Hadron spectroscopy and the new unexpected resonances

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Villas de Paraty

Book of Abstracts

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Production of meson molecules in ultra-peripheral heavy ion collisions

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In this work we present a calculation of exotic charmonium production in ultra-peripheral collisions, in which the exotic state is explicitly treated as a meson molecule. Our formalism is general but we focus on the lightest possible exotic charmonium state: a D^+D^- molecular bound state. It was proposed some time ago and it has been the object of experimental searches. Here we study the production of the open charm pair in the process $\gamma\gamma \rightarrow D^+D^-$. Then we use a prescription to project the free pair $|D^+D^-\rangle$ onto a bound state at the amplitude level and compute the cross section of the process $\gamma \rightarrow B$ (where B is the bound state). Finally, we convolute this last cross section with the equivalent photon distributions coming from the projectile and target in an ultra-peripheral collision and find the $AA \rightarrow AAB$ cross section, which, for $PbPb$ collisions at $\sqrt{s} = 5.02$ TeV, is of the order of 3 μb.

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Study of the first excited state of the 4He nucleus in coupled-channels Halo EFT

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This work focuses on investigating the first excited state ($J^\pi = 0^+$) of the ^{4}He nucleus, the α-particle. This excited state, probably associated with a four-body Efimov state, is found between the $p + {}^3$H and $n + {}^3$He thresholds, allowing for the use of coupled-channels formalism. It is thought to have a $3 + 1$ halo structure, making it suitable for investigation using a Halo effective field theory framework. This resonance may influence the ^{3}H$(p, e^+e^-)^3$He reaction and shed light on the ATOMKI anomaly reported by Krasznahorkay *et al.*, where an excess of produced lepton pairs suggests the existence of a new boson, with an approximate mass of 17 MeV, and that can be a possible candidate for dark matter.

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Decay widths of an N* state with hidden strangeness

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The study of exotic hadrons and their properties has recently experienced a colossal boom. The development in this area is so tremendous that studying exotic hadrons has become one of the main, and more prolific, research lines at experimental facilities like BES and LHC. There is an intrinsic challenge when studying these particles as they belong to the non-perturbative region of QCD. The use of effective Lagrangians to study hadron systems at such energies is a very powerful tool nowadays. By using these Lagrangians with the relevant symmetries for the system is possible to calculate the corresponding T-matrix in a coupled channel approach and obtain physical observables such as invariant mass distributions, cross sections and decay widths. In particular, through the vector meson and baryon dynamics was observed a N* resonance, thus isospin $1/2$, with spin-parity $J^P = \frac{3}{2}^-$, mass $M_{\mathrm{N}^*} = 2071$ MeV and decay width $\frac{\Gamma_{\mathrm{N}^*}}{2} = 70$ MeV. The properties of this state were in agreement with those of the N*(2080) listed by the PDG, however, nowadays, this entry among others nucleonic resonances have been compacted into the N*(2120) state. The interesting fact of the above mentioned state is that it can be the hidden-strange partner of some of the P_c states recently discovered by the LHCb collaboration. In order to further investigate the properties of the N* resonance, or P_s state, we calculate the decay widths to pseudoscalar meson and baryonic resonance as a consequence of the exotic nature of the state. In the same way, it is possible to obtain the decay widths to pseudoscalar meson and baryon channels. Once obtained, it is possible to determine which invariant mass of two hadrons could be the most promising to observe the properties of the P_s state.

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Infrared dynamics of the three and four-gluon vertices

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In this talk, we present recent results on the transversely-projected three- and four-gluon vertices. Our approach is based on the one-loop dressed Schwinger-Dyson equations derived from the nPI effective action. The key hypothesis in both cases is the planar degeneracy property of these vertices, which becomes apparent when the Bose symmetry of the vertices are properly exploited. The planar degeneracy enables a particularly simple parametrization of the vertices, reducing their kinematic dependence to essentially a single variable. The primary outcome of these considerations is a highly compact description of the both vertices, which can significantly simplify the nonperturbative applications involving them. In addition, our results reveal a considerable suppression relative to their tree-level counterparts, and show excellent agreement with available lattice simulations.

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Production of D^+D^- molecules in ultra-peripheral Pb-Pb collisions

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In this work we discuss exotic charmonium production by photon-photon interactions in ultraperipheral heavy ion collisions. We are interested in the production of the bound molecular state (D^+D^-). Our calculations are performed in the impact parameter space, where we consider different levels of precision for the treatment of the absorptive effects and for the nuclear form factor. Additionally,

we use an analytical expression for the photoproduction cross section of the bound state. We present our predictions for the total cross section of the production process $AA \to AA\,(D^+D^-)$ and the rapidity distribution in PbPb collisions at LHC energies $\left(\sqrt{s_{NN}} = 5.02\text{TeV}\right)$.

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B^+ decay to $K^+\eta\eta$ with ($\eta\eta$) from the $D\bar{D}(3720)$ bound state

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We search for a B decay mode where one can find a peak for a $D\bar{D}$ bound state predicted in effective theories and in Lattice QCD calculations, which has also been claimed from some reactions that show an accumulated strength in $D\bar{D}$ production at threshold. We find a good candidate in the $B^+ \to K^+\eta\eta$ reaction, by looking at the $\eta\eta$ mass distribution. The choice of $\eta\eta$ to see the peak is based on results of calculations that find the $\eta\eta$ among the light pseudoscalar channels with stronger coupling to the $D\bar{D}$ bound state. We find a neat peak around the predicted mass of that state in the $\eta\eta$ mass distribution, with an integrated branching ratio for $B^+ \to K^+$($D\bar{D}$, bound) ; ($D\bar{D}$, bound) $\to \eta\eta$ of the order of 1.5×10^{-4}, a large number for hadronic B decays, which should motivate its experimental search.

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Hadron Physics Opportunities at ELSA

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The ELSA electron accelerator at Bonn university, Germany, has a long record of contributions to hadron physics with electromagnetic probes, electrons up to 3.2 GeV beam energy and photons from bremsstrahlung conversion including polarization degrees of freedom. In particular, the experiments (currently the BGO-OD setup and CB- ELSA/TAPS) allow to measure across the baryon spectrum. An up-to-date account of the status will be given elsewhere [J. Hartmann, this workshop]. This presentation will introduce the planned experiments utilizing an improved setup around the recently upgraded Crystal Barrel calorimeter. The high-resolution endcap setup of the planned PANDA experiment at the future FAIR complex is close to completion and will soon be available for experiments in Bonn, where it will replace the TAPS BaF calorimetry of photons in forward direction. Additionally, high-resolution tracking close to the interaction point of the photon beam with the liquid-hydrogen target and forward spectroscopy in a magnetic dipole field will facilitate identification of hyperons and kaons, so that the baryon spectroscopy program can be extended into the strangeness sector, where results are still sparse and first experience has already been gathered in previous setups, recently with BGO-OD. Details on the status of detector commissioning, plans and ideas for the physics program will be given.

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Production of fully-heavy tetraquark states through the double parton scattering mechanism in pp and pA collisions

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The production of fully - heavy tetraquark states in proton-proton (pp) and proton - nucleus (pA) collisions at the center-of-mass energies of the Large Hadron Collider (LHC) and at the Future Circular Collider (FCC) is investigated considering that these states are produced through the double parton scattering mechanism. We estimate the cross sections for the T_{4c}, T_{4b} and T_{2b2c} states and present predictions for pp, pCa and pPb collisions considering the rapidity ranges covered by central and forward detectors. We demonstrate that the cross sections for pA collisions are enhanced in comparison to the pp predictions scaled by the atomic number. Moreover, our results indicate that a search of these exotic states is, in principle, feasible in the future runs of the LHC and FCC.

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Exploring the covariant form factor for spin-1 particles

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The spin-1 particles is an admirable two quarks bound state system to understand electromagnetic properties from hadronic states. These systems are generally relativistic, and therefore need an approach using quantum field theory. In the present work, we will use both the quantum field theory at the instant form, as well, quantum field theory on the light-front˜(LFQFT). In general, it is used to calculate the electromagnetic properties of spin-1 vector particles in the LFQFT formalism, with the plus component of the electromagnetic current. In the present work, we used, in addition to the plus component of the electromagnetic current; the minus component of the current, and we use that components o the current, to extract the covariant form factors; showing that to have an equivalence between these we need to add non-valence terms to the electromagnetic current, in order to restore the covariance, and obtain exactly the same results when using the instant form quantum field theory.

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The structure of the pion in Minkowski space

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In this seminar I will analyze the structure of the pion obtained from a dynamical model based on the solution of the Bethe-Salpeter equation in Minkowski space. The components of the Bethe-Salpeter amplitude are written in terms of the Nakanishi integral representation. The interaction kernel has

massive quark and gluon propagators and an extended quark-gluon vertex. Within this model, we obtain the pion weak decay constant, the valence probability, the LF-momentum distributions, the distribution amplitudes, the probability densities both in the LF-momentum space and the 3D space given by the Cartesian product of the covariant Ioffe-time and transverse coordinates [1]. We also calculate hadronic observables as the pion electromagnetic form factor [2], the parton distribution function [3] and the unpolarized transverse momentum distribution[4].

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3. W. de Paula, E. Ydrefors, J. H. Alvarenga Nogueira, T. Frederico and G. Salme, Phys. Rev. D 105 (2022) L071505
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Exploring the Dyson-Schwinger equations and the pion in Minkowski

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In recent years, significant efforts have been developed to formulate and solve the Bethe-Salpeter and Dyson-Schwinger equations (DSE) directly in Minkowski space, in contrast to the usual procedure of formulation in the Euclidean space and subsequent extension to Minkowski space, which is the approach used in lattice gauge theories. In this talk, the solution for the Dyson-Schwinger equation (DSE) in Minkowski space for the quark propagator in a QCD-inspired model is presented, with a focus on the realization of dynamical chiral symmetry breaking (DCSB) in the large coupling regime. It will be shown that this simple model offers the possibility of the exploration of many different physical problems, such as the chiral symmetry breaking region, and could provide a phenomenological model for the pion, its observables, and momentum distributions.

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Introduction W.E. Heraeus director and organizers

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QCD matter in strong electric fields

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Currently, the effect of strong magnetic fields on the QCD phase diagram in the $(T \times eB)$ plane is well-established, thanks to extensive research using effective QCD models and lattice simulations. However, the situation is different when it comes to incorporating electric fields. Electric fields make the QCD action complex, making standard lattice simulations impractical. To tackle this issue, alternative methods have been proposed, such as using imaginary electric fields and Taylor expansions. There is a noted discrepancy between the predictions of effective models of QCD and lattice simulations regarding the behavior of the deconfinement phase transition. While models predict a decrease in the pseudocritical temperature as the electric field grows, lattice simulations suggest an increase. In this presentation, we will outline the problem and share our recent findings on the impact of a strong electric field on the deconfinement and chiral transitions, using different effective models of QCD.

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Exotic mesons with functional methods

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We summarize recent results for exotic mesons, i.e. glueballs and four-quark states, using functional methods. We explain the generation and present results for the spectrum of glueballs in pure Yang-Mills theory and discuss prospects for full QCD results. We furthermore discuss the spectrum and the internal structure of open flavour four-quark states in the charm and bottom energy region.

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Nucleon structure in Minkowski space

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I will review the application of few-body methods to explore the structure of light hadrons in Minkowski space. The description of the nucleon is based on the solution of the Bethe-Salpeter equation in Minkowski space built with phenomenological kernels. In particular, it will be presented a quantitative exploration of the proton properties obtained by solving the projected Faddeev-Bethe-Salpeter equation onto the light-front. The proton valence parton distribution, transverse momentum distributions and the image of the valence state on the null-plane will be shown. In addition, it will be discussed the solution of the Bethe-Salpeter equation in Minkowski space for a quark-diquark model obtained with the one-gluon exchange kernel, as well as its ultraviolet properties in covariant gauges. Some future prospects of research will be provided.

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Testing Chiral Perturbation Theory in Soft Hadron-Photon Reactions at COMPASS and AMBER

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In meson-photon collisions resonances may be formed, such as the $\rho(770)$ or $a_2(1320)$ for pions, and $K^*(892)$ when kaons collide with photons. For low collision energies, chiral dynamics governs the process, eventually leading to final states with additional mesons that do not come from resanace decays. The production of an additional pi0 is determined by the chiral anomaly, and its value is an important test for chiral perturbation theory.

At COMPASS, such meson-photon collisions can be realized in Primakoff processes, initiated by the high-energy hadron beam from the CERN Super Proton Synchrotron on nuclear targets. The energy is sufficiently high such that the full spectrum including the formed resonances and their interference with the non-resonant contributions is visible. This allows for a determination of the chiral anomaly and radiatve widths of resonances with a new level of precision. The investigations are foreseen to be continued with the new possibilities of AMBER, the successor experiment of COMPASS at the same beamline of the SPS.

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Production of exotic systems by photon-induced interactions at the LHC and EIC: Recent results and prospects

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In this contribution, I will present a brief review of the recent results that demonstrate that the study of particle production by photon - induced interactions at the Large Hadron Collider (LHC) can be used to improve our understanding about exotic systems as, e.g., tetraquarks and pentaquarks. In addition, prospects to investigate these particles in the future electron-ion collider (EIC) will also be discussed.

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Accelerating Coupled Channel Analyses Using the PAWIAN Framework

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Over recent decades, the continuous increase of experimental data in high-energy physics applications has led to significant demand in computational resources. In particular, the time-consuming coupled channel analyses, which sometimes require fits with several hundred free parameters extending over several weeks, are an area where such optimization is of great value. To address this issue, we are currently integrating various AI tools into PAWIAN (PArtial Wave Interactive ANalysis),

a software package developed at Ruhr-University Bochum for conducting partial wave analysis more efficiently. PAWIAN's architecture enables the simultaneous analysis of data from various hadron physics experiments and supports sophisticated dynamical models such as K-matrix formalism and tensor formalism. These efforts include improvements within the minimization procedure by changing from numerical methods towards automatic differentiation within the intermediate derivative computations. With this we intend to not only speed up each minimization step but also avoid instabilities due to the higher precision of the derivatives compared to numerical results. By utilizing ADAM (Adaptive Movement Estimation Algorithm), problems such as slow convergence and local minima are intended to be resolved. Furthermore, we are working on pseudo-event binning, where events are grouped to optimize the number of function evaluations without losing precision. Preliminary results of these efforts and specific benchmark cases regarding the implementation of these AI techniques will be presented.

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Molecular states from effective field theory

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The last 20 years are being highlighted by theoretical and experimental endeavours towards understanding all possible hadronic structures allowed by QCD. Since the discovery of the exotic meson $X(3872)$ by the Belle Collaboration, a handful amount of other exotic hadrons with unexpected properties appeared in particle accelerations around the world. As for their elusive structure, one of the most popular and successful explanations is of a weakly-bound, molecule-like state made of other conventional hadrons.

Weakly-bound molecular structures play a driving role in low-energy nuclear and cold-atom physics. The main physics and associated phenomena have been successfully addressed with short-range contact interactions, especially in the framework of effective field theories, with the emergence of universal correlations associated with the Efimov effect. In this talk I will introduce the counter-intuitive Efimov effect and the related correlations that appear in systems with two, three, and four particles.

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Understanding vector-quarkonia: from bottomonium to charmonium

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In recent years, a large number of charmonium- and bottomonum-like states have been found in experiments like LHCb, BESIII, Belle(II) and BaBar. While some, like the charged charmonium-like $\mathrm{Zc}(3900)$, are openly exotic, vector mesons like the bottomonium-like $\Upsilon(10753)$ or the charmoniumlike psi(4230) and psi(4360) are more difficult to interpret. Strong signals in hidden-charm (hiddenbottom) decays alongside the absence of matching states in potential model calculations are frequent arguments for an exotic interpretation, although suprisingly little is known about conventional vector quarkonia above open-flavour threshold. Here, I will present the first global, unitary analysis of e+e-to bb and the work towards a global analysis of $\mathrm{e+e}$ - to cc.

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Dibaryons and Hyperon EM Form Factors

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In this talk I will make a short summary of the history of dibaryons, i.e. resonant states containing six quarks. Dibaryons are looked at sceptically (apart from the deuteron) because of the many states that have been predicted by theory and claimed in experiments that did not survive more careful investigations. I will give one example of an almost discovery and present a relatively recent discovery by the WASA@COSY experiment that has survived all tests, the $d^*(2380)$. I will also discuss very recent result on hyperon time-like electromagnetic form factors from the BESIII experiment via $e^+e^- \to \bar{Y}Y$ reactions, where Y denotes a hyperon, both in the strange and charm quark sector. These results show interesting and unexpected features that so far are unexplained.

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Hybrids and other exotic mesons in the light-quark sector

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Author: Bernhard Ketzer
The unambiguous detection of exotic non-qqbar states and their identification in terms of quark and gluonic degrees of freedom is one of the most ambitious goals of hadron spectroscopy. In the charm- and bottom-quark regime, many of the new X, Y, Z states are believed to be of exotic nature, but until now the internal structure of almost all of them is still a matter of debate. One of the reasons for this is that all of the newly discovered states have quantum numbers that can in principle also be formed by a qqbar pair.

States with spin-exotic quantum numbers provide a smoking gun of non-qqbar configurations. In the light-quark sector, though generally believed to be more challenging both experimentally and theoretically because of the wide and overlapping nature of states, several signals with spin-exotic quantum numbers have been claimed in the past. High-statistics data from the COMPASS-experiment have settled a decade-long dispute on the resonant nature of some of these. Together with theory predictions, the $\pi_1(1600)$ is now generally accepted as the lightest hybrid meson in nature. Very recently, BESIII has announced the discovery of the $\eta_1(1855)$, which may be the isoscalar partner of the $\pi_1(1600)$. In order to fully understand the spectrum of light hybrid mesons, further work on branching ratios and the identification of possible strange partners in the multiplet are needed. The talk will summarize the status of exotic-meson searches in the light-quark sector and discuss future plans in this direction.

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Exotic three-meson molecular states

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In this talk I discuss the formation of molecular resonances of three-hadrons. We solve Faddeev equations for three-meson systems or that of two-meson and one baryon. We find a special characteristics of the dynamics in such systems, which is a cancellation of the different amplitudes of three-body forces. I will show the results of some of our recent studies.

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The PANDA Forward-Endcap EMC Test-Beamtime @COSY

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The PANDA experiment at FAIR will in future provide outstanding data to advance the field of hadron spectroscopy.

One of its essential detector components, the forward endcap (FWEC) of the electromagnetic calorimeter was recently tested at the COSY accelerator, equipped with 20% of its crystals under final operation conditions.

The test beamtimes conducted in August and September 2023 with a 2.74 GeV/c proton beam and a plastic target, collected extensive data via full waveform readout.
Key achievements included e.g. a stable operation of the FWEC at -25°C and its first measurement of a π^0-signal decaying into two photons, which will also be essential for calibration of the detector system.

This poster presents the FWEC assembly process, data pre-processing, and reconstruction using PandaRoot, leading to the observation of the π^0 signal.

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Measurement of $\Sigma^+ K^0$ and η photoproduction with the CBELSA/TAPS experiment

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The CBELSA/TAPS experiment is especially well suited to measure photons from neutral meson decays to study N^*- and Δ^*-resonances which are created via photoproduction off the nucleon. Investigating triple neutral pion photoproduction, the kaon-hyperon final state, $\Sigma^+ K^0$, as well as the photoproduction of η mesons decaying into $3\pi^0$ can be studied.

The photoproduction of neutral kaons is of particular interest as the t-channel kaon exchange is suppressed which makes the channel more sensitive to resonant s-channel contributions. Data in the $\gamma p \to \Sigma^+ K^0$ channel is, however, still scarce.

A challenge in the analysis presented, is the careful separation of the $\Sigma^+ K^0 \rightarrow p3\pi^0$-signal from other triple neutral pion events not originating from kaon photoproduction.

This contribution in form of a poster will focus on the selection of $\gamma p \rightarrow p3\pi^0$ events and discuss preliminary results in the $\Sigma^+ K^0$ and η photoproduction channels.

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J/ψ-nucleon and J/ψ-pion interactions

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Accelerating Monte Carlo Simulations Using Neural Networks

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In recent times, the amount of data collected from high-energy experiments has increased continuously. In order to match this amount of data, significantly more Monte Carlo data is required as well. These simulations often take a long time and occupy a lot of computing power. For complex simulation steps, such as the simulation of electromagnetic calorimeters, neural networks can offer considerable acceleration and thus make these steps not only faster, but also more resource-efficient. In this talk, use cases of neural networks in Monte Carlo simulations are presented and the development is explained using the forward endcap of the EMC of the PANDA experiment. Furthermore, possibilities are presented to use the results of complex partial wave analyses to produce Monte Carlo events more accurately and faster.

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The light meson regime with coupled-channel analyses

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Nowadays, experimentally observed states that are often assigned to the light meson or charmonium sector might indicate an exotic nature. Such exotic particles include e.g. glueballs, hybrids, and tetraquarks. Not only do these states pose a theoretical challenge, but experimentally it is often difficult to distinguish exotic and non-exotic matter and to characterise their nature. In such cases, it helps to compare different production mechanisms and decay patterns. This provides additional constraints and allows for a coupled channel partial wave analysis to describe the different spectra simultaneously, respecting unitarity and analyticity. The importance need of adequate models to

interpret data is rising not only due to rising statistics which enhance the sensitivity towards theoretical models. Therefore, gluon-poor two-photon fusion events and gluon-rich hadronic reactions as e.g. radiative J/ψ decays can be used to disentangle the highly populated light meson spectrum. The talk will discuss recent experimental results from coupled channel analyses as and interlink with modern analysis methods. Special emphasis will be on the models used and the associated software tools.

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Flavor quark and meson mixings from vacuum polarization

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By considering a quark-antiquark interaction mediated by one (non perturbative) gluon exchange, standard techniques are applied to derive effective interactions between meson fields, that are arranged in $U(N_f)$ flavor multiplets, and constituent quark currents. A large quark mass (and / or gluon effective mass) expansion of the quark determinant leads to a wide variety of effective quark-antiquark / meson interactions. Among them, second order meson mixing interactions and third order three meson interactions will be presented being responsible for different effects. Meson (flavor) mixing effects arise for non-degenerate quark masses, being somewhat similar to the mixings obtained by 't Hooft determinantal interactions. Sixth order quark interactions break $U_A(1)$ symmetry and they lead to three-meson interactions that also undergo flavor mixings. Some phenomenological consequences are discussed.

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Nonperturbative structure of the transversely projected quark-gluon vertex

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In this work, we study the quark-gluon vertex in the context of unquenched QCD with two degenerate light dynamical quarks in the Landau gauge. We determine the eight form factors of the transversely projected quark-gluon vertex in general kinematics by solving its Schwinger-Dyson equation, derived from the 3PI effective action formalism. For the analysis, we employ as input the lattice data for the gluon and quark propagators, as well as for the three-gluon vertex. The classical form factor was decoupled and solved iteratively, revealing a significant angular dependence and showing excellent agreement with recent lattice data in the soft-gluon configuration. The remaining form factors are computed through a single integration, confirming a clear hierarchy consistent with previous results.

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Final state interactions: the troublemaker

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Hadronic final state interactions (FSI) play a major role in hadronic decays. They can generate new mechanisms for CP violation in $B \to 3h$ decays at low and high mass regions. We explained LHCb observation for CP violation in $D \to 2h$ as a FSI mechanism, contrary to QCD-based approaches that claim new physics. It is also needed to explain unexpected large branching fractions of some rare processes and, more recently, we show that we can understand the barionic $B \to p\bar{p}\pi$ and $B \to p\bar{p}K$ opposite angular signature with an FSI model. I will present an overview of those different "trouble-solver" FSI mechanisms, focusing on our last founds.

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Short rangeness, mass intervals and other classicalities from Yang-Mills fields

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The Yang-Mills theory is revisited from the point of view of classical configurations starting from wave modes. This reveals a kind of classical solutions which reconstruct effective Klein-Gordon excitations, along with a new mass generation mechanism. The effective Klein-Gordon equation gives rise to a set of equations of motion whose solutions may exhibit a confined behavior. Furthermore, the physical consistencies for the perturbations in the scalar fields arisen from the original theory may suffice to produce interesting predictions about the mass intervals for the gauge bosons: they can exist within a causal and a real range, between tachyon and instanton limits.

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N^* resonances: from hidden strangeness to hidden charm

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Investigating the multiplicities and femtoscopic correlation functions of heavy-flavor and exotic hadrons

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In this seminar we discuss how the heavy ion collisions (HICs) appear as a promising scenario to investigate the properties of the non-conventional hadronic states. In the sequence we present some of our contributions on this topic, focusing on how to distinguish the intrinsic nature of these exotic states from the relevant observables, such as their multiplicities and femtoscopic correlation functions.

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Influence of magnetic field-induced anisotropic gluon pressure during pre-equilibrium

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Magnetic fields of a large intensity can be generated in peripheral high-energy heavy-ion collisions. Although the intensity drops down fast and, moreover, it is not clear whether the fields last long enough to induce a magnetization during the quark-gluon plasma phase, most of the models and simulations predict a significant intensity that lasts up to proper times of order 1 fm after the beginning of the reaction, which is a typical time for the hydrodynamical phase to start. This interval of time is referred to as the pre-equilibrium stage. One can expect that the evolution of the reaction during pre-equilibrium is likely to be influenced by these fields. In this work we adopt a strong field approximation to study the effects of the magnetic field-induced anisotropy in the gluon pressure. We include this anisotropy within the description obtained by means of effective kinetic theory and explore the consequences to reach isotropization at proper times of order 1 fm.

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The $X(3872)$ to $\psi(2S)$ yield ratio in heavy-ion collisions

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In this work we show how to evaluate the $X(3872)$ to $\psi(2S)$ yield ratio $(NX/N\psi(2S))$ in $PbPb$ collisions, taking into account the interactions of the $\psi(2S)$ and $X(3872)$ states with light mesons in the hadron gas formed at the late stages of these collisions. We employ an effective Lagrangian approach to estimate the thermally-averaged cross sections for the production and absorption of the $\psi(2S)$ and use them in the rate equation to determine the time evolution of $N\psi(2S)$. The multiplicity of these states at the end of mixed phase is obtained from the coalescence model. The multiplicity of $X(3872)$, treated as a bound state of $(D\bar{D}^* + c.c.)$ and also as a compact tetraquark, was already calculated in previous works. Knowing these yields, we derive predictions for the ratio $NX/N\psi(2S)$ as a function of the centrality, of the center-of-mass energy and of the charged hadron multiplicity measured at mid-rapidity $[dN_{ch}/d\eta(\eta < 0.5)$]. Finally, we make predictions for this ratio in $PbPb$ collisions at $\sqrt{s_{NN}} = 5.02$ TeV to be measured by the ALICE Collaboration in the Run 3. This contribution is based on the paper arXiv:2401.11320 and contains more discussion on the results.

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Light and Strange Mesons - Spectroscopic Methods and Results

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The COMPASS experiment has collected the largest data set of diffractively produced excitations using beams of pions and kaons at 190 GeV energy. The search for resonances and new phenomena among light hadrons has been carried out for decades by partial wave analyses. The large amount of data available and the availability of large computing power have allowed the development of new statistical methods. We will present the challenges and the results of several new methods for light and strange hadrons. Among the new features observed are a strange meson spectrum revealing the existence of a crypto-exotic state and new excited light mesons up to masses of 2.5 GeV/c^2.

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Quark confinement from an infrared safe approach

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We study the nonabelian dipole problem in the context of a simple semiclassical approach which incorporates some essential features of the infrared sector of Yang-Mills theories in the Landau gauge, in particular, the fact that the running coupling remains of moderate size at infrared scales and gluons acquire a mass while ghosts remain massless. We obtain a simple flux-tube solution in a controlled approximation scheme, that we compare to the results of lattice simulations.

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Modified NJL models and applications

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There is a great interest in magnetized hadronic matter due to the intense magnetic fields reported by experiments in heavy-ion collisions and also present in compact stars. We review some results obtained with modified NJL models, like condensates, meson masses, magnetization and other thermodynamic quantities.

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Exotic spectroscopy at LHCb

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The LHCb experiment, focused on studying heavy-flavor hadrons, provides crucial insights into the quark binding mechanisms within hadrons and makes valuable contributions to understanding the non-perturbative regime of QCD. In this presentation, we highlight the latest results from LHCb on exotic hadron spectroscopy, with a particular focus on the diffractive production of these states.

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Parton distribution functions and transverse momentum dependence of heavy mesons

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In this talk, we explore the light-front wave functions of heavy quarkonia, , and mesons by deriving their leading Fock state components from the projections of Bethe-Salpeter wave functions onto the light front. We focus on computing the leading-twist time-reversal even transverse momentum distributions and parton distribution functions for these mesons.

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Studying strong interactions and the hadron spectrum in photoproduction with the GlueX experiment

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The GlueX Collaboration, based at Jefferson Lab, has collected a unique set of photon-proton collision data using linearly polarized photons in the 8-12 GeV energy range. This data set permits a study of the production dynamics of resonances and searches for new states, including hybrid mesons. I will present recent results on the production of established light mesons and the J/ψ as well as the prospects for searching for hybrid mesons in photoproduction. The plans and longterm prospects for future running of the GlueX experiment will also be discussed.

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The effects of quark anomalous magnetic moment in the magnetized QCD phase diagram

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Recently, the quark anomalous magnetic moment (AMM) has been applied in the context of the two-flavor Nambu–Jona-Lasinio model to explore different aspects of the magnetized phase diagram of quantum chromodynamics. By means of the Schwinger ansatz, the quark AMM has been considered a new parameter, chosen to reproduce the proton and neutron magnetic moments. Then, in the mean field approximation, some of the model predictions suggest inverse magnetic catalysis at low temperatures and first-order phase transitions at magnetic fields $\mathrm{eB} < 1\mathrm{GeV}^2$. However, these effects are not observed by lattice QCD. In this work, we show analytically and numerically that the model results are due to regularization prescriptions which entangle vacuum and magnetic field contributions in the thermodynamical potential. To avoid these problems, we apply the vacuum magnetic regularization scheme, which enables us to properly separate all the contributions in the thermodynamical potential. We also show that the Schwinger ansatz is valid only in the limit where $eB/M_0^2 \ll 1$, in which M_0 is the vacuum effective quark mass.

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Charmed mesons production in high multiplicity pPb collisions

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In this work we study the influence of proton and lead structures in charmed mesons production. We investigate the role of the spatial distribution of partons in the proton and in the nuclei by assuming that the proton has an Y shape. In this configuration, quarks are more at the surface, and gluons in the inner part of the proton. Going from peripheral to more central, and then to ultra-central collisions, the production enhancement is given by the high concentration of partons in the center of the nuclei and since $\sigma(g + g \to c + \bar{c}) \gg \sigma(q + \bar{q} \to c + \bar{c})$, almost all mesons are created from gluon interactions. These effects can explain the growth seen in the data and corroborates to stablish the Y picture of the proton, which can be extended to YY (butterfly) configuration to study heavy tetraquarks spectra.

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Flavor-singlet meson and glueball mixing in lattice QCD

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A careful study of the low-lying flavor-singlet meson spectrum using lattice QCD can help to better understand the nature of the current glueball candidates. We use light meson, charmonium, glueball and two-pion operators to map this spectrum and quantify the mixing between the different states. We increase the overlap with physical states by using highly improved mesonic and gluonic operators, which allows us to extract the spectrum and mixing overlaps between the states of interest and those created by the operators. These overlaps are useful to understand the nature of the states. The study is done in $N_f = 3 + 1$ QCD with pion masses $m_\pi \approx 800, 420$ MeV, where the pion mass tuning is particularly useful to control possible decay channels of the scalar glueball.

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Amplitude Analysis of $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ at Belle

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We present a partial-wave analysis of $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$ decays using the world's largest sample of these decays from the Belle experiment at KEK, Japan; and we discuss challenges of this analysis. We give preliminary results on light-meson resonances appearing in the $\pi^-\pi^-\pi^+$system, including $a_1(1420)$, and in the $\pi^-\pi^+$subsystem, measured using the so-called freed-isobar method; and we give prospects for spectroscopy measurements at Belle II.

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B_c-nucleus system bound states with/without the Coulomb force

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We estimate for the first time the bound-state energies and the corresponding coordinate space radial wave functions of B_c-nucleus systems using a momentum space calculation. We compare the bound-state energies obtained with and without the Coulomb potential, and discuss the interference effect of the strong (nuclear) potential in the Coulomb interaction.