XV Hadron Physics 2020

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Book of Abstracts

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Seminars / 6

Strong Interactions and Fundamental Symmetries

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Effective field theories allow us to track the violation of symmetries across energy scales. I will discuss the manifestation in nuclei of the lowest-dimension interactions beyond the Standard Model which violate lepton number, baryon number, and time reversal. Specific processes/quantities involved include neutrinoless double-beta decay, the deuteron lifetime, and electric dipole moments of the neutron and light nuclei.

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Low energy constituent quark couplings from a dynamical approach

Author: Fabio Braghin[1]

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Recent work on the derivation of light quark-antiquark mesons couplings to baryon's constituent quarks will be presented by starting from a quark-quark interaction mediated by one non-nonperturbative gluon exchange. Some well known methods are considered and they provide complete well known effective models with their parameters such as coupling constants, and also form factors and averaged quadratic radii. These quantities are written in terms of components of quark and non perturbative gluon propagators, of the quark-gluon (running) coupling constant and u and d quark masses. Among the resuling couplings there is a whole constituent quark Large Nc EFT proposed by Weinberg with its electromagnetic couplings. Light vector and axial mesons couplings to constituent quarks and to the photon are also obtained in such dynamical way. Some effects of a relatively weak magnetic field on all these couplings may be shortly addressed. The constituent quark-level Goldberger Treiman and the GellMann Oakes Renner relations are obtained among other new relations.

Lectures / 9

NN short-ranged correlations: From Theory to Experiment in 65 Years

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The physics of short-ranged correlations is reviewed from a pedagogical standpoint that is aimed to provide background sufficient for students to do research in the field. The lectures discuss:

1) how the earliest efforts allowed physicists to understand the qualitative features of nuclear binding and saturation.

2) the technical improvements, including relativistic effects

3) short-range correlations in the context of effective field theory

4) recent experimental findings related to short range correlations

5) future prospects

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Heavy ion and fixed target physics at the LHCb experiment

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The LHCb experiment explores the heavy ion and fixed target physics using some of its specific features. Particle production of particles, notably heavy flavour states, can be studied at LHC energies in the forward rapidity region, providing complementary measurements to the other LHC experiments. An overview of these results obtained on the LHCb heavy ion program will be given.

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Heavy and exotic hadrons in heavy ion collisions

Author: Luciano Abreu[1]

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We discuss how the production and dissociation of hadron states are affected by reactions during the expansion of hadronic matter. We give emphasis to recent works on quarkonia and exotic states in charm sector.

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Multiquark state: from meson and baryons to exotic tetraquarks and pentaquarks.

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I will give a presentation on this hot field of research initiated
fifteen years ago with the discovery of Ds0(2317) and X(3872) and that is giving now so many discoveries. In particular, I will review recent experimental discoveries of new tetra and pentaquark states and theoretical works on them.

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Diffusion of conserved charges in relativistic heavy ion collisions

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The bulk nuclear matter produced in heavy ion collisions carries a multitude of conserved quantum numbers: electric charge, baryon number and strangeness. Therefore, the diffusion processes associated to these conserved charges cannot occur independently and must be described in terms of a set of coupled diffusion equations. This physics is implemented by replacing the traditional diffusion coefficients for each conserved charge by a diffusion coefficient matrix, which quantifies the coupling between the conserved quantum numbers. The diagonal coefficients of this matrix are the usual charge diffusion coefficients, while the off-diagonal entries describe the diffusive coupling of the charge currents. In this seminar, we provide the first calculation of this diffusion coefficient matrix for a hadron resonance gas and a gas of partons. In order to provide some insight on the influence that the coupling between the net charge diffusion currents can have on heavy ion observables, we present first results for the diffusive evolution of a hadronic system in a simple (1+1)D-fluid dynamics approach.

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Self-consistent Modelling of Nuclear Processes in Solar Flares using FLUKA

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We use the Monte Carlo particle physics code FLUKA to calculate gamma-ray spectra expected from solar flare energetic ion distributions. The FLUKA code includes robust physics-based models for electromagnetic, hadronic and nuclear interactions, sufficiently detailed for it to be a useful tool for calculating nuclear de-excitation, positron annihilation and neutron capture line fluxes and shapes, as well as ~GeV continuum radiation from pion decay products. We show nuclear de-excitation gamma-ray line model spectra from a range of assumed primary accelerated ion distributions and find them to be in good agreement with those found using the code built by Ramaty and collaborators, currently one of the main tools for the analysis of solar flare gamma-ray data. We also show full gamma-ray model spectra which exhibit all the typical structures of gamma-ray spectra observed in solar flares. From these model spectra we build templates which are incorporated into the software package Objective Spectral Executive (OSPEX) and used to fit the combined Fermi Gamma-ray Burst Monitor (GBM)/Large Area Telescope (LAT) spectrum of the 2010 June 12 solar flare, providing a statistically acceptable result. To the best of our knowledge, the fit carried out with the FLUKA templates for the full gamma-ray spectrum can be regarded as the first attempt to use a single code to implement a self-consistent treatment of the several spectral components in the energy range from ~ 100s keV to ~100s MeV.

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Low-Q^2 parametrizations of the $\gamma^* N \to N^*$ transition amplitudes

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The electromagnetic structure of the nucleon resonances N^* are usually parametrized by $\gamma^* N \to N^*$ helicity amplitudes, at the resonance rest frame. Those amplitudes are, however, constrained by kinematic conditions in the limit where the photon three-momentum vanishes (pseudothreshold limit). Although the pseudothreshold limit is below the photon point ($Q^2 = 0$) it has an impact on the structure of the helicity amplitudes at low-Q^2. Most of the empirical parametrizations of the data ignore those constraints. In our work we study the effect of the pseudothreshold constraints on some analytic parametrizations of the data, be performing analytic continuations of these parametrizations to the $Q^2 < 0$ region. We conclude that the pseudothreshold constraints are fundamental for some resonances.

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Nambu-Jona-Lasinio model at strong constant magnetic field

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In this work we calculate corrections to the NJL model coupling constant in the presence of a uniform magnetic field. Starting with the Nambu-Jona-Lasinio Lagrangian coupled with a U(1) gauge field, namely a magnetic field, the background field method is employed. By expanding the quark determinant in terms of the quark bilinears we show that the first-order term provides a correction to the quark masses that corresponds to the one from the gap equation.
The second-order term of the expansion provides a correction to the NJL coupling constant, which decreases with increasing magnetic field.

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Confinement/deconfinement transition in a thermodynamically consistent quark matter model

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Since an absolute stable strange quark matter was conjectured [1], based on a simple model known as the MIT bag model [2], different versions of density dependent quark models were proposed, but they lack thermodynamic consistency [3]. By using a thermodynamically consistent quark

matter model called equiparticle model [4], that is based on a density dependent mass, the confinement/deconfinement transition is studied. In order to do that, the model is modified by the introduction of a dependence on the traced Polyakov loop [5] at zero temperature. The results are presented once the grand canonical potential is obtained and suggests that the model is now capable of describing confined and deconfined thermodynamical phases.

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QCD phase diagrams combining QHD and MIT based models

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In the present work phase diagrams of QCD are obtained by means of two effective models. For the description of the quark matter we make use of the MIT bag model and a modification of this model, and for the description of the hadronic matter we make use of the non-linear Walecka model (NLWM). The Gibbs conditions are used to establish the crossing points of the pressures in function of the chemical potentials obtained in both phases. Some restrictions are imposed when choosing models. The MIT based models are used only with constant values satisfying the lower limit of the Bodmer-Witten conjuncture. The NLWM, in turn, is restricted to parameterizations that satisfy several nuclear and astrophysical properties. Two situations are considered for the description of the hadronic matter; in the first situation we consider symmetrical matter, and in the second one the conditions of matter of compact stars are imposed and the model is extrapolated to finite temperatures.

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Quark-antiquark potentials in nonperturbative models

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Many models have tried to explain some non-perturbative aspects of the strong interactions, in particular, the color confinement hypothesis of quantum chromodynamics (QCD), but actually, they do not fully explain it. In this work, we investigate some of these non-perturbative models for QCD with the purpose of testing its validity in the perturbative region of nuclear interactions where the perturbative predictions with quasi-free quarks are in agreement with the experimental data, as well as to explore its behavior in the infrared region. In particular, we focused on the calculations and analysis of the potentials between heavy quarks and antiquarks, since this observable might reveal the appearance of confinement properties in non-perturbative models through a linear growth at large and intermediate distances. We calculated the potentials associated with the Massive Gluon (Yukawa), Gribov-Zwanziger and Gribov-Zwanziger Refined models at tree level for the non-relativistic case. In addition, we have included the flux of the Renormalization Group in the QCD coupling constant, which allowed us to study the energy-scale dependence of the parameters of the potentials treated here. Our results indicate that, in the tree-level approximation, all potentials we have obtained can reproduce the perturbative result at high energies and some of them bring significant non-perturbative corrections. We also present one-loop corrections and discuss the two-loop modifications in the case of the Curci-Ferrari model.

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Measuring the speed of sound of the quark-gluon plasma in ultracentral nucleus-nucleus collisions

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We show that, within the hydrodynamic framework of heavy-ion collisions, the mean transverse momentum of charged hadrons ($\langle p_t \rangle$) rises as a function of the multiplicity in ultra-central nucleus-nucleus collisions. The relative increase is proportional to the speed of sound squared (c_s^2) of the quark-gluon plasma, that is therefore accessible experimentally using ultra-central data. Based on the value of c_s^2 calculated in lattice QCD, we predict that $\langle p_t \rangle$ increases by $\approx$ 18 MeV between 1$\%$ and 0.001$\%$ centrality in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV.

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Fluctuations in the nuclear pasta phase

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Exotic shapes of nuclei, known as nuclear pasta phase, can exist in the crust of neutron star and in supernovae exposions. Calculations involving the pasta assume a perfectly crystalline structure, described by identical Wigner-Seitz cells, but such an approximation is unrealistic due to the small free energy variation with respect to the different pasta configurations, and these may coexist in equilibrium. The presence of different types of clusters leads to an impure system, that can have macroscopic consequences in the star, such as alteration of the thermo-magneto evolution, neutrino opacities and of gravitational wave production. In this work we calculate the amount of different pasta structures at a given depth of the star and introduce the anisotropic impurities of the pasta, that are essential to calculate the transport coefficients, with the IU-FSU force.

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Neutron stars: The journey from birth to death.

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Neutron star observations, including those from Chandra, XMM-Newton, LIGO and NICER missions, continue to provide a unique insight into the role that neutron stars (NS) play in stellar evolution and the nature of dense matter in the NS core. After being born in a core-collapse supernova explosion, the NS first minutes (as a "proto-neutron star) are critical. It is during this brief time the NS final mass, composition, and fate are decided. Development of the NS dynamics and cooling in later times provides important clues about the first moments. NSs do not generate any light or heat on their own. Thus, over millions of years, the latent heat inherited at birth will be exhausted. Most of the NSs become cold dark objects, unless they meet another NS or a black hole to engage in a spectacular collision or they accrete mass from a binary companion and recycle into a millisecond pulsar. In my lectures, I will discuss some of these events.

In my first lecture, I will introduce the history of NSs discovery and their general structure going from the envelope through outer and inner crusts to the core. I will also survey the latest astrophysical observation and terrestrial data on the NS properties.

The second lecture will be devoted to exploration of the NS Equation of State (EoS) which is still unknown and is subject of extensive research. Among the variety of theoretical and empirical models of the EoS currently in the literature, I will describe in more detail the Quark-Meson-Coupling (QMC) Model, an effective relativistic mean-field model in which the forces between individual baryons are self-consistently mediated by exchange of virtual mesons between the valence quarks in the baryons.

The neutron star merger (BNSM) and the related gravitational waves will be subject of the final, third lecture. This topic is currently most actively explored, using novel frameworks of multimessenger technics. Advantages and disadvantages of this trend will be discussed.

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Non-Perturbative Information from QCD Green Functions

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We review the computation of the two-point (propagators) and the quark-gluon vertex using non-perturbative first principle methods. Topics concerned with quark and gluon confinement together with chiral symmetry breaking and there relation with the propagators and vertex are also addressed.

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Parton distribution functions from lattice QCD

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Parton Distribution Functions (PDFs) are the fundamental objects containing information on the flavour structure of hadrons, and on how the hadron spin and momentum are distributed among its constituents, quarks and gluons. Because they are non-perturbation quantities, we must rely on non-perturbative methods for their computation. Lattice QCD (LQCD) is the most successful method to access the non-perturbative physics. Even so, in the case of PDFs LQCD is, essentially, not useful because PDFs are given by light-cone correlations, while LQCD is applicable to real-time correlations. However, several years ago Ji proposed a new method to compute PDFs in LQCD based on Large Momentum Effective Theory. Within this method, one computes purely spatial correlations, accessible to LQCD, which can be related, upon a suitable perturbative calculation, to the light-cone correlations. The Fourier transform of the purely spatial matrix elements are called quasi-PDFs. In this talk, we will give an overview of the quasi-PDF approach, showing how to obtain light-cone PDFs from quasi-PDFs. We will present the state-of-art of the lattice computations of PDFs as well as discussing future directions to this field.

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Photon induced processes from semi-central to ultraperipheral heavy-ion collisions

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Ultrarelativistic heavy ions are accompanied by a large flux of quasi-real Weizsäcker-Williams photons. This opens a broad range of research possibilities, as the Weizsäcker-Williams photons can be used to study photon-photon fusion reactions as well as photonuclear reactions in a wide range of energies, see for example the review [1].

Of special interest here are diffractive photoproduction reactions, which appear in two major classes: the coherent diffraction in which the target nucleus stays intact and the incoherent (or quasielastic) diffraction in which the nucleus breaks up, but no additional particles are produced in the nuclear fragmentation region.

We will discuss the coherent and incoherent diffractive photoproduction of heavy vector mesons J/ψ and Y based on our recent papers [2, 3]. Good agreement with available experimental data by the ALICE and LHCb collaborations can be obtained within a color-dipole approach. Diffractive photoproduction of heavy-flavour vector mesons has long been discussed as a probe of the target's gluon distribution, and we will discuss implications for the nuclear glue. Here additional nuclear shadowing from the $c\bar{c}g$-Fock state is needed to obtain agreement with data.

Very recently, the role of Weizsäcker-Williams photons in peripheral, inelastic, heavy ion collisions has come under scrutiny. Recent measurements of dilepton production of the STAR collaboration in √sN N =200 GeV Au-Au collisions indicate an excess at small pair pT most notably in peripheral collisions. We show, that it can be that has attributed to the initial photon fusion which is most significant at small pair transverse momenta [4]. The centrality dependence of the pair transverse momentum distribution is calculated in a novel factorization approach involving Wigner distributions

of photons [5].

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FSI in 3-body decay: challenges and future

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Three-body hadronic decays of B and D mesons are a superb laboratory for studying Charge-Parity (CP) violation and hadronic Final states Interactions. The gigantic samples of B and D decays collected by the LHCb (and more to come from others) experiments motivated theoretical efforts in the past decade towards building models that are based on more solid grounds. In this talk I will preesent an overview of these models In particular, interesting results one obtain for $B^+ \rightarrow \pi^-\pi^+\pi^+$ with novel mechanisms of the CP asymmetries pattern observed in the Dalitz plot.

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Relativistic Landau levels via Feynman-Gell-Mann formulation

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The planar motion of spin-1/2 fermions under the influence of a homogeneous magnetic field is described by the Feynman-Gell-Mann formulation of the Dirac equation. The axially symmetric gauge is used for the vector potential in such a way that the Dirac spinor is written in terms of eigenstates of the quiral operator and the third component of the total angular momentum operator. The spinors are split in eigenstates of the third component of the spin operator and the corresponding radial functions obey uncoupled second-order equations similar to the singular harmonic oscillator in the nonrelativistic theory.

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Exclusive photoproduction of quarkonia in ultraperipheral collisions

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We discuss the exclusive photoproduction of ground and excited states of ψ(1S,2S) and Υ(1S,2S) in ultraperipheral collisions. Using the potential model in order to obtain the vector meson wave function, we find a good agreement of our calculations with data from the LHC and HERA colliders for J/ψ(1S,2S) and Υ(1S) in γp collisions. We extend the calculations to the nuclear target case applying them to AA UPCs with the use of the gluon shadowing and finite coherence length effects fitted to the data. Our results are compared to the recent LHC data for coherent (J/Ψ(1S) at 2.76 and 5.02 TeV) processes.

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Momentum transfer squared dependence of exclusive quarkonia photoproduction in UPCs

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In this work, the exclusive photoproduction of the ground and excited states of the heavy vector mesons $\psi(1S)$, $\psi(2S)$, $\Upsilon(1S)$ and $\Upsilon(2S)$ are discussed in ultraperipheral hadron collisions (UPCs) with proton and nucleus targets. Since we are interested in scatterings with the projectile being a virtual photon produced by the incoming hadron, we employ the color dipole model, which permits the factorization of the process in three steps. The first one is the splitting of the photon in a $q\bar{q}$ pair, which is described by a perturbatively calculated wave function. The second is the interaction of this pair with the target, this part is described by a parametrized dipole cross section, in order to account for the non-perturbative effects. In this work, we used two different b-dependent parametrizations for the evaluation of the t-dependent cross sections: one obtained by solving the Balitsky–Kovchegov equation with the collinearly improved kernel and the other with a Gaussian impact-parameter dependent profile. The third step is the transition of the $q\bar{q}$ pair into the vector meson, this part is obtained in the framework of the interquark potential model incorporating the Melosh spin transformation. With this formalism and the proton as a target, we compared our results with the available data from the HERA collaboration and found a good agreement between the both. For the nuclear case, we extended our calculations making use of the Glauber-Gribov theory and applied it to the coherent photoproduction of vector mesons in UPCs with the inclusion of the gluon shadowing effects fitted to data. We compared our results to the recently published ALICE data for the $\psi(1S)$ photoproduction as well as made predictions for other states: $\psi(2S)$, $\Upsilon(1S)$ and $\Upsilon(2S)$ at $s_{NN} = 5.02$ TeV, which can be useful in the future with new measurements on the large particle colliders.

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Delta Baryons in Neutron-Star Matter under Strong Magnetic Fields

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In this work, we study magnetic field effects on neutron star matter containing the baryon octet and additional heavier spin 3/2 baryons (the Δ's). We make use of two different relativistic hadronic models that contain an additional vector-isovector self interaction for the mesons: one version of a

relativistic mean field (RMF) model and the Chiral Mean Field (CMF) model. We find that both the additional interaction and a strong magnetic field enhance the Δ baryon population in dense matter, while decreasing the relative density of hyperons. At the same time that the vector-isovector meson interaction modifies neutron-star masses very little (<0.1 M⊠), it decreases their radii considerably, allowing both models to be in better agreement with observations. Together, these features indicate that magnetic neutron stars are likely to contain Δ baryons in their interior.

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Orbital Properties and Gravitational Waves Signatures of Strange Crystal Planets

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In this work we consider the possibility that strange quark matter may be manifested in the form of strange crystal planets. These planet-like objects are made up of nuggets of strange quark matter (SQM), organized in a crystalline structure. We consider the so−called strange matter hypothesis proposed by Bodmer, Witten and Terazawa, in that, strange quark matter may be the absolutely stable state of matter. {\bf In this context, we analyze planets made up} entirely of strangelets arranged in a crystal lattice. Furthermore we propose that a solar system with a host compact star may be orbited by strange crystal planets. Under this assumption we calculate the relevant quantities that could potentially be observable, such as the planetary tidal disruption radius, and the gravitational waves signals that may arise from potential star-planet merger events. Our results show that strange crystal planets could potentially be used as an indicator for the the existence of SQM.

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The gap equation in QCD and the origin of constituent quarks

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I will briefly review the gap equation which in QCD is given by the Dyson-Schwinger equation (DSE) for a quark of given flavor. Whether a gap occurs, and therefore dynamical chiral symmetry breaking that leads to a constituent-quark mass two orders heavier than the current-quark mass, depends on the DSE kernel. One crucial ingredient, besides the strong coupling itself, is the quark-gluon vertex whose tensorial structure is complex once it is dressed with gluons.

A nonperturbative approach to derive the vertex is based on longitudinal and transverse Slavnov-Taylor identities rather than on perturbative dressing or solving the inhomogeneous Bethe-Salpeter equation. The adequate manipulation of these identities with projections leads to the functional form of all twelve form factors that describe the dressed quark-gluon vertex. We combine this novel vertex with lattice QCD simulations for the gluon and ghost propagators and solve the DSE numerically.

The dynamical chiral symmetry breaking this vertex induces is very large and gives rise to a realistic mass gap for all quark flavors, compatible with those of the usual phenomenological interaction models in DSE calculations. Finally, we test the gauge covariance of our DSE kernel by studying the gauge dependence of the quark mass and wave renormalization function as well as of the quark condensate.

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Dynamic gluon mass generation from the effective potential of the Gribov-Zwanziger theory

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The Gribov-Zwanziger theory takes into account the effect of Gribov gauge copies and may provide an effective description of the infrared regime of QCD. The success of this approach is based on the compatibility of its predictions with the available lattice data for correlation functions, especially gluon and ghost propagators, which point towards a dynamic mass generation in the form of dimension-2 condensates of the gluon and auxiliary fields. In this talk, we address the task of computing explicitly these condensates within the Gribov-Zwanziger framework by minimizing the corresponding one-loop effective potential in a fully BRST-invariant setting.

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Symmetry restoration and the gluon mass in the Landau gauge

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We investigate the generation of a gluon screening mass in Yang-Mills theory in the Landau gauge. We propose a gauge-fixing procedure where the Gribov ambiguity is overcome by summing over all Gribov copies with some weight function. This can be formulated in terms of a local field theory involving constrained, nonlinear sigma model fields. We show that a phenomenon of radiative symmetry restoration occurs in this theory, similar to what happens in the standard nonlinear sigma model in two dimensions. This results in a nonzero gluon screening mass, as seen in lattice simulations.

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Vector meson spin alignement as a probe of spin hydrodynamics at freeze-out

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We argue that a detailed analysis of the spin alignement of vector mesons can serve as a probe of two little-understood aspects of spin dynamics in the vortical fluid: The degree of relaxation between vorticity and parton spin polarization, and the degree of coherence of the hadron wavefunction at freeze-out.
We illustrate these with a coalescence model.

Based on https://arxiv.org/abs/2104.12941

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Chiral symmetry breaking in massive-gluon QCD

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Lattice simulations show that the running coupling constants obtained through QCD vertices differ in the infrared even though their bare values are the same. For instance, at low momenta the strength of the quark-gluon coupling is about twice the ghost-gluon coupling. None of them diverge in the infrared as it is predicted by standard perturbation theory. Moreover, the ghost-gluon coupling remains moderate even in the infrared. This observation motivates the use of perturbation theory in the ghost-gluon sector in the frame of a massive deformation of QCD Lagrangian in Landau gauge. However, perturbation theory in the quark sector within this massive Lagrangian doesn´t bring as good results as in the pure Yang-Mills case, as should be expected from the larger value of the quark-gluon coupling constant.
We propose a controlled systematic expansion in full QCD based in two small parameters: first the Yang.Mills sector couplings and second the inverse of the number of colors (large-Nc limit). This systematic expansion allows us to properly introduced the use of the renormalization group for the rainbow resummation.
At leading order, this double expansion leads to the well-known rainbow approximation for the quark propagator whose solution shows spontaneous chiral symmetry breaking for sufficiently large quark-gluon coupling constant.

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Experimental opportunities in hadron physics

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Quantum Chromodynamics is the accepted theory of the strong interaction. The gauge bosons transmitting the force are gluons. However, the non-perturbative part of QCD is far from being understood on a fundamental level. Non-perturbative aspects of QCD can be especially well studied when the gauge fields play a prominent role. A typical example are glueballs, massive particles composed solely of a priori massless gluons, which are an excellent case to proof our understanding of non-perturbative QCD. The only problem that remains is the unambiguous identification glueballs and interpretation of glueballs. Other unusual quark-gluon configurations predicted as well by QCD hhave been clearly identified in recent years by experiments and will pave the path for a deeper understanding of the underlying theory. The talk reviews the current status and future perspectives on experimental studies of non-perturbative QCD.

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Studies of the 3D Structure of the Nucleon

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The quark-gluon dynamics manifests itself in a set of non-perturbative functions describing all possible spin-spin and spin-orbit correlations. The Transverse Momentum Dependent parton distributions (TMDs) and Generalized Parton Distributions (GPDs) carry information not only on the longitudinal but also on the transverse momentum and position of partons, providing rich and direct information on the orbital motion of quarks. Single and Dihadron semi-inclusive and hard exclusive production, both in current and target fragmentation regions, provide a variety of spin and azimuthal angle dependent observables, sensitive to the dynamics of quark-gluon interactions. Studies of the 3D PDFs are currently driving the upgrades of several existing facilities (JLab, COMPASS and RHIC), and the design and construction of new facilities worldwide, in particular the Electron Ion Collider. In this lectures, we will present an overview of the current status and some future measurements of the orbital structure of nucleons and nuclei at Jefferson Lab and future EIC.

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A Simple Analytical Approach to Heavy Quarkonium Spectrum

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Meson spectroscopy can be theoretically studied with lattice QCD, QCD sum rules and quark models. In all these approaches the results are obtained numerically. It would be useful to have an analytical formula for the energy levels of the meson systems. In this work we use the variational principle and apply it to heavy mesons. We derive an expression for the energy levels which depends on the principal (n) and angular (l) quantum numbers.

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Isolated photon production in the color dipole picture

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A phenomenological study of the isolated photon production within the color dipole formalism is performed. Using the dipole approach we investigate the isolated photon cross section differential in the transverse momentum of the photon in *pp* collisions at RHIC and LHC energies considering three different phenomenological models for the dipole cross section. The predictions for the rapidity

dependence of the nuclear ratio is also presented. As a further test of the color dipole formalism, we study also the correlation function in azimuthal angle between the photon and a forward pion $\Delta\phi$ for different energies and photon rapidites. The characteristic double-peak structure of the correlation function around $\Delta\phi \simeq \pi$ found for photons at forward rapidities in pp and pA collisions can be tested by future measurements.

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Thermodynamics of the three flavor PNJL0 model

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The effective quark model Polyakov-Nambu-Jona-Lasinio (PNJL) incorporates the effect of confinement/deconfinement on the original Nambu-Jona-Lasinio model (NJL) by inserting the Polyakov Loop (Φ) on the equations of states~(EOS) at finite temperature. However, at zero temperature regime, the PNJL loses all contributions of Φ and the EOS returned for the same as original NJL equations on $T = 0$. In this work, we present the SU(3) PNJL model at zero temperature, called SU(3) PNJL0. The model is based on the modification of coupling constants, by making them dependents of Φ and adding a dependent term of Φ in the grand canonical potential, limiting the loop in $0 \leq \Phi \leq 1$ and favors nonvanishing Φ solutions. We impose that in the free quarks regime(deconfinement) all interactions vanish. We investigate how are the first order phases transitions and how the strange quark favors the restoration of chiral symmetry. Another point discussed is how the constants G_V and a_3 (parameter of Polyakov potential) affect the quarkyonic phase on this model.

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Double parton scattering mechanism for associated c and b quark production in ultraperipheral collisions AA.

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The double–parton scattering (DPS) at the hadron coliiders such as the LHC is sensitive to correlations in the double–parton distributions. When looking at inclusive observables, it is dominated at high energies (small x) by the interaction of 4 gluons in the initial state. In order to extract different information about the partons, we are interested in the interaction between two gluons and two photons. To do so, we look at the associated c and b quarks production in the DPS process in ultraperipheral collisions (UPCs) AA. We derive an analogue of the pocket formula for this DPS and the photon-energy dependent effective cross section at high energies. We provide numerical predictions for this DPS cross sections at the typical energies of the LHC and FCC colliders.

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DPS mechanism for associated $c\bar{c}l^+l^-$ production in AA UPCs as a probe for photon density inside the nucleus

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We discuss the associated $c\bar{c}$ and l^+l^- pairs production in ultraperipheral heavy-ion collisions at high energies. Such a channel provides a novel probe for double-parton scattering (DPS) at small x enabling one to probe the photon density inside the nucleus. We have derived an analog of the standard central *pp* pocket formula and studied the kinematical dependence of the effective cross section. Taking into account both elastic and non-elastic contributions, we have shown predictions for the DPS $c\bar{c}l^+l^-$ production cross section differential in charm quark rapidity and dilepton invariant mass and rapidity for LHC and a future collider.

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Exotic heavy hadrons with a three-body nature

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Recently, we have studied several three-body systems made of heavy mesons, like DDK, $KD\bar{D}^*$, $DK\bar{K}$, $ND\bar{D}^*$ and we have predicted the formation of nucleon and K^* states with hidden charm, a D meson state with a mass around 2900 MeV as well as an exotic state with charm +2 and strangeness +1. The three-body T-matrices have been determined by solving the Faddeev equations in a coupled channel approach and all input two-body scattering matrices have been obtained by solving Bethe-Salpeter equations for different channels coupling to same quantum numbers. In this talk, I shall discuss these results.

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Study of prompt photon production at the CERN LHC energies

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We study the prompt photon production at the CERN LHC energies considering the color dipole approach. We estimate the rapidity and transverse momentum distributions of prompt photon production considering the more recent phenomenological models for the dipole-proton scattering amplitude, which are able to describe the inclusive and exclusive ep HERA data. A comparison between the predictions from distinct models for the dipole cross section is done, which is expected to allow us to improve our understanding of the QCD dynamics and be important at the forward rapidities in pp and pA collisions at the LHC.

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Propagators for a SU(3) Gauge Theory on the Lattice

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Gauge symmetries are pervasive in particle physics, guiding the formulation of all interactions within the Standard Model. Usual methods for the calculation of processes, observables and properties of particles rely on perturbative expansions, which fail to converge for non-abelian gauge theories in the low-energy regime. The lattice formulation of a gauge theory, inherently non-perturbative, provides an alternative for these methods. In it the Lorentz symmetries are broken before taking the limit to the continuum because of the space-time discretization implemented by the lattice (in which the spacing between sites acts as an ultraviolet regulator making the theory finite), but gauge symmetry is kept exact at all steps. Moreover, one works in Euclidean spacetime, which allows one to use tools from Statistical Mechanics. We present the formulation for SU(3) gauge theory on the lattice and some preliminary results for the gluon and quark propagators.

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K^* Decay and the K^*/K Ratio in Heavy Ion Collisions

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When relativistic heavy ions collide, a plasma of quarks and gluons (QGP) is created. This system cools down, expands and eventually reaches hadronization temperature, when a hadron gas is formed. During this phase, the constituents of the gas, among which are the K and K*mesons, can undergo further interactions and change their abundances with respect to predictions by statistical hadronization models. In a previous article [1], we studied the role of the cooling of the gas, the freeze-out temperature and the interaction cross sections on the K*/K yield ratio. In the present work, we investigate the effect of the different reaction mechanisms on this ratio. Our analysis has shown that, out of all of the possible interaction mechanisms that the K*and K mesons can undergo in the hadron gas, only the K* decay and it's inverse mechanism are indeed necessary to be considered in order to describe the observed yield in several collision systems studied by the ALICE collaboration.

References

[1] Le Roux, C.; Navarra, F. S.; Abreu, L. M. Understanding the K*/K Ratio in Heavy Ion Collisions. Phys. Lett. B 2021, 817, 136284.

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Magnetic field in relativistic heavy-ion collisions: how good is the classical approximation?

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In relativistic non-central heavy-ion collisions an intense magnetic field is produced. Classical fields can be used to describe quantum fields when the occupation of each field mode is sufficiently high. In this work, we test the classical magnetic field approximation in heavy-ion collisions. First, we use a classical field to study the forward pion production by the magnetic excitation of nucleons through the Δ, in the process $N \rightarrow \Delta \rightarrow N + \pi$. We suggest that the pions produced in this process can be detected by the ZDC's, and this detection would be a measure of the magnetic field intensity. Then, we replace this field with a flux of photons and use the photoproduction of pions as the analogous process of magnetic excitation. In the end, we compare the two calculations and present our conclusions.

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Improving the Drell–Yan probe of small x partons at the LHC via an azimuthal angle cut

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Predictions for Drell–Yan lepton pair production at low dilepton mass and small x at the LHC usually have a large scale dependence, that can be decreased through obtaining an optimal factorization scale. In this paper, we reduce this scale by imposing a cutoff in azimuthal angle between the transverse momentum of the leptons, properly taking into account Sudakov effects. This would allows one to probe the parton distributions at smaller scales eliminating most of the current theoretical uncertainty.

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Thermal Relaxation of Neutron Stars near the Direct Urca Onset

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In this work we revisit the thermal relaxation of neutron stars. We focus particularly on the cooling of neutron stars whose mass is slightly greater than the value above which the direct urca process sets in. Considering different mechanisms for neutrino production in each region of the star, and working with some equations of state whose saturation properties as well its predicted neutron star maximum mass were previously tested with empirical values, we solve numerically the differential equations of energy balance and heat transport for a star with macroscopical structure given by the TOV equation. We show that the star in that condition exhibits neither a fast cooling, nor a slow cooling as they are commonly presented in the literature. Contrary to common behavior, its surface temperature undergoes a second sudden drop and the relaxation time is unusually high, reaching a few hundreds of years in some extreme cases.

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Nucleon Electromagnetic and Axial Form Factors with a Light-front Constituent Quark Model

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In this work we study the effect of scalar spin coupling of constituent quarks on nucleon electroweak properties by introducing a two momentum scales wave function. By comparing the one scale wave function and the two scales wave function models, we found that the last case has shown a reasonable description of static observables and of the ratio μpGEp/GMp in which the value of the zero of G_Ep appears at squared momentum transfer of about 15GeV^2. We have also shown results for the axial coupling gA and Axial Nucleon form factor. The best result for gA was obtained when the parameters of the nucleon wave function model were such that the experimental value of the neutron magnetic moment is reproduced.

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White dwarfs with finite temperature: consequences of general relativity and nuclear reactions in their structure and stability

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We investigate the structure of massive white dwarfs with finite temperature and their stability against radial oscillations, pycnonuclear reactions, and the inverse β-decay. Regarding the stellar fluid, we consider that it is composed of nucleons and electrons confined in a Wigner-Seitz cell surrounded by free photons. The star is considered with an isothermal core and a non-degenerate envelope in which a temperature distribution dependent on the mass density is implemented. We obtain stable equilibrium configuration sequences that are compared with some white dwarfs from Ultraviolet Explorer Survey (EUVE) and Sloan Digital Sky Survey (SDSS). We note that some high surface gravity white dwarfs observed are well described by our curves with higher central temperatures, which motivated us to investigate them. We select some of them to obtain mass and radius according to their observed effective temperature and gravity in our model. We found results in a similar range compared to those in the literature, except those that present masses $M \geq 1.37 M_{\odot}$, which is a range affected by general relativity. For a few central temperatures and surface gravity above $2.5 \times 10^4 g_{\odot}$ considering general relativity, we derive a relation between mass and surface gravity that can be useful for astronomers to obtain white dwarf masses through their observed surface gravity values and effective temperature [1]. We obtain that the maximum mass point and the zero eigenfrequencies of the fundamental mode are determined at the same central energy density; thus, indicating that the maximum total mass marks the beginning of radial instability in a sequence of equilibrium configurations with fixed temperature. Furthermore, regarding low-temperature stars, we show that

pycnonuclear reactions occur in almost similar central energy densities, and the central energy density threshold for inverse β-decay is not modified. For central temperatures, $T_c \geq 10^8$ [K], the onset of the radial instability is attained before the pycnonuclear reaction and the inverse β-decay.

[1] Síilvia P. Nunes, José D. V. Arbañil and M. Malheiro, "The structure and stability of massive hot white dwarfs", to be published in ApJ; http://arxiv.org/abs/2108.08238

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Efimov signatures of the K(1460) resonance

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The Efimov effect is a counterintuitive phenomenon concerning three non-relativistic particles with pairwise interactions supporting only one very shallow, two-particle bound state. In the so-called unitary limit, where the two-particle bound state energy goes to zero, the three-particle spectrum exhibits an infinite tower of bound states geometrically separated by a constant factor ~ 515. Efimov physics deals not only with the strict unitary regime, but also with the richer phenomenology slightly away from it, as long as the two-particle energies can still be considered shallow.

Observations of Efimov physics appear in cold atom experiments where the two-atom interactions can be tuned at will around the unitary regime via Feshbach resonance. In hadron physics, there are attempts at investigating some heavy exotic mesons as two- and three-body molecules and looking for universal correlations that are signatures of the Efimov effect. In this work we move away from the heavy quark sector, investigating a system with two kaons and one anti-kaon. The motivation is the shallow energies of the a_0 ($\sim$ 12 MeV) and f_0 ($\sim$ 2 MeV) below the two-kaon threshold. We present results for observables and evidence of universal correlations in the $K - f_0$ and $K - a_0$ scattering and the K(1460) state as candidate of an Efimov state.

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Kaon and nucleon states with hidden charm

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We have recently studied the interactions of $D{-}\bar{D}$ + c.c with a nucleon, with the motivation to find formation of P_c like states. We consider all interactions in s-wave and solve scattering equations. We find formation of nucleons with hidden charm, spin 1/2, 3/2 and positive parity. We earlier studied the interaction of $D{-}\bar{D}$ with a kaon, where a K^*-meson is found to arise. In this talk I will discuss the formalism of our works and the results found in the two cases.

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Lee-Wick field in presence of semi-transparent boundaries

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In this study I analyze the scalar and vectorial Lee-Wick field, achieving analytically the propagator and numerically the energy and force. It is analyzed the interaction between charge and a conductive plate, which simulates a semi-transparent mirror. For both cases, scalar and vectorial, the interaction force shows extrema points for finite values of the Lagrangian coupling parameters. The analysis of extrema cases shows that these parameters generate consistent results previously obtained.

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Opening

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Superconductivity of Confined Particles in a field-theory model

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In this work, a simple model of superconductivity of confined particles, which constitute low energy hadrons, such as quarks and gluons. Many models like these of superconductivity are already present in high energy physics, mainly in the study of color superconductivity. These models use in general a gluon propagator with specific electrical and magnetic effects, and after several approximations resulting in a differential gap equation, first obtained by Son. These gaps were frequency dependent and could reach results in the order of 100 MeV, as shown numerically by Wilczek and Schäfer. In this work we will adapt the color superconductivity model by changing the usual Gluon propagator, to a confining propagator, such as encountered in Gribov-Zwanziger and Refined Gribov-Zwanziger theories. An analysis of the differential gap equation and the gap function will compare how the effect of corrections originated from the new propagators modify the results in the literature. This will allow us to assess how nonperturbative confinement effects might affect the phenomenon of color superconductivity at intermediate densities. Two mass limits in the bosonic propagator must be reached: the high mass limit, reproducing the behavior of the "point like" approximation, making the gap function behave like a usual BCS superconductivity and the small mass, making the gap function behave similar to early results in color superconductivity .

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Approaching small- and large-box regimes in field theory

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We propose to investigate in detail how field theory behaves in restricted spaces. To do so, we consider a parametric representation of Feynman amplitudes, which allows us to discuss the behavior up to all orders in a perturbative expansion and extract consequences valid in a global setting. As a first step, we employ periodically compactified spaces and consider a scalar field theory. We show two valid and equivalent representations: a large-box representation (best suited near the bulk limit) and a small-box representation (best suited near the limit of dimensional reduction). In the small-box regime, we discuss the approach to dimensional reduction and show how it differs from a static-mode approximation.

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Electrically charged strange stars with an interacting quark matter equation of state

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We investigate the properties of electrically charged strange quark stars using an interacting quark matter equation of state (EoS) based on cold and dense perturbative quantum chromodynamics (pQCD). The stability of strange stars is analyzed considering different models for the electric charge distribution inside the star as well as for distinct values for the total electric charge. A comparison with the predictions derived using the MIT bag model is also presented. We show that the presence of a net electric charge inside strange stars implies in a larger maximum mass in comparison to their neutral counterparts. Moreover, we demonstrate that the pQCD EoS implies in larger values for the maximum mass of charged strange stars, with very heavy charged stars being stable systems against radial oscillations. For an electric charge distribution given by $q(r) = \beta r^3$, the pQCD EoS implies in unstable configurations for large values of the renormalization scale as well as for large values of β, in contrast to the MIT bag model predictions.

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Asymptotic solutions to the full next-to-leading order Balitsky-Kovchegov equation

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The high energy regime of quantum chromodynamics (QCD) has been under intense investigation in electron-hadron and hadron-hadron collisions. In this regime, saturation effects associated with the high gluonic density are expected to modify the QCD dynamics, implying the presence of non-linear effects that reduce the growth of the gluon distribution at small-x. The description of the saturation region is given by the Color Glass Condensate (CGC), which is an effective theory for the high density regime. The CGC theory implies that the dipole-hadron scattering amplitude satisfies the Balitisky-Kovchegov (BK) equation in the mean-field approximation, which allows us to estimate the contribution of the non-linear effects. In recent years, several authors have obtained the numerical solution of the BK equation at leading order in the full kinematical range, as well as its analytical solutions in the linear and saturation regimes. On the other hand, the description of the next-to-leading order (NLO) corrections for the BK equation is still a theme of intense debate in the literature.

Currently, there are different treatments for the NLO corrections and distinct prescriptions for the hard scale of the running coupling constant. One of them is the full next-to-leading order correction which consists of the implementation of the quark and gluon loops to the BK equation, which is called the full Next-to-leading order BK equation (BK - fNLO). We derive a solution to the NLO BK equation on the saturation regime for the hard scale given by Q_s^2, and compares this solution with the others' analytics solutions to the NLO BK equation in the saturation regime derived for the different prescriptions to the hard scale, present in the literature.

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Production of QED bound states in photon induced processes

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One interesting subject of the QED are the lepton – antilepton bound states, which are atom – like systems. These systems are ideal to test the ground of QED, once they allow us to test the CPT invariance of the theory, as demonstrated by several authors. Besides that, recent studies point out that these QED bound states can be sensitive to Beyond Standard Model Physics. Currently, we can study the QED bound states in photon induced processes present in heavy ion collisions at the Large Hadron Collider (LHC) and Relativistic Heavy Ion Collider (RHIC). The advantage of these collisions is the strong electromagnetic field produced by heavy ions, which are associated with photon fluxes proportional to Z^2, leading to large production rates for bound states. In this work we investigate the photoproduction of QED bound states in proton – proton, proton – nucleus and nucleus – nucleus ultraperipheral collisions at RHIC, LHC and FCC energies. We estimate the total cross sections and rapidity distributions for the production of singlet states $(l^+l^-)_S$ with $l = e, \mu, \tau$, considering different form factors for heavy nucleus. The impact of the Coulomb corrections on the $(e^+e^-)_S$ production in heavy ion collisions is estimated. We predict a large number of events associated to the production of the parapositronium and paramuonium states, which indicate that a future experimental analysis of these states is, in principle, feasible in hadronic collisions.

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Spin in two-dimensional fermion motion with circular symmetry

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We study two-dimensional fermion motion with circular symmetry using both 3+1 and 2+1 Dirac equations with a general Lorentz structure. Using a different approach than usual, we fully develop the formalism for these equations using cylindrical coordinates and discuss the quantum numbers, spinors and differential equations in both cases when there is circular symmetry. Although there is no spin quantum number in the 2+1 case, we find that, as remarked already by other authors, in this case the spin projection s in the direction perpendicular to the plane of motion can be emulated by a parameter preserving the anti-commutation relations between the Dirac matrices. The formalism developed allowed us to recognize an equivalence between a pure vector

potential and a pure tensor potential under circular symmetry, if the
former is multiplied by s, for any functional form of these
potentials. We apply the formalism, both in the 3+1 and 2+1 cases, to
the problem of a uniform magnetic field perpendicular to the plane of
motion. We fully discuss its solutions, their properties, including the energy spectra, compare them to the
relativistic Landau problem and obtain the non-relativistic
limit as well. This calculation enabled us to clarify the physical meaning of
the s parameter, representing the spin quantum number in the 3+1 case and
just a parameter in the Hamiltonian in the 2+1 case.

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Slow stable hybrid stars: a new class of compact stars that fulfills all current observational constraints

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We study hybrid stars considering the effects on stellar stability of the hadron-quark conversion speed at the sharp interface. The equation of state is constructed by combining a model-agnostic hadronic description with a constant speed of sound model for quark matter. We show that current LIGO/Virgo, NICER, low-density nuclear and high-density perturbative QCD constraints can be satisfied in two scenarios with low and high transition pressures. If the conversion speed is slow, a new class of hybrid objects is possible and very stiff hadronic equations of state cannot be discarded.

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Improvements in the treatment of peripheral heavy ion collisions

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Recently, STAR made measurements of pair production at very low transverse momenta and a significant excess with respect to hadronic cocktail in peripheral Hadronic Heavy Ion Collisions (HHICs) was observed. The excess pairs have transverse momenta $p_T < 150$ MeV/c and are most prominent in peripheral gold-gold and uranium-uranium collisions. The ALICE Collaboration observes a similar excess in peripheral lead-lead collisions for dileptons from the J/Ψ decay. The description of these data sets is still a subject of intense debate. In peripheral collisions we expect a dominance of hadronic processes so, usually, the dilepton production is studied with models based on strong interactions. Nevertheless, the excess can not be described by these models, motivating the proposition of additional sources of dileptons. An alternative, considering pair production at very low transverse momenta, is the dilepton production by photon−photon interactions in peripheral heavy ion collisions. At ultrarelativistic energies, the heavy nuclei are sources of strong electromagnetic

fields, and the dilepton production in nucleus-nucleus collision can be studied with Equivalent Photon Approximation (EPA). In EPA, the nucleus-nucleus cross section can be factorized in terms of photon flux, associated to each nuclei, and the elementary photont-photon cross section. In this contribution we investigate the impact for different treatments of nuclear form factor in the rapidity and invariant mass distributions for the dimuon production in peripheral heavy ion collisions at LHC energies considering distinct centralities. We present our predictions for the realistic and pointlike models and demonstrate that the pointlike approximation for the calculation of the photon spectra, present in the StarLight Monte Carlo, disregards a significant part of the spectra responsible for the production of dileptons. In addition, we propose a modfication in the point like model in order to make its predictions more realistic. We argue that this modification can be used in future analysis to improve the StarLight Monte Carlo predictions.

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Tidal Deformability of Quark Stars with Repulsive Interactions

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The QCD phase diagram at low temperature and high chemical potential still remains poorly understood. Several calculations suggest that, in this region, matter deconfines into a phase of quarks and gluons (known as cold QGP or quark matter), which can exist in the core of neutron stars. It is even possible that neutron stars are formed entirely by cold QGP. Usually we model neutron stars with the help of phenomenological models of the equation of state (EoS) that can describe matter in this region. With a given EoS we calculate quantities that can be compared with experimental data.

In view of the rapid experimental progress in the field, we update a model already used in a previous work called MFTQCD. It assumes that the gluon field can be decomposed into gluons with high and low momentum. The former can be treated with a mean field approximation and the latter yield expectation values which are related to the gluon condensates. We calculate the mass-radius diagram, we obtain the tidal deformability and compare the results with the new astrophysical observations. We conclude that our model remains compatible with the experimental data. However, the parameter window is now narrower.

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A simple model for the moments of multiplicity distributions in pp collisions at the LHC.

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Our first goal in this work is to evaluate the moments of the multiplicity distributions (MD) in pp collisions recently measured on the LHC, as the moments have not been published by the collaboration.

We explore the possibility of fitting this moments with negative binomial distribution (NBD) describing the MD, using a simple power law to describe dependence on energy of the mean multiplicity and a logarithmic expression for the second moment C2.
The behaviour of the k parameter of the NDB gives a measure of KNO violation. We obtain a reasonably good fit of the data, with the parameter k of the NDB increasing with energy, in contradiction with what is expected on the IP-Glasma description.

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Study of the effects of strong electric and magnetic fields on hadronic matter through the NJL SU(2) Model

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In this work, it is done a study of the quark matter accordingly to the two-flavor Nambu-Jona Lasinio model, which it is considered only the up and down quark flavors, and it is done an analysis adding non-linear effects from QED (Quantum Electrodynamics) through the use of the effective lagrangian of Euler and Heisenberg. From the complete lagrangian, we obtain the gap equation that dictates the effective mass of the quarks in the model. We discuss the behavior of the effective mass in three different scenarios: adding only magnetic field, only electric field, and adding both magnetic and electric field parallel. From the first scenario, we can notice the behavior dictated by the phenomenon of magnetic catalysis. From the second one, we can notice the opposite, the inverse catalysis, demonstrating that the electric field tends to restore the chiral symmetry of the model. Finally, in the third scenario, we produced an effective mass surface plot as a function of both fields, so we could evaluate the limit of null magnetic field and null electric field separately, beyond that, we obtain the behavior of both fields increasing in the same intensity, in order to analyze this competition between phenomena. This last result shows that for the most intense fields, in general, the effect of the electric field is predominant and makes the effective mass decrease. Beyond the results for effective mass, we calculate another result predicted by the QED: the Schwinger pair production rate, Γ, specifically the rate in units of GeV^4 for the production of quark-antiquark pairs in our approximation within the model in the case of magnetic and electric fields parallel. We obtained a Γ surface plot as a function of both fields and evaluated the limit of null magnetic field so we could summarize the known result of only the electric field already described in the literature. Finally, we evaluate and analyze the behavior of the pressure of the matter as a function of the magnetic and electric field intensities.

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Impact of initial condition characteristics on hybrid simulation models of relativistic heavy-ion collisions

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The main interest in relativistic heavy-ion collisions is the study of properties of the Quark Gluon Plasma (QGP). From a theoretical point of view, hybrid approaches, where different models are used to describe specific stages of the heavy-ion collision have had great success in describing a wide

range of final state hadronic observables. Most of these models include an initial conditions generator that produces an energy density profile of the two colliding nuclei, followed by a hydrodynamic simulation. Glauber-based models and the Color Glass Condensate model (CGC), which is based in Yang-Mills theory, are among the most common approaches on generating such an initial energy density profile. In this work, we analyze the shape of initial conditions generated by the Glauber-inspired model TRENTo, and its dependence on the value of the nucleon-width parameter. The nucleon-width is one of the free parameters in the hybrid models, and is adjusted to best reproduce the experimental data. Hence it is important to understand and characterize the effects of this parameter on the initial conditions prior to the hydrodynamic evolution and connect that to its effects in final state observables. We calculate the eccentricity harmonics ε2, ε3, ε4 and ε5, and calculate some of the most commonly used quantities in surface roughness analysis to quantify the "spikeyness" of the initial profiles for several nucleon-width values.

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Machine Learning Strategies for a Global Equation of State and a Better Description of Neutron Stars

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Extremely massive objects such as neutron stars serve as unique laboratories that allow the study of nuclear matter in exotic environments impossible to be reproduced on Earth. The microscopic description of the nuclear structure of neutron stars represents a big challenge for theoretical models. The large densities present in these stars, possibly beyond the nuclear density equilibrium, lead to strong sensitivity of the mass-radius relation. This, opens space for several theoretical parameterization and constraints that are often applied case by case or to different classes of stars.

Even though the first observations and theoretical models were proposed several years ago, a complete description of such objects is still missing due to the complexity of the calculations involved. Today's successful approaches require many constrains in a variety of nuclear models in an attempt to reproduce astrophysical observations.

In this work, we make use of modern supervised machine learning techniques that allow us to determine different properties present in a sample of EoS generated from different physical models. Our objective is to obtain a global parameterization of different classes of equations of states. We will present selected results for representative cases.

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Neutron stars in f(R, T) gravity using realistic equations of state in the light of massive pulsars and GW170817

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In this work, we investigate neutron stars (NS) in $f(\mathcal{R},\mathcal{T})$ gravity for the case $R+2\lambda\mathcal{T}$, $\mathcal{R}$ is the Ricci scalar and $\mathcal{T}$ the trace of the energy-momentum tensor. The hydrostatic equilibrium equations are solved considering realistic equations of state (EsoS). The NS masses and radii obtained are subject to a joint constrain from massive pulsars and the event GW170817. We found that the increment in the star mass is less than 1%, much smaller than previous ones obtained not considering the realistic stellar structure. The finding that using several relativistic and non-relativistic models the variation on the NS mass is almost the same for all the EsoS, manifests that our results are insensitive to the high density part of the EsoS. We highlight that our results indicate that conclusions obtained from NS studies done in modified theories of gravity without using realistic EsoS that describe correctly the NS interior can be unreliable.

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Leading neutron production at the EIC and LHeC: estimating the impact of the absorptive corrections

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Leading neutron (LN) production in *ep* collisions at high energies is investigated using the color dipole formalism and taking into account saturation effects. We update the treatment of absorptive effects and estimate the impact of these effects on LN spectra in the kinematical range that will be probed by the Electron Ion Collider (EIC) and by the Large Hadron electron Collider (LHeC). We demonstrate that Feynman scaling, associated to saturation, is not violated by the inclusion of absorptive effects. Moreover, our results indicate that the LN spectrum is strongly suppressed at small photon virtualities. These results suggest that absorptive effects cannot be disregarded in future measurements of the *gamma-pi* cross section to be extracted from data on leading neutron production.

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Cosmological implications of the QCD phase transition in the Early Universe

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Quantum Chromodynamics (QCD) theory predicts that at high temperatures quarks and gluons are in a state of asymptotic freedom, constituting with leptons and photons the primitive plasma present in the Early Universe. When the plasma temperature drops below a certain critical value T_c, consequence of the expansion of the Universe, quarks become confined into hadrons. This process is usually described as a phase transition whose order is still under debate. In this contribution we consider different models for the equation of state (EoS) of the QGP and hadronic phases and investigate the impact of these distinct modelling on the thermodynamical and cosmological parameters. In particular, we study the behaviour of the Hubble H, deceleration q and jerk j parameters during the phase transition and demonstrate that they are sensitive to the treatment of the EoS.

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Can the anomalous X-ray pulsar 4U~0142+61 be described as an accreting white dwarf?

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The quiescent emission of the anomalous X-ray pulsar (AXP) 4U 0142+61 extends over a broad range of energy, from radio up to hard X-rays. In particular, this object is unique among soft gamma-ray repeaters (SGRs) and AXPs in presenting simultaneously mid-infrared emission and pulsed optical emission. In spite of the many propositions to explain this wide range of emission, it still lacks one that reproduces all the observations. In this poster, we present a model to reproduce the quiescent spectral energy distribution of 4U 0142+61 from mid-infrared up to hard X-rays using plausible physical components and parameters. We propose that the persistent emission comes from a magnetic accreting white dwarf (WD) surrounded by a debris disk. This model assumes that (I) the hard X-rays are due to the bremsstrahlung emission from the postshock region of the accretion column, (II) the soft X-rays are originated by hot spots on the WD surface, and (III) the optical and infrared emissions are caused by an optically thick dusty disk, the WD photosphere, and the tail of the postshock region emission. In this scenario, the fitted model parameters indicate that 4U 0142+61 harbors a fast-rotator magnetic near-Chandrasekhar WD, which is very hot and hence young. Such a WD can be the recent outcome of a merger of two less massive WDs. In this case, 4U 0142+61 can evolve into a supernova Ia and hence give hints of the origin of these important astrophysical events.

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Production of charmed mesons, baryons and tetraquarks in heavy-ion collisions at the LHC

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We investigate the production of charmed hadrons ($\bar{D}$, Λ_c, Ξ_{cc}) and exotic tetraquarks (T_{cc}, T_{bc}) in relativistic heavy-ion collisions using the quark coalescence model. The yields are given by the overlap of the density matrix of the constituents in the emission source with the Wigner function of the produced meson, baryon and tetraquark. The wave functions are obtained from exact solutions of the two-, three- and four-body problem using a realistic constituent quark model. It contains a chromoelectric part made of a Coulomb-plus-linear interaction together with a chromomagnetic spin-spin term described by a regularized Breit-Fermi interaction with a smearing parameter that depends on the reduced mass of the interacting quarks. We take into account effects of temperature on the masses of the light quarks that enter in the quark model. The temperature dependence of those quantities are taken from the Nambu–Jona-Lasinio model. We found that the production yields of mesons, baryons and tetraquarks are typically one order of magnitude smaller than previous estimations based on simplified wave functions. We also evaluate the consequences of the partial restoration of chiral symmetry at the hadronization temperature on the coalescence probability. Such effects, in addition to increasing the stability of the tetraquarks, lead to an enhancement of the production yields.

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Neutrino physics in the r-process nucleosynthesis

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In recent years new processes involving weak nuclear interactions have been studied experimentally and theoretically [1]. This kind of interactions play a fundamental role in the understanding heavier elements nucleosynthesis in the universe. The presence of heavy elements is only understood if stellar reactions take place involving regions of the nuclear chart far away from the stability line [2]. The process is supposed to occurs in astrophysics sites of high energy events in the galaxy such as supernova explosion and halo of merging binary system [3]. The later has been studied due to recently multi-messenger observations from neutron star collisions. Neutrinos fluxes are produced in this high energy events, thus it important to discuss the role of
neutrinos in nucleosynthesis of heavy elements. There are three processes responsible of heavy element formation: the s-, the p- and the r-process. We are interested in sites with temperature and neutron density very high, so the r-process is predominant. In order to discuss this process, we need to evaluate the half-lives of beta-decay, the neutrino and the electron capture rates, that are in competition with the neutron and proton capture by nucleus. For this, we adopted the Gross Theory of Beta Decay (GTBD) [4] in this work, which presents a great advantage over the other approaches specially in astrophysical applications.

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Renormalization group improved QCD thermodynamics

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We use the renormalization group optimized perturbation theory (RGOPT) to evaluate the quark contribution, Pq, to the QCD pressure at NLO (two loop level). In this seminal application the complete QCD pressure is then obtained simply by adding the perturbative NLO contribution from massless gluons to the resummed Pq. At the central scale M~2πT our complete QCD pressure, P=Pq+Pg, shows a remarkable agreement with lattice predictions for 0.25⊠T⊠1GeV. As expected, the RG properties native to the RGOPT resummation significantly reduce the embarassing scale dependence that plagues popular analytical methods such as standard thermal perturbative QCD and hard thermal loop perturbation theory (HTLpt).

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Deformed Neutron Stars and the Photosphere

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The effect of deformation on compact stars, especially neutron stars, is widely known. This can happen for several reasons: intense magnetic fields and high rotation are the main ones. In this sense, taking into consideration influences both in the metric and in the matter structure, through deformed geometries, anisotropies in the energy-momentum tensor, or adequate equations of state, a more realistic analysis of stellar dynamics can be obtained. To this extent, the stars are studied using non-spherical models. Through the employment of a modified Tolman-Oppenheimer-Volkoff equation and selected equations of state, the deformation of neutron stars is investigated. Furthermore, the so-called ultracompact stars, considered in our larger study of neutron stars, can reach unusual levels of compactness, making it possible for a photosphere to appear outside the star. The present paper investigates the possibility of the manifestation of a new phenomenon, in which the deformation of the star allows the photosphere to manifest itself internally and externally, simultaneously.

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Relativistic Mean Field Model constrained by Astrophysical Measurements

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In this work, we present a preliminary study where the Bayesian analysis is used to constraint saturation properties of nuclear matter. For this, an equation of state (EoS) that allows $\omega-\rho$ interactions is considered. Regarding the priors, uniform distribution on the values of saturation density, binding energy, effective mass, incompressibility, symmetry energy, and its slope at nuclear saturation density have been used. Their ranges are in accordance with the current literature. The posteriors are computed through the procedure of Bayesian inference where observational data of neutron star masses and radii are employed. These data include the gravitational wave event GW170817 and also the recent data published from NICER. The results indicates lower values of L_0 for the EoS with $\omega-\rho$ interactions if compared to $\sigma^3-\sigma^4$ ones, $63.3^{+13.5}_{-9.7}$ MeV and $82.3^{+4.8}_{-3.2}$ MeV respectively.

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Exclusive vector meson production in electron – ion collisions at the future colliders

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The exclusive vector meson production in electron – ion collisions for the energies of the future colliders is investigated. We present predictions for the coherent and incoherent Phi and J/psi production in eAu collisions considering the possible states of nucleon configurations in the nuclear wave function and taking into account of the non - linear corrections to the QCD dynamics. The cross sections and transverse momentum distributions are estimated assuming the energies of the Electron - Ion Collider (EIC), Large Hadron Electron Collider (LHeC) and Future Circular Collider (FCC – eh). Our results indicate that a future experimental analysis of these processes can shed light on the modeling of the gluon saturation effects and constrain the description of the QCD dynamics at high energies.

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The anomalous magnetic moment key on NJL-SU(2) model

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Magnetars and heavy-ion-collisions (HIC) are environments where only a robust theory to strong interactions can extract reasonable quantities in account with the astronomical observations and HIC-experiments nowadays. Because of the sign problem, the Quantum Chromodynamics (QCD) isn't treatable to important cases where there are finite chemical potentials. From Nambu–Jona-Lasinio (NJL) model, one of the most prominent among the effective models for QCD, a lot of questions in hadron and low energy physics were found. Under an electromagnetic field and taking a phenomenological term of anomalous magnetic moment, thermodynamic properties, and so the QCD phase diagram, can be altered in a non-negligible way. In this talk, I will present the general formalism and get the effective quark masses using different regularization schemes.

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Production of dark photons in electron-nucleus collisions via compton-like process

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Dark photon is a theoretical boson that mediates the interaction between dark matter particles. The dark photon can interact with the Standard Model photon by kinetically mixing with it. In this work, we study the dark photon production via Compton-like process in ultrarelativistic electron-ion collisions. We search for massive dark photons in planned electron-ion collider machines such as the Electron-ion collider in China (EicC), the Polarized Electron-Ion Collider at Jefferson Lab (JLEIC), the Electron Ion Collider (EIC), the Large Hadron Electron Collider (LHeC) and the Future Circular Collider (FCC-eh). The total cross section and number of events for dark photon production in these experiments are computed in terms of the mass, $m_{\gamma'}$, and the kinetic mixing parameter, ε. It is considered the mass range, 100 MeV < $m_{\gamma'}$ < 500 MeV and fixed mixing parameter $\varepsilon \sim 10^{-3}$. The ultrarelativistic heavy ions are treated as sources of quasi-real photons described by the equivalent photon approximation. The cross section is numerically computed as a function of the incident photon energy for fixed dark photon mass and kinetic mixing parameter. We calculated the expected number of events by using the expected luminosities of the experiments. We found that the integrated cross section for dark photon production through the Compton-like process decreases monotonically with the dark photon mass and reaches large values at the small mass region. The cross section of dark photon production reaches units of picobarns and number of events $\sim 10^5$ for a one year run. This study complements existing search strategies for massive dark photons in the investigated mass range.

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A comparative analysis for the form factors and coupling constant of the DsDK* meson vertex

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Recently, we made a calculation of the form factors and coupling constant of $DsDK^*$ using the QCD Sum Rules. This information is fundamental to compute the amplitude for the process $B \to K^*\pi$ in effective theories. The method used considers the three cases of different off-shell mesons. After an extrapolation of the results of QCD Sum rules, we obtain the coupling constant of the vertex. The uncertainties of these results are analyzed as well as the variations of sum rules' parameters. Moreover, the conditions of the contribuitions of the pole and continuum also are accurately analyzed. In view of this complete analysis, we perform a comparative study of the form factors and coupling constant obtained by other methods.

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The Color Glass Condensate: Big picture questions, interdisciplinary connections and some recent developments

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At very high energies, the multitude of gluons and sea quark fields that fundamentally make up the structure of hadrons, organize themselves on very short time and distance scales, as a form of strongly correlated matter called the Color Glass Condensate (CGC). Though intrinsically quantum in nature, it behaves as a classical lump and many of its features can be explored using semi-classical methods in quantum field theory. Remarkably, key features may be universal and share properties with systems across energy scales, ranging from Black Holes to ultracold atomic gases. The CGC can be probed cleanly at the Electron-Ion Collider, which will commence operations at decade's end; we will briefly address its discovery potential and related theory challenges.

The CGC framework also provides a first principles understanding of the Glasma matter formed in the thermalization process towards the formation of a Quark-Gluon plasma (QGP) in ultrarelativistic heavy-ion collisions. We will outline some of the striking phenomena in the Glasma, in particular the discovery of turbulent nonthermal fixed and universal features they share with cold atomic gases. We will end these lectures with a discussion of the possible role of the CGC in spin diffusion within polarized protons at high energies. This can be understood as a fascinating interplay between the topology of the QCD vacuum represented by instanton-anti-instanton tunneling between vacua and over-the-barrier sphaleron-like transitions induced by CGC fields.