XXXIII International (ONLINE) Workshop on High Energy Physics ”Hard Problems of Hadron Physics: Non-Perturbative QCD & Related Quests”

Monday 08 November 2021 - Friday 12 November 2021

Book of Abstracts

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(Fabian Rennecke is not able to give a talk due to illness but uploaded pdf if you are interested) Moat Regimes and their Signatures in Heavy-Ion Collisions

Fabian Rennecke[1] ; Robert D. Pisarski[2]

[1] *Justus Liebig University Giessen*

[2] *Brookhaven National Laboratory*

Corresponding Author(s): pisarski@bnl.gov, fabian.rennecke@theo.physik.uni-giessen.de

Dense QCD matter can exhibit spatially modulated regimes. They can be characterized by particles with a moat spectrum, where the minimum of the energy is over a sphere at nonzero momentum. Such a moat regime can either be a precursor for the formation inhomogeneous condensates, or signal a quantum pion liquid. We introduce the quantum pion liquid and discuss the underlying physics of the moat regime based on studies in low-energy models and preliminary results in QCD. Heavy-ion collisions at small beam energies have the potential to reveal the rich phase structure of QCD at low temperature and nonzero density. We show how moat regimes can be discovered through such collisions. Particle production is enhanced at the bottom of the moat, resulting in a peak at nonzero momentum, instead of zero, in the particle spectrum. Particle number correlations can even increase by several orders of magnitude at nonzero momentum in the moat regime.

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A lattice QCD view of the hadronic contributions to the anomalous magnetic moment of the muon

Harvey Meyer[1]

[1] *Johannes Gutenberg University Mainz*

The recent confirmation of the Brookhaven measurement of the anomalous magnetic of the muon by the Fermilab g-2 experiment has increased the tension with the theory prediction for g-2 compiled in a 2020 White Paper. The uncertainty of the theory prediction is entirely dominated by the hadronic vacuum polarisation (HVP) and the hadronic light-by-light (HLbL) contributions. I review the status of the lattice QCD based calculations of these contributions.

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Abelian monopoles of the Dirac type and color confinement in QCD

Tsuneo Suzuki[1] ; Ishiguro Katsuya[2]

[1] *Research Center for Nuclear Physics, Osaka University*

[2] *Library and Information Technology, Kochi University,*

Corresponding Author(s): ishiguro@kochi-u.ac.jp, suzuki0526@gmail.com

When non-Abelian gauge fields in SU(3) QCD have a line-singularity leading to non-commutativity with respect to successive partial-derivative operations, the non-Abelian Bianchi identity is violated. The violation as an operator is shown to be equivalent to violation of the Abelian-like Bianchi identities. Then there appear eight Abelian-like conserved magnetic monopoles of the Dirac type in SU(3) QCD. Using lattice Monte-Carlo simulations, perfect Abelian and monopole dominances are shown to exist upon this idea when we define lattice Abelian-like monopoles following the DeGrand-Toussaint method adopted in the study of the Dirac monopole in lattice compact QED. The Abelian dual Meissner effect around a pair of static quark and antiquark is caused by the solenoidal Abelian monopole current. The continuum limit of the lattice monopoles is proved with the help of the block-spin renormalization group study.

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Anomalies for anomalous symmetries

Avner Karasik[1]

[1] *Department of Applied Mathematics and Theoretical Physics University of Cambridge*

4d gauge theories with massless fermions typically have axial U(1) transformations that suffer from the ABJ anomaly. One can modify the theory of interest by adding more fields in a way that restores the axial symmetry, and use it to derive rigorous ’t-Hooft anomaly matching conditions. These conditions are not valid for the original theory of interest, but for the modified theory. We show that the modification can be done in a specific way that allows us to relate the dynamics of the modified theory to the dynamics of the original theory. In this way, the anomaly matching conditions of the modified theory can be used to learn new things on the original theory even though they involve axial transformations which are not a symmetry of the original theory.
We describe this method and discuss some applications to various examples.

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Applying machine learning methods to prediction problems of lattice observables

Nikolai Gerasimeniuk[1] ; Alexander Molochkov[1] ; Maxim Chernodub[2] ; Vladimir Goy[1] ; Sergei Liubimov[1] ; Denis Boyda[1]

[1] *FEFU*

[2] *University Of Tours*

Corresponding Author(s): gerasimenyuk_nv@dvfu.ru

This talk is devoted to machine learning methods applied to predict the critical behavior of lattice observables, in particular at the confinement / deconfinement phase transition in SU (2) and SU (3) gauge theories. We find that at the phase of deep deconfinement the neural network, trained on the lattice configurations of gauge fields as input data, finds correlations with the target observable (Polyakov Loop), which is also true in the critical region of the parameter space where the neural network wasn’t trained. We have verified that the neural network constructs a gauge-invariant function, and this property doesn’t change over the entire range of the parameter space.

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Central exclusive diffractive production of axial-vector f1 mesons in proton-proton collisions

Author(s): Piotr Lebiedowicz[1]

Co-author(s): Josef Leutgeb ; Otto Nachtmann ; Anton Rebhan ; Antoni Szczurek

[1] *IFJ PAN, Cracow*

Corresponding Author(s): piotr.lebiedowicz@ifj.edu.pl

We discuss the central exclusive production (CEP) of f1 mesons in high-energy proton-proton collisions, where the diffractive pomeron-pomeron fusion process is expected to be dominant [1]. The theoretical results are calculated within the tensor-pomeron approach [2]. Two ways to construct the pomeron-pomeron-f1 coupling are discussed. First we consider phenomenological approach. We adjust the parameters of model to the WA102 experimental data [3]. We compare these predictions with those of the Sakai-Sugimoto model [4], where the couplings are determined by the mixed axial-gravitational anomaly of QCD. The total cross section and several differential distributions are presented. Our results may be used to investigate the $pp \to pp\pi^+\pi^-\pi^+\pi^-$ reaction at LHC energies. Some effort to measure central exclusive four-pion production was initiated already by the ATLAS Collaboration [5]. Experimental studies of single meson CEP reactions by the LHC collaborations (ALICE, ATLAS, CMS, LHCb) will allow to extract many pomeron-pomeron-meson coupling parameters. Their theoretical calculation is a challenging problem of nonperturbative QCD.

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[5] R. Sikora, CERN-THESIS-2020-235

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Centre Vortex Structure of QCD-Vacuum Fields and Confinement

Author(s): Derek Leinweber[1]

Co-author(s): James Biddle [1] ; Waseem Kamleh [1]

[1] *CSSM, University of Adelaide*

Corresponding Author(s): waseem.kamleh@adelaide.edu.au, derek.leinweber@adelaide.edu.au, james.biddle@adelaide.edu.au

The non-trivial ground-state vacuum fields of QCD generate quark and gluon condensates and form the foundation of matter. Using modern visualization techniques, this presentation examines the microscopic structure of these fields. Of particular interest are the centre vortices identified within the ground-state fields of lattice QCD. This vortex structure is illustrated through renderings of oriented spatial plaquettes. Our current focus is on understanding the manner in which light dynamical fermions in the QCD vacuum alter the centre-vortex structure. The impact of dynamical fermions is not subtle, changing both the density of vortices and the complexity of the vortex structures observed. The results provide new insights into the role of centre vortices in underpinning both confinement and dynamical chiral symmetry breaking in QCD. Indeed, vortex-only models of the QCD-vacuum structure are sufficient to capture the salient features of QCD.

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Chiral separation effect and Kondo effect in finite-density SU(2) gauge theory with dynamical fermions

Buividovich Pavel[1] ; Dominik Smith[2] ; Lorenz von Smekal[None]

[1] *University of Liverpool*

[2] *GSI Center for Heavy-Ion Collisions*

Corresponding Author(s): pavel.buividovich@liverpool.ac.uk

We present the results of a first-principles lattice study of the Chiral Separation Effect in finite-density gauge theory with dynamical fermions. We find that the CSE is well described by the free quark result in the high-temperature quark-gluon plasma phase. As one enters the confinement regime with broken chiral symmetry at chemical potential smaller than half of the pion mass, the CSE response is gradually suppressed towards low temperatures in comparison to the free quark result. This suppression can be approximately described by assuming that the CSE current is proportional to the charge density, rather than the chemical potential, as suggested in ArXiv:1712.01256. We also present numerical evidence for the enhancement of the CSE response in the presence of heavy quarks, which, according to ArXiv:2012.15173, might be a manifestation of Kondo effect in non-Abelian gauge theory.

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Chiral symmetry restoration with three chiral partners

Juan Torres-Rincon[1]

[1] *Goethe University Frankfurt*

Corresponding Author(s): torres-rincon@itp.uni-frankfurt.de

In this contribution I consider masses of chiral partners in the context of the chiral symmetry restoration at finite temperature. Using an effective quark model I first review the common situation where two mesonic chiral partners become nearly degenerate when temperature is increased above the chiral restoration one. Then I turn to an effective hadron theory for describing charm mesons where the chiral companion of the D meson is generated dynamically as a “double pole structure”. In such a case three different masses (ground state + two poles) are to be analysed as functions of the temperature. I suggest a possible restoration pattern at high temperature when the back-reaction of the quark condensate is incorporated.

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Chiralspin symmetry and confinement in QCD

Marco Catillo[None]

Corresponding Author(s): mcatillo@phys.ethz.ch

I present an overview about chiralspin symmetry and its relation with confinement and the deconfined phase of QCD, as well as its chirally restored phase. I focus on high temperature QCD and some interesting “truncated” lattice studies, proposing an alternative chiralspin group which would be worth to check at high temperature QCD.

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Closing address

Corresponding Author(s): vladimir.petrov@ihep.ru

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Confinement, mass gap and gauge symmetry in the Yang-Mills theory

Kei-Ichi Kondo[1]

[1] *Chiba University*

Corresponding Author(s): keiichi@kondo.sakura.ne.jp

I will discuss the possible relationship between confinement mechanism and the existence of mass gap in the Yang-Mills theory by respecting gauge symmetry.

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Deconfining Phase Boundary of Rapidly Rotating Hot and Dense Matter and Analysis of Moment of Inertia

Author(s): Yuki Fujimoto[1]

Co-author(s): Kenji Fukushima [1] ; Yoshimasa Hidaka [2]

[1] *The University of Tokyo*

[2] *KEK*

Corresponding Author(s): fuku@nt.phys.s.u-tokyo.ac.jp, fujimoto@nt.phys.s.u-tokyo.ac.jp

The effect of rotation changes the critical temperature in the phase diagram of hot and dense hadronic matter explored in heavy-ion collision experiments. The recent lattice-QCD calculation suggests that the rotation effect pushes up the critical temperature, and there has been some controversy over the interpretation of this result. In this talk, we use a parameter-free approach, which is the hadron resonance gas model, to address this issue. We found that the critical temperature should be lowered with increasing rotation. We also establish a method to quantitatively evaluate the radial dependence of pressure and the moment of inertia of hadronic matter. The talk will be based on PLB 816, 136184 (2021) [arXiv:2101.09173].

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Determination of light scalar meson properties from dispersive and analytic methods applied to meson-meson scattering

José R. Peláez[1] ; Arkaitz Rodas[2] ; Jacobo Ruiz de Elvira[3]

[1] *Universidad Complutense de Madrid*

[2] *College of William & Mary and Thomas Jefferson National Laboratory*

[3] *Universidad Complutense*

Corresponding Author(s): jacobore@ucm.es, jrpelaez@fis.ucm.es, arodas@jlab.org

In this talk I will review dispersive an analytic methods that have been used used to determine, in a a model-independent way, the existence and properties of light scalar mesons from scattering data. These include dispersive pole determinations of the long debated f_0(500) or sigma, K_0*(700) or kappa and f0(980). We also discuss the combination of dispersive scattering data analyses with sound analytic continuation methods to determine all strange resonances below 2 GeV and our preliminary results on the f_0(1370).

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Discussion 1

Corresponding Author(s): klempt@hiskp.uni-bonn.de

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Discussion 10

Corresponding Author(s): evgeny.epelbaum@rub.de

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Discussion 2

Corresponding Author(s): torrieri@unicamp.br

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Discussion 3

Corresponding Author(s): antonio.vairo@tum.de

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Discussion 4

Corresponding Author(s): vladimir.petrov@cern.ch

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Discussion 5

Corresponding Author(s): lombardo@fi.infn.it

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Discussion 6

Corresponding Author(s): gerrit.schierholz@desy.de

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Corresponding Author(s): jgreensite@gmail.com

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Discussion 8

Corresponding Author(s): robert.shrock@stonybrook.edu

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Corresponding Author(s): pavel.buividovich@liverpool.ac.uk

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Double-J/psi system in the spotlight of recent LHCb data

Alexey Nefediev[1]

[1] *Lebedev Physical Institute of RAS*

Corresponding Author(s): a.nefediev@gmail.com

Recently the LHCb Collaboration announced intriguing results on the double-J/psi production in proton-proton collisions. A coupled-channel interpretation of the measured di-J/psi spectrum is presented and a possible nature of the near-threshold state X(6200) is discussed.

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Electromagnetic conductivity of quark-gluon plasma at non-zero baryon density

Victor Braguta[1]

[1] *MISIS, JINR*

Corresponding Author(s): victor.v.braguta@gmail.com

We present our results on the study of the electromagnetic conductivity in dense quark-gluon plasma obtained within lattice simulations with N_f=2+1 dynamical quarks. We employ stout improved rooted staggered quarks at the physical point and the tree-level Symanzik improved gauge action. The simulations are performed at imaginary chemical potential and the Backus-Gilbert method is used to extract the conductivity from current-current correlators. Our preliminary results show an increase of conductivity with real baryon density.

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Excited States of Isolated Fermions in the Higgs phase of gauge Higgs theories

Kazue Matsuyama[None] ; Jeff Greensite [1]

[1] *San Francisco State University*

Corresponding Author(s): kazuem@sfsu.edu, greensit@sfsu.edu

I present numerical evidence that the gauge+Higgs fields surrounding isolated charged fermions, in a variety of gauge Higgs theories, have a spectrum of localized excited states. This would appear as a mass spectrum of "elementary" fermions, taken to be static for simplicity.

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Hadron matrix elements, lattice QCD and the Feynman-Hellmann approach

Horsley Roger[1]

[1] *University of Edinburgh*

Corresponding Author(s): rhorsley@ph.ed.ac.uk

A major objective of lattice QCD is the computation of hadronic matrix elements. The standard method is to use three-point and four-point correlation functions. An alternative approach, requiring only the computation of two-point correlation functions is to use the Feynman-Hellmann theorem. In this talk we develop this method up to second order in perturbation theory, in a context appropriate for lattice QCD. This encompasses the Compton Amplitude (which forms the basis for deep inelastic scattering) and hadron scattering. Some numerical results are presented showing results indicating what this approach might achieve.

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Hadron potential at large distances and fine structure of the diffraction peak at 13 TeV.

Oleg Selyugin[1]

[1] *BLTPh JINR*

O.V. Selyugin
BLTPh JINR, 141980 Dubna, Russia

Many models predict that soft interactions will enter a new regime at the LHC: given the huge energy, unitarization may play a crucial role as the central part of the protons becomes black [1]. In most part, this depends on the behaviour of the hadron potential at large distances. Our analysis of dσ/dt of the TOTEM Collaboration data, carried out without model assumptions, shows the existence of a new effect (oscillations) in the behavior of the hadron scattering amplitude at a small momentum transfer at a high confidence level [2].
The quantitative description of the data in the framework of the high energy generalized structure (HEGS) model supports this phenomenon. The analysis of the new TOTEM data at 13 TeV in a wide momentum transfer region reveals an unusual phenomenon - the presence in the elastic scattering amplitude of a term with a very large slope [3] that is responsible for the behaviour of hadron scattering at a very small momentum transfer. These phenomena can be connected with hadron interactions at large distances.

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Hadron production on heavy-ion and pp collisions at the LHC with ALICE

Anton Andronic[None]

Corresponding Author(s): andronic@uni-muenster.de

Hadron yields measured in Pb-Pb collisions by the ALICE experiment at the LHC are very well described by the statistical hadronization model, leading to the phenomenologial determination of the hadronization temperature, which is in a very good agreement with predictions from Lattice QCD. This applies not only for hadrons carrying the u,d,s quarks, but also to hadrons with charm quarks, in particular the J/psi meson. The event-multiplicity dependence of strange hadron yields for pp and p-Pb collisions shows a significantly-increasing trend, indicating that the limit of statistical hadronization may be reached in high-multiplicity pp (p-Pb) collisions.
I will present a selection of results on this topic and complement it with recent results on charm baryon production, which exhibits in pp collisions at the LHC a significantly larger fragmentation compared to measurements in e+e-.

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Heavy exotic mesons at LHCb

Vitaly Vorobyev[1]

[1] *BINP*

Corresponding Author(s): vvorob@inp.nsk.su

Recent results on heavy exotic hadrons obtained by the LHCb experiment are discussed:

- Tetraquarks with hidden charm (X(3872), T_{cccc}(6900), Z_{cs}(4xxx)+, X(46xx))
- Pentaquarks with hidden charm (P_c(4xxx)+, P_{cs}(4459)0)
- Doubly charmed tetraquark (T_{cc}+)

Most of the results are based on an analysis of the full runs I and II LHCb dataset.

This talk is dedicated to the memory of Simon Eidelman (1948-2021)

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Heavy quark spectral functions and charm diffusion

Olaf Kaczmarek[1]

[1] *Bielefeld University*

Corresponding Author(s): okacz@physik.uni-bielefeld.de

I will discuss recent results of quarkonium spectral functions and heavy quark diffusion coefficients. Our results are based on continuum extrapolated lattice correlation functions and spectral reconstructions that are constrained by perturbation theory.

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Holographic nuclear matter with isospin asymmetry

Andreas Schmitt[None]

Corresponding Author(s): a.schmitt@soton.ac.uk

I will present the latest progress in describing ultra-dense matter within the gauge-gravity correspondence. Using the holographic Sakai-Sugimoto model, I will discuss the phase structure at nonzero baryon and isospin chemical potentials, in particular pointing out the coexistence of baryonic matter and a pion condensate. As an application, I will show how this holographic approach can be used to construct neutron stars entirely within a single framework, including the crust of the star.

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Hybrid phenomenology in a chiral symmetric model

Walaa Eshraim[None] ; Christian Christian [1] ; Francesco Giacosa[2] ; Denis Parganlija[None]

[1] *Giessen Uni*

[2] *Jan Kochanowski U.*

Corresponding Author(s): weshraim@th.physik.uni-frankfurt.de, christian.fischer@theo.physik.uni-giessen.de

We study the vacuum properties of hybrids by using the so-called extended Linear Sigma Model (eLSM). This model includes scalar and pseudoscalar mesons, as well as vector and axial-vector mesons. We enlarge the eLSM by including the low-lying hybrid nonet with exotic quantum numbers $J^{PC} = 1^{-+}$ and the nonet of their chiral partners with $J^{PC} = 1^{+-}$ to a global $U(3)_r \times U(3)_l$ chiral symmetry. Then, we predict the hybrid nonets masses and their decay ratios that may guide ongoing and upcoming experiments

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Inclusive Decays of Heavy Quark Hybrids

Abhishek Mohapatra[1]

[1] *TUM*

Corresponding Author(s): abhishek.mohapatra@tum.de

In order to understand the nature of the XYZ particles, theoretical predictions of the various XYZ decay modes are essential. In this work, we focus on the semi-inclusive decay of heavy quarkonium hybrids into traditional quarkonium in the Born Oppenheimer EFT (BOEFT) framework. We present results of the decay rates for several heavy quark hybrids. We also develop a systematic framework in which the theoretical uncertainty can be systematically improved.

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Influence of relativistic rotation on the confinement-deconfinement transition within lattice simulation

Victor Braguta[1] ; Andrey Kotov[2] ; Denis Kuznedelev[3] ; Artem Roenko[1]

[1] *JINR, BLTP*

[2] *Jülich Supercomputing Centre*

[3] *MIPT*

Corresponding Author(s): kotov.andrey.yu@gmail.com, roenko@theor.jinr.ru, victor.v.braguta@gmail.com

The influence of relativistic rotation on the confinement/deconfinement transition in gluodynamics has been studied within lattice simulation. The simulation is performed in the reference frame which rotates with the system under investigation, where rotation is reduced to external gravitational field. Different types of boundary conditions (open, periodic, Dirichlet) are imposed in directions, orthogonal to rotation axis. It is shown, that the critical temperature of the confinement/deconfinement transition in gluodynamics grows quadratically with increasing angular velocity. This conclusion does not depend on the boundary conditions used in our study and we believe that this is universal property of gluodynamics.
First preliminary results of the study of the phase diagram of rotating QCD matter with fermions are also presented. The results indicate, that effect of the rotation on fermions is opposite to gluons: it leads to the decrease of the critical temperature.

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Jet transport coefficient qhat in lattice QCD

Author(s): Johannes Heinrich Weber[1]

Co-author(s): Amit Kumar [2] ; Abhijit Majumder [3]

[1] *Humboldt-Universität zu Berlin*

[2] *McGill University*

[3] *Wayne State University*

Corresponding Author(s): kumar.amit@wayne.edu, johannes.weber@physik.hu-berlin.de

We present the first calculation of the jet transport coefficient $\hat{q}$ in quenched and (2+1)-flavor QCD on a 4-D Euclidean lattice. The light-like propagation of an energetic parton is factorized from the mean square gain in momentum transverse to the direction of propagation, which is expressed in terms of the thermal field-strength field-strength correlator. The leading-twist term in its operator product expansion is calculated on the lattice. Continuum extrapolated quenched results, and full QCD estimates based on un-renormalized lattice data, over multiple lattice sizes, are compared with (non) perturbative calculations and phenomenological extractions of $\hat{q}$. The lattice data for $\hat{q}$ show a temperature dependence similar to the entropy density. Within uncertainties, these are consistent with phenomenological extractions, contrary to calculations using perturbation theory.

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Lattice simulations of the QCD chiral transition at real baryon density

Szabolcs Borsanyi[1] ; Zoltan Fodor[1] ; Matteo Giordano[2] ; Sandor Katz[2] ; Daniel Nogradi[2] ; Attila Pasztor[2] ; Chik Him Wong[1]

[1] *University of Wuppertal*

[2] *Eotvos University, Budapest*

Corresponding Author(s): nogradi@bodri.elte.hu, borsanyi@uni-wuppertal.de, giordano@bodri.elte.hu, fodor@bodri.elte.hu, apasztor@bodri.elte.hu, katz@bodri.elte.hu, cwong@uni-wuppertal.de

State-of-the-art lattice QCD studies of hot and dense strongly interacting matter currently rely on extrapolation from zero or imaginary chemical potentials. The ill-posedness of numerical analytic continuation puts severe limitations on the reliability of such methods. We performed simulations of the QCD chiral transition at finite real baryon density with the more direct sign reweighting approach. The method does not require analytic continuation and avoids the overlap problem associated with generic reweighting schemes, so has only statistical but no uncontrolled systematic uncertainties for a fixed lattice setup. This opens up a new window to study hot and dense strongly interacting matter from first principles. We performed simulations up to a baryochemical potential-temperature ratio of $\mu_B/T = 2.7$, covering most of the RHIC Beam Energy Scan range in the chemical potential. I will also clarify the connection of the approach to the more traditional phase reweighting method. Based on 2108.09213 [hep-lat]

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Making sense of Hydrodynamics with 50 particles

Giorgio Torrieri[1]

[1] *State University of Campinas (Unicamp),Brasil*

The observation, in hadronic collisions, of "ideal fluid" type behavior in systems of a comparatively small number of particles, presents a conceptual puzzle, since the way we usually derive hydrodynamics is via approximating "many" particles as a continuum. I will argue that making sense of this requires re-deriving relativistic hydrodynamics as a "bottom-up" theory, with no reference to microscopic physics except the local emergence of a thermalized system. This is in contrast to usual attempts to understand hydrodynamics as a "top-down" theory, in terms of models such as transport and holographic strongly coupled systems. We attempt to do this using basic statistical mechanics, and find the apparently counter-intuitive conclusion that in the small viscosity limit it might indeed be that smaller systems could thermalize faster.

Morning session 9 / 1

Measurements of leptons from HF decays and understanding small systems

Das Debasish[1]

[1] *Saha Institute of Nuclear Physics*

Corresponding Author(s): debasish.das@saha.ac.in

Briefly after the Big Bang, the early universe was in a high temperature and high density environment. In order to recreate this state of matter in the laboratory, mini bangs are created by colliding heavy ions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and subsequently at the Large Hadron Collider (LHC) at CERN. In this talk I shall be covering on the selected results from LHC and RHIC. I shall be covering spectra and correlations (flow) and also nuclear modification factor. I shall be discussing quarkonia flow in further detail. Due to the larger mass of the bottomonium states compared to the charmonium ones,the measurement of bottomonia production in proton-nucleus collisions allows a study of CNM effects in a different kinematic regime, therefore complementing the J/Psi studies[1]. For smaller systems like p+A and p+p we have less deeply bound bottomonia states and thus a comparatively larger chance to escape. This means that more states become measurable, which is a positive feature. On the other hand,it also means that the escape mechanism which underlies the anisotropic flow of bottomonia may become largely ineffective, in particular for the Upsilon(1S). Accordingly,the measurement of a sizable flow for Upsilon(1S) in small systems[2] would probably hint at the importance of initial-state correlations. Hence understanding small systems becomes very important and such studies will be also stressed and presented including the opportunities which will be possible in LHC Run-3 small system data-sets.

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Muon g-2: hadronic contributions

Alex Keshavarzi[1]

[1] *alexander.keshavarzi@manchester.ac.uk*

Corresponding Author(s): alexander.keshavarzi@manchester.ac.uk

The Fermilab Muon g-2 Experiment recently reported their first result for the anomalous magnetic moment of the muon that differs from the Standard Model (SM) prediction by 4.2$ standard deviations. The error on the SM prediction, which is comparable in size to the experimental uncertainty, is entirely dominated by the determination of the hadronic contributions, which arise from the low-energy, non-perturbative nature of hadronic interactions. In this talk I will review the status of the

calculations of both the hadronic vacuum polarisation (HVP) and hadronic light-by-light contributions, detailing the progress that has been achieved through the efforts of the Muon g-2 Theory Initiative and its groups within. I will place particular focus on the status of the HVP contributions, which dominate the hadronic uncertainty, and report on the comparison between the results from data-driven dispersive approaches and from lattice QCD.

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Nuclear Lattice Simulations with Chiral Effective Field Theory

Dean Lee[1]

[1] *Michigan State University*

Corresponding Author(s): lee.dean.j@gmail.com

This talk is intended as an introduction to the application of chiral effective field theory to lattice simulations of nuclear systems. I present work by the Nuclear Lattice Effective Field Theory Collaboration studying the connection between microscopic nuclear forces and nuclear structure and reactions. I also describe recent results calculating nuclear thermodynamics and the phase diagram of symmetric nuclear matter.

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Nucleon axial form factors from lattice QCD

Constantia Alexandrou[1]

[1] *Univ. of Cyprus*

Corresponding Author(s): alexand@ucy.ac.cy

I will review recent progress in the calculation of the axial and induced pseudoscalar form factors of the proton and neutron within lattice QCD.
In particular, I will emphasise results computed using physical point ensembles. The PCAC and Goldberger-Treiman relations will be discussed as well as the strange axial form factors.

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Phase diagram of QCD with helically imbalanced quarks

Victor E. Ambrus[1] ; Maxim Chernodub[2]

[1] *Goethe University*

[2] *University Of Tours*

Corresponding Author(s): vambrus@itp.uni-frankfurt.de

Due to the recent STAR data on the polarization of the Λ hyperons produced in heavy ion collisions, it is interesting to consider the QCD phase transition in a medium exhibiting persistent polarization. Since during the chiral phase transition, the quarks acquire dynamical mass and the conservation

of the axial charge current J_A^μ is broken, the chiral chemical potential μ_A is not suitable to thermodynamically account for the fermion polarization. Noting that the helicity current J_H^μ remains conserved even at finite fermion mass, we propose to model the fermion polarization via the helicity chemical potential μ_H. In the framework of the linear σ model with quarks, LSM$_q$, we show that the vector and helical chemical potentials μ_V and μ_H form a dual pair, due to the symmetry of the free energy $\Omega(\mu_V, \mu_H) = \Omega(\mu_H, \mu_V)$. In this talk, we discuss on the impact of a finite μ_H on the phase diagram associated with the chiral phase transition with a particular focus on the new critical points that emerge at sizable μ_H.

Evening session 10 / 23

Precision nuclear physics with chiral effective field theory

Evgeny Epelbaum[1]

[1] *Ruhr University Bochum*

Corresponding Author(s): evgeny.epelbaum@rub.de

Chiral effective field theory is been advanced to a precision tool for analyzing low-energy few-nucleon dynamics. I will outline the foundations of this theoretical framework and discuss our recent and ongoing precision studies of the electromagnetic structure of light nuclei.

Morning session 3 / 57

Production of D-wave states of bc quarkonium at the LHC

Ilia Belov[1] ; Alexander Berezhnoy[1] ; Anatolii Likhoded[2]

[1] *SINP MSU*

[2] *NRC Kurchatov Institute IHEP*

Corresponding Author(s): in.belov@physics.msu.ru, alexander.berezhnoy@cern.ch, anatolii.likhoded@ihep.ru

We study the hadronic production of D-wave states of $\bar{b}c$ quarkonium. The relative yield of such states is estimated for kinematic conditions of LHC experiments. The direct $B_c(D)$ production is complemented by NRQCD contributions being the same order $O(v^4)$. The NRQCD matrix elements are estimated within naive velocity scaling rule.

Evening session 4 / 70

Prospect for new physics observation with the CMS Precision Proton Spectrometer (PPS)

Nicola Turini[1]

[1] *INFN and University of Siena*

Corresponding Author(s): nicola.turini@unisi.it

The Proton Precision Spectrometer is exploring gamma gamma collisions at high energy opening up a different window where to search for new physics beyond Standard Model. I will present the PPS potentiality looking for anomalies either for exclusive CEP or invisible particles production.

Morning session 5 / 38

QCD phase transition for various number of flavours

Andrey Kotov[None]

Corresponding Author(s): kotov.andrey.yu@gmail.com

We discuss thermal QCD phase transition for various number of flavours. We review the results for the transition from $N_f = 3$ to larger values. We discuss the universality class for $N_f = 2$, along the critical line for two massless light flavours and a third flavour whose mass serves as an interpolator between $N_f = 2$ and $N_f = 3$. We identify a possible scaling window for the 3D O(4) universality class transition and its crossover to a mean field behaviour.

Morning session 1 / 47

Recent Progress in Partial-Wave Analysis

Sarantsev Andrey[1]

[1] *NRC Kurchatov Institute, PNPI*

Corresponding Author(s): andsar@hiskp.uni-bonn.de

The current status of the Bonn-Gatchna partial wave analysis is presented. The main attention will be devoted to the analysis of the data with production of the baryon states in gamma-N collision where new baryon states had been found. The results of the combined analysis of these data, measured by the CLAS, CB-ELSA and MAMI collaborations together with earlier measured data are presented. The future perspectives and some new analysis of the meson production data are discussed.

Evening session 6 / 7

Recent progress in partonic structure of the nucleon from lattice QCD

Krzysztof Cichy[1]

[1] *Adam Mickiewicz University*

Corresponding Author(s): krzysztof.cichy@gmail.com

We review the latest progress in lattice QCD calculations of x-dependent partonic distributions in the nucleon. These calculations rely on matrix elements probing spatial correlations between partons in a boosted hadron, that can be matched to light-cone correlations defining the relevant distributions. We discuss the recent theoretical and practical refinements of this strategy, as well as new exploratory directions. The latter include generalized parton distributions (GPDs), distributions beyond leading twist, flavor-singlet distributions and transverse-momentum dependent PDFs (TMDs). We also shortly consider the potential future impact of lattice data on phenomenology.

Evening session 2 / 2

Relativistic formulation of spin hydrodynamics framework based on GLW spin and energy-momentum tensors.

Rajeev Singh[1]

[1] *Institute of Nuclear Physics Polish Academy of Sciences*

Corresponding Author(s): rajeev.singh@ifj.edu.pl

Since the first positive measurement of the Λ-hyperon global spin polarization in heavy-ion collisions by STAR in 2017, the understanding of the nature of this phenomenon is one of the most intriguing challenges for the community. As relativistic fluid dynamics celebrates multiple successes in describing collective dynamics of the QCD matter in such reactions, the natural question arises whether the spin dynamics can also be modeled in such a framework. In this talk, the motivation for and recent outcomes of the experimental hunt for the macroscopic footprints of quantum spin in the relativistic heavy-ion collisions will be presented and the theoretical challenges connected with formulating its collective description will be discussed.

Evening session 8 / 16

Rigorous reconstruction of gluon propagator in the presence of complex singularities

Author(s): Yui Hayashi[1]

Co-author(s): Kei-Ichi Kondo [1]

[1] *Chiba University*

Corresponding Author(s): yhayashi@chiba-u.jp, keiichi@kondo.sakura.ne.jp

It has been suggested that the Landau-gauge gluon propagator has complex singularities, which invalidates the Källén–Lehmann spectral representation. Since such singularities are beyond the standard formalism of quantum field theory, the reconstruction of Minkowski propagators from Euclidean propagators has to be carefully examined for their interpretation. In this talk, we present rigorous results on this reconstruction in the presence of complex singularities. As a result, the analytically continued Wightman function is holomorphic in the usual tube, and the Lorentz symmetry and locality are kept valid. On the other hand, the Wightman function on the Minkowski spacetime is a non-tempered distribution and violates the positivity condition. Finally, we discuss an interpretation and implications of complex singularities in quantum theories, arguing that complex singularities correspond to zero-norm confined states.

Morning session 3 / 5

SU(3) hybrid static potentials at small quark-antiquark separations from fine lattices

Marc Wagner[1]

[1] *Goethe University Frankfurt*

Corresponding Author(s): mwagner@itp.uni-frankfurt.de

I discuss recent progress concerning the computation of the Π_u and Σ_u^- hybrid static potentials at small quark-antiquark separations. Such potentials are important for investigating masses and properties of heavy hybrid mesons in the Born-Oppenheimer approximation.

Evening session 8 / 52

Some Recent Results on Renormalization-Group Properties of Quantum Field Theories

Robert Shrock[1]

[1] *Stony Brook University*

Corresponding Author(s): robert.shrock@stonybrook.edu

We discuss higher-loop calculations of renormalization-group (RG) flows of quantum field theories. We focus on properties at infrared fixed points of the RG in vectorial asymptotically free gauge theories with various gauge groups and fermion contents, including the anomalous dimensions of the fermion bilinear operator $\bar{\psi}\psi$.
We have calculated these with inputs up to five-loop order in powers of the IR coupling α_{IR}. It is also valuable to perform corresponding calculations with a method that is independent of the scheme used for regularization and renormalization, and we have done this, using a manifestly scheme-independent variable. Much of this work is in collaboration with T. Ryttov. Comparisons are made with lattice measurements of these anomalous dimensions. We also mention the results of our investigations, using the six-loop beta function, to assess the possibility of an ultraviolet fixed point of the RG in a non-asymptotically free model, namely the O(N) $\lambda|\vec{\phi}|^4$ theory.

Morning session 3 / 42

Spectroscopy of exotic mesons from lattice simulations

Sasa Prelovsek[None]

Corresponding Author(s): sasa.prelovsek@ijs.si

Recent lattice QCD studies of charmonium-like and bottomonium-like states will be presented. The masses and widths of charmonium-like states with isospin zero are extracted by considering the scattering on the lattice. We find conventional charmonia with J=0,1,2,3 in line with experiment and two exotic candidates just below D barD and Ds barDs thresholds. The bottomonium-like system with isospin one is studied with static b quarks and shows an indication for the Zb resonance.

Morning session 9 / 20

Spin-momentum correlation in hot and dense QCD matter

Yi Yin[1]

[1] *Institute of modern physics, Chinese Academy of Sciences*

Corresponding Author(s): yiyin@impcas.ac.cn

The transport phenomena involving spin are instrumental in investigating quantum effects in many-body systems. In heavy-ion collisions, the recent measurement of spin polarization and spin alignment opens a new avenue to explore the properties of hot and dense QCD matter. Based on linear response theory and quantum kinetic equation, we have systematically studied spin-momentum correlation induced by hydrodynamic gradients [1]. In addition to the widely studied thermal vorticity effects, we identify an undiscovered contribution from the fluid shear [2]. This shear-induced polarization (SIP) can be viewed as the fluid analog of strain-induced polarization observed in elastic and nematic materials. The possible signature of SIP at RHIC and LHC will be elaborated. Finally, we shall briefly discuss how to employ Spin Hall effect to explore the properties of QCD matter with high baryon density [3,4].

[1] Shuai Y.F. Liu and Yi Yin, JHEP 07 (2021) 188, arXiv: 2103.09200.

[1] Baochi Fu, Shuai Y.F. Liu, Longgang Pang, Huichao Song and Yi Yin, Phys.Rev.Lett. 127 (2021) 14, 142301, arXiv: 2103.10403.

[3] Shuai Y.F. Liu and Yi Yin, Phys.Rev.D 104 (2021) 5, 054043, arXiv: 2006.12421

[4] Baochi Fu, Shuai Y.F. Liu, Longgang Pang, Huichao Song and Yi Yin, arXiv: 2103.10403

Morning session 5 / 35

Static quark-antiquark interactions at non-zero temperature from lattice QCD

Johannes Heinrich Weber[1]

[1] *Humboldt-Universität zu Berlin*

Corresponding Author(s): johannes.weber@physik.hu-berlin.de

We study the interactions of a static quark-antiquark pair at non-zero temperature using realistic (2+1)-flavor lattice QCD calculations. The study consists of two parts: the first investigates the properties of Wilson line correlators in Coulomb gauge and compares to predictions of hard-thermal loop perturbation theory. As a second step we extract the spectral functions underlying the correlators using four conceptually different methods: spectral function fits, a HTL inspired fit for the correlation function, Padé rational approximation and the Bayesian BR spectral reconstruction. We find that our high statistics Euclidean lattice data are amenable to different hypotheses for the shapes of the spectral function and we compare the implications of each analysis method for the existence and properties of a well defined ground state spectral peak.

Evening session 6 / 15

Strong CP problem, neutron electric dipole moment, and the fate of axions

Gerrit Schierholz[1]

[1] *DESY*

Corresponding Author(s): gerrit.schierholz@desy.de

The strong CP problem is one of the greatest puzzles in particle physics. It is fuelled by the absence of an electric dipole moment of the neutron. Peccei and Quinn proposed a new symmetry that suppresses CP-violating terms in the strong interactions, at the expense of predicting the existence of a new particle, the axion. In this talk I present a natural solution of the problem, arising entirely out of the long-distance properties of the theory. The QCD vacuum turns out to be unstable under the Peccei-Quinn transformation, which thwarts the axion conjecture.

Evening session 4 / 31

Study of central exclusive production with the CMS Precision Proton Spectrometer (PPS)

Maria Margherita Obertino[1]

[1] *Università di Torino*

Corresponding Author(s): margherita.obertino@cern.ch

The Precision Proton Spectrometer (PPS) is a subdetector of the CMS experiment that facilitates the study of Central Exclusive Production (CEP) in proton-proton collisions at the LHC, in standard data taking conditions, by measuring protons scattered at very small angles. It started operating in 2016 and collected more than 110 fb-1 throughout the LHC Run 2. In this talk the physics program of PPS will be presented with focus on the measurements performed with Run 2 data. Ongoing studies and prospects for the upcoming Run 3 will also be discussed.

Evening session 8 / 49

Studying mass generation in Landau-gauge Yang-Mills theory

Gernot Eichmann[None]

Corresponding Author(s): gernot.eichmann@tecnico.ulisboa.pt

A longstanding question in QCD is the origin of the mass gap in the Yang-Mills sector of QCD, i.e., QCD without quarks. In Landau gauge QCD this is encoded in a mass gap of the gluon propagator, which is found both in lattice simulations and with functional approaches. While functional methods are well suited to unravel the mechanism behind the generation of such a mass gap, a fully satisfactory answer has not yet been found. In this talk I discuss a recent solution of the coupled Dyson-Schwinger equations for the ghost propagator, gluon propagator and three-gluon vertex. Here the mass gap generation is tied to the longitudinal projection of the gluon self-energy, which acts as an effective mass term in the equations. Because an explicit mass term is in conflict with gauge invariance, this leaves two possible scenarios: If it is viewed as an artifact, only the scaling solution with an infrared dominance of the ghost survives; if it is dynamical, gauge invariance can only be preserved if there are longitudinal massless poles in either of the vertices. We find that there is indeed a massless pole in the ghost-gluon vertex, however in our approximation with the assumption of complete infrared dominance of the ghost this pole is only present for the scaling solution. To this end, we put forward a possible mechanism that may reconcile the scaling solution with the decoupling solutions based on longitudinal poles in the three-gluon vertex as seen in the PT-BFM scheme.

Evening session 10 / 10

TBA

TBA

Morning session 5 / 24

The η/η' system and large-N_c ChPT: A Lattice QCD Study

Author(s): Gunnar Bali[1]

Co-author(s): Jakob Simeth ; Sara Collins

[1] *Universität Regensburg*

Corresponding Author(s): gunnar.bali@ur.de

We compute the masses, decay constants and gluonic matrix elements on the η and η' mesons in lattice simulations across four lattice spacings with the light quark masses reaching down to the physical point. A comparison is made to the Large-N_c chiral perturbation theory (ChPT) predictions and the NLO low energy constants are determined.

Evening session 2 / **67**

The chiral phase transition for different numbers of quark flavours

Owe Philipsen[1]

[1] *Goethe University Frankfurt*

The chiral phase transition for different numbers of quark flavours

Evening session 4 / **53**

The discovery of the odderon by the D0 and TOTEM collaborations

Christophe Royon[None]

Corresponding Author(s): christophe.royon@cern.ch

We will describe the odderon discovery by the TOTEM and D0 experiments. The analysis compares the p pbar elastic cross section as measured by the D0 Collaboration at a center-of-mass energy of 1.96 TeV to that in pp collisions as measured by the TOTEM Collaboration at 2.76, 7, 8, and 13 TeV. The two data sets disagree at the 3.4 sigma level and thus provide evidence for the t-channel exchange of a colorless, C-odd gluonic compound, also known as the odderon. We combine these results with a TOTEM analysis of the same C-odd exchange based on the total cross section and the ratio of the real to imaginary parts of the forward elastic strong interaction scattering amplitude in pp scattering, leading to a combined significance larger than 5 sigma.

Evening session 6 / **27**

The gauge group and flavor number dependence of m_V/f_{PS}

Daniel Nogradi[None]

Corresponding Author(s): nogradi@bodri.elte.hu

Composite Higgs model often feature a new strongly interacting sector based on some gauge group and some number of fermions (flavors). The physical scale is typically set by the Goldstone decay constant f_{PS} and a meson state with the appropriate quantum numbers is identified with the Higgs. The lightest vector meson in these scenarios is a potential new, so far undetected, particle. Its mass in

physical units m_V/f_{PS} can be unambiguously obtained from non-perturbative lattice simulations and serves as a concrete prediction for every choice of gauge group and flavor number. Results will be shown for $SU(3)$ and $N_f = 2, \ldots, 10$ as well as a compilation of results from the literature with other gauge groups and/or fermion content, including the large-N limit. Interestingly, the m_V/f_{PS} ratio is finite both inside and outside the conformal window and displays a peculiar N_f-dependence.

Evening session 8 / 4

The mixed 0-form/1-form anomaly in Hilbert space: pouring new wine into old bottles

Erich Poppitz[1]

[1] *University of Toronto*

Corresponding Author(s): poppitz@physics.utoronto.ca

We study four-dimensional gauge theories with arbitrary simple gauge group with 1-form global center symmetry and 0-form parity or discrete chiral symmetry. We canonically quantize on a three-torus in a fixed background field gauging the 1-form symmetry. We show that the mixed 't Hooft anomaly results in a central extension of the global-symmetry operator algebra. We determine this algebra in each case and show that the anomaly implies degeneracies in the spectrum of the Hamiltonian at any finite-size torus. We discuss the consistency of these constraints with both older and recent semiclassical calculations in SU(N) theories, with or without adjoint fermions, as well as with their conjectured infrared phases.

Morning session 1 / 8

The scalar and tensor glueball in production and decay

Eberhard Klempt[1]

[1] *University of Bonn*

Corresponding Author(s): klempt@hiskp.uni-bonn.de

Evidence for the scalar and the tensor glueball is reported. The evidence stems from an analysis of BESIII data on radiative J/ψ data into $\pi^0\pi^0$, K_SK_S, $\eta\eta$, and $\phi\omega$. The coupled-channel analysis is contrained by a large number of further data. The scalar intensity is described by ten scalar isoscalar mesons, covering the range from $f_0(500)$ to $f_0(2330)$. Five resonances are interpreted as mainly-singlet states in SU(3), five as mainly-octet states. The mainly-singlet resonances are produced over the full mass range, the production of octet state is limited to the 1500 to 2100\,MeV mass range. The peak is interpreted as scalar glueball. Its mass,
width and yield are determined to $\mathrm{M}_{\mathrm{glueball}} = (1865{\pm}25)\,\mathrm{MeV}, \Gamma_{\mathrm{glueball}} = (370{\pm}50^{+30}_{-20})\,\mathrm{MeV}, \mathrm{Y}_{J/\psi\to\gamma\mathrm{G}_0} = (5.8\pm1.0)\cdot10^{-3}$ The study of the decays of the scalar mesons identifies significant glueball fractions. The tensor wave shows the $f_2(1270)$ and $f_2'(1525)$ but no clear structure above their masses. An interpretation of these data is suggested.

Evening session 2 / 45

The strong CP problem, general covariance, and horizons

Giorgio Torrieri[1]

[1] *State University of Campinas (Unicamp),Brasil*

We discuss the strong CP problem in the context of quantum field theory in the presence of horizons. We argue that general covariance places constraints on the topological structure of the theory. In particular, as in QCD, it means that different topological sectors of the theory can only sum incoherently, because the degrees of freedom beyond the horizon must be traced over for general covariance to apply. This might lead to a solution of the so-called strong CP problem without extra observable dynamics.

Morning session 7 / 19

Thermal monopoles in full QCD

Massimo D'Elia[1]

[1] *University of Pisa and INFN*

Corresponding Author(s): massimo.delia@unipi.it

We investigate the properties of thermal magnetic monopoles in the high temperature phase of QCD with 2+1 flavours and physical quark masses, with a particular focus on their condensation and its possible relation with other non-perturbative features of strongly interacting matter.

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Corresponding Author(s): vladimir.petrov@ihep.ru