ECT*
EUROPEAN CENTRE
FOR THEORETICAL STUDIES
IN NUCLEAR PHYSICS AND RELATED AREAS
FONDAZIONE BRUNO KESSLER

ANNUAL REPORT 2019

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

Institutional Member of the European Science Foundation Expert Committee NuPECC

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Contents

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 is 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 944 scientists from 42 countries have visited the ECT* in 2019 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 2019 ECT* held:

- 21 Workshops and 3 collaboration meetings on recent developments in nuclear- and hadronic physics from the lowest to the highest energies, nuclear astrophysics, topics in QCD, quantum many-body systems and related areas in condensed matter and atomic physics.
- a Doctoral Training Programme: "ECT* Summer School on Effective Field Theory Techniques" that lasted three weeks and was attended by 33 students from 16 countries worldwide.
- a TALENT School: "From Quarks and Gluons to Nuclear Forces and Structure" that lasted three weeks and was attended by 28 students from 14 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 strongly interacting matter, nuclear astrophysics and neutron stars, many-body theory and computational physics. This research was performed by the in-house group of Junior Postdoctoral Fellows and Senior Research Associates in close interaction with each other, with the Director of the Centre, and with scientific visitors and collaborating physicists elsewhere. The research activities of the Centre are documented in detail in Chapters 3 and 4 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 2019 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), Russia (JINR in Dubna, the Joint Institute for Nuclear Research), and the Swiss National Science Foundation (SNSF), ECT signed in 2019 an MoU with the Max Planck Institut für Physik in Germany and an MoU with the University of Zagreb in Croatia for a financial contribution to ECT*.

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

The existence and the continuing success of ECT* rests upon the "bottom-up" initiatives, pursued by the physics communities in Europe and worldwide. Maintaining ECT*´s high level of scientific activity and visibility in 2019 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, Croatia, Czech Republic, Finland, France, Germany, Italy, the Netherlands, Romania, Russia, Switzerland and the United Kingdom. ECT* also acknowledges additional partial support for its workshops, received in 2019 from: the University of Trento (Italy), CERN (Switzerland), Fermilab (USA), EMMI (Germany), the University of Ulm (Germany), Michigan State University (USA), Jefferson Laboratory (USA), the University of Regensburg (Germany), INFN Frascati (Italy), TIFPA (Italy) and the CNR-INO BEC center (Italy).

As for the European projects within the new Framework Programme Horizon 2020, the ENSAR2 project has started on March 1, 2016 and is projected until 31 December 2020. Its transnational access activities have partially supported 6 workshops in 2019 that were selected by the Director in accordance with the International Scientific Committee. The Strong 2020 project has started on June 1, 2019 and is projected until May 31, 2023. Its transnational access activities have partially supported 6 workshops in 2019 that were selected by the Director in accordance with the International Scientific Committee.

Finally, it is a great pleasure to thank the members of the Scientific Board, the organizers of the Doctoral Training Programme, Martin Savage and Roxanne Springer, the organizers of the TALENT School, Andrea Shindler and Dean Lee, the DTP 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 2019 is available on the ECT* website (www.ectstar.eu).

Trento, April 2020

Jochen Wambach
Director of ECT*

Scientific Board, Staff and Researchers

1. Scientific Board, Researchers and Staff

1.1 Scientific Board and Director

Gert Aarts (Chairman)	Swansea University, UK
Carlo Barbieri (from October 2019)	University of Surrey, UK
Omar Benhar (until October 2019)	INFN/Università "La Sapienza", Rome, Italy
Anna Corsi (from October 2019)	IRFU/DPhN, France
Marcella Grasso	CNRS-INP Orsay, France
Morton Hjorth-Jensen	Michigan State Univ., USA and Univ. of Oslo, Norway
Nicole d'Hose (until October 2019)	CEA Saclay, France
Marek Lewitowicz	NuPECC/GANIL, France
Dirk Rischke (until October 2019)	J.W. Goethe-Universität, Frankfurt, Germany
Martin Savage	INT & Univ. Washington, Seattle, USA
Marc Vanderhaeghen	University of Mainz, Germany
Urs Wiedemann (from October 2019)	CERN-TH, Switzerland

Honorary Member of the Board

Ben Mottelson	NORDITA, Copenhagen, Denmark

ECT Director*

Jochen Wambach – ECT*	ECT* and TU Darmstadt, Germany

1.2 Resident Researchers

- *ECT* Researchers*

Daniele Binosi, Italy*
Arianna Carbone, Italy (until September 2019)
Minghui Ding, China (from September 2019)
Jarkko Peuron, Finland
Alessandro Pilloni, Italy
Naoto Tanji, Japan (until February 2019)
Dionysis Triantafyllopoulos, Greece*
Shu-Yi Wei, China (from September 2019)

- *ECT*/LISC Researchers*

Martina Azzolini, Italy (until April 2019)
Maurizio Dapor, Italy* (Head of ECT*-LISC Research Unit)
Giovanni Garberoglio, Italy*
Andrea Pedrielli, Italy
Tommaso Morresi, Italy (until July 2019)
Simone Taioli, Italy*
Paolo Trevisanutto, Italy (from May 2019)

* Permanent Researchers

1.3 Staff

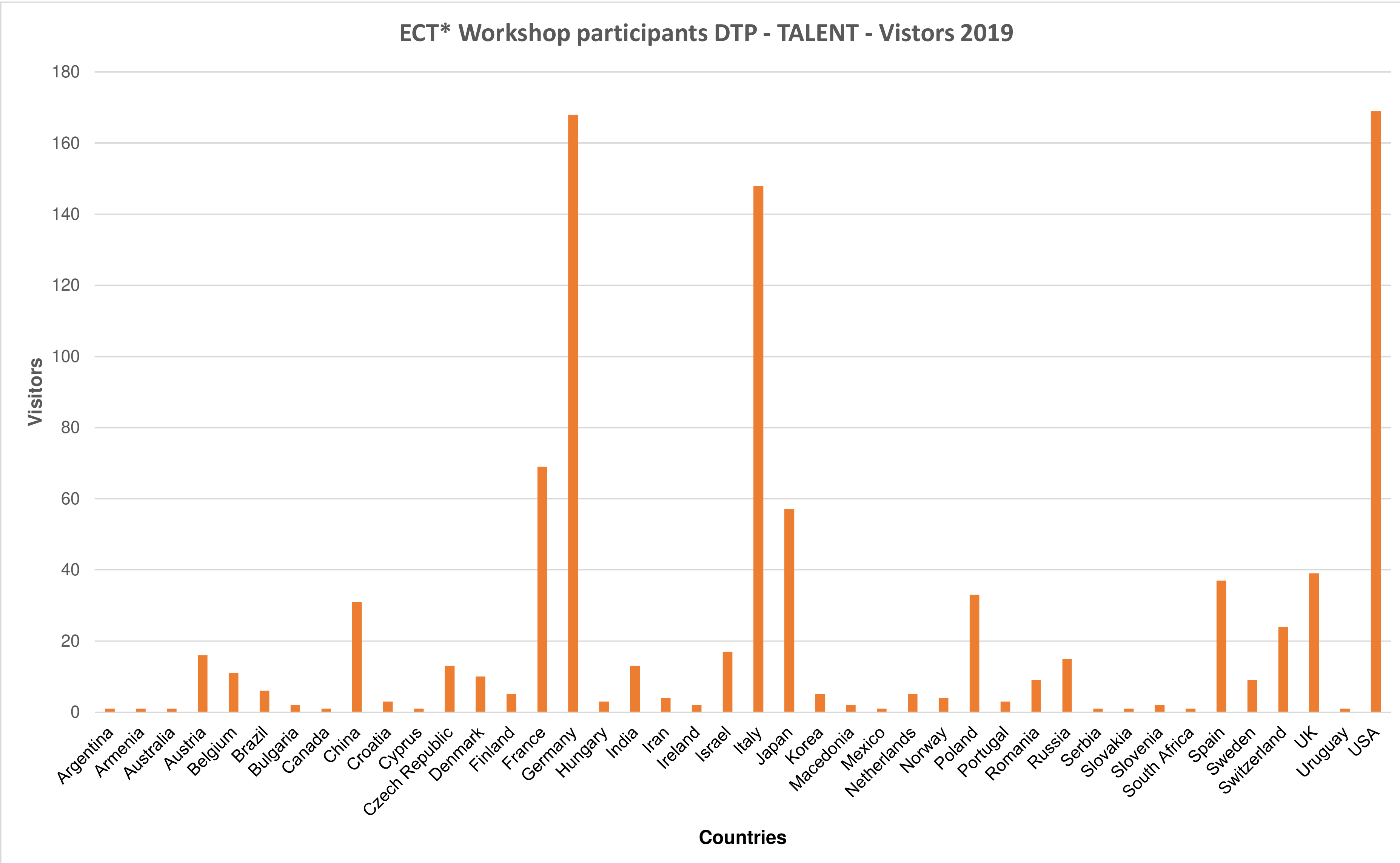
Serena degli Avancini (until 30.9.2019)
Ines Campo (part time) (until 30.9.2019)
Barbara Currò Dossi (until 30.6.2019)
Susan Driessen (part time)
Christian Fossi (until 12.3.2019)
Barbara Gazzoli (from 1.10.2019)
Michela Chistè (from 1.7.2019)

1.4 Visitors in 2019

Marcel Algueró (24.6-12.7)	Institut de Física d'Altes Energies (IFAE), Spain (DTP)
Carlo Barbieri (12-29.8)	University of Surrey, UK (VS)
Saar Beck (24.6-2.8)	Hebrew University of Jerusalem, Israel (DTP+TS)
Georgios Billis (24.6-12.7)	DESY, Germany (DTP)
Jean-Paul Blaizot (7-21.7)	CEA Saclay, France (VS)
Nora Brambilla (7-10.7)	TU Munich, Germany (DTP)
Gabriel Brandao de Gracia (24.6-12.7)	Institute of Theoretical Physics-UNESP, Brazil (DTP)
Pierre Henri Cahue (15.7-2.8)	LPSC, France (TS)
Jorge David Castaño Yepes (24.6-12.7)	UNAM, Mexico (DTP)
Zohreh Davoudi (14.7-5.8)	University of Maryland, USA (TS)
Hilla De Leon (6.3)	Hebrew University of Jerusalem, Israel (VS)
Stéphane Delorme (24.6-12.7)	IMT Atlantique, France (DTP)
Evgeny Epelbaum (23-31.7)	Ruhr-Universität Bochum, Germany (TS)
Tim Engel (24.6-12.7)	University of Zurich, Switzerland (DTP)
Patrick Fasano (15.7-2.8)	University of Notre Dame, USA (TS)

Elena Filandri (24.6-2.8)	Università degli studi di Trento, Italy (DTP+ TS)
Mikael Frosini (15.7-2.8)	CEA Saclay, France (TS)
Jan Franz (13-26.9)	Politechnika Gdansk, Poland (VS)
Malgorzata Franz (13-26.9)	Politechnika Gdansk, Poland (VS)
Ritesh Ghosh (24.6-12.7)	Saha Institute Of Nuclear Physics, India (DTP)
Lukas Graf (24.6-12.7)	(MPIK), Germany (DTP)
Peter Gysbers (15.7-2.8)	University of British Columbia, Canada (TS)
Siddhartha Harmalkar (15.7-2.8)	Univ. of Maryland, College Park, USA (TS)
Matthias Heinz (15.7-2.8)	TU Darmstadt, Germany (TS)
Jan Lucas Hoppe (15.7-2.8)	TU Darmstadt, Germany (TS)
Paul Hoyer (1-8.9)	University Helsinki, Finland (VS)
Marc Illa Subiña (24.6-12.7)	Universidad de Barcelona, Spain (DTP)
Saurabh Vasant Kadam (15.7-2.8)	Univ. of Maryland, College Park, USA (TS)
Natalie Klco (24.6-12.7)	University of Washington, USA (DTP)
Laetitia Laub (24.6-12.7)	University of Bern, Switzerland (DTP)
Hong An Le (24.6-12.7)	The Australian National University, Australia (TS)
Dean Lee (24.7-3.8)	Michigan State University, USA (TS)
Thomas Luu (14.7-26.7)	FZ Jülich & Universität Bonn, Germany (TS)
Songlin Lyu (24.6-12.7)	Sichuan University, China (DTP)
Yuanzhuo Ma (15.7-2.8)	Peking University, China (TS)
Joachim Monnard (24.6-12.7)	University of Bern, Switzerland (DTP)
Gloria Montana Faiget (15.7-2.8)	Universidad de Barcelona, Spain (TS)
Alexander Moore (24.6-12.7)	University of Manchester, UK (DTP)
Arghya Mukherjee (24.6-12.7)	Saha Institute Of Nuclear Physics, India (DTP)
Fabian Müller (24.6-12.7)	Universität Bonn, Germany (DTP)
Martin Novoa Brunet (24.6-12.7)	CNRS, Saclay, France (DTP)
Felipe Ortega Gama (15.7-2.8)	College of William & Mary, USA (TS)
Monica Pate (22.6-8.7)	Harvard University, USA (DTP)
Hans Peter Pavel (4-15.11)	JINR, Dubna, Russia (VS)
Francesco Pederiva	Università degli Studi di Trento, Italy (TS)
Giovanni Pederiva (15.7-2.8)	Michigan State University, USA (TS)
Elisabetta Perotti (24.6-5.7)	Uppsala University, Sweden (DTP)
Jan Pokorný (15.7-2.8)	Czech Technical Univ., Prague, Czech Republic (TS)
Andrea Quadri (8-13.7)	INFN Milano, Italy (VS)

Thomas Richardson (24.6-12.7)	University of South Carolina, USA (DTP)
Achim Richter (24.7-4.8 + 5-12.10)	TU Darmstadt, Germany (VS)
Georges Ripka (20.6-21.7)	CEA Saclay, France (DTP)
Matthew Rizik (15.7-2.8)	Michigan State University, USA (TS)
Dmitry Rodkin (24.6-12.7)	Dukhov Research Ubst. for Automatics, Moscow, Russia (DTP)
Camilo Alejandro Rojas Pacheco (24.6-12.7)	Univ. of Barcelona, Spain (DTP)
Keita Sakai (15.7-2.8)	Tohoku University, Japan (TS)
Jordi Salinas San Martin (24.6-12.7)	UNAM, Mexico (DTP)
Adrian Horacio Santana-Valdés (15.7-2.8)	UNAM, Mexico (TS)
Nils Sass (18-22.2)	University of Frankfurt, Germany (VS)
Martin Savage (22.6-13.7)	INT & University of Washington, USA (DTP)
Andrea Shindler (14.7-4.8)	Duke University, Michigan State University, USA (TS)
Pooja Siwach (24.6-2.8)	Indian Institute of Technology, Roorkee, India (DTP+TS)
Hershdeep Singh (24.6-2.8)	Duke University, USA (DTP+TS)
Andrew Shaw (24.6-2.8)	University of Maryland, USA (DTP+TS)
Jing Song (15.7-2.8)	Beihang University, China (TS)
Roxanne Springer (22-29.6)	Duke University, USA (DTP)
Halvard Sutterud (15.7-2.8)	University of Oslo, Norway (TS)
Frank Tackmann (9-12.7)	DESY, Germany (DTP)
Azar Tafrihi (24.6-12.7)	Isfahan University of Technology, Iran (DTP)
Adam Takacs Takacs (24.6-12.7)	University of Bergen, Norway (DTP)
Pulak Talukdar (24.6-12.7)	Indian Inst. of Technology, Guwahati, India (DTP)
Ubaid Tantary (24.6-12.7)	Kent State University, USA (DTP)
Arnold Tripolt (18-22.2 + 1-29.9)	University of Frankfurt, Germany (VS)
Natsuki Tsukamoto (15.7-2.8)	Tohoku University, Japan (TS)
Francesco Turro (24.6-2.8)	Università degli Studi di Trento, Italy (DTP+TS)
Yukari Yamauchi (24.6-12.7)	University of Maryland - College Park, USA (DTP)
Boyao Zhu (15.7-2.8)	Michigan State University, USA (TS)
Lars Zurek (15.7-2.8)	TU Darmstadt (TS)


ECT* Workshop participants DTP - TALENT - Vistors 2019
Visitors
180
160
140
120
100
80
60
40
20
0
Argentina
Armenia
Australia
Austria
Belgium
Brazil
Bulgaria
Canada
China
Croatia
Cyprus
Czech Republic
Denmark
Finland
France
Germany
Hungary
India
Iran
Ireland
Israel
Italy
Japan
Korea
Macedonia
Mexico
Netherlands
Norway
Poland
Portugal
Romania
Russia
Serbia
Slovakia
Slovenia
South Africa
Spain
Sweden
Switzerland
UK
Uruguay
USA
Countries

Scientific Projects in 2019

2. Scientific Projects in 2019

2.1 Summary

Altogether 26 scientific projects have been run in 2019: 21 workshops, 3 collaboration meetings, a Doctoral Training Programme and a Talent School. This chapter collects the scientific reports written by the workshop organizers, by Georges Ripka who coordinated the Doctoral Training Programme and by Dean Lee who coordinated the TALENT School.

2.2 Workshops and Schools (Calendar)

Feb 05-08	*Eutopia-1: First meeting of the European Topology Interdisciplinary Initiative* (collaboration meeting) R. POTESTIO (University of Trento)
Feb 11-15	*Workshop on Precision Measurements of the Strong Coupling Constant* D. D'ENTERRIA (CERN) S. Kluth (MPP, Munich)
April 08-12	*Precise Beta-Decay Calculations for Searches of New Physics* D. GAZIT (Hebrew University of Jerusalem) A. Garcia (University of Washington) D. Philips (Ohio University)
April 15-19	*Atomic Nuclei as Laboratories for BSM Physics* T. KATORI (Queen Mary University of London) V. Cirigliano (LANL) S. Gandolfi (LANL) R.F. Garcia Ruiz (CERN) J. Holt (TRIUMF)
May 07-10	*Continuum Functional Methods for QCD at New Generation Facilities* (collaboration meeting) D. BINOSI (ECT*) L. Chang (Nankai University) J. Papavassiliou (University of Valencia & CSIC) C. Roberts (ANL)

May 13-17 — *SN Neutrinos at the Crossroads: Astrophysics, Oscillations, and Detection*
A. MIRIZZI (Bari University & INFN Bari)
B. Dasgupta (Tata Institute for Fundamental Research)

May 20-24 — *Challenges to Transport Theory for Heavy-Ion Collisions*
M. COLONNA (INFN-LNS)
H. Wolter (University of Munich)
P. Danielewicz (NSCL, MSU)
A. Ono (Tohoku University)
J. Xu (SINAP, CAS)

May 27-31 — *Neutrini and Nuclei, Challenges and Opportunities for Nuclear Theory*
N. ROCCO (University of Surrey)
S. Pastore (LANL)
A. Lovato (INFN-TIFPA)
J. Nieves (IFIC, CSIC & University of Valencia)

June 03-07 — *Testing and Improving Models of Neutrino-Nucleus Interactions in Generators*
F. SANCHEZ-NIETO (University of Geneva)
M. Barbaro (University of Torino)
N. Jachowicz (Ghent University)
C. Wilkinson (University of Bern)
K. McFarland (University of Rochester)
G. Perdue (FNAL)

June 10-14 — *High-Energy Physics at Ultra-Cold Temperatures*
A. BERMUDEZ CARBALLO (Universidad Complutense de Madrid)
G. Aarts (Swansea University)
M. Lewenstein (ICFO)

June 24-July 04 — Doctoral Training Programme:
ECT Summer School on Effective Field Theory Techniques*
M. SAVAGE (INT & University of Washington)
R.P. Springer (Duke University)

June 17-21 — *Antiproton-Nucleus Interactions and Related Phenomena*
A. OBERTELLI (TU Darmstadt)
J. Carbonell (IPN Orsay)
U.-G Meißner (University of Bonn & FZ Jülich)
E. Widmann (SMI)

July 1-5 — *Nuclear and Astrophysics Aspects for the Rapid-Neutron-Capture Process in the Era of Multimessenger Observations*
A. KANKAINEN (University of Jyväskylä)

A.-C. Larsen (University of Oslo)
S. Goriely (Université Libre de Bruxelles)
O. Sorlin (GANIL)
A. Estrade (Central Michigan University)

July 15-19 *Progress and Challenges in Neutrinoless Double-Beta-Decay*
E. MEREGHETTI (LANL)
J. Menendez (University of Tokyo)
A. Nicholson (University of North Carolina)
S. Pastore (Washington University & LANL)
A. Walker-Loud (LBNL)

15 July-2 August *TALENT School: From Quarks and Gluons to Nuclear Forces and Structure*
A. SHINDLER (MSU)
D. Lee (MSU)

July 22-26 *Simulating Gravitation and Cosmology in Condensed Matter and Optical Systems*
I. CARUSOTTO (INO-CNR BEC Center, Trento)
M. Rinaldi (University of Trento)
R. Balbinot (University of Bologna)
R. Sturani (IIP, UFRN, Natal)

August 5-9 *Random Matrix Theory in High-Energy Physics and Beyond*
M. KIEBURG (Bielefeld University)
K. Splittorff (NBI)
T. Wettig (University of Regensburg)

September 2-6 *Light Clusters in Nuclei and Nuclear Matter: Nuclear Structure and Decay, Heavy-Ion Collisions, and Astrophysics*
G. ROEPKE (University of Rostock)
P. Schuck (IPN, Université Paris-Sud)
H. Horiuchi (RCNP, Osaka University)
D. Blaschke (University of Wroclaw)

September 9-13 *LFC19: Strong Dynamics for BSM Physics at the LHC and Future Colliders*
G. CORCELLA (LNF-INFN)
S. De Curtis (INFN Firenze)
S. Moretti (University of Southampton)
G. Pancheri (LNF-INFN)
R. Tenchini (INFN Pisa)
M. Vos (IFIC, CSIC & University of Valencia)

September 23-27	*Diquark Correlations in Hadron Physics: Origin, Impact and Evidence* J. SEGOVIA (IFAE & University of Barcelona) C. D. Roberts (ANL) E. Santopinto (INFN Genova) B. Wojtsekhowski (JLab)
Sep- 30-Oct. 4	*Open Quantum Systems: From Atomic Nuclei to Ultracold Atoms and Quantum Optics* P. NAVRATIL (TRIUMF) M. Efremov (University of Ulm) A. Gade (MSU) M. Gattobigio (INPHYNI) H.-W. Hammer (TU Darmstadt)
October 7-11	*Universal Physics in Many-Body Quantum Systems – From Atoms to Quarks* M. OKA (JAEA) H.-W. Hammer (TU Darmstadt), A. Hosaka (RCNP, Osaka University) E. Hiyama (Kyushu/RIKEN) P. Gubler (JAEA) S. Koenig (TU Darmstadt)
October 14-18	*The First Compact-Star-Merger Event – Implications for Nuclear and Particle Physics* D. BLASCHKE (University of Wroclaw) M. Colpi (University of Milano Bicocca) T. Fischer (University of Wroclaw) D. Radice (Princeton University)
October 21-25	*STRANEX: Recent Progress and Perspectives in Strange Exotic Atoms Studies and Related Topics* C. CURCEANU (LNF-INFN) A. Ramos (University of Barcelona) J. Mares (NPI, Rez/Prague) S. Okada (RIKEN) J. Zmeskal (SMI)
December 18-20	*JPAC Collaboration Meeting* A. PILLONI (ECT*)

2.3 Workshop Reports

2.3.1 *EUTOPIA-1: First Meeting of the European Topology Interdisciplinary Initiative*

Date	February 5-8, 2019
Organizers	
Raffaello Potestio	University of Trento
Franco Ferrari	University of Stettin
Luca Tubiana	University of Vienna
Number of Participants:	9

Main topics

The physical properties of many systems often crucially depend on those global features that cannot be ascribed to a particular geometry or arrangement, rather to a more abstract notion: topology. The latter manifests itself in the knotted state of proteins and artificial polymers, the intertwining among DNA rings, or the topologically distinct classes of defect lines that can be found in liquid crystals. A better understanding of the interplay between a system's topological state, its three-dimensional structure, and its overall characteristics paves the way to an improved control of relevant natural molecules or human-made materials, with remarkable impact on fundamental science as well as high-tech applications. The aim of this meeting was to kick-off the scientific activity of the recently established European Topology Interdisciplinary Action (EUTOPIA COST Action) which gathers scientists from 22 different European countries and from fields ranging from mathematics to biology, physics and chemistry.

Eutopia-1 covered the following topics

- WG1: Theory of topological entanglement in polymers and fibers
- WG2: Polymeric and fibrous topological materials
- WG3: Entangled and self-entangled proteins
- WG4: DNA, chromosomes, and other entangled genetic material
- WG5: Topologically complex fluids

Speakers

Andonovic Beti	Faculty of Technology and Metallurgy, Macedonia
Babaev Egor	KTH, Sweden
Barbensi Agnese	University of Oxford, UK
Buck Dorothy	University of Bath, England
Carlon Enrico	KU Leuven, Belgium
Cartwright Julyan	CSIC, Spain
Chiriac Aurica	Petru Poni Institute, Romania
Cieplak Marek	Polish Academy of Sciences, Poland

Coluzza Ivan	CIC Bioma GUNE, Spain
Dabrowski-Tumanski Pawel	University of Warsaw, Poland
Dimitrov Aleksandar	Faculty of Technology and Metallurgy, Macedonia
Drakopoulos Vasileios	University of Thessaly, Greece
Eber Nandor	Wigner Research Centre for Physics, Hungary
Fajstrup Lisbeth	Aalborg University AAU, Denmark
Ferrari Franco	University of Szczecin, Poland
Forte Giada	University of Edinburgh, UK
Giacometti Achille	Università Ca' Foscari Venezia, Italy
Goundaroulis Dimos	University of Lausanne, Switzerland
Greń Bartosz	University of Warsaw, Poland
Hurley Eoin	Trinity College Dublin, Ireland
Ilieva Nevena	Bulgarian Academy of Sciences, Bulgaria
Kaplan Noam	Technio, Israel
Lattanzi Gianluca	University of Trento, Italy
Locatelli Emanuele	University of Vienna, Austria
Lopez Leon Teresa	ESPCI, France
Lucic Bojana	Heidelberg University Hospital, Germany
Micheletti Cristian	SISSA, Italy
Michieletto Davide	University of Edinburgh, UK
Milchev Andrey	Bulgarian Academy of Sciences, Bulgaria
Miller Mark	Durham University, UK
Moreno Angel	CSIC, Spain
Morozov Alexei	ITEP, Russia
Niemi Antti	NORDITA, Sweden
Niemyska Wanda	University of Warsaw, Poland
Niewieczerzal Szymon	University of Warsaw, Poland
Novotna Vladimira	Institute of Physics, Czech Republic
Orlandini Enzo	Universita' di Padova, Italy
Peneva Kalina	Friedrich Schiller University Jena, Germany
Piatek Marcin	University of Szczecin, Poland
Potestio Raffaello	University of Trento, Italy
Racko Dusan	Slovak Academy of Sciences, Slovakia
Rapa Maria	University Politehnica of Bucharest, Romania
Romano Flavio	Ca' Foscari, Italy
Rosa Angelo	SISSA, Italy
Salamon Peter	Wigner Research Centre for Physics, Hungary
Salminen Tiina	Åbo Akademi University, Finland
Scarpa Marina	University of Trento, Italy
Schacher Felix	Friedrich-Schiller-University Jena, Germany
Smrek Jan	University of Vienna, Austria
Stasiak Andrzej	University of Lausanne, Switzerland
Stephanou Pavlos	Novamechanics Ltd, Cyprus
Sulkowska Ja	University of Warsaw, Poland
Sułkowski Piotr	University of Warsaw, Poland
Tubiana Luca	University of Vienna, Austria
Zdravkovic Slobodan	Vinca Institute of Nuclear Sciences, Serbia

Zhao Yani	MPIP, Germany
Zumer Slobodan	Jozef Stefan Institute, Slovenia
Čopar Simon	University of Ljubljana,Slovenia

Scientific report

The meeting has successfully kicked-off the COST Action Eutopia. The workshop featured more than 40 contributed talks divided in the Action's 5 main topics. The working group leaders presented in detail the state of the art of their respective groups. Together with the other contributions, they helped shaping the research lines for the action in the following Grant Period, May 2019 - April 2020.

Results and Highlights

The workshop succeeded in bringing together scientists working in fields as diverse as pure mathematics, biology, physics, and chemistry. The five sessions in which the workshop was subdivided were all attended by all participants, which allowed for interesting, lively, and original discussions on all topics. In particular, the workshop not only resulted in a set of well-defined research lines to be followed in 2019 by each group, but has also given birth to a set of interdisciplinary collaborations, in particular among WG 2 (polymers), 3 (proteins), and 4 (DNA), and between WG 1 (mathematics and field theory) and WG 5 (liquid crystals).

2.3.2 *ALPHAS-2019: Workshop on Precision Measurements of the QCD Coupling Constant*

Date	February 11-15, 2019
Organizers	
David d'Enterria	CERN, Switzerland
Stefan Kluth	MPI für Physik, Germany
Number of participants	32

Main topics

The strong coupling constant α_S is the least well known of all constants of nature, which play a role in the Standard Model (SM) of particle physics and related fields such as cosmology and astrophysics. For many searches for new physics beyond the SM as well as for some important precision tests of the SM using collider data the uncertainty on the value of α_S is a limiting factor. In recent years progress in theoretical predictions of Quantum Chromodynamics (QCD), and the availability of collider data at the highest energies has led to many improved determinations of α_S. The current world average quotes an uncertainty of less than 1%. However, there are noticeable discrepancies between different categories of determinations of α_S, which may limit the ultimate precision of future world averages. This workshop brought together the leading experts on determinations of α_S from theory and experiment and all important extraction categories.

The topics of discussion included:

Current status of the α_S world average

Lattice QCD results

α_S from hadronic tau decays

α_S from e-p deep inelastic scattering

α_S from e^+e^- hadronic final states

α_S from electroweak observables

α_S from pp collisions

New α_S extraction approaches

Particle Data Group (PDG) approach to α_S world average and uncertainty estimation

Speakers

Sergey Alekhin	U. Hamburg, Germany
Fernando Barreiro	UAM Madrid, Spain
Siegfried Bethke	MPI für Physik, Germany
Nora Brambilla	TU München, Germany
Daniel Britzger	MPI für Physik, Germany
Stan Brodsky	SLAC, USA
Stefano Camarda	CERN, Switzerland
David d'Enterria	CERN, Switzerland

Mattia Dalla Brida	U. Milano & INFN, Italy
Maarten Golterman	SF State Univ., USA
Joey Huston	MSU Michigan, USA
Johann Kühn	KIT Karlsruhe, Germany
Ramon Miravitllas	UAB Barcelona, Spain
Redamy Pérez-Ramos	IPSA Paris, France
Santi Peris	UAB Barcelona, Spain
Peter Petreczky	BNL Upton, USA
Joao Pires	CFTP Lisbon, Portugal
Andres Poldaru	LMU München, Germany
Klaus Rabbertz	KIT Karlsruhe, Germany
Felix Ringer	LBNL Berkeley, USA
Stefan Sint	Trinity College Dublin, Ireland
Rainer Sommer	DESY Zeuthen, Germany
Gabor Somogyi	MTA Debrecen, Hungary
Hiromasa Takaura	Kyushu University, Japan
Andrii Verbytskyi	MPI für Physik, Germany

Scientific report

The strong coupling α_S is one of the fundamental parameters of the Standard Model (SM), setting the scale of the strength of the strong interaction theoretically described by Quantum Chromodynamics (QCD). Its measured value amounts to $\alpha_S(m_Z)$ = 0.1181 ± 0.0011 at the reference Z peak mass scale, with an uncertainty of about 1%, which is orders of magnitude larger than that of the any other fundamental coupling in nature. The strong coupling is the least precisely known of all fundamental constants in nature. Improving our knowledge of α_S is crucial to reduce the theoretical uncertainties in the calculations of all high-precision perturbative QCD (pQCD) processes whose cross sections or decay rates depend on higher-order corrections, as is the case for virtually all those measured at the LHC. In the Higgs sector, in particular, the uncertainty on α_S is currently the second major contributor (after the bottom quark mass) to the parametric uncertainties of its dominant H -> bb partial decay. The same applies for the extraction of the charm quark Yukawa coupling via future H -> cc measurements.

The workshop "alphas-2019: Precision measurements of the QCD coupling constant" was held at EC* in Trento, on February 11-15, 2019, and brought together experts from several different fields to explore in depth the latest developments on the determination of the QCD coupling α_S from the key categories where high precision measurements are currently available, and put its emphasis on the following issues:

What is the current state-of-the-art of each one of the α_S determination methods, from the theoretical and experimental perspectives?

What is the current size of the theoretical (missing higher orders, electroweak corrections, power corrections, hadronization corrections,...) and experimental uncertainties associated to each measurement?

With those goals in mind, the workshop was organized along four broad groups of sessions:

An introductory session, presenting the motivations of the workshop, the current status of the world average of the strong coupling, the impact of α_S on Higgs cross sections and branching ratios, and on new physics constraints.

Sessions dedicated to α_S determinations at low energy scales including results from lattice QCD, tau lepton decays, QQ decays, and soft parton-to-hadron fragmentation functions.

Sessions dedicated to α_S determinations at higher energy scales including global fits of parton distribution functions, hard parton-to-hadron fragmentation functions, jets in deep-inelastic scattering and photoproduction in e^+e^- collisions, e^+e^- event shapes, and jets, hadronic Z and W decays, (e^+e^- -> hadrons), and the SM electroweak global fit.

Recent experimental and theoretical results and plans for α_S measurements at the LHC via top-quark pair and jets cross sections.

One important goal of the workshop was to facilitate discussion between the different groups, and in particular to give speakers the opportunity to explain details that one would normally not be able to present at a conference, but which have an important impact on the analyses. About 30 physicists took part in the workshop, and 25 talks were presented. Slides as well as background reference materials are available on the conference website: http://indico.cern.ch/e/alphas2019.

The sessions and talks in the workshop program were organized as follows:

Introduction

"Introduction and goals of the workshop", D. d'Enterria and S. Kluth
"World Summary of α_S before 2019", S. Bethke

Measurements of α_S on the lattice

"α_S from the lattice: FLAG 2019 average", R. Sommer
"Strong coupling constant from the moments of quarkonium correlators", P. Petreczky
"α_S from lattice ALPHA collaboration (part I)", S. Sint
"α_S from the QCD static energy", N. Brambilla
" α_S from lattice ALPHA collaboration (part II)", M. Dalla Brida
"α_S from the static QCD potential with renormalon subtraction", H. Takaura

α_S and perturbative theory

"The QCD coupling at all scales and the elimination of renormalization scale uncertainties", S.J. BrodskyS.J. Brodsky
"The five-loop beta function of QCD", J.H Kühn

Measurements of α_S from e-p collisions and PDF fits

"α_S, ABM PDFs, and heavy-quark masses", S. Alekhin
"α_S from H1 jets", D. Britzger
"α_S from parton densities", J. Huston

Measurements of α_S from e^+e^- final states

“Old and new observables for α_S from e^+e^- to hadrons”, G. Somogyi
“α_S from 2-jet rate in e^+e^-”, A. Verbytskyi
“The strong coupling from low-energy e^+e^- to hadrons”, M. Golterman
“α_S from parton-to-hadron fragmentation”, R. Perez-Ramos

Measurements of α_S at the LHC

“α_S from jets in pp collisions”, J. Pires
“α_S from jet substructure and a possible determination of the QCD coupling”, F. Ringer
“Extractions of α_S from ATLAS”, F. Barreiro
“α_S determinations from CMS”, K. Rabbertz
“α_S from inclusive W and Z cross sections at the LHC”, A. Poldaru
“Determination of α_S from the Z-boson transverse momentum distribution”, S. Camarda

Measurements of α_S from tau lepton decays and electroweak observables

“α_S from hadronic tau decay”, S. Peris
“QCD coupling-scheme variations and tau decays”, R. Miravitllas
“α_S from hadronic W (and Z) decays”, D. d’Enterria

Discussion and Summary

“α_S world average”, all participants

2.3.3 *Precise Beta Decay Calculations for Searches for New Physics*

Date	April 8-12, 2019
Organizers	
Doron Gazit	Hebrew University of Jerusalem
Daniel Philips	Ohio University
Alejandro Garcia	University of Washington
Number of participants	27

Main topics

Nuclear beta decay can be used as a wide net to detect new physics by searching for violations of fundamental properties built into the Standard Model. New experimental efforts and techniques have opened new avenues for reaching unprecedented sensitivity. With sensitivities reaching beyond the per-thousand level, beta decay experiments probe new physics beyond the 5 TeV scale, which shows promise for uncovering physics unseen by other experiments, including those at the LHC. However, in order to reach the ultimate sensitivity, improvements in nuclear- and nucleon-structure calculations are needed to allow accurate determination of Standard Model backgrounds. These theoretical needs, namely pin-pointing the theoretical needs to support the world-wide experimental program of precision beta-decay measurements, were the main topic of the workshop. In particular, we highlight in the workshop the following topics:

On-going and planned, next decade, precision beta-decay experiments.

Radiative corrections of nuclear beta-decays, status and open questions, particularly nuclear structure related.

Effective field theory of weak nuclear reactions.

Quantitative uncertainty estimates formalism.

Ab-initio nuclear studies: current abilities and future prospects.

Speakers

Acharya Bijaya	Johannes Gutenberg University of Mainz, Germany
Ando Shung-Ichi	Sunmoon University, Republic of Korea
Bacca Sonia	Johannes Gutenberg University, Germany
Cirigliano Vincenzo	Los Alamos National Laboratory, USA
Deleon Hilla	Hebrew University of Jerusalem, Israel
Engl Jonathan	University of North Carolina, USA
Forssén Christian	Chalmers University of Technology, Sweden
Gandolfi Stefano	Los Alamos National Laboratory, USA
Gazit Doron	Hebrew University of Jerusalem, Israel
Glick-Magid Ayala	Hebrew University of Jerusalem, Israel
Gorshteyn Mikhail	Mainz University, Germany
Hayen Leendert	LKU Leuven, Belgium
Melconian Dan	Cyclotron Institute, Texas A&M University, USA
Menendez Javier	Center for Nuclear Study, Japan

Naviliat-Cuncic Oscar	Michigan State University, USA
Phillips Daniel	Ohio University,TU Darmstadt & GSI, USA and Germany
Platter Lucas	University of Tennessee, Knoxville, USA
Ramsey-Musolf Michael	University of Massachusetts Amherst, USA
Ron Guy	Hebrew University of Jerusalem, Israel
Schwenk Achim	TU Darmstadt, Germany
Seng Chien Yeah	Universität Bonn, Germany
Taioli Simone	ECT*, Italy
Young Albert	North Carolina State University, USA

Scientific report

Worldwide, several experiments are searching for physics beyond the Standard Model (BSM) by performing precision measurements of nuclear beta decay. These experiments aim at 0.1% precision and will have comparable control over systematic uncertainties. Next generation experiments will surpass LHC constraints on models of BSM physics. In order to achieve the full potential of such experiments we need a Standard-Model prediction of the pertinent beta-decay observables of comparable accuracy. This involves consideration of corrections that have not previously been thoroughly investigated, e.g., the effect of the nuclear finite size on Coulomb interactions, radiative corrections to beta decay, recoil corrections, etc. For many of these, an accurate result requires forefront nuclear-structure calculations. The workshop's goal was to convey to the theorists what the most interesting experimental initiatives are, and to initiate theoretical efforts towards the needed calculations.

Results and Highlights

In view of the goal of the workshop, we have emphasized two main subjects. One is related to the relatively mature example of the searches for evidence of non-unitarity of the CKM matrix. In order to use the ft-values measured in 0+→0+ beta-decay transitions to extract V_{ud} (by far the largest element in the CKM matrix first row) at the 0.1% level, crucial calculations need to be under control. Remarkably, recently C.-Y. Seng, M. Gorshteyn, and M. J. Ramsey-Musolf have shown a way to calculate the "W" box for the nucleon, which reduced its uncertainty by a factor of approx. 2. However, their new result differs significantly from the results of A. Czarnecki, W. J. Marciano, and A. Sirlin. So much so, that now the best estimate is that the CKM matrix is short of unitarity by about 4 standard deviations. During the workshop Ramsey-Musolf et al. presented evidence that there is something amiss in the treatment of a radiative correction that can be considered the `nuclear relative' to the nucleon "W" box. Similar problems in the treatment of isospin-breaking corrections were discussed, and it was agreed to that the uncertainties used in the previous work by Towner and Hardy may be underestimated. The problem of how to estimate theoretical uncertainties is thus crucial to solve this issue. The general issue of estimation of uncertainties in the context of ab-initio calculations seems tractable, while in the previous methodology uncertainties are only estimated by comparing the $0^+ \to 0^+$ beta-decay ft-values across a wide range of proton number.

The other main avenues for experiments are precision measurements of correlations (between the leptons, or between the polarization of the initial nucleus and the beta, etc.) in beta decay and of beta-decay spectra, both sensitive to chirality-flipping interactions. Experiments are now aiming at measurements with uncertainties of approx. 0.1%. Thus, a comparison with theoretical calculations, similarly to the $0^+ \rightarrow 0^+$ beta-decay ft-values, is highly called for. Of particular interest is the role of nuclear structure in the quantitative estimation of such effects, as they create a systematic bias. In the workshop, the figure of merit of nuclear structure effects has been identified and their origin has been discussed. For example, recoil-order corrections, such as weak magnetism, are of the order of the momentum transfer over the nuclear mass, while effects of many-body correlations in the nucleus are of the order of 30%, stemming from the effective field theory used to describe the low energy nuclear problem. In addition, a large body of work in the nuclear structure community of weak and electromagnetic observables has been shown in the workshop, to lay out the feasibility of reaching the needed accuracy to pinpoint beyond the standard model effects in the on-going and planned experiments. General and nucleus-specific uncertainties were discussed.

The workshop was very successful, attracting 27 scientists, from 10 different countries; 15% of the participants were women. The first day reviewed the experimental situation. The second day discussed radiative corrections to beta decay, showcasing recent progress and important issues that need to be resolved regarding radiative and isospin-breaking corrections. The third day provided a common language for connection of BSM physics to beta-decay observables, a framework for computing recoil and finite-size corrections to nuclear observables, and a set of small parameters by which these corrections are suppressed. Thursday surveyed the *ab initio* tools available for those calculations, while Friday provided some concluding remarks about uncertainty quantification and ongoing experiments. Progress during the week was remarkable. Already during the workshop practitioners began *ab initio* calculations that will address its key questions. The workshop forged crucial links between experimentalists and theorists who will provide the calculations needed for interpretation of these precision experiments.

2.3.4. *Atomic Nuclei as Laboratories for BSM Physics*

Date	April 14-19, 2019
Organizers	
Vincenzo Cirigliano	LANL, USA
Ronald Fernando Garcia Ruiz	MIT, USA
Stefano Gandolfi	LANL, USA
Jason Holt	TRIUMF, Canada
Teppei Katori	King's College London, UK
Number of participants	24

Main topics

High-precision measurements of low energy processes provide powerful tools to explore fundamental symmetries and to search for new physics beyond the standard model (BSM). While large colliders explore the energy frontier, high-precision experiments of nuclear, atomic and molecular properties offer a complementary approach. The interpretation of these modern experiments requires a truly interdisciplinary research, with a joint effort between experimentalists and theorists from particle, nuclear, atomic and quantum chemistry. Accurate calculations with quantifiable uncertainty are imperative to disentangle the fundamental physics observables from measurements of nuclear, atomic and molecular properties.

This workshop will be focused on the recent theoretical and experimental progress related to the use of low energy probes in the studies of fundamental symmetries and the search of new physics BSM. A special emphasis will be given to the modern development on nuclear theory and their relevance in studies of fundamental symmetries, neutrino physics and dark matter search.

1. Accurate calculations of nuclear matrix elements
2. High precision experiments on nuclear, atomic and molecular systems
3. Parity violation in nuclei and neutrino oscillation
4. EDM effects in nuclei
5. Dark matter interactions in nuclei
6. BSM effects in beta- and double-beta decays
7. Nuclear physics as a systematic error to search BSM physics

Speakers

Henrique Araujo	Imperial College London
Robert Berger	University of Marburg
Evan Berkowitz	Institut für Kernphysik, Forschungszentrum Jülich
Alfredo Galindo-Uribarri	ORNL
Stefano Gandolfi	LANL
Ronald Fernando Garcia Ruiz	CERN
Carlo Giunti	INFN, Sezione di Torino
Evan Grohs	LANL

Gaute Hagen	ORNL
Baishan Hu	Peking University
Yoshinari Hayato	ICRR/University of Tokyo
Jason Holt	TRIUMF
Takeyasu Ito	LANL
Jonathon Jordan	University of Michigan
Teppei Katori	King's College London
Pierre Lasorak	University of Sussex
Andreoli Lorenzo	University of Trento
Stephan Malbrunot-Ettenauer	CERN
Dan Melconian	Texas A&M University
Emanuele Mereghetti	LANL
Florian Piegsa	University of Bern
Michael Ramsey-Musolf	remote speaker, University of Massachusetts
Grayson Rich	University of Chicago
Ruben Saakyan	University College London

Scientific report

Recently, computationally intensive nuclear calculations have provided important results in our fundamental understanding of the atomic nucleus. One example presented in the workshop was the quenching of axial coupling in beta decay. This long-standing problem is now explained by the quenching of matrix elements, thanks to new calculations including two-body currents. This has given new insights into our knowledge of the nuclear electroweak structure, and has provided critical input for current experimental efforts that aim to perform measurements of the neutrinoless double beta decay (0νβ decay). Similarly, a complication of nuclear dynamics shown for neutrino-nucleus scattering is related to the future long-baseline neutrino oscillation experiment design. These are critical inputs since multi-billion particle physics project designs rely on nuclear theory input. We discussed various new theoretical results from a variety of approaches. There is a key challenge, however, namely the understanding of nucleon correlations and many-body currents in nuclei. This challenge connected the four major topics discussed in the workshop; electric dipole moment (EDM) measurements, neutrino oscillation experiments, 0νβ decay physics, and direct dark matter detection.

Results and Highlights

There were two main outcomes of this workshop. Firstly, it has fostered existing collaborations and communications. This was achieved within the four different communities involved in this workshop; neutrino oscillation experiments, neutrinoless double beta decay, direct dark matter detection, electric dipole moment (EDM) physics. Within these communities, theorists and experimentalists meet each other and the meeting at ECT* provided additional opportunities to discuss ongoing subjects, including new results from recent many-body calculations and their impact in the current experimental efforts.

The other important outcome was that it generated new communications beyond existing communities. This was the goal of this workshop and we think it was achieved very well. For example, double beta decay experimentalists and direct dark matter detection experimentalists are connected because of the nature of the low background and low-temperature experiments. This is the main reason why 0νβ decay is included in APPEC (Astroparticle Physics European Consortium) roadmap even though 0νβ decay is not astroparticle physics. However, experimentalists were not aware that their theoretical systematic errors have common nuclear physics roots. And this meeting served as the first place to discuss common issues, for example, the role of two-body current in matrix elements and structure functions, which are important for both 0νβ and dark matter physics.

Another interesting example is the neutrino-nucleus scattering problem in long-baseline neutrino oscillation measurements. This type of experiments is the flagship of particle physics in Japan and USA, both cost multi-billion investments and they required extremely careful designing. The systematic errors from nuclear physics are known to be the largest, and active discussions happen many times at various places including at ECT* (for example, ECT* workshops May 27-31, June 3-7, 2019). This workshop was different from others because we shared neutrino-nucleus scattering problem with people beyond neutrino oscillation community but including others such as EDM, 0νβ decay and direct dark matter detection, where the underlying problem is also related many-body nuclear theory and common for these communities. This opens up new opportunities to both theorists and experimentalists, and a similar workshop in the near future will be beneficial to continue this important effort.

2.3.5 *Continuum Functional Methods for QCD at New Generation Facilities (collaboration meeting)*

Date	May 7-10, 2019
Organizers	
Daniele Binosi	ECT*, Italy
Lei Chang	Nankai University, China
Craig Roberts	Argonne National Laboratory, US
Joannis Papavassiliou	Universidad de Valencia, Spain
Number of participants	15

Main topics

The last decade has seen a dramatic change in the way we understand the structure of hadrons. Advances in the use of nonperturbative continuum functional methods (NpCFMs) for the boundstate problem in QCD, particularly Dyson-Schwinger equations, have played a key role in these developments. The future promises new challenges and opportunities with, e.g. JLab now operating at 12 GeV, a science case being developed for an electron ion collider, discoveries with the LHCb detector at CERN, and high-precision data anticipated from next-generation e- e+ colliders. The use of NpCFMs has spread into all these areas; and great potential exists for additional growth and expanded, insightful leadership. This collaboration meeting therefore gathered a subset of the international NpCFM community to undertake a critical review of existing opportunities, consolidating facts, and therefrom develop a coherent five-year plan for contributing toward the advancement of strong-QCD physics in this new era of rapid growth.

Speakers

Cristina Aguilar	Universidade Estadual de Campinas, Brazil
Zhan Bai	Peking University, China
Daniele Binosi	ECT*, Italy
Muyang Chen	Nankai University, China
Minghui Ding	Nankai University, China
Fei Gao	University of Valencia, Spain
Xiang Li	Peking University, China
Joannis Papavassiliou	University of Valencia, Spain
Pianpian Qin	Peking University, China
Khépani Raya-Montaño	Nankai University, China
Craig Roberts	Argonne National Laboratory, US
José Rodríguez Quintero	University of Huelva, Spain
Jorge Segovia	University Pablo De Olavide, Spain
Quan Yu Wang	Nankai University, China
Shu-Sheng Xu	Nanjing University of Posts and Telecommunications, China
Pei-Lin Yin	Nanjing University of Posts and Telecommunications, China

Scientific report

Five years ago, top-down NpCFMs had delivered a solution to the puzzle of how dimensional transmutation translated into the appearance of a dynamically-generated mass-scale in QCD's gauge sector and provided a detailed profile of the interaction between coloured charges. On the other hand, bottom-up NpCFMs were making predictions for the masses of a range of ground-state hadrons and their elastic form factors that compared favourably with experiment. The problem at the time, highlighted by Michael Pennington at the ECT* workshop on Dyson-Schwinger Equations in Modern Mathematics & Physics, 22-26 Sep 2014, was that the phenomenological successful bottom-up predictions were being made using an interaction which did not match that predicted by the top-down approaches. This problem was solved at that workshop, and published a few months later (Phys. Lett. B 742 [2015]).

A rapid expansion in the application and impact of NpCFMs has occurred in the intervening years. For instance, the technique has delivered: the first QCD-connected predictions for the pointwise behaviour of meson and baryon parton distribution amplitudes; the first such predictions for meson GPDs; predictions for pion and kaon parton distribution functions that form the basis for a new arm in the EIC science case; a process-independent effective charge in QCD which proves the absence a Landau pole in QCD; a unification of the electromagnetic transition form factors of all neutral pseudo-scalar mesons, including those affected by the non-Abelian anomaly; distribution amplitudes for heavy-light mesons and therefrom a prediction for the branching fraction of rare B-meson decays; and complete solutions of the Poincaré-covariant Faddeev equation for ground and excited state baryons.

Building upon these advances, this collaboration meeting charted the way toward preparing for the new challenges that must be anticipated: (i) from data obtained using new generation facilities; and (ii) in planning for the future of strong QCD and hadron tomography.

Results and Highlights

As a result of the thorough reviews and subsequent discussion sessions a concrete research plan has emerged to address the following topics:

- Explore means by which the in-hadron gluon condensate can be calculated and related to the emergence of mass in the Standard Model.
- Consider how experience gained in analysing the hybrid meson spectrum can be exploited in delivering predictions for glueball masses.
- Introduce methods for delivering nucleon elastic and transition form factors on the entire domain of photon virtuality that will be explored at JLab 12.
- Discuss techniques enabling predictions for the pointwise behaviour of hadron GPDs and TMDs; and, consequently, hadron Wigner functions.
- Discuss extensions of Poincaré-covariant Faddeev equation studies to the prediction of form factors necessary in treating neutrino-nucleus scattering, as relevant to neutrino oscillation experiments.

- Explain how NpCFMs can be used to develop quantum mechanics models for tetra- and penta-quarks.

The ECT* team provided excellent assistance with local arrangements for all participants, and ensured that all went smoothly.

2.3.6 *SN Neutrinos at the Crossroads: Astrophysics, Oscillations and Detection*

Date	May 13-17, 2019
Organizers	
Mirizzi Alessandro	Bari Univ. & INFN Bari, Italy
Dasgupta Basudeb	TIFR Mumbai, India
Number of participants	46

Main topics:

The aim of the workshop was to review and discuss the recent advances in the study of supernova (SN) neutrinos and future perspectives, ranging from SN simulations, neutrino oscillations, nucleosynthesis, gravitational waves, and SN neutrino experimental searches. The workshop was structured to address these broad issues in a synergistic interdisciplinary way and to stimulate discussions and collaborations among scientists working on SN neutrinos from different perspectives.

The main topics were

- Core-collapse simulations
- Microphysics of supernova core
- Stellar nucleosynthesis
- Neutrino flavor conversions
- Exotic particle emissions
- Neutrino detection strategies

Speakers

Abbar Sajad	APC, Paris, France
Balantekin Baha	University of Wisconsin, USA
Beacom John	Ohio State University, USA
Betranhandy Aurore	Stockholm University, Sweden
Capozzi Francesco	Max Planck Institute For Physics, Germany
Chakraborty Sovan	Indian Institute of Technology, Guwahati, India
Cherry John	University of South Dakota, USA
Dasgupta Basudeb	Tata Institute of Fundamental Research, Mumbai, India
Dighe Amol	Tata Institute of Fundamental Research, Mumbai, India
Döring Christian	Max-Planck-Institut für Kernphysik, Germany
Fischer Tobias	Institute of Theoretical Physics, University of Wroclaw, Poland
Fröhlich Carla	North Carolina State University, USA
Gallo Rosso Andrea	Laurentian University, Canada
Giannotti Maurizio	Barry University, USA
Guo Gang	GSI, Germany
Janka H.T.	Max Planck Institute for Astrophysics, Germany
Köpke Lutz	Johannes Gutenberg University Mainz, Germany
Kotake Kei	Fukuoka University, Japan

Kulikovskiy Vladimir	INFN Sezione di Genova, Italy
Kushnir Doron	Weizmann Institute of Science, Israel
Langanke Karlheinz	GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany
Li Huiling	Institute of High Energy Physics, China
Volpe Maria Cristina	Astroparticules et Cosmologie (APC), France
Martellini Cristina	University of Roma Tre, Italy
Martinez-Pinedo Gabriel	GSI Darmstadt, Germany
Mezzacappa Anthony	University of Tennessee, USA
Mirizzi Alessandro	University of Bari, Italy
O'Connor Evan	Stockholm University, Sweden
Orekhov Vsevolod	Johannes Gutenberg-Universität Mainz, Germany
Raffelt Georg	Max Planck Institute for Physics, Germany
Scholberg Kate	Duke University, USA
Sen Manibrata	Northwestern University, USA
Shalgar Shashank	Niels Bohr Institute, Denmark
Sieverding Andre	University of Minnesota, USA
Sigl Günter	Universität Hamburg, Germany
Smirnov Alexei	Max-Planck-Institut für Kernphysik, Germany
Stapleford Charles	North Carolina State University, USA
Stirner Tobias	Max Planck Institute for Physics, Germany
Straniero Oscar	Italian National Institute of Astrophysics, Italy
Stringer Mark	Queen Mary University of London, UK
Suliga Anna	Niels Bohr Institute, University of Copenhagen, Denmark
Tamborra Irene	Niels Bohr Institute, University of Copenhagen, Denmark
Vagins Mark	Kavli IPMU/UTokyo, Japan
Walk Laurie	Niels Bohr Institute, Denmark
Wurm Michael	JGU Mainz, Germany
Zhou Shun	Institute of High Energy Physics, Chinese Academy of Sciences China

Scientific report

The experimental landscape for low-energy neutrino astronomy (few to few tens of MeV) is evolving rapidly. Several existing or planned large detectors worldwide will produce high-statistics signals of the next Galactic stellar-collapse event (supernova or black-hole formation). The diffuse supernova neutrino background (DSNB) is coming into reach with the Gadolinium enhancement of Super-Kamiokande and the JUNO scintillator detector. This topical workshop was meant to interface the communities of supernova and neutrino theorists and protagonists of the evolving experimental side. The goals were to enhance the information flow and mutual understanding between these communities and to develop a better definition of the observational targets (What can we learn?) and of the deliverables that should be provided by neutrino and SN theory as possible benchmarks for detector optimization and observation strategies (What should we do?).

The topical workshop was focused on the following important topics:

- What are the perspectives to measure MeV neutrinos from stellar explosions? Which sources are the most promising ones, in particular for multi-messenger supernova (SN) physics?
- What are the current model predictions for individual SNe, and the diffuse supernova neutrino background (DSNB)?
- What are the current frontiers in describing the microphysics needed for the source modeling? What are major uncertainties?
- What can we learn about the core-collapse physics from a future galactic SN event?
- What do we know about neutrino-flavor oscillations in SNe?
- What is the impact of non-standard physics scenarios on the expected neutrino signal from SNe?
- What “hard” signatures of oscillations and core-collapse physics are predicted for the SN neutrino signal (i.e., features fairly independent of underlying model assumptions)?
- Which is the potential of upcoming large-scale neutrino detectors such as the Hyper- Kamiokande Cherenkov detector, the JUNO scintillator detector and the DUNE liquid argon detector? To what extent can the enrichment of the existing Super-Kamiokande detector with gadolinium and other novel techniques improve the SN neutrino detection?

Results and Highlights

These major topics were covered by one to two overview talks per day and a number of shorter contributions in the afternoon sessions. Each day of the workshop was dedicated to a particular topic, namely:

- Astrophysics

  It was stressed that neutrinos play a crucial role in the collapse and explosion of massive stars, governing the infall dynamics of the stellar core, triggering and fueling the explosion and driving the cooling and deleptonization of the newly formed neutron star. Due to their role neutrinos carry information from the heart of the explosion and, due to their weakly interacting nature, offer the only direct probe of the dynamics and thermodynamics at the center of a supernova. The present status of modeling the neutrino physics and signal formation in collapsing and exploding stars was reviewed. In particular, a detailed comparison of the outcome of SN simulations in multi-dimensional models as well as in spherically symmetric cases was presented.

- Neutrino flavor conversions

  Supernovae represent an extreme environment to probe neutrino flavor conversions in extreme density conditions. In this regard, the current understanding of self-induced flavor conversions associated with neutrino-neutrino interactions that occur in the deepest stellar regions was discussed. The first results of studies exploring a possible impact of the self-induced neutrino flavor conversions on the SN dynamics were presented.

- Nucleosynthesis and exotic particles emission

  It was highlighted that neutrino process that occurs in the outer stellar shells during a supernova explosion and involves neutrino-nucleus reactions produces a range of rare, stable and radioactive isotopes. The ν process establishes a direct connection between the production of individual isotopes and supernova neutrinos. This allows in principle to constrain the neutrino spectra with nucleosynthesis, even though uncertainties of nuclear and neutrino physics require such arguments to be taken with caution. The potential of the next galactic SN explosion to probe new light particle emission (like axions) due to an excessive energy loss on top of the standard neutrino one was discussed.

- Neutrino detection strategies.

  The capability of a variety of current and planned large underground neutrino detectors to yield faithful information of the time and flavor dependent neutrino signal from a future Galactic supernova was assessed. It was shown how the observable neutrino burst would provide a benchmark for fundamental supernova physics with unprecedented richness of detail. Our current understanding of the formation of the diffuse supernova neutrino background was highlighted and the perspectives for a detection of this relic signal in the context of gadolinium doped Super-Kamiokande were analyzed.

  Among the most relevant open problems, the following points were indicated to be of very high priority: an improved conceptual understanding and a more rigorous solution of neutrino-flavor oscillations in the neutrino-dense SN environment; the exploration of consequences of non-standard neutrino physics on the source dynamics and associated neutrino-signal predictions; a better theoretical and experimental consolidation of neutrino interactions with heavy nuclei in the upcoming new detector facilities; the possible benefit of combining the findings of present (and future) neutrino observatories in deciphering the signatures of core-collapse and oscillation physics embedded in the SN neutrino signal.

2.3.7 *Challenges to Transport Theory for Heavy-Ion Collisions*

Date	May 20-24, 2019
Organizers	
Maria Colonna	INFN-LNS, Italy
Hermann Wolter	University of Munich, Germany
Akira Ono	Tohoku University, Japan
Pavel Danielewicz	NSCL-MSU, USA
Jun Xu	SINAP-CAS, China
Number of participants	45

Main topics

Transport theory is the main tool to extract physical information from heavy-ion collisions (HIC), like the nuclear equation-of-state. In this workshop we reviewed the challenges and demands on transport theory in view of new facilities and experiments, and of new astrophysical observations. We focus on energies and corresponding densities, where a hadronic representation is appropriate, but also took a look at methods and concepts employed at higher energies where parton degrees of freedom become important. At present, transport dynamics is treated essentially as a semi-classical 1-body description. Necessary extensions are the specification of fluctuations, the introduction of dynamical correlations and clustering, including short-range correlations, and the treatment of off-shell effects of particle with widths. The workshop discussed these questions and ways to replace the empirical treatments often used today. Code comparisons under controlled conditions for heavy-ion-collisions and box calculations were reviewed and further extensions were discussed.

The main topics were

- Fluctuations and fragmentation dynamics in transport theories
- Clusters and short-range correlations in transport theories
- Quantum and off-shell effects
- Meson and isobar production
- Effective interactions, equation-of-state and astrophysical implication

Speakers

Joerg Aichelin	SUBATECH, Univ. of Nantes, France
Sakir Ayik	Tennessee Tech. Univ., USA
Andreas Bauswein	GSI Helmholtz-Zentrum, Germany
Marcus Bleicher	Univ. of Frankfurt, Germany
Bernard Borderie	IPN2P3, CNRS, France
Elena Bratkovskaya	GSI Helmholtz-Zentrum, Germany
Fiorella Burgio	INFN Catania, Italy
Stefano Burrello	LNS, INFN, Italy
Lie-Wen Chen	Shanghai Jiao Tong Univ., China

Maria Colonna	LNS, INFN, Italy
Dan Cozma	IFIN-HH, Romania
Pawel Danielewicz	NSCL, MSU, USA
Zao-Qing Feng	South China Univ. of Technology, China
Vincenzo Greco	Univ. of Catania, Italy
Kris Hagel	Texas A&M Univ., USA
Natsumi Ikeno	Tottori Univ., Japan
Myungkuk Kim	Pusan National Univ., South Korea
Young-Min Kim	UNIST, South Korea
Che-Ming Ko	Texas A&M Univ., USA
Denis Lacroix	IPN Orsay, France
Arnaud LeFevre	GSI Helmholtz-Zentrum, Germany
Chang-Hwan Lee	Pusan National Univ., South Korea
Yvonne Leifels	GSI Helmholtz-Zentrum, Germany
Hao Lin	MSU, USA
Steffen Maurus	TU Munich, Germany
Paolo Napolitani	IPN Orsay, CNRS France
Dmytro Oliinychenko	LBL, USA
Akira Ono	Tohoku Univ., Japan
Massimo Papa	INFNCatania, Italy
Constanca Providencia	Univ. of Coimbra, Portugal
Gerd Roepke	Univ. of Rostock, Germany
Jun Su	Sun Yat-Sen Univ., China
Wolfgang Trautmann	GSI Helmholtz-Zentrum, Germany
Betty Tsang	Michigan State University, USA
Chun Yuen Tsang	Michigan State University, USA
Stefan Typel	Technische Universität Darmstadt, Germany
Rui Wang	SINAP, CAS, China
Yongjia Wang	Huzhou Univ., China
Hermann Wolter	Univ. of Munich, Germany
Jun Xu	SINAP, CAS, China
Gao-Chan Yong	IMP, CAS, China
Feng-Shou Zhang	BNU, China
Yingxun Zhang	CIAE, China

Scientific report

A main motivation to study heavy-ion collisions (HIC) is to obtain information on the nuclear equation-of-state (EoS) from very low to several times saturation density, which is an important ingredient for the physics of neutron stars and their mergers and for supernovae. Since HIC are non-equilibrium processes, transport theory is necessary to connect the static concept of an EoS with the highly dynamic HIC. Because of the advent of new experimental facilities and the spectacular qualitative increase of astronomical observations, higher demands on the theoretical foundation and reliability of transport approaches are required. The workshop was centred on the energy regime where hadronic degrees of freedom are appropriate, which covers also the relevant density regime for astrophysics, but we also explored connections to methods and concepts (such as hydrodynamical methods) employed at higher energies where parton degrees of freedom become important (Greco, Bleicher).

A chain of approximations is necessary to arrive from a quantum transport theory, in particular the Kadanoff-Baym theory, at the essentially semi-classical transport theories used today. These theories work at the mean field level with two-body dissipation. There are many indications that methods beyond the mean field level are important today. Also, quantum effects should be important, especially at low energies. It was the main purpose of the workshop to discuss critically the attempts to do so.

The truncation of the BBGKY hierarchy on the 1-body level neglects two and higher order correlations. However, correlations play an important role in the analysis of HIC. A substantial part of the final state in a HIC consists in light clusters, particularly up to alpha particles, which a transport theory has to be able to treat realistically. Short range correlations are an important question in nuclear structure, but they should also play an important role in HIC, where large momenta are involved.

The effect of the neglected correlations can be mimicked by considering a stochastic term in the evolution of the one-body density. However, how to introduce the fluctuations physically is an important issue. It also constitutes the main difference between the two families of transport equations, the Boltzmann-Vlasov type, usually called BUU, and the molecular dynamics type, often called QMD.

The quasi-particle approximation replaces the imaginary part of the self-energy, which describes the collisional width of a particle by the pole part. The role and treatment of off-shell transport is an open question (Bratkovskaya). Today the transport of particles with a decay width, like the Delta resonance, is usually replaced by a mass distribution, which is treated as a distribution of on-shell particles. This might play an important role in the production of particles near thresholds.

The physical input of a transport approach consists of the isospin- and momentum - dependent mean field potential, i.e. the EoS, and an in-medium cross section, plus eventually of a specification of the fluctuations. For these inputs one needs a consistent approach which also yields a connection between the different ingredients. While temperature is not really a concept in a transport approach, it is clear that the medium is highly excited, and that a zero-temperature density functional is questionable. The EoS determined in HIC has to be checked against the constraints obtained from astrophysical observations, like the mass-radius relation of a neutron star, or its deformability. These astrophysical constraints were discussed in detail at the workshop (Burgio, Bauswein, Tsang).

To assess the reliability of present-day transport descriptions, a code evaluation program was initiated already many years ago, in fact, here at the ECT* in Trento. This project has started with comparisons of full HIC under controlled conditions. It has now been found very illuminating to make comparisons in the better controlled conditions of infinite matter, approximated by a periodic box, of the different aspects: collisions, blocking, mean field propagation and particle production. These comparisons not only provide a kind of systematic theoretical error of transport codes, but this study also gave and continues to give valuable insight into the properties of simulations of transport, e.g. the importance of numerical or physical fluctuations on the evolution of the system (Wolter).

The question was discussed, whether a benchmarking of heavy ion codes beyond the code comparison should be undertaken, like in other fields (Leifels). This would include experimental data in a standard format, and well documented open transport codes. The opinions on this were divided.

Results and Highlights

The final state of a HIC is made up to a large part of light clusters, even at higher energies, which are often used to infer the temperature, density, entropy, and isospin asymmetry of the state of matter. However, light clusters are not well described by the mean field forces employed and coalescence prescriptions are not reliable for these. More physical ways to treat light clusters in transport were discussed in detail. One approach is to isolate the few-body correlation into cluster densities and to treat these as explicit degrees of freedom (Danielewicz), where the medium properties of the clusters and their transition matrix elements have to be taken into account (Röpke). Another approach implemented in anti-symmetrized molecular dynamics (AMD) uses the quantum wave function of the light cluster for the probability of its formation in a two-body collision (Ono), and this can be extended to cluster-cluster collisions. Both approaches can show successes in describing cluster observables, but also need further development. Another type of correlations are short-range correlations (SRC), which lead to high momenta, and should make a difference in the spectral dependence of observables. It is, however, debated, how to incorporate SRC into transport theories. One proposal was to introduce a high-momentum tail in the initial momentum distribution (Yong), but also 3-body collisions may be an alternative.

EoS's with clusters are important not only for HIC, but also in astrophysics, in the very dilute matter in the supernova neutrino sphere and in the crust of neutron stars (Providencia). We discussed how such EoS's can be formulated in a generalized relativistic mean-filed (RMF) approach with cluster degrees of freedom (Typel), coupled with quantum statistical calculations of in-medium cluster wave functions (Röpke). Thus experiments of the decay of the fireball in HIC, can give information on the supernova EoS (Hagel).

The way to include fluctuations in the transport equations, going beyond a pure mean-field picture, was reviewed (F-S Zhang), also with the aim of establishing connections between quantum stochastic mean-field treatments (Ayik, Lacroix), semi-classical Boltzmann-Langevin approaches (Napolitani) and QMD-like models (Papa, Zhang). In semi-classical approaches, the fluctuation term can been derived on the same footing of the 2-body collision term, but there are also fluctuations due to the neglect of higher order correlations. Therefore, several approaches have taken the view, that the fluctuations can be specified as statistical locally in phase space (Colonna, Napolitani). A question of discussion was the strategy to identify fragments in the final state of a collision. The usual coalescence or minimum-spanning-tree algorithms need a long time to be effective, but the long-time evolution is often not reliable. Dynamical methods to identify fragments early in the evolution were presented and lead to further insights of the fragment formation (LeFevre, Aichelin).

The code comparison investigations in a box described above have shown that fluctuations also have strong influences in the general evolution of a HIC, for the Pauli blocking terms and also for the mean-field propagation, leading to a larger damping of collective modes. Here is a rather significant difference between BUU- and QMD-type transport approaches. The appropriate treatment of fluctuations in transport is still under vivid debate.

Meson production in intermediate energy HIC has been shown to be a sensitive probe of the EoS generally, in particular for the determination of the density dependence of the nuclear symmetry energy. But lately the interpretation of pion ratios has led to widely different conclusions. Meson production proceeds mainly through the production of nuclear isobars, e.g. for the pion production via the excitation and decay of the Delta resonance, and thus involves the specification of additional physics, like meson and isobar potentials, inelastic cross sections, threshold and off-shell effects. This topic was discussed in depth, as well as from imminent new experimental results (Tsang), as from the theoretical questions. The width of the resonances makes it necessary to consider the spectral function and the details of threshold in the inelastic collisions (Ko). The energy conservation in inelastic processes with momentum dependent potential is non-trivial and can influence the pion ratios (Cozma), as can the consideration of clusters in the evolution (AMD, Ikeno). Of great interest is also a recently completed code comparison in a box including pions and resonances, which showed substantial differences between codes with standardized physical input. Many of these differences could be traced to choices in the strategies of the simulations, like time steps, ordering of elastic and inelastic collisions, and higher-order correlations between subsequent collisions.

On the afternoon of the last day of the workshop, there was a special session of the participants of the code comparison group, to consider further steps in this project. Besides discussing the understanding and elimination of the differences in the box-pion production, ongoing studies of pion production in HIC were discussed, as well as studies of the mean field propagation. Publications on these projects in the near future will be a direct result of the workshop. It was also thought to be important to investigate further the fragmentation behaviour in a box from initialization in the unstable regime, which will help to understand better the role of fluctuations.

2.3.8 *Neutrini and Nuclei, Challenges and Opportunities for Nuclear Theory*

Date May 27-31, 2019

Organizers

Noemi Rocco	Argonne National Laboratory-Fermilab, USA
Alessandro Lovato	Argonne National Laboratory-TIFPA, USA
Juan Nieves	Instituto de Fisica Corpuscular - CSIC & Universidad de Valencia, Spain
Saori Pastore	Washington University, USA

Number of participants: 20

Main topics

This workshop was aimed at defining the best strategy to be pursued to achieve an accurate description of neutrino-nucleus interactions in the broad kinematical region relevant for neutrino-oscillation experiments. Many experiments explore wide ranges of energies, where different reaction mechanisms are at play. Their comprehensive and consistent description poses a formidable task to the nuclear and particle physics communities.

The main topics were

- Test the validity of Effective Field Theories in high energy regions
- How to transition to regions where single-nucleon excitations, resonance- and meson-production occur
- How to properly incorporate relativistic effects

Speakers

Luis Alvarez-Ruso	IFIC, Spain
Lorenzo Andreoli	University of Trento, Italy
Mack Atkinson	Washington University, USA
Sonia Bacca	Johannes Gutenberg University, Germany
Omar Benhar	INFN, Italy
Joseph Carlson	Los Alamos National Laboratory, USA
Arturo De Pace	INFN, Italy
Hilla Deleon	ECT*, Italy
Raul Gonzalez Jimenez	Universidad Complutense de Madrid, Spain
Hermann Krebs	Ruhr-University Bochum, Germany
Alexis Nikolakopoulos	University of Ghent, Belgium
Giuseppina Orlandini	University of Trento, Italy
Assumpta Parreno	University of Barcelona, Spain
Francesco Raimondi	CEA, France
Toru Sato	Osaka University, Japan
Rocco Schiavilla	Old Dominion University-JLab, USA
Joanna Sobczyk	IFIC, Spain
Michele Viviani	INFN, Italy

Scientific report

Current and next-generation neutrino-oscillation experiments require nuclear physics calculations of structure and electroweak properties of atomic nuclei with quantified theoretical uncertainties. Modeling neutrino-nucleus interactions in the region of interest for neutrino oscillation experiments, extending up to few GeV, is a very complicated problem.

Nuclear responses to electroweak probes, e.g., electrons and neutrinos, are determined by a variety of mechanisms-involving both nucleon and nuclear excitation modes–whose contributions strongly depend on the energy and momentum transfer. In the quasielastic region, one- and two-nucleon emission processes dominate. For larger values of the energy transferred by the probe, we have excitation of nuclear resonances that subsequently decay into pions and deep inelastic effects leading to hadron production.

Nuclear effective field theories (EFTs), coupled to accurate nuclear many-body methods, allow for a consistent description of nuclear structure and low-energy electroweak observables. Besides providing interactions that reflect the symmetries of the underlying theory of QCD, EFTs allow for a viable way of estimating theoretical uncertainties. This picture has been largely and successfully tested against available low-energy electroweak data, such as electromagnetic moments and transitions, and beta decay rates. However, the possible extension of EFTs to account for processes characterized by momentum and energy scales larger than the pion mass is a nontrivial problem.

During the workshop we discussed how to connect EFTs and more phenomenological models currently used to provide predictions at higher values of energy and momentum transfer. In addition to the main topics already listed, we also discussed

- What it is the status of Lattice QCD calculations of nucleonic properties relevant for neutrino oscillation experiments (f.e. nucleon form factors)
- How effective field theories can be used for the description of dark matter-nucleon interactions

Results and Highlights

The Workshop gave us the opportunity to call for a joint effort from the particle and nuclear physics communities.

The results for nuclear structure and interactions obtained form EFTs and different nuclear-many body approaches have been discussed. We addressed open issues such as the determination of the low-energy constants entering the EFTs and the dependence of nuclear observables from different cutoffs and range of energies used to fit them. The interplay with lattice QCD offers new possibilities in this direction. We also analyzed additional constraints to determine three body forces. Our goal is to achieve a good description of spectra and electroweak transitions of light-nuclei, as well as the infinite nuclear matter equation of state. Three-body scattering observables have emerged as one of the most promising way to determine sub-leading corrections in three-nucleon forces.

We discussed how to transition between EFT-based non-relativistic calculations and more phenomenological ones that account for relativistic effects. Among the different attempts in this direction, the Short Time Approximation and the spectral function approaches are probably the most relevant ones, as they retain a sufficiently accurate description of nuclear dynamics in the initial target state. Additional comparisons with ab-initio calculations in the low-energy region should be performed to further constrain these methods. Understanding whether the structure of two-body current operators obtained from EFT is applicable at high momenta (order of GeV) is still an open question.

The description of the pion production region is extremely intricate. Some of the more approximated approaches violate unitarity and lead to the appearance of divergencies at large values of the energy transfer. Extensions in the high-energy regime through partial unitarization and Regge theory were presented. In this regard, we identified the clear role of lattice QCD calculations of nucleon transition form factors carried out at physical pion masses.

2.3.9 *Testing and Improving Models of Neutrino Nucleus Interactions In Generators*

Date June 3-7, 2019

Organizers

Sanchez Federico	University de Genève
Barbaro Maria	Turin Univeristy
Jachowicz Natalie	University of Ghent
Wilkinson Callum	University of Bern
McFarland Kevin	University of Rochester
Perdue Gabriel	Fermilab

Number of participants 30

Main topics

- Model implementations in generators
- Nuclear rescattering models
- Comparison of Pion production to 0pi Final States
- Comparison of Ab Initio Calculations to generators
- Low momentum and high momentum transfer model consistency
- SuperScaling (SuSa) model
- Neutrino Generators and Models
- Spectral functions
- Electron scattering

Speakers

We list the speakers of the plenary and some talks given in parallel sessions:

Fields L.	Fermilab, USA
Hayato Y.	Kamioka Obs., ICRR, The University of Tokyo, Japan
Hen O.	MIT, USA
Ashkenazi A.	MIT, USA
McFarland K.	University of Rochester, USA
Udias J.	Universidad Complutense de Madrid, Spain
Roda M.	University of Liverpool, UK
Megias G.	DPhP, CEA-Irfu, University Of Paris-Saclay, France
Dolan S.	LLR / CEA Saclay / CERN, France
Dytman S.	Univ. of Pittsburgh, USA
Bodek A.	University Of Rochester, USA
Nikolakopoulos A.	Ghent University, Belgium
Gardiner S.	Fermilab, USA
Gimenez R.	Complutense University of Madrid, Spain
Lovato A.	Argonne National Laboratory, USA
Pickering L.	Michigan State University, USA
Niewczas K.	University of Wrocław, Poland
Rocco N.	ANL- FNAL, USA

Scientific report

The precision investigation of neutrino oscillations is a major worldwide research thrust in particle physics. Since the year 1998, the oscillation research has moved from the discovery stage to a mature field providing successively more accurate results leading to a better understanding of flavour and masses in the standard model. Current experiments and those in the coming decades seek to measure the ordering of the neutrino masses, important for models of neutrino mass generation, and the discovery of CP violation, which provides another plausible source for the CP violation observed in today's Universe. The extraction of neutrino properties requires the knowledge of the incoming neutrino energy and the efficiency in detectors which compromise between capabilities and total detector mass. The partial information available to such detectors must be mapped to true neutrino energies using data from neutrino experiments and models that attempt to describe these interactions. This workshop seeks to compare these models to data, and to implement new models in generators that are used commonly for the analysis of data.

The task of the neutrino energy reconstruction is complicated by the fact that all ongoing or planned neutrino long-baseline experiments use nuclei, such as C, O or Ar, as targets. Recovering neutrino properties from oscillation experiments thus requires the understanding of neutrino interactions with nuclei at an unprecedented level of precision. Since the experiments rely on the interactions of neutrinos with bound nucleons inside atomic nuclei, the planned advances in the scope and precision of these experiments require a commensurate effort in the understanding and modeling of the hadronic and nuclear physics of these interactions beyond the capabilities of current models. These nuclear models need to be incorporated in neutrino event generators.

The understanding of the nuclear models and their implementation in the generators is crucial to the progress of the field. This requires the contribution from several communities: nuclear physics experimentalists, nuclear physics theorists and neutrino experimentalists. These communities have been disconnected by structural issues, mainly because long-baseline neutrino oscillation experiments are performed in high-energy laboratories and by high-energy physicists rather than nuclear physicists. As this collaboration has evolved, the two communities have developed a common understanding of the improved theoretical tools available from nuclear theorists. However, a major barrier has been the incorporation of such theories into neutrino interaction simulations. These simulations, numerical models implemented in Monte-Carlo codes, are essential to every phase of experimental analyses. Their theoretical uncertainties play an important role in interpreting every result.

Implementation of models in generators normally encountered a list of issues: the validity of the models over a large range of neutrino energies, the speed of the calculations that is often not suitable for large statistics production and the fact that some of the models cannot describe all final states of the neutrino interactions. We explored solutions to these problems with experts from theoretical and generator communities.

Due to the limited time available, we selected a set of urgent topics to be addressed during the meeting. This list did not pretend to be exhaustive, but it was meant to cover the more urgent needs of the field according to the organizers of the workshop that include representatives from different experiments and some of the most prominent model builders.

Workshop organisation

Previous to the workshop, conveners identified the main topics to be discussed during the workshop week and appointed world experts to lead the discussion. The discussion groups were organized as independent working groups. Some groups proposed a set of tasks to be carried out prior to the workshop: generating MC samples and model predictions under certain common conditions to facilitate comparisons. Working groups were reorganized in bigger groups when common issues were identified. The week was organized as one and a half day of plenaries were one of the coordinators of the WG presents the status of the topic and proposes goals for the week. This session was followed by two days of parallel WG meetings. They were organized dynamically, WG were holding independent meetings or common with other WG under the request of the conveners. The meetings showed a variety of configurations, from formal presentations to round table discussions or actual work in front of the computer. The remaining time was dedicated to discussing in common the conclusions of the WG following a short presentation on the outcome of the different WG meetings.

Results and Highlights

The following is a list of discussions and highlights of the workshop. Many of the topics have been actually opened during this week and they will need time to produce results. The opinion of the participants is that the discussions were very useful and most of them consider the workshop the beginning of a series of similar events in the future. The condensed list of highlights reads as follows,

- Discussion on a universal interface to allow model builders to interface with the actual generators. This interface will allow model builders to describe the model in software that can be integrated in running and future generators.
- Discussion on the evolution of the actual generator models to define a long-term plan for the field. What is the best integration model? Can we learn something from other similar particle physics problems? Discussions started during the workshop but are far from being finished.
- Comparison of the similarities and difference of the implementation of some models such as Spectral Functions in different generators. The comparison allowed identifying different approaches and the effect on the predictions.
- Detailed comparisons of nuclear reinteraction models based on a set of pre-agreed data samples. Discussion of observables to facilitate the comparison among different implemented models: quasi-classical cascades with transport theory, etc… The analysis went far enough to propose the possibility of a publication based on the discussesd arguments.
- Clarification of some confusing terms between physics models and generator builders. One interesting case is the concept of Final State Interactions asso-

ciated to real and imaginary optical potentials and the relation with the intranuclear cascades. This discussion lead to new ideas on how to compare models in future developments.

- Clarification of the implementation of Coulomb potential corrections in the final states and implementation in different models and generators.
- Discussion about the physics phenomena overlapping in different models. For example: initial state correlations in Spectral Functions and Fermi models. This is a relevant aspect to pay attention to when building generators to avoid double counting of physics phenomena.
- There was a lively discussion about the optimal implementations of electron scattering models in the neutrino interaction generators. The proper implementation will help the neutrino community to access the large and precise electron scattering data to constrain the validity of their approximations. Few proposals were discussed, and a review of the different attempts took place during the workshop.
- There were also discussions about the implementation and the physics meaning of the removal energy or binding energy and comparison between different generators. This is still a confusing term in the community with different approaches: from theoretically based to more phenomenological. The relations between them were discussed by the people who actually implemented them in their generator models.
- Experiences of the implementation and limitations of some models (mainly Mean Field models) using the inclusive hadron tensor implementation that facilitate the integration in models at the cost of reducing predictability.

In some informal discussions, the issue of the implementation of a pure exclusive description of the interaction of neutrinos with nuclei was addressed. A few ideas came up during the discussion that will be tried in future developments.

2.3.10 *High-Energy Physics at Ultra-Cold Temperatures*

Date	June 10-14, 2019
Organizers	
Gert Aarts	Swansea University
Alejandro Bermudez	Universidad Complutense de Madrid
Maciej Lewenstein	Institute of Photonic Sciences (ICFO)
Number of participants	30

Main topics

The most fundamental laws of physics are routinely explored by experiments at large facilities, which probe the highest energies, smallest distances and shortest times. However, models and underlying theories designed to explain the observations may also emerge as effective descriptions of many-body systems at lower energies, e.g. in condensed-matter physics. The recent advances in the field of atomic, molecular, and (AMO) physics have allowed experimentalists to control these many-body systems to such an extent that it is nowadays possible to shape the emergence of those effective descriptions, targeting a particular model of high-energy physics (HEP). In this way, interesting and difficult problems of high-energy physics may soon be explored at ultra-cold temperatures, with the advantage that parameters can be changed by turning the experimental knobs.

This workshop has covered the following main topics, pursuing scientific goals that can be organized in two broad themes:

1. *Equilibrium phenomena in lattice quantum field theories:* The attendees have addressed specific questions, such as:
   - Recent advances in phase structure of lattice gauge theories (LGTs), including at finite temperatures and finite densities. Overview of current knowledge, and state-of-the-art in lattice field theory numerical simulations (Monte Carlo, tensor-network RG…). Overview of current proposals for AMO-based quantum simulators.
   - Low-dimensional relativistic and effective QFTs: recent advances in the AMO- based quantum simulation of LGTs, traditional lattice methods (large-N, renormalization group (RG), numerical techniques) and quantum-information inspired methods (tensor-network variational ansatz and RG, quantum variational eigensolvers). Connection to topological phases of matter.
2. Non-equilibrium phenomena in lattice quantum field theories: We have addressed specific questions, such as
   - Real-time dynamics in relativistic QFTs: Functional and Langevin methods for LGTs, tensor-network techniques for dynamics, AMO-based real-time observables for LGTs and other relativistic QFTs, including experiments. Adiabatic/fast quenches in lattice QFTs: dynamical phase transitions, including string breaking (experiments). Connection to topological phases of matter via topological pumping.

Speakers

Gert Aarts	Swansea University, UK
Monika Aidelsburger	LMU, Munich, Germany
Maria Bañuls	Max Planck Institute of Quantum Optics, Germany
Luca Barbiero	Université Libre de Bruxelles, Belgium
Alessio Celi	Autonomous University of Barcelona, Spain
Titas Chanda	Jagiellonian University, Poland
Ignacio Cirac	Max Planck Institute of Quantum Optics, Germany
Joaquin Drut	University of North Carolina, USA
Patrick Emonts	Max Planck Institute of Quantum Optics, Germany
Daniel Gonzalez	ICFO, Spain
Fabian Grusdt	TU Munich, Germany
Philipp Hauke	Heidelberg University, Germany
Fred Jendrzejewski	Heidelberg University, Germany
Leonardo Mazza	LPTMS and Université Paris-Sud, Francia
Yannick Meurice	University of Iowa, USA
Javier Molina	Universidad Politécnica de Cartagena, Spain
Giandomenico Palumbo	Université Libre de Bruxelles, Belgium
Joao Pinto Barros	Bern University, Germany
Lukas Rammelmüller	TU Darmstadt, IKP Theory Center, Germany
Enrique Rico Ortega	UPV/EHU & Ikerbasque, Spain
David Schaich	University of Liverpool, UK
Chris Self	University of Leeds, UK
Sandro Stringari	University of Trento, Italy
Luca Tagliacozzo	Universidad de Barcelona / University of Strathclyde, Spain
Emanuele Tirrito	ICFO – The institute of Photonic Sciences, Spain
Xhek Turkeshi	SISSA, Italy
Judah Unmuth-Yockey	Syracuse University, Italy
Christof Weitenberg	University of Hamburg, Germany
Torsten Zache	Heidelberg University, Germany
Erez Zohar	Max Planck Institute of Quantum Optics, Germany

Scientific report

The general scope of this workshop was the exploration and widening of the connections between the physics of atomic, molecular, and optical (AMO) physics at ultra-cold temperatures, on the one hand, and the physics of relativistic quantum field theories (QFTs) operating at much higher energy scales. In order to achieve this, the ECT* workshop has succeeded at gathering experts from AMO and HEP in a multi-disciplinary environment, fostering a very open and useful dialogue. We have discussed recent advances in both fields and, more importantly, we have identified key points/questions that may be tackled in the near future in this exciting field of research.

Recent advances in the AMO community, including experiments with real atoms (e.g. neutral atoms and trapped ions) and artificial ones (e.g. superconducting circuits), indicate that these setups can serve as a playground to *explore high-energy* *physics models in well-isolated environments at ultracold temperatures*. The workshop has included talks discussing the advances in these platforms, imparted by either experimental colleagues with a practical background in these platforms, or by theory colleagues who have close collaborations/connections to the various experimental systems. In particular, the strength of Floquet engineering in the field of AMO quantum simulations, both analog and digital, has been discussed at length with very promising prospects in the simulation of low-dimensional discrete lattice Gauge theories.

Likewise, the workshop has included various talks concerning the present status of numerical techniques to explore equilibrium and off-equilibrium properties in quantum many-body systems, paying special attention to lattice field theories and HEP-inspired models. Among the various topics discussed, we´ve had talks on the use of Monte Carlo, Complex Langevin, tensor network techniques, both from an RG perspective as from a variational-ansatz MPS view point (also combined with Monte Carlo), continuous multi-scale renormalization methods, and the prospects of dualities to achieve purely-bosonic lattice gauge theories with interesting prospects in the sign problem. This has prepared the stage to discuss at length about these methods, so that each community has gained an overall perspective on many new aspects.

Results and highlights

The balanced mixture of different and complementary expertise in the invited speakers has given rise to many open and interesting discussions. The general consensus is that there is a very high *potential of AMO systems to shed light into relevant HEP questions*, especially in the non-perturbative and off-equilibrium regime of lattice Gauge theories. On the other hand, despite recent important advances in the field that have had representation among the speakers, the general feeling is that there is still a long road ahead before the experimental quantum simulation of large-scale non-Abelian gauge theories becomes a useful reality. The aforementioned recent advances include digital simulations of small-scale 1+1 quantum electrodynamics (Innsbruck), as well as the analog quantum simulation of 1+1 lattice gauge theories with matter coupled to discrete Z2 gauge fields via Floquet engineering (Munich).

Another promising direction, reported during the workshop (Heidelberg), is the analog quantum simulation of 1+1 QED exploiting spin-changing collisions in atomic mixtures. A question of particular relevance that should be addressed in the future, both experimentally and from a theoretical perspective, is the role of spurious perturbations, likely present in the experimental realization, that explicit break the gauge invariance but are sufficiently weak so that their effect will only become apparent at longer time-scales. Can one quantify precisely the role of these terms? Are there situations where such perturbations are irrelevant from the RG sense in the vicinity of the fixed points where a continuum gauge theory is expected to be recovered? Can we turn their existence into a feature, meaning will there be interesting phase transitions where gauge-invariant and non-gauge-invariant terms compete? All these are important questions, inspired by the workshop, which will be addressed in the near future.

This workshop also joined theoretical physicists with a diverse background, and there were very interesting discussions on the prospects of various numerical tools: Matrix product state and multi-scale renormalization ansätze, tensor-network renormalization group, Monte Carlo, complex Langevin methods, etc. In particular, it was very interesting to see the potential of current MPS approaches, which are dealing with low-dimensional LGTs and accessing the physics even at finite densities without encountering any sign problem (Munich). Likewise, MPS approaches are being applied to extract real-time phenomena, such as quenches, in low- dimensional LGTs (Barcelona). It will be interesting to see how this approach handles higher- dimensional models in the future. There was also an update on the use of the Complex Langevin method (Swansea) for out-of-equilibrium phenomena, and its success in non-relativistic quantum many-body systems (Darmstadt). The AMO community, not at all familiarized with these techniques, found this method very interesting and it will potentially lead to new applications in the near future.

Last but not least, there were interesting talks on the use of dualities to get rid of the fermionic content of a model at the expense of introducing discrete gauge fields. The general consensus about these ideas is that they are very promising both for the quantum simulation platforms (where fermions are non existing or are much more difficult to control), as well as from the classical simulation perspective (i.e. in case the sign problem can be avoided in this way).

2.3.11 *Antiproton-Nucleus Interactions and Related Phenomena*

Date	June 17-21, 2019
Organizers	
Jaume Carbonell	Institut de Physique Nucléaire Orsay, France
Ulf-G. Meißner	University of Bonn / Forschungszentrum Jülich, Germany
Alexandre Obertelli	TU Darmstadt, Germany
Eberhard Widmann	Stefan Meyer Institute for Subatomic Physics, Austria
Number of participants	37

Main topics

Low energy antiprotons as a probe for nuclear structure remains unexploited despite past pioneer works at Brookhaven and CERN. The advent of new facilities, namely the ELENA low energy antiproton ring at CERN and the European Facility for Antiproton and Ion Research (FAIR) in Germany opens a wide range of perspectives. Nuclear structure studies with antiprotons require microscopic potentials and approaches to describe the interaction of low energy antiprotons with nuclei. The formation and decay processes of antiprotonic atoms is important to address the sensitivity of antiprotons to the nuclear density radial distribution. In this workshop, past work with low energy antiprotons for nuclear physics was reviewed in a critical way. New perspectives opened by the recent developments in the theory of nuclear interactions and in the treatment of the nuclear many-body problem, as well as the new facilities ELENA at CERN and FAIR were discussed.

The topics of the workshop included:

- physics with antiprotons
- antiprotonic atoms and nuclear structure
- antiproton-nucleon and antiproton-nucleus potentials
- antinucleon-nucleus annihilation cross sections
- new facilities and projects

Speakers

Akitaka Ariga	University of Bern, Switzerland
Claude Amsler	Stefen Meyer Institute, Austria
Michael Doser	CERN, Switzerland
Paolo Finelli	University of Bologna, INFN, Italy
Eliahu Friedman	Racah Institute of Physics, Israel
Aida Galoyan	DUBNA, JINR, Russia
Angela Gligorova	Stefen Meyer Institute, Austria
Detlev Gotta	Forschungszentrum Jülich, Germany
Johann Haidenbauer	Forschungszentrum Jülich, Germany
Jaroslava Hrtankova	Nuclear Physics Institute, Rez, Czech Republic
Guillaume Hupin	IPN Orsay, France
Paul Indelicato	Laboratoire Kastler Brossel, France

Rimantas Lazauskas	IPHC, France
Noritsugu Nakatsuka	TU Darmstadt, Germany
Josef Pochodzalla	Mainz University, Germany
Ryoichi Seki	RCNP, Japan
Agnieszka Trzińska	Heavy Ion Laboratory, University of Warsaw, Poland
Stefan Ulmer	RIKEN, Japan
Ivan Vorobyev	TU Munich, Germany
Michiharu Wada	KEK, Japan
Eberhard Widmann	Stefen Meyer Institute, Austria
Slawomir Wycech	Andrzej Soltan Institute, Poland

Scientific report

The past investigations at the AD at CERN on the interaction of antiprotons with nucleons and stable nuclei was reviewed with a focus on scattering experiments and nucleon-antiproton annihilation. Open questions about nucleon-antinucleon annihilations were reviewed (Amsler). Antiprotonic atoms have been investigated with stable nuclei at the LEAR facility of CERN (Doser). Today, the physics program at CERN with low-energy antiprotons focuses on physics beyond the standard model: CPT symmetry and behaviour of antimatter in the gravitational field of the earth (Ulmer). The AD and the new facility ELENA are the only place facilities worldwide dedicated to physics with low-energy antiprotons. Complementary physics programs were foreseen at FAIR under the FLAIR project (Widmann), although not pursued in the near future.

The formation and decay of antiprotons atoms have been investigated (Seki, Gotta). In particular the PS175 experiment at CERN provided unique X-ray information on the formation and decay of antiprotons atoms. Antiprotonic atoms, and exotic atoms in general, are the object of ongoing studies (Indelicato).

Antiprotonic atoms have been used to investigate the tail and surface of the nuclear matter density in stable nuclei. The main experiment on the topic at CERN was PS209 (Trzcinska). Theoretical frameworks for these studies were presented (Friedman, Wycech). A new project, PUMA, aims at extending these studies to radioactive nuclei where halos and neutron skins are expected to develop (Wada, Nakatsuka).

The state of the art to treat the interaction of antiprotons with nuclei has been extensively discussed. A first full microscopic calculation of antiproton-nucleus elastic scattering was presented (Finelli). The ASACUSA experiment provided recently new information on the pion production from annihilation of antiprotons with several target nuclei (Gligorova) while the current implementation of this process in GEANT4 and its limitations were discussed (Galoyan).

Antiproton nucleus annihilations can also produce, in rare events, hypernuclei which can be investigated with the emulsion technique (Ariga).

Antideuteron-nucleus interaction cross sections are needed to be known experimentally to constrain the adsorption of antideuteron produced in the universe, possible from dark matter. Such information can be extracted from ALICE/LHC data (Vorobyev).

High energy antiprotons at FAIR will be the core ingredient for the PANDA experiment (Pochodzalla).

Results and Highlights

The workshop was timely: it represented a bridge between past studies at CERN on antiprotonic atoms and, more generally, on studies with antiprotons, and future plans at new facilities focusing on antiprotons as a probe (CERN/AD/ELENA and FAIR). The use of antiprotons for nuclear physics shows a gap of 20 years between past activities and future plans. It is therefore important that the expertise developed so far is transferred to the new generation of experimentalists and theorists interested in these topics.

Antimatter, the interaction of antiprotons with nuclei and antinuclei have indeed a large prospect in subatomic physics. The annihilation process from few body systems, such as the Pontecorvo reaction, should reveal unique mechanisms in QCD. Annihilation onto unstable nuclei could reveal halos and could contribute to characterise the development of neutron skins along isotopic chains. Low-energy antineutrons represent a unique probe for indirect Dark Matter searchers in space. The interaction of high-energy antiprotons at FAIR with nuclei will provide a unique way to produce and study exotic atoms not accessible so far.

The physics program at low energy foreseen at the new ELENA facility, which should start operating at nominal values in 2021, is getting broader than set of activities currently carried at the AD. The interest for a continuous extraction of antiprotons, feasible but not yet developed, has been raised. Projects for transportable traps to deliver antiprotons to other research institutes have been presented and could favour a development of antiproton physics. At higher energy, the delivery of antiprotons at FAIR will lead to a wide and exciting physics program, in particular at the PANDA experiment.

The past-year developments in Chiral effective field theory and in ab initio methods to compute the many-body problem opens new ways to describe the interaction of antiprotons with nucleons and light nuclei, as well as to calculate light antiprotonic atoms. The workshop allowed to review these different initiatives and to exchange ideas about the new initiatives.

The workshop was the occasion to forge new collaborations: (i) joint interests between the ASACUSA collaboration and members of the PUMA project, (ii) modelling of annihilations from Monte-Carlo approaches in view of recent results from ASACUSA, (iii) test of different nucleon-antinucleon potentials in antiprotonic atom calculations, (iv) benchmark of light antiprotonic atoms for various ab initio methods, (v) joint plans for X-ray measurements from the decay of antiprotonic atoms.

2.3.12 *Nuclear and Astrophysics Aspects for the Rapid Neutron Capture Process in the Era of Multimessenger Observations*

Date	July 1-5, 2019
Organizers	
Anu Kankainen	University of Jyväskylä, Finland
Alfredo Estrade	Central Michigan University, USA
Stephane Goriely	Université Libre de Bruxelles, Belgium
Ann-Cecilie Larsen	University of Oslo, Norway
Olivier Sorlin	GANIL/CEA/DSMCNRS/ IN2P3, France
Number of participants	38

Main topics

The general theme of the workshop concerned the astrophysical rapid-neutron capture process (r-process), which is responsible for producing around half of all stable nuclides heavier than iron. One site for the r process was recently confirmed: the advanced LIGO and Virgo detectors observed two neutron stars merging and immediate follow-up observations were compatible with a kilonova, a thermal "afterglow" powered by radioactive decay of newly synthesized r-process material. Moreover, the observations indicated that neutron-star mergers produce a blue lanthanide-free signal followed by a red lanthanide-rich component, contrary to expectations. Although neutron-star mergers are now known to be r-process element factories, this might not be the only r-process site, and a comprehensive understanding and description of the r-process is still lacking. The workshop brought together theorists and experimentalists to address the many aspects of nuclear physics and astrophysics that must be considered and properly understood in order to model the r-process in the era of multimessenger observations from compact binary mergers.

The main topics were:

- Astrophysical site(s) of the rapid neutron capture process (r-process)
- Observational data related to the r-process
- Galactic chemical evolution and the r-process
- Sensitivity studies for the r-process
- Theoretical nuclear physics inputs for the r-process
- Nuclear physics experiments for the r-process

Speakers

Gabriele Cescutti	Osservatorio Astronomico di Trieste, INAF, Italy
Benoit Côté	Konkoly Observatory, Hungary
Nils Paar	Faculty of Science, University of Zagreb, Croatia
Oliver Just	RIKEN, Japan
Carla Fröhlich	North Carolina State University, USA
Gail McLaughlin	North Carolina State University, USA

Tobias Fischer	Institute of Theoretical Physics, University of Wroclaw, Poland
Jean-François Lemaître	Université Libre de Bruxelles, Belgium
Jutta Escher	Lawrence Livermore National Laboratory, USA
Stylianos Nikas	TU Darmstadt and GSI, Germany
Marco La Cognata	INFN-LNS, Italy
Artemis Spyrou	Michigan State University, USA
Matthew Mumpower	Los Alamos National Laboratory, USA
Boris Pritychenko	Brookhaven National Laboratory, USA
Frederic Nowacki	IPHC Strasbourg, France
Jérôme Margueron	Institut de Physique Nucléaire de Lyon, France
Iris Dillmann	TRIUMF, Canada
Shunji Nishimura	RIKEN, Japan
Dennis Muecher	University of Guelph, Canada
Leo Neufcourt	Michigan State University/FRIB, USA
Laetitia Canete	University of Jyväskylä, Finland
Friedrich-K. Thielemann	University of Basel and GSI, Switzerland and Germany
Andreas Bauswein	GSI, Germany
Anton Wallner	The Australian National University, Australia
Marius Eichler	TU Darmstadt, Germany
Marco Pignatari	University of Hull, United Kingdom
Sergio Cristallo	INAF - Osservatorio Astronomico d'Abruzzo, Italy
Rebecca Surman	University of Notre Dame, USA
Amber Lauer	TUNL Duke University, USA
Horst Lenske	University of Giessen, Germany
Ante Ravlic	University of Zagreb, Croatia
Mustafa Rajabali	Tennessee Technological University, USA
Alfredo Estrade	Central Michigan University, USA

Scientific report

The workshop aimed at covering different aspects of the astrophysical rapid neutron-capture process (r process), by bringing together experimentalists and theorists both from the nuclear physics and astrophysics communities to discuss the remaining open questions and the current status. The multimessenger observations from the binary neutron star (NS) merger GW170817 triggered many new questions, such as whether NS mergers are the only site for the r process and the role of neutrinos both in NS mergers and core-collapse supernovae. Meanwhile, nuclear theory as well as nuclear physics experiments at present and forthcoming radioactive ion beam facilities have provided/will provide essential data that should be taken into account in r-process calculations and in the interpretation of observations. The workshop aimed to serve as a platform for knowledge exchange between these exciting fields, and to explore required nuclear physics data (theory and experiments).

The main topics of the workshop were well covered by the scientific programme. For example:

- *Astrophysical site(s) of the r process* were discussed in many presentations. F.-K. Thielemann gave a review talk on possible r-process sites. This was followed by Andreas Bauswein's talk on the mass ejection from neutron-star mergers. Carla Fröhlich presented results related to massive stars and how their evolution into neutron stars or black holes depends on various factors. Tobias Fischer discussed massive star explosions and the role of hadron-quark phase transitions and neutrinos. Marius Eichler talked about nucleosynthetic signatures of astrophysical r-process sites. Oliver Just's presentation pointed out the important role neutrinos play in the simulations of neutron-star mergers and core-collapse supernovae.

- *Observational data related to the r process* were discussed in many presentations. The r-process abundances are determined from the observed solar system abundances from which the abundances stemming from the rather well-known slow neutron capture process (the s process) and tiny p-process contributions have been subtracted. Marco Pignatari and Sergio Cristallo discussed these residual abundances, and whether we fully understand what is not an s-process. Potential other scenarios, such as rotating massive stars and the intermediate neutron capture process (the i-process), were discussed. Anton Wallner discussed observational data based on atomic mass spectrometry of different kinds of samples from deep-sea sediments or crusts, and how they point toward a rare astrophysical event as the source of ^{244}Pu which is an r-process element. The observations of blue and red kilonova from the neutron star merger GW170817 were discussed in several talks.
- *Galactic chemical evolution* and the r process were covered by the talks of Gabriele Cescutti, Benoit Côté and F.-K. Thielemann. The main challenges, such as how to explain the wide-spread in the observed europium abundances at low metallicities and the existence of actinide-boost stars, were discussed. The difficulties related to simulating the chemical evolution from neutron star mergers due to their delay time was also nicely demonstrated by Côté.
- *Sensitivity studies* for the r process probe which nuclear properties have the highest impact on the calculated r-process abundances for different astrophysical scenarios. Rebecca Surman, Matthew Mumpower and Gail McLaughlin covered this topic in their presentations with respect to sensitivity studies on nuclear masses, neutron-capture rates, beta-decay half-lives and fission properties. Stylianos Nikos discussed on the impact of masses and beta-decay half-lives on the process.
- *Theoretical nuclear physics inputs for the r process* were discussed in many talks. Nils Paar presented recent energy-density functional calculations. Léo Neufcourt talked about Bayesian extrapolation of nuclear observables based on neural networks. Frédéric Nowacki presented the current state-of-the-art shell-model results on neutron-rich nuclei. Jean-Francois Lemaître talked about the microscopic description of fission which is an essential property for the r process. Jutta Escher highlighted how to theoretically treat neutron captures. Jêrome Margueron discussed the dense nuclear matter and what kind of new constraints can be obtained from forthcoming gravitational wave observations.

- *Nuclear physics experiments for the r process* were broadly discussed. Nuclear mass measurements were covered by the talks of Laetitia Canete, Alfredo Estrade as well as Stylianos Nikas. Beta-decay half-lives and beta-delayed neutron studies were presented by Iris Dillmann and Shunji Nishimura. Neutron-capture rate studies via the Oslo method and via (d,p)-reactions in inverse kinematics were discussed by Artemis Spyrou and Dennis Mücher.

In addition to these main themes there were a number of other subjects covered in the Workshop, represented by one or a few speakers each, including:

- Stellar models for the r-process modelling (A. Lauer), planned experiments for the r-process (M. Rajabali), plans to measure opacities needed for interpreting the kilonova light curves from neutron-star mergers (M. La Cognata), and nuclear data libraries (B. Pritchyenko) and how the pygmy modes can affect the astrophysical reaction rates (H. Lenske).

Results and Highlights

The Workshop was a very useful opportunity to discuss different aspects related to the r process. In addition to the talks, we had a short discussion session after each talk and every day ended with a longer, more open discussion session where the word was free, but the discussion was led by a chair. The participants were very active with questions during the talks as well as in the discussion sessions, and they gave very positive feedback on the workshop.

The participants considered binary neutron-star mergers as the dominant astrophysical site for the r process but acknowledged that other sites can contribute to the observed r-process abundances, and in many cases, would provide a better explanation for the observations. Related to the observational data, the observed kilonova in neutron-star merger event GW170817, was discussed a lot. A kilonova or macronova is the thermal afterglow produced by the decay of the r-process nuclei. The observed two components from GW170817, the blue and red kilonova, imply two things: 1) neutrinos (or the weak interaction) must play a role in the process to produce the component with higher electron fraction and 2) the red kilonova does not prove that gold or other heavier elements than lanthanides were made in GW170817. More observational data would be needed. Here, the forthcoming kilonova light curves will be interesting. Some sensitivity studies indicate the central role of the spontaneous fission of ^{254}Cf in the light curves. Other studies, however, do not find such a strong correlation but rather propose that alpha-decay chains of heavier isotopes could contribute. Fission plays an essential in the r process, and hence it was discussed a lot. Ideas for measurements of fission yields were discussed. The observational data from massive binary mergers or pulsars will also help to constrain the equation of state for dense nuclear matter. The present nuclear theory models predict rather strict ranges of possible neutron star radii and masses, and future observations will provide essential constraints to test these models.

The role of isomers in the r process was discussed in one of the open discussion sessions. There are hundreds of long-living isomeric states in neutron-rich nuclei, and in particular also close to the magic shell closures at N=50, 82 and 126. At the moment these are not taken into account in any of the r-process calculations although they may contribute to the process. For example, the fission cycling can predominantly populate the more prolate-deformed long-living state, which in turn, can have different beta-decay half-lives, beta-delayed neutron capture probabilities and neutron-capture rates. Low-lying isomeric states can also be thermally populated in the r process. Perhaps a showcase example e.g. from the second abundance peak region close to ^{132}Sn could be studied to demonstrate the effect of isomeric states.

The open discussion sessions were one of the highlights of the workshop. For example, we discussed how to treat neutron capture rates close to the driplines or near closed neutron shells. The Hauser-Feshbach treatment requires a sufficient level density to be a valid approach. This is not necessarily fulfilled at shell closures. When approaching the neutron dripline, the direct captures will become more important. There are also challenges how to treat the data from (d,p)-reactions forming a compound nucleus, depending on the region of interest. These discussions are invaluable for future experiments trying to constrain the neutron-capture rates via different kinds of measurements.

The rare-earth abundance peak of the r-process has been used to reverse-engineer nuclear properties (masses) assuming the observed abundance pattern was produced by a particular type of an astrophysical scenario. For the first r-process abundance peak region at around A=80, the situation is different. The recent theoretical and experimental efforts around the doubly magic ^{78}Ni have provided a good understanding of nuclear properties in this region. The challenges in translating these nuclear data into the interpretation of the astrophysical origins of the first abundance peak are much more complicated than for the rare-earth region. There are many potential astrophysical scenarios that could contribute; however, it will be interesting to know how the nuclear data can possibly constrain the astrophysical sites for the lighter r-process elements.

2.3.13 *Progress and Challenges in Neutrinoless Double Beta Decay*

Date	July 15-19, 2019
Organizers	
Javier Menendez	Center for Nuclear Study - University of Tokyo, Japan
Amy Nicholson	University of North Carolina, USA
Saori Pastore	Washington University, USA
Andre Walker-Loud	Lawrence Berkeley National Laboratory, USA
Emanuele Mereghetti	Los Alamos National Laboratory, USA
Number of participants	29

Main topics

The workshop assembled experts from the lattice QCD (LQCD), chiral EFT, few body and many-body communities to address several open questions in the theory of neutrinoless double beta decay (NLDBD).

NLDBD is a rare weak process in which two neutrons are converted into two protons, with the emissions of two electrons and no neutrinos, thus violating lepton number (L) by two units. Since L is conserved in the Standard Model (SM), an observation of NLDBD would be a clear signal of physics beyond the SM (BSM). It would imply that neutrinos are Majorana particles and shed light on the mechanism of neutrino mass generation. By itself the observation of NLDBD would not immediately point to the underlying physical origin of lepton number violation (LNV). While NLDBD searches are commonly interpreted in terms of the exchange of a light Majorana neutrino, in generic BSM models, NLDBD receives contributions from several competing mechanisms. The interpretation of NLDBD experiments in terms of neutrino parameters or LNV parameters in BSM theories relies on a seamless connection between the theory at quark and nuclear level, and reliable calculations of the nuclear matrix elements, with robust estimates of the uncertainties.

The workshop brought together experts that are working at the intersection of different regimes of the strong interactions, with the goal of carefully assessing all the sources of uncertainties in double beta calculations. In particular, the main topics were

- determination of the NLDBD transition operators for the standard mechanism of exchange of light Majorana neutrinos,
- determination of the NLDBD transition operators for short-range LNV mechanisms, especially using input from LQCD and chiral EFT,
- set up a strategy to include two-body currents in the calculation of nuclear matrix elements. In a second-order operator two-body currents in general give raise to four-body operators, which are difficult to handle in most many-body approaches,

- test nuclear matrix element calculations in very light nuclei, comparing quantum Monte Carlo results with other many-body approaches, such as the nuclear shell model, which can be applied in heavier nuclei directly relevant for experiments,
- approximate test of the role of two-body currents for the nuclear quantum Monte Carlo calculations in very light-nuclei,
- determine which observables, or set of observables, can be used to validate nuclear matrix-element calculations: e.g. single-beta decay, two-neutrino double-beta decay, double charge-exchange reactions, or muon-capture inelastic neutrino scattering (that operate in a similar momentum-transfer regime as NLDBD),
- connection with collider and phenomenology.

Participants

Raul Briceno	Old Dominion University, USA
Manuela Cavallaro	INFN Catania, Italy
Luigi Coraggio	INFN Napoli, Italy
Zoreh Davoudi	University of Maryland, USA
Jordy de Vries	University of Massachusetts Amherst, USA
Wouter Dekens	University of California, San Diego, USA
Frank Deppisch	University College, London, United Kingdom
Michelle Dolinski	Drexel University, USA
Jonathan Engel	University of North Carolina, USA
Evgeny Epelbaum	Rurh University Bochum, Germany
Dong Liang Fang	Chinese Academy of Science, China
Luca Girlanda	University of Salento, Italy
Lukas Graf	Max Planck Institute for Nuclear Physics, Germany
Mihai Horoi	Central Michigan University, USA
Kenneth McElvain	University of California, Berkeley, USA
Javier Menendez	University of Tokyo, Japan
Emanuele Mereghetti	Los Alamos National Laboratory, USA
Henry Monge-Camacho	University of North Carolina, USA
David Murphy	Massachusetts Institute of Technology, USA
Samuel Novario	University of Tennessee, USA
Takaharu Otsuka	University of Tokyo/RIKEN, Japan
Saori Pastore	Washington University in St. Louis, USA
Ann Kathrin Perrevoort	Nikhef, Netherlands
Maria Piarulli	Washington University in St. Louis, USA
Matthias Schindler	University of South Carolina, USA
Ubirajara van Kolck	Institut de Physique Nucleaire d'Orsay, France
Petr Vogel	California Institute of Technology, USA
Andre Walker-Lou	Lawrence Berkeley National Laboratory, USA
Xiaobao Wang	Huzhou University, China

Scientific report

Neutrinoless double-beta decay is the most sensitive laboratory probe of lepton number violation (LNV), and its detection is being pursued by ambitious experimental programs in the United States, Europe, Japan and China. The observation of this decay will have far reaching consequences: demonstrate that neutrinos are Majorana fermions, shed light on the neutrino absolute masses and mass-generation mechanism, and give insight into leptogenesis scenarios key to understand the matter-antimatter asymmetry in the universe. The interpretation of a positive or null measurement, however, requires several steps.

It is first of all necessary to have a general framework to discuss sources of LNV. In the most popular scenario, LNV is mediated by the Majorana mass of three left-handed neutrinos, via a non-renormalizable dimension-five effective operator. In the light Majorana neutrino exchange mechanism, NLDBD is directly related to neutrino oscillation experiments, and the next generation of experiments will probe the entire parameter space of the inverted hierarchy. This scenario, though minimal, is however not the most general and in several models NLDBD receives important contributions from new heavy particles and new interactions. One goal of the workshop was to classify various LNV scenarios, in a general and model-independent way, and to explore the possibility to disentangle them in NLDBD experiments and at colliders.

In the second step, the LNV operators expressed in terms of microscopic degrees of freedom need to be matched onto hadronic operators. The infinite tower of hadronic operators can be organized using the tools of nuclear effective field theories, such as chiral EFT. The matching however is essentially nonperturbative. In recent years the problem has attracted the interest of several lattice QCD (LQCD) groups. A second goal of the workshop was to review the progress in the determination of the coupling constants of LNV operators involving pions, induced by both long-distance light-neutrino exchange and short-distance mechanisms. We then aimed to discuss the formalism required to perform more complicated LQCD calculations, as, for example, two-nucleon LNV scattering amplitudes mediated by light and heavy neutrinos.

The third step is the derivation of the NLDBD transition operator, for various LNV mechanisms. An open issue in the field is the determination of the correct form of the short-distance component of the NLDBD transition operators, in light of problems with the ultraviolet behavior of LNV scattering amplitudes computed in chiral EFT. Another interesting issue is the relevance of formally sub-leading contributions to the neutrino potential, as for example those induced by two-body weak currents.

Finally, the last important aspect of the problem is the calculation of the nuclear matrix elements of the transition operators in the nuclei of experimental interest. These matrix elements are computed with a variety of methodologies, such as the shell model, the quasiparticle random phase approximation, or the non-interacting boson model. Recently, there has also been an effort in the community to develop *ab initio* approaches, using methods such as coupled clusters and the similarity renormalization group. Another goal of the workshop was to compare the strengths and weaknesses of these methods, and discuss the progress by various groups. Further, we explored the possibility that *ab initio* calculations of NLDBD matrix elements in light nuclei could provide a useful benchmark for many-body methods. Finally, we wanted to identify the constraints on NLDBD matrix elements from processes that operate in a similar momentum-transfer regime as NLDBD, such as double-charge-exchange reactions.

From this schematic discussion, one can appreciate that neutrinoless double beta decay is a process sensitive to a variety of scales. The main objective of the workshop was to combine the expertise of scientists working in different regimes of the strong interaction, and favour the communications between different communities, with the goal of taming the large uncertainties that affect NLDBD calculations.

Results and Highlights

The workshop had 25 talks and 4 one-hour discussion sessions, in addition to abundant time devoted to informal discussions. There were two comprehensive introductory reviews. Michelle Dolinski reviewed the status of NLDBD searches, while Petr Vogel gave an overview of the nuclear theory challenges in NLDBD calculations.

The implications of NLDBD on new physics were discussed in four talks. L. Graf and W. Dekens illustrated two competing frameworks for the model-independent classification of non-standard scenarios of lepton-number-violation, and discussed how to reconcile discrepancies between the two approaches. F. Deppisch discussed in depth the implications of NLDBD experiments on the understanding of the matter-antimatter asymmetry in the Universe. K. Perrevoort presented results on LNV searches at the Large Hadron Collider and their complementarity with NLDBD.

The second topic of the workshop, namely LQCD calculations of LNV processes in few-hadrons systems, was covered in the talks by Z. Davoudi, D. Murphy and H. Monge-Camacho. R. Briceno and M. Schindler further discussed the formalism to match finite and infinite volume calculations of processes with few hadrons and the insertions of one or two weak currents. The development of this formalism is crucial to the calculation of LNV nucleon-nucleon scattering amplitudes induced by light Majorana neutrinos, which are important to determine the short-range structure of the NLDBD operator.

Chiral EFT for weak and LNV processes was discussed by J. de Vries, E. Epelbaum, B. van Kolck and M. Piarulli, with particular attention to the development of a consistent power counting and the intricacies of renormalization in chiral EFT. L. Girlanda gave a stimulating talk on three-nucleon forces and their power counting. The generalization to three-nucleon LNV operators, as those induced by two-body weak currents, was one of the subjects discussed in the discussion sessions. Ken McElvain addressed NLDBD in a different effective theory, HOBET.

J. Engel, X.-B. Wang, D.-L. Fang, T. Otsuka, M. Horoi, L. Coraggio and S. Novario discussed advances in many body methods. T. Otsuka and M. Horoi focused on the shell model, while D.-L. Fang covered the quasiparticle random phase approximation. J. Engel, S. Novario and L. Coraggio discussed how to tackle double beta with *ab initio* methods, while Wang showed a comparison between shell model and Variational Monte Carlo calculations in light nuclei. Finally, M. Cavallaro gave a very interesting talk on double-charge exchange reactions, and their potential for validation of NLDBD matrix elements. Overall, the workshop had a stimulating atmosphere, with a lot of exchanges between different communities.

2.3.14 *Simulating Gravitation and Cosmology in Condensed Matter and Optical Systems*

Date	July 22-25, 2019

Organizers

Iacopo Carusotto	INO-CNR BEC Center, Trento, Italy
Massimiliano Rinaldi	Università di Trento, Italy
Roberto Balbinot	Università di Bologna, Italy
Riccardo Sturani	International Institute of Physics, Federal University of Rio Grande do Norte, Natal, Brasil

Number of participants	around 60 (plus around 10 visitors from local institutions)

Main topics

The central questions that have been explored during the workshop concern the possibility of exploiting condensed matter analog systems as experimental tools to understand the physics of astrophysical objects such as black holes and semiclassical phenomena like particle creation at the end of cosmological inflation. The basic idea of such an analog gravity program is to have experimentally accessible systems whose behavior follows equations of motion that are similar to the ones of gravitational systems. On-going experiments along these lines – e.g. the recent experimental report of analog Hawking processes – hold a strong promise in view of shedding light on a variety of intriguing effects that have been anticipated in a gravitational context but are inaccessible to experiment.

In specific, the main topics of the workshop were

- Analog black holes in atomic, optical, hydrodynamic systems and analog Hawking radiation
- Analog models of cosmological processes
- New experimental perspectives with analog models
- (Quantum) simulation of gravitational, cosmological and astrophysical problems.

Speakers

UL-G-Th - Renaud Parentani	LPT Orsay, France
UL-CM-Exp - Jeff Steinhauer	Technion, Haifa, Israel
UL-G-Th - Bei-Lok Hu	Univ. Maryland, USA
S-CM-Th - Salvatore Butera	Univ. Trento, Italy
S-CM-Th - Stefano Giovanazzi	Univ. Heidelberg, Germany
L-CM-Exp - Ulf Leonhardt	Weizmann Inst., Israel
L-CM-Th - Daniele Faccio	Univ. Glasgow, UK
S-CM-Th - David Bermudez	CINVESTAV, Mexico
S-CM-Th - Scott Robertson	Laboratoire de l’Accélérateur Linéaire, Orsay, France
S-CM-Th - Maxime Jacquet	Univ. Vienna, Austria

L-CM-Th - Victor Galitski	Univ. Maryland, USA
UL-G-Th - Paolo Pani	Univ. Roma “Sapienza”, Italy
UL-G-Exp - Yosuke Mizuno	Frankfurt Univ., Germany
UL-CM-Th - Eugene Demler	Harvard Univ., USA
S-CM-Exp - Jacqueline Bloch	C2N, Palaiseau, France
S-CM-Th - Dimitri Solnyshkov	Clermont-Ferrand, France
S-CM-Exp - Maxime Richard	Lab. Néel, Grenoble, France
S-CM-Exp - Quentin Glorieux	LKB, Paris, France
L-CM-Exp - Silke Weinfurtner	Univ. Nottingham, UK
L-CM-Th - Uwe Fischer	Seoul National Univ., Korea
L-CM-Th - Thomas Gasenzer	Univ. Heidelberg, Germany
S-CM-Th - Alexander Chatrchyan	Univ. Heidelberg, Germany
S-CM-Th - Mathieu Isoard	LPTMS Orsay, France
UL-G-Th - Silke Klemm	Univ. Milano, Italy
UL-G-Th - Ted Jacobson	Univ. Maryland, USA
UL-G-Th - Sabino Matarrese	Univ. Padova, Italy
L-G-Th - Valerio Faraoni	Bishop’s Univ., Canada
L-CM-Th - Richard Dudley	Wake Forest Univ., USA
L-CM-Th - Manuele Tettamanti	Univ. Milano-Bicocca, Italy
S-CM-Th - Luca Giacomelli	Univ. Trento, Italy
S-CM-Th - Dries Sels	Harvard U., USA
S-CM-Th - Sebastian Erne	Univ. Nottingham, UK
L-G-Th - Kostas Kokkotas	Univ. Tuebingen, Germany
L-G-Th - Ruth Gregory	Durham Univ., UK
L-G-Th - Ian Moss	Newcastle Univ., UK
S-(G+CM)-Th - Florent Michel	Durham Univ., UK
L-G-Th - Salvatore Capozziello	Univ. Napoli “Federico II”, Italy
S-CM-Th - Tommaso Morresi	ECT*, Trento, Italy
S-G-Th - Alfredo Iorio	Charles Univ., Prague, Czech Republic
S-CM-Th - Salvatore Manmana	Univ. Goettingen, Germany
S-CM-Th - Gabriel Menezes	Federal Rural University of Rio de Janeiro, Brasil
S-CM-Th - Maria Luisa Chiofalo	Univ. Pisa, Italy
S-G-Th - Giovanni Tricella	SISSA, Trieste, Italy
S-G-Th - Fabio Scardigli	Politecnico Milano, Italy

Scientific report

The goal of the workshop was to gather at an interdisciplinary meeting a number of specialists from theoretical and experimental condensed matter physics and quantum optics and from theoretical cosmology, gravitation and astrophysics. The central questions to be explored concerned the possibility of exploiting condensed matter analog models as experimental tools to understand the physics of astrophysical objects such as black holes and semiclassical phenomena like particle creation at the end of cosmological inflation.

After a few decades of purely theoretical results, experiments have in fact recently managed to realize analog black holes in the lab and, in this way, obtain evidence of the related analog Hawking radiation in a few different material systems, in particular sound waves in quantum fluids of ultracold atoms flowing in suitably designed traps (Steinhauer, Nat. Phys. 2016) and surface waves on top of water flowing in suitably designed tanks (Torres, Nat. Phys. 2017; Euvé et al., arxiv 2018). The basic idea of such analog gravity programs is to have experimentally accessible systems whose behavior follows equations of motion that are similar to the ones of gravitational systems. As such, these pioneering experiments hold a strong promise in view of shedding light on a variety of intriguing effects that have been anticipated in a gravitational context but are inaccessible to experiment.

The workshop was organized around a few ultra-long (UL) talks where world-class specialists of the different fields gave very general and introductory presentations of their field that set the stage for the more specialized presentations. These latter consisted in long (L) talks by senior researchers that combined an introduction to a specific research line with their latest results, and short (S) talks by young researchers at the PhD or PostDoc level. This format allowed each community to get familiar with the main concepts of the other, and stimulated scientific discussions and, hopefully, new collaborations.

In addition to the usual spontaneous and informal discussions facilitated by the pleasant atmosphere of the ECT* garden, we organized two round tables (on the second and the last day) where i) experimentalists and theorists confronted their views in the field and ii) the most promising future developments of the field were sketched. Finally, on the evening of the second day, a “Beer & Physics” event was organized in town in collaboration with AISF (Associazione Italiana Studenti di Fisica). In this event, a few selected speakers of the workshop introduced the concept of analog model to the big public. The participation was unexpectedly large, with almost 100 participants of all ages and backgrounds.

As already mentioned, the main objective of the event was to establish and reinforce a operational two-directional connection between the two worlds: during the workshop, condensed matter physicists have illustrated to the gravitational community the power of their analog models, and these latter have suggested to the former some important open questions for which experimental experiments with analog models may provide useful insight. As a proof of the level of interdisciplinarity of the event, we have indicated for each speaker whether he/she spoke from a Gravitational or Condensed-Matter perspective and whether he/she was primarily a theorist or an experimentalist. The great scientific diversity of the participants is apparent.

As compared to similar events that were organized on related topics in the last years, we made a special effort not to restrict the speakers’ list to the well-established leaders of the field of analog models, but also to actively involve top-level researchers that have manifested some interest in the topic but have not yet given crucial contributions to it. Since the first and long awaited milestone of the field has been finally reached, namely the experimental realization of analog Hawking radiation from analog black holes, we felt it was time to enlarge the international community of analog models and revive it with novel ideas and methods and, even more importantly, new challenges.

The success of our initiative is apparent in the variety of topics that were covered and the new challenges that are nowadays in front of the community. A brief discussion of the main ones is summarized in the next section.

Results and Highlights

A few years after the first experimental observations of Hawking processes from analog black holes in ultracold atomic gases and in surface waves on flowing classical fluids that have completed the pioneering phase, the field of analog models is nowadays in the course of making the step towards full maturity, with an explosion of new directions in which it is developing. The workshop was focused on the many directions that the international community has identified as most promising and challenging.

The latest results from on-going experiments have been presented by the main actors worldwide, e.g. the measurement of the thermal nature of the analog Hawking emission and the simulation of the expansion of Universe in expanding quantum fluids. Future steps in the simulation of cosmological processes such as particle creation and preheating in the early universe were also discussed and the key conceptual difficulties pointed out and characterized.

The physics of superradiance in rotating geometries has been widely covered from different points of view, from its observational implications in astrophysics and cosmology, to its experimental realization in rotating classical fluids. The link between ergoregion and black-hole instabilities of space-times have been related to the fundamental problem of the stability of quantized vortices in quantum fluids.

Going beyond the mere kinematic aspects of quantum field theories on curved space-times, strong attention is now beginning to be paid to the so-called back-reaction effects. The archetypes of such effects are black hole evaporation under the effect of Hawking radiation and the mechanical friction experienced by moving mirrors under the effect of dynamical Casimir emission. In the workshop, attempts to theoretically model subtle features of these processes were intermixed with phenomenological studies of specifc effects in gravitation and in condensed matter analogs.

Another exciting extension of the analog model paradigm involves the coupling of emitters (e.g. two-level atoms) to the quantum field in curved space-time and the study of the new electrodynamics processes that stem from the extreme relativistic motion that can be simulated.

The application of condensed matter systems – e.g. cold atomic clouds – to the quantum simulation of first-order phase transitions was discussed in connection to the physics of the Higgs field and its vacuum state in a cosmological context. Special attention was paid to the microscopic process underlying the nucleation and the eventual growth of droplets of an energetically-favoured phase from a metastable initial state.

New experimental platforms that may be useful in future studies of this physics in new geometries and new regimes have been presented, so to identify which one could better serve to address a given problem. These platforms include dipolar atomic gases, polariton fluids in microcavities, fluid of light propagating along nonlinear crystals, pulses launched along nonlinear optical fibers. In this context, a special attention was devoted to analog models based on graphene with its peculiar relativistic dispersion of electrons.

We expect that all these developments may result in the next years in exciting experiments where condensed matter and optical systems are used as analog models to better understand a variety of key problems of gravitational physics, well beyond Unruh's original proposal of Hawking radiation. In parallel to this by now traditional perspective, a novel point of view was also explored in which the analogy is applied in the opposite direction, so that concepts of gravitational physics serve as tools to shed new light on purely condensed matter problems such as the stability of quantized vortices, the motion of impurities in quantum fluids, and novel quantum-fluctuation-driven phase transitions to self-bound droplet states.

2.3.15 *RMT in Sub Atomic Physics and Beyond*

Date	August 5-9, 2019
Organizers	
Mario Kieburg	The University of Melbourne, Australia
Kim Splittorff	Niels Bohr Institute, Denmark
Tilo Wettig	University of Regensburg, Germany
Number of participants	28

Main topics

The highlighting of the enormous impact of Jacobus Verbaarschot's research was one of the central themes of this workshop. Here, the emphasis was not only on its past scientific success but mainly on its influence on recent hot research topics such as the SYK model, the still-unsolved sign problem originating from various sources, as well as new quantum chaotic measurements and theoretical predictions. To achieve this purpose, we had invited a broad community of researchers ranging from experimentalists to theoretical and mathematical physicists. The participants spanned several generations, allowing young and senior researchers to discuss. Our hope was that the exchange of ideas, foreign in some areas while elaborate in others, would provide an ideal atmosphere to initiate new collaborations and projects that lead to novel progress in diverse problems such as the understanding of the deviations of the number variance of spectra at long distances, particularly whether they are universal or not, or the origin of the breakdown of complex Langevin simulations and how to amend it.

The main topics were

- Many-Body Systems, especially the SYK model
- QCD and Lattice QCD as systems with a Sign Problem
- Quantum Chaotic Measurements and Exact Results
- Eigenvector and Eigenvalue Statistics of Random Matrix Models

Speakers

Gernot Akemann	Bielefeld, Germany
Alexander Altland	University of Cologne, Germany
Jacques Bloch	University of Regensburg, Germany
Poul Damgaard	Niels Bohr Institute, Denmark
Barbara Dietz	Lanzhou University, China
Hidenori Fukaya	Osaka University, Japan
Antonio Garcia-Garcia	Shanghai Jiao Tong University, China
Urs Heller	American Physical Society, USA
Yiyang Jia	Stony Brook University, USA
Eugene Kanzieper	Holon Institute of Technology, Israel
Frithjof Karsch	Bielefeld University, Germany
Mario Kieburg	The University of Melbourne, Australia
Maria Paola Lombardo	INFN, Florence, Italy

Adam Mielke	Bielefeld University, Germany
Shinsuke Nishigaki	Shimane University, Japan
Jun Nishimura	KEK, Japan
Maciej Nowak	Jagiellonian University, Poland
Achim Richter	TU Darmstadt, Germany
Thomas Seligman	Universidad Nacional Autonoma de Mexico, Mexico
Misha Stephanov	University of Illinois at Chicago, USA
Jacobus Verbaarschot	Stony Brook University, USA
Jochen Wambach	ECT*, Italy
Hans Weidenmüller	Max-Planck-Institute of Nuclear Physics at Heidelberg, Germany
Savvas Zafeiropoulos	Heidelberg University, Germany
Ismael Zahed	Stony Brook University, USA
Martin Zirnbauer	University of Cologne, Germany

Scientific report

Jacobus Verbaarschot's scientific career has been outstanding. Starting his work in nuclear physics in the 80's, he soon went to QCD, the theory describing strong interactions, for a long time and contributed seminal articles that explained the observed spectral properties of the Dirac operator and helped to understand proposed effective field theories that suffer from a sign problem. Yet, his influence even went beyond these research fields. His outstanding work in the Heidelberg group in the 80's has heavily exploited in scattering of quantum chaotic systems, his work on chiral operators was also helpful in understanding condensed matter systems with Dirac points, and quite recently he has joined the endeavour of understanding the SYK model, a rather simple many body system of strongly coupled Majorana fermions, where he crucially contributed in understanding the spectral properties of the corresponding Hamiltonian.

All his research projects have had two things in common, effective field theories, such as chiral perturbation theory and general non-linear sigma models, and random matrix theory. While the latter is a mathematical modelling tool idealizing the structure of an operator to study generic spectral statistics, the former connects these rather artificial systems to physical ones. The existence of non-linear sigma models is also the reason why random matrix spectral statistics are so universal and can be found in physical systems ranging over several scales of energy and size. Exactly this point has been the reason why Verbaarschot's work has found such a big resonance and many scientists joined his approach, either from the experimental and numerical point of view or from a more theoretical and mathematical way.

One of the big problems that has also been addressed at the present workshop has been the sign problem. Though still unsolved apart from rather mild sign problems, Verbaarschot's work together with his many collaborators has been essential to comprehend in which regimes the sign problem is severe and what are its general mechanisms, especially why for example reweighting fails to work. Furthermore, random matrix theory helped to derive the spectral statistics of the Dirac operator in the infrared limit, which has been intrinsically obstructed by a non-positive statistical weight. About one third of the attendees have reported on the current progress in lattice simulations of this problem as well as related ones, and usually random matrix models served as their toy model to test how well their approaches worked out.

Another new development had been achieved in the SYK model due to Kitaev's recent simplification of the model by Sachdev and Ye to strongly coupled Majorana modes. This model serves as a blueprint for general many-body systems since the dimension of the Hilbert space and thus the number of eigenvalues of the Hamilton operator grows exponentially with the number of particles involved while the spectral support only increases linearly. About one quarter of the speakers has talked about the statistical properties of the eigenvalues and eigenfunctions of the corresponding Hamiltonian. The latter has also been a recent hot topic in random matrix theory itself for Hermitian and non-Hermitian operators. Thus, it perfectly complemented the SYK talks to also invite experts like the Bielefeld group around Akemann and the Krakow group around Nowak. Furthermore, a talk on the particle-hole symmetry shed light from a more mathematical angle to many-body systems. It underlined the subtleties in the change of the unitary and anti-unitary symmetries when going over from first to second quantization.

In addition to these themes there was a number of other subjects covered in the Workshop, represented by one or a few speakers each:

1. Perturbative general relativity theory has been presented to illustrate how familiar and even intimately related it is to perturbation theory of strongly interacting gauge theories though it is still dealt with in its classical framework.
2. New experimental data of quantum billiards have been shown that can nowadays be realized with true quantum mechanical systems like graphene and neutrino billiards. Formerly these billiards have only been realised by the classical analogue of microwave billiards.
3. Moreover, an exact analytical approach has been proposed to show that chaotic quantum graphs indeed yield exactly the random matrix predictions, while another exact calculation has exhibited corrections to the power spectrum, which have not been conjectured originally. Both presentations have shown ways to overcome the highly involved mathematical obstacles.
4. Finally, one talk has been presented about the application of random matrices in time series analysis. The considered empirical correlation matrices have been measured in Ising models and financial markets.

Results and Highlights

The workshop has been a great success with respect to the exchange of ideas between different communities. This became evident during the talks where critical questions and even lively discussions have been initiated and continued during the breaks.

For instance, in one of the talks about the SYK model the question has arisen whether the distribution of the eigenvector components is totally different from the Porter Thomas distribution or whether only the scaling with the system size changes. Another debatable observation has been on the origin of the deviations of the number variance of the eigenvalues of the SYK Hamiltonian from random matrix results, which shows similar behaviour with other chaotic systems as well as with the QCD Dirac operator. It has been proposed that the deviations originate in collective fluctuations of the eigenvalues and might be universal. Both issues have not been resolved, yet. However, it seems that new projects on analysing these effects have started at the workshop.

More consensus has been found regarding the curing of the reweighting method for the sign problem that results from fermion determinant comprising non-zero chemical potential. Although it has been proved that it indeed works and completely solves the sign problem, random matrix simulations have shown that the numerical effort still grows exponentially with the matrix size and, thence, with the lattice size in QCD. Also new complex Langevin simulations have been presented. The simulations still suffer from the fact that quite often, in particular when the sign problem is severe, the process runs into the wrong minimum. However, a criterion has been presented when the flow approaches the correct result.

At last we would like to mention the new experimental data of quantum billiards based, e.g., on graphene. The new systems are no longer based on microwaves that are classical counterparts since they solve differential equations which are effectively the same as the Schrödinger equation. Those new systems are true quantum systems. Especially, it has been shown that the spectral properties change drastically when the boundary conditions are changed.

It has been a pleasure to organise the workshop at ECT*. The environment is extremely stimulating and the professional support from the ECT* staff is unparalleled. Even as a main organiser one can focus almost entirely on the physics problems during the workshop.

We are also grateful for the economic support from the ECT* as well as from SFB/TRR-55 without which the workshop would not have been possible.

2.3.16 *Light Clusters in Nuclei and Nuclear Matter: Nuclear Structure and Decay, Heavy Ion Collisions and Astrophysics*

Date	September 2-6, 2019
Organizers	
Gerd Roepke	Universität Rostock
Peter Schuck	Université Paris-Sud -IN2P3/CNRS -Orsay
David Blaschke	University of Wroclaw and JINR Dubna
Masaaki Kimura	Hokkaido University, Sapporo
Hisashi Horiuchi	RCNP -Osaka University
Number of participants	50

Main topics

Recent progress to treat clustering in nuclear systems has an impact to different branches of nuclear theory. Numerical methods as well as many-body theory (Green-function methods) have been worked out to describe few-body clusters in a nuclear environment where medium effect, in particular the antisymmetrization of the wave function (Pauli blocking), are of relevance. Nuclear structure (Hoyle – like states), nuclear reactions, and consequences for astrophysics (neutron stars, supernova explosions) are emerging applications.

The main topics were

1. Cluster models, structure of light nuclei, cluster quantum phase transition
2. Reaction theory, α-decay of heavy and superheavy nuclei
3. Clustering in nuclear matter and consequences for thermodynamic properties
4. Heavy-ion collisions and clustering in non-equilibrium systems, transport codes
5. Astrophysical consequences of clustering

Speakers

Yoshiko Kanada-En'yo	Kyoto University
Makoto Ito	Kansai University
Mengjiao Lyu	Osaka University
Dario Vretenar	University of Zagreb
Thomas Neff	GSI Darmstadt
Yasuro Funaki	Kanto Gakuin University
Jiaxing Han	Peking University
Yuki Fujikawa	Kyoto University
Masaaki Kimura	Hokkaido University
Doru-Sabin Delion	NIPNE Bucharest
Zhongzhou Ren	Tongji University, Shangai
Francesco Iachello	Yale University
Chang Xu	Nanjing University
Dong Bai	Nanjing University

Tzany Kokalova	U Birmingham
Takahiro Kawabata	Osaka University
Pedro Santa Rita	U Birmingham
Timur Shneydman	JINR Dubna
Yang Liu	Peking University
Peter Schuck	Université Paris-Sud - IN2P3/CNRS - Orsay
Joe Natowitz	TAMU
Hermann Wolter	LMU Munich
Jérome Gauthier	TAMU
Marina Barbui	TAMU
Helena Pais	U Coimbra
Pavel Zarubin	JINR Dubna
Irina Zarubina	JINR Dubna
Bo Zhou	Hokkaido University
Taiichi Yamada	Kanto Gakuin University
Kai Gallmeister	U Frankfurt
Marina Kozhevnikova	JINR Dubna
Gerd Röpke	Universität Rostock
Benjamin Doenigus	U Frankfurt
Stanislaw Mrowczynski	NCBJ Warsaw
Melanie Szala	Goethe University Frankfurt
Krzysztof Pysz	INP, Polish Academy of Sciences
Niels-Uwe Bastian	U Wroclaw
Mihail Mirea	IFIN-HH Bucharest
Raphael-David Lasseri	CEA Saclay
Masatoshi Itoh	Tohoku University
Alexandru Dumitrescu	NIPNE Bucharest
Virgil Baran	NIPNE Bucharest
David Blaschke	University of Wroclaw and JINR Dubna
Stefan Typel	TU Darmstadt
Tobias Fischer	U Wroclaw
Shalom Shlomo	TAMU

Scientific report

Nuclear systems are important examples for strongly interacting quantum liquids. The treatment of correlations beyond the mean-field theory has been discussed. The THSR approach has been further developed (Zhou, Funaki, Yamada) and applied to light nuclei (Kanada-Enyo, Lyu, Kimura, Fujikawa). New results have been obtained for such nuclei with additional nucleons (e.g. the ^{9}B and $^{(9\text{-}11)}$Be nuclei). Special attention was given to new experiments (Itoh, Kokalova, Santa Rito, Kawabata, Zarubin, Liu, Han, Barbui). Comparisons with other ab initio approaches (Neff, Iachello, Shneydman, Lasseri, Dumitrescu, Baran, Shlomo) have been discussed.

Starting from a Green-function approach, the in-medium Schrödinger equation for pairing and quartetting wave functions are derived and applied to clustering in heavy nuclei. Clustering is of relevance for radioactive decay, alpha preformation and the lifetime of heavy nuclei. Different approaches (Xu, Bai, Ren, Delion, Mirea) and new calculations have been presented.

Correlations and cluster formation are also an important issue in warm and dense nuclear matter. Theoretical approaches (Wolter, Typel) have been used to describe results of heavy-ion collisions (Natowitz, Gauthier) at moderate energies as well as the highest energies (Gallmeister, Doenigus, Szala, Pysz, Mrowczynski). The role of medium effects has been intensely discussed.

Clustering in nuclear matter is also essential in astrophysics, for instance in the simulation of supernova explosions. As pointed out in several contributions (Fischer, Bastian, Pais), the inclusion of clustering is a necessary prerequisite for describing the structure and time evolution, for instance the cooling by neutrino transport, of compact objects produced by supernova explosions or neutron-star mergers. It was of interest to know recent progress and to discuss the implementation and the experience of clustering in a dense medium.

Results and Highlights

The workshop was a very useful opportunity to present and discuss new developments in the investigation of clustering in nuclear systems, in particular to bring together the leading groups in Japan and China with European and US physicists. A long-standing and very successful collaboration exploring the THSR approach used the workshop to discuss future projects and collaboration. Of importance are the discussions with other groups and the comparison of different approaches. A main issue were the discussions with the experimentalists about the interpretation of new measurements and the identification of special nuclei which should be investigated in future experiments.

Alpha decay of heavy nuclei is a long-standing problem in nuclear physics, in particular, alpha preformation. The new approach based on the quartetting wave function will be worked out further. The local density (Thomas-Fermi) approach will be improved using shell-model wave functions. Recent results are promising but have to be worked out more in detail in common collaborations of the participants.

A main puzzle in heavy-ion collisions at the highest energies is the description of the yield of light clusters by a simple chemical equilibrium picture. With respect to the preparing of experiments at new facilities now under construction, predictions about light cluster formation are of interest to characterize the state of hot and dense nuclear matter. At lower energies, results have been presented for light nuclei $A > 4$ to be explained within the collaboration of participants of the workshop.

There is emerging interest in the treatment of light clusters in connection with simulations of supernova explosions and related events. Simple approaches neglecting medium effects will be improved, first estimations have already been done by the participants of the workshop and will be completed next time.

The workshop did not only help to stimulate the discussion between different groups working on related projects but initiated also common work and possible common publication when results have been obtained. In addition, it is proposed to prepare a Topical issue of EPJA related to the field of research related to the workshop. A call has been set up and the publication will become a sustainable result of the workshop. The website is available under:

https://epja.epj.org/epja-open-calls-for-papers

or

https://epja.epj.org/open-calls-for-papers/122-epj-a/1788-epja-topical-issue-light-clusters-in-nuclei-and-nuclear-matter-nuclear-structure-and-decay-heavy-ion-collisions-and-astrophysics.

2.3.17 *LFC19: Strong Dynamics for Physics Within and Beyond the Standard Model at LHC and Future Colliders*

Date	September 9-13, 2019
Organizers	
Gennaro Corcella	INFN, LNF, Italy
Stefania De Curtis	INFN, Florence, Italy
Stefano Moretti	University of Southampton, UK
Giulia Pancheri	INFN, LNF, Italy
Roberto Tenchini	INFN, Pisa, Italy
Marcel Vos	IFIC and University of Valencia, Spain
Number of participants	46

Main topics

The LFC19 workshop discussed the current projects for future colliders, taking particular care about the role played by strong interactions. In particular, plans towards the high-luminosity phase of the Large Hadron Collider (HL-LHC), as well as the possible construction of new facilities, such as linear (ILC and CLIC) and circular (FCC-*ee)* and FCC-*hh*) colliders, were reviewed. Once again, special attention was paid to strong- interaction phenomena described by Quantum Chromodynamics, in both perturbative and non-perturbative regimes. Furthermore, we debated the precision attainable in Standard Model studies, such as measurements of top-quark and Higgs properties (mass and couplings for example), as well as the fundamental constants, such as the strong coupling α_S or the weak mixing angle θ_W. As for electroweak symmetry breaking and physics beyond the Standard Model, we explored those new physics scenarios which are based on strong interactions, such as composite-Higgs models, wherein new fermions appear as mediators of a new strong force.

The workshop was organized according to an opening session introducing strong inter- actions at present and future colliders and topical working groups chaired by our conveners. The last session contained further overview talks as well as concluding remarks.

The main topics were the following:

- Projects for Future Colliders;
- Quantum Chromodynamics;
- Top Quark Physics;
- Electroweak Symmetry Breaking;
- Beyond the Standard Model

Conveners

Quantum Chromodynamics: Giancarlo Ferrera (University of Milan, Italy)

Top Quark Physics: Francesco Tramontano (University of Naples, Italy)

Beyond the Standard Model: Aldo Deandrea (University of Lyon, France)
Electroweak Symmetry Breaking: Roberto Franceschini (University of Rome 3, Italy)

Participants:

Alekhin Sergey	Hamburg University, Germany
Banfi Andrea	University of Sussex, United Kingdom
Bedeschi Franco	INFN Pisa, Italy
Beraudo Andrea	INFN Turin, Italy
Blanke Monika	Karlsruhe Institute of Technology, Germany
Bozzi Giuseppe	University of Pavia, Italy
Corcella Gennaro	INFN LNF, Italy
D'Hondt Jorgen	Vrije Universiteit Brussels, Belgium
De Curtis Stefania	INFN Florence, Italy
Deandrea Aldo	University of Lyon, France
Erler Jens	JGU Mainz, Germany
Fanò Livio	University of Perugia, Italy
Ferrari Ruggero	University of Milan, Italy
Ferrario Ravasio Silvia	IPPP, University of Durham, United Kingdom
Ferrera Giancarlo	University of Milan, Italy
Flacke Thomas	IBS CTPU, South Korea
Franceschini Roberto	University of Rome 3, Italy
Frezzotti Roberto	University of Rome Tor Vergata, Italy
Frigerio Michele	Laboratoire Charles Coulomb and CNRS, France
Fuks Benjamin	LPTHE and Sorbonne University, France
Giannuzzi Floriana	University of Bari, Italy
Gouskos Loukas	CERN, Switzerland
Hoyer Paul	University of Helsinki, Finland
Liu Tao	Hong Kong University of Science and Technology, China
Mahmoudi Nazila	University of Lyon, France
Mason Lara	University of Johannesburg, South Africa, and Lyon, France
Mastrolia Pierpaolo	University of Padua, Italy
Mazzitelli Javier	University of Zurich, Switzerland
Mele Barbara	INFN Rome, Italy
Melini Davide	Technion, Haifa, Israel
Meyer Andreas	DESY, Germany
Mitov Alexander	University of Cambridge, United Kingdom
Pancheri Giulia	INFN LNF, Italy
Panizzi Luca	University of Uppsala, Sweden
Rinaldi Enrico	RIKEN, Japan
Rodriguez-Sanchez Antonio	University of Lund, Sweden
Roloff Jennifer	Brookhaven National Laboratory, USA
Roloff Philipp	CERN, Switzerland
Salvioni Ennio	Technical University of Munich, Germany
Scott Darren	University of Amsterdam, Netherlands
Spadaro Norella Elisabetta	University of Milan, Italy
Stelzl Stefan	Technical University of Munich, Germany
Tenchini Roberto	INFN Pisa, Italy

Tramontano Francesco	University of Naples Federico II, Italy
Vos Marcel	IFIC and University of Valencia, Spain
Wever Chris	Technical University of Munich, Germany

Scientific report

This workshop aimed at gathering theorists and experimentalists working on LHC and future colliders, with expertise in the realm of strong interactions, within and beyond the Standard Model. LFC19 has been an international meeting which followed a renowned series of similar workshops, which have been held over the last few years in Florence, Frascati (twice), Perugia and the ECT* itself (2011, 2013, 2015 and 2017). The workshop reviewed LHC results, paying special attention to QCD measurements and calculations, and presented the state of the art of projects of facilities like ILC, CLIC, FCC-ee, CEPC, FCC-hh, as well as the high-luminosity upgrade of the LHC, the so-called HL-LHC.

As for QCD, processes mediated by the strong interactions are background for new physics searches and therefore they are to be measured and computed with the highest possible precision. Non-perturbative phenomena like hadronization or underlying event are also of paramount importance and one needs to model them in a reliable manner to meet the accuracy goals of LHC and future accelerators.

Top-quark phenomenology plays a crucial role in most searches of physics beyond the Standard Model: in fact, the top quark is the heaviest elementary particle and processes with production of top-antitop pairs lead to final states with jets and possibly leptons and missing energy, which are the typical signature of physics beyond the Standard Model, such as supersymmetry. Furthermore, it is well known that the values of top and Higgs masses are crucial to explore whether our universe is stable, unstable or metastable.

Concerning physics beyond the Standard Model, we mostly concentrated on strongly- interacting new physics scenarios, such as composite Higgs models, predicting, among others, light hidden mesons, vector-like quarks, exotic top partners, composite resonances, pseudo-scalar bosons. Dark Matter models based on strong dynamics were debated as well.

Results and Highlights

Hereafter, we shall discuss the main results presented in the review talks and in the topical sessions.

The introductive session dealt with the projects for future colliders and had some review talks on QCD measurements and calculations at LHC and next generation of accelerators. In particular, the session featured reviews on the European strategy for particle physics, high-luminosity LHC, FCC-hh, circular (FCC-ee and CEPC) and linear (ILC and CLIC) $e+e-$ colliders. On the one hand, all projects sound interesting and promising, on the other, as far as our community is concerned, we are all eager to wait for the decision of the European Committee for particle physics, expected in early 2020.

In the topical QCD session, we discussed hard QCD measurements at the LHC (jet production and substructure, vector bosons plus jets, double parton scattering, with all results confirming Standard Model predictions), progress in parton distribution functions, using LHC Drell–Yan data and extracting the charm and top MS masses from HERA and LHC data, respectively. Moreover, still in the field of perturbative QCD, presentations on transverse-momentum-dependent parton densities, capable of describing transverse- momentum distributions at low qT, new techniques to compute Feynman integrals and resum the Higgs qT spectrum were given. Regarding Monte Carlo event generators, novel methods to match parton showers and exact matrix elements, based on the so-called recoil scheme and angular ordering, were shown; as for heavy ions, new results on the calculation of the transport coefficient for heavy quarks and the evolution of the quarkonium in a dense medium were presented. The LHCb Collaboration presented new measurements on hadron spectroscopy and exotic states, such as Λ0, ηc(1S) and ^{b}b-flavored pentaquarks. As for low-energy QCD, the workshop featured talks on the possible application of perturbative techniques to regimes where $\alpha S/\pi \sim 0.14$, so-called QCD soft-wall models, AdS/CFT correspondence for out-of-equilibrium systems and quark-gluon plasma, the possibility to obtain the particle masses from a non-perturbative anomaly.

Concerning top-quark physics, we had a review on the latest LHC measurements (total and differential $t\bar{t}$ cross section, charge asymmetry, the CKM element Vtb, top width, top mass and Yukawa coupling), all in agreement with Standard Model predictions. Also, the relation between reconstructed mass and pole mass was debated, taking particular care about the role played by renormalons in the pole mass. Higher-order calculations of the tt total cross section and transverse-momentum distribution were presented: the cross section included NNLO+NNLL' contributions in QCD and NLO in the electroweak sector, the qT spectrum was instead calculated at NNLO in QCD. The overall result was that precise computations are mandatory to reach the precision goals of the LHC and future accelerators. Challenges in the determination of the top-quark Yukawa coupling at future e+e– facilities were explored, finding that it can be obtained with a precision of 0.6%, higher than the foreseen 5-10% at HL-LHC and FCC-hh.

Regarding physics beyond the Standard Model, we focused on models based on strong dynamics and their predictions for the LHC and experiments at higher energy and luminosity, in both pp and e+e– regimes. In detail, possible signatures of strongly-interacting new physics could be: light hidden mesons produced through the Z portal, vector-like quarks with large width, exotic top partners, novel pseudo-scalar bosons, heavy composite resonances, long-lived charged scalars and so-called quirks and twin glueballs. We also discussed strongly-interacting models for dark matter and methods to combine supervised learning and particle detection in such a way to create the basis for future data analysis. All such scenarios sound quite intriguing and well posed from the mathematical viewpoint: one can thus just look forward to next LHC run or the building of new accelerators to test such models.

Finally, the last day of the workshop featured general talks on the state of the art of the Standard Model fits and their ultimate perspectives, flavor physics at present and future machines, the connection between low- and high-energy observable, mostly via Effective Field Theories, and concluding presentations summarizing the main results presented at the meeting.

Model fits and their ultimate perspectives, flavor physics at present and future machines, connection between low- and high-energy observable, mostly via Effective Field Theories, and conclusive presentations summarizing the main results presented at the meeting.

2.3.18 *FRGIM - Functional and Renormalization-Group Methods*

Date	September 16-20, 2019

Organizers

Gian Paolo Vacca	INFN-BO, Italy
Alfio Bonanno	INAF-CT, Italy
Roberto Percacci	SISSA, Italy
Andrea Trombettoni	CNR-TS, Italy
Luca Zambelli	University of Jena, Germany

Number of participants	47

Main topics

Since the seminal work by Wilson and Kadanoff the renormalization group has represented a revolutionary and universal conceptual paradigm. Starting from its early applications to the theory of phase transitions and critical phenomena, it has been by now adopted in a multitude of research areas, for its unifying power and practical convenience. On the other hand, the functional methods, pioneered by Schwinger, Feynman and Dyson, are nowadays considered a reference point and one of the common languages for the community of theoretical physicists. This international conference focuses on the latest scientific developments at the interface of functional and renormalization-group methods, and aims at favoring interdisciplinary discussions between communities interested in these two cornerstones of theoretical physics, both at the formal level and at the modern frontiers of their applications. The latter include for instance: the UV completion problem in particle physics and quantum gravity; nonperturbative gauge theories and nuclear physics; out of equilibrium and fluid effective dynamics; strongly correlated fermions in condensed matter; statistical mechanical models; active matter systems; cosmological evolution and astrophysics. The conference is part of a project sponsored by ACRI under the grant “Young Investigator Training Program 2018”, which is intended to foster young international researchers and to promote their scientific collaboration with a network of Italian research institutions. The main topics were

- Methodological and Theoretical Advances in Field Theory with applications to:
- QCD, Physics Beyond the Standard model Asymptotic Safety
- Cosmology and Quantum Gravity
- Condensed Matter
- Non-Equilibrium Phenomena
- Neural Networks

Speakers

S. Asnafi	Institute for Research in Fundamental Sciences, IRAN
R. Ben Ali Zinati	SISSA, Italy
A. Bonanno	INAF-CT, Italy

F. Caravelli	Los Alamos National Laboratories, USA
A. Codello	Sustech, China
M. D'Elia	Depart. of Physics, University of Pisa, Italy
N. Defenu	University of Heidelberg, Germany
B. Delamotte	Sorbonne University, France
A. Duarte Pereira Junior	Universitade Federal Fluminense, Brasil
N. Dupuis	Sorbonne University, France
U. Ellwanger	LPT Orsay, France
K. Falls	SISSA, Italy
S. Franchino	UNLP, Argentina
G. Gori	CNR-IOM, Italy
A. Khosravi	Radboud University, Netherlands
M. Koch-Janusz	ETH Zurich, Switzerland
D. Litim	University of Sussex, United Kingdom
T. Macri	Universitade Federal do Rio Grande do Norte, Natal, Brasil
W. Metzner	MPI for Solid State Research, Stuttgart, Germany
G. Moreau	Université Paris Diderot, France
T. Morris	University of Southampton, United Kingdom
C. Nieto	SISSA, Italy
C. Pagani	Institute of Physics (WA THEP), Johannes Gutenberg Universität, Germany
R. Percacci	SISSA, Italy
A. Pithis	University of Heidelberg, Germany
M. Piva	Depart. of Physics, University of Pisa, Italy
L. Rachwal	Czech technical University, Czech Republic
M. Reichert	CP3 Origins, University of Southern Denmark, Denmark
M. Safari	Institute for Research In Fundamental Sciences, IRAN
R. Sondenheimer	Graz University, Austria
D. Squizzato	University of Heidelberg, Germany
C. Steinwachs	University of Freiburg, Germany
A. Stergiou	Los Alamos National Laboratories, USA
T. Steudtner	University of Sussex, United Kingdom
A. Tonero	Carleton University, Canada
R. A. Tripolt	Goethe University Frankfurt, Germany
A. Trombettoni	CNR-IOM, Italy
A. Ugolotti	Friedrich-Schiller-Universität, PAF Germany

Scientific report

Quantum and statistical field theories (FTs) occupy a central position in contemporary theoretical physics thanks to their wide application range and to their predictive power. Yet a complete definition of such theories and the computational control over their properties are in most cases hard to achieve. Although these goals are most challenging in the strongly interacting regime, they affect the weakly coupled domain as well, were nonperturbative aspects are also relevant (e.g. renormalons, nontrivial vacua, topological effects). Hence the need for a pool of general nonperturbative methods able to address these properties, and for a constant comparison among their results. The focus of this conference was on one particular such approach, the functional renormalization group (FRG), but reports on advances in other approaches (lattice, conformal bootstrap, information theory, machine learning) were also presented.

The FRG is a representation of FTs based on the formulation of an exact renormalization group (RG) equation for a generating function or effective action, whose integration with a given initial condition (e.g. a bare action) is tantamount to the computation of the corresponding functional integral. While the first FRG equations where discovered by Wilson, Wegner and Houghton in the early Seventies, the appreciation and the diffusion of this method for quantitative computations, especially in strongly coupled FTs, dates to the late Nineties and to the beginning of the new century. This success was largely due to the development of approximation schemes and the understanding of their systematics, as well as to successful applications, first of all to the theory of critical phenomena and then to a wide class of problems, e.g. effective models of low-energy QCD and quantum gravity (QG). Nowadays the FRG community is wide and diverse, yet the theoretical and methodological issues faced are often as universal as FT itself. Hence the need for workshops dedicated to functional and RG method themselves, where specialists of different areas can report on their own progress.

The present research on the FRG can be mainly classified in two groups:

A) Applications: exploring new areas of application of the method and advancing the understanding of specific problems by means of the FRG.

F) Foundations: improving the understanding of the method itself and of some general theoretical issues associated to it.

The questions addressed during this workshop include:

A1) Can the FRG reproduce exact nonperturbative results obtained by means of other methods, and confirm or disqualify related conjectures?

A2) Is the FRG a competitive method for precise computations of universal quantities at phase transitions?

A3) Is the FRG suited to compute observables of low-energy QCD, such as masses and decay constants of hadrons and mesons?

A4) What is the status of the asymptotic safety program for QG?

A5) What is the status of RG based research on UV complete models for beyond the Standard Model physics?

F1) Is the quantitative control on approximations of the FRG good enough?

F2) Is the understanding of regulator dependence of the FRG good enough? Can new optimization criteria be devised to generically improve FRG results?

F3) Which FRG implementation is best suited for preserving gauge symmetries?

Results and Highlights

The workshop was organized in days devoted to different applications, thus favoring the goal of answering questions regarding applications (A) rather than foundations issues (F). Despite this structure, the staying of participants over several days and the presence of introductory talks in the schedule stimulated many discussions on the state-of-the-art and on the future development of specialized research fields. This also applies to the other methods which were represented at the workshop, such as the lattice, the conformal bootstrap, conventional perturbative RG methods, information theory and machine learning. The discussions were inclusive in the sense that often the know-how of one specialized field was tried to be transferred to other fields. For instance, see the discussion on the answer F2 below.

Answers to several specific FRG questions were addressed in dedicated talks:

A1) The FRG was successfully employed to confirm a conjecture regarding non-perturbative properties of two-dimensional FTs obtained by means of conformal methods and to generalize such studies to more complicated models which escape exact treatments (talk by N. Dupuis).

A2) More precise estimates of the critical exponents of the 3D and 2D Ising models have been recently obtained by applying the derivative expansion to the FRG at third order (talk by B. Delamotte). The results are (compatible and) competitive with the most precise results available (by the conformal bootstrap).

A3) Recent efforts to apply the FRG to the computation of spectral functions have been described in the talk by R. A. Tripolt. Despite these successful studies in toy models, similar computations in more realistic parametrizations of infrared QCD are yet to come.

A4) The day dedicated to gravitation started with a heated discussion about the status of asymptotic safety in QG. The community appears to universally agree about the solidity of the Reuter fixed point and of its properties, but its phenomenological (astrophysical, cosmological and particle-physics oriented) implications and the theoretical methods to address them appear to be controversial. Much of the current research appears focused on these matters. On the formal and mathematical side, two active lines of research are: relating the FRG studies of asymptotic safety to the results of other QG communities (dynamical and causal triangulations, Regge calculus, spin foams and tensor networks) and revising the usual treatment of perturbative renormalization in QG.

A5) The discussion mainly focused on the Litim-Sannino proposal for asymptotic safety in beyond the Standard Model physics. The latter proposal appears to be in a crucial stage where its viability in models with small number of fields and small symmetry groups (i.e. far away from the Veneziano limit) has to be assessed. Attempts in this sense have been reported, based on either conventional perturbation theory with and without resummations, or on the FRG. Promising positive results have been found, whose stability and reliability is however still not assessed. Applications of RG methods in constraining infrared quantities have also been presented.

F1) The convergence of the derivative expansion of FRG equations has been tested and found to be present and rather fast. This discovery has been used to improve FRG estimates of universal quantities (talk by B. Delamotte).

F2) The topic of using information theory to construct an RG transformation (and mutual information as an optimal choice) was discussed not only in an overview talk on machine learning (talk by M. Koch-Janusz) but also in a specialized FRG talk where a new optimization criteria for FRG regulators was suggested (talk by F. Caravelli). On the last day of the conference, the topic of a perturbative FRG based on dimensional regularization was also discussed, with emphasis on its advantages and predictive power.

F3) The issue of gauge invariance in the FRG was discussed in a couple of talks. While the first proposed a novel way to regulate the theory while preserving BRST symmetry (talk by S. Asnafi), the second one focused on the application of the traditional regulator-dependent quantum master equation in new constructions of perturbative QG. These exploratory works signal a renewed interest of the FRG community in this problem, despite the existence of a widely accepted and by now standard treatment in terms of background fields (reviewed in the talk by A. Pereira).

Overall, the workshop was enriched by reports of remarkable advances in both formal and applicated research areas, and was quite interdisciplinary, with the two largest communities provided by scholars in high-energy physics and statistical mechanics. Its main characteristic feature was the intense participation of young researchers, due to the associated “ACRI Young Investigator Training Project 2018”.

2.3.19 *Diquark Correlations in Hadron Physics: Origin, Impact and Evidence*

Date	September 23-27, 2019
Organizers	
Jacopo Ferretti	Yale U., USA & Jyväskylä U. Finland
Craig D. Roberts	Nanjing U., China
Elena Santopinto	INFN-GE, Italy
Jorge Segovia	Pablo de Olavide U. of Seville, Spain
Bogdan Wojtsekhowski	Jefferson Lab, USA
Number of participants	26

Main topics

The last decade has seen a dramatic shift in the way we understand the internal structure of hadronic systems. Modern experimental facilities, new theoretical techniques for the continuum bound-state problem and progress with lattice-regularized QCD have provided strong indications that soft quark-quark (diquark) correlations play a crucial role in hadron physics. For example, theory indicates that the appearance of such correlations is a necessary consequence of dynamical chiral symmetry breaking, viz. the mechanism responsible for the emergence of almost all visible mass in the Universe; experiment has uncovered signals for such correlations in the flavour-separation of the proton's electromagnetic form factors; and phenomenology suggests that diquark correlations might be critical to the formation of exotic tetra- and penta-quark hadrons. This workshop gathered experimentalists and theorists to undertake a critical review of existing information, consolidate the facts, and therefrom develop a coherent, unified picture of hadron structure.

The main topics were

- Emergence of mass in the Standard Model
- Diquark Correlations in baryons
- Theoretical Approaches to "Strong QCD"
- Phenomenology for hadron structure
- Exposing diquarks in hadron-structure measurements

Speakers

Mikhail Barabanov	JINR Dubna, Russia
Marco Antonio Bedolla	MCTP, Mexico
William Brooks	Santamaría U., Chile
Gordon Cates	Virginia U., USA
Chen Chen	Giessen U., Germany
Ying Chen	IHEP Beijing, China
Evaristo Cisbani	INFN-Rome, Italy
Minghui Ding	ECT*, Italy
Gernot Eichmann	CFTP Lisbon, Portugal

Rolf Ent	Jefferson Lab, USA
Jacopo Ferreti	Yale U., USA & Jyväskylä U. Finland
Ralf Gothe	South Carolina U., USA
Tanja Horn	Catholic U. America, USA
Simonetta Liuti	Virginia U., USA
Cedric Mezrag	INFN-Rome, Italy
Alessandro Pilloni	ECT*, Italy
Andrew Puckett	Connecticut U., USA
Patrizia Rossi	Jefferson Lab, USA
Giovanni Salmé	INFN-Rome, Italy
Elena Santopinto	Genoa U., Italy
Jorge Segovia	Pablo de Olavide U. of Seville, Spain
Sergey Syritsyn	SUNY Stony Brook U., USA
Makoto Takizawa	Showa Pharmaceutical U., Japan
Egle Tomasi-Gustafson	CEA Saclay, France
Philipp Wein	Regensburg U., Germany
Bogdan Wojtsekhowski	Jefferson Lab, USA

Scientific report

Elucidating the importance of correlations within wave functions has long been a central theme of both experimental and theoretical nuclear physics. Now, modern developments have pushed this to the forefront of hadron physics, too. Fifty years ago, it was argued that pointlike diquarks might simplify the treatment of the baryon bound-state problem and, subsequently, that they could explain the so-called missing resonance problem. Today, analyses of the three valence-quark bound-state problem in quantum field theory predict that a baryon can be understood as a Borromean bound-state, in which non-Abelian features of QCD generate confined, non-pointlike yet strongly correlated colour-antitriplet diquark clusters inside baryons. This diquark clustering is an emergent phenomenon, driven by the same mechanism which is responsible for approximately 98% of the visible mass in the Universe. There is evidence for such clusters in simulations of lattice-QCD; and their presence within baryons is predicted to have numerous observable consequences, some of which already have strong experimental support. The idea of diquark clustering is also prominent amongst competing explanations of the existence and structure of tetra- and penta-quark bound-states; and there is extensive use of the diquark notion in nuclear and high-energy physics phenomenology.

Evidently, the notion of diquark correlations is spread widely across modern nuclear and high-energy physics. At issue, however, is whether all these things called diquarks are the same; and if there are dissimilarities, can they be understood and reconciled so that experiment can properly search for clean observable signals.

This workshop gathered 26 experts in experiment and theory in order to address the following key questions:

- What does lattice QCD have to say about the existence and character of diquark correlations in baryons and multiquark systems?

- How firmly founded are continuum theoretical predictions of diquark correlations in hadrons?
- Are there strategies for combining lattice and continuum methods in pursuit of an insightful understanding of hadron structure?
- Can theory identify experimental observables that would constitute unambiguous measurable signals for the presence of diquark correlations?
- Is there a traceable connection between the so-called diquarks used to build phenomenological models of high-energy processes and the correlations predicted by contemporary theory; and if so, how can such models be improved therefrom?
- Are diquarks the only type of two-body correlations that play a role in hadron structure?
- Which new experiments, facilities and analysis tools are best suited to testing the emerging picture of two-body correlations in hadrons?

Presentations of all speakers were of 60 minutes duration, which included 15-20 minutes of discussion/question time. In order to provide additional time for discussion, 90 minutes were allocated to the lunch breaks and another 30 minutes at the end of each day. One can state that all discussion time was used and resulted in a very lively workshop with great interaction between participants. From the final programme of the workshop one can see that each session block was led by an experimental presentation, followed by an array of related theory presentations.

Results and Highlights

Modern facilities will probe hadronic interiors as never before, e.g. JLab12 will push form factor measurements to unprecedented values of momentum transfer and will use various charge states, enabling flavour separations; an EIC will measure valence-quark distribution functions with previously unachievable precision; and elsewhere, collaborations like BaBar, Belle, BESIII, LHCb, are discovering new hadrons whose structure does not fit once viable paradigms. The wealth of new and anticipated information demands that the issue of correlations within hadrons be settled. This workshop has kick-started that effort. It has:

1. elucidated the impacts on our understanding of Nature delivered by the emerging picture of diquark correlations within hadrons;
2. discussed the reliability of contemporary predictions for empirical signals of diquarks;
3. identified impediments to lattice-QCD delivering a detailed understanding of the character of diquarks and their role in hadron structure;
4. fostered cooperation between continuum- and lattice-QCD that will expedite delivery of real QCD predictions for hadron spectra and structure in the foreseeable future;
5. identified experiments that can validate the notion of hadrons built from diquark correlations and discuss known analysis challenges and possible remedies.

It has thereby charting a trail toward a definitive explanation of the internal structure of hadrons with more than two valence partons. Unofficially, participants agreed to work collaboratively, and in a coordinated way, on a white paper which will collect the ideas discussed during the workshop.

2.3.20 *Open Quantum Systems: From Atomic Nuclei to Ultracold Atoms and Quantum Optics*

Date	September 30 - October 04, 2019
Organizers	
Hammer Hans-Werner	TU Darmstadt, Germany
Navratil Petr	TRIUMF, Canada
Gade Alexandra	Michigan State University, USA
Efremov Maxim	Ulm University, Germany
Gattobigio Mario	Université de Nice-Sophia Antipolis, France
Number of participants	24

Main topics:

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

The main topics were:

- Driven open quantum systems
- Dynamical phase transitions and quantum phase transitions
- Weakly bound and unbound nuclei; dripline physics
- Nuclear scattering, resonances, and reactions
- Quantum computing
- Modern computational approaches and coupling to the continuum
- Open effective field theory and nonhermitian Hamiltonians

Speakers

Ankerhold Joachim	Ulm University, Institute for Complex Quantum Systems, Germany
Brown Kyle	FRIB/MSU, USA
Carbonell Jaume	CNRS/IPN, Orsay, France
Faccioli Pietro	Trento University, Italy
Fossez Kevin	Michigan State University and Argonne National Laboratory, USA
Guardo Giovanni Luca	INFN-LNS, Italy
Hammer Hans-Werner	TU Darmstadt, Germany
Jochim Selim	Heidelberg University, Germany
Kievsky Alejandro	INFN, Italy

Kunitski Maksim	Goethe-Universität Frankfurt Am Main, Germany
Lazauskas Rimantas	IPHC, France
Leamer Jacob	Tulane University, USA
Leuchs Gerd	Max Planck Institute for the Science of Light, Germany
Matzkin Alex	CNRS, France
McCaul Gerard	Tulane University, USA
Navratil Petr	TRIUMF, Canada
Pederiva Francesco	Trento University, Italy
Ploszajczak Marek	GANIL, France
Richter Achim	TU Darmstadt/Institute of Nuclear Physics, Germany
Volya Alexander	Florida State University, USA
Wanjura Clara	University of Cambridge, United Kingdom

Scientific report

In this workshop, we have focused on the physics of open quantum systems and gathered experts from particle and nuclear physics to atomic physics and quantum optics covering both theory and experiment.

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

In low-energy atomic physics, the use of effective Hamiltonians has attracted a lot of recent attention, with the advent of experimental possibilities using ultracold atoms and well controlled light-matter interactions. We have focused on driven, open quantum systems including superconducting circuits utilized as testbeds for atomic physics and quantum optics, coupling of radiation with a single atom in a cavity or in free space, demonstrations of weak measurements with photon interferometry as well as with polarized neutrons.

In low-energy nuclear physics, the growing interest in open quantum systems is largely associated with experimental achievements in producing weakly bound and unbound nuclei in the vicinity of the particle driplines, and efforts in studying structures and reactions with those nuclei. On the theory side there has been progress on the unification of nuclear structure and nuclear reactions as demonstrated in talks covering ab initio no-core shell model with continuum, Gamow shell model, the Faddeev-Yakubovsky method now applicable to up to five nucleon systems. These approaches together with modern effective field theories allow studying nuclear resonance phenomena from an ab initio perspective and will offer insights into the physics that is being explored with radioactive beam experiments. Another specific component of the nuclear many-body problem discussed in several talks at the workshop, are the strong particle correlations, which impose the need for a simultaneous description of the configuration mixing and the coupling to open decay channels.

A new theoretical development is the establishment of so-called ``open effective field theories'' whose density matrices satisfy the Lindblad equation. The theories are designed to describe multi-particle systems with deeply inelastic reactions that produce particles with large momenta outside the domain of validity of the effective theory.

A new feature of the present workshop was the discussion of the emerging field of quantum computing that naturally fits into this workshop series theme. In particular, there was an overview quantum computing talk covering activity at Lawrence Livermore Laboratory. In addition, potential of superconducting circuits with Josephson junctions to quantum computing applications was presented in one of the talks.

Results and Highlights

This workshop, with dedicated free time for discussions, has provided a great opportunity for exchange of ideas, and to come up with relevant research projects that are of general interest. It has been very fruitful in several ways. First, it has allowed learning about the latest development in the field of open quantum system, both in cold atom physics as in nuclear physics and quantum optics. Overall, the majority of speakers allowed the participants less familiar with one of these fields of research to have an introduction into the field and learn about the open questions. Given the relaxed schedule, discussions were quite lengthy both during and after the talks. Questions raised by experts from one field of research for the speakers of the other field have shown that common questions and techniques exist and allowed to see which part of one's research can be useful to a larger community of researchers.

One important aspect has been the time taken for coffee and lunch breaks, which are essential to allow all the participants to meet each other and continue in the discussions and at some occasion engage in new collaborations. Also, the time after the afternoon sessions have been used by many participants meeting at this workshop to work together on precise aspects of their research.

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

2.3.21 *Universal Physics in Many-Body Quantum Systems – From Atoms to Quarks*

Date September 7-11, 2019

Organizers

Philipp Gubler	JAEA, Japan
Hans-Werner Hammer	TU Darmstadt, Germany
Emiko Hiyama	Kyushu/RIKEN, Japan
Atsushi Hosaka	Osaka University, Japan
Sebastian Koenig	TU Darmstadt, Germany
Makoto Oka	JAEA, Japan

Number of participants 26

Main topics

The workshop provided an interdisciplinary setting to discuss recent advances and challenges for physicists working on a wide range of systems, ranging from quarks and hadrons to cold atoms and molecules. Universality is now recognized as a common feature of strongly interacting quantum systems, independent of the details of the interaction at short distances. It is expected to provide a basis for the solution of various quantum phenomena in few- and many-body systems. The topics covered at the workshop were:

- Universality physics in cold atoms, dimers, trimers
- Universal phenomena in hadron resonances, quark correlations
- Strong correlations and universal phenomena in exotic nuclei, di-nucleon correlations
- New methods of treating quantum many-body systems

Speakers

Hans-Werner Hammer	TU Darmstadt, Germany
Munekazu Horikoshi	Osaka City University, Japan
Mario Gattobigio	Institut De Physique De Nice, France
Sebastian Koenig	TU Darmstadt, Germany
Ulf Meissner	Bonn University/ Forschungszentrum Jülich, Germany
Elisabetta Prencipe	Forschungszentrum Jülich, Germany
Laura Tolos	University of Frankfurt/ICE Barcelona, Germany/Spain
Takayuki Myo	Osaka Institute of Technology, Japan
Yutaka Utsuno	Advanced Science Research Center, JAEA, Japan
Hiroshi Masui	Kitami Institute of Technology, Japan
Toshiki Maruyama	Advanced Science Research Center, JAEA, Japan
Wael Elkamhawy	TU Darmstadt, Germany
Fabian Hildenbrand	TU Darmstadt, Germany
Lucas Platter	University of Tennessee, USA
Tetsuo Hyodo	Tokyo Metropolitan University, Japan
Emiko Hiyama	Kyushu University/RIKEN, Japan

Yoshiko En'yo	Kyoto University, Japan
Kazuki Yoshida	Advanced Science Research Center, JAEA, Japan
Yusuke Nishida	Tokyo Institute of Technology, Japan
Manuel Pavon Valderrama	Beihang University, China
Pascal Naidon	RIKEN, Japan
Christiane Schmickler	RIKEN, Japan
Philipp Gubler	Advanced Science Research Center, JAEA, Japan
Atsushi Hosaka	RCNP, Osaka University, Japan
Noriyoshi Ishii	RCNP, Osaka University, Japan
Makoto Oka	Advanced Science Research Center, JAEA, Japan

Scientific report

Universality provides a new paradigm for understanding strongly interacting quantum systems in different fields of physics by focusing on generic properties, independent of the details of the interaction of the constituents at short distances. The concept of universality is closely connected to the emergence of effective low-energy degrees of freedom close to scattering thresholds. Halo nuclei and hadronic molecules are prominent examples of such systems, yet their emergence from the fundamental degrees of freedom is not well understood. The objective of this workshop was to bring together various physics communities (hadronic, nuclear, atomic, molecular physics), to discuss such "exotic" phenomena, clarify their universal features, and discuss the pertinent concepts and methodologies.

The workshop, with dedicated free time for discussions and two organized discussion sessions, has provided a great opportunity for the exchange of ideas and the development of research projects of general interest. The workshop has been very fruitful in several ways.

First, it has established a discussion of universal phenomena across the boundaries of hadronic, nuclear, atomic, molecular physics. The expansion around the unitality limit emerged as one possible way to describe universal aspects of shallow bound states and different strategies for its implementation were debated. Secondly, several scenarios for distinguishing universal from non-universal states, such as the Weinberg method, as well as the limits of universality were discussed. The vigorous discussions led to the identification of common questions and techniques and possible future collaborations. Moreover, a few experimentalists joined the workshop and introduced new experimental techniques, challenges and results in the universality-related physics.

For the organized discussion sessions, two topics, (1) Unitarity limit of Nuclear Physics and (2) Dynamics and Structures of Hadronic Molecules, were adopted and lead to intensive and fruitful discussions.

Results and Highlights

The workshop was very successful in developing a common understanding among the physicists in hadron, nuclear, atom and molecular physics. A key concept was shared by the workshop attendants: “Universality” enables us to understand various physical phenomena without relying on specific models or viewpoints, to separate the scales of systems and extract characteristic dynamics with a few variables, to find common features among diverse physics subjects.

The organized discussion sessions had two main topics for the discussions and several key questions.

(1) "Unitarity Limit in Nuclear Physics"

How useful is the unitarity limit in nuclear physics? Do the expansions around the unitality limit work in nuclear physics? What are the main ingredients for the effective theory?

(2) "Dynamics and Structures of Hadronic Molecules"

What is a driving force? Is the Weinberg-Tomozawa interaction suitable for heavy hadron systems?

Why are the hadronic molecules mostly around the thresholds? Is there a deeply bound hadronic molecule? How is the compositeness useful to classify hadron resonances?

These questions are not all answered at the workshop but are recognized as the common question for possible future collaborations. Many interesting subjects were introduced in the presentations of the workshop attendants. Some of them are itemized. The unitarity limit enables us to separate the long-range and short-range dynamics. The short-range dynamics is controlled by a cutoff (range) parameter. The long-range physics has universal features. The scale invariance in the 3-body system is broken by a 3-body force, resulting a remaining discrete symmetry (limit cycle). Deviations of nuclear physics from the unitarity limit can be controlled by a new (3-body) scale parameter or the effective range. Expansion in 1/a from the unitarity limit may work. This approach is complementary to the conventional nuclear physics approach treating the short-range correlations. Various new techniques are available to treat correlations, such as n/p halo, tensor, 4p-4h, d/d*, alpha, of nucleons in nuclei. How a cluster structure evolves in nuclei might be a key to understand physics around thresholds. New ideas and techniques have been developed in cold atom physics, such as cluster excitation, time dependent scattering length, fermion systems, Coulomb systems. There are many candidates of hadron molecule states, most of which appear near the two-hadron thresholds. The Efimov-like three-body states may be seen in various hadronic systems, involving K, D mesons. The spectrum, structure and compositeness of hadron resonances are not yet fully controlled. Hadron resonances in finite T/ρ may help understanding the nature of the resonances.

2.3.22 *The First Compact Star Merger Event – Implications for Nuclear and Particle Physics*

Date	October 14-18, 2019

Organizers

Blaschke David	BLTP at JINR Dubna, Russia & University of Wroclaw, Poland
Colpi Monica	University of Milano Bicocca, Italy
Fischer Tobias	University of Wroclaw, Poland
Radice David	The Pennsylvania State University, University Park PA, USA

Number of participants	37

Main topics

Multimessenger observation of compact stars (CSs) mergers have the potential to revolutionize nuclear astrophysics. Data from the first detection, now called GW170817, has already provided strong hints that heavy elements are produced in CS mergers and first constrains the properties of dense matter. It is expected that the Advanced LIGO & Virgo detector network will discover several new events in the first months of the new observing run, which should start soon after a series of upgrades to the detectors that should boost their sensitivities by a factor ~3. A vibrant collaborative effort involving nuclear physicists, computational astrophysicists, and GW and EM observers will be key for the interpretation of past and future observations. This workshop aimed at bringing together prominent members of these communities in order to discuss the scientific impact of CS merger observations in nuclear astrophysics and synchronize punchlines of future research in these communities.

The main topics were

- search for and measuring of gravitational waves: opportunities and challenges
- constraints on compact star structure and equation of state from GW170817
- simulations of compact star mergers
- observations and modelling of electromagnetic signals and neutrinos
- modelling kilonovae, testing consistency between the GW and EM signals

Speakers

Alvarez-Castillo, David	JINR Dubna, Russia
Alvear Terrero, Diana	Univ. Wroclaw, Poland
Baldo, Marcello	INFN & Univ. Catania, Italy
Barbieri, Claudio	Univ. Milano-Bicocca, Italy
Bastian, Niels-Uwe	Univ. Wroclaw, Poland
Bauswein, Andreas	GSI Darmstadt, Germany
Bhat, Sajad	Saha Institute, India
Blaschke, David	Univ. Wroclaw, Poland

Breschi, Matteo	FSU Jena, Germany
Bulik, Tomasz	CAMK Warsaw, Poland
Burgio, Fiorella	INFN & Univ. Cataniak Italy
Capano, Collin	AEI Potsdamk Germany
Cierniak, Mateusz	Univ. Wroclawk Poland
Ecker, Christian	Utrecht University, Netherlands
Figura, Antonio	INFN & Univ. Catania, Italy
Grigorian, Hovik	JINR Dubna, Russia
Harutyunian, Arus	Bjurakan Astrophys. Observatory, Armenia
Horowitz, Charles	Indiana University, USA
Jakobus, Pia	FIAS, Germany
Lee, Chang Hwan	Pusan National University, Korea
Lu, Jia Jing	Fudan University, China
Marczenko, Michal	Univ. Wroclaw, Poland
Meliani, Zakharia	Observatoire de Paris, France
Nedora, Vsevolod	FSU Jena, Germany
Nijs, Govert	Utrecht University, Netherlands
Nikas, Stylianos	TU Darmstadt, Germany
Oertel, Micaela	LUTH-CNRS/Observatoire de Paris, France
Perego, Albino	Trento University, Italy
Raduta, Ariana	IFIN-HH Bucarest, Romania
Schulze, Hans-Josef	INFN & Univ. Catania, Italy
Sedrakian, Armen	FIAS, Germany
Soma, Shriya	FIAS, Germany
Sourie, Aurelien	Univ. Libre Bruxelles, Belgium
Truemper, Joachim	MPE Garching, Germany
Van der Schee, Wilke	CERN, Switzerland
Wei, Jinbiao	INFN & Univ. Catania, Italy
Weih, Lukas	Goethe University Frankfurt, Germany

Scientific report

The recent observation of gravitational waves (GWs), gamma-rays, x-rays, optical, infrared and radio waves from a compact star (CS) merger event, now called GW170817, has the potential to revolutionize nuclear astrophysics. Data from this event has already provided strong hints that heavy elements are produced in CS mergers, and that these elements directly influence the observed optical and infrared light curves. Properties of dense matter which are expected to play a key role also appear to be essential in interpreting the GW data.

With the new LIGO observing run that started in April 2019, the present workshop on “The first compact star merger event – Implications for nuclear and particle physics” was very timely, just before new observations of CS mergers and the first CS mass-radius measurements by the NICER experiments were published. This workshop did serve perfectly the goal of bringing together the communities of Nuclear, Particle and Astrophysicists and continued the great tradition at ECT* Trento in this direction with most recent examples being the workshops on “New Perspective of

Neutron Star Interiors" (October 9-13, 2017), "Nuclear Astrophysics in the Gravitational Wave Astronomy Era" (June 12-16, 2017) and "Bridging Nuclear and Gravitational Physics – the Dense Matter Equation of State" (June 5 – 9, 2017). At the present workshop the focus was on the new perspectives for Nuclear Astrophysics and the understanding of matter under extreme conditions that were opened by the observation of GW170817 as the first event in the era of multi-messenger astronomy.

We brought together 37 participants with the great dominance of young researchers and the majority of people being theorists from the Nuclear and Particle Physics community (27) working on the astrophysical constraints for the equation of state of dense matter and QCD phase transitions. While the borders between the communities are getting more diffuse with progress in this interdisciplinary research direction, we would count 4 participants as members of collaborations observing gravitational wave and/or electromagnetic signals and 6 participants from groups in computational astrophysics that perform advanced large-scale simulations of the merger events including the so-called "kilonova" phenomena.

Some key questions raised in presentations and during the discussion times concerned:

- the equation of state of strongly interacting matter at extreme densities, temperatures and asymmetries, including a possible phase transition to the quark-gluon plasma;
- the simulation of compact star merger events using the advanced tools of numerical relativity and realistic equations of state, fulfilling basic constraints from compact star observations and heavy-ion collision experiments;
- modelling of observable signals in gravitational waves and their spectrum, as well as electromagnetic signals such as light curves;
- elucidating new aspects of the synthesis of heavy (and super-heavy) elements and how they correlate with the properties of the equation of state of strongly interacting matter and the QCD phase diagram.

The files of the presentations and of the material prepared for triggering the four discussion sessions (Monday – Thursday) at the end of the programme of presentations, are available via the ECT* homepage of the workshop.

Results and Highlights

The workshop provided a useful forum for members of the three involved communities:

- Nuclear and particle physics of dense matter,
- Computational astrophysics, and
- Gravitational wave and electromagnetic observations

to meet, exchange their views and learn from each other. The aspect of information transfer between the communities and between generations of scientists played an important role. This is a booming topic with more than 50% of participants being PhD students or young postdocs and only one quarter being senior staff faculty members.

From the results of the discussions during presentations and in the discussion sessions, we would like to highlight the following:

1. The possibility that the binary merger GW170817 involved a black hole (BH) was excluded.

The discussion was centered around the tidal deformability Λ of the merging stars and that Λ=0 (corresponding to a black hole) could be excluded. Another argument was that a neutron star (NS) – black hole merger would have resulted in the absence of a gamma ray burst and a kilonova light curve so that it could be excluded also with this reasoning. From the kilonova light curve itself the amount of heavy (Lanthanide) elements could be deduced which required a sufficient lifetime for the hypermassive, rapidly spinning, hot compact star before turning to a black hole.

2. *The possibility of third and fourth family sequences of compact hybrid stars (HS) with exotic matter interiors.*

   The existence of HS in the mass range of the merger (1.2 – 1.6 M_sun) could enrich the number of possible scenarios from just a binary NS merger to NS–HS, HS-NS and HS-HS mergers. In the corresponding plot of the probability for the tidal deformabilities of the two merging stars (Λ_1 - Λ_2 Plot) consequently a pattern of four branches was predicted and presented in the talk by D. Alvarez-Castillo and thoroughly discussed. Such a pattern should become apparent when a sufficient number of mergers of the same class as GW170817 was observed. With just one event one naturally discusses only one case.

   In the talk by A. Sedrakian the case of a fourth family has been discussed, based on his PRL (2017) with Mark Alford and the fact that in cold quark matter a sequence of first-order phase transitions can occur which under certain conditions lead to separate families of hybrid stars. The possible existence of two distinct phases such as 2SC and CFL matter, when leading to HS1 and HS2 branches, opens in principle the possibility of 9 different possibilities for mergers like GW170817. The detection of CS mass twins or triples as a consequence of these scenarios would prove the existence of a strong phase transition in cold and dense strongly interacting matter! For the observers and computational astrophysicists in the audience these scenarios were new and raised questions related to the completeness of their systematic studies, involving, e.g., Bayesian analysis techniques.

3. *Gravitational wave signals for a deconfinement phase transition from the merger event*

   Following their publications in PRL (2017), L. Weih (Uni Frankfurt) and A. Bauswein (GSI Darmstadt) have discussed their suggested signals of a deconfinement transition during the merger in the post-merger gravitational wave spectrum which, unfortunately, for GW170817 could not be detected. As was also clarified in the discussion session on observations on Wednesday evening, the suggestion by Bauswein et al. to plot the so-called peak frequency of the post-merger against the tidal deformability measured the inspiral phase will result in an unambiguous signal once the post-merger GW becomes observable for a future merger event.

4. *Hyperon puzzle and stiffness of (quark) matter at high densities*

   In the discussion session led by H.-J. Schulze the hyperon puzzle was reconsidered in light of the tidal deformability limits measured by the LVC for GW170817. The favored solution by deconfinement of hyperonic matter to stiff quark matter raised the discussion about the possible origin for the stiffness of high-density quark matter required for this solution (and other related phenomena like the mass twins and triples) that is at tension with the asymptotic freedom of QCD expected for asymptotically high densities. The discussion was inconclusive but pointed to the urgent need for a better understanding of the transitory regime of dense quark matter between the hadronic phases and the perturbative QCD asymptotics.

5. *Hot nuclear matter EoS and explosive phenomena (supernovae and mergers)*

   C.J. Horowitz raised the issue of nucleon-nucleon interactions at finite temperatures and cooling processes in compact stars which could be used for calibrating them. He focussed on the data for the fast cooling of transients which seems to require fast processes like the direct Urca process. He suggested that experiments with cold atoms in traps might be used to simulate NN interactions and in particular the spin response which can be essential also for triggering supernova explosions (neutrino-nucleon cross sections). To connect the solution of puzzling astrophysical phenomena with terrestrial experiments was very inspiring and opening perspectives for cross-community collaborations.

6. *Exploring neutron-rich matter in terrestrial experiments (PREXII, CREX)*

   Along the lines of 5. the actual status of measurements of the neutron skin thickness of nuclei was discussed by C.J. Horowitz in the context of the tidal deformability measurements. A possible tension between a large neutron skin thickness and the resulting symmetry energy behaviour and the requirement of a small tidal deformability Λ(1.4 M_sun)= 190 +390 -120 was pointed out. This interrelation of merger data and nuclear structure experiments was a very nice example for the possible implications of the observation of GW170817 for nuclear physics.

All themes highlighted above have raised or are still raising follow-up research papers and ongoing discussions in the community. Some of the issues will appear in the upcoming Topical Issue of Eur. Phys. J. A. The workshop did fulfil all its goals in an excellent manner.

2.3.23 *STRANEX: Recent Progress and Perspectives in Strange Exotic Atoms Studies and Related Topics*

Date	October 21-25, 2019
Organizers	
Catalina Curceanu	LNF – INFN Frascati
Jiri Mares	Nuclear Physics Institute - Rez/Prague
Shinji Okada	RIKEN
Angels Ramos	University of Barcelona
Johann Zmeskal	Stefan Meyer Institute
Number of participants	40

Main topics

The STRANEX workshop focused on the most recent achievements and open problems in the studies of strange exotic atoms & related topics. World-leading experts and young scientists, working in theory and experiment, provided a state-of-the-art overview on strange exotic atoms research and related topics performed worldwide by pioneering and leading groups in the field. The workshop addressed questions as: How does QCD behave at very low energies in systems with strangeness and how strange exotic atoms contribute to its understanding? What is the nature of Lambda(1405) and how strongly bound are kaonic nuclei? What is the role of strangeness in neutron stars?

The main topics were

- Kaonic atoms physics: theory and experiments
- Hypernuclear physics, in particular hypertriton puzzle
- Femptoscopy
- Strangeness and neutron stars
- Kaonic nuclear bound states: theory and experiment
- New detector systems for kaonic atoms and related measurements

Speakers

P.C. Bruns	Czech Acad. of Sciences, Czech Republic
A. Cieply	NPI, Czech Acad. of Sciences Czech Republic
C. Curceanu	LNF-INFN, Italy
R. Del Grande	INFN-LNF, Italy
L. Fabbietti	TU München, Germany
A. Feijoo Aliau	NPI, Czech Acad. of Sciences, Czech Republic
A. Filippi	INFN Torino, Italy
E. Friedman	Hebrew University, Jerusalem, Israel
A. Gal	Hebrew University of Jerusalem, Israel
T. Hashimoto	JAEA, Japan
B. Hohlweger	TU München, Germany
J. Hrtankova	ASCR, Czech Republic

M. Iwasaki	RIKEN, Japan
K. Kacprzak	Jagiellonian University, Poland
A. Khreptak	Jagiellonian University, Poland
M. Merafina	University of Rome La Sapienza, Italy
M. Miliucci	LNF-INFN, Italy
H. Ohnishi	ELPH, Tohoku University, Japan
A. Ramos	University of Barcelona, Spain
B. Reingruber	SMI, Austria
F. Sakuma	RIKEN, Japan
S. Scherl	Austrian Acad.of Sciences, Austria
T. Schäfer	NPI, Academy of Sciences Czech Republic
S. Scordo	Laboratori Nazionali di Frascati, Italy
K. Simonov	University of Vienna, Austria
D. Sirghi	INFN-LNF, Italia
F. Sirghi	INFN, Italia
M. Skurzok	LNF-INFN, Italy
M. Steinen	Helmholtz-Institute Mainz, Germany
H. Tamura	Tohoku University, Japan
M. Tüchler	Stefan Meyer Institute, Austria
O. Vazquez Doce	TU-Munich, Germany
I. Vidaña	INFN, Italy
W. Weise	TU Munich, Germany
S. Wycech	Nat. Centre for Nuclear Research, Poland
T.O. Yamamoto	Japan Atomic Energy Agency, Japan

Scientific report

Kaonic atoms are a very useful instrument to understand the QCD in non-perturbative regime in systems with strangeness. New and planned kaonic atoms measurements set new standards for QCD inspired theories, such as optical models, chiral perturbation theories, which have a strong impact also in astrophysics for the study of the equation of state of neutron stars.

We discussed the most recent results for kaonic helium measurements performed at J-PARC in Japan, and future plans for kaonic deuterium measurements in Italy at DAFNE, SIDDHARTA-2, and J-PARC (Japan), E57. Also, new detector developments, such as VOXES system, TES detectors and new SDD detectors, were presented for future high precision measurements, for example of the 2p state of kaonic helium 3 and 4.

Hypernuclear physics, in particular the hypertriton puzzle was also discussed, from experimental and theoretical point of view and with its implication in our understanding of QCD.

Studies of reactions from the interaction of kaons with nuclear matter, producing hyperons in the final state or deeply bound kaonic nuclei, were shown and discussed, by AMADEUS and E15 at J-PARC. Also, the hottest topics in astrophysics related to hyperon puzzle and strangeness in neutron stars were presented in detail, with future plans for theory and experiments.

Femptoscopy, a new method to study strangeness in ALICE, was presented and the latest results were shown. Recent HADES results on hyperon propagation in matter and phi in-medium properties were discussed in detail.

Another hot topic in strangeness low-energy physics which was object of many talks at the workshop was the structure of Lambda(1405) – results from AMADEUS and J-PARC experiments, with results studying its structure in final channels as Lambda-proton and Sigma-proton, were presented.

The possible role of strange matter as a dark matter component was also discussed, together with items related to other exotic atoms, such as heavy Ξ- atoms at PANDA, search for a Stable Six-Quark State at BABAR, and eta-mesic bound states.

Results and Highlights

The “STRANEX: Recent progress and perspectives in STRANge EXotic atoms studies and related topics” workshop focused on the most recent achievements and open problems in kaonic atoms physics and related topics, both in theory and experiment, investigating also the implications in and from astrophysics and cosmology, in particular the equation of state for neutron stars.

Future perspectives and possible solutions to puzzles as the hypertriton lifetime, the hyperon puzzle in neutron stars or the still-unknown structure of the Lambda(1405) were thoroughly discussed, together with the possible contribution of strange matter to the dark matter in the Universe.

Experiments on kaonic atoms and kaon-nuclei interaction studies performed or under preparation to facilities with kaon beams, such as DSAFNE and J-PARC, were discussed, and a future plan for optimizing the use of the experimental data by theoreticians prepared, in a common strategy, involving also the participation to the European project STRONG-2020.

New detector systems for extreme high precision kaonic atoms are being developed, such as TES and VOXES systems, which will produce new results in the coming year with high potential for better understanding QCD at low energy.

It was the right time for the various communities working in this field to come together, discuss their findings and plan future activities towards an even deeper understanding of the role of strangeness in the Universe.

The STRANEX workshop created a profitable cooperation between experimental and theoretical physicists working in several European and Japanese laboratories. A sizable fraction (30%) of the participants were young or very young scientists presenting the results of their works.

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

2.3.24 *JPAC Collaboration Meeting*

Date	December 18-20, 2019
Organizers	
Alessandro Pilloni	ECT*
Number of participants	18

Main topics

Recently there have been dramatic advancements in accelerator technologies, detection techniques and on the theoretical side, algorithms for first-principles QCD analyses. These have led to several candidates for possible "exotic" hadrons, i.e., quark-gluon hybrids or quark-hadron molecular states. It thus appears that interpretation of the entire hadron spectrum in terms of the most-naive constituent quark model is no longer possible. If confirmed, such exotic hadrons could drastically alter our understanding of strong QCD and shed new light on the confinement of quarks. Given the wide interest in hadron spectroscopy, the Joint Physics Analysis Center (JPAC) has been dedicated to the development of theoretical and phenomenological analysis methods for the analysis of hadron reactions. Amplitude models based on principles of *S*-matrix theory are developed for various reactions of interest to the hadron physics community and QCD practitioners. JPAC members work in close collaboration with experimentalists on implementing theoretical innovations into the existing data analysis streams.

The workshop was organized in five different sessions:

- Pole searches: devoted to the ongoing analysis on the determination of resonance parameters from existing high statistics data, in particular on the $J/\psi \to \gamma\pi^0\pi^0$ data, where the scalar glueball candidate is expected to be seen, and on $\pi\pi$ and $K\acute{K}$ scattering data. Attention was also put on other numerical techniques to perform analytic continuation.
- LHCb: devoted to the discussion of helicity formalisms in Dalitz plot analysis, and to the presentation of ongoing analyses in LHCb of interest for spectroscopy, in particular of channels involving $J/\psi p$ pentaquark resonances.
- CLAS12: the session was devoted to establishing the activity of the Italian branch of the CLAS12 Collaboration, for what the spectroscopy is concerned. The synergies with theorists were also discussed.
- Remote: members of the JPAC collaboration who were not able to attend in person had an afternoon dedicated slot.
- Diverse: other discussions, related to the nature of exotic states and presentation of other projects.

Attendees

Andrea Bianconi	Università di Brescia, Italy
Daniele Binosi	ECT*, Italy
Letterio Biondo	Università di Messina, Italy

Andrea Celentano	INFN Genova, Italy
Giovanni Costantini	Università di Brescia, Italy
Jinlin Fu	Università di Milano, Italy
Robert Kaminski	Institute of Nuclear Physics PAS, Poland
Giuseppe Mandaglio	Università di Messina, Italy
Daniele Marangotto	Università di Milano, Italy
Luca Marsicano	INFN Genova, Italy
Vincent Mathieu	Università Complutense, Spain
Mikhail Mikhasenko	CERN, Switzerland
Nicola Neri	Università di Milano, Italy
Jannes Nys	University of Ghent, Belgium
Alessandro Pilloni	ECT*, Italy
Arkaitz Rodas	College of William and Mary, USA
Elisabetta Spadaro Norella	Università di Milano, Italy
Luca Venturelli	Università di Brescia, Italy

Remotely

Miguel Albaladejo	JLAB
Łukasz Bibrzycki	INP Krakow
Igor Danilkin	JGU Mainz
Sebastian Dawid	Indiana University
Cesar Fernández-Ramírez	UNAM
Sergi Gonzàlez-Solís	Indiana University
Andrew Jackura	Old Dominion University
Viktor Mokeev	JLAB
Robert Perry	Adelaide University
Adam Szczepaniak	Indiana University
Daniel Winney	Indiana University

Scientific report

The JPAC Collaboration Meeting took place at the Villa Tambosi of ECT* in Trento from 18 to 20 December 2019. The objective of the workshop was to exchange views on strong dynamics for physics at the frontier between theory and experiments. The program contained discussions on ongoing amplitude analyses on LHCb, CLAS12 and BESIII data. The workshop aimed at providing an informal environment to develop new ideas, and crossing the boundaries between theory and experiment as needed to make further progress in the field. The format chosen for the workshop has long presentations and foresaw ample time for discussion. The joint lunches and dinners offered further chances to continue the discussion.

The workshop was attended by 18 physicists, from 5 European countries. One participant was able to come from the United States (JLab). The workshop attendants represent a healthy mix of young theorists and experimentalists involved in hadron spectroscopy. The vast majority of attendants were students and postdocs at the early stages of the career. Other 10 people from Germany, US and Taiwan were interested in the topic but could not attend in person. They were able to participate the workshop through remote connection. The list of attendants includes theorists as

Robert Kaminski (INP-PAS, Krakow), Vincent Mathieu (Madrid), Alessandro Pilloni (ECT*), and experimentalists as Andrea Celentano (INFN Genova), Giuseppe Mandaglio (Messina), Nicola Neri (Milano), Luca Venturelli (Brescia). The atmosphere at the workshop was very open and intense, with lots of active discussions on formal and practical aspects of the techniques to extract the physics from data analysis.

Results and Highlights

- Pole searches: devoted to the ongoing analysis on the determination of resonance parameters from existing high statistics data, in particular on the $J/\psi \rightarrow \gamma\pi^0\pi^0$ data, where the scalar glueball candidate is expected to be seen, and on $\pi\pi$ and $K\acute{K}$ scattering data. Attention was also put on other numerical techniques to perform analytic continuation.
- LHCb: devoted to the discussion of helicity formalisms in Dalitz plot analysis, and to the presentation of ongoing analyses in LHCb of interest for spectroscopy.
- CLAS12: the session was devoted to establishing the activity of the Italian branch of the CLAS12 Collaboration, for what the spectroscopy is concerned. The synergies with theorists were also discussed. In particular theorists committed to provide a Monte Carlo code with the best description available of single meson electroproduction processes.
- Remote: members of the JPAC collaboration who were not able to attend in person had an afternoon dedicated slot. Ongoing projects on 3-body interaction were discussed.
- Diverse: other discussions, related to the nature of exotic states, and how to use the information on the lineshape to distinguish the various phenomenological models. An international outreach project to transform cellphones into cosmic ray detectors was also presented.

2.4 Doctoral Training Program 2019

ECT Doctoral Training Program "Effective Field Theory Techniques"*
June 24 - July 12, 2019
(Report by G. Ripka)

The 2019 ECT* Doctoral Training Program on "*Effective Field Theory Techniques"* was held at ECT* from June 24 to July 12. The program organizers were Martin Savage (INT & University of Washington) and Roxanne Springer (Duke University). *Georges Ripka (IPhT, Saclay and ECT*) attended as student coordinator.* The local administrative coordinator was Serena degli Avancini.

The program focused on techniques and applications of effective field theories in sub-atomic physics. The aim was to guide participants from the basic underpinnings of low-energy effective field theories describing regimes of quantum systems, through to state-of-the-art techniques applied to perform precision calculations in quantum chromodynamics and the standard model. The lectures included techniques for describing jets at the LHC, precision heavy-flavor physics, nuclear forces from lattice QCD calculations, operator analyses for the search for physics beyond the standard model, along with new insights into quantum gauge theories.

The program featured two presenters each week, each providing about 7 hours of lectures, supplemented with exercises. Students had opportunities to interact with the presenters and organizers outside the presentations, tutorials, and problem-solving sessions. Students were given access to the computing facilities of ECT*.

The 2019 Doctoral Training Program was attended by 33 students, among which 32 were working towards their PhD and one was post-PhD. The attendees are listed at the end of this report.

There were 2 lecturers each week, altogether 6 lecturers. Two 1½ hour lectures were given each morning, with a ½ hour coffee break between them. Probably a 5-minute break in the middle of each 1½ hour lecture would have been more efficient. It was suggested to some lecturers, but they declined to implement it.

2.4.1. Lectures

The following lectures were given:

Brian Tiburzi (City College of New-York, USA)
Introduction to effective field theories

Martha Constantinou (Temple University, USA)
QCD and Effective Operator Renormalization

Silas Beane (University of Washington, USA)
Effective Field Theories for Many-Hadron Systems

Monica Pate (Harvard University, USA)
Infrared Structure of Gravity and Gauge Theories

Nora Brambilla (TU München, Germany)
Nonrelativistic Effective Field Theories of QCD and QED

Frank Tackmann (DESY, Germany)
Effective Field Theories for Jet Physics

The 2019 DTP was the first DTP program during which the organizers, Martin Savage and Roxanne Springer, were present the whole time, which, of course, proved very useful. They decided to make video recordings of all lectures, and of most of the seminars. Barbara Curro Rossi was an invaluable resource for this effort, using her considerable technical expertise to solve audio and video problems. The lecturers and the students who gave seminars were, of course, asked if they permitted their presentations to be video recorded. Two lecturers, Monica Pate and Frank Tackmann, specified that their videos may be made available via a password-protected site to students who attended the DTP, but that the videos should not be made publically available. It is presently studied to find how the recordings can be made available to the students. Some lecturers also prepared lecture notes and problem sets were made available to the students. It was commented by some students that the diversity in lecturers (50% men and 50% women, ages ranging from ~30 through to ~60) was nice to see.

As in previous Doctoral Training Programs, the students gave short seminars. This year, only 19 of the students gave seminars on their work. This is regrettable since, student seminars are quite useful to the participants, stimulating discussions and interactions. Some of the seminar time was allotted to lecturers who presented their current research interests -typically somewhat external to their lectures - as well as to Professor Francesco Pederiva (University of Trento) who discussed the use of effective field theories in quantum simulations. Some students individually expressed enthusiasm about the presentations, but more specific data will be collected via a survey that the organizers will send to the DTP participants.

Weekly evening gatherings for the students and the lecturers were also organized at several Trento pizzerias.

The weather proved to be the most significant challenge to the program, with record heat during the first week and flooding of the lecture hall at the beginning of the second week. The high heat stressed the air conditioning in the lecture hall, and the flood damage to the floor lead to moving the lectures to the third floor.

In this context, the presence of Serena degli Avancini – as usual responsible for organizing the general logistics of the DTP - was essential to help find practical solutions for coping with the challenging situation.

2.4.2. *List of Students*

Algueró Marcel	Institut de Física d'Altes Energies. IFAE, Spain
Beck Saar	Hebrew University of Jerusalem, Israel
Billis Georgios	DESY, Germany
Brandao de Gracia Gabriel	Institute of Theoretical Physics-UNESP, Brazil
Castaño Yepes Jorge David	Instituto de Ciencias Nucleares UNAM, Mexico

Delorme Stéphane	IMT Atlantique, France
Engel Tim	Paul Scherrer Institute, University of Zurich, Switzerland
Filandri Elena	Università degli studi di Trento, Italy
Ghosh Ritesh	Saha Institute of Nuclear Physics, India
Graf Lukas	Max-Planck-Institut für Kernphysik, MPIK, Germany
Illa Subiña Marc	Universitat de Barcelona, Spain
Klco Natalie	University of Washington, USA
Laub Laetitia	University of Bern, Switzerland
Lyu Songlin	Sichuan University, China
Monnard Joachim	University of Bern, Switzerland
Moore Alexander	University of Manchester, UK
Mukherjee Arghya	Saha Institute of Nuclear Physics, India
Müller Fabian	Rheinische Friedrich-Wilhelms-Universität Bonn, Germany
Novoa Brunet Martin	CNRS, Univ. Paris-Sud, Université Paris-Saclay, France
Perotti Elisabetta	Uppsala University, Sweden
Richardson Thomas	University of South Carolina, USA
Rodkin Dmitry	Dukhov Research Institute for Automatics, Moscow, Russia
Rojas Pacheco Camilo Alejandro	Universidad Autonoma de Barcelona, Spain
Salinas San Martín Jordi	Universidad Nacional Autónoma de México, Mexico
Shaw Andrew	University of Maryland, USA
Singh Hersh	Duke University, USA
Siwach Pooja	Indian Institute of Technology, Roorkee, India
Tafrihi Azar Isfahan	University of Technology, Iran
Takacs Adam Takacs	University of Bergen, Norway
Talukdar Pulak	Indian Institute of Technology, Guwahati, India
Tantary Ubaid	Kent State University, USA
Turro Francesco	Università degli Studi di Trento, Italy
Yamauchi Yukari	University of Maryland - College Park, USA

2.5 Talent School 2019

From Quarks and Gluons to Nuclear Forces and Structure

July 15 – August 02, 2019

(Report by A. Shindler)

Organizers

Dean Lee - Michigan State University - leed@frib.msu.edu

Andrea Shindler - Michigan State University - shindler@frib.msu.edu

We have organized a three-week TALENT (Training in Advanced Low Energy Nuclear Theory) summer school entitled "From Quarks and Gluons to Nuclear Forces and Structure" at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) in Trento. From July 15 to August 2, a group of 28 advanced graduate students from 14 different countries on 4 different continents took part in lectures and exercises presented by us as well as Zohreh Davoudi from the University of Maryland, Evgeny Epelbaum from Ruhr University Bochum, Thomas Luu from Forschungszentrum Jülich, and Francesco Pederiva from the University of Trento.

Students were trained in state-of-the-art methods and concepts in first principles nuclear theory such as lattice quantum chromodynamics, chiral effective field theory, finite-volume methods, and lattice effective theory. The purpose of the summer school was to train the next generation of nuclear theorists in computing physical properties of nuclear systems using *ab initio* methods based on the fundamental theory of the strong interactions. Understanding how quarks and gluons give rise to nucleonic properties and nuclear forces and using those nuclear forces to predict nuclear structure and the limits of stability are vital components of the science mission of FRIB. Training the next generation of researchers in these areas will ensure the continued development and vitality of FRIB science for years to come. We have prepared a web page https://indico.ectstar.eu/event/38/ for the TALENT School containing all the lectures and exercises presented.

Some of the topics covered by the course include:

1. Path integral and functional methods
2. Relativistic scalar, fermion, and gauge fields on the lattice
3. LQCD computational methods and approaches to nuclear physics
4. Properties of two-hadron systems: two mesons and two-baryon scattering and hadronic in- teractions
5. Multi-hadron systems with LQCD: multi-mesons and multi-baryon systems
6. Chiral symmetry breaking in QCD and its implication for the low-energy theory
7. Pion self interactions and pion-nucleon interactions
8. Two-nucleon and three-nucleon interactions in chiral effective field theory
9. Pionless and pionfull effective field theory of nuclear forces and transitions in the KSW power counting scheme

10. Nuclear lattice EFTs: computational methods and approaches: lattice simulations using auxiliary fields and pinhole algorithm for nuclear densities
11. Chiral EFT interactions and scattering on the lattice
12. Progress and challenges in other nuclear many-body techniques

2.5.1 *Lectures*

Zohreh Davoudi - University of Maryland
Evgeny Epelbaum - Ruhr University Bochum
Dean Lee - Michigan State University
Thomas Luu - Forschungszentrum Jülich
Francesco Pederiva - University of Trento
Andrea Shindler - Michigan State University

2.5.2 *List of Students*

Saar Beck	Hebrew University of Jerusalem, Israel
Pierre Henri Cahue	LPSC, France
Patrick Fasano	University of Notre Dame, USA
Elena Filandri	Università degli studi di Trento, Italy
Mikael Frosini	CEA Saclay, France
Peter Gysbers	University of British Columbia, Canada
Siddhartha Harmalkar	Univ. of Maryland, College Park, USA
Matthias Heinz	TU Darmstadt, Germany
Jan Lucas Hoppe	TU Darmstadt, Germany
Saurabh Vasant Kadam	Univ. of Maryland, College Park, USA
Hong An Le	The Australian National University, Australia
Yuanzhuo Ma	Peking University, China
Gloria Montana Faiget	Universidad de Barcelona, Spain
Felipe Ortega Gama	College of William & Mary, USA
Giovanni Pederiva	Michigan State University, USA
Jan Pokorný	Czech Technical Univ., Prague, Czech Republic
Matthew Rizik	Michigan State University, USA
Keita Sakai	Tohoku University, Japan
Adrian Horacio Santana-Valdés	UNAM, Mexico
Pooja Siwach	Indian Institute of Technology, Roorkee, India
Hershdeep Singh	Duke University, USA
Andrew Shaw	University of Maryland, USA
Jing Song	Beihang University, China
Halvard Sutterud	University of Oslo, Norway
Natsuki Tsukamoto	Tohoku University, Japan
Francesco Turro	Università degli Studi di Trento, Italy
Boyao Zhu	Michigan State University, USA
Lars Zurek	TU Darmstadt

Research at ECT*

3. Research at ECT*

3.1 Projects of ECT* Researchers

DANIELE BINOSI

Effective charge from lattice QCD

In collaboration with Z.-F. Cui (Nanjing University), J.-L. Zhang (Nanjing University), F. de Soto (Pablo de Olavide University, Seville), C. Mezrag (IRFU, Saclay), J. Papavassiliou (Valencia University), C. D. Roberts (Nanjing University), J. Rodríguez-Quintero (Huelva University), J. Segovia (Pablo de Olavide University, Seville), S. Zafeiropoulos (Marseille, CPT)

Using lattice configurations for quantum chromodynamics (QCD) generated with three domain-wall fermions at a physical pion mass, we obtain a parameter-free prediction of QCD's renormalisation-group-invariant process-independent effective charge, α(k2). Owing to the dynamical breaking of scale invariance, evident in the emergence of a gluon mass-scale, this coupling saturates at infrared momenta: α(0)/π=0.97(4). Amongst other things: α(k2) is almost identical to the process-dependent (PD) effective charge defined via the Bjorken sum rule; and also that PD charge which, employed in the one-loop evolution equations, delivers agreement between pion parton distribution functions computed at the hadronic scale and experiment. The diversity of unifying roles played by α(k2) suggests that it is a strong candidate for that object which represents the interaction strength in QCD at any given momentum scale; and its properties support a conclusion that QCD is a mathematically well-defined quantum field theory in four dimensions.

Drawing insights from pion parton distributions

In collaboration with M. Ding (ECT/FBK, Trento & Nankai U.), K. Raya (IFM-UMSNH, Michoacan), L. Chang (Nankai University), C. D. Roberts (Argonne, PHY and Nanjing University), S. M. Schmidt (IAS, Jülich)

A symmetry-preserving continuum approach to the two valence-body bound-state problem is used to calculate the valence, glue and sea distributions within the pion; unifying them with, inter alia, electromagnetic pion elastic and transition form factors. The analysis reveals the following momentum fractions at the scale ζ2:=2 GeV: ⟨xvalence⟩=0.48(3), ⟨xglue⟩=0.41(2), ⟨xsea⟩=0.11(2); and despite hardening induced by the emergent phenomenon of dynamical chiral symmetry breaking, the valence-quark distribution function, qπ(x), exhibits the x≃1 behaviour predicted by quantum chromodynamics (QCD). After evolution to ζ=5.2GeV, the prediction for qπ(x) matches that obtained using lattice-regularised QCD. This confluence should both stimulate improved analyses of existing data and aid in planning efforts to obtain new data on the pion distribution functions.

Elastic electromagnetic form factors of vector mesons

In collaboration with: Y.-Z. Xu (Nanjing University), Z.-F. Cui (Nanjing University and Purple Mountain Observ.), B.-L. Li (Nanjing University), C. D. Roberts (Nanjing University and Purple Mountain Observ.), S.-S. Xu (Nanjing University Posts Telecom), H. S. Zong (Nanjing University)

A symmetry-preserving approach to the two valence-body continuum bound-state problem is used to calculate the elastic electromagnetic form factors of the ρ-meson and subsequently to study the evolution of vector-meson form factors with current-quark mass. To facilitate a range of additional comparisons, K* form factors are also computed. The analysis reveals that vector mesons are larger than pseudoscalar mesons; composite vector mesons are nonspherical, with magnetic and quadrupole moments that deviate ∼30% from point-particle values; in many ways, vector-meson properties are as much influenced by emergent mass as those of pseudoscalars; and vector-meson electric form factors possess a zero at spacelike momentum transfer. Qualitative similarities between the electric form factors of the ρ and the proton, GEp, are used to argue that the character of emergent mass in the Standard Model can force a zero in GEp. Moreover, the existence of a zero in vector-meson electric form factors entails that a single-pole vector-meson dominance model can only be of limited use in estimating properties of off-shell vector mesons, providing poor guidance for systems in which the Higgs mechanism of mass generation is dominant.

Exploring event horizons and Hawking radiation through deformed graphene membranes

In collaboration with: T. Morresi (ECT, Trento & Trento U.), S. Simonucci (Camerino U.), R. Piergallini (Camerino U.), S. Roche (ICN2 & ICREA), N.M. Pugno (Trento U. & Ket-Lab & Queen Mary U.), S. Taioli (ECT, Trento)

Analogue gravitational systems are becoming an increasing popular way of studying the behaviour of quantum systems in curved spacetime. Setups based on ultracold quantum gases in particular, have been recently harnessed to explore the thermal nature of Hawking's and Unruh's radiation that was theoretically predicted almost 50 years ago. For solid state implementations, a promising system is graphene, in which a link between the Dirac-like low-energy electronic excitations and relativistic quantum field theories has been unveiled soon after its discovery. Here we show that this link extends to the case of curved quantum field theory when the graphene sheet is shaped in a surface of constant negative curvature, known as Beltrami's pseudosphere. Thanks to large-scale simulations, we provide numerical evidence that energetically stable negative curvature graphene surfaces can be realized; the ratio between the carbon-carbon bond length and the pseudosphere radius is small enough to allow the formation of an horizon; and the associated Local Density Of States evaluated at horizon's proximity has a thermal nature with a characteristic temperature of few tens of Kelvin. Such findings pave the way to the realization of a solid-state system in which the curved spacetime dynamics of quantum many body systems can be investigated.

Pion and kaon structure at the electron-ion collider

In collaboration with A. C. Aguilar (Campinas State U.), Z. Ahmed (Regina U.), C. Aidala (Michigan U.), S. Ali (Catholic U.), V. Andrieux (Illinois U., Urbana (main) & CERN), J. Arrington (Argonne (main)), A. Bashir (IFM-UMSNH, Michoacan), V. Berdnikov (Catholic U.), L. Chang (Nankai U.), C. Chen (Giessen U.), M. Chen (Nankai U.), J. Pacheco B.C. de Melo (Cruzeiro do Sul U.), M. Diefenthaler (Jefferson Lab), M. Ding (ECT/FBK, Trento & & Nankai U.), R. Ent (Jefferson Lab), T. Frederico (Sao Paulo, Inst. Tech. Aeronautics), F. Gao (Heidelberg U.), R. W. Gothe (South Carolina U.), M. Hattawy (Old Dominion U.), Timothy J. Hobbs (Southern Methodist U.), Tanja Horn (Catholic U.), Garth M. Huber (Regina U.), Shaoyang Jia (Iowa State U.), Cynthia Keppel (Jefferson Lab), Gastão Krein (Sao Paulo, IFT), Huey-Wen Lin (Michigan State U.), Cédric Mezrag (INFN, Rome), Victor Mokeev (Jefferson Lab), Rachel Montgomery (Glasgow U.), Hervé Moutarde (AIM, Saclay), Pavel Nadolsky (Southern Methodist U.), Joannis Papavassiliou (Valencia U. & Valencia U., IFIC), Kijun Park (Jefferson Lab), Ian L. Pegg (Catholic U.), Jen-Chieh Peng (Illinois U., Urbana (main)), Stephane Platchkov (AIM, Saclay), Si-Xue Qin (Chongqing U.), Khépani Raya (Nankai U.), Paul Reimer (Argonne (main)), David G. Richards (Jefferson Lab), Craig D. Roberts (Argonne (main)), Jose Rodríguez-Quintero (Huelva U. & IPM, Tehran), Nobuo Sato (Jefferson Lab), Sebastian M. Schmidt (IAS, Jülich & JARA, Aachen), Jorge Segovia (Pablo de Olavide U., Seville), Arun Tadepalli (Jefferson Lab), Richard Trotta (Catholic U.), Zhihong Ye (Argonne (main)), Rikutaro Yoshida (Jefferson Lab), Shu-Sheng Xu (NUAA, Nanjing).

Understanding the origin and dynamics of hadron structure and in turn that of atomic nuclei is a central goal of nuclear physics. This challenge entails the questions of how does the roughly 1GeV mass-scale that characterizes atomic nuclei appear, why does it have the observed value, and, enigmatically, why are the composite Nambu-Goldstone (NG) bosons in quantum chromodynamics (QCD) abnormally light in comparison? In this perspective, we provide an analysis of the mass budget of the pion and proton in QCD, discuss the special role of the kaon, which lies near the boundary between dominance of strong and Higgs mass-generation mechanisms, and explain the need for a coherent effort in QCD phenomenology and continuum calculations, in exa-scale computing as provided by lattice QCD, and in experiments to make progress in understanding the origins of hadron masses and the distribution of that mass within them. We compare the unique capabilities foreseen at the electron-ion collider (EIC) with those at the hadron-electron ring accelerator (HERA), the only previous electron-proton collider, and describe five key experimental measurements, enabled by the EIC and aimed at delivering fundamental insights that will generate concrete answers to the questions of how mass and structure arise in the pion and kaon, the Standard Model's NG modes, whose surprisingly low mass is critical to the evolution of our Universe.

Symmetry, symmetry breaking, and pion parton distributions

In collaboration with: Minghui Ding (ECT/FBK, Trento & Nankai U.), Khépani Raya (IFM-UMSNH, Michoacan), Lei Chang (Nankai U.), Craig D. Roberts (Argonne, PHY and Nanjing U.), Sebastian M Schmidt (IAS, Jülich)

A symmetry-preserving approach to the two valence-body continuum bound-state problem is used to calculate the valence, glue and sea distributions within the pion; unifying them with, inter alia, the electromagnetic pion elastic and transition form factors. The analysis reveals the following light-front momentum fractions at the scale ζ2:=2 GeV: ⟨xvalence⟩=0.48(3), ⟨xglue⟩=0.41(2), ⟨xsea⟩=0.11(2); and despite hardening induced by the emergent phenomenon of dynamical chiral symmetry breaking, the valence-quark distribution function, qπ(x), exhibits the x≃1 behaviour predicted by quantum chromodynamics (QCD). After evolution to ζ=5.2GeV, the prediction for qπ(x) matches that obtained using lattice-regularised QCD. This confluence should both stimulate improved analyses of existing data and aid in planning efforts to obtain new data on the pion distribution functions.

Spectral functions of confined particles
In collaboration with Ralf-Arno Tripolt (Frankfurt U.)

We determine the gluon and ghost spectral functions along with the analytic structure of the associated propagators from numerical data describing gauge correlators at space-like momenta obtained by either solving the Dyson-Schwinger equations or through lattice simulations. Our novel reconstruction technique shows the expected branch cut for the gluon and the ghost propagator, which, in the gluon case, is supplemented with a pair of complex conjugate poles. Possible implications of the existence of these poles are briefly addressed.

Off-shell renormalization in the presence of dimension 6 derivative operators. II. UV coefficients
In collaboration with: A. Quadri (INFN Milan)

The full off-shell one loop renormalization for all divergent amplitudes up to dimension 6 in the Abelian Higgs-Kibble model, supplemented with a maximally power counting violating higher-dimensional gauge-invariant derivative interaction ∼g ϕ†ϕ(Dμϕ)†Dμϕ, is presented. This allows one to perform the complete renormalization of radiatively generated dimension 6 operators in the model at hand. We describe in detail the technical tools required in order to disentangle the contribution to UV divergences parameterized by (generalized) non-polynomial field redefinitions. We also discuss how to extract the dependence of the β-function coefficients on the non-renormalizable coupling gg in one loop approximation, as well as the cohomological techniques (contractible pairs) required to efficiently separate the mixing of contributions associated to different higher-dimensional operators in a spontaneously broken effective field theory.

ARIANNA CARBONE
Ab initio constraints on thermal effects of the nuclear equation of state (EOS)
In collaboration with A. Schwenk (Univ. Darmstadt)

We studied first ab initio self-consistent Green's function (SCGF) calculations of thermal effects on the nuclear EOS using different chiral two- and three-nucleon interactions. In particular, we analyzed for symmetric nuclear and pure neutron matter the thermal energy and thermal pressure, from which we accessed the behavior of the thermal index used widely in astrophysical simulations. Our calculations show how a density-dependent thermal index, which is, e.g., based on ideal-gas thermal contributions, does not capture the thermal effects based on ab initio calculations. We have also explored a functional form for thermal index based on the density dependence of the nucleon effective mass, which captures the behavior of the thermal index remarkably well. In particular, this shows that a calculation of the effective mass, beyond the Hartree-Fock level or mean-field approximation, is necessary to capture these thermal effects. This work is a first step towards a more comprehensive analysis of thermal effects in the nuclear EOS and a full finite-temperature description based on realistic nuclear interactions.

Nuclear matter properties at finite temperatures from effective interactions

In collaboration with J. Xu (Shangai), Z. Zhang (Sun Yat-Sen University) and C.-M. Ko (Texas A&M)

We studied if commonly used nucleon-nucleon effective interactions, obtained from fitting the properties of cold nuclear matter and of finite nuclei, can properly describe the hot dense nuclear matter produced in intermediate-energy heavy-ion collisions. We used two representative effective interactions, i.e., an improved isospin- and momentum-dependent interaction with its isovector part calibrated by the results from the *ab initio* nonperturbative SCGF approach with chiral forces, and a Skyme-type interaction fitted to the equation of state of cold nuclear matter from chiral effective many-body perturbation theory and the binding energy of finite nuclei. In the mean-field approximation, we evaluate the equation of state and the single-nucleon potential for nuclear matter at finite temperatures and compare them to those from the SCGF approach. We find that the improved isospin- and momentum-dependent interaction reproduces reasonably well the SCGF results due to its weaker momentum dependence of the mean-field potential than in the Skyrme-type interaction. Our study thus indicates that effective interactions with the correct momentum dependence of the mean-field potential can properly describe the properties of hot dense nuclear matter and are thus suitable for use in transport models to study heavy-ion collisions at intermediate energies.

Setting ab initio uncertainties on finite-temperature properties of neutron matter

We employed state-of-the-art chiral interactions, proven successful in describing finite nuclei and zero-T infinite matter, to set an uncertainty band on finite-T properties of neutron matter. We provided an error analysis that accounts for uncertainties in the interaction, the many-body method truncation and the thermodynamical consistency of the approach. The major uncertainty on the PNM finite-T pressure is related to the chiral interaction, being this at twice saturation density four times larger than the error associated to the many-body method. On the contrary, this behavior is reversed for microscopic properties, such as the effective mass or the single-particle potential, where the full many-body error is more than twice the chiral interaction uncertainty band at twice saturation density. This underlines the fact that beyond first-order calculations of the nucleon effective mass are mandatory, especially in view of recent studies that show how parametrized functions of this quantity can mimic the thermal part of the EoS.

MINGHUI DING

Symmetry, symmetry breaking, and pion parton distributions

In collaboration with K. Raya (Nankai University, China & IFM-UMSNH, Michoacan), D. Binosi (ECT*, Trento, Italy), L. Chang (Nankai University, China), C. D. Roberts (ANL, Lemont, USA), and S. M. Schmidt (IAS, Jülich, Germany)

A symmetry-preserving approach to the two valence-body continuum bound-state problem is used to calculate the valence, glue and sea distributions within the pion; unifying them with, inter alia, the electromagnetic pion elastic and transition form factors [1]. The analysis reveals the following light-front momentum fractions at the scale ζ = 2 GeV: <x_{valence}> = 0.48(3), <x_{glue}> = 0.41(2), <x_{sea}> = 0.11(2); and despite hardening induced by the emergent phenomenon of dynamical chiral symmetry breaking, the valence-quark distribution function, q^π(x), exhibits the x~1 behaviour predicted by quantum chromodynamics (QCD). After evolution to ζ = 5.2 GeV, the prediction for q^π(x) matches that obtained using lattice-regularised QCD; hence two disparate treatments are now seen to yield the same prediction. This confluence should both stimulate improved analyses of existing data and aid in motivating and supporting efforts to obtain new data on the pion distribution functions at existing and anticipated facilities.

Kaon parton distribution function

In collaboration with K. Raya (Nankai University, China), D. Binosi (ECT*, Trento, Italy), L. Chang (Nankai University, China), C. D. Roberts (Nanjing University, China), and S. M. Schmidt (IAS, Jülich, Germany)

We study on the valence-quark, glue and sea parton distribution functions within the kaon using a symmetry preserving continuum approach to the two-body bound state problem in quantum field theory [2]. We investigate how to determine the value of the hadronic scale, at which kaon is purely bound state of dressed-quark and dressed-antiquark. We calculate the distributions at the hadronic scale and take the evolution to two typical scales for comparison with NA3 spectrometer experiment data at CERN SPS, phenomenology and lattice regularized QCD.

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JARKKO PEURON

Self-similarity and spectral properties of non-Abelian plasmas at the initial stages

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

The initial non-equilibrium evolution of the matter created in ultrarelativistic heavy-ion collisions can be described in terms of classical color fields when the occupation numbers are nonperturbatively high [1]. The classical description however has an overlapping range of validity with kinetic theory approach [2]. We study the interface of these two theories by studying the spectral properties of classical gluodynamics in the self-similar regime.

Previously we have extracted the spectral function of the classical gluodynamics in three-dimensional nonexpanding system [3]. In this study we establish that there indeed are quasiparticles in the system and measure their damping rate as a function of momentum for the first time. Since we expect the initial state in ultrarelativistic heavy-ion collisions at high energy to be approximately boost invariant, we have studied two-dimensional Yang-Mills system [4]. In [4] we have established that the two-dimensional system also features self-similar behavior. This enables us to measure the spectral properties of the two-dimensional system, which more accurately mimics the boost invariant system predicted by the color glass condensate framework at high energy. In this way we gain information whether the matter created shortly after the heavy-ion collision has a quasiparticle description.

Heavy quark diffusion coefficient out of equilibrium

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

Theoretical evaluation of transport properties of the matter created in ultrarelativistic heavy-ion collisions has been a longstanding problem. However so far transport coefficients have been estimated for matter in equilibrium. Our aim in this project is to measure the heavy quark diffusion coefficient far from equilibrium for the first time using real time lattice simulations by measuring suitable unequal time electric field correlator corresponding to the unequal time Lorentz force-force correlation function as done in [5]. We will also be using our data on the gluon spectral functions [3] to better understand the signal arising from the measurement.

Non-equilibrium quark production at the initial stages of ultrarelativistic heavy-ion collisions

In collaboration with S. Schlichting (University of Bielefeld, Germany)

Understanding quark production from the first principles in the weak coupling framework is important for understanding chemical thermalization in heavy-ion collisions. The initial state is dominated by overoccupied gluon fields. However, in equilibrium a significant fraction of the energy density is carried by quarks. This raises the question of how these quarks are generated during the nonequilibrium evolution. Our aim in this project is to extract the time-evolution of the initial quark spectrum using real time lattice techniques. We aim to carry out the simulation using the formulation developed in [6], where the quark spinors are formulated boost invariantly.

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ALESSANDRO PILLONI

Study of exotic resonances in the light and heavy sectors

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. We recently showed that the two hybrid candidates seen by COMPASS can be explained as single exotic resonances, thus restoring the agreement between theory and experiment [1]. We also studied which observables are most sensitive to the presence of an exotic wave in photoproduction experiments [2]. In the heavy sector, the new discovery of hidden charm pentaquarks at LHCb (where I signed the analysis as affiliated theorist) [3] has triggered several studies on their interpretation [4], as well as new proposals for searching these exotic candidates in other reactions. We proposed to use the peculiar features of the CEBAF accelerator to measure double polarization asymmetries in J/ψ photoproduction, which turn to be very sensitive to the presence of the pentaquarks claimed by LHCb [5].

Study of 3-body formalisms

In collaboration with Joint Physics Analysis Center

The 3-body problem is one of the most important problems in nuclear and particle physics. The role of the 3-nucleon force, for example, is central in many nuclear models. As for Hadron Spectroscopy, the 3-body dynamics is responsible for many new states decaying into three particles. In the near future, experiments will provide data on 3-body heavy meson decays with unprecedented statistics. We discussed two possible solutions of the $3\to 3$ elastic unitarity equation, and discuss how to use them in practical data parameterizations [6]. The 3-body problem is the cutting edge in Lattice QCD. There are different formalisms in the literature to derive quantization conditions for the 3-body problem. We proved that two of them are equivalent, namely that the kernels of the integral equations of the two formalisms can be derived one from another by means of a real integral equation [7]. The presence of spins complicates further the 3-body equations. In [8] we showed how to properly take particle with spin into account in 3-body decays, both in helicity and covariant formalisms.

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NAOTO TANJI

Gauge ambiguity of the quark spectrum in the Color Glass Condensate

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

In the Color Glass Condensate, the inclusive spectrum of produced quarks in a heavy ion collision is obtained as the Fourier transform of a 2-fermion correlation function. Due to its non-locality, the two points of this function must be linked by a Wilson line in order to have a gauge invariant result, but when the quark spectrum is evaluated in a background that has a non-zero chromo-magnetic field, this procedure suffers from an ambiguity related to the choice of the contour defining the Wilson line. In Ref. [1], we use an analytically tractable toy model of the background field in order to study this contour dependence. We show that for a straight contour, unphysical contributions to the spectrum in p^{-2} and p^{-3} cancel, leading to a spectrum with a tail in p^{-4}. If the contour defining the Wilson line deviates from a straight line, the path dependence is at most of order p^{-5} if its curvature is bounded, and of order p^{-4} otherwise. When the contour is forced to go through a fixed point, the path dependence is even larger, of order p^{-2}.

Angular mode expansion of the Boltzmann equation in the small-angle approximation

In collaboration with J. P. Blaizot (Université Paris-Saclay CEA, France)

In Ref. [2], we use an expansion in angular mode functions in order to solve the Boltzmann equation for a gluon plasma undergoing longitudinal expansion. By comparing with the exact solution obtained numerically by other means we show that the expansion in mode functions converges rapidly for all cases of practical interest, and represents a substantial gain in numerical effort as compared to more standard methods. We contrast the cases of a non expanding plasma and of longitudinally expanding plasmas, and follow in both cases the evolutions towards thermalization. In the latter case, we observe that, although the spherical mode function appears to be well reproduced after some time by a local equilibrium distribution function depending on slowly varying temperature and chemical potential, thereby suggesting thermalization of the system, the longitudinal and transverse pressures take more time to equilibrate. This is because the expansion hinders the relaxation of the first angular mode function. This feature was also observed in a simpler context where the Boltzmann equation is solved in terms of special moments within the relaxation time approximation, and attributed there to the particular coupling between the first two moments of the distribution function. The present analysis confirms this observation in a more realistic setting.

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DIONYSIOS TRIANTAFYLLOPOULOS

Non-linear small-x evolution in QCD beyond leading order

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

High-energy evolution in perturbative QCD and in the presence of gluon saturation, based either on the more general framework of the Color Glass Condensate [1] or in the simpler setup of the Balitsky-Kovchegov (BK) equation [2,3,4], suffers from instabilities due to the presence of double transverse logarithms, which occur in all orders starting with the next-to-leading one [5,6]. It has been possible to resum such higher order corrections by imposing time-ordering for the successive gluon emissions [7,8].

In [9] we realized that the instability is not completely cured by these methods. This happens because different prescriptions for doing the resummation lead to very different physical results and therefore one is left with no predictive power. Taking as an example Deep Inelastic Scattering (DIS) off a hadron, we argued that the problem can be avoided by using as the evolution variable the rapidity of the hadronic target (corresponding to the familiar Bjorken x) instead of the one of the projectile. This choice is automatically consistent with the aforementioned proper time-ordering and furthermore allows for a direct interpretation of the results. Performing this change of variables at NLO, we observed that a new class of double logarithmic corrections emerges, and which eventually gives a new instability. The latter is less severe because these new logarithms become significantly large only in regimes which are highly disfavored by the typical evolution. We proposed several prescriptions for the necessary resummation, and we indeed found a weak scheme dependence, since all the results were consistent to each other to the order of accuracy. We further showed that the approach can be combined with the full set of NLO corrections in order to arrive at a new state of the art evolution at small Bjorken-x.

HERA data and collinearly-improved BK dynamics

In collaboration with B. Ducloué (Edinburgh), E. Iancu and G. Soyez (IPhT, Saclay, France)

Having established the above collinearly-improved version of the BK equation for the resummations of double logarithms, we used it to fit the HERA data for inclusive DIS at small Bjorken-x [10]. The equation further included an all-order resummation of single transverse logarithms [11] (due to DGLAP evolution) and running coupling corrections. Excellent fits for reasonable values of all the four fit parameters were obtained. We noticed that the fit quality improved when we included all resummation effects together with a physically-motivated initial condition (a particular version of the McLerran-Venugopalan model [12]). Single Inclusive DIS is another suitable process to study gluon saturation and its study using the same framework is in working progress.

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JOCHEN WAMBACH

My research in 2019 included the following topics:

- Collective properties and damping mechanisms in nuclei
- Pygmy dipole excitations
- 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 and the United States. In the following selected examples are summarized.

Gross, intermediate and fine structure of nuclear giant resonances: Evidence for doorway states

In collaboration with P. von Neumann-Cosel, V. Yu Ponomarev and A. Richter (TU Darmstadt)

We have revisited the phenomenon of fine structure of nuclear giant resonances and its relation to different resonance decay mechanisms in a review article. We described wavelet analyses of the experimental spectra that provide quantitative information on the fine structure in terms of characteristic scales. A comparable analysis of resonance strength distributions from microscopic approaches incorporating one or several of the resonance decay mechanisms allows for conclusions on the source of the fine structure. For the isoscalar giant quadrupole resonance (ISGQR), spreading through the first step of the doorway mechanism, i.e. coupling between one- particle one-hole ($1p1h$) and two-particle two-hole ($2p2h$) states can be identified as the relevant mechanism. In heavy nuclei the coupling is dominated by mixing with low-lying surface vibrations, while in lighter nuclei stochastic coupling becomes increasingly important. The fine structure observed for the isovector giant dipole resonance (IVGDR) arises mainly from the fragmentation of the $1p1h$ strength (Landau damping), although some indications for the relevance of the spreading width can also be found.

Excitation of the electric pygmy dipole resonance by inelastic electron scattering

In collaboration with V. Yu. Ponomarev, A. Richter (TU Darmstadt) and D.H. Jakubassa-Amundsen (TU München)

Pygmy dipole resonances (PDR) in neutron-excess nuclei are of continued interest, since they relate to the dynamics of the neutron skin and thus provide valuable information of the nuclear symmetry energy. To complete earlier studies of the properties of the PDR, obtained in various nuclear reactions, the excitation of the 1^- states in ^{140}Ce by (e,e') scattering for momentum transfers q=0.1–1.2~fm^{-1} were calculated within the plane-wave and distorted-wave Born approximations. The excited states of the ^{140}Ce nucleus were described within the Quasiparticle Random Phase Approximation (QRPA), but also within the Quasiparticle-Phonon Model (QPM) by accounting for the coupling to complex configurations. We have demonstrated that the excitation mechanism of the PDR states in (e,e') reactions is predominantly of transversal nature for scattering angles $\theta_e \approx 90^o - 180^o$. Being thus mediated by the convection and spin nuclear currents, inelastic (e,e') scattering, like the (γ,γ') reaction, may provide additional information to that obtained from Coulomb- and hadronic excitations of the PDR in (p,p'), (α,α'), and heavy-ion scattering reactions. The calculations predict that the (e,e') cross sections for the strongest individual PDR states are in general about three orders of magnitude smaller as compared to the one of the lowest 2^+ state for the studied kinematics. They may become dominant, however, under extreme backward angles.

Fermionic spectral functions from the Functional Renormalization Group

In collaboration with L. von Smekal (Giessen University) and R.-A. Tripolt (Frankfurt University)

Having explored the spectral properties of mesonic fluctuations within the Functional Renormalization Group approach in the past, we continue working on the calculation of fermionic spectral functions. One of the aims is to explore the interplay between chiral dynamics and the Fermi-liquid behavior of collective modes in the vicinity of the Fermi edge in the 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 the past. 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. Currently we are extending the calculations to finite temperatures and baryochemical potentials. The results, which will be published soon, 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.

Dilepton rates and polarization observables in heavy-ion collisions

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

Polarization observables in the dilepton emission from heavy-ion collisions contain valuable information on the nature of the emitting fireball. Based on work by B. Friman and E. Speranza on polarized dilepton radiation from a thermal QCD medium we continue to work on realistic predictions for the λ_θ –Parameter based on calculated rates that quantitatively describe the unpolarized dilepton data of many heavy-ion experiments. First results 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
   (Physics with Relativistic Heavy Ions, Understanding Element Production in the Universe, Dark Matter and Dark Matter Detectors)
   Schleching, Germany, February 21 - 28, 2019

2. International School of Nuclear Physics, 41^{th} Course:
   Star Mergers, Gravitational Waves, Dark Matter and Neutrinos in Nuclear, Particle and Astro-Particle Physics, and in Cosmology
   Erice, Italy, Sept. 16 - 24, 2019

SHU-YI WEI
Sudakov Resummation in small-x physics

In collaboration with G. Giacalone, C. Marquet, M. Matas and B.W. Xiao

The CGC framework provides the description of dense parton density and predicts the gluon saturation phenomenon at small-*x*. We are now interested in the phenomenological studies that can establish a bridge between the CGC theory and the experimental measurements. In return, it can improve our knowledge on the saturation physics and the nonlinear QCD evolution.

The Z^0-boson production in forward pp and pA collisions is a clean and controllable process to probe the small-*x* saturation physics. In a recent work [1], we incorporate the Sudakov resummation into both collinear factorization and CGC frameworks to study the transverse momentum distribution and the nuclear modification. This is the first numerical study of the Z^0-boson production process in the small-*x* framework. The upcoming experimental data from the LHC can be used to constrain the uncertainty of the nuclear PDFs (in the collinear factorization framework) and probe the saturation physics (in the CGC framework) at small-*x*.

In [2], we studied the dihadron back-to-back angular correlations in forward pp and pA collisions within the CGC+Sudakov resummation framework. Recently, the ATLAS collaboration measured the dijet angular correlation in the forward rapidity as well. The non-perturbative effects can be reduced, since no fragmentation function is involved. We are currently working on this [3].

Threshold Resummation in small-x physics
In collaboration with B.W. Xiao

In the CGC framework, the cross section of inclusive hadron production process in forward proton-nucleus collisions becomes negative at large transverse momentum (nearby the threshold). We are now trying to solve this problem by performing the threshold resummation.

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3.2 Publications of ECT* Researchers in 2019

DANIELE BINOSI

Y.-Z. Xu, D. Binosi, Z.-F. Cui, B.-L. Li, C. D. Roberts, S.-S. Xu, H. S. Zong
Elastic electromagnetic form factors of vector mesons
Phys. Rev. D100 (2019) no.11, 114038

A. C. Aguilar et al.
Pion and kaon structure at the electron-ion collider
Eur. Phys. J. A55 (2019) no.10, 190

Daniele Binosi, Andrea Quadri
Off-shell renormalization in the presence of dimension 6 derivative operators. Part I. General theory
JHEP 1909 (2019) 032

D. Binosi, L. Chang, M. Ding, F. Gao, J. Papavassiliou, C. D. Roberts
Distribution amplitudes of heavy-light mesons
Phys. Lett. B790 (2019) 257-262

C. Chen, Y. Lu, D. Binosi, C. D. Roberts, J. Rodríguez-Quintero, J. Segovia
Nucleon-to-Roper electromagnetic transition form factors at large-Q^2
Phys .Rev. D99 (2019) no.3, 034013

M. Ding, K. Raya, A. Bashir, D. Binosi, L. Chang, M. Chen, C. D. Roberts
$\gamma{*}\gamma\rightarrow\eta$,' transition form factors
Phys. Rev. D99 (2019) no.1, 014014

Preprints

Z.-F. Cui, J.-L. Zhang, D. Binosi, F. de Soto, C. Mezrag, J. Papavassiliou, C. D. Roberts, J. Rodríguez-Quintero, J. Segovia, S. Zafeiropoulos
Effective charge from lattice QCD
arXiv:1912.08232 [hep-ph]

M. Ding, K. Raya, D. Binosi, L. Chang, C. D. Roberts, S. M. Schmidt
Drawing insights from pion parton distributions
arXiv:1912.07529 [hep-ph]

K. Raya, L. Chang, M. Ding, D. Binosi, L. Chang, C. D. Roberts
Unveiling the structure of pseudoscalar mesons
arXiv:1911.12941 [nucl-th]

M. Ding, D. Binosi, K. Raya, L. Chang, L. Chang, C. D. Roberts
Two photon transition form factors of neutral pseudoscalar mesons
arXiv:1911.12657 [nucl-th]
J. Rodríguez-Quintero, D. Binosi, C. Chen, Y. Lu, C. D. Roberts, J. Segovia
Form factors for the Nucleon-to-Roper electromagnetic transition at large-Q^2
arXiv:1909.13793 [nucl-th]

T. Morresi, D. Binosi, S. Simonucci, R. Piergallini, S. Roche, N. M. Pugno, S. Taioli
Exploring event horizons and Hawking radiation through deformed raphene membranes
arXiv:1907.08960 [cond-mat.mes-hall]

M. Ding, K. Raya, D. Binosi, L. Chang, C. D. Roberts, S. M. Schmidt
Symmetry, symmetry breaking, and pion parton distributions
arXiv:1905.05208 [nucl-th]

D. Binosi, R. A. Tripolt
Spectral functions of confined particles
arXiv:1904.08172 [hep-ph]

D. Binosi, A. Quadri
Off-shell renormalization in the presence of dimension 6 derivative operators. II. UV coefficients
arXiv:1904.06693 [hep-ph]

ARIANNA CARBONE

J. Xu, A. Carbone, Z. Zhang and C. M. Ko
Nuclear matter properties at finite temperatures from effective interactions.
Phys. Rev. C 100 (2019) 024618

A. Carbone and A. Schwenk
Ab initio constraints on thermal effects of the nuclear equation of state.
Phys. Rev. C 100 (2019) 025805

HILLA DE LEON
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Physical Review C 100, 055502 (2019)

MINGHUI DING

M. Ding, K. Raya, A. Bashir, D. Binosi, L. Chang, M. Chen, C. D. Roberts
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M. Ding, D. Binosi, K. Raya, L. Chang, C. D. Roberts
Two photon transition form factors of neutral pseudoscalar mesons
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JARKKO PEURON

K. Boguslavski, A. Kurkela, T. Lappi, J. Peuron
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ALESSANDRO PILLONI

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A. Cerri *et al.*,
Opportunities in Flavour Physics at the HL-LHC and HE-LHC
CERN Yellow Rep. Monogr. **7** (2019), 867-1158

BaBar Collaboration (J.P. Lees *et al.*)
Search for $B^- \to \Lambda$ *pbar v vbar with the BaBar experiment*
Phys. Rev. D100 (2019), 111101

BaBar Collaboration (J.P. Lees *et al.*)
Measurement of the absolute branching fractions of $B^\pm \to K^\pm X_{ccbar}$
arXiv:1911.11740, submitted to Phys. Rev. Lett.

M. Mikhasenko, M. Albaladejo, L. Bibrzycki, C. Fernández-Ramírez, V. Mathieu, S. Mitchell, M. Pappagallo, A. Pilloni, D. Winney, T. Skwarnicki, and A. Szczepaniak
Dalitz-plot decomposition for three-body decays
arXiv:1910.04566, submitted to Phys. Rev. D

M. Albaladejo, D. Winney, I. Danilkin, C. Fernández-Ramírez, V. Mathieu, M. Mikhasenko, A. Pilloni, J. A. Silva-Castro, and A. Szczepaniak
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Phys. Rev. Lett. 123 (2019), 091801

C. Fernández-Ramírez, A. Pilloni, M. Albaladejo, A. Jackura, V. Mathieu, M. Mikhasenko, J. Silva-Castro, and A. Szczepaniak
Interpretation of the LHCb $P_c(4312)$ signal
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D. Winney, C. Fanelli, A. Pilloni, A. Hiller Blin, C. Fernández-Ramírez, M. Albaladejo, V. Mathieu, V. Mokeev, and A. P. Szczepaniak
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M. Mikhasenko, Y. Wunderlich, A. Jackura, V. Mathieu, A. Pilloni, B. Ketzer, and A. P. Szczepaniak
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arXiv:1905.00608, submitted to Phys. Rev. Lett.

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Phys. Rev. Lett. 122 (2019), 081802

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Gauge ambiguity of the quark spectrum in the Color Glass Condensate
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Nucl.Phys. A982 (2019) 271

JOCHEN WAMBACH

P. von Neumann-Cosel, V. Yu. Ponomarev, A. Richter, J. Wambach
Gross, intermediate and fine structure of nuclear giant resonances
Eur. Phys. J. A. (2019) 55 : 224
V. Yu. Ponomarev, D. H. Jabubassa-Amundsen, A. Richter, J. Wambach
Excitation of the electric pygmy dipole resonance by inelastic electron scattering
Eur. Phys. J. A. (2019) 55: 236

Jochen Wambach and Renzo Leonardi
The 25th Anniversary of ECT: Fostering nuclear theory in Europe*
Nuclear Physics News ISSN 1061-9127

Jochen Wambach
Fostering nuclear theory in Europe
SCITECH EUROPA Quarterly Issue 30 p.72

3.3. Talks Presented by ECT* Researchers in 2019

DANIELE BINOSI

Schlessinger Point Method: theory and applications

Talk delivered at the workshop “Continuum Functional Methods for QCD at New Generation Facilities”,

ECT*, Italy

May 2019

and at the collaboration meeting “JPAC Collaboration Meeting”,

ECT*, Italy

December 2019

ARIANNA CARBONE

Predicting nuclear matter at finite-temperature with the use of chiral interactions

Seminar given at the University of Milano, Italy

June 2019

Predicting nuclear matter at finite-temperature with the use of chiral interactions

Seminar given at Los Alamos National Laboratory, USA

June 2019

Equation of state for neutron stars within the Green’s function approach and chiral forces

Talk delivered at: PHAROS Conference 2019: the multi-messenger physics and astrophysics of neutron stars, Platja d’Aro, Spain

April 2019

Advances in predicting nuclear matter at finite temperature

Talk delivered at: International Workshop “Infinite and Finite Nuclear Matter" (INFINUM), JINR Dubna, Russia

March 2019

Finite-temperature nuclear matter for improved astrophysics applications

Talk delivered at: Joint LIA COLL-AGAIN, COPIGAL, and POLITA Workshop, Warsaw, Poland

March 2019

MINGHUI DING

$\gamma^{*}\gamma \to \eta, \eta'$ transition form factors

Invited talk at the workshop on Continuum Functional Methods for QCD at New Generation Facilities

ECT*, Trento, Italy

May 2019

Partonic structure of neutral pseudoscalars via two photon transition form factors

Talk delivered at the 18th International Conference on Hadron Spectroscopy and Structure (HADRON 2019)

GXNU, Guilin, China

August 2019

Pion parton distribution function

Invited talk at the workshop on Diquark Correlations in Hadron Physics: Origin, Impact and Evidence

ECT*, Trento, Italy

September 2019

Pion parton distribution function

Talk delivered at ECT* board meeting

ECT*, Trento, Italy

October 2019

JARKKO PEURON

Heavy quark momentum diffusion coefficient in 3D gluon plasma

Seminar given at University of Jyväskylä, Finland

February 2019

Heavy quark momentum diffusion coefficient in 3D gluon plasma

Seminar given at University of Jyväskylä, Finland

August 2019

Heavy quark momentum diffusion coefficient in 3D gluon plasma

Seminar given at University of Bielefeld, Germany

October 2019

Heavy quark momentum diffusion coefficient in 3D gluon plasma

Seminar given at Vienna University of Technology, Austria

December 2019

Self-similarity and spectral functions of non-Abelian plasmas in 2+1D

Talk given at the “Initial Stages 2019”, New York, USA

June 2019

Heavy quark momentum diffusion coefficient in 3D gluon plasma
Talk given at “XXVIIIth International Conference on Ultra-relativistic Nucleus-Nucleus Collisions”
November 2019, Wuhan, China

ALESSANDRO PILLONI
The pole hunter: searching (exotic) resonances in the hadron spectrum
ECT* seminar, Italy
February, 2019

DIONYSIOS TRIANTAFYLLOPOULOS
Non-linear evolution in QCD at small-x beyond leading order
Talk at the “XXVII International Workshop on DIS and Related Subjects”, Torino, Italy
April 2019

JOCHEN WAMBACH
*Transnational access to ECT**
Talk presented at the STRONG-2020 Kick-off meeting:
The strong interaction at the frontier of knowledge: fundamental research and applications, Nantes, France
October 2019

Spectral properties of extreme QCD matter
Talk presented at the ECT* workshop: “RMT in Sub-Atomic Physics and Beyond”, Trento, Italy
August 2019

3.4. Seminars and Colloquia at ECT*

The pole hunter: searching (exotic) resonances in the hadron spectrum
February, 2019
Alessandro Pilloni (ECT*)

Light-nuclei electro-magnetic interaction in pionless effective field theory
March, 2019
Hilla De Leon (Hebrew University of Jerusalem)

Schlessinger Point Method: Theory and Applications
Talk delivered at the workshop “Continuum Functional Methods for QCD at New Generation Facilities”,
Daniele Binosi, ECT*, Italy May 2019
and at the collaboration meeting “JPAC Collaboration Meeting”,
Daniele Binosi, ECT*, Italy, December 2019

$\gamma^{\square}\gamma \to \eta, \eta'$ *transition form factors*
Invited talk at the workshop on Continuum Functional Methods for QCD at New Generation Facilities
May, 2019
Minghui Ding (ECT*)

Generation and transport of electrons by particle impact in materials of technological and radiobiological interest
May, 2019
Rafael Garcia-Molina (Universidad de Murcia)

Quantum simulation for nuclear physics
June, 2019
Martin J. Savage (INT- Seattle)

Pion parton distribution function
Invited talk at the workshop on Diquark Correlations in Hadron Physics: Origin, Impact and Evidence
September 2019
Minghui Ding (ECT*)

Pion parton distribution function
Talk delivered at ECT* board meeting
October 2019
Minghui Ding (ECT*)

Spectral properties of extreme QCD matter
Talk presented at the ECT* workshop: "RMT in Sub-Atomic Physics and Beyond"
August 2019
Jochen Wambach (ECT* & TU Darmstadt)

Low-energy spectrum of the SU(3) Yang-Mills quantum mechanics of spatially constant gluon-fields
November 2019
Hans-Peter Pavel (Dubna & Humboldt University)

Spectral functions with the Functional Renormalization Group
September
Ralf-Arno Tripolt (Goethe University Frankfurt)

Perturbative aspects of soft QCD dynamics
September 2019
Paul Hoyer (University of Helsinki)

Research at ECT*-LISC

4. Research at ECT*-LISC

4.1 Projects of ECT*-LISC Researchers

MAURIZIO DAPOR

Mapping polymer molecular order

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

We studied secondary electron (SE) spectroscopy and secondary electron hyperspectral imaging, which make an exciting alternative approach to probing molecular ordering in poly(3-hexylthiophene) (P3HT) with scanning electron microscope-enabled resolution. We demonstrated that the crystalline content of a P3HT film is reflected by its SE energy spectrum. The origin of SE spectral features was investigated using both experimental and modelling approaches, and it was found that the different electronic properties of amorphous and crystalline P3HT result in SE emission with different energy distributions. This effect is exploited by acquiring hyperspectral SE images of different P3HT films to explore localized molecular orientation.

Complex carbon and metal/carbon systems

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

We investigated a spectroscopic technique based on secondary electrons and demonstrated its capacity to reveal chemical variations of carbon. The effectiveness of this approach is validated experimentally through spatially averaging spectroscopic techniques and using Monte Carlo modelling. Characteristic spectra shapes and peak positions for varying contributions of sp^2 -like or sp^3 -like bond types and amorphous hydrogenated carbon were investigated under circumstances which might be observed on highly oriented pyrolytic graphite (HOPG) surfaces as a result of air or electron beam exposure. The spectral features identified above are then used to identify the different forms of carbon present within the metallic films deposited from reactive organometallic inks. Our work revealed the inhomogeneous incorporation of carbon on the nanoscale but also uncovers a link between local orientation of metallic components and carbon form.

Secondary electron emission spectra of metals

In collaboration with R. Cimino (INFN)

Secondary electron energy spectra of metals were simulated. The calculations proceeded 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. The generation of secondary electrons upon ionization of the samples was implemented in the Monte Carlo simulation. A remarkable agreement was obtained between both theoretical and experimental secondary electron emission spectra and yield curves.

GIOVANNI GARBEROGLIO

Open quantum fermi systems

In collaboration with A. Recati (INO-CNR, BEC center), P. Faccioli and S. Giorgini (University of Trento)

In this project I am investigating numerically the dynamics of impurities (polarons) in a bath of fermionic particles in one dimension.

I developed an efficient numerical scheme based on time-dependent density-functional theory. This method enables calculations with impurities interacting with hundreds of bath particles in trapped systems, as well as the phenomenological inclusion of zero-temperature Langevin process to describe coupling with an external bath.

Ab-initio calculation of viral coefficients

In collaboration with A. Harvey (NIST, USA), B. Jeziorski and R. Moszynski (University of Warsaw, Poland)

We developed a path-integral approach to calculate dielectric virial coefficients of monoatomic gases (He, Ne, and Ar) with no uncontrolled approximations, using pair potential and pair polarizabilities obtained by ab-initio calculations. In the case of Helium, we showed that largest contribution to the overall uncertainty of the theoretical values of the second dielectric virial comes from the uncertainty in the pair polarizability. For the other gases, a full determination of the uncertainty was not possible because of the undetermined uncertainty on the pair potentials and polarizabilities, but the theoretical results are in very good agreement with experimental data.

In the case of polyatomic gases, we are currently developing a path-integral method to enable the calculation of temperature derivatives of virial coefficients, which could lead to an estimation of the value of acoustic virials in the presence of quantum effects (most notably, the case of water) without uncontrolled approximation.

References

Towards quantum-based realisations of the Pascal “QuantumPascal”, financed by Horizon2020 and EURAMET through the initiative EMPIR (30k€)
Realisation of the redefined Kelvin “Real-K”, financed by Horizon2020 and EURAMET through the initiative EMPIR (40k€).

TOMMASO MORRESI

Exploring event horizons and Hawking radiation through deformed graphene Membranes

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. In order to reach a big simulation cell, 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.

Structural, electronic and mechanical properties of all-sp^2 carbon allotropes with density lower than graphene

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 sp^2 bonded carbon based 2D materials with low density and study their electronic and mechanical properties with ab-inito methods, comparing the results with the ones of graphene. We developed a method to decrease the packing factor of sp^2 geometries and with that we introduced four new structures, one of which we claim to be the lowest density sp^2 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. Furthermore we tested the mechanical stability of the new structures with DFT ab-initio methods and we fully characterize the electronic properties, finding flat bands around the Fermi level for the augmented geometries. This work was published in the journal 'Carbon' [4].

References

[1] A. Iorio and C. Lambiase, Phys. Rev. D 90, 025006, July (2014)

[2] A.H. Castro Neto, F. Guinea, N. M. R. Peres, K. S. Novoselov and A. K. Geim, Rev. Mod. Phys., Volume 81, January (2009)

[3] A. Weiße, G. Wellein, A. Alvermann, and H. Fehske, Rev. Mod. Phys., 78, 275, March (2006)

[4] T. Morresi, A. Pedrielli, S. a Beccara, R. Gabbrielli, N. M Pugno, S. Taioli, Carbon, December (2019)

ANDREA PEDRIELLI

Study of two dimensional sp^2 carbon based materials

In collaboration with: T. Morresi and S. Taioli (ECT*), N.M. Pugno (University of Trento), S. a Beccara, R. Gabbrielli

Due to the ever-increasing interest in low dimensional materials and the broad range of possible applications, we proposed a few novel energetically and dynamically stable all- sp^2 carbon-based architectures with low density obtained by augmenting planar three-coordinated uniform tessellations. We found some of the least dense structures of all- sp^2 bonded carbon allotropes that could ever be synthesised. We compared our findings with already synthesised carbon-based materials, in particular graphene, and we found that in the lowest–density structures the mechanical rigidity is considerably depleted, while other specific mechanical characteristics, such as toughness and strength, are comparable to the relevant specific values of graphene. Furthermore, a flat band at the Fermi level emerges in the electronic band structure of the augmented geometries, which is a feature similarly appearing in Kagome lattices. This work has been published in Carbon journal [1].

Calculation of thermodynamical properties of magnesium hydride nanoparticles from stochastic self-consistent harmonic approximation (SSCHA)

In collaboration with: G. Garberoglio and S. Taioli (ECT*), N. M. Pugno (University of Trento), L. Monacelli (Università di Roma La Sapienza)

While a body of literature has been devoted to the calculation of thermodynamical properties of magnesium hydride nanoparticles by means harmonic approximation, the assessment of these properties in a fully anharmonic framework is still lacking. We assessed the free energy calculation as well as the desorption temperature calculation by means of stochastic self-consistent harmonic approximation (SSCHA) combined with ab initio evaluation of potential energy surface and forces using density functional theory.

Study of high-Z ceramics nanoparticles as enhancers in proton therapy

In collaboration with: G. Garberoglio, S. Taioli and M. Dapor (ECT*), N. M. Pugno (University of Trento), P. de Vera Gomis and R. Garcia Molina, (University of Murcia), I . Abril (University of Alicante), E. Scifoni, M. Schwarz

High-Z ceramics such as cerium and tantalum oxide are promising for increasing the relative biological effectiveness in proton beam therapy. We study the secondary electrons production in these materials by means of monte carlo simulations based on ab initio calculations in order to design optimal nanostructures.

References

[1] Tommaso Morresi, Andrea Pedrielli, Silvio a Beccara, Ruggero Gabbrielli, Nicola M. Pugno, Simone Taioli
Structural, electronic and mechanical properties of all-sp^2 carbon allotropes with density lower than graphene. Carbon Volume 159, 15 April 2020, Pages 512-526 https://doi.org/10.1016/j.carbon.2019.12.024

SIMONE TAIOLI

Relativistic theory of nuclear beta-decay in heavy-nuclei and lithium novel rate assessment

In collaboration with T. Morresi (ECT*), S. Simonucci (University of Camerino), M. Busso (University of Perugia), S. Palmerini (University of Perugia)

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. We apply this ab-initio approach to the assessment of the electron-capture in ^7Be, which is the main production channel for ^7Li in several astrophysical environments. Theoretical evaluations have to account for not only the nuclear interaction, but also the processes in the plasma in which ^7Be ions and electrons interact. In recent decades several estimates were presented, pointing out that the theoretical uncertainty in the rate is in general of a few percent.

In the framework of fundamental solar physics, we consider our evaluation for the $^7Be+e^-$ rate, in the estimate of neutrino fluxes. In particular, we analyzed the effects of the new assumptions on standard solar models (SSMs) and compared the results obtained by adopting the revised $^7Be+e^-$ rate to those obtained by that reported in a widely used compilation of reaction rates (ADE11). We found that new SSMs yield a maximum difference in the efficiency of the ^7Be channel of about 4% with respect to what is obtained with the previously adopted rate. This fact affects the production of neutrinos from ^8B, increasing the relative flux up to a maximum of 2.7%. Negligible variations are found for the physical and chemical properties of the computed solar models [see Refs. 1,2].

Carbon-based materials with low-density

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

In this work a systematic approach to the search for all-bonded carbon allotropes with low density is presented [3]. 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.

Models of analog gravity

In collaboration with D. Binosi, T. Morresi (ECT*) and S. Roche (ICREA)

Analogue gravitational systems are becoming an increasing popular way of studying the behaviour of quantum systems in curved spacetime. Setups based on ultracold quantum gases in particular, have been recently harnessed to explore the thermal nature of Hawking's and Unruh's radiation that was theoretically predicted almost 50 years ago. For solid-state implementations, a promising system is graphene, in which a link between the Dirac-like low-energy electronic excitations and relativistic quantum field theories has been unveiled soon after its discovery. Here we show that this link extends to the case of curved quantum field theory when the graphene sheet is shaped in a surface of constant negative curvature, known as Beltrami's pseudosphere [4]. Thanks to large-scale simulations, we provide numerical evidence that energetically stable negative curvature graphene surfaces can be realized; the ratio between the carbon-carbon bond length and the pseudosphere radius is small enough to allow the formation of an horizon; and the associated Local Density Of States evaluated at horizon's proximity has a thermal nature with a characteristic temperature of few tens of Kelvin. Such findings pave the way to the realization of a solid-state system in which the curved spacetime dynamics of quantum many body systems can be investigated.

Energy deposition around carbon ion tracks for proton therapy applications

In collaboration with M. Dapor (ECT*), R. Garcia-Molina (University of Murcia), I. Abril (University of Alicante)

The effective use of energetic ion beams in cancer treatment relies on the accurate understanding of their energy-loss mechanisms within the biological tissue, which typically lead to a sharp peak appearing at the end of their depth-dose profile.

To investigate the chemical-physical processes initiated by the ion slowing-down, here we assess from computer simulations the radial dose deposited by secondary electrons around a track of swift (2 MeV/u) carbon ions in different ionization states moving through liquid water. In particular, we determine first the energy spectrum and angular pattern of the primary electrons produced by the carbon beam in its way within the water medium. Primary energy-loss processes include both electronic excitation and ionization of the target atoms. The Bethe surface of liquid water is obtained from first principles simulations of the electronic structure of liquid water over the whole excitation spectrum and transferred momenta.

Finally, we input this information into an event-by-event Monte Carlo approach to assess the radial dose deposited around the ion track by the cascade of harmful low-energy secondary electrons generated by the electron-target molecule interaction. In the charge transport Monte Carlo analysis we deal with both elastic and inelastic collisions via the dielectric response function formalism, also including solid state effects, such as the electron-phonon and electron-polaron coupling.

Artificial intelligence for quantum systems

In collaboration with P. Trevisanutto (ICT@FBK & ECT*), M. Cristoforetti (ICT@FBK, FBK), M. De Domenico (ICT@FBK), G. Garberoglio (ECT*)

Several quantum systems can be modeled using spin Hamiltonians, either with short-range (e.g., Ising or Heisenberg models) or long-range interactions (e.g., the recent realization of dipolar BEC in optical lattices). Unfortunately, numerically exact solutions are limited to systems of about 20 objects, as memory requirements to exactly represent the quantum state of a set of spins scale exponentially with their number. This shortcoming prevents accurate numerical studies of several interesting phenomena, such as entanglement properties, the consequences of disorder, and the dynamics of subsystems. For this reason, many efforts have been devoted to the development of approximate yet accurate representations of the quantum state of interacting spins. In 1D, the density matrix renormalization group has been proven to be an optimal tool, whereas in two or more dimensions tensor network states have been shown to be a very good tradeoff between accuracy and scaling. Recently, computational techniques borrowed from the Machine Learning community have been put forward as an even more effective way to represent the quantum state of interacting spins. Within this approach, preliminary promising results have been obtained using Restricted Boltzmann Machines (RBM). Despite its simplicity, this type of network has been found capable of finding a solution of a 2D spin system with smaller energy than that given by state-of-the-art tensor networks, displaying only a polynomial dependence of memory requirements on the system size. This clearly suggests that by looking at more sophisticated architectures in the landscape of the artificial neural networks and deep learning, one could tackle more complex problems in the context of quantum many-body physics and, more in general, materials science.

In this project, we aim at developing novel numerical approaches based on artificial neural networks and deep learning techniques to represent in a memory-efficient way the statistical operator (density matrix) of a quantum system. In the direction of an extension of the results obtained with RBM we will explore the use of other unsupervised algorithms such as variational autoencoders and generative adversarial networks.

Furthermore, we will investigate efficient methods based on neural networks to represent statistical operators in large Hilbert spaces when they are obtained as the exponential of a matrix. We remind that in quantum statistical mechanics the density matrix of a system in thermodynamical equilibrium is given by the exponential of the Hamiltonian divided by the temperature. Finally, we also plan to investigate the temporal evolution of the density matrix, either under unitary evolution (the quantum Liouville equation) or under the non-unitary evolution characteristic of a system in contact with a heat bath (the Lindblad equation).

References

[1] D. Vescovi, L. Piersanti, S. Cristallo, M. Busso, F. Vissani, S. Palmerini, S. Simonucci, S. Taioli
The effects of a revised Be e-capture rate on solar neutrino fluxes
Astronomy & Astrophysics 623 (A126), 7 (2019)

[2] D. Vescovi, L. Piersanti, S. Cristallo, M. Busso, F. Vissani, S. Palmerini, S. Simonucci, S. Taioli
VizieR Online Data Catalog: Effects of a revised 7Be e--capture rate
VizieR Online Data Catalog 362 (2019) [3] M. Azzolini, M. Angelucci, R. Cimino, R. Larciprete

[3] T. Morresi, A. Pedrielli, S. a Beccara, R. Gabbrielli, N. Pugno, S. Taioli
Structural, electronic and mechanical properties of all-sp^2 carbon allotropes with density lower than graphene
Carbon 159, 512-526, (2019)

[4] T. Morresi, D. Binosi, S. Simonucci, R. Piergallini, S. Roche, N. Pugno, S. Taioli
Exploring event horizons and Hawking radiation through deformed graphene membranes
arXiv preprint arXiv:1907.08960 (2019)

PAOLO EMILIO TREVISANUTTO

Artificial intelligence for quantum systems

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Several quantum systems can be modeled using spin Hamiltonians, either with short-range (e.g., Ising or Heisenberg models) or long-range interactions (e.g., the recent realization of dipolar BEC in optical lattices). Unfortunately, numerically exact solutions are limited to systems of about 20 objects, as memory requirements to exactly represent the quantum state of a set of spins scale exponentially with their number. This shortcoming prevents accurate numerical studies of several interesting phenomena, such as entanglement properties, the consequences of disorder, and the dynamics of subsystems. For this reason, many efforts have been devoted to the development of approximate yet accurate representations of the quantum state of interacting spins. In 1D, the density matrix renormalization group has been proven to be an optimal tool, whereas in two or more dimensions tensor network states have been shown to be a very good tradeoff between accuracy and scaling. Recently, computational techniques borrowed from the Machine Learning community have been put forward as an even more effective way to represent the quantum state of interacting spins. Within this approach, preliminary promising results have been obtained using Restricted Boltzmann Machines (RBM). Despite its simplicity, this type of network has been found capable of finding a solution of a 2D spin system with smaller energy than that given by state-of-the-art tensor networks, displaying only a polynomial dependence of memory requirements on the system size. This clearly suggests that by looking at more sophisticated architectures in the landscape of the artificial neural networks and deep learning, one could tackle more complex problems in the context of quantum many-body physics and, more in general, materials science.

In this project, we aim at developing novel numerical approaches based on artificial neural networks and deep learning techniques to represent in a memory-efficient way the statistical operator (density matrix) of a quantum system. In the direction of an extension of the results obtained with RBM we will explore the use of other unsupervised algorithms such as variational autoencoders and generative adversarial networks.

Furthermore, we will investigate efficient methods based on neural networks to represent statistical operators in large Hilbert spaces when they are obtained as the exponential of a matrix. We remind that in quantum statistical mechanics the density matrix of a system in thermodynamical equilibrium is given by the exponential of the Hamiltonian divided by the temperature. Finally, we also plan to investigate the temporal evolution of the density matrix, either under unitary evolution (the quantum Liouville equation) or under the non-unitary evolution characteristic of a system in contact with a heat bath (the Lindblad equation).

4.2 Publications of ECT*-LISC Researchers in 2019

AZZOLINI MARTINA

R.C. Masters, N. Stehling, K. Abrams, V. Kumar, M. Azzolini, N.M. Pugno, M. Dapor, A. Huber, P. Schäfer, D.G. Lidzey, C. Rodenburg

Mapping polymer molecular order in the SEM with secondary electron hyperspectral imaging

Advanced Science **6.5,** 1801752 (2019)

K. J. Abrams, M. Dapor, N. Stehling, M. Azzolini, S.J. Kyle, J. Schäfer, A. Quade, F. Mika, S. Kratky, Z. Pokorna, I. Konvalina, D. Mehta, K. Black, C. Rodenburg

Making sense of complex carbon and metal/carbon systems by secondary electron hyperspectral imaging

Advanced Science 6.19, 1900719 (2019)

M. Azzolini, O. Ridzel, P. Kaplya, V. Afanas'ev, N. M. Pugno, S. Taioli, M. Dapor

A comparison between Monte Carlo method and the numerical solution of the Ambartsumian-Chandrasekhar equations to unravel the dielectric response of metal

Computational Material Science 109420 (2019)

MAURIZIO DAPOR

Robert C. Masters, Nicola Stehling, Kerry J. Abrams, Vikas Kumar, Martina Azzolini, Nicola M. Pugno, Maurizio Dapor, Andreas Huber, Philip Schäfer, David G. Lidzey, and Cornelia Rodenburg

Mapping polymer molecular order in the SEM with secondary electron hyperspectral imaging

Adv. Sci. **6** (2019) 1801752

Kerry J. Abrams, Maurizio Dapor, Nicola Stehling, Martina Azzolini, Stephan J. Kyle, Jan Schäfer, Antje Quade, Filip Mika, Stanislav Kratky, Zuzana Pokorna, Ivo Konvalina, Danielle Mehta, Kate Black, and Cornelia Rodenburg

Making sense of complex carbon and metal/carbon systems by secondary electron hyperspectral imaging

Adv. Sci. **6** (2019) 1900719

Martina Azzolini, Marco Angelucci, Roberto Cimino, Rosanna Larciprete, Nicola M Pugno, Simone Taioli, and Maurizio Dapor

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

J. Phys.: Condens. Matter **31** (2019) 055901

GIOVANNI GARBEROGLIO

Claudia Backes et al.

Production and processing of graphene and related materials. 2D Materials, in press

TOMMASO MORRESI

T. Morresi, A. Pedrielli, S. a Beccara, R. Gabbrielli, N. M Pugno, S. Taioli

Structural, electronic and mechanical properties of all-sp^2 carbon allotropes with density lower than graphene

Elsevier, Carbon, 159 (2020) 512-526

ANDREA PEDRIELLI

Tommaso Morresi, Andrea Pedrielli, Silvio a Beccara, Ruggero Gabbrielli, Nicola M Pugno, Simone Taioli

Structural, electronic and mechanical properties of all-sp^2 carbon allotropes with density lower than graphene

Carbon Volume 159, 15 April 2020, Pages 512-526

SIMONE TAIOLI

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A comparison between Monte Carlo method and the numerical solution of the Ambartsumian-Chandrasekhar equations to unravel the dielectric response of metals

Computational Materials Science 173, 109420 (2019)

T. Morresi, D. Binosi, S. Simonucci, R. Piergallini, S. Roche, N. Pugno, S. Taioli

Exploring event horizons and Hawking radiation through deformed graphene membranes

arXiv preprint arXiv:1907.08960 (2019)

D. Vescovi, L. Piersanti, S. Cristallo, M. Busso, F. Vissani, S. Palmerini, S. Simonucci, S. Taioli

The effects of a revised Be e-capture rate on solar neutrino fluxes

D. Vescovi, L. Piersanti, S. Cristallo, M. Busso, F. Vissani, S. Palmerini, S. Simonucci, S. Taioli

Astronomy & Astrophysics 623 (A126), 7 (2019)

VizieR Online Data Catalog: Effects of a revised 7Be e-capture rate

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Production and processing of graphene and related materials
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Excitons: Modulation of new xxcitons in transition metal dichalcogenide ‐ perovskite oxide system , Adv. Sci., 6: 1970073.

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*Point defects and localized excitons in 2D Wse2***,** *ACS Nano* 2019 *13* (5), 6050-6059.

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Quantum correlated plasmons and their tunability in undoped and doped Mott-insulator cuprates. ACS Photonics 2019 *6* (12), 3281-3289

4.3 Talks presented by ECT*-LISC Researchers in 2019

Maurizio Dapor

M. Dapor, S. Taioli, I. Abril, P. de Vera, R. Garcia-Molina

Energy deposition around swift carbon ion tracks in liquid water

105° Congresso Nazionale Società Italiana di Fisica

L'Aquila, September 2019

Giovanni Garberoglio

What moves the sun and all the other stars? The elementary (but not trivial) physics of star structure and formation

Talk given to the participants of the national selection of the Italian team for the 50th International Physics Olympiads

Senigallia, April, 2019

Tommaso Morresi

Forging graphene pseudospheres to mimic curved space–times

Talk at the conference 'Simulating gravitation and cosmology in condensed matter and optical systems'

July 2019, ECT*, Trento, Italy

Andrea Pedrielli

Graphene foams, pillared graphene frameworks and low-density 2D carbon allotropes: a computational overview

Poster presentation at the conference "Graphene 2019"

Rome, 2019, June

Simone Taioli

Invited talk

Relativistic theory and ab initio simulations of electroweak decay spectra in medium-heavy nuclei

Talk given at the conference "Precise beta decay calculations for searches for new physics"

April 2019, Trento, Italy

Invited talk

Enabling materials by dimensionality: from 0D to 3D carbon-based nanostructures

Talk given at the conference "15th International Conference of Computational Methods in Sciences and Engineering (ICCMSE 2019)"

May 2019, Rhodos, Greece

Invited talk

Relativistic approaches to beta-decays in stellar plasmas

Talk given at the conference "PANDORA: Measuring beta-decays in plasmas"

October, 2019, Perugia, Italy

Computing Facilities

5. 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); in case of 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:

Laptops Lenovo ThinkPad T480 with Lenovo Docking Stations ThinkPad. English keyboard and monitor Philips Brilliance 272B (27")

One Workstation DELL 1500 has been installed recently in the entrance of the Rustico for the registration of the workshop participants.

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./ from October 31st we have reduced the number of the licenses in order to use the Mathematica Cloud: 5 licenses Home use + 5 Cloud licenses. (35 cloud licenses for DTP for 3 weeks and 35 cloud licenses for TALENT for 3 weeks will be available in 2020).

Services

All services are running using 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 one can 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, worldwide 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 2.350 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.