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 2019, 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 2019 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 semi-leptonic and fully hadronic finale states for the resolved and boosted regimes. In particular, the final measurement of the semileptonic channel has been published [1)] in 2019 while the completion of the analysis of the fully hadronic channel (presently at the editorial board stage) is foreseen by summer 2020. The group also contributes 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 containing b-hadrons is a crucial ingredient for many physics analyses of the ATLAS experiment. The group contributed to the development of a new method to calibrate the identification efficiency of such 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 LHC 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 flavour composition and the b-jet identification efficiency. The analysis is in an advanced state and an ATLAS internal note is in preparation. These results will be part of a publication, on b-tagging techniques in ATLAS, expected for the second half of 2020.

2.3 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 results based on the full Run2 13 TeV statistics (140 fb^{-1}) are expected by the end of 2020. 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 2019 twenty-four complete modules have been produced and fully assembled and some of them tested at the gamma irradiation facility at CERN.

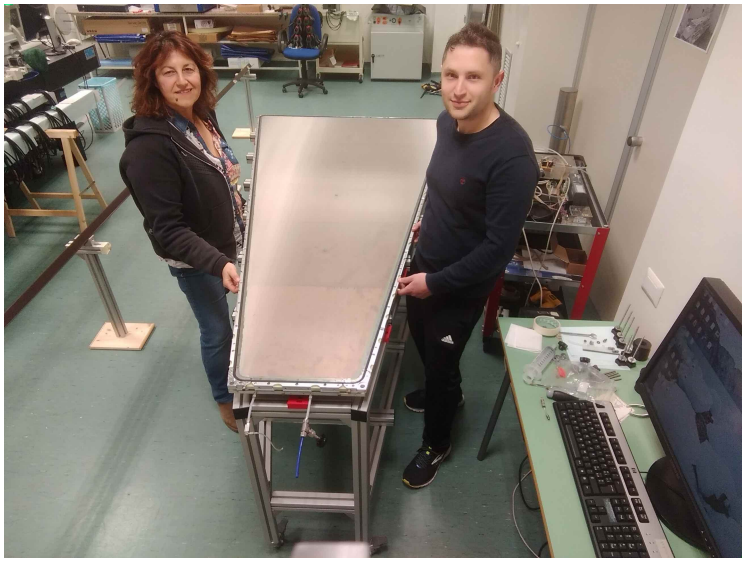

Figure 1: *Preparation of the drift modules at the "Alte Energie" Laboratory of Cosenza.*

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. In summer 2018 the preparation of the drift modules have been transferred at "Alte Energie" laboratory of Cosenza where the raw panels produced by Roma1 are cleaned, dressed with other elements (interconnection holders and spacers, mesh frames and O-Rings) and tested. Once the panels are ready they are transferred to LNF where they are completed with the mesh. The group has the responsibility of the finalization 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. In the year 2019 all the drift panels have been produced and equipped with the final elements in the Cs laboratory. Only the spare panels (9 in total) remains to be finalized in 2020.

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

In the 2018 the group got the responsibility to build and test one fourth 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 15 years ago. To increase the discrimination power for muons coming from the interaction point, the ATLAS collaboration agreed to the construction of the fourth 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 will start 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

1. E. Meoni, Monte Carlo generators for the modelling of multijet processes in ATLAS at 13 TeV, XXVII International Workshop on Deep Inelastic Scattering and Related Subjects (DIS2019), 8-12 April 2019, Torino, Italy.

2. E. Meoni, Measurement of V+jets production at ATLAS, European Physical Society Conference on High Energy Physics (EPS-HEP), 10-17 July 2019, Ghent, Belgium.

3. E. Tassi, Highlights of top-quark production measurements at ATLAS, 22nd High-Energy Physics International Conference in Quantum Chromodynamics (QCD19), 2-5 July 2019, Montpellier, France.

4. F. La Ruffa, Determination of proton parton distribution functions using ATLAS data, XXVII International Workshop on Deep Inelastic Scattering and Related Subjects (DIS2019), 8-12 April 2019, Torino, Italy.

5. G. Carducci, The ATLAS New Small Wheel Project: SM1 drift panel assembly and finalization, IFAE 2019, 8-10 April 2019, Napoli, Italy.

6. A. Mastroberardino, Utilizzo delle radiazioni ionizzanti e radioprotezione all' Unical, Conferenza La protezione ambientale e sanitaria del territorio calabrese. Programmare la rinascita: il caso Crotone, 15 November 2019, Crotone, Italy.

5 Publications

References

1. ATLAS Collaboration, "Measurements of top-quark pair differential and double-differential cross-sections in the l+jets channel with pp collisions at $\sqrt{s} = 13$TeV using the ATLAS detector" , Eur. Phys. J. C79 (2019) 1028.

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 is currently taking data at the upgraded e+e- DAFNE collider. 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 tacking until the end of the physics program and to the analysis of data.

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 relativistic quantum theories of single particle

Relativistic quantum theories of single free particle without the inconsistencies of the theories yielded by canonical quantization have been developed [1][2] by means of a purely deductive method, starting from two physical principles: *invariance ot the theory under Poincarè group* and *covariance of the position observable* with respect to relativistic tranformations. In so doing six inequivalent complete consistent theories for spin 0 massive particles (*Klein-Gordon particles*) have been derived. They are not affected by the inconsistencies of Klein-Gordon theory. Two of them are new species of theories, in the sense that do not find correspondence in the known theories.

The present lack of explicit quantum transformation relations of position with respect to boosts makes unable the approach to identify the theories of non zero spin particle, such as Dirac particles. These relations can be nowadays determined only in the already identified complete theories for spin 0 particles, where they can be directly calculated, all involved operators being explicitly known; they turn out to coincide with the transformation relation (JM) adopted by Jordan and Mukunda [Phys.Rev.**132**,1842] for all spins. Dirac theory turn out to be consistent with (JM), provided that new classes of representations of Poincaré group are adopted. This fact could be taken as an argument supporting the *general* validity of (JM). On the other hand, (JM) turn out to be inconsistent with the existence of localizable particle with positive energy and spin $s > 0$. Hence there are arguments in favor but also against the general validity of (JM). To attempt to solve the dilemma, the efforts are directed towards the derivation of the explicit mathematical relation (KQ) that expresses the covariance of position with respect to boosts from sound physical principles, analogously to what done in [1][2] for euclidean transformations. Whenever such a deduction will be successful, one of the following statements will hold.

Either *(KQ) are equivalent to (JM).* In this case there would be precise consequences; for instance, one consequence will be that Poincaré invariance is incompatible with the existence of particles with positive energy and non zero spin.

Or *(KQ) are not equivalent to (JM) in some theories.* In this case we should investigate which position operators are consistent with (KQ). If they exist, we would have determined a theory *alternative* to that of Dirac, implied by physical principles without canonical quantization.

The work of 2019 was devoted also to extend the approach to zero mass theories.

References

1. Nisticò G. 2019 *New representations of Poincare group for consistent Relativistic Particle Theories*, Journal of Physics: Conf. Series **1275** 012034.

2. Nisticò G. 2019 *Group Theoretical Settling of Spin Zero Relativistic Particle Theories*, Journal of Physics: Conf. Series **1194** 012082.

GAST - Gauge and string theories

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

1 Scattering amplitudes in $\mathcal{N} = 4$ Super Yang-Mills

The $\mathcal{N} = 4$ Super Yang-Mills (SYM) theory appears at one side of one example of AdS/CFT correspondence and, interestingly, shows remarkable connections with 1+1 dimensional integrable models. Recently, techniques coming from integrable systems have been used for exact computations of gluon scattering amplitudes. Technically, the amplitudes are expressed in the form of a Operator Product Expansion (OPE) and each term in the series is computable by using form factors theory, Bethe Ansatz and S-matrix bootstrap - all techniques developed and used in 1+1 integrable models. And, thanks to the AdS/CFT correspondence, such results can be tested by comparisons with string theory predictions.

In a series of papers of which [1)] is the last, I have studied the strong coupling behaviour of null polygonal Wilson loops (which are equivalent to gluon scattering amplitudes in $\mathcal{N} = 4$ SYM), by a peculiar expansion of the amplitudes - the previously mentioned OPE series - and its integrability features. In [1)] we have completed our analysis by rigorously showing, at strong coupling, the appearance of a new effective particle in the series: a fermion-antifermion bound state, the so-called meson. We discuss interactions of the meson with itself - which determine the formation of bound states - and with the gluons and bound states of them. We showed that all together these effects lead the OPE series to the known AdS_5 minimal area result of Alday, Gaiotto and Maldacena for the Wilson loops, described in terms of a set of Thermodynamic Bethe Ansatz equations. This approach allows us to detect also all the one-loop corrections to the leading strong coupling result, which are classified and partially computed in the paper.

References

1. *Fermions and scalars in N=4 Wilson loops at strong coupling and beyond*
Alfredo Bonini, Davide Fioravanti, Simone Piscaglia, Marco Rossi,
Nucl.Phys. B (2019) 114644 and arXiv:1807.09743.

NEMESYS

A. Sindona (Resp., National coord.), P. Riccardi (Ass.), F. Plastina (Ass.),
J. Settino (Dott.), F. Alessandro (Dott.)

1 Research Activity

Following its initial proposal made in 2016, the NEMESYS specific initiative (SI) has been developing models and highly demanding computational strategies to explore the excited state properties, collective excitations, transport phenomena and other many-body properties of low dimensional systems of uttermost importance both for the fundamental and practical points of views, covering range of applications spanning from nano-electronics to biomedicine. With the end of the SI, in 2019, the CS unit has completed the coordination the activities of the four nodes involved in the project, which were committed with time-dependent density functional theory, many body perturbation theory and non-equilibrium Green's functions simulations on graphene-like and beyond graphene systems in planar or linear configurations. In particular, 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.** Exploiting the relative entropy of coherence, the coherent contribution in the energetics of a driven nonequilibrium quantum system was isolated. It was proved that a division of the irreversible work can be made into a coherent and incoherent part. This provides an operational criterion for quantifying the coherent contribution in a generic nonequilibrium transformation on a closed quantum system. It was then studied such a contribution in two physical models of a driven qubit and kicked rotor. In addition, it was shown that coherence generation is connected to the nonadiabaticity of a

processes, for which it gives the dominant contribution for slow-enough transformations. The amount of generated coherence in the energy eigenbasis is equivalent to the change in diagonal entropy, which fulfills a fluctuation theorem [5]. Besides, the paradigmatic case of an array of nearest-neighbor coupled quantum harmonic oscillators interacting with a thermal bath and subjected to a quench of the inter-oscillator coupling strength was fully investigated [6].

Talks

- A. Sindona, "Electromagnetic response of graphene nanoribbons in planar array configuration: a time-dependent density functional approach" Nanoscience and Nanotecnology 2019, 15-18/10/2019, Frascati (RM), Italy.
- A. Sindona, "Nemesys Specific Initiative: status and perspectives", SM&FT 2019 Bari, 11-13/12/2019.
- F. Plastina, "The role of coherence in the Thermodynamics of Quantum Systems", invited talk at the conference "Quantum Technologies with ultra-strong couplings", Catania 4/10/2019.
- F. Plastina, "Decoherence in a synthetic fermion environment: from orthogonality catastrophe to Fano physics", invited talk given at the conference "IQISC2019", Milano 9-12/09/2019.
- F. Plastina, "Coherence Generation, Irreversible Entropy production and non-Adiabaticity in Quantum Processes", invited talk at the "Quantum Hiking Conference", Dolomiti 15-19/07/2019.
- F. Plastina, "Decoherence in a synthetic fermion environment: from orthogonality catastrophe to Fano physics", invited talk at the conference "ICQOQI 2019", Minsk (Belarus) 13-17/05/2019.

References

1. A. Sindona, A. Cupolillo, F. Alessandro, M. Pisarra, D. C. Coello Fiallos, S. M. Osman, and L. S. Caputi, "Interband π-like plasmon in silicene grown on silver", Physical Review **B 97**, 041401(R), 2018.
2. A. Sindona, M. Pisarra, C. Vacacela Gomez, P. Riccardi, G. Falcone, S, Bellucci, "Calibration of the fine-structure constant of graphene by time-dependent density-functional theory", Physical Review **B 96**, 201408(R), 2017.
3. A. Sindona, M. Pisarra, S. Bellucci, T. Tene, M. Guevara, and C. Vacacela Gomez, "Plasmon oscillations in two-dimensional arrays of ultranarrow graphene nanoribbons", Physical Review **B 100**, 235422, 2019.
4. B. Ghosh, F. Alessandro, M. Zappia, R. Brescia, C.-N. Kuo, C. S. Lue, G. Chiarello, A. Politano, L. S. Caputi, A. Agarwal, A. Cupolillo, "Broadband excitation spectrum of bulk crystals and thin layers of $PtTe_2$" Physical Review **B 99**, 045414, 2019.
5. G. Francica, G. Goold, F. Plastina, "Role of coherence in the nonequilibrium thermodynamics of quantum systems" Physical Review **E 99**, 042105, 2019.
6. M. Paternostro, G. De Chiara, A. Ferraro, M. Campisi, J. Goold, F. L. Semiao, F. Plastina and V. Vedral, "Out of equilibrium thermodynamics of quantum harmonic chains", Journal Of Statistical Mechanics-Theory And Experiment 10, 104014, 2019.

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)

Using lattice Monte Carlo simulations of SU(3) pure gauge theory, we have determined the spatial distribution of all components of the color fields created by a static quark and antiquark. We have identified the components of the measured chromoelectric field transverse to the line connecting the quark-antiquark pair with the transverse components of an effective Coulomb-like field $\vec{E}_C$ associated with the quark sources. Subtracting $\vec{E}_C$ from the total simulated chromoelectric field $\vec{E}$ yields a non-perturbative, primarily longitudinal chromoelectric field $\vec{E}_{NP}$, which we identify as the confining field. This was the first time that the chromoelectric field was separated into perturbative and nonperturbative components, creating a new tool to study the color field distribution between a quark and an antiquark, and thus the long distance force between them.

2 Three-quark potentials

Three-quark potentials have been studied in great details in the three-dimensional SU(3) pure gauge theory at finite temperature, for the cases of static sources in the fundamental and adjoint representations. For this purpose, the corresponding Polyakov loop model in its simplest version has been adopted. The potentials in question, as well as the conventional quark–anti-quark potentials, have been calculated numerically both in the confinement and deconfinement phases. Results have been compared to available analytical predictions at strong coupling and in the limit of large number of colors N. The three-quark potential has been tested against the expected Δ and Y laws and the three-quark string tension entering these laws has been compared to the conventional quark-antiquark string tension. As a byproduct of this investigation, essential features of the critical behaviour across the deconfinement transition have been elucidated.

3 Talks in Year 2019

1. V. Chelnokov,
   The confining color field in the SU(3) gauge theory,
   presented at "SM&FT 2019", Bari, December 12, 2019.

References

1. M. Baker, P. Cea, V. Chelnokov, L. Cosmai, F. Cuteri and A. Papa,
   Isolating the confining color field in the SU(3) flux tube,
   Eur. Phys. J. C **79** (2019) no.6, 478, doi:10.1140/epjc/s10052-019-6978-y [arXiv:1810.07133 [hep-lat]].

2. O. Borisenko, V. Chelnokov, E. Mendicelli and A. Papa,
Three-quark potentials in an $SU(3)$ effective Polyakov loop model,
Nucl. Phys. B **940** (2019) 214, doi:10.1016/j.nuclphysb.2019.02.002 [arXiv:1812.05384 [hep-lat]].

PLEXNET
Physics of Complex Networks

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

1 Mathematical Models for Semiconductors

1) Study of heat and charge transport in graphene by a fluid-dynamical model based on the maximum entropy method [1)].

2) Study of an extended hydrodynamical model for plasmas, based on the moments of a particle distribution function which satisfies the Fokker-Planck-Landau (FPL) transport equation.

3) Study of the steady-state and dynamical thermal conductivity of graphene nanoribbons including the analysis of the effect the scattering due the under-coordinated atoms at the edges of the nanoribbons [2)].

3) Coupled models: coupling of partial derivative equations and differential-algebraic equations, that is, PDAE (partial-differential-algebraic equations). In particular existence and uniqueness of solutions to parabolic PDAE with applications to the description of circuit integrated in semiconductors.

6) Model Order Reduction (MOR) for nonlinear DAEs with tractability index 1, with application to gas transport network.

2 Generalized Quantum Observables and Phase Space Quantum mechanics

1) Space Localization of the Photon

   The space localization of the photon cannot be described mathematically by means of self-adjoint operators. That would indeed correspond to a "sharp" localization which is forbidden by a result of Hegerfeld. Hegerfeld showed the incompatibility between sharp localization and relativistic causality. It is instead possible an "unsharp" localization described by a POVM. In particular, we derived the space localization of the photon in the framework of the phase space formulation of quantum mechanics [3)].

2) Quantum observables

   It is well known that a POVM F is commutative if and only if it is the random version of a self-adjoint operator with the randomization generated by a Feller Markov kernel. We proved [5)] that there is a universal Markov kernel, i.e., a Markov kernel ω such that every commutative POVM F is the random version of a self-adjoint operator A with the randomization generated by ω . Moreover, we have shown that every weak Markov kernel is functionally subordinated to the universal Markov kernel. We also analyzed the implications of that result to the characterization of a Markov kernel as a Choquet's integral on the space of deterministic Markov kernels [4)].

3 Congresses

1) ICTT 2019, Paris Francia, September 22 - 27, 2019, (G.Mascali, Title of the talk: A macroscopic model for phonon transport in graphene).
2) Workshop "Mathematical Foundations of Quantum Mechanics in Memoriam Paul Busch", 18-19 June 2019, YORK, UK. Invited Speaker. (R. Beneduci, Title of the talk: Space Localization of the Photon).

References

1. M. Coco, G. Mascali, V. Romano, Charge and phonon transport in suspended monolayer graphene, in preparation (2019).
2. G. Mascali, V. Romano, A Hierarchy of Macroscopic Models for Phonon Transport in Graphene, under review, Physica A (2019).
3. R. Beneduci, F.E. Schroeck, Space Localization of the Photon, Foundations of Physics, 49 (2019) 561-576.
4. R. Beneduci, Universal randomization of Quantum Observables, Int. J. Theor. Phys., (2019) DOI: 10.1007/s10773-019-04090-y.
5. R. Beneduci, Universal Markov Kernel for Quantum Observables, , Geometric Methods in Physics XXXVI workshop 2017, Trends in Mathematics, 21-29, Birkauser (2019).

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, two processes have been considered: the inclusive production at the LHC of a Higgs and a jet, featuring a large separation in rapidity, and that of two rapidity-separated heavy quarks. In both cases, 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 ρ and ϕ light vector mesons. The investigation of this kind of processes, which is currently under way, provides a useful tool for discriminating among alternative models for UGDs.

2 Talks in Year 2019

1. A. Papa,
   QCD in the high-energy limit: from gluon Reggeization to hadron phenomenology,
   seminar given at the Dipartimento di Fisica, Università di Pavia, February 20, 2019.

2. A. Papa,
   Inclusive production of two rapidity-separated heavy quarks as a probe of BFKL dynamics,
   XXVII International Workshop on Deep-Inelastic Scattering and Related Subjects, "DIS 2019", Turin, April 9, 2019.

3. A. Papa,
   BFKL resummation in inclusive processes,
   Low-x Meeting, Nicosia (Cyprus), August 26, 2019.

4. M.M.A. Mohammed,
   BFKL Resummation in the inclusive Higgs Boson Plus Jet production at the LHC,
   Low-x Meeting, Nicosia (Cyprus), August 26, 2019.

5. A.D. Bolognino,
   Diffractive leptoproduction of ρ and ϕ light vector mesons via small-x unintegrated gluon density,
   Workshop on Resummation, Evolution, Factorization (REF 2019), Pavia, November 26, 2019.

6. M. Fucilla,
   BFKL resummation in heavy-quark pair hadroproduction,
   Workshop on Resummation, Evolution, Factorization (REF 2019), Pavia, November 28, 2019.

References

1. A.D. Bolognino, F.G. Celiberto, M. Fucilla, D.Yu. Ivanov and A. Papa,
   High-energy resummation in heavy-quark pair hadroproduction,
   Eur. Phys. J. C **79** (2019) no.11, 939, doi:10.1140/epjc/s10052-019-7392-1 [arXiv:1909.03068 [hep-ph]].

SFT - Statistical Field Theory and Applications

D. Giuliano (Resp.), F. Plastina (Ass.), R. Giuliano (Dott.)

1 Statistical Field Theory and Applications

We have analyzed the definition and the calculation of the impurity entropy to systems with boundary interactions depending on zero-mode real fermion operators (Majorana modes as well as Klein factors). As specific applications of our method, we have discussed a junction between N interacting quantum wires and a topological superconductor, as well as a Y-junction of three spinless interacting quantum wires. As a by-product of our derivation, we have evidenced a remarkable correspondence between the N=2 topological superconductor junction and the Y-junction. On one hand, this allows for determining the range of the system parameters in which a stable phase of the N=2 junction is realized as a nontrivial, finite-coupling fixed point corresponding to the M-fixed point in the phase diagram of the Y-junction. On the other hand, it enables to show the occurrence of a novel "planar" finite-coupling fixed point in the phase diagram of the Y-junction [1)].

We have shown how to estimate the screening length associated to the Kondo effect at a Y-junction of quantum Ising chains from the scaling behavior of the local magnetization at the junction. In doing so, we proposed a simple way to probe the Kondo screening length in a system whose parameters, including the effective length of the chains, can be in principle tuned at wish [2)].

We proposed that a pertinently engineered double superconducting island connected to two spinless one-dimensional conducting leads can work as a tunable spin/charge-Kondo system. In particular, we evidenced how to probe the various phases by measuring the dependence on the temperature of the conductance properties of our system, by emphasizing the features that should allow to identify the onset of the so far quite elusive charge-Kondo effect [3)].

A substantial part of the research of the unit has been devoted to the non-equilibrium thermodynamics of quantum systems. In particular, quantum work statistics and its role as a tool in order to gain insight on the universal features of non-equilibrium many-body systems has been investigated in [4)]. There, we illustrated this idea by focusing on the two point measurement approach to work, to show how the related irreversible entropy production, defined for a unitary process, can be related to many-body features. As a specific example, we explored the physics of sudden quenches from the point of view of work statistics and showed how the characteristic function of work can be expressed as the partition function of a corresponding classical statistical physics problem in a film geometry. This, in turns, imply that the same quantity is connected to the concept of fidelity susceptibility. The quantum-to-classical mapping turns out to have close connections with the historical problem of orthogonality catastrophe: we therefore discussed how this relationship may be exploited in order to experimentally extract quantum work statistics in many-body systems.

In general terms, the thermodynamic implications for the out-of-equilibrium dynamics of many-body quantum systems are to date largely unexplored. In Ref. [6)], we investigated the

paradigmatic case of an array of nearest-neighbor coupled quantum harmonic oscillators interacting with a thermal bath and subjected to a quench of the inter-oscillator coupling strength. We studied the work done on the system and its irreversible counterpart, and characterized analytically the fluctuation relations of the ensuing out-of-equilibrium dynamics. Finally, we showcased an interesting functional link between the dissipated work produced across a two-element chain and their degree of general quantum correlations. Our results suggest that, for the specific model at hand, the non-classical features of a harmonic system can influence significantly its thermodynamics.

The latter is an example of a more general theme, which can be resumed in the question: what is the role (if any) of inherently quantum features (such as quantum coherence and correlations) in the thermodynamic behavior? We have provided a partial answer to this question for the case of quantum coherence. Indeed, exploiting the relative entropy of coherence, in Ref. [5], we isolated the coherent contribution in the energetics of a driven nonequilibrium quantum system, and demonstrated that a division of the irreversible work can be made into a coherent and an incoherent part, which both fulfill fluctuation theorems. In addition, we also showed that coherence generation is connected to the non-adiabaticity of a processes, for which it gives the dominant contribution for slow-enough transformations.

2 Conference Talks by Cosenza SFT Researchers in 2019

1. D. Giuliano, "Current transport properties and phase diagram of a Kitaev chain with long-range pairing", SM&FT 2019, Bari, Italy.

2. F. Plastina, "The role of coherence in the Thermodynamics of Quantum Systems", invited talk at the conference "Quantum Technologies with ultra-strong couplings", Catania 4/10/2019.

3. F. Plastina, "Decoherence in a synthetic fermion environment: from orthogonality catastrophe to Fano physics", **invited talk** given at the conference "IQISC2019", Milano 9-12/09/2019.

4. F. Plastina, "Coherence Generation, Irreversible Entropy production and non-Adiabaticity in Quantum Processes", invited talk at the "Quantum Hiking Conference", Dolomiti 15-19/07/2019.

5. F. Plastina, "Decoherence in a synthetic fermion environment: from orthogonality catastrophe to Fano physics", invited talk at the conference "ICQOQI 2019", Minsk (Belarus) 13-17/05/2019.

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3. Domenico Giuliano, Luca Lepori, and Andrea Nava, arXiv:1911.07331.

4. J. Goold, F. Plastina, A. Gambassi, A. Silva, "*The Role of Quantum Work Statistics in Many-Body Physics*", in: F. Binder, L. Correa, C. Gogolin, J. Anders, G. Adesso G. (eds) "*Thermodynamics in the Quantum Regime*". Fundamental Theories of Physics, vol 195, Springer, Cham (2019), doi: $10.1007/978-3-319-99046-0\_13$.

5. G. Francica, J. Goold, F. Plastina, "*The role of coherence in the non-equilibrium thermodynamics of quantum systems*", Phys. Rev. E **99**, 042105 (2019).

6. M. Paternostro, G. De Chiara, A. Ferraro, M. Campisi, J. Goold, F. L. Semião, F. Plastina, V. Vedral "*Out of equilibrium thermodynamics of quantum harmonic chains*", J. Stat. Mech. **2019**, 104014 (2019).

COMPUTATION TECHNOLOGY

The ReCaS Cosenza Data Center

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

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 2019 with very high efficiency and stability. As an example, Fig. 2 shows

for the ATLAS virtual organization a comparison, in terms of slots of running Grid jobs, of the performance of the ReCaS Cosenza Data Center w.r.t. that of the Italian ATLAS Tiers 2 sites for year 2019; the comparison demonstrates the excellent perfomance of the ReCaS infrastructure.

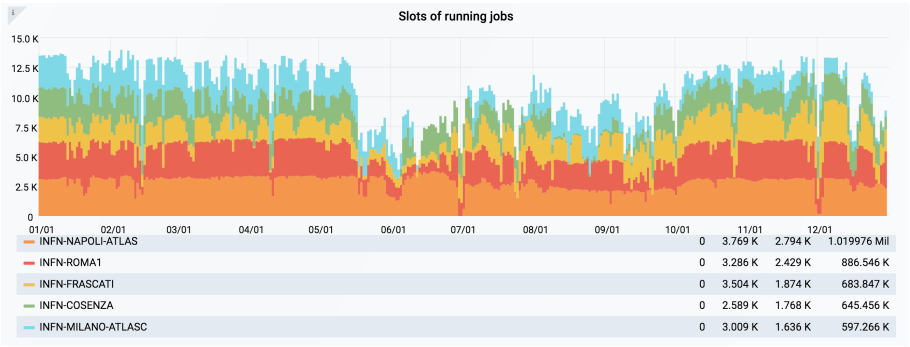

Figure 2: *A comparison of the slots of running jobs in 2019 for the ATLAS Tier2 centers and the ReCaS Cosenza Data Center.*

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 should start in 2020.

COMMUNICATION AND OUTREACH

European Researchers' Night 2019, International Physics MasterClasses 2019 and the OCRA project

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E. Meoni (Ass.), A. Olivieri (Stud.), J. Orbe (Dott.), S. Palazzo (Ass.),
A. Papa (Ass.), F. Percivalle (Stud.), C. Petronio (Ass.), W. Reino (Stud.)
P. Riccardi (Ass.), V. Romano (Tecn.), C. Romeo (Stud.), M. Rossi (Ass.),
D. Salvatore (Ass.), M. Schioppa (Resp.), M. Scornajenghi (Dott.),
F. Stabile (Tecn.), A. Tarasio(Tecn.), E. Tassi (Ass.), R. Tucci (Ass.), P. Turco (Tecn.)

1 European Researchers Night 2019

For the european researcher's night 2019 two groups of activities have been organized. A stand with posters and a brochure about INFN and its research activities to be distributed to the visitors. Here sketches and interviews were made. Guided visits to the INFN Alte Energie laboratories. Here the visitors were able to see real particle detectors build for fundamental physics and know their functionalities and further applications. These events turned out to be very successful. The various activities are described here.

1.1 Radon gas, particle physics and gender issues in science

[M.Capua (Resp.)]

Measurements of activity concentration of radon gas in spring water intended for human consumption Groups of students or citizens were able to visit the laboratory of the Physics Department dedicated to research activities in environmental physics and health, and to know about problems such as the presence of the radioactive radon-222 gas in the environment and its effect on health. Guests were invited to bring a sample of spring water and perform explorative measurements of activity concentration of radon gas.

Find the quarks! The fascinating world of particle physics introduced with a game. Little girls and boys who reached the stand were invited to try to compose particles made of quarks (e.g. protons and neutrons) finding the appropriate constituents. Those who managed to compose a particle within three minutes received the certificate of *Promise of particle physics 2018*.

Flair for particles! After a brief introduction to particle physics, CERN and the ATLAS experiment, it was shown how the sophisticated technology with which the ATLAS detector was made allows to observe particles. At the end of the short presentation, students took part in the search for particles, observing 15 events collected by the ATLAS experiment and trying to recognize all the particles present in each event.

Science is a game for girls At the stand of the University Women's Studies Centre, information material on gender issues in scientific research was distributed. In addition, the game Guess who is? in which images of female scientists and 3 clues have been proposed in order to recognize them.

We go under the sea to study cosmic rays The project and the first prototype of an experimental apparatus were presented to carry out a real experiment together with students from schools of all levels. Furthermore, the participants were able to participate in two competitions: one to decide the name and the other to decide the logo of the experiment.

1.2 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 50 MRPCs telescopes are operative in Calabria. The inhomogeneous grid of telescopes allows a multiple, thrilling approach to the study of cosmic rays. Single detector: the EEE telescope is a high precision tracking detector that can study the flux of secondary cosmic muons, their arrival directions and upward-going particles. Cluster of detectors: in a radius of few kilometers they can study the properties of the EAS in which muons are originated; eventually an array, using sites far apart, makes it possible to investigate time correlations between EAS events. In 2019 two new telescopes add to the existing one in Calabria (Rende and Reggio Calabria). 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 2019

[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 2019 two one-day events took place:

- February 11, special event for the International Day of Women in Science, 42 students from 11 schools (agenda.infn.it/event/mcg2019cs)

- March 20, standard events, 41 students from 13 schools (agenda.infn.it/event/mc2019cs)

with an overall enthusiastic participation of students and high-school teachers, as confirmed by students' interviews.

3 The OCRA project of INFN-CC3M

[M.Schioppa (Resp.)]

In the year 2019 the group starts participating 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 is planed for spring 2020. In November the group has coordinated the

International Cosmic Day 2019 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 2019

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, Catania, Lecce, LNS, Milan, Naples, Siena, Trieste, Turin also participate (https://web.infn.it/RadioLab).

The aim of the project is to integrate didactics with scientific communication and research on radioactivity, with special emphasis on the radon gas. 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). The students performed measurements on radon gas concentraction of activity in samples of water and indoor air. 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 students and families and the society connected to them.

Two students of the group were able to participate in the EtnaRadioLab Summer School organized in Catania in September 2019.

Four Calabrian schools (113 students) and two Riobamba schools were involved and they performed two set of interviews: on the radon risk problem perception and gender differences and STEM and organized events durin the ENR 2019 and Festival della Scienza at Vibo Valentia.

Figure 1: *RadioLab Workshop 2019 poster.*

On November 7, all the Calabrian students involved, and a group of students from a Riobamba high school in Ecuador, concluded their activities by organizing a Regional Workshop in the main hall of the University of Calabria. The students managed the event completely, from the invitations, the secretariat and the press office and presented the results of their activities and discussed them with local experts. The event was attended by schools, local experts (physicists, geologists, ARPACAL staff, etc.) and public administrators (mayors, assessors, etc.) corresponding to about 600 guests. The poster is shown in Figure 1.

At the end of the year a new group of 130 students from 5 schools have started a new cycle of studies.

Premio Asimov 2019

G. Alì (Ass.), A. Papa (Resp.), M. Rossi (Ass.)

The INFN group of Cosenza has joined since 2018 the "Premio Asimov" initiative (web site: https://asimov.gssi.it/) and coordinates the related activities in the Region 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, October 18-19 in Catania.

The edition of 2019 counted overall about 2500 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 90 students from eight different high schools. On April 13 a local ceremony at the Physics Department of the University of Calabria took place, with the participation of some of the Calabrian students to be rewarded as best reviewers.