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 2020, 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 our group are briefly reviewed below.

2 Physics Analysis

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

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 2020 the group has been actively involved in the measurements, based on the 2015-2016 Run2 ATLAS data samples, of the particle- and parton-level single and double differential cross sections for the production of $t\bar{t}$ pairs in the fully hadronic finale state in which all six decay jets are separately resolved [1)]. Emphasis is placed on well-measured observables in fully reconstructed final states, as well as on the study of correlations between the top-quark pair system and additional jet radiation identified in the event. The group is also actively contributing to phenomenological analyses that exploit the measured Run 2 double differential cross sections to determine the top quark pole mass and the PDFs.

2.2 Measurement of the b-jet identification efficiency using one-lepton boosted $t\bar{t}$ events

The identification of jets initiated by a b-quark is a crucial ingredient for many physics analyses of the ATLAS experiment. The group has contributed a novel method to calibrate the b-jet identification efficiency for b-jets at high transverse momentum, extending the coverage of existing calibrations by using boosted one-lepton $t\bar{t}$ events. The proton-proton collision data recorded between 2015 and 2018 by the ATLAS detector at the Large Hadron Collider, are used, representing an integrated luminosity of 139 fb^{-1}. The method relies on efficiently selecting boosted $t\bar{t}$ events by the identification of a large-radius ($R = 1.0$) jet, and the subsequent construction of an event-level variable independent on the b-tagging information, allowing to constrain simultaneously the flavor composition and the b-jet identification efficiency. An ATLAS public note has just passed the editorial board stage and will be released early 2021.

2.3 Measurements of the cross-section for the production of a W/Z boson in association with b-jets

Measurements of the production cross section of a vector boson (V = W or Z) in association with b-jets in proton-proton collision provide an important test of pQCD. Moreover these processes are sensitive to heavy flavor quarks in the initial state. A detailed knowledge of V +b-jets production is also a key element in the understanding of Higgs-boson processes, indeed they form one of the main backgrounds for the Higgs decay into a b-quark pair in associated production with a W/Z boson and they constitute also background to many other processes, from top-quark production to searches for beyond Standard Model processes including SUSY and other exotica. 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 publication presenting the results obtained with the analysis of the partial 13 TeV dataset have been published recently [2)] 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.

2.4 Search for long-lived neutral particles with the ATLAS experiment at LHC

Signatures of displaced vertices or collimated lepton/light meson tracks (lepton-jets) from the decay of long-lived neutral particles (LLNP) gained considerable interest over years: LLNPs arise in several theory models, including SUSY, Hidden Sector theories and Dark Matter models that explain the open questions in modern particle physics. The group is actively involved in the reconstruction techniques (reconstruction of the displayed vertex) for the selection of events with displaced vertices and lepton-jets, as well as in the analysis and the theory interpretation of the selected LHC collision data. Results based on the LHC Run1 and Run2 data have been published on major referred journals and presented at international conferences. The editorial board for the analysis based on the full Run2 13 TeV statistics (140 fb^{-1}) was required. The group is started to participate to the muon chamber timing for better reject cosmic rays. The group is also collaborating to the organization of theory-experimental joint workshops to discuss the theory interpretation and the presentation of the experimental LHC results and set new search directions.

3 Phase-I and Phase-II Upgrades

3.1 Phase-I: Construction and test of the ATLAS-NSW SM1 modules, their integration

To benefit from the expected high luminosity of Phase-I upgraded LHC, the first station of the forward ATLAS muon spectrometer (Small Wheel, SW) will be replaced in 2020. The new detectors will operate up to 15 kHz/cm^2 with high precision as well as furnishing information for the Level-1 trigger. The new SW has two detector technologies: micromegas mainly for precision tracking and small strip TGC for mainly L1 trigger. An INFN consortium formed by Cs, LNF, Le, Na, Pv, Rm1, Rm3 has the responsibility of the construction and test of the MM modules (SM1) located in a small-sector closed to the beam line. After the construction of the first two full size MM prototypes their performances have been checked in a test-beam at CERN and in the second semester of 2017 the series production has started. In the year 2020 all SM1 modules have been produced, fully assembled, tested and shipped to CERN. Some of them have been tested at the gamma irradiation facility at CERN. Here the group has the responsibility for the gas tightness validation of modules, as well as the HV testing and for the validation of the modules at the gamma irradiation facility at CERN. The group had the responsibility of the preparation, test and finalization with the mesh

of the 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 NSW project. Figure 1 shows the first small sector installed on the wheel A at the beginning of 2020.

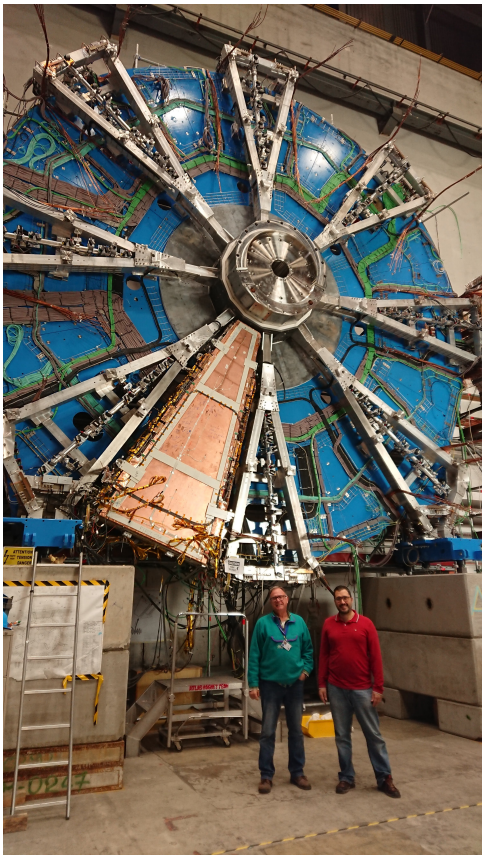

Figure 1: *The first small sector installed on the wheel A at the beginning of 2020.*

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

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 the Cosenza Group more than 16 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 install on top of the existing BIL tracking chamber. The preparation of the laboratory started in the second part of the 2019, while the construction of the first tools to build and test the RPC chambers is started in 2020.

3.3 Phase-II: R&D Phase-II Atlas Pixel

Over the next decade the Large Hadron Collider at CERN will undergo a series of upgrades, increasing both the energy and the luminosity, culminating in the Phase-II upgrade that will deliver an unprecedented instantaneous luminosity of $5 \cdot 10^{34} cm^{-2} s^{-1}$ at 14 TeV centre-of-mass energy. In particular, the current Inner Tracker will need to be replaced with a new all silicon

Inner Tracker (ITK) to maintain tracking performance in the high occupancy environment and to cope with the increase of approximately a factor of ten in the total radiation fluence. An intense R&D program is currently underway at CERN to develop the new sensor technologies meeting this challenge. With the support and engagement of the local research groups of Electronics and Mechanical Engineering, the Cosenza Unit participates in R&D for the second 3D generation sensor and is involved in the design, construction and tests of the ITK cooling system, coordinated by the Genoa Team. Prototypes and thermo mechanical tests are performed in the local laboratories.

4 List of Conference Talks and Poster by LNF Authors in Year 2020

1. G. Carducci & M. Schioppa, Study of the HV stability in the ATLAS New Small Wheel upgrade Micromegas detector, 106 Congresso Nazionale SIF 2020, 14-18 settembre 2020, Milano, Italy

2. I. Gnesi, The Micromegas chambers for the ATLAS New Small Wheel upgrade, Instrumentation for Colliding Beam Physics (INSTR 2020), 24-28 February 2020, Novosibirsk, Russia.

References

1. ATLAS Collaboration, "Measurements of top-quark pair single- and double-differential cross-sections in the all-hadronic channel in p-p collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector", JHEP 01 (2021) 033.

2. ATLAS Collaboration, "Measurements of the production cross-section for a Z boson in association with b-jets in proton-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", JHEP 07 (2020) 44.

KLOE-2 and MATHUSLA

M. Schioppa (Resp.)

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

The KLOE-2 experiment at the INFN Laboratori Nazionali di Frascati at the upgraded e+e- DAFNE collider, completed its data taking in march 2018. KLOE-2 represents the continuation of the KLOE experiment with a new physics program. The KLOE detector has undergone several upgrades including 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 taking until the end of the physics program and currently it is focused on the data analysis.

2 MATHUSLA

Lifetime is a free parameter in the models predicting LLNP. The only upper limit comes from the Nucleosynthesis after Big Bang (BBN): $c\tau \sim 10^{7\div 8}$ m. Given the not optimal design of the LHC detectors to searches for particles with long life, the upper limit in lifetime reachable after the High Luminosity LHC phase (assuming an integrated luminosity of $\sim 3\ ab^{-1}$) is $\sim 10^3$ m. The Cosenza group is member of the MAssive Timing Hodoscope for Ultra Stable neutraL pArticles (MATHUSLA) collaboration. The goal is to propose a large area detector to be installed at the ground level over the ATLAS or the CMS detector to explore the lifetime frontier collecting data during the High Luminosity LHC phase. The group is contributing to the simulation studies and experimental tests on a small detector prototype that are mandatory for the preparation of the experiment proposal.

THEORETICAL PHYSICS

BELL
Fundamental Problems in Quantum Physics

G. Nisticò (Resp.)

1 Consistent derivation of relativistic quantum theories of single particle

Relativistic quantum theories obtained by canonical quantization, e.g. Klein-Gordon theory, turned out to be plagued by well known problems, such as negative values of probability densities. So, Theoretical Physics turned on Quantum Field Theory to model particle physics. In order to develop relativistic quantum theories of single free particle without the problems that plagued the early theories, we have pursued an approach, based on group theoretical methods, that develops the theory deductively from two physical principles: *invariance ot the theory under Poincarè group* and *covariance of the position observable*. These methodological commitments prevent from the mentioned inconsistencies. In so doing, six inequivalent complete consistent theories for spin 0 and positive mass particles have been derived, amomg which the theories for particles of Klein-Gordon kind [1)], but free from inconsistencies.

We are specializing the approach to the case of an *elementary massless systems*. Our method leads to determine definite contraints that were not releaved before. These contraints allow to establish which generalized representations can be taken to develop the quantum theory of the system under investigation and which representations must be discarded. It turns out that representations adopted in the literature violate these contraints, and therefore the outcoming theories are inconsistent with the starting physical principles.

The problem is also addressed of establishing which of these consistent theories is a theory of massless *particle*, i.e. which of them admit a unique tern (Q_1, Q_2, Q_3) of quantum observables representing the three coordinates of the position of the particle. In so doing known results about such a problem can be generalized and detailed.

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1. Nisticò G. 2020 *Group Theoretical Derivation of Consistent Free Particle Theories*, Foundations of Physics (2020) 50:977–1007 https://doi.org/10.1007/s10701-020-00364-2

GAST - Gauge and string theories

M. Rossi (Ass. nodo di Bologna dell'IS Gast)

1 Research activity in 2020

My research activity in 2020 concerned the following topics.

- Application of integrability techniques to the computation of scattering amplitudes in gauge theory with supersymmetry. This project, in collaboration with D. Fioravanti (INFN Bologna) and H. Shu (Nordita, Stockholm) produced a paper published in JHEP [1)] and is now continuing with the computation of exact spectrums of Schroedinger operators by means of techniques coming from integrable models: TBA equations, Bethe Ansatz, Non-linear integral equations.
- In collaboration with A. Nava, D. Giuliano and A. Papa (INFN Cosenza) we studied a generalized Susceptible- Exposed-Infectious-Recovered (SEIR) model on a graph, describing the population dynamics of an open crowded place with an arbitrary topology. On this topic we wrote the paper [2)].
- In collaboration with V.Denisi (Master student) and A.Papa (INFN Cosenza) we revisited the problem of the covariance of Dyson series when interaction depends on derivatives of the fields and we gave a proof based on Wick's theorem. On this subject we wrote a preprint [3)], at present under review in Theoretical and Mathematical Physics.
- In collaboration with A. Nava and D. Giuliano (INFN Cosenza) we investigated an interacting one dimensional electronic chain connected to two reservoirs and by means of Lindblad equation approach we derived the range of the system parameters in which an optimal working point emerges in the non equilibrium stationary state. The preprint [4)], at present under review in Physical Review B, is about this topic.

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2. A. Nava, A. Papa, M. Rossi, and D.Giuliano, Phys. Rev. Research 2, 043379 (2020) and arXiv:2006.03157 [physics.soc-ph];
3. V.Denisi, A. Papa, M.Rossi, arXiv:2008.03168 [hep-th];
4. A. Nava, M. Rossi, and D. Giuliano, arXiv:2010.04533 [cond-mat.str-el].

LINCOLN
Learning Complex Networks

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

1 Mathematical Models for Semiconductors

1) A hierarchy of macroscopic models for phonon transport in graphene, study of the thermal conductivity [1)].

2) Comparison of a kinetic and a macroscopic model for charge transport in graphene [2)].

3) Analysis of the moment method for charge transport in low dimensional semiconductor devices [3)]

4) Study of coupled models of PDAEs (partial-differential-algebraic equations), with application to the modeling of integrated circuits in microelectronics: existence and uniqueness results for multidimensional parabolic PDAEs [4)].

5) Model Order Reduction (MOR). Extension of IMOR (Index-aware MOR) method and IIMOR (Implicit Index-aware MOR) method to nonlinear DAEs.

2 Generalized Quantum Observables and Phase Space Quantum mechanics

1) Naimark's dilation theorem

   In [5)] we introduced a partial order relation in the set of Naimark's dilations, showed that there is a minimal element and that it is unique. Minimality is a consequence of the partial ordered structure and coincides with the usual definition of minimal Naimark's dilation.

2) Quantum observables

   In [6)] we proved that there is a universal Markov kernel μ^U such that every commutative POVM F is the random version of a self-adjoint operator A^F with the randomization generated by μ^U. Moreover, we showed that every weak Markov kernel is functionally subordinated to the universal Markov kernel [6)]. That extends and generalizes some previous results [7, 8)]. We also analyzed the relevance of such results to the theory of fuzzy sets and fuzzy observables.

3 Congresses

Organization of the international conference IQSA2020, postoponed to 2022 because of Covid-19 emergency.

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1. G. Mascali, V. Romano, A Hierarchy of Macroscopic Models for Phonon Transport in Graphene, Physica A 548, 124489 (2020).

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3. D. V. Camiola, G. Mascali, V.Romano, The moment method for charge transport in low dimensional semiconductor devices, Springer (2020).

4. G. Alí, N. Rotundo, Existence and uniqueness of solution for multidimensional parabolic partial differential-algebraic equations arising in semiconductor modeling, Math Meth Appl Sci. 1-26 (2021). (DOI: 10.1002/mma.7175)

5. R. Beneduci, Notes on Naimark's dilation theorem, Journal of Physics: Conference Series, 1638, 012006 (2020).

6. R. Beneduci, T. Gentile, Universal Markov Kernel and the Universal Family of Fuzzy Sets (submitted).

7. R. Beneduci, Universal randomization of Quantum Observables, Int. J. Theor. Phys., (2019) DOI: 10.1007/s10773-019-04090-y

8. R. Beneduci, Universal Markov Kernel for Quantum Observables, , Geometric Methods in Physics XXXVI workshop 2017, Trends in Mathematics, 21-29, Birkauser (2019).

NEMESYS and Time2Quest

A. Sindona (Resp., National/Local coord.), P. Riccardi (Ass.), F. Plastina (Ass.),
J. Settino (Ass.), M. Pisarra (Ass.)

1 Research Activity

The first half of 2020 has been committed with the closing activities of the NEMESYS specific initiative (SI), which was initiated at the beginning of 2017 and coordinated over the subsequent four-year period by Antonello Sindona from the CS unit. The second half of the 2020 has been focused on the development of a new proposal, abbreviated as Time2Quest, which is the natural continuation of NEMESYS. 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 novel project, share their expertise in time-dependent density functional theory and out of equilibrium thermodynamics

The CS unit has specifically explored the following topics:

(i) **plasmon excitations, dielectric, electromagnetic, and fundamental properties of graphene and beyond graphene systems.** 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 [1)], and setting up an ab initio framework to determine the effective fine-structure constant of graphene [2)], the efforts of this research line were focussed on charge-carrier density oscillations in atomically precise graphene nanoribbons, organized in planar array form [3)]. In particular, 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.

(ii) **Electron excitations in bulk materials.** The broadband excitation spectrum of bulk $PtTe_2$ was explored using electron energy-loss spectroscopy and density-functional theory. In addition to infrared modes related to intraband three-dimensional (3D) Dirac plasmon, and interband transitions between the 3D Dirac bands, three modes at 3.9, 7.5, and 19.0 eV in the ultraviolet region. [4)].

(iii) **Out of equilibrium thermodynamics.** Constraints on work extraction are fundamental to our operational understanding of the thermodynamics of both classical and quantum systems. In the quantum setting, finite-time control operations typically generate coherence in the instantaneous energy eigenbasis of the dynamical system. Thermodynamic cycles can, in principle, be designed to extract work from this nonequilibrium resource. Here, we isolate and study the quantum coherent component to the work yield in such protocols.

Specifically, we identify a coherent contribution to the ergotropy (the maximum amount of unitarily extractable work via cyclical variation of Hamiltonian parameters). We show this by dividing the optimal transformation into an incoherent operation and a coherence extraction cycle. We obtain bounds for both the coherent and incoherent parts of the extractable work and discuss their saturation in specific settings. Our results are illustrated with several examples, including finite-dimensional systems and bosonic Gaussian states that describe recent experiments on quantum heat engines with a quantized load [5]- [7].

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5. G. Francica; F.C. Binder; G. Guarnieri; M.T. Mitchison; J. Goold; F. Plastina, "Quantum Coherence and Ergotropy", Physical Review Letters, 180603, 125, 2020

6. G. Guarnieri; D. Morrone; B. Cakmak; F. Plastina; S. Campbell, S, "Non-equilibrium steady-states of memoryless quantum collision models", Physics Letters A 126576, 384, 2020

7. J. Settino; N. W. Talarico; F. Cosco; F. Plastina, F; S. Maniscalco; N. Lo Gullo , "Emergence of anomalous dynamics from the underlying singular continuous spectrum in interacting many-body systems", Physical Review B 144303, 101, 2020

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

V. Chelnokov (Ass.), A. Papa (Resp.)

1 Flux tubes in pure-gauge SU(3)

We have extended a previous numerical study of SU(3) Yang-Mills theory in which we measured the spatial distribution of all components of the color fields surrounding a static quark–antiquark pair and provided evidence that the simulated gauge invariant chromoelectric field can be separated into a Coulomb-like 'perturbative' field and a 'nonperturbative' confining field. We have hypothesized that the fluctuating color fields not measured in our simulations do not contribute to the string tension. Under this assumption the string tension is determined by the color fields we measure, which form a field strength tensor pointing in a single direction in color space. We call this the 'Maxwell picture of confinement'. We have provided an additional procedure to isolate the confining field. We have then extracted the string tension from a stress energy-momentum tensor having the Maxwell form, constructed from the simulated non-perturbative part of the field strength tensor. To test our hypothesis we have calculated the string tension for values of the quark-antiquark separation ranging from 0.37 fm to 1.2 fm. We have also calculated the spatial distributions of the energy-momentum tensor surrounding static quarks for this range of separations, and we have compared with the distributions obtained from direct simulations of the energy-momentum tensor.

2 Models for infection spread

We have formulated a generalized Susceptible Exposed Infectious Recovered (SEIR) model on a graph, describing the population dynamics of an open crowded place with an arbitrary topology. As a sample calculation, we have discussed three simple cases, both analytically, and numerically, by means of a cellular automata simulation of the individual dynamics in the system. As a result, we have provided the infection ratio in the system as a function of controllable parameters, which allows for quantifying how acting on the human behavior may effectively lower the disease spread throughout the system.

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The confining color field in SU(3) gauge theory,
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2. A. Nava, A. Papa, M. Rossi, D. Giuliano,
Analytical and Cellular Automaton approach to a generalized SEIR model for infection spread in an open crowded space,

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QFT@COLLIDERS
Precision calculations for collider physics

A.D. Bolognino (Dott.), M. Fucilla (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 inclusive production at the LHC of two Λ-hyperons or of a single Λ-hyperon in association with a jet, featuring high transverse momenta and large separation in rapidity. The process-independent part of the calculation was taken in the NLA.

Within the BFKL approach at the LLA, it is straightforward to introduce the small-x unintegrated gluon density (UGD), which enters the theoretical description of diffractive processes, such as the leptoproduction of the ϕ light vector meson. In particular, we have investigated the production of the ϕ meson in deep-inelastic scattering in the cases of helicity-conserving transition from longitudinal or transverse virtual photon to the ϕ vector meson. The investigation of this kind of processes provides a useful tool for discriminating among alternative models for UGDs.

2 Talks in Year 2020

1. M. Fucilla,
   Heavy-flavored emissions in the high-energy limit of strong interactions,
   EF06 meeting - Forward QCD, SnowMass 2021 (June 17, 2020)
   https://indico.fnal.gov/event/43786/

2. M. Fucilla,
   High energy QCD at colliders: semi-hard reactions and un integrated gluon densities (LOI),
   EF06 meeting - Forward QCD, SnowMass 2021 (August 26, 2020)
   https://indico.fnal.gov/event/44148/

3. M. Fucilla,
   Heavy-flavour production as a new channel for the investigation of BFKL dynamics,
   106° Congresso Nazionale SIF 2020 (Milan, September 14-18, 2020)
   https://agenda.infn.it/event/23656/contributions/

4. M. Fucilla,
   High-energy limit of strong interaction: BFKL and related topics,
   EF06/EF07 meeting - Saturation, SnowMass 2021 (October 21, 2020)
   https://indico.fnal.gov/event/45580/

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SFT - Statistical Field Theory and Applications

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

1 Tunable spin/charge Kondo effect at a double superconducting island connected to two spinless quantum wires [1)]

We propose that a double superconducting island connected to two spinless one-dimensional conducting leads can work as a tunable (iso)spin Kondo and charge Kondo system. By tuning a single gate voltage applied to the island, it is possible to make the system switch from the (iso)spin Kondo to the charge-Kondo phase. Eventually, we evidence how to probe the various phases by measuring the ac conductance tensor of the system.

2 Equivalent critical behavior of a helical point contact and a two-channel Luttinger liquid - topological superconductor junction [2)]

We demonstrate the equivalence between a one-dimensional topological superconductor coupled at one end to the ends of two single channel Luttinger liquids and a point contact in the quantum spin Hall effect. In particular, we show they are related by a duality transformation, with similar, nontrivial intermediate critical points. The correspondence allows us to make new predictions about the topological superconductor-Luttinger liquid junction, in particular about the global behavior of the critical conductance, the critical exponents and the universal crossover scaling functions.

3 Tunable Kondo screening length at a Y-junction of three inhomogenous spin chains [3)]

We derive the topological Kondo Hamiltonian describing a Y junction of three XX-spin chains connected to outer quantum Ising chains with different tilting angles for the Ising axis. We show that different tilting angles induce nonzero equilibrium spin (super)currents through the junction. Eventually, we derive the scaling formulas for the equilibrium spin currents and prove that it is possible to estimate the Kondo screening length by monitoring the crossover in the current pattern.

4 Analytical and cellular automaton approach to a generalized SEIR model for infection spread in an open crowded space [4)]

We formulate a generalized susceptible exposed infectious recovered (SEIR) model on a graph, describing the population dynamics of an open crowded place with an arbitrary topology. As a sample calculation, we discuss three simple cases, both analytically, and numerically, by means of a cellular automata simulation of the individual dynamics in the system. As a result, we provide the infection ratio in the system as a function of controllable parameters, which allows for quantifying how acting on the human behavior may effectively lower the disease spread throughout the system.

5 Emerging Majorana Modes in Junctions of One-Dimensional Spin Systems [5)]

The non-local effects induced by Majorana fermions in field theories for condensed matter systems are deeply related to the fermion charge fractionalization discovered by Roman Jackiw in relativistic field theories. We show how the presence of Majorana fermions may be mimicked in pertinent networks of spin chains inducing a spin analogue of the multi-channel Kondo effect. The relevance of this spin analogue of the Kondo effect for networks of Josephson arrays and Tonks-Girardeau gases is highlighted.

6 Dynamical properties of many-body systems [6)]

In collaboration with J. Settino (Salerno) and with the group of S. Maniscalco and N. Lo Gullo (Turku, Finland), we obtained a theoretical description of the anomalous slow dynamics observed in a recent experiment with trapped cold atoms. In particular, we were able to track this effect back to the properties of the underlying geometry of the system and to the emergence of a singular-continuous branch of the spectrum in the Aubry-André model.

7 Role of Quantum coherence in non-equilibrium thermodynamics [7)]

In collaboration with G. Francica (Salerno) and with the group of J. Goold (Trinity College, Dublin), we investigated the effects resulting from the presence of quantum coherence in the thermodynamics of small quantum systems, with particular reference to work/energy extraction processes. This led us to define a coherent contribution to ergotropy.

8 Quantum Collision models [8)]

In collaboration with G. Guarnieri and S. Campbell (Dublin) and B. Cakmak (Istanbul) and together with D. Morrone (student, Cosenza), we investigated the steady state properties arising from the open system dynamics described by a memoryless (Markovian) quantum collision model, corresponding to a master equation in the ultra-strong coupling regime. We showed, in particular, that the collision dynamics lead to a non-equilibrium steady state supported by steady-state energy and coherence currents.

9 Supersensitive quantum sensor based on criticality in an antiferromagnetic spinor condensate [9)]

We show that an antiferromagnetic Bose-Einstein condensate in a transverse magnetic field with a fixed macroscopic magnetization exhibits two different critical behaviors, corresponding to transitions from polar to broken-axisymmetry and from antiferromagnetic to broken-axisymmetry phases. We exploit both types of system criticality as a resource in the precise estimation of the control parameter value. We quantify the achievable precision by the quantum Fisher information. We demonstrate supersensitivity and show that the precision scales with the number of atoms up to N4 around criticality. In addition, we study the precision based on the error-propagation formula, which provides a simple-to-measure signal whose scaling coincides with the quantum Fisher information. Finally, we take into account the effect of nonzero temperature and show that sub-shot-noise sensitivity in the estimation of the control parameter is achievable in the low-temperature limit.

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COMPUTATION TECHNOLOGY

The ReCaS Cosenza Data Center

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1 Introduction

The ReCaS Cosenza Data Center (see Fig. 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

Completed by the end of 2015, and operational since then, the ReCaS Cosenza Data Center has operated also for the year 2020 with very high efficiency and stability. As an example, Fig. 2 shows

for the ATLAS virtual organization a comparison of the performance of the ReCaS Cosenza Data Center w.r.t. that of other Italian ATLAS Tiers 2 sites for year 2020; the comparison demonstrates the excellent perfomance of the ReCaS infrastructure.

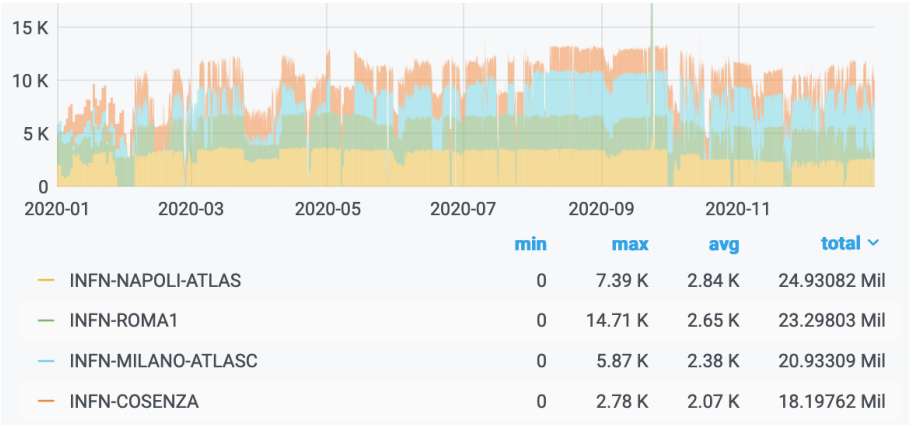

Figure 2: *A comparison of the slots of running jobs in 2020 for a selection of ATLAS Tier2 centers and the ReCaS Cosenza Data Center.*

3 Upgrade

In spring 2018 an upgrade project of the research infrastructure STAR (Southern Europe Thomson Backscattering Source for Applied Research) was submitted as part of the EU PON programme "Research and Innovations" 2014-2020 and in the context of this upgrade project an important synergy between ReCaS and STAR was established with the main goal to use the ReCaS Data Center as the main computing facility of STAR for the storage, reconstruction and analysis of the very high resolution tomographic images that will be produced by the facility.

In March 2019 the STAR 2 upgrade project (project 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. The upgrade works of the ReCaS Data Center, delayed due to the COVID-19 emergency, are planned to start in mid 2021.

COMMUNICATION AND OUTREACH

European Researchers' Night 2020, International Physics MasterClasses 2020, the LHC World Wide Data Day 2020 and the OCRA project

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1 European Researchers Night 2020

1.1 The Cosmic Rays as messangers to investigate the Universe

[M. Schioppa (Resp.)]

Is out of doubt that learning by doing is the most powerful method to teach physics to young and less young students. The group has started more than 10 years ago to open the "Alte Energie" laboratory to students and to go into the schools 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 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 operative in Calabria. In 2020 EEE project becomes a special INFN project under the supervision of Prof. L. Cifarelli. The EEE telescopes activities into the schools are only a part of the group activities. The group organizes seminars, masterclasses, participate to the ICD and to the program ASL (work-school alternation) where the students work both into they laboratories and in the "Alte Energie" laboratory.

2 International Physics MasterClasses 2020

[M. Capua (Resp.)]

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 Region.

In 2020, due to the Covid-19 pandemia, just one-day event took place:

- February 11, special event for the *International Day of Women in Science*, attended by 44 students from 13 schools. (agenda.infn.it/event/mcg2020). The event was characterized by an overall enthusiastic participation of students and high-school teachers, as confirmed by students' interviews.

3 The LHC World Wide Data Day 2020

[M. Capua (Resp.)]

Also in 2020, we participated to the *LHC World Wide Data Day*, in which students from around the world analyzed LHC data and shared results. The project is designed for high schools students that select dimuon events (open data from ATLAS) and calculate the Φ angle of each muon selected in the plane tranverse to the beampline.

4 OCRA project of INFN-CC3M

[M. Schioppa (Resp.)]

In the year 2020 the group has participated to the OCRA project of the INFN-CC3M scientific group. The group has built three cosmic rays telescopes with scintillators and measured the absorption power of the atmosphere atoms together the high school students and teachers. In the same year the group has started new project to measure the cosmic ray flux into water at different deeps. The experiment was planed for spring 2020, but the measures to deal with the COVID-19 emergency did not allow the experiment to be carried out. In November the group has coordinated the International Cosmic Day 2020 of the Calabrian schools. They presented the measurement of the cosmic rays flux as a function of the zenith angle, determining the effect of atmosphere as particle absorber.

RADIOLAB 2020

M. Capua (Resp.), L. La Rotonda (Ass.), P. Riccardi (Ass.), J. Orbe (Dott.)

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). This project has immediate consequences in terms of dissemination of the contribution of the scientific approach to the assessment of the problem, social awareness, risk awareness, both for the students and the families and the society connected to them.

In 2020 the second three-year cycle has begun. Five Calabrian schools and two schools in Riobamba in Ecuador (more then 150 students) participated and more than 500 interviews to citizens were made at the beginning of the activity to understand the degree of knowledge of the radon risk. The experience was a great success, as also documented in the presentation at the PLS Congress in Catania (February 2021) (see www.laureescientifichefisica.unict.it/content/convegno-febbraio-2021).

On the 7th of November, Marie Skłodowska Curie's birthday, we organised an open meeting with the Calabria Region, in particular the Research Department, in which Radiolab students explained the importance of the project. Among others there were the contributions of the national leaders of Radiolab, the Regional Council for School and Research and the representative of the Regional School Office. In addition to the wide participation of schools and teachers and experts (up to the limit of 300 people), the Councilor for Education, University, Scientific Research and Innovation, stimulated by the experience shared by the students, announced important interventions in favor of the scientific laboratories of the schools to support the activity in all areas of physics related to health and the environment.

Premio Asimov 2020

G. Alì (Ass.), D. Giuliano (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 15, 2020. The recording of this event is available in the YouTube channel of Premio Asimov, https://www.youtube.com/c/PremioAsimov.

The edition of 2020 counted overall about 2000 participants from more than 100 school in the Regions Abruzzo, Campania, Emilia Romagna, Lazio, Marche, Puglia, Sardinia, Sicily, Tuscany, Umbria and, of course, Calabria, which contributed with about 130 students from nine different high schools. On April 27, 2020 a videoconference took place, organized by the Physics Department of the University of Calabria and INFN-Cosenza, with the participation of some of the Calabrian students to be rewarded as best reviewers. The recording of this event is available in the YouTube channel of Premio Asimov, https://www.youtube.com/c/PremioAsimov.