ECT*

Annual Report 2018

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

Institutional Member of the European Science Foundation Expert Committee NuPECC

Edited by
Barbara Currò Dossi and Susan Driessen

1 Preface

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

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

Altogether 745 scientists from 39 countries have visited the ECT* in 2018 and have participated in the activities of the Centre. As in previous years this reconfirms ECT*'s worldwide visibility and its key importance for the European and international nuclear physics communities.

In 2018 ECT* held:

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

- a Doctoral Training Programme on "QCD Under Extreme Conditions" that lasted four weeks and was attended by 39 students from 15 countries worldwide.

In addition to these 23 scientific events, ECT* supported:

- basic research on nuclear structure and reactions, non-perturbative QCD and hadron physics, the theory of hadronic and nuclear collisions at high energy, phases of strong-interaction matter, nuclear astrophysics and neutron stars, many-body theory and computational physics. This research was performed by the in-house group of Junior Postdoctoral Fellows and Senior Research Associates in close interaction with each other, with the Director of the Centre, and with scientific visitors and collaborating physicists elsewhere. The research activities of the Centre are documented in detail in Chapters 4 and 5 of this Annual Report. Altogether, 36 publications by the ECT* and ECT*-LISC researchers in refereed journals represent a sizable fraction of all publications produced in 2018 within the Fondazione Bruno Kessler in the same year.
- In addition to the previously established international cooperation agreements with major research institutions in Japan (RIKEN Nishina Centre, the Advanced Science Research Center ASRC of JAEA and NAOJ, the National Astronomical Observatory), Korea (the Asian Pacific Centre for Theoretical Physics, APCTP), China (the ITP of the Chinese Academy of Sciences), and Russia (JINR in Dubna, the Joint Institute for Nuclear Research), ECT* signed in 2018 an MoU with the Swiss National Science Foundation (SNSF) for a financial contribution towards ECT*.

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

The existence and the continuing success of ECT* rests upon the “bottom-up” initiatives, pursued by the physics communities in Europe and worldwide. Maintaining ECT*´s high level of scientific activity and visibility in 2018 has only been possible through a stable operating budget in recent years. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research institutions in Belgium, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Russia, Switzerland and the United Kingdom. ECT* also acknowledges additional partial support for its workshops, received in 2018 from: EMMI (Germany), Universität Regensburg (Germany), Justus-Liebig-Universität Gießen (Germany), Goethe Universität Frankfurt (Germany), FIAS (Germany), University of Stavanger (Norway), Jefferson Lab. (USA), Universität Bern (Switzerland), CERN (Switzerland), University of Guelph (Canada), Argonne National Laboratory (USA), Universität Heidelberg (Germany), Kirchhoff-Institut für Physik (Germany), HGSFP-Heidelberg Graduate School of Fundamental Physics (Germany), University of Toronto (Canada), CNRS-IPNO (France) and Helmholtz-Institut Mainz (Germany). To ensure access to High-Performance-Computing (HPC) resources for the ECT* researchers the Forschungszentrum Jülich (Germany) has granted funds for a sizable amount of time on the JUQUEEN supercomputer. The allocated computer time of 10 million core hours, available until the end of March 2018, was fully used, demonstrating ECT*’s need for adequate HPC resources.

As for the European projects within the new Framework Programme Horizon 2020, the ENSAR2 project has started on March 1, 2016 and will run for another year. Its transnational access activities have partially supported 7 workshops in 2018 that were selected by the Director in accordance with the International Scientific Committee. ECT* is also involved as a transnational access facility in the STRONG-2020 initiative in Hadron Physics, which has been approved in the meantime, and funding will start in the spring of 2019.

In several respects the year 2018 was special for ECT*. The 25th Anniversary of its foundation was celebrated in a memorable event on August 31 at Villa Tambosi and a public lecture on September 01 at the Museo delle Scienze (MUSE) in Trento. As stipulated in its Statutes, ECT* also underwent a five-year review on April 26-27, 2018 at Villa Tambosi. The International Review Committee, chaired by Larry McLerran (University of Washington), assessed the ECT* activities, performance, structure, funding and future perspectives. The very favourable report of the Committee was communicated to the various funding agencies of the European countries, participating in the financial support of ECT*, as well as to the International Scientific Board and the Bruno Kessler Foundation. In particular, the report served as a basis for the renewal of the Memorandum of Understanding with the funding agencies for continued financial contributions to ECT*.

Finally, it is a great pleasure to thank the members of the Scientific Board, the organizers of the Doctoral Training Programme Gert Aarts and Dirk Rischke and the coordinator 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 2018 is available on the ECT* website (www.ectstar.eu).

Trento, March 28, 2019 *Jochen Wambach*
*Director of ECT**

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2 ECT* Scientific Board, Staff and Researchers

2.1 ECT* Scientific Board and Director

Gert Aarts	Swansea University, UK
Omar Benhar	INFN/Università "La Sapienza", Rome, Italy
Marcella Grasso (from June)	CNRS-INP Orsay, France
Nicole d'Hose	CEA Saclay, France
Morten Hjorth-Jensen	Michigan State Univ., USA and Univ. of Oslo, Norway
Marek Lewitowicz (from June)	NuPECC/GANIL, France
Sanjay Reddy (until June)	Univ. Washington, Seattle, USA
Dirk Rischke	Johann Wolfgang Goethe-Universität, Frankfurt, Germany
Martin Savage (from June)	INT & Univ. Washington, Seattle, USA
Marc Vanderhaeghen	University of Mainz, Germany
Ubirajara van Kolck (until June)	IPN Orsay, France

Honorary Member of the Board

Ben Mottelson	NORDITA, Copenhagen, Denmark

ECT* Director

Jochen Wambach	ECT*, Italy and TU Darmstadt, Germany

2.2 ECT* Staff

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

2.3 Resident Researchers

- **ECT* Postdocs**

Daniele Binosi, Italy
Arianna Carbone, Italy
Jesus Casal Berbel, Spain (until September)
Minghui Ding, China (from September)
Jarkko Peuron, Finland (from October)
Alessandro Pilloni, Italy (from November)
Naoto Tanji, Japan
Dionysis Triantafyllopoulos, Greece
Ralf-Arno Tripolt, Austria (until September)

- **ECT*/LISC Postdocs**

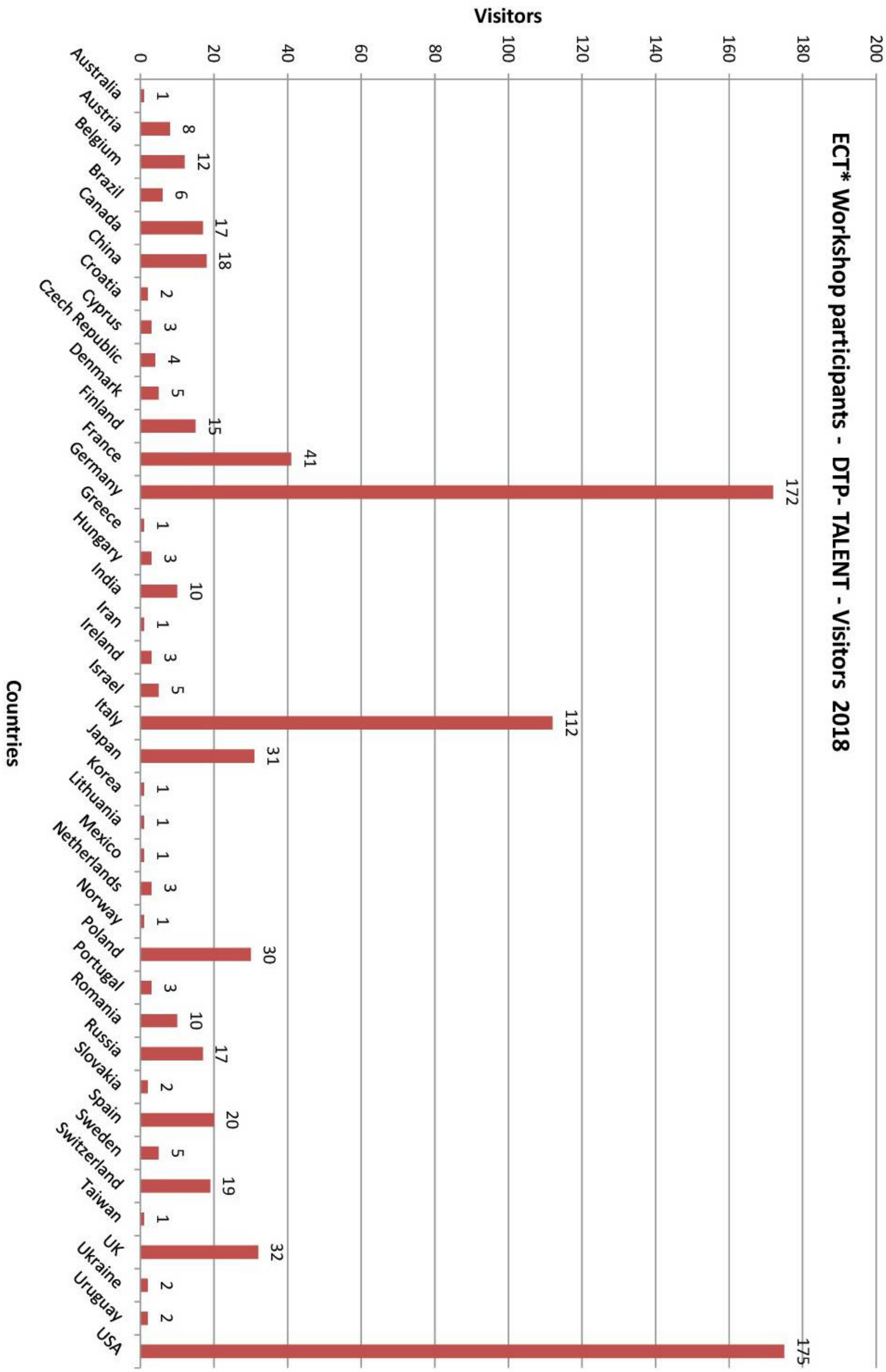
Martina Azzolini, Italy (PhD Student)
Maurizio Dapor, Italy (Head of ECT*-LISC Research Unit),
Giovanni Garberoglio, Italy
Andrea Pedrielli, Italy (PhD Student)
Tommaso Morresi, Italy (PhD Student)
Simone Taioli, Italy

2.4 Visitors in 2018

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 visitors in occasion of the Review Committee meeting (RC) and in occcasion of the 25th Anniversary of ECT* (25A).

Gert Aarts (25-28/04, 03-09/06, 31/08)	Swansea University, UK (RC, DTP, 25A)
Moussa Agah Nouhou (28/05-22/06)	Subatech, France (DTP)
Denys Yen Arrebato Villar (28/05-22/06)	Subatech, France (DTP)
Juha Äystö (25-30/04)	University of Jyväskylä, Finland (RC)
Dibyendu Bala (28/05-22/06)	Tata Institute of Fundamental Research, India (DTP)
Gabor Balassa (28/05-22/06)	Wigner Research Centre for Physics, Hungary (DTP)
Stefano Bellucci (10-24/08)	INFN-LNF, Italy (VS)
Omar Benhar (31/08)	Sapienza University of Rome and INFN, Italy (25A)
Michael Birse (31/08)	University of Manchester, UK (25A)
Diego Bisero (18-20/06)	INFN Ferrara, Italy (VS)
Deeptak Biswas (28/05-22/06)	Bose Institute, India (DTP)
Jean-Paul Blaizot (17/06-02/07, 31/08-07/09)	CEA Saclay, France (VS, 25A)
Marc Borrell Martínez (28/05-22/06)	Universität Bielefeld, Germany (DTP)
Angela Bracco (26-27/04, 31/08)	University/INFN Milano, Italy (RC, 25A)
Peter Braun-Munzinger (31/08)	University of Heidelberg, EMMI/GSI, Germany (25A)
David Brink (31/08)	Oxford University, UK (25A)
Tommaso Calarco (31/08)	University of Ulm, Germany (25A)
Gianluigi Casse (26-27/04)	FBK, Italy (RC)
Alexis Diaz-Torres (16/08-01/09, 31/08)	University of Surrey, UK (VS, 25A)
Jacek Dobaczewski (25-28/04)	University of York, UK (RC)
Liepi Du (28/05-22/06)	Ohio State University, USA (DTP)
Marco Durante (26/04)	TIFPA Trento, Italy (RC)
Alexander Maximilian Eller (28/05-22/06)	TU Darmstadt, Germany (DTP)
Carlo Ewerz (31/08)	EMMI/GSI, Germany (25A)
Sara Ferrari (31/08)	PAT Trento, Italy (25A)
Fernando Ferroni (31/08)	Sapienza University of Rome, INFN, Italy (25A)
Georgios Filios (28/05-22/06)	University of Stavanger, Norway (DTP)
David Fuseau (28/05-22/06)	Subatech, France (DTP)
Giuseppe Gagliardi (28/05-22/06)	Universität Bielefeld, Germany (DTP)
Paolo Giubellino (31/08)	FAIR/GSI, Germany (25A)
Judith McGovern (31/08)	University of Manchester, UK (25A)
Carlo Guaraldo (26-27/04, 31/08)	INFN-LNF, Italy (RC, 25A)
Fernando Guarino (31/08)	PAT Trento, Italy (25A)
Philipp Gubler (31/08)	RIKEN, Japan (25A)
Pascal Gunkel (28/05-22/06)	Justus-Liebig-Universität Gießen, Germany (DTP)
Simon Hands (31/08)	Swansea University, UK (25A)
Ulrich Heinz (17-23/06)	Ohio State University, USA (DTP)
Paul Hoyer (31/08-08/09)	University Helsinki, Finland (VS, 25A)
Andreas Ipp (31/08)	TU Wien, Austria (25A)
Shiori Kajimoto (28/05-22/06)	Osaka University, Japan (DTP)
Bithika Karmakar (28/05-22/06)	Saha Institute of Nuclear Physics, India (DTP)
Frithjof Karsch (25-27/04)	University of Bielefeld, Germany (RC)
Farideh Kazemian Torbaghan (28/05-22/06)	Shahrood Univ. of Technology, Iran (DTP)
Alan-Francis Kirby (28/05-22/06)	Swansea University, UK (DTP)
Adrian Koenigstein (28/05-22/06)	Johann Wolfgang Goethe-Universität, Germany (DTP)
Eugeny Kolomeitsev (31/08)	Matej Bel University, Slovakia (25A)
Sissy Körner (31/08)	NuPECC, Germany (25A)
Mikko Kuha (28/05-22/06)	University of Jyväskylä, Finland (DTP)
Philip Lakaschus (11-15/02)	Johann Wolfgang Goethe-Universität, Germany (DTP)
Tuomas Lappi (16-24/06)	University of Jyväskylä, Finland (DTP)
Jim Lattimer (31/08)	Stony Brook University, USA (25A)

Renzo Leonardi (31/08)	University of Trento, ECT*, Italy (25A)
Larry McLerran (22-29/04)	University of Seattle, USA (RC)
Marek Lewitowicz (31/08)	NuPECC, GANIL, France (25A)
Jan Maelger (28/05-08/06)	École Polytechnique, Université Paris Diderot, France (DTP)
Diego Marinho Rodrigues (28/05-22/06)	Federal University of Rio de Janeiro, Brazil (DTP)
Marek Matas (28/05-22/06)	Czech Technical University, Czech Republic (DTP)
Mario Motta (28/05-22/06)	Università di Torino, Italy (DTP)
Abishek Mukherjee (31/08)	REXai Amsterdam, Netherlands (25A)
Piet Mulders (31/08)	Nikhef, VU Amsterdam, Netherlands (25A)
Valeriya Mykhaylova (28/05-22/06)	University of Wroclaw, Poland (DTP)
Michael McNelis (28/05-22/06)	Ohio State University, USA (DTP)
Samuel Offler (28/05-22/06)	University of Swansea, UK (DTP)
Jean-Yves Ollitrault (25-28/04)	CNRS, France (RC)
Giuseppina Orlandini (26/04)	University of Trento, Italy (RC)
Juuso Österman (28/05-08/06)	University of Helsinki, Finland (DTP)
Konstantin Otto (28/05-22/06)	Justus-Liebig-Universität Gießen, Germany (DTP)
Paolo Parotto (28/05-22/06)	University of Houston, USA (DTP)
Barbara Pasquini (31/08)	University of Pavia, INFN, Italy (25A)
Lorenzo Pavesi (31/08)	University of Trento, Italy (25A)
Francesco Pederiva (31/08)	University of Trento, INFN-TIFPA, Italy (25A)
Jan Pawlowski (10-16/06)	Universität Heidelberg, Germany (DTP)
Francesco Pederiva (26/04)	University of Trento, Italy (RC)
Jarkko Peuron (28/05-22/06)	University of Jyväskylä, Finland (DTP)
Israel Portillo Vazquez (28/05-22/06)	University of Houston, USA (DTP)
Andrea Quadri (01-05/05, 25-30/11)	University of Milano, Italy (VS)
Mahfuzur Rahaman (28/05-22/06)	Variable Energy Cyclotron Centre, Kolkata, India (DTP)
Claudia Ratti (03-08/06, 31/08)	University of Houston, USA (DTP, 25A)
Luciano Rezzolla (31/08)	University of Frankfurt, Germany (25A)
Achim Richter (22/05-08/06, 20/08-07/09)	TU Darmstadt, Germany (VS, 25A)
Georges Ripka (22/05-02/07, 31/08)	CEA Saclay, France (DTP, 25A)
Dirk Rischke (27/05-02/06, 31/08)	J. W. Goethe-Universität Frankfurt, Germany (DTP, 25A)
Luca Riz (28/05-22/06)	Università degli Studi di Trento, Italy (DTP)
Azumi Sakai (28/05-22/06)	Sophia University, Japan (DTP)
Elio Salvadori (31/08)	FBK CREATE-NET, Italy (25A)
Andreas Schmitt (09-16/06)	University of Southampton, UK (DTP)
Dominik Schweitzer (28/05-22/06)	Justus-Liebig-Universität Gießen, Germany (DTP)
Achim Schwenk (31/08)	TU Darmstadt, Germany (25A)
Pracheta Singha (28/05-22/06)	Bose Institute, India (DTP)
Noriyuki Sogabe (28/05-22/06)	Keio University, Japan (DTP)
Johanna Stachel (31/08)	University of Heidelberg, Germany (25A)
Sandro Stringari (31/08)	University of Trento, Italy (25A)
Anurag Tiwari (28/05-22/06)	Tata Institute of Fundamental Research, India (DTP)
Marco Traini (31/08)	University of Trento, INFN-TIFPA, Italy (25A)
Aleksi Vuorinen (26/05-02/06)	University of Helsinki, Finland (DTP)
Xiao-Dan Wang (28/05-22/06)	Central China Normal University, China (DTP)
Wolfram Weise (25-28/04, 31/08)	TU München, Germany (RC, 25A)


ECT* Workshop participants - DTP- TALENT - Visitors 2018
Visitors
Countries
0
20
40
60
80
100
120
140
160
180
200
Australia 1
Austria 8
Belgium 12
Brazil 6
Canada 17
China 18
Croatia 2
Cyprus 3
Czech Republic 4
Denmark 5
Finland 15
France 41
Germany 172
Greece 1
Hungary 3
India 10
Iran 1
Ireland 3
Israel 5
Italy 112
Japan 31
Korea 1
Lithuania 1
Mexico 1
Netherlands 3
Norway 1
Poland 30
Portugal 3
Romania 10
Russia 17
Slovakia 2
Spain 20
Sweden 5
Switzerland 19
Taiwan 1
UK 32
Ukraine 2
Uruguay 2
USA 175

3 ECT* Scientific Projects in 2018

3.1 Summary

Altogether 22 scientific projects have been run in 2018: 22 workshops and a Doctoral Training Programme. This chapter collects the scientific reports written by the workshop organizers and by Georges Ripka who coordinated the Doctoral Training Programme.

3.2 Workshops and Schools (Calendar)

Mar 05 – 09	**Recent Advances and Challenges in the Description of Nuclear Reactions at the Limit of Stability** **Pierre Capel** (Université libre de Bruxelles) Jesus Casal (ECT*) José Antonio Lay (University of Sevilla) Antonio Moro (University of Sevilla)
Mar 26 – 30	**Determination of the Absolute Electron (Anti)-Neutrino Mass** Loredana Gastaldo (Heidelberg University) **Kathrin Valerius** (KIT, Karlsruhe)
Apr 09 – 13	**Spontaneous and Induced Fission of Very Heavy and Super-Heavy Nuclei** Nicolae Carjan (JINR Dubna & NIPNE-HH Bucharest) Yuri Oganessian (JINR Dubna) **Emanuele Vardaci** (University of Napoli)
Apr 16 – 20	**Exposing Novel Quark and Gluon Effects in Nuclei** **Ian Cloet** (ANL, Lemont) Raphael Dupre' (CNRS-IN2P3 - Orsay) Seamus Riordan (ANL, Lemont)
Apr 23 – 27	**Exploring the Role of Electro-Weak Currents in Atomic Nuclei** Stefano Gandolfi (LANL, Los Alamos) **Ronald Fernando Garcia Ruiz** (University of Manchester) Gaute Hagen (ORNL, University of Tennessee) Jason Holt (TRIUMF, Vancouver) Alexandre Obertelli (CEA Paris-Saclay)
May 07 – 11	**Foundational Aspects of Relativistic Hydrodynamics** Ulrich Heinz (Ohio State University) Michal Heller (MPI for Gravitational Physics) **Guy Moore** (TU Darmstadt)
May 21 – 25	**Probing QCD at the High Energy Frontier** Nestor Armesto (University of Santiago de Compostela) **Guillaume Clement Beuf** (University of Jyväskylä) Tuomas Lappi (University of Jyväskylä) Cyrille Marquet (École Polytechnique Palaiseau)
May 28 – Jun 01	**Gauge Topology 3: from Lattice to Colliders** **Massimo D'Elia** (University of Pisa) Edward Shuryak (Stony Brook University)
Jun 04 – 08	**New Ideas in Constraining Nuclear Forces** Andreas Ekström (Chalmers University of Technology)

Jason Holt (TRIUMF, Vancouver)
Joel Lynn (TU Darmstadt)
Ingo Tews (INT, University of Washington)

Jun 18 – 22 **Exploring Nuclear Physics with Ultracold Atoms**
Tilman Enss (Heidelberg University)
Alex Gezerlis (University of Guelph)
Joseph Thywissen (University of Toronto)

Jul 02 – 06 **Nucleon Spin Structure at Low Q: A Hyperfine View**
Ido Antognini (ETH Zürich)
Jian-Ping Chen (JLab, Newport News)
Alexandre Deur (JLab, Newport News)
Vladimir Pascalutsa (University of Mainz, PRISMA)
Marc Vanderhaeghen (University of Mainz, PRISMA)

Jul 09 – 13 **Modeling Neutrino-Nucleus Interactions**
Maria M. Barbaro (Turin University)
Deborah Harris (FNAL)
Natalie Jachowicz (Ghent University)
Ulrich Mosel (Giessen University)
Federico Sanchez (Barcelona Institute of Science and Technology)

Jul 16 – 20 **Probing Exotic Structure of Short-Lived Nuclei by Electron Scattering**
Carlo Barbieri (University of Surrey)
Takaharu Otsuka (RIKEN, Wako)
Haik Simon (GSI, Darmstadt)
Toshimi Suda (Tohoku University)

Sep 03 - 07 **Quantum Gravity meets Lattice QFT**
Norbert Bodendorfer (Regensburg University)
Kristina Giesel (University of Erlangen)
Masanori Hanada (Kyoto University, Livermore, Stanford University)
Marco Panero (Turin University)
Andreas Schäfer (Regensburg University)
Larry Yaffe (Seattle University)

Sep 10 - 14 **Mapping Parton Distribution Amplitudes and Functions**
Gunnar Bali (University of Regensburg)
Cynthia Keppel (JLab, Newport News)
Cédric Mezrag (INFN Roma)
Craig Roberts (ANL, Lemont)

Sep 17 – 21 **Emergent Mass and its Consequences in the Standard Model**
Cristina Aguilar (University of Campinas)
Daniele Binosi (ECT*, Trento)
Joannis Papavassiliou (University of Valencia)
Craig Roberts (ANL, Lemont)

Oct 01 – 05 **Interdisciplinary Approach to QCD-like Composite Dark Matter**
Mikael Chala (University of Valencia, CSIC)
Germano Nardini (University of Bern)
Michael Ramsey-Musolf (University of Massachusetts Amherst, Kellogg Radiation Laboratory, CALTEC)
Veronica Sanz (University of Sussex)
David Schaich (University of Bern)

Oct 8 – 12	**Discrete Symmetries in Particle, Nuclear and Atomic Physics and implications for our Universe** Dmitry Budker (Univ. of Mainz, HIM, Univ. of California, Berkeley) Catalina Curceanu (LNF – INFN, Frascati) Derek Kimball (California State University) Andrzej Kupsc (Uppsala University) **Pawel Moskal** (Jagiellonian University, Krakow)
Oct 15 – 19	**Observables of Hadronization and the QCD Phase Diagram in the Cross-over Domain** Francesco Becattini (University of Florence, INFN) Rene Bellwied (University of Houston) Marcus Bleicher (Goethe University Frankfurt, FIAS) Jan Steinheimer (FIAS, Frankfurt) **Reinhard Stock** (Goethe University Frankfurt, FIAS)
Nov 05 – 09	**Indirect Methods in Nuclear Astrophysics** **Livius Trache (**IFIN-HH Bucharest) Carlos Bertulani (Texas A&M University-Commerce) Zsolt Fulop (MTA ATOMKI Debrecen) Tohru Motobayashi (RIKEN, Wako) Angela Bonaccorso (INFN Pisa)
Nov 26 – 30	**Electromagnetic Radiation from Hot and Dense Hadronic Matter** **Gabor David** (Stony Brook University) Charles Gale (McGill University)
Dec 19 – 21	**The Spectroscopy Program at EIC and Future Accelerators** Marco Battaglieri (INFN Genova) **Alessandro Pilloni** (ECT*) Adam Szczepaniak (Indiana University, JLab, Newport News)

3.3 Workshop reports

3.3.1 RECENT ADVANCES AND CHALLENGES IN THE DESCRIPTION OF NUCLEAR REACTIONS AT THE LIMIT OF STABILITY

DATE: March 05 – 09, 2018

ORGANIZERS:

Pierre Capel (Université libre de Bruxelles)
Jesus Casal (ECT*)
José Antonio Lay (University of Sevilla)
Antonio Moro (University of Sevilla)

NUMBER OF PARTICIPANTS: 30

MAIN TOPICS:

The workshop aimed at discussing the most recent advances and future developments in nuclear reaction models. In particular, we put an emphasis on the description and interpretation of different types of direct reactions: elastic/inelastic scattering, breakup, quasi-free (p,pN) processes, charge-exchange, etc.
The workshop has gathered experts in structure and reaction theories, to discuss about the state of the art of nuclear models and foresee possible developments. Additionally, several key representatives from leading experimental facilities have provided an overview of the ongoing and planned experiments.

The main topics were:

- Few-body reaction models
- Eikonal and semiclassical models
- Coupled-channels (with and without inclusion of the continuum)
- Nuclear reactions from ab-initio calculations
- Theoretical support to experiments

SPEAKERS:

S. Burrello (LNS-INFN Catania, Italy)

M. Cavallaro (LNS-INFN Catania, Italy)

A. Deltuva (Vilnius University, Lithuania)

L. Fortunato (University of Padova, Italy)

M. Gomez Ramos (Univ. of Sevilla, Spain)

C. Hebborn (University of Brussels, Belgium)

G. Hupin (CNRS IPNO, France)

M. Hussein (University of Sao Paulo, Brazil)

A. Idini (Lund University, Sweden)

F. Nunes (Michigan State University, USA)

A. Obertelli (TU Darmstadt, Germany)

K. Ogata (RCNP University of Osaka, Japan)

G. Orlandini (University of Trento, Italy)

C. Qi (Royal Institute of Technology - KTH, Sweden)

K. Riisager (Aarhus University, Denmark)

M. Rodríguez-Gallardo (University of Sevilla, Spain)

H. Simon (GSI, Germany)

K. Jones (University of Tennessee, USA)

R. Kanungo (St Mary's University and TRIUMF, Canada)

E. Lanza (LNS-INFN Catania, Italy)

L. Moschini (University of Brussels, Belgium)

T. Nakamura (Tokyo Inst. of Technology, Japan)

A. Vitturi (University of Padova, Italy)

M. Vorabbi (TRIUMF, Canada)

J. Yang (University of Brussels, Belgium)

K. Yoshida (RCNP University of Osaka, Japan)

SCIENTIFIC REPORT:

Nuclei are quantum many-body systems consisting of protons and neutrons strongly bound together. Understanding the properties of such complex systems in terms of their constituent particles and the interaction between them is a true challenge, as the dimension of the nuclear many-body problem is overwhelming. Nuclei are exceedingly difficult to describe; they contain too many nucleons to allow for an exact treatment and far too few to disregard finite-size effects.

Our current understanding of the nuclear properties stems to a large extent from the information obtained through nuclear reactions. This includes elastic/inelastic scattering, breakup, transfer reactions, knockout and quasi-free scattering (p,pN), charge exchange,... In the past few decades, the development of Radioactive-Ion Beam (RIB) facilities has enabled the study of nuclei far from stability. A strong effort has been devoted to understand the structure and decay modes associated with the exotic properties of these systems. In this context, the advances in nuclear-reaction theory have played a fundamental role in exploring the edges of the nuclear landscape.

The theoretical description of nuclear reactions needs to incorporate the relevant degrees of freedom, which are probed in specific processes. In addition to developing more elaborate theoretical frameworks to capture the essence of the different reactions, the nuclear-structure inputs need to properly combine single-particle and collective aspects of nuclei. Therefore, it is important to highlight the connection between reaction observables and the underlying nuclear-structure properties.

Recent advances at the leading experimental facilities walk towards the production and study of heavier and more exotic nuclei along the driplines. The analysis of the increasingly large amounts of nuclear data demands new theoretical developments. A strong interaction between experimental collaborations and theoretical groups is needed. Theoreticians and experimentalists should discuss together what information can be extracted and which is the best way to analyse future measurements.

To this end, we have gathered experts from theoretical and experimental nuclear physics to foster discussions. The various speakers have covered most of the recent advances in theoretical descriptions of nuclear reactions used to study the nuclear structure and decay at, or even beyond, the limit of stability. The subject covered by these speakers include:

- knock-out reactions;
- transfer reactions;
- breakup;
- charge exchange;
- indirect techniques in astrophysics, like the Trojan-Horse and surrogate methods;
- the systematic study of the uncertainty within reaction calculations.

In addition to these contributions, which covered reaction modelling, various speakers have presented new results in nuclear-structure theory, which will have a significant impact in the near future in reaction descriptions:

- ab-initio theory for exotic nuclei, including their continuum;
- clustering in nuclei.

To stay in touch with what is actually measured, various renowned experimentalists have presented the latest results for RIB facilities throughout the world (ISOLDE, GSI, RIKEN, TRIUMF, LNS…).

The programme was organised in such a way to let enough time between the presentations and also during the lunch and coffee breaks to enable the participants to discuss their latest results. In addition to these opportunities, we have organised two discussion sessions to debate about various topics suggested by the audience beforehand. The first one focussed mostly on the low-energy strength in the elastic-breakup of halo nuclei. Results about, e.g., ^{6}He, ^{11}Be, and ^{11}Li have been discussed and compared. In particular, the problematic of the extraction of the dB(E1)/dE has been discussed. In the second discussion session, we have considered one-neutron knockout reactions in Borromean systems and compared the results obtained from this technique of analysis to other reactions that lead to the same remnant nucleus (one-proton knockout or one-neutron transfer).

Results and Highlights

During this workshop, a variety of hot current issues in nuclear reactions involving exotic nuclei have been addressed. Most of them were directly related to recent developments in theoretical description of reactions. The interactions with nuclear-structure theorists attending the workshop were very constructive, because the goal of the study of nuclear reactions at the limit of stability is in fine to improve our knowledge on nuclear structure of radioactive nuclei. The presentations from the experimentalists provided us with the latest results at various RIB facilities, including measurements still at a preliminary stage and not yet published. These results have shown the needs in theory to reliably analyse these data.
From these presentations and the discussions about them during the workshop, most of us went back home with clear homeworks and new ideas to improve our models or start calculations to analyse new sets of data that will come out in a near future. This is the kind of interactions that make such a workshop successful, because they foster discussions within the community, bring up new ideas in the analysis of data or in data taking, and even lead to the development of collaborations. All three aspects have been observed during the present workshop.
One particular point that was addressed by various speakers under different viewpoints is that of the so-called reduction of spectroscopic factors observed in knock-out reactions measured at MSU. Since such a reduction is not observed in transfer reactions on the same nuclei, it is assumed that at least part of the problem arises from the description of the reaction used in the analysis. Various efforts, on both the experimental and theoretical sides have been discussed during the different talks addressing this issue.
The discussion sessions scheduled in the programme enabled us to go more in depth in a few aspects of the study of nuclear structure away from stability through reactions. One conclusion that came out of the first discussion session on E1 strength in halo nuclei is that the extraction of the dB(E1)/dE directly from experimental data can be unreliable and that it is best to compare theoretical predictions with the measured cross sections. A close collaboration between theorists and experimentalists should also be sought to properly account for the experimental uncertainty in these comparisons.
The second discussion session has shown that the various ways to study nuclei beyond the dripline, viz. using different reactions, can lead to seemingly contradictory results. That session has also illustrated the current efforts to try to make sense of these differences and see if they can be related merely to the reaction processes or if they emphasise unexpected exotic features in the structure of these unbound nuclei.
The feedback we have received from the different participants of the workshop in a whole was very positive. They have liked the loose schedule that we have planned and that left much time for discussion. Both discussion sessions were animated with contributions from the various attendants and led to constructive comments from all areas of research represented within the audience.

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

DATE: March 26 – 30, 2018

ORGANIZERS:

Loredana Gastaldo (Heidelberg University)
Kathrin Valerius (KIT, Karlsruhe)

NUMBER OF PARTICIPANTS: 46

MAIN TOPICS:

The absolute neutrino mass scale could be the key for theories beyond the Standard Model. Since the analysis of cosmological observations is approaching sensitivities close to the minimal allowed sum of neutrino masses and experiments searching for neutrinoless double beta decay are getting more sensitive, the quest for results from direct searches for the electron (anti-)neutrino mass by means of kinematic analysis is becoming very pressing.
Presently two isotopes are in the spotlight: ^{3}H and ^{163}Ho. KATRIN, Project 8 and PTOLEMY using ^{3}H and ECHo and HOLMES using ^{163}Ho aim to reach sub-eV sensitivity within the next few years.
The objective of this 2nd workshop was to foster the exchange between theorists and experimentalists in the light of new results achieved by experiments and to open a platform for discussions about future approaches to extend the sensitivity of kinematic measurements of the neutrino mass below 100 meV.

The main topics were:

- Physics implications of neutrino mass
- Role of massive neutrinos in cosmology
- Cosmic neutrino background
- Neutrino oscillations
- Supernova neutrinos and time-of-flight measuraments
- ^{3}H-based experiments
- ^{163}Ho-based experiments
- Modelling and interpretation of the measured ^{3}H and ^{163}Ho spectra
- Challenges related to the ^{3}H and ^{163}Ho source
- Challenges for detector and read-out systems
- Identification and suppression of background sources
- Sensitivity of ^{3}H and ^{163}Ho-based experiments to sterile neutrinos.

The workshop programme comprised 35 talks and the presentation of 7 posters. The names of the speakers and the poster presenters are listed below.

SPEAKERS:

J. Behrens (KIT, Karlsruhe, Institute for Nuclear Physics, Germany)

T. Lasserre (CEA, Saclay, France and TUM, Munich, Germany)

S. Böser (Johannes Gutenberg Universität, Mainz, Germany)

C. Brofferio (Università di Milano Bicocca, Italy)

A. Cocco (INFN Napoli, Italy)

H. Dorrer (Johannes Gutenberg Universität, Mainz, Germany)

G. Drexlin (KIT, Karlsruhe, Institute for Nuclear Physics, Germany)

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

M. Faverzani (Università di Milano Bicocca, Italy)

E. Ferri (Università di Milano Bicocca, Italy)

F. Fränkle (KIT, Karlsruhe, Institute for Nuclear Physics, Germany)

G. Gallucci (INFN Genova, Italy)

C. Giunti (INFN Torino, Italy)

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

C. Hassel (Kirchhoff Institute for Physics, Heidelberg University, Germany)

M. W. Haverkort (Institute for Theoretical Physics, Heidelberg University, Germany)

S. Kempf (Kirchhoff Institute for Physics, Heidelberg University, Germany)

M. Klein (KIT, Karlsruhe, Institute of Experimental Particle Physics, Germany)

K. Koehler (Los Alamos National Laboratory, USA)

A. Lindman (Johannes Gutenberg Universität, Mainz, Germany)

S. Mertens (TUM and Max Planck Institute for Physics, Munich, Germany)

D. Parno (Carnegie Mellon University, Pittsburgh, USA)

P. Chung-On Ranitzsch (Münster University, Institute for Nuclear Physics, Germany)

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

L. Saldana (Yale University, New Haven, USA)

M. Schlösser (KIT, Karlsruhe, Institute for Technical Physics, Germany)

F. Simkovic (University of Bratislava, Slovakia)

M. Slezák (Max Planck Institute for Physics, Munich, Germany)

N. Steinbrink (Münster University, Institute for Nuclear Physics, Germany)

T. Thümmler (KIT, Karlsruhe, Institute for Nuclear Physics, Germany)

C. Tully (Princeton University, USA)

F. Vissani (LNGS & GSSI, L'Aquila, Italy)

M. Wegner (Kirchhoff Institute for Physics, Heidelberg University, Germany)

K. (Johannes Gutenberg Universität, Mainz, Germany)

A. Ziegenbein (Tübingen University, Germany)

POSTER PRESENTERS:

M. Braß (Institute for Theoretical Physics, University of Heidelberg, Germany)

M. De Gerone (INFN Genova, Italy)

M. Fedkevych (Münster University, Institute for Nuclear Physics, Germany)

F. Mantegazzini (Kirchhoff Institute for Physics, Heidelberg University, Germany)

M. Rabin (Los Alamos National Laboratory, USA)

R. Sack (Münster University, Institute for Nuclear Physics, Germany)

M. Wegner (Kirchhoff Institute for Physics, Heidelberg University, Germany)

SCIENTIFIC REPORT:

The mass scale of neutrinos is one of the fundamental open questions in modern physics, having important implications from cosmology to particle physics. The determination of absolute neutrino masses, in addition to the relative splittings, which are observed through neutrino oscillations, will pave the way to look beyond the Standard Model of particle physics. Precision measurements of the kinematics of weak decays in unstable nuclides are regarded to be the approach to address this question, which is less dependent on theoretical models. Nowadays two nuclides are considered to be suitable for the determination of the electron neutrino mass: ^{3}H, which undergoes beta decay, and ^{163}Ho, which decays through electron capture. The next milestone is to reach sub-eV sensitivity with respect to the electron (anti-) neutrino mass.

Three large experiments will be focusing on the spectral endpoint region of electrons emitted in ^{3}H beta decays: KATRIN, Project 8 and PTOLEMY. Likewise, two large experiments are addressing the precise calorimetric measurement of the ^{163}Ho electron capture spectrum: ECHo and HOLMES. The success of these experiments relies on a multidisciplinary approach in which particle physics, nuclear physics, atomic physics and statistical physics are strongly interconnected. Moreover, the development of cutting-edge techniques for ultra-precise detector fabrication, identification and suppression of background, and advanced data analysis tools play a crucial role.

The goal of this workshop thus was to bring together theorists and experimentalists involved in the above-mentioned efforts to discuss recent advances in the fields of neutrino mass phenomenology and direct neutrino mass measurements. In 2016 a first workshop at ECT* dedicated to the determination of the (anti-)neutrino mass and implications of this observable in fields like particle physics and cosmology attracted more than 50 physicists from different universities and scientific institutes around the world. Among them were numerous PhD students who had the possibility to present their work with posters and discuss with distinguished experts. For the 2018 edition, we continued along the successful concept of combining experimental/theory/interlacing topics, and we strived to maintain the well-proven participant mixture of senior experts and early-career researchers. For the 2nd workshop, again, this concept was perceived as very fruitful and beneficial to the workshop goal by the attendees.

The number of talks has been reduced from 43 in the 2016 edition of the workshop to 35 in the 2018 edition, in order to leave more time for discussions and group work on common topics and future goals. With this realigning of the 2nd workshop programme we were responding to the development of our fast-evolving field, in which several large experiments are now beginning to take data after long preparation phases, and new ideas for future directions are starting to be discussed.

The presentation programme (see timetable below) was composed of **fifteen 40-minute introductory & overview talks and twenty shorter talks of about 25 minutes**.

The overview talks covered the following topics:

- implications of neutrino masses in particle physics and cosmology (2 talks)
- status reports of the individual ^{3}H and ^{163}Ho direct neutrino mass experiments (5 talks)
- a review of current activities in the neighbouring field of neutrinoless double beta decay (1 talk)
- theoretical aspects of the physics involved in neutrino mass determination from kinematical measurements (supernova neutrino time-of-flight, beta decays and electron capture; 3 talks)
- the current picture of sterile neutrino phenomenology and the prospects of searching for sterile neutrinos in direct kinematical experiments (2 talks)
- determination of important experimental parameters for direct neutrino mass determination (Q-values of β-decay and EC isotopes and tritium molecular final states; 2 talks)

The shorter talks were dedicated to the challenges in various complementing aspects of the experiments and proved very useful in illuminating the different approaches used by the individual collaborations, for example for the production/purification/handling of the radioactive ^{3}H and ^{163}Ho sources or for the identification and suppression of major background sources.

One afternoon was reserved for the poster session. Seven posters presented mainly by PhD students and young researchers were lining the walls of the ECT* Conference Room. The very positive experience of the poster session as a driver for lively exchange and communication, with which we had already been rewarded in 2016, was confirmed also this time.

Finally, we devoted the last day of the workshop to the planning of a White Paper initiative. With this document, our community aims to reflect the exciting and very encouraging current achievements and position the kinematic measurements as main tool for the determination of the neutrino mass scale. At the same time this paper will show how the high precision kinematic measurements of beta and electron capture spectra would allow for new investigations not only related to neutrino physics, but also more exotic particle physics as well as high precision atomic physics. A last goal of this paper is then to discuss perspectives (and set the basis) for larger and more sensitive next-generation experiments.

Results and Highlights

The workshop took place at a most exciting time when several large experiments are completing their construction and commissioning phases and transitioning to data taking. This development was reflected in the composition of talk topics at this year's workshop, and was noted as a very positive drive throughout our community. With the traditional build-up of excitement and anticipation of experimental results to be presented at the XXVIII International Conference on Neutrino Physics and Astrophysics in Heidelberg in June 2018, the timing of the ECT* workshop about 2.5 months ahead of the conference was ideal to discuss important developments and progress in a smaller round and a more interactive atmosphere. The format and scope of the workshop allowed us to explore the tight connections between experimentalists and theorists in multiple ways:

- Impact of theory on experiment — at Trento, we heard reports about recent progress in the description of basic theoretical foundations such as ab-initio calculations of the ^{163}Ho electron capture spectrum, the interface between nuclear physics and neutrino physics, and important initiatives to cross-validate results by investigating different isotopes.
- Impact of experiment on theory — we discussed prospects of broadening the physics reach of current and next-generation experiments beyond neutrino mass determination and thus enabling to probe a larger scope of emerging theoretical concepts and ideas (e.g., searches for light and medium-mass sterile neutrinos, for contributions of right-handed weak currents or exotic forms of weak interactions, constraints on the cosmic relic neutrino background, etc.).

- Interfacing topics between experiment and theory — the TRIMS experiment reported on first data taken in the endeavour of solving long-standing open questions on the theory of molecular and dissociative final states in ^3H beta-decay. New insights into the experimental determination of Q-values for the EC and beta-decay nuclides, which form a crucial input for the spectral models employed in direct neutrino-mass experiments, were presented.

One of the highlights of the 2018 ECT* workshop was the launch of the White Paper initiative on Direct Neutrino Mass Measurement, which was met with large enthusiasm among the participants. The organizers greatly appreciated that many of the attendees offered immediate input and most valuable contributions to shaping the paper. At Trento, we collected input in two ways: first, in a plenary session, we discussed the scope and aims of such a White Paper. Subsequently, the participants split up into several working groups in which different parts of the paper were addressed. As an outcome of this successful kick-off of the project at Trento, we have assembled an outline of the White Paper which is presently prepared for a larger exposure within our international community. As a next step, we will use a collaborative writing platform to fine-tune the shape and contents of the document further and to collect individual contributions. Building on sustained efforts throughout the community, we envision to prepare a first overall draft of the White Paper leading up to the spring 2019.

We are very grateful to ECT* for hosting and supporting this workshop, which has become an internationally recognized, influential meeting for experts and early-career researchers in our field alike. By choosing the interactive format of a workshop over the more informative one of a conference we succeeded in fostering lively exchange on in-depth matters of the field, both experimental and theoretical in nature, and in strengthening existing collaborative links. We believe that, thanks to this workshop, many new contacts within our research community have been established. The large quantity of unanimously positive feedback the organizers received during and after the workshop supports us in this view.

3.3.3 SPONTANEOUS AND INDUCED FISSION OF VERY HEAVY AND SUPER-HEAVY NUCLEI

DATE: April 09 – 13, 2018

ORGANIZERS:

Nicolae Carjan (JINR Dubna, NIPNE-HH Bucharest)
Yuri Oganessian (JINR Dubna)
Emanuele Vardaci (University of Napoli)

NUMBER OF PARTICIPANTS: 33

MAIN TOPICS:

The main goal of the workshop was to discuss the state of the art of our present knowledge of nuclear processes such as fission and quasifission in the region of the very heavy and superheavy nuclei and to identify possible physics cases to be explored with the two new facilities under development, the Super Heavy Element (SHE) factory in Dubna (Russia) and Selective Production of Exotic Species (SPES) in Legnaro (Italy). These two facilities can play an extremely important and unique role in accessing, with different capabilities, unexplored regions of the nuclear chart, in particular the unknown neutron rich side. This area of research is particularly relevant because it is of interest for the nucleosynthesis of the elements heavier than iron (r-process) and for the understanding of the existence and persistence of the shell closures. The latter are the main ingredients for the predicted survival of superheavy elements against fission.

The main topics were:

- Fission of very superheavy elements
- Fission modes, fission barriers and half-lives
- Fission fragment properties
- Fission competition with α-decay
- Fusion and quasifission competition
- Production of superheavy elements
- Fission studies with radioactive ion beams

The Workshop was also intended as a platform for proposals regarding experimental programs during the years of operation of the above facilities.

SPEAKERS:

M. Block (GSI, Darmstadt, Germany)

W. Brodzińki (NCBJ, Warsaw, Poland)

N. Carjan (JINR Dubna, NIPNE-HH Bucharest, Romania)

G. Chubarian (Cyclotron Lab, Texas A & M, USA)

R. Clark (LBNL, Berkeley, USA)

G. de Angelis (LNL, Legnaro, Italy)

S. Dmitriev (JINR, Russia)

P. Möller (LANL, Los Alamos, USA)

Y. Oganessian (JINR, Russia)

D. Poenaru (IFIN-HH, Bucharest, Romania)

G. Prete (LNL, Legnaro, Italy)

D. Regnier (IPN, Orsay, France)

K. Rykaczewski (ORNL, Oak Ridge, USA)

G. Scamps (University of Tsukuba, Japan)

I. Silisteanu (IFIN-HH, Bucharest, Romania)

F. P. Heßberger (GSI, Darmstadt, Germany)

I. Itkis (JINR, Russia)

M. Itkis (JINR, Russia)

A. Karpov (JINR, Russia)

M. Kowal (NCBJ, Warsaw, Poland)

P. Magierski (Warsaw University, Poland)

Z. Matheson (Michigan State University, USA)

J, Skalski (NCBJ, Warsaw, Poland)

G. Ter-Akopian (JINR, Russia)

E. Vardaci (University of Napoli)

D. Vretenar (University of Zagreb, Croatia)

C. Zachary (Vanderbilt University, Nashville, USA)

SCIENTIFIC REPORT:

Immediately after the discovery of nuclear fission by Hahn and Strassmann a first theory of the mechanism for nuclear fission was proposed by Bohr and Wheeler. They calculated, among others, that a liquid drop becomes unstable against prompt disruption at Z^2/A=(48-49). This means that spontaneous fission lifetimes in the order of 1 microsecond (the limit of detection) are reached around Z=106. However, extrapolations of the nuclear shell model into regions far beyond the heaviest known spherical proton (Z = 82) and neutron (N = 126) shells, lead to the prediction of spherical shells at Z = 114 and N = 184 with shell correction energies of up to -9 MeV, resulting in a stabilization against spontaneous fission. Those nuclei were named "superheavy" and the synthesis and investigation of the nuclear, atomic and chemical properties have been a research topic in low-energy nuclear physics for already five decades. The reactions for the synthesis of superheavy elements have also given rise to the appearance of a new mechanism called quasifission. Its properties are still a matter of current investigation being the main antagonist mechanism against the fusion of heavy ions.

The scope of this workshop was to discuss the status of the present knowledge on basic properties of fission and quasifission, such as fission barriers, half-lives, hindrance factors, total kinetic energy (TKE) distributions, mass distributions and prompt neutron multiplicity of induced or spontaneous fission of very heavy (Z>100) and superheavy nuclei (Z>110).

The following topics were considered:

- The analysis of the differences between fission half-lives and branching ratios from different compilations.
- The role, played by the fission barriers in understanding the fission process, and thus also the stability of superheavy nuclei. The theoretical understanding is still limited and rather contradictory results are obtained within different models. The origin of these differences was the primary focus.
- Fission half-lives are determined by the transition probability through the barrier along the fission path. It means, that they are dependent on inertial mass, the height and the shape of the barrier. In particular, the influence of the latter can be very strong and thus fission half-lives alone do not allow to extract the height of the barrier.
- The problem of the fission hindrance in nuclei with odd number of nucleons was addressed.
- Fragment mass distributions and total kinetic energy release were discussed in connection with the existence of the fission modes (symmetric-asymmetric, compact-elongated).

- The problem of the overlap of fission and quasifission in the symmetric mass region was addressed.
- The exploration of unknown heavy-mass regions of the nuclear chart with radioactive neutron-rich beam was addressed as well.

The heaviest element for which fission-fragment mass and TKE distributions have been measured is Rf (Z=106) represented by 4 isotopes with N=152, 154, 156 and 158. During the last 20 years there has been no new measurements of fission fragment mass and TKE distributions in the region Z > 100. The heaviest nuclei for which SF has been detected are: 279-281Ds (Z=110), 281Rg, 282-284Cn and 284-286Fl (Z=114) but the number of collected events was not enough to build distributions. However, a comprehensive study of the fission properties of the above mentioned nuclei will be soon possible with the SHE-Factory under construction at FLNR of JINR-Dubna that is planned to deliver the first beam in 2018. Further studies might be possible with radioactive beams being produced at SPES facility.

During the workshop the existing theoretical and experimental results concerning fission and quasifission (such as fission barriers, half-lives, branching ratios, hindrance factors, mass and TKE distributions) were reviewed, and emphasis was given to the study of fission and quasifission in unexplored regions of the chart of nuclei, like the “Terra Incognita” or the new island of stability, which are of profound interest for the stellar nucleosynthesis and for the understanding of the survival of the shell effects.

Results and Highlights

The workshop was the ideal setting to discuss the state of the art in the present knowledge of the fission process, in particular, in the region of the nuclear chart of the very heavy and superheavy nuclei. Well known experts in the field, both experimentalists and theorists, have traced the present status and the basis for future developments. Traditional theories, based on the liquid drop model (LDM) and shell corrections, and further extended to include a larger set of collective variables, have shown their renewed power in predicting new features of the fission process, like more realistic predictions of the spontaneous fission decay rates and, above all, the prediction of the fission modes (double humped total kinetic energy distribution for the same mass division in two fragments) in the mass range between A=256 and A=276. Modern microscopic theories such as time-dependent HFB and density functionals have emerged and show their potential. These theories are not based on general assumptions like in the LDM but give rise to a much higher computational complexity. The most important effect that has been neglected in traditional theories so far but that emerges from microscopic ones is the pairing correlations. The latter assume a paramount importance because they drive the fission time, namely the dynamics of the process. The fact that the fission process is considered slow with respect to prescission particle emission rates has brought forward the idea that nuclear matter has a viscosity: the higher the viscosity, the slower the process of division in two fragments. The pairing field indeed drives the appearance of additional degrees of freedom, which affect the fission time and has triggered a new idea of what the fission process is. In simple words, the fission is slower or faster according to the strength of the pairing in a given nucleus. If the pairing field is strong, the available energy needs to be distributed between a larger number of degrees of freedom, both shape and pairing modes, and the process is slower. If the pairing field strength is weaker, energy can be more likely stored in fewer degrees of freedom, such as shape only, and the fission is faster. This is a kind of revolutionary result that requires a dedicated experimental verification.
On the experimental side, the advent of the new facilities, such as the Super Heavy Element Factory at JINR (Dubna) and SPES in Legnaro (Italy), opens the possibility to access a wealth of new reactions to study the phenomena predicted by these emerging microscopic theories. Moreover it opens the possibility to produce, in large amounts (enough for chemical and nuclear spectroscopy analysis), new more proton and neutron rich superheavy isotopes, even in cases where the production cross sections are at the level of tens of nanobarn. This will allow the extension of our understanding of the nuclear structure of super heavy elements, the possibility to get closer to the center of the island of stability and to produce new isotopes of the Terra Incognita region, which is of extreme interest for the r-process of nucleosynthesis of the elements heavier than iron. Reactions, detectors and spectroscopic analysis have been

discussed in detail to face this new era. Proposals for day-one experiments in these facilities have also been discussed. It is very likely that the discussions at ECT* will continue between the participants with beneficial outcome.

3.3.4 EXPOSING NOVEL QUARK AND GLUON EFFECTS IN NUCLEI

DATE: April 16 – 20, 2018

ORGANIZERS:

Ian Cloet (ANL, Lemont)
Raphael Dupré (CNRS-IN2P3, Orsay)
Seamus Riordan (ANL, Lemont)

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

The main theme of this workshop was to discuss different aspects of nucleon modification in the nuclear medium, review the latest theoretical understanding, and discuss how different experimental observables and techniques may complement each other. Nuclear modification is an important and wide reaching subject in nuclear physics and identification of the underlying mechanism has remained unresolved since its first positive experimental identification over 30 year ago. The intent of this workshop was to help strengthen the case for a broad set of modification studies, both experimental and theoretical, and identify what may be uncovered by using information from a coherent set of observables.

The main topics were:

- Parton distribution function (PDF) fits
- Inclusive deep inelastic scattering including parity-violating and spin channels
- Drell-Yan with fixed nuclear targets
- Nuclear generalized parton distribution functions
- Short range correlation measurements

SPEAKERS:

W. Armstrong (ANL, USA)

J. Arrington (ANL, USA)

W. Brooks (Universidad Técnica Federico Santa María, Chile)

I. Cloët (ANL, USA)

W. Cosyn (Ghent University, Belgium)

W. Detmold (MIT, USA)

R. Dupré (CNRS-IN2P3, Orsay)

M. Ehrhart (IPN Orsay, France)

N. Fomin (University of Tennessee, USA)

J. Adam Freese (ANL, USA)

S. Fucini (University of Perugia, Italy)

D. Gaskell (Jefferson Lab, USA)

M. Hattawy (ANL, USA)

S. Luiti (University of Virginia, USA)

G. Miller (University of Washington, USA)

E. Pace (University of Rome, Tor Vergata, Italy)

S. Platchkov (CEA Saclay, France)

P. E Reimer (ANL, USA)

M. Sargsian (Florida International University, USA)

I. Schienbein (Université Grenoble Alpes, France)

S. Scopetta (INFN & University of Perugia, Italy)

P. Shanahan (College of William and Mary, USA)

A. Thomas (Univ. of Adelaide, Australia)

C. Keppel (Jefferson Lab, USA) M. Zurita (BNL, USA)

SCIENTIFIC REPORT:

The modification of bound protons and neutrons within nuclei is a central and unresolved topic within nuclear physics. Nuclear modification reaches into many important physical processes, such as deep inelastic scattering with leptons or neutrinos, quasielastic and multi-nucleon knockout processes, determination of properties of the neutron for which no free neutron target exists, determination of standard model parameters with experiments and require nuclear observables, and neutron star structure. While our modern understanding of these effects has constrained them to a degree, lack of precision data and a fundamental description of the mechanism or mechanisms by which these properties change is a significant obstacle in a complete understanding of the strong force. It lies at the boundary between the low energy nucleon description of nuclear physics and the high-energy limit where quarks and gluons are the relevant degrees of freedom.

The first observation that the properties of nucleons will change was observed in 1983 at CERN by the European Muon Collaboration, which saw a significant deviation from unity in the deep inelastic structure ratio between deuterium and iron. Despite over 30 years of effort, no single mechanism or theory has been able to fully explain these observations. There has been significant expansion in the body of data including studying a broad set of nuclei, the use of lepton and neutrino beams, and measurements of Drell-Yan processes with nucleons and mesons on fixed nuclear targets. While these cover a large kinematic phase space for the unpolarised nuclear parton distribution functions, there remains a significant set of observables which have not yet been explored. Of the most important, the EMC effect has been largely assumed to be isoscalar in nature and totally dependent on the nuclear mass number A.

This concept has been challenged by inconsistencies in PDF extractions from neutrino scattering data, which utilize different sets of couplings, as well by general arguments of the relative size of the symmetry energy to the total binding energy in a nucleus in mean field models. As many of the nuclei studied have only small asymmetries between the number of protons and neutrons, the size of such an effect has been poorly constrained. It is identified that both asymmetric nuclear targets combined with traditional and novel probes, such as through parity-violating electroweak couplings, a variety of Drell-Yan, or semi inclusive deep inelastic scattering, are critical in constraining this aspect. The inclusion of modest isovector effects in mean field calculations is able to largely resolve the NuTeV anomaly.

A spin-dependent EMC effect has been entirely unexplored experimentally for sufficiently heavy nuclei. This presents an opportunity for new measurements and testing novel models, which must explain any spin-dependent observations in addition to the unpolarised data.

In addition, underlying challenges in extracting the u- and d-quark PDFs for free protons and neutrons exist from the reliance on deuterium or other light nuclear data. Such data requires model-dependent corrections due to motion, binding, and off-shell effects. In general relating deep inelastic and Drell-Yan data is also complicated by initial interactions of the quarks in the cold nuclear medium creating energy losses and a spread in the transverse momentum of the final states.

Significant progress is being made on several other fronts, which will provide valuable data parallel to inclusive deep inelastic scattering. The remarkable correspondence between short-range correlations of nucleon pairs and the structure function ratios for Bjorken-x > 1 and the size of the EMC effect has generated considerable excitement. Such data suggests modification is due to local nuclear densities and naturally incorporate isoscalar and isovector degrees of freedom.

Future planned programs involving nuclear generalized parton distributions and spectator tagging offer critical opportunities to obtain data in new observables with extra kinematic degrees of freedom which will be important in resolving contributions from mean field and local density fluctuations, relating deep inelastic scattering observables to elastic structure functions, and probing nuclear gluon distributions through coherent phi or J/psi production. Of great importance in studying isovector observables is the ability to perform isotope identification in spectator tagging.

Important progress is also being made in developing the formalism for spin-1 nuclear generalized parton distributions, which is required for studying deuterium. Defining a set of spin-dependent observables, how these relate to experimental configurations, and establishing analogous relations to the energy-momentum tensor (EMT) as for the spin-1/2 case is critical. Due to the richness of a higher spin system, for example the shear-stress components in the EMT become potentially identifiable from experiment.

Modelling and calculations for light nuclei is also making important progress. While an EMC effect is expected to be weak for such system, these are important for the extraction of many observables and are within the reach (though still challenging) with modern computational techniques. The lattice offers one of the most exciting opportunities to make predictions for very light nuclei, though is still computationally expensive and observables are limited by practical sets of operators and come often in the form of ratios.

Results and Highlights

This workshop was attended by the leaders in the experimental and theory communities in studying medium modification and represented a number of different groups and facilities around the world. This diversity was instrumental in sharing different ideas and highlighting common issues. In particular, it was clear that the efforts represented by the attendees are part of a large common program, which must be carried out coherently.

Several major themes emerged which will help support the program going forward. First, it was accepted that medium modification is likely a combination between local density and mean field effects and new experiments, which are sensitive to these aspects are needed on all fronts. Nuclear PDF data are incomplete, have notable inconsistencies in data sets, and often corrections applied which cannot be removed. Studies of a more complete set of nuclei with attention to isovector observables and varying local densities are planned at Jefferson Lab. These will be complimented by new short-range correlation measurements reaching into the $x>1$ and even potentially $x>2$ regimes. Proposals for parity-violating electron scattering with SoLID at Jefferson Lab, Drell-Yan at COMPASS and Fermilab with nuclear targets were also highlighted, with these two methods identified as complementary in accessing isovector observables with very different systematic uncertainties. A novel spin-dependent program, which was approved for CLAS12 at Jefferson Lab, was presented.

Also highlighted were experimental and theoretical developments for nuclear generalized parton distributions (GPDs). New results on 4He GPDs, which represent the simplest spin-0 nuclear system to be tested, were presented with deviations from theoretical predictions. New results on developing the GPD formalism for deuterium were presented by several attendees. They represent new opportunities for future observables relating them to fundamental QCD objects such as the energy-momentum tensor.

Tagged spectator experiments, such as deeply virtual Compton scattering (which may access GPDs), and deeply virtual meson production were identified as an important direction in adding new degrees of freedom to modification observables. For example, using missing momentum as a metric for off-shell effects, one may help disentangle the role of local density effects and mean field effects. By adding isotope identification in the tagging process, isovector observables may be included. Plans for such measurements have been made for CLAS12 at Jefferson Lab in the ALERT program.

Recent lattice calculations for nuclei, both for common observables as well as the gluon structure were also highlighted as well as the challenges for producing operators for desirable observables and the numerical issues reaching to heavier nuclei.

The organizers and participants are working to produce a publication, which highlights the workshop.

3.3.5 EXPLORING THE ROLE OF ELECTRO-WEAK CURRENTS IN ATOMIC NUCLEI

DATE: April 23 – 27, 2018

ORGANIZERS:

Stefano Gandolfi (LANL, Los Alamos)
Ronald Fernando Garcia Ruiz (University of Manchester)
Gaute Hagen (ORNL, University of Tennessee)
Jason Holt (TRIUMF, Vancouver)
Alexandre Obertelli (CEA, Paris-Saclay)

NUMBER OF PARTICIPANTS: 27

MAIN TOPICS:

An accurate description of electro-weak processes in nuclei plays a key role in our understanding of nuclear dynamics and has direct implications in the study of fundamental questions of modern physics. Phenomenological effective operators such as effective charges, effective g-factors, effective axial masses, and quenching of nuclear matrix elements, are commonly introduced in nuclear theory to account for neglected many-body currents. However, the ambiguities of this approach entail contradictory interpretations of nuclear structure, and do not comply with the needs demanded by modern high-precision experiments, which require accurate nuclear matrix elements with quantifiable uncertainty. This workshop discussed the current theoretical developments and experimental efforts that are being pursued to understand the role of electro-weak currents in nuclei and their relation with six major topics of general interest.

The main topics were:

- Relative importance of nuclear interactions, correlations, and electro-weak currents
- Electro-weak reactions of few-nucleon systems
- Microscopic origin of effective charges and g factors in atomic nuclei
- Quenching of Gamow-Teller matrix elements and neutrinoless double beta-decay
- Effects beyond standard model
- Electron/neutrino –scattering

SPEAKERS:

S. Bacca (Johannes Gutenberg University Mainz, Germany)

N. Barnea (The Hebrew University of Jerusalem, Israel)

M. Bissell (The University of Manchester, UK)

K. Blaum (Max-Planck-Institut für Kernphysik, Germany)

V. Cirigliano (LANL, USA)

E. Epelbaum (Ruhr-University Bochum, Germany)

A. Lovato (INFN-TIFPA, Italy)

J. Lynn (TU Darmstadt, Germany)

J. Menendez (Center for Nuclear Study, Tokyo, Japan)

J. Naganoma (Rice University, USA)

P. Navratil (TRIUMF, Canada)

A. Obertelli (TU Darmstadt, Germany)

S. Pastore (LANL, USA)

R. Schiavilla (Old Dominion University/Jefferson Lab, USA)

K. Flanagan (University of Manchester, UK)

D. Gazit (Racah Institute of Physics, Israel)

G. Hagen (Oak Ridge National Laboratory, USA)

R. Henning (U. of North Carolina at Chapel Hill, USA)

J. Holt (TRIUMF, Canada)

T. Katori (Queen Mary University of London, UK)

A. Schwenk (TU Darmstadt, Germany)

I. Sick (University of Basel, Switzerland)

T. Suda (Tohoku University, Japan)

K. Wendt (Lawrence Livermore National Laboratory, USA)

SCIENTIFIC REPORT:

During the last few years, the developments in many-body methods and the progress on chiral effective field theory have opened the doors for the long sought consistent and model-independent treatment of electroweak processes in nuclei. The role of many-body currents was shown to be essential to describe the properties of few nucleon systems and electromagnetic properties of light nuclei. A worldwide effort to extend these studies to medium- and heavy-mass nuclei is underway. These new developments have allowed for a more direct and consistent comparison between electromagnetic transitions and the response of nuclei. Remarkably, the understanding of electro-weak processes in nuclei impacts different fields, i.e., studies of fundamental symmetries, neutrino physics, nuclear structure, dark-matter searches, and astrophysics. The accuracy of the fundamental physics observables extracted from modern high-precision experiments is, in many cases, limited by the inaccurate knowledge of calculated nuclear structure parameters. It is therefore imperative to identify common grounds and establish new ties that could provide a deeper understanding of electroweak interactions in nuclei. The workshop addressed four major questions related to this topic: Can we derive electro-weak currents consistently with nuclear Hamiltonians? What is the regime of validity of these calculations in terms of momenta? What is the importance of many-body correlations in the nuclear wave function? And what is its connection with modern high-precision experiments?

Results and Highlights

The different approaches that are being developed towards the description of electro-weak currents consistently with nuclear Hamiltonians were presented. Chiral effective field theory has shown to be a unique tool in these developments. Thanks to these advances and the progress on ab initio many-body methods, the role of electroweak currents in nuclei has been addressed in the description of electromagnetic properties of few nucleon systems. The latest results towards the extension of these studies to medium and heavy nuclei were presented.

Through discussions with world leading experts from experiment and theory working on the field, several shortfalls in our current description of nuclear structure and dynamics were identified. While experimentalists from the different international collaborations presented the latest results and the main needs from nuclear structure theory, representatives from theoretical groups exposed the current theoretical progress on our understanding of electro-weak currents. These fruitful discussions helped to establish common short- and long-term plans that would stimulate future developments on both experiment and theory. Several open questions remain in our microscopic understanding of electromagnetic operators.

Overall, the workshop was considered a great success, and we envision follow up workshops in the future.

3.3.6 FOUNDATIONAL ASPECTS OF RELATIVISTIC HYDRODYNAMICS

DATE: May 07 – 11, 2018

ORGANIZERS:

Ulrich Heinz (Ohio State University)
Michal Heller (MPI for Gravitational Physics)
Guy Moore (TU Darmstadt)

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

The workshop aimed at exchanging recent developments in the theory of relativistic hydrodynamics, from its fundamental underpinnings to its domain of validity to its applications in heavy ion collisions. Through a week of intense discussion among leading representatives with different backgrounds (weakly vs. strongly coupled systems, formal theorists vs. phenomenologists, theories formulated in four vs. more space-time dimensions, nuclear vs. particle theorists, etc.) we sought to make conceptual advances towards understanding the transition to hydrodynamics in quantum field theories, the mathematical foundations of that theory, and the problems and successes in applying it to describing heavy ion data.

The main topics were:

- Excitations of equilibrium plasmas in quantum field theories: excitations at weak coupling through kinetic theory, at strong coupling through holographic methods, and the role of long-time tails and thermal fluctuations of hydrodynamic degrees of freedom.
- Validating hydrodynamics with ab-initio simulations of quantum field theories, and especially understanding "hydronization", the transition of a system into displaying the same behaviors as a hydrodynamical system even if it is not very close to local isotropy.
- Different formulations of hydrodynamics and its behaviors. This includes attempts at accelerated convergence of the hydrodynamic expansion, a better understanding of the microscopic nonhydrodynamic degrees of freedom, and an understanding of why the hydrodynamic expansion is asymptotic and whether it might be resummed using trans-series.

SPEAKERS:

M. Attems (University of Santiago de Compostela, Spain)

F. Becattini (University of Florence, Italy)

N. Borghini (University of Bielefeld, Germany)

J. Brewer (MIT, USA)

C. Chattopadhyay (TIFR Mumbai, India)

G. Denicol (Universidade Federal Fluminense, Brazil)

M. Dumbser (University of Trento, Italy)

J.-Y. Ollitrault (IPhT Saclay, France)

H. Petersen (Goethe University Frankfurt, Germany)

N. Pinzani Fokeeva (KU Leuven, Belgium)

L. Rezzolla (Goethe University Frankfurt, Germany)

D. Rischke (Goethe University Frankfurt, Germany)

P. Romatschke (University of Colorado Boulder, USA)

M. Spaliński (National Centre for Nuclear Research, Poland)

E. Grossi (University of Heidelberg, Germany)

J. Jankowski (University of Warsaw, Poland)

P. Kovtun (University of Victoria, BC, Canada)

L. J. Liao (Indiana University, USA)

M. Martinez Guerrero (North Carolina State University, USA)

J. Noronha (University of Sao Paulo, Brazil)

M. Stephanov (University of Illinois, Chicago, USA)

M. Strickland (Kent State University, USA)

V. Svensson (National Centre for Nuclear Research, Poland)

D. Teaney (Stony Brook University, USA)

W. Van der Schee (Utrecht University, Netherlands)

L. Yan (McGill University, Canada)

SCIENTIFIC REPORT:

The workshop had the right number of attendants so that (except for the 3 organizers) every participant could present some of their work. We had 24 talks of 30 minutes length each, with another 30 minutes allocated for discussion, as well as additional discussion time available between seminars. Since the workshop brought together scientists with very different backgrounds and expertise, ranging from phenomenology to mathematical physics and computer science, these discussions were very important and a priority of the organizers. Many of the participants were exposed to areas of theoretical physics in which they had no prior personal experience, and the workshop helped them to bridge the gaps of knowledge and intuition between their own area of expertise and those represented by participants from other subfields. This had been one of the organizers' main goals, and it was achieved. Oral feedback from many participants indicates that this aspect of the meeting was well received.

A full listing of all presentations as well as the presentation materials are available on the ECT* web site at https://indico.ectstar.eu/event/11/timetable/. Major guiding themes were

- What are the processes driving a many-particle system towards thermal equilibrium?
- How do these processes manifest themselves in relativistic heavy-ion collisions and elsewhere in the cosmos?
- What are the conditions under which hydrodynamics is applicable, and does hydrodynamics manifest itself in relativistic heavy-ion collisions and elsewhere in the cosmos?
- How can hydrodynamics be derived from microscopic dynamics, how precise are the hydrodynamic approximations derived in this way, and how can we tell?
- How accurate are numerical codes for solving the hydrodynamic equations in realistic situations, and what are the most efficient modern algorithms for solving hydrodynamics?
- What are hydrodynamic attractors, how do they arise mathematically, and how, or to what extent, does their existence explain the approach towards hydrodynamic behavior in realistically expanding systems?
- How can we use hydrodynamic modeling to extract information about the transport coefficients of very hot and dense matter (such as the quark-gluon plasma created in ultrarelativistic heavy-ion collisions) by comparison with experimental data collected at RHIC and the LHC?
- What is the role of thermal fluctuations in hydrodynamic evolution, and how can we implement them in numerical simulations?
- How are quantum anomalies, magnetic fields, and the dynamics of critical fluctuations in the neighborhood of phase transitions and critical points in the phase diagram of strongly interacting matter?

To each of these themes we heard excellent reports on the latest insights, breakthroughs, and remaining or newly open questions. Several new ideas emerged at the workshop, and we are sure that more were generated and taken home for further consideration by the participants.

Results and Highlights

At the end of the workshop, the attendants were asked what they thought were the most exciting and/or important questions and problems on which they will (or would like to) spend time in the coming years, preferably before the next workshop in this series. (A second workshop with similar goals will take place in Banff, Alberta in November 2019.) The following is a bullet list of themes and keywords that resulted from this exercise:

- ATTRACTORS:
  - Is there a formal definition of attractor?
  - What is the relevance of attractors for far-from-equilibrium hydrodynamics?
  - Do attractors exist for (3+1)-dimensional flows?
- FUNDAMENTALS OF NON-EQUILIBRIUM STATISTICAL MECHANICS:
  - How does hydrodynamic behavior emerge from underlying microscopic physics?
  - Fluctuation-dissipation theorem out-of-equilibrium?
  - Is there a controllable approach to far-from-equilibrium hydrodynamics?
  - Role and implementation of thermal fluctuations in hydrodynamics?
- NON-HYDRODYNAMIC MODES:
  - What is the role and physical interpretation of non-hydrodynamic modes or (in kinetic theory) non-hydrodynamic moments?
  - How to formalize a definition of a non-hydrodynamic mode? (Existing definition is in terms of singularities of retarded 2-point functions of conserved currents.)
  - What are parametrically slow non-hydrodynamic modes? (In Misha Stephanov's talk they were related to being in the vicinity of a critical point.)
- CODES:
  - Making a close comparison of different formulations of hydrodynamics (introducing also a set of "standard tests")
  - Incorporating ADER in heavy-ion collision codes
  - Writing holographic codes for colliding objects with finite widths, with velocity being a tunable parameter
- VARIOUS ITEMS
  - Color-charged fluids, color-separation effects?
  - Relation between what Pavel Kovtun presented in his talk and earlier works
  - Vorticity from 2-point functions?

We believe that this list of "exciting questions" (as perceived by the participants) represents the highlights of our discussions and the result of the workshop on our thinking (as a community) more accurately than could be achieved by any polished prose.

3.3.7 PROBING QCD AT THE HIGH ENERGY FRONTIER

DATE: May 21 – 25, 2018

ORGANIZERS:

Nestor Armesto (University of Santiago de Compostela)
Guillaume Clement Beuf (University of Jyväskylä)
Tuomas Lappi (University of Jyväskylä)
Cyrille Marquet (École Polytechnique, Palaiseau)

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

This workshop has focused on recent advances towards a better understanding of QCD in the high-energy regime. This field has seen many advances in theoretical developments in the recent years. On the other hand there is a broad experimental program at the LHC, and active plans for new deep inelastic scattering experiments at high energy. The goal of the workshop was to focus on recent advances that are pushing the theory of QCD in the high energy limit to higher orders in perturbation theory, and towards a controlled first principles understanding of new processes, such as the initial stages of heavy ion collisions, exclusive processes and multi-particle collisions.

The main topics were:

- Phenomenology of QCD at high energy/low x
- Higher order calculations and resummations in QCD at low x
- Correlations of produced particles in high-energy collisions
- Relations between the CGC, BFKL and TMD formalisms
- Links between low x QCD and Heavy Ion Collisions

SPEAKERS:

T. Altinoluk (National Centre For Nuclear Research, Poland)

L. Apolinário (LIP, Portugal)

M. Barabanov (JINR, Russia)

R. Boussarie (Institute of Nuclear Physics PAN, Poland)

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

G. A. Chirilli (University of Regensburg, Germany)

B. Ducloué (IPhT Saclay, France)

A. Dumitru (Baruch College, City University of New York, USA)

P. Guerrero Rodríguez (CPHT École Polytechnique, France)

Y. Mulian (IPhT, France)

H. Mäntysaari (University of Jyväskylä, Finland)

R. Paatelainen (Helsinki Institute of Physics, Finland)

A. Ramnath (University of Jyväskylä, Finland)

A. Sabio Vera (Universidad Autónoma De Madrid, Spain)

M. Serino (Ben Gurion University of The Negev, Israel)

A. Stasto (Penn State University, USA)

P. Taels (INFN Pavia, Italy)

D. Triantafyllopoulos (ECT*/FBK, Italy)

K. Watanabe (Jefferson Lab, USA)

M. Hentschinski (Universidad De Las Americas Puebla, Mexico)

E. Iancu (IPhT, France)

A. Kovner (University of Connecticut, USA)

K. Kutak (IFJ PAN, Poland)

M. Mace (Stony Brook University/Brookhaven National Lab, USA)

L. McLerran (Institute For Nuclear Theory, University of Washington, USA)

S. Yi Wei (CPHT École Polytechnique, France)

D. Wertepny (Universidade De Santiago De Compostela, Spain)

M. Winn (Laboratoire de l'accélérateur linéaire, France)

SCIENTIFIC REPORT:

Quantum Chromodynamics (QCD) is well established as the correct theory for the strong nuclear force, and is thus one of the main pillars of the Standard Model of particle physics. In QCD, perturbative calculations can be done in a controlled way despite confinement, thanks to collinear factorization theorems based on the parton picture. However, this very successful approach is valid only for hard scattering processes, with for example a large momentum transfer or the production of heavy particles, whereas soft processes are driven by non-perturbative physics.

The LHC, the FCC and future deep inelastic scattering experiments probe QCD at unprecedentedly high collision energies. This opens up a large phase space for semi-hard physics. Indeed, typical high-energy collisions of protons or nuclei, as performed at the LHC, do not involve a too hard momentum transfer, far lower than the total energy of the collision. That hierarchy of scales produces large logarithms in the perturbative series, which require a resummation, first performed in the BFKL formalism. That resummation leads to an effective increase with energy of the phase-space density for gluons.

Eventually, individual quarks and gluons are not resolved anymore in semi-hard high-energy collisions, but rather undergo coherent multiple scattering, which is beyond the scope of the usual perturbative QCD approach. In that case, the nonlinearity of the gluon field dynamics is fully relevant, and the partonic picture of QCD breaks down. Nevertheless, in that regime of gluon saturation as well it is possible to build a framework allowing systematic calculations from QCD first principles. Instead of relying on the parton picture for an incoming hadron or nucleus, one can describe its soft gluon component as a strong semi-classical field, and then perform perturbative calculations in the presence of that background field, in the eikonal approximation justified by the high-energy kinematics. That approach, often called Color Glass Condensate (CGC), is relevant for collisions processes at high energy and not too hard.

Moreover, when colliding nuclei instead of hadrons, the validity regime of that approach widens towards lower energies, due to the enhanced non-linear high-density effects. The gluon saturation dynamics is then relevant for Deep Inelastic Scattering (DIS) at very low x on a proton (or a nucleus) - possibly at HERA and at a future Electron Ion Collider (EIC)- and for proton-proton (pp) and proton-nucleus (pA) collisions at LHC (and to some extent at RHIC). That approach also allows in principle to calculate the dynamics in the earliest stages of heavy ions collisions at LHC and RHIC, providing the initial conditions for the formation of a QGP.

High-energy QCD, particularly in the gluon saturation regime, has been studied mostly at leading order (LO) in the QCD coupling constant (including however the resummation of high-energy leading logarithms (LL) together with running coupling effects). At this accuracy, the results are in qualitative agreement with the available data from the experiments at the LHC or at earlier collider, like HERA or RHIC. However, theoretical uncertainties remain too large to make precise, quantitative predictions.

It is then necessary to push the theoretical calculations to the next-to-leading order (NLO) in perturbation theory, with resummation of next-to-leading logarithms (NLL), in order to obtain fully reliable theoretical results, and compare them with the available experimental data. Such accuracy has been the standard for a while for studies in the linear BFKL regime. However, in the non-linear CGC regime, theoretical calculations at that accuracy have become available only recently, and no phenomenological study fully at NLO has yet been performed. Both in the linear and in the nonlinear regimes, higher orders bring specific complications. Notably, a naive NLL resummation leads to unstable results, requiring further resummations.

Moreover, both the transition from the hard process physics to the semi-hard high-energy physics and the transition from the linear to the nonlinear regimes are expected to be smooth and gradual. Hence, it is difficult to delimitate unambiguously the validity regimes of each of the theoretical approaches to QCD, both a priori or by comparison to the data.

A possible solution to this issue is to consider less inclusive observables, such as multi-particle correlations, which are believed to be sensitive to the dynamics in a more detailed way.

Results and Highlights

The workshop was a very useful opportunity to bring together people in the community to review the recent progress on theoretical issues. It also reinforced emerging connections between different approaches that have heretofore been pursued in somewhat separate communities. Instead of separate discussion sessions, the most productive discussions took place during and after the talks. These discussions gave the workshop participants the possibility to understand both the more physical and also technical aspects of recent calculations, providing a more clear understanding in the community of the relations between different theoretical formulations.

- The workshop started with several talks on recent calculations of scattering processes at next-to-leading order in QCD perturbation theory in the “dipole picture” of dilute-dense scattering process. Here, Paatelainen and Boussarie discussed inclusive and exclusive DIS processes, Iancu and Ducloué single inclusive particle production in proton-nucleus collisions, Mulian dijet and trijet production and Triantafyllopoulos high energy evolution. These calculations represent the very forefront of theoretical progress in the field, and the discussions at this workshop were helpful in assessing the status of the field and what still needs to be done to apply the results to phenomenology. In particular, one has been able to identify crucial technical issues related to high energy factorization and the treatment of the running coupling in these calculations, but in spite of some suggestions there is still no consensus in the field on what is the best way to solve these in practical calculations.
- Several talks (Mäntysaari, Dumitru, Ramnath) also discussed implications of JIMLWK evolution for different processes and Serino the interpretation of high energy evolution in terms of the concept of entropy. Although these works are still at leading order in perturbation theory, they represent qualitatively new kinds of applications and interpretations of the CGC formalism.
- Several talks discussed the current state of the art in phenomenological applications. These are mostly still at leading order accuracy, but covering a larger set of processes that eventually must also be addressed at NLO: subeikonal corrections and spin (Chirilli), exclusive vector mesons (Cepila), inclusive heavy flavor (Watanabe)
- The prospect of probing the small-x wave function through multi-particle correlations has raised a lot of discussion lately. Here, one talk (Kovner) gave an overview of the overall physical picture. This was followed by several talks (Wertepny, Altinoluk, Mace, Wei) of specific recent calculations.
- An important aspect of the program was to elucidate connections to related fields that have typically used a slightly different language, but need to be discussed in a more coherent way to make progress. Here two talks (Taels, Kutak) discussed the physics of the transverse momentum-dependent distribution (TMD) formalism, which is the momentum-space counterpart of the CGC dipole picture that is most naturally expressed in coordinate space. Two talks (Sabio Vera, Hentschinski) discussed recent advances in the dilute-limit BFKL picture; in particular the recent rederivation of the Lipatov effective action for BFKL evolution from the CGC picture. The physics of the initial stage of heavy ion collisions is an important application of the CGC formalism,

but requires a different calculational approach because it is not done in the simple dilute-dense limit. Here McLerran discussed the space-time structure of baryon number at forward rapidities, and Guerrero Rodriguez the initial correlation structure for hydrodynamics. The formalism of jet quenching in a quark-gluon plasma is very similar to the CGC, and a closer interaction between communities working on the two could be very helpful, this topic was discussed in one talk (Apolinário).

- On the second day of the workshop there was one extensive review (Winn) of experimental results from the LHC experiments relevant for the physics discussed at the workshop.

Overall the general view of the organizers was that the workshop was very successful. There is a lot of ongoing progress in the field, and talks at this workshop identified challenges that must be addressed in the future to connect theory to experiment. We anticipate that this will require several new meetings with a similar structure. In some sense this workshop was a premature start for the “Small-x physics at the LHC and future DIS experiments” NRA (coordinated by workshop organizers N. Armesto and T. Lappi and sharing many of the workshop participants as network members) of the Strong2020 Horizon 2020 network, which had been recently submitted at the time of the workshop and has since been approved by the Commission. A continuation of the efforts within the NRA (and hopefully also with the ECT*) is a goal for the organizers.

3.3.8 GAUGE TOPOLOGY 3: FROM LATTICE TO COLLIDERS

DATE: May 28 – June 01, 2018

ORGANIZERS:

Massimo D'Elia (University of Pisa)
Edward Shuryak (Stony Brook University)

NUMBER OF PARTICIPANTS: 22

MAIN TOPICS:

As in previous editions, the purpose of this meeting was to discuss the most recent developments in many and interrelated aspects of topology in Gauge Theories.

The main topics were:

- General observables sensitive to color confinement, deformed QCD.

  Electric color confinement is a complicated phenomenon, detected by VEV of the Polyakov line. While in general it happens at strong coupling, in some special cases or in versions of the "deformed QCD" with extra action, it may persist at weak coupling. If so, a semiclassical description is possible.

- Topological susceptibility at finite temperatures.

  The topological susceptibility (and higher moments of the topological charge distribution) reflects fluctuations of the topological charge as a function of temperature. It is expected, and confirmed by lattice studies, that at high temperatures (T>350 MeV) topology can be described by a dilute Instanton gas. Establishing precise properties of such fluctuations at lower temperatures, all the way to T=0, is important for understanding the role of gauge topology in deconfinement and chiral transitions.

- Semiclassical theory of instanton-dyons.

  Instanton constituents known as instanton-dyons (or instanton-monopoles) are semiclassical solitons possessing topological, electric and magnetic charges. Analytical and numerical studies of their ensemble, at T from Tc/2 to 2Tc, have shown that they drive the deconfinement and chiral transitions. Yet, quantitative calculations of topological fluctuations and their comparison to the lattice data are still to be done.

- Monopole effects in the quark-gluon plasma.

  For a long time confinement has been associated with Bose-Einstein condensation of color-magnetic monopoles. Recent work has shown how chiral symmetry breaking can also be explained in the monopole framework. Phenomenological application to rescattering in the QGP and recent work on monopole contribution to jet quenching establish monopoles as important quasiparticles needed to explain the heavy-ion collisions. However, in spite of many lattice works identifying monopoles, we still do not have an analytic understanding of what they are. Unlike some theories with extended supersymmetry, QCD does not have adjoint scalars which are needed for the 't Hooft-Polyakov solution. Yet it has been shown that the partition function in terms of monopoles and the semiclassics in terms of instanton-dyons lead to identical partition functions. The relation between them, via the so-called Poisson duality, is not on the level of configuration-to-configuration.

- Trans-series and resurgence.

  Trans-series is a mathematical construction combining perturbative series with non-perturbative (instanton or semiclassical) series, in a way in which unphysical effects (imaginary parts of the Borel transforms) cancel out between them. Resurgence is a generic name for relations connecting perturbative series around the vacuum with perturbative series around instantons. A number of such relations, recently confirmed by hard explicit calculations for some quantum-mechanical examples, are known. Whether such relations exist and what can be their derivation for field theories remains unknown.

- Chiral magnetic effect, sphalerons.

  Sphalerons are semiclassical solutions, which describe thermal excitations of the topological charge. In heavy-ion collisions these describe the possible creation of domains with chiral imbalance. In this case, a number of effects are expected, e.g. a non-dissipative current along the applied QED magnetic field. Lattice and other numerical studies of these effects are in progress, as well as experimental search for these effects in heavy-ion collisions.

SPEAKERS:

A. Athenodorou (Cyprus Institute, Cyprus)

C. Bonanno (Pisa University and INFN, Italy)

C. Bonati (Pisa University and INFN, Italy)

M. Cardinali (Pisa University and INFN, Italy)

M. Caselle (University of Torino, Italy)

F. de Soto (Univ. Pablo de Olavide and Univ. de Granada, Spain)

G. Dunne (University of Connecticut, USA)

C. Gattringer (University of Graz, Austria)

L. Glozman (University of Graz, Austria)

J. Greensite (San Francisco State University, USA)

M. Faber (TU, Wien, Austria)

A. Kotov (Moscow Institute of Physics and Technology, ITEP, JINR, Russia)

M.P. Lombardo (LNF, INFN, Frascati, Italy)

K. Marathe (City University of New York, USA)

A. Ramamurti (Stony Brook University, USA)

S. Sharma (The Institute of Mathematical Sciences, India)

M. Shifman (University of Minnesota, Minneapolis, USA)

E. Shuryak (Stony Brook University, USA)

N. Tanji (ECT*/FBK, Trento, Italy)

J. Verbaarschot (Stony Brook University, USA)

SCIENTIFIC REPORT:

Progress in computer power and algorithms has recently allowed to simulate QCD with realistic quark masses, with results directly comparable with hadronic phenomenology. In this sense, one may say that QCD is numerically solved. This, however, does not imply that it is well understood, and many phenomena such as, e.g. deconfinement and chiral phase transitions, need to be studied in much greater detail. As in the previous workshops of this series, this one also focused on the role of topological solitons, namely instantons and their constituents (instanton-dyons), magnetic monopoles, vortices as well as QCD flux tubes.

Recently new numerical lattice measurements of the topological susceptibility, and even higher moments of the topological charge distribution in the QCD vacuum have been performed by a number of groups. Their findings indicate that topology is present in a form of a dilute ensemble of instantons at rather high temperatures only, T > 400 MeV or so. Those are interesting for the axion phenomenology, but unfortunately not to most QCD applications. In particular, the quark-gluon plasma created in heavy-ion collisions at RHIC and LHC has temperatures well below this value.

New studies regarding the topological susceptibility were reported by Claudio Bonati, Maria Paola Lombardo and Sayantan Sharma. Extensive studies of the theta-dependence in $CP^{(N-1)}$ models have been reported by Claudio Bonanno. The talk by Andrea Athenodorou instead focused on the determination of the topological susceptibility in QCD by gluonic and fermionic observables, and on the relation between topology and chiral symmetry breaking. Feliciano de Soto reported on extensive study of lattice gluon correlation functions, focusing on the ratio of the powers of the 3-point to 2-point ones, producing an "effective coupling". While at large momenta it shows the expected perturbative behavior, at small momenta k<< 1 GeV it shows a new regime proportional to k^4. The authors argued that such behavior is obtained in an ensemble of instantons. Performing various cooling procedures, such as the gradient flow, they observe that the perturbative behavior is changed to the k^4 regime even at large momenta. The authors find that cooling dynamics is well explained by the instanton-antiinstanton annihilation process. The "cooled" results depend on the cooling time, but the authors were able to extrapolate to time zero, and conclude that the instanton density in the QCD vacuum is about one order of magnitude higher than what is used in the "instanton liquid model". Mikhail Shifman discussed theories with adjoint fermions and a compactification to R^3xS^1 with variable periodicity angle φ. The central question is whether there can be preservation of confinement (unbroken center symmetry) even in weak coupling (that is, at small circle radii). He concluded that this happens if |φ|<2*π/3Nc. Shifman emphasized that the absence of the deconfinement transition must imply that a very strict "spectral conspiracy" between the Fermi and Bose Reggions must exist, to cancel the Hagedorn transition. Related to the same topic was the talk by Marco Cardinali, who showed that the topological properties of pure gauge theories compactified with a small radius but with a trace deformation which keeps center symmetry unbroken are very similar to those of the standard confined phase.

Edward Shuryak discussed the progress made in finite-temperature QCD using semiclassical objects known as instanton-dyons, and their interrelation with monopoles. He concluded that in theories in which both are well-known semiclassical objects, the corresponding partition functions are related by the so-called Poisson duality. This fact was recently used to get some information about QCD monopoles for which semiclassical a description is not available. Shuryak also discussed variable periodicity angles for fermions - not adjoint but fundamental- as for quarks. He showed that the semiclassical theory based on instanton-dyons has multiple phase transitions as a function of these angles, which are explained by "jumps" of the topological zero modes from one dyon type to another. He discussed a particular setting in which chiral symmetry (not confinement) is preserved even in the weak-coupling limit. The talks of both Shuryak and Adith Ramamurti discussed the growing role of monopoles – as quasiparticles in quark-gluon plasma – in heavy-ion phenomenology, such as viscosity and jet quenching parameters.

Sayantan Sharma discussed the $U_A(1)$ axial chiral symmetry at finite temperatures and its topological origins. He presented lattice data focusing at the lowest Dirac eigenvalues and their relation instanton-antiinstanton pairs, as well as to the instanton-dyons. Both the peak at zero eigenvalues and the spectrum of quasi-zero modes contribute to the violation of the $U_A(1)$ axial chiral symmetry. Gerald Dunne gave a very pedagogical review of semiclassical theory and related trans-series. Using a number of examples, mostly integral representations of certain special functions, he showed how the inclusion of non-perturbative terms cancels the divergent part of the perturbative series.

Christof Gattringer described a lattice approach to baryons in which their motion as a whole is included explicitly and separated from color-dependent interactions between quarks. A review of the effective theory of QCD flux tubes, known also as QCD strings, has been given in the talk by Michele Caselle. He has shown that with a recent increase in precision of the lattice evaluation of the static potential it was possible to see not only the main confining term O(r) and universal Lüscher term O(1/r), but the next universal term $O(1/r^3)$ and even new term of order $O(1/r^4)$, originating from the string boundary action. There was a discussion on how these results can be generalized to finite temperature as well as to the theory of Pomerons. A general discussion about confinement was provided in the opening talk by Jeff Greensite, who illustrated a new possible confinement criterion based on the possibility of flux tube creation.

Leonid Glozman discussed a large set of hadronic correlation functions (calculated in spatial direction) at relatively high (T about 400 MeV). A very striking observation is that the results are grouped into multiplets which are larger than those expected from restoration of only $SU(N_f)$ and $U_A(1)$ chiral symmetries. Glozman pointed out that they can be interpreted as an effective switching off of all magnetic interactions between quarks. Sphaleron rates at finite temperatures were discussed by A. Kotov, who compared the perturbative and lattice results. The related talk, about the chiral anomaly and quark production at early stages of heavy-ion collisions, has been given by N. Tanji. An interesting talk on topological excitations in a scalar SO(3) theory was given by Manfred Faber. A general overview on the usage of gauge fields and their topology in mathematics has been given by K. Marathe.

Results and Highlights

The main progress reported at this conference, which has been achieved in the field since the last Gauge Topology 2 workshop we had at ECT* in 2016, can be summarized as follows:

1. The determination of the theta-dependence in QCD and QCD-like theories has reached a mature level of precision: large-N predictions are being checked, results for full QCD at high T, which are relevant to axion cosmology, see a general convergence of efforts and results from different lattice groups;
2. Studies regarding the role of monopoles and dyons have been the subject of renewed interest, which will hopefully lead to a better understanding of many important properties of the QGP in the near future;
3. Even if it is a quantity of interest since the early days of QCD, the color flux tube, its dynamics and effective theory description represent a continuous source of novel understanding of the non-perturbative dynamics of strong interactions;
4. Chiral properties in the confined phase and in the high-temperature phase are now known with a high level of precision from lattice simulations; new unexpected and effectively enlarged symmetries are emerging in the high-temperature phase;
5. Yang-Mills theories, compactified on a circle with small radius and with preserved center symmetry become more and more interesting as a laboratory where non-perturbative properties can be inferred in a semiclassical regime;
6. A deep interplay between perturbative expansions and non-perturbative phenomena is being unveiled by the steady progress achieved with resurgence theory.

As in the previous edition, most of the success of the workshop has been based on the possibility of ample and interesting discussions among the participants, which have been fostered by the exceptional environment provided by ECT*.

3.3.9 NEW IDEAS IN CONSTRAINING NUCLEAR FORCES

DATE: June 04 – 08, 2018

ORGANIZERS:

Andreas Ekström (Chalmers University of Technology)
Jason Holt (TRIUMF, Vancouver)
Joel Lynn (TU Darmstadt)
Ingo Tews (INT, University of Washington)

NUMBER OF PARTICIPANTS: 25

MAIN TOPICS:

A sound theoretical description of the nuclear force is pivotal for understanding many important physical observables over a wide range of energy scales and densities. For example, in few-body physics where there exists tantalizing experimental evidence for exotic few-neutron resonances; in nuclear structure observables in the medium- to heavy- mass region of the nuclear chart, in particular towards the driplines, which set the nucleosynthesis path far away from stability; and in astrophysical phenomena, such as the properties of neutron stars, an excellent example of a system that can only be studied indirectly here on earth. A systematic and precise theory for nuclear Hamiltonians is crucial to providing accurate predictions for these systems.

The main topics were:

- Constraining nuclear forces with few- and many-body observables
- Current limitations of nuclear Hamiltonians
- Improving nuclear forces with novel fitting strategies and higher orders in chiral EFT
- Power counting: Beyond Weinberg
- Constraining nuclear forces from lattice QCD calculations

SPEAKERS:

C. Barbieri (University of Surrey, UK)

Z. Davoudi (University of Maryland, USA)

C. Drischler (University of California, Berkeley, USA)

A. Ekström (Chalmers University of Technology, Sweden)

E. Epelbaum (Ruhr-University Bochum, Germany)

C. Forssén (Chalmers University of Technology, Sweden)

S. Gandolfi (Los Alamos National Laboratory, USA)

A. Gezerlis (University of Guelph, Canada)

H. W. Griesshammer (George Washington University, USA)

H. Krebs (Ruhr-University Bochum, Germany)

D. Lee (Michigan State University, USA)

B. Long (Sichuan University, China)

M. Piarulli (ANL, USA)

A. Roggero (LANL, USA)

J. Ruiz de Elvira (University of Bern, Switzerland)

K. Sasaki (YITP, Kyoto University, Japan)

A Schwenk (TU Darmstadt, Germany)

R. Stroberg (Reed College, USA)

U. van Kolck (IPNO, France)

C. Wellenhofer (TU Darmstadt, Germany)

K. Hebeler (TU Darmstadt, Germany)

H. Hergert (NSCL/FRIB, Michigan State University, USA)

J. Holt (Texas A&M University, College Station, USA)

S. Koenig (TU Darmstadt, Germany)

S. Wesolowski (Salisbury University, USA)

C. Yang (George Washington University, USA)

SCIENTIFIC REPORT:

Within the last few decades, significant progress in nuclear physics has been made possible, in part, due to the algorithmic and theoretical development of powerful *ab initio* many-body methods and their combination with modern interactions from chiral effective field theory (EFT). The many-body methods amount to different approximate solutions of the many-body Schrödinger equation and include, e.g., quantum Monte Carlo methods, the no-core shell model, the coupled-cluster method, the self-consistent Green's function method, and the in-medium similarity renormalization group. With increasing computational power and continuous development of these many-body methods, we have entered an era of precision nuclear physics where many-body errors can be better controlled and very often accounted for in a systematic way. The remarkable agreement between predictions of different many-body approaches is also very encouraging. Overall, the tremendous progress in recent decades means that uncertainties from the nuclear Hamiltonian now dominate over uncertainties from the many-body methods.

Modern nuclear Hamiltonians are derived within chiral EFT, which is constrained by the symmetries of the fundamental theory, quantum chromodynamics. In contrast to phenomenological interactions, chiral EFT provides an organized expansion that offers a systematic way to improve nuclear interactions order by order. Assuming a controlled, converging expansion, this allows for the estimation of theoretical uncertainties. The expansion is governed by a power-counting scheme that arranges different interaction mechanisms according to their relative importance. However, several open questions within chiral EFT persist. These include questions about renormalization and the power-counting scheme itself, about optimization and fitting to data, about regularization, and about the role of Bayesian uncertainty analysis.

These open questions can lead to sizable uncertainties in the nuclear Hamiltonian that must be quantified or at least estimated. Currently, the systematic uncertainties of the nuclear Hamiltonian are the main limitation for making accurate predictions for, e.g., the equation of state of nuclear matter, the nuclear symmetry energy and its density dependence, nuclear energy levels far away from stability, the location of nuclear driplines, and *ab initio* nuclear matrix elements for neutrinoless double beta decay. Clearly, any uncertainty in nuclear physics will propagate and impact predictions for astrophysics, e.g. for the structure and the mass-radius relation of neutron stars and simulations of supernovae and neutron-star mergers, as well as to searches for beyond Standard Model physics, such as the search for Majorana neutrinos and direct detection of dark matter. To improve the nuclear Hamiltonian, and reach a precision era in nuclear physics, significant effort has been invested within the last few years in several complementary directions. These include developing new optimization strategies and statistical analyses of theoretical models, improved regularization schemes and analyzing the renormalization group properties of nonperturbative EFTs, or exploring possible paths of matching nuclear interactions to lattice QCD simulations.

Results and Highlights

Given the diversity of the participants' research areas and the controversial or disputable nature of some of the topics, the workshop was very lively and filled with several long debates and discussions. Although this can be either distracting or productive, depending on the attitudes of the participants, in this case, it was very productive. From the feedback that we received, we gathered that the community responded very well to our efforts to both acknowledge the successes of current approaches and to confront their shortcomings. In fact, the organizers were asked by an associate editor of the Journal of Physics G, who had not attended the workshop, to prepare a Topical Review covering the topics of the workshop and the content of the talks and discussions. Essentially, we are now preparing a "white paper" on these topics based on the workshop. We would also like to stress that our workshop was, by intention, particularly attended by young scientists, with 64% of the participants younger than 40, and 40% of the participants in the post- doctoral stage of their careers. Below, we present some highlights that are organized according to the main topics of the workshop. Though consensus was not always reached, the workshop nevertheless served in these cases to clarify open questions, and spawn new research projects.

Constraining nuclear forces with few- and many-body observables

One of the most interesting agreements reached among the participants was that fits of nuclear forces may require some input from many-body observables. Though the 25 participants are by no means a complete representation of the low-energy nuclear physics community, they represent a cross section of it and this agreement in principle marks a shift in thought to a new mindset, away from a more fundamental one where two-body interactions should be based solely on two-body experimental inputs and three-body interactions should be based solely on three-body experimental inputs. Instead, it was recognized that it is key to inform low-energy theories using low-energy data. It is however not entirely clear how to *a priori* determine the relevant momentum scale for an observable of a nuclear bound state.

A second theme that was addressed in some detail was the question of whether or not few- or many-body scattering observables should be included as constraints, as reproduction of scattering phase shifts alone is not sufficient. Though, in this case, no real consensus was reached, various participants who have explored this avenue have found nuclear interactions to be significantly sensitive to scattering observables such as *n-α*, *α-α*, or *N-d* scattering. Most participants agreed that this is a direction worthy of more investigation.
During the discussions, it was also pointed out that a theoretical model can be optimized to any set of data if the theoretical uncertainty is properly accounted for. Although, it is a theoretical and computational challenge to incorporate expected theory errors *a priori.*

Current limitations of nuclear Hamiltonians

One of the main topics of conversation was the question "Up to which densities/momentum scales can Hamiltonians derived within chiral EFT be useful?" Chiral EFT is a low-momentum expansion, and so there must be a point at which the relevant momentum scale in a nuclear system (for example, extended nuclear matter) is too large to trust the expansion. However, at what values of density or nucleus size or scattering energy this takes place is difficult to know *a priori*. While determinations of the breakdown scale using Bayesian methods put it around 600 MeV, or even below, a question addressed in the workshop was what is the relevant momentum scale in a given system, and what is the resulting expansion parameter. The participants agreed that Bayesian inference is a tool well suited to address these questions.

Also, a second major topic throughout the workshop was the determination of meaningful uncertainties. Workshop participants had longer discussions about the question to which extent the comparison of individual Hamiltonians makes sense, if no uncertainties are provided. The participants agreed, that calculations using chiral interactions should reflect truncation uncertainties in the future, as well as an order-by-order analysis of the computed observables. In this context, the participants discussed if the inclusion of Delta degrees of freedom is necessary in chiral interactions. It was shown by some participants, that several observables show an improved convergence behavior in the Delta-full theory.

Improving nuclear forces with novel fitting strategies and higher orders in chiral EFT

Several pathways were addressed by the participants. The first one was, that nuclear lattice EFT offers a way to improve nuclear interactions by providing access to e.g. α-α scattering data, if the continuum limit is within reach. Indeed, this would enable the lattice to directly provide information about nuclear interactions that could be used in other many-body methods. In this context, it was discussed if finite temperature observables could be useful to constrain nuclear interactions, as calculations at finite temperature are easier to perform on the lattice.

Another important topic was to fit nuclear forces using Bayesian inference and/or Gaussian processes, which by design easily offer a statistically meaningful interpretation of the posterior distributions of coupling constants.

Power counting: Beyond Weinberg

During the workshop, several modified and related power counting schemes were presented. The main question in this topic was how the many-body community can include modified power-counting schemes in many-body methods. Several problems appear. For example, in some versions of the modified power counting, there are spurious bound states in certain *NN* scattering channels. This may present a difficulty for some many-body methods. The participants agreed that it would be good if the power-counting community could provide interactions, which project out these bound states. Another problem is the analysis of high-cutoff potentials, which are too “hard” to be treated in most of the many- body methods. However, it was established, that “softer” (lower cutoff) interactions can be used, if renormalization group invariance has already been established in smaller nuclear systems. Despite the challenges, the many-body community was eager to implement new power counting schemes to hopefully make progress in addressing the shortcomings of chiral interactions and the question of nonperturbative renormalization in EFT.

Constraining nuclear forces from lattice QCD calculations

Finally, the participants addressed the prospect of inputs and constraints from lattice QCD. Lattice QCD provides us with the possibility to address systems that are difficult to reach experimentally. We discussed interactions that were derived directly from the lattice and initial results for nuclei using these interactions. A question that was raised was how systematically these interactions can be constructed, since they depend on the lattice setup.
The discussions brought up a clearer way forward; to construct a pionless EFT that is adjusted to lattice results. The participants discussed the problem that this EFT leads to an oxygen-16 nucleus which is unbound with respect to break-up into four α particles (helium-4 nuclei), which in turn lead to the question of whether pionless EFT is valid for these larger systems and the role of power counting and perturbative pions.

3.3.10 EXPLORING NUCLEAR PHYSICS WITH ULTRACOLD ATOMS

DATE: June 18 – 22, 2018

ORGANIZERS:

Tilman Enss (Heidelberg University)
Alex Gezerlis (University of Guelph)
Joseph Thywissen (University of Toronto)

NUMBER OF PARTICIPANTS: 24

MAIN TOPICS:

Over the last two decades, experimentalists working with cold atomic systems have been able to trap, cool, and probe dilute gases of neutral fermionic atoms, directly accessing quantum many-body properties. Importantly, experimentalists have been able to tune the interactions between the particles via the use of Feshbach resonances: this tunability provides access to novel states of matter (such as unitarity in three-dimensional, homogeneous and trapped, cold Fermi systems) as well as regimes known from nuclear physics but beyond experimental reach with nucleons (like the physics of neutron-star crusts and heavy nuclei). Thus, compact stars, which exhibit several exotic properties, can be indirectly probed via the use of experiments with cold Fermi atoms. This workshop explored how to expand upon this success, to further constrain nuclear many-body theory with cold-atom experiments.
The workshop focused on how experiments with cold Fermi atoms can help constrain nuclear theory.

The main topics were:

- Population-imbalanced systems
- Two-, three-, and many-species systems
- Lower-dimensional systems
- Optical lattices and neutron-star crusts

SPEAKERS:

W. Bakr (Princeton University, USA)
D. Blume (University of Oklahoma, USA)
A. Bulgac (University of Washington, USA)
J. Carlson (LANL, USA)
N. Defenu (Heidelberg University, Germany)
M. Horikoshi (The University of Tokyo, Japan)
S. Jensen (Yale University, USA)
S. Jochim (Heidelberg University, Germany)
D. Lacroix (IPN Orsay, France)
H. Moritz (University of Hamburg, Germany)
N. Navon (Yale University, USA)
A. Nicholson (University of North Carolina, Chapel Hill, USA)
A. Recati (University of Trento, Italy)
C. Sa de Melo (Georgia Institute of Technology, USA)
T. Schaefer (North Carolina State University, USA)
J. Thomas (North Carolina State University, USA)
M. Urban (IPN Orsay, France)

G. I. Martone (LPTMS, CNRS and Université Paris-Sud, France)

S. Yip (Institute of Physics, Academia Sinica, Taiwan)

SCIENTIFIC REPORT:

The workshop brought together a diverse group of researchers from nuclear theory, cold atom theory, and cold atom experiment. All speakers made an effort to present their methods and results to a diverse audience. Different from a typical meeting, discussion time after each talk was nominally "unlimited": talks were ordered, but without specific start times in each session. As a result, 30-minute talks were often followed by 30 minutes of discussion. This allowed exchanges and in-depth discussions between practitioners from different fields.

Results and Highlights

A central goal of the meeting was to design demanding benchmarks of theory through analogue quantum simulations. The equation of state provides a promising example: experimental data from unitary Fermi gases has stimulated a lively discussion (Jensen, Bulgac) of the systematic effects of cutoffs. While much previous cold-atom work focused on describing zero-range interactions at unitarity, new cold-atom measurements (Horikoshi) and proposals to optically tune the atomic effective range independently from the scattering length (Thomas) could match the finite range in nuclear matter more closely and thereby allow for a meaningful comparison with nuclear theory. This is intimately connected with the search for good density functionals for cold atoms and nuclear matter: several talks related to how Quantum Monte Carlo (Carlson, Bulgac), lattice gauge theory (Nicholson), exact few-body calculations (Blume) and diagrammatic approaches (Lacroix) can couple to a DFT approach. In this context, the newly achieved experimental control over external trapping potentials in cold fermionic gases (Moritz) aims to realize unconventional paired phases in spin polarized systems, and can provide new data to test spin-polarized DFT.

Beyond thermodynamics, several speakers addressed the dynamical properties of strongly interacting fermions both in nuclear and cold atom physics, in particular the pairing mechanism in theory (Gezerlis, Urban, Jensen) and cold atom experiment (Jochim), which is remarkably similar. Even in scale-invariant unitary Fermi gases where the equation of state is known, a challenge is the unified description of transport both in dense collisional and dilute collisionless regions in space, which can be achieved by anisotropic hydrodynamics (Schaefer). Breaking of scale invariance strongly affects the transport properties (Defenu), and quantum bounds to transport coefficients (Enss) could provide a unifying framework for discussing transport in strongly interacting nuclear and atomic systems and beyond.

Finally, new cold-atom transport experiments on quantum turbulence (Navon) could give an intriguing glimpse of vortices in neutron stars (Bulgac). Surprisingly, lattice particle transport measurements (Bakr) challenge theory at relatively high temperature on the order of the bandwidth, while previous numerical efforts in condensed matter have largely focused on lower temperature in the context of high-Tc superconductors. Looking ahead, new types of excitations are found in multicomponent Bose mixtures (Recati, Martone) and three-component fermions (Sa de Melo), or may lead to nonanalytic terms (Yip). These proposals aim to create quantum simulations with degrees of freedom closer to QCD. On the other hand, introducing dynamical gauge degrees of freedom into cold-atom experiments remains an outstanding challenge.

The meeting highlighted several future avenues of exploration. Improved magnetic susceptibility measurements of unitary Fermi gases would help benchmark recent QMC calculations. Similarly, more sensitive measures of the pairing gap would be helpful. Uniform trapping potentials ("box traps") will address the expected breakdown of the local-density approximation in Fermi superfluids. Discussion also pointed out how lattice-based experiments are so far disconnected from nuclear theory calculations, even though the latter are by themselves often lattice-based. Given the rapid progress in lattice quantum simulators, this could be fertile ground for future synergy between the two fields.

3.3.11 NUCLEON SPIN STRUCTURE AT LOW Q: A HYPERFINE VIEW

DATE: July 02 – 06, 2018

ORGANIZERS:

Ido Antognini (ETH Zürich, Paul Scherrer Institute)
Jian-Ping Chen (JLab, Newport News)
Alexandre Deur (JLab, Newport News)
Vladimir Pascalutsa (Universität of Mainz, PRISMA)
Marc Vanderhaeghen (Universität of Mainz, PRISMA)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The low-energy strong interaction, underpinned by Quantum Chromodynamics (QCD), exhibits a variety of non-perturbative phenomena arising at low-energy (or low-Q) - color confinement, mass gap generation, dynamical chiral symmetry breaking, - which yet remain to be fully understood within the QCD itself. Q is the magnitude of the momentum exchanged in the scattering reaction used to probe the nucleon.
The nucleon spin structure allows one to explore these phenomena, using the spin as leverage. New developments on the nucleon spin structure at low-Q are exciting and pertain to both theory and experiments: results from the spin physics program at Jefferson Lab are being finalized, while new experiments on spin polarizabilities at large distance are planned or being performed at HIγS, JLab and MAMI. These developments are complemented by significant theoretical advances. Meanwhile, atomic experiments aimed at measuring the ground-state hyperfine splitting in muonic hydrogen are being prepared at PSI (Switzerland), RAL (UK) and J-PARC (Japan). These new measurements provide a new tool to either precisely study the proton structure or to probe possible new physics if the understanding of the proton structure is precise enough.
The purpose of this workshop was to bring together experimentalists and theorists in the nuclear and atomic physics communities with expertise relevant to nucleon spin structure at low-Q, to review the recent developments, discuss the interpretation of the results, help further our understanding and provide guidance for the near-future progress.

The main topics were:

- Electron-nucleon scattering experiments
- Compton scattering experiments
- Hyperfine splitting in muonic hydrogen
- Advances in Lattice QCD
- Advances in Effective Field Theories
- Advances in Dispersion Relations and Sum Rules

SPEAKERS:

M. W. Ahmed (Duke University, USA)

J. M. Alarcon (Universidad Complutense de Madrid, Spain)

C. Alexandrou (University of Cyprus, Nicosia, Cyprus)

A. Antognini (ETH Zürich & PSI, Switzerland)

J. Bernauer (MIT, USA)

C. Carlson (College of William and Mary, USA)

J.-P. Chen (JLab, USA)

A. Deur (JLab, USA)

M. Distler (University of Mainz, Germany)

A. Gasparian (North Carolina A&T, USA)

F. Hagelstein (University of Bern, Switzerland)

S. Kanda (Riken, Japan)

S. Kuhn (Old Dominion University, USA)

V. Lensky (University of Mainz, Germany)

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

P. Martel (University of Mainz, Germany)

K. Ottnad (University of Mainz, Germany)

E. Pace (University of Rome Tor Vergata and INFN, Italy)

K. Pachucki (University of Warsaw, Poland)

V. Pascalutsa (University of Mainz, Germany)

A. Pineda Ruiz (IFAE, Barcelona, Spain)

J. Rijneveen (University of Bochum, Germany)

M. Ripani (INFN Genoa, Italy)

S. Sconfietti (INFN Pavia, Italy)

K. Slifer (University of New Hampshire, USA)

N. Sparveris (Temple University, USA)

A. Vacchi (INFN Trieste, Italy)

M. Vanderhaeghen (University of Mainz, Germany)

SCIENTIFIC REPORT:

The goals of the workshop were:

- To review the latest experimental and theoretical developments on the low-Q nucleon spin structure functions and related sum rules, nucleon form factors and polarizabilities.
- To discuss the muonic hydrogen hyperfine structure at the intersection between nuclear and atomic physics.
- To interpret the new nucleon spin and hyperfine data by comparing them with the latest theories.
- To identify experimental and theoretical developments needed to advance the above topics.

The reactions used to investigate the nucleon spin structure are electron scattering off the nucleon or light nuclei, Compton scattering, and nucleon photoabsorption reactions. The internal structure of the nucleon - including its spin structure - is parameterized by form factors, structure functions or polarizabilities, depending on the reaction considered.

The main such quantities that are of interest to this workshop are:

- The spin structure functions g_1 and g_2. At high energy, g_1 is interpreted as the quark polarization distribution in the nucleon. g_2 has a more complicated interpretation, but contributes only to second order. At the lower energy relevant to the workshop, g_1 and g_2 can be linearly combined into the partial cross-sections σ_{TT} and σ_{LT}. Those can then be interpreted as the dependence of the nucleon response to the spin of the probing virtual photon.

- The electromagnetic form factors G_m and G_e, which contain the information on the nucleon charge and magnetization spatial distributions.
- The polarizabilities α_E, β_M, Σ_{2x}, Σ_{2z}, Σ_3, γ_0, δ_{LT}, γ_{E1E1}, γ_{E1M2}, γ_{M1E2}, γ_{M1M1}, which convey how the nucleon internal distributions deform whilst the nucleon is probed. The δ_{LT} polarizability in particular presents a puzzle because it was expected to be calculable in the most reliable way but early data were found to disagree with calculations ("δ_{LT} puzzle").

Integrals of structure functions can be related to charges, polarizabilities, or other static property of the nucleon, by relations called "sum rules". New sum rules involving g1, γ_0, γ_{M1E2}, have been recently derived and discussed in the workshop.

The structure of the nucleon at low Q is connected to hyperfine splitting (HFS) of atomic energy levels because the atom's orbiting electron wavefunctions extends to inside the nucleus. Thus, its structure - including its spin structure - contributes to the magnitude of the hyperfine splitting. Knowledge of g1 and g2 at very low-Q is necessary to compute the splitting, but such data has been scarce.

Preliminary and final results from the JLab low-Q program, a set of four electron-scattering experiments measuring g1 and g2 on the proton, deuteron and Helium-3, were presented and compared to recent Chiral Effective Field Theory (χEFT) calculations. These data offer a comprehensive set of observables to test the χEFT approach to non-perturbative QCD.

An active program is being run at MAMI, JLab and HiγS to measure polarizabilities at Q=0 on nucleon and light nuclei. Preliminary results from all these facilities were shown.

Data on the nucleon form factors were presented, including preliminary ones from JLab at very low Q (PRad experiment). Preliminary analysis of the latter hints towards the smaller proton radius as measured from muonic hydrogen. However, the situation for the proton radius remains unclear, as new measurements with normal hydrogen give contradictory results. Extraction of the Zemach radius from the measured form factors and its correlation to the charge radius has been also discussed. A precise extraction of the Zemach radius is vital for finding the HFS transition in muonic hydrogen and eventually for the extraction of the polarizability contribution from the spectroscopy experiment. An improved analysis of the magnetic form factor at low Q from the recent MAMI data and related extraction of the magnetic radius of the proton has been also proposed. The results would impact the understanding of the proton radius puzzle and result in a better extraction of the Zemach radius.

Advances in χEFT and lattice computation of form factors were also reported. The higher-moments of the charge distribution obtained from a χEFT framework have been used to guide the extraction of the lower moments, such as the proton radius, from the measured form factors.

The status of three experiments, aiming at the measurement of the HFS in muonic hydrogen at the ppm level has been presented: from the FAMU (RAL, UK), the J-PARC (Japan) and the CREMA (PSI, Switzerland) collaborations. Even though the theoretical prediction of the HFS splitting improved significantly in the recent years, experimental discovery of the resonance is only possible by a further factor of 4 improvement of the TPE prediction (down to 25 ppm of the total line splitting). For this purpose, both theoretical and experimental efforts have to be undertaken. These comprise new calculations of the TPE contribution from chiral perturbation theory, re-evaluation of the TPE from the dispersive approach which can capitalize on new measurements of the g2 and g1 structure functions at low Q and calculation of the mixed QED-nuclear-structure-dependent effects in the muonic atom.

Results and Highlights

The highlights and main conclusions of the workshop are:

- The two available χEFT calculations (Lensky et al. and Bernard et al.) are in disagreement. Its origin is not yet known. The data on g_1's first moment agree well with one of the χEFT calculation (Lensky et al.). However, data on other moments disagree with it, especially when they involve g_2. Data agree with the Bernard et al.'s calculation only at the lowest Q. The consistency of the data set, once all the analyses are finalized, is not evident and must be verified, as well as their consistency with low Q 1-pion production data. The δ_{LT} puzzle remains. The compatibility of the σ_{LT} data with the Schwinger sum rule should be checked. Thus, more data analysis and theoretical development are necessary to clarify how well χEFT describe QCD at low energy.

- The new g_2 data are consistent with the Burkhardt-Cottingham sum rule.
- A global parameterization of g_1 and g_2, and G_m and G_e - including constraint from 1-pion production – should be performed as a near-term goal.
- High-energy measurements to test the convergence of the Gerasimov-Drell-Hearn sum rule are highly desirable with both real photon and electron beams. They may also help to exclude a possible subtraction term in the TPE contribution to the muonic hydrogen HFS.
- Lattice results for the g_1 and g_2 moments at low-Q are unavailable. They would require calculation of 4-point correlation functions. Pioneering efforts for such calculation are desirable, as such result would be important.
- Predictions for the TPE of the HFS in muonic hydrogen have to be improved, both using χEFT as well as data-driven dispersive approaches.

3.3.12 MODELING NEUTRINO-NUCLEUS INTERACTIONS

DATE: July 09 – 13, 2018

ORGANIZERS:

Maria M. Barbaro (Turin University)
Deborah Harris (FNAL)
Natalie Jachowicz (Ghent University)
Ulrich Mosel (Giessen University)
Federico Sanchez (Barcelona Institute of Science & Technology)

NUMBER OF PARTICIPANTS: 26

MAIN TOPICS:

The precise measurement of neutrino properties has become one of the highest priorities in fundamental particle physics, involving many experiments worldwide. Since the extraction of neutrino properties requires the knowledge of the incoming neutrino energy, the reconstruction of that energy from the final state products of the interactions is a critical element in these experiments.
The goal of the workshop was to improve the neutrino-nucleus interaction generators used by the neutrino experiments, while paying special attention to their theory content and numerical implementation.

The main topics were:

- Modelling electron scattering on nuclei and potential impact in neutrino scattering.
- Detailed description of actual neutrino event generators: GiBuu, Genie, Neut, Nuwro,
    - Quasielastic.
    - Pion production
    - Shallow and deep inelastic interactions.
- SuperScaling and possible applications in generator models.
- Mean Field approximations and potential implementations in generator models.
- Cascade and transport models in nuclei.
- Nuclear initial state description.
- Spectral functions.
- Nucleon-nucleon correlations.
- Meson exchange currents.
- Inclusive vs. exclusive interaction descriptions and effects on experimental observables.
- Application of advanced mathematical tools to interaction modelling: deep learning,
- Experimental approaches to neutrino interaction modelling: Dune, T2K, Nova, etc.

SPEAKERS:

L. Alvarez Ruso (IFIC, Spain)

M. B. Barbaro (University of Turin, Italy)

C. Barbieri (University of Surrey, UK)

O. Benhar (INFN and Sapienza University, Italy)

J. A. Caballero (University of Sevilla, Spain)

S. Dolan (Laboratoire Leprince-Ringuet and CEA Saclay, France)

T. Donnelly (Massachusetts Institute of Technology, USA)

R. Gran (University of Minnesota Duluth, USA)

D. Harris (Fermilab, USA)

C. Horowitz (Indiana University, USA)

N. Jachowicz (Ghent University, Belgium)

T. Katori (Queen Mary University of London, UK)

K. Mahn (Michigan State University, USA)

K. McFarland-Porter (University of Rochester, USA)

G. D. Megias (University of Seville and CEA-Irfu Spain)

G. Miller (University of Washington, USA)

U. Mosel (Giessen University, Germany)

K. Niewczas (Ghent University, Belgium)

A. Nikolakopoulos (Ghent University, Belgium)

G. Perdue (Fermi National Accelerator Laboratory, USA)

F. Sanchez (IFAE/BIST, Spain)

P. Sala (CERN, Switzerland)

J. Sobczyk (Wroclaw University, Poland)

H. Yoshinari (Kamioka Obs., ICRR, the Univ. of Tokyo, Japan)

SCIENTIFIC REPORT:

An accurate determination of the neutrino energy is essential for neutrino oscillation experiments. The current and upcoming generation of neutrino oscillation experiments hence requires an unprecedented level of precision on the description of neutrino-nucleus interactions. There are several concerns within the community that directly affect the analysis of these oscillation searches:

- The reconstruction of the neutrino energy from the final-state particles detected after the interaction of neutrinos with nuclei. As reactor-based neutrino experiments have to rely on neutrino beams spanning a large energy range, this is a task that requires a detailed understanding and modelling of neutrino interactions for various interaction channels and over a broad range of incoming energies.
- Potential differences between neutrino- and antineutrino-induced scatterings off nuclei have to be understood and modelled.
- The precision on the determination of the ratio of the electron-neutrino and muon-neutrino cross-section with nuclei is crucial for oscillation analyses.
- Most of the recent model developments have been carried out in light nuclei such as carbon or oxygen while new experiments will require precise predictions for heavier non-isoscalar nuclei such as argon.
- A valid model needs to cover a large range of energies from non-relativistic nuclear descriptions able to describe low-energy phenomena sensitive to nuclear structure details, up to fully relativistic modelling, meanwhile covering several reaction production thresholds.

All these questions are related to the description of the neutrino interaction with nuclei. The overall systematic error induced by uncertainties on these models should be of the order of 5% or lower to achieve the expected precision in CP violation and Mass Hierarchy measurements in the near future. Contrary to most of the electron scattering experiments, neutrino energy reconstruction relies on the understanding of the final-state particles, including hadrons emitted during the interaction. Huge development on the modelling of neutrino-nucleus interactions took place during the last decade: description of meson-exchange currents, improvements on pion production, description of the nuclear initial state. Genuine theoretical models usually do not include a detailed description of the hadronic final states. On the other hand, most of the neutrino interaction generators have not been able to cope with the theoretical developments limited by technical problems, consistency of the models, lack of the full description of the final states, etc…

The goal of this workshop was to explore the state-of-the-art of these generators, confront experimental needs and the status of theoretical models, and discuss strategies to incorporate new developments in an efficient and physically consistent manner in generators. In the program of the workshop, these issues were implemented by providing a broad overview of recent theoretical developments (contributions of L. Alvarez Ruso, C. Barbieri, O. Benhar, J.A. Caballero, G. Megias), of advances in generator development (contributions of R. Gran, Y. Hayato, C, Juszczak, U. Mosel, K. Niewczas, G. Perdue, P. Sala, J. Sobczyk), and of the approaches adopted by different experiments, including potential applications and requirements (contributions of A. Ashkenazi, T. Katori, K. Mahn, A. Mislivec, K. McFarland, J. Nowak). Ample room for discussion in the timetable resulted in various in-depth discussions of the issues mentioned by different speakers and raised by the audience.

The variety of theoretical approaches, the fact that they need to cover a large energy range and different target nuclei, makes the implementation very difficult and introduces discussions about the limits on the range of validity of models and the risk of double counting when combining different models and merging them in a generator. The discussions on the implementations are intrinsically related to the limits of the models themselves.

A final issue that starts to arise is that the complexity of some of the calculations requires a processing load that is not sustainable for experimental purposes. Experiments need to generate hundreds of millions of events in a fast way and this is incompatible with some complex calculations. Faster numerical implementation of models might allow implementing more complex and precise models reducing the systematic errors. In this context, the requirement of a full precise description of the kinematics of all possible final state products is relevant in detectors with fine granularity such as the liquid argon or highly segmented near detectors. New observables based on the transverse imbalance of momentum might be affected by the simplifications of the final-state description.

Results and Highlights

This workshop has set a list of questions that need to be answered to facilitate progress in this field. The general feeling emerging from the participants is that the effort started at this workshop, should be continued in a meeting focusing on direct comparisons between models and implementations. This ‘next-generation’ workshop should concentrate on direct comparisons between generators and data. It will require a careful preparation and sufficient commitment of the participants, including some preparatory work by the different generator groups.

Central issues ensuing from this workshop that are to be addressed in future meetings are:

- Tension between inclusive and (semi-exclusive cross-sections and modelling, and effect on new observables in models and experiments (contribution of T. Donnelly).
    - Limits on hadron-tensor implementation.
    - Are our exclusive models really exclusive?
    - Analysis of the degrees of freedom.
    - Degeneracies between models can be resolved going to more exclusive descriptions.
- Cascade model vs nuclear transport (contributions of J. Sobczyk, U. Mosel, G. Perdue).
    - Model differences and physics implications.
    - Are differences detectable at the experimental level?
- Initial state description and the importance of electron scattering data.

    - Relevance of new experiments such as the (e,e’) spectral function measurements at JLab.
    - Differences in neutrino-nucleus and electron-nucleus scattering modelling.
    - Testing of generators against (semi-exclusive) e-scattering data.
    - Relevance of consistent electron and neutrino scattering models.
    - Concept and implementation of removal/binding energy and the impact of numerical approximations.
- Differing approaches and ingredients in the description of 2p2h contributions in models (i.e. number of responses, interference) (contribution of L. Alvarez-Ruso).
- Spectral function implementation (contribution of O. Benhar) in actual models and double counting.
    - Initial state correlated pairs, Meson exchange currents and spectral functions.
    - Are the actual Monte Carlo models implementing SF in the right way?
- Readiness of the Mean Field Approximations and possible Monte Carlo implementations.
- Do we need four Monte Carlo generators?
    - Physical process vs. numerical implementations.
- Can the community converge towards a ‘universal interface’ for embedding theory developments into generators?
- New mathematical models using deep learning (contribution of G. Perdue).
    - Principal sampling.
    - Parameterization of complex multivariable functions.

3.3.13 PROBING EXOTIC STRUCTURE OF SHORT-LIVED NUCLEI BY ELECTRON SCATTERING

DATE: July 16 – 20, 2018

ORGANIZERS:

Carlo Barbieri (University of Surrey)
Takaharu Otsuka (RIKEN, Wako)
Haik Simon (GSI, Darmstadt)
Toshimi Suda (Tohoku University)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The workshop capitalized on future prospects of electron scattering off exotic nuclei, a novel technique in order to probe these species with a clean electromagnetic probe. The workshop aimed at a survey of the status of several planned facilities worldwide together with the already existing SCRIT facility at RIKEN, Japan. The prospects of these facilities were discussed in view of the expectations from theory side when opening this experimentally challenging field.

The main topics were:

- Survey of facilities, with a focus on strength and weaknesses
- Electron scattering in view of fundamental properties, proton shell structure, short-range correlations and symmetry energy
- Electron scattering in view of excitation modes in nuclei
- Ab-initio predictions to be probed
- Competing other experimental methods

SPEAKERS:

A. Andreyev (University of York, UK)

T. Aumann (TU Darmstadt, Germany)

C. Bertulani (Texas A&M University-Commerce, USA)

A. Carbone (ECT*/FBK, Italy)

A. Corsi (CEA Saclay, France)

W. Dickhoff (Washington University in St. Louis, USA)

T. Dong (Purple Mountain Observatory, China)

T. Duguet (CEA-DPhN Saclay, France)

S. Gales (IPN Orsay, France)

R. F. Garcia Ruiz (CERN, Switzerland)

C. Giusti (University of Pavia, Italy)

L. Grigorenko (JINR, Russia)

H. Nakada (Chiba University, Japan)

T. Nakatsukasa (University of Tsukuba, Japan)

T. Neff (GSI Darmstadt, Germany)

T. Otsuka (University of Tokyo and RIKEN, Japan)

F. Pederiva (University of Trento, Italy)

F. Raimondi (University of Surrey, UK)

Z. Ren (Tongji University, China)

J. Ryckebusch (University of Ghent, Belgium)

P. Shatunov (Budker Institute of Nuclear Physics, Russia)

H. Simon (GSI Darmstadt, Germany)

D. Sokhan (University of Glasgow, UK)

M. Kimura (Hokkaido University, Japan)

A. Leviatan (The Hebrew University of Jerusalem, Israel)

V. Soma (CEA Saclay, France)

T. Suda (Tohoku University, Japan)

C. Barbieri (University of Surrey, UK)

K. Tsukada (Tohoku University, Japan)

D. Verney (IPN Orsay, France)

M. Wakasugi (RIKEN, Nishina Center, Japan)

SCIENTIFIC REPORT:

Electron scattering off radioactive species is a novel field being currently explored in nuclear physics studies. The advent of a clean leptonic probe promises to be clearly advantageous compared to conventional experimental techniques in view of studying the electromagnetic response of nuclei situated away from the stability line in the nuclear chart. Ground state properties like not only the charge radius but also charge distributions are expected to become experimentally accessible for the first time. The same holds for transition densities allowing studying the electromagnetic response of these nuclei. Of particular interest is also the possible access to shell structure that has been shown by (e,e'p) studies for stable nuclei. The pronounced asymmetry in proton-to-neutron ratio leads to the possible observations of clustering phenomena and the appearance of neutron skins and nuclear bubbles. Theoretically these phenomena can be predicted with different methods including ab-initio calculations, e.g for ground state properties, or predicting electromagnetic excitation modes, but the conditions and requirements on experiments under the challenging conditions using rare isotope beams is clearly a matter of debate.

The main subject of the workshop, thus, aimed at (i) presenting the status of the experimental approaches to the participants, and present experimental challenges, (ii) to discuss the discovery potential and sensitivity of the new probe with theorists, and (iii) outline the competitiveness to other methods like laser spectroscopy and nuclear probes.

Results and Highlights

The presented overview was clearly appreciated by all participants as many of the new projects are in proposal phase and, thus, not easily accessible via literature surveys. The boundary conditions and timelines could be presented and discussed in view of their discovery potential.

There have been lively discussions on the accessibility of nuclear properties using electron scattering in the adverse conditions of restricted luminosities for rare isotopes. The limitations of other methods have been contrasted to the principle advantages of conventional electron scattering. Of particular importance has been the input by theorists on the required quality of data for meaningful comparison to theoretical predictions and models.

The workshop triggered further collaborative efforts aiming exploring the powerful technique.

3.3.14 QUANTUM GRAVITY MEETS LATTICE QFT

DATE: September 03 – 07, 2018

ORGANIZERS:

Norbert Bodendorfer (Regensburg University)
Kristina Giesel (University of Erlangen)
Masanori Hanada (Kyoto University, Livermore, Stanford University)
Marco Panero (Turin University)
Andreas Schäfer (Regensburg University)
Larry Yaffe (Seattle University)

NUMBER OF PARTICIPANTS: 27

MAIN TOPICS:

The central theme of the workshop was to bring together scientists working in lattice gauge theory and quantum gravity and to establish connections and collaborations between those fields via the gauge / gravity duality to work towards quantitative agreement. From the gauge theory side, this in particular requires to first better understand supersymmetric theories that are known to have a holographic dual. On the quantum gravity side, this requires to understand quantum and finite coupling corrections to the classical limit usually employed in the gauge / gravity correspondence.

The main topics were:

- Lattice gauge theory, in particular large N and supersymmetry
- Monte Carlo simulations of Matrix models
- Loop quantum gravity, in particular its relation to lattice gauge theory
- holography
- Corrections to the large N and large Lambda limit of N=4 SYM via holography

SPEAKERS:

G. Bergner (Friedrich-Schiller-Universität Jena, Germany)

E. Berkowitz (FZ Jülich, Germany)

P. Buividovich (Regensburg University, Germany)

P. Damgaard (Niels Bohr Institute, Denmark)

A. Dapor, University of Erlangen-Nürnberg, Germany)

B. Dittrich (Perimeter Institute, Canada)

G. Dvali (LMU Munich, Germany)

V. Forini (University of London, UK)

K. Hashimoto (Osaka University, Japan)

G. Ishiki (University of Tsukuba, Japan)

B. Müller (Duke University, USA)

D. O'Connor (Dublin Institute for Advanced Studies, Ireland)

D. Oritim (Max Planck institute for gravitational physics, Germany)

A. Rabenstein (Regensburg University, Germany)

A. Riello (Perimeter Institute, Canada)

E. Rinaldi (RIKEN - BNL Research Center, USA)

P. Romatschke (CU Boulder, USA)

D. Schaich (University of Bern, Switzerland)

F. Vidotto (University of The Basque Country, Spain)

D. Kadoh (Keio University, Japan)

B. Lucini (Swansea University, UK)

F. M. Mele (Regensburg University, Germany)

S. Waeber (Regensburg University, Germany)

SCIENTIFIC REPORT:

AdS/CFT has been one of the most fruitful approaches to analyse the qualitative aspects of the dynamics of strongly interacting QFTs, most prominently QCD. As an approach to understanding the early stage of high-energy heavy-ion collisions, but also proton-proton collisions at LHC, it is, in fact, one of very few systematic approaches. However, it is not clear how reliable the description is quantitatively, because QCD is not a N=4, supersymmetric, conformal, SU(N) gauge theory with infinite N and the QCD coupling constant is of limited size. Individual contributions exist on both sides of the duality calculating the size of the relevant corrections (like the perturbative calculation of quantum corrections on the gravity side for finite N and finite coupling strength, the lattice simulation of SU(N) gauge theories with N>3, the calculation of perturbative corrections from non-conformality on the QFT side, lattice simulation with partial supersymmetry ...) but no systematic effort. In addition, more general scenarios for gauge/gravity dualities have been studied, extending beyond the realms of AdS, CFT, and string theory. The probability is high that quantitative contact can only be made on the basis of nonperturbative calculations on both sides, which is a very tall order. On the QFT side, lattice QFT is the best-established tool to do so, while on the quantum gravity side resummed string theory is the main approach. In addition, there is an increased recent interest within loop quantum gravity in holographic computations. In the light of this state of affairs, it is important to bring some of the internationally leading experts in these fields together and to formulate a more systematic strategy to proceed. This was the aim of the workshop. The focus was on the following points of contact between the different approaches:

a) large-N gauge theory:

Most holographic computations are performed in the classical limit on the gravity side, leading to predictions in large-N gauge theories. Understanding the precise relation between large N and “real world” N=3 is therefore mandatory. Often, corrections can be parametrized in an expansion in $1/N^2$ and it turns out that N=3 appearing in quantum chromodynamics is close to the large N limit.

b) Matrix models:

Matrix models arise as dimensionally reduced N=4 Super Yang-Mills theory and therefore can be studied as simplified settings of the Maldacena conjecture. Since they are computationally easier accessible, quantum corrections can be compared with holographic predictions with impressive precision. Understanding their holographic structure is therefore of high importance and is expected to provide valuable guidance for more complicated models.

c) Loop quantum gravity:

Computing quantum corrections in holography from string theory is often prohibitively hard with standard methods. It is therefore interesting to ask whether alternative approaches to quantum gravity that are under control in different parameter regimes also have holographic duals. Due to much recent work on this question within loop quantum gravity and the conceptual closeness of loop quantum gravity to lattice gauge theory, we chose to focus on this approach.

Results and Highlights

The workshop was successful in its aim to bring together the different scientific communities involved in applying the gauge / gravity correspondence to study strongly coupled quantum field theories. Next to allowing for detailed interaction between people working on similar problems, it offered a broad perspective on main current trends. The interesting possibilities offered by matrix models to study the gauge / gravity correspondence quantitatively beyond the classical limit was nicely summarized by a variety of talks of the leading experts in this subfield. This so far led to the start of a collaboration between a matrix model collaboration and researchers with a loop quantum gravity background with the eventual aim to compare properties of quantum black holes. New developments in formulating supersymmetric theories on the lattice were presented, making clear that N=4 Super-Yang Mills is increasingly better understood in this context. This should in particular stimulate further investigations of this theory by lattice gauge theorists with the aim to quantitatively test the AdS/CFT correspondence, or use lattice gauge theory techniques to study string theory via the duality. To conclude, the intersection of lattice gauge theory and holography is a dynamical field that has seen important developments in recent years in various directions. The workshop brought many leading experts together to discuss these developments and to foster new collaborations, in which is has succeeded.

3.3.15 MAPPING PARTON DISTRIBUTION AMPLITUDES AND FUNCTIONS

DATE: September 10 – 14, 2018

ORGANIZERS:

Gunnar Bali (Regensburg University)
Cynthia Keppel (JLab, Newport News)
Cédric Mezrag (INFN Roma)
Craig Roberts (ANL, Lemont)

NUMBER OF PARTICIPANTS: 29

MAIN TOPICS:

Parton distribution amplitudes (PDAs) and distribution functions (PDFs) play a key role in hadron physics. Their (x,Q)-dependence reveals basic facts about the emergence of mass scales in the Standard Model, provides insights into confinement and bound-state structure, and delivers critical inputs to hard-scattering formulae and cross-sections for deep-inelastic scattering and Drell-Yan processes. New theoretical techniques yield novel and much needed predictions for the x-dependence of PDAs and PDFs and enable their correlation with measurable quantities that will allow for experimental validation at existing, upgraded and planned facilities. It is crucial to exploit these developments, building on synergies between different sub-disciplines.

The main topics were:

- QCD theory and phenomenology
- Computing parton distribution amplitudes and functions
- Extracting parton distributions from data
- Hard exclusive reactions
- Deep-inelastic scattering and Drell-Yan processes
- Potential of modern and proposed facilities

SPEAKERS:

V. Andrieux (CERN, Switzerland)
G. Bali (Regensburg University, Germany)
D. Binosi (ECT*/FBK, Italy)
V. Braun (Regensburg University, Germany)
L. Chang (Nankai University, China)
S. Collins (Regensburg University, Germany)
M. Ding (Nankai University, China)
R. Ent (JLab, USA)
F. Gao (IFIC, Valencia University, Spain)
T. Hobbs (South Methodist University, USA)
S. Moch (University of Hamburg, Germany)
H. Moutarde (Irfu, CEA Saclay, France)
P. Nadolsky (Southern Methodist University, USA)
J.-C. Peng (University of Illinois, USA)
S. Platchkov (Irfu, CEA Saclay, France)
K. Raya (Nankai University, China)
P. Reimer (ANL, USA)
D. Richards (JLab, USA)
C. Roberts (ANL, USA)
G. Salmè (INFN, Italy)

T. Horn (Catholic University of America, USA)

C. Keppel (JLab, USA)

G. Koutsou (Cyprus Institute, Cyprus)

H. Wen Lin (Michigan State University, USA)

C. Mezrag (INFN Roma, Italy)

R. Sandapen (Acadia University, Canada)

N. Stefanis (Ruhr University Bochum, Germany)

A. Sternbeck (Friedrich-Schiller-University Jena, Germany)

B. Wojtsekhowski (JLab, USA)

SCIENTIFIC REPORT:

Among the various interactions established today, the so-called strong interaction, and the theory describing it, Quantum Chromodynamics (QCD), holds a particular place. Its fundamental degrees of freedom, quarks and the gluons, are known since the 1970s. They cannot be directly observed, but remain trapped inside hadrons, a phenomenon known as confinement. In such circumstances, the understanding of how these degrees of freedom are organised to build hadrons, i.e. what is the structure of hadrons in terms of quarks and gluons, becomes a critical question.

It has become fashionable nowadays to look at distributions related to the 3D structure of hadrons. One should keep in mind however that 1D distributions, although introduced more than 50 years ago, remain largely unexplained. Parton Distributions Amplitudes, (PDA) play the role of the 1D Schrödinger wave function of hadrons, describing how the momentum is shared between the valence quarks, but they do not have a direct probabilistic interpretation. Parton distribution functions on the other hand, offer a direct probabilistic interpretation and are key elements to describe deep-inelastic scattering and Drell-Yan processes.

Both PDAs and PDFs are non-perturbative objects, describing the internal structure of bound-states. This prevents any description of the latter using solely perturbative expansions of QCD. From that fact, two possibilities can be explored:

- Extraction of PDFs and PDAs from available experimental data, using the framework of collinear factorisation. Within this approach, observables are written as a convolution between the PDFs and a hard kernel, whose calculation is done in perturbation theory and can be systematically improved order by order. Today this is undoubtedly our main source of information concerning PDFs, while on the PDA side, this technique has been hardly used.
- Direct and indirect calculations using genuine non-perturbative methods, including modelling, light-front holographic QCD, lattice-regularised QCD or continuum QCD-connected techniques. Major progress has been made in the recent years both for calculating PDFs and PDAs through these techniques.

These two approaches have until now mainly gone forward independently. However, the progress made recently in both push the community to ask the question how and in which cases can these two approaches complete each other to improve our knowledge of PDAs and PDFs. In particular, the state of the art of the techniques used have been presented, highlighting their strengths and weaknesses, emphasizing the points where using complementary ones may significantly increase our current knowledge of the structure of hadrons.

In parallel, the question of the potential of current and future facilities in the fields of PDFs and PDAs has to be discussed. Once again, the focus on 3D Imaging should not hide the possibilities of breakthrough concerning both PDFs and PDAs. This is especially true for the former where, in the meson sector, our experimental knowledge is currently rather scarce. This is highly relevant as multiple theoretical predictions are available in the meson sector, coming from various understandings of the underlying QCD dynamics. Forthcoming experiments may be able to confirm or disprove various hypotheses.

In addition, we need to mention that topics close, but not directly related to PDFs and PDAs were covered during the workshop. Among them we highlight: lattice evaluations of truncation schemes used in continuum techniques; the comparison between Euclidean and Minkowski solutions of continuum techniques; the possibilities of 3D imaging at JLab through semi-inclusive deep-inelastic scattering; the possibilities to extend some techniques which apply to PDFs and PDAs to Generalised Parton Distributions (GPDs) guaranteeing that the GPD theoretical constraints are fulfilled a priori.

Results and Highlights

The workshop was an excellent opportunity to shed light on the state of the art of PDFs and PDAs for their experimental extractions as well as to review the status of the theoretical approaches.

The most recent calculations of the Mellin moments of PDFs using lattice-regularised QCD techniques were shown by different collaborations, highlighting the recent progress and the compatibility between the results. We can conclude that the computations of the moments are now realistic, and the community focuses on reducing the systematic uncertainties. Direct access to the x-dependence using the novel LaMET technique was also discussed, both in terms of reliability and results. It appears that the LaMET technique should be able to provide trustable results within a range of x between 0.2 and 0.6, large and small x kinematics being spoiled by higher-twist effects, although some caveat concerning the renormalisation procedure have been raised during the discussions. On the other hand, continuum techniques focus on the large-x behaviour of PDFs, trying to compute their power-decreasing law, together with the large-x limit of the light quark PDF ratio, providing therefore a complementary picture to lattice computations.

On the phenomenological side, multiloop extractions of PDFs keep gaining precision. New data from LHC help to constraint light-flavour sea quarks, although the HERA data seem to remain the ones having the strongest influence on the extraction. A possible issue concerning the s quark in recent LHC data was also pointed out. In addition to the PDFs themselves, their ratios were also discussed. SeaQuest and JLab 12 should be able to greatly improve our experimental knowledge of these ratios. On a longer time-scale, the Electron Ion Collider (EIC) is expected to have a critical impact on our knowledge of PDFs.

Discussions have been raised on how non-perturbative techniques and phenomenology could complementarily improve our knowledge of PDFs. Both including the lattice Mellin moments in the phenomenological fitting machineries, and constraining the large-x behavior of the fitting parameterisations following continuum technique predictions, were suggested. However, no consensus has been found on these questions.

Concerning PDAs, strong efforts have been made through continuum techniques to compute them in the meson heavy-heavy and heavy-light sectors. From these computations, an interesting picture seems to emerge: the PDAs of light-quark mesons are broader than the asymptotic PDAs, while in the heavy sector the PDAs are narrower. In parallel, lattice-regularized computations have improved the precision on the calculation of the second moment of the pion PDA and progress has been done using the Non-local Condensate (NLC) approach. The latter seems now to favor a unimodal PDA for light mesons, in agreement with continuum computations, while lattice-regularized QCD is in agreement with both unimodal and bimodal PDAs. A second point raised, was the possibility of “hidden” higher twist within the heavy-heavy PDA presented. No conclusion was reached on that point.

Baryon PDAs were also mentioned, together with the possibility of describing the Form Factors using hard scattering formulae. The discussions highlighted the possibility of computing higher twist PDAs. It was concluded that this is desirable, as they should dominate the calculations of the Form Factors at experimentally achievable energies.

Discussions on the drafting of an EIC white paper dedicated to the structure of meson have been carried on informally. A first draft, that will be available within a couple of weeks, highlights the importance of the EIC in the determination of both the PDFs and the PDAs of mesons. The participants received this enthusiastically. Other related topics were briefly discussed, during fruitful discussions between the speakers and the audience. Since they were not at the heart of the workshop they will not be reported here.

3.3.16 EMERGENT MASS AND ITS CONSEQUENCES IN THE STANDARD MODEL

DATE: September 17 – 21, 2018

ORGANIZERS:

Cristina Aguilar (University of Campinas)
Daniele Binosi (ECT*/FBK)
Joannis Papavassiliou (University of Valencia)
Craig Roberts (ANL, Lemont)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The most fundamental emergent phenomena in Quantum Chromodynamics (QCD), e.g. confinement, dynamical chiral symmetry breaking, mass generation for both gluons and quarks, and bound state formation, can only be tackled using non-perturbative methods. In the last decade, our theoretical understanding of these issues has improved considerably, owing to major advances in the approaches used to address them. In particular, marked progress in functional techniques (such as Schwinger-Dyson and Bethe-Salpeter equations) enables us now to investigate, with quantitative accuracy, the complicated dynamics of QCD's basic Green functions, establish subtle connections between them and interpret their field-theoretic origin, and combine this information to obtain crucial predictions for observables. At the same time, high-precision lattice simulations are furnishing valuable information on some of the most theoretically intractable facets of QCD, and new generation experiments (such as GlueX, PANDA, SoLID, EIC) promise to expose the structure of hadrons with unprecedented detail. We are thus on the edge of a new era in studying strong interactions within the Standard Model. The aim of the workshop was to gather a selected group of experts to discuss the most exciting recent developments, identify new goals, and lay a path toward completion of the most pressing tasks in strong QCD.

The main topics were:

- Confinement
- Chiral Symmetry Breaking
- Continuous and discrete approaches to QCD
- Hadron phenomenology
- Experimental hadron physics

SPEAKERS:

C. Aguilar (University of Campinas, Brazil)

D. Binosi (ECT*/FBK, Italy)

S. Brodsky (SLAC - Stanford University, USA)

L. Chang (Nankai University, China)

M. Chen (Nankai University, China)

M. Ding (Nankai University, China)

G. Eichmann (IST, Lisbon, Portugal)

C. Mezrag (INFN Sezione di Roma 1, Italy)

V. Mokeev (Jlab, USA)

J. Papavassiliou (University of Valencia, Spain)

J. M. Pawlowski (Heidelberg University, Germany)

M. Peláez (Universidad De La República, Uruguay)

R. Ent (Jlab, USA)

F. Gao (University of Valencia, Spain)

S. Glazek (University of Warsaw, Poland)

R. Gothe (University of South Carolina, USA)

P. Hoyer (Helsinki University, Finland)

M. Huber (Graz University, Austria)

G. Krein (Universidade Estadual Paulista, Brazil)

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

Z.-E. Meziani (ANL, USA)

O. Philipsen (Goethe University Frankfurt, Germany)

S. Qin (Chongqing University, China)

A. Khépani Raya-Montaño (Nankai University, China)

C. Roberts (ANL, USA)

J. Rodríguez Quintero (University of Huelva, Spain)

K. Serafin (University of Warsaw, Poland)

F. Siringo (University of Catania, Italy)

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

SCIENTIFIC REPORT:

Understanding the character of emergent mass within the Standard Model requires a synergistic effort, joining experiment and a wide array of theory. Our programme was therefore focussed on identifying key concepts and questions that need to be exploited and addressed by this effort. In particular:

- Contemporary and planned facilities will shed light on two basic mysteries in the Standard Model: confinement and dynamical chiral symmetry breaking. Strong evidence suggests that these two emergent phenomena are intimately connected, and rely on the appearance of momentum-dependent masses for gluons and quarks. Modern theory indicates that these phenomena are forcefully expressed in hadronic observables, bringing us to a point wherefrom we may empirically verify their appearance and expression in the Standard Model.
- It has emerged that one may define and compute a unique, process- independent effective charge in QCD, which appears in the kernel of every dynamical equation supported by QCD. The result predicted by a combination of continuum- and lattice-methods shows a remarkable correspondence with a process-dependent charge inferred from deep-inelastic scattering and matches that derived via light-front holography. A thorough exploration of the properties and consequences of this novel effective charge is critical to understanding QCD and illuminating its potential to serve in extending the Standard Model.
- As lattice-QCD has moved beyond the “quenched approximation”, so must continuum methods leave behind the simplest truncations of QCD’s field equations. Sophisticated, nonperturbative, symmetry-preserving schemes exist. Their implementation, exploitation and continued improvement are critical to exposing the full effects of emergent phenomena in experiment.
- Achieving that goal requires further study of the gluon-quark and 3-gluon vertices, whose infrared structure is important, e.g. to determining which bound-states are supported by strong dynamics. Continuum and lattice methods suggest that the 3-gluon vertex is much weaker than its perturbative strength at infrared momenta; and phenomenological studies indicate that such behaviour can have an enormous impact on the appearance of “exotic” and “hybrid” hadrons in the spectrum. Such ideas must be tested and further implications identified and explored.

This is critical because the search for exotic and hybrid states – systems not supported by constituent-quark models – is a worldwide priority. The existence of such states would lead to a dramatic reassessment of the distinction between matter and force fields, which has existed since Maxwell, and flagship experiments are underway or planned at all facilities around the world that can produce hadrons.

Results and Highlights

The goal of this workshop was therefore to bring together experimentalists, theorists and phenomenologists from the different communities working on different aspects of QCD and find common goals and interests, possibly nurturing new collaborations.

The pattern of each full day was the same, with the kick-off being a theme-setting experimental presentation, which was followed by a string of theory talks and associated discussions that explored questions related to the day's general themes. Monday began with Rolf Ent (JLab) sketching the possibilities for charting the origin and distribution of mass in QCD's Nambu-Goldstone modes, which can be realized at JLab 12 and with an EIC; and describing progress toward a White Paper that details these ideas. Wednesday's opening was delivered by Zein-Eddine Meziani (ANL), who described the potential for revealing the origin and distribution of the nucleon's mass using heavy-quarkonium production near threshold at JLab 12 and an EIC. Additional themes were added on Tuesday (Ralf Gothe, U. South Carolina) and Thursday (Victor Mokeev, JLab), which saw detailed analyses of the capacity of JLab 12 to expose fundamental structural features of baryon ground- and excited-states using the anticipated wealth of high-Q2 data on nucleon elastic and transition form factors. The theory presentations complemented these themes and additionally addressed issues such as gluon and light-quark confinement and dynamical chiral symmetry breaking; the role of an emergent gluon mass-scale in stabilizing the infrared properties of QCD; exploiting synergies between continuum and lattice methods in the computation of propagators, vertices and observables; and novel approaches to the prediction of the spectrum and properties of hybrid mesons. Ample time was provided for discussions and they were lively.

Christian Fossi (ECT*) provided excellent assistance with local arrangements for all participants; he and the other members of the ECT* team ensured that all went smoothly; and Trento displayed all its beauty in warmth under sunny skies for the entire week.

3.3.17 INTERDISCIPLINARY APPROACH TO QCD-LIKE COMPOSITE DARK MATTER

DATE: October 01 – 05, 2018

ORGANIZERS:

Mikael Chala (University of Durham, UK)
Germano Nardini (University of Stavanger, Norway)
Michael Ramsey-Musolf (University of Massachusetts Amherst & California Institute of Technology, United States)
Veronica Sanz (University of Sussex, UK)
David Schaich (University of Bern, Switzerland)

NUMBER OF PARTICIPANTS: 28

MAIN TOPICS:

The main goal of the workshop was promoting progress in composite dark matter research through an interdisciplinary approach that brought together experts from different fields ranging from model building, connections to composite Higgs models, direct detection experiments, galactic structure anomalies potentially related to large dark matter self-interactions, lattice and strongly coupled quantum field theory to exchange knowledge and plan future joint efforts.
To our knowledge, this has been the first time that so different communities have met to make progress on the same topic of research.

The main topics were:

- Direct detection of composite dark matter via its interactions with nuclei
- The confinement phase transition of the strongly coupled dark sector
- Insight from astrophysics and cosmology on the dark matter and its self-interactions
- Composite dark sectors on the lattice
- Model building and connections to composite Higgs models

SPEAKERS:

O. Antipin (Institut Rudjer Boskovic, Croatia)

N. Bozorgnia (University of Durham, UK)

J. Brod (TU Dortmund, Germany)

S. Bruggisser (University of Heidelberg, Germany)

A. Carmona (Johannes Gutenberg University, Germany)

M. Chala (University of Durham, UK)

E. Del Nobile (University of Nottingham, UK)

V. Drach (Plymouth University, UK)

M. Faber (Atominstitut, Austria)

A. Kamada (IBS-CTPU, Korea)

C. Kouvaris (CP3-Origins, Denmark)

G. Kribs (University of Oregon, USA)

M. Laine (University of Bern, Switzerland)

L. Lopez-Honorez (ULB, Belgium)

M. P. Lombardo (INFN, Italy)

A. Maas (University of Graz, Austria)

M. Ramos (Porto University, Portugal)

E. Rinaldi (RIKEN BNL Research Center, USA)

G. Schierholz (DESY, Germany)

J. Scholtz (IPPP Durham University, UK)

A. Francis (CERN, Switzerland)
L. Vecchi (EPFL, Switzerland)
M. Garny (TUM Munich, Germany)
D. Weir (University of Helsinki, Finland)

SCIENTIFIC REPORT:

The idea that dark matter (DM) particles may be composite states of a new strongly coupled gauge sector like QCD is very appealing, and is receiving increased interest among many communities. Attractive features of this paradigm include a natural explanation of the stability of DM particles (e.g., through an analogue of baryon number conservation), highly suppressed interactions with nuclei in accord with results from direct-detection experiments, and connections to composite Higgs models (CHMs) motivated by the gauge hierarchy problem. The confinement phase transition of the strongly coupled dark sector can also produce gravitational waves (GWs), opening a new route to discovery in addition to more traditional searches.

Thus a successful understanding of composite DM requires an interdisciplinary approach encompassing nuclear physics and strongly coupled quantum field theory, model building, cosmology and astrophysics. Given the mature stage of the LHC and DM direct detection, the rapid progress in lattice explorations and understanding gravitational waves, and sophistication of model-building, it was very timely to further this area by bringing together experts from these fields to exchange knowledge and plan future efforts. The workshop served as a platform to start addressing the following questions across communities:

1. Model building and lattice communities:

What models provide viable composite DM candidates and which are more attractive (motivated by connections to CHMs, baryogenesis, flavour physics)? Which theories play nicely with lattice space-time? What models may have useful "non-QCD-like" features/dynamics? What observables/quantities are more relevant/accessible to compute on the lattice, given the huge resources needed for this? What conventions are the most useful to connect the ultraviolet (UV) degrees of freedom to the infrared (IR) observables?

2. Model building and astrophysics communities:

What model assumptions go into stated constraints from direct and indirect detection experiments that might not applied to composite DM?

3. Astrophysics and lattice communities:

How cold is composite dark matter? Which observables could be appropriate to understand its compositeness?

Results and Highlights

Thanks to the very active participation of the attendees, this workshop was a great opportunity to discuss the questions above. Among the most fruitful results, we founds answers such as:

1. Due to the limited number of CHMs with UV completions and the important puzzle set by the hierarchy problem, they were mentioned as the most promising to be studied on the lattice. We singled out: SU(3)xSU(3)/SU(3), SO(6)/SO(5) and SU(5)/SO(5).
The most interesting observables, being relatively easy to access at the lattice as well as very important regarding the collider phenomenology include: mass spectra, decay constants, form factors. It was noted that, in models already studied on the lattice, the naive ordering of resonances in CHMs normally taken by model builders is not realistic. Concerning the last question, it was suggested to work with scheme-dependent quantities such as 'dark quark' masses and Lambda parameter.

2. The constraints computed by the experimental collaborations usually assume spin-independent (SI) or spin-dependent (SD) interactions. It was clarified that equal DM-proton and DM-nucleon couplings are assumed for the SI interaction, while scattering with either

protons or neutrons is assumed for the SD interaction. Also, the hadronic form factors are usually taken to be constant, so their energy dependence is neglected.
If the DM-nucleon scattering amplitude depends on energy and/or velocity (as in models with DM form factors, light or massless mediators, DM with electric or magnetic dipole moment, DM with a pseudoscalar interaction with the nucleon, and so on), then the experimental bounds do not apply and the constraint must be computed from scratch.
The experimental collaborations also assume a specific DM velocity distribution, known as the Standard Halo Model (SHM). Different choices of velocity distribution would shift the bounds. In this respect, it was noted that the DM velocity distribution depends on the particle physics nature of DM. For example, for cold collisionless DM, cosmological simulations of galaxy formation including baryons (i.e. hydrodynamic simulations) find that the local DM velocity distribution of simulated Milky Way-like galaxies are indeed Maxwellian but with a peak speed which can be different from the local circular speed assumed in the SHM. However, if DM self-interactions are included in the simulations, the results for the DM velocity distribution may be different.

3. Among a plethora of other comments, it was noted that DM can affect the amount of power at small scales due to collisional damping. This is for example the case of DM interacting with light degrees of freedom such as neutrinos, photons or dark photons. A more general description of non-cold dark matter (including warm, ETHOS like, etc.) imprint on the DM power spectrum and halo mass function has been proposed in arXiv:1704.07838 and allowed to derive constraints from Milky Way satellites and the Lyman-α forest.
Many other proposals and question were raised, too, including: What constraints does CMB impose? Which input should be provided to gravitational wave experts to compute the confinement phase transition in QCD-like theories? Can the mixed neutron-DM form factor interaction be computed on the lattice? Can current EFTs be extended to address this issue?
On top of these, questions regarding future efforts were also posted: Direct detection and indirect detection constraints come from different "communities". Can they be presented in a unified framework? What are the relevant timescales for all these efforts (MITP workshop 2019, indico.mitp.uni-mainz.de/event/185/overview, MIAPP workshop 2020, Vienna, Leiden, Benasque...)?

In this respect, organizers and participants have committed to keep working together on the basis of an ongoing document that will be eventually translated into a white paper.

3.3.18 DISCRETE SYMMETRIES IN PARTICLE, NUCLEAR AND ATOMIC PHYSICS AND IMPLICATIONS FOR OUR UNIVERSE

DATE: October 08 – 12, 2018

ORGANIZERS:

Dmitry Budker (Universität Mainz)
Catalina Curceanu (LNF – INFN Frascati)
Derek Kimball (California State University)
Andrzej Kupsc (Uppsala University)
Pawel Moskal (Jagiellonian University)

NUMBER OF PARTICIPANTS: 39

MAIN TOPICS:

The general theme of the workshop concerned questions such as: Why do we observe a Universe of only matter? Are the discrete symmetries, such as CPT, Lorentz or spin-statistics violated? How are they tested in particle, nuclear and atomic systems, and which are the implications for our Universe? Our main hope and aim was to provide a state-of-the-art overviews on discrete symmetries research performed worldwide by pioneering and leading groups to the scientists from different fields of physics and to share and exchange experience and research methods between communities of particle, nuclear and atomic physicists.

The main topics were:

- Test of discrete symmetries and spin statistics with hadronic and nuclear systems.
- Search for the discrete symmetries violation in the purely leptonic sector.
- Test of discrete symmetries and spin statistics with atomic systems.

SPEAKERS:

N. Akerman (Weizmann Institute of Science, Israel)

D. Aybas (Boston University, USA)

M. Bala (Jagiellonian University, Poland)

D. Budker (Helmholtz Institute, Johannes Gutenberg University Mainz, Germany & University of California at Berkeley, USA)

R. Caravita (CERN, Switzerland)

C. Curceanu (LNF-INFN, Italy)

E. Czerwinski (Jagiellonian University, Poland)

R. Del Grande (LNF-INFN, Italy)

A. Derevianko (University of Nevada, USA)

A. Di Domenico (Sapienza University of Rome, Italy)

A. Melissinos (University of Rochester, USA)

E. Milotti (University of Trieste, Italy)

P. Moskal (Jagiellonian University, Poland)

H. Mueller (University of California at Berkeley, USA)

T. Nakaya (Kyoto University, Japan)

C. Panda (Harvard University, USA)

R. Parker (University of California at Berkeley, USA)

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

J. Pretz (FZ Juelich, Germany)

S. Pustelny (Jagiellonian University, Poland)

A. Dolgov (Novosibirsk State University, Russia)

K. Dulski (Jagiellonian University, Poland)

M. Gorshteyn (Mainz University, Germany)

H. Haeffner (UC Berkeley, USA)

B. Hiesmayr (University of Vienna, Austria)

D. Kimball (California State University - East Bay, USA)

W. Krasny (CERN, Switzerland)

A. Kupsc (Uppsala University, Sweden)

J. Marton (Stefan Meyer Institute, Austria)

N. Meinert (CERN, Switzerland)

M. Safronova (University of Delaware, USA)

S. Sharma (Jagiellonian University, Poland)

M. Silarski (Jagiellonian University, Poland)

M. Skurzok (Jagiellonian University, Poland)

W. Snow (Indiana University, USA)

D. Soldi (Universita Degli Studi Di Torino, Italy)

A. Viatkina (Johannes Gutenberg University Mainz, Germany)

A. Wickenbrock (Helmholtz Institute, Johannes Gutenberg University Mainz, Germany)

K. Zioutas (University of Patras, Greece)

SCIENTIFIC REPORT:

We owe our existence to the asymmetry between matter and antimatter, which must have appeared at an early stage of the evolution of the Universe: if Nature were utterly symmetric matter would not exist. Surprisingly, however, processes driven by gravitational, electromagnetic and strong interactions seem to be symmetric with respect to basic discrete symmetries such as reflection in space (P), reversal in time (T) and charge conjugation (C). So far violations of these symmetries were observed only in processes governed by the weak interaction. Yet, the excess of matter over anti-matter, which we observe in the Universe is by about nine orders of magnitude larger with respect to the theoretical estimations based on the presently known sources of the discrete symmetries violations.

The explanation of this asymmetry, essentially identical with the explanation of the existence of matter in general, is one of the most interesting challenges of modern physics and cosmology. Therefore, the physical processes that took place in the early stages of the universe's evolution are of considerable interest and their study has contributed to a wide variety hypotheses about the early universe. To date, though, none of these hypotheses can give a complete explanation of the violation of symmetry between matter and antimatter without reference to entities or phenomena that are experimentally unconfirmed. The themes addressed in the workshop can be summarized as follows:

- Test of discrete symmetries and spin statistics with hadronic and nuclear systems.
- Search for the discrete symmetries violation in the purely leptonic sector.
- Test of discrete symmetries and spin statistics with atomic systems.

Results and Highlights

The workshop brought together world-leading experts and young scientists (from 11 countries) working on the exploration of discrete symmetries both in theory and experimental sectors in the field of atomic, nuclear and particle physics. The question: Why do we observe much more matter than antimatter, was at the core of the workshop. The meeting constituted an excellent possibility for exchanging ideas and for broadening scientific horizons of participants who could learn and discuss about broad range of complementary approaches shedding light on this puzzling question. We discussed results of recent experimental and theoretical works concerning tests of discrete symmetries in hadronic, leptonic and atomic systems.

For example we discussed to what extent the origin of the excess of matter over anti-matter in the Universe might be explained by the appearance of lepton-antilepton asymmetry in the early stage of its evolution. Therefore, part of the workshop including the poster session was devoted to the tests of discrete symmetries in decays of positronium atoms, and purely leptonic systems. Such studies are challenging and therefore the best so far performed experiments with positronium atoms excluded violation of discrete symmetries as CP, T or CPT only at the level of about 0.3% which is many orders of magnitude worse with respect to accuracies achieved in the hadronic and atomic sector. At the workshop we have discussed the near future possibilities of improving this precision by more than few order of magnitudes. Breaking of discrete symmetries in electromagnetic or strong interaction would imply existence of new particles or new interactions. Therefore, another exciting part of the workshop was devoted to the discussions about a way of how to search for the hypothetical new forces and new particles (not included in the standard model of particle physics).

Another major theme of the workshop was the discussion of the origin of dark matter whose composition remains unknown, even though dark matter constitutes about 80% of all the matter in the universe. Among the highlights of the Workshop were the reported evidence for anomalies, including possible correlation of solar activity with “dark matter streams” (K. Zioutos) and signals that may point to violation of Lorentz invariance based on auxiliary optical measurements with the LIGO interferometer (A. Melissinos).

Other focal point of the discussions at the Workshop were the fundamental aspects of the interpretation of the Pauli-principle tests such as the VIP-2 experiment (E. Milotti and J. Marton) and the introduction of the new powerful experimental platform for cross-disciplinary physics, the Gamma Factory at CERN (W. Krasny).

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 fields of atomic and low-energy nuclear and particle physics. The young participant’s percentage was more than 30%, which is one of the successes of the Workshop.

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

Last but not least a note of merit: the organization of the Workshop by ECT* (special thanks to Susan Driessen, Ines Campo, and to the ECT* Director, Prof. Jochen Wambach) was excellent.

3.3.19 OBSERVABLES OF HADRONIZATION AND THE QCD PHASE DIAGRAM IN THE CROSS-OVER DOMAIN

DATE: October 15 – 19, 2018

ORGANIZERS:

Francesco Becattini (University and INFN Florence)
Marcus Bleicher (FIAS Frankfurt)
Rene Bellwied (University of Houston)
Jan Steinheimer (FIAS Frankfurt)
Reinhard Stock (FIAS Frankfurt)

NUMBER OF PARTICIPANTS: 41

MAIN TOPICS:

The position, and the nature of the QCD confinement transition QCD phase diagram remains an essential, open topic of QCD. At low baryochemical potential Lattice QCD has demonstrated a crossover transition for chiral symmetry breaking at T=154 MeV. This domain is covered in nuclear collisions at LHC and RHIC energies, which have presented a wealth of relevant data, such as hadron multiplicities and fluctuations of conserved net charges. These data have been confronted with numerical lattice QCD calculations of charge susceptibilities, and various models of the equilibrium Hadron-Resonance Gas (HRG), as well as with transport models. The workshop will attempt a coherent discussion of the open problems of the various theoretical efforts, such as: hadronization, sequential freeze-out, final state distortions, LQCD at finite μ_B, variants of the HRG model, and identification of a critical point of QCD, to arrive at a state-of-the-art view of the QCD phase diagram.

The main topics were:

- Susceptibilities and fluctuations
- Bound states and the freeze-out process
- Statistical hadronization in HI

SPEAKERS:

J. Aichelin (SUBATECH, France)

A. Andronic (University of Münster, Germany)

A. Bazavov (Michigan State University, USA)

F. Becattini (University of Florence, Italy)

V. Begun (Warsaw University of Technology, Poland)

R. Bellwied (University of Houston, USA)

D. Blaschke (JINR, Russia)

M. Bleicher (Goethe University Frankfurt, Germany)

M. Bluhm (University of Wroclaw, Poland)

U. Heinz (The Ohio State University, USA)

A. Kalweit (CERN, Switzerland)

V. Koch (LBNL, USA)

W.J. Llope (Wayne State University, USA)

M. Lorenz (Goethe University Frankfurt, Germany)

M. Nahrgang (Subatech, France)

A. Ohlson (Heidelberg University, Germany)

D. Oliinychenko (LBNL, USA)

C. Ratti (University of Houston, USA)

K. Redlich (University of Wroclaw, Poland)

A. Rustamov (GSI/NNRC, Germany)

E. Bratkovskaya (GSI, Germany)

P. Braun-Munzinger (GSI, Germany)

A. Bzdak (AGH University of Science And Technology, Poland)

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

B. Dönigus (Goethe-University Frankfurt, Germany)

A. Friesen (JINR, Russia)

T. Galatyuk (TU Darmstadt, Germany)

R. V. Gavai (Tata Institute of Fundamental Research, India)

M. Gorenstein (Bogolyubov Institute For Theoretical Physics, Ukraine)

R. Greifenhagen (Helmholtz-Zentrum Dresden-Rossendorf, Germany)

C. Greiner (Goethe University, Germany)

J. N. Guenther (University of Regensburg, Germany)

H. Satz (University of Bielefeld, Germany)

C. Schmidt-Sonntag (Bielefeld University, Germany)

J. Schukraft (Niels Bohr Institute, Denmark)

J. Stachel (University of Heidelberg, Germany)

J. Steinheimer (FIAS, Germany)

H. Stoecker (GSI, FIAS, Goethe University Frankfurt, Germany)

J. Stroth (Goethe University Frankfurt, Germany)

D. Tlusty (Rice University, USA)

V. Vovchenko (Goethe University Frankfurt, Germany)

SCIENTIFIC REPORT:

The discussions at this ECT* workshop focused on the recent progress in theory and experiment that could shed a light on the parton to hadron transition occurring at the QCD phase boundary in the (T- μ_B) diagram, a key open question of intense ongoing research. A key conceptual problem concerning the parton-hadron transformation line arises from the recent recognition that at low baryochemical potential (accessible, in particular, through recent studies at the LHC) the phase transformation is of crossover nature, thus requiring re-thinking of the detailed mechanisms driving hadronization/confinement. Overall, the workshop addressed the main resulting questions and observations:

1. Lattice QCD has recently converged in a kind of universal agreement, from a variety of probes into the location, in the (T- μ_B) plane, of the effective transition temperature, the pseudo-critical T_C which, at low μ_B, falls somehow in the middle of the corridor spanned by the cross-over transition: T_C results, universally, near 155+/-5MeV. But the major question remains: what is the relation of this Lattice T_C to the set of experimental observables aimed at determination of T_C, as delivered by Statistical Model, hadron equilibrium species distribution analysis, or conserved charge fluctuation analysis related to Lattice susceptibility results. Here, a severe problem is the absence of an agreed-upon model of QCD hadronization.

2. There is recent intense debate/controversy concerning the information from light nuclei production (d, t, He and anti-particles), an old problem for the understanding in the framework of the statistical hadronization model and/or the coalescence picture. This has inspirited an intense new discussion owing to the unprecedented new ALICE-LHC data. How to explain the apparent chemical equilibrium of the light nuclei multiplicities with the other produced hadrons, at 150 to 160 MeV, although they could not possibly decouple right after hadronization, at least in a quasi-classical transport model view? This topic has caused a renewed fundamental discussion about the hadronization temperature delivered by SHM analysis, and its resemblance to Lattice T_C.

3. The third major topic of the workshop was related to the interpretation of identified particle number fluctuations and correlations in the context of available lattice QCD data and a conjectured critical endpoint and phase transition at large chemical potentials. Even in the crossover region of the QCD phase diagram the so called conserved charge susceptibilities significantly differ from those obtained from a hadron resonance gas and their measurements

could give a direct confirmation of the crossover in nuclear collisions. In addition these fluctuations should also show effects of criticality near the conjectured critical point. The qualitative effect of the crossover and phase transition on the measured susceptibilities remains, however, an open question and was widely discussed at the workshop.

Results and Highlights

The workshop started with a day devoted to present Lattice QCD accomplishments and problems. Many approaches toward a pseudocritical "temperature" T_C at μ_B about zero converge with modern, superior actions and realistic pion masses (from chiral restoration tests and Polyakov loop consideration, etc.). Thus there seems no discernible difference for hadronization driven by, either, chiral restoration or deconfinement. But, from Lattice point of view, the relationship between the derived T_C (of about 154 MeV), and the various observables remains open. It is commonly elaborated by comparing Hadron-Resonance-Gas predictions for observables to Lattice results, as function of T. This procedure is subject to intense discussion, recently. A further topic of recent Lattice research is the extension to finite baryochemical potential, however with the feature of a possible critical point of QCD (and thus the onset of a first order phase transition) still remaining evasive (as it is also true concerning possible experimental investigation).

Regarding the formation of light nuclei in high energy nuclear collisions it was shown in several talks, that the observed ‘near thermal’ yields of these particles, together with their spectra can be consistently described within the coalescence approach where nuclei are formed after the kinetic decoupling of hadrons, thus de-mystifying the topic of nuclei production.

Finally, it was shown that the net-baryon fluctuation measurements at the highest beam energies available (LHC and RHIC) is well described by assuming uncorrelated particle emission plus global charge conservation. Thus, no clear indications for a crossover or phase transition can be found here. At much lower beam energies however, the observed proton susceptibilities cannot be described by such an approach. In fact it was shown that the STAR data hints at two distinct production sources of baryons. Whether these sources are of physical origin (e.g. two different phases) or an experimental artifact needs to be further investigated.

3.3.20 INDIRECT METHODS IN NUCLEAR ASTROPHYSICS

DATE: November 05 – 09, 2018

ORGANIZERS:

Carlos Bertulani (Texas A&M University-Commerce)
Angela Bonaccorso (INFN Pisa)
Zsolt Fulop (MTA ATOMKI Debrecen)
Tohru Motobayashi (RIKEN, Wako)
Livius Trache (IFIN-HH Bucharest)

NUMBER OF PARTICIPANTS: 31

MAIN TOPICS:

The general theme of the workshop was nuclear astrophysics. As this is a field becoming more complex and more encompassing, many talks were dedicated to different parts of it and of their interaction. However, the focus was on what is specifically called "nuclear physics for astrophysics" (NPA), and mostly concentrated on the indirect methods used in NPA, hence the title of the workshop. Talks were given to review the status of different subjects of common interest, as well as talks on detailed specific cases encountered in the use of indirect methods for nuclear astrophysics. There were talks on: nuclear astrophysics for practitioners, nuclear data needs, experiments, stellar dynamics, nucleosynthesis modelling, and observations. Existing indirect methods in nuclear astrophysics were discussed: "the list" of indirect methods, their specifics, assessment of problems with their use, etc. Reviews of experimental methods, equipment and specifics as well as new facilities, including RIB facilities, and their nuclear astrophysics programs, were included. New directions were also touched upon.

The main topics were:

- Nuclear physics for astrophysics
- Stellar dynamics
- Nucleosynthesis modelling
- Specific astronomy observations, cosmology

SPEAKERS:

S. Bishop (TU München, Germany)

A. Bonasera (Texas A&M University, USA)

A. Chilug (IFIN-HH, Romania)

L. Chulkov (NRC Kurchatov Institute, Russia)

G. de Angelis (LNL, Italy)

R. Diehl (MPE, Germany)

B. Fields (University of Illinois, USA)

B. Guo (China Institute of Atomic Energy, China)

R. Hirschi (Keele University, UK)

J. Jose (UPC Barcelona, Spain)

J. Natowitz (Texas A&M University, USA)

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

A. Petrovici (IFIN-HH, Romania)

A. Spiridon (IFIN-HH, Romania)

A. Spyrou (Michigan State University, USA)

L. Trache (IFIN-HH, Romania)

A. Tumino (Università "Kore" Enna & INFN-LNS, Italy)

S. Typel (IKP, TU Darmstadt, Germany)

F. Xu (Peking University, China)

L. Lamia (LNL, Italy)

P. Mohr (Institute for Nuclear Research Atomki, Hungary)

J. Mrazek (NPI CAS, Czech Republic)

T. Nakamura (Tokyo Institute of Technology, Japan)

T. Nakatsukasa (Center for Computational Sciences (University of Tsukuba, Japan)

H. Yamaguchi (Center for Nuclear Study, University of Tokyo, Japan)

S.-G. Zhou (Institute of Theoretical Physics, CAS, China)

SCIENTIFIC REPORT:

Nuclear physics for astrophysics is that branch of nuclear physics where its research motivation is to measure or determine cross sections or rates for reactions that took or take place in cosmic events or objects. These topics are currently part of the research programs of virtually all major nuclear physics laboratories. Two rather different approaches are available for these purposes: to measure the exact reactions at the very low energies they happen in stars – a very difficult task experimentally due to the low cross sections involved (or close to those energies and then extrapolate, with all uncertainties that may be inherent to the procedure) – another is to use indirect methods, with experiments at projectile energies where measured cross sections are larger, followed by the use of theory to evaluate the actual reaction rates needed in nuclear astrophysics. The latter approach is in many cases the only one available, when we talk about processes that involve unstable nuclei. The indirect methods used or usable in these latter cases were the focus of the workshop. Existing indirect methods in nuclear astrophysics were discussed: “the list” of indirect methods, their specifics, assessment of limitations in their use, importance of calculated absolute values, codes, etc. Review of methods, experimental equipment and specifics, as well as presentations of new facilities, including radioactive ion beam facilities, and their nuclear astrophysics programs, were included.

Starting from the list of IMNA, we discussed dedicated methods:

- Coulomb dissociation
- Single-particle transfer reactions – ANC method
- (Nuclear) breakup reactions
- Trojan Horse Method
- Spectroscopy of resonances:
  - transfer reactions
  - gamma-ray spectroscopy
  - beta-delayed proton emission
  - thick-target inverse kinematics

with examples for the application of them. Since most of the methods listed above involve RIBs (but not all), the status of some of the RIB facilities was presented. Among the new topics, we would like to mention the efforts made to include the contribution of excited states in the reactions that take place in cosmic plasmas (while not present in the current terrestrial experiments) and the discussions on reactions in laser induced plasmas.

The meeting succeeded in its major intention: to bring together scientists working in nuclear astrophysics, a research domain that now consists or is close to: nuclear physics for astrophysics, stellar dynamics, nucleosynthesis modelling, specific astronomic or terrestrial observations, and cosmology. Talks were given to review the status of these subjects and of topics of common interest, as well as talks on detailed specific cases encountered in the use of indirect methods for nuclear astrophysics. There were talks on: nuclear astrophysics for practitioners, nuclear data needs, experiments, experimental methods and devices, stellar dynamics, nucleosynthesis modelling, observations.

Results and Highlights

Scientifically, the most important achievements were presented above. The most important one, we stress again was that specialists in various subjects met and talked. As the realm of nuclear astrophysics gets richer and contains now, or is very close to:

- nuclear physics for astrophysics
- stellar dynamics
- nucleosynthesis modeling
- specific astronomy observations
- cosmology

it is of paramount importance that we cooperate closely and that new connections are being formed among the specialists in its different sub-fields. Same importance has the fact that also theoreticians and experimentalists were talking to each other.

Another one important consequence may be considered that at the end we decided to have another proposal for an ECT* workshop on key reactions in nuclear astrophysics and that a group of initiative was set up already.

Over 30 participants registered to this event. 26 presentations of over 45 min each were given. The participants were mostly from Europe, but we had a reasonably large number of participants from USA and from Japan and China. Three late cancellations were motivated by personal problems of the registrants (one each from China, Spain and USA). Two of their talks were successfully covered by other participants. The participants were mostly senior level scientists, but we had also 4 young students, of which 2 have presented communications of 20 min each. Among the participants 7 were females.

The assistance from the local support staff of ECT* was excellent.

The support under ENSAR2 Networking Activity NuSPRASEN and TNA10 ECT* was an important contribution to the success of the workshop.

3.3.21 ELECTROMAGNETIC RADIATION FROM HOT AND DENSE HADRONIC MATTER

DATE: November 26 – 30, 2018

ORGANIZERS:

Gabor David (Stony Brook University)
Charles Gale (McGill University)

NUMBER OF PARTICIPANTS: 36

MAIN TOPICS:

This workshop brought together theorists and experimentalists working on direct photons and dileptons in (ultra)relativistic heavy-ion collisions. Beyond the survey of the current status, a large emphasis was given to open discussions on the new possibilities offered by the widening range of colliding systems and collision energies. Another important goal was to move toward more consistent analysis methods, to make data from different experiments easier to compare with each other, and with theory calculations.

The main topics were:

- Moving toward a consistent approach of background estimation between experiments such that comparisons with other data, and with theory calculations become easier
- Re-examining the “direct photon puzzle” and whether it is present in small-on-large and/or lower energy collisions
- Are high-multiplicity p+p and p+A collisions still “baseline measurements”, or do they share some of the characteristics found in larger systems (like photon flow, etc.)?
- Explore whether initial state vs. medium effects can be separated experimentally
- Heavy-ion collisions can generate some of the strongest magnetic fields known to exist. What is the effect of such critical field strengths on electromagnetic observables?
- Is there a connection between the Chiral Magnetic Effect and electromagnetic observables?
- What is the electromagnetic emissivity of the pre-hydrodynamics phase(s) of relativistic heavy-ion reactions?

SPEAKERS:

Y. Akiba (AKIRIKEN)

H. Appelshäuser (Goethe University Frankfurt, Germany)

F. Bock (CERN, Switzerland)

P. Braun-Munzinger (GSI, Germany)

W. Cassing (Institute of Theoretical Physics, Germany)

P. Dasgupta (Variable Energy Cyclotron Centre, India)

A. Drees (Stony Brook, USA)

J. Jung (Goethe University Frankfurt, Germany)

N. Novitzky (University of Tsukuba, Japan)

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

K. Reygers (Heidelberg University, Germany)

L. Ruan (BNL, USA)

T. Sakaguchi (BNL, USA)

A. Schäfer (FIAS, Goethe University Frankfurt, Germany)

W. Fan (Stony Brook University, USA)
T. Galatyuk (TU Darmstadt, GSI, Germany)
C. Gale (McGill University, Canada)
F. Geurts (Rice University, USA)
J. Ghiglieri (CERN, Switzerland)
M. Greif (Goethe University Frankfurt, Germany)
S. Harabasz (TU Darmstadt, Germany)
S. Hauksson (McGill University, Canada)
C. Shen (Wayne State University, USA)
E. Speranza (Goethe University Frankfurt, Germany)
J. Staudenmaier (Goethe University Frankfurt (FIAS), Germany)
R.-Arno Tripolt (University of Frankfurt, Germany)
G. Usai (University of Cagliari, Italy)
H. van Hees (Goethe University Frankfurt, Germany)

SCIENTIFIC REPORT:

Electromagnetic probes enjoy a unique status in studies of strongly interacting systems. They represent radiation that can be at the same time penetrating and soft: no other observable can claim this set of features. Consequently, measurements of real and virtual photons form an ideal complement to those of hadronic particles and can reveal local characteristics of the hot and dense strongly interacting environments – such as those created during the collisions of heavy ions – that lie beyond the reach of other probes.

Owing much to constant progress in theory and experiments over the last decade, photons and dileptons have been linked to signals of chiral symmetry restoration in hot and dense systems, to the local extraction of temperature and of transport coefficients of QCD (shear and bulk viscosity), to non-perturbative effects occurring near the cross-over transition, and to the non-perturbative nature of the nuclear initial state probed at high-energy. Importantly, because of the very fact that electromagnetic probes are penetrating, the interpretation of the information they convey is linked to the accuracy of the space-time modelling approach. In fact, this is not a bug but a feature: known and calibrated sources can then be used as standard candles to assist in the development of approaches that are realistic, especially in the early instants of the hadronic collision. This intimate connection does imply, however, that successful interpretations of electromagnetic signals depend not only on the soundness of theoretical principles, but also on the sophistication of the dynamical modeling.

Results and Highlights

Measurements and calculations of electromagnetic signals have entered a mature stage, reflected both by their degree of sophistication and also by the depth of challenges encountered. All of the scientific presentations were of great quality, and the question periods following the talks were lively, useful, and productive. Much of the free-style discussion time was devoted to reviewing the status of “the photon flow puzzle”. To recapitulate, the puzzle has to do with measured values of photon flow coefficients which are not only comparable in magnitude with their hadronic counterpart, but also much larger than those predicted by serious theory calculations.

Another facet of the conversation was spent on trying to isolate the source of the difference in measured photon yield between PHENIX and STAR. Some progress was made on both fronts, but it is fair to write that the discrepancy remains between experiments, and the gap between theory and those RHIC measurements is still an open question. The workshop also featured photon data and theory obtained for small systems (either light nucleus-light nucleus, or proton-nucleus collisions). Those recent developments (in data and theory) are especially exciting as they could very well support the interpretation of the formation of small droplets of quark-gluon plasma being formed. This would represent a paradigm shift. Progress was also reported on a variety of theory subjects. Several presentations focused on the properties of strongly interacting matter away from equilibrium, with methods ranging from transport models to relativistic field theory calculations. The official release of SMASH, a modern transport model, was announced at this workshop by Professor Elfner from FIAS (University of Frankfurt).

At lower energies, we heard plans to pursue the HADES measurements at GSI, and the STAR experiment operating in the Beam Energy Scan phase of RHIC. A proposal to upgrade ALICE with a novel, nearly massless detector optimized to electromagnetic probes down to ultra-low transverse momenta was first unveiled at this workshop and generated intense interest and discussions. The workshop attendance was also excited to hear plans for a new experimental collaboration proposal at the CERN SPS: NA60+. This planned experiment intends to push the resolution of the very successful NA60 Collaboration to new limits.

The workshop was a resounding success. The degree of collaboration across the theoretical-experimental boundary was apparent and even noticeably increased. The organizers noted with great satisfaction the large number of young scientists in the audience. The future of our field is in good hands.

3.3.22 THE SPECTROSCOPY PROGRAM AT EIC AND FUTURE ACCELERATORS

DATE: December 19 – 21, 2018

ORGANIZERS:

Marco Battaglieri (INFN Genova)
Alessandro Pilloni (ECT*/FBK)
Adam Szczepaniak (Indiana University, JLab, Newport News)

NUMBER OF PARTICIPANTS: 44

MAIN TOPICS:

Hadron spectroscopy is of key importance to unravel the mechanisms of QCD in binding quarks. Several present and forthcoming experiments devote part of their programs to spectroscopy. The highest priority project of the American Nuclear Physics community is the realization of an unprecedented Electron-Ion Collider (EIC), to be built in the next decade. While the main purpose of this machine is to clarify the structure of hadrons and nuclei, and to understand the gluon saturation at low x, several opportunities are open to develop an ambitious spectroscopy program.
Given the energy range of the new accelerator, the study of heavy (open and hidden) flavour hadrons looks promising. In particular, the study of the several XYZ states seen at the B- and charm factories can benefit from yet another production mechanism as the one realized at an EIC. Also, the production of states with gluonic degrees of freedom is expected to be enhanced in specific kinematics that the EIC will reach.
The EIC will have full control of the beam polarizations. This, together with a hermetic detector, will allow for detailed studies of diffractive production mechanisms, which will complement the ones ongoing at COMPASS or at the LHC. Having nuclear beam at our disposal, one can study the propagation of heavy flavour mesons in a cold nuclear medium. This is crucial to understand more details on how the partons hadronize.

The main topics were:

- Multiquark states: lessons learned from the XYZ quarkonium-like states, and prospects for the EIC - conveners: Feng-Kun Guo (CAS, China) and Ryan Mitchell (Indiana University, USA)
- Gluonic states: lessons learned from light spectroscopy, and prospects for searches of heavy hybrids at the EIC – conveners: Nora Brambilla (TUM, Germany) and Umberto Tamponi (INFN Torino, Italy)
- Diffractive production of resonances: lessons and differences with existing experiments in exclusive channels – conveners: Wolfgang Schaefer (INP-PAS) and Ronan McNulty (UCD, Ireland)
- Interaction of heavy flavor with media: exclusive and inclusive processes, and probes for QCD matrix elements – conveners: Christian Weiss (JLab) and Giuseppe Bruno (Politecnico di Bari, Italy)

SPEAKERS:

P. Antonioli (INFN Bologna, Italy)

N. Brambilla (TUM, Germany)

G. E. Bruno (Politecnico di Bari, Italy)

R. McNulty (University College Dublin, Ireland)

A. Pilloni (ECT*/FBK, Italy)

V. Crede (Florida State University, USA)

A. D'Angelo (Università di Roma Tor Vergata, Italy)

A. Deshpande (Stony Brook University, USA)

S. Dobbs (Florida State University, USA)

E. Eichten (Fermilab, USA)

S. Fazio (BNL, USA)

D. Glazier (University of Glasgow, UK)

A. Guskov (JINR, Russia)

L. Jenkovszky (Bogolyubov Institute for Theoretical Physics, Ukraine)

B. Ketzer (University of Bonn, Germany)

R. Ma (BNL, USA)

P. Rossi (JLab, USA)

W. Schaefer (INP-PAS)

P. Schweitzer (University of Connecticut, USA)

E. Scomparin (INFN Torino, Italy)

C. Van Hulse (University College Dublin, Ireland)

I. Vitev (LANL, USA)

C. Weiss (JLab, USA)

M. Winn (CEA Saclay, IRFU/DPhN, France)

J. Wu (CAS, China)

X. Yao (Duke University, USA)

Q. Zhao (CAS, China)

SCIENTIFIC REPORT:

The experimental programs at LHCb, BaBar, Belle, and BESIII have produced results that challenge the quark model paradigm of hadrons. The parallel, rapid developments of lattice QCD simulations and new analysis methods give hope that the novel discoveries in hadron spectroscopy will be confronted with QCD predictions. The workshop aimed at reviewing the current status of light and heavy quark spectroscopy, with particular emphasis on exotic states (e.g. XYZ in the charmonium sector), and focused on new experiments and calculations required to close the gap between phenomenology and QCD. More specifically, the workshop explored opportunities and possibilities for a comprehensive hadron spectroscopy program at the Electron-Ion collider (EIC), which is the highest priority project for the QCD community, expected to be built in the USA during the next decade. The EIC would be distinguished from all past, current, and contemplated facilities around the world, by being at the intensity frontier with a versatile range of kinematics and beam polarizations, as well as beam species, allowing the above questions to be tackled at one facility. In particular, the EIC design exceeds the capabilities of HERA, the only electron-proton collider to date, by adding polarized proton and light-ion beams, a wide variety of heavy ion beams, two to three orders of magnitude increase in luminosity, and a wide energy variability. This new experiment demands an unrivalled degree of detail in modelling the dynamics of strong interaction processes if new discoveries and insights into the hadron structure are to result. An international effort, coordinated among the existing facilities in EU, Asia and US will provide the necessary skills to face and win the technical challenges posed by such ambitious project.

Results and Highlights

The workshop represented a good occasion to gather together theorists and experimentalists from different communities to define the physics case and discuss the technical challenges for a spectroscopy program at the Electron Ion Collider. Contributions from the communities working at the existing facilities (CERN, China, Japan and US) provided competences and new ideas to run a hadron spectroscopy program in the next 20 years.

- In the diffractive session, differences with past and existing experiments, as LHC, COMPASS, HERA and JLab have been discussed. Diffractive production can provide a tool to study the structure of excited vector resonances, as well as the structure of exotic candidates, e.g. the Y family. It emerged the need for a detector with large acceptance, able to tag the recoiling proton.
- In the Heavy Flavor in media session, the role of open and closed heavy flavor meson as probes to access QCD observables has been discussed. Moreover, the propagation

of heavy flavour mesons in a cold nuclear medium is crucial to understand the hadronization mechanisms, as well as the hadronic interaction, which can lead to the production of exotic pentaquarks.

- In the multi-quark and gluonic sessions, the role of amplitude analysis in the extraction of the exotic spectrum has been highlighted. This calls for a detector with high acceptance and high resolution. Preliminary estimates for the cross section of exotic states show interesting opportunities for the EIC kinematics. Several interesting channels have been discussed. Also, EIC will have the unique opportunity to confirm or disprove the elusive $\tilde{X}$ state claimed by COMPASS.

In the coming months we expect to write a white paper with contributions from the participants to the workshop and other scientists from the international community. The white paper will be included in the EIC Physics case representing the manifesto of an active working group interested in pursuing hadron spectroscopy in the future.

3.4 ECT* Doctoral Training Program 2018

QCD under extreme conditions

ECT, May 28 – June 22, 2018*

(Report by G. Ripka)

The 2018 ECT* Doctoral Training Program on "*QCD under extreme conditions"* was held at ECT from May 28 to June 22, 2018 for a duration of 4 weeks. The organizers were Gert Aarts (Swansea University, UK) and Dirk Rischke (Johann Wolfgang Goethe-Universität Frankfurt, Germany), the local coordinator, in charge of the finance, lodging and other administrative tasks of the students and lecturers was Serena Degli Avancini. Georges Ripka (*IPhT, Saclay and ECT**) attended as student coordinator.

The 2018 Doctoral Training Program was attended by 39 students, who were working on their PhD. This is almost twice the number of students attending previous Doctoral Training Programs. The students are listed at the end of this report.

There were 2 lecturers each week, altogether 8 lecturers. The lectures were delivered in the morning. Each lecturer gave two consecutive 45-minute sessions, with a short break between the two. There was a coffee break between the two 1h1/2 sessions assigned to each lecturer.

Because of the large number of students, most of the Doctoral Training Program was held in the refurbished ECT* meeting room on the ground floor of the Rustico, instead of the smaller lecture room on the second floor. However, this is not recommended for future Doctoral Training Programs. The ground floor meeting room is too large. In addition, each seat has an electric plug attached to it, which encourages students to leave their computers switched on much of the time, without following the ongoing lecture.

Each student was asked to give a so-called Flash Talk, consisting of a 10-minute presentation of his/her research followed by a 5-minute discussion (in previous Doctoral Training Programs, each student was asked to give a ½ hour seminar.) The student Flash Talks, as well as the student seminars given in previous DTP's, are very useful because they encourage discussions with other students as well as with some of the lecturers. The student Flash Talks were held on Monday and Wednesday afternoons, with an average of five Flash Talks during each session.

Most lecturers made slides, handwritten notes and other files available to the students. The files were placed in a Private Area of a FKB website, which could only be accessed from ECT, using a password given to each student by ECT. Most lecturers made their slides as well as occasional handwritten notes available to the students.

The ECT website, giving practical information to the students, was designed by Barbara Curro' Dossi and proved very useful to the students.

At the end of the program, the students were asked to write an informal (and not necessarily signed) report. They were encouraged to state what difficulties they were confronted with and what could possibly be improved. The reports were handed to the ECT* Director. According to what was remarked by some students, it would help if someone from ECT*, speaking Italian, could go with the students to the Italian immigration office. Some students also had financial difficulties because their 700€ scholarship could only be paid by the time they were leaving.

3.4.1 Lectures

The lecturers were encouraged to use the blackboard rather than PowerPoint like presentations and they mostly did so. Plots of results were, of course, projected on a screen.

Week 1 (May 28-June 1, 2018)
Dirk Rischke (J. W. Goethe-Universität Frankfurt, Germany)
Symmetries in Quantum Mechanics and Particle Physics
Aleksi Vuorinen (University of Helsinki, Finland)
Basics of thermal field theory - a tutorial on perturbative computations

Week 2 (June 4-8, 2018)
Gert Aarts (Swansea University, UK)
Sign problem at nonzero density
Claudia Ratti (University of Houston, USA)
QCD thermodynamics

Week 3 (June 11-15)
Andreas Schmidt (University of Southampton, UK)
Dense matter
Jan M Pawlowski (Universität Heidelberg, Germany)
Functional Renormalization Group

Week 4 (June 18-22)
Tuomas Lappi (University of Jyväskylä, Finland)
Early stages of heavy-ion collisions
Ulrich Heinz (Ohio State University, USA)
Hydrodynamical description of heavy-ion collisions

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3.4.2 List of students

Agah Nouhou Moussa	Subatech, France
Arrebato Villar Denys Yen	Subatech, France
Bala Dibyendu	Tata Institute of Fundamental Research, India
Balassa Gabor	Wigner Research Centre for Physics, Hungary
Biswas Deeptak	Bose Institute, India
Borrell Martínez Marc	Universität Bielefeld, Germany
Du Lipei	Ohio State University, USA
Eller Alexander Maximilian	TU Darmstadt, Germany
Filios Georgios	University of Stavanger, Norway
Fuseau David	Subatech, France
Gagliardi Giuseppe	Universität Bielefeld, Germany
Gunkel Pascal	Justus-Liebig-Universität Gießen, Germany
Kajimoto Shiori	Osaka University, Japan
Karmakar Bithika	Saha Institute of Nuclear Physics, India
Kazemian T. Farideh Sadat	Shahrood University of Technology, Iran
Kirby Alan-Francis	Swansea University, UK
Koenigstein Adrian	Johann Wolfgang Goethe-Universität, Germany
Kuha Mikko	University of Jyväskylä, Finland
Lakaschus Phillip	Johann Wolfgang Goethe-Universität, Germany
Maelger Jan	Ecole Polytechnique, Université Paris Diderot, France
Marinho Rodrigues Diego	Federal University of Rio de Janeiro, Brazil
Matas Marek	Czech Technical University, Czech Republic
McNelis Michael	Ohio State University, USA
Motta Mario	University of Torino, Italy
Mykhaylova Valeriya	University of Wroclaw, Poland

Offler Samuel	University of Swansea, UK
Österman Juuso	University of Helsinki, Finland
Otto Konstantin	Justus-Liebig-Universität Gießen, Germany
Parotto Paolo	University of Houston, USA
Peuron Jarkko	University of Jyväskylä, Finland
Portillo Vazquez Israel	University of Houston, USA
Rahaman Mahfuzur	Variable Energy Cyclotron Centre, Kolkata, India
Riz Luca	Università degli Studi di Trento, Italy
Sakai Azumi	Sophia University, Japan
Schweitzer Dominik	Justus-Liebig-Universität Gießen, Germany
Singha Pracheta	Bose Institute, India
Sogabe Noriyuki	Keio University, Japan
Tiwari Anurag	Tata Institute of Fundamental Research, India
Wang Xiao-Dan	Central China Normal University, China

4 Research at ECT*

In this chapter the 2018 activities of the scientific researchers at ECT*, i.e. of the Postdoctoral Fellows and Senior Research Associates, the Director, the long-term Visitors and their collaborators are briefly summarized. The contributions are listed in alphabetical order. Cooperations of the scientists within the Centre are most often joint projects with colleagues at institutions elsewhere. Pursuing such collaborations, with ECT* as a "brain-storming" focal point, is an essential element of the scientific life at the Centre and of the activities conducted by the in-house research group. In parallel to their research, the Director and Daniele Binosi have been involved in the planning and organization of the Q@Tn – Quantum Science and Technology, a Trento Initiative of the Bruno Kessler Foundation, the Institute for Photonics and Nanotechnology (CNR) and the University of Trento. Dionysios Triantafyllopoulos conducts research primarily focusing on QCD at the highest energy densities. At the same time he continues to represent ECT* in the PhD Committee of the Physics Department of the University of Trento.

4.1 Projects of ECT* Researchers

Daniele Binosi

$\gamma *\gamma \to \eta, \eta'$ transition form factors

In collaboration with M. Ding, K. Raya (Nankai University, China), A. Bashir (Universidad Michoacana de San Nicolás de Hidalgo, Mexico), L. Chang, M. Chen (Nankai University, China), C. D. Roberts (ANL, Lemont, USA)

Using a continuum approach to the hadron bound-state problem, we calculate $\gamma * \gamma \to \eta, \eta'$ transition form factors on the entire domain of spacelike momenta, for comparison with existing experiments and in anticipation of new precision data from next-generation e+e– colliders. One novel feature is a model for the contribution to the Bethe-Salpeter kernel deriving from the non-Abelian anomaly, an element which is crucial for any computation of η, η' properties. The study also delivers predictions for the amplitudes that describe the light- and strange-quark distributions within the η, η'. Our results compare favourably with available data. Important to this at large-Q2 is a sound understanding of QCD evolution, which has a visible impact on the η' in particular. Our analysis also provides some insights into the properties of η, η' mesons and associated observable manifestations of the non-Abelian anomaly.

Nucleon-to-Roper electromagnetic transition form factors at large-Q2

In collaboration with C. Chen (São Paulo State University), Y. Lu (Nanjing University, China), D. Binosi (ECT/FBK, Italy), C. D. Roberts (ANL, Lemont, USA), J. Rodríguez-Quintero (University of Huelva, Spain), J. Segovia (IFAE, Spain)*

High-precision nucleon-resonance electroproduction data on a large kinematic domain of energy and momentum transfer have proven crucial in revealing novel features of strong interactions within the Standard Model and unfolding structural details of baryon excited states. Thus, in anticipation of new data reaching to unprecedented photon virtuality, we employ a quark-diquark approximation to the three valence-quark bound-state problem to compute $\gamma * p \to R+$ and $\gamma * n \to R0$ transition form factors on Q2/mN2 ∈ [0, 12], where mN is the nucleon mass. Having simultaneously analysed both charged and neutral channels, we also provide a quark-flavour separation of the transition form factors. The results should be useful in planning new-generation experiments.

Distribution Amplitudes of Heavy-Light Mesons

In collaboration with L. Chang, M. Ding (Nankai University, China), F. Gao, J. Papavassiliou (University of Valencia, Spain), C. D. Roberts (ANL, Lemont, USA)

A symmetry-preserving approach to the continuum bound-state problem in quantum field theory is used to calculate the masses, leptonic decay constants and light-front distribution amplitudes of empirically accessible heavy-light mesons. The inverse moment of the B-meson distribution is particularly important in treatments of exclusive B-decays using effective field theory and the factorisation formalism; and its value is therefore computed: $\lambda B(\zeta = 2$ GeV$) = 0.54(3)$ GeV. As an example and in anticipation of precision measurements at new-generation B-factories, the branching fraction for the rare $B \rightarrow \gamma(E\gamma)l\nu l$ radiative decay is also calculated, retaining $1/mB2$ and $1/E\gamma 2$ corrections to the differential decay width, with the result $\Gamma B\rightarrow\gamma l\nu l/\Gamma B = 0.47(15)$ on $E\gamma > 1.5$ GeV.

Off-shell renormalization in the presence of dimension~6 derivative operators. I. The Abelian case

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

The consistent recursive subtraction of UV divergences order by order in the loop expansion for spontaneously broken effective field theories with dimension-6 derivative operators is presented for an Abelian gauge group. We solve the Slavnov-Taylor identity to all orders in the loop expansion by homotopy techniques and a suitable choice of invariant field coordinates (named bleached variables) for the linearly realized gauge group. This allows one to disentangle the gauge-invariant contributions to off-shell 1-PI amplitudes from those associated with the gauge-fixing and (generalized) non-polynomial field redefinitions (that do appear already at one loop).

Arianna Carbone

Microscopic predictions of the nuclear matter liquid-gas phase transition

In collaboration with A. Polls (University of Barcelona, Spain) and A. Rios (University of Surrey, UK)

We studied first-principles predictions for the liquid-gas phase transition in symmetric nuclear matter employing both two- and three-nucleon chiral interactions. Our work focused on the sources of systematic errors in microscopic quantum many-body predictions. On the one hand, we tested uncertainties of our results arising from changes in the construction of chiral Hamiltonians. We used five different chiral forces with consistently derived three-nucleon interactions. On the other hand, we compared the ladder resummation in the self-consistent Green’s functions approach to finite-temperature Brueckner-Hartree-Fock calculations. We found that systematics due to Hamiltonians dominate over many-body uncertainties. Based on this wide pool of calculations, we estimated that the critical temperature is $Tc = 16 \pm 2$MeV, in reasonable agreement with experimental results. We also found that there is a strong correlation between the critical temperature and the saturation energy in microscopic many-body simulations. A publication on this work was presented.

Nuclear physics constraints on the equation-of-state thermal effects

In collaboration with A. Schwenk (University of Darmstadt, Germany)

We exploited the many-body self-consistent Green's function method to analyze finite-temperature properties of infinite nuclear matter and explored the behavior of the adiabatic index used to simulate thermal effects in equations of state for astrophysical applications. We showed how this index is both density and temperature dependent, unlike often considered, and we provided an error estimate based on our ab initio calculations. The inclusion of many-body forces was found to be fundamental to define the trend of thermal effects. We presented a functional form to parametrize the index via sole knowledge of the nucleon effective mass. We found it to be strongly dependent on the effective mass density-dependence behavior. Our study questions the validity of predictions made for the gravitational-wave signal from neutron-star merger simulations with constant-index equations of state. A publication on this work is in process.

Discriminating reliable ab initio nuclear matter results for neutron star applications

Within the many-body self-consistent Green's function approach, we calculated the energy per nucleon versus density of symmetric nuclear matter using several different nuclear Hamiltonians derived from chiral effective field theory. Comparing to mean-field theory results, we selected the ones that best reproduce the empirical saturation point in terms of either density or binding energy. Analizing both microscopic and bulk properties, we showed how fairly well saturating potentials can behave drastically different in pure neutron matter and predict poorly the symmetry energy and its slope parameter at saturation density. Finally we imposed recent constraints on the density dependence of the symmetry energy and defined reliable asymmetric matter equation of states to be used in astrophysical applications. A publication on this work is in preparation.

Jesús Casal Berbel

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

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

One-nucleon removal (p,pN) reactions in inverse kinematics provide a powerful tool to extract spectroscopic information of exotic nuclei, such as separation energies, spin-parity assignments, and occupation probabilities. In the case of three-body Borromean projectiles, the reaction products after one nucleon removal are unbound systems, which will automatically decay. Therefore, the study of these processes allows us to extract spectroscopic information on exotic three-body projectiles, by probing the continuum wave function of the unbound binary fragments. Recently [1], we developed a novel method to study (p,pN) reactions induced by systems comprising a compact core and two valence nucleons, such as two-neutron halo nuclei. The theoretical framework incorporates a proper three-body structure model for the projectile [2] and a reliable reaction formalism: the Transfer to the Continuum method [3], here extended for core+N+N systems. In our prescription, all the structure information is contained in the overlaps between the three-body ground-state wave function of the projectile and the two-body continuum states after one nucleon removal. We explored the effect of these structure properties on the computed cross sections and compared with the available experimental data for the 11Li(p,pn)10Li reaction at 280 MeV/u [1]. The 11Li model providing the best agreement with (p,pn) data was found to be the same describing satisfactorily the11Li(p,d)10Li transfer reaction at 5.7 MeV/u [4]. We have applied the method to 14Be(p,pn)13Be, in which gamma coincidences from the decay of the 12Be core in 13Be (12Be+n) were previously observed [5]. To describe this feature, we have considered the inclusion of core excitations in the structure description (e.g., as in Ref. [6]). The interpretation of new experimental data is ongoing [7].

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

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

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

Three-body radiative capture reactions

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

In Refs. [2], we developed a three-body model to compute radiative capture reaction rates of astrophysical interest. We applied the method to the 4He(2n,g)6He [2] and 4He(4He n, g)9Be [10] reactions at astrophysical conditions, which could play a role in neutron-rich environments for the r-process [11,12]. We showed the relevance of the direct or three-body capture at low temperatures compared to sequential estimations. More recently, we applied the same method to the 15O(2p,g)17Ne [13] capture, which has been proposed as a key ingredient for the rp-process controlling the trigger conditions of type I x-ray bursts. However, theoretical estimations of these rates are subject to large uncertainties. For this reason, we proposed a novel theoretical procedure to estimate the rate from inclusive breakup measurements at low energies [14]. In this line, we presented a Letter of Intent, which was recently updated to a full proposal (E774S GANIL PAC Nov. 2018) to measure 6He breakup below the Coulomb barrier at very forward angles and with high precision. These measurements are expected to provide solid constraints on the 4He(2n,g)6He reaction and to open new possibilities for exotic systems of astrophysical interest.

Two-nucleon correlations in light exotic nuclei

Exotic nuclei far from stability give rise to unusual properties and decay modes [15]. Large efforts have been devoted to understanding the properties of two-neutron halo nuclei, for which theoretical investigations in core + n + n models indicate that the correlations between the valence neutrons play a fundamental role in shaping their properties [16]. The evolution of these correlations beyond the driplines has implications for two-nucleon radioactivity [17,18]. I have been recently working on the description of unbound three-body (core + N + N) systems, using a pseudostate method [2] in hyperspherical coordinates, to analyze their structure in terms of nucleon-nucleon correlations. The application to 16Be (14Be+n+n) and 6Be (4He+p+p) [19] confirmed the strong dineutron and diproton configurations observed experimentally in the decay of these systems [20,21]. Interestingly, the pseudostate method, although being less demanding computationally, provided similar results compared to the calculation of actual three-body scattering states [17]. This applies also to the determination of resonance widths [22], and is currently being extended to describe the energy and angular correlations of the emitted nucleons. In addition, this method can be applied in general to three-body systems comprising several charged particles, for which the scattering asymptotic behavior is not known in general. This opens the possibility to perform a systematic study of two-nucleon emitters, such as the exotic oxygen isotopes 24O, 26O, 11O. The decay from excited states of dripline nuclei, e.g., the resonances in 6He or 17Ne, could also be studied. Work along these lines is ongoing.

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Minghui Ding

γ ∗γ → η, η' transition form factors

In collaboration with D. Binosi (ECT/FBK, Italy), K. Raya (Nankai University, China), A. Bashir (Universidad Michoacana de San Nicolás de Hidalgo, Mexico), L. Chang, M. Chen (Nankai University, China), C. D. Roberts (ANL, Lemont, USA)*

In this project we study the medium properties of the out of equilibrium matter created in the initial stages in ultrarelativistic heavy-ion collisions. In the weak coupling description the initial stage is dominated by overoccupied gluon fields, which can be described using classical fields [1]. In practice, we simulate classical Yang-Mills theory on the lattice using the classical statistical approximation. In this way we can study the real time evolution of the strongly interacting matter created in ultrarelativistic heavy-ion collisions and extract some properties of this medium.

The heavy quark diffusion coefficient can be extracted by studying the unequal time electric field correlator corresponding to the unequal time Lorentz force-force correlation function as done in [2]. However, in [2] Ads/CFT correspondence is used to extract the diffusion coefficient. Heavy quark diffusion has been addressed also in classical lattice gauge theory [3]. Our aim is to extract the diffusion coefficient in the self-similar regime [4], which we have addressed before in several studies [5,6,7].

Transport coefficients measure the rate at which the perturbed system returns to equilibrium. They can be extracted using linear response theory. We have developed a method which allows us to simulate linearized perturbations on top of a classical Yang-Mills background [8]. The algorithm has already been successfully used in [7] where we study spectral properties of overoccupied gluon plasma by extracting the spectral function of the out of equilibrium gluon fields using linear response analysis. Thus using our machinery we should be able to extract also other transport coefficients, such as shear viscosity.

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Jarkko Peuron

Heavy quark diffusion and transport coefficients in overoccupied gluon plasma

In collaboration with K. Boguslavski (University of Jyväskylä, Finland), A. Kurkela (CERN, Geneva, Switzerland), and T. Lappi (University of Jyväskylä, Finland)

In this project we study the medium properties of the out of equilibrium matter created in the initial stages in ultrarelativistic heavy-ion collisions. In the weak coupling description the initial stage is dominated by overoccupied gluon fields, which can be described using classical fields

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Alessandro Pilloni

Study of hybrid mesons in the light sector

In collaboration with Joint Physics Analysis Center

Mapping states with explicit gluonic degrees of freedom in the light sector is a challenge, and has led to controversies in the past. In particular, the experiments have reported two different hybrid candidates with spin-exotic signature, $\pi_1(1400)$ and $\pi_1(1600)$, which couple separately to $\eta\pi$ and $\eta'\pi$. This picture is not compatible with recent Lattice QCD estimates for hybrid states, nor with most phenomenological models. We consider the recent partial wave analysis of the $\eta^{(\prime)}\pi$ system by the COMPASS collaboration. We fit the extracted intensities and phases with a coupled-channel amplitude that enforces the unitarity and analyticity of the S-matrix. We provide a robust extraction of a single exotic resonant pole, with mass and width 1564 ± 24 ± 86 and 492 ± 54 ± 102 MeV, which couples to both $\eta^{(\prime)}\pi$ channels. We find no evidence for a second exotic state. We also provide the resonance parameters of the $a_2(1320)$ and $a_2(1700)$. A first paper has already been published [1], and a longer paper, which explains the details on how to disentangle the physical states from the artefacts of the parameterization, is in preparation.

The spectroscopy program at EIC and future accelerators

In collaboration with M. Battaglieri (INFN Genova, Italy) and A. Szczepaniak (Indiana University and JLab, USA)

The highest priority project for the Nuclear Physics division of the Department of Energy is the Electron Ion Collider (EIC), expected to be built during the next decade. The EIC will be distinguished from all past and future facilities around the world due to its versatile range of kinematics, beam polarizations, and beam species. The EIC will be a unique leader in the intensity frontier of nuclear physics. Although the main goal of this facility will be the study of the proton structure, there are opportunities to create a comprehensive hadron spectroscopy program, to support and strengthen the EIC physics case. We created a working group interested in pursuing hadron spectroscopy at EIC. The kick-off workshop was held in December at ECT*. We are collecting written contributions from the whole international community, which will merge into a white paper to appear in the summer. The white paper will be included in the EIC Physics case representing the manifesto of an active working group interested in pursuing hadron spectroscopy in the future.

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Naoto Tanji

Real-time lattice simulations of axial charge production in expanding color flux tubes

In relativistic heavy-ion collisions, CP-violating configurations of color gauge fields can be generated locally by gauge field dynamics at the instant of a collision. Quarks produced from such gauge fields induce the imbalance of axial charge due to the quantum phenomenon of axial anomaly. In presence of a strong $U(1)$ magnetic field, which may be generated in off-central collisions, the axial charge asymmetry can be converted to a flow of electric current along the magnetic field. This exotic transport phenomenon is called chiral magnetic effect. To make reliable predictions about the chiral magnetic effect, the understanding of the axial charge production at the early stage of heavy-ion collisions is indispensable. In Ref. [1], we have investigated the nonequilibrium process of the axial charge production in CP-violating gauge field configurations by using a real-time lattice simulation technique. Starting from initial conditions given by the Color Glass Condensate effective theory, the time evolution of quantum quark fields under the classical color gauge field is computed on a lattice in longitudinally expanding geometry. We consider simple color charge distributions in Lorentz contracted nuclei that realize flux tube-like configurations of color fields carrying nonzero topological charge after a collision. By employing the Wilson fermion extended to the longitudinally expanding geometry, we demonstrate the realization of the axial anomaly on the real-time lattice.

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

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

Photons and dileptons are useful probes for the space-time history of heavy-ion collisions since they can escape from strongly-interacting matter almost unaffected. To find possible experimental probes for the chiral symmetry restoration, we study the photon and dilepton production at finite temperature and chemical potential within low-energy effective model for

QCD. As a nonperturbative method that can describe critical phenomena correctly and is free from the sign problem at finite chemical potential, we employ the analytically-continued functional renormalization group (FRG) method [2]. To include the effects of rho-meson resonances, we assume the vector-meson dominance model and derived a formula for the dilepton production rate.

Statistical fluctuations of correlators in the Color Glass Condensate

In collaboration with F. Gelis (Université Paris-Saclay CEA, France)

In the Color Glass Condensate effective theory for high-energy nuclei, correlators of Wilson lines are given by an average over an ensemble of random color sources. In numerical implementations, these averages are approximated by a Monte-Carlo sampling. In [3], we study the statistical error made with such a sampling, with emphasis on the momentum dependence of this error. Using the example of the dipole amplitude, we consider various approximants that are all equivalent in the limit of infinite statistics but differ with finite statistics and compare their statistical errors. For correlation functions that are translation invariant, we show that averaging over the barycenter coordinate drastically reduces the statistical error and more importantly modifies its momentum dependence.

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Dionysios Triantafyllopoulos

NLO BK evolution with decreasing Bjorken's x

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

At ultra-relativistic energies, the wave function of a generic hadron (ranging from a proton to a large nucleus) exhibits gluon saturation [1] for modes which carry a small fraction of the hadron's longitudinal momentum. Even though the transverse momentum of these modes is larger than the confinement scale, which means that the problem can be addressed with weak coupling techniques, strong-field methods must be used due to the high occupancy of gluons.

The main tool for studying this phenomenon is the Balitsky-Kovchegov (BK) equation [2,3] which gives the rapidity evolution of the scattering of a color dipole off the hadron under consideration. This leading order (LO) equation is good enough for qualitative understanding, but is very poor for any kind of phenomenological discussions. While the next-to-leading order (NLO) corrections have been also calculated [4], they are not sufficient to resolve the issue, since they include very large collinear logarithms which in turn lead to unstable unphysical results [5,6,7]. It was shown that the double collinear logarithms are due to soft emissions strictly ordered in lifetime, and the respective resummation to all-orders was performed [8,7] leading to a stabilization of the evolution.

When solving the BK equation (at LO, NLO or resummed), one needs an initial condition which is typically given by the McLerran Venugopalan (MV) model [9] or some variant of it. The evolution equation beyond LO is derived in terms of the projectile rapidity (Y-representation), and due to that it was already observed in [9] that the initial condition also receives very large corrections at NLO. Although no special attention had been paid into this so far, one must construct this initial condition, or one must solve a boundary value problem.

In [10] we show that all this procedure in the Y-representation is very ambiguous, even using the resummed evolution. We have managed to write the proper evolution, with NLO corrections included and with large collinear logarithms resummed, *in terms of the target rapidity* (η-representation) [10]. This means that one can simply solve, as in LO evolution, an initial value problem. This constitutes a new state of the art evolution at small Bjorken'x which should lead to more accurate phenomenology in semi-hard QCD processes.

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Ralf-Arno Tripolt

In-medium spectral functions and dilepton rates with the Functional Renormalization Group

In collaboration with Ch. Jung, L. von Smekal (Giessen University, Germany), N. Tanji and J. Wambach (ECT/FBK, Italy)*

In Ref. [1] we presented first results on vector and axial-vector meson spectral functions as obtained by applying the non-perturbative functional renormalization group (FRG) approach to an effective low-energy theory motivated by the gauged linear sigma model. We extended this model by introducing a U(1) symmetry and the corresponding gauge field, i.e. the photon. Based on this model, we derived flow equation for the electromagnetic (EM) spectral function at finite temperature and chemical potential and solved them numerically. These EM spectral functions were then used as input for the calculation of thermal dilepton rates, in particular near the crossover transition and the critical endpoint in the phase diagram of the model. Preliminary results were presented at the Quark Matter 2018 conference in Venice [2].

Numerical analytic continuation of Euclidean data

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

In Ref. [3] we showed how complex resonance poles and threshold energies for systems in hadron physics can be accurately obtained by using a Padé-like method. Also the possibility to use this method to obtain real-time correlation functions from their imaginary-time counterparts was mentioned. This year, we finished a paper on the direct comparison of three different numerical analytic continuation methods: the Maximum Entropy Method, the Backus-Gilbert method and the Padé-like, so-called Schlessinger-point-method. First, we performed a benchmark test based on a model spectral function and studied the regime of applicability of these methods depending on the number of input points and their statistical error. We then applied these methods to more realistic examples, namely to numerical data on Euclidean propagators obtained from a Functional Renormalization Group calculation, to data from a Lattice Quantum Chromodynamics simulation and to data obtained from a tight-binding model for graphene in order to extract the electrical conductivity.

Fermionic spectral functions with the Functional Renormalization Group

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

We are working on the calculation of fermionic spectral functions with the FRG at finite temperature and chemical potential. Our method is based on a well-defined analytic continuation procedure from imaginary to real energies that was developed recently for bosonic spectral functions [4]. In order to demonstrate the applicability of the method also for fermions we applied it to the quark-meson model and calculate the real-time quark propagator as well as the quark spectral function in the vacuum [5]. We are working on an extension of these results towards finite temperature, finite chemical potential and finite momentum. An application of these techniques to the parity-doublet model will allow for the calculation of in-medium nucleon spectral functions.

The low-temperature behavior of the quark-meson model

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

We revisit the phase diagram of strong-interaction matter for the two-flavor quark-meson model using the Functional Renormalization Group [5]. In contrast to standard mean-field calculations, an unusual phase structure is encountered at low temperatures and large quark chemical potentials. In particular, we identify a regime where the pressure decreases with increasing temperature and discuss possible reasons for this unphysical behavior. We are working on identifying the source of this anomalous behavior.

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Jochen Wambach

My research in 2018 included the following topics:

- Equilibrium properties of hot and dense strong-interaction matter
- Medium modification of the spectral properties of hadrons
- Dilepton rates and polarization observables in heavy-ion collisions

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

The low-temperature behavior of the quark-meson model

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

As an effective low-energy description of QCD the Quark-Meson model (QM) is widely used to compute the phase diagram of strong-interaction matter. When imposing spatial homogeneity, a first-order chiral transition at low temperature is found in the mean-field (MF) approximation, which ends in a critical point. In this point the phase transition is of second order and lies in the same universality class as the liquid-gas transition. Standard MF calculations in the QM model lead to a first-order phase transition line that is consistent with the Clausius-Clapeyron relation. The phase diagram of the QM model has also been calculated using the Functional Renormalization Group (FRG) approach in Ref. [1], which is much more powerful than MF theory in describing phase transitions. There it was found that at low temperatures, the curvature of the phase boundary bends the `wrong way' in the sense of the Clausius-Clapeyron relation. We have revisited this problem in Ref. [2] and have identified a region of negative entropy density, driven by fermionic fluctuations. We have also discussed possible reasons for this unphysical behavior. A likely possibility is that the truncation of the flow equations to lowest order in the gradient expansion produces this unphysical thermodynamic behavior, which is remedied if next-order wavefunction renormalization is taken into account. This will have to be studied further [3].

Color superconductivity from the chiral quark-meson model

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

Another possible source of the region of negative entropy density in the FRG treatment of the QM phase diagram may be a Cooper instability of the Fermi surface to 2SC color superconductivity. It is easy to show that the interactions between quarks that are generated by pion and sigma exchanges are attractive. Starting from the Nambu-Gor'kov propagator in a real-time formulation we have derived in Ref. [4] a set of finite temperature Eliashberg-type gap equations for the quark gap functions in terms of in-medium spectral functions for pions and sigma mesons. Exact numerical solutions of the coupled nonlinear integral equations for the real and imaginary parts of the gap function were obtained in the zero-temperature limit. Future extensions of this approach may involve the evaluation of the components of the 2SC gap function using spectral functions of the QM model directly for specific values of density and temperature of quark matter.

Fermionic spectral functions from the Functional Renormalization Group

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

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

(QM) model and have calculated in a first step the real-time quark propagator as well as the quark spectral function in the vacuum [7]. Currently we are extending the calculations to finite temperatures and baryochemical potentials. First results [8] indicate interesting collective, low-energy dynamics at high temperatures and low chemical potentials, with features similar to what is found in hard-thermal loop QCD calculations.

In-medium vector-meson spectral functions and Dilepton rates

In collaboration with Ch. Jung, L. von Smekal (Giessen University, Germany), Naoto Tanji (ECT/FBK, Italy) and R.-A. Tripolt (ECT*/FBK, Italy, and Frankfurt University, Germany)*

Based on results for the in-medium spectral functions of vector- and axial-vector mesons [9], the electromagnetic (EM) spectral functions and dilepton rates are being calculated using the FRG approach. Our method is based on an analytic continuation procedure that allows to calculate real-time quantities like spectral functions at finite temperature and chemical potential. As an effective low-energy model for Quantum Chromodynamics (QCD) we use an extended linear-sigma model including quarks where vector- axial-vector mesons as well as the photon are introduced as gauge bosons. It has been shown in [9] that the ρ- and a1-spectral functions become degenerate at high temperatures or chemical potentials as required by the restoration of chiral symmetry. Preliminary results for the EM spectral function and the dilepton production rate are being calculated [10] with a focus on the possibility to identify signatures of the chiral crossover and the critical endpoint (CEP) in the QCD phase diagram. Another focus is the calculation of the temperature- and chemical- potential dependence of the electrical conductivity, which results from the low-energy limit of the EM spectral function [11].

Dilepton rates and polarization observables in heavy-ion collisions

In collaboration with B. Friman (GSI, Germany), E. Speranza, H. van Hees (Frankfurt University, Germany), and R. Rapp (Texas A&M University, USA)

Based on recent work by B. Friman and E. Speranza on polarized dilepton radiation from a thermal QCD medium [12] we have started to make realistic predictions for the $\lambda\theta$ –Parameter based on calculated rates that quantitatively describe the unpolarized dilepton data of many heavy-ion experiments [13]. First results [14] indicate a sizable polarization for invariant masses below 1.5 GeV especially for collision energies around 10 GeV and below.

Other scientific activities

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

1. "Arbeitstreffen Kernphysik" Schleching:
Deep inelastic scattering, hadron physics, modern data analysis, AdS/CFT holography
Schleching, Germany, February 15 - 22, 2018

2. International School of Nuclear Physics, 40th Course:
The Strong Interaction: From Quark and Gluons to Nuclei and Stars
Erice, Italy, Sept. 16 – 24, 2018

In this school I presented a talk:
Amand Fäßler and the Erice International School for Nuclear Physics,
honoring the many contributions of Professor Amand Fäßler to the Erice School.

On November 14-15, 2018 I served on the DOE Review Committee for the Institute of Nuclear Theory in Seattle, USA.

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4.2 Publications of ECT* Researchers in 2018

Daniele Binosi

D. Binosi, J. Papavassiliou
Coupled dynamics in gluon mass generation and the impact of the three-gluon vertex
*Phys. Rev. **D97** (2018) no.5, 054029*

D. Binosi, A. Quadri
Off-shell renormalization of dimension 6 operators in Higgs effective field theories
JHEP 1804 (2018) 050

A. C. Aguilar, D. Binosi, C. T. Figueiredo, J. Papavassiliou
Evidence of ghost suppression in gluon mass dynamics
*Eur. Phys. J. **C78** (2018) no.3, 181*

D. Binosi, C. Mezrag, J. Papavassiliou, C. D. Roberts, J. Rodriguez-Quintero
Process-independent effective coupling. From QCD Green's functions to phenomenology
*Few Body Syst. **59** (2018) no.6, 121*

B. Berthou, D. Binosi, N. Chouika, L. Colaneri, M. Guidal, C. Mezrag, H. Moutarde, J. Rodríguez-Quintero, F. Sabatié, P. Sznajder, J. Wagner
PARTONS: PARtonic Tomography of Nucleon Software: A computing framework for the phenomenology of Generalized Parton Distributions
*Eur. Phys. J. **C78** (2018) no.6, 478*

Arianna Carbone

A. Carbone, A. Polls and A. Rios
Microscopic predictions of the nuclear matter liquid-gas phase transition.
Phys. Rev. ***C98*** *(2018) 025804*

Jesús Casal

J. Casal and J. Gómez-Camacho
Two-nucleon emitters within a pseudostate approach
arXiv:1811.02826 [nucl-th], to appear in Springer Proceedings in Physics
Proceedings of the conference "Few-Body Problems in Physics XXII" (July 2018, Caen, France)

J. Casal and J. Gómez-Camacho
Identifying structures in the continuum: Application to 16Be
arXiv:1810.06447 [nucl-th], submitted to Phys. Rev. C

A. Arazi, J. Casal, et al.
9Be+120Sn scattering at near-barrier energies within a four body model
Phys. Rev. ***C97*** *(2018) 044609, arXiv:1801.01272 [nucl-th]*

J. Casal
Two-nucleon emitters within a pseudostate method: The case of 6Be and 16Be
Phys. Rev. ***C97*** *(2018) 034613, arXiv:1801.01280 [nucl-th]*

Alessandro Pilloni

BaBar Collaboration (J.P. Lees *et al.*)
Study of the reactions $e^+e^- \to \pi^+\pi^-\pi^0\pi^0\pi^0\gamma$ and $e^+e^- \to \pi^+\pi^-\pi^0\pi^0\eta\gamma$ at center-of-mass energies from threshold to 4.35 GeV using initial-state radiation
Phys. Rev. ***D98*** *(2018) no.11, 112015*

Naoto Tanji

R.-A. Tripolt, C. Jung, N. Tanji, L. von Smekal, J. Wambach
In-medium spectral functions and dilepton rates with the Functional Renormalization Group
arXiv:1807.04952 [hep-ph]
Proceedings of the "27th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2018)" (14-19 May 2018. Venice, Italy)

N. Tanji, J. Berges
Nonequilibrium quark production in the expanding QCD plasma
arXiv:1807.05033 [hep-ph]
Proceedings of the "27th International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (Quark Matter 2018)" (14-19 May 2018. Venice, Italy)

N. Tanji
Nonequilibrium axial charge production in expanding glasma flux tubes

Phys. Rev. ***D98*** *(2018) no.1, 014025, arXiv:1805.00775 [hep-ph]*

N. Tanji, J. Berges
Nonequilibrium quark production in the expanding QCD plasma
Phys. Rev. ***D97*** *(2018) no.3, 034013, arXiv:1711.03445 [hep-ph]*

Dionysios Triantafyllopoulos

Y. Hatta, E. Iancu, A.H. Mueller and D.N. Triantafyllopoulos
Resumming double non-global logarithms in the evolution of a jet
JHEP 1802 (2018) 075

B. Ducloué, E. Iancu, T. Lappi, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos and Y. Zhu
On the use of a running coupling in the NLO calculation of forward hadron production
Phys. Rev. ***D97*** *(2018) no.5, 054020*

D.N. Triantafyllopoulos
Forward particle production in proton-nucleus collisions at next-to-leading order
EPJ Web Conf. 192 (2018) 00014

Ralf-Arno Tripolt

R.-A. Tripolt, C. Jung, N. Tanji, L. von Smekal, J. Wambach
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arXiv:1807.04952, Quark Matter 2018 Proceedings

R.-A. Tripolt, J. Weyrich, L. von Smekal, J. Wambach
Fermionic spectral functions with the Functional Renormalization Group
arXiv:1807.11708, Phys. Rev. **D98** (2018), no9., 094002

Jochen Wambach

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Fermionic Spectral functions with the Functional Renormalization Group
Phys. Rev. **D98**, 094002 (2018), arXiv:1807.11708

T. Galatyuk, H. van Hees, R. Rapp, J. Wambach
Extrem und strahlend
Physik Journal, (2018), 10 / 2018, 41s

R.-A. Tripolt, Ch. Jung, N. Tanji, L. von Smekal, J. Wambach
In-medium spectral functions and dilepton rates with the Functional Renormalization Group
Quark Matter 2018 proceedings, arXiv:1807.04952

A. Sedrakian, R.-A. Tripolt, J. Wambach
Color superconductivity from the chiral quark-meson model
Phys. Lett. **B780** (2018) 627, arXiv:1711.04269

R.-A. Tripolt, B.-J. Schaefer, L. von Smekal, J. Wambach
The low-temperature behavior of the quark-meson model
Phys. Rev. **D97** 034022 (2018), arXiv:1709.05991

4.3 Publications of ECT* long term Visitors in 2018

Achim Richter

LB. Dietz and A. Richter
From graphene to fullerene: experiments with microwave photonic crystals
Phys. Scr. ***94*** *(2019) 014002*

4.4 Talks presented by ECT* Researchers in 2018

Daniele Binosi

Dynamical gluon mass generation: Theory and Applications
Invited talk at the 666 WE-Heraeus-Seminar “From Correlation Functions to QCD Phenomenology”
Physikzentrum Bad Honnef, Germany
April 2018

Colored bound states and dynamical gluon mass generation
Invited talk at the workshop “Bound states in strongly coupled systems”
Galileo Galilei Institute, Florence, Italy
March 2018

Emergent phenomena in strong dynamics and curved space-times
Invited talk at the ECT* 25th Anniversary
ECT*, Italy
August 2018

Parton Distribution Amplitudes for heavy-light pseudoscalar mesons
Invited talk at the workshop “Mapping Parton Distribution Amplitudes and Functions”
ECT*, Italy
September 2018
and
Invited talk at the workshop “Non perturbative QCD 2018”
Sevilla, Spain
November 2018

Emergent phenomena in strong dynamics
Invited talk at the workshop “Emergent mass and its consequences in the Standard Model”
ECT*, Italy
September 2018

Arianna Carbone

Predicting nuclear matter at finite temperature with the use of chiral interactions
Seminar given at TU Darmstadt
December 2018, Darmstadt, Germany

Advances in ab initio nuclear matter from a Green's function perspective
Seminar given at GANIL
November 2018, GANIL, France

Advances in ab initio nuclear matter from a Green's function perspective
Seminar given at the University of Barcelona
November 2018, Barcelona, Spain

Predicting the symmetry energy from saturating potentials
Talk delivered at: NuSYM18
September 2018, Busan, South Korea

Ab initio studies of nuclear matter from a Green's function approach
Talk delivered at: ENSAR2 Town Meeting

April, Groningen, Netherlands

Ab initio studies of nuclear matter from a Green's function approach.
Seminar given at the University of York
February 2018, York, UK

Ab initio studies of nuclear matter from a Green's function approach.
Seminar given at the University of Manchester
February 2018, Manchester, UK

Jesús Casal Berbel

Two-nucleon emitters within a pseudostate approach
Talk given at the XXII International Conference on Few-body Problems in Physics (FB22)
July 2018, Caen, France

Linking structure and dynamics in (p,pN) reactions induced by Borromean nuclei
Talk given at the X International Conference on Direct Reactions with Exotic Beams (DREB2018)
June 2018, Matsue, Japan

Linking structure and dynamics in (p,pN) reactions induced by Borromean nuclei
Talk given at the ENSAR2 Town Meeting
April 2018, Groningen, The Netherlands

Minghui Ding

Parton distribution amplitudes of neutral pseudoscalar mesons
Invited talk at the workshop “Mapping Parton Distribution Amplitudes and Functions”
ECT*, Italy
September 2018

Parton Distribution Amplitudes of s-wave and p-wave heavy quarkonium
Invited talk at the workshop “Emergent mass and its consequences in the Standard Model”
ECT*, Italy
September 2018
and
Invited talk at the workshop “Non perturbative QCD 2018”
Sevilla, Spain
November 2018

Jarkko Peuron

Quasiparticle properties of nonequilibrium gluon plasma
Talk given at the University of Stavanger
November 2018, Stavanger, Norway

Quasiparticle properties of nonequilibrium gluon plasma.
Talk given at ECT*
December 2018, ECT, Italy*

Alessandro Pilloni

Light and Heavy Hybrids
Invited talk given at the workshop “The spectroscopy program at EIC and future accelerators”
December 2018, ECT, Italy*

Naoto Tanji

Nonequilibrium axial charge production in expanding color fields
Talk given at the workshop “Chirality, Vorticity and Magnetic Field in Heavy Ion Collisions”
March 2018, Florence, Italy

Nonequilibrium quark production in the expanding QCD plasma
Talk given at the 27th International Conference “Ultrarelativistic Nucleus-Nucleus Collisions” (Quark Matter 2018)
May 2018, Venice, Italy

Nonequilibrium axial charge production in expanding Glasma flux tubes
Invited talk given at SFB-TR 211 Meeting
May 2018, Darmstadt, Germany

Nonequilibrium axial charge production in expanding Glasma flux tubes
Talk given at the ECT* workshop "Gauge Topology 3: from Lattice to Colliders"
June 2018, Trento, Italy

Dionysios Triantafyllopoulos

Saturation fronts in resummed high energy evolution
Talk given at the workshop "Probing QCD at the high energy frontier"
May 2018, Trento, Italy

Forward particle production in proton-nucleus collisions at NLO
Talk given at the workshop "QCD at Work"
June 2018, Matera, Italy

Resummed high-energy non-linear evolution at NLO
Talk given at the workshop "Probing Nucleons and Nuclei in High Energy Collisions"
November 2018, INT Seattle, USA

Ralf-Arno Tripolt

Spectral functions and dilepton rates with the FRG
Talk at CRC-TR retreat
March 2018, Bielefeld, Germany

In-medium spectral functions of hadrons with the Functional Renormalization Group
Talk at 666. WE-Heraeus-Seminar "From correlation functions to QCD phenomenology"
April 2018, Bad Honnef, Germany

In-medium spectral functions of hadrons with the Functional Renormalization Group
Talk at Quark Matter 2018
May 2018, Venice, Italy

Quark and meson spectral functions with the functional renormalization group
Talk at the ECT* workshop "Emergent mass and its consequences in the Standard Model"
September 2018, Trento, Italy

Jochen Wambach

ECT* and NUSTAR
Talk presented at "NUSTAR WEEK 2018"
September 2018, Milano, Italy

Amand Fäßler and the Erice International School for Nuclear Physics
Talk presented at the International School for Nuclear Physics 40th Course
"The Strong Interaction: From Quarks and Gluons to Nuclei and Stars"
September 2018, Erice, Italy

The 25th Anniversary of ECT*
Talk presented at the ECT* 25th Anniversary meeting
August 2018, Trento, Italy

Spectral properties of matter under extreme conditions: What have we learned from photons?
Talk presented at "New Frontiers in QCD 2018", Yukawa Institute of Theoretical Physics
June 2018, Kyoto, Japan

Spectral properties of matter under extreme conditions: What have we learned from photons?
Theory Colloquium, University of Torino
February 2018, Torino, Italy

4.5 Seminars and colloquia at ECT*

Quantum simulation of Majorana fermions in cold atoms
09 Mar 2018
Leonardo Mazza (École Normale Supérieure, Paris)

A cosmological model from loop quantum gravity on lattice
13 Sep 2018
Andrea Dapor (Friedrich-Alexander-Universität Erlangen-Nürnberg)

Partonic structure of neutral pseudoscalars via two photon transition form factors
12 Dec 2018
Minghui Ding (ECT*/FBK)

Quasiparticle properties of nonequilibrium gluon plasma
19 Dec 2018
Jarkko Peuron (ECT*/FBK)

Properties of strongly interacting matter from first principles
31 August 2018, 25th Anniversary Symposium
Claudia Ratti (Houston)

From fundamental interactions to structure and stars
31 August 2018, 25th Anniversary Symposium
Achim Schwenk (TU Darmstadt)

Emergent mass in strong interactions
31 August 2018, 25th Anniversary Symposium
Daniele Binosi (ECT*/FBK Trento)

GW170817 and the history of the r-process
31 August 2018, 25th Anniversary Symposium
Jim Lattimer (Stony Brook)

Twenty years of Quantum Science and Technologies at ECT*: From the Star to Q@TN
31 August 2018, 25th Anniversary Symposium
Tommaso Calarco (Ulm University)

5 Research at ECT*-LISC

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

5.1 Projects of ECT*-LISC Researchers

Martina Azzolini

Calculation of reflection electron energy loss spectra with Monte Carlo simulation and numerical solution method

In collaboration with S. Taioli and M. Dapor (ECT/FBK, Italy), N. M. Pugno (University of Trento, Italy & Queen Mary University of London, UK), O. Y. Ridzel (University of Wien, Austria & Moscow Power Engineering Institute, Russia) and P. S. Kaplya (Moscow Power Engineering Institute, Russia)*

In Ref. [1] a method to directly compute the Reflection Electron Energy Loss (REEL) spectrum without the calculation of the electron trajectories is presented. It consists in the Numerical Solution of the Ambartsumian-Chandrasekhar equations, obtained by the application of the invariant embedding method. The Monte Carlo simulation and the numerical solution methods were applied to the calculation of REEL spectra of three materials (Copper, Silver. Gold). The comparison between the spectra shows the equivalence of these models in the REEL spectra calculation. The Numerical Solution method can be employed to quickly test the dielectric description of the target material. Once the Energy Loss function is tested the complete Monte Carlo simulation can be performed to calculate the secondary electron emission spectrum and the secondary electron emission yield.

Investigation on the influence of molecular ordering in secondary electron emission spectrum of P3HT

In collaboration with M. Dapor (ECT/FBK, Italy), N. M. Pugno (University of Trento, Italy & Queen Mary University of London, UK), R. C. Masters and C. Rodenburg (University of Sheffield, UK)*

Understanding nanoscale molecular ordering within organic electronic materials is a crucial factor in building better organic electronic devices. We investigated the material properties that influence the shape of the secondary electron emission spectrum from poly(3-hexylthiophene) (P3HT), a semicrystalline polymer with organic electron applications. We found out that the secondary electron emission spectrum reflects the presence of crystalline or amorphous phases in the sample. In particular, these phases are characterized by different electron affinity value. Thus the Monte Carlo simulation considered two different values of electron affinities corresponding to different areas of the irradiated sample. As a result we found a good agreement between calculated and experimental results. This investigation was therefore published in Advanced Science [2].

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

In collaboration with T. Morresi, S. Taioli, M. Dapor (ECT/FBK, Italy), N. M. Pugno (University of Trento, Italy & Queen Mary University of London, UK) and C. Rodenburg (University of Sheffield, UK)*

In Ref. [3] we applied the Monte Carlo method to calculate reflection electron energy loss spectra of Highly Oriented Pyrolytic Graphite by considering only in-plane inelastic interactions. The comparison with experimental data demonstrated the need to include also intra-planar inelastic interactions. Thus the Monte Carlo code was modified to consider both interaction directions. Moreover, the secondary electron emission spectrum was calculated by using this new model and compared with experimental data provided by Prof. C. Rodenburg. The results of this study were published in *The Journal of Physical Chemistry C* [4].

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

In collaboration with S. Taioli and M. Dapor (ECT/FBK, Italy), N. M. Pugno (University of Trento, Italy & Queen Mary University of London, UK), I. Abril and P. de Vera (University of Alicante, Spain), R. Garcia-Molina (University of Murcia, Spain)*

The focused electron beam induced deposition technique is applied in order to deposit 2D or 3D nanostructures on different substrates. In order to simulate the entire process, the coupling between Monte Carlo simulation and Molecular Dynamics simulation is required.
With the Monte Carlo method, we simulated the propagation of primary electrons and the emission of backscattered and secondary electrons. Emitted electrons were recorded accordingly to the distance between the center of the beam and the emission position. The electron fluences are then used as input for molecular dynamics simulation of the second part of the process that will be performed by P. de Vera. As a case study a layer of W(CO)6 deposited on SiO2 was considered. With Monte Carlo simulations we investigated the primary and secondary electron transport in the target material. Moreover, we calculated the electron emission yield at different primary emission energies as well as the distribution of depth of electron path in the solid target.

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

In collaboration with S. Taioli and M. Dapor (ECT/FBK, Italy), N. M. Pugno (University of Trento, Italy & Queen Mary University of London, UK), M. Angelucci, R. Cimino and R. Larciprete (INFN, Italy)*

Monte Carlo simulations were performed to calculate the secondary electron emission yield curves of Copper, Silver and Gold. To obtain a good agreement with experimental data provided by INFN Laboratories [5] we found that Energy Loss Function (ELF) has to be considered as an effective ELF, which also includes surface excitations [6]. The achieved results were presented at the ECLOUD'18 conference (June 2018) and a paper was published in *Journal of Physics: Condensed Matter* [7].

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[7] M. Azzolini et al., *Journal of Physics: Condensed Matter **31***(5), 055901 (2018)

Maurizio Dapor

Energy deposition around swift proton and carbon-ion tracks in biomaterials

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

Hadron therapy is a modern cancer treatment based on the interaction of proton or heavier ion beams with living tissue, whose purpose is the destruction of the malignant tumor cells producing minimal effects on the surrounding healthy tissue. To study the physical basis of the Relative Biological Effectiveness (RBE) of different projectiles, such as protons or carbon ions, we calculate the radial distribution of energy deposited by the secondary electrons generated in biomaterials by these ions at characteristic energies around the Bragg peak. This is done by means of the simulation code SEED, which follows in detail the motion and interactions of the secondary electrons as well as the subsequent electron cascade.

Highly oriented pyrolitic graphite secondary electron spectra

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

A model which properly considers weighted interplanar and intraplanar interactions in the simulation of electron transport in layered materials is used for taking into account the anisotropic structure of highly oriented pyrolitic graphite (HOPG) in the Monte Carlo simulations of charge transport. Monte Carlo simulated spectra, obtained with this anisotropic approach, are compared with acquired experimental data of secondary electron spectra.

Giovanni Garberoglio

Ab-initio calculation of virial coefficients for molecular gases

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

We continued the on-going collaboration for the ab-initio calculation of virial coefficients of molecular gases extending our methodologies to general flexible models of molecules. In Ref. [1] we validated our procedure in the case of water, showing that state-of-the-art potentials provide results of comparable quality to experimental data for the second virial coefficient. A fully ab-initio calculation of the third virial coefficient for water is currently not feasible due to limitations of the three-body potentials.

Mechanical and electronic properties of carbon based materials

In collaboration with N.M. Pugno (University of Trento) and A. Pedrielli (ECT/FBK)*

In Ref. [5] we proposed a novel structure of carbon nanofoam, and characterized its mechanical and thermal properties. While foam thermal conductivity is affected by both connectivity and defects our results indicate that topology is the critical factor affecting thermal transport in these structures.
In Ref. [4] we proposed novel functionalized-graphene materials and characterized their performance for gas adsorption and separation. Good performance for the gas separation in CH_4/H_2, CO_2/H_2 and CO_2/N_2 mixtures was found, with values comparable to those of metal-organic frameworks and zeolites.

Other collaborations

In Ref. [2] we used a mixed experimental and theoretical approach to characterize and investigate the properties of Silicon Carbide - Silica nanowires. In particular, we provide an accurate interpretation of the recorded X-ray absorption near-edge spectra enabling the optimal design and application of these nanosystems in actual devices.
In Ref. [4] we analyzed the time correlation functions of simple liquid metals, presenting a novel analysis of the longitudinal and transverse current correlation functions, enabling us to identify the various dynamical processes in different frequency ranges.

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Tommaso Morresi

Graphene on a Beltrami pseudosphere

In collaboration with S. Taioli, D. Binosi (ECT/FBK), S. Simonucci (University of Camerino), R. Piergallini (University of Camerino), N. M. Pugno (University of Trento), S. Roche (Institut Català de Nanociència i Nanotecnologia, Barcelona)*

The goal of this work is to model a structure made of 3-coordinated carbon atoms on the surface of a Beltrami pseudosphere and to calculate the electronic properties of this system. Indeed, in Ref. [1] a theoretical proof that graphene can be used as a realization of the Hawking-Unruh effect is given. This is due to the particular properties of electrons in graphene [2]. We want to study and demonstrate this effect using computational methods. In the first part of the project we have obtained the geometry of the system for different numbers of atoms. At least 10^6 particles are needed to demonstrate the hypothesis devised in Ref. [1]. In order to reach such a big number of atoms, we developed a method that increases particles with a dualization algorithm up to ~10^6 starting from a small configuration, in reasonable computational time. Next step, in collaboration with Prof. Stephan Roche, was the calculation of the Local Density of States (LDOS) of the optimized structures, for which we exploited a multi-orbital Tight Binding approach and the Kernel Polynomial method for the approximation of LDOS [3]. We implement the codes for electronic structure calculations on GPUs, allowing us to speed up the computations. Finally, in order to have a correct interpretation of results, we have to cut out from LDOS spectra the noise given by defects present on our structures. The LDOS observable will give information on the behaviour of quantum fields in a curved spacetime with a horizon. This work will be soon submitted to some high impact factor journal.

Modeling and simulations of SiO_x and SiC/SiO_x core/shell nanowires photoluminescence spectra

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

In this work we want to reproduce the experimental measurements performed by the group led by M. V. Nardi of photoluminescence and XEOL spectra in SiO_x and SiC/SiO_x core/shell nanowires. These systems are interesting in cancer treatment because the 3C-SiC green emission can be used to activate the singlet oxygen production by porphyrins, the dominant cytotoxic agent produced during photodynamic therapy [4]. We developed a realistic model of a single SiC/SiO_x core/shell nanowire and we characterized this structure both geometrically and electronically comparing our results with the literature. We calculated XANES spectra and we were able to reproduce rather accurately the experimental spectra. These results were published in Nanoscale [5]. Then we want to study the luminescence spectra after the excitation of the nanowires by X-rays and photons in the visible range, to understand how the coupling between the luminescence of nanowires and absorption of porphyrins could be maximized.

Study of two-dimensional sp2 carbon based materials

In collaboration with S. Taioli, A. Pedrielli (ECT/FBK), N. M. Pugno (University of Trento)*

The aim of this work was to find some new sp2 bonded carbon based 2D materials with low density and study their electronic and mechanical properties with ab-initio methods, comparing the results with the ones of graphene. We developed a method to decrease the packing factor of sp2 geometries and with that we introduced 3 new structures, one of which we claim to be the lowest density sp2 2D material under the constraint of the locally jammed packing conditions. We found that while the absolute properties such as Young modulus or strength decrease by lowering densities, their specific counterpart are comparable with graphene characteristics. This work is currently submitted to the journal '2D Materials'.

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Andrea Pedrielli

Mechanical and thermal properties of graphene random nanofoams via Molecular Dynamics simulations

In collaboration with S. Taioli, G. Garberoglio (ECT/FBK), N. M. Pugno (University of Trento)*

Graphene foams have recently attracted a great deal of interest for their possible use in technological applications, such as electrochemical storage devices, wearable electronics, and chemical sensing. In a previous work [1] we investigated the mechanical properties of face centered cubic carbon nanotrusses finding peculiar properties such as negative Poisson's ratio and mechanical instabilities. We extended this work on 3D graphene-based porous nanostructures focusing on random nanofoams. By using molecular dynamics with reactive potentials, we performed investigations of the mechanical and thermal properties of graphene random nanofoams. In particular, we assessed the mechanical and thermal performances of four families of random foams characterized by increasing mass density and decreasing average pore size. We find that the foams' mechanical performances under tension cannot be rationalized in terms of mass density, while they are principally related to their topology. Furthermore, we assess the thermal conductivity of these random foams using the Green–Kubo approach. While foam thermal conductivity is affected by both connectivity and defects, nevertheless we obtain similar values for all the investigated families, which means that topology is the critical factor affecting thermal transport in these structures. These results were published in Carbon [2].

Modeling and simulations of SiO_x and SiC/SiO_x core/shell nanowires photoluminescence spectra

In collaboration with T. Morresi, S. Taioli, G. Garberoglio (ECT/FBK), N. M. Pugno (University of Trento), M.V. Nardi (CNR, Trento), M. Tiempel (CNR, Trento) and R. Tatti (CNR, Trento)*

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Study of two-dimensional sp2 carbon based materials

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Francesco Segatta

Modeling of nonlinear spectroscopy of Light Harvesting complexes (LHC)

In collaboration with G. Cerullo (Politecnico di Milano, Italy) and S. Ruhman (Hebrew University, Israel)

In Ref. [1] we combined experimental investigation and theoretical modelling of non-linear multi-dimensional spectroscopies, revealing the signatures of the energy transfer process in xanthorhodopin. Xanthorhodopin is a light-driven transmembrane proton pump with just two chromophores – a carotenoid donor and a retinal acceptor – and one of the simplest LHCs present in nature. This work allowed to interpret experimentally recorded signals, and to connect the observed spectral features to their microscopic molecular origin.

Simulation of the fast photoinduced trans-azobenzene dynamics

In collaboration with G. Cerullo (Politecnico di Milano, Italy)

In Ref. [2] we unravel the ultrafast photoinduced dynamics of trans-azobenzene and, by a joint experimental and theoretical analysis of time-resolved pump-probe spectra, we delivered a solid explanation for the observed Kasha rule violation.

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Simone Taioli

Relativistic theory of nuclear beta-decay in heavy-nuclei

In collaboration with T. Morresi (ECT/FBK, Italy) and S. Simonucci (University of Camerino, Italy)*

In this work a novel theoretical and computational method for computing electroweak beta decay spectra of medium and heavy-mass nuclei, as well as the electronic structure of atomic and molecular systems is developed. In particular, starting from the phenomenological electroweak interaction of the Standard Model (SM) of particles, a general expression of the beta decay rate was derived. Relativistic effects are taken into account by solving the many-electron Dirac equation from first-principles. Furthermore, an extension of this approach to include the nucleon-nucleon interaction at the same level of theory of the electronic correlations has been devised. It is shown that post-collisional effects, and to a lesser extent the electronic exchange and correlation, can modify significantly the cross-section only at low energies (<10 keV), while nuclear correlations considerably affect the lineshape of both the absorption and emission spectra particularly in odd-odd nuclear transitions, where the independent particle approximation, on which the nuclear shell model is framed, is more likely to fail. These findings demonstrate the importance of moving beyond the independent particle picture to obtain an accurate description of the experimental data by adding the many-body correlations between the spectator and participator hadrons and leptons involved in the decay. The application of our approach to a number of test cases, such as the modeling of beta decay of ^{36}Cl, ^{63}Ni, ^{129}I, ^{210}Bi, ^{241}Pu and of the electron capture of $^{138}La^{3+}$, leads to an extremely good agreement with the relevant experimental data. Finally, the extension of this method to atomic and molecular systems by calculating the electronic structures of $^{138}La^{3+}$ and several isomers (MgCN, MgNC) and molecules (HMgCN, MgCNO, and $BrCF_3$) relevant to astrophysical scenarios is presented. This method, which is capable to deal with both nucleonic and electronic degrees of freedom, has far-reaching implications also in neutrino physics and nuclear astrophysics (see Ref. [1]).

Gas adsorption and dynamics in Pillared Graphene Frameworks

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

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

Monte Carlo simulations of measured electron energy-loss spectra and secondary emission in metals

In collaboration with M. Azzolini, M. Dapor (ECT/FBK, Italy), and R. Cimino (INFN, Frascati, Italy)*

In this work, we present a computational method, based on the Monte Carlo statistical approach, for calculating electron energy emission and yield spectra of metals, such as copper, silver and gold [3]. The calculation of these observables proceeds via the Mott theory with a Dirac–Hartree–Fock spherical potential to deal with the elastic scattering processes, and by using the Ritchie dielectric approach to model the electron inelastic scattering events. In the latter case, the dielectric function, which represents the starting point for the evaluation of the energy loss, is obtained from experimental reflection electron energy loss spectra. The generation of secondary electrons upon ionization of the samples is also implemented in the calculation. A remarkable agreement is obtained between both theoretical and experimental electron emission spectra and yield curves.

Theory and simulations of two-dimensional electronic spectra of bio-molecules

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

We combine sub-20 fs transient absorption spectroscopy with state-of-the-art computations to study the ultrafast photoinduced dynamics of trans-azobenzene (AB) [4]. We are able to resolve the lifetime of the $\pi\pi^*$ state, whose decay within ca. 50 fs is correlated to the buildup of the $n\pi^*$ population and to the emergence of coherences in the dynamics, to date unobserved. Nonlinear spectroscopy simulations call for the CNN in-plane bendings as the active modes in the subps photoinduced coherent dynamics out of the $\pi\pi^*$ state. Radiative to kinetic energy transfer into these modes drives the system to a high-energy planar $n\pi^*$/ground state conical intersection, inaccessible upon direct excitation of the $n\pi^*$ state, that triggers an ultrafast (0.45 ps) nonproductive decay of the $n\pi^*$ state and is thus responsible for the observed Kasha rule violation in UV excited trans-AB. On the other hand, cis-AB is built only after intramolecular vibrational energy redistribution and population of the NN torsional mode. Furthermore, by comparing two-dimensional electronic spectroscopy (2DES) and Pump-Probe (PP) measurements on xanthorhodopsin (XR) and reduced-xanthorhodopsin (RXR) complexes, the ultrafast carotenoid-to-retinal energy transfer pathway is revealed, at very early times, by an excess of signal amplitude at the associated cross-peak and by the carotenoid bleaching reduction due to its ground state recovery [5]. The combination of the measured 2DES and PP spectroscopic data with theoretical modelling allows a clear identification of the main experimental signals and a comprehensive interpretation of their origin and dynamics. The remarkable velocity of the energy transfer, despite the non-negligible energy separation between the two chromophores, and the analysis of the underlying transport mechanism, highlight the role played by the ground state carotenoid vibrations in assisting the process.

Theoretical and experimental model of SiC/SiO_x core/shell nanowires for their optimal design

In collaboration with A. Pedrielli, T. Morresi, G. Garberoglio (ECT/FBK, Italy), M. Timpel, and M.V. Nardi (University of Trento, Italy)*

In this work we propose a realistic model of nanometer-thick SiC/SiO_x core/shell nanowires (NWs) using a combined first-principles and experimental approach. SiC/SiO_x core/shell NWs were first synthesised by a low-cost carbothermal method and their chemical–physical experimental analysis was accomplished by recording X-ray absorption near-edge spectra [6]. In particular, the K-edge absorption lineshapes of C, O, and Si are used to validate our computational model of the SiC/SiO_x core/shell NW architectures, obtained by a multiscale approach, including molecular dynamics, tight-binding and density functional simulations. Moreover, we present ab initio calculations of the electronic structure of hydrogenated SiC and SiC/SiO_x core/shell NWs, studying the modification induced by several different substitutional defects and impurities into both the surface and the interfacial region between the SiC core and the SiO_x shell. We find that on the one hand the electron quantum confinement results in a broadening of the band gap, while hydroxyl surface terminations decrease it. This computational investigation shows that our model of SiC/SiO_x core/shell NWs is capable to deliver an accurate interpretation of the recorded X-ray absorption near-edge spectra and proves to be a valuable tool towards the optimal design and application of these nanosystems in actual devices.

Carbon-base materials with low-density

In collaboration with A. Pedrielli, T. Morresi (ECT/FBK, Italy) and N. Pugno (University of Trento, Italy)*

In this work a systematic approach to the search for all-bonded carbon allotropes with low density is presented [7]. In particular, we obtain a number of novel energetically stable crystal structures, whose arrangement is closely related to the topology of graphene, by modifying the packing of congruent discs under the condition of local stability. Our procedure starts from an initial parent topology and proceeds to generate daughter architectures derived by lowering the packing factors. Furthermore, we assess both the electronic properties, such as the band structure and the density of states, and the mechanical properties, such as the elastic constants and the stress--strain characteristics, of parent's and daughter's geometries from first-principle simulations. We find, using geometrical packing arguments, that some arrangements lead to a density as low as half that of graphene, obtaining some of the least dense structures of all- bonded carbon allotropes that could ever be synthesized. Nevertheless, a threshold value of the density exists below which the mechanical rigidity of graphene is irreparably lost, while keeping other mechanical characteristics, such as the specific toughness and strength, almost unchanged with lower weight.

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5.2 Publications of ECT*-LISC Researchers in 2018

Martina Azzolini

M. Azzolini, T. Morresi, K. Abrams, R. Masters, N. Stehling, C. Rodenburg, N. M. Pugno, S. Taioli, M. Dapor
Anisotropic Approach for Simulating Electron Transport in Layered Materials: Computational and Experimental Study of Highly Oriented Pyrolitic Graphite
*The Journal of Physical Chemistry C **122** (18), 10159-10166 (2018)*

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Secondary electron emission and yield spectra of metals from Monte Carlo simulations and experiments.
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Maurizio Dapor

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UV-light-induced vibrational coherences: The key to understand Kasha rule violation in trans-Azobenzene
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M. Dapor
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Giovanni Garberoglio

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A novel combined experimental and multiscale theoretical approach to unravel the structure of SiC/SiO$_x$ core/shell nanowires for their optimal design
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Andrea Pedrielli

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Francesco Segatta

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arXiv preprint arXiv:1811.01112 (2018)

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Nuclear beta decay: relativistic theory and ab initio simulations of electroweak decay spectra in medium-heavy nuclei and of atomic and molecular electronic structure
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Ultrafast carotenoid to retinal energy transfer in xanthorhodopsin revealed by the combination of transient absorption and two-dimensional electronic spectroscopy
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T. Morresi, M. Timpel, A. Pedrielli, G. Garberoglio, R. Tatti, R. Verucchi, L. Pasquali, N.M. Pugno, M.V. Nardi, S. Taioli
A novel combined experimental and multiscale theoretical approach to unravel the structure of SiC/SiOx core/shell nanowires for their optimal design
Nanoscale 10, 13449-13461 (2018)

M. Azzolini, T. Morresi, K. Abrams, R. Masters, N. Stehling, C. Rodenburg, N.M. Pugno, S. Taioli, M. Dapor
Anisotropic approach for simulating electron transport in layered materials: computational and experimental study of highly oriented pyrolitic graphite
The Journal of Physical Chemistry C 122 (18), 10159-10166 (2018)

A. Nenov, R. Borrego-Varillas, A. Oriana, L. Ganzer, F. Segatta, I. Conti, J. Segarra-Martí, J. Omachi, M. Dapor, S. Taioli, C. Manzoni, S. Mukamel, G. Cerullo, M. Garavelli
UV-light induced vibrational coherences, the key to understand Kasha rule violation in trans-azobenzene
The journal of physical chemistry letters 9, 1534-1541 (2018)

5.3 Talks presented by ECT*-LISC Researchers in 2018

Martina Azzolini

Monte Carlo simulation of secondary electron yield for noble metals
Talk given at the Conference “ECLOUD'18”
June 2018, Elba Island, Italy

Maurizio Dapor

Radial dose around carbon ion tracks in liquid water
34th European Conference on Surface Science (ECOSS34)
26-31 August 2018, Aarhus, Denmark

Spin-polarization of electron beams elastically scattered by atoms
Quantum Technology International Conference (QTech2018)
5-7 September 2018, Paris, France

Giovanni Garberoglio

Ab-initio calculation of virial coefficients
Invited talk given during at the 20th Symposium of Thermophysical Properties
June 2018, Boulder, Colorado, United States of America

Tommaso Morresi

Modeling and Simulations of Carbon pseudospheres
Talk at the conference 'Low Dimensional Materials 2018 – Theory and Experiments'
July 2018, Joint Institute For Nuclear Research - Dubna, Russia

Francesco Segatta

Modeling quantum properties and nonlinear spectroscopy in complex systems of interacting molecules
Oral presentation at FBK-PhD DAY (2018)
February 2018, Trento, Italy

Simone Taioli

Invited talk
The chemistry and physics of carbon from first-principles, multiscale simulations, and experiments
Talk given at the conference "7th Workshop on Nanocarbon Photonics and Optoelectronics (NPO2018)"
August 2018, Savolinna, Finland

Invited talk
First-principles simulations of carbon base materials
Talk given at the conference "14th International Conference of Computational Methods in Sciences and Engineering"
2018, Thessaloniki, Greece

6 ECT* Computing Facilities

CONNECTIVITY

- The main network infrastructure is connected by 3 switches PoE - Power over Ethernet- (DELL Power Connect 5548P).

- 7 switches Dell Power Connect 5548 were installed in order to improve the connectivity in Villa Tambosi.

- The Rustico and the Villa at ECT* are connected by two multi-mode optical fibers.

- Between ECT* and FBK the connection is also provided by fiber (2Gbps).

ECT*'s access to the Internet is transmitted through the FBK. FBK is a BGP Autonomous System; The Internet connection is provided by Trentino Network s.r.l. (bidirectional 1 Gbit/s full speed) and GARR as back-up connection (100Mbit/s); by network problems, the connection through the GARR is automatically activated.

HARDWARE

PC clients:
10 PCs for the local research:
Workstation DELL Precision T1500
Workstation DELL Precision T1600

8 PCs/laptops for the staff:
Workstation DELL Precision T1500
Workstation DELL Precision T1600
The laptops DELL latitude E5440 have been recently replaced by laptops Lenovo ThinkPad T480 with Lenovo Docking Stations ThinkPad. The monitors DELL 24" have been replaced by Philips Brilliance 272B (27")

26 PCs for the participants of the schools and for visiting scientists:
Workstation DELL Precision T1500
Workstation DELL Optiplex 755

A pool of 4 laptops for the workshop participants:
Laptops DELL latitude E6510
Laptop DELL latitude E6220
Laptops DELL latitude E4310
Laptops DELL latitude E4300

MAIN SOFTWARE for the research activity: Mathematica version 11.X: 1 network license server + 7 concurrent processes + 7 "Home Use" licenses.

SERVICES

All services are running on the hardware of the FBK datacenter. All users can access all services offered by the FBK and through the Google service.
The following useful Google services can be accessed through login on the "ectstar.eu" domain:

1. Google mail (using the "ectstar.eu" e-mail domain)
2. Google Cloud Print
3. Google Drive
4. Google Team Drive (since 22/11/17)

5. Google Hangouts
6. Google Classroom

WiFi Networks

Inside the ECT* buildings you can also access the following WiFi networks:

- GuestsFBK
- EduRoam

GuestsFBK is the WiFi network of the Fondazione Bruno Kessler. One can access this network using his/her own user credentials or, if one has an Italian mobile phone number, by registering on the web portal access page: the password will be sent via SMS to the indicated number. In this case the credentials are valid for that particular day.

Eduroam (http://www.eduroam.org) is the secure, world-wide roaming access service developed for the international research and education community. Eduroam allows students, researchers and staff from participating institutions to obtain Internet connectivity across campus and when visiting other participating institutions by simply opening their laptop.

HIGH PERFORMANCE COMPUTING: THE KORE CLUSTER

Kore is an HPC (High Performance Computer) Cluster System created by FBK in collaboration with the Fondazione Edmund Mach and Trentino Network using the new Province-wide optical fiber networking infrastructure.

Today, the Kore system is made up of about 1.436 cores (based on Intel Xeon processors) and 439TB of distributed storage, interconnected both among and within computers by a high speed network ranging from 1Gbit/s to 10Gbit/s with some branches running on InfiniBand, a low latency network featuring very high throughput. In the last years some node for GPGPU calculation have been installed: at the moment the Kore system has 6 nodes with two Nvidia Tesla K80 cards, 1 node with 4 Nvidia Tesla V100 cards and 1 node with 8 Nvidia GTX1080TI cards to perform parallel programming on the CUDA platform.

The Kore infrastructure grew keeping in mind the concept of scalability and easy upgradeability that would fit current and future needs in complex and high performance computing, for general-purpose applications.

The Kore system global uptime has been about 99,9% since it started in the spring of 2009.

7 25th Anniversary of ECT*

The 25th Anniversary of the foundation of ECT* in 1993 was celebrated on August 31, 2018. The event started at 9:00 with several welcome addresses by

Gert Aarts (Chair, ECT* Scientific Board)
Sara Ferrari (Assessore of PAT)
Fernando Ferroni (President of INFN)
Paolo Giubellino (Director of FAIR)
Marek Lewitowicz (Chair of NuPECC)
Lorenzo Pavesi (Head of the UniTN Physics Department)
Jochen Wambach (Director of ECT*)

that were followed by a daylong scientific program:

Chair: David Brink (Oxford)

10:00 - 11:00 *The birth of ECT* in Trento*
Renzo Leonardi (Trento)

11:00 - 11:30 Coffee break

Chair: Jean-Paul Blaizot (Saclay)

11:30 - 12:15 *Properties of strongly interacting matter from first principles*
Claudia Ratti (Houston)

12:15 - 14:00 Lunch at Villa Tambosi

Chair: Achim Richter (Darmstadt)

14:00 -14:45 *From fundamental interactions to structure and stars*
Achim Schwenk (Darmstadt)

14:45 - 15:30 *Emergent mass in strong interactions*
Daniele Binosi (Trento)

15:30 - 16:00 Coffee break

Chair: Wolfram Weise (München)

16:00 -16:45 *GW170817 and the history of the r-process*
Jim Lattimer (Stony Brook)

16:45 -17:30 *Twenty years of Quantum Science and Technologies at ECT*: From the Star to Q@TN*
Tommaso Calarco (Ulm)

18:00 Dinner at Villa Tambosi

Besides an account of the history of ECT* by Renzo Leonardi, the scientific presentations featured current topics in nuclear physics and related areas of interest to ECT*. Except for Jim Lattimer, the talks were presented by former Postdoctoral Fellows, a former board member and a current ECT* senior researcher. The sessions were chaired by previous ECT* directors. In an outreach to the general public a lecture by Luciano Rezolla from the Goethe University, Frankfurt on General Relativity and its applications to compact objects in the Universe was given.

This event was well received by the audience and publicized in the local news media.