steve Biller brought in examples from astroparticle physics, i.e. the SNo experiment.
On the last day dedicated to astroparticle physics various analysis methods were introduced which are applied to direct dark matter searches in experiments like CRESST, LUX and DAMA. This was done by Franz Proebst and Chiara Arina. Frederik Beaujean talked about variational Bayes techniques and the C++ code PYPMC which he developed together with his student Stephan Jahn.

Results and Highlights

The interdisciplinary meeting was very successful because communities which did not meet before are now in close contact. In particular, it was fruitful to involve people applying the same techniques, but coming from different communities. The meeting established new connections between cosmologists and particle physicists in particular. Students benefitted very much from the Trento meeting because they got an introduction into the interdisciplinary field of statistical and analysis techniques on the first day. After each session during the following two days, students had the opportunity to present their own work and to get advice for some very concrete problems. This was greatly appreciated. The speakers together with the audience succeeded in presenting two complementary techniques, Bayesian and frequentist methods. In consequence, the meeting was also successful from the networking aspect because the participants soon found a suitable contact among the other participants who could help with their individual research problem. At the end, one could feel from the spirit of the meeting that the attendees will surely come together at a later opportunity to discuss the progress in each field.

3.3.19 FROM NUCLEAR STRUCTURE TO PARTICLE-TRANSFER REACTIONS AND BACK

DATE: November 10 - 14, 2014

ORGANIZERS:

J. Dobaczewski *(University of Warsaw, Poland)*
M. Ploszajczak *(GANIL, France)*

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

The main topics of the workshop related to interconnections between the nuclear structure and nuclear reactions approaches as applied to the specific problem of transfer reactions. The essential questions were how to (i) advance the reaction theory and its methods for the description of spectroscopic properties of weakly bound and exotic isotopes, (ii) provide a microscopic input for transfer and knockout reactions from most advanced nuclear structure models, and (iii) study nucleon-nucleon correlations in exotic nuclear systems that are close to the breakup threshold and whose properties are determined by a combination of many-body correlations and couplings to the continuum. The workshop focused on the most advanced structure and reaction theories that are being currently developed.

The main topics were:

- Pair correlations in heavy ion transfer reactions
- Three-body models of (d,p) reactions: Where on earth do they come from?
- Ab-initio many-body calculations of single-nucleon transfer reaction and application to the astrophysically relevant reaction 7Li(d,p)8Li
- Pairing vibrations and pygmy resonance in halo nuclei with two-nucleon transfer reactions
- Nuclear Field Theory as a tool for particle transfer calculations
- Towards a unified picture of structure and reaction in the Gamow Shell Model
- Non-observable nature of the nuclear shell structure: meaning, illustrations and consequences
- Simple regularization scheme for multi-reference Density Functional Theory
- Systematic study of energy differences between analogue excited states
- Neutron correlations at the drip-line and neutron transfer reactions
- New constrained-path quantum Monte-Carlo approach for the shell model
- Relation between asymptotic normalization coefficients and spectroscopic factors
- Nuclear reactions within Time Dependent Superfluid Local Density Approximation
- Time-dependent few-body approaches to low-energy reaction dynamics of weakly-bound nuclei
- Transfer dynamics in the Time-Dependent Hatree-Fock theory deduced from particle-number projection method
- Isospin non-conserving shell model with applications to decay modes of proton-rich nuclei and nuclear astrophysics

- Isospin-symmetry-breaking and shape-coexistence effects in A~70 analogue states within beyond-mean-field approach
- Studying the structure of exotic nuclei via nucleon transfer with gamma-ray coincidences
- Calculation of transfer and charge exchange reactions in three- and four-body systems
- Nucleon transfer reactions at intermediate energy to exotic nuclei using inverse kinematics
- Testing nuclear overlap at and beyond the drip line
- Two-nucleon transfer with light heavy nuclei
- Proton induced alpha-particle emission into the continuum of outgoing energies
- Prompt core excitation in transfer reactions in DWBA
- Breakup reactions as a tool to study exotic cluster structures
- Pairing versus quarteting coherence length in nuclei

SPEAKERS:

J. Bonnard (University of Padova, Italy)
R. Broglia (University of Milano, Italy)
P. Capel (Université Libre de Bruxelles, Belgium)
W. Catford (University of Surrey, UK)
L. Corradi (INFN-Legnaro, Italy)
D. Delion (NIPNE-Bucharest, Romania)
A. Deltuva (University of Vilnius, Lituania)
A. Diaz-Torres (ECT* Trento, Italy)
S. Dimitrova (INRNE Sofia, Bulgaria)
T. Duguet (SPhN Saclay, France)
L. Fortunato (University of Padova, Italy)
M. Gomez-Ramos (Universidad de Sevilla, Spain)
A. Idini (University of Jyväskylä, Finland)
R. Johnson (University of Surrey, UK)
S. Lenzi (University of Padova, Italy)
P. Magierski (Warsaw University of Technology, Poland)
A. Matta (University of Surrey, UK)
N. Michel (GANIL, France)
A. Petrovici (NIPNE-Bucharest, Romania)
F. Raimondi (TRIUMF, Canada)
W. Satula (University of Warsaw, Poland)
K. Sekizawa (University of Tsukuba, Japan)
S. Shimoura (University of Tokyo, Japan)
N. Smirnova (CENBG, France)
J. Antonio Lay Valera (University of Padova, Italy)

SCIENTIFIC REPORT:

The workshop was dedicated to the discussion of the interface between nuclear structure models and nuclear transfer reaction methods with an emphasis on future advances needed to provide useful theoretical tools for weakly bound or unstable rare isotopes. The meeting was a follow-up of a similar workshop, which was held in November 2013, and thus it allowed for evaluating the progress achieved and maintaining collaborations across different groups.
A fundamental and critical review of the three-body models of the (d,p) transfer reactions has been presented by Ron Johnson. He begun by discussing fundamentals of the n-A scattering in the many-body, optical-model, and Feshbach formulations. Then he attempted formulating

the analogous approaches for the n+p+A system. This allowed him to formulate the following general comments and observations:

1. A 3-body model of the n+p+A system can be defined by finding an exact formula for an effective interaction in the coordinates of n and p that drives the projection of the many-body wave function onto the target A ground state.

2. This effective interaction can NOT be expressed as a sum of potentials depending separately on the n and p coordinates.

3. Physical processes that contribute to the effective interaction include, e.g., excitation of A by n followed by de-excitation by p back to the ground state of A. They can be thought of as a 3-body force contribution. The magnitude of these terms is currently unknown.

4. Even if the effects in 3. are ignored there are still problems in interpreting the effective interaction in terms of energy dependent nucleon optical potentials.

5. Approximate solutions of these problems depend on the context, e.g., elastic deuteron scattering or stripping, and require a prescription for how the model wave function is to be used.

Thomas Duguet had presented a similarly critical overview of possible definitions and extraction from data of nuclear shell properties. He has shown that many concepts currently in use are in fact ill defined and do depend on underlying assumptions that are seldom made explicit and used consistently. In particular, he has pointed out that the single-nucleon shell structure is a non-observable quantity, similar as is for spectroscopic factors, correlations, wave-functions, which are quantities that provide a scale/scheme dependent interpretation of observables. They are also often based on explicit or implicit factorisation/partitioning theorems, as is, e.g., for simple factorisation of many-body cross section for direct processes and simple partitioning of one-nucleon separation energies, two-nucleon shell gaps, etc.
Talks were scheduled for 35 minutes and were always followed by a 15-minute discussion period. All talks lead to extensive and intensive discussions in which all communities participated. In particular, four afternoon discussion sessions were organisers by conveners, who were nominated by the organizers, and who chaired and led short presentations and then introduced the subjects of discussion.

Results and Highlights
The workshop was the second one in the series of those organized within the framework of the theoretical activity SARFEN (Structure and Reactions for Exotic Nuclei) established in Europe in 2011 in the framework of the recent ERANET-NuPNET [http://www.nupnet-eu.org/wps/portal/index.html] call for proposals. This collaborative 2012-2015 effort brings together theorists from 8 countries and 11 institutions with the common goal of providing experimental infrastructures with advanced modern theoretical tools. The scope of the workshop was significantly augmented by linking its activities to the ENSAR-THEXO project funded within the FP7-Infrastructures program European Nuclear Science and Application Research [http://www.ensarfp7.eu/].

Although a significant progress has been made since the 2013 workshop, many open questions remain and give rise to many more fruitful discussions. Here we only mention the discussed themes, like

- how to make corrections to the adiabatic approximation to 3-body effects in a practical way if we are to meet the aims of describing the (d,p) transfer reactions

- how to develop consistent structure and reaction many-body theories, revisit/develop factorization/partitioning theorems, and identify quantitatively kinematical regime of validity?
- how to pursue the ab-initio many-body calculations of single-nucleon transfer reactions?
- how to employ the time-dependent methods to describe transfer and tunnelling effects?

The highlights of the workshop were certainly presented by Arnoldas Deltuva, who showed solutions of the Alt-Grassberger-Sandhas (AGS) 3-body equations for a description of transfer reactions on few-body systems with Coulomb forces included exactly.

There was a general agreement that this series of ECT* workshops should be continued even beyond the lifetime of the current SARFEN and ENSAR-THEXO collaborations. The participants have informally encouraged Lorenzo Corradi to take a lead in proposing a new activity of this kind in late 2015 or early 2016.

It is a pleasure for us to thank the ECT*, in particular Prof. Dr. Wolfram Weise, for their support and hospitality. Also we are grateful to Ines Campo for the administrative support. It was a real joy for us to work with both of them.

3.3.20 3RD ADAMAS COLLABORATION MEETING: ADVANCED DIAMOND ASSEMBLIES AT ECT*

DATE: November 19 - 20, 2014

ORGANIZERS:

E. Berdermann *(GSI, Germany)*
C. J. Schmidt *(GSI, Germany)*
M. Kiš *(GSI, Germany)*
M. Träger *(GSI, Germany)*

NUMBER OF PARTICIPANTS: 49

MAIN TOPICS:

The common topic of the meeting was the use of advanced CVD-diamond materials for particle and photon detection in hadron physics and related fields. The status of diamond sensors and their associated electronics were reviewed. Diamond assemblies were assessed and their potential and current limitations were discussed in the context of the corresponding fields of application. These comprised accelerator high-energy, hadron and nuclear physics research at modern light sources and XFELs, plasma physics with petawatt lasers, radiotherapy, and space science. Associated with this broad range of applications, the presentations included detectors consisting of all types of high-quality CVD-diamond materials available on the market. The goal was to find or initiate solutions for common technological problems independent of a specific application and to explore future alternatives.

The main topics were:

R&D

- Diamond-on-Iridium (DOI) for detector applications
- crystal structure, defects, impurities, and electronic properties
- Radiation Hardness of diamond - new results and simulations
- Front-End Electronics and DAQ for single and multichannel diamond sensors

Applications - State-of-the-art and future

- Diamond detectors in hadron physics
- Diamond detectors in related fields

SPEAKERS:

S. Matthias (Element Six, Ltd, UK)
G. Lefeuvre (Micron Semiconductor, Ltd, UK)
D. Hüffner (Diamtec GmbH, Germany)
A. Galbiati (Solaris Photonics, UK)
E. Griesmayer (CIVIDEC, Austria)

M. Schreck (Univ. of Augsburg, Germany)
E. Berdermann (GSI, Germany)
K. Afanaciev (NC PHEP Minsk, Belarus)
M. Guthoff (CERN, Switzerland)
W. Lohmann (BTU Cottbus, Germany)
F. Kassel (KIT, Germany)
S. Lagomarsino (INFN Firenze, Italy)
T. Apostolova (INRNE Sofia, Bulgaria)
A. Oh (Univ. of Manchester, UK)
L. Vitale (INFN Trieste, Italy)
M. Pomorski (CEA/LIST Saclay, France)
R. Jackman (Univ. College London, UK)
P. Bergonzo (CEA/LIST Saclay, France)
F. Schirru (GSI, Germany)
J. Dueñas (Univ. de Huelva, Spain)
O. Beliuskina (GSI, Germany)
M. Jastrzab (IFJ Krákow, Poland)
L. Chlad (UJF Řež, Czech Republic)
A. Rost (TU Darmstadt, Germany)
L. Donaldson (University of the Witwatersrand, South Africa)
S. Schuwalow (DESY, Germany)
A. Ignatenko (DESY, Germany)
J. Grünert (European XFEL, Hamburg, Germany)
J. Morse (ESRF, France)
C. Burman (ESRF, France)
A. Lohstroh (University of Surrey, UK)
C. Delfaure (CEA/LIST, France)
M. Bartosik (CERN, Switzerland)
S. Sciortino (INFN Firenze, Italy)
K. Kanxheri (INFN Perugia, Italy)
R. Pleskac (GSI, Germany)
D. Jahn (TU Darmstadt, Germany)
M. Ciobanu (ISS Bucharest, Romania)

SCIENTIFIC REPORT:

It is presumed that the origin of the unique properties of diamond is the close distance of neighbouring carbon atoms in the diamond unit cell and the resulting strong covalent tetrahedral (sp3) bonding of the carbon atoms in the diamond lattice. A range of crucial consequences distinguishes diamond from other detector materials. Its wide band gap (5.47 eV), high displacement energy (42 eV), and extreme thermal conductivity (2000 W m_1 K_1) are the characteristics, that are most likely responsible for the observed radiation and temperature tolerance of diamond sensors. Intrinsic diamond detectors do not need darkness, neither pn-junction nor cooling. The high mobility and drift velocity of electrons and holes, in combination with very high ohmic resistivity, facilitate an ultrafast collection of charge. The above features counterbalance the drawback of the relatively small detector-signal amplitudes which are also originating from the otherwise favorable wide band gap of diamond.

Their well-known radiation hardness has been the most important property rendering diamond sensors competitive to traditional detectors - impending to be overburdened by the steady increasing radiation load on the detectors of modern colliders and heavy-ion accelerators. The second reason to push forward the development of diamond sensors was the appearance of artificial diamond materials on the market, which were grown by Chemical Vapor Deposition (CVD) of carbon atoms onto suitable substrates forming diamond of ‘electronic-grade’ quality. The most distinctive feature determining the detector properties is the crystalline structure of the diamond materials, which varies from single crystals over (highly-oriented) heteroepitaxial to polycrystals characterized by large-angle grain boundaries. From all these materials, homoepitaxial single-crystal CVD diamond (scCVDD) sensors display the best detector performance in all relevant aspects. However, the small

area of available scCVDD samples demanded the development of improved heteroepitaxial diamond. For many reasons, not discussed here, Iridium is the only non-diamond substrate capable of providing large-area sensors of ‘slightly defective’ scCVDD properties. DOI diamond is in any aspect of much better quality than polycrystalline materials.
The central questions addressed at the workshop can be summarized as follows:

- Does our present understanding of the radiation hardness of diamond sensors confirm earlier expectations, and what do simulations say about the recent results of operational devices?
- How much can we win on radiation hardness by thinning down samples to the lowest acceptable thickness (given by the S/N ratio in each application)?
- Were earlier efforts too much focused on ‘electronic grade’ high-quality diamond for detector applications instead of exploring also the potential of other wide band gap materials for this purpose, for instance, ‘optical grade’ CVDD or Sapphire?

Results and Highlights
The meeting was a useful opportunity to discuss, prove, and consolidate the different concepts of diamond-detector developments ongoing within the ADAMAS collaboration, both material growth and sensor technologies. We were highly pleased to welcome several new European groups entering the field, international diamond experts and diamond suppliers, and in particular, many undergraduate students and young researchers from all over the world.

The main results are summarized as follows:

- The single-crystal diamond luminosity sensors of the CMS at LHC showed radiation damage at much lower fluencies than that expected according to RD42 results. Sensors positioned near the interactions point and used in the fast beam condition monitors experience exposure to a different particle composition and showed less deterioration. A quantitative comparison, using reference energy is still missing. Progress was made in the development of models for a quantitative understanding of radiation damage in diamond sensors. Using these models, predictions in the signal loss at future facilities will potentially be possible.
- Inexpensive, optical-grade (OG) diamond sensors of Ib type quality, were tested for optimized high-rate heavy-ion timing at HADES and CBM. The time resolution was excellent (σ-widths of 23ps and 7ps for relativistic carbon and samarium ions, respectively). The authors suggested that ‘high beam intensity results in OG diamond performing similarly to EG diamond’ (tbc). This is an astonishing new result, in particular in the view of old findings, according to which ‘a perfect crystal structure’, typical for Ib diamond, ‘does not compensate the disadvantages caused by the too high nitrogen content’ of this type of diamond (trapping and recombination).
- Super-thin diamond membrane detectors (thickness ~ few micrometers) become more and more on vogue. While presently produced from scCVDD plates, it is planned to apply also pcCVDD and DOI samples for this purpose. Potential application fields are: heavy-ion detection and X-ray monitoring at synchrotrons. A ‘deep etching’ program has been started at ESRF.
- The development of 3D and SOD devices are yet underpinned by theoretical calculations concerning the device damage during laser graphitization (INRNE).
- Very interesting beam-halo monitors (BHM) made of Sapphire were presented. A first BHM has been successfully commissioned and reliably operated at FLASH since September 2009 (DESY). A second BHM is in preparation for the European XFEL.
- The structural properties of the DOI material have been further improved. DOI samples with an area of several square centimeters can be yet grown routinely. However, post-processing to prepare thin plates without cracking still represents a major challenge which requires intensive further work. For the first time it was possible to visualize the defect band structures typical for DOI material by performing IBIC experiments with carbon micro beams at GSI. The data analysis is still ongoing. We hope to learn more

about the dislocation structure of the material by comparing IBIC mapping with Raman imaging.

- Concluding, in spite of all remaining challenges the use of diamond detectors in Europe and elsewhere is clearly increasing. Diamonds are now established as a beam-loss monitoring tool at LHC, including cryogenic diamond sensors for the protection of super-conductive magnets. Further niche applications along the line of radiation monitoring are being developed throughout Europe.

3.4 ECT* DOCTORAL TRAINING PROGRAM 2014

Heavy ion collisions: exploring nuclear matter under extreme conditions

(Report written by Georges Ripka)

The 2014 ECT* Doctoral Training Program on Heavy Ion Collisions: exploring nuclear matter under extreme condition lasted 6 weeks, from April 7 to May 16, 2014. It was organized by François Gélis and Jean-Yves Ollitrault (both from CEA, Saclay, France). The finance, lodging and other administrative tasks of both the students and the lecturers were taken care of by Serena degli Avancini. Georges Ripka (CEA, Saclay and ECT*) attended as student coordinator.

The Doctoral Training program was attended by 29 full-time and 6 part-time students. This is roughly two times more than the number of students attending the previous Doctoral Training Programs. The number was limited by ECT* mainly because of lodging limitations. The students came from laboratories in the following countries: USA (8 students), Italy (6 students of which 2 coming from Trento), India (3 students), Japan (3 students), Germany (3 students), Canada (2 students), Russia (2 students), Argentina (1 student), Belgium (1 student), Canada (1 student), France (1 student), Hungary (1 student), Poland (1 student), Slovakia (1 student), South Africa (1 student) and Spain (1 student). A detailed list of the students is given below.

There were altogether 8 lecturers during the 6 weeks period of the program: four weeks with one lecturer and two weeks with two. Two one-hour lectures were delivered each morning from Monday to Friday.

The students were asked to give a seminar on their current research (the list of the student seminars is given below). Half-hour student seminars were held in the afternoon on Tuesdays and Thursdays. The fact that the afternoons were otherwise free and that the lecturers were present at ECT* allowed the students to discuss with the lecturers and to continue working on their PhD project. Two students from the University of Trento, two from Catania did not give seminars, nor did they attend the full course of lectures. One student from Duke University did not give a seminar.
At the end of the program, the students were asked to write an informal report about the program. The reports, which were not required to be signed, were handed to the ECT* Director. Almost all said that the Doctoral Training program was very instructive and they appreciated how helpful was Serena. Many expressed satisfaction to have lectures delivered on the board. I also encouraged them to voice criticisms. Among these some said that there were not enough problem sessions in the afternoons, that there was not enough time to work on their PhD, in particular because the students were required to leave ECT* at 9pm in the evening and it was not easy for them to work elsewhere. Some considered that the lectures covered too many topics. The new lodging at Agritur Ponte Alto was greatly appreciated by all.

The lecturers were asked by the organizers to use the board to explain the theory, rather than slides and power-point like presentations. This is the first time that all lecturers complied to this request, with the obvious exception that experimental results as well as detailed descriptions of experimental detectors (Alice, CMS,...) were projected on a screen. In their informal reports, many students appreciated this. The lecturers were all considerably younger than the average in previous Doctoral Training programs. Most lecturers left (sometimes hand-written) lecture notes which the students could download from an internal ECT* website, which is only accessible from ECT*.
The aim of the Doctoral Training program is to give the students an in-depth understanding of the theory. The students work on their PhD projects which cover various domains: some

make hydrodynamic calculations, others calculate jet production, others make AdS/CFT calculations, and more. It would be useful, at the beginning of the program, to reserve some time during which all the terms used in the various lectures are properly defined and explained. For example, Glauber approximations were mentioned in passing in almost all the lectures, yet they were never defined. The light-cone coordinate properties might have been given a bit more time at the beginning of the program.

In spite of the difficulties entailed in organizing and scheduling the Doctoral Training program, I would suggest that the organizers do a bit more preparatory work. They could, for example, gather all the lecturers through virtual meetings (using Skype or the like) in order to discuss and possibly harmonize the various subjects treated. They could give one of the lecturers the extra task of giving a set of preliminary lectures in which the prerequisites for the lectures would be clearly spelled out and recalled (no matter how elementary they might be). Giving a unitary structure and a sense of continuity between the different subjects treated is what distinguishes a “training program” and a loose set of lectures. This should form part of the guidelines given to DTP organizers.
The lectures delivered during the 2014 Doctoral Training program are listed in the next chapter.

3.4.1 Lecture Programme

Week 1, April 7-11

Derek Teany *(Stony-Brook, USA)*
Relativistic hydrodynamics

Teany explained how the impact parameter of a collision was determined from relative multiplicity of events. He defined rapidity and pseudo-rapidity and estimated the number of particles per unit rapidity and per unit participant pair (about 12 at the LHC). He described the Bjorken picture of two nuclei which are flattened out by relativity to become two colliding slabs, leaving behind a quark gluon plasma (QGP) which expands and hadronizes. He formulated a hydrodynamical description of the expanding plasma, the equations of motion and entropy conservation. He described the conditions which must be met to justify the ‘hydro’ description. He defined and evaluated the shear viscosity and its particular temperature dependence. He discussed viscous Bjorken flow. The lectures were done entirely on the board and Teany had many discussions with the students, which made some of his lectures better defined. He promised to send lecture notes but he did not.

Week 2, April 14-18

Guilherme Milhano *(CENTRA, Lisbon and CERN)*
Jets in heavy ion collisions

Milhano lectured on the formation of jets, their propagation in the quark-gluon plasma and how they may be used to probe the quark-gluon plasma (QGP). He discussed the dynamics and the propagation of energetic partons in the QGP and how they initiate jets, the parton distribution functions, factorization, the initial jet formation and its propagation in the medium. He described the various scales relevant to factorization, to renormalization (at which the QCD is evaluated) and the hard scale for the parton-parton scattering). He discussed medium induced radiation and the time it takes to emit a gluon with a given energy and at an angle from its emitter. He described the Gyulassy-Wong model and the eikonal trajectory of a highly energetic particle. He calculated the successive steps of the scattering of a Dirac particle in the medium, as well as medium induced radiation.
He delivered his lectures on the board and left hand-written notes which the students could download from the internal ECT* website.

Gregory Soyez *(CEA, Saclay, France)*
Jets from $e^+ e^-$ to AA collisions

Soyez calculated the process $e^+ e^- \rightarrow \Upsilon \rightarrow$ parton together with first order corrections. Infrared divergences were identified and their cancellation discussed. Jets were described as collimated particles. The JADE, K_t and Cambridge/Aachen algorithms were discussed. He then discussed the deep inelastic scattering process $e^{\pm}p \rightarrow e^{\pm}$ X, the proton structure functions, and the scattering of the photon with the partons (quarks) in the proton. He discussed scaling violations due to radiated gluons and the DGLAP equations. He explained QCD in pp collisions at the Tevatron. The parton distribution functions at the LHC, jets at lowest order, the precise definition and recognition of jets, how one can do better than the Sternman Weinberg cone, how to track back time sequential recombination. He left hand-written notes which the students could download from the internal ECT* website.

Week 3, April 22-25

Marco van Leeuwen *(Nikhef and Utrecht University)*
Experimental techniques

Van Leeuwen described detectors, luminosity, on-line triggering, and correlation measurements. He discussed in detail statistical and systematic uncertainties in experiments, how they can be evaluated and taken into account, giving examples for proton structure functions, factorization in DIS and parton distribution functions. He described $p-\bar{p}$ the dijets at the Tevatron, the LHC p+p and Pb+Pb collisions. He described detection principles involving ionization energy loss, bremsstrahlung, transition radiation, Cherenkov radiation and scintillation. He described wire and gas amplification, drift tubes, plate and time projection chambers. He displayed a TPC event in ALICE, tracking and silicon detectors. He described event triggers at ALICE, centrality distributions, CMS triggers. He lectured mostly on slides, which is understandable in view of the subject and he left detailed lecture notes for the students.

Week 4, April 28-May 2

Mikko Laine *(Universität Bern, Switzerland)*
QCD at finite temperature

Laine began by deriving basic expressions for the partition function, particle number distributions for free fermions and bosons, the use of Matsubara frequencies. He showed how to construct an effective theory for a zero Matsubara mode for massless particles. He explained the path integral expression of the partition function for QCD, the Schwinger-Keldysh contour, the thermal gluon mass, equilibration rates, transport coefficients, basics of lattice simulations and Wilson loops. He lectured on the board and gave the web site from which a 189 page file of lectures he had given in 2013 could be downloaded.

Week 5, May 5-9

Dionysis Triantafyllopoulos *(ECT*, Trento)*
Color Glass Condensate

Triantafyllopoulos began by explaining the time scales and how hadronic fluctuations can live for a long time and become quasi-real. He gave an example of DIS (e^-p) scattering and how the photon resolves quarks with perpendicular momentum up to Q^2. He made a detailed calculation of the gluon spectrum generated from a single color charge: he first solved the classical equation of motion in the presence of the fast moving quark source; and then quantized the gluon field and calculated the density of produced gluons; he showed that lifetimes are proportional to the large longitudinal momenta, whence the term glass; he finally generalized this to gluons produced by the two sources with opposite charge (color dipole). He then derived the BFKL equation for the dipole density and discussed its solutions. He proceeded to discuss the occupation number and distribution of gluons, leading to parton saturation, whence the term condensate. He proceeded to discuss the JIMWLK evolution in Langevin form. He discussed the solution to the BK equation. He left excellent and carefully hand written lecture notes. He should have been assigned a larger number of lectures.

François Gélis *(CEA, Saclay, France)*
The Color Glass Condensate effective theory in heavy ion collisions

Gélis described the system in which the gluon density saturates with an occupation number of the order of $1/\alpha_s$. He employed a toy model involving scalar fields with a ϕ^3 interaction and a source term and showed that the leading order diagrams had a tree structure. He used the Schwinger-Keldysh formalism to evaluate the expectation value of the field and showed how, at leading order, the tree diagrams lead to the classical equation of motion for the field. He then set up the same calculation for sources arising from heavy ion collisions and for gluon QCD fields. He discussed the convenient choice of gauge and calculated the gauge field at a short $\tau = \varepsilon$ just above the forward light cone. He then proceeded to evaluate next to leading order one loop diagrams, and showed how they reduce to a single diagram with a dressed propagator. He discussed the equations and boundary conditions for the dressed propagator and methods to solve the equations. He finally discussed instabilities in the Yang-Mills equations of QCD. His lectures were very rigorous and delivered on the board. He left hand-written lecture notes.

Week 6, May 12-16

During the last week, in addition to the lectures of Peter Arnold, a workshop on 'Hydrodynamics for strong coupling techniques' took place at ECT*. Several students of the Doctoral Training Program wished to attend some of the workshop presentations and Peter Arnold accepted to adjust the schedule of his lectures accordingly.

Peter Arnold (University of Virginia, USA)
Strong coupling techniques

Arnold lectured on gauge-gravity duality, often called AdS/CFT. He described in detail the super-symmetric Yang-Mills theories and classical gravity in anti-de Sitter space and its relation with QCD at temperatures above the transition temperature, in the large Nc and strong coupling limits. He discussed expressions for the free energy and the entropy at finite temperature, and finally derived an expression for the ratio of the shear viscosity to the entropy.
His lectures were delivered on the board. They were very wordy and not easy to follow. Only 20 students were present at his last lectures. He left no lecture notes but instead gave Arxiv references of some relevant papers.

3.4.2 List of Participants

Full time students:

Jonah Bernhard	Duke University, Durham, USA
Juan Pablo Carlomagno	Duke University, USA
Thomas Epelbaum	IphT, CEA/Saclay, France
Zuzana Feckova	Pavol Josef Safarik University, Kosic, Slovakia
John Fuini	University of Washington, USA
Masaru Hongo	RIKEN, University of Tokyo, Japan

Vladimir Kovalenko	Saint Petersburg State University, Russia
Robert Lang	TU München, Germany
Zhe Liu	Columbia University, New-York, USA
Kiminad Mamo	University of Illinois, Chicago, USA
Surasree Mazumder	Variable Energy Cyclotron Centre, India
Ben Meiring	University of Cape Town, South Africa
Sukanya Mitra	Variable Energy Cyclotron Centre, India
Pablo Morales	Keio University, Yokohama, Japan
J. Scott Moreland	Duke University, Durham, USA
Saehanseul Oh	Yale University, USA
Kazuhisa Okamoto	Nagoya University, Japan
Dmytro Oliinychenko	Frankfurt Institute of Advanced Studies, Germany
Daniel Pablos	Universitat de Barcelona, Spain
Jean-Francois Paquet	McGill University, Montreal, Canada
Semyon Pozdnyakov	Saint-Petersburg State University, Russia
Jean-Bernard Rose	McGill University, Montreal, Canada
Andrey Sadofyev	Massachusetts Institute of Technology, USA
Enrico Speranza	GSI, Darmstadt, Germany
Iwona Sputowska	Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland
Pieter Taels	Universiteit Antwerpen, Belgium
Douglas Wertepny	Ohio State University, USA
Mohammed Younus	Bose Institute, Kolkata, India
Anna Julia Zsigmond	Wigner Research Centre for Physics, Budapest, Hungary

Part time students:

Paolo Giuseppe Alba	Università degli Studi di Torino, Italy
Francesco Fambri	Università degli Studi di Trento, Italy
Vincenzo Minissale	Università degli Studi di Catania, Italy
Lucia Oliva	Università degli Studi di Catania, Italy
Armando Puglisi	Università degli Studi di Catania, Italy
Olindo Zanotti	Università degli Studi di Trento, Italy

3.4.3 Seminars delivered by the students

Kiminad Mamo (University of Illinois, Chicago, USA): *Transport coefficients and thermal photon production rate at strong coupling*

Dmytro Oliinychenko (Frankfurt Institute of Advanced Studies, Germany): *Transition between hydrodynamics and transport*

Robert Lang (TU München, Germany): *Shear viscosity from a large-Nc NJL model*

Masaru Hongo (RIKEN, University of Tokyo, Japan): *Anomalous hydrodynamics and charge dependent elliptic flow*

Andrey Sadofyev (Massachusetts Institute of Technology, USA): *Chiral effects and physics of chiral media*

Paolo Alba (Università degli Studi di Torino, Italy): *Freeze-out parameters from a hadron resonance model*

Surasree Mazumder (Variable Energy Cyclotron Centre, India): *When a heavy quark recoils while propagating in a QGP*

Pablo Morales (Keio University, Yokohama, Japan): *Effect of the topological axial current on holographic QCD at finite density and magnetic field*

Enrico Speranza (GSI, Darmstadt, Germany): *Dileptons in heavy ion collisions*

Jean-Bernard Rose (McGill University, Montreal, Canada): *Exploring the effects of shear and bulk viscosities in a higher order hydrodynamic simulation*

Daniel Pablos (Universitat de Barcelona, Spain): *A hybrid strong/weak coupling approach to jet quenching*

Vladimir Kovalenko (Saint Petersburg State University, Russia): *Colour string fusion model in high energy pp, pA and AA collisions*

Thomas Epelbaum (IphT, CEA/Saclay, France): *Early isotropization of the quark gluon plasma*

Ben Meiring (University of Cape Town, South Africa): *A first calculation for the energy momentum tensor for jet production in finite time*

Jean-Francois Paquet (McGill University, Montreal, Canada): *A hydrodynamic approach to direct photon production in heavy ion collisions*

Lucia Oliva (Università degli Studi di Catania, Italy): *Thermodynamics of the quark-gluon plasma at high temperature with a quasiparticle model coupled with a Polyakov loop*

Pieter Taels (Universiteit Antwerpen, Belgium*): A Wilson line approach to the study of jet quenching*

Sukanya Mitra (Variable Energy Cyclotron Centre, Kolkata, India): *Medium effects on the transport coefficients of hadronic systems*

Mohammed Younus (Bose Institute, Kolkata, India): *Charm quarks and parton cascade model*
Anna Julia Zsigmond (Wigner Research Centre for Physics, Budapest, Hungary): *Electroweak boson production in Pb-Pb collisions in CMS*

Douglas Wertepny (Ohio State University, USA): *Two-gluon correlations in heavy-light ion collisions*

Zhe Liu (Columbia University, New-York, USA): *Dijet and heavy-quarkonium energy loss in pA collisions*

Zuzana Feckova (Pavol Josef Safarik University, Kosic, Slovakia): *Testing a new hydrodynamics code*

John Fuini (University of Washington, USA): *Far from equilibrium isotropization of a non abelian plasma with a chemical potential or magnetic field*

Iwona Sputowska (Institute of Nuclear Physics, Polish Academy of Sciences, Krakow, Poland): *Study of long-range correlations in Pb+Pb collisions*

Kazuhisa Okamoto (Nagoya University, Japan): *A new scheme for the relativistic hydrodynamics; Riemann solver for QGP*

Semyon Pozdnyakov (Saint-Petersburg State University, Russia): *Multi-Pomeron vertices*

Jonah Bernhard (Duke University, Durham, USA): *QGP parameter extraction via a global analysis of event-by-event flow coefficient distributions*

Saehanseul Oh (Yale University, USA): *Correction methods for finite acceptance effects in two-particle correlation analysis*

Juan Carlomagno (IFLP, Buenos Aires, Argentina): *Deconfinement and chiral restoration in nonlocal SU(3) chiral quark models*

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

Density Functional Theory and Self-Consistent Methods

This document aims at giving a summary, including background information, of the Nuclear Talent course on Density Functional Theory and Self-Consistent Methods. 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 14 to August 1, 2014. This report first contains a general introduction to the Nuclear Talent initiative. Thereafter follows a detailed description of the course, with a summary of the experiences made. Finally, reports from the participants are included.

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 Density Functional Theory and Self-Consistent Methods

Density functional theory (DFT) is the method of choice for large-scale electronic structure calculations in condensed matter physics, quantum chemistry and even materials science or molecular biology. This popularity results from the fact that DFT calculations are comparatively simple to implement, yet are often very accurate with a computational cost that makes them the ideal choice for systems with large numbers of electrons. For the same reasons, energy density functional (EDF) approaches play a central role in nuclear theory since they offer the only computationally feasible many-body framework capable of describing nuclei across the mass table. EDF approaches to nuclear structure are analogous to electronic DFT in that they map the computationally prohibitive many-body problem onto an effective one-body problem. Besides the obvious computational simplifications, this so-called Kohn-Sham framework provides a mean-field-like description in terms of intrinsic shape and single-particle degrees of freedom that lends itself to simple and physically intuitive interpretations. The price to pay for these simplifications is that the unknown EDF must be approximated with phenomenological functionals (e.g., Skyrme, Gogny, etc.), typically expressed as local powers and gradients of ground state nucleon densities and currents with empirical couplings adjusted to data. As a consequence of this phenomenological nature, it is difficult to systematically improve the performance of nuclear EDFs or provide reliable error estimates of theoretical predictions away from stability. In this course, students will learn, through various computational projects and hands-on exercises, the fundamental concepts and methods of modern density functional theory. Most of the course will be focused on nuclear structure applications, with short excursions in the theory of nuclear forces and electronic structure theory.

Aims and Learning Outcomes

The goals of the course were threefold: (i) gain an in-depth understanding of the basic concepts, mathematical methods, and computational techniques used to solve the quantum many-body problem within the framework of density functional theory, (ii) learn about the current developments, challenges, and research opportunities in the specific context of nuclear structure, (iii) conduct and manage a small computational nuclear physics project. The skills acquired in this course will enable participants to quickly and efficiently write their own codes using state-of-the-art methods of scientific computing. The experience gained will also facilitate student's insertion in research groups that already maintain a nuclear DFT software base. The course gave the participants the necessary proficiency to tackle a broad spectrum of research problems in atomic and nuclear physics.

Detailed Course Content

The program of the course was designed so that students can start working on their computational projects and hands-on exercises as quickly as possible.

First week: *Basic techniques of quantum many-body physics*

- Reminder of advanced quantum mechanics: Coordinate and momentum representations of the Hilbert space, discrete bases, operators, Schrödinger equation, spin, isospin, Dirac equation;
- Second quantization: Fermions and bosons, Fock space, Wick theorem, equivalence between representations;
- Hartree-Fock (HF) theory: product states, density matrices, variational principle, Thouless theorem, Koopman's theorem;
- Pairing correlations: Spontaneous symmetry breaking, BCS theory, pairing tensor, Hartree-Fock-Bogoliubov (HFB) theory;
- Random Phase Approximation (RPA): Introduction to time-dependent HartreeFock (TDHF) theory, linear response, stability matrix.

Second week: *Density functional theory for atoms and nuclei*

- Nuclear forces: Invariance properties, meson exchange, basic notions of relativistic quantum field theory;
- Phenomenological nuclear forces: Skyrme and Gogny forces, concept of energy density functional (EDF), relativistic EDFs, effective pseudopotentials, experimental constraints;
- Density functional theory (DFT): Existence theorems, Kohn-Sham schemes, local density approximation, gradient exchanges, exchange-correlation, self-interaction;
- Realistic nuclear potentials: Introduction to chiral effective field theory, diagrammatic expansions, power counting;
- Non-empirical functionals: Brueckner theory, density matrix expansions, three-body orces.

Third week: *Applications of nuclear DFT*

- Symmetries: Spontaneous symmetry breaking, nuclear deformation, symmetry restoration, multi-reference DFT;
- Nuclear collective motion: collective variables, residual interactions, configuration mixing;
- Computational nuclear structure: DFT solver schemes, large-scale applications;

- Open questions in nuclear DFT: non-empirical functionals, inclusion of collective correlations, symmetries;
- Course summary, discussions.

Teaching

The course was held from July 14 to August 1 in 2014 at the ECT* (Villazzano) in Trento, Italy. It was organized in collaboration with the University of Trento. The course took the form of an intensive program of three weeks, with a total time of 45 h of lectures and directed exercises, about 75 h devoted to a computational project and a final assignment worth approximately 2 weeks of work. The total workload amounted to 150 hours, corresponding to **6 ECTS** in Europe. The final assignment was graded with marks A, B, C, D, E and failed for Master students and passed/not passed for PhD students.

The organization of the day was as follows:

- 9am - 12pm: Lectures, directed exercises
- 12pm - 2pm: Lunch
- 2pm - 6pm: Hands-on sessions, computational projects
- 6pm - 7pm: Wrap-up of the day

The final assignments were extensions of the core computational project that was developed during the three weeks of the course. Throughout the course, special attention was paid to (i) the actual resolution of the problem, (ii) the use of modern programming concepts such as, e.g., modularity, objects and classes, abstraction layers, etc., (iii) the efficiency of the program (resource consumptions), (iv) the proper documentation and user-friendliness of the source code, see Summary and Recommendations for some of the tools that we used.

Teachers

The teachers were:
Scott Bogner (Michigan State University, USA), bogner@nscl.msu.edu
Peter Ring (Technische Universität München, Germany), peter.ring@tum.de
Nicolas Schunck (Lawrence Livermore National Laboratory, USA), schunck1@llnl.gov
Dario Vretenar (University of Zagreb, Croatia), vretenar@phy.hr

The organizers were:
Morten Hjorth-Jensen (Michigan State University, USA and University of Oslo, Norway) and contact person, hjensen@nscl.msu.edu
Giuseppina Orlandini (Università di Trento, Italy), orlandin@science.unitn.it

Participants and their home institution

The target group was students currently pursuing a Master of Science, a Ph.D., as well as early post-doctoral fellows. Students were either experimentalists and/or theorists. Students were expected to have working proficiency in quantum mechanics. This includes knowledge of the following basic physics concepts and mathematical tools: concept of wave-function, Schrödinger equation, spin, Hilbert spaces, linear operators, differential operators, group theory. Students were also expected to have strong operating programming skills in Fortran, C/C++ and/or Python, which were the only languages we accepted to support. The participants had very varying skills both in quantum mechanics, nuclear theory and computing. While the quickest students were done with the full Hartree-Fock solver by the beginning of the third week, several were still struggling with the truncated HF solver at the end of the course. The number of students for the course was capped at 25. There were only three female students.

Name	**Institution**
Arzhanov Alexander	Technische Universität Darmstadt, Germany
Chen Wei-Chia	Florida State University, USA
Colle Camille	Ghent University, Belgium
Contessi Lorenzo	Università degli Studi di Trento, Italy

Dyhdalo Alexander	Ohio State University, USA
Ferrari Ruffino Fabrizio	Università degli Studi di Trento, Italy
Gao Yuan	University of Jyväskylä, Finland
Giuliani Samuel Andrea	Technische Universität Darmstadt, Germany
Jones Adam	Michigan State University, USA
Karakatsanis Konstantinos	Aristotle University of Thessaloniki, Greece
Konieczka Maciej	University of Warsaw, Poland
Lietz Justin	Michigan State University, USA
Mecca Angela	Università degli Studi di Roma, La Sapienza, Italy
Morris Titus	Michigan State University, USA
Negrea Daniel Ciprian	National Institute of Physics, Bucarest, Romania
Orioli Simone	Università degli Studi di Trento, Italy
Parzuchowski Nathan	Michigan State University, USA
Regnier David	Lawrence Livermore National Laboratory, Fremont, USA
Repko Anton	Charles University in Prague, Czech Republic
Roca Fernando	Universidad Autónoma de Madrid, Spain
Rocco Noemi	Università degli Studi di Roma, La Sapienza, Italy
Stevens Sam	Ghent University, Belgium
Vale Deni	University of Zagreb, Croatia
Ward Daniel	Lund University, Sweden
Zhang Chunli	University of Tennessee, USA

3.5.3 Summary and recommendations

Overall, this Talent course was a very positive experience for both teachers and students. The support from the ECT*, and its year-long experiences with running doctoral training programs, was central to the success of the course. Of uttermost importance was Serena degli Avancini's help will all administrative matters, from housing to minor practicalities. Without her help and the other staff of the ECT*, and the director's (Prof. Wolfram Weise) enthusiastic support, it is unlikely that this course could ever have been organized. For the Talent initiative this start-up help from the ECT* has been crucial.

What follows here are various recommendations for new Talent courses based on the views of the organizers, teachers and the feedback from the students. The reports from the students follow thereafter.

- For courses which plan larger computational elements (this applies to several Talent courses), good computing facilities may be needed. However, all students in this course came with their own laptops, and the computational project did not require supercomputers. In this course, the only requirements were therefore (i) enough space with good WiFi access, (ii) access to printing.
- To assist with the course, we set up a Wiki page hosted at Michigan State University. The Wiki contained practical information, slides from the morning classes, exercises, and documentation for the computational project. We also set up a git repository on GitHub. This was part of an effort to have students be aware of, and comply with, modern programming techniques. Part of the first day was devoted to giving them some quick start how to about version control systems (git) and Makefiles. The git repository was also very convenient to (i) share programs between teachers and students, (ii) follow student's progress, (iii) evaluate student's achievements. We recommend the use of such technology (wiki and version control system) for all Talent courses.
- All students were assigned the same core computational project. It consisted in writing, from scratch, a computer program solving the Hartree-Fock equations in the Harmonic oscillator basis for a system of interacting neutrons confined in a harmonic trap. The interaction was chosen as the finite-range Minnesota potential. All calculations were done in spherical symmetry. Choosing a project from scratch by contrast to using/modifying existing codes was deemed more rewarding for the students, and with greater pedagogical potential since it would force them to build a full computational framework. In the same time, simple systems such as neutrons in a

trap and Gaussian interactions are common benchmarks in the community. In addition, we let students the choice of their favorite programming language. One should note that a majority of students is more familiar with object-oriented programming languages like C++ than with Fortran, see the list of students.

- Because of the heterogeneity of the participants, the project was broken into several steps:

    - Computing the Hydrogen atom in the Harmonic oscillator basis. This allows students to set up their integration scheme (Gauss quadrature or direct numerical method).
    - HF solver in a truncated HO basis with only $\ell = 0$ states. This is an intermediate step meant to avoid complex angular momentum algebra, which was deemed too distracting for the purpose of the project.
    - Full HF solver using precomputed matrix elements. These matrix elements were provided through an external computer code.

  Absolute benchmarks were provided by the teaching team at each step.

- This core solver was supposed to be the basis to explore additional features/techniques encountered in DFT such as pairing (HFB), collective vibrations (RPA), deformation (deformed HF) and reduction of finite-range potentials to a functional of the local density (density matrix expansion).
- The core computational project was ambitious, and we underestimated the work needed to put it into a form manageable by the students. In practice, the most advanced students had a truncated HF solver by the beginning of the second week, and the full solver by the beginning of the third week. Because of a bug in our external program generating the matrix elements, no student was able to start going beyond HF as planned. Three PhD students who needed credits for the course did work on a HFB solver, a RPA solver and a full proton+neutron HF solver.
- The students were asked to fill out an online exit survey to gauge their overall satisfaction with the course. In the table below, we summarize their ratings of various aspects of the course (1 = outstanding, 2 = very good, 3 = satisfactory, 4 = less satisfactory, 5 = unsatisfactory). The students were also asked to provide feedback as to what they most liked and disliked about the course, and to give suggestions for improving future iterations of the course. Despite the open-ended and subjective nature of these questions, several trends emerged in the replies:
    1. The computational project was the clear-cut favorite aspect for most of the students, as it allowed them to see how the formal concepts covered during the lectures are implemented in practice. Many students also commented that the project fostered fruitful interactions with their fellow students, and that they very much enjoyed the warm/informal interactions with the lecturers.
    2. A common criticism was that the analytic exercises were too advanced given the strong time demands of the computational project and the (often times too rapid) pace of the morning lectures. This issue was exacerbated in part because we substantially underestimated the time scale for the computational project. As a consequence, time that was originally set aside for hands-on problem sessions was sacrificed to work on the computational project. As a result, the students generally felt lost when it came to the analytic exercises.
    3. In future iterations of the course, it was suggested that the lecturers compile a list of background material that the students should review prior to the start of the course due to the wide variations in the students' backgrounds in many-body theory. Likewise, it was suggested that online tutorials on mundane but important software tools (e.g., Makefiles, GitHub, LAPACK/BLAS libraries, etc.) be made available before the course so that everyone can have a working computational environment on day 1.

	1	2	3	4	5
Overall experience	33.3% 6	61.1% 11	5.6% 1	0.0% 0	0.0% 0
Daily workload	5.6% 1	77.8% 14	16.6% 3	0.0% 0	0.0% 0
Interactions with instructors	44.4% 8	44.4% 8	11.2% 2	0.0% 0	0.0% 0
Content of lectures	27.8% 5	55.6% 10	16.6% 3	0.0% 0	0.0%0
Pedagogical quality of lectures	5.6% 1	50.0% 9	38.9% 7	5.6% 1	0.0% 0
Interest and relevance of exercises	11.1% 2	50.0% 9	33.3% 6	5.6% 1	0.0% 0
Level of exercises	11.1% 2	27.8% 5	44.4% 8	16.6% 3	0.0% 0
Interest and relevance of computational projects	61.1% 11	33.3% 6	5.6% 1	0.0% 0	0.0% 0
Level of computational projects	33.3% 6	55.6% 10	11.1% 2	0.0% 0	0.0% 0
Interactions with fellow students	55.6% 10	38.9% 7	5.6% 1	0.0% 0	0.0% 0
The working environment at the ECT*	77.8% 14	22.2% 4	0.0% 0	0.0% 0	0.0% 0
Living accommodations	41.2% 7	41.2% 7	0.0% 0	11.8% 2	5.9% 1

UNIVERSITÀ DEGLI STUDI DI TRENTO
Dipartimento di Fisica

universität innsbruck

INNSBRUCK – TRENTO
Joint Meeting on

QUANTUM GASES
Trento (29 – 30 September 2014)

Organized by
Francesca Ferlaino (Innsbruck) and Sandro Stringari (Trento)

Tuesday, September 30 th (ECT*, Villa Tambosi, Villazzano)

09.00 – 10.15	**G. Lamporesi/ D. Papoular** Experiments in Trento [defect dynamics, transport phenomena]
10.15 – 10.45	**F. Meinert** Bosons in optical lattice [Bose-Hubbard model; quench dynamics]
	Coffee Break
11.15 – 12.00	**P. Hauke** Many-body localization and ergodicity [spin systems with long-range interactions]
12.00 – 12.45	**I. Carusotto** Quantum fluids of light [from superfluid light towards quantum Hall liquids]
	Lunch (*Villa Tambosi*)

4 Research at ECT*

In this chapter the activities of the scientific researchers at ECT* in 2014, i.e. of the Postdoctoral Fellows, 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 researchers 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 European projects in the field of quantum information 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 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

Daniele Binosi

Effects of divergent ghost loops on the Green's functions of QCD

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

In this work we discuss certain characteristic features encoded in some of the fundamental QCD Green's functions, whose origin can be traced back to the nonperturbative masslessness of the ghost field, in the Landau gauge. Specifically, the ghost loops that contribute to these Green's functions display infrared divergences, akin to those encountered in the perturbative treatment, in contradistinction to the gluonic loops, whose perturbative divergences are tamed by the dynamical generation of an effective gluon mass. In d=4, the aforementioned divergences are logarithmic, thus causing a relatively mild impact, whereas in d=3 they are linear, giving rise to enhanced effects. In the case of the gluon propagator, these effects do not interfere with its finiteness, but make its first derivative diverge at the origin, and introduce a maximum in the region of infrared momenta. The three-gluon vertex is also affected, and the induced divergent behavior is clearly exposed in certain special kinematic configurations, usually considered in lattice simulations; the sign of the corresponding divergence is unambiguously determined. The main underlying concepts are developed in the context of a simple toy model, which demonstrates clearly the interconnected nature of the various effects. The picture that emerges is subsequently corroborated by a detailed nonperturbative analysis, combining lattice results with the dynamical integral equations governing the relevant ingredients, such as the nonperturbative ghost loop and the momentum-dependent gluon mass.

Renormalization group analysis of the gluon mass equation

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

In this work we carry out a systematic study of the renormalization properties of the integral equation that determines the momentum evolution of the effective gluon mass. A detailed, all-order analysis of the complete kernel appearing in this particular equation reveals that the renormalization procedure may be accomplished through the sole use of ingredients known from the standard perturbative treatment of the theory, with no additional assumptions. However, the subtle interplay of terms operating at the level of the exact equation gets distorted by the approximations usually employed when evaluating the aforementioned kernel. This fact is reflected in the form of the obtained solutions, whose deviations from the correct behavior are best quantified by resorting to appropriately defined renormalization-group invariant quantities. This analysis, in turn, provides a solid guiding principle for improving the form of the kernel, and furnishes a well-defined criterion for discriminating between various possibilities. Certain renormalization-group inspired Ans\"atze for the kernel are then proposed, and their numerical implications are explored in detail. One of the solutions obtained fulfills the theoretical expectations to a high degree of accuracy, yielding a gluon mass that is positive-definite throughout the entire range of physical momenta, and displays in the ultraviolet the so-called "power-law" running, in agreement with standard arguments based on the operator product expansion. Some of the technical difficulties thwarting a more rigorous determination of the kernel are discussed, and possible future directions are briefly mentioned.

High-energy QCD evolution from BRST symmetry

In collaboration with A. Quadri (University of Milan, Italy), D. N. Triantafyllopoulos (ECT)*

In this work we show that the (gauge fixed) classical action of the Color Glass Condensate is invariant under a suitable Becchi-Rouet-Stora-Tyutin symmetry that holds after the gluon modes are split into their fast, semi-fast and soft components, according to the longitudinal momenta they carry. This entails the existence of a corresponding Slavnov-Taylor identity which in turn strongly constrains the effective field theory arising when integrating out the semi-fast modes. Specifically, we prove that this identity guarantees the gauge invariance of the resulting effective theory. In addition, we use it to demonstrate that the integration over the semi-fast modes does not deform the classical Yang-Mills equations of motion, thus validating a key assumption in the usual procedure adopted when deriving the renormalization group equation governing the evolution with energy of the effective theory. As far as the latter are concerned, we finally prove that its functional form is common, and it is determined by symmetries arguments alone. The formal properties of these equations valid in different regimes and/or approximations (e.g., the JIMWLK equation and its BFKL limit) can be therefore derived in a unified setting within this algebraic approach.

A new method for determining the quark-gluon vertex

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

In this work we present a novel nonperturbative approach for calculating the form factors of the quark-gluon vertex, in a general covariant gauge. The key ingredient of this method is the exact all-order relation connecting the conventional quark-gluon vertex with the corresponding vertex of the background field method, which is Abelian-like. When this latter relation is combined with the standard gauge technique, supplemented by a crucial set of transverse Ward identities, it allows the approximate determination of the nonperturbative behavior of all twelve form factors comprising the quark-gluon vertex, for arbitrary values of the momenta. The actual implementation of this procedure is carried out in the Landau gauge, in order to make contact with the results of lattice simulations performed in this particular gauge. The most demanding technical aspect involves the calculation of certain (fully-dressed) auxiliary three-point functions, using lattice data as input for the gluon propagators appearing in their diagrammatic expansion. The numerical evaluation of the relevant form factors in three special kinematical configurations (soft gluon and quark symmetric limit, zero quark momentum) is carried out in detail, finding rather good agreement with the available lattice data. Most notably, a concrete mechanism is proposed for explaining the puzzling divergence of one of these form factors observed in lattice simulations.

Nonperturbative study of the four gluon vertex

In collaboration with D. Ibañez (ECT), J. Papavassiliou (University of Valencia, Spain)*

In this paper we study the nonperturbative structure of the SU(3) four-gluon vertex in the Landau gauge, concentrating on contributions quadratic in the metric. We employ an approximation scheme where "one-loop" diagrams are computed using fully dressed gluon and ghost propagators, and tree-level vertices. When a suitable kinematical configuration depending on a single momentum scale p is chosen, only two structures emerge: the tree-level four-gluon vertex, and a tensor orthogonal to it. A detailed numerical analysis reveals that the form factor associated with this latter tensor displays a change of sign (zero-crossing) in the deep infrared, and finally diverges logarithmically. The origin of this characteristic behavior is proven to be entirely due to the masslessness of the ghost propagators forming the corresponding ghost-loop diagram, in close analogy to a similar effect established for the three-gluon vertex. However, in the case at hand, and under the approximations employed, this particular divergence does not affect the form factor proportional to the tree-level tensor, which remains finite in the entire range of momenta, and deviates moderately from its naive tree-level value. It turns out that the kinematic configuration chosen is ideal for carrying out lattice simulations, because it eliminates from the connected Green's function all one-particle reducible contributions, projecting out the genuine one-particle irreducible vertex. Motivated by this possibility, we discuss in detail how a hypothetical lattice measurement of this quantity would compare to the results presented here, and the potential interference from an additional tensorial structure, allowed by Bose symmetry, but not encountered within our scheme.

Renormalization Group Equation for Weakly Power Counting Renormalizable Theories

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

In this paper we study the renormalization group flow in weak power counting (WPC) renormalizable theories. The latter are theories which, after being formulated in terms of certain variables, display only a finite number of independent divergent amplitudes order by order in the loop expansion. Using as a toolbox the well-known SU(2) non linear sigma model, we prove that for such theories a renormalization group equation holds that does not violate the WPC condition: that is, the sliding of the scale μ for physical amplitudes can be reabsorbed by a suitable set of finite counterterms arising at the loop order prescribed by the WPC itself. We explore in some detail the consequences of this result; in particular, we prove that it holds in the framework of a recently introduced beyond the Standard Model scenario in which one considers non-linear Stuckelberg-like symmetry breaking contributions to the fermion and gauge boson mass generation mechanism.

Bridging a gap between continuum-QCD and ab initio predictions of hadron observables

In collaboration with C. D. Roberts (Argonne NL, USA), J. Papavassiliou (University of Valencia, Spain)

Within contemporary hadron physics there are two common methods for determining the momentum-dependence of the interaction between quarks: the top-down approach, which works toward an ab initio computation of the interaction via direct analysis of the gauge-sector gap equations; and the bottom-up scheme, which aims to infer the interaction by fitting data within a well-defined truncation of those equations in the matter sector that are relevant to bound-state properties. In this paper we unite these two approaches by demonstrating that the renormalisation-group-invariant running-interaction predicted by contemporary analyses of QCD's gauge sector coincides with that required in order to describe ground-state hadron observables using a nonperturbative truncation of QCD's Dyson-Schwinger equations in the matter sector. This bridges a gap that had lain between nonperturbative continuum-QCD and the ab initio prediction of bound-state properties.

Proceedings

D. Binosi, A. Quadri and D. N. Triantafyllopoulos, *High-energy QCD evolution from BRST symmetry*, Eur. Phys. J. C 74, 2928 (2014)

D. Binosi and D. Ibañez, *Nonperturbative effects of divergent ghost loops*, Acta Phys. Polon. Supp. 7, no. 3, 591 (2014)

Maddalena Boselli

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

In collaboration with A. Diaz-Torres (ECT)*

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.

At the present, 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. In particular, during this 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 (see Ref. [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. This last part took more time than what initially thought, as the method presented in Ref. [2] had to be adapted to the context of the toy model. 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 Ref. [1].

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Marco Cristoforetti

Quantum field theories on the Lefschetz thimble

M. Cristoforetti (ECT), A. Mukherjee (ECT*), F. Di Renzo (Parma U. & INFN, Parma), L. Scorzato (INFN)*

We proposed an efficient method to compute the so-called residual phase that appears when performing Monte Carlo calculations on a Lefschetz thimble. The method is stochastic and its cost scales linearly with the physical volume, linearly with the number of stochastic estimators and quadratically with the length of the extra dimension along the gradient flow. This is a drastic improvement over previous estimates of the cost of computing the residual phase [1].

We showed how this method can be useful not only in the context of computation high energy quantum field theory but also treating problems in many-body theories to perform fully nonperturbative calculations of quantum corrections about mean-field solutions. In [2] we discuss an explicit algorithm for implementing our method, and present results for the repulsive Hubbard model away from half-filling at intermediate temperatures. Our results are consistent with those from other state-of-the-art calculations.

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Alexis Diaz-Torres

Low-energy reaction dynamics of weakly-bound nuclei

In collaboration with experimenters in Italy (INFN-Legnaro), France (IPHC-Strasbourg), Mexico (ININ), Brazil (Fluminense U), Poland (Warsaw University) and Australia (ANU)

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. 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 [6], 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 a PhD student (Maddalena Boselli) at the ECT*. This PhD project is based on solving the time-dependent Schrödinger equation of a three-body scattering problem. The first results obtained within a toy-model have been published [7].

Quantum decoherence in low-energy nuclear collision dynamics

In collaboration with A.M. Moro (Sevilla University, Spain)

An investigation of quantum decoherence effects on low-energy heavy-ion fusion cross sections was initiated in Ref. [8]. It has been motivated by systematic disagreements between high-precision measurements of sub-Coulomb fusion cross sections and calculations based on the standard coupled-channel model [9]. An innovative approach [10] that is based on the time propagation of a coupled-channel density matrix (CCDM) is being developed, which includes decoherence and dissipation. These are caused by a high-density of single-particle states that affect the dynamics of low-lying collective states of the colliding nuclei. Decoherence is not included in the widely used optical potential model [11]. An analysis of recent elastic-scattering data for ^{11}Be + ^{64}Zn and ^{6}He + ^{208}Pb at near-barrier energies has been performed from an open-quantum-system perspective [12]. It appears that low-energy elastic scattering of halo nuclei could be a useful tool for investigating the dynamics of open quantum systems in nuclear physics.

Quantifying low-energy heavy-ion fusion with the time-dependent wave-packet method

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

A number of critical heavy-ion reactions for stellar burning have been investigated within the time-dependent wave-packet method [13]. 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 [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 will be carried out as well.

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

In collaboration with theorists from JINR-Dubna in Russia

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.

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Daniel Gazda

Ab initio description of light hypernuclei

In collaboration with P. Navrátil (TRIUMF, Canada), J. Mareš (Nuclear Physics Institute, Czech Republic), R. Roth, and R. Wirth (TU Darmstadt, Germany)

Modern developments of hyperon–nucleon interactions based on chiral SU(3) dynamics and advances in computational nuclear many-body methods open a new way for understanding the properties of hypernuclei and hyperons in dense nuclear matter from the underlying theory of strong interactions. Experimental efforts already provide wealth of measurements of hypernuclear spectra and are now intensified in several present and future high-precision experiments at international facilities like J-PARC, JLab, and FAIR.

No-core shell model (NCSM) [1] is one of the most versatile modern ab initio methods successfully applied in nuclear structure calculations. We formulated NCSM methodology to accommodate different species of fermions and to incorporate the coupled-channel nature of hypernuclear systems [2, 3]. Two variants of the NCSM were developed. NCSM formulated in relative Jacobi-coordinate harmonic oscillator basis allows calculations of light hypernuclear systems in very large model spaces and enables direct comparison with existing exact calculations. On the other hand, NCSM formulated in Slater-determinant harmonic oscillator basis becomes more efficient for a larger number of particles. To obtain satisfactory convergence of our calculations similarity renormalization group effective interaction was implemented, optionally accompanied by importance truncation of the model space basis [3]. In our calculations we employed state-of-the-art two-nucleon [4] and three-nucleon [5] interactions derived within chiral perturbation theory together with chiral [6] as well as phenomenological [7] hyperon–nucleon interactions.

In Refs. [2, 3] we demonstrated that NCSM presents a powerful reliable method to study nuclear systems with strangeness and performed for the first time ab initio calculations of heavier p-shell Λ hypernuclei. We showed that chiral hyperon–nucleon interactions, contrary to the phenomenological interactions, predict hypernuclear ground-state and lower excited-state energies that generally agree with experimental values. Calculations of the first negative-parity excited states indicate deficiencies of higher partial waves of the chiral hyperon–nucleon interactions. This illustrates the potential of systematic ab initio studies of heavier hypernuclei to improve our understanding of the hyperon-nucleon interactions.

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Philipp Gubler

Application of the operator product expansion, sum rules and the maximum entropy method to the 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], 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 φ meson spectral function in nuclear matter from an effective 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 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 [3], it is now possible to study the φ meson modification with much less systematic uncertainty. The results of this study will hence allow a more accurate interpretation of the experimental results of KEK and J-PARC.

Higher twist effects in vector meson correlators in QCD

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.

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.

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David Ibáñez Gil de Ramales

Effects of divergent ghost loops on the Green's functions of QCD

In collaboration with A. C. Aguilar (Campinas State University, Brazil), D. Binosi (ECT, Trento) and J. Papavassiliou (Valencia University and IFIC, Spain)*

In Ref. [1] we discuss certain characteristic features encoded in some of the fundamental QCD Green's functions, whose origin can be traced back to the nonperturbative masslessness of the ghost field, in the Landau gauge. Specifically, the ghost loops that contribute to these Green's functions display infrared divergences, akin to those encountered in the perturbative treatment, in contradistinction to the gluonic loops, whose perturbative divergences are tamed by the dynamical generation of an effective gluon mass. In d = 4, the aforementioned divergences are logarithmic, thus causing a relatively mild impact, whereas in d = 3 they are linear, giving rise to enhanced effects. In the case of the gluon propagator, these effects do not interfere with its finiteness, but make its first derivative diverge at the origin, and introduce a maximum in the region of infrared momenta. The three-gluon vertex is also affected, and the induced divergent behavior is clearly exposed in certain special kinematic configurations, usually considered in lattice simulations; the sign of the corresponding divergence is unambiguously determined. The main underlying concepts are developed in the context of a simple toy model, which demonstrates clearly the interconnected nature of the various effects. The picture that emerges is subsequently corroborated by a detailed nonperturbative analysis, combining lattice results with the dynamical integral equations governing the relevant ingredients, such as the nonperturbative ghost loop and the momentum-dependent gluon mass.

Nonperturbative effects of divergent ghost loops

In collaboration with D. Binosi (ECT, Trento)*

In this contribution to the Proceedings of Excited QCD 2014, February 2-8 (2014), Bjelasnica (Sarajevo) [2], we report on a recently unveiled connection at the nonperturbative level between the masslessness of the ghost, the precise form of the gluon propagator in the deep infrared, and the divergences observed in certain kinematic limits of the three-gluon vertex.

New method for determining the quark-gluon vertex

In collaboration with A. C. Aguilar (Campinas State University, Brazil), D. Binosi (ECT, Trento) and J. Papavassiliou (Valencia University and IFIC, Spain)*

In [3] we present a novel nonperturbative approach for calculating the form factors of the quark-gluon vertex, in a general covariant gauge. The key ingredient of this method is the exact all-order relation connecting the conventional quark-gluon vertex with the corresponding vertex of the background field method, which is Abelian-like. When this latter relation is combined with the standard gauge technique, supplemented by a crucial set of transverse Ward identities, it allows the approximate determination of the nonperturbative behavior of all twelve form factors comprising the quark- gluon vertex, for arbitrary values of the momenta. The actual implementation of this procedure is carried out in the Landau gauge, in order to make contact with the results of lattice simulations performed in this particular gauge. The most demanding technical aspect involves the calculation of certain (fully-dressed) auxiliary three-point functions, using lattice data as input for the gluon propagators appearing in their diagrammatic expansion. The numerical evaluation of the relevant form factors in three special kinematical configurations (soft gluon and quark symmetric limit, zero quark momentum) is carried out in detail, finding rather good agreement with the available lattice data. Most notably, a concrete mechanism is proposed for explaining the puzzling divergence of one of these form factors observed in lattice simulations.

Nonperturbative study of the four gluon vertex

In collaboration with D. Binosi (ECT, Trento) and J. Papavassiliou (Valencia University and IFIC, Spain)*

In Ref. [4] we study the nonperturbative structure of the SU(3) four-gluon vertex in the Landau gauge, concentrating on contributions quadratic in the metric. We employ an approximation scheme where “one-loop” diagrams are computed using fully dressed gluon and ghost propagators, and tree-level vertices. When a suitable kinematical configuration depending on a single momentum scale $\mathbf{p}$ is chosen, only two structures emerge: the tree-level four-gluon vertex, and a tensor orthogonal to it. A detailed numerical analysis reveals that the form factor associated with this latter tensor displays a change of sign (zero-crossing) in the deep infrared, and finally diverges logarithmically. The origin of this characteristic behavior is proven to be entirely due to the masslessness of the ghost propagators forming the corresponding ghost-loop diagram, in close analogy to a similar effect established for the three-gluon vertex in Ref. [1]. However, in the case at hand, and under the approximations employed, this particular divergence does not affect the form factor proportional to the tree-level tensor, which remains finite in the entire range of momenta, and deviates moderately from its naive tree-level value. It turns out that the kinematic configuration chosen is ideal for carrying out lattice simulations, because it eliminates from the connected Green’s function all one-particle reducible contributions, projecting out the genuine one-particle irreducible vertex. Motivated by this possibility, we discuss in detail how a hypothetical lattice measurement of this quantity would compare to the results presented here, and the potential interference from an additional tensorial structure, allowed by Bose symmetry, but not encountered within our scheme.

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Daisuke Satow

Dilepton and photon production in semi-QGP

In collaboration with C. Gale, S. Jeon, J. F. Paquet, G. Vujanovic (McGill University, Canada), Y. Hidaka (RIKEN, Japan), S. Lin, R. Pisarski (BNL, USA), V. Skokov (Western Michigan Univ., USA)

Monte Carlo simulation of quantum chromodynamics (QCD) [1] showed that, even above the transition temperature, the value of the Polyakov loop, which is approximate order parameter of confinement, is different from the perturbative value. This result suggests the importance of considering the effect of nontrivial value of the Polyakov loop effect, in analysing the properties of quark-gluon plasma (QGP).
We calculated the photon and the dilepton production rates [2] in QGP, by using a model [3] in which the effect of the nontrivial Polyakov loop is taken into account as a gluon condensate. As a result, we found that the photon production is suppressed compared with the calculation in which the Polyakov loop effect is neglected, while the dilepton production is slightly enhanced. We discussed how these modifications of the production rates change the elliptic flow of photon in heavy ion collision, by using a simulation with hydrodynamics.
Currently, I have been working on inclusion of constituent quark mass in the analysis above with W. Weise in our group.

Nambu-Goldstone fermion in Bose-Fermi cold atom system

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

It was suggested that supersymmetry (SUSY), which is related to interchange between a boson and a fermion, is broken at finite temperature, and as a result of the symmetry breaking, a Nambu-Goldstone fermion (goldstino) related to SUSY breaking appears [4], in the context of high-energy physics. Since dispersion relations of quarks and gluons in QCD are almost degenerate at extremely high temperature, quasi-zero energy quark excitation was suggested [5, 6] to exist in QGP, though QCD does not have exact SUSY. However, experimental observation of quark spectrum in such system is difficult, so this quasi-zero mode of the quark has not been observed yet. On the other hand, in condensed matter system, a setup of cold atom system in which the Hamiltonian has SUSY was proposed [7], the goldstino was suggested to exist, and the dispersion relation of that mode at zero temperature was obtained recently [8].
We obtained the expressions for the dispersion relation of the goldstino in cold atom system at finite temperature, and compared it with the dispersion of the quasi zero-mode in QGP. Furthermore, we showed that the form of the dispersion relation of the goldstino can be understood by using an analogy with a magnon in ferromagnet. We also discussed on how the dispersion relation of the goldstino is reflected in observable quantities in experiment.
We are currently writing an article that includes the result above, and are going to submit it to journal.

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Dionysis Triantafyllopoulos

Running coupling effects in the evolution of jet quenching

In collaboration with E. Iancu (IPhT, Saclay, France)

The jet quenching parameter is a transport coefficient quantifying the modification of a jet when transversing a medium. In [1] we studied the consequences of including the running of the QCD coupling in the equation describing the evolution of the jet quenching parameter in the double logarithmic approximation [2,3,4]. We constructed approximate solutions in the form of truncated series obtained via successive iterations, whose convergence is well under control. We deduced the dominant asymptotic behavior of the jet quenching parameter in the limit of large $Y=\log(L/\lambda)$, with L the size of the medium and λ the typical wavelength of a medium constituent. The asymptotic expansion is universal with respect to the choice of the initial condition at $Y=0$ and, moreover, it is remarkably similar to the corresponding expansion for the saturation momentum of a "shockwave" (a large nucleus). As expected, the running of the coupling significantly slows down the increase with Y in the asymptotic regime of very large Y. For the phenomenologically interesting value $Y=3$, we found an enhancement factor close to 3, independently of the initial condition and for both fixed and running coupling.

The Boltzmann equation in classical Yang-Mills theory

In collaboration with V. Mathieu (Indiana University, USA) and A.H. Mueller (Columbia University, USA)

The Boltzmann equation provides a tool for studying the approach to equilibrium after an ultra-relativistic heavy ion collision when the gluon occupation numbers are already smaller than the inverse QCD coupling [5]. The Boltzmann equation has a certain limit in classical field theory and for a scalar self-interacting field with quartic interactions the respective derivation was given in [6] by using a method (doubling of the fields) based on the real time formulation of a statistical system. In [7] we finished a work, already started last year, where we give a detailed derivation first in a scalar theory with both cubic and quartic interactions and subsequently in a Yang-Mills theory. Our method was based on a diagrammatic approach representing the classical solution to the problem and it provides for a very intuitive derivation of the Boltzmann equation.

Resummation of higher order corrections in the Color Class Condensate

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

The Color Glass Condensate aims to describe the phenomenon of parton saturation in the infinite momentum frame of a nucleus and finds applications in the initial stage of ultra-relativistic heavy-ion collisions and in various semi-hard processes [8]. One of the basic elements 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 [9], however it is expected to have pathologies, like its linearized version, the NLO BFKL equation. Indeed such a behavior was demonstrated in [10] by investigating the effects of a saturation boundary on BFKL evolution at NLO. In [11] we have done significant progress in the problem, mainly by resumming the most dominant corrections to all orders, a procedure which leads to a well-defined evolution equation.

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Wolfram Weise

The topics of my research in 2014 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 and USA. Selected examples are reported in the following.

Structure and dynamics of hadrons with strangeness and hypernuclei

In collaboration with Y. Ikeda, S. Ohnishi, E. Hiyama (RIKEN, Japan), T. Hyodo (Yukawa Institute for Theoretical Physics, Kyoto, Japan) 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 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 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 [1,2,3]. Moreover, selected light hypernuclei have been studied with a density-dependent hyperon-nucleon interaction based on chiral SU(3) effective field theory, including two-pion exchange processes combined with associated three-body mechanisms [4].

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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 for the nuclear many-body problem. The investigations have resulted in a systematic treatment of the thermodynamics of isospin-symmetric and asymmetric 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 [5,6] and review articles [7,8].

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

In collaboration with M. Drews, T. Hell 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: modeling the phase diagram in terms of Nambu & Jona-Lasinio approaches combined with Polyakov loop effective potentials (the PNJL model) [9,10]; investigating transport properties (such as the shear viscosity) in the vicinity of the deconfinement transition [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 renormalization group methods to treat important fluctuations beyond mean-field approximation [13,14].

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4.2 Publications of ECT* Researchers in 2014

Daniele Binosi

A. C. Aguilar, D. Binosi, D. Ibañez, J. Papavassiliou
A new method for determining the quark-gluon vertex
Phys. Rev. D90 (2014) 065027

D. Binosi, D. Ibañez, J. Papavassiliou
Nonperturbative study of the four gluon vertex
JHEP 1409 (2014) 059

D. Bettinelli, D. Binosi, A. Quadri
Renormalization group equation for weakly power counting renormalizable theories
Eur. Phys. J. C74 (2014) 9, 3049

A. C. Aguilar, D. Binosi, D. Ibañez, J. Papavassiliou
Effects of divergent ghost loops on the Green's functions of QCD
Phys.Rev. D89 (2014) 085008

A. C. Aguilar, D. Binosi, J. Papavassiliou
Renormalization group analysis of the gluon mass equation
Phys.Rev. D89 (2014) 085032

D. Binosi
Gauge theories with non-trivial backgrounds
PoS QCD-TNT-III (2014) 006

D. Binosi, A. Quadri, D.N. Triantafyllopoulos
High-energy QCD evolution from BRST symmetry
Eur. Phys. J. C74 (2014) 2928

Daniele Binosi, David Ibañez
Nonperturbative effects of divergent ghost loops
Acta Phys. Polon. Supp. 7 (2014) 3, 591

Marco Cristoforetti

A. Mukherjee, M. Cristoforetti
Lefschetz thimble Monte Carlo for many-body theories: A Hubbard model study
Phys.Rev. B90 (2014) 035134

Alexis Diaz-Torres

Maddalena Boselli, Alexis Diaz-Torres
Unambiguous separation of low-energy fusion processes of weakly bound nuclei
Journal of Physics G: Nucl. Part. Phys. 41 (2014) 094001

V.V. Sargsyan, G.G. Adamian, N.V. Antonenko, A. Diaz-Torres, P.R.S. Gomes, H. Lenske
Extracting integrated and differential cross sections in low-energy heavy-ion reactions from backscattering measurements
European Physical Journal A 50 (2014) 168

A. Diaz-Torres, G.G. Adamian, V.V. Sargsyan, N.V. Antonenko
Energy-shifting formulae yield reliable reaction and capture probabilities
Physics Letters B 739 (2014) 348

V.V. Sargsyan, G.G. Adamian, N.V. Antonenko, A. Diaz-Torres, P.R.S. Gomes, H. Lenske
Deriving capture and reaction cross sections from observed quasi-elastic and elastic backscattering
Physical Review C 90 (2014) 064601

A. Diaz-Torres, M. Wiescher
Quantum partner-dance in the 12C + 12C system yields sub-Coulomb fusion resonances
Journal of Physics: Conference Series 492 (2014) 012006

A. Diaz-Torres, A.M. Moro
Insights into low-energy elastic scattering of halo nuclei
Physics Letters B 733 (2014) 89

Matthias Drews

Matthias Drews, Thomas Hell, Bertram Klein, Wolfram Weise
Dense nucleonic matter and the renormalization group
EPJ Web of Conf. 66 (2014) 04008

Matthias Drews, Wolfram Weise
Functional renormalization group approach to neutron matter
Phys. Lett. B738 (2014) 187

Victor Efros

V. D. Efros, P. von Neumann-Cosel, and A. Richter
Properties of the first excited state of ^{9}Be derived from (γ,n) and (e,e') reactions
arXiv: 1308.1563; Phys. Rev C 89 (2014) 027301

Daniel Gazda

Roland Wirth, Daniel Gazda, Petr Navrátil, Angelo Calci, Joachim Langhammer, and Robert Roth
Ab initio description of p-shell hypernuclei
Physical Review Letters 113 (2014) 192502

Daniel Gazda, Jiří Mareš, Petr Navrátil, Robert Roth, Roland Wirth
No-core shell model for nuclear systems with strangeness
Few-Body Systems 55 (2014) 857

Thomas Hell

T. Hell, B. Röttgers, W. Weise
How neutron stars constrain the nuclear equation of state
EPJ Web of Conf. 66 (2014) 04011

Matthias Drews, Thomas Hell, Bertram Klein, Wolfram Weise
Dense nucleonic matter and the renormalization group
EPJ Web of Conf. 66 (2014) 04008

Thomas Hell, Wolfram Weise
Dense baryonic matter: constraints from recent neutron star observations
Phys.Rev.C90 (2014) 045801

David Ibanez Gil de Ramales

A. C. Aguilar, D. Binosi, D. Ibañez, J. Papavassiliou
A new method for determining the quark-gluon vertex
Phys. Rev. D90 (2014) 065027

D. Binosi, D. Ibañez, J. Papavassiliou
Nonperturbative study of the four gluon vertex
JHEP 1409 (2014) 059

A. C. Aguilar, D. Binosi, D. Ibañez, J. Papavassiliou
Effects of divergent ghost loops on the Green's functions of QCD
Phys.Rev. D89 (2014) 085008

Daniele Binosi, David Ibañez
Nonperturbative effects of divergent ghost loops
Acta Phys. Polon. Supp. 7 (2014) 3, 591

Achim Richter

V.D. Efros, P. von Neumann-Cosel, A. Richter
Properties of the first excited state of 9Be derived from (gamma,n) and (e, e') reactions
Phys. Rev. C 89 (2014) 027301

Dionysios Triantafyllopoulos

E. Iancu, D.N. Triantafyllopoulos
JIMWLK evolution: from color charges to rapidity correlations
Nucl. Phys. A932 (2014) 63

E. Iancu, D.N. Triantafyllopoulos
Running coupling effects in the evolution of jet quenching
Phys.Rev. D90 (2014) 074002

E. Iancu, D.N. Triantafyllopoulos
JIMWLK evolution for multi-particle production with rapidity correlations
Nucl. Phys. A926 (2014) 166

D. Binosi, A. Quadri, D.N. Triantafyllopoulos
High-energy QCD evolution from BRST symmetry
Eur. Phys. J. C74 (2014) 2928

V. Mathieu, A.H. Mueller, D.N. Triantafyllopoulos
The Boltzmann equation in classical Yang-Mills theory
Eur. Phys. J. C74 (2014) 2873

Wolfram Weise

T. Hell, B. Röttgers, W. Weise
How neutron stars constrain the nuclear equation of state
EPJ Web of Conf. 66 (2014) 04011

Emiko Hiyama, Yasuro Funaki, Norbert Kaiser, Wolfram Weise
Alpha-clustered hypernuclei and chiral SU(3) dynamics
Prog. Theor. Exp. Phys. (2014) 013D01

Matthias Drews, Thomas Hell, Bertram Klein, Wolfram Weise
Dense nucleonic matter and the renormalization group
EPJ Web of Conf. 66 (2014) 04008

S. Ohnishi, Y. Ikeda, T. Hyodo, E. Hiyama, W. Weise
K^- d $\rightarrow \pi\ \Sigma$ n reactions and structure of the Λ (1405)
J. Phys. Conf. Ser. 569 (2014) 012077

M. Altenbuchinger, L.-S. Geng, W. Weise
Scattering lengths of Goldstone bosons off D mesons and dynamically generated heavy-light mesons
Phys. Rev. D 89 (2014) 014026

Robert Lang, Wolfram Weise
Shear viscosity from Kubo formalism: NJL model study
Eur. Phys. J. A 50 (2014) 63

Thomas Hell, Wolfram Weise
Dense baryonic matter: constraints from recent neutron star observations
Phys.Rev.C90 (2014) 045801

Matthias Drews, Wolfram Weise
Functional renormalization group approach to neutron matter
Phys. Lett. B738 (2014) 187

C. Wellenhofer, J.W. Holt, N. Kaiser, W. Weise
Nuclear thermodynamics from chiral low-momentum interactions
Phys. Rev. C89 (2014) 064009

4.3 Talks presented by ECT* Researchers

Daniele Binosi

Nonperturbative effects of divergent ghost loops
Invited talk at the workshop "Excited QCD 2014", Bjelasnica (February 2-6 2014, Bosnia); "Non-perturbative QCD 2014", Punta Umbrìa (September 30, October 4, Spain); "DISCRETE 2014", London (December 2-6, UK)

Marco Cristoforetti

Quantum field theory on the Lefschetz thimble
Invited talk to the workshop “Lattice QCD at finite temperature and density”, (KEK Tsukuba, Japan)
21 Jan 2014

Quantum field theory on the Lefschetz thimble
Group seminar at Quantum Hadron Physics Laboratory (RIKEN Tokyo, Japan)
23 Jan 2014

Alexis Diaz-Torres

Probing the dynamics of open quantum systems with elastic scattering of halo nuclei
Invited Talk at the ECT* Workshop on Quantum Mechanics Tests in Particle, Atomic, Nuclear and Complex Systems, Trento, Italy
27 Feb 2014

The astrophysical S-factor of critical heavy-ion collisions within a nuclear molecular picture
Invited Talk at the II Workshop on Nuclear Astrophysics, IEA-USP, Sao Paolo, Brazil
16 Apr 2014

Role of the Coulomb-nuclear interference in the elastic scattering of halo nuclei
Talk at the ECT* Workshop on Low-Energy Reaction Dynamics of Heavy-Ions and Exotic Nuclei, Trento, Italy
26 May 2014

Probing the dynamics of open quantum systems with low-energy elastic scattering of halo nuclei
Invited Talk at the ECT* Workshop on Resonances and Non-Hermitian Quantum Mechanics in Nuclear and Atomic Physics, Trento, Italy
25 Jun 2014

Insights into elastic scattering of halo nuclei from an open-quantum-system perspective
Talk at the International Conference on Direct Reactions with Exotic Beams (DREB2014), Darmstadt, Germany
01 Jul 2014

Quantifying low-energy reaction dynamics of complex nuclei
Invited Talk at the International Workshop on Physics of Strong Interacting Systems, Dubna, Russia
15 Jul 2014

Relating molecular structure and low-energy fusion through time-dependent wave-packet dynamics
Invited Talk at the 15th International Symposium on Capture Gamma-Ray Spectroscopy and Related Topics, Dresden, Germany
28 Aug 2014

Time-dependent few-body approaches to low-energy reaction dynamics of rare isotopes
Invited Talk at the ECT* Workshop "From Nuclear Structure to Particle-Transfer Reactions and Back II", Trento, Italy
12 Nov 2014

Low-energy reaction dynamics of heavy-ions and exotic nuclei: Solving important issues from a time-dependent perspective
Invited Seminar at MSU, USA
02 Dec 2014

Daniel Gazda

No-core shell model for nuclear systems with strangeness
Talk at the International School for Strangeness Nuclear Physics, Tokai and Sendai, Japan
15 Feb 2014

No-core shell model for hypernuclei
Talk at the SPHERE Network meeting, Prague, Czech Republic.
09 Sep 2014

No-core shell model for hypernuclei
Talk at the ECT* workshop "Achievements and Perspectives in Low-Energy QCD with Strangeness", Trento, Italy.
25 Oct 2014

Dionysios Triantafyllopoulos

Running coupling corrections to pT-broadening of a parton in a medium
Seminar at IPht, Saclay, France
08 Jul 2014

Running coupling corrections to the evolution of jet quenching
Talk at the conference "Strong and Electroweak Matter", Lausanne, Switzerland
17 Jul 2014

The Boltzmann equation in classical field theory
Seminar at IPht, Saclay, France
01 Dec 2014

Wolfram Weise

From nuclear matter to neutron stars
Seminar at RIKEN-Nishina Center, Japan
12 May 2014

Topics in low-energy QCD with strange quarks
Invited talk at the International Conference MESON2014, Krakow, Poland
31 May 2014

Topics in low-energy QCD with strange quarks
LNF seminar, Frascati, Italy
20 Jun 2014

Phases of strongly interacting matter
Colloquium talk at ITP, Chinese Academy of Sciences, Beijing, China
31 Jul 2014

Topics in low-energy QCD with strange quarks
Invited talk at the International Conference EXA 2014, Vienna, Austria
15 Sep 2014

Nuclear chiral thermodynamics and the functional renormalization group
Invited plenary talk at the International Conference ERG 2014, Lefkada, Greece
22 Sep 2014

Phases of strongly interacting matter
Special colloquium at University of Graz, Austria
13 Oct 2014

Phases of strongly interacting matter
Physics colloquium, University of Torino, Italy
24 Oct 2014

Pending issues in low-energy strong interactions with strangeness
Invited talk, ECT* Workshop "Achievements and Perspectives in Low-Energy QCD with Strangeness"
27 Oct 2014

Low-energy QCD with strange quarks - from antikaon-nuclear interactions to hyperons in neutron stars
Invited talk, Symposium "What next LNF: Prospectives of Fundamental Physics at the Frascati Laboratory, Frascati, Italy"
10 Nov 2014

From quarks to nuclei and neutron stars
Physics Colloquium, University of Wuppertal, Germany
17 Nov 2014

4.4 Courses taught by ECT* Researchers

Dionysis Triantafyllopoulos

Quantum Chromodynamics

In the spring of 2014 I taught, for a fourth consecutive year, a 21-hour course on Quantum Chromodynamics (QCD) at the PhD School of the University of Trento. The goal was to introduce and/or review QCD, study in detail some of its characteristic features and present the concept of parton evolution. It was a small class composed of four PhD students and the prerequisites to attend the course were knowledge of Quantum Field Theory and of basics of Group Theory. All lectures were done on the blackboard.

I started by presenting the reasons that lead to QCD, I introduced its Lagrangian and then discussed its symmetries. I reviewed the path integral formulation of Quantum Mechanics and Quantum Field Theory including the case of fermions and the necessary introduction of Grassmann variables. Then I discussed the gauge fixing, the emergence of the Faddeev-Popov ghosts, and elaborated on covariant and light-cone gauges. I stressed the importance of the equality of all coupling constants appearing in the QCD Lagrangian. Focusing on the quark-antiquark-gluon vertex I emphasized the need for renormalization and presented most parts of the calculation which lead to the QCD β-function. Then I went to describe electron-positron to hadrons at NLO and how this process is infrared safe. Using this particular process and the β-function presented earlier I introduced the running of the coupling. Finally I moved to DIS and discussed the the relevant time scales in the process and the necessity to work in the infinite momentum frame in order to reveal the partonic content of the hadron. Then I went on to calculate gluon emission from fast color sources both in the light-cone and covariant gauges. I applied the result to a source consisting of color dipoles and derived the BFKL equation in the multicolor limit.

All students attended all the lectures. As part of the exam, and after the end of the course, one of them presented a lecture with the title “Lattice QCD”.

Color Glass Condensate

In May 2014 I participated in the ECT* Doctoral Training Program “Heavy Ion Collisions: exploring nuclear matter under extreme conditions” by lecturing on the “Color Glass Condensate”. I gave 5 hours of lectures using the blackboard and in addition to that I did a 2-hour problem session. More details on the content of this mini-course can be found in the corresponding chapter of this Annual Report.

4.5 Seminars and colloquia at ECT*

Amplitude analysis for hadron spectroscopy experiments
ECT Seminar*
09 Jan 2014
Vincent Mathieu (University of Indiana, USA)

Reaction dynamics of weakly bound nuclei at near barrier energies: quantum mechanical toy model
ECT Seminar*
15 Jan 2014
Maddalena Boselli (ECT*)

Neutron stars, the Hubbard model and Monte Carlo
ECT Seminar*
22 Jan 2014
Abhishek Mukherjee (ECT*)

Neutron stars, the Hubbard model and Monte Carlo (2nd part)
ECT Seminar*
29 Jan 2014
Abhishek Mukherjee (ECT*)

Computer simulations using path integrals: a lookback perspective
ECT - LISC Seminar*
05 Feb 2014
Giovanni Garberoglio (LISC-FBK, Trento)

Dominant reaction pathways for protein folding and conformational transitions
ECT - LISC Seminar*
12 Feb 2014
Silvio a Beccara (LISC - FBK, Trento)

Functional renormalization group applied to asymmetric nuclear matter
ECT-TUM Seminar*
19 Feb 2014
Matthias Drews (ECT* Trento-TU Munich)

Shear viscosity from the Nambu-Jona-Lasinio model at next-to-leading order in a large N_c expansion
ECT-TUM Seminar*
19 Feb 2014
Robert Lang (ECT* Trento -TU Munich)

Nuclear thermodynamics with chiral low-momentum interactions
ECT-TUM Seminar*
19 Feb 2014
Corbinian Wellenhofer (ECT* Trento -TU Munich)

Skyrme interaction including tensor terms to second order in nuclear matter
ECT-TUM Seminar*
19 Feb 2014
Norbert Kaiser (ECT* Trento -TU Munich)

The growth of carbon-based materials by supersonic beam epitaxy: experiments, theory and calculations
ECT - LISC Seminar*
05 Mar 2014
Simone Taioli (LISC-FBK, Trento)

Investigation of the incomplete fusion reaction mechanism in the 20Ne+122Sn reaction
ECT Seminar*
19 Mar 2014
Jan Mierzejewski (Heavy Ion Laboratory, University of Warsaw, Poland)

Nonperturbative analysis of seagull divergences in QCD
ECT Seminar*
02 Apr 2014
David Ibanez (ECT*)

Supernova neutrinos: challenges and its physics potential
ECT Colloquium*
08 Apr 2014
Sanjay Reddy (INT Seattle, USA)

From jet quenching to wave turbulence
ECT Seminar*
09 Apr 2014
Edmond Iancu (CEA Saclay, France)

Composite weak bosons and the new boson at the LHC
ECT Colloquium*
16 Apr 2014
Harald Fritzsch (LMU Munich)

Ab initio calculations of light hypernuclei
ECT Seminar*
23 Apr 2014
Daniel Gazda (ECT*)

The era of precision nuclear structure and reactions
ECT Colloquium*
07 May 2014
Dick Furnstahl (The Ohio State University)

Flavour physics from lattice QCD
ECT Seminar*
20 May 2014
Nuria Carrasco Vela (INFN Sezione Roma Tre, Italy)

Research on superheavy nuclei
ECT Colloquium*
28 May 2014
Sigurd Hofmann (GSI, Darmstadt)

Quantum diffusion approach to low-energy heavy-ion fusion
ECT Seminar*
11 Jun 2014
Vazgen Sargsyan (JINR-Dubna, Russia)

Transport in the earth's core
ECT Colloquium*
19 Jun 2014
Dario Alfe' (UCL London)

The Boltzmann equation in classical Yang-Mills theory
ECT Seminar*
25 Jun 2014
Dionysis Triantafyllopoulos (ECT*)

Exciting baryons: where do we stand?
ECT Colloquium*
01 Jul 2014
Annalisa D'Angelo (University of Rome Tor Vergata)

Progress and challenges in the chiral effective field theory description of neutron-rich matter
ECT Seminar*
11 Jul 2014
Jeremy Holt (University of Washington, Seattle, USA)

Present and future of beyond-mean-field methods for nuclear structure
ECT Colloquium*
17 Jul 2014
Paul-Henri Heenen (Université Libre de Bruxelles)

Introduction to quark and gluon angular momentum
ECT Colloquium*
25 Aug 2014
Cédric Lorcé (IPN Orsay)

Bottomonium in the plasma: lattice results
ECT Seminar*
04 Sep 2014
Maria Paola Lombardo (INFN-LNF)

Strangeness in nuclei and neutron stars: a challenging puzzle
ECT Seminar*
04 Sep 2014
Diego Lonardoni (Argonne National Laboratory)

Lessons from cosmic gamma-ray observations
ECT Colloquium*
09 Sep 2014
Roland Diehl (MPI for Extraterrestrial Physics, Munich)

Understanding the reaction dynamics in low-energy collisions of halo nuclei
ECT Seminar*
11 Sep 2014
Maddalena Boselli (ECT*)

Calories for quarks: the origin of mass
ECT Colloquium*
23 Sep 2014
Craig Roberts (Argonne National Lab.)

Energy-shifting formulae yield reliable reaction and capture probabilities
ECT Seminar*
01 Oct 2014
Alexis Diaz-Torres (ECT*)

Seagull cancellations and gluon mass generation
ECT Seminar*
15 Oct 2014
David Ibanez (ECT*)

Nuclear chiral thermodynamics and the functional renormalization group
ECT Seminar*
22 Oct 2014
Wolfram Weise (ECT*)

Highlights and open problems in low-energy strong interaction with strangeness
ECT Colloquium*
28 Oct 2014
Johann Marton (Stefan Meyer Institute, Vienna, Austria)

Functional renormalization group approach to thermodynamics of nuclear matter
ECT - TUM Seminar*
06 Nov 2014
Matthias Drews

Transport properties of hot and dense matter from a large-N_c Nambu-Jona-Lasinio model
ECT - TUM Seminar*
06 Nov 2014
Robert Lang (ECT*-Munich)

Dynamical locking mechanism for phase transitions in QCD at finite chemical potentials
ECT - TUM Seminar*
06 Nov 2014
Paul Springer (TU Munich)

G-matrix calculation of hyperon mean-field potentials in nuclear matter
ECT - TUM Seminar*
06 Nov 2014
Stefan Petschauer (TU Munich)

Thermodynamics of symmetry energy and equation of state of asymmetric nuclear matter
ECT - TUM Seminar*
06 Nov 2014
Corbinian Wellenhofer (TU Munich)

Chiral nucleon-nucleon potential: Three-pion exchange with virtual Delta-isobar excitation
ECT - TUM Seminar*
06 Nov 2014
Norbert Kaiser (TU Munich)

Effect of confinement on thermal production and elliptic flow of dileptons and photons
ECT Seminar*
12 Nov 2014
Daisuke Satow (ECT*)

How does the measurement of the phi-meson mass shift in nuclear matter constrain the strangeness content of the nucleon?
ECT Seminar*
19 Nov 2014
Philipp Gubler (ECT*)

Tetraquarks: why they are so difficult to model
ECT Seminar*
27 Nov 2014
Pedro Bicudo (CFTP Lisboa)

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 2013 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.

6 ECT* Computing Facilities

CONNECTIVITY

- The core of the computational infrastructure at ECT* has recently been improved.
- The main network infrastructure is connected by 3 switches PoE - Power over Ethernet- (DELL Power Connect 5548P).
- 7 switches Dell Power Connect 5548 will be installed in order to improve the connectivity in the Villa Tambosi.
- The Rustico and the Villa 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 100 Mbps (by GARR) plus 100Mbps (by Trentino Network).

HARDWARE
Servers:
Virtual servers are running based on the hardware in the FBK datacenter.

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

38 PCs for workshops and schools:
Workstation DELL Precision T1500
Workstation DELL Optiplex 755

IMPORTANT SOFTWARE: Mathematica ver. 10: 1 network license server + 7 concurrent processes.

MANAGEMENT
The PC's and laptops of the staff and of the local researchers are managed by the FBK IT group.

The PC's for the schools and the workshops are managed directly by ECT*. The services on this network are distributed over the following virtual servers:

1. The Windows Server 2012 provided the following services: Active Directory Server, Network Information Server (logins, groups, hosts database…), Domain Name Server, Windows Print Server, Update Services (for Windows clients).
2. Linux server Red Hat 6.5 provides the following services: Domain Name Server forwarder, e-mail server, Common Unix Print Server.

3. Gate server Red Hat 6.3 for access from outside.