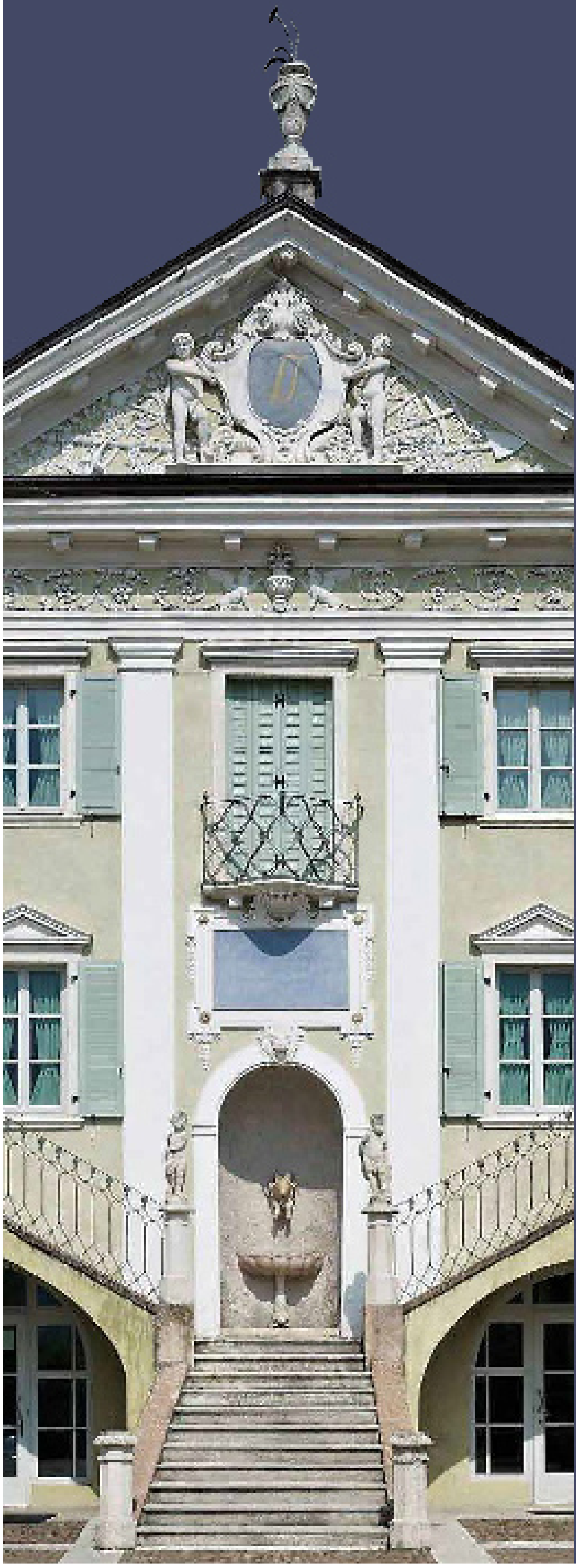
ECT*
EUROPEAN CENTRE FOR THEORETICAL STUDIES IN NUCLEAR PHYSICS AND RELATED AREAS

FONDAZIONE BRUNO KESSLER



ANNUAL REPORT 2022

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

Institutional Member of the European Science
Foundation Expert Committee NuPECC

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Preface

The *European Centre for Theoretical Studies in Nuclear Physics and Related Areas* (ECT*) has been established in 1993 in a bottom-up approach by the European nuclear physics community and is an Institutional Member of the European Expert Committee NuPECC (Nuclear Physics European Collaboration Committee). Since 2008 it is one of the Research Centres of the Fondazione Bruno Kessler (FBK). Its objectives – as stipulated in its statutes – are:

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

The year 2022 saw a return of visitors and workshop participants to ECT*, with 18 workshops held in hybrid mode and 3 workshops run remotely. The Doctoral Training Programme, on *Hadron Physics with Functional Methods*, was run entirely as an in-person school during 3 weeks in May, which was very much appreciated by the 23 participants, the lecturers, and the organisers. While hybrid meetings offer certain advantages in terms of reach and inclusivity, we are keen to move back to proper in-person meetings and indeed, the focus of the 2023 programme will be to bring researchers together again in the much-loved Villa Tambosi, to enable scientific discussion in a stimulating environment. I am pleased to note that the number of proposals submitted for the 2023 programme exceeded capacity, indicating the appetite of the community to consider ECT* as an outstanding venue for scientific exchanges.

The start of 2022 was dominated by the invasion of Ukraine by Russia. Following NuPECC and the national funding agencies, ECT* condemned the aggression of the Russian Federation against Ukraine by Russia and suspended its MoU with JINR (Dubna). To make a constructive contribution, we launched a Fellowship scheme for Ukrainian researchers, and eventually welcomed Borys Hryniuk as a Research Fellow, for a period of 9 months. It is my hope that a similar scheme will continue within the Fondazione Bruno Kessler to support researchers affected by future conflicts (even though in an ideal world it would not be needed at all of course).

Locally, the five permanent researchers in nuclear and computational physics continued their research in nuclear structure and reactions, non-perturbative QCD and hadron physics, the theory of hadronic and nuclear collisions at high energy, phases of strongly-interaction matter, nuclear astrophysics, neutron stars, and many-body theory. We were sad to see three postdoctoral researchers leave during the year: Saga Sappi, Francesco Celiberto and Hilla de Leon, but pleased to welcome four new postdoctoral researchers at ECT*: Achille Fiore, Tommaso Morresi, Alex Gnech and Zhao-Qian Yao, working across nuclear theory on neutron stars, hadron therapy and computational physics, nuclear structure, and Schwinger-Dyson equations respectively. Constantinos Constantinou will continue with his postdoc position. The research activities of the Centre are documented in detail in Chapter 4 of this Annual Report. Altogether, more than 50 publications by ECT* researchers were reported for the year 2022.

The number of PhD students doubled: Luis and Luca are joined by Francesco and Giovanni, sponsored by the European MIMOSA project under supervision by Simone Taioli. The MIMOSA project will run from September 2022 until August 2026 and will focus on the four-dimensional microscopy of biological materials by short pulse terahertz sources.

At the European level, the STRONG-2020 project continued during 2022, supporting 10 workshops and the Doctoral Training Programme, while the newly awarded EURO-LABS network started on the 1st of September, supporting thirty-nine Research Infrastructures across Europe, including ECT*, for four years. ECT* is in particular involved with the *Theory Support for Experiments* Task and will host a number of workshops in this domain over the coming years.

Further international activities revolved around the NuPECC Long Range Plan 2024, which was launched in May 2022, with ECT* playing an important role in the Steering Committee. We also renewed the MoU with the FRIB Theory Alliance EUSTIPEN Programme, to facilitate collaborations between U.S.-based and Europe-based scientists working on exotic nuclei.

The existence and the continuing success of ECT* rests upon the “bottom-up” initiatives, pursued by the physics communities in Europe and worldwide. Maintaining ECT*´s high level of scientific activity and visibility in 2022 has only been possible through a stable operating budget in recent years. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research institutions in Belgium, Croatia, Czech Republic, Finland, France, Germany, Hungary, Italy, the Netherlands, Poland, Romania, Switzerland and the United Kingdom. ECT* also acknowledges additional partial support for its workshops received in 2022 from: EMMI, MPP and TU Darmstadt (Germany) and INFN Frascati (Italy). During 2023 we will proceed with the five-year review and the renewal of the MoUs, for which the community support is essential.

2022 was my second year as ECT* Director, and it is a pleasure to have people returning to Trento in person. As before, I am grateful to the Scientific Board, the local research group, the FBK, INFN, NuPECC, the University of Trento and all stakeholders for the support provided. I want to thank especially the administrative staff, who keep ECT* running on a daily basis.

As its predecessors the Annual Report of 2022 is available on the ECT* website (www.ectstar.eu).

Trento, April 2023

Gert Aarts
*Director of ECT**

Scientific Board, Staff and Researchers

1. Scientific Board, Staff and Researchers

1.1 Scientific Board and Director

Constantia Alexandrou	University of Cyprus & the Cyprus Institute, Cyprus
Almudena Arcones	TU Darmstadt, Germany
Carlo Barbieri	University of Milan, Italy
Anna Corsi	IRFU/DPhN, France
David Kaplan	University of Washington, USA
Denis Lacroix	CNRS/IN2P3, France
Marek Lewitowicz	NuPECC/GANIL, France
Barbara Pasquini	University of Pavia, Italy
Urs Wiedemann (Chairman)	CERN-TH, Switzerland
Sandro Stringari (Ex officio)	University of Trento, Italy
Victor Braguta (Ex officio until March 2022)	JINR, Russia

Honorary Member of the Board

Ben Mottelson (until May)	NORDITA, Copenhagen, Denmark

ECT Director*

Gert Aarts	ECT*, Italy and Swansea University, UK

1.2 Resident Researchers

- *Nuclear Physics*

Daniele Binosi, Italy*
Francesco Celiberto, Italy (until October 2022)
Tommaso Morresi, Italy (from July 2022)
Saga Aurora Säppi, Finland (until September 2022)
Dionysis Triantafyllopoulos, Greece*
Zhao-Qian Yao, Japan (from October 2022)
Alex Gnech, Italy (from October 2022)

- *Computational Physics*

Maurizio Dapor, Italy (Head of ECT*-LISC Research Unit)*
Achille Fiore, Italy (from April 2022)

Giovanni Garberoglio, Italy*
Simone Taioli, Italy*

- *ECT*/TIFPA Researchers*

Constantinos Constantinou, Cyprus

- *ECT* PhD Students*

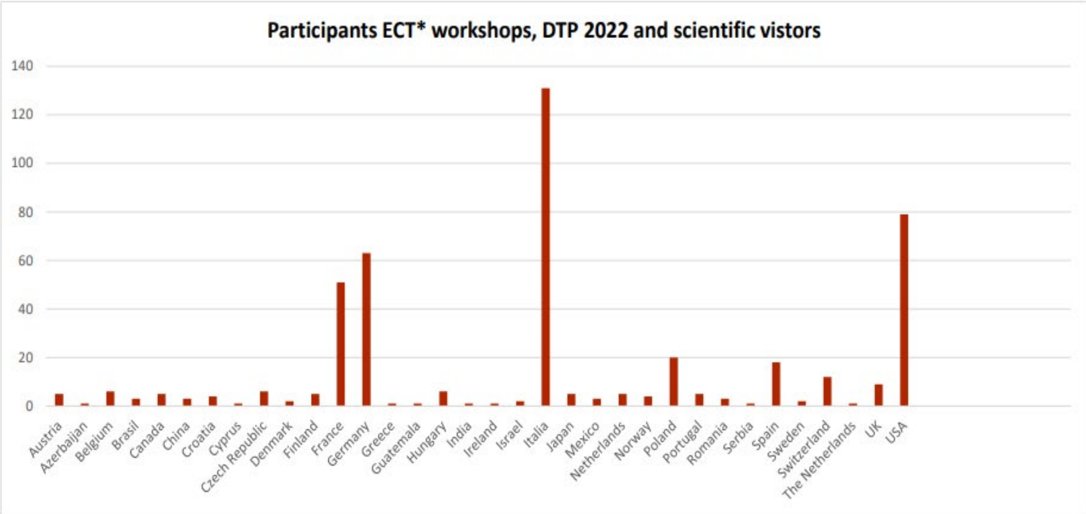
Luis Benjamín Rodríguez Agui, Guatemala
Francesco Carnovale, Italy (from November 2022)
Giovanni Novi Inverardi, Italy (from November 2022)
Luca Vespucci, Italy

- *ECT* Fellows*

Borys Hryniuk, Ukraine (from July 2022)
*Permanent Researchers

1.3 Staff

Susan Driessen
Barbara Gazzoli
Michela Chistè



Participants ECT* workshops, DTP 2022 and scientific vistors
140
120
100
80
60
40
20
0
Austria
Azerbaijan
Belgium
Brasil
Canada
China
Croatia
Cyprus
Czech Republic
Denmark
Finland
France
Germany
Greece
Guatemala
Hungary
India
Ireland
Israel
Italia
Japan
Mexico
Netherlands
Norway
Poland
Portugal
Romania
Serbia
Spain
Sweden
Switzerland
The Netherlands
UK
USA

Scientific Projects in 2022

2. ECT Scientific Projects in 2022

2.1 Summary

Altogether 22 scientific projects have been run in 2022: 21 workshops (3 online) and a Doctoral Training Programme. This chapter collects the scientific reports written by the workshop organizers and by Reinhard Alkofer, Gernot Eichmann and Markus Huber who organized the DTP.

2.2 Workshops and School (Calendar)

31 Jan - 4 Feb	*Alpha_S (2022): Workshop on Precision Measurements of the Strong Coupling Constant* D. Enterria (CERN) S. Kluth (MPP) G. Zanderighi (MPP)
Apr 11-15	*Nuclear Physics from Atomic Spectroscopy (Online)* L. Platter (University of Tennessee) R. Garcia Ruiz (MIT) C. Ji (Central China Normal University)
May 02-20	*Doctoral Training Program: Hadron Physics with Functional methods* R. Alkofer (University of Graz) G. Eichmann (LIP Lisboa) M. Huber (Giessen University)
May 23-27	*Gauge Topology, Flux Tubes and Holographic Models: The Intricate Dynamics of QCD in Vacuum and Extreme Environments* E. Shuryak (Stony Brook University) M. D'Elia (University of Pisa) J. Greensite (San Francisco State University) E. Kiritsis (University of Crete) I. Zahed (Stony Brook University)

June 06-10	*Connections between Cold Atoms and Nuclear Matter: From Low to High Energies* C. Sa de Melo (Georgia Institute of Technology) A. Gezerlis (University of Guelph)
June 13-17	*Jet Quenching in the Quark-Gluon Plasma* J. Mulligan (UC Berkeley) Y.-J. Lee (MIT) K. Tywoniuk (University of Bergen) L. Cunqueiro (École Politechnique) S. Cao (Shandong University)
June 20-24	*Neutron Stars as Multi-Messenger Laboratories for Dense Matter* I. Tews (LANL, Los Alamos) B. Giacomazzo (University of Milano-Bicocca) S. Guillot (IRAP Toulouse) J. Margueron (IP21 Lyon) S. Nissanke (University of Amsterdam)
27 June - 01 July	*Saturation and Diffraction at the LHC and the EIC* C. Royon (University of Kansas) A. Sabio Vera (Universidad Autonoma de Madrid) S. Schlichting (University of Bielefeld) A. Deshpande (Stony Brook University) G. Soyez (IPhT Saclay) M. Hentschintski (Universidad de las Americas Puebla)
July 04-08	*Nuclear Physics at the Edge of Stability* G. Hupin (IJClab) O. Sorlin (GANIL) A. Gade (MSU) L. Platter (UTK)
July 11-15	*Advances on Giant Nuclear Monopole Excitations and Applications to Multi-messenger Astrophysics* Y. Blumenfeld (IJCLab) G. Colò (University of Milan & INFN) U. Garg University of Notre Dame E. Khan (IJCLab) M. Vandebrouck (DPhN & CEA)

July 18-22	*Radiative Corrections from Medium to High Energy Experiments* E. Cline (Stony Brook University) A. Afanesev (George Washington University) S. Barkanova (Memorial University of Newfoundland) Jan Bernauer (Stony Brook University) Ron Gilman (Rutgers University) Hubert Spiesberger (Johannes Gutenberg University of Mainz)
July 25-29	*Nuclear and Atomic Transitions as Laboratories for High Precision Tests of Quantum Gravity Inspired Models* A. Marciano (Fudan University & LNF-INFN) E. Barberio (Melbourne University) K. Piscicchia (Centro Fermi Rome) C. Curceanu (LNF-INFN) S. Alexander (Brown University, Providence) N. Yunes (University of Illinois at Urbana-Champaign)
August 01-05	*Neutron Electric Dipole Moment: from Theory to Experiment* A. Athenodorou (University of Pisa) D. Giataganas (National Sun Yat-sen University) B. Lucini (Swansea University) E. Rinaldi (University of Michigan) K. Cranmer (New York University) C. Alexandrou (University of Cyprus & The Cyprus Institute)
29 Aug - 02 Sep	*LFC22: Strong Interactions from QCD to New Strong Dynamics at LHC and Future Colliders* G. Corcella (INFN Frascati) S. De Curtis (INFN Firenze) S. Moretti (University of Southampton) G. Pancheri (INFN Frascati) R. Tenchini (INFN Pisa) M. Vos (Universidad de Valencia)
September 5-9	*From Hadrons to Therapy: Fundamental Physics Driving New Medical Advances* P. De Vera Gomis (Universidad de Murcia) M. Durante (GSI)

	C. Hoehr (TRIUMF) K. Parodi (Ludwig-Maximilians-Universität München) V. Conte (INFN LNL) J. Kohanoff (Universidad Politécnica de Madrid) M. Schwarz (Azienda Provinciale per i Servizi Sanitari, Trento)
September 12-16	*Revealing Emergent Mass through Studies of Hadron Spectra and Structure (Online)* D. Binosi (ECT*) T. Horn (Catholic University of America) H.W. Lin (Michigan State University) C. Roberts (Nanjing University)
September 26-30	*Opportunities with JLab Energy and Luminosity Upgrade* H. Avagyan (JLAB) J. Arrington A. Bacchetta (University of Pavia) O. Hen (MIT) X. Ji (UMD) k. Joo (UConn) X. Zheng (UVa)
October 03-14	*Reduced Density-Matrix Functional Theory: Improving its Foundation and Extending its Scope* C. Benavides-Riveros (Max Planck Institute for Com-plexed Systems) E. K. Gross (Hebrew University) C. Schilling (LMU, Munich)
October 17-21	*EXOTICO: EXOTIc Atoms Meet Nuclear Collisions for a New Frontier Precision Era in Low-Energy Strangeness Nuclear Physics* O. Vazquez-Doce (LNF-INFN) C. Curceanu (LNF-INFN) A. Ramos (Universitat de Barcelona) J. Zmeskal (SMI-Vienna) J. Mareš (Czech Academy of Sciences)
October 24-28	*Giant and Soft Modes of Excitation in Nuclear Structure and Astrophysics*

	E. Litvinova (Western Michigan University) R. Broglia (Niels Bohr Institute) H. Lenske (Justus-Liebig-Universität Giessen)
November 9-10	*Tomography of Light Nuclei at an EIC (Online)* A. Freese (University of Washington) W. Cosyn (Ghent University & Florida International University) I. Cloët (ANL) P. Shanahan (MIT)
December 12-16	*Key Reactions in Nuclear Astrophysics* A. Tumino (Univ. degli Studi di Enna "Kore" & INFN-LNS Catania) J. José (Technical University of Catalonia) C. Bertulani (Texas A&M University-Commerce) R. Diehl (MPI Munich) L. Trache (IFIN-HH Bucarest-Magurele)

2.3 Workshop Reports

2.3.1 Alpha_S (2022): Workshop on Precision Measurements of the Strong Coupling Constant

Date	31 January – 04 February 2022
Organizers	
David D'Enterria	CERN, Switzerland
Stefan Kluth	MPP, Germany
Giulia Zanderighi	MPP, Germany
Number of participants	89 (74 online + 14 in-person)

Main topics

The strong coupling constant αS 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 αS 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 αS. The current world average quotes an uncertainty of less than 1%. However, there are noticeable discrepancies between different categories of determinations of αS, which may limit the ultimate precision of future world averages. The workshop brought together the leading experts on determinations of αS 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), and 2019 (ECT*, Trento).

The workshop aimed at exploring in depth the current status and upcoming prospects in the determination of the QCD coupling constant αS(mZ) from the key observables where high- precision experimental measurements and theoretical calculations are (or will be) available. Each of the proposed extraction methods provided a "wish list" of experimental and theoretical developments required in order to achieve an ideal per-mil precision on αs(m2Z) within the next 10 years. 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 αS world average
- Impact of αS on precision and BSM physics, and beyond

- Lattice QCD results
- αS from hadronic tau decays
- αS from e-p deep inelastic scattering
- αS from e+e- hadronic final states
- αS from electroweak observables
- αS from pp collisions
- New αS extraction approaches.
- Evaluation of future achievable precision extractions of αS(mZ)
- PDG approach to αS world average and uncertainty estimatio

Preparation of the proceedings to be included into the Snowmass'21 White Paper "The strong coupling constant: State of the art and the decade ahead".

Speakers

Abhinav Choudhury	ICFAI University, Dehradun, India
Alberto Ramos Martinez	Univ. of Valencia and CSIC, Spain
Alessandro Guida	DESY, Germany
Alexander Nesterenko	JINR, Russia
Alexandre Deur	Jefferson Lab, USA
Alexei Bazavov	Michigan State University, USA
Ali M. Ruzbahani	Semnan University, Iran
Aliaksei Hrynevich	INP BSU, Belarus
Amanda Sarkar	University of Oxford, United Kingdom
Anatoly Kotikov	JINR, Russia
Andre Hoang	University of Vienna, Austria
Andreas Kronfeld	Fermilab, USA
Andrii Verbytskyi	Max Planck Society, Germany
Antonio Pich	IFIC, University of Valencia CSIC, Spain
Barbara Mele	INFN Rome, Italy
Ben Nachman	LBNL, USA
Bharadwaj Harikrishnan	CNRS, France
Bogdan Malaescu	LPNHE, CNRS France
Claire Gwenlan	University of Oxford, UK
Cristian B. Barrera	CNRS, France
Daniel Britzger	Max-Planck-Institut für Physik München, Germany
Daniel Savoiu	KIT, Karlsruhe Institute of Technology, Germany
David d'Enterria	CERN, Switzerland
Diogo Boito	Universidade de São Paulo, Brazil & Univ. of Vienna, Austria
Emily Ann Smith	University of Chicago, USA
Federico Vazzoler	Deutsches Elektronen-Synchrotron, Germany
Francesco Giuli	CERN - European Organization for Nuclear Research, Italy
German Sborlini	DESY, Germany and University of Salamanca, Spain
Giulia Zanderighi	Technische University Munich, Germany
Gorazd Cvetic	Universidad Tecnica Federico Santa Maria, Chile
Hamzeh Khanpour	Maynooth University, Dept. of Theoretical Physics, Ireland
Jad Sardain	CNRS, France
Javier Llorente Merino	Simon Fraser University, Canada
Jennifer Kathryn Roloff	Brookhaven National Laboratory, USA

Joey Huston	Michigan State University, USA
Johannes Bluemlein	DESY Germany
Johannes Heinrich Weber	Humboldt University of Berlin, Germany
José L. Carrasco Huillca	Instituto De Física-UNAM, Peru
Juan Rojo	VU Amsterdam and Nikhef, Netherlands
Katerina Lipka	DESY, Germany
Keping Xie	University of Pittsburgh, USA
Kim Maltman	York University, Canada
Klaus Rabbertz	KIT - Karlsruhe Institute of Technology, Germany
Leticia Cunqueiro Mendez	École Polytechnique, France
Luc Poggioli	LPNHE Paris, France
Lucian Harland-Lang	University of Oxford, UK
Luigi Del Debbio	University of Edinburgh, UK
Maarten Golterman	San Francisco State University, USA
Marcel Vos	IFIC Valencia, Spain
Markus Wobisch	Louisiana Tech University, USA
Matt LeBlanc	CERN, Canada
Matthias Schott	CERN - University of Mainz, Germany
Mattia Dalla Brida	CERN, Switzerland
M. A. Benitez-Rathgeb	University of Vienna Austria
Mikhail Barabanov	JINR, Russia
Noah Bray-Ali	Mount Saint Mary's University, Los Angeles, USA
Nora Brambilla	TUM, Germany
Oldrich Kepka	CAS, Czech Republic
Paolo Nason	INFN, Italy
Patricia Rebello Teles	CBPF, Brazil
Pavel Nadolsky	Southern Methodist University, USA
Pavel Starovoitov	Ruprecht Karls Universität Heidelberg, Germany
Peter Petreczky	BNL, USA
Pier Monni	CERN, Switzerland
Ranjit Nayak	Tel Aviv University, Israel
Redamy Perez Ramos	IPSA-Paris, LPTHE, France
Richard Ball	University of Edinburgh, UK
Roger Horsley	University of Edinburgh, UK
Roy Lemmon	STFC Daresbury Laboratory, UK
Santi Peris	UA Barcelona, IFAE and BIST, Spain
Shivam Raj	NISER, India
Siegfried Bethke	Max-Planck-Institute of Physics, Munich, Germany
Simone Amoroso	Deutsches Elektronen-Synchrotron, Germany
Simone Marzani	Università Genova & INFN Genova, Italy
Stanley Brodsky	SLAC National Accelerator Lab, Stanford University,USA

Stefan Kluth	Max Planck Society, Germany
Stefan Sint	Trinity College Dublin, Ireland
Stefano Camarda	CERN Switzerland
Sven-Olaf Moch	Universität Hamburg, Germany
Thomas Cridge	University College London, UK
Tobias Neumann	BNL, USA
Toni Makela	Deutsches Elektronen-Synchrotron, Germany
Valentina Guglielmi	Deutsches Elektronen-Synchrotron, Germany
Valerio Bertone	CEA Saclay, France
Vicent Mathieu	University of Salamanca, Spain
Vitalii Okorokov	MEPhI, Russia
Zafer Acar	CERN, United States
Zahra Farazpay	Louisiana Tech. University, USA
Zdenek Hubacek	Technical University Prague, Czechia

Scientific report

The strong coupling αS sets the scale of the strength of the strong interaction, theoretically described by Quantum Chromodynamics (QCD), and 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 αS coupling is the only free parameter of QCD. Starting at an energy scale of order Lambda_QCD~0.2 GeV in the vicinity of the Landau pole, αS(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 pole mass amounts to αS(mZ) = 0.1179 +- 0.0009 with a ~0.8% uncertainty that is orders of magnitude larger than that of the other three interaction (QED, weak, and gravitational) couplings. Improving our knowledge of αS 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 αS, as is the case for virtually all those measured at the LHC. In the Higgs sector, our imperfect knowledge of αS propagates today into total final uncertainties for key processes such as the Higgs gg-fusion and ttbar-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 αS(mZ) 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 its Yukawa coupling. Last but not least, the value of αS(mZ) 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. in 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 αS, the workshop brought together experts from all relevant subfields to explore in depth the latest developments on the determination of αS 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 αS extraction methods? What needs to be achieved in order to reach a O(0.1%) precision? In this context, each contributor was requested to provide a few pages summary of their presented work addressing, in particular, the following questions:

Theory: What is the current state-of-the-art with regards to higher-order corrections (pQCD, mixed QCD-EW) of your calculations of αS-sensitive observables? What is the impact of non-pQCD corrections/uncertainties? (Are there new techniques to reduce them?) Provide your personal wish-list in theory/data developments needed to reach your ultimate αS precision.

Experiment: What are the current leading systematics/statistical uncertainties of your favourite αS-sensitive observable? What are the future reductions of systematic/statistical uncertainties expected with current and future (e+e-, e-p, p-p) machines? (Are there new observables being considered?) Provide your personal wish-list in data/theory developments needed to reach your ultimate αS precision.

Results and Highlights

The written contributions of all participants (and associated collaborators) were part of a writeup (130 pages, 82 figures) "The strong coupling constant: State of the art and the decade ahead" (https://arxiv.org/abs/2203.08271) that served the double purpose of reporting the αS(2022) workshop proceedings, as well as being incorporated into the ongoing discussions of the Proceedings of the US Community Study on the Future of Particle Physics (Snowmass 2021). The result of our workshop has therefore had a significant impact on the pQCD community, and our comprehensive review report will likely collect many citations in the near future.

2.3.2 Nuclear Physics from Atomic Spectroscopy

Date	April 11-15, 2022

Organizers

Lucas Platter	University of Tennessee, Knoxville, US & Oak Ridge National Laboratory, USA & TU Darmstadt, Germany
Chen Ji	Central China Normal University, China
Ronald Garcia	Massachusetts Institute of Technology, USA
Saori Pastore	Washington University, USA

Number of participants	55

Main topics

Atomic and molecular spectroscopy offer unique ways to obtain information about the structure of nuclei, nucleons, and fundamental particles: It is the primary tool to measure the charge radius and electromagnetic moments of few- and many-nucleon systems, including exotic ones. Nuclear theory has parallelly undergone several essential developments: Our knowledge of the many-body nuclear Hamiltonian and electroweak currents has dramatically improved, while at the same time, quantum many-body calculations have reached a wide range of nuclei and a variety of nuclear properties. This workshop was focused on the interplay between experiment and theory in atomic, molecular, and nuclear physics, exploring the potential for further developments in experiment and theory that can provide insights into the structure of the nuclear interaction and the coupling of nuclei to external probes. Moreover, a robust and solid understanding of nuclear structure and dynamics will enable the identification of new physics in future experiments. Our workshop explored these exciting developments and their potential for further progress in experiment and theory.

The main topics of this workshop were:

- Nuclear structure from spectroscopy of light atoms
- Nuclear structure from spectroscopy of medium atoms
- Nuclear structure from spectroscopy of heavy mass atoms
- Fundamental symmetries in atoms and molecules
- Theory for BSM searches with atoms and molecules

Speakers

Simone Li Muli	Mainz University, Germany
Paul Gerhard Reinhard	Erlangen University, Germany

Wei Sun	Chinese Academy of Sciences, Wuhan, China
Krzystof Pachucki	Warsaw University, Poland
Randolf Pohl	Mainz University, Germany
Wilfried Nörtershäuser	TU Darmstadt, Germany
Gordon Drake	University of Windsor, Canada
Nick Hutzler	Caltech, USA
Marianna Safranova	University of Delaware, USA
Kieran Flanagan	University of Manchester, UK
Kei Minamisono	Michigan State University, USA
Heiko Hergert	Michigan State University, USA
Ruben DeGroote	KU Leuven, Belgium
Jordy de Vries	University of Amsterdam, Netherlands
Robert Berger	University of Marburg, Germany
Maria Piarulli	Washington University, USA
Silvio Udrescu	MIT, USA
Anastasia Borschevsky	University of Groningen, Netherlands
Jacek Dobaczewski	University of York, UK
Jon Engel	University of North Carolina, USA
Emanuele Mereghetti	Los Alamos National Laboratory, USA

Scientific report

Atomic and molecular spectroscopy offer unique ways to obtain information about the structure of nuclei, nucleons, and fundamental particles: It is the primary tool to measure the charge radius and electromagnetic moments of few- and many-nucleon systems, including exotic ones. Nuclear theory has parallelly undergone several vital developments: Our knowledge of the many-body nuclear Hamiltonian and electroweak currents has dramatically improved, while at the same time, quantum many-body calculations have reached a wide range of nuclei and a variety of nuclear properties. This workshop was focused on the interplay between experiment and theory in atomic, molecular, and nuclear physics and explore the potential for further developments in experiment and theory that can provide insights into the structure of the nuclear interaction and the coupling of nuclei to external probes. Moreover, a robust and solid understanding of nuclear structure and dynamics will enable the identification of new physics in future experiments.

The workshop's focus was recent progress with measurements of the properties of nuclei using atomic and molecular physics techniques. A central component of this workshop was spectroscopic measurements of Lamb shifts, isotope shifts, hyperfine structures of atoms, and symmetry-violating nuclear properties with molecules. These observables carry unique information on the electroweak structure of nuclei: For light systems, these techniques provide an unprecedented level of accuracy of quantities such as charge radii, electric quadrupole moments, and magnetic moments. For heavier, exotic systems with short lifetimes, moments cannot be measured using electron scattering, and laser spectroscopic measurements are the only high-precision tool. In addition, the measured electromagnetic moments of nuclei unveil fruitful information on the internal structure of nuclei, such as nucleon space/momentum configuration, shell evolution, shape deformation, halo structure, neutron skin thickness, etc.

The recent developments of precision laser techniques, combined with the developments of radioactive beam facilities such as FRIB (US), TRIUMF (Canada), and ISOLDE (CERN), are enabling measurements of nuclear electromagnetic properties at the extreme of the nuclear chart.

In theoretical nuclear physics, several developments have been happening in parallel. Specifically, effective field theories (EFT) have been developed to describe many-body interactions among nucleons and nucleons and clusters of correlated nucleons with external electroweak probes. Concurrently, theorists are developing new and improved many-body computational methods, which, combined with the ever-escalating computational resources, allow them to calculate the properties of an increasing number of nuclei.

Meanwhile, the interplay between theory and experiment has significantly improved the precision in determining nuclear structural properties. Nuclear theory and quantum electrodynamics are utilized to assess nuclear-structure corrections to atomic spectrum measured in atomic spectroscopy.

Results and Highlights

Our workshop participants were from diverse groups that usually focus on systems with different sizes or different observables. The presentations and discussions displayed the similarities of the techniques used in these groups. They gave, of course, an overview of the generally available methods used to obtain observables relevant to atomic spectroscopy of nuclear physics observables. Many exciting developments were shared, and it became clear that the field is making tremendous progress. In particular, the number of experiments that are searching for symmetry violating interactions using novel methods such as molecules have increased significantly. For example, while atoms currently have the best sensitivity to the electron EDM, it is clear that there are fantastic new tools for the measurement of EDMs as new experiments exploit the feature that the polarizability of molecules enhances the sensitivity to the EDM by a factor of 1000. Molecules are also expected to provide a new window into our knowledge of nuclear electroweak properties such as anapole moments. The quantum chemistry calculations for such experiments, for example relativistic coupled-cluster, are very advanced and have an impressive accuracy.

One of the important outcomes of the workshop were questions that have to be addressed by theorists and experimentalists to move the field forward. In the context of electromagnetic observables, it was highlighted that it is important to understand the relationship between the accuracy of the nuclear model and the predicted uncertainties for observables such as the Lamb shift, hyperfine shift, and Zemach radii. Such analyses have been carried out for the Lamb shift for some systems but need to be extended. In the same spirit, one also needs to return to the question of the relation between the Zemach radii extracted from electron-scattering experiments and those from spectroscopy experiments. Are these indeed the same, and what approximations (if any) hold for these relationships.

Furthermore, discussions showed that there is a strong need to understand the charge radii of heavier systems better from the ab initio perspective. For heavier systems, the need for rigorous uncertainty quantification across the nuclear chart was pointed out. This will provide information on the limit of ab initio nuclear theory.

The situation for electric dipole moments is somewhat different. This section of the workshop emphasized that experiments will need to provide measurements from many different systems to pin down the sources of the potentially measured EDMs. On the other hand, more effort will need to be devoted to calculating hadronic and nuclear EDMs on the theory side. Here it was emphasized that lattice QCD efforts are making significant progress towards calculating such relevant matrix elements. However, also in this arena, it was remarked that ab initio nuclear theory based on effective field theory Hamiltonians will need to be tested systematically for larger systems where symmetry-violating observables in such calculations are the Schiff moment, anapole moment, and magnetic quadrupole moment. Presentations on modern ab initio methods such as the in-medium similarity renormalization group methods indicated that the reach of these tools will increase further in the future. This gives more reason to improve our understanding of modern EFT Hamiltonians, associated currents and their corresponding uncertainties.

2.3.3 Gauge Topology, Flux Tubes and Holographic Models: the intricate dynamics of QCD in vacuum and extreme environments

Date May 23-27, 2022

Organizers

Edward Shuryak	Stony Brook University, New York, USA
Massimo D'Elia	University of Pisa, Pisa, Italy
Jeff Greensite	San Francisco State University, San Francisco, USA
Elias Kiritsis	APC, University of Paris /FR and University of Crete, Greece
Ismail Zahed	Stony Brook University, New York, USA

Number of participants 21 in person + 28 online

Main topics

The workshop focused on a wide range of topics in Nonperturbative QCD. The series of such meetings started in 2015 at Simons Center for Geometry and Physics, followed by two meetings held at ECT* Trento in 2016 and 2018 and two summer seminar series (Simons center) during the summers of 2020 and 2021. As the title suggests, QCD dynamics is intricate; the theory of strong interactions is notoriously difficult to understand at hadronic scales. In spite of tremendous progress, particularly in quantitative questions that can be addressed by lattice Monte Carlo methods, it is fair to say that a complete and comprehensive description of the physics of hadrons is still lacking. Key questions faced by theory include chiral symmetry breaking and the confinement mechanism, the confinement-deconfinement phase transitions, the QCD phase diagram and hadronic dynamics at high baryon densities, hadronic spectroscopy in quark models and on the lattice, hadronic parton distribution functions and much more. Many of these questions have a direct bearing on current LHC/RHIC experiments and future FAIR and EIC experiments.

The main topics were:

- Instanton effects in QCD: theory and phenomenology
- Topological defects and models of color confinement
- Holographic approaches to the study of strong interactions
- The phase diagram of QCD in extreme conditions Flux-tubes
- Theta-dependence at zero and finite temperature

Speakers

Navid Abassi	Lanzhou University, China

Andrei Alexandru	The George Washington University, US
Maximiliam Attems	CERN, Switzerland
Claudio Bonanno	INFN Firenze, Italy
Szabolcs Borsanyi	Wuppertal University, Germany
Stanley Brodsky	Stanford University, US
Michele Caselle	Torino University, Italy
Heng-Tong Ding	CCNU, China
Francesco Di Renzo	University of Parma, Italy
Gergely Endrodi	University of Bielefeld, Germany
Manfried Faber	TU Wien, Austria
Zoltan Fodor	Wuppertal University, Germany
Matteo Giordano	Eotvos University, Hungary
Anna Hasenfratz	Colorado University, US
Ivan Horvath	Czech Academy of Sciences, Czech Republic
Hiroaki Ito	Osaka University, Japan
Matti Jarvinen	Pohang University, South Korea
Matthias Kaminski	University of Alabama, US
Valentin Khoze	Durham University, UK
Masakiyo Kitazawa	Osaka University, Japan
Tamas Kovacs	Eotvos University, Hungary
Derek Leinweber	Adelaide University, Australia
Yang Li	University of Science and Technology of China, China
Yizhuang Liu	Jagiellonian University, Poland
Mariapaola Lombardo	INFN Firenze, Italy
Lorenzo Maio	University of Pisa, Italy
Gergely Marko	Bielefeld University, Germany
David Mateos	University of Barcelona, Spain
Yousuf Musakhanov	National University of Uzbekistan, Uzbekistan
Daniel Nogradi	Eotvos University, Hungary
Robert Pisarski	BNL, US
Edwan Preau	APC, Paris, France
Gerrit Schierholz	DESY, Germany
Sayantan Sharma	Institute of Mathematical Sciences, Chennai, India
Edward Shuryak	Stony Brook University, US
Jacob Sonnenschein	Tel Aviv University, Israel
Tsuneo Suzuki	Osaka University, Japan
Michael Teper	Oxford University, UK
Ismail Zahed	Stony Brook University, US

Scientific report

First of all, we would like to emphasise that, for many participants, this was the first workshop they were participating in person after a long while, due to the Covid pandemic. Actually, this was also one of the first workshops at ECT* with a number of in person participants comparable to the pre-Covid experience. Apart from a very positive impact from the purely human point of view, there was also an extremely positive impact on the scientific side: the possibility of discussing scientific topics even after the talk sessions, i.e., during coffee breaks, lunch breaks, social dinners, or even travel time, was felt by the in-person participants as a sort of renaissance, and the emerging warm and exciting atmosphere was engaging even for people participating online. The common thread of the whole workshop was centered around the various and interwining non-perturbative and infrared properties of strong interactions, studied using different tools, going from lattice QCD simulations to holographic techniques, and considering various different aspects, going from color confinement and the hadron spectrum to the properties of strong interactions in extreme conditions, and to models and signals for new physics. Progress in analytic approaches, as well as in computer power and algorithms, allowed to discuss significant new results compared to previous editions of the workshop. The discussion around various kinds of topological defects (e.g., vortices or magnetic monopoles), possibly involved in the mechanism of color confinement, characterized the talks by D. Leinweber, T. Suzuki and M. Faber. An interesting related discussion was that around the role and properties of color flux tubes, of their effective string description (see, e.g, the talks by M. Caselle, M. Teper and M. Kitazawa. Following the two seminar series held in 2020 and 2021, this edition of the workshop has been characterized by an important contribution from the scientific community adopting holographic approaches to the study of non-perturbative physics. Interesting talks about holography applied to hadron physics were given by C. Sonnenschein, E. Preau, S. Brodsky, Y. Li, M. Attems and M. Kaminski. Partially related to that, we also had a couple of interesting talks regarding the application of holographic approaches in gravitational wave physics (M. Jarvinen and D. Mateos). The role of semiclassical solutions of the Yang-Mills equations, in particular instantons, was discussed in various interesting talks, like those by E. Shuryak, Y. Musakhanov, I. Zahed, D. Nogradi. In connection to that, there were also various interesting talks regarding the study of theta-dependence and the role of topology in finite temperature QCD, around and above the deconfinement phase transition: C. Bonanno presented new results for the behavior of the topological susceptibility above Tc. Other interesting talks regarding theta-dependence and topology were given by R. Pisarski, G. Schierholz, S. Sharma and T. Kovacs. A partially related subject was that regarding the properties of the spectrum of the Dirac operator, in particular around the deconfinement transition, which were discussed in the talk by M. Giordano, I. Horvath and A. Alexandru. Finally, a particularly interesting talk was the one given by V. Khoze, regarding the possibility of detecting non-perturbative effects related to instantons and topological fluctuations in particle colliders. Progress in the study of the Phase Diagram of QCD and QCD-like theories was discussed in various talks, in particular those by A. Hasenfratz, M. Lombardo, S. Borsanyi, F. Di Renzo, L. Maio, H.T. Ding and G. Endrodi. Finally, we had an extremely interesting talk by Z. Fodor, regarding in particular the lattice QCD input on the so-called muon (g-2) puzzle, i.e. the apparent discrepancy between experimental results and theoretical predictions, which however seems to be much less significant in view of such lattice results.

Results and Highlights

As already emphasized, one of the most intriguing aspect was the possibility, after more than two years, to have extensive and relaxed in person scientific discussions.

Indeed, as in the previous editions, most of the success of the workshop has been based on the possibility of ample and interesting discussions among the participants, which have been fostered by the exceptional environment provided by ECT*. The main progress reported at this conference, which has been achieved since the last editions, can be summarized as follows: Studies regarding the role of topological defects in the study of color confinement have seen much progress. We had, for instance, first results regarding center vortices in the presence of dynamical fermions presented by D. Leinweber; 1) progress made by holographic approaches was impressive and summarized in very interesting talks. We have found of particular interest the new applications in the field of neutron star mergers and gravitational waves; 2) regarding instanton physics, the most intriguing new results regarded the possibility of detecting instanton effects in cross sections measured in particle colliders (talk by V. Khoze). One of the outcomes is that such effects could be better visible in diffractive processes; 3) regarding the phase diagram of QCD and QCD-like theories, A. Hasenfratz presented new lattice results regarding the possible presence of an IR fixed point in the theory with 8 flavours. A nice review about possible approaches to overcome the sign problem was presented by F. Di Renzo. Interesting new results about the QCD transition with and without external background fields were presented by M. Lombardo, S. Borsanyi, L. Maio, H.T. Ding and G. Endrodi. 4) The nice talk by Z. Fodor brought a new perspective on the muon (g-2) puzzle: lattice QCD results show that the discrepancy between theory and experiment is brought back below the 2 sigma level.

2.3.4 Connections between Cold Atoms and Nuclear Matter: from Low to High Energies

Date	June 06-10, 2022
Organizers	
Alexandros Gezerlis	University of Guelph, Guelph/CA, USA
Carlos Sa de Melo	Georgia Institute of Technology, Atlanta, USA
Number of participants	65

Main topics

In this workshop, theorists working in cold atoms and nuclear matter were brought together to exchange ideas between the two fields. Given that ultracold atoms are used as quantum simulators of situations that are relevant to nuclear matter, a few experimentalists working with ultracold bosons and fermions presented new results that require deeper theoretical understanding. The experimental talks stimulated cross-pollination between theorists working in the two communities.

The topics covered in the workshop included unitary gases, long-ranged dipolar interactions, optical lattices and lattice chromodynamics, artificial spin-orbit coupling, supersolidity and collective excitations.

Speakers

Monika Aidelsburger	Ludwig Maxillimian University, Germany
Joe Carlson	Los Alamos National Laboratory, USA
Yvan Castin	École Normale Supérieure, France
Francesco Marino	University of Milano, Italy
Denis Lacroix	IJCLab, Orsay, France
Dean Lee	University of Michigan, USA
Piotr Magierski	University of Warsaw, Poland
Giovanni Modugno	University of Pisa, Italy
Henning Moritz	University of Hamburg, Germany
Sergei Moroz	University of Karlstadt, Sweden
Nir Navon	Yale University, USA
Amy Nicholson	University of North Carolina, USA
Silke Ospelkaus	University of Hannover, Germany
Thomas Papenbrock	University of Tennessee, USA
Guido Pupillo	University of Strasbourg, France
Alessio Recati	University of Trento, Italy
Alessandro Roggero	University of Trento, Italy
Luis Santos	University of Hannover, Germany
Srimoyee Sen	Iowa State University, USA

Sandro Stringari	University of Trento, Italy
Andrea Trombettoni	University of Trieste, Italy
Michael Urban	University of Paris – Saclay, France
Senne Van Loon	University of Antwerp, Belgium
Neil Warrington	University of Washington, USA
Daisuke Yamamoto	Nihon University, Japan

Scientific report

Since the workshop was hybrid and spanned several time zones, we had 5 talks per day scheduled, starting at 15:00hs local time (Trento), with a 30 min break at 16:30hs and a conclusion session at 18:00hs, and we had to compress the schedule to the hybrid nature of the meeting. Nevertheless, we achieved our goal of bringing together theorists from the nuclear and atomic physics communities working in theoretical problems at the interface of the two areas. The workshop covered boundary areas between nuclear and atomic physics, as ultracold atoms have become ideal quantum simulators of nuclear phenomena. Common areas explored in this workshop included: a) superfluidity and supersolidity in dipolar and spin-orbit coupled systems, phases that may occur also in neutron stars; b) collective excitations in cold atoms and nuclear matter; c) cold fermions near unitarity, a phenomenon occurring also in dilute neutron matter; and d) SU(N) ultracold fermions, with important connections to quantum chromodynamics and lattice gauge theories.

A few key experimentalists delivered wonderful talks highlighting what is now possible to achieve in the laboratory. The theoretical presentations either directly addressed current experiments or provided suggestions and connections to possible future experiments. Open questions and new directions were discussed during the meeting. On the topic of supersolidity in dipolar and spin-orbit-coupled systems, several scientific questions were addressed including: What is the precise definition of a supersolid? Can supersolids be truly created in the laboratory and their properties be uniquely determined? Can the non-classical moment of inertia be measured? Another topic that was discussed extensively was the existence of collective excitations in nuclear and atomic physics as revealed by measurements of sound modes and dynamical structure factors of ultracold fermions and bosons in box potentials. Such excitations can now be studied experimentally as a function of interactions and temperature and have opened the possibility of investigating Goldstone, roton, Higgs and other modes in a variety of superfluids and supersolids. Questions related to universality in neutron matter and ultracold fermions in the vicinity of a diverging scattering length were also broadly discussed, such as: What is the role of effective range? What are the experimentally measureable universal properties near unitarity? Furthermore, important issues related to SU(N) Fermi atoms such as ^{173}Yb were discussed and their connection to high energy and nuclear physics were highlighted: Can lattice gauge theories be simulated using Fermi atoms? What are the measurements needed to characterize such lattice gauge theories?

Results and Highlights

The workshop was very successful in bringing together experimentalists from cold atoms and theorists from nuclear, condensed matter and atomic physics to discuss the latest experimental and theoretical developments. The interactions were fruitful and have led to further discussions beyond the workshop amongst theorists in different communities and amongst experimentalists and theorists. It was worth highlighting those experiments with ultracold magnetic atoms have potentially revealed the existence of one-dimensional supersolids, but additional experiments in higher dimensions are necessary to clarify the preliminary findings. If further investigations confirm the existence of magnetic dipolar supersolids, this would be very exciting, because such phases were not found in ^{4}He, although there were initial claims of supersolidity in these systems. Another interesting experimental highlight is the progress that has been made in studying long-ranged interactions with dipolar molecules, which are being close to be brought to quantum degeneracy, and it may be possible to use them to study quantum chemical reactions. Another exciting result from the experimental side is development of box potential for Fermions, where now these systems have uniform density within the box, rather than a non-uniform density profile as encountered in harmonically confined systems. The reported results bring experiments closer to earlier theoretical work describing translationally invariant systems. It has been reported that uniform potentials reduce losses of fermions with more than two internal states, which opens the door for the exploration of more complex systems. Further experimental results covering collective modes in two- and three-dimensional Fermi superfluids have revealed the entire energy dispersion of the low-energy modes via the dynamical structure factor. Fascinating experimental work on the use of fermionic Yb atoms in optical lattices was also reported on, motivated by the goal of eventually simulating lattice gauge theories.

On the theory front, one of the highlights was the discussion that traditionally accepted calculations by Landau and collaborators for the collective modes of Fermi gases were wrong, due to a mathematical error in computing the relevant physical processes (diagrams). Another interesting theoretical result is that the simulation of quantum field theories in cold atoms is getting close to reality both from the perspective of condensed matter and nuclear physics. Strong connections between nuclear physics and cold atoms were discussed extensively in systems close to unitarity like neutron matter and ^{6}Li or ^{40}K, and properties such the dynamical and static factors were deemed important to sharpen this connection. Another interesting result was the realization of a Devil's staircase of supersolids for spin-orbit coupled bosons in a lattice due to Umklapp scattering, which are absent in continuum or box potentials, but can be importance in optical lattices. The dynamics and localization properties of dipolar gases were discussed in anticipation of potential experiments where extrinsic disorder is included in additional to trapping potentials to confine the system. Interesting counterparts of the experimental approaches to lattice field theory were also well represented in the theoretical talks of the workshop. Another important direction involved both cold atoms and nuclear physics as well as the interplay with experiment, in the context of applications of density functional theory to strongly interacting matter.

Turning to the makeup of the participants: out of 25 speakers there were 4 women. The speaker list involved both well-established scientists, as well as more junior researchers (including one PhD student and two postdocs). The non-speaker participants involved a good number of graduate students, probably more than would have been the case in a fully in-person meeting. Also worth emphasizing were the discussion sessions that took place at the end of each day's session (led by Y. Castin, L. Santos, D. Lacroix, A. Trombettoni, and A. Roggero); despite the difficulty imposed by the hybrid format, there was lively discussion, especially on big-picture questions regarding the future of the field. Apparently, this was continued in the lunch/dinner breaks by the in-person participants.

2.3.5 Jet Quenching in the Quark-Gluon Plasma

Date	June 13-17, 2022

Organizers

S. Cao	Shandong University, China
L. Cunquiero	Sapienza University, Italy
Y.-J. Lee	MIT, USA
J. Mulligan	UC Berkeley, USA
K. Tywoniuk	University of Bergen, Norway

Number of participants	35 in-person + 20-40 online

Main topics

Jet quenching is one of the smoking-gun signatures of the quark gluon plasma (QGP) created in relativistic heavy-ion collisions, and offers the long-term prospect to elucidate the microscopic degrees of freedom that emerge as QCD becomes deconfined. Over the past two decades, considerable progress has been made in understanding the medium modification of hard parton splittings as well as the medium's response to jet propagation, both of which are essential ingredients needed to extract medium properties. In this workshop, we aimed to understand both common and disparate features between various theoretical approaches to jet quenching, and formulate strategies to disentangle them with novel experimental measurements. By assessing the theoretical and experimental progress that has been made since the discovery of the QGP, we revisited the long-term goal of extracting medium properties with jet observables and formulate a roadmap to constrain QGP properties.

The main topics were:

- Understanding parton splitting in medium
- How to interface jet evolution with medium evolution, and implement in Monte Carlo simulations
- Jet thermalization and medium response
- Connecting specific theory features to experimental observables
- Extraction of QGP properties: current status and future strategies

Speakers

M. Verweij	Utrecht University, Netherlands
C. Andres	École Polytechnique, France
F. Dominguez	University of Santiago de Compostela, Spain

J. Isaksen	University of Bergen, Norway
U. Wiedemann	CERN, Switzerland)
C. Sirimanna	Wayne State University, USA
I. Soudi	Wayne State University, USA
V. Vaidya	MIT, USA
S. Adhya	IFJ-PAN, Poland
A. Soto-Ontoso	IPhT, France
P. Caucal	Brookhaven National Laboratory, USA
M. Li	University of Santiago de Compostela, Spain
D. Zigic	Institute of Physics Belgrade, Serbia
S. Schlichting	Universität Bielefeld, Germany
A. Majumder	Wayne State University, USA
W. Ke	Los Alamos National Laboratory, USA
R. Cruz-Torres	Lawrence Berkeley National Lab, USA
Y. Tachibana	Akita International University, Japan
X.-N. Wang	Lawrence Berkeley National Laboratory, USA
G.-Y. Qin	Central China Normal University, China
A. Sadofyev	University of Santiago de Compostela, Spain
J. Barata	Brookhaven National Lab, USA
C. McGinn	University Colorado Boulder, USA
D. Pablos	INFN Torino, Italy
S. Tapia	Iowa State University, USA
M. Rybar	Charles University, Czech Republic
L. Havener	Yale University, USA
R. Ehlers	Lawrence Berkeley National Laboratory, USA
M. Ploskon	Lawrence Berkeley National Laboratory, USA
L. Apolinário	Laboratory of Instrumentation and Experimental Particle Physics, Portugal
A. Takacs	University of Bergen, Norway
F. Krizek	NPI, Czech Academy of Sciences, Czech Republic
P. Jacobs	Lawrence Berkeley National Laboratory, USA
K. Rajagopal	MIT, USA
Y. Mehtar-Tani	Brookhaven National Lab, USA
A. Sickles	University of Illinois, USA
M. van Leeuwen	Nikhef, Netherlands
G. Roland	MIT, USA
N. Armesto	University of Santiago de Compostela, Spain
Y. Chen	MIT, USA
G. Nijs	MIT, USA
W. Qian	Iowa State University, USA
A. Czajka	National Centre for Nuclear Research, Poland

S. Hauksson IPhT, Saclay, France
Z. Kang University of California Los Angeles, USA

Scientific report

High energy jets serve as microscopic probes of the deconfined state of QCD, known as the quark gluon plasma (QGP), produced in ultrarelativistic heavy-ion collisions. In this workshop, we brought theorists and experimentalists together to assess the current and future prospects of using jet measurements to extract microscopic properties of the QGP.

Over the past two decades, considerable progress has been made in understanding the medium modification of hard parton splittings as well as the medium's response to jet propagation. These include analytical approaches, such as the improved opacity expansion or SCET, numerical approaches, and Monte Carlo (MC) approaches such as JETSCAPE or JEWEL. However, these commonly used theoretical approaches differ in their detailed implementation of jet-QGP interactions, and in describing the dominant mechanisms that drive the medium modification of different jet observables such as jet substructures and the cone-size dependence of jet quenching.

We set out with three main scientific goals with this workshop.

First, we sought to understand similarities and differences between various state-of-the-art theoretical approaches and numerical implementations of jet-medium interactions, including jet quenching and jet-induced medium excitation. What approximations have been applied in different theoretical approaches? When are these approximations applicable? Is there a way to combine different approaches into a unified framework for describing jet-QGP interactions? We hope, in this way, to clarify the relations between analytical calculations, numerical calculations, and MC implementations of medium-induced radiation and jet-induced medium excitation.

Second, we sought to formulate strategies to distinguish these theoretical approaches phenomenologically by comparing them to experimental measurements. We aimed to discuss comparisons both of the effects of medium-induced radiation and jet-induced medium excitation in different models and explore strategies to construct new observables that could provide insight in delineating them.

Finally, given the immense theoretical and experimental progress of the last years, we sought to revisit the question: What are the prospects to make model-independent statements about the microscopic degrees of freedom of the QGP using jet measurements? This involves considering different theoretical models of the medium, including different formulations of a "medium PDF", as well as which observables are most promising to distinguish them – and ultimately Bayesian inference with well characterized uncertainty quantification. We aimed to assess the prospects for these extractions, identify the main hurdles, and formulate a roadmap of how best to proceed.

Results and Highlights

We began the week with a focus on the theoretical underpinnings, and progressively moved towards phenomenology, experimental results, and future strategies. The complexity of the topic of jet quenching required bringing together participants with a variety of expertise, from those focused on perturbative calculations to Monte Carlo modeling to phenomenology to experimentalists from the LHC and RHIC. Each day was filled with lively discussion and energetic and constructive debate as we synthesized progress over the last few years in both theory and experiment. Below we highlight several outcomes of the workshop.

With regard to theoretical developments of medium-modified parton splitting, we witnessed an impressive consolidation of theoretical progress calculating parton splittings – with analytical and numerical methods from various authors beginning to converge after many years of work. This has established that the basic unit of jet quenching calculations is under reasonably good theoretical control, with improving understanding of where analytical calculations break down. The state-of-the-art calculations presented are not yet implemented in Monte Carlo jet quenching simulations; it was discussed how this can be implemented as a next step.

In order to compare to experimental measurements, additional ingredients are needed beyond the calculation of medium-induced emission spectra. Several key items still remain to be improved in this respect. One such item is a more careful theoretical treatment of the pp baseline – we had intensive discussion about the extent to which the heavy-ion jet community needs to adopt state-of-the-art the methods high-energy perturbative QCD community, or whether simplified approximations are sufficient. Another item is the treatment of the spacetime evolution of the QGP, which is treated differently by different models. While no consensus was reached on how to approach these issues, we had vital discussion and heard several novel approaches that may be able to address these questions, such as (i) carefully benchmarked parton showers, (ii) a systematically improvable factorization-based approach to jet quenching, and (iii) quantum computing algorithms for real-time evolution of QCD, among other ideas.

We accordingly had in-depth discussion of how best to test these various theoretical approaches by comparing them to experimental data. We had crucial discussion on the controversial topic of whether to judge models by their agreement with data or by the theoretical soundness of controlled approximations. Along with presentation of the latest experimental results, we discussed a variety of proposals for new experimental observables to be measured, such as novel heavy flavor and photon-tagged observables that may be reachable at upcoming facilities -- with model-based studies of the sensitivity of certain observables to certain medium properties. Efforts to extract medium properties using Bayesian inference were presented, along with limitations due to the aforementioned theoretical uncertainties, and proposals for more precise experimental uncertainty reporting. While no consensus was reached on a single strategy to proceed with (e.g. how to disentangle medium-induced radiation from medium response), there was a widespread sentiment that progress on many exciting new ideas was apparent, and that a multi-pronged approach pursuing multiple of these ideas is the necessary next step.

2.3.6 Neutron Stars as Multi-Messenger Laboratories for Dense Matter

Date	June 20-24, 2022
Organizers	
Ingo Tews	LANL, USA
Bruno Giacomazzo	University of Milano-Bicocca, Italy
Sebastien Guillot	IRAP Toulouse, France
Jérôme Margueron	IN2P3, France
Samaya Nissanke	University of Amsterdam, Netherlands
Number of participants	24 (in-person) + 20 (remote)

Main topics

The equation of state (EOS) for strongly-interacting matter is of great interest for nuclear physics and astrophysics, and there are strong theoretical, experimental, and observational efforts to elucidate its properties at supra-nuclear densities. Many new observational data from gravitational wave facilities, X-ray satellites, and nuclear experiments are becoming available. This wealth of new results is expected to improve the understanding of the neutron-star core and the supra-nuclear EOS. In the future, even more data is expected from these observatories, requiring us to examine these individual pieces of data, their robustness and precision, and to obtain robust constraints on the EOS of dense matter.

Key speakers

Sarah Antier	Nice Observatory, France
Sebastiano Bernuzzi	Jena, Germany
Collin Capano	Max-Planck Institute for Gravitational Physics, Germany
Thankful Cromartie	University of Virginia, USA
Tim Dietrich	University of Potsdam, Germany
Cristobal Espinoza	University of Santiago De Chile, Chile
Farrukh Fattoyev	Manhattan College, USA
Francesca Gulminelli	LPC Caen, France
Sabrina Huth	Darmstadt, Germany
Cole Miller	University of Maryland, USA
Joonas Nattila	Columbia University, USA
Geert Raaijmakers	Amsterdam, The Netherlands
Jocelyn Read	CalState Fullerton, USA
Tom Riley	University of Amsterdam, The Netherlands

Scientific report

The workshop “neutron stars as multi messenger laboratories for dense matter” has been held at ECT* Trento from June 20 to 24, 2022. It has brought together three different scientific communities: gravitational-wave physicists from LIGO and Virgo interferometers as well as from other theory groups modelling binary mergers, electro-magnetic observers (radio and X-ray), and nuclear physicists from experimental to theoretical groups who model the properties of dense matter. Each day a different aspect of neutron stars was discussed as follows: on Monday we addressed gravitational waves, on Tuesday the radio and X-ray observations, on Wednesday the nuclear physics aspects, and on Thursday and Friday the multi-messenger analyses of the various data. Every day morning talks were given by in-person participants (in a very informal way regarding the talks and the discussions), and all in-person participants were given the chance to present their research or ideas. Afternoon talks (3 to 4) were mostly remote and a hybrid discussion session was set-up to find the conclusion of the day.

Results and Highlights

Our workshop illustrates the rich and prolific exchanges between observers and modelers for the understanding of dense matter, the existence of phase(s) transition(s), and the wide amount of data allowing for multi-messenger and multi-physics analyses. In particular, we discussed the impact of the recent detection of gravitational waves from binary neutron stars mergers and the measurements by NICER of the masses and radii of PSR J0030+0451 and J0740+6620, the radio observation of massive pulsars, the PREX and CREX measurements of neutron skins in atomic nuclei, and a variety of nuclear models from microscopic to agnostic approaches. The workshop finished on Friday with a general discussion of all topics raised during the week. Participants expressed their strong interest for this workshop to be organized on a regular basis. It was also suggested to setup a database collecting the different astrophysical results in a standard format that could be useful for the neutron-star matter community.

2.3.7 Saturation and Diffraction at the LHC and the EIC

Date	June 27- July 01, 2022
Organizers	
Néstor Armesto	Universidad de Santiago de Compostela, Spain
Abhay Deshpande	Stony Brook University & BNL, USA
Martin Hentschinski	Universidad de Las Americas Puebla, Mexico
Tuomas Lappi	University of Jyväskylä, Finland
Agustín Sabio Vera	Universidad Autónoma de Madrid, Spain
Soeren Schlichting	University of Bielefeld, Germany
Gregory Soyez	CEA Saclay, France
Christophe Royon	University of Kansas, USA
Number of participants	32 in-person participants: 40 remote participants

Main topics

The general scientific goal of this workshop is related to QCD at high gluon densities and diffraction at the Large Hadron Collider (LHC), the future Electron Ion Collider (EIC) to be built in the US at BNL, as well as proposed facilities dedicated to the study of the proton structure in deep-inelastic scattering at CERN, the Large Hadron-electron Collider (LHeC) and the Future Circular Collider in electron-hadron mode (FCC-eh). Concretely, this event aims to stimulate discussions between experimentalists and theorists in forward hadronic physics, QCD dynamics at low-x, diffractive processes, and parton saturation effects in light- and heavy-nuclei.

The event took place in the ECT* institute in Trento, Italy from June 27 to July 1, 2022. All sessions consisted of plenary talks.

The topics discussed during the workshop are:

- Low-x, parton saturation in light- and heavy-nuclei
- Photon-exchange, pomeron exchange, and hard diffraction
- Total cross section and soft diffraction
- Spin, generalized parton distribution functions, and transverse momentum dependent PDFs
- Cosmic ray physics
- Future experiments and instrumentation

This was also a workshop of the Networking activity NA2-Small-x: Physics at the LHC and future DIS experiments of STRONG-2020 “The strong interaction at the frontier of knowledge: fundamental research and applications” (http://www.strong-

2020.eu/), an Integrating and Opening Research Infrastructures of European Interest action which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093. The event is also financially supported by the ECT* institute hosting the meeting (https://www.ectstar.eu/node/4559).

Speakers

Luis Fernando Alcerro	University of Kansas, USA
Eugenio Berti	University and INFN, Florence, Italy
Renaud Boussarie	CPHT, CNRS, École Polytechnique, IP Paris, France
Francesco Giovanni Celiberto	ECT*/FBK & INFN -TIFPA, Italy
Giovanni Antonio Chrilli	University pf Regensburg, Germany
Janusz Chwastowski	Polish Academy of Science, Poland
Dimitri Colferai	University of Florence, Italy
Federico Deganutti	The University of Kansas, USA
Abhay Deshpande	Stony Brook University (SUNY), USA
Michael Fucilla	University of Calabria, Italy
Pablo Gonzales	WWU Muenster, Germany
Martin Hentschinski	Universidad de las Americas Puebla, Mexico
Edmond Iancu	Institut de Physique Théorique, France
Jamal Jalilian-Marian	Baruch College, CUNY, USA
Mats Kampshoff	The University of Kansas, USA
Valery Khoze	University of Durham, UK
Piotr Korcyl	Jagiellonian University, Poland
Piotr Kotko	AGH University of Science and Technology, Poland
Georgios Krintiras	The University of Kansas, USA
Krzysztof Kutak	Instytut Fizyki Jadrowej Polskiej Akademii Nauk, Poland
Tuomas Lappi	University of Jyväskylä, Finland
Maciej Lewicki	INP, Polish Academy of Sciences, Poland
Ronan McNulty	University College, Dublin, Ireland
Leszek Motyka	Jagiellonian University, Poland
Yair Mulian	University of Santiago de Compostela, Spain
Michael Murray	The University of Kansas, USA
Frigyes Janos Nemes	CERN and Wigner RCP Budapest, Hungary
Javier Alberto Murillo Quijada	Universidad de Sonora, Mexico
Risto Paatelainen	University of Helsinki, Finland
Alessandro Papa	Università della Calabria & INFN-Cosenza, Italy
Jani Penttala	University of Jyväskylä, Finland
Michael Pitt	CERN, Switzerland
Christophe Royon	University of Kansas, United States
Agustin Sabio Vera	Universidad Autónoma de Madrid, Spain

Michael Sanhueza	Universidad Técnica Federico Santa María, Chile
Bjoern Schenke	Brookhaven National Lab, USA
Farid Salazar	UCLA/UCB/LBNL, USA
Soeren Schlichting	Universität Bielefeld, Germany
Anna Stasto	Penn State University, United States
Mark Strikman	Penn State University, USA
Daniel Tapia Takaki	University of Kansas, United States
Dionysios Triantafyllopoulos	ECT*, Italy
Maciej Trzebinski	Institute of Nuclear Physics PAN, Poland
Andreas van Hameren	INP, Polish Academy of Sciences, Poland

Scientific report

For successful runs at any colliders, such as the LHC at CERN or the incoming EIC at BNL, and future projects such as FCC at CERN, it is fundamental to understand fully the complete final states. This obviously includes the central part of the detector that is used in BSM searches and also the forward part, the kinematic region close to the outgoing beam remnants after collision. The detailed understanding of final states with high forward multiplicities, as well as those with the absence of energy in the forward region (the so-called rapidity gap), in elastic, diffractive, and central exclusive processes is of greatest importance.

Some of these configurations originate from purely nonperturbative reactions, while others can be explained in terms of multi-parton chains or other extensions of the perturbative QCD parton picture such as the Balitsky-Fadin-Kuraev-Lipatov (BFKL) formalism.

When the parton momentum fraction x becomes small, small-x logarithms ln(1/x) become significant, and require all-order resummation to obtain a good convergence of the QCD theory. This can be achieved through the BFKL formalism which resumes such logarithms to all orders in the strong coupling and predicts a powerlike rise of the gluon distribution with 1/x. While such a rise is clearly seen in data, unitarity bounds prohibit such a rise to continue forever: at a certain value of x, this rise must slow down and eventually come to hold. The latter is strongly related with the formation of an over-occupied system of gluons, known as the Color Glass Condensate, whose exploration is one of the central physics goals of a future Electron Ion Collider (EIC).

Besides the direct interaction of partons at very low proton momentum fraction, this type of physics can be also studied with so-called diffractive events. The latter are characterized through the presence of large rapidity gaps and therefore probe physics beyond conventional collinear factorization. In the case of hard events, they give access to complementary information on the physics of high gluon densities as well as corrections due to soft re-scattering.

At the same time such processes are themselves of direct interest for the exploration of electroweak physics and physics beyond the Standard Model: due to the presence of rapidity gaps, such events are characterized through a very few numbers of particles in the final state and allow therefore for very clean measurements with a strongly reduced background, in comparison to conventional LHC measurements.

Closely related to such diffractive events are photon-induced reactions, which can be observed at the LHC. In such events, either one or both of the two scattering protons or ions at the LHC at as a photon source. The former allows for the study of exclusive photon-hadron interaction at highest center of mass energies and yields therefore another tool for the study of highest gluon densities, with high precision.

Results and Highlights

The workshop was very successful in bringing together different communities from the LHC, the EIC and theorists. One of the main results of the workshop was to understand in greater detail the BFKL equations and the implications at the LHC and the EIC. There were many contributions about different probes at gluon dynamics and their impacts on our knowledge on PDFs; for example, the gap between jets or the Mueller Navelet jet configurations, and vector meson production. A second related aspect was how saturation could be probed at the EIC and the LHC via the colour glass condensate framework implemented in exclusive vector meson production, the JIMWLK equations for the PDF evolutions. Another point that was heavily discussed was related to diffraction. The first aspect deals with the recent discovery of the odderon by the D0 and TOTEM collaborations. The discovery was presented, and other new possible observables were discussed in pA or AA collisions. The diffractive production of jets of vector mesons as well as the diffractive PDFs extracted from inclusive diffractive measurements and their implications at the EIC was also discussed in detail, stressing the complementarity between the LHC and the EIC since they reach different center-of-mass energies. Finally, the relation between forward physics (and measuring intact protons at the LHC) and beyond standard model physics in order to probe anomalous couplings between photons and W/Z bosons, top quark, photons, as well as the search for axion-like particles was one of the hotly discussed topic at this workshop.

2.3.8 Nuclear Physics at the Edge of Stability

Date	July 04-08, 2022

Organizers

Alexandra Gade	MSU, USA
Guillaume Hupin	IJCLab, France
Lucas Platter	UTK, USA
Olivier Sorlin	GANIL, France

Number of participants	28 in person + 28 remote

Main topics

The research area of the workshop is the physics of open quantum systems (OQS). These are systems strongly influenced by the coupling to an external environment. This topic is common to various fields of physics (e.g., nuclear, atomic and molecular physics, mesoscopic physics, and quantum optics) in which experimental and theoretical developments are currently being carried out worldwide. Among the general phenomena that appear in open quantum systems, one can mention tunneling effects and dynamics, exotic decay modes, exceptional points, quantum chaotic scattering and extended structures such as halos or Efimov states.

The workshop focused on the open questions in nuclear physics and, in particular, how experimental observations can be connected to theory to arrive at an interpretation of the measurements.

Speakers

Paul Andre	CEA, France
Hugo Arellano	University Chile
Yassid Ayyad	USC, Spain
Carlos Bertulani	Texas A&M, USA
Jérôme Beugnon	LKB, France
Manuel Caamaño	USC, Spain
Bob Charity	Washington University St. Louis, USA
Meytal Duer	TUD, Germany
Hans Fynbo	Aarhus University
Michael Gennari	TRIUMF
Jérôme Giovinazzo	LP2I-Bordeaux, France
Emiko Hiyama	Kiushu University
Souichi Ishikawa	Hōsei University, Japan
Shumpei Koyama	GANIL, France

Live-Palm Kubushishi	University of Mainz, Germany
Rimantas Lazauskas	IPHC, France
Dean Lee	MSU, USA
Cyril Lenain	CEA, France
J.-P. Linares	GANIL, France
Chiara Mazzocchi	Warsaw University
Nicolas Michel	Chinese Academy of Sciences, China
Belen Monteagudo Godoy	MSU, USA
Takashi Nakamura	Titech, Japan
Witek Nazarewicz	MSU, USA
Frederic Nowacki	IPHC, France
Alexander Obertelli	TUD, Germany
Gregory Rogachev	Texas A&M, USA
Hiroyuki Sagawa	Aizu University, Japan
Dam Than Son	University of Chicago, USA
Andrea Tononi	LPTMS, France
Alexander Volya	FSU, USA
Juzo Zenihiro	Kyoto University, Japan

Scientific Report

Exploring the properties of the most exotic nuclei, including those beyond the dripline and/orabove particle emission thresholds, is one of the most drastic ways to test our understanding of the organization of nucleons within the atomic nucleus. Our ultimate goal is to reach a fullymicroscopic understanding of how the strong force binds neutrons and protons together.

Since all nuclear binding mechanisms take on a considerable importance at the dripline, its vicinity provides an ideal microscope to challenge our understanding of the nucleus. This regime can be used as probe for continuum effects in light of certain recent advances: (i) Nuclear theory baseline, which has made very significant progress in recent years with the development of a range of sophisticated approaches, from *ab initio* to reaction models, and which are able to explicitly incorporate the continuum and reactions; (ii) Experimental advances, notably in terms of new facilities and spectrometers, active targets, and associated multi-detector systems for tracking charged particles and neutrons. These have made it possible to reach very neutron-rich systems in recent years and study particle correlations. Very recently, the first steps in the exploration of the most neutron-rich O and F isotopes, including unbound low-lying states in the continuum, have been undertaken ($^{26\text{-}28}$O, $^{28\text{-}30}$F). Significant results were presented during this workshop notably on the experimental existence of a tetraneutron resonance, the non-observation of ^{7}H state at the threshold and the 4n decay of the ^{28}O ground state. These outstanding results were shown for the first time since their publication or have not yet been submitted to peered review journals but ignited serious discussions among the participants.

From the systematic observation of narrow resonant states with clustered structure close to the corresponding particle-emission thresholds, it was proposed that the Ikeda conjecture can be generalized to two or four nucleon clusters. In the last few years, adding to the very weakly-bound ^{11}Li that exhibits a two-neutron halo configuration, two remarkable examples of this generalized conjecture have been found in ^{15}F and ^{26}O. Both nuclei indeed exhibit narrow resonances very close (a few tens of keV) to the respective 2p and 2n thresholds. The properties of these nuclei can be understood in terms of universal features of few-body systems. For loosely-bound systems, a lower resolution scale is sufficient i.e., an interacting three-body system determined by a few universal parameters will be able to reproduce the observables and allow to understand their correlations. There is already a significant body of evidence indicating that resonances close to thresholds have been missed in data evaluations.

Understanding the role of the reaction mechanism in revealing the existence of correlated neutrons or protons in bound atomic nuclei is an unavoidable topic. The central question is tounderstand how the memory of the pair structure from the initial nucleus survives in the reaction observables. So far, little effort has been devoted to bridging the gap between low- energy nuclear structure, especially for shallow states such as exotic clusters or halos, and practical experimental observables. Indeed, many experimental facilities study exotic systemsin inverse kinematics at higher relative energies than the prototypical low energy expansion used in microscopic methods. With the exception of rare, ideal, and weakly interacting nucleonic systems, there is little hope of achieving a complete microscopic calculation of complicated reactions.

Results and Highlights

We tailored the workshop to have an equilibrium between reports on the current status of experimental investigation and theoretical developments ranging from *ab initio* methods to reaction theory with unstable beams. Unlike during the online edition of the workshop, we were not assisted by conveners to organize the discussion. Another essential requirement from the organizers to the chairs was also to offer as many opportunities as possible for young researchers to present their work.

Below, we discuss in more details the results and highlights that were presented during the workshop focusing on its main themes:

1. Clustering

It was shown in the literature that the spatial extension of the proton and neutron distribution is a sensitive probe of nuclear clustering. Traditionally, charge density is probed in (e, e') experiments. From complementary elastic scattering (eventually polarized for higher precision observable such as the A_y) supplemented by nuclear structure and reaction theory,one can extract the nuclear distribution. At this stage, most of the community is focused on calculating infinite nuclear matter properties such as the symmetry energy parameter L and the incompressibility K_c as they can be obtained from the isoscalar and isovector densities. Similarly, the nucleon distributions that may be inferred from experiment, can be used to study charge symmetry breaking in nuclei. So far, no study of clustering based on experimental measurements related to nucleon distributions has been reported.

Many developments were reported regarding the extension of nuclear structure methods to compute states in the continuum. Among them, the most accurate rely on efficient shell- model effective interactions coupled that the continuum with ad-hoc continuum coupling interaction. However, few attempts are reported to start from the microscopic proton and neutron interaction in the vacuum, but work in this direction are ongoing.

There is an accumulation of experimental evidence e.g., in the Be isotopic chain, proton-rich oxygen or fluorine that cluster states are populated in the vicinity of the reaction thresholds with respect to the nature of the cluster state. It is still an outstanding problem to model the properties of many-body states below or at the reaction threshold. The lack of predictivity of nuclear models is particularly acute if experimentalist interpretation of data relies on theory to assess qualitative details of the considered state or at least to predict with some degree of confidence its location and width (if applicable). Furthermore, it is challenging to calculate under the same accuracy the experimental observations of the particle decay in term of cross- section. On the other hand, the origin of the emergence of cluster states is still unknown froma fundamental point of view, especially since it is hardly achievable to compute them using *abinitio* methods, and if so, no systematic study of the nuclear force parameters controlling their properties were conducted so far. Yet, we know these states may be essential for accurate evaluation of reactions relevant to nuclear astrophysics due to their impact on the S-factor. It is now possible to study nuclear systems with nucleons on a lattice through effective field theory. The infamous example of 12C was shown where it is found α cluster structures with two different geometries.

On the experimental side, studies on the conjecture that cluster states may exist on the surface of nuclei and that the preformation probability of the α is significantly high to lead to the emission of 4He during knock-out reactions, are being conducted. It is expected that final results will be obtained in the near future, which will revitalize theoretical studies of these systems and reiterate the need for more elaborate ^{3}H, ^{4}He etc… optical potentials to interpret the data.

2. Proton-rich sector

We had a report on the 2p radioactive emission from ^{48}Ni. The preliminary analysis shows that events were observed. The interpretation of data will help to determine the nuclear structure of the ground state and discriminate between the different theoretical predictions that either grasp the nuclear structure in the continuum or the dynamics of the decaying 2p state but rarely both. Another recent result obtained at RIKEN on 2p decay of ^{54}Zn was discussed and the same conclusion regarding the inaccuracy of the prediction is expected. These presentations were complemented by the experimental study of short-lived proton radioactivity of ^{54m}Ni and proton radioactivity of ^{53m}Co. This work shows in particular that it is possible to test the isospin non-conserving terms and effective charges used in effective interactions, but highlights that no theoretical calculations can successfully reproduce all experimental observables associated with many-particle particle decays. The same type of experimental apparatus is able to observable exotic nuclear and weak decay, and in particular particle-emission beta delayed decays such as in the case of the 23Si, which emits 3p after beta-decaying. It was concluded that accurate beta decay branching ratios can be obtained and that searches for very rare decays or charged-particle decays obscured by β background are now achievable by the community.

We were presented a wealth of broad resonances seen in the decays of very proton-rich unstable nuclei. These states populated by (p, d) reactions are all located in the vicinity of reaction threshold xp, H, ^{3}He etc... to this date, there is no evaluation that reports on the existence of such cluster states and their very existence as a resonance is not established by theory. These studies are also important to understand the unknown spectra of their neutron- rich mirror nuclei. It is expected that these campaigns will stimulate theoretical progresses to compute charged decay and proton-rich resonance properties.

3. Tetraneutron – ^{7}H

The existence of quasi-bound tetra-neutron resonances, as an ensemble of four interacting neutrons, was proposed on the basis of experimental results, in stark contrast with predictions from most of the state-of-the-art models. An experimental campaign performed at RIKEN showed for the first time an unambiguous structure decoupled from the continuum contribution of the direct decay. The resonance parameters of this state are orders of magnitude of the prediction of the most accurate exact calculation of four-body systems. This will challenge theoretical developments for the next decade.

We were reported recent results about the low-energy resonances of 7H. This system has been controversial since decades due to low-statistic experiments, which interpret the low-energy enhancement of the 7H breakup as a near threshold resonance. Thanks to high-intensity radioactive beam of RIKEN, it is now demonstrated that the first resonance of 7H is located around 3 MeV rather than at the threshold, which signifies that the pattern hypothesized in this isotopic chain of an extra stability gain as N increase do not exist. Many theoretical calculations support the experimental confirmation of RIKEN.

4. Be isotopic chain

The Beryllium chain is a prototype example of the evolution of clustering where α structures are well identified and transform into halos and many-particle unstable systems when reaching the neutron and proton driplines. The scientific objectives in these systems are to infer the thee-body structure of the nucleus ground-state from measurements of many- neutron correlations observed from the decay of the state. This is both a theoretical and experimental challenge, which required state-of-the-art neutron detection as well as three- body dynamic as the initial correlation between neutrons is slowly washed out by the final state interaction. Nevertheless, significant progresses have been obtained.

The community was eager to understand the origin of the discrepancy between the calculation of the β decay of ^{11}Be compared to the measurement that is orders of magnitude larger. It was confirmed by three independent experiments that a ½+ state at E_x~11.400 MeV exists in ^{11}B and explains the enhancement observed in the β decay emission -no charged particle detector was used in the original β decay experiment. All experimental investigation shows a strong spectroscopic factor of ~ 0.2 − 0.3. Models with coupling to the continuum, including *ab initio* calculations, can reproduce these properties and agree with the enhanced β decay emission.

2.3.9 Advances on Giant Nuclear Monopole Excitations and Applications to Multi-messenger Astrophysics

Date	July 11-15, 2022

Organizers

Yorick Blumenfeld	IJCLab, France
Gianluca Colò	University of Milan & INFN, Italy
Umesh Garg	University of Notre Dame, USA
Elias Khan	IJCLab, France
Marine Vandebrouck	DPhN - CEA, Saclay-Paris, France

Number of participants	80

Main topics

The giant monopole response of nuclei is intimately linked to the compressional properties of bulk nuclear matter. Recently much progress in the subject has been made, both theoretically and experimentally. This also provides nuclear physics inputs of paramount importance for our modeling and understanding of core-collapse supernovae, neutron star properties, and merging of astrophysical compact objects.

This workshop addressed three main topics of approximately equal importance: experimental, theoretical, and applications to multi-messenger astrophysics. The experimental advances centered around new background-free measurements for stable nuclei and new techniques for unstable nuclei. The theoretical novelties included energy density functional calculations, ab initio approaches, and new methods for deducing the nuclear compression modulus. The astrophysics section concentrated on the influence of nuclear equation of state parameters on astrophysical simulations and our understanding of recent observations of gravitational waves, electromagnetic signals, and neutrinos (that contribute to so-called "multi-messenger" astrophysics).

The main topics were:

- Improving our knowledge of K_∞
- Evolution with n-p asymmetry and K_τ
- Connections with astrophysical objects and gravitational waves
- Future approaches
- A discussion session was devoted to each of these topics

Participants

Alessandro Pastore	CEA Cadarache, France

Andrea Porro	CEA IRFU, Université Paris-Saclay, France
Andreas Bauswein	GSI Helmholtzzentrum fuer Schwerionenforschung, Germany
Andrew Steiner	University of Tennessee, Knoxville, USA
Anthea F. Fantina	GANIL, France
Armand Bahini	iThemba Laboratory, South Africa
Baishan Hu	TRIUMF, Canada
Bao-An Li	Texas A&M University-Commerce, USA
Bijay Agrawal	Saha Institute of Nuclear Physics, India
Damien Thisse	CEA IRFU, Université Paris-Saclay, France
Danilo Gambacurta	INFN-LNS, Catania, Italy
Elena Litvinova	Western Michigan University, USA
Elias Khan	IJCLab, Orsay, France
Gianluca Colò	University of Milano and INFN, Milan, Italy
Hiroyuki Sagawa	RIKEN/University of Aizu, Japan
Istenio de Morais	Universidade Federal de São João del-Rei, Brazil
Iyabo Usman	School of Physics, University of the Witwatersrand, South Africa
Jorge Piekarewicz	Florida State University, USA
Joseph Arroyo	University of Notre Dame, USA
Juan Zamora	Facility for Rare Isotope Beams (FRIB), USA
Jérôme Margueron	IP2I Lyon, France
Kenichi Yoshida	Kyoto University, Japan
Lindsay Donaldson	iThemba Laboratory, South Africa
Marine Vandebrouck	DPhN - CEA, Saclay, France
Masaaki Kimura	RIKEN, France
Mikael Frosini	CEA - DES, IRESNE, DER, SPRC, LEPh, France
Mohamad Chamseddine	IP2I Lyon, France
Mohammad Abdullah	Indian institute of technology, Dhanbad, India
Muhsin Harakeh	University of Groningen, Netherlands
Peter von Neumann-Cosel	Institut für Kernphysik, TU Darmstadt, Germany
Ramon Alves dos Santos	Universidade Estadual do Sudoeste da Bahia, Brazil
Retief Neveling	iThemba LABS, South Africa
Riccardo Raabe	KU Leuven, Belgium
Shinsuke Ota	RCNP, Osaka University, Japan
Sophie Péru	CEA, France
Soumya Bagchi	Indian Institute of Technology Dhanbad, India
Tan Ahn	University of Notre Dame, USA
Umesh Garg	University of Notre Dame, USA
Yorick Blumenfeld	IJCLab, Orsay, France
Zafar Iftikhar	TU-Darmstadt/GSI, Germany

Scientific Report

The monopole response of nuclei is a unique way to access the compressional properties of nuclear matter. Although this is not a new subject, we believe that we can achieve significant progress guided by the discussions at this workshop, and that this progress will be highly beneficial also for those who work in multi-messenger nuclear astrophysics.

Since the discovery of the "giant" monopole resonance in the mid- to late 1970s, it has been evident that inferring the value of the incompressibility K_∞ of nuclear matter from its properties is extremely difficult: scarce data points in the isotope chart are not enough to extrapolate to the infinite system. At the turn of the century, the range of the allowed values for K_∞ has narrowed thanks to extensive analyses by many practitioners. Still, the extraction of K_∞ is, to some extent, model-dependent. New efforts to provide a sound assessment of the theoretical uncertainty of K_∞, using all available input (including monopole data in deformed or "soft" nuclei), should be undertaken. Resorting to new ways for deducing K_∞ and related quantities, based on advanced statistical inference methods, is quite timely.

Experimentalists play a key role in this sort of discussion. The progress in experimental techniques has been strong, but still some open questions exist. Even more importantly, a crucial point to address is the feasibility of new measurements of the monopole in neutron-rich nuclei. A coordinated, streamlined plan to produce clean monopole data in existing and planned Radioactive Beam Facilities is called for.

Indeed, the nuclear compression modulus does play a role in core-collapse supernovae and in the physics of neutron stars. Recently, this domain is experiencing a Renaissance: from the merging of neutron stars, we have started to observe gravitational waves, as well as electromagnetic signals that testify to the production of elements heavier than iron. How this "gold mine" works is the subject of investigations that must rely on realistic nuclear physics input. Therefore, a further point to discuss is how exactly our understanding of K_∞, and of the nuclear Equation of State (EoS) as a whole, is relevant for multi-messenger astrophysics. We aim at establishing new collaborations, so that observations, astrophysical simulations, and nuclear physics can go hand-in-hand to tackle the big questions: do we understand the structure and dynamics of neutron stars? Do we know how heavy elements are made?

Results and Highlights

The monopole resonance is best excited in (α, α') scattering. Experiments can be placed into two categories: experiments on stable nuclei in direct kinematics, and experiments on unstable nuclei in reverse kinematics. The former make use of high-resolution magnetic spectrometers such as those available at RCNP Osaka, iThemba South Africa, and Texas A&M. Their aim is to obtain a precise mapping of the monopole strength. Some of the recent work concentrates on deformed nuclei and has shown the splitting of the GMR strength in, for example, ^{24}Mg, ^{28}Si, and the Mo and Nd isotopic chains. This splitting can be interpreted in terms of the coupling between the monopole and the quadrupole responses.

Globally, the data on stable nuclei is generally consistent between the different groups, but some discrepancies remain to be elucidated. This could be approached through the systematic measurements planned at iThemba Labs in South Africa, or through some targeted measurements at RCNP Osaka. The community should determine which measurements of stable nuclei would be the most effective in reducing the error bar on K_∞. Currently, values between typically 210 MeV and 240 MeV are considered. Experimentalists await theoretical input on the most pertinent nuclei to study.

In recent years, much progress has been made on the measurement of the GMR in unstable nuclei. Two technologies have been employed: active target and scattering in storage rings. In the first case, the limitations come from the limited size of the detectors, and the difficulty to measure below 1.5 degrees (centre of mass). One should envisage the construction of a larger TPC, allowing the use of lower pressure, and hence a lower threshold for the detection of the recoiling α particles. Such a TPC will have to be surrounded by scintillators or silicon detectors in order to measure the high-energy particles which will not stop in the gas. It was shown that coupling such a TPC to a magnetic spectrometer to identify the outgoing heavy partner leads to a strong reduction of the background.

The storage ring is a very attractive solution but is limited by the lifetime of the projectile and the copious production of delta electrons during the projectile-target interaction. The threshold of the Silicon detector is also a limitation. Today, only GSI/FAIR has a storage ring (ESR) adapted to such measurements and future developments at FAIR are limited by the absence of coupling of the new Super FRS to the ESR.

In order to decide about the next nuclei to be measured, experimentalists should provide a list of available unstable beams with sufficient intensity. The theoreticians shall then be able to suggest most compelling measurement on the basis of the following fundamental questions:

- What is the value of K_∞ ?
- How to conciliate K_∞ extracted from GMR measurements with values from Gravitational waves and Neutron Star mergers or Kaon production? Recent Bayesian analysis seem to point to a lower K_∞ than the standard value from the GMR.
- What is the value of K_τ and the behavior of the n-rich EoS?
- Are there other EoS quantities that can be related to the GMR measurement?
- What is the solution to the Pb/Sn puzzle, that Sn is softer than Pb?
- Are there soft monopole modes, at which energy, and which collectivity? Can they teach us something about incompressibility?
- Are there cluster modes in light nuclei?

The measurement of the isovector monopole response could lend complementary information on specific modes in which neutrons may significantly contribute. This could be achieved through the measurement of isobaric analog states using the (^{3}He,t) reaction (or reverse).

The presence of soft monopole modes was predicted by several models and some first experimental indications have been observed. Experimental setups should be tuned to search for modes of low energy. Theoretical models should be confronted to each other in order to study the nature of these modes. A workshop dedicated to soft monopole modes has been suggested.

It has been shown through various theoretical interpretations, that the monopole strength does not only provide a constraint of K_∞ but also on other related EoS quantities such as K_τ, L_{sym} and Q_{sat}. This calls for additional work on the method of extraction of the EoS quantities from the monopole strength interpretation, but also for additional experimental constraints such as those provided by astrophysical observations.

Significant recent advances have also been made in the microscopic description of the monopole response, including multiparticle-multihole contributions, particle-vibration coupling or ab initio approaches.

Recent Bayesian analysis, including data from GW emission from neutron star mergers, provides a renewed range of values for the EoS parameters, sometimes at variance with the values extracted from the GMR measurements. An open question concerns the existence of a quark phase in neutron stars, which impacts the values of the EoS parameters obtained from the Bayesian analysis.

2.3.10 Radiative Corrections from Medium to High Energy Experiments

Date	July 19-21, 2021

Organizers

Ethan Afanesev	George Washington University, USA
Jan Bernauer	Stony Brook University, USA
Ethan Cline	Stony Brook University, USA
Ron Gilman	Rutgers University, USA
Hubert Spiesberger	Johannes Gutenberg University of Mainz, Germany

Number of participants	55

Main topics

Historically, radiative corrections had often been applied through pre-calculated, approximate correction factors to experimental data. Modern high-precision experiments require a more careful treatment implementing radiative processes in a full experimental simulation. A particular challenge for efficiency and stability of the Monte Carlo simulation is due to the fact that the cross section for radiation depends strongly on the kinematic variables and quickly rises over many orders of magnitude when extra emitted photons are soft or collinear with other scattering particles in the initial or final state. In addition, high precision theory predictions may require to include two-loop virtual corrections. Some parts of both the real and virtual corrections are model dependent and require a special treatment during the physics analysis of experimental data. The workshop brought together experts from both theory and experiment who develop and use tools for the application of radiative corrections in existing, upcoming or planned measurements, with a focus on lepton-nucleon scattering at medium energies. The goal was to identify existing problems and missing ingredients required for the next-generation Monte Carlo event generators and initiate further developments.

Speakers

Igor Akushevich	Duke University, USA
Adi Ashkenazi	Tel Aviv University, Israel
Jan Bernauer	Stony Brook University and RIKEN-BNL Research Center, USA
Johannes Bluemlein	DESY, Germany
Peter Blunden	University of Manitoba, Canada
Ethan Cline	Stony Brook University, USA
Jan Friedrich	TU Munich, Germany
Ashot Gasparian	NC A and T State University, NC, USA

Ronald Gilman	Rutgers, The State University of New Jersey, USA
Jose Goity	Hampton University and Jefferson Lab, USA
Mikhail Gorshteyn	JGU Mainz, Germany
Tomas Husek	Lund University, Sweden
Doris Jakubassa-Amundsen	LMU Munich, Germany
Norbert Kaiser	TU Munich, Germany
Michael Kohl	Hampton University, USA
Clement Legris	ELPH, Tohoku University, Japan
Miha Mihovilovic	Jozef Stefan Institute and Physics University of Ljubljana, Slovenia
Fred Myhrer	University of South Carolina, USA
Gil Paz	Wayne State University, USA
Axel Schmidt	George Washington University, USA
Adrian Signer	PSI / UZH, Switzerland
Steffen Strauch	University of South Carolina, USA
Oleksandr Tomalak	Los Alamos National Laboratory, V
Egle Tomasi-Gustafsson	CEA Saclay, France
Yannick Ulrich	University of Durham, UK
Xiaochao Zheng	University of Virginia, Charlottesville, USA

Scientific report

The precise and detailed treatment of radiative corrections are an area of ongoing studies in the scattering community. During the workshop, there was extensive discussion from both the theoretical and experimental communities on the appropriate treatment of these corrections covering processes at many orders of magnitude in energy. Of particular interest is the Two-Photon Exchange, the higher-order correction involving the exchange of two hard photons. The treatment of the model dependent intermediate states is an outstanding issue. Many different theoretical treatments are developed, often in the framework of effective theories. There are also several planned experiments that are expected to provide information about the size of the two photon exchange across a wide range of kinematics. Each experiment has its own unique radiative correction treatment. The techniques used in SIDIS, PVDIS, meson decays, muon as opposed to electron scattering, and neutrino scattering often follow a similar thread as seen in the workshop. Dedicated studies of corrections by the experimental groups is often necessary due to their strong dependence on the experimental setup, kinematics, and acceptance. This makes precise theoretical calculations for each setup time consuming. A coordination of the ongoing efforts will be particularly important when high-precision experiments will need to include also second-order corrections.

Results and Highlights

There is a clear necessity to coordinate future efforts. The community should compile a list of existing tools, i.e. numerical programs and Monte Carlo generators, and determine the best application for each tool. There is also strong support for a database of experimental results including cross sections and form factors, and specific details of the radiative corrections that were applied. This database can be hosted publicly and freely accessible to all interested parties. Future activities are needed to foster the exchange of ideas and results between different groups, theoreticians and experimentalists. More work is also needed to prepare for data analysis of the future EIC experiments. In light of this, the participants of the workshop agreed that a summary paper including all recent work from theory and experimentalists should be written and signed by all attendees of the meeting. Following this, there should be future workshops aimed at addressing the existing questions and unresolved issues. These future workshops should also aim to broaden the physics representation to better understand different methods of calculating and measuring radiative corrections.

2.3.11 Nuclear and Atomic Transitions as Laboratories for High Precision Tests of Quantum Gravity Inspired Models

Date	September 19-23, 2022

Organizers

Antonio Marciano	Fudan University, PRC, China
Stephon Alexander	Brown University, USA
Elisabetta Barberio	Melbourne University, Australia
Catalina Curceanu	LNF-INFN Frascati, Italy
Kristian Piscicchia	Centro Studi e Ricerche Enrico Fermi, Italy
Nicolas Yunes	University of Illinois at Urbana-Champaign, USA

Number of participants	40 (in person and remote)

Main topics

The main questions that have been faced concern: i) the development of effective models of quantum gravity able to probe either the quantum nature of gravity or its emergence; specifically, whether these models may leave an observable imprinting on atomic and nuclear transitions, such as transitions violating the Pauli Exclusion principle; ii) the development of the phenomenology and theory related to models of (gravitationally induced) collapse of the wave-functions of quantum systems. Experiments, in particular in underground laboratories, are performing high precision measurements of atomic and nuclear transitions, looking for effects that encode signature on quantum gravity models, including possible deviations from Lorentz invariance, either deformations or violations, which are induced by quantum gravity effects, observer independent scales, or any other scale in high-energy physics, including extra dimensions.

On the other hand, ultra-high sensitive measurements of electromagnetic radiation in the X-ray energy range enable the falsification of models proposed for the comprehension of the collapse of the wave functions of quantum systems. Phenomenological analyses have been recently developed, along the line of studies that over the last decades have established the field of the foundations of quantum mechanics.

The possible link explored between the models of quantum gravity and the foundations of quantum mechanics provide a new class of universality to test quantum gravity models.

The topics discussed by the speakers included:

- Deformation of the Lorentz symmetry and PEP violations
- Tests of QG and NCQG, including discrete symmetries, GW and astrophysics

- Theory and phenomenology of models for the collapse of the wave-function
- Ultra-high sensitive measurement of X-rays
- Gravitational decoherence and entanglement
- Fundamental principles of quantum theories and the gravity
- New phenomenological opportunities in refined comprehension of quantum processes
- Stochastic quantization and effects of chaos on matter dynamics in astrophysics
- New exclusion statistics

Speakers (on-line)*

A. Addazi	Sichuan University, PRC
S. Alexander*	Brown University, USA
G. Amelino-Camelia*	Università di Napoli Federico II, Italy
M. Arzano*	Università di Napoli Federico II, Italy
A. Bassi*	Università di Trieste, Italy
P. Belli	INFN-Roma2 & Università di Roma Tor Vergata, Italy
F. Briscese	Università di Padova, Italy
C. Curceanu	INFN-LNF, Italy
S. Donadi*	Università di Trieste, Italy
J. Ellis*	King's College, UK
F. Giacosa	Jan Kochanowski University, Poland EU
M. Lulli*	SUSTech, PRD
S. Manti	INFN-LNF, Italy
A. Marciano'	Fudan University, PRC
F. Napolitano	INFN-LNF, Italy
A. Porcelli	CREF, Italy
K. Piscicchia	CREF, Italy
A. Scordo	INFN-LNF, Italy
G. Torrieri	University of Campinas, Brazil
Y.S. Wu*	Utah University, USA

Scientific report

Recent developments of Quantum Gravity inspired models have produced a wealth of new predictions which are being tested in laboratories. In particular, many of these models foresee the non-commutativity of space-time coordinates, which, in turn, induces a deformation of the Lorentz symmetry and of the locality principle and naturally encodes the violation of the Pauli Exclusion Principle. These studies opened a new window of opportunities to test these models by performing high-precision measurements of atomic and nuclear transitions. Our workshop has hinged on the new profound implications of Quantum Gravity models on the nuclear and atomic physics observables and on the experimental constraints on effective quantum gravity models that arise from atomic and nuclear physics experiments. The workshop has been opened to world-leading experts and young scientists exploring several quantum gravity scenarios from complementary theoretical top-down and bottom-up approaches, to boost progress in this field. In particular, the workshop had the aim to put together, for the first time in a dedicated and focused meeting, experimentalists and theoreticians working in high precision studies of atomic and nuclear physics transitions and related fields, and theoreticians who work on developing Quantum Gravity Inspired Models (QGIM) that predict effects, special signatures of the models, which can be measured in atomic and nuclear transitions. From a QGIM theoretical perspective, the optimal phenomenological framework to be invoked while developing most part of these models is the arena of non-commutative space-time variables. These latter naturally realize the long-wavelength limit of quantum gravity models, and hence provide a class of universality for a large number of them. Specifically, space-time non-commutativity may induce deformation of the CPT and discrete symmetries, and of the spin-statistics relations, with eventual observable signatures in atomic and nuclear energy- level transitions that violate the Pauli exclusion principle, which can be tested in high precision measurements.

More in detail, the space-time non-commutativity induces a deformation of the Lorentz symmetry and of the locality principle and hence naturally encodes the violation of PEP. PEP violation is suppressed with (E/Enc)^n, where the power n depends on the specific model, E is the energy of the PEP violating transition, Enc is the scale of the space-time non-commutativity emergence. Since the power n is about unity for the most accredited formulations, high precision low background atomic tests of the PEP violation figure to be the most stringent probes of QG, capable to test Enc with a sensitivity which is orders of magnitude higher than the energy scale reached at the Large Hadron Collider.

The perspective to strongly constrain QG models can be attained in precision atomic and nuclear physics tests. Huge progresses were obtained by replying complementary techniques in high sensitivity underground experiments in Italy and Japan (such as VIP, DAMA/LIBRA,BOREXINO, CUORE, XENON, KAMIOKANDE). Future experiments, in Italy, Japan, China, Australia, such as JUNO, SABRE and HYPER-KAMIOKANDE, may strengthen the experimental limits and open broader scenarios, like exploring the predicted anisotropy in space and time of the PEP violations.

The main questions that have been faced are:

- whether effective models of quantum gravity that are meant to probe either the quantum nature of gravity or its emergence, may leave an observable imprinting on atomic and nuclear transitions, such as transitions violating the Pauli Exclusion principle.
- whether underground laboratories might have enough statistics and sensitivity to constrain and eventually rule out the aforementioned models of non-commutative space-time, which individuate class of universalises in quantum gravity.
- experiments, in particular in underground laboratories, are performing high precision measurements of these transitions, looking for effects that encode signature on quantum gravity models, including possible deviations from Lorentz in-

variance, either deformations or violations, which are induced by quantum gravity effects, observer independent scales, or any other scale in high-energy physics, including extra dimensions.

Results and Highlights

The workshop provided a very fruitful chance to confront different viewpoints and strategies concerning the field of quantum gravity phenomenology. The confrontation has involved detailed discussions on both on-going experimental procedures and forthcoming experimental strategies, intertwining among atomic and nuclear physics and particle and astroparticle physics. Discussions have pointed toward the necessity to further strengthen the interaction among experimentalists and theorists, in order to elaborate new common strategies, and thus provide theoretical models with the possibility to be tested.

2.3.12 Neutron Electric Dipole Moment: from Theory to Experiment

Date	August 1-5, 2022

Organizers

Andreas Athenodorou	The Cyprus Institute, Larnaca, Cyprus & Pisa University, Italy
Maria Paola Lombardo	INFN, Firenze, Italy
Andrea Shindler	Michigan State University, East Lansing, USA

Number of participants	32

Main topics

The workshop brought together researchers working on different aspects of the investigation of the Neutron Electric Dipole Moment such as experiments, phenomenological approaches, purely theoretical perspectives, as well as calculations in lattice QCD. The goal of this workshop was to better identify the practical, theoretical as well as computational challenges towards the extraction of the nEDM.

The main topics were:

- Lattice investigations of nEDM
- The physics of the theta term
- Phenomenology
- Chiral Perturbation Theory and nEDM
- nEDM and Cosmology
- Experiment

Speakers

Constantia Alexandrou	University of Cyprus, Nicosia, Cyprus
Walker-Loud Andre	Lawrence Berkeley National Laboratory, Berkeley, USA
Claudio Bonanno	INFN. Firenze, Italy
Laura Covi	Georg-August-Universität Göttingen, Germany
Massimo D'Elia	Pisa University, Pisa, Italy
Skyler Degenkolb	Heidelberg University, Germany
Bjorn Garbrecht	Technical University Munich, Germany
Takeyasu Ito	Los Alamos National Laboratory, Los Alamos, USA
Jangho Kim	Forschungszentrum Jülich, Jülich, Germany
Kent Leung	Montclair State University, Montclair, USA
Keh-Fei Liu	University of Kentucky, Lexington, USA
Ulf Meißner	Bonn University, Bonn, Germany

Emanuele Mereghetti	Los Alamos National Laboratory, Los Alamos, USA
Florian Piegsa	Bern University, Bern, Switzerland
Michael Ramsey-Musolf	University of Massachusetts, Amerst, USA
Gerrit Schierholz	DESY, Hamburg, Germany
Philipp Schmidt-Wellenburg	Paul Scherrer Institute, Villigen, Switzerland
Carlos Tamarit	Technische Universität München, Munich, Germany
Michael Teper	Oxford University, Oxford, UK
Boram Yoon	Los Alamos National Laboratory, Los Alamos, USA

Scientific report

The workshop aimed to bring together world-leading experts working on different aspects of the investigation of the Neutron Electric Dipole Moment (nEDM) including experimental searches, phenomenological approaches, purely theoretical perspectives, as well as first principles calculations as lattice QCD. The purpose of this workshop was to better understand the practical, theoretical as well as computational challenges towards the extraction of the nEDM and initiate a coordinated effort in addressing this quest. Furthermore, participants had the chance to discuss funding opportunities to secure funds for networking as well as for hiring doctoral students and early career researchers to work on related topics.

Results and Highlights

The workshop attracted the attention of approximately 40 participants representing the broad field of researchers working on nEDM including Lattice QCD, phenomenological approaches, purely theoretical perspectives, as well as experimental searches. Twenty speakers presented their work covering the full spectrum of investigations. Among them two female researchers presented their recent findings on the topic. The feedback received from the speakers as well as from the participants were rather positive and we foresee continuing organizing similar events. A number of early stage scientists were given the opportunity to present their recent work. The workshop helps us to understand where we stand regarding the experimental investigations of nEDM, to understand the practical difficulties fased by experimentalists. It also enabled us to identify fundamental questions regarding the theta-vacuum that need to be addressed accordingly. Finally, we provided a stimulating environment, which initiated interesting discussions between the speakers and the participants leading to sharing new suggestions and ideas.

2.3.13 LFC22: Strong Interactions from QCD to New Strong Dynamics at LHC and Future Colliders

Date	August 29 – September 02, 2022

Organizers

Gennaro Corcella	INFN, LNF, Italy
Aldo Deandrea	Lyon 1 University, France
Stefania De Curtis	INFN Florence, Italy
Stefano Moretti	Southampton U. & NExT Institute, United Kingdom
Giulia Pancheri	INFN, LNF, Italy
Roberto Tenchini	INFN Pisa, Italy
Marcel Vos	IFIC & University of Valencia, Spain

Number of participants	42

Main topics

The general theme of the workshop was triggered by the European Strategy Particle Physics proposals and the foreseen progresses of the Japanese project on the International Linear Collider. The workshop was devoted to the implications of the current Large Hadron Collider (LHC) upgrades and the proposals for future accelerators, taking particular care of the role played by strong interactions in the physics case of such colliders. We reviewed perturbative QCD calculations and whether they are able to describe the current LHC data and meet the accuracy necessary at future colliders. Furthermore, the state of the art of non-perturbative QCD was discussed, investigating both hadronization models in Monte Carlo generators and computations of power corrections. A special session was devoted to top-quark phenomenology: on the one hand, future colliders will be capable of measuring the top properties, such as its mass, with an unprecedented accuracy, on the other hand, processes with the production of top quarks are background to most searches for physics beyond the Standard Model. Scenarios that are capable of solving the current open problems of the Standard Model, such as composite-Higgs models and other strong-dynamics solutions in the electroweak sector, were discussed in depth. The connections between measurements at low and high-energy accelerators, as well as comparisons of astrophysics and collider observations were highlighted. New as well as standard tools of the field, such as machine learning, Effective Field Theories, simplified models, recasting and global interpretation of LHC data were discussed in depth during the workshop.

The main topics were:

- Strong interaction at colliders (LHC and future colliders)
- Top quark physics in the standard model and beyond
- Perturbative and non-perturbative QCD techniques
- Monte Carlo generators and tools for collider physics
- Composite-Higgs models
- Effective field theories and simplified models
- Implications for Dark Matter and Cosmology

Speakers

Martin Aleksa	CERN, Switzerland
Rafael Aoude	UCLouvain, Belgium
Nedaa-Alexandra Asbah	Harvard, USA
Lorenzo Bianchini	University of Pisa, Italy
Marco Bonvini	INFN Roma 1, Italy
Giacomo Cacciapaglia	IP2I Lyon, France
Alberto Calivà	University of Salerno and INFN, Italy
Luc Darmé	IN2P3, Lyon, France
Mirco Dorigo	INFN Trieste, Italy
Gabriele Ferretti	Chalmers University, Sweden
Raghuveer Garani	INFN, Florence, Italy
Gabriella Gaudio	INFN Pavia, Italy
Andrea Ghira	INFN Genova, Italy
Francesco Giuli	CERN, Switzerland
Maxime Gouzevitch	IP2I Lyon, France
Tobias Hurth	JGU Mainz, Germany
Suchita Kulkarni	Graz Univ., Austria
Laura Lopez Honorez	ULB, Belgium
Giulia Manco	Pavia Univ., Italy
Simone Marzani	Università di Genova, Italy
Daniela Mascione	University of Trento and Fondazione Bruno Kessler, Italy
Victor Miralles	INFN Roma1, Italy
Nicola Neri	INFN and University of Milan, Italy
Nadia Pastrone	INFN-Torino, Italy
Simon Plätzer	University of Graz, Austria
Massimiliano Procura	University of Vienna, Austria
Roman Pöschl	IJCLab, France
Lorenzo Ricc	EPFL, Switzerland
Swathi Sasikumar	Max Planck Institute for physics, Germany
Chiara Signorile-Signorile	Karlsruhe Institute of Technology, Germany
Giovanni Stagnitto	University of Zurich, Switzerland

Thomas Strebler CPPM, Aix-Marseille Université, France
Natascia Vignaroli University of Naples, Italy
Martin Vollmann University of Tübingen, Germany

Scientific report

The workshop addressed the physics goals of future colliders, from the perspective of strong interactions, in and beyond the Standard Model. Higher-order QCD calculations (fixed-order, resummed or Monte Carlo parton showers) were carefully discussed as they provide precise predictions for processes mediated by the strong interactions in the Standard Model and backgrounds for the new physics searches. An accurate treatment of non-perturbative corrections, described in terms of phenomenological models or possibly computable power corrections, is also fundamental to meet the collider precision goals. The tools of machine learning for particle phenomenology, in particular for parton distribution and jet physics, was discussed. A session on top-quark phenomenology allowed to discuss the role played by strongly-interacting physics in top production and decay. Recent progress in QCD calculations as well as parton shower implementation were explored, taking care of the uncertainties in the top properties induced by non-perturbative effects, such as colour reconnection in top production and decay phases, hadronization and underlying event. Strong physics within the approach of Effective Field Theories was also discussed. Concerning the physics beyond the Standard Model and the searches which are foreseen at LHC and future accelerators, it is well known that strong interactions are a key player in almost any model, even besides the obvious backgrounds. An interesting example is given by composite models, describing the Higgs boson as a pseudo-Nambu-Goldstone boson, made of new fundamental fermions, which can be investigated at LHC and at future colliders, providing bounds and possible evidence of this scenario. Exploration of strongly-interacting new physics signals within simplified models and effective theories was lively discussed. In particular, such frameworks can be used for the purpose of recasting and reinterpreting the LHC analyses and possibly setting bounds on the reaches of future accelerators.

Results and Highlights

The workshop was a very useful opportunity to discuss the subjects of the physics at LHC and future colliders, from the perspective of strong interactions, in and beyond the Standard Model. It was also important to establish links between different topics and suggest new avenues at the cross-road of strong interactions and beyond the standard model physics as well as implications for dark matter and cosmology. The workshop also allowed discussing the new scenarios in high-energy physics from the LHC upgrades and the recommendations for future colliders from the European Strategy Particle Physics and the Japanese ILC project.

2.3.14 From Hadrons to Therapy: Fundamental Physics Driving New Medical Advances

Date	September 5-9, 2022

Organizers

Valeria Conte	LNF-INFN, Italy
Pablo De Vera Gomis	Universidad de Murcia, Spain
Marco Durante	GSI, Germany
Rafael Garcia-Molina	Departamento de Física, Universidad de Murcia, Spain
Cornelia Hoehr	TRIUMF, Canada
Jorge Kohanoff	Universidad Politécnica de Madrid, Spain
Katia Parodi	Ludwig-Maximilians-Universität München, Germany
Marco Schwarz	University of Washington Seattle, USA

Number of participants	54 (28 in person attendance)

Main topics

The development of modern radiation-based medical imaging and treatment tools is closely interlinked with the progress in Nuclear Physics and related areas. Improving cutting-edge cancer therapies (such as radiotherapy using ion beams, targeted radionuclide therapy, or their enhancement by means of nanotechnology) and imaging techniques (e.g. positron emitting tomography) requires intensive research in Nuclear Physics along with Atomic-Molecular and Condensed-Matter Physics.

Research in these fields is necessary to get a better understanding of the plethora of fundamental processes underlying their medical applications, including nuclear reactions of energetic ions in the body, radioactive decay of their fragments or of supplied radioisotopes, or the many-body processes involved in the nanoscale biomolecular radiation damage mechanisms in the condensed-phase.

This workshop aims to gather theoretical, experimental and clinical experts from these diverse fields in order to foster multidisciplinary understanding and collaboration, for the advancement of radiation-based medical techniques and their fundamental physical understanding.

The main topics were:

- Research in hadrontherapy and associated technologies, including: measurement and fundamental understanding of nuclear reactions of ion beams in tissue and their impact on treatment and monitoring; application of radioactive ion beams for combined treatment and monitoring; challenges in monitoring and imaging techniques (PET and others) and for verification of ion ranges in tissue.

- Research in targeted radionuclide therapy and associated technologies, including: production of novel medical radioisotopes; cancer cell targeting and radioisotope delivery.
- Micro- and nanodosimetry, including: experimental devices for micro and nanoscopic distributions of energy deposition; assessment of complex damage patterns in subcellular and DNA scales; links of micro- and nanodosimetry to biological effects of radiation; challenges in monitoring techniques for verification of radiation quality.
- Modelling of radiation propagation, effects and radiobiology, including: development of radiobiological models for radiation effects in cells; Monte Carlo simulation of radiation transport in condensed matter on the macro-, micro- and nanometre scales; radiation damage in biological (condensed matter as well as molecular) systems; multiscale modelling comprising ab initio, Monte Carlo and/or radiobiological approaches.
- Radiation sensitisers and enhancers, including: the role of nanoparticles as radiosensitisers in the enhancement of the relative biological effectiveness and in medical imaging.

Speakers

Mohammed A. A. Abujami	Università degli Studi di Torino, INFN, Italy
Silva Bortolussi	University of Pavia and INFN, Unit of Pavia, Italy
Daria Boscolo	GSI, Darmstadt, Germany
Giorgio Cartechini	University of Trento, Italy
Marco Cianchetti	Trento Proton therapy Centre, Italy
Fabrizio Cleri	University of Lille, France
Valeria Conte	INFN - Laboratori Nazionali di Legnaro, Legnaro, Italy
Pablo de Vera Gomis	Universidad de Murcia, Murcia, Spain
George Dedes	Department of Medical Physics, LMU Munich, Germany
Michael Dingfelder	East Carolina University, USA
Hélène Elleaume	INSERM, Grenoble, France
Elena Fogazzi	University of Trento, Italy
Francesco Fracchiolla	Trento Proton Therapy Center, Italy
Jan Franz	Gdansk University of Technology, Poland
Gustavo Garcia Gómez-Tejedor	CSIC, Madrid, Spain
Cornelia Hoehr	TRIUMF and University of Victoria, Canada
Jorge Kohanoff	Universidad Politécnica de Madrid, Madrid, Spain
Julie Lascaud	LMU Munich, Germany
Daniel Muñoz-Santiburcio	Universidad Politécnica de Madrid, Spain
Gaia Pupillo	INFN-LNL, Legnaro, Italy
Jean-Luc Ravanat	CEA, Grenoble, France

Anatoly Rosenfeld	University Of Wollongong, Australia
Antoni Rucinski	Polish Academy of Sciences, Krakow, Poland
Leon Sanche	Université de Sherbrooke, Canada
Emanuele Scifoni	TIFPA-INFN, Trento, Italy
Joao Seco	DKFZ German Cancer Research Center, Heidelberg, Germany
Jefferson Shinpaugh	East Carolina University, USA
Nidhi Sinha	Korea Institute of Fusion Energy, Korea
Simone Taioli	ECT*, Trento, Italy
Francesca Triggiani	Università degli Studi di Camerino, INFN Perugia, Italy
Hua Yang	TRIUMF and University of Victoria, Canada
Yi Zheng	Fuzhou University, China

Scientific report

Medicine relies on advanced techniques for imaging and treatment, based on the fundamental development of Nuclear Physics and related areas. Representative examples of these include, among others: (i) radiotherapy for cancer treatment using ion beams (hadrontherapy), featuring unprecedented dose-delivery precision and cancer cell-killing ability (minimising damage to healthy surrounding tissues); (ii) targeted radionuclide therapy (TRT), in which antibodies or other cancer-cell targeting molecules are linked to alpha-, beta- or Auger-emitting radionuclides, whose emitted radiations of different penetration range are suitable for treating either extended tumours or small cell-scale metastases; (iii) positron emission tomography (PET), widely used for imaging or dose-delivery monitoring, which can also be combined with therapy (theragnosis).

Despite such techniques are well-established, there is intensive research aiming for their improvement, including directions such as the use of radioactive ion beams for theragnosis in hadrontherapy, the development of “modern alchemy” for the clinical-scale particle accelerator-based production of more suitable TRT radionuclides, or the exploitation of nanotechnology to improve the effectiveness of radiotherapy (e.g. using radioenhancing nanoparticles).

Such developments require multidisciplinary efforts, not only by clinical researchers but also by experimental and theoretical physicists. For example, energetic ion beams used in hadrontherapy can undergo different nuclear reactions, whose fragments can affect the energy delivery in the body or can be used for dose monitoring by PET (especially for radioactive beams). The combination of nanoparticles with radiotherapy requires the crossover with Condensed-Matter Physics in order to understand how the excitation and decay of radiation-induced excitations in solids contribute to the production of low-energy electrons, which play a central role in the damage of biomolecules such as DNA.

For these purposes, new experimental and theoretical tools are needed, able to better measure and model the propagation and effects of radiation both on the macroscale (relevant for treatment planning) and on the nanoscale (essential to understand the damage of sensitive biomolecules such as DNA, underlying the biological consequences of radiation). The aim of this workshop (the first at ECT* devoted to medical applications of Nuclear Physics) has been to gather researchers from different disciplines (theoretical, experimental and clinical) working in complementary fields, so to make clinicians acquainted with the latest theoretical and experimental developments, while basic researchers can tune their work to better satisfy the actual medical needs.

Results and Highlights

The workshop provided a wide and general overview of many aspects of relevance on the applications of radiation in medicine and the physical basis for their use. On the first day already several talks showed connections between fundamental physics and applications, with theoretical calculations of charged particle cross sections, their implementation in Monte Carlo radiation transport simulation codes, and the combination of the latter with cell culture experiments in order to shed light on the mechanisms behind the biological effects of different types of radiations (electron, ion beams).

New experimental physics developments were addressed regarding the practical application of proton beams for hadrontherapy. One of the current research directions for further improvement of protontherapy is the more accurate determination of proton ranges in tissue, together with their online verification, which can have an impact on the dose margins used for preventing irradiation of healthy tissues as a consequence of range uncertainties. Current developments on the use of ion acoustics and radioactive ion beams were explained during Monday, showing promising results on the monitoring of proton beam doses and range verification.

Experimental and modelling insights were given on Tuesday regarding the promising FLASH technique in hadrontherapy, a yet unexplained effect related to the irradiation with ultra-high dose rates, which reduces radiation side effects on healthy tissues, while not in cancer tissue. Experimental evidences on potential mechanisms were given, while further theoretical insights were provided on the basis of track-structure Monte Carlo simulations including the chemical stage of irradiation and other modelling approaches.

On Tuesday, interesting developments were also explained on different applications of nuclear physics in medicine. Several talks were devoted to the production of innovative radioisotopes for targeted radionuclide therapy, while very interesting experimental insights were given on the new therapy modality of boron neutron capture therapy, involving the neutron capture by boron atoms introduced in tumour tissue, which induces the emission of short-ranged lithium and alpha particles within cancer cells. Technical aspects of this technique, related to the production of clinical neutron beams, beam shaping, boron targeting, etc. were discussed in detail, together with the complex and challenging dosimetry for this technique, which involves mixed radiation fields (neutrons, alpha particles, lithium ions, photons, etc.), unavoidably requiring modelling by means of Monte Carlo simulations.

The participants could explore down the scales of the problem on Wednesday, when most of the program focused on microdosimetry and nanodosimetry in hadrontherapy. State-of-the-art devices for the measurement of ionisation yields at the microscale and for counting ionisation clusters at the nanoscale were discussed, together with their connection to the evaluation and monitoring of the relative biological effectiveness of ion beams in cells. Important discussions were motivated by these talks as, surprisingly (as noted by some of the participants), the assessment of the direct physical effects of radiation at the micro- and nanoscale seemed to give a rather accurate prediction of biological effects in cells, despite not directly considering chemical or biological effects. The program finished on Wednesday with interesting experimental talks on the direct measurement of DNA damage in relatively simple model systems, such as plasmid DNA, which reveal the crucial role of low-energy electrons in biomolecular damage (single and double strand breaks, etc.), as well as the fundamental mechanisms responsible for it, e.g. dissociative electron attachment or other types of excitations. The talks were followed by a visit to the Trento protontherapy centre, where a medical doctor responsible of the protontherapy unit and a TIFPA-INFN researcher, expert on biophysics, guided the workshop participants through the treatment rooms and experimental facilities.

The importance of nanoscale phenomena on the induction of complex biomolecular damage during hadrontherapy and other radiotherapies was highlighted during Thursday. During the morning sessions, several theoretical approaches were explored, useful to describe the electronic excitation of DNA systems under charged particle irradiation by ab initio and modelling approaches, together with the quantum-chemical simulation of very-low energy electron attachment to DNA components and the subsequent bond breaking. Insights from large-scale classical molecular dynamics simulations were also given, showing how physics approaches can shed light on the complex biological mechanisms of DNA repair after radiation damage. During the afternoon sessions, experimental physical, chemical, and biological insights were given on the use of heavy-metal radiosensitisers. Basic physical information (both experimental and theoretical) was also provided, on the low energy electron emission from metal surfaces and nanostructures, fundamental for the understanding of radiosensitisation mechanisms.

The Friday session was devoted again to more practical issues: a couple of talks were devoted to the new experimental procedure for imaging and monitoring of protontherapy by means of proton tomography, while two experts from the Trento Protontherapy Centre informed the participants on the current status and challenges of protontherapy in Italy, and the recent developments that the Trento treatment centre is introducing regarding the reduction of dosimetry uncertainties, especially by reducing the impact of patients' organ motion during irradiation.

Overall, many participants explicitly manifested their satisfaction with the program, in which each researcher was, for a few days, taken out from their niche of (theoretical, experimental or medical) research. Even though the number of topics was broad and it was not so easy for some participants to fully follow all the talks, there were many compliments on the possibility offered to see how different fields of research complement each other, and how particular results from some participants could be useful for others. The relatively long talks given by the most experienced researchers (30 minutes talks followed by 10 minutes discussions) allowed addressing each topic in sufficient details, so as to be better understood by people less familiarised, and fruitful discussions were typically engaged after each talk. The presence of clinical experts was highly valued by the more fundamental physics researchers, and it was suggested that, in a potential future edition of the workshop (see next paragraph), an effort should be done to bring a larger number of them to talk.

It was also recognised by participants that such a meeting was very useful in order to consolidate a research community with common interests, but which is often scattered due to the multidisciplinary character of the research topic. During the final discussion, the question on how to keep such a community cohesive arose, being suggested the possibility that the workshop could be further developed as a series within the ECT* program, possibility which will be considered by the organising committee.

2.3.15 Reveiling Emergent Mass through Studies of Hadron Spectra and Structure (online)

Date	September 12-16, 2022

Organizers

Daniele Binosi	ECT*, Italy
Tanja Horn	Catholic University of America, USA
Huey-Wen Lin	Michigan State University, USA
Craig Roberts	Nanjing University, China

Number of participants	45

Main topics

Exposing the origin of the proton's mass is one of the most profound challenges in physics. The goal's simplicity hides its breadth. Solving this puzzle will explain, inter alia: why the proton is stable; why the mass of the proton is roughly 2000 times that of the electron; and why the strongly interacting pion possesses a lepton-like mass. The last decade has seen considerable improvements in our theoretical understanding of these issues, owing to major advances in continuum and lattice methods.

Moreover, new generation experiments, in operation or planning, promise to expose the spectrum and structure of hadrons with unprecedented detail. We are on the verge of a new era in strong interaction physics.

This workshop gathered a group of experts to discuss key recent developments, identify new goals, and plan the next steps forward in strong QCD.

Speakers

Daniele Binosi	ECT*, Italy
Lei Chang	University of Macau, China
Sara Collins	University of Regensburg, Germany
Aurore Courtoy	Instituto de Física, UNAM, México
Annalisa D'Angelo	Univ. Rome Tor Vergata and INFN, Italy
Gernot Eichmann	University of Graz, Austria
Rolf Ent	Jefferson Lab, USA
Ralf Gothe	University of South Carolina, USA
Tanja Horn	Catholic University of America, Washington, USA
Chueng-Ryong Ji	North Carolina State University, USA
Shunzo Kumano	Japan Women's University / KEK, Japan
Huey-Wen Lin	Michigan State University, USA

Cédric Mezrag	Irfu, CEA, Université Paris-Saclay, France
Hervé Moutarde	Irfu, CEA, France
Joannis Papavassiliou	University of Valencia, Spain
Peter Petreczky	BNL, USA
Jianwei Qiu	Jefferson Lab, USA
Catarina Quintans	LIP, Portugal
Craig Roberts	Nanjing University, China
José Rodríguez-Quintero	University of Huelva, Spain
Jorge Segovia	Universidad Pablo de Olavide, de Sevilla, Spain
Adam Szczepanak	Indiana University, USA
David Wilson	University of Cambridge, UK
Bowen Xiao	CUHK-Shenzhen, China
Zhen-Ni Xu	SEU, China

Scientific report

Identifying and understanding the mechanisms underlying the emergence of nuclear-scale mass within the Standard Model requires a synergistic effort, joining experiment and a wide array of theory. Our programme will therefore focus on identifying key concepts and questions that need to be exploited and addressed by this effort.

1. Contemporary and planned facilities will shed light on two basic mysteries in the Standard Model: confinement and dynamical chiral symmetry breaking. Accumulating evidence suggests that these two phenomena are intimately connected; rely on the appearance of momentum-dependent masses for gluons and quarks; and arise as corollaries of the emergence of mass. Moreover, since they are implicit in all hadronic observables, well-planned experiments can verify both their appearance and expression in the Standard Model.
2. The past decade has revealed that one can compute a unique, process-independent effective charge in QCD, which appears in the kernel of every dynamical equation supported by QCD. The result predicted by combining continuum- and lattice-methods shows a remarkable correspondence with a process-dependent charge inferred from deep-inelastic scattering. Exploration of the properties and consequences of this novel effective charge is critical to understanding QCD and illuminating its potential to serve in extending the Standard Model.
3. Continuum methods must move beyond the simplest truncations of QCD’s field equations. Nonperturbative, symmetry-preserving schemes exist; and their implementation, exploitation and continued improvement are critical to exposing the full effects of emergent phenomena in experiment. This is an essential prerequisite for the study of, inter alia, glueball and hybrid states, the search for which is a worldwide priority.
4. The past decade has also been distinguished by rapid progress with lattice-QCD algorithms that enable predictions to be delivered for the Q2 dependence of form factors and the pointwise behaviour of parton distribution amplitudes and functions. Regarding studies aimed at exposing the structure of Nature’s

most fundamental Nambu-Goldstone bosons, pions and kaons, this is valuable progress. Amongst many other things, it promises: a resolution of the thirty-year controversy over the large-x behaviour of the pion's valence-quark distribution function; tight constraints on π and K sea and glue distributions, about which practically nothing is now known, because the first continuum and lattice results have recently become available for the pion's glue distribution; and validated ab initio predictions for meson form factors because continuum and lattice results are newly available for both the pion and kaon form factors on a large, overlapping Q2-domain.

Results and Highlights

This ECT* workshop served as an integral part of a broad international effort to raise awareness and deliver understanding of the character of tangible mass. Indeed, there are two types of such mass in nature. One is generated by couplings to the Higgs boson in the Standard Model Lagrangian. Yet, significant as this source of mass is, the other – emergent mass – is more important in many ways. Modern theory suggests that emergent mass is, inter alia, the origin of nuclear scale masses for the proton, neutron, and almost all other hadrons; the explanation for the appearance and properties of the Standard Model's Nambu-Goldstone bosons, e.g., the pion and kaon; and the key to proton stability, without which our Universe could not exist. Science is therefore striving to change emergent mass from a phenomenon into a collection of mechanisms.

Owing once again to the Covid-19 pandemic, this meeting became an online workshop. This changed its character, reducing the length and number of presentations and requiring that all interactions take place via the ZOOM platform. Nevertheless, each of the five days saw 5 presentations followed by an active discussion session, coordinated by an experienced moderator.

Modern and planned facilities will deliver spectra and probe hadronic interiors with unprecedented precision. Consequently, the programme included leading theoretical physicists proposing explanations of the observation through sounding nonperturbative results. Particular emphasis was placed on the progress in developing of a consistent framework for describing the infrared dynamics of QCD and its experimental consequences. In this respect, a thorough presentation and discussion of upcoming experiments and their potential reach has been carried out.

There was also a thorough discussion of the potential differences in experimental signatures in the spectra and structure of mesons and baryons (e.g., parton distributions, elastic and/or transition form factors) due to alternative field theoretic explanations for the interaction of QCD's emergent phenomena. This discussion lead to several advancements in the search for effective methods of differentiating between competing and complementing approaches.

Furthermore, despite limitations posed by the online workshop structure, relationships between experimentalists and theorists and practitioners of all methodologies that allow access to strong QCD were strengthened. The rate at which science can deepen its understanding of the fundamental mechanics behind dynamical mass creation and uncover the observable signatures is accelerating because to these improved personal connections amongst practitioners around the world.

2.3.16 *Opportunities with Jlab Energy and Luminosity Upgrade*

Date	September 26-30, 2022

Organizers

Alessandra Bacchetta	University of Pavia, Italy
Harut Avakian	Jlab, USA
John Arrington	LBNL, USA
Kyungseon Joo	PI, UCONN
Lamiaa El Fassi	MSU
Marco Battaglieri	INFN Genova, Italy
Moscow Amaryan	OLD Dominion University, USA
Or Hen	MIT, USA
Ralf Gothe	University of South Carolina, USA
Xiangdong Ji	University of Maryland, USA
Xiaochao Zheng	UVA, USA

Number of participants	64

Main topics

- The near-threshold charmonium photoproduction, exotic states XYZ
- Anomalous contribution to the mass of the proton, gravitational form factors, and the mass radius of the proton
- Structure of excited nucleon states at the distances corresponding to the transition between quark-gluon confinement and the pQCD regime
- Understanding the QCD dynamics in studies of kinematical and evolution properties of the 3D partonic distributions, quark gluon and spin-orbit correlations

Speakers

Will Brooks	Universidad Técnica Federico Santa María, Chile
Mariangela Bond	INFN - Sezione di Catania, Italy
Martha Constantinou	Temple University, USA
Marco Contalbrigo	Ferrara University, Italy
Pasquale Di Nezza	INFN e Laboratori Nazionali di Frascati, Italy
Sean Dobbs	Florida State University, USA
Raphaël Dupré	IJCLab - CNRS - Univ. Paris-Saclay, France
Ahmed El Alaoui	Universidad Técnica Federico Santa María, Chile

Liping Gan	University of North Carolina Wilmington, USA
Garth Huber	University of Regina, Canada
Wenliang Li	CFNS, Stony Brook University, USA
Keigo Mizutani	Jefferson Lab, USA
Andrea Moretti	University of Trieste and INFN, Italy
Aram Kotzinian	INFN/Torino, Italy & AANL YerPhI, Yerevan, Armenia
Jen-Chieh Peng	University of Illinois, USA
Alessandro Pilloni	Università di Messina, Italy
Patrizia Rossi	Jefferson Lab/INFN-LNF, Italy
Craig Roberts	Nanjing University, China
Misak Sargsian	Florida International University, USA
Nobuo Sato	Jefferson Lab, USA
Andrea Signori	INFN/Torino and Torino University, Italy
Paweł Sznajder	National Centre for Nuclear Research, Poland
Anselm Vossen	Duke University, USA
Yong Zhao	ANL, USA

Scientific report

The Jlab upgrade will provide a globally unique possibility to access the detailed dynamics of strongly interacting matter, allowing studies of transverse partonic structure of the nucleons and nuclei, the hadronization process, correlations of partons and hadrons in the nuclear medium, and the spectroscopy of exotic states amongst others with unprecedented precision.

The main items addressed in the workshop can be summarized as follows:

The increase of energy and luminosity at JLab beyond the 12-GeV era will allow us to explore the structure of excited nucleon states at the distances corresponding to the transition between quark-gluon confinement and the pQCD regime of the strong interaction, where the dominant part of hadron mass is generated and quark-gluon confinement emerges. Studies of the Q^2-evolution of the $N \rightarrow N^\ast$ electroexcitation amplitudes for excited nucleon states of different structure in combination with studies of the pseudo-scalar meson and nucleon ground state structure will address key open problems of the Standard Model on the emergence of hadron mass and quark gluon confinement.

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:

- Lattice studies of the 3D PDFs including TMDs and GPDs
- Exclusive processes and access to transverse space distributions of partons
- Possibilities with muon beams at JLab
- Medium modifications of nuclear structure and MC simulations

Results and Highlights

The workshop played an important role in contemplating the exchange of ideas between the various physics communities, involving collaborators worldwide, and the coordination of effortson supporting ongoing and future studies of the nuclear structure. The workshop was focused on the development of a strong future physics program for JLab at 20+~GeV. The contributions from different groups will be included in the final document on the physics program of the JLab upgrade.

2.3.17 *Reduced Density-Matrix Functional Theory: improving its Foundation and Extending its Scope*

Date	October 03-14, 2022

Organizers

Carlos L. Benavides-Riveros	Max-Planck Institute for Complex Systems, Germany
Eberhard K. U. Gross	The Hebrew University of Jerusalem
Christian Schilling	LMU Munich, Germany

Number of participants	13

Aim of the workshop

The aim of this international workshop was to discuss and explore new aspects and challenges in Reduced Density Matrix Functional Theory (RDMFT). For this, 13 experts in RDMFT were present at the ECT* Center in Trento (Italy) for an intensive and informal meeting during 3-14 October. This in-person workshop was complemented by five mini-symposia (hybrid format), open to a broad international audience: 85 scientists (ranging from Ph.D. students and postdocs to professors and leading experts) were present during the discussions. Each symposium consisted of 6 talks of 22 min + 8 min for questions and further discussions.

Speakers

Carlos L. Benavides-Riveros	Max-Planck Institute for Complex Systems, Germany
Sofia Bousiadi	University of Athens, Greece
Federico Castillo	Pontificia Universidad Catolica de Chile, Chile
Jerzy Cioslowski	University of Szczecin, Poland
Thierry Deutsch	CEA, France
Lexin Ding	LMU Munich, Germany
Emmanuel Fromager	University of Strasbourg, France
Eberhard Gross	The Hebrew University of Jerusalem, Israel
Paul Johnson	Université Laval, Canada
Derk Kooi	Vrije Universiteit Amsterdam, Netherlands
Julia Liebert	LMU Munich, Germany
Tomasz Maciazek	University of Bristol, UK
David Mazziotti	University of Chicago, USA
Giuseppina Orlandini	University of Trento, Italy
Mario Piris	DIPC & EHU/UPV & IKERBASQUE, Spain
Neil Qiang Su	Nankai University, China

Alessio Recati	University of Trento, Italy
Mauricio Rodriguez Mayorca	Vrije Universiteit Amsterdam, Netherlands
Pina Romaniello	Université de Toulouse, France
Christian Schilling	LMU Munich, Germany
Sarina Sutter	VU Amsterdam, Netherlands
Jian Wang	Zhejiang university, China

Scientific report

It is a fact that the energies and other electronic properties of atomic and molecular ground states can be computed directly from the two-electron reduced density matrix. Yet, since each subfield of the quantum sciences typically restricts to systems all characterized by a fixed pair interaction, the ground-state problem should de facto involve the one-particle reduced density matrix (1RDM), only. The corresponding exact theory is known as Reduced Density Matrix Functional Theory (RDMFT) which is based on the existence of an exact energy functional of the 1RDM [1]. Compared to the widely used Density Functional Theory (DFT), RDMFT has some significant conceptual advantages: the kinetic energy is described exactly and strong electronic correlations can be described efficiently. Benchmark calculations have revealed indeed that the common functionals in RDMFT can yield correlation energies that are a precision comparable to Møller- Plesset second-order perturbation theory. RDMFT has also succeeded in predicting more accurate gaps of conventional semiconductors than semi-local DFT. Recently, we have witnessed remarkable progress on RDMFT along several lines:

- The first RDMFT software code has been made public [2].
- RDMFT has been extended to excited states by generalizing the work on ensemble DFT [3].
- Novel ideas were proposed to improve the numerical minimization of functionals [4].
- RDMFT has been extended to bosonic quantum systems, including ultra-cold gases [5].
- The cusp condition due to the Coulomb interaction has finally been translated into a property of the 1RDM [6].
- Modern machine learning techniques were put forward for improving functional approximations [7].

Most of these novel ideas are rather challenging, fundamental, and of potentially high impact. A crucial challenge is to combine them to improve the foundation of RDMFT, overcome its recent limitations, and extend its scope.

During the workshop, it was clear that the community requires better coordination of efforts such that the results in RDMFT can be quickly acknowledged and improved by other groups. The need to have better codes that are accessible to the community at large was also highlighted. Machine learning is an opportunity for that purpose. It is important to differentiate the term RDMFT from other acronyms used in different fields (for instance, DMFT sometimes is also used for density matrix functional theory which is somehow confusing). The participants agreed that a more convenient acronym is 1RDMFT. It is also quite important to organize a similar workshop in the future. Between the workshop organized in Lausanne in 2017 and this one in Trento in 2022, 5 years elapsed, which may be too much time to structure a better development of the field. One possibility is to establish a workshop on a regular basis every two years with the support of CECAM and other funding agencies. Finally, the communication of new ideas could be done outside of papers and conferences. A step in that direction is the site on youtube where the talks of our workshop can be found (shorturl.at/FLO79).

As organizers, we wanted that our workshop reached people who could not be physically in Trento. For that reason, we organized a sequence of 5 hybrid symposia. The talks can be found on youtube. Furthermore, the slides of the presentations and other materials can be found on the webpage of the workshop: https://indico.ectstar.eu/event/153/. As a result, any person in the world can follow the main outcomes of our work in Trento. Yet, the main benefit of developing RDMFT is the idea of capturing strong correlations in an effective but exact manner. This will result in the exploration of new strong-correlated quantum regimes that can lead to the understanding of new chemical reactions or find new stable chemical compounds that cannot be found using DFT. A more ambitious goal is the fact that RDMFT for superconductors can potentially lead to a novel route for understanding non-conventional superconductivity, an outstanding yet unsolved problem in electronic-structure theory.

2.3.18 EXOTICO: EXOTIc Atoms Meet Nuclear Collisions for a New Frontier Precision Era in Low-Energy Strangeness Nuclear Physics

Date	October 17-21, 2022

Organizers

Otón Vazquez-Doce	LNF-INFN, Italy
Catalina Curceanu	LNF-INFN, Italy
Angels Ramos	Universitat de Barcelona, Spain
Johann Zmeskal	SMI-Vienna, Austria
Jiří Mareš	Czech Academy of Sciences, Czechia

Number of participants	49

Main topics

The EXOTICO workshop addressed the most important open issues in the field of the strong interactions of hadrons with strangeness content. This field has recently received new experimental input from facilities ranging from low-energy to multi-TeV environments and heavy ion collisions. Such data is enabling updated calculations and precise tests of the theoretical approaches describing the hadronic interactions.

The present status and the open topical questions were discussed for the first time in a unique framework. The main topics were:

- Properties of kaonic nuclear matter
- The nature of the Lambda (1405) resonance
- Compatibility of kaonic atoms measurements with femtoscopy and theoretical approaches
- The description of the hadronic interactions starting from first principles
- The possible presence of strangeness in the core of the Neutron Stars

Speakers

Albert Feijoo	IFIC Valencia, Spain
Hiroyuki Noumi	RCNP Osaka University, Japan
Shinji Okada	Chubu University, Japan
Jaroslava Obertova	CAS, Czech Republic
Simone Manti	INFN Frascati, Italy
Florin Sirghi	INFN Frascati, Italy
Alejandro Kievsky	INFN Pisa, Italy
Zhan-Wei Liu	Lanzhou University, China
Tetsuo Hyodo	Tokyo Metropolitan University, Japan

Magdalena Skurzok	Jagiellonian University, Poland
Yuki Kamiya	HISKP, Bonn University, Germany
Ramona Lea	INFN Pavia, Italy
Francesco Sgaramella	INFN Frascati, Italy
Alessandro Scordo	INFN Frascati, Italy
Yuta Sada	ELPH, Tohoku University, Japan
Emma Chizzali	TU-Munich, Germany
Johann Haidenbauer	FZ Jülich, Germany
Isaac Vidaña	INFN Catania, Italy
Abraham Ga	HU, Jerusalem, Israel
Eliahu Friedman	HU, Jerusalem, Israel
Martin Schafer	Nuclear Physics Institute CAS, Czech Republic
Stanisław Mrowczynski	Jan Kochanowski University, Kielce, Poland
Ke Mi	Heidelberg University, Germany
Laura Fabbietti	TU-Munich, Germany
Kazuyuki Ogata	Kyushu University, Japan
Domenico Logoteta	University of Pisa, Italy
Hristijan Kochankovski	Universitat de Barcelona, Spain
Francesco Celiberto	ECT*/FBK Trento, Italy
Fabrizio Napolitano	INFN Frascati, Italy
Nina Shevchenko	Nuclear Physics Institute CAS, Czech Republic
Takumi Yamaga	RIKEN, Japan
Raffaele del Grande	TU-Munich, Germany
Tadashi Hashimoto	JAEA ASRC, Japan

Scientific report

The main objective of the EXOTICO workshop is to find a common ground for the current approaches to study one of the most fundamental problems in nuclear physics, namely the measurement and quantitative understanding of the strong interaction between hadrons with strangeness content. The theoretical approaches in this sector are not only tested but anchored to the experimental results and the feedback between theoreticians and experimentalists is of particular importance in a moment of important experimental developments.

Effective theories in the strangeness sector in non- perturbative regime of the low-energy QCD, like the chiral effective SU(3) theories, under continuous development, are anchored to the experimental results, while first principle Lattice QCD calculations are supposed to deliver reliable predictions in the baryon-baryon sector.

The former are very successful in precisely describing the nucleon-nucleon interactions but they lack sufficient data to be anchored to in order to achieve reliable predictions in the strangeness sector. In the case of the Lattice QCD, the higher the mass, more stable predictions are expected, so the measurements of hyperon-nucleon and hyperon-hyperon interactions will be used to validate these first principles calculations.

In particular in the strangeness S=-1 sector, the interaction of kaons with nucleons has a dominant role in thedescription of low-energy QCD with strangeness, in a regime where chiral symmetry breaking is dominant. The kaon-nucleon interactions constitute the building blocks of low energy QCD, and the effective theories are anchored to these interactions. Theoretical models for the kaon-nucleon interaction need to take into account several physics processes that arise from the underlying strong interaction leading to the formation of resonances and bound states.

From the experimental point of view the strong interaction among hadrons has been measured in the past byscattering experiments and described by effective theories anchored to such data. But while this technique was successful in providing information about the nucleon-nucleon interactions, when it comes to hadrons with strangeness, the experiments and the theoretical description of the related strong interaction become much more challenging. The current experimental approaches cover from low-energy experiments, like the measurement of the kaonic deuterium and other types of exotic atoms, to high-energy facilities and heavy ioncollisions with the femtoscopic studies.

Indeed the last few years, the femtoscopic studies on pairs of stable and unstable hadrons measured in nucleus-nucleus and heavy-ion collisions by ALICE at the LHC and STAR at RHIC, provided a new method to investigate the strong interaction among hadrons and are also extended to the studies of hyperon-nucleon and hyperon-hyperon interactions.

The current difficulties in the description of the hadronic interactions with strangeness content has also implications for astrophysics. Neutron stars, for example, could be constituted from nucleons, hyperons and kaons and their properties mostly depend upon the interactions among these hadrons.

Results and Highlights

The most recent results from experiments located at facilities at very different energy regimes (from low energy kaon beams to high-energy nucleus-nucleus collisions), using very different experimental techniques (X-ray spectroscopy, absorption experiments, analysis of invariant mass, two-particle correlations), and delivering complementary but different observables have been shown.

Experiments at the DAFNE collider and at J-PARC significantly contribute to this field providing measurements of kaonic atoms and nuclei at high precision level. The SIDDHARTA-2 experiment will soon be delivering the first ever experimental results for the measurement of the kaonic deuterium, with a setup that is ready and has delivered precise results for the Kaonic-helium measurements, presented here for the first time. Also for the first time we saw the results from systematic studies at J-PARC of the signal from the formation of different kaonic nuclei.

The femtoscopy technique at LHC and RHIC has been proved to be very sensitive to the underlying strong interaction whether if studied in small collision systems (proton-proton or proton-nucleus) or heavy ion collisions. This technique shows indeed the potential to deliver in the future measurements sensitive to the strong interaction of any hadron pair even in the charm sector, in particular with the upcoming Run-3 of the LHC. Future plans and preliminary results of interactions of few-body objects like the deuteron with baryons or mesons are on the pipeline and open the door for studying experimentally the three (and beyond) -body hadronic interactions.

Theoreticians have shown the development of the state-of-the-art models in the hadron physics sector, from chiral SU(3) models, pionless EFT calculations, Lattice QCD and phenomenological models addressing the interactions between two or more hadrons. Indeed, we see a quick feedback between experimentalists and theoreticians and even new predictions of new observables as the three-body correlation functions have been shown for the first time.

he workshop has helped reinforcing the network between experimentalists and theoreticians and in bringingtogether the high and low energy physics communities working in particle and hadronic physics, as well as inastrophysics, opening the door to a deeper understanding of the role of strangeness in nuclear matter and the Universe. Indeed, we have been shown that the studies of interactions among hadrons are crucial to describe the properties of matter under extreme conditions, as a complementary approach to recent and famous astrophysical observations.

An updated general picture at the end of the workshop shows us how with the presented new precision measurements and the validation and actualization of the theory of the hadronic interactions, long pending issues, like the debated nature of the Lambda(1405) and other exotic states recently discovered, the strength of the Kbar-N Isospin zero interaction triggering the formation of exotic Kbar-multiN states, the presence of hyperons in the core of Neutron stars, and other fundamental problems of nuclear physics can be addressed more successfully.

2.3.19 Giant and Soft Modes of Excitation in Nuclear Structure and Astrophysics

Date	October 24-28, 2022

Organizers

Horst Lenske	Justus-Liebig-Universität Giessen, Germany
Elena Litvinova	Western Michigan University, Kalmazoo/Michigan, USA

Number of participants	44

Main topics

The main topics were:

- Multi-messenger approaches to experiment and theory of nuclear dipole response functions for electric, magnetic, and weak transitions.
- Survey of latest experimental results on soft and giant dipole modes.
- Investigating dipole modes by electromagnetic and hadronic probes: To what extend are the results compatible and what are the differences and limitations?
- Survey of nuclear many-body theory beyond mean-field dynamics.
- Ab initio effective field theory and implementation into the nuclear many-body scheme.
- Advanced shell model theory capable to describe spectroscopic fine structures.
- Signatures for and identification of nuclear skin modes versus bulk excitations.
- Nature of pygmy dipole states: Toroidal oscillations or vibrations of the neutron skin?
- Isospin characteristics of soft and giant dipole modes.
- What do we learn from dipole excitations on the nuclear polarizability and other sum rules?
- What do we learn from dipole excitations on the nuclear symmetry energy?
- Can we constrain the symmetry pressure by skin modes?
- Neutron star physics and stellar nucleo-synthesis: demands of astrophysics to nuclear physics and vice versa.

Speakers

Sonia Bacca	Johannes Gutenberg University, Germany
Francisco Barranco	University of Seville, Spain
Jessica Bellone	University of Catania and INFN-LNS, Italy
Isabelle Brandherm	Technische Universität Darmstadt, Germany
Danilo Gambacurta	INFN-LNS, Italy
Stephane Goriely	Université Libre de Bruxelles, Belgium
František Knapp	Charles University, Czech Republic

Edoardo Lanza	INFN Catania, Italy
Horst Lenske	U. Giessen, Germany
Elena Litvinova	Western Michigan University, USA
Maria Markova	University of Oslo, Norway
Miriam Müscher	University of Cologne, Germany
Nils Paar	University of Zagreb, Croatia
Panagiota Papakonstantinou	IBS, South Korea
Jorge Piekarewicz	Florida State University, USA
Peter Ring	TU München, Germany
Xavier Roca-Maza	University and INFN Milan, Italy
Hiroyuki Sagawa	RIKEN/University of Aizu, Japan
Kamila Sieja	IPHC/ CNRS Strasbourg, France
Mark-Christoph Spieker	Florida State University, USA
Atsushi Tamii	Osaka University, Japan
Nadia Tsoneva Larionova	ELI-NP, Romania
Enrico Vigezzi	University and INFN Milan, Italy
Peter von Neumann-Cosel	Institut fur Kernphysik, TU Darmstadt, Germany
Michael Weinert	University of Cologne, Germany
Herlik Wibowo	Department of Physics, University of York, UK
Andreas Zilges	University of Cologne, Germany

Scientific report

Objectives and Goals: The workshop, originally planned to take place already in 2020, was intended to focus on the properties of nuclear excitations at and below the particle emission threshold and in the continuum region up to the giant resonances. Among the multitude of states dipole modes with total angular momentum and parity $J^p=1^\pm$ of natural $(p=(-)^J)$ and unnatural parity $(p=(-)^{J+1})$, respectively, are of special interest for nuclear structure physics and astrophysics. For decades the most prominent examples of "electric" dipole excitations were the $J^p=1^-$ Giant Dipole Resonance (GDR). They are observed in practically all known nuclei as a cluster of strongly excited states, sticking out prominently in the spectral distributions measured in electromagnetic and hadronic reactions. Since the GDR is playing a key role in neutron capture and knock-out processes, it is of high interest for the nucleosynthesis in stellar environments, supernovae, and neutron star mergers.

However, over about the last two decades, growing experimental and theoretical evidence was collected for the existence of additional dipole excitations in neutron-rich nuclei. At much lower energies than the GDR unexpected groups of states are found on the low—energy tail of the GDR distribution. These clusters of dipole states, appearing just above or below the particle emission threshold are known as the Pygmy Dipole Resonance (PDR), indicating that the PDR transition strength is only a fraction of one contained in the highly collective GDR states, albeit varying with neutron excess. A theme discussed repeatedly at the workshop was the question whether these states are new modes of excitations of a generic character, or do they belong to the seemingly well understood GDR. Under astrophysical aspects, the PDR region is of interest because the strength collected in these soft modes will affect the reaction rates for nucleosynthesis. The urgent quest for clarification of the many open issues on the physics of nuclear dipole excitations was in fact decisive for the preparation of the workshop.

Thematically, the workshop covered a broad range of experimental and theoretical research issues on the properties of the low-energy “soft” PDR modes and the energetically higher lying GDR modes. The emphasis was on the role played by soft and giant dipole modes in nuclear structure physics, as evidenced in neutron radii, the neutron skins and halo configurations, and the relation of these phenomena to the isospin dynamics and the dipole polarizability of nuclei and nuclear matter. The central objective of the workshop was to elaborate research strategies for better understanding the microscopic mechanisms underlying the low-energy dipole excitations, especially in nuclear systems away from the valley of stability. Capabilities and challenges of currently available methods were assessed in a dialogue between the theoretical and experimental nuclear structure and reaction communities for which ECT* provided the ideal environment.

Organizational Aspects: The initial proposal was submitted in 2019 and the workshop was then scheduled for 2020. However, the series of Covid-related lockdowns in 2020 and in 2021 imposed repeated delays, merging finally to the date in October 2022. In order to comply with the still active preventive health restrictions a hybrid form was chosen. Finally, about half of the in total 46 participants opted for in-person attendance at the ECT*. Another consequence of the remarkable delays was that the program had to be updated several times. This gave the opportunity to adjust the list of topics to the latest research issues and inviting speakers representing research activities of highest actuality, which may be considered as a positive and finally productive side effect of the shift by more than two years.

The idea for the workshop goes back to an initiative by Ricardo Broglia who remained over the years the driving force behind the scientific program and the whole project. In June 2022, he had to resign by health reasons. A few weeks before the start of the workshop, we received the sad news of his death. A special session of the workshop was devoted to his highly recognized research work in theoretical nuclear physics and many-body theory in general, in fact continued until the very end.

Results and Highlights

The final program had a strong focus on the latest results of studying soft and giant dipole modes by a broad spectrum of probes which became available rather lately. Measurements are now being performed by inelastic photon and electron scattering and in addition to these electromagnetic probes reactions with hadronic beams are used, the latter ranging from proton to alpha beams. As emphasized by the speakers and in the discussions, this multi-messenger approach has a high discovery potential, being able to reveal indeed the spectral properties of the states under scrutiny. The importance of developing clear theoretical and experimental signatures for distinguishing unambiguously between PDR and GDR modes was a major issue. Theoretically, the two classes of excitations are predicted to be distinguishable by the shape of their transition form factors, in principle accessible by high precision measurements of angular distributions. The PDR transitions are dominated by compressional oscillations of the outer layer of the nuclear surface, leaving the radius untouched but changing periodically the diffusivity. Since that part of the nuclear density distribution is composed essentially by the excess neutrons, this picture interprets the PDR phenomenon as an oscillation of the excess matter against the bulk of the nucleus. In deformed nuclei toroidal modes may become important additionally. GDR modes, however, are well understood as counter-phase oscillations of protons against neutrons which among themselves move in coherent manner, giving rise to the observed collective enhancement of transition strength although in total the motion is of small amplitude. The GDR transition densities are centered typically around the nuclear radius.

In a series of talks, another distinctive feature of PDR and GDR modes was worked out: Experiments and theoretical studies have gained clear evidence that PDR modes are of a mixed isospin character or even dominantly of isoscalar nature while in the GDR region almost pure isovector modes prevail. It was impressive to see that these differences have been verified meanwhile experimentally. A clear proof of this picture emerges from comparing spectra of isospin-blind electromagnetic (g,g') reactions to the hadronic (p,p') and (a,a') reactions where the latter is a pure isoscalar probe. In the future, these features will be studied systematically by the international PANDORA project, newly founded at the RCNP laboratory at Osaka/Japan and presented at the workshop.

A topic of its own interest - and with its own demands – is to explore the magnetic excitations of unnatural parity. Under nuclear structure aspects, this requires a safe knowledge of the spin dependent nuclear effective in-medium interactions which, however, up to now still suffer from a lack of accuracy. The reason is that the database of such modes is not as large as the one for natural parity states. An exception are $J^p=1^+$ charge-exchange excitations known as Gamow-Teller resonances which play a prominent role in nuclear beta decay, also addressed at the workshop. Besides the positive parity 1^+ states, the 0^- and 2^- partners of the natural parity dipole excitations are of special interest for the complete picture, especially in deformed nuclei. A largely unexplored issue is to what extent these states are affected by higher order configuration mixing leading to the so—called quenching phenomenon. Open questions also persist on the composition of the transition operator, e.g. possible contributions of meson exchange currents.

An especially important topic was to understand the conflicting latest PREX and CREX (e,e') results from JLab-experiments on the neutron skins in ^{208}Pb and ^{48}Ca, respectively. These data stirred intense discussions on the implied constraints for the nuclear asymmetry energy and the symmetry pressure and the far-reaching consequences for neutron star studies and nuclear astrophysics in general. An important message of the workshop is that PDR studies seemingly are giving in an unprecedented manner a handle on the nuclear symmetry energy and as such on nuclear isospin dynamics.

The investigations of the complex interplay of PDR and GDR dynamics are a challenge to nuclear theory. In an ideal world, theory would be capable to describe within the same approach the evolution of configurational phases between proton and neutron components over the nuclear volume as typical for PDR modes and the phase coherence within proton and neutron components but out-of-phase oscillations of the two fluids as characteristic for GDR transitions. At the same time, also the fine structure of the spectra should be reproduced or even predicted and the whole set phenomena would be described with full accuracy in spherical and deformed nuclei. The workshop has indicated important encouraging steps eventually approaching these goals. A clear message of the workshop is the demand on nuclear theory to go beyond the still prevailing mean-field and one particle-one hole methods and the related interaction models. In other words, a fresh view on both the interaction models and the theoretical many-body frame work has to be taken. Both aspects were addressed in presentations elucidating the status and the perspectives of interactions derived by chiral effective field theory in conjunction with many-body shell model methods, and density functional theory eventually removing the uncertainties inherent in phenomenological approaches. However, for the time being the latter are indispensable by their still unbeaten flexibility and - within certain limits - predictive power. As shown at the workshop, modern effective interactions combined with advanced numerical methods allow to go beyond the harmonic limit. Theoretical methods like higher order RPA theory, multi-phonon approaches, and advanced quasiparticle theories accounting for polarization effects allow to explore anharmonicities in nuclear spectra to a hitherto unreached degree of accuracy. Promising results were presented and became a major issue at the workshop, indicating the new momentum gained by the field. Such multi-messenger approaches are the future of nuclear theory, both in structure and reaction physics. As emphasized in the panel discussion session developments in that direction will become of major importance for the field and will meet the quest of astrophysics for accurate nuclear structure and reaction input.

2.3.20 *Tomography of Light Nuclei at an EIC (ONLINE)*

Date	November 9-10, 2022

Organizers

Adam Freese	University of Washington, USA
Wim Cosyn	Ghent University, Belgium & Florida International University, USA
Ian Cloët	ANL, USA
Phiala Shanahan	MIT, USA

Number of participants	51

Main topics

A high-luminosity electron ion collider (EIC) is highly anticipated in the United States, and should give an unprecedented opportunity to perform tomographic imaging of protons and nuclei alike. The partonic tomography of nuclei in particular would present novel opportunities for observing how QCD manifests within conventional nuclear structure., It would provide information on the spatial correlations between the quarks and gluons in nuclei, and reveal medium modifications in multidimensional partonic distributions such GPDs and TMDs, and give insight into how inter-nucleon forces arise from QCD. This workshop explored what aspects of QCD in particular can manifest in nuclei at an EIC, what measurements would be sensitive to these manifestations, and what design parameters are needed to make such measurements possible.

The main topics were:

- The intersection between nuclear structure and quantum chromodynamics
- Three-dimensional partonic tomography of nuclei (GPDs, TMDs)
- The EMC effect and generalizations (e.g., an EMC effect for nuclear GPDs)
- Relativistic effects in nuclear structure

Speakers

Herlik Wibowo	Department of Physics, University of York, UK
Shunzo Kumano	Japan Women's University, Japan
Sara Fucini	Institut de Physique Nucléaire d'Orsay, France
Raphaël Dupré	Institut de Physique Nucléaire d'Orsay, France
Christian Weiss	Jefferson Lab, USA
Charles Hyde	Old Dominion University, USA
Pawel Nadel-Turonski	StonyBrook University, USA
Jerry Miller	University of Washington, USA

Tony Thomas	University of Adelaide, Australia
Herman Krebs	Ruhr-University Bochum, Germany
Pieter Maris	Iowa State University, USA
Giovanni Salmè	Istituto Nazionale di Fisica Nucleare, Italy
Will Detmold	Massachusetts Institute of Technology, USA)
Misak Sargsian	Florida International University, USA
James Vary	Iowa State University, USA

Scientific report

This workshop explored the opportunities for nuclear partonic tomography offered by the upcoming electron-ion collider (EIC). The multidimensional partonic structure of hadrons and

nuclei glimpsed by such tomography can be characterized by either generalized parton distributions (GPDs), which encode the spatial structure of hadrons, or transverse momentum distributions (TMDs). Additionally, both of these distributions can be understood as projections of the Wigner distribution, a quasi-probability distribution giving a simultaneous picture in terms of both spatial structure and momentum. The EIC will offer an unprecedented opportunity to perform tomographic imaging of nuclei in particular, since the recoiling nucleus (or nuclear remnants) can be detected using the forward detectors expected to be present in the EIC.

This workshop focused predominantly on light nuclei, from A=2 to A=4. The relatively simple structure of few-nucleon systems allows a greater focus on the way that QCD degrees of freedom may manifest in nuclear structure. Moreover, nuclear structure input can be calculated from first principles for these light nuclei, allowing for better theoretical control of nuclear effects. The deuteron in particular is of special interest, both due to the novel opportunities offered by a spin-one system with a tensor polarization mode, to the opportunity that a two-nucleon bound state offers to study the nucleon-nucleon force from a QCD perspective, and to the novel structures present in spin-one targets that will provide experimental access tointrinsic glue in the nuclear environment.

The main objectives of this workshop were to determine which aspects of nuclear tomography are most accessible to an EIC, which aspects can provide the most insight into the deep mysteries of QCD, and what design parameters the EIC would need in order to perform the coveted measurements. Questions addressed included:

- To what extent can GPDs be extracted from observables? How model-dependent are theextractions?
- What can these measurements tell us about nuclear modification that the traditionalEMC effect cannot?
- What does a conventional nuclear structure calculation for GPDs look like? Do we have agood theoretical control on relativistic effects, final state interactions, etc.?
- How important is ion polarization in this endeavor?

Results and Highlights

One of the main topics of this workshop was the presence of QCD effects in nuclei, and two recurring themes kept emerging regarding this. One of these was the existence of structures that only exist in spin-one targets such as the deuteron, and which are absent from nucleontargets. Shunzo Kumano pointed to the b_1 structure function and gluon transversity PDF as examples in his opening talk. The limited data that exist for the b_1 structure function are already at odds with a simple convolution picture of the deuteron, suggesting exotic QCD effects, and measuring a non-zero gluon transversity PDF at all would indicate intrinsic but extra-nucleonic glue.

The other recurring theme was the importance of having a well-controlled "conventional" nuclear benchmark. This theme occurred during the question and discussion sessions after the talks of Sara Fucini and Raphaël Dupré. It will be difficult to definitively identify QCD effects in incoherent DVCS, owing to a lack of theoretical control on conventional nuclear effects such asfinal state interactions. The theoretical effects in coherent DVCS are better understood, making this a better process for experimentally detecting deviations from the "conventional" benchmark. In SaraFucini's talk, TOPEG (The Orsay-Perugia Event Generator) was advertised as an event generator for creating this benchmark.

In contrast to the "conventional" benchmark, Gerald Miller and Anthony Thomas gave talks onthe EMC effect. Miller spoke on recent work on the EMC effect where light front holographic QCD provides input for the distribution of nucleon point-like configurations. These calculationsgive a decent description of the data and would point towards large virtualities (which can be associated with nuclear short-range correlations) giving the dominant contribution to the EMC effect. Thomas discussed how interpretations of the EMC effect in terms of mean-field effects and/or short range correlations can be confronted through the combination of experimental data, models, and input from lattice QCD.

With regards to future measurements, the possibilities for light ion tomography at the future EIC were covered in talks by Christian Weiss, Pawel Nadel-Turonski and Charles Hyde.

Christian Weiss gave a pedagogical overview of the use of the different reference frames and associated kinematic variables in theoretical and experimental analyses of processes measured at colliders. The focus of the talk was on a Lorentz invariant construction of kinematical variables and how these could be converted to variables such as pseudorapidity. Pawel Nadel-Turonski discussed the impact that a secondary focus would have at an EIC interaction region. This secondary focus allows for detection of final state particles at much smaller momentum transfers (angles), which is especially important for coherent reactions on light nuclei. Charles Hyde gave a talk on simulations for coherent DVCS on 4He. He showed that a high resolution EMcal detector has a significant impact on bin migration effects over a wide range of t, which is important for tomography studies.

An important theme of the workshop was using light-front Hamiltonian dynamics to describe few nucleon and few-parton systems, such as light nuclei and as an approximation to the nucleon. Giovanni Salme presented a framework for the description of ^{3}He TMDs in this approach that respects both the baryon number and momentum sum rules. This study is of importance to the current Jefferson Lab program and the forthcoming Electron Ion Collider. Similarly, James Vary used an analogous approach and presented results for quark and gluon PDFs in the nucleon. The calculation of both quark and gluon PDFs in the same framework is novel and represents important progress in modeling of hadron structure. A new approach to describing nucleon and nuclear structure was presented by Misak Sargsian, which is a spectral function approach used to describe valence quarks. This framework makes several novel predictions for the behavior of valence PDFs which will be tested in future experiments.

Another theme of the workshop was the evolution of ab-initio calculations of nuclear structure, as described by Pieter Maris and Hermann Krebs, allowing studies of nuclei as large as ^{16}O with the same interaction used in structure and scattering calculations. William Detmold described the simultaneous progress in lattice QCD which has enabled the first direct constraints on parton distributions functions in light nuclei via this approach.

2.3.21 Key Reactions in Nuclear Astrophysics

Date	December 12-16, 2022

Organizers

Aurora Tumino	Univ. degli Studi di Enna “Kore” & INFN-LNS Catania, Italy
Carlos Bertulani	Texas A&M University-Commerce, USA
Roland Diehl	MPI Munich, Germany
Jordi José	Technical University of Catalonia, Spain
Livius Trache	IFIN-HH Bucarest-Magurele, Romania

Number of participants	49

Main topics

The aim of the workshop was to discuss existing results in nuclear astrophysics and to identify key reactions for which the stable and RIB facilities need to assess information. The community enjoyed interesting talks and endless discussions to assess the importance and feasibility of key reaction networks, and contributions from direct as well as indirect approaches for nuclear astrophysics. The main topics of the workshop were:

- Massive stars environments
- Heavy-ion fusion reactions
- Theoretical development for sub-barrier fusion cross sections
- Indirect Methods
- Mass measurements
- Plasma traps for beta-decay and opacity studies
- Coulomb explosions in the plasma
- Underground projects and measurements
- Isotopic abundance studies in meteorites and metal-poor-stars
- N-induced reactions for nuclear astrophysics
- Astrophysical sources
- Studies involving radioactive ions: the CRYRING project, the CRIB and the CIRCE programs.

Speakers

A. Bonasera	Cyclotron Institute, T&A University, College Station, Texas, USA
A. Best	Università di Napoli “Federico II”, Napoli, Italy
M. Bezmalinovich	University of Camerino, Camerino, Italy and INFN Perugia, Italy

J. Bishop	Cyclotron Institute, T&A University, College Station, Texas, USA
A. Bonaccorso	INFN Pisa, Italy
A. Caciolli	Università di Padova, Italy
A. Chieffi	INAF, Rome, Italy
S. Cristallo	INFN Perugia & INAF, Teramo, Italy
G. D'Agata	INFN-Laboratori Nazionali del Sud, Catania, Italy
R. Depalo	Università di Milano, Italy
I. Friščić	University of Zagreb, Croatia
M. Gai	University of Connecticut, Groton, USA
L. Gialanella	Università Vanvitelli, Caserta, Italy
L. Guardo	INFN-Laboratori Nazionali del Sud, Catania, Italy
T. Kajino	National Astr. Observatory of Japan, Tokyo, & Beihang Univ., China
F. Hammache	IJCLab, Université Paris-Saclay, CNRS/IN2P3, Orsay, France

Scientific Projects in 2022

2.4 ECT* Doctoral Training Program

Hadron Physics with Functional methods

Date	*May 02-20, 2022*

Organizers

Reinhard Alkofer	University of Graz
Gernot Eichmann	LIP Lisboa
Markus Huber	Giessen University

Number of participants	*23*

Aim of the DTP

The aim of the Doctoral Training Program was to provide the participants with a pedagogical introduction to functional methods, a comprehensive overview of their current applications in hadron physics, and in particular to provide them with the computational techniques to solve Dyson-Schwinger equations (DSEs) and Bethe-Salpeter equations (BSEs) for state-of-the-art problems in QCD and related areas. By the end of the program, the participants were expected to have a thorough understanding of the current status quo in solving two- and three-body systems, and they should be equipped with the numerical tools to make their own contributions in tackling open problems.

Main topics

The DTP covered various topics ranging from basic introductions on the numerical background, different functional equations and state-of-the-art results in hadron physics to solving functional problems. The program consisted of several modules:

- Lectures on applications of functional equations in QCD (Christian Fischer, Pieter Maris);
- Lectures on closely related topics in hadron phenomenology such as hadron spectroscopy, amplitude analyses and quark models (Alessandro Pilloni, Astrid Hiller Blin, Elena Santopinto; unfortunately, the lectures by Ian Cloet on EIC physics had to be canceled on short notice due to unforeseen circumstances);
- Lectures on basic concepts, numerical techniques and parallel programming, together with practical parts for the students where they learned how to write integration codes and solve integral equations;

The main problem-solving component, where the students could choose one of six projects and develop their own computer codes to solve them.

Lecturers:

Christian S. Fischer	University of Giessen, Germany
Alessandro Pilloni	Università di Messina, Italy
Astrid N. Hiller Blin	University of Tübingen, Germany
Pieter Maris	Iowa State University, USA
Jan M. Pawlowski	University of Heidelberg, Germany
Elena Santopinto	INFN, Genova, Italy

2.4.1 List of students

An, Di	China
Balassa, Gàbor	Hungary
Carvalho Ferreira, Luigi	Italy
Chevalier, Cyrille	Belgium
Cimino, Lorenzo	Belgium
Correa da Silveira, Roberto	Brasil
Debnath, Manas	India
Ferreira, Eduardo	Portugal
Gkiatas, Dimitrios	Greece
Hagel, Stephan	Germany
Higuera-Angulo, Isela-Melany	Mexico
Jafarzade, Shahrivar	Azerbaijan
Kiefer, Lutz	Germany
Murgana, Fabrizio	Italy
Rodriguez-Aguilar, Benjamin	Guatemala
Sattler, Franz-Richard	Germany
Schmieden, Richard	Germany
Da Cunha Torcato, André	Brasil
Torres Rojas, Luis-Raul	Mexico
Trotti, Enrico	Italy
Vereijken, Arthur	Netherlands
Wesseley, Jonas	Germany
Zemimiani, Guilherme	Brasil

Scheduling of the lessons

The program consisted of 25 lectures in total, including lectures given by the organizers on numerical techniques to prepare the students for the problem-solving sessions. All students gave 25-minute presentations on their research projects at the beginning of the program. On two afternoons, we hosted open discussion rounds with the speakers of the respective weeks, where the participants could ask additional questions. One afternoon in the first week was reserved for initial exercises in programming. The participants then organized themselves in groups of 2-5 persons

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and decided on one of six available project topics. Supervised by the present organizers and lecturers, they wrote their own numerical codes to calculate the (a) quark propagator, (b) the quark-photon vertex or (c) the gluon and ghost propagators. On the last day of the program, they presented their results in 20-minute flash talks. As a follow-up to a dedicated lecture on high performance computing, the participants also had the opportunity to explore parallelizing code on a cluster of the University of Trento.

Results and Highlights

At the end of the DTP the students presented the results from their projects. The projects were designed to offer something for beginners and advanced practitioners alike. Two groups chose more advanced topics such as solving the BSE for the quark-photon vertex or the DSEs for the Yang-Mills propagators. The former project was quite extensive, but it was interesting to see how the work was distributed in the group and how the students put together one final code to which everybody from the five people contributed.

Many students from the other groups were beginners and some of them did not have any experience with numeric programming at all. Nevertheless, all five groups managed to solve the quark gap equation for real momenta. Three groups even obtained results for complex momenta. An interesting development was that every group chose a different programming language: The problem was solved with Mathematica, Fortran, C++, Python and Matlab. The presentations were used to discuss the advantages and disadvantages of these different languages.

The many questions asked in the two discussion sessions indicate that the topics of the lectures resonated well with the students. In general, the feedback from the students has been very positive. From the progress they made in their projects, we are also confident that everybody learned new things. As an especially useful aspect, they mentioned that the DTP equipped them with numerical tools which will help them with their own PhD projects.

Research at ECT*

3. Research at ECT*

3.1 Projects of ECT* Researchers

Nuclear Physics

GERT AARTS

Machine learning for quantum field theories

In collaboration with B. Lucini, D. Bachtis (Swansea University) and others.

Project abstract: Recently machine learning methods have gained popularity for addressing problems in theoretical physics, in particular in quantum field theory. We are exploring several applications, focussing on the use of quantum-field theory concepts. This has led to several review and white papers with researchers mainly in the USA.

Related publications: [GA1], [GA2], [GA5], [GA6], [GA7], [GA8], [GA9], [GA10], [GA11], [GA17]

QCD under extreme conditions

In collaboration with C. Allton, T. Burns, A.A. Nikolaev, S. Offler, B. Page, T. Spriggs (Swansea University), S. Hands (Liverpool University), B. Jäger (Odense), S. Kim (Sejong University), M.-P. Lombardo (INFN, Firenze), S. M. Ryan (Trinity College Dublin) and J.-I. Skullerud (Maynooth University)

Project abstract: QCD at nonzero temperature and density is a rich field, with applications to heavy-ion collisions and neutron stars. In this project we use large-scale simulations of QCD discretised on a spacetime lattice using national and international high-performance computing facilities to study a variety of questions nonperturbatively, including the phase structure with Wilson quarks, D mesons in a thermal hadronic gas, and spectral reconstruction using a number of methods.

Related publications: [GA3], [GA4], [GA12], [GA13], [GA14], [GA15], [GA16]

DANIELE BINOSI

Emergence of pion parton distributions

In collaboration with Z.-F. Cui (Nanjing U.), Minghui Ding (HZDR, Dresden), J.M. Morgado (Huelva U.), K. Raya (Granada U. and Mexico U., ICN), L. Chang (Nankai U.), F. De Soto (Pablo de Olavide U., Seville), C.D. Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.), S.M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)

Project abstract: Supposing only that there is an effective charge which defines an evolution scheme for parton distribution functions (DFs) that is all-orders exact, strict lower and upper bounds on all Mellin moments of the valence-quark DFs of pionlike systems are derived. Exploiting contemporary results from numerical simulations of lattice-regularized quantum chromodynamics (QCD) that are consistent with these bounds, parameter-free predictions for pion valence, glue, and sea DFs are obtained. The form of the valence-quark DF at large values of the light-front momentum fraction is consistent with predictions derived using the QCD-prescribed behavior of the pion wave function.

Related publication: [DB1]

Emergent Hadron Mass in Strong Dynamics

Project abstract: Emergent Hadron Mass (EHM) is a mechanism capable of explaining both the unnaturally small (pion) and large (proton) masses of hadrons and if not the origin of confinement, then intimately connected with it. Even though the modern formulation of EHM has only recently been completed, it is rapidly becoming a fundamental focus for modern and future experimental efforts aimed at understanding the strong force within the Standard Model. Using Dyson–Schwinger equations for the gluon, ghost and quark propagators, I will introduce the main EHM concepts and illustrate how far this framework can take us in understanding strong interaction phenomenology.

Related publication: [DB2]

Hadron and light nucleus radii from electron scattering

In collaboration with Zhu-Fang Cui (Nanjing U.), Craig D. Roberts (Nanjing U.), Sebastian M. Schmidt (Forschungszentrum Dresden Rossendorf and RWTH Aachen U.)

Project abstract: Conceptually, radii are amongst the simplest Poincaré-invariant properties that can be associated with hadrons and light nuclei. Accurate values of these quantities are necessary so that one may judge the character of putative solutions to the strong interaction problem within the Standard Model. However, limiting their ability to serve in this role, recent measurements and new analyses of older data have revealed uncertainties and imprecisions in the radii of the proton, pion, kaon, and deuteron. In the context of radius measurement using electron+hadron elastic scattering, the past decade has shown that reliable extraction requires minimisation of bias associated with practitioner-dependent choices of data fitting functions. Different answers to that challenge have been offered; and this perspective describes the statistical Schlessinger point method (SPM), in unifying applications to proton, pion, kaon, and deuteron radii. Grounded in analytic function theory, independent of assumptions about underlying dynamics, free from practitioner-induced bias, and applicable in the same form to diverse systems and observables, the SPM returns an objective expression of the information contained in any data under consideration. Its robust nature and versatility make it suitable for use in many branches of experiment and theory.

Related publication: [DB3]

Study for a model-independent pole determination of overlapping resonances

In collaboration with Alessandro Pilloni (Messina U. and INFN, Catania), Ralf-Arno Tripolt (Giessen U. and Unlisted, DE)

Project abstract: We apply a model-independent reconstruction method to experimental data in order to identify complex poles of overlapping resonances. The algorithm is based on the Schlessinger Point Method where data points are interpolated using a continued-fraction expression. Statistical uncertainties of the experimental data are propagated with resampling. In order to demonstrate the feasibility of this method, we apply it to the S-wave J/ψ→γπ0π0 decay. We benchmark the method on known analytic models, which allows us to estimate the deviation from the true value. We then perform the pole extraction from BESIII data, and identify the f0(1500), f0(1710), and f0(2020) scalar states. Our results are in reasonable agreement with recent results, which suggests the proposed method as a promising model-independent alternative for the determination of resonance poles that is solely based on available experimental data.

Related publication: [DB4]

Fresh look at experimental evidence for odderon exchange

In collaboration with Zhu-Fang Cui (Nanjing U.), Craig D. Roberts (Nanjing U.), Sebastian M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.), D.N. Triantafyllopoulos (ECT, Trento)

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

Related publication: [DB5]

Renormalizable extension of the Abelian Higgs-Kibble model with a dimension-six operator

In collaboration with A. Quadri (INFN, Milan)

Project abstract: A deformation of the Abelian Higgs Kibble model induced by a dimension-six derivative operator is studied. A novel differential equation is established fixing the dependence of the vertex functional on the coupling z of the dimension-six operator in terms of amplitudes at z=0 (those of the power-counting renormalizable Higgs-Kibble model). The latter equation holds in a formalism where the physical mode is described by a gauge-invariant field. The functional identities of the theory in this formalism are studied. In particular, we show that the Slavnov-Taylor identities separately hold true at each order in the number of internal propagators of the gauge-invariant scalar. Despite being nonpower-counting renormalizable, the model at z≠0 depends on a finite number of physical parameters.

Related publication: [DB6]

Awards

Three results reported last year in the publications Phys.Rev.Lett. 127 (2021) 9, 092001, Phys.Lett.B 822 (2021), 136631 and Chin.Phys.Lett. 38 (2021) 12, 121401 are now listed in the 2022 edition of the PDG.

Two papers have been awarded the “Top cited paper” prize of IoP Publishing.

FRANCESCO CARNOVALE

My task during this first year of doctoral study will be to support, using theoretical models, the findings from the European "MIMOSA" project's experimental laboratories. In particular, I am performing molecular dynamics simulations of protein systems in aqueous solutions containing silica compounds. Additionally, I will study and use the "Real Time Time-Dependent Density Functional Theory" (TD-DFT), which will enable me to perform *ab initio* calculations necessary to examine the interaction between a specific type of terahertz laser and biological material of interest (at the moment, small molecules/proteins)."

FRANCESCO GIOVANNI CELIBERTO

Hadron structure and proton 3D tomography at new-generation colliding Machines

In collaboration with: A. Bacchetta (Università degli Studi di Pavia), M. Radici (Università degli Studi di Pavia), and A. Signori (Università degli Studi di Torino)

Project abstract: I have been working on the analytical calculation of TMD parton density and on their extraction from global fits via advanced fitting techniques. In particular, I am involved in the study of new models for unpolarized and polarized TMD gluon distributions in the proton and in spin-1 targets, with the short-term goal of carrying out exploratory analyses of the hadron structure through three-dimensional tomographic studies. Taking advantage of my experience in the high-energy field, I have effectively embodied high-energy effects into these gluon densities, tracing a new line of research focused on the definition of new observables sensitive to both TMD and BFKL dynamics, as well as on the possible inclusion of saturation effects. I have been working closely with the experimental community of physicists interested in the study of TMD densities at new-generation facilities, such as HL-LHC, EIC NICA-SPD and the Forward Physics Facility (FPF). Common perspectives were recently presented in review articles written in synergy with them, while I actively participate in the meetings of the collaborations: “EIC User Group (EIGUG)”, “NICA-SPD”, “Quarkonia As Tools” and “Snowmass 2021”. I am also interested in the extension of these analyses to generalized parton densities (GPD), of great importance in the hadronic structure through exclusive processes.

Related publications: [FGC1], [FGC2], [FGC6], [FGC10], [FGC12], [FGC18], [FGC19], [FGC21], [FGC23], [FGC24], FGC27]

TMD factorization (breaking)

In collaboration with: A. Bacchetta (Università degli Studi di Pavia)

Project abstract: It is widely recognized that QCD factorization for TMD parton distribution functions is violated in hadroproduction of almost back-to-back hadrons with high transverse momentum. Currently we are working to figure out to which level (observables and perturbative order) factorization-breaking effects come into play in processes sharing the same formalism, as photon- jet hadroproduction and di-hadron production in SIDIS.

Unintegrated gluon densities at small-x

In collaboration with: A. Papa (Università della Calabria), D. Y. Ivanov (Sobolev Institute of Mathematics and Novisibirsk State University, Russia) and A. D. Bolognino (Università della Calabria), A. Szczurek (IFJ Crakow), and W. Schäfer (IFJ Crakow)

Project abstract: Sufficiently inclusive processes, like the deep inelastic lepton-proton scattering, are described in terms of scale-dependent parton distributions, which correspond to the density of partons in the proton with longitudinal momentum fraction x, integrated over the parton transverse momentum. For less inclusive processes it is, however, necessary to consider distributions unintegrated over the transverse momentum. In the small-x regime, the dominant contribution to the amplitude comes from the exchange of a very large number of gluons strongly ordered in rapidity, which is described by the so-called BFKL Green's function. The convolution between the Green's function and the impact factor of the target hadron defines an unintegrated gluon distribution (UGD), whose functional dependence on the gluon kinematical variable has not yet been constrained and is still an object of study and debate. Pursuing the goal to combine small-x effects together with the ones coming from other approaches (DGLAP resummation, etc…), several parameterizations have been proposed. The comparison of these models via the investigation of different reactions represents the core of a new research line, recently opened.

Related publications: [FGC2], [FGC11], [FGC22], [FCG24], [FGC26]

Higgs phenomenology

In collaboration with: A. Papa (Università della Calabria), D. Y. Ivanov (Sobolev Institute of Mathematics and Novosibirsk State University, Russia), M. Fucilla Università della Calabria), and M. M. A. Mohammed (Università della Calabria)

Project abstract: We have recently started a study, done at the hand of the high-energy resummation in the NLA accuracy, of transverse-momentum and rapidity distributions for the inclusive Higgs-plus-jet production, highlighting how the inclusion of high-energy effects is necessary to get a consistent description of the considered process in the corresponding kinematic regions. The need for inclusion of the soft-gluon resummation, as well as of the threshold-logarithm one, is also pointed out and represents a matter of our interest for prospective developments. Furthermore, I am recently involved in the extraction of gluon TMD PDFs from the Higgs production channels, in collaboration with Prof. Alessandro Bacchetta. Related publications: [FGC4], [FGC5], [FGC14], [FGC15], [FGC16], [FGC20], [FGC25]

Jet physics at the LHC and EIC

In collaboration with: A. Papa (Università della Calabria), D. Y. Ivanov (Sobolev Institute of Mathematics and Novisibirsk State University, Russia), A. D. Bolognino (Università della Calabria), and M. Fucilla (Università della Calabria)

Project abstract: I have been working on the study of the production of light- and heavy-flavor jets in kinematic configurations typical of current analyses at LHC and future ones at EIC, with particular interest in a unified description of differential distributions in rapidity and transverse momentum, in terms of different resumming mechanisms (BFKL, soft and collinear, threshold and so on). I plan to extend the study to the substructure of jets, namely the description of hadronic states within jets in terms of transverse- momentum-dependent (TMD) parton distribution functions.

Related publications: [FGC7], [FGC8], [FGC9], [FGC13], [FGC14], [FGC15] [FGC16], [FGC17], [FGC25], [FGC28]

Heavy-flavor physics at high-energies

In collaboration with: A. Papa (Università della Calabria), D. Y. Ivanov (Sobolev Institute of Mathematics and Novisibirsk State University, Russia), and M. Fucilla (Università della Calabria)

Project abstract: I have proposed the study of semi-hard reactions characterized by the emission of hadronic states with heavy flavor (Λ c baryons, D mesons and bottomed hadrons) as a testing ground for the manifestation of stabilization effects of the BFKL series with respect to higher-order corrections. I am also interested in the study of the production mechanisms of quarkonium states both at high energies and in the TMD regime. I coordinate the working group on high-energy heavy-flavor emissions, made up of young researchers from the Physics Department of the University of Calabria.

Related publications: [FGC1] [FGC2] [FGC3] [FGC4] [FGC7] [FGC8] [FGC13] [FGC15] [FGC17] [FGC25] [FGC27] [FGC28] [FGC29] [FGC30]

CONSTANTINOS CONSTANTINOU

A framework for phase transitions between the Maxwell and Gibbs constructions

In collaboration with T. Zhao (Ohio University), S. Han (Tsung-Dao Lee Institute, Shanghai Jiao Tong University), and M. Prakash (Ohio University)

Project abstract: By taking the nucleon-to-quark phase transition within a neutron star as an example, we present a thermodynamically-consistent method to calculate the equation of state of ambient matter so that transitions that are intermediate to those of the familiar Maxwell and Gibbs constructions can be described. This method does not address the poorly known surface tension between the two phases microscopically (as, for example, in the calculation of the core pasta phases via the Wigner-Seitz approximation) but instead combines the local and global charge neutrality conditions characteristic of the Maxwell and Gibbs constructions, respectively. Overall charge neutrality is achieved by dividing the leptons to those that obey local charge neutrality (Maxwell) and those that maintain global charge neutrality (Gibbs). The equation of state is obtained by using equilibrium constraints derived from minimizing the total energy density results of which are then used to calculate neutron star mass-radius curves, tidal deformabilities, equilibrium and adiabatic sound speeds and non-radial g-mode oscillation frequencies for several intermediate constructions. Various quantities of interest transform smoothly from their Gibbs structures to those of Maxwell as the local-to-total electron ratio g, introduced to mimic the hadron-to-quark interface tension from 0 (Gibbs) to ∞ (Maxwell), is raised from 0 to 1. A notable exception is the g-mode frequency for the specific case of g=1 for which a gap appears between the quark and hadronic branches.

Related publication: [Co1]

ACHILLE FIORE

Linking kilonova spectra to nucleosynthesis

In collaboration with A. Perego (University of Trento), E. Loffredo (GSSI)

Project abstract: We produce detailed synthetic spectra calculations with the Monte-Carlo based software TARDIS assuming a given ejecta model to account for its peculiar thermodynamics. In particular, we predict the chemical abundances of the ejecta by combining detailed nucleosynthesis calculations with the outcome of numerical relativity merger simulations.

Related publication: [AF1]

Thermalization of radioactive-decay products into the ejecta of binary neutron star mergers

In collaboration with A. Perego (University of Trento), T. Morresi, S. Taioli, M. Dapor (ECT*)

Project abstract: We are developing an analytic scheme to compute the thermalization factor of beta-decay products of radioactive-decay products in binary neutron star merger ejecta. Seminal works expressed it as function of time and assign a time-variation law for the density profile. As particles/photons are expected to give up their energy into the ejecta via collisions/radiation-matter interactions, we find reasonable looking for a closed-form expression which readily points out the dependency of the thermalization efficiency on the ejecta-matter density itself.

Related publication: [AF1]

Unveiling the nature of superluminous supernovae

In collaboration with Padova-Asiago SN group (INAF, Osservatorio Astronomico di Padova), the extended Public ESO Spectroscopic Survey of Transient Objects and the NOT Unbiased Transient Survey

Project abstract: Superluminous supernovae are among the brightest transient events in the Universe. They are usually discovered in dwarf, metal-poor host galaxies which share some analogies with the environment hosting long and ultra-long gamma ray bursts. Contrary to their ordinary, classical siblings, their absolute luminosity at maximum may largely exceed -20 magnitudes in optical bands and cannot be easily reconciled with the classical 56Ni-radioactive decay picture. Among the proposed explanations, one of the most promising hypotheses considers the contribution of the magnetic-braking, spindown radiation from a newly-born, highly-magnetized millisecond magnetar to boost the maximum luminosities of such unexpectedly bright transients. Alternatively, the shock-mediated interaction of the supernova ejecta with a circumstellar material could also account for at least some properties of superluminous supernovae. To shed light on their puzzling origin, we model their pseudo-bolometric light curves and their pseudo-nebular spectra to estimate the physical parameters of the explosion.

Related publications: [AF3], [AF6]

Follow-up observations of astronomical transients

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

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

Related publications: [AF3], [AF4], [AF5], [AF6], [AF7]

ALEX GNECH

Theoretical study of electroweak interactions with light-nuclei

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

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

Related publication: [AG1]

Accurate calculation of beta-decay rates of light nuclei

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

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

Artificial neural network for nuclear bound state

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

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

Solving the homogeneous Bethe-Salpeter equation on a quantum annealer

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

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

Related talks: [AG2]

BORYS HRYNIUK

Exact analytical solutions and model-independent results in nuclear physics

In collaboration with I.V.Simenog (Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine)

Project abstract: For the systems of strongly interacting particles there exist a possibility to obtain some fundamental asymptotically exact results due to the short range of nuclear forces. We consider in detail the three-nucleon nd- scattering problem in the quartet state.

A model-independent description of the phase shift of the elastic nd-scattering in the quartet state is grounded, and explicit solutions for the low-energy scattering parameters (the quartet scattering length a3/2 and effective range r3/2) are obtained in the form of asymptotically exact expansions in terms of the ratio of the experimental two-nucleon low-energy scattering parameters.

Related publication: [BG1]

Cluster structure of light nuclei and their structure functions

In collaboration with V. S. Vasilevsky and D. V. Pyatnytskyi (Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine)

Project abstract: Light nuclei in the ground and the lowest excited states can be considered as consisting of a few α-particles plus some extra nucleons. This approach appeared to be competitive with the ones where all the nucleon degrees of freedom are taken into account, but needs much less efforts to find the necessary experimentally important nuclear characteristics.

In the framework of the Project, the structure functions of the ground and the first excited state of mirror nuclei ^{14}C and ^{14}O are studied within the five-cluster model (three α-particles plus two extra nucleons) on the ground of variational calculations with the use of Gaussian bases. It is shown that the first excited 0^+ state as compared to the ground state reveals itself in a change of the spatial structure of the two-nucleon subsystem moving in the field of the ^{12}C cluster. Root mean square radii and relative distances between particles are calculated. Density distributions and electric form factors (both elastic and transition ones) are studied. Pair correlation functions and momentum distributions of particles for the excited state of these nuclei are found. For all the obtained structure functions, a comparison is carried out with the corresponding functions of the ground state. Two main configurations in the ground state and excited one of ^{14}C and ^{14}O nuclei are revealed.

Related publication: [BG2]

A problem of spatial collapse in an infinite systems of Bose-particles

In collaboration with K. A. Bugaev (Bogolyubov Institute for Theoretical Physics of the National Academy of Sciences of Ukraine)

Project abstract: A problem of spatial collapse in an infinite system of Bose-particles discovered experimentally for a system of rubidium atoms [1] is considered for the hypothetical nuclear matter consisting of α-particles on the basis of the variational principle. This enables to establish some fundamental results concerning the conditions for such effect to be observed.

Within this Project, a sufficient criterion for a possibility of the spatial collapse effect in an infinite system of Bose-particles is established on the ground of the variational principle with the use of Jastrow correlation factors in the wave function. It is demonstrated, that the two-particle scattering length has no relation to a criterion of possibility for the spatial collapse to take place, on the contrary to the statement based on the Gross-Pitaevskii equation. Using the obtained sufficient criterion, we show that in hypothetical nuclear matter, if it consisted of α-particles, spatial collapse would take place under the assumption of any αα-interaction potential from the known set of Ali-Bodmer ones.

[1] *S. L. Cornish, N. R. Claussen, J. L. Roberts, E. A. Cornell, C. E. Wieman*. Stable ^{85}Ru Bose-Einstein Condensates with Widely Tunable Interactions. – Phys. Rev. Lett. **85**, 1795 (2000).

https://doi.org/10.1103/PhysRevLett.85.1795

LUIS BENJAMIN RODRIGUEZ AGUILAR

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

Supervisor: Dionysios Triantafyllopoulos (ECT*/FBK)

Project abstract: We study incoherent diffractive dijet production in electron-nucleus deep inelastic scattering at small x_{Bj} within the Color Glass Condensate. We follow the general approach of [1] but we focus first on the “strict” correlation limit, that is, when the momentum transfer $\Delta_\perp$ and the gluon saturation momentum Q_s of the nucleus are much smaller than the individual jet momentum $P_\perp$. We arrive at analytic expressions for the dijet

cross section, which can be written as a sum of four terms which exhibit factorization: each such term is a product between a hard factor, which includes the decay of the virtual photon to the quark-antiquark pair, and a semi-hard one which involves the dipole-nucleus scattering amplitude. We further calculate the azimuthal anisotropies $\langle \cos 2\varphi \rangle$ and $\langle \cos 4\varphi$. They are of the same order in the hard momentum $P_\perp$, but the $\langle \cos 4\varphi \rangle$ is logarithmically suppressed due to its dependence on the semi-hard factor. Finally, in order to extend the validity of our result towards the perturbative domain, we calculate the first higher kinematic twist, i.e. the correction of relative order $\Delta^2_\perp / P^2_\perp$.

[1] H. Mantysaari, N. Mueller, F. Salazar, and B. Schenke, “Multigluon Correlations and Evidence of Saturation from Dijet Measurements at an Electron-Ion Collider,” Phys.Rev.Lett. 124 (2020) no. 11, 112301, arXiv:1912.05586 [nucl-th].

Giovanni Inverardi

My PhD scholarship is part of a European project/consortium, whose ultimate goal is to build a so-called "4D microscope", starting from an experimental technique called Atom Probe Tomography (APT), extending it to applications in the biological field. The final goal of the large European consortium is therefore to design a new experimental technique for the determination of protein structures in three dimensions. Specifically, my task is to support the results deriving from experimental laboratories, through theoretical models. Classical and reactive Molecular Dynamics simulations will be implemented to meticulously study the behavior of biological materials (mainly proteins) in contact with the APT matrices derived from silica gels. Moreover, also the interaction between the APT laser and proteins will be investigated, with ab initio calculations using Density Functional Theory and, if possible, Real Time Dependent Density Functional Theory will be implemented.Consequently, the whole APT experimental protocol will be validated in a theoretical way, providing significant information regarding the possible success of the newly designed procedure on a variety of biological samples.

Saga Säppi

Pressure of NNNLO cold dense pQCD with and without HTL

In collaboration with T. Gorda (TU Darmstadt), A. Kurkela (Stavanger University), J. Österman (Helsinki University), R. Paatelainen (Helsinki University), P. Schicho (Helsinki University, Goethe U., Frankfurt), K. Seppänen (Helsinki University), A. Vuorinen (Helsinki University)

Project abstract: Knowledge of the pressure of cold and dense QCD is vital for astrophysical purposes, particularly in order to understand the equation of state of neutron stars. The current state-of-the-art calculations are probing the next-to-next-to-next-to-leading order (NNNLO). The problem is theoretically interesting---while there are no fundamental obstacles to computing purely perturbative corrections (in contrast to the case of finite temperature, where the Linde problem appears at NNNLO), zero-temperature loop integrals in the imaginary-time formalism pose some unique challenges. Some of these were studied in [SA4], and a better understanding is expected to facilitate further computations of four-loop integrals. [SA4] also has some potential for applications in low-energy condensed matter systems and other cold and dense field-theoretical problems. As far as explicit calculations go, the low-energy (soft) degrees of freedom of thermal pQCD can be correctly described using the Hard Thermal Loop (HTL) framework. This has successfully been used in the past to determine the pressure of the soft sector by myself and collaborators, and this year the methods used previously were extended to the "mixed" sector [SA3] (using results from [SA2]) in an Abelian theory, acting as an important explicit demonstration of the cancellation of the intermediate scales in the computation, required for consistency. In the near future, the computation will be finished in full QCD, resulting in the determination of the second partial NNNLO order, the subleading logarithmic term. Furthermore, the evaluation of complete hard four-loop QCD diagrams is now in its early stages---this would represent the final, analytic and IR-insensitive hard contribution computed in pure QCD, to the pressure.

Related publications: [SA2], [SA3], [SA4]

Gauge boson self-energy at finite density

In collaboration with T. Gorda (TU Darmstadt), A. Kurkela (Stavanger University), J. Österman (Helsinki University), R. Paatelainen (Helsinki University), P. Schicho (Helsinki University, Goethe U., Frankfurt), K. Seppänen (Helsinki University), A. Vuorinen (Helsinki University)

Project abstract: The evaluation of the mixed terms described above requires knowledge of the self-energy of the gauge boson in the appropriate (HTL) limit at finite density to next-to-leading order in two senses of the word: Next-to-leading in the loop counting, and next-to-leading in the HTL expansion, ie, in the external momenta, the latter of which have been dubbed "power corrections", as opposed to "loop corrections". The Abelian case was obtained in [SA2], as a generalisation of an earlier finite-temperature computation by a disjoint collaboration. The finite-density self-energy displayed interesting functional structures absent from the finite-temperature case. Similarly to the pressure, this is being generalised to QCD, and is nearing completion. Perhaps even surprisingly, it is considerably more involved, and has required the development of an integration-by-parts reduction code for reducing the thermal master integrals, as well as a rethinking of the expansions that can be performed in HTL.

Related publication: [SA2]

Dense pQCD with finite masses and temperatures

In collaboration with J. Cruz (APCTP, Pohang), T. Gorda (TU Darmstadt), C. Hoyos (University of Oviedo), N. Jokela (Helsinki University), M. Järvinen (APCTP Pohang), A. Kurkela (Stavanger University), R. Paatelainen (Helsinki University), J. Remes (University of Oviedo), A. Vuorinen (Helsinki University)

Project abstract: While the evaluation of the NNNLO pressure is underway, efforts can be made to further generalise the lower-order results. In [SA1], an expansion scheme was developed that allows for a very efficient evaluation of the QCD pressure at finite temperature and density with a massive strange quark by making use of the coincidental fact that the physical value of the strange quark mass at densities relevant to neutron stars is what is known as a soft quantity. In the past, the mass-dependence was known to NLO, or NNLO at zero temperature, but both results involved complicated numerics. With [SA1], these results take a much simpler form. Partially encouraged by this, there is a currently ongoing project for evaluating transport quantities, namely the susceptibility of dense quark matter relevant for example for neutron star mergers. This will involve a comparison of the pQCD results with a two different holographic models, in order to compare the different methods, with preliminary results showing promise.

Related publication: [SA1]

DIONYSIOS TRIANTAFYLLOPOULOS

Probing Parton Saturation and the Gluon Dipole via Diffractive Jet Production at the Electron-Ion Collider

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

Project abstract: We demonstrate that hard dijet production via coherent inelastic diffraction is a promising channel for probing gluon saturation at the Electron-Ion Collider. By inelastic diffraction, we mean a process in which the two hard jets — a quark-antiquark pair generated by the decay of the virtual photon — are accompanied by a softer gluon jet, emitted by the quark or the antiquark. This process can be described as the elastic scattering of an effective gluon-gluon dipole. The cross section takes a factorized form, between a hard factor and an unintegrated ("Pomeron") gluon distribution describing the transverse momentum imbalance between the hard dijets. The dominant contribution comes from the black disk limit and leads to a dijet imbalance of the order of the target saturation momentum Qs evaluated at the rapidity gap. Integrating out the dijet imbalance, we obtain a collinear factorization where the initial condition for the Dokshitzer-Gribov-Lipatov-Altarelli-Parisi evolution is set by gluon saturation.

Related publication: [TRI1]

Fresh look at experimental evidence for odderon exchange

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

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

Related publication: [TRI2]

Gluon dipole factorisation for diffractive dijets

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

Project abstract: Within the colour dipole picture for deep inelastic scattering at small Bjorken x, we study the production of a pair of relatively hard jets via coherent diffraction. By “relatively hard” we mean that the transverse momenta of the two jets — the quark and the antiquark generated by the decay of the virtual photon — are much larger than the target saturation momentum Qs evaluated at the rapidity gap Yp. We argue that the typical final-state configurations are such that the hard quark-antiquark dijets are accompanied by a semi-hard gluon jet, with a transverse momentum of the order of Qs(Yp). The presence of this third jet ensures that the scattering is strong and thus avoids the strong suppression of exclusive (hard) dijet production due to colour transparency. For such “2+1” jet configurations, we demonstrate that both the emission of the semi-hard gluon and its scattering with the hadronic target can be factorised in terms of an effective gluon-gluon dipole.

This effective description, builds a bridge between the colour dipole picture and the transverse-momentum dependent (TMD) version of the collinear factorisation: the cross-section for diffractive 2+1 jets can be written as the product between a hard factor describing the quark-antiquark dijets and a semi-hard factor expressing the unintegrated gluon distribution of the Pomeron. The latter is controlled by gluon dipole scattering in the black disk limit and hence is strongly sensitive to gluon saturation. By integrating out the kinematics of the 3 jets, we obtain the quark-antiquark-gluon contribution to the diffractive structure function in collinearly-factorised form.

Related publication: [TRI3]

LUCA VESPUCCI

Optimizing Quantum Simulations for Trapped-Ion qubits

Supervisors: D. Binosi (ECT*/FBK), A. Roggero (University of Trento)

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

Computational Physics

MAURIZIO DAPOR

Calculation of the differential elastic scattering cross-section of spin-polarized electron beams impinging on neutral atoms

In collaboration with: G. Garberoglio and S. Taioli

Project abstract: We investigate the effects of spin-polarization on the differential elastic scattering cross-section of electrons impinging on neutral atoms using the relativistic partial wave expansion method. The calculations can be used to establish the polarization degree of a given electron beam by comparing the theoretical calculations with experimental data.

Related publications: [Md1], [Md2]

Simulation of reflection electron energy loss spectra

In collaboration with: P. de Vera (University of Murcia), G. Garberoglio, S. Taioli

Project abstract: We compare experimental and Monte Carlo data concerning reflection electron energy loss spectra in order to understand the interplay between surface and bulk features for incident electrons in solid targets.

Related publication: [Md3]

Swift carbon-ion tracks in liquid water

In collaboration with: P. de Vera (University of Murcia), S. Taioli, P. E. Trevisanutto, M. Dapor, I. Abril (University of Alicante), S. Simonucci (University of Camerino), R. Garcia-Molina (University of Murcia)

Project abstract: Swift carbon ions are promising projectiles used for cancer radiotherapy. A thorough knowledge of how the energy of these ions is deposited in biological media (mainly composed of liquid water) is required. This can be attained by means of detailed computer simulations, both macroscopically (relevant for appropriately delivering the dose) and at the nanoscale (important for determining the inflicted radiobiological damage). We simulate the radial dose around the ion's path, as well as the distributions of clustered events in nanometric volumes like the dimensions of DNA convolutions, contributing to the biological damage for carbon ions in a wide energy range, covering from the plateau to the maximum of the Bragg peak.

Related publications: [Md4], [Md5]

GIOVANNI GARBEROGLIO

Towards quantum-based realisations of the pascal (QuantumPascal)

In collaboration with Allan H. Harvey (NIST) and Bogumil Jeziorski (University of Warsaw).
Project abstract: This project has received funding from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme (30 k€)

In this project, we performed an accurate ab-initio calculation of the third dielectric virial coefficient of helium. We re-assessed the incompatible theoretical derivations of a quantum-statistical formula for this quantity and developed a path-integral approach to compute it. Accurate ab-initio calculations for the three-body polarizability and dipole moment of helium atoms enabled us to compute the third dielectric virial of both ^{4}He and ^{3}He with rigorously defined uncertainties completely from first principles.

A paper detailing these results is currently being finalized.

Realisation of the redefined kelvin (Real-K)

In collaboration with Allan H. Harvey (NIST), Bogumil Jeziorski (University of Warsaw) and Daniele Binosi (ECT*).

Project abstract: This project has received funding from the European Metrology Programme for Innovation and Research and from the EU Horizon 2020 research and innovation programme (40k€)

In this project, we performed an accurate ab-initio calculation of the third density virial coefficient of ^{4}He and ^{3}He using an highly accurate three-body potential that include relativistic corrections. This enabled us to lower by 5 times the theoretical uncertainty on the first principles calculations of this quantity (performed without uncontrolled approximations) with respect to our previous calculations.

Additionally, we performed highly accurate calculations of the third acoustic virial coefficient. Theoretical and computational improvements enabled us to estimate this quantity in the range 1K-3000K being limited only by the propagated uncertainty of the interaction potentials.

For this project we were awarded 100k CPU hours at the Italian Supercomputing Center (CINECA), under the ISCRA-C initiative.

Two papers detailing these results are currently being finalized.

Dynamics of impurities in ultracold Fermi gases

In collaboration with Matteo Sighinolfi, Alessandro Roggero and Pietro Faccioli from UNITN Alessio Recati from CNR-BEC and Davide De Boni

Project abstract: We developed theoretical and computational methods to investigate the dynamics of heavy impurities in Fermi gases

Related publication: [GG1]

Other collaborations

- Calculation of the first dielectric virial coefficient of water isotopologues. A paper is being finalized.
- Hydrogen desorption in $(MgH_2)_n$ clusters [GG2]

[GG1] Sighinolfi, M., De Boni, D., Roggero, A., Garberoglio, G., Faccioli, P. and Recati, A., 2022. Stochastic dynamics and bound states of heavy impurities in a Fermi bath. *Physical Review A*, **105**, p.043308

[GG2] Pedrielli, A., Trevisanutto, P.E., Monacelli, L., Garberoglio, G., Pugno, N.M. and Taioli, S., 2022. Understanding anharmonic effects on hydrogen desorption characteristics of Mg_nH_{2n} nanoclusters by ab initio trained deep neural network. *Nanoscale*, 14, pp.5589-5599.

SIMONE TAIOLI

Nanoparticle Enhanced Hadron-therapy: a comprehensive Mechanistic description

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

Project abstract: This project is aimed at applying basic physics and chemistry methods to uncover the microscopic mechanisms behind nanoparticle enhancement of hadron-therapy for cancer treatment (or ion beam cancer therapy). Hadron-therapy (radiotherapy using accelerated ion beams) is one of the most advanced radiotherapies available, with superior dose delivery and biological effectiveness as compared to conventional radiotherapy. The increased effectiveness of hadron-therapy relies on physico-chemical phenomena occurring at the nanoscale. There is experimental evidence pointing to nanoparticles enhancing the biological effects of ion beams. Since nanoparticles can be tuned to target cancer cells, they might be used to further improve hadron-therapy. However, it is still unknown how nanoparticles produce this effect. A proper exploitation of the nanoparticle radioenhancement in hadron-therapy depends on improving the understanding of the physico-chemical mechanisms responsible for it. In this project, a theoretical and computational method is proposed, in which a series of semiempirical and ab initio approaches will be extended and interfaced with Monte Carlo track-structure simulation tools [ST1, ST2], in order to advance the basic understanding of the nanoparticle enhanced hadron-therapy physical and chemical mechanisms.

Related publications: [ST1], [ST2]

Thermodynamic properties of energy materials by machine learning

In collaboration with: G. Garberoglio, A. Pedrielli (ECT*), N. M. Pugno (University of Trento), P. Trevisanutto (STFC, UK)

Project abstract: Magnesium hydride (MgH_2) has been widely studied for effective hydrogen storage. However, its bulk desorption temperature (553 K) is deemed too high for practical applications. Besides doping, a strategy to decrease such reaction energy for releasing hydrogen is the use of MgH_2-based nanoparticles (NPs). In this project, we investigate first the thermodynamic properties of Mg_nH_{2n} NPs ($n < 10$) from first-principles [ST3], in particular by assessing the anharmonic effects on the enthalpy, entropy and thermal expansion by means of the stochastic self consistent harmonic approximation (SSCHA). This method goes beyond previous approaches, typically based on molecular mechanics and the quasi-harmonic approximation, allowing the *ab initio* calculation of the fully-anharmonic free energy. We find an almost linear dependence on temperature of the interatomic bond lengths – with a relative variation of a few percent over 300 K – alongside with a bond distance decrease of the Mg–H bonds. In order to increase the size of Mg_nH_{2n} NPs toward experiments of hydrogen desorption we devise a computationally effective machine learning model trained to accurately determine the forces and total energies (*i.e.* the potential energy surfaces), integrating the latter with the SSCHA model to fully include the anharmonic effects. We find a significant decrease of the H-desorption temperature for sub-nanometric clusters Mg_nH_{2n} with $n \leq 10$, with a non-negligible, although little effect due to anharmonicities (up to 10%).

Related publication: [ST3]

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

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

Project abstract: Experiments performed at storage rings have shown that the lifetimes of β-radionuclides can change significantly as a function of the ionization state. A new experimental approach, based on the use of a compact plasma trap to simulate selected stellar-like condition, has been proposed by the PANDORA [ST4] project with the aim to measure, for the first time in a plasma outside a storage ring, nuclear β-decay rates of radionuclides involved in nuclear-astrophysics processes. To achieve this task a compact magnetic plasma trap has been designed, allowing to reach the needed plasma densities, temperatures and charge states distributions. Plasma parameters will be measured online with a multi-diagnostic setup and correlated with the decay rate of the radionuclides, which will be measured through the detection of the γ-rays emitted by the daughter nuclei following the β-decay. These γ-rays will be detected using an array of 14 HPGe detectors placed around the trap. For the first experimental campaign, three physics cases were selected, ^{176}Lu, ^{134}Cs, ^{94}Nb. The newly designed plasma trap will also represent a tool of choice to measure plasma opacities, a quantity experimentally poorly known, which has a great impact on the energy transport and spectroscopic observations of many astrophysical objects. The Pandora project also relies on theoretical models and computer simulations carried out using newly implemented methods in astrophysical scenarios to study the chemical evolution of the Universe and interpret observations [ST4], [ST5], [ST6]

Related publications: [ST4], [ST5], [ST6]

Monte Carlo simulation of secondary electron generation and emission

In collaboration with: M. Dapor (ECT*), LISA Collaboration (UniTN)

The space environment encountered by operating spacecraft is populated by a continuous flux of charged particles that penetrate into electronic devices inducing phantom commands and loss of control, eventually leading to satellite failure. Moreover, electron static discharge that results from secondary electron emission of the device materials can also be responsible for satellite malfunction. In this regard, the estimate of the total electron yield is fundamental for our understanding of the test-mass charging associated with galactic cosmic rays in the LISA Pathfinder mission and in the forthcoming gravitational wave observatory LISA. To unveil the role of low energy electrons in this process owing to galactic and solar energetic particle events, in this project we study the interaction of keV and sub-keV electrons with a gold slab using a mixed Monte Carlo and ab-initio framework [ST7]. We determine the energy spectrum of the electrons emerging from such a gold slab hit by a primary electron beam by considering the relevant energy loss mechanisms as well as the elastic scattering events. We also show that our results are consistent with experimental data and Monte Carlo simulations carried out with the GEANT4-DNA toolkit [ST8].

Related publications: [ST7, ST8]

Mechanical properties of twisted carbon nanotube bundles with carbon linkers via molecular dynamics

In collaboration with: M. Dapor (ECT*), N. M. Pugno (University of Trento), K Gkagkas (Toyota)

Project abstract: For real-world high-end applications, ranging from bulletproof tissues to aeronautics and aerospace, high modulus and strength fibers are of paramount importance. Carbon nanotubes represent the ideal candidates for the realization of such fibers. However, although fully aligned, the nanotubes are much shorter than the whole fibers so that their mechanical performance is difficult to bring up to the macroscale, due to the low load transfer between bare nanotubes. A strategy to overcome this problem is represented by twisting the fiber or the single bundle. This can be coupled with the introduction of chemical linkers in order to increase the load transfer within the fiber. In this project, we exploit molecular dynamics simulations to investigate the effect of twist on the mechanical properties of nanotube bundles in which linkers are composed of single carbon atoms [ST9].

Related publication: [ST9]

Horizon Europe Programme HORIZON-EIC-2021-PATHFINDEROPEN-01

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

In collaboration with: A. Vella (University of Rouen), G. Lattanzi (University of Trento), D. Paparo, A. Rubano (CNR Napoli & Federico II University), M. Andersson (Chalmers University of Technology)

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

3.2 Publications of ECT* Researchers in 2022

GERT AARTS

[GA1] J. I. Skullerud, G. Aarts, C. Allton, M. N. Anwar, R. Bignell, T. Burns, S. C. Garcia-Mascaraque, S. Hands, R. H. D'Arcy and B. Jaeger, et al.
Hadrons at high temperature: An update from the FASTSUM collaboration
EPJ Web Conf. 274 (2022), 05011
doi:10.1051/epjconf/202227405011
[arXiv:2211.13717 [hep-lat]]

[GA2] G. Aarts, C. Allton, R. Bignell, T. J. Burns, S. C. Garcia-Mascaraque, S. Hands, B. Jaeger, S. Kim, S. M. Ryan and J. I. Skullerud
Open charm mesons at nonzero temperature: results in the hadronic phase from lattice QCD
[arXiv:2209.14681 [hep-lat]]

[GA3] P. Shanahan, K. Terao, D. Whiteson, G. Aarts, A. Adelmann, N. Akchurin, A. Alexandru, O. Amram, A. Andreassen and A. Apresyan, et al.
Snowmass 2021 Computational Frontier CompF03 Topical Group Report: Machine Learning

[arXiv:2209.07559 [physics.comp-ph]]

[GA4] D. Boyda, S. Cali, S. Foreman, L. Funcke, D. C. Hackett, Y. Lin, G. Aarts, A. Alexandru, X. Y. Jin and B. Lucini, et al.
Applications of Machine Learning to Lattice Quantum Field Theory
[arXiv:2202.05838 [hep-lat]]

[GA5] C. Allton et al. [FASTSUM],
Recent results from the FASTSUM Collaboration
PoS LATTICE2022 (2022), 198
doi:10.22323/1.430.0198
[arXiv:2301.10282 [hep-lat]]

[GA6] T. Spriggs, G. Aarts, C. Allton, T. Burns, R. H. D'Arcy, B. Jaeger, S. Kim, M. P. Lombardo, S. Offler and B. Page, et al.
A comparison of spectral reconstruction methods applied to non-zero temperature NRQCD meson correlation functions
EPJ Web Conf. 258 (2022), 05011
doi:10.1051/epjconf/202225805011
[arXiv:2112.04201 [hep-lat]]

[GA7] B. Page, G. Aarts, C. Allton, B. Jaeger, S. Kim, M. P. Lombardo, S. Offler, S. M. Ryan, J. I. Skullerud and T. Spriggs,
Spectral Reconstruction in NRQCD via the Backus-Gilbert Method
PoS LATTICE2021 (2022), 134
doi:10.22323/1.396.0134
[arXiv:2112.02075 [hep-lat]]

[GA8] S. Offler, G. Aarts, C. Allton, B. Jaeger, S. Kim, M. P. Lombardo, B. Page, S. M. Ryan, J. I. Skullerud and T. Spriggs,
Reconstruction of bottomonium spectral functions in thermal QCD using Kernel Ridge Regression
PoS LATTICE2021 (2022), 509
doi:10.22323/1.396.0509
[arXiv:2112.02116 [hep-lat]]

[GA9] T. Spriggs, G. Aarts, C. Allton, T. Burns, B. Jaeger, S. Kim, M. P. Lombardo, S. Offler, B. Page and S. M. Ryan, et al.
Bottomonium spectral widths at nonzero temperature using maximum likelihood
PoS LATTICE2021 (2022), 077
doi:10.22323/1.396.0077
[arXiv:2112.01599 [hep-lat]]

[GA10] G. Aarts, C. Allton, S. Hands, B. Jaeger, S. Kim, M. P. Lombardo, A. A. Nikolaev, S. M. Ryan and J. I. Skullerud,
Lattice QCD at nonzero temperature and density
J. Phys. Conf. Ser. 2207 (2022) no.1, 012055

doi:10.1088/1742-6596/2207/1/012055
[arXiv:2111.10787 [hep-lat]]

[GA11] S. C. Garcia-Mascaraque, G. Aarts, C. Allton, T. Burns, S. Hands and B. Jaeger
Meson thermal masses at different temperatures
PoS LATTICE2021 (2022), 523
doi:10.22323/1.396.0523
[arXiv:2111.00784 [hep-lat]]

[GA12] D. Bachtis, G. Aarts and B. Lucini
Quantum field theories, Markov random fields and machine learning
J. Phys. Conf. Ser. 2207 (2022) no.1, 012056
doi:10.1088/1742-6596/2207/1/012056
[arXiv:2110.10928 [cs.LG]]

[GA13] G. Aarts, D. Bachtis and B. Lucini,
Interpreting machine learning functions as physical observables
PoS LATTICE2021 (2022), 248
doi:10.22323/1.396.0248
[arXiv:2109.08497 [hep-lat]]

[GA14] D. Bachtis, G. Aarts and B. Lucini,
Machine learning with quantum field theories
PoS LATTICE2021 (2022), 201
doi:10.22323/1.396.0201
[arXiv:2109.07730 [cs.LG]]

[GA15] D. Bachtis, G. Aarts, F. Di Renzo and B. Lucini,
Inverse Renormalization Group in Quantum Field Theory
Phys. Rev. Lett. 128 (2022) no.8, 081603
doi:10.1103/PhysRevLett.128.081603
[arXiv:2107.00466 [hep-lat]]

[GA16] G. Martin-Vazquez, G. Aarts, M. Mueller and A. Bermudez,
Long-Range Ising Interactions Mediated by lambda phi4 Fields: Probing the Renormalization of Sound in Crystals of Trapped Ions
PRX Quantum 3 (2022) no.2, 020352
doi:10.1103/PRXQuantum.3.020352
[arXiv:2105.06886 [quant-ph]]

[GA17] G. Aarts, C. Allton, J. Glesaaen, S. Hands, B. Jaeger, S. Kim, M. P. Lombardo, A. A. Nikolaev, S. M. Ryan and J. I. Skullerud, et al.
Properties of the QCD thermal transition with Nf=2+1 flavors of Wilson quark
Phys. Rev. D 105 (2022) no.3, 034504
doi:10.1103/PhysRevD.105.034504
[arXiv:2007.04188 [hep-lat]]

DANIELE BINOSI

[DB1] Z. F. Cui, M. Ding, J. M. Morgado, K. Raya, D. Binosi, L. Chang, F. De Soto, C. D. Roberts, J. Rodŕıguez-Quintero and S. M. Schmidt
Emergence of pion parton distributions
Phys. Rev. D 105 no.9, L091502 (2022)

[DB2] D. Binosi
Emergent Hadron Mass in Strong Dynamics
Few Body Syst. 63, no.2, 42 (2022)

[DB3] Z. F. Cui, D. Binosi, C. D. Roberts and S. M. Schmidt
Hadron and light nucleus radii from electron scattering
Chin. Phys. C 46 no.12, 122001 (2022)

[DB4] D. Binosi, A. Pilloni and R. A. Tripolt
Study for a model-independent pole determination of overlapping resonances
arXiv:2205.02690 [hep-ph]

[DB5] Z. F. Cui, D. Binosi, C. D. Roberts, S. M. Schmidt and D. N. Triantafyllopoulos
Fresh look at experimental evidence for odderon exchange
arXiv:2205.15438 [hep-ph]

[DB6] D. Binosi and A. Quadri
Renormalizable Extension of the Abelian Higgs-Kibble Model with a dimension 6 operator
Phys. Rev. D 106, no.6, 065022 (2022)
Published preprints from 2021 projects

[DB7] Z. F. Cui, F. Gao, D. Binosi, L. Chang, C. D. Roberts and S. M. Schmidt.
Valence quark ratio in the proton
Chin. Phys. Lett. 39 no.4, 041401 (2022)

[DB8] Z. F. Cui, M. Ding, J. M. Morgado, K. Raya, D. Binosi, L. Chang, J. Papavassiliou, C. D. Roberts, J. Rodrıguez-Quintero and S. M. Schmidt.
Concerning pion parton distributions
Eur. Phys. J. A 58 no.1, 10 (2022)

FRANCESCO GIOVANNI CELIBERTO

[FGC1] E. Chapon, …, F. G. Celiberto, et al.
Prospects for quarkonium studies at the high-luminosity LHC
Prog. Part. Nucl. Phys. 122 (2022) 103906, 87 pages [arXiv:2012.14161]
doi:10.1016/j.ppnp.2021.103906

[FGC2] L. A. Anchordoqui, …, F. G. Celiberto, et al.

The Forward Physics Facility: Sites, Experiments, and Physics Potential
Phys. Rept. 968 (2022) 1-50, 50 pages [arXiv:2109.10905]
doi:10.1016/j.physrep.2022.04.004

[FGC3] F. G. Celiberto
High-energy emissions of light mesons plus heavy flavor at the LHC and the Forward Physics Facility
Phys. Rev. D 105 (2022) 11, 114008, 40 pages [arXiv:2204.06497]
doi:10.1103/PhysRevD.105.114008

[FGC4] F. G. Celiberto (corresponding author), M. Fucilla, M. M. A. Mohammed
Ultraforward production a charmed hadron plus a Higgs boson in unpolarized proton collisions
Phys. Rev. D 105 (2022) 11, 114056, 14 pages [arXiv:2205.13429]
doi:10.1103/PhysRevD.105.114056

[FGC5] F. G. Celiberto, M. Fucilla (corresponding author), D. Yu. Ivanov, M. M. A. Mohammed, A. Papa
The next-to-leading order Higgs impact factor in the infinite top-mass limit JHEP 08 (2022) 092, 57 pages [arXiv:2205.02681] doi:10.1007/JHEP08(2022)092

[FGC6] R. Abdul Khalek, …, F. G. Celiberto, et al.
Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report
Nucl. Phys. A 1026 (2022) 122447, 902 pages [arXiv:2103.05419]
doi:10.1016/j.nuclphysa.2022.122447

[FGC7] F. G. Celiberto (corresponding author), M. Fucilla
Diffractive semi-hard production of a J/ψ or a Υ from single-parton fragmentation plus a jet in hybrid factorization
Eur. Phys. J. C 82 (2022) 10, 929, 21 pages [arXiv:2202.12227]
doi:10.1140/epjc/s10052-022-10818-8

[FGC8] F. G. Celiberto
The high-energy spectrum of QCD from inclusive emissions of charmed B-mesons
Phys. Lett. B 835 (2022) 137554, 8 pages [arXiv:2206.09413]
doi:10.1016/j.physletb.2022.137554

[FGC9] F. G. Celiberto (corresponding author), A. Papa
Mueller-Navelet jets at the LHC: hunting data with azimuthal distributions
Phys. Rev. D 106 (2022) 11, 114004, 19 pages [arXiv:2207.05015]
doi:10.1103/PhysRevD.106.114004

[FGC10] F. G. Celiberto
A journey into the proton structure: Progresses and challenges
Universe 8 (2022) 12, 661, 12 pages [arXiv:2210.08322]
doi:10.3390/universe8120661

[FGC11] A. D. Bolognino, F. G. Celiberto, D. Yu. Ivanov, A. Papa (proceeding)
Exclusive emissions of rho-mesons and the unintegrated gluon distribution
SciPost Phys. Proc. 8, (2022) 089, 7 pages [arXiv:2107.12725]
doi:10.21468/ScipostPhysProc.8.089

[FGC12] A. Bacchetta, F. G. Celiberto, M. Radici, P. Taels (proceeding)
A spectator-model way to transverse-momentum-dependent gluon distribution functions
SciPost Phys. Proc. 8 (2022) 040, 6 pages [arXiv:2107.13446]
doi:10.21468/ScipostPhysProc.8.040

[FGC13] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, A. Papa (proceeding)
Hybrid high-energy/collinear factorization in a heavy-light dijets system reaction
SciPost Phys. Proc. 8 (2022) 068, 6 pages [arXiv:2107.12120]
doi:10.21468/ScipostPhysProc.8.068

[FGC14] F. G. Celiberto, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding)
High-energy resummation in inclusive hadroproduction of Higgs plus jet
SciPost Phys. Proc. 8 (2022) 068, 6 pages [arXiv:2107.13037]
doi:10.21468/ScipostPhysProc.8.039

[FGC15] F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding)
BFKL phenomenology: resummation of high-energy logs in inclusive processes
SciPost Phys. Proc. 10 (2022) 002, 9 pages [arXiv:2110.12649]
doi:10.21468/SciPostPhysProc.10.002

[FGC16] F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding)
Higgs-plus-jet inclusive production as stabilizer of the high-energy resummation
PoS EPS-HEP2021 (2022) 589, 6 pages [arXiv:2110.09358]
doi:10.22323/1.398.0589

[FGC17] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, A. Papa (proceeding)
Heavy-flavored emissions in hybrid collinear/high-energy factorization
PoS EPS-HEP2021 (2022) 389, 6 pages [arXiv:2110.12772]
doi:10.22323/1.398.0389

[FGC18] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
Toward twist-2 T-odd transverse-momentum-dependent gluon distributions: the f-type Sivers function
PoS EPS-HEP2021 (2022) 376, 6 pages [arXiv:2111.01686]
doi:10.22323/1.398.0376

[FGC19] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
Toward twist-2 T-odd transverse-momentum-dependent gluon distributions: the f-type Sivlinearityers function
PoS PANIC2021 (2022) 378, 5 pages [arXiv:2111.03567]
doi:10.22323/1.380.0378

[FGC20] F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding)
Higgs boson production in the high-energy limit of pQCD
PoS PANIC2021 (2022) 352, 4 pages [arXiv:2111.13090]
doi:10.22323/1.380.0352

[FGC21] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
Towards leading-twist T-odd TMD gluon distributions
JPS Conf. Proc. 37 (2022) 020124, 5 pages [arXiv:2201.10508]
doi:10.7566/JPSCP.37.020124

[FGC22] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, A. Papa, W. Schäfer, A. Szczurek (proceeding)
Hadron structure via small-x unintegrated gluon distributions
Rev. Mex. Fis. Suppl. 3 (2022) 3, 0308109, 5 pages [arXiv:2202.02513]
doi:10.31349/SuplRevMexFis.3.0308109

[FGC23] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
Unveiling the proton structure via transverse-momentum-dependent gluon distributions
Rev. Mex. Fis. Suppl. 3 (2022) 3, 0308108, 5 pages [arXiv:2206.07815]
doi:10.31349/SuplRevMexFis.3.0308108

[FGC24] F. G. Celiberto (proceeding)
Phenomenology of the hadronic structure at small-x
Proceedings of Low-x 2021, 10 pages [arXiv:2202.04207]

[FGC25] F. G. Celiberto, M. Fucilla, A. Papa (proceeding)
The high-energy limit of perturbative QCD: Theory and phenomenology
EPJ Web Conf. 270 (2022) 00001, 8 pages [arXiv:2209.01372]
doi:10.1051/epjconf/202227000001

[FGC26] A. D. Bolognino, F. G. Celiberto, D. Yu. Ivanov, A. Papa, W. Schäfer, A. Szczurek (proceeding)
Exclusive emissions of polarized ρ mesons at the EIC and the proton content at low x
Zenodo DIS2022, 7 pages [arXiv:2207.05726] doi:10.5281/zenodo.7112750

[FGC27] A. Bacchetta, F. G. Celiberto, M. Radici, A. Signori (proceeding)
Phenomenology of gluon TMDs from $\eta_{b,c}$ production
Zenodo DIS2022, 6 pages [arXiv:2208.06252] doi:10.5281/zenodo.7085045

[FGC28] F. G. Celiberto, M. Fucilla (proceeding)
Inclusive J/ψ and Υ emissions from single-parton fragmentation in hybrid high-energy and collinear factorization
Zenodo DIS2022, 11 pages [arXiv:2208.07206] doi:10.5281/zenodo.7237044

[FGC29] F. G. Celiberto (proceeding)
Stabilizing BFKL via heavy-flavor and NRQCD fragmentation
to appear in Acta. Phys. Polon. Supp. [arXiv:2211.11780]

[FGC30] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding)
High-energy signals from heavy-flavor physics
to appear in Acta. Phys. Polon. Supp. [arXiv:2211.16818]

CONSTANTINOS CONSTANTINOU

[CC1]
Quasinormal g-modes of neutron stars with quarks
T. Zhao, C. Constantinou, P. Jaikumar, and M. Prakash
Phys. Rev. D 105, 103025 (2022)

MAURIZIO DAPOR

[MD1] M. Dapor
Electron–Atom Collisions. Quantum-Relativistic Theory and Exercises
Berlin, Boston, De Gruyter, 2022.

[MD2] M. Dapor
Differential elastic scattering cross-section of spin-polarized electron beams impinging on uranium
Journal of Physics B: Atomic Molecular Optical Physics, 2022 55, 095202, pp. 1–9

[MD3] M. Dapor
Aluminum electron energy loss spectra. A comparison between Monte Carlo and experimental data
Frontiers in Materials, 2022, 9:1068196, pp. 1–12

[MD4] P. de Vera, S. Taioli, P. E. Trevisanutto, M. Dapor, I. Abril, S. Simonucci, R. Garcia-Molina
Energy Deposition around Swift Carbon-Ion Tracks in Liquid Water
International Journal of Molecular Sciences, 2022, 23, 6121, pp. 1–39

[MD5] P. de Vera, S. Simonucci, P. E. Trevisanutto, I. Abril, M. Dapor, S. Taioli, R.Garcia-Molina
Simulating the nanometric track-structure of carbon ion beams in liquid water at energies relevant for hadrontherapy.
Journal of Physics: Conference Series, 2022, 2326, 012017, pp. 1–8

ACHILLE FIORE

[AF1] : Perego A., Vescovi D., Fiore A., Chiesa L., Vogl C., Benetti, S., Bernuzzi S., Branchesi M., Cappellaro, E., Cristallo S., Flörs A., Kerzendorf W. E., Radice D. *Production of Very Light Elements and Strontium in the Early Ejecta of Neutron Star Mergers*, The Astrophysical Journal, Volume 925, Issue 1, id.22, 17 pp.

[AF2]: Agudo I., Amati L., An T., Bauer F. E., Benetti S., Bernardini M. G., Beswick R., Bhirombhakdi K., de Boer T., Branchesi M., Brennan S. J., Caballero-García M. D., Cappellaro E., Castro Rodríguez N., Castro-Tirado A. J., Chambers K. C., Chassande-Mottin E., Chaty S., Chen T. -W., Coleiro A. , Covino S., D'Ammando F., D'Avanzo P., D'Elia V., Fiore A., Flörs A., Fraser M., Frey S., Frohmaier C., Galbany L., Gall C., Gao H., García-Rojas J., Ghirlanda G., Giarratana S., Gillanders J. H., Giroletti M., Gompertz B. P., Gromadzki M., Heintz K. E., Hu Y. -D., Huber M. E., Inkenhaag A., Izzo L., Jin Z. P., Jonker P. G., Kann D. A., Kool E. C., Kotak R., Leloudas G., Levan A. J., Lin C. -C., Lyman J. D., Magnier E. A., Maguire K., Mandel I., Marcote B., Mata Sánchez D., Mattila S., Melandri A., Michałowski M. J., Moldon J., Nicholl M., Nicuesa Guelbenzu A., Oates S. R., Onori F., Orienti M., Paladino R., Paragi Z., Perez-Torres M., Pian E., Pignata G., Piranomonte S., Quirola-Vásquez J., Ragosta F., Rau A., Ronchini S., Rossi A., Sánchez-Ramírez R., Salafia O. S., Schulze S., Smartt S. J., Smith K. W., Sollerman J., Srivastav S., Starling R. L. C., Steeghs D., Stevance H. F., Testa V., Torres M. A. P., Vergani S. D., Vescovi D., Wainscost R., Watson D., Wiersema K., Wyrzykowski Ł., Yang J., Yang S., Young D. R.
Panning for gold, but finding helium: discovery of the ultra-stripped supernova SN2019wxt from gravitational-wave follow-up observations, submitted to A&A.

[AF3]: Gutiérrez C. P., Pastorello A., Bersten M., Benetti S., Orellana M, Fiore A., Karamehmetoglu E.,Kravtsov T., Reguitti A., Reynolds T. M., Valerin G., Mazzali P., Sullivan M., Cai Y. -Z., Elias-Rosa N., Fraser, M., Hsiao E. Y., Kankare E., Kotak R., Kuncarayakti H., Mattila S., Mo J., Moran S. , Ochner P., Shahbandeh M., Tomasella L., Wang X., Yan S., Zhang J., Zhang T., Stritzinger M. D.
SN 2020wnt: a slow-evolving carbon-rich superluminous supernova with no O II lines and a bumpy light curve, Monthly Notices of the Royal Astronomical Society, Volume 517, Issue 2, pp.2056-2075

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GIOVANNI GARBEROGLIO

[GG1] Sighinolfi, M., De Boni, D., Roggero, A., Garberoglio, G., Faccioli, P. and Recati, A.
Stochastic dynamics and bound states of heavy impurities in a Fermi bath
Physical Review A, **105**, p.043308

[GG2] Pedrielli, A., Trevisanutto, P.E., Monacelli, L., Garberoglio, G., Pugno, N.M. and Taioli, S.

Understanding anharmonic effects on hydrogen desorption characteristics of Mg_nH_{2n} nanoclusters by ab initio trained deep neural network
Nanoscale, 14, pp.5589-5599.

ALEX GNECH

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Muon capture on deuteron using local chiral potentials
Front. Phys. 10 (2023). DOI:10.3389/fphy.2022.1049919

BORYS HRYNIUK

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Model-Independent Solution of nd-Scattering Problem in the Quartet State
Ukr. J. Phys. 2022. Vol. 67, No. 5, p. 322-326.
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[BG2] Grinyuk, B.E., Piatnytskyi, D.V., Vasilevsky, V.S.
The lowest excited states of 14C and 14O nuclei within a five-cluster model
Nuclear Physics A 1030 (2023) 122588.
https://doi.org/10.1016/j.nuclphysa.2022.122588

TOMMASO MORRESI

[TM1] T. Morresi, R. Vuilleumier, M. Casula
Hydrogen phase-IV characterization by full account of quantum anharmonicity
Phys. Rev. B 106, 054109 (2022)

[TM2] F. Mohuat, M. Peria, T. Morresi, R. Vuilleumier, A.M. Saitta, M. Casula
Thermal dependence of the hydrated proton and optimal proton transfer
Submitted to Nature Communications
(HTTPS://DOI.ORG/10.48550/ARXIV.2301.01825)

[TM3] F. Triggiani, T. Morresi, S. Taioli, S. Simonucci
Elastic scattering of electrons by water: an ab initio study
Submitted to Frontiers in Materials
(HTTPS://DOI.ORG/10.48550/ARXIV.2301.07017)

SAGA SÄPPI

[SA1] T. Gorda, S. Säppi
Cool quark matter with perturbative quark masses
Phys.Rev.D 105 (2022) 11, 114005, hep-ph/2112.11472 (preprint from 2021)

[SA2] T. Gorda, A. Kurkela, J. Österman, R. Paatelainen, S. Säppi, P. Schicho, K. Seppänen, A. Vuorinen
Soft photon propagation in a hot and dense medium to next-to-leading order
hep-ph/2204.11279, Accepted to Phys.Rev.D, awaiting publication

[SA3] T. Gorda, A. Kurkela, J. Österman, R. Paatelainen, S. Säppi, P. Schicho, K. Seppänen, A. Vuorinen
Degenerate fermionic matter at N33LO: Quantum Electrodynamics
hep-ph/2204.11893, Accepted to Phys.Rev.D, awaiting publication

[SA4] T. Gorda, J. Österman, S. Säppi
Augmenting the residue theorem with boundary terms in finite-density calculations
Phys.Rev.D 106 (2022) 10, 105026, hep-th/2208.14479

SIMONE TAIOLI

[ST1] P. de Vera, S. Simonucci, P. E. Trevisanutto, I. Abril, M. Dapor, S. Taioli, R. Garcia Molina
Simulating the nanometric track-structure of carbon ion beams in liquid water at energies relevant for hadrontherapy
J. Phys.: Conf. Ser. 2326, 012017 (2022)

[ST2] P de Vera, S Taioli, PE Trevisanutto, M Dapor, I Abril, S Simonucci, R. Garcia Molina
Energy deposition around swift carbon-ion tracks in liquid water
International Journal of Molecular Sciences 23 (11), 6121 (2022)

[ST3] A Pedrielli, PE Trevisanutto, L Monacelli, G Garberoglio, N Pugno, S Taioli
Understanding Anharmonic Effects on Hydrogen Desorption Characteristics of Mg_nH_{2n} Nanoclusters by ab initio trained Deep Neural Network
Nanoscale 14, 5589-5599 (2022)

[ST4] D. Mascali, D. Santonocito, S. Amaducci, L. Andò, V. Antonuccio, S. Biri, A. Bonanno, V. P. Bonanno, S. Briefi, M. Busso, L. Celona, L. Cosentino, S. Cristallo, M. Cuffiani, C. De Angelis, G. De Angelis, J. E. Ducret, D. De Salvador, L. Di Donato, A. E. Vakili, U. Fantz, A. Galatà, C. S. Gallo, S. Gammino, T. Isernia, H. Koivisto, K.-L. Kratz, R. Kronholm, M. La Cognata, S. Leoni, A. Locatelli, M. Maggiore, F. Maimone, L. Malferrari, G. Mancini, L. Maunoury, G. S. Mauro, M. Mazzaglia, A. Mengoni, A. Miraglia, B. Mishra, M. Musumeci, D. R. Napoli, E. Naselli, F. Odorici, L. Palladino, G. Palmisano, S. C. Pavone, S. Pennisi, A. Perego, A. Pidatella, R. Rácz, R. Reitano, D. Rifuggiato, M. Rinaldi, A. D. Russo, F. Russo, G. Schillaci, S. Selleri, S. Simonucci, G. Sorbello, R. Spartá, S. Taioli, K. Tinschert, G. Torrisi, A. Trifirò, S. Tsikata, A. Tumino, D. Vescovi, L. Vincetti
A novel approach to β-decay: PANDORA, a new experimental setup for future in-plasma measurements
Universe 8 (2), 80 (2022)

[ST5] _S Taioli, D Vescovi, M Busso, S Palmerini, S Cristallo, A Mengoni, S Simonucci
Theoretical estimate of the half-life for the radioactive ^{134}Cs and ^{135}Cs in astrophysical scenarios
The Astrophysical Journal 933, 158 (2022)

[ST6] D Mascali, D Santonocito, M. Busso, L Celona, A Galatà, M La Cognata, G Mauro, A Mengoni, E Naselli, F Odorici, S. Palmerini, A Pidatella, R Ràcz, S Taioli, G Torrisi
A new approach to β-decays studies impacting nuclear physics and astrophysics: the PANDORA setup
EPJ Web of Conferences, accepted (2022)

[ST7] A Pedrielli, NM Pugno, M Dapor, S Taioli
In search of the ground state crystal structure of Ta O from ab-initio and Monte Carlo simulations
Computational Materials Science 216, 111828 (2022)

[ST8] S Taioli, M Dapor, F Dimiccoli, M Fabi, V Ferroni, C Grimani, M Villani, WJ Weber
The role of low-energy electrons in the charging process of LISA test masses
arXiv preprint arXiv:2209.1279 (2022)

[ST9] A Pedrielli, M Dapor, K Gkagkas, S Taioli, NM Pugno
Mechanical Properties of Twisted Carbon Nanotube Bundles with Carbon Linkers from Molecular Dynamics Simulations
International Journal of Molecular Sciences *24*(3), 2473 (2022)

DIONYSIOS TRIANTAFYLLOPOULOS

[TRI1] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos
Probing Parton Saturation and the Gluon Dipole via Diffractive Jet Production at the Electron-Ion Collider
Phys. Rev. Lett. 128 (2022) 20, 202001, arXiv: 2112.06353

[TRI2] Z.F. Cui, D. Binosi, C.D. Roberts, S.M. Schmidt, D.N. Triantafyllopoulos
Fresh look at experimental evidence for odderon exchange
arXiv: 2205.15438, submitted to Phys. Lett. B

[TRI3] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos, S.Y. Wei
Gluon dipole factorisation for diffractive dijets
JHEP 10 (2022) 103, arXiv: 2207.06268

3.3 Talks Presented by ECT* Researchers in 2022

GERT AARTS

*News from ECT**
Presentation at the NuPECC meeting
Vienna, Austria
December 1-2, 2022

Machine learning for lattice field theory and back
Invited colloquium at KIAS, Seoul, South Korea
November 2, 2022

Machine learning for lattice field theory and back
Invited talk at the workshop for Korea-UK AI/ML Research in Fundamental Sciences, Sejong University, Seoul, South Korea
October 31-Nov 4, 2022

ECT and STRONG2020*
Presentation at STRONG2020 Annual meeting, Paris, France
October 17-19, 2022

Theory support in EURO-LABS
Presentation at the EURO-LABS Kick-off meeting, Bologna
Oct 3-5, 2022

Spectroscopy at T>0 with heavy quark
Invited talk at STRONG2020 Hadron Spectroscopy (HaSP) General Workshop, Munich, Germany
September 13-16, 2022

Machine learning for lattice field theory and back
Invited talk at the 8th International Workshop on the Sign Problem in QCD and Beyond (SIGN 22), Tel Aviv, Israel
September 5-9, 2022

New ML/AI paradigms for quantum field theories
Invited talk (online) at Platform for Advanced Scientific Computing Conference (PASC 2022), Basel, Switserland
June 27-29, 2022

Machine learning for lattice field theory and back
Invited seminar (online) at Jagiellonian University, Krakow, Poland
June 7, 2022

Machine learning for lattice field theory and back
IMSc Diamond Jubilee Dinstinguished Lecture (invited, online), IMSc Chennai, India,
June 1, 2022

Thermal QCD and chiral symmetry
Invited talk at the UKLFT Annual Meeting*,* University of Liverpool
May 26-27, 2022

Training for postgraduate research students
Invited talk at the 2nd Joint ECFA-NuPECC-ApPEC Symposium (JENAS), Madrid, Spain
May 3-6 2022

(Lattice) QCD at nonzero temperature
Seminar at Queen Mary University London
April 14 2022

Lattice QCD at finite temperature and density: some selected topics Invited Plenary talk at Quark Matter 2022, Krakow, Poland
April 4-10, 2022

Quantum fields and machine learning
Invited talk (online) at Phase transitions in particle physics, Galileo Galilei Institute for Theoretical Physics, Florence, Italy
March 28-April 3, 2022

Machine learning for lattice field theory and back
Invited colloquium (online) at Trinity College Dublin, Dublin, Ireland
March 23, 2022

AIMLAC: Training the next generation of data/ML scientists
Talk at IAIFI-AIMLAC meeting, IAIFI, MIT, Cambridge, USA
March 2-4, 2022

DANIELE BINOSI

EHM, pion DFs and J/ψ production
Perceiving the Emergence of Hadron Mass through AMBER@CERN VII
Online talk
May 10-13, CERN

EHM, pion DFs and J/ψ production: an update
Revealing emergent mass through studies of hadron spectra and structure September 12-16, ECT*

Data-driven determination of (overlapping) resonances
NSTAR 2022
October 17-21, S. Margherita Ligure

Data-driven extraction of hadron radii
Baryons 2022

November 7-11, Seville

FRANCESCO GIOVANNI CELIBERTO

Invited talks Celiberto

QCD Working Group: High-energy opportunities at the Forward Physics Facility
4th FPF Meeting, online
1 February, 2022

Toward precision studies of high-energy QCD via a FPF+ATLAS tight timing coincidence
4th FPF Meeting, online
2 February, 2022

Hadron structure at small-x via unintegrated gluon densities
Parton Branching TMD Meeting, online
24 February, 2022

Accessing the proton content via transverse-momentum-dependent gluon distributions
Correlations in Partonic and Hadronic Interactions (CPHI-2022), Duke University, USA
10 March, 2022

Gluon and nucleon polarization at small-x
Saturation and Diffraction at the LHC and the EIC, ECT/FBK*, Trento
28 June, 2022

An overview of gluon TMD PDFs and polarization
EICUG Early Career Workshop, CFNS Stony Brook
24 July, 2022

Stabilizing BFKL with heavy-flavor and NRQCD fragmentation
Diffraction and Low-x 2022, Corigliano Calabro
28 September, 2022

Precision studies of semi-inclusive Higgs production at new-generation Forward Facilities
LHC Forward Physics Meeting, CERN
24 October, 2022

Invited overview talks Celiberto

Gluon TMDs and quarkonia
Quarkonia As Tools 2022, Centre Paul Langevin, Aussois, France
12 January, 2022

Proton structure at the precision frontier: transverse-momentum-dependent parton distribution functions
Snowmass 2021 EF06 meeting – PDFs, online
26 January, 2022

Hadronic structure and high-energy QCD at new-generation colliders Snowmass 2021 EF06 meeting – Forward Physics, BFKL, and Saturation Physics, online
2 February, 2022

Model calculations of gluon TMDs and applications to quarkonium production at the EIC
EICUG Meeting, CFNS Stony Brook
28 July, 2022

Round tables Celiberto

Discussion on TMD Matching
Quarkonia As Tools 2022, Centre Paul Langevin, Aussois, France
14 January, 2022

Discussion on AdS/CFT and high energy resummation
Diffraction and Low-x 2022, Corigliano Calabro
25 September, 2022

Discussion on CGC and saturation
Diffraction and Low-x 2022, Corigliano Calabro
25 September, 2022

Discussion on high-energy QCD and resummations
Diffraction and Low-x 2022, Corigliano Calabro
25 September, 2022

Invited seminars Celiberto

Toward precision studies of high-energy QCD via Higgs and heavy-flavor hadroproduction?
Argonne National Laboratory, High Energy Physics Division, Chicago, USA
22 June, 2022

High-energy QCD for Higgs and heavy-flavor physics
University of California, Los Angeles, USA
23 February, 2022

Contributed talks Celiberto

Phenomenology of gluon TMDs from $\eta_{c,b}$ production
DIS 2022, Santiago de Compostela
4 May, 2022

Exclusive emissions of polarized ρ mesons at the EIC and the proton content at low-x
DIS 2022, Santiago de Compostela
4 May, 2022

From LHC to FCC: The high-energy dynamics of Higgs-plus-jet correlations
108° Congresso Nazionale SIF, Università degli Studi di Milano
14 September, 2022

A high-energy QCD portal to exotic matter: heavy-light tetraquarks at the HL-LHC
EXOTICO Workshop, ECT*/FBK, Trento
20 October, 2022

Posters Celiberto

F. G. Celiberto (presenter), A. Papa
The high-energy QCD dynamics from Higgs-plus-jet correlations at FCC collision energies
FCC Week 2022, 2022, 30 May - 3 June, Campus des Cordeliers - Sorbonne Université, Parigi

CONSTANTINOS CONSTANTINOU

g-mode ode Oscillations in Neutron Stars
FELLINI General Meeting, Ferrara
31 May 2022

INVITED SEMINAR:
g-mode Oscillations in Neutron Stars
Theory Seminar at the T.D. Lee Institute (online)
30 November 2022

ALEX GNECH

A generalized eigenvalue problem via a quantum annealer
Quantum Computing @ INFN, Bologna, Italy
14-15 November, 2022

TOMMASO MORRESI
Anharmonic phonons in hydrogen rich materials,
Journée de la matière condensée, Lyon
22-26 August 2022

SAGA SÄPPI

N3LO cold dense perturbation theory using hard thermal loops

Talk at funQCD (workshop), Valencia, Spain
11 June, 2022

Soft scales with HTL in high-density perturbation theory
Talk at SEWM2022 (conference), IPhT Saclay – Université Paris VI, Paris & Saclay, France
21 June, 2022

Dense pQCD at N3LO: (partially) soft contributions with HTL
Talk at workshop "From holography to machine learning: novel takes on dense matter"
University of Helsinki, Helsinki, Finland
25 October, 2022

Seminars Saga Säppi

Dense pQCD and Hard Thermal Loops at NNNLO
Seminar (online) at the Technical University of Munich, Munich, Germany
11 March, 2022

SIMONE TAIOLI

INVITED TALKS

The influence of electronic and nuclear correlation on weak decays
The 13th Torino Workshop on AGB stars & the 3rd Perugia Workshop on Nuclear Astrophysics, Perugia
19-24 June 2022

On the relative role o the physical mechanisms on complex biodamage induced by carbon irradiation
ECT* Workshop "From Hadrons to Therapy: Fundamental Physics Driving New Medical Advances"
5-9 September 2022, ECT*

The lure and the lore of condensed matter research
Invited seminar, 24 November 2022, University of Alicante

Simulation of electronic spectra of molecules and solids from first-principles
Kick-off meeting of the Mimosa Project
Invited seminar, 27 September 2022, University of Rouen

The lure and the lore of condensed matter research
Invited seminar, 29 November 2022, University of Murcia

LECTURES SIMONE TAIOLI

Modern Problems in Condensed Matter Physics

60 hours course to Master Students in PHYSICS, Peter the Great St. Petersburg Polytechnic University
Academic year 2021-2022

Scattering Theory
Extended 20 hours course to PhD Students in physics
Gdansk Polytechnic University
July 2022

DIONYSIOS TRIANTAFYLLOPOULOS

Gluon Dipole and Factorization in Diffractive DIS
Talk (online) at the workshop "Physics of Saturation - precision and quasicollectivity", Beer Sheva, Israel
26 May 2022

Gluon Dipole and Factorization in Diffractive DIS
Talk at the workshop "Saturation and Diffraction at the LHC and the EIC", Trento, Italy
30 June 2022

Gluon Dipole Factorization and Saturation in Diffractive Dijet Production
Talk at the workshop "Diffraction and Low-x 2022", Corigliano Calabro, Italy
25 September 2022

Gluon Dipole Factorization and Saturation in Diffractive Dijet Production
Talk at the workshop "Saturation at the EIC", Orsay, France
17 November 2022

LUCA VESPUCCI

Quantum Computing applications of the Hubbard-Stratonovich transformation
Talk given in presence at the "Quantum Computing for Many-Body problems (QCMB): atomic nuclei, neutrinos, and other strongly correlated Fermi systems" workshop in Orsay, France
22-24 November 2022

Zhao-Qian Yao
Invited talk
Semileptonic decays of heavy+light and heavy+heavy mesons
2022 International Conference on the Structure of Baryons (Baryons-22)
Seville, Spain
November 8, 2022

3.4 ECT* Seminars

Rajeev Singh
Current status of spin hydro based on GLW definitions of energy-momentum and spin tensors (online)
17 February 2022

Joannis Papavassiliou
Emergence of scale in the gauge sector of QCD (online)
24 March 2022

Craig Roberts
Emergence of mass in the standard model (online)
31 March 2022

Tyler Gorda
High-density quark matter in the cores of neutron stars (online)
31 March 2022

Edmond Iancu
Jet evolution in a dense quark-gluon plasma (online)
12 May 2022

Gordon Baym
Evolution of primordial neutrino helicities in gravitationla inhomogeneities, ans cosmic and galactic magnetic fields (hybrid)
13 October 2022

Borys Hryniuk
Structure of some light nuclei with two extra nucleons (in presence)
3 November 2022

Borys Hryniuk
About conditions of spatial collapse in an infinite system of interacting bose particles (in presence)
15 December 2022

Computing Facilities

4 ECT* Computing Facilities

CONNECTIVITY

- The main network infrastructure is connected by 5 switches PoE - Power over Ethernet- (Aruba 2930M 48G PoE+).
- 5 switches Aruba 2930M 48G PoE+ were installed in order to improve the connectivity in Villa Tambosi.
- The Rustico and the Villa at ECT* are connected by two multi-mode optical fibers.
- Between ECT* and FBK the connection is also provided by fiber (2Gbps).

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

Hardware

PC clients:

9 PCs for the local research and visiting scientists:

8 Workstation DELL Precision T1500
1 Workstation DELL Precision T1600

3 PCs/laptops for the staff:

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

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

3 laptops DELL Latitude E5430
1 laptop DELL Latitude E5440

Conference room and Lecture room

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

Main software for the research activity:

Mathematica Cloud: 5 licenses Home use + 5 Cloud licenses. (35 cloud licenses for DTP for 3 weeks and 35 cloud licenses for TALENT for 3 weeks were available in 2021). Since December 2021 the version 13 is available.

Service

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

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

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

1. PaperCut Print Management Software
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 Meetings

WiFi Networks

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

- GuestsFBK
- EduRoam

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

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