FONDAZIONE BRUNO KESSLER

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

ANNUAL REPORT 2024

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

Institutional Member of the European Science
Foundation Expert Committee NuPECC

ECT* | Strada delle Tabarelle 286 | Villazzano (Trento)
Info: staff@ectstar.eu

ECT* - European Centre for Theoretical Studies in Nuclear Physics and Related Areas
Fondazione Bruno Kessler
Strada delle Tabarelle, 286
I - 38123 Trento – Villazzano
https://www.ectstar.eu
info: staff@ectstar.eu

Editing and layout:
Editoria Weber

Document for internal use

Contents

Preface

The year 2024 saw changes at ECT*. In February, Professor Gert Aarts of Swansea University stepped down from the position of ECT* Director, which he occupied since 2021, following years of service as Chair of the Scientific Board. Gert did an exceptional job under extremely difficult circumstances. He took over shortly after a reorganization of the administrative staff, when some personnel and tasks were moved to the central administration of the Fondazione Bruno Kessler (FBK), ECT*'s parent organization. Gert managed the return of the center to pre-COVID activity levels in 2023, when he also organized the celebration for ECT*'s 30-year anniversary. And Gert did all this while also tending to his home-university duties. The nuclear community will always be indebted to Gert for protecting and preserving this venerable institution during a challenging time.

After eight months as “Incoming Director”, I officially took over the position of Director in November. It is an honor to serve this institution. I first attended an ECT* workshop in September 1993, shortly after getting my PhD. Mannque Rho and Wolfram Weise (who later served twice as ECT* Director) organized an exciting program on the nuclear implications of chiral symmetry, which attracted the world's leading researchers. It was my first chance to present my work at a nuclear physics workshop, and over the years ECT* continued to have an oversized influence on my career -- including a workshop that I organized with Ben Gibson, Alfred Stadler, and Rob Timmermans, which was instrumental in the subsequent embracing of effective field theories (EFTs) by the nuclear community. I am passionate about ECT*, and hope to fill the big *klompen* left by Gert.

What ECT* has done for nuclear EFTs and my career is by no means an exception. For 32 years now, ECT* has been playing a unique role in the European nuclear ecosystem. As envisioned by its founders, ECT* is *the* venue where the newest ideas are presented, scrutinized, trimmed, and reinforced -- a process informed by, but not limited to, specific national or local interests. ECT* is widely recognized as an engine of change in theoretical paradigms and tools, as highlighted in the 2024 Long-Range Plan of the European Science Foundation's Nuclear Physics European Collaboration Committee (NuPECC), accessible at www.nupecc.org/lrp2024/Documents/nupecc_lrp2024_web.pdf.

My initial period as Director has been one of intense learning about the multifaceted operations of the center. The Director and all activities are overseen by the ECT* Scientific Board, a diverse group of distinguished physicists mostly from various European countries. I thank Constantia Alexandrou, Marek Lewitowicz, and Chair Urs Wiedemann for the years of outstanding service that ended in 2024. In turn, the Board welcomed Gilberto Colangelo, Assumpta Parreño, and Eberhard Widmann as new members, while Barbara Pasquini assumed the chairpersonship. The personnel directly involved with the center is described in Ch. 1 of this report.

We are fortunate to count with the continuing financial support of many European agencies and institutions -- in 2024, from Belgium, Czech Republic, Finland, France, Germany, Hungary, Italy, Netherlands, Romania, Switzerland, and United Kingdom. We are also grateful for support from all over the world for specific activities and their participants. In 2024, two workshops were supported by EMMI (Darmstadt) and one by MPP (Garching). ECT* participates, as a transnational access facility, in European networks: eight activities received support from EURO-LABS and seven from STRONG-2020 (prior to its conclusion in July). INFN provides a complementary fund for Italy-based physicists and FRIB-TA's EUSTIPEN program extends support for US-based researchers in low-energy nuclear theory. Great leverage for the nuclear community's investment is provided by the Province of Trento through FBK. Despite its complexity, the widespread support we receive is a strength, particularly in days of budget instabilities.

This support enables a vigorous program of activities, which are selected by the ECT* Scientific Board from proposals submitted in response to two calls a year. In 2024, our program amounted to 22 workshops and a Doctoral Training Program (DTP) spread through 25 weeks. Topics covered all the major areas of nuclear physics -- hadron physics, strongly-interacting matter at extreme conditions, nuclear structure and reaction dynamics, nuclear astrophysics, symmetries and fundamental interactions -- and beyond, including particle, atomic and laser physics, quantum gravity, quantum science and technology, and machine learning. While remote attendance is possible, in-person participation is crucial for the scientific discussions that spill over the grounds of the magnificent Villa Tambosi. The 843 visitors from almost all European countries and continents in 2024 ranged from famous researchers such as Roger Penrose to a large number of talented early-career researchers (ECRs). As part of ECT*'s mission to train ECRs, in 2024 the DTP organized by Almudena Arcones, Bruno Giacomazzo, and Jorge Piekarewicz was dedicated to "Nuclear Theory in Astrophysics" and covered all the hot topics of this vibrant field, for example the connections between the neutron-star equation of state and multimessenger astronomy. The DTP was attended by a select group of 24 students from all over the world. While all our workshops attract ECRs, none does it more than "Quantum Science Generation", which itself is organized by ECRs and covers various aspects of the fast-developing field of quantum science and technology. 2024 marked the second consecutive edition of this workshop series, and a third edition is planned for 2025. Our 2024 meetings are described in detail in Ch. 2.

In addition to meetings, ECT* houses a vibrant research group, with interests that span from gluon saturation and hadrons to atomic and condensed-matter physics. The five permanent researchers -- Daniele Binosi, Maurizio Dapor, Giovanni Garberoglio, Simone Taioli, and Dionysios Triantafyllopoulos -- regularly secure project funding from various sources. Together with the Director, they mentor postdoctoral associates as well as graduate students from the Università di Trento (UniTN). In 2024, postdocs Tommaso Morresi and Zhao-Qian Yao finished their tenure at ECT*, and we welcomed Dr. Elena Filandri as new postdoctoral fellow. Dr. Lucas Madeira was selected to start in early 2025 as a joint postdoc with INFN's Trento Institute for Fundamental Physics and Applications (TIFPA). ECT* researchers co-advised four PhD students, taught a UniTN course, and organized a pizza-fueled PhD seminar series. ECT* has also opened its installations to scientific meetings run by researchers from UniTN and other FBK centers. FBK, UniTN, and TIFPA provide the local intellectual milieu where our researchers thrive. Our 2024 research output of 30 publications and preprints, as well as a similar number of talks, is described in Ch. 3, followed in Ch. 4 by a list of our computing resources.

Before taking the directorship, I of course knew how well ECT* workshops ran. Still, I am astonished by all that is accomplished every day by a staff of only three. Ines Campo, Susan Driessen, and Barbara Gazzoli form an efficient and motivated team, which coordinates not only all meetings but also a complex array of day-to-day operations. Their unparalleled dedication is what makes everything move.

As its predecessors, this Annual Report for 2024 is available on the ECT* website (www.ectstar.eu).

Trento, May 2025

Ubirajara van Kolck
*Director of ECT**

Scientific Board, Staff and Researchers

1. Scientific Board, Staff and Researchers

1.1 Scientific Board and Director

Constantia Alexandrou (until Jan.)	University of Cyprus & the Cyprus Institute, Cyprus
Almudena Arcones	TU Darmstadt, Germany
Gilberto Colangelo (from Oct.)	University of Bern, Switzerland
David Kaplan	University of Washington, USA
Denis Lacroix	CNRS/IN2P3, France
Marek Lewitowicz (until Dec.)	NuPECC/GANIL, France
Alexandre Obertelli	TU Darmstadt, Germany
Barbara Pasquini (Chairperson from Oct.)	University of Pavia, Italy
Assumpta Parreño Garcia (from May)	University of Barcelona, Spain
Vittorio Somà	CEA Saclay, France
Eberhard Widmann (from Dec.)	NuPECC/Stefan Meyer Institute, Austria
Urs Wiedemann (Chairperson until May)	CERN-TH, Switzerland
Albino Perego (Ex officio)	University of Trento, Italy

ECT Director* (until March)
Gert Aarts — ECT*, Italy and Swansea University, UK

ECT Incoming Director* (March-November)
Ubirajara van Kolck — ECT*, Italy, CNRS, France and University of Arizona, USA

ECT Director* (from November)
Ubirajara van Kolck — ECT*, Italy, CNRS, France and University of Arizona, USA

1.2 Resident Researchers

Permanent Researchers

Nuclear Physics (ECT-Core Research Unit)*

Daniele Binosi, Italy
Dionysis Triantafyllopoulos, Greece

Computational Physics (ECT-LISC Research Unit)*

Maurizio Dapor, Italy (Unit Head)
Giovanni Garberoglio, Italy
Simone Taioli, Italy

Postdoctoral associates

Elena Filandri, Italy (from Oct.)
Tommaso Morresi, Italy
Zhao-Qian Yao, China (until Nov.)

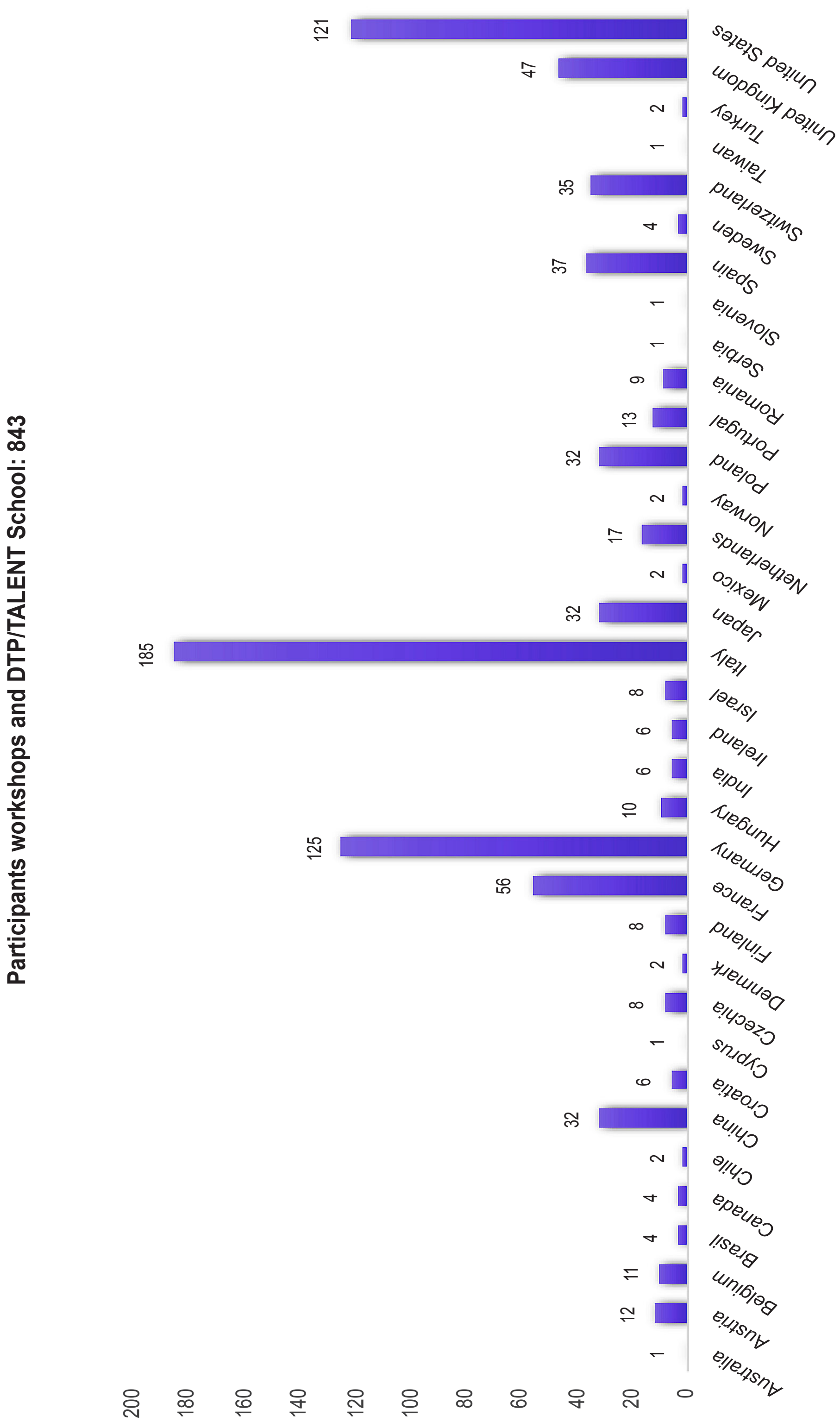
PhD Students

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

1.3 Staff

Ines Campo
Susan Driessen
Barbara Gazzoli

Participants workshops and Doctoral Training Program/TALENT School 2024



ECT Scientific Projects in 2024

2. ECT* Scientific Projects in 2024

2.1 Summary

Altogether, 23 scientific projects took place at ECT* in 2024: 22 workshops and a Doctoral Training Program/TALENT School. This chapter collects the scientific reports written by the workshop and school organizers.

2.2 Workshops and School (Calendar)

February 5-9	*alpha_s(2024): Workshop on precision measurements of the strong coupling constant* D. d'Enterria (CERN) S. Kluth (MPP) G. Zanderighi (MPP)
February 12-16	*New Jet Quenching Tools to Explore Equilibrium and Non-Equilibrium Dynamics in Heavy-Ion Collisions* A. Sadofyev (LIP) C. Andres (LIP) J. Barata (BNL) C. Salgado (IGFAE)
Feb 26 – Mar 1	*Inaugural Workshop on Nuclear Astrochemistry* N. Mason (University of Kent) D. Bemmerer (HZDR) E. Masha (HZDR) D. Mifsud (Atomki)
March 4-8	*EDMs: Complementary experiments and theory connections* S. Degenkolb (University of Heidelberg) P. Schmidt-Wellenburg (Paul Scherrer Institute) G. Pignol (LPSC) J. de Vries (University of Amsterdam) R. Berger (Philipps Universität Marburg)
April 15-19	*Bridging Scales: At the crossroads among renormalisation group, multi-scale modelling, and deep learning* R. Menichetti (University of Trento) F. Pederiva (University of Trento) R. Potestio (University of Trento) A. Roggero (University of Trento)

April 22-26	*The Physics of Strongly Interacting Matter: Neutron stars, cold atomic gases and related systems* A. Schwenk (TU Darmstadt) F. Ferlaino (University of Innsbruck) C. Pethick (Niels Bohr Institute) A. Watts (University of Amsterdam)
May 6-10	*Quantum Science Generation 2024* D. De Bernardis (INO-CNR) V. Panizza (University of Trento) L. Vespucci (University of Trento) A. Baldazzi (University of Trento) V. Amitrano (University of Trento) C. Benavides Riveros (INO-CNR) A. Berti (INO-CNR) A. Nardin (University of Trento)
May 13-17	*SPICE: Strange hadrons as a Precision tool for strongly InteraCting systEms* J. Pochodzalla (University of Mainz) C. Curceanu (INFN-LNF) B. Doenigus (University of Frankfurt) L. Fabbietti (TU Munich) S. Nakamura (University of Tokyo) F. Sakuma (RIKEN) I. Vidana (INFN Catania)
May 20-24	*Beyond-Eikonal Methods in High-Energy Scattering* J. Jalilian-Marian (Baruch College) A. Czajka (NCBJ) Y. Kovchegov (Ohio State University)
May 27-31	*Machine Learning and the Renormalization Group* J. Urban (MIT) D. Hackett (Fermilab) A. Hasenfratz (University of Colorado Boulder) J. Pawlowski (Heidelberg University) B. Lucini (Swansea University)
June 3-7	*A Modern Odyssey: Quantum gravity meets quantum collapse at atomic and nuclear physics energy scales in the cosmic silence* C. Curceanu (INFN-LNF) A. Bassi (University and INFN Trieste) L. Baudis (University of Zurich) A. Marciano (Fudan University China) K. Piscicchia (Centro Ricerche Enrico Fermi) L. Diosi (Wigner Research Center, University of Budapest)

June 10-14	*Diffraction and Gluon Saturation at the LHC and the EIC* C. Royon (University of Kansas) M. Hentschinski (Universidad de las Americas Puebla) A. Sabio Vera (Universidad Autonoma de Madrid) S. Schlichting (University of Bielefeld) A. Deshpande (Stony Brook University)
June 17-21	*Towards a Consistent Approach for Nuclear Structure and Reaction: Microscopic optical potentials* C. Barbieri (University of Milan) C. Elster (Ohio University) C. Hebborn (FRIB) A. Obertelli (TU Darmstadt)
July 1-5	*New Opportunities and Challenges in Nuclear Physics with High-Power Lasers* C.-J. Yang (ELI-NP) K. Spohr (ELI-NP) P. Tomasini (ELI-NP) Y. Fukada (Kansai Photon Science Institute) V. Horny (ELI-NP) L. Gizzi (INO) D. Domenico (ELI-NP)
July 8-12	*Synergies between LHC and EIC for Quarkonium Physics* F. Celiberto (Universidad de Alcalà) C. Van Hulse (Universidad de Alcalà) J.P. Lansberg (CNRS) D. Kikola (Warsaw University of Technology) D. Boer (University of Groningen) E. Gonzales-Ferreiro (IGFAE) C. Flore (University of Turin)
July 15 – Aug 2	*Doctoral Training Program: Nuclear Theory for Astrophysics* A. Arcones (TU Darmstadt) B. Giacomazzo (Università degli Studi di Milano-Bicocca) J. Piekarewicz (Florida State University)
August 5-9	*Towards Improved Hadron Tomography with Hard Exclusive Reactions* M. Boer (Virgina Tech) A. Camsonne (JLab) J. Wagner (NCBJ)
August 19-23	*The Nuclear Interaction: Post-modern developments* R. Timmermans (University of Groningen) J. McGovern (University of Manchester)

	M. Piarulli (Washington University) U. van Kolck (IJClab Orsay)
September 9-13	*New Developments in Studies of the QCD Phase Diagram* H. Ding (Central China Normal University) F. Karsch (University of Bielefeld) M.P. Lombardo (INFN Florence) P. Petreczky (BNL)
September 16-20	*Spin and Quantum Features of QCD Plasma* F. Becattini (University and INFN Florence) X. Huang (Fudan University) D. Rischke (Goethe University Frankfurt) Y. Yin (CAS)
Sep 30 – Oct 4	*KAMPAI - Kaonic, Antiprotonic, Muonic, Pionic and “onia” exotic Atoms: Interchanging knowledge* A. Scordo (INFN Frascati) P. Indelicato (Laboratoire Kastler Brossel) J. Obertova (Czech Technical University, Prague) C. Curceanu (INFN-LNF) A. Knecht (PSI) M. Skurzok (Jagiellonian University of Krakow) T. Hashimoto (JAEA)
October 21-25	*Measuring Neutrino Interactions for Next-Generation Oscillation Experiments* S. Dolan (CERN) C. Wilkinson (LBNL) C. Wret (University of Oxford) L. Pickering (Rutherford Appleton Laboratory)
November 4-8	*Universal Themes in Bose-Einstein Condensation* J. Carusotto (INO-CNR BEC Center) T. Giamarchi (University of Geneva) G. Ferrari (University of Trento) D. Snoke (University of Pittsburgh) P. Littlewood (University of Chicago) F. M. Marchetti (UAM) N. Proukakis (University of Newcastle)

2.3 Workshop reports

2.3.1 *alpha_s(2024): Workshop on precision measurements of the strong coupling constant*

Date	5-9 February 2024
Organizers	
David d'Enterria	CERN, Switzerland
Stefan Kluth	MPP, Germany
Giulia Zanderighi	MPP, Germany
Number of participants	44

Main topics

The strong coupling constant α_s is the least well known of all constants of nature and plays a key role in the Standard Model (SM) of particle physics and related fields such as cosmology and astrophysics. For many searches for new physics beyond the SM as well as for some important precision tests of the SM using collider data, the uncertainty on the value of α_s is a limiting factor. In recent years progress in theoretical predictions of Quantum Chromodynamics (QCD) and the availability of collider data at the highest energies has led to many improved determinations of α_s. The current world average quotes an uncertainty of less than 1%. However, there are noticeable discrepancies between different categories of determinations of α_s, which may limit the ultimate precision of future world averages. The workshop brought together the leading experts on determinations of α_s from theory and experiment in all important observable categories. Presentations of the latest results and intense discussion by all participants led to a global view of the advantages and challenges associated to each method, and of their combination into a world-average value. This workshop is the fourth of a series of alpha_s meetings that took place in 2011 (MPI, Munich), 2015 (CERN), 2019 and 2022 (ECT*).

The workshop aimed at exploring in depth the current status and upcoming prospects in the determination of the QCD coupling constant from the key observables where high-precision experimental measurements and theoretical calculations are (or will be) available. All talks were plenary and of the same length (20'+10' questions) with ample time for discussion.

The topics of discussion included:

- Current status of the world average of α_s
- Impact of on precision and BSM physics, and beyond
- Lattice QCD results
- α_s from hadronic tau decays

- α_s from e-p deep inelastic scattering
- α_s from e+e- hadronic final states
- α_s from electroweak observables
- α_s from pp collisions
- New α_s extraction approaches
- PDG approach to α_s world average and uncertainty estimation
- A preliminary new average (?) and future of α_s

Speakers

David d'Enterria	CERN, Switzerland
Giulia Zanderighi	Max Planck Institute for Physics, Germany
Stefan Kluth	Max Planck Institute for Physics, Germany
Joey Huston	Michigan State University, USA
Klaus Rabbertz	KIT, Germany
Paolo Nason	University and INFN, Milano-Bicocca, Italy
Mohd Siddique Akbar Alam Khan	Indian Institute of Science Bangalore, India
Cesar Ayala	Universidad de Tarapaca, Chile
Cristian Baldenegro Barrera	Sapienza University and INFN, Italy
Andrea Barontini	Milano University, Italy
Fernando Barreiro Alonso	Autonomous University of Madrid, Spain
Miguel Ángel Benitez Rathgeb	University of Salamanca, Spain
Johannes Bluemlein	DESY, Germany
Alexandre Deur	Jefferson Lab, USA
Stanley J. Brodsky	SLAC, USA
Patrick Connor	Hamburg University, Germany
Thomas Cridge	DESY, Germany
Gorazd Cvetic	Federico Santa María Technical University, Chile
Giancarlo Ferrera	Milan University & INFN Milano, Italy
Paris Gianneios	Free University of Brussels ULB, Belgium
Andre Hoang	Vienna University, Austria
Andreas Kronfeld	FNAL, USA
Christopher Lee	LANL, USA
Viljami Leino	Mainz University, Germany
Florian Lorkowski	Zürich University, Switzerland
Vicent Mateu	University of Salamanca, Spain
Julian Mayer-Steudte	TU Munich, Germany
Shubham Mishra	IIT Hyderabad, India
Stephan Narison	Montpellier University, France
Redamy Pérez-Ramos	IPSA/LPTHE, Paris, France
Santi Peris	Barcelona University, Spain
Peter Petreczky	BNL, USA
Antonio Pich	Valencia University and CSIC, Spain
Antonio Rodriguez Sanchez	SISSA, INFN, Italy

Jian-Ming Shen	Hunan University, China
Hai-Tao Shu	BNL, USA
Stefan Sint	Trinity College Dublin, Ireland
Meng Xiao	Zhejiang University, China
Matthias Schott	Mainz University, Germany
Alberto Ramos Martinez	Valencia University and CSIC, Spain
Rainer Paul Sommer	DESY, Germany
Alexandre Deur	Jefferson Lab, USA
Luigi Del Debbio	University of Edinburgh, UK

Scientific report

The strong coupling α_s sets the scale of the strength of the strong interaction, theoretically described by Quantum Chromodynamics (QCD). It is one of the fundamental parameters of the Standard Model (SM). In the chiral limit of zero quark masses and for fixed number of colours N_C=3, the α_s coupling is the only free parameter of QCD. Starting at an energy scale of order Λ_{QCD}~0.2 GeV in the vicinity of the Landau pole, $\alpha_s(Q)$ approximately decreases as $1/\log(Q^2/\Lambda_{QCD}^2)$, where Q is the energy scale of the underlying QCD process. Its value at the reference Z peak mass amounts to $\alpha_s(m_Z)$ = 0.1179 +/- 0.0009 with a ~0.8% uncertainty that is orders of magnitude larger than that of the other three interactions (electromagnetic, weak, and gravitational) couplings. Improving our knowledge of α_s is crucial, among other things, to reduce the theoretical "parametric" uncertainties in the calculations of all perturbative QCD (pQCD) processes whose cross sections or decay rates depend on powers of α_s, as is the case for virtually all those measured at the LHC. In the Higgs sector, our imperfect knowledge of α_s propagates today into total final uncertainties for key processes such as Higgs gluon-gluon-fusion and top anti-top associated production cross sections of ~2-3%, or of ~4% (combined with that of the charm mass) for H → gg, ccbar partial widths. In the electroweak sector, the input $\alpha_s(m_Z)$ value is the leading source of uncertainty in the computation of crucial precision pseudo-observables such as the total and partial hadronic Z boson widths. The QCD coupling plays also a fundamental role in the calculation of key quantities in top-quark physics, such as the top mass, width, and Yukawa coupling. Last but not least, the value of $\alpha_s(m_Z)$ and its energy evolution have also far-reaching implications including the stability of the electroweak vacuum, the existence of new coloured sectors at high energies, and our understanding of physics approaching the Planck scales, such as e.g. of the precise energy at which the interaction couplings may unify.

In order to discuss the current state-of-the-art, challenges, and prospects in the experimental and theoretical study of the strong coupling α_s, the workshop brought together experts from all relevant subfields to explore in depth the latest developments on the determination of α_s from the key categories where high-precision measurements and theoretical calculations are currently available. The overarching themes were: What is the current state-of-the-art and the ultimate theoretical and experimental precision of all α_s extraction methods? What needs to be achieved in order to reach an O(0.1%) precision?

Results and highlights

The next report on the status of research about the strong interaction and world average value of $\alpha_s(m_Z)$ will among other sources be informed by the results of this workshop, see S. Navas et al. (Particle Data Group), Phys. Rev. D 110, 030001 (2024) for its current edition and pdg.lbl.gov for updates.

2.3.2 *New Jet Quenching Tools to Explore Equilibrium and Non-Equilibrium Dynamics in Heavy-Ion Collisions*

Date	12-16 February 2024
Organizers	
Andrey Sadofyev	LIP, Lisbon, Portugal
Carlos Salgado	IGFAE, USC, Spain
Carlota Andres	LIP, Lisbon, Portugal
João Barata	BNL, USA
Number of participants	46

Main topics

This workshop focused on jet quenching tools and their applications to explore the properties of nuclear matter in heavy-ion collisions from the initial moments, where the matter is formed far from equilibrium, to the final stages, where the hot nuclear medium transforms into multiple hadrons. Among the primary motivations of this meeting, there were recent developments in the theory of probe-matter interactions during the initial stages and new results on the coupling of jets with the matter hydrodynamic evolution. We particularly aimed to provide a stage to discuss these recent advances, aiming to facilitate this progress and build new collaborations in the subfield.

The main topics were

- Jet quenching and hard probes in evolving matter
- Jet quenching and hard probes in initial stages
- Jet quenching and hard probes from non-equilibrium to equilibrium phase
- The experimental status of jet tomography

Speakers

Alba Soto Ontoso	CERN, Switzerland
Aleksas Mazeliauskas	Heidelberg University, Germany
André Cordeiro	LIP/IST, Portugal
Ankita Budhraja	NIKHEF, Netherlands
Barbara Jacak	University of California, Berkeley/LBNL, USA
Carlos Lamas Rodríguez	IGFAE, USC, Spain
Christine Nattrass	University of Tennessee, Knoxville, USA
Dana Avramescu	University of Jyväskylä, Finland
Fabio Dominguez	IGFAE, USC, Spain
Florian Cougoulic	USC, Spain
Florian Lindenbauer	TU Wien, Austria

Guilherme Milhano	LIP/IST, Portugal
Hannah Bossi	MIT, USA
Ismail Soudi	University of Jyväskylä, Finland
Jack Holguin	University of Manchester, UK
Jacopo Ghiglieri	SUBATECH, France
Jeremy Hansen	Iowa State University, USA
Joseph Bahder	New Mexico State University, USA
João A. Gonçalves	LIP/U. Lisboa, Portugal
João Silva	LIP/IGFAE, USC, Portugal/Spain
Konrad Tywoniuk	University of Bergen, Norway
Krishna Rajagopal	MIT, USA
Leticia Cunqueiro	Rome Sapienza University, Italy
Magdalena Djordjevic	Institute of Physics Belgrade, University of Belgrade, Serbia
Marco van Leeuwen	NIKHEF, Netherlands
Mateusz Ploskon	Lawrence Berkeley National Laboratory, USA
Matthew Sievert	New Mexico State University, USA
Michal Heller	Ghent University, Belgium
Nuno Olavo Madureira	LIP, Portugal
Pablo Guerrero-Rodríguez	LIP, Portugal
Paul Caucal	SUBATECH, France
Sergio Barrera Cabodevila	IGFAE, USC, Spain
Shu-Yi Wei	Shandong University, China
Sigtryggur Hauksson	IPhT, CEA, Université Paris-Saclay, France
Tuomas Lappi	University of Jyväskylä, Jyväskylä, Finland
Weiyao Ke	Central China Normal University, China
Xiaojian Du	IGFAE, USC, Spain
Xin An	National Centre for Nuclear Research, Poland
Xoán Mayo López	IGFAE, USC, Spain
Yen-Jie Lee	MIT, USA
Yeonju Go	BNL, USA

Scientific report

The nuclear matter produced in heavy-ion collisions (HICs) starts as a far-from-equilibrium system, thermalizing into a nearly ideal liquid known as the quark-gluon plasma (QGP). To reach this collective state of matter, the system has to evolve from an initial state characterized by strong color fields, through intermediate relaxation processes, which can be described within an effective kinetic theory. Experimental studies of the matter produced in HICs are highly non-trivial, since the information about its evolution is entangled in the correlations of the multiple detected particles. An opportunity to overcome this issue is provided by self-generated hard probes (HPs) such as hadronic jets, which essentially X-ray the matter.

Since the early days of the field, these highly energetic particles have been successfully used to extract the time-averaged properties of the QGP. However, it was not until very recently that the possibility of using jets to access the complete time dependence of the system's evolution started gaining greater attention. Such a real-time tomography of the matter created in HICs requires a detailed understanding of the probe-medium interactions throughout the entire evolution of the underlying medium. Therefore, recently, there were multiple theoretical developments aiming at a more accurate description of the probe-matter interactions, during both the initial and intermediate stages of a HIC. Additionally, there have been novel improvements in the descriptions of jets' evolution in the QGP phase, taking into account its underlying structure and evolution. Moreover, these theoretical efforts are strongly motivated by the ongoing and near-future experimental programs. Indeed, the push towards high luminosity at HL-LHC and sPHENIX will provide access to the jets and their substructure in an enlarged phase space.

In this workshop, we focused on the physics of the QCD matter produced in HICs, with particular stress on the latest theoretical and experimental developments aiming at reconstructing the complete space-time picture of the underlying QCD matter using hard probes, such as jets, and their flavor dependencies. The workshop brought together the experimental and theoretical communities as well as groups working in jet quenching and initial stage physics, serving as a focal point for the recent experimental and theoretical developments carried out independently.

Results and highlights

This workshop was highly successful in providing the community with an opportunity to put the most recent developments in jet quenching together into the bigger context of actual jet tomography. It resulted in multiple new collaborations among the participants from different subfields of HIC physics, as can be seen by now, and attracted additional interest to the overall goal of the community to use the hard probes to probe the matter produced in HICs.

We discussed the experimental results from the Large Hadron Collider (LHC) and Relativistic Heavy-Ion Collider (RHIC), the roadmap of their upcoming runs, and the opportunities provided by the recent theoretical progress. We particularly focused on the current and future jet measurements, which can give a differential picture of the QCD matter evolution and provide access to its 3D structure. We explored the potential capabilities for jet tomography offered by the near future sPHENIX and HL-LHC experiments. These programs will allow reconstructing a larger portion of the jet Lund plane, which could be accessed using the up-to-date jet substructure techniques, especially with the recent developments on the theoretical side. From the theoretical side, new techniques allowing to couple jets to different properties of the underlying medium -- both in and out of equilibrium – were discussed.

Such a targeted discussion of these theoretical advancements took place for the first time during this workshop, and provided an important milestone for the community. The participants agreed on that a unified picture is crucial for the proper interpretation of future precision-era HIC experimental data and that building such a description becomes feasible with the ongoing improvement. We paid particular attention to the Monte Carlo codes available for jet quenching simulations, and concluded that some improvements were pressing in the light of the most recent developments in the description of probe-matter interactions.

2.3.3 *Inaugural Workshop on Nuclear Astrochemistry*

Date	26 February – 1 March 2024

Organizers

Nigel Mason	University of Kent and Europlanet, United Kingdom
Daniel Bemmerer	HZDR and ChETEC, Germany
Duncan Mifsud	HUN-REN Institute for Nuclear Research, Hungary
Eliana Masha	Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany

Number of participants	28

Main topics

The goal of the workshop was to introduce a new interdisciplinary field called “Nuclear Astrochemistry”. To this end, it brought together both leading and early career researchers in the fields of nuclear astrophysics, astrochemistry, astrobiology, and the origins of life. It emerged that researchers working at the intersections of these disciplines have much in common: They strive to understand the fundamental mysteries surrounding the genesis of life-sustaining elements and molecules on Earth. This quest cannot be from the study of possible life beyond the confines of Earth and of our solar system. There were deep and insightful discussions regarding strategies to advance the field through existing and innovative experimental, theoretical, and observational approaches.

Topics covered during the workshop included:

- Big Bang and stellar nucleosynthesis processes
- Propagation of elemental and isotopic abundances throughout the history of the universe and of our sun
- Cosmological interpretations of the evolution of life
- Astrochemistry models and observations of molecules in the interstellar medium (ISM)
- Chemical and biological bases for the origin of life on Earth and on exoplanets
- Future missions and prospects for studying exoplanets

Speakers

Nadia Balucani	DCBB - Università degli Studi di Perugia, Italy
Umberto Battino	University of Hull, UK
Daniel Bemmerer	Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany
Bertram Bitsch*	University College Cork, Ireland

Jana Bocková	CNES, Institut de Chimie de Nice, Université Côte d'Azur, France
Mattias Ek	ETH Zürich, Switzerland
Felipe Fantuzzi	University of Kent, UK
Federico Ferraro	INFN Laboratori Nazionali del Gran Sasso, Italy
Wolf Geppert	Stockholm University, Sweden
Perry Hailey*	University of Kent, UK
Keyron Hickman-Lewis	Università di Bologna, Italy
Sergio Ioppolo	Aarhus University, Denmark
Camilla Juul Hansen	IAP, Goethe University Frankfurt, Germany
Maria Lugaro	Konkoly Observatory, Hungary
Eliana Masha	Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Germany
Nigel Mason	University of Kent and Europlanet, UK
Eva Mateo Marti*	Centro de Astrobiología (CSIC/INTA), Spain
Heidy Mayerly Quitian-Lara	University of Kent, UK
Stephen Mojzsis	HUN-REN, CSFK, Hungary
Heike Rauer*	DLR, Institut für Planetenforschung, TU Berlin, Germany
Paul Rimmer	University of Cambridge, UK
Aldo Serenelli	ICE, CSIC, Spain
Tamás Szücs	HUN-REN Institute for Nuclear Research (Atomki), Hungary
Aurora Tumino	Università degli Studi di Enna "Kore" & INFN-LNS, Italy
Benjamin Wehmeyer	University of Wrocław, Poland
Laurent Wiesenfeld	Laboratoire Aimé Cotton, CNRS, Université Paris-Saclay, France
Matthew Williams	University of Surrey, UK

*Online speakers

Scientific report

The workshop served as a foundation platform for developing an interdisciplinary approach to exploring and addressing two of the greatest scientific questions: "How did life evolve on Earth?" and "Is life widespread throughout the Universe?" Solving these questions requires, as a first step, a deeper knowledge of the foundation physics and chemical processes essential for the formation of elements and molecules during the early stages of the Universe. The physical foundation is given by nuclear astrophysics, with its study of the synthesis of elements and isotopes within stellar and other astrophysical environments, providing insight into the chemical make-up of cosmic entities as a function of time. The chemical foundation is given by astrochemistry, which is investigating the chemical processes underlying the formation and evolution of molecules in interstellar space, planetary atmospheres, and beyond, exploring the conditions that support the beginning of life.

Up to now, there have been few collaborative efforts between these two foundation science communities. This gap must be bridged in order to enable progress, for example on the interplay between stellar dynamics and molecular evolution. Recent observations have revealed chemical transitions in stars, moving from an oxygen-rich to a carbon-rich phase. This transformation impacts the molecular composition of the stellar wind in these solar systems, with an impact on the rate of creation (or not) of biological molecules in them. Further examples are the heavy elements needed as catalysts necessary for biomolecular assembly. They are mainly produced in nuclear processes in rather massive stars, meaning in solar systems with a light star like our own Sun they need to be provided by galactic chemical enrichment from the debris of earlier and more massive stars. The same applies for studies of phosphorus enriched-stars, needed to provide the phosphorus containing species which are key components in DNA.

In addition to creating an interconnection between nuclear astrophysics and astrochemistry, the workshop aimed to include also astrobiology, providing a strong motivation to work together. This nascent interdisciplinary community has the tools needed to explore questions of elemental abundance, molecular complexity, and planetary habitability, and therefore advance our understanding of the universe’s origins and its capacity to support life.

The workshop was organised around a series of presentations in which the speakers developed the background to their research field (important for what was a diverse audience) and then went on to show their cutting-edge research and discussed the most important open questions. The diverse ecosystem of facilities available in Europe that enable such research to be performed was a key part of the discussion: large-scale telescopes, accelerator facilities, underground laboratories, photochemistry simulation chambers, synchrotron facilities, and molecular beam apparatus, to name just a few.

The workshop included ample space to topic-based and free discussions in its program, with 30% of the time set aside for discussion. However, discussions were usually so lively that even this generous allocation was exceeded, reducing (but fortunately not to zero) coffee and lunch break time.

On the first day of the workshop, the participants were divided into two different working groups, maintaining a balance of disciplinary, methodical (theory, model, experiments and observations), and career-stage perspectives. The working groups then addressed questions directly connected to the goal of the workshop. Here we list some of them:

- What are the major challenges that need to be addressed to understand the origins of the elemental and molecular constituents of the Universe and their evolution to their present form?
- What are “roadblocks” to performing such research? How may these be overcome?
- How can we best coordinate and ensure collaboration and cross-fertilization between the disparate communities of astrophysics, astrochemistry and astrobiology?

- What facilities are there in Europe and beyond to pursue these studies? Are there facilities and infrastructures that are currently lacking?

Summaries of each working group discussion were presented to the whole conference and a more general discussion was held on the last day.

Results and highlights

It emerged during the talks and discussions that a more in-depth examination of the elemental composition of the solar neighbourhood over time is crucial for comprehending the chemical evolution of galaxies and the development of planetary systems. In particular, there is a need for further investigation into the abundances of vital elements such as carbon, hydrogen, oxygen, nitrogen, phosphorus, and sulfur.

A second finding was that isotopic signatures may play a key role in identifying chemical pathways to life. Here, the need for interconnections between nuclear astrophysics (providing the isotopic abundances as a function of galactic and cosmic time and stellar scenario), astrochemistry (tracing chemical processes through minute isotopic variations), and astrobiology (identifying the life-supporting chemical molecules to be addressed) is particularly acute. For example, isotopic variations on $^{16,17,18}O$, $^{12,13}C$, and others may help explore chemical processes and, eventually, planetary habitability. The same is true for radioactive species, including ^{40}K, in identifying the sources of chemical energy and of chirality in biomolecules.

The debate surrounding the origin of homochirality in biomolecules has prompted investigations into magnetism, polarized light, and the potential formation of life molecules in interstellar space. It was recognized that approaches to study the entire system and its evolution rather than single factor, one-by-one studies, may provide new insights into the pathways to life on Earth and elsewhere in the Universe.

A new and unique source of data on the chemical origins of our own solar system is given by elemental and isotopic analyses of extra-terrestrial materials such as meteorites, lunar and Mars samples. Especially for these previous samples, sample stewardship is needed to optimize sample usage, favoring non-destructive analysis methods, limiting inevitable sample consumption, and maintaining sample libraries for use with new and more sensitive techniques to be expected in the future.

Given the complexity and depth of nuclear astrochemistry, in the discussion sessions it was emphasized that physics and chemical processes must be studied together, leading to a need for further interdisciplinary collaboration along several axes:

- Examination of existing models of stellar synthesis, planet formation, and molecular evolution in the interstellar medium, with the aim to integrate them into a coherent framework to advance our understanding of cosmic evolution.
- Integration of laboratory studies with observations and models. There remain many gaps in our knowledge of key physical and chemical processes and their quantification (e.g. by cross sections and rate constants). Identifying these gaps and the level of accuracy that is needed is an important next step. In cases

where experimental studies are impractical or too slow, theoretical calculations must be used requiring engagement with the theoretical/computational physics and chemistry communities.

- Provision of open access to databases (simulations, experimental data, observations) is crucial to facilitating data sharing and collaboration across scientific disciplines. There are already disciplinary EU-supported research infrastructure projects such as Europlanet2024RI and ChETEC-INFRA. These infrastructures nurture a first push in this direction within their communities, and obviously these efforts must be merged to support the nascent nuclear astrochemistry community. This step will not be easy and will require effort, willingness to compromise on overarching data formats, a significant investment of personnel, to be supported both by research institutions and by the European Union.
- Validation and accessibility of existing data. How can one select the “best” data set for models or further comparisons? How can the data be validated and how often should we update the “recommended values” that the community can use for modeling or other analysis?

Arising from the discussions were some recommendations and action plans:

- Nuclear astrochemistry as an interdisciplinary field requires the provision of transdisciplinary training and communications for all researchers – professors as well as early career researchers. Indeed, several senior attendees at the workshop noted that in contrast to many meetings they attended in their own discipline, at this workshop they were taking many notes as they were introduced to ideas and concepts from the other disciplines.
- It is necessary to provide further assistance for the infrastructures supporting such an interdisciplinary field and, above all, secure regular and open access to them. This will require sustainability plans to be developed for the current, EU-supported research infrastructures Europlanet2024RI (https://www.europlanet-society.org/europlanet-2024-ri/) and ChETEC-INFRA (https://www.chetec-infra.eu).
- It is timely to launch collaborative initiatives to build this new community and continue to momentum generated in the workshop. Options such as European, but also national and international opportunities should be explored and acted upon.

Overall, the workshop was a great success, fostering collaboration, knowledge exchange, and interdisciplinary research in this newly, hopefully evolving field. Looking ahead, the insights gained from this five-day workshop are expected to continue and further develop nuclear astrochemistry research, increasing our understanding of the cosmos and the potential for life beyond Earth.

2.3.4 *EDMs: Complementary experiments and theory connections*

Date	4-8 March 2024

Organizers

Skyler Degenkolb	Universität Heidelberg, Germany
Philipp Schmidt-Wellenburg	Paul Scherrer Institute, Switzerland
Guillaume Pignol	LPSC Grenoble, France
Jordy de Vries	University of Amsterdam / Nikhef, Netherlands
Robert Berger	Philipps-Universität Marburg, Germany

Number of participants	42

Main topics

The general theme of the workshop concerned permanent electric dipole moments (EDMs), including closely-connected topics relating to sources and signals of CP violation within and beyond the Standard Model. Of critical interest were complementary developments in the global analysis of a very broad portfolio of experimental measurements, leading both to model-independent constraints on CP-violating parameters and the evaluation of many experimental systems as potential targets for new measurements. Advances in theoretical calculations and experimental limits, and new measurement opportunities at European facilities, were extensively surveyed by invited presentations and developed via moderated discussions. A major theme throughout was the establishment of common vocabulary and conventions across the numerous and diverse research fields that are involved in studying EDMs. Several opportunities were identified for significantly improving uncertainties in this collective framework, whether for experiments or theory. Community-level challenges for training young researchers and maintaining a strong European program in EDM physics were also a key focus.

The main topical themes were:

- Global analysis and complementarity of experiments
- Nuclear observables and calculations relating to EDMs
- Effective field theory and effective interactions
- Experimental measurements with open-shell atoms and molecules
- Experimental measurements with closed-shell atoms and molecules
- Experimental measurements with nuclei, nucleons, and particles
- Uncertainties and correlations
- Novel experimental methods
- Community-level challenges and self-organization

Speakers

Andreas Crivellin	UZH & PSI, Switzerland
Diego Sanz-Becerra	Paul Scherrer Institut, Switzerland
Fabian Allmendinger	Physikalisches Institut, Heidelberg University, Germany
Gerda Neyens	KU Leuven (IKS), Belgium
Giorgia Tonani	University of Milano, Italy
Karim Bennaceur	Université Claude Bernard Lyon 1, IP2I, France
Kieran Flanagan	University of Manchester, UK
Konstantin Gaul	Philipps-University Marburg, Germany
Kseniia Svirina	Institut Laue-Langevin, France
Marco Guarise	University of Ferrara and INFN Ferrara, Italy
Markus Kortelainen	University of Jyväskylä, Finland
Maxim Pospelov	University of Minnesota, USA
Michael Tarbutt	Imperial College London, UK
Michail Athanasakis-Kaklamanakis	Imperial College London, UK
Moritz Pascal Reiter	University of Edinburgh, UK
Nina Elmer	Heidelberg University, Germany
Patrick Mullan	ETH Zürich, Switzerland
Sara Cesare	INFN Milano, Italy
Skyler Degenkolb	Heidelberg University, Germany
Steven Hoekstra	University of Groningen and Nikhef, The Netherlands
Tian Xia	University of Science and Technology of China, China
Tilman Plehn	Heidelberg University, Germany
Ubirajara van Kolck	ECT*, Italy, IJCLab Orsay, France, University of Arizona, USA
Yan Zhou	University of Nevada, Las Vegas, USA

Scientific report

Permanent electric dipole moments provide a key experimental test of Standard Model CP violation, and also a means to search for and constrain new physics processes that violate both parity and time-reversal. Whether motivated by the CP violation needed to explain our universe's observed matter-antimatter asymmetry, or by searching for T-violating operators more broadly, EDMs are the most constraining measurements of this type. These motivations and impact on high-energy physics unite EDM research, which relies on a diverse set of experimental methods and theoretical tools to fully develop its potential. This workshop was based in a European initiative to identify and strengthen connections among the groups pursuing improved measurements and calculations, as well as conceptual bridges including phenomenology and global analysis. The major classes of experimental systems were all represented (leptons, hadrons, closed- and open-shell atoms and molecules), with several new initiatives also highlighted. Key theoretical topics for the interpretation of experimental results were emphasized (nuclear DFT, lattice QCD, atomic and molecular structure, chiral EFT) in addition to dedicated calculations of the observables arising from specific models. The theoretical framework for EDMs spans a huge range of energy scales, from very high energies far beyond the Standard Model electroweak scale all the way down to tiny energy shifts and systematics on the order of 10^{-22} eV or less.

Standard Model Effective Field Theory and renormalization group running in a perturbative framework were presented from the perspective of high-energy physics with tools and techniques that are already successfully adapted for EDM studies. The treatment of correlations and theory uncertainties at all energy scales can be approached via the same methods, which in this context are highly advanced. Nonperturbative physics, especially in the energy scales from ~100 MeV to ~1 GeV, presents a particularly difficult aspect of this multiscale problem that was addressed by multiple speakers from different perspectives (mainly symmetries and effective field theory; a presentation on lattice QCD calculations for EDMs was unfortunately canceled due to speaker illness). Nuclear energy scales were addressed by presentations on nuclear Schiff moment calculations, and discussions particularly emphasized the connection of these to hadronic- and atomic-level quantities. Atomic and molecular structure was also addressed, both as a general introduction and in relation to the global analysis of the EDM experiments (i.e., the quest for significant enhancements or complementarity).

Experimental presentations covered a variety of atomic and molecular systems, which are often categorized as “paramagnetic” or “diamagnetic” – although, as articulated at the workshop the respective terms “open-shell” and “closed-shell” are more appropriate in this context. Discussions of open-shell systems focused heavily on molecules, with novel approaches to measure molecular ions or magnetic quadrupole moments presented alongside experiments and technology for neutral molecules with similar underlying sensitivities. Several closed-shell EDM systems including both warm and cold neutral atoms were presented, including prospects for quantum-limited measurements to combat systematics or improve statistics. For particle systems, overview and detailed presentations were given for the neutron and muon EDMs as well as Lambda baryons at the LHC. This clearly illustrated the range of experimental energy scales, from charm baryons produced with ~1 TeV to ultracold neutrons with ~100 neV.

A fast-growing theme of exploiting radioactive molecules was well-represented both by presentations on the experimental challenges of producing and extracting molecules at beam facilities, and on the potential physics reach for several candidate systems. There are both experimental and theoretical challenges in identifying good candidates, as the nuclear moments and deformations which are calculated do not correspond directly to experimental observables. Nevertheless, strong evidence and significant advances in the production of radioactive molecules for offline measurements give a clear motivation for further pursuing this hot topic. It was raised in discussions whether neutral atoms or bare nuclei (thus avoiding the Schiff screening) would be worthy objects of investigation, for some of the same nuclides.

Results and highlights

The targeted research areas included all experimental and theoretical approaches to measuring, calculating, and interpreting permanent electric dipole moments. This was intentionally very broad, including observables such as magnetic dipole/quadrupole moments and hadronic parity violation that can be interpreted in a common framework. Also included in the scope were “broader outputs”; such as medical applications of the magnetometers and quantum sensors developed for EDM experiments, or large-scale computing and machine learning in connection with lattice QCD (these were less emphasized in presentations, but raised and elaborated in discussions). While this workshop began as a European initiative, international colleagues from the US and Asia were strongly involved, and were explicitly invited and welcomed to this event.

The workshop was characterized by energetic and wide-ranging discussions. In particular, structured and moderated discussions around the following questions are highlighted.

- **Complementarity of experiments and consistent approaches:** Which experiments most complement each other in terms of their methods? In terms of their constraining power? Can we establish common ground for notations and physics conventions, to lower the barriers for understanding each other’s work?
- **Toward a doctoral network for EDMs, advanced training and networks:** How can we best support advanced training for students across a geographically dispersed community, with relatively few students at any one institution? How can we establish networks to ease the transfer of students and postdocs among groups, thus mitigating painful recruitment challenges of recent years? How can we better impress the field of EDMs on a broader particle physics program? (This already improved a lot, but still can be improved further.) What is concretely needed to install an efficient European training network on EDM physics for Master/PhD level students? (Schools, workshops, etc.) Theoretical inputs, uncertainties, and interpretation: What theoretical inputs are most needed for completing, or reducing uncertainty in, the interpretation of experimental results? How can these calculations be validated?
- **Landscape and strategy – new facilities and challenges/broader impact on particle physics**: Which experimental systems are now facing new challenges, and which ones show the most potential for improvements? What new facilities and technologies are on the horizon, and which experiments or calculations could most profit from them?
- **Technological challenges, new techniques and opportunities:** Are there methods or technologies under development (or already developed), for which awareness is lacking among people and groups who could use them? What are common technological challenges across the various experimental searches, and how can we collaborate (including industry connections)?

A key discussion point concerned the basic motivation for EDM searches: the absence of new light scalar particles from LHC data can be interpreted as disfavoring electroweak baryogenesis (no strong first-order phase transition). In this view serious consideration must be given to alternative scenarios, e.g. leptogenesis, that do not necessarily produce large EDMs. While EDM measurements can still play a key role in confirming or rejecting such a scenario, it was argued that the matter/antimatter asymmetry may no longer be the strongest motivation to pursue EDM measurements in general. On the other hand, time-reversal violation is well- established and we also expect time-reversal violation from higher-order operators: the motivation for EDMs includes searching for signals from these. The workshop participants agreed that it should be a priority for the community going forward to update our motivating arguments in presentations and publications. New slides and figures from both theorists and experimentalists should emphasize this, in order to present a modern and scientifically correct topical introduction – whether for specialists or for broader audiences.

Two preprints on the global analysis of EDMs were discussed at, and revised during, the workshop. Intensive discussions were needed to clarify the correctness and complementarity of the different approaches, and an important science message is that the current portfolio of experimental measurements significantly underconstrains the set of CP-violating effective operators already at the ~1 GeV energy scale. Different approaches were discussed to confront this challenge, including better error estimates from theory and experimental measurements on new systems. Several ambiguities in sign and normalization conventions, and the definitions of effective operators, still remain in literature as potential traps for the unwary.

While some experiments reported on significant laboratory-scale advances (e.g., novel EDM measurements with cold atoms), others rely heavily on major infrastructure (e.g., rare-isotope beamlines and neutron/muon facilities, or even the LHC). Many interesting candidate atomic and molecular systems involve unstable nuclei, and therefore significant interest was expressed in developing technology and expertise for extracting and using rare isotopes – especially in the context of molecules with significant Schiff enhancements. Shortly after the workshop this science case was also presented at the CERN Physics Beyond Colliders meeting, leading to a proposal and ultimately opening a position at CERN for CP-violating probes. While not solely responsible for it, workshop participants were heavily engaged in this process. A potential program at PSI for rare-isotope production was also discussed.

Feedback from the workshop participants was overwhelmingly positive. The community has engaged to maintain momentum in this research area, with follow-up meetings and summer schools/training events planned on a regular basis. The workshop has also informed and helped to structure inputs for the NuPECC Long-Range Plan 2024 and the ongoing European Strategy Update for Particle Physics, as well as topical workshops and roadmap exercises at European facilities (in particular CERN, ILL, and the ESS). A next workshop is already planned at Les Houches (March 1-6, 2026).

2.3.5 *Bridging scales: At the crossroads among renormalisation group, multi-scale modelling, and deep learning*

Date	15-19 April 2024

Organizers

Roberto Menichetti	UniTN, Italy
Raffaello Potestio	UniTN, Italy
Alessandro Roggero	UniTN, Italy
Francesco Pederiva	UniTN, Italy

Number of participants	30

Main topics

Machine learning will define the 21st century: from simple image classification to text generation and decision making, its impact on society will be nothing but immense. At present, the detailed mechanisms behind the power of AI still evade our understanding; growing evidence, however, suggests that it is possible to rationalise how deep learning works in terms that are very familiar to theoretical physicists, that is, the renormalisation group. The systematic, hierarchical coarsening of detailed information into increasingly simpler and more collective features is a cornerstone of modern physics, and it can be leveraged not only to make sense of machine learning's baffling capabilities, but also and most importantly to steer its development. This workshop explored the area where the fields of soft and condensed matter, fundamental interactions, and deep learning overlap, looking for novel and more powerful tools to model, investigate, and understand the world around us.

The main topics were

- Renormalisation group in field theory and high energy physics
- Multi-scale modelling in soft and biological matter physics
- Theoretical foundations and multidisciplinary applications of deep learning and artificial intelligence

Speakers

Alessandro Ingrosso	The Abdus Salam Int. Centre for Theoretical Physics, Trieste, Italy
Alessandro Roggero	University of Trento and INFN-TIFPA, Italy
Alessio Lugnan	University of Trento, Italy
Andrea Pedrielli	FBK, Italy
Andreas Ipp	TU Wien, Austria
Antonio Trovato	University of Padova - Department of Physics and Astronomy, Italy

Arnau Rios Huguet	Institute of Cosmos Sciences, University of Barcelona, Spain
Beatriz Seoane Bartolome	LISN, Paris-Saclay, France
Christine Peter	University of Konstanz, Germany
Danial Ghamari	University of Trento, Italy
Di Luo	Massachusetts Institute of Technology, USA
Emanuele Locatelli	University of Padova, Italy
Fabrizio Napolitano	INFN - Laboratori Nazionali di Frascati, Italy
Federica Gerace	Scuola Internazionale Superiore di Studi Avanzati, Italy
Federico Grasselli	EPFL, Switzerland
Francesco Pederiva	University of Trento and INFN-TIFPA, Italy
Guglielmo Grillo	University of Trento, Italy
Jean Barbier	ICTP, Italy
Kai Zhou	CUHK-Shenzhen, China
Luca Tubiana	University of Trento, Italy
Margherita Mele	University of Trento, Italy
Matteo Scandola	University of Trento, Italy
Mattia Scandolo	CNR-ISC, Italy
Oriel Kiss	CERN, Switzerland
Pietro Faccioli	University of Milan-Bicocca, Italy
Pratyush Tiwary	University of Maryland, College Park, USA
Raffaello Potestio	UniTn - Physics Dept., Italy
Roberto Menichetti	Physics Department, University of Trento, Italy
Sanghamitra Neogi	University of Colorado Boulder, USA
Susana Marin Aguilar	Sapienza University of Rome, Italy
Tristan Bereau	Heidelberg University, Germany
Will Noid	Penn State University, USA
Yannick Meurice	University of Iowa, USA

Scientific report

The growing concerns about the impact of artificial intelligence and machine learning algorithms in several aspects of our lives (education, work, creativity…) on the one hand, and, on the other, pressing technological issues, such as the mitigation of climate change or the development of more sustainable materials, might seem very different problems with similarly distinct and non-overlapping solutions. On the contrary, these and many other scientific and technological challenges entail the same core issue, namely a fundamental, rigorous, and practical understanding of the underpinnings of machine learning.

A concrete comprehension of the mechanisms that allow AI to perform so excellently at several tasks would not only enable a much more effective way to control its outcomes and implications; it would also represent a substantial step forward in the comprehension of natural phenomena that manifest generative patterns akin to those that occur in deep learning.

This workshop has addressed these aspects in a concurrent, integrated manner. Researchers have presented their work in a range of areas, making remarkable and successful efforts in the cross-fertilisation of distinct fields. The renormalisation group (RG) has been identified as a common ground to quantum field theory (QFT), soft matter (SM) modelling, and deep learning (DL); the open issues that still require important work to be done have been discussed, such as the possibility of extending the framework of RG to non-equilibrium, or the limitations of sampling techniques in computational physics.

The workshop has served the purpose of establishing novel collaborations in a lively and friendly environment, and has contributed to establishing the scientific ecosystem of Trento as one of the key players on the international stage.

Results and highlights

The workshop gathered in Trento 33 researchers from the whole world, with the aim of discussing contact points and synergistic aspects among the physics of fundamental interactions, coarse-graining and multi-scale modelling in soft and condensed matter, and the theory of deep learning in artificial intelligence. The first two have succeeded in providing us with a profound knowledge of matter over a wide range of scales, from quarks to soft and biological materials, up to astronomical objects; the third is proving to be an extremely rich source of novel tools for applications in practically all fields of science and technology.

In the course of the week, young as well as more senior researchers presented their work, and discussed what connections their fields have in common and what more can be done to benefit from one another. As it turns out, the three areas under examination share a lot, both in terms of methodology and objectives.

Various seminars have addressed those aspects of deep learning that share interesting and remarkable characteristics with the RG flow. In particular, it was shown that the machinery of RG developed in statistical and quantum field theory can fruitfully serve as a powerful framework for interpreting and rationalising how DL algorithms work. This is critical for the comprehension of machine learning, and hence to further develop it and make it more efficient.

Soft-matter physics, and multi-scale modelling in particular, has been a central topic of the workshop. It was demonstrated that coarse-graining as a methodological approach owes a great lot to RG techniques, and as such it can largely benefit from further cross-fertilisation with the areas of QFT and nuclear physics. Complementarily, methods developed in the field of soft matter can greatly contribute to both deep learning and theoretical high-energy physics, in particular as far as the ubiquitous issue of *sampling* is concerned. A very broad range of computational techniques has been crafted in the course of the last decades to computationally sample configurations of complex soft-matter systems; critically, these methods are very general, and can be easily adapted to address particular problems in other areas.

Last but not least, in the course of the workshop various speakers have discussed the advantages that machine learning in general, and deep learning in particular, can provide to both soft-matter and high-energy physics, not only as a tool to “speed up calculations”, but also as a novel way to look at old problems from a different perspective.

Lively discussions were carried out, which raised exciting questions and hinted at interesting new concepts. To capitalise scientifically on these conversations, the idea of writing an opinion paper on the interplay between RG, SM, and DL was proposed. This possibility is currently being scrutinised and discussed by a subgroup of the workshop participants.

In conclusion, the workshop proved to be the occasion for researchers from various areas to share ideas, establish collaborations, and address problems with new tools and from original viewpoints, ushering the perspective of a systematic and fruitful scientific cross-fertilisation.

2.3.6 *The physics of strongly interacting matter: Neutron stars, cold atomic gases and related systems*

Date	22-26 April 2024

Organizers

Francesca Ferlaino	University of Innsbruck, Austria
Christopher Pethick	Niels Bohr Institute, Denmark & Nordita, Sweden
Achim Schwenk	TU Darmstadt, Germany
Anna Watts	University of Amsterdam, The Netherlands

Number of participants	34

Main topics

The workshop brought together experts from nuclear physics, astrophysics, and cold atomic gases to develop an improved understanding of the physics of strongly interacting matter, with a particular focus on neutron stars.

The main topics of the workshop were:

- Microscopic calculations of the equation of state
- Insights from other systems such as cold atomic gases
- Observations of neutron stars and neutron star mergers
- Physics of the neutron star crust
- Experimental constraints on neutron-rich matter

Speakers

Adriana Raduta	IFIN-HH Bucharest, Romania
Andreas Bauswein	GSI, Germany
Charles Horowitz	Indiana University, USA
Christoph Eigen	University of Cambridge, UK
Dam Son	University of Chicago, USA
Daniel Pęcak	Warsaw University of Technology, Poland
Elena Poli	University of Innsbruck, Austria
Elinor Kath	University of Heidelberg, Germany
Francesco Marino	University of Mainz, Germany
Gabriel Wlazłowski	Warsaw University of Technology, Poland
György Wolf	Wigner RCP, Hungary
Isak Svensson	TU Darmstadt, Germany
Jocelyn Read	CSU Fullerton, USA
Maciej Galka	University of Heidelberg, Germany

Maria Colonna	INFN-LNS Catania, Italy
Melissa Mendes	TU Darmstadt, Germany
Michael Kramer	MPI for Radio Astronomy, Germany
Nicolas Chamel	Université Libre de Bruxelles, Belgium
Sandro Stringari	University of Trento, Italy
Sebastien Guillot	IRAP/CNRS Toulouse, France
Silas Beane	University of Washington, USA
Thomas Schäfer	North Carolina State University, USA
Wolfram Weise	TU Munich, Germany
Yuki Fujimoto	Institute for Nuclear Theory, USA

Scientific report

The workshop focused on the physics of strongly interacting matter in neutron stars, combining astrophysical observations, advances on the nuclear equation of state, constraints from nuclear experiments, and insights and opportunities with cold atomic gases and related systems.

The wealth of new observations of neutron stars in recent years has given insight into the properties of dense matter. Among recent developments are improved data on their masses and radii from neutron stars in binary systems and from the modulation of the X-ray signal of isolated neutron stars. Observations of the gravitational wave signal from the merging of a neutron star with either another neutron star or a black hole provide another new channel for information about neutron stars.

Complementary to these novel astrophysical constraints, significant progress has been achieved in constraining properties of dense matter based on microscopic calculations and nuclear interactions derived within chiral effective field theory. Such ab initio studies provide constraints for the nuclear symmetry energy, which can also be benchmarked against results from laboratory experiments. These studies are naturally limited to lower densities, up to about nuclear saturation density for neutron-rich systems. This limitation makes it necessary to combine such theoretical constraints with information from observations including laboratory experiments in order to obtain a comprehensive understanding of the equation of state over the full density range relevant for neutron stars.

Interdisciplinary constraints on strongly interacting matter have been obtained with studies of cold atomic gases, in particular for the equation of state of the unitary Fermi gas and superfluid properties. New opportunities are emerging from supersolid phases connecting to the physics of the neutron star crust.

The workshop discussed these strongly interconnected developments in an informal and open atmosphere and with many outstanding contributions from junior scientists.

Results and highlights

The workshop grouped together experts from nuclear physics, astrophysics, and cold atomic gases. The program benefited strongly from talks by junior scientists. The program had ample time for discussions, and all talks are available on the ECT* indico page of the workshop. By all accounts the workshop was a great success. The participants commented in particular that the workshop was very successful in the interdisciplinary discussions triggering new ideas in the respective fields.

The highlights of the workshop included:

- A critical survey of present observational data on neutron star masses, radii, tidal deformability and moments of inertia, to understand all aspects in the modelling processes needed to extract these, and what one can expect from future observations.
- Exploring matter with low proton concentrations encountered in neutron stars at around nuclear density and in imbalanced cold atomic gases.
- Discussions on the physics of the neutron star crust, the dynamics of pasta phases in neutron stars and supersolid phases in cold Fermi gases.
- Constraints on the equation of state at supranuclear densities from experiments and from lattice QCD and perturbative QCD. Discussions on the origin of the maximum in the sound velocity at high densities deduced from observations of neutron stars.
- Constraints on the properties of dense matter from nuclear experiments, both at relatively low energies (e.g., measurements of the thickness of the neutron skin in neutron-rich nuclei) as well as in heavy-ion experiments at higher energies.
- Discussions on possible cold-gas experiments that could illuminate unresolved issues.

2.3.7 *Quantum Science Generation 2024*

Date	6-10 May 2024
Organizers	
Alberto Nardin	LPTMS Université Paris Saclay, France
Alessio Baldazzi	UniTN - Nanolab, Italy
Anna Berti	INO-CNR Pitaevskii BEC Center, INFN, Italy
Carlos Benavides-Riveros	Univ. of Trento, INO-CNR Pitaevskii BEC Center, Italy
Daniele De Bernardis	INO-CNR c/o LENS, Italy
Luca Vespucci	UniTN, INO-CNR Pitaevskii BEC Center, INFN, Italy
Valentina Amitrano	INFN, Ferrara, Italy
Veronica Panizza	UniTN, INO-CNR Pitaevskii BEC Center, INFN, Italy
Number of participants	77

Main Topics

The workshop covered some of the most important aspects of the fast-developing field of quantum technology and provided an equilibrated up-to-date overview of the most active areas of research within this field. These included recent breakthroughs in quantum simulations, the exploration of innovative platforms for near-future quantum technologies, and the development of hybrid quantum algorithms. The workshop was designed to specifically target young researchers at the PhD and postdoc levels, active in quite different areas of quantum science and technologies with the aim of promoting and initiating fruitful interactions. We scheduled talks given by senior and junior invited speakers, in addition to further contributions selected among all the participants. Importantly, we had special contributed talks from company and start-up representatives working on several industrial applications of quantum science.

Key topics covered during the workshop included:

- advancements in quantum computing and simulations
- evolution of novel platforms for quantum technologies
- hybrid quantum algorithms for optimization challenges
- industrial applications of leading-edge quantum technologies

Speakers

Senior speakers:
- Artur Izmaylov (University of Toronto, Canada)
- Carlo Sias (LENS, INRiM, Florence, Italy)
- Claudiu Genes (Max Planck Institute for the Science of Light, Erlangen, Germany)
- Frank Pollmann (Technische Universität München, Germany)
- Giuseppe Vallone (Università di Padova, Italy)
- Nathan Wiebe (University of Toronto, Canada)
- Virginia D'Auria (Institut de Physique de Nice, France)

Junior speakers:
- Christian Schilling (LMU Munich, Germany)
- Denis Vasilyev (Innsbruck, Austria)
- Francesco Preti (Forschungszentrum Jülich, Germany)
- Gian Marcello Andolina (Collège de France)
- Giuliano Chiriacò (Università di Catania, Italy)
- Jeremy C. Adcock (University of Bristol, UK)
- Maja Colautti (INO-CNR and Università di Firenze, Italy)
- Marco Govoni (Modena, Italy)
- Markus Schmitt (Regensburg, Germany)
- Matthew Eiles (MPI-PKS, Dresden, Germany)
- Oriel Kiss (CERN, Switzerland)
- Taira Giordani (Sapienza University of Rome, Italy)

  + 20 submitted abstracts

Companies (speakers):
- APS - American Physical Society (speaker Mauro Schiulaz)
- Kipu Quantum - Quantum computing for early industrial usefulness (speaker Enrique Solano, CVO)
- Optica - Leading society in optics and photonics (delegate Yann Amouroux)
- Planckian - Powering quantum science (speaker Marco Polini, Chief Scientific Officer)
- QTI - Quantum Telecommunications Italy (speaker Claudio Pereti)
- Single Quantum - Excellence in photon detection (speaker Federica Facchin)
- Think Quantum - Quantum Technologies for Cyber Security (speaker Simone Capeleto, Co-founder & CEO)

Scientific report

The workshop was the second edition of Quantum Science Generation, following the 2023 edition also organized at the premises of ECT* in May 2023. The aim of QSG 2024 was to provide a platform for leading experts, researchers, and practitioners to share their insights, ideas, and recent contributions to the field of quantum science and technology. This report offers a summary of the key topics discussed during the conference, focusing in particular on five distinct areas:

(1) Quantum technologies with superconducting circuits: during the workshop significant advancements in quantum technologies utilizing superconducting circuits were presented and discussed. In particular, the workshop featured discussions on the ultrastrong coupling regime of superconducting-circuit quantum electrodynamics and the mathematical methods employed to analyze and manipulate it. Attendees explored further potential applications of superconducting circuits in quantum computation and quantum simulation.

(2) Quantum-computational methods for quantum many-body systems: the conference highlighted the importance of novel and future quantum-computational methods for studying many-body problems in quantum science. Experts presented advances in the variational ansatz for correlated many-body systems, such as chemical compounds, correlated electronic systems and complex classical systems, where truly quantum advantage can be shown to exist. Discussions revolved around the need to develop efficient algorithms and high-performance computing approaches, and to improve unitary (e.g., coupled-cluster) ansätze. Current challenges and opportunities for tackling quantum many-body problems towards real applications were also discussed.

(3) Quantum algorithms: recent progress in finding quantum advantage for the simulation of classical problems were discussed in depth during the workshop.

(4) Advancements in photonics emerged as a vital area of research at the worshop. Participants explored the problem of creation of entangled photon states using ions and quantum dots, with an emphasis on experimental achievements and the potential for scalable quantum information processing.

(5) Recent developments in quantum optics, trapped ions & hybrid platforms and Rydberg atom arrays. The workshop was successful in showcasing recent advances in quantum optics and the fields of trapped ions & hybrid platforms and Rydberg atom arrays. Researchers presented not only cutting-edge techniques for manipulating ultracold atomic gases or controlling quantum materials, but also novel numerical methodologies and theoretical methodologies to simulate those quantum systems. Follow-up discussions encompassed applications such for quantum simulation or quantum information processing, and the exploration of exotic quantum phases.

During the workshop, we also had discussions on quantum key distribution for cryptographic applications, quantum error correction, quantum state preparation, Rydberg molecules, counteradiabatic quantum simulations, and striking physical properties of quantum many-body systems, including bosonic and fermionic mixtures. To sum up, the workshop covered diverse topics, ranging from quantum technologies with superconducting circuits and cavity-induced modifications of matter to quantum chemistry where computational methods for many-body problems are crucial. The workshop also addressed advances in photonics and single-photon technology, as well as recent developments in quantum optics and Rydberg (atom and molecule) arrays.

We believe the insights and lively discussions of our workshop are poised to shape the future of quantum science and technology, fueling further progress and innovation in the field. The diverse collection of topics put together during the week in Trento made our workshop a unique venue to promote cross-fertilization between different subfields. All in all, QSG 2024 was very successful in bringing together world-leading experts, researchers and students to share their knowledge, recent progress and curiosity about quantum science and related technologies.

Results and highlights

QSG 2024 proved to be a truly scientific success due not only to its broad range of topics but also to the intensive knowledge exchange between disciplines within quantum science and technology. Factors contributing to the conference's success included the generation of new ideas and projects through interdisciplinary discussions, as well as the significant presence of senior and young speakers who brought fresh perspectives and cutting-edge research ideas to the forefront. The diverse range of subjects facilitated cross-fertilization 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 purpose of innovative projects and ideas.

The engagement of young speakers combined with all the social activities proposed by the organizers (two aperitif poster sessions, a social dinner, and a visit to a local winery) also created an ideal environment conducive to mentorship and networking. Established, world-leading researchers readily engaged with younger 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. It is also worth mentioning that many open positions were announced during the conference, which in turn proved that the workshop is important to help the students to enhance their future career prospects. The presence of representatives of six international quantum technological start-ups furthered the ambitious scope of the workshop.

In conclusion, QSG 2024 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.

2.3.8 *SPICE: Strange hadrons as a Precision tool for strongly InteraCting systEms*

Date	13-17 May 2024

Organizers

Benjamin Doenigus	University Frankfurt, Germany
Catalina Curceanu	LNF-INFN Frascati, Italy
Fuminori Sakuma	RIKEN Nishina Center of Accelerator-Based Science, Japan
Isaac Vidana	INFN Catania, Italy
Josef Pochodzalla	University Mainz, Germany (chair)
Laura Fabbietti	TU Munich, Germany
Satoshi Nakamura	University Tokyo, Japan

Number of participants	51

Main topics

Neutron stars are rich laboratories for physics, combining all four fundamental interactions and many phenomena associated with them under extreme conditions. One of the most intriguing questions is: what type of matter do we find in the core of such a compact object? One of the conceivable composition is strangeness-dominated hadronic matter. However, the determination of the EOS of such neutral hadronic matter remains, even after many decades of research, one of the biggest challenges. Hadrons with strangeness embedded in the nuclear environment, hypernuclei, strange atoms, and multiparticle correlations are the most relevant terrestrial laboratories to approach the many-body aspect of the three-flavor strong interaction in the laboratory. The goal of the workshop was to assess the present status of the field, to agree upon future cutting-edge studies and to define the experimental objectives. The workshop helped to identify potential synergies between the different activities, which might set the framework for new networking activities between researchers.

The three main topics were

- Recent results and future planned experiments on hypernuclei
- Femtoscopy to study hyperon-nucleon interactions
- Status of and prospects for kaonic nuclear systems

Speakers

Carlos Bertulani	Texas A&M University-Commerce, USA
Damir Bosnar	University of Zagreb, Croatia
Raffaele Del Grande	Technical University Munich, Germany
Andrea Di Donna	TIFPA–UniTN, Italy

Albert Feijoo	TU Munich, Germany
Alessandra Filippi	INFN Torino, Italy
Avraham Gal	Hebrew University, Jerusalem, Israel
Daniel Gazda	Nuclear Physics Institute CAS, Czech Republic
Toshiyuki Gogami	Kyoto University, Japan
Fabian Hildenbrand	FZ Jülich, Germany
Emiko Hiyama	Tohoku/RIKEN, Japan
Yudai Ichikawa	Tohoku University, Japan
Masahiro Isaka	Hosei University, Japan
Asanosuke Jinno	Kyoto University, Japan
Ayumi Kasagi	Rikkyo University, Japan
Alejandro Kievsky	INFN Pisa, Italy
Ryoko Kino	Tohoku University, Japan
Rimantas Lazauskas	IPHC, CNRS, Strasbourg, France
Horst Lenske	U. Giessen, Germany
Valentina Mantovani Sarti	TU Munich, Germany
Francesco Mazzaschi	CERN, Switzerland
Marco Merafina	University of Rome La Sapienza - Department of Physics, Italy
Han Miao	Institute of High Energy Physics, China
Koji Miwa	Tohoku University, Japan
Kotaro Murakam	Tokyo Institute of Technology, Japan
Sho Nagao	University of Tokyo, Japan
Andreas Nogga	IAS-4, Forschungszentrum Jülich, Germany
Jaroslava Obertova	FNSPE CTU in Prague, Czech Republic
Assumpta Parreño Garcia	University of Barcelona, Spain
Xiu-Lei Ren	Helmholtz-Institut Mainz, Germany
Takehiko Saito	RIKEN and GSI, Japan and Germany
Sakuma, Fuminori	RIKEN Nishina Center of Accelerator-Based Science, Germany
Martin Schafer	Nuclear Physics Institute of the CAS, Rez, Czech Republic
Alessandro Scordo	Laboratori Nazionali di Frascati INFN, Italy
Takayasu Sekihara	Kyoto Prefectural University, Japan
Francesco Sgaramella	INFN-LNF, Italy
Tianhao Shao	JGU Mainz, Germany
Nina Shevchenko	Nuclear physics institute, Rez, Czech Republic
Florin Sirghi	INFN-LNF, Italy
Dalibor Skoupil	NPI CAS, Czech Republic
Simon Spies	Goethe-University Frankfurt, Germany
Kiyoshi Tanida	Japan Atomic Energy Agency, Japan
Laura Tolos	ICE (CSIC, Barcelona), Spain
Junko Yamagata-Sekihara	Kyoto Sangyo University, Japan

Scientific report

Hadrons with strangeness embedded in the nuclear environment, hypernuclei or strange atoms, are the only available tool to approach the many-body aspect of the three-flavor strong interaction. During the first two decades of hypernuclear research, nuclear emulsions were the main source of information about hypernuclei. Even today, data from emulsions still provide for many hypernuclei the most precise information on their binding energy. Around the turn of the century high-resolution γ-spectroscopy of hypernuclei with germanium detectors became the most important tool for decay studies. These measurements provide precise information on the level schemes of various hypernuclei and allowed to extract different spin-dependent components of the Λ-nucleon interaction. On the other hand, employing quasi two-body kinematics, ground and excited hypernuclear states can be identified by a missing-mass analysis of the incident beam and the observed associated meson. Since these reactions require stable target nuclei, the hypernuclei accessible by these reactions lie on or near the β-stability line. Even though a number of new experimental techniques have been pioneered in the field of hypernuclear physics in the last decade, our knowledge is still limited to a small number of hypernuclei. Furthermore, the number of observed events is often rather low and in many cases also the resolution is limited. Luckily, several experiments planned or already operative at various laboratories (JLab, J-PARC, FAIR) all over the world will help to enter the high precision and high statistics era of strangeness nuclear physics. The complementarity of these different experimental approaches and the guidance by state-of-the-art theories will provide a wide basis for a comprehensive understanding of strange hadrons in cold hadronic matter. During the workshop several speakers presented these new proposals.

Three topics were in the focus of this workshop:

- Production and structure of light hypernuclei
- Femtoscopic studies of two-body interactions in SU(3)
- Kaon-nucleon interactions and kaonic atoms

In addition to these main themes there were a number of other subjects covered in the workshop, represented by one or a few speakers each, including the role of hyperons in neutron stars and extremely neutron-rich conventional nuclei.

Result and highlights

In the following we summarize the three main themes addressed in the workshop:

The lightest hypernucleus $^{3}_{\Lambda}H$

The lightest hypernucleus $^{3}_{\Lambda}H$, the hypertriton consisting of a proton, a neutron and a Λ hyperon, was addressed in several talks during the meeting. This and other light hypernuclei are particularly interesting since not only phenomenological models but also ab initio studies based on chiral effective field theory including three-baryon forces can be performed. Furthermore, lattice quantum chromodynamics calculations are within reach for such nuclei. A profound understanding of the lightest hypernuclei is a cornerstone for any strong-interaction theory dealing with strange baryons. A precise and accurate measurement of the hypertriton binding energy gains further relevance by recent hypernuclear studies in ultra-relativistic heavy-ion collisions. The large size of the 'ultimate halo nucleus' ${}^{3}_{\Lambda}H$ makes it a unique probe for the fragment formation process in ultra-relativistic heavy ion collisions. In the coming years, several experiments will produce more precise and accurate lifetime and binding energy data of the hypertriton. The WASA-FRS Collaboration at GSI/FAIR, the P73/P77 collaboration at J-PARC, ALICE during LHC Run3 and Run4, and an experiment at ELPH at the Tohoku University will improve our knowledge on the lifetime of ${}^{3}_{\Lambda}H$ and ${}^{4}_{\Lambda}H$. One of the activities of the Extension Project for the J-PARC Hadron Experimental Facility is focussing on γ-ray spectroscopy of hypernuclei and will search for the γ-ray transitions of ${}^{3}_{\Lambda}H$. A unique experiment at R3B spectrometer of GSI/FAIR will probe the Λ halo structure of ${}^{3}_{\Lambda}H$. New and accurate measurements of the ${}^{3}_{\Lambda}H$ binding energy are expected from the Mainz Microtron (MAMI), JLab, ALICE, and the J-PARC E07 emulsion experiment. These many attempts attest to the importance of the hypertriton as a benchmark for any hypernuclear structure calculation.

Two- and multi-particle hyperon correlations

Recently, a new methodology has been developed to study the strong interaction for two- and three-body unbound hadron systems. Correlations in momentum space measured in p-p and p-Pb collisions at the most violent energy available to this end at the LHC and AGS have been exploited to validate for the first time lattice calculations of the nucleon-ϕ, nucleon-Ξ and nucleon-Ω interactions. Very precise data for the p-Λ and p-K correlations have complemented low statistics scattering data with highly precise measurements and these measurements can be used today to constrain more precisely chiral effective models. The future perspective in this field is to exploit the high statistics expected from the Run 3 campaign at the LHC and the newly upgraded high-rate ALICE detector to be able to investigate the so far poorly known nucleon-Σ interaction. The program also includes the investigation of three body forces by means of the measurement of the momentum correlation for triplets such as p-p-Λ or p-p-Σ, but also exploiting deuteron-Λ and deuteron-Σ correlations to investigate the isospin dependence of the three-body force. These studies are accompanied by elementary scattering experiments as well as modern theoretical developments.

Kaonic atoms

Among strange exotic atoms, the kaonic ones play a special role, since they permit linking the isospin-dependent scattering lengths to the kaon-nucleus potential below threshold. In the coming years experiments both at the DAFNE collider at INFN-LNF (SIDDHARTA-2) and at J-PARC (E57) will perform the first measurement of kaonic deuterium transitions, which will help to separate the isoscalar and isovector parts of the antikaon-nucleon scattering length. Future measurements, along the whole periodic table, going from light to heavy exotic strange atoms will be possible by using a series of complementary radiation detector systems recently developed. The new data base of kaonic atoms will become a bedrock for low-energy QCD.

2.3.9 *Beyond-Eikonal Methods in High-Energy Scattering*

Date	20-24 May 2024

Organizers

Alina Czajka	National Centre for Nuclear Research, Warsaw, Poland
Jamal Jalilian-Marian	Baruch College, CUNY, USA
Yuri V. Kovchegov	The Ohio State University, USA

Number of participants	25

Main topics

- Sub-eikonal (order-x) corrections to particle production in high-energy collisions
- Proton spin physics at small x
- Intersections of small- and large-x physics, unification of DGLAP and small-x evolution

Speakers

Daniel Adamiak	Jefferson Lab, USA
Pedro Agostini	IGFAE/USC, Spain & Nat. Centre for Nuclear Research, Poland
Tolga Altinoluk	National Centre for Nuclear Research, Poland
Ian Balitsky	Old Dominion University/Jefferson Lab, USA
Guillaume Beuf	National Centre for Nuclear Research, Poland
Giovanni Chirilli	University of Salento, Italy
Florian Cougoulic	University of Santiago de Compostela, Spain
Xabier Feal	IGFAE/USC, Spain
Yoshitaka Hatta	Brookhaven National Lab, USA
Ming Li	Ohio State University, USA
Tiyasa Kar	North Carolina State University, USA
Alexander Kovner	University of Connecticut, USA
Michael Lublinsky	Ben-Gurion University of the Negev, Israel
Yacine Mehtar-Tani	Brookhaven National Lab, USA
Swaleha Mulani	National Centre for Nuclear Research, Poland
M. Gabriel Santiago	Center for Nuclear Femtography, USA
Vladimir Skokov	North Carolina State University, USA
Yossathorn Tawabutr	University of Jyväskylä, Finland
D. Triantafyllopoulos	ECT*, Italy
Bowen Xiao	CUHK-Shenzhen, China
Feng Yuan	Lawrence Berkeley National Lab, USA

Scientific report

The goal of the workshop was to discuss small-x physics in the beyond-eikonal approximation. By going beyond the eikonal approximation, one concentrates on the phenomena suppressed by one or more powers of Bjorken x which are usually neglected in the traditional eikonal small- x physics. These phenomena include mainly two regions of high-energy physics. The first one is the proton spin structure involving the spin-dependent PDFs and TMDs, and the efforts aim at solving the spin puzzle at small x. The other topic focuses on effects with the power-of-x corrections to the eikonal scattering on a dense nucleus, which are enhanced by the powers of the atomic number of the nucleus. As a result of going to beyond-eikonal limit, the longitudinal structure of a Lorentz contracted nucleus has to be studied in detail. In addition, attempts at unifying large-x and small-x evolution were also discussed. All efforts to understand these phenomena are central to physics which will be probed at the future Electron-Ion Collider (EIC), where center-of-mass energies will not be very high and thus allow for resolving subtle effects at beyond-eikonal accuracy.

During the five-day workshop, we discussed the structures of beyond-eikonal corrections to high-energy scattering processes, their origin, meaning and consistency between different approaches to study them. Three main formalisms to calculate beyond-eikonal quantities were presented as well. One is due to the Warsaw group (T. Altinoluk, G. Beuf, A. Czajka, aka the ABC formalism), another one was developed by G. Chirilli, and yet another one by the Ohio State group (Y. Kovchegov, D. Pitonyak, M. Sievert, F. Cougoulic, M.G. Santiago, A. Tarasov, Y. Tawabutr). (Another formalism recently developed by M. Li was mentioned as well.) The community greatly benefited from this apples-to-apples comparison of different algorithms.

Particle production processes discussed included dijet and gluon production, with the latter studied in the context of the double longitudinal spin asymmetries. Higher-order corrections to the hybrid (collinear + small-x) formalism for forward particle production also received considerable attention. Signals of saturation physics using dijet production were explored too.

Small-x evolution for spin and orbital angular momentum-dependent observables were also discussed, along with their phenomenology, spin-orbit correlations, and leading-twist quark TMDs at small x.

Efforts at unifying large- and small-x physics were discussed as well. Those included Sudakov resummation, TMD factorization and evolution.

Results and highlights

Comparison of different formalisms uncovered a good amount of overlap between them. Still, helicity evolution equations obtained by G. Chirilli still do not quite agree with those obtained by the Ohio State group. Note that the latter agrees with existing polarized DGLAP anomalous dimensions to three loops, while it was pointed out that the former approach cannot yet derive the leading-order DGLAP evolution as a limit of their evolution.

The Warsaw and Chirilli formalisms have a sub-eikonal operator F^{+-}, which is absent in the Ohio State groups sub-eikonal formalism. While the Ohio State group recognizes that such operator does enter high-energy scattering, they believe it enters the physical observables along with PDFs and TMDs at the sub-sub-eikonal order. Further discussions and work are needed to settle this question.

There was an overall agreement that a large number of sub-eikonal contributions to particle production cross sections has been found by the assembled researchers. This thrust of sub-eikonal research appears to be ready for phenomenological applications, both in the unpolarized and longitudinal spin-dependent cases. In the spin-dependent case, the phenomenology would also be further improved by the recently derived helicity evolution equations.

Unification of small-x and large-x physics is still a work in progress. The participants could not even agree on the right operator definition for the TMDs which would interpolate between the two limits. Indeed, this is a very challenging problem. We will need to organize several more workshops at ECT* in order to solve it.

2.3.10 *Machine Learning and the Renormalization Group*

Date	27-31 May 2024
Organizers	
Julian Urban	MIT, USA
Daniel Hackett	Fermilab, USA
Jan Pawlowski	University of Heidelberg, Germany
Biagio Lucini	University of Swansea, Germany
Anna Hasenfratz	University Colorado Boulder, USA
Number of participants	28

Main topics

This interdisciplinary workshop concerned the relationship between modern machine learning (ML) approaches and renormalization group (RG) theory. On the one hand, this refers to practical applications of RG concepts and ideas in the construction and training of deep neural network architectures for different purposes, as well as using ML algorithms to define RG-like transformations for various types of synthetic and real-world data. On the other hand, RG techniques and more generally the machinery of quantum field theory (QFT) can be used to achieve a better theoretical understanding of deep neural networks at initialization as well as during and after optimization. Both types of perspectives were explored in a series of talks from experts working in a variety of scientific areas.

The main topics were:

- Applying RG methods to the theory of deep learning
- RG-inspired ML architectures
- ML-assisted RG methods for lattice QFT and beyond
- Functional RG and optimal transport
- RG perspectives on diffusion models

Speakers

Harold Erbin	CEA-IPHT, France
Friederike Ihssen	University Heidelberg, Germany
Maciej Koch-Janusz	Haiqu Inc., USA
Anindita Maiti	Perimeter Institute, Canada
Raffaello Potestio	University of Trento, Italy
Dimitrios Bachtis	ENS Paris, France
Nicolo Defenu	ETH Zurich, Switzerland
Misaki Ozawa	CNRS, France

Jim Halverson	Northeastern University, USA
Kieran Holland	University Pacific, USA
Urs Wenger	University Bern, Switzerland
Jacob Finkenrath	University Wuppertal, Germany
Fernando Romero-Lopez	MIT, USA
Jascha Sohl-Dickstein	Anthropic, USA
Sho Yaida	Meta AI, USA
Kai Zhou	CUHK-Shenzen, China
Semon Rezchikov	University Princeton, USA
Xavier Crean	University Swansea, UK
Lingxiao Wang	RIKEN, Japan
Ouraman Hajizadeh	Leftshift One, Austria
Gert Aarts	University Swansea, UK

Scientific report

Although RG methods were originally developed specifically for the study of divergences in high-energy physics and later also critical phenomena in statistical mechanics, similar ideas and techniques can be useful in a wide variety of scientific contexts. In particular, the coarse-graining or information-compression rationale seems to underlie many of the empirically successful ML architectures developed in the past two decades. This is most apparent in models that exhibit an a priori hierarchical structure and are trained with optimization objectives geared towards learning efficient internal representations of high-dimensional features, e.g. within natural image data. Similarly, research into generative modeling with normalizing flows for lattice field theory can be understood within the framework of trivializing maps and the associated RG flow or decimation interpretation. Furthermore, straightforward connections between powerful diffusion models and stochastic quantization based on Fokker-Planck/Langevin-type stochastic differential equations provide a natural avenue for the application of RG concepts. This also extends to recent efforts towards establishing theoretical insight into the emergent structure and dynamics of deep neural networks themselves, as well as overparameterized probabilistic models in general. Of particular interest in this regard is recent work on utilizing the machinery of QFT and non-perturbative functional RG methods for the characterization of non-Gaussian corrections to the infinite-width limit. On the other hand, the information bottleneck theory approach to understanding deep learning appears to also have formal and intuitive connections to the RG paradigm that are just now starting to be investigated. Finally, the recently uncovered mathematical equivalences of certain functional RG equations and optimal transport problems provide an exciting new arena for the exploration of novel ideas, with potentially far-reaching implications for practical applications.

While a rigorous mathematical understanding of the equivalences and differences between the intuitively related concepts of ML and the RG is both necessary and instructive, establishing strict technical criteria concerning what does and does not constitute renormalization in this context was not the main intention of this workshop. Rather, we aimed to provide an open platform for the discussion of all ML-related research which has an RG ‘flavor’, and encouraged submissions from all corners of the computational sciences where the identification of relevant directions or collective degrees of freedom in high-dimensional spaces constitutes a central theme. The eventual programme of the event reflected this aim, with experts from a variety of scientific areas presenting research into many different aspects of the spectrum of ideas relating ML and RG concepts.

Result and highlights

The primary goal of this workshop was a synchronization effort across a wide range of scientific fields, bringing together like-minded individuals who apply RG techniques and ideas to a variety of different computational and theoretical problems in their ML-related research. Feedback by participants was very positive and the event was arguably a success, featuring many excellent presentations and lively discussions. Interesting connections between largely unrelated work were identified, sparking new ideas and potential future collaborative efforts. The workshop enabled participants to achieve both an improved technical understanding of RG theory and its formal relation to various ML algorithms, as well as to inform themselves about the landscape of related ideas and research efforts.

2.3.11 *A Modern Odyssey: Quantum gravity meets quantum collapse at atomic and nuclear physics energy scales in the cosmic silence*

Date	3-7 June 2024

Organizers

Angelo Bassi	University and INFN Trieste, Italy
Antonino Marciano	FUDAN Univ. China and INFN-LNF Frascati, Italy
Catalina Curceanu	INFN-LNF, Frascati, Italy
Kristian Piscicchia	CREF, Rome and INFN-LNF, Frascati, Italy
Lajos Diósi	Wigner RCP and Eötvös Loránd Univ. Budapest, Hungary
Laura Baudis	University of Zurich, Switzerland

Number of participants	27

Main topics

The main topic of the workshop was to discuss the interplay between quantum gravity and quantum collapse models, in particular in relation to nuclear and atomic physics energy scale signatures for experiments in underground laboratories, which, thanks to their extreme precision, can test theories beyond the Standard Model facing the clash between quantum theory and gravity. Following topics were discussed: effective quantum gravity models; relation with spin-statistics and its possible violation; experimental signatures from QG models; experimental testing at low-energy scale; comparison with astrophysical observations; future possible experiments and theoretical developments.

Speakers

Alexander Bismark	University of Zurich, Switzerland
Andrea Vinante	Istituto di Fotonica e Nanotecnologie (IFN-CNR), Trento, & FBK, Italy
Antoine Tilloy	Mines Paris - PSL, France
Antonino Marciano	Fudan University, China & INFN, Italy
Aurelian Isar	Institute of Physics and Nuclear Engineering (IFIN-HH), Romania
Carmine De Rosa	Università di Trento, Italy
Catalina Curceanu	LNF - INFN Frascati, Italy
Fabrizio Piacentini	INRIM - Istituto Nazionale di Ricerca Metrologica, Italy
Felix Finster	University of Regensburg, Germany

Francesco Artibani	Laboratori Nazionali di Frascati - INFN & Roma Tre University, Italy
Francesco Sgaramella	INFN-LNF, Italy
José Luis Gaona Reyes	Università degli Studi di Trieste, Italy
Kristian Piscicchia	Centro Studi e Ricerche “Enrico Fermi” & LNF (INFN), Italy
Lajos Diósi	Wigner Research Center for Physics & Eötvös Loránd University, Hungary
Laria Figurato	Università di Trieste, Italy
Lorenzo Pettinari	University of Trento, Italy
Luca De Paolis	LNF-INFN, Italy
Nicola Bortolotti	Sapienza University, Centro ricerche Enrico Fermi (CREF), Italy
Pierluigi Belli	INFN Roma Tor Vergata, Italy
Siddhant Das	Faculty of Physics, Ludwig-Maximilians-Universität München, Germany
Simone Manti	INFN LNF, Italy
Tejinder Singh	IUCAA, Pune University, India
Roger Penrose (online)	Oxford University, UK
Ugo Moschella	Università dell’Insubria, Italy

Scientific report

The workshop gathered together in the excellent and stimulating ECT* environment, for the first time in a dedicated and focused meeting to discuss the interplay between quantum physics and gravity: i) experimentalists working in atomic and nuclear physics experiments, part of them performed in underground laboratories, testing physics beyond the Standard Model, and ii) theorists who develop quantum gravity (QG) models and quantum collapse (QC) theories that predict effects, which are special signatures of the models and can be measured in atomic and nuclear physics experiments in the cosmic silence (i.e. underground laboratories) as well as in other laboratories (such as those at FBK in Trento)

It was discussed that from the QG theoretical perspective, the optimal phenomenological framework to be invoked while developing most of these models is connected to non-commutative space-time variables, which may induce deformation of the CPT and discrete symmetries, translated as violations of the spin-statistics connection, resulting in atomic and nuclear transitions that violate the Pauli exclusion principle, which can be tested in high precision measurements in underground laboratories. Experiments studying these effects (VIP, GATOR, DAMA/LIBRA) were thoroughly discussed.

On the other side, QC models, proposed as solutions of the “measurement problem” in quantum physics, with some of the models relating collapse with gravity, also predict specific signatures, such as spontaneous radiation, which can be ideally addressed in atomic and nuclear physics experiments in underground laboratories, as discussed by Diosi; Penrose added to the discussion future possible developments.

The workshop gathered together the communities of theorists and experimentalists (see list of speakers) working in quantum physics and gravity, and set the ideal arena for discussing the interplay between the quantum gravity and quantum collapse in the unitary framework of atomic and nuclear physics experiments performed underground. Experiments as VIP, DAMA/LIBRA, XENON, GATOR proved to be extremely efficient in testing both classes of theories. More and more realistic quantum gravity and quantum collapse models are being developed which need experimental verification. On theoretical side, among the various arguments, the following were discussed: gaussian quantum entanglement in curved spacetime; effectiveness of collapse in the Diósi-Penrose model; incorporating a spontaneous collapse mechanism in a Wheeler-DeWitt equation; causal fermion systems as a dynamical collapse theory.

While theories continue to be developed or refined, future experiments in Italy, USA, Japan, China, and Australia, such as JUNO, SABRE and LEGEND, may strengthen the experimental limits on our theories beyond the Standard Model and open broader scenarios, providing a glimpse on a new theory.

During the workshop two round tables were dedicated to the interplay between gravity and collapse; theory and experiments.

Results and highlights

The workshop was extremely timely and very successful; it succeeded in bringing together, for the first time in a dedicated and unique framework, world-leading experts and young scientists who belong to two very different research communities: experimentalists and theorists active in (high-precision measurements of) nuclear and atomic physics based experiments performed in underground laboratories as well as other laboratories as table-top experiments, for example in levitated magnetomechanics, and theorists working in quantum foundations and quantum gravity (string theory and loop quantization) phenomenology.

The main scientific result of the workshop was to contribute to the investigation of the biggest mesmerizing open questions in modern physics, namely the interplay between quantum physics and general relativity (i.e. gravity), in connection to experimental signatures in extreme precision nuclear and atomic physics experiments presently being performed (or planned to be performed) in underground laboratories and other laboratories with table-top apparatuses. In particular, we investigated in detail how experiments testing the possible Pauli exclusion principle violation in atomic and nuclear transitions and how measurements of spontaneous radiation can encode signatures of quantum gravity models, including possible deviations from the Lorentz invariance and the existence of extra dimensions, as well as signatures of dynamic collapse models, in particular of the dissipative and non-Markovian ones, which are being recently developed. We also discussed within two round tables organized during the workshop which experiments could better tests quantum gravity and quantum collapse models and in which regime, towards the rising of a global strategy facing quantum foundations in underground laboratories, a topic which was recently recognized as a third pillar in the physics investigated in the cosmic silence (in underground laboratory) – as also demonstrated by the inclusion of this topic in the

Snowmass 2021 Topical Report on Synergies in Research at Underground Facilities (e-Print:2210.03145, 2022).

The young participants to the workshop, in particular early career scientists and PhD students, did benefit from the workshop also by receiving training from the experts in the sectors that were present in the workshop, and, consequently, increased their knowledge and established new contacts towards new research opportunities.

2.3.12 *Diffraction and Gluon Saturation at the LHC and the EIC*

Date	10-14 June 2024

Organizers

Abhay Deshpande	Stony Brook University, USA
Agustín Sabio Vera	Universidad Autónoma de Madrid, Spain
Christophe Royon	University of Kansas, USA
Martin Hentschinski	Universidad de las Américas Puebla, Mexico
Sören Schlichting	Universität Bielefeld, Germany

Number of participants	31

Main topics

The main topic the workshop addressed are QCD at high gluon densities and diffraction at the Large Hadron Collider (LHC) and the future Electron-Ion Collider (EIC), which is currently being built in the US at Brookhaven National Laboratory. Both collider experiments allow to study collisions of both protons and heavy ions which is highly beneficial for the study of saturation phenomena. It will allow to study those phenomena for heavier ions such as Pb or Au and compare the results to lighter ions such as He or Ar. Saturation phenomena refer here to the exploration of strong interaction in a novel regime, characterized by high gluon densities and potential strong collective phenomena. Exploration of this new regime is of particular interest since it allows to explore the non-linear structure of Quantum Chromodynamics (QCD) in a weak coupling set-up. Here QCD denotes the microscopic theory of strong interactions formulated in terms of quark and gluon degrees of freedom. In the weak coupling limit, QCD allows for a controlled perturbative expansion and recent calculations within the Color Glass Condensate framework at next-to-leading order make predictions more reliable. QCD evolution equations predict that at sufficiently high energies, hadronic matter will turn so dense that the gluon occupation number saturates, i.e., reaches the maximal value permitted by the gluon mutual repulsion. This dense system of gluons is practically unexplored experimentally and the best observables to observe these new phenomena have still to be defined. Diffractive events are events where protons or ions are intact in the final state and can be measured directly using roman pot detectors or using the rapidity-gap method. They allow for a further exploration of the odderon, which has been recently discovered by the D0 and TOTEM experiments. In the case where the final state consists of the intact initial hadrons with an additionally produced vector meson, such events allow for the further exploration of non-linear QCD dynamics in photon-nucleus collisions at the LHC. In addition, complementary diffractive studies in a wide kinematical region of the LHC and the EIC allow to constrain better the pomeron structure in terms of quarks and gluons by studying double pomeron exchange and single diffractive events, e.g. the measurement of diffractive structure functions F_2^D and F_L^D at the EIC. Finally, photon exchange events allow to strengthen bounds on beyond the Standard Model physics, e.g. extra-dimensions and axion-like particles through a measurement of diphotons at high mass.

Speakers

Abhishek Rajak	Queen Mary University of London, UK
Alessandro Papa	Università della Calabria & INFN-Cosenza, Italy
Alexander Bylinkin	University of Bergen, Norway
Anna Stasto	Penn State, USA
Carlisle Aurabelle Casuga	University of Jyväskylä, Finland
Christophe Royon	University of Kansas, USA
Cristian Baldenegro	Sapienza Università di Roma, Italy
Daniel Ernani Martins Neto	IFJ - PAN Kraków, Poland
Dionysios Triantafyllopoulos	ECT*, Italy
Edmond Iancu	IPhT Saclay, France
Feng Yuan	Lawrence Berkeley National Laboratory, USA
Frigyes Nemes	CERN, Switzerland
Georgios Krintiras	University of Kansas, USA
Gian Michele Innocenti	MIT, USA
Giulia Pancheri	INFN Frascati National Laboratories, Italy
Grigorios Chachamis	LIP Lisbon, Portugal, online participation
Heikki Mäntysaari	University of Jyväskylä, Finland
István Szanyi	Eötvös University, Hungary and University of Kansas, USA
Jani Penttala	UCLA, USA
Jarno Vierros	University of Kansas, USA
Krzysztof Kutak	IFJ - PAN Kraków, Poland
Lydia Beresford	DESY, Germany
Maciej Trzebinski	IFJ - PAN Kraków, Poland
Martin Hentschinski	Universidad de Las Americas Puebla, Mexico
Michael Fucilla	Saclay, France
Michael Pitt	University of Kansas, USA
Minjung Kim	UC Berkeley, USA
Nicolas Strangmann	Goethe University Frankfurt, Germany
Ronan McNulty	University College Dublin, Ireland
Sanjin Benic	University of Zagreb, Croatia
Tamas Csorgo	Gyongyos and Wigner RCP, Budapest, Hungary
Tuomas Lappi	University of Jyväskylä, Finland
Valeri Khoze	IPPP, Durham University, UK

Scientific report

The first day of the workshop was dedicated to diffraction and the odderon discovery. Frigyes Nemes reviewed the discovery of the odderon by the TOTEM and D0 collaborations. Sanjin Benic discussed the possibilities to observe the odderon in electron-proton scattering through the observation of exclusive χ_c production and predicted a few dozen events per month at the EIC, operating at highest energy and highest luminosity. While an observation at HERA was not possible, higher luminosity of the EIC should potentially allow for observation. Tamas Csorgo and István Szanyi discussed the use of Levy distributions in elastic proton-proton collisions. Anna Stasto and Feng Yuan initiated the theory discussion on hard diffraction. Anna Stasto presented results on the extraction of the reggeon contribution in the determination of the diffractive parton distribution functions, while Feng Yuan addressed the possibility to calculate diffractive parton distributions with and without transverse-momentum dependence from low x dipole amplitudes. Maciej Trzebinski and Daniel Ernani Martins Neto provided finally experimental results for hard diffraction. Maciej Trzebinski summed up recent ATLAS forward detector results, while Daniel Ernani Martins Neto presented results on diffractive top-quark pair production.

The discussion of hard diffraction continued the second day, with a presentation by Cristian Baldenegro on photonuclear jets, measured by both ATLAS and CMS collaboration, and on single diffractive dijets (both ATLAS and CMS), as well as results on so-called jet-gap-jet events (measured by the CMS collaboration). Christophe Royon addressed in his talk apart from jet-gap-jet events also Mueller-Navelet jets and forward-jet measurements. The follow-up discussion was then dedicated to the jet observables and their use to observe signs of BFKL evolution. Valeri Khoze addressed various aspects of the phenomenology of events with large rapidity gaps, whereas Martin Hentschinski presented ongoing work on the formalization of high-energy factorization at next-to-leading order. Alessandro Papa presented a detailed discussion of the high-energy expansion in the case of forward Higgs production in the infinite top-mass limit. The day closed with a lecture on the life of Bruno Touschek by Giulia Pancheri.

The third day has been dedicated to the the exploration of gluon saturation, highlighting both recent experimental and theory results. Gian Michele Innocente presented recent LHC results on heavy quark production in hadronic and ultraperipheral collisions, Heikki Mäntysaari discussed state-of-the-art theory descriptions of exclusive vector-meson production within the gluon saturation framework, Alexander Bylinkin presented recent results on J/psi photoproduction in UPCs with ALICE, while Jani Penttala discussed the relevance of including impact parameter dependence in the phenomenology of the color glass condensate. Tuomas Lappi presented a summary of recent next-to-leading order results within the color dipole description and its relevance for the phenomenology of the color glass condensate, while Nicolas Strangmann discussed opportunities for future phenomenology studies within the ALICE FoCal upgrade. Minjung Kim presented studies for the exploration of light hadrons within ultra-peripheral Pb-Pb collisions at the ALICE experiments, while Carlisle Aurabelle Casuga discussed the determination of initial conditions for BK dipole amplitudes, based on a Bayesian workflow.

The morning of fourth day was dedicated to central exclusive production in photon-photon and pomeron-pomeron collisions. Michael Pitt presented results and prospects for central exclusive reactions measured at the CMS precision proton spectrometer, Lydia Beresdorf provided a summary of exclusive and diffractive physics results with the ATLAS experiment, Ronan McNulty summed up LHCb results on tetraquark candidates in central exclusive production, while Georgios Krintiras addressed electroweak precision studies in heavy ion and ultraperipheral collisions at the LHC. The afternoon section returned to the discussion of the phenomenology of gluon saturation. Dionysios Triantafyllopoulos presented results on diffractive jet production in photon-nucleus collisions, whereas Edmond Ianco discussed aspects of TMD evolution at low x. Michael Fucilla provided finally results on the twist three corrections for deeply virtual meson production and discussed their relevance for exploring gluon saturation.

The last day was dedicated to an overview talk on the physics of the Electron Ion Collider (EIC) by Anna Stasto, opportunities for forward physics at the EIC by Michael Pitt, as well as the possibility to run LHC in different ion modes, presented by Gian Michelle Innocenti. The scientific program was concluded by a summary on photon-photon physics at the LHC by Christophe Royon as well a talk on the Lund jet plan analysis presented by Cristian Baldenegro.

Result and highlights

One of the first highlights was the discussion about the odderon discovery. While it is widely admitted that the observed differences between pp and ppbar interactions is indeed evidence for the existence of the odderon at LHC energies, it would be nice to obtain an independent confirmation using vector mesons such as the exclusive χ_c production at the EIC and the LHC. It was also noticed that this discovery was confirmed independently using the Levy polynom approach. The LHC predictions have still to be computed but the EIC predictions already show some promising expectations.

The other topic that was discussed on diffraction is the parton density in the pomeron that can be further constrained at the LHC and the future EIC. At the LHC, measuring jets and top quarks in diffractive events can allow constraining further the PDFs, while the high luminosity at the EIC will allow constraining further the reggeon contribution (at HERA, it was described by the pion PDF, but it is not well constrained).

The other main topic of the workshop was the possible observation of BFKL resummation effects at low x and then saturation. Jet-gap events measured by the CMS collaboration are definitely a clean sign of BFKL dynamics and are now found in agreement with BFKL calculation. For the first time, the NLO BFKL cross section was computed (included the NLO impact factors) for this process, and no large difference with the LO calculation has been found, which shows the relevance of the calculation. The next step is to identify the effects of saturation in the LHC data, and the measurements of vector meson production such as J/Psi at high energy (so small x) has a tendency to indicate that saturation might have already been observed in Pb-Pb data at the LHC. This will have to be confirmed using additional observables such as the measurement of charm events in Pb-Pb collisions at the LHC. Other observables such as the measurement of very forward jets in the FOCAL calorimeter to be installed in the ALICE collaboration will represent a great improvement to probe saturation effects in Pb-Pb collisions at the LHC. Additional observables such as forward Higgs boson production at the LHC or vector meson production at the EIC were also discussed. More theoretical developments in the Color Glass Condensate formalism were also presented, especially the relevance of taking into consideration the impact parameter dependence of the cross sections.

One other additional highlight of the workshop was the discussion of the LHC as a photon-photon collider. This leads to very clean events with, for instance, two photons, a pair of W or Z bosons, top-antitop quarks, or one photon and one Z boson, in addition to the presence of intact protons in the final state. It leads to the best sensitivities to quartic anomalous couplings at the LHC and also to axion-like particles at high mass. Recently, measuring exclusive tau production at LHC allowed to constrain g-2 with high precision.

There was some discussion about the physics at the EIC and the complementarity of running the LHC in the heavy ion mode at the same time at the EIC at higher energy with different heavy ions. While no decision is taken, it is important to develop a key physics program to run the LHC with different kinds of heavy ions.

2.3.13 *Towards a Consistent Approach for Nuclear Structure and Reaction: Microscopic optical potentials*

Date	17-21 June 2024

Organizers

Carlo Barbieri	Università degli Studi di Milano, Italy
Charlotte Elster	Ohio University, USA
Chloë Hebborn	FRIB, Michigan State University, USA
Alexandre Obertelli	TU Darmstadt, Germany

Number of participants	30

Scientific goals of the meeting and main topics

The goal of the workshop was to enable the necessary steps to make the next generation of optical potentials (OPs) available to the experimental programs on exotic isotopes. We intended to expose the opportunities of advancement that the microscopic approaches give in controlling the errors and extrapolating to dripline isotopes. Focus was given to the simplest case of elastic nucleon-nucleus potential, which is the fundamental building block to most reaction mechanisms. To do so, experts from all relevant areas gathered at the ECT* to discuss the following topics:

1) Status of OPs from ab initio theory. This is a computationally intensive task and a major challenge at the forefront of nuclear many-body theory, but such OPs are becoming more accurate and can be applied to dripline isotopes.
2) Consistency among structure and reaction mechanisms. The lack of this feature has been a critical issue to nuclear physics for decades and it can originate discrepancies in the interpretation of different data.
3) Uncertainties. The ab initio approach based on (chiral) EFT interactions holds the promise for systematic improvement of the Hamiltonian and preserves links to the underlying QCD.
4) Implementing microscopic nucleon-nucleus optical potentials in actual reactions.
5) Nuclear correlations and applications. We discussed opportunities in using optical potentials to improve on our understanding of nuclear physics.

Speakers

Mack Atkinson	Lawrence Livermore National Laboratory, USA
Guillaume Blanchon	CEA, France
Jennifer Boström	Lund University, Sweden
Angela Bonaccorso	INFN Pisa, Italy
Stefano Brolli	University and INFN Milan, Italy

Pierre Capel	Johannes Gutenberg Universität Mainz, Germany
Willem Dickhof	Washington University In St. Louis, USA
Pierre-Yves Duerinck	Université Libre De Bruxelles, Belgium
Paolo Finelli	University of Bologna & INFN, Italy
Abraham Flores	Washington University In St. Louis, USA
Andrea Gottardo	INFN LNL, Italy
Joaquin Gomez Camacho	CNA - University Of Sevilla, Spain
Jose Pablo Linares Fernandez	Louisiana State University, USA
Gavin Lotay	University Of Surrey, UK
Atul Kedia	North Carolina State University, USA
Filomena Nunes	Michigan State University, USA
Alexandre Obertelli	TU Darmstadt, Germany
Francesco Pederiva	University of Trento and INFN-TIFPA, Italy
Salvatore Simone Perrotta	Lawrence Livermore National Laboratory, USA
Gregory Potel Aguilar	Lawrence Livermore National Laboratory, USA
Grigor Sargsyan	Michigan State University, USA
Kazuki Yoshida	Japan Atomic Energy Agency, Japan
Enrico Vigezzi	INFN Milano, Italy
Matteo Vorabbi	University of Surrey, UK
Sibo Wang	Southwest University, USA
Guohao Yang	Chongqing University, China

Scientific report

Direct nuclear reactions, processes such as nucleon transfer, knockout, anti-nucleon capture, have been extensively exploited by experiments to learn about the structure of exotic isotopes far away from stability, to infer properties of the nuclear forces, to describe nucleosynthesis and to learn about the nuclear equation of state. In this respect, nucleon-nucleus optical potentials are of great importance since they are the fundamental building blocks needed to predict reaction observables to address such a wide range of nuclear physics facets. The workshop gave emphasis to alternatives to the traditional optical-potential parameterizations: because of their phenomenological content the traditional optical models are fully reliable only in specific regions of the nuclear chart, near the stable isotopes they were fitted to. One alternative is dispersive optical models, which are phenomenological but are global parametrizations and driven by microscopic theory to allow extrapolation to unstable regions of the nuclear chart. New generation of microscopic optical potentials are based on ab initio theory and aim at the calculation of the nuclear self-energy. Microscopically derived potentials can be systematically extended to isotopes far from stability and it allows to handle of uncertainty propagation from the nuclear Hamiltonian. Isotopes far from stability are the focus of modern experimental searches but microscopic potentials need to go beyond state-of-the-art ab initio theory to achieve sufficient accuracy. Work in this direction was discussed during the workshop.

Results and highlights

Nearly all participants to the workshop contributed with a presentation, with the exception of all but one organizer (who gave an introductory talk) and a very young student at the beginning of his PhD. The cohort was quite well balanced among young and senior researchers and with active contributions from all genders. The number of participants was optimal to allow covering all expertise on the subject and at the same time leaving time for focused daily discussions. The overall environment was particularly informal and friendly, and it enabled high-level discussions.

Introductory talks, from the experimental point of view, were given by Obertelli and Gottardo who focussed on the needs for the analysis of experiments and the implicit uncertainties in the interpretation of particle transfer reactions. A complementary introduction from the theorist point of view by Nunes covered challenges in constraining optical models. Among the theory approaches, the dispersive optical potential is now being refined exploiting weak charge data. Microscopic ab initio methos are being advanced and exploit the nuclear irreducible self-energy to provide both scattering and structure information. The irreducible self-energy is obtained either through direct computation using SCGF methods or by inversion of the Green’s function. Within the direct computation method, sophisticated all-order summations are being pursued with the Diagrammatic Monte Carlo method. At higher energies, above 100 MeV, microscopic spectator models can reach good accuracy even with current chiral EFT interactions. Microscopic approaches based on NN interactions will be the basis for providing antiproton-nucleus potentials. The impact of current OPs on astrophysical applications was discussed, with focus on analyzing reactions for explosive events in nuclear astrophysics and in the understanding of Kilonovas. More refined models are needed for spectroscopy halo nuclei.

2.3.14 *New Opportunities and Challenges in Nuclear Physics with High Power Lasers*

Date	1-5 July 2024

Organizers

Chieh-Jen Yang	ELI-NP, Romania
Klaus Spohr	ELI-NP, Romania
Paolo Tomassini	ELI-NP, Romania
Yuji Fukuda	Kansai Photon Science institute, QST, Japan
Vojtech Horny	ELI-NP, Romania
Leonida Gizzi	Istituto Nazionale di Ottica, Italy
Domenico Doria	ELI-NP, Romania

Number of participants	22

Main topics

This workshop has brought together interdisciplinary researchers, including the broadly defined nuclear and laser-plasma communities, to share existing ideas and discuss key issues.

The main topics were:

- Basis of nuclear theory and its uncertainty
- Laser-driven particle accelerations
- Laser-driven neutron/gamma-ray sources
- Multi-photon and electron pumping of nuclear isomer states
- Neutron captures related to nucleosynthesis
- Medical physics applications
- Gamma-ray lasers
- Strong QED effects

Speakers

Adriana Palffy	University of Wurzburg, Germany
Akifumi Yogo	Institute of Laser Engineering, Osaka University, Japan
Antonino Di Piazza	University of Rochester, USA
Bharat Mishra	INFN – LNS, Italy
Bradley Meyer	Clemson University, USA
Carlos Bertulani	Department of Physics Texas A&M University-Commerce, USA

Chad Forrest	University of Rochester, USA
Chieh-Jen Yang	ELI-NP, Romaina
Edison Liang	Rice University, USA
Harald Griesshammer	George Washington University, USA
Ishay Pomerantz	University Tel Aviv, Israel
Jorge Vieira	Instituto Superior Tecnico, Portugal
Karoly Osvay NLTL	University of Szeged, Hungary
Klaus M. Spohr	Extreme Light Infrastrucuture - Nuclear Physics, Romania
Matej Lipoglavsek	Jozef Stefan Institute, Slovenia
Paolo Tomassini	IFIN-HH/ELI-NP, Romania
Paul McKenna	University of Strathclyde, UK
Peter Thirolf	LMU Munich, Germany
Philip Walker	University of Surrey, UK
Siegfried Glenzer	SLAC National Accelerator Laboratory, USA
Silvia Pisano	Laboratori Nazionali di Frascati - INFN & Centro Fermi, Italy
Takehito Hayakawa	National Institutes for Quantum Science and Technology, Japan
Ubirajara van Kolck	ECT*, Italy
Vojtech Horny	ELI-NP, Romania
Yasuhiro Kuramitsu	Osaka University, Japan
Yuanbin Wu	Nankai University, China
Yuji Fukuda	Kansai Institute for Photon Science (KPSI), QST, Japan
Zechen Lan	Institute of Laser Engineering, Osaka Univ., Japan

Scientific report

Laser-driven ion and electron accelerations open a unique opportunity to probe/trigger new phenomena in nuclear physics. The intensive beams produced by high-power lasers can generate neutrons/gamma rays which can be orders of magnitude denser both in time and space than classical accelerators. With laser-plasma-based beams, many interesting physics could occur.

In this workshop, we have gathered 30 world experts in nuclear and laser-plasma communities (both experimentalists and theorists) to discuss various new opportunities as well as existing challenges. On the first day, the speakers and discussions were focused on recent progress in laser-plasma-based neutron sources and their applications to, e.g., nucleosynthesis and fundamental nucleon-nucleon interaction. On Tuesday, new ways toward efficient isomer pumping/depletion and new/existing schemes to generate intense gamma- and electron beams were discussed. On Wednesday, strong-field physics and some recent experimental findings were reported. On Thursday, various laser-plasma interaction results were covered. Finally, laser-based fusion and medical applications were discussed on Friday.

The main theme of all the discussions converged on the core essential question: What can high-power laser systems do differently to forward the field of nuclear physics in a way that an existing accelerator system cannot provide? During the workshop, both theoretical and experimental efforts were presented, which can be summarized as follows:

1. Intensity is the key to making a difference. With the ingredient of intense gamma and optical photon sources, multi-photon absorption in nuclear transitions could be drastically enhanced due to the non-linear dependence on the intensity.
2. The neutron source generated via laser-plasma interaction can be important for astrophysics studies, provided that one could design a new scheme to generate focused neutrons.
3. Using liquid targets will allow a high-repetition-rate of laser shots, and therefore further boosts the final yields from the intense beams.

Result and highlights

Several topics were discussed and at the end of the workshop the participants agreed to provide the group's viewpoints on the current and emerging areas in the field of high-power laser science and applications to nuclear physics. A few of our discussion points emerged as a group consensus for the physics that can be also achieved at the ELI-NP. They are:

- There is an urgent need to accelerate our efforts to explore new frontiers of various laser-matter interaction schemes to generate a high-intensity γ−flash (with $E_\gamma \approx$ 100 keV -- 10 MeV) of importance for nuclear photonics.
- Theoretical and experimental studies of nuclear isomers and their transitions utilizing intense electron and/or γ−beams generated by high-power laser systems (HPLS) could lead to new breakthroughs in manipulating nuclear transitions with huge applications.
  – Broadband γ− and/or X-ray spectra could be useful to investigate energy integrated direct photo-excitation cross sections for isomer pumping and compare with alternate techniques such as NEEC.
- The use of liquid targets could be very advantageous in terms of boosting a higher repetition rate, which has been demonstrated in the TW-class laser systems.
  – Adding a cryogenic layer of hydrogen could produce more mono-energetic ion beams.
- Accelerating the improvements of intense neutron sources will allow exciting breakthroughs in nuclear and medical physics, ranging from the fundamental level (such as an accurate determination of the neutron-neutron scattering length) to practical applications (BNCT therapy).
  – Novel target designs to focus the high-yield neutrons into a smaller solid angle must be developed.
- It is necessary to optimise laser accelerated electron flux from thin (~ 500 nm), solid converter targets. This would in turn optimise the trailing proton flux and the potential to convert to a large neutron flux with an additional converter target.

– A high electron flux will also provide the potential for large Bremsstrahlung x-ray flux from additional converter mechanisms to populate excited atomic states in the main target and permit the requirements for NEEC. Methods should be explored then to switch mechanically or magnetically the preferred flux of particles on command, in coincidence with long-pulse heating of the experimental target.

– This technique will provide additional opportunities in astrophysics to explore r, s and rp process cross sections (and the impact that isomeric states can have on them) that are inaccessible by accelerators.

- Converging shock-induced compression of ions and electrons inside the laser irradiated cryogenic micron-scale cluster targets, such as ^{14}N, could be a good benchmark test for the “plasma screening effect”.
- Advanced laser-ion acceleration schemes typically involve very thin targets (~ 100 nm) combined with ultra-high laser intensities exceeding 1021 W/cm^2, utilizing the enormous radiation pressure of the laser and/or the onset of relativistic induced transparency to generate extreme localized space charge fields (> 10 TV/m). It is expected that utilizing higher laser intensities will also result in improved conversion efficiency from laser to ion energy. Therefore, ELI-NP can exploit and extend these advanced schemes to generate high fluxes of energetic particles to drive nuclear reactions, for example, for collimated neutron generation.

2.3.15 *Synergies between LHC and EIC for Quarkonium Physics*

Date	July 8-12, 2024

Organizers

Francesco Celiberto	UAH, Madrid, Spain
Jean-Philippe Lansberg	IJCLab, Orsay, France
Charlotte Van Hulse	UAH, Madrid, Spain
José Manuel Alarcón	UAH, Madrid, Spain
Daniël Boer	University of Groningen, Netherlands
Carlo Flore	University of Cagliari & INFN, Italy
Elena G. Ferreiro	University of Santiago de Compostela, Spain
Carlo Luis Guerrero Contreras	UAH, Madrid, Spain
Daniel Kikola	WUT, Warsaw, Poland

Number of participants	36

Main topics

The main topics were

- Quarkonia in inclusive reactions
- TMD physics and (semi-)inclusive reactions
- Quarkonia in exclusive and diffractive processes
- Experimental requirements and measurements
- From LHC to EIC: Assets and synergies

Speakers

Liupan An	Peking University, China
Maria Elena Ascioti	University of Perugia & INFN, Italy
Daniël Boer	Univ. of Groningen, Netherlands
Jelle Bor	Paris-Saclay University, France
Alessia Bruni	INFN Bologna, Italy
Lidia Carcedo	UAH Madrid & IGFAE-USC Sant. de Compostela, Spain
Alice Colpani Serri	Warsaw University of Technology, Poland
Salvatore Fazio	University of Calabria & INFN-Cosenza, Italy
Chris Flett	IJCLab Orsay, France
Carlo Flore	University of Cagliari & INFN, Italy
Michael Fucilla	IJCLab Orsay, France
Elena G. Ferreiro	University of Santiago de Compostela, Spain
Tomas Jezo	University of Münster, ITP, Germany

Vato Kartvelishvili	Lancaster University, UK
Nanako Kato	University of Cagliari, Italy
Daniel Kikola	Warsaw University of Technology, Poland
Jean-Philippe Lansberg	Université Paris-Saclay, CNRS, IJCLab, France
Kate Lynch	Univ. College Dublin, Ireland & Paris-Saclay Univ., France
Laboni Manna	Warsaw University of Technology, Poland
Luca Maxia McNulty	University of Groningen, Netherlands Ronan University College Dublin, Ireland
Saad Nabeebaccus	Université Paris-Saclay, CNRS, IJCLab, France
Emanuele Roberto Nocera	University of Turin & INFN, Italy
Cristian Pisano	University & INFN Cagliari, Italy
Andry Rakotozafindrabe	CEA Saclay, IRFU/DPhN, France
Matteo Rinaldi	INFN Perugia, Italy
Anton Safronov	Warsaw University of Technology, Poland
Anna Stasto	Penn State University, USA
Charlotte Van Hulse	UAH Madrid, Spain
Xiangpeng Wang	Technical University of Munich, Germany
Yelyzaveta Yedelkina	Université Paris-Saclay, CNRS, IJCLab, France
Shinsuke Yoshida	South China Normal University, China

Scientific report

The main scope of the workshop was bringing together the communities of the LHC and the EIC, with the focus on quarkonium studies and their sensitivity to hadron structure and saturation. This includes shedding light on an enhanced understanding of quarkonium production mechanisms. Reactions involving quarkonia can provide us with a novel channel to access (gluon) spin-dependent and multi-dimensional observables. At the same time, they offer us additional constraints on the collinear nucleon and nuclear parton distributions. With the EIC at present in the R&D phase, this is a most favorable time to gather both the theory and experimental communities of the LHC and EIC.

Result and Highlights

Advancing the study of multi-dimensional hadron structure. The workshop successfully addressed key aspects of hadron structure, focusing on gluon parton distribution functions (PDFs), transverse-momentum-dependent PDFs (TMDs), generalized parton distributions (GPDs), and generalized TMDs (GTMDs). These distributions provide insights into parton dynamics by mapping their longitudinal momentum fraction, transverse momentum, and spatial distribution. A major emphasis was placed on the role of quarkonium production as a powerful tool to access gluon distributions. To achieve a comprehensive multi-dimensional understanding, discussions highlighted the necessity of exploring a broad kinematic range, leveraging the complementary capabilities of the LHC and the EIC.

Testing factorization and probing universality. A critical objective of the workshop was to examine factorization and assess the universality of the distributions extracted from experimental measurements. The discussions underscored how the distinct collision processes provided by the LHC and the EIC offer a valuable testing ground for these fundamental principles. The complementarity between the two facilities was extensively analyzed, reinforcing their role in validating theoretical frameworks.

Investigating the spin dependence of parton distributions. The workshop provided a platform to explore spin-dependent and spin-independent gluon distributions. At the LHC, studies in collision mode focused on accessing spin-independent distributions and select spin-dependent observables, such as linearly polarized gluon TMD PDFs related to the Boer-Mulders effect. Prospects were also discussed, particularly the potential of LHC RUN 5+6, where data collection at LHCb with a transversely polarized gaseous fixed target could enable further investigations into spin asymmetries, including the Sivers effect. At the EIC, the availability of longitudinally polarized lepton beams and both longitudinally and transversely polarized light-hadron beams was highlighted to achieve full access to all spin-dependent distributions.

Enhancing the understanding of quarkonium production and polarization. The mechanisms underlying quarkonium formation remain an open question in the field. Throughout the workshop, different theoretical approaches—such as NRQCD, single-parton fragmentation, and TMD shape functions—were examined in detail. Particular attention was given to the challenge of identifying the dominant production mechanism in different kinematic regimes. Discussions also emphasized how phenomenological studies of quarkonium production at both low and high transverse momentum can provide crucial tests for the validity of the proposed theoretical models.

2.3.16 Towards Improved Hadron Tomography with Hard Exclusive Reactions

Date	5-9 August 2024
Organizers	
Marie Boër	Virginia Tech University, USA
Alexandre Camsonne	Jefferson Laboratory, Newport News, USA
Jakub Wagner	NCBJ, Warsaw, Poland
Martha Constantinou	Temple University, Philadelphia, USA
Charlotte Van Hulse	University of Alcalá, Madrid, Spain
Number of participants	35

Main topics

The goal of the workshop was to bring together theorists and experimentalists in hadronic physics to discuss recent progress and explore ways to enhance our understanding of hard exclusive reactions and their interpretations, such as hadron imaging. The main topics included:

- New theoretical developments
- New experimental developments
- Lattice QCD (LQCD) calculations
- New computing methods

Speakers

Shohini Bhattacharya	Los Alamos National Laboratory, USA
Stepan Stepanyan	Jefferson Lab, USA
Andrzej Sandacz	National Centre For Nuclear Research, Warsaw, Poland
Garth Huber	University of Regina, Canada
Andrei Afanasev	The George Washington University, USA
Vladimir Braun	Regensburg University, Germany
Wim Cosyn	Florida International University, USA
Kirill Semenov	KNU, India
Abigail Rodrigues Castro	IRFU/CEA-Sacla, France
Patrizia Rossi	Jefferson Lab, USA & /INFN-LNF, Italy
Charlotte Van Hulse	University of Alcalá, Spain
Dalibor Djukanovic	Helmholtz Institute Mainz, Germany
Simone Bacchio	The Cyprus Institute, Cyprus
Sergey Syritsyn	Stony Brook University, USA
Dukhishyam Mallick	IJClab, Orsay, France

Laure Massacrier	IJClab, Orsay, France
Maxim Nefedov	IJClab, Orsay, France
Stephen Kay	University of York, UK
Alex Jentsch	BNL, USA
David Richards	Jefferson Lab, USA
Krzysztof Cichy	Adam Mickiewicz University, Poland
Martha Constantinou	Temple University, USA
Paweł Sznajder	NCBJ, Poland
Kresimir Kumericki	University of Zagreb, Faculty Of Science, Croatia
Anthony Thomas	University of Adelaide, Australia
Kazuki Makino	Florida International University, USA
Eric Fuchey	William and Mary, USA
Maxime Defurne	CEA Saclay, France
Victor Martinez	NCBJ, Poland
Sebastian Alvarado	IJCLab, IN2P3, France
Marie Boer	Virginia Tech, USA
Nikola Crnković	Rudjer Boskovic Institute, Croatia
Wassim Hamdi	Jefferson Lab, USA
Douglas Adams	University of Virginia, USA
Simonetta Liuti	Virginia Tech, USA
Marija Čuić	University of Virginia, USA
Kornelija Passek-Kumericki	Rudjer Boskovic Institute, Croatia
Garth Huber	University of Regina, Canada
Brandon Kriesten	University of Virginia, USA

Scientific report

A particular focus of the workshop was placed on “novel” reactions that access generalized parton distributions (GPDs), as well as new techniques for models, projections, and future measurements. Several new reactions were presented that could provide access to quantities previously thought to be challenging, such as generalized transverse-momentum distributions (GTMDs) or tunknown GPDs, e.g., transversity or non-singlet combinations. Advanced calculations were also discussed, including higher-twist terms that enable the extraction of additional data from the existing high-accuracy datasets.

This edition of the workshop emphasized lattice QCD (LQCD) and emerging computing techniques for theoretical and analytical advancements, such as machine learning. Major progress made in recent years has significantly improved computational efficiency. Form factors and moments of GPDs can now be computed on the lattice. Although further improvements are needed to incorporate these data into global GPD fitting, quantitative information can already be extracted from LQCD. Several initiatives to extract GPDs were presented, with AIML methods showing promise for model-independent extractions. Additionally, the discussions covered various physics topics, including the hard exclusive production of mesons, lepton pairs, and meson pairs in both fixed-target and collider experiments, including ultra-peripheral collisions. The sensitivity of these reactions to GPDs, GTMDs, gravitational form factors, and spin was also addressed.

Results and highlights

The primary objective of the workshop was to advance the understanding of hadronic physics by focusing on hard exclusive reactions and the imaging of hadrons. The event aimed to unite theorists and experimentalists to discuss recent progress and identify new approaches for studying GPDs and GTMDs. Key goals included exploring theoretical advancements, including LQCD calculations, and leveraging emerging computing techniques, such as machine learning. Another major objective was to investigate novel reactions that could provide access to previously challenging quantities, thus broadening the scope of hadron tomography research.

The workshop successfully met its objectives by presenting new approaches to study GPDs and GTMDs. Participants shared advanced theoretical developments and computational techniques, including the use of machine learning and LQCD. The discussions also highlighted experimental strategies for probing GPDs through novel exclusive processes, directly addressing the workshop's goal of enhancing methods for hadron tomography. The workshop directly addressed its goals by fostering discussions between theorists and experimentalists on improving methods for investigating the hadron structure.

2.3.17 *The Nuclear Interaction: Post-modern developments*

Date	19-23 August 2024

Organizers

Rob Timmermans	Rijksuniversiteit Groningen, Netherlands
Judith McGovern	University of Manchester, UK
Maria Piarulli	Washington University, USA
Ubirajara van Kolck	IJCLab Orsay, France, Univ. of Arizona, USA and ECT*, Italy

Number of participants	32

Main topics

The workshop marked the 25th anniversary of the ECT* workshop “The nuclear interaction: modern developments”, which was attended by all the most influential researchers then working on nuclear forces. The earlier workshop was a watershed event, after which nuclear potentials and currents based on effective field theories (EFTs) gradually replaced more phenomenological approaches. The 2024 workshop was an opportunity to take stock of what we have learned about nuclear forces since.

Questions that were addressed included:

- Have potentials inspired by Chiral EFT fully replaced more phenomenological approaches?
- What are their phenomenological limitations and how can they be improved?
- Have they achieved the goal of providing a model-independent and systematic description of nuclei with controlled uncertainties?
- Does the community agree on a power counting?
- What are the lessons one can draw from the consistency and successes of Pionless and Halo/Cluster EFTs?
- Do we understand the dynamical implications of QCD?

Speakers and discussion leaders

Sonia Bacca	University of Mainz, Germany
Carlo Barbieri	Università di Milano, Italy
Nir Barnea	Hebrew University, Israel
Silas Beane	University of Washington, USA
Mike Birse	University of Manchester, UK
Jason Bub	Washington University, USA
Ylenia Capitani	University of Salento, Italy
Lorenzo Contessi	IJCLab Orsay, France

Luigi Coraggio	University of the Campania, Italy
David Rodriguez Entem	University of Salamanca, Spain
Evgeny Epelbaum	Bochum University, Germany
Elena Filandri	University of Pisa, Italy
Ashot Gasparyan	Bochum University, Germany
Jambul Gegelia	Bochum University, Germany
Alex Gnech	Old Dominion University, USA
Harald Griesshammer	George Washington University, USA
Winfried Leidemann	University of Trento, Italy
Alejandro Kievsky	University of Pisa, Italy
Bingwei Long	Sichuan University, China
Songlin Lyu	University of the Campania, Italy
Giuseppina Orlandini	University of Trento, Italy
Manuel Pavon Valderrama	Beihang University, China
Daniel Phillips	Ohio University, USA
Lucas Platter	University of Tennessee, USA
Francesca Sammarruca	University of Idaho, USA
Martin Schaefer	Czech Academy of Sciences, Czech Republic
Oliver Thim	Chalmers University, Sweden
Jerry Yang	ELI-NP, Romania

Scientific report

The 25 years since the 1999 workshop have seen the establishment of chiral potentials and currents based on Chiral EFT as the preferred input to ab initio methods to solve the many-nucleon problem. Chiral potentials are organized according to a power counting proposed by Weinberg in the very early days of nuclear EFT. Some of the phenomenological successes of this approach are well known and were mentioned in various talks. In particular, a session was dedicated to the memory of Rupert Machleidt, who attended the 1999 workshop, was instrumental in converting the community to chiral potentials, and had been invited to the present workshop.

Weinberg's prescription has been known since before the 1999 workshop to be inconsistent with the renormalization group. This inconsistency has led to development of simpler EFTs --- Pionless and Halo/Cluster --- whose successes have informed Chiral EFT with alternative power countings. The workshop dealt with some of the successes and limitations of simpler and more effective EFTs, and the lessons they hold for Chiral EFT.

Regardless of model dependence, chiral potentials at high orders in Weinberg's power counting offer a description of light nuclei comparable to that of phenomenological potentials like those of the Argonne family. However, frequently leading-order results are not even provided, despite the EFT requirement that leading order captures the essential physics. The convergence of chiral potentials with respect to order was discussed.

Moreover, deficiencies exist, particularly for heavier nuclei, for which various remedies have been proposed, such as different fitting strategies, different regulators, inclusion of delta isobars, higher orders --- not all equally reasonable from an EFT perspective. Some problems with state-of-the-art chiral potentials were identified, and discussions were held on the needed improvements as well as the future of this approach. All these discussions were informed by the techniques for uncertainty quantification based on Bayesian methods, which have been developed over the last few years.

The workshop was carried out in true workshop fashion, with all invited participants given equal time and an opportunity to participate in all discussions. Speakers were asked to end their talks by raising issues for discussions in specific sessions led by a moderator, who was asked to ensure the discussions remained constructive and inclusive. The talks themselves included significant discussions.

Results and highlights

The emphasis of the workshop was on the limitations of the current use of chiral potentials and currents, which might point to future advances. One example was a discussion of the monopole transition between the alpha particle's two lowest states, which was remeasured recently at Mainz. The best calculation based on the presumably best chiral potential was scrutinized, and some agreement was reached that the factor-2 disagreement with data does indeed constitute a puzzle akin of the ancient A_y puzzle. It was agreed that it most likely stems from the poor value for the energy of the excited state in these otherwise sophisticated potentials.

Central to the discussions was the inconsistency between most existing potentials and renormalization-group (RG) invariance. Although RG invariance is achieved in Pionless and Halo/Cluster EFTs, some speakers have maintained that it is neither needed nor desirable in Chiral EFT, where potentials and currents should continue to be constructed under Weinberg's prescription. Even in this case, it was disclosed that existing potentials suffer from a lack of chiral symmetry at high orders.

Several talks reviewed the construction of power countings that replace Weinberg's prescription while retaining RG invariance, both in Pionless and Chiral EFTs. Although they differ in detail, a common feature of these power countings is that subleading orders need to be treated in distorted-wave perturbation theory (DWPT) because of the singular nature of the subleading interactions. Solutions were proposed to overcome difficulties to the renormalization of Chiral EFT at next-to-leading order (NLO) posed by a discrete set of cutoff values.

While high-order many-body calculations are difficult in DWPT, accounting for the proper hierarchy of interactions might lead to good results already at NLO. An example was the report of the first NLO calculation in Pionless EFT of nucleon-alpha scattering, which gave results as good as a chiral potential two orders further in Weinberg's prescription. For larger systems, however, an RG-consistent LO developed for light systems suffers from instability problems. In Pionless EFT, it was suggested that including some subleading interactions that preserve the RG could solve the instability problem. In Chiral EFT, it was proposed instead that the power counting should include a combinatorial (not quite binomial) enhancement of few-body forces as the number of nucleons increases.

First steps were also taken to explain the unrenormalized chiral potential approach from the perspective of Chiral EFT. A highlight of the workshop were two talks reporting the use of Bayesian techniques to assess the convergence of pionless approaches to two-nucleon scattering. The RG-consistent Pionless EFT was found to have a breakdown scale somewhat above the pion mass, in agreement with previous estimates based on Lepage plots. In contrast, a pionless potential inspired by Weinberg's prescription and known to suffer from the Wigner bound gave contradictory results at different orders. These two calculations lay the ground for a similar analysis comparing RG- consistent Chiral EFT with chiral potentials based on Weinberg's prescription.

Overall, the workshop exposed ways in which EFTs can further improve our understanding of the essential elements of nuclear forces captured by chiral potentials.

2.3.18 *New Developments in Studies of the QCD Phase Diagram*

Date	9-13 September 2024
Organizers	
Heng-Tong Ding	Central China Normal University, China
Frithjof Karsch	Bielefeld University, Germany
Maria Paola Lombardo	INFN, Italy
Peter Petreczky	Brookhaven National Laboratory, USA
Number of participants	36

Main topics

The workshop highlighted recent conceptual and technical advancements in understanding the QCD phase diagram and the nature of the chiral phase transition. Key topics included:

1) The nature of the chiral phase transition: The order and universality class of the chiral phase transition has not been determined yet. This is mainly hampered by the undetermined fate of the axial U(1) anomaly at the chiral phase transition temperature.

2) Critical behavior at the QCD phase transition and its connection to the physical world: True phase transitions of strong-interaction matter are only expected in the limits of massless and infinitely heavy quarks, or beyond a certain value of baryon number density and other external parameters. The development of QCD critical behavior requires control over parameters that do break symmetries of QCD explicitly, e.g. quark masses. Only then the influence of external parameters such as chemical potentials on the occurrence of phase or crossover transitions of strong-interaction matter in physical world can be analyzed reliably.

3) Manifestation of critical behavior in heavy ion collision experiments: Searching for the QCD critical end point (CEP) has been one of the central goals in the heavy-ion collision experiments. Systematic uncertainties are inherent in predictions for the location of the CEP obtained within different theoretical frameworks, using lattice QCD (LQCD) calculations, functional renormalization group (FRG) methods and others.

Speakers

Marco Aliberti	University of Parma and INFN, Italy
Yasumichi Aoki	RIKEN Center for Computational Science, Japan

Aminul Islam Chowdhury	University of Chinese Academy of Sciences, China
Francesco Di Renzo	Università di Parma and INFN, Italy
Wei-Jie Fu	Dalian University of Technology, China
Kenji Fukushima	The University of Tokyo, Japan
Jin-Biao Gu	Central China Normal University, China
Jana N. Guenther	Wuppertal University, Germany
Ivan Horvath	Nuclear Physics Institute, Czechia & University of Kentucky, USA
Wei-Ping Huang	Central China Normal University, China
Andrey Kotov	Juelich Forschungszentrum, Germany
Tamas G. Kovacs	Eotvos Lorand University, Budapest, Hungry
Arpith Kumar	Central China Normal University, China
Pok Man Lo	University of Wroclaw, Poland
Yi Lu	Peking University, China
Xiaofeng Luo	Central China Normal University, China
Shijun Mao	Xi’an Jiaotong University, China
Michał Marczenko	University of Wrocław, Poland
Sabarnya Mitra	Bielefeld University, Germany
Jan M. Pawlowski	University of Heidelberg, Germany
Peter Petreczky	BNL, USA
Owe Philipsen	Goethe University Frankfurt, Germany
Rob Pisarski	Brookhaven National Laboratory, USA
Chihiro Sasaki	University of Wroclaw, Poland & SKCM2 at Hiroshima University, Japan
Christian Schmidt	Bielefeld University, Germany
Andreas Schmitt	University of Southampton, UK
Sipaz Sharma	Bielefeld University, Germany
Udita Shukla	University of Wroclaw, Poland
Rajeev Singh	Stony Brook University & NISER, USA
Simran Singh	Universität Bielefeld, Germany
Misha Stephanov	University of Illinois Chicago, USA
Rui Wen	University of Chinese Academy of Sciences, China
Kevin Zambello	University of Pisa and INFN, Italy
Yu Zhang	Bielefeld University, Germany

Scientific report

The workshop brought together leading researchers from the fields of lattice QCD, effective theories, and experimental nuclear physics to address current challenges in understanding the QCD phase diagram and critical behavior under extreme conditions. A comprehensive exchange of ideas occurred regarding:

1) Axial U(1) anomaly and the chiral phase transition: Participants discussed the order and universality class of the chiral phase transition, emphasizing the uncertainties introduced by the unresolved status of the axial U(1) anomaly at the chiral phase transition temperature, particularly in the case of three degenerate flavors. The role of the axial anomaly and the nuances of the Columbia plot were debated, with a focus on insights from LQCD studies and recent advances in discretization schemes.

2) QCD criticalities and external control parameters: Talks and discussions explored the influences of quark masses, baryon density and magnetic fields on critical phenomena and QCD thermodynamics, with an emphasis on applications to high-energy nuclear physics and neutron stars.

3) Experimental implications and critical endpoints: Identifying the CEP remains a major goal in heavy-ion collision experiments. The workshop reviewed the systematic uncertainties inherent in current theoretical predictions, discussing CEP location results from LQCD, FRG, and other approaches.

The workshop facilitated a greater consensus on the critical questions in QCD phase transitions and the experimental observables associated with critical behavior. In addition to these main themes there were a number of other subjects covered in the workshop, represented by one speaker each, including: application of machine learning techniques to explore the finite-size scaling trained by LQCD data; chiral soliton lattice turns into 3D crystal; quark pairing in the strong coupled quark-gluon plasma.

Result and highlights

The workshop proved instrumental in addressing fundamental discrepancies within the QCD community, especially concerning the nature of the chiral phase transition as well we the possible signatures for the critical end point and axial U(1) anomaly. Notable outcomes include:

1) Advances in lattice and continuum frameworks: Theoretical progress in lattice and continuum methods, including the FRG, has enhanced our understanding of critical behavior at high densities and temperatures. One novel approach in LQCD computations involved the use of Lee-Yang edge singularities to estimate the possible location of the CEP. Additionally, exploring QCD thermodynamics in small volumes at low temperatures was identified as a promising avenue for future studies.

2) Insights into the Columbia Plot: LQCD computations with various discretization schemes suggest that the first-order chiral phase transition in the lower-left region of the Columbia plot (e.g., in 3-flavor QCD) is likely absent. However, the underlying cause of this absence, such as the role of the axial U(1) anomaly, requires further investigation. Meanwhile, substantial evidence supports a second-order phase transition in the chiral limit of light quarks in (2+1)-flavor QCD.

3) Progress in CEP searches: Recent data from the Beam Energy Scan II (BES-II) program were presented and discussed, with consensus emerging from FRG and

LQCD computations regarding the possible location of the CEP. However, further studies are needed to establish a consistent baseline for the BES-II data and to reduce uncertainties stemming from theoretical predictions and dynamic modelling in the evolution of heavy-ion collisions.

2.3.19 *Spin and quantum features of QCD plasma*

Date	16-24 September 2024
Organizers	
Francesco Becattini	University of Florence and INFN, Italy
Xu-Guang Huang	Fudan University, China
Dirk Rischke	Goethe University Frankfurt, Germany
Yi Yin	Institute of Modern Physics, Chinese Academy of Science, China
Number of participants	30

Main topics

The general theme of the workshop concerned spin and quantum features of the Quantum Chromodynamics (QCD) plasma which is produced in heavy-ion collision experiments at RHIC and LHC. The recent measurement of the spin polarization of particles produced in these collisions has opened a new frontier for the study of strongly interaction matter under extreme conditions. On the theoretical front, there is rapid progress in discovering new effects that polarize spin. However, the understanding of these new effects as well as their implementation in dynamical frameworks such as quantum hydrodynamics and kinetic theory are still under development. The goal of the workshop was to gather experts from both theory and experiment to determine the state-of-the-art knowledge in the field, to exchange ideas and methods, and to initiate new developments.

The main topics were:

- Experimental results of spin polarization and alignment from RHIC and LHC
- Spin hydrodynamics
- Quantum kinetic theory with spin degrees of freedom
- New theoretical developments towards understanding spin-polarization phenomena

Speakers

Aihong Tang	Brookhaven National Laboratory, USA
Amos Yarom	Technion, Israel
Andrea Palermo	Stony Brook University, USA
Annamaria Chiarini	Goethe University, Germany
Asaad Daher	IFJ PAN, Poland
David Wagner	Florence University, Italy
Debojit Sarkar	Niels Bohr Institute, Copenhagen, Denmark

Di-Lun Yang	Institute of Physics, Academia Sinica, Taiwan
Dirk Rischke	Johann Wolfgang Goethe-Universität Frankfurt, Germany
Francesco Becattini	Università & INFN Firenze, Italy
Kazuya Mameda	Tokyo University of Science, Japan
Kenji Fukushima	The University of Tokyo, Japan
Koichi Hattori	Zhejiang University, Zhejiang, China
Masoud Shokri	Goethe University, Germany
Matteo Buzzegoli	West University of Timisoara, Romania
Rajeev Singh	Stony Brook University & NISER, USA
Shi Pu	USTC, Anhui, China
Shuai Liu	Hunan University, China
Sushant Kumar Singh	University of Florence, Italy
Thierry Valet	Spintec, UGA, CNRS, CEA, France
Umut Gursoy	Utrecht University, Netherlands
Wojciech Florkowski	Jagiellonian University, Krakow, Poland
Xin-li Sheng	INFN Firenze, Italy
Zhenyu Chen	Shandong University, China
Zhong-Hua Zhang	Fudan University, China

Scientific Report

Spin is a fundamental intrinsic property of elementary particles. It is a specific form of angular momentum that is purely quantum in nature. Many notable quantum phenomena arise from spin, such as the spin Hall effect, Landau paramagnetism, and the Zeeman effect. In recent years, significant progress has been made in detecting spin polarization of hadrons produced in relativistic heavy-ion collisions, which are designed to study the unique properties of matter governed by the strong interaction. In these collisions, large nuclei---such as gold or lead---are accelerated to nearly the speed of light and collide head-on, achieving extremely high energy densities. These conditions mimic those present microseconds after the Big Bang in the early Universe, leading to the creation of a new state of matter known as quark-gluon plasma (QGP). By studying the properties of the QGP, we can gain valuable insights into the nature of the strong interaction and its quantum theory---QCD. Traditionally, QGP properties are probed using observables like collective flow of charged hadrons and energetic jets propagating through the plasma. The successful detection of spin polarization opens new avenues for probing the QGP, particularly in revealing its transport properties, its vortical structure, and its topological sectors owing to gauge field fluctuations.

The study of spin in the context of the QCD plasma is an exciting and rapidly evolving field. Currently, the global spin polarization of hyperons can be well interpreted in the framework of local equilibrium statistical mechanics and hydrodynamics; as a consequence of spin-orbit coupling, part of the orbital angular momentum of the colliding nuclei is transferred to the spin of the produced hadrons and the spin polarization turns out to be related to the formation of fluid vortices in the QGP. However, the azimuthal dependence of this spin polarization, and chiefly the spin polarization of vector mesons (in this context, what is measured is actually one particular component of the spin-density matrix of the vector meson), are not yet fully understood. Many ideas have been proposed to give explanations for the experimental results, such as the shear tensor-induced spin polarization and the possible appearance of strong mesonic forces. In light of these unexplained phenomena, we have scheduled a five-day workshop to gather experts for discussions on relevant topics. In particular, we have outlined the key themes of the workshop as follows:

- The recent experimental results for hyperons spin polarization and vector-meson spin alignment at both RHIC and LHC.
- Understanding these experimental results through simulations based on relativistic hydrodynamics and transport models. In particular, we discussed how different sources—such as thermal vorticity, thermal shear, and (chromo)electromagnetic fields—behave in these simulations and which factors dominate under specific conditions.
- How to formulate a hydrodynamic theory for spin transport. What role does the pseudo-gauge choice play in this formulation, and how might it influence simulations of the spin polarization. How to implement spin-hydrodynamics in simulations of heavy-ion collisions.
- Progress in the kinetic description of spin polarization and transport: How does the collision term contribute to additional new sources for spin polarization. Would such a contribution be dissipative or non-dissipative. What is the connection between the relativistic and non-relativistic formulations.
- New ideas and new theoretical developments.

Result and Highlights

The workshop was a very useful opportunity to gather experts with both experimental and theoretical background to exchange views, address common challenges, and explore potential future collaborations. A total of 24 talks were presented in this workshop, covering the aforementioned topics, leading to many lively discussions. Below, we summarize the main results from the workshop.

1) Three review talks highlighted the experimental findings on hyperon spin polarization and vector-meson spin alignment at RHIC and LHC. Notably, the CMS collaboration reported measurements of Lambda spin polarization along the beam direction in p+Pb collisions, revealing values surprisingly comparable to those in AA collisions, despite the smaller size of the pA system. Various scenarios were discussed to explain this phenomenon, suggesting that the small system could exhibit stronger velocity gradients and that hadronic spin physics might play a significant role in local spin polarization. The spin alignment results for D* and J/Psi mesons showed a consistent trend in their transverse-momentum dependence, with $\rho(00)>1/3$ at high transverse momentum and $\rho(00)<1/3$ at lower transverse momentum, while for phi mesons at lower transverse momentum, $\rho(00)>1/3$. The previously proposed strong-field scenario faces challenges in explaining these differences, indicating the potential existence of different sources of spin alignment.

2) There were extensive discussions regarding the pseudo-gauge dependence in describing spin polarization at local equilibrium, which is significant in both hydrodynamic and kinetic frameworks. The concept of local equilibrium prompted intense debates, particularly as the definitions in quantum kinetic theory and quantum statistical field theory appear to differ. It was clarified that while global equilibrium is unique and independent of the pseudo-gauge choice, the definition of local equilibrium is susceptible to pseudo-gauge ambiguity. The situation becomes even more complex when considering dissipative effects (i.e., going beyond local equilibrium), with several talks exploring these topics from various perspectives.

3) The workshop also examined connections with condensed-matter physics, particularly spintronics. It was shown that the quantum kinetic framework developed in high-energy physics could be effectively applied to condensed-matter systems, providing powerful tools for describing spin transport in solid-state materials.

4) Several new theoretical developments were reported. A full analytical freeze-out formula up to second order in gradients for the tensor polarization of vector mesons was derived, which can be utilized in hydrodynamical simulations. For the first time, numerical results from spin-hydrodynamics simulations were presented, demonstrating the promising application of spin hydrodynamics in heavy-ion collisions. Additionally, the development of spin hydrodynamics for conducting media (dubbed spin magnetohydrodynamics) up to first order in gradients was discussed, revealing intriguing collective modes. Furthermore, a calculable holographic framework for spin hydrodynamics was introduced and formulations of quantum kinetic theory in curved spacetime were discussed.

In summary, this workshop showcased a number of new results, primarily from the theoretical perspective, highlighting that spin and quantum features of QCD plasmas represent a very active research frontier and have strong connections to other areas of physics. We believe this workshop has inspired new ideas and fostered collaborations among attendees. We extend our gratitude to ECT* for providing this opportunity and for their excellent hospitality in Trento.

2.3.20 *KAMPAI - Kaonic, Antiprotonic, Muonic, Pionic and "onia" exotic Atoms: Interchanging knowledge*

Date	9 September – 4 October 2024
Organizers	
Alessandro Scordo	INFN, Italy
Paul Indelicato	Laboratoire Kastler Brossel, France
Jaroslava Obertova	Czech Technical University in Prague, Czech Republic
Catalina Curceanu	Laboratori Nazionali di Frascati INFN, Italy
Andreas Knecht	Paul Scherrer Institute, Switzerland
Magdalena Skurzok	Jagiellonian University Krakow, Poland
Tadashi Hashimoto	JAEA, Japan
Number of participants	*28*

Main topics

The general aim of the KAMPAI workshop was to bring together experts, both on the theoretical and experimental sides, on the investigation of exotic atoms and systems. The workshop provided insight on kaonic, pionic and muonic atoms, as well as on other systems like positronium. With the intention to share among the various communities not only the physics results and goals, but also the technologies used to achieve them, talks about state-of-art radiation detectors have been included. Two talks in memories of Prof. Carlo Guaraldo and Prof. Johann Zmeskal have been presented in the first day.

The main topics were

- Memorial talks
- Kaonic atoms
- Muonic atoms
- Pionic atoms
- Positronium
- Detectors
- Interdisciplinary

Speakers

Adrian Hilier	ISIS Neutron and Muon Facility, Italy
Alessandro Scordo	Laboratori Nazionali di Frascati INFN, Italy
Andrea Zappettini	CNR-IMEM, Italy
Andreas Knecht	Paul Scherrer Institute (PSI), Switzerland

Ben Ohayon	Technion IIT, Israel
Catalina Curceanu	LNF - INFN Frascati, Italy
Damir Bosnar	University of Zagreb, Croatia
Diana Sirghi	INFN-LNF, Italy
Eberhard Widmann	Stefan Meyer Institute, Austrian Academy of Sciences, Austria
Elmer Gründeman	ETH Zürich, Switzerland
Florian Sirghi	INFN-LNF, Italy
Francesco Giacosa	Jan Kochanowski University, Kielce, Poland
Jaroslava Obertova	Czech Technical University in Prague, Czech Republic
Joel Ullom	National Institute of Standards and Technology, USA
Loredana Gastaldo	Universität Heidelberg, Germany
Magdalena Skurzok	Jagiellonian University, Poland
Masaki Hori	Imperial College London, UK
Mihail Antoniu Iliescu	INFN-LNF, Italy
Milena Piotrowska	Jan Kochanowski University, Poland
Natalia S. Oreshkina	MPIK (Heidelberg), Germany
Patrick Strasser	KEK, Japan
Paul Indelicato	Laboratoire Kastler Brossel, CNRS, France
Philipp Blumer	ETH Zurich, Switzerland
Roberto Brusa	UNITN and TIFPA/INFN, Italy
Ruggiero Caravita	Università di Trento, Italy
Shinji Okada	Chubu University, Japan
Simone Manti	INFN-LNF, Italy
Sonia Bacca	Johannes Gutenberg University, Germany
Sushil Sharma	Jagiellonian University, Poland
Tadashi Hashimoto	RIKEN, Japan

Scientific report

Kaonic atoms, which are Coulomb-bound states of an anti-kaon and a nucleus, are primarily useful for studying the K^-N strong interaction because the strong force affects low-lying energy levels. They represent a unique and very important tool to study such interaction below threshold. The description of low-energy meson-baryon interactions is currently provided by chiral coupled-channel interaction models which represent synergy of chiral perturbation theory and coupled-channel T-matrix resummation techniques. A sensitive test of a K^-N interaction model is its ability to describe the broad data base of kaonic atom data from old bubble chamber experiments as well as from current experiments.

X-ray spectroscopy is a traditional method to deduce the strong-interaction effect, and by employing the state-of-the-art X-ray detectors valuable data are still being produced at DAFNE in Italy and J-PARC in Japan. In this workshop, the latest experimental status of these two facilities and also the latest theoretical situation to interpret the kaonic-atom X-ray data were discussed.

Attempts to make new and precise experimental measurements in kaonic deuterium, kaonic helium and kaonic neon led to development of sensitive silicon drift detectors as well as to development of Monte Carlo simulations technique and cascade models. The measurement in kaonic deuterium will allow the first precise experimental extraction of the isospin dependent antikaon-nucleon scattering lengths.

Moreover, knowledge of the charged kaon mass is very important for particle physics, e.g. for the D^0 mass and charmonium spectra. However, the two most precise measurements of the charged kaon mass are not compatible with each other and lead to the kaon mass puzzle. In the future, the charged kaon mass could be measured at DAFNE using high resolution X-ray detectors or laser spectroscopy.

Experiments with muonic atoms and muonium have been on the rise in the recent years with a lot of activities taking place around the world. They include laser and microwave spectroscopy of low-Z muonic atoms and muonium and x-ray spectroscopy for the higher-Z atoms to extract nuclear properties and fundamental constants; applied research such as elemental analysis through by means of detecting the muonic x rays; and the necessary advances in theory and detector technology.

One session was devoted to positronium research including fundamental studies related to positronium decays (entanglement, discreet symmetries tests) as well as possible medical applications (ex. ortho-positronium lifetime studies as a diagnostic marker). Theoretical approaches and new results of a few experimental groups has been presented and discussed. Measurements of photons from the annihilation of a positronium atom (a bound state of an electron and positron) allow us to study the properties of this lightest pure-leptonic system, which is both an atom and an antiatom. Moreover, the properties of positronium decay can be used in imaging the patient's body, and thus in cancer diagnostics.

During the workshop a new theoretical approach of the positronium decay rate determination has been presented as well as experimental results of the decay rate ratio has been shown by the J-PET group member. Moreover, the studies towards improving the sensitivity of discrete symmetry testing in positronium decays using the J-PET detector were presented. The studies were done by measuring angular correlation operators that are odd under the CP or CPT symmetry transformation defined for the annihilation photons of the ortho-positronium atom. The observation of any non-zero mean correlation would constitute evidence of symmetry violation. The precision achieved so far in J-PET measurements is 10^{-4} (one order of magnitude better than in other experiments), and the group is working now to aim for a precision of 10^{-5}.

Another interesting aspect in positronium research was related to measurements of the polarization correlation of photons produced in positronium decays, in order to investigate the quantum entanglement of these high-energy photons. J-PET detection system allows to use Compton scattering as an analyzer of the polarization of high-energy photons (since the direction of photon scattering depends to a large extent on their polarization). Obtained results are very promising. The J-PET group developed a new imaging method based on the positronium lifetime in tissues. The first human-brain positronium image was obtained recently and show big potential of the new diagnostic method in future.

The novelty on pionic atoms presented during KAMPAI was the first measurement of transition energies of the metastable Rydberg states in pionic He^+. This kind of measurements have enabled to measure with great accuracy the antiproton mass in the ASACUSA experiment. Here it will require more work to extract a mass as it has been performed in a superfluid He target, in which collisions can translate into a shift. From the detectors' development point of view, state-of-art radiation detectors such as TES, MMC and CdZnTe have been presented.

There were two talks about microcalorimeter X-ray detectors, which allow for unprecedented resolution in the x-ray energy range interesting for exotic atoms. We had a presentation on the NIST "transition edge sensors" microcalorimeters, which were used at J-PARC on muonic atoms (HEATES collaboration) and will be use on the PAX project on antiprotonic atoms at CERN. There was also a presentation of the magnetic microcalorimeters from the KIP at the University of Heidelberg which have been used at the ESR (GSI/FAIR) on highly-charged uranium and on the QUARTET collaboration measurements of muonic x-rays of light atoms (Li, Be, B) to improve their charge radii. The results at J-PARC obtained with TES detector were presented independently. One talk was devoted to the description of the performances of CdZnTe detectors, especially for their utilization in kaonic atoms' experiments at DAFNE. These type of detectors offer worse resolution with respect to the microcalorimeters, but can be easily operated at room temperature and offer resolutions of the same order of magnitude as silicon or germanium detectors, depending on the energy range of interest. The low cost and easy operability make this detectors ideal for large area coverage and experiments.

Among the topics covered during the workshop, the new perspectives on in-beam hyperfine spectroscopy of antihydrogen, hydrogen, and deuterium for tests of CPT and Lorentz invariance have been presented, together with an overview of the future of the ELENA facility at CERN.

Results and highlights

Highlights of the recent kaonic-atom experiments reported in this workshop are the first kaonic deuterium measurement at DAFNE and the unprecedented high-resolution X-ray spectroscopy of kaonic helium at J-PARC. The former is a long-awaited measurement to disentangle the isospin 0 and 1 components of the K^-N interaction. The analysis is still at the preliminary analysis stage, so the final results are eagerly awaited. The importance of cross-checking for this vital measurement is also discussed. The latter was the first challenge to use a TES microcalorimeter in this field and thus became an important milestone for the broader use of TESs for exotic-atom studies. There was also an intensive discussion about the kaon mass measurement using kaonic atoms. A plan to perform a laser-spectroscopy is presented, and an improvement of the mass accuracy via X-ray spectroscopy beforehand is crucial for the efficient resonant frequency search.

Recent development in chiral meson-baryon interaction model which includes hadron self-energies together with development of microscopic model for K^-NN absorption in nuclear medium led for the first time to a microscopic K^-nuclear potential capable to describe available data energy shifts and widths in kaonic atoms. The SIDDHARTA-2 collaboration finished data taking for first kaonic deuterium energy shift and width measurement. To optimize the setup parameters, various measurements with helium-4 and neon gas targets were realized. To analyze the results in kaonic neon the model for cascade calculations of fluorescence yields was developed and the results of model calculations were compared with data. The new possibilities offered by HPGe and CdZnTe detectors were discussed, with the first kaonic lead and aluminium spectra obtained at DAFNE.

The workshop covered basic research in the field of nuclear and particle physics as well as issues related to the development of new medical technologies, including imaging methods. The workshop hosted around 30 speakers including senior researchers as well as PhD students who delivered lectures on the latest scientific achievements, and the high level of content of the presentations enriched the intellectual atmosphere of the conference. The interaction between young researchers and experienced experts created an opportunity to exchange ideas.

Bringing all the various communities together was very beneficial to discuss recent progress and share experimental techniques, insights and advances. The various discussion sessions were very active with people finding similarities and exchanging know-how. We are confident, that the progress on detector technology presented in some of the talks will enable and allow further experiments in the future as well as the discussions on theoretical advances.

In particular, a nice discussion has been brought forward among the kaonic atoms' community, people working on TES detectors, and the group of laser spectroscopy at the Imperial College. As a main outcome, the idea that a new K^- mass measurement should be soon performed with traditional high-resolution radiation detectors has been stressed, with the aim to provide useful information and hints for the refined tuning of the laser need to perform the final and most precise measurement of the charged kaon mass. The interplay between the communities and the experimental techniques have been discussed, as well as the possibility to put forward a joint proposal for a measurement campaign at DAFNE.

2.3.21 *Measuring Neutrino Interactions for Next-Generation Oscillation Experiments*

Date	21-25 October 2024

Organizers

Stephen Dolan	CERN, Switzerland
Luke Pickering	Rutherford Appleton Laboratory, UK
Callum Wilkinson	Lawrence Berkeley National Laboratory, USA
Clarence Wret	University of Oxford, UK

Number of participants	*27*

Main topics

The workshop centered on exploring the measurements and theory developments in neutrino-nucleus interactions that are required to mitigate uncertainties for the next-generation long-baseline neutrino oscillation experiments, Hyper-Kamiokande and DUNE. Achieving these goals will enable and extend the experiments' extraordinary physics goals, like measuring CP violation in neutrinos, establishing the neutrino mass ordering, and measuring the octant of θ_{23}.

The main topics of the workshop were:

- An overview and introduction to the theory and experimental landscapes in neutrino interaction physics
- Uncertainties in experimental approaches to measuring neutrino cross sections, and their impact on oscillations
- Uncertainties in different theory approaches
- Role of final-state interactions and hadron transport, and different treatments in determining neutrino interaction cross sections
- A discussion of alternate probes of nuclear effects and structure, e.g. electrons, hadrons, and neutrino SIS/DIS probes
- The quasi-elastic interaction on the nucleon: bubble chambers, nuclear targets, and lattice QCD
- Nuclear effects in deuterium and implications for bubble chamber data
- The role of lattice QCD: Interfacing neutrino interaction generators, free-nucleon measurements on nuclear targets, expanding beyond quasi-elastic and into the resonance region
- Neutron detection in scintillator and liquid-argon based detectors, its role in oscillation analyses, and possible areas of model dependence and model improvement
- Developments in neutrino cross-section extraction, including machine learning techniques and novel approaches for mitigating model dependence
- Improving data releases, presentation, and preservation efforts

Speakers

Callum Wilkinson	Lawrence Berkeley National Laboratory, USA
Jeremy Wolcott	Tufts University, USA
Patrick Stowell	University of Sheffield, UK
Julia Tena-Vidal	Tel-Aviv University, Israel
Kevin McFarland	University of Rochester, USA
Raul Gonzalez-Jimenez	Universidad de Sevilla, Spain
Natalie Jachowicz	Ghent University, Belgium
Andrew Furmanski	University of Minnesota, USA
Kamil Skwarczynski	Royal Holloway, University of London, UK
Afroditi Papadopoulou	Argonne National Laboratory, USA
Deborah Harris	York University, USA
Joanna Sobczyk	Johannes Gutenberg University Mainz, Germany
Laura Munteanu	CERN, Switzerland
Juanma Franco Patiño	IFIC Valencia, Spain
Kajetan Niewczas	Ghent University, Belgium
Anna Ershova	LLR, École Polytechnique, France
Jean-Chris David	CEA Saclay, France
Vladimir Grichine	CERN, Switzerland
Artur Ankowski	University of Wroclaw, Poland
A. Ashkenazi	Tel-Aviv University, Israel
Anežka Klustova	Imperial College London, UK
Richard Diurba	University of Bern, Switzerland
Aron Meyer	Lawrence Livermore National Laboratory, USA
Minoo Kabirnezhad	Imperial College London, UK
Sara Collins	University of Regensburg, Germany
Stephen Dolan	CERN, Switzerland
Andrew Olivier	University of Notre Dame du Lac, USA
Steve Manly	University of Rochester, USA
Lukas Koch	Johannes Gutenberg University Mainz, Germany
Steven Gardiner	Fermilab, USA
Andrew Cudd	University of Colorado, USA
Luke Pickering	Rutherford Appleton Laboratory, UK
Guillermo D. Megias	Universidad de Sevilla, Spain
Daniel Cherdack	University of Houston, USA

Scientific report

Accelerator-based long-baseline neutrino oscillation experiments have the potential to revolutionize our understanding of fundamental physics. They offer an opportunity to characterize charge-parity violation in the lepton sector, to determine the neutrino mass ordering, and to explore physics beyond three-flavor neutrino mixing, e.g. unitarity tests and searches for non-standard interactions. As more data is collected, the next generation of experiments, DUNE and Hyper-Kamiokande, will require increasingly precise control over the systematic uncertainties in their analyses to benefit from the increased statistics and detector precision.

The leading uncertainty is the modeling of neutrino-nucleus interactions at 3-5%, arising because inferring the neutrinos' oscillations from measured events depends on the neutrino interaction cross section, as well as the oscillation probability. The sources of these uncertainties are often related to subtle details of the pertinent nuclear physics. For example, those of the target nucleus ground state, and the transport of hadrons through the nuclear medium, which are challenging to control with sufficient precision, especially with neutrino data alone. Confronting these uncertainties requires significantly improved modeling of the neutrino-nucleus interactions which are most likely to bias or induce the dominant systematic uncertainties in future neutrino oscillation measurements.

In turn, the improved modeling requires new, novel neutrino-nucleus interaction measurements to inform theoretical development, to benchmark current and future models, and to constrain the parameters within the models. This is particularly timely, as both Hyper-Kamiokande and DUNE embark on designing their upgraded near detectors, which need to be sensitive to the uncertainties which limit the neutrino oscillation analyses at the far detectors.

This workshop brought together experts across a range of research fields to discuss challenges and obstacles in making experimental measurements of neutrino-nucleus interactions that will maximally benefit the GeV-scale neutrino oscillation programme. The workshop served as an opportunity for cross-field discourse, with attendees spanning experimentalists in neutrino oscillations, neutrino-interaction and nuclear theorists, and those leading efforts to measure neutrino-nucleus interactions.

The main goals of the workshop were to:

- Ascertain what aspects of neutrino interactions must be most carefully controlled to avoid biases or large systematic uncertainties for DUNE and Hyper-Kamiokande
- Establish which experimental measurements can be made to constrain them
- Determine how to best ensure the longevity of these measurements for experiments taking place in a decade's time (i.e. how to manage model dependence).

Results and highlights

The workshop was a very useful opportunity for cross-field discourse on the challenges that must be addressed in neutrino interaction physics for the next-generation long-baseline neutrino oscillation experiments to be successful.

A major challenge is the development of a comprehensive parameterisation of uncertainties on neutrino interaction models, i.e. needing to quantify what we do not know. A major part of the workshop concerned experimental and theoretical perspectives on this topic. An early dedicated talk on the experiments' treatment of uncertainties identified key differences, highlighting opportunities for model development, for example applying elements of T2K's uncertainties to the DUNE uncertainty model or vice-versa. It also highlighted areas where community-wide attention is required, particularly concerning higher-energy neutrino interactions, which have historically received less attention but are critically important to DUNE. Similarly, two theoretical perspectives on the uncertainties on the microscopic interaction models quantified exactly what is (and is not) covered by such models, and subsequent discussion helped to identify potential strategies to use these uncertainties in experimental analyses.

Another highlight of the workshop was the discussion of the use of lattice quantum chromodynamics (LQCD) to provide robust theoretical calculations, complete with uncertainties, on the neutrino-nucleon interaction cross section. Two theory talks highlighted the broad scope of application of LQCD calculations for current and next-generation experiments, and emphasised that future calculations will require justifiable experimental goals on the precision, which has now begun. Furthermore, experimental possibilities for measurements to validate or benchmark LQCD predictions were discussed, for example isolating neutrino-nucleon interactions that occur off the $\Delta^{++}(1232)$ resonance, which constrains neutrino-induced single-pion production.

A key success of the workshop was the dedicated discussion time that allowed experimental requirements from theoretical models to be communicated with greater clarity than at previous workshops and conferences. In particular, it became clear that experimentalists occasionally need to extrapolate models beyond their intended range of validity. Discussion on the models' behaviour in such regions was invaluable and is critical to building a robust model of the uncertainties.

Another focal point concerned the utility of electron scattering measurements to constrain the key physics of interest for neutrino oscillation experiments. Talks from electron scattering experimentalists and theorists with dedicated discussion time allowed identification of the key measurements of interest for the neutrino oscillation community; both those already made and yet to be utilised, and future measurement by for instance CLAS12 at Jefferson lab.

Beyond useful technical talks and discussion, the workshop opened and closed with summary talks from established experts in the field, covering the status and challenges faced by experiments and theoretical modelling. We asked speakers to cover projects beyond their own, which led to insightful comparisons and conclusions, and we hope will be repeated at future neutrino interaction workshop and conferences. Discussions at the workshop has led to numerous new collaborations starting between interaction theorists and experimentalists.

2.3.22 *Universal Themes in Bose-Einstein Condensation*

Date	November 4-8, 2024
Organizers	
Iacopo Carusotto	INO-CNR BEC Center, Italy
Thierry Giamarchi	University of Geneva, Switzerland
Gabriele Ferrari	University of Trento, Italy
David Snoke	University of Pittsburgh, USA
Peter Littlewood	University of Chicago, USA
Francesca M. Marchetti	UAM Madrid, Spain
Nick Proukakis	University of Newcastle, UK
Michiel Wouters	University of Antwerp, Belgium
Stefano Giorgini	University of Trento, Italy
Corinna Kollath	University of Bonn, Germany
Number of participants	62

Main topics

The workshop aimed to gather specialists from theoretical and experimental condensed matter, atomic physics, nuclear physics, and gravitational physics to discuss interdisciplinarily the concept of Bose-Einstein condensation and its realizations in different areas of the physical sciences.

It was the 2024 edition (coinciding with the centenary of Satyendra Bose's pioneering first work) of a series of key events that started in Levico (near Trento) back in 1993 and were instrumental to the impressive developments that research on BECs displayed in the last three decades. As compared to other events focussing on specific systems, the distinctive feature of our workshop was its commitment to have a broad spectrum of participants and topics, with the goal of fostering and nurturing existing interdisciplinary connections and facilitating new, unexpected ones. With this objective in mind, the structure of the workshop was designed with specific attention to stimulate unexpected long-range connections between distinct fields.

The main topics were

- Condensation in gases of ultracold atoms and in liquid Helium
- Condensation of quasi-particles (magnons, excitons, polaritons) in solids
- Driven-dissipative condensates
- Condensation of light and in laser physics
- Universality and criticality in equilibrium and non-equilibrium condensation
- Excitonic insulators
- Superfluidity, vortices, and topological defect
- Few- and many-body phenomena

- Condensates as a quantum simulator of gravitational and/or high-energy physics
- Turbulence phenomena
- Supersolidity phenomena
- Condensates in gravitation and cosmology

Speakers

Sandro Stringari	Università di Trento, Italy
David Snoke	Univ. Pittsburgh, USA
Carlo Barenghi	Newcastle University, UK
Thomas Gasenzer	Heidelberg University, Germany
Catalin-Mihai Halati	DQMP, University of Geneva, Switzerland
Oleksandr Serha	University of Kaiserslautern-Landau, Germany
Martin Weitz	Institute of Applied Physics, Universität Bonn, Germany
Giovanni Italo Martone	CNR NANOTEC and INFN, Lecce, Italy
Lucas Madeira	University of São Paulo, Brazil
Hanns-Christoph Nägerl	Universität innsbruck, Austria
Markus Oberthaler	Univ. Heidelberg, Germany
David Clement	Institut d'Optique, Palaiseau, France
Alessandro Zenesini	CNR-INO, Trento, Italy
Ubirajara van Kolck	ECT*, Italy & IJCLab Orsay, France & Univ. of Arizona, USA
Yvan Castin	Laboratoire Kastler Brossel de l'ENS, France
Ralf Klemt	Physikalisches Institut, Universität Stuttgart, Germany
Dimitrios Trypogeorgos	CNR Nanotec, Lecce, Italy
Nicolò Antolini	LENS, University of Florence, Italy
Davide Nigro	University of Pavia, Italy
Niccolò Preti	Università degli studi di Firenze, Italy
Tomasz Zawiślak	University of Trento, Pitaevskii BEC Center, Italy
Samuli Autti	Lancaster University, UK
Antonio Picozzi	CNRS - University of Bourgogne, France
Alexander Dikopoltsev	ETH Zurich, Switzerland
Yusuke Morita	Institute for Photon Science and Technology, Univ. Tokyo, Japan
Nigel Cooper	University of Cambridge, UK
Massimo Rontani	CNR-NANO, Modena, Italy
Mudit Jain	King's College London, UK *
Daniele Oriti	Universidad Complutense Madrid, Spain
Nicolas Chamel	Université Libre de Bruxelles, Belgium
Ronen Rapaport	The Hebrew University, Israel
Lorenzo Pizzino	University of Geneva, Switzerland
Deborah Capecchi	CNR Nanotec, Lecce, Italy

Dario Bettoni	León University, Spain
Nick Proukakis	Univ. Newcastle, UK
Gerasimos Rigopoulos	Newcastle University, UK
Alice Sinatra	Laboratoire Kastler Brossel de l'ENS, France
Zoran Hadzibabic	University of Cambridge, UK
Marzena Szymanska	University College London, UK
Alberto Bramati	LKB, Paris, France
Anna Minguzzi	LPMMC, Grenoble, France
Gabriele Spada	Univ. Camerino, Italy
Feng Wu	IJCLab, Orsay, France
Nur Ünal	University of Cambridge, UK
Onur Umucalilar	Mimar Sinan Univ., Istanbul, Turkey
Andrea Richaud	Universitat Politècnica De Catalunya, Spain (Universitat Politècnica De Catalunya, Spain)

* Online talk

Scientific report

The general objective of the workshop was to gather specialists from a wide range of theoretical and experimental physics disciplines to discuss interdisciplinary the concept of Bose-Einstein condensation and its realizations in different areas of the physical sciences.

As a first step in order to achieve this objective, the historical organizing team of the previous UBEC events was reinforced with a few more colleagues. This resulted in a quite large set of organizers, which allowed them to identify prospective participants in a wider range of areas and motivate them to actively participate in the event. Starting from a core of well-selected key speakers, the list of participants kept growing until the very end with more and more people being contacted or contacting the organizers. As a general idea, we tried to have most participants present their research in one way or another: senior researchers were given relatively long slots for their talks, while younger ones were offered a shorter slot or a poster presentation. This scouting activity was quite successful and resulted in a very interdisciplinary list of presentations. The active involvement of young researchers has also been a very important success of the workshop: a number of top-level results have been presented by postdocs and a quite sizable fraction of the participants consisted of early-stage researchers. This suggests an important impact of the event on the training of the next generation of researchers, for which an interdisciplinary approach to research will hopefully be more and more familiar.

Special attention was paid to two emerging areas of research, namely condensates in gravitation and cosmology, and supersolidity phenomena. The former topic has been under the spotlight of the organizers from the beginning and was the object of specific efforts to secure the participation of prominent international experts. As such we could have a couple of sessions dedicated to discussions on the link between condensation and dark matter, on the role of superfluidity at the galactic scale, and of condensation phenomena in astrophysics. The latter topic rose to the attention of the organizers at a later stage, mostly stimulated by recent experimental advances: the main international groups working on supersolidity in different contexts were specifically contacted, which gave rise to an exciting session where this concept was discussed in different platforms such as ultracold atoms, polariton condensates, and laser devices.

In the final wrap-up session, the numerous participants who remained until the end of the event discussed the possibility of organizing further events to continue the UBEC series. There was, in fact, unanimous agreement among participants about the added value of interdisciplinary events. On this basis, the organizing team will keep in touch in the coming months and try to converge on a decision on the location and the time for the new edition to be held in a few years.

Going beyond science and looking at our event from a more general perspective, the success of this event has once more confirmed the leading role that the Trento scientific ecosystem is playing in the international research on condensation phenomena. The tradition initiated with the 1993 event in Levico has kept growing over the years and is showcased by the wide network of scientific connections that workshops like this contribute to developing and reinforcing between the Trento institutions and the international community.

Results and highlights

The workshop provided a rich and very interdisciplinary overview of different areas of the physical sciences where the concept of condensation is nowadays playing a central role. This allowed us to identify points of contact and common open questions between different fields and stimulated unexpected new interdisciplinary collaborations.

One of the most significant outcomes of the workshop has been to unveil new unexpected connections among them and give new twists to the ones already present in the literature. As a few most remarkable examples: The conceptual connection between equilibrium Bose-Einstein condensation in different material platforms is nowadays well established and collaborations between researchers in these fields have been active already for some years. What appeared instead as a quite exciting surprise during our workshop is the deep interconnection between the time-dependent aspects of the condensation process (e.g. coarsening phenomena), the development of turbulence phenomena in different systems, and the statistical mechanics of non-equilibrium condensates (e.g. Kardar-Parisi-Zhang universality and diffusive Goldstone modes). As participants presented their latest results in these areas from different perspectives, it became immediately apparent that close relations exist between their works but, at the same time, that very different questions are addressed in each field. This clearly shows the need for an interdisciplinary approach to these problems, trying to translate questions and answers from one area to another so as to get a unified picture of the underlying physics.

Along similar lines, concepts and techniques of Bose-Einstein condensation are being translated to optoelectronic devices for generating and manipulating coherent light. During the workshop, such ideas have been specifically investigated in the context of photon condensates, solid-state lasers and multi-mode fiber optics. Also the results on few-body physics, so far mostly presented in the context of nuclear or atomic physics, are expected to play a central role in the development of quantum opto-electronic devices based on the strong interactions mediated by the optical nonlinearities between a few photons. We are confident that the next few years will see many such interdisciplinary developments.

The session on condensation phenomena in gravitation and cosmology has fully met the expectations of the organizers, by highlighting exciting pioneering work on condensation and superfluidity phenomena of dark matter and their possible role in astrophysical objects at the galactic and cosmological scales. Somehow specularly, the successful use of atomic condensates as a platform for quantum simulation of cosmological and high-energy phenomena was also reported, both at the level of quantum field theories on curved space-times and of false vacuum decay from metastable energy minima.

The discussions on supersolidity have identified exciting directions for further investigations that take full advantage of interdisciplinary exchanges of ideas between optical and atomic systems: on the one hand, optical supersolids still lack a detailed understanding of their collective excitation modes, which, in analogy with atoms, are expected to display several branches but, at the same time, to also show specific features related to the non-equilibrium condition; on the other hand, novel spatial structures have been observed in strongly driven atomic condensates which display strong analogies with the observation in polariton supersolids.

2.4 ECT* Doctoral Training Program/TALENT School: Nuclear Theory for Astrophysics

Date	15 July - 2 August 2024

Organizers

Almudena Arcones	TU Darmstadt, Germany
Bruno Giacomazzo	University of Milano-Bicocca, Italy
Jorge Piekarewicz	Florida State university; USA

Number of participants	24

Aim of the DTP

The school focused on neutron stars and the strong link between nuclear physics and astrophysics. In the last years, there was enormous progress in theory, experiments, and observations and the aim of the doctoral training program was to give the students a broad overview combined with concrete and practical exercises.

Main topics

The school was truly multidisciplinary as it addressed fundamental questions in fields as diverse as astrophysics, gravitational physics, nuclear physics, and particle physics. The course consisted of three main topics with neutron stars at the center and focus on different exciting aspects:

1. *Nuclear physics of neutron stars.* The lectures explained how to build an equation of state for neutron rich matter that is consistent with known properties of finite nuclei and neutron stars. The students learnt how to build a TOV solver in order to compute the mass-radius relation for a small sample of realistic equations of state.

2. *Birth of neutron stars in core-collapse supernovae.* We briefly reviewed the stellar evolution of massive stars and discussed in detail their collapse and explosions as supernovae. The students gained a deep understanding of the explosions and the role of the equation of state on the supernova dynamics, neutrino emission and nucleosynthesis. The lectures covered neutrino astrophysics and the role of magnetic fields in supernovae.

3. *Neutron star mergers*. We organized a series of lectures and tutorials on numerical relativity simulations of neutron star mergers where the students also familiarized themselves with some open source codes used in the community. The lectures also covered our current understanding of the gravitational and electromagnetic emission that can be produced by these systems, including r-process/kilonova and short gamma ray bursts.

Scheduling of the lessons

The schedule consisted of lectures from 9:30 to 12:30 (with 30 min coffee break), exercises from 14:00 to 17:00, and wrap-up from 17:00 to 18:00. The full program of the school can be found here: https://indico.ectstar.eu/event/221/overview.

Lecturers

Adriana Raduta	IFIN-HH Bucharest, Romania
Concettina Sfienti	Johannes Gutenberg-Universität, Germany
Serena Vinciguerra	University of Amsterdam, Netherlands
Anna Puecher	University of Potsdam, Germany
Martin Obergaulinger	University of Valencia, Spain
Moritz Reichert	University of Valencia, Spain
Andre da Silva Schneider	Universidade Federal de Santa Catarina, Brazil
Francesco Capozzi	Università degli Studi dell'Aquila, Italy
Albino Perego	University of Trento, Italy
Alejandra Gonzalez	University of Jena, Germany
Om Sharan Salafia	INAF, Italy

Lectures

- CompOSE. Tables for state of the art equations of state (A. R. Raduta)
- NICER:past, present and future in constraining the EOS from EM observations (S. Vinciguerra)
- PREX/MREX and laboratory constraints on the neutron skin and symmetry energy (C. Sfienti)
- GW: past, present and future in constraining the EOS from GW detections (A. Puecher)
- EOS in core-collapse supernovae (A. da Silva Schneider)
- Magneto-rotational supernovae (M. Obergaulinger)
- Nucleosynthesis in supernovae (M. Reichert)
- Supernova neutrinos (F. Capozzi)
- The CORE database (A. Gonzalez)
- r-process/kilonova theory (A. Perego)
- GRB theory - jet launching (O. Sharan Salafia)

2.4.1. List of students

Milena Albino	University of Coimbra, Portugal
Alexander Clevinger	Kent State University, USA
Kutay Arınç Çokluk	Ege University, USA
Nithish Kumar Covalam Vijayakuma	TU Darmstadt, Germany
Tiago Custódio	University of Coimbra, Portugal
Andrea Di Donna	Unitn – TIFPA, Italy
Yannick Dietz	TU Darmstadt, Germany
Achille Fiore	Goethe University Frankfurt, Germany
Hannah Göttling	TU Darmstadt, Germany
Marcus Hatton	University of Southampton, UK
Marcel Humbert	TU Darmstadt, Germany
Finia Jost	TU Darmstadt, Germany
Heamin Ko	TU Darmstadt, Germany
Nikita Kozyrev	Johannes Gutenberg-Universität Mainz, Germany
Sinan Long	University College London, UK
Rajes Maiti	Inter-University Centre for Astronomy and Astrophysics, India
Martin Javier Nava Callejas	Universidad Nacional Autónoma de México, Mexico
Giuseppe Rivieccio	Universitat de Valencia, Spain
Marc Salinas	Florida State University, USA
Luigi Scurto	CFisUC, University of Coimbra, Portugal
Shahina Shahina	University of Notre Dame, USA
Estuti Shukla	Penn State University, USA
Duvier Suarez Fontanella	University of Salamanca, Spain
Wei Sun	University of Notre Dame, USA
Stefanos Tsiopelas	University of Wrocław, Poland

Results and highlights

The school brought together a highly capable and engaged cohort of students who fully immersed themselves in every activity, from the first day to the last. This enthusiasm enabled lecturers to maintain a consistently high intellectual level throughout the program. The lectures were organized in a carefully sequenced, bottom-up approach—beginning with an introduction to neutron stars and their equation of state, followed by sessions on core-collapse supernovae and neutron star mergers. It was especially rewarding to witness the students forming a unified, inclusive, and multicultural group from the beginning. Their strong teamwork and productive discussions, particularly during the afternoon sessions, had a positive impact on the learning environment, supporting everyone's engagement with the lectures. The quality of the lectures was exceptional, and we received enthusiastic feedback from the participants. The students achieved a comprehensive understanding of neutron stars from the nuclear and astrophysics perspectives.

Research at ECT*

3. Research at ECT*

3.1 Projects of ECT* Researchers

Investigating the dynamics of learning in machine learning algorithms is important for understanding how and why an approach may be successful

Gert Aarts

In collaboration with: L. Wang (iTHEMS, RIKEN), K. Zhou (Chinese U. Hong Kong), B. Lucini (Swansea U.)

Project abstract: The tools of physics and statistics provide a robust setting for such investigations. We followed two approaches
- We apply concepts from random matrix theory and statistical field theory to describe stochastic weight matrix dynamics, using the framework of Dyson Brownian motion.
- Diffusion models are currently the leading generative AI approach used for image generation in e.g. DALL-E and Stable Diffusion. We relate diffusion models to stochastic quantisation in field theory and employ it to generate configurations for scalar fields on a two-dimensional lattice.

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

Daniele Binosi

In collaboration with: A. Acardi (Hampton U.) et al.

Project abstract: The initial scientific case for upgrading the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab (JLab) to 22 GeV was made. It was 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 encompasses 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, the significant physics outcomes and unique aspects of these programs that distinguish them from other existing or planned facilities were outlined. There is 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: [1]

Pseudoscalar Mesons and Emergent Mass

Daniele Binosi

In collaboration with: K. Raya (Huelva U.), A. Bashir (Huelva U. and IFM-UMSNH Michoacan), C.D. Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.)

Project abstract: Despite its role in the continuing evolution of the Universe, only a small fraction of the mass of visible material can be attributed to the Higgs boson alone. The overwhelmingly dominant share may/should arise from the strong interactions that act in the heart of nuclear matter; namely, those described by quantum chromodynamics. This contribution describes how studying and explaining the attributes of pseudoscalar mesons can open an insightful window onto understanding the origin of mass in the Standard Model and how these insights inform our knowledge of hadron structure. The survey ranges over distribution amplitudes and functions, electromagnetic and gravitational form factors, light-front wave functions, and generalized parton distributions. Advances made using continuum Schwinger function methods and their relevance for experimental efforts are highlighted.

Related publication: [2]

Kaon Distribution Functions from Empirical Information

Daniele Binosi

In collaboration with: Z.-N. Xu (Huelva U.), C. Chen (USTC Hefei), K. Raya (Huelva U.), C.D. Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.)

Project abstract: Using available information from Drell-Yan data on pion and kaon structure functions, an approach is described which enables the development of pointwise profiles for all pion and kaon parton distribution functions (DFs) without reference to theories of hadron structure. The key steps are construction of structure-function-constrained probability-weighted ensembles of valence DF replicas and use of an evolution scheme for parton DFs that is all-orders exact. The DFs obtained express qualitatively sound features of light-meson structure, e.g., the effects of Higgs boson couplings into QCD and the size of heavy-quark momentum fractions in light hadrons. In order to improve the results, additional and more precise data on the u-quark-in-kaon, u^K, to u-quark-in-pion, u^π, DF ratio would be necessary. Of greater

value would be extraction of u^K alone, thereby avoiding inference from the ratio: currently, the data-based form of u^K is materially influenced by results for u^π.

Related publication: [3]

A tailor-made quantum state tomography approach

Daniele Binosi
Maurizio Dapor
Giovanni Garberoglio

In collaboration with: D. Maragnano (Pavia U.), M. Liscidini (Pavia U.)

Project abstract: Quantum state tomography (QST) aims at reconstructing the state of a quantum system. However, in conventional QST, the number of measurements scales exponentially with the number of qubits. Here, we propose a QST protocol in which the introduction of a threshold allows one to drastically reduce the number of measurements required for the reconstruction of the state density matrix without compromising the resulting accuracy. In addition, one can also use the same approach to reconstruct an approximated density matrix tailoring the number of measurements on the available resources. We experimentally demonstrate this protocol by performing the tomography of states up to seven qubits on the IBMQ platform. We show that our approach can lead to results in agreement with those obtained by QST even when the number of measurements is reduced by more than two orders of magnitude.

Related publications: [4], [5]

Ab initio *calculation of virial coefficients*

Daniele Binosi
Giovanni Garberoglio

In collaboration with: A.H. Harvey (NIST, Boulder) and several metrological groups in Europe.

Project abstract: This project is devoted to the *ab initio* calculation of pressure, acoustic and dielectric virial coefficients of gases that have metrological interest. It is funded by the EMPIR initiative, which is co-funded by participating states and the European Union's Horizon 2020 Research and Innovation Programme, through the project MQB-Pascal (Metrology for quantum-based traceability of the pascal, 22IEM04).

This year, improved two-body and three-body potentials for helium have been used to calculate from first principles the third density and acoustic virial coefficients for both ^{4}He and ^{3}He. For the third density virial coefficient $C(T)$, uncertainties have been reduced by a factor of 4–5 compared to the previous state of the art; the accuracy of first-principles $C(T)$ now exceeds that of the best experiments by more than two orders of magnitude. The range of calculations has been extended to temperatures as low as 0.5 K. For the third acoustic virial coefficient $\gamma_a(T)$, we applied the Schlessinger Point Method, which can calculate γ_a and its uncertainty based on $C(T)$ data, overcoming some limitations of direct path-integral calculations. The resulting γ_a are calculated at temperatures down to 0.5 K; they are consistent with available experimental data but have much smaller uncertainties. The first-principles data presented here will enable improvement of primary temperature and pressure metrology based on gas properties. This work represents a successful collaboration among ECT* researchers, as techniques originally developed in nuclear physics were applied to analyze computational data and provide independent methods for calculating the acoustic virial coefficient, along with its associated uncertainty, from the density virial coefficient. This validation enabled the estimation of the third acoustic virial coefficient at temperatures too low for a direct computational approach to be feasible.

We also made significant progress on the dielectric virial front, publishing a comprehensive first-principles calculation of the first dielectric virial coefficient of water and presenting our results for the third dielectric virial coefficient of helium isotopologues. These calculations utilized the most recent potential energy, polarizability, and dipole moment surfaces. Notably, our approach is characterized by the absence of uncontrolled approximations and includes rigorous uncertainty propagation, enabling our results to be directly applied in primary metrology. The quality of our work was recognized by The Journal of Chemical Physics, which selected one of our papers as an Editor's Pick.

Related publications: [6], [7], [8]

Optimizing Quantum Simulations for Trapped-Ion Qubits

Daniele Binosi

Luca Vespucci

In collaboration with: A. Roggero (U. Trento)

Project abstract: We Investigate 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. We aim to identify the most effective methodology to translate near-term trapped-ion quantum computing into meaningful quantum simulations of microscopic systems.

Developing predictions for pion fragmentation functions

Daniele Binosi

Zhao-Qian Yao

In collaboration with: H.-Y. Xing (Nanjing U.), B.-L. Li (Shanghai U.), Z.-F. Cui (Nanjing U.), and C.D. Roberts (Nanjing U.)

Project abstract: Exploiting crossing symmetry, the hadron scale pion valence quark distribution function was 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 in this work could potentially provide useful guidance for future such studies.

Related publication: [9]

Nucleon charge and magnetisation distributions: flavour separation and zeroes

Daniele Binosi
Zhao-Qian Yao

In collaboration with: Z.-F. Cui (Nanjing U.), C.D. Roberts (Nanjing U.)

Project abstract: A symmetry-preserving truncation of the quantum field equations describing hadron properties is used to deliver parameter-free predictions for all nucleon elastic electromagnetic form factors and their flavour separation to large values of momentum transfer, Q^2. The proton electric form factor, G_E^p, possesses a zero, whereas that of the neutron, G_E^n, does not. The difference owes to the behaviour of the Pauli form factor of the proton's singly-represented valence d-quark. Consequently, $G_E^n > G_E^p$ on a material large-Q^2 domain. These predictions can be tested in modern experiments.

Related publication: [10]

Onset of scaling violation in pion and kaon elastic electromagnetic form factors

Daniele Binosi
Zhao-Qian Yao

In collaboration with: Z.-F. Cui (Nanjing U.), C.D. Roberts (Nanjing U.)

Project abstract: Using a symmetry-preserving truncation of the quantum field equations describing hadron properties, parameter-free predictions are delivered for pion and kaon elastic electromagnetic form factors, $F_{P=\pi,K}$, thereby unifying them with kindred results for nucleon elastic electromagnetic form factors. Regarding positive-charge states, the analysis stresses that the presence of scaling violations in QCD entails that $Q^2F_P(Q^2)$ should exhibit a single maximum at $Q^2 > O$. Locating such a maximum is both necessary and sufficient to establish the existence of scaling violations. The study predicts that, for charged π, K mesons, the $Q^2F_P(Q^2)$ maximum lies in the neighborhood of $Q_N^2 \simeq 5\,\mathrm{GeV}^2$. Foreseeable experiments will test these predictions and, providing their Q^2 reach meets expectations, potentially also provide details on the momentum dependence of meson form-factor scaling violation.

Related publication: [11]

Nucleon Gravitational Form Factors

Daniele Binosi
Zhao-Qian Yao

In collaboration with: Y.-Z. Xu (Huelva U.), Z.-F. Cui (Nanjing U.), M. Ding (Nanjing U. and Helmholtz-Zentrum Dresden-Rossendorf), K. Raya (Huelva U.), C.D. Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.), S.M. Schmidt (Helmholtz-Zentrum Dresden-Rossendorf)

Project abstract: A symmetry-preserving analysis of strong-interaction quantum field equations is used to complete a unified treatment of pion, kaon, nucleon electromagnetic and gravitational form factors. Findings include: a demonstration that the near-core pressure in the pion is roughly twice that in the proton, so both are significantly greater than that of a neutron star; parton species separations of the nucleon's three gravitational form factors, in which, inter alia, the glue-to-quark ratio for each form factor is seen to take the same constant value, independent of momentum transfer; and a determination of proton radii orderings, with the mechanical (normal force) radius being less than the mass-energy radius, which is less than the proton charge radius. This body of predictions should prove useful in an era of anticipated experiments that will enable them to be tested.

Related publication: [12]

Likelihood of a zero in the proton elastic electric form factor

Daniele Binosi
Zhao-Qian Yao

In collaboration with: P. Cheng (Anhui Normal U.) and C.D. Roberts (Nanjing U.)

Project abstract: Working with the 29 available data on the ratio of proton electric and magnetic form factors, $Q^2 \leq 13.06\ \mathrm{GeV}^2$, and independent of any model or theory of strong interactions, we use the Schlessinger point method to objectively address the question of whether the ratio possesses a zero and, if so, its location. Our analysis predicts that, with 50% confidence, the data are consistent with the existence of a zero in the ratio for $\mu_p G_E^p(Q^2) / G_M^p(Q^2)$. The level of confidence increases to 99.9% for $Q^2 \leq 13.06\ \mathrm{GeV}^2$. Significantly, the likelihood that existing data are consistent with the absence of a zero in the ratio for $Q^2 \leq 14.49\ \mathrm{GeV}^2$ is 1/(1 million).

Related publication: [13]

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

Francesco Carnovale
Tommaso Morresi
Giovanni Novi Inverardi
Simone Taioli

In collaboration with: A. Vella (U. Rouen), G. Lattanzi (U. Trento), D. Paparo (CNR), M. Andersson (Chalmers U.)

Project abstract: Cryo-electron microscopy and tomography are among the greatest achievements in biological imaging. However, these techniques suffer from insufficient chemical resolution. In this regard, the European HORIZON-EIC-2021 PATHFINDEROPEN-01 project MIMOSA aims to create an alternative to nanoscale tomography with a high chemical resolution for biological and medical systems based on the Tomographic Atom Probe (TAP). We are developing the prototype of a new TAP triggered by intense terahertz (THz) pulses that are stable at high repetition rates and have versatile and customised properties. In parallel, we are exploring a new THz source technology based on using ultrafast high-energy fiber lasers. This source can be used in nanotomography for biological and medical applications, but also as a test platform for the foreseeable commercialisation of THz-triggered TAP. MIMOSA relies on the integration of transdisciplinary fields such as bio-imaging, optics, ultrafast lasers and intense THz sources, big data treatment and physics of interaction between THz waves and matter, such as proteins embedded in silica-based cages. 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.

In an experimental and theoretical collaboration, we investigated the emission of cations from silica samples by single-cycle THz pulses, focusing on the influence of pulse polarity. Negative THz pulses were found to efficiently trigger the evaporation of cations from nanoneedles in amorphous silica samples compared to positive pulses. Conversely, this dependence on pulse polarity could not be found in samples with metallic behaviour such as LaB_6 and when multi-cycle pulses in different frequency ranges such as ultraviolet (UV) are used. By performing first-principles simulations using TDDFT+Ehrenfest dynamics on silica under THz laser irradiation, we show critical fields for ion evaporation of hydroxyl groups from $Si(OH)_4$, which serves as a model precursor molecule for the amorphous solid matrix. To explain experimental results, we proposed a simplified theoretical model that determines the role of the polarity of the THz pulse by taking into account the differences in electron mobility between silica and semi-metallic samples. The study explores the nonlinear microscopic mechanisms of atomic evaporation under external static and THz laser fields, and clarifies the dynamics of THz-enhanced APT and related applications.

One important aspect of this project is the modeling of the interaction between the biological sample and the silica matrix. We are improving a published molecular dynamics (MD) protocol by modelling the protein embedding procedure in a solution of water and also oligomers/polymers of the orthosilicic acid (the precursor of the silica matrix), allowing for a better treatment of the silica embedding shell. Our assessment offers a detailed mechanistic insight of the effects of orthosilicate polymers constituting the silica matrix, thereby validating its use in the proposed innovative application of TAP to the structural resolution of protein molecules. A further and final step consists of the addition of a reactive coarse-grained part to our model.

Related publications: [14], [15]

Electron Compton scattering

Maurizio Dapor

Project abstract: Recoil energy is a phenomenon that is observed in various spectroscopy experiments. Electron Compton scattering (ECS) studies the shape of the elastic peak resulting from electron scattering from solid targets. As the atoms move around their equilibrium position, they scatter the distribution of recoil energies, resulting in a broadening of the elastic peak known as Doppler broadening. Since the hydrogen peak has the largest recoil energy shifts due to the low mass of hydrogen, ECS is ideal for the detection of hydrogen. The most important aspects of this method for the detection of hydrogen include electron-induced hydrogen desorption and, in dielectric materials, charge phenomena.

Related publications: [16], [17], [18]

Nanoparticle Enhanced Hadron Therapy: a comprehensive mechanistic description

Maurizio Dapor
Simone Taioli

Project abstract: This project aims to apply fundamental physical and chemical methods to uncover the microscopic mechanisms behind the improvement of hadron therapy for cancer treatment using nanoparticles. Hadron therapy (or ion-beam cancer therapy, i.e. radiotherapy using accelerated ion beams) is one of the most advanced radiotherapies, with superior dose delivery and biological effectiveness as compared to conventional radiotherapy using photons. The increased effectiveness of hadron therapy is due to the physico-chemical phenomena triggered by the passage of the ion beam through the biomaterial on the nanoscale. There is experimental evidence that gold nanoparticles enhance the biological effect of ion beams. As nanoparticles can be tuned to cancer cells, they could be used to further improve hadron therapy. However, it is not yet known how nanoparticles produce this effect. Appropriate utilization of nanoparticle-induced radiation enhancement in hadron therapy depends on a better understanding of the physico-chemical mechanisms responsible. In this project, a theoretical and computational method is proposed in which a series of semiempirical and *ab initio* approaches are extended and linked to Monte Carlo track structure simulation tools to improve the fundamental understanding of the mechanisms at the nanoscale and to evaluate the dose deposited by the beam. Computer simulations based on first principles and Monte Carlo methods have become a rapidly growing field for modeling the interaction of charged particles, such as electron, proton, and ion beams, with various systems, such as slabs, nanostructures, and crystals. This project addresses the theoretical and computational approaches to model the physicochemical mechanisms that occur when charged beams interact with a medium.

Related publication: [19]

Charge transport in solids

Maurizio Dapor
Simone Taioli

In collaboration with: P. Trevisanutto (UKRI)

Project abstract: High-resolution imaging has revolutionized materials science by providing detailed insights into the atomic structures of materials. Electron microscopy and spectroscopy rely on analyzing backscattered and transmitted electrons as well as stimulated radiation emission to create structural and chemical maps. These signals contain information about the elastic and inelastic electron scattering processes within the sample, including collective and single electron excitations such as plasmons, inter- and intraband transitions. In this study, *ab initio* and Monte Carlo simulations were performed to investigate the behavior of high-energy primary and secondary electrons in scanning transmission experiments on $CsPbBr_3$ nanosamples. $CsPbBr_3$ is a perovskite material known for its high photoluminescence quantum yield, which makes it promising for applications in light-emitting devices and solar cells. This study investigates and estimates the reflection and transmission of primary and secondary electrons based on their kinetic energy as well as sample thickness and work function. The spatial distribution and energy spectra of the secondary electrons are also investigated and calculated to understand their generation depth and energy dynamics. These results provide a theoretical framework for studying the interactions between electrons and materials and can help optimize scanning microscopy techniques for imaging and characterizing advanced materials.

Related publications: [20]

Theoretical description of X17 boson-nucleon interactions using Chiral Effective Field Theory

Elena filandri

In collaboration with: A. Kievsky (U. Pisa), L. Girlanda (U. Lecce), L.E Marcucci (U. Pisa), M. Viviani (INFN- Pisa)

Project abstract: We study electron-positron pair production in the $d(p,e^+e^-)^3He$ and $d(n,e^+e^-)^3H$ processes, to evidentiate possible effects due to the exchange of a hypothetical low-mass boson, the so-called X17. We first analyze them as purely electromagnetic processes, in the context of a state-of-the-art approach to nuclear strong-interaction dynamics and nuclear electromagnetic currents, derived from Chiral Effective Field Theory (χEFT). Next, we studied explicitly the case of scalar, pseudoscalar, vector and axial couplings of the unknown X17 boson to u and d quarks and leptons, considering only the χEFT lowest-order transition operator. We examine how the exchange of a hypothetical low-mass boson would impact the cross sections for such processes. The main aim of the study is to exploit the specular structure of the ^{3}He and ^{3}H nuclei to investigate the isospin dependency of the X17-nucleon interaction, as the alleged "protophobicity".

Related Publication: [21]

Alpha-cluster nuclei and reactions with near-zero-range αα interactions

Elena filandri

In collaboration with: A. Kievsky (U. Pisa), L. Girlanda (U. Lecce), L.E Marcucci (U. Pisa), M. Viviani (INFN- Pisa)

Project abstract: We study ^{12}C and ^{16}O nuclei as systems composed of α-particle clusters using the effective near-zero-range field theory approach. The fundamental and excited states of the studied nuclei are calculated within an ab initio approach, using the hyperspherical harmonics method. Thanks to the two-body potential and fine-tuning of the leading-order three-body force, we find that the ^{12}C system turns out to be reproduced by theory. However, for the ^{16}O case it is necessary to include a four-body force in the description. Furthermore, we study $\alpha+\alpha+\alpha\to{}^{12}C+\gamma$ and $^{12}C+\alpha\to{}^{16}O+\gamma$ radiative captures, of paramount importance in stellar evolution.

Normal liquid ^{3}He studied by path-integral Monte Carlo simulations with a parametrized partition function

Giovanni Garberoglio

Tommaso Morresi

Project abstract: In this work we focus on the energy per particle of normal liquid ^{3}He in the temperature range 0.15−2 K using path-integral Monte Carlo simulations, leveraging a recently proposed method to overcome the sign problem, which is a long-standing challenge in many-body fermionic simulations. This approach is based on introducing a parameter ξ into the partition function, which allows a generalization from bosons (ξ=1) to fermions (ξ=−1). By simulating systems with $\xi \geq 0$, where the sign problem is absent, one can then extrapolate to the fermionic case at ξ=−1. Guided by an independent-particle model that uncovers non-analytic behavior due to the superfluid transition, which is moderated by finite-size effects, we develop a tailored extrapolation strategy for liquid ^{3}He that departs from the extrapolation schemes shown to be accurate in those cases were quantum degeneracy effects are weak, and enables accurate results in the presence of Bose-Einstein condensation and superfluidity for ξ>0. Our approach extends the previously proposed framework and yields energy-per-particle values in excellent agreement with experimental data.

Related publication: [22]

Revisiting the properties of superfluid and normal liquid ^{4}He using ab initio *potentials*

Giovanni Garberoglio
Tommaso Morresi

Project abstract: We study liquid helium in both normal and superfluid phases using path-integral Monte Carlo simulations with *ab initio* pair, three-body, and four-body potentials. Focusing on the energy per particle, we apply a perturbative approach to quantify contributions from many-body interactions and their uncertainties. Three-body and four-body terms contribute around 4% and 0.5%, respectively, with the dominant uncertainty arising from the four-body potential. Additional observables—superfluid fraction, condensed fraction, and pair distribution function—show excellent agreement with experiments.

Quantum symmetrization transition in superconducting sulfur hydride from quantum Monte Carlo and path-integral molecular dynamics

Tommaso Morresi

In collaboration with: M. Casula (CNRS & Sorbonne U.), M. Cherubini (CNRS & Sorbonne U.), R. Taureau (Sorbonne U.)

Project abstract: In this project we studied the structural phase transition of sulfur hydride. This transition is associated with the superconducting transition, at the record-breaking critical temperature T_c of 203 K. A quantitative description of the pressure dependence of this phase transition has been elusive for any *ab initio* theory attempted so far, raising questions on the actual mechanism leading to the maximum of T_c . Here, we estimate the critical pressure of the hydrogen bond symmetrization in the Im3m structure, by combining Density Functional Theory and Quantum Monte Carlo simulations for electrons with path-integral molecular dynamics for quantum nuclei. We find that the T_c maximum corresponds to pressures where an instantaneous local polarization forms on the hydrogen sites, a precursor of the ferroelectric Im3m-R3m transition, happening at lower pressures. For comparison, we also apply the self-consistent harmonic approximation, whose critical pressure lies in between the ferroelectric transition estimated by path-integral molecular dynamics and the local polarization formation. Nuclear quantum effects play a major role in a significant reduction (≈ 50 GPa) of the classical ferroelectric transition pressure at 200 K and in a large isotope shift (≈ 25 GPa) upon hydrogen-to-deuterium substitution of the local polarization formation pressure, in agreement with the corresponding change in the Tc maximum location.

Related publication: [23]

Depth-dependent study of time-reversal symmetry-breaking in the kagome superconductor AV_3Sb_5

Tommaso Morresi

In collaboration with: P. Bonfà (U. Modena and Reggio Emilia)

The breaking of time-reversal symmetry (TRS) in the normal state of kagome superconductors AV_3Sb_5 stands out as a significant feature, but its tunability is unexplored. Using low-energy muon spin-rotation experiments and local field numerical analysis, we study TRS breaking as a function of depth in single crystals of RbV_3Sb_5 (with charge order) and $Cs(V_{0.86}Ta_{0.14})_3Sb_5$ (without charge order). In the bulk of RbV_3Sb_5 (>33 nm from the surface), we observed an increase in the internal magnetic field width in the charge-ordered state. Near the surface (<33 nm), the muon spin relaxation rate is significantly enhanced and this effect commences at temperatures significantly higher than the onset of charge order. In contrast, no similar field-width enhancement was detected in $Cs(V_{0.86}Ta_{0.14})_3Sb_5$, either in the bulk or near the surface. These observations indicate a strong connection between charge order and TRS breaking and suggest that TRS breaking can occur prior to long-range charge order.

Related publication: [24]

Incoherent diffractive production of jets in electron DIS off nuclei at high energy

Benjamin Rodriguez-Aguilar
Dionysios Triantafyllopoulos

In collaboration with: S.-Y. Wei (Shandong U.)

Project abstract: We study incoherent diffractive production of two and three jets in electron-nucleus deep inelastic scattering (DIS) at small x_{Bj} using the color dipole picture and the effective theory of the Color Glass Condensate (CGC). We consider color fluctuations in the CGC weight-function as the source of the nuclear break-up and the associated momentum transfer squared $|t|$. We focus on the regime in which the two jets are almost back-to-back in transverse space and have transverse momenta P much larger than both the momentum transfer and the saturation scale Q_s. The cross section for producing such a hard dijet is parametrically dominated by large size fluctuations in the projectile wave-function that scatter strongly and for which a third, semi-hard, jet appears in the final state. The 2+1 jets cross section can be written in a factorized form in terms of incoherent quark and gluon diffractive transverse momentum distributions (DTMDs) when the third jet is explicit, or incoherent diffractive parton distribution functions (DPDFs) when the third jet is integrated over. We find that the DPDFs and the corresponding cross section saturate logarithmically when $|t| \ll Q_s^2$, while they fall like $1/|t|^2$ in the regime $Q_s^2 \ll |t| \ll P^2$. We further show that there is no angular correlation between the hard jet momentum and the momentum transfer. For typical EIC kinematics the 2 jets and 2+1 jets cross sections are of the same order.

Related publication: [25]

Mechanical properties of carbon-based materials

Simone Taioli

In collaboration with: A. Pedrielli (FBK), N. Pugno (U. Trento)

Project abstract: Self-locking structures are often studied in macroscopic energy absorbers, but the concept of self-locking can also be effectively applied at the nanoscale. In particular, we can engineer self-locking mechanisms at the molecular level through careful shape selection or chemical functionalization. The present work focuses on the use of collapsed carbon nanotubes (CNTs) as self-locking elements. We start by inserting a thin CNT into each of the two lobes of a collapsed larger CNT. We aim to create a system that utilizes the unique properties of CNTs to achieve stable configurations and enhanced energy absorption capabilities at the nanoscale. We used molecular dynamics simulations to investigate the mechanical properties of periodic systems realised with such units. This approach extends the application of self-locking mechanisms and opens up new possibilities for the development of advanced materials and devices.

Related publication: [26]

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

Simone Taioli

In collaboration with: D. Mascali (LNS), M. Busso (UniPg), 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 depending on the ionisation state. The PANDORA project has proposed a new experimental approach based on the use of a compact plasma trap to simulate selected stellar-like conditions. The aim is to measure for the first time in a plasma outside a storage ring the β-decay rates of radionuclides involved in nuclear-astrophysical processes. For this purpose, a compact magnetic plasma trap was developed that makes it possible to achieve the required plasma densities, temperatures and charge state distributions. The plasma parameters are measured online with a multi-diagnostic setup and correlated with the decay rate of the radionuclides, which is measured by detecting the γ-rays emitted by the daughter nuclei after β-decay. These γ-rays are detected with an array of 14 HPGe detectors placed around the trap. Three physical cases have been selected for the first experimental campaign: ^{176}Lu, ^{134}Cs and ^{94}Nb. The newly designed plasma trap will also be a tool of choice to measure plasma opacity, a quantity that is poorly known experimentally and has a large impact on the energy transport and spectroscopic observations of many astrophysical objects, such as kilonovae. The PANDORA project also relies on theoretical modeling and computer simulations carried out with newly implemented methods in astrophysical scenarios to study the chemical evolution of the universe and interpret observations, such as the decay of ^{7}Be.

Related publication: [27]

TMD factorisation for diffractive jets in photon-nucleus interactions

DIONYSIOS TRIANTAFYLLOPOULOS

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

Project abstract: Using the colour dipole picture and the colour glass condensate effective theory, we study the diffractive production of two or three jets via coherent photon-nucleus interactions at high energy. We consider the hard regime where the photon virtuality and/or the transverse momenta of the produced jets are much larger than the saturation momentum Q_s of the nuclear target. We show that, despite this hardness, the leading-twist contributions are controlled by relatively large parton configurations, with transverse sizes $R \sim 1/Q_s$, which undergo strong scattering and probe gluon saturation. We demonstrate that these leading-twist contributions admit transverse-momentum dependent (TMD) factorisation, in terms of quark and gluon diffractive TMD distribution functions, for which we obtain explicit expressions from first principles. We go beyond our previous work by evaluating the contributions involving the quark diffractive distributions and by establishing that their DGLAP evolution emerges via controlled calculations within the colour dipole picture. We find the same expression for the quark diffractive TMD in two different processes (semi-inclusive diffraction and the diffractive production of quark-gluon dijets), thus demonstrating its universality.

Related publication: [28]

Improved Actions for Nuclear Effective Field Theories

UBIRAJARA VAN KOLCK

In collaboration with: L. Contessi (IJCLab Orsay), A. Gnech (Old Dominion U.), A. Lovato (ANL), M. Pavón Valderrama (Beihang U.), M. Schäfer (NPI/CAS)

Project abstract: Previous renormalizable formulations of nuclear effective field theories have encountered significant challenges in describing nuclei beyond the first closed shell due to leading-order instability. We are addressing this issue in Pionless Effective Field Theory by introducing a finite range at leading order which is compensated for in perturbation theory at higher orders. Explicit calculations of the two-body phase shifts and charge form factor indicate that, except for extreme choices, resummation of such subleading corrections do not alter the convergence of the EFT expansion and are often beneficial at the lowest orders. Improvement was also seen for bosonic many-body systems, even though they do not suffer from leading-order instability. Work is in progress for fermionic many-body systems.

Related publication: [29]

Nuclear Time-Reversal Violation

Ubirajara van Kolck

Project abstract: The pattern of electric dipole moments of light nuclei, if measured and described with nuclear effective field theories, is likely to give clues about sources of time-reversal violation beyond the phase in the CKM matrix. One example is the Weinberg three-gluon operator, which serves to illustrate one of the very many influential aspects of Weinberg's research life.

Related publication: [30]

3.2 Publications of ECT* Researchers in 2024

[1]
A. Accardi, …, D. Binosi et al.
Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at Jefferson Lab
Eur. Phys. J. A 60, 173 (2024)

[2]
A. Bashir, D. Binosi, K. Raya, C.D. Roberts, J. Rodríguez-Quintero
Pseudoscalar Mesons and Emergent Mass
Few Body Syst. 65, 60 (2024)

[3]
N. Xu, D. Binosi, C. Chen, K. Raya, C.D. Roberts, J. Rodríguez-Quintero
Kaon Distribution Functions from Empirical Information
arXiv: 2411.15376 [hep-ph]

[4]
D. Binosi, G. Garberoglio, D. Maragnano, M. Dapor, M. Liscidini
A tailor-made quantum state tomography approach
APL Quantum 1, 036112 (2024)

[5]
D. Maragnano, D. Binosi, G. Garberoglio, M. Dapor, M. Liscidini
Threshold quantum state tomography
Proceedings: CLEO 2024, Optica Publishing Group (2024)

[6]
D. Binosi, G. Garberoglio, A.H. Harvey
Third density and acoustic virial coefficients of helium isotopologues from ab initio calculations
J. Chem. Phys. 160, 244305 (2024)

[7]
G. Garberoglio, C. Lissoni, L. Spagnoli, A.H. Harvey
Comprehensive quantum calculation of the first dielectric virial coefficient of water
J. Chem. Phys. 160, 024309 (2024)

[8]
G. Garberoglio, A.H. Harvey, J. Lang, M. Przybytek, M. Lesiuk, B. Jeziorski
Path-integral calculation of the third dielectric virial coefficient of helium based on ab initio three-body polarizability and dipole surfaces
J. Chem. Phys. 161, 144111 (2024). Highlighted as Editor’s Pick

[9]
H.-Y. Xing, Z.-Q. Yao, B.-L. Li, D. Binosi, Z.-F. Cui, C.D. Roberts
Developing predictions for pion fragmentation functions
Eur. Phys. J. C 84, 82 (2024)

[10]
Z.-Q. Yao, D. Binosi, Z.-F. Cui, C.D. Roberts
Nucleon charge and magnetisation distributions: flavour separation and zeroes
arXiv: 2403.08088 [hep-ph]

[11]
Z.-Q. Yao, D. Binosi, C.D. Roberts
Onset of scaling violation in pion and kaon elastic electromagnetic form factors
Phys. Lett. B 855, 138823 (2024)

[12]
Z.-Q. Yao, Y.-Z. Xu, D. Binosi, Z.-F. Cui, M. Ding, K. Raya, C.D. Roberts, J. Rodríguez-Quintero, S.M. Schmidt
Nucleon Gravitational Form Factors
arXiv: 2409.15547 [hep-ph]

[13]
P. Cheng, Z.-Q. Yao, D. Binosi, C.D. Roberts
Likelihood of a zero in the proton elastic electric form factor
arXiv: 2412.10598 [hep-ph]

[14]
M. De Tullio, G. Novi Inverardi, M. Karam, J. Houard, M. Ropitaux, I. Blum, F. Carnovale, G. Lattanzi, S. Taioli, G. Eriksson, M. Hulander, M. Andersson, A. Vella, T. Morresi
Evaporation of cations from non-conductive nano-samples using single-cycle THz pulses: an experimental and theoretical study
arXiV:2403:04470 [cond-mat.mtrl-sci]

[15]
G. Lattanzi, S. Taioli, G. Novi Inverardi, F. Carnovale
Atom probe tomography: Computational challenges and perspectives
Biophysical Journal 123, 424A (2024)

[16]
M. Dapor
Electron-induced hydrogen desorption from selected polymers (polyacetylene, polyethylene, polystyrene, and polymethyl-methacrylate)
Physica Scripta 99, 0659b4 (2024)

[17]
M. Dapor
Unveiling Doppler effects and charge phenomena in the elastic scattering of keV electrons on polystyrene
Physica Scripta 99, 115976 (2024)

[18]
M. Dapor
Charge phenomena in the elastic backscattering of electrons from insulating polymers
Polymers 16, 2329 (2024)

[19]
S. Taioli, M. Dapor
Advancements in secondary and backscattered electron energy spectra and yields analysis: From theory to applications
Surface Science Reports 80, 100646 (2024)

[20]
P.E. Trevisanutto, S. Taioli, M. Dapor, C.S. Allen, G. Teobaldi
The role of primary and secondary electrons in scanning transmission electron microscopy of hybrid perovskites: the $CsPbBr_3$ *case*
arXiv:2412.16704v1 [cond-mat.mtrl-sci]

[21]
M. Viviani, E. Filandri, L. Girlanda, C. Gustavino, A. Kievsky, L.E. Marcucci
The X17 boson and the $d(p,e^+e^-)^3He$ *and* $d(n,e^+e^-)^3He$ *processes: a theoretical analysis*
arXiv: 2408.167442 [nucl-th]

[22]
T. Morresi, G. Garberoglio
Normal liquid ^3He *studied by path-integral Monte Carlo with a parametrized partition function*
arXiv: 2410.01569 [cond-mat.quant-gas]

[23]
R. Taureau, M. Cherubini, T. Morresi, M. Casula
Quantum symmetrization transition in superconducting sulfur hydride from quantum Monte Carlo and path-integral molecular dynamics
npj Computational Materials 10, 56 (2024)

[24]
J.N. Graham, C. Mielke III, D. Das, T. Morresi et al.
Depth-dependent study of time-reversal symmetry-breaking in the kagome superconductor AV_3Sb_5
Nature Communications *15*, 8978 (2024)

[25]
B. Rodriguez-Aguilar, D.N. Triantafyllopoulos, S.-Y. Wei
Incoherent diffractive production of jets in electron DIS off nuclei at high energy
Phys. Rev. D 110, 074018 (2024)

[26]
A. Pedrielli, S. Taioli, N. Pugno
Self-Locking in Collapsed Carbon Nanotube Stacks via Molecular Dynamics
International Journal of Molecular Sciences 25, 10635 (2024)

[27]
B. Mishra, A. Pidatalla, S. Taioli, S. Simonucci, D. Mascali
Plasma Induced Variation of Electron Capture and Bound-State β *Decays*
arXiv:2407.01787 [physics.plasm-ph]

[28]
S. Hauksson, E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos, S.Y. Wei
TMD factorisation for diffractive jets in photon-nucleus interactions
JHEP 06, 180 (2024)

[29]
L. Contessi, M. Pavón Valderrama, U. van Kolck
Limits on an Improved Action for Contact Effective Field Theory in Two-Body Systems
Phys. Lett. B 856, 138903 (2024)

[30]
U. van Kolck
Weinberg, Effective Field Theories, and Time-Reversal Violation
Nucl. Phys. B 1004, 116574 (2024)

3.3. Presentations by ECT* Researchers in 2024

Daniele Binosi

Practitioner-unbiased interpolation and extrapolation of (precise) data
Strong QCD from Hadron Structure Experiments - VI, Nanjing University, China
May 2024

Emergent Hadron Mass, pseudoscalar PDA/PDF/Form factors and J/Ψ production
Elucidating the Structure of Nambu-Goldstone Bosons, Stony Brook, USA
June 2024

Giovanni Garberoglio

Fully Quantum Calculation of Dielectric Virial Coefficients for Molecular Gases
XXII Symposium on Thermophysical Properties, Boulder, USA
June 2024

Maximum Precision: the role of ab initio calculations in gas-based primary metrology of temperature and pressure
Helmut-Schmidt- Universität, Hamburg, Germany
October 2024

Tommaso Morresi

Ab initio simulations of $Si(OH)_4$ under electrostatic fields and laser irradiation & vibrational properties of strongly anharmonic systems
Université de Normandie, Rouen, France
January 2024

TDDFT study of the orthosilicic acid molecule under electrostatic field and laser irradiation
DPG meeting, Berlin, Germany
March 2024

A simple (but understandable) ab initio 1D-model of evaporation & Optical absorption spectra of silica matrices with defects
Université de Normandie, Rouen, France
June 2024

Luis Benjamin Rodriguez-Aguilar

Incoherent diffractive production of jets in electron-nucleus DIS at high energies
Workshop on Resumation, Evolution and Factorization, Saclay, France
October 2024

Simone Taioli

Electron collisions: From materials science to astrophysics
4th DEA Club Meeting, Potsdam, Germany
June 2024

Towards realistic secondary electron simulation
FIT4NANO WG2, Vienna, Austria
June 2024

Evaporation of cations from non-conductive nano-samples using single-cycle THz pulses: an experimental and theoretical study
3rd Mimosa Meeting, Goteborg, Sweden
September 2024

Evaporation of cations from non-conductive nano-samples using single-cycle THz pulses: an experimental and theoretical study
International Symposium on Ultrafast Phenomena and THz Waves (ISUPTW), Guangzhou, China
November 2024

Dionysios Triantafyllopoulos

Diffractive jet production in photon-nucleus interactions
Workshop on Beyond-Eikonal Methods in High-Energy Scattering, ECT*, Trento, Italy
May 2024

Diffractive jet production in photon-nucleus collisions
Workshop on Diffraction and Gluon Saturation at the LHC and the EIC, ECT*, Trento, Italy
June 2024

Small-x Physics at the LHC and future DIS experiments
STRONG-2020 Annual Meeting, Frascati, Italy
June 2024

Quantum Field Theory II
Course at the University of Trento, Master's Degree in Physics [0518H]
Fall 2024 (from 23/09/2024 to 20/12/2024)

Ubirajara van Kolck

EDMs from EFTs: Next nuclear steps
Workshop on EDMs: Complementary experiments and theory connections, ECT*, Trento, Italy
March 2024

Atomic Nuclei in the Standard Model and Beyond: status and perspectives
Extreme Light Infrastructure-Nuclear Physics (ELI-NP), Magurele, Romania
April 2024

Why EFT Should Not Be Escoffier's Veal in Your Nuclear Cooking
ESNT Workshop on Effective Field Theory and Strong Interaction with Accurate Error Estimation, CEA, Saclay, France
April 2024

Quantum Fractals
XIV Latin-American Symposium on Nuclear Physics and Applications, Universidad Nacional Autónoma, Ciudad de México, Mexico
June 2024

Unitarity and Discrete Scale Invariance in Bosonic Clusters
32nd Annual International Laser Physics Workshop, Universidade de São Paulo, São Carlos, Brazil
July 2024

The Discrete Charm of Scale Invariance
The Henryk Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN), Krakow, Poland
September 2024

Universality with Large, Negative Two-Body Effective Range
Workshop on Intersections of Cold Atoms, Nuclear Physics, and Quantum Simulation, Institute for Nuclear Theory, Seattle, USA
October 2024

Improved Actions for Short-Range Effective Field Theory
Program on Quantum Few- and Many-Body Systems in Universal Regimes, Institute for Nuclear Theory, Seattle, USA
October 2024

Bosonic Clusters in the Unitarity Limit
Workshop on Universal Themes in Bose-Einstein Condensation, ECT*, Trento, Italy
November 2024

Neutrinoless Double-Beta Decay in Effective Field Theory
Istituto Nazionale di Fisica Nucleare (INFN), Napoli, Italy
November 2024

Quantum Fractals

Università degli Studi della Campania, Caserta, Italy
November 2024

Some Landmarks on the Scenic Route from Hadrons and Nuclei to Beyond the Standard Model

Kick-off Workshop on Hadrons and Nuclei as Discovery Tools, Helmholtz Institute, Mainz, Germany
December 2024

Zhao-Qian Yao

Nucleon charge and magnetisation distributions: flavour separation and zeroes

Nanjing, China
May 2024

Hadron electromagnetic form factors using Dyson-Schwinger equations

IJCLab, Orsay, France
June 2024

3.4. **ECT* Seminars 2024** (PhD seminars)

Elena Fogazzi (University of Trento, Italy)
A proton computed tomography system for proton therapy
05 April 2024

Gianmarco Zanardi (University of Trento, Italy)
Meta-plasticity and memory in multi-level recurrent feed-forward networks
12 April 2024

Ludovica Zullo (University of Trento, Italy)
Unraveling and exploiting highly doped transition metal dichalcogenides in misfit-layer compounds
10 May 2024

Alessandro Martini (University of Trento, Italy)
Noisy environments: detecting signals in gravitational-wave detectors
14 June 2024

Manuel Micheloni (University of Trento, Italy)
Supercoiling-induced structural dynamics of DNA defects
18 October 2024

Andrea Corradini (University of Trento, Italy)
A machine learning approach to light-induced order-disorder phase transitions large-scale long-time simulations with ab initio accuracy
15 November 2024

3.5 Meetings organized by ECT* researchers in 2024

Ubirajara van Kolck

Workshop on The Nuclear Interaction: post-modern developments
ECT*, Trento, Italy
August 2024
(Co-organized with J. McGovern, M. Piarulli, and R. Timmermans)

ECT* Computing Facilities

4 ECT* Computing Facilities

HARDWARE

Server LETICIA: 2 CPU Intel Xeon 20 core, 128 GB RAM, 3 graphic cards NVIDIA RTX A5000, 8TB storage

Server QORE: 2 CPU AMD Epyc 48 core, 512 GB RAM, 8 TB storage

PC clients:

9 PCs for local researchers 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")

4 laptops for workshop participants (2 with the Home Use license of Mathematica):
3 laptops DELL Latitude E5430
1 laptop DELL Latitude E5440

1 laptop for speakers to present slides:
1 laptop DELL Latitude E5440 at the conference/lecture room

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 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); the connection through the GARR is automatically activated by network problems.

SERVICES

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

1. PaperCut Print Management Software
2. 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

MAIN SOFTWARE for the research activity

Wolfram Mathematica Premier Service Plus, which includes 5 Home Use + 5 Cloud licenses. The Cloud licenses can be shared with scientific visitors and scholars (for DTP and TALENT schools, up to 35 individual calculation slots are available). Since July 2024, version 14.1 is available.

WiFi NETWORKS

Inside the ECT* buildings one can access the WiFi networks:

- GuestsFBK
- eduroam

GuestsFBK is the WiFi network of the Fondazione Bruno Kessler. One can access this network using one's own user credentials or, if one has an Italian mobile phone number, by registering on the web portal access page: the password is sent via SMS to the indicated number. 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.