ANNUAL REPORT 2023

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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Preface

In 2023, the *European Centre for Theoretical Studies in Nuclear Physics and Related Areas* (ECT*) celebrated its 30-year anniversary.

This special occasion was commemorated via a one-day symposium on the 4th of October. After a welcome by the ECT* Director and words of congratulations by representatives from the Bruno Kessler Foundation, the University of Trento, NuPECC, FAIR, and the ECT* Scientific Board, the scientific programme was opened by Sonia Bacca (Johannes Gutenberg University Mainz) who spoke on “Computing the Heart of Matter”, followed by Francesco Pederiva (University of Trento) on “Ab-initio Nuclear Physics in Trento”. After an enjoyable lunch in the Villa Tambosi, the programme continued with a presentation by Dionysios Triantafyllopoulos (ECT*) on the “Color Glass Condensate in Collider Physics” and Almudena Arcones (TU Darmstadt) on “Cosmic Laboratories for Nuclear Physics”. Morten Hjorth-Jensen (Michigan State University and University of Oslo) included several historical comments in his presentation “Cosmic Thirty Years of Education and Research”, having been one of the first postdoctoral researchers employed at ECT*. The final talk of the day was delivered by Ubirajara van Kolck (Orsay and University of Arizona), on “Quantum Fractals”. The symposium concluded with a buffet, during which guests enjoyed catching up with current and previous ECT* colleagues and Scientific Board members.

The occasion was also celebrated for a general audience and members of the University Physics Society with a public talk on the 7th of October, downtown Trento, by Laura Fabbietti (Technische Universität München) on “The Long Journey of Anti-Nuclei”.

It is my pleasure to thank all the speakers for their engagement and exciting presentations.

In 2023 ECT* was assessed by an independent Review Committee, consisting of Sonia Bacca (Johannes Gutenberg University Mainz), Barbara Erazmus (SUBATECH), Richard Hall-Wilton (FBK), Maria Paola Lombardo (INFN) (chair), Piotr Magierski (Warsaw University of Technology), Ulf-G. Meißner (University of Bonn & Forschungszentrum Jülich) and Sanjay Reddy (University of Washington). This review, which takes place every five years and precedes the renewal of the Memoranda of Understanding with the European institutional funding agencies, found that the ECT* is performing its core mission well – executing a successful and impactful workshop and training programme and generating significant scientific output – while a number of areas for future improvement has been identified. On behalf of ECT* and the wider community, I thank the Review Committee for their efforts and constructive insights, and the funding agencies and external partners for their renewal of the MoUs. As always, both intellectual and financial support are required to keep ECT* up and running!

Concerning the annual workshop and training programme, in 2023 ECT* hosted 23 workshops and two collaboration meetings. All meetings were held in-person, with limited hybrid options. This return to in-person participation as the preferred way of interaction was a deliberate choice made by the Scientific Board and the Director to stimulate scientific discussion in the informal and creative environment ECT* is known for. A total of 944 participants were welcomed, with the largest meeting attended by 64 researchers. The 2023 Doctoral Training Programme, entitled “Ab Initio Methods and Emerging Technologies for Nuclear Structure”, was organised by Carlo Barbieri and Alessandro Roggero and run over a period of three weeks in July. The DTP was attended by 33 PhD students from all over the world. “Quantum Science Generation” was a new initiative proposed by PhD students and postdocs at the University of Trento, organised by and aimed at early-career researchers in the areas of quantum information and theoretical physics. It attracted no less than 64 participants, all but a handful in the ECR category. This successful event is set to return in 2024. Another link with the Physics Department was established via a joint pizza-enhanced seminar series for and by PhD students and organised by the ECT* researchers Constantinos Constantinou, Alex Gnech and Tommaso Morresi.

The workshop and training programme continues to be supported by the European projects: during 2023 STRONG-2020 supported 7 workshops while EURO-LABS supported 3 workshops and the Doctoral Training Programme. We are also grateful for support from EMMI, INFN, and the many external contributions to individual workshops.

Locally, the five permanent researchers, the postdocs and PhD students continued their research in nuclear structure and reactions, non-perturbative QCD and hadron physics, the theory of hadronic and nuclear collisions at high energy, phases of strongly-interaction matter, nuclear astrophysics, neutron stars, and many-body theory. Particular attention was paid to quantum tomography, supported via the National Recovery and Resilience Plan (PNNR) of the Italian Government. ECT* postdoc Alex Gnech accepted a tenure-track position in Old Dominion and Jlab, and left ECT* at the end of 2023. The research activities of the Centre are documented in detail in Chapter 4 of this Annual Report. Altogether, more than 40 publications by ECT* researchers were reported for the year 2023.

Finally, after having served as ECT* Director for three+ years, it is a pleasure to welcome the new Director, Ubirajara van Kolck, also in this Annual Report. With the renewal of the MoUs and under Bira’s leadership, ECT* is set to continue its successful workshop, training, and research programme into the future, covering theoretical nuclear physics in the broadest sense, encompassing quantum information and machine learning as they relate to nuclear physics as current popular topics. I take this opportunity to thank, once again, the ECT* Scientific Board, the local research group, the FBK, INFN, NuPECC, the University of Trento and all stakeholders for the support provided. I want to thank especially the administrative staff, Susan, Barbara, Michela (who moved to another FBK position during 2023) and Ines (who rejoined ECT* during 2023) for all their efforts and pleasant collaboration over these years.

Trento, April 2023

Gert Aarts
*Director of ECT**

Scientific Board, Staff and Researchers

1. Scientific Board, Staff and Researchers

1.1 Scientific Board and Director

Constantia Alexandrou	University of Cyprus & the Cyprus Institute, Cyprus
Almudena Arcones	TU Darmstadt, Germany
Carlo Barbieri (until May)	University of Milan, Italy
Anna Corsi (until May)	IRFU/DPhN, France
David Kaplan	University of Washington, USA
Denis Lacroix	CNRS/IN2P3, France
Marek Lewitowicz	NuPECC/GANIL, France
Alexandre Obertelli (from May)	TU Darmstadt, Germany
Barbara Pasquini	University of Pavia, Italy
Vittorio Somà (from May)	CEA Saclay, France
Urs Wiedemann (Chairman)	CERN-TH, Switzerland
Sandro Stringari (Ex officio, until May)	University of Trento, Italy
Albino Perego (Ex officio, from October)	University of Trento, Italy

ECT Director*

Gert Aarts	ECT*, Italy and Swansea University, UK

1.2 Resident Researchers

*Permanent Researchers

- *Nuclear Physics*

Daniele Binosi, Italy*
Dionysis Triantafyllopoulos, Greece*
Alex Gnech, Italy
Tommaso Morresi, Italy
Zhao-Qian Yao, Japan

- *Computational Physics*

Maurizio Dapor, Italy (Head of ECT*-LISC Research Unit)*
Giovanni Garberoglio, Italy*
Simone Taioli, Italy*
Achille Fiore, Italy (until 31/03/2023)

- *ECT*/TIFPA Researchers*

Constantinos Constantinou, Cyprus (until 30/11/2023)

- *ECT* PhD Students*

Luis Benjamín Rodríguez Agui, Guatemala
Francesco Carnovale, Italy
Giovanni Novi Inverardi, Italy
Luca Vespucci, Italy

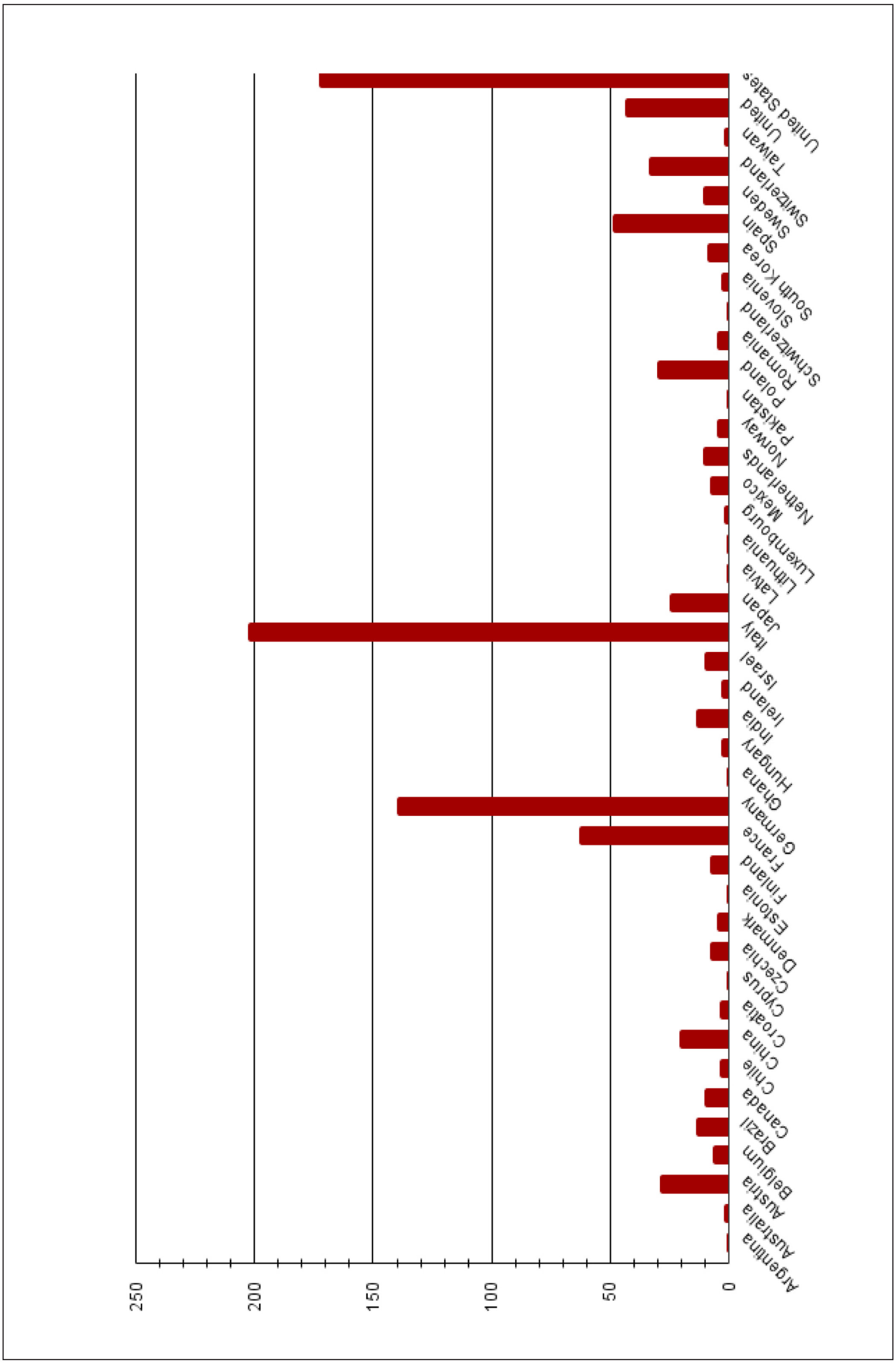
- *ECT* Fellows*

Borys Hryniuk, Ukraine (until 31/03/2023)

1.3 Staff

Ines Campo (from October 2023)
Michela Chistè (until October 2023)
Susan Driessen
Barbara Gazzoli

Participants workshops and Doctoral Training Program 2023



ECT Scientific Projects in 2023

2. ECT Scientific Projects in 2023

2.1 Summary

Altogether, 26 scientific projects have been run in 2023: 23 workshops, 2 collaboration meetings and a Doctoral Training Programme. This chapter collects the scientific reports written by the workshop organizers and by Carlo Barbieri and Alessandro Roggero who organized the DTP.

2.2 Workshops and School (Calendar)

31 Jan-2 Feb	*Structure and Topology of RNA in Living Systems (self-supported)* L. Tubiana (University of Trento) S. Pasquali (University Paris Cité) A. Bozic (IJS, Ljubjlana)
February 20-24	*LaVA Meeting (Collaboration meeting)* C. Bonanno (INFN Firenze) M.P. Lombardo (INFN Firenze) M. Peardon (Trinity College Dublin)
March 13-17	*Holographic Perspectives on Chiral Transport* K. Landsteiner (IFT-UAM/CSIC Madrid) U. Gursoy (University of Utrecht) M. Kaminski (University of Alabama)
March 20-24	*The Gradient Flow in QCD and other Strongly Coupled Field Theories* C. Monahan (William & Mary) R. Harlander (University of Aachen) A. Hasenfratz (University of Colorado, Boulder) O. Witzel (Siegen University)
May 2-5	*Quantum Science Generation | QSG* D. De Bernardis (INO-CNR BEC Center) V. Amitrano (University of Trento – INO-CNR)

A. Baldazzi (University of Trento)
A. Berti (University of Trento – INO-CNR)
I. Carusotto (INO-CNR BEC Center)
D. Contessi (University of Trento – INO-CNR)
A. Nardin (University of Trento – INO-CNR)
L. Pavesi (University of Trento)

May 15-19 *Color Glass Condensate at the Electron-Ion Collider*
D. Triantafyllopoulos (ECT*)
N. Armesto (University of Santiago de Compostela)
E. Iancu (University of Paris-Saclay, IphT)
T. Lappi (University of Jyväskylä)

May 22-26 *From First Principles QCD to Experiments*
M. Huber (Giessen University)
G. Eichmann (LIP Lisbona)
M.P. Lombardo (INFN Firenze)
P. Maris (Iowa State University)
J.M Palowski (Heidelberg University)

May 29- June 1 *2nd CMS Heavy Ion Workshop: Bringing Together the LHC Heavy Ion Community*
G. Krintiras (The University of Kansas)
Y.J. Lee (MIT)
W. Li (Rice University)
C. Lourenco (CERN)
A. Stahl (CERN)

June 5-9 *Nuclear and Partical Physics on a Quantum Computer: Where do we stand now?*
A. Bazavov (MSU)
Z. Davoudi (University of Maryland)
D. Lee (MSU)
A. Roggero (University of Trento)

June 12-16 *Precision Tests of Fundamental Physics with Light Mesons*
S. Schadmand (GSI Darmstadt)
I. Jaegle (Jefferson Lab)
B. Kubis (HISKP) Bonn
D. Lersch (FSU Tennessee)

June 19-23	*Quantum Simulation of Gravitational Problems on Condensed Matter Analog Models* I. Carusotto (INO-CNR Bec Center) R. Balbinot (University of Bologna) G. Ferrari (University of Trento) M. Rinaldi (University of Trento)
June 26-30	*Machine Learning for Lattice Field Theory and Beyond* D. Hackett (MIT) G. Aarts (Swansea University & ECT*) D. Bachtis (Swansea University) B. Lucini (Swansea University) P. Shanahan (MIT)
July 3-7	*COLMO: Quantum Collapse Models investigated with Particle, Nuclear, Atomic and Macro Systems* C. Curceanu (INFN-LNF) A. Bassi (University and INFN Trieste) M. Derakhsani (Rutgers University) L. Diosi (University of Budapest) S. Donadi (INFN Trieste) K. Piscicchia (CREF)
July 10-28	*Doctoral Training Program: Ab Initio Methods and Emerging Technologies for Nuclear Structure* C. Barbieri (University of Milan) A. Roggero (University of Trento)
July 10-14	*Tensor Spin Observables* K. Slifer (University of New Hampshire) D. Higinbotham (Jlab) D. Keller (University of Virginia) E. Long (University of New Hampshire) W. Cosyn (Florida International University)
July 17-21	*Short-Distance Nuclear Structure and PDF* N. Fomin (University of Tennessee) J. Arrington (LBNL) W. Cosyn (Florida International University) N. Rocco (Fermi National Laboratory)

July 31 – August 4	*Quantum Sensing and Fundamental Physics with Levitated Mechanical Systems* A. Vinante (IFN-CNR) D. Budker (Johannes Gutenberg University Mainz) G. Hetet (École Normal Supérieure Paris) H. Ulbricht (University of Southampton)
August 21-25	*ECT*-APCTP Joint Workshop: Exploring Resonance Structure with Transition GPDs* S. Diehl (Justus Liebig University Giessen) V. Braun (University Regensburg) K. Joo (University of Connecticut) Y. Oh (Kyungpook National University) C. Van Hulse (University of Alcalà, Madrid) C. Weiss (Jlab) C.-H. Lee (Pusan National University & APCTP, South Korea)
August 31- Sep 1	*2ND MIMOSA Collaboration Meeting (Collaboration meeting)* G. Lattanzi (University of Trento) S. Taioli (ECT*) A. Vella (University of Rouen)
September 4-8	*Many-Body Quantum Physics with Machine Learning* A. Rios-Huguet (University of Barcelona) G. Carleo (EPFL) E. Inack (PITP) A. Lovato (ANL & TIFPA)
September 11-15	*MICRA 2023: Microphysics in Computational Relativistic Astrophysics* E. O'Connor (Stockholm University) C. Frohlich (Carolina State University) A. Perego (University of Trento)
September 18-22	*Parton Distribution Functions at a Crossroad* M. Ding (Helmholtz Centrum Dresden Rosendorf) J. Papavassiliou (University of Valencia) C. Quintans (LIP, Lisbon) C. Roberts (Nanjing University)

September 25-29	*Strongly Interacting Matter in Extreme Magnetic Fields* S. Varese (UNICAMP) A. Ayala (UNAM) D. Blaschke (University of Wroclaw) G. Endrodi (University of Bielefeld) R. Faria (Universidade Federal de Santa Maria)
October 9-13	*ROCKSTAR: Towards a Roadmap of the Crucial measurements of Key observables in Strangeness reactions for neutron sTARs equation of state* A. Scordo (LNF-INFN) D. Bosnar (University of Zagreb) C. Curceanu (LNF-INFN) A. Ramos (Institut de Ciences del Cosmo, Barcelona) F. Sakuma (RIKEN) Q. Vazques-Doce (LNF-INFN) I. Vidana (INFN Catania)
October 23-27	*Critical Stability of Few-Body Quantum Systems* A. Kievsky (INFN Pisa) T. Frederico (Instituto Tecnologico De Aeronautica, Brazil) O. Fynbo Aarhus University J.M. Richard (IPNL, IN2P3)
November 20-24	*ALPACA: modern ALgorithms in machine learning and data analysis: from medical Physics to research with ACcelerAtors and in underground laboratories* F. Napolitano (INFN-LNF) R. Del Grande (TU Munich) M. Skurzok (Jagiellonian University Kraków) F. Grosa (CERN, Switzerland)

2.3 Workshop reports

2.3.1 *Structure and Topology of RNA in Living Systems*

Date 31 January – 02 February 2023

Organizers

Luca Tubiana	University of Trento, Italy
Samuele Pasquali	University Paris Cité, France
Anze Bozic	IJS, Ljubjlana, Slovenia

Number of participants 39

Main topics

- RNA structure and topology
- RNA viruses
- RNA bioinformatics

RNA is an incredibly versatile biological macromolecule whose function is carried out not only on the level of its primary sequence of nucleotides, but also by the local and global structures that are created when the constituent nucleotides form base pairs. Many RNA structures are thus involved in translational control, RNA localization, gene regulation, RNA stability, and more. Furthermore, in a large number of bacterial, plant, animal, and human viruses, positive-strand RNA takes on the role of their genomes. Far from simply coding for the protein products, both local structural elements as well as long-range structural interactions in the genomes of RNA viruses are involved in many fundamental viral processes such as virus disassembly, translation, genome replication, and packaging, and are thus in general important for viral fitness. The aim of the workshop is to bring together researchers working on various aspects of RNA structure, topology, and function from both theoretical and experimental point of view, with a special focus on the genomes of RNA viruses.

Speakers

R. Amit	Technion, Israel
A.L. Bozic	IJS, Slovenia
G. Bussi	SISSA-ISAS, Italy
M. Comas-Garcìa	University of S. Louis Potosi, Mexico
M. Hagan	Brandeis University, USA
C. Micheletti	SISSA-ISAS, Italy
S. Pasquali	University Paris Cité, France
K. Roeder	University of Cambridge, UK

B. Sargueil	University Paris Cité, France
R. Smyth	Helmholtz Institute for RNA-based infection research, Germany
G. Stirnemann	University of Paris, France
M. Szachniuk	Poznan University of Technology, Poland
J. Trylska	University of Warsaw, Poland
M. Zurkowski	Poznan University of Technology, Poland

Scientific report

The workshop brought together researchers studying different aspects of RNA Physics and Biology, using different tools. The talks presented covered the physics of RNA going from detailed models of short RNA fragments, like siRNA, to coarse-grained one of long RNAs like mRNA and viral genomes. One major topic has been that of understanding the physical properties of RNA: this has been discussed based on SHAPE and translocation assays on the experimental side, and by using different kinds of simulations, mathematical frameworks, as well as webservers and data-based tools on the theoretical one. The schedule, the availability of discussion sessions, and the relatively large time dedicated to Q&A after each talk has brought a very fruitful discussion between researchers working on all these topics, which we hope will give birth to new collaborations in the future.

Results and Highlights

The workshop has been a precious opportunity to introduce complementary communities, particularly the one of RNA modelling, experimentalist working to understand RNA folding, and physicists and biologists working to understand the life cycle of RNA viruses. The interdisciplinary character of the workshop has been deeply appreciated by its participants, and several proposals to build stronger interactions between these communities have emerged. The physics of RNA viruses have been identified as a possible macro topic where the interests of all participants could converge.

2.3.2 *LaVA Meeting (collaboration meeting)*

Date	February 20-24, 2023

Organizers

Claudio Bonanno	INFN Firenze, Italy
Mariapaola Lombardo	INFN Firenze, Italy
Mike Peardon	Trinity College Dublin, Ireland

Number of participants	17

Main topics

LaVA is a virtual platform for advanced e-learning and mixed learning in Lattice Field Theory and related areas which is under development within the Strong-2020 project and supported by FBK and by the INFN communication office. The pandemic has lead to the production of a large collection of video material. Now that we are coming back to normality, it is of utmost importance that such legacy is not lost, but saved, collected and organised, including ad-hoc developed documents, for the benefit of the scientific community. The goal of LaVA is to provide students and early-stage researchers with a wide collection of recorded video-lessons and written lecture notes that is able to give a thorough introduction to the main current research areas in Lattice Field Theory. Covered topics will include Lattice QCD in extreme conditions, precision flavor physics, lattice quantum simulations and machine learning applications to Lattice Field Theory.

Speakers

Andreas Athenodorou	The Cyprus Institute, Nicosia, Cyprus
Christof Gattringer,	Austrian Science Fund FWF, Austria
Claudio Bonanno	IFT UAM/CSIC Madrid, Spain
Davide Vadacchino	University of Plymouth, UK
Ed Bennett, SA2C	Swansea University, UK
Francesco Di Renzo	University of Parma, Italy
Giuseppe Gagliardi	INFN Roma Tre, Italy
Gregorio Herdoiza	IFT UAM-CSIC Madrid, Spain
Gunnar Bali	Universität Regensburg, Germany
Maria Paola Lombardo	INFN Firenze, Italy
Michael Peardon	Trinity College Dublin, Ireland
Sara Collins	University of Regensburg, Germany
Simon Hands	University of Liverpool, UK
Tereza Mendes	University of São Paulo, Brazil
Tomasz Korzec	University of Wuppertal, Germany

Scientific report

During the workshop, several speakers presented the tentative syllabus and structure of each section of the webpage of the platform. After each talk, an extensive discussion session took place to discuss the proposed syllabus. Also, dedicated discussion sessions took place to agree upon the main topics covered on the platform, which can be summarized as follows:

- Essentials of Lattice Field Theory
- Algorithms
- Data Analysis
- Fermion Discretizations and Chiral Symmetry
- Renormalization and Improvement
- Thermal Field Theory
- Approaches to Systems with Sign Problems
- Quantum Computing and Tensor Networks
- Machine Learning
- Hardware and Software
- Hadron Physics Essentials
- Hadron Structure
- Hadron Spectroscopy
- Precision Frontier
- Beyond the Standard Model Field Theories
- Critical Phenomena and Renormalization Group
- Vacuum Structure and Confinement
- Reproducibility and Open Science

The syllabus of each section can be found in the slides discussed at the workshop, which are publicly available on the Indico webpage of the workshop, kindly provided by ECT*.

Results and Highlights

At the end of the workshop, a consensus about the following goals for LaVA was reached:

- Provide students and early-stage researchers with a wide collection of recorded video lecture and written lecture-notes in Lattice Field Theories (LFTs)
- The platform will include both links to pre-existing public material publicly available online (e.g., video recordings and lecture notes from past school or training events) and new ad-hoc material that will be developed for LaVA (video-recorded lecture snippets with related notes/slides)
- Provide organizes list of topics, each one with its syllabus, so that users (both within and outside the Lattice community) can be more easily introduced to the main active research areas in LFTs, as well as to the basic foundations of the field

- Covered topics will range from very introductory (e.g., how to discretize scalar fields) to more advanced one (e.g. precision physics, quantum simulations, machine learning applications, and more)
- Important to improve diversity and inclusivity in our field: LaVA can help aspirant lattice practitioners from under-represented categories to enter the Lattice community

A Beta version of the webpage of LaVA was prepared according to the suggestions of Gaia Stirpe (INFN), and thanks to the technical help provided by Barbara Gazzoli from ECT*. The first contents for the “Essentials” section (shown partially at the workshop) are already online.

2.3.3 *Holographic Perspectives on Chiral Transport*

Date	March 13-17, 2023

Organizers

Karl Landsteiner	IFT-UAM/CSIC Madrid, Spain
Umut Gursoy	University of Utrecht, Netherlands
Matthias Kaminski	University of Alabama, USA
Dmitri Kharzeev	Stony Brook University, USA

Number of participants	39

Main topics

Chiral anomalies can lead to new transport phenomena such as the chiral magnetic and the chiral vortical effects. Due to the universality of anomalies these effects play an important role in many different areas ranging from the physics of heavy ion collisions to condensed matter systems such as Weyl- and Dirac metals. From the very beginning, the theory of anomaly induced transport has received important inputs from holography (the "gauge/gravity" duality). In particular in view of the ongoing search for anomaly induced effects in heavy ion collisions it is necessary to deepen our theoretical understanding, develop new models and arrive at quantitative predictions. Holography is a very powerful tool that holds the promise to be able to successfully address all these issues. In order to apply methods based on the gauge/gravity duality to real world problems a vivid interaction with experts in related theoretical and experimental fields of research is needed. The workshop gathered leading experts and related fields to discuss the status quo and foster new ideas and collaborations.

The main topics were:

- Holographic methods for chiral transport
- Experimental results from the quark gluon plasma
- Relativistic hydrodynamics
- Spin hydrodynamics
- Non-Hermitian physics of opens systems
- Effective field theories of chiral transport
- High density systems and neutron stars
- Fracton hydrodynamics

Speakers

Navid Abbasi	Lanzhou University, China
Martin Ammon	University of Jena, Germany
Daniel Arean Fraga	IFT Madrid, Spain

Francesco Becattini	University & INFN Firenze, Italy
Daniel Brattan	CPhT, Ecole Polytechnique, France
Sasey Cartwright	Utrecht University, Netherlands
Jesus Cruz	APCTP, Pohang, South Korea
Arpit Das	Durham University, UK
Tuna Demircik	Wroclaw University of Science and Technology, Poland
Alexandru Dobrin	Institute of Space Science, Romania
Wojciech Florkowski	Jagiellonian University, Krakow, Poland
Kenji Fukushima	The University of Tokyo, Japan
Sebastian Grieninger	Stony Brook University, USA
Sašo Grozdanov	University of Edinburgh, UK & University of Ljubljana, Slovenia
Juan Hernandez	Vrije Universiteit Brussel, Belgium
Nabil Iqbal	Durham University, UK
Matti Jarvinen	APCTP, Pohang, South Korea
Niko Jokela	Helsinki Institute of Physics, Finland
Pawel Matus	MPI, Germany
Eugenio Megias	University of Granada, Spain
Sergio Morales Tejera	IFT Madrid, Spain
Francesco Nitti	APC, Université Paris Cité, France
Jorge Noronha	University of Illinois at Urbana-Champaign, USA
Jacquelyn Noronha-Hostler	University of Illinois Urbana-Champaign, USA
Francisco Pena-Benitez	Wroclaw University of Science and Technology, Poland
Andrey Sadofyev	IGFAE, Spain
Pablo Saura Bastida	UPCT and IFT-UAM/CSIC, Spain
Sharareh Sayyad	MPI for the Science of Light, Germany
Mikhail Stephanov	University of Illinois at Chicago, USA
Piotr Surówka	Wroclaw University of Science and Technology, Poland
Wilke van der Schee	CERN, Switzerland
Amos Yarom	Technion, Israel

Scientific report

Holography is a theoretical framework that aims to describe certain types of quantum field theories using gravity in one additional dimension. This framework is known as the AdS/CFT correspondence, or gauge/gravity duality. It has been used to study a variety of physical phenomena, including strongly-coupled systems, quantum phase transitions, and the quark-gluon plasma produced in heavy-ion collisions.

Chiral transport refers to the transport of particles with a handedness, or chirality. Particular important examples are the chiral magnetic and the chiral vortical effects. Both can be understood as macroscopic manifestations of chiral anomalies.

The chiral magnetic effect (CME) is a phenomenon in which an electric charge separation is generated along the direction of an external magnetic field in the presence of a topological imbalance of chirality. The CME is a consequence of the chiral anomaly, which is a non-conservation of axial current in the presence of external electromagnetic fields in theories with chiral fermions.

In the context of the quark-gluon plasma (QGP), the CME is expected to play an important role in the early stages of heavy-ion collisions, where strong magnetic fields are produced. The QGP is a state of matter consisting of deconfined quarks and gluons that is created when heavy nuclei collide at high energies. The strong magnetic fields generated during these collisions can lead to a separation of electric charges along the direction of the magnetic field, resulting in a net electric charge along the magnetic field axis.

The CME has been studied in experiments at the Relativistic Heavy Ion Collider (RHIC) and the Large Hadron Collider (LHC), through the measurement of charge-dependent azimuthal correlations in the final state of heavy-ion collisions. These measurements provide important insights into the properties of the QGP and the behavior of strongly-interacting matter in extreme conditions.

Holography, specifically the AdS/CFT correspondence, has been used to study the chiral magnetic effect (CME) in the quark-gluon plasma (QGP). The AdS/CFT correspondence provides a theoretical framework for studying strongly-coupled gauge theories, such as the QGP, by mapping them to weakly-coupled gravity theories in one additional dimension.

One of the key advantages of using holography to study the CME is that it allows for the calculation of transport coefficients, such as the chiral conductivity and the chiral magnetic conductivity, which are difficult to determine directly in experiments. These transport coefficients can be calculated using the Kubo formula, which relates the conductivity to the response of the system to a small perturbation.

Holographic calculations of the chiral conductivity and chiral magnetic conductivity have been carried out in a number of different models, including those with back reacting magnetic fields and finite temperature and density. These calculations have provided important insights into the behavior of the QGP under extreme conditions, such as those produced in heavy-ion collisions. In addition, holography has also been used to study the dynamics of the CME in the QGP, such as the time evolution of the chiral magnetic wave and the effects of hydrodynamic fluctuations. These studies have shed light on the interplay between the CME and other transport phenomena, such as the chiral vortical effect and the anomalous Hall effect. Overall, the use of holography to study the CME in the QGP is a fruitful approach that has led to important insights into the behavior of strongly-coupled systems under extreme conditions.

The main focus of the workshop was therefore to understand how holography can help to better understand the realization of the CME in a highly dynamical non-equilibrium situation as it arises in the quark gluon plasma.

A closely related field is the investigation of spin transport in the quark gluon plasma. Spin transport and polarization in the final state of a heavy ion collision is driven by vorticity in a way very similar to the chiral vortical effect. There are different approaches to address this problem ranging from field theory methods, Wigner function methods to hydrodynamics.

The most important topics included

- Experimental status of CME measurements
- Holographic models of chiral transport
- Hydrodynamics description of chiral transport
- Initial state effects
- Spin hydrodynamics

The workshop drew great interest form researchers in neighbouring and related fields. This led to a number of interesting contributions branching out into exciting new territories such as non-Hermitian physics, Fracton dynamics and holographic models of inflation.

Results and Highlights

Before going into the details of the scientific results and highlights it has to be mentioned that the format of the workshop was highly innovative and also a full success. Concretely the format consisted of one-hour blocks with two thematically linked talks each of strictly 20 minutes length followed by a 20 minute discussion period in which both speakers could address questions from the audience. This format was indeed a highlight, it led to very lively discussions which always continued into the following coffee or lunch breaks. The feedback the organizers received from the participants was unanimously positive.

One of the backbones of the workshop was the talk by A. Dobrin on the experimental status of CME measurements by the ALICE experiment at the LHC at CERN. The upshot was that for the time being it is still difficult to completely disentangle background from signal. However new innovative methods of analysis can be employed and hint towards a positive signal in the range of 5%-7%. This situation makes it ever more clear that a better theoretical understanding is needed. This was directly addressed by J. Noronha-Hostler who presented new results on how initial state fluctuations can contribute to the background.

Naturally many talks focused on improved holographic models (E. Megias, S. Tejera, S. Grieninger, N. Abbasi, A. Das, K. Fukushima). One of the significant improvements compared to early works is that in the new models the dynamics of the anomaly due to gauge fields is taken into account. Two approaches have been discussed: one based on massive gauge fields a la Stueckelberg and one using higher form symmetries. The difference between the two is that the Stueckelberg mechanism allows to capture the dynamics of the anomaly due to non-Abelian gauge fields whereas the approach based on higher form symmetry allows to include dynamical Abelian gauge fields. One drawback of the current models is that still the magnetic field is taken to be static or at most dilution due to expansion is taken into account. Here came an important input from W. van der Schee who showed how a holographic model of inflation manages to couple the metric dynamics of general relativity with a strongly coupled gauge theory. It should be possible to apply these ideas to the dynamics of the magnetic field interacting with a strongly coupled plasma. It was agreed that this problem must be solved in a collaborative effort involving a number of the participants (C. Cartwright, S. Grieninger, M. Kaminski, K. Landsteiner, U. Gursoy, D. Kharzeev, …).

Another important topic was chiral and spin hydrodynamics. It was pointed out that ideal chiral hydrodynamics suffers from causality violation in certain frames and must be supplemented by additional first order terms similar to what happens in dissipative hydrodynamics in Landau frame (J. Noronha). A new form of magnetohydrodynamics based on higher form symmetries was presented by S. Grozdanov. Spin hydrodynamics was discussed from several different viewpoints. A. Yarom pointed out that in an ultrarelativistic setting the spin current is slaved to the energy and momentum transport. However, it is not clear at the moment if this scenario applies in full to the situation present in heavy ion collisions and alternative approaches have also been discussed (W. Florkowski, M. Stephanov). Other aspects of chiral hydrodynamics such as magneto conductivities of dimensional reduction and pseudo-goldstone bosons were discussed by K. Fukushima, D. Brattan, J. Hernandez, P. Saura-Bastida and M. Ammon.

An important recent application of holographic models is to the physics of neutron stars. This was discussed in the contributions of J. Cruz, T. Demircik, M. Jarvinen and N. Jokela. F. Nitti presented a description of baryons in improved holographic QCD.

Two fields that have seen increased interest in recent years are non-Hermitian physics and the new idea of fractons. The first was presented by S. Sayyad who discussed a non-Hermitian realization of the chiral anomaly. D. Arean presented a holographic model of a non-Hermitian but PT symmetric theory. The physics of fractons was discussed by F. Pena-Benitz and P. Surowka.

A general form for currents of a massless Dirac fermion under rotation and acceleration at finite temperature was presented by F. Becattini. S. Sadofyev discussed an effective axion theory describing the dynamics of the chiral anomaly.

Unfortunately our workshop was not completely free of Corona related problems. P. Matus was not able to attend in person due to a Corona infection. He was however well enough to present his talk on anomaly induced transport in Weyl semi-metals via Zoom.

2.3.4 *The Gradient Flow in QCD and other Strongly Coupled Field Theories*

Date	March 20-24, 2023

Organizers

Christopher Monahan	William & Mary, USA
Robert Harlander	RWTH Aachen, Germany
Anna Hasenfratz	University of Colorado-Boulder, USA
Oliver Witzel	Siegen University, Germany

Number of participants	29

Main topics

The central theme of the workshop was the gradient flow, a field transformation that continuously smooths ultraviolet fluctuations by introducing a new parameter, the flow time. The gradient flow has a wide variety of applications in quantum field theories, including quantum chromodynamics (QCD), the gauge theory of the strong nuclear force, and other nonperturbative field theories. The gradient flow has been used extensively in lattice gauge theory calculations, both in QCD and in beyond-the-standard-model settings for applications including scale setting, the determination of the running coupling constant and the corresponding renormalization group beta function, and the topological structure of the vacuum. Many of these emerging applications depend on the perturbative connection of the gradient flow and continuum renormalization schemes, requiring difficult perturbative calculations that match the non-perturbative methods. This workshop brought together experts in applications of the gradient flow to lattice QCD, beyond-the-standard-model theories on the lattice, and in perturbative quantum field theories. These practitioners discussed recent developments in both nonperturbative and perturbative methods and identified areas of overlap and common research interests. A particular focus was “translating” methodologies from lattice QCD to perturbative QCD and vice versa, by developing a dictionary that enabled theorists to share common ideas and techniques.

The main topics can be summarized as:

- Nonperturbative renormalization schemes for composite operators on the lattice and connecting or translating those schemes to the MS-bar scheme at high scales, using multi-loop perturbation theory.
- Defining and refining nonperturbative continuous beta functions to explore the coupling constants of beyond-the-standard-model theories and to map out their phase diagrams.
- Application of the gradient flow to the electroweak Hamiltonian and other higher-dimension operators.
- Application of the gradient flow to Wilson-line operators in heavy quark effective theory.

Speakers

Andrea Carosso	George Washington University, USA
Andrea Shindler	RWTH Aachen, Germany
Andrey Kotov	Juelich Forschungszentrum, Germany
Janosch Borgulat	RWTH Aachen, Germany
Matthew Black	Siegen University, Germany
Nora Brambilla	Technical University Munich, Germany
Luigi Del Debbio	University of Edinburgh, United Kingdom
Michael Eichberg	Frankfurt University, Germany
Jonas Kohnen	RWTH Aachen, Germany
Zeno Kordov	Technical University Munich, Germany
Julius Kuti	University of California, San Diego, USA
Fabian Lange	Karlsruhe Institute of Technology, Germany
Viljami Leino	Johannes Gutenberg University, Mainz, Germany
Martin Luescher	CERN, Switzerland
Julian Mayer-Steudte	Technical University Munich, Germany
Curtis Peterson	University of Colorado-Boulder, USA
Simone Romiti	University of Bonn, Germany
Gerrit Schierholz	DESY, Germany
Stefan Sint	Trinity College Dublin, Ireland
Rainer Sommer	DESY & Humboldt University, Germany
Ivan Soler	Friedrich-Schiller University of Jena, Germany
Hiroshi Suzuki	Kyushu University, Japan
Benjamin Svetitsky	Tel Aviv University, Israel
Xiangpeng Wang	Technical University Munich, Germany
Chik Him Wong	University of Wuppertal

Scientific report

Strongly-coupled field theories describe a wide range of physical phenomena, from the quarks and gluons that form the basic building blocks of all nuclear matter to novel two- and three-dimensional states of matter that have only recently been discovered or created in the laboratory. Unfortunately, the strongly-coupled nature of these systems makes them exceedingly difficult to solve analytically and precludes a meaningful treatment using perturbation theory.

Quantum chromodynamics (QCD), the gauge field theory of the strong nuclear force, is the paradigm example of a strong-coupled, or nonperturbative, theory. Over the last half century, lattice QCD has evolved from an abstract theoretical approach to a widely-used and highly precise method for extracting numerical information about QCD from Monte Carlo simulations. Lattice QCD is formulated on a discrete hypercube of Euclidean spacetime, where the inverse of the lattice spacing serves as an ultraviolet regulator in momentum space. To connect lattice calculations, of QCD or any other lattice field theory, to experimental observables typically requires a procedure for nonperturbative renormalization (which enables the continuum limit to be taken, to remove the lattice regulator) and a matching procedure that relates this nonperturbative renormalization scheme to perturbative schemes, such as the MS-bar scheme.

The gradient flow has provided one such framework for relating lattice calculations to experimental observables. The gradient flow is a one-parameter mapping of the fields that exponentially suppresses ultraviolet fluctuations by smearing the fields in coordinate space. In pure Yang-Mills theories, the gradient flow introduces no new ultraviolet divergences to the renormalized theory, and in QCD the only additional renormalization required is a multiplicative fermionic wavefunction renormalization. The gradient flow can be carried out nonperturbatively and is gauge invariant. Various flows have been developed and applied to other strongly-coupled field theories beyond QCD.

Over the last decade, applications of the gradient flow include scale setting, the determination of the running coupling constant and the corresponding renormalization group beta function, and the topological structure of the vacuum. Many of these emerging applications depend on the perturbative connection of the gradient flow and continuum renormalization schemes, requiring difficult perturbative calculations that match the non-perturbative methods. In particular, the calculation of precision quantities (in, for example, heavy quark flavor physics), requires multi-loop matching calculations. These calculations require specialized knowledge and highly refined theoretical and mathematical techniques that are not well-known or widely used in the lattice community.

This workshop brought together experts in applications of the gradient flow to lattice QCD, beyond-the-standard-model theories on the lattice, and in perturbative quantum field theories to discuss recent developments in both nonperturbative and perturbative methods. A focus was “translating” methodologies from lattice QCD to perturbative QCD and vice versa, by developing a dictionary that enabled theorists to share common ideas and techniques.

In particular, the participants discussed in detail new proposals for nonperturbative renormalization techniques that use the gradient flow and clarified what corresponding perturbative calculations would be required to match these lattice renormalization schemes to the MS-bar scheme. The perspective of the real-space renormalization group, more commonly used in condensed matter systems, was also a significant topic of discussion that produced new insight into traditional techniques for many participants. The workshop discussed the most recent developments in understanding the phase diagrams of strongly-coupled gauge theories with multiple species of fermions and the extraction of nonperturbative matrix elements of Wilson-line operators relevant to nonrelativistic QCD and its application to heavy quark systems.

Results and Highlights

The workshop provided a unique opportunity for lattice practitioners and perturbative QCD experts to discuss in detail what theoretical and mathematical techniques are necessary to connect novel nonperturbative calculations to the MS-bar scheme.

Many participants volunteered informal feedback to the organizers that they had found the workshop extremely useful and the discussions very thought provoking. The large number of early career researchers was noted as a particular strength of the workshop.

One of the key outcomes was clarification of recent proposals to apply the gradient flow as a tool for determining nonperturbative anomalous dimensions, which characterize the scale dependence of renormalized operators. The real-space renormalization group framework provided particular insight into the applicability of nonperturbative definitions of anomalous dimensions and the relationship to the standard definitions in the MS-bar scheme was clarified. Discussions showed that further nonperturbative numerical work is necessary to demonstrate the feasibility of the gradient flow as a tool for extracting nonperturbative anomalous dimensions, with particular attention necessary to determine the “window” in which the scheme is applicable. “Window problems” are common in lattice calculations and indicate that a particular framework is only valid within a certain range (or window) of physical scales that may or may not be practically accessible with current computational resources. Window problems are observable dependent and must be studied numerically to clarify whether they pose significant challenges for particular lattice calculations.

The status and structure of the phase diagrams of beyond-the-standard-model theories is still unclear. Several talks provided conflicting numerical evidence of the behavior of various fixed points and the need for continued study was emphasized by the participants.

The status of, and ongoing need for, dedicated studies of the gradient flow in nonrelativistic QCD was a topic of several talks and new research avenues in this direction were identified.

In summary, the workshop was found to be novel, productive and generative, providing a unique opportunity for practitioners from different communities to engage in meaningful and fruitful discussions. Existing proposals for novel developments were clarified and multiple directions for future research were identified, with several topics likely to lead to future collaborations.

2.3.5 *Quantum Science Generation* | *QSG*

Date	May 2-5, 2023

Organizers

Daniele De Bernardis	INO-CNR BEC Center, Italy
Valentina Amitrano	University of Trento, INO-CNR, Italy
Alessio Baldazzi	University of Trento, Italy
Anna Berti	University of Trento, INO-CNR, Italy
Iacopo Carusotto	INO-CNR BEC Center, Italy
Daniele Contessi	University of Trento, INO-CNR, Italy
Alberto Nardin	University of Trento, INO-CNR, Italy
Lorenzo Pavesi	University of Trento, Italy

Number of participants	64

Main topics

The first aim of the QSG workshop is to offer seminars held by young scientists and leading researchers in theoretical and experimental quantum physics. The talks were divided between senior and junior invited speakers, in addition to further contributions selected among all the participants. Moreover, we had special contributed talks from company and start-up representatives working in the field of quantum science and technology. As a second purpose, the QSG workshop promoted and facilitated discussions between the students, postdocs, young researchers and experienced professors through some social activities.

The scientific program covered among the most important areas of research in quantum science and technology.

Specifically we had:

- Advances in quantum computing and quantum simulations
- Development of new platforms for quantum technologies
- Computational methods
- Industrial application of cutting-edge research

Speakers

Joan Agusti	Walther-Meißner-Institut, Germany
Syeda Aliya Batool	Research Assistant at TU Wien, Austria
Valentina Brosco	CNR, ISC, Università ‘La Sapienza’ di Roma, Italy
Tommaso Calarco	Forschungszentrum Jülich GmbH, Universität zu Köln, Germany

Giuseppe Calajò	Università di Padova, INFN, Italy
Marco Canteri	University of Innsbruck, Austria
Federica Cataldini	TU Wien, Austria
Olesia Dmytruk	CNRS, Ecole Polytechnique, France
Clément Duval	Sorbonne Université, France
Gerald Fux	ICTP, UK
Louis Garbe	TU Wien, Austria
Juan Jose Garcia-Ripoll	Instituto de Física Fundamental, Spain
Carlos Gonzalez-Ballestero	University of Innsbruck, Austria
Andreas Haller	University of Luxembourg, Luxembourg
Rui Lin	ETH Zurich, Switzerland
Yijian Meng	University of Copenhagen, Denmark
Yuri Minoguchi	TU Wien, Austria
Carmelo Mordini	ETH Zurich - Institute for Quantum Electronics, Switzerland
Alice Pagano	University of Padova, Italy
Hannes Pichler	University of Innsbruck, Austria
Ulrich Schollwöck	University of Munich, Germany
Fabio Sciarrino	Università 'La Sapienza' di Roma, Italy
Andrea Stanco	Università di Padova, Italy
Hamid Tebyanian	University of York, UK
Filippo Vicentini	Ecole Polytecnique Paris, France
Caterina Vigliar	Danmarks Tekniske Universitet, Denmark
Nicola Carlon Zambon	ETH Zürich, Switzerland

Scientific report

The Quantum Science and Technology Conference, hosted at the European Centre for Theoretical Studies in Nuclear Physics and Related Areas (ECT*) in Trento, provided a platform for leading experts, researchers, and practitioners to share their insights and advancements in the field of quantum science and technology. This report offers a summary of the key topics discussed during the conference, focusing on five distinct areas: 1) quantum technologies with superconducting circuits, 2) cavity-induced modifications of matter, 3) computational methods for treating many-body problems in quantum science, 4) advancements in photonics and single photon technology, and 5) recent developments in quantum optics and Rydberg atom arrays.

- Quantum Technologies with Superconducting Circuits: prominent researchers presented significant advancements in quantum technologies utilizing superconducting circuits. The conference featured discussions on the ultrastrong coupling regime of superconducting circuit Quantum Electrodynamic (QED) and the mathematical methods employed to analyze and manipulate it. Attendees explored the potential applications of superconducting circuits in quantum computation and quantum simulation, considering both theoretical frameworks and experimental progress.

- Cavity-Induced Modifications of Matter: the conference addressed the intriguing concept of using cavities to induce modifications in matter. Researchers discussed the possibility of manipulating matter's topology or altering properties such as superconductivity through the interaction with cavity fields. Theoretical models and experimental demonstrations were presented, providing insights into the fundamental understanding of cavity-induced modifications and their potential impact on material science and quantum technology.
- Computational Methods for Many-Body Problems in Quantum Science: the conference highlighted the importance of computational methods for studying many-body problems in quantum science. Experts presented advanced numerical analysis techniques applied to real materials, such as complex spin chains and correlated electron systems. Discussions revolved around the development of efficient algorithms, high-performance computing approaches, and novel mathematical frameworks for tackling challenging many-body problems.
- Advancements in Photonics and Single Photon Technology: Photonics and single photon technology emerged as a vital area of focus at the conference. Researchers explored the problem of boson sampling and various approaches to its realization using photonic setups. Additionally, the creation of entangled photon states using ions and quantum dots was discussed, with an emphasis on experimental achievements and the potential for scalable quantum information processing.
- Recent Developments in Quantum Optics and Rydberg Atom Arrays: The conference provided a platform to showcase recent advancements in quantum optics and the field of Rydberg atom arrays. Researchers presented cutting-edge techniques for manipulating ultracold atomic gases and controlling quantum materials. The discussions encompassed applications such as quantum simulation, quantum information processing, and the exploration of exotic quantum phases.

In conclusion the Quantum Science and Technology Conference at ECT* in Trento successfully brought together experts and researchers to share their knowledge and advancements in quantum science and technology. The conference covered diverse topics, ranging from quantum technologies with superconducting circuits and cavity-induced modifications of matter to computational methods for many-body problems, advancements in photonics and single photon technology, and recent developments in quantum optics and Rydberg atom arrays. The insights and discussions from the conference are poised to shape the future of quantum science and technology, fueling further progress and innovation in the field.

Results and Highlights

The Quantum Science Generation conference, held recently, proved to be a resounding success due to its broad range of topics and the extensive knowledge exchange between disciplines within the quantum science field. This report highlights the key factors that contributed to the conference's success, including the generation of new ideas and projects through interdisciplinary discussions, as well as the significant presence of young speakers who brought fresh perspectives and cutting-edge research ideas to the forefront. The conference covered a wide spectrum of topics within the realm of quantum science, including quantum technologies, computational methods, photonics, quantum optics, and more. This diverse range of subjects facilitated cross-pollination of ideas and encouraged attendees to explore new avenues of research. The interdisciplinary nature of the conference allowed participants to gain insights from different fields, enabling fruitful collaborations and stimulating the generation of innovative projects and ideas. One notable aspect of the conference was the prominent presence of young speakers. Their active involvement greatly enhanced the discussions and exchange of ideas among attendees. Their contributions sparked excitement and enthusiasm, inspiring attendees to think beyond conventional boundaries and consider new directions for future research and technological advancements. The engagement of young speakers combined with all the social activities proposed by the organizers (2 aperitif poster session, social dinner, and visit to the Marzadro distillery) also created an environment conducive to mentorship and networking. Established researchers and experts readily engaged with the young speakers, providing valuable guidance and support. The open and collaborative atmosphere fostered meaningful interactions and facilitated the exchange of knowledge and experiences between participants at all career stages. The conference succeeded in nurturing a vibrant community of quantum science enthusiasts, fostering an environment where ideas were freely shared, discussed, and refined. The integration of young speakers alongside established researchers led to a diverse range of perspectives and insights, ultimately enriching the overall discourse and encouraging participants to think outside the box. In conclusion, the Quantum Science Generation conference exemplified the power of interdisciplinary collaboration and the importance of including young speakers in scientific gatherings. The broad range of topics and the active participation of young researchers generated an atmosphere of creativity and innovation. By facilitating knowledge exchange and promoting cross-disciplinary discussions, the conference sparked new ideas and projects that have the potential to shape the future of quantum science.

2.3.6 *Color Glass Condensate at the Electron-Ion Collider*

Date	May 15-19, 2023

Organizers

Dionysios Triantafyllopoulos	ECT*, Italy
Nestor Armesto	University of Santiago de Compostela, Spain
Edmond Iancu	University of Paris-Saclay, IphT, France
Tuomas Lappi	University of Jyväskylä, Finland

Number of participants	38

Main topics

Quantum Chromodynamics is widely accepted as the fundamental theory of strong interactions and has been very successful in describing a wide range of phenomena. A particularly interesting regime occurs in high energy collisions involving hadrons, when one probes transverse momenta of the order of a few GeV. Even though weak coupling techniques apply for such semi-hard momenta, parton distributions become large and non-linear phenomena associated with strong gauge fields take place and lead to gluon saturation. The effective theory of the Color Glass Condensate (CGC) has emerged as a successful tool to explain qualitatively and quantitatively these kind of processes in preceding and current experiments at colliders like DESY, RHIC and LHC. The Deep Inelastic Scattering of electrons off nuclei in the forthcoming EIC and future electron-hadron/nucleus colliders will further offer a cleaner environment to explore the dynamics in the presence of gluon saturation.

The main topics were:

- The Electron Ion Collider
- Gluon Saturation in Deep Inelastic Scattering
- Diffractive Processes
- Multi-particle Production and Correlations
- Transverse Momentum Distributions at low-x

Participants

Tolga Altinoluk	National Centre for Nuclear Research, Poland
Nestor Armesto	University of Santiago de Compostela, Spain
Ian Balitsky	JLAB and Old Dominion University, USA
Sanjin Benic	University of Zagreb, Croatia
Guillaume Beuf	National Centre for Nuclear Research, Poland
Renaud Boussarie	Ecole Polytechnique, France
Jan Cepila	FNSPE CTU in Prague, Czech Republic

Giovanni Antonio Chirilli	University of Santiago de Compostela, Spain
Brian Cole Columbia	University, USA
Guillermo Contreras Nuno	Czech Technical University, Prague
Florian Cougoulic	University of Santiago de Compostela, Spain
Yoshitaka Hatta	RIKEN BNL, USA
Edmond Iancu	Saclay, France
Jamal Jalilian-Marian	Baruch College, CUNY, USA
Piotr Korcyl	Jagiellonian University, Poland
Yuri Kovchegov	Ohio State University, USA
Alexander Kovner	University of Connecticut, USA
Krzysztof Kutak	IFJ PAN, Poland, Finland
Tuomas Lappi	University of Jyväskylä, Finland
Anh-Dung Le	University of Jyväskylä, Finland
Michael Lublinsky	Ben-Gurion University of the Negev, Israel
Yacine Mehtar-Tani	BNL, USA
Leszek Motyka	Jagiellonian University, Poland
Alfred Mueller	Columbia University, USA
Swaleha Mulani	National Centre for Nuclear Research, Poland
Yair Mulian	University of Santiago de Compostela, Spain
Risto Paatelainen	Helsinki Institute of Physics, Finland
Jani Penttala	University of Jyväskylä, Finland
Christophe Royon	University of Kansas, USA
Farid Salazar	University of California Los Angeles, USA
Vladimir Skokov	North Carolina State University, USA
Tomasz Stebel	Jagiellonian University, Poland
Pieter Taels	Universiteit Antwerpen, Belgium
Daniel Tapia Takaki	University of Kansas, USA
Yossathorn Tawabutr	University of Jyväskylä, Finland
Dionysios Triantafyllopoulos	ECT*, Italy
Charlotte Van Hulse	University of Alcala, Spain
Bin Wu	University of Santiago de Compostela, Spain

Scientific report

QCD is the underlying theory of the strong force. It has been efficient and crucial at describing quantitatively hard collisions which are typically characterized by a large transverse momentum scale. In this regime quark and gluon distributions are dilute and hence higher twist effects are negligible. Under these circumstances the perturbative expansion of scattering amplitudes is accurate and one can safely predict observable quantities like cross-sections involving the production of hard jets.

The situation changes when parton distributions get large and gluon saturation starts to play a dominant role: in a hadronic or nuclear wave-function, emission of small-x gluons with momenta below the saturation scale Qs are suppressed. Such a dynamical scale grows with the collision energy and the nuclear atomic number and, if sufficiently above the confinement scale, allows the use of weak coupling methods.

The CGC is the effective theory which resums soft gluon emissions in the presence of strong gauge fields and provides the main tool for studying semi-hard processes. The amplitude for the scattering of a color dipole off a hadron is the central quantity and can be calculated by taking into account the most important higher order logarithmic corrections that include contributions from the running of the coupling and from collinear resummations. The amplitudes for the scattering of more complicated multipoles, which appear in multi jet cross sections can be obtained by solving a Langevin equation or, modulo certain exceptions, can be accurately expressed in terms of the dipole using a Gaussian approximation. These quantities are universal. On the contrary, impact factors depend on the process and substantial progress has been achieved with their NLO calculation for quark - hadron and virtual photon - hadron collisions. This framework has provided us a way to consistently describe a vast array of experimental results, like total and diffractive cross section in DIS of electrons off protons at HERA, particle multiplicities in lead - lead collisions at the LHC, angular correlations in forward di-hadrons in deuteron - gold collisions at RHIC etc.

The concepts and the methods of the CGC share similarities with those used by the practitioners of transverse momentum distributions (TMDs). Unpolarized TMDs at small-x can be obtained almost straightforwardly from the appropriate correlators in the CGC. Spin-dependent ones are more involved, they are related to sub-eikonal, or equivalently finite target length, corrections and their exploration is being pursued over the last few years.

Results and Highlights

There were 38 participants, out of which 5 experimentalists representing the ALICE, ATLAS and CMS collaborations. The 33 theorists included many leading experts of the field worldwide and some of the most promising PhD students and young postdoctoral fellows. The workshop lasted four and a half days and each of 35 participants contributed with a talk. The experimental talks were typically given in the beginning of a session. All talks lasted 30 + 5 minutes, but there was a certain amount of flexibility when interesting questions led to critical and important discussions. Concerning the experimental talks, an extensive coverage of photon-nucleon processes in Ultra-Peripheral Collisions (UPCs) at LHC was given, with particular emphasis on the production of forward hard dijets in diffractive scattering and their sensitivity to gluon saturation. Processes with two jets widely separated in rapidity in proton-proton collisions, like the Mueller Navelet jets or the Mueller Tang jets (the former is inclusive, whereas in the latter there is a large gap between the jets) were studied at NLO and suggested as a process to test BFKL dynamics at LHC. A description of the EIC was given and the possibilities to measure spin-dependent observables at low-x, diffractive cross sections and dihadron production were carefully analysed. Regarding the theoretical presentations, many of them were devoted to next-to-eikonal corrections to DIS of electrons of hadrons and/or nuclei. They allow one to calculate contributions to the proton spin at small-x and the hope is to be able eventually to address the spin-puzzle. Furthermore, by performing such non-eikonal calculations in the CGC, one is able arrive at the quark TMD, including the valence contributions. Significant work on other various types of corrections to DIS was presented and discussed. This included impact factors with finite quark masses at NLO, matching of small-x to moderate values of x and high energy evolution beyond NLO at the level of the JIMWLK equation. The long-standing problem regarding the hybrid factorisation of the single inclusive cross section in proton nucleus collisions has been revisited and a systematic description at NLO has been given. Another topic in which there was great interest, was the production of forward hard dijets in DIS and UPCs, both in inclusive and diffractive processes. It was shown how Sudakov logarithms emerge in the inclusive case, which is a solid step towards their resummation in order to reliably calculate the respective cross section. In the case of diffractive dijets in coherent reactions (i.e when the target remains intact) it was explained why a configuration with a third, semi-hard, jet gives the dominant contribution in the twist counting. The dominant physical mechanisms which lead to incoherent diffraction were explored. In general, a recurring theme was the calculation and the understanding of angular correlations between final state particles, whether they are (at the parton level) quarks or gluons. Last but not least, a detailed procedure for computing diffractive structure functions at NLO was shown. There was no doubt that the workshop was successful and productive and the participants expressed their willingness to get together again at ECT in 2-3 years.

2.3.7 *From First Principles QCD to Experiments*

Date	May 22-26, 2023

Organizers

Markus Huber	Giessen University, Germany
Gernot Eichmann	LIP Lisbona, Portugal
Maria Paola Lombardo	INFN, Firenze, Italy
Pieter Maris	Iowa State University, USA
Jan Martin Palowski	Heidelberg University, Germany

Number of participants	38

Main topics

The main theme of the workshop was nonperturbative calculations of QCD concerning the structure of hadrons and the QCD phase diagram:

- Spin and flavor structure of hadrons
- Formation mechanisms of hadrons
- Real-time properties of hadrons
- QCD phase structure

To be more specific, the following key questions were addressed during the workshop:

- What is the quark-gluon structure of hadrons?

  To answer this, one needs to cross over from spacelike to real-time and light-like kinematics, e.g., through first-principles calculations of (generalized) parton distribution functions and transverse momentum distributions. In this way, the spin and flavor structure of the nucleon can be described and the distribution of gluons and sea quarks in hadrons and nuclei be determined.
- What are the properties of the QCD phase diagram and what are suitable observables to connect experiment and theory?

  On the lattice, both the computation of higher order fluctuations of conserved charges as well as the understanding of the convergence properties by now give a firm access to the phase structure for small chemical potential. In turn, functional computations provide access to higher chemical potential. Another question is what happens when baryons overlap because they are densely packed together, such as in extreme astrophysical environments like the core of neutron stars where they may dissolve to form color-superconducting quark matter.
- How can we determine real-time properties of QCD?

The input to fluid dynamics and transport equations is the equation of state, transport coefficients, and further real-time correlation functions in QCD. Their computation with functional approaches and lattice reconstructions has entered a quantitative state with decreasing systematic errors. With their use in fluid dynamics and transport approaches a quantitative comparison to experimental data becomes feasible.

Speakers

Reinhard Alkofer	University of Graz, Graz, Austria
Martha Constantinou	Temple University, Philadelphia, USA
Francesca Cuteri	Goethe University, Frankfurt, Germany
Feliciano de Soto	Universidad Pablo de Olavide, Sevilla, Spain
Alessandro Drago	University of Ferrara, Ferrara, Italy
Christian S. Fischer	Giessen University, Giessen, Germany
Wei-ji Fu	Dalian University of Technology, Dalian, China
Fei Gao	Beijing Institute of Technology, Peking, China
Claudia Höhne	Giessen University, Giessen, Germany
Peter Lowdon	Goethe University, Frankfurt, Germany
Orlando Oliveira	University of Coimbra, Coimbra, Portugal
Peter Petrecky	Brookhaven National Laboratory, Brookhaven, USA
Fabian Rennecke	Giessen University, Giessen, Germany
Piotr Salabura	Jagiellonian University, Krakow, Poland
Giovanni Salmè	INFN - Sezione di Roma, Rome, Italy
Bernd-Jochen Schaefer	Giessen University, Giessen, Germany
Ralf-Arno Tripolt	Giessen University, Giessen, Germany
Raju Venugopalan	Brookhaven National Laboratory, Brookhaven, USA
Nicolas Wink	TU Darmstadt, Darmstadt, Germany
Savvas Zafeiropoulos	CNRS and Aix Marseille University, Marseille, France
Dibyendu Bala	Universität Bielefeld, Bielefeld, Germany
Eduardo Ferreira	University of Graz, Graz, Austria
Eduardo Grossi	Florence University, Florence, Italy
Langtian Liu	Giessen University, Giessen, Germany
Yi Lu	Peking University, Peking, China
Ugo Mire	Giessen University, Giessen, Germany
Theo Motta	Giessen University, Giessen, Germany
Mauricio Narciso Ferreira	University of Valencia and CSIC, Valencia, Spain
Harshit Pandey	The Institute of Mathematical Sciences (IMSc), Chennai, India
Fernando Romero-Lopez	MIT, Cambridge, USA
Xin-Li Sheng	INFN Firenze, Florence, Italy
Paulo Silva	University of Coimbra, Coimbra, Portugal
Jonas Turnwald	TU Darmstadt, Darmstadt, Germany

Jonas Wessely	ITP Heidelberg, Heidelberg, Germany

Scientific report

The past decade has seen rapid and impressive progress in experimental and theoretical hadron and nuclear physics. Ongoing experiments such as the Beam Energy Scan at STAR (RHIC, Brookhaven), the high density experiment HADES (GSI, Darmstadt), or the ALICE experiment (CERN, Geneva), and planned ones such as CBM and PANDA (FAIR, Darmstadt) or the EIC (BNL, Brookhaven) will offer a plethora of data that give access to the dynamical properties and the phase structure of QCD. In parallel, several theoretical methods aim at a comprehensive understanding of QCD at low energies, among them large-scale (Euclidean or space-like) numerical simulations with lattice QCD as well as computations of space- and timelike processes with functional approaches.

The structure of hadrons as described by (generalized) parton distribution functions and transverse momentum distributions was addressed by several talks and a dedicated discussion session. The lattice community seems to make steady progress in this direction. For functional methods, calculating timelike quantities is a challenge as well. On the one hand, models are used to develop the necessary tools which will be applied to QCD later on. This can be simple scalar models for exploratory studies, but also phenomenologically minded models that provide a qualitative and in some cases even a quantitative description. On the other hand, in some limited instances functional calculations already can perform first-principles calculations.

The current status of the QCD phase diagram was thoroughly reviewed. Connections between theory and experiment were discussed, for example, via fluctuations of conserved charges. The complementary character of continuum and lattice methods was also emphasized: Using the latter at small chemical potential to adjust model input for the former, they can be used to go to higher chemical potential with $\mu_B/T > 3$. On the question of the critical endpoint it seems that different functional approaches have now converged to the same region of the μ-T-plane, μ_B/T ~5.5 - 6, or beam energies per nucleon of ~4 GeV. The investigation of the high density region as relevant for neutron stars faces additional challenges for which new methods were suggested. Another discussed aspect was real-time properties and how to deal with the technical challenges of calculating them.

Results and Highlights

The backgrounds of the participants of the workshop covered many different approaches to the workshop theme of nonperturbative QCD physics. This was reflected in the wide range of topics in the talks and offered plenty of opportunities for discussions, comparisons and establishing connections between the different methods. In this respect, the workshop provided the perfect environment for exchange between practitioners of different fields and techniques. As already explained above, the complementarity of different methods was a recurring topic. This workshop has contributed towards an even better appreciation of this fact and has helped to strengthen the 'team spirit'.

In summary, there were 20 talks of invited key speakers and 14 contributed talks of participants. On two afternoons, dedicated and moderated discussions about the

QCD phase diagram and hadron structure, respectively, took place where open problems and challenges for the future were discussed.

Finally, we want to emphasize the extremely constructive atmosphere created by all participants during the whole workshop, in particular during the question and discussion sessions.

2.3.8 *2023 CMS Heavy Ion Workshop: Bringing Together the LHC Heavy Ion Community*

Date	May 29 – June 01, 2023

Organizers

Georgios Krintiras	The University of Kansas, USA
Yen Jie Lee	MIT, USA
Wei Li	Rice University, USA
Carlos Lourenco	CERN, Switzerland
Andre Stahl	CERN, Switzerland
Yi Chen	MIT/Vanderbilt University USA

Number of participants	35 in person (in total: 75)

Main topics

The main topics were:

- Initial state and global analysis of nuclear modifications of the parton distributions
- Macroscopic QGP Properties
- QGP tomography
- Open heavy flavor and quarkonia
- Small size/far-from-equilibrium limit of QGP
- Ultraperipheral collisions
- Wrap up discussion of public part
- CMS internal part (including the feedback from the public part)

Speakers

Jasmine Brewer	CERN, Switzerland
Zhenyu Chen	Shandong University, China
David d'Enterria	CERN, Switzerland
Gian Michele Innocenti	CERN, Switzerland
Tomas Jezo	University of Münster, ITP, Germany
Mariola Klusek-Gawenda	Institute of Nuclear Physics PAN, Poland
Luciano Musa	CERN, Switzerland
Helena Santos	LIP, Portugal
Jiayin Sun	INFN Cagliari, Italy
Wilke van der Schee	CERN, Switzerland
Jing Wang	CERN, Switzerland
Zhong Yang	Central China Normal University, China

Zhenyu Ye University of Illinois at Chicago, US
Jiaxing Zhao SUBATECH, France

Scientific Report

The successful heavy ion (HI) program at the LHC, initially focused on characterizing quark-gluon plasma (QGP) in lead-lead (PbPb) collisions, has evolved into an indispensable part of the LHC physics program. This program, enriched by data from proton-lead (pPb), proton-proton (pp), and xenon-xenon (XeXe) collisions, has made significant strides in understanding partonic nuclear structure, collectivity in smaller collision systems, and electromagnetic interactions.

The CMS workshop in 2023 provided a unique platform to shape the Collaboration's perspective on the scientific potential of ultrarelativistic HI beams in the next decade. Discussions during the workshop, involving theory and LHC experimental communities, delved into crucial open questions in the field that could be addressed by CMS and/or in collaboration with other LHC experiments. With a tenfold increase in PbPb integrated luminosity and enhanced detector components, the workshop emphasized the opportunity for precise studies of QGP properties, complementing the LHC pp program.

The envisioned advancements underscore the wealth of physics awaiting exploration at the LHC, surpassing its original design goals. However, realizing these opportunities necessitates synergies across accelerator, experimental, and theory domains, along with sustained commitments to developing relevant technologies throughout the LHC program's lifetime.

Moreover, the workshop aimed to engage the European community and its international partners, aligning with the recently concluded European Strategy for Particle Physics and Snowmass 2022 exercise. These inputs are vital for proposed extensions of the European and US Long-Range Plans for Nuclear Physics.

Results and Highlights

We deem (and this was in fact perceived by all the participants) the following physics topics particularly well suited to be covered, in a unique way, by general purpose detectors like the CMS experiment:

- **Initial-state physics**: There is still much to be uncovered regarding the precise nature of the initial state from which thermal QCD (Quantum Chromodynamics) matter originates. Uncertainties persist about parton densities within nuclei across a wide kinematic range, the potential onset of parton saturation, and how these properties vary throughout the phase diagram. Measurements taken during LHC Runs 1 and 2 in lead-lead (PbPb) and proton-lead (pPb) collisions have already allowed for constraining nuclear modifications in PDFs derived from free protons. The forward physics instrumentation at CMS enables the exploration of the dense QCD state, as high-gluon densities are generated through the low-x evolution of the gluon distribution within the lead ion. This forward physics program at the LHC is anticipated to complement the physics program at the planned Electron-Ion Collider (EIC) facility.
- Top of Form

- **Macroscopic QGP properties**: By capitalizing on advancements in experimental data-acquisition systems during the HL-LHC era, the CMS experiment is poised to record exceptionally large datasets from minimum bias (MB) pp, pPb, and PbPb collisions. Notably, in 2023, the experiment has already exceeded the 15 million MB event threshold. These upgrades enable the enhancement of experimental precision across an extended range of final-state particle multiplicity and pseudorapidity ($|\eta| < 4$). This increase is instrumental in unraveling the origins of collectivity in nuclear collisions and constraining the transport QGP properties. Observables demonstrating heightened sensitivity to medium properties, such as higher order flow harmonics, stand to benefit significantly from the HL-LHC data due to their statistically demanding nature. This wealth of data is expected to contribute substantially to a more nuanced understanding of the QGP and the intricate dynamics of nuclear collisions.
- **Particle collectivity in small systems**: In addition to serving as a valuable tool for constraining the parameter space within formulated nPDFs, the increased data samples for collision systems like pPb will yield a substantial improvement in statistical uncertainty. This enhancement is particularly beneficial for more intricate flow variables that are sensitive to the initial state and its subnucleon fluctuations. For instance, the implementation of the subevent method, designed to significantly suppress contributions unrelated to flow, will enable the examination of collectivity even at very low multiplicities. This approach facilitates the study of the onset of flow in small systems, offering insights into the dynamics of these less-explored scenarios. Moreover, the increased data samples, when coupled with azimuthally sensitive femtoscopy techniques, are anticipated to bring about improvements in understanding the system size of collisions. This will be achieved by measuring the Hanbury Brown and Twiss radii in small systems, providing a more detailed perspective on the spatial extent and correlations within these collision environments.
- **QGP tomography/Open heavy flavor (HF) and quarkonia**: The emergence of collective QGP properties at a microscopic level, arising from interactions among individual quarks and gluons, becomes visible when the liquid is probed with high resolution. Studies of jet and hadron modifications in HI collisions offer insights into the interaction between high-energy partons and the QGP. With the substantial data samples and enhanced jet reconstruction resulting from CMS tracker and calorimeter upgrades, there will be a notable reduction in statistical and systematic uncertainties for key measurements related to the medium modification of both light and heavy quark jets. Simultaneously, there is an intense ongoing effort in developing generalized jet (sub)structure variables at the LHC to maximize the efficiency of discovery measurements. This involves improving quark/gluon discrimination and enhancing the tagging of boosted objects. Charm and beauty quarks, due to their substantial masses, are predominantly produced during the early stages of the collision. Furthermore, quarkonia can undergo dissociation or recombination in the medium. Hence, the measurement of HF hadrons can offer crucial information on the complete evolution of the system and the quark-mass dependence of medium-induced processes across a wide kinematic range offered by CMS. The larger experimental data samples anticipated at HL-LHC, coupled with improved CMS detector performance and measurement techniques, are expected to lead to significant advancements over current HF measurements.

- **Ultraperipheral collisions**: Beyond the primary focus on hadronic collisions within the HI program at the LHC, the large electromagnetic fields generated by ultrarelativistic charged ions open avenues for interactions with the nucleus, known as photo-nuclear processes, or with each other through photon-photon interactions. Photo-nuclear collisions provide a means to probe nuclear structure, offering constraints on nPDFs. Conversely, photon-photon interactions serve as a calibration tool for high-uncertainty inputs to QED calculations, such as the photon flux. Additionally, these interactions contribute to the search for physics beyond the Standard Model. The CMS Collaboration has an extensive suite of measurements focused on the photoproduction of vector mesons, exclusive lepton pair production, and light-by-light scattering processes related to these topics. The relevance of these measurements is expected to be enhanced by planned upgrades to the Zero Degree Calorimeters, improving triggering capabilities, segmentation, and radiation hardness. These advancements will contribute to a more comprehensive understanding of the intricacies of electromagnetic interactions in ultrarelativistic HI collisions.

Last but not least, we anticipate that the interdisciplinary nature of the workshop has facilitated knowledge transfer, fostering innovative ideas and approaches that are poised to propel further advancements in research. The inclusion of a dedicated session specifically designed for young students has enriched educational initiatives, actively contributing to the development of a skilled and knowledgeable workforce in the field. Moreover, the event has played a pivotal role in network building, serving as a platform that nurtured collaborative relationships among CMS nuclear physics groups. The potential for these collaborations to extend beyond the workshop into joint research projects is substantial, promising a lasting impact on the collaborative spirit within the community. This collaborative ethos is expected to yield positive outcomes through joint grant applications and research projects, potentially attracting external funding for CMS. Such support reinforces the Collaboration's unwavering dedication to pushing the boundaries of nuclear physics, ensuring continued progress and breakthroughs in the field.

2.3.9 *Nuclear and Partical Physics on a Quantum Computer: Where do we stand now?*

Date	June 5-9, 2023

Organizers

Alexei Bazavov	Michigan State University, USA
Zohreh Davoudi	University of Maryland, USA
Dean Lee	Michigan State University, USA
Alessandro Roggero	University of Trento, Italy

Number of participants	43

Main topics

The main purpose of the workshop was to create a space for the nuclear and particle physics community to share the recent progress on using quantum technologies to tackle outstanding problems in the field as well as to establish a coherent vision of the outstanding questions to be addressed in the near future. The field has made tremendous progress in exploiting the rapid improvements in the fidelity of available quantum hardware and has started to tackle important issues such as: how to encode, and preserve, local symmetries in digital and analog simulations, how to use informations about quantum correlations to devise efficient simulation methods and how to leverage error correction and error mitigation to get the most out of current and near term devices.

The main topics were

- Analog quantum simulations
- Opportunities enabled by different experimental platforms
- Formulation of nuclear physics problems on digital platforms
- Abelian and non-abelian gauge symmetries in digital simulations
- Error correction and error mitigation

Participants

Valentina Amitrano	University of Trento, Italy
Jonas Boym Flaten	University of Oslo, Norway
Giuseppe Carleo	EPFL, Switzerland
Iacopo Carusotto	University of Trento, Italy
Iyadh Chaker	University of Trento, Italy
Filippo Fornetti	University of Perugia, Italy
Juan José Gálvez Viruet	Universidad Complutense de Madrid, Spain

Daniel González Cuadra	University of Innsbruck & IQOQI, Austria
Philipp Hauke	University of Trento, Italy
Morten Hjorth-Jensen	Michigan State University, USA
Leon Hostetler	Michigan State University, USA
Andrea Idini	Lund University, Sweden
Calvin Johnson	San Diego State University, USA
Denis Lacroix	IJCLab Orsay, France
Ryan LaRose	EPFL, Switzerland
Oskar Leinonen	University of Oslo, Norway
Chiara Lissoni	University of Trento, Italy
Piero Luchi	University of Trento, Italy
Alessandro Mariani	University of Bern, Switzerland
Antonio Marquez Romero	University of Barcelona, Spain
Yannick Meurice	University of Iowa, USA
Julius Mildenberger	University of Trento, Italy
Niklas Mueller	University of Washington, USA
Ravi Naik	Lawrence Berkeley National Laboratory, USA
Robert Ott	University of Innsbruck & IQOQI, Austria
Giovanni Pederiva	Forschungszentrum Jülich, Germany
Axel Perez Obiol	Barcelona Supercomputing Center, Spain
Abhishek Rajput	University of Washington, USA
Caroline Robin	Bielefeld University, Germany
Martin Savage	INT & University of Washington, USA
Diego Scantamburlo	University of Trento, Italy
Hersh Singh	University of Washington, USA
Luca Spagnoli	University of Trento, Italy
Jesse Stryker	University of Maryland, USA
Luca Vespucci	University of Trento, Italy
Jacob Watkins	Michigan State University, USA
James Watson	University of Maryland, USA
Kyle Wendt	Lawrence Livermore National Laboratory, USA
Xiaojun Yao	University of Washington, USA
Erez Zohar	Racah Institute of Physics & Hebrew University of Jerusalem, Israel

Scientific Report

The first day of the workshop, Monday, June 6, featured four talks. Kyle Wendt spoke about “Hybrid Algorithms for Low Energy Nuclear Physics” and the use of pulse-level control to reduce gate depths and noise on near term hardware. In “Quantum Algorithms for Simulating Nuclear Effective Field Theories” James Watson discussed algorithms and computational cost estimates for nuclear lattice effective field theory on a quantum computer. In “Real-time quantum Lanczos for nuclear structure”, Calvin Johnson presented quantum Krylov methods which use real time evolution to construct variational basis states. In “Simulating nuclei in digital quantum computers”, Antonio Marquez Romero explained how to use the adaptive variational quantum eigensolver (ADAPT-VQE) for shell model calculations. In the afternoon, we had a group discussion about opportunities, challenges, and promising strategies for simulating nuclear and neutrino Hamiltonians.

Tuesday, June 6, had six talks. In “Quantum Simulation of Standard Model Physics”, Martin Savage presented lattice gauge theories in 1+1D and the real time dynamics of decay processes. In “Quantum Simulation of Lattice Gauge Theories in more than 1+1D” Erez Zohar described the enforcement of gauge invariance in 2+1D using cold atoms. In “Quantum simulating non-Abelian lattice gauge theories: gauge invariance, point splitting, and magnetic”, Jesse Stryker spoke about different basis choices and point splitting techniques for vertices arising in non-Abelian gauge theories. In “Trapped-Ion Quantum Simulation of Collective Neutrino Oscillations”, Valentina Amitrano discussed Hamiltonian simulation results for neutrinos with all-to-all interactions. In “Lattice gauge theory with Rydberg atoms”, Yannick Meurice covered scalar QED, implementations on Rydberg arrays, and results obtained on QuEra. In “Quantum simulation of asymptotically free theories and θ terms”, Hersh Singh spoke about the O(3) nonlinear sigma model at arbitrary θ. In the afternoon group session, we discussed strategies and challenges for quantum simulations of gauge theories, especially in higher dimensions and non-Abelian gauge theories.

Wednesday, June 7, had six talks. Ravi Naik presented “Extending the reach and capabilities of a superconducting quantum testbed for nuclear physics simulations” about the features and science capabilities of the machines at the Advanced Quantum Testbed (AQT) at Lawrence Berkeley National Laboratory. In “Quantum Error Correction with Gauge Symmetries”, Abhishek Rajput covered the integration of gauge symmetry in error correction codes. In “Improved Error Scaling for Trotter Simulations through Extrapolation”, Jacob Watkins showed improved Trotter error bounds using polynomial extrapolation methods. In “Using symmetry breaking/restoration for many-body problem on quantum devices”, Denis Lacroix spoke about symmetry breaking/restoration with several different state preparation algorithms. Daniel González Cuadra presented “Hardware-efficient quantum simulation of lattice gauge theories with neutral atom arrays” and their theoretical proposal for gauge theories using Rydberg arrays. In “Symmetry Breaking and Clock Model Interpolation in 2D Classical O(2) Spin Systems”, Leon Hostetler spoke about phase transitions of the extended 2D clock model. In the afternoon group discussion, we speculated on resource requirements for fault tolerant calculations of particle and nuclear physics problems.

Thursday, June 8, had six talks. In “Entanglement and quantum simulations of nuclear systems in effective model spaces”, Caroline Robin spoke about entanglement in shell model calculations of light nuclei and the Lipkin and Agassi models. In “Coulomb interaction driven entanglement of electrons on helium, theory and experiment”, Morten Hjorth-Jensen discussed studies of two electrons trapped in a potential well on the surface of liquid helium. In “Random measurements and entanglement for nuclear and particle physics exploration”, Niklas Mueller talked about topological order and efficient algorithms using randomized measurements. In “Testing Eigenstate Thermalization Hypothesis for Non-Abelian Lattice Gauge Theory”, Xiaojun Yao presented tests of the eigenstate thermalization hypothesis for an SU(2) gauge theory in 2+1D. In “Entanglement entropies in atomic nuclei within the nuclear shell model”, Axel Pérez-Obiol showed results for orbital entanglement in nuclear shell model calculations. In “Learning Hamiltonians in Quantum Simulation of Field Theories”, Robert Ott discussed how to learn effective Hamiltonians from the real time simulations of field theories. In the afternoon discussion, we debated the role of entanglement in equilibrium and non-equilibrium conditions for particle and nuclear physics systems.

Friday, June 9, had five talks. In “Learning Hamiltonians in Quantum Simulation of Field Theories”, Iacopo Carusotto presented superfluid systems behaving as approximate analogs of Hawking radiation from black holes. In “Squeezing the most performance out of quantum computers”, Ryan Larose spoke about effective quantum volume and the improved performance one can make using error mitigation methods. In “Efficient State Preparation Algorithms for the Schwinger Model”, Giovanni Pederiva covered state preparation for the Schwinger model using adiabatic evolution, the quantum approximate optimization algorithm, and the rodeo algorithm. In “Quantum simulation of lattice gauge theories in cold atoms and superconducting qubits”, Phillip Hauke talked about Trotter and gauge symmetry errors in lattice gauge theories and the detection of entanglement. In “Enabling Hybrid

Classical-Quantum Computing”, Giuseppe Carleo discussed several new algorithms for quantum many-body systems and the use of tensor networks and machine learning for quantum algorithms. The organizers then presented some summary remarks and closed the workshop.

Results and Highlights

The workshop was very successful in managing to establish a bridge between diverse communities interested in quantum simulations for different applications: from non-relativistic nuclear structure to out-of-equilibrium relativistic gauge theories. Particularly stimulating were discussions about algorithm efficiency and whether the cost bounds that can be obtained through analytical manipulations can really be used to guide the design of algorithms or even just allow a practitioner to select the most appropriate scheme to deploy on a given quantum device. Another big topic of vigorous discussion concerned the expectation of a quantum advantage, a situation where a calculation that would be near impossible to carry out on a classical device is made possible by using a quantum computer, especially for calculations of static properties of interacting many-body systems. For instance, it is not clear whether variational schemes that are very popular at the moment can prove to be competitive to alternative classical algorithms with polynomial scaling such as the Coupled Cluster method. The importance of successfully preparing initial states with a good overlap with the interacting ground state was also highlighted and various strategies to use the information that can be accessed in current state-of-the-art classical simulations.

Talks covering the capabilities offered by recently emerging technologies, such as Rydberg atom arrays and superconducting circuits tailored to have access to multi-level systems, have also sparked interesting discussions on how to best use these capabilities in the simulation of more realistic systems relevant for nuclear and high-energy physics.

2.3.10 *Precision Tests of Fundamental Physics with Light Mesons*

Date	June 12-16, 2023

Organizers

Susan Schadmand	GSI Darmstadt, Germany
I. Jaegle	Jefferson Lab, USA
B. Kubis	HISKP, Germany
D. Lersch	FSU Tennessee, USA

Number of participants	43

Main topics

- Dalitz Plot Analyses for Light Meson Decays
- Rare Decays
- Beyond the Standard Model
- Transition Form Factors
- Experiments and Prospects for Future Studies
- Primakoff Experiments

Speakers

Hakan Akdag	Bonn University, Germany
Miguel Albaladejo	IFIC, Spain
Malte Albrecht	Jefferson Lab, USA
Marco Battaglieri	INFN-Genova, Italy
Anastasios Belias	GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany
Luigi Capozza	Helmholtz Institute Mainz, Germany
Saskia Charity	University of Liverpool, UK
Izabela Ciepał	Institute of Nuclear Physics PAS, Kraków, Poland
Olga Cortes Becerra	The George Washington University, USA
Andreas Crivellin	UZH & PSI, Switzerland
Igor Danilkin	Johannes Gutenberg University of Mainz, Germany
Shuangshi Fang	Institute of High Energy Physics, CAS, China
Liping Gan	University of North Carolina Wilmington, USA
Susan Gardner	University of Kentucky, USA
Ashot Gasparian	NC A and T State University, NC, USA
Antoine Gérardin	CPT Marseille, France
Simona Giovannella	INFN Frascati, Italy

Sergi Gonzalez-Solis	Los Alamos National Laboratory, USA
Martin Hoferichter	University of Bern, Switzerland
Bai-Long Hoid	University of Bern, Switzerland
Simon Holz	University of Bern, Switzerland
Garth Huber	University of Regina, Canada
Tomáš Husek	Charles University, Czech Republic
Igal Jaegle	Jefferson Lab, United States
Karol Kampf	Charles University, Czech Republic
Yannis Korte	Uni Bonn, Germany
Bastian Kubis	HISKP Bonn, Germany
Andrzej Kupsc	Uppsala University, Sweden
Sebastian Lutterer	Universität Bochum, Germany
Rory Miskimen	University of Massachusetts, Amherst, USA
Edoardo Mornacchi	University of Mainz, Germany
Bachir Moussallam	Universite Paris-Saclay, IJCLab, France
Frederic Noël	ITP, AEC, Uni Bern, Germany
Konstantin Ottnad	JGU Mainz, Germany
Emilie Passemar	IFIC Valencia, Spain
Alessandro Pilloni	Universita di Messina e INFN Catania, Italy
Pablo Sanchez Puertas	University of Granada, Spain
Susan Schadmand	GSI Darmstadt, Germany
Hannah Schäfer	HISKP, Bonn University, Germany
Adam Szczepanak	IU/Jlab, USA
Simon Taylor	Jefferson Lab, USA
Sean Tulin	York University, UK
Marvin Zanke	HISKP, University of Bonn, Germany
Maximilian Zillinger	University of Bern, Germany

Scientific report

The meeting opened with a wider overview illustrating the importance of Dalitz plot analyzes for predicting (exotic)meson resonances and their properties from lattice QCD. The interest extends into the region of light mesons where the tools for interpretation are similar but the goals range from low-energy precision tests of the Standard Model, like CP violation, to the impact of quark mass differences and meson mixing. A lively discussion highlighted the need for consistent theoretical approaches as well as a gold standard for the necessary precision of the experiments.

The three strongholds of the study of rare decays were discussed in a session by looking at probing Low-Energy QCD, fundamental symmetry and physics beyond the standard model via decays of π0, η and η' mesons. Various experiments and theoretical approaches were discussed and it is important to keep an eye on new and existing experimental data as well as theoretical developments. A further session was dedicated to physics beyond the standard model discussing C and CP violation in eta decays as well as searches for new particles in light meson decays. In the ensuing discourse the question was brought up whether the signatures of new physics can be significant in the low energy regime discussed here. It seems that this question can be answered in the near future.

The session on transition form factors of light mesons started with an experimental overview of the topic as such and its importance for hadronic contributions to the anomalous magnetic moment of the muon. The connection to the g-2 measurement was further described in a theoretical overview, followed by news from the currently running g-2 experiment at Fermilab. Experimental plans and results for time and space like transition form factor measurements from pions, eta, omega, and eta' mesons as well as the theory status were discussed in depth. The important aspect of radiative corrections of final state leptons was presented. Here, calculations are under development and should be included in the interpretation of the experimental results.

Finally, new experiments, highlighting electro and photo production as well as Primakoff experiments, and prospects for further studies at higher luminosities and energies were presented and the possibilities discussed.

Results and Highlights

Hadronic and radiative decays of light mesons provide a unique laboratory to test low-energy Quantum Chromodynamics and search for new physics beyond the Standard Model. Recent years have brought advances in theoretical and experimental approaches throughout the hadron and particle physics community. New experimental data will soon offer critical input to precisely determine e.g., the light quark mass ratios, meson mixing parameters, and hadronic contributions to the anomalous magnetic moment of the muon. The approaches provide sensitive probes to test potential new physics including searches for hidden photons, light Higgs scalars, and axion-like particles that are complementary to worldwide efforts to detect new light particles below the GeV mass scale, as well as tests of discrete symmetry violation.

We used this pivotal moment to bring together experts and respective communities in the unique scientific atmosphere at ECT* Trento. We discussed updates on theoretical developments and experimental strategies, and identified further research. The presentations and fruitful discussions in an in-person workshop format were simply excellent. The limited participant format combined senior researchers of the highest scientific standing and bright young scientists that clearly will have a lot to contribute. Having achieved this level of communication and collaboration, we agreed on a follow-up workshop in 2-3 years to take stock of the latest developments.

2.3.11 *Quantum Simulation of Gravitational Problems on Condensed Matter Analog Models*

Date	June 19-23, 2022

Organizers

Roberto Balbinot	University of Bologna, Italy
Jacqueline Bloch	C2N-CNRS, Palaiseau, France
Iacopo Carusotto	INO-CNR BEC Center, Italy
Gabriele Ferrari	University of Trento, Italy
Massimiliano Rinaldi	University of Trento, Italy
Scott Robertson	Institut Pprime, Poitiers, France

Number of participants	Around 55 participants plus around 10 visitors from local institutions, especially for the special celebration day (Wed. 21st) in memory of Renaud Parentani.

Main topics

This interdisciplinary workshop gathered specialists from theoretical and experimental condensed matter physics, quantum optics, quantum information, and from theoretical cosmology, gravitation and astrophysics. It is the 4th edition of a series of key events that have fostered the transition of analog models from being a scientific curiosity towards being a useful quantum simulation tool to experimentally explore new physics. Our specific goal was to stimulate interdisciplinary studies of condensed matter analog models of gravity as a concrete experimental tool to attack outstanding problems that arise in the context of gravitation, cosmology and astrophysics. The present challenge is to keep extending the range of configurations that can be simulated, and to identify the most important questions to be addressed. As a key novelty of this event, ample space was devoted to the use of condensed matter analog models to attack those quantum information issues that arise from black hole theory.

In specific, the main topics of the workshop were:

- Analog black holes in atomic, optical, hydrodynamic systems and analog Hawking radiation. Black hole lasing phenomena.
- Superradiance phenomena in rotating geometries.
- Analog models of cosmological processes
- Analog models beyond the linear regime; preheating and back-reaction phenomena
- False vacuum decay in analog models
- Entanglement and quantum information puzzles with black holes; new investigation strategies using analog models.

Speakers

D. Bermudez	Department of Physics, Cinvestav, Mexico
A. Berti	Univ. Trento, Italy
M. Blencowe	Dartmouth College, USA
A. Bossard	Inst. Pprime, Poitiers, France
M. C. Braidotti	Univ. Glasgow, UK
S. Butera	Univ. Glasgow, UK
A. Coutant	CNRS Marseille, France
H. Culetu	Ovidius University, Romania
S. Erne	TU Wien, Austria
A. Fabbri	Univ. Valencia, Spain
L. Farrell	McMaster Univ., Canada
L. Fernandes	Univ. Antwerp, Belgium
H. A. Fernandez Melendez	University of Southampton
G. Ferrari	Univ. Trento, Italy
U. Fischer	Seoul National Univ., Korea
I. Fuentes	Univ. Southampton, UK
C. Fulgado-Claudio	UAM-CSIC, Madrid, Spain
A. Haller	University of Luxemburg
B.-L. Hu	Univ. Maryland, USA
T. Jacobson	Univ. Maryland, USA
M. Jacquet	Sorbonne, Paris, France
H. Katayama	Hiroshima, Univ., Japan
F. Koenig	Univ. St. Andrews, UK
P. Kumar	Swansea Univ., UK
A. Legramandi	Univ. Trento, Italy
U. Leonhardt	Weizmann Institute, Israel
S. Liberati	SISSA, Italy
M. Mannarelli	LNGS-INFN, Italy
S. Massar	Univ. Libre Bruxelles, Belgium
F. Michel	former student of RP
A. Micheli	IAP and Univ. Paris-Saclay, France
I. Moss	Newcastle Univ., UK
M. Oberthaler	Univ. Heidelberg, Germany
A. Parola	Univ. Insubria, Italy
S. Robertson	Inst. Pprime, Poitiers, France
N. Pavloff	Univ. Paris Saclay, France
D. Solnyshkov	University Clermont-Ferrand, France
F. Sols & J.-R. Munoz de Nova	Univ. Complutense, Madrid, Spain
J. Steinhauer	Technion, Israel

S. Trabucco	LNGS-INFN, Italy
P. Uhrich	Univ. Trento, Italy
W. G. Unruh	Univ. British Columbia, Canada and Texas A&M, USA
S. Weinfurtner	Univ. Nottingham, UK
C. Westbrook	Institut d'Optique, Palaiseau, France

Scientific report

This interdisciplinary workshop has gathered specialists from a wide variety of areas of the physical sciences, from theoretical and experimental condensed matter physics, to quantum optics, quantum information, and theoretical cosmology, gravitation and astrophysics. The variety of scientific background of the speakers is highlighted in the speakers' list by the CM/G label indicating whether they are original from a condensed matter or a gravitational background.

The aim of the event was to stimulate interdisciplinary studies of condensed matter analog models of gravity as a concrete experimental tool to attack outstanding problems that arise in the context of gravitation, cosmology and astrophysics. While the observation of analog Hawking emission from analog black holes was a major step in this adventure around a decade ago, the present challenge is to extend the range of configurations that can be simulated to novel geometries and novel regimes, and, at the same time, to identify the most important conceptual questions that can be addressed using the new tools.

As it happened in the previous editions of this event, the interaction between the different communities has been very efficient: a comprehensive coverage of the recent milestone achievements was given, as a number of exciting new perspectives were sketched.

The workshop included a small number of ultra-long (UL) talks that combined a tutorial part and/or a historical account with the presentation of new results. Speakers of these UL talks were selected among the most celebrated senior scientists. A series of long (L) talks then gave a comprehensive coverage of on-going research in the field of analog models and quantum simulation as well as in neighboring fields that have promising points of contact with them.

A most remarkable example of this interdisciplinary spirit has concerned quantum information features of black holes and the so-called information paradox. In order for the analog model community to get aware of the main questions in this field, a special effort was made to involve specialists from the black hole information community: the stimulating exchanges that followed the presentations on this matter have been instrumental to begin clarifying the scientific landscape and to define new angles of attack to these outstanding problems.

Finally, ample space has been offered to younger participants at the PhD or Post-Doc level to present their own research in short talks. To reinforce their motivation, a prize in memory of Renaud Parentani was given to the best young presentation. This "Parentani medal" prize was created with the support of the SIGRAV (Società Italiana di Relatività Generale e Fisica della Gravitazione, i.e. Italian Society of General Relativity and Gravitational Physics) and aims at establishing itself as a most prestigious prize in our community. The evaluation committee (S. Liberati, B.-L. Hu, C. Westbrook, M. Rinaldi) decided that the prize should be given ex-aequo to Liam Farrell (McMaster Univ., Canada) and Anna Berti (Univ. Trento, Italy).

In addition to the standard scientific talks, on the evening of Tue.20th a general public event in Italian was organized on “Un buco nero in un bicchier d’acqua - modelli analoghi di gravità” in collaboration with AISF (Associazione Italiana Studenti di Fisica). Speakers were M. C. Braidotti, S. Liberati and S. Robertson and moderators: I. Carusotto, R. Balbinot, G. Ferrari. The success of the event is witnessed by the large participation of undergraduate students and general Trento people. A flyer of the event is included in the report.

On Wed. 21st, we had a special day in memory of Renaud Parentani. The talks in the above list indicated by RP were part of this celebration and, in addition to a scientific part, also included some personal memories of our colleague who sadly passed away in 2020. Parentani’s partner also attended the event, as well as several former students of his. As one can imagine, the celebration day turned out to be an emotionally very intense moment for everybody who had a personal or scientific link with him. A flyer of this special day is included in the report.

In the wake of the workshop, a special issue of the scientific journal *Comptes Rendus Physique* published by the French *Académie des Sciences* in the memory of Renaud Parentani is being prepared, with J. Bloch, I. Carusotto (co-organizers) and C. Westbrook (speaker) as co-editors. The first manuscripts have been recently submitted to the special issue and are presently under external review.

The variety of scientific topics that were covered by the workshop is reviewed in the next section.

Results and Highlights

The workshop has provided a comprehensive overview of the recent advances of the field of analog models and quantum simulation of gravitational systems, as well as of the open questions that were sitting in front of the community. The latest results from on-going experiments on analog black holes, rotational superradiance, black hole lasing, and cosmological problems have been presented by the main actors world-wide. This included experiments with both ultracold atomic gases and surface waves on water, which addressed new regimes involving non-Euclidean spatial geometries or time-dependent backgrounds. Novel platforms based on spinor atomic condensates were discussed and their advantages in view of a next generation of analog models were pointed out. New perspectives towards using quantum fluids of light and superconducting devices as alternative analog models were also discussed and their specificities highlighted in view of attacking specific questions. Going beyond the linearized formalism that traditionally underlies analog models, the consequences of non-linear effects stemming from interaction between modes have been investigated. In particular, this included back-reaction effects from the quantum emission onto the background as well as effective damping and harmonic generation induced by preheating effects analogous to the cosmological ones. Pushing this idea to the extreme, experimental evidence of the analog of a thermally-activated false vacuum decay process was reported in a spinor condensate initially prepared in a metastable state and a comprehensive theoretical interpretation of the observation was discussed. These achievements result from a long effort from a wide community and open exciting perspectives in the use of analog models in new regimes that go far beyond the original concept, namely as quantum simulators of strongly non-perturbative quantum field effects. Ramping up in conceptual complexity, quantum entanglement effects between the two sides of an analog horizon (or more generally between pairs of produced quasiparticles) have been explored in different configurations. As a new direction, the community has also started to lay the grounds of a new generation of experiments using cold-atom-based analog models of quantum SYK models displaying scrambling features resembling black hole physics and to explore general quantum information aspects of black hole evaporation. As we had foreseen in the proposal, the opening of this new perspective on the information loss paradox is indeed going to provide a freshly new point of view on some of the deepest mysteries of gravitational physics. Extrapolating from the successful results presented in the workshop and the number of open questions that were identified, we anticipate that 2025 will be the right time for a new edition of this workshop where the different communities interested in analog modes meet again in an interdisciplinary event, discuss the next generation of achievements, and plan the next steps of this exciting field of research. In the meanwhile, the community is considering setting up a website were information about workshops, seminars, outstanding results in the field could be collected.

External funding

This workshop was co-funded by:

- the Q@TN consortium: 3 keuro
- the Physics Department of Trento University: 1.5 keuro
- the BEC Center: 2 keuro
- INFN group 4: 2 keuro
- SIGRAV: 300 euro for Parentani prize

2.3.12 *Machine Learning for Lattice Field Theory and Beyond*

Date	June 26-30, 2023

Organizers

Daniel Hackett	MIT, USA
Dimitrios Bachtis	LPENS, France
Biagio Lucini	Swansea University, UK
Gert Aarts	ECT*, Italy and Swansea University, UK
Phiala Shanahan	MIT, USA

Number of participants	45

Main topics

The workshop concerned the relation of machine learning (ML) to topics in theoretical particle/nuclear physics, with an emphasis on numerical quantum field theory (QFT) and especially lattice QFT. While this broad topic of inquiry has seen intensive exploration over the past several years, it is not yet clear where the greatest opportunities for benefit and insight will arise. The workshop brought together researchers exploring various directions, with the intention of cross-pollinating methods, generating new ideas, and assessing the state of the field to guide further exploration.

The main topics covered were:

- Generative models for configuration generation, especially approximate trivializing maps (flows)
- Learned approaches to mitigating the sign problem
- Symmetry-equivariant architectures for gauge theories
- Multi-scale parametrizations
- The relation between statistical mechanics and deep learning
- Physics-inspired models for more traditional ML problems

Speakers

Gurtej Kanwar	U Bern, Switzerland
Neill Warrington	U Washington, USA
Evan Berkowitz	IAS Jülich, Germany
Alexander Rothkopf	U Stavanger, Norway
Elia Cellini	U Torino, Italy
Kai Zhou	FIAS, Germany
Yukari Yamauchi	U Washington, USA
Andreas Ipp	TU Wien, Austria

Daniel Schuh	TU Wien, Austria
Matteo Favoni	TU Vienna, Austria
Piotr Bialas	Jagiellonian U, Poland
Mathis Gerdes	U Amsterdam, Netherlands
Lorenz Vaitl	TU Berlin, Germany
Nobuyuki Matsumoto	RIKEN BNL, USA
Urs Wenger	U Bern, Switzerland
Kiaran Holland	U of the Pacific, USA
Misaki Ozawa	U Grenoble Alpes, France
Tilo Wettig	U Regensburg
Aurélien Decelle	U Complutense de Madrid, Spain
Alfonso Navas Gomez	U Complutense de Madrid, Spain
Kim Nicoli	U Bonn, Germany
Alessandro Nada	U degli Studi di Torio, Italy
Daniel Spitz	Heidelberg, Germany
Roberto Verdel Aranda	ICTP Trieste, Italy
Jorge Fernandez de Cossio Diaz	ENS Paris, France
Ouraman Hajizadeh	Arteria Technologies
Chan Ju Park	Swansea U, UK
Anindita Maiti	Harvard, USA
Pietro Rotondo	U Parma, Italy
Javad Komijani	ETH Zurich, Switzerland
Julian Urban	MIT, USA

Scientific report

Flow-based generative models were a major topic of interest, representing a plurality of the talks by subject and attendees by interest. The past several years have seen intensive exploration of these methods in lattice QFT. The idea is to construct and train a learned diffeomorphic flow which (approximately) maps a complicated probability distribution of physical interest to a simpler, potentially trivial distribution. In lattice QFT, if models with appropriate properties can be constructed, it may be possible to use them to alleviate sampling problems in lattice quantum chromodynamics (QCD), namely critical slowing down and topological freezing, which currently prevent e.g. working closer to the continuum limit. Early results over the last several years in applications to lower-dimensional theories have shown great promise for this application, and work proceeds on how to apply these methods to QCD calculations at state-of-the-art scales. Theoretical applications are not limited to QCD, however, and include string theories and condensed matter systems.

Another primary topic of discussion was integral contour deformations—or, more generally, control variates—to alleviate intractably poor signal-to-noise arising from sign problems. Such sign problems prevent access in the lattice QFT framework to physics at finite density, real-time dynamics, and certain QCD observables including especially baryonic correlation functions. Learned parametrizations of such observables have long been a topic of interest, and demonstrations in simpler examples continue to advance. Recent work on flow models have prompted exploration of flow-based parametrizations for this purpose.

Applying ML to physical problems often benefits from—or, in some cases, requires—the incorporation of a priori physics knowledge in the architecture of the ML models. One important realization of this is designing architectures which incorporate the symmetries of the problem. In the case of gauge theories, the most important symmetry to incorporate is the high-dimensional continuous gauge symmetry defining the theory. Various approaches have been developed over the past few years to construct gauge-equivariant linear operators, (convolutional) neural networks, and flows. Ongoing work presented at the workshop continues to explore further parametrization possibilities to see what architectures are best suited for which tasks.

One interesting class of functions to parametrize which are relevant to QFT are those which parametrize physics across many different length scales in a natural way. Such functions are naturally related to renormalization group (RG) transformations, a critical theoretical tool in understanding QFTs which often inspires useful tools in the lattice QFT setting. Interesting examples under exploration include hierarchical flow models which relate a sequence of QFTs defined on increasingly fine lattices; multigrid preconditioners, linear operators which parametrize an approximation of the quark propagator across different length scales; and learned RG-inspired lattice actions with smoother approaches to the continuum limit.

The primary object of interest in both lattice QFT and ML are functions or, more specifically, exploring parametrized spaces of functions. (In lattice QFT, functions are parametrized by their values on a grid and sampled from; in ML, they are most often parametrized by neural networks and optimized.) This simple similarity suggests that there should be useful connections between these two topics, with great potential for insight into the dynamics of ML and the possibility of new methods for numerical QFT. One direction of exploration represented in several talks explore the following analogy: random neural network initializations define a distribution over functions; these functions can be thought of as fields; the distribution of fields can thus be thought of as a QFT. It has been known that in the infinite-width limit, neural networks correspond to free scalar field theory, but work proceeds to understand the more interesting interacting case, which arises e.g. at finite width.

Discretized QFTs are statistical mechanical systems. Decades of experience enable efficient sampling of and inference about the properties of the probability distributions corresponding to these systems. This experience may be usefully re-applied in the context of generative ML modelling of unknown data. Specifically, “energy-based models” in ML can be thought of as generalizations of lattice QFTs. The same sampling strategies can be applied, and intuition from thinking about these systems like QFTs can be applied to understand their dynamics. Restricted Boltzmann Machines are a popular example of such energy-based models and analogous to lattice spin systems, and were a significant topic of interest at the workshop.

Other topics represented at the workshop by one or a few speakers each were ML tools for inverse problems, new approaches to thermodynamics and thermodynamic observables, ML-accelerated algorithms, and improvements to gradient estimators for training.

Results and Highlights

As discussed above, the workshop covered a variety of topics at the intersection of ML and QFT. Fascinating new developments were presented across each.

An important recent development in flow methods, presented from several angles, is the construction of *exact* trivializing maps. While intractable to implement in practice for higher-dimensional gauge theories, in two dimensions they can be done explicitly. In abstract, these constructions provide important guidance for what form a learned approximation of such a map must take.

It remains unclear whether direct generative modelling of the path integral, fully replacing traditional sampling algorithms with flows, will be usefully applicable to lattice QCD at state-of-the-art scales. The consensus was that this question must be resolved by direct experimental investigation of flow applications to lattice QCD itself. Progress proceeds on these computationally demanding investigations. Disagreement persists on the relevance and applicability of results obtained from tests in simpler systems. These discussions and questions regarding scalability emphasized the importance of investigating "hybrid" sampling schemes, which employ flows to augment or accelerate the performance of traditional sampling algorithms, rather than fully replacing them.

Some participants brought up the need for open-source reference implementations of various algorithms and methods, especially flow techniques. Preliminary discussions occurred around a community-driven effort to build a public library of such implementations.

Contour deformations in analytically-continued path integrals have long been considered a promising option for alleviating sign problems. A recent and useful reframing discussed at the workshop presents contour deformations as a subcase of a more general method known as "control variates", suggesting new possibilities for methods.

Recent work has demonstrated the alleviation of sign-problems in simple example theories using very simple deformations. In condensed matter systems, these methods may already be sufficient for first-principles calculations of previously inaccessible dynamics. Further work is required to fruitfully apply these methods in the context of gauge theories, but this is underway. It remains unsettled how to most generally parametrize a useful learned deformation, but various approaches were presented, including especially learned holomorphic flows. It is unclear whether a flow-like architecture with the holomorphicity constraint relaxed will be possible.

Very recent developments about neural network parametrizations of actions and preconditioners were presented. These new applications are simple but promising. ML is most often useful when unstructured, end-to-end training may be employed, and approximations made by the neural networks do not compromise the utility of the solutions thy provide. These applications fulfil those requirements in straightforward ways, and numerical investigations—already at significant scale—appear to be approaching advantageous performance already. Discussions followed on generalizations of these ideas, other applications of the architectures presented, and opportunities for other, similar applications.

It has been known that in the infinite-width limit, neural networks sampled over random initializations correspond to a Gaussian process and thus free scalar field theory. The workshop heard about fascinating work to understand how an interacting field theory arises, for example away from finite width neural networks, and effective descriptions of the dynamics of these systems. Discussions arose on how such neural-network field theories might be applied in practice to nonperturbative QFT calculations, and complementarily, how our intuition from sampling lattice-discretized functions spaces translates to sampling of neural-net function spaces, and how that intuition can be translated to the more typical ML case of optimization.

The space of interesting possibilities at the intersection of ML and QFT is vast. Given this complexity, it is of critical importance to maintain and facilitate communications among the researchers investigating this to both share developing ideas and generate new ones. In this regard, the workshop was a resounding success, setting the stage for further fascinating exploration.

2.3.13 *COLMO: Quantum Collapse Models investigated with Particle, Nuclear, Atomic and Macro Systems*

Date	July 3-7, 2023

Organizers

Catalina Curceanu	INFN, LNF, Italy
Angelo Bassi	University and INFN Trieste Italy
Maneeli Derakhsani	Rutgers University, USA
Lajos Diosi	University of Budapest, Hungary
Sandro Donadi	Queens University Belfast, UK
Kristian Piscicchia	CREF, Italy

Number of participants	30

Main topics

The COLMO workshop had the goal to bring together world-leading experts and young scientists working in the foundations of quantum mechanics, towards a better understanding of the collapse models proposed to solve the major open question in quantum physics: the collapse mechanism, also known as the “measurement problem”. The interplay between quantum physics and gravity was discussed, also in relation to possible experiments in various environment.

The main topics of the workshops were:

1) the status of Collapse Models from a theoretical point of view and outline of open issues
2) the status of Collapse Models from the experimental point of view by searching for the spontaneous radiation: VIP, MAJORANA, XENON and other underground experiments.
3) the status of Collapse Models from an experimental point of view, by searching for the anomalous heating effects: cantilever, opto-mechanical systems
4) future theoretical implementations of the collapse models with dissipative and memory effects; gravity-related collapse
5) future experiments testing collapse models in underground laboratories, with opto-mechanics experiments; and experiments in space
6) Round Table discussion on developing and testing realistic Collapse Models in particle, nuclear, atomic, and meso/macroscopic systems.

Speakers

Matteo Carlesso	Univ and INFN Trieste, Italy
Sandro Donadi	Queen’s University Belfast, UK

Giovanni Di Bartolomeo	Univ. Trieste, Italy
Kristian Piscicchia	CREF, Italy
Nicola Bortolotti	Univ. La Sapienza and CREF, Italy
Antonio Di Domenico	La Sapienza Univ. And INFN Roma, Italy
Alessio Avella	INRIM, Italy
Lajos Diosi	Wigner Research Center for Physics, Hungary
Antonio Pontin	Univ. College London, UK
Alessio Porcelli	CREF and INFN-LNF
Fabrizio Napolitano	INFN-LNF, Italy
Claudio Paganini	Universität Regensburg, Germany
Felix Finster	Universität Regensburg, Germany
Jakub Wardak	University of Southampton, UK
Anirudh Gundhi	Univ. of Trieste, Italy
José Luis Gaona Reyes	Univ. of Trieste, Italy
Carsten Henkel	Univ. Potsdam, Germany
Bassano Vacchini	Univ. Milano, Italy
Federica Mantegazzini	FBK, Italy
Felix Klaus Ahrens	FBK & CNR-IFN, Italy
Antonino Marciano	Fudan Univ., China
Kyrylo Simonov	Univ. Vienna, Austria
Andrea Vinante	Istituto di Fotonica e Nanotecnologie (IFN-CNR), Italy
Matteo Fadel	ETH, Zurich, Switzerland
Andrea Addazi	Sichuan University, China
Pierluigi Belli	Tor Vergata Univ., Italy
Javad Shabani	NYU, USA

Scientific report

Within the COLMO workshop, the most recent theoretical developments of realistic collapse models implementing dissipative effects and non-Markovianity (memory) were discussed by theoreticians and experimentalists, with the aim of extracting those experimental signatures which can then be searched for in new-generation experiments. The experiments extend from particle, nuclear, and atomic physics ones, like those searching for the spontaneous radiation in the Gran Sasso underground laboratory, to experiments sensitive to anomalous heating effects in opto-mechanical systems.

Among the collapse models, the gravity related ones, so-called Diósi-Penrose, play a special role, since they clearly identify a relation between quantum mechanics and gravity, with the latter one mediating the collapse. These models were discussed in detail, as recent measurements exclude the simplest versions, and new updated models are being developed that need experimental verification. Some of these models are also relating the collapse with the dark sector, i.e., dark energy and dark matter. These connections were discussed, also taking into account the possible cosmological implications. The energy non-conservation related to the spontaneous radiation may be “cured” by assuming that the missing energy leaks into the dark sector. We discussed about this relation and its possible future development.

By the end of the workshop, a strategy emerged which sets a pathway towards a comprehensive theoretical development of realistic collapse models, the extraction of experimental signatures, and setting up a series of experiments performing searches of collapse signals in various systems, ranging from particles and nuclei to atoms and meso/macroscopic systems, from underground to space.

The impact of the findings on future quantum technologies, such as quantum computers and quantum sensors, was also investigated, by addressing the question: what limits do the collapse models findings set for the “macroscopicity” of those systems used in quantum technology, which rely on coherent quantum superpositions?

Results and Highlights

COLMO addressed the major conundrum in quantum theory: for a perfectly isolated quantum system, regardless of its size, will the linear and unitary Schroedinger evolution be indefinitely valid? Since the inception of quantum physics huge theoretical efforts have been dedicated to address and solve the related measurement problem; COLMO addressed a possible solution to this problem.

Among the proposed solutions the Objective Reduction models naturally collapse the wave function by adding non-linear and stochastic terms to the Schroedinger equation: dynamical collapse models. Various collapse models have been developed over the years, including the so-called Continuous Spontaneous localization and the gravity-related collapse. Very recently experimental efforts, in particular the search for the predicted spontaneous radiation, excluded the simplest versions of gravity-related collapse (Diósi-Penrose models) and set very stringent limits on CSL. This has led to the ongoing development of more realistic collapse models, by including complex dissipative dynamics and memory effects; these realistic models were discussed in detail within the workshop, together with future developments and implications in physics and cosmology.

Experimental signatures for collapse models are being studied, including the first systematic studies of the patterns of the predicted spontaneous radiation and of the heating effects, as trademarks of the models. While theory advances, also on experimental side there has been real progress with experiments ranging from particle and nuclear physics, such as searches of spontaneous radiation at the LNGS underground laboratory (VIP) to opto-mechanical and cantilever experiments (TEQ), investigating anomalous heating, which were analysed in comparing the different outcomes, strengths and potentialities.

The COLMO workshop strongly promoted discussions and collaboration between the communities working in quantum collapse and contributed to advancing the field by setting up a strategy towards a synergetic effort for a deeper understanding of collapse models and their experimental signatures, also at the interface with quantum gravity developments.

This type of research is also very relevant for the emergent quantum technologies which rely on quantum theory. Theoreticians addressed central questions such as:

how dissipative and memory effects are to be considered, what is the role of gravity, are there connections with the dark sector (matter and energy) and which are the observable experimental signatures. Experimentalists discussed novel concepts in experimental testing of the proposed models in a plethora of systems going from particles and nuclei, to meso/macroscopic ones.

The main result and highlight of the workshop was to contribute to the progress in understanding one of the most puzzling issues of our quantum Universe: the way in which collapse is achieved, by an intertwined theoretical and experimental investigation of this issue, relying on novel concepts and a broadening of the experimental search of predicted signatures.

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 quantum foundations and interplay with gravity.

The COLMO workshop created a profitable cooperation between experimental and theoretical physicists working in several laboratories across the world. A sizable fraction (50%) 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.

Last but not least a note of merit: the organization of the Workshop by ECT* (special thanks to Susan Driessen) was excellent. We acknowledge the ECT* support.

2.3.14 *Tensor Spin Observables*

Date	July 10-14, 2023

Organizers

Karl Slifer	University of New Hampshire, USA
Doug Higinbotham	Jefferson Lab, USA,
Wim Cosyn	Florida International University, USA
Elena Long	University of New Hampshire, USA
Simon Sirca	Faculty of Mathematics and Physics, U of Ljubljana,Slovenia

Number of participants	24

Main topics

Several experiments are planned at Jefferson Lab and other facilities, which will utilize a solid tensor polarized target. This new program will help clarify how the properties of the nucleus arise from the underlying partons, and provide novel information about gluon contributions, quark angular momentum, and the polarization of the quark sea that is not accessible in spin-1/2 targets.

The main topics were:

- Tensor Polarization in DIS
- Tensor Structure Functions
- Hidden Color atlarge x
- Tensor Observables in x > 1
- Solid Tensor Polarized Target Development
- Elastic Deuteron Form Factors
- Tensor Polarization at the EIC and other facilities
- New Experiments

Speakers

Wim Cosyn	Florida International, USA
Ishara Fernando	University of Virginia, USA
Douglas Higinbotham	Jefferson Lab, USA
Sabine Jeschonnek	The Ohio State University, USA
Dustin Keller	University of Virginia, USA
Shunzo Kumano	KEK, Japan
Simonetta Liuti	University of Virginia,USA
Elena Long	University of New Hampshire, USA

David Mack	TJNAF, USA
Thorsten Maly	Bridge12 Magnetic Resonance LLC, USA
James Maxwell	Jefferson Lab, USA
Michael McClellan	University of New Hampshire, USA
Jennifer Rittenhouse West	Lawrence Berkeley National Laboratory, USA
Misak Sargsian	Florida International University,USA
Devin Seay	University of Virginia,USA
Simon Sirca	Faculty of Mathematics and Physics, U of Ljubljana, Slovenia
Karl Slifer	University of New Hampshire, USA
Mark Strikman	Penn State university,USA
Christian Weiss	Jefferson Lab,USA
Carlos Yero	Old Dominion University,USA
Allison Zec	University of New Hampshire,USA

Scientific report

This workshop has focused on a discussion of several experiments planned at Jefferson Lab and other facilities which will utilize a solid tensor-polarized deuteron target. Many of the experimental and theoretical techniques relevant to this program have already been developed, but the progress on both these fronts in the past decade sparked a renewed interest in vector and tensor observables accessible by using the deuteron target.

On the first day (July 10), the workshop kicked off with two introductory and pedagogical talks on the main topics of the workshop, one from the experimental perspective (K. Slifer) and one from the theoretical (W. Cosyn). This was followed by a general discussion on the fundamental concepts addressed in this workshop. One outcome here was the need/desire for a more unified terminology, where different names are in use originating in different subfields (quasi-elastic, deep-inelastic, etc.).

In the afternoon, the talks focussed on the tensor polarized structure function b1, which is the leading twist tensor polarized structure function that is accessible in inclusive DIS. S. Kumano give a general overview on the b1 structure function, detailing past and future possible measurements and the theoretical background. This was followed by A. Zec who gave a talk on the relation between the experimental observable (the tensor polarized asymmetry, usually denoted Azz) and the several structure functions that appear in it. The main message from the talk was that the Azz asymmetry will have other higher twist contributions appearing in

it and that these should be disentangled from the observable of interest b1, using theoretical guidance and simulations. The first day finished with a talk on the experimental schedule and new opportunities at Jefferson Lab (JLab) by D. Higinbotham, followed by a discussion on possible new measurements at JLab with tensor polarized targets, such as tensor polarized SIDIS with the SOLID detector.

Day 2 started with an overview and status report of the planned quasi-elastic and elastic scattering experiment with tensor polarized deuteron at JLab (E. Long). Next, we had two theoretical talks: in the first, V. Biloshytskyi sketched the structural links between light by light scattering and polarized spin-1 scattering. Next, J. Rittenhouse West gave an overview of diquark physics and potential applications for a tensor polarized deuteron. In the afternoon D. Seay presented machine learning methods to monitor deuteron polarization and T. Maly offered his perspective on solid state millimeter wave sources for Dynamic Nuclear Polarization. The day was concluded with a discussion on software and hardware issues related to the polarized targets.

On Day 3 we started with a historical overview and lessons learnt from previous elastic and quasi-elastic polarized deuteron scattering experiments from NIKHEF and BATES [S. Sirca] and a talk on the advantages of using machine learning and AI methods in modern measurement methods [D. Keller]. The second part of the morning was devoted to talks on the farther future, with the possibilities for polarized deuteron scattering at the electron-ion collider (EIC). D. Higinbotham sketched the situation and associated challenges to operate EIC with polarized deuterons which involves running the accelerator at certain “magic” energies (this was done before at NIKHEF in a different energy range). Next C. Weiss discussed the advantages that spectator nucleon tagging at the EIC could bring to polarized deuteron measurements. In the afternoon D. Mack discussed current designs to monitor the beam current in the polarized experiments and J. Maxwell gave an overview of the performance and lessons learnt in the running with polarized ammonium and deuterated ammonium in HallB at JLab. The last talk of the day was given by S. Jeschonnek who discussed spin observables in theoretical calculation of deuteron breakup. The need for dedicated calculations specific to the kinematics was stressed as in general there is little that can be extrapolated from one situation to another when discussing spin observables in these reactions. The day was wrapped up with a discussion on the tasks left for the jeopardy review of the two tensor polarized deuteron experiments at JLab.

On day 4 we started with two theoretical talks on deuteron structure in light-cone dynamics. M. Strikman discussed the general features of light-cone dynamics and high-energy nuclear scattering and how tensor polarized observables provide unique windows on these dynamics. M. Sargsian then discussed how non-nucleonic degrees of freedom (such as Delta resonances) could be probed using tensor polarized observables. Next, S. Liuti discussed deeply virtual Compton scattering (DVCS) on the deuteron, with a focus on tensor polarized observables. The last talk of the morning was given by C. Yero who discussed doing a quasi-elastic tensor polarized deuteron breakup measurement at JLab 12GeV which would extend the high Q^2 frontier for these observables and is an experiment that could be proposed and run in the near future (before EIC operations).

On the last day we had two more target related talks: James Maxwell described the new Jefferson Lab NMR system and the polarized target performance during the recent Run Group C experiment in Hall B. He also described a Letter of Intent to measure the double helicity flip tensor structure function at Jefferson Lab using an N14 target. And Michael Mclellan discussed new efforts at UNH to extract tensor and vector polarization values from the NMR lineshape of deuterated materials. Finally, I. Fernando gave an overview of the Spinquest experiment at Fermilab which measures Drell-Yan reactions, and the possibilities to do these measurements with a polarized deuteron target to probe polarized deuteron (spin-1) transverse momentum distributions. The workshop was wrapped up with a general discussion on the most important topics that came up during the time of the workshop (see highlights below) and the plan to organize a special journal volume around the main results of the workshop.

Results and Highlights

The tensor-deuteron program at Jefferson Lab will help to clarify how the properties of the nucleus arise from the underlying partons, and provide novel information about gluon contributions, quark angular momentum, and the polarization of the quark sea that is not accessible in spin-1/2 targets. This ECT* workshop brought together the foremost experts in the field who have managed to devise a clear strategy for moving forward on both the theoretical and the experimental front, thereby ensuring the success of the planned experiments and a tremendous increase of our knowledge of the deuteron.

The main results of the workshop are:

- We identified a clear roadmap for the planned tensor polarized experiments at Jefferson Lab and theoretical needs that need to be addressed in relation to it.
- We discussed further realistic opportunities for measurements with tensor polarized targets (SIDIS and deep exclusive processes at JLab, quasi-elastic deuteron breakup, advocacy for polarized deuteron at the electron-ion collider)
- We recognized the need for unified terminology for observables and distributions, and identified avenues to establish this consistent terminology.
- We surveyed the state of technical developments for the tensor polarized solid target and discussed opportunities for improvement and further work.
- We intend to prepare a special journal volume dedicated to the topics discussed and results achieved at this workshop.

2.3.15 Short-Distance Nuclear Structure and PDF

Date	July 17-21, 2023

Organizers

Nadia Fomin	University of Tennessee, USA
John Arrington	LBNL, USA
Noemi Rocco	Fermi National Laboratory, Italy
Raphaël Dupré	IJCLab - CNRS - Univ. Paris-Saclay, France

Number of participants	31

Main topics

Over the last decade, a number of explanations for the modification of nucleon quark distributions in nuclei (the EMC effect) have been put forth, leveraging information from the 6 GeV JLab program. In particular, new information on the A dependence in light nuclei and the correlation with the observation of high-momentum nucleons born in two nucleon correlations (2N SRCs). By the time of the workshop, several 12 GeV measurements had been completed that will significantly expand on what was learned at 6 GeV. EMC and SRC data on many new nuclei from several experiments at Jefferson Lab will be available to more meaningfully probe these relationships, examine the mass and isospin dependence, and study the momentum dependence of the nucleons. In addition, measurements using spectator tagging have been performed that will help study the impact of virtuality on the nucleon structure. The workshop examined the status of the field, ascertained what we can learn from new and upcoming data and set goals for the next 5 years, both theory and experimental.

The main topics were:

- Short-range correlations (SRCs): A-dependence, isospin dependence, momentum dependence, nuclear structure calculations, reaction mechanisms, isolating 3N-SRCs.
- EMC effect - new data, viable explanations, new observables including spin-dependent, momentum-dependent, and flavor-dependent modification, as well as modification of anti-quarks.
- EMC-SRC correlation - what can we learn about EMC effect from SRCs and vice-versa? Data on many new nuclei will help significantly flesh out this landscape.

Speakers

Alberto Accardi	Hampton University / Jefferson Lab, USA
Lorenzo Andreoli	Washington University in St Louis, USA
Omar Benhar	INFN and Sapienza University, Rome, Italy

Jiunn-Wei Chen	National Taiwan University, Taiwan
Wim Cosyn	Florida International University, USA
Cameron Cotton	University of Virginia,USA
Mark Dalton	Jefferson Lab, USA
Raphael Dupré	IJCLab - CNRS - Univ. Paris-Saclay, France
Burcu Duran	University of Tennessee, USA
Pit Duwenstaster	University of Jyväskylä, Finland
Justin Estee	MIT, USA
Nadia Fomin	University of Tennessee, USA
Filippo Fornetti	Università degli Studi di Perugia, INFN Sezione di Perugia, Italy
Tyler Hague	LBNL, USA
Florian Hauenstein	Jefferson Lab, USA
Julian Kahlbow	MIT, USA
Tyler Kutz	MIT, USA
Shujie Li	LBNL, USA
Alessandro Lovato	ANL, , USA & TIFPA, Italy
Casey Morean	University of Tennessee, USA
Dien Nguyen	Jefferson Lab, USA
Ramon Ogaz	University of Tennessee, USA
Mathieu Ouillon	IJCLAB, France
Valerii Panin	GSI, Germany
Paul E Reimer	Argonne National Laboratory, USA
Matteo Rinaldi	INFN Perugia, Italy
Jan Ryckebusch	Ghent University, Belgium
Nathaly Santiesteban	UNH, USA
Misak Sargsian	Florida International University, USA
Abhyuday Sharda	University of Tennessee, USA
Joanna Sobczyk	IFIC, Spain
Mark Strikman	Penn State University, USA
Anthony Tropiano	Argonne National Laboratory, USA
Zhoudunming Tu	BNL, USA
Ronen Weiss	LANL, USA
Christian Weiss	Jefferson Lab, USA
Carlos Yero	Old Dominion University, USA

Scientific report

The workshop aimed to evaluate the impact of recent JLab data from multiple experiments as well as new efforts at low energy facilities on the current SRC and EMC landscape. In addition to an overview of the last several decades of experiments, early analyses of recently completed experiments were presented and impact as well as theory support was enthusiastically discussed. Additionally, plans and ideas for new experiments at multiple facilities - near term and longer term - were presented, with scientific feedback and discussion.

A very productive set of discussions was had between early career experimentalists and theorists and how to best collaborate, what was within computational reach within the next few years and what experimental input would be useful to benchmark such calculations. Additionally, discussions were held on what theory advances are needed to provide cleaner interpretation of the data and self-consistent descriptions of multiple observables.

Outlook

In the final session of the workshop, group discussion identified some major unanswered physics questions in the field as well as questions as to what to pursue. These included

- How large is the isovector or isospin dependence?
- Is there any benefit to more inclusive, EMC-focused, DIS studies beyond the data we have at JLab kinematics?
- Is there any nuclear dependence to nuclear LT separated cross sections, R_{LT}?
- Confirm that meson exchange current contributions are suppressed
- Slow delta (N*) measurements are desirable

In the next five years, experimental results from a number of JLab efforts (XEM2, RGM, CaFe) will be finalized and will greatly expand our knowledge of short-range correlations as well as EMC effect. The analysis will provide information on

- Nuclear dependence of a_2
- Potentially the first observation of a_3 - 3N SRC plateau
- Superfast Quarks at moderate values of Q^2

Inclusive studies will be complemented by a series of tagged experiments (BAND, LAD, ALERT),experiments at low energy facilities (GSI, Dubna) as well as data from the high energy SeaQuest experiment.

Looking farther into the future (>5 years), studies of polarized EMC effect, parity-violating EMC effect, A=3 studies in Hall B, as well as DIS at EIC are being planned, with some already approved.

The workshop included active participation from many early career physicists. There are many theoretical efforts under way and experimental searches with upcoming results as well as additional measurement campaigns in the works. The feedback from participants has been overwhelmingly positive and new working relationships were initiated.

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2.3.16 *Quantum Sensing and Fundamental Physics with Levitated Mechanical Systems*

Date	July 31- August 4, 2023

Organizers

Andrea Vinante	IFN-CNR, Italy
Dmitry Budker	Johannes Gutenberg University, Germany
Gabriel Hetet	Ecole Normal Supérieure Paris, France
Hendrik Ulbricht	University of Southampton, UK
Angelo Bassi	University of Trieste, Italy

Number of participants	51

Main topics

The general theme of the workshop concerned the field of levitated nano/micromechanical systems using various platforms (optical, electrical, magnetic, free-fall) and the application of these systems in the context of quantum sensing and fundamental physics. Relevant science goals are very challenging, and include generating massive quantum superpositions, testing the macroscopic limits of quantum mechanics, testing quantum gravity, searching for dark matter and new physics beyond standard model. A critical aspect common to all platforms is the understanding and mitigation of different sources of noise and decoherence. The Workshop has been largely devoted to discuss these aspects and find new solutions.

Speakers

Felix Ahrens	CNR-IFN Trento
Matteo Carlesso	University of Trieste
Andrejs Cebers	University of Latvia
Yaakov Fein	Univesity of Vienna
Ron Folman	Ben Gurion University
Tim Fuchs	Leiden University
Giorgio Gratta	Stanford University
Alexander Heidt	University of Hannover
Gerard Higgins	Chalmers University
Wei Ji	University of Mainz
Francesco Marin	University of Firenze
Nadine Meyer	ETH Zurich
James Millen	King’s College London
David Moore	Yale University

Lukas Novotny	ETH Zurich
Tracy Northup	University of Innsbruck
Mauro Paternostro	Queen's University Belfast
Maxime Perdriat	ENS Paris
Martin Plenio	University of Ulm
Martino Poggio	University of Basel
Antonio Pontin	University College London
Oriol Romero-Isart	University of Innsbruck
DaLi Schaefer	Harvard University
Ben Stickler	University of Duisburg-Essen
Chris Timberlake	University of Southampton
Marko Toros	University of Glasgow
Jason Twamley	Okinawa Institute of Science and Technology
Christian Vogt	University of Bremen
Bill Weber	University of Trento

Scientific report

Micro and nanoobjects can be nowadays levitated and controlled in vacuum with a number of different techniques (optical, magnetic or electrical), leading to the development of extremely sensitive and highly versatile systems. In fact, the tunability of the trapping potential allows a higher flexibility with respect to conventional mechanical resonators, which allows for the realization of hybrid quantum system where the motional degrees of freedom are coupled to quantum devices such as optical cavities, single spins or superconducting quantum devices. In a long-term prospect, these systems appear as the optimal platform for the realization of massive mechanical quantum states, which will eventually allow to attack some key questions of modern physics, such as probing the macroscopic limits of quantum mechanics and/or experimentally probing the quantum nature of gravity or the interplay between gravity and quantum mechanics. On a more practical level, the extreme isolation from the environment of these systems leads to very low thermal noise, which can be exploited for the realization of a new class of sensors (accelerometers, magnetometers, gravimeters, force sensors) with unprecedented sensitivity. A natural field of application is fundamental physics, for instance the test of exotic interactions mediated by particles beyond standard model (e.g. axions). Mechanical sensing or decoherence-based quantum sensing based on levitated systems may also become a potential route towards direct detection of dark matter. The workshop has covered all these theoretical and experimental aspects by gathering together senior and young researchers from the most relevant groups actively working on these topics.

On experimental side, large part of the workshop has been devoted to the discussion of different levitation methods, advantages and drawbacks, common issues and possible synergies. The optomechanical approach is generally perceived as the most mature, with nonclassical states being routinely realized and exploited in several labs, and the potential for the generation of massive quantum superpositions. Nonetheless, optical levitation in vacuum is facing some fundamental limitations due to high temperature and photon-induced decoherence. Possible solutions are the use of different approaches, such as electrodynamical levitation (Paul traps) or magnetic levitation, with the latter being particularly promising as it can be operated with passive static fields, and is therefore compatible ultralow temperature ultraisolated environment. Another solution is moving to microgravity in drop towers or in space experiments. Bottom-up approaches trying to extend atom interferometric techniques to spin-mechanical systems with spins in diamond have been discussed. Particular emphasis has been given in the Workshop to the levitation of magnetic microparticles: given the early stage of experiments, researchers working in related fields such as nanomagnetism, have been invited. Several approaches to exploit the ultrahigh sensitivity of levitated systems to forces, torques, gravity, magnetic fields and other effects have been recently put forward theoretically. Experiments are still in a pioneering phase but are showing some first interesting results. The Workshop has been an excellent opportunity to gather together the main relevant groups, highlight the current attempts in this direction and exchange ideas for future developments.

The Workshop has been complemented by several top-level theoretical talks, discussing potential future developments such as tests of quantum gravity, tests of wave function collapse models, rotational interferometry, entanglement from rotation, quantum machine learning.

Results and Highlights

The Workshop was successful in gathering together relevant speakers working on different levitation platforms, and the lively atmosphere was positively felt by all participants, with a good balance between senior and young researchers and ample space for discussions provided by the two poster sessions.

Several novel results have been presented. One of the most interesting is the integration of different levitation methods in a hybrid configuration for generating quantum superpositions. In particular, optical levitation has been integrated with a Paul trap: the general strategy is to use optics to generate nonclassical states, and the Paul trap to let the macroscopic quantum state evolve in a ultralow decoherence environment. This approach is apparently able to overcome the most serious decoherence issues. In a different experiment, Paul trap levitation itself has demonstrated a very promising and exceptionally high mechanical quality factor in excess of 10^{10}, higher than any mechanical system to date. At the same time, new protocols for generation and manipulation of massive quantum superpositions have been proposed and discussed, making this achievement more feasible compared to early proposals. The case for quantum interferometry in microgravity or in space has been also discussed, with several contributions from drop-tower and space-based experiments, including the LISA gravitational wave detector. Currently, it is not clear if a free-fall environment is compelling for massive quantum interferometry. Different points of view have emerged among participants. In general, space will become necessary if ground-based approaches fail. The future outcome of current attempts towards quantum interferometry with optically levitated particles and spin-mechanical diamonds on ground will provide a more definite answer.

Magnetic levitation platforms have shown first interesting results: on-chip levitation of superconducting microspheres has been demonstrated, while levitated magnets have been used both for gravity measurements and for ultrasensitive magnetic field sensing. The latter result is particularly promising in the search for new forces beyond standard model and axion-like dark matter. First results towards a magnetic particle in free-fall have been reported: this experiment aims at observing atomic features, i.e. Larmor precession, in a macroscopic magnet. This will eventually allow for the realization of ultrasensitive gyroscopes and magnetometers.

Finally, interesting new results have been reported on the detection of weak forces with optically levitated nanoparticles. These experiments aim at investigations in the context of fundamental and particle physics: detection of nonnewtonian gravity at short distance, tests of charge neutrality, neutrino mass investigations and search for dark matter through recoil measurements.

2.3.17 *ECT*-APCTP Joint Workshop: Exploring Resonance Structure with Transition GPDs*

Date	August 21-25, 2023

Organizers

Stefan Diehl	Justus Liebig University Giessen, Germany
Vladimir Braun	University of Regensburg, Germany
Charlotte Van Hulse	University of Alcala, Madrid Region, Spain
Chang-Hwan Lee	Pusan National University & APCTP, South Korea
Kyungseon Joo	University of Connecticut, United States
Christian Weiss	Jefferson Lab, United States

Number of participants	30

Main topics

Generalized Parton Distributions (GPDs) are a well-established tool for exploring the 3D structure of the nucleon and mechanical properties such as the distributions of energy/momentum and forces in the system. While extensive studies have been performed for the ground-state nucleon, little is known about the 3D structure of resonances. The nucleon-to-resonance (N→N*) transition GPDs provides a unique tool for exploring the 3D structure and mechanical properties of nucleon resonances. They can be measured in exclusive processes with N→N* transitions. First data on these reactions are becoming available from experiments at JLab12, and strategies for their analysis and theoretical interpretation need to be developed. The workshop brought together theorists and experimentalists, in particular, including scientists from APCTP and ECT* member countries, to review the status of nucleon GPDs, present the first experimental results for transition GPDs, develop a strategy for analysis and interpretation, and discuss the prospects of future experimental programs (JLAB, EIC, J-PARC, PANDA).

The main topics were

- GPD analysis
- DVCS and transition GPDs
- Lattice calculations of GPDs
- Transition GPD properties and models
- GPDs with hadron and photon beams
- Baryon resonances
- Meson production and transition GPDs
- GPDs at collider experiments
- Future program in experiment and theory

Speakers

Valerio Bertone	IRFU
Vladimir Braun	University Regensburg, Germany
Wen-Chen Chang	Institute of Physics, Academia Sinica, Taiwan
Pierre Chatagnon	Jefferson Laboratory, USA
Martha Constantinou	Temple University, USA
Stefan Diehl	Univ. Giessen, Germany & Univ. of Connecticut, USA
Yuxun Guo	Maryland University, USA
Alex Jentsch	Brookhaven National Lab, USA
Hyon-Suk Jo	Kyungpook National University, South Korea
Kyungseon Joo	University of Connecticut, USA
Jun-Young Kim	JLab, USA
Andrey Kim	University of Connecticut, USA
Peter Kroll	University of Wuppertal, Germany
Shunzo Kumano	Japan Women's University / KEK, Japan
Chang-Hwan Lee	Pusan National University, South Korea
Simonetta Liuti	University of Virginia, USA
Ronan McNulty	University College Dublin, Ireland
Deborah Roenchen	FZ Juelich, Germany
Kirill Semenov-Tyan-Shanskiy	Kyungpook National University, South Korea
Hyun-Dong Son	Korea University, South Korea
Paweł Sznajder	National Centre for Nuclear Research, Poland
Ali Usman	University of Regina, Canda
Charlotte Van Hulse	University of Alcala, Spain
Marc Vanderhaegen	Mainz University, Germany
Christian Weiss	Jefferson Lab, USA
Michael Winn	CEA/Irfu Saclay, France

Scientific report

The workshop reviewed the status of theory/analysis/experiments in N → N GPDs, explored the extension to transition GPDs (N → πN, Δ, N*, …) with upcoming experimental and theoretical results and formulated a future program for 12 GeV JLab and beyond, based on EIC far-forward physics and with photon and hadron beams. In the first session, the status of the extraction of N → N GPDs was discussed. Here, the status of the general theory of deeply virtual Compton scattering (DVCS) and deeply virtual meson production (DVMP) was presented. Furthermore, tools for the extraction of GPDs from experimental data as well as models for the evolution of GPDs and a global extraction and parameterisation of GPDs were reviewed and discussed. The second session reviewed the status of DVCS measurements with CLAS12. In addition, model calculations for the description of the N→N* DVCS process were presented and perspectives and first results for the measurement of this process with

CLAS12 were presented. Based on the presentations, the future program for such measurements and the required cooperation between theory and experiment were discussed. The next session focussed on the review and discussion of lattice QCD calculations of GPDs and the potential extension of such calculations to transition GPDs. Another session was focussed on the properties of transition GPDs and the further development of models which connect the transition GPDs to experimental observables. Also the application of transition GPDs to understand the basic properties of resonance, like the angular momentum was discussed based on recently published theoretical models. Another focus was set on the exploration of GPDs and transition GPDs with hadron and photon beams and potential future perspectives at facilities like J-PARC. As a key to analyse the resonance spectrum, which is generated by the N→N* transitions, the status of classical N* physics with CLAS and CLAS12 as well as the recent developments in the field of coupled channel analyses were reviewed and discussed. Another main pillar of the experimental and theoretical program is the deeply virtual meson production (DVMP). Here, the status of N → N DVMP measurements at JLAB as well as the newest results were reviewed. After and overview on the theoretical description of the N →N* DVMP process based on transition GPDs, first experimental results on the measurement of the N →N* DVMP process at JLAB were presented and discussed. The future perspectives for such a program were evaluated and the cooperation between theory and experiment was discussed. The last session focussed on the measurement of GPDs and the potential for the measurement of transition GPDs at collider experiments like LHC and the future EIC. In this context also previous measurements at HERA were reviewed. As an extension of the scope, a general overview on the APCTP activities in nuclear and hadronic physics was presented.

Results and Highlights

The workshop was very successful in bringing together experimentalists and theorists, on the one side, and scientists working on different experiments around the world, on the other side. The cooperation with APCTP enabled the participation of a significant amount of participants from Asian countries and allowed a coordination of the activities between experimental facilities in Europe, Asia and the United States.

Highlights in terms of the investigation of transition GPDs were:

- A theoretical description of the N→N* DVCS process has been recently extended to higher resonances and adjusted to the kinematics currently accessible at JLAB. First experimental results on this channel are very promising and are planned to be ready for publication in the near future.
- Furthermore, the first theoretical description of the N→N* DVMP process and the first experimental results for this process, which were partly recently published, were presented.
- New theoretical models, which were shown at the workshop, allow a connection of the transition GPDs to basic properties of the resonances, like their angular momentum.
- Also new studies and methods to prove the factorisation of the measured processes in terms of transition GPDs were discussed and provide a strong foundation for the existing descriptions of the experimental processes.

The workshop allowed the development of a clear outline for future activities in the field and initiated the planning for beam time applications for more detailed and fully differential measurements of the relevant processes. A whitepaper summarizing the status of the theoretical and experimental investigation of transition GPDs and the results of the workshop discussions is currently under preparation.

2.3.18 2nd *MIMOSA Collaboration Meeting*

Date	August 31-September 1, 2023

Organizers

Gianluca Lattanzi	University of Trento, Italy
Simone Taioli	ECT*, Italy
Angela Vella	University of Rouen, France

Number of participants	14

Main topics

This is the second annual meeting, after the kick-off in Rouen, of the Supervisory Board of the HORIZON-EIC-2021 PATHFINDEROPEN-01 European project MIMOSA (4D Microscopy of biological materials by short pulse terahertz sources). Mimosa Supervisory Board is composed of one representative per partner institution and is the ultimate decision-making body chaired by the Coordinator. The Supervisory Board supervises the scientific and technological progress of the project, the communication development and the scientific publications or patents via regular videoconferences and a yearly face-to-face meeting. These meetings are open to all the scientific MIMOSA project collaborators and are scheduled in a format that allows all the partners to present the scientific and technological progress during the first day, and have open discussions on the second day.

The main topics were:

- Presentation of the main scientific achievements from all the consortium partners
- Discussion on the deliverables and milestones to be accomplished over the next year
- Finalizing the periodic report on the EU portal
- Synergy among the partners of the consortium
- Discussion of the objectives of Mimosa dissemination plan

Speakers

Anna Martinez	CNR & University of Naples Federico II, Italy
Domenico Paparo	CNR, Italy
Rebeca Tudor	IMT-Bucharest, Romania
Cristian Kusko	IMT-Bucharest, Romania
Ammar Hideur	University of Rouen, France
Matteo De Tullio	University of Rouen, France
Angela Vella	University of Rouen, France
Mats Huvander	Chalmers University, Sweden

Giovanni Novi Invenrardi University of Trento
Tommaso Morresi ECT*, Italy

Scientific report

Cryo electron microscopy and tomography have been among the greatest achievements in biological imaging. However, these techniques suffer from insufficient chemical resolution. The ultimate goal of MIMOSA is to provide an alternative to tomography at the nanoscale with a high chemical resolution for biological and medical systems, based on Tomographic Atom Probe (TAP).

According to this challenging goal, this collaboration meeting was extremely useful to openly discuss several aspects and technical/scientific issues reported by the single participating partners as well as to strengthen common strategies and future collaboration, and devise novel approaches for a successful management of the project.

In particular, the interdisciplinary focus of Mimosa in bio-imaging, optics, ultrafast lasers and intense THz sources, big-data treatment and the fundamental physics of the interaction between THz waves and matter emerged clearly as a pivotal point and remarkable feature of the project from such discussions.

The scientific talks outlined our advances in prototyping a new TAP triggered by intense terahertz (THz) pulses that are stable at high repetition rates and exhibit versatile and tailored properties and, in parallel, an efficient intense THz source based on a new technology with ultrafast high-energy fiber lasers. This source can be used in nano-tomography for biological and medical applications but also as a test platform for a foreseeable commercialization of the THz-triggered TAP. Moreover, the theoretical and computational challenges to model the protein-cage interaction using molecular dynamics simulations and to study from first-principles the interaction of the protein with both the static electromagnetic and THz laser fields were recognized. Plans to solve and mitigate these issues were devised.

Finally, the MIMOSA project will enable the team members to become leaders in TAP development, 3D medical and bio-imaging, ultrafast lasers development with advanced techniques for shaping and control of the optical beam's properties and in the computational modeling of laser-matter interaction. With MIMOSA we are uniquely positioned to succeed and to raise the competitiveness of Europe in microscopy development on the international scene.

Results and Highlights

The two days of scientific discussion and informal activities (coffee, lunch, dinners and walk by the lake and in the city center) have been very fruitful for scientific exchange and to strengthen our collaboration.

Four main collaborative research actions have been initiated as a result of these two day discussions:

- W1: THz beam shaping and spectral filtering using metasurface optical devices (IMT, CNR and CNRS).
- WP2: comparative study of SiO2 using LEAP and THz-TAP between GPM and Chalmers.

- WP3 : Comparative study of biomolecules imbedded in silicate gel environment (Trento and Chalmers).
- WP3: Comparative study of TAP analysis of silicate samples and DFT calculation of absorption spectra and field evaporation (ECT*-CNRS).

The presentations given during the meeting have been uploaded on the shared web-space.

2.3.19 *Many-Body Quantum Physics with Machine Learning*

Date	September 4-8, 2023

Organizers

Arnau Rios-Huguet	University of Barcelona, Spain
Giuseppe Carleo	EPFL, Switzerland
Estelle Inack	PITP, Canada
Alessandro Lovato	ANL, USA & TIFPA, Italy

Number of participants	36 + *2 online*

Main topics

This program revolved around recent developments on machine learning (ML) tools to solve quantum many-body problems, the so-called Neural Quantum State approach. The program brought together practitioners from different fields in physics, including experts in condensed matter, quantum computing, quantum chemistry and nuclear physics, to discuss advances in techniques that tackle the many-body problem. Physical systems that were discussed during the workshop included:

1. Fermionic spin systems
2. Continuous boson and fermionic systems in 1D, 2D and 3D
3. Atoms and molecules (from a quantum chemistry perspective)
4. Atomic nuclei
5. Neutron stars
6. Quantum field theories, including both fields and matter

In particular, the workshop was structured to address the following goals:

1. To review past achievements and discuss recent progress on qML techniques.
2. To identify common tools in different fields and, possibly, benchmarks to compare the currently available pipelines.
3. To identify opportunities or bottlenecks in time-dependent applications of ML.
4. To pin down similarities across disciplines to boost the use of ML in different physics applications.

Speakers

Amir Azzam	Institute of Cosmos Sciences, University of Barcelona, Spain
Carlo Barbieri	University of Milan & INFN Milan, Italy
Andrea di Donna	University of Trento, Italy
Mehdi Drissi	TRIUMF, Canada

Bryce Fore	Argonne National Laboratory, USA
Clemens Giuliani	EPFL, Switzerland
Markus Holzmann	LPMMC, Grenoble, France
James Keeble	University of Surrey, UK
Jane Kim	Ohio State University, USA
David Linteau	EPFL, Switzerland
Piero Luchi	University of Trento, Italy
Elad Parnes	Hebrew University of Jerusalem
David Pfau	Deepmind, UK
Sebastiano Pilati	University of Camerino, Italy
Pedro Pérez-Fernandez	University of Sevilla, Spain
Javier Rozalén	Institute of Cosmos Sciences, University of Barcelona, Spain
Alvaro Saiz-Castillo	University of Sevilla, Spain
Alessandro Sinibaldi	EPFL, Switzerland
Di Luo	MIT, USA
Roberto Verdel Aranda	ICTP, Italy
Filippo Vicentini	École Polytechnique, Paris, France
Pengsheng Wen	Texas A&M University

Scientific report

Most of the discussions at the workshop centred around Neural Quantum States (NQSs). In this approach, the many-body wave function is described in terms of a neural network and the energy is a cost function to minimise. This is similar to traditional Variational Monte Carlo (VMC) methods, but with the added flexibility associated to the use of machine learning (ML) tools for coding the wavefunction and minimising the associated energy. Discussions in our workshop covered mainly 3 broad umbrella topics: new applications of NQS; recent developments of the NQS method; and discussions of associated methodologies.About half of the talks of our workshop focused on new implementations of NQSs to a variety of physical systems, including ultracold unitary Fermi gases; extended bosonic systems, like 4He; and low-dimensionality many-body fermionic systems. Within nuclear physics, speakers discussed applications of NQSs to nuclei and hypernuclei; neutron matter and lattice systems, and a special emphasis on pionless EFT method. NQSs are particularly flexible and also allow for the description of mixed states for open quantum systems research. These talks provided a broad overview of the method, with speakers focusing on specific implementation details of NQSs in different groups. This rich overview of systems clearly indicates that NQS methods are become a universal tool in the quantum many-body arena. Talks at the workshop also reviewed several new methodological advances of NQSs. These included recent applications to excited states in quantum chemistry; the development of new, tailored minimisation methods for NQSs; the exploitation of transfer learning in NQS minimisation strategies and the implementation of symmetries in many-body settings. New developments in the field of quantum field theory have also successfully employed NQSs to describe many Fock spaces at once.

Moreover, recent approaches have employed NQSs in a time-dependent setting as well as Kernel methods in the minimisation strategy. Developments to measure the complexity of these states were also discussed. All in all, it is clear that there is space for further formal developments of NQSs that can potentially extend its applicability. Finally, the workshop provided ample space for discussions of adjacent fields that can either inspire new developments in NQSs or are part of their applications. There are synergies between traditional Quantum Monte Carlo methods (VMC, but also projective MC methods) and NQSs that were discussed both for the electron gas and spin systems. The connections between Quantum Computing and NQSs (variational solvers, wavefunction encoding, etc) are also rich, and were addressed in the context of specific quantum readout applications. In the workshop, we also reviewed the use of unsupervised ML techniques to identify different phases of many-body systems. In terms of nuclear theory, ML tools are nowadays also employed in the generation of Monte Carlo sampling for perturbation theory applications and in the development of nuclear interactions. All in all, there seems to be a thriving community of researchers employing ML in very many different applications of quantum many-body theory. Overall, our workshop showed that ML techniques have a broad, appealing appeal for different communities that employ them in a rich variety of endeavours. More specifically, NQSs provide competitive, state-of-the-art methods with a relatively low entry level cost, which make them very appealing broadly. Here, it is worth emphasizing that the well-established NetKet suite (https://www.netket.org/) is a key tool in most of these developments, employed by practitioners across several different fields. A common theme across the whole workshop was the developments of open source code. Most groups in the NQS community currently share their implementations as open sources.

Results and Highlights

The Workshop was a very useful opportunity to enhance the interaction between different fields employing common techniques. It is clear that the flourishing NQS community is evolving, providing cutting-edge results for several systems, while being relatively young. Anecdotally, we stress that the majority of participants in our workshop were PhD students. The common tools that this community employs (based on ML algorithms) are rather universal, and extremely useful when it comes to training. The workshop provided a very lively atmosphere for deep discussions involving several key issues of the current status and future of this discipline. In addition to the talks, two key highlights of the workshop involved the discussion sessions and a careers sessions. The discussion sessions provided a key platform to discuss the key discussion points of our workshop. The key discussion points that were addressed in the two discussion sessions were:

1. Are there limits to the representability of neural network states when it comes to many-body systems?

We agreed that strict representability theorems may be useful in theoretical terms, although not necessary to evolve the current status of the field. For instance, heuristic determinations based on observed computational limitations or on specific quantifications (like the V-score from Vicentini et al) may provide solid enough indications of the complexity of the many-body problem at hand. Other measures based on entanglement may also provide ideas on how to efficiently encode wavefunctions in NQS.

2. What are the optimal architectures to employ in different systems?

So far, applications of NQSs have often been tailored to specific systems (eg Boltzmann machines are natural encodings for spin systems, but perhaps not so much for continuous ones). The community may want to work towards a more universal approach to employ common NQS architectures. One key aspect here is to try and develop common code (eg employing the well-established NetKet suite as a basis for further developments). A key recent development in ML is the use of large language models (LLMs) to encode large amounts of data in a flexible, portable way. The community may want to see if there are generic embeddings based on LLMs that can be employed across systems. Together with a system-specific final layer, an approach like this may have the potential to provide a "universal" embedding of quantum many-body systems.

3. What are the challenges in many-body real-time dynamics with ML approaches?

One of the talks at the workshop focused specifically on dynamics of many-body systems (Sinibaldi's talk). Here, new techniques allow for unbiasing the simulations whenever zeros appear in the many-body wavefunction. These techniques may have promising applications in different many-body systems.

4. Are ML simulations scalable to large systems (particularly in the context of nuclear physics)?

Several results presented at the workshop indicate that the scalability of NQS simulations is quite good, sometimes beating the expected scaling based on computational complexity. Medium-mass nuclei are within reach and simulations at relatively large densities are already available. Transfer learning here provides a useful starting point in simulations and a substantial speed-up when it comes to solving the variational problem.

5. Can we establish links between ML approaches and other methods (eg diagrammatic approaches, coupled cluster, etc)? Can other, non-variational methods be reformulated with ML ideas?

There were at least two talks that discussed links between NQSs and other quantum many-body approaches. On the one hand, diagrammatic Monte Carlo offers an MC approach but based on the sampling in diagram space. Here, ML has been used in the sampling procedure and further analysis of this approach may provide additional benefits (Barbieri's talk). On the other hand, one can also obtain components of the self-energy from VMC simulations (eg static self-energies, discussed as in Holzmann's talk). Similar techniques could be employed in NQS simulations to gauge their quality against other methods.

6. What are the connections with quantum information science? Several connections between current quantum computing applications and NQS. Among others, we highlight those obtained in the context of open quantum systems, where NQSs have provided state-of-the-art results at a very reasonable computational cost. Finally, we stress again that a unique feature of our event was that the majority of attendees were PhD students. ML in science is also remarkable in that there is a strong link with industry, either through training of early career researchers or with actual research developments carried out in a private setting (eg, David Pfau's group at Deepmind). With this in mind, we decided to organise a careers session that took place on Wednesday afternoon. The session involved 1 academic (Rios); 1 entrepreneur (Innack) and 1

employee of a private research organisation (Deepmind) discussing their past career and how their current work looks like. This event was a highlight across all participants, especially those at an early career stage. Based on this response, we strongly encourage the organisation of similar careers sessions in future workshops of this topic.

2.3.20 MICRA 2023: Microphysics in Computational Relativistic Astrophysics

Date	September 11-15, 20232

Organizers

Evan O'Connor	Stockholm University, Sweden
Carla Frohlich	North Carolina State University, USA
Albino Perego	University of Trento, Italy

Number of participants	62

Main topics

The MICRA workshop focuses on the microphysics input to extreme relativistic astrophysical systems. This brings together nuclear, neutrino, and particle theorists together with numerical relativists. A large focus on the workshop is then to share the recent developments and state-of-the-art techniques used in these different disciplines with the goal of enabling collaborations to develop that will push forward the boundaries of our ability to model and understand extreme astrophysical environments.

The main topics were:

- Core-Collapse Supernovae
- Nuclear Equation of State
- Merging Compact Objects
- Neutrinos
- Nucleosynthesis & Observations

Speakers

Ryuichiro Akaho	Waseda University, Japan
Haakon Andresen	Stockholm University, Sweden
Almudena Arcones	TU Darmstadt and GSI, Germany
Debades Bandyopadhyay	Aliah University, India
Aurore Betranhandy	Max Planck for gravitational astrophysics, Germany
Sebastiano Bernuzzi	FSU Jena, Germany
Mikhail Beznogov	IFIN-HH, Romania
Bhaskar Biswas	Hamburg University, Germany
Sebastian Blacker	TU Darmstadt, Germany
Luca Boccioli	University of Notre Dame, USA
Pablo Bosch	GRAPPA - University of Amsterdam, Netherlands
Alessandro Camilletti	University of Trento, Italy
Patrick Chi-Kit Cheong	University of New Hampshire, USA

Leonardo Chiesa	Università degli Studi di Trento, Italy
Constantinos Constantinou	INFN/TIFPA, Italy
William Cook	Friedrich-Schiller-Universität Jena, Germany
Coleman Dean	University of Alberta, Canada
Samuel Dunham	Vanderbilt University, USA
Oliver Eggenberger Andersen	Stockholm University, Sweden
Eirik Endeve	Oak Ridge National Laboratory, USA
Jacob Fields	The Pennsylvania State University, USA
Carla Frohlich	North Carolina State University, USA
Bruno Giacomazzo	University of Milano-Bicocca, Italy
Mariam Gogilashvili	Florida State University, LANL, USA
Mirco Guerrini	University of Ferrara, Italy
Goni Halevi	Northwestern University/CIERA, USA
Peter Hammond	Pennsylvania State University, USA
Kai Hebeler	TU Darmstadt, Germany
Harry Ho-Yin NG	Frankkurt University, Germany
Maximilian Jacobi	TU Darmstadt, Germany
Finia Jost	TU Darmstadt, Germany
Noshad Khosravi Largani	University of Wroclaw, Poland
Kelsey Lund	North Carolina State University, USA
Fabio Magistrelli	Friedrich-Schiller Universitat Jena, Germany
Gail McLaughlin	North Carolina State University, USA
Bronson Messer	Oak Ridge National Laboratory, USA
Kanji Mori	National Astronomical Observatory of Japan, Japan
Masamitsu Mori	National Astronomical Observatory of Japan, Japan
Jeremiah Murphy	Florida State University, USA
Hiroki Nagakura Japan	National Astronomical Observatory of Japan,
Gerard Navo	TU Darmstadt, Germany
Anna Neuweiler	University of Potsdam, Germany
Micaela Oertel	LUTH-CNRS/Observatoire de Paris, France
Nils Paar	Faculty of Science University of Zagreb, Croatia
Michael Pajkos	Caltech, USA
Adriana R. Raduta	IFIN-HH, Romania
Moritz Reichert	Universitat de Valencia, Spain
Giacomo Ricigliano	TU Darmstadt, Germany
Stephan Rosswog	University of Hamburg, Germany
Swapnil Shankar	API, University of Amsterdam, Netherlands
Daniel Siegel	University of Greifswald, Germany

Andrew Steiner	University of Tenessee - Knoxville, USA
Rebecca Surman	University of Notre Dame, USA
Konrad Topolski	Goethe University Frankfurt, Germany
Benjamin Wehmeyer	Konkoly Obs & Univ Hertfordshire, Hungary

Scientific report

Some of the most extreme astrophysical events occur in environments where all four fundamental forces play leading roles. Such environments include core collapse supernovae and compact object mergers. Gravity in these environments is important because of the extreme amount of mass in a very small volume of space which means relativistic effects cannot be ignored. The weak force is important in the environments because the matter is dense and hot enough to produce neutrinos and for neutrinos to interact with the matter. The strong force in these environments is incredibly important, because it is the residual nuclear force between the nucleons that support these extreme objects, like neutron stars, against the extreme curvature of spacetime. Finally, the electromagnetic force is important, because photons are one way (the other ways being via neutrinos and gravitational waves) that we see and understand these events.

However, understanding such a multi-physics environment requires a comprehensive understanding of all these forces and therefore requires a strong collaboration between experts in all of these areas. This is the long-term goal of the MICRA series of workshops where the main aim is to bring together multiple fields to tackle the problem of microphysics in extreme astrophysical systems. In particular the focus this year was on bringing experts in neutrino physics and neutrino theory, as well as experts in the nuclear equation state together with experts modeling core collapse supernova and compact object mergers together in order to collectively move the field forward by enabling new collaborations and sharing new results.

Our goal in hosting MICRA this year was to accomplish three main tasks. The first task is to inform the participants of the latest developments across the range of physics relevent for MICRA. We accomplished this with excellent invited talks from speakers spanning the key areas. This included talks on “Neutrino flavor transformations in neutron star mergers” from Gail McLaughlin, “Jets from neutron star merger remnants” by Daniel Siegel updates on the “Nuclear EOS for general proton fractions and temperature based on chiral EFT interactions” from Kai Hebeler, “Nuclear physics of r-process observables” from Rebecca Surman and “Core-Collapse Supernovae: current status, open questions and multimessenger prospects” by Haakon Andresen. The second goal we had was to allow the community to share the most recent, state of the art, results being done now. This was incredibly successful with talks from graduate students and postdocs, showing new and upcoming results that highlight the focus and dedication people have to understanding the microphysics in these extreme environments. We highlight several areas of interest among many participants below. The final goal of the organizers was to enable debate and discussion on techniques and strategies we use within our research in order to understand these extreme environments and the microphysics in them. This is a unique and very successful aspect of the MICRA workshops. The discussion sessions each day were lively, energetic, informative, and incredibly useful for all the participants.

Results and Highlights

Many new and interesting results were presented across all the major themes of the workshop. We present here a selection of highlights, particularly around themes that kept coming up throughout the week.

- For many years in the computational community, we have heard about the on-coming shift away from CPUs towards GPUs. While this has been slow to be realized, it is now in full force with modern super-computing architecture now being dominated by GPUs, and several new hydrodynamic and relativistic codes being developed and used to study relativistic astrophysical systems. Among the presentations including long term simulations of jet-driven supernovae on GPUs and neutrino transport on GPUs. Expect to see more of this in the future!
- Over half of the day on core-collapse supernovae was spent on topics related to collapsars, i.e. a proposed mechanism for long gamma ray bursts. Collapsars are notorious for being astrophysical systems that are rarely modelled from end-to-end consistently. This is because of the tremendous range of scales in the problem. However, work at this MICRA workshop shows that increasingly efforts are able to include more and more of the problem (and microphysics) self-consistently. This is crucial to fully understand this proposed mechanism.
- The elephant in the room when it comes to the role of neutrinos in relativistic astrophysical systems is the impact of neutrino oscillations. This has been a re-occurring theme at all MICRA workshops in the past and tremendous progress occurs every two years. This MICRA workshop saw recent progress in both the understanding of neutrino fast flavor oscillations in these dense environments as well as the potential impact on both supernovae and compact object mergers. There were calls for more investigations of potential impacts since neutrino are critical to setting the electron fraction of the ejecta, which is turn sets the character of the nucleosynthesis yields.

2.3.21 *Parton Distribution Functions at a Crossroad*

Date	September 18-22, 2023

Organizers

Minghui Ding	Helmholtz Centrum Dresden Rosendorf, Germany
Joannis Papavassiliou	University of Valencia, Spain
Catarina Quintans	LIP, Lisbon, Portugal
Craig Roberts	Nanjing University, China

Number of participants	26

Main topics

The key focus of the workshop was the field of parton distribution functions (DFs), which are physical quantities basic to describing and understanding hadron structure. DFs have long been a top priority in hadron physics. For instance, historically, their study led to the discovery of quarks, for which the associated experimental physicists were awarded the Nobel Prize in Physics, and DF analyses advanced the development of quantum chromodynamics (QCD). The workshop concentrated on two very important hadrons in Nature: the proton, which lies at the heart of all visible matter; and the pion, Nature's most fundamental Nambu-Goldstone boson. Attention was given to the DFs of these two particles as a way of elucidating their structure, whose understanding may be key to explaining the mechanisms behind the Emergence of Hadron Mass (EHM). Participants were particularly interested in getting a clearer picture of the structure of proton and pion, a process advanced at the workshop through the exchange of ideas between experts in different approaches (experimental, global fits, Lattice QCD and continuum field theory frameworks).

The main topics were

- Emergence of hadron mass
- Non-perturbative QCD methods
- Parton distribution functions of hadron
- Spin and 3D Structure
- Hadron form factors
- Future Experiments

Speakers

Vincent Andrieux	University of Illinois at Urbana-Champaign, USA
Daniele Binosi	ECT*, Italy
Stanley Brodsky	SLAC National Accelerator Laboratory, Stanford University, USA
Aurore Courtoy	Instituto de Física, UNAM, Mexico

Oleg Denisov	Istituto Nazionale di Fisica Nucleare, sezione di Torino, Italy
Minghui Ding	Helmholtz-Zentrum Dresden-Rossendorf, Germany
Mauricio Narciso Ferreira	University of Valencia and CSIC, Spain
Ralf Gothe	University of South Carolina, USA
Cédric Mezrag	Irfu, CEA, Université Paris-Saclay, France
Joannis Papavassiliou	University of Valencia, Spain
Stephane Platchkov	IRFU, CEA, University Paris-Saclay, France
Craig D. Roberts	Nanjing University, China
David Richards	Jefferson Lab, USA
José Rodríguez-Quintero	University of Huelva, Spain
Giovanni Salme’	INFN - Sezione di Roma, Italy
Rong Wang	Chinese Academy of Sciences, China
Hui-Yu Xing	Nanjing University, China
Yin-Zhen Xu	University of Huelva, Spain
Zhao-Qian Yao	ECT*, Italy
Jianhui Zhang	The Chinese University of Hong Kong, Shenzhen, China

Scientific report

The study of the internal structure of hadrons (e.g., proton, pion) is essential for understanding the strong interaction and the mechanism(s) behind the emergence of hadron mass. It is extremely difficult to study the structure of hadrons, and today, some 50 years after the introduction of quantum chromodynamics (QCD), the fundamental theory of the strong interaction, the QCD calculation of hadron parton distribution functions (DFs) is still a challenge.

The current understanding of DFs comes from three main sources: firstly, global fits to experimental data for processes such as deep inelastic scattering (DIS), the Drell-Yan process, and quarkonium production processes, the results of which depend in part on the parametric form of the DFs. The currently available experimental data are not sufficient to support a reliable global fit to the DFs, the x-dependence of the valence quark DFs obtained by the different methods varies, and the sea quark and gluon DFs are still subject to large uncertainties. The second is lattice QCD, with which DFs can be calculated from first principles. Usually, the determination of DFs with lattice QCD focuses on computing DF Mellin moments, but the computation of higher order moments is practically impossible. However, using large momentum effective theory (LaMET), which has been developed in recent years, it has become possible to obtain information on the pointwise behaviour of DFs using the lattice regularised theory. The third approach is provided by continuum Schwinger function methods. Following developments in the past five years, this approach has begun to deliver predictions for all proton and pion DFs, *viz*. valence, glue, and four-flavour-separated sea, and both unpolarised and polarised DFs.

The workshop involved presentations by, and discussions between, experts from all research areas mentioned above. The key issues addressed at the workshop can be summarised as follows:

- What is the difference between the DFs of pion and proton? Are the DFs of the pion the most dilated? If so, what is the relevance of this feature to the mechanism(s) behind the emergence of hadron mass?
- Is it necessary to consider the constraints of QCD on the large x behaviour of the DFs in making global fits? If it is necessary, do the results of the global fits change when these constrains are considered?
- Are there some processes that are particularly sensitive to gluon DFs and is it possible to advance the measurement of them experimentally, or to include contributions from these processes in the global fits to improve the reliability of the fitted gluon DFs?
- What is the achievable accuracy of future DF measurements at high-luminosity, high-energy accelerators (*e.g.*, CERN – AMBER, JLab, Electron-Ion Collider (EIC), Electron-Ion Collider in China (EicC))?
- Can hadron structure be further explored by studying the multidimensional structure functions of hadrons, such as transverse momentum dependent (TMD) parton distribution functions and generalized parton distributions (GPD)?

In addition to these themes, the workshop covered a number of other topics, each with one or more speakers, including the following:

Emergence of a gluon mass through the Schwinger mechanism; constraining the pion distribution amplitude using Drell-Yan reactions on a proton; light front wave functions of the nucleon; pion gravitational form factors; multi-parton distributions with Lattice QCD; weak and electromagnetic form factors of octet baryons; nucleon resonances at JLab22+; holographic light-front QCD; Evolution of DFs; and Boer-Mulders functions.

Results and Highlights

The workshop provided a valuable opportunity for participants from different research approaches to discuss how far we know the DFs of the proton and pion and how that knowledge can be improved in the future.

Regarding the key issues on which the workshop focused, firstly, participants agreed that pion DFs are fundamentally different from proton DFs. For a long time, attention has been focused only on proton DFs, however, the study of pion DFs is equally important, since the pion is Nature's most fundamental Nambu-Goldstone boson, the study of which contributes to understanding the character of the strong interactions as well as the mechanism(s) behind the emergence of hadron mass. Calculations using continuum Schwinger methods have shown that the pion DFs are the most dilated. This remains to be verified by other methods. There is growing awareness that it is crucial to focus on the structure of proton and pion in a unified way.

Some participants advocated that QCD constraints on the large x behaviour of DFs should be implemented in global fits. Indeed, the practitioner-dependence of global fits was much discussed.

The quarkonium production process is particularly sensitive to gluon DFs, and AMBER @ CERN has the potential to advance experimental measurements of this process. Some participants suggested that the contribution of the quarkonium production process be included in the global fits to improve the reliability of fit-inferred gluon DFs.

Regarding mesons, the currently available experimental data are very scarce and insufficient to support giving very accurate global fits to their DFs, all of which have large uncertainties. Experimental physicists argued, via simulation results, that the accuracy of DFs obtained from measurements at high-luminosity, high-energy accelerators will be substantially improved in the future.

The study of the multidimensional structure functions is potentially able to give a multidimensional picture of the hadron. In this connection, transverse momentum dependent parton distribution functions (TMDs) and generalised parton distributions (GPDs) have received focused experimental and theoretical attention. Notably, in calculations, a nontrivial “Wilson line” contribution is essential to obtaining a nonzero result for time-reversal odd TMDs (*e.g.*, the Boer-Mulders function). This contribution was much discussed. The GPD is related to the electromagnetic and gravitational form factors, and thus its study is also of great interest. Some participants suggested the study of multi-parton distribution functions.

2.3.22 *Strongly Interacting Matter in Extreme Magnetic Fields*

Date October 23-27, 2023

Organizers

Alejandro Ayala	UNAM, México
David Blaschke	U. Wroclaw, Poland
Gergely Endrodi	U. Bielefeld, Germany
Ricardo L. S. Farias	UFSM, Brasil
Varese S. Timóteo	UNICAMP, Brasil

Number of participants 39

Main topics

The main topics of the workshop were:

- Dense magnetized matter
- Phase diagram
- Chiral magnetic effect
- Lattice QCD
- Neutron stars
- Theory developments
- Effective models

Participants

Prabal Adhikari	Saint Olaf College
Jens Oluf Andersen	NTNU
Alejandro Ayala	Universidad Nacional Autónoma De Mexico, Mexico
Gunnar Bali	Universität Regensburg
Aritra Bandyopadhyay	Heidelberg University
David Blaschke	University of Wroclaw
Fabio Braghin	Federal University Of Goias
Pavel Buividovich	University of Liverpool
Jorge David Castaño Yepes	Instituto De Física, Pontificia Universidad Católica De Chile
Maxim Chernodub	Institut Denis Poisson, Tours, France
Aminul Islam Chowdhury	University of Chinese Academy Of Sciences
Sidney Dos Santos Avancini	UFSC -Federal University of Santa Catarina
Mariana Dutra	Institut de Physique des 2 Infinis - IP2I

Gergely Endrodi	University of Bielefeld, Germany
Eduardo Fraga	Instituto de Física, Universidade Federal Do Rio De Janeiro
Kenji Fukushima	The University of Tokyo
Andrey Kotov	Juelich Forschungszentrum
Tamas Kovacs	Eotvos Lorand University, Budapest
Gastao Inacio Krein	Instituto de Física Teórica, Universidade Estadual Paulista
Pok Man Lo	University of Wroclaw
Marcelo Loewe Lobo	Universidad San Sebastian, Santiago, Chile
Odilon Lourenço	Institut De Physique Des 2 Infinis - IP2I
Ricardo L. S. Farias	Federal University of Santa Maria
Gergely Marko	Bielefeld University
Kauan Marquez	Universidade de Coimbra
Ana Mizher	UNICID
Enrique Munoz	Pontificia Universidad Catolica De Chile
Manuel M Oliveira	Aeronautics Institute of Technology
Helena Pais	University of Salamanca
Debora Peres Menezes	UFSC
Alfredo Raya	IFM-UMSNH
Varese Salvador Timóteo	University of Campinas - UNICAMP, Brazil
Norberto Scoccola	Comision Nacional De Energia Atomica
William Rafael Tavares	UERJ
Maria Elena Tejeda-Yeomans	Universidad De Colima
Laura Tolos	ICE (CSIC, Barcelona)
Cristian Villavicencio	Universidad Del Bio-Bio
Fuqiang Wang	Purdue University
Shigehiro Yasui	WPI-SKCM2, Hiroshima University

Scientific report

The properties of strongly interacting systems under the influence of magnetic fields have become an intense field of study at the crossroads of nuclear, particle and astrophysical research. Some of the key questions that research in this field aims to address are related to the modifications experienced by static as well as dynamical properties of the particles that make up these systems. In the presence of these fields, these modifications can show up both in vacuum as well as at finite temperature and density. Effective model descriptions, helpful to get intuitive pictures of these properties, are constantly being put to the test by lattice QCD results. At the same time, experimental results from heavy-ion collisions and from the analysis of signals from astrophysical systems provide useful constraints for a clearer picture to emerge. The aim of the workshop was to gather specialists working on strongly interacting matter under extreme conditions. The program included seminars from all participants and daily discussions sessions where the main points raised during the seminars were discussed.

Results and Highlights

The main achievement of the workshop was the melting pot of ideas on strongly interacting systems under extreme magnetic fields brought by specialists in the field. There is a potential for many works to arise from the discussions and seminars presented during the workshop. Also, with the agreement from the Editor-in-Chief of Progress in Particle and Nuclear Physics, we decided to prepare a whitepaper with the current status and perspectives in strongly interacting matter under extreme magnetic fields.

2.3.23 *ROCKSTAR: Towards a ROadmap of the Crucial measurements of Key observables in Strangeness reactions for neutron sTARs equation of state*

Date	9-13 October, 2023

Organizers

Alessandro Scordo	INFN, Sezione di Pisa, Italy
Catalina Curceanu	Laboratori Nazionali di Frascati INFN, Italy
Angels Ramos	Institut de Ciències del Cosmo, Barcelona, Spain
Fuminori Sakuma	RIKEN, Advanced Science Institute (ASI), Japan
Damir Bosnar	University of Zagreb, Croatia
Oton Vazquez Doce	Laboratori Nazionali di Frascati INFN, Italy

Number of participants	41

Main topics

The main topics of the workshop were related to Low Energy Strangeness QCD (LESQCD), the theory that governs the interaction, near-threshold, between strange and standard nuclear matter with implications in fundamental physics and astrophysics. Given its non-perturbative nature, LESQCD is described by several theoretical models using different approaches. These models need experimental input parameters measurable with various complementary techniques, including kaonic atoms, kaon/hyperon interactions with one or more nucleons, and strangeness femtoscopy. Advancing the theoretical predictions demands improving the quality of the experimental observables; some of them still must be measured for the first time, and others need enhanced precision. During the workshop, we hoped that a stronger collaboration between the theoreticians and the experimentalists would help establishing the most relevant measurements to be performed in the future.

The main topics were:

- EOS of neutron stars
- Hyperon Puzzle
- Kaonic Atoms and Kaonic Nuclei
- KN interaction experiments
- KN interaction theoretical models
- Lattice QCD
- Hypernuclear physics
- Strangeness in stars

Speakers

Albino Perego	University of Trento, Italy

Ales Cieply	Nuclear Physics Institute of the Czech Academy of Sciences, Czech Rep.
Andreas Nogga	IAS-4, Forschungszentrum Juelich, Germany
Anthony Thomas	University of Adelaide, Australia
Bikram Keshari Pradhan	IUCAA, Pune, India
Catalina Curceanu	INFN-LNF, Italy
Debarati Chatterjee	Inter-University Centre for Astronomy and Astrophysics, Pune, India
Diana Sirghi	INFN-LNF, Italy
Eliahu Friedman	Racah Institute of Physics, Hebrew University, Jerusalem Israel
Florin Sirghi	INFN-LNF, Italy
Francesco Artibani	INFN-LNF, Italy
Francesco Clozza	INFN-LNF, Italy
Francesco Sgaramella	INFN-LNF, Italy
Fuminori Sakuma	RIKEN, Japan
Hans-Josef Schulze	INFN Catania, Italy
Hiroaki Ohnishi	ELPH, Tohoku University, Japan
Hoai Le	Forschungszentrum Juelich, Germany
Hristijan Kochankovski	Institut de Ciencies del Cosmos, Spain
Jaroslava Obertova	FNSPE CTU in Prague, CZech Republic
Jesper Leong	University of Adelaide, Australia
Jia-jun Wu	University of Chinese Academy of Sciences, China
Johann Zmeskal	Stefan Meyer Institute, Austria
Josef Pochodzalla	University Mainz, Germany
Luca De Paolis	LNF-INFN, Italy
Marc Illa, IQuS	UW, USA
Martin Schäfer	CAS, Czech Republic
Masahiko Iwasaki	RIKEN, Japan
Mihail Antoniu Iliescu	INFN-LNF, Italy
Nina Shevchenko	CAS, Czech Republic
Ryo Kobayakawa	Osaka University (RCNP), Japan
Tadashi Hashimoto	Japan Atomic Energy Agency, Japan
Takumi Yamaga	RIKEN, Japan
Takuya Nanamura	Japan Atomic Energy Agency, Japan
Thuin Malik	University of Coimbra, Portugal
Wolfram Weise	TU, University of Munich, Germany
Yuki Kamiya	HISKP, Bonn University, Germany

Scientific report

The workshop was devoted to discussing the recent progress and open problems in topics involving the interaction of strange particles with nucleons and nuclei. It started with a review by J. Pochodzalla on the achievements of the European Network Activity THEIA and aims for the remaining funding period of the European Network Activity THEIA. The still open problems in the field of strangeness nuclear physics were addressed, pointing out possible strategies for the future.

The rest of the workshop evolved through presentations on the most recent advances in the field, which stimulated lively debates. There were many interesting discussions about the comparison between the latest experimental and theoretical findings on the interaction between kaons and one or many nucleons, emphasizing the need for a better understanding of the kaon-nucleon interaction, to which the experiments on kaonic deuterium especially, and kaonic atoms in general, will provide crucial constraints. The connection of hypernuclear physics with astrophysical observables was also amply discussed, such as the impact of a three-body hyperonic force on the properties and composition of neutron stars, or the capability of gravitational waves emitted in a binary neutron star merger to signal the presence of hyperons in the hot and dense matter created.

All these aspects were further discussed in a very fruitful round table session. It started with an analysis of the situation of the well-known “hyperon puzzle”, i.e., the difficulty of reconciling the presence of hyperons in neutrons stars with the recent observation of highly massive neutron stars, and its possible solutions, particularly the role of hyperonic three body forces. Taking profit of the presence among the participants of people from the astrophysical community, it was discussed which astrophysical observables, besides mass and radius, could also tell us in an unambiguous way whether hyperons are or are not present in neutron stars. Multimessenger observations from binary neutron star mergers were pointed out as providing some answers. The discussion continued with some of the other topics of addressed during the week, with an emphasis in defining which would be the most relevant and realistic experiments to be carried at the present or future facilities (DAPHNE, JPARC, FAIR,…) to learn about the interaction of antikaons with nucleons and nuclei.

Overall, it was a fruitful meeting, which covered the progress and the still open problems in the strangeness nuclear physics field and pointed at the possible strategies to tackle them in the near future.

Results and Highlights

Following the introductory talk of J. Pochodzalla, who summarized the activities and future plans of the European Network Activity THEIA, the workshop evolved around several presentations showing the most recent theoretical advances and experimental results in the field of strangeness nuclear physics, the highlights of which can be divided in several broad topics:

Hyperon-nucleon forces (YN, YNN) and hypernuclear physics:

It is well known that the hyperon-nucleon interaction is subject to large uncertainties due to the scarce available data from scattering experiments. The situation is changing thanks to the recent new scattering data obtained at JPARC (at large momentum) and to the low-momentum interactions that can be inferred from femtoscopy studies at STAR and ALICE. In this workshop, we heard about how Lattice QCD can provide complementary valuable information on two-baryon interactions with strangeness and what the present status of the simulations is (M. Illa). We also heard about the state-of-the art chiral YN forces of the Jülich group at NNLO and how an appropriate description of light hypernuclei points towards the need of a YNN force (A. Nogga and H. Lee). Similar results are found with a pionless effective field theory applied to hypernuclei (M. Schafer). The requirement of a three-body force to describe hypernuclei is also obtained from phenomenological analysis of the systematics of their L-separation energies (A. Friedman). Finally, an interesting extension to the charm sector emphasized the similarities and differences between charmed Lc-hypernuclei and L-hypernuclei (H.J. Schulze), worth being explored experimentally in the future.

Equation of State of neutron star matter, “hyperon puzzle” and astrophysical observables:

The knowledge of the Equation of State of dense nuclear matter is of paramount importance as it determines the properties of neutron stars, affects the outcome of their mergers and drives the evolution of a proto-neutron star into a supernova. Modelling the EoS has been the subject of many studies, with a special emphasis on the “hyperon puzzle”. In this workshop, we heard about the properties of dense (hyper) nuclear matter, relevant for astrophysical scenarios like neutron stars or binary neutron star mergers, obtained from the quark-meson coupling (QMC) model supplemented with a phenomenological short distance repulsion (J. Leong). The details of the QMC model, how it was constructed to describe finite nuclei and hypernuclei, and how it is extended to dense matter, were also extensively discussed by A.W. Thomas. It was noted that the short distance repulsion emerging at higher densities can in fact be attributed to the YNN force needed to describe hypernuclei, when it is extended to a few times nuclear matter density. This force can even preclude the appearance of hyperons in neutron stars as noted by W. Weise, who also showed that a crucial signature for a possible phase transition, such as the quark matter transition discussed by B.K. Pradhan, or the appearance of exotic degrees of freedom in dense baryonic matter, is the speed of sound. D. Chatterjee showed that combining data from nuclear and hypernuclear physics, heavy-ion physics as well as multi-messenger astrophysical observations from neutron stars provide important insights into the behaviour of hyperons in dense matter. Based on recent simulations in numerical relativity, A. Perego illustrated how the presence of quarks or hyperons can impact binary neutron star merger observables, including gravitational wave emission, and showed that the determination of the prompt collapse threshold can provide information on the particle composition of neutron star interiors. The influence of hyperons in the merger observables is associated to their thermal behavior, which induces a significant drop of the thermal pressure, leading to an increase of the dominant post-merger gravitational wave frequency that could potentially be observed (K. Kochankowski). We also heard about the power of artificial intelligence and machine learning in the analysis and understanding of astrophysical observations (T. Malik).

Kaonic atoms, nuclear kaonic clusters and antikaon-nucleon interaction:

Establishing the properties of the antikaon-nucleon interaction is important for understanding fundamental questions, such as the flavor symmetry of the chiral dynamics of QCD at low energies, and for resolving the potential occurrence of astrophysical phenomena, such as kaon condensation in neutron stars. The experimental programmes with low momentum antikaons at DAPHNE and those with higher energy antikaons at J-PARC aim at providing newer constraints to the interaction of antikaons with nucleons and nuclei, the latter focused to pin down the subthreshold properties, which presents a too large model dependence. The presently ongoing measurement of the kaonic deuterium from the SIDDHARTA-2 collaboration at the INFN Laboratory of Frascati was reported by F. Sirghi, spokesperson of the collaboration, who also gave a nice overview of the experimental apparatus, while the new and most precise ever measurements on gaseous kaonic helium have been presented by D. Sirghi, who also reported on the very interesting analysis on the kaonic helium M-lines; the measurement of these transitions, beyond representing an interesting and important measurement by itself, opens also the door towards new possibility to improve the machine background rejection by means of L-M lines coincidences. F. Sgaramella reported on how future measurements with solid targets at DAFNE, in parallel with the SIDDHARTA-2 Kd experiment, could lead to an improved precision measurement of the charged kaon mass, still a very puzzling open problem in our field. The SIDDHARTA-2 collaboration has also proven to be very active in the preparation and proposal of future measurements to be performed on solid targets or improved detectors, such as the very promising and interesting measurements of the E2 nuclear resonance effect presented by L. De Paolis, or the possibility of measuring precise X-rays for a variety of kaonic atoms (F. Artibani, F. Clozza). The last contribution on kaonic atoms was given by J. Zmeskal, spokesperson of the E57 experiment at J-PARC, who reported the status and the ongoing activities of the collaboration towards a second measurement of the kaonic deuterium. A status report on the antikaonic-nuclear clusters was presented by M. Iwasaki, which made evident the important information that can be gathered from the experimental studies of KbarNN and KbarNNNN bound systems, presented by T. Yamaga, T. Hashimoto, respectively, and how they contrast with the expectations of the theoretical models which employ realistic KbarN interactions. While the theoretical calculations reproduce the experimental binding energy of the K-pp cluster, the mesonic absorption width appears to be largely underestimated (N. Shevchenko). The inclusion of many-body corrections in the KbarN amplitude may help in resolving this issue (J. Obertova). A new search of the KbarNN has been conducted using the gamma-induced reaction of gd à K0(K0*)Lp at the SPring-8/LEPS2 experiment, which is now under analysis (R. Kobayakawa). For the future, a series of experimental proposals for the systematic investigation of light kaonic nuclei, from KbarN (L(1405)) to KbarNNNN, have been prepared at J-PARC using a newly constructed large spectrometer, starting with the E80 experiment (T. Nanamura). C. Curceanu presented a review of the results of the AMADEUS collaboration, which, taking advantage of the interactions of low energy of antikaons with 4He and 12C present in the KLOE detector at DAPHNE, has provided multinucleon absorption rates, a very interesting measurement of the isospin I=1 K-n à p-L amplitude at subthreshold energies and a precise measurement of the K-p à S0p0, Lp0 cross-sections at the lowest K- momentum ever. The latest two measurements set important new constraints to the models of the KbarN interaction, hence contributing sensibly to the advance of its characterization. As shown in the presentation by A. Cieply, one may alternatively also aim at constraining this coupled channel-interaction, which is governed by the dynamics of the I=0 L(1405) resonance, from fits to Jlab pS photo-production data, which, in turn, may also contain information on the possible existence of an I=1 JP=1/2- state around 1400 MeV predicted by various interaction models, as discussed by J.J. Wu. Another avenue to learn about the hadron-hadron interactions at low energies is that provided by femtoscopic analysis of hadron pairs produced in relativistic pp or heavy-ion collisions, as discussed by Y. Kamiya, who showed that the KbarN interaction models present still some deficiencies in reproducing the K-p correlation function obtained by the ALICE collaboration. Lastly, we also heard about the efforts to extract the K+N and K+-nucleus interaction, for which there is a shortage of data, taking advantage of the low momentum K+'s produced at DAPHNE (H. Ohnishi).

Round Table:

On Thursday 12/10/2023, a very interesting and stimulating Round Table was organized, with the aim to discuss about the topics covered during the workshop and, most important, to share ideas for future experiments and collaborations. The discussion was very sparkling and one of the main outcomes, pointed out by J. Pochodzalla, was the need to start thinking and planning the future facilities for nuclear physics experiment while, in parallel, reinforce the collaborations among different groups to perform new experiments on the existing ones.

2.3.24 *Critical Stability of Few-Body Quantum Systems*

Date	October 23-27, 2023

Organizers

Alejandro Kievsky	INFN, Sezione di Pisa, Italy
Tobias Frederico	Instituto Tecnologico de Aeronautica, Brazil
Otto-Uldall Fynbo	Department of Physics and Astronomy Aarhus University, Denmark
Jean-Marc Richard	Institut de Physique des 2 Infinis de Lyon, France

Number of participants	38

Main topics

The main purpose of the workshop is to bring people together from different few-body communities, and focus on the interdisciplinary aspects of techniques, methods and concepts surpassing the specialization of the different subfields of physics. In particular, it is our intention to meet in person during the workshop to discuss the following items:

- Universality in Few-Body Physics
- Finite-range corrections to Universality
- From few to many degrees of freedom
- Dimensional crossover and constrained systems
- Effective Field Theory formulations
- Structure and Reactions in weakly bound systems

Speakers

Sonia Bacca	Johannes Gutenberg University, Mainz, Germany
Doerte Blume	University of Oklahoma, USA
Jaume Carbonell	Université de Paris-Saclay/IJCLab/Orsay, France
Lorenzo Contessi	IJCLab - CNRS - Université Paris Saclay, France
Arnas Deltuva	Vilnius University, Lithuania
Dérick dos Santos Rosa	Instituto Tecnológico de Aeronáutica, Brazil
Dmitri Fedorov	Aarhus University, Denmark
Francesca Ferlaino	Universität Innsbruck, Austria
Christian Forssen	Chalmers University, Sweden
Eduardo Garrido	Instituto de Estructura de la Materia – CSIC, Spain
Mario Gattobigio	Université Côte d’Azur - Institut de Physique de Nice, France

Alex Gnech	ECT*, Italy
Panagiotis Giannakeas	Max Planck Inst. for the Physics of Complex Systems, Germany
Matthias Goebel	INFN-Pisa, Italy
Lucas Happ	RIKEN, Nishina Center, Japan
Emiko Hiyama	Tohoku Univ./RIKEN, Japan
Aksel Stenholm Jensen	Aarhus University, Denmark
Garrett B. King	Washington University in St. Louis, USA
Servaas Kokkelmams	Eindhoven University of Technology, The Netherlands
Maksim Kunitski	Goethe-Universität Frankfurt am Main, Germany
Rimantas Lazauskas	IPHC, CNRS, Strasbourg, France
Eleonora Lippi	University of Heidelberg, Germany
Lucas Madeira	University of São Paulo, Brazil
Miguel Marques	LPC-Caen, France
Pascal Naidon	RIKEN, Japan
Petr Navratil	TRIUMF, Canada
Giuseppina Orlandini	University of Trento, Italy
Francesco Pederiva	University of Trento and INFN-TIFPA, Italy
Jesus Perez Rios	Stony Brook University, USA
Dmitry Petrov	CNRS, France
Jean-Marc Richard	Institut de Physique des 2 Infinis de Lyon, France
Alejandro Saenz	Humboldt-Universität zu Berlin, Germany
Aurora Tumino	Università degli Studi di Enna “Kore” & INFN-LNS, Italy

Scientific report

The goals of the meeting was to discuss in a common language aspects of very different systems when they live close to edge of stability. Main topics discussed between experimentalists and theoreticians were the following:

The halo concept and the Efimov effect have spread from nuclear physics to atomic and molecular physics. They are the background for systematic investigations of scaling properties and universal features of different systems. In nuclei the finite-range character of the interaction is almost always important. This concept was taken into account in the discussions regarding universal features, continuum properties, resonances, decay or capture processes, and transitions between continuum states. Specific topics discussed were correlations in few-neutron systems and the effects of Coulomb free pp scattering. Rich-neutron nuclei forming a neutron halo constitute a nice example of critically stable system, their structure has been discussed as well as different techniques to determine the spectrum. When the description is based on an effective field theory (EFT), the importance of few-nucleon forces has been discussed as well as the implementation of different leading order terms. Moreover the discussion of how to estimate the theoretical error in a description based on the EFT formalism was faced. Ab initio descriptions play an important role in the description of critical stable systems, different examples have been shown in few-body reactions, in the description of near-threshold resonances and the response function. Moreover a connection between EFT and the density functional theory has been shown. Essential elements of the nuclear binding have been discussed using neural networks and the pion cloud. In atoms, Efimov physics is now understood as physics of universality, that is describable by universal properties with no need for interaction details, or in other words essentially model independent. A number of different new experiments have recently established many properties of Efimov physics. In particular the very recent investigations on the structure and field-induced dynamics of small helium clusters have been illustrated. Due to the extremely low binding energy of the helium dimer, clusters of helium represent a good example in which critical stability can be studied arriving to the description of the helium equation of state. For this reason helium systems were discussed many time along the workshop. However at present other molecular systems,critically bound, are intensively studied as rare-gas molecules. Trap atoms remain one of the main techniques to study different phenomena in few-atom systems through the formation of Feshbach molecules using Feshbach resonances to from resonance two-body states. Recombination processes allow to go beyond two-body physics allowing to study different aspects of the dynamic as its multichannel character. The interference of different Efimov states using magnetic fields is another opportunity to study different trimer states. The study of impurities in trap atoms is now one of the frontiers Fermi-Bose mixtures as well as the study of vortices in dipolar quantum gases. The latter provides a nice connection with neutron stars in which the super solid character of the system allows the formation of a vortice dynamics with a pronounced effect in the angular velocity of the solid. Low-dimensional physics is a rapidly developing field, in particular due to dipolar atoms and molecules in different controlled topologies. Different questions can be faced as for example how a light particle could bound heavy fermion particles. Detailed studies in terms of the mass ration m/M, light-heavy, have been done. From a more general perspective low-dimensional systems can be studied to analyse the life-time of resonances as well as bound-state problems with contact interactions. Questions about how the change of the dimension modifies different phenomena have been discussed. Hadron physics and hypernuclei represents another sector of physics in which critical stable systems can be observed and studied. The former refers to different configurations of heavy and light quarks for antiquarks. The light-pentaquark problem is resolved but an issue has emerged recently for tetraquarks and very recently for heavy pentaquarks. Hypernuclei are at present intensively studied due to appearance of new data allowing for a better understanding of the hyperon-nucleon interaction. To this respect the hyperon-nucleon-nucleon three-body interaction could have a prominent role in the determination of the equation of state of dense matter.

Results and Highlights

The presence of participants from different communities allowed for many discussions in which the different particularities that charaterize the different sectors of physics were put on similar grounds.

This was one of the main objectives of the workshop since critical systems appear in many different sectors of physics. To enhance this aspect, discussion sessions were prepared every day, after lunch, regarding the arguments of the preceding presentations. These discussion sessions were very fruitful helping to clarify aspects beyond the discussions that took place at the end of each talk. To be specific, one of the subjects discussed regarded effective descriptions. At present effective field theories (EFTs) are intensively pursued in nuclear physics, however the concept can be extended to other sectors. Many discussions were made regarding effective descriptions of bosonic systems, in particular the helium system. Moreover there was a presentation regarding how to construct an improved action paving a new way to construct the leading order term of an effective description, making a bridge between phenomenological models and EFT approaches. To this respect, the implementation of the theoretical error is another example of an argument that spread from nuclear physics to other sectors and it was discussed many times. Another argument extensively discussed during the workshop, appearing in different sectors, was the description of resonances. This topic was discussed in the context of neutron-rich nuclei, in weakly bound nuclear systems and in the continuum spectrum of hypernuclei. However it has been discussed in the context of low-dimensional systems studying the effects of dimensionality in the resonance life time. Dimensionality was another argument intensively discussed. The Efimov disappears moving from 3D to 2D, however other phenomena could appear. In particular the binding of heavy fermion particles by a light particle was discussed in different dimensionalities. Though many talks regarded theoretical approaches, the connection with experimental results were always taken into account. This was the case with the Coulomb explosion, a very sophisticated technique used to measure helium dimer and trimer binding energies and, through the application of magnetic fields, their dynamics. At the same time the helium systems were many time discussed from a theoretical point of view with a strict connection between theoretical approaches and experiments. Along the same line were the discussion of vortices in dipolar quantum gases and its connection with glitches in the rotation frequency of pulsars and, regarding nuclear physics, the discussion of pp free Coulomb scattering using the Trojan horse method and its connection with universality. The workshop was useful to highlight some controversial topics that need further discussions between experimentalist and theoreticians. Neutron correlations is one of this as well as the first excited state, 0+ state, of the alpha particle. The corresponding presentations triggered many discussions showing the particular interest they have due to the close connection with aspects of the nuclear interaction. Following the previous editions of the workshop, many of the results presented will be collected in a special issue of the journal Few-Body Systems. It is the intention of the organizers to organize a new edition of the workshop in two or three years.

2.3.25 *ALPACA: modern ALgorithms in machine learning and data analysis: from medical Physics to research with ACcelerAtors and in underground laboratories*

Date	October 23-27, 2023

Organizers

Fabrizio Napolitano	INFN, Sezione di Pisa, Italy
Fabrizio Grosa	CERN, Switzerland
Raffaele del Grande	TUM, Germania
Magdalena Skurzok	Jagiellonian University, Poland

Number of participants	37

Main topics

The general them of the workshop concerned the use of state-of-the-art techniques of modern algorithms in machine learning and data analysis, in particle, nuclear and medical physics, above and below ground. In a field where progresses are being driven at an increasingly fast pace, it is important to bring together researchers to various filed, stimulating cross fertilization of ideas. The ALPACA workshop addresses the central question in experimental and computational physics: maximizing information extraction from data. In the past two decades, the remarkable advancements in artificial intelligence and machine learning algorithms have revolutionized experimental physics, providing unprecedented opportunities for smaller groups and individuals to engage in complex experiments. ALPACA, aims to foster cross-disciplinary collaboration by bringing together researchers from various fields of fundamental and medical physics.

The main topics were:

- Challenges and Opportunities in Modern Preclinical and Clinical Imaging
- Machine Learning Applications in Particle Physics Experiments
- AI-Assisted Design of Experiments and Computational Methods
- Generative Models for Particle Physics Data
- ML in biophysical data
- Bayesian Statistics in Julia and High Performance Scientific Computing
- Neural Networks using Silicon Microring Resonators
- Reservoir Computing Model for Multi-Electrode Electrophysiological Data Analysis
- ML in Nuclear Astrophysics
- ML and differentiable programming in nuclear spectroscopy experiment
- ML in industry

Speakers

Lucio Anderlini	INFN Firenze, Italy
Ilya Auslender	University of Trento, Italy
Andrea Barontini	University of Milan, Italy
Fabio Catalano	CERN, Switzerland
Marco Cristoforetti	FBK, Italy
Andrea Di Luca	FBK, Italy
Tommaso Dorigo	INFN Sezione di Padova, Italy
Kamil Dulski	LNF, Italy
William Korcari	University of Hamburg, Germany
Wojciech Krzemien	National Centre for Nuclear Research, Poland
Daniel Lang	TUM, Germany
Bartosz Leszczynski	Jagiellonian University, Poland
Alessio Lugnan	University of Trento, Italy
Laura Manduchi	University of California, Santa Cruz, USA
Simone Manti	INFN-LNF, Italy
Margherita Mele	University of Trento, Italy
Roberto Menichetti	University of Trento, Italy
Fabrizio Napolitano	INFN - Laboratori Nazionali di Frascati, Italy
Andrea Palladino	GSK, IT
Takehiko Saito	RIKEN and GSI, Japan
Guido Sanguinetti	University of Edinburgh, UK
Andre Scaffidi	SISSA, Italy
Oliver Schulz	MPI for Physics, Munich, Germany
Florin Sirghi	INFN-LNF, Italy
Jakub Skowronski	Universita degli Studi di Padova, Italy
Thomas Spieker	Robert Bosch GmbH, Germany
Sofia Vallecorsa	CERN, Switzerland
Kavya Valsan Eliyan	National Centre for Nuclear Research, Poland
Pietro Vischia	Universidad de Oviedo and ICTEA, Spain

Scientific report

The ALPACA workshop featured diverse discussions that underscored the interdisciplinary nature of this field. One key theme explored the application of machine learning methodologies for biology. Notably, the splicing signal in single cells was identified as inherently noisy, prompting a novel approach involving the coupling of components in a physics-informed machine learning framework. The proposal suggested the existence of an underlying low-dimensional nonlinear dynamical system governing long-term transcriptome evolution.

Quantum computing's potential revolutionary impact on machine learning was another focal point. The challenges posed by high-dimensional experimental data in high-energy physics (HEP) were addressed, emphasizing the need to define performance metrics and validate results in realistic use cases. The intersection of quantum technologies and machine learning in HEP raised intriguing questions about effective algorithm training, data reduction techniques, and leveraging physics laws to enhance algorithmic performance.

The MODE collaboration highlighted the fusion of physics and computer science in optimizing the design of experiments, particularly in particle physics applications. The initiative aimed to develop fully differentiable pipelines for end-to-end optimization, ensuring optimal detector performance, analysis potential, and cost-effectiveness.

Several talks delved into the critical role of data preparation in different contexts. One presentation emphasized its prominence in geomagnetic storm prediction using deep learning. Another explored the thermodynamic characterization of the system at various energy levels, providing insights into the learning process and the impact of input-output correlation structure on learning problem density.

The workshop also featured discussions on simplifying complex systems for better understanding. Information-theoretic approaches, including CG filters and deep graph networks, were proposed to gain insight into high-dimensional simulation datasets of biological systems. The application of mapping entropy protocols to neural systems revealed maximally informative neurons in a Hopfield model and phase separation based on observational detail.

Generative models emerged as a viable strategy at the LHC, demonstrating their potential to significantly reduce computing time for simulated samples in experiments. The challenges of training and deploying these models in the high-energy physics software environment were acknowledged and highlighted as areas requiring dedicated effort.

The intersection of computational imaging and AI in medicine, as well as the exploration of photonic spiking neural networks using silicon microring resonators, showcased the broad applications of machine learning in medical and photonics domains.

The workshop included two hands-on sessions that enriched the scientific discourse. The first session delved into scientific high-performance programming in Julia language, focusing on Bayesian analysis and machine learning. Participants engaged in practical exercises, gaining proficiency in leveraging Julia for computational tasks related to Bayesian analysis and implementing machine learning algorithms. This hands-on experience provided a practical dimension to the more abstract discussions, emphasizing the importance of efficient programming in advancing machine learning methodologies.

The second hands-on session, conducted in collaboration with the MODE initiative, centered on differentiable optimization of detector geometries. Participants actively participated in optimizing the South Wide-Field Gamma-ray Observatory (SWGO) telescope array. This immersive experience allowed attendees to contribute to the optimization process, gaining insights into the challenges and intricacies of experimental design in particle physics. The collaboration between detector designers and ML in the MODE initiative provided a unique opportunity for interdisciplinary learning.

An integral part of the conference was the industry session, where key challenges in machine learning validation were addressed. The session emphasized the critical importance of rigorous validation processes, including considerations such as verifying the appropriateness of data distribution, ensuring dataset size adequacy relative to the input space, and maintaining reasonable train-test splits to avoid self-deception. A key takeaway was the central role of performance metrics in measuring system-relevant properties, ensuring the reliability of machine learning applications. Topics ranged from utilizing natural language processing (NLP) for extracting information from DNA sequences to image recognition in medical contexts, predictive analytics for vaccine responses using biomarkers, and employing dimensionality reduction and clustering for biomarker grouping.

Results and Highlights

The workshop was a very useful opportunity to share challenges and solutions among divers fields in particle nuclear and medical physics. Since the advent of machine learning and artificial intelligence technologies, pioneered in various contexts decades ago in physics, their use has showcased incredible gains in the scientific reach. Still, the consensus among the participants was that even greater gains are yet to be uncovered, as new techniques and paradigms emerge from research in hard sciences and industry.

In particular, the workshop yielded insights in various fields. As an example, advancements in quantitative biology were presented, emphasizing the coupling of components in a physics-informed machine learning framework for more accurate measurements.

In the field of quantum computing, the potential in high-energy physics was explored, raising questions about effective algorithm training and leveraging physics laws.

The MODE collaboration's innovative approach to optimizing experimental design showcased the high gains achievable in terms of physics reach and project's costs. Talks on data preparation highlighted its critical role in various contexts, from geomagnetic storm prediction to exploring the thermodynamic characterization of learning problems.

Simplifying complex systems for better understanding was a recurring theme, with information-theoretic approaches providing insights into high-dimensional simulation datasets of biological systems. Generative models at the LHC were identified as a promising strategy to reduce computing time, though challenges in deployment were acknowledged.

The intersection of computational imaging and AI in medicine demonstrated the broad impact of machine learning in medical applications. Additionally, the potential of silicon microring resonators in photonic spiking neural networks underscored the versatility of integrated photonics in neural network development.

Overall, the workshop showcased the diverse and impactful applications of machine learning across various domains, emphasizing collaboration between disciplines and the need for innovative approaches to address challenges in experimental design, data preparation, and model deployment.

The hands-on sessions at the workshop offered tangible experiences and practical applications of machine learning concepts. The scientific high-performance programming session in Julia equipped participants with valuable skills in implementing Bayesian analysis and machine learning algorithms. This not only enhanced their technical capabilities but also underscored the practical relevance of efficient programming in the context of scientific research.

The second hands-on session, in collaboration with the MODE initiative, demonstrated the power of differentiable optimization in the context of detector geometries. Participants actively contributed to the optimization of the SWGO telescope array, gaining firsthand experience in addressing real-world challenges in particle physics experiments. The collaborative nature of the MODE initiative highlighted the importance of interdisciplinary collaboration in achieving optimal experimental designs.

Overall, the hands-on sessions complemented the theoretical discussions, providing participants with a holistic learning experience. The practical application of scientific high-performance programming and differentiable optimization showcased the real-world impact of machine learning methodologies in advancing research in particle nuclear and medical physics. The workshop, enriched by these interactive sessions, emphasized the importance of both theoretical understanding and practical implementation offering the opportunity of a working setup, useful especially to students.

2.4 ECT* Doctoral Training Program

Ab Initio Methods and Emerging Technologies for Nuclear Structure

Date	July 10-28, 2023

Organizers

Carlo Barbieri	University of Milan, Italy
Alessandro Roggero	University of Trento and INFN-TIFPA, Italy

Lecturers

Andreas Ekström	Chalmers University of Technology, Sweden
Alexander Tichai	Technische Universität Darmstadt, Germany
Vittorio Somà	Université Paris-Saclay and CEA, France
Alessandro Lovato	Argonne National Laboratory, USA
Filippo Vicentini	Ecole Polytechnique and EPFL, France
Kyle Wendt	Lawrence Livermore National Laboratory, USA
Joanna Sobczyk	Johannes Gutenberg-Universität Mainz, Germany

Number of participants	33

Aim of the DTP

The aim of the doctoral training program was to provide the participants with a pedagogical introduction to the state-of-the-art ab initio approaches for nuclear structure theory. We distinguished two classes of scientific frontiers: the first one is related to *existing methods* that have become very mature and sophisticated and require a profound knowhow that is not always available to young researchers who wish to enter the field. The second class relates to the *novel technologies* based on Machine Learning and Quantum Computing algorithms that are already transforming other fields of Physics. These topics not only hold a promise to impact nuclear theory but will likely attract promising researchers to our field.

By the end of the program, the participants were expected to have a thorough understanding of the current status quo in solving the nuclear many-body problem from first principles, and they should be equipped with the numerical tools to make their own contributions in tackling open problems.

Main topics

The DTP covered various topics ranging from basics of modeling nuclear forces with Chiral EFT to many-body approaches and quantum computing. The program consisted of several modules:

- Introductory lectures on realistic nuclear interactions based on (chiral) Effective

Field Theory, including techniques used to estimate uncertainties and fit the LECs.

- Lectures on many-body perturbation theory (MBPT) that provide the simplest and less computationally intensive example of polynomiallly scaling method.
- Lectures on self-consistent Green's functions (SCGF) and their applications to study medium-heavy masses and to single particle spectroscopy.
- Lecture on Quantum Monte Carlo (QMC) methods for nuclear theory.
- Lecture on Neural Network Quantum States (NQS). This is a new machine learning approach that represents a major step forward beyond the traditional QMC.
- Introductory lectures on Quantum Computing (QC).
- Three stand alone seminars covered specific topics: (1) optical potentials for nuclear physics, (2) interaction of nuclei with electroweak probes, and (3) application of QC to nuclear physics problems.

2.4.1 *List of students*

Antoine Belley	TRIUMF, Canada
Stefano Brolli	Università degli Studi di Milano, Italy
Jason Bub	Washington University in St. Louis, USA
Nicholas Cariello	Michigan State University, USA
Margarida Companys Franzke	Technische Universität Darmstadt, Germany
Patrick Cook	Michigan State University, USA
Alireza Dehghani	University of Paris-Saclay, IJCLab/CNRS, France
Pepijn Demol	KU Leuven, Belgium
Michael Gennari	University of Victoria, Canada
Rongzhe Hu	Peking University, China
Danny Jammooa	Michigan State University, USA
Chongji JIang	Peking University, China
ShaoLiang Jin	Peking University, China
Marco Knöll	Technische Universität Darmstadt, Germany
Lorenzo Lazzarino	Università degli Studi di Milano, Italy
Junzhe Liu	Tongji University, China
Abdullah Modabbir	Aligarh Muslim University, Aligarh, India
Viswanathan Palaniappan	IJCLab, France
Federico Rocco	University of Bielefeld, Germany
Javier Rozalén	Universitat de Barcelona, Spain
Edgar Andrés Ruiz Guzman	CNRS/IN2P3, IJCLab, Paris-Saclay University, France
Subhrajit Sahoo	Indian Institute of Technology (IIT), Roorkee, India
Alberto Scalesi	CEA, France
Alexandra Semposki	Ohio University, USA
Haoyu Shang	Peking University, China
Shweta Sharma	Indian Institute of Technology Roorkee, India
Betània Camille Tumelero Backes	University of York, UK
Xinyu Xu	Peking University, China
Osama Yaghi	IJCLAB-the University of Paris-Saclay, France
Lars Zurek	Technische Universität Darmstadt, Germany
Luca Vespucci	Università degli studi di Trento, Italy
Ilyad Chacker	Università degli studi di Trento, Italy
Tomoya Naito	RIKEN, Japan

Scheduling of the lessons

The program consisted of 30 theory lectures, 12 hands-on computing sessions in total and two student talks sessions (for a total of 87 contact hours). The theory lectures included 3 seminars given by the organizers and an invited speaker (J. Sobczyk) that covered applications of the techniques being taught to current problems in nuclear physics. The two student talks sessions were held in week 2 and 3, all participants gave 10-minute presentations on their research projects. The computing sessions were held in the afternoons and were scheduled to match the arguments in the same morning. Each lecturer prepared computing exercises of increasing difficulty where students were asked to implement the ab initio techniques for simple test cases. Weeks 1 and 2 focused on well-established ab initio approaches and were coordinated in such a way that each practical session would build on the work done in previous days: students learned (1) about building models of the nuclear interaction and estimating uncertainties, (2) they were given matrix element of the nuclear force with which they build mean-field and then perturbation theory applications, and (3) they exploited the same infrastructure codes (from perturbation theory) to gradually implement self-consistent Green's function computations. At the end of each day, solutions of the computing exercises were handed out so that students working at different speeds could catch up for the next session. The final week was dedicated to emerging approaches for solving the many body-problem and covered (4) Monte Carlo and neural network quantum states and (5) quantum computing. The computational sessions for the latter were still coordinated with the morning lectures but independent from those of the initial weeks.

Results and Highlights

The school was characterized by a cohort of very strong and active students. All participants engaged fully with the activities, from the first to the last day, which allowed the lecturers to maintain a high intellectual level throughout. Lectures were organized sequentially in a bottom up fashion, starting with aspects of the nuclear force and gradually going to more and more complex methods, ending with the most novel developments. It is a pleasure to remark that the students formed a very united and inclusive multicultural group since the very beginning of the school. The strong collegiality and friendly discussions, especially during the afternoon computing session, had a positive impact and contributed to ensuring that all participants kept up with the lectures. The quality of all lectures was high and we received positive feedback on all lectures. Several students particularly appreciated the theoretical lecture on NQS done at the blackboard.

Research at ECT*

3. Research at ECT*

3.1 Projects of ECT* Researchers

Nuclear Physics

Gert Aarts

QCD under extreme conditions

In collaboration with C. Allton, N.M. Anwar, R. Bignell, T. Burns (Swansea University), B. Jaeger (Odense), J.-I. Skullerud (Maynooth University) and others

Project abstract: QCD at nonzero temperature and density is a rich field, with applications to heavy-ion collisions and neutron stars. In this project we use large- scale simulations of QCD discretised on a spacetime lattice using national and international high-performance computing facilities to study a variety of questions non-perturbatively, including the behaviour of hadrons containing charm quarks as the temperature increases.

Related publications: [GA1], [GA2], [GA6]

Machine learning for quantum field theories

In collaboration with B. Lucini, C. Park (Swansea University), L. Wang and K. Zhou (FIAS, Frankfurt)

Project abstract: We have continued our investigation in establishing links between lattice quantum field theory and machine learning. In particular, we analysed the Restricted Boltzmann Machine from the perspective of scalar fields on the lattice, and established the relation between Diffusion Models, a popular method in Generative AI, and Stochastic Quantisation.

Related publications: [GA3], [GA4], [GA5]

Daniele Binosi

Developing predictions for pion fragmentation functions

In collaboration with H.-Y. Xing (Nanjing U.), Z.-Q. Yao (ECT), B.-L. Li (Shanghai U. Sci. Tech.), Z.-F. Cui (Nanjing U.), C.D. Roberts (Nanjing U.)

Project abstract: Exploiting crossing symmetry, the hadron scale pion valence quark distribution function is used to predict the kindred elementary valence quark fragmentation function (FF). This function defines the kernel of a quark jet fragmentation equation, which is solved to obtain the full pion FFs. After evolution to a scale typical of FF fits to data, the results for quark FFs are seen to compare favourably with such fits. However, the gluon FF is markedly different. Notably, although FF evolution equations do not themselves guarantee momentum conservation, inclusion of a gluon FF which, for four quark flavours, distributes roughly 11% of the total light-front momentum fraction, is sufficient to restore momentum conservation under evolution. Overall, significant uncertainty is attached to FFs determined via fits to data; hence, the features of the predictions described herein could potentially provide useful guidance for future such studies.

Related publication: [DB1]

Data-Driven Extraction of Hadron Radii

Project abstract: We describe the statistical Schlessinger Point Method. Grounded in analytic function theory, this method returns an objective assessment of the information contained in any data under consideration, which is independent of assumptions about underlying dynamics, and thus free from practitioner-induced bias. As a test to its robust nature and versatility, we apply it to a fully data-driven extraction of the proton, pion, and deuteron radii.

Related publication: [DB2]

Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at Jefferson Lab

In collaboration with A. Accardi (Hampton U.), P. Achenbach (Jefferson Lab), D. Adhikari (Virginia Tech.), A. Afanasev (George Washington U.), C.S. Akondi (Florida State U.) *et al.*

Project abstract: This document presents the initial scientific case for upgrading the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (JLab) to 22 GeV. It is the result of a community effort, incorporating insights from a series of workshops conducted between March 2022 and April 2023. With a track record of over 25 years in delivering the world‘s most intense and precise multi-GeV electron beams, CEBAF‘s potential for a higher energy upgrade presents a unique opportunity for an innovative nuclear physics program, which seamlessly integrates a rich historical background with a promising future. The proposed physics program encompass a diverse range of investigations centered around the nonperturbative dynamics inherent in hadron structure and the exploration of strongly interacting systems. It builds upon the exceptional capabilities of CEBAF in high-luminosity operations, the availability of existing or planned Hall equipment, and recent advancements in accelerator technology. The proposed program cover various scientific topics, including Hadron Spectroscopy, Partonic Structure and Spin, Hadronization and Transverse Momentum, Spatial Structure, Mechanical Properties, Form Factors and Emergent Hadron Mass, Hadron-Quark Transition, and Nuclear Dynamics at Extreme Conditions, as well as QCD Confinement and Fundamental Symmetries. Each topic highlights the key measurements achievable at a 22 GeV CEBAF accelerator. Furthermore, this document outlines the significant physics outcomes and unique aspects of these programs that distinguish them from other existing or planned facilities. In summary, this document provides an exciting rationale for the energy upgrade of CEBAF to 22 GeV, outlining the transformative scientific potential that lies within reach, and the remarkable opportunities it offers for advancing our understanding of hadron physics and related fundamental phenomena.

Related publication: [DB3]

Study for a model-independent pole determination of overlapping resonances

In collaboration with C. Cusano (Pavia U.), M. Dapor (ECT), G. Garberoglio (ECT), M. Liscidini (Pavia U.), and D Maragnano (Pavia U.)

Project abstract: We developed a novel method, named threshold Quantum State Tomography, aimed at optimizing the number of measurements for the quantum-state characterization of medium-scale noisy systems of N qubits, where the number of measurements for a full tomographic reconstruction scales at least as 4^N. Our approach is particularly suited for those states where the density matrix is sparse and has a much more favorable scaling, $O(2^N)$ without appreciable loss in the fidelity of the reconstructed state.

Related publication: [DB4]

Francesco Carnovale

During this first year (and few months) of PhD my task was to support the results from the experimental laboratories of the European project ‚MIMOSA' with theoretical models. In the first few months, I collaborated with my colleague Giovanni Novi Inverardi in the final analyses and drafting of the article ‚Silica In Silico: A Molecular Dynamics Characterization of the Early Stages of Protein Embedding for Atom Probe Tomography - G.N. Inverardi, F. Carnovale, L. Petrolli, S. Taioli, G. Lattanzi'.

At the same time, I studied the basics of ‚Density Functional Theory' (DFT) and ‚Time Dependent - Density Functional Theory' (TD-DFT). I then proceeded to install, both locally and on the university cluster, the various software needed to carry out DFT and TD-DFT simulations. Once I was familiar with the software, I worked on modelling the laser-protein interaction. The first studies were conducted on small molecules such as H2 and Si. Having developed the simulation protocol, I then focused on simulating molecules used by experimental collaborators, namely monomers and dimers of orthosilicic acid: Si(OH)4 and Si2H607. These simulations allowed to study the dynamics of Si-OH bond breaking and the evaporation process, a critical step in Atom Probe Tomography. In addition to the time evolution of the electronic states of the various systems, I focused also on the study of absorption spectra, as requested by the experimental collaborators. In parallel to this, I carried out a collaboration with researcher R. Covino (research group leader at FIAS - Frankfurt Institute for Advanced Studies). The project consists of studying the Interleukin 22 receptor-protein complex by means of molecular dynamics simulations, both with atomistic and coarse grained models. The ultimate aim of the collaboration is an in-depth study of coarse grained models and machine learning techniques, thanks to the expertise of the research group led by R. Covino. This expertise will be useful for near future developments of my PhD project within ‚Mimosa'. During this second year of PhD I will still be studying protein systems in aqueous solution containing silicon-based compounds. However, I will focus more on the study, by means of TD-DFT simulations, of laser-protein and laser-silicon interaction. More specifically, I'm currently setting-up simulations of SiO2 bulks in order to study if and how the defects present in the silica entrapping matrix can affect the evaporation mechanism and the absorption properties of the material. On the other hand, I will continue with simulations of small systems composed of a few Si molecules, with the intention of extending to models containing a larger number of molecules (and possibly aminoacids). The ultimate aim will be to be able to reproduce and study the properties of the silicon matrix used in the laboratory to trap the proteins of interest and on which APT is then carried out.

Related publication: [FC1]

Constantinos Constantinou

Identifying nuclear physics parameters to fold in to EOS determinations from astrophysics

In collaboration with T. Zhao (Ohio U.) and M. Prakash (Ohio U.)

Project abstract: The analyses of data from X-ray pulsations in NSs with the NICER observatory as well as gravitational waves from mergers of binary NSs with the LIGO/Virgo collaboration involves modeling with the dense matter EOS as an essential input. Often, such analyses have been performed with parametrized EOSs that are agnostic to the many constraints from laboratory data near the nuclear equilibrium density as well as those up to 4 times that value from flow measurements in heavy-ion collisions. It is the objective of this work to develop procedures to fold nuclear physics constraints from data as well as from first-principle calculations of the EOS up to twice the nuclear equilibrium density. When extrapolations beyond a certain density is required as in the case of NSs with masses close to 2M, physics-based models that are consistent with causality will be developed so that finite temperature extensions can be carried out. The latter will be pertinent to simulations of core-collapse supernovae and of post-merger evolution of NS mergers. Our aim is to reach and inform the astrophysical community of how nuclear physics inputs can a play a crucial role in the analyses of current and future astrophysical data.

Quarkyonic matter with a crossover transition

In collaboration with T. Zhao (Ohio U.), P. Jaikumar (CSU Long Beach), M. Prakash (Ohio U.)

Project abstract: In its current stage of development, the quarkyonic model of McLerran et al. when generalized to beta-equilibrated matter as in Zhao and Lattimer has the limitation that at the onset of quarks, the adiabatic sound speed becomes infinite whereas the equilibrium sound speed remains finite. This deficiency precludes its use in calculating g-mode oscillations as the latter depend on both sound speeds. We are developing a model in which such a limitation can be overcome. In such a model, the transition to quarks needs to be of a crossover nature without any discontinuities. Once developed, the model will be used to calculate g−mode frequencies and compared with our earlier results from transitions treated using the Gibbs construction and the crossover model of Kapusta and Welle so that features specific to quarkyonic matter can be isolated.

The influence of superfluidity on the oscillation modes of neutron stars with quarks

In collaboration with T. Zhao (Ohio U.), P. Jaikumar (CSU Long Beach), M. Prakash (Ohio U.)

Project abstract: The spectrum of thermal g-modes in superfluid NSs is significantly different than non-SF NSs owing to new sources of stratification and buoyancy in the former. To date, such investigations have been limited to nucleon and hyperon SF components. It is the purpose of this project to explore g-modes in SF NSs containing quarks employing the Gibbs construction or a crossover approach. A comparison of the ensuing results with those in our earlier work on hybrid stars in which quark SF was not considered will reveal the extent to which the g-mode is affected by quark SF.

Exploration of various realizations of) Hybrid matter at finite temperature in astrophysical systems

In collaboration with M. Guerrini (U. Ferrara), T. Zhao (Ohio U.), and M. Prakash (Ohio U.)

Project abstract: Previously, we presented a thermodynamically-consistent method by which constructions for first-order phase transitions intermediate to Maxwell and Gibbs can be realized at T=0. We argued that, in such cases, the phase boundary is semi-transparent allowing for mixing in its vicinity while maintaining phase separation further away. For the specific example of the hadron-to-quark transition in compact stars, this means that charge neutrality is partially local and partially global. The equilibrium state of matter is obtained via the minimization of the system's energy density with respect to its internal variables under the constraints of baryon and lepton conservation, and charge neutrality. Currently, we are dealing with the extension of this method to finite temperature. The task requires minimization of the free energy of the system which, now, must also include antiparticle components, while the aforementioned constraints are expressed in terms of the net particle fractions. The phase equilibrium relations derived thus, are to be solved numerically in order to generate EOS tables for use in simulations of core-collapse supernovae and binary mergers of compact objects. We will employ different families of phenomenological nucleonic (Skyrme, Relativistic Mean-Field, Zhao-Lattimer) and quark (MIT, Bag, NJL) EOSs in stages to implement this framework as well as a crossover transition (KW); both being the first such applications at finite temperature. Subsequently, hyperons and meson condensates will be introduced.

Related publication: [Co1]

Outreach

January 2023 – May 2023: Coorganizer (with Alex Gnech and Tommaso Morresi) of the ECT* PhD Seminars. This is an initiative to increase the involvement of the Physics students of Trento University in the scientific activities of ECT* by having them present their own research. The first series consisted of six invited talks delivered by students from the Department of Physics hosted at ECT*. A proposal to integrate these seminars in the scientific program of ECT* has been submitted.

Achille Fiore

Follow-up observations of astronomical transients

In collaboration with Padova-Asiago SN group (INAF, Osservatorio Astronomico di Padova) and the extended Public ESO Spectroscopic Survey of Transient Objects

Project abstract: The last two decades have witnessed a huge increase of new (often exotic) astronomical transient discoveries thanks to the advent of wide-field surveys which repeatedly scan almost the entire sky with a cadence of a few days. After their discovery, spectro-photometric follow-up observations are then mandatory to get an insight of the mechanisms ruling their physics: to ensure observing time for optical/near-infrared follow-up observations at the Nord Optical Telescope (NOT), Canary Islands, Spain, I am member of the NOT Unbiased Transient Survey (NUTS2, observing with NOT+ ALFOSC/NOTCam), where we volunteer on a rota to trigger Target of Opportunities (ToO) to the NOT staff.

Related publications: [AF1], [AF2], [AF3]

Alex Gnech

Theoretical study of electroweak interactions with light-nuclei

In collaboration with L.E Marcucci (University of Pisa), M. Viviani (INFN-Pisa), R. Schiavilla (ODU-JLAB), M. Piarulli (Washington University), S. Pastore (Washington University) and K. Garrett (Washington University)

Project abstract: The aim of this project is the study and the characterization of the electroweak structure of light nuclei using the most modern ab-initio techniques in nuclear physics combined with chiral effective field theory. In the contest of the projects we plan to obtain prediction both for the nuclear electroweak structure of bound states and the nuclear reactions involving electroweak reactions.

Related Publications: [AG1,AG2]

Related Talks: [AG3, AG4]

Accurate calculation of beta-decay rates of light nuclei

In collaboration with A. Gnech (ECT*), S. Taioli (ECT*), S. Simonucci (University of Camerino)

Project abstract: In this work, we aim to compute beta decay rates of light nuclei such as Tritium or Helium-6 fully ab-initio. While the leptonic matrix elements are easier to obtain within different approximations for light and heavy nuclei, hadronic currents are challenging and nuclear wavefunctions are fully reliable only for light nuclei. Although in this region of the N-Z plane, beta decays are usually allowed (meaning that the total angular momentum change is 0 or 1), we investigate the role of leptonic matrix elements in the total rate. By taking into account all the possible effects using state-of-the-art techniques for calculating hadronic and leptonic wavefunctions, such as Dirac-Hartree-Fock self-consistent equations for the latter, this work is meant to benchmark all the approximations usually done to compute beta decay currents. Also, given the unprecedented accuracy that we want to reach, by tuning the neutrino mass up to the current limit given by experiments and by comparing with experimental measurements, our method is suitable for the determination of the neutrino mass from the shape of the endpoint spectrum.

Artificial neural network for nuclear bound state

In collaboration with A. Lovato (ANL) and N. Rocco (FermiLab)

Project abstract: Artificial neural networks have proven to be able to compactly represent the wave functions of nuclei with up to A = 4 nucleons. In this project we extend this approach to heavier system up to medium mass nuclei. The goal is to study the electroweak structure of medium mass nuclei with nuclear wave function computed with artificial neural networks. Related Publications: [AG5]

Related Talks: [AG6]

Solving the homogeneous Bethe-Salpeter equation on a quantum annealer

In collaboration with F. Fornetti (University of Perugia), G. Salme' (INFN-Roma), T. Federico (ITA-Brasile), F. Pederiva (Unitn), M. Rinaldi (University of Perugia), A. Roggero (Unitn), S. Scopetta (University of Perugia), M. Viviani (INFN Pisa)

Project abstract: The goal of the projects is to solve the homogeneous Bethe-Salpeter equation (BSE), that describes a bound system in a genuinely relativistic quantum-field theory framework, has been using quantum annealer by D-Wave. After applying standard techniques, the BSE can be formally transformed in a generalized eigenvalue problem (GEVP), with two square matrices: one symmetric and the other non-symmetric. This last matrix poses the challenge to attain a form for the investigated GEVP that might be suitable for a treatment on a quantum annealer, namely to be re-expressed as a quadratic unconstrained binary optimization problem.

Borys Hryniuk

Few-Body Problem in Quantum Mechanics

In collaboration with O.B. Gryniuk (Trento Institute for Fundamental Physics and Applications, Trento, Italy)

Project abstract: An extremely important mathematical problem of nuclear physics is a solution of an N-particle problem for a given (more or less realistic) Hamiltonian of the nucleus. The most efficient method of finding the spectrum and wave functions of the system appeared to be the variational method, which is usually used within the procedure of expanding the solutions into the series in some basic functions in order to reduce the problem to a system of linear algebraic equations.

A new basis is proposed for variational calculations of the bound states of a few-particle system. For an N-particle system with pairwise interactions, the matrix elements of the Hamiltonian are found in an explicit form. A modified version of the basis invariant with respect to spatial translations is considered as well. As an example, the ^{12}C nucleus is considered as a system consisting of three α-particles, and the convergence of the method is studied.

Related publications: [BH1]

Luis Benjamin Rodriguez Aguilar

Incoherent diffraction in electron DIS off nuclei at high energy

Supervisor: Dionysios Triantafyllopoulos (ECT*/FBK)

In collaboration with Shu-Yi Wei (Shandong University)

Project abstract: We study the incoherent diffractive dijet production in electron-nucleus deep inelastic scattering at small-xBj. At leading order in the strong coupling, this is given by the diffractive production of a quark-antiquark pair which interacts with a target nucleus that breaks up in the final state. Analytical expressions can be found in the correlation limit, where the transferred momentum from the target to the diffractive system and the gluon saturation momentum are much smaller than the individual jet momentum. When going to the next-to-leading order in the strong coupling, the quark-antiquark pair can be treated as an effective gluon and it is accompanied by an emitted soft gluon, thus forming a gluon dipole. The cross section is factorized in the hard factor, which includes the decay of the virtual photon to the quark-antiquark pair and the subsequent emission of the gluon, and the semi-hard factor, which involves the gluon dipole scattering off the nucleus. This work is oriented to study the effects of gluon saturation in the forthcoming Electron-Ion Collider.

Related publication: [LR1]

Giovanni Inverardi

During this first year of my PhD my research activity has focused on the European project "4D Microscopy of biological materials by short pulse terahertz sources (MIMOSA)". This project bases its foundations on a novel procedure for the application of Atom Probe Tomography (APT) to the structural analysis of biological systems, whereby the specimen is embedded by a silica matrix and ablated by a pulsed laser source. Such technique requires that the silica primer be properly inert and bio-compatible, keeping the native structural features of the system at hand while condensing into an amorphous, glassy-like coating. In this framework, I have been – and currently am – involved in two major research lines. The first one aims at modeling the interaction between the biological sample and the silica matrix. Specifically, I implemented a Molecular Dynamics protocol depicting and characterizing the earliest stages of the embedding process of proteins in a solution of water and orthosilicic acid, taken as a precursor of the silica matrix (published paper: *Silica In Silico: A Molecular Dynamics Characterization of the Early Stages of Protein Embedding for Atom Probe Tomography*, Biophysica 2023). While further scrutiny is in order, our assessment offers a first mechanistic insight of the effects of orthosilicic acid, thereby validating its use in the proposed innovative application of APT to the structural resolution of protein molecules. The second research line focuses on the interaction between the laser and the protein-matrix complex. To better understand such process, I am currently performing ab initio calculations, involving Density Functional Theory (DFT) – derived methods (mainly DFT, Real Time, Time dependent DFT) on the orthosilicic acid molecule and its polymer forms, that resemble a small matrix structure. These simulations give initial insights about the rupture mechanism exerted by the laser on the matrix precursor molecule (Si(OH)4), matching somehow experimental data generated by our collaborators.

Related publication: [GI1]

Dionysios Triantafyllopoulos

Fresh look at experimental evidence for odderon exchange

In collaboration with Z.F. Cui (Nanjing U.), D. Binosi (ECT*, Trento), C.D. Roberts (Nanjing U.), S.M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)

Project abstract: Theory suggests that in high-energy elastic hadron+hadron scattering, t-channel exchange of a family of colourless crossing-odd states — the odderon — may generate differences between and cross-sections in the neighbourhood of the diffractive minimum. Using a mathematical approach based on interpolation via continued fractions enhanced by statistical sampling, we develop robust comparisons between elastic differential cross-sections measured at =1.96 TeV by the D0 Collaboration at the Tevatron and function-form-unbiased extrapolations to this energy of kindred measurements at /TeV=2.76, 7, 8, 13 by the TOTEM Collaboration at the LHC and a combination of these data with earlier cross-section measurements at /TeV=23.5, 30.7, 44.7, 52.8, 62.5 made at the intersecting storage rings. Focusing on a domain that straddles the diffractive minimum in the and cross-sections, we find that these two cross-sections differ at the (2.2 - 2.6) σ level; hence, supply evidence with this level of significance for the existence of the odderon. If combined with evidence obtained through different experiment-theory comparisons, whose significance is reported to lie in the range (3.4 - 4.6) σ, one arrives at a (4.0 - 5.2) σ signal for the odderon.

Related publication: [TRI1]

Incoherent diffractive dijet production in electron DIS off nuclei at high energy

In collaboration with Benjamin Rodriguez-Aguilar (ECT*, Trento), S.Y. Wei (Shandong U.)

Project abstract: We study incoherent diffractive dijet production in electron-nucleus deep inelastic scattering at small xBj within the Color Glass Condensate. We focus on the correlation limit, that is, when the momentum transfer Δ and the gluon saturation momentum Qs of the nucleus are much smaller than the individual jet momentum P. We arrive at analytic expressions for the dijet cross section, which can be written as a sum of four terms which exhibit factorization: each such term is a product between a hard factor, which includes the decay of the virtual photon to the quark-antiquark pair, and a semihard one which involves the dipole-nucleus scattering amplitude. We further calculate the azimuthal anisotropies <cos2φ> and <cos4φ>. They are of the same order in the hard momentum P, but the <cos4φ> is logarithmically suppressed due to its dependence on the semihard factor. Finally, in order to extend the validity of our result towards the perturbative domain, we calculate the first higher kinematic twist, i.e. the correction of relative order Δ^2/P^2.

Related publication: [TRI2]

Probing gluon saturation via diffractive jets in ultra-peripheral nucleus-nucleus collisions

In collaboration with E. Iancu (IPhT, Saclay), A.H. Mueller (Columbia U.), S.Y. Wei (Shandong U.)

Project abstract: We argue that semi-inclusive photo-production of a pair of hard jets via coherent diffraction in nucleus-nucleus ultra-peripheral collisions at high energy is a golden channel to study gluon saturation. The dominant contribution is the diffractive production of three jets in an asymmetric configuration. Two of the jets are hard and propagate at nearly central pseudo-rapidities. The third jet is semi-hard, with transverse momentum comparable to the nuclear saturation momentum, and is well separated in pseudo-rapidity from the hard dijets. The emission of the semi-hard jet allows for strong scattering, thus avoiding the "higher-twist" suppression of the exclusive dijet production due to colour transparency. We compute the trijet cross-section using the diffractive TMD factorisation which emerges from the CGC effective theory at high energy. The cross-section is controlled by gluon saturation, which leaves its imprints on the structure of the final state, notably on the rapidity distribution.

Related publication: [TRI3]

Luca Vespucci

Optimizing Quantum Simulations for Trapped-Ion qubits

Project abstract: Investigation of the optimization of quantum simulations on trapped-ion quantum processors. The use of quantum optimal control techniques to tailor 'analog' gates at the laser pulse level is explored, as well as the optimization of 'digital' quantum circuits built on predetermined primitive gates. The study will identify the most effective methodology to translate near-term trapped-ion quantum computing into meaningful quantum simulations of microscopic systems.

Zhao-Qian Yao

Bethe–Salpeter kernel and properties of strange-quark mesons

In collaboration with Zhen-Ni Xu (Nanjing U.), Si-Xue Qin (Chongqing U.), Zhu-Fang Cui (Nanjing U.), Craig D. Roberts (Nanjing U.)

Published in: Eur. Phys. J. A 59 (2023) 3, 39 • e-Print: 2208.13903 [hep-ph]

Project abstract: Focusing on the continuum meson bound-state problem, a novel method is used to calculate closed form Bethe-Salpeter kernels that are symmetry consistent with any reasonable gluon-quark vertex, Γv, and therewith deliver a Poincar´e-invariant treatment of the spectrum and decay constants of the ground- and first excited states of u, d, s mesons. The predictions include masses of as-yet unseen states and many unmeasured

decay constants. The analysis reveals that a realistic, unified description of meson properties (including level orderings and mass splittings) requires a sound expression of emergent hadron mass in bound-state kernels; alternatively, that such properties may reveal much about the emergence of mass in the standard model.

Developing predictions for pion fragmentation functions

In collaboration with H.-Y. Xing (Nanjing U.), B.-L. Li (Shanghai U. Sci. Tech.), D. Binosi (ECT, Trento and Fond. Bruno Kessler, Trento), Z.-F. Cui(Nanjing U.), C. D. Roberts (Nanjing U.)

Published in: Eur. Phys. J. C (accepted)

Project abstract: Exploiting crossing symmetry, the hadron scale pion valence quark distribution function is used to predict the kindred elementary valence quark fragmentation function (FF). This function defines the kernel of a quark jet fragmentation equation, which is solved to obtain the full pion FFs. After evolution to a scale typical of FF fits to data, the results for quark FFs are seen to compare favourably with such fits. However, the gluon FF is markedly different. Notably, although FF evolution equations do not themselves guarantee momentum conservation, inclusion of a gluon FF which, for four quark flavours, distributes roughly 11% of the total light-front momentum fraction, is sufficient to restore momentum conservation under evolution. Overall, significant uncertainty is attached to FFs determined via fits to data; hence, the features of the predictions described herein could potentially provide useful guidance for future such studies.

Computational Physics

Maurizio Dapor

Understanding of the test-mass charging associated with cosmic rays in the Laser Interferometer Space Antenna (LISA) Pathfinder mission

In collaboration with: S. Taioli (ECT*), F. Dimiccoli, V. Ferroni, and W. J. Weber (University of Trento), C. Grimani, M. Fabi, and M. Villani (University of Urbino)

Project abstract: Understanding the total electron yield estimate is crucial in comprehending the test-mass charging caused by cosmic rays in the LISA Pathfinder mission and the upcoming LISA gravitational wave observatory. In this study, we investigate the interaction between keV and sub-keV electrons and a gold slab using a combination of Monte Carlo (MC) simulations and ab initio methods. By considering various energy loss mechanisms and elastic scattering events, we determine the energy spectrum of electrons that emerge from the gold slab when it is hit by a primary electron beam. Furthermore, we demonstrate that our findings align with both experimental data and MC simulations conducted using the GEANT4-DNA toolkit.

Related publications: [MD1], [MD2]

Quantum State Tomography

In collaboration with: D. Binosi and G. Garberoglio (ECT*) and M. Liscidini and D. Maragnano (University of Pavia)

Project abstract: We developed a novel method, named threshold Quantum State Tomography, aimed at optimizing the number of measurements for the quantum-state characterization of medium-scale noisy systems of N qubits, where the number of measurements for a full tomographic reconstruction scales at least as 4N. Our approach is particularly suited for those states where the density matrix is sparse and has a much more favorable scaling, O(2N) without appreciable loss in the fidelity of the reconstructed state.

Related publications: [MD3]

Giovanni Garberoglio

Ab-initio calculation of virial coefficients

In collaboration with Allan H. Harvey (NIST) and several metrological groups in Europe. This research line has been funded by the EMPIR programme co-financed by

the Participating States and from the European Union’s Horizon 2020 research and innovation programme through the projects *Real-K (Realising the redefined Kelvin, 18SIB02)*, *QuantumPascal (Towards quantum-based realisation of the pascal),* and *MQB-Pascal (Metrology for quantum-based traceability of the pascal, 22IEM04)*

This research line is devoted to the *ab-initio* calculation of pressure, acoustic and dielectric virial coefficients of gases that have metrological interest. During 2023, the Real-K and QuantumPascal project ended, and the MQB-Pascal project started.

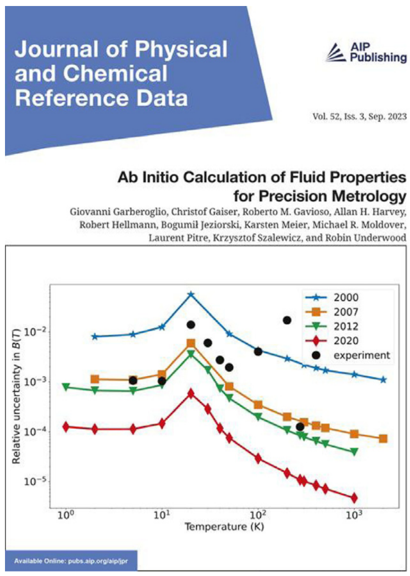
We summarized the results obtained in Real-K and QuantumPascal in [GG1] and [GG2], both of which have been selected to illustrate the covers of the respective journals.

In [GG1] we reported our results on the third density and acoustic virial coefficient of helium, computed ab-initio using a novel three-body potential that includes relativistic effect. This accuracy enabled us to provide values of third virial coefficient with rigorously determined uncertainties that are 5 times more accurate than previous calculations, and one order of magnitude more accurate than the best experimental results.

[GG2] reviews the progress of the last 20 years in temperature and pressure metrology, highlighting the interplay between theoretical calculations and experimental advances. In several cases, theoretical input based from completely *ab initio* approaches with well-defined uncertainties are crucial in determining the accuracy of primary and secondary standards of temperature and pressure.

These results have been presented in two invited seminars:

1. The 2023 CCM & IMEKO International Conference on Pressure and Vacuum Metrology, Washington D.C. (USA), May 2023
2. The Annual Meeting of the International Association for the Properties of Water and Steam, Turin (Italy), September 2023.



In [GG3] we extended our *ab initio* calculations to the fourth virial coefficient, *D(T)*, of ^{4}He, using for the first time a four-body non-additive potential energy surfaced derived from first principles. We were able to uncertainties.provide valued of *D(T)* in the range 10K-2000K with rigorously propagated

Quantum State Tomography

In collaboration with D. Binosi and M. Dapor (ECT*) and M. Liscidini and D. Maragnano (University of Pavia)

We developed a novel method, named *threshold Quantum State Tomography*, aimed at optimizing the number of measurements for the quantum-state characterization of medium-scale noisy systems of *N* qubits, where the number of measurements for a full tomographic reconstruction scales at least as 4^N. Our approach is particularly suited for those states where the density matrix is sparse and has a much more favorable scaling, O(2^N) without appreciable loss in the fidelity of the reconstructed state.

Related publication: [GG4]

Simone Taioli

Nanoparticle Enhanced Hadron-therapy: a comprehensive mechanistic Description

In collaboration with M. Dapor (ECT*), P. de Vera Gomis and R. Garcia Molina, (University of Murcia), I. Abril (University of Alicante), S. Simonucci, F. Triggiani (University of Camerino)

Project abstract: This project aims to apply fundamental physics and chemistry methods to uncover the microscopic mechanisms behind nanoparticle enhancement of hadron-therapy for cancer treatment. Hadron-therapy (or ion beam cancer therapy, that is radiotherapy using accelerated ion beams) is one of the most advanced radiotherapies available, with superior dose delivery and biological effectiveness as compared to conventional radiotherapy with photons. The increased effectiveness of hadron-therapy relies on the physico-chemical phenomena initiated at the nanoscale by the crossing of the ion beam through the biomaterial. There is experimental evidence pointing to gold nanoparticles enhancing the biological effects of ion beams. Since nanoparticles can be tuned to target cancer cells, they might be used to further improve hadron-therapy. However, it is still unknown how nanoparticles produce this effect. A proper exploitation of the nanoparticle radio enhancement in hadron-therapy depends on improving the understanding of the physico-chemical mechanisms responsible for it. In this project, a theoretical and computational method is proposed, in which a series of semiempirical and ab initio approaches are extended and interfaced with Monte Carlo track-structure simulation tools [St1, St2] in order to advance the basic understanding of the mechanisms at the nanoscale and to assess the dose deposited by the beam.

Related publications: [ST1], [ST2]

The role of low-energy electrons in the charging process of LISA test Masses

In collaboration with: M. Dapor (ECT*), V. Ferroni, F. Dimiccoli, W.J. Weber (University of Trento), Michele Fabi, Mattia Villani, Catia Grimani (University of Urbino)

Project abstract: The estimate of the total electron yield is fundamental for our understanding of the test-mass charging associated with cosmic rays in the Laser Interferometer Space Antenna (LISA) Pathfinder mission and in the forthcoming gravitational wave observatory LISA. To unveil the role of low energy electrons in this process owing to galactic and solar energetic particle events, in this work [ST3] we aim to implement a novel computational framework based on a mixed Monte Carlo (MC) and ab-initio model to study the interaction of keV and sub-keV electrons with a gold slab. We determine the energy spectrum of the electrons emerging from such a gold slab hit by a primary electron beam by considering the relevant energy loss mechanisms as well as the elastic scattering events. We also show that our results are consistent with experimental data and MC simulations carried out with the GEANT4-DNA toolkit.

Related publications [ST3]

Monte Carlo simulation of secondary electron generation and emission

In collaboration with: M. Dapor (ECT*), P. Trevisanutto (UKRI), J. Franz (Gdańsk University of Technology)

Project abstract: A detailed approach able to accurately describe elastic and inelastic scattering of low energy electrons in solid and liquid targets and to appropriately take into account the energy straggling is required for the description of secondary electron cascade. The whole cascade of secondary electrons must be followed: indeed any truncation, or cut-off, underestimates the secondary electron emission yield. Also, for insulating materials the main mechanisms of energy loss cannot be limited to the electron-electron interaction for, when the electron energy becomes very small (lower than 10-20 eV, say), inelastic interactions with other particles or quasi-particles are responsible for electron energy losses. In particular, at very low electron energy, electron-phonon interactions are the main mechanisms of electron energy loss. Even phonon annihilations and the corresponding energy gains should be taken into account. The secondary electron emission simulation allows the evaluation of electron spectra. We are applying such an approach to the assessment of the optical and electronic properties of perovskites for photovoltaic applications and to organic compounds [ST4].

Related publications [ST4]

PANDORA: Plasma for Astrophysics, Nuclear Decays Observation and Radiation for Archaeometry

In collaboration with D. Mascali (LNS), M. Busso, S. Palmerini (UniPg), A. Mengoni, F. Odorici (INFN Bologna), S. Simonucci (Unicam), S. Cristallo (INAF)

Project abstract: Experiments performed at storage rings have shown that the lifetimes of β-radionuclides can change significantly as a function of the ionization state. A new experimental approach, based on the use of a compact plasma trap to simulate selected stellar-like condition, has been proposed by the PANDORA [ST5] project with the aim to measure, for the first time in a plasma outside a storage ring, nuclear β-decay rates of radionuclides involved in nuclear-astrophysics processes. To achieve this task a compact magnetic plasma trap has been designed, allowing to reach the needed plasma densities, temperatures and charge states distributions. Plasma parameters will be measured online with a multi-diagnostic setup and correlated with the decay rate of the radionuclides, which will be measured through the detection of the γ-rays emitted by the daughter nuclei following the β-decay. These γ-rays will be detected using an array of 14 HPGe detectors placed around the trap. For the first experimental campaign, three physics cases were selected, 176 Lu, 134 Cs, 94 Nb. The newly designed plasma trap will also represent a tool of choice to measure plasma opacities, a quantity experimentally poorly known, which has a great impact on the energy transport and spectroscopic observations of many astrophysical objects, such as kilonovae. The Pandora project also relies on theoretical models and computer simulations carried out using newly implemented methods in astrophysical scenarios to study the chemical evolution of the Universe and interpret observations [ST6, ST7].

Related publications [ST5, ST6, ST7]

MIMOSA: 4D Microscopy of biological materials by short pulse terahertz Sources

In collaboration with A. Vella (University of Rouen), T. Morresi (ECT*), G. Lattanzi (University of Trento), Domenico Paparo (CNR, Italy), Martin Andersson (Chalmers University)

Project abstract: Cryo electron microscopy and tomography have been among the greatest achievements in biological imaging. However, these techniques suffer from insufficient chemical resolution. In this respect, the HORIZON-EIC-2021 PATHFINDEROPEN-01 European project MIMOSA aims to provide an alternative to tomography at the nanoscale with a high chemical resolution for biological and medical systems, based on Tomographic Atom Probe (TAP). MIMOSA aims to prototype a new TAP triggered by intense terahertz (THz) pulses that are stable at high repetition rates and exhibit versatile and tailored properties. MIMOSA relies on the integration of transdisciplinary fields in bio-imaging, optics, ultrafast lasers and intense THz sources, big-data treatment and physics of the interaction between THz waves and matter, such as protein embedded in silica-based cages [ST8]. MIMOSA aims to prototype in parallel an efficient intense THz source based on a new technology with ultrafast high-energy fiber lasers. This source can be used in nano- tomography for biological and medical applications but also as a test platform for a foreseeable commercialization of the THz-triggered TAP. The MIMOSA team members are leaders in TAP development, 3D medical and bio-imaging, ultrafast lasers development with advanced techniques for shaping and control of the optical beam's properties and theoretical physics. With MIMOSA we are uniquely positioned to succeed and to raise the competitiveness of Europe in microscopy development on the international scene.

Related publications [ST8]

Mechanical Properties of carbon-based materials

In collaboration with A. Pedrielli (FBK), N. Pugno (University of Trento), K. Gkagkas (Toyota Motor Europe)

Project abstract: The manufacturing of high-modulus, high-strength fibers is of paramount importance for real-world, high-end applications. In this respect, carbon nanotubes represent the ideal candidates for realizing such fibers. However, their remarkable mechanical performance is difficult to bring up to the macroscale, due to the low load transfer within the fiber. A strategy to increase such load transfer is the introduction of chemical linkers connecting the units, which can be obtained, for example, using carbon ion-beam irradiation. In this work [ST9], we investigate, via molecular dynamics simulations, the mechanical properties of twisted nanotube bundles in which the linkers are composed of interstitial single carbon atoms. We find a significant interplay between the twist and the percentage of linkers. Finally, we evaluate the suitability of two different force fields for the description of these systems: the dihedral-angle-corrected registry-dependent potential, which we couple for non-bonded interaction with either the AIREBO potential or the screened potential ReboScr2. We show that both of these potentials show some shortcomings in the investigation of the mechanical properties of bundles with carbon linkers.

Related publications [ST9]

3.2 Publications of ECT* Researchers in 2023

Gert Aarts

[GA1] G. Aarts, J. Aichelin, C. Allton, A. Athenodorou, D. Bachtis, C. Bonanno, N. Brambilla, E. Bratkovskaya, M. Bruno and M. Caselle, et al.
Phase Transitions in Particle Physics: Results and Perspectives from Lattice Quantum Chromo-Dynamics
Prog. Part. Nucl. Phys. 133 (2023), 104070
doi:10.1016/j.ppnp.2023.104070
[arXiv:2301.04382 [hep-lat]]

[GA2] G. Aarts, C. Allton, M. N. Anwar, R. Bignell, T. J. Burns, B. Jaeger and J. I. Skullerud,
Non-zero temperature study of spin 1/2 charmed baryons using lattice gauge theory
Eur. Phys. J. A 60 (2024) no.3, 59
doi:10.1140/epja/s10050-024-01261-2
[arXiv:2308.12207 [hep-lat]]

[GA3] G. Aarts, B. Lucini and C. Park,
Scalar field restricted Boltzmann machine as an ultraviolet regulator
Phys. Rev. D 109 (2024) no.3, 034521
doi:10.1103/PhysRevD.109.034521
[arXiv:2309.15002 [hep-lat]]

[GA4] L. Wang, G. Aarts and K. Zhou,
Diffusion Models as Stochastic Quantization in Lattice Field Theory
Accepted for publication in JHEP
[arXiv:2309.17082 [hep-lat]]

[GA5] L. Wang, G. Aarts and K. Zhou,
Generative Diffusion Models for Lattice Field Theory
Contribution to NeurIPS 2023
[arXiv:2311.03578 [hep-lat]].

[GA6] R. Bignell, G. Aarts, et al. [FASTSUM],
Reconstructed (charm) baryon methods at finite temperature on anisotropic lattices
PoS LATTICE2023 (2024), 199
doi:10.22323/1.453.0199
[arXiv:2312.03560 [hep-lat]].

Daniele Binosi

[DB1] H.-Y. Xing, Z.-Q. Yao, B.-L. Li, D. Binos, Z.-F. Cui, C. D. Roberts
Developing predictions for pion fragmentation functions
e-Print: 2311.01613 [hep-ph]

[DB2] D. Binosi
Data-Driven Extraction of Hadron Radii
Few Body Syst. 64, no.4, 85 (2023)

[DB3] A. Accardi, P. Achenbach, D. Adhikari, A. Afanasev, C.S. Akondi, *et al.*
Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at Jefferson Lab
e-Print: 2306.09360 [nucl-ex]

[DB4] D. Maragnano, D. Binosi, G. Garberoglio, C. Cusano, M. Dapor, M. Liscidini
Threshold Quantum State Tomography
23rd International Conference on Transparent Optical Networks (ICTON), 1 (2023), DOI:10.1109/ICTON59386.2023.10207290

Published preprints from 2022 projects

[DB5] D. Binosi, A. Pilloni and R.A. Tripolt
Study for a model-independent pole determination of overlapping resonances
Phys.Lett.B 839, 137809 (2023)

[DB6] Z.F. Cui, D. Binosi, C.D. Roberts, S.M. Schmidt and D.N. Triantafyllopoulos
Fresh look at experimental evidence for odderon exchange
Phys.Lett.B 839, 137826 (2023)

Francesco Carnovale

[FC1] G. Novi Inverardi, F. Carnovale, L. Petrolli, S. Taioli, G. Lattanzi
Silica In Silico: A Molecular Dynamics Characterization of the Early Stages of Protein Embedding for Atom Probe Tomography
Biophysica *3*, 276 (2023)

Constantinos Constantinou

[CO1] C. Constantinou, T. Zhao, S. Han and M. Prakash
Framework for phase transitions between the Maxwell and Gibbs constructions
Phys. Rev. D 107, 074013 (2023)

Luis Benjamin Rodriguez-Aguilar

[LR1] B. Rodriguez-Aguilar, D.N. Triantafyllopoulos, and S.Y. Wei,
Incoherent diffractive dijet production in electron DIS off nuclei at high energy
Phys. Rev. D 107 (2023) no. 11, 114007, arXiv:2302.01106 [hep-ph].

Maurizio Dapor

[MD1] M. Dapor
Transport of Energetic Electrons in Solids
Computer simulation with applications to materials analysis and characterization
Springer Nature Switzerland AG 2023, 4th edition

[MD2] S. Taioli, M. Dapor, F. Dimiccoli, M. Fabi, V. Ferroni, C. Grimani, M. Villani, W. J. Weber
The role of low-energy electrons in the charging process of LISA test masses
Class. Quantum Grav. 40 (2023) 075001

[MD3] D. Maragnano, D. Binosi, G. Garberoglio, C. Cusano, M. Dapor, M. Liscidini
Threshold Quantum State Tomography 2023
23rd International Conference on Transparent Optical Networks (ICTON), Bucharest, Romania, 2023, pp. 1-4, doi: 10.1109/ICTON59386.2023.10207290D

[MD4] M. Dapor, R. Garcia-Molina, P. E. Trevisanutto, Z. Ding, S. Taioli
Editorial: Methodological and computational developments for modeling the transport of particles within materials,

Front. Mater. 10 (2023) 1302000

[MD5] A. Pedrielli, N. M. Pugno, M. Dapor, S. Taioli
In search of the ground-state crystal structure of Ta2O5 from ab initio and Monte Carlo simulations
Computational Materials Science 216 (2023) 111828

[MD6] A. Pedrielli, M. Dapor, K. Gkagkas, S. Taioli, N.M. Pugno
Mechanical properties of twisted carbon nanotube bundles with carbon linkers from molecular dynamics simulations
Int. J. Mol. Sci. 24 (2023) 2473

[MD7] K. Wiciak-Pawłowska, A. Winiarska, S. Taioli, M. Dapor, M. Franz, J. Franz
The role of molecular structure in Monte Carlo simulations of the secondary electron yield and backscattering coefficient from Methacrylic Acid,
Molecules 28 (2023) 1126

[MD8] M. Dapor
Spin-polarization after scattering
Physics Open 14 (2023) 100134

ACHILLE FIORE

[AF1] A. Pastorello, G. Valerin, M. Fraser et al.
Forbidden hugs in pandemic times. IV. Panchromatic evolution of three luminous red novae
2023, Astronomy & Astrophysics, Volume 671, id.A158, 33 pp.
[https://arxiv.org/pdf/2208.02782.pdf]

[AF2] I. Agudo, L. Amati, T. An et al.
Panning for gold, but finding helium: Discovery of the ultra-stripped supernova SN 2019wxt from gravitational-wave follow-up observations 2023, Astronomy & Astrophysics, Volume 675, id.A201, 34 pp. [https://arxiv.org/pdf/2208.09000.pdf *]*

[AF3] J. M. DerKacy, S. Paugh, E. Baron
SN *2021fxy: mid-ultraviolet flux suppression is a common feature of Type Ia supernovae*
Monthly Notices of the Royal Astronomical Society, Volume 522, Issue 3, pp. 3481-3505 [https://arxiv.org/pdf/2212.06195.pdf]

GIOVANNI GARBEROGLIO

[GG1] J. Lang, G. Garberoglio, M. Przybytek, M. Jeziorska, B. Jeziorski
Three-body potential and third virial coefficients for helium including relativistic and nuclear-motion effects
Physical Chemistry Chemical Physics **25**, 23395 (2023)

[GG2] G. Garberoglio, C. Gaiser, R.M. Gavioso, A.H. Harvey, R. Hellmann, B. Jeziorski, K. Meier, M.R. Moldover, L. Pitre, K. Szalewicz, R. Underwood *Ab Initio Calculation of Fluid Properties for Precision Metrology*
J. Phys. Chem. Ref. Data **52**, 031502 (2023)

[GG3] R.J. Wheatley, G. Garberoglio, A.H Harvey
Four-Body Nonadditive Potential Energy Surface and the Fourth Virial Coefficient of Helium
J. Chem. Eng. Data **68**, 3257(2023)

[GG4] D. Maragnano, D. Binosi, G. Garberoglio, C. Cusano, M. Dapor, M. Liscidini

Threshold Quantum State Tomography
23rd International Conference on Transparent Optical Networks (ICTON), 1 (2023)
https://doi.org/10.1109/ICTON59386.2023.10207290

Alex Gnech

[AG1] L. Ceccarelli, A.G., L.E. Marcucci, M. Piarulli and M. Viviani,
Muon capture on deuteronusing local chiral potentials
Front. Phys. 10 (2023). DOI:10.3389/fphy.2022.1049919

[AG2] A.G., L.E. Marcucci and M. Viviani
Bayesian analysis of muon capture on deuteron inchiral effective field theory
arXiv:2305.07568 (2023). Under review on PRC

[AG5] A.G., B. Fore and A. Lovato
Distilling the essential elements of nuclear binding vianeural-network quantum states
arXiv:2308.16266 (2023). Submitted to PRL

Borys Hryniuk

[BG1] O.B. Gryniuk, B.E. Grinyuk.
Universal Coordinate Gaussian Basis for Calculations of the Bound States of a Few-Particle System
Ukr. J. Phys. **68**, No. 9, p. 587-593 (2023).
https://doi.org/10.15407/ujpe68.9.587

Tommaso Morresi

[TM1] F. Mohuat, M. Peria, T. Morresi, R. Vuilleumier, A.M. Saitta, M. Casula
Thermal dependence of the hydrated proton and optimal proton transfer in the protonated water hexamer
Nature Communications 14 (1), 6930 (2023)

[TM2] I.B. Garba, T. Morresi, C. Bouillaguet, M. Casula, L. Paulatto
Reciprocal space temperature-dependent phonons method from ab-initio dynamics
Journal of Physics: Condensed Matter 35 395402 (2023)

[TM3] R. Taureau, M. Cherubini, T. Morresi, M. Casula
Quantum symmetrization transition in superconducting sulfur hydride from quantum Monte Carlo and path integral molecular dynamics
Submitted to NPJ Computational Materials (arXiv:2307.15684v2)

Giovanni Novi Inverardi

[GI1] G. Novi Inverardi, F. Carnovale, L. Petrolli, S. Taioli, G. Lattanzi
Silica In Silico: A Molecular Dynamics Characterization of the Early Stages of Protein Embedding for Atom Probe Tomography
Biophysica *3*, 276 (2023)

Simone Taioli

[ST1] M. Dapor, R. Garcia-Molina, P.E. Trevisanutto, Z. Ding, S. Taioli

Editorial: Methodological and Computational Developments for Modeling the Transport of Particles within Materials
Frontiers in Materials *10* (2023)

[ST2] F. Triggiani, T. Morresi, S. Taioli, S. Simonucci
Elastic scattering of electrons by water: an ab initio study
Frontiers in Materials *10*, 1145261 (2023)

[ST3] S. Taioli, M. Dapor, F. Dimiccoli, M. Fabi, V. Ferroni, C. Grimani, M. Villani, W.J. Weber
The role of low-energy electrons in the charging process of LISA test masses
Classical and Quantum Gravity *40*, 075001 (2023)

[ST4] K. Wiciak-Pawlowska, A. Winiarska, S. Taioli, M. Dapor, M. Franz, J. Franz
The Role of Molecular Structure in Monte Carlo Simulations of the Secondary Electron Yield and Backscattering Coefficient from Methacrylic Acid
Molecules *28*(3), 1126 (2023)

[ST5] D Mascali et al.
A new approach to beta-decays studies impacting nuclear physics and astrophysics: The PANDORA setup
EPJ Web of Conferences *279*, 06007 (2023)

[ST6] S. Palmerini, M. Busso, D. Vescovi, S. Cristallo, A. Mengoni, S. Simonucci, S. Taioli
Presolar grain isotopic ratios as constraints to nuclear physics inputs for s-process calculations
EPJ Web of Conferences *279*, 06006 (2023)

[ST7] C. Agodi et al.
Nuclear physics midterm plan at LNS
The European Physical Journal Plus *138*, 1038 (2023)

[ST8] G. Novi Inverardi, F. Carnovale, L. Petrolli, S. Taioli, G. Lattanzi
Silica In Silico: A Molecular Dynamics Characterization of the Early Stages of Protein Embedding for Atom Probe Tomography
Biophysica *3*, 276 (2023)

[ST9] A. Pedrielli, M. Dapor, K. Gkagkas, S. Taioli, N.M. Pugno
Mechanical Properties of Twisted Carbon Nanotube Bundles with Carbon Linkers from Molecular Dynamics Simulations
International Journal of Molecular Sciences *24*(3), 2473 (2023)

Dionysios Triantafyllopoulos

[TRI1] Z.F. Cui, D. Binosi, C.D. Roberts, S.M. Schmidt, D.N. Triantafyllopoulos
Fresh look at experimental evidence for odderon exchange
Phys. Lett. B 839 (2023) 137826, arXiv: 2205.15438

[TRI2] B. Rodriguez-Aguilar, D.N. Triantafyllopoulos, S.Y. Wei
Incoherent diffractive dijet production in electron DIS off nuclei at high energy
Phys. Rev. D 107 (2023) 11, 114007, arXiv: 2302.01106

[TRI3] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos, S.Y. Wei
Probing gluon saturation via diffractive jets in ultra-peripheral nucleus-nucleus collisions
Eur.Phys.J.C 83 (2023) 11, 1078, arXiv: 2304.12401

3.3 Talks Presented by ECT* Researchers in 2023

Gert Aarts

Machine learning for lattice field theory and back
Invited talk at *International Conference on Machine Learning Physics*
Yukawa Institute for Theoretical Physics, Kyoto, Japan,
Nov 13-18, 2023

Machine learning for lattice field theory and back
Invited talk at *XQCD 2023*
University of Coimbra, Portugal
Jul 26-28, 2023

Opportunities of AI
Invited talk at the *ExaTEPP* workshop
Swansea University, UK
Jun 21-22 2023

Discussion on machine learning and lattice field theories
Invited discussion leader at *Algorithms23*
University of Edinburgh, UK
April 24-27, 2023

Quantum-field theoretical machine learning
Invited talk at AI Hub meeting
Swansea University, UK
March 2023

Machine learning for lattice field theory and back
invited talk (online) at the Perimeter Institute
Waterloo, Canada
March 10, 2023

Machine learning and quantum field theories
Invited talk at the workshop *Machine learning approaches in Lattice QCD -- an interdisciplinary approach*, IAS
Munich, Germany
February 27 - March 3, 2023

Daniele Binosi

Drell-Yan and Pion Distribution Functions
Impromptu INP Workshop on QCD and Hadron Structure
Nanjing University, China
May 11-12, 2023

Parton Distribution Functions at a Crossroad
ECT*, Italy
September 18–22, 2023

Constantinos Constantinou

Contributed talks:
Dense nuclear matter in the multi-messenger era
FELLINI General Meeting, Rome
February 14, 2023

First-order hadron-to-quark phase transitions and g-mode oscillations in compact stars
INT Workshop INT-22r-2a: Neutron Rich Matter on Heaven and Earth, Seattle, Washington, USA
June 28, 2023

First-order nucleon-to-quark phase transition: Thermodynamically-consistent constructions other than Maxwell and Gibbs
ECT* Workshop MICRA2023: Microphysics in Computational Relativistic Astrophysics, Trento
September 12, 2023

Invited seminars:
g-mode oscillations in neutron stars
NTG Seminar at Ohio University, Athens, Ohio, USA
September 27, 2023

g-mode oscillations and first-order deconfinement transitions in neutron stars
CNR Seminar at Kent State University, Kent, Ohio, USA
October 24, 2023

Alex Gnech

Constraining nuclear currents for electroweak processes (invited talk) 25th European Conference on Few-Body Problems in Physics, Mainz, Germany
Jul. 31-Aug. 5, 2023

Electroweak processes on light nuclei" (invited talk)
Marciana 2023 - Lepton Interactions with Nucleons and Nuclei, Marciana Marina (Isola d'Elba), Italy
Sept. 3-8, 2023

Distilling the essential elements of nuclear binding with Neural Network Quantum states",
Workshop Critical stability of few-body quantum systems, ECT* Trento, Italy
Oct. 23- 27, 2023

Seminars
The Hyperspherical Harmonic basis for ab-initio nuclear theory
Tongji University,Shanghai, China
November 9, 2023

Borys Hryniuk

Conditions of Spatial Collapse in an Infinite Bose-System, or Why a Hypothetical Nuclear Matter Cannot Consist of α-Particles
Seminar dedicated to the memory of academician O. G. Sitenko. – Kyiv, Ukraine
February 14, 2023 (by Zoom)

Conditions of Spatial Collapse in an Infinite Bose-System, or Why a Hypothetical Nuclear Matter Cannot Consist of α-Particles
Seminar «Problems of theoretical physics» for students, post graduate students and scientists
Kyiv, Ukraine
March 14, 2023 (by Zoom)

Tommaso Morresi

Path Integral MD/MC for many-body properties & Ab-initio Beta-decay calculations
INFN MONSTRE meeting Milan (Italy)
11-12 May, 2023

A DFT and TDDFT study of the orthosilicic acid molecule under electrostatic field and laser irradiation
MIMOSA meeting, Trento, Italy
31 August – 1 September, 2023

Path Integral study of phonons and structural phase transition in the superconducting regime of H3S
FISMAT 2023 Milan (Italy)
4-8 Septembe,r 2023

Teaching

Molecular Dynamics and Path Integral Molecular Dynamics
Course for PhD students University of Trento
Academic year 2022-2023 (24 hours)

Simone Taioli

Invited talks

Relative Role of Physical Mechanisms on Complex Biodamage Induced by Carbon Irradiation
(CMD30-FisMat2023) Milan
04-08/09/2023

Electronic excitation spectra and yield: from ab initio dielectric response functions to charge transport Monte Carlo simulations (CMD30-FisMat2023) Milan
04-08/09/2023

Lectures

Density functional approaches to the many-body problem,
3rd year degree in Physics
Gdansk University of Technology
March - May, 2023

Dielectric-response models within an ab-initio framework
Summer school in Multiscale Methods to PhD students in Physics
Gdansk University of Technology
July, 2023

Dionysios Triantafyllopoulos

Incoherent Diffractive Dijet Production in Electron DIS off Nuclei
Talk at the workshop “Color Glass Condensate at the EIC”
Trento, Italy
19 May, 2023

Incoherent Diffractive Dijet Production in Electron DIS off Large Nuclei
Talk at the workshop “Low-*x*”
Leros, Greece
05 September, 2023

Color Glass Condensate in Collider Physics
Talk at the “Symposium in occasion of the 30th anniversary of ECT*”
Trento, Italy
04 October, 2023

Quark and Gluon Diffractive Distributions at small-x_P
Talk at the workshop “Resummation, Evolution and Factorization”
Madrid, Spain
24 October, 2023

Zhao-Qian Yao

Seminar
Weak and EM form factors of octet baryons using a three-body Faddeev equation
INP, Nanjing, China
October 25, 2023

Invited talk
Parton Distribution Functions at a Crossroad
ECT*, Trento, Italy
18-22 September, 2023

3.4 ECT* Seminars 2023

Michele Viviani (INFN Pisa)
The X17 Anomaly
21 June, 2023

Malte Albrecht (Jlab)
Search for Exotic Hadrons in $\eta(')\pi$ *at GlueX*
14 June, 2023

Piero Luchi (University of Trento and TIFPA)
PhD Seminar: Enhancing Qubit Readout with Autoencoders
26 May, 2023

Danial Ghamari (University of Trento)
PhD Seminar: Noisy Quantum Computers in Complex Systems Research
19 May, 2023

Marco Volponi (CERN and University of Trento)
PhD Seminar: Measuring the Fall of Antimatter in Earth's Gravitational Field
14 April, 2023

Salamat Ali (University of Trento)
PhD Seminar: Photonic limiter based on exceptional point spectral degeneracies
31 March, 2023

Chiara Cecchini (University of Trento and TIFPA-INFN)
PhD Seminar: Inflationary helical magnetic fields with a sawtooth coupling
03 March, 2023

Enrico Pierobon (University of Trento and TIFPA)
PhD Seminar: Development and characterization of the novel Hybrid Detector for Microdosimetry (HDM)
27 January, 2023

ECT* Computing Facilities

4. ECT* Computing Facilities

CONNECTIVITY

- The main network infrastructure is connected by 5 switches PoE - Power over Ethernet- (Aruba 2930M 48G PoE+).
- 5 switches Aruba 2930M 48G PoE+ 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 (1 Gbit/s); by network problems, the connection through the GARR is automatically activated.

HARDWARE

PC clients:

9 PCs for the local research and visiting scientists:

1 Workstation DELL Precision T1600

3 PCs/laptops for the staff:

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

A pool of 4 laptops for the workshop participants (the Home Use license of Mathematica is installed on two of them):

3 laptops DELL Latitude E5430

1 laptop DELL Latitude E5440

Conference room and Lecture room

1 laptop DELL Latitude E5440 that can be used by the speakers to present the slides

MAIN SOFTWARE for the research activity: 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 were available in 2021). Since December 2021 the version 13 is available.

SERVICES

All services are running using the hardware of the FBK datacenter.

All users can access all services offered by the FBK and the Google and the Microsoft suites.

The following useful services can be accessed through login on the “ectstar.eu” domain:

1. PaperCut Print Management Software
1. Google mail (using the “ectstar.eu” e-mail domain)
3. Google Drive
4. Google Team Drive
5. Google Hangouts
6. Google Classroom
7. Google Meet
8. Microsoft Teams
9. Zoom Meetings

WiFi Networks

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

- GuestsFBK
- EduRoam

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

Eduroam (http://www.eduroam.org) is the secure, 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.