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 2022 in physics analyses, covering a wide range of important topics of the LHC physics program, as well as in the Phase-I and Phase-II upgrade activities. The most relevant contributions of Cosenza group are briefly reviewed below.

2 Physics Analysis

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

Studies of top-quark production and decay are major research goals at the LHC, providing both a precise probe of the Standard Model and a window on physics beyond the Standard Model. The measurements of the differential cross-sections for the production of $t\bar{t}$ pairs provide, in particular, stringent tests of pQCD calculations with heavy quarks and allow a precise determination of the top-quark mass and of the proton's parton distribution functions (PDFs) in a well-defined theoretical framework. In the year 2022 the group has been actively involved in the measurements, based on the full Run 2 ATLAS data sample, of the particle- and parton-level differential cross sections for the production of $t\bar{t}$ pairs in the lepton+jet finale state. Both analyses are presently at the editorial board stage and their pubblication is foreseen by mid 2023.

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

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

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

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

3 Phase-I and Phase-II Upgrades

3.1 Phase-I: The ATLAS-NSW SM1 modules

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

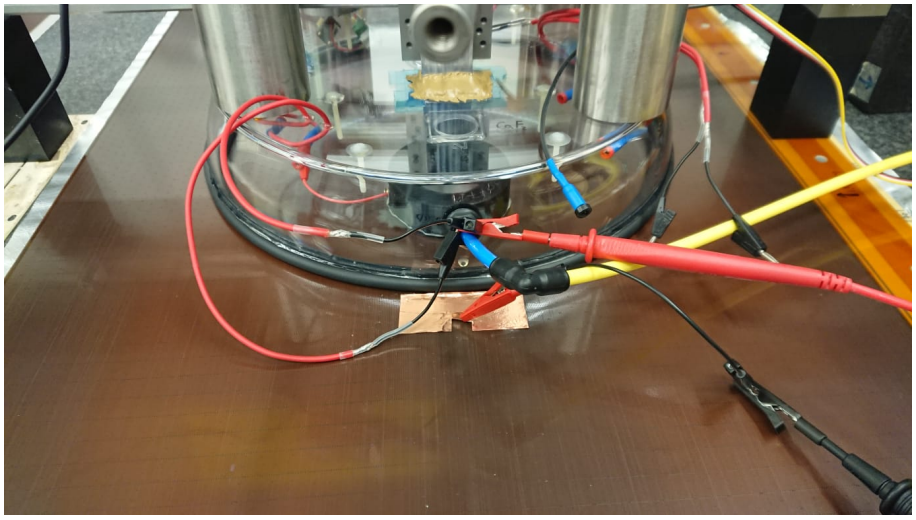

Figure 1: *The sutup employed to measure the Paschen curve for pure Ar, Ar:CO2 (93:7), Ar:CO2:isoC4H10 (93:5:2),*

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

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

4 List of Conference Talks and Poster by LNF Authors in Year 2022

1. G. Falsetti, Assembly procedures and QA/QC tests of the new double-ends readout panels of the new layer of trigger chambers for the phase II upgrade of the ATLAS barrel muon spectrometer, 108 Congresso Nazionale SIF, Milano, 12-16 settembre 2022.
2. D. Liguori, Misura del flusso di radiazione cosmica nell'acqua in funzione della profondità del rivelatore, 108 Congresso Nazionale SIF, Milano, 12-16 settembre 2022.
3. D. Malito, Top-antitop (l+jets) differential measurements at parton level, ATLAS Top Workshop, 4-6 May 2022, Valencia (Spain).
4. M. Schioppa, Measurement of the Paschen curves for the ATLAS NSW micromegas electrodes, for pure Ar and CO2 gases, and for Ar:CO2 gas mixture, 108 Congresso Nazionale SIF, Milano, 12-16 settembre 2022.
5. M. Schioppa, The readout panels for the BI-RPC project for ATLAS Phase-II upgrade, XVI Workshop on RPC and Related Detectors - 26-30 Sep, 2022 CERN.
6. M. Schioppa, Measurement of the cosmic radiation rate in water as a function of detector depth, CRIS2022, Napoli, 12-16 settembre 2022.
7. G. Tassone, Misura del tempo medio di cattura nucleare di μ^- in Fe, 108 Congresso Nazionale SIF, Milano, 12-16 settembre 2022.
8. E. Meoni, on behalf of the ATLAS Collaboration, "Determination of proton parton distribution functions using ATLAS data", 30th International Symposium on Lepton Photon Interactions at High Energies , LP 2021, 10-14 January 2022 , on-line.

5 Publications

References

1. J. Agarwala et al., Construction and test of the SM1 type Micromegas chambers for the upgrade of the ATLAS forward muon spectrometer, Nuclear Inst. and Methods in Physics Research, A, Volume 1040, 1 October 2022, 167285.

2. D. Liguori, D. Passarelli, M. Schioppa on behalf of OCRA collaboration, MoCRiL: Pacini's experiment in a modern and educational way, Journal of Physics: Conference Series, Volume 2429, DOI 10.1088/1742-6596/2429/1/012043.

3. J.F. La Porte, M. Schioppa, P. Schune, Calculation model of the electrical resistance of the resistive strips employed in the ATLAS NSW Micromegas chambers, ATL-COM-MUON-2022-024.

4. The ATLAS Collaboration,"Measurement of cross-sections for production of a Z boson in association with a flavor-inclusive or doubly b-tagged large-radius jet in proton-proton collisions at sqrt s = 13 TeV with the ATLAS experiment", arXiv:2204.12355 [hep-ex], Accepted by PRD.

5. The ATLAS Collaboration,"Cross-section measurements for the production of a Z-boson in association with high-transverse-momentum jets in pp collisions at sqrt s= 13 TeV with the ATLAS detector", arXiv:2205.02597 [hep-ex], Accepted by JHEP.

6. The ATLAS Collaboration, "Observation of gauge boson joint-polarisation states in $W^{\pm}Z$ production from pp collisions at sqrt s = 13 TeV with the ATLAS detector", arXiv:2211.09435 [hep-ex], Submitted to PLB - Chair of ATLAS Editorial Board is a member of Cosenza Group.

KLOE-2

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

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

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

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

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

EIC_net

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

1 The Electron-Ion Collider and the proposed ATHENA detector

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

Cosenza's group is part of the EIC Users' Group [M. Capua, Institutional Representative (I.R.)] and the ePIC Collaboration [S. Fazio, Collaboration Council representative (C.C.)]. In the year 2022 we have contributed to finalize the ATHENA proposal [1)] for a detector capable of delivering the EIC science case [S. Fazio, Exclusive P.W.G. co-coordinator] and the joined ePIC, the detector Collaboration which resulted from the merging of the ATHNA and ECCE proto-Collaborations. Cosenza's group is involved in the Simulation & physics Working Group [S. Fazio, co-coordinator]. This group puts together INFN-associated researchers involved or interested in the software, Monte Carlo simulation and physics performance studies at EIC, in order to discuss the coming developments.

Cosenza's group is also part of the R&D efforts on the realization of a dual RICH detector in the forward region of ePIC. Together with the INFN Sections of Bologna and Ferrara and the eRD110 Consortium for "photon sensors", we have applied to the EIC Project's call for targeted R&D and obtained co-funding for a postdoc hiring dedicated to the caracterization of SiPMs.

1.1 E*p*IC - a novel event generator

S. Fazio originally proposed a joint effort with key collaborators at BNL, CEA-Saclay, NCBJ-Warsaw, Mainz U. and Zagreb U. with the objective to develop a MC event generator for exclusive processes, based on most recent extractions of GPDs. In 2022, we have released a generator called E*p*IC [2)], which features a novel architecture based on the modular programming paradigm. In this way, the addition of new developments, such as new channels or models, is made as easy as possible. The E*p*IC generator is now being used to perform studies of Deeply Virtual Compton Scattering, Time-Like Compton Scattering, and exclusive π^0 production with the ePIC detector.

References

1. J. Adam *et al.* [ATHENA], JINST **17**, no.10, P10019 (2022) doi:10.1088/1748-0221/17/10/P10019 [arXiv:2210.09048 [physics.ins-det]].

2. E. C. Aschenauer, V. Batozskaya, S. Fazio, K. Gates, H. Moutarde, D. Sokhan, H. Spiesberger, P. Sznajder and K. Tezgin, Eur. Phys. J. C **82**, no.9, 819 (2022) doi:10.1140/epjc/s10052-022-10651-z [arXiv:2205.01762 [hep-ph]].

THEORETICAL PHYSICS

BELL
Fundamental Problems in Quantum Physics

G. Nisticò (Resp.)

1 Consistent derivation of relativistic quantum theories of single particle

The quantum theory of a spin 1/2 particle formulated by Dirac in 1928 suffered several problems that have their roots in the method of *canonical quantization* Dirac used to build up his theory. In fact canonical quantization does not derive the theory deductively from sound basic principles: it is just a procedure to build up *models* of specific quantum theories.

The lack of a deductive path makes ultimately very hard to identify the causes of the difficulties encountered by Dirac theory. One of these problems is the fact that according to Dirac theory each component $\dot{Q}_j$ of the quantum velocity has its absolute value equal to the speed of light; moreover, the solutions of the free Dirac equation predict violent oscillations of the expectation value of the particle position, a phenomenon called *zitterbewegung*.

In the present work a different approach is followed. We start from the following question: is zitterbewegung a necessary feature of the physics of a spin 1/2 particle? In other words it is asked whether Dirac theory is the unique possible theory for this kind of particle. This question is particularly interesting in relation to the fact that there is an approach for developing the quantum theory of a free particle, alternative to canonical quantization, which makes use of group theoretical methods. Differently from canonical quantization, this alternative method deductively develops the theory from two basic principles: invariance of the theory and covariance of position with respect to relativistic transformations. A theory developed according to this method does not suffer the problems of canonical quantization: the validity of its predictions is implied by the validity of the basic principles, and therefore inconsistencies, such as the negative probabilities of Klein-Gordon theory, should be avoided. For these reasons, our work strictly complies with this epistemically grounded method.

Our results ascertain that Dirac theory is just one of the consistent theories for a free Dirac particle. The class of possible quantum theories for free Dirac particle is explicitly determined. A special subclass is identified whose theories are free from singular features, such as luminal velocity for massive particles and zitterbewegung. Each theory is characterized by a particular transformation property of position with respect to boosts. Dirac theory is *completely* characterized by its peculiar such a transformation property.

An ideal experimental test is designed for a free Dirac particle, such that the predictions of the results by Dirac theory and one of the alternative theories are different, so that the problem of which theory is empirically valid can be experimentally settled, at least in principle.

References

1. Nisticò G. 2022 *Consistent Theories of Free Dirac Particle Without Singular Predictions,* Particles (2022) 2023:1-16 https://doi.org/10.3390/particles6010001

GAST

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

1 Research activity in 2022

During the year 2022 my research activity concerned the following topics:

• In collaboration with D. Fioravanti (INFN Bologna, IS GAST) we developed a formalism which allows to associate to a generic quantum integrable model (in $1+1$ dimensions) a differential equation. We tested our proposal for sine-Gordon model (a QFT) and more importantly for spin chains. Our constructions explains the deep reasons of the appearing of the so-called Ordinary Differential Equations/Integrable Models correspondence. On these topics we wrote the paper [1)], which was accepted in Phys. Lett. B in January 2023, and the conference paper [2)]. We are now preparing a longer paper on the same subject.

• In collaboration with A. Nava, D. Giuliano and A. Papa (INFN Cosenza) we proposed a model to implement and simulate different traffic-flow conditions in terms of quantum graphs hosting an (N+1)-level dot at each site. Our model applies for instance to a traffic junction, with quantum levels keeping track of the type and of the destination of each vehicle. Our predictions agree with real data of traffic in a junction. The paper [3)] on this subject was published in SciPost Phys.Core.

• I continued the study of various applications of Lindblad equation approach. For instance, in collaboration with A. Nava, D. Giuliano and L.Lepori (INFN Cosenza) we studied the nonequilibrium stationary state of a benzene ring connected to two reservoirs in the large bias regime, a prototype of a generic molecular electronic device. These original results were published in the conference paper [4)].

2 List of Conference Talks in Year 2022

1. M. Rossi, On the origin of the correspondence between integrable models and differential equations, ICHEP2022, Formal theory parallel section, 6-13 Luglio 2022, https://agenda.infn.it/event/28874/;

2. M. Rossi, On the origin of the correspondence between integrable models and differential equations, Recent Advances in the Theory of Quantum Integrable Systems, Lyon, 29 Agosto-2 Settembre 2022, https://lapth.cnrs.fr/conferences/RAQIS/RAQIS22/;

3. M. Rossi, On the origin of the correspondence between integrable models and differential equations, SM&FT 2022, Bari, 19-21 Dicembre 2022, https://agenda.infn.it/event/28754/.

References

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

2. D. Fioravanti, M. Rossi, On the origin of the correspondence between classical and quantum integrable theories, PoS ICHEP2022 439, contribution to: ICHEP 2022, 439

3. A. Nava, D. Giuliano, A. Papa, M. Rossi, Traffic models and traffic-jam transition in quantum (N+1)-level systems, SciPost Phys.Core 5 (2022) 022

4. A. Nava, D. Giuliano, L. Lepori, M. Rossi, Out of equilibrium charge transport in molecular electronic devices, J.Phys.Conf.Ser. 2164 (2022) 012060 and 2203.10275 [cond-mat.str-el], contribution to SCES 2020

LINCOLN
Learning Complex Networks

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

1 Mathematical Models for Semiconductors

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

2) Analysis of themoconductivity in semiconductors [2)].

3) Model order reduction [3)].

2 Quantum Measurement

1) Fuzzy observables [4)]

   We proved that there is a universal Markov kernel μ^U (to which there corresponds a universal family of fuzzy events) such that every commutative POVM F is the fuzzification of a self-adjoint operator A^F with the fuzzification realized by μ^U. Moreover, we showed that every weak Markov kernel is functionally subordinated to the universal Markov kernel.

2) Quantum-like systems [5)]

   We provided a quantum description of angles in the plane providing illustration of covariant integral quantization, linear polarisation of light as a quantum measurement, entanglement, violation of Bell inequalities, spin one-half coherent states.

3 Integral Quantization [6)]

Analysis of POVMs in the Euclidean plane: compatibility, Naimark's dilation, Toeplitz quantization, Stokes parameters and fuzzy observables.

3 General probabilistic models

We gave necessary and sufficient conditions for two effects in a general probabilistic model to be incompatible [7)].

4 Modelling of real world problems

1) We provided a non-linear space time probabilistic model for forest fire spreading (work in progress).

2) Wave propagation in concrete [8)].

5 Congresses

[1] Organization of the international conference "Fifteenth International Quantum Structures Conference" IQSA2022, Tropea, Italy.

References

1. G. Mascali, Some electric, thermal and thermoelectric properties of suspended monolayer graphene, to appear on **SIAM Journal of Applied Mathematics**.

2. G. Mascali, 35. G. Mascali, Exploitation of the Maximum Entropy Principle in the Study of Thermal Conductivity of Silicon, Germanium and Graphene, **Energies**, 15, 4718 (2022).

3. N. Banagaaya, G. Alì, S. Grundel, P.Benner, Index-Aware Model-Order Reduction for a Special Class of Nonlinear Differential-Algebraic Equations, **Journal of Dynamics and Differential Equations**, 34(3) (2022) 2465–2489.

4. R. Beneduci, T. Gentile, Universal Markov Kernel and the Universal Family of Fuzzy Sets, **Fuzzy Sets and Systems**, 444 (2022) 206-221.

5. R. Beneduci, E. Frion, J.P. Gazeau, Quantum description of angles in the plane, **Acta Polythecnica**, 62 (2022) 8-15.

6. R. Beneduci, E. Frion, J.P. Gazeau, A. Perri, Quantum formalism on the plane: POVM-Toeplitz quantization, Naimark theorem and linear polarization of the light, **Annals of Physics**, 447 (2022) 169134.

7. R. Beneduci, L. Loveridge, Incompatibility of Effects in a General probabilistic model, **Journal of Physics A**, 55 (2022) 254005.

8. G. Alì, F. Demarco, C. Scuro, Propagation of Elastic Waves in Homogeneous Media: 2D Numerical Simulation for a Concrete Specimen, **Mathematics**, 10(15) (2022) 2673.

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

A. Papa (Resp.)

1 Flux tubes in pure-gauge SU(3)

A characteristic signature of quark confinement is the concentration of the chromoelectric field between a static quark–antiquark pair in a flux tube. However, the structure of this flux tube, and hence of the confining force, has not been completely understood. We performed new lattice measurements of field distributions on smeared Monte Carlo ensembles in SU(3) gauge theory. On the basis of these simulations, we demonstrated that the confining force can be understood using the analogy with the basic principles of electromagnetism as elucidated by Maxwell. We derived a chromomagnetic Lorentz force density coupling the chromoelectric field to chromomagnetic currents and integrated this force density over the flux tube interior to obtain a Maxwell-like force that squeezes the flux tube in the transverse direction. We showed that the strength of this transverse confining force is equal to the value of the string tension calculated numerically from the chromoelectric field on the midplane between the quarks, verifying the consistency of these two complementary pictures of confinement.

2 QCD phase diagram from Polyakov loops effective models

We studied a 3D Polyakov loop model, constructed as an effecive theory of QCD at finite baryon density, which is free from the sign problem and is therefore amenable of direct Monte Carlo simulations. We computed several correlation functions of the Polyakov loops, by means of which we can get information on the QCD phase diagram in the regime of strong coupling and heavy quark masses. A paper reporting our results is in preparation.

3 Traffic models

We proposed a model to implement and simulate different traffic-flow conditions in terms of quantum graphs hosting an $(N+1)$-level dot at each site, which allows us to keep track of the type and of the destination of each vehicle. By implementing proper Lindbladian local dissipators, we derived the master equations that describe the traffic flow in our system. To show the versatility and the reliability of our technique, we employed it to model different types of traffic flow (the symmetric three-way roundabout and the three- road intersection). Eventually, we successfully compared our predictions with results from classical models.

References

1. M. Baker, V. Chelnokov, L. Cosmai, F. Cuteri and A. Papa,
"Unveiling confinement in pure gauge SU(3): flux tubes, fields, and magnetic currents,
Eur. Phys. J. C **82** (2022) no.10, 937 [arXiv:2207.08797 [hep-lat]].

2. A. Nava, D. Giuliano, A. Papa and M. Rossi,
"Traffic models and traffic-jam transition in quantum $(N+1)$-level systems,"
SciPost Phys. Core **5** (2022), 022.

QFT@COLLIDERS
Precision calculations for collider physics

M. Fucilla (Dott.), G. Gatto (Dott.), M.M.A. Mohammed (Dott.), A. Papa (Resp.)

1 Semihard processes in perturbative QCD

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

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

- the production of a charm-flavored hadron in association with a Higgs boson, featuring large transverse momenta and produced with a large rapidity distance. Taking advantage of a narrow timing coincidence between the ATLAS detector and the future Forward Physics Facility (FPF) ones, we studied the behavior of cross sections and azimuthal correlations for ultraforward rapidities of the detected hadron. We provided evidence that the hybrid high-energy and collinear factorization, encoding the BFKL resummation of large energy logarithms and supplemented by collinear densities and fragmentation functions, offers a fair description of this process and comes out as an important tool to deepen our understanding of strong interactions in ultraforward production regimes.

- the production of Mueller-Navelet jets in the kinematics of CMS at $\sqrt{s} = 7$ TeV. We provided an evidence that the study of azimuthal distributions, calculated as a Fourier sum of correlation moments and embodying the high-energy signal coming from all conformal-spin modes, permits us to overcome the well-known issues emerging in the description of Mueller-Navelet final states at natural values of the renormalization scale. We came out with a clear indication that the next-to-leading BFKL description of these observables at natural scales is valid when the rapidity interval between the two jets is large, and it allows us to catch the core high-energy dynamics emerging from data.

We calculated the next-to-leading order correction to the impact factor (vertex) for the production of a forward Higgs boson, obtained in the infinite top-mass limit. We presented the result both in the momentum representation and as superposition of the eigenfunctions of the leading-order BFKL kernel. This impact factor is a necessary ingredient for the description of the inclusive hadroproduction of a forward Higgs in the limit of small Bjorken x, as well as for the study of inclusive forward emissions of a Higgs boson in association with a backward identified object.

2 Talks in Year 2022

1. M. Fucilla,
   Inclusive J/Ψ and Υ emissions from single-parton fragmentation in hybrid high-energy and collinear factorization,
   DIS2022: XXIX International Workshop on Deep-Inelastic Scattering and Related Subjects, Santiago De Compostela, May 5, 2022
   https://indico.cern.ch/event/1072533/

2. M. Fucilla,
   Inclusive J/Ψ and Υ emissions from single-parton fragmentation in hybrid high-energy and collinear factorization,
   Assemblée Générale du GDR QCD, Île d'Oléron, May 25, 2022
   https://indico.in2p3.fr/event/25992/

3. A. Papa,
   The high-energy limit of perturbative QCD: theory and phenomenology,
   QCD@work - International Workshop on QCDF - Theory and Experiment, Lecce, June 27, 2022
   https://agenda.infn.it/event/20170

4. M. Fucilla,
   Forward Higgs boson production in high-energy QCD at next-to-leading order,
   Saturation and diffraction at the LHC and the EIC, Trento, ECT*, June 28, 2022
   https://indico.cern.ch/event/1134310/

5. A. Papa,
   Recent results in BFKL phenomenology,
   Saturation and diffraction at the LHC and the EIC, Trento, ECT*, June 29, 2022
   https://indico.cern.ch/event/1134310/

6. M. Fucilla,
   High-energy signals from heavy-flavor physics,
   Diffraction and Low-x 2022, Corigliano Calabro, September 25, 2022
   https://indico.cern.ch/event/1148802/

7. M. Fucilla,
   The next-to-leading order Higgs impact factor in theinfinite top-mass limit,
   Diffraction and Low-x 2022, Corigliano Calabro, September 28, 2022
   https://indico.cern.ch/event/1148802/

8. M. Fucilla,
   Signals of BFKL dynamics at LHC;Saturation at the EIC,
   Saturation at the EIC, Orsay, November 28, 2022
   https://indico.in2p3.fr/event/28274/

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QFT-HEP
Physics of the Standard Model and beyond SM

L. Delle Rose (Resp.)

1 Bubble wall dynamics at the electroweak phase transition

First order phase transitions could play a major role in the early universe, providing important phenomenological consequences, such as the production of gravitational waves and the generation of baryon asymmetry. An important aspect that determines the properties of the phase transition is the dynamics of the true-vacuum bubbles, which is controlled by the density perturbations in the hot plasma. We study this aspect presenting the full solution of the linearized Boltzmann equation for the top quark species coupled to the Higgs field during a first-order electroweak phase transition. Our approach, differently from the traditional one based on the fluid approximation, does not rely on any ansatz and can fully capture the density perturbations in the plasma. We find that our results significantly differ from the ones obtained in the fluid approximation (including its extensions and modifications), both at the qualitative and quantitative level. In particular sizable differences are found for the friction acting on the bubble wall.

2 Multi-step phase transitions and gravitational waves in the inert doublet model

The inert doublet model is a well-motivated extension of the Standard Model that contains a dark matter candidate and modifies the dynamics of the electroweak symmetry breaking. In order to detail its phenomenology, we perform a comprehensive study of cosmic phase transitions and gravitational wave signals implied by the framework, accounting for the latest results of collider experiments. We require the neutral inert scalar to constitute, at least, a subdominant part of the observed dark matter abundance. While most of the phase transitions proceed through a single step, we identify regions of the parameter space where the electroweak vacuum is reached after multiple phase transitions. The resulting gravitational wave spectrum is generally dominated by single-step transitions and, in part of the parameter space, falls within the reach of future gravitational wave detectors such as LISA, BBO or DECIGO. We find that direct detection experiments efficiently probe the part of parameter space associated with multi-step phase transitions, which remain unconstrained only in the Higgs resonance region testable with future monojet searches.

3 Talks in Year 2022

1. *Dynamics of bubble walls at the electroweak phase transition*
   10th International Workshop on QCD - Theory and Experiment (QCD@Work 2022)
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SFT - Statistical Field Theory and Applications

D. Giuliano (Resp.), L. Lepori (Ass.), A. Nava (Ass.), F. Plastina (Ass.), J. Settino (Ass.)

1 Quasi-one-dimensional ^{4}He in nanopores : [1]

We theoretically investigate the structural and superfluid properties of ^{4}He confined in cylindrical nanopores are theoretically investigated by means of first principle Quantum Monte Carlo simulations. We show that, in the limit of pore length greatly exceeding its radius, the ^{4}He fluid always displays markedly one-dimensional behavior, with no "dimensional crossover" above some specific pore radius and/or as multiple concentric shells form, in contrast to what recently claimed by other authors.

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

We use the Lindblad equation method to investigate the onset of a mobility edge and the topological phase transition in the disordered SSH chain connected to two external baths in the large bias limit. From the scaling properties of the nonequilibrium stationary current flowing across the system, we recover the localization/delocalization in the disordered chain. We use the even-odd differential occupancy as a mean to discriminate topologically trivial from topologically nontrival phases in the out-of-equilibirum system. Eventually, we argue how to generalize our method to similar systems.

3 Multi-particle scattering and breakdown of the Wiedemann-Franz law at a junction of N interacting quantum wires and in the topological Kondo model [3, 4]

We analyze the charge and thermal transport at a junction of interacting quantum wires close to equilibrium within the framework of Tomonaga-Luttinger liquids.We show how connecting external reservoirs to the quantum wires affects the conductance tensors close to the various fixed points of the phase diagram of the junction. We therefore distinguish two types of violation of the Wiedemann-Franz law: a "trivial" one, independent of the junction dynamics and arising from the breakdown of the Fermi-liquid picture in the wire, and a junction-related counterpart, arising from multi-particle scattering processes at the junction. An example of the latter, we study the thermal transport through a Majorana island connected to multiple external quantum wires.We find that the Wiedemann-Franz law is nontrivially violated at low temperature, contrarily to what happens for the overscreened Kondo effect and for nontopological junctions, and that the Lorenz ratio is rescaled by a universal factor 2/3, which we attribute to the presence of localized Majorana modes on the island.

4 Dissipative cooling induced by pulse perturbations: [5])

We investigate the dynamics brought on by an impulse perturbation in two infinite-range quantum Ising models coupled to each other and to a dissipative bath. We show that, if dissipation is faster the higher the excitation energy, the pulse perturbation cools down the low-energy sector of the system, at the expense of the high-energy one, eventually stabilising a transient symmetry-broken state at temperatures higher than the equilibrium critical one. Such non-thermal quasi-steady state may survive for quite a long time after the pulse, if the latter is properly tailored.

5 Out of equilibrium charge transport in molecular electronic devices [6])

Using the Lindblad equation approach, we study the nonequilibrium stationary state of a benzene ring connected to two reservoirs in the large bias regime, a prototype of a generic molecular electronic device. We show the emergence of an optimal working point (corresponding to a change in the monotonicity of the stationary current, as a function of the applied bias) and its robustness against chemical potential and bond disorder.

6 Quantum Information transfer in spin chains [7], [8], [9])

The transfer of quantum information between different locations is key to many quantum information processing tasks. Whereas the transfer of a single qubit state has been extensively investigated, the transfer of a many-body system configuration has insofar remained elusive.We addressed the problem of transferring the state of n interacting qubits. Both the exponentially increasing Hilbert space dimension, and the presence of interactions significantly scale-up the complexity of achieving high-fidelity transfer. By employing tools from random matrix theory and using the formalism of quantum dynamical maps, we derive a general expression for the average and the variance of the fidelity of an arbitrary quantum state transfer protocol for n interacting qubits. Finally, by adopting a weak-coupling scheme in a spin chain, we obtain the explicit conditions for high-fidelity transfer of three and four interacting qubits.

7 Quantum Computing Approach for Energy Optimization in a Prosumer Community [10], [11])

We have been putting forward a quantum approach for the formulation and solution of the prosumer problem, i.e., the problem of minimizing the energy cost incurred by a number of users in an energy community, while addressing the constraints given by the balance of energy, and the user requirements. As the problem is NP-complete, a hybrid quantum/classical algorithm could help to acquire a significant speedup, which is particularly useful when the problem size becomes large. This work describes the steps through which the problem can be transformed, reformulated and given as an input to Quantum Approximate Optimization Algorithm (QAOA), and reports some experimental results, in terms of the quality of the solution and the time required to achieve it, obtained with a quantum simulator, when varying the number of constraints and, correspondingly, the number of qubits.

List of Conference talks:

1. A. Nava, Local organizer of Quantum Structures 2022 (IQSA22), Tropea, Italy.

2. A. Nava, Speaker at Quantum Structures 2022 (IQSA22), Tropea, Italy.

3. A. Nava, Local organizer of Diffraction and Low-x 2022, Corigliano, Italy.

4. A. Nava, "Lindblad master equation approach to the topological phase transition in the disordered Su-Schrieffer-Heeger model", SM&FT 2022, INFN, Sez. di Bari, Bari, Italy.

5. D. Giuliano, "Finite-temperature BKT phase transition in the ψ^4 potential with a strongly modulating potential", SM&FT 2022, INFN, Sez. di Bari, Bari, Italy.

6. F. Plastina, "Quantum Coherence and Work Processes ", (Post)Modern-Thermodynamics, School and Workshop, Luxembourg, 8-12-2022.

7. F. Plastina, "A hybrid classical-quantum approach to improve Q-learning ", Conference on Complex Systems - CCS2022, Satellite event QUANTUMCCS2022, Palma de Malorca (Spagna), 19-10-2022.

8. J. Settino, "Preparation of a Gibbs state on a Quantum Computer", Italian Quantum Information Science Conference, Palermo, 15-09-2022.

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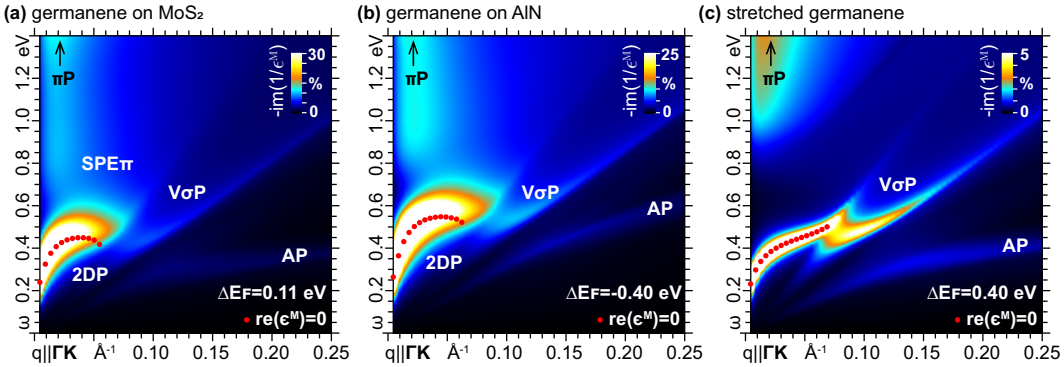
Contribution to Time2Quest

contributors: A. Sindona (A. S., local coord.), P. Riccardi (P. R.), F. Plastina (P. F.), N. Logullo (N. L.), J. Settino (J. S., Post Doc), M. Pisarra (M. P., Post Doc)

1 Research Activity

As specified in its project proposal, the specific initiative Time2Quest aims at exploring highly demanding computational strategies to unravel excited state properties, collective excitations, transport phenomena and other many-body effects in low dimensional systems of uttermost importance for quantum information processing. The researchers from the CS unit, being one of the four nodes of this project, share their expertise in time-dependent density functional theory and out of equilibrium thermodynamics In particular, during the course of 2022, the CS unit has specifically explored the following topics:

(i) **plasmon excitations, dielectric, electromagnetic, and fundamental properties of two-dimensional Dirac nano objetcs.** A self-consistent strategy, based on time-dependent density functional theory, was applied to several nanostructures based on Carbon, Silicon, Germanium and Tin. After having outlined a new possible direction towards the synthesis of silicene [PRB 97, 041401(R), 2018], and setting up an ab initio framework to determine the effective fine-structure constant of graphene [PRB 96 201408(R) 2017], the efforts of this research line were initially focused on charge-carrier density oscillations in atomically precise graphene nanoribbons, organized in planar array form [PRB 100 235422, 2019]. In our recent activity, a bulk and an edge quantized oscillations (better known as plasmons) were identified at far infrared to visible energies, and over a broad range of momentum transfers. Further scrutiny is being placed on the possibility to establish a true one-dimensional confinement of the charge carrier density on individual nanoribbons [1, 2].



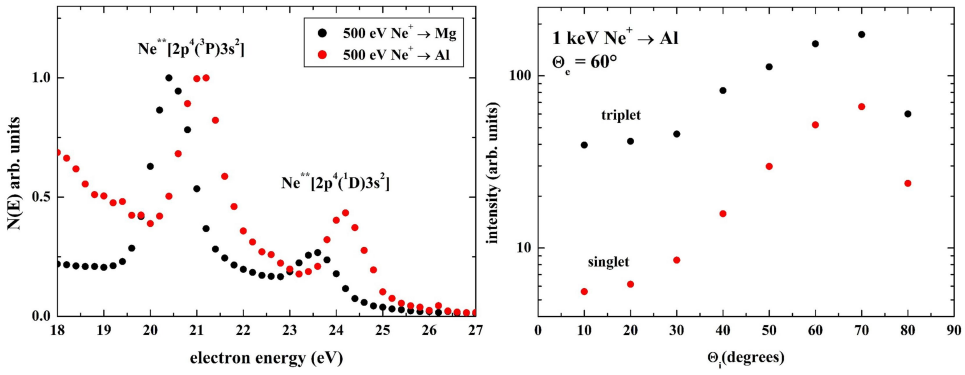
Dielectric response of germanene grown on top of (a) MoS2, (b) AlN, and (c) stretched free-standing germanene. Different doping conditions (ΔE_F) are considered, over a broad range applied momentum transfers ($\mathbf{q}$), along high-symmetry directions of the associated reciprocal

lattices. Unprecedented plasmon modes (2DP, VσP,AP) are observed, which originate from the coexistence of parabolic and conic bands, around the Fermi Level. The dominant feature is due to the 2DP mode, whose dispersion is reported with red dots.

Another important achievement has been concerned with the detection of virtually massless and massive plasmon modes in germanene sheets synthesized on top on large gap insulators (AlN) and semiconductors (Mo2), thus establishing novel platforms for photonic and electronic nano-device architectures [3, 4] (see also figure above). Further results came from synthesis and design of two-dimensional supramolecular assemblies with specific functionalities, for molecule-based electronics [5, 6].

(ii) **Many-body processes in strongly correlated systems** The non-equilibrium Green's function (NEGF) approach to quantum transport was extended to include inter-particle interactions, via diagrammatic techniques, based on so-called embedding and inbedding methods. It was shown how the NEGF formalism elegantly reduces to well-known formulae in quantum transport, in the non-interacting and steady-state limits. Several time-dependent drive-encompassing pump-probe scenarios were tested, with a particular focus on one- and two-dimensional electronic systems, such as topological superconductors, and optically responsive molecular junctions, coupled to lattice vibrations [7].

(iii) **Electron processes at surfaces.** Measurements of the energy distribution of electrons emitted by Aluminum surfaces, under the impact of low energy singly charged Neon ions, were performed focusing on the Auger decay of electronic excitations produced in both projectile and target atoms, during binary atomic collisions. These excitations were shown to be well described by the Fano-Lichten molecular orbital promotion model adopted for gas-phase experiments [8]. As a further development, the long standing issue of the dominant excitation of the triplet 2p(4)(3P)3s(2) state in the scattering of Neon projectiles from Magnesium, Aluminum and Silicon surfaces, which is not predicted by the Fano-Lichten Molecular orbital promotion model, was addressed, as reported in the figure below [9].



(Left) Singlet and triplet autoionization peaks for the impact of 500 eV Ne+ on Mg and Al. (Right) Intensities of the singlet and triplet peaks vs the ion incident angle Θ_i

(iv) **Out of equilibrium thermodynamics.** The transfer of quantum information between different locations is key to many quantum information processing tasks. Whereas, the transfer of a single qubit state has been extensively investigated, the transfer of a many-body

system configuration has insofar remained elusive. In this respect, the problem of transferring the state of n interacting qubits was addressed. Both the exponentially increasing Hilbert space dimension, and the presence of interactions significantly scale-up the complexity of achieving high-fidelity transfer. By employing tools from random matrix theory and using the formalism of quantum dynamical maps, a general expression for the average and the variance of the fidelity of an arbitrary quantum state transfer protocol for n interacting qubits was derived. Finally, by adopting a weak-coupling scheme in a spin chain, the explicit conditions for high-fidelity transfer of three and four interacting qubits was obtained [10, 11].

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STAR Project

STAR
Southern Europe Thomson Backscattering Source for Applied Research

S. Donato (Ass.)

- Test and evaluation of the performances of two detectors for X-ray tomography to be installed in the two beamlines of the STAR project: 1) a large area flat panel designed for energies up to 250 keV and 2) a sCMOS based commercial detector for high-resolution images. Tests were performed by using an X-ray laboratory source with conical emission. Evaluation of the linearity of each sensor at different energies, measurements of the noise response, frame rate, spatial resolution, and testing the different acquisition modalities available for each detector. Acquisitions of both planar and tomographic images on test objects.

- Study of the optimization of a customized GPU-based simultaneous algebraic reconstruction technique (cSART) in the field of phase-contrast breast computed tomography (bCT). The algorithm features a 3D bilateral regularization filter to be tuned in order to yield optimal performances for clinical image visualization or tissue segmentation. Optimization performed on a test object and validated on a breast surgical tissue ate the Elettra synchrotron facility of Trieste. Comparison of the performances with the gold-standard filtered back-projection algorithm and standard SART. Image segmentation was performed both with gray scale-based and supervised machine-learning approaches. The proposed algorithm can yield images with a higher CNR(by 35% or more), retaining a high spatial resolution while preserving their textural properties.Alternatively, at the cost of an increased image 'patchiness', the cSART can betuned to achieve a high-quality tissue segmentation, suggesting the possibility of performing an accurate glandularity estimation potentially of use in the realization of realistic 3D breast models starting from low radiation dose images. The study indicates that dedicated iterative reconstruction techniques could provide significant advantages in phase-contrast bCT imaging. [1)]

- Optimization of the acquisition parameters, namely the propagation distance and the pixel size, with the aim of providing adequate spatial resolution and sensitivity for virtual histology of breast surgery specimens, scanned with a phase-contrast microtomography (μCT) system employing a commercial sCMOS detector at the SYRMEP beamline of the Italian synchrotron facility Elettra (Trieste, Italy). Experiments performed at different pixel size and propagation distances on a surgical breast tissue embedded in paraffin. Experimental results were compared to a theoretical model taking into account the actual point spread function of the employed imaging system. The measured gain of SNR associated with the application of the phase-retrieval matched the predictions for large Fresnel numbers ($N_F > 2$). For each pixel size, an optimal range of propagation distances was found. Optimal μCT reconstructions were then compared with their respective histopatological images, showing an excellent visibility of relevant structures. The optimization performed in this study will allow to select the most appropriate geometrical configurations for future acquisitions of virtual histology images of different specimens via phase-contrast microtomography. [2)]

- Morphological analyses of insects by means of synchrotron radiation X-ray computed microtomography. Three investigation were performed at the Italian synchrotron facility Elettra (Trieste, Italy) in collaboration with the Department of Biology, Ecology and Earth Science of the University of Calabria, and the Animal Evolutionary Ecology Group at the Institute for Evolution and Biodiversity of the University of Münster (Germany).
  In the first study it was investigated the internal anatomy of the reproductive system of female samples of the ground beetle Pterosticus Melas, an important predator of the trophic web in cropland involved in pest biological control. The investigation adds to the scarce information on internal genitalia of carabid females and provides a basis for further research on the reproductive strategies of the analysed beetle [3].
  In the second work it is reported the study of compound eyes in insects, which are primary visual receptors of surrounding environments. In this study, Synchrotron radiation X-ray phase-contrast microtomography was used to describe the eye structure of four coleopteran species, showing species-specific habitat demands and different feeding habits. Virtual sections and 3D volume renderings of the heads were performed to evaluate the application and limitations of this technique for studying the internal dioptrical and sensorial parts of eyes, and to avoid time-consuming methods such as ultrastructural analyses and classic histology. The study provides, for the first time, morphological descriptions of the compound eyes in these species, supplementing their ecological and behavioural traits [4].
  The last study it was described, in situ, the internal organs of the red flour beetle Tribolium castaneum Herbst 1797, a widespread pest of cereals and stored food causing serious damage to the human economy. Two-dimensional virtual sections and volumetric reconstructions of the nervous, alimentary and reproductive systems were carried out in both sexes. The results provided a comprehensive overview of the morphological characteristics of this species. Given the great interest in this model species in experimental biology and forensic entomology, complete knowledge of the general anatomy is required for future functional applications in pest control and experimental studies [5].
  Those three studies confirms Synchrotron radiation X-ray phase-contrast microtomography as a powerful and innovative tool in entomology, particularly suitable for small species and chitinized structures that are difficult to analyse using conventional dissection and histological methods, and serve as pathfinders for systematic studies that could be carried out at the STAR source when it will be fully operational and open to access by researchers.

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STAR
Beamline simulation and optimisation

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

1 Introduction

In the year 2022 the research activity, was devoted to the upgrade of the STAR2 Linac simulation. The main activities were:

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

The simulation has been implemented and carried out using Astra (A Space Charge Tracking Algorithm), a simulation framework that allows to track particles under the influence of electric and magnetic fields along the beamline.

2 Simulations

The first goal of the simulation work has been that of reproducing in detail, with the Astra framework, the electron beam performance results presented in the Complete Detailed Design Report of the STAR2 upgrade project, including emittance, energy spread and beam envelope along the three cavities (S-band and C-band), in the dispersion and interaction regions (HE-line) and along the dump dipole.

Together with colleagues of the INFN Milan unit and in order to achieve improved results, we worked on replacing the simulated analytical dipole with detailed 3D field maps of the dipole in the dispersion region: then we studied and verified the consistency of the beam performance in this region. Having obtained a slight variation in the beam trajectory along the beamline, we optimized the positions of the beamline elements: in particular, we found that by varying the coordinates of the quadrupoles (QUAHEL01 and QUAHEL03) along X coordinate by 90 μm, we obtain more consistent results.

Then, the performance of the beam at the interaction point (IP) in the high-energy line (HE-Line) was evaluated. Slight variations in the gradients of the quadrupoles were useful to achieve the minimum σ_x, σ_y at the IP. To verify the stability of the facility, all the beam characteristics in the range 100-140 MeV were analyzed. As an example, the main performances of a 120 MeV electron beam are shown in Figure 1.

With the introduction of the 3D dipole field maps in the low-energy line (LE-Line), we will perform the same studies in the range 60-100 MeV. At the same time, the framework Giotto (Genetic Interface for OpTimising Tracking with Optics), a program based on genetic algorithms, will be used for the optimization phase.

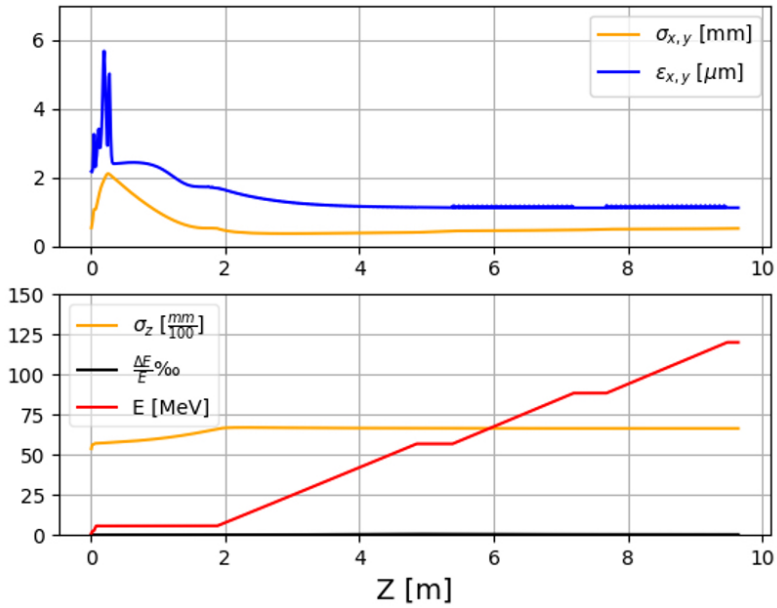

Figure 1: *BD linac simulation for a 120 MeV HE-line WP. The upper plot shows the normalized emittance (in blue) and the beam envelope (in yellow). The lower plot shows the bunch length (in yellow), the relative energy spread (in black) and the energy gain (in red).*

COMPUTATION TECHNOLOGY

The ReCaS Cosenza Data Center

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

1 Introduction

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

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

2 Performance and software developments

The ReCaS Cosenza Data Center has operated for the year 2022 with good efficiency and stability with the exception of the period May-July for a technical failure of both chiller systems. Figure 2 shows, for the ATLAS virtual organization, a comparison of the performance (quantified in terms of slots of running jobs) of the ReCaS Cosenza Data Center w.r.t. that of other Italian ATLAS Tiers 2 sites for year 2022.

After the adoption of HTCondor, the software development during the year 2022 has focused on improved authorization methods. The Token Based Authentication has been enabled beside

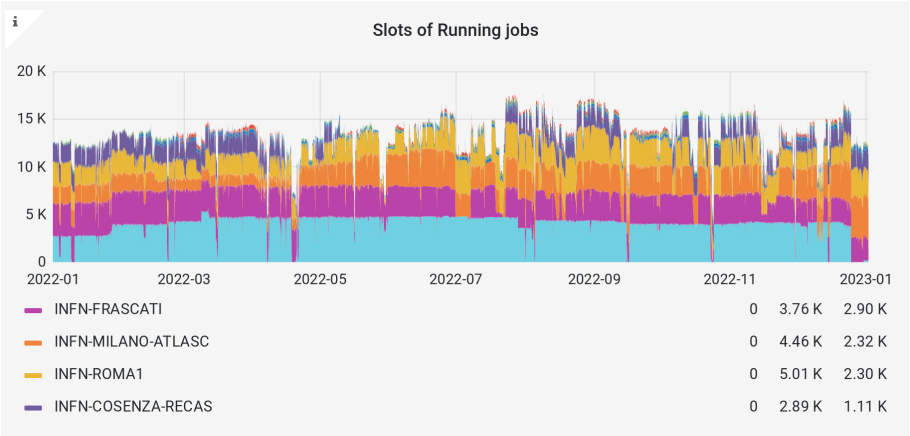

Figure 2: *A comparison of the slots of running jobs in 2022 for the ATLAS Tier2 centers and the ReCaS Cosenza Data Center.*

the previously used GSI-based method. The two authorization systems will coexist until the new one will become the standard. An important migration is also in progress: the porting of the linux operating system to the new Alma 9 release that will garantee up-to-date packages and security support in the next years. As a consequence the two storage system architectures presently used will need heavy changes. Gluster needs to be updated while DOME DPM needs to be abandoned in favor of DCACHE, the most used storage system in the actual ATLAS grid infrastructure. The monitoring tools also need porting for security reasons.

As usual the most relevant setup steps have been adopted in coordination with the other INFN ATLAS grid sites so contributing to improve the content of the related public wiki page.

3 Upgrade

In March 2019 the STAR 2 upgrade project (EU PON programme “Research and Innovations” 2014-2020, code: PIR0_100008) has been funded for a total budget of approximately 17.5 Million Euros and with it the upgrade of the ReCaS Data Center that will be used as the main computing facility for the storage, reconstruction and analysis of the high resolution tomographic images produced by STAR. Two tenders were issued during 2022 for the purchase of network equipment, for high-speed connection (up to 40 Gbps) between the ReCaS data center and the STAR building, and next-generation servers for tomographic image reconstruction and analysis. A third tender on the upgrade of the Recas data center is being prepared.

COMMUNICATION AND OUTREACH

RADIOLAB

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

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 project is an excellent example of *citizen science*. 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.

Six schools in Calabria and three schools in Riobamba (Ecuador) corresponding to more then 150 students are taking part in the project and numerous interviews have been made. From 2021 RadioLab includes the sub-project called ISORADIOLAB aimed at involving minor island students in outreach INFN projects, therefore from November 2021 the Istituto Comprensivo Isole Eolie that includes 155 students of the medium schools of 6 of the 7 islands is involved in the project.

The Radiolab-CS group, for the first time in Italy for high school students, realized the spring school on radon measurement techniques in water, realized in Vibo Valentia in April 2022. The two-day school, supported by the Liceo Berto of Vibo Valentia, was attended by students from Sardinia, Puglia, Lombardy, Tuscany, Veneto and Calabria. The satisfaction questionnaires filled out for the various events have been fully positive.

Radiolab's activities have led to national and international communications, including:

1. GIORNALE DI FISICA VOL. XLIII, PLS-Fisica-SPI 2022, *Il progetto RadioLab per le scuole: Le attività di RadioLab-Calabria, The RadioLab project: The activities of RadioLab-Calabria.*, M. Capua, P. Riccardi et al., DOI: 10.1393/gdf/i2022-10450-0;

2. Proceeding 108° Congresso della SIF Capua M. et al., *Misure di concentrazione di radon in acqua - spring school*, Atti del Congresso, 2022, 134-135, ISBN: 978-88-7438-130-2

3. Proceeding MARC XII, Twelfth International Conference on Methods and Applications of Radioanalytical Chemistry Groppi F., Capua M., Manenti S., Tucci R., Cagnetta M.F., Colucci M., *Particle Therapy International Masterclass: The First Italian Experience*, MARC XII: Book of Abstract 2022, 149

INTERNATIONAL PHYSICS MASTERCLASSES 2022

M. Capua (Resp.), S. Fazio (Ass.), L. La Rotonda (Ass.), E. Meoni (Ass.), A. Olivieri (Stud.), M. Rossi (Ass.), D. Salvatore (Ass.), E. Tassi (Ass.), C. Petronio (School prof. Ass.), R. Tucci (School prof. Ass.), F. Stabile (Tecn.Ass), A. Tarasio (Tecn.Ass)

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

In 2022, three events were organized:

- February 11, Internazional Masterclasses-Hands on particle physics - special event for the International Day of Women in Science, about 80 girls from Basilicata and Calabria high schools. (agenda.infn.it/event/mcg2022).
- March 24, Internazional Masterclasses-Hands on particle physics, about 40 students from Basilicata and Calabria high schools. (agenda.infn.it/event/mc2022).
- March 18, Particle Therapy Masterclasses, about 40 students from Basilicata and Calabria high schools. (agenda.infn.it/event/pt2022).

The overall enthusiastic participation of students and high-school teachers is confirmed by the results of the satisfaction questionnaires.

The special event of February 11, had a common moment among all the girls participating in the day organized by the group of Cosenza and the INFN units of Rome 3 and Naples. All participants attended the presentation of the physicist and writer Ilenia Picardi *Gender Equity in Science: Challenges for Girls in STEM* and took part at the following discussion.

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

1. Proceeding MARC XII, Twelfth International Conference on Methods and Applications of Radioanalytical Chemistry Groppi F., Capua M., Manenti S., Tucci R., Cagnetta M.F., Colucci M., *Particle Therapy International Masterclass: The First Italian Experience*, MARC XII: Book of Abstract 2022, 149

WORLD WIDE DATA DAY 2022

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

Also in 2022, we participated to the LHC World Wide Data Day, in which students from eround the world analyze LHC data and share results. The project is designed for high schools students that select dimuon events (open data from ATLAS) and calculate the Φ angle of each muon selected in the plane tranverse to the beamline.

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

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

1 The Cosmic Rays as messengers to investigate the Universe

Is out of doubt that learning by doing is the most powerful method to teach physics to young and less young students. The Cosenza group has started more than 10 years ago to open the "Alte Energie" laboratory to students and to go into the schools to meet students and teachers with the aim to make experiments to measure the cosmic ray flux and the muon mean life time, but also to demonstrate the existence of cosmic ray showers at earth surface. In 2010 the group agreed to participate in the EEE (Extreme Energy Events) project, under the convincing push of Dr. R. Baldini Celio Ferroli, director of this project of Centro Fermi. The EEE project is dedicated to the study of Extensive Atmospheric Showers through a network of muon telescopes, installed in High Schools, with the main objective of introducing young students to particle and astroparticle physics, making them participate in the construction detectors at CERN and involving them in the operation, maintenance and monitoring of EEE stations. Each telescope is a tracking detector composed of three Multi-Gap Resistive Plate Chambers with an active area of 1.60 x 0.80 m. At present 5 MRPCs telescopes are installed in Calabria. In 2020 EEE project becomes a special INFN project under the supervision of Prof. L. Cifarelli.
Another important activity launched in 2022 was the study of the use of new gas mixtures for the EEE MRPC in order to contribute to the reduction of the global warming potential (GWP) or the ability of each greenhouse gas to trap heat in the atmosphere. F-gases have higher GWP values than other substances and the recommendation is to limit or completely avoid their use. To limit the impact of GWP gas emissions from elementary particle physics experiments, the EEE collaboration has undertaken very thorough studies to target new low-impact GWP gases. In particular, the hydrofluoroolefin gas (R1234ze) mixed with He was tested at the Physics Department of UNICAL as a filling gas for "multi glass thin gaps RPC" devices. This gas mixture has GWP=4 (compared with the standard gases that has GWP greater than 4000) and the detector performances are in line with that required for EEE physics programs. The gas flow is very low (0.9l/h) ensuring a complete volume change every three full days further reducing the amount of greenhous gas into the atmosphere. Once the new gas mixture was validated by the EEE collaboration, 6 schools were supplied with new gases to start testing within the schools. One of these 6 schools is the IIS Patrizi of Cariati (Cosenza).
The 2022 has seen the group start a new activity to reproduce the historical experiments of D. Pacini in 1910-1912. Using the ArduSiPM detector designed by V. Bocci of INFN of Rome 1, 5 hermetic containers houses as many ArduSiPM with a microprocessor M5Stack, a whether station to measure the inside ambient conditions and a GPS sensor to localize the detector. The M5Stack has been use to store data collected by the detector, ambient conditions and geographical position and to allow wi-fi connection with a smartphone/tablet/PC. The measurement campaign started the first of April in 4 calabrian schools measuring the cosmic flow rate day by day to get practice with the setup and with the collected data. The May 31st the schools meet all together at Lago

Arvo in Lorica (1300 m asl) and collect data on the lake shore, above the lake surface and below the lake surface. The work was presented at the 2022 SIF National Congress where it was selected for the special series of the Nuovo Cimento C, it was published in the SIF Journal of Physics, it was presented in the outreach session of the CRIS2022 international conference, and finally was selected by ASI Education Office, ESA Education Office, ESERO Italy with the following motivation:
"The work was highly appreciated for its educational value, for the quality of the proposed path and for the ability to involve male and female students in space-themed STEM disciplines in a new, inclusive and active way. We therefore point out that, for this work, you will receive an autographed certificate from Samantha Cristoforetti by the end of the school year. We also wish to further congratulate you on the specific qualities of the project and inform you of our willingness to present your work as a 'Best practice' of the use of Space as an educational context of STEM subjects for the benefit of other teachers at national and international level. To this end, we intend to publish the work in a special section of the ESERO Italia website and promote it through the ESERO Italia social channels. the project would therefore be made public, alongside other projects received, which we believe may be of interest to the community à of the Italian teachers."
Moreover, the cosmic ray outreach Cosenza group organizes seminars, masterclasses, participates in the ICD and in the PCTO program (Paths for Soft Skills and Orientation) where students work both in their laboratories and in the "High Energies" laboratory of the physics department of UNICAL by building and testing detectors or part of them.
The Cosenza group has olso organized together with Pia Astone (Rome1), Franco La Cava (Rome1), Vitaliano Chiarella (LNF), Margherita Primavera (Lecce) the third series of the seminars "Un tuffo nel sapere: colloqui in rete" (https://agenda.infn.it/event/30556/) with the aim to offer a series of educational seminars that can be used anywhere. These were remote meetings with high-level scientists, who illustrate the most recent acquisitions in the field of Physics and the use of technologies, developed for research, which find application today in everyday life.
Last but not least, the group organized seminars for celebrate the 10th anniversary of the discovery of the Higgs boson in the high schools A. Volta of Reggio Calabria, IIS of Tropea (VV), E. Fermi of Catanzaro, Siciliano of Bisignano (Cs), Patrizi of Cariati (Cs) and E. Fermi of Cosenza.

2 OCRA project of INFN-CC3M

In the year 2022 the group actively participated in the OCRA activities of the INFN-CC3M scientific group. As described in the introduction the group has assembled 5 autonomous scintillating detectors (ArduSiPM) to measure the flux of cosmic rays in the water basin (lake) at different depths. The experiment was scheduled for spring 2020, but the measures to deal with the COVID-19 emergency did not allow it to be carried out. For this region the measurement campaign was done in 2022. The measurement campaigns were divided into two parts: one in the schools (four schools adhere to this project and acquire data day by day for about 2 months), while the second part is an entire day at Lake Arvo (Lorica) where the students put into practice the experience gained in the school by taking measurements at the lakeside, on the lake surface and below the lake surface. Figure 1 shows a picture of a detector. In November, the group coordinated the International Cosmic Day 2022 of Calabrian schools. They presented the measurement of cosmic ray flux as a function of water depth, providing a physical interpretation of the results. This experiment has been selected by the OCRA collaboration for the next OCRA national internship which will take place at LNL in 2024.

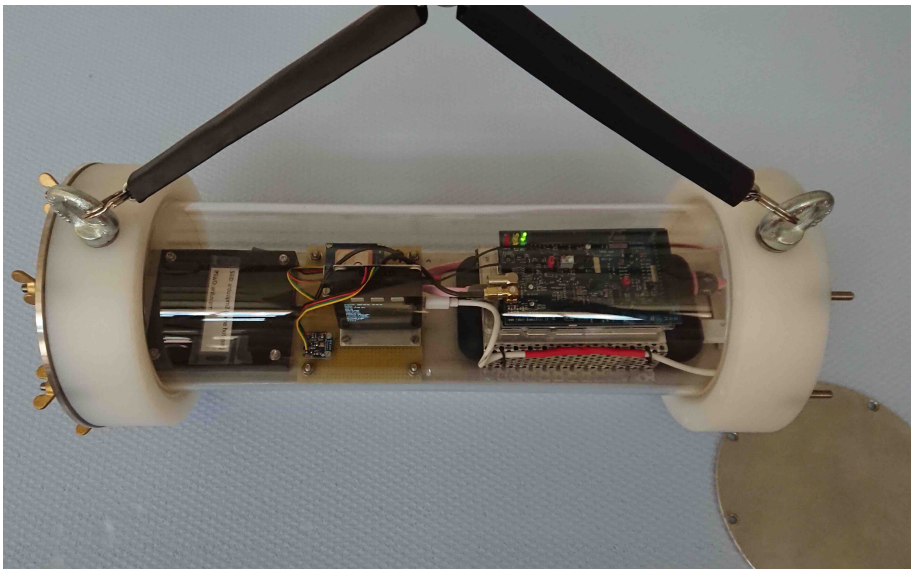

Figure 1: *The detector employed during the measurements at schools and at lake.*

Lab2Go

P. Riccardi (Resp.)

1 Outreach Activity

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

For year 2022 the activity in Calabria has been the subject of the pubblications [1)] to [4)].

Figure 1: *Laboratory instruments recovered through the scheme Lab2go at the Liceo "G. Berto" in Vibo Valentia. School pupils showcased the instruments at science festivals.*

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Premio Asimov 2022

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

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

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

The award is named after the writer Isaac Asimov, author of numerous scientific publications as well as several novels and stories. It is aimed at high-school students who were directly involved both as jurors, since they had to rate the best scientific books published during the year before, and as competitors, since the best among their reviews were rewarded during the closing ceremony, held in videoconference on May 29, 2020. The recording of this event is available in the YouTube channel of Premio Asimov, https://www.youtube.com/c/PremioAsimov.

The edition of 2022 counted overall about 12000 participants from 272 schools in the Regions Abruzzo, Basilicata, Campania, Emilia Romagna, Lazio, Liguria, Lombardia, Marche, Molise, Piemonte, Puglia, Sardinia, Sicily, Tuscany, Umbria and, of course, Calabria, which contributed with about 350 students from ten different high schools. On May 5, 2022 a cerimony took place in the Aula Caldora of the Università della Calabria, organized by the Physics Department and INFN-Cosenza, with the participation of most of the Calabrian students rewarded as best reviewers. The recording of this event is available in the YouTube channel of Premio Asimov, https://www.youtube.com/c/PremioAsimov.