FONDAZIONE BRUNO KESSLER

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

ANNUAL REPORT 2021

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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Editoria FBK

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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 2021 was very much dominated by the ongoing Covid-19 pandemic. However, after the near-complete shutdown in 2020, ECT* was able to deliver again a full programme of workshops, Doctoral Training Programme and TALENT School, albeit that most activities took place online. I am grateful to the community for its ongoing support to contribute to the scientific programme, even under these difficult circumstances. To prepare ECT* for "the new normal", the *Aula Renzo Leonardi* was fitted with cameras and microphones, to have the opportunity to hold hybrid meetings. The system was put to the test in the autumn of 2021, with 3 workshops run in hybrid mode, with limited occupancy. The possibility to talk in person and continue the discussion over coffee and snacks was much appreciated by those who attended in person. Through these activities ECT* was able to maintain its worldwide visibility and demonstrate its key importance for the European and international nuclear physics communities.

In 2021, ECT* held the following scientific events:

- 17 Workshops – 14 of which were run remotely and 3 were run in hybrid mode. The topics of the latter were "*Machine Learning for High Energy Physics, on and off the Lattice*", "*Exploring High-MuB Matter with Rare Probes*", and "*Quark-Gluon Plasma Characterisation with Heavy Flavour Probes*".
- A Doctoral Training Programme (on-line) on "*High-Energy and Nuclear Physics within Quantum Physics*", which lasted four weeks and was attended by 28 students from 10 countries worldwide.

- A TALENT School (on-line) on "*Machine Learning applied to Nuclear Physics, experiment and theory*", which lasted two weeks and was attended by 63 students from 16 countries worldwide.
- In April 2021, the community thanked outgoing ECT* Director Prof Jochen Wambach with a scientific symposium held online, attended by over 100 colleagues and friends. Jochen served as ECT* Director from January 2016 to December 2020.

At the European level, ECT* joined in the successful *Euro-LABS* bid to the *Horizon Europe* call for *Research Infrastructures*, bringing together many nuclear physics and particle physics facilities. ECT* is keen to continue to provide a stimulating environment bringing together researchers in the field of theoretical and experimental nuclear physics. *Euro-LABS* will become active in the autumn of 2022.

Another significant development was the strengthening of the collaboration with the Physics Department of the University of Trento. This was made concrete by the signing of a common Agreement in July 2021; I am grateful to Prof Franco Dalfovo (Director of the Physics Department) and Prof Francesco Pederiva for the constructive discussions we have had over the past year. A tangible outcome is already visible: 2 jointly-funded PhD students have started their research projects in November 2021.

Locally, the artificial barrier between the researchers in nuclear physics (ECT*) and in computational physics (ECT*-LISC) was removed, creating a more supportive and flourishing research environment. With collaborations already taking place, this was the obvious next step to allow the local research team to reach its full potential. The five permanent researchers and the group of up to ten postdoctoral researchers carried out 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 and neutron stars, many-body theory and computational physics. The research activities of the Centre are documented in detail in Chapter 4 of this Annual Report. Altogether, 60 publications by ECT* researchers were reported for the year 2021.

ECT* researchers obtained some individual successes worth mentioning:

- Francesco Celiberto, postdoctoral researcher, was awarded an international fellowship at Jefferson Lab to help advance the science programme of the Electron-Ion Collider (EIC).
- the paper entitled "*Drawing insights from pion parton distributions*" published in Chinese Physics C **44** (2020) 031002 and co-authored by Minghui Ding and Daniele Binosi, won the Most Influential Paper Award given by Chinese Physics Society in 2021.
- the paper "*Path-integral calculation of the third dielectric virial coefficient of noble gases*" by Giovanni Garberoglio was selected as Editor's Pick in The Journal of Chemical Physics.

– The paper "*Precision mass measurement of lightweight self-conjugate nucleus ^{80}Zr",* co-authored by Samuel Giuliani was published in Nature Physics **17** (2021) 1408.

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 2021 has only been possible through a stable operating budget in recent years. We gratefully acknowledge the local support from the FBK/PAT, the contributions from European funding agencies and research institutions in Belgium, Croatia, Czech Republic, Finland, France, Germany, Italy, the Netherlands, Poland, Romania, Russia, Switzerland and the United Kingdom. ECT* also acknowledges additional partial support for its workshops received in 2021 from: EMMI (Germany), INFN Frascati (Italy) und TU Darmstadt (Germany).

As for the European projects within the new Framework Programme Horizon 2020, the Strong2020 project started on June 01, 2019, and will end on December 31, 2023. Its transnational access activities have supported 12 workshops in 2021.

2021 was my first year as ECT* Director, after having served on the ECT* Scientific Board since 2016 (as Chair since 2017). COVID affected many aspects, including this Directorship, which was not planned. I am grateful to the Scientific Board, 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* going, in all circumstances, including a pandemic.

As its predecessors the Annual Report of 2021 is available on the ECT* website (www.ectstar.eu). Finally, we note that ECT* joined Twitter in April 2021 and can be found at @EctTrento.

Trento, February 2022 *Gert Aarts*

*Director of ECT**

Scientific Board, Staff and Researchers

1. Scientific Board, Staff and Researchers

1.1 Scientific Board and Director

Almuedena Arcones (from Oct)	TU Darmstadt, Germany
Carlo Barbieri	University of Surrey, UK
Anna Corsi	IRFU/DPhN, France
Marcella Grasso (Chairman & member until Nov)	CNRS-INP Orsay, France
Morton Hjorth-Jensen (until Oct.)	Michigan State Univ., USA and Univ. Oslo, Norway
Marek Lewitowicz	NuPECC/GANIL, France
Barbara Pasquini (from Oct)	INT & Univ. Washington, Seattle, USA
Martin Savage (until June)	INT & Univ. Washington, Seattle, USA
Marc Vanderhaeghen (until Oct)	University of Mainz, Germany
Urs Wiedemann (Chairman from Nov)	CERN-TH, Switzerland
Sandro Stringari (Ex officio)	University of Trento, Italy
Victor Braguta (Ex officio)	JINR, Russia

Honorary Member of the Board

Ben Mottelson — 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
Minghui Ding, China (until Sept)
Saga Aurora Säppi, Finland
Dionysis Triantafyllopoulos, Greece*
Shu-Yi Wei, China (until Sept)

- *Computational Physics*

Maurizio Dapor, Italy (Head of ECT*-LISC Research Unit)*
Pablo de Vera Gomis, Spain (until Oct)

Giovanni Garberoglio, Italy*
Samuel Giuliani, Italy
Andrea Pedrielli, Italy (until Oct)
Simone Taioli, Italy*
Paolo Trevisanutto, Italy (until Aug)

- *ECT*/TIFPA Researchers*

Hilla De Leon, Israel
Constantinos Constantinou, Cyprus

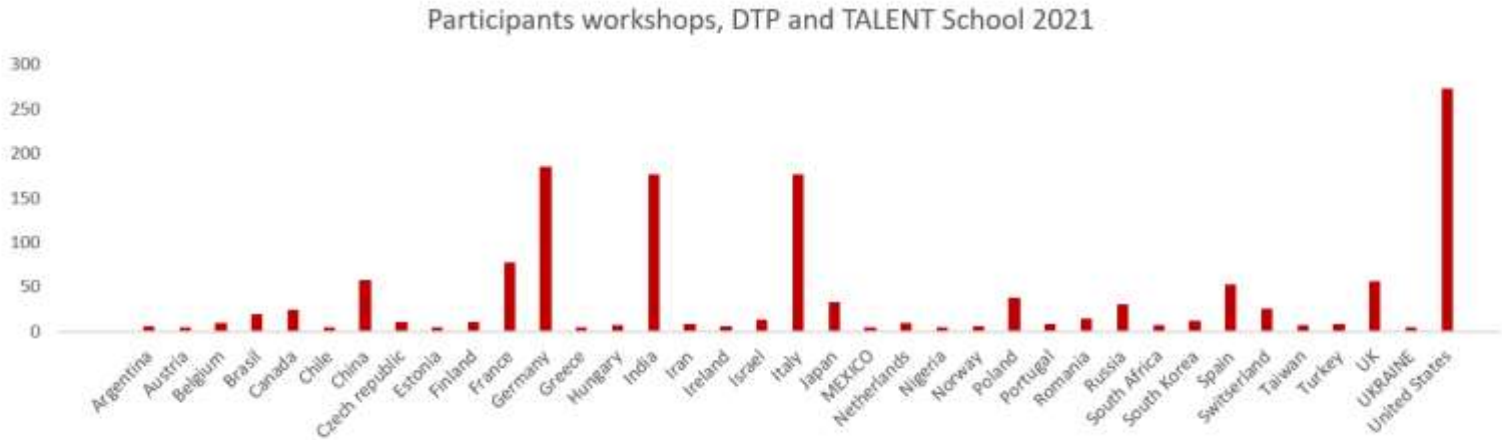
- *ECT* PhD Students*

Luis Benjamín Rodríguez Agui, Guatemala (from Nov)
Luca Vespucci, Italy (from Nov)

*Permanent Researchers

1.3 Staff

Susan Driessen (part time)
Barbara Gazzoli
Michela Chistè


Participants workshops, DTP and TALENT School 2021
300
250
200
150
100
50
0
Argentina
Austria
Belgium
Brasil
Canada
Chile
China
Czech republic
Estonia
Finland
France
Germany
Greece
Hungary
India
Iran
Ireland
Israel
Italy
Japan
MEXICO
Netherlands
Nigeria
Norway
Poland
Portugal
Romania
Russia
South Africa
South Korea
Spain
Switzerland
Taiwan
Turkey
UK
UKRAINE
United States

Scientific Projects in 2021

2. ECT Scientific Projects in 2021

2.1 Summary

Altogether 19 scientific projects have been run in 2021: 17 workshops (14 online), a Doctoral Training Programme (online) and a TALENT School (Online). This chapter collects the scientific reports written by the workshop organizers, by Enrico Rico Ortega who coordinated the DTP, and by Morten Hjorth-Jensen who coordinated the TALENT School.

2.2 Workshops and Schools (Calendar)

Apr 19-23	*Mass in the Standard Model and Consequences of its Emergence (Online)* D. Binosi (ECT*) C. Fischer (Justus-Liebig-Universität Giessen) T. Horn (Catholic University of America) C. Roberts (ANL)
Apr 26-30	*Heavy-Flavor Transport in QCD Matter (Online)* R. Rapp (Texas A&M University) R. Averbeck (GSI, Darmstadt) X. Dong (LBL, Berkeley) P. Gossiaux (Subatech, Nantes) X.-N. Wang (CCNU Wuhan)
20-21 May	*Heavy-Ions and New Physics (Online)* M. Drewes (UCLouvain) D. D'Enterria (CERN) A. Giammanco (UCLouvain) J. Hajer (University of Basel)
24-28 May	*STRANU: Hot Topics in STRANgeness NUclear and Atomic Physics (Online)* K. Piscicchia (Centro Fermi, Roma) C. Curceanu (LNF-INFN, Frascati) D. Gazda (Czech Academy of Sciences) E. Hyama (Kyushu University-RIKEN Nishina Center, Wako) P. Moskal (Jagiellonian University, Krakow) F. Sakuma (RIKEN Nishina Center, Wako)

14-17 June *Neutron Stars as Multi-Messenger Laboratories for Dense Matter (Online)*
I. Tews (LANL, Los Alamos)
B. Giacomazzo (University of Milano-Bicocca)
S. Guillot (IRAP Toulouse)
J. Margueron (IP21 Lyon)
S. Nissanke (University of Amsterdam)

22-23 June *Key Reactions in Nuclear Astrophysics (Online)*
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)

28 June – 23 July *Doctoral Training Program: High-Energy and Nuclear Physics within Quantum Technologies (Online)*
P. Hernandez (University of Valencia)
S. Montangero (University of Padova)
Y. Omar (University of Lisbon)
E. Ortega (UPV/EHU, Ikerbasque)

28 June – 01 July *Nuclear Physics at the Edge of Stability (Online)*
G. Hupin (IJClab)
O. Sorlin (GANIL)
A. Gade (MSU)
L. Platter (UTK)

29 June-01 July *Saturation and Diffraction at the LHC and the EIC (Online)*
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)

05-09 July *Relativistic Fermions in Flatland: Theory and Application (Online)*
S. Hands (Swansea University)
H. Gies (Friedrich Schiller University Jena)
J. Gracey (University of Liverpool)
I. Herbut (Simon Fraser University)

12-16 July *Probing Nuclear Physics with Neutron Star Mergers (Online)*
C. Fryer (LANL)
J. Lippuner (LANL)
M. Mumpower (LANL)

A. Steiner (University of Tennessee)
B. Cote (Konkoly Observatory)
R. Surman (University of Notre Dame)
S. Rosswog (Stockholm University)

19-21 July *Nuclear Physics Meets Condensed Matter: Symmetry, Topology, and Gauge (Online)*
A. Gezerlis (University of Guelph)
A. Roggero (University of Washington)
C. Sa de Melo (Georgia Tech)

19-30 July *TALENT School: Machine Learning applied to Nuclear Physics: Ex-periment and Theory (Online)*
D. Bazin (MSU)
M. Hjorth-Jensen (MSU & University of Oslo)
M. Kuchera (Davidson College)
S. Liddick (MSU)
R. Ramamujan (Davidson College)

27-29 July *Nuclear and Atomic Transitions as Laboratories for High Precision Tests of Quantum Gravity Inspired Models (Online)*
A. Marciano (Fudan University)
C. Curceanu (LNF-INFN Frascati)
K. Piscicchia (Centro Fermi, Roma)
N. Yunes (University of Illinois at Urbana-Champaign)

06-10 September *LFC21: Strong Interactions from QCD to New Strong Dynamics at LHC and Future Colliders (Online)*
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)

13-17 September *Tackling the Real-Time Challenge in Strongly Correlated Systems: Spectral Properties from Euclidean Path Integrals (Online)*
S. Ryan (Trinity College Dublin)
A. Rothkopf (University of Stavanger)
A. Francis (CERN)

27 Sep-01 Oct *Machine Learning from High Energy Physics: On and Off the Lattice (Hybrid)*
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)

11-15 October *Exploring High MuB-Matter with Rare Probes (Hybrid)*
E. Scomparin (INFN Torino)
T. Galatyuk (TU Darmstadt)
M.P. Lombardo (INFN-LNF)
R. Rapp (Texas A&M University)
G. Usai (University and INFN Cagliari)

15-18 November *Quark-Gluon Plasma Characterisation with Heavy Flavour Probes (Hybrid)*
G. Bruno (University and INFN Bari)
J. Aichelin (SUBATECH)
R. Averbeck (GSI & EMMI)
F. Grosa (INFN Torino)

2.3 Workshop reports

2.3.1 Mass in the Standard Model and Consequences of its Emergence (Online)

Date	April 19-23, 2021
Organizers	
Daniele Binosi	ECT*, Italy
Christian Fischer	Justus-Liebig-Universität Giessen, Germany
Tanja Horn	Catholic University of America, USA
Craig Roberts Nanjing	University, China
Number of participants	81

Main topics

The USA's National Academy of Science, assessing the case for an electron ion collider (EIC), stated that revealing the origin of the proton's mass is one of the most profound questions in physics. The question's simplicity hides its breadth. Its answer will explain, inter alia: why the proton is stable; why mproton ≈ 2000 melectron; and why the strongly-interacting pion possesses a lepton-like mass. Not all answers may need to wait for an EIC.

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 promise to expose the structure of hadrons with unprecedented detail. We are on the verge of a new era in strong interaction physics.

This workshop will therefore gather a group of experts to discuss significant developments, identify new goals, and plan the next steps forward in strong QCD.

Speakers

Patrick Barry	Thomas Jefferson National Accelerator Facility, USA
Daniele Binosi	ECT*, Italy
Daniel Carman	Thomas Jefferson National Accelerator Facility, USA
Chen Chen	University of Giessen, Germany
Alaa Dbeyssi	Helmholtz-Institut Mainz, Germany
Oleg Denisov	INFN Torino, Italy
Alexandre Deur	Thomas Jefferson National Accelerator Facility, USA
Minghui Ding	ECT*-FBK, Italy
Dalibor Djukanovic	Helmholtz Institute Mainz, Germany
Gernot Eichmann	LIP & IST Lisboa, Portugal

Rolf Ent	Thomas Jefferson National Accelerator Facility, USA
Feng-Kun Guo	Inst. of Theoretical Physics, Chinese Academy of Sciences, China
Gastao Krein	Instituto de Fisica Teorica, Brasil
Shunzo Kumano	KEK, Japan
Huey-Wen Lin	Michigan State University, USA
Hervé Moutarde	IRFU, CEA, France
Sebastian Neubert	Helmholtz-Institut für Strahlen- und Kernphysik, Germany
Elisabetta Prencipe	Physikal. Institut, Justus-Liebig-Universität Gießen, Germany
Jianwei Qiu	Jefferson Lab, USA
Khépani Raya	Nankai University, China
Sinéad Ryan	Trinity College Dublin, Ireland
Jorge Segovia	University Pablo de Olavide, Seville, Spain
Adam Szczepaniak	Indiana University, USA
Bogdan Wojtsekhowski	TJNAF, USA
Bowen Xiao	The Chinese University of Hong Kong, Shenzhen, China

Scientific report

Understanding the character of emergent mass within the Standard Model requires a synergistic effort, joining experiment, phenomenology, and theory. This programme therefore focused on identifying key concepts and questions that need to be exploited and addressed by this effort. Emphasis was accorded to the following topics.

Contemporary and planned facilities. Accumulating evidence suggests that confinement and dynamical chiral symmetry breaking are intimately connected; rely on the appearance of momentum-dependent masses for gluons and quarks; and arise as corollaries of the emergence of mass. Since they are implicit in all hadronic observables, well-planned experiments can verify both their appearance and expression in the Standard Model.

QCD's Effective Charge. The past decade has revealed that QCD possesses a unique, process-independent effective charge in QCD, which appears in the kernel of every dynamical equation supported by the theory. A thorough exploration of the properties and consequences of this novel effective charge is critical to understanding QCD and illuminating QCD's potential to serve in extending the Standard Model.

Continuum Schwinger function methods. Continuum methods 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.

Non-Abelian essence of QCD. Continuum and lattice methods suggest that the 3-gluon interaction is much weaker than its perturbative strength at infrared momenta;

and phenomenological studies indicate that such behaviour can be crucial to the emergence of “glueball” and “hybrid” hadrons in the spectrum. Such ideas must be tested, and further implications identified and explored.

Glueball and hybrid states. The existence of such states would lead to a dramatic reassessment of the distinction between matter and force fields, which has existed since Maxwell, and flagship experiments are underway or planned at all facilities around the world that can produce hadrons. Theory and phenomenology must deliver sound tools for the prediction of glueball and hybrid properties and how experiment can best reveal them.

Result 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 to the Covid-19 pandemic, this meeting became a virtual workshop. This changed the character of the meeting, 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 five presentations followed by an active discussion session, coordinated by an experienced moderator.

Modern and planned facilities will probe hadronic interiors with an unprecedented level of detail. Therefore, the programme included high-level explanations, delivered by leading experimental physicists, of research plans and goals at the world’s leading accelerator facilities, including those proceeding toward construction or in planning. These presentations were complemented by an array of oral papers on phenomenology and theory, which described the development of new tools for analysis and prediction of novel phenomena.

Importantly, given that alternative field theoretic mechanisms accounting for the interplay between QCD’s emergent phenomena may have differing experimental signatures in the spectra and properties of mesons and baryons, e.g., parton distributions, electromagnetic and/or transition form factors, there was a thorough discussion of these possible differences. Steps were made toward identifying efficacious ways of discriminating between competing and complementary approaches.

In addition, despite being hampered by the virtual workshop format, closer ties were drawn between practitioners of all methods that provide access to strong QCD, and between experimentalists and theorists. These enhanced personal contacts are enabling a freer exchange of ideas between the world's practitioners, thereby accelerating the rate at which science can deepen its understanding of the fundamental mechanisms underlying dynamical mass generation and identify the measurable signatures.

The discussion sessions were very valuable, with a high level of participation each day. Ensuring this was non-trivial, given that each day of the virtual workshop ran to the midnight hours for many of those taking part. The candid discussions raised awareness of novel research efforts by the participants and have spawned many new collaborations.

2.3.2 *Heavy-Flavor Transport in QCD Matter (Online)*

Date April 26-30, 2021

Organizers

Ralf Averbeck	GSI, Germany
Xin Dong	LBNL, USA
Pol Gossiaux	SUBATECH, France
Ralf Rapp	Texas A&M University, USA
Xin-Nian Wang	LBNL, USA

Number of participants 69

Main topics

The theme of the workshop was focused on the theoretical description of the transport of heavy-flavor particles (i.e., charm and bottom quarks and the hadrons containing them) in hot QCD matter and its phenomenological applications to high-energy heavy-ion collisions at RHIC and the LHC. The discussions were organized according to a decomposition into basic building blocks in the transport approaches:

- Heavy-quark (HQ) diffusion in the quark gluon plasma (QGP)
- Hadronization of heavy quarks into heavy-flavor hadrons
- Gluon radiation off heavy quarks
- Bulk evolution models for heavy-ion collisions

Speakers

Joerg Aichelin	University of Nantes, France
Ralf Averbeck	GSI, Germany
Steffen Bass	Duke University, USA
Andrea Beraudo	INFN Torino, Italy
Elena Bratkovskaya	GSI, Germany
Peter Braun-Munzinger	GSI, Germany
Giuseppe Bruno	INFN and University of Bari, Italy
Shanshan Cao	Shandong University, China
Andrea Dainese	INFN Padova, Italy
Santosh Das	IIT Goa, India
Xin Dong	LBNL, USA
Wenkai Fan	Duke University, USA
Marco Giacalone	University of Bologna, Italy
Pol Gossiaux	Subatech, France
Min He	Nanjing University of Science & Technology, China

Roland Katz	Subatech, France
Weiyao Ke	UC Berkeley & LBNL, USA
Viljami Leino	Technical University of Munich, Germany
Jinfeng Liao	Indiana University, USA
Shuai Liu	IMP Lanzhou, China
Marlene Nahrgang	IMT Atlantique, France
Lucia Oliva	Goethe University Frankfurt, Germany
Peter Petreczky	BNL, USA
Salvatore Plumari	University of Catania, Italy
Guang-You Qin	CCNU, China
Ralf Rapp	Texas A&M University, USA
S. Shi McGill	University, Canada
Taesoo Song	GSI, Germany
Johanna Stachel	University of Heidelberg, Germany
Hendrik van Hees	Goethe University Frankfurt, Germany
Ivan Vitev	ANL, USA
Xin-Nian Wang	LBNL, USA

Scientific report

Heavy-flavor (HF) particles are key probes of hot and dense QCD matter as produced in high-energy collisions of heavy nuclei. Intense experimental efforts have been undertaken to measure HF observables at RHIC and the LHC and are underway in upgrade projects that will provide a major increase in precision of existing, as well as access to new, observables. These improvements pose an urgent need for a robust theoretical modelling of HF transport through the quark-gluon plasma, its hadronization and the subsequent hadronic phase, which forms the basis for a quantitative extraction of transport properties along with an understanding of the underlying microscopic interactions. The large masses of the charm and bottom quarks (relative to the typical temperatures in the system) play a key role in this endeavour: at low-momentum, they exert “Brownian motion” enabling a unique access to the HF diffusion coefficient; the delay in their thermalization time (compared to light partons) offers unique insights into the interaction strength and scattering rates in the medium; and their color-neutralization into different hadrons (e.g., D, D_s, Λ_c) gives valuable information on mechanisms of hadronization. Toward higher momenta, a transition into a radiative energy-loss regime is expected, which allows to scrutinize gluon radiation mechanisms and their competition with elastic interactions.

The idea was to bring together the different research groups working in this field and perform critical inspections and comparisons of the main components in their HF transport approaches. Due to the conversion from the original onsite meeting (scheduled for Feb 24-28, 2020) to a full online format, the meeting was organized into 4 compact (but intense) daily sessions (14:00-19:00 local time, with 2 breaks in between), followed by a wrap-up on Friday afternoon.

The first day of the meeting started out with symposium-style presentations, surveying the state-of-the-art and future perspectives of HF experiments, lattice-QCD computations on the HF transport coefficients and related quantities (e.g., Euclidean correlators, HQ free energies and in-medium HQ masses), and brief reports of previous working-group style meetings on the topic (EMMI Rapid Reaction task force and a HF-jet working group), highlighting some of the open issues. The day wrapped up with a critical discussion of theoretical calculations of transport coefficients and hadronization ratios (provided by 9 groups) that the organizers had designed as a pre-meeting activity for the various groups. While some degree of agreement was found for quantities related to observables, the input transport coefficients still showed a large spread, in particular also for the 3-momentum dependencies.

On day-2 the focus was on the (low-momentum) diffusion properties of heavy quarks in the QGP. After an initial lattice-QCD presentation, 11 presentations from different transport groups were given. Most groups are relying on effective one-gluon exchange diagrams as their effective HQ interaction with light quarks and gluons, albeit with rather different prescriptions to upscale the interaction strength needed to be able to describe heavy-ion data, in particular the observed low-momentum elliptic flow. Two groups are currently using nonperturbative approaches, either in terms of a resummed T-matrix with residual confining interactions constrained by lattice-QCD data (TAMU), or an effective quark-meson model with D-meson resonances (Frankfurt). There was some consensus that resummations should also be considered in effective perturbative interactions, and that all models should attempt to implement constraints from lattice-QCD, such as mesonic correlation functions in the color-singlet channels. It was also agreed that the large spread in the 3-momentum dependence of the transport coefficients deserves further scrutiny, as there should be a unique answer on this from QCD which the models should strive to unravel.

On day-3 the focus was on HQ hadronization models, with 10 groups presenting their pertinent approach. The Statistical Hadronization Model is based on the assumption of full thermalization of charm quarks (which in transport models requires a very strong HQ-medium coupling), resulting in a good overall description of available open-charm and charmonium yields and transverse-momentum spectra up to $p_T \sim 5$GeV. Most approaches employ instantaneous coalescence models (ICMs), where heavy- and light-quark distributions are projected into schematic HF hadron wave functions; the employed parameter values, e.g., the light-parton masses, the number of light partons in the system, and the wave function parameters, differ considerably. A calculation implementing energy conservation in ICMs via final-state pion emission, which recovers kinetic equilibrium for c-hadrons in a static medium, was reported by the LBNL group. Two groups are using a different approach, i.e., the resonance recombination model (TAMU group) which conserves 4-momentum and recovers equilibrium abundances and spectra, and in-medium string fragmentation with thermal partons (Torino group). The importance of benchmark tests was realized, e.g., by scrutinizing parameter dependencies to minimize deviations from basic principles or making connections to the underlying QCD interactions.

On day-4 the gluon radiation off heavy quarks was discussed, with 6 pertinent presentations. Soft collinear effective theory (SCET) was emphasized as a systematic approach to account for multiple emission and interference effects; it was shown to describe HQ observables for momenta above $p_T \sim 10$ GeV. Stochastic and non-local implementations of the nontrivial path length dependence due to interference effects in gluon radiation were reported in 3 transport approaches (LBNL, Duke and Nantes); these satisfy constraints from a static medium and generally lead to a good description of high-p_T HF data. The role of thermal gluon masses (as, e.g., in hard-thermal loop calculations) in the radiation spectrum was discussed, which was found to be large in a schematic nonperturbative setting (TAMU).

Results and Highlights

The workshop provided a unique forum to carry out in-depth comparisons of key model components in the description of HF transport in heavy-ion collisions, which is critical toward a reliable interpretation of experimental data from RHIC and the LHC, thus benefitting the broader "hot-QCD" community. While the online format did not reach the level of scrutiny that an in-person meeting achieves, the mutual exchange of different viewpoints and ideas led to significant progress in the understanding of the virtues and shortcomings of the various model components that are currently being used in comparisons to data. This sets a stage for improving the quality of all models involved, ultimately leading to a significant reduction in the systematic error of the transport results.

The last afternoon on day-5 was used to reiterate the most important issues. The following list of recommendations and intents that were broadly supported by the participants attest to the success of the meeting:

- A common state-of-the-art bulk-medium evolution model (viscous hydrodynamics) should be used to run with as many of the available HQ transport coefficients as possible.
- Within the different bulk evolution models currently in use, a temperature (or energy density) profile as encountered by a charm quark propagating from the center of the fireball should be evaluated.
- Charm-quark spectra unfolded from the state-of-the-art charm-hadron spectra measured at the LHC (using, e.g., FONLL) should be employed by all groups.
- Systematic constraints from lattice-QCD correlators should be pursued by projecting HQ scattering amplitudes, as used by the various groups, into color-neutral channels as available from the lattice.
- The parameter dependence in the various hadronization models should be studied for a simplistic fireball model at a given hadronization temperature, in connection with a common charm-quark distribution function as transported through the QGP.

- Gluon mass effects in the emission spectra should be analyzed conceptually and quantitatively

2.3.3 *New Physics Searches in Heavy Ion Collisions (Online)*

Date	May 20-21, 2021

Organizers

Marco Drewes	UCLouvain, Belgium
David d'Enterria	CERN, Switzerland
Andrea Giammanco	UCLouvain, Belgium
Jan Hajer	University of Basel, Switzerland

Number of participants	142

Main topics

The goal of the workshop was to provide a platform for an open discussion of the potential to search for New Physics in heavy ion collisions. Specific topics include:

- What signatures can be searched for?
- What new particles can be found?
- Which new exotic phenomena in the Standard Model can be probed?
- Which ions should be used?
- How can the integrated luminosity in heavy ion runs be optimized?
- How can the experimental triggers be optimised?
- How can one exploit the absence of pile-up in heavy ion collisions?
- Are there well-motivated hardware modifications?
- What are the implications for future colliders?

Speakers

Roderik Bruce	CERN
Survat Rao	Hamburg University
Emilien Chapon	IHEP Beijing
Kristof Schmieden	Mainz University
Murilo Rangel	University Rio de Janeiro
Mateusz Dyndal	Krakow
Artu Rajantie	Imperial College
Aditya Upreti	University of Alabama
James Pinfold	University of Alberta
Yen-Jie Lee	MIT
Taku Gunji	University of Tokyo
Susanne Westhoff	Heidelberg

Hesham El Faham	UCLouvain
Ralf Ulrich	CERN
Oliver Fischer	Liverpool
Glennys Farrar	New York University
Lucien Harland Lang	Oxford

Scientific report

During the workshop various ideas to search for new phenomena were discussed. A main focus was the potential to use the LHC as a photon collider by exploiting the strong electromagnetic fields generated in heavy ion collisions. A related discussion concerned the possibility to exploit production mechanisms that are absent or suppressed in proton collisions, such as non-perturbative production of monopoles through the Schwinger effect or thermal production in the quark gluon plasma. Other topics included the possibility to take advantage of the different backgrounds and systematic limitations in heavy ion collisions compared to proton collisions (such as the absence of pile-up and the possibility to lower the trigger thresholds), new detectors (MAPP, Castor), the benefit of heavy ion collisions for the understanding of cosmic air showers, and measurements of g-2 in heavy ion collisions. Finally, there were summary talks on recent developments and future perspectives on the accelerator as well as software sides. A summary of the main results can be found in the Snowmass White Paper [1].

Result and Highlights:

The workshop resulted in a report [1] that was submitted to the Snowmass Energy Frontier [2].

Program

All details can be found on the Workshop Website [3].

[1] https://arxiv.org/abs/2203.05939

[2] https://snowmass21.org/submissions/ef

[3] https://indico.cern.ch/event/831940/

2.3.4 *STRANU: Hot Topics in STRANgeness NUclear and Atomic Physics (Online)*

Date	May 24-28, 2021

Organizers

Kristian Piscicchia	Centro Ricerche Enrico Fermi, Italy
Catalina Catalina	LNF-INFN, Italy
Daniel Gazda	NPI, Czech Academy of Sciences, Czech Republic
Emiko Hyama	Kyushu Univ./RIKEN Nishina Center for Accelerator-Based Science, Japan
Pawel Moskal	Jagiellonian University, Poland
Fuminori Sakuma	RIKEN Nishina Center for Accelerator-Based Science, Japan

Number of participants	78

Main topics

The STRANU workshop focused on the recent results, developments and open questions in the low-energy strangeness physics sector and related areas. The workshop brought together world-leading experts, young scientists and students, from both the theoretical and experimental sides. The present status and the open topical questions were discussed, among which the properties of kaonic nuclear matter, the nature of the Lambda(1405) and the role of strangeness in astrophysics. The workshop was dedicated to the career, research activities and the fundamental contributions, which Prof. Sławomir Wycech has given and continues to give to strangeness nuclear and atomic physics.

The main topics were:

- Kaon-nucleon/nuclei interaction
- Kaonic atoms
- Anti-Kaon-Nucleon scattering
- Nature of the Lambda(1405)
- Strangeness in compact stars
- Hyperon-Nucleon many body interaction
- Hypernuclei

Speakers

Nir Barnea	Hebrew University, Jerusalem, Israel
Emma Chizzali	TUM, Germany
Ales Cieply	Nuclear Physics Institute, Rez, Czech Republic
Raffaele Del Grande	TUM, Germany
Alessandro Drago	University of Ferrara, Italy

Albert Feijoo	IFIC, Spain
Eli Friedman	Hebrew University, Jerusalem, Israel
Avraham Gal	Hebrew University, Jerusalem, Israel
Fabian Hildenbrand	TU Darmstadt, Germany
Parada Hutauruk	Pukyong National University (PKNU), South Korea
Marc Illa	Universitat de Barcelona, Spain
Masahiko Iwasaki	RIKEN, Japan
Maximilian Korwieser	TU Munich, Germany
Győző Kovács	WIGNER, Hungary
Péter Kovács	WIGNER, Hungary
Benoit Loiseau	LPNHE, France
Georgios Mantzaridis	MSU, USA
Marco Miliucci	Hebrew University, Jerusalem, Israel
Raquel Molina	UV-IFIC, Spain
Pawel Moskal	Jagiellonian University, Poland
Tomofumi Nagae	Kyoto University, Japan
Fabrizio Napolitano	INFN - Laboratori Nazionali di Frascati, Italy
Hiroyuki Noumi	Osaka University, Japan
Alexandre Obertelli	TU Darmstadt, Germany
Jaroslava Obertova	ASCR, Rez, Czech Republic
Shinji Okada	Chubu University, Japan
Peter Pauli	University of Glasgow, Scotland
Axel Pérez-Obiol	Barcelona Supercomputing Center, Spain
Kristian Piscicchia	Centro Ricerche Enrico Fermi, LNF (INFN), Italy
Angels Ramos	University of Barcelona, Spain
Takehiko Saito	RIKEN, GSI and Lanzhou University
Martin Schäfer	Hebrew University, Jerusalem, Israel
Alessandro Scordo	LNF-INFN, Italy
Francesco Sgaramella	LNF-INFN, Italy
Nina Shevchenko	Nuclear physics institute
Rajeev Singh	INP Polish Academy of Sciences, Poland
Diana Sirghi	LNF-INFN, Italy
Magdalena Skurzok	Jagiellonian University, Poland
Laura Tolos	ICE, Spain & University of Stavanger, Norway
Isaac Vidana	INFN, Italy
Slawomir Wycech	National Centre for Nuclear Research, Poland

Scientific report

The experimental investigation of strange exotic atoms and low-energy interactions of anti-kaons and hyperons with nucleons and nuclei provides fundamental constraints on theoretical models describing the strong interaction in the low-energy regime. The physics of strange hadrons at low energies is extremely challenging since the meson-baryon interaction requires a complex, multichannel and non-perturbative approach. Kbar-N interaction is the ideal testing ground to explore the fundamental symmetries of the strong interaction, such as the chiral symmetry in its breakdown in the strangeness sector. During the workshop, the most recent theoretical and experimental results were presented and discussed, covering the following items:

- the near-threshold interactions of strange hadrons,
- Kbar-N interaction above and below the threshold and Kbar in medium properties,
- hyperon-nucleon/s interactions properties by exploiting femptoscopic techniques as well as in-medium final state interaction processes,
- the nature of the Lambda(1405) state, investigation of the Lambda(1520),
- the nature of the dibaryon d*(2380),
- Electroweak properties of kaons in a nuclear medium,
- Vorticity and polarization of Lambda hyperons,
- the strength of the Kbar-N Isospin zero interaction triggering the formation of exotic Kbar-multiN states,
- Hypernuclear physics,
- The role of strangeness in neutron stars,
- Three-flavor vector meson extended PQM model
- Kaonic atoms

The second day of the workshop was dedicated to the career of Prof. Sławomir Wycech. In this occasion, seminars were given outlining the efforts and the achievements of the last fifty years of strangeness nuclear physics. In addition to this main theme, a number of other subjects were also discussed, including:

- Baryonia
- Borromean objects
- Antiprotonic atoms and nuclear structure

Results and Highlights

Hot and debated topics in strangeness physics are going to be better understood, and eventually solved, in the coming years. The workshop represented a perfect stage, for the several experimental groups participating, to update the community on the newest measurements and constraints. From the theoretical point of view the development of the models, based on the new inputs, as well as the future landscapes of the calculations were presented, which served as a guide for the discussion and design of the future experiments. The important implications on the study of the equation of state of neutron stars were discussed, which turn to be of great interest for the possible consequences in gravitational waves measurements.

During the session dedicated to the fundamental research achievements of Prof. Sławomir Wycech, him and other eminent personalities outlined the major issues in strangeness low-energy physics, by addressing questions such as: what is the nature of hadron interactions at very low-energies? How are the ongoing experimental searches on kaonic atoms, kaon and hyperon interactions with nucleons above and below threshold helping to unveil it? Are we about to solve the puzzle of the Lambda(1405) and Kbar-multi nucleon bound states? What is the future of nuclear structure investigation by means of antiprotonic atoms?

The new panorama of the research in the field was defined. The perspectives of the researches were outlined, thus setting the direction of the future experimental investigations (in Europe at DAFNE and CERN and in Japan at RIKEN), of the technical development of new radiation detector systems, and of the theoretical studies in the leading groups of this field. STRANU represented the perfect occasion for taking stock and glance at new horizons.

2.3.5 *Neutron Stars as Multi-Messenger Laboratories for Dense Matter (Online)*

Date	June 14-17, 2021
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	Approx. 100

Main topics

The general theme of the workshop concerned multi-messenger observations of neutron stars and neutron-star mergers, and their impact on our understanding of strongly-interacting matter. This understanding is encoded the nuclear equation of state (EOS) that can be inferredfor nuclear theory, experiment, and astrophysical observations of neutron stars. In the pastfew years, many new observational data of neutron stars became available: gravitational-waveobservations of neutron star mergers by LIGO/Virgo, electromagnetic observations of kilonovae, radio signals, and X-ray signals (both with and without time variation). In this workshop, we brought together experts for these various new observational techniques,nuclear experimentalists, and nuclear theorists with the goal to update each other on recent developments, critically examine the new data, and identify shortcomings and future pathwaysfor improvement to obtain a better understanding of the EOS.

The main topics addressed in the workshop were:

- Gravitational waves, electromagnetic counterparts and neutron-star merger simulations
- Observation by the Neutron-Star Interior Composition Explorer and other observations
- Nuclear physics input for the EOS from experiment and theory.

Speakers

Almudena Arcones	TU Darmstadt, Germany
Sebastiano Bernuzzi	University of Jena, Germany
Slavko Bogdanov	Columbia University, USA
Thankful Cromartie	Cornell University, USA
Soumi De	Los Alamos National Laboratory, USA
Tim Dietrich	University of Potsdam, Germany

Anthea Fantina	GANIL, France
Tetyana Galatyuk	GSI Darmstadt, Germany
Tyler Gorda	TU Darmstadt, Germany
Charles Horowitz	Indiana University, USA
Jay Kalinani	University of Padua, Italy
Mansi Kasliwal	California Institute of Technology, USA
Ben Margalit	University of California Berkeley, USA
Cole Miller	University of Maryland, USA
Francesco Pederiva	University of Trento, Italy
Geert Raaijmakers	University of Amsterdam, The Netherlands
David Radice	Pennsylvania State University, USA
Nanda Rea	Institute of Space Sciences Barcelona, Spain
Jocelyn Read	California State University Fullerton, USA
Andrew Steiner	University of Tennessee Knoxville, USA
Anna Watts	University of Amsterdam, The Netherlands
Natalie Webb	IRAP Toulouse, France

Scientific Report

Neutron stars are ideal laboratories for dense nuclear matter because neutron star interiors reach the highest densities in the universe. The structure of neutron stars is described by the equation of state (EOS) which depends on the microscopic interactions among neutrons and protons and maybe other exotic particles in the neutron-star cores. Neutron-star observations offer an ideal tool to measure the EOS and, hence, strong interactions in dense matter that cannot be investigated in laboratories on Earth. During the last decades, neutron-star observations have been in the center of dense-matter nuclear astrophysics.

Until a few years ago, the most stringent constraints on neutron stars came from mass observations of heavy pulsars. In the last few years, new techniques and observations have become available. In 2017, the first gravitational waves from a binary neutron-star merger, GW170817, have been detected by the LIGO and VIRGO Collaborations. In addition to the gravitational-wave signal, telescopes around the world observed electromagnetic counterparts:a so-called kilonova and a gamma-ray burst. This “multimessenger” signal has started a new field of scientific research. Furthermore, since 2019, the Neutron-Star Interior Explorer(NICER) mission of NASA has measured the radii of two neutron-stars using X-ray pulse-profilemodelling. These various neutron-star observations offer new and exciting possibilities to constrain the nuclear EOS in the neutron-star regime.

This variety of new data from different sources is accompanied by different systematic and statistical uncertainties and requires modelling of various physical processes. Pulsar mass- measurements using Shapiro Delay provide a reliable way to determining masses of neutron stars and are mainly limited by statistics but otherwise very precise as they are based in timing observations. In contrast, NICER measures the X-ray pulse profile of rotating millisecond pulsars to extract the neutron stars mass and radius. This requires extensive modelling of the X-ray emission from pulsars, e.g., its geometrical hot-spot configuration. This challenging task is performed independently by two groups within the NICER collaboration who find compatible results that were presented during the workshop. For one of the NICER targets,differences between the two groups' analyses seem to indicate uncertainties due to modelling choices. In contrast, information can also be extracted by modelling time-independent X-ray emissions of neutron stars. Furthermore, gravitational-wave observations by LIGO are sensitive to the inspiral of two neutron stars in a binary shortly before their coalescence, and measure the neutron stars' deformability due to the gravitational field of the partner. This requires extensive modelling of these processes in the strong gravitational fields described by General Relativity and numerical simulations. These simulations are also important to extract properties of the electromagnetic counterparts, which currently are the only means of probing the post-merger phase and provide additional constraints on the nuclear EOS.

Important information on neutron-rich matter explored in neutron stars can also be extracted from nuclear theory and experiment. For example, the recent PREX experiment at JeffersonLab in the USA measured the neutron-skin thickness of ^{208}Pb and extracted a large symmetry energy, leading to a “stiff” low-density EOS, in contrast to predictions of nuclear theory that favour a soft EOS at low densities. In addition, information on the EOS in the limit (n> 40 nsat)can be obtained from perturbative QCD simulations. These different inputs can be combined using multimessenger frameworks that use many available data to constrain the nuclear EOS. During the workshop, several such approaches were extensively discussed and compared.

Finally, the workshop included extensive discussion time in which discussion leaders (chosen experts in the fields) discussed shortcomings and uncertainties, solutions and future pathways of the individual approaches to extract information on dense matter. In addition to these topics,the following topics have been discussed during the workshop: models for the neutron-star crusts at finite temperatures and connecting r-process simulations to observations.

	GW	Radio	X-ray
Mass	Inspiral (+ kilonova?)	Radio pulsar timing	Pulse profile modelling Cooling/burst spectroscopy Resonant shattering flare (EM-GW) Fe-line + kHz QPOs
Radii	Indirect (from inspiral and maybe eventually ringdown)		Pulse profile modelling Cooling/burst spectroscopy Resonant shattering flare (EM-GW) Fe-line + kHz QPOs
MOI		Radio pulsar timing	
Tidal deformability	Inspiral		
Atm composition			Spectral modelling X-ray absorption lines Burst properties
Magnetic field		Radio pulsar timing (only dipoles)	Spectral modelling X-ray absorption lines X-ray cooling Pulse profile modeling (geometry)
Crustal composition	In principle yes in practice hard?	Glitches	X-ray cooling (Super)burst ignition
Impurity fraction		Spin period distributions	Spin period distribution X-ray cooling

Results and Highlights

The workshop provided the participants with an excellent opportunity to discuss and critically examine the many new pieces of information on neutron stars and their EOS. This was appreciated by the workshop participants.

An important theme during the workshop where uncertainties for different extractions of the EOS, from uncertainties in the analysis of the PREX-II experiment and its extrapolation to neutron-star conditions to uncertainties in the different observational techniques. In particular,the discussion session provided the participants with ample time to address the individual sources of uncertainty for the various neutron star data. A highlight was a slide prepared bythe discussion session leaders Profs. A. Watts and N. Rea that showed how well different observational techniques can infer different neutron-star properties (attached: green small systematic uncertainties, orange: systematic modelling uncertainties, red: cannot be inferred).

This slide summarizes the main results of the workshop well. Gravitational-wave observations can accurately determine neutron star masses and tidal deformabilities which are parameters that are imprinted in the gravitational waveform. Given current detectors, systematic uncertainties due to waveform modelling are not yet large enough but they may become important in future with improving detectors. Additional constraints on radii etc. are possible, but necessary model assumptions introduce systematics. Radio observations can measure masses and the neutron star moment of inertia very well, because these can be inferred from accurate timing measurements. Finally, X-ray observations are very versatile and can be used to infer many neutron-star observables, but both time-dependent (NICER) and time- independent X-ray observations suffer from larger systematic uncertainties. These need to be addressed in future.

In addition to this slide covering the various observational aspects addressed during the workshop, important results included the discussion of the recent PREX-II measurement and different schemes to combine various observations. For the former, the participants actively discussed modelling assumptions made by the PREX collaboration and how they might have affected their surprising result. Regarding the latter, the participants discussed various approaches to extract "multimessenger" constraints on the EOS and the influence of different modelling assumptions, e.g., the use of Bayesian inference vs. more general analyses, different nuclear-physics prior choices, and different ways of including astrophysical data.

2.3.6 *Key Reactions in Nuclear Astrophysics (Online)*

Date	June 22-23, 2021
Organizers	
Aurora Tumino	Università degli studi di Enna “Kore” & INFN-LNS, Italy
Jordi José	Technical University of Catalonia, Italy
Carlos Bertulani	Texas A&M University-Commerce, USA
Livius Trachel	FIN-HH Bucharest-Magurele, Romania
Roland Diehl	MPP, Germany
Number of participants	100

Main topics

This online workshop intended to promote the in-presence workshop that will take place at ECT* next year (12-16 December 2022) and whose aim is todiscuss existing results in nuclear astrophysics and to identify key reactions for which the stable and RIB facilities need to assess information. The online workshop was focused on activities connected to the chemical evolution of massive stars and to the nucleosynthesis of elements heavier than iron.

The main topics were

- Massive stars environments
- Heavy-ion fusion reactions
- The r-process
- Astrophysical sources

Speakers

Alessandro Chieffi	Istituto Nazionale di Astrofisica – IAPS, Rome, Italy
Sandrine Courtin	Institut Pluridisciplinaire Hubert Curien, Strasbourg, France
Scilla Degl’Innocenti	Università di Pisa, Italy
Carla Frohlich	North Carolina State University, North Carolina, USA
Moshe Gai	University of Connecticut, Groton, USA
Taka Kajino	National Astr. Observatory of Japan, Tokyo, Japan & Beihang Univ., Beijing, China
Grant Mathews	Center for Astrophysics, Notre Dame University, Indiana, USA
Jorge Pereira	National Superconducting Cyclotron Laboratory, MSU, USA
Giuseppe G. Rapisarda	Università degli Studi di Catania, Italy & INFN-LNS
Robin Smith	Sheffield Hallam University & University of Connecticut, USA
Alexandra Spiridon	Institute of Physics and Nuclear Engineering, IFIN-HH, Romania
Rebecca Surman	Dept. of Physics, University of Notre Dame, Indiana, USA

Scientific report

The chemical evolution of the Universe is governed by an intricate pattern of nuclear processes that take place in stars, both during quiescent evolution and explosive scenarios. The initial chemical composition and mass of a star govern which reactions in turn dominate the burning processes, thus affecting and regulating the star's evolutionary fate. Topic of the first day of the workshop was the evolution of massive stars through the analysis of crucial nucleosynthesis branches such as 12C(□,□)16O and 12C+12C fusion. The 12C(α,γ)16O reaction determines the 12C/16O ratio at the end of helium burning. This in turn affects the onset of the next stages of stellar burning, that of carbon and oxygen fusion. The 12C+12C fusion governs the stage of carbon-burning and is extremely important to understand supernovae outcomes and X-ray superbursts origin. The second day was dedicated to the origin and nucleosynthesis of r-process elements in the Universe. The goal of understanding nuclear processes far from stability is to provide reliable interpretations of the light curves and production patterns of heavy elements observed in multi-generational stars or those associated with stellar explosions.

Results and Highlights

The online workshop was a very useful opportunity to advertise some of the topics of the in-presence workshop. It provided the community with the latest news and results on the addressed topics and of course they will deserve additional discussion. There are numerous open questions associated with stellar nucleosynthesis, which require improved data and improved modeling to reliably address the underlying physics of stellar evolution.

The cross sections at astrophysical energies are extremely low, in the sub-femtobarn range and rely strongly on the low energy extrapolation of the laboratory data. Several experimental and theoretical methods and techniques have been developed over the years to measure and model the reaction mechanisms towards stellar energies, but there are still shortfalls. Direct measurements are pursued by on-surface as well as on underground accelerator measurements to reduce the cosmic-ray induced background in the detector materials. The very low cross-sections at the relevant energies constrain physicists to long experiment with not always controlled backgrounds. These techniques are complemented by indirect methods, seek to populate the compound nucleus by transfer reactions or Coulomb-, electron-, or photon-disintegration processes to explore the nuclear structure near the threshold and/or to determine the relevant two body cross-sections at energies not accessible to direct measurements. These techniques require careful cross-checks for their predictions to be reliable. As for the measurement of nuclear reactions on unstable nuclei, this is a challenge because of difficulties producing sufficiently intense radioactive ion beams at energies relevant for stars and stellar explosions. The new generation of radioactive beam facilities will allow to measure nuclear reaction and nuclear structure parameters that are important for improved simulations of the reactionpaths far from stability, mapping the observational results. Further and more in-depth discussion is postponed to the in-person workshop.

2.3.7 *Nuclear Physics at the Edge of Stability (Online)*

Date	June 28-July 01, 2021

Organizers

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

Number of participants	45

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, 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 haloes or Efimov states.

Due to the online nature of the workshop, only half of the topics selected in the call for proposals were covered during the 2021 edition of the workshop. Those are:

– Can the Ikeda conjecture, originally proposed for alpha clusters, be generalized to 2n, 2p, 4n, and 4p clusters? Experimentally, this would imply the presence of narrow resonant states at the corresponding emission thresholds. Are there specific conditions for the occurrence of these cluster states, and what is their nature (compact or dilute, close or far away from the core nucleus)? Do 4n or 4p clusters exist?

– How to interpret decays in the continuum from particle emission correlations? What are the robust models able to interpret particle correlation emission and connect it to the nuclear structure of the source nucleus?

Speakers

V. Alcindor	TUD, Germany
Y. Ayyad	MSU, USA
K. Kravvaris	LLNL, USA
D. Lee	MSU, USA
S. Koyama	GANIL, France

A. Revel	CEA, France
B. Monteagudo Godoy	MSU, USA
Y. Jin	PKU, China
T. Nakamura	TiTech, Japan
D. Philips	Ohio Univ., USA
C. Hebborn	MSU, USA
W. Elkamhawy	TU Darmstadt, Germany
J. Casal	Univ. Sevilla, Spain
MC. Atkinson	LLNL, USA
S. Ishikawa	Hosei, Japan
J. Tanaka	RIKEN, Japan
W. Nazarewicz	MSU, USA
M. Free	Univ. of Birmingham, UK
G. Rogachev	TA&M, USA
S. Quaglioni	LLNL, USA
H. Fynbo	AU, Denmark
B. Charity	AU, Denmark
T. Papenbrock	UTK, USA
D. Beaumel	IJCLab, France
S. Wang	Transition to new scientific position

Scientific report

Exploring the properties of the most exotic nuclei, including those beyond the dripline and/or above 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 a reach a fully microscopic 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) 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 ($^{26-28}$O, $^{28-30}$F).

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 few 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 understand their correlations. There is already a significant body of evidence indicating that resonances close to thresholds have been missed in data evaluations.

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. Even if the existence of a quasi-bound tetra-neutron cannot be confirmed or does not exist, the coupling of four neutrons or protons together could, like the two neutron or two-proton cases, play a significant role in the atomic nucleus (such as for their superfluidity) and in the reaction mechanism.

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 to understand 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 systems in inverse kinematics at higher relative energies than the prototypical low energy expansion used in microscopic methods. With the exception of rare, ideal, and weakly nucleonic systems, there is little hope of achieving a complete microscopic calculation of the complicated reaction.

Results and Highlights

We tailored the workshop to have an equilibrium between reports on the current status of the experimental investigation and theoretical developments ranging from *ab initio* methods to reaction theory with unstable beams. We contacted four conveners of sessions and selected the speakers together with them. These chair persons (Prof. M. Ploszajczak, Prof. L. Sobotka, Prof. M. Marques and Prof. H.-W. Hammer) were in charge of moderating their sessions and providing a brief historical context of their research fields. They were chosen based on their global knowledge of the fields and their ability to animate debates and discussions. 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. This was consensually agreed.

We scheduled a few long talks to provide further depth and framework to each session topic. In general, those followed a short introduction on the session physics from the chairs. They were provided by senior scientists (Prof. W. Nazarewicz, Prof. G. Rogachev, Dr. D. Beaumel, Prof. M. Freer, Prof. B. Charity, Dr. S.M. Wang, Prof. H. Fynbo, Prof. T. Nakamura and Dr. S. Quaglioni).

We were also pleased to highlight a number of up-and-coming young, talented female scientists, and the gender balance of the conference was in line with the community representation.

Below, we discuss in more details the results and highlight those that were presented during the online workshop split between each topic covered by the 2021 edition:

1. Generalized Ikeda conjecture

a. Proton-rich sector

It was reported that the sequential decay process of protons is by far dominant in the proton-rich region of the nuclear chart, contrary to neutron-rich nuclei where direct decay is also widely observed. In ^{15}F for instance, the structure and decay of the resonances were discussed and the long half-life of the two first states above the Coulomb barrier are consistent with a 2p correlation picture. There was also the first report of evidence of ^{3}He clustering and its persistence in the N=2 proton-rich light systems. This will undeniably trigger calculations to find and characterize them.

Multiparticle emission (beyond two protons) is also being searched for, as well as a way to better understand correlations inside the nucleus and their role to describe their superfluidity.

b. Clustering, alpha and others to Hoyle and Efimovian physics

There is no evidence to date, that any nuclear systems belong to the universality class of Efimov states. However, almost all exotic Hoyle state are in the vicinity of the parametric region of the Efimov tower of excited states, which anyway may not be observable by the current experimental means if they exist in nuclear physics. We covered the traditional means for elucidating the clustering nature of a nuclear state by looking at its rotational band head or democratic emission in the continuum. This was particularly explored to understand the properties of the Hoyle state, as it was reported that its democratic decay has been observed so far exclusively, probably due to phase space restrictions.

Experimental investigations are underway to uncover the onset of clustering in neutron-rich systems. The long spatial extension of the tail of the nuclear wave function in these systems is expected to increase the probability of pre-formation of an ejectile due to its very dilute nature. Direct reactions in a quasi-free configuration were performed and required reaction modeling to extract the cluster spectroscopic amplitude, as in 2b.

For a long time, it was expected that a particle can condensate like a Bose-Einstein condensate. Recent experimental measurements do not corroborate this theoretical prediction. Interpretation of Hoyle state decay correlation measurements suggested rather an equidistant 3-alpha state.

c. Threshold phenomena

Several talks discussed the importance of threshold effects. This is documented in the literature and in textbooks on reaction theory and known as a cusp effect in the phase shifts. Interestingly, this may not be seen in the eigen-phase shifts. It was reminded that the phenomenology of threshold effects can be understood by slowly varying the strength of the interaction potential showing the coalescence of bound/virtual state to exceptional points or decaying or capturing resonances.

2. Decays in the continuum

a. Correlation experiments

It was reported in great detail that final state interactions will wash out almost all information carried by the correlated pair emitted into the continuum about the initial structure of the nucleons in the atomic nuclei. It was thus suggested to use the effect of final state interactions to study the neutron-neutron pair size. A new type of naturally unfavored nuclear de-excitation was reported by gamma-ray emission into the continuum. This may only happen for states whose structure are unfavored by the particle-emission threshold in its vicinity. However, it was suggested to possibly happen in handful of nuclei on the proton-rich side of the chart. The 4n emission of the supposedly doubly-magic ^{28}O was reported for the first time. The property of this resonance (width, centroid), together with the decay mode of the four neutrons is planned to shed light on many of the aspects discussed earlier, in particular the generalized Ikeda conjecture and its application to 4n systems.

b. Reaction models

To relate the observations made in the laboratory to the structure of the nucleus, it appears essential to make progress on reaction theory and in particular on optical potentials for exotic nuclei. During the workshop, a report was made on the progress of *ab initio* reaction theory, which may provide reliable results based on microscopic NN forces but confined to light systems. Multiple talks reported on progress either to remove approximations made in reaction theory, use consistent reaction and structure modelling or to improve optical potentials used for the analysis of data.

2.3.8 *Saturation and Diffraction at the LHC and the EIC (Online)*

Date	June 29- July 01, 2021
Organizers	
Christophe Royon	University of Kansas, USA
Agustin Sabio Vera	University of Madrid, Spain
Soeren Schlichting	University of Bielefeld, Germany
Abhay Deshpande	University of Stony Brook, USA
Gregory Soyez	IPhT Saclay, France
Martin Hentschinski	Universidad de Las America Puebla, Mexico
Number of participants	63

Main topics

The goals of the workshop are twofolds. We intend to define the best observables sensitive to BFKL resummation effects at low x and the way to see saturation at the LHC and the EIC. Many LHC data have been accumulated in the different experiments, and it is also worth to explore the difference between the general ATLAS and CMS experiments and the specificities of Alice and LHCb allowing to run at lower pile up or with a lower cut on track momentum. The complementarity between the different experiments is an important tool to be discussed in order to reach the best possible sensitivity to saturation effects. Related to this topic is the important aspect of building the best detector possible at the EIC to be sensitive to these effects (by measuring hadrons in the very forward region as an example) since it is now time to define the detectors for the EIC.

The second topic deals with diffraction at the LHC and the EIC and a better understanding of the Pomeron models and structures. Following the experience at HERA and the Tevatron, it is useful to define the best possible measurements to be performed at the LHC and then the EIC to get a better insight into diffraction. Measurement different productions of jets, photons, vector mesons and disentangling these measurements from survival probability effects is crucial. We also discussed the recent discovery of the odderon made by the D0 and TOTEM experiments and the implications.

The main topics were:

1) Low x physics and Balitsky Fadin Kuraev Lipatov resummations

2) Diffraction and the odderon discovery

3) EIC physics and the high gluon density regime

Speakers

Nestor Armesto	IGFAE, Spain
Cristian Baldenegro Barrera	The University of Kansas, USA
Irais Bautista	CINVESTAV-BUAP, Mexico
Paul Caucal	Brookhaven National Laboratory, USA
Giovanni Antonio Chirilli	University of Regensburg, Germany
Abhay Deshpande	Stony Brook University (SUNY), USA
Yoshitaka Hatta	Brookhaven National Laboratory, USA
Or Hen	MIT, MA, USA
Martin Hentschinski	Universidad de las Americas Puebla, Mexico
D. I. Sobolev	Institute of Mathematics, Russia
Piotr Kotko	AGH University of Science and Technology, Poland
Georgios Krintiras	The University of Kansas, USA
Anh Dung Le	Centre de Physique Théorique (CPHT), France
Heiki Mäntysaari	University of Jyväskylä, Finland
Cyrille Marquet	CNRS, France
E. M. Bogolyubov	Institute for Theoretical Physics of NAS of Ukraine, Ukraine
Dmitri Melnikov	International Institute of Physics – UFRN, Brazil
Leszek Motyka	Jagiellonian University, Poland
Yair Mulian	University of Jyväskylä, Finland
Javier A. Murillo Quijada	Universidad de Sonora, Mexico
Jani Penttala	University of Jyväskylä, Finland
Timothy Raben	Michigan State University, USA
Augustin Sabio Vera	Universidad Autónoma de Madrid, Spain
Farid Salazar	Stony Brook University, USA
Gregory Soyez	IPhT/CNRS/CEA Saclay, France
Anna Stasto	Penn State, USA
Chung I. Tan	Brown University, USA
Zhoudunming Tu	BNL, USA

Scientific Report

The first day of the workshop was dedicated to the discussion about the new QCD regime at low x (the momentum fraction of the proton carried by the interaction quark/gluon) both at the LHC and the incoming EIC. The issue is to know if we can see the high gluon density regime (or saturation effects) in a complementary way between the two accelerators in proton-proton or heavy ion mode at the LHC. The

EIC and the LHC allow accessing different kinematical domains because of the difference in their center-of-mass energies and are complementary to look for the saturation regime or the quark-gluon plasma. The EIC, benefitting from its high luminosity and precision and the LHC, benefitting from its higher center-of-mass energies can access these new phenomena in a new way and complementary mode. After presenting the latest results from the LHC and prospects from the EIC, we discussed more specific observables such as the top antitop production at the LHC that might lead to new evidence for quark gluon plasma. On the other hand, the EIC will lead to unprecedented results on gluon imaging in protons and heavy ions. Detectors that will be built at the EIC also need to be discussed so that the full physics programme can be achieved.

The second day of the workshop was dedicated to diffraction and the discovery of the odderon by the D0 and TOTEM collaborations since this was one of the major discoveries this year. The results were reported in detail and the implications were discussed. It is also important to see if the discoveries of the odderon can be confirmed independently in additional channels such as meson production at the LHC or glueball production. Following the discovery at the LHC, we also discussed the possibility to see the odderon at the EIC in a different kinematical domain. The other topics related to diffraction discussed at the workshop (that are also sensitive to saturation phenomena) are vector meson and jet production, and the cross section calculation following the BFKL and color glass condensate formalism.

The last day was dedicated to BFKL studies and observables at the LHC and the EIC. The idea is to define new observables that are sensitive to low x resummation effects. The usual inclusive measurements (such as jet cross sections for instance) are too inclusive to be sensitive to BFKL resummations and one needs more complicated dedicated observables. Recent measurements of so-called Mueller Navelet jets and jet gap jet production were discussed as well as new methods to improve these observables to see BFKL effects. It is important to find new observables that should not be too dependent on non-perturbative effects such as hadronization or also on multi-parton interactions. Since we want to find observables that might lead to differences between BFKL and DGLAP resummations, we want also these observables to be stable versus the order at which they are computed (LO. NLO, NNLO, etc…).

The follow up of this online workshop will be an in-person workshop that should happen in July 2022 if the pandemic situation allows.

Results and Highlights

The workshop was a very good opportunity to discuss these new important results and views and was well received by all participants, especially at the time of Covid where discussions and interactions between participants are more difficult. We managed to create some discussion sessions where different ideas were exchanged and these interactions will be pursued further next year during the in-person workshop.

The main topic was definitely the discovery of the odderon by the D0 and TOTEM collaborations. The first aspect was to discuss in detail the analysis and the experimental results. We compared the results with expected theoretical implications. There is a clear agreement that we see a 3 gluon compound in data and more analyses could be performed in order to know the odderon intercept. This result could be model dependent but will allow to understand the energy dependence of the odderon cross section. Other potential observables where one can look for the odderon were proposed in exclusive processes and polarized hadron scattering (that could be studied at the EIC). The possible relation with glueball production at the LHC was also discussed and the search can definitely be pursued at the LHC. New ideas about a spin dependent odderon that could be probed at the EIC were also presented and present a new independent way to see the odderon.

The search for BFKL resummation effects also led to extensive discussions and new possible more dedicated observables were proposed, such as the measurements of “mini-jets” between the two Mueller-Navelet jets, that can be measured in CMS at the LHC as an example, or the importance of the method to define gaps in jet gap jet events. This can again lead to new measurements by ATLAS, CMS, LHCb and ALICE that are more sensitive to BFKL dynamics. The importance of low x physics (and more generally forward physics) and its relation with cosmic ray physics was also stressed since it allows to compare recent cosmic ray data (for instance the muon puzzle) with tuned Monte Carlo using forward data.

Saturation was also a major topic for discussion. This is one of the main goals of the EIC. New possible observables were presented that also highlight the complementarity between the EIC and the LHC. Detailed studies were started to show how the quark gluon plasma could be observed in top antitop events at the LHC whereas tops cannot be produced at the EIC because of their high mass. On the contrary, high precision data (transverse and longitudinal structure functions, vector mesons, etc…) can probe saturation using high mass heavy ions, comparing with lighter ions where no saturation is expected. This show again the complementarity between accelerators.

This workshop was definitely a success and represents a first step towards the one-week workshop that will be hosted in July 2022 at ECT, hopefully in person. This paved the way for the topics that we want to discuss next year, and we look forward seeing new theoretical and experimental results.

2.3.9 *Relativistic Fermions in Flatland: Theory and Application (Online)*

Date	July 05-09, 2021

Organizers

Simon Hands	Swansea University, UK
Holger Gies	Friedrich Schiller University Jena, Germany
John Gracey	University of Liverpool, UK
Igor Herbut	Simon Fraser University, Canada

Number of participants	71

Main topics

Planar fermions underpin much interesting physics in layered systems and are extensively studied in condensed matter physics; for instance, electronic properties of graphene have long been understood in terms of relativistic fermions centred on Dirac points in momentum space, but the influence of interactions between charge-carrying degrees of freedom is less well-understood and remains an active field of study. Other examples are furnished by cuprate superconductors and materials with symmetry-protected topological phases. Quantum fermions in 2+1d also present many theoretical challenges, and there is an encouraging parallel renaissance of interest involving workers in large loop-order perturbation theory, functional renormalisation group, conformal bootstrap, and lattice simulation, for whose practitioners such systems encapsulate essential challenges for their respective agendas.

The main topics were

- Hubbard/Gross-Neveu models
- QED_3, large N and critical behaviour
- Condensed matter applications
- Numerical simulations
- Supersymmetry and beyond

Speakers

Sandro Sorella	SISSA, Italy
Sabine Andergassen	University of Tübingen, Germany
Vieri Mastropietro	University of Milan, Italy
Ian Affleck	University of British Colombia, Canada
Peter Marquard	DESY Zeuthen, Germany
Daniel Litim	University of Sussex, UK
David Poland	Yale University, USA
Joseph Maciejko	University of Alberta, Canada

Fakher Assaad	University of Würzburg, Germany
Lukas Janssen	TU Dresden, Germany
Shouryya Ray*	TU Dresden, Germany
Johann Ostmeyer*	University of Bonn, Germany
Maksim Ulubyshev*	University of Würzburg, Germany
Bitan Roy	Lehigh University, USA
Hong Yao	Tsinghua University, China
Andreas Wipf	University of Jena, Germany
Pavel Buividovich	University of Liverpool, UK
Nikhil Karthik	JLAB, William & Mary University, USA
Omar Zanusso	University of Pisa, Italy
David Schaich	University of Liverpool, UK
Shailesh Chandrasekharan	Duke University, USA
Simon Catterall	Syracuse University, USA

The speakers marked * are ECRs who contributed posters and were invited to speak at short notice due to the late withdrawal of an invited speaker.

Scientific Report

Many strands of contemporary condensed matter physics have driven a resurgence of interest in fermions with Dirac-like dispersion in 2 spatial dimensions. The systems are theoretically interesting due to their support of strong correlation effects and interacting renormalisation group fixed points, amenable to study by a variety of techniques such as ε- and 1/N expansions, functional renormalisation group, conformal bootstrap, and numerical methods such as QMC and HMC simulations, and tensor networks. Applications include the electronic structure of graphene, nodal fermions in cuprate superconductors, spin liquids, and topological insulators. By now there is a paradigmatic system, the Hubbard model on a honeycomb lattice, with a transition for semimetal to AFM phase characterised by the Gross-Neveu-Yukawa universality class, whose critical exponents are known with steadily increasing precision. Potentially there are other fixed points to explore characterised by different symmetries, or even phases where mass generation is not accompanied by long range order. The workshop aimed to review recent developments and to bring together workers from diverse communities to exchange insights.

Results and Highlights

– By now diagrammatic techniques have been extended to 4 loops

- Results were reported for enhanced emergent symmetries at RG fixed points such as SO(5) or supersymmetry. Lattice models with both emergent and exact SUSY were presented
- A tension between results for the critical exponent ν in the GNY model between CBS and other approaches has significantly lessened
- Realistic HMC simulations of suspended graphene are consistent with analytic predictions of a logarithmic correction to the Fermi velocity, and are possibly consistent with a conformal fixed point at the transition between semimetal and AFM
- Estimates for the critical flavor number in the Thirring model have decreased compared to early work, though different fermion regularisations (SLAC vs. DWF) still disagree as to whether N_c is greater or less than 1
- QED_3 with minimal flavor number appears to support a conformal fixed point in the IR with no dynamical symmetry breaking: the role of instantons in the compact model, their interaction with fermion zero modes, and the question of whether confinement persists in the presence of fermions remain live issues
- The importance of ‘t Hooft anomaly matching conditions and their consequent constraints for models exhibiting symmetric mass generation was highlighted

Due to persisting Covid restrictions of travel and social contact, the workshop was held on line. Videos of the presentations are available on the ECT* YouTube Channel: https://www.youtube.com/c/ECTstar/playlists. The workshop registrants came from institutions spanning 16 timezones. Typical attendance at the Zoom sessions at any one time was O(40).

Each day featured a 90-minute session held in the virtual Gather Town environment permitting informal contact and discussion between small groups of participants, as well as a poster session. The 20 contributed posters were available for viewing throughout the week

The posters and most of the slides of the talks are available on the Indico page of the workshop: https://indico.ectstar.eu/event/80/.

2.3.10 *Probing Nuclear Physics with Neutron Star Mergers (Online)*

Date	July 12-16, 2021

Organizers

Christopher Fryer	LANL, USA
Jonas Lippuner	LANL, USA
Mattew Mumpower	LANL, USA
Andrew Steiner	University of Tennessee, USA
Benoit Cote	Konkoly Observatory, Hungary
Rebecca Surman	University of Notre Dame, USA
Stephan Rosswog	Stockholm University, Sweden

Number of participants	80

Main topics

With the first gravitational wave observation of the merger of two neutron stars (GW170817), scientists have definitive observations of the ejecta from this event. The broadband observations of this merger provide a window into the nuclear physics and, for the first time, detailed nuclear physics effects of the r-process can be distinguished in an astrophysical event.

In this workshop, we bring together experts in nuclear cross-sections, dense nuclear matter and neutrino physics with astrophysicists modeling the ejecta and emission from neutron star mergers and observers of neutron-star merger events to determine the potential links between the latest advances in nuclear physics on the observation of GW170817 and future neutron star mergers.

The main topics were

- Modeling neutron star mergers
- Nuclear equations of state
- Nuclear experiment
- Nucleosynthesis from neutron star mergers

Speakers

Stephan Rosswog	Stockholm University, Sweden
Almudena Arcones	TU Darmstadt, Germany
Jonah Miller	Los Alamos National Laboratory, USA
Meng-Ru Wu	Academia Sinica, Taiwan
Abishek Das	Penn State University, USA
Oleg Korobkin	Los Alamos National Laboratory, USA
Jolie Cizewski	Rutgers University, USA
Sabrina Huth	TU Darmstadt, Germany

Willem Dickhoff	Washington University in St. Louis, USA
Charles Horowitz	Indiana University, USA
Catalina Curceanu	LNF - INFN Frascati, Italy
Wendell Misch	Los Alamos National Laboratory, USA
Debarati Chatterjee	Inter-University Centre for Astronomy and Astrophysics, India
Grant Mathews	Notre Dame, USA
Loïc Perot	Université Libre de Bruxelles, Belgium
Armen Sedrakian	Frankfurt Institute for Advanced Studies, Germany
Atul Kedia	Notre Dame, USA
Shinya Wanajo	Max Planck Institute for Gravitational Physics, Germany
Aviral Prakash	Penn State Univ., USA
Carlos Bertulani	Texas A&M Univ., USA
Janos Takatsy	Wigner Research Centre for Physics, Hungary
Elias Most	Princeton University, USA
Lattimer James	Stony Brook Univ., USA
Nicole Vassh	Notre Dame, USA
Friedrich Thielemann	University of Basel, Switzerland
Toshitaka Kajino	Beihang University, China
Trevor Sprouse	Los Alamos National Laboratory, USA
Martinez-Pinedo Gabriel	GSI and TU Darmstadt, Germany
Artemis Spyrou	Michigan State Univ., USA

Scientific Report

The first gravitational-wave detection of a neutron star merger (GW170817) demonstrated both that these mergers could produce gamma-ray bursts and that these mergers contribute significantly to the r-process elements observed in the universe. Initial analyses of GW170817 produced highly discrepant results: arguing that neutron star mergers account for 1-100% of the total r-process production in the universe. Spurred by this observation and the wide range of analysis results, increasingly sophisticated models were developed to simulate the mergers. These calculations identified a number of critical nuclear physics topics that must be understood to reduce the uncertainties in these calculations and better infer the abundance measurements from these mergers. The goal of this meeting is to bring together experts in nuclear theory and experiment with computational astrophysicists to both educate these disciplines of the state of the art in each individual field so that these scientists can identify inter-disciplinary projects that will allow them drive innovation in this multi-physics problem.

Simulations of neutron star mergers have now reached the state where they are modelling the general relativistic neutrino-radiation hydrodynamics at sufficient fidelity that these calculations are both ready to implement, and the science requires it, higher-fidelity physics in the equation of state and neutrino transport. Implementing this physics requires tight coupling between experts in dense nuclear matter. Similarly, calculations of the post-merger disk evolution have advanced to a stage that nuclear physics uncertainties are key uncertainties in the calculations. And, for both, the nucleosynthetic yields are limited by our lack of understanding of the nuclear reactions, capture rates, fission, etc. The presentations in the meeting provided overviews of the current state-of-the-art in these simulations.

While simulation requirements for neutron star mergers have advanced, so has our understanding of the dense nuclear physics and its effect on equations of state and neutrino emission and interactions. Presentations at this meeting reviewed the state-of-the-art of this field and described the new experimental opportunities to probe this physics.

Nuclear reaction measurements have steadily improved, but with the launch of the Facility for Rare Isotope Beams, we expect a dramatic acceleration in our ability to improve measurements. These improved measurements will allow nuclear theorists to improve models both for neutron capture and for

The Facility for Rare Isotope Beams (FRIB), the most powerful heavy-ion accelerator in the world, will enable scientists to make discoveries about the properties of rare isotopes (that is, short-lived nuclei not normally found on Earth) for nuclear astrophysics. This facility has just now produced its first studies of rare isotopes. Combined with the current and upcoming nuclear facilities in Europe and Asia, we are entering an era of exploration and discovery for much of the nuclear physics needed to study neutron star mergers. Many of the talks in this workshop focused on leveraging these new facilities to push forward our understanding of this critical physics for neutron star mergers.

Gamma-ray satellite missions provide the potential for a stronger tie between the nuclear physics community and the astrophysics community. During this meeting, a number of satellite proposals were being developed: COSI, AMEGO, LOX. And this meeting provided the much of the background information to strengthen those proposals and make the connections between these satellite missions and the nuclear experimental facilities.

Results and Highlights

The primary goal of this meeting was to bring together scientists in nuclear experiment, nuclear theory and computational astrophysics to build the connections between these communities to both prepare for upcoming nuclear experimental facilities and new astrophysics satellite missions. Despite the fact that this meeting was entirely virtual, it built the several connections that produced the multi-disciplinary teams to develop proposals for upcoming satellite missions and new collaborations. The talks provided an excellent review of the state-of-the-art in this field. Here we list a few of the presentation highlights.

Stephan Rosswog presented preliminary results from a new, general-relativistic smooth particle hydrodynamics code. In the past, the strength of smooth particle hydrodynamics has been the fact that it can easily model vacuum spaces, ensuring that the ejecta properties are not affected by artificially-high circum-binary densities used in grid calculations. However, until this new code, general relativity in smooth particle hydrodynamics codes was limited to post-Newtonian or other approximate techniques. This new code will help explain the differences between grid- and particle-based techniques, removing one of the major uncertainties in kilonova ejecta properties from neutron star mergers.

Wendell Misch presented recent work studying astrophysically-relevant isomers, so called isomers. Isomers may effect the yields and decay rates from neutron star mergers, altering the emission from this ejecta. He has developed an isomer package to facilitate the incorporation of isomer studies in nuclear networks and presented some preliminary studies with these isomers. He also described new experiments that will help constrain the properties of these isomers and, hence, determine their role in neutron star mergers.

Almudena Arcones described the recent results comparing observations of NS mergers like the gravitational + electromagnetic wave detected merger GW170817. These studies have identified many of the uncertainties in the nuclear reactions that set the final yields. Combined with other talks, e.g. from Kajino Toshitaka, Friedrich Thielemann and Gabriel Martinez-Pinedo, the presentations highlighted the issues in the astrophysics problems in the r-process.

Artemis Spyrou reviewed the experimental constraints on neutron capture reactions. In addition to providing a review of the latest constraints, she described the potential new experiments with upcoming facilities.

2.3.11 *Nuclear Physics Meets Condensed Matter: Symmetry, Topology, and Gauge (Online)*

Date	July 19-21, 2021
Organizers	
Alexandros Gezerlis	University of Guelph, Canada
Alessandro Roggero	University of Washington, USA
Carlos Sa de Melo	Georgia Tech, USA
Number of participants	30

Main topics

This workshop brought together nuclear and condensed matter theorists to discuss common topics involving the physics of few particles and the many-body problem. Attention was also paid to highly controllable ultra-cold atom experiments that test theoretical ideas originated in nuclear and condensed matter physics. Issues touched upon involved Abelian and non-Abelian gauge theories, topological states of matter, color and other superconductivity in neutron stars, relevance to/of quantum computing, as well as other topics that arise at the crossroads between nuclear and condensed matter physics.

The main topics were

- Few-body physics
- Dipolar quantum gases
- Color superconductivity
- Topological states of matter

Speakers

Mark Alford	Washington University, USA
Luca Asteria	University of Hamburg, Germany
Doerte Blume	University of Oklahoma, USA
Joe Carlson	LANL, USA
Iacopo Carusotto	University of Trento, Italy
Marcello Dalmonte	ICTP, Trieste, Italy
Zohreh Davoudi	University of Maryland, USA
Joaquin Drut	University of North Carolina, USA
Francesca Ferlaino	University of Innsbruck, Austria
Hans-Werner Hammer	TU Darmstadt, Germany
Piotr Magierski	University of Washington, Poland
Sergej Moroz	TUM, Germany

Thomas Papenbrock	University of Tennessee, USA
Francesco Pederiva	University of Trento, Italy
Arnau Rios	University of Surrey, UK
Srimoyee Sen	Iowa State University, USA
Päivi Törmä	Aalto University, Finland

Scientific report

Recently, the interface between nuclear and condensed matter physics became much larger due to the experimental realization of physical systems that can simulate properties of nuclear matter and that can be tuned nearly continuously from few- to many-particles. Experimental advances were accomplished via the trapping and manipulation of atoms with Fermi and Bose statistics in harmonic, box, and optical potentials, which in turn provided the playing field for theoretical progress that deepened our understanding of the connections between symmetry, topology, and gauge.

The workshop covered an emerging research area where mixtures of bosons and fermions of nearly equal masses can be created in the laboratory, also investigating analogous systems in nuclear structure and astrophysics. One guiding theme was the study of superconductivity. This touched upon both novel theoretical formalism, as well as predictions of cold-atom systems or neutron-star matter. The latter ranged from ab initio computations of quantum many-body systems to an investigation of the concept of quantum geometry. An exciting new topic involved the study of conformal symmetry in nuclear reactions.

Another main thread involved the study of topology in quantum states of matter. This was introduced via an experimental talk on ultracold atoms in hexagonal optical lattices, and was further expanded on via discussions of linear and nonlinear topological optics. The quantum Hall effect provided a common theme and was addressed both for quantum fluids and light, as well as in relativistic quantum field theories. The presence of topological order and excitations was encountered, with special emphasis being placed on potential experimental signatures.

A third main theme involved Abelian or non-Abelian gauge theories. More than one talk investigated the relevance of quantum simulation and its significance for nuclear-like systems. This involved both gauge-field theory dynamics on trapped-ion simulators, as well as detailed aspects of how imaginary-time propagation is carried out on a quantum chip. Another topic was the coupling of discrete gauge fields to fermionic matter. A very exciting development, right at the interface of condensed-matter and nuclear physics involved recent work on-abelian gauge potentials in the description of odd-mass deformed nuclei.

While the above summary has grouped topics according to the workshop's title (symmetry, topology, and gauge), it goes without saying that both overall and in individual talks these topics were fruitfully intermixed. A number of talks and discussions touched upon cross-pollination arising when one borrows ideas from different areas of physics. In short, the participation of key speakers from nuclear, condensed matter, and atomic physics in both the talks and the discussion sessions addressed several open questions of common interest and possible new research directions.

Results and Highlights

This meeting was initially scheduled to take place in May 2020 at ECT*, but was postponed due to the COVID-19 pandemic. It was postponed to November 2020, in the hope that it could take place face-to-face. When it became clear that the pandemic was here to stay, the meeting was moved online and scheduled for July 2021, where it took place on the Zoom platform. The organization (by Ms. Driessen) was flawless and really contributed toward making this workshop a success.

The workshop included a mixture of big-picture/overview talks, typically at the start of a session, as well as more seminar-like presentations, reporting on new and exciting results. After a Welcome by the ECT* Director, the meeting was kicked off by a talk viewing neutron-star mergers as materials science, followed by an examination of the commonalities between nucleonic matter and cold-atomic experiments.

A crucial aspect of both the design of this workshop and of its actual implementation was that it was truly interdisciplinary, involving neutron-star experts, nuclear theorists, solid-state physicists, and cold-atom experts (both in experiment and theory). As a result, both relativistic and non-relativistic systems were discussed, with a guiding theme of the workshop consistently being the attempt to connect across different areas. One way this was accomplished was via the use of theoretical tools for more than one physical system (e.g., quantum Monte Carlo or density-functional theory) whereas another was via the emerging use of quantum computing in solid-state vs nuclear physics.

The makeup of the participants is worth emphasizing. Out of 17 speakers there were 5 women. The speaker list involved both well-established scientists, as well as more junior researchers (including one PhD student). The non-speaker participants involved a good number of graduate students, probably more than would have been the case had the meeting taken place in Trento. Also worth emphasizing were the discussion sessions that took place at the end of each day's session (led by D. Blume, P. Torma, and F. Pederiva, respectively); despite the difficulty imposed by the virtual format, there was lively discussion, especially on big-picture questions regarding the field(s) future.

2.3.12 *Nuclear and Atomic Transitions as Laboratories for High Precision Tests of Quantum Gravity Inspired Models (Online)*

Date July 27-29, 2021

Organizers

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

Number of participants 10

Main topics

The main question that has been faced is 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. 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 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.

The main topics were:

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

Speakers

G. Amelino-Camelia	Università di Napoli Federico II, Italy EU
K. Piscicchia	Storico della Fisica e Centro Studi e Ricerche Enrico Fermi, Italy
A. Marciano	Fudan University, PRC
M. Arzano	Università di Napoli Federico II, Italy
A. Derevianko	University of Nevada, USA
G. Torrieri	University of Campinas, Brazil

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 universalities 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 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.

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.

2.3.13 *LFC21: Strong Interactions from QCD to New Strong Dynamics at LHC and Future Colliders (Online)*

Date	September 06-10, 2021
Organizers	
Gennaro Corcella	INFN, LNF, Italy
Stefania De Curtis	INFN Florence, Italy
Stefano Moretti	University of Southampton, UK
Giulia Pancheri	INFN, LNF, Italy
Roberto Tenchini	INFN Pisa, Italy
Marcel Vos	IFIC & University of Valencia, Spain
Number of participants	42

Main topics

The workshop debated the recommendations of the European Strategy Particle Physics committee on future accelerators, taking particular care about the role played by strong interactions in the physics case of future colliders.

It reviewed the status of calculations and measurements in perturbative and non- perturbative QCD and whether their accuracy is sufficient to meet the goals of LHC andother accelerators. Special attention was paid to the phenomenology of top quarks, which play a role in all searches for new physics, either as background or as proxy to new particle signals.

From the perspective of physics beyond the Standard Model, we explored strongly- interacting scenarios, which are capable of solving the current open problems of the StandardModel, such as composite-Higgs and other strong-dynamics models. The effect of strong interactions in flavour physics and cosmology observations, and the connection with colliderphysics was be debated too.

The workshop was organized according to opening and closing sessions with pretty general talks and topical sessions chaired by our conveners.

The main topics were the following:

- Projects for future colliders;
- Connection between astrophysics and collider physics;
- Quantum Chromodynamics;
- Top-quark physics;
- Electroweak symmetry breaking;
- Beyond the Standard Model.

Conveners

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

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

Beyond the Standard Model: Aldo Deandrea (University of Lyon I, France)

Electroweak symmetry breaking: Roberto Franceschini (University of Rome 3, Italy)

Participants

Kaustubh Agashe	Maryland U., USA
Raffaele D'Agnolo	IPhT, Saclay, France
Dario Buttazzo	INFN Pisa, Italy
Marco Bonvini	INFN Rome, Italy
Luca Buonocore	Zurich U., Switzerland
Stefano Camarda	CERN, Switzerland
Pierre Chatagnon	INFN Genoa, Italy
Gennaro Corcella	INFN LNF, Italy
Stefania De Curtis	INFN Florence, Italy
Daniel de Florian	ICAS, Buenos Aires, Argentina
Aldo Deandrea	IO2I, Lyon, France
David d'Enterria	CERN, Switzerland
Caterina Doglioni	Lund U., Sweden
Adam Falkowski	Orsay LPT, France
Giancarlo Ferrera	Milan U., Italy
Roberto Franceschini	Rome III U., Italy
Claudia Frugiuele	INFN Milan, Italy
Antoine Gérardin	CPT Marseille, France
Stephen Gibson	Royal Holloway, London, UK
Massimiliano Grazzini	Zurich U., Switzerland
Flavio Guadagni	Zurich U., Switzerland
Mehmet Gumus	SISSA, Trieste, Italy
Julia Harz	TUM Munich, Germany
David Kaplan	Johns Hopkins U., USA
Lara Mason	Cape Town U., South Africa
Stefano Moretti	Southampton U., UK
Yasunori Nomura	UC Berkeley, USA

Giulia Pancheri	INFN LNF, Italy
Davide Racco	Perimeter Institute, Canada
Michele Redi	INFN Florence, Italy
Philipp Roloff	CERN, Switzerland
Jonathan Ronca	Valencia U., Spain
Jennifer Smillie	Edinburgh U., UK
Daniel Stolarski	Carleton U., Canada
Alessandro Strumia	Pisa U., Italy
Tim Tait	Irvine U., USA
Roberto Tenchini	INFN Pisa, Italy
Francesco Tramontano	Naples U., Italy
Alfredo Urbano	Rome Sapienza U., Italy
Marcel Vos	IFIC and Valencia U., Spain
Andreas Weiler	TUM Munich, Germany
Jure Zupan	Cincinnati U., USA

Scientific report

Following the LFC series, this workshop aimed at gathering theorists and experimentalists working on LHC and future colliders, mostly with a strong expertise in the realm of strong interactions, within and beyond the Standard Model. Because of the Covid-19 pandemic, it was an online meeting, with pretty long talks and much room for discussion. The European strategy for future colliders is obviously focused on the High-Luminosity LHC in the near future, while Linear Colliders, such as ILC or CLIC, as well as circular accelerators (FCC-ee and CEPC) are the mid-term plans, with muon colliders and advanced accelerators being the foreseen long-term projects.

The workshop had a special focus on Quantum Chromodynamics (QCD), the theory of strong interactions. In fact, processes mediated by the strong interactions are fundamental tests of the Standard Model, as well as background for new physics searches. It is there- fore mandatory calculating them with the highest possible accuracy, improving the current fixed-order and resummed computations. Needless to say, phenomena like hadronization or underlying event cannot rely on such perturbative calculations, but are typically described by models, often based on phenomenological assumptions, which require continuous comparisons with data at both high and low energies.

Strictly related to QCD, the physics of the top quark plays a fundamental role in tests of strong and electroweak interactions and acts as a background to several searches for new physics, containing final states with b-flavoured jets, charged leptons and missing energy. The mass of the top quark, whose interpretation in terms of well-posed field-theory definitions is still an open issue, is indeed one of the main Standard Model parameters, concerning even the stability of the universe and the inflation theory.

Regarding physics beyond the Standard Model, one should acknowledge that the most popular scenarios like supersymmetry or theories with extra dimensions have given no signal yet at LHC, and therefore looking for alternatives is mandatory. A firm observation is certainly Dark Matter, and therefore any reliable model should be capable of predicting it. From this perspective, high-energy colliders like LHC or the future FCC and ILC should be able to learn a lot from the measurements undertaken at low energies, such as beta decays or fixed-target experiments searching for axions and dark photons. Moreover, the anomalies observed in B-meson decays should help to shed light on such models.

Results and Highlights

Hereafter, we summarize the main results discussed in the general talks and in the topical sessions. Regarding the future of accelerator physics, as anticipated above, in the near future it will be the HL-LHC the main collider which will run worldwide, with the goal of performing extremely precise tests of the Standard Model and exploring all possible new physics scenarios. The technology developments necessary for HL-LHC are applicable to other machines, both leptonic and hadronic, namely novel collimation, crab-cavities, cold powering and laser surface engineering. As discussed above, the long-perspective European plan concerns Linear Colliders (ILC, CLIC), Future Circular Accelerators (FCC-ee, CEPC) as well as muon colliders. The roadmap towards laser-plasma accelerators and a possible circular collider on the moon, with 11,000 km in circumference and 14 PeV of centre-of-mass energy, were sketched too. The strict interplay between FCC-ee and FCC-hh was debated as well. In particular, at FCC-ee one will be able to study Z, W and top physics with an unprecedented precision, while FCC-hh will allow the exploration of high-mass systems, thus setting direct or indirect constraints on a number of BSM models. Also, Yukawa couplings, right-handed neutrinos, QCD, flavour physics and Dark Matter will be tested with high accuracy at both machines.

The interplay between astroparticle and collider physics was explored too: in fact, astroparticle physics is capable of connecting the cosmology of the early universe with elementary particle physics. However, there are still may open issues concerning, e.g., dark matter, baryon asymmetry and neutrinos and certainly future colliders should be able to contribute to solve such problems. Collider physics should also enjoy the great complementarity between low- and high-energy experiments, as well as energy and intensity frontiers. For this purpose, we had a thorough discussion on the dark sectors, which contain new particles interacting with the visible sector, beyond gravitation, via unknown forces. Indeed, the possible existence of dark sectors affects neutrino masses, the strong CP problem and its solution through the Peccei–Quinn axion, baryogenesis, Dark Matter and may give explanations to the lightness of the Standard Model Higgs boson and to the flavour problem. In the topical QCD session, we discussed precise QCD measurements at LHC and future colliders, taking particular care about the interplay between strong and electroweak precision measurements (W/Z transverse momentum, pseudorapidity and angular coefficients in the Drell–Yan process, W mass), the strong coupling constant and parton distribution functions. For example, one will be able to measure the W mass with an uncertainty, due to statistics and parton densities, about 6 MeV at HL-LHC, 6-7 MeV at ILC, 0.5 MeV at FCC-ee. The precision on $\alpha_S(m_Z)$ will instead reach the per-mille level at FCC-ee. An observable which can be measured very precisely, calculated to a very high accuracy and provide stringent tests of physics beyond the Standard Model is the muon gyromagnetic moment, the so-called $g - 2$. The latest results on its theoretical prediction were presented, paying special attention to the role of hadronic contributions. It is cumbersome that, at the moment, the Standard Model predictions are about four standard deviations away from the experimental average. Work in progress based on the lattice has nonetheless reduced the tension with the experimental data, with the whole community awaiting for the final results which may confirm or disprove a possible claim for new physics. Still on issues related to non-perturbative QCD, novel cosmologies were investigated, including the possibility that QCD could exhibit at an early epoch a pretty different value of the strong coupling constant with respect to the Standard Model one, with a confining scale much above 1 GeV. Then, just before the Big-Bang Nucleosynthesis the coupling started to behave like in the Standard Model: this model was shown to be capable of describing the baryon asymmetry, rescuing WIMP Dark Matter and possibly predicting observations in axion cosmology. As far as perturbative QCD is concerned, the so-called soft-gluon effective coupling, measuring the intensity of soft-gluon radiation, was constructed in order to resume multiple parton emissions. Results were presented up to NNLO and the prospects for applications to precision measurements at LHC and FCC discussed.

Concerning top-quark physics, we had a review on top-quark measurements at future colliders, above all e^+e^- machines (FCC-ee, CLIC and ILC), with a few highlights on FCC-hh. All foreseen lepton colliders have a well-defined program at and above the $t\bar{t}$ threshold: a threshold scan is in fact the best possible manner to measure the top mass with a precision about 50 MeV. Furthermore, with a centre-of-mass energy above 550 GeV, one would be able to carry out a direct measurement of the top-Yukawa coupling and access the CP mixing in the $t\bar{t}H$ vertex. The prospects to explore signals due to four-fermion operators, as well as flavour-changing neutral currents, were underlined. From the theory side, top production and decay at NNLO was presented, and in particular the NNLO $t\bar{t}$ cross section in the $\overline{MS}$ scheme for both inclusive and differential quantities. Such results agree with previous computation, after making consistent choices of parameters and schemes. Apparently, the $\overline{MS}$ calculation exhibits a faster convergence with respect to the on-shell one (pole mass), but nevertheless this may be due to the choice of the central value of factorizazion and renormalization scales.

As for physics Beyond the Standard Model, results from LHC were presented, emphasizing the search for Dark Matter and the complementarity with other colliders. In particular, the quest for Dark Matter at high-energy colliders is naturally linked to companion research in astrophysics and cosmology, and therefore sharing computing tools among different communities has become mandatory. It was then discussed how nuclear physics experiments may play a role in discovering new physics, with beta decays having lately reached an unprecedented precision. They can be competitive and complementary to the LHC to constraint new physics coupled with the first generation of quarks and leptons, such as models predicting leptoquarks or right-handed W bosons. By using Effective Field Theories, one can obtain limits on the so-called Wilson coefficients of such Lagrangians, at the level of per-mille (Leptoquarks) and percent (right-handed W).

Regarding flavour physics, it can definitely be a tool to prove new physics, characterized by both heavy and light particles, and the current experimental anomalies, such as those in the measurements of $g - 2$ or transitions like $b \to s\mu^+\mu^-$ and $b \to cl\nu$, could be a first evidence of phenomena beyond the Standard Model.

Our final talk dealt with the prospects for QCD at present and future colliders, namely the observation of exotic hadrons, such as doubly-charmed tetraquarks, the extraction of the strong coupling constant, the so-called race for NNLO computations, with the alternative approaches of q_T /antenna subtraction and the Forest Formulas, and the development of strategies to match such calculations with parton showers. The state of the art of re- summation in perturbative QCD, parton distributions, double parton scattering, as well as results of collective behaviours, which could be described by fluid dynamics, was reviewed too.

2.3.14 *Tackling the Real-Time Challenge in Strongly Correlated Systems: Spectral Properties from Euclidean Path Integrals (Online)*

Date	September 13-17, 2021
Organizers	
Sinead Ryan	Trinity College Dublin, Ireland
Alexander Rothkopf	University of Stavanger, Norway
Anthony Francis	CERN, Switzerland
Number of participants	36

Main topics

The workshop focused on real-time challenges in strongly interacting systems with a particular emphasis on extracting spectral information from Euclidean path integrals. Experts from a broad field of related disciplines within theory and experiment came together to discuss the challenge and their methods to address it, generating a fruitful exchange of ideas. The potential of new methods including e.g. in machine learning and noise reduction was addressed during round table sessions.

The meeting was arranged around two main topics:

1. *Bridging the gap: numerical methods for inverse problems.*

Spectral functions are typically determined from discrete correlation functions using probabilistic methods with the probability dependence encoded in the mathematics of an inverse transformation. Meanwhile, scattering parameters are extracted by solving a generalized eigenvalue problem, yielding discrete energy levels. In principle, the same spectral information as from the inverse transform is accessible, if the full discrete, finite-volume spectrum were calculable. Talks covered

- Advances in extraction of spectral functions in nuclear and condensed matter physics.
- Advances in finite-volume spectral analysis of vacuum states in lattice QCD.
- Connecting spectral function reconstruction and specific finite volume approaches.
- Systematics and complementarities of methods for inverse problems.

2. *Novel techniques: improving access to real-time properties.*

High-precision simulation data opens new avenues towards spectral information but demands novel techniques for noise reduction (algorithmically or through physics input) while also providing fertile ground for machine learning techniques. The techniques discussed included:

- Machine/deep learning for spectral functions.
- Noise reduction for high-precision simulations.
- Noise distributions for improved access to spectral information.

Speakers

Martha Constantinou	Temple University, USA
Julian Urban	Heidelberg University, Germany
Andrey Mischenko	RIKEN, Japan
Hiroshi Shinaoka	Saitama University, Japan
Etsuko Itou	RIKEN, Japan
Shoji Hashimoto	KEK, Japan
Kostas Orginos	William & Mary, USA
Nazario Tantalo	University of Roma "Tor Vergata", Italy
John Bulava	University of Southern Denmark, Denmark
Gaurang Parkar	Stavanger University, Norway
Maxwell Hansen	Edinburgh University, UK
Harvey Meyer	Mainz University, Germany
Chris Allton	Swansea University, UK
Jon-Ivar Skullerud	Maynooth University, Ireland
Keh-Fei Liu	Kentucky University, USA
Stefano Carrazza	University of Milan, Italy
Tim Harris	Edinburgh University, UK

Scientific report

Real-time challenges of the type discussed in this workshop are ubiquitous in science. The applications range from medical imaging to geological surveying to the physics of condensed matter systems and material science in the laboratory. For example, experiments at the forefront of particle physics study the real-time properties of strongly correlated quantum systems, from the transport of quarks and gluons in a Quark-Gluon Plasma created in a heavy-ion collision to the conduction of electrons in a highly complex functional material. While simulations of Euclidean path integrals already provide unprecedented non-perturbative insight into the static properties of strongly correlated systems, access to real-time properties in the form of spectral information is still severely limited. Over the past decade the field has however witnessed significant progress in tackling this real-time challenge based on both conceptual developments, as well as improved data analysis strategies involving probabilistic reasoning. The goal of the workshop was to bring together experts from different fields and in different methods, to discuss and explore synergies among these recently developed methods and chart a path towards robust determination of spectral real-time information from Euclidean path integrals.

The workshop was hosted virtually via Zoom, one year later than originally planned, due to the ongoing pandemic. The timeline nevertheless worked well and this workshop can be viewed as a continuation in a series of events on the same theme, beginning with a CERN workshop in 2019, continued with a meeting in Amherst in 2020 and in 2021, this meeting. Due to the virtual format and to accommodate participants across the globe, sessions alternated between morning and afternoon/evening on each day.

Results and Highlights

The workshop created a dynamic forum to foster exchange and intensify collaboration between researchers studying real-time properties of strongly correlated systems in diverse fields ranging from high-energy nuclear physics to condensed matter physics.

Two **guided discussion sessions** were held during the workshop:

Tuesday 14th: Applications

Discussion was led by M. Hansen. Participants considered a range of issues pertinent for short term and longer term developments including:

Current relevant questions:

- What is the most useful way to define the severity of (or otherwise characterize) an inverse problem?
- Which sources of systematic uncertainty are most important and do we need a better understanding? (both on the input data and in the reconstruction)
- How do we organize the landscape of reconstruction methods?
- What are the best criteria for judging a given reconstruction method? ... systematic / linear / completely data driven
- Is it always necessary to regularize these inverse problems? Do we always see how the regulator enters?

Longer-term questions:

- Can we identify (observable/field-dependent) opportunities to (partially) circumvent the inverse problem?
- Can systematic uncertainties be estimated reliably

    - ... for smeared spectral functions reconstructed using linear methods?
    - ... for smeared spectral functions reconstructed using non-linear methods?
    - ... for un-smeared spectral functions?
- Are we constantly re-discovering each other's methods?
- Do Minkowski-time calculations remove the need for solving inverse problems?
- What could progress look like ~10 years from now, or ~20 years from now?

Thursday 16th: Methods

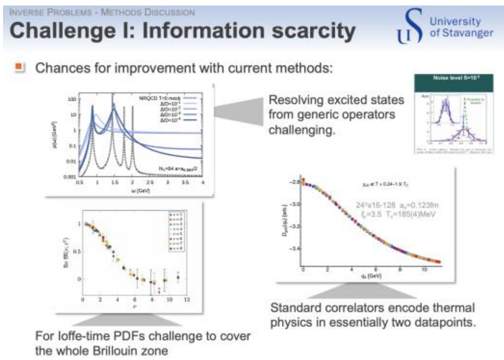
Discussion was led by A. Rothkopf.

The central goal - to reconstruct spectral functions encoded in simulation data was laid out as motivation. In the course of the discussion, three strategies and associated challenges were identified and explored. These are summarised in the Table below.

Strategy I	Strategy II	Strategy III
do not accept the premise. (smeared SPF or purely Euclidean quantity)	accept premise and focus on information within the data.	accept premise and attempt to supply as much extra info as possible.
Challenges	Challenges	Challenges
Identify the physical problems that can benefit from knowledge of smeared SPF or avoid inverse problem all together.	Need to find optimal bases for sparse modelling / correlation structure for GP. What about non pos.?	How can Bayesian methods encode more specific prior info? Beyond positivity and smoothness.

In order to kindle discussions among participants from different fields we highlighted common challenges encountered in each line of research:

➢ The scarcity of information in the input data, which may prevent a successful reconstruction even if highly specific reconstruction procedures are available. This issue was shown to be particularly pressing for lattice QCD at T>0, where the thermal effects are most dominantly encoded in the lowest two or three Matsubara frequencies only. In the case of PDFs and T=0 the challenge is less of a principal



nature and the use of optimized operators is deployed to partially mitigate it.

- competing interests: which refers to the fact that methods developed to improve the information content in the input data (e.g. smearing, extended operators) may interfere with the spectral reconstruction, as they introduce artifacts that prevent established reconstruction methods to succeed (e.g. due to positivity violation). As spectral reconstructions are carried out on state-of-the-art lattices with highly improved actions the questions of non-reflection positivity of these actions becomes relevant.

- specificity: Many of the regulators currently deployed in the literature are very generic and do not incorporate specific domain knowledge on the spectral functions of interest. The discussion focussed on possible paths towards incorporating e.g. the analytic structure of correlation functions to amend the prior information of reconstruction algorithms.

- comparability: multiple approaches, such as MEM, BR, Tikhonov, SAI, SOR can be brought under the umbrella of Bayesian methods, allowing to explicitly test the effect of data quality and regulator choice. Since machine learning approaches encode prior information via training data we identified the quantification of systematic uncertainty from the choice of training data as one central challenge.

Junior researchers methods talks: With the upcoming generation of physicists growing into a research landscape heavily influenced by machine learning and Bayesian reasoning, we set out to highlight these two fields by inviting two PhD students Julian Urban and Gaurang Parkar to give us insight into their latest work, the former speaking about Gaussian processes for the reconstruction of gluon spectral functions, the latter about Bayesian approaches to spectral function reconstruction. Both talks were well received and elicited lively exchange in the guided discussion sessions.

The workshop clearly showed that the high energy and condensed matter communities are working on very similar inverse problems. On the other hand the challenges differ due to the different quality of the input data (e.g. DFT vs. lattice QCD). In the former field, one incorporates systematic approximations but can evaluate correlators at machine precision for many Euclidean times, while in the latter field computations are genuinely ab-initio but limited to a small number of datapoints (~32) with errors at best at the per-mille level. The workshop highlighted the exchange between the communities through works on sparse modelling of spectral functions in the context of band structure of solids and the estimation of the transport properties of the quark-gluon-plasma. These topical intersections bode well for future exchanges between the communities.

Workshop timetable with speakers and talk titles in Indico: https://indico.ectstar.eu/event/101/.

2.3.15 *Machine Learning from High Energy Physics: On and Off the Lattice (Hybrid)*

Date	September 27-01 October, 2021
Organizers	
Andreas Athenodorou	Università di Pisa, Italy
Dimitrios Giataganas	National Sun Yat-sen University, Taiwan
Biagio Lucini	Swansea University, UK
Enrico Rinaldi	University of Michigan, ISA
Kyle Cranmer	New York University, USA
Constantia Alexandrou	University of Cyprus & The Cyprus Institute, Cyprus
Number of participants	14 in-presence participants and 87 remote participants

Main topics

The workshop will focus on developing applications of Machine Learning (ML) techniques to High Energy Theoretical Particle Physics, leveraging on numerical Lattice Field Theory methods.

A pioneering approach has connected Lattice Field Theory and Machine Learning, which were considered as separate scientific fields until very recently. Numerical data from Lattice Field Theory can be studied using all three types of ML models: Supervised, Unsupervised and Self-Learning. Examples in supervised ML are classification tasks with Support Vector Machines (SVMs) or (convolutional) Neural Networks applied to the discovery of phase transitions. For unsupervised learning, examples such as Principal Component Analysis (PCA), Restricted Boltzmann Machines (RBMs) and Autoencoders are used to gain insights on the phase diagram of lattice models and discover parameters of fundamental Hamiltonians. Self- learning policies are also applied to Monte Carlo methods to improve statistical sampling for physics formulated on lattices.

We are planning to cover a broad range of topics such as the investigation of the phase structure of statistical models and gauge theories using ML techniques, the relation of ML with the Renormalisation Group flow, the application of such methods on Lattice Field Theories, focusing on an efficient production of lattice configurations, optimization of action parameters, and extraction of hadronic quantities, as well as the connection between deep learning and gauge/gravity correspondence.

Exchange of ideas and extended discussion sessions among the participants are expected to be mutually beneficial for the evolution and better understanding of both scientific fields. The meeting is designed so that it brings together experts working on applications of machine learning in Lattice Field Theory and using ML in experimental high energy physics. We also welcome participants from industry.

It is actually a fact that many methods which have been recently deployed in Lattice Field Theory and High Energy Physics have been used in industry applications before, mainly in the field of Computer Vision or Artificial Intelligence. The workshop will give the opportunity to early stage researchers (doctoral students and young postdoctoral researchers) to present their work as invited speakers and, thus, to enhance their academic exposure. Special focus is given to gender balance as well as to the representation of female scientists in the Workshop.

Speakers

Andrei Alexandru	The George Washington University, USA
Dimitrios Bachtis	Swansea University, UK
Barak Bringlotz	Sight Diagnostics, Israel
Juan Carrasquilla	Vector Institute for Artificial Intelligence, Canada
Marco Cristoforetti	Fondazione Bruno Kessler, Italy
Robert de Mello Koch	Huzhou Univ. and Univ. of the Witwatersrand, South Africa
William Detmold	Massachusetts Institute of Technology, USA
Tommaso Dorigo	INFN Padova, Italy
Sam Foreman	Argonne National Laboratory USA
Koji Hashimoto	Kyoto University - Physics Department, Japan
Yang-Hui He	London Institute, Royal Institution, UK
Gurtej Kanwar	University of Bern, Switzerland
Ava Khamseh	The University of Edinburgh, UK
Di Luo	University of Illinois, Urbana-Champaign, USA
Thomas Luu	Forschungszentrum Jülich; University of Bonn, Germany
Marina Marinkovic	ETH Zurich, Switzerland
Srijit Paul	Johannes Gutenberg University Mainz, Germany
Giovanni Pederiva	Michigan State University, USA
Nicholas Sale	Swansea University, United Kingdom
S. Shiba Funai	Okinawa Institute of Science and Technology, Japan
Sebastian Wetzel	Perimeter Institute for Theoretical Physics, Canada
Boram Yoon	LANL, US

Scientific report

Machine Learning has been recently used as a very effective tool for the study and prediction of data in various fields of physics, from statistical physics to theoretical high energy physics. A pioneering work by Carrasquilla and Melko in 2017 demonstrated that machine learning techniques can be used successfully for the detection of phase transitions as well as of order parameters. This initiated the beginning of an exciting field which brought together statistical physics, lattice gauge theories as well as theoretical high energy physics with Machine Learning. Since then, Machine Learning has found applications in several different directions such as Renormalization Group, Gauge Gravity correspondence, production of configurations in Lattice Gauge Theories and estimation of observables in Lattice QCD.

The aim of the workshop was to bring together active researchers on Machine Learning and Physics to interact and initiate a collaborative effort to investigate timely problems on Lattices and Theoretical High Energy Physics. Hence we welcomed scientists with research areas covering a broad spectrum to present their work. The workshop begun with two introductory presentations by Cristoforetti and Wetzel where they provided open questions in the field as well as an interpretation of the neural networks in the context of Theoretical Physics respectively. Four presentations focused in phase transition recognition in statistical mechanics (Marinkovic, Paul, Khamseh, Sale). Furthermore, the workshop included a presentation by Juan Carrasquilla on applications of autoregressive neural networks in many-body physics focussing on representing quantum states, reconstructing quantum states, simulating real-time dynamics as well as approximating ground states of classical and quantum many-body systems.

On Monday, Bachtis presented the first talk on Machine Learning with Quantum Field Theories focussing on the case of φ^4 theory, demonstrating that the scalar field theory on a square lattice satisfies the Hammersley-Clifford theorem, therefore recasting it as a Markov random field from which neural networks are additionally derived. Two of the talks (Yoon, Pederiva) focussed on the extraction of observables in Lattice QCD using machine learning techniques. Moreover, five seminars (Kanwar, Foreman, Luo, Alexandru, Deltmold) presented recent progress on the production of configurations in Lattice Gauge Theories using machine learning techniques, focussing on flow-based generative models, gauge equivariant neural networks, topological samplers as well as neural networks for bypassing the calculation of the fermion determinant. Complementarily, Luu presented how machine learning can be used to alleviate the sign problem in stochastic simulations of low-D systems. Two presentations namely by Funai Shiba and De Mello Koch focussed on Machine Learning and its relation with Renormalization Group. Hashimoto's presentation focused on Deep Learning and AdS/CFT correspondence while He's presentation dealt with applications of Machine Learning in String Theory.

In addition, the participants had the opportunity to take a "crash course" on applications of Artificial Intelligence in experimental High Energy physics from one of the world experts on this topic, Tommaso Dorigo. The purpose of this talk was to bridge the two scientific fields and share methods and techniques of Machine Learning used in experimental physics, which can potentially find applications in theoretical high energy physics. Finally, the attendees had also the opportunity to attend a talk by Barak Bringoltz in machine learning applications on optical metrology used in blood diagnostics in order for them to take a taste of the usage of Machine Learning applications in industry.

All seminars raised questions, which led to fruitfull discussions, exchange of ideas and suggestions of future projects.

Result and Highlights

The workshop attracted the attention of approximately 100 participants representing the broad field of theoretical physics, including Lattice Gauge Theories, Statistical Physics, String Theory, Holography, Phenomenology as well as Cosmology. Twenty-two speakers presented their work, including a researcher currently working in industry as well as a researcher working on experimental physics. Among them two female researchers presented their recent findings on the topic. The feedback received from the speakers as well as the participants were rather positive and we foresee continuing organizing similar events. Four early stage scientists were given the opportunity to present their work; namely between 1st - 4th days, the last slot was dedicated to young researchers. Finally, we provided a stimulating environment which initiated interesting discussions between the speakers and the participants leading to sharing new suggestions and ideas.

2.3.16 *Exploring High MμB Matter with Rare Probes (Hybrid)*

Date	October 11-15, 2021

Organizers

Enrico Scomparin	INFN Torino, Italy
Tetyana Galatyuk	TU Darmstadt, Germany
Maria Paola Lombardo	INFN – LNF, Italy
Ralf Rapp	Texas A&M University, USA
Gianluca Usai	Università di Cagliari and INFN, Italy

Number of participants	19 participants and 20-35 remote participants

Main topics

The workshop focused on the study of the high-μ_B region of the QCD phase diagram, which is a key objective of a broad experimental and theoretical program in high-energy nuclear physics. The specific topic of the meeting in this context was the investigation of rare processes, related to the emission of electromagnetic (EM) radiation and heavy-flavor (HF) particles, to be used as probes of the medium created in relativistic nuclear collisions up to center-of-mass energies of $\sqrt{s}$~20 GeV. This energy regime is of high interest for creating a maximal net baryon density in the collisions, with a possible occurrence of a first-order phase transition, where the fundamental question of chiral symmetry restoration can be studied with low-mass dilepton measurements. It also offers unique opportunities in connection with open and hidden charm hadrons, to study their transport properties and probe (the approach to) their kinematic pp production threshold in the heavy-ion systems. These studies pose considerable experimental challenges, due to the low production cross sections involved, that require to sustain very large interaction rates in the detectors. These topics were the main focus of the presentations and discussions at the workshop, which also had the aim of better defining synergies and complementarity between the experimental programs at the various facilities (FAIR/SPS/RHIC/NICA/JPARC-HI).

Speakers

Massimo Mannarelli	INFN LNGS, Italy
Szymon Harabasz	Technische Universität Darmstadt, Germany
Christoph Blume	University Frankfurt am Main, Germany
Marek Gazdzicki	Goethe-Univ. Frankfurt, Germany/Jan Kochanowski Univ. Kielce, Poland
Alessandro De Falco	Università di Cagliari, Italy
Kyoichiro Ozawa	KEK, Japan
Frank Geurts	Rice University, USA
Itzhak Tserruya	Weizmann Institute of Science, Israel
Christian Schmidt	Bielefeld University, Germany

Volker Koch	Lawrence Berkeley National Laboratory, USA
Arno Tripolt	University of Graz (Austria
Joachim Stroth	Goethe University / GSI (Germany
Axel Drees	Stony Brook University (USA
Chihiro Sasaki	University of Wroclaw (Poland
Sudhir Pandurang Rode	Joint Institute for Nuclear Research (Russia
Jan Steinheimer	Froschauer Frankfurt Institute for Advanced Studies (Germany
Lijuan Ruan	Brookhaven National Laboratory, USA
Olaf Kaczmarek	Bielefeld University (Germany
Hendrik van Hees	Goethe University Frankfurt (Germany
Elena Bratkovskaya	GSI (Germany
Santosh Das	Indian Institute of Technology Goa (India)
Xin Dong	Lawrence Berkeley National Laboratory (USA)
Taesoo Song	GSI (Germany)
Francesco Prino	INFN Torino (Italy)
Min He	Nanjing University of Science & Technology (China)
Anton Andronic	University of Muenster (Germany)
Pawel Staszel	Jagiellonian University (Poland)
Robert Pisarski	Brookhaven National Laboratory (USA)
Piotr Salabura	M. Smoluchowski Institute of Physics (Poland)
Baoyi Chen	Tianjin University (China)
Roberta Arnaldi	INFN Torino (Italy)
Michael Strickland	Kent State University (USA)
David Blaschke	University of Wroclaw (Poland)
Michael Winn	CEA IRFU (France)
Elena Ferreiro	University of Santiago de Compostela (Spain)
Xiaojian Du	Bielefeld University (Germany)
Ramona Vogt	Lawrence Livermore National Laboratory and UC Davis (USA)
Sourendu Gupta	TIFR (India)

Scientific report

The meeting was organized into 4 days of presentations, starting with overview-type talks on Monday, three topical days on Tuesday, Wednesday and Thursday centered around electromagnetic, open heavy-flavor and quarkonium probes, respectively, and a wrap-up discussion on Friday morning.

On day-1, general features of the QCD phase diagram were discussed. Two theoretical talks highlighted effective model and lattice-QCD approaches, discussing possible locations of a critical point and how it is affected by different approximation schemes, different thermodynamic conditions (e.g. isospin chemical potential), and its possible manifestation in experiment. The remainder of the talks presented the capabilities of the various experiments planning to address the high-μ_B region via nuclear collisions, including HADES and J-PARC on the low-energy end, CBM at “intermediate energies” around the charm production threshold, and NA60+, NA61, NICA, and STAR toward higher energies around 10 GeV. These talks highlighted the broad experimental efforts undertaken worldwide to study high-μ_B matter, which also reiterated the importance of adequate theory support to be developed in the coming years. The possibility of taking data at large interaction rates in nuclear collisions (with values up to ~10^7/s) was recognized as central for the study of hard and electromagnetic probes in this energy domain. A follow-up discussion on Tue morning set the stage for the upcoming day. In particular, central questions were postulated and multiple observables using heavy-flavor and quarkonium, dileptons and photons were identified. The capabilities of measuring those were discussed in the follow-up talks and discussion sessions.

On day-2 (afternoon), electromagnetic (EM) probes were discussed, starting with a theoretical overview that highlighted the current understanding of calculations of the in-medium vector spectral function and its relation to chiral symmetry restoration via ρ-a_1 degeneracy and chiral mixing. Novel signatures of chiral restoration due to the Wess-Zumino-Witten term in presence of an omega condensate at finite density were presented predicting additional peak structures in the mass spectra, although collisional broadening was found to mitigate the effect. Theoretical investigations of dilepton production were also reported for low SPS energies from coarse-graining methods, transport and hydrodynamic approaches. In particular, the implementation of a first-order phase transition at HADES energies was shown to give a factor of ~2 increase in the low-mass dilepton yield compared to a cross-over or transport models. From the experimental side, the importance of a comprehensive understanding of observed dilepton spectra across all available collision energies (from SIS-18 via SPS and RHIC to the LHC) was emphasized, including elementary collision systems where vector-meson lineshape in cold nuclear matter (in pA collisions) and elementary production processes can be tested and constrained. Measurements in both the dielectron and dimuon channels are foreseen, with complementary features in terms of background and kinematic reach. Recent results from direct photon production at RHIC were presented, which currently pose a challenge to experimental models, both in terms of (centrality dependent) yields and elliptic flow. Follow-up discussions on the following morning reiterated the current understanding of low-mass dileptons in terms of a degeneracy of chiral partners where the a_1 mass drops down to the ρ mass with the latter essentially unchanged and both undergoing a strong broadening. The associated “melting” of the ρ meson, on the other hand, likely signals a transition to partonic degrees of freedom. The interpretation of the ρ melting at HADES energies, and more generally at high μ_B, remains an open question. As a potential signal of chiral restoration a very-low mass enhancement of dileptons due to the degeneracy of the nucleon with its chiral partner, the N*(1535), was proposed. It was also debated what the microscopic mechanism of the so-called chiral mixing in the M=1-1.5 GeV, in particular a more realistic manifestation of the pi-a_1 mixing possibly mediated by in-medium ρ’ decays. Perspectives to extract the electric conductivity from the transport peak at vanishing di-electron energy (small mass and small pair momentum) were discussed.

On day-3, open HF probes of QCD matter were scrutinized. Theoretical presentations pointed at the importance of hadronic effects in the diffusion of charm-particles in the SPS energy regime and below. Of particular interest is the (near-) threshold regime where heavy-flavor diffusion to transverse momenta beyond the kinematic limit of pp collisions can be studied, a novel effect corresponding to an infinite nuclear modification factor. Likewise, sub-threshold charm production (relative to the available excess energy in pp collisions) will probe uncharted territory of nonperturbative and/or collective mechanisms that reveal novel insights into QCD dynamics. Predictions of the statistical hadronization model were discussed, including the effects of canonical suppression for small production numbers, also in connection with non-monotonic features in the excitation function of strangeness in AA vs. pp collisions. From the experimental side, no results are available below $\sqrt{s}$=27 GeV, and the rapid decrease of the production cross sections at lower energies makes such measurements rather challenging. Very promising simulation results for the measurements of open-charm hadrons (D and D_s mesons, and even Λ_c baryons) were shown by the NA60+ collaboration, which would allow for measurements of nuclear modification factors and elliptic flow, the two key observables to probe transport and hadronization properties of the produced medium.

On day-4, the role of heavy quarkonia in the study of high-μ_B QCD matter was assessed. An overarching question in this context is how the basic QCD force between heavy quarks is modified in the medium and manifests itself in the spectral functions of charmonia and bottomonia. From the theoretical side, the main tool in describing quarkonium production in heavy-ion collisions to date remains semiclassical transport theory. Within this framework, a rather comprehensive description of the centrality, transverse-momentum and collision energy dependence of charmonium and bottomonium observables, from SPS via RHIC to LHC energies has been achieved. There is consensus that suppression mechanisms, due to a combination of in-medium screening and inelastic dissociation reactions, are the main effect at SPS and RHIC energies, while regeneration mechanisms in QCD matter are at the origin of the remarkable increase of J/ψ production at LHC energies. More recent developments include the concepts of open quantum systems in the dissociation dynamics, thus constrained to weak coupling methods in the bottomonium sector, albeit the significance of the genuine quantum effects needs to be elaborated. At SPS energies and below, as pertinent to the main focus of the meeting, the so-called nuclear absorption from the incoming primordial nucleons becomes a dominant suppression. Detailed experimental studies of this effect in pA collisions, as carried out at the SPS and reviewed at the meeting, were thus identified to be mandatory as a prerequisite to extract medium effects. Inelastic interactions with the hadronic medium, sometimes also referred to as comover interactions, are expected to become more important as the QGP lifetime presumably becomes rather small at collision energies around and below 10 GeV. As the hot-matter suppression of the J/ψ is not large already at SPS energies, a measurement of excited states (ψ(2S) and χ_c states), would be desirable albeit experimentally challenging. This would allow for systematic studies of how the basic QCD force is screened in a baryon-rich medium.

Also in this sector, no results are available for nuclear collisions below top SPS energy, and in particular for this observable the availability of large integrated luminosities is an experimental must.

The last day of the meeting, consisting of 2 morning sessions, was dedicated to summarize discussions of the main ideas and insights generated at this workshop. It was deemed that the intellectual progress achieved at this meeting warrants the preparation of a concise document that, on the one hand, updates the current understanding of probes targeted at heavy-ion collisions in the high-μ_B regime and, on the other hand, stimulates theoretical investigations to further sharpen the case and aid in the planning of pertinent experimental facilities at CERN, FAIR, NICA, PARC and RHIC.

Results and Highlights

The workshop demonstrated that the field of heavy-ion physics in the collision energy regime of roughly 3-15 GeV enjoys broad interest and support in the QCD matter community, due to its projected ability of probing the QCD phase diagram in a "critical" region where the transition from meson to baryon-dominated matter occurs and the existence of phase transitions is rather conceivable. So far, very little experimental information exists in this regime, especially for the "rare" probes -- the focus of this meeting -- which have proven extremely informative in the high-energy regime. A variety of pertinent facilities will come online (FAIR, NICA, JPARC-HI) in the next 5-10 years or are already operative (SPS), allowing for high reaction rates which will enable first class data on charm/onium production and electromagnetic radiation. For the latter, measurements of the spectral shape of the rho-meson and possibly its excited state, the ρ', are expected to give new and improved insights into the mechanisms of chiral restoration, such as the mass degeneration and the so-called chiral mixing. Blue-shift free temperature measurements for masses above 1.5 GeV, and true lifetime measurements (possibly sensitive to a first-order transition), through excitation functions, are also compelling objectives, and pertinent expectations from theory have been sharpened. The complementary energy coverage of experiments as HADES, CBM and NA60+ will definitely allow a mapping of the caloric curve of the strongly interacting medium, with the aim of detecting signals from the phase transition and its order. In the open-charm sector, the NA60+ collaboration presented exciting prospects for precise D and D_s flow measurements (possibly even Λ_c), which are likely to advance our understanding of the heavy-flavor transport coefficient in (baryon-rich) QCD matter, with possibly novel signatures such as a diffusion to high momentum, even beyond the kinematic limit in pp collisions (implying an infinite nuclear modification factor). For charmonia, current measurements at higher energies suggest that the J/ψ may not be much affected by the energy densities reached in collision energies below 10 GeV, but its modified yields from the feeddown of higher states remain of substantial interest. In particular, the production ratio of charmonia to open charm hadrons, which is typically around 1% at higher energies, has exciting prospects at lower energies, as it may undergo a rapid rise toward lower energies as the open charm threshold is higher than the one for the J/ψ. This would provide genuine tests of nonperturbative and/or collective forces in the charm sector.

2.3.17 *Quark-Gluon Plasma Characterisation with Heavy Flavour Probes (Hybrid)*

Date	November 15-19, 2021
Organizers	
Giuseppe Bruno	Politecnico & INFN Bari, Italy
Joerg Aichelin	SUBATECH, France
Ralf Averbeck	GSI & EMMI, Germany
Fabrizio Grosa	INFN Torino, Italy
Number of participants	60 (about 20 in persons and 40 from remote)

Main topics

Heavy flavor (HF) quarks are excellent probes for the properties of the QGP created in ultra-relativistic heavy-ion collisions. Open HF hadron production allows one to determine the transport coefficients of the QGP. At high transverse momentum, they serve to study parton energy-loss mechanisms in the QGP. Present models, however, differ in many details. In the quarkonia sector, open questions include: up to which temperature can the different quarkonium states survive in a QGP and how do these objects interact with the QGP? How can the recombination of HF quarks/antiquarks from independent hard parton-parton interactions be described in an expanding medium? How constraining is the knowledge of the total HF production cross section? How do quarkonia interact with the expanding gas of hadrons?

Speakers

A. Andronic	University of Münster, Germany
R. Arnaldi	INFN Torino, Italy
B. Audurier	CNRS, France
A. Beraudo	INFN Torino, Italy
E. Bratkovskaya	GSI, Germany
S. Cao	Shandong University, China
Y. Chen	MIT, USA
F. Colamaria	INFN Bari, Italy
Z. Conesa del Valle	CNRS/IN2P3, France
F. Damas	CNRS, France
X. Dong	LBNL, USA
M. Durham	LANL, USA
M. Faggin	University of Padua, Italy
W. Fan	Duke University, USA
P.B. Gossiaux	Subatech, France
R. Granier de Cassagnac	CNRS, France

V. Greco	University of Catania, Italy
M. He	Nanjing University of Science and Technology, China
Q. Hu	LLNL, USA
G.M. Innocenti	CERN, Switzerland
A. Kalweit	CERN, Switzerland
Y.J. Lee	MIT, USA
G. Manca	University of Cagliari, Italy
L. Micheletti	INFN Torino, Italy
A. Palasciano	Università degli Studi di Bari, Italy
S. Plumari	University of Catania, Italy
F. Prino	INFN Torino, Italy
V. Pugatch	National Academy of Sciences of Ukraine, Ukraine
R. Rapp	Texas A&M University, USA
A. Rossi	INFN Padua, Italy
A. Rothkopf	University of Stavanger, Norway
M.L. Sambataro	University of Catania, Italy
E. Scomparin	Politecnico di Torino, Italy
T. Song	GSI, Germany
J. Sun	INFN Cagliar, Italy
Z. Tang	University of Science and Technology of China, China
P. Vander Griend	TU Munich, Germany
J. Wang	MIT, USA
X.N. Wang	LBNL, USA
J. Weber	Humboldt-University of Berlin, Germany
W. Zha	University of Science and Technology of China, China

Scientific Report

By colliding nuclei accelerated by the Large Hadron Collider at ultra-relativistic energies, one can produce and study in a laboratory the conditions of the early Universe, as it was a few micro-second after the Big Bang, when quarks and gluons formed a hot deconfined plasma, the so-called Quark-Gluon Plasma (QGP).

From the thousands of particles produced in heavy-ion collisions at very high energies, several observables can be defined to study the properties of the QGP and, more in general, the dynamics of the collisions. After more than 30 years of research in this sector, with experimental programs at fixed target and in collider mode, conducted at CERN and at the BNL, the following picture has emerged for the dynamical evolution of nuclear collisions at high energy: i) initial state (with peculiar aspects, such as the nuclear modifications of the parton distribution function of protons and neutrons); ii) very short pre-equilibrium phase (lasting O(1 fm/c) or less), after which a local thermal equilibrium is reached; iii) QGP phase, lasting O(10 fm/c) at top RHIC energy or longer at the LHC, characterized by an explosive collective expansion (v>0.5c) well described by relativistic hydrodynamical models with minimal shear viscosity/entropy density ratio, during which the system cool down till T~160 MeV and undergoes iv) the phase transition to the hadronic phase; v) further expansion and cooling of the fireball in hadronic phase (and eventually first in a mixed phase) till reaching first a "chemical equilibrium" (the relative abundancies of produced particles are well described by statistical models with T~155 MeV), and then the final freeze-out when the temperature is about T~120 MeV.

Among the several observables, those exploiting "heavy flavour" (i.e. charm and beauty), play a special role. In fact, due to the large mass, ccbar and bbbar pairs (QQbar in the following) can be produced only in the very early stage of the collision (formation time of a QQbar pair is ~ $1/m_{QQ}$), in hard partonic scattering processes with large four-momentum transfer squared (Q^2). Therefore, they are sensitive probes of the full evolution of the collision, since its early and hotter stage. The QQbar production cross-section rapidly increases with the nucleon-nucleon center-of mass collision energy ($\sqrt{s_{NN}}$), and at the LHC energy they are finally abundantly produced.

The possible experimental observables now include y-differential, pt-differential, and double or triple-differential (pt,y, and azimuthal direction) single HF open hadron production, fully reconstructed HF jets, baryon vs. meson production, production of HF hadrons with strange contents or multi-HF hadrons (e.g. B_c meson), exotic HF hadrons. The equivalent list in the hidden HF sector has also significantly expanded thanks to the large amount of data collected in the 2nd LHC run period (run2) and will expand further with the next LHC runs.

The theoretical interpretation of the wealth of data obtained from the experiments requires a strict collaboration among several theory groups, to develop models aiming at the description of the entire evolution of the ultra-relativistic collisions, in its several facets, and between the theory community and the experiments for steering new campaigns of measurements. The workshop at ECT* was proposed with that in mind.

Results and Highlights

We have made an assessment of the whole field of heavy hadron production in ultra-relativistic collisions: key people from all experiments at LHC and RHIC as well as European and non-European theorists of the concerned fields have joined and fruitfully participated to the workshop. The following goals have been reached:

- identification of the key issues which have to be addressed on the theory side (initial condition, hadronization, validity of the transport approaches);
- identification of the key observables which may validate the different approaches in the theoretical description, posed in respect to the achievable experimental uncertainties (present, midterm, and long-term future upgrades and/or new experiments);

– starting of common efforts (supported by the STRONG-2020 NA7 network) to address the open questions.

A dedicated session was devoted to a detailed comparisons of the recombination and hadronisation schemes implemented in the different transport models, by also performing simulations on reference processes. A road-map of actions to be taken over the first half of 2022 was agreed among the major theory groups.

The workshop has also served to start a discussion for the preparation of a Review Paper, a main deliverable expected from NA7, with recommendations for the dedicated heavy-ion periods at the LHC, with a focus on the runs after the 3rd Long Shutdown (run4, run5 and beyond), for the different LHC experiments.

The agenda of the workshop with all PDF files of the presentations is available at this web-page: https://indico.ectstar.eu/event/102/

2.4 ECT* Doctoral Training Program

High-Energy and Nuclear Physics within Quantum Technologies

28 June - 23 July 2021

(Report by Enrique Rico Ortega)

2.4.1 *Organizers*

Pilar Hernandez	University of Valencia
Simone Montangero	University of Padua
Yasser Omar	University of Lisbon
Enrique Rico Ortega	UPV/EHU, Ikerbasque

Number of participants 28

Aims of the DTP

In the past few years, noteworthy progress has been achieved in the understanding and control of quantum many-body systems that are relevant to solving models in high-energy, nuclear, and condensed matter physics.

This progress has been to a substantial extent the result of a collaborative effort of different communities. New tools and concepts from quantum information and quantum optics are now supplying new avenues to address open problems in particle, nuclear, and statistical physics, complementing more traditional approaches.

The purpose of this school was to bring together experts and leaders in quantum information and high-energy physics to train a new generation of researchers in the state-of-the-art methods, applications, and open problems in both fields. This school will have an important impact on enhancing synergies and further progress in this fast-developing field.

Main Topics

The following lectures were given:

28 June – 02 July	Christof Gattringer: *Lattice QCD methods*
	Philipp Hauke: *Open Quantum Systems and Optical Lattice*
05 July – 09 July	Mari Carmen Bañuls: *Tensor network methods*
	Zohreh Davoudi: *Nuclear Physics and effective theories*

12 July – 16 July	Fred Jendrzejewski: *Experimental tools in cold gases and optical lattices* Stefan Schaefer: *Challenges in Lattice QCD*
19 July – 23 July	Martin Ringbauer: *Experimental tools in ion traps* David Kaplan: *Chiral Theories*

2.4.2 *Lecturers*

Mari Carmen Bañuls	Max-Planck-Institute of Quantum Optics
Zohreh Davoudi	University of Maryland
Christof Gattringer	Austrian Science Fund - FWF
Philipp H. J. Hauke	University of Trento - Department of Physics
David B. Kaplan	University of Washington - Institute for Nuclear Theory
Martin Ringbauer	Universität Innsbruck - Institut für Experimentalphysik
Stefan Schaefer	NIC - DESY
Fred Jendrzejewski	University of Heidelberg - Kirchhoff Institute for Physics

Supervisors

Claire Edmunds	Universitat Innsbruck
Dorota Grabowska	CERN
Apoorva Hedge	Kirchhoff Institute for Physics
Irene Papaefstathiou	Max Planck Institute of Quantum Optics
Carlos Roberto Pena Ruano	Instituto de Física Teórica UAM/CSIC, Madrid
Andreas Risch	Deutsches Elektronen-Synchrotron DESY
Fernando Romero-López	Instituto de Física Corpuscular (Parque Científico), Patena
Philipp Uhrich	INO-CNR BEC Center and Physics Dep., Univ. of Trento

2.4.3 *List of students*

Albandea, Jjordan	Spain
Andrade, Barbara	Spain
Baeza, Ballesteros	Spain
Bangar, Shikha	USA
Barreiro, Julio	USA
Catumba, Guilherme	Spain
Choudhary, Priyanka	India
Dhindsa, Navdeep Singh	India
Duan, Haowu	USA

Fernandez, Aitor	Spain
Gallimore, Daniel	USA
Kadam Saurabh, Vasant	USA
Kaundilya, Dipankar	India
Laudicina, Davide	Italy
Luo, Di Luo	USA
Mandl, Michael	Germany
Oriel, Kiss	Switzerland
Pavan, Pavan	India
Pederiva, Giovanni	USA
Polykratis, Georgios	Cyprus
Rigobello, Marco	Italy
Saez Gonzalvo, Alejandro	Spain
Saraswati, Pandey	India
Saxena, Archana	India
Sharifian, Mohammad	Iran
Shen, Jiayu	USA
Wadhia, Vivek	UK
Zhang, Zhenyu	China

Scheduling of the lessons

The DTP was online, via Zoom. The daily program was scheduled to start at 2 pm CET and last until 6 pm CET.

Results and Highlights

A total of 30 teaching hours on lattice QCD methods and another 30 teaching hours on Quantum Simulation methods were given by the lecturers. Moreover, there were another 20 hours of tutorial classes with discussions of exercises among the students led by the supervisors and tutors on lattice QCD and Quantum Simulation. As a result of the active participation of the students in the doctoral training school, the University of Trento gave a certification including the number of credits during the ECT* PhD school.

The DTP is included in the Doctoral Programme in Physics of the University of Trento: https://www.unitn.it/drphys/en/129/training-programme

2.5 ECT* TALENT School

Machine Learning applied to Nuclear Physics: Experiment and Theory

19-30 July 2021

(Report by Morten Hjorth-Jensen)

2.5.1 Organizers and lecturers

Pilar Hernandez	University of Valencia
Morten Hjorth-Jensen	Michigan State University & University of Oslo
Simone Montangero	University of Padua
Yasser Omar	University of Lisbon
Enrique Rico Ortega	UPV/EHU, Ikerbasque

Student coordination

Morten Hjorth-Jensen	Michigan State University & University of Oslo

Number of participants: 63

Why a course on Machine Learning for Nuclear Physics?

Probability theory and statistical methods play a central role in science. Nowadays we are surrounded by huge amounts of data. For example, there are about one trillion web pages; more than one hour of video is uploaded to YouTube every second, amounting to 10 years of content every day; the genomes of 1000s of people, each of which has a length of more than a billion base pairs, have been sequenced by various labs and so on. This deluge of data calls for automated methods of data analysis, which is exactly what machine learning provides. The purpose of this Nuclear Talent course is to provide an introduction to the core concepts and tools of machine learning in a manner easily understood and intuitive to physicists and nuclear physicists in particular. We will start with some of the basic methods from supervised learning and statistical data analysis, such as various regression methods before we move into deep learning methods for both supervised and unsupervised learning, with an emphasis on the analysis of nuclear physics experiments and theoretical nuclear physics. The students will work on hands-on daily examples as well as projects than can result in final credits. Exercises and projects will be provided and the aim is to give the participants an overview on how machine learning can be used to analyze and study nuclear physics problems (experiment and theory). The major scope is to give the participants a deeper understanding on what Machine learning and Data Analysis are and how they can be used to analyze data from nuclear physics experiments and perform theoretical calculations of nuclear many-body systems.

The goals of the Nuclear Talent course on Machine Learning and Data Analysis are to give the participants a deeper understanding and critical view of several widely popular Machine Learning algorithms, covering both supervised and unsupervised learning. The learning outcomes involve an understanding of the following central methods:

- Basic concepts of machine learning and data analysis and statistical concepts like expectation values, variance, covariance, correlation functions and errors;
- Estimation of errors using cross-validation, blocking, bootstrapping and jack-knife methods;
- Optimization of functions
- Linear Regression and Logistic Regression;
- Dimensionality reductions, from PCA to clustering
- Boltzmann machines;
- Neural networks and deep learning;
- Convolutional Neural Networks
- Recurrent Neureal Networks and Autoencoders
- Decisions trees and random forests
- Support vector machines and kernel transformations

We are targeting an audience of graduate students (both Master of Science and PhD) as well as post-doctoral researchers in nuclear experiment and theory.

The teaching teams consists of both theorists and experimentalists. We believe such a mix is important as it gives the participants a better understanding on how data are obtained, and what are the limitations and possibilities in understanding and interpreting the experimental information.

Aims

This two-week online TALENT course on nuclear theory will focus on Machine Learning and Data Analysis algorithms for nuclear physics and to use such methods in the interpretation of data on the structure of nuclear systems.

We propose approximately twenty hours of lectures over two weeks and a comparable amount of practical computer and exercise sessions, including the setting of individual problems and the organization of various individual projects.

The mornings will consist of lectures and the afternoons will be devoted to exercises meant to shed light on the exposed theory, the computational projects and individual student projects. These components will be coordinated to foster student engagement, maximize learning and create lasting value for the students. For the benefit of the TALENT series and of the community, material (courses, slides, problems and solutions, reports on students' projects) will be made publicly available using version control software like git and posted electronically on github (this site).

Learning Outcomes

At the end of the course the students should have a basic understanding of

- Statistical data analysis, theory and tools to handle large data sets.
- A solid understanding of central machine learning algorithms for supervised and unsupervised learning, involving linear and logistic regression, support vector machines, decision trees and random forests, neural networks and deep learning (convolutional neural networks, recursive neural networks etc)
- Be able to write codes for linear regression, logistic regression and use modern libraries like Tensorflow, Pytorch, Scikit-Learn in order to analyze data from nuclear physics experiments and perform theoretical calculations
- A deeper understanding of the statistical properties of the various methods, from the bias-variance tradeoff to resampling techniques.

2.5.2 List of students

Alaaeddine, Lahbas	Morocco
Alam, Naosad	India
Alexandropoulou,	Stamatina, UK
Alpana, Alpana	India
Bala, Renu	India
Barman, Jinti	India
Barman, Ranojit	India
Bellinzona, Elettra Valentina	Italy
Bhoy, Bharti	India
Choudary,Prinaka	India
Dao, Thanh Thuy	Singapore
Das, Monalisa	India
Das, Biswajit	India
Das, Harish Chandra Das	India
De, Sukendu	India
Dissanayake, Susantha	UK
Dong, Yunsheng	Italy
Eiji Tamayose, Leonardo	Brazil
Ferrari Fortino, Guilherme	Brazil
Fox, Jordan	United States
Gang, Swati	China

Gao, Yonghao	China
Génard, Tom	France
Hasegawa, Naoto	Japan
Imam, Sk MD Adil	India
Jain, Nishu	India
Junchao, Guo	China
Kakkar, Pragati	UK
Katoch, Vikas	India
Klink, Clara	Germany
Kurmanova, Alma	Italy
Kushwaha, Harsh	India
Li Muli, Simone Salvatore	Germany
Lynch, Warren	UK
Majekodunmi, Joshua	Malaysia
Makowski, Andrezej	Poland
Manju, Manju	India
Mazzei, Gaston	Argentina
Mishra, Bharat	Italy
Montenegro, David	Brazil
Neto, David	USA
Neubüser, Coralie	Italy
Ngo, Tan Anh Khoa	France
Nguyen, Dang Khoa	France
Nguyen, Hong Ha	France
Pamar, Vishal Thapar	India
Patel, Deepak	India
Patra, Naresh Kumar	India
Pattnaik, Jeet Amrit	India
Quddus, Abdul	India
Rana, Shilpa Thapar	India
Ribeiro, Jônatas	Brazil
Sadhukhan, Jhilam	India

Sahoo, Subhajit	India
Sarma, Chandan	India
Sharma, Shweta	India
Shukla, Sakshi	India
Singh, Jagjit	Japan
Sousa, Thomàs	Portugal
Tran, Tri Dat Can Tho	Vietnam
Wang, Jiaqi	China
Yadav, Praveen Kumar	India
Zacarias, Sabrina	Germany

Research at ECT*

3. Research at ECT*

3.1 Projects of ECT* Researchers

Nuclear Physics

GERT AARTS

Machine learning for fundamental physics

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

Project abstract: Recently machine learning methods have gained popularity for addressing problems in theoretical physics, in particular in quantum field theory. In a series of papers, we have explored several applications, including histogram reweighting, transfer learning, the addition of machine-learning functions within system Hamiltonians, and the use of quantum-field theory concepts.
Related publications: [GA1], [GA2], [GA4] - [GA6]

Inverse Renormalisation Group

In collaboration with D. Bachtis, B. Lucini (Swansea University), and F. di Renzo (Parma University)

Project abstract: Inverse renormalization group (RG) transformations are usually hard to construct, since one has to add degrees of freedom, rather than integrating them out. We use machine-learning methods to construct local inverse RG steps within the context of quantum field theory, and demonstrate that the formulation produces the appropriate critical fixed point structure, gives rise to inverse flows in parameter space, and evades the critical slowing down effect in calculations pertinent to criticality.
Related publications: [GA3]

Electrical conductivity in thermal QCD

In collaboration with A. Nikolaev (Swansea University)

Project abstract: In this review, a discussion on the electrical conductivity of the quark-gluon plasma as determined by lattice QCD is given. Various methods for spectral reconstruction are reviewed, including the use of Ansätze and sum rules, the Maximum Entropy and Backus-Gilbert methods, and Tikhonov regularisation. A comprehensive overview of lattice QCD results obtained so far is given, including a comparison of the different lattice formulations. A noticeable consistency for the conductivities obtained is seen, in spite of the differences in the lattice setups and spectral reconstruction methods.
Related publications: [GA7]

Quantum fields with trapped ions

In collaboration with G. Martín-Vázquez (Universidad Complutense Madrid), M. Müller (Forschungszentrum Jülich and Aachen University) and A. Bermudez (Universidad Complutense Madrid)

Project abstract: In this project, we show that the generating functional of a self-interacting scalar quantum field theory (QFT), which contains all the relevant information about real-time dynamics and scattering experiments, can be mapped onto a collection of multipartite-entangled two-level sensors via an interferometric protocol that exploits a specific set of source functions.
Related publications: [GA8]

THOR COST action

In collaboration with J. Aichelin (SUBATECH Nantes), M. Bleicher (Goethe University Frankfurt), E. G Ferreiro (Universidade de Santiago de Compostella), L. Tolos (Institut of Space Science, Barcelona), B. Tomášik (Univerzita Mateja Bela)

Project abstract: The authors edited a topical issue of EPJA, which summarises some of the results realised thanks to the COST Action CA15213, which was running under the acronym THOR—short for *Theory of hot matter and relativistic heavy-ion collisions*—from November 2016 until April 2021.
Related publications: [GA9]

QCD under extreme conditions

In collaboration with C. Allton, T. Burns, 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, parity doubling for baryons, and spectral reconstruction using a number of methods.
Related publications: [GA10] - [GA15]

DANIELE BINOSI

Concerning pion parton distributions

In collaboration with Z.-F. Cui (Nanjing U.), M. Ding (HZDR, Dresden), J.M. Morgado (Huelva U.), K. Raya (Granada U., Theor. Phys. Astrophys. and Mexico U., ICN), L. Chang (Nankai U.), J. Papavassiliou (Valencia U. and Valencia U., IFIC), C.D. Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.), S.M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)

Project abstract: Analyses of the pion valence-quark distribution function (DF), $u^{\pi}(x;\zeta)$, which explicitly incorporate the behaviour of the pion wave function prescribed by quantum chromodynamics (QCD), predict $u^{\pi}(x\simeq 1;\zeta)\sim(1-x)^{\beta(\zeta)}$, $\beta(\zeta>m_p)>2$, where m_p is the proton mass. Nevertheless, more than forty years after the first experiment to

collect data suitable for extracting the $x \simeq 1$ of u^π, the empirical status remains uncertain because some methods used to fit existing data return a result for u^π that violates this constraint. Such disagreement entails one of the following conclusions: the analysis concerned is incomplete; not all data being considered are a true expression of qualities intrinsic to the pion; or QCD, as it is currently understood, is not the theory of strong interactions. New, precise data are necessary before a final conclusion is possible. In developing these positions, we exploit a single proposition, viz. there is an effective charge which defines an evolution scheme for parton DFs that is all-orders exact. This proposition has numerous corollaries, which can be used to test the character of any DF, whether fitted or calculated.
Related publications: [DB1]

Semileptonic transitions: B(s) → π(K); Ds → K; D → π,K; and K → π

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

Project abstract: Continuum Schwinger function methods for the strong-interaction bound-state problem are used to arrive at a unified set of parameter-free predictions for the semileptonic *K→π*, *D→π,K* and *Ds→K*, *B(s)→π(K)* transition form factors and the associated branching fractions. The form factors are a leading source of uncertainty in all such calculations: our results agree quantitatively with available data and provide benchmarks for the hitherto unmeasured *Ds→K0*, *B¯s→K+* form factors. The analysis delivers a value of |Vcs|=0.974(10) and also predictions for all branching fraction ratios in the pseudoscalar meson sector that can be used to test lepton flavour universality. Quantitative comparisons are provided between extant theory and the recent measurement of *BBs0→K−μ+vμ*. Here, further, refined measurements would be useful in moving toward a more accurate value of |Vub|.
Related publications: [DB2]

Pauli radius of the proton

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

Project abstract: Using a procedure based on interpolation via continued fractions supplemented by statistical sampling, we analyze proton magnetic form factor data obtained via electron+proton scattering on $Q^2 \in [0.027,0.55]$ GeV^2 with the goal of determining the proton magnetic radius. The approach avoids assumptions about the function form used for data interpolation and ensuing extrapolation onto $Q^2 \sim 0$ for extraction of the form factor slope. In this way, we find r_M=0.817(27) fm. Regarding the difference between proton electric and magnetic radii calculated in this way, extant data are seen to be compatible with the possibility that the slopes of the proton Dirac and Pauli form factors, F1,2(Q2), are not truly independent observables; to wit, the difference $F'_1(0) - F'_2(0)/\kappa_p = [1+\kappa_p]/[4m_p^2]$, viz., the proton Foldy term.
Related publications: [DB3]
This publication is featured on the cover of the corresponding issue of CPL.

Valence quark ratio in the proton
In collaboration with Z.-F. Cui (Nanjing U.), F. Gao (U. Heidelberg, ITP), L. Chang (Nankai U.), C. D. Roberts (Nanjing U.), S. M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)
Project abstract: Beginning with precise data on the ratio of structure functions in deep inelastic scattering (DIS) from ^{3}He and ^{3}H, collected on the domain $0.19<x_B<0.83$ where x_B is the Bjorken scaling variable, we employ a robust method for extrapolating such data to arrive at a model-independent result for the x_B=1 value of the ratio of neutron and proton structure functions. Combining this with information obtained in analyses of DIS from nuclei, corrected for target-structure dependence, we arrive at a prediction for the proton's valence-quark ratio: $d_v/u_v|_{x_B\to 1}=0.230(57)$. Requiring consistency with this result presents a challenge to many descriptions of proton structure.
Related publications: [DB4]

Pion charge radius from pion+electron elastic scattering data
In collaboration with Z.-F. Cui (Nanjing U.), C. D. Roberts (Nanjing U.), S.M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)

Project abstract: With the aim of extracting the pion charge radius, we analyse extant precise pion+electron elastic scattering data on $Q^2\in[0.015,0.144]$ GeV^2 using a method based on interpolation via continued fractions augmented by statistical sampling. The scheme avoids any assumptions on the form of function used for the

representation of data and subsequent extrapolation onto $Q^2 \simeq 0$. Combining results obtained from the two available data sets, we obtain r_π=0.640(7) fm, a value 2.4σ below today's commonly quoted average. The tension may be relieved by collection and similar analysis of new precise data that densely cover a domain which reaches well below Q^2=0.015 GeV^2. Considering available kaon+electron elastic scattering data sets, our analysis reveals that they contain insufficient information to extract an objective result for the charged-kaon radius, r_K. New data with much improved precision, low-Q^2 reach and coverage are necessary before a sound result for r_K can be recorded.
Related publications: [DB5]

Vector-meson production and vector meson dominance

In collaboration with Y.-Z. Xu (Nanjing U.), S. Chen (Nanjing U.), Z.-Q. Yao (Nanjing U.), Z.-F. Cui (Nanjing U.), C. D. Roberts (Nanjing U.)

Project abstract: We consider the fidelity of the vector meson dominance (VMD) assumption as an instrument for relating the electromagnetic vector-meson production reaction $e+p \to e'+V+p$ to the purely hadronic process $V+p \to V+p$. Analyses of the photon vacuum polarisation and the photon-quark vertex reveal that such a VMD Ansatz might be reasonable for light vector-mesons. However, when the vector-mesons are described by momentum-dependent bound-state amplitudes, VMD fails for heavy vector-mesons: it cannot be used reliably to estimate either a photon-to-vector-meson transition strength or the momentum dependence of those integrands that would arise in calculations of the different reaction amplitudes. Consequently, for processes involving heavy mesons, the veracity of both cross-section estimates and conclusions based on the VMD assumption should be reviewed, e.g., those relating to hidden-charm pentaquark production and the origin of the proton mass.
Related publications: [DB6]

Semileptonic $B_c \to \eta_c, J/\psi$ transitions

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

Project abstract: Using a systematic, symmetry-preserving continuum approach to the Standard Model strong-interaction bound-state problem, we deliver parameter-free predictions for all semileptonic $B_c \to \eta_c, J/\psi$ transition form factors on the complete domains of empirically accessible momentum transfers. Working with branching fractions calculated therefrom, the following values of the ratios for τ over μ final states are obtained: $R_{\eta c}$=0.313(22) and $R_{J/\psi}$=0.242(47). Combined with other recent results, our analysis confirms a 2 σ discrepancy between the Standard Model prediction for $R_{J/\psi}$ and the single available experimental result.
Related publications: [DB7]

Distribution amplitudes of light diquarks

In collaboration with Y. Lu (Nanjing U.), M. Ding (ECT, Trento), C. D. Roberts (Nanjing U.), H.-Y. Xing (Nanjing U.), C. Xu (Nanjing U.)

Project abstract: Accumulating evidence indicates that soft quark+quark (diquark) correlations play an important role in the structure and interactions of hadrons constituted from three or more valence-quarks; so, it is worth developing insights into diquark structure. Using a leading-order truncation of those equations needed to solve continuum two-valence-body bound-state problems, the leading-twist two-parton distribution amplitudes (DAs) of light-quark scalar and pseudovector diquarks are calculated. The diquark DAs are narrower and taller than the asymptotic profile that characterises mesons. Consequently, the valence quasiparticles in a diquark are less likely to carry a large light-front fraction of the system's total momentum than those in a meson. These features may both influence the form of baryon DAs and be transmitted to diquark distribution functions (DFs), in which case their impact will be felt, e.g. in the proton's u and d valence-quark DFs.
Related publications: [DB8]

Revealing the structure of light pseudoscalar mesons at the electron–ion collider

In collaboration with J. Arrington (LBL, Berkeley), C. Ayerbe Gayoso (Mississippi State U.), P.C. Barry (Jefferson Lab and North Carolina State U.), V. Berdnikov (Catholic U.), L. Chang (Nankai U.), M. Diefenthaler (Jefferson Lab), M. Ding (ECT, Trento and FBK, Trento), R. Ent (Jefferson Lab), T. Frederico (Sao Paulo, Inst. Tech. Aeronautics), Y. Furletova (Jefferson Lab), T.J. Hobbs (Jefferson Lab and Southern Methodist U. and IIT, Chicago), T. Horn (Jefferson Lab and Catholic U.), G.M. Huber (Regina U.), S.J.D. Kay (Regina U.), C. Keppel (Jefferson Lab), H.W. Lin (Michigan State U.), C. Mezrag (IRFU, Saclay), R. Montgomery (Glasgow U.), I.L. Pegg (Catholic U.), K. Raya (Nankai U. and CINVESTAV, IPN), P. Reimer (Argonne (main)), D.G. Richards (Jefferson Lab), C.D. Roberts (Nanjing U. and Purple Mountain Observ.), J. Rodríguez-Quintero (Huelva U.), D. Romanov (Jefferson Lab), G. Salmè (INFN, Rome), N. Sato (Jefferson Lab), J. Segovia (Pablo de Olavide U., Seville), P. Stepanov (Catholic U.), A.S. Tadepalli (Jefferson Lab), R.L. Trotta (Catholic U.)

Project abstract: The questions of how the bulk of the Universe's visible mass emerges and how it is manifest in the existence and properties of hadrons are profound, and probe the heart of strongly interacting matter. Paradoxically, the lightest pseudoscalar mesons appear to be key to a further understanding of the emergent mass and structure mechanisms. These mesons, namely, the pion and kaon, are the Nambu–Goldstone boson modes of quantum chromodynamics (QCD). Unravelling their partonic structure and the interplay between emergent and Higgs-boson mass mechanisms is a common goal of three interdependent approaches—continuum QCD phenomenology, lattice-regularised QCD, and the global analysis of parton distributions—linked to experimental measurements of hadron structure. Experimentally, the anticipated electron–ion collider will enable a revolution in our ability to study pion and kaon structures, accessed by scattering from the 'meson cloud' of the proton through the Sullivan process. With the goal of enabling a suite of measurements that can address these questions, we examine key reactions that identify the critical detector-system requirements needed to map tagged pion and kaon cross-sections over a wide range of kinematics. The excellent prospects for extracting pion structural, functional, and form-factor data are outlined, and similar

prospects for kaon structures are discussed in the context of a worldwide programme. The successful completion of the programme outlined herein will deliver deep, far-reaching insights into the emergence of pions and kaons, their properties, and their role as QCD's Goldstone boson modes.
Related publications: [DB9]

Fresh extraction of the proton charge radius from electron scattering

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

Project abstract: We present a novel method for extracting the proton radius from elastic electron-proton (ep) scattering data. The approach is based on interpolation via continued fractions augmented by statistical sampling and avoids any assumptions on the form of function used for the representation of data and subsequent extrapolation onto $Q^2 \simeq 0$. Applying the method to extant modern ep datasets, we find that all results are mutually consistent and, combining them, we arrive at r_p=0.847(8) fm. This result compares favorably with values obtained from contemporary measurements of the Lamb shift in muonic hydrogen, transitions in electronic hydrogen, and muonic deuterium spectroscopy.
Related publications: [DB10]

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 P. Taels (École Polytechnique, Paris-Saclay)

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: [FGC2], [FGC6], [FGC10], [FGC11]

TMD factorization (breaking)

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

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)

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], [FGC3], [FGC17], [FGC18]

Higgs phenomenology

In collaboration with: A. Papa (Università della Calabria), D. Y. Ivanov (Sobolev Institute of Mathematics and Novosibirsk State University, Russia), 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: [FGC8], [FGC9], [FGC13], [FGC14], [FGC15]

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: [FGC5], [FGC7], [FGC16]

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: [FGC4], [FGC12], [FGC14]

CONSTANTINOS CONSTANTINOU

Quasi-normal g-modes of neutron stars with quarks

In collaboration with T. Zhao (Ohio University), P. Jaikumar (California State University Long Beach), and M. Prakash (Ohio University)

Project abstract: Quasi-normal oscillation modes of neutron stars provide a means to probe their interior composition using gravitational wave astronomy. We compute the frequencies and damping times of composition-dependent core g-modes of neutron stars containing quark matter employing linearized perturbative equations of general relativity. We find that ignoring background metric perturbations due to the oscillating fluid, as in the Cowling approximation, underestimates the g-mode frequency by up to 10% for higher mass stars, depending on the parameters of the nuclear equation of state and how the mixed phase is constructed. The g-mode frequencies are well-described by a linear scaling with the central lepton (or combined lepton and quark) fraction for nucleonic (hybrid) stars. Our findings suggest that neutron stars with and without quarks are manifestly different with regards to their quasi-normal g-mode spectrum, and may thus be distinguished from one another in future observations of gravitational waves from merging neutron stars.

g-modes of neutron stars with hadron-to-quark crossover transitions

In collaboration with S. Han (INT, University of Washington and University of California, Berkeley), P. Jaikumar (California State University Long Beach), and M. Prakash (Ohio University)

Project abstract: We perform the first study of the principal core g-mode oscillation in hybrid stars containing quark matter, utilizing a crossover model for the hadron-to-quark transition inspired by lattice QCD. The ensuing results are compared with our recent findings of g-mode frequencies in hybrid stars with a first-order phase transition using Gibbs constructions. We find that models using Gibbs construction yield g-mode amplitudes and the associated gravitational energy radiated that dominate over those of the chosen crossover model owing to the distinct behaviors of the equilibrium and adiabatic sound speeds in the various models. Based on our results, we conclude that were g-modes to be detected in upgraded LIGO and Virgo detectors it would indicate a first-order phase transition akin to a Gibbs construction.
Related publications: [Co1]

g-mode Oscillations in hybrid stars: A tale of two sounds

In collaboration with P. Jaikumar (California State University Long Beach), A. Semposki (Ohio University), and M. Prakash (Ohio University)

Project abstract: We study the principal core g-mode oscillation in hybrid stars containing quark matter and find that they have an unusually large frequency range (≈ 200 - 600 Hz) compared to ordinary neutron stars or self-bound quark stars of the same mass. Theoretical arguments and numerical calculations that trace this effect to the difference in the behaviour of the equilibrium and adiabatic sound speeds in the mixed phase of quarks and nucleons are provided. We propose that the sensitivity of core g-mode oscillations to non-nucleonic matter in neutron stars could be due to the presence of a mixed quark-nucleon phase. Based on our analysis, we conclude that for binary mergers where one or both components may be a hybrid star, the fraction of tidal energy pumped into resonant g-modes in hybrid stars can exceed that of a normal neutron star by a factor of 2-3, although resonance occurs during the last stages of inspiral. A self-bound star, on the other hand, has a much weaker tidal overlap with the g-mode. The cumulative tidal phase error in hybrid stars, $\Delta\varphi \cong 0.5$ rad, is comparable to that from tides in ordinary neutron stars, presenting a challenge in distinguishing between the two cases. However, should the principal g-mode be excited to sufficient amplitude for detection in a post-merger remnant with quark matter in its interior, its frequency would be a possible indication for the existence of non-nucleonic matter in neutron stars.
Related publications: [Co2]

The effect of charge, isospin, and strangeness in the QCD phase diagram critical end point

In collaboration with K. Aryal (Kent State University), R. L. S. Farias (Universidade Federal de Santa Maria), and V. Dexheimer (Kent State University)

Project abstract: In this work, we discuss the deconfinement phase transition to quark matter in hot and dense matter. We examine the effect that different charge fractions, isospin fractions, net strangeness, and chemical equilibrium with respect to leptons have on the position of the coexistence line between different phases. In particular, we investigate how different sets of conditions that describe matter in neutron stars and their mergers, or matter created in heavy-ion collisions affect the position of the critical end point, namely where the first-order phase transition becomes a crossover. We also present an introduction to the topic of critical points, including a review of recent advances concerning QCD critical points.
Related publications: [Co3]

HILLA DE LEON

Use of a physical model to predict the spread of the corona virus in the presence of effective vaccines

In collaboration with D. Gazit (HUJI), F. Pederiva (UNIT) and D. Aran (Technion, Haifa, Israel)
Project abstract: The physical model for predicting the spread of the corona which was developed by Prof. Pederiva and myself has been used for decisions making in the state of Israel from January 2021 until April 2021 for the prediction of the spread of the pandemic in the presence of effective vaccines. During that time, I advised (using this model) to the Hebrew University COVID-19 pandemic monitoring team that advised the Israeli government during the crisis in Israel. The team's work has been presented regularly in the Corona Cabinet of ministers. It has been the scientific basis for some of the decisions made by the government during this period. See https://coronaanalysis.huji.ac.il (in Hebrew) for some of the presentations, as well as some of the media coverage.
In addition, I advised the Israeli government about the effect of the third vaccine on the disease, and I am currently a member of a forum of scientists and doctors in Israel who advise the government in light of the spread of the Omicron variant in Israel.
Related publications:
https://www.medrxiv.org/content/medrxiv/early/2021/02/03/2021.02.02.21250630.full.pdf, https://journals.aps.org/pre/abstract/10.1103/PhysRevE.104.014132, https://scholar.google.com/citations?view_op=view_citation&hl=en&user=t5yFcx0AAAAJ&citation_for_view=t5yFcx0AAAAJ:Tyk-4Ss8FVUC]

MINGHUI DING

Higgs modulation of emergent mass as revealed in kaon and pion parton distributions
In collaboration with Z.-F. Cui (Nanjing U. and Nanjing U. (main)), F. Gao (Heidelberg U.), K. Raya (Nankai U.), D. Binosi (ECT, Trento), L. Chang (Nankai U.), C. D.

Roberts (Nanjing U.), J. Rodríguez-Quintero (Huelva U.), S. M. Schmidt (HZDR, Dresden and RWTH Aachen U.)

Project abstract: Strangeness was discovered roughly seventy years ago, lodged in a particle now known as the kaon, K. Kindred to the pion, π; both states are massless in the absence of Higgs-boson couplings. Kaons and pions are Nature's most fundamental Nambu-Goldstone modes. Their properties are largely determined by the mechanisms responsible for emergent mass in the standard model, but modulations applied by the Higgs are crucial to Universe evolution. Despite their importance, little is known empirically about K and π structure. This study delivers the first parameter-free predictions for all K distribution functions (DFs) and comparisons with the analogous π distributions, i.e. the one dimensional maps that reveal how the light-front momentum of these states is shared amongst the gluons and quarks from which they are formed. The results should stimulate improved analyses of existing data and motivate new experiments sensitive to all K and π DFs.
Related publications: [Di1], [Di4], [Di5]

Rainbow modified-ladder approximation and degenerate pion

In collaboration with L. Chang (Nankai U.)

Project abstract: Correlation functions can be described by the corresponding equations, viz., gap equation for quark propagator and the inhomogeneous Bethe-Salpeter equation for vector dressed- fermion Abelian-gauge-boson vertex in which specific truncations have to be implemented. The general vector and axial-vector Ward-Green-Takahashi identities require these correlation functions to be interconnected, in consequence of this, truncations made must be controlled consistently. It turns out that if the rainbow approximation is assumed in gap equation, the scattering kernel in Bethe Salpeter equation can adopt the ladder approximation, which is one of the most basic attempts to truncate the scattering kernel. Additionally, a modified-ladder approximation is also found to be a possible symmetry-preserving truncation scheme. As an illustration of this approximation for application a treatment of pion is included. Pion mass and decay constant are found to be degenerate in ladder and modified-ladder approximations, even though the Bethe-Salpeter amplitude are with apparent distinction. The justification for the modified-ladder approximation is examined with the help of the Gell-Mann-Oakes-Renner (GMOR) relation.
Related publications: [Di3]

Distribution amplitudes of light diquarks

In collaboration with Y. Lu (Nanjing U.), D. Binosi (ECT, Trento), C. D. Roberts (Nanjing U.), H.-Y. Xing (Nanjing U.), C. Xu (Nanjing U.)

Project abstract: Accumulating evidence indicates that soft quark+quark (diquark) correlations play an important role in the structure and interactions of hadrons constituted from three or more valence-quarks; so, it is worth developing insights into diquark structure. Using a leading-order truncation of those equations needed to solve continuum two-valence-body bound-state problems, the leading-twist two-parton distribution amplitudes (DAs) of light-quark scalar and pseudovector diquarks

are calculated. The diquark DAs are narrower and taller than the asymptotic profile that characterizes mesons. Consequently, the valence quasiparticles in a diquark are less likely to carry a large light-front fraction of the system's total momentum than those in a meson. These features may both influence the form of baryon DAs and be transmitted to diquark distribution functions (DFs), in which case their impact will be felt, e.g. in the proton's u and d valence-quark DFs.
Related publications: [Di2], [Di6]

LUIS BENJAMIN RODRIGUEZ AGUILAR

Gluon Saturation at the Electron Ion Collider

Supervisor: Dionysios Triantafyllopoulos (ECT*/FBK)

Project abstract: Quantum Chromodynamics (QCD) is the theory of the strong nuclear forces. At ultra-relativistic energies the degrees of freedom are quarks and gluons and their interactions can be calculated with weak coupling methods. For sufficiently high energies, the gluon density becomes large leading to strong non-linear effects whose description is the goal of the Color Glass Condensate (CGC) effective theory. We apply the latter for studying cross sections in the forthcoming Electron Ion Collider (EIC).

SAGA SÄPPI

Soft pressure of NNNLO cold dense pQCD
In collaboration with T. Gorda (TU Darmstadt), A. Kurkela (Stavanger University), R. Paatelainen (Helsinki University), and A. Vuorinen (Helsinki University).

Project abstract: The low-energy (soft) degrees of freedom of thermal pQCD can be correctly described using the Hard Thermal Loop (HTL) framework. In doing so, the infrared divergences are correctly cancelled by a resummation of the soft sector. In the cold and dense setting — relevant for understanding the equations of state of compact stars — obtaining perturbative results to high orders is particularly important for astrophysical purposes, and no analog to the finite-temperature Linde problem is present. A significant milestone was reached earlier this year, when the pressure of the soft sector of next-to-next-to-next-to leading order (NNNLO) pQCD was computed in [Sa1], [Sa2]. This was achieved through a direct evaluation of the two-loop resummed HTL pressure, with [Sa2] consisting of a roadmap for evaluating the complete pressure and classifying its elements. The computation also represented a significant improvement in the understanding of Euclidean HTL theory, and involved explicit computations using HTL vertices which required the numerical evaluation of high-dimensional Feynman integrals. In future, investigations of the soft sector at higher orders are expected to lead to an improved understanding of the behaviour of the non-analytic terms of the pressure.
Related publications: [Sa1], [Sa2]

Gauge boson self-energy and logarithmic contributions to the pressure at finite density

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

Project abstract: In addition to the purely soft contributions discussed above, the dense pQCD pressure contains contributions arising from the interplay of soft and hard scales as described in [Sa2]. At NNNLO, these contributions can be associated with various corrections to the gluon self-energy. A simplified version of the calculation can be achieved by considering an *Abelian* gauge theory instead, and a soon-to-be-published paper will discuss this by generalising a known finite-temperature result to finite densities and temperatures. This will simultaneously lead to a new perturbative coefficient in the dense QED pressure at NNNLO. A subset of the authors are also preparing a manuscript on some of the technical details of the finite-density integrals encountered in the process. A follow-up objective is to generalise both the relevant corrections to the self-energy as well as the pressure calculation to full QCD. Following this, the full pole structure (and, consequently, the logarithms of the coupling) of dense pQCD will be known to NNNLO accuracy, leaving only the evaluation of the IR-insensitive hard contributions to the pressure.
Related publications: [Sa2]

Extensions of the validity of lower-order dense pQCD results

In collaboration with T. Gorda (TU Darmstadt)

Project abstract: In the above computations, simplifying assumptions such as massless quarks and a vanishing temperature are often used. While these are valid approximations in certain physical context, others may require relaxing them, and from a theoretical perspective a more complete understanding is desirable. The pQCD pressure is known at finite temperatures and densities and (separately) at finite densities and with finite quark masses to NNLO. However, in particular the latter result is presented in a rather complicated form. The full temperature, density, and mass -dependence is only known to NLO, or $O(g^4)$. In a very recent preprint [Sa3] an approximation of perturbatively small masses, valid for the relevant physical quark masses in the applicable energy scales was introduced, showing great agreement with a nonperturbative treatment of the masses. Using this method, we are able to include $O(g^5)$ mass effects at both finite temperature and densities, and while NNNLO effects are yet to be incorporated, the results are presented in a considerably simpler form than eg. the full NNLO cold and massive results. A future prospect is to relax the zero-temperature assumption of the current NNNLO computations, relevant in particular for the study of neutron star mergers.
Related publications: [Sa3]

DIONYSIOS TRIANTAFYLLOPOULOS

Saturation in Single Inclusive Deep Inelastic Scattering at forward rapidities

In collaboration with E. Iancu (IPhT, Saclay), A.H. Mueller (Columbia U.), S.Y. Wei (ECT*/FBK)

Project abstract: We use the dipole picture for electron-nucleus deep inelastic scattering at small Bjorken x to study the effects of gluon saturation in the nuclear target on the cross-section for SIDIS (single inclusive hadron, or jet, production). We argue that the sensitivity of this process to gluon saturation can be enhanced by tagging on a hadron (or jet) which carries a large fraction of the longitudinal momentum of the virtual photon. This opens the possibility to study gluon saturation in relatively hard processes, where the virtuality is much larger than the target saturation momentum. For sufficiently low transverse momenta of the produced particle, the dominant contribution comes from elastic scattering in the black disk limit, which exposes the unintegrated quark distribution in the virtual photon. For larger momenta, inelastic collisions take the leading role. They explore gluon saturation via multiple scattering, leading to a Gaussian distribution transverse momentum. This results in a Cronin peak in the nuclear modification factor (the RpA ratio) at moderate values of x. With decreasing x, this peak is washed out by the high-energy evolution and replaced by nuclear suppression up to large transverse momenta. We also compute SIDIS cross-sections integrated over transverse momenta and we find that both elastic and inelastic scattering are controlled by the black disk limit, so they yield similar contributions, of zeroth order in the QCD coupling.
Related publications: [Tri1]

Parton saturation and the gluon dipole in diffractive jet production at the Electron-Ion Collider

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

Project abstract: We show that hard dijet production via coherent inelastic diffraction is a promising channel for probing gluon saturation at the Electron-Ion Collider. 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 and this process can be described as the elastic scattering of an effective gluon-gluon dipole. The cross section assumes a factorised form between a hard factor and the 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 evaluated at the rapidity gap. Integrating out the dijet imbalance, we obtain a collinear factorization where the initial condition for the DGLAP evolution is determined by gluon saturation.
Related publications: [Tri2]

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.

SHU-YI WEI

Collectivity in small collisional system

In collaboration with Y. Shi (Central China Normal University), L. Wang (Central China Normal University), B.W. Xiao (Chinese University of Hong Kong (Shenzhen)), L. Zheng (China University of Geosciences (Wuhan))

Project abstract: ATLAS collaboration reported collective phenomenon in the photo-nuclear ultra-peripheral AA collisions (UPC). There is a nice similarity between light hadron v2 in photon-nucleus collisions and in pA collisions, which suggests that the wave function of a low-virtuality photon contains a Fock state with quite a few active partons due to rare QCD fluctuation. The dominant contribution to the high multiplicity events comes from such a partonic structure. Therefore, the collective phenomenon in UPC can be naturally described under the CGC framework [5].
Following this perception, we predict an evident collective phenomenon can also be observed at the low-Q region of the upcoming Electron-Ion Collider (EIC). With the unprecedented precision and the ability to change size of the collisional system, the high luminosity EIC will open a new window to explore the physical mechanism responsible for the collective phenomenon.
Related publication: [We1]

Polarized fragmentation functions and isospin symmetry

In collaboration with K.B. Chen (Shandong Jianzhu University), Z.T. Liang (Shandong University), Y.L. Pan (Shandong University), Y.K. Song (University of Jinan)

Project abstract: In 2019, Belle collaboration published the first measurement upon the $D_{1T}^{\perp}$ fragmentation function. To describe the experimental data, DMZ and CKT parameterizations introduced a significant isospin symmetry violation. This is shocking news since the hadronization of a high-energy parton is dominated by strong interaction where isospin symmetry violation is not expected. In our works, we propose an isospin symmetric parameterization for $D_{1T}^{\perp}$, which can also describe the Belle data well. Thus, we demonstrate that the Belle data does not automatically translate into isospin symmetry violation. Furthermore, we propose to test the isospin symmetry at the future EIC experiment.
Related publications: [We4], [We5].

Single inclusive hadron production in forward pA collisions

In collaboration with Y. Shi (Shandong University), L. Wang (Central China Normal University), B.W. Xiao (Chinese University of Hong Kong (Shenzhen)

Project abstract: We implement threshold resummation to single inclusive hadron production in forward pA collisions.
Related publications: [We6]

Computational Physics

MAURIZIO DAPOR

Monte Carlo simulation of secondary electron generation and emission

In collaboration with: S. Taioli, G. Garberoglio, P. de Vera, P. Trevisanutto, A Pedrielli (ECT*/FBK), N. M. Pugno (University of Trento), R. Garcia Molina (University of Murcia), I. Abril (University of Alicante)

Project abstract: A detailed approach able to accurately describe elastic and inelastic scattering of low energy electrons in solid and liquid targets and to appropriately take into account the energy straggling is required for the description of secondary electron cascade. The whole cascade of secondary electrons must be followed: indeed any truncation, or cut-off, underestimates the secondary electron emission yield. Also, for insulating materials the main mechanisms of energy loss cannot be limited to the electron-electron interaction for, when the electron energy becomes very small (lower than 10-20 eV, say), inelastic interactions with other particles or quasi-particles are responsible for electron energy losses. In particular, at very low electron energy, electron-phonon interactions are the main mechanisms of electron energy loss. Even phonon annihilations and the corresponding energy gains should be taken into account. The secondary electron emission simulation allows the evaluation of electron spectra.
Related publications: [Md1], [Md2], [Md3].

PABLO DE VERA GOMIS

Nanoparticle Enhanced Hadron-therapy: a comprehensive Mechanistic description

In collaboration with M. Dapor and S. Taioli (ECT*/FBK) and E. Scifoni (TIFPA, Trento)

Project abstract: NanoEnHanCeMent (Nanoparticle Enhanced Hadron-therapy: a comprehensive Mechanistic description, https://nanoenh.fbk.eu) is an action aimed to apply 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 on the nanoscale. There is experimental evidence pointing out 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 theory and modelling approach is proposed, in which a series of semiempirical and ab initio methods will be extended and interfaced with Monte Carlo track-structure simulation tools, in order to advance the basic

understanding of the nanoparticle enhanced hadron-therapy physical and chemical mechanisms.
Related publications: [Ve1], [Ve2], [Ve3], [Ve4], [Ve5]

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

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

Project abstract: High-Z ceramics such as cerium and tantalum oxide are promising for increasing the relative biological effectiveness in proton beam therapy. We study the secondary electrons production in these materials by means of Monte Carlo simulations based on ab initio calculations in order to design optimal nanostructures.
Related publications: [Ve1], [Ve2], [Ve3], [Ve4]

Interaction of low energy electrons with nanosystems

In collaboration with R. Garcia-Molina (University of Murcia, Spain), I. Abril (University of Alicante, Spain), J. M. Fernández-Varea (University of Barcelona, Spain), M. Dapor (ECT*/FBK), D. Emfietzoglou (University of Ioannina, Greece) and A. V. Solov'yov (MBN Research Center, Frankfurt, Germany)

Project abstract: The interaction of ionizing radiation with matter is used routinely as a tool both to modify or analyse properties of materials and also to gain basic knowledge on their internal structure. As a result of the interactions, in most cases secondary electrons are produced, which propagate degrading their energy through the traversed medium. Low-energy (less than 100 eV) electrons are generated abundantly, and are known to have an important role on the fabrication techniques of nanostructured devices, such as electron-beam lithography or focused electron beam induced deposition-FEBID (whose resolution and composition can be affected by the energetic and spatial distribution of the electrons), and vice-versa, when electrons are produced or move in close proximity of metallic nanoparticles or interfaces (which can influence the energetic characteristics of the electrons). Moreover, low-energy electrons play a crucial role in radiobiology (owing to their relevant effects in biodamage). In this context, the aim of the present research is to achieve a detailed knowledge of the interactions with, and effects on, nanosystems of electrons in this energy range, which are required in order to understand and improve the yield of the above-mentioned processes. With these aims in mind, there are several goals in this research project. On the one hand, we will calculate doubly-differential (in energy and angle), singly-differential and total ionization cross sections for low-energy electrons interacting with different materials, such as heavy metals (Au, Cu, Ag, Pt, Gd), insulators and polymers (SiO2, PMMA...), biological (liquid water, DNA, protein, lipid, carotene, sugar and other cellular constituents), paying special attention to the condensed phase nature of these targets. Furthermore, we will obtain cross sections for Auger and Coster-Kronig electron emission resulting from proton- and electron-impact ionization in the aforementioned materials. The relevance of these cross sections lies in their use for detailed event-by-event Monte Carlo simulations aimed at predicting radiation-induced damage (or modification) of the target properties. On the other hand, the influence of interfaces (either flat as in charged-particle lithography or FEBID or curved as in sensitising

metallic nanoparticles) close to the electron trajectories deserves a careful study, since surface excitations can modify the electron cascade spectrum. The planned research will be performed using both analytical and simulation tools. The former are based on the dielectric formalism (with possible corrections to this first-order Born approximation) to study the interaction of charged particles with condensed matter (even when interfaces are present), with a proper description of the target excitation and ionization spectrum obtained either from optical experimental data or time dependent density functional theory calculations. The latter will combine Monte Carlo and molecular dynamics techniques to describe the motion and energy transfer of the electrons through cellular environments, and close to interfaces, as well as the possible effects of the energy deposition.
Related publications: [Ve1], [Ve2], [Ve3], [Ve4], [Ve5], [Ve6]

Electron production in radioenhancing metals (EleMetal)

In collaboration with M. Dapor (ECT*/FBK), S. Taioli (ECT*/FBK), G. Garberoglio (ECT*/FBK), P. Trevisanutto (ECT*/FBK), A. Pedrielli (ECT*/FBK)

Project abstract: EleMetal is a ISCRA class C project for computing time at CINECA, aiming to calculate accurate real and imaginary parts of the dielectric function of bulk Au, Pt, Cu and Mo in a wide energy and momentum range by time-dependent density functional theory (TDDFT). This is needed to obtain realistic inelastic cross sections for accelerated ions and electrons in these metals for hadrontherapy radioenhancement. Understanding charged particle interaction with metals is essential for further developing ion beam cancer therapy, which is being improved by the use of transition metals (as Au or Pt), enhancing the production of secondary electrons in cancer cells. Nanoparticles (NP) are being explored as radioenhancers, as experiments show that their presence in cells enhances the biological effects of ion beams. However, it is still unknown why they are so effective, which evidences a lack of basic knowledge which has to be addressed. To accurately know metal NP inelastic cross sections is important for achieving a better understanding of the underlying radioenhancing mechanisms. A first step in this endeavour is to improve the basic knowledge on the production of electrons in bulk metals, which can be achieved by combining the dielectric formalism (a theory which allows obtaining inelastic cross sections in solids from the complex dielectric function) with TDDFT.

Multiscale irradiation and chemistry driven processes and related technologies (COST Action MultIChem)

In collaboration with A. V. Solov'yov (MBN Research Center, Frankfurt, Germany)

Project abstract: Radiation is an inevitable element of the world. It may affect life and likely was involved in its origin. The fundamental understanding of radiation was often at the heart of the most important scientific and technological breakthroughs (Maxwell theory, Einstein photo-effect, relic radiation, synchrotron, FEL, etc.) and it remains so. One of the big current challenges concerns the quantitative understanding of the complex processes in various systems, including the living ones, induced by their irradiation by photons, charged particles, or neutrons. These processes may lead, for instance, to the therapeutic effects of radiation, new pathways for the controlled fabrication of nanosystems with desired properties, energy conversion and storage, catalytic activity, or be in the heart of technologies for the construction of novel light sources. Despite a large variety of possible applications, the fundamental principles of irradiation-driven processes in different systems are similar. One of such features is the multiscale spatiotemporal nature of the processes extending the direct outcomes of irradiation over large time-&-space dimensions and linking them to a variety of relevant phenomena. The advances in this interdisciplinary area became possible only recently due to the development of powerful computers and modern experimental techniques. The Action MultIChem aims to establish a broad international interdisciplinary intersectoral cooperation aiming to advance our fundamental understanding of the multiscale irradiation-driven processes and related technologies paving the path towards major scientific and technological breakthroughs, and socio-economic impacts. These goals require a pan-European approach and COST is the most appropriate instrument for their realization.

GIOVANNI GARBEROGLIO

Realising the redefined kelvin (Real-K)

In collaboration with NIST and various European Metrological Institutes. 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€)

Project abstract: In this project, I am developing ab-initio calculations for density virial coefficients of quantum gases (helium, neon and argon) with no uncontrolled approximations. We published our results for the fourth density virial coefficient of helium isotopes, including degeneracy effects at low temperatures. We propagated the known uncertainties from the two- and three-body potential and estimated the contribution from the four-body potential, which is presently unknown.
Related publications: [Gg1]

Towards quantum-based realisations of the pascal (QuantumPascal)

In collaboration with NIST and various European Metrological Institutes. 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€)

Project abstract: In this project, I am developing ab-initio calculations for the dielectric virial coefficients of quantum gases (helium, neon and argon) with no uncontrolled approximations. We extended the path-integral approach developed for the second dielectric virial coefficient to the third dielectric virial coefficient and computed values for helium, neon and argon. In all of these cases we used ab-initio determined surfaces for the pair potential, the three-body potential and the pair polarizability. The three-body polarizability was approximated using the venerable superposition approximation, while an approximate form of the three-body dipole term was used. These calculations showed that ab-initio methods could provide very accurate values for the third dielectric virial coefficient and paved the way for a fully

first-principles calculation for helium with ab-initio determined three-body polarizability and dipole moment, which is currently underway.
Related publications: [Gg2], which was selected as Editor's Pick in The Journal of Chemical Physics.

Atomistic computer simulation of fluid properties.

In collaboration with EPFL-Lausanne, the University of Patras and the University of Porto.

Project abstract: I contributed to a review paper detailing the state-of-the-art of atomistic simulations of interfacial systems. In particular, I contributed to the sections describing the computer simulation of adsorption – classical and quantum using Grand Canonical Monte Carlo – and the effects at solid-fluid interfaces involving metal-organic frameworks.
Related publications: [Gg3]

Quantum sieving in nanoporous materials

In collaboration with the University of Pittsburgh, Shinshu University and other international institutes.

Project abstract: I contributed to the theoretical section of a paper demonstrating quantum sieving of oxygen isotopologues using carbon-based nanoporous materials. I studied the equilibrium differential adsorption of molecular oxygen isotopologues in carbon-based materials with fixed pores. Our results agreed with the long-time limit of breakthrough experiments.
Related publications: [Gg4]

SAMUEL ANDREA GIULIANI

The work of Samuel Andrea Giuliani was supported by the Caritro Foundation (Rif. Int.: 2020.0259).

Microscopic calculations of nuclear structure and nucleosynthesis of heavy element during the r process

In collaboration with G. Martínez Pinedo (GSI and Technische Universität Darmstadt), C. Robin (GSI and Universität Bielefeld), L. M. Robledo (Universidad Autónoma de Madrid), S. Taioli (ECT*), A. Perego (Università di Trento).

Project abstract: Half of the elements heavier than iron that we observe in nature are produced during the rapid neutron capture process (r process). During the r-process, thousands of neutron-rich nuclei are synthesized in little more than one second. Hence, a crucial ingredient in nuclear network calculations simulating the occurrence of the r-process are the nuclear properties of such short-lived exotic nuclei, most of which have never been measured in laboratories.
We computed the nuclear structure properties of heavy and superheavy neutron-rich nuclei using the Density Functional Theory (DFT). Three parametrizations of the Gogny interaction have been employed in the estimation of fission barriers and binding energies using the Hartree-Fock-Bogoliubov method with constraining operators. The role of triaxial shapes in lowering the fission barriers' height has been

explored in several nuclei, and found to be larger in systems close to the valley of stability than around the r-process path. The DFT results have been employed in the calculation of cross sections and stellar reaction rates of neutron-induced reactions. We are currently working in the application of such rates to nuclear network calculations simulating the occurrence of the r-process in different astrophysical conditions. The main focus will be the role of fission in shaping the r-process abundances and the light curves produced by the electromagnetic counterparts of neutron star mergers.

Precision mass measurement of lightweight self-conjugate nucleus ^{80}Zr

In collaboration with A. Hamaker, E. Leistenschneider, R. Jain, G. Bollen, K. Lund, W. Nazarewicz, L. Neufcourt, C. R. Nicoloff, D. Puentes, R. Ringle, C. S. Sumithrarachchi & I. T. Yandow (Facility for Rare Isotope Beams, Michigan State University, East Lansing, MI, USA).

Project abstract: The mass of nuclei $^{80–83}$Zr has been measured at the LEBIT facility at the National Superconducting Cyclotron Laboratory in Michigan. The study of different mass filters show that the self-conjugate nucleus ^{80}Zr is more bound than what was expected from extrapolations from the 2016 Atomic Mass Evaluation, confirming the existence of a double deformed shell gap at protons (Z) and neutrons (N) number N=Z=40. A statistical Bayesian model mixing analysis has been performed using 11 nuclear mass models. Bayesian emulators providing uncertainty quantifications of theoretical predictions have been constructed using Gaussian processes modelling the discrepancies between experimental data and theoretical predictions The results showed the difficulties of current global nuclear models in reproducing the observed mass anomaly. This is because ^{80}Zr is a system where several effects, such as shape coexistence and proton-neutron pairing, can coexist. Therefore, a consistent microscopic description of this nucleus is extremely challenging. Those models including a phenomenological description of the Wigner energy, which accounts for the extra binding of nuclei with the same number of protons and neutrons, show a better agreement with the LEBIT data but still fall short in reproducing the experimental trend. Further refinements in sizing the deformed shell closure at N=Z=40 will come with the next-generation radioactive ion beam facilities, shining more light regarding the interplay between deformations effects, isospin symmetry effects and proton-neutron pairing in this region of the nuclear chart.
Related publications: [Gi1]

ANDREA PEDRIELLI

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

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

Project abstract: High-Z ceramics such as cerium and tantalum oxide are promising for increasing the Relative Biological Effectiveness (RBE) in proton beam therapy. We study the secondary electrons production in these materials by means of Monte Carlo simulations based on ab-initio calculations in order to design optimal nanostructures. The interaction between electrons and these nanostructures can be described using well stated Monte Carlo simulations. However, in order to improve the predictive power of this method it should be informed from ab-initio calculations, going beyond typical semi-empirical approach in the assessment of the response function. We performed ab-initio calculation of full momentum-dependent dielectric response function for bulk Ce^{O2} and Ce^{2O3} from Time Dependent Density Functional Theory method (TDDFT). We compared the optical properties derived from the dielectric response function in the optical limit with the experimental data from the literature, finding a good agreement. In addition, the calculation of the Energy Loss Function (ELF) at finite transferred momentum is performed. We calculated the Inelastic Mean Free Path (IMFP) and the comparison with the experimental data from the literature. Finally, we verified the predictive power of ab-initio informed Monte Carlo simulations, computing the Reflection Electron Energy Loss Spectroscopy (REELS) of bulk cerium oxides and comparing them with experimental data. We furthermore studied the ELF of ditantalum pentoxide polymorphs. By comparing the results with experimental data we found that the only model structure that allows to correctly reproduce the experimental spectra is the recently proposed gamma phase.
Related publications: [Pe1]

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

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

Project abstract: While a body of literature has been devoted to the calculation of thermodynamic properties of magnesium hydride nanoparticles by means of a harmonic approximation, the assessment of these properties in a fully anharmonic framework is still lacking. We assessed the free energy calculation as well as the desorption temperature calculation by means of Stochastic Self Consistent Harmonic Approximation (SSCHA) combined with ab-initio evaluation of potential energy surfaces and forces using density functional theory. In particular, we calculated the H desorption temperature for representative magnesium hydride nanoparticles. In parallel, in order to study large nanoparticles and, at the same time, make the most of computationally expensive DFT calculations performed on small clusters, a Machine Learning model has been trained to determine the forces, total energies (and then, the potential energy surfaces) of the molecular clusters. For this purpose, we have employed the Schnet Neural-Network package, integrating this last with the Atomic Simulation Environment (ASE) and SSCHA python code.
Related publications: [Pe2]

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

In collaboration with: S. Taioli, M. Dapor (ECT*), N. M. Pugno (University of Trento)

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 are 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.

SIMONE TAIOLI

Nanoparticle Enhanced Hadron-therapy: a comprehensive Mechanistic description

In collaboration with M. Dapor, 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]

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

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

Project abstract: This project is aimed at designing and characterizing novel nanoplatforms to be used in mediated cancer therapy to enhance the Relative Biological Effectiveness (RBE). In particular, the major goals of this project are three.

First, small diameter (1-5 nm) nanosystems, based on tantalum pentoxide (Ta^{2O5}) and cerium oxide (Ce^{O2}) [ST3] and characterized by different shapes and terminations, will be studied. This investigation will be carried out by using both Molecular Dynamics (MD) and first-principles computational methods. Subsequently, the influence of the main parameters such as shape, termination, and doping of the nanosystems on the electron and proton cross sections will be assessed. Moreover, the interaction of protons and secondary electrons with these nanosystems will be dealt with a tailored Monte Carlo approach.
The second part of this project will focus on the interaction of these nanosystems with the biological environment. In particular, a study of the effects of the solvent on the electronic properties and the charge distribution of the nanosystems will be performed. Furthermore, the interaction of these structures with molecules of biological interest will be investigated.
Finally, the third part concerns the charge transfer and the excitation at the interface between the nanostructures and the solvent. In particular, starting from electronic excited states in the nanosystems the possible creation of reactive species, such as radicals and harmful molecules, within the surrounding media will be investigated.
Related publications: [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 [ST5, ST6, ST7].
Related publications [ST4, ST5, ST6, ST7]

Microscopic, nuclear structure calculations and nucleosynthesis of heavy elements via r processes

In collaboration with S. Giuliani (ECT*), S. Simonucci (University of Camerino), A. Perego (University of Trento)

Half of the atomic nuclei heavier than iron found in nature were created in the *r* process. According to the most recent models, this process occurs in collisions between two neutron stars or between a neutron star and a black hole. As a result of radioactive processes, the heavy nuclei thus synthesized produce a characteristic light emission, called kilonova. In this process of stellar nucleosynthesis the formation of heavy elements occurs through the competition of two nuclear reactions: on the one hand neutron capture, which produces nuclei with an extra neutron, and on the other hand beta decay, which transforms a neutron into a proton. This competition produces heavier and heavier nuclei opening a path in the most extreme regions of the table of nuclides in the vicinity of the nuclear drip line, before reaching the region where the nuclei decay, through fission, in smaller fragments.
A key ingredient in simulations of nucleosynthesis from r-process is the assessment of the nuclear properties of thousands of unstable atomic nuclei. The goal of this project is to perform calculations of nuclear structure from microscopic models within the framework of Density Functional Theory. These results will then be used in detailed simulations of r-process nucleosynthesis. A crucial aspect of the project will be the estimation of the error bars of the theoretical calculations, which will be calculated through machine learning algorithms. This will allow for the first time to accurately determine the variation in the estimates of astronomical observables resulting from uncertainties in the nuclear calculations, allowing for more accurate future astronomical observations of the electromagnetic counterparts produced in events such as neutron star mergers.

Artificial Intelligence for Quantum Systems

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

Project abstract: Several quantum systems can be modeled using spin Hamiltonians, either with short-range (e.g., Ising or Heisenberg models) or long-range interactions (e.g., the recent realization of dipolar BEC in optical lattices). Unfortunately, numerically exact solutions are limited to systems of about 20 objects, as memory requirements to exactly represent the quantum state of a set of spins scale exponentially with their number. This shortcoming prevents accurate numerical studies of several interesting phenomena, such as entanglement properties, the consequences of disorder, and the dynamics of subsystems. For this reason, many efforts have been devoted to the development of approximate yet accurate representations of the quantum state of interacting spins. In 1D, the density matrix renormalization group has been proven to be an optimal tool, whereas in two or more dimensions tensor network states have been shown to be a very good tradeoff between accuracy and scaling. Recently, computational techniques borrowed from the Machine Learning community have been put forward as an even more effective way to represent the quantum state of interacting spins. Within this approach, preliminary promising results have been obtained using Restricted Boltzmann

Machines (RBM). Despite its simplicity, this type of network has been found capable of finding a solution of a 2D spin system with smaller energy than that given by state-of-the-art tensor networks, displaying only a polynomial dependence of memory requirements on the system size. This clearly suggests that by looking at more sophisticated architectures in the landscape of the artificial neural networks and deep learning, one could tackle more complex problems in the context of quantum many-body physics and, more in general, materials science.

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

Furthermore, we will investigate efficient methods based on neural networks to represent statistical operators in large Hilbert spaces when they are obtained as the exponential of a matrix. We remind that in quantum statistical mechanics the density matrix of a system in thermodynamic equilibrium is given by the exponential of the Hamiltonian divided by the temperature. Finally, we also plan to investigate the temporal evolution of the density matrix, either under unitary evolution (the quantum Liouville equation) or under the non-unitary evolution characteristic of a system in contact with a heat bath (the Lindblad equation). We will also apply Neural Networks to the simulation of materials properties [ST8].

Related publications [ST8]

PAOLO E. TREVISANUTTO

Monte Carlo simulation of secondary electron generation and emission

In collaboration with: S. Taioli, G. Garberoglio, P. de Vera, P. Trevisanutto, A Pedrielli (ECT*/FBK), N. M. Pugno (University of Trento), R. Garcia Molina (University of Murcia), I. Abril (University of Alicante)

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

Related publications: [TRE2], [TRE3].

Collective excitations and quantum incompressibility in electron-hole bilayers

In collaboration with: S. De Palo (CNR-IOM-DEMOCRITOS Trieste), G. Senatore (Università di Trieste), G. Vignale (University of Missouri)

Project abstract: We apply quantum continuum mechanics to the calculation of the excitation spectrum of a coupled electron-hole bilayer. The theory expresses excitation energies in terms of ground state intra- and inter-layer pair correlation functions, which are available from Quantum Monte Carlo calculations. The final formulas for the collective modes deduced from this approach coincide with the formulas obtained in the "quasi-localized particle approximation" by Kalman et al., and likewise the theory predicts the existence of gapped excitations in the charged channels, with the gap arising from electron-hole correlation. An immediate consequence of the gap is that the static density-density response function of the charged channel vanishes as q^2 for wave vector $q \to 0$, rather than linearly in q, as commonly expected. In this sense, the system is incompressible. This feature, which has no analogue in the classical electron-hole plasma, is consistent with the existence of an excitonic ground state, and implies the existence of a discontinuity in the chemical potential of electrons and holes when the numbers of electrons and holes are equal. It should be experimentally observable by monitoring the densities of electrons and holes in response to potentials that attempt to change these densities in opposite directions.
Related publications: [TRE1]

In-plane field-driven excitonic electro-optic modulation in monolayer semiconductor

In collaboration with: D. Vella (University of Ljubljana), B Barbosa, I Verzhbitskiy, J. Yong Zhou, G. Eda (National University of Singapore), K. Watanabe (National Institute for Materials Science, Tsukuba), T. Taniguchi (International Center for Materials Nanoarchitectonics, Tsukuba), K. Kajikawa (Institute of Technology, Nagatsuta, Midori-ku, Yokohama)

Project abstract: 2D semiconductors are attractive candidates for on-chip electro-optic modulators due to their ease of integration and rich exciton-mediated phenomena. While electrostatic doping and out-of-plane field effect have been extensively studied, in-plane field-induced phenomena remain largely unexplored. Here electro-optic response of monolayer WSe_2 subject to modulating in-plane electric fields probed by electroabsorption and electroreflectance spectroscopy is reported. The devices are found to exhibit spatially varying response near exciton resonance, which cannot be explained by predicted effects such as Pockels and excitonic Stark effect. It is shown that the modulation signal is dominated by exciton linewidth broadening and narrowing associated with local accumulation and depletion of free holes. The field and frequency dependence of the devices is distinct from those of charge modulation devices. The observed behavior is ascribed to elastic scattering of excitons with field-driven intrinsic free carriers.
Related publications: [TRE5].

3.2 Publications of ECT* Researchers in 2021

GERT AARTS

[GA1] D. Bachtis, G. Aarts and B. Lucini
Adding machine learning within Hamiltonians: Renormalization group transformations, symmetry breaking and restoration
Phys. Rev. Res. 3 (2021) 1, 013134

[GA2] D. Bachtis, G. Aarts and B. Lucini
Quantum field-theoretical machine learning
Phys. Rev. Res. D 103 (2021) 7, 074510

[GA3] D. Bachtis, G. Aarts, F. di Renzo and B. Lucini
Inverse renormalisation group in quantum field theory
Submitted to Phys. Rev. Lett. (2021) [https://arxiv.org/abs/2107.00466]

[GA4] D. Bachtis, G. Aarts and B. Lucini
Machine learning with quantum field theories
PoS LATTICE2021 (2021), 201 [https://arxiv.org/abs/2109.07730]

[GA5] G. Aarts, D. Bachtis and B. Lucini
Interpreting machine learning functions as physical observables
PoS LATTICE2021 (2021), 248 [https://arxiv.org/abs/2109.08497]

[GA6] D. Bachtis, G. Aarts and B. Lucini
Quantum field theories, Markov random fields and machine learning
Submitted to the Proceedings of the *XXXII IUPAP Conference on Computational Physics 21*, Coventry, UK [https://arxiv.org/abs/2110.10928]

[GA7] G. Aarts and A.A. Nikolaev
Electrical conductivity of the quark-gluon plasma: perspective from lattice QCD
Eur.Phys.J.A 57 (2021) 4, 118 [https://arxiv.org/abs/2008.12326]
[GA8] G. Martinez Vasquez, G. Aarts, M. Müller and A. Bermudez
Long-range Ising interactions mediated by $\lambda\phi 4$ fields: probing the renormalisation of sound in crystals of trapped ions
Submitted to Phys. Rev. X [https://arxiv.org/abs/2105.06886]

[GA9] G. Aarts, J. Aichelin, M. Bleicher, E. Ferreiro, L. Tolos and B. Tomasik
Theory of hot matter and relativistic heavy-ion collisions (THOR)
Eur.Phys.J.A 57 (2021) 6, 175
[GA10] S. Chaves García-Mascaraque G. Aarts, C. Allton, S. Hands and B. Jäger
Meson thermal masses at different temperatures
PoS LATTICE2021 (2021), 523 [https://arxiv.org/abs/2111.00784]

[GA11] G. Aarts, C. Allton, S. Hands, B. Jäger, S. Kim, M.-P. Lombardo, A. A. Nikolaev, S.M. Ryan and J.-I. Skullerud
Lattice QCD at nonzero temperature and density
Submitted to the Proceedings of the *XXXII IUPAP Conference on Computational Physics 21*, Coventry, UK [https://arxiv.org/abs/2111.10787]

[GA12] T. Spriggs, G. Aarts, C. Allton, T. Burns, B. Jäger, S. Kim, M.-P. Lombardo, S. Offler, B. Page, S.M. Ryan, and J.-I. Skullerud
Bottomonium spectral widths at nonzero temperature using maximum likelihood
PoS LATTICE2021 (2021), 077 [https://arxiv.org/abs/2112.01599]

[GA13] B. Page, G. Aarts, C. Allton, B. Jäger, 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 (2021), 134 [https://arxiv.org/abs/2112.02075]

[GA14] S. Offler, G. Aarts, C. Allton, B. Jäger, 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 (2021), 509 [https://arxiv.org/abs/2112.02116]

[GA15] T. Spriggs, G. Aarts, C. Allton, T. Burns, R. Horohan D'Arcy, B. Jäger, S. Kim, M.-P. Lombardo, S. Offler, B. Page, S.M. Ryan and J.-I. Skullerud
A comparison of spectral reconstruction methods applied to non-zero temperature NRQCD meson correlation functions
Submitted to Proceedings of *A Virtual Tribute to Quark Confinement and the Hadron Spectrum*, University of Stavanger, Stavanger, Norway [https://arxiv.org/abs/2112.04201]

Daniele Binosi

[DB1] Z.-F. Cui (Nanjing U.), M. Ding (HZDR, Dresden), J.M. Morgado (Huelva U.), K. Raya (Granada U., Theor. Phys. Astrophys. and Mexico U., ICN), D. Binosi (ECT, Trento and Fond. Bruno Kessler, Trento) et al.
Concerning pion parton distributions
Eur.Phys.J.C (accepted)
https://arxiv.org/abs/2112.09210

[DB2] Z.-Q. Yao (Nanjing U.), D. Binosi (ECT, Trento and Fond. Bruno Kessler, Trento), Z. F. Cui (Nanjing U.), C. D. Roberts (Nanjing U.)
Semileptonic transitions: B(s) → π(K); Ds → K; D → π,K; and K → π
Phys.Lett.B 824 (2022), 136793

[DB3] Z.-F. Cui (Nanjing U.), D. Binosi (ECT, Trento), C. D. Roberts (Nanjing U.), S. M. Schmidt (HZDR, Dresden and RWTH Aachen U.)
Pauli Radius of the Proton
Chin.Phys.Lett. 38 (2021) 12, 121401

[DB4] Z.-F. Cui (Nanjing U. and Nanjing U. (main)), F. Gao (U. Heidelberg, ITP), D. Binosi (ECT, Trento and Fond. Bruno Kessler, Trento), L. Chang (Nankai U.), C. D. Roberts (Nanjing U. and Nanjing U. (main)) et al.
Valence quark ratio in the proton
https://arxiv.org/abs/2108.11493

[DB5] Z.-F. Cui (Nanjing U. and Nanjing U. (main)), D. Binosi (ECT, Trento), C. D. Roberts (Nanjing U. and Nanjing U. (main)), S. M. Schmidt (HZDR, Dresden and Aachen, Tech. Hochsch.)
Pion charge radius from pion+electron elastic scattering data
Phys.Lett.B 822 (2021), 136631

[DB6] Y.-Z. Xu (Nanjing U.), S. Chen (Nanjing U.), Z.-Q. Yao (Nanjing U.), D. Binosi (ECT, Trento), Z.-F. Cui (Nanjing U.) et al.
Vector-meson production and vector meson dominance
Eur.Phys.J.C 81 (2021), 895

[DB7] Z.-Q. Yao (Nanjing U. and Nanjing U. (main)), D. Binosi (ECT, Trento), Z.-F. Cui (Nanjing U. and Nanjing U. (main)), C. D. Roberts (Nanjing U. and Nanjing U. (main))
Semileptonic $B_c \to \eta_c, J/\psi$ *transitions*
Phys.Lett.B 818 (2021), 136344

[DB8] Y. Lu (Nanjing U.), D. Binosi (ECT, Trento), M. Ding (ECT, Trento), C. D. Roberts (Nanjing U.), H.-Y. Xing (Nanjing U.) et al.
Distribution amplitudes of light diquarks
Eur.Phys.J.A 57 (2021) 4, 115

[DB9] J. Arrington (LBL, Berkeley), C. Ayerbe Gayoso (Mississippi State U.), P.C. Barry (Jefferson Lab and North Carolina State U.), V. Berdnikov (Catholic U.), D. Binosi (ECT, Trento and Fond. Bruno Kessler, Trento) et al.
Revealing the structure of light pseudoscalar mesons at the electron–ion collider
J.Phys.G 48 (2021) 7, 075106

[Db10] Z.-F. Cui (Nanjing U.), D. Binosi (ECT, Trento), C. D. Roberts (Nanjing U.), S. M. Schmidt (Tech. U., Dortmund (main) and HZDR, Dresden)
Fresh Extraction of the Proton Charge Radius from Electron Scattering
Phys.Rev.Lett. 127 (2021) 9, 092001

FRANCESCO GIOVANNI CELIBERTO

[FGC1] F. G. Celiberto (corresponding author), M. Fucilla, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa
Bottom-flavored inclusive emissions in the variable-flavor number scheme: a high-energy analysis. Phys. Rev. D 104 (2021) 11, 114007, 24 pages [arXiv:2109.11875] doi:10.1103/PhysRevD.104.114007

[FGC2] A. D. Bolognino, F. G. Celiberto (corresponding author), D. Yu. Ivanov, A. Papa, W. Schäfer, A. Szczurek
Exclusive production of ρ-mesons in high-energy factorization at HERA and EICEur. Phys. J. C 81 (2021) no.9, 846, 12 pages [arXiv:2107.13415] doi:10.1140/epjc/s10052-021-09593-9

[FGC3] F. G. Celiberto

3D tomography of the nucleon: transverse-momentum-dependent gluon distributions. Nuovo Cim. C 44 (2021) n. 36, 4 pages [arXiv:2101.04630] doi:10.1393/ncc/i2021-21036-3

[FGC4] F. G. Celiberto (corresponding author), D. Yu. Ivanov, M. Fucilla, A. Papa
High-energy resummation in Λ_c *baryon production Eur. Phys. J.* C 81 (2021) no.8, 780, 16 pages [arXiv:2105.06432] doi:10.1140/epjc/s10052-021-09448-3

[FGC5] F. G. Celiberto
Hunting BFKL in semi-hard reactions at the LHC Eur. Phys. J. C 81 (2021) no.8, 691, 39 pages [arXiv:2008.07378] doi:10.1140/epjc/s10052-021-09384-2

[FGC6] A. Arbuzov, A. Bacchetta, M. Butenschoen, F. G. Celiberto, U. D'Alesio, *et al.*
On the physics potential to study the gluon content of proton and deuteron at NICA SPD Prog. Part. Nucl. Phys. 119 (2021) 103858, 43 pages [arXiv:2011.15005] doi: 10.1016/j.ppnp.2021.103858

[FGC7] A. D. Bolognino, F. G. Celiberto (corresponding author), M. Fucilla, D. Yu. Ivanov, A. Papa
Inclusive production of a heavy-light dijet system in hybrid high-energy/collinear factorization Phys. Rev. D 103 (2021) no.9, 094004, 17 pages [arXiv:2103.07396] doi:10.1103/PhysRevD.103.094004

[FGC8] F. G. Celiberto (corresponding author), D. Yu. Ivanov, M. M. A. Mohammed, A. Papa
High-energy resummed distributions for the inclusive Higgs-plus-jet production at the LHC Eur. Phys. J. C 81 (2021) no.4, 293, 16 pages [arXiv:2008.00501] doi:10.1140/epjc/s10052-021-09063-2

[FGC9] 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 to appear in *PoS PANIC2021* [arXiv:2111.13090]

[FGC10] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
Toward twist-2 T-odd transverse-momentum-dependent gluon distributions: the f-type linearity function to appear in *PoS PANIC2021* [arXiv:2111.03567]

[FGC11] A. Bacchetta, F. G. Celiberto, M. Radici (proceeding)
*Toward twist-2 T-odd transverse-momentum-dependent gluon distributions: the f-type Sivers function*to appear in *PoS EPS-HEP2021* [arXiv:2111.01686]

[FGC12] A. D. Bolognino, F. G. Celiberto, M. Fucilla, D. Yu. Ivanov, A. Papa (proceeding)
Heavy-flavored emissions in hybrid collinear/high-energy factorization to appear in *PoS EPS-HEP2021* [arXiv:2110.12772]

[FGC13] 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 to appear in *PoS EPS-HEP2021* [arXiv:2110.09358]

[FGC14] 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 to appear in *SciPost* [arXiv:2110.12649]

[FGC15] F. G. Celiberto, D. Yu. Ivanov, M. M. A. Mohammed, A. Papa (proceeding) *High-energy resummation in inclusive hadroproduction of Higgs plus jet* to appear in *SciPost* [arXiv:2107.13037]

[FGC16] 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 to appear in *SciPost* [arXiv:2107.12120]

[FGC17] A. Bacchetta, F. G. Celiberto, M. Radici, P. Taels (proceeding)
A spectator-model way to transverse-momentum-dependent gluon distribution functions to appear in *SciPost* [arXiv:2107.13446]

[FGC18] A. D. Bolognino, F. G. Celiberto, D. Yu. Ivanov, A. Papa
(proceeding)*Exclusive emissions of rho-mesons and the unintegrated gluon distribution* to appear in *SciPost* [arXiv:2107.12725]

GIOVANNI GARBEROGLIO

[GG1] G. Garberoglio, A.H. Harvey
Path-integral calculation of the fourth virial coefficient of helium isotopes
J. Chem. Phys. 154, 104107 (2021)

[GG2] G. Garberoglio, A.H. Harvey, B. Jeziorski
Path-integral calculation of the third dielectric virial coefficient of noble gases
J. Chem. Phys. 155, 234103 (2021). Selected as Editor's Pick.

[GG3] M. Lbadaoui-Darvas, G. Garberoglio, K.S. Karadima, M. Natália D.S. Cordeiro, A. Nenes, S.i Takahama
Molecular simulations of interfacial systems: challenges, applications and future perspectives
Molecular Simulation (2021), DOI: 10.1080/08927022.2021.1980215

[GG4] S.K. Ujjain, A. Bagusetty, Y. Matsuda, H. Tanaka, P. Ahuja, C. de Tomas, M. Sakai, F. Vallejos-Burgos, R. Futamura, I. Suarez-Martinez, M. Matsukata, A. Kodama, G. Garberoglio, Y. Gogotsi, J.K. Johnson and K. Kaneko.
Adsorption separation of heavier isotope gases in subnanometer carbon pores
Nature Communications 12, 546 (2021)

SAGA SÄPPI

[SA1] T. Gorda, A. Kurkela, R. Paatelainen, S. Säppi, A. Vuorinen
Soft Interactions in Cold Quark Matter
Phys. Rev. Lett. 127 (2021) 16, 162003, hep-ph/2103.05658

[SA2] T. Gorda, A. Kurkela, R. Paatelainen, S. Säppi, A. Vuorinen
Cold quark matter at N^3LO: Soft contributions
Phys. Rev. D 104 (2021) 7, 074015, hep-ph/2103.07427

[SA3] T. Gorda, S. Säppi
Cool quark matter with perturbative quark masses
Preprint, hep-ph/2112.11472

DIONYSIOS TRIANTAFYLLOPOULOS

[TRI1] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos, S.Y. Wei
Saturation effects in SIDIS at very forward rapidities
JHEP 07, 2021, 196

[TRI2] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos
Probing parton saturation and the gluon dipole via diffractive jet production at the Electron-Ion Collider
arXiv: 2112.06353, Submitted to Phys. Rev. Lett.

[TRI3] B. Ducloué, E. Iancu, A.H. Mueller, G. Soyez, D.N. Triantafyllopoulos
Collinear resummations for the non-linear evolution in QCD at high energy
Nucl. Phys. A 1005 (2021) 121832

SHU-YI WEI

[WE1] Y. Shi, L. Wang, S.Y. Wei, B.W. Xiao, L. Zheng
Exploring collective phenomenon at the Electron-Ion Collider
Phys.Rev.D103, 054017. (2021)

[WE2] S.Y. Wei
Exploring the non-perturbative Sudakov factor via Z0-boson production in pp collisions
Phys.Lett.B817, 136356. (2021)

[WE3] E. Iancu, A.H. Mueller, D.N. Triantafyllopoulos, S.Y. Wei
Saturation effects in SIDIS at very forward rapidities
JHEP07, 2021, 196. (2021)

[WE4] K.B. Chen, Z.T. Liang, Y.L. Pan, Y.K. Song, S.Y. Wei
Isospin symmetry of fragmentation functions
Phys.Lett.B816, 136217. (2021)

[WE5] K.B. Chen, Z.T. Liang, Y.K. Song, S.Y. Wei
Longitudinal and transverse polarizations of Λ hyperon in unpolarized SIDIS and e+e− annihilation
arXiv:2108.07740. (2021)

[WE6] Y. Shi, L. Wang, S.Y. Wei, B.W. Xiao
Pursuing the Precision Study for Color Glass Condensate in Forward Hadron Productions

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MAURIZIO DAPOR

[MD1] A. Pedrielli, P. de Vera, P. E. Trevisanutto, N. M. Pugno, R. Garcia-Molina, I. Abril, S. Taioli, M. Dapor
Electronic excitation spectra of cerium oxides: from ab initio dielectric response functions to Monte Carlo electron transport simulations
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[MD2] S. Taioli, P. E. Trevisanutto, P. de Vera, S. Simonucci, I. Abril, R. Garcia-Molina, M. Dapor
Relative role of physical mechanisms on complex bio-damage induced by carbon irradiation
Journal of Physical Chemistry Letters, 2021, 12(1), pp. 487–493

[MD3] 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
arXiv preprint arXiv:2111.13963 (2021)

PABLO DE VERA GOMIS

[VE1] S. Taioli, P. E. Trevisanutto, P. de Vera, S. Simonucci, I. Abril, R. Garcia-Molina, M. Dapor
Relative role of physical mechanisms on complex bio-damage induced by carbon irradiation
Journal of Physical Chemistry Letters, 2021, 12(1), pp. 487–493

[VE2] P. de Vera, I. Abril, R. Garcia-Molina,
Excitation and ionisation cross-sections in condensed-phase biomaterials by electrons down to very low energy: application to liquid water and genetic building blocks
Physical Chemistry Chemical Physics, 2021, 23, pp. 5079–5095

[VE3] A. Pedrielli, P. de Vera, P. E. Trevisanutto, N. M. Pugno, R. Garcia-Molina, I. Abril, S. Taioli, M. Dapor
Electronic excitation spectra of cerium oxides: from ab initio dielectric response functions to Monte Carlo electron transport simulations
Physical Chemistry Chemical Physics, 2021, 23(35), pp. 19173–19187

[VE4] 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
arXiv preprint arXiv: 2111.13963 (2021)

[VE5] I. Abril, P. de Vera, R. Garcia-Molina

Calculated energy loss of swift light ions in platinum and gold: importance of the target electronic excitation spectrum
arXiv preprint arXiv: 2111.13968 (2021)

[VE6] Y. Fortouna, P. de Vera, A. V. Verkhovtsev, A. V. Solov'yov
Molecular dynamics simulations of sodium nanoparticle deposition on magnesium oxide
Theoretical Chemistry Accounts, 2021, 140, p. 84

Andrea Pedrielli

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Electronic excitation spectra of cerium oxides: from ab initio dielectric response functions to Monte Carlo electron transport simulations
Physical Chemistry Chemical Physics, 2021, 23(35), pp. 19173–19187

[PE2] A. Pedrielli, P. E. Trevisanutto, L. Monacelli, G. Garberoglio, N. M. Pugno, S. Taioli
Understanding Anharmonic Effects on Hydrogen Desorption Characteristics of MgnH2n Nanoclusters by ab initio trained Deep Neural Network
arXiv:2111.13956

Minghui Ding

[DI1] Z.-F. Cui, M. Ding, F. Gao, K. Raya, D. Binosi, L. Chang, C. D. Roberts, J. Rodríguez-Quintero, S. M. Schmidt
Higgs modulation of emergent mass as revealed in kaon and pion parton distributions
Eur.Phys.J.A 57 (2021) 1, 5

[DI2] M.Yu. Barabanov et al.
Diquark Correlations in Hadron Physics: Origin, Impact and Evidence
Prog.Part.Nucl.Phys. 116 (2021) 103835

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Rainbow modified-ladder approximation and degenerate pion
Phys.Rev.D 103 (2021) 7, 074001

[DI4] Daniele P. Anderle et al.
Electron-ion collider in China
Phys.(Beijing) 16 (2021) 6, 64701

[DI5] J. Arrington et al.
Revealing the structure of light pseudoscalar mesons at the electron–ion collider
J.Phys.G 48 (2021) 7, 075106

[DI6] Y. Lu, D. Binosi, M. Ding, C. D. Roberts, H. Xing, C. Xu
Distribution amplitudes of light diquarks
Eur.Phys.J.A 57 (2021) 4, 115

SIMONE TAIOLI

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Simulating the nanometric track-structure of carbon ion beams in liquid water at energies relevant for hadrontherapy
arXiv preprint arXiv: 2111.13963 (2021)

[ST2] S. Taioli, P. E. Trevisanutto, P. de Vera, S. Simonucci, I. Abril, R. Garcia-Molina, M. Dapor
Relative Role of Physical Mechanisms on Complex Biodamage Induced by Carbon Irradiation
The Journal of Physical Chemistry Letters 12 (1), 487-493 (2021)

[ST3] A. Pedrielli, P. de Vera, P.E. Trevisanutto, N. M Pugno, R. Garcia-Molina, I. Abril, S. Taioli, M. Dapor
Electronic excitation spectra of cerium oxides: from ab initio dielectric response functions to Monte Carlo electron transport simulations
Physical Chemistry Chemical Physics 23 (35), 19173-19187 (2021)

[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 (accepted - January 2022)

[ST5] S. Palmerini, M. Busso, D. Vescovi, E. Naselli, A. Pidatella, R. Mucciola, S. Cristallo, D. Mascali, A. Mengoni, S. Simonucci, S. Taioli
Presolar Grain Isotopic Ratios as Constraints to Nuclear and Stellar Parameters of Asymptotic Giant Branch Star Nucleosynthesis
The Astrophysical Journal 921 (1), 7 (2021)

[ST6] S. Taioli, S Simonucci
Relativistic quantum theory and algorithms: a toolbox for modeling many-fermion systems in different scenarios
Annual Reports in Computational Chemistry 17 (2021)

[ST7] 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
https://arxiv.org/abs/2109.14230 (2021)

[ST8] A. Pedrielli, P. E. Trevisanutto, L. Monacelli, G. Garberoglio, N. M. Pugno, S. Taioli
Understanding Anharmonic Effects on Hydrogen Desorption Characteristics of MgH Nanoclusters by ab initio trained Deep Neural Network
arXiv preprint arXiv:2111.13956 (2021)

[ST9] A. Carvalho, P. E. Trevisanutto, S Taioli, A. H. Neto
Computational methods for 2D materials modelling
Reports on Progress in Physics 84 (106501) (2021)

[ST10] S. Taioli, S. Simonucci
The Resonant and Normal Auger spectra of Ozone
Symmetry 13 (3), 516 (2021)

Paolo Emilio Trevisanutto

[TRE1] S. De Palo, P. E. Trevisanutto, G. Senatore, G. Vignale
Collective excitations and quantum incompressibility in electron-hole bilayers
Physical Review B 104 (11), 115165 (2021)

[TRE2] A. Pedrielli, P. de Vera, P. E. Trevisanutto, N. M. Pugno, R. Garcia-Molina, I. Abril, S. Taioli, M. Dapor
Electronic excitation spectra of cerium oxides: from ab initio dielectric response functions to Monte Carlo electron transport simulations
Physical Chemistry Chemical Physics, 2021, 23(35), pp. 19173–19187

[TRE3] S. Taioli, P. E. Trevisanutto, P. de Vera, S. Simonucci, I. Abril, R. Garcia-Molina, M. Dapor
Relative role of physical mechanisms on complex bio-damage induced by carbon irradiation
Journal of Physical Chemistry Letters, 2021, 12(1), pp. 487–493

[TRE4] A. Carvalho, P. E. Trevisanutto, S. Taioli, A. H. Castro-Neto
Computational methods for 2D materials modelling
Rep. Prog. Phys. 84 106501 (2021)

[TRE5] D. Vella, M. B. Barbosa, P. E. Trevisanutto, I. Verzhbitskiy, J. Yong Zhou, K. Watanabe, T. Taniguchi, K. Kajikawa, G. Eda
In-Plane Field-Driven Excitonic Electro-Optic Modulation in Monolayer Semiconductor
Adv. Optical Mater. 2021, 2102132 (2021)

SAMUEL A. GIULIANI

[GI1] A. Hamaker, E. Leistenschneider, R. Jain, G. Bollen, S. A. Giuliani, K. Lund, W. Nazarewicz, L. Neufcourt, C. R. Nicoloff, D. Puentes, R. Ringle, C. S. Sumithrarachchi, and I. T. Yandow.

Precision Mass Measurement of Lightweight Self-Conjugate Nucleus 80Zr.
Nature Physics **17**, 1408 (2021).

CONSTANTINOS CONSTANTINOU

[CO1] C. Constantinou, S. Han, P. Jaikumar, and M. Prakash
g-modes of neutron stars with hadron-to-quark crossover transitions
Phys. Rev. D 104, 123032 (2021)

[CO2] P. Jaikumar, A. Semposki, M. Prakash, and C. Constantinou
g-mode oscillations in hybrid stars: A tale of two sounds
Phys. Rev. D 103, 123009 (2021)

[CO3] K. Aryal, C. Constantinou, R. L. S. Farias, and V. Dexheimer
The Effect of Charge, Isospin, and Strangeness in the QCD Phase Diagram Critical End Point
Universe 2021, 7(11), 454

3.3. Talks Presented by ECT* Researchers in 2021

GERT AARTS

Quantum field-theoretic machine learning
Seminar (online) at the Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany
10 March, 2021

A physicist's approach to machine learning
Seminar (online) at the Department of Physics, University of Stavanger, Stavanger, Norway
13 April, 2021

A physicist's approach to machine learning
Colloquium (online) at the Department of Physics, University of Würzburg, Würzburg, Germany
19 April, 2021

A physicist's approach to machine learning
Seminar (online) at the Institut für Kernphysik, Technische Universität Darmstadt, Darmstadt, Germany
May 6, 2021

Interpreting machine learning functions as physical observables
Talk (online) at *Lattice 2021*, MIT, USA
July 26-30, 2021

Lattice QCD at nonzero temperature and density
Invited talk (online) at *XXXII IUPAP Conference on Computational Physics*, Coventry, UK
August 1-5, 2021

The strong interaction under extreme conditions
invited talk (online) at the *Cardiff Astronomical Society*, Cardiff, UK
November 11, 2021

Machine learning with quantum fields
poster presented (online) at *Quantum Techniques in Machine Learning 2021*, RIKEN, Japan
November 8-12, 2021

DANIELE BINOSI

Fresh extraction of the proton radius from electron scattering
Mass in the standard model and consequences of its emergence
Online talk
ECT*, April 19 – 23, 2021

Model independent extraction of hadron radii
Perceiving the Emergence of Hadron Mass through AMBER@CERN 7

Online talk
CERN, April 27– 30, 2021

Hadron radii from precise low-Q^2 e-p scattering data
Strong QCD from Hadron Structure Experiments 4
Online talk
Nanjing University, June 7– 10, 2021

Data driven extraction of proton's valence quark ratio
Perceiving the Emergence of Hadron Mass through AMBER@CERN 6
Online talk
CERN, September 27– 29, 2021
and
Workshop on Hadron Structure at High-Energy, High-Luminosity Facilities
Online talk
Nanjing University, October 25– 27, 2021

Emergent phenomena in strong dynamics
Baryons 21
Online lectures
Sevilla, October 18– 22, 2021

SHU-YI WEI

Longitudinal and transverse polarizations of Λ hyperons in unpolarized SIDIS and e+e− annihilations
Spin2021 (Online talk) Japan
18 October, 2021

Minghui Ding

Distribution amplitudes of light diquarks
Workshop on FunQCD: from first principles to effective theories, University of Valencia and IFIC e-Workshop (per COVID-19)
29 March – 1 April, 2021

Distribution amplitudes of light diquarks
Workshop on Mass in the Standard Model and Consequences of its Emergence, ECT* e-Workshop (per COVID-19)
19-23 April, 2021

Nanmbu-Goldstone bosons as the clearest window onto EHM.
The 8th EicC workshop in Lanzhou (Online)
27-29 August, 2021

FRANCESCO GIOVANNI CELIBERTO

Invited talks

Workshop on Forward Physics and QCD with LHC, EIC, and cosmic rays, online

22 January, 2021
Phenomenological aspects of hadronic structure at small-x
LHC Forward Physics Meeting, online
5 March, 2021

A journey into the proton structure: progresses and challenges
XVI Congreso Internacional de Investigación Científica, República Dominicana, online
10 June, 2021

Towards twist-2 T-odd gluon TMDs
MAP Collaboration Meeting, online
29 June, 2021

Unveiling the proton structure via TMD gluon distributions
HADRON2021, Mexico City
28 July, 2021

Towards twist-2 T-odd TMD gluon distributions
EICUG Early Career Workshop, online
30 July, 2021

Gluon TMDs and hadronic collisions
Sar WorS 2021 - Sardinian Workshop on Spin studies, Cagliari
7 September, 2021

Phenomenology of the hadronic structure at small-x
Low-x Meeting 2021, Isola d'Elba
28 September, 2021

Accessing the proton UGD via exclusive polarized ρ-meson leptoproduction at HERA and the EIC
MPI 2021, Lisbon
14 October, 2021

Invited overview talks

Quarkonium emissions as probes of the hadronic structure at small-x
Quarkonia As Tools 2021, online
24 March, 2021

NINPHA: theoretical activities on QCD and hadronic structure
TNPI2021, Pisa
23 November, 2021
Round tables
Factorization formalisms for kT-dependent quarkonium production Quarkonia As Tools 2021, online
24 March, 2021

Invited seminars

Electron-Ion Collider Physics

Studies on the hadronic structure via gluon distributions at the EIC", 61. Cracow School of Theoretical Physics Cracow
20 September, 2021

3D imaging of the proton at new-generation colliding machines
Università della Calabria, Dipartimento di Fisica & INFN-Cosenza
21 December, 2021
Contributed talks
3D proton tomography at the EIC: TMD gluon densities
EIC opportunities at Snowmass, online
26 January, 2021

A spectator-model way to TMD gluon distribution functions
DIS 2021, Stony Brook, New York
13 April, 2021

Exclusive emissions of -mesons and the unintegrated gluon distribution
DIS 2021, Stony Brook, New York
14 April, 2021

A model-calculation of unpolarized and polarized transverse-momentum-dependent distribution functions
9th Workshop of the APS Topical Group on Hadronic Physics (GHP), online
15 April, 2021

Hadronic structure at a Forward Physics Facility
2nd FPF Meeting, online
28 May, 2021

Higgs-plus-jet differential distributions as stabilizers of the high-energy resummation
EPS-HEP 2021, online
26 July, 2021

Proton 3D imaging via TMD gluon densities
EPS-HEP 2021, online
26 July, 2021

A study of Higgs-plus-jet distributions in hybrid high/energy collinear factorization
107° Congresso Nazionale della Società Italiana di Fisica, online
September, 2021

A model calculation of T-odd gluon TMD distributions at twist-2
PANIC 2021, Lisbon (online)
8 September, 2021

3D proton imaging at low- and moderate-x via TMD gluon distributions
QCD-N2021, Alcalá de Henares, Spain
7 October, 2021

Toward leading-twist T-odd TMD gluon distributions
SPIN2021, Matsue, Japan
19 October, 2021
T-odd TMD gluon distributions in a spectator model

Resummation, Evolution, Factorization 2021, online
16 November, 2021

Proton 3D tomography at low- and moderate-x via TMD gluon densities
Light Cone 2021, Jeju Booyoung Hotel, South Korea
2 December, 2021

Posters

F. G. Celiberto, D. Yu. Ivanov, M.M.A. Mohammed (presenter), A. Papa
High-energy resummation in inclusive hadroproduction of Higgs plus jet
DIS 2021, 2021, 12 - 16 April, Stony Brook, New York

F. G. Celiberto, M. Fucilla (presenter), D. Yu. Ivanov, M.M.A. Mohammed, A. Papa
Higgs boson production in the high-energy limit of pQCD
PANIC 2021, 2021, 5 - 10 April, Lisbon

PABLO DE VERA GOMIS

Irradiation driven molecular dynamics interfaced with Monte Carlo for detailed simulations of focused electron beam induced deposition
Invited talk at the Sixth International Conference "Dynamics of Systems on the Nanoscale" (DySoN) and the tenth International Symposium "Atomic Cluster Collisions" (ISACC), Santa Margherita-Ligure, Italy
19 October, 2021

Modelling swift charged particles interaction with biologically-relevant materials for a deeper understanding of ion-beam radiation biodamage
Talk (online) at the 11th Young Researcher Meeting, Trento, Italy
7 September, 2021

Calculated energy loss of swift light ions in transition metals: importance of the target electronic excitation spectrum
Talk (online), given by co-author R. Garcia-Molina (Universidad de Murcia, Spain), at the 25th International Conference on Ion Beam Analysis & 17th International Conference on Particle Induced X-ray Emission & International Conference on Secondary Ion Mass Spectrometry, Institute of Physics, UK
15 October, 2021

Simulating the nanometric track-structure of carbon ion beams in liquid water at energies relevant for hadrontherapy
Poster (online) at the 25th International Conference on Ion Beam Analysis & 17th International Conference on Particle Induced X-ray Emission & International Conference on Secondary Ion Mass Spectrometry, Institute of Physics, UK
15 October, 2021

Excitation and ionisation cross-sections of condensed-phase biomaterials by electrons down to very low energy
Special Report Talk (online) at the 32nd (Virtual) International Conference on Photonic, Electronic and Atomic Collisions
20 July, 2021

Detailed simulation of carbon ions track-structure in liquid water: from ab initio excitation spectrum to biodamage on the nanoscale
Poster (online) at the 32nd (Virtual) International Conference on Photonic, Electronic and Atomic Collisions
20 July, 2021

Electronic excitation spectra of cerium oxides: an ab initio{informed study supported by Monte Carlo transport simulations
Poster (online) at the 32nd (Virtual) International Conference on Photonic, Electronic and Atomic Collisions
20 July, 2021

Monte-Carlo simulations of electron emission from liquid water
Poster (online) at the 32nd (Virtual) International Conference on Photonic, Electronic and Atomic Collisions
20 July, 2021

Electronic interactions of swift ions and their secondary electrons in biologically relevant materials
Invited talk (online) at the International Symposium on Ion-Atom Collisions (ISIAC), Cluj, Romania
14 July, 2021

Predicting the outcomes of focused electron-beam nanoprinting by means of multiscale computer simulations
Poster (online) at the International Conference on Applied Surface Science (ICASS 2021)
28 June, 2021

Monte Carlo simulation of cerium oxides REELS based on accurate ab initio electronic excitation spectra
Talk (online) at the European Conference on Surface and Interface Analysis (ECASIA 2021), University of Limerick, Ireland
18 June, 2021

SIMONE TAIOLI

Invited Talks

The half-life for the radioactive ^{134}Cs and ^{135}Cs in astrophysical scenarios 2nd PANDORA Progress Meeting, 16- 17 December 2021, Laboratori Nazionali del Sud, Catania

Simulation of low energy electron transport in condensed matter for technological and medical applications
Dynamics of Systems on the Nanoscale (DySoN-ISACC 2021), 18-22/10/2021, Santa Margherita Ligure (Italy)

Exploring Event Horizons and Hawking Radiation through Deformed Graphene Membranes

Global Summit and Expo on Graphene and 2D Materials (2DMAT2021), 23-25/08/2021, Paris (France)

Invited Plenary Lecture

Graphene pseudospheres, foams, low-density carbon allotropes and all that
Quantum Science Symposium of 17th International Conference of Computational Methods in Sciences and Engineering (ICCMSE 2021), 04-07/09/2021, Heraklion, Crete (Greece)

Lectures

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: short - 3 hours course to PhD Students in PHYSICS, Gdansk Polytechnic University (Academic year 2021-2022)
Scattering Theory: extended - 15 hours course to PhD Students in PHYSICS, Gdansk Polytechnic University (Academic year 2021-2022)

3.4. Seminars and Colloquia at ECT*

FRANCESCO GIOVANNI CELIBERTO

Studies on the hadronic structure at high energies
18 May 2021

MAURIZIO DAPOR

Spin-Polarization of Electron Beams Elastically Scattered by Ar, Kr, and Xe Atoms
30 March, 2021

MINGHUI DING

Distribution amplitudes of diquark correlations
ECT* e-seminar
9 March 2021

GERT AARTS

Thermal transition in QCD with N_f=2+1 flavours of Wilson quarks
16 February, 2021

PABLO DE VERA GOMIS

Computational science to uncover the physical and chemical processes underlying hadrontherapy
9 February, 2021

Computing Facilities

5. 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.

Services

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

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

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

1. PaperCut Print Management Software
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.