Bound states in strongly coupled systems

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GGI

Book of Abstracts

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Supersymmetric Features of Hadron Physics and other Novel Properties of Quantum Chromodynamics from Light-Front holography and Superconformal Algebra

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A fundamental question in hadron and nuclear physics is how the mass scale for protons and other hadrons emerges from QCD, even in the limit of zero quark mass. I will discuss a new approach to the origin of the QCD mass scale and color confinement based on "lightfront holography", a formalism which relates the bound-state amplitudes in the fifth dimension of AdS space to the boost-invariant light-front wavefunctions describing the structure of hadrons in physical space-time. The result is a set of Poincarè-invariant bound-state wave equations which incorporate quark confinement and predict many observed spectroscopic and dynamical features of hadron physics, such as linear Regge trajectories with identical slope in both the radial quantum number and the internal orbital angular momentum.

Generalizing this procedure using superconformal algebra leads to a unified Regge spectroscopy of meson, baryon, and tetraquarks, including remarkable supersymmetric relations between the masses of mesons and baryons. The pion bound-state, although composite, is massless for zero quark mass.

One also can predict nonperturbative hadronic observables such as structure functions, transverse momentum distributions, and the distribution amplitudes defined from the hadronic light-front wavefunctions.

The analytic behavior of the QCD coupling controlling quark and gluon interactions at large and small distances is also determined. The result is an effective coupling defined at all momenta with a transition mass scale which sets the interface between perturbative and nonperturbative hadron dynamics. One also obtains a relation between the perturbative QCD mass scale and hadron masses. I will also briefly discuss how conformal constraints lead to the elimination of the renormalization scale ambiguity for perturbative QCD calculations.

Summary:

I will discuss a new approach to the origin of the QCD mass scale and color confinement based on "light-front holography", a formalism which relates the bound-state amplitudes in the fifth dimension of AdS space to the boost-invariant light-front wavefunctions describing the structure of hadrons in physical space-time. The result is a set of Poincarè-invariant bound-state wave equations which incorporate quark confinement and predict many observed spectroscopic and dynamical features of hadron physics.

Generalizing this procedure using superconformal algebra leads to a unified Regge spectroscopy of meson, baryon, and tetraquarks, including remarkable supersymmetric relations between the masses of mesons and baryons.

One also can predict nonperturbative hadronic observables such as structure functions, transverse momentum distributions, and the

distribution amplitudes defined from the hadronic light-front wavefunctions.

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Bound States and Spectral Models

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We apply the gauge technique to conserved currents and look for the consequences for bound states.

XYZ and Heavy quarks / **7**

Understanding the positive-parity charm mesons

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Since the discovery of the D_{s0}^*(2317) and the D_{s1}(2460) in 2003, there have been 3 puzzles in the spectroscopy of positive-parity charm mesons: (1) why are the D_{s0}^*(2317) and D_{s1}(2460) masses much lower than the quark model predictions for the lowest positive parity charm mesons? (2) why is the mass difference between the D_{s0}^*(2317) and the D_{s1}(2460) is equal to that between the D and the D^* within 2 MeV? (3) why do the nonstrange partners of these two charm-strange mesons have masses larger than or similar to them? In this walk, I will show that all these puzzles find a natural resolution in the picture that these lowest positive-parity charm mesons are dynamically generated from the interaction between the light pseudoscalar mesons and ground-state charm mesons.

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Large-N QCD as a topological twistor string theory

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Large-N QCD as a topological twistor string theory

QCD theory/phenomenology / **9**

Lattice QCD studies of pseudo-PDFs

Author: Savvas Zafeiropoulos[1]

Co-authors: Anatoly Radyushkin [2]; Joseph Karpie [3]; Kostas Orginos [4]

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Ioffe-time distributions, which are functions of the Ioffe-time ν, are the Fourier transforms of parton distribution functions with respect to the momentum fraction variable x. These distributions can be obtained from appropriate equal time, quark bilinear hadronic matrix elements which can be calculated from first principles via lattice QCD methods. Here, we present the first numerical results of the Ioffe-time distributions of the nucleon.

Dyson-Schwinger / **10**

Hadron phenomenology from first-principle QCD studies

Author: Joannis Papavassiliou[1]

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The dressed gluon-quark vertex is a fundamental ingredient of the kernels appearing in the one- and two-body problems.
We present a novel representation of this vertex in terms
of the gluon-quark scattering matrix, and develop a method capable of
elucidating a quark-antiquark Bethe-Salpeter kernel that is symmetry-consistent with a given quark gap equation.
A main advantage of this scheme is its ability to expose and capitalize on graphic symmetries within the kernels. We then focus on the first element of the resulting Bethe-Salpeter kernel, namely the one-gluon exchange diagram with both gluon-quark vertices fully dressed, and show how a renormalization-group
invariant and process independent combination may be constructed, which serves as a bridge between "bottom-up"and "top down"approaches.

Amplitude analysis and Light Quarks / **12**

The GlueX Experiment: Status and Prospects

Author: Matthew Shepherd[1]

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If one examines the rules for constructing hadrons as suggested by the QCD Lagrangian, there is no obvious reason why nature should be limited to just quark-antiquark mesons and three-quark baryons. In the last decade, numerous new experimental results, primarily for hadrons containing

charm quarks, suggest that the hadron spectrum may in fact contain more complex constructions of quarks and gluons. At the same time evidence for the existence of such states in the light quark system has also emerged from the high-intensity pion beam data collected at COMPASS. The GlueX experiment has presently collected the world's most statistically precise data for studying the photoproduction of mesons in the region up to charmonium threshold, which provides a unique new avenue for experimentally studying light hadron spectroscopy. I will discuss preliminary results obtained from these data and discuss the prospects for the GlueX physics program in the next few years.

BSM and QCD / **13**

Present and future hadron spectroscopy at JLab

Author: Marco Battaglieri[1]

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The distinctive property of confinement in strong interactions, which are described by QCD, prevents quarks and gluons from appearing as free particles. Hadron spectroscopy represents a powerful tool to investigate the nature of the strong interactions. Beside the traditional use of hadron probe (pion, kaons, proton and anti-proton) and e+e0- colliders, a new generation of electron- and photoproduction experiments is ready to provide precise and abundant data on light quark sector. In this talk I'll report about the Jefferson Lab hadron spectroscopy program (CLAS, GLUEX and CLAS12) reviewing some selected results and showing plans for the future.

QCD theory/phenomenology / **14**

The string-junction picture of multiquark states

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We start with a discussion of hadronic duality recalling why in the presence of baryons one needs to introduce the notion of string-junction J, to complement the conventional classification of hadrons based just on their quark-antiquark constituents. In this picture single hadronic states are associated with "irreducible" gauge-invariant operators consisting of Wilson lines (visualized as strings of color flux tubes) that may either end on a quark or an antiquark, or annihilate in triplets at a junction Jor an anti-junction Jbar. For the junction-free sector (ordinary q qbar mesons and glueballs) the picture is supported by large-N (number of colors) considerations as well as by a (lattice) strong-coupling expansion. Both imply the famous OZI rule suppressing quark-antiquark annihilation diagrams. The same expansions support the existence of states with more than one junction, e.g. two for tetraquarks, and three for pentaquarks (baryonium states), as well as a generalization of the OZI rule (the JOZI rule) providing a suppression of J-Jbar annihilation diagrams. The JOZI rule implies that baryonium states are "mesophobic" and thus unusually narrow if they are below threshold for decaying into as many baryons as their total number of junctions.

BSM and QCD / **15**

Bound states and Interquark Potential in High Temperature Lattice Gauge Theories

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Conformal perturbation is a powerful tool to describe the behaviour of statistical mechanics models and quantum field theories in the vicinity of a critical point. It was widely used in the past to describe two dimensional models and has been recently extended, thanks to the remarkable results of the bootstrap approach, also to three dimensional models.
We show here that it can be also used to describe the behaviour of (3+1) lattice gauge theories in the vicinity of a critical point.
We discuss as an example the behaviour of Polyakov loop correlators in the vicinity of the deconfinement transition of the (3+1) SU(2) Lattice Gauge Theory. We show that the short distance behaviour of the correlator (and thus of the interquark potential) is precisely described by conformal perturbation theory and that this result can be used to
improve our understanding of the spectrum of bound states of the theory.

QCD theory/phenomenology / **16**

Unitarity constraint on three-to-three scattering amplitude

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Parameterizing the two-body scattering amplitude by an isobar in each partial wave, we are able to express the three-body scattering amplitude in terms of the isobar propagator and isobar-spectator scattering amplitude in terms of Bethe-Salpeter equation. Analytic properties of all building blocks are determined exactly, imposing three-body unitarity. Subsequently dispersion relations are used to determine explicit form of the three-to-three scattering amplitude.

Subsequent application towards the determination of the finite-volume energy spectrum will be presented at the end of the talk.

BSM and QCD / **17**

Nonperturbative applications of the functional renormalization group

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The functional renormalization group is a nonperturbative semi-analytic tool for continuum computations in quantum field theory and high energy theory, and I will present some illustrative examples

of its modern applications. It has been quite successful in describing chiral symmetry breaking and quantum criticality in three dimensional fermionic systems, as I will briefly review with some remarks on the phenomenon of emergent supersymmetry. It is also extensively used to provide a first-principle account of the strongly interacting regime of QCD, although special care is required concerning the treatment of gauge symmetry in this formalism. I will shortly outline some ongoing work on this particular problem. Finally, it has been applied to the electroweak sector of the Standard Model, in the search for a more complete field-theoretical understanding of it. In particular, I will mention some results on the possible UV completion of the Standard Model through complete asymptotic freedom.

QCD theory/phenomenology / **18**

Energy-momentum tensor for unpolarized proton target

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The expectation value of the quantum energy-momentum tensor (EMT) for an unpolarized proton target in the Breit frame can be matched with an anisotropic perfect fluid EMT. This matching offers the possibility of interpreting the EMT form factors in terms of the internal energy and transverse/radial pressure inside an unpolarized proton target.

The generalization of this result to a more general class of frames leads to additional terms in the anisotropic fluid EMT, which can be related to the rotation and spin of proton.

We illustrate these results using current phenomenological knowledge of the EMT form factors.

Dyson-Schwinger / **19**

Understanding baryons with Dyson-Schwinger and Bethe-Salpeter equations

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The calculation of hadronic observables using a combination of Dyson-Schwinger and Bethe-Salpeter equations has developed dramatically in recent years. The method aims at the calculation of hadronic properties
from the underlying QCD degrees of freedom, without abandoning the realm of continuum quantum field theories.

We report on the most recent calculations of the spectrum and electromagnetic properties of baryons in this
framework, highlighting the physical mechanisms that are currently included/excluded in those calculations.
Moreover, we outline the developments that will, foreseeably, take place in the near future, and how

theywill make the corresponding results reliable enough to be use as input for calculations in which hadronic
information is needed.

XYZ and Heavy quarks / **20**

Spin-splittings in heavy quarkonium hybrids

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The unambiguous establishment of a gluonic spectroscopy (glueballs and quark-gluon hybrids) will change the way we think the matter is constructed: gluons participate at the same level than quarks in building it. This feature is unique in quantum chromodynamics (QCD) and can be traced back to the self-interaction capacity of gluons. It is difficult to single out which states of the hadronic spectrum are glueballs due to the (expected) strong mixing between them and conventional mesons. However, valence gluonic degrees of freedom increase the quantum numbers that are available to quark-antiquark systems and thus they cannot be confused. The Born-Oppenheimer effective field theory has been designed to describe quark-gluon hybrids containing heavy quarks. The charmonium- and bottomonium-hybrid multiplets within this approach were presented elsewhere and compare nicely with the most recent lattice results for ccg mesons (no lattice simulations of the same multiplets have been performed for the bottomonium hybrids since the full treatment of the b-quark on the lattice seems to be tricky). We focus now on the computation of spin-dependent splittings of charmonium hybrids that belong to the lowest multiplets. This involves nonperturbative contributions that should be fitted attending to Lattice results. We naturally extend our study to the bottomonium sector and thus present a novel prediction of the low-lying bottomonium hybrids which is QCD-based, model independent and systematically improvable.

Amplitude analysis and Light Quarks / **21**

Excited mesons and resonances from lattice QCD

Author: Christopher Thomas[1]

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I will discuss recent progress in studying excited and exotic mesons using first-principles lattice QCD calculations, an area where there have been significant advances in the last few years. In particular, some results on excited mesons, resonances and related phenomena in the light and heavy sectors will be highlighted, including work on heavy tetraquarks, open-charm mesons and light scalar mesons. I will comment on applications to other phenomenologically-interesting channels and future prospects.

QCD theory/phenomenology / **22**

Solving the Homogeneous Bethe-Salpeter Equation in Minkowski space

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Co-authors: Michele Viviani [2]; Tobias Frederico [3]

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Recently a new formal tool, based on both the Nakanishi integral representation of the Bethe-Salpeter amplitude and the so called light-front projection, has been adopted for obtaining actual solutions of the Bethe-Salpeter equation. A wide investigation of both spectra and light-cone momentum distributions have been carried on for bound systems with and without spin degrees of freedom, in ladder approximation. Some physically relevant cases will be discussed, as well as some perspectives, like the possibility to dress the propagators of both constituents and exchanged boson, as well as the interaction vertex.

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Simple states of QCD's nearest relatives

Author: Thomas DeGrand[1]

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I'll describe lattice spectroscopy of SU(N) gauge theories with N in the range 2-7, with a small number of fermion degrees of freedom. These are systems which are most similar to QCD: they are confining and chirally broken. The simple states are s-wave mesons and baryons.
Specific systems I have studied are SU(N) gauge theories, quenched or with Nf=2 fundamental quarks and SU(4) with two index antisymmetric (AS2) representation fermions and with fermions in both fundamental and AS2. The most naive application of the nonrelativistic quark model combined with 't Hooft large N counting seems
to explain all the lattice data. Baryons show clear evidence for a rotor spectrum.
Mixed states (baryons made of two representations of quarks) show regularities
related to the different color charges of the two representations.

QCD theory/phenomenology / 24

Confinement Criteria and the Higgs Mechanism

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Although color neutrality of the QCD spectrum is the historical definition of confinement, we know that a color neutral particle spectrum is also a feature of gauge-Higgs theories in the Higgs regime, and this means that such theories are also "confining,"at least by the historical definition. In this talk I will suggest that a confinement property stronger than color neutrality, which generalizes Wilson's area-law criterion in a pure gauge theory, holds in QCD and in the QCD-like regime of gauge-Higgs theories. I will also address the question of what symmetry is actually broken in the Brout-Englert-Higgs mechanism.

Amplitude analysis and Light Quarks / **25**

Companion poles in light and heavy mesonic sectors

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A standard quark-antiquark state gets dressed by meson-meson clouds corresponding to its decay product and its pole moves down in the complex plane. If some conditions are met (coupling constant strong enough nearby energy threshold(s)), additional. so-called companion poles may emerge, which correspond to a type of dynamically generated states. For instance, the light scalar states $K_0^*(800)$ and $a_0(980)$ can be interpreted as a companion poles of the predominantly standard quark-antiquark state $K_0^*(1430)$ and $a_0(1450)$. In the charmonium sector, the predominately charm-anticharm resonance $\psi(3770)$ is also described by two poles, a standard quark-antiquark pole and a companion one, the latter being responsible for the peculiar form of the left part of its spectral function. In the future, the mechanism of companion poles can be tested on other yet unexplained X and Y resonances.

QCD theory/phenomenology / **26**

An approach to QCD bound states

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Light hadrons are relativistic, strongly bound states with large gluon and sea quark distributions. Interestingly, hadrons also have properties akin to non-relativistic atoms, despite confinement and chiral symmetry breaking. Hadron quantum numbers appear to be determined by the valence quarks only. The quark model is quite successful, especially for quarkonia. The OZI rule and duality provide further clues to hadron dynamics.

The understanding of bound states developed gradually in QED. NRQED provides an efficient expansion in the rest frame, where solutions of the Schr\"odinger equation appear at lowest order. Various forms of the Bethe-Salpeter equation define equivalent, alternative approaches. Bound state perturbation theory is not unique since atomic wave functions are exponential, gauge dependent functions of the coupling α. However, all approaches must give the same perturbative series for the (measurable) binding energies.

The Schr\"odinger equation defines a "bound state Born term" in an $\hbar$ expansion of QED, where the classical fields of the constituents provide the binding. The instantaneous nature of the A^0 gauge field allows a corresponding Born approximation also for relativistic bound states in QCD. Poincar\'e invariance implies a linear confining potential when a non-vanishing boundary condition is imposed on the classical solutions of Gauss' law for A^0_a. The boundary condition defines the \order{\alpha_s^0} dimensionful constant Λ_{QCD}, and a perturbative expansion around the Born term may be envisaged. I describe some results obtained in such an approach to hadrons.

Amplitude analysis and Light Quarks / **27**

Quark mass dependence of photon pion scattering

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Usually the simulation of scattering processes in lattice QCD is carried out at unphysical high values of the quark masses [1]. Hence, a method to extrapolate data obtained in lattice calculations to physical masses is needed to allow for comparison between theory and experiment. To obtain a sound extrapolation, dispersion relations and chiral perturbation theory can be invoked. While a simple combined approach known as the inverse amplitude method allows for a successful extrapolation of $\pi\pi \to \pi\pi$ data [2], a more complicated framework is needed for inelastic processes such as $\gamma\pi \to \pi\pi$. By extending the dispersive description derived in Ref. [3], the extrapolation can be performed for $\gamma\pi \to \pi\pi$ both for on-shell as well as virtual photons. This particular process is interesting due to both its contribution to the anomalous magnetic moment of the muon and its connection to the axial anomaly.

References:
- [1] Briceno et al.: https://arxiv.org/abs/1507.06622
- [2] Bolton, Briceno, Wilson: https://arxiv.org/abs/1507.07928
- [3] Hoferichter, Kubis, Sakkas: https://arxiv.org/abs/1210.6793

Summary:

We investigate the quark mass dependence of the process $\gamma\pi \to \pi\pi$ using dispersion relations and chiral perturbation theory.

Amplitude analysis and Light Quarks / **28**

Resonant scattering amplitudes from lattice QCD

Author: John Bulava[1]

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I will review the methods used to calculate two-hadron scattering
amplitudes from lattice QCD. Particular emphasis will be placed on controlling the various systematic errors inherent in such calculations, such as those due to the lattice spacing and finite volume. As illustrative examples, I will discuss recent and ongoing results for amplitudes containing the rho(770), K*(892), Delta(1232), and Lambda(1405) resonances.

XYZ and Heavy quarks / **29**

Hybrid and pentaquark states

Author: Elena Santopinto[1]

[1] *INFN*

Theoretical predictions on hybrid and pentaquark spectroscopy will be presented and discussed

Amplitude analysis and Light Quarks / 30

Light-meson spectroscopy with COMPASS

Author: Boris Grube[1]

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COMPASS is a multi-purpose fixed-target experiment at the CERN Super Proton Synchrotron aimed at studying the structure and spectrum of hadrons. One of the main goals of the experiment is the study of the light-meson spectrum. In diffractive reactions with a 190 GeV/c negative pion beam, a rich spectrum of isovector mesons is produced. The resonances decay typically into multi-body final states and are extracted from the data using partial-wave analysis techniques. We have performed the so far most comprehensive analysis of this kind on the \pi^-\pi^-\pi^+ final state, for which COMPASS has acquired a large data set of 46 million event. In a novel approach, we take into account the dependence of the production process on the squared four-momentum transfer t from the beam to the target particle. As a consequence, we are able to better separate resonant and non-resonant contributions and we extract for the first time the dependence of the resonant and non-resonant amplitudes on t. We will present results and discuss the challenges of this analysis.

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Dispersive Analysis of Mesonic 3-Body Decays

Author: Tobias Isken[1]

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I will present a dispersive analysis of mesonic 3-body decay amplitudes based on the fundamental principles of analyticity and unitarity. In this framework the leading final-state interactions are fully taken into account.

The first part of the talk will focus on the $\eta' \to \eta\pi\pi$ decay channel [arXiv:1705.04339 [hep-ph]]. This decay offers several features of interest: due to final-state interactions it can be used to constrain $\eta\pi$ scattering. The neutral channel ($\eta' \to \eta\pi^0\pi^0$) shows a cusp effect within the physical decay region. It is also an essential input for a study of inelastic effects in the decay $\eta' \to 3\pi$.

The second part of the talk is focused on the $\omega \to 3\pi$ decay. I will demonstrate how the dispersive framework can be used to investigate the quark mass dependence for a 3-body resonance. This can serve as extrapolation tool for lattice QCD calculations. Here the ω serves as paradigm case, the framework can be generalised to other 3-body decay processes.

BSM and QCD / 32

S-matrix bootstrap revisited

Author: Joao Penedones[1]

[1] *EPFL*

Inspired by the recent success of the numerical approach to the conformal bootstrap, we revisit the S-matrix bootstrap program. We shall explain how to obtain analytic bounds on the interaction strength in 1+1 QFT. In higher dimensions, we propose a numerical algorithm that seems to converge to optimal bounds.

BSM and QCD / 33

Numerical exploration of a mass-split model with four light and eight heavy flavors

Author: Oliver Witzel[1]

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Using the specific example of four light and eight heavy flavors we explore mass-split models using fully dynamical numerical simulations. We present results for the meson spectrum showing states made up of only light or only heavy flavors in order to verify theoretical expectations. With results obtained at two values of the bare gauge coupling, five different values for the mass of heavy flavors, and up to six different light quark masses, we demonstrate hyperscaling and the irrelevance of the gauge coupling. We find that the heavy-heavy spectrum is qualitatively different from QCD, e.g. the mass of the heavy-heavy quarkonia is no longer proportional to the constituent quark mass.

We close by presenting an outlook on ongoing work with four light and six heavy flavors. The aim of this work is to confirm our previous findings and explore a system expected to have a larger anomalous dimension critical for phenomenological applications.

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Exotic hadrons with heavy quarks: experimental perspective

Author: Skwarnicki Tomasz[1]

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B-factory, charm-factory and hadron-collider experiments have produced evidence for a large number of heavy hadronic structures with unusual properties. We will discuss their experimental signatures, together with underlying uncertainties and future prospects for improvement.

Amplitude analysis and Light Quarks / **36**

Dispersive and analytic approach to pion and kaon interactions

Author: Jose Pelaez[1]

[1] *Universidad Complutense de Madrid*

I present here some recent results we obtained by applying dispersion relations and other methods based on analyticity on the complex plane, to determine scattering amplitudes with pions and kaons from data and to determine resonance parameters.

QCD theory/phenomenology / **37**

Baryons in the Dyson-Schwinger approach

Author: Gernot Eichmann[1]

[1] *IST Lisboa*

I will present results for light and strange baryons in the Dyson-Schwinger/Bethe-Salpeter approach. Their ground-state properties obtained from three-quark and quark-diquark calculations agree well, and with a few exceptions also the excited-state spectra can be well reproduced and interpreted from their underlying diquark structure. The formalism provides a path towards addressing multiquark systems and as an example I will discuss the case of the light scalar mesons.

BSM and QCD / **38**

Large scale separation from mass-split BSM models

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Beyond Standard Model theories describing the electro-weak sector
with a 125 GeV Higgs boson but with so far no other observed resonances must be consistent with large scale separation or "walking". Large separation of scales arises naturally and in a tunable manner in mass-split models that are built on a conformal fixed point in
the ultraviolet. When the fermion masses are split, with some kept
light (or massless) and others are heavy, the system exhibits
conformal behavior in the ultraviolet but is chirally broken in the
infrared.

XYZ and Heavy quarks / **39**

Conventional quarkonia: few experimental ideas

Author: Umberto Tamponi[1]

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The quarkonium physics has developed a double nature in the past decade. While the spectrum above the open flavour threshold is revealing an increasing number of unexpected states of exotic nature, the narrow states below the threshold are an ideal environment to test the QCD effective field theories at the limits of their precision. The current generation of experiments, like Belle II, BESIII and LHCb offer a unique, and maybe last chance to this kind of study. We will present here the experimental prospects on the study of the narrow quarkonia structure, with a focus on the bottomonium sector. The search for rare decays and the opportunities to perform precision measurements of the ground states parameters will be discussed, together with an overview of the opportunities to investigate the light mesons and baryons properties offered by the study of the quarkonium inclusive annihilation.

BSM and QCD / 40

Dark Matter from new strong dynamics

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The observed abundance of Dark Matter may be explained by particle candidates which are bound states of new strongly-interacting dynamics. Stability of such candidates can be the consequence of accidental symmetries as it happens for the proton in the Standard Model. I will consider theories with fermions in the adjoint representation of the dark gauge group and discuss their rich phenomenology.

BSM and QCD / 41

QCD screening masses in external fields

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We discuss recent lattice results concerning the influence of external backgrounds, such as magnetic fields and chemical potentials, on the confining and screening properties of the QCD thermal medium.

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Pentaquarks and Hadronic Interactions

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The phenomenology of the LHCb pentaquarks is studied with special attention to the role that hadronic interactions play. Among these are electroweak decays, final state interactions, and one-pion exchange.

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Flavor hierarchies from dynamical scales

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One main obstacle for any BSM scenario solving the hierarchy problem is its potentially large contributions to electric dipole moments. An elegant way to avoid this problem is to have the light SM fermions couple to the BSM sector only through bilinears. This possibility can be neatly implemented in composite Higgs models by dynamically generating the fermion Yukawa couplings at different scales and relating larger scales to lighter SM fermions. In this way, all flavor and CP-violating constraints can be easily accommodated for a BSM scale of few TeV, without requiring any extra symmetry. Contributions to B physics are mainly mediated by the top, giving a predictive pattern of deviations in flavor observables that could be seen in future experiments.

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Exotic hadron spectroscopy results and perspectives in CMS

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Hadron Spectroscopy has experienced a renaissance in the last 15 years thanks to the experimental findings at B-factories, Tevatron and - in the last years - at the LHC. Quarkonium has become again a tool for discoveries of new phenomena in the complex realm of low-energy QCD. The analyses of LHC Run-I data are contributing to provide new experimental observations and measurements for the exotic (quarkonium-like) mesons. Despite of the absence of an hadronic identification, and thanks to its tracking and muon identification capabilities, CMS has provided few important results in this sector of QCD: study of the production of the X(3872) and search for its neutral bottomonium partner, observation of peaking structures into J/psiPhi mass spectrum, observation of double quarkonia production, the search for the unconfirmed X(5568). CMS can continue playing a relevant role with analyses of Run-II data. The aformentioned results will be reviewed in their wider context and the perspectives with Run-II data will be discussed.

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Production of light mesons in central diffractive pp collisions

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We discuss central exclusive diffractive production of light mesons in the reactions $pp \to pp\pi^+\pi^-$ and $pp \to ppK^+K^-$ at high energies. The calculation is based on a tensor pomeron model [1] and the amplitudes for the processes are formulated in an effective field-theoretic approach. We include a purely diffractive dipion continuum, the scalar and tensor resonances decaying into the $\pi^+\pi^-$ pairs [2, 3] as well as the photoproduction contributions (ρ^0, Drell-S\"oding) [4]. The theoretical results are compared with existing STAR, CDF, and CMS experimental data. Predictions for planned or being carried out experiments ALICE, ATLAS, LHCb are presented. We show the influence of the experimental cuts on the integrated cross section and on various differential distributions for outgoing particles. Distributions in rapidities and transverse momenta of outgoing protons and pions as well as correlations in azimuthal angle between them are presented. We discuss how two pomerons couple to tensor meson $f_2(1270)$ and the interference effects of resonance and dipion continuum. We discuss the $pp \to pp\pi^+\pi^-\pi^+\pi^-$ reaction via the intermediate $\sigma\sigma$ and $\rho\rho$ states [5]. The correct inclusion of the pomeron spin structure seems crucial for the considered sequential mechanisms in particular for the $\rho\rho$ contribution. We consider also the central exclusive production of the $p\bar{p}$ in the continuum and via resonances in proton-proton collisions [6]. We discuss the diffractive mechanism calculated within the tensor-pomeron approach including both pomeron and reggeon exchanges.

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Constraining the production mechanisms of mesonic systems

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We have conducted studies on the production mechanism of various channels, which are being analyzed at Jefferson Lab. These include pseudoscalar and vector meson production. Using the constraint of analyticity of the amplitudes, we are able to propagate experimental information from one energy regime to the other. This approach relates properties of the baryon spectrum to the dynamics of meson exchanges. These models will be useful in the hunt for exotic mesons at JLab in the near future.

QCD theory/phenomenology / 47

Relativistic three-particle bound states in a box

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Numerical lattice QCD calculations are necessarily restricted to a finite volume and this can significantly modify observables, especially those involving multi-hadron states. Over the past few years, great progress has been made in deriving and generalizing quantization conditions that relate finite-volume energies to infinite-volume two- and three-particle scattering amplitudes. Using a relativistic version of this formalism, I will present numerical results relating the properties of three-particle bound states in finite and infinite volume.

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Light meson spectroscopy on the lattice

Author: Raul Briceno[1]

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The non-perturbative nature of quantum chromodynamics (QCD) has historically left a gap in our understanding of the connection between the fundamental theory of the strong interactions and the rich structure of experimentally observed phenomena. For the simplest properties of stable hadrons, this can now be circumvented using lattice QCD. In this talk I discuss a path that will allow us to access a variety of previously unexplored sectors of QCD. I will focus my attention to the isoscalar mesonic sector of QCD. Carrying the quantum numbers of the vacuum, this is perhaps one the most interesting channels in hadronic physics.

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Multiquarks Hadrons and QCD with Many Colours

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Conventional and exotic meson states in the DSE/BSE framework

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We summarize recent results on the spectrum (and form factors) of conventional and exotic meson states in the DSE/BSE framework. We contrast states with conventional and exotic quantum numbers and outline the ability of the framework to accommodate for glueball, hybrid and four-quark states.

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S matrix approach to 2 and 3 body interactions

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I will talk about the S matrix approach to describe 2 and 3 body hadron interactions

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EIC Discussion

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Amplitude analysis for exotic states

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I will discuss some recent development in amplitude analysis to improve the description of exotic states

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TBD

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Colored bound states and dynamical mass generation

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The dynamics leading to the formation of coloured composite massless excitations in Yang-Mills theory is interlocked with the one leading to the generation of a gluon mass scale in the infrared. I will discuss how the Bethe-Salpeter equation leading to the former structures is coupled to the Schwinger-Dyson equation leading to the latter phenomenon, paying particular attention to the self-consistency of the entire picture.

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Welcome

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Concluding remarks

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Discussion