

PARTICLE PHYSICS EXPERIMENTS

ATLAS Experiment

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1 Introduction

The researchers of the ATLAS Cosenza group have been actively involved in the year 2025 in physics analyses, covering a wide range of important topics of the LHC physics programme, 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 Calibration of the b -tagging efficiency at high- p_T using multijet and single-lepton boosted $t\bar{t}$ events

The identification of jets originating from the fragmentation of b -quarks (b -tagging) is a critical tool within the ATLAS physics programme. The group is contributing with two analyses to the b -tagging efficiency calibration for the GN2v01 algorithm, the current state-of-the-art tagging algorithm adopted by the collaboration.

The first calibration analysis is performed on a sample of $t\bar{t}$ events in the single-lepton channel, exploiting a specific boosted topology. In this process, one W boson is required to decay into a lepton and a neutrino, while the other decays hadronically in a highly collimated configuration, reconstructed as a large-radius jet (large-R jet) with high mass. This selection allows for the construction of a high-purity sample where the efficiency is measured on the b -jet associated with the leptonically decaying top quark (the so-called “probe jet”). Thanks to the large production cross-section of $t\bar{t}$ and the efficiency of the selection based on large-R jets, this approach provides crucial access to the high transverse momentum kinematic region ($p_T > 250$ GeV), extending the calibration up to approximately 800-900 GeV, where standard methods lack statistical precision. The analysis is based on a partial Run 3 dataset.

The second calibration analysis is performed using a multijet event sample in which jets are geometrically associated with muons, exploiting the semileptonic decays of b -quarks to enhance the purity of the selected sample. Due to the large production cross-section of these processes, this approach provides unique access to jets at high transverse momentum (p_T), a kinematic region where standard calibrations (based on $t\bar{t}$ events) are limited by the rapid decrease of the jet p_T spectrum. This analysis is covering the full Run 2 dataset and a subset of the Run 3 data.

2.2 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 2025 the group has been actively involved in the measurements, based on the full Run 2 ATLAS data sample, of the parton-level differential cross sections for the production of $t\bar{t}$ pairs in the lepton+jet finale state. The analysis is presently at the editorial board stage and its publication is foreseen by mid 2026. 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.

2.3 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 heavy-flavour jets, and in particular b-jets, in proton-proton collisions provide an important test of perturbative QCD (pQCD). In this context, jet substructure observables offer direct insight into the radiation dynamics of heavy quarks. The W/Z + b-jets processes are also among the dominant backgrounds in Higgs boson measurements, particularly in studies of Higgs boson decays into two b-jets produced in association with a W or Z boson, as well as in searches for physics beyond the Standard Model. Precision measurements therefore provide valuable input for improving the Monte Carlo modelling of W/Z + b-jets backgrounds. Moreover, measurement of W/Z+b-jets processes are sensitive to potential effects of new physics in the high-momentum regime, where new phenomena coupled to W/Z production could modify Standard Model predictions. The group is contributing to measurements of differential Z + b-jets cross sections as a function of several observables, covering both the resolved regime at moderate transverse momenta where the two b-jets are reconstructed as distinct objects and the boosted regime at high transverse momenta, where the two b-jets are highly collimated and reconstructed as a single large-R jet. The analysis also includes measurements of jet substructure observables, such as jet angularities and the Lund jet plane. This study is performed using the full Run-2 proton-proton collision dataset, corresponding to an integrated luminosity of about 140 fb^{-1} at a centre-of-mass energy of 13 TeV. More recently, the group has initiated a dedicated study of W-boson production in association with two b-jets, with the goal of performing the first differential cross-section measurement of this process at the LHC. This analysis is based on Run 3 proton-proton collision data collected at a centre-of-mass energy of 13.6 TeV.

2.4 Search for long-lived neutral particles decaying into displaced lepton-jets in the ATLAS experiment in p-p collisions at $\sqrt{s} = 13.6 \text{ TeV}$

The group has made significant contributions to the search for long-lived light particles produced in the decay of the Higgs boson, with signatures consisting of collimated pairs of leptons or light hadrons in proton–proton collisions at $\sqrt{s} = 13.6 \text{ TeV}$, using data from Run 3 of the ATLAS detector. Key components of the analysis framework were developed and consolidated within the team, particularly through contributions to the development of the TopCPToolkit and the FastFrame Analysis Framework, which constituted the reference software infrastructure for the analysis. Truth-Matching studies and detailed studies of the reconstruction efficiency of muonic and hadronic lepton jets as a function of the properties of the simulated dark photon were also conducted, providing a quantitative characterization of the detector’s performance for this type of non-standard signature. The group identified and defined the most appropriate trigger and event selection strategy for Run 3, innovatively introducing information on displaced vertices in the Muon Spectrometer as a criterion discriminating between events compatible with the decay of a long-lived particle and Standard Model processes. The results obtained were used to fully develop and validate the muon channel of the analysis and to prepare the framework necessary for the systematic study of the

other decay channels. Finally, a systematic comparison of the results with published data and Monte Carlo simulations was performed to validate the robustness of the analytical approach and the methodological choices adopted.

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 2000 mm 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 μ sv), was measured for Ar:CO₂ and Ar:CO₂:Iso mixtures and at different amplification region gains.

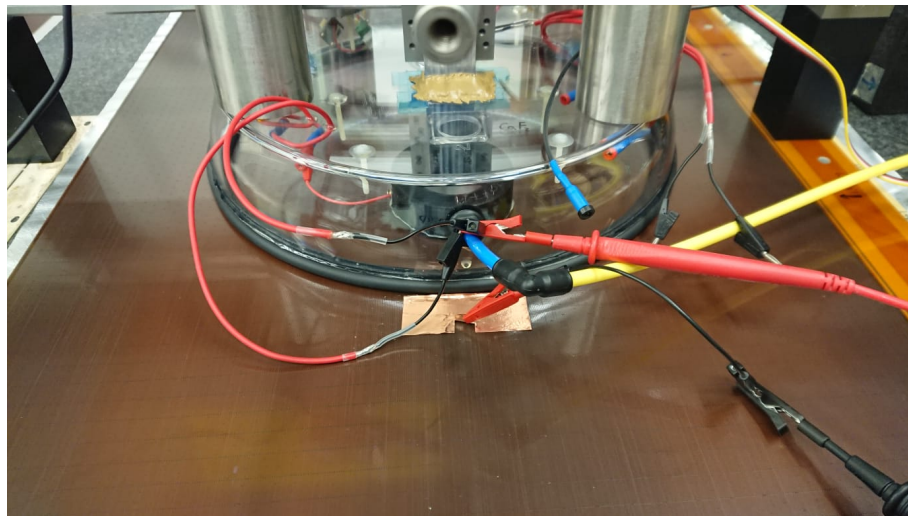


Figure 1: *The setup employed to measure the Paschen curve for pure Ar, Ar:CO₂ (93:7), Ar:CO₂:isoC₄H₁₀ (93:5:2).*

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

In the 2020 the group got the responsibility to build and test the read-out panels of the trigger chambers to be paired to the BIL tracking detector of the muon spectrometer. The BIL tracking chambers were built by a consortium of INFN groups: Pavia, Rome 1, Rome 3 and Cosenza about 25 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 2500x650x0.4 mm FR4 PCB on which the strips are photo-etched and a PCB of the same size which acts as a ground plane. The two PCBs are glued on the opposite sides of a 2500x650x3 mm paper honeycomb sheet with the copper facing outwards. In the 2022 the group has developed the majority of all the necessary tools, has participated to the procurement of the needed material (FR4, paper honeycomb, photo-etching of the strip plates), has developed the local data base where store the data, tested the pre-series ground plates and coordinated the activity of read-out panel design. In 2023 the group completed the construction and test of all the components of the readout panels assembling line in Cosenza. A pre-series of 12 BIL-RPC 2511x658x0.4 mm 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 2025, about 770 readout panels (100% 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 2025, about 70 RPC detectors were assembled. Quality control of these detectors is checked at every stage of assembly. Since the pre-series front end electronics was ready only at the end on 2025, two module zeros were assembled and tested with encouraging results. Figure 2 shows the RPC-BIL680 module zero of the BI project.

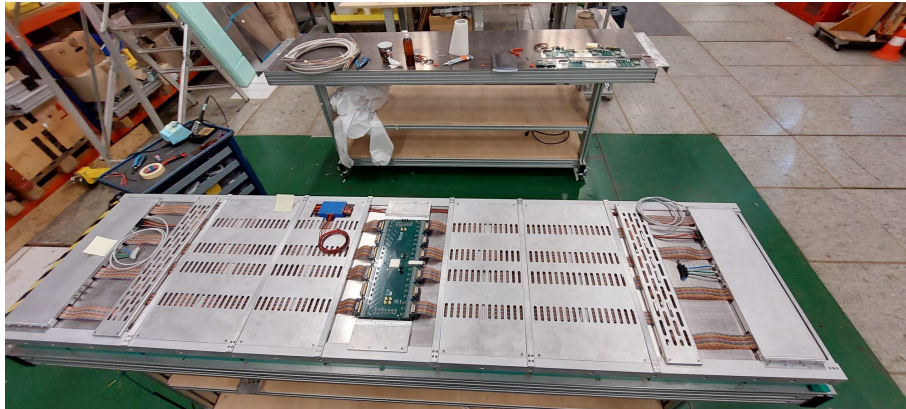


Figure 2: *The module zero of the RPC-BIL680 chamber.*

4 List of Conference Talks and Poster by LNF Authors in Year 2025

1. G. Falsetti, The ATLAS RPC Phase II upgrade for High Luminosity LHC era, Vienna Conference on Instrumentation, Vienna 17-21 February 2025.
2. G. Falsetti, ATLAS Muon Detectors upgrades for High Luminosity LHC, EPS-HEP 2025 Marseille 7-11 July 2025.

3. M.F. Perrone, Misura della diffusione di Ar nella miscela TFE:SF₆:iso-C₄H₁₀ per i volumi di gas degli RPC di ATLAS fase 2, 111°Congresso Nazionale della Società Italiana di Fisica, Palermo 22-26 September 2025.
4. M. Arcuri, Studio delle performance dei rivelatori RPC per ATLAS fase 2 con raggi cosmici, 111°Congresso Nazionale della Società Italiana di Fisica, Palermo 22-26 September 2025.
5. G. Santoro, Misure della produzione di un bosone Z in associazione a 2 b-jets con l'esperimento ATLAS ad LHC, IFAE, Cagliari 9-11 April 2025.
6. G. Santoro, Measurements of the production of a Z boson in association with 2 b-jets with the ATLAS experiment at LHC, 111°Congresso Nazionale della Società Italiana di Fisica, Palermo 22-26 September 2025. E. Meoni on behalf of the ATLAS Collaboration: "Measurement of vector boson plus jets and multi-jets production in ATLAS", Low-x 2025, 8-12 September 2025, Medulin (Croatia)

5 List of papers in Year 2025

1. ATLAS collaboration, Measurements of the production of a Z boson in association with 2 b-jets with the ATLAS experiment at LHC, 10.1393/ncc/i2026-26042-3
2. ATLAS Collaboration, Measurements and interpretations of $W^\pm Z$ production cross-sections in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, JHEP 11 (2025) 006.
3. ATLAS Collaboration, Cross-section measurements for the production of a W -boson in association with high-transverse-momentum jets in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Eur. Phys. J. C 85 (2025) 738.
4. ATLAS Collaboration, Electroweak, QCD and flavour physics studies with ATLAS data from Run 2 of the LHC, Phys. Rep. 1116 (2025) 57-126.

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 participated 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 Italia

M. Capua (Resp.), S. Fazio (Ass.), H. Hashamipour (Ass.), L. Occhiuto (Dott.),
V. Romano (Tec.), C. Romeo (Laur.), 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]. The group is also part of the ePIC Collaboration since its inception [S. Fazio, Collaboration Council Representative]. The ePIC collaboration (<https://www.epic-eic.org/>) 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.

The Cosenza's group involvement within ePIC is multifold:

- Leading role in **Physics Analysis** and Physics performance studies, with S. Fazio appointed Physics Analysis Coordinator (PAC) starting March 2023 and confirmed for a second term starting in March 2025. S. Fazio also serves as an ex-officio member of the ePIC Executive Board. The main focus in 2025 continued to be the physics chapter of a preliminary version of the Technical Design Report (pre-TDR), with a [version 3.1](#) released in mid December 2025. In June 2025, the ePIC Collaboration received a formal charge by the BNL and JLAB Associate Lab Directors to assess the scientific impact achievable at the EIC within the first 5 years of running. The Early Science Report (ESR) became the other topmost priority for the Physics Analysis Coordination office, together with the TDR. In order to facilitate the TDR and ESR studies by the physics working groups in ePIC, during 2025 S. Fazio co-organized two dedicated topical workshops: the [Early Science Workshop](#) at Center for Frontiers in Nuclear Science, Stony Brook University (USA) and the first [Physics Readiness Workshop](#) at the Institute of Physics, London (UK). In 2025 H. Hashamipour, supervised by E. Tassi, M. Capua, and S. Fazio, continued his work on the assessment of the impact of ePIC data to the extraction of diffractive PDFs (DPDFs), by analysing a sample of simulated inclusive single-diffractive events that have passed the full ePIC detector simulation and reconstruction. In 2025, S. Fazio was one of the two key editors (together with M. Radici, Sezione PV) of the a document assessing the synergies between the EIC and the European research in particle physics [\[4\]](#) submitted to the panel on European Strategy for Particle Physics. In 2025, S. Fazio and other collaborators finalized the publication of an impact study on measurements of exclusive photon production at the EIC [\[5\]](#), a process known as deeply virtual Compton Scattering (DVCS), used to extract generalized parton distribution functions (GPDs). This paper marks the culmination of a 2023 milestone by ePIC Italia.
- Active participation into **R&D efforts** on the realization of a dual radiator RICH (dRICH)

detector in the forward region of ePIC. In 2025, the local laboratory, devoted to the characterization of Silicon Photo-multipliers (SiPMs) as preferred photosensors for the dRICH, has been further equipped with a compressed air system, in order to control the humidity in the peltier-box containing the sensors. In 2025 the group has an undergraduate student, C. Romeo, who did an internship on the SiPMs characterization. In December 2025, M. Capua and S. Fazio have participated to irradiation tests using gamma rays at the GIF++ facility at CERN. In 2025, L. Occhiuto played a leading role on the task of simulating the geometry of the eRICH apparatus in the GEANT4 framework of the ePIC detector, by finalizing the simulation of the aerogel radiator. She presented her results at the Giornate Nazionali of ePIC Italia in Padua and at the EPS HEP 2025 Conference in Marsiglia (France). L. Occhiuto has also edited a proceeding [\[6\]](#).

- In 2025, M. Capua has led the efforts towards an outreach program targeting the high-school students. The event, called “Vi presento ePIC” was premiered by the GC Cosenza and replicated by several other INFN sections. More information under the outreach session of our group.

2 List of Conference Talks by GC-CS authors in year 2025

1. L. Occhiuto, “The dRICH detector at the future ePIC experiment”, EPS-HEP 2025, Marsiglia, France.
2. L. Occhiuto, “Aerogel studies for the dRICH detector”, ePIC Italia Giornate Nazionali 2025, Padua, Italy.
3. H. Hashamipour, ePIC Collaboration Meeting Jan 2025, Frascati, Italy.
4. H. Hashamipour, “Diffractive DIS in ePIC”, ePIC Collaboration Meeting July 2025, JLAB, USA.
5. M. Capua, A. De Caro, M. Ruspa, and C. Tuvè (speaker), “Vi presento ePIC! Una fantastica esperienza!”, ePIC Italia Giornate Nazionali 2025, Padua, Italy.
6. S. Fazio, “Analysis Coordination Report”, ePIC Collaboration Meeting Jan 2025, Frascati, Italy.
7. S. Fazio, R. Reed (speaker), “Use Case: Data Inputs and Requirements for Physics Analysis”, ePIC Collaboration Meeting Jan 2025, Frascati, Italy.
8. S. Fazio, “Analysis Priorities and Goals”, ePIC Collaboration Meeting Jan 2025, Frascati, Italy.
9. S. Fazio, “Physics Analysis activities at the ePIC experiment”, ePIC Italia Giornate Nazionali 2025, Padua, Italy.
10. S. Fazio (speaker), R. Montgomery, R. Reed, “ePIC Physics Analysis Status”, ePIC Collaboration Meeting July 2025, JLAB, USA.
11. S. Fazio, “Physics Analysis activities at the ePIC experiment”, BNL-INT Joint Workshop: Bridging Theory and Experiment at the Electron-Ion Collider, INT, Seattle, USA.
12. S. Fazio, “Early physics running at the EIC”, EIC France Meeting, Orsay, France.
13. S. Fazio, “Physics Performance of the ePIC Detector - Ongoing and Planned Studies”, Joint ECFA-NuPECC-APPEC Workshop on Synergies between the EIC and the LHC, Krakow, Poland.

3 Publications in year 2025

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1. B. R. Achari, N. Agrawal, M. Alexeev, C. Alice, P. Antonioli, C. Baldanza, L. Barion, A. Calivà, M. Capua and M. Chiosso, *et al.* “The SiPM photodetector of the ePIC dual-radiator RICH at the EIC: overview and beam test results”, *JINST* **20** (2025) no.08, C08025 doi:10.1088/1748-0221/20/08/C08025
2. R. Preghenella, B. R. Achari, N. Agrawal, M. Alexeev, C. Alice, P. Antonioli, C. Baldanza, L. Barion, M. Capua and M. Chiosso, *et al.* “Beam test results of the SiPM photodetector prototype for the ePIC-dRICH detector at the EIC”, *JINST* **20** (2025) no.07, C07005 doi:10.1088/1748-0221/20/07/C07005
3. D. D. Gruttola, B. R. Achari, N. Agrawal, M. Alexeev, C. Alice, P. Antonioli, C. Baldanza, L. Barion, M. Capua and M. Chiosso, *et al.* “Studies of radiation damage and mitigation strategies for the SiPM of the ePIC-dRICH detector at the EIC”, *Nuovo Cim. C* **48** (2025) no.4, 194 doi:10.1393/ncc/i2025-25194-x
4. S. Diehl *et al.* [ePIC and EIC User Group], “Synergies between a U.S.-based Electron-Ion Collider and European Research in Particle Physics”, [arXiv:2504.01236 [hep-ex]].
5. E. C. Aschenauer, V. Batozskaya, S. Fazio, A. Jentsch, J. Kim, K. Kumerički, H. Moutarde, K. Passek-K., D. Sokhan and H. Spiesberger, *et al.* “Study of deeply virtual Compton scattering at the future electron-ion collider”, *Phys. Rev. D* **112** (2025) no.3, 036010 doi:10.1103/fy8y-bjc9
6. L. R. M. Occhiuto, P. Antonioli, L. Barion, F. Bellini, R. S. Bhadauriya, A. Bressan, A. Calivà, M. Capua, C. Chatterjee and M. Contalbrigo, *et al.* “The dRICH detector at the ePIC experiment”, *PoS QNP2024* (2025), 009 doi:10.22323/1.465.0009

THEORETICAL PHYSICS

LINCOLN Learning Complex Networks

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Modelling of real world problems

- 1) 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. Both stochastic and deterministic models are relevant; the former due to the stochastic nature of forest fire spreading, the latter for their computational efficiency. We developed both deterministic and stochastic models ^{1, 2, 3}).
- 2) Predator-prey models are a subject of research interest in ecological systems. Numerous models have been introduced for the interaction between prey and predators. We investigate a reaction-diffusion system governing the predator-prey interaction with specialist predator and herd behavior for prey ⁴).
- 3) Deep eutectic solvents (DESs) are gaining attention as sustainable alternatives to traditional organic solvents, particularly for applications involving nonpolar substances. We studied the dispersion behavior of beeswax in a selection of hydrophobic natural deep eutectic solvents using both theoretical and experimental approaches. A model of the dispersion has been provided ⁵).
- 4) Partial Differential Equations (PDEs) play a fundamental role in modeling complex systems in physics, biology, and engineering, such as in the context of monitoring systems. In recent years, Neural Networks (NNs) have emerged as a powerful tool for approximating PDE solutions. In this paper, we propose the use of Neural Networks to solve PDEs applied in monitoring systems. To illustrate this concept, we apply it to the Fisher Kolmogorov-Petrovsky-Piskunov Equation ⁶

Mathematical Models for Semiconductors

- 1) A new optimization framework to design steady equilibrium solutions of the Vlasov-Poisson system by means of external electric fields has been introduced ⁷).
- 2) Estimating crystal inhomogeneities in semiconductors noninvasively holds significance for various industrial applications. In order to detect inhomogeneities, variations, and defects in the doping profile noninvasively, one may systematically generate electron-hole pairs through some form of electromagnetic radiation and attach an external circuit to measure the resulting

current. Several different types of technologies rely on this physical principle. In our work, we focused on Lateral Photovoltage Scanning method (LPS) for which we found analytical results for the so-called forward LPS problem. 8).

Quantum Measurement, Quantum Observables, and Quantum Logic

- 1) The analysis of the measurement process show that positive operator valued measures (POVMs) are the right mathematical tool to represent quantum observables. Fuzzy observables are special kind of POVMs and play a very important role in the approximate joint 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 that commutative unsharp observables can be defuzzified in order to obtain the sharp observables of which they are the fuzzy versions. Moreover, we proved that the joint measurability of two commutative (but generally not commuting) POVMs F_1 and F_2 corresponds to the existence of two commuting self-adjoint operators A_1^+ A_2^+ in an extended Hilbert space \mathcal{H}^+ whose projections are the sharp versions of F_1 and F_2 , respectively 9).
- 2) The most important “logical revolution” of quantum theory concerns a divergence between the concepts of maximal information and logically complete information. This is a natural consequence of Heisenberg’s uncertainty principle: any quantum pure state represents a maximal information that cannot be consistently extended to a richer knowledge about the physical system under consideration. At the same time, such information is logically incomplete, since it cannot decide all relevant properties of the system in question. We discuss the implications of such a “logical revolution” both in the framework of sharp quantum logic and unsharp quantum logic, by using techniques from logic and functional analysis 10).
- 3) A macroscopic hydrodynamic system that couples a particle and a wave has recently renewed interest in the question as to what extent a classical system may reproduce quantum phenomena. Here we investigate single-particle interactions with a barrier and slits of increasing width by focusing on the near field. We find single-particle diffraction arising as wavelike patterns in the particles’ position statistics, which we compare to the predictions of quantum mechanics 11).

Conferences

- 1) 5° CONGRESO INTERNACIONAL DEL HÀBITAT Y SUSTENTABILIDAD: : Futuros posibles más allá del 2030, ITESO, Universidad Jesuita de Guadalajara, Mexico, April 9–11, 2025 (communication).
- 2) New trends in charge and phonon transport in low dimensional structures, Villa Citelli, Catania, Italy, 16-18 June 2025 (communications).
- 3) New trends in fluid and solid models, 04-06 September 2025, Vietri, Italy (communications)
- 4) Quantum Theory, Reasoning and Computation, 18-19/07/2025, Barberino Mugello, Italy.
- 5) Lectures in Nonlinear Analysis and Differential Equations, LNADE 2025, University of Calabria 10-14 March 2025 (communications).
- 6) ICIRBM 2025, 46th Edition of Italian Conference on Integrated River Basin Management, Mediterranea University of Reggio Calabria, 18-19 September 2025 (communication).

- 7) Workshop on Mathematical Models for Quantum and Semiclassical Dynamics, Villa Ruspoli, Florence, Italy, 10–12 September 2025 (communication)
- 8) XXIII International Conference on WAVes and Stability in COntinuous Media (WASCOM), Parma (Italy), June 9–13, 2025 (communication).

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1. R. Beneduci, G. Mascali, A Reduced Stochastic Model for Wildfire Spreading based on PDEs (submitted).
2. P.A. Fusaro, P. Pantano, G. Ali, R. Mangiardi, Geospatial Methods in Fire Hazard Assessment, 2025 IEEE International Workshop on Metrology for Living Environment Metrolivenv, 2025 Proceedings pp. 333–338
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8. G. Ali, P. Farrell, N. Rotundo, Forward lateral photovoltage scanning problem: Perturbation approach and existence-uniqueness analysis, *Journal of Mathematical Analysis and Applications*, 541(2) (2025) 128725.
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NPQCD

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

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

1 Flux tubes QCD

We have studied the chromo-electric field generated by a static quark-antiquark pair at finite temperature, in lattice QCD with 2+1 dynamical staggered fermions at physical quark masses. We have investigated the evolution of the field as the temperature increases through and beyond the chiral transition. For all the temperatures considered we have found clear evidence of a chromo-magnetic current and of a longitudinal nonperturbative chromo-electric field that stays almost uniform along the flux tube. In the high-temperature region the magnitude of the flux-tube field is determined by an effective string tension that decreases exponentially as the temperature increases, while the flux-tube width decreases according to an inverse-temperature law. Our results suggest that beyond the chiral pseudocritical temperature the quark-antiquark system can be characterized by a screened string tension.

A paper on this research has been accepted for publication on Eur. Phys. J. C.

2 Gauge-Higgs lattice theories

We have reexamined by numerical simulation the phase structure of the three-dimensional Abelian lattice gauge theory with $Z(2)$ gauge fields coupled to $Z(2)$ -valued Higgs fields. Concretely, we have 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. The latter operator is an analog of the overlap Edwards-Anderson order parameter for spin glasses. According to it, the Higgs phase is realized as a glassy phase of the gauge system. For this reason standard tricks for simulations of spin-glass phases have been utilized, namely tempered Monte Carlo and averaging over replicas. In addition, we have also presented results for a certain definition of distance between Higgs field configurations. Finally, we have calculated various gauge-invariant correlation functions in order to extract the corresponding masses ¹).

We have studied by numerical simulation the phase structure of the (3+1)-dimensional $SU(2)$ lattice gauge theory with gauge fields coupled to Higgs fields at finite temperature. Concretely, we have 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 ²).

3 The 't Hooft-Veneziano limit of lattice gauge theories at finite baryon density

An exact solution of one-dimensional lattice gauge theory at finite temperature and non-zero chemical potential has been reviewed for the gauge groups $G = Z(N)$, $U(N)$, $SU(N)$ for all values of N and the number of fermion flavors N_f . Calculated are the partition function, free energy, the Polyakov loop expectation values, baryon density, quark condensate, meson and baryon correlation functions. Detailed analysis of the exact solutions has been done for $N = 2, 3$ with one and two fermion flavors. In the large N_f limit we have uncovered the Roberge-Weiss phase transition and discussed its remnants at finite N_f . In the case of N_f degenerate flavors we have also calculated 1) the large N limit, 2) the large N_f limit and 3) the 't Hooft-Veneziano limit of all models. The critical behavior of the models in these limits has been studied and the phase structure has been described in details. A comparison of all limits with $U(3)$ and $SU(3)$ QCD has also performed. In order to achieve these results we have explored several representations of the partition function of one-dimensional QCD ³⁾.

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QFT@COLLIDERS
Precision calculations for collider physics

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

1 Semihard processes in perturbative QCD

High-energy reactions falling in the so-called *semi-hard* sector, where the scale hierarchy, $s \gg Q^2 \gg \Lambda_{\text{QCD}}^2$ holds (here, s is the squared center-of-mass energy, Q the hard scale given by the process kinematics and Λ_{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, the following investigations have been carried out.

- We have presented a general formula for the amplitude of forward exclusive hadronic processes, by means of the next-to-leading order eigenfunctions of the BFKL kernel, as constructed by Chirilli and Kovchegov. We have discussed some formal subtleties in the check of compatibility with the similar formula based on the use of the leading-order BFKL eigenfunctions. Finally, in the specific case of the electroproduction of two light vector mesons, we have considered the numerical stability of the amplitude when one or the other set of eigenfunctions is adopted ¹).
- We have studied the semi-inclusive hadroproduction of tetraquarks, in the doubly bottomed configuration (Xbb^-qq^-) and fully bottomed one ($T4b$), to which we collectively refer as “bottomoniumlike” states. We have relied upon the variable-flavor number-scheme fragmentation at leading power, where a single parton perturbatively splits into the corresponding Fock state, which then hadronizes into the color-neutral, observed tetraquark. To this end, we have built new sets of DGLAP/hf-nrevo consistent, hadron-structure oriented collinear fragmentation functions, which we name TQHL1.1 and TQ4Q1.1 parametrizations. They extend and supersede the corresponding 1.0 versions recently derived in previous works. The first family describes the fragmentation of doubly heavy tetraquarks and is based on an improved version of the Suzuki model for the heavy-quark channel. The second family depicts the fragmentation of fully heavy tetraquarks and embodies initial-scale inputs for gluon and heavy-quark channels, both of them calculated by the hands of potential nonrelativistic QCD. As a phenomenological application, we have provided novel predictions for tetraquark-plus-jet high-energy distributions, computed within the NLL/NLO+ hybrid factorization from (sym)jethad, at 14 and 100 TeV FCC ²).

2 Collider phenomenology of BSM models and interplay with cosmology

We investigated a class of Beyond the Standard Model (BSM) scenarios featuring an extended Higgs sector and initiated a study of the interplay between collider phenomenology and the cosmology of first-order phase transitions. On the cosmological side, we analyzed how the dynamics of true-vacuum bubble nucleation during a first-order phase transition are affected by the distribution functions of particle species in the plasma ³⁾, assuming local thermal equilibrium. An accurate modeling of these dynamics is essential for a quantitative description of early-universe phase transitions and for reliable predictions of their cosmological relics, including the stochastic gravitational-wave background and the dark matter abundance ⁴⁾.

We have performed global fits ⁵⁾ on the parameter-space of the CP-conserving aligned-two-Higgs-doublet-model (A2HDM), which is a BSM extension in scalar sector, taking into account all the theoretical and experimental constraints on the model. We have shown that despite all the constraints A2HDM can accommodate one or multiple BSM scalars lighter than the SM Higgs. We have also looked into the effects of CP-violating A2HDM on the electric dipole moment of electron (eEDM) in the decoupling limit ⁶⁾. Through two-loop full-theory calculation as well as SMEFT framework we have demonstrated that the complex alignment parameters in the A2HDM introduce additional diagrams – absent in the conventional 2HDM – that lead to enhanced contributions to the eEDM.

We have explored the axion phenomenology within 3-3-1-1 model ⁷⁾, a unified framework addressing Dirac neutrino mass generation, dark matter, the number of fermion families, and the strong CP problem simultaneously. We have shown that its axion is distinct from the KSVZ and DFSZ types and this model leads to novel flavor-changing axion-emitting two-body decays of K, B, and D mesons.

We studied the effective action in quantum gravity, emphasising the role played by the path integral measure and the definition of the physical cutoff scale, both in the context of one-loop calculations ⁸⁾ and of the Wilsonian renormalisation group approach ⁹⁾. Our results highlight subtle points crucial for assessing non-perturbative renormalisability of gravity. Diffeomorphism invariance was also proven ¹⁰⁾, clarifying a long-standing issue.

We also performed a renormalisation group analysis of a recently proposed model with extended Higgs and gauge sectors and a leptonic portal ¹¹⁾.

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. We have conducted this exploration on various fronts and with different methods.

We have explored a model where the dark matter is composed by massive gauge bosons from a non-Abelian group. In its minimal realisation, where the only interaction between the dark sector and the Standard Model is via the quartic coupling between the scalar doublet which gives mass to the dark gauge bosons and the Higgs boson (Higgs portal), we investigate the complementarity of constraints from cosmology, Higgs sector and electroweak precision tests on the new-physics parameter space. For the same model, we have computed the prediction for gravitational waves signals originating during the phase transitions where masses are generated, and compared them with the sensitivity range of future experiments ⁴⁾.

In case the Higgs portal is closed, a possible way to connect the dark and visible sectors is through the fermionic portal, which we already developed. In this context we have analysed the muonic realisation, where the dark sector interacts with the SM through the muons. We have

explored cosmological and collider constraints and evaluated how new physics might affect the measurement of the anomalous magnetic moment of the muon, under the hypothesis that the tension between theoretical prediction and experimental measurements is still there, or in the case it has been solved, as recent claims imply. This work is currently under peer review for JHEP, but it is available as a preprint on arXiv.

Still about dark matter, we have edited and authored a white paper for the LHC DM working group about t -channel scenarios: a large and comprehensive work discussing multiple aspects related to, cosmology, collider, parametrisation and tools, embedding in theoretical constructions, providing guidelines for future experimental searches and theoretical/phenomenological studies ¹³⁾.

We have considered a scenario where new vector-like quarks interact with SM quarks of the first generation. This scenario is predicted by various theories which address the mass hierarchy between different fermion flavours. In this context, we have analysed the role of finite width and coupling chiralities in the determination of signal predictions at the LHC, focusing on the complementarity between QCD pair production and same-charge pair production, the cross-section of which is enhanced by the up-quark PDF ¹²⁾.

On the Higgs sector, we have performed a complete analysis of new physics contributions given by any number of new coloured and neutral scalars to di-Higgs production at the LHC, and reinterpreted the results for the NMSSM ¹⁴⁾.

We have also evaluated for the first time the role of the uncertainties on the top Yukawa coupling in the determination of the triple Higgs cross-section, and compared with current constraints and NNLO contributions. This work is currently under peer review for PRD, but it is available as a preprint on arXiv.

For all these activities we developed 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.

4 Threshold resummation for W boson pair production

The study of the production of a pair of massive gauge bosons (W) via quark-antiquark annihilation offers an unique opportunity to investigate the electroweak symmetry breaking mechanism of the Standard Model. The study of fixed-order cross sections for this process have been achieved up to next-to-next-to-leading order (NNLO) in a perturbative expansion of the strong coupling constant. Yet there are large theoretical uncertainties in some kinematic regions of phase space that can spoil the reliability of perturbative predictions. Using QCD factorization theorem and the renormalization group equation, we have set up a framework in which we can resum the large contributions up to next-to-next-to-leading logarithmic (NNLL) accuracy. In a paper accepted for publication on Eur. Phys. J C (2026), we find that the unphysical renormalization and factorization scale uncertainties at NNLO+NNLL decrease by ~ 2 -3%, in comparison to NNLO results.

5 Mini-review on threshold resummation

In this mini review ¹⁵⁾ we have briefly summarized the theoretical status, both in fixed order as well as in resummation, for the production of a pair of on-shell Z bosons. We have reviewed a theoretical framework for threshold resummation, which we plan to implement in our effort towards a joint resummation of threshold and high-energy logarithms.

6 Talks in Year 2025

1. A. Papa,
“BFKL phenomenology via eigenfunctions of the NLO kernel”,
Low-x Meeting, Medulin (Croatia), September 8-12, 2025
<https://indico.cern.ch/event/1490864/>
2. C. Branchina,
“Bubble wall dynamics at the electroweak phase transition”,
2025 CAU-IBS Beyond the Standard Model Workshop, Seoul, February 17-21, 2025
<https://indico.cern.ch/event/1492675/>
3. C. Branchina,
“Bubble wall dynamics and the electroweak phase transition”,
Advancing gravitational wave predictions from cosmological first-order phase transitions,
Geneva, August 25-29, 2025
<https://indico.cern.ch/event/1511688/>
4. C. Branchina,
”Bubble wall dynamics and the electroweak phase transition”,
Scalars 2025: Higgs bosons and cosmology, Warsaw, September 22-25, 2025
<https://indico2.fuw.edu.pl/event/16/>
5. C. Branchina,
“Bubble wall dynamics and the electroweak phase transition”,
Quantum Universe 2025, Avellino, October 27-31, 2025
<https://www.quantumuniverse.it/>
6. C. Branchina,
“Bubble wall dynamics and the electroweak phase transition”,
Quantum Universe 2025, Avellino, October 27-31, 2025
<https://www.quantumuniverse.it/>
7. C. Branchina,
“(A)dS Dilatonic Black Holes”,
QGSKY Annual meeting 2025, Catania, October 27-31, 2025
<https://agenda.infn.it/event/48671/overview>
8. M.Razzaq,
“Electroweak Phase Transition in a Non-Abelian Vector Dark Matter Scenario”,
Scalars 2025: Higgs Bosons and Cosmology, Warsaw, September 22 -25, 2025
<https://indico2.fuw.edu.pl/event/16/overview>
9. M.Razzaq,
“Probing the Electroweak Phase Transition in the Dark Sector”,
Beyond the Standard Model : From Theory to Experiment (BSM-2025), Istanbul, October
06 -09, 2025
<https://indico.cern.ch/event/1507517/>
10. A. Conaci,
“Bubble wall dynamics at the EW phase transition”,
New Frontiers in Theoretical Physics, Cortona, May 20-23, 2025
<https://agenda.infn.it/event/44589/>

11. A. Conaci,
“Bubble wall dynamics at the EW phase transition”,
Quantum Universe Attract.Workshop, Hamburg, November 23-25, 2025
<https://indico.desy.de/event/50023/>
12. L. Panizzi,
“Deconstructing signals of new physics at colliders - a case study with Higgs pair production”,
IRN Terascale @ Montpellier, Montpellier, 24-26 November 2025
<https://indico.in2p3.fr/event/36777/overview>
13. L. Panizzi,
“t-channel DM models benchmark proposal”,
LHC BSM Working Group general meeting, CERN, 10-13 November 2025
<https://indico.cern.ch/event/1550647/>
14. L. Panizzi,
“Width and interference effects in BSM searches”,
LHC Higgs Working Group WG3 (BSM) – Extended Higgs Sector subgroup meeting, online,
5 November 2025,
<https://indico.cern.ch/event/1605113/>
15. L. Panizzi,
“Deconstruction approach to di-Higgs production and application to NMSSM”,
Higgs@Capri 2025, Anacapri, 6-10 October 2025
<https://agenda.infn.it/event/45337/overview>
16. L. Panizzi,
Dark Tools, Torino, 16-19 June 2025,
”t-channel dark matter and Madanalysis 5”
<https://agenda.irmp.ucl.ac.be/event/5375/>
17. P. Banerjee,
“Decay of pseudoscalar Higgs boson to three partons at higher orders in the dimensional
regulator”,
RADCOR 2025, October 5-10 Puri, India
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“Light scalars within the \mathcal{CP} -conserving Aligned-two-Higgs-doublet model,”
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“The Electric Dipole Moment of the electron in the decoupling limit of the aligned two-Higgs doublet model,”
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“Flavor-changing axions and Dirac neutrino masses,”
Phys. Rev. D **111** (2025) no.11, 11 [arXiv:2502.16000 [hep-ph]].
8. C. Branchina, V. Branchina, F. Contino and A. Pernace,
“Path integral measure and the cosmological constant,”
Phys. Rev. D **111** (2025) no.10, 105018 [arXiv:2412.10194 [hep-th]].
9. C. Branchina, V. Branchina, F. Contino and A. Pernace,
“Path integral measure and RG equations for gravity,”
Phys. Rev. D **111** (2025) no.12, 125021 [arXiv:2412.14108 [hep-th]].
10. C. Branchina, V. Branchina, F. Contino, R. Gandolfo and A. Pernace,
“Diffeomorphism invariance of the effective gravitational action,”
Phys. Rev. D **112** (2025) no.4, 045002 [arXiv:2506.05100 [hep-th]].
11. C. Branchina, H. M. Lee and K. Yamashita,
“Standard Model anomalies and vacuum stability for lepton portals with extra U(1) symmetry”,
JHEP **03** (2025), 122 [arXiv:2407.14826 [hep-ph]].
12. S. Moretti, L. Panizzi and L. Shang,
“Vector-like tops from first generation quarks: the role of width and coupling chiralities in same-charge production at the LHC”,
JHEP **06** (2025), 132 [arXiv:2504.05476 [hep-ph]].
13. C. Arina, B. Fuks, L. Panizzi, M. J. Baker, A. S. Cornell, J. Heisig, B. Maier, R. Pedro, D. Trischuk and D. Agin, *et al.*
“t-channel dark matter models – a whitepaper”,
Eur. Phys. J. C **85** (2025), 975 [erratum: Eur. Phys. J. C **85** (2025) no.10, 1105] [arXiv:2504.10597 [hep-ph]].
14. S. Moretti, L. Panizzi, J. Sjölin and H. Waltari,
“Deconstructing resonant Higgs boson pair production at the LHC: Effects of colored and neutral scalars in the NMSSM test case”,
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15. P. Banerjee,
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SFT - Statistical Field Theory and Applications

B. Dey (Ass.), E. G. Cinnirella (Ass.), D. Giuliano (Resp.),
F. Plastina (Ass.), J. Settimo (Ass.)

1 Phase diagram of the disordered Kitaev chain with long range pairing connected to external baths : 1)

We have studied the phase diagram of a disordered Kitaev chain with long-range pairing when connected to two metallic leads exchanging particles with external Lindblad baths. Along our work, we (i) monitor the subgap modes at increasing disorder, (ii) compute the current flowing across the system at a finite voltage bias between the baths, and (iii) study the normal single particle lead correlations across the chain. Throughout our derivation, we evidence the interplay between disorder and topology. In particular, we evidence the reentrant behavior of the massive, topological phase at limited values of the disorder strength, similar to what happens in the short-range pairing Kitaev model. Our results suggest the possibility of a disorder-induced direct transition between the massive and the short-range topological phase of the long-range pairing Kitaev model.

2 Phase diagram of the disordered open longer-range Kitaev chain: 2)

We have computed the disorder averaged dc conductance in the non-equilibrium steady state that sets in between a longer-range Kitaev chain and a metallic lead connected to an external reservoir, as a function of the system parameters and of the disorder strength. From our results, we have mapped out the phase diagram of the disordered chain for different types of disorder and discuss the corresponding effects of the interplay between topology and disorder in the system. To do so, we set up a combined analytical and numerical approach, which is potentially amenable of straightforward generalizations to other disordered topological systems.

3 Pontus Mpemba effect and dynamical phase transitions: 3)

We have demonstrated that open quantum systems exhibiting dynamical phase transitions (DPTs) allow for efficient protocols implementing the Pontus-Mpemba effect. The relaxation speed-up toward a predesignated target state is tied to the existence of a long metastable time window preceding the DPT and can be exploited in applications to systematically optimize quantum protocols. As paradigmatic example for the connection between DPTs and quantum Mpemba effects, we study one-dimensional (1D) interacting lattice fermions corresponding to a dissipative variant of the Gross-Neveu (GN) model.

4 Spin and thermal current scaling at a -junction of XX spin chains: 4)

We have studied the boundary phase diagram and the low-temperature heat and magnetization transport at a -junction of XX spin chains. Depending on the magnetization axis anisotropy

between the magnetic exchange interactions at the junction, the system exhibits two different strong-coupling regimes at low energies/temperatures, similar to the overscreened (topological) four- and to the two-channel Kondo fixed points. Using renormalization group arguments combined with boundary conformal field theory methods, we show the instability of the former under any XY-type anisotropy at the junction. We analyze the low-temperature spin and the heat conductances. We find evidence of spin fractionalization of the elementary excitations at the four-channel Kondo fixed point by means of the magnetic Wiedemann-Franz law. We caution that the instability under XY anisotropy may hinder the detection of the phenomenology related to the four-channel Kondo effect, therefore requiring careful control in experimental realizations.

5 Post-quench relaxation dynamics of Gross-Neveu lattice fermions : 5)

We have studied the quantum relaxation dynamics for a lattice version of the one-dimensional (1D) N -flavor Gross-Neveu (GN) model after a Hamiltonian parameter quench. Allowing for a system-reservoir coupling γ , we numerically described the system dynamics through a time-dependent self-consistent Lindblad master equation. For a closed ($\gamma = 0$) finite-size system subjected to an interaction parameter quench, the order parameter dynamics exhibits oscillations and revivals. In the thermodynamic limit, our results imply that the order parameter reaches its post-quench stationary value in accordance with the eigenstate thermalization hypothesis (ETH). However, time-dependent finite-momentum correlation matrix elements equilibrate only if $\gamma > 0$. Our findings highlight subtle yet important aspects of the post-quench relaxation dynamics of quantum many-body systems

6 Theory of charge-to-spin conversion under quantum confinement: 6)

We have developed a microscopic scattering-matrix theory for charge-to-spin conversion in quantum-confined Rashba systems. We derive real-space linear-response spin/charge currents including confinement and orbital magnetic effects, and relate the framework to Hall-bar conversion signals.

7 Topology-enhanced superconducting qubit networks for in-sensor quantum information processing: 7)

We have studied how network topology impacts the magnetic response of inductively coupled flux-qubit arrays. By contrasting linear and cross-shaped geometries, we show a cooperative enhancement of susceptibility that supports in-sensor processing and reservoir-computing functionalities.

8 Probing graph topology from local quantum measurements: 8)

We have shown that global properties of an unknown quantum graph can be inferred from strictly local measurements on a small subset of nodes. Using short-time probing with a lightweight learning-style readout, we extract topology indicators relevant for network diagnostics and intrusion detection.

9 Hybrid Quantum Reservoir Computing: 9, 10)

Reservoir computing (RC) is an effective method for predicting chaotic systems by using a high-dimensional dynamic reservoir with fixed internal weights, while keeping the learning phase linear, which simplifies training and reduces computational complexity compared to fully trained recurrent neural networks (RNNs). Quantum reservoir computing (QRC) uses the exponential growth of

Hilbert spaces in quantum systems, allowing for greater information processing, memory capacity, and computational power. However, the original QRC proposal requires coherent injection of inputs multiple times, complicating practical implementation. We presented a hybrid quantum-classical approach that implements memory through classical post-processing of quantum measurements, which avoids the need for multiple coherent input injections. Our approach is evaluated on benchmark tasks, including the chaotic Mackey-Glass time series prediction. Furthermore, we have introduced a multi-dimensional extension of our hybrid quantum reservoir computing architecture, to forecast low-dimensional chaotic dynamics. The approach combines quantum evolution with enhanced memory and is benchmarked on reduced 2D Navier–Stokes and Lorenz-63, improving the prediction horizon in suitable regimes.

10 Numerical investigations of turbulence in Mediterranean cyclone events: insights from the Turbimecs project: 11)

We have investigated turbulence in Mediterranean tropical-like cyclones through high-resolution WRF simulations of representative Medicanes. Sensitivity studies and Proper Orthogonal Decomposition are used to disentangle multi-scale contributions and identify coherent structures during cyclone maturation.

11 Quantum Extreme Learning Machines: 12, 13)

Quantum Machine Learning (QML) has emerged as a promising framework to exploit quantum mechanics for computational advantage. We have investigated Quantum Extreme Learning Machines, a quantum analogue of classical Extreme Learning Machines in which training is restricted to the output layer. Our architecture combines dimensionality reduction (via PCA or Autoencoders), quantum state encoding, evolution under an XX Hamiltonian, and projective measurement to produce features for a classical single-layer classifier. By analyzing the classification accuracy as a function of evolution time, we identified a sharp transition between low- and high-accuracy regimes, followed by saturation. Remarkably, the saturation value coincides with that obtained using random unitaries that generate maximally complex dynamics, even though the XX model is integrable and local. We showed that this performance enhancement correlates with the onset of entanglement, which improves the embedding of classical data in Hilbert space and leads to more separable clusters in measurement probability space.

12 Quantum kernel models: 14, 15)

Among quantum-inspired machine learning algorithms, the Projected Quantum Kernel (PQK) stands out for its elegant solution of projecting the data encoded in the Hilbert space into a classical space. We explored how a PQK approach can be employed to construct a prediction model on IoT data, and compared PQK with common Quantum Kernel methods and their classical counterparts, while also investigating the impact of various feature maps in encoding classical IoT data into quantum computers. In a different context, we used a support vector regressor based on a projected quantum kernel method to predict the density structure of 1D fermionic systems of interest in quantum chemistry and quantum matter. The kernel is built on with the observables of a quantum reservoir implementable with interacting Rydberg atoms. Training and test data of the fermionic system are generated using a Density Functional Theory approach. We found that the method outperforms the classical linear kernel method if one wait long enough before performing measurement and that it's competitive with the radial basis function method.

13 Quantum State transfer protocols: 16)

Quantum state transfer protocols are a major toolkit in many quantum information processing tasks, from quantum key distribution to quantum computation. To assess performance of a such a protocol, one often relies on the average fidelity between the input and the output states. Going beyond this scheme, we analyzed the entire probability distribution of fidelity, providing a general framework to derive it for the transfer of single- and two-qubit states.

List of Conference talks:

1. D. Giuliano, “Current correlations for anyonic particles in the edge states of a Fractional Quantum Hall system”, invited talk, 09/07/2025, FisMat2025 conference, Venezia.
2. B. Dey presented poster on “Quenches and symmetry restoration in 1 + 1 dimensional Gross-Neveu model connected to bath” at Joint ICTP-WE Heraeus Conference on Non-equilibrium Quantum Statistical Physics, ICTP, 21 – 23/07/2025.
3. E. G. Cinnirella, ”Phase diagram of the disordered Kitaev chain with long range pairing connected to external baths”, poster, 21-23/07/2025, Joint ICTP-WE Heraeus Conference on Non-Equilibrium Quantum Statistical Physics, Trieste.
4. E. G. Cinnirella, ”Fate of high winding number topological phases in the disordered extended Su-Schrieffer-Heeger model”, talk, 14/01/2025, 11th International conference on Quantum Simulation and Quantum Walks, Napoli.
5. J. Settimo, “Hybrid Quantum Computing applied to Complex Systems”, invited talk, 28/11/2025, Workshop on Open Problems in Quantum Machine Learning, Milan, Italy.
6. J. Settimo, “Hybrid Quantum Reservoir Computing applied to complex systems”, invited talk, 09/09/2025, 25th Italian Quantum Information Science Conference (IQIS25), Bologna, Italy.
7. J. Settimo, “Hybrid Quantum Computing for Optimization and Machine Learning”, invited talk, 20–24/06/2025, 29th International Conference on Circuits, Systems, Communications and Computers (CSCC), Salerno, Italy.
8. F. Plastina, “Quantum Coherence and Anomalous Work Extraction in qubit gates Dynamics”, talk, 28/08/2025, Fundamental Limits of Quantum Technologies, Dublino.
9. F. Plastina, “Non-adiabaticity and irreversible entropy production in the quantum regime”, invited talk, 10/07/2025, FisMat25 - WS 46: Quantum energetics and resource theories, Venezia, Italy.
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Contribution to TIME2QUEST

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M. Pisarra (M. P., RTT), J. Settimo (J. S., Post Doc), F. Percivalle (F. P., Post Doc),
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The TIME2QUEST initiative aims to establish a unified theoretical and computational framework for the investigation of ultrathin two-dimensional materials (2DMs) and their integration into emerging quantum technologies. The program combines *ab initio* electronic-structure methods, primarily density-functional theory (DFT), complemented by time-dependent (TD) DFT and many-body perturbation theory (MBPT), with quantum thermodynamics and quantum-information approaches. Its dual objective is: (i) to elucidate emergent quantum phenomena in low-dimensional systems, including flat bands, topological states, defect-driven localization, excitonic effects, and spin-orbit engineering; and (ii) to translate these phenomena into quantum functionalities, such as quantum simulation, quantum-enhanced computation, and noise-resilient architectures. The 2025 research activities have substantially advanced both pillars through coordinated theoretical development, high-performance computing, quantum machine learning, and excited-state many-body simulations.

1 Geometric Control of Correlated Phases in Twisted Bilayers

A central achievement of the initiative is the demonstration that magic-angle twisted bilayer graphene belongs to a broader class of geometrically tunable structures. A rigorous equivalence relation linking twist angle θ and interlayer distance d was established ¹⁾, showing that quasi-flat-band physics is not uniquely tied to the canonical magic angle ($\sim 1.05^\circ$), but can be reproduced at larger twist angles via interlayer compression. The resulting spectra are homothetic within a controlled scaling regime. The mapping was validated at three complementary levels: continuum Bistritzer-MacDonald theory, tight-binding models with exponential interlayer hopping, and fully *ab initio* DFT calculations. “Magic distances” were identified at $\theta \approx 3^\circ\text{--}5^\circ$, where quasi-flat bands with bandwidths of a few tens of meV emerge while maintaining tractable supercells ($\sim 400\text{--}1100$ atoms), enabling first-principles access to correlated flat-band physics. Complementary experimental-theoretical investigations resolved twisted bilayer and trilayer domains in three-dimensional nanoporous graphene through STM imaging and DFT modeling ²⁾, consolidating the connection between atomic-scale structure and electronic reconstruction. In parallel, spin-orbit coupling was engineered via Te intercalation in graphene/Ir(111) ³⁾, inducing a room-temperature spin-orbit gap up to 240 meV. Spin-resolved ARPES and DFT revealed a quasi-chiral spin texture dominated by intrinsic (Kane-Mele type) coupling, with tunable Dirac-point position and preserved linear dispersion. The combined observation of gap opening, spin splitting, and edge-state signatures provides evidence for a proximity-induced topological regime, establishing graphene/Te/Ir(111) as a platform for spin-dependent transport and quantum spin Hall physics.

2 Defect Physics in Two-Dimensional Transition-Metal Dichalcogenides

Scanning tunneling spectroscopy combined with DFT enabled identification of defect ionization levels in monolayer MoTe₂ ⁴⁾. Bias-dependent charging rings revealed sub- and supra-Fermi-

level ionization mechanisms, establishing a quantitative link between local electronic structure and defect-driven charge trapping. In parallel, MoS₂ nanoribbons were investigated to elucidate the interplay between edge passivation, quasiparticle corrections, and plasmonic excitations ¹²). DFT, G_0W_0 , TDDFT-RPA, and BSE calculations show that one-dimensional confinement and chemical edge engineering drive controlled transitions between semiconducting and semimetallic regimes, with tunable excitonic and plasmonic responses. Together, these studies provide a microscopic picture of defect-induced localization, edge-state engineering, and collective excitations in 2D semiconductors.

3 Excited-State Many-Body Modeling of Molecular Quantum Materials

The MBPT framework was extended to photoactive organic systems relevant for quantum photonics and optoelectronics. TDDFT, TDDFT-RPA, and GW-BSE approaches were benchmarked for singlet-fission chromophores and TADF emitters ¹⁰), establishing a methodological hierarchy from screening-level TDDFT to quantitatively reliable BSE-GW for strongly correlated excitonic states. Complementary analyses clarified the interplay between charge-transfer character, singlet-triplet gaps, and many-body corrections in organic emitters ¹¹). Porphyrin-based nanoribbons were further investigated via combined DFT, GW, TDDFT, and BSE simulations ¹³). The coexistence of dispersive and quasi-flat bands in porphyrin-nickel nanostructures yields sharp, structurally tunable excitonic and plasmonic features, consolidating the capability to describe quasiparticle and collective excitations across inorganic and organic low-dimensional systems within a unified MBPT framework.

4 Quantum Machine Learning and Nonequilibrium Functional Theories

Quantum-enhanced learning methods were interfaced with density-functional datasets. A projected-quantum-kernel support vector regression scheme predicts fermionic densities generated via DFT ⁵), while a memory-augmented hybrid quantum reservoir architecture enables extended chaotic time-series prediction ⁶). Quantum extreme learning machines were further demonstrated for classification tasks ⁷). In addition, a density-functional framework for full quantum work statistics in interacting many-body systems was developed and submitted to *Quantum Science and Technology* ⁹), bridging nonequilibrium quantum thermodynamics and functional theory. An improved Bayesian measurement-error mitigation protocol for multiqubit superconducting platforms was introduced ⁸). By incorporating detector-response modeling and optimized noise representations, the approach enhances reliability in noisy intermediate-scale quantum devices and supports hybrid quantum-materials simulations within TIME2QUEST.

Conclusion

The 2025 activities define a coherent trajectory combining geometric band engineering, defect-driven quantum functionality, many-body excitonic modeling, quantum-enhanced density prediction, and noise-resilient quantum-information protocols. Strategic directions for 2026–2027 include time-dependent DFT studies of plasmon excitations in magic-distance bilayers, GW/BSE investigations of excitonic instabilities in twisted heterostructures, integration of quantum reservoir methods with realistic material Hamiltonians, and extension of geometric equivalence concepts to heterogeneous twisted multilayers. TIME2QUEST has consolidated a national research network addressing correlated-electron physics, excitonic phenomena, and quantum-information applications within a unified first-principles framework. The integration of geometric control, many-body

electronic structure, and quantum-information methodologies positions the initiative at the interface between quantum materials science and quantum engineering.

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STAR Project

STAR Southern Europe Thomson Backscattering Source for Applied Research

S. Donato (Ass.)

1 Reconstruction algorithms for breast computed tomography with synchrotron radiation

This study, in collaboration with the University of Trieste, the INFN of Trieste and Cagliari, the universities of Sydney and Melbourne, and the Australian synchrotron, presents a systematic comparison of three CT reconstruction algorithms (FBP, UTR, and cSART) for phase-contrast breast CT imaging using fresh mastectomy samples. Both objective image quality metrics (spatial resolution, contrast, SNR, CNR) and subjective evaluations by experienced radiologists were assessed, providing a holistic approach to image quality analysis. While cSART outperformed the other algorithms in objective metrics, FBP consistently received higher subjective ratings, highlighting a discrepancy potentially explained by the emphasis radiologists place on image contrast over noise-related factors. Conducted under clinically relevant conditions, including realistic doses and beamline setups, this work bridges computational imaging and clinical application, offering key insights for future breast CT imaging protocols. Additionally, the study introduces a robust methodology combining physics-based and radiologist-centered evaluations, contributing to the development of hybrid imaging assessment tools. The findings support the clinical translation of phase-contrast CT imaging, paving the way for live patient studies at the Australian Synchrotron.

2 Multidisciplinary study on Messinian halite facies

This study, in collaboration with the universities of Calabria, Napoli and Galway, investigates the Messinian halite facies to better understand the processes of halite crystallisation and the associated depositional environments during the Messinian Salinity Crisis. By integrating geochemical analyses, petrographic observations, and fluid inclusion studies, we reconstructed the physicochemical conditions of halite formation, including brine composition, temperature, and evaporation dynamics. The study distinguishes between different halite growth mechanisms and depositional settings, such as shallow brine pans versus deeper water environments, and provides insights into the evolution of evaporitic systems during extreme salinity events. Overall, the work contributes to refining paleoenvironmental models of Messinian evaporite deposition and improves our understanding of large-scale evaporitic processes in restricted marine basins.

3 Advances in Spectral Phase-Contrast X-ray Imaging Using High-Resolution Detectors

This study, undertaken by INFN's Sphere-X project implemented at the Elettra Sincrotrone Trieste, explores spectral phase-contrast X-ray imaging using high-resolution detectors, focusing on how energy-resolving detection can enhance both phase and material sensitivity. It discusses the underlying principles of spectral phase-contrast imaging, detector requirements, and reconstruction

approaches, and demonstrates how combining spectral information with phase contrast improves image quality, material discrimination, and quantitative analysis. The study highlights the advantages of high-resolution spectral detectors for advanced X-ray imaging applications, particularly in cases where conventional absorption-based imaging is limited.

4 Simultaneous Spectral and Phase-Contrast X-ray Micro-CT Using a Dual-Detector System

The last study, in collaboration with the universities of Trieste and Ferrara, within the activities of the INFN's Sphere-X project, presents the design and implementation of a dual-detector X-ray μ -CT system that enables the simultaneous acquisition of spectral and phase-contrast information. By combining an energy-resolving detector with a high-resolution detector positioned at different propagation distances, the system captures complementary absorption, spectral, and phase-contrast signals in a single scan. The study describes the system architecture, data acquisition strategy, and reconstruction workflow, and demonstrates its capability to improve material discrimination and image contrast compared to conventional μ -CT. The proposed approach highlights the potential of dual-detector configurations for efficient, quantitative, and multimodal X-ray imaging in advanced microtomography applications.

5 List of Conference Talks

1. S. Donato, 20th European Molecular Imaging Meeting, 11-14 March 2025, Bilbao, Spain (poster and oral presentation - invited speaker).
2. S. Donato, EuAPS Annual Meeting 2025, 4-5 July 2025, Laboratori Nazionali del Sud, Catania (CT), Italy (oral presentation - invited speaker).
3. S. Donato, International Workshop on Imaging (Imaging 25) - Villa Monastero, Varenna, Italy September 23 - 25, 2025 (oral presentation and chair).

6 Publications

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STAR: a Compton scattering X-ray source

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

1 Introduction

In 2025, the research activity focused on improving the operational setup of the STAR ICS source^{1) 2)}, with two goals: (i) strengthening the EPICS-based control system to enable reliable machine operation and scalable subsystem integration, and (ii) carrying out the first commissioning campaign, from RF conditioning to electron-beam transport.

2 Research activities

The STAR control system relies on the EPICS framework, which enables control of devices and organizes data into Process Variables that are distributed across the LAN. The operator environment was enhanced and updated through the migration from CSS to Phoebus, improving maintainability and consolidating core tools for displays, monitoring, trending, and alarm handling; this enabled more consistent integration across the system. The main STAR subsystems were integrated in a unified operational environment. This included beam diagnostics and transport monitoring, camera-based visualization of beam flags along the beamline, as well as the supervision of magnets, vacuum and cooling systems, low-level RF interfaces, and timing/synchronization services. The guiding goal was to improve observability and reproducibility in operations, ensuring that machine status can be assessed quickly, interlock and alarm conditions can be interpreted clearly, and consistent machine configurations can be applied and restored.

To enable advanced tuning of STAR beamline, a real-time optimization approach was defined by integrating genetic-algorithm tools with the EPICS control system. The proposed framework supports automatic tuning procedures in which machine settings are adjusted via the control system and evaluated online using beam diagnostics to drive the optimization.

Commissioning activities progressed in parallel, aiming at stable RF operation and the validation of the injector and beamline chain. The campaign included RF conditioning and tuning of the accelerating sections, extending from S-band operation toward C-band structures, with attention to stable vacuum behavior and acceptable reflected power. Electron beam generation and propagation along the beamline was monitored using screen stations and camera readout integrated into the control environment, enabling fast validation of beam presence and trajectory. Subsequent transport steps demonstrated delivery up to the interaction chamber³⁾. Although beam parameters were not yet tuned for inverse Compton performance, the achieved beam delivery demonstrates the robustness of the facility and the soundness of the beamline design, providing a solid foundation for further optimisation and radiation production.

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3. A. Olivieri et al., “Status project of STAR: a Compton scattering X-ray source”, submitted for publication to *Journal of Advanced Instrumentation in Science*, 2026.

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, initially 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 system (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.*

The capabilities of the Data Center were significantly expanded in the year 2024 and consist now of a total of eight fully conditioned racks. A new network equipment for the high-speed connection (up to 40 Gbps) between the ReCaS data center and the STAR building is now operational and the two next-generation GPU-servers for tomographic image reconstruction and analysis are fully exploited thanks to the installation of a Kubeflow instance on each of them. Six NVIDIA A100 80GB and four NVIDIA L40S 40GB are currently hosted by the two most powerful computing servers mentioned above.

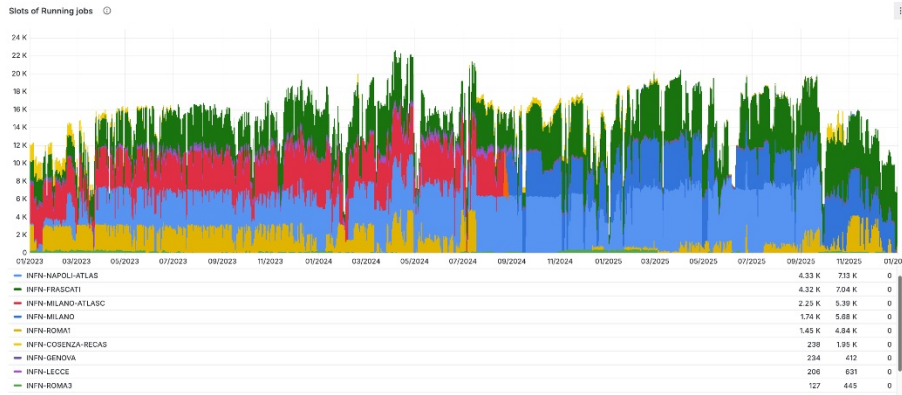


Figure 2: A comparison of the slots of running jobs in the period 2023-2025 for the ATLAS Tier2/3 centers and the ReCas Cosenza Data Center

2 2025 Performance and software developments

The ReCaS Cosenza Data Center has operated (see Figure 2) for the most part of the year 2025 with an intermittent efficiency and stability using only a portion of the computing resources as a security measure. This decreased number of the overall cpu/core utilized was caused by the loss of redundancy on the cooling system. A new chiller is still needed for the future to bring cooling redundancy operational and cpu/core on full usage again. Concerning the software developments, several activities have been carried out during 2025. Most of them have been mostly devoted to the following main area: the grid hardware and software infrastructure upgrade, the testing and improvement of a new web based user interface with a machine learning (ML) toolkit for kubernetes (Kubeflow), the customization of docker images and JupyterLab dashboard for several scientific research needs (high resolution tomographic images for the STAR project, ATLAS analyses and ML driven projects).

A full migration of the grid site to ipv6 involved a complete reconfiguration of the network layout. The DNS was moved from the Physics Department network center to the Data Center and other services will be moved too, to grant a complete independence of The Data Center from any other infrastructure (L3 routing included). This work is currently in progress and will end with a direct ipv6 link of the Data Center to the GARR POP.

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 two high schools in Riobamba, Ecuador, are taking part in the project and were coordinated by the INFN-Cosenza group.

From April 2 to 4, 2025, the meeting *Tra Calabria e Ecuador - Liceali a lavoro insieme su temi legati alle radiazioni ionizzanti* was held in collaboration with the Physics Department of UNICAL and the Fermi Scientific High School - Brutium Technical Center in Cosenza. Over the three days, the students worked side by side with experts from various scientific fields related to the topic of ionizing radiation, seen both as a cause of health risks and as a method of diagnosing and treating diseases, such as cancer treatment. In particular, during the first day they participated in the meeting with experts from the Italian public and private sectors to whom they presented radon gas concentration measurements performed in Italy or Ecuador as part of the INFN RadioLab project. On the second day, they actively participated in soil radon gas concentration measurements conducted together with expert geologists from the CNR-IRPI and carried out radon gas concentration measurements in spring water in the Municipality of Montalto Uffugo. On the third day, at the Physics Department of the University of Calabria, they participated in the International Masterclass in Particle Therapy, coordinated by CERN and the German GSI Institute, to simulate the treatment plan for head, prostate, or liver cancer with external particle beams. The event was also covered by RaiNews Calabria (see <https://sl1nk.com/rainews-radiolab>).

The event was financially supported by the Calabrian Order of Geologists, the FUCSA project and with the patronage of the Province of Cosenza, the Municipality of Montalto Uffugo, and ARPA Calabria.

Vi presento ePIC

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

In 2025 INFN launched its participation to the international ePIC project, currently underway at BNL (USA). The INFN-Cosenza group conceived and implemented the *Vi presento ePIC* event for the INFN units contributing to the experiment, where the project was presented to high school students from various Italian cities. Following the event, based on what they learned, students were invited to create a video dissemination of the ePIC experiment to middle school students. The two winners (from Salerno and Lamezia Terme) participated to the ePIC Italia Collaboration meeting, held in Padua from 16 to 18 June 2025 (<https://agenda.infn.it/event/44600>).

In Calabria, 35 students from 5 schools participated. The event will be organized and replicated in 2026 with additional INFN units.

HOP – Hands on Physics 2025

M. Capua (Resp.), A. Chisari (Stud.), S. Fazio (Ass.), T. Rania (Dott.),
P. Riccardi (Ass.), C. Romeo (Stud.), G. Santoro (Dott.), 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 20 teachers from 11 Calabrian schools (<https://agenda.infn.it/event/48178/>) 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 offered 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.),
G. Santoro (Dott.), 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 2025, two events were organized:

- February 11, International Masterclasses - Hands-on particle physics - a special event for the International Day of Women in Science, with 31 students from Calabria high schools. (<https://agenda.infn.it/event/45078/>)
- April 4, Particle Therapy Masterclasses, with 32 students from Calabria high schools and 6 students from Ecuador (on site to take part in the RadioLab project). (<https://agenda.infn.it/event/45079/>)

The special event on February 11 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 included a talk by Maria Giovanna Durante, an internationally recognized researcher and pioneer in earthquake engineering, who shared her academic and professional journey with students, offering an inspiring example of women's impact in STEM.

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.) D. Liguori (Ass.),
A. Mastroberardino (Ass.), C. Petronio (Ass.), G. Santoro (Dott.),
M. Schioppa (Resp.), P. Turco (Tecn.)

1 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 the 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 2025 the group actively participated in the OCRA activities of the INFN-CC3M scientific commission. The group designed and built an experiment to be sent into the stratosphere with the aim of environmental monitoring of the stratosphere through the use of a light-type hot air balloon. The SEM (Stratosphere's Environmental Monitoring) project was born as a school-work alternation program at the Cariati Scientific High School in collaboration with the ABProject Space and as an implementation of the MoCRiS (Measurement of Cosmic Rays in Stratosphere) project [MOCRIS and MOCRIS2]. The data collected and analyzed by various ionizing radiation detectors have shown that ionizing radiation comes from the cosmos, that most of this radiation is made up of charged particles and that in the atmosphere they produce particle showers. Fig. 1 shows the balloon immediately after being launched. Fig. 2 shows the group of students, teachers



Figure 1: *The balloon and its payload immediately after launch.*

and researchers before the launch. In November, the group coordinated the International Cosmic Day 2025 of Calabrian schools. Students presented measurements of cosmic ray flux as a function of altitude and the Forbush decrease occurred the first June 2025, providing a physical interpretation of the results.



Figure 2: *The group of students, teachers and researchers just before the launch.*

3 List of Conference Talks and Poster by LNF Authors in Year 2025

1. G. Santoro, M. Schioppa, Measurement of the cosmic rays rate at different altitudes in the range 220-1880 masl from Cosenza to Botte Donato refuge in Sila Grande, 111° Congresso Nazionale della Società Italiana di Fisica, Palermo 22-26 September 2025.

References

1. D. Liguori et al., MoCriS: Misura di raggi cosmici in stratosfera, *Astronomia*, XLV, 1, p. 31-36, (2020).
2. D. Liguori et al., Misura di raggi cosmici con il progetto MoCRiS2, *La Fisica nella Scuola*, Anno LVI n. 4, 2023.

Premio Asimov 2025

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 2025 counted overall more than 15000 participants from 347 schools in all Italian Regions (except Aosta Valley). Calabria Region contributed with about 423 students from 11 different high schools. On May 15, 2025 a ceremony took place in an ancillary room of Aula Magna 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.