PARTICLE PHYSICS EXPERIMENTS

ATLAS Experiment

E. Bisceglie (Ass.), M. Capua (Ass.), G. Carducci (Ass.), G. Falsetti (Ass.),
I. Gnesi (Ass.), A. Mastroberardino (Ass.), E. Meoni (Ass.), M. F. Perrone (Tecn.),
T. Rania (Ass.), V. Romano (Tecn.), G. Santoro (Ass.), M. Schioppa (Resp.), A. Tarasio (Tecn.),
E. Tassi (Ass.), P. Turco (Tecn.)

1 Introduction

The researchers of the ATLAS Cosenza group have been actively involved in the year 2024 in physics analyses, covering a wide range of important topics of the LHC physics program, as well as in the 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 2024 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. The particle level analysis has beeen published and the parton level analysis is presently at the editorial board stage and its pubblication is foreseen by the end of 2025.

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. Till October 2024, E.Tassi has been 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 Z+b-jets cross-sections and Z+c-jets in several observables have been published

in the resolved regime at moderate transverse momenta in the 2024, the measurements provide strong experimental constraints to improve the theoretical description. During 2024, the group also started two new activities in this field: a dedicated study of the W-boson production in association with 2 b-jets in order to perform the first differential cross-section measurement of this process at the LHC and a new analysis targeting the Z+2 b-jets production in the boosted regime, where the 2 b-jets are very close to each other and are reconstructed as an unique large-R jets and are disentangled afterwards with jet substructure techniques.

3 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. The signal produced within the amplification region, by electrons emitted from a small radioactive source (about $0.1\mu sv$), was measured for Ar:CO_2 and Ar:CO_2:Iso mixtures and at different amplification region gains.

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

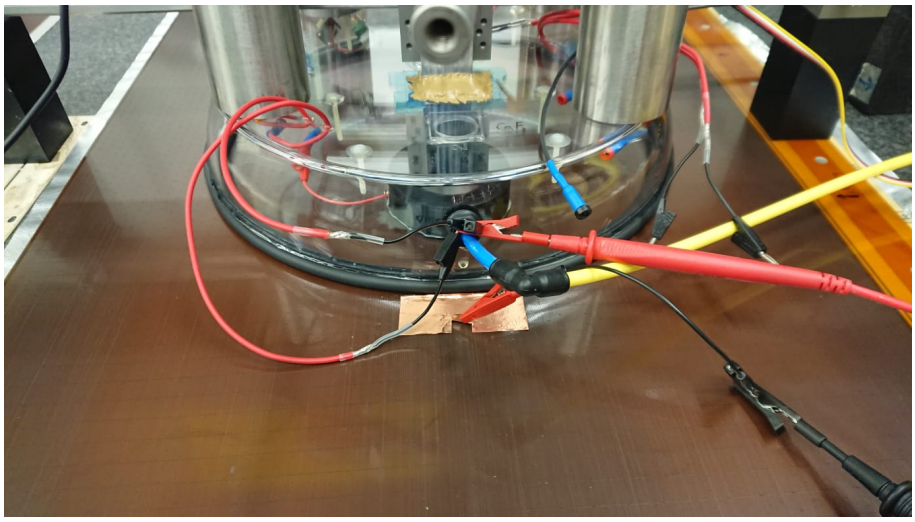

Figure 1: *The sutup employed to measure the Paschen curve for pure Ar, Ar:CO2 (93:7), Ar:CO2:isoC4H10 (93:5:2).*

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. A pre-series of 12 BIL-RPC 2511x658x0.4mm was built between June and July 2023 and sent to CERN. In October the assembling and testing line of the readout panels passed the review and in November 2023 the mass production started. In 2024, 550 readout panels (about 90% of the total) were built and tested, ready to be used to assemble detectors. In 2024, the group led the construction of the detector assembly line at CERN. In 2024, about 40 RPC detectors were assembled. Quality control of these detectors is checked at every stage of assembly. Since the electronics are not yet ready, the detectors have been placed in a parking area. The construction of 130 chambers is expected to be completed by the end of 2026.

4 List of Conference Talks and Poster by LNF Authors in Year 2024

1. M. Schioppa, Production and test of RPC detectors for the large sectors of the ATLAS Inner Barrel (BIL) Phase II upgrade, XVII international Conference on Resistive Plate Chambers and Related Detectors (RPC2024), Santiago de Compostela, 9-13/9/2023 - Talk.

2. G. Falsetti, RPC-BI Test for ATLAS Muon Spectrometer Phase-II Upgrade, Incontri di Fisica delle Alte Energie 2024 - Firenze, 3-5 Aprile 2024

3. G. Falsetti, The ATLAS RPC Phase-II Upgrade for High Luminosity LHC era, 16th Pisa meeting on Advanced Detectors - La Biodola, Isola d'Elba, 26 Maggio - 1 Giugno 2024

4. G. Falsetti, Production and test of RPC-BI detectors for ATLAS Phase-II upgrade, 160th LHCC - Cern, 18 Novembre 2024

5. M.F. Perrone, Production and test of BI-RPC detectors for ATLAS Phase II upgrade, 16th Pisa meeting on Advanced Detectors - La Biodola, Isola d'Elba, 26 Maggio - 1 Giugno 2024

6. E. Meoni on behalf of the ATLAS Collaboration, " V+heavy flavour measurements at ATLAS", talk at "New Trends in High-Energy and Low-x Physics", Sfantu Gheorghe (Romania), 1-5 September 2024

7. A. Harareh, E.Meoni, "Sviluppo di un'analisi multivariate per lo studio della produzione di un bosone W in associazione a 2 b-jets con l'esperimento ATLAS ad LHC", poster at "Incontri di Fisica Delle Alte Energie 2024 (IFAE 2024)", Firenze (Italy), 3-5 April 2024

8. D. Passarelli, Study of the propagation signal along the conductive strips of the BIL-RPC of ATLAS phase 2 muon spectrometer upgrade, 110 Congresso Nazionale della SIF, Bologna 9-13/9/2024, Talk.

9. G. Tassone, The certification tests of the BIL-RPC chambers of the ATLAS muon spectrometer phase 2 upgrade, 110 Congresso Nazionale della SIF, Bologna 9-13/9/2024, Talk.

5 List of papers in Year 2024

1. ATLAS Collaboration, "Measurements of the production cross-section for a Z boson in association with b- or c-jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", Eur. Phys. J. C 84 (2024) 984.

2. ATLAS Collaboration, "Measurement of differential cross-sections in $t\bar{t}$ and $t\bar{t}$+jets production in the lepton+jets final state in pp collisions at $\sqrt{s} = 13$ TeV using 140 fb^{-1} of ATLAS data", JHEP **08** (2024), 182.

KLOE-2

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 partecipated to the construction and test of the new detectors for the upgrade, to the data tacking until the end of the physics program and to the analysis of data.

ePIC

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

1 The Electron-Ion Collider and the ePIC detector

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.)]. The group is also part of the ePIC Collaboration since it's inception [S. Fazio, Collaboration Council representative (C.C.)]. The ePIC collaboration (https://www.bnl.gov/eic/epic.php) was formed in July 2023 with the goal of designing, building and operating a general purpose experiment capable of delivering on the whole EIC science case. In 2024, H. Hashamipour has joined the group as a postdoc.

The Cosenza's group involvement within ePIC is multifold:

- Leading role in Analysis and Physics performance studies, with S. Fazio appointed Analysis Coordinator (AC) starting March 2023, and ex-officio member of the ePIC Executive Board. The main focus in 2024 was to work on the physics chapter of a preliminary version of the Technical Design Report (pre-TDR). During 2024 the AC lunched also the effort of assessing the impact of the EIC early science, achievable within the first 5 years of running. An other key effort was to facilitate the development of analysis tools (e.g. the electron finder). An other key involvement of the group in the science of ePIC is on the assessment of the impact of diffractive PDFs (DPDFs). H. Hashamipour, M. Capua, and S. Fazio have been working on data simulation of inclusive single-diffractive events.

- 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. In 2024, L Occhiuto and S. Fazio have participated to beam tests and irradiation tests at CERN, at TIFPA-Trento, and Legnaro, using protons, neutrons and gamma. L. Occhiuto has also taken up on the task of simulating the geometry of the eRICH apparatus in the GEANT4 framework of the ePIC detector.

- In 2024, M. Capua has led the efforts towards an outreach program targeting the high-school students. She has set up a framework, including a dedicated event display and shared the framework with all other groups within ePIC Italia.

Conference talks

1 - S. Fazio - Invited talk at the Workshop on: Synergies between LHC and EIC for quarkonium physics, ECT, Trento (Italy) July 8-12, 2024 - Title of the talk: "Measurements of mesons at ePIC";
2. L. Occhiuto - Talk at the 10th International Conference on Quarks and Nuclear Physics (QNP2024), Barcelona (Spain), July8-12, 2024 - Title of the talk: "The dRICH detector at the ePIC experiment".

References

1. M. Capua, S. Fazio, L. Occhiuto, E. Tassi, et al., "ALCOR: A mixed-signal ASIC for the dRICH detector of the ePIC experiment at the EIC", Nucl.Instrum.Meth .A 1069 (2024) 169817.

2. M. Capua, S. Fazio, L. Occhiuto, E. Tassi, et al., "A large-area SiPM readout plane for the ePIC-dRICH detector at the EIC: Realisation and beam test results", Nucl.Instrum.Meth. A 1068 (2024) 169669.

3. M. Capua, S. Fazio, L. Occhiuto, E. Tassi, et al., "SiPM photosensors for the ePIC dual-radiator RICH detector at the EIC", PoS EPS-HEP2023 (2024) 515.

THEORETICAL PHYSICS

BELL
Fundamental Problems in Quantum Physics

G. Nisticò

An alternative approach to the problem of the emergence of classicality has been viably introduced. This problem comes from the fact there was always evidence that at a macroscopic level world behaves according to classical physical laws rather than quantum laws. Then the universality of quantum theory requires that this emergence be explained, i.e. requires to establish the conditions in the specific quantum theory such that the classical behaviour can be derived according to quantum laws. The literature provides us with a rich collection of proposals to answer the question. Typically, these approaches derive classical behaviour of a quantum system from conditions on the value of the parameters deemed responsible of non-classicality; an early condition was that the Planck constant vanishes.

Our alternative approach is based on the following two validated remarks.

(1) Non-classicality of quantum physics originates from the fact that each specimen of the physical system cannot always be assigned a value of every magnitude, as an objective property of the specimen.

(2) In some circumstances this limitation to a consistent simultaneous assignment can be overcome by making use of "evaluations", a quantum concept investigated in *Int.J.Theor.Phys.* **55** 1798.

The essential research strategy of the work is to extend the concept of evaluation in such a way that it can be applied to the observables describing a phenomenon that exhibits classicality. In general these observables are non-commuting, so that a consistent simultaneous value assignment by measurements is forbidden. However, the work proves that in the case of the motion of the center of mass of a rigid body, where the incompatible observables are the position and the velocity of the center of mass, evaluations exist which realize a consistent simultaneous value assignment to both the position and the velocity of the center of mass; in doing so classicality of its motion is explained. The research locates the emergence of classicality in quantum physics to a deep conceptual level. For this reason in the author's opinion Foundations of Physics is its natural place.

References

1. Nisticò G. 2024, *Consistent Value Assignments Can Explain Classicality* arXiv, https://arxiv.org/abs/2412.07453 .

GAST

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

1 Research activity in 2024

During the year 2024 my research activity concerned the following topics:

• In collaboration with D. Fioravanti (INFN Bologna, IS GAST) we wrote the preprint [1]. In this paper, we studied the connection between the theory of Painlevé equation and supersymmetric $\mathcal{N} = 2$ quantum field theories. In specific we proved that a particular limit of Painlevé equations appears as Nekrasov-Shatashvili quantisations/deformations of Seiberg-Witten differentials for $\mathcal{N} = 2$ super Yang-Mills gauge theories. In addition, we gave explicit expressions for the dual period of gauge theory and as a byproduct of our construction also a solution of the so-called Painlevé connection problem.

• In collaboration with D. Fioravanti we are finishing a preprint concerning the explicit computation of dual period of supersymmetric $\mathcal{N} = 2$ gauge theories. These computations hinge upon the relation between these quantum field theories and integrability.

• Two other preprints, in collaboration with D.Fioravanti, D. Gregori (Soochow Univ., China), R. Mahanta (Winnipeg Univ., Canada), are at their last stages. They concern 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 Organisation of Conferences in Year 2024

I was organiser of the conference 'Exact techniques and their applications: InTropea2024' , Tropea 2-6 September 2024, https://sites.google.com/view/intropea2024.

References

1. D. Fioravanti and M. Rossi, From Painlevé equations to $\mathcal{N} = 2$ susy gauge theories: prolegomena, arXiv:2412.21148 [hep-th].

LINCOLN
Learning Complex Networks

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

Modelling of real world problems

Forest fires are responsible for 23 percent of global fossil fuel CO2 emissions, are affected by human activities and play a role in the Earth's ecosystem that cannot be underestimated. In addition, an increase in the frequency and severity of large forest fires has been observed. This emphasizes the importance of forest fire management to mitigate the effects of forest fires on biota and climate change. One of the main tool in forest fire management is mathematical modelling. Forest fire spreading is a stochastic phenomenon, whose stochastic effects are very relevant during the first stages, when the number of firing trees is small, and during fire spotting events.

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

2) We developed a stochastic model for fire spreading based on a reaction-diffusion-convection differential equation [2)].

3) We applied a preliminary mathematical reaction-diffusion model [3)] aimed at predicting the development of forest fires. The model was applied using data obtained through the estimation of the pyrological potential in terms of heat energy produced per surface unit (1 hectare) and the variation in the critical surface intensity.

4) We also provided [4)] new results regarding the localization of the solutions of nonlinear operator systems. We make use of a combination of Krasnosel'skiĭ cone compression–expansion type methodologies and Schauder-type ones. In particular we establish a localization of the solution of the system within the product of a conical shell and of a closed convex set. By iterating this procedure we prove the existence of multiple solutions.

5) We implemented a monitoring system based on IoT technologies and predictive mathematical models, designed to detect environmental conditions conducive to the development of fires [5)].

Mathematical Models for Semiconductors

We studied a mathematical model for semiconductor laser diodes, consisting of the semiconductor equations coupled with a Helmholtz equation for the optical part. The drift-diffusion equations for the semiconductor include a stimulated recombination term that is related to the eigenvalues and eigenfunctions of the Helmholtz equation. In turn, the refractive index that appears in the Helmholtz equation depends on the semiconductor variables. For this coupled problem, which has not yet been studied in the literature, we have obtained a first existence result, local in time [6)].

Quantum Measurement

The analysis of the measurement process show that positive operator valued measures (POVMs) are the right mathematical tool to represent quantum observables. This can be seen by the operational analysis of the measurement process. Fuzzy observables are special kind of POVMs and play a very important role in the approximate measurement of incompatible observables. Moreover, through the theory of fuzzy sets and weak Markov kernels, they can be interpreted as fuzzification or randomization of sharp observables (represented by self-adjoint operators). 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 [7]. We also studied the representation of fuzzy events in the framework of fuzzy observables [8].

Conferences

1) Mathematical aspects in non equilibrium systems: from micro to macro, Erice 30 October-03 November 2024 (communications).

2) Sixteenth Biennial IQSA Quantum Structure 2024, Bruxelles, 22-26 July 2024 (communication)

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1. R. Beneduci, G. Mascali, Forest Fire Spreading: a non-linear stochastic model in space and time, Studies in Applied Mathematics, 153 (2024) e12696.

2. R. Beneduci, G. Mascali, A Reaction-Diffusion-Convection Model for Stochastic Fire Spreading (submitted).

3. P.A. Marziliano, F. Lombardi, M.F. Cataldo,M. Mercuri, S.F. Papandrea, L.M. Manti, S. Bagnato, G. Ali, P. Fusaro, P.S. Pantano, C. Scuro, Forest Fires: Silvicultural Prevention and Mathematical Models for Predicting Fire Propagation in Southern Italy, Fire, 7(8) (2024) 278.

4. G. Mascali, G. Infante, J. Rodríguez–López, A hybrid Krasnosel'skiĭ-Schauder fixed point theorem for systems, Nonlinear Analysis: Real World Applications, 80 (2024) 104165.

5. C. Scuro, G. Alì, P.A. Fusaro, S. Nisticò, Forest fire prevention: Application of mathematical models for the realization of an IoT based monitoring system, Proceedings - 2024 IEEE International Conference on Big Data, BigData 2024, 2024, pp. 4711–4719.

6. G. Alì, Z. Amer, P. Farrell, N. Rotundo, On the mathematical modelling of semiconductor laser diodes, invited talk at AMaSiS 2024: Applied Mathematics and Simulation for Semiconductor Devices, September 10–13, 2024, Weierstrass Institute Berlin.

7. R. Beneduci, Fuzzy observables: from weak Markov kernels to Markov kernels, International Journal of Theoretical Physics, 62 (2023) 226.

8. R. Beneduci, Fuzzy observables and representations of fuzzy events (in preparation).

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

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

1 Flux tubes QCD

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)].

During the year 2024 this analysis has been extended to the case of QCD with 2+1 dynamical staggered fermions at physical masses.

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)].

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 [3].

4 Gauge-Higgs lattice theories

During the year 2024, we completed a numerical study of the phase structure of the three-dimensional Abelian lattice gauge theory (LGT) with Z(2) gauge fields coupled to Z(2)-valued Higgs fields. We explored two different order parameters which are able to distinguish the three phases of the theory: (i) the Fredenhagen-Marcu operator used to discriminate between deconfinement and confinement/Higgs phases and (ii) the Greensite-Matsuyama overlap operator proposed recently to distinguish confinement and Higgs phases.

5 Talks in Year 2024

1. O. Borisenko,
   "Phase transitions in gauge-Higgs theories: Z(2) gauge-Higgs LGT as a spin-glass model ",
   Recent advances in high temperature QCD, Budapest, October 28 - 30, 2024,
   https://bodri.elte.hu/budqcd2024/

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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",
   Eur. Phys. J. C **84** (2024) no. 2, 50 [arXiv:2310.04298 [hep-lat]].

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",
   Nucl. Phys. B **998** (2024) 116424 [arXiv:2309.06104 [hep-lat]],

3. O. Borisenko, V. Chelnokov, S. Voloshin,
   "The Polyakov loop models in the large N limit: Correlation function and screening masses",
   Phys. Rev. D **109** (2024) no. 9, 094503 [arXiv:2311.03907 [hep-lat]].

QFT@COLLIDERS
Precision calculations for collider physics

P. Banerjee (Ass.), C. Branchina (Ass.), A. Conaci (Dott.), G. Gatto (Dott.),
L. Delle Rose (Ass.), L. Panizzi (Ass.), A. Papa (Resp.), M. Razzaq (Dott.)

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 BFKL 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 inclusive production of fully charmed tetraquarks, $T_{4c}(0^{++})$ or $T_{4c}(2^{++})$ radial excitations, in high-energy proton collisions. We built our study upon a framework similar to the one described at the previous point. We provided predictions for high-energy observables sensitive to T_{4c} plus jet emissions at center-of-mass energies ranging from 14 TeV at the LHC to the 100 TeV nominal energy of the FCC [2)].

- The one-loop effective vertex for the interaction of a gluon with a Reggeized gluon and a Higgs boson in the infinite-top-mass limit, which is described by a dimension-5 non-renormalizable operator. The effective vertex is extracted from the high-energy behavior of two-to-two amplitudes for the Higgs production in parton-parton collisions and relies on the validity of the Regge form for these amplitudes. We found that the usual eikonal approximation (Gribov prescription) for the Regge limit and the known region-expansion technique in this limit lead to an incomplete result for the amplitude. The discrepancy is traced back to the non-renormalizable nature of the involved operator. However, the Regge limit of the

exact QCD amplitude agrees with the Regge-pole exchange form at one loop, nontrivially supporting the Reggeization hypothesis [3].

- The real corrections to the impact factor for the production of a forward Higgs boson, retaining full top-mass dependence. We demonstrated that the rapidity divergence is the one predicted by the BFKL factorization and performed the explicit subtraction in the BFKL scheme. We showed that the IR-structure of the impact factor is the expected one and that, in the infinite-top-mass approximation, the previously known result is recovered [4].

2 Collider phenomenology of BSM models and interplay with cosmology

We explored a class of Beyond Standard Model (BSM) theories featuring an extended Higgs sector and initiated a study on the interplay between the collider phenomenology of double-Higgs production [5] and the cosmology of first-order phase transitions. On the cosmological side, we examined how the dynamics of true-vacuum bubble nucleation during a first-order phase transition is influenced by the distribution functions of particle species in the plasma [6]. Accurately modeling this process is crucial for quantitatively describing early-universe phase transitions and determining their cosmic relics, including the stochastic gravitational wave background and dark matter abundance [7, 8].

We also investigated the role of the cosmological constant in the Swampland relation at the basis of the Dark Dimension proposal from the side of the (4+1)-dimensional effective field theory where it is formulated [9, 10]. We showed that boundary charges of higher dimensional fields generate UV-sensitive terms that are not canceled by SUSY, and, differently from what expressed in previous literature, the Swampland relation can only be reproduced in the EFT after a fine-tuning of the cosmological constant.

3 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. It is therefore 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 new physics signals at collider. With this principle, we have explored the phenomenology of scenarios with new vector-like quarks belonging to triplets with exotic hypercharge, and featuring decays to new neutral, charged and doubly-charged scalars, predicted for example by classes of models of composite Higgs [11]. In this work we assessed the importance of a model-independent approach with uses global observables to improve the performance of new searches and account for the presence of multiple new particles with almost degenerate masses contributing to the same final state, possibly with large object multiplicity. We also performed a comprehensive overview of the interplay between vector-like quark decays into SM particles and exotic particles in single and pair production, assessing the regions of parameters for which specific processes dominate or are suppressed, and highlighting the potential for improving the reach of experimental searches depending on the considered scenario [12].

4 Threshold resummation for vector boson pair production

The study of the production of a pair of massive gauge bosons (Z) via quark-antiquark annihilation offers an unique opportunity to investigate the electroweak symmetry breaking mechanism of the

Standard Model. Study of fixed order cross section for this process has been achieved till next-to-next-to-leading order (NNLO) in a perturbative expansion of the strong coupling constant. However, in certain kinematical regions, particularly at the end points of phase space, appearance of threshold logarithms can spoil the predictability of the perturbation theory. We have used [13] QCD factorization theorem and renormalization group equation to set up a framework in which we can resum the threshold logarithms up to next-to-next-to-leading log (NNLL) accuracy. We find that the unphysical renormalization and factorization scale uncertainties at NNLO+NNLL decrease by $\sim$ 1-2%, in comparison to NNLO results.

5 Matrix elements for Pseudo-scalar Higgs boson decaying to three partons.

Virtual matrix elements are essential ingredients for a full fixed-order cross section, both at inclusive as well as differential level. For a full N^{3}LO level study, one needs the one-loop results expanded to ϵ^4, the two-loop results expanded to ϵ^2, and three-loop level results expanded to ϵ^0 level (ϵ is the dimensional regularization parameter.) We have studied [14] the decay of a pseudo-scalar Higgs boson to three partons in an effective theory and computed up to $\mathcal{O}(\epsilon^2)$ matrix elements at NNLO, in QCD perturbation theory. To achieve this, we have used our in-house codes as well as the public package KIRA, where the latter implements the integration-by-parts reduction algorithm. Our results have been simplified and optimized in a way that it can used in any Monte-Carlo studies. We have also made these matrix elements publicly available, by implementing them in a FORTRAN-95 routine.

6 Talks in Year 2024

1. A. Papa,
   "Forward Higgs production in the infinite-top-mass limit",
   Diffraction and gluon saturation at the LHC and the EIC, ECT*, June 10-14, 2024
   https://indico.ectstar.eu/event/208/

2. A. Papa,
   "Forward Higgs production: a challenge in high-energy perturbative QCD",
   QCD@work, Trani, June 18-21, 2024
   https://agenda.infn.it/event/37243/

3. A. Papa,
   "Forward Higgs production at high energies",
   The 9th International Conference "Hadron Structure and Fundamental Interactions: from Low to High Energies" (HSFI), Gatchina, July 8-12, 2024 (online presentation)
   https://hepd.pnpi.spb.ru/hsfi/

4. G. Gatto,
   "The next-to-leading order Higgs impact factor at finite top-mass at the NLO: the real corrections",
   Diffraction and Low-x 2024, Trabia (Palermo), September 8 - 14, 2024 (poster)
   https://indico.cern.ch/event/1354173/

5. M. Razzaq,
   "Electroweak phase transition in a vector dark matter scenario",
   QCD@Work, International Workshop on QCD, theory and experiment, Trani (Italy), June 18 - 21, 2024 (poster)
   https://agenda.infn.it/event/37243

6. C. Branchina,
"Path integral measure and the RG equations of pure gravity",
4th International FLAG Workshop: The Quantum and Gravity, Catania, September 9 - 11, 2024
https://agenda.infn.it/event/40951/

7. L. Delle Rose,
"Bubble wall velocity in cosmological phase transitions",
New Physics Directions in the LHC era and beyond, Heidelberg, April 22 -26, 2024
https://indico.global/event/6518/

8. L. Delle Rose,
"Collision Integrals for First-Order Phase Transitions",
QCD@work, Trani, June 18-21, 2024
https://agenda.infn.it/event/37243

9. L. Delle Rose,
"Composite Higgs",
Higgs 2024, Uppsala, November 4 - 8, 2024
https://indico.cern.ch/event/1391236/

10. L. Panizzi,
"A theory overview on t-channel models and their LHC phenomenology",
Roadmap of Dark Matter models for Run 3, CERN, 13-17 May 2024
https://indico.cern.ch/event/1340162/overview

11. L. Panizzi,
"Dark Matter at colliders",
LFC24 - Fundamental Interactions at Future Colliders, SISSA, 16-20 September 2024
https://agenda.infn.it/event/41113/overview

12. P. Banerjee,
"Threshold resummation for Z boson pair production",
Diffraction and Low-x 2024, Trabia (Palermo), September 8 - 14, 2024
https://indico.cern.ch/event/1354173/

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"Fully charmed tetraquarks from LHC to FCC: natural stability from fragmentation,
Eur. Phys. J. C **84** (2024) no.10, 1071 [arXiv:2405.14773 [hep-ph]].

3. M. Fucilla, M.A. Nefedov and A. Papa,
"On the breakdown of eikonal approximation and survival of Reggeization in presence of dimension-5 Higgs-gluon coupling,
JHEP **04** (2024), 078 [arXiv:2401.17843 [hep-ph]].

4. F.G. Celiberto, L. Delle Rose, M. Fucilla, G. Gatto and A. Papa,
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9. C. Branchina, V. Branchina, F. Contino and A. Pernace, "Does the Cosmological Constant really indicate the existence of a Dark Dimension?", International Journal of Geometric Methods in Modern Physics, doi:10.1142/S0219887824503055 [arXiv:2308.16548 [hep-th]].

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13. P. Banerjee, C. Dey, M.C. Kumar, and V. Pandey "Threshold resummation for Z-boson pair production at NNLO+NNLL", [arXiv:2409.16375] [hep-ph]].

14. P. Banerjee, C. Dey, M.C. Kumar, and V. Ravindran "Pseudo-scalar Higgs decay to three parton amplitudes at NNLO to higher orders in dimensional regulator", [arXiv:2411.17611] [hep-ph]].

SFT - Statistical Field Theory and Applications

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

1 Dissipation driven dynamical topological phase transitions in two-dimensional superconductors: [1)]

We have studied 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. To characterize the phase transition, we have computed the fidelity and the spin-Hall conductance of the open system. Our approach has shown to provide crucial informations for experimental implementations, such as the dependence of the critical time on the system-bath coupling.

2 High winding number topological phases in the disordered extended Su-Schrieffer-Heeger model: [2)]

We have used the Lindblad equation approach to investigate 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 have probed 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 either preserving, or not, the symmetries of the Hamiltonian.

3 Interfaces of nodal-line semimetals: drum states, transport and refraction: [3)]

We have studied transport through interfaces in topological nodal-line semimetals, focusing on two geometries: a single interface between two large samples, one nodal-line semimetal and one metal, and an infinite nodal-line semimetal slab in between two metallic regions. We have investigated the dependence of the spectra on the boundary conditions, showing how they affect the surface states and the band dispersion. We have accordingly found a set of drum states, arising from the hybridization of the drumhead states on opposite surfaces at finite slab width, and describe their signatures in the transport properties of a clean sample. Finally, we have computed the electronic trajectories in the ballistic regime, by showing that there is a series of resonant angles that ensure perfect transmission. We have also shown how the current density profile acquires an inhomogeneous distribution in the radial direction.

4 Non-Abelian anyon statistics through AC conductance of a Majorana interferometer: [4])

We have demonstrated the non-Abelian Ising anyon statistics of Majorana zero modes in a physical platform. In particular, we have shown that the linear low-frequency charge conductance of a Majorana interferometer containing a floating superconducting island can reveal the topological spin of quantum edge vortices. The latter are associated with chiral Majorana fermion edge modes and represent "flying" Ising anyons. We have also describe possible device implementations and outline how to detect non-Abelian anyon braiding through AC conductance measurements.

5 Tunneling current and current correlations for anyonic quasiparticles of $\nu = 1/2$ chiral Luttinger liquid in multi-edge geometries: [5])

We have considered anyonic quasiparticles with charge $e/2$ described by the $\nu = 1/2$ chiral Luttinger liquid, which collide in a Hong-Ou-Mandel-like interferometer. These colliding anyonic channels can be formally viewed as hosting Laughlin-like fractional $\nu = 1/2$ quasiparticles. More specifically, we have considered two possible geometries: (i) a two-edge-channel setup where anyons originate from equilibrium reservoirs; (ii) a four-edge-channel setup where nonequilibrium anyons arrive at the collider in the form of diluted beams. For both setups, we have calculated the tunneling current and the current correlations. For setup (i), our results provide analytically exact expressions for the tunneling current, tunneling-current noise, and cross-correlation noise, The exact relation between conductance and noise is demonstrated. For setup (ii), we show that the tunneling current and the generalized Fano factor are finite for diluted streams of $\nu = 1/2$ anyons. This is due to the processes where nonequilibrium anyons, supplied via either source edge, directly tunnel at the central QPC. Thus, to obtain meaningful results in this case, one should go beyond the so-called time-domain braiding processes, where nonequilibrium anyons do not tunnel at the collider, but rather indirectly influence the tunneling by braiding with the quasiparticle-quasihole pairs created at the collider. This has suggested that the effect of direct tunneling and collisions of diluted anyons in the Hong-Ou-Mandel interferometer can be important for various observables in physical quantum-Hall edges at Laughlin filling fractions.

6 Phase diagram of the disordered Kitaev chain with long range pairing connected to external baths: [6])

We have studied the interplay between topology and disorder in the disodered Kitaev model with long range pairing, connected to two metallic leads exchanging particles with external Lindblad baths. In particular, we have studied how the phase diagram of the system is affected by the disorder by monitoring the subgap modes at increasing disorder, by computing the current flowing across the superconductor at a finite voltage bias between the baths, and by looking at the normal, single particle lead correlations across the Kitaev long range chain. In particular, we have evidenced the reentrant behavior of the massive, topological phase at limited values of the disorder strength, that has no analog in the disordered, short range pairing Kitaev model, thus rising the question of whether it is possible to recover a disorder triggered direct transition between the massive and the short range topological phase of the long range pairing Kitaev model.

7 Variation Quantum Algorithms to solve optimization problems: [7], [8], [9])

We devised and employed Variational Quantum Algorithms (also executing them on real quantum hardware) to address a series of optimization problems. In particular we applied these quantum

algorithm to 1) the cloud/edge problem, to obtain the optimal assignment and scheduling of computation on the different nodes which is known to be a NP-hard problem; 2) the preparation of an equilibrium thermal state of a quantum spin system; 3) the "prosumer problem", i.e., the problem of scheduling the household loads on the basis of the user needs, the electricity prices, and the availability of local renew- able energy, with the aim of reducing costs and energy waste. For all of these very different problems, we were able to show that VQA are able to give a solution, limited only by the number of available qubits in today's NISQ devices.

8 Quantum Thermodynamics: [10])

Recent advances in experimental techniques for controlling and preparing interacting quantum systems have increased interest in their non-equilibrium thermodynamic behavior, as they have the potential to drive the development of quantum technologies. We presented a density-functional-theory based approach to extract detailed information about the statistics of work and the irreversible entropy associated with quantum quenches at finite temperature performed on such systems. Specifically, we demonstrated that both of the thermodynamic quantities can be expressed as functionals of thermal and out-of-equilibrium densities, which may serve as fundamental variables for understanding finite-temperature many-body processes. We, then, applied our method to the case of the inhomogeneous Hubbard model, showing that a DFT-based approach can be usefully employed to unveil the distinctive roles of interaction and external potential on the thermodynamic properties of such a system.

9 Quantum information transfer in spin systems: [11])

Quantum state transfer protocols are a major toolkit in many quantum information processing tasks, from quantum key distribution to quantum computation. To assess the performance of such a protocol, one often relies on the average fidelity between the input and the output states. Going beyond this scheme, we analyze the entire probability distribution of fidelity, providing a general framework to derive it for the transfer of single- and two-qubit states. Starting from the delta-like shape of the fidelity distribution, characteristic of perfect transfer, we analyze its broadening and deformation due to realistic features of the process, including non-perfect read-out timing. Different models of quantum transfer, sharing the same value of the average fidelity, display different distributions of fidelity, providing thus additional information on the protocol, including the minimum fidelity.

10 Quantum kernels for data analysis: [12])

With the aim of describing how a Projected Quantum Kernel approach can be used to develop a prediction model on internet-of-things (IoT) data, we used a quantum machine learning algorithm with a dataset produced by IoT devices without requiring feature reductions. In particular, the Projected Quantum Kernel that we implemented allows for projecting the data encoded in Hilbert space into classical space, in order to obtain a prediction.

11 Majorana bound states in two-dimensional electron gases: [13, 14])

We theoretically discussed the emergence of fractional Shapiro steps in a Josephson junction created by confining a two-dimensional electron gas at an oxide interface. The presence of fractional Shapiro steps can be associated with the creation of Majorana bound states at the boundaries of the

superconducting leads. Our findings represent a route for the identification of topological superconductivity in non-centrosymmetric materials and confined systems in the presence of spin–orbit interaction. Furthermore, we explored the geometric control of the superconducting diode effect in a kinked nanostrip Josephson junction based on a two-dimensional electron gas with Rashba spin-orbit interaction. Our analysis revealed a rich phase diagram, showcasing a geometry and field-controlled diode effect, and we were able to relate the anomalous Josephson effect to the emergence of trivial zero-energy Andreev bound states, which can evolve into Majorana bound states.

List of Conference talks:

1. D. Giuliano, "Non-Abelian anyon statistics through AC conductance of a Majorana interferometer", invited talk, 15/09/2024, International Conference on Advances in Modern Quantum Science: From Quantum Materials to Quantum Technologies, Bukhara, Uzbekistan.

2. E. G. Cinnirella, "Interplay between topology and disorder in the eSSH chain", short talk, InTropea2024 - Tropea (VV) 03/09/2024.

3. E. G. Cinnirella, "Fate of high winding number topological phases in the disordered extended Su-Schrieffer-Heeger model", contributed talk, 11th International conference on Quantum Simulation and Quantum Walks - Napoli 14/01/2025.

4. J. Settino, "Memory-Augmented Hybrid Quantum Reservoir Computing", invited Talk to the Working Party on Quantum Reservoir Computing QRC2024 Ettore Majorana Foundation and Centre for Scientific Culture, International School on Nonequilibrium Phenomena, Erice (TP) 17/10/2024.

5. J. Settino, "Memory enhanced hybrid quantum reservoir computing for predicting chaotic systems", contributed talk, 110° Congresso Nazionale SIF – 9-13 settembre 2024 – Bologna.

6. F. Plastina, J. Settino, Organization of the XVI Italian Quantum Information Science Conference, IQIS 2024, Pizzo (VV) 16 - 20 /09 /2024.

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13. A. Maiellaro, M. Trama, J. Settino, C. Guarcello, F. Romeo, R. Citro, "*Engineered Josephson diode effect in kinked Rashba nanochannels*", SciPost Phys. **17**, 101 (2024).

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Contribution to Time2Quest

Contributors: A. Sindona (A. S., National coordinator., PA), F. Plastina (P. F., PO), N. Logullo (N. L., RTDB), M. Pisarra (M. P., RTDA), J. Settino (J. S., Post Doc), F. Perciavalle (F. P., Post Doc) F. Mazzei (F. M., PhD), A. Palamara (A. P., PhD)

As outlined in its project proposal, the Time2Quest initiative explores advanced computational strategies to investigate excited-state properties, collective excitations, transport phenomena, and other many-body effects in low-dimensional systems crucial for quantum information processing. The researchers from the CS unit, serving as the coordinating node of this project, contribute their expertise in time-dependent density functional theory, many-body perturbation theory, and out-of-equilibrium thermodynamics.

Throughout 2024, the CS unit has specifically focused on the following topics:

1 Plasmon excitations, dielectric, electromagnetic, and fundamental properties of one-dimensional nano-objects

(i) Optoelectronic response of organic nanoribbons. Nanoribbon structures are promising prototypes for high-performance, atomically compact, and ultra-low-power devices, whose operation is governed by charge density waves induced at the material–dielectric interface.

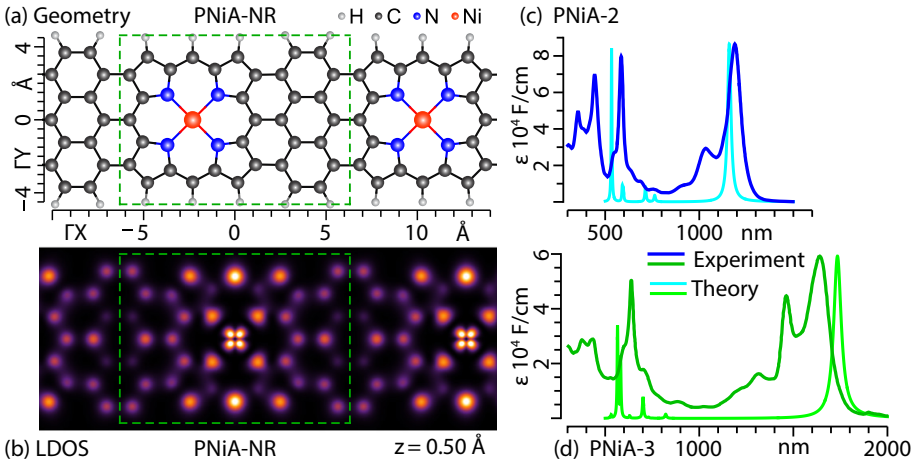

Figure 1: (a) Optimized geometries and (b) local density of states (LDOS) for a porphyrin-nickel-anthracene nanoribbon (PNiA-NR). (c), (d) Permittivity response of PNiA dimers (2) and trimers (3) from experiments in toluene at room temperature and TDDFT calculations.

In this context, the optoelectronic properties of one-dimensional porphyrin-based chains were investigated, revealing their enhanced tunability compared to their graphene-based nanoribbon counterparts. Electronic structures were computed using density functional theory (DFT), employing

a cluster approach for finite-length polymer chains and periodic boundary conditions for infinitely extended nanoribbons. Optical absorption was analyzed using time-dependent (TD) DFT within the Casida framework for clusters and the random-phase approximation (RPA) for periodic systems. Comparison with experimental data on porphyrin-nickel-anthracene dimers and trimers in toluene showed strong agreement with simulations. Benchmarking against the Bethe-Salpeter equation (BSE) formalism provided insights into the interplay between dispersive valence and conduction bands and distinctive flat bands in shaping the nanoribbon optical response.
The plasmonic properties of the nanoribbons were further examined within the RPA, considering both isolated one-dimensional configurations and periodic two-dimensional (2D) arrays. Additionally, more complex nanoribbon systems, including those based on transition metal dichalcogenides (MoS_2, WS_2) were also analyzed [1)].

(ii) Plasmon excitations from flat bands in Kagome metals

The kagome lattice of three-dimensional transition metal ions serves as 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 consists of layered, overlapping triangles and large hexagonal voids. This geometry induces a flat electronic band structure with Dirac crossings, leading to strong correlations in low-energy electron dynamics.

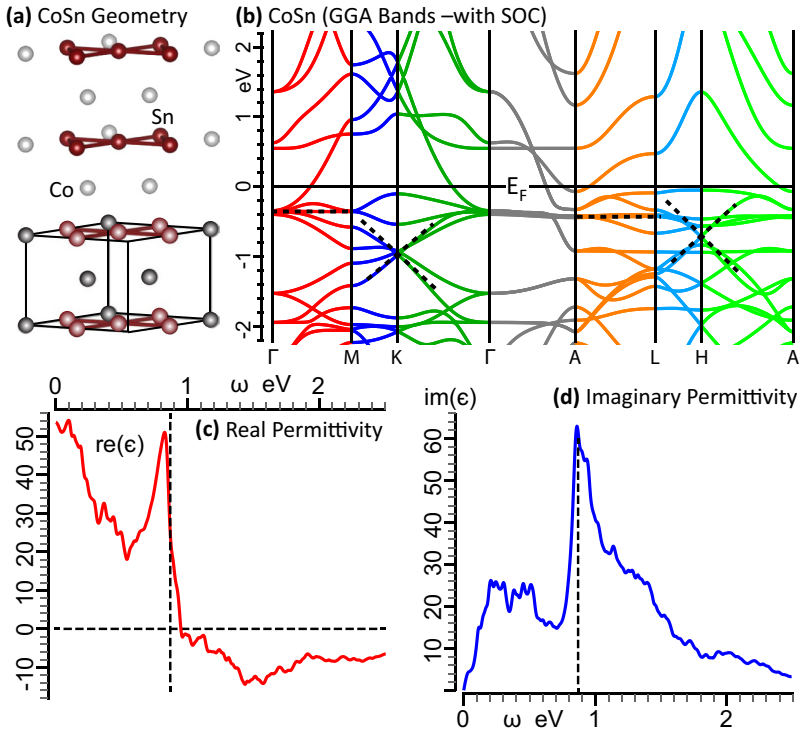

Figure 2: (a) Geometry, (b) band structure, (c) real permittivity, and (d) imaginary permittivity of kagome CoSn.

A novel plasmon excitation was identified in kagome CoSn, evidenced by a sign change in the real permittivity and a sharp peak in the imaginary permittivity (absorption spectrum). The calculations were performed using TDDFT and the BSE formalism. If confirmed experimentally, these findings would open new perspectives in ferromagnetic quantum materials [2)].

2 Electronic and structural properties of low-dimensional layered materials.

(i) 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. However, these rotational misalignments, which lie below 1.1°, result in long-period moiré crystals whose anomalous electronic properties remain challenging to access through reliable atomistic simulations. A mapping was established to link differently stacked graphene sheets at arbitrary rotation angles, corresponding to precise interplanar distances, within an equivalence class represented by *magic-angle* twisted bilayer graphene. In particular, the equivalence relation was formulated within a continuum model and subsequently extended to a tight-binding approach. DFT calculations suggest that the *magic-angle* physics can be characterized using computationally expensive strategies on a twisted bilayer geometry with conveniently larger stacking angles. These findings may open new avenues for the *ab initio* characterization of unconventional topological phases and related excitations associated with currently observed low-energy quasi-flat bands [3].

(ii) Interplay of multilayer domains in nonporous graphene. The investigation of intricate alignments in 2D materials has garnered significant attention, driven by the growing ability to precisely manipulate and engineer electronic properties through controlled stacking and orientation. Recent observations of spontaneous arrangements in multilayer materials with stochastic twist angles offer new opportunities to elucidate the unique physics governing moiré superstructures and the critical role of electronic coupling between layers. In this context, the atomic-scale characterization of nanoporous graphene was focused on, with particular emphasis on regions formed by misoriented graphene layers that assemble into crumpled, continuous patterns. Despite the absence of flat domains at the submicron scale, scanning tunneling microscopy (STM) was employed to identify dominant twisted multilayer structures in the samples. To complement the experimental observations, a simplified yet effective exponential parametric model was introduced, merging independent analytic electron densities to estimate the number of misaligned layers in the scanned areas. This approach was further refined through DFT calculations of projected electron densities from graphene, rotated and stacked at adjusted interlayer distances. The synergy between the two models provided a robust framework for distinguishing between twisted bilayer and twisted trilayer domains, as observed in constant-current imaging. Finally, a comprehensive DFT analysis was conducted on simple few-layer graphene structures, assessing the role of interlayer correlations. The research provided an atomic-level description of porous graphene while offering accessible tools for simulating twisted layered materials [4, 5].

(iii) Chemical activity of graphene on ruthenium. Graphene adsorbed on Ru(0001) has been widely used as a template for adsorbing and isolating molecules, assembling organic-molecule structures with desired geometric and electronic properties, and even inducing chemical reactions that are challenging to achieve in the gas phase. To fully exploit the potential of this substrate, for example, by tuning a graphene-based catalyst to perform optimally under specific conditions, it is crucial to understand the factors and mechanisms governing the molecule-substrate interaction. To contribute to this effort, a combined experimental and theoretical study of the adsorption of cyanomethyl radicals (-CH_2CN) on this substrate was conducted below room temperature, involving STM experiments and DFT simulations. The main result was the observation that some -CH_2CN molecules can jump back and forth between adsorption sites, whereas such dynamics are not observed above room temperature. This finding was interpreted as a consequence of the molecules being adsorbed in a secondary adsorption configuration, where they are bound to the surface through the nitrogen atom. This secondary configuration is much less stable than the primary one, in which the molecule is bound through the -CH_2 carbon atom due to an sp^2-to-

sp^3 hybridization transition. The secondary configuration adsorption is achieved only when the cyanomethyl radical is deposited at low temperature. Increasing the substrate temperature provides the molecule with enough energy to reach the most stable adsorption configuration, thereby preventing the jumping [6, 7].

(iv) Density functional approach to quantum thermodynamics. Recent advances in experimental techniques for controlling and preparing interacting quantum systems have increased interest in their non-equilibrium thermodynamic behavior, as they have the potential to drive the development of quantum technologies. A DFT-based approach was presented to extract detailed information about the statistics of work and the irreversible entropy associated with quantum quenches at finite temperature performed on such systems. Specifically, it was demonstrated that both thermodynamic quantities can be expressed as functionals of thermal and out-of-equilibrium densities, which may serve as fundamental variables for understanding finite-temperature many-body processes. The method was then applied to the case of the inhomogeneous Hubbard chain, showing that a DFT-based approach can be effectively employed to unveil the distinctive roles of interaction and external potential on the thermodynamic properties of the structure [8].

3 Many-body excited state phenomena in nanostuctured systems

(i) Interacting Electrons in a Flat-Band System. The nonequilibrium Green's function approach was employed to study transport across a correlated 1D system featuring a flat band in its single-particle energy spectrum. Specifically, the results of the solution to the stationary Dyson equation were compared with those obtained from the generalized Kadanoff-Baym ansatz (GKBA) master equation. A good agreement was found between the two, although the GKBA approach used does not account for correlations in the retarded propagator. Strikingly, the restoration of transport was observed through the otherwise nonconductive flat band [9].

(ii) Electron delocalization in a 2D Mott insulator. The prominent role of electron-electron interactions in 2D materials gives rise to a wide variety of fermionic correlated states reported in the literature. Artificial van der Waals heterostructures comprising single layers of highly correlated insulators allow for the exploration of the effect of subtle interlayer interactions on the way electrons interact. In this context, the temperature dependence of the electronic properties of a van der Waals heterostructure, composed of a single-layer Mott insulator lying on a metallic substrate, was studied by performing quasi-particle interference (QPI) maps. The emergence of a Fermi contour in the 2D Mott insulator at temperatures below 11 K was observed and attributed to the delocalization of Mott electrons associated with the formation of a quantum coherent Kondo lattice. The comparison between experiments and DFT calculations provided a complete picture of the delocalization of the highly correlated electrons from the 2D Mott insulator [10].

(iii) vibronic transitions in molecules. The ability to excite, probe, and manipulate vibrational modes is essential for understanding and controlling chemical reactions at the molecular level. Recent advancements in tip-enhanced Raman spectroscopy have enabled the probing of vibrational fingerprints in a single molecule with Ångström-scale spatial resolution. However, achieving controllable excitation of specific vibrational modes in individual molecules remains a challenge. In this work, the selective excitation and probing of vibrational modes in single deprotonated phthalocyanine molecules were demonstrated using resonance Raman spectroscopy in a scanning tunneling microscope. Selective excitation was achieved by finely tuning the excitation wavelength of the laser to be resonant with the vibronic transitions between the molecular ground electronic state and the vibrational levels in the excited electronic state, resulting in the state-selective enhancement of

the resonance Raman signal. This approach contributes to setting the stage for steering chemical transformations in molecules on surfaces through selective excitation of molecular vibrations [11].

4 Quantum information processes

(i) Variation Quantum Algorithms A series of variational quantum algorithms (VQAs) were devised and employed, including execution on real quantum hardware, to address the following problems: (a) the cloud/edge problem, which involves obtaining the optimal assignment and scheduling of computation across different nodes, a problem known to be NP-hard; (b) the preparation of an equilibrium thermal state of a quantum spin system; (c) the "*prosumer problem*", i.e., the scheduling of household loads based on user needs, electricity prices, and the availability of local renewable energy, with the aim of reducing costs and energy waste. For all of these diverse problems, it was demonstrated that VQAs can provide solutions, limited only by the number of available qubits in today's NISQ devices [12, 13, 14].

(ii) Quantum information transfer in spin systems. Quantum state transfer protocols are essential tools in many quantum information processing tasks, ranging from quantum key distribution to quantum computation. To assess the performance of such a protocol, the average fidelity between the input and output states is often used as a benchmark. Going beyond this approach, the entire probability distribution of fidelity was analyzed, providing a general framework for deriving it in the transfer of single- and two-qubit states. Starting from the delta-like shape of the fidelity distribution, which is characteristic of perfect transfer, its broadening and deformation were studied due to realistic features of the process, including non-perfect read-out timing. Different models of quantum transfer, which share the same value for the average fidelity, were found to display distinct fidelity distributions, thereby providing additional insights into the protocol, including the minimum fidelity [15].

(iii) Quantum kernels for data analysis With the aim of demonstrating how a Projected Quantum Kernel approach can be used to develop a prediction model on Internet-of-Things (IoT) data, a quantum machine learning algorithm was employed with a dataset produced by IoT devices, without the need for feature reduction. In particular, the implemented Projected Quantum Kernel enables the projection of the data encoded in Hilbert space into classical space, thereby facilitating the prediction process [16].

(iv) Majorana bound states in 2D electron gases The emergence of fractional Shapiro steps in a Josephson junction, created by confining a 2D electron gas at an oxide interface, was discussed. The presence of fractional Shapiro steps was found to be associated with the creation of Majorana bound states at the boundaries of the superconducting leads. These findings provide a route for identifying topological superconductivity in non-centrosymmetric materials and confined systems in the presence of spin–orbit interaction [17]. Furthermore, the geometric control of the superconducting diode effect in a kinked nanostrip Josephson junction was explored, based on a 2D electron gas with Rashba spin-orbit interaction. This analysis revealed a rich phase diagram, showcasing a geometry- and field-controlled diode effect, and the anomalous Josephson effect was related to the emergence of trivial zero-energy Andreev bound states, which can evolve into Majorana bound states [18].

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Conference talks

(i) N. Lo Gullo, "Mitigating qubit readout errors using bayesian learning", invited talk at Lakeside Quantum Dialogue, Jyäskylä, Finland, 15/05/2024;
(ii) J. Settino, "Memory-Augmented Hybrid Quantum Reservoir Computing", invited Talk at the Working Party on Quantum Reservoir Computing QRC2024 Ettore Majorana Foundation and Centre for Scientific Culture, International School on Nonequilibrium Phenomena, Erice (TP) 17/10/2024.
(iii) J. Settino, "Memory enhanced hybrid quantum reservoir computing for predicting chaotic systems", contributed talk, 110° Congresso Nazionale SIF – 9-13 settembre 2024 – Bologna.

Conference organization

(i) N. Lo Gullo, M. Pisarra, F. Plastina, J. Settino, Organization of the XVI Italian Quantum Information Science Conference, IQIS 2024, Pizzo (VV) 16 - 20 /09 /2024 (iqis2024.unical.it)
(ii) N. Lo Gullo, Workshop PHYS-HPC2024, within Europar2024, Madrid (Spain), 27/08/2024 (physhpc.github.io)

STAR Project

STAR Southern Europe Thomson Backscattering Source for Applied Research

Sandro Donato (Ass.)

- The first study, a review paper, highlights X-ray phase-contrast microtomography (PhC-CT) as a complementary tool to conventional histology, addressing its limitations in providing 3D visualization of breast tissue. The manuscript describes how breast cancer is detected using imaging techniques and the major role played by histology for accurate staging. In this context, PhC-CT offers high-resolution, nondestructive imaging, aiding in early breast cancer detection and improving diagnostic precision. A key finding is that PhC-CT enhances histological analysis by overcoming the bi-dimensionality of traditional slides, preserving morphological details, and improving spatial representation of tumor structures. The study illustrates some of the possible clinical application of PhC-CT, which can be especially useful in breast-conserving surgery and complex tissue characterization and is compared to other techniques. The steps toward the transition to clinics are also discussed. Another critical aspect discussed is the global shortage of pathologists, which PhC-CT could help to mitigate by enabling digital imaging and remote consultations. Coupled with artificial intelligence, it streamlines complex analyses and supports pathologists in making accurate diagnoses. While PhC-CT requires specialized equipment, ongoing research focuses on improving its resolution, sensitivity, and feasibility for clinical use. The review concludes that PhC-CT holds promise for enhancing breast cancer diagnosis and patient outcomes as technology advances. [1)]

- The second study examines X-ray phase-contrast microtomography (PhC-CT) as a tool to complement traditional histopathology, particularly in assessing tumor invasiveness in breast, cervical, and thyroid carcinomas. PhC-CT provides high-resolution, 3D imaging, addressing the limitations of conventional histology, which relies on 2D sections and may miss crucial invasion sites. Key findings demonstrate that PhC-CT enhances visualization of micro-invasive lesions. It aids in distinguishing between invasive and non-invasive tumors, detecting basement membrane infiltration, and identifying vascular and capsular invasion in thyroid cancer. These capabilities contribute to more accurate classification and staging. Additionally, PhC-CT supports pathologists by enabling continuous 3D examination, reducing false negatives, and improving lesion assessment. Its ability to guide tissue sectioning optimizes histological analysis, ensuring representative cross-sections for better diagnostic accuracy. While PhC-CT currently requires specialized equipment, recent studies highlight its potential for clinical use with compact laboratory setups. Further research is needed to validate its feasibility, but initial findings suggest that this technology could significantly enhance cancer diagnosis and improve patient outcomes. [2)]

- The third study highlights the potential of X-ray phase-contrast microtomography (PhC-CT) as a complementary tool to conventional histology for breast tissue analysis with specific examples of in-situ and invasive forms of breast cancer. Key findings demonstrate that PhC-CT enhances visualization of breast tissue morphology, including stromal tissue, fibrovascular cores, basement membranes, and tumor encapsulation. The technique aids in

identifying clinically relevant features, offering improved guidance for histological sectioning and surgical margin evaluation. Despite not reaching cellular-level resolution, PhC-CT allows for the assessment of breast tissue alterations with high contrast and spatial detail. It supports pathologists by reducing information loss and providing a global tissue representation, improving diagnostic accuracy and efficiency. Although PhC-CT requires specialized equipment, ongoing research aims to enhance its resolution and clinical applicability. This method shows promise in advancing breast cancer diagnosis and may be extended to other malignancies and fibrotic conditions in future studies. [3)]

- The last study demonstrates synchrotron X-ray PhC-CT is a non-destructive tool for imaging internal anatomical changes in two insect species (Tribolium castaneum and Tenebrio molitor) during pupation. The technique provided high-resolution 3D visualization of gut, nervous system, and reproductive organ remodelling, revealing species-specific differences in development timing. Key findings reveal that while overall anatomical structures are similar between the two beetle species, the timing and duration of organ development vary, likely due to species-specific ecological adaptations. The study highlights the utility of PhC-CT in tracking developmental processes with minimal sample processing, improving efficiency compared to traditional histological methods. PhC-CT improves efficiency over traditional histology but has limitations in detecting cellular-level changes, requiring complementary methods. This research advances understanding of beetle metamorphosis and provides valuable data for developmental biology, physiology, and entomology. [4)]

Conference participation

- 19^{th} European Molecular Imaging Meeting (EMIM) - 12-15 March 2024, Porto, Portugal (oral presentation)
- 25th International Workshop on Radiation Imaging Detectors - IWORID 2025, Lisbon, Portugal, 30 June - 4 July, 2024 (oral presentation – invited speaker).
- Convegno della Società Italiana Luce di Sincrotrone (SILS 2024), Rende (CS), Italy, 5-7 September, 2024 (oral presentation)
- Fundamental research and applications with the EuPRAXIA facility at LNF, 04-06 December 2024, Frascati (RM), Italy (oral presentation – invited speaker)

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STAR
Beamline simulation and optimisation

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

1 Introduction

In the year 2024, the research activity was devoted to the upgrade of the STAR2 beam dynamics (BD) optimization and the enhancement of the control system [1) 2)].
The simulations have 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 Research activities

Different simulations were performed to analyze and optimize beam transport. The Astra tracking code was used to model photocathode electron beam extraction while considering space charge effects in three dimensions. The genetic algorithm-based software GIOTTO was also implemented to optimize BD: this approach allowed for identifying optimal beam setups that improve performance while reducing operational inefficiencies.

In the low-energy line (LE-Line), optimization processes were carried out with particular attention to the space charge effects, wakefields, and energy spread, which can lead to instabilities. GIOTTO was extensively used to mitigate these issues.

For the high-energy line (HE-Line), the focus was on achieving optimal beam transport especially at 140 MeV, to produce high-energy photons via Inverse Compton Scattering. The optimization efforts concentrated on reducing beam energy spread and maintaining emittance throughout the transport process.

In addition to beam optimization, significant improvements were made to the STAR control system. The system, which operates on the EPICS framework, was enhanced by transitioning from Control System Studio (CS-Studio) to the latest GUI software, Phoebus. This transition provided several key benefits, such as improved performance and stability, a modernized architecture, long-term support and maintainability.
The ongoing implementation of artificial intelligence on the control system for real-time BD optimization is expected to lead to significant advances in accelerator technology. Preliminary results suggest that real-time adjustments of the beam and machine parameters improve stability, reduce manual tuning efforts, and increase operational efficiency.

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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 year 2024 with the usual efficiency and stability but only a 20% of the computing resources were used as a security measure. This decreased number of the overall cpu/core utilized was caused by the loss of redundancy on the cooling system.
About the software development, several activities has been done during 2024. Most of them has been mostly devoted to four main area: the grid software infrastructure upgrade, the implementation of web based machine learning toolkit for kubernetes (Kubeflow), the customization of docker

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.*

images and JupyterLab dashboard for several scientific research needs.

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.

The capabilities of the Data Center were significantly expanded at the end of 2023 and beginning of 2024. The upgrade has allowed to reach a total of eight fully conditioned racks. The new network equipment for the high-speed connection (up to 40 Gbps) between the ReCaS data center and the STAR building is operational and the two next-generation GPU-servers for tomographic image reconstruction and analysis are fully used thanks to the installation of a Kubeflow instance on each of them. A new purchase of additional 4 Nvidia L40S GPU to further increase the two server computing power is on going.

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 and 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.

Three Calabrian high schools and a high school in Riobamba, Ecuador, are taking part in the project and numerous interviews have been made. The results have been published in [1].

The Radiolab-CS group, for high school students, realized the third national spring school on radon measurement techniques in water. The three-day school of physics for high school students hosted 22 students from all over Italy and Ecuador. The students learned radon in water measurement techniques and carried out measurements themselves.

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PHYSICS CLOSE TO YOU 2024

M. Capua (Resp.), A. Olivieri (Stud.), L. Panizzi (Ass.), E. Tassi (Ass.), R. Tucci (School prof. Ass.), P. Riccardi (Ass.) V. Romano (Tecn.Ass), A. Tarasio (Tecn.Ass)

The INFN group, in collaboration with the Physics Department of UNICAL, on 26 March 2024, organized an event in Basilicata to make known the contribution of physics for science and society. The event, open to the public and schools, was held in Trecchina (PZ) in the main square of the town and some halls made available by the mayor of the town. Several stands were set up and the main activities carried out by our researchers and their scientific and social relevance were shown. The event was attended by about 300 people and was widely reported by TGR Basilicata. For details see https://agenda.infn.it/e/Basilicatainphysics2024

HOP – Hands on Physics 2024

M. Capua (Resp.), S. Fazio (Ass.), P. Riccardi (Ass.), E. Tassi (Ass.)

HOP - Hands on Physics, organized for Italy by the INFN in collaboration with the Agnelli Foundation and CERN, proposes tools and ideas for teaching the scientific method, sciences and, in particular, physics. The 25 teachers from 16 Calabrian schools who have participated in HOP had the opportunity to attend a free training course that will allow them to carry out practical activities in class, thanks to the experimental kit given to them.

INTERNATIONAL PHYSICS MASTERCLASSES

A. Olivieri (Resp.), M. Capua (Ass.), A. Conaci (Dott.), L. Delle Rose (Ass.), S. Fazio (Ass.), E. Meoni (Ass.), L. Occhiuto (Dott.), T. Rania (Dott.), E. Tassi (Ass.), R. Tucci (Ass.), F. Stabile (Ass.), A. Tarasio (Ass.)

Since 2013, the INFN Group of Cosenza has been organizing the Physics MasterClasses for high-school students from the Calabria and Basilicata regions in partnership with the IPPOG Masterclasses International Project and with the collaboration of the Physics Department of the University of Calabria.
In 2024, two events were organized:

- February 9, International Masterclasses - Hands-on particle physics - a special event for the International Day of Women in Science, with 59 students from Basilicata and Calabria high schools (https://agenda.infn.it/event/39195/).
- February 27, Particle Therapy Masterclasses, with 40 students from Basilicata and Calabria high schools (https://agenda.infn.it/event/39196/).

The special event on February 9 was held on the International Day of Women in Science to promote gender equality and equal access, as well as participation in science. This event had a common talk, organized by the INFN groups of Cosenza and Roma Tor Vergata: a presentation by Venus Keus, a young Iranian researcher and theoretical physicist in Dublin, was held at INFN-CS and attended by all participants in person and remotely.
The Masterclass in Particle Therapy introduces students to the applications of physics in cancer treatment, focusing on radiotherapy and hadrontherapy. It highlights how fundamental research directly benefits society by applying knowledge of particle properties, acceleration techniques, and their interactions with matter to develop effective cancer treatments. In the morning, the students participated in a virtual tour of the CNAO in Pavia, along with the scheduled seminars. In the afternoon, they simulated treatment plans for prostate, liver, or brain cancer using different particle beams. The day ended with a joint videoconference at CERN, where students from various countries discussed their results.

The Cosmic Rays as messengers to investigate the Universe

G. Carducci (Ass.), G. Falsetti (Ass.), I. Gnesi (Ass.),
D. Liguori (Ass.), A. Mastroberardino (Ass.), C. Petronio (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 in 2009 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 from 2008 to 2014. 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. The Cosenza group worked so that the Calabria region could also participate in the EEE project and have its own telescopes. From 2010 to 2018, 5 Calabrian cities obtained the telescope after having demonstrated to be strongly interested in the project and reliable: Cosenza, Reggio Calabria, Catanzaro, Cariati, Rende. The Cosenza group is responsible for all the Calabrian telescopes.
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 or HFO) 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. Four of them are in Calabria.
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 organized seminars 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.

2 OCRA project of INFN-CC3M

In the year 2024 the group actively participated in the OCRA activities of the INFN-CC3M scientific commission. The group assembled in the period 2020-2023, 7 portable scintillation detectors (based on ArduSiPM technology) to measure the cosmic ray flux in different environments (fig.1). The signal produced by the ionizing particles that pass through the plastic scintillation tile is recorded by a microprocessor on a microSD card together with the GPS position, orientation of the detector and the environmental conditions (T, P, RH) where the detector operate. The instrument, the software and the programs to analyze the data were developed by the Cosenza group [1]. In May 2024, during a mini-school organized by the OCRA-Cs group at UNICAL and open to high schools of the Calabria region, a campaign was carried out to measure the rate of cosmic rays as a function of altitude from Cosenza to the Monte Botte Donato refuge, in Sila Grande. Fig.4 shows the results of this campaign and the group of students, teachers and researchers who took part in the measurement campaign. In November, the group coordinated the International Cosmic Day 2024 of Calabrian schools (fig.5). Students presented measurements of cosmic ray flux as a function of altitude at the ICD24 international conference, providing a physical interpretation of the results.

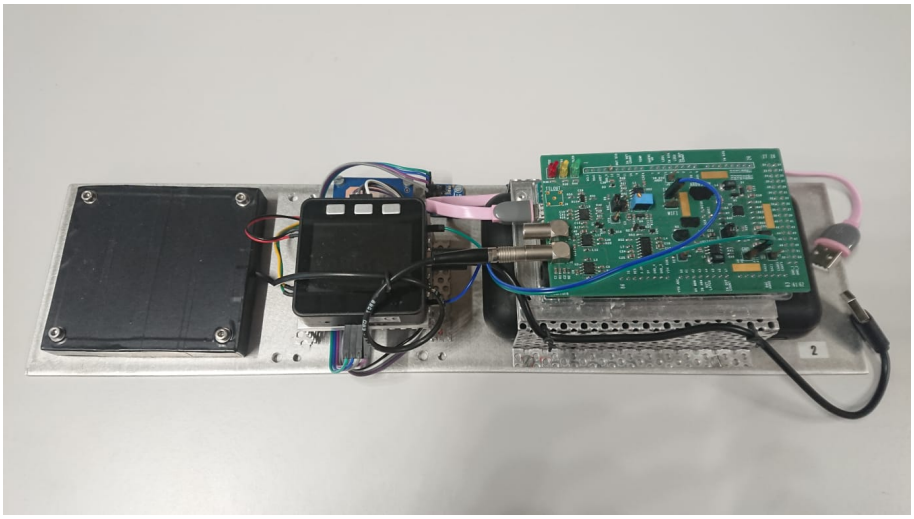

Figure 1: *The detector was provided on loan to Calabrian schools for measuring the frequency of cosmic rays in different operating conditions: in air and in water.*

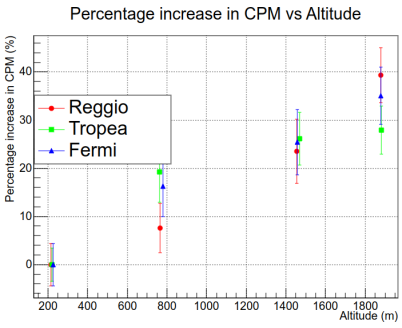

Figure 2:

Figure 3:

Figure 4: (a) The results obtained during the cosmic ray velocity measurement campaign from Cosenza (220 m asl) to the Monte Botte Donato refuge (1880 m asl). (b) Students, teachers and researchers at the Monte Botte Donato refuge.

Figure 5: *Students, teachers and researchers during ICD24 activities.*

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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 2023-2024 the involved schools were: Liceo Scientifico "G. Berto" in Vibo Valentia, Liceo Scientifico "A. Volta" Reggio Calabria, Liceo Scientifico "E.Fermi" Cosenza, Liceo Scientifico Corigliano(CS) and Liceo Scientifico di Lungro (CS). Some of the recovered instruments (see Figure 1) are being used for didactic activities developed for the International Year of Quantum Science and Technologies.

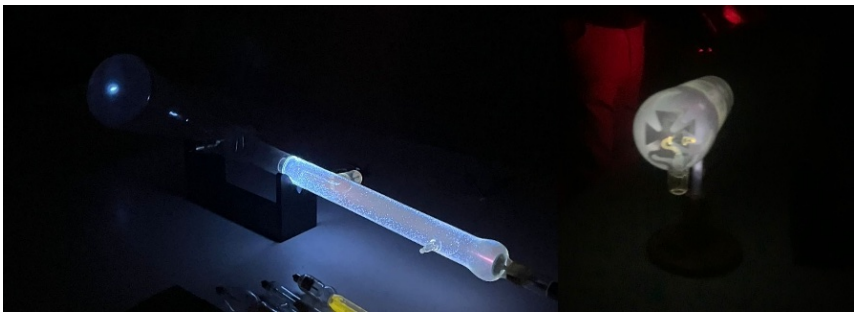

Figure 1: *Two cathode ray tubes recovered during the activities of lab2go.*

For year 2024 the activity in Calabria has been the subject of the pubblications [1)] to [4)].

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Premio Asimov 2024

L. Delle Rose (Ass.), D. Giuliano (Ass.), L. Panizzi (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 five scientific books published during the year before and selected by the Asimov National Committee, and as *competitors*, since the best among their reviews were rewarded.

The edition of 2024 counted overall more than 13000 participants from 333 schools in all Italian Regions (except Aosta Valley). Calabria Region contributed with about 420 students from 15 different high schools. On May 7, 2024 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.