# ABSTRACTS

## QCD SUM RULES AT FINITE TEMPERATURE: A REVIEW OF RECENT APPLICATIONS

**Author:** ***Cesareo Dominguez***

The analytical method of QCD sum rules is based on the Operator Product Expansion of current correlators at short distances together with Quark-Hadron Duality, invoking Cauchy's theorem in the complex square-energy plane. This technique was extended to finite temperature in the late 1980's and used in a plethora of applications to determine the thermal behavior of hadronic as well as QCD quantities. A review of the subject will be presented, with emphasis on the most important results obtained in this framework.

## NUMERICALLY COMPUTING QCD LAPLACE SUM-RULES USING PYSECDEC

**Author:** *Derek Harnett*

PySecDec is a program that numerically calculates dimensionally regularized integrals. We use pySecDec to compute QCD Laplace sum-rules for pseudoscalar charmonium hybrids, and compare the results to published analytic expressions. We find that the error introduced by the use of numerical integration methods is negligible compared to the errors associated with the parameters of QCD (i.e., quark masses, the coupling constant, and condensate values) and the renormalization scale that are already present in the sum-rules.

## MESON-HYBRID MIXING IN 1-- HEAVY QUARKONIUM FROM QCD SUM-RULES

**Author:** *Alex Palameta*

We present the results of a QCD Laplace sum-rule exploration of heavy quarkonium mixing in the JPC=$1^{--}$ channel. Our cross-correlator calculation supplements the perturbative result with non-perturbative contributions proportional to the four-dimensional and six-dimensional gluon condensates and the three-dimensional quark condensate. We then use experimentally determined hadronic masses to build several single and multi-resonance models of the cc – and bb - mass spectra. These models and the QCD Laplace sum-rule are then used to test resonances for meson-hybrid mixing.

## DI-MUON PRODUCTION IN HEAVY ION COLLISIONS: A SIGNAL FOR QUARK-GLUON DECONFINEMENT

**Author**: *Luis Hernandez*

The process of di-muon production in heavy ion collisions at very high energies is a clean probe of the quark-gluon deconfinement phase transition. In particular, in the energy region of the rho-meson substantial modifications to the spectrum have been observed when compared with expectations from a standard, zero-temperature scenario. In fact, the hadronic width of the rho-meson is substantially larger, and the peak height is appreciably lower than in the vacuum. Lately, specific models have been used to understand this behaviour. Instead, a description entirely in the framework of QCD at finite temperature will be discussed in this talk. This approach involves as sole inputs the temperature dependence of the rho-meson mass, width, and leptonic coupling. This temperature dependence of the rho-meson parameters was previously obtained from QCD sum rules, so that the di-muon production rate is essentially a parameter-free prediction. This will be followed by a discussion of the di-muon production results, and their comparison with LHC data from the NA60 Collaboration.

## INTRODUCTION TO THE ADS/CFT CORRESPONDENCE, APPLIED TO QCD

**Author:** *Ivan Schmidt*

An introduction to the AdS/CFT correspondence, applied to QCD, is presented, and as an example, the electromagnetic properties of the deuteron are calculated using this formalism.

## MASS SPECTRUM OF OPEN-FLAVOUR HEAVY-LIGHT HYBRIDS FROM QCD SUM-RULES

**Author:** *Jason Ho*

Leading-order diagonal correlation functions for heavy-light open-flavour hybrid mesons are computed, including up to dimension six gluon condensate contributions. QCD Laplace sum rule results are presented, and hybrid mass predictions for all JP∈0±, 1± are reported. Possible mixing effects with conventional meson states are discussed.

## EXPLORING INFRARED QCD WITH SCHWINGER-DYSON EQUATIONS

**Author:** *Arlene Cristina Aguilar*

In this talk, I will review some of the crucial aspects of the current efforts to understand the infrared dynamics of the QCD Green’s functions. The Green’s functions are the basic QCD building blocks describing the fundamental physical degrees of freedom of the theory (gluon and quark propagators and the fundamental vertices). Even though it is well-known that these quantities are not physical, since they depend on the gauge-fixing scheme and parameters used to quantize the theory, it is widely believed that QCD Green's functions encode crucial information about the most characteristic nonperturbative phenomena, such as confinement, mass generation, and bound-state formation.

We will present the main results derived from the close synergy between Schwinger-Dyson equations and lattice simulations. Particular attention is dedicated to the nonperturbative mechanisms that endow the gluons and the quarks with dynamical masses and its relation with the chiral symmetry breaking. In addition, we will discuss the infrared behavior of the vertices and the definition of the non-perturbative QCD effective charge.

## HOLOMORPHIC LATTICE-MOTIVATED COUPLING WITH ZERO IR LIMIT AND PERTURBATIVE IN THE UV REGIME

**Author:** *Gorazd Cvetic*

A nonperturbative generalization $\boldsymbol{A}(Q^2)$ of the perturbative QCD running coupling $a(Q^2)$ $(\alpha_s(Q^2)/\pi)$ can be represented as the product of the gluon dressing function and the square of the ghost dressing function in the Landau gauge in the MiniMOM scheme. This coupling has been calculated to a high precision at low $ Q^2 \lesssim 1 \ {\rm GeV}^2 $ in recent large volume lattice calculations, and has the intriguing property that it goes to zero (as $\sim Q^2$) when $Q^2 \to 0$. We construct a QCD coupling $\boldsymbol{A}(Q^2)$ which fulfills this condition and also various other physically motivated conditions: at high momenta it merges with the underlying perturbative coupling $a(Q^2)$ to a very high precision; and at intermediate momenta $ Q^2 \sim 1 \ {\rm GeV}^2 $ it reproduces the phenomenology of the semihadronic decays of $\tau$-lepton as measured to a high precision by OPAL and ALEPH. The construction of the coupling is made by dispersive methods, and it results in a behavior $\boldsymbol{A}(Q^2)$ in the complex $Q^2$-plane which reflects qualitatively the holomorphic behavior of spacelike QCD observables. Several applications of the coupling to the QCD phenomenology at intermediate momenta $\sim 1 \ {\rm GeV}^2$ are performed. It turns out that the OPE approach with this coupling gives in general results which are significantly better than those obtained in the OPE with the usual (${\overline {\rm MS}}$) perturbative QCD coupling.

## COMMENTS ON THE COMPATIBILITY OF THERMODYNAMIC EQUILIBRIUM CONDITIONS WITH LATTICE PROPAGATORS

**Authors:** *Alex Giacomi*

The compatibility of the non-perturbative equations of state of quarks and gluons arising from the lattice with some natural requirements for self-gravitating objects at equilibrium is analyzed: the existence of an equation of state (namely, the possibility to define the pressure as a function of the energy density), the absence of superluminal propagation and Le Chatelier's principle. It is discussed under which conditions it is possible to extract an equation of state (in the above sense) from the non-perturbative propagators arising from the fits of the latest lattice data. In the quark case, there is a small but non-vanishing range of temperatures in which it is not possible to define a single-valued functional relation between density and pressure. Interestingly enough, a small change of the parameters appearing in the fit of the lattice quark propagator (of around 10~\%) could guarantee the fulfillment of all the three conditions (keeping alive, at the same time, the violation of positivity of the spectral representation, which is the expected signal of confinement). As far as gluons are concerned, the analysis shows very similar results. Whether or not the non-perturbative quark and gluon propagators satisfy these conditions can have a strong impact on the estimate of the maximal mass of quark stars

## THE GRIBOV CONFINEMENT PRESCRIPTION IN A LORENTZ BREAKING SCENARIO.

**Author:** *Igor F. Justo*

In this seminar, the Gribov procedure applied to unambiguously fix the gauge freedom of Yang-Mills theories will be described, culminating in a possible confinement interpretation of gluons by looking at their propagators. Particularly, some analysis on the gauge field propagator, considering Gribov's prescription within an SU(2) Yang-Mills theory in the Landau gauge presenting an effective Lorentz symmetry breaking, will be presented. Besides, two interesting possible situations for the Lorentz symmetry breaking, concerning the gauge field propagator, will be shown.

## QUASI-RELATIVISTIC SYSTEMS IN A STRONG MAGNETIC FIELD

**Author:** *Igor Shovkovy*

Relativistic matter in strong magnetic fields is a very popular direction of research in high-energy physics. The interest is driven by potential applications in studies of neutron stars, the Early Universe, and heavy-ion collisions. Surprisingly, the same physics is also relevant for a large class of novel condensed matter materials, namely the Dirac and Weyl semimetals. Such materials hold a great potential for technological applications. I will review recent theoretical ideas regarding the corresponding states of quasi-relativistic matter in strong magnetic fields.

## ASPECTS OF GRAPHENE PHYSICS FROM A QFT FRAMEWORK

**Author:** *Alfredo Raya*

In this talk I describe several aspects of graphene physics in the framework of QFT under extreme conditions.

## LINKING HIGH ENERGY PHYSICS TO CONDENSED MATTER

**Author:** *Ana Julia Silveira*

The chiral magnetic effect (CME) constitutes a macroscopic manifestation of the chiral anomaly. Despite of the effort to observe it in the quark gluon plasma produced in heavy ion collisions, no definitive measurements have been achieved in order to prove it. By the other side, certain condensed matter systems that contain Dirac-like charge carriers have shown to be a suitable environment to reproduce the CME. We propose that, besides the zirconium pentatelluride in which the CME has been observed, it must be possible to construct an arrangement based on planar Dirac materials that works as an analogue of the CME.

## QUARK MATTER AND NEUTRAL MESON PROPERTIES IN A NON LOCAL CHIRAL QUARK MODEL UNDER A STRONG MAGNETIC FIELD

**Author:** Norberto Scoccola

We study the behavior of strongly interacting matter under an external constant magnetic field in the context of nonlocal chiral quark models. We find that at zero temperature the behavior of the quark condensates and the neutral meson properties are in good quantitative agreement with lattice QCD results.

On the other hand when the analysis is extended to finite temperatures our results show that nonlocal models naturally lead to the Inverse Magnetic Catalysis effect for both the quiral restoration and the deconfinement temperatures.

## MAGNETIC SEED AND COSMOLOGY AS QUANTUM HALL EFFECT

**Author**: Jorge Gamboa

We discuss the restoration of causality between two points in cosmology through a mapping similar to the quantum Hall effect. Firstly, we show how the modified FLRW equations are mapped to an anisotropic two-dimensional charged harmonic oscillator in a constant magnetic field with the frequencies of the oscillator being the analogue of the cosmological constants. If the cosmological constants of both regions are denoted by $\Lambda_{a, b}$ and $\theta$ is the magnetic field, we show that when $\sqrt{3|\Lambda_{a, b}|}\ll 2\theta$, the Hamiltonian is equivalent to the Landau problem and the spectrum of energies and eigenstates are constructed through the Lowest Landau Level. The map between cosmology and quantum Hall effect also provides a natural explanation for the magnetic seed (magnetogenesis). Our approach is an example of non-perturbative solubility in cosmology.

## PRECISION QFT IN 2, 3 AND 4 DIMENSIONS

**Author:** *York Schröder*

The renormalization group (RG) lies at the heart of quantum field theory. I will review recent progress in developing tools that enable to determine RG coefficients with high accuracy. Applications to a variety of problems are sketched, ranging from graphene to QCD.

## INVERSE MAGNETIC CATALYSIS: MARCELO'S QUEST FOR THE STRONG AND THE EXTREME

**Author:** *Alejandro Ayala*

In this talk I describe one of the achievements of a long and fruitful collaboration initiated between Marcelo's group at PUC and my group at ICN-UNAM. The collaboration started by Marcelo's initiative and was based on our common interest to use effective QCD theories to explore the properties of strongly interacting matter under extreme conditions. We showed that the Lattice QCD results for the behavior of the critical temperature for the chiral transition in the background of a magnetic field can be described using the linear sigma model, including the quark contribution and the thermo-magnetic effects induced on the coupling as well as plasma screening effects.

## INTEGRABILITY AND CHEMICAL POTENTIAL IN THE (3+1)-DIMENSIONAL SKYRME MODEL

**Author:** *Fabrizio Canfora*

Using a remarkable mapping from the original (3+1)dimensional Skyrme model to the Sine-Gordon model, the first analytic examples of Skyrmions as well as of Skyrmions–anti-Skyrmions bound states within a finite box in 3+1 dimensional flat space-time are constructed. An analytic upperbound on the number of these Skyrmions–anti-Skyrmions bound states is derived. The critical isospin chemical potential beyond which these Skyrmions cease to exist is also computed.

## DEEP INELASTIC SCATTERING AS A PROBE OF ENTANGLEMENT

**Author:** *Eugene Levin*

Using non-linear evolution equations of QCD, we compute the von Neumann entropy of the system of partons resolved by deep inelastic scattering at a given Bjorken-x and momentum transfer $q^2 = - Q^2$. We interpret the result as the entropy of entanglement between the spatial region probed by deep inelastic scattering and the rest of the proton. At small $x$ the relation between the entanglement entropy $S(x)$ and the parton distribution $xG(x)$ becomes very simple: $S(x) = Ln\, xG(x)$.

In this small-x large rapidity Y regime, all partonic micro-states have equal probabilities -- the proton is composed by an exponentially large number $e^{\Delta Y}$ of micro-states that occur with equal and exponentially small probabilities $e^{-\Delta Y}$, where $\Delta$ is defined by $xG(x) = 1/x^{\Delta}$. For this equipartitioned state, the entanglement entropy is maximal -- so at small-x, deep inelastic scattering probes a ***maximally entangled state***. We propose the entanglement entropy as an observable that can be studied in deep inelastic scattering. This will require event-by-event measurements of hadronic final states, and would allow to study the transformation of entanglement entropy into the Boltzmann one. We estimate that the proton is represented by the maximally entangled state at $x< 10^{-3}$, this kinematic region will be amenable to studies at the Electron Ion Collider.

## BOOSTED SATURATION SCALE IN HEAVY ION COLLISIONS

**Author:** *Boris Kopeliovich*

Interaction with a nucleus in *pA* collisions enhances the higher Fock components in the projectile proton. Effectively, this corresponds to an increase of the hard scale of the process by the saturation momentum $Q^2 \to Q^2 + Q^2_{sA}$, which leads to an increased gluon distribution function at small-x (but suppressed at $x\to1$) compared to that in *pp* collisions. In the case of *AA* collisions the gluon distributions of bound nucleons in both nuclei turn out to be enhanced, i.e. mutually boosted to higher saturation scales compared to *pA* collisions. A set of bootstrap equations relating the saturation scales in the colliding nuclei is derived. The boosting effect has a moderate magnitude at the energies of RHIC, but becomes significant at the LHC.

## STUDIES OF NONPERTURBATIVE STRUCTURE OF HADRONS FROM LEPTON PRODUCTION EXPERIMENTS

**Author:** *Marat Siddikov*

In this talk we discuss how the nonperturbative structure of the hadron, encoded in Generalized Parton Distributions of the target, can be studied in electron- and neutrino-induced processes in Bjorken limit. We will make a short overview of opportunities and challenges in analysis of Deeply Virtual Compton Scattering (DVCS) and Deeply Virtual Meson Production (DVMP), which will be studied at Jefferson laboratory (JLAB) and MINERvA collaborations at Fermilab. Also, we will present our results on loop corrections to deeply virtual pion and kaon production in neutrino experiments.

**NUCLEAR EFFECTS IN SINGLE SPIN ASYMMETRY AT SMALL ANGLES**

**Author:** *Michal Krelina*

We investigate the single spin asymmetry, $A_N(t)$, arising from Coulomb-nuclear interference (CNI) at small-angle proton-gold scattering. Previous theoretical attempts fail to explain the recent data from the PHENIX experiment at RHIC on polarized proton-gold scattering, exposing a nontrivial $t$-dependence of $A_N$. Previously, we found that the absorptive corrections in the Coulomb amplitude of ***pA*** elastic scattering play significant role. However, the single spin asymmetry is highly sensitive for nuclear corrections. Therefore, we build a model, where we attempt to include some of expected corrections such as Gribov corrections or *NN*-correlations to obtain the full relevant picture of the elastic proton-nucleus scattering.

**COSMIC CENSORSHIP AND QUANTUM EFFECTS**

**Author** : *Jorge Zanelli*

Cosmic censorship understood as the absence of naked singularities in gravitation theory, is a consistency requirement in our understanding of Nature, similar to the stability of the atom. The stability of the atom results from the fact that quantum mechanics prevents the collapse of electrons into the nucleus. In relation to cosmic censorship, we found that naked singularities in 2+1 dimensions become "dressed" by a horizon that develops around them, generated by quantum effects. The dresses around the singularities turn them into something resembling a Planck-sized classical black hole, avoiding paradoxical inconsistencies.

**NONCOMMUTATIVITY AND COSMIC EXPANSION**

**Author:** *Horacio Falomir*

We consider two sectors of the Universe (or, alternatively, a bimetric model) described by Friedmann-Lemaître-Robertson-Walker (FLRW) metrics with scale factors $a(t)$ and $b(t)$ respectively. We induce between them an effective interaction through a deformation of the Poisson structure for an equivalent mechanical system with two degrees of freedom, whose Hamilton's equations are numerically and perturbatively studied. It is shown that one sector appears as an effective source of density and pressure for the second one. We find that this coupling between otherwise disconnected sectors of the Universe gives rise to accelerating or periodic evolutions, depending on the value taken by the noncommutativity parameter.

## EFFECTIVE FIELD THEORY WITH HIGHER-ORDER LORENTZ VIOLATION

**Author** : *Marat Reyes*

Effective field theory has shown to be a powerful method in searching for quantum gravity effects and in particular for CPT and Lorentz symmetry violation. In this work, we study an effective field theory with higher-order Lorentz violation; specifically we consider a modified model with scalars and modified fermions interacting via the Yukawa coupling. We study its renormalization properties, that is, its radiative corrections and renormalization conditions in the light of the requirements of having a finite and unitary ***S***-matrix.

## ON THE CALCULATION OF TRIANGLE LADDER FEYNMAN DIAGRAMS

**Author:** *Igor Kondrashuk*

Old results about the calculation of the ladder diagrams is reviewed briefly. The method to reduce the number of loops in the triangle ladder Feynman diagrams in an arbitrary number of space-time dimensions is given.

## EXPERIMENTAL BOUNDS FOR A TWO PARTICLE HIDDEN SECTOR WITH ALP AND HIDDEN PHOTON

**Author**: *Pedro Alvarez*

I will introduce a model for the dark sector that contains axion-like particles and hidden photons. In this model, both particles can couple to photons. We provide bounds for the couplings versus the mass, using current results from ALPS-I and PVLAS

## A FIRST APPROACH TO THE MIXING PHENOMENA IN RELATIVISTIC KINETIC GAS DISTRIBUTIONS AROUND BLACK HOLES.

**Author**: *Paola Rioseco*

Mixing phenomena is well known in the context of plasma physics and galactic dynamics. The same phenomena can occur for a relativistic kinetic collisionless gas in a strong gravitational field, as is the case for example for stars orbiting a Kerr black hole. As a first approximation, I will explain the phenomenon of mixing and why it occurs for the simplest case of a potential in one dimension and gas particles that satisfy the Vlasov equation. Finally, I will discuss some applications to the evolution of inhomogeneities in dark matter halos.

## THE PATH INTEGRAL OVER RELATIVISTIC WORLD-LINES

**Author**: *Benjamin Koch*

The straightforward path integral over the square root action of the relativistic point particle produces notorious problems and inconsistencies. It is shown how those problems can be circumvented by the consideration of an additional local symmetry.