

# Excited QCD 2015

Sunday, 8 March 2015 - Saturday, 14 March 2015

Tatranska Lomnica, Slovakia



## Book of Abstracts



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Thursday Morning / 3

## Towards a consistent description of in-medium parton branching

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Ultra-relativistic heavy-ion collisions are a window of opportunity to study QCD matter under extreme conditions of temperature and density, such as the quark-gluon plasma. Among the several possibilities, the study of jet quenching - generic name given to in-medium energy loss modifications of the parton branching - is a powerful tool to assess the properties of this new state of matter. The description of the parton shower is very well understood in vacuum (controlled reference) and medium-induced modifications of this process can be experimentally accessed through jet measurements. Current experimental data, however, cannot be entirely explained only with energy loss phenomena. Transverse momentum broadening and decoherence effects, both theoretically established by now, are necessary to fully explain the current jet-related observables. Nonetheless, the interplay between these phenomena is essential to build a consistent picture of the medium-modifications of the parton branching and to achieve a correct description of the current experimental data. In this talk, I will present the latest developments that address such unified description

Wednesday Afternoon / 23

## $\pi\eta$ photoproduction on the nucleon

**Author:** Lukasz Bibrzycki<sup>1</sup>

**Co-author:** Kaminski Robert <sup>2</sup>

<sup>1</sup> *Pedagogical University of Cracow*

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We present the Born amplitudes for the  $\pi\eta$  photoproduction on the nucleon. These amplitudes and the corresponding partial wave amplitudes are essential for the description of the photoproduction of isovector resonances with masses below 2 GeV. Some of these resonances, in particular  $a_0(980)$  and  $a_0(1450)$  are believed to have a substantial molecular admixture. These molecular states can be effectively described in terms of the final state interactions. The model can also be applied to the photoproduction of the elusive  $\pi_1(1400)$  meson which decays to the  $\pi\eta$  system.

Monday Afternoon / 19

## Unquenching the three-gluon vertex

**Author:** Adrian Lorenz Blum<sup>1</sup>

**Co-authors:** Markus Huber <sup>1</sup>; Reinhard Alkofer <sup>1</sup>

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The Dyson-Schwinger equation for the three-gluon vertex in Landau gauge is solved without and with the quark triangle included. Hereby we concentrate on quarks in the chiral limit and discuss implications of our findings for the quark-gluon vertex.

**Thursday Afternoon / 9**

## Deconfinement in dense (two-color) matter

**Author:** Tomas Brauner<sup>1</sup>

<sup>1</sup> *Vienna University of Technology*

I will review our current understanding of the phase diagram of two-color quark matter with emphasis on the comparison of model and lattice results. Reproducing even *qualitatively* the thermodynamic observables measured on the lattice requires augmenting the standard Polyakov loop Nambu-Jona-Lasinio model with two new elements: renormalization of the Polyakov loop, and explicit chiral symmetry breaking in the contact interaction. Finally, I will argue how the lattice data for the Polyakov loop expectation value in cold and dense two-color matter may be used to improve existing models of the real, three-color world.

**Monday Morning / 36**

## Ultra-relativistic light-heavy nuclear collisions and collectivity

**Author:** Wojciech Broniowski<sup>1</sup>

**Co-authors:** Enrique Ruiz Arriola <sup>2</sup>; Piotr Bozek

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I will talk about collective aspects in theoretical description of ultra-relativistic p-A, d-A, and 3He-A (A is a heavy nucleus) collisions, where recent measurements have been carried out at RHIC and the LHC. I will also show predictions for 12C-A reactions, where the harmonic flow patterns are sensitive to the deformation of the 12C ground-state wave function, thus offering a new probe of the lowest-energy nuclear dynamics.

**Tuesday Afternoon / 21**

## The $\pi\pi$ scattering amplitude and the $\sigma$ meson

**Author:** Petr Bydzovsky<sup>1</sup>

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We constructed the multichannel  $\pi\pi$  amplitudes in the S- and P-waves which satisfactorily describe the  $\pi\pi$  scattering data [1]. In the construction we have utilized the uniformizing variable and formulas for analytical continuation of the S-matrix elements to all sheets of the Riemann surface but we did not fully include the constraint on the crossing symmetry which is especially important in the S wave. We modified, therefore, the amplitudes using the once-subtracted dispersion relations with imposed crossing symmetry (the GKPY equations [2]) to get amplitudes consistent also with the crossing symmetry [3]. The most pronounced changes of parameters of the amplitudes due to the modification will be presented and discussed, particularly a position of the  $\sigma$ -meson pole (the  $f_0(500)$  resonance).

1. Yu.S. Surovtsev, P. Bydovskiy, R. Kamiński, M. Nagy: Phys. Rev. D 81 (2010) 016001.
2. R. Garcia-Martín, R. Kamiński, J.R. Peláez, J. Ruiz de Elvira, F.J. Ynduráin: Phys. Rev. D 83 (2011) 074004.
3. P. Bydovskiy, R. Kamiński, V. Nazari: Phys. Rev. D 90 (2014) 116005.

**Tuesday Morning / 18**

## The anomalous magnetic moment of the muon from lattice QCD

**Author:** bipasha chakraborty<sup>1</sup>

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The anomalous magnetic moment of the muon, defined as the fractional difference of its gyromagnetic ratio from the naive value of 2, has been measured with an impressive accuracy of 0.54 parts per million in experiment (BNL E821), thus providing one of the most stringent tests of the Standard Model. Intriguingly, the experimentally measured anomaly disagrees by around 3 standard deviations with the calculated value from the Standard Model. The current theoretical uncertainty is dominated by that from the calculation of the lowest order “hadronic vacuum polarisation (HVP)”. Improvements in the experimental uncertainty by a factor of 4 in the upcoming experiment at Fermilab (E989) are expected and improvements in the theoretical determination would make the discrepancy (if it remains) really compelling in trying to ascertain the possibility of new physics beyond the Standard Model. I will report on progress (Phys. Rev. D 89, 114501 (2014)) and plans for improving the theoretical calculation of the HVP contribution to the anomaly using our (HPQCD) new lattice QCD method.

**Wednesday Morning / 26**

## Some new insights into confinement

**Author:** Thomas Cohen<sup>1</sup>

<sup>1</sup> *University of Maryland*

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This talk reviews some recent progress in making sense of confinement. The focus of the talk is on cousins of QCD, rather than QCD itself; these cousin theories have features lacking in QCD which facilitate the analysis. One critical feature of this sort is center symmetry, and the core of the talk is an exploration of the connection of center symmetry to confinement. One principal way to gain insight into this connection is via the study of gauge theories in which matter fields destroy invariance under the full center of the group but preserve a nontrivial subgroup. A second way to gain insight is via a study role of center symmetry in the limit where the number of colors goes to infinity. The large  $N_c$  limit is useful as a tool due to its tractability.

**Tuesday Morning / 35**

## Universality of the hard-loop action

**Author:** Alina Czajka<sup>1</sup>

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The effective actions of gauge bosons, fermions and scalars, which are obtained within the hard-loop approximation, are shown to have unique forms for a whole class of gauge theories including QED, scalar QED, super QED, pure Yang-Mills, QCD, super Yang-Mills. The universality occurs irrespective of a field content of each theory and of variety of specific interactions. Consequently, the long-wavelength or semiclassical features of plasma systems governed by these theories such as collective excitations are almost identical. An origin of the universality, which holds within the limits of applicability of the hard-loop approach, is discussed.

**Monday Morning / 2**

## The role of the kinematical constraint and non-linear effects in the CCFM equation

**Authors:** Krzysztof Kutak<sup>1</sup>; Michal Deak<sup>2</sup>

<sup>1</sup> *Instytut Fizyki Jądrowej Polskiej Akademii Nauk*

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The importance of application of the kinematical constraint on the evolution of unintegrated parton density functions in the BFKL formalism was studied in recent publications. In this talk we focus on the role of the kinematical constraint in the CCFM equation and its non-linear extension. We compare numerical results obtained by solving the CCFM equation and argue that kinematical constraint represents an important correction.

**Wednesday Morning / 24**

## Simulations at fixed topology: fixed topology versus ordinary finite volume corrections



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Lattice QCD simulations tend to become stuck in a single topological sector at fine lattice spacing, or when using chirally symmetric overlap quarks. In such cases computed observables differ from their full QCD counterparts by finite volume corrections, which need to be understood on a quantitative level. We discuss extensions of existing relations from the literature between correlation functions at fixed topology and hadron masses at unfixed topology including parity mixing. Particular focus is put on combining topological finite volume effects with ordinary finite volume effects. Numerical results for SU(2) Yang-Mills Theory will be presented

**Tuesday Afternoon / 11**

## **Scalar meson $f_0(500)$ from the analysis of pion scalar form factor and the correct S-wave isoscalar $\pi\pi$ phase shift data**

**Author:** Stanislav Dubnicka<sup>1</sup>

**Co-authors:** Anadrej Liptaj<sup>1</sup>; Anna Zuzana Dubnickova<sup>2</sup>; Kaminski Robert<sup>3</sup>

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In the recently elaborated fully solvable mathematical problem to be concerned of a finding of an explicit form of the pion scalar form factor the inaccurate experimental information in the elastic region on the S-wave isoscalar  $\pi\pi$  phase shift, is replaced by the data with theoretical errors to be generated by the Garcia-Martin-Kaminski-Pela'ez-Yndurain Roy-like equations and as a result the most precise parameters of the  $f_0(500)$  scalar meson are determined in the framework of the pion scalar form factor analysis.

**Wednesday Afternoon / 38**

## **Tetraquark bound states in a Bethe-Salpeter approach**

**Author:** Gernot Eichmann<sup>None</sup>

**Co-authors:** Christian Fischer<sup>1</sup>; Walter Heupel<sup>2</sup>

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I will present results for tetraquark masses in the covariant Dyson-Schwinger/Bethe-Salpeter approach. We study two setups: in the first one, the system is simplified to a coupled diquark/antidiquark-meson/meson equation. In the second case we solve a genuine four-body equation where quarks interact via gluon exchange. In both cases we find a light scalar-isoscalar state in the  $\sim 500$  MeV region. The second approach is especially interesting because no meson or diquark ingredients appear in the equation. However, one can exploit the properties of the permutation group  $S_4$  to isolate the phase space domains that are influenced by pion poles in unphysical regions. If these kinematic domains are excluded by hand, the mass goes up to 1.5-2 GeV, as one might expect for a four-quark state without further non-trivial dynamics. These results suggest that the  $\sigma/f_0(500)$  is a four-quark bound state that is strongly dominated by pion-pion components. The masses of the remaining multiplet members,  $\kappa$  and  $a_0/f_0$ , behave similarly.

**Friday Afternoon / 1**

## A QCD Vacuum of Center Vortices

**Author:** Manfred Faber<sup>1</sup>

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We present evidence why center vortices are a complete model of quark confinement and how they break chiral symmetry, thus unifying these non-perturbative phenomena of the QCD vacuum in a common framework.

**Monday Morning / 16**

## A new hydrodynamic model using an exact Riemann solver

**Author:** Zuzana Feckova<sup>None</sup>

**Co-author:** Boris Tomasik<sup>1</sup>

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Hydrodynamic modeling of quark-gluon plasma requires sophisticated numerical schemes that have low numerical viscosity and are able to cope with high gradients of energy density that may appear in initial conditions. We propose to use the Godunov method with an exact Riemann solver for ideal hydrodynamic modeling to meet these conditions. We present the results of numerical tests of the method, such as the sound wave propagation and the shock tube problem, which show both high precision of the method and low numerical viscosity.

**Friday Afternoon / 30**

## Hadron Spectroscopy with CLAS and CLAS12

**Author:** Derek Glazier<sup>1</sup>

<sup>1</sup> *University of Glasgow*

Investigating the spectrum of hadrons provides many interesting topics and helps to validate QCD as the underlying mechanism behind the strong interaction. In recent years photoproduction data has added to the wealth of data that can be used to determine the existence and properties of hadronic states. The real photon beam in Hall B at Jefferson Lab is providing particularly rich data due to its range of energy, high intensity and large acceptance CLAS spectrometer for detecting particles produced in the final state. Currently, the data produced have been largely focussed on baryon resonance production, but with the recent beam energy upgrade mesonic states will become much more accessible. As a result the MesonEx experiment at CLAS12 will supplement the planned spectrometer with a quasi-real photon tagger to provide a high yield of mesonic states produced with an effectively linearly polarised photon beam. While the hardware for this experiment is currently under construction effort is being put into preparing a suitable data and amplitude analysis framework through the HASPECT collaboration.

**Friday Afternoon / 20**

## Effects of scalar mesons in a skyrmion model with the hidden local symmetry

**Author:** Bing-Ran He<sup>1</sup>

<sup>1</sup> *Nagoya Univ.*

We construct a skyrmion model including a two-quark and a four-quark scalar mesons as well as the pion, rho and omega mesons within a framework of the hidden local symmetry. We investigate the effects of scalar mesons in the model, we show that the scalar mesons reduce the skyrmion mass.

**Friday Morning / 6**

## Dyson-Schwinger studies of Yang-Mills vertices at zero and non-vanishing temperatures

**Author:** Markus Huber<sup>1</sup>

**Co-authors:** Anton Cyrol<sup>2</sup>; Lorenz von Smekal<sup>3</sup>

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Green functions are useful quantities whose applications in quantum chromodynamics range from bound state calculations to investigations of the phase diagram. Obtaining them from functional equations faces the challenge of devising a proper truncation scheme. I will report on recent progress to determine the correlation functions of pure QCD in the vacuum and at non-zero temperature from Dyson-Schwinger equations. Results for two-, three- and four-point functions were obtained that hint at favorable convergence properties of the system. This helps to establish functional equations as a first principles method in QCD.

**Monday Afternoon / 39**

## Hydrodynamics of QCD

**Author:** Pasi Huovinen<sup>1</sup>

<sup>1</sup> *Johann Wolfgang Goethe-Universität*

In this talk I will review the use of hydrodynamics to model heavy-ion collisions at ultrarelativistic energies, and what such modeling has taught us about the properties of QCD matter.

**Thursday Afternoon / 33**

## Overview of the Run 1 Higgs Boson Physics Results at ATLAS

**Author:** Jelena Jovicevic<sup>1</sup>

<sup>1</sup> *TRIUMF (CA)*

**Corresponding Author:** jelena.jovicevic@cern.ch

TBA

**Wednesday Morning / 27**

## Phase diagram of QCD with Complex Langevin simulations

**Author:** Benjamin Jäger<sup>1</sup>

<sup>1</sup> *Swansea University*

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Simulations with a finite chemical potential typically lead to a severe sign problem, prohibiting any standard Monte Carlo approach. For simulations of QCD we use the complex Langevin method, for which we apply adaptive step-sizes and gauge cooling to ensure the convergence. We present preliminary results for heavy quark QCD and explore the application for two dynamical quarks.

**Friday Afternoon / 7**

## Perspectives of charmonium spectroscopy at PANDA

**Author:** Anastasia Karavdina<sup>1</sup>

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The new Facility for Antiproton and Ion Research (FAIR) is under construction at GSI in Darmstadt (Germany). The PANDA experiment is one of the major projects in preparation at the FAIR. In this

experiment an antiproton beam in the momentum range from 1.5 to 15 GeV/c will be exploited to address a wide range of topics in Hadron Spectroscopy, Nucleon Structure, Hadrons in Matter and Hypernuclei Physics. The coverage of a such broad range of different aspects of QCD is possible due to the multi-purpose PANDA detector in combination with an intense and high quality anti-proton beam.

In this talk, in addition to presentation of the facility and the detector, an overview of the PANDA physics program will be given, with focus on the unique capabilities for performing studies in the field of charmonium spectroscopy.

**Tuesday Afternoon / 12**

## **Recent results on charmonium-like states at BESIII**

**Author:** Myroslav Kavatsyuk<sup>1</sup>

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Despite the successes of the Standard Model, the QCD-based nature of the strong interaction is insufficiently understood. Charmonium spectroscopy is an ideal tool to provide insight into the non-perturbative dynamics of the strong force. It provides rigorous guidelines to various theoretical approaches, thereby, gaining insight into quark confinement and the formation of hadronic matter. The charmonium system has been systematically studied with the BESIII spectrometer operated at the BEPCII electron-positron collider at IHEP Beijing, China. The world's largest data set of charmonium states produced at the  $J/\psi$ ,  $\psi'$  and  $\psi''$  masses, allows precision studies of hadronic states. Moreover, systematic measurements in the mass range between 3.85 and 4.6 GeV/c<sup>2</sup> opened up the possibility of studying "X, Y, Z" states. These measurements recently resulted in the discovery of indisputable examples of multi-quark hadrons in the charmonium mass regime. A complete understanding of the properties of these unconventional charmonium-like states will give insight into the dynamics of the strong force. In particular a systematic study of the various decay modes of these states and their excitation pattern will potentially reveal their dynamics. During the presentation, I will present a few highlights of the most recent BESIII results.

**Monday Afternoon / 37**

## **Chiral phase transition scenarios from the vector meson extended Polyakov quark meson model**

**Author:** Peter Kovacs<sup>1</sup>

<sup>1</sup> *Wigner RCP*

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Chiral phase transition is investigated in a  $SU(3)_L \times SU(3)_R$  symmetric vector meson extended linear sigma model with additional constituent quarks and Polyakov loops (extended Polyakov quark meson model). The parameterization of the Lagrangian is done at zero temperature in a hybrid approach, where the mesons are treated at tree-level, while the constituent quarks at 1-loop level. The temperature and baryochemical potential dependence of the two assumed scalar condensates are calculated from the hybrid 1-loop level equations of states. The order of the phase transition along the  $T=0$  and  $\mu_B=0$  axes are determined for various parameterization scenarios. We find that in order to have a first order phase transition at  $T=0$  as a function of  $\mu_B$  a light isoscalar particle is

needed. We also investigate the  $T/\mu_B$  dependence of the scalar meson curvature masses, where the exact fermion contribution to the masses are taken into account.

**Tuesday Morning / 32**

## A Simple Model for the Glasma

**Author:** Larry McLerran<sup>1</sup>

<sup>1</sup> *BNL*

I discuss a simple description of the distribution of quarks and gluons in the Glasma. This is motivated by transport equation for over occupied systems.

**Thursday Morning / 10**

## Latest results on anisotropy in pPb and PbPb collisions from CMS

**Author:** Jovan Milosevic<sup>1</sup>

<sup>1</sup> *Vinca Institute of Nuclear Sciences (VINCA)*

In this talk we present some of the heavy-ion results from CMS, restricting on anisotropic particle emission. Consistency between the results obtained using four-, six and eighth-particle correlation as well as the Lee-Yang zero method reveals a multi-particle nature of the long-range correlations observed in pPb collisions. By correlating an identified strange hadron ( $K_S^0$  or  $\Lambda/\bar{\Lambda}$ ) with a charged particle, at large relative pseudorapidity, the magnitude of the elliptic and triangular flow of strange particles from both pPb and PbPb collisions have been extracted. The results for  $K_S^0$  and  $\Lambda/\bar{\Lambda}$  scaled by the number of constituent quarks as a function of transverse kinetic energy per quark are in a mutual agreement (within 10%) for both  $v_2$  and  $v_3$  over a wide range of particle transverse kinetic energy and event multiplicities. Due to the initial-state fluctuations, the event-plane angle depends on both, transverse momentum ( $p_T$ ) and pseudorapidity ( $\eta$ ), which consequently induce breaking of the factorization of the two-particle azimuthal anisotropy into a product of single-particle anisotropies. For  $p_T$ , maximal effect of factorization breaking of about 20% is observed in ultra-central PbPb collisions. For  $\eta$ , the effect is weakest for mid-central PbPb events and gets larger for more central or peripheral PbPb collisions as well as for high multiplicity pPb collisions. The experimental results are consistent with recent hydrodynamic predictions in which the factorization breakdown effect is incorporated. It is found that the effect is mainly sensitive to the initial-state conditions rather than the shear viscosity of the medium.

**Wednesday Afternoon / 34**

## Heavy ions at the LHC

**Author:** Andre Mischke<sup>1</sup>

<sup>1</sup> *Utrecht University (NL)*

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Ultra-relativistic collisions of heavy ions allow studying strongly interacting matter at extreme energy densities and temperatures. Quantum-Chromodynamics predicts that at such conditions normal, hadronic matter turns into a plasma of deconfined quarks and gluons, which are the constituents of atomic nuclei. In cosmology, it is believed that matter in the early universe must have existed in this Quark-Gluon Plasma (QGP) state within the first microseconds after the Big Bang. After the compelling evidence for the existence of the QGP from the previous heavy-ion accelerators SPS and RHIC, the Large Hadron Collider (LHC) at CERN marks the beginning of the exploration the QGP properties. In this contribution, I will present an overview of the recent results from the LHC and discuss them in relation to the previous findings.

**Friday Morning / 42**

## Search for the exotic matter at low energies

**Author:** Pawel Moskal<sup>1</sup>

<sup>1</sup> *Jagiellonian University*

The talk will be divided into two parts.

We will discuss

- (i) the search for the new kind of nuclear matter in the form of the mesic-nuclei, and
- (ii) the discovery of the di-baryon state with the WASA detector at COSY

**Friday Afternoon / 43**

## Status of FAIR

**Author:** Diana Nicmorus<sup>1</sup>

<sup>1</sup> *Facility for Antiproton and Ion Research*

The new international accelerator facility FAIR under construction in Darmstadt aims at studying matter at atomic, nuclear, and hadronic levels. I will review different aspects of the current status of the Facility for Antiproton and Ion Research. I will present the focus of the experimental programmes at FAIR, with highlight on open questions addressed by developments in hadron physics, nuclear structure and compressed nuclear matter physics, plasma and atomic physics, as well as related applications.

**Monday Morning / 41**

## Holographic Scalar and Tensor Glueballs

**Author:** Denis Parganlija<sup>None</sup>

Glueballs are expected to emerge in the non-perturbative region of QCD building an abundant spectrum with already established states (quarkonia) and those whose identification is still elusive (tetraquarks, molecular and exotic states and others). I present a top-down holographic approach, featuring one free parameter and an overall scale, that allows for calculation of mass spectra in the scalar and tensor (as well as other) glueball channels. In addition, decay rates in  $2\pi$ ,  $2\rho$  and various

other channels are presented, together with a discussion of experimental uncertainties hampering a clear identification of glueballs even after decades of research.

**Thursday Afternoon / 40**

## **Non-ordinary meson couplings in the $1/N_c$ expansion**

**Author:** Jose R. Pelaez<sup>1</sup>

<sup>1</sup> *Universidad COmplutense*

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We study the large  $N_c$  behavior of couplings among light meson states with different compositions in terms of quarks and gluons. We shortly review the most common compositions of mesons, which are of interest for the understanding of low-lying meson resonances, namely, the ordinary quark-antiquark states as well as the non-ordinary, glueball, tetraquark, etc. We dedicate special attention to Jaffe's generalization of the tetraquark with  $N_c-1$  quark-antiquark pairs, that is the only type of state we have identified, whose width does not necessarily vanish with large  $N_c$  while it does decouple exponentially with  $N_c$  from the pion-pion channel, so that is weakly coupled to the meson-meson system. (see arXiv:1405.4831, Phys.Rev. D90 (2014) 3, 036003)

**Wednesday Morning / 29**

## **Saturation and geometrical scaling: from DIS to HI**

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Saturation of gluon distribution is a consequence of non-linear evolution equations of QCD. Saturation implies the existence of so called saturation momentum which is gluon density per unit rapidity per transverse area. At large energies for certain kinematical domains saturation momentum is the only scale for physical processes. As a consequence different observables exhibit so called geometrical scaling (GS). We shall discuss a number of examples of GS and its violation in different reactions.

**Thursday Morning / 28**

## **Quark properties from the Hadron Resonance Gas**

**Author:** Enrique Ruiz Arriola<sup>1</sup>

**Co-authors:** Eugenio Megias<sup>2</sup>; Lorenzo Luis Salcedo<sup>1</sup>

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This work is based on our recent works

1) Quark Hadron Duality at Finite Temperature

By E. Ruiz Arriola, L.L. Salcedo, E. Megias.

arXiv:1410.3869 [hep-ph].

10.5506/APHysPolB.45.2407.

Acta Phys.Polon. B45 (2014) 2407.

2) Polyakov loop spectroscopy in the confined phase of gluodynamics and QCD

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1409.0773 [hep-ph].

3) Polyakov loop in various representations in the confined phase of QCD

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1311.2814 [hep-ph].

10.1103/PhysRevD.89.076006.

Phys.Rev. D89 (2014) 7, 076006.

4) Polyakov loop, Hadron Resonance Gas Model and Thermodynamics of QCD

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1310.3079 [hep-ph].

10.1063/1.4901767.

AIP Conf.Proc. 1625 (2014) 73-79.

5) Constituent Quarks and Gluons, Polyakov loop and the Hadron Resonance Gas Model ,

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1307.7523 [hep-ph].

10.1051/epjconf/20146604021.

EPJ Web Conf. 66 (2014) 04021.

6) Excited Hadrons, Heavy Quarks and QCD thermodynamics

By E. Ruiz Arriola, L.L. Salcedo, E. Megias.

arXiv:1304.2245 [hep-ph].

10.5506/APHysPolBSupp.6.953.

Acta Phys.Polon.Supp. 6 (2013) 3, 953-958.

7) The Hadron Resonance Gas Model: Thermodynamics of QCD and Polyakov Loop

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1207.7287 [hep-ph].

10.1016/j.nuclphysbps.2012.12.039.

Nucl.Phys.Proc.Suppl. 234 (2013) 313-316.

8) From Chiral quark dynamics with Polyakov loop to the hadron resonance gas model

By E. Ruiz Arriola, E. Megias, L.L. Salcedo.

arXiv:1207.4875 [hep-ph].

10.1063/1.4795954.

AIP Conf.Proc. 1520 (2013) 185-190.

9) The Polyakov loop and the hadron resonance gas model

By E. Megias, E. Ruiz Arriola, L.L. Salcedo.

arXiv:1204.2424 [hep-ph].

10.1103/PhysRevLett.109.151601.

Phys.Rev.Lett. 109 (2012) 151601.

**Summary:**

We show how quark properties can be determined from the Hadron Resonance Gas model below the de-confinement phase transition. This makes use of Quark-Hadron duality necessitating a tower of excited states and poses the interesting problem of identification of degrees of freedom at increasing temperatures, as well as the relevance of string breaking.

**Thursday Morning / 5**

## **Dilepton production from the quark-gluon plasma using (3+1)-dimensional anisotropic dissipative hydrodynamics**

**Author:** Radoslaw Ryblewski<sup>1</sup>

<sup>1</sup> *Institute of Nuclear Physics PAS*

**Corresponding Author:** radoslaw.ryblewski@ifj.edu.pl

We compute dilepton production from the deconfined phase of the quark-gluon plasma using leading-order (3+1)-dimensional anisotropic hydrodynamics. The anisotropic hydrodynamics equations employed describe the full spatiotemporal evolution of the transverse temperature, spheroidal momentum-space anisotropy parameter, and the associated three-dimensional collective flow of the matter. The momentum-space anisotropy is also taken into account in the computation of the dilepton production rate, allowing for a fully self-consistent description of dilepton production from the quark-gluon plasma. For our final results, we present predictions for high-energy dilepton yields as a function of invariant mass, transverse momentum, and pair rapidity. We demonstrate that high-energy dilepton production is extremely sensitive to the assumed level of initial momentum-space anisotropy of the quark-gluon plasma. As a result, it may be possible to experimentally constrain the early-time momentum-space anisotropy of the quark-gluon plasma generated in relativistic heavy ion collisions using high-energy dilepton yields.

### **Summary:**

Based on :R.Ryblewski, M.Strickland, forthcoming

**Tuesday Afternoon / 14**

## **Is the spacetime Euclidean inside the hadrons?**

**Author:** Vladimir Sauli<sup>1</sup>

<sup>1</sup> *Nuclear Institute Rez near Prague*

**Corresponding Author:** sauli@ujf.cas.cz

Solution of Schwinger-Dyson and Bethe-Salpeter Equations for excited and ground state pions will be presented. The quark gap equation has been solved directly in our Minkowski space-time and the solution, according to confinement, does not allow a free quark propagation. The Minkowski space solution for confining QCD as will be shown, is not only numerically accessible, but also provides a reasonable description of the pseudoscalar meson system. An unknown and unusual features of confinement in Minkowski space will be discussed for unobservable QCD Greens function as well as the implication for observables will be mentioned. The question in the title will not be answered by the speaker.

**Tuesday Morning / 22**

## **Refined lattice/model investigation of $u d \bar{b} \bar{b}$ tetraquark candidates with heavy spin effects taken into account**

**Author:** Jonas Benedict Scheunert<sup>1</sup>

**Co-authors:** Marc Wagner <sup>2</sup>; Pedro Bicudo <sup>3</sup>

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We investigate four-quark systems consisting of two heavy anti-bottom quarks and two light up/down quarks. To this end we solve a coupled Schrödinger equation for the anti-bottom-anti-bottom separation using potentials computed via lattice QCD in the limit of static anti-bottom quarks. This coupled Schrödinger equation allows to incorporate effects due to the heavy anti-bottom spins.

**Friday Morning / 25**

## A short review of some double-parton scattering processes

**Author:** Antoni Szczurek<sup>1</sup>

<sup>1</sup> *Institute of Nuclear Physics*

We review double parton scattering (DPS) effects in three selected reactions: production of  $c\bar{c}\bar{c}$ , production of jets with large rapidity distance and  $W^+W^-$  production.

We present QCD leading-order predictions for energy dependence of  $c\bar{c}\bar{c}$  production.

The DPS cross section for  $c\bar{c}\bar{c}$  grows faster than that for  $c\bar{c}$  production.

This is generalized to include higher-order corrections within  $k_t$ -factorization approach with unintegrated gluon distributions. Hadronization of  $c$ -quarks to  $D$ -mesons is taken into account in the fragmentation function formalism.

Several differential distributions for two  $D$  mesons, both containing  $c$  quark or both containing  $\bar{c}$  antiquark, are presented and compared to the LHCb collaboration data.

The results of double-parton scattering are compared with those of single-parton scattering.

We discuss also multiple  $c\bar{c}$  production in the impact parameter space.

We discuss contribution of double-parton scattering to production of jets with large rapidity distance.

We compare contribution of DPS with those from the BFKL Mueller-Navelet jets and with results of the  $k_t$ -factorization.

We discuss how the DPS effect could be verified when studying four-jet sample.

Finally we discuss DPS production of two vector gauge bosons.

We show results and discuss how the DPS contribution could be identified when looking at leptons from the decay of the gauge bosons.

**Thursday Afternoon / 31**

## Latest developments in anisotropic hydrodynamics

**Author:** Leonardo Tinti<sup>1</sup>

<sup>1</sup> *Jan Kochanowski University*

In ultrarelativistic heavy-ion collisions nuclear matter is heated to a temperature exceeding that necessary to create a quark-gluon plasma (QGP). Traditionally, second order viscous hydrodynamics has been used to reproduce the soft collective flow of the QGP and hadronic spectra; however, due to rapid longitudinal expansion in the early stages of evolution, the system may possess substantial pressure anisotropies which are a consequence of large viscous corrections.

These large corrections violate the viscous hydrodynamics assumption of small deviation from local equilibrium. They may lead to unphysical results, and, comparing to the exact 0+1 solutions of the Boltzmann equation, they often badly reproduce the longitudinal pressure (especially for initial stages) and provide the wrong asymptotic behavior.

In order to more accurately treat systems possessing large pressure anisotropies, a new approach called anisotropic hydrodynamics was recently developed. In this approach, the pressure anisotropy is treated non-perturbatively at leading order in the hydrodynamic expansion. This allows one to match with second order viscous hydrodynamics in the close to equilibrium limit and to also have a striking agreement with the exact solution for large anisotropies. I am presenting the latest formulation of leading-order anisotropic hydrodynamics which uses (1) an ellipsoidal ansatz for the underlying distribution function, allowing non trivial transverse dynamics; and (2), dynamical equations resulting from the second moment of the Boltzmann equation.

### References

- [1] L. Tinti and W. Florkowski, Projection method and new formulation of leading-order anisotropic hydrodynamics, arXiv:1312.6614.
- [2] W. Florkowski, R. Ryblewski, L. Tinti, and M. Strickland, Leading-order anisotropic hydrodynamics for systems with massive particles, arXiv:1403.1223.
- [3] L. Tinti, (3+1)-dimensional framework for leading-order non conformal anisotropic hydrodynamics, arXiv:1411.726

**Wednesday Afternoon / 15**

## Flow anisotropies due to momentum deposition from hard partons

**Author:** Boris Tomasik<sup>1</sup>

**Co-author:** Martin Schulc<sup>2</sup>

<sup>1</sup> *Univerzita Mateja Bela (SK)*

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Anisotropies of transverse expansion flow in ultrarelativistic nuclear collisions are nowadays precisely measured and potentially carry important information about the transport properties of hot deconfined matter. In order to extract this information reliably from data analysis one must take into account other effects which can cause flow anisotropies. Hard partons, produced copiously at the LHC, deposit their energy and momentum into quark-gluon plasma. We show, that since there may be a multitude of them in one event, this mechanism contributes visibly to all orders of flow anisotropies.

Monday Afternoon / 17

## The latest STAR results on quarkonium production

**Author:** Barbara Trzeciak<sup>1</sup>

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The suppression of quarkonium production in high energy heavy-ion collisions relative to proton-proton collisions due to color screening was proposed as a signature of Quark-Gluon Plasma formation. Studies of quarkonium production in nuclear collisions can provide insight into the thermodynamic properties of the hot and dense medium created in relativistic heavy-ion collisions at RHIC. However, there are other effects that may affect the observed yields and complicate this simple picture, such as cold nuclear matter effects or recombination. Measurements of the quarkonium production and elliptic flow ( $v_2$ ) in different colliding systems, centralities and collision energies may help to systematically understand their production mechanisms and interactions with nuclear matter.

In this talk, recent STAR quarkonium measurements will be highlighted. We will present  $J/\psi$  and  $\Upsilon$  studies via the dielectron decay channel at various colliding systems and energies. Energy dependence of  $J/\psi$  production in Au+Au collisions at  $\sqrt{s_{NN}} = 39, 62.4$  and 200 GeV and in U+U collisions at  $\sqrt{s_{NN}} = 193$  GeV will be shown.  $\Upsilon$  production will be reported in  $p + p$ ,  $d+Au$  and Au+Au collisions at  $\sqrt{s_{NN}} = 200$  and in U+U collisions at  $\sqrt{s_{NN}} = 193$  GeV. We will also present  $J/\psi$   $v_2$  results in Au+Au collisions at  $\sqrt{s_{NN}} = 200$  GeV and the first  $\psi(2S)$  to  $J/\psi$  ratio measurement in  $p + p$  collisions at  $\sqrt{s} = 500$  GeV. Moreover, prospects of quarkonium measurements with the newly upgraded STAR detector will be reported.

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## Probing QCD at HERA

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Measurements of ep collisions at HERA which probe and constrain QCD are presented from the H1 and ZEUS Collaborations. The HERA combined measurements of the inclusive deep inelastic scattering cross sections provide the strongest constraint of the structure of the proton. High-precision jet cross sections are presented which allow a world-competitive measurement of the strong coupling constant. The structure of the proton is also constrained through measurements of heavy-quark production which are sensitive to the gluon and heavy-quark content of the proton; the measurements also allow extractions of the heavy-quark masses. The nature of diffractive processes is still poorly understood and new measurements both in inclusive and exclusive final states aim to shed more light on the subject. A review of the current status of probes of QCD at HERA will be presented and open issues highlighted.

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## Opening of eQCD 2015 talks

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## **Closing of eQCD 2015 talks**