

# **HADRON 2017**

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## **Book of Abstracts**



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**Analysis tools / 1****Dispersive Analysis Tools for Light Hadrons****Authors:** Jose R. Pelaez<sup>None</sup>; Arkaitz Rodas Bilbao<sup>1</sup><sup>1</sup> *Universidad Complutense de Madrid***Corresponding Authors:** jrpelaez@fis.ucm.es, arodas@ucm.es

I review recent results on dispersive analyses of pion-pion and kaon-pion amplitudes and the extraction of resonance parameters using dispersion relations or analytic methods

**Exotic states and candidates / 3****Hidden charm pentaquarks and tetraquark states****Authors:** Hua-Xing Chen<sup>1</sup>; Wei Chen<sup>2</sup>; Xiang Liu<sup>3</sup>; Shi-Lin Zhu<sup>4</sup><sup>1</sup> *Beihang University*<sup>2</sup> *University of Saskatchewan*<sup>3</sup> *Lanzhou University*<sup>4</sup> *Peking University***Corresponding Authors:** hxchen@aliyun.com, xiangliu@lzu.edu.cn, wec053@mail.usask.ca

In the past decade many charmonium-like states were observed experimentally, including many charmonium-like XYZ states and the hidden-charm pentaquark states Pc(4380) and Pc(4450). We systematically investigate their mass spectra using the method of QCD sum rules. Especially, we pay attention to their internal structure by constructing all the relevant local hidden-charm tetraquark and pentaquark currents. Through these currents, we also investigate their possible decay modes.

**Poster session / 4****Compton scattering off the proton in the resonance region****Authors:** Xu Cao<sup>None</sup>; Horst Lenske<sup>None</sup>

Compton scattering off the proton in the third resonance region is analyzed, owing to the full combined analysis of pion- and photo-induced reactions in a coupled-channel effective Lagrangian model with K-matrix approximation. Two isospin  $I=3/2$  resonances D33(1700) and F35(1930) are found to be essential in the range of 1.6 - 1.8 GeV. The recent beam asymmetry data of Compton scattering from the GRAAL facility are used to determine the helicity couplings of these resonances, and strong constraints are coming also from  $\pi N$  and  $K\Sigma$  photoproduction data. The possible spin and parity of new narrow resonances is discussed.

**Analysis tools / 7****The  $a_1(1420)$  peak as the special decay mode of the  $a_1(1260)$** **Authors:** Lianrong Dai<sup>1</sup>; Francesca Aceti<sup>None</sup>; Eulogio Oset<sup>None</sup>

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I will present the recent work [Phys Rev D94(2016) 096015] about the  $a_1(1420)$  peak which is experimentally and theoretically interesting. We study the decay mode of the  $a_1(1260)$  into  $\pi^+ \pi^-$  in p-wave and the  $f_0(980)$  that decays into  $\pi^+ \pi^-$  in s-wave. The mechanism proceeds via a triangular mechanism where the  $a_1(1260)$  decays into  $\bar{K} K$ , the  $K$  decays to an external  $\pi^+$  and an internal  $K$  that fuses with the  $\bar{K}$  to produce the  $f_0(980)$  resonance. The mechanism develops a singularity at a mass of the  $a_1(1260)$  around 1420 MeV, producing a peak in the cross section of the  $\pi^+ \pi^-$  reaction, used to generate the mesonic final state, which provides a natural explanation of all the features observed in the COMPASS experiment, where a peak observed at this energy is tentatively associated to a new resonance called  $a_1(1420)$ . On the other hand, the triangular singularity studied here gives rise to a remarkable feature, where a peak is seen for a certain decay channel of a resonance at an energy about 200 MeV higher than its nominal mass.

**Spectroscopy of mesons / 8**

## The study of B weak decay and the scalar $D\bar{D}$ bound state

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I will present our recent work of [Eur Phys J C76 (2016) 121]. We study the B weak decay based on the chiral unitary approach that generates the  $X(3720)$  resonance, and make predictions for the  $D\bar{D}$  invariant mass distribution. From the shape of the distribution, the existence of the resonance below threshold could be induced. We also predict the rate of production of the  $X(3720)$  resonance to the  $D\bar{D}$  mass distribution with no free parameters.

**Hadron decays / 9**

## Electric dipole transitions in potential nonrelativistic QCD

**Authors:** Nora Brambilla<sup>1</sup>; Jorge Segovia<sup>1</sup>; Sebastian Steinbeißer<sup>1</sup>; Antonio Vairo<sup>1</sup>

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Electric (E1) and magnetic (M1) dipole transitions have been studied since the early days of hadron spectroscopy because they allow to access heavy quarkonium states which are below open-flavour threshold. Moreover, these reactions are interesting by themselves because they are an important tool to check particular regions of the hadrons' wave function and thus to determine their internal structure and dynamics.

Electromagnetic transitions between heavy quarkonium states have been treated for a long time by means of potential models that use nonrelativistic reductions of phenomenological interactions. However, the progress made in effective field theories (EFTs) for studying heavy quarkonia and the new large set of accurate experimental data taken in the heavy quark sector by  $B$ -factories (BaBar, Belle and CLEO),  $\tau$ -charm facilities (CLEO-c, BESIII) and even proton-proton colliders (CDF, D0, LHCb, ATLAS, CMS) ask for a systematic and model-independent analysis.

This contribution aims to present the first numerical determination of the electric dipole transitions:  $\chi_{b,J}(1P) \rightarrow \gamma\Upsilon(1S)$  (with  $J = 0, 1, 2$ ) and  $h_b(1P) \rightarrow \gamma\eta_b(1S)$ , using the low-energy EFT called potential nonrelativistic QCD (pNRQCD). At the first instance, we assume that the heavy mesons involved in the studied reactions lie in the strict weak-coupling regime of pNRQCD and thus a full perturbative calculation can be performed. Relativistic corrections of relative order  $\mathcal{O}(v^2)$  are included. The analysis separates those contributions that account for the  $v^2$ -suppressed electromagnetic interaction terms in the pNRQCD Lagrangian and those that account for quarkonium state corrections of relative order  $\mathcal{O}(v^2)$ . Within the last ones, corrections come from higher-order potentials ( $\mathcal{O}(1/m)$  and  $\mathcal{O}(1/m^2)$  terms) and from higher Fock states which account for the coupling of the quark-antiquark state to other low-energy degrees of freedom and thus demand nonperturbative input.

Results within the former scheme show dramatic dependence on the renormalization scale, leading to final numbers with large theoretical uncertainties. We then repeat the calculation including exactly the static potential in the leading order Hamiltonian and also resumming the large logarithms associated with the heavy quark mass scale. The effect of the new power counting and the exact treatment of the soft logarithms of the static potential makes the factorization scale dependence much smaller. Since the convergence in the new scheme is found to be quite good, we give solid predictions for the E1 transitions studied.

Poster session / 10

## On the $J/\psi \rightarrow \gamma\eta_c \rightarrow \gamma X$ line-shape in pNRQCD

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The  $J/\psi \rightarrow \gamma\eta_c$  branching fraction was first measured in 1986 by the Crystal Ball Collaboration in the inclusive photon spectrum and the value  $\mathcal{B}(J/\psi \rightarrow \gamma\eta_c \rightarrow \gamma X) = (1.27 \pm 0.36)\%$  was obtained. There are many theoretical predictions for this decay rate, based on potential models, QCD sum rules, nonrelativistic EFTs and lattice QCD, but as a rule they lead to values approximately twice as large as the Crystal Ball result. No new measurements of this branching fraction were performed until 2009 when the CLEO Collaboration reported a value  $\mathcal{B}(J/\psi \rightarrow \gamma\eta_c) = (1.98 \pm 0.09 \pm 0.30)\%$ , closer to theoretical predictions. Combining the Crystal Ball and CLEO results, PDG obtained  $\mathcal{B}(J/\psi \rightarrow \gamma\eta_c) = (1.7 \pm 0.4)\%$ . More recently the KEDR Collaboration measured the transition and reported a much higher figure,  $(3.40 \pm 0.33)\%$ , triggering questions on the actual value of this branching fraction and on possible issues when extracting it experimentally.

One of the crucial ingredients in the determination of the branching fraction from experimental measurements is the photon spectrum line-shape used in the analysis. The CLEO Collaboration observed for the first time a clear asymmetry in the photon energy spectrum line-shape due to phase-space and energy-dependent terms in the  $J/\psi \rightarrow \gamma\eta_c$  transition matrix element. In order to obtain a good fit to the data, the photon spectrum line-shape was constructed with a relativistic Breit-Wigner distribution modified by a factor  $k^3$ , where  $k$  is the photon energy. However, adding this factor led to a divergent tail at large photon energies and an *ad hoc* damping function was included in order to suppress this behaviour, arguing that it modeled the overlap between the charmonium wave functions. Nevertheless, such damping factor does not appear in the theoretical studies of the same branching fraction and thus it is not well justified. The analysis by the KEDR Collaboration followed a similar approach incorporating a different, non-theoretically motivated, damping function, and found that the sensitivity of its branching ratio measurement with respect the damping function is actually quite large.

We calculate the photon spectrum line-shape for the  $J/\psi \rightarrow \gamma\eta_c \rightarrow \gamma X$  process using a well suited effective field theory approach called weakly-coupled pNRQCD. We argue that the large energy tail of the line-shape is due to either polynomially or logarithmically divergent terms. Integrating the line-shape over the photon energy using DR, an analytical expression for the widths of the

$J/\psi \rightarrow \gamma\eta_c \rightarrow \gamma X$  and  $J/\psi \rightarrow \gamma\eta_c$  processes are obtained. Upon integration in DR, the polynomially divergent terms give no contribution and the logarithmically divergent term produces an UV divergence that can be subtracted in  $\overline{\text{MS}}$  scheme and renormalized.

We propose to analyze CLEO's data using a photon spectrum line-shape in which the UV divergent terms are subtracted in a manner consistent with the calculation of the decay width in DR and  $\overline{\text{MS}}$  scheme. The signal over background ratio depends on the tail of the line-shape at large photon energies. Using either an unsubtracted line-shape or a hard cut-off in its integration, the large energy tail leads to a determination of a branching fraction which is incompatible with the above theoretical estimate and with the PDG's average value. The subtracted line-shape shows a suppression at large photon energies that leads to compatible experimental and theoretical determinations of the branching fractions for the processes  $J/\psi \rightarrow \gamma\eta_c \rightarrow \gamma X$  and  $J/\psi \rightarrow \gamma\eta_c$ .

**Poster session / 13**

## Shannon entropy and hadron decays

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How much information is added to the Review of Particle Physics when a new decay branching ratio of a hadron is measured and reported? This is quantifiable by Shannon's information entropy. It may be used at two levels, the distribution of decay-channel probabilities, and the distribution of individual quantum-state probabilities (integrating the later provides the former). We illustrate the concept with some examples.

**Analysis tools / 15**

## Three-body scattering in isobar ansatz

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In the so-called isobar ansatz the three-particle states can only be populated via an interacting two-particle system (resonant or non-resonant), and a spectator. Using this ansatz, we derive the isobar-spectator interaction such that the three-body unitarity is ensured exactly.

Some of the final equations are similar to the old Amado/Aaron/Young approach, however do not rely on arguments which are valid for bound-state isobars only. Possible extensions and applications are discussed as well.

**Analysis tools / 16**



## Model selection for pion photoproduction

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Partial-wave analysis of meson and photon-induced reactions is needed to enable the comparison of many theoretical approaches to data. In both energy-dependent and independent parametrizations of partial waves, the selection of the model amplitude is crucial. Principles of the S matrix are implemented to a different degree in different approaches; but a many times overlooked aspect concerns the selection of undetermined coefficients and functional forms for fitting, leading to a minimal yet sufficient parametrization. We present an analysis of low-energy neutral pion photoproduction using the least absolute shrinkage and selection operator (LASSO) in combination with criteria from information theory and K-fold cross validation. These methods are not yet widely known in the analysis of excited hadrons but will become relevant in the era of precision spectroscopy. The principle is first illustrated with synthetic data; then, its feasibility for real data is demonstrated by analyzing the latest available measurements of differential cross sections, photon-beam asymmetries, and target asymmetry differential cross sections in the low-energy regime.

### Spectroscopy of mesons / 17

## Coherent double neutral Pion Photoproduction off Deuterons

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Photoproduction of meson pairs off nucleons has gained a lot of interest mainly because it allows to study sequential decays of nucleon resonances via some intermediate excited states. This may give access to states that have only tiny decay branching ratios for direct decays to the nucleon ground state by emission of a single meson. In particular, pion pairs and pi-eta pairs have been studied in detail during the last few years.

In the present talk we will discuss recent results from the production of  $\pi^0$  pairs from deuterons. The study of quasifree production from protons and neutrons bound in the deuteron helps to disentangle the isospin decomposition of the production amplitudes.

However, for  $\pi^0$  pairs also the coherent reaction mechanism off the deuteron, i.e. the final state  $\pi^0\pi^0d$  is of great interest. Also this reaction can of course contribute to the isospin decomposition but there is a more exciting aspect. Recently, a narrow resonance structure has been observed in the  $pn \rightarrow d\pi^0\pi^0$  reaction which has been discussed as a possible candidate for an unconventional six-quark,  $d(2380)$  di-baryon resonance. *If such a state exists it should in principle also show up in  $\gamma d \rightarrow d\pi^0\pi^0$ , although the production cross section would be much smaller than in the hadron induced reaction.*

*Coherent photoproduction of mesons off the deuteron or other light nuclei has so far almost not been explored. The only final state which is reasonably well studied is  $d\pi^0$  in the energy range of the  $\Delta$  resonance. Apart from that there are only few results for  $\eta$ ,  $\eta'$ , and  $\eta\pi$  production.*

*In the present contribution we summarize recent preliminary results for the  $\gamma d \rightarrow d\pi^0\pi^0$  reaction. The experiment was performed at the tagged photon beam of the MAMI accelerator in Mainz with the combined Crystal Ball/TAPS electromagnetic calorimeter. The excitation function for this reaction was studied from the energy region of the tentative  $d(2380)$  state throughout the second and third resonance region of the nucleon.*

### Exotic states and candidates / 18

## Shedding light on Hexaquarks

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Several new findings in the four, five and six quark systems reheat the interest in the field of multi-quark states (beyond trivial  $q\bar{q}$  and  $qqq$ ). A lot of progress has recently been made in the  $6q$  sector, on both the theoretical and experimental side. A resonance like structure observed in double-pionic fusion to the deuteron, at  $M=2.38$  GeV with  $\Gamma = 70$  MeV and  $I(J^P) = 0(3^+)$  has been consistently observed in a wealth of reaction channels, supporting the existence of a resonant dibaryon state - the  $d(2380)$ . *These studies include measurement of all the principle strong decay channels in  $pn$  collisions in the quasi-free mode by the WASA-at-COSY and HADES collaborations.*

*The internal structure of the  $d(2380)$  is largely unknown. It can contain various hidden color  $6q$  configurations,  $\Delta\Delta$  molecular states with angular momentum  $L=0,2,4,6$  as well as meson-assisted dressed dibaryon structures. The large set of experimental data obtained to date gives some constraints on the internal structure of the  $d(2380)$  dibaryon, but does not settle the issue. The  $d$  is the only multi-quark state which can be produced copiously at current facilities, offering unique access to information beyond its basic quantum numbers, particularly its physical size and internal structure. The first exciting new results on  $d$  photoproduction will be reported. Future plans to improve our understanding of the  $d$  will also be presented, including the exciting possibilities for investigation of the SU(3) multiplet companions and mirror partners of the  $d^*$ .*

**Poster session / 20**

## Hadroproduction and production on nuclear targets of phi-mesons in the Quark-Gluon String model

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We use the Quark-Gluon String Model to obtain a quantitatively good description of the phi-meson production experimental data in hadron-nucleon collisions on the spectra of secondary phi, as well as on the ratios of phi/pi- and phi/K- production cross sections, for a wide energy region. We also consider the experimental data on phi-meson production on nuclear targets, and we find that they present unusually small shadow corrections for the inclusive density in the midrapidity region.

**Poster session / 21**

## Formulating electroweak pion decays in functional methods

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In binary neutron star mergers the dynamical backcoupling of the electroweak interaction to the neutron matter is relevant. To describe this, a coupled non-perturbative treatment of both sectors is necessary. Functional methods, like Bethe-Salpeter-Equations and the Functional-Renormalization-Group can be used for this purpose. Since the dominant process is beta-decay, a first necessary step is to describe the weak pion decay with these methods. We present how to implement this process in these functional methods, and provide first results of this description.

**Spectroscopy of baryons / 22**

## Mass spectra of triply beauty $\Omega_{bbb}$ baryon

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$\Omega_{bbb}$  is triply heavy beauty quark baryon which makes the system very interesting. We do not have any experimental observed states for  $\Omega_{bbb}$  \cite{olive}; but many lattice calculations \cite{brown, PAD2014} as well as theoretical predictions \cite{vijande2015, kwei2} have been performed for ground and excited states of this baryons. We use Hypercentral Constituent Quark model \cite{EPJC} with Coulomb plus power potential by varying potential index  $\nu$  value from 0.5 to 2.0. Our Model also identified the radial and orbital excited state masses for the baryon and try to give the range of the resonance it can be found.

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**Spectroscopy of baryons / 23**

## Study of non-strange dibaryon resonances via coherent double neutral-pion photoproduction on the deuteron

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The search for non-strange dibaryon bound/resonance states has a long history. A dibaryon state is of interest, which can be a molecule consisting of

two baryons or a spatially compact hexaquark object. The  $d^*(2380)$  resonance observed in the  $pn$ -collision reactions by the CELESIUS/WASA and WASA-at-COSY [1,2] collaborations may be attributed to an isoscalar  $\Delta\Delta$  quasi-bound state  $\mathcal{D}_{03}$ , predicted by Dyson and Xuong [3]. The  $\gamma d \rightarrow \pi^0\pi^0d$  reaction has been experimentally investigated using energy-tagged bremsstrahlung photon beams at the Research Center for Electron Photon Science (ELPH), Tohoku University, Japan [4]. The  $\gamma d$  center of mass energy  $W_{\gamma d}$  is covered from 2.38 to 2.80 GeV. All the final-state particles are detected with an electromagnetic calorimeter FOREST [5]. No clear resonance-like behavior is observed in the excitation function near  $W_{\gamma d} = 2.38$  GeV [6], where the  $d^*(2380)$  dibaryon resonance is expected to appear. The measured excitation function is consistent with the existing theoretical calculation for this reaction. At high incident energies,  $\pi^0d$  invariant-mass distributions show a peak at approximately 2.15 GeV, which can be attributed to a  $N\Delta$  quasi-bound state  $\mathcal{D}_{12}$ . We also discuss the properties of the peak observed in the  $\pi^0d$  channel.

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## Spectroscopy of baryons / 24

### Photoproduction of $\pi^0\pi^\pm$ pairs off nucleons

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Photoproduction of meson pairs (in particular  $\pi\pi$  and  $\pi\eta$  pairs) has gained a lot of interest because it gives access to nucleon resonances that decay not directly to the nucleon ground state but in a cascade decay involving an excited intermediate state. Much emphasis has been put on neutral final states ( $\pi^0\pi^0$  and  $\pi^0\eta$  pairs) which are not much effected by non-resonant background contributions. However, there are several issues which can only be investigated when also pairs with charged mesons are studied. The isospin decomposition of the reaction amplitudes is one of them. But an even more important one is that only pion pairs with charged pions allow to study the contribution of the  $\rho$  meson to nucleon resonance decays (the  $\rho^0 \rightarrow \pi^0\pi^0$  decay is isospin forbidden).

Previous results [1] have suggested that already at low incident photon energies the  $D_{13}(1520)$  nucleon resonance has a surprisingly large decay branching ratio to the  $N\rho$  final state. This is not only important for the study of free nucleon resonances. A long standing problem is the strong suppression of the second and third nucleon resonance region in total photoabsorption reactions. A possible explanation discussed for the second resonance bump is a strong in-medium modification of the  $D_{13}(1520)$  resonance caused by its coupling to the  $\rho$ -meson. For the  $\rho$  itself strong in-medium modifications have been discussed in the framework of many models and indications from experimental data have also been found (see [2] for a review). The  $\rho$ - $D_{13}$  coupling could than trigger the corresponding modifications of the  $D_{13}$ .

In a series of experiments with the Crystal Ball/TAPS detector at the Mainz MAMI accelerator we have started to study in detail the production of  $\pi^0\pi^\pm$  pairs off the free proton, the deuteron, and heavier nuclei. In the present talk mainly results from the free  $\gamma p \rightarrow p\pi^0\pi^\pm$  reaction will be presented which aim at a more precise investigation of the  $D_{13}(1520) \rightarrow N\rho$  decay and also at a detailed

investigation of the reaction amplitudes from the  $N\rho$  decay channel and sequential resonance decays at higher incident photon energy. First, preliminary results from quasi-free production of  $\pi^0\pi^\pm$  pairs off the deuteron will also be discussed in view of the isospin composition of the reaction. Data from a  $^4\text{He}$  target, which due to the high density of the helium nucleus should show significant in-medium effects, have been measured very recently, but are still in an early state of analysis.

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## QCD and hadron structure / 25

### Pion wavefunction with dynamical spin effects

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We present our predictions for pion mean charge radius, decay constant, spacelike electromagnetic form factor, twist-2 Distribution Amplitude and the photon-to-pion transition form factor when a dynamical spin structure for the pseudoscalar particle is considered along with a holographic light-front wavefunction. Our results show significant improvement in agreement with available data.

## Hadrons in matter including hypernuclei / 26

### $\phi$ meson mass and decay width in nuclear matter and nuclei

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The mass and decay width of the  $\phi$  meson in cold nuclear matter are computed in an effective Lagrangian approach. The medium dependence of these properties are obtained by evaluating kaon-antikaon loop contributions to the  $\phi$  self-energy, employing the medium-modified kaon masses, calculated using the quark-meson coupling model. The loop integral is regularized with a dipole form factor, and the sensitivity of the results to the choice of cutoff mass in the form factor is investigated. At normal nuclear matter density we find a downward shift of the  $\phi$  mass by a few percent, while the decay width is enhanced by an order of magnitude. For a large variation of the cutoff mass parameter, the results for the  $\phi$  mass and the decay width turn out to vary very little. Our results support results in the literature which suggest that one should observe a small downward mass shift and a large broadening of the decay width.

In order to explore the possibility of studying the binding and absorption of  $\phi$  mesons in nuclei, we also present the single-particle binding energies and half-widths of  $\phi$ -nucleus bound states for some selected nuclei.

### Spectroscopy of mesons / 27

## Revisiting the axial anomaly: from pseudotensor mesons to the pseudoscalar glueball

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The axial anomaly is responsible for the masses and mixing of the mesons  $\eta$  and  $\eta'$  (especially the latter). An open question is if it affects also other sectors of hadronic phenomenology. We show that anomalous terms can be important to understand the spectroscopy of pseudotensor mesons  $\eta_2(1645)$  and  $\eta_2(1870)$  (which can be investigated in the GlueX experiment at Jefferson Lab). Moreover, the axial anomaly can be also coupled to baryons (within the mirror assignment), explaining the large decay width  $N^*(1535) \rightarrow N\eta$ . Finally, the axial anomaly is naturally related to the pseudoscalar glueball: coupling of the latter to mesons and baryons are analyzed. The hope is to single out some channels where the pseudoscalar glueball can be looked for in the ongoing BESIII and the future PANDA experiments.

### Analysis tools / 28

## Study of Initial- and Final-state effects through polarisation Observables

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The CEBAF Large Acceptance Spectrometer (CLAS) housed in Hall B of the Thomas Jefferson Accelerator Facility provides us with the experimental tools to study strongly-interacting matter and its dynamics. Polarisation observables, accessible utilising polarised beams, allow us to performed detailed studies on the underlying dynamics of both initial and final state interactions as well as disentangle signal from background events. We have implemented this novel approach to study the interaction between Hyperons and Nucleons through Final state interactions in  $g d \rightarrow K + \Lambda$ , as well as study initial state by direct comparison of results on the reaction with free proton data.

### QCD and hadron structure / 29

## Quarkonium production to explore hadron 3D structure

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The exploration of hadron 3-dimensional structure in high-energy collisions can help us better understand QCD, and how the properties of hadrons arise from the dynamics of their internal constituents. In this talk I will address the quarkonium production in lepton-hadron and hadron-hadron collisions, which proves to be a very useful tool to unravel the gluon content of hadrons.

By applying the effective field theory machinery, in particular soft-collinear effective theory and non-relativistic QCD, I will show how to derive the relevant factorization theorems, which allow to properly extract from experimental data the involved transverse-momentum-dependent parton distribution functions (TMDPDFs).

Then I will perform a phenomenological study, giving predictions which can be tested at current and future colliders.

**Hadrons in matter including hypernuclei / 30**

## Properties of open and hidden charm meson in pionic matter

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With various experiments studying heavy-ion collisions a demand exists in the hadron physics community for theoretical predictions of hadronic properties at temperatures and densities far from standard nuclear physics scenarios. In this work we will study the implications of light-quark mesonic matter at finite temperatures on the open and hidden charm mesons. We will apply a chiral unitary approach which accounts for coupled channels. The in-medium solution accounts for the change in self-energy that the mesons acquire from interacting with the surrounding light quark mesonic matter, most notably pions. Ultimately, the solutions to the corresponding Lippmann-Schwinger Equations will be used to calculate observables such as the spectral function or the pion-induced width.

**Poster session / 31**

## Revisit the polarizations of colour field

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In analogy to the QED, we analyze the polarizations of gluon and clarify the role of colours within gluons. The effect of polarizations is associated with the spin angular momentum of gluon. Consequently we point out the dependence between colour field and angular-momentum, which can give us an explanation why we cannot confirm the total angular momentum of a high-energy scattering system. Since the stimulation of the colour field is equal to stimulating angular-momentum of the system.

**Spectroscopy of mesons / 32****An analysis of the lattice QCD spectra for  $D_{s0}^*(2317)$  and  $D_{s1}^*(2460)$** **Author:** Martinez Torres Alberto<sup>None</sup>**Co-authors:** Eulogio Oset ; Sasa Prelovsek ; Angels Ramos

In this talk I will present our results from a reanalysis of the energy levels obtained in a lattice QCD simulation from where the existence of bound states of  $KD$  and  $KD^*$  are induced and identified with the states  $D_{s0}^*(2317)$  and  $D_{s1}^*(2460)$ . The study is done using effective field theories in a finite volume.

**Spectroscopy of mesons / 33****Searching for Hybrid Mesons with GlueX****Author:** Sean Dobbs<sup>1</sup><sup>1</sup> *Florida State University***Corresponding Author:** sdobbs@fsu.edu

Hybrid mesons consist of a quark-antiquark pair bound together by a gluonic field that is in an excited state. A rich spectrum of hybrid meson states has been predicted, but only a few experiments have reported evidence of their existence. Measuring the spectrum of these states will provide valuable information on the gluonic degrees of freedom of QCD in the quark-confinement regime.

The GlueX experiment at Jefferson Lab is designed to search for and measure the spectrum of light-mass hybrid mesons, and began its physics run in Spring 2017. For the experiment, a 12 GeV electron beam incident on a diamond radiator is used to produce a linearly-polarized, coherent bremsstrahlung tagged-photon beam with a coherent peak at 9 GeV. The linearly-polarized photon beam is incident on a proton target located within the hermetic GlueX detector, which can detect many different final states to which the hybrid mesons are predicted to decay. Early GlueX physics will be shown, including several beam asymmetry measurements and near-threshold charm production.

**Plenary / 34****Hadrons in nuclei****Author:** Laura Tolos<sup>None</sup>**Corresponding Author:** tolos@ice.csic.es

I will present a review on the state of the art of hadrons in nuclei. In particular, I will discuss the properties of hadrons with strangeness, charm and beauty for the experimental conditions from RHIC to FAIR energies, paying a special attention to the formation of exotic bound states in nuclei.

**Exotic states and candidates / 35****Multiquark states**



**Author:** Alessandro Pilloni<sup>1</sup>

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The observation of the unexpected  $XYZ$  resonances has challenged the ordinary heavy quarkonium framework, and their microscopic nature remains an unsettled topic.

We review the status of the multi-quark phenomenology, and show how the large prompt production cross-section of the  $X(3872)$ , compared with the light nuclei production data, disfavors loosely-bound molecules, and calls for other interpretations for the exotic hadron resonances.

We also show how amplitude analysis can distinguish the possible scenarios of a QCD state, virtual state, or a kinematical enhancement, helping to solve the controversy.

**Analysis tools / 36**

## Covariant and helicity formalisms

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The use of covariant formalisms in amplitude analysis is becoming more and more popular among the experimental collaborations. We discuss some of the tensor formalisms available in the literature, and check whether or not they satisfy the  $S$ -matrix constraints. We match these to the usual helicity amplitudes, showing that there is no need for “relativistic” corrections.

**Spectroscopy of baryons / 37**

## $\eta$ and $\eta'$ photoproduction with $\eta$ MAID

**Authors:** Victor Kashevarov<sup>1</sup>; Lothar Tiator<sup>None</sup>; Michael Ostrick<sup>2</sup>

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Photoproduction of  $\eta$  and  $\eta'$  on the nucleons was analyzed within a new version of the  $\eta$ MAID model.

The model includes 23 nucleon resonances in the  $s$  channel and  $t$ -channel exchange of vector and axial-vector mesons with Regge cuts.

Parameters of the resonances were obtained from a fit to the new experimental data of the A2 Collaboration and available data from CBELSA/TAPS, CLAS, and GRAAL Collaborations for  $\eta$  and  $\eta'$  photoproduction on protons and neutrons.

Dominant role of  $1/2^-$  resonances is discussed.

The total cross section for the  $\gamma p \rightarrow \eta p$  reaction demonstrates a cusp at the energy  $W \sim 1.9$  GeV.

The cusp is explained as a threshold effect due to the opening  $\eta' p$  decay channel of the  $N(1895)1/2^-$  resonance.

The model well describes both differential cross sections and polarisation observables for photoproduction of  $\eta$  and  $\eta'$  on the nucleons at photon beam energies from the threshold upto  $8$  GeV.

The model does not require additional contributions from exotic resonances to explain a narrow structure observed in  $\gamma n \rightarrow \eta n$  reaction at  $W \sim 1.67 \text{ GeV}$ .

Poster session / 38

## Coupled channel $J/\psi N$ interactions and the $P_c(4450)$ state

Author: Chuwen Xiao<sup>1</sup>

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Using the chiral unitary approach, combining with the heavy quark spin symmetry, we investigate the interactions of  $J/\psi N$  with its coupled channels and look for the dynamical resonances in the interactions. One of the two  $P_c$  states,  $P_c(4450)$ , found by LHCb experiments, is explained as a  $\bar{D}^* \Sigma_c$  bound state in our theoretical model. To understand the properties of this state, we also study the  $J/\psi N$  cross sections, the s-/u- channel contributions, and the  $\Lambda_b^0 \rightarrow J/\psi K^- (\pi^-) p$  decays.

Plenary / 39

## Phenomenology of baryon resonances

Author: Michael Doring<sup>1</sup>

Co-authors: Deborah Ronchen<sup>2</sup>; Helmut Haberzettl<sup>3</sup>; Justin Landay<sup>3</sup>; Maxim Mai<sup>4</sup>; Raquel Molina Peralta<sup>4</sup>; Kanzo Nakayama<sup>5</sup>; Daniel Sadasivan<sup>3</sup>; Ron Workman<sup>3</sup>

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Results for baryon spectroscopy by different collaborations and, generally, the state of the art in the subfield will be reviewed. Highlights contain common efforts of different phenomenology groups and the impact of recent high-precision data from ELSA, JLab, MAMI, and other facilities. Questions will be addressed of how to proceed to reach conclusive answers in baryon spectroscopy, on one side, and how phenomenology can be connected to theory in a meaningful way, on the other side.

Analysis tools / 40

## Dispersive analysis of pion-nucleon scattering and the pion-nucleon sigma term

Authors: Bastian Kubis<sup>1</sup>; Jacobo Ruiz de Elvira<sup>2</sup>; MARTIN HOFERICHTER<sup>3</sup>; Ulf Meißner<sup>4</sup>

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A precise understanding of low-energy pion-nucleon interactions is central for many areas in nuclear and hadronic physics, ranging from the scalar couplings of the nucleon to the long-range part of two-pion-exchange potentials and three-nucleon forces in Chiral Effective Field Theory. We present a calculation that combines the general principles of analyticity, unitarity, and crossing symmetry with modern high-precision data of hadronic atoms, leading to a phenomenological description of the pion-nucleon amplitude with unprecedented rigor and accuracy. Consequences for the pion-nucleon sigma-term and the matching to Chiral Perturbation Theory will be also discussed.

**Poster session / 41**

## Free Energy of a Large- $N$ Pion Gas and Chiral Symmetry Restoration

**Authors:** Santiago Cortes<sup>1</sup>; Ángel Gómez Nicola<sup>2</sup>; John Morales<sup>3</sup>

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We study thermal properties of a large- $N$  massless pion gas via a low-energy QCD approach given by an  $O(N + 1)/O(N)$  nonlinear sigma model. In order to attain this, we build diagrammatically the associated free energy to  $O(TM^3)$  in the pion mass expansion through an effective vertex; we consider this since all its contributions coming from closed diagrams are to be taken into account. At this perturbative order, we do not have to deal with tadpole-like divergences or higher order loop contributions, thus yielding finite thermodynamical potentials. This allows us to calculate finite order parameters such as the quark condensate and its respective derivative, i.e., the scalar susceptibility, in the chiral limit, along with their associated critical exponents. These results are compared with our previous unitarized scattering analyses, where the chiral transition was studied via thermal properties of the scalar resonance  $f_0(500)$ . After all this, we finally show that these more recent results reasonably agree both with lattice simulations and with our  $f_0(500)$  studies for the chiral transition universality class.

**Spectroscopy of mesons / 42**

## $\bar{B}^0$ , $B^-$ and $\bar{B}_s^0$ decays into $J/\psi$ and $K\bar{K}$ or $\pi\eta$

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We study the  $\bar{B}_s^0 \rightarrow J/\psi K^+ K^-$ ,  $\bar{B}^0 \rightarrow J/\psi K^+ K^-$ ,  $B^- \rightarrow J/\psi K^0 K^-$ ,  $\bar{B}^0 \rightarrow J/\psi \pi^0 \eta$  and  $B^- \rightarrow J/\psi \pi^- \eta$  decays and compare their mass distributions with those obtained for the  $\bar{B}_s^0 \rightarrow J/\psi \pi^+ \pi^-$  and  $\bar{B}^0 \rightarrow J/\psi \pi^+ \pi^-$ . The approach followed consist in a factorization of the weak part and the hadronization part into a factor which is common to all the processes. Then what makes the reactions different are some trivial Cabibbo-Kobayashi-Maskawa matrix elements and the weight by which the different pairs of mesons appear in a primary step plus their

final state interaction. These elements are part of the theory and thus, up to a global normalization factor, all the invariant mass distributions are predicted with no free parameters. Comparison is made with the limited experimental information available. Further comparison of these results with coming LHCb measurements will be very valuable to make progress in our understanding of the meson-meson interaction and the nature of the low lying scalar meson resonances,  $f_0(500)$ ,  $f_0(980)$  and  $a_0(980)$ .

### Spectroscopy of baryons / 43

## Baryon states with open and hidden charm in the extended local hidden gauge approach

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We examine the interaction of  $DN$  and  $D^*N$  states, together with their coupled channels, by using an extension of the local hidden gauge formalism from the light meson sector, which is based on heavy quark spin symmetry. The scheme is based on the use of the impulse approximation at the quark level, with the heavy quarks acting as spectators, which occurs for the dominant terms where there is the exchange of a light meson. The pion exchange and the Weinberg-Tomozawa interactions are generalized and with this dynamics we look for states generated from the interaction, with a unitary coupled channels approach that mixes the pseudoscalar-baryon and vector-baryon states. We find two states with nearly zero width which are associated to the  $\Lambda_c(2595)$  and  $\Lambda_c(2625)$ . The lower state, with  $J^P = 1/2^-$ , couples to  $DN$  and  $D^*N$ , and the second one, with  $J^P = 3/2^-$ , to  $D^*N$ . In addition to these two  $\Lambda_c$  states, we find four more states with  $I = 0$ , one of them nearly degenerate in two states of  $J = 1/2, 3/2$ . Furthermore we find three states in  $I = 1$ , two of them degenerate in  $J = 1/2, 3/2$ .

The  $s$ -wave interaction of  $\bar{D}\Lambda_c, \bar{D}\Sigma_c, \bar{D}^*\Lambda_c, \bar{D}^*\Sigma_c$  and  $\bar{D}\Sigma_c^*, \bar{D}^*\Sigma_c^*$ , is studied within a unitary coupled channels scheme with the extended local hidden gauge approach. In addition to the Weinberg-Tomozawa term, several additional diagrams via the pion-exchange are also taken into account as box potentials. Furthermore, in order to implement the full coupled channels calculation, some of the box potentials which mix the vector-baryon and pseudoscalar-baryon sectors are extended to construct the effective transition potentials. As a result, we have observed six possible states in several angular momenta. Four of them correspond to two pairs of admixture states, two of  $\bar{D}\Sigma_c - \bar{D}^*\Sigma_c$  with  $J = 1/2$ , and two of  $\bar{D}\Sigma_c^* - \bar{D}^*\Sigma_c^*$  with  $J = 3/2$ . Moreover, we find a  $\bar{D}^*\Sigma_c$  resonance which couples to the  $\bar{D}\Lambda_c$  channel and one spin degenerated bound state of  $\bar{D}^*\Sigma_c^*$  with  $J = 1/2, 5/2$ .

### Hadron decays / 44

## $\Lambda_b \rightarrow \pi^-(D_s^-)\Lambda_c^*$ and $\Lambda_b \rightarrow \bar{\nu}_l l \Lambda_c^*$ decays in the molecular picture of $\Lambda_c(2595)$ and $\Lambda_c(2625)$

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From the perspective that the  $\Lambda_c(2595)$  and  $\Lambda_c(2625)$  are dynamically generated resonances from the  $DN, D^*N$  interaction and coupled channels, we have evaluated the rates for  $\Lambda_b \rightarrow \pi^- \Lambda_c(2595)$

and  $\Lambda_b \rightarrow \pi^- \Lambda_c(2625)$  up to a global unknown factor that allows us to calculate the ratio of rates and compare with experiment, where good agreement is found. Similarly, we can also make predictions for the ratio of rates of the, yet unknown, decays of  $\Lambda_b \rightarrow D_s^- \Lambda_c(2595)$  and  $\Lambda_b \rightarrow D_s^- \Lambda_c(2625)$  and make estimates for their individual branching fractions.

We evaluate the partial decay widths for the semileptonic  $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2595)$  and  $\Lambda_b \rightarrow \bar{\nu}_l \Lambda_c(2625)$  decays from the perspective that these two  $\Lambda_c^*$  resonances are dynamically generated from the  $DN$  and  $D^*N$  interaction with coupled channels. We find that the ratio of the rates obtained for these two reactions is compatible with present experimental data and is very sensitive to the  $D^*N$  coupling, which becomes essential to obtain agreement with experiment. Together with the results obtained for the  $\Lambda_b \rightarrow \pi^- \Lambda_c^*$  reactions, it gives strong support to the molecular picture of the two  $\Lambda_c^*$  resonances and the important role of the  $D^*N$  component neglected in prior studies of the  $\Lambda_c(2595)$  from the molecular perspective.

Poster session / 45

## Possible effect of mixed phase and deconfinement upon spin correlations in the $\Lambda\bar{\Lambda}$ pairs generated in relativistic heavy-ion collisions

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Spin correlations for the  $\Lambda\Lambda$  and  $\Lambda\bar{\Lambda}$  pairs, produced in relativistic heavy-ion collisions, and related angular correlations at the joint registration of space-parity nonconserving hadronic decays of two hyperons are theoretically analyzed. These correlations give important information about the character and mechanism of multiple processes, and the advantage of the  $\Lambda\Lambda$  and  $\Lambda\bar{\Lambda}$  systems over others is conditioned by the fact that the  $P$ -odd decays  $\Lambda \rightarrow p + \pi^-, \bar{\Lambda} \rightarrow \bar{p} + \pi^+$  serve as effective analyzers of spin states of the  $\Lambda$  and  $\bar{\Lambda}$  particles. The correlation tensor components can be derived by the method of “moments” – as a result of averaging the combinations of trigonometric functions of proton (antiproton) flight angles over the double angular distribution of flight directions for products of two decays. The properties of the “trace”  $T$  of the correlation tensor (a sum of 3 diagonal components), which determines the angular correlations as well as the relative fractions of the triplet states and singlet state of respective pairs, are discussed.

In the present report, spin correlations for two identical particles ( $\Lambda\Lambda$ ) and two non-identical particles ( $\Lambda\bar{\Lambda}$ ) are generally considered from the viewpoint of the conventional model of one-particle sources. In the framework of this model, correlations vanish at enough large relative momenta. However, under these conditions (especially at ultrarelativistic energies), for two non-identical particles ( $\Lambda\bar{\Lambda}$ ) the two-particle annihilation sources – quark-antiquark and two-gluon ones – start playing a noticeable role and lead to the difference of the correlation tensor from zero. In particular, such a situation may arise, when the system passes through the “mixed phase” and – due to the multiple production of free quarks and gluons in the process of deconfinement of hadronic matter – the number of two-particle sources strongly increases.

Spectroscopy of mesons / 46

## On the pair correlations of neutral $K$ , $D$ , $B$ and $B_s$ mesons with close momenta produced in inclusive multiparticle processes

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The phenomenological structure of inclusive cross-sections of the production of two neutral  $K$  mesons in hadron–hadron, hadron–nucleus and nucleus–nucleus collisions is theoretically investigated taking into account the strangeness conservation in strong and electromagnetic interactions. Relations describing the dependence of the correlations of two short-lived and two long-lived neutral kaons  $K_S^0 K_S^0$ ,  $K_L^0 K_L^0$  and the correlations of “mixed” pairs  $K_S^0 K_L^0$  at small relative momenta upon the space-time parameters of the generation region of  $K^0$  and  $\bar{K}^0$  mesons have been obtained. These relations involve the contributions of Bose-statistics and  $S$ -wave strong final-state interaction of two  $K^0$  ( $\bar{K}^0$ ) mesons and of the  $K^0$  and  $\bar{K}^0$  mesons, as well as the additional contribution of transitions  $K^+ K^- \rightarrow K^0 \bar{K}^0$ , and they depend upon the relative fractions of generated pairs  $K^0 K^0$ ,  $\bar{K}^0 \bar{K}^0$  and  $K^0 \bar{K}^0$ . It is shown that under the strangeness conservation the correlation functions of the pairs  $K_S^0 K_S^0$  and  $K_L^0 K_L^0$ , produced in the same inclusive process, coincide, and the difference between the correlation functions of the pairs  $K_S^0 K_S^0$  and  $K_S^0 K_L^0$  is conditioned exclusively by the production of the pairs of non-identical neutral kaons  $K^0 \bar{K}^0$ .

For comparison, analogous correlations for the pairs of neutral heavy mesons  $D^0$ ,  $B^0$  and  $B_s^0$ , generated in multiple inclusive processes with charm ( beauty ) conservation, are also theoretically analyzed – neglecting, just as for the  $K^0$  mesons, the weak effects of  $CP$  violation. These correlations are described by quite similar expressions: in particular, just as for the case of  $K^0$  mesons, the correlation functions for the pairs of states with the same  $CP$  parity ( $R_{SS} = R_{LL}$ ) and with different  $CP$  parity ( $R_{SL}$ ) do not coincide, and the difference between them is conditioned exclusively by the production of pairs  $D^0 \bar{D}^0$ ,  $B^0 \bar{B}^0$  and  $B_s^0 \bar{B}_s^0$ . However, contrary to the case of  $K^0$  mesons, here the distinction of  $CP$ -even and  $CP$ -odd states encounters difficulties – due to the insignificant differences of their lifetimes and the relatively small probability of purely  $CP$ -even and  $CP$ -odd decay channels. Nevertheless, one may hope that it will become possible at future colliders.

**Hadrons in matter including hypernuclei / 47**

## High-precision measurement of the hypertriton mass

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Recent high-precision measurements in light hypernuclei using magnetic spectrometers have changed our knowledge of the  $\Lambda N$  interaction. Accessible observables are  $\Lambda$  binding energies, excitation spectra (if particle-bound excited states exist), spins, lifetime and decay branching ratios. Substantial differences between emulsion studies and recent magnetic spectrometer measurements, e.g. differences in binding energy from -700 keV to +200 keV for individual hypernuclei, are suggestive that emulsion data could have larger uncertainties than published and that systematic uncertainties change with different hypernuclei. Especially unfortunate is the fact, that for the most elemental hypernucleus, the hypertriton, so far no reliable magnetic spectrometer data for its binding energy is available. Therefore, no crosscheck of the emulsion studies exist.

Like the deuterium for conventional baryon interactions, the hypertriton provides several important benchmarks for any strong interaction theory dealing with strange baryons. As the hypertriton is so little bound its lifetime and its  $\Lambda$  binding energy are expected to be intimately related. Its very small binding energy as observed by the emulsion technique implies that the bound  $\Lambda$  has an extended wave function and should have properties similar to the free  $\Lambda$ . In contrast, its lifetime observed in heavy-ion collisions is 30-40% shorter than the free  $\Lambda$  lifetime leading to a strongly debated puzzle. The situation calls for new precision measurements for the hypertriton.

I will discuss ongoing activities and future projects for the determination of ground state masses of light hypernuclei –in particular of the hypertriton. In order to reduce the systematic uncertainty of current pion-decay spectroscopy data at MAMI a novel high precision beam energy measurement based on interfering undulator radiation is presented.

**Analysis tools / 48**

## Amplitude Analysis at JPAC

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The Joint Physics Analysis Center (JPAC) was formed in 2013 to develop theoretical and phenomenological methods that would lead to a better understanding of production and decays of hadron resonances. JPAC does not rely on a single model or approach, but it is inclusive to various methodologies. JPAC products not only provide a better understanding of hadron phenomena but are of direct use in analysis and interpretation of experimental data and lattice gauge simulations. This is achieved thanks to close collaborations with theorists, experimentalists and lattice QCD practitioners. I will review the current work carried at JPAC on amplitude analysis and recent progress towards understanding of the hadron spectrum

**QCD and hadron structure / 49**

## Testing Non-universality of TMD Sivers Functions in COMPASS Polarized Drell-Yan Experiment

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Next-generation nucleon parton density functions (PDFs) with additional transverse momentum dependence (TMD) provide crucial information to understand the role of partonic orbital angular momentum in the nucleon spin. Among them, Sivers function characterizes the distribution of unpolarized quarks with nonzero transverse momentum inside a transversely polarized nucleon. Based on TMD factorization, the difference between the final-state interactions in SIDIS process and the initial-state interactions in the Drell-Yan process leads to an opposite sign in the TMD Sivers function of nucleon quarks entering these two processes. Since measurements of Sivers asymmetries in SIDIS have been available, the testing of this non-universality (sign change) of Sivers function in the polarized DY process becomes a major challenge in hadron physics.

In this talk, we will report the first measurement of TMD azimuthal asymmetries in the pion-induced Drell-Yan process [1]. We use the CERN SPS 190 GeV/c pion beam and a transversely polarized ammonia target. Three spin-dependent azimuthal asymmetries representing different TMD PDFs are extracted using large-mass dimuon events. The observed sign of the Sivers asymmetry is found to be consistent with the fundamental prediction of QCD.

[1] M. Aghasyan et al. (COMPASS Collaboration), “First measurement of transverse-spin-dependent azimuthal asymmetries in the Drell-Yan process”, arXiv:1704.00488 [hep-ex].

Poster session / 50

## On the coherent inelastic binary and multiparticle processes in ultrarelativistic hadron-nucleus, photon-nucleus and nucleus-nucleus collisions

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The coherent inelastic processes of the type  $a \rightarrow b$ , which may take place in the interaction of hadrons and  $\gamma$  quanta with nuclei at very high energies (the nucleus remains the same), are theoretically investigated. For taking into account the influence of matter inside the nucleus, the optical model based on the concept of

refraction index is applied. Analytical formulas for the effective cross section  $\sigma_{\text{coh}}(a \rightarrow b)$  are obtained, taking into account that at ultrarelativistic energies the main contribution into  $\sigma_{\text{coh}}(a \rightarrow b)$  is provided by very small transferred momenta in the vicinity of the minimum longitudinal momentum transferred to the nucleus. It is shown that the cross section  $\sigma_{\text{coh}}(a \rightarrow b)$  may be expressed through the “forward” amplitudes of inelastic scattering  $f_{a+N \rightarrow b+N}(0)$  and elastic scattering

$f_{a+N \rightarrow a+N}(0), f_{b+N \rightarrow b+N}(0)$  on a separate nucleon,

and it depends on the ratios  $L_a/R, L_b/R$ , where  $L_a$  and  $L_b$  are the respective mean free paths in the nucleus matter for the particles  $a, b$  and  $R$  is the nuclear radius.

In doing so, several characteristic cases with different relations of the magnitudes

$L_a, L_b, R$  are considered in detail – in particular, the cases  $L_a/R \gg 1, L_b/R \sim 1$  and  $L_a/R \gg 1, L_b/R \ll 1$  ( which correspond, e.g., to the coherent production of vector mesons  $\rho^0, \omega, \phi$  at the interaction of very high energy photons with nuclei ), and some numerical estimates are made for the coherent process  $\gamma \rightarrow \rho^0$  on the  $Pb$  nucleus .

The above formalism is generalized also for coherent inelastic multiparticle processes on a nucleus of the type

$a \rightarrow \{ b_1, b_2, b_3 \dots b_i \}$  and for the case of coherent processes in collisions of two ultrarelativistic nuclei.

Poster session / 51

## AdS/QCD Modified Soft Wall Model and Light Meson Spectra

**Authors:** Santiago Cortes<sup>1</sup>; Miguel Ángel Martín Contreras<sup>2</sup>; José Rolando Roldán<sup>2</sup>

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We analyze here the mass spectrum of light vector and scalar mesons applying the novel approach developed in [1], where a modified soft wall model that includes a UV-cutoff at a finite  $z$ -position in the AdS space is used, thus introducing an extra energy scale. For this model, we found that the masses for the scalar and vector spectra are well fitted within  $\delta_{\text{RMS}} = 6.88\%$  for these states, with



non-linear trajectories given by two common parameters, the UV locus  $z_0$  and the quadratic dilaton profile slope  $\kappa$ . We also concluded that in this model the  $f_0(500)$  scalar resonance cannot be fitted holographically as a  $q\bar{q}$  state since we could not find a trajectory that included this pole. This result is in agreement with the most recent phenomenological and theoretical methods.

[1] N. R. F. Braga, M. A. Martin Contreras and S. Diles,  
Phys. Lett. B 763, 203 (2016).

## Analysis tools / 52

### Revising the $f_1(1420)$ resonance

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We have studied the production and decay of the  $f_1(1285)$  into  $\pi a_0(980)$  and  $KK^-$  as a function of the mass of the resonance and find a shoulder around 1400 MeV, tied to a triangle singularity, for the  $\pi a_0(980)$  mode, and a peak around 1420 MeV with about 60 MeV width for the  $KK^-$  mode. Both these features agree with the experimental information on which the  $f_1(1420)$  resonance is based. In addition, we find that if the  $f_1(1420)$  is a genuine resonance, coupling mostly to  $KK^-$  as seen experimentally, one finds unavoidably about a 20% fraction for  $\pi a_0(980)$  decay of this resonance, in drastic contradiction with all experiments. Altogether, we conclude that the  $f_1(1420)$  is not a genuine resonance, but the manifestation of the  $\pi a_0(980)$  and  $KK^-$  decay modes of the  $f_1(1285)$  at higher energies than the nominal one.

## Poster session / 53

### The process of Coulomb dissociation of weakly bound relativistic hypernuclei within the two-cluster model

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Using the analogy with the problem of ionization and excitation of atoms at the propagation of relativistic charged particles through matter, the process of Coulomb dissociation of weakly bound relativistic nuclei and hypernuclei is theoretically investigated in the framework of the two-cluster deuteron-like model. Explicit expressions for the total cross-section of Coulomb disintegration of weakly bound systems are derived, taking into account the corrections connected with the finite size of the target nucleus; numerical estimates for the Coulomb dissociation of relativistic hypernuclei  ${}^3H_\Lambda$  and  ${}^6He_\Lambda$  are performed. It is shown that, due to the sharp dependence of the cross-section of Coulomb dissociation upon the binding energy, the experimental measurement of this cross-section in the case of weakly bound relativistic nuclei and hypernuclei allows one to determine the values of binding energy for these systems.

## QCD and hadron structure / 54

## The scalar and electromagnetic form factors of the nucleon in dispersively improved Chiral EFT

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In this talk I will show how to combine Chiral EFT and dispersion theory in order to get an improved prediction of the form factors of the nucleon. As an example, I will show the case of the scalar and electromagnetic form factors, and how the chiral prediction, improved with dispersion theory, shows an excellent agreement with independent determinations from purely dispersive calculations

Poster session / 55

## The Intrinsic heavy mechanism: some applications and the role at modern colliders

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Even though the mechanism is still under discussion, the intrinsic heavy quark mechanism is a rigorous prediction of Quantum Chromodynamics. Assuming this mechanism to exist, in our talk we discuss how we can naturally explain one of the most intriguing and surprising results in modern baryonic physics, namely the production properties of the double charmed baryons measured by the SELEX experiment (Phys.Lett. B765 (2017) 171-174 ; 1605.03070). We investigate the beautiful prediction given by the intrinsic heavy mechanism, where heavy quark particles are produced from the target with a momentum of the final state of less than 10 GeV/c (1704.02850). We also discuss the role of the intrinsic heavy quark mechanism at modern colliders (Nucl.Phys. B915 (2017) 384-391 ; 1611.08149) . Finally, we give a review of possible experimental confirmations at the current experiments.

Analysis tools / 56

## Coupled-channel scattering on the lattice and its application to Zc(3900)

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I will discuss the structure of the tetraquark candidate Zc(3900) from the meson-meson coupled-channel scattering on the lattice. The Zc(3900) is experimentally reported as a peak in the pi J/psi invariant mass in the Y(4260) -> pi pi J/psi decay. To understand the nature of the Zc(3900), it is most important to extract the coupled pi J/psi - rho eta\_c - anti-D D interactions faithful to QCD S-matrix. For this purpose, we employ the coupled-channel HAL QCD method, and the s-wave coupled-channel meson-meson potential relevant to the Zc(3900) is extracted.

*Scattering observables such as invariant mass spectra and the pole position of the S-matrix on the complex energy plane are calculated. Our results show that the  $Z_c(3900)$  is not a conventional resonance but a threshold cusp associated with the opening of the anti- $D$  threshold.*

## Spectroscopy of baryons / 57

### Baryon spectroscopy in the unquenched quark model

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The constituent quark model (CQM) describes the nucleon as a system of three constituent, or valence, quarks. Despite the successes of the CQM (e.g. masses, electromagnetic couplings, and magnetic moments), there is compelling evidence for the presence of sea quarks from other observables such as the observed flavor asymmetry of the proton, the proton spin crisis, and the systematics of strong decays of baryons.

In this contribution, I present the unquenched quark model as an extension of the CQM that includes the effects of sea quarks via a  $^3P_0$  quark-antiquark pair-creation mechanism. Particular attention is paid to the spin and flavor content, magnetic moments, and  $\beta$  decays of baryons, as well as the strangeness suppression in the proton. It is shown that the observed discrepancies between the experimental data and the predictions of the CQM can be accounted for in large part by the effects of sea quarks in the unquenched quark model.

## Exotic states and candidates / 58

### Muoproduction of exotic charmonia at COMPASS

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Exotic charmonium-like XYZ states have been targeted by various experiments in the last 15 years, but their nature still is unknown. Photo-(muo)production, is a new promising instrument to study them.

COMPASS, a fixed target experiment at CERN, analyzed the full set of the data collected with a muon beam between 2002 and 2011, covering the range from 7 GeV to 19 GeV in the centre-of-mass energy

of the photon-nucleon system.

Production of the  $X(3872)$  state in the reaction  $\mu^+ N \rightarrow \mu^+(J/\psi\pi^+\pi^-)\pi^\pm N'$  has been observed with a statistical significance of around  $5\sigma$ . The product of the cross section and the branching fraction of the  $X(3872)$  decay into  $J/\psi\pi\pi$  is estimated as  $71 \pm 28(\text{stat}) \pm 39(\text{syst})$  pb.

The results obtained for the production of the  $Z_c^\pm(3900)$  will be also reported as well as future perspectives.

## Hadron decays / 59

## The $B_c \rightarrow J/\psi DK$ weak decay testing the molecular nature of $D^* s_0(2317)^+$

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We study the relationship between the  $D^* s_0(2317)^+$  resonance and the decay of the  $B_c$  meson into  $J/\psi DK$ . In this process, the  $B_c$  meson decays first into  $J/\psi$  and the quark pair  $cs^+$ , and then the quark pair hadronizes into  $DK$  or  $D_s \eta$  components, which undergo final state interaction. This final state interaction, generating the  $D^* s_0(2317)^+$  resonance, is described by the chiral unitary approach. With the parameters which allow us to match the pole position of the  $D^* s_0(2317)^+$ , we obtain the  $DK$  invariant mass distribution of the decay  $B_c \rightarrow J/\psi DK$ , and also the rate for  $B_c \rightarrow J/\psi D^* s_0(2317)^+$ . The ratio of these two magnitude is then predicted.

Poster session / 60

## The $\rho B^* \bar{B}^*$ System within the Fixed Center Approximation to The Faddeev Equations

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We study the  $\rho B^* \bar{B}^*$  three-body system solving the Faddeev equations in the fixed center approximation. We assume the  $B^* \bar{B}^*$  system forming a cluster, and in terms of the two-body  $\rho B^*$  unitarized scattering amplitudes in the local Hidden Gauge approach we find a new  $I(J^{PC})=1(3^{--})$  state. The mass of the new state corresponds to a two particle invariant mass of the  $\rho B^*$  system close to the resonant energy of the  $B^* 2(5747)$ , indicating that the role of this  $J=2$  resonance is important in the dynamical generation of the new state.

Analysis tools / 61

## Triangle Singularities in the $\Lambda b \rightarrow J/\psi K-p$ Reaction

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We have analyzed the singularities of a triangle loop integral in detail and derived a formula for an easy evaluation of the triangle singularity on the physical boundary. It is applied to the  $\Lambda b \rightarrow J/\psi K-p$  process via  $\Lambda^*$ -charmonium-proton intermediate states. Although the evaluation of absolute rates is not possible, we identify the  $\chi_{c1}$  and the  $\psi(2S)$  as the relatively most relevant states among all possible charmonia up to the  $\psi(2S)$ . The  $\Lambda(1890)\chi_{c1}p$  loop is very special as its normal threshold and triangle singularities merge at about 4.45 GeV, generating a narrow and prominent peak in the amplitude in the case that the  $\chi_{c1}p$  is in an S-wave. We also see that loops with the same charmonium and other  $\Lambda^*$  hyperons produce less dramatic peaks from the threshold singularity alone. For the

case of  $\chi_{c1}p \rightarrow J/\psi p$  and quantum numbers  $3/2^-$  or  $5/2^+$  one needs P- and D-waves, respectively, in the  $\chi_{c1}p$ , which drastically reduce the strength of the contribution and smooth the threshold peak. In this case we conclude that the singularities cannot account for the observed narrow peak. In the case of  $1/2^+$ ,  $3/2^+$  quantum numbers, where  $\chi_{c1}p \rightarrow J/\psi p$  can proceed in an S-wave, the  $\Lambda(1890)\chi_{c1}p$  triangle diagram could play an important role, though can neither assert their strength without further input from experiments and lattice QCD calculations.

### Spectroscopy of mesons / 62

## ARE THE X(4260) AND X(4360) MOLECULAR STATES?

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We investigate the X(4260) and X(4360) within the framework of the Faddeev Equations under the fixed center approximation. We find a state of  $I=1$  with masses around 4320 MeV and width about 25 MeV for the case of  $\rho - X(3700)$  and 4256 MeV for the case of  $\bar{D}D_1(2420)$  with similar width to that of the  $\rho - X(3700)$ . Hence these states could be associated with the X(4260) and X(4360).

### Spectroscopy of baryons / 63

## Structure of hadron resonance with nearby CDD zero

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We discuss the method to investigate the hadron compositeness from the analytic structure of the scattering amplitude.

Recently, there have been the discussions on the relation between the hadron structure and the position of the CDD (Castillejo-Dalitz-Dyson) zero, which is defined as the zero of an amplitude [1].

We consider a resonance in a coupled channel amplitude, in which a CDD zero exists near the resonance pole in one of the channels.

We show that, by taking the zero coupling limit, the resonance pole and the CDD zero merge and vanish at the position of the pole in the other channel.

Then we find that the compositeness of the state is small when the pole is accompanied by a nearby CDD zero.

As an application, the fraction of the  $\bar{K}N$  ( $\pi\Sigma$ ) component is small for the lower (higher) pole of the  $\Lambda(1405)$  baryon [2].

[1] Y. Kamiya and T. Hyodo, Prog. Theor. Exp. Phys. (2017) 023D02.

[2] Y. Kamiya and T. Hyodo in preparation.

### QCD and hadron structure / 64

## Baryon-(anti-)baryon interaction cross-section measurement with femtoscopy technique in heavy-ion collisions

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Interaction cross-sections for baryon pairs are of fundamental interest and they are actively investigated theoretically. They are known well for pairs of common (anti-)baryons, however there is a lack of precise experimental data for heavier baryons, including the ones carrying strangeness. The two-particle correlation formalism (femtoscopy) is sensitive to the interaction kernel for a pair of particles, which is related to the pair interaction cross-section [1]. The formalism is extensively used to measure two-particle correlations in heavy-ion collisions. In particular the collisions at RHIC and LHC produce simultaneously large number of baryons and anti-baryons. We show how this formalism can be used to extract the cross-sections from the femtoscopic baryon-(anti-)baryon correlation functions [2]. The analysis is complicated by the presence of the so-called “residual correlations” arising from weak decay products in the measured sample. We show how this effect can be exploited to gain further insight into the cross-sections of even heavier baryons. We discuss the limitations of the measurement technique and estimate the discovery potential of currently available and soon-to-be-collected heavy-ion collision datasets at RHIC and at the LHC.

[1] A. Kisiel, H. Zbroszczyk, M. Szymanski; “Extracting baryon-antibaryon strong interaction potentials from p- $\Lambda$  femtoscopic correlation functions”; *Phys.Rev. C*89 (2014) 5, 054916

[2] R. Lednicky, V.L. Lyuboshits; “Final State Interaction Effect on Pairing Correlations Between Particles with Small Relative Momenta”; *Sov.J.Nucl.Phys.* 35 (1982) 770, *Yad.Fiz.* 35 (1981) 1316-1330

**Poster session / 66**

## Role of a triangle singularity in the $\pi N(1535)$ contribution to $\gamma p \rightarrow p\pi^0\eta$

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We have analyzed the  $\gamma p \rightarrow p\pi^0\eta$  process with a particular focus on the role of the triangle singularity which appears in the decay of the  $\Delta(1700)$  into  $\eta\Delta(1232)$ , where the  $\Delta(1232)$  goes into  $p$  emitting a  $\pi^0$ , while the  $N(1535)$  is formed from the  $\eta p$  interaction. In addition to the triangle diagram, we take account of the tree level contribution stemming from the  $\gamma p \rightarrow \Delta(1700) \rightarrow \eta\Delta(1232)$  process, followed by  $\Delta(1232) \rightarrow \pi^0 p$ . We have obtained a characteristic energy dependence from the triangle diagram in the  $\pi^0 N(1535)$  production, and a good agreement with the experimental determination up to 1.3 GeV. Furthermore, we found some differences between our results in the  $\eta\Delta(1232)$  production and the analysis performed in the experiment,

which might indicate the importance of incorporating the contribution from the triangle diagram in the standard partial wave analysis.

### Spectroscopy of baryons / 67

## Polarization Observables in $\gamma p \rightarrow K^+ + \Lambda$ and $K^+ + \Sigma^0$ Using Circularly Polarized Photons on a Polarized Frozen Spin Target

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The search for undiscovered excited states of the nucleon continues to be a focus of experiments at the Thomas Jefferson National Accelerator Facility (JLab). A large effort was done using the CEBAF Large Acceptance Spectrometer (CLAS) detector to provide the database, which will allow nearly model-independent partial wave analyses (PWA) to be carried out in the search for such states. Polarization observables play a crucial role in the effort, as they are essential in disentangling the contributing resonant and non-resonant amplitudes. Recent coupled-channel analyses have found strong sensitivity of the  $K^+ + \Lambda$  channel to several higher mass nucleon resonances. In 2008 and 2010, double-polarization data were taken at JLab using circularly and linearly polarized tagged photons incident on a longitudinally and transversely polarized frozen spin butanol target (FROST), operated at the temperature of 30~mK. The reaction products were detected in CLAS. This work is based on the analysis of FROST data and the extraction of the  $E$ ,  $L_x$ ,  $L_z$ ,  $T$ ,  $F$ ,  $T_x$ , and  $T_z$  asymmetries of the  $K^+ \Lambda$  and  $K^+ \Sigma^0$  final states and their comparison to predictions of recent multipole analyses. There are very few published measurements of the  $T$  asymmetry and none for the  $E$ ,  $L_x$ ,  $L_z$ ,  $F$ ,  $T_x$ , and  $T_z$  asymmetries for the  $K^+ \Lambda$  final state. The  $K^+ \Sigma^0$  final state has no published measurements for these asymmetries. This work is the first of its kind and will significantly broaden the world database for these reactions.

### Poster session / 68

## Polarization Observables in Meson Photoproduction with the Crystal Ball/TAPS at MAMI

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A comparison of experimentally observed excited nucleon states to model predictions or lattice QCD calculations is made, large differences arise, specifically concerning the number of excited states. In order to fully understand the strong interaction in the non-perturbative region, the excitation spectrum of nucleons is an important tool to use. The electromagnetic coupling of photons to protons is different than that of neutrons in certain states. Several experimental facilities have dedicated programs to measure polarization observables in different photoproduction reactions including the Crystal Ball/TAPS setup at the MAMI accelerator in Mainz, Germany. A complete partial wave analysis (PWA) can assist in yielding more information about any reaction with polarization observables playing a crucial role. Spin observables are essential in disentangling the contributing resonant and non-resonant amplitudes, whereas cross-section data alone is not sufficient for separating resonances. Preliminary results of polarization observables ( $E$ ,  $T$ , and  $F$ ) of  $\eta$ , single, and double  $\pi$  production will be shown with comparison to predictions of recent multipole analyses. These results will allow for significantly increasing the world database on these reactions.

### Hadron decays / 69

## Calculation of the ratios and absolute rates of the $\bar{b} \rightarrow \bar{c} (D_s^-)_c^0(2790)_c^0(2815)$ and $\bar{b} \rightarrow \bar{l} l_c^0(2790)_c^0(2815)$ decays

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In this work we calculate the ratios of rates of the  $\bar{b}$  nonleptonic and semileptonic decays into the  $\bar{c}(2790)$  and  $\bar{c}(2815)$  ( $\bar{c}^*$ ) resonances. These resonances are dynamically generated from the pseudoscalar-baryon and vector-baryon interactions, whose mixing is done using the chiral Weinberg-Tomozawa (WT) meson-baryon interaction extended to four flavors. The first part of the decay is a weak decay that we analyse through their quark constituents where it is noted that only the heavy quarks ( $b$  and  $c$ ) participate in the interaction, leaving the light pair ( $ds$ ) as spectators. This first decay then produces a meson-baryon pair that creates the  $\bar{c}^*$  through the WT interaction. We then proceed to calculate the decay rates to  $\bar{c}(2790)$  and  $\bar{c}(2815)$  for both the nonleptonic and semileptonic cases and then calculate the ratios between them. We do this calculation nonrelativistically and fully relativistically and notice that, even though both approaches yield very different results in the rates, the ratios are very similar (difference on the order of 1%) in both cases. The absolute values of the decay rates are also successfully calculated by obtaining the rates between our decays and  $\bar{b} \rightarrow \bar{c}(2595)_c(2625)$  and  $\bar{b} \rightarrow \bar{l} l_c(2595)_c(2625)$  for which there are experimental results and the momentum transfer is similar such we can cancel out the influence of the quark wave functions.

Based on arXiv:1701.06914 [hep-ph]

**Analysis tools / 70**

## Bayesian Analysis of Photoproduction Reactions

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We lay out a framework that can be used to obtain estimates of the possible impact of (combinations) of polarization measurements in pseudoscalar-meson photoproduction from the nucleon. To this end, we quantify the distance between models for pseudoscalar-meson photoproduction in amplitude space. Experimental observables, with finite accuracy, map to probability distributions in amplitude space, and the characteristic width scale of such distributions needs to be smaller than the distance between models if the observable data are going to be useful. We therefore also introduce a method for evaluating probability distributions in amplitude space that arise as a result of one or more measurements, and show how one can use this to determine what further polarization measurements are going to be necessary to be able to discriminate among models.

Additionally, we illustrate how a Bayesian analysis can shed light onto the resonance content of, amongst others, pseudoscalar meson photoproduction reactions. Hereby, not only the point estimate from a best chi-square analysis is relevant, but rather the weight of the parameter space which is



compatible with a given measurement must be taken into account. We illustrate how, in this context, a chi-square analysis compares to a Bayesian analysis which includes the full parameter space.

### Spectroscopy of baryons / 71

## Regge phenomenology and the nature of the $\Lambda(1405)$ resonance

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We use Regge phenomenology and the structure of the hyperon ( $\Lambda$  and  $\Sigma$ ) spectrum to gain insight on the nature of the two  $\Lambda(1405)$  resonances. We find that only of these resonances is compatible with a three-quark state.

### Spectroscopy of mesons / 72

## Heavy meson interquark potential from a modified Schwinger-Dyson strong coupling

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A truncated solution of a gauge invariant subset of the Schwinger-Dyson (SD) equations for QCD leads to a functional form of the strong running coupling showing a freezing in the infrared, which is best understood as a dynamical generation of a gluon mass function, giving rise to a momentum dependence which is free from infrared divergences. The generation of such a mass is associated with the existence of infrared finite solutions for the gluon propagator that has been confirmed by lattice QCD. From this coupling and propagator a non confining One Gluon Exchange (OGE) non perturbative interaction comes out [1].

By assuming that the SD coupling contains the physics at intermediate and large momenta but it lacks some vertex corrections at low momenta, we incorporate an infrared singularity in the simplest possible ad hoc manner. Then the non perturbative OGE interaction gives rise, with all the parameters fixed to their SD values, to a Cornell like potential for heavy quarkonia [2].

[1]: P. Gonzalez, V. Mathieu and V. Vento, Phys. Rev. D 84, 114008 (2011).

[2]: C. Ayala, P. González and V. Vento, J.Phys. G 43, 125002 (2016).

### Hadron decays / 73

## Role of the $h_1(1800)$ and $f_1(1285)$ states in the $J/\psi$ decays

**Author:** Ju-Jun Xie<sup>None</sup>

The BES data on the  $J/\psi \rightarrow \eta K^{*0} \bar{K}^{*0}$  reaction show a clear enhancement in the  $K^{*0} \bar{K}^{*0}$  mass distribution close to the threshold of this channel. Such an enhancement is usually a signature of a  $L = 0$  resonance around threshold, which in this case would correspond to an  $h_1$  state with quantum numbers  $I^G(J^{PC}) = 0^-(1^{+-})$ . We study the state around 1800 MeV results from the interaction of the  $K^* \bar{K}^*$  in  $J/\psi \rightarrow \eta K^{*0} \bar{K}^{*0}$  decay, confirming the relationship of the enhancement in the invariant mass spectrum with the  $h_1$  resonance. The role of  $f_1(1285)$  resonance in the  $J/\psi \rightarrow \phi \bar{K} K^*$  and  $J/\psi \rightarrow \phi f_1(1285)$  decays are also investigated. The theoretical approach is based on the results of chiral unitary theory where the  $f_1(1285)$  resonance is dynamically generated from the  $K^* \bar{K} - c.c.$  interaction. In order to further test the dynamical nature of the  $f_1(1285)$  state, we investigate the  $J/\psi \rightarrow \phi \bar{K} K^*$  decay close to the  $\bar{K} K^*$  threshold and make predictions for the ratio of the invariant mass distributions of the  $J/\psi \rightarrow \phi \bar{K} K^*$  decay and the  $J/\psi \rightarrow \phi f_1(1285)$  partial decay width with all the parameters of the mechanism fixed in previous studies. The results can be tested in future experiments and therefore offer new clues on the nature of the  $h_1(1800)$  and  $f_1(1285)$  states.

Poster session / 74

## Influence of $f_0(500)$ and scalar glueball on pion-pion and pion-nucleon scattering within the extended linear sigma model

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We investigate the two-flavor version of the extended linear sigma model (eLSM), which contains, besides the standard scalar and pseudoscalar quark-antiquark degrees of freedom, also vector and axial-vector mesons, as well as the nucleon and its chiral partner. We extend this model by an additional light scalar meson, a potential four-quark state, and the scalar glueball. We investigate several possible interaction terms of these states with the other particles, some of which preserve and some of which explicitly break the  $U(1)_A$  symmetry. We test our model by performing a global fit to masses and decay widths of the scalar resonances and pion-pion scattering lengths, obtaining quite reasonable results. We also discuss the influence of the additional scalar resonances on the baryon sector by evaluating pion-nucleon scattering parameters. Finally, we elaborate on some problems and extensions to improve our approach.

Hadron decays / 75

## Predictions for $\eta_c \rightarrow \eta \pi^+ \pi^-$ producing $f_0(500)$ , $f_0(980)$ and $a_0(980)$

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We perform calculations for the  $\eta_c \rightarrow \eta \pi^+ \pi^-$  decay using elements of  $SU(3)$  symmetry to see the weight of different trios of pseudoscalars produced in this decay, prior to the final state interaction of the mesons. After that, the interaction of pairs of mesons, leading finally to  $\eta \pi^+ \pi^-$ , is done

using the chiral unitary approach. We evaluate the  $d\Gamma/dM_{\pi^+\pi^-}$  and  $d\Gamma/dM_{\pi^+\eta}$  mass distributions and find large and clear signals for  $f_0(500)$ ,  $f_0(980)$  and  $a_0(980)$  excitation. The reaction is similar to the  $\chi_{c1} \rightarrow \eta\pi^+\pi^-$ , which has been recently measured at BESIII and its implementation and comparison with these predictions will be very valuable to shed light on the nature of the low mass scalar mesons.

**QCD and hadron structure / 76**

## Recent NA48 results on QCD and ChPT

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The NA48/2 experiment at CERN collected a very large sample of charged kaon decays into multiple final states.

This data allow measurements related to QCD and Chiral Perturbation Theory, and the an updated measurement of  $|V_{US}|$ .

In particular, we collected about 1500 events of the very rare decay  $K^{*+} \rightarrow \mu^+ \nu_e e^-$  over almost negligible background in the region with  $m(e^+e^-)$  above 140 MeV, which is of great interest in Chiral Perturbation Theory, thanks to the  $m_{ee}$  spectrum and a model-independent measurement of the decay rate for this region.

Also we performed the first observation of the rare decay  $K^+$  to  $\pi^+\pi^0 e^+e^-$ , with about 5000 candidates and 5% background contamination, and the preliminary branching ratio in the full kinematic region is measured to be  $(4.22 \pm 0.15) \times 10^{-6}$ , in perfect agreement with theoretical predictions based on Chiral Perturbation Theory.

Finally, we obtained our final measurement of the charged kaon semileptonic decays form factors based on 4.28 million  $K^{\pm}e^3$  and 2.91 million  $K^{\pm}\mu^3$  selected decays, with the smallest uncertainty for  $K^{\pm}e^3$  and a competitive result for  $K^{\pm}\mu^3$  and leading to the most precise combined  $K^{\pm}l^3$  result that reduces the form factor uncertainty of  $|V_{US}|$ .

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## Recent results from NA62

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$K^+ \rightarrow \pi^0 \nu \nu$  is one of the theoretically cleanest meson decay where to look for indirect effects of new physics complementary to LHC searches. The NA62 experiment at CERN SPS is designed to measure the branching ratio of the  $K^+ \rightarrow \pi^0 \nu \nu$  decay with 10% precision. NA62 took data in 2015 and 2016 reaching the Standard Model sensitivity. The experiment will be reviewed, and recent results and prospects will be presented, also on heavy neutrinos limits.

**Spectroscopy of baryons / 78**

## Doubly-polarised pion photoproduction and the GDH sum rule on the nucleon at MAMI

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New measurements of the helicity dependence of the total inclusive photo-absorption cross section and of the partial cross sections for several reaction channels on the proton and on the neutron were carried out at the tagged photon beam facility of the MAMI accelerator (Mainz) by the A2 experiment in the energy region  $200 < E_\gamma < 1500$  MeV.

These new, high-quality doubly-polarized pion-photoproduction data sets give a valuable input to the study of the nucleon structure and excitation spectra of protons and neutrons, by providing a contribution to the partial wave analysis models and by allowing to constrain the multipole solution of the different analyses.

Furthermore, the helicity dependent observables provide the main ingredient for the verification of the well-known Gerasimov-Drell-Hearn (GDH) sum rule, which relates the helicity-dependent photoabsorption process to the main static nucleon properties (mass, charge, spin). For this reason, such a verification is of particular interest in the understanding of the nucleon spin structure, the  $\gamma$ -N interaction, as well as the physics of strongly interacting systems. Thanks to the use of polarized deuteron and <sup>3</sup>He targets, the A2 experiment can study all the  $\gamma N \rightarrow N\pi(\pi)$  partial channels, as well as the total cross sections, for the neutron too.

The new precise results on double-polarization measurements of the total and differential cross sections for the partial  $\gamma N \rightarrow \pi X$  channels on the proton and on the neutron, obtained by the A2 collaboration, are compared to the existing model predictions and to the few, available results. These new data are significantly increasing the available statistics, especially on the neutron, thus providing an important testing ground for all existing models. Moreover, the results obtained on <sup>3</sup>He give information not only on the GDH integral on the neutron, but also on the <sup>3</sup>He nuclear structure and allow an investigation of the nucleon properties inside this nucleus.

**Poster session / 79**

## Isospin-violation in the extended linear sigma model

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We study isospin-breaking effects in the extended linear sigma model (eLSM) for  $N_f = 3$  quark flavors. The eLSM contains scalar, pseudoscalar, vector, and axial-vector mesons, which consist of quarks and antiquarks. It is constructed on the basis of a global chiral  $U(N_f)_L \times U(N_f)_R$  symmetry which is spontaneously broken by a quark-antiquark condensate, as well as explicitly broken by the  $U(1)_A$  anomaly of quantum chromodynamics and non-vanishing quark masses. Unequal masses for the non-strange and strange quarks lead to a splitting between the vacuum expectation values for the non-strange scalar-isoscalar field  $\sigma_N$  and the strange  $\sigma_S$ . Analogously, unequal masses for the up- and down quarks lead to a non-vanishing vacuum expectation value for the neutral scalar-isotriplet  $a_0^0$  field. We explicitly compute the effect of isospin breaking on meson masses within the eLSM.

**Poster session / 80**

## Thermal Properties of the Tetraquark X(3872) in Diquark-antidiquark Approach

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During last decade properties of the tetraquark states, which may play an essential role in understanding of hadron dynamics, are among widely discussed problems in the literature. In this work we investigate the thermal features of the state X(3872) with the quantum numbers  $JPC = 1^{++}$ . We consider it as a diquark-antidiquark bound state and use QCD sum rule method to explore the nature of this exotic resonance. By using a relevant interpolating current we calculate the two-point correlation function including contributions of nonperturbative condensates up to six dimensions. Equating the expression of the correlation function obtained using the operator product expansion and its hadronic representation, we derive thermal QCD sum rules for parameters of the X(3872) state. Our numerical calculations demonstrate that in the low temperature region the mass and decay constant of X(3872) are insensitive to temperature, but they decrease significantly before the critical temperature. At the deconfinement temperature the decay constant and mass attain approximately to 32% and 74 % of their vacuum values, respectively. Our zero-temperature results are in good agreement with the experimental measurements and other theoretical works presented in the literature.

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## Isospin breaking in the decay constants of heavy mesons from QCD sum rules

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We propose a new method for calculating the dependences of the decay constants of heavy-light mesons on the light-quark mass  $m$  based on QCD sum rules at infinitely large Borel mass parameter. For an appropriate choice of the correlation functions, all condensate contributions vanish and the  $m$ -dependence of the decay constants is shown to be mainly determined by the known analytic  $m$ -dependence of the diagrams of perturbative QCD. The results for strong isospin breaking in the decay constants of heavy pseudoscalar and vector mesons are reported.

Poster session / 82

## Narrow Exotic Tetraquarks in large- $N_c$ QCD

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We study four-point functions of bilinear quark currents in QCD at large- $N_c$  and obtain conditions for the existence of narrow tetraquark states. We then discuss three-point functions involving one tetraquark interpolating current and two bilinear quark currents and obtain the large- $N_c$  behavior of the tetraquark decay constants. Finally, we discuss the implications of these results for the analyses of tetraquark mesons within the method of QCD sum rules.

**Poster session / 83**

## Instantaneous Bethe–Salpeter look at the lightest pseudoscalar mesons

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The consistent simultaneous interpretation of pions and kaons both as bound states of quark and antiquark and as the (almost) massless boson states related, according to Goldstone's theorem, to the dynamical (and explicit) breakdown of the chiral symmetries of QCD still represents a major challenge. Applying inversion to sufficiently simplified versions of the homogeneous Bethe–Salpeter equation, governing bound states in quantum field theory, enables us to get straightforwardly a qualitative idea of how the underlying effective interactions might look like in this case.

**Poster session / 84**

## Measurement of the proton scalar polarizabilities at MAMI

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The electric ( $\alpha_{E1}$ ) and magnetic ( $\beta_{M1}$ ) scalar polarizabilities are fundamental properties related to the internal structure of the nucleon. They play a crucial role not only in our understanding of the nucleon, but also in other areas such as atomic physics. In the past, the values of  $\alpha_{E1}$  and  $\beta_{M1}$  were determined from the unpolarized differential cross-section of the Compton scattering  $\gamma p \rightarrow \gamma p$ . The measurement of the beam asymmetry  $\Sigma_3$ , provides an alternative approach to the extraction of the scalar polarizabilities, with different sensitivity and systematics compared to the unpolarized cross-section. This asymmetry was measured for the first time below the pion photoproduction threshold by the A2 Collaboration with the Crystal Ball/TAPS experiment at MAMI (Mainz, Germany). A linearly polarized photon beam impinged on a liquid hydrogen target and the scattered photons were detected with the Crystal Ball/TAPS setup, providing almost  $4\pi$  coverage. A new high precision measurement of both unpolarized cross-section and beam asymmetry  $\Sigma_3$  will be performed in the near future and polarizabilities  $\alpha_{E1}$  and  $\beta_{M1}$  will be extracted with unprecedented precision. The impact of the recently obtained and expected results on the extraction of the scalar polarizabilities will be discussed in this talk.

**QCD and hadron structure / 85**

## Recent results from the SND experiment at VEPP-2000 collider

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Latest results on study of processes of  $e^+e^-$  annihilation into exclusive hadronic states with  $\sqrt{s} < 2$  GeV obtained in the SND experiment at the VEPP-2M and VEPP-2000 colliders are presented. In particular, we announce results of the precise measurements of the  $e^+e^- \rightarrow \gamma\pi^0$  and  $e^+e^- \rightarrow K^+K^-$  cross sections, the first measurements of the  $e^+e^- \rightarrow \omega\pi^0\eta$  and  $e^+e^- \rightarrow \pi^+\pi^-\pi^0\eta$  reactions and preliminary results of measurement of the  $e^+e^- \rightarrow \pi^+\pi^-$  cross section in energy range  $0.5 < \sqrt{s} < 0.9$  GeV.

### Spectroscopy of mesons / 86

## An Effective Theory approach to $\bar{B}_s$ mesons involving $SU(3)$ heavy meson symmetry and constituent quark-model states

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The bottom partners of the  $D_{s0}(2317)$  and  $D_{s1}(2460)$  have not been measured yet but the existence of these bottom-strange  $J^P = 0^+$  and  $1^+$  states is motivated by heavy quark flavor symmetry (HQFS) and heavy quark spin symmetry (HQSS).

In this talk we will present the predictions for such heavy quark partners using a unitarized effective approach involving  $SU(3)$  chiral heavy meson symmetry and incorporating explicit di-quark Fock components ( $Q\bar{q}$ ) to the theory in a HQFS/HQSS consistent way.

We take advantage of the energy levels spectrum for  $0^+$  and  $1^+$   $B_s$  mesons obtained in a recent lattice QCD simulation to constrain the coupling of the  $Qq$  components. By fitting the lattice QCD energy levels with the energy levels obtained with the model in finite volume, we are able to make predictions for these exotic  $\bar{B}_s$  mesons. Our predictions are compatible with the lattice QCD results and previous heavy meson chiral perturbation theory predictions. In the same line, results for charm-strange mesons will be presented.

### QCD and hadron structure / 88

## Charge Symmetry Breaking in the Reaction $dd \rightarrow 4He\pi^0$ with WASA-at-COSY

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Probing elementary symmetries and symmetry breaking tests our understanding of the theory of strong forces, Quantum Chromodynamics. Investigations of charge symmetry breaking is one of the primary goals for the WASA-at-COSY experiment. The presented study concentrates on the charge symmetry forbidden reaction  $dd \rightarrow {}^4\text{He}\pi^0$ .

The aim is to provide experimental results for comparison with predictions from Chiral Perturbation Theory ( $\chi_{PT}$ ) to study effects induced by quark masses on the hadronic level, e.g., the proton-neutron mass difference. In addition, data are needed to determine certain parameters of  $\chi_{PT}$  and to describe the initial and final state interactions. First steps towards a theoretical understanding of the  $dd \rightarrow {}^4\text{He}\pi^0$  reaction have already been taken, however, it was found that the existing data are not sufficient. New data should comprise the measurement of the charge symmetry forbidden  $dd \rightarrow {}^4\text{He}\pi^0$  reaction and the charge symmetry conserving  $dd \rightarrow {}^3\text{He}n\pi^0$  reaction at sufficiently high energy where the contribution of higher partial waves becomes important. Results from a first  $dd \rightarrow {}^4\text{He}\pi^0$  measurement with the WASA detector setup at a beam momentum of 1.2 GeV/c had been already published, but the limited statistics did not allow a decisive interpretation.

A second measurement using an improved detector setup aiming at higher statistics has been performed in spring 2014. For the first time, the differential cross section has been determined, showing the importance of the contribution of higher partial waves. The results from the new measurement will be presented.

**Exotic states and candidates / 89**

## Study of the $DK\bar{K}$ and $DK\bar{K}^*$ systems

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Using the Fixed Center Approximation to Faddeev equations we have investigated the  $DK\bar{K}$  and  $DK\bar{K}^*$  three-body systems, with the input of two-body interactions obtained from the chiral unitary approach, and considering that the  $D_{s_0}^*(2317)$ , generated from the  $DK$  interaction, acts as the heavy cluster. For the  $DK\bar{K}$  system we have found evidence of a state with  $I(J^P) = 1/2(0^-)$  and mass about 2833 – 2858 MeV, above the  $D_{s_0}^*(2317)\bar{K}$  threshold. Our findings indicate that this state is dominated by a  $Df_0(980)$  component, and it could be searched for in the  $\pi\pi D$  invariant mass. Our results also corroborate with different approaches from the literature, using Sum Rules and Faddeev equations without the FCA approximation. On the other hand, no clear bound states or resonances were found in the exotic  $DK\bar{K}$  system.

**Spectroscopy of mesons / 91**

## Hadronic transitions in bottomonium at Belle

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The study of hadronic transitions among bottomonium states, and their relative magnitude, can be used as a bench test for non-perturbative



approaches to QCD. In particular, transitions through an eta meson, despite involving a heavy quark spin symmetry violation, have been measured to have an unexpectedly enhanced branching fraction with respect to those through a dipion system. A set of recent results obtained using the data collected by the Belle experiment at the energy of the Upsilon(4S) and Upsilon(5S) resonances will be presented. They include the observation of the transition Upsilon(5S)  $\rightarrow$  eta Upsilon(1D), an updated measurement of the branching fractions of Upsilon(4S)  $\rightarrow$  eta Upsilon(1S) and Upsilon(4S)  $\rightarrow$  pi+pi-Upsilon(1S,2S) decays, and searches for other possible transitions involving an eta meson.

Poster session / 92

## Recent results on exotics states at Belle

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A new alternate chi\_c0(2P) charmonium state, X\*(3860), has been observed with a significance of 6.5sigma using full amplitude analysis of the process e+e-  $\rightarrow$  J/psi D Dbar. We also perform search for exotic states such as hidden-strangeness penta-quark. All the results presented here exploits the full data set of Belle.

Spectroscopy of baryons / 93

## Charmed baryon spectroscopy and decays at Belle

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Using more than 900 fb<sup>-1</sup> data collected with the Belle detector at the KEKB asymmetric-energy e+e- collider, we report observation of excited charmed baryon states. We also provide their mass and width measurements (with an order of magnitude of improvement). In addition, direct production cross-section of charmed baryons is also presented.

Poster session / 94

## Production rates of hyperons and charmed baryons from e+e- annihilation near $\sqrt{s} = 10.52$ GeV

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We measure the inclusive production cross sections of hyperons and charmed baryons from  $e^+e^-$  annihilation using a 800 fb<sup>-1</sup> data sample taken near the  $Y(4S)$  resonance with the Belle detector at the KEKB asymmetric-energy  $e^+e^-$  collider. The feed-down contributions from heavy particles are subtracted using our data, and the direct production cross sections are compared for the first time. The results are discussed from the viewpoint of the diquark structure in baryons.

**Spectroscopy of mesons / 95**

## Energy scan results at Belle

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<sup>1</sup> I

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Using Belle energy scan data we report first evidence for the  $\Upsilon(6S) \rightarrow \phi\chi_{bJ}(1P)$  transitions and measure the energy dependence of the  $e^+e^- \rightarrow \phi\chi_{bJ}(1P)$  cross sections. We report also on energy dependence for other final states that consist of bottomonia and light hadrons. Using Belle data collected at the  $Y(5S)$  we measure the  $B_s \rightarrow D_s X$  inclusive branching fraction; this result is useful, in particular, to tag relative contributions of  $B$  and  $B_s$  mesons in the total  $bb$  hadronic cross section above the  $B_s\bar{B}_s$  threshold.

**Hadron decays / 96**

## Recent measurements of branching fractions and CP asymmetries of charmless hadronic B meson decays at Belle

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Hadronic B decays without a charm quark constitute a powerful probe to search for physics beyond the standard model as well as provide constraints of CP-violation parameters. We report the final measurements from Belle of the branching fraction and CP asymmetry for the decays  $B^0 \rightarrow \pi^0\pi^0$ ,  $B^\pm \rightarrow K^+K^-\pi^\pm$  and preliminary results for  $B \rightarrow KS_0KS_0h$  ( $h=K,\pi$ ) and  $B^\pm \rightarrow \pi^+\pi^-\pi^\pm$ . All investigations employ the full data sample delivered by the KEKB  $e^+e^-$  collider. The  $B^0 \rightarrow \pi^0\pi^0$  measurements enable improved constraints on the angle  $\phi_2$  of the CKM unitarity triangle. For  $B^\pm \rightarrow K^+K^-\pi^\pm$  we measure CP asymmetry as a function of the invariant-mass of the  $K^+K^-$  system, where we find strong evidence for large direct CP-violation as well as a large increase in yield at low mass. This measurement challenges conventional theoretical approaches since the result requires a large enhancement in both tree and loop diagrams in the same small region of phase-space. The three-body decay final states  $\pi^+\pi^-\pi^\pm$  and  $KS_0KS_0h$  ( $h=K,\pi$ ) proceed mostly via flavor-changing neutral currents and are thus sensitive to new physics via enhanced CP-asymmetry due to interference from non-SM amplitudes in loops. The final measurement plays an important role in understanding the B decay dynamics and improving the deviation boundary of  $\sin 2\phi_1$  obtained in  $b \rightarrow cqq^-$  and  $b \rightarrow sqq^-$  decays.

## Spectroscopy of baryons / 97

**Photoproduction of  $\pi^- \Delta^{++}$  and  $\pi^+ \Delta^0$  on the proton for the comparison of  $\bar{u}u$  and  $\bar{d}d$  productions****Author:** Hideki Kohri<sup>1</sup>**Co-author:** SPring-8/LEPS collaboration<sup>1</sup> RCNP, Osaka University**Corresponding Author:** kohri@rcnp.osaka-u.ac.jp

We carry out hadron photoproduction experiments at  $E_\gamma=1.5-3.0$  GeV at SPring-8/LEPS. We took charged pion data on the proton at forward angles for the first time and the data were analyzed recently. The differential cross sections for the  $\pi^- \Delta^{++}$  and  $\pi^+ \Delta^0$  reactions are compared. In the  $\pi^- \Delta^{++}$  reaction  $\bar{u}u$  is produced, while in the  $\pi^+ \Delta^0$  reaction  $\bar{d}d$  is produced. If the isospin=1 exchange in the t-channel is dominant, the cross section ratio  $\sigma(\pi^+ \Delta^0)/\sigma(\pi^- \Delta^{++})$  becomes 1/3. Preliminary experimental cross section ratios are close to 1/3 at small  $\pi$  angles, while they are larger than 1/3 at large  $\pi$  angles. Larger ratios suggest that the  $\bar{d}d$  production is enhanced compared with the  $\bar{u}u$  production. This result might be a hint to clarify the pion photoproduction reactions.

We also report recent physics results in our group.

We are developing a polarized HD target and large acceptance spectrometer for near future experiments. The present status of these developments is also reported.

## QCD and hadron structure / 98

**KLOE-2 results on hadron physics****Author:** Paolo Gauzzi<sup>1</sup><sup>1</sup> INFN**Corresponding Author:** paolo.gauzzi@roma1.infn.it

The KLOE experiment has collected  $2.5 \text{ fb}^{-1}$  at the  $e^+e^-$  collider DAPHNE. The upgraded detector KLOE-2 has already collected  $3.5 \text{ fb}^{-1}$  with a new beam crossing scheme, allowing for a reduced beam size and increased luminosity. Analysis of KLOE data is still in progress, providing new important results in the light meson sector.  $\text{VP}\gamma^*$  transitions have been studied using the  $\phi \rightarrow \eta e^+e^-$ ,  $\phi \rightarrow \pi^0 e^+e^-$  decays. For both processes, we obtain the most precise determination of the BR and of the transition form factor.

KLOE data have been also exploited to obtain a new, precise result on the isospin-violating decay  $\eta \rightarrow \pi^+ \pi^- \pi^0$ , aiming to a better determination of the light-quark mass ratio. The analysis determines with very good accuracy the parameters of the decay matrix element. The Dalitz plot density is parametrised as a polynomial expansion up to cubic terms in X and Y. The measurement is sensitive to all charge conjugation conserving terms, providing an improvement of a factor of two on the statistical uncertainty of all parameters with respect to previous experiments. Smaller systematic uncertainties have been also achieved. The un-binned integrated left-right, quadrant and sextant charge asymmetries have also been measured, providing an accurate test of C parity conservation. The values extracted are consistent with zero at  $10^{-4}$  level, thus improving existent evaluations.

Precision physics requires appropriate inclusion of higher order effects and the knowledge of very precise input parameters of the electroweak Standard Model. The running of the QED coupling constant  $\alpha$  in the time-like region in the energy range 0.6-0.975 GeV has been measured for the first time using the KLOE detector. The result shows a clear contribution of the rho-omega resonances to the photon propagator with a significance of the hadronic contribution of more than 5 sigmas. For the first time the real and imaginary part of  $\Delta(\alpha(s))$  have been extracted.

**Hadron decays / 99** **$f_0(980)$  production in  $D_s^+ \rightarrow \pi^+\pi^+\pi^-$  and  $D_s^+ \rightarrow \pi^+K^+K^-$  decays****Author:** Jorgivan Morais Dias<sup>1</sup>**Co-authors:** Fernando Navarra<sup>2</sup>; Marina Nielsen<sup>3</sup>; Eulogio Oset<sup>4</sup><sup>1</sup> *Instituto de Física Corpuscular - Universidad de Valencia, Spain.*<sup>2</sup> *Instituto de Física, Universidade de São Paulo, Brazil.*<sup>3</sup> *Instituto de Física, Universidade de São Paulo*<sup>4</sup> *Departamento de Física Teórica and IFIC, Centro Mixto Universidad de Valencia-CSIC***Corresponding Authors:** oset@ific.uv.es, mnielsen@if.usp.br, navarra@if.usp.br, jdias@if.usp.br

We study the  $D_s^+ \rightarrow \pi^+\pi^+\pi^-$  and  $D_s^+ \rightarrow \pi^+K^+K^-$  decays adopting a mechanism in which the  $D_s^+$  decays weakly into a  $\pi^+$  and a  $q\bar{q}$  component, which hadronizes into two pseudoscalar mesons. The final state interactions between these two pseudoscalar mesons is taken into account by using a chiral unitary approach in coupled channels, which gives rise to the  $f_0(980)$  resonance. Hence, we obtain the invariant mass distribution of the pairs  $\pi^+\pi^-$  and  $K^+K^-$  after the decay of that resonance and compare our theoretical amplitudes with those available from the experimental data. Our results are in a fair agreement with the shape of these data, within large uncertainty, and a  $f_0(980)$  signal is seen in both the  $\pi^+\pi^-$  and  $K^+K^-$  distributions. Predictions for the relative size of  $\pi^+\pi^-$  and  $K^+K^-$  distributions are made.

**Poster session / 100****Mass spectra of di-baronic systems in charm sector****Authors:** D. P. Rathaud<sup>1</sup>; Ajay Kumar Rai<sup>1</sup>**Co-author:** Zalak Marfatia<sup>2</sup><sup>1</sup> *Sardar Vallabhbhai National Institute of Technology Surat*<sup>2</sup> *Sardar Vallabhbhai National Institute of technology***Corresponding Authors:** zalak.physics@gmail.com, raiajayk@gmail.com, dharmeshphy@gmail.com

In the potential model frame work, we study the S-wave molecular like structure of the di-baronic systems which consist baryon-baryon or baryon-antibaryon as a constituents. The mass spectra of the  $\Sigma_c - \Sigma_c$  and  $\Sigma_c - \bar{\Sigma}_c$  are predicted. By taking the deuteron as an approximation for our model calculation, the S-wave mass spectra of the molecular di-baronic systems are extracted. The One Boson Exchange potential(OBE) is being used for the inter baryon-baryon(antibaryon) interactions. The calculated mass spectra with possible quantum numbers are compared with the observed exotic resonances and other theoretical predictions in a possible molecular interpretation.

**Hadron decays / 101****Heavy Quark Spin Symmetry Violating Hadronic Transitions of Higher Charmonia****Authors:** Muhammad Naeem Anwar<sup>1</sup>; Bing-Song Zou<sup>1</sup><sup>1</sup> *Institute of Theoretical Physics, Chinese Academy of Sciences*

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In heavy quarkonia, hadronic transitions serve as an enlightened probe for the structure and help to establish the understanding of light quark coupling with a heavy degree of freedom. Moreover, in recent years, hadronic transitions revealed remarkable discoveries to identify the new conventional heavy quarkonia and extracting useful information about the so called “XYZ” exotic states.

In this contribution, we present our predictions for the HQSS breaking hadronic transitions of higher  $S$  and  $D$  wave vector charmonia based on our recently proposed model (inspired by Nambu-Jona-Lasinio model) to create light meson(s) in heavy quarkonium transitions [1]. We also suggest spectroscopic quantum number ( $n^{2S+1}L_J$ ) assignments for several experimentally observed charmonium-like states. Invoked by the recent evidence of  $e^+e^- \rightarrow \eta h_c$  at center-of-mass energy  $\sqrt{s} = 4.358$  GeV at BESIII, we delve into the  $Y(4360)$  through its HQSS breaking hadronic transitions. Our analysis indicates that it is most likely to be a  $D$  wave dominant state. Our predictions provide useful references to determine the properties of higher charmonia in ongoing and forthcoming experiments.

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**Spectroscopy of baryons / 102**

## Regge-like relation and universal description of heavy-light systems

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Using the Regge-like formula  $(M - m_Q)^2 = \pi\sigma L$  between hadron mass  $M$  and angular momentum  $L$  with a heavy quark mass  $m_Q$  and a string tension  $\sigma$ , we analyze heavy-light systems like  $D/D_s/B/B_s$  mesons and charmed and bottomed baryons.

Numerical plots are obtained for  $D/B$  mesons of experimental data whose slope coefficient becomes nearly equal to 1/2 of that for light mesons as expected, while the slope deviates from 1/2 for  $D_s/B_s$ . Assuming that charmed and bottomed baryons consist of one heavy quark and one light cluster of two light quarks (diquark), we apply the formula to all the heavy-light baryons including recently discovered  $\Omega_c$ 's and find that  $\Lambda_c/\Lambda_b$  baryons well satisfy the above formula. We predict the average mass of  $\Lambda_b(3/2^+, 5/2^+)$  as 6.150 GeV, assignments of  $J^P$  of five  $\Omega_c$ 's. Successful results of  $\Lambda_Q$  suggests that these baryons can be safely regarded as heavy quark-light cluster configuration. We also find a universal description for  $D/B$  mesons as well as  $\Lambda_c/\Lambda_b$  baryons, i.e., one unique line is enough to describe both of charmed and bottomed heavy-light systems.

**Poster session / 103**

## $\eta^-$ and $\pi^0$ -production in proton-deuteron fusion to ${}^3\text{He}X$ with WASA-at-COSY

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The production of mesons in proton-deuteron fusion has historically received considerable interest as a natural way to study the interaction between mesons and nuclear matter through final state interactions. Thus, the near threshold regions for the production of  $\eta$  and  $\pi^0$  mesons in  $pd \rightarrow {}^3\text{He}X$  are already well explored, yet still subject of active research. Especially the  ${}^3\text{He}\eta$  final state is of great interest, as a sharp rise of the total cross section within the first few MeV of excess energy has repeatedly been linked to the possible existence of a  ${}^3\text{He}\eta$  (quasi-)bound state. However, at higher excess energies, the database for these reactions becomes much more sparse. Here, the  $pd \rightarrow {}^3\text{He}\eta$  centre-of-mass angular distributions are forward peaked already at low excess energies, in contrast to theoretical calculations based on two-step models. This observation has raised questions about a change of production mechanism within an excess energy interval in which the  $pd \rightarrow {}^3\text{He}\eta$  reaction can nicely be studied with the WASA-at-COSY experiment. For this reason, a measurement of this reaction at 15 excess energies between  $Q_\eta \approx 13$  MeV and  $Q_\eta \approx 81$  MeV with a step size of  $\Delta Q \approx 4.8$  MeV was performed in 2014. Precise angular distributions can be extracted, that allow for the first time to study their behavior with rising energy over a large excess energy region, without involving systematical uncertainties between different experimental setups, that have hindered detailed comparisons in the past.

In case of the  ${}^3\text{He}\pi^0$  final state, there exists a sizable database for collinear production  $\cos \vartheta_{\pi^0}^{\text{cm}} = \pm 1$ , whereas not much information is available on angular distributions. While a smooth decrease of the cross section is observed for forward scattered pions, the database for  $\cos \vartheta_{\pi^0}^{\text{cm}} = -1$  exhibits a minimum in the energy region covered by the dataset presented. With our measurement, a detailed extraction of the differential distributions between  $\cos \vartheta_{\pi^0}^{\text{cm}} \approx -1$  and  $\cos \vartheta_{\pi^0}^{\text{cm}} \approx -0.4$  is performed for excess energies between  $Q_{\pi^0} \approx 426$  MeV and  $Q_{\pi^0} \approx 494$  MeV.

The current status of the analyses regarding both the  ${}^3\text{He}\eta$ , as well as the  ${}^3\text{He}\pi^0$  final state will be presented.

## Spectroscopy of baryons / 104

### Strangeness photoproduction at the BGO-OD experiment

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The BGO-OD experiment at the ELSA accelerator facility uses an energy tagged bremsstrahlung photon beam to investigate the internal structure of the nucleon. The setup consists of a highly segmented BGO calorimeter surrounding the target, with a particle tracking magnetic spectrometer at forward angles.

BGO-OD is ideal for investigating the photoproduction of hadrons of non-zero strangeness. The high momentum resolution at forward angles covers a kinematic region where t-channel exchange mechanisms play a dominant role. Access to this low momentum transfer region also allows the investigation of degrees of freedom not derived from constituent quark models, for example, the role of vector meson-baryon interactions and dynamically generated states in photoproduction reactions.

Data taking for the first part of an extensive physics programme is complete. Preliminary results for differential cross sections and recoil polarisation measurements, in particular at extremely forward angles, for the photoproduction of  $K^+\Lambda$  and higher lying hyperons will be presented.

**Exotic states and candidates / 105****Production of exotic charmonium in heavy ion collisions****Author:** Fernando Navarra<sup>1</sup><sup>1</sup> *University of São Paulo***Corresponding Author:** navarra@if.usp.br

We will present an introduction to the physics of exotic charmonium, describing the most popular configurations proposed for these states: tetraquark and meson molecules. I will then show how these states can be produced in hadronic collisions and in heavy ion collisions, both in central and peripheral reactions. I will present our latest results on the production cross sections, abundancies and rapidity distributions. The talk will be based on material published in arXiv:1704.08781; arXiv:1610.06604; arXiv:1604.07716; arXiv:1511.05209 and arXiv:1405.7583. Ongoing calculations will be presented.

**Exotic states and candidates / 106****Y(4260) and Phi(2170) as exotic vector mesons****Authors:** Sachiko Takeuchi<sup>1</sup>; Makoto Takizawa<sup>2</sup><sup>1</sup> *Japan College of Social Work*<sup>2</sup> *Showa Pharmaceutical University***Corresponding Authors:** takizawa@ac.shoyaku.ac.jp, s.takeuchi@jcsu.ac.jp

The  $u\bar{u}c\bar{c}$ ,  $u\bar{u}b\bar{b}$ , and  $u\bar{u}s\bar{s}$   $J^{PC} = 1^{--}$  states are investigated by a coupled-channel two-meson model. We used the complex scaling method with 14 two-meson channels with an effective hadron interaction originated from interaction between quarks. The coupling between channels is obtained from the quark rearrangement.

We have found a pole each in the  $u\bar{u}c\bar{c}$  and in the  $u\bar{u}s\bar{s}$  systems. The pole in the hidden charm system appears 1 MeV below the  $\bar{D}D_1'$  threshold, 4289 MeV, with a few MeV width. A similar pole appears just below  $\bar{K}^*K_1$  threshold, 2163 MeV, in the hidden strange system. We argue that they are important components of  $Y(4260)$  or  $\phi(2170)$ , respectively, which are considered to be exotic mesons.

**Hadrons in matter including hypernuclei / 107****Determination of the  $\eta'$ -nucleus potential at low momenta \*****Author:** Mariana Nanova<sup>1</sup><sup>1</sup> *II. Phys. Inst., University of Giessen, Germany***Corresponding Author:** mariana.nanova@exp2.physik.uni-giessen.de

The real part of the  $\eta'$ -nucleus potential has been determined at low momenta by analyzing the  $\eta'$  kinetic energy distribution and the excitation function in photoproduction of  $\eta'$  mesons off C in coincidence with forward going protons. The forward going protons take over most of the momentum of the incoming photon beam and thus their detection allows the study of the  $\eta'$ -nucleus interaction

at very low relative momentum. This experimental approach was previously used in the determination of the  $\omega$  -nucleus potential [1]. The present measurement extends earlier determinations of the  $\eta'$  -nucleus potential at higher average momenta [2,3], towards the production threshold. A comparison of the data with calculations by E. Paryev [4] yields a potential depth of about -40 MeV. In agreement with [5], this indicates that the deep  $\eta'$  - nucleus potentials of  $\geq 100$  MeV, predicted in [6], can be excluded also at low momenta. Within the experimental uncertainties, there is no indication of a momentum dependence of the  $\eta'$  - Carbon potential.

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#### Poster session / 108

### Study of baryonic resonances in the reaction $pp \rightarrow pp\pi^+\pi^-$ at 3.5 GeV with HADES

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Pion production in NN collisions is one of the sources of information on the NN interaction and on the contribution of nucleon resonances. In particular, two-pion production in the few energy range, carries information both on  $\pi\pi$  dynamics and on single and double baryon excitation.

The High Acceptance Di-Electron Spectrometer (HADES) [1] installed at GSI Helmholtz-Zentrum für Schwerionenforschung in Darmstadt, designed to investigate dielectron production in heavy-ion collisions in the range of kinetic beam energies 1-3 A GeV is also an excellent detector for charged hadron detection, due to its tracking capabilities.

Recently, differential and integrated cross sections for the reactions  $pp \rightarrow pp\pi^0$ ,  $pp \rightarrow pn\pi^+\pi^-$  [2-3-4],  $pp \rightarrow pp\pi^+\pi^-$ ,  $pn \rightarrow pn\pi^+\pi^-$  [5],  $pn \rightarrow d\pi^+\pi^-$  have been investigated with HADES at kinetic energies 1.25, 2.2 and 3.5 GeV. This talk will focus on the analysis of the  $pp \rightarrow pp\pi^+\pi^-$  channel at 3.5 GeV, using results from  $pp \rightarrow pp\pi^0$ ,  $pp \rightarrow pn\pi^+$  [3] and  $pp \rightarrow pK\Lambda$  [6] measured at the same energy by HADES. The contributions of the excitation on one or two baryonic resonances with masses up to 1,9 GeV and of the  $\rho$  production can be quantified. The results are compared with two theoretical models [7-8].

The results of this study provide strong constraints on the pion production mechanisms, and on the various resonance contributions ( $\Delta^0(1232)$ ,  $N^*(1440)$ , ...), as well as on the double resonance excitation and the direct  $\rho$  production. These aspects are closely related to the interpretation of the dielectron spectra measured by the HADES collaboration. Baryonic resonances are indeed important sources of dileptons through two mechanisms: the Dalitz decay (e.g.  $R \rightarrow Ne^+e^-$ ) and the mesonic decay with subsequent dielectron production.

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 [8] X. Cao et al., Phys. Rev. C81, 065201 (2010).

**Poster session / 109**

## Phenomenology of excited vector mesons and predictions for a yet undiscovered $\bar{s}s$ state $\phi(1930)$

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**Co-authors:** Francesco Giacosa<sup>2</sup>; Christian Reisinger<sup>3</sup>

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We study the decays of two nonets of excited vector mesons which predominantly correspond to  $n^{2s+1}L_J = 2^3S_1$  (radially excited vector mesons) and  $n^{2s+1}L_J = 1^3D_1$  (angular-momentum excited vector mesons). By using a quantum field theoretical approach we evaluate the decay widths of these mesons into two pseudoscalar mesons and into pseudoscalar and ground-state vector mesons. Moreover by introducing vector meson dominance we study radiative decays of excited vector mesons into a photon and a pseudoscalar meson. We compare our results with the experimental data from PDG. We also make predictions for an unknown  $s\bar{s}$  state in  $1^3D_1$  nonet, that we call  $\phi(1930)$ . This state was not yet discovered but can be found in the upcoming Gluex and Mesonex experiments at Jefferson lab.

**QCD and hadron structure / 110**

## Recent measurements of exclusive hadronic cross sections at BABAR and the implication for the muon g-2 calculation

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The BABAR Collaboration has an intensive program studying hadronic cross sections in low-energy  $e^+e^-$  annihilations, which are accessible with data taken near the  $\Upsilon(4S)$  via initial-state radiation. Our measurements allow significant improvements in the precision of the predicted value of the muon anomalous magnetic moment. These improvements are necessary for shedding light on the current  $\sim 3$  sigma difference between the predicted and the experimental values. We have previously published results on a number of processes with two to six hadrons in the final state. We report here on several recent measurements of hadronic cross sections in  $e^+e^-$  annihilations.

**Hadron decays / 111**

## Search for the $B$ -meson decay to four baryons $B \rightarrow p\bar{p}p\bar{p}$ at BaBar

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The  $B$  mesons are the lightest mesons which can decay to various final states containing different baryons. Up to now, the discrepancy between the inclusive branching fraction of all  $B$  meson decay modes with at least a couple of baryons in the final state, measured by ARGUS to be  $(6.8 + 0.6)\%$ , and the sum of exclusive baryonic channels, averaged on neutral and positive  $B$  mesons at less than 1%, represents an open issue. The measurement and comparison of exclusive branching fractions of baryonic  $B$  decays as well as studies on the dynamic of the decay, may allow better understanding of baryon production in  $B$  decays and, more generally, hadron fragmentation into baryons. We present here a search for the decay of a  $B$  meson in four baryons:  $B \rightarrow p\bar{p}p\bar{p}$ , not yet observed. The data set consists of about 470 million  $B\bar{B}$  pairs collected with the BaBar detector at the SLAC National Accelerator Laboratory.

**Spectroscopy of mesons / 112**

## Three-body decays of quarkonium states at BABAR

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We report about recent results obtained at BABAR on three-body decays of charmonium and bottomonium states.

We present Dalitz plot analyses of  $J/\psi$  three-body hadronic decays to  $\pi^+\pi^-\pi^0$ ,  $K^+K^-\pi^0$  and  $K_S K^\pm \pi^\mp$  using the isobar and Veneziano models. The  $J/\psi$  is produced through the Initial-State-Radiation process. We also perform Dalitz plot analyses of  $\eta_c$  three-body hadronic decays to  $K^+K^-\pi^0$  and  $K_S K^\pm \pi^\mp$ , where the  $\eta_c$  is produced in two-photon interactions. An isobar model is used, as well as a Model Independent Partial Wave Analysis which allows to extract the amplitude and phase of the  $K\pi$   $S$ -wave up to a mass of 2.5 GeV.

Finally, we present a study of the reactions  $\Upsilon(1S) \rightarrow \gamma\pi^+\pi^-$  and  $\Upsilon(1S) \rightarrow \gamma K^+K^-$ . The  $\Upsilon(1S)$  candidates are obtained from the data samples collected at the peak of the  $\Upsilon(2S)$  and  $\Upsilon(3S)$  selecting the decays  $\Upsilon(2S, 3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$ .

**Hadron decays / 113**

## Searches for a Lepto-phobic “Dark Omega” with the GlueX Detector

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The GlueX experiment has had several run periods with a 9 GeV photon beam, its ultimate goal being the search for exotic hybrid mesons. While we improve our understanding of the GlueX detector needed for a high precision PWA, it is possible to carry out a dark matter search now. Constraints on

the allowed coupling versus mass of a dark lepto-phobic boson, a hypothetical state with  $JPC = 1^{--}$  called the dark omega or  $\omega_D$ , are surprisingly weak.<sup>1</sup> For example, for  $0.4-1.0 \text{ GeV}/c^2$ , a coupling constant as large as  $\alpha_{EM} \sim 1/137$  has not yet been excluded. Light meson decays can yield greatly improved constraints in the mass range  $0.15-0.5 \text{ GeV}/c^2$  where the  $\omega_D$  would decay predominantly to  $\pi^0 + \gamma$ . The irreducible SM backgrounds are rare decays of the initial mesons, so the principle experimental challenges are to produce a large number of appropriate mesons with good acceptance for photons, hence well-suited to GlueX. Direct production via  $\gamma + p \rightarrow p + \omega_D$  is an exciting new proposal which covers an even broader mass range<sup>2</sup>, and may be the best way to access the  $0.5-1 \text{ GeV}/c^2$  mass region where the  $\omega_D$  would decay predominantly to  $\pi^+\pi^-\pi^0$ . The SM backgrounds are relatively large in the direct case, but they only dilute the sensitivity of the measurement by the inverse square root of the background. The status and potential sensitivity of dark omega searches with GlueX will be summarized.

<sup>1</sup> S. Tulin, <https://arxiv.org/abs/1404.4370>,

<sup>2</sup> C. Fanelli and M. Williams, <https://arxiv.org/abs/1605.07161>

## Exotic states and candidates / 114

### Search for the H-dibaryon near $\Lambda\Lambda$ and $\Xi^-p$ thresholds at J-PARC

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Recent Lattice QCD predictions for the mass of H-dibaryon pointing to the mass region near  $\Lambda\Lambda$  and  $\Xi^-p$  thresholds encourage experimental searches. A dedicated experiment (J-PARC E42) has been prepared for hunting the H-dibaryon close to  $\Lambda\Lambda$  and  $\Xi^-p$  thresholds. The experiment was designed to measure  $\Lambda p \pi^-$ ,  $\Lambda\Lambda$  and  $\Xi^-p$  decays from the H-dibaryon in the  $^{12}\text{C}(K^-, K^+)$  reaction at the K1.8 beam line of J-PARC. A new superconducting spectrometer (Hyperon Spectrometer) is now under commissioning, consisting of a conduction-cooled superconducting dipole magnet and a time projection chamber. This talk will review our new attempt to find evidence supporting the existence of the H-dibaryon in the wide mass region as well as the current status of the Hyperon Spectrometer.

## Hadrons in matter including hypernuclei / 115

### On the structure observed in the in-flight $^3\text{He}(K^-, \Lambda p)n$ reaction at J-PARC

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Recently, a peak structure was observed near the  $K^-pp$  threshold in the in-flight  $^3\text{He}(K^-, \Lambda p)n$  reaction of the E15 experiment at J-PARC. This peak could be a signal of the lightest kaonic nuclei, that is, the  $\bar{K}NN(I = 1/2)$  state, which has been intensively studied both experimentally and theoretically in the last decade. In this contribution we theoretically investigate what is the origin of the peak structure observed in the E15 experiment at J-PARC. Since the peak exists near the  $K^-pp$  threshold, we expect two scenarios to produce the peak. One is that the  $\Lambda(1405)$  is generated but it does not correlate with  $p$ , and the uncorrelated  $\Lambda(1405)-p$  system subsequently decays into  $\Lambda p$ . The other is that the  $\bar{K}NN$  quasi-bound state is indeed generated and decays into  $\Lambda p$ . We calculate

the  $\Lambda p$  invariant mass spectrum of the reaction with these two scenarios and compare it with the experimental one to interpret the experimental peak structure.

**Exotic states and candidates / 116**

## Masses of $T_{4c}$ tetra quark state in a relativistic formalism

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After the discovery of X(3872) many new and unexplained X Y Z states have been discovered experimentally in recent times [1]. It has helped in our faith towards the existence of multi quark states. Most of these unknown states consist of hidden heavy quark anti quark pair with combinations of quark/antiquark in the lighter sector ( $cq\bar{c}$  or  $bq\bar{b}$  where  $q \in u, d, s$ ). However, the tetra quark state containing all heavy flavor like  $T_{4Q}$  ( $Q \in c, b, \bar{c}$  and  $\bar{b}$ ) has not been investigated rigorously. So we have selected a single flavor (all charm) tetra quark system to study the mass spectra and hadronic decays. Based on diquark - antidiquark model we have developed a relativistic approach to study exotic hadron spectroscopy, where in, the four body system is considered as three subsequent two body systems. We have solved Dirac equation by using Cornell like confinement potential for two body Interaction and for the construction of tetra quark system ( $cc\bar{c}\bar{c}$ ). The Spin dependent parts are also employed to understand the splitting structure of tetra quarks. The contribution of each term is well analyzed. Our predicted mass for first radially excited state with  $J^{PC}$  value  $0^{++}, 1^{+-}, 2^{++}$  are 6.495, 6.595 and 6.68 which are in a good agreement with other theoretical model predictions [2]. More experiments and theoretical attempts are required to understand the interactions and nature of all heavy tetra quark states. We hope that forthcoming experiments such as Belle II and LHC at 13 TeV gives more information about doubly hidden charm tetra quark hadronic state.

**Key words:** All charm tetra quark, diquark -diantiquark model, Dirac formalism and mass spectra

1. Lu Zhao, Wei-Zhen Deng, and Shi-Lin Zhu, Phys. Rev. D 90, 094031 (2014).

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**Analysis tools / 117**

## Coupled-channel $\Lambda_c N - \Sigma_c N$ interaction from lattice QCD

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We study the  $\Lambda_c N - \Sigma_c N$  system on the basis of the coupled-channel HAL QCD method. The potentials are extracted from Nambu-Bethe-Salpeter wave functions on the lattice, which are faithful to S-matrix in QCD. One of the advantages of this approach is that it is possible to extract the potentials without any assumptions. I will present our results of the coupled-channel potentials in the  $\Lambda_c N - \Sigma_c N$  in  $J^P = 1^+$  system and scattering observables such as phase shifts and mixing angles. We observe that the coupling between the  $\Lambda_c N$  and  $\Sigma_c N$  channel is weak and the attraction in  $\Sigma_c N$  channel is stronger than that in  $\Lambda_c N$  channel.

**Hadrons in matter including hypernuclei / 118****Patterns and partners for chiral symmetry restoration****Authors:** Angel Gomez Nicola<sup>1</sup>; Jacobo Ruiz de Elvira<sup>2</sup><sup>1</sup> *Universidad Complutense Madrid*<sup>2</sup> *ITP, University of Bern***Corresponding Authors:** gomez@fis.ucm.es, elvira@itp.unibe.ch

The nature of chiral symmetry restoration and the identification of its correct pattern in terms of  $O(4)$  and  $U(1)_A$  restoration are central problems for our present understanding of the QCD phase diagram, which are not fully settled in lattice simulations. We will present a theoretical analysis based on Ward Identities which sheds light on this issue and where partner degeneration is systematically studied and connected with physical processes for the full scalar/pseudoscalar  $U(3)$  meson nonets. Model-independent results are derived, which in addition allow to understand the temperature dependence of lattice screening masses through particular quark condensate combinations. Their realization in  $U(3)$  Chiral perturbation Theory for the hadron sector will also be described. Special attention will be paid to the role of the thermal  $f_0(500)$  state to describe lattice data for the scalar susceptibility through thermal corrections to its pole parameters generated from unitarized pion scattering.

**Exotic states and candidates / 119****Exotic states at threshold and threshold scan at PANDA@FAIR****Author:** Elisabetta Prencipe<sup>1</sup><sup>1</sup> *Forschungszentrum Juelich***Corresponding Author:** e.prencipe@fz-juelich.de

The future experiment PANDA@FAIR is a fix-target ppbar machine that will run in the energy range [1.5-15.0] GeV, and it is supposed to reach a peak luminosity of about  $2 \cdot 10^{31}$  cm<sup>-2</sup> s<sup>-1</sup> in the first phase of data taking. This will allow to perform a number of analyses which are suppressed or forbidden at e+e- colliders, especially in the sector of charm- and charmonium physics. To investigate narrow resonances, measure their width and understand their properties is the core of the PANDA physics program in the “day-one” experiment. This contribution reports about the feasibility studies for new supposedly exotic states at the DDbbar threshold in PANDA, and the technique to measure the width of very narrow states by performing a threshold scan. The case of the Ds2317 will be discussed and preliminary Monte Carlo simulations will be shown together with new theoretical developments to evaluate cross section and rates for the process ppbar → DsDs2317, as an original part of the PANDA physics program. Eventually new ccbarsbar resonances could be investigated in the DsDs2317 system. We recall that recently LHCb published on four ccabssbar resonances in the Jpsi-phi invariant mass system through B decays. We also recall that recently charged Z states at DD and DD\* thresholds have been observed by BES III, namely the Z(3900) and the Z(4020). However, a Z states at the DD threshold has not been found yet, although theoretically possible. Due to the expected quantum numbers (predicted 0+ in S-wave) it cannot be observed in pi\pi transitions from an initial 1- state. Using antiproton-proton annihilation at PANDA@FAIR a copious production of such a state would be feasible, in particular when 0+ tetraquark is present near the DD threshold.

**QCD and hadron structure / 120**

## Global analysis on determination of fracture functions considering sea quark asymmetries in the nucleon

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In recent years, several experiments at the  $e^-p$  collider HERA have collected high precision data on the spectrum of leading-baryons carrying a large fraction of the proton's energy. In this paper, we have analyzed recent experimental data on the production of forward proton and neutrons in deep inelastic scattering at HERA in the framework of a perturbative QCD.

We propose a technique based on the fracture functions framework, and extract the fracture functions (FFs)  $M_2^{(B/p)}(\beta, Q^2, x_L)$  from global QCD analysis of DIS data measured by H1 and ZEUS collaborations. We have shown that an approach based on the fracture functions approach allows us phenomenologically parametrize the FFs.

Considering both leading proton as well as leading neutron production data in reaction  $\gamma p \rightarrow BX$  and applying isospin symmetry, we present the results for the separate parton distributions for all parton species, including valence quark densities, the anti-quark densities, the strange sea distribution functions, and the gluon distribution.

We proposed several parameterizations for the FFs and open the possibility of these asymmetries.

The extracted results for the  $t$ -integrated fracture functions  $F_2^{LB(3)}(\beta, Q^2, x_L)$  are in good agreement with all data analyzed, for a wide range of scaled fractional momentum variable  $\beta$  as well as the longitudinal momentum fraction  $x_L$ .

Poster session / 121

## Pionic transitions to the 1P states of excited charmed mesons in the covariant oscillator quark model

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Since 2010, candidates for the highly excited states of charmed mesons have been successively observed by the BABAR and LHCb collaborations. Although several theoretical studies have been done, spectroscopic assignments for these states still remain to be completely elucidated.

In this work, following our previous work [1], we study extensively the pionic decays of the radial and highly orbital excited charmed mesons by adopting the covariant oscillator quark model. In particular, our special attention is paid to the transitions to the 1P final states that could have a major impact on the total widths. In addition, similarly to the preceding study, we carefully examined the relativistic effect to the calculated widths, not been incorporated into the nonrelativistic models.

Based on the results obtained, we will discuss the possible assignments for newly discovered states,  $D(2550)$ ,  $D^*(2600)$ ,  $D(2750)$ ,  $D_1^*(2760)$  and  $D_3^*(2760)$ . Moreover, predicted widths for experimentally missing states may be helpful for the future searches.

Reference

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Poster session / 122

## Light-Meson Spectroscopy in Strong Magnetic Field

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The spectra of charged and neutral rho and pi-mesons in uniform homogeneous magnetic field (MF) are discussed in the framework of the path integral formalism and vacuum correlator method. The spectra of all 12 spin-isospin s-wave meson states were obtained analytically using the Hamiltonian for quarks with confinement potential in strong magnetic field. The states have 3 different types of asymptotics in strong MF: two of them are growing with MF and the last one tends to be a constant (zero mode). The mass of the zero mode becomes small in MF which can be the source of the meson collapse. It was shown that the potential collapse has two different sources (color Coulomb and hyperfine interactions) and it doesn't occur for the  $MF < 2 \text{ GeV}^2$ . The analytic data presented is in a good agreement with lattice calculations.

Poster session / 123

## Low-energy limit of the 3-flavor extended Linear Sigma Model

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The extended Linear Sigma Model (eLSM) is an effective hadronic model based on the linear realization of chiral symmetry  $U(N_f)_L \times U(N_f)_R$ , with (pseudo-)scalar and (axial-)vector mesons as degrees of freedom. We study the low-energy limit of the eLSM for  $N_f = 3$  by integrating out all fields except for the (pseudo-)Nambu-Goldstone bosons of chiral symmetry breaking. After keeping only terms that enter at tree level and up to fourth order in powers of derivatives, we compare the results with the Low Energy Constants (LECs) of the Chiral Perturbation Theory (ChPT). We find that the LECs of the eLSM are in good overall agreement with those of ChPT.

Exotic states and candidates / 124

## Search for the X(5568) state in the Bs pi decays

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The evidence for an unexpected narrow Bs pi structure claimed by the D0 Collaboration and named X(5568) has triggered its search in other hadron collider experiments including CMS. Its interest

resides in its possible interpretation as a compact hadronic state composed of four different quark flavours (udsb). The CMS search is performed using an integrated luminosity of  $19.7\text{fb}^{-1}$  of pp collisions at  $\sqrt{s}=8\text{TeV}$  and provides the current most stringent Upper Limits on the ratio of the production rates of  $X(5568)$  and  $B_s$  multiplied by the unknown branching fraction of the  $B_s \pi$  decay, given in two different kinematic regions defined on the basis of the transverse momentum of the  $B_s$ . The obtained CMS upper Limits contradict the D0 measurement and are in agreement with the results by the LHCb Collaboration.

**QCD and hadron structure / 125**

## CMS recent results in heavy flavour production and properties

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Using large data samples of di-muon events, CMS has performed detailed measurements in the field of double quarkonium production. In the double quarkonium final states potential resonances, such as heavy quark tetra-quarks governed by strong interaction, have been predicted. The first observation of  $Y(1S)$  pair production has been recently performed, with both quarkonia fully reconstructed from oppositely charged muon pairs, by exploiting proton-proton collisions at  $\sqrt{s} = 8 \text{ TeV}$ . A fiducial cross section of the  $Y(1S)$  pair production is provided within the single- $Y$  acceptance  $|\text{rapidity}(Y)| < 2$ . An effective cross-section is also estimated on the basis of the fiducial cross-section and the fraction of DPS contribution. The study of  $J/\psi$  pair final state produced in proton-proton collisions at  $\sqrt{s} = 7 \text{ TeV}$  is foreseen to be extended to a center-of-mass of  $8\text{TeV}$  providing the total and differential cross sections measured in a phase space defined by the individual  $J/\psi$  transverse momentum and rapidity. These observations allow us to access, for the first time, to the high-transverse-momentum region of  $J/\psi$  pair production where model predictions are not yet established. The first cross section complementary measurements in CMS and LHCb allowed to set up production models that not only include single-parton scattering but also double-parton scattering and consider color singlet and color octet intermediate  $J/\psi$  states. Indeed it is a crucial step to isolate double quarkonium signals by understanding the non-resonant pair production.

**QCD and hadron structure / 127**

## Magnetized QCD phase diagram

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Presently the study of the phase diagram of QCD is the subject of both theoretical and experimental studies under extreme conditions of density and temperature.

In particular, it is expected that the phenomenon of deconfinement occurs in relativistic heavy-ion collisions and in the interior of compact stars.

Also the understanding of the effect of an external magnetic field on the structure of the QCD phase diagram is very important once extremely strong magnetic fields are relevant for compact objects like magnetars and are expected to affect measurements in heavy ion collisions at very high energies or the behavior of the first phases of the universe.



We examine possible effects of an external magnetic field on the phase diagram structure of QCD. The study is performed using the Polyakov-Nambu-Jonas-Lasinio model. We focus on the influence of a magnetic field on the chiral and deconfinement phase transitions. Possible consequences of the Inverse Magnetic Catalysis effect on the QCD phase diagram at both finite chemical potential and temperature is analysed. We devote special emphasis on how the location of the Critical-End-Point (CEP) changes in a magnetized medium.

**QCD and hadron structure / 128**

## Measurement of inelastic cross sections at LHCb

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The forward acceptance of LHCb,  $2.0 < y < 5.0$ , provides a complementary reach to the general purpose detectors at the LHC. LHCb measurements of the inelastic cross-section and related results will be presented, as well as a comparison to Run 1 results.

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## Measurement of Bose-Einstein correlations at LHCb

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The forward acceptance of LHCb,  $2.0 < y < 5.0$ , provides a complementary reach to the general purpose detectors at the LHC. LHCb measurements of Bose-Einstein correlations in particle production will be presented.

**Poster session / 131**

## Decays of the vector glueball

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We calculate two- and three-body decays of the (lightest) vector glueball into (pseudo)scalar, (axial-)vector, as well as pseudovector and excited vector mesons in the framework of a model of QCD. While absolute values of widths cannot be predicted because the corresponding coupling constants are unknown, some interesting branching ratios can be evaluated by setting the mass of the yet hypothetical vector glueball to 3.8 GeV as predicted by quenched Lattice QCD. We find that the decay mode  $\omega\pi\pi$  should be one of the largest (both through the decay chain  $O \rightarrow b 1 \pi \rightarrow \omega\pi\pi$  and through the direct coupling  $O \rightarrow \omega\pi\pi$ ). Similarly, the (direct and indirect) decay into  $\pi K K^*(892)$  is sizable. Moreover, the decays into  $\rho\pi$  and  $K^*(892)K$  are, although subleading, possible and could play a role in explaining the  $\rho\pi$  puzzle of the charmonium state  $\psi(2S)$  thanks to a (small) mixing with the vector glueball. The vector glueball can be directly formed at the ongoing BESIII experiment as well as at the future PANDA experiment at the FAIR facility. If the width is sufficiently small ( $\sim 100$  MeV) it should not escape future detection.

**Hadron decays / 133**

## Baryonic and charmless B decays at LHCb

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The mechanisms behind baryonic decays of heavy flavoured particles remain mysterious and challenging to describe theoretically. Interesting properties of such decays include the suppression of branching fractions to two-body final states and threshold enhancements in higher multiplicity decays. The large data sample accumulated by the LHCb experiment between 2011 and 2016 enables a variety of studies to be performed and new decay modes to be explored. The latest LHCb results on charmless decays of B mesons are reviewed with an emphasis on decays to baryonic final states.

**Hadron decays / 134**

## CPV with b-hadrons, including baryons, at LHCb

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The phenomenon of CP violation has been observed in the K- and B-meson systems, but not yet with any baryonic particle. Charmless decays of beauty baryons are of particular interest in with this respect, as they receive contributions from both tree- ( $b \rightarrow u$ ) and loop-level ( $b \rightarrow d$  and  $b \rightarrow s$ ) transitions with similar magnitude. We present the most recent measurements of CP violation observables in b hadron decays with emphasis on charmless decays of beauty baryons performed by the LHCb experiment.

**Spectroscopy of mesons / 135**

## Spectroscopy of charm hadrons at LHCb

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LHCb continues to expand its world-leading sample of charmed hadrons collected during LHC's Run 1 (2010-2012) and Run 2 (2015- present). With this data set, LHCb is discovering many previously unobserved charmed states and making the most precise determinations of the properties of known states. LHCb's latest work on the spectroscopy of charmed hadrons is presented.

**Hadron decays / 136**

## Measurement of suppressed charm decays and search for CP violation at LHCb

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LHCb continues to expand its world-leading sample of charmed hadrons collected during LHC's Run 1 (2010-2012) and Run 2 (2015- present). This sample is yielding some of the most stringent tests of the Standard Model understanding of charm physics. This includes sensitive searches for direct and indirect CP violation in charm interactions and for charm decays that are heavily suppressed or forbidden in the Standard Model. The latest LHCb measurements from these research areas are presented.

**Poster session / 138**

## Hidden-charm meson-baryon molecules with a short-range attraction from five quark states

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The observation of the hidden-charm pentaquarks by the LHCb collaboration indicates an existence of exotic hadrons close to hidden-charm meson-baryon thresholds. In the literature, various model calculations have been performed such as the hadronic molecules and the compact multi-quark states. The observed states appear below the thresholds, and it indicates that the states are a loosely

bound state of the hidden-charm meson-baryon. On the other hand, in the quark cluster model, the compact five-quark states are discussed to describe the short range part of the interaction.

In this talk, we study the hidden-charm pentaquark systems as a molecule of  $\bar{D}^{(*)}\Lambda_c$  and  $\bar{D}^{(*)}\Sigma_c^{(*)}$  with coupling to the five-quark state  $(qqq\bar{c}\bar{c})$ , where the three light quark part  $(qqq)$  is the color octet. The five-quark component is introduced as the short range potential between the meson and the baryon. The long range force is given by the one pion exchange potential (OPEP). By solving the Schrödinger equation, we study the bound and resonant states for  $J^P = \frac{1}{2}^-, \frac{3}{2}^-$  and  $\frac{5}{2}^-$  with isospin  $I = \frac{1}{2}$ . In the charm sector, we obtain that the short range potential plays an important role to produce the states, while we obtain no state only with the OPEP. The spectrum structure is affected by the spectroscopic factor of the coupling between the five-quark and the meson-baryon components.

### Spectroscopy of baryons / 139

## Spectroscopy of beauty hadrons and doubly-heavy baryons at LHCb

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We report on the first observation of excited hadronic states in the beauty sector, with emphasis on beauty baryons.

Similar techniques are used to search the LHCb data for states observed in other datasets, such as the tetraquark state X(5568) whose evidence was reported by D0.

Furthermore, we discuss the searches for doubly heavy baryons, such as the doubly charmed Xicc and charmed-beauty Xibc states, with LHCb data.

### Spectroscopy of mesons / 142

## Bottom quark mass determination from bottomonium at N<sup>3</sup>LO

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The precise determination of hadron spectroscopy from fundamental principles pursues to unveil QCD at its non-perturbative regime.

The non-perturbative nature of QCD at hadronic scales implied the development of phenomenological approaches such as quark models or, more recently, computer-based calculations using Lattice QCD.

However, the unique properties of heavy quarkonium systems allow an entire calculation in terms of non-relativistic perturbative QCD.

Within NRQCD

the predictions of heavy quarkonium energy levels rely on the accurate description of the static QCD potential  $V_{\text{QCD}}(r)$ .

Most recent calculations computed the energy levels of the lower-lying bottomonium states up

to  $\mathcal{O}(\alpha_s^5 m)$  and  $\mathcal{O}(\alpha_s^5 m \log \alpha_s)$  utilizing pNRQCD [1], which describes the interactions of a non-relativistic system with ultrasoft gluons organizing the perturbative expansions in  $\alpha_s$  and the velocity of heavy quarks systematically. A closed expression for arbitrary quantum numbers can be found in Ref. [2].

The convergence of the perturbative expansion depends, though, on the short-distance mass scheme selected to ensure the  $\mathcal{O}(\Lambda_{\text{QCD}})$  renormalon cancellation. The authors of Ref. [3] employed the well-known  $\overline{\text{MS}}$  scheme, commonly used for physical situations in which the relevant scale is of the order or larger than the heavy quark mass. For quarkonium the typical scale is much smaller, therefore the results can be substantially improved by switching to a low scale short-distance scheme. Thus, in this work we study the predictions of the energy levels of heavy quarkonium at N<sup>3</sup>LO using the MSR scheme [4], and determine the bottom quark mass including charm quark mass effects. Our results have smaller perturbative uncertainties than a similar recent analysis [5], which uses the Renormalon-Subtracted mass scheme.

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## Spectroscopy of baryons / 145

### Understanding the properties of Xi(1690) and Xi(2120)

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We have recently studied the interaction of meson-baryon systems with strangeness -2 and our results explain why some Xi-baryons are narrower than expected. For instance, the latest BABAR and BELLE data show that the width of  $\Xi(1690)$  is of the order of 10 MeV. With our coupled channel calculation of the pseudoscalar meson-baryon and vector meson-baryon systems with chiral and hidden local symmetry Lagrangians, we find properties of Xi(1690) which are in excellent agreement with recent data. We find that the known mass, width, spin-parity and branching ratios of  $\Xi(1690)$  can be naturally explained in terms of coupled channel meson-baryon dynamics. We find another narrow resonance which can be related to  $\Xi(2120)$ . We also look for exotic states  $\Xi^{*+}$  and  $\Xi^{*-}$  but find none. We also obtain the cross sections for the anti-kaon induced Xi production processes, with the motivation for obtaining information which can be useful for understanding the enhanced yield of  $\Xi$  in the heavy ion collisions.

## Spectroscopy of mesons / 146

### Tensor resonances in $\eta\pi$ using COMPASS data

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We present results on the extraction of tensor resonances in the  $\eta\pi$  system in a joint analysis between the JPAC and COMPASS collaborations. We use  $S$ -matrix principles unitarity and analyticity to constrain the reaction model. We find two  $J^{PC} = 2^{++}$  resonance poles, the  $a_2$  and  $a_2'$ . We discuss extensions of the model to coupled channel systems and the  $3\pi$  sector.

**QCD and hadron structure / 147**

## Multi-strange hadron production at the LHC with ALICE

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A strongly interacting state of matter known as the Quark-Gluon Plasma (QGP) is formed in the high temperature and energy density conditions reached in ultra-relativistic heavy-ion collisions. One of the key measurements for the understanding of the thermal properties of the fireball created in these collisions is the study of the production of strange and particularly multi-strange hadrons in the final state. The ALICE detector is ideally suited to study identified particle production rates. The excellent tracking and particle identification capabilities allow the reconstruction of multi-strange baryons ( $\Xi^-$ ,  $\Xi^+$ ,  $\Omega^-$  and  $\Omega^+$ ) via their weak decay channels over a large range in transverse momentum ( $p_T$ ). In this work, we report on the  $p_T$  spectra and total yield of such hadrons at central rapidity in Pb-Pb collisions measured by ALICE at the unprecedented energy of  $\sqrt{s_{NN}} = 5.02$  TeV in several centrality classes. The yields are normalized by the corresponding measurement of pion production in the same centrality class in order to study the enhancement of multi-strange hadrons. Comparison of hyperon-to-pion ratio between different systems, such as pp, p-Pb and Pb-Pb collisions shows that production of multi-strange baryons relative to pions follows a continuously increasing trend from low multiplicity pp to central Pb-Pb collisions. Predictions of thermal models and QCD-inspired generators for the small system are compared to the results. Furthermore, comparison of hyperon-to-pion ratios in Pb-Pb collisions at two different energies ( $\sqrt{s_{NN}} = 2.76$  TeV and 5.02 TeV) are presented and discussed.

**QCD and hadron structure / 148**

## D-meson and charmed-baryon measurement in pp and p–Pb collisions with ALICE at the LHC

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Measurements of charmed-hadron production in pp collisions are important to test predictions from perturbative QCD and provide an essential baseline for the studies in A–A collisions. Measurements in p–A collisions also allow studies of possible modifications of the charmed-hadron yields due to cold nuclear matter effects. The study of charm production as a function of the multiplicity of charged particles produced in the collision can give insight into multi-parton interactions and into the interplay between hard and soft processes. The charmed baryon-to-meson ratio is sensitive to hadronisation mechanisms in pp and p–A collisions and it will offer a unique probe of the role of coalescence and predicted presence of diquark states in A–A collisions.

The high precision tracking, good vertexing capabilities and excellent particle identification offered by ALICE allows us to measure hadrons containing charm quarks in wide momentum and rapidity ranges in pp and p-A collisions.

We will present the recent results for  $D^0$ ,  $D^+$ ,  $D^{*+}$  and  $D_s^+$  mesons reconstructed via their hadronic decays at mid-rapidity in pp collisions at  $\sqrt{s} = 5.02, 7, 8$  and 13 TeV and in p-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV, collected with the ALICE detector during the LHC Run-1 and Run-2. In particular, we will show the production cross section, nuclear modification factor, multiplicity-dependent studies and the charm production measurement down to  $p_T = 0$ .

We will report the first measurement of the  $p_T$ -differential cross section of the  $\Lambda_c^+$  baryon in pp collisions at  $\sqrt{s} = 7$  TeV, and in p-Pb collisions at  $\sqrt{s_{NN}} = 5.02$  TeV through the full reconstruction of two of its hadronic decay channels and the partial reconstruction of one of its semileptonic decay channels. We will also show the  $p_T$ -differential cross section times branching ratio of the  $\Xi_c^0$  baryon measured in the decay channel  $\Xi_c^0 \rightarrow e^+ \Xi^- \nu_e$  in pp collisions at  $\sqrt{s} = 7$  TeV. The results will be compared with theoretical model predictions.

## QCD and hadron structure / 149

### Investigation of the proton structure at PANDA-FAIR

**Authors:** Iris Zimmermann<sup>1</sup>; Alaa Dbeyssi<sup>1</sup>; Dmitry Khanef<sup>1</sup>

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An important goal of the future PANDA Experiment at FAIR (Darmstadt, Germany) is the investigation of the proton structure. Electromagnetic form factors parameterize the electric and magnetic structure of protons. In the time-like region electromagnetic proton form factors can be accessed experimentally through the annihilation processes  $p\bar{p} \rightarrow l^+l^-$  ( $l = e, \mu$ ), assuming that the interaction takes place through the exchange of one virtual photon. In frame of the PANDARoot software, which encompasses detector simulation and event reconstruction, the statistical precision at which the proton form factors will be determined at PANDA is estimated for both signal processes  $p\bar{p} \rightarrow l^+l^-$  ( $l = e, \mu$ ). The signal identification and the suppression of the main background process ( $p\bar{p} \rightarrow \pi^+\pi^-$ ) is studied. Different methods have been used to generate and analyse the processes of interest. The results show that time-like electromagnetic proton form factors can be measured at PANDA with high statistical accuracy over a large kinematical region.

## Poster session / 150

### Chiral-scale effective theory and emergent symmetry in dense matter

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Symmetry and symmetry breaking play significant roles in physics. In this contribution, we will discuss our recent progress on the emergent symmetry in dense nuclear matter which are hidden in the matter-free space. This discussion sheds light on the mechanisms of chiral symmetry breaking, scale symmetry breaking and also the flavor symmetry breaking.

## Exotic states and candidates / 151

## Lambda\_b -> J/Psi phi Lambda decay and search for exotic hadrons

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We study the weak decay of the  $\Lambda_b$  baryon into  $J/\Psi\phi\Lambda$  states and the possibility of producing exotic hadrons via final state interaction in  $J/\Psi\phi$  and  $J/\Psi\Lambda$  channels.

The elementary weak transition at the quark level proceeds via the creation of a  $J/\Psi(\bar{c}c)$  meson and an excited **sud** system with  $\mathbf{I} = \mathbf{0}$ , which upon hadronization leads to  $\phi\Lambda$  and  $\bar{K}N$  meson-baryon pairs, the later one undergoing final state interaction in coupled channels and ending up as an observed  $\phi\Lambda$  pair.

The hidden-charm pentaquark  $P_c(4450)$  observed recently by the LHCb collaboration [1] may be of molecular nature, as advocated by some unitary approaches that also predict pentaquark partners in the strangeness  $\mathbf{S}=-1$  sector [2]. This strange hidden charm pentaquark can be produced via  $J/\Psi\Lambda$  final state interaction in our reaction and, as we shall see, such a state could be seen in  $\Lambda_b \rightarrow J/\Psi\phi\Lambda$  decay as a peak in the  $J/\Psi\Lambda$  invariant mass distribution. A similar study and conclusions have been performed in [3], but looking at the  $\Lambda_b$  decay into  $J/\Psi\eta\Lambda$  final states.

On the other hand, studying the invariant mass spectrum of  $J/\Psi\phi$  pairs from  $\Lambda_b \rightarrow J/\Psi\phi\Lambda$  decay, one can also observe the peaks corresponding to the  $X(4140)$  and  $X(4274)$  exotic hadrons discovered by CDF [4] and recently reconfirmed in B decay at LHCb [5].

[1] R. Aaij, B. [LHCb collaboration], Phys. Rev. Lett. **115**, 072001 (2015).

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## Molecules of hadrons bound by pion exchange

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Heavy hadrons interacting via pion exchange can form bound states (hadronic molecules), analogous to conventional nuclei. A large number of possible states is controlled by the same interaction potential, and although the binding energy in a given channel depends sensitively on the details of the potential, the overall pattern of binding does not. In particular, bound states arise only for a restricted set of spin and flavour quantum numbers, leading to sharp predictions for experiment. In comparison with other models for exotic states, which typically predict a proliferation of states with all possible quantum numbers, this renders the molecular hypothesis uniquely falsifiable. The implications for  $P_c(4450)$  and other exotic states are discussed.



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## Heavy-quark spin-symmetry partners of hadronic molecules

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Implications of heavy-quark spin-symmetry (HQSS) are investigated for the isoscalar charmonium-like state  $X(3872)$  and the isovector bottomonium-like states  $Z_b(10610)$  and  $Z_b(10650)$  under the assumption of the latter being bound states of the nearby heavy meson-antimeson pairs (see Refs. [1,2] for more details). We formulate and solve a system of the integral equations for a coupled-channel problem involving the  $P\bar{P}$ ,  $P\bar{V}$ , and  $V\bar{V}$  channels (with  $P$  and  $V$  being either  $D$  and  $D^*$  or  $B$  and  $B^*$ ) to determine the scattering amplitudes with the quantum numbers  $J^{PC} = 1^{++}, 1^{+-}, 0^{++}$ , and  $2^{++}$ . The coupled-channel potentials incorporate the contact and one-pion exchange (OPE) interactions derived in a chiral effective field theory approach and iterated to all orders.

Once two contact terms at leading order are adjusted to reproduce the binding energies of the states used as input, the approach can be employed to predict the mass and the prominent contributions to the width of the spin-partner states with the quantum numbers  $J^{++}$  ( $J = 0, 1, 2$ ). In particular, in the  $b$ -quark sector we predict the existence of a narrow  $2^{++}$  tensor state  $W_{b2}$ , with the width of the order of a several MeV, lying a few MeV below the  $B^*\bar{B}^*$  threshold which is, therefore, expected to produce a visible resonant structure in the line shapes. The corresponding tensor state in the  $c$ -quark sector is also predicted but it is shown to have a much larger width.

It is pointed out that the OPE potential in combination with the HQSS breaking due to the nonvanishing  $V$ - $P$  mass splitting has a significant impact on the location of the partner states. The leading effect from the OPE originates from the (S-D) tensor forces that implies that a perturbative inclusion of OPE is not sufficient. We emphasize that many particle coupled-channel transitions between various heavy meson-antimeson pairs are governed by the tensor part of OPE and thus a proper account for the coupled-channel dynamics is important to allow for reliable predictions of the spin-partner states.

[1] V. Baru, E. Epelbaum, A. A. Filin, C. Hanhart and A. V. Nefediev, "Spin partners of the  $Z_b(10610)$  and  $Z_b(10650)$  revisited," arXiv:1704.07332 [hep-ph].

[2] V. Baru, E. Epelbaum, A. A. Filin, C. Hanhart, U.-G. Meißner and A. V. Nefediev, "Heavy-quark spin symmetry partners of the  $X(3872)$  revisited," Phys. Lett. B763, 20 (2016).

## QCD and hadron structure / 154

## Hyperon production in annihilation reactions

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Strange and charmed hyperons are an ideal tool to study the strong interaction in the transition region between non-perturbative and perturbative QCD regime.

In this presentation prospects for antihyperon-hyperon studies in elementary annihilation reactions are reviewed. Special emphasis is put on recent results from BESIII and prospect for the future PANDA experiment at FAIR.

### Spectroscopy of mesons / 155

## Line-shape analysis of charmonium resonances

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Using an unitarized effective Lagrangian, we study the deformed line-shape of the  $\psi(3770)$ , and of other charmonium resonances which were very recently discovered by the BESIII Collaboration. Nearby threshold effects are taken into account.

### Poster session / 156

## GEM based TPC for the high intensity beam at J-PARC

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The time projection chamber(HypTPC) has been developed for the H-dibaryon search experiment via (K-,K+) reactions at J-PARC. The high rate secondary beam up to  $10^6$  Hz from the world highest intensity proton beam should be taken into account. The HypTPC has the octagonal drift volume defined by the field cage, the cathode plane at the top and the amplification region at the bottom. The drift length is 55 cm. The Helmholtz type superconducting magnet applies the uniform magnetic field to the drift volume of the TPC. The target is located at 143 mm upstream from the center of TPC inside the drift volume. The outermost gas vessel is filled with P-10 gas. To avoid the charge build-up of field cage in the high rate beam, we cut the exposed insulator part of field cage around beam through region. When charged particles pass through the gas volume, ionized electrons along the track drift downward to first meet the gating grid plane and then triple GEMs, which are adopted to reduce ion back flows in the high rate beam. The amplified electron signals from GEM can be read out by almost 6000 pads which has a concentric configuration around the target. The GET(Generic Electronic System for TPCs) is used for the data acquisition. We adopted the partial readout mode and the zero suppression to reduce the dead time of DAQ combined with (K-,K+) trigger at the high beam intensity. We will report commissioning of the HypTPC and the DAQ performance test.

### Poster session / 157

## Feasibility study of searches for transitions between X(3872) and charged Z states with the PANDA experiment at FAIR

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Following the discovery of the X(3872), several exotic states, collectively known as XYZ states, have recently been identified in the energy region of charmonium. Searches with proton-antiproton collisions, such as the upcoming PANDA experiment at FAIR, will play an essential role in the effort to shed light on the nature of these states, since the direct production mechanisms and high rates enable studies of processes and decay modes which are inaccessible at  $e^+e^-$  facilities. Although transitions between X and Y states, and Y and Z states, were observed at the BESIII experiment, transitions between X and Z states have as of today not yet been observed. Furthermore, the observation of charged Z states near the  $DD^*$  and  $D^*D^+$  threshold suggests the existence of similar states near the  $DD$  threshold. This contribution will report on the first preliminary results of a feasibility study of a search for transitions between the X(3872) and a charged Z(3730), in the decay channel where  $X(3872) \rightarrow Z(3730)^\pm \pi^\mp$ ,  $Z(3730)^\pm \rightarrow \chi_{c1} \pi^\pm$ ,  $\chi_{c1} \rightarrow J/\psi \gamma$  and  $J/\psi \rightarrow$  leptons, using a Monte Carlo simulation of the PANDA detector with the PandaRoot software framework

**QCD and hadron structure / 158**

## **BChPT x 1/Nc in SU(3): baryon masses and current**

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The framework of BChPT combined with the  $1/N_c$  expansion is implemented for three flavors and applied to the octet and decuplet baryon masses and currents. Results to one-loop in the chiral expansion, and subleading order in the  $1/N_c$  expansion will be presented. Particular emphasis will be made on the improvements resulting from the constraints implied by consistency with the  $1/N_c$  expansion. Several new parameter independent relations that result at the order of the analysis will be discussed. Connections to lattice QCD will be made.

**Spectroscopy of mesons / 159**

## **The effects of explicit chiral symmetry breaking multiquark interactions on the spin 0 and 1 meson nonets: the ruling of the vector mesons.**

**Author:** Jorge Morais<sup>1</sup>

**Co-authors:** Brigitte Hiller<sup>2</sup>; Alexander A. Osipov<sup>3</sup>

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We have recently extended the scalar-pseudoscalar sector of a generalized NJL Lagrangian that includes all NLO non derivative interactions in  $N_c$  counting (including explicit symmetry breaking ones) in order to incorporate the spin 1 mesons in the low-lying ground state of QCD [1]. Upon bosonization, the well known mixing of the scalar-vector and of the pseudoscalar- axial-vector fields occurs in the quadratic part of the Lagrangian. We show that a linearized diagonalization of these terms can be effected in a completely general way without compromising the underlying symmetries of the Lagrangian [2]. The resulting spin 1 mass spectra evidence a relation involving only the vector and axial-vector meson masses and the constituent quark masses. We discuss the dominant role of this relation in the fits and we show that the model may be fitted to accommodate to a very good accuracy the 4 low-lying meson spectra.

[1] J. Morais, B. Hiller, and A.A. Osipov, Phys. Rev. D 95, 074033 (2017) (arXiv:1702.06894 [hep-ph])

[2] (arXiv:1705.04644 [hep-ph])

**QCD and hadron structure / 160**

## Tensor meson contribution to three pion axial-vector form-factor in tau decays

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By means of resonance chiral theory we compute the contribution of spin-2 resonances to the  $\tau \rightarrow \nu \pi \pi \pi$  decay. We build a chiral invariant Lagrangian for tensor and axial-vector resonances that implements chiral symmetry (and isospin) in the process. This ensures that the hadronic amplitudes follow the low-energy behaviour prescribed by chiral perturbation theory. Likewise, by imposing Brodsky-Lepage high energy form-factor constraints, we fix the new parameters for this channel. Thus we provide an appropriate description of the resonance, low-energy and high-energy regions of the three-pion axial-vector form-factor mediated by a tensor resonance. Finally, We will comment on the (on-going) implementation of this new channel in the TAUOLA event generator.

**Spectroscopy of baryons / 161**

## Amplitude analyses at LHCb

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The search for resonances, both exotic and otherwise, as intermediate states in beauty and charm hadron decays at LHCb has been extremely productive in recent times. We present recent results in the amplitude analysis of these decays. Among others, this includes studies of  $L_b \rightarrow D p \pi$  decays, which allow to constrain the spin/parity of the  $L_c(2940)^+$  state for the first time, and evidence for a the new resonance  $L_c(2860)$  as well as determination of its quantum numbers.

## QCD and hadron structure / 162

**Monte Carlo Top Quark Mass Calibration**

**Authors:** Vicent Mateu Barreda<sup>1</sup>; Andre Hoang<sup>2</sup>; Iain Stewart<sup>3</sup>; Mathias Butenschön<sup>4</sup>; Moritz Preisser<sup>2</sup>; Bahman Dehnadi<sup>5</sup>

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The top quark is the heaviest of all discovered particles so far. Knowing its mass precisely is of utmost importance to test the validity of the Standard Model. The most precise measurements performed at Hadron Colliders determine the MC top quark mass parameter. Relating this parameter to a field-theoretically well defined mass is necessary if those determinations are to be used as input to high-order perturbative computations. In this talk I will show how this calibration can be performed by comparing hadron-level MC output to ab-initio computations within QCD. For this comparison to work, one must choose a low-scale short-distance mass. In our analysis we employ the so called MSR mass, and find out that the MC top quark mass parameter is numerically very close to the MSR mass with  $R = 2$  GeV, but far off the pole mass.

## Plenary / 163

**Overview of multiquark states**

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In this talk I will give a general overview on recent results from several groups on the spectrum and properties of three- and four-quark states as obtained in the framework of Dyson-Schwinger and Bethe-Salpeter equations. I will discuss the spectrum of light baryons with focus on the comparison with quark model expectations, the impact of dynamical mass generation and explain the importance of relativistic components in the wave functions of baryons. For four-quark systems I will summarise results for light quarks and discuss the prospects of the approach to discriminate between tetraquark, molecule or hadro-quarkonium configurations in heavy-light states.

## Exotic states and candidates / 164

**Status of the Dibaryon Resonance  $d^*(2380)$  \***

**Authors:** Tatiana Skorodko<sup>1</sup>; Michail BAshkanov<sup>None</sup>; Heinz Clement<sup>None</sup>

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The dibaryon resonance  $d(2380)$  with  $I(JP) = 0(3+)$  – first observed in the double-pionic fusion to the deuteron [1] – has meanwhile been detected in all relevant two-pion production channels in incident neutron-proton collisions [2]. In addition, its resonance pole has been revealed in neutron-proton scattering [3].

Theoretical calculations describe this state either as a compact hexaquark [4] or a dilute molecular-like object [5]. Whereas the  $d$  decay into two-pion channels does not discriminate between these two scenarios, the decay into single-pion channels is very discriminatory. In the hexaquark case this decay is heavily suppressed with a branching less than 1% [4]. In the molecular-like case a branching of as much as 18% is expected.

In order to clarify this situation we have measured the isoscalar single-pion production in the energy region of  $d^*(2380)$ . As a result we find no evidence for such a decay with an upper limit of smaller than 9%. This is in support of the hexaquark interpretation – at least as the dominant configuration, possibly surrounded by a cloud of molecular-like configurations [6].

\* supported by DFG (CL214/3-2) and STFC (ST/L00478X/1)

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- [6] A. Gal, Phys. Lett. B 769 (2017) 436

## Exotic states and candidates / 165

### Lattice studies of charmonia and exotics

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I will present some recent lattice QCD studies of charmonia and exotic hadrons.

Belle experiment found an alternative candidate  $X^*(3860)$  for the excited scalar charmonium  $\chi_{c0}(2P)$  in 2017. I will report on the preliminary results on the related scalar resonance obtained by simulating  $D\bar{D}$  scattering on the CLS lattice ensembles. D0 experiment claimed the evidence for an exotic hadron  $X(5568)$  in 2016 and I will report on the lattice QCD search for this hadron in  $B_s\pi$  scattering.

## Spectroscopy of mesons / 166

### Calculation of strange resonances from $K\pi$ scattering

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We present a determination of the mass, width and coupling of the strange resonances appearing in pion-kaon scattering, the much debated  $K_0(800)$ , the scalar  $K_0(1430)$ , the  $K_1(892)$  and  $k_1(1410)$  vectors, the spin-two  $K_2(1430)$  as well as the spin-three  $K_3(1780)$ . The parameters of each resonance will be determined using a direct analytical continuation of the pion-kaon partial waves by means of Padé approximants, thus avoiding any particular model description and taking into account the analytic requirements imposed by dispersion relations.

**Hadron decays / 167**

## Scalar form factors of semi-leptonic $D \rightarrow \pi/\bar{K}$ transitions with coupled-channel effects

**Author:** De-Liang Yao<sup>None</sup>

**Co-authors:** Miguel Albaladejo ; Pedro Fernandez-Soler ; Feng-Kun Guo ; Juan Nieves

By solving the Muskhelishvili-Omnes integral equations, coupled-channel effects are taken into account for the scalar form factors of semi-leptonic  $D \rightarrow \pi$  and  $D \rightarrow \bar{K}$  transitions, denoted by  $f_0^{D \rightarrow \pi}$  and  $f_0^{D \rightarrow \bar{K}}$ , respectively. As inputs, we employ the unitarized amplitudes from chiral effective theory for the intermediate region, while, at high energy, proper asymptotic conditions are imposed. The scalar form factors are expressed in terms of Omnes matrix multiplied by a vector polynomials. We reduce the number of subtraction constants by performing matching to the scalar form factors which are derived in chiral perturbation theory at tree-level. The simulated lattice QCD data for  $f_0^{D \rightarrow \pi}$  and  $f_0^{D \rightarrow \bar{K}}$  can be well described simultaneously. We predict the scalar form factors corresponding to  $D \rightarrow \eta$ ,  $D_s \rightarrow \bar{K}$  and  $D_s \rightarrow \eta$  transitions, which can be checked in future by lattice QCD so as to improve precision determination of the Cabibbo-Kobayashi-Maskawa elements of  $|V_{cd}|$  and  $|V_{cu}|$ . The approach used in this work can be straightforwardly extended to the semi-leptonic decays of  $B$  mesons whenever new experimental or lattice QCD data come up for scattering at or above the threshold region.

**Spectroscopy of baryons / 168**

## Recent polarization observables results in $\pi^0$ - and $\eta$ -photoproduction off the proton

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A comparison of experimentally observed excited nucleon states to phenomenological quark model predictions or lattice QCD calculations reveal large differences, especially concerning the number of excited states. An important tool to probe the nucleon excitation spectrum is the study of meson photoproduction reactions. In order to extract the contributing resonances from the experimental data partial wave analyses need to be performed. For an unambiguous solution the measurement of single and double polarization observables is essential. Several experimental facilities have dedicated programs to measure polarization observables in different photoproduction reactions using a polarized photon beam and a polarized target, e.g. the CBELSA/TAPS experiment located at the electron stretcher accelerator ELSA in Bonn or the Crystal Ball experiment located at the accelerator facility MAMI in Mainz.

This talk will present recent results concerning the polarization observables  $\Sigma$  and  $E$  in the  $\gamma p \rightarrow p\pi^0$  and  $\gamma p \rightarrow p\eta$  reactions measured at the CBELSA/TAPS and the Crystal Ball experiment, respectively. This work is supported by the Deutsche Forschungsgemeinschaft (SFB/TR16 and SFB1044), Schweizerischer Nationalfonds and Hadron Physics 3 under the 7th Framework Program of the EU.

### Spectroscopy of baryons / 169

## Measurement of the double polarization observables $G$ and $E$ in the reactions $\gamma p \rightarrow p\pi^0/n\pi^+$

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A powerful tool to investigate the properties of nucleon resonances is the detailed study of the excitation spectrum of the nucleons. It consists of many resonances which contribute with different strength to distinct decay channels. To obtain information about the contributing resonances, the experimental measurement of several well chosen single and double polarization observables is needed in different decay channels.

These observables are used as input for Partial Wave Analyses (PWA) which identify the resonances and characterize their properties.

The polarization observables are measured at the Crystal Ball experiment at MAMI in Mainz, using polarized photons and polarized nucleons. The setup covers nearly  $4\pi$  of the solid angle and has a high detection efficiency for neutral and charged final states.

The preliminary results of the double polarization observable  $G$  and  $E$  in the reactions  $\gamma p \rightarrow p\pi^0$  and  $\gamma p \rightarrow n\pi^+$  are presented.

They have been determined in a beam energy range starting from 266 MeV to 860 MeV for  $G$  and from 266 MeV to 1400 MeV for  $E$ , using a linearly/circularly polarized photon beam in combination with a longitudinally polarized butanol target.

Supported by the Deutsche Forschungsgemeinschaft (SFB1044), Schweizerischer Nationalfonds and Hadron Physics 3 under the 7<sup>th</sup> Framework Program of the EU.

### Poster session / 170

## Thermodynamic characterizations of Exotic States: Fluctuations and Correlations of conserved quantities

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Thermal shifts and fluctuations at finite temperature below the deconfinement crossover from hadronic matter to the quark-gluon plasma provide a viable way to look for missing states with given quantum number in the hadronic spectrum. We study a realization of the hadron resonance gas (HRG) model in the light quark (uds) flavour sector of QCD to study the fluctuations of baryon number, charge and strangeness, and study from it the thermodynamics characterization of exotic states like



the hybrids  $q\text{-}\bar{q}\text{-}q$  from a comparison with lattice data. We find that the highest temperature of agreement between the lattice and the HRG seems to be  $\sim 150$  MeV [1].

This study is then extended to compute the correlation of these conserved quantities in the confined phase of QCD. We obtain general formulas for the correlators of currents of any spin at zero and finite temperature, and apply them within the HRG model to obtain the correlators in QCD. It is also emphasized an interesting duality between the correlators at zero temperature and large distances, and the fluctuations of integrated quantities at low temperatures.

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## Analysis tools / 171

### Fitting and selecting Scattering Data

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The main purpose of scattering experiments is to unveil the underlying structure of the colliding particles. Typically one has scattering observables at discrete angles and energies and some decision has to be made on what are the maximal amount of data which are mutually compatible among themselves and with a sufficiently flexible model with a minimal number of theoretical assumptions. We show examples where this can be done in a self-consistent manner.

## Spectroscopy of baryons / 172

### Spin observables in charged pion photo-production from polarized neutrons in solid HD at Jefferson Lab

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While QCD is regarded as a mature theory of interacting quarks, due to the complexity of the nucleon, a successful description of its spectrum of excited states remains a huge challenge. The photo-couplings to excited  $N$  states provide benchmark tests for models. These require a determination of photo-production amplitudes and are extracted through detailed partial-wave analyses (PWA), which must be fit to many different polarization observables to control ambiguities. Since the electromagnetic interaction is not isospin invariant, the  $N$  photo-couplings for neutron and proton targets are different. While there are considerable proton data, there are very little neutron target data and almost

no spin-dependent data. As a result, the photo-couplings to states excited from neutrons are very poorly determined. To address this issue, the Jlab E06-101 (*g14*) experiment was performed during 2011-2012 using the CLAS detector in Hall B with circularly and linearly polarized photons incident on longitudinally polarized Deuterons in frozen-spin targets of solid Hydrogen-Deuteride (HD). First results will be discussed for the beam-target helicity asymmetry ( $E$ ) in the  $\gamma + n(p) \rightarrow \pi^- + p(p)$  reaction spanning the nucleon resonance region from invariant mass  $W = 1500$  to 2300 MeV. These will be compared to PWA predictions with their associated photo-couplings<sup>1</sup>. Other observables are under study and preliminary results will be presented.

1. This work has been accepted by Physical Review Letters; arXiv:1705.04713

#### Exotic states and candidates / 173

### $D_0^*(2400)$ (and partners) from unitarity, heavy quark spin-flavor and chiral symmetries

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In this talk we will study the implications on heavy hadron molecules (containing one constituent heavy quark) of heavy quark spin-flavor and chiral symmetries (together with unitarity). We start by studying the  $D\pi$ ,  $D\eta$  and  $D_s\bar{K}$  scattering with  $(I, J^P) = (1/2, 0^+)$  quantum numbers. In this sector there appears the so far only known charmed non-strange scalar meson, namely  $D_0^*(2400)$ . We show that there are actually two poles in this energy region. With all the parameters involved in the amplitudes previously fixed, we predict the energy levels for the coupled-channel system in a finite volume, and find that they agree remarkably well with recent lattice QCD calculations. This successful description of the lattice data is regarded as a strong evidence for the two-pole structure of  $D_0^*(2400)$ . When the physical quark masses are considered, the poles are located at  $(2105_{-8}^{+6} - i 102_{-12}^{+10})$  MeV and  $(2451_{-26}^{+36} - i 134_{-8}^{+7})$  MeV, being the largest couplings to the  $D\pi$  and  $D_s\bar{K}$  channels, respectively. The higher pole is close to the  $D_s\bar{K}$  threshold, and hence a threshold enhancement in the  $D_s\bar{K}$  invariant mass distribution is to be expected. This predicted effect could be checked by future experiments.

The former amplitudes incorporate chiral symmetry, and hence they can be related with the ones in other strangeness-isospin sectors. Indeed, we also show that the lower pole belongs to the same  $SU(3)$  multiplet as the  $\bar{D}_{s0}^*(2317)$  state. By means of **heavy quark spin symmetry**, predictions can also be given for  $J = 1$  sectors, involving a heavy vector meson. Further, due to **heavy flavour symmetry**, predictions for partners in the bottom sector are also given.

#### Plenary / 174

### Traps in hadron spectroscopy (thresholds, triangle singularities, ...)

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In addition to the normal hadron resonances, kinematical singularities such as the two-body threshold cusps and triangle singularities can also produce peaks. Such structures may mimic resonances, and lead to ambiguities in interpretations. In this talk, I will discuss various aspects of kinematical singularities, including how to distinguish them from resonances and how to make use of them.

Plenary / 175

## Experimental Aspects of Heavy Quark Exotica

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Striking new phenomena in the charmonium and bottomonium regions have been uncovered in the past few years that likely point to the existence of configurations of quarks and gluons beyond the traditional quark-antiquark picture of mesons and the three-quark picture of baryons. I will review recent progress, highlight outstanding puzzles, and give some indication for how future progress might be made.

QCD and hadron structure / 176

## Hadrons in Born approximation

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Hadrons have several remarkable features, which call for an understanding within QCD. In addition to confinement and chiral symmetry breaking these include:

- Hadrons can generally be classified as  $q\bar{q}$  or  $qqq$  states. Sea quarks and gluons do not enrich the spectrum. Heavy quarkonia ( $c\bar{c}$ ,  $b\bar{b}$ ) are well described by the Schrödinger equation with a  $V(r) = cr - C_F\alpha_s/r$  potential.
- The excitation energy of dynamical (transverse) gluons is  $\geq 1$  GeV. Glueballs and hybrids (if any) are heavy. Processes such as  $\phi \rightarrow \pi\pi\pi$  that only proceed through gluonic intermediate states are suppressed (OZI rule).
- Perturbative parton dynamics mirrors non-perturbative hadron dynamics. Duality is pervasive and manifest even at low scales in DIS ( $ep \rightarrow eX$ ) and in inclusive hadron production ( $e^+e^- \rightarrow h + X$ ).
- Quenched lattice calculations give a better than 10% description of the hadron spectrum. The heavy quark potential calculated on the lattice agrees with the phenomenological quarkonium potential.

These observations motivate an approach to hadrons based on the number of loops, *i.e.*, an  $\hbar$  expansion. In QED the description of Positronium given by the Schrödinger equation is of lowest order in  $\hbar$  (whereas the wave function is non-polynomial in  $\alpha$ ). The Dirac equation provides a Born (tree-level) description of relativistic binding in an external field. Dirac bound states have Fock components with additional  $e^+e^-$  pairs, yet their spectrum is characterized by the quantum numbers of a single electron.

I consider a Hamiltonian description of QCD bound states at Born level. The color field in  $H_{QCD}$  is determined by the classical field equations. In the absence of quark and gluon loop corrections the  $\Lambda_{QCD}$  confinement scale arises from a boundary condition on the classical gauge field at spatial infinity. Translation invariance requires the strength of such a color field to be spatially constant, which implies an exactly linear confinement field  $A_a^0$  (*boldsymbol{x*). Explicit solutions are found for each  $q_A\bar{q}_A$  and  $q_Aq_Bq_C$  component of color singlet mesons and baryons, but not for states with a larger number of valence quarks. The total field obtained by a summing over quark colors vanishes since the states are (globally) color singlets. Hadrons therefore do not interact with each other via the confining field, only through perturbative gluon exchange and  $q\bar{q}$  annihilation.

Born level hadrons have features which resemble dual models. For  $m_q = 0$  the states lie on linear Regge trajectories with parallel daughter trajectories. Quark-hadron duality emerges analytically. Hadron decays occur via  $q\bar{q}$  creation (string breaking) generated by the confining field, and can be addressed as an expansion in  $1/N_c$ , the number of colors. Iterations give rise to hadron loop contributions, allowing unitarity to be satisfied at  $O(\hbar^0)$  for hadrons. Many further issues can be addressed, including scattering and chiral symmetry breaking. The approach leads to a Poincaré covariant example of confined bound states quantized at equal time. Provided higher orders of the  $\hbar$  (loop) expansion can be included it may qualify as a first principles approach to hadrons in QCD.

Plenary / 177

## Pole structure and compositeness for a (near-threshold) state

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We elaborate on the compositeness relation for poles in the two-body scattering amplitudes, and discuss different methods to calculate the compositeness of a resonance and bound state. We study in detail the case of validity of the effective-range expansion for near-threshold poles and its limitations, providing then a more general parameterization from S-matrix theory. The application of these results to different states is also discussed.

Poster session / 178

## Spectroscopy of the All-Charm Tetraquark

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We introduce a non-relativistic framework to study the spectroscopy of hadronic bound states composed of four charm quarks in the diquark-antidiquark picture. By numerically solving the Schrödinger equation with two different Cornell-inspired potentials in a similar way of heavy quarkonium models of mesons, we factorize the 4-body problem into three 2-body systems: first the diquark and the antidiquark, which are composed of 2 quarks (antiquarks) into a color antitriplet state. In the next step they are considered as the tetraquark building blocks, where their interaction leads to a color singlet. Spin-dependent terms (spin-spin, spin-orbit and tensor) are used to describe the splitting structure of the spectrum and account for different quantum numbers of each state. Special attention is given to the tensor interaction between two particles of spin 1, with a detailed discussion of

the adopted strategy. The spin-spin interaction is addressed perturbatively in the first model and included in the zeroth-order potential in the second one. The contribution of each interaction term is also analysed and compared. Recent experimental data of reasonably well-established charmonium mesons are used to fix the parameters of both models (with a fitting procedure minimizing  $\chi^2$ ), obtaining a satisfactory reproduction of charmonium spectrum. The differences between models are discussed in the charmonium, diquark and tetraquark context. We conclude that almost all the S and P waves (and respective first radial excitations), of the all-charm tetraquark composed by spin 1 diquarks are in the range between 5.8 to 7 GeV, above the threshold of spontaneous decay in low-lying charmonium pairs, like two  $\eta_c$  or  $J/\psi$ , what suggests that this could be the ideal channels to look for these states, and develop the current understanding of multi-quark states.

**QCD and hadron structure / 179**

## Pion multiplicities from CLAS

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In this talk I will present preliminary results on  $\pi^+$ ,  $\pi^-$  and  $\pi^0$  multiplicity ratios measured as a function of multiple kinematical variables in semi-inclusive DIS on three nuclei (C, Fe, Pb) normalized to deuterium. The series of measurements presented here were performed at Jefferson Lab with 5.014 GeV electron beam incident on a double-target system in which liquid deuterium and one of the solid targets were exposed simultaneously to the beam. These measurements will further be extended in the approved experiment E12-06-117 following JLab upgrade to 12 GeV.

The goal of this experiment is to study hadronization process by providing new insights on parton propagation inside nuclear medium and formation of hadrons. This topic has been of interest to multiple communities such as Drell-Yan measurements at Fermilab, heavy-ion collisions in RHIC and LHC and SIDIS measurements from HERMES and CLAS. The advantages of SIDIS are well understood nuclear medium and its ability to investigate time-dependence of hadronization by embedding it in nuclei of increasing size. It is to be hoped that these studies, once matured, can influence the interpretation of what is seen in the hot dense systems (LHC), in addition to their intrinsic interest for QCD.

**Hadrons in matter including hypernuclei / 180**

## Masses and spectral functions for anti-D mesons in nuclear matter and partial restoration of chiral symmetry

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We investigate the in-medium masses of a  $\bar{D}$  ( $0^-$ ) meson and a  $\bar{D}_0^*$  ( $0^+$ ) meson, and spectral functions for  $\bar{D}$  and  $\bar{D}_0^*$  meson channels in nuclear matter. These mesons are introduced as chiral partner in the chiral symmetry broken vacuum,

hence they are useful to explore the partial restoration of the broken chiral symmetry in nuclear matter.

We consider the linear sigma model to describe the chiral symmetry breaking and to see a qualitative tendency of changes of  $\bar{D}$  mesons at low density.

Our study

shows that the loop corrections to  $\bar{D}$  and  $\bar{D}_0^*$  meson masses

provide a smaller mass splitting at finite density than that in vacuum, whose result indicates a tendency of the restoration of the chiral symmetry.

We investigate also the spectral function for  $\bar{D}_0^*$  meson channel, and find three peaks.

The first peak which corresponds to the resonance of  $\bar{D}_0^*$  meson is broadened by collisions with nucleons in medium, and the peak position shifts to lower mass due to the partial restoration of chiral symmetry as the density increases.

The second peak

is identified as a threshold enhancement which shows a remarkable enhancement as the density increase. The third peak is Landau damping.

The obtained properties of  $\bar{D}$  and  $\bar{D}_0^*$  mesons in nuclear matter will provide useful information for experiments.

### Spectroscopy of mesons / 181

## The glueball and meson spectrum, the meson weak decay constants and the strong effective coupling with the analytic (infrared) confinement

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The properties of two-particle bound states have been investigated within a relativistic quantum-field model based on the analytically confined propagators of the constituents. The spectra of quark-antiquark and two-gluon stable states are defined by master equations similar to the ladder Bethe-Salpeter equation. The conventional meson spectrum has been estimated with reasonable accuracy in a wide range of mass (from hundreds MeV up to 9.5 GeV) by introducing a minimal set of model parameters. An independent and analytic estimate is obtained for the lowest glueball mass, and we found it around  $\sim 1700 \pm 50$  MeV [1]. We also estimate the strong effective charge  $\alpha_s$  in the low-energy region (below  $\sim 2$  GeV) by exploiting the meson spectrum. In doing so, we found a new and specific infrared-finite behavior. Particularly, an infrared fixed point is extracted [2]. A new insight into the problem of generating the hadron mass has been provided by using the underlying principle of the compositeness condition. This allows one to express the Fermi coupling ( $G$ ) as a function of meson mass  $M$ , while the Yukawa coupling ( $g$ ) of the meson-quark interaction is defined by other model parameters. Both equations allow to provide an interpretation of the meson field as the bound state of its constituent fermions (quarks). We evaluate and vary the values of the masses in such a way to obtain a smooth behavior for the resulting dependence  $G(M)$ . The mass spectrum obtained in this manner was found to be in good agreement with the experimental data [3]. We also compared the behavior of the obtained  $G(M)$  with the strong QCD coupling  $\alpha_s$  calculated in a QCD-inspired approach [4].

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**Exotic states and candidates / 183****New results from charged and neutral Z states at BESIII****Author:** Pei-Rong Li<sup>1</sup><sup>1</sup> *University of Chinese Academy of Sciences (CN)***Corresponding Author:** pei-rong.li@cern.ch

The BESIII Experiment at the Beijing Electron Positron Collider (BEPC2) has accumulated the world's largest samples of  $e^+e^-$  collisions in the tau-charm region. Cross sections of  $e^+e^- \rightarrow \pi^+\pi^- \psi(2S)$  above 4.0 GeV, and a charged structure has been observed in the  $\pi^+\psi(2S)$  mass spectrum. Cross sections of  $e^+e^- \rightarrow \text{KKbar } J/\psi$  between 4189 and 4600 MeV. Compared with  $\pi^+\pi^- J/\psi$ , more complex structure in the line shape is observed. Quantum number  $J^P$  of  $Z_c(3900)$  is determined to be  $1^+$  by partial wave analysis of  $e^+e^- \rightarrow \pi^+\pi^- J/\psi$  at 4.23 and 4.26 GeV. Observation of  $e^+e^- \rightarrow \eta' J/\psi$  at center-of-mass energies between 4.190 and 4.600 GeV.

**Exotic states and candidates / 184****New results from Y(4260) decays at BESIII****Author:** Ke LI<sup>None</sup>**Corresponding Author:** like@ihep.ac.cn

The BESIII Experiment at the Beijing Electron Positron Collider (BEPC2) has accumulated the world's largest samples of  $e^+e^-$  collisions in the tau-charm region. Based on these data samples, some new results from the Y(4260) decays will be shown.

**QCD and hadron structure / 185****Hadron form factors at BESIII****Author:** Paul Larin<sup>1</sup><sup>1</sup> *Helmholtz Institute Mainz***Corresponding Author:** paullarin86@gmail.com

Electromagnetic form factors of baryon provide fundamental information about its structure and dynamics. They constitute a rigorous test of nonperturbative QCD as well as of phenomenological models. Using data samples collected with BESIII detector at BEPCII collider, We measure Born cross section of  $e^+e^- \rightarrow p\bar{p}$  at center-of-mass energy between 2.0GeV and 3.08GeV. The ratio  $|G_E/G_M|$  and  $|G_M|$  are extracted by fitting polar angle distribution of proton for data samples with large statistics. For BESIII data between 3.773 and 4.6GeV, We also use initial state radiation (ISR) method to study  $e^+e^- \rightarrow p\bar{p}$  by tagged ISR photon or un-tagged ISR photon. The cross section of  $e^+e^- \rightarrow p\bar{p}$  and ratio  $|G_E/G_M|$  are obtained. For  $e^+e^- \rightarrow \Lambda_c^+ \Lambda_c^-$  process, very weak energy dependence of cross section near threshold indicates that traditional theoretical prediction, which does not take into account strong interaction, needs to be modified. With the large statistics of multiple decay modes, The ratio  $|G_E/G_M|$  and  $|G_M|$  are extracted.

**Hadron decays / 186**

## Charm meson physics at BESIII

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BESIII Collaboration has accumulated the world's largest e+e- collision samples at  $E_{cm} = 3.773, 4.009, 4.18$  GeV. From analyses of pure leptonic decay  $D(s)^+ \rightarrow l^+ \nu$  ( $l = \mu$  or  $\tau$ ), semileptonic decays of  $D \rightarrow K(\pi)l^+ \nu$  ( $l = e$  or  $\mu$ ),  $D^+ \rightarrow K^+ \pi^0 e^+ \nu$ ,  $D^+ \rightarrow \omega e^+ \nu$ ,  $D_0^+ \rightarrow f_0(980) e^+ \nu$ ,  $D_s^+ \rightarrow \eta' e^+ \nu$ , and  $D_s^+ \rightarrow \eta e^+ \nu$ , we report the determinations of their absolute branching fractions, CKM matrix elements  $|V_{cs}(d)|$ , the  $D(s)^+$  decay constants, the form factors of  $D$  semi-leptonic decays. These are important to calibrate the LQCD calculations of decay constants and form factors and to test the CKM unitarity. We have performed an amplitude analysis of  $D_0 \rightarrow K^+ \pi^- \pi^0$ , and have measured the asymmetries of  $D^+ \rightarrow K_S^0 L K^+ (\pi^0)$  and  $D_0 \rightarrow K_S^0 L \pi^0 (\pi^0)$ , as well as the branching fractions for  $D_0^+ \rightarrow PP$  and some decays containing two KSs. In addition, we also measure the branching fractions for  $D_s^+ \rightarrow \omega \pi^+$ ,  $\omega K^+$  and baryon decay of  $\Lambda_c$ .

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## Lambda\_c physics at BESIII

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In 2014, BESIII collected a data sample of 567 pb<sup>-1</sup> at  $E_{cm} = 4.6$  GeV, which is just above the  $\Lambda_c^+$  pair production threshold. By analyzing this data sample, we have measured the absolute branching fractions for many decays of  $\Lambda_c^+$  for the first time. These decays include the semileptonic decays of  $\Lambda_c^+ e^+ \nu$ ,  $\Lambda_c^+ \mu^+ \nu$ , the hadronic decays of  $pK^+$ ,  $pK^+ \pi^+$ ,  $pK^+ \pi^0$ ,  $\Lambda_c^+ \pi^+$ ,  $\Lambda_c^+ \pi^0$ ,  $\Sigma^+ \pi^0$ ,  $\Sigma^+ \pi^+$ ,  $\Sigma^+ \pi^+$ ,  $\Sigma^+ \pi^0$ ,  $\Sigma^+ \omega$ ,  $\phi$ ,  $pK^+ K^- |non-\phi$ ,  $\Sigma^+ \pi^-$ ,  $nK^+ \pi^+$ ,  $\Sigma^+ \pi^+ \pi^0$  and inclusive decay  $\Lambda_c^+ anything$ . The decays of  $\Sigma^+ \pi^-$ ,  $nK^+ \pi^+$  and  $\Sigma^+ \pi^+ \pi^0$  are observed for the first time and the others are measured with significantly improved precision. These results are important to benefit the development of the related theories, and provide important inputs for both charmed baryons and B physics.

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## Light hadron spectroscopy at BESIII

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The unambiguous identification and systematic study of bound states beyond the constituent quark degrees of freedom, e.g., multi-quark states or states with gluonic degrees of freedom (hybrids, glueballs) would provide validation of and valuable input to the quantitative understanding of QCD. Hadron spectroscopy is one of the most important physics goals of BESIII. Since 2009, BESIII has collected  $1.3 \cdot 10^8 J/\psi$  and  $0.410 \cdot 10^8 \psi'$ , which are the world's largest data samples of  $J/\psi$  and  $\psi'$  from e+e- collision. Radiative decays of charmonium provide a gluon-rich environment and are therefore regarded as one of the most promising hunting grounds for gluonic excitations. Significant progresses in the light-quark sector have been made with the unprecedented high statistics data sets. Several recent results on light hadron spectroscopy and light hadron decays will be reported, including:



- 1, the observation of the anomalous line shape of X(1835) near pp mass threshold and related studies;
- 2, studies of glueballs in J/psi radiative decays; 3, search for 1- + exotic in chi\_c1->eta pi pi.

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## Light meson decays at BESIII

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At present the world's largest sample of 1.3 billion J/psi events was accumulated at the BESIII detector, which provides a unique opportunity to investigate the eta/eta' decays via J/psi radiative or hadronic decays. The eta and eta' hadronic decays are sensitive tools for investigations of pi-pi and eta-pi interactions, symmetry breaking, and serve as a test of Chiral Perturbation Theory. In recent years considerable results on eta/eta' decays were achieved at BESIII experiment. In this talk we present the significant progresses focusing on amplitude analyses of Dalitz decays (e.g. eta'->3 pi PRL 118, 012001 (2017) ), observation new decay modes and search for rare/forbidden decays (e.g. eta'->gamma gamma pi0, arXiv: 1612.05721).

Hadron decays / 191

## Charmonium decays at BESIII

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The BESIII Experiment at the Beijing Electron Positron Collider (BEPC2) has accumulated the world's largest samples of e+e- collisions in the tau-charm region. Using a sample of 106 million psi(3686) decays, the branch fractions of psi(3686) -> gamma chi\_c0, gamma chi\_c1, gamma chi\_c2 are determined to be (9.389 +- 0.014 +- 0.332)%, (9.905 +- 0.011 +- 0.353)%, and (9.621 +- 0.013 +- 0.272)%, respectively. The branching fraction and the angular distributions of J/psi and psi(3686) decays to Lambda anti-Lambda and Sigma^0 anti-Sigma^0 final states are measured. J/psi and psi(3686) decays to Sigma(1385)^0 anti-Sigma(1385)^0 and Xi^0 anti-Xi^0 are measured. The decays to Sigma(1385)^0 anti-Sigma(1385)^0 are observed for the first time, and the angular parameters of these decays are also measured first time. Observation of hc radiative decay hc -> gamma eta' and evidence for hc -> gamma eta. The branching fractions are measured to be (1.52 +- 0.27 +- 0.29)/10^3 and (4.7 +- 1.5 +- 1.4)/10^4, respectively. Both of them are the first observations. Measurement of higher-order multipole amplitudes in psi(3686) -> gamma chi\_c1,2 with chi\_c1,2 -> gamma J/psi and search for the eta\_c(2S) -> gamma J/psi transition. The normalized magnetic-quadrupole (M2) amplitude for psi(3686) -> gamma chi\_c1,2 -> gamma gamma J/psi and the normalized electricoctupole (E3) amplitudes for psi(3686) -> gamma chi\_c2, chi\_c2-> gamma J/psi are determined. The decays psi(3686) -> e+ e- chi\_c0,1,2 and chi\_c0,1,2 -> e+ e- J/psi are searched, and they are observed for the first time. Improved measurements of branching fractions for eta\_c -> phi phi and omega phi. The branching fraction of eta\_c -> phi phi is measured with improved precision. No significant signal for the double OZI-suppressed decay of eta\_c -> omega phi is observed, and the upper limit on the branching fraction is determined.

Exotic states and candidates / 192

## Hidden charm pentaquarks in $\Lambda_b \rightarrow J/\psi K^- p$ decay

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In this talk I would like to present a series of theoretical works regarding the  $\Lambda_b \rightarrow J/\psi K^- p$  reaction from where a recent experiment by the LHCb collaboration at CERN claimed the existence of two hidden charm pentaquarks,  $P_c(4380)^+$  and  $P_c(4450)^+$ .

We discuss the possible explanations of the pentaquark states found within the picture of a dynamical meson-baryon molecule previously predicted made up mostly from  $\bar{D}^*\Sigma_c$  and  $\bar{D}^*\Sigma_c^*$  components. We consider the total  $K^- p$  and  $J/\psi p$  data including all the relevant resonances contributing to the spectra, and discuss the possible nature of both  $P_c(4380)^+$  and  $P_c(4450)^+$ . We also discuss several important topics, like the role of the  $\Lambda(1405)$  resonance, the effect of the contact term in the reaction, the viability of reproducing the data without the  $P_c(4380)^+$  and the possible quantum numbers assignment to these pentaquarks.

**Poster session / 193**

## Dalitz decays of $\pi^0$ , $\eta$ and $\eta'$ mesons

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$\eta$  and  $\eta'$  transition form factors and Padé approximants

**Hadron decays / 194**

## Test Fundamental Symmetries via Precision Measurements of $\pi^0$ , $\eta$ and $\eta'$ Decays

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Light neutral meson decays provide a unique laboratory to probe fundamental symmetries. A comprehensive Primakoff experimental program at Jefferson Laboratory (JLab) is aimed at gathering high precision measurements on the two-photon decay widths and the transition form factors at low four-momentum transfer squares of  $\pi^0$ ,  $\eta$  and  $\eta'$  via the Primakoff effect. Completed experiments on the  $\pi^0$  radiative decay width at JLab 6 GeV, and planned measurements of  $\eta$  and  $\eta'$  at JLab 12 GeV will provide sensitive probes to test the chiral anomaly and to study the origin and dynamics of chiral symmetry breaking in the confinement QCD. Recently developed Jlab Eta Factory (JEF) experiment in Hall D will measure the rare  $\eta$  and  $\eta'$  decays. The result of these measurements will offer a strong constraint on a leptophobic gauge boson  $B'$  in the sub-GeV mass range (with a sensitivity to the baryonic fine structure constant as low as  $10^{-7}$ ) and provide a unique probe for new source of CP violation by directly testing C-violating, P-conserving interactions. A preliminary result of the  $\pi^0$  radiative decay width and the status of planned  $\eta$  and  $\eta'$  measurements will be presented.

**Spectroscopy of baryons / 195**

## Structure of excited charmed baryons studied by pion emission decays

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We investigate the decays of the charmed baryons aiming at the systematic understanding of hadron internal structures based on the quark model by paying attention to heavy quark symmetry. We evaluate the decay widths and branching ratio for the pion emission for the known excited  $\Lambda_{cb}$  baryons. We find an interesting selection rule for the decays depending on their internal structure. We find that pion emission processes, which will be studied in future J-PARC experiments, provide us information on the structure of heavy quark systems.

Poster session / 196

## Study of Light Baryon Resonances in a Chiral Quark Model

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In this work, we study the properties of the light baryons employing a constituent quark model in the hypercentral approach. The model considers through the interacting potential one-gluon exchange, Goldstone boson exchange and confinement, aspects of underlying theory, quantum chromodynamics. We introduce three different potential models and solve Schrodinger equation of the baryonic system employing different methods. Finally, we study the properties of light baryon resonances and also present a comparison between our three models.

Exotic states and candidates / 198

## Charm tetraquarks in lattice QCD

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We present a recent lattice QCD investigation of charm tetraquarks. After describing some of our new methodology, we demonstrate its use in calculations with unphysically heavy light quarks such that the pion mass is 391 MeV. Spectra in the doubly charmed and hidden charmed sector will be shown including those which are of relevance to the experimentally observed charged  $Z_c$  states.

## Exotic states and candidates / 199

**: Analysis of X(4140) like states and their radial excitations in QCD****Authors:** arzu türkan<sup>1</sup>; huseyin dag<sup>1</sup><sup>1</sup> *ozyegin university***Corresponding Authors:** huseyin.dag@ozyegin.edu.tr, arzu.turkan@ozyegin.edu.tr

In this work, we investigate the ground states and their radial excitations which couple to scalar, axial vector and tensor, molecular and diquark-antidiquark currents via QCD sum rules. In operator product expansion, we considered quark, gluon and mixed condensates up to dimension eight. For the ground states coupling to these currents, we estimated degenerate masses within 10 MeV neighborhood of exotic meson X(4140) [1]. Thus, for the ground states, we concluded that, there may be three states degenerate in mass, with positive charge conjugation and different isospins. For the excited states, we found that scalar and tensor currents are coupling to  $D_s^*(D_s^*)^-$  threshold. However for the axial vector currents, the first excited states found to have mass compatible with X(4274). Thus we conclude that, X(4274) might be the first radial excitation of X(4140) [2].

## Spectroscopy of mesons / 200

**D- $\rightarrow$ 4 $\pi$ , D- $\rightarrow$ KK $\pi$  $\pi$  amplitude analyses and properties of a1(1260),  $\pi$ (1300), a1(1640)****Authors:** Nicola Anne Skidmore<sup>1</sup>; Philippe D'Argent<sup>2</sup>; Samuel Thomas Harnew<sup>1</sup>; Paras Naik<sup>1</sup>; Evelina Mihova Gersabeck<sup>2</sup>; Jeremy Peter Dalseno<sup>1</sup>; Jonas Rademacker<sup>1</sup>; Claire Prouve<sup>1</sup>; Jack Benton<sup>1</sup><sup>1</sup> *University of Bristol (GB)*<sup>2</sup> *Ruprecht-Karls-Universitaet Heidelberg (DE)***Corresponding Authors:** sh7566@bristol.ac.uk, paras.naik@bristol.ac.uk, jonas.rademacker@bristol.ac.uk, evelina.gersabeck@cern.ch, jack.b.benton@gmail.com, p.dargent@cern.ch, j.dalseno@bristol.ac.uk, nicola.skidmore@cern.ch, claire.prouve@cern.ch

The resonant substructure of the four-body decays  $D_0 \rightarrow \pi^+\pi^-\pi^+\pi^-$  and  $D_0 \rightarrow K^+K^-\pi^+\pi^-$  is studied using data collected by the CLEO experiment. An amplitude analysis is performed in order to disentangle the various intermediate state contributions. To limit the model complexity a data driven regularization procedure is applied. The broad resonances  $a_1(1260)^+$ ,  $\pi(1300)^+$  and  $a_1(1640)^+$  are studied in detail, including quasi-model-independent parametrizations of their lineshapes. The mass and width of the  $a_1(1260)^+$  meson are determined to be  $m(a_1(1260)^+) = [1225 \pm 9(\text{stat}) \pm 17(\text{syst}) \pm 10(\text{model})] \text{MeV}/c^2$  and  $\Gamma(a_1(1260)^+) = [430 \pm 24(\text{stat}) \pm 25(\text{syst}) \pm 18(\text{model})] \text{MeV}$ . For further details, see arXiv:1703.08505 (<http://inspirehep.net/record/1519168?ln=en>).

## Plenary / 201

**Scattering and resonances from lattice QCD****Author:** Raul Briceno<sup>1</sup><sup>1</sup> *Thomas Jefferson National Accelerator Facility***Corresponding Author:** rbriceno@jlab.org

In recent years we have seen significant progress in our ability to study scattering reactions and resonances using lattice QCD. Quantities that were previously believed to be inaccessible from lattice

QCD (e.g., scattering amplitudes of coupled-channel systems) are now being rigorously studied. For some reactions, the procedure for accessing amplitudes and their corresponding resonance content from lattice QCD mimics that of experiment. Going beyond this, lattice QCD promises to allow us to peer into experimentally inaccessible reactions, which will compliment our understanding of QCD at low-energies. In this talk, I discuss some of the formal and technological developments that have made this progress possible. I will review some of the more recent numerical results pertaining to the study of resonances on the lattice, and I will give an outlook for where the field is heading.

**Hadron decays / 202**

## Charm rescattering contribution to charmless three-body B decays

**Authors:** Patricia Magalhaes<sup>1</sup>; Ignacio De Bediaga Hickman<sup>1</sup>; Tobias Frederico<sup>2</sup>

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Experimental results on three-body charmless non-leptonic B decays have shown a considerable amount of direct CP asymmetry localized in specific regions of the Dalitz plot. In the low hadron-hadron mass region, we recently showed that the final state interactions (FSI) play a very important role, providing through  $\pi\pi \rightarrow KK$  rescattering the strong phase difference needed for direct CP violation.

In the present work we investigate the possibility of  $B \rightarrow D\bar{D}P$  ( $P = \pi, K$ ) decays to contribute for charmless three-body B decays.

This could be possible through a rescattering of  $DD \rightarrow PP$ , where P are light pseudoscalars, which could produce the strong phase one need to explains the CP violation at high hadron-hadron masses. A possible suppression of the  $DD \rightarrow PP$  rescattering would be compensated by the much larger branching fractions of  $B \rightarrow D\bar{D}P$  decays, which might also leave a signature in the Dalitz plot.

There are two kinds of weak topologies that can generate the intermediate double charm state in B charmless decay: the vector ones  $B^+ \rightarrow D_{(s)}^{*+}\bar{D}^0$ , and the axial  $B^+ \rightarrow D\bar{D}P$ .

The vector topology gives rise to a triangle hadronic loop that has been investigated within different contexts and is also called charm penguin contribution. Hadronic loops contribute to the class of three-body final state interactions, since the momentum is shared between all the particles in the final state. On the other hand, the axial contribution is restricted to  $(2 + 1)$  FSI and is proportional to a bubble loop. Both processes are proportional to rescattering amplitude  $D\bar{D} \rightarrow PP$  and will contribute to a nonresonant amplitude. Our studies show that these two possible contributions have clear signatures in the Dalitz plot which could give some hints of the importance of this kind of final state interaction in those decays.

Initially we focus our study in the  $B^+ \rightarrow K^- K^+ K$  decay in which the vector topology is given by  $B^+ \rightarrow D_s^{*+}\bar{D}^0$  whereas axial one is given by  $B^+ \rightarrow D^0\bar{D}^0 K^+$ .

In order to calculate the hadronic decays amplitude in either topologies, one need the rescattering amplitude  $\bar{D}^0 D^0 \rightarrow K^+ K^-$ , which was built inspired by a phenomenological approach considering the dumping factor of the S-matrix, in a similar way that was done previously to  $\pi\pi \rightarrow KK$ .

**QCD and hadron structure / 203**

## Partonic quasidistributions of the pion in chiral quark models

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The evaluation of partonic distributions presents a challenge for QCD, and in particular for its lattice realization. Recently, objects called quasidistributions (which become standard distributions in a limit of the longitudinal momentum of the target hadron going to infinity) have been proposed, but their features are not fully comprehended. We present a dynamical evaluation of the quark quasidistribution amplitude (QDA) and the valence quark quasi-distribution function (QDF) of the pion in the framework of chiral quark models (the Nambu–Jona-Lasinio model and the spectral quark model). We arrive at simple but nontrivial analytic expressions, where the dependence on the longitudinal momentum, the momentum fraction, or the transverse-momentum (for the unintegrated objects) can be explicitly assessed. We carry out the necessary QCD evolution from the constituent quark model scale to higher scales accessible on the lattice, and compare favorably to the recent QCD lattice simulations.

**Poster session / 204**

## **The hadronization into the octet of pseudoscalar mesons in terms of SU(N) gauge invariant Lagrangian**

**Author:** Andrew Koshelkin<sup>1</sup>

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By breaking the initial SU(N) symmetry, we derive the Lagrangian[1] governing the dynamics of the massive scalar particles, which can be treated as the octet of the pseudoscalar mesons. The contribution of both the quark-gluon interaction and self-interaction gluon fields into the masses of the octet of particles is considered. Provided that the hadronization of the confinement matter into the pion triplet occurs, the coupling constant is evaluated in the developed model.

1.A. V. Koshelkin, Phys.Rev.D, v.92 , 045017 (2015).

**Plenary / 205**

## **Electromagnetic form factor of pseudo scalar bound state**

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A continuum approach to the pion, kaon and pseudoscalar  $ss$  bound-state problems is used to reveal their electromagnetic structures. For these systems, when used with parton distribution amplitudes appropriate to the scale of experiment, Standard Model hard-scattering formulae are accurate to within 25 % at medium momentum transfers. The large  $Q^2$  evolution is accurately described by the hard scattering formulae. These results should prove useful in Lattice simulation and in planning next-generation experiments.

## Poster session / 206

**Mesonic string of diquark-quark configuration at finite temperature****Author:** Ahmed Bakry<sup>1</sup>**Co-authors:** Xurong Chen<sup>2</sup>; Maksym Deliyergiyev<sup>3</sup>; Ahmed Galal<sup>4</sup>; Peng-Ming Zhang<sup>1</sup><sup>1</sup> *Institute of Modern Physics, CAS*<sup>2</sup> *Institute of Modern Physics, CAS*<sup>3</sup> *Institute of Modern Physics*<sup>4</sup> *Azhar University***Corresponding Authors:** aagalal@yahoo.com, xchen@impcas.ac.cn, zhpm@impcas.ac.cn, deliyergiyev@impcas.ac.cn, abakry@impcas.ac.cn

Using Polyakov loop correlators, we calculate the quark potential and energy density profile in pure SU(3) Yang-Mills theory. We investigate the limiting case where the string in baryonic quark configuration approaches the behavior of mesonic strings. We compare the potential and the energy density width profile of diquark-quark and mesonic strings. For isosceles triangular quark configurations of base length 0.2 fm, we found the potential to give rise to the same slope as that of the mesonic configuration only for string length  $R > 0.5$  fm. The string tension in the Baryon  $3Q$  is found to be the same as the string tension in the meson  $QQ$  at this distance scale. However, near the deconfinement point, differences in the slope of the potential and energy density profile between both configurations manifest in the intermediate distances. The mesonic limit for the diquark-quark configuration is approached for larger source separation  $R > 0.9$  fm. We consider larger base length of diquark-quark configuration and establish the mesonic limit.

## Spectroscopy of mesons / 207

**Decay width and coupling constants of charm and bottom mesons.****Author:** Pallavi Gupta<sup>1</sup>**Co-author:** alka Upadhyay<sup>2</sup><sup>1</sup> *Thapar University, Patiala*<sup>2</sup> *Associate Professor***Corresponding Authors:** 10gupta.pallavi@gmail.com, alka.iisc@gmail.com

In the last decade, charmed and bottom meson spectroscopy have seen great success in experimental sector. Experiments like LHCb, Babar etc are providing many new states which are being added to their spectroscopy. Newly predicted states like B(5970), D<sub>2</sub>(3000), D\*(3000), B(5840) and many more still need to assign their proper place in the spectroscopy. So we explored these newly observed states in detail using the heavy quark effective theory as our model. We analysed the two-body strong decays to their ground state mesons and light pseudo-scalar mesons. We also obtain the ratios among the strong decays, which can be confronted to the experimental data for the verification of the JP states. As a byproduct, we also study the strong decays of the unobserved states of their spin and strange partners, which can be useful for future experiments in searching for these heavy-light mesons.

## Exotic states and candidates / 208

## The nature of the $X(3915)/X(3930)$ resonances from a coupled-channels approach

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The measured properties of the  $X(3915)$  and  $X(3930)$  make difficult their theoretical description. These charmonium resonances, firstly detected by the Belle and BaBar Collaborations in  $\gamma\gamma$  fusion process, were measured in different final channels: the  $X(3915)$  was discovered in the  $\omega J/\psi$  [1, 2] invariant mass distribution whereas the  $X(3930)$  was seen in the  $D\bar{D}$  one [3, 4]. Both Collaborations rapidly agreed that the  $X(3930)$  has most likely  $J^{PC} = 2^{++}$  quantum numbers based on the angular distribution of the initial  $\gamma\gamma$  particles. Therefore, this state was identified as the  $\chi_{c2}(2P)$  state in the Particle Data Group (PDG), despite the fact that most quark models predict masses above the experimental one.

The assignment for the  $X(3915)$  is being more controversial. Both  $J^{PC} = 0^{++}$  and  $2^{++}$  quantum numbers are allowed, although BaBar data clearly prefers the  $0^{++}$  assignment. Following the predictions of different quark models [5, 6], finding good agreement with experiment on the state's mass and width, the  $X(3915)$  was assigned to the  $\chi_{c0}(2P)$  in the PDG. However, the  $\chi_{c0}(2P)$  assignment was challenged by Olsen [7], who pointed out that the decay patterns of the  $X(3915)$  do not fit with those expected for the  $\chi_{c0}(2P)$  state. Moreover, new theoretical and experimental studies reanalyzed the available data and concluded that a  $J^P = 2^+$  assignment is preferred if some assumptions taken by BaBar Collaboration in their original work were abandoned. Consequently, PDG relabeled the state back to  $X(3915)$ .

Additionally, a new charmonium-like state dubbed  $X(3860)$  with a mass  $3862_{-32-13}^{+26+40}$  MeV and width  $201_{-67-82}^{+154+88}$  MeV has been recently reported by the Belle Collaboration [8]. The existence of this state agrees with the suggestion of Ref. [9], where the authors identify the broad bump below the narrow peak of the  $\chi_{c2}(2P)$  with the real  $\chi_{c0}(2P)$ . Also, its mass coincides with the predictions of dynamical coupled-channel models for the  $\chi_{c0}(2P)$ .

In view of the assignment puzzle of the  $X(3915)$  and  $X(3930)$  resonances, and to explore the possible non- $q\bar{q}$  components of these resonances, in this work we perform a coupled-channels calculation in the framework of the constituent quark model (CQM) proposed in Ref. [10, 11], following the formalism in Ref. [12]. Our results favors the hypothesis that the  $X(3915)$  and the  $X(3930)$  resonances are the same  $J^{PC} = 2^{++}$  state with a large molecular component, whereas the  $J^{PC} = 0^{++}$  state appears with a mass  $M = 3890 \text{ MeV}/c^2$ , lowered by nearby threshold effects.

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## Spectroscopy of baryons / 211

### Overview about recent results from the A2 real photon facility at MAMI

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The A2 Collaboration at the Mainz Microtron MAMI measures photon absorption cross sections using circularly and linearly polarized ‘Bremsstrahlung’ photons up to an energy of  $\sim 1.5$  GeV and a polarized Frozen Spin Target. We use a 4  $\pi$  detection system with the ‘Crystal Ball’ as central part. One important experimental topic is the investigation of the nucleons excitation spectrum. Measurements with both longitudinally and transversely polarized protons and deuterons are essential to disentangle the broad and overlapping resonances. Several recently published data for single and double polarization observables will be presented.

## Spectroscopy of mesons / 212

### Recent Results on Light-Meson Spectroscopy from COMPASS

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COMPASS is a multi-purpose fixed-target experiment at CERN aimed at studying the structure and spectrum of hadrons. The two-stage spectrometer has a good acceptance over a wide kinematic range and is thus able to measure a wide range of reactions. Light mesons are studied with a negative hadron beam (mostly  $\pi^-$ ) with a momentum of 190 GeV/c. The light-meson spectrum is investigated in various final states produced in diffractive dissociation. The flagship channel is the  $\pi^- \pi^+ \pi^-$  final state, for which COMPASS has acquired the so far world’s largest dataset of 46 M exclusive events. We report on new results for this final state, which allows us to investigate  $a_J$  and  $\pi_J$  mesons, employing partial-wave analysis (PWA). In this method, the decay into  $\pi^- \pi^+ \pi^-$  is modeled as subsequent two-body decays in order to disentangle the contributions of different partial waves. The large size of our dataset allows to perform this analysis in narrow bins of the squared four-momentum transfer  $t'$ . Thus, we can also extract the  $t'$  dependence of the various components from the data. Finally, the resonance parameters of  $a_J$  and  $\pi_J$  mesons are measured by disentangling resonant and non-resonant parts of 14 selected partial waves simultaneously in a resonance-model fit. Combining 14 partial waves in a single resonance-model fit allows us to study also weaker

signals, e.g. from excited  $a_1$ ,  $a_2$ , or  $\pi_2$  states, by making use of their interference pattern and their different couplings to the various decay modes.

### Spectroscopy of mesons / 213

## Chiral model for the $D^+ \rightarrow K^+ K^- K^+$ decay amplitude

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Isobar models, successful as they are in providing fits for heavy meson decays, rely on both parameters which are not physically transparent and sums of Breit-Wigner functions.

As an alternative, we propose a Multi-Meson-Model (Triple-M) for the  $D^+ \rightarrow K^+ K^- K^+$  amplitude.

The decay is assumed to be dominated by the process

$D^+ \rightarrow W^+ \rightarrow K^+ K^- K^+$  and, therefore,

driven by axial current matrix elements:

$$\mathcal{A} = \langle (KKK)^+ | A_\mu | 0 \rangle \langle 0 | A^\mu | D^+ \rangle.$$

In the want of a complete unitary description of this amplitude, we consider the so called (2 + 1) approximation,

in which two-body unitarized amplitudes are coupled to spectator particles.

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In the Triple-M, we depart from lagrangians employed in chiral perturbation theory with resonances (R $\chi$ PT),

which describe interactions of pseudoscalar mesons by means of both leading order (LO) contact terms

and next-to-leading order (NLO) resonance exchanges.

The NLO LECs are assumed to be saturated by resonances.

%

We consider all channels in the  $K^+ K^-$  subsystem with spin  $J = 1, 0$  and isospin  $I = 1, 0$ , associated with the resonances  $\rho$ ,  $\phi$ ,  $a_0$  and two  $f$ -scalar states, corresponding to a singlet and to a member of an octet of  $SU(3)$ .

The physical  $f_0(980)$  is then a linear combination of these scalar states.

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The unitarization of two-body amplitudes is performed by resumming geometrical Dyson series, based on interaction kernels and two-meson propagators, involving  $\pi\pi$ ,  $KK$ ,  $\eta\eta$  and  $\eta\pi$  intermediate states.

The ensuing coupled channel systems give naturally rise to the widths of resonances and, in the case of the

scalar-isoscalar channel, to an amplitude which is more consistent than a sum of Breit-Wigners.

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The main features of the Triple-M read:

\\

{bf 1.} it incorporates resonances and extends the isobar model;

\\

{bf 2.} it includes a non-resonant contribution, a consequence of chiral symmetry, which is a real function, fully determined by theory;

\\

{bf 3.} all imaginary terms in the amplitude are completely determined by unitarity and no free complex parameters are employed;

\\

{bf 4.} all free parameters represent either meson masses or coupling constants and, therefore,

have a rather transparent physical meaning.

\\

A check of the Triple-M was made with the amplitude used in the analysis of the isobar model and it will be tested directly against data, in the near future.

Plenary / 214

## Light quark baryons from photoproduction and electroproduction experiments

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One of the remaining challenges within the standard model is to gain a good understanding of QCD in the non-perturbative regime. A key step towards this aim is baryon spectroscopy, investigating the spectrum and the properties of baryon resonances. To gain access to resonances with small  $\pi N$  partial width, experiments with electromagnetic probes provide essential information. Partial wave analyses need to be performed to extract the contributing resonances. Here, a complete experiment is required to unambiguously determine the contributing amplitudes. This involves the measurement of carefully chosen single and double polarization observables.

In a joint endeavor by Jefferson Lab, MAMI, and ELSA, a new generation of experiments with polarized beams, polarized proton and neutron targets, and  $4\pi$  particle detection have been started in recent years. Many results of unprecedented quality were recently published and included by the various partial wave analysis groups in their analyses, leading to substantial improvements, e.g. a more precise determination of resonance parameters. In this talk, an overview of recent results is given, and their impact on our understanding of the nucleon excitation spectrum is discussed.

Plenary / 215

## Review of production of hadron resonances in e+e- collisions

**Author:** Galina Pakhlova<sup>1</sup>

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We present recent results on hadron production in e+e- annihilation including double charmonium production, gamma-gamma fusion, hadron production with initial state radiation and from decays of B-mesons. We discuss the status of both standard and exotics hadron searches. Our review covers new results from Belle, BaBar, BESIII Collaborations and discussion of perspectives for future experiments such as Belle-II and Super c-tau factory

Spectroscopy of mesons / 216

## Light exotic meson candidates in COMPASS

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The COMPASS experiment at CERN uses a high-energy pion beam scattered off protons and heavier nuclei to produce mesonic excitations, which are observed in multi-particle final states subjected to partial-wave analyses. In addition to studying the properties of established mesons with unprecedented accuracy, the large existing data samples allow us to detect possibly exotic states. These either do not fit current theoretical expectations, like the recently observed  $a_1(1420)$ , or carry spin-exotic quantum numbers, like the  $\pi_1(1600)$ . The talk will give an update on ongoing studies of these states involving novel analysis techniques and discuss possible interpretations.

**Analysis tools / 217**

### A resonance-like phenomenon $a_1(1420)$

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**Co-authors:** Mathias Wagner<sup>2</sup>; Bernhard Ketzer<sup>1</sup>; Andrey Sarantsev<sup>3</sup>

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We investigate the resonance-like structure with quantum numbers  $J^{PC} = 1^{++}$  in the  $f_0\pi$  P-wave recently observed at a mass 1.4 GeV by the COMPASS Collaboration. The signal was tentatively assigned to be an axial resonance,  $a_1(1420)$ , although it does not fit the  $q\bar{q}$ -model, which suggests an exotic nature. We present an elegant explanation of the phenomenon without introducing a new state. We show that in the presence of a significant inelasticity, particularly  $3\pi - K\bar{K}\pi$  coupling, strong effects due to rescattering appear, producing a resonance-like enhancement in the three-body invariant mass. The model which does not have free parameters is tested with the COMPASS data, showing that both the peak in the intensity and the phase variation can be reproduced.

We see that the common approach called the isobar model, which assumes that a decay to multi-particle final states is described by sequential two-body decays, requires rescattering corrections. The studies of the generalization of the isobar model guided by subchannel unitarity and three-body unitarity will be discussed.

**Hadrons in matter including hypernuclei / 218**

### Structure of $\Xi$ hypernuclei and $\Xi N$ interaction

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It is important to study  $\Xi N$  interaction in hypernuclear physics. However, due to no  $\Xi N$  scattering data, it is essential to study  $\Xi$  hypernuclei. Recently, we observed a  $\Xi$  hypernucleus, called as Kiso event, to have a bound state for the first time. From this data, we found that  $\Xi N$  interaction should be attractive. In this conference, we discuss that what kind of  $\Xi N$  interaction should be obtained from the data and in the future what kinds of  $\Xi$  hypernuclei we should have at J-PARC facility.

## Spectroscopy of mesons / 220

### First results from an extended freed-isobar analysis at COMPASS

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One of the goals of the COMPASS experiment is the precision study of light meson spectroscopy, with data for various final states collected in two years of data taking. With  $46 \cdot 10^6$  exclusive events, the process  $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$  constitutes the flagship of these channels.

Based on this data set, an extensive Partial Wave Analysis, using a total of 88 partial waves in the model, was published in 2017 [1]. Along with it, results of a first study of the so-called freed-isobar method were shown. Here, the fixed amplitudes for appearing  $\pi^+ \pi^-$  intermediate states used in the conventional analysis were replaced by sets of piecewise constant functions to extract the amplitudes of the  $\pi^+ \pi^-$  subsystems directly from the data. In this first study, this was done for three  $J^{PC} = 0^{++}$  intermediate  $\pi^+ \pi^-$  states.

The promising results inspired further extension of this method, by also including intermediate  $\pi^+ \pi^-$  states with  $J^{PC} = 1^{--}$  and  $2^{++}$ . With this extension of the sets of freed waves, mathematical ambiguities in the model arise due to the much higher freedom in the model. We will present first results of these extended studies on COMPASS data along with methods to overcome the arising ambiguities.

[1] COMPASS collaboration, Phys.Rev. D95 (2017) no.3, 032004

## Hadron decays / 221

### Decay behaviors of hadronic molecule pentaquark states

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**Co-authors:** Chao-Wei Shen<sup>1</sup>; Feng-Kun Guo<sup>1</sup>; Yong-Hui Lin<sup>1</sup>

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The  $P_c(4380)$  and  $P_c(4450)$  states observed recently by LHCb experiment were proposed to be either  $\bar{D}\Sigma_c^*$  or  $\bar{D}^*\Sigma_c$  bound states. We analyze the decay behaviors of such two types of hadronic molecules within the effective Lagrangian framework. With branching ratios of ten possible decay channels calculated, it is found that the two types of hadronic molecules have distinguishable decay

patterns. While the  $\bar{D}\Sigma_c^*$  molecule decays dominantly to  $\bar{D}^*\Lambda_c$  channel with a branching ratio by 2 orders of magnitude larger than to  $\bar{D}\Lambda_c$ , the  $\bar{D}^*\Sigma_c$  molecule decays to these two channels with a difference of less than a factor of 2. Our results show that the total decay width of  $P_c(4380)$  as the spin-parity- $\frac{3}{2}^-$   $\bar{D}\Sigma_c^*$  molecule is about a factor of 2 larger than the corresponding value for the  $\bar{D}^*\Sigma_c$  molecule. It suggests that the assignment of  $\bar{D}\Sigma_c^*$  molecule for  $P_c(4380)$  is more favorable than the  $\bar{D}^*\Sigma_c$  molecule. In addition,  $P_c(4450)$  seems to be a  $\bar{D}^*\Sigma_c$  molecule with  $J^P = \frac{5}{2}^+$  in our scheme. Based on these partial decay widths of the  $P_c$  states, we estimate the cross sections for the reactions  $\gamma p \rightarrow J/\psi p$  and  $\pi p \rightarrow J/\psi p$  through the s-channel  $P_c$  states. The forthcoming  $\gamma p$  experiment at JLAB and  $\pi p$  experiment at JPARC should be able to pin down the nature of these  $P_c$  states.

We also study the decay behaviors of the strange partners of these  $P_c$  states.

QCD and hadron structure / 222

## Strongly Interacting Matter Phase Diagram in the presence of Magnetic Fields in an Extended Effective Lagrangian Approach with Explicit Chiral Symmetry Breaking Interactions

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Extensions of the NJL model which go beyond the original 4-quark interaction, which drives the dynamical mass generation, have proven to be quite successful in describing low energy hadronic phenomenology. The inclusion of 8-quark interaction terms solved a metastability problem of the effective potential

introduced by the inclusion of the 6-quark 't Hooft determinant term in the 3-flavor version of the model (needed to eliminate the unwanted U(1) axial symmetry) [1]. This model, that has proven to be quite powerful and feature-rich, has been expanded to include all the spin-0 terms, without and with chiral symmetry breaking, which are of the same order as the 't Hooft flavor determinant in a  $1/N_c$  expansion resulting in an unprecedented success in reproducing the low lying scalar and pseudoscalar meson spectra [2].

The influence of magnetic fields in the Phase Diagram has been under intense scrutiny due to their relevance for instance in the context of Heavy Ion Collisions, compact stars and early Universe phases. Here we will present recent results pertaining the Phase Diagram under the influence of Magnetic Fields within the framework of our extended model.

[1] B. Hiller, J. Moreira, A. A. Osipov, and A. H. Blin, Phys. Rev. D 81, 116005

[2] J. Moreira, J. Morais, B. Hiller, A. A. Osipov, and A. H. Blin, Phys. Rev. D 91, 116003

QCD and hadron structure / 223

## COMPASS legacy results concerning longitudinal spin structure of the nucleon.

**Author:** Elena Zemlyanichkina<sup>1</sup>

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The talk will include the summary of COMPASS measurements of gluon polarisation in the nucleon and the final results concerning the spin dependent structure function  $g_1$ . In order to improve flavour-by-flavour knowledge of the spin structure of the nucleon the so called semi-inclusive measurements of hadron asymmetries were performed. To fully profit from these measurements a more precise knowledge of fragmentation functions is needed. In view of this COMPASS recent results concerning pion and kaon multiplicity will be discussed. Besides a global overview of the COMPASS multiplicity data, special attention will be given to kaon production, in the cases where the kaon carries high energy fraction of the virtual photon energy. In this region, the multiplicity ratio of  $K^+/K^-$  obtained is much larger than the limit permitted by LO QCD.

**QCD and hadron structure / 224**

## Deeply Virtual Compton Scattering at 11GeV in Jefferson Lab Hall A

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Introduced in the mid 90's, Generalized Parton Distributions (GPDs) are now a key element in the study of the nucleon internal structure. Indeed, GPDs encapsulate both spatial and momentum distributions of partons inside a nucleon, and through the Ji sum rule, they also allow to derive the total orbital angular momentum of quarks.

GPDs are experimentally accessible through Deeply Virtual Compton Scattering (DVCS) and its interference with the Bethe-Heitler process at high momentum transfer  $Q^2$ . A worldwide experimental program was started in the early 2000's to extract these GPDs. The subject of this presentation, a DVCS  $ep \rightarrow e\gamma$  experiment performed at Jefferson Laboratory, Hall A (Virginia, USA) between 2014 and 2016, is encompassed in this program.

The aim of this experiment is to extract the DVCS helicity-dependent cross sections as a function of the momentum transfer  $Q^2$ , for fixed values of the Bjorken variable  $x_B$ , on a proton target. The recent upgrade of the accelerator facility to 12 GeV allows to cover a larger lever arm in  $Q^2$  than for previous measurements, while the polarized electron beam will allow the separation of the contributions from the real and imaginary parts of the DVCS amplitude to the total cross section.

This talk will present an overview of the ongoing data analysis for this experiment.

**Spectroscopy of mesons / 225**

## Hadron phenomenology from Dyson-Schwinger equations

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The Green's functions of QCD encode the properties of hadrons, with the appearance of (colour singlet) poles in  $n$ -point functions corresponding to bound-states and resonances. There are several techniques by which such information may be extracted, including lattice QCD and functional

methods. We discuss recent progress in applying nPI effective action techniques to the systematic truncation of Dyson-Schwinger and Bethe-Salpeter equations, with particular emphasis on the spectrum of mesons and baryons.

**Poster session / 227**

## **X(5568) in finite volume**

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We report on a recent study of the  $B_s\pi$  and  $BK^-$  interactions in finite volume [1]. We show the discrete energy levels in two scenarios whether the coupled channel interactions are either strong enough to dynamically generate the X(5568) or too weak to produce it. Supplemented by the state of the art lattice QCD simulations, our study supports the picture that the interactions are weak and the X(5568) can not be a dominant  $B_s\pi$  and  $BK^-$  molecule.

[1] Jun-Xu Lu, Xiu-Lei Ren, Li-Sheng Geng, Eur.Phys.J. C77 (2017) 94, e-Print: arXiv:1607.06327 [hep-ph]

**Spectroscopy of baryons / 228**

## **Spectroscopy of charm baryons at LHCb**

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LHCb continues to expand its world-leading sample of charmed hadrons collected during LHC's Run 1 (2010-2012) and Run 2 (2015- present). With this data set, LHCb is discovering many previously unobserved charmed states and making the most precise determinations of the properties of known states. LHCb's latest work on the spectroscopy of charmed hadrons is presented.

**Hadron decays / 229**

## **Radiative decays of light-quark mesons to a pion revisited in the covariant oscillator quark model**

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We revisit the treatment of radiative decay processes of light-quark  $q\bar{q}$  mesons to a pion in the covariant oscillator quark model. Since the pion has an exceptionally light mass compared with



other ground-state hadrons, we have difficulty in dealing with pions within the constituent quark model, including the covariant oscillator quark model. The pion is a pseudo-Nambu-Goldstone boson associated with the spontaneous breaking of chiral symmetry in QCD. The NG boson nature of the pion is not incorporated into the covariant oscillator quark model. In the case of the radiative decay processes this difficulty appears as the anomalous behaviors of decay form factors, which come from overlaps between initial- and final (pion)-state wave functions, due to too small mass of the pion. In actual applications so far there has been “physical vs. symmetric” ambiguity on the treatment of mass of the pion. In this talk we present a possible approach to solution of the difficulty with pions in the covariant oscillator quark model.

**QCD and hadron structure / 230**

## The Pion Form Factor in Lattice QCD

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The determination of the pion form factor to high  $Q^2$  provides an important measure of the transition to quark and gluon degrees of freedom in hadrons. Its measurement to  $Q^2$  in excess of  $6 \text{ GeV}^2$  is an approved experiment of the 12 GeV upgrade. In this talk, we present recent progress aimed at computing the pion form factor in lattice QCD to values of  $Q^2$  commensurate with the upcoming experimental measurements. We apply some of the novel methods developed for lattice calculations of the excited-state spectrum to isolate the ground-state pion, and use a basis of interpolating operators for the pion that reflect the symmetries of the lattice to facilitate calculations at high momentum transfers. Finally, we describe how the methods can aid in the calculation of quasi-PDFs of the pion.

**Plenary / 231**

## Experimental searches for light exotica

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The search mesons composed of light quarks with combinations of angular momentum (J), parity (P), and charge conjugation (C) that cannot be formed by a quark-antiquark pair has been a topic of experimental interest for several decades. While QCD does not seem to forbid the formation of exotic mesons, the evidence supporting their existence in nature is sparse. If such mesons do exist in nature, they would shed light on the role of gluonic degrees of freedom in the construction of hadrons. In the last decade the experimental search for exotics has been further motivated by lattice QCD predictions of a spectrum of exotic and non-exotic hybrids. At the same time, several experiments have produced data sets of unprecedented statistical precision, which has both enabled and required a more thorough understanding the underlying reaction dynamics to extract robust signals for new resonances. And more data from complementary experiments are expected in the near future. In this talk I will try to capture the recent developments in what is a long history of experimental activities, discuss them in the broader context of hadron spectroscopy, and highlight future prospects for discovery and study of light quark exotica.

Poster session / 232

## SYMMETRY-MOTIVATED ANALYSIS OF PARTICLE MASS DATA

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In this work a continuation of an analysis of fine structure effects in nuclear data is combined with the analysis of particle mass data.

The material used in the work is based on nuclear data compilations collected in PNPI and data from the Compilations PDG-2016 and the evaluation CODATA. These data provide a base for the combined analysis of all existing information for suggested by Y.\,Nambu further development of the Standard Model (SM). Involvement of nucleon masses into correlations with masses of other particles, including such fundamental particles as leptons, the pion and masses of vector and scalar fields allowed a combined consideration of data in all these data files due to the commonly accepted basic role of the QCD (one of SM components) in the mass generation and in the nucleon interaction.

We start with CODATA relations for the electron and nucleon masses:

$$\begin{equation} \{m_n = 115 \cdot 16 m_e - m_e - \delta m_N / 8\} \sim \{m_p = 115 \cdot 16 m_e - m_e - 9 \delta m_N / 8\}. \end{equation}$$

Here the shift in the neutron mass (relative to the integer number of  $m_e$ )  $\delta m_n = 161.65$  keV is exactly rational  $8(1.000(1))$  to the nucleon mass splitting  $\delta m_N = 1293.3$  keV. It was found that the fine structure period 161 keV from this ratio is very close (but not coincident) with the value  $m_e/3 = 170.3$  keV which can be considered as an additional shift (assigned to each of three quarks of the nucleon).

The relation in mass shifts confirmed with analysis of nuclear data was an indication on the presence of very general dynamics connected with charge discreteness in the Standard Model, with symmetry properties of the fermion system and the nature of the physical condensate [1].

\noindent

1. S.I. Sukhoruchkin, Nucl. Part. Phys. Proc. **282--284** (2017) 189.

Spectroscopy of mesons / 233

## "Diffractive production of $\pi^- \pi^- \pi^+$ and $\pi^- \pi^0 \pi^0$ systems at VES."

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The VES experiment has collected high statistics for exclusive reactions with three pion final states:  $\pi^- \pi^- \pi^+$  (about  $30 \cdot 10^6$  events) and  $\pi^- \pi^0 \pi^0$  (about  $16 \cdot 10^6$  events).

The  $3\pi$  systems are produced by  $\pi^-$  beam ( $E_{beam} = 28.9$  GeV) impinging on the beryllium target.

The dominant production mechanism is the pomeron exchange between incoming beam pion and the target.

At low momentum transfer squared  $t' < 0.05 \text{ GeV}^2$  the data clearly shows coherent diffractive production on the whole nucleus which is replaced by incoherent process on the individual nucleons at higher  $0.05 < t' < 1 \text{ GeV}^2$ .

The mass-independent partial wave analysis is performed dividing data into the bins of  $m(3\pi)$  and  $t'$ .

The comparison of results with two models of PWA: using formalism of full rank density matrix and, oppositely, using rank=1 is presented.

The predicted isospin relations (assuming  $I = 1$  of  $3\pi$  systems) and observed ones for intensities and relative phases in  $\pi^- \pi^- \pi^+$  and  $\pi^- \pi^0 \pi^0$  are shown.

Plenary / 235

## Experimental Overview of Light Mesons

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The spectrum of light-quark (uds) mesons has been studied since the mid-20th century, yet these simplest of hadrons are still providing new insight into the nature of the strong interaction and presenting new experimental challenges. In this talk, I will discuss the current status of light mesons, show some of the most exciting new results in this area, and discuss the prospects for future progress with the availability of huge, high-quality data sets alongside new theoretical tools to understand them.

Poster session / 236

## Effective quarks and gluons in heavy-flavor QCD

**Authors:** Stanisław Glazek<sup>1</sup>; Maria Gomez Rocha<sup>None</sup>; JAI MORE<sup>2</sup>; Kamil Serafin<sup>1</sup>

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Hadrons composed of heavy quarks are the simplest ones to study in QCD.

They provide an affordable theoretical laboratory for investigating the dynamics of gluons, mainly because quarks move slowly with respect to each other as the sources of gluons and in the analysis of heavy meson states one can safely take advantage of asymptotic freedom and expand renormalized interactions in powers of the coupling constant [1].

The effective quarks and gluons are introduced using the renormalization group procedure for effective particles (RGPEP), whose details are addressed in the abstract submitted by Maria Gomez-Rocha to HADRON2017 [2]. We use the RGPEP to derive the leading-order renormalized light-front QCD Hamiltonian and to formulate its eigenvalue problem for mesons in terms of the Fock components with smallest possible number of effective particles, which resembles the constituent quark model. However, the dynamics of quarks

originates in the gluons in higher Fock sectors. In the second-order calculation we describe here, only the Fock sector with one gluon in addition to quarks matters. However, in order to approximately account for the non-abelian and non-perturbative effects due to higher sectors, we introduce a mass ansatz for the gluon. As a result, we obtain the Coulomb force plus a harmonic oscillator force between heavy quarks in the quark-antiquark Fock sector. In this first approximation, the harmonic oscillator potential does not depend on the assumed gluon mass or on the generator of the RGPEP [3].

[1] M. Gómez-Rocha, S. D. Glazek, Phys. Rev. D 92, 065005

[2] María Gómez-Rocha's abstract submitted to HADRON2017.

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QCD and hadron structure / 237

## Effective-particle approach to bound states of quarks and gluons in QCD

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A general approach to the construction of bound states in quantum field theory, called the renormalization group procedure for effective particles (RGPEP), is applied to single heavy-flavor QCD in order to study its utility beyond illustration of its general features. This heavy-flavor QCD is chosen as the simplest available context in which the dynamics of quark and gluon bound states can be studied with required rigor using the Minkowski-space Hamiltonian operators in the Fock space, taking the advantage of asymptotic freedom [1]. The effective quarks and gluons differ from the point-like canonical ones by having a finite size  $s$ . Their size plays the role of renormalization group parameter. However, instead of integrating out high energy degrees of freedom, our RGPEP procedure is based on a transformation of the front-form QCD Hamiltonian from its canonical form with counterterms to the renormalized, scale dependent operator that acts in the Fock space of effective quanta of quark and gluon fields, keeping all degrees of freedom intact but accounting for them in a transformed form. We discuss different behavior of effective particles interacting at different energy scales, corresponding to different size  $s$ . Namely, we cover phenomena ranging from asymptotic freedom at highest energies down to the scales at which the formation of bound states occurs. We briefly present recent applications of the RGPEP to quarks and gluons in QCD, which have been developed using expansion in powers of the Fock-space Hamiltonian running coupling. After observing that the QCD effective Hamiltonian satisfies the requirement of producing asymptotic freedom [1], we derive the leading effective interaction between quarks in heavy-flavor QCD [2]. An effective confining effect is derived as a result of assuming that the non-Abelian and non-perturbative dynamics causes effective gluons to have mass. This talk provides a theoretical background to the talk whose proposed abstract is submitted by Kamil Serafin to HADRON 2017[3].

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[3] K. Serafin's abstract submitted to HADRON2017.

**QCD and hadron structure / 239****Heavy quark masses with calibrated uncertainty****Authors:** Jens Erler<sup>1</sup>; Pere Masjuan Queral<sup>None</sup>; Hubert Spiesberger<sup>2</sup><sup>1</sup> *IF-UNAM*<sup>2</sup> *University Mainz***Corresponding Authors:** hspiesb@zino.physik.uni-mainz.de, erler@fisica.unam.mx, masjuan@ifae.es

A determination of the heavy quark masses from combinations of QCD sum rules of the moments of the vector current correlator calculated in perturbative QCD are presented. Only experimental data for the resonance below the continuum threshold are needed in our approach, while the continuum contribution is determined by requiring self-consistency between various sum rules and the zeroth moment. Special attention to the theory uncertainty is given.

**Hadrons in matter including hypernuclei / 241****AntiKaons in Matter****Author:** laura fabbietti<sup>1</sup><sup>1</sup> *Technische Universität München***Corresponding Author:** laura.fabbietti@ph.tum.de

Several experiments have been devoted to the study of the antikaon properties within nuclear matter to understand the interaction between antikaons and nucleons at different density conditions. Experimental evidence delivered by kaonic atoms, kaon scattering data and the existence of the L(1405) resonance proves the antikaon-nucleon interaction to be attractive in the vacuum but the behavior within nuclear matter is far from being settled. One of the major issues in these investigations is the understanding of absorption processes of antikaon on nucleons. We present in this talk recent measurements of antikaon absorptions as measured by the AMADEUS collaboration exploiting slow antikaons beams and by the HADES collaboration with pion-induced reactions on light and heavy nuclei.

The AMADEUS results delivers precise measurements on single, doublet and triplet of nucleons while the HADES data do allow to measure the total absorption of antikaon on carbon and lead nuclei, also including the effect of the  $f$  resonance.

The results are discussed to attempt to reach a coherent explanation for the absorption phenomena of antikaons.

**Hadrons in matter including hypernuclei / 242****Strong interaction studies with kaonic atoms****Author:** Johann Zmeskal<sup>1</sup><sup>1</sup> *Austrian Academy of Sciences (AT)***Corresponding Author:** johann.zmeskal@oeaw.ac.at

The understanding of the strong interaction between hadrons in the strangeness sector are an important testing ground for chiral SU(3) symmetry due to the large mass of the strange quark. The antikaon-nucleon interaction at low energy is studied using non-perturbative coupled-channel techniques based on chiral SU(3) effective Lagrangians.

With SIDDHARTA kaonic hydrogen and helium atoms were studied with up to know unrivalled precision at the DAΦNE electron positron collider of Laboratori Nazionali di Frascati. DAΦNE delivers low-energy charged kaon pairs due to the decay of phi-mesons, which are produced nearly at rest.

For kaonic hydrogen atoms a energy shift of the ground state has been measured with respect to the pure QED value, as well as an broadened ground state level, caused by nuclear absorption. By measuring these observables, the s-wave kaon-nucleon scattering lengths at zero energy could be extracted, which are sensitive measures of the chiral and isospin symmetry breaking pattern in QCD. Because of isospin conservation only the average value of the isospin  $I=0$  and  $I=1$  scattering lengths ( $a_0$  and  $a_1$ ) could be obtained from a kaonic hydrogen measurement. Therefore, in order to determine the isospin dependent scattering lengths, a measurement of the shift and width of both kaonic hydrogen and kaonic deuterium atoms are necessary and will represents the most important experimental information missing in the field of low-energy antikaon-nucleon interactions today.

The final results of SIDDHARTA and as well as plans for kaonic deuterium measurements at DAΦNE and J-PARC will be presented.

## Hadrons in matter including hypernuclei / 243

### S=-2 Systems

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At J-PARC, we are conducting spectroscopic studies of strangeness -2 systems, such as  $\Xi^-$  and double- $\Lambda$  hypernuclei. The experimental information on these systems is so far limited with several emulsion events; the “Nagara” event for  $\Lambda\Lambda^6\text{He}$  and the “Kiso” event for a strong candidate of a  $\Xi$  hypernucleus. In this talk, I will introduce a preliminary result on  $\Xi^{12}\text{Be}$  obtained in the pilot run of E05 experiment in 2015, and the status of E07 experiment, a hybrid-emulsion measurement, taking the data just recently in 2017. In the E05 experiment, we are going to measure the  $\Xi^{12}\text{Be}$  spectrum with an energy resolution of better than 2 MeV(FWHM) by constructing a new spectrometer S-2S. Before the completion of the S-2S, we measured an excitation energy spectrum of the  $^{12}\text{C}(K^-,K^+)X$  reaction at 1.8 GeV/c with an energy resolution of 6 MeV, which is the best energy resolution ever achieved in studying this reaction. The measurement was performed at the K1.8 beam line of the J-PARC hadron experimental hall by using the SKS spectrometer. The K- beam intensity at the primary proton beam power of 39 kW was typically  $6 \times 10^5$ /spill with 5.5-sec. beam cycle. The energy resolution was estimated from the peak observed in the  $p(K^-,K^+)\Xi^-$  reaction from a 9.54-g/cm<sup>2</sup> CH<sub>2</sub> target. We took the data on the  $^{12}\text{C}(K^-,K^+)X$  reaction with a 9.4-g/cm<sup>2</sup> C target for about 10 days. We have observed about 60k events of quasi-free  $\Xi^-$  production, and several tens of events in the bound region. Although the analysis is still preliminary, we could see clear enhancements in the bound region above a flat background. The up-to-date analysis result will be presented. In June, 2017, we have successfully completed the E07 data taking exposing a lot of stacks of emulsions. We estimate the number of stopped  $\Xi$  events would be an order of magnitude larger than ever. The data taking conditions and prospect of the data analysis will be reported.

## Hadrons in matter including hypernuclei / 244

### Results from the hypernuclear physics experiments at JLab and future perspectives

**Author:** Satoshi Nakamura<sup>1</sup>

<sup>1</sup> *Tohoku University*

Spectroscopic study of Lambda hypernuclei has started at Jefferson Lab in 2000, the last year of the 20th century.

There were many experimental difficulties such as small production cross section, huge electron background and so on.

We, finally, established the Lambda hypernuclear spectroscopy with electron beam by introducing novel experimental techniques and efforts of more than a decade.

JLab hypernuclear collaboration is now preparing for a new experiment (JLab E12-15-008) to investigate isospin dependence of Lambda hypernuclei with Ca40 and Ca48 targets.

I will overview unique feature of hypernuclear study with electron beams and highlight of the results obtained at JLab.

Physics goal and preparation status of the new experiment will be also discussed.

Plenary / 245

## Heavy quarks and quarkonia production in high-energy experiments

Author: Sandro Palestini<sup>1</sup>

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Data collected at LHC have extended the observable kinematical range for the production of quarkonia and open charm/beauty hadrons, and made possible the study of associated production of quarkonium pairs and of heavy quarks together with W, Z, or jets. The measurements have tested QCD based predictions and provided constraints for parton distribution functions. The talk will review and discuss the most recent and relevant results.

Hadrons in matter including hypernuclei / 246

## Search for eta-nucleus bound states

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We will report on the status of the search for the eta-mesic nuclei and the studies of the interaction of the eta and eta-prime meson with nucleons. The existence of the eta-mesic nucleus was postulated over twenty nine years ago, however, till now it was not confirmed experimentally. Such system in the form of the eta mesic-helium may be created for example in the deuteron-deuteron or proton-deuteron fusions. The talk will be focused on the status and perspectives of the search for the eta-mesic helium, and in addition we will report on new results on the analyzing power for the pp->ppeta reaction with more than an order of magnitude improved precision which shed new light on the proton-eta interaction as well as on the production mechanism of the eta meson in nucleon-nucleon collisions.

Hadrons in matter including hypernuclei / 247

## Meson-Nucleus bound states

**Author:** Kenta Itahashi<sup>1</sup>

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Spectroscopy of meson-nucleus bound systems provide precious opportunities to study low-energy QCD in view of partial restoration of the chiral symmetry in nuclear medium. Non-perturbative nature of the QCD in the low energy region exhibits many interesting features, which include chiral symmetry breaking, non-trivial structure of vacuum, and so on. We will discuss recent progress and future perspectives in the spectroscopy of pionic atoms and eta/eta'-mesic nuclei.

**Exotic states and candidates / 248**

## **Excited mesons and resonances from lattice QCD**

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

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I will discuss recent progress in studying the spectra of mesons using first-principles lattice QCD calculations. In particular, some results on excited mesons, resonances and related phenomena in the light and heavy sectors will be highlighted, including work relevant for puzzling/exotic states such as the Ds(2317). I will also comment on future prospects.

**Plenary / 249**

## **About the structure of the proton at very low momentum**

**Author:** Antonio Pineda<sup>1</sup>

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We discuss the present status of the determination and measurement of the low moments of the proton tested by the electromagnetic interactions: Proton radius, Zemach moments, two-photon exchange corrections, etc... Special attention is paid to understanding their chiral structure and to give a unified description of all of them by relating them with Wilson coefficients of effective field theories of QCD.

**Spectroscopy of baryons / 250**

## **Recent results from CLAS**

**Author:** Kenneth Hicks<sup>1</sup>

<sup>1</sup> *Oho University*



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This talk will discuss recent results from the CLAS Collaboration of interest to the Hadron Physics community. This will include a number of recent publications on the topic of hadron spectroscopy and also some information about upcoming hadron physics experiments planned at CLAS12. In particular, new results from two-pion electroproduction will be compared with calculations, in a search for new  $N^*$  resonances, and new data on coherent vector meson photoproduction from the deuteron will be presented.

**Spectroscopy of baryons / 251**

## The Bonn-Gatchina analysis of the data from the Kp collision reactions

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In the framework of the Bonn-Gatchina approach we performed a combined analysis of the Kp collision reactions. All available data from the reactions with one and two pseudo-scalar mesons in the final states are included in the analysis as well as the data with production of one vector meson. The analysis shows clearly the existence of new hyperons in the mass region above 1900 MeV and a rather interesting structures in the mass region 1650-1900 MeV which can be considered as indications for “missing hyperon states”.

**Spectroscopy of mesons / 252**

## $\eta \rightarrow 3\pi$ decays and coupled channel extension of the Khuri-Treiman formalism

**Authors:** Miguel Albaladejo Serrano<sup>1</sup>; Bachir Moussallam<sup>None</sup>

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There have recently been several high-statistics new measurements of the isospin violating decay  $\eta \rightarrow 3\pi$ . Besides the interest in its analysis, these and other data on three-body decays of mesons have originated a revival on the study and the application of the Khuri-Treiman equations. This is a dispersive formalism which allows to simultaneously incorporate the two-body elastic unitarity constraints in the  $s$ -,  $t$ -, and  $u$ -channels. In our study, we have extended this formalism so as to take into account coupled channels effects, thus extending the range of applicability of the equations. Concerning specifically the decay  $\eta \rightarrow 3\pi$ , we include the effects of the  $K\bar{K}$  channel in  $I = 0$ , as well as of the  $\eta\pi$  and  $K\bar{K}$  channels in  $I = 1$ . In this way the effect of the  $f_0(980)$  and  $a_0(980)$  resonances can be simultaneously studied. In our approach the needed subtraction constants are fixed by matching our dispersive amplitude with the chiral one at low energies. This allows to compute the amplitude in the physical region without free parameters, except for an overall factor. We find that our predictions tend to improve the agreement between the theoretical approaches and the recent experimental results.

**Hadrons in matter including hypernuclei / 253**

## Studies of mesic atoms and nuclei

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Mesic nuclei in which a meson is bound by the strong interactions to atomic nuclei have been predicted for antikaons, eta and eta', omega and phi mesons, and for other mesons of mass above 1 GeV. While experimental searches are ongoing in several accelerator facilities for antikaons, eta and eta' mesons, no unambiguous identification of mesic nuclei has ever been achieved, partly owing to potentially large conversion and absorption widths. In this talk, using pionic atoms as a test-ground [1], I will review the theoretical methodology in this field, focusing on: (i) the information one gets from antikaonic atoms [2] on the complex in-medium antikaon-nucleon interaction that enters the antikaon-nucleus binding energy evaluation [3], and (ii) recent theoretical studies of eta mesic nuclei, particularly regarding the onset of eta-nuclear binding [4,5,6].

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### QCD and hadron structure / 254

## The Generalized Polarizabilities of the proton

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The Generalized Polarizabilities are fundamental quantities of the nucleon and as such they are extremely valuable for a more complete understanding of the nucleon structure. The GPs can be accessed experimentally through measurements of the Virtual Compton Scattering reaction. They can be seen as Fourier transforms of local polarization densities (electric, magnetic, and spin) and therefore are a probe of the nucleon dynamics, allowing us, e.g., to study the role of the pion cloud and quark core contributions to the nucleon GPs at various length scales. In this talk recent results from MAMI will be presented and future experimental prospects will be discussed.

### Analysis tools / 255

## Automated selection of partial waves for meson analysis

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The measurement of the excitation spectrum of light-quark hadrons often requires to apply partial-wave analysis methods. The building blocks of the physical models used in such analyses are the partial waves, which are defined by the quantum numbers and the decay paths of the produced resonances. In diffractive dissociation reactions, in principle, infinitely many partial waves can contribute. However, for finite data samples, only a finite number of waves carry relevant information. Finding these waves is in general a difficult task. We present a method that derives sparse models from systematically constructed sets of possible partial waves by introducing a regularization term into the likelihood function. As an example, we show results of the application of this method to simulated data for diffractively produced  $\pi^-\pi^-\pi^+$  events.

**Exotic states and candidates / 256**

## Status of Exotics at Belle

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We describe studies of heavy states with charm and beauty in the Belle experiment. Particular attention is drawn to production and decays of heavy quarkonia for which the interpretation is not yet clear. Also discussed is a search for a pentaquark.

**QCD and hadron structure / 258**

## Measurement of the weak charge of the proton: $Q_{\text{weak}}$ at Jefferson Lab

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The Standard Model makes a definite prediction for the neutral weak charge of the proton; deviation from this value would be a signature of physics beyond the Standard Model.

The  $Q_{\text{weak}}$  experiment has determined the weak charge of the proton by measuring the parity-violating asymmetry in elastic e-p scattering at  $Q^2 = 0.03 \text{ (GeV}/c)^2$  with a total precision of less than 10 ppb.

The experiment was carried out in Hall C of Jefferson Laboratory in the period 2010-2012, using longitudinally-polarized electrons of energy 1.16 GeV, a 35 cm long liquid hydrogen target, and custom detector apparatus.

This determination of the proton's weak charge may be used to determine the running of the weak mixing angle,  $\sin^2 \theta_W$ , to low  $Q^2$  with a relative error of about a half percent.

Further, in combination with measurements from atomic parity violation, this measurement imposes a strong constraint on the values of the vector weak charges of the  $u$  and  $d$  quarks,  $C_{1u}$  and  $C_{1d}$ .

The final results of  $Q_{\text{weak}}$  will be presented, along with a discussion of

the new constraints imposed by these results on additional parity-violating physics beyond the Standard Model.

**Analysis tools / 259**

## Exotic candidates with heavy quark(s)

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A large number of exotic candidates, especially in the heavy sector, have been observed in experiment, such as Zc(3900), Zc(4020), Pc(4380), Pc(4450), X(5568) and so on. To understand their nature, numerous explanations are proposed within different frameworks. I will give an overall review of the status of these studies and emphasize key issues to be answered by these solutions. Crucial experimental observables are also proposed to distinguish them.

**Hadrons in matter including hypernuclei / 260**

## Search for phi-nucleus bound states

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In Universe there are many varieties of matter created by the strong interaction, such as hadrons, nuclei and the very high density quark matter which might be formed inside a neutron star. Because those particles and matter are generated by the strong interaction, the theory of strong interaction, i.e. the Quantum Chromo dynamics(QCD), will give answers how those states are forming from elementary particles, i.e. quarks and gluons.

One of the main questions in hadron physics is how the mass of the hadron is generated within QCD. As we know that more than 98% of the hadron mass is generating dynamically via the spontaneous breaking of chiral symmetry( $\chi$ SB) in the QCD vacuum, therefore the properties of the hadron should strongly be coupled with the order parameter of the  $\chi$ SB, i.e. the value of quark condensate,  $\langle \bar{q}q \rangle$ .

One way to study this question is to investigate the properties of mesons inside nuclei, because a partial restoration of the chiral symmetry is expected inside the high density environment, even with normal nuclear matter, where the value of  $\langle \bar{q}q \rangle$  could be decreased compared with the value in vacuum. Thus, if the origin of the hadron mass is indeed the  $\chi$ SB, a reduction of the hadron mass or an attractive interaction between the meson and nuclei will appear. Here we are focusing on the  $\phi$  meson in nuclei studies.

There are experimental challenges to investigate the property of  $\phi$  meson in nuclear matter. The NA60 experiment at CERN presented the mass and width of the  $\phi$  meson in high energy indium-indium collisions as a function of collision centrality, which is equivalent to the energy density of the created high temperature matter. The result shows that no clear modification of the  $\phi$  meson property inside a high temperature environment. On the other hand, KEK-PS E325 experiment reported about 3.4% mass reduction of the  $\phi$  meson in medium-heavy nuclei (Cu). This result is

possibly an indications of the partial restoration of chiral symmetry in nuclei, however, it is hard to derive strong conclusions from the data.

If the mass of the  $\phi$  mesons reduced in nuclei, it may indicate an attractive interaction between  $\phi$  meson and nucleus. If the attraction is strong enough, the formation of a  $\phi$  meson nucleus bound state is expected. Therefore, we are proposing a new experiment at J-PARC to search for a  $\phi$ -nucleus bound state and measure its binding energy, using  $\bar{p}p \rightarrow \phi\phi$  reaction as an elementary process to produce slowly moving  $\phi$  mesons. We demonstrate that a completely background-free missing-mass spectrum can be obtained efficiently by spectroscopy together with  $K+\Lambda$  tagging.

This paper gives an overview of the physics motivation and detector concept, explains the direction of the initial research and give the recent status of the detector development. This presentation is an invited talk to the Session 7 of the conference.

## Hadrons in matter including hypernuclei / 261

### Eta-mesic nuclei

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<sup>1</sup> N

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Recent theoretical studies of eta nuclear quasi-bound states in few- and many-body systems are reviewed [1,2,3,4].

Underlying energy-dependent eta-N interactions are derived from coupled-channel models that incorporate the  $N^*(1535)$  resonance. The role of self-consistent treatment of the strong energy dependence of the subthreshold eta-N amplitudes is discussed.

Binding energies and widths of eta-nuclear states were calculated within several eta-N interaction models. No etaNN bound state was found. The onset of etaNNN binding occurs for the etaN scattering length  $\text{Re}a_{\{\eta N\}}$  close to 1 fm, binding eta-4He requires  $\text{Re}a_{\{\eta N\}}$  larger than 0.7 fm. Bound states of eta in 12C are unlikely in models with  $\text{Re}a_{\{\eta N\}}$  less than 0.5 fm, while  $\text{Re}a_{\{\eta N\}}$  about 0.9 fm is required to reproduce the etaN bound-state candidate in 25Mg from the COSY-GEM experiment [5].

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## Hadrons in matter including hypernuclei / 262

### Recent achievements on A=3,4 Lambda hypernuclear systems

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In a recent experiment performed at the electron accelerator MAMI a systematic study on the ground state binding energy of hyperhydrogen 4LH was performed. The energy was deduced from the spectroscopy of mono-energetic pions from the two-body decays of hyperfragments, which were produced and stopped in a 9Be target. While the ground state binding energy difference of  $\text{DBL}(0+g.s.) = \text{BL}(4\text{LHe}(0+g.s.)) - \text{BL}(4\text{LH}(0+g.s.)) = 233 \pm 92 \text{keV}$  is smaller as measured by the emulsion technique

it still supports a sizable CSB effect in the LN interaction. Furthermore, it suggests a negative binding energy difference between the excited states of  $DBL(1+exc) = BL(4LHe(0+g.s.)) - BL(4LH(1+exc)) = -83 \pm 94 \text{keV}$ . While the total error of the MAMI binding energy data is of the same order than that of the compiled results from the emulsion technique, it is currently dominated by the systematic uncertainty of the absolute momentum calibration, which can be improved further. Current developments at MAMI are aiming at a higher accuracy of the calibration, which could reduce the error on the binding energy by a factor of four. Finally, I will also discuss recent developments and perspectives in the hypertriton system.

**Analysis tools / 263**

## From Experimental Data to Pole Parameters in a Model Independent Way

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It is well known that unconstrained single-energy partial wave analysis (USEPWA) gives many equivalent discontinuous solutions, so a constraint to some theoretical model must be used to ensure the uniqueness. It can be shown that it is a direct consequence of not specifying the angle-dependent part of continuum ambiguity phase which mixes multipoles, and by choosing this phase we restore the uniqueness of USEPWA, and obtain the solution in a model independent way [1].

Up to now, there was no reliable way to extract pole parameters from so obtained SE partial waves, but a new and simple single-channel method (Laurent + Pietarinen expansion) applicable for continuous and discrete data has been recently developed [2-5]. It is based on applying the Laurent decomposition of partial wave amplitude, and expanding the non-resonant background into a power series of a conformal-mapping, quickly converging power series obtaining the simplest analytic function with well-defined partial wave analytic properties which fits the input. The method is particularly useful to analyse partial wave data obtained directly from experiment because it works with minimal theoretical bias since it avoids constructing and solving elaborate theoretical models, and fitting the final parameters to the input, what is the standard procedure now. The generalization of this method to multi-channel case is also developed and presented. Tests are performed on Bonn-Gatchina P11  $\pi N$  partial wave amplitudes taken from BG2011-2 solution [6] by comparing our results with exact results obtained by analytic continuation [7]. As a demonstration this method is applied to GWU-SAID [8]  $E1+$  and  $M1+$  multipoles.

Unifying both methods in succession, one constructs a model independent procedure to extract pole parameters directly from experimental data without referring to any theoretical model.

We give preliminary results for USEPWA of kaon photoproduction on the world collection of real data.

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#### QCD and hadron structure / 264

## Results from the OLYMPUS Experiment on the Contribution of Hard Two-Photon Exchange to Elastic Electron-Proton Scattering

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Measurements of the ratio of the elastic form factors of the proton ( $\mu_p G_E/G_M$ ) exhibit a strong discrepancy. Experiments using unpolarized beams and Rosenbluth separation to determine the form factors consistently have found values of the ratio approximately consistent with unity over a wide range of  $Q^2$ , while polarization transfer experiments suggest that the ratio decreases as a function of  $Q^2$ . The most widely-accepted hypothesis to explain this discrepancy is that hard two-photon exchange (TPE) significantly contributes to the elastic  $ep$  cross section. Hard TPE has been neglected in previous analyses of electron-proton scattering experiments, in part due to the fact that there exists no model independent way to calculate the contribution. The effect may be measured experimentally, however, via precise determination of the ratio of the electron-proton and positron-proton elastic cross sections. The OLYMPUS experiment collected more than  $3 \text{ fb}^{-1}$  of exclusive  $\text{ep}$  and  $\text{pp}$  elastic scattering data at DESY in 2012, and has determined the elastic  $\text{ep}$  ratio to unprecedented precision up to  $Q^2 \approx 2.2 \text{ (GeV}/c)^2$ ,  $\epsilon \approx 0.4$ . This presentation will discuss the OLYMPUS experiment and analysis, and present the recently published results from OLYMPUS in the context of the results from the other two TPE experiments.

#### QCD and hadron structure / 265

## PARTONS project and fits to high precision DVCS data

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Generalized Parton Distributions (GPDs) provide a comprehensive description of the partonic structure of the nucleon and contain a wealth of new information. In particular, they provide a description of the nucleon as an extended object, referred to as 3-dimensional nucleon tomography, and give an access to the orbital angular momentum of quarks.

In my talk I will focus on the GPD phenomenology. PARTONS project - the platform devoted to study GPDs, will be presented and the fits obtained by the PARTONS collaboration to the high-precision Deeply Virtual Compton Scattering (DVCS) data will be shown.

Exotic states and candidates / 266

## Plans for exotic bottomonium-like states at Belle II

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Large mass, non-relativistic dynamics, large energy level spacing and clear experimental signature are unique characteristics of the bottomonium states that make this sector so rich with a wide range of opportunities for new studies, ranging from the spin structure of QCD to the extensions of the SM Lagrangian, from the non- $q\bar{q}$  states and light quarks dynamics to the gluon fragmentation functions.

Experimentally only high-luminosity  $e^+e^-$  colliders with  $\sqrt{s} > 9$  GeV can collect enough statistics to study this system in details fully exploiting its potential. For this reason the BelleII experiment at Super-KEKB collider offers the most promising prospects for the study of this sector in the next decade.

We will here review the opportunities offered by data taking periods at the  $\Upsilon(3S)$ ,  $\Upsilon(5S)$  and  $\Upsilon(6S)$  energies, focusing on the variety of studies that can be conducted using bottomonium annihilations: study of conventional and exotic quarkonium spectroscopy, the search for new physics in rare decays of heavy mesons, the study of the light scalar meson family using di-pion transitions among bottomonia, and study of QCD bound states like deuteron and di-baryons with astrophysics implications.

QCD and hadron structure / 267

## Deeply Virtual Compton Scattering off $^4\text{He}$ : Toward the 3D Tomography of the Atomic Nuclei

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We will report on the first measurement of the beam-spin asymmetry in the exclusive process of coherent deeply virtual Compton scattering off a nucleus. The experiment used the 6 GeV electron beam from the CEBAF accelerator at Jefferson Lab incident on a pressurized  $^4\text{He}$  gaseous target placed in front of the CEBAF Large Acceptance Spectrometer (CLAS). The scattered electron was detected by CLAS and the photon by a dedicated electromagnetic calorimeter at forward angles. To ensure the exclusivity of the process, a specially designed radial time projection chamber was used to detect the recoiling  $^4\text{He}$  nuclei. We measured beam-spin asymmetries larger than those observed on the free proton in the same kinematic domain. From these, we were able to extract, in a model-independent way, the real and imaginary parts of the only  $^4\text{He}$  Compton form factor,

$\text{cal}H_A$ . We will conclude with our prospects to extend this experiment at JLab 12 GeV to access both quarks and gluons distributions in the nucleus.



## Analysis tools / 268

**Determining dominant partial waves in photoproduction**

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Important contributions to the study of the excitation spectra of baryons are provided by measurements of polarization observables in reactions that involve particles with spin. Pseudoscalar meson photoproduction poses an example-reaction that has been under intense investigation recently.

The extraction of resonance-parameters from the polarization-data in so-called energy-dependent fits, often involving sophisticated reaction-theories and analyzing several reaction-channels at once, represents the state-of-the-art method to get to the spectrum. While yielding important scientific insights, the construction and handling of such models is very sophisticated.

The analysis of partial waves at single energies in so-called energy-independent fits represents a simpler problem. However, due to mathematical ambiguities rising exponentially in number with the amount of non-zero partial waves, such analyses still require some experience. In order to obtain first insights into a newly measured polarization dataset, simpler alternatives are desirable.

This talk will present the very basic method of moment-analysis for pseudoscalar meson photoproduction, which proceeds by analyzing just the angular distributions. The order of the dominant partial waves contributing in the data can be extracted quickly using this method. Furthermore, the coefficients extracted from the angular distributions show interesting composition-patterns in terms of multipoles and allow for instructive comparisons to models.

A survey of recently published polarization data will be given using this method.

This work was supported by the Deutsche Forschungsgemeinschaft (SFB/TR16).

## Poster session / 269

**Exploring Timelike Region for the Meson-Photon Transitions in the Light-Front Quark Model**

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We investigate  $(\pi^0, \eta, \eta^0) \rightarrow \gamma^* \gamma$  transition form factors (TFFs) for both space- and timelike regions using the light-front quark model. For the low energy regime, we compare our LFQM results of the TFFs for low timelike

momentum transfer region and the slope parameters at  $q^2 = 0$  with the recent experimental data from the Dalize decays of  $(\pi^0, \eta, \eta^0)$ . For the high energy regime, we show the asymptotic behavior of TFFs for both space- and time-like regions and compare them with the available experimental data. Especially, we develop the new direct method to explore the timelike region without resorting to mere analytic continuation from space- to time-like region. Our direct calculation in timelike region shows the complete agreement with not only the analytic continuation result from spacelike region but also the result from the dispersion relation between the real and imaginary parts of the form factor.

**Poster session / 270**

## Does X(3872) count?

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Counting hadronic states and QCD thermodynamics in a finite box are intimately related. At small temperatures hadronic states are expected to saturate the partition function, so, accepting the Particle Data Group (PDG) table [1] as the reference for hadronic states, all the states listed by the PDG should also be counted as genuine contributions to the QCD partition function and, hence, blindly included in the Hadron Resonance Gas (HRG).

However, Dashen and Kane [2] pointed out the possibility that not all hadron states should be counted on a hadronic scale as they become fluctuations in a mass-spectrum coarse grained sense. Hence, the proliferation of new XYZ states and their inclusion in the PDG poses the natural question whether or not these states have some degree of redundancy in order to build the hadron spectrum [3, 4].

In this work, we analyze if the renowned X(3872), a weakly bound state right below the  $DD^*$

threshold, should effectively enter a hadronic representation of the QCD partition function. This can be decided by analyzing the  $DD^*$  scattering phase-shifts

in the  $JPC = 1^{++}$  channel and their contribution to the level density in the continuum from which the abundance in a hot medium can be determined. For that purpose we use a recent coupled-channels calculation [5] which includes the effect of nearby  $DD^*$  threshold on the dynamics of the bare  $cc^*$  spectrum.

We show that in a purely molecular picture the bound state contribution cancels the continuum providing a vanishing occupation number density at finite temperature and the X(3872) does not count below the Quark-Gluon Plasma crossover happening at  $T \sim 150\text{MeV}$ . In contrast, for a non vanishing  $cc^*$  content the cancellation does not occur due to the onset of the X(3940) which effectively counts as an elementary particle for temperatures above  $T \sim 250\text{MeV}$ . Thus, a blind inclusion of the X(3872) in the Hadron Resonance Gas is not justified.

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Poster session / 271

## Extraction of chiral order parameters from $\eta \rightarrow 3\pi$ and $\pi\pi$ scattering

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The  $\eta \rightarrow 3\pi$  decays are a valuable source of information on low energy QCD. We present our updated results

for the extraction of the three flavor chiral symmetry breaking order parameters from these processes.

We use a Bayesian approach in the framework of resummed chiral perturbation theory to extract information on the quark condensate and pseudoscalar decay constant in the chiral limit, as well as the mass difference of the light quarks. We compare our results with recent CHPT and lattice QCD fits and find some tension, as the  $\eta \rightarrow 3\pi$  data seem to prefer a larger ratio of the chiral order parameters. The results also disfavor a very large value of the chiral decay constant, which was found by some recent works.

Hadron decays / 272

## Insisting on the role of experimental data: the pseudoscalar-pole piece to the $(g_\mu - 2)$ and the $|V_{ub}|$ from $B \rightarrow \pi \ell \nu_\ell$ and $B \rightarrow \eta^{(\prime)} \ell \nu_\ell$ differential branching ratios

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We employ a mathematical framework based on rational approximants in order to calculate meson form factors. The method profits from unitarity, is systematic and data based, and is able to ascribe a systematic uncertainty which provides for the desired model independence.

Two examples are discussed: the pseudoscalar-pole piece of the hadronic light-by-light contribution to the anomalous magnetic moment of the muon, and the  $B \rightarrow \pi \nu$  and  $B^- \rightarrow \eta$

(0)

-v differential

branching ratios which allows to determine both the  $|V_{ub}|$  and the  $\eta$ - $\eta$

0

mixing.

Poster session / 273

## O(N) sigma models for a non-standard Higgs

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We continue previous studies of  $O(N)$  sigma models whose symmetry suffers of a spontaneous breaking down to  $O(N-1)$ . We also consider soft explicit breaking terms, first, through an ad hoc variation of the potential and, in a second step, via one-loop corrections to the effective potential. These models are of a high interest for beyond Standard Model extensions (the minimally composite Higgs models, with  $N \geq 5$ ) where, in addition to the spontaneous chiral symmetry breaking in the scalar sector, the Higgs arises as an additional (pseudo) Goldstone boson.

**Hadrons in matter including hypernuclei / 274**

## Status and perspectives of Hypernuclear Physics in ultra-relativistic heavy ion collisions

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In the last decade, heavy-ion collision experiments have brought new insight to the study of (anti-)hypernuclei. Experiments using heavy ion collisions for hypernuclear research focus on two distinct aspects: the production mechanism and the lifetime estimation, in particular for the hypertriton. The ALICE experimental observations which allow to test models of the production mechanism responsible for the formation of the (anti-)hypertriton in heavy ion-collision the LHC energy regime will be presented. Those results will be compared with the results obtained at lower energy by the STAR experiment and with the two theoretical approaches we have at disposal: the statistical thermal model and the coalescence approach.

The discussion of the current experimental knowledge of hypertriton lifetime will be presented including the latest ALICE results from the study of its two-body mesonic decay at the unprecedented energy of 5.02 TeV.

A look to the future experimental effort needed and planned in this physics sector will be discussed.

**QCD and hadron structure / 275**

## Photon and $\pi^0$ electroproduction in Jlab Hall A (6 GeV experiments)

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Generalized Parton Distribution (GPDs) are universal functions which provide a comprehensive description of hadron properties in terms of quarks and gluons. GPDs can be accessed experimentally with hard exclusive processes such as Deeply Virtual Compton Scattering (DVCS) and deeply virtual  $\pi^0$  production. Two experiments were performed in the Hall A of Jefferson Lab to measure the unpolarized cross sections of these two processes off the proton and off the neutron in the valence region ( $x_B=0,36$ ) at  $Q^2=1,5-2 \text{ GeV}^2$ . After a brief description of the experimental setup, the p-DVCS results will be discussed and interpreted as being unexpectedly sensitive to gluons. Then, the longitudinal/transverse separation of the  $\pi^0$  electroproduction cross sections, showing a dominance of the transverse terms, will be presented. Finally, an estimation of the quarks up and down contributions

to the  $\pi^0$  electroproduction cross sections, by combining the proton and the neutron measurements, will be shown.

**QCD and hadron structure / 276**

## Exclusive muon-induced reactions at COMPASS

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Investigation of GPDs and TMDs represents the major goal of the COMPASS-II program. Together, GPDs and TMDs provide the most complete description of the partonic structure of the nucleon. GPDs are experimentally accessible via lepton-induced exclusive reactions, in particular DVCS and DVMP. At COMPASS, these processes are investigated using a 160 GeV high intensity muon beam and a 2.5 m long liquid hydrogen target. In order to optimize the selection of exclusive reactions at these energies, the target is surrounded by a new barrel-shaped time-of-flight system to detect the recoiling particles.

The pure DVCS cross-section and its  $|t|$ -dependence are extracted from the sum of cross-sections measured with opposite beam charges and polarizations. From this measurement, the first estimate of the transverse size of the nucleon in the uncharted  $x_B$  domain from 0.02 to 0.20 will be given. COMPASS is also capable of accessing several DVMP channels, from which different combinations of quark and gluon GPDs can be extracted. In this talk we will report on the first measurement of the exclusive  $\pi^0$  cross section and its  $|t|$ -dependence in the same  $x_B$  domain from 0.02 to 0.20.

**Plenary / 277**

## Experimental studies of high density baryonic matter with and without strangeness

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One of the most challenging subjects in nuclear and hadron physics today is to clarify high density baryonic matter in the core of neutron stars. Most of nuclear theories have been constructed referring to experimental data of nuclei with a density equal or less than  $\rho_0$  and cannot be reliably extrapolated to the density larger than  $\rho_0$ . In particular, considering the Fermi energy of neutrons and rather strong attraction between a  $\Lambda$  hyperon and a nucleon,  $\Lambda$ 's are expected to appear at  $\sim 2-3 \rho_0$ . The other hyperons ( $\Xi$  and  $\Sigma$ ) may also appear if their interactions with neutrons are attractive enough. However, appearance of hyperons makes the Equation Of State too soft and results in serious discrepancy against recently-observed heavy neutron stars with 2 solar masses.

To solve this problem called "Hyperon Puzzle", we first need to determine various hyperon-nucleon interactions. The  $\Xi - N$  interaction has recently been found attractive from a clear evidence for a  $\Xi$ -nuclear bound state [1]. Another experimental evidence has been also found at J-PARC in the  ${}^1_2C(K^-, K^+)$  reaction spectrum, which shows bound-state events of  $\Xi$ -hypernuclei [2]. In addition,  $\Xi$ -atomic X-ray measurement has also been attempted at J-PARC. As for the  $\Sigma - N$  interaction, we are preparing for a high statistics  $\Sigma - p$  scattering experiment. Our recent observation of a very larger charge symmetry breaking effect in  $A=4$  hypernuclei [3] suggests that the  $\Lambda N$  interaction can be different in neutron-rich nuclear matter in neutron stars than in symmetric nuclear matter in hypernuclei.

The most difficult task is to obtain experimental information on nuclear density dependence of baryon-baryon interactions at high density regions, in another word, three-body baryonic forces, which presumably induces strong repulsion. For non-strange nuclear systems, a nucleus-nucleus collision experiment with neutron-rich nuclei has been performed at RIBF, which will provide valuable information on the stiffness of the neutron star EOS at around  $2\rho_0$ . For higher density regions, however, 3-body forces with hyperons play essential roles. To search for possible effects by the  $\Lambda N N$  force, we are planning to measure the  $\Lambda$ 's single-particle energies in various hypernuclei in a wide mass number range with an accuracy of  $\Delta E \sim 0.1$  MeV. Such experiments are proposed at JLab and also planned at J-PARC via the  $(e, e' K^+)$  and the  $(\pi^+, K^+)$  reactions, respectively.

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Plenary / 278

## Experimental status of transverse nucleon structure

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In the past years, distribution functions depending on the transverse momentum of partons in the nucleon (TMDs) have been intensely studied in spin physics. The TMDs represent one approach to disentangle the multi-dimensional structure of the nucleon. Correlations of the transverse spin of quarks with their transverse momentum can be observed by measuring spin azimuthal asymmetries. Recent experimental results from BNL, CERN, DESY and Jefferson Laboratory are presented and an outlook to upcoming measurements at some of these facilities is given.

Plenary / 279

## Accessing Quarks and Gluons at a Future EIC

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The Electron-Ion Collider (EIC) is envisioned as the next generation facility for exploring the strong interaction (Quantum Chromodynamics, QCD). Our understanding of QCD has advanced enormously in the past decades. Both experimentally and theoretically, the perturbative regime in QCD has been explored and understood with precision. At the same time, lattice QCD calculations have begun to yield quantitative results on properties of hadrons. The understanding of how nucleons and nuclei are formed from their constituent quarks and gluons and their interactions has also made progress via new experiments and theoretical frameworks such as GPDs (Generalized Parton Distributions) and TMDs (Transverse Momentum Dependent distributions). Along with these developments, a new experimental facility is needed to bring the understanding of nucleon and nuclear structure and dynamics to a new level. The proposed EIC is such a facility, and has the highest priority for new nuclear physics construction in the US. The EIC will provide beams of polarized electrons and light ions, as well as unpolarized heavy ions, to fully map the spin and spatial structure of the quark and gluon sea in the nucleon, understand the emergence of hadronic matter from color charge, explore low-x phenomena, and probe the gluon fields of nuclei. This talk will present the physics to be explored at the EIC, outline the current status of the project, and discuss technical plans for the accelerator and detectors.

**Plenary / 280**

## Heavy quark baryons and exotica

**Author:** Sebastian Neubert<sup>1</sup><sup>1</sup> *Ruprecht Karls Universitaet Heidelberg (DE)***Corresponding Author:** sebastian.neubert@cern.ch

Heavy quark baryons provide an excellent laboratory for tests of effective theories of the strong interaction. Recently a wealth of data on those systems has become available at the large hadron collider, such as the first observation of a doubly-charmed baryon, several new  $\Omega_c$  states and exotic baryons with hidden charm. For beauty-baryons these new data allow precision measurements of their fundamental properties. This talk will review recent experimental results and their impact on effective models of QCD.

**Plenary / 281**

## Frontiers in New Physics Searches with Hadrons

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Low-energy experiments with hadrons can identify physics beyond the Standard Model (SM), through either the observation of an unexpected breaking of its symmetries or that of a significant departure from a precise SM prediction. I will review some possibilities and highlight new opportunities for the discovery of new sources of CP violation and of light, weakly coupled new physics.

**Plenary / 282**

## Experimental overview of spectroscopy from heavy hadron decays

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Some experimental approaches involving spectroscopy from heavy meson decays going to light mesons will be presented. Along with this, we will display several experimental results coming from J/Psi, D and B decays with a particular emphasis to the scalar resonance  $f_0(980)$ . We will also show how the CP violation observed in charmless three body decay can be used as tool to understand hadron hadron interaction at low mass region.

**Hadrons in matter including hypernuclei / 283**

## Search for the simplest kaonic nuclear bound state " $K^-pp$ " via ${}^3\text{He}(K^-; n)$ reaction at J-PARC

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By embedding mesons into nuclei and studying the property change of those particles in nuclear media, one can access the physics at densities beyond standard nuclear density, e.g., in neutron star matter, as well as the origin of matter (hadron) mass, in which the standard scenario is that the hadron masses are generated by the spontaneous chiral symmetry breaking of the vacuum. In this context, one of the most interesting meson is the anti-kaon ( $\bar{K}$ ) in the second-lightest  $K$ -meson group having the strange (s)-quark as a constituent quark, namely  $K^-$  and  $\bar{K}^0$ .

The confirmation of strong attraction of the  $KN$  interaction in the  $I = 0$  channel (1,2) opens up very curious question. The  $KN$  attraction is so strong that it is more natural to form a bound state between a kaon and proton. In fact, there is a well-known resonance called  $\Lambda(1405)$  the mass of which is located just below the mass threshold of the kaon and proton,  $M(K^-p)$ ; the resonance is assumed to be an excited state of a member of the  $\Lambda$  hyperon, i.e.; it is an excited uds-quark baryon system. Thus, it is very natural to ask whether  $\Lambda(1405)$  can be interpreted as a bound state of a kaon and proton due to the strong interaction, i.e.;  $\Lambda(1405) = "K^-p"$ : If this is true, then the kaon can form a variety of nuclear bound states together with various nuclear systems. The strong  $KN$  attractive interaction might help form a high-density nuclear object beyond the standard nuclear density spontaneously. It might also help the study of the in-medium property change of mesons in nuclei. Therefore, a variety of experimental studies have been conducted by a number of experimental groups to identify the simplest kaonic nuclear bound state, " $K^-pp$ ." The detection of the kaonic nuclear state formation is difficult from the kaon absorption at rest because the kaon mainly reacts with one of the nucleons in the mesonic channel and produces a hyperon ( $\Lambda$  or  $Y$ ) as  $K^-N \rightarrow \pi N$ , without forming a kaonic nuclear state. It can also be absorbed by two nucleons simultaneously as  $K^-NN \rightarrow \Lambda N$ , and this process produces huge backgrounds. The direct kaon production channel is also attempted via the  $pp \rightarrow K^+ + "K^-pp"$  reaction. However, this channel has large ambiguity due to the presence of  $N^*(1410)$  resonance, which can decay strongly to  $K^+\Lambda$ . Obviously, no  $K^-$  (nor  $\bar{K}$ ) is generated in this reaction channel, and the channel is energetically easier to be produced compared to the  $K^+K^-$ -pair production. One can easily be misled by the reaction chain of  $pp \rightarrow N^*(1410) + p \rightarrow (K^+\Lambda) + p$  to be a " $K^-pp$ " formation signal, if one believes the  $\Lambda p$  in the final state (wrong pair) is the decay product of " $K^-pp$ ", i.e.;  $pp \rightarrow K^+ + "K^-pp" \rightarrow K^+ + (\Lambda p)$ . There are also other experimental studies to search for the kaonic bound state, but those are limited by either null results or insufficient in statistics. Therefore, there is no convincing and conclusive experimental evidence of the existence of the kaonic nuclear bound state.

We employed an entirely different approach at J-PARC K1.8BR beam-line in our experiment E15. We bombarded a  $K^-$  beam on a  ${}^3\text{He}$  target to knockout a neutron from the target nucleus at 1 GeV/c ( $\sqrt{s_{KN}} \sim 1.8\text{GeV}/c^2$ ), i.e.;  $K^- + {}^3\text{He} \rightarrow K^-p_s p_s + n$  ( $p_s$  denotes spectator proton). The cross section of this reaction is rather high, because of the presence of the  $Y^*$  resonance near 1.8 GeV/ $c^2$ , which decays strongly to  $KN$ . There are several key advantages in this reaction channel to search for the kaonic bound state. First, the recoil kaon momentum (or momentum transfer),  $q_K$ , is as small as  $\sim 200$  MeV/c ( $\sim p_F$ ) in this reaction; therefore, one can expect very efficient nuclear formation as  $K^-p_s p_s \rightarrow K^-pp$ . Another advantage is that the presence and the commitment of  $K^-$  in this channel is secured from the beginning. Still another advantage is that the two- (or multi-) nucleon absorption reaction can be expected to have a small cross section. Finally, we can cover the target region with a cylindrical detector system (CDS) to identify the final state of " $K^-pp$ " with sensitivity to the decay process. We also placed large-volume neutron counter arrays in the forward direction 15 m away from the target system to identify neutrons in the production channel with a high missing-mass resolution of about 10 MeV/ $c^2$ .

The pilot run of J-PARC E15 (E151st) showed quite remarkable results. The semi-inclusive forward neutron spectrum shows a large yield below the mass threshold of  $M(K^-pp)$  as a long tail from the quasielastic kaon scattering, implying the existence of strong  $KN$  attractive interaction.<sup>3)</sup> An even more impressive spectrum was obtained in the  $\Lambda p$  invariant mass spectrum of the  $\Lambda pn$  final state, in which we observed an event concentration near the



$M(K^-pp)$  threshold, and the centroid of the event concentration is well within the bound region.<sup>4)</sup> Thus, we conducted a new beam time for further study, especially focusing on the  $\Lambda pn$  final state (E15<sup>2nd</sup>).

We are still in an analysis phase, but the preliminary result is truly astonishing. As shown in Fig. 1, the event concentration near the  $M(K^-pp)$  threshold is not a single peak structure, as we simply assumed in our previous publication,<sup>4)</sup> but it has clear internal structures separated by the threshold energy indicated by the dashed line. First, the only reasonable explanation of the peak-structure formation below the  $M(K^-pp)$  threshold is the kaonic nuclear bound state formation of “ $K^-pp$ .” Events below the threshold can be generated when virtual kaons below the rest mass are produced in a quasi-elastic (QE) reaction. The peak structure can only be formed when there exists a resonance pole below the threshold, while a smooth tail is formed below the threshold if a pole does not exist. The  $\Lambda p$  pair in the final state, together with the forward neutron, ensures that the backscattered  $K^-$  interacts with the other two spectator protons. Thus,  $K^-$ ,  $\bar{K}^0$ , or  $\Lambda(1405)$  escaping channels are naturally suppressed substantially, in contrast to the semiinclusive missing-mass spectra of  ${}^3He(K^-; n)X$ .<sup>3)</sup> The peak centroid is located around  $\sim 40$  MeV, which is much deeper than that of the normal nuclear system about 10 MeV.

The existence of the structure above the threshold provides further confirmation that the structure below the threshold is actually the nuclear bound state of “ $K^-pp$ ,” in which the constituent particles do not lose their identity in the system. Generally, the peaks in a mass spectrum are isolated in the case of baryonic resonance. In contrast, nuclear-state formations are always associated with the so-called quasi-free (QF) processes in the unbound energy region, which indicate that the constituent particles can be dissolved. In this case, the structure above the threshold can be interpreted as the initial kaon backscattered at an energy above the kaon mass in the QE channel, followed by internal conversion (IC) with two spectator protons resulting in  $\Lambda p$  in the final state. Thus, this successive reaction can be treated as a QF process of the  ${}^3He(K^-; \Lambda p)n$  reaction channel.

To finalize the present study, we are analyzing the angular distribution of the particles in the final state, to study the form factor, spin, and parity of the observed state, and to prepare an independent analysis of the data so as to reach a confirmative result on the kaonic nuclear bound state “ $K^-pp$ .” The peak in the bound region would suggest that the  $\sim$  on-shell  $K^-$  (or  $\bar{K}$ ) can form a nuclear bound state (Boson & Fermion hybrid system), where u- and u-quarks coexist, at-least within a time scale allowed by the width of the bound state. It is quite important and interesting to know how the hadron identity is conserved even in nuclear media.

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### Status of exotic states at ATLAS

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We review the status of searches and measurements of exotic hadron states at ATLAS. Among them: the search for the beauty partner of  $X(3872)$  charmonium state, the measurement of differential cross-section of the prompt and non-prompt production of  $X(3872)$  in the  $J/\psi\pi\pi$  final states, the search for the structure in the  $B_s\pi$  invariant mass, reported by D0 experiment, search for exotic

states in B-hadron decays: pentaquarks in  $\Lambda_b$  decays and tetraquarks in  $B$ -meson decays. ATLAS results and ongoing analyses perspectives are highlighted together with CMS and LHCb results.

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## Update on the hadron structure explored at existing and future facilities

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Hadrons emerge as strongly interacting, relativistic bound states of quarks and gluons in Quantum Chromodynamics (QCD), the theory of the strong force. They are not static but have complex dynamical internal structure, which are only beginning to be revealed in modern experiments. Since no modern detector can see quarks and gluons in isolation, it is an unprecedented intellectual challenge to “see” and quantify the hadron structure. In this talk, I will provide an update on what have we learned about the hadron structure? how to quantify the hadron structure? and what do we expect to learn in a near future with the existing and future facilities, as well as lattice QCD?

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## Exotic states and candidates at LHCb

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The observation of two pentaquark resonances and the proof of the resonant nature of the  $Z_c$  state opened to the search for the many isospin partner of these multi-quark states. We review the studies of these states and discuss the prospects for the analyses of the LHCb Run2 data,

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## Effects of $Z_b$ states in $\Upsilon(3S, 4S)$ dipion transitions

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There has been a long-standing puzzle in understanding why the dipion invariant distribution for the  $\Upsilon(3S) \rightarrow \Upsilon(1S)\pi\pi$  transition shows a double-bump structure while other analogous transitions have only one. By including the  $\pi\pi$  final state interaction and effects from the  $Z_b$  states, we show that this phenomenon can be understood. However, this requires the partial widths of the  $Z_b$  states to be much larger than those naively calculated from the measured branching fractions. The analysis is further extended to the dipion transition from the  $\Upsilon(4S)$  to the  $\Upsilon(1S)$ , and we predict a nontrivial structure at around 1 GeV in the dipion invariant spectrum for this process.

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## **Hadrontherapy: an innovative technique to fight cancer**

This session, open to the non-expert public, introduces physical and clinical aspects of hadrontherapy, as an example on how basic investigation may produce applied results.

In contrast with conventional X-ray radiotherapy, where energy is continuously deposited before reaching the tumor, in hadrontherapy the majority of this energy is deposited in single point, thus avoiding damage in the surrounding healthy tissue. In the future, this will be the preferred technique for sensitive areas like the eyes or the marrow.