PARTICLE PHYSICS EXPERIMENTS

ATLAS Experiment

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1 Introduction

The researchers of the ATLAS Cosenza group have been actively involved in the year 2023 in physics analyses, covering a wide range of important topics of the LHC physics program, as well as in the Phase-I and Phase-II upgrade activities. The most relevant contributions of Cosenza group are briefly reviewed below.

2 Physics Analysis

2.1 Measurements of the differential cross-sections for $t\bar{t}$ production and phenomenological studies

Studies of top-quark production and decay are major research goals at the LHC, providing both a precise probe of the Standard Model and a window on physics beyond the Standard Model. The measurements of the differential cross-sections for the production of $t\bar{t}$ pairs provide, in particular, stringent tests of pQCD calculations with heavy quarks and allow a precise determination of the top-quark mass and of the proton's parton distribution functions (PDFs) in a well-defined theoretical framework. In the year 2023 the group has been actively involved in the measurements, based on the full Run 2 ATLAS data sample, of the particle- and parton-level differential cross sections for the production of $t\bar{t}$ pairs in the lepton+jet finale state. Both analyses are presently at the editorial board stage and their pubblication is foreseen by mid 2024.

The group also contributes to a phenomenological analysis that exploits the measured Run 2 parton level triple and double differential cross sections to determine simultaneously the top quark pole mass and the proton's PDFs. Since October 2022, E.Tassi is co-convener of the ATLAS Standard Model PDF Forum.

2.2 Measurements of the cross-section for the production of a W/Z boson in association with heavy-flavour jets

Measurements of the production cross section of a vector boson (V = W or Z) in association with b-jets or c-jets in proton-proton collision provide an important test of pQCD. Moreover these processes are sensitive to the proton structure. In particular precise measurements of Z + c-jets production allows to constrain the charm component of the proton parton distribution functions (PDFs). Moreover a detailed knowledge of V+b-jets production is also a key element in the understanding of Higgs-boson into a b-quark pair in associated production with a W/Z boson, indeed V+b-jets processes constitute one of the main backgrounds. In general V+ heavy-flavour jets are also background to many searches for beyond Standard Model processes. The studies, to which our group contributes, are conducted using data collected at the centre-of-mass energy of 13 TeV. Differential V +b-jets cross sections in several observables in a fiducial phase space are going to provide strong experimental constraints to improve the theoretical description. The group

also contributes to modelling studies of inclusive V +jets and V+b-jets processes to establish the best configuration of state-of-art Monte Carlo generators to be employed in future measurements with the aim of reducing mis-modelling and related uncertainties as much as possible.

3 Phase-I and Phase-II Upgrades

3.1 Phase-I: The ATLAS-NSW SM1 modules

To benefit from the expected high luminosity of Phase-I upgraded LHC, the first station of the forward ATLAS muon spectrometer (Small Wheel, SW) was replaced in 2021. The new SW has two detector technologies: micromegas mainly for precision tracking and small strip TGC for mainly trigger. An INFN consortium formed by Cs, LNF, Le, Na, Pv, Rm1, Rm3 was responsible for the construction and testing of the MM modules (SM1) located in a small-sector closed to the beam line. The series production started in 2017 and ended in 2020. The Cosenza group was responsible of the preparation, test and finalization with the mesh of the SM1 drift panels and of the logistic and data base of all the material need for the construction of all types of modules present in the MM-NSW project. Moreover the group was responsible of the gas tight validation of all the micromegas chambers, as well as the HV testing and for their validation at the gamma irradiation facility at CERN. The group was also responsible for the long term gamma irradiation of some chambers fed with a ternary gas mixture Ar:CO2-iso-C4H10 (93:5:2). Last but not least the group is studying the sparking voltage on MM electrodes in Ar, Ar:CO2 (93:7) and Ar:CO2:isoC4H10 (93:5:2) gas mixtures. These studies are conducted using real MM PCB and a small mesh stretched on a piano-convex lens of 2000mm focal length in order to reduce at minimum the surface interested to avalanches . The mesh-probe can be sited on pillars or attached to a slider that suspend the mesh-probe above the anode at the desired distance. In this last way the Paschen curve can be obtained. The mesh-probe is placed inside a gas tight box and filled with a gas mixture. Figure 1 shows the employed box for these measurements.

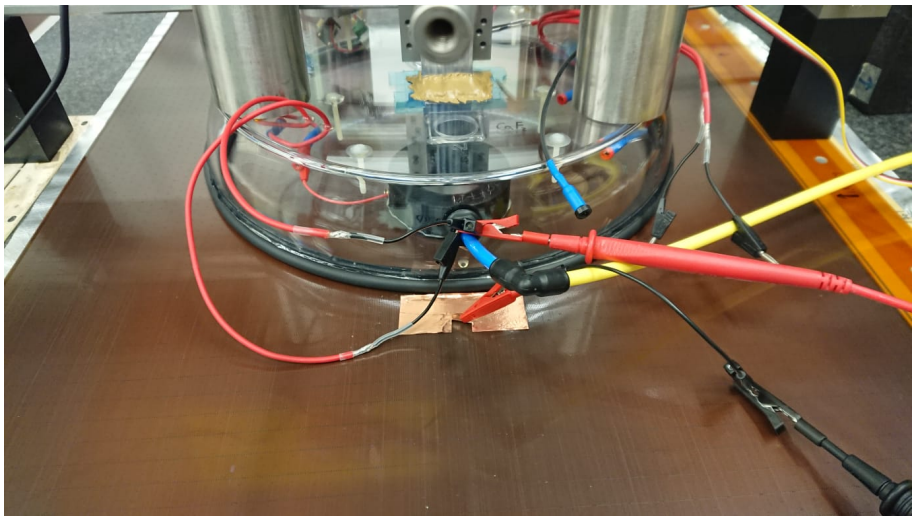

Figure 1: *The sutup employed to measure the Paschen curve for pure Ar, Ar:CO2 (93:7), Ar:CO2:isoC4H10 (93:5:2).*

3.2 Phase-II: Construction and test of the ATLAS BIL RPC chambers

In the 2020 the group got the responsibility to build and test the read-out panels of the trigger chambers to be paired to the BIL tracking detector of the muon spectrometer. The BIL tracking chambers were built by a consortium of INFN groups: Pavia, Rome 1, Rome 3 and Cosenza about 20 years ago. To increase the discrimination power for muons coming from the interaction point, the ATLAS collaboration agreed to the construction of the forth multilayer of RPC chamber to pair to the existing BIL tracking chamber, while in the short sectors also the tracking chambers will be replaced. During the year 2021, the group built and tested 12 prototypes of the new RPC read-out panel, which were then sent to CERN for electrical and mechanical testing. Each read-out panel consists of a 2500x650x0.4mm FR4 PCB on which the strips are photo-etched and a PCB of the same size which acts as a ground plane. The two PCBs are glued on the opposite sides of a 2500x650x3 mm paper honeycomb sheet with the copper facing outwards. In the 2022 the group has developed the majority of all the necessary tools, has participated to the procurement of the needed material (FR4, paper honeycomb, photo-etching of the strip plates), has developed the local data base where store the data, tested the pre-series ground plates and coordinated the activity of read-out panel design. In 2023 the group completed the construction and test of all the components of the readout panels assembling line in Cosenza. In October the assembling and testing line of the readout panels passed the review and in November the mass production started. The end of the production is expected for the end of the 2024. In 2023 the group started also to design and build the detector assembling line at CERN. The quality control of the detectors are checked in each phase of the assembling. When the singlets are assembled and the electronics are soldered onto the strip panels a complete test with cosmic rays is done. The construction of 130 chambers is expected to be completed at the end of 2025.

4 List of Conference Talks and Poster by LNF Authors in Year 2023

1. G. Falsetti, Results on pre-series production and QA/QC tests of the double-ends readout panels of the new layer of the trigger chambers for the ATLAS Muon Spectrometer phase 2 upgrade - IFAE2023 - Catania - April,12-14 2023 - Talk.

2. I. Gnesi, Flow and transverse momentum fluctuations in Pb+Pb and Xe+Xe collisions with ATLAS: assessing the initial condition of the QGP, The 11th International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions, Aschaffenburg (Germany), March 26-31, 2023 - Poster.

3. E. Bisceglie, E. Meoni, M. Schioppa, “Measurements of Z boson production in association with heavy-flavour jets at ATLAS”, 109° Congresso Nazionale SIF – September 11-15, 2023 – Dipartimento di Fisica dell’Università di Salerno (Fisciano) - Talk.

4. D. Passarelli, M. Schioppa, “Measurement of signal propagation in RPC readout panels for ATLAS Phase 2 upgrade”, 109° Congresso Nazionale SIF – September 11-15, 2023 – Dipartimento di Fisica dell’Università di Salerno (Fisciano) - Talk.

5. G. Tassone, P. Girotti, G. Venanzoni, M. Schioppa, “Measurement of the anomalous precession frequency in the Muon g-2 Experiment at Fermilab”, 109° Congresso Nazionale SIF – September 11-15, 2023 – Dipartimento di Fisica dell’Università di Salerno (Fisciano) - Talk.

KLOE-2

F. Curciarello (Ass.), L. Longo (Ass.), M. Schioppa (Resp.)

1 KLOE-2 experiment at Daphne e+e- collider

The KLOE-2 experiment at the INFN Frascati National Laboratories collected data at DAFNE e^+ e^- collider up to a few years ago. KLOE-2 represents the continuation of the KLOE experiment with a new physics program and with several detector upgrade. These upgrades include state-of-the-art cylindrical GEM Inner Tracker, electron-positron taggers for the $\gamma\gamma$ - physics studies and new calorimeters around the interaction point. The group has collaborated to the data tacking until the end of the physics program and to the analysis of data.

1.1 Measurement of the $\pi^0 \to \gamma\gamma$ width with KLOE-2 High Energy Taggers

The measurement of the $\pi^0 \to \gamma\gamma$ width is considered an important test of the strong interaction dynamics at low energy and is one of the goals of the KLOE-2 experiment. A way to achieve a precision able to test theory predictions is to exploit the π^0 production through $\gamma\gamma$ fusion in the $e^+e^- \to e^+e^-\gamma^*\gamma^* \to e^+e^-\pi^0$ reaction. To reduce the background from ϕ-meson decays, two High Energy Tagger (HET) stations have been installed in the DAΦNE machine layout in order to tag off-energy leptons scattered in the final state. The $\gamma\gamma \to \pi^0$ signal is expected in the coincidence window between HET and KLOE while the remaining buffer depth, acquired together with the coincidence sample, is used to evaluate the amount of uncorrelated time coincidences between the two detectors (accidentals). The accidental background is modeled using the HET data acquired out of coincidence window with the KLOE detector, while the $\gamma\gamma \to \pi^0$ signal is taken from the Ekhara simulation interfaced with the BDSIM transport of the leptons through the beam line. Statistical evidence of correlated coincidence events between the electron tagger station and the KLOE calorimeter has been observed on a sample of 3 fb^{-1} with a precision of 10% and in a KLOE-HET coincidence window of few bunches. A first evidence of π^0 production from $\gamma\gamma$ scattering has been also obtained on the positron side.
Currently, we are working to: i) improve fit quality and precision on π^0 counting ii) measure the actual HET acceptance ii) extract the preliminary measurement of the $\gamma\gamma \to \pi^0$ cross section.

EIC_net

M. Capua (Resp.), S. Fazio (Ass.), L. Occhiuto (Ass.), and E. Tassi (Ass.)

1 The Electron-Ion Collider and the ePIC detector

Starting November 2023, M. Capua is serving as Cosenza's local representative within EIC_net, replacing S. Fazio on the same role.

The Electron-Ion Collider (EIC) is a major new research facility to be built at Brookhaven National Laboratory (BNL) in partnership with Thomas Jefferson National Accelerator Facility (JLAB) in the U.S.A. The EIC is designed to advance the long-term vision for Nuclear Physics to discover and understand the emergent phenomena of Quantum Chromo-Dynamics.

Cosenza's group is part of the EIC Users' Group [M. Capua, Institutional Representative (I.R.)] and the newly formed ePIC Collaboration [S. Fazio, Collaboration Council representative (C.C.)]. In July 2023 the ePIC collaboration (https://www.bnl.gov/eic/epic.php) was formed, by merging the communities involved the previous two detector proposals, ECCE and ATHENA. The ePIC detector, funded by the EIC Project, will be a general purpose experiment capable of delivering the EIC science case. The Cosenza's group involvement within ePIC is multifold:

- Leading role in Analysis and Physics performance studies, with S. Fazio appointed Analysis Coordinator starting March 2023, and ex-officio member of the ePIC Executive Board. The main focus in the early start of the ePIC Collaboration, was to appoint Physics Working Group (PWG) conveners, and facilitate early performance studies, physics performance plots and benchmarks and development of analysis tools.

- Active participation into R&D efforts on the realization of a dual radiator RICH (dRICH) detector in the forward region of ePIC. We have set up a local laboratory devoted to the characterization of Silicon Photo-multipliers (SiPMs) as preferred photosensors for the dRIHC. E. Tassi, M. Capua, and S. Fazio have participated to beam tests at CERN and to irradiation campaigns at TIFPA-Trento and Legnaro, using protons and a neutrons respectively. L. Occhiuto graduated with a master's thesis on the characterization of SiPMs. In November 2023, she started a Ph.D. program, finalizing the study of radiation damage to SiPMs by protons at different energies. She has also started to be involved in the GEANT4 simulation efforts of the dRICH detector.

- In 2023, we have obtained 25 k$ Project Engineering and Design (PED) funds by the EIC Project and we are using them to co-fund the hiring of a dedicated junior postdoc, who will start in 2024.

- M. Capua and E. Tassi hosted and chaired the "1st European School on the Physics of the Electron-Ion Collider", 18-22 June 2023, Corigliano-Rossano (CS, Italy). This successful event saw the participation of 46 students and lecturers from around the world, strenghtening the engagement of a young generation of scientists. [https://agenda.infn.it/event/33450/]

2 List of Conference Talks and Poster by LNF Authors in Year 2023

1. L. Occhiuto, "Performance study of SiPM sensors for the dRICH detector at the ePIC experiment", 109° Congresso Nazionale SIF – September 11-15, 2023 – Dipartimento di Fisica dell'Università di Salerno (Fisciano) - Talk.

THEORETICAL PHYSICS

BELL
Fundamental Problems in Quantum Physics

G. Nisticò (Resp.)

1 Consistent derivation of relativistic quantum theories of single particle

Relativistic quantum theories of single free particle can be deductively derived from the principles of *relativistic invariance* and *covariance*; these principles imply that the Hilbert space of the quantum theory of a free particle must admit a *transformer triplet* $(U, \mathfrak{S}, \mathfrak{T})$ formed by a unitary representation U of the universal covering group $\tilde{\mathcal{P}}_+^\uparrow$ of the proper orthochronus Poincaré group $\mathcal{P}_+^\uparrow$ and by the operators $\mathfrak{S}$ and $\mathfrak{T}$, which realize the quantum transformations implied by the transformations of $\mathcal{P}_+^\uparrow$, by space inversion $\mathfrak{s}$ and by time reversal $\mathfrak{t}$, respectively. Yet the literature excludes transformer triplets with $\mathfrak{S}$ anti-unitary or with $\mathfrak{T}$ unitary. In so doing robust classes of possible theories are lost, such as theories for Klein-Gordon particles.

Our work shows how a strictly deductive development of consistent quantum theories of elementary free particle can be successfully carried out without *apriori* preclusions about the unitary or anti-unitary character of $\mathfrak{S}$ or $\mathfrak{T}$. As results, classes of consistent possible theories for a positive mass particle are expicitly identified, which meaningfully extend the class of the current theories; in particular, consistent theories of Klein-Gordon particle are derived. Also in the case of a massless particle the approach extends the class of possible theories. Furthermore, the non-localizability theorem for non zero helicity massless particles is extended to the new theories with $\mathfrak{T}$ unitary or $\mathfrak{S}$ anti-unitary.

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GAST

Marco Rossi (associato al nodo di Bologna dell'IS GAST)

1 Research activity in 2023

During the year 2023 my research activity concerned the following topics:

• In collaboration with D. Fioravanti (INFN Bologna, IS GAST) we published the paper [1]. In this paper, we proposed a method which allows to associate to a generic quantum integrable model (in $1+1$ dimensions) a differential equation. We tested our proposal for sine-Gordon model (a QFT) and more importantly for spin chains. Our constructions explains the deep reasons of the appearing of the so-called Ordinary Differential Equations/Integrable Models correspondence.

• In collaboration with D. Fioravanti we are finishing two preprints concerning the relation between Painlevé equations and supersymmetric $\mathcal{N}=2$ gauge theories.

Another preprint, a collaboration with D. Fioravanti, D. Gregori (Soochow Univ., China), R. Mahanta (Winnipeg Univ., Canada), is at its last stages. It concerns the relation between connection coefficients of solutions of Confluent Heun equations and the 'prepotential' of $SU(2)$ $\mathcal{N}=2$ super Yang-Mills gauge theories.

2 List of Conference Talks in Year 2023

1. M. Rossi, "New frontiers in integrability", Dublin, 13-16 June 2023 (invited talk) https://sites.google.com/view/hmi-integrability-workshop23/

2. M. Rossi "10th Bologna Workshop on CFT and integrable models", 4-7 Settembre 2023 (talk) https://agenda.infn.it/event/33911/

3 Organisation of conferences

• Organisation of the Conference 'InTropea2023', https://sites.google.com/view/intropea2023/home, 28th of August to 1st of September 2023

References

1. D. Fioravanti and M. Rossi, On the origin of the correspondence between classical and quantum integrable theories, Phys. Lett. B 838 (2023) 137706

LINCOLN
Learning Complex Networks

G. Alì (Ass.), R. Beneduci (Resp.), G. Mascali (Ass.)

1 Mathematical Models for Semiconductors

1) We analyzed the thermal, electric and thermoelectric properties of graphene temperature [1)].

2) We provided an Extended hydrodynamical model for plasmas [2)] Optimal design of equilibrium solutions of the Vlasov-Poisson system by an external electric field.

2 Quantum Measurement

1) Fuzzy observables

   We proved the equivalence between weak Markov kernels and Markov kernels, then we used the result in order to generalize some previous results on the characterization of fuzzy observables [3)].

3 Modelling of real world problems

1) We provided a non-linear space time probabilistic model for forest fire spreading [4)].

2) We provided a deterministic reaction-diffusion model for forest fire spreading [5)].

3) Optimal design of equilibrium solutions of the Vlasov-Poisson system by an external electric field [6)].

4 Conferences

1) Joint European Thermodynamics Conference 2023, Salerno, June 12-17, (Communication).

2) ECMI2023 (22nd ECMI Conference on Industrial and Applied Mathematics), Wroclav, Poland, 26-30 June 2023 (Communication).

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1. G. Mascali, Some electric, thermal and thermoelectric properties of suspended monolayer graphene, SIAM Journal of Applied Mathematics, 83(2), (2023) 770–790.

2. G. Alì, G. Mascali, O. Pezzi, F. Valentini, Extended hydrodynamical models for plasmas, Continuum Mechanics and Thermodynamics, 35(5), (2023) 2003–2016.

3. R. Beneduci, Fuzzy observables: From weak Markov kernels to Markov kernels, International Journal of Theoretical Physics (2023) DOI: https://doi.org/10.1007/s10773-023-05475-w.

4. R. Beneduci, G. Mascali, Forest Fire Spreading: a non-linear stochastic model in space and time arXiv:2309.00660 (submitted).

5. G. Alì, F. Demarco, D. Gaudio, P.A. Fusaro, R.S. Olivito, C. Scuro, A mathematical model for the propagation of wildfires, (2023) IEEE International Workshop on Metrology for Living Environment, MetroLivEnv.

6. A. Borzì, G. Infante, G. Mascali, Optimal design of equilibrium solutions of the Vlasov-Poisson system by an external electric field (submitted).

NPQCD
Understanding the properties of strong interactions at large distances and in extreme conditions

A. Papa (Resp.), O. Borisenko (Ass.)

1 Flux tubes in pure-gauge SU(3)

A characteristic signature of quark confinement is the concentration of the chromoelectric field between a static quark–antiquark pair in a flux tube. However, the structure of this flux tube, and hence of the confining force, has not been completely understood.

We determined, by numerical Monte Carlo simulations on a space-time lattice, the chromoelectric fields in a flux tube created by a static quark-antiquark pair in the finite-temperature SU(3) gauge theory. Below the deconfinement temperature the field behavior is similar to the zero-temperature case. Above the deconfinement temperature the field shape remains the same, but the field values drop when the distance between quark and antiquark increases, thus showing the disappearance of confining potential [1)].

2 QCD phase diagram from Polyakov loops effective models

Computations of screening masses in finite-temperature QCD at finite density are plagued by the sign problem and have been performed so far with an imaginary chemical potential. We have used a dual formulation of a Polyakov-loop model which allowed the determination of screening masses at real baryon chemical potential. This was a second paper in a series devoted to a detailed study of dual Polyakov-loop models at finite density. While the first paper was mainly devoted to establishing the phase diagram of the model, in this work we computed correlation functions of the Polyakov loops and the second-moment correlation length at non-zero chemical potential. This enabled us to evaluate numerically the screening masses from correlations of the real and imaginary parts of the Polyakov loops. We also computed these masses in the mean-field approximation and compared with numerical results. In addition, we provided a quantitative improvement of the general phase diagram presented in the first paper [2)].

The effective action of the SU(N) Polyakov-loop model in the strong coupling region and in the static limit for the quark determinant can be mapped onto the Ising model in any dimensions, with the Ising variables attached on the links of the lattice. We used this reformulation to study the finite temperature SU(2) lattice gauge theory at finite baryon density [3)].

3 The 't Hooft-Veneziano limit of Polyakov loop models at finite baryon density

The 't Hooft-Veneziano limit of the Polyakov loop models with a static quark determinant was studied at finite baryon chemical potential. In particular, we calculated the two- and N-point correlation functions of the Polyakov loops. This gave a possibility to compute the various potentials in the confinement phase and to derive the screening masses outside the confinement region. We established the existence of complex masses and an oscillating decay of correlations in a certain

range of parameters, like the gauge coupling constant and quark mass. It was shown that the calculation of the N-point correlation function in the confinement phase reduces to the geometric median problem. This leads to a large-N analog of the Y law for the baryon potential [4].

References

1. M. Baker, V. Chelnokov, L. Cosmai, F. Cuteri and A. Papa,
   "Unveiling SU(3) Flux Tubes At Nonzero Temperature: Electric Fields and Magnetic Currents",
   [arXiv:2310.04298 [hep-lat]], to appear on Eur. Phys. J. C.

2. O. Borisenko, V. Chelnokov, E. Mendicelli and A. Papa,
   "Dual simulation of a Polyakov loop model at finite baryon density: Correlations and screening masses",
   [arXiv:2309.06104 [hep-lat]], to appear on Nucl. Phys. B.

3. B. Allés, O. Borisenko, A. Papa and S. Voloshyn,
   "Lattice gauge theories in the strong coupling and static limits as a sign-problem-free Ising model",
   Phys. Rev. D **108** (2023) no.5, 054505 [arXiv:2307.06641 [hep-lat]].

4. O. Borisenko, V. Chelnokov, S. Voloshin,
   "The Polyakov loop models in the large N limit: Correlation function and screening masses",
   [arXiv:2311.03907 [hep-lat]], to appear on Phys. Rev. D.

QFT@COLLIDERS
Precision calculations for collider physics

M. Fucilla (Dott.), G. Gatto (Dott.), L. Panizzi (Ass.), A. Papa (Resp.)

1 Semihard processes in perturbative QCD

High-energy reactions falling in the so-called *semi-hard* sector, where the scale hierarchy, $s \gg Q^2 \gg \Lambda^2_{\rm QCD}$ holds (here, s is the squared center-of-mass energy, Q the hard scale given by the process kinematics and $\Lambda_{\rm QCD}$ the QCD mass scale) represent an excellent channel to probe and deepen our knowledge of strong interactions in kinematic ranges so far unexplored.

The study of these processes by fixed-order calculations in perturbative QCD misses the effect of large energy logarithms, entering the perturbative series with a power increasing along with the order, thus compensating the smallness of the strong coupling, α_s. The Balitsky-Fadin-Kuraev-Lipatov (BFKL) approach represents the most powerful tool to resum to all orders, both in the leading (LLA) and the next-to-leading (NLA) approximation, these large-energy logarithmic contributions. Within this approach, we have considered

- the inclusive hadroproduction of a neutral heavy-light, hidden-flavored tetraquark ($X_{c\bar{u}\bar{c}u}$ or $X_{b\bar{s}\bar{b}s}$ state), in association with a heavy (single c- or b-flavored) hadron or a light jet at the (HL-)LHC. We made use of the JETHAD multi-modular working package to provide predictions for rapidity, azimuthal-angle and transverse-momentum distributions calculated via the hybrid high-energy and collinear factorization, where the Balitsky–Fadin–Kuraev–Lipatov resummation of energy logarithms is supplemented by collinear parton densities and fragmentation functions. We relied upon the single-parton fragmentation mechanism, valid in the large transverse-momentum regime, to describe the tetraquark production. Our study represents a first attempt at bridging the gap between all-order calculations of high-energy QCD and the exotics [1)].

- the effective Reggeon-Reggeon-gluon vertex, known as Lipatov vertex, being the key ingredient that allows to develop the BFKL approach in QCD. Within the next-to- leading logarithmic approximation, it is sufficient to know its one-loop corrections, in dimensional regularization ($D = 4 + 2\epsilon$), up to the constant term in the ϵ-expansion. In the next-to-next-to-leading approximation, however, the one-loop Lipatov vertex is needed up to the order ϵ^2. We presented the expression for this vertex in dimensional regularization up to the required accuracy [2)].

2 Physics Beyond the Standard Model at colliders

Multiple observations which cannot be explained within the Standard Model of particle physics require the introduction of new physics, the origin of which is still unknown. Testing new phenomena at colliders requires building numerical models which can describe a large range of new theoretical scenarios. At the same time, it is necessary to develop and optimize analysis strategies

which minimize the number of relevant new parameters to be probed while being as accurate as possible in the description of the kinematics of collision events involving new physics. We have performed phenomenological analyses according to the aforementioned principles [3, 4] for a dark matter scenario and for a composite Higgs scenario, and continued the development of a framework for this kind of analysis, described with a di-Higgs analysis [5], to enlarge its scope and address different processes, such as pair production of new charged scalars and a comprehensive analysis of dark matter signatures at the LHC.

3 Talks in Year 2023

1. M. Fucilla,
   "Higgs boson production at next-to-leading logarithmic accuracy",
   57th Rencontres de Moriond on QCD and High Energy Interactions (Moriond QCD 2023), La Thuile, March 25 - April 1, 2023,
   https://moriond.in2p3.fr/2023/QCD/Program.html

2. M. Fucilla,
   "High-energy resummation in Higgs production at the next-to-leading order",
   16th International Symposium on Radiative Corrections: Applications of Quantum Field Theory to Phenomenology (RADCOR 2023), Edinburgh, May 28 - June 2, 2023,
   https://higgs.ph.ed.ac.uk/workshops/RADCOR2023/

3. G. Gatto,
   "Resummed high-energy distributions for Higgs-plus-jet at the LHC",
   Resummation, Evolution, Factorization (REF2023), Marid, October 23-27, 2023,
   https://indico.fis.ucm.es/event/19/

4. L. Panizzi,
   "Deconstructing signals of new physics at collider - a case study with Higgs pair production and other applications",
   IPHC Strasbourg, April 18, 2023.

5. L. Panizzi,
   "Vector-like quarks beyond minimality: large width, NLO and exotic decays",
   B2G Spring workshop 2023, CERN, April 25-27, 2023
   https://indico.cern.ch/event/1258044/sessions/485772/#all

6. L. Panizzi,
   "Deconstructing signals of new physics at collider - a case study with Higgs pair production and other applications",
   University of Southampton, June 16, 2023
   https://www.hep.phys.soton.ac.uk/events/B432

7. L. Panizzi,
   "Deconstructing signals of new physics at collider",
   (Re)interpretation of the LHC results for new physics, Durham University, August 29 - September 1, 2023
   https://conference.ippp.dur.ac.uk/event/1178/

8. L. Panizzi,
   "Vector-like quarks",

CERN collider cross-talk, CERN, November 16, 2023
https://indico.cern.ch/event/1317807/

9. L. Panizzi,
3 talks for CMS and 1 for ATLAS, internal meetings

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"Comprehensive exploration of t-channel simplified models of dark matter,"
Phys. Rev. D **108** (2023) no.11, 115007 [arXiv:2307.10367 [hep-ph]].

4. A. Banerjee, V. Ellajosyula and L. Panizzi,
"Heavy vector-like quarks decaying to exotic scalars: a case study with triplets",
to appear on JHEP [arXiv:2311.17877 [hep-ph]].

5. S. Moretti, L. Panizzi, J. Sjölin and H. Waltari,
"Deconstructing squark contributions to di-Higgs production at the LHC",
Phys. Rev. D **107** (2023) no.11, 115010 [arXiv:2302.03401 [hep-ph]].

QFT-HEP
Physics of the Standard Model and beyond SM

L. Delle Rose (Resp.), M. Razzaq (Dott.)

1 Collision integrals for cosmological phase transitions

The dynamics of the true-vacuum bubbles nucleated during a first-order phase transition is affected by the distribution functions of the particle species in the plasma, driven out-of-equilibrium by the travelling domain wall. An accurate modelling of this phenomenon is relevant for a quantitative description of phase transitions in the early universe and for the determination of the corresponding cosmic relics, such as, among the others, the stochastic background of gravitational waves. We address this problem in [1)] by developing a new spectral method devised for a fast and reliable computation of the collision integral in the Boltzmann equations. In a scalar singlet extension of the Standard Model chosen as a benchmark scenario, we test our algorithm, determining the bubble speed and profile, and we asses the impact of the out-of-equilibrium dynamics.

2 BSM interpretation of the X17 anomaly

An hypothetical particle can explain the resonant structure observed at $\simeq 17$ MeV in the invariant mass of electron-positron pairs, produced after excitation of nuclei such as ^{8}Be and ^{4}He by means of proton beams at the Atomki Laboratory in Debrecen. In [2)] we contribute to provide a theoretical interpretation of the anomaly as well as to discuss present and future experiments aiming at confirming the result and/or at providing experimental evidence for its interpretation.

3 Talks in Year 2023

1. L. Delle Rose,
   "Bubble dynamics of first order electroweak phase transitions",
   26th International Conference on Particle Physics and Cosmology (COSMO 2023), Madrid, September 11-15, 2023,
   https://workshops.ift.uam-csic.es/COSMO23

2. L. Delle Rose,
   "Bubble dynamics of first order electroweak phase transitions',
   Phoenix 2023, Hyderabad, December 18-20, 2023
   https://indico.cern.ch/event/1313315/

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2. D. S. M. Alves, D. Barducci, G. Cavoto, L. Darmé, L. Delle Rose, L. Doria, J. L. Feng, A. Frankenthal, A. Gasparian and E. Goudzovski, *et al.* "Shedding light on X17: community report," Eur. Phys. J. C **83** (2023) no.3, 230

SFT - Statistical Field Theory and Applications

E. G. Cinnirella (Ass.), D. Giuliano (Resp.), F. Plastina (Ass.), J. Settino (Ass.)

1 Lindblad master equation approach to the topological phase transition in the disordered Su-Schrieffer-Heeger model : [1, 2]

Using the Lindblad equation method, we have investigated the onset of a mobility edge and the topological phase transition in the disordered SSH chain connected to two external baths in the large bias limit. From the scaling properties of the nonequilibrium stationary current flowing across the system, we have recovered the localization/delocalization in the disordered chain. Eventually, we proposed to probe the topological phase transition in the presence of disorder, by using the even-odd differential occupancy as a mean to discriminate topologically trivial from topologically nontrival phases in the out-of-equilibirum system. At a second stage of the project, we have studied topological phases hosting more than one localized state at each side of a disordered SSH chain with properly tuned long range hoppings. Inducing a non equilibrium steady state across the chain, we probe the robustness of each phase and the fate of the edge modes looking at the distribution of electrons along the chain and the corresponding standard deviation in the presence of different kinds of disorder.

2 Uniaxial modulation and the Berezinskii-Kosterlitz-Thouless transition [3]

We have theoretical studied the Berezinskii-Kosterlitz-Thouless transition of a two-dimensional superfluid in the presence of an externally imposed density modulation along a single axis. By means of a pertinent combination of analytical and numerical techniques, we have shonw that, as the amplitude of the modulation increases, the physics of the system approaches that of the anisotropic x-y model, with a suppressed superfluid transition temperature and an anisotropic response, but with no dimensional crossover.

3 Lindblad master equation approach to the dissipative quench dynamics of planar superconductorsl: application to the dissipation driven dynamical topological phase transitions in two-dimensional superconductors [4, 5]

Using Lindblad master equation method, we have studied the nonequilibrium dynamics following a parametric quench in the Hamiltonian of an open, two-dimensional superconducting system coupled to an external bath. We have shown how the dissipation works as an effective stabilization mechanism in the time evolution of the system after the quench. Eventually, we evidenced how the mismatch between the phases corresponding to the initial and to the final state of the system determines a dynamical phase transition between the two distinct phases. Our method allows for fully characterizing the dynamical phase transition in an open system in several cases of physical relevance, by means of a combined study of the time-dependent superconducting gap and of the

fidelity between density matrices. As a paradigmatic application of our approach, we have analyzed a topological dynamical phase transition between two planar superconducting phases. Using the Lindblad equation to account for the interactions of Bogoliubov quasiparticles among themselves and with the fluctuations of the superconducting order parameter, we have derived the relaxation dynamics of the order parameter. Finally, to characterize the phase transition, we have computed the fidelity and the spin-Hall conductance of the open system.

4 Understanding Traffic Jams Using Lindblad Superoperators: [6]

We have proposed a model to simulate different traffic-flow conditions in terms of quantum graphs hosting an (N+1)-level dot at each site. Our model has allowed us to keep track of the type and of the destination of each vehicle. The traffic flow inside the system is encoded in a proper set of Lindbladian local dissipators that describe the time evolution of the system density matrix. Taking advantage of the invariance of the Lindblad master equation under inhomogeneous transformations we have derived the quantum Hamiltonian for the bulk dynamics in a proper experimental setup.

5 Multiple entanglement: [7]

We have discussed under which conditions multipartite entanglement in mixed quantum states can be characterized only in terms of two-point connected correlation functions, as it is the case for pure states. In turn, the latter correlations are defined via a suitable combination of (disconnected) one- and two-point correlation functions. In contrast to the case of pure states, conditions to be satisfied turn out to be rather severe. However, we were able to identify some interesting cases, as when the point-independence is valid of the one-point correlations in each possible decomposition of the density matrix, or when the operators that enter in the correlations are (semi-)positive/negative defined.

6 Variational quantum algorithms for energy optimization and the thermal-state preparation of a many-body system [8, 9]

Quantum computing has emerged as a powerful paradigm for solving complex problems that are intractable with classical computers, but limitations of available quantum hardware hinder the use of pure quantum algorithms. In the current noisy intermediate-scale quantum (NISQ) era, variational quantum algorithms (VQAs) represent a valid alternative: a set of classically optimized tunable parameters controls the quantum computation. In this presentation, we show how a Quantum Approximate Optimization Algorithm (QAOA) can be used to tackle the NP-Hard prosumer problem, which consists in identifying the most economical combinations for the production, purchase, and sale of energy in a community. Moreover, we develop a VQA for preparing a Gibbs state of a many-body system on a quantum computer, which represents a fundamental ingredient for investigating thermalization and out-of-equilibrium thermodynamics, and providing helpful initial resources for other quantum algorithms. To overtake the constraints of existing hardware, we implement an innovative, efficient, and accurate readout measurement scheme for single- and multi-qubit states, based on Bayesian inference

7 Quantum Algorithms [10]

We introduced a classical-quantum hybrid approach to computation, allowing for a quadratic performance improvement in the decision process of a learning agent. Using the paradigm of quantum

accelerators, we introduced a routine that runs on a quantum computer, which allows for the encoding of probability distributions. Then, we employed this quantum routine in a reinforcement learning set-up, to encode the distributions that drive action choices. Our routine is well-suited in the case of a large, although finite, number of actions and can be employed in any scenario where a probability distribution with a large support is needed. We assessed the routine performance in terms of computational complexity, needed quantum resource, and accuracy. Finally, we designed an algorithm showing how to exploit it in the context of Q-learning.

8 Entanglement in spin chains [11])

A commonly adopted setup for distributing entangled quantum states envisages their creation in one location, with one (or more) of the parties later sent to (possibly different) distant receivers through some quantum channels. While it is, perhaps, intuitively expected that the distribution of entangled quantum states is less efficient than that of product states, a thorough quantification of this inefficiency (namely, of the difference between the quantum-state transfer fidelity for entangled and factorized states) has not been performed up to now. To this end, we considered n-independent amplitude-damping channels, acting in parallel, i.e., each, locally, on one part of an n-qubit state. We derive exact analytical results for the fidelity decrease, with respect to the case of product states, in the presence of entanglement in the initial state, for up to four qubits. Interestingly, we found that genuine multipartite entanglement has a more detrimental effect on the fidelity than two-qubit entanglement. Our results hint at the fact that, for larger n-qubit states, thedifference in the average fidelity between product and entangled states increases with increasing single-qubit fidelity, thus making the latter a less trustworthy figure of merit.

9 Majorana states in Josephson junctions [12])

We investigated the topological properties of a Josephson junction obtained by constraining a two-dimensional electron gas at the oxide interface to form a quasi-one-dimensional conductor. We revealed an anomalous critical current behavior with a magnetic field applied perpendicular to the Rashba spin-orbit one. We related the observed critical current enhancement at small magnetic fields with the appearance of orbital-flavored Majorana bound states (OMBSs) pinned at the edges of the superconducting leads. Signatures of OMBSs also include a sawtooth profile in the current-phase relation. Our findings allow us to recognize fingerprints of topological superconductivity in noncentrosymmetric materials and confined systems with a spin-orbit interaction. They also explain recent experimental observations for which a microscopic description is still lacking.

List of Conference talks:

1. D. Giuliano, "Current transport properties and phase diagram of a Kitaev chein with long-range pairing", invited talk, 13/07/2023, International Conference on Statistical Physics 2023, Crete, Greece.
2. F. Plastina, "Quantum coherence and thermodynamics", invited talk, NES 23 - New Trends in Non-Equilibrium Thermodynamics - Erice 13/10/2023.
3. F. Plastina, "Quantum coherence and thermodynamics", invited talk, 109^o congresso SIF - Salerno 12/09/2023.
4. J. Settino, "Variational quantum algorithms for energy optimization and the thermal-state preparation of a many-body system", talk, 109^o congresso SIF - Salerno 12/09/2023.

5. F. Plastina, "Optimization problems and Variational Quantum Algorithms", invited talk, XIX Workshop ICAR 2023 - Pizzo Calabro (VV) 07/09/2023.

6. F. Plastina, "Quantum Coherence and Thermodynamics", invited Key-note lecture, QIM Workshop Malta 2023 - Msida (Malta) 01/06/2023.

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2. E. G. Cinnirella, A. Nava, G. Campagnano, and D. Giuliano, *The fate of high winding number topological phases in the disordered extended Su-Schrieffer-Heeger model*, Phys. Rev. B **109**, 035114 (2024).

3. D. Giuliano, P. H. Nguyen, A. Nava, and M. Boninsegni, *Uniaxial modulation and the Berezinskii-Kosterlitz-Thouless transition*, Phys. Rev. B **107**, 195439 (2023).

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5. A. Nava, C. A. Perroni, R. Egger, L. Lepori, and D. Giuliano, *Dissipation driven dynamical topological phase transitions in two-dimensional superconductors*, Phys. Rev. B **109**, L041107 (2024).

6. A. Nava, D. Giuliano, A. Papa, M. Rossi, *Understanding Traffic Jams Using Lindblad Superoperators*, Int. J. Theor. Phys. **62**, 37 (2023).

7. L. Lepori, A. Trombettoni, D. Giuliano, J. Kombe, J. Yago Malo, A. J. Daley, A. Smerzi, M. L. Chiofalo, *Can multipartite entanglement be characterized by two-point connected correlation functions ?*, J. Phys. A: Math. Theor. **56** 305302 (2023).

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9. C. Mastroianni, F. Plastina, L. Scarcello, J. Settino, A. Vinci, *Assessing Quantum Computing Performance for Energy Optimization in a Prosumer Community*, IEEE Transactions on Smart Grid, vol. **15**, no. 1, pp. 444-456 (2024).

10. A. Sannia, A. Giordano, N. Lo Gullo, C. Mastroianni, F. Plastina, *A hybrid classical-quantum approach to speed-up Q-learning*, Sc. Reports **13**, 3913 (2023).

11. T. J. G. Apollaro, S. Lorenzo, F. Plastina, M. Consiglio, K. Zyczkowski, *Entangled states are harder to transfer than product states*, Entropy **25**, 46 (2023).

12. A. Maiellaro, J. Settino, C. Guarcello, F. Romeo, R. Citro, *Majorana states in Josephson junctions*, Phys. Rev. B **107**, L201405 (2023).

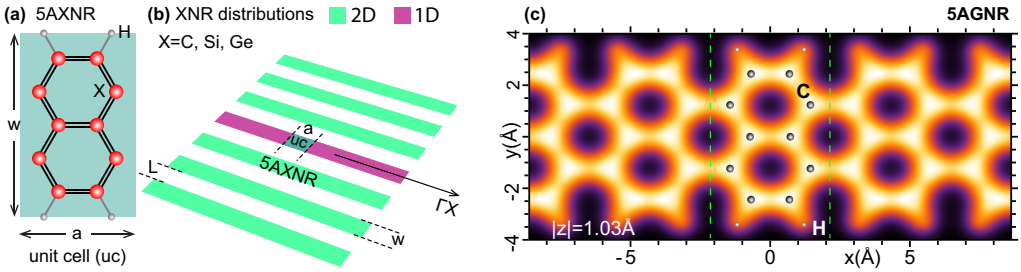
Time2Quest

A. Sindona (Resp.), P. Riccardi (Ass.), F. Plastina (Ass.),
N. Logullo (Ass.), J. Settino (Ass.), M. Pisarra (Ass.),
F. Mazzei (Dott.), A. Palamara (Dott.)

1 Research Activity

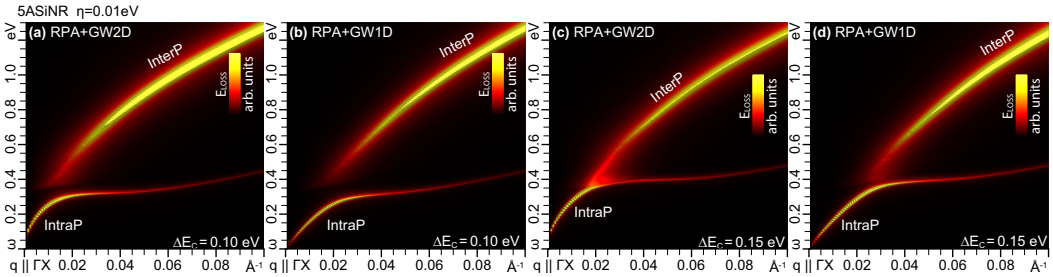
As specified in its project proposal, the specific initiative Time2Quest aims at exploring highly demanding computational strategies to unravel excited state properties, collective excitations, transport phenomena and other many-body effects in low dimensional systems of uttermost importance for quantum information processing. The researchers from the CS unit, being the coordinating node of this project, share their expertise in time-dependent density functional theory, many-body parturbation theory and out-of-equilibrium thermodynamics. During the course of 2023, the CS unit has specifically explored the following topics:

(i) **plasmon excitations, dielectric, electromagnetic, and fundamental properties of one-dimensional nano objects.** Nanoribbon based structures are promising prototypes for high-performance, atomically-compact and ultra-low power devices, whose functioning is controlled by charge density waves induced at the interface of the materials with the external dielectric environment.



(a) Unit-cell, and (b) planar array (2D) vs isolated (1D) configurations of nanoribbons with armchair shaped edges, which are made of 5 *dimers of carbon, silicon, and germanium atoms, passivated by hydrogen atoms. (c) Valence electron density of (c) 5AGNR represented at a distance* $|z|$ *of* $\sim$1 *Å, perpendicular to the NR-axis* x*.*

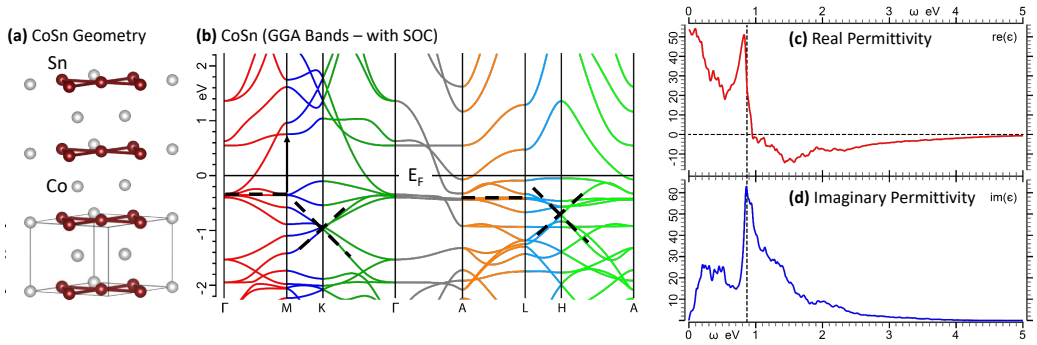
The associated plasmon modes were scrutinized by looking at the frequency-dependent permittivity of a class of few-atom-wide graphene, silicene, and germanene nanoribbons over the whole optical range, from the far-infrared to the near-ultraviolet. Time-dependent density functional theory was used, with a specifically developed cutoff strategy on the bare Coulomb interaction, which provide the diverse dielectric response of isolated (purely one-dimensional) nanoribbons and correlated (two-dimensional) nanoribbon arrays. Many-body interaction were taken into account at the level of the so-called GW approximation.



Plasmon spectrum of a five-atom-wide silicene nanoribbon with armchair edges (5ASiNR) in periodic-planar array configuration [(a), (c)] and isolated form [(b), (d)]. Two different doping conditions are tested, which simulate electron injection in the conduction band by ΔE_c=0.10 *eV [(a), (b)] and* ΔE_c=0.15 *eV [(c), (d)]. An edge and a bulk plasmons are clearly outlined, whose intensity and interaction are modulated by the geomatry of the systems and the injected electron concentrations.*

Further many-electron correlations were taken into account, at the level of the Bethe-Salpeter equation formalism. The main technological interest is on the bulk plasmon, whose propagation and interplay with the edge plasmons were comprehensively analyzed down to the terahertz domain, which is expected to guide the implementation of novel graphene nanoribbon architectures [1]. Other more sophisticated nanoribbon systems, originating from transition metal dichalcogenides (MoS_2, WS_2), or including porphyrin fragments were scrutinized [2].

(ii) **plasmon excitations from flat bands in Kagome metals.** A kagome lattice of three-dimensional transition metal ions is a versatile platform for correlated topological phases hosting symmetry-protected electronic excitations and magnetic ground states. More specifically, the atomic lattice of a kagome magnet is made of layered overlapping triangles and large hexagonal voids, which induces flat electronic band structure with Dirac crossings, in which the low-energy electron dynamics correlate strongly. We discovered a novel plasmon excitation occurring in Kagome CoSn, attested by a change of sign in the real permittivity and a sharp peak in the imaginary permittivity or absoprtion spectrum of the system.



(a) Geometry, (b) band structure, (c) real permittivity and (d) imaginary permittivity of CoSn

The calculations were performed using time-dependent density-functional theory, and the Bethe-Salpeter equation formalism. If verified by experiments, these findings would open novel perspectives in ferromagnetic quantum materials [3].

(iii) **Magic distances for flat bands in twisted bilayer graphene.** Twisted bilayer graphene is known to host isolated and relatively flat bands near charge neutrality, when tuned to specific *magic* angles. Nonetheless, these rotational misalignments, lying below 1.1 degrees, result in long-period moiré crystals, whose anomalous electronic properties are hardly accessible to reliable atomistic simulations. We determined a map of differently stacked graphene sheets, at arbitrary rotation angles corresponding to precise interplanar distances, into an equivalence class represented by *magic-angle* twisted bilayer graphene. In particular, we defined the equivalence relation in the class within a continuum model, and extended its definition to a tight-binding approach. Then, we used density functional theory to suggest that the *magic-angle* physics may be characterized by costly computational strategies on a twisted bilayer geometry, with conveniently large stacking angles. Our results may pave the way for an ab initio characterization of the unconventional topological phases and related excitations, associated with currently observed low-energy quasi-flat bands [4].

(iv) **Electronic and structural properties of low-dimensional layered materials.** State-of-the art ab initio computations were performed on graphene-like, layered transition metal dichalcogenides, and 2D self assemblies of organic molecules. A first focus was on Kondo lattices, i.e., systems with unusual electronic properties that stem from strong electron correlation, typically studied in intermetallic 3D compounds containing lanthanides or actinides. Lowering the dimensionality of the system enhances the role of electron correlations providing a new tuning knob for the search of novel properties in strongly correlated quantum matter. The realization of a 2D Kondo lattice by stacking a single-layer Mott insulator on a metallic surface was reported. The temperature of the system was steadily lowered by using high-resolution scanning tunneling spectroscopy, the phase transition leading to the Kondo lattice was characterized. Above 27 K the interaction between the Mott insulator and the metal was found to be negligible. Below 27 K the Kondo screening of the localized electrons in the Mott insulator was observed to begin and below 11 K the formation of a coherent quantum electronic state extended to the entire sample, i.e., the Kondo lattice, was detected. By means of density functional theory, the electronic properties of the system and its evolution with temperature were explained [5]. Another interest was on the synthesis and design of two-dimensional supramolecular assemblies with specific functionalities, being one of the principal goals of the emerging field of molecule-based electronics, which is relevant for many technological applications [6, 7].

(iv) **Out of equilibrium thermodynamics.** The distribution of entangled states is a key task of utmost importance for many quantum information processing protocols. A commonly adopted setup for distributing quantum states envisages the creation of the state in one location, which is then sent to (possibly different) distant receivers through some quantum channels. While it is undoubted and, perhaps, intuitively expected that the distribution of entangled quantum states is less efficient than that of product states, a thorough quantification of this inefficiency (namely, of the difference between the quantum-state transfer fidelity for entangled and factorized states) has not been performed. To this end, iwe considered n-independent amplitude-damping channels, acting in parallel, i.e., each, locally, on one part of an n-qubit state. We derived exact analytical results for the fidelity decrease, with respect to the case of product states, in the presence of entanglement in the initial state, for up to four qubits. Interestingly, we found that genuine multipartite entanglement has a more detrimental effect on the fidelity than two-qubit entanglement. Our results hint at the fact that, for larger n-qubit states, the difference in the average fidelity between product and entangled states increases with increasing single-qubit fidelity, thus making the latter a less trustworthy figure of merit. [8, 9].

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STAR Project

STAR Southern Europe Thomson Backscattering Source for Applied Research

Sandro Donato (Ass.)

- Geological characteristics and magmatic activity of Piton de la Fournaise, an active shield volcano situated in Réunion Island's eastern region within the Indian Ocean. The volcano has the propensity for both effusive and explosive eruptions, primarily emitting scarcely differentiated magmas of tholeiitic affinity. The volcano's active structure has developed within the Enclos Fouqué caldera, bordered to the west by the Bellecombe vertical cliffs. A geological examination of the Bellecombe area, characterized by a sequence of 12 lava flows intersected by a dike aged over 5.5 kyrs, was conducted using various analytical techniques including X-ray fluorescence, Inductively Coupled Plasma Mass Spectroscopy, Scanning Electron Microscopy, and X-ray computed microtomography. The objective was to understand the evolution of the magmatic system preceding the collapse of the Enclos Fouqué caldera. 1)

- Study of the challenges in differentiating breast tissues using conventional X-ray imaging due to their similar linear attenuation coefficients. The work introduces spectral computed tomography (CT) as a promising technique for more quantitative tissue characterization by leveraging the energy dependence of attenuation coefficients to determine tissue density (ρ) and effective atomic number (Z_{eff}). The study aimed to explore the potential of ρ/Z_{eff} decomposition in spectral breast CT to enhance tissue characterization and improve diagnostic accuracy. The study evaluated five mastectomy samples and a phantom mimicking breast soft tissues using a propagation-based phase-contrast setup at the SYRMEP beamline at the Italian national synchrotron Elettra. Imaging was performed at multiple monochromatic energy levels, and a custom algorithm was developed to extract density and effective atomic number values for various tissue types, including adipose, fibro-glandular, pure glandular, tumor, and skin, from radiologist-selected regions. Main findings suggest that spectral CT enables enhanced tissue differentiation, with adipose, fibro-glandular, and tumorous tissues exhibiting distinct average effective atomic numbers and densities. The integration of both quantitative values facilitates improved discrimination between these tissue types, potentially enhancing diagnostic capabilities in breast imaging. 2)

- Study of explore of the potential of propagation-based phase-contrast computed tomography (CT) techniques for multiscale X-ray imaging of the breast at the Elettra synchrotron facility in Trieste, Italy. Phase-contrast imaging methods aim to address the challenge of poor soft-tissue contrast in traditional X-ray imaging by utilizing a coherent photon beam and long sample-to-detector distances, available at synchrotron facilities. The experiments were conducted on two whole breast mastectomy samples using propagation-based breast-CT with a monochromatic synchrotron beam, achieving a pixel size of 60 μm. Additionally, paraffin-embedded tissue blocks from the same samples underwent scanning with propagation-based micro-CT imaging using a polychromatic synchrotron beam, achieving a pixel size of 4 μm.

The resulting images were spatially registered to compare whole breast imaging with breast-CT and virtual histology with micro-CT. The transition from whole breast imaging to virtual histology provided by these techniques was evident in the registered images. Phase-contrast imaging offered high resolution and low noise, facilitating precise matching between virtual and conventional histology. These methods enabled clear visualization of breast structures, lesions, and microcalcifications, presenting a promising clinically-compatible tool for breast imaging across multiple scales. They can assist in cancer detection in full volume breast samples and complement structure identification in paraffin-embedded tissue samples. [3)]

- Study of the three-dimensional spatial distribution of corpora amylacea (CA). CA are small, spherical bodies primarily composed of carbohydrates, specifically glycogen, in the form of aggregated polyglucosans. They are commonly found in various tissues throughout the human body, particularly in the central nervous system, but also in other organs such as the prostate gland and salivary glands. CA tend to accumulate with age, and their formation is associated with normal aging processes as well as certain pathological conditions. CA have been implicated in certain neurodegenerative diseases, such as Alzheimer's disease and Parkinson's disease, where their accumulation may contribute to pathological processes. Volumetric images of four human brain stems were obtained using MRI and phase-contrast X-ray microtomography, validated with Periodic acid Schiff stain. CA appeared as hyperintense spheroid structures, with diameters reaching up to 30 μm. An automated pipeline was developed for CA segmentation, enabling the investigation of over 200,000 individual CA. The study found a significantly higher density of CA in the dorsomedial column of the periaqueductal gray compared to the superior colliculus. Approximately 2% of CA were located near vessels or in the peri-vascular space. While CA were rare in the ependymal lining of the cerebral aqueduct, several were observed in the sub-pial tissue of the anterior and posterior midbrain. In the sample with the highest CA density, MRI quantitative maps revealed elevated R2* values and a diamagnetic shift in a region spatially coinciding with the dense CA region. [4)].

- With the wide range of new brain imaging methods under development, there is a need for a gold standard method. Researchers within the neuroscience community are beginning to endorse phase contrast X-ray microtomography as a putative novel gold standard for structural imaging. This study describe a step-by-step guideline for imaging unstained human brain tissue, starting from tissue preparation and measurement to image processing, at resolutions of a few micrometers using Synchrotron Radiation Phase Contrast CT (SR PhC-CT) at the SYRMEP beamline of Elettra, the Italian synchrotron facility. Examples are provided to demonstrate how blood vessels and neurons appear in the acquired images with voxel sizes of a few micrometers. This voxel size allows for identifying large blood vessels and delineating the boundary between grey and white matter. Additionally, the protocol can be applied to study other biological substrates such as neuromelanin or corpora amylacea, with specialized segmentation tools validated by classical histology methods. SR PhC-CT, when used with the proposed protocols for data acquisition and image processing, offers a viable approach to investigate the cellular-level anatomy of the human brain in 3D. [5)]

Conference participation

- 18^{th} European Molecular Imaging Meeting (EMIM) - 14-17 March 2023, Salzburg, Austria (poster presentation and oral presentation – invited speaker)

- 109° Congresso Società di Fisica Italiana – SIF 2023, Fisciano (SA), Italy, September 11-15,2023 (oral presentation – invited speaker).

- International Workshop on Imaging - Villa Monastero, Varenna, Italy September 26 - 29, 2023 (poster and oral presentation)

Roles in editorial committees

- Guest Editor for the special issue "Artificial Intelligence Applications for Imaging in Life Sciences" in the LIFE journal (MDPI)
- Guest Editor for the special issue "Advances of Synchrotron Radiation-Based X-Ray Imaging in Biomedical Research" in the Frontiers in Physics journal (Frontiers)

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STAR
Beamline simulation and optimisation

E. Tassi (Resp.), A. Olivieri (Ass.)

1 Introduction

In the year 2023 the research activity was devoted to the upgrade of the STAR2 Linac simulation. The main activities were:

1. the development of a new simulation for the detailed study of the electron beam dynamics;
2. the characterisation, optimisation and tune-up of the upgraded beamline.

The simulation has been implemented and carried out using Astra (A Space Charge Tracking Algorithm), a simulation framework that allows the tracking of particles under the influence of electric and magnetic fields along the beam-line. The optimization process has been conducted using the framework Giotto (Genetic Interface for OpTimising Tracking with Optics), a program based on genetic algorithms.

2 Simulations

In collaboration with the STAR (Southern European Thomson source for Applied Research) infrastructure at the University of Calabria, studies were conducted on electron beam dynamics (evaluating emittance, energy spread, beam envelope, etc...) through simulations obtained with the Astra code, within the 100-140 MeV range of the high-energy line (HE-Line). One of the earliest activities was the introduction into the Astra code of the 3D dipole field maps in the dispersion region and the optimization of the beam transport line elements. To improve the performance of the beam, intensive linac optimization work was required, conducted through the Giotto framework. Meanwhile, verification of the stability of the facility in the low-energy line (LE-Line) was conducted; in particular, the beam characteristics in WPs 20 MeV, 30 MeV, 60 MeV were analyzed. Coordinates of beam-line elements (both LE-Line and HE-Line) were updated following the latest layout of STAR. After testing and evaluating the benefits of the optimization process, the same was conducted on both beam-lines to improve beam performance, with special emphasis on the Interaction Point.

Optimization work has begun on the facility parameters to obtain a beam suitable for studying the energy distribution of a relativistic electron beam as a result of Compton back-scattering. At this stage, with colleagues of the INFN Milan unit, we are focusing in particular on the optimization of the dispersion and interaction regions to achieve the lowest possible energy spread. In parallel, a project aiming at implementing Giotto directly on the STAR control system has started. This allows the machine parameters to be optimized in real-time and fine-tuned according to different operating energies or set-up changes. Moreover, it can rapidly explore various parameter configurations in search of optimal solutions: this efficient exploration capability contributes to identifying configurations that enhance performance in a relatively short period.

COMPUTATION TECHNOLOGY

The ReCaS Cosenza Data Center

A. Tarasio (Ass.), E. Tassi (Resp.)

1 Introduction

The ReCaS Cosenza Data Center (see Figure 1) represents a unique IT infrastructure in the Calabria region. A medium-sized Data Center, funded with a total budget of 1.3 M€, is characterized by an efficient, scalable and state-of-the-art support infrastructure that guarantees very high operational standards. Its present computing and storage resources (more than 1.2 PB raw storage capacity and 3500 cores) contribute in a substantial way, jointly with the other ReCaS Data Centers, to the computing needs of all the experiments at the LHC as well as others diverse scientific communities.

Figure 1: *(Left) The two-Chiller sytem (with integrated free cooling) installed at the ReCaS Cosenza Site. (Right) The white space and the racks (with LCPs) hosting part of the IT equipment.*

2 Performance and software developments

The ReCaS Cosenza Data Center has operated for the most part of the second half of year 2023 with a rather low efficiency and poor stability due to a series of technical failures of the two-chiller system. At the beginning of 2024 the technical problems have been solved and it is expected that the performance of the Data Center will soon return to the high levels shown in the past years.

As far as the software development is concerned the activity in 2023 has been mostly devoted to the implementation of new monitoring tools to increase reliability and security and to the substitution (that is presently still underway) of the DOME DPM system with DCACHE that is

Figure 2: *(Left) The two GPU-server (each equipped with three GPU NVIDIA Tensore Core A100 80 Gb) and one of the new switches (Right) The new white space and racks that will host the new STAR IT equipment.*

the most used storage system in the ATLAS grid infrastructure. In addition the Ovirt virtualization system has been replaced by kvm.

3 Upgrade

In March 2019 the STAR 2 upgrade project (EU PON programme "Research and Innovations" 2014-2020, code: PIR0_100008) has been funded for a total budget of approximately 17.5 Million Euros and with it the upgrade of the ReCaS Data Center that will be used as the main computing facility for the storage, reconstruction and analysis of the high resolution tomographic images produced by STAR. Three tenders issued in the years 2022-2023 have been finalised at the end of 2023. These have allowed the purchase of a) new network equipment for the high-speed connection (up to 40 Gbps) between the ReCaS data center and the STAR building b) two next-generation GPU-servers for tomographic image reconstruction and analysis and c) three additional (fully conditioned) racks (see Figure 2). This new equipment, that has been already installed and tested, will significantly expand the capabilities of the Data Center.

COMMUNICATION AND OUTREACH

RADIOLAB

M. Capua (Resp.), P. Riccardi (Ass.), R. Tucci (Ass.), M. Marrella (Stud.)

The INFN Group of Cosenza, since 2017, participates to the RADIOLAB scientific dissemination project aimed at high school students and in which the INFN units of Cagliari, Lecce, LNS, Milan, Naples, Siena, Trieste, Turin also participate.

The aim of the project is to integrate didactics with scientific communication and research on radioactivity with special emphasis on the radon gas. The students are directly involved in laboratory activities, following the footsteps of researchers in the field and making measurements in their territory (schools but also homes or facilities considered by them of interest as far as radon risk is concerned). In addition, actions to raise awareness of radon risk and its remedies are carried out through public events and interviews. This project has immediate consequences in terms of dissemination of the contribution of the scientific approach to the assessment of the problem, social awareness, risk awareness, both for the students and the families and the society connected to them.

In 2023 six Calabrian schools and three schools in Riobamba, in Ecuador, corresponding to more then 215 students took part in the project and numerous interviews were made.

The Radiolab-CS group, for high school students, realized the spring school on radon measurement techniques in water. The three-day school of physics for high school students, hosted 20 students from all over Italy at the IRSOIL2023 national intercomparison on measurements of concentration of activity of radon in water and soil. The students learned and carried out measurements in the water themselves.

The satisfaction questionnaires filled out for the various events have been fully positive.

INTERNATIONAL PHYSICS MASTERCLASSES

M. Capua (Resp.), L. Delle Rose (Ass.), S. Fazio (Ass.), A. Harareh (Stud.),
M. Marrella (Stud.), E. Meoni (Ass.), A. Olivieri (Ass.), M. Rossi (Ass.),
D. Salvatore (Ass.), G. Scalzo (Stud.), E. Tassi (Ass.), C. Petronio (Ass.),
R. Tucci (Ass.), F. Stabile (Ass.), A. Tarasio (Ass.)

In partnership with the IPPOG Masterclasses International Project and with the collaboration of the Physics Department of the University of Calabria, the INFN Group of Cosenza organizes, since 2013, the Physics MasterClasses for high-school students from the whole Calabria and Basilicata Regions.

In 2023, three events were organized:
- February 10, Internazional Masterclasses-Hands on particle physics - special event for the International Day of Women in Science, about 42 girls from Basilicata and Calabria high schools. (agenda.infn.it/event/mcg2023).
- February 28, Internazional Masterclasses-Hands on particle physics, 31 students from Basilicata and Calabria high schools. (agenda.infn.it/event/mc2023).
- March 31 Particle Therapy Masterclasses, 31 students from Basilicata and Calabria high schools. (agenda.infn.it/event/pt2023).

The overall enthusiastic participation of students and high-school teachers was confirmed by the satisfaction questionnaire.

The special event of February 10, had a common moment, organized by the INFN groups of Cosenza, Rome 2 and Rome 3, among all the girls participating. All, in the presence or remotely, attended the presentation of physics Alessia Bruni *A special day* and were able to discuss with her.

The aim of the Masterclass in Particle Therapy is to bring students closer to the applications of physics for cancer therapy through conventional radiotherapy and adrotherapy and to show them the importance of fundamental research and its direct impact on society. This branch of science uses the knowledge acquired on the properties of particles, techniques to accelerate them and the mechanisms of interaction with matter, applying them to cure cancer. In addition to the proposed seminars, the morning was organized a virtual visit of the CNAO of Pavia. In the afternoon session the students simulated treatment plans to cure prostate, liver or brain cancer using different beams of particles. Finally, a joint videoconference meeting was held at CERN to discuss the results obtained by the students of different countries where the event takes place at the same time.

WORLD WIDE DATA DAY 2023

M. Capua (Resp.), C. Petronio (Ass.)

Also in 2023, we participated to the LHC World Wide Data Day, in which students from around the world analyzed LHC data and shared results. The project is designed for high schools students that select dimuon events (open data from ATLAS) and calculate the Φ angle of each muon selected in the plane tranverse to the beamline.

The Cosmic Rays as messengers to investigate the Universe and the OCRA project

G. Carducci (Ass.), G. Falsetti (Ass.), G. Fiamingo (ass.), I. Gnesi (Ass.),
D. Liguori (Ass.), A. Mastroberardino (Ass.), C. Petronio (Ass.), D. Salvatore (Ass),
M. Schioppa (Resp.), P. Turco (Tecn.)

1 The Cosmic Rays as messengers to investigate the Universe

Is out of doubt that learning by doing is the most powerful method to teach physics to young and less young students. The Cosenza group has started more than 10 years ago to open the "Alte Energie" laboratory to students and to go into the schools to meet students and teachers with the aim to make experiments to measure the cosmic ray flux and the muon mean life time, but also to demonstrate the existence of cosmic ray showers at earth surface. In 2010 the group agreed to participate in the EEE (Extreme Energy Events) project, under the convincing push of Dr. R. Baldini Celio Ferroli, director of this project of Centro Fermi. The EEE project is dedicated to the study of Extensive Atmospheric Showers through a network of muon telescopes, installed in High Schools, with the main objective of introducing young students to particle and astroparticle physics, making them participate in the construction detectors at CERN and involving them in the operation, maintenance and monitoring of EEE stations. Each telescope is a tracking detector composed of three Multi-Gap Resistive Plate Chambers with an active area of 1.60 x 0.80 m. At present 5 MRPCs telescopes are installed in Calabria. In 2020 EEE project becomes a special INFN project under the supervision of Prof. L. Cifarelli.
Another important activity launched in 2022 was the study of the use of new gas mixtures for the EEE MRPC in order to contribute to the reduction of the global warming potential (GWP) or the ability of each greenhouse gas to trap heat in the atmosphere. F-gases have higher GWP values than other substances and the recommendation is to limit or completely avoid their use. To limit the impact of GWP gas emissions from elementary particle physics experiments, the EEE collaboration has undertaken very thorough studies to target new low-impact GWP gases. In particular, the hydrofluoroolefin gas (R1234ze) mixed with He was tested at the Physics Department of UNICAL as a filling gas for "multi glass thin gaps RPC" devices. This gas mixture has GWP=4 (compared with the standard gases that has GWP greater than 4000) and the detector performances are in line with that required for EEE physics programs. The gas flow is very low (0.9l/h) ensuring a complete volume change every three full days further reducing the amount of greenhouse gas into the atmosphere. In 2023 many schools had furnished with the new gas mixture. Three of them are in Calabria.
The 2022 has seen the group start a new activity to reproduce the historical experiments of D. Pacini in 1910-1912. Using the ArduSiPM detector designed by V. Bocci of INFN of Rome 1, 5 hermetic containers houses as many ArduSiPM with a microprocessor M5Stack, a whether station to measure the inside ambient conditions and a GPS sensor to localize the detector. The M5Stack has been use to store data collected by the detector, ambient conditions and geographical position and to allow wi-fi connection with a smartphone/tablet/PC. The measurement campaign started the first of April in 4 calabrian schools measuring the cosmic flow rate day by day to get practice with the setup and with the collected data. The May 31st the schools meet all together at Lago Arvo in Lorica (1300 m asl) and collect data on the lake shore, above the lake surface and below

the lake surface. The work was presented at the 2022 SIF National Congress where it was selected for the special series of the Nuovo Cimento C, it was published in the SIF Journal of Physics, it was presented in the outreach session of the CRIS2022 international conference, and finally was selected by ASI Education Office, ESA Education Office, ESERO Italy with the following motivation:
"The work was highly appreciated for its educational value, for the quality of the proposed path and for the ability to involve male and female students in space-themed STEM disciplines in a new, inclusive and active way. We therefore point out that, for this work, you will receive an autographed certificate from Samantha Cristoforetti by the end of the school year. We also wish to further congratulate you on the specific qualities of the project and inform you of our willingness to present your work as a 'Best practice' of the use of Space as an educational context of STEM subjects for the benefit of other teachers at national and international level. To this end, we intend to publish the work in a special section of the ESERO Italia website and promote it through the ESERO Italia social channels. The project would therefore be made public, alongside other projects received, which we believe may be of interest to the community of the Italian teachers."
Moreover, the cosmic ray outreach Cosenza group organizes seminars, masterclasses, participates in the ICD and in the PCTO program (Paths for Soft Skills and Orientation) where students work both in their laboratories and in the "High Energies" laboratory of the physics department of UNICAL by building and testing detectors or part of them.
The Cosenza group has olso organized together with Pia Astone (Rome1), Franco La Cava (Rome1), Vitaliano Chiarella (LNF), Margherita Primavera (Lecce) the third series of the seminars "Un tuffo nel sapere: colloqui in rete" (https://agenda.infn.it/event/30556/) with the aim to offer a series of educational seminars that can be used anywhere. These were remote meetings with high-level scientists, who illustrate the most recent acquisitions in the field of Physics and the use of technologies, developed for research, which find application today in everyday life.
Last but not least, the group organized seminars for celebrate the 10th anniversary of the discovery of the Higgs boson in the high schools A. Volta of Reggio Calabria, IIS of Tropea (VV), E. Fermi of Catanzaro, Siciliano of Bisignano (Cs), Patrizi of Cariati (Cs) and E. Fermi of Cosenza.

2 OCRA project of INFN-CC3M

In the year 2023 the group actively participated in the OCRA activities of the INFN-CC3M scientific group. As described in the introduction the group has assembled 7 autonomous scintillating detectors (ArduSiPM) to measure the flux of cosmic rays in the water basin at different depths. The experiment was scheduled for spring 2020, but the measures to deal with the COVID-19 emergency did not allow it to be carried out. For this region the measurement campaign was done in 2022. The measurement campaigns were divided into two parts: one in the schools (four schools adhere to this project and acquire data day by day for about 2 months), while the second part is an entire day at Lake Arvo (Lorica) where the students put into practice the experience gained in the school by taking measurements at the lakeside, on the lake surface and below the lake surface. Fig.1) shows an image of the detector during the measurement campaign at Lake Arvo in 2022. In November, the group coordinated the International Cosmic Day 2023 of Calabrian schools. They presented the measurement of cosmic ray flux as a function of water depth, providing a physical interpretation of the results.

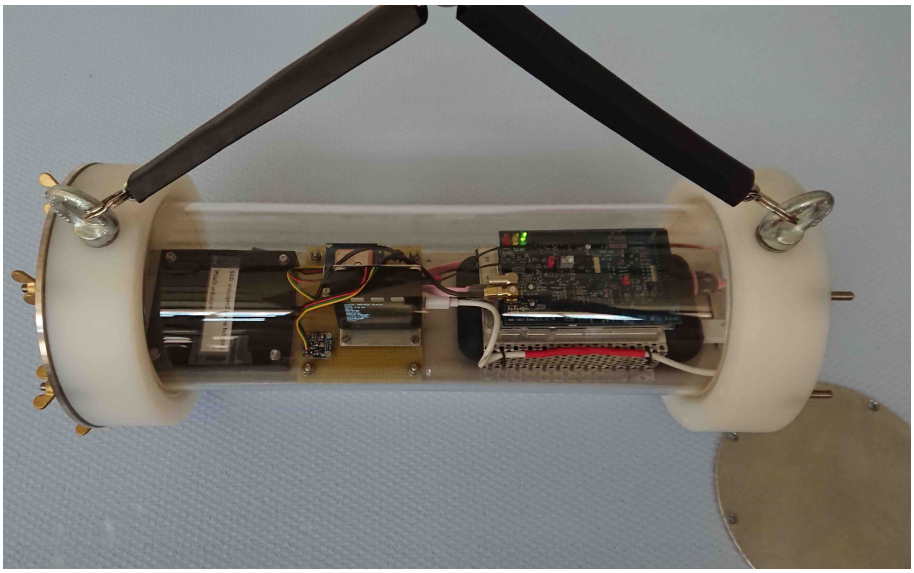

Figure 1: *The detector employed during the measurements at schools and at lake.*

3 List of Conference Talks and Poster by LNF Authors in Year 2023

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Lab2Go

P. Riccardi (Resp.)

1 Outreach Activity

This activity is devoted to the recovery of disused instrumentation of the physics laboratories in some schools of the region of Calabria. The activity started in our department as a School-Work Alternation scheme in 2016. Our program joined the national initiative Lab2Go in school year 2021-2022. In the school year 2022-2023 the schools involved are: Liceo Scientifico "G. Berto" in Vibo Valentia, Liceo Scientifico "A. Volta" Reggio Calabria, Liceo Scientifico "E.Fermi" Cosenza, Liceo Scientifico Corigliano(CS), Liceo Scientifico in Lungro (CS).

For year 2023 the activity in Calabria has been the subject of the pubblications [1)] to [5)].

Figure 1: *The stand of the school Liceo Scientifico "E. Fermi" during the EU researchers' night at University of Calabria on September 29, 2023.*

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Premio Asimov 2023

L. Delle Rose (Ass.), D. Giuliano (Ass.), A. Nava (Ass.), A. Papa (Resp.), M. Rossi (Ass.)

The INFN group of Cosenza has joined since 2018 the "Premio Asimov" initiative (web site: https://www.premio-asimov.it/) and coordinates the related activities in Calabria.

Established in 2015 by the Gran Sasso Science Institute (GSSI) of L'Aquila, the "Asimov Prize for scientific popular publishing" aims at bringing young generations closer to science through the critical reading of works of scientific divulgation. It was born from an idea by Francesco Vissani and is inspired by the prizes awarded by the Royal Society for books on scientific divulgation.

The award is named after the writer Isaac Asimov, author of numerous scientific publications as well as several novels and stories. It is aimed at high-school students who were directly involved both as jurors, since they had to rate the best scientific books published during the year before, and as competitors, since the best among their reviews were rewarded during the closing ceremony, held on April 27, 2023 at the Physics Department of the University of Calabria.

The edition of 2023 counted overall about 13000 participants from 320 schools in the Regions Abruzzo, Basilicata, Campania, Emilia-Romagna, Latium, Liguria, Lombardy, Marche, Molise, Piedmont, Apulia, Sardinia, Sicily, Trentino-Alto Adige, Tuscany, Veneto, Umbria and, of course, Calabria, which contributed with about 390 students from 13 different high schools. On April 27, 2023 a ceremony took place in the seminar room of the Physics Department of the Università della Calabria, organized by the Physics Department and INFN-Cosenza, with the participation of most of the Calabrian students rewarded as best reviewers. The recording of this event is available in the YouTube channel of Premio Asimov, https://www.youtube.com/c/PremioAsimov.