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Santa Margherita Ligure

Book of Abstracts

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1

Opening

Parallel 1 / 3

Heavy baryon spectrum in a quark-diquark approach

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We present results for the heavy baryon spectrum for ground and excited states with quantum numbers $J^P = 1/2^+$ and $3/2^+$ using functional methods in QCD. To this end, we reduce the three-quark Faddeev equations to two-body equations via the quark-diquark approach, where the baryons are treated as bound states of quarks and effective diquarks. The resulting Bethe-Salpeter equation amounts to a quark ping-pong exchange for the interaction kernel, where the quark and diquark ingredients are determined in a rainbow-ladder truncation. Our results show an overall agreement of the ground state masses with experiment. The single charmed baryon ground state masses agree with lattice QCD and theoretical calculations using QCD potential models. Double and triple charmed baryons were also calculated. A partial wave analysis of the ground and excited states shows that relativistic effects are present in the baryon amplitudes.

Parallel 2 / 6

Exploring the hadronic phase of ultrarelativistic heavy-ion collisions with resonances in ALICE

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Unlike stable hadrons, whose production yield in relativistic heavy-ion collisions is established by the temperature at the chemical freeze-out, hadron resonances are subject to final-state interactions occurring in the late hadron-gas phase of the collision after the chemical freeze-out. Processes such as the rescattering of the decay products and the regeneration are competing out of chemical equilibrium until the final thermal freeze-out, when all the interactions cease. Consequently, the measured production yield of resonances is modified according to the net balance of these processes, which depend on the time span between chemical and thermal freeze-out, on the cross sections and on the properties of the resonance in the medium.
Resonance yields are measured in central ion-ion collisions, where final-state effects are expected to be large and are compared to the yields measured in peripheral ion-ion collisions and in proton-proton collisions, where a hadron-gas phase is not expected. Also, the comparison with model predictions with and without hadronic interactions helps to disentangle the final-state effects contributing to the measured resonance yields.
With its excellent tracking and particle identification capabilities, the ALICE experiment at the LHC has measured a comprehensive set of both meson and baryon resonances with proper lifetimes ranging from 1.3 fm/c for ρ to 46.3 fm/c for φ. Measurements of the yield of resonances as a function of the collision centrality show a suppression of short-lived resonances increasing from peripheral to

central collisions. This is understood as due to the rescattering dominating over regeneration. This allowed for a simple quantitative estimation of the duration of the hadronic phase, spanning from the chemical to the thermal freeze-out, under the assumption that regeneration can be neglected. The results will be critically discussed, showing that the scenario of a sudden thermal freeze-out of all particle species at the same time is likely too simplistic and may indicate that the decoupling of particles from the expanding hadron gas is a continuous process, which takes place over a range of times and temperatures that are different for different hadron species.

Parallel 3 / 7

Going to the light-front with contour deformations

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Hadrons are strongly interacting particles composed of quarks and gluons and described by Quantum Chromodynamics (QCD). Their internal structure can be described in terms of structure functions that encode, for example, the momentum and spin distributions of their constituents. Parton distribution functions (PDFs), for example, describe the quark and gluon momentum distributions inside a hadron. These distribution functions are, however, not easy to calculate, because they are defined on the light front, whereas most hadron calculations are performed in a Euclidean metric and yield, for instance, the hadron's Bethe-Salpeter wave functions. The main problem is then to project these Bethe-Salpeter wave functions onto the light front.

We present a new method to compute the light-front wave functions using contour deformations, which we illustrate for a simple system of two interacting scalar particles of equal mass. After solving the two-body Bethe-Salpeter equation, the projection onto the light front is done through a combination of contour deformations and analytic continuation methods. The resulting light-front wave functions and distribution amplitudes are in agreement with the Nakanishi method frequently used in the literature. We show that the contour deformation method can also be used for particles of unequal masses, as well as particles with complex conjugate propagators poles, to make contact with QCD. Finally, we explore ways of extending this method to the calculation of more general parton distributions, such as transverse momentum distributions (TMDs) and generalized parton distributions (GPDs).

Parallel 3 / 8

Studying Laws of Nature with Polarisation Observable

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Hadrons are strongly interacting systems whose dynamics is driven by complex intercommunication between quarks and gluons. The theory of strong interaction, Quantum ChromoDynamics (QCD) , is supposed to describe all particles, however, due to numerical complexity we are still far away from reaching this goal. In such a situation, experimental knowledge about existing resonances becomes crucial. Over the last decade photoproduction proved to be a very valuable tool in extraction of resonance properties - all 6 new three/four-star N*resonances accepted by the Particle Data Group*

in 2004-2020 years originated from a clean and controlled photoproduction environment. One of the main features which allows photoproduction to be such a superior technique is the ability to access very sensitive polarisation observables. Single and double polarisation observables are a lot more sensitive in resonance searches compared to trivial bump-hunting technique. Due to technical limitations most groups are concentrated on polarisation observables which involve beam and/or target polarisation. In this research we present new data on the so-called spin-transfer variable Cx, which describes polarisation dependence of the recoil nucleon from photon helicity. The talk will present the world first results of neutron Cx for deuteron photodisintegration reaction and for single-pion photoproduction on the proton, obtained with the Crystal Ball at MAMI with linearly and circularly polarised photon beams. The first reaction is very interesting for the study of the first hexaquark state, the . The second reaction constraints systematical errors from more conventional double-polarisation observables and complement baryonic "missing resonance" searches. The new analysis indicated that the is likely to be excited predominantly through an M3 transition rather than an E2 transition, which is consistent with its proposed compact nature, thus constraining the $d(2380)$ shape.

On behalf the the A2@MAMI Collaboration

Parallel 3 / 9

Exotic Baryons

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The last two decades have witnessed the discovery of a myriad of new and unexpected hadrons. Hadron spectroscopy provides direct physical measurements that shed light on the non-perturbative behavior of quantum chromodynamics (QCD) and the new pentaquark states observed by LHCb offer unique insights into the QCD dynamics in hadron structures. In this talk, some of the main experimental findings and theoretical predictions given before the experimental discoveries regarding the pentaquark states will be presented and discussed.

Parallel 2 / 10

Pentaquarks in a two-body Bethe-Salpeter equation

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In the past two decades there has been tremendous progress in the theoretical and experimental investigation of multiquark states, which has expanded our understanding of what a "hadron" is. Experimental evidence suggests that Nature does not only form "conventional" hadrons such as mesons as quark-antiquark states and baryons as three-quark states, but also more exotic combinations such as tetraquarks and pentaquarks. We present results on pentaquark states in QCD obtained with the Bethe-Salpeter formalism in order to describe the observed LHCb states made of light and charm quarks. We solved the two-body equations for the meson-baryon system which couples the relevant channels in the equation. The interaction that binds such meson-baryon molecules is shaped by one-boson exchanges. Solving the equation allows us to determine the masses of the bound states.

Plenary / 11

Recent results from the A2 collaboration at MAMI

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The study of the nucleon structure and of its excited states is a powerful tool in order to gain a better understanding of the dynamics inside the nucleon and of the non-perturbative regime of QCD.

The different observables accessible using polarized photon beams and/or polarized nucleon targets play an essential role in this experimental research due to their enhanced sensitivity both to the individual resonances and to the deformation of the nucleon ground state caused by an incoming photon.

A systematic measurement of these observables is being carried out by the A2@MAMI collaboration at the tagged photon facility of the MAMI-Mainz accelerator and for energies ranging up to 1.5 GeV. The large acceptance Crystal Ball/TAPS detection set-up is used for this purpose.

The present talk will give an overview of the wide range of observables measured so far on different reactions together with a perspective on future experiments.

Plenary / 12

Baryon spectra and (transition) form factors from functional methods

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In this talk we will give a general overview on recent results from several groups on the spectrum and properties of light baryons as obtained in the framework of Dyson-Schwinger and Bethe-Salpeter equations.
We will discuss the spectrum of light baryons with focus on the comparison with quark model expectations and explain the importance of relativistic components in the wave functions of baryons. We will also discuss spacelike (transition) form factors with special emphasis on (missing) meson cloud effects and highlight possibilities to generalize into the timelike momentum domain.

Plenary / 13

N^* Studies from Exclusive Electroproduction off Protons with CLAS and CLAS12

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The study of the spectrum and structure of excited nucleon (N*
) states via the electroproduction of exclusive reactions is an important avenue for exploring the nature of the non-perturbative strong interaction. The $\gamma_v pN^*$ electrocouplings of N* states in the mass range below 1.8 GeV have been determined from analyses of CLAS πN, ηN, and $\pi\pi N$ data at beam energies up to 6 GeV at four momentum transfers Q^2 up to 5 GeV^2 . Consistent results from independent analyses of these different channels have provided new insights into the emergence of hadron mass. These experimental results, together with data on the nucleon and pion/kaon elastic form factors, are critical in order to validate the relevance of dressed quarks as the active constituents in the structure of the pion/kaon and in the nucleon and its excited states. New data from CLAS12 on πN, $\pi\pi N$, and KY electroproduction at beam energies up to 11 GeV will extend the Q^2 range of the $\gamma_v pN^*$ electrocouplings to 10 GeV^2 to probe the dressed quark mass over the full range of distances where the dominant part of hadron mass emerges from QCD. They will also allow for more detailed explorations of higher-mass N* states to help resolve the long-standing "missing"resonance problem. Experimental results from both CLAS and CLAS12 will be highlighted and prospects for future studies will be discussed.

Parallel 1 / **14**

Status of the MUSE experiment

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In 2010, high-precision studies of muonic hydrogen found notably smaller values for the charge radius than earlier results that have been extracted from elastic electron-scattering data and through the spectroscopy of atomic hydrogen. The MUon Scattering Experiment (MUSE) at the Paul Scherrer Institute (PSI) has been developed to address this so-called proton-radius puzzle. The experiment will measure elastic electron-proton and muon-proton scattering data with positively and negatively charged beams in a four-momentum-transfer range from 0.002 to 0.08 GeV2. Each of the four sets of data will allow the extraction of the proton charge radius. In combination, the data test possible differences between the electron and muon interactions and two-photon exchange effects. The status of the experiment, with a focus on radiative corrections, will be discussed.

This material is based upon work supported by the National Science Foundation under NSF grant PHY-2111050. The MUSE experiment is supported by the Department of Energy, NSF, PSI, and the US-Israel Binational Science Foundation.

Parallel 2 / **15**

Laurent + Pietarinen partial wave analysis (L+P PWA)

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A new approach has been developed to energy-dependent, single-channel partial wave analysis which does not require constructing and solving elaborate theoretical model of analyzed two body reaction, but uses general principles of analyticity instead. Standard approach of obtaining energy

dependent two body partial waves (multipoles) was to create a theoretical model, solve it, fit the free parameters to the data, and make partial wave reconstruction of obtained reaction amplitudes. Instead of constructing the theoretical model it is proposed to decompose the partial waves (multipoles) of a particular two body process in Laurent form where regular part is expanded in fast converging series in particular conformal variable called Pietarinen expansion. Free parameters (pole parameters and Pietarinen coefficients) are then fitted to world collection of observables of a particular reaction. The expansion is fairly well defined as for a particular reaction one has the fairly confident knowledge of all needed partial wave singularities (poles and branch-points), so the complexity of constructing and solving in principle elaborated theoretical model is avoided. The model is presented for a $K\Lambda$ photo-production where there exists a good and confident data base. However, complicated formalism and a lot of fitting parameters create the problem which is hard to be handled by standardly available computers, so certain simplifications of analytic structure of Laurent+Pietarinen expansion are introduced. The deviation between the simplified and the true solution are investigated by using the advantages of newly developed amplitude + partial wave analysis (AA/PWA) method, and successfully implemented for $K\Lambda$ photoproduction.

Parallel 1 / 16

Development of Reaction Models for KY Photo- and Electroproduction

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New models for photo- and electroproduction of kaons on the proton were constructed [1,2,3] utilizing new experimental data from LEPS, GRAAL, and particularly CLAS collaborations. The higher spin nucleon (spin-3/2 and spin-5/2) and hyperon (spin-3/2) resonances were included using a consistent formalism and they were found to play an important role in the data description. In these analyses, we paid close attention to model predictions of the cross section at small kaon angles which are vital for accurate calculations of the hypernucleus-production cross section.

In order to account for the unitarity corrections at the tree level, we have introduced energy-dependent widths of nucleon resonances, which affect the choice of hadron form factors and the values of their cutoff parameters extracted in the fitting procedure.

We have implemented a new shape of electromagnetic form factors so that we are now able to describe also the process of electroproduction [4]. Moreover, for a reliable description of $K^+\Lambda$ electroproduction at small Q^2 within our models it is necessary to take into account also a longitudinal coupling of virtual photons to nucleon resonances.

For the investigation of kaon photoproduction off the proton target, we have exploited also the hybrid Regge-plus-resonance (RPR) model [3] which provides an acceptable description of data in and above the resonance region. A novel feature of our version of the RPR model consists in applying a different scheme for the gauge-invariance restoration [5], which results in a need for a contact current. We reveal that the choice of the gauge-invariance restoration method may play a significant role for cross-section predictions at forward angles where data are scarce.

After focusing on the $K^+\Lambda$ channel, we utilized our isobar model to investigate the $K^+\Sigma^-$ photoproduction off a neutron target. A novel feature of the fitting procedure is the use of a regularization method and information criteria for choosing the best fit.

The sets of chosen nucleon resonances in our recent models are mutually quite well consistent and they also greatly overlap with the set selected in the Ghent analysis [6]. The results of our new isobar and RPR models will be compared with photo- and electroproduction experimental data and the properties of the models will be discussed.

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Parallel 3 / 17

Overview of hadron photoproduction studies at LEPS/LEPS2

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The photo-induced reactions are complementary to hadron-induced reactions in the study of excited baryons.
In particular, GeV photon beam can provide information on highly excited hadrons.
In the LEPS experiment at SPring-8, hadron photoproduction reactions have been studied using linearly polarized photons from laser Compton scattering up to 2.9 GeV. The LEPS experiment measured production cross sections and spin observables of hyperons at forward angle, as well as searched for exotic hadrons such as penta-quark Θ^+.
The LEPS experiment has completed data collection, and upgraded experiments are ongoing at a newly constructed beamline (LEPS2 beamline).
The LEPS2 beamline has a high-quality electron beam and a new laser system that enables experiments using high-intensity photon beams.
At the LEPS2 beamline, BGOegg experiments using a BGO electromagnetic calorimeter and LEPS2 solenoid experiments using a large solenoid magnet are currently being performed.
The purpose of these experiments is to further validate the results obtained at LEPS and to open up new physics channels.
In this talk, the recent results obtained from these experiments are reviewed, and future plans are reported.

Parallel 3 / 18

Development of Coupled-Channel Reaction Models for KY Photo- and Electroproduction

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Not long ago, we have developed and implemented a novel (Jülich-Bonn-Washington) model for pion electroproduction off the proton. Based on phenomenological (Jülich-Bonn) model, it incorporated constraints from the photoproduction and scattering data. Going to non-zero virtuality of the photon (Q^2>0) it allows now to address the abundant (O(10^5)) electroproduction data.

In this talk we present general construction principles (including gauge invariance and threshold behavior constraints) of this approach and its generalisation to etaN and KLambda electroproduction channels.

Parallel 1 / 19

Physics Opportunities for Meson Beams

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During the past several decades a large quantity of high-quality mesonic photo- and electroproduction data of have been measured at electromagnetic facilities worldwide. By contrast, meson-beam data for these same final states are mostly outdated, largely of poorer quality, or even non-existent. Thus existing meson beam results provide inadequate input to interpret, analyze, and exploit the potential of the new electromagnetic data. To achieve full benefit of these high-precision electromagnetic data, new high-statistics data from measurements with meson beams, with good angle and energy coverage for a wide range of reactions, are critically needed to advance our knowledge in baryon and meson spectroscopy and other related areas of hadron physics. To address this situation, a state-of-the-art meson-beam facility is needed. This presenation summarizes unresolved issues in hadron physics and outlines the opportunities and advances that are possible with such a facility.

Parallel 3 / 20

Electromagnetic interaction of baryon resonances in the timelike region studied via the reaction π+N -> Ne+e-

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A very important contribution of dilepton production in pion-nucleon collisions comes from the Dalitz decay of s-channel baryon resonances, R->Ne+e-. These dileptons originate from a virtual photon with small timelike squared four-momentum q^2, therefore the study of this reaction gives access to the electromagnetic interaction of baryon resonances in a kinematical domain inaccessible elsewhere. In this contribution we discuss what space-time symmetries teach us about the anisotropy of dileptons in pi+N -> Ne+e-. Then we present an effective Lagrangian model and its predictions for the cross section of the reaction. This work is motivated by recent pion-beam experiments of the HADES collaboration at the CM energy of 1.49 GeV where baryons of the second resonant region are expected to give important contributions.

Parallel 1 / 21

Quasi-free Photoproduction of π0π± off Unpolarized and Polarized Deuterons

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Exploring the low energy region of QCD requires a detailed study of the nucleon resonances and their decays. Analysing the excitation spectrum of (quasi-) free nucleons is essential to establish a baseline for comparisons with in-medium modifications. Of particular interest are the mixed-charged channels of double-pion photoproduction, as they are sensitive to sequential decays of Δ resonances, but also to the charged ρ channel. The coupling to a ρ could induce substantial in-medium effects when the ρ spectral function is modified in the medium. Recent analysis results from data taken with the A2 experiment at MAMI are presented and compared to recent MAID model calculations. The focus of this talk is on two different experiments. The unpolarized cross sections could be obtained by collecting data with a liquid deuterium target. The double polarization observable E (showing the helicity dependence) could be extracted with a circularly polarized photon beam and a longitudinally polarized D-butanol target. Both observables show a significant contribution of the ρ channel to the second resonance peak.

Parallel 2 / **22**

Overview of partial-wave analyses for baryon spectroscopy

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The talk will provide an overview of the newly-obtained knowledge about the light-baryon spectrum, as well as of the energy-dependent partial-wave analysis models which have been used to attain said knowledge. Some details will be provided on how these models can be classified, in particular with regard to their incorporation of S-Matrix constraints. An outlook will be given at the end of the talk regarding the necessity of further measurements of polarization observables, as well as on the feasibility of so-called complete experiments for baryon spectroscopy.

Parallel 2 / **23**

Studies of low-energy K- - nucleus/nuclei interactions by AMADEUS

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The experimental investigation of the low-energy negatively charged kaons interaction with the nuclear matter is very important to understand the strength of the K-nuclei interaction and to provide essential input for understanding of the non-perturbative QCD in the strangeness sector. It has strong consequences in various sectors of physics, like nuclear and particle physics as well as astrophysics.

The AMADEUS collaboration aims to provide new experimental contraints to the K-−N strong interaction in the regime of non-perturbative QCD, exploiting low-energy □–hadronic interactions with light nuclei (e.g. H,4He,9Be and 12C). The investigations are mainly focused on Λ(1405) properties studies and clarification of an existence of deeply bound kaonic states. The studies are performed with low-momentum kaons (□□~127 MeV/c) produced at the DAΦNE collider ideal to explore both stopped and in-flight □–nuclear captures. The KLOE detector is used as active target, allowing to achieve excellent acceptance and resolutions for the data.

In the talk the results obtained from the recent AMADEUS studies will be presented.

Parallel 1 / 24

Studies of Two-Pion Production and Time-like Electromagnetic Structure of Baryons in Pion-Induced Reactions

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The High Acceptance Di-Electron Spectrometer (HADES) [1], installed at GSI Helmholtzzentrum in Darmstadt, was designed for spectroscopy of positron-electron pairs with excellent purity and mass resolution. The experimental program of HADES focuses on two main goals: (I) measurements of dielectron emission of a compressed baryonic matter formed in 1-2 AGeV heavy-ion collisions and investigate in-medium hadron properties, and (ii) studies of dielectrons production in elementary proton–proton (pp) and pion–proton (pp) collisions. The latter one provides a crucial baseline to understand in-medium effects in hot and dense baryonic matter.
The elementary collisions, especially those with pion beams, offer a great opportunity to study baryon resonance Dalitz decays (R $\rightarrow$ Ne+e−) and role of the vector mesons $\rho/\omega/\varphi$ in the corresponding time-like electromagnetic transition form factors (eTFF). In order to separate contributions 0f various resonances a systematic energy scan and high precision data are needed.
In 2014 a large dataset of π^--p scattering have been obtained at the four pion beam momenta 0.656, 0.69, 0.748 and 0.8 GeV/c [2]. For the first time, combined analysis of hadronic and dielectron final states have been performed, using polyethylene and carbon targets. Two-pion channels have been included into the multichannel Partial Wave Analysis (PWA) developed by the Bonn-Gatchina group [3]. As a result cross sections for $\Delta\pi$, Nσ, Nρ isobar contributions have been obtained. Very crucial for the dilepton studies was the extraction of resonance Dalitz decay followed by investigation of spin density matrix elements (the helicity structure of baryon eTFF).
In this talk, a set of differential cross-section distributions of the two-pion final states ($\pi^+\pi^-$ and $\pi^-\pi^0$) in a function of invariant masses, di-pion emission angle, helicity and Gottfried-Jackson angles will be presented and compared to the PWA solutions [2]. The special attention will be paid to the role of ρ-N coupling for N*(1520) and N*(1535) and extraction of the mass dependence of the effective time-like eTFF. The eTFF will be compared to various versions of the Vector Dominance Model [4] and to quark-constituent model calculations [5].
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Parallel 1 / 26

Exploring the production of N*s with pion and electron beams

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The study of electromagnetic transitions opens a window into the very nature of the strong interaction. And, indeed, such a study of how a ground-state nucleon transitions to an excited state, over a broad range of q^2, will provide keen insight into the evolution of how dynamically-generated masses emerge from the asymptotically-free, nearly massless quarks of perturbative QCD as well as provide information on the ancillary effects from the meson-baryon cloud. The space-like ($q^2 < 0$) region has been explored more intensively, particularly at JLab, but efforts are well under way in studying the time-like ($q^2 > 0$) region with HADES at GSI. We further expect to collect data with J-PARC Experiment E45 in 2025 using the Hyperon Spectrometer in the K1.8 beamline.

We initiated these discussions at the May 2017 ECT*workshop, which was titled space-like and time-like electromagnetic baryonic transitions. The ECT* workshop established the need and made the first

steps towards a consistent description spanning the two kinematical regimes in q^2. This talk will continue the discussions of space-like and time-like baryonic transition form factors. The world' s data in the second and third resonance regimes are dominated by the electroproduction of Ns. *We will ultimately require a coupled-channel approach for properly ascertaining the complementary features and overlapping information in forming excited baryons through employing both pion beams and electron/photon beams. Such partial-wave amplitude analyses are especially relevant in the two-pion decay mode (including the $K\Lambda$ and $N\omega$ channels), where the pion-induced N* data at these higher energies are, at best, sparse to altogether nonexistent. These studies will require the apt coordination of experimental and theoretical groups in Asia, Europe, and North America.

Parallel 1 / **27**

Investigation of proton and pion production in the π⁻+C reaction at an incident momentum of 0.7 GeV/c with HADES

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The pion-nucleus reaction is an important source of information about hadronic matter. At incident momenta below 2 GeV/c, it gives access in a very unique way to the properties of baryonic resonances in the nuclear medium. While the region of the Δ(1232) resonance, corresponding to incident pion beam momenta of about 300 MeV/c, was studied in detail in the past, only very scarce measurements were provided at higher energies, e.g. in the second resonance region (N(1440), N(1520), N(1535),..). Such information is needed in the context of dense hadronic matter studies for the description of heavy-ion reactions at a few GeV, where pion-nucleus dynamics plays a crucial role. More general, measurements of proton and pion differential spectra are needed to validate transport models or hadronic cascades used in GEANT4 for various applications involving pion detection. This talk will focus on the analysis of π^- +C reactions performed with HADES [1], using the GSI pion beam at an incident pion momentum of 0.7 GeV/c. Pion and proton differential spectra measured in various final states (inclusive, $p\pi^-$, $p\pi^+$, pp, $p\pi^+\pi^-$,⋯, ππpp) are compared to predictions of the INCL++ cascade [2] and of transport models (SMASH [3,4], rQMD [5], GIBUU [6],⋯). The results test selectively the capacity of the models to describe the various mechanisms (quasi-elastic scattering, multipion production, re-scattering and pion absorption). The sensitivity of the data measured in the quasi-elastic channel to short range correlations is also investigated.

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Parallel 2 / **28**

Explanations for the d*(2380) Dibaryon Peak

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We study the two step sequential one pion production mechanism, $np(I = 0)^{-}pp$, followed by the fusion reaction $pp \rightarrow {}^{+}d$, in order to describe the $np \rightarrow {}^{+-}d$ reaction with ${}^{+-}$ in $I = 0$, where a narrow peak, so far identified with a "d(2380)"dibaryon, has been observed. We find that the second step $pp \rightarrow {}^{+}d$ is driven by a triangle singularity that determines the position of the peak of the reaction and the large strength of the cross section. The combined cross section of these two mechanisms produce a narrow peak with the position, width and strength compatible with the experimental observation within the approximations done. This novel interpretation of the peak without invoking a dibaryon explains why the peak is not observed in other reactions where it has been searched for.

Parallel 3 / **29**

Baryon resonance studies at the LEPS2 BGOegg experiment

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Photoproduction of a neutral pion, omega, or eta meson on the proton has been experimentally studied in their neutral decay modes at the LEPS2 BGOegg experiment with incident photon energies ranging from 1.3 GeV to 2.4 GeV. Differential cross sections, photon beam asymmetries, and spin density matrix elements are measured with high statistics and a wide angular region by using a large acceptance calorimeter (BGOegg) and forward-angle charged-particle detectors. Systematic comparisons of them with other experiment data and partial wave analyses are discussed. In particular, a bump structure at W = 2.0–2.3 GeV in the differential cross section of γp→ηp was confirmed at extremely backward η polar angles, where the existing data are inconsistent with each other. This bump structure is likely associated with high-spin resonances that couple with $s\bar{s}$ quarks. The photon beam asymmetries in a wide polar angle range for the photon beam energies above 2 GeV are reported for the first time, providing additional constraints to nucleon resonance studies at high energies. Other recent studies in the BGOegg experiment will also be presented.

Parallel 3 / **30**

Overview of strangeness photoproduction studies at GlueX

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The GlueX experiment at Jefferson Lab studies the spectrum of hadrons in photoproduction on a LH2 target. Its almost hermetic detector configuration is optimized to measure both charged and neutral final state particles with good resolutions. This allows GlueX to measure a wide range of different reactions, including those with strangeness. In this talk we are going to present our ongoing studies into the Lambda(1405) lineshape as well as results on Lambda(1520) spin-density matrix elements and differential cross-sections. We will also discuss prospects for the measurements of Xi(*) photoproduction. We will end with an outlook on future opportunities for strangeness photoproduction in GlueX.

Parallel 3 / **31**

Coherent description of the space and time structure of hadrons

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Hadron electromagnetic form factors describe the intrinsic dynamics of the charge and magnetic distributions in composite particles. They are experimentally accessible through (un)polarized cross sections measurements and angular distributions in the crossing symmetry related reactions : electron-hadron elastic scattering and electron-positron annihilation into hadron-antihadron (and its time reverse). Assuming that these reactions occur through the exchange of a virtual photon of squared four momentum q2, form factors parametrize the hadron electromagnetic current, being functions of only one variable, q2. Very recently, precise data were collected in the annihilation region by the BESIII collaboration, with the first separation of electric and magnetic form factors (in moduli) as well as unique data on the neutron. We will present a coherent description of the world data in space and time-like regions, that accounts for the main features of form factors, namely the monopole decrease of the electric to magnetic form factor ratio. We give an interpretation to the specific structures observed in the time-like region that become regular when plotted as a function of the relative momentum of the formed hadrons. Our model suggests the presence of an inner neutral screened region at very small distances and of a significative diquark component at a specific phase of the hadron formation. Interesting correlations are visible among proton, neutron and also hyperon form factors, that allow to fix the scale of the time evolution of the system from the annihilation point. For the space-like region, the model predicts that the electric form factor will stay small at large energies, with no zero crossing.

Parallel 3 / 32

Scattering amplitude analysis using neural networks

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A rigorous identification of physical states from scattering experiments is possible by tracing the pole origin of the observed peaks. The identification becomes nontrivial if a peak appears very close to a two-hadron threshold. In this work we discuss how one can utilize a neural network to help map the observed peaks with the nature of S-matrix pole. Specifically, we can teach a deep neural network to identify different line shapes that are consistent with the requirements of S-matrix such as unitarity and analyticity. We apply our method to the case of single-channel low energy nucleon-nucleon scattering and the coupled channel of pion-nucleon system. The information extracted via the deep learning approach can be used as a supplementary method in the extraction of resonance parameters.

Parallel 1 / 33

The BGOOD experiment at ELSA - Multi quark structures in the light quark sector

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The discoveries of the pentaquark, P_C, states and XYZ mesons in the charmed quark sector initiated a new epoch in hadron physics. The existence of exotic multi-quark states beyond the conventional $q\backslash overline\{q\}$ and qqq systems has obviously been realised. Such states could manifest as single colour bound objects, or evolve from meson-baryon and meson-meson interactions, creating molecular like systems and re-scattering effects near production thresholds.

Intriguingly, similar effects may be evidenced in the light, uds sector. To study a molecular-like and spatially extended baryonic system access to a low momentum exchange and therefore forward meson production region is crucial. The BGOOD photoproduction experiment is uniquely designed to explore this kinematic region; it is comprised of a central calorimeter complemented by a magnetic spectrometer in forward directions.

BGOOD has a rich programme of strangeness photoproduction studies off both proton and neutron (deuterium) target. Recent highlights include a peak-like structure in the $\gamma n \rightarrow K^0\Sigma^0$ cross section at $W \sim 2$ GeV consistent with a meson-baryon interaction model which predicted the charmed P_C states. The $K^*\Sigma$ molecular nature of this proposed N*(2030) is also supported in our measurement of $\gamma p \rightarrow K^+\Lambda(1405)(\rightarrow \pi^0\Sigma^0)$, where it is predicted to drive a triangle singularity mechanism.

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Baryon spectroscopy with Hyp-TPC at J-PARC

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At J-PARC, we built a large acceptance time-projection chamber, named Hyp-TPC, for various studies on baryons. Especially, E45 experiment will study exotic nucleon/Delta resonances via $p(\pi, 2\pi)$ reactions. We will also introduce the other experiments with Hyp-TPC, namely:

- H-dibaryon search (E42)
- Exotic hyperon resonance search (E72)
- ΣN cusp study with $d(K^-, \pi^-)$ reaction

Parallel 2 / 35

Prospects for searches for a stable double strange hexaquark at Belle II

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QCD-motivated models for hadrons predict a wide variety of multi-quark states beyond ordinary mesons and baryons, known as exotic states.
The first observation of a heavy exotic state by Belle in 2003 has triggered a huge experimental effort,

and the last 20 years have marked a turning point in the field.
To date, states composed of four and five valence quark have been observed and their existence confirmed. The possible observation of six-quark states would give us further insight into understanding and describing the strong interaction.
In particular, the search for a stable double strange hexaquark, which was put forward also as a dark matter candidate, is part of the Belle II physics program, and a fraction of the experiment data taking period is plan to be dedicated to run at the energy of the $\Upsilon(3S)$ resonance, particularly well suited for searches for multiquark states with non-zero strangeness.
This talk presents a feasibility study for the search for a stable double strange six-quark state S produced in $\Upsilon(3S)$ decays, with a focus on the obtained predictions for both existing and novel measurements.

Parallel 2 / **36**

Multi-meson photoproduction off the proton - recent results from the CBELSA/TAPS experiment

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A good understanding of the spectrum and the properties of baryon resonances requires a detailed study of the excited states and their decays. To extract contributing resonances from data, cross sections and polarization observables must be determined and further investigated by partial wave analysis. Multi-meson final states are particularly important at high energies, where resonances are still predicted that have so far remained unobserved. They also allow the interesting study of sequential decay chains, where a high-mass resonance decays via an intermediate excited state into the ground state.

The Crystal Barrel/TAPS experiment is ideally suited to measure the photoproduction of neutral mesons decaying into photons due to its good energy resolution, high detection efficiency for photons, and the nearly complete solid angle coverage. A longitudinally or transversely polarized target and a linearly or circularly polarized photon beam allow extensive measurements of polarization observables.

Recent results are presented, giving a particular emphasis to $\gamma p \to p\pi^0\pi^0$.

Parallel 2 / **37**

Hidden-charm pentaquarks as a hadronic molecule coupled to compact multiquarks

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Accelerator experiments have reported the exotic hadrons that cannot be understood in the ordinary hadron picture, describing baryons as qqq and mesons as $q\bar{q}$. The experimental observations indicate that the exotic hadrons have multiquark structures such as a compact multiquark, e.g. $qq\bar{q}\bar{q}$ and $qqqq\bar{q}$, and a hadron composite state called hadronic molecule. There have been a lot of works by using an effective model, QCD sum rules, lattice QCD, experimental studies etc. However, the exotic hadron problem is still an open question.

In this work, we investigate the hidden-charm pentaquarks P_c and P_{cs}, reported by the LHCb collaboration recently. Interestingly, there masses appear near the meson-baryon thresholds, indicating that a main component of the pentaquarks is a hadronic molecule. On the other hand, a compact-state structure has also been discussed in literature, where structures of their internal degrees of freedom, namely color, flavor and spin, have been investigated. In this study, we employ the hybrid model considering the mixture of the hadronic molecule and compact state. The hadronic molecular component has been considered to dominate in exotic hadrons near thresholds. We discuss the role of the coupling to the compact state, which plays an important role to provide the strong attraction in the hadronic molecule. By employing the hybrid model, we compute energies of these exotics and also discuss roles of the interactions.

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Polarisation Observables from Strangeness Photoproduction on a Polarised Target at Jefferson Lab

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The FROST experiment at Jefferson Lab used the CLAS detector in Hall B with the intention of performing a complete and over-determined measurement of the polarisation observables associated with strangeness photoproduction, in combination with data from previous JLab experiments as part of the N* program. This was achieved by utilising the FROST polarised target in conjunction with polarised photon beams, allowing direct measurement of beam-target double polarisation observables.

Although sufficient observables have now been measured to enable the associated reaction amplitudes to be determined, facilitating a near model-independent partial wave analysis, global data in strangeness channels is a couple of orders of magnitude smaller than pion photoproduction, so some ambiguities remain. These can be resolved by measuring observables spanning combinations of beam, target and recoil polarisation. Furthermore, the recent revision to the value of the weak decay parameter makes a wider range of observable measurements even more desirable as a cross-check of interpretations of previous data. Studies on strangeness photoproduction reactions may provide evidence of previously undetermined resonances, due to the different coupling strengths of these states to other reaction channels.

The G polarisation observable is one of the beam-target double polarisation observables, associated with a longitudinally polarised target and a linearly polarised photon beam, and its measurement for the strangeness reaction $\gamma p \to K^+\Lambda$ is the focus of the work presented. Prospects for measuring target-recoil observables on this data will also be discussed.

Parallel 2 / 39

CLAS baryon spectroscopy programme

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CLAS baryon spectroscopy programme

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One of the major thrusts in hadronic physics is to more fully understand the internal structure of baryonic matter. The challenges presented in understanding baryonic structure are large, in part due to the complexity of strongly interacting system and the presence of many broad and overlapping resonances. The CLAS baryon spectroscopy programme has utilized the CLAS detector at Jefferson Lab in combination with polarized beams and targets to study the states of excited baryons, with the more recently built CLAS12 detector allowing for better exploration of high-mass states. An overview of the past and present CLAS Baryon programme will be presented.

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Parallel 3 / **40**

Beam asymmetry of the photoproduction of the ω meson off bound protons in CLAS

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Our research contributes to a larger experimental program that seeks to shed light on the evolving status of the proton spectrum. Determining the hadronic spectrum is a complicated task due to the high number of excited states of the nucleon, all of which have large widths causing resonances to overlap. Also, these resonances may decay into a multitude of decay channels.

In this talk, we focus on the photoproduction of ω mesons off the bound proton in the deuterium which is a significant channel for several reasons. First, the ω meson being isospin 0 acts as an isospin filter, providing us information specifically about N^* resonances. Second, since its threshold is above the π and η photoproduction thersholds, it should give information for higher mass resonances. Third, by studying production on protons bound in deuterium will also help with a greater understanding of the quasi-free events, which is of vital importance for the study of reactions with a bound neutron target.We present preliminary results for the quasi-free $\vec{\gamma}d \rightarrow \omega p(n)$ photon beam asymmetry polarization observable. The data where taken with the CLAS detector in Hall B at the Thomas Jefferson National Accelerator Laboratory (JLab). The experiment provided high-quality beam of linearly-polarized photons in the energy range from 1.1 to 2.3 GeV.

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N* spectrum and Strong QCD

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Plenary / **46**

Recent Results form the CBELSA/TAPS experiment at ELSA

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Parallel 1 / **47**

Evidence of a dibaryon spectrum in coherent π0π0d photoproduction

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Parallel 3 / **51**

(Transition) form factors of baryons

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Parallel 2 / **52**

Charmed baryons and excited hyperons at Belle

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Parallel 2 / **53**

Results on Hadron Spectroscopy at LHCb

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Parallel 3 / **54**

AI/ML Tools for analysis of hadron spectroscopy data

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Physics at the EIC

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Opportunities with JLab energy and luminosity upgrade

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Highlights from the MARATHON experiment at Jefferson Lab

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Amplitude analysis of photo-/electroproduction data in the resonance region

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Multiquark States and Form Factors

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Recent results from BGOOD

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The proton charge radius

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Effective Theories and Resonances

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Recent results on baryonic resonances in ALICE

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Nucleon Electroexcitation off Free and Bound Nucleons

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Why nucleon resonance excitations play a unique role in leading the path towards a comprehensive QCD theory will be laid out and illustrated by recent exclusive meson electroproduction results off free and bound nucleons. Near- and potential long-term achievements will highlight upcoming opportunities.

Parallel 1 / 78

Opportunities for hadron spectroscopy @JLab hi-lumi/hi-energy

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Parallel 3 / **80**

Differential Cross Section of γp □ K+Σ0 at the BGOOD Experiment

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Parallel 1 / **81**

Challenges and prospects for baryonic resonances from lattice QCD

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I will review recent progress in lattice QCD calculations of the hadron spectrum, with a focus on baryonic resonances. The talk will highlight formal progress in extracting various multi-hadron amplitudes as well as recent numerical results. In the presentation I will highlight key challenges faced by lattice calculations, e.g. due to the restriction to a Euclidean finite-volume spacetime. I will also emphasise recent progress in the rigorous treatment of three-hadron channels, expected to play an important role for many baryonic resonances.

Parallel 2 / **85**

Proposed measurements of electromagnetic dipole moments of strange and charm baryons at LHC

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Electromagnetic dipole moments of fundamental particles provide powerful probes for physics within and beyond the Standard Model. For the case of short-lived particles these have not been experimentally accessible to date due to the difficulties imposed by their short lifetimes. Novel experimental techniques have been developed to allow a unique program of direct measurements of electric and magnetic dipole moments of strange and charm baryons at the LHC. In recent years significant R&D and feasibility studies have been carried on with encouraging results. The physics program and the projected sensitivities for different luminosity scenarios are discussed.

Parallel 3 / **90**

Insights into proton structure

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Baryon Spectroscopy at GlueX

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High-energy electrons and photons are a remarkably clean probe of hadronic matter, essentially providing a microscope for examining atomic nuclei and the strong nuclear force. One of the most striking phenomena of Quantum Chromodynamics (QCD) is the formation of the nucleon out of massless gluons and almost massless quarks. This system of confined quarks and gluons serves as the basic constituent of ordinary baryonic matter and exhibits the characteristic spectra of excited states, which are sensitive to the details of quark confinement. Complementary to nucleon structure studies in deep inelastic scattering experiments, nucleon excitations provide the unique opportunity to explore the many aspects of non-perturbative QCD. While the last few years have seen significant progress toward the mapping of the nucleon and Δ spectrum, experimental information on the spectrum, structure, and decays of strangeness -2 baryons remains sparse compared to non-strange and strangeness -1 baryons. Moreover, the photoproduction mechanism for these so-called Cascade resonances is not well understood and expected to proceed via highly excited intermediate singly strange hyperons in reactions such as $\gamma p \to K\,Y^*\,(\Lambda^*, \Sigma^*) \to KK\,\Xi^{(*)}$.

The GlueX experiment in Hall D at Jefferson Lab has accumulated high-statistics samples of photoproduction data in recent years. Since the lowest-lying Cascade states are expected to have narrow widths (as compared to the broad and overlapping N^* states), GlueX will be able to shed more light on the systematics of the spectrum of excited states and their properties. Copious data for excited strangeness -1 baryons have also been collected with GlueX, e.g. for the $\Lambda(1405)$ and $\Lambda(1520)$, along with the data for Cascade baryons in this experimental hyperon program. In this talk, I will discuss preliminary GlueX results on photoproduced Cascade baryons, including differential cross section measurements for the $\Xi(1320)^-$ octet ground state, recent results for excited strangeness -1 baryons, including the measurement of spin-density matrix elements for the $\Lambda(1520)$, and give a brief outlook on the GlueX potential for a spectroscopy program on excited Λ^* baryons.

Parallel 1 / 94

Helicity Dependence for Single π0 Photoproduction from the Deuteron

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Parallel 2 / 95

Measurements of resonances and exotic bound states with ALICE at LHC

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Light-flavor hadrons constitute the bulk of particle production in ultrarelativistic hadron-hadron collisions at the LHC. The study of their production yields, differential in transverse momentum and multiplicity, is fundamental to constrain hadron production models and to investigate the hadronization process. In this context, hadronic resonances are particularly interesting tools since they give also crucial information on the post-hadronization phase. Due to their short lifetimes, most resonances decay shortly after their production, and their decay daughters might scatter off other particles which are produced in the collision. In a high-density particle system, such as that created in heavy-ion collisions, the interaction rate is so large that the interactions among hadrons are expected to contribute to resonance regeneration. Precise modeling of such rescattering and regeneration processes, typically implemented in transport approaches, needs experimental constraints.
The study of the hadronization mechanism can be complemented by investigating the production of exotic bound states. In the case of multi-baryon states with hyperons, the study of their properties gives independent constraints on the hyperon-nucleon and hyperon-hyperon interaction, complementary to scattering experiments and the femtoscopic correlation technique. The study of hadronic interactions involving hyperons is crucial to study the internal structure of neutron stars and constraining their equation of state. Further implications in the field of astrophysics can be obtained with the searches of compact exotic multi-quark states, like the sexaquark, which could be good dark matter candidates.

In this contribution, a review of recent experimental results on both baryonic and mesonic resonances measured by ALICE will be presented. These results are presented in the context of existing hadron production and transport models. Measurements of the hypertriton production and properties as well as searches for exotic bound states are also presented. Prospects for future searches of compact multi-quark states and exotic hadrons are discussed.

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The light baryon resonance spectrum in a coupled-channel approach – recent results from the Juelich-Bonn model

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In order to connect predictions for the baryon spectrum from quark models or lattice calculations to experimental data, coupled-channel frameworks are especially suited. In those approaches a simultaneous partial-wave analysis of multiple reactions with different initial and final states is performed. I will present recent results from the Juelich-Bonn dynamical coupled-channel approach, where the spectrum of nucleon and Delta resonances is extracted based on a combined study of the pion- and photon-induced production of πN, ηN, $K\Lambda$ and $K\Sigma$ final states.

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Results on $\pi^+\pi^-$ photoproduction on the nucleon

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The exclusive double pion electromagnetic production is an important tool for the study of Nand excitations and for the search of missing baryonic resonances. As far as photoproduction is concerned, the two pion channel represents the dominant contribution to the total cross section especially in the second resonant region, therefore the formation of resonances coupling directly to the N vertex and decaying to this final state could be favored.
Several measurements of unpolarized p cross sections exist and have been reported in the past years by a few experiments (like CLAS, A2 and CB-ELSA just to mention a few); however, since several states are expected to populate the same region of the mass spectrum, and overlap due to their large widths, the extraction of their features provided by the study of cross sections only is, in general, difficult.
A different approach for their study is to resort to polarization variables, which are theoretically related to partial wave amplitudes and which have the potential to provide much more detailed information on the interference pattern among them. This can be achieved investigating data collected with both a polarized beam and a polarized target. Such polarization variables are experimentally related to asymmetries in the cross sections measured in different combinations of beam helicity and target polarization.
In the g14-CLAS experiment, run in 2011-2012, a circularly polarized photon beam, with momentum in the 0.6-2.3 GeV/c range, could be exploited, interacting on a HD polarized target, so these experimental conditions could be met. In this talk, results on beam-helicity and target-spin dependent asymmetries in the study of the π+π- final state with such data will be shown and compared to earlier results by CLAS with unpolarized target, disclosing the potential strength of this analysis approach.

Parallel 3 / 102

Recent results on Compton scattering at MAMI and on extraction of the proton polarizabilities

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The electric (α_{E1}) and magnetic (β_{M1}) scalar polarizabilities describe the response of the nucleon to an applied electric or magnetic field. They are not only fundamental properties related to the internal structure and dynamics of the nucleon, but they are important also in other areas of physics, such as atomic structure.
The A2@MAMI Collaboration has recently published the highest statistics Compton scattering data ever measured on the proton, using the Crystal Ball/TAPS setup. These new data, along with two effective field theories and one fixed-t dispersion relation model, were used used to extract the two scalar dipole polarizabilities with unprecedented precision.
The impact of the recently obtained results on the extraction of the proton polarizabilities will be also discussed in this talk.
*On the behalf of A2 Collaboration.

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Results on Hadron Spectroscopy at BESIII

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Using large datasets on the charmonium resonances J/ψ, ψ(3686) and ψ(3770) as well as at various other center-of-mass energies between 3.8 and 5.0 GeV, the BESIII experiment has a strong hadron spectroscopy program in both the light-quark and charmonium sectors. During this talk, recent highlights will be presented including studies of gluon-rich radiative J/ψ decays, the observation of a new iso-vector state in weak decays of open-charm mesons and updates on the spectroscopy of charmonium-like XYZ states.

Parallel 1 / **104**

Belle II Perspectives for Baryon Physics

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Recent Belle II results on charmed baryon lifetimes are presented. In addition prospects for other baryon analyses expected to be performed using Belle II data in the future are reviewed.

Parallel 1 / **105**

Electromagnetic production of strangeness

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The Mainz Microtron (MAMI), operated by the Institute for Nuclear Physics at the Gutenberg University Mainz, provides unpolarized and polarized electron beams of up to 1604 MeV energy. These beams have been used in the multi-spectrometer facility (called A1) to probe kaon electro-production reactions including studies of hypernuclei. In parallel, studies of photo-induced kaon production reactions used the Crystal Ball and TAPS multiphoton spectrometers together with the
photon tagging facility (called A2).
The A2 Collaboration measured $\gamma p \to K^+\Lambda$, $\gamma p \to K^+\Sigma^0$, $\gamma n \to K^0\Lambda$, $\gamma n \to K^0\Sigma^0$ and $\gamma p \to K^0\Sigma^+$ cross sections as well as recoil polarization in the latter reaction. Neutral kaon events were reconstructed using $K^0 \to \pi^0\pi^0$ decays and charged kaon events were accessed through the dominant decay modes $K^+ \to \mu^+\nu$ and $K^+ \to \pi^+\pi^0$. These experiments provide insight into the properties of N* resonances, in particular of those states that couple only weakly to the πN channel.
The A1 Collaboration pioneered the strangeness-tagged decay-pion spectroscopy. Precise Λ-binding energies of light hypernuclei, accessible by this method, are of high importance for understanding the Λ–N interaction and are used to constrain state-of-the-art calculations that describe the internal structure of nuclei. An experiment is currently running at MAMI to determine the hypertriton Λ-binding energy that is an important piece in the so-called lifetime puzzle of strangeness nuclear physics.
At MAMI, the direction of future experiments is moving away from strangeness production channels. Further, the University is currently constructing the novel continuous-wave multi-turn electron accelerator MESA. Its maximum beam energy will be 155 MeV, below all strangeness production thresholds.

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Physics at MESA

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The Mainz Energy-Recovery Superconducting Accelerator MESA is currently under construction at the Institute of Nuclear Physics in Mainz. In this talk, we report on the comprehensive physics program of the various fixed-target experiments at MESA. The versatile MAGIX experiment will use MESA's innovative energy recovery technique, which enables very high beam intensities. The setup is equipped with a gas jet target and magnetic spectrometers. The science focus is on high-precision scattering experiments including dark sector searches, the study of hadron structure and few-body systems, and investigations of reactions relevant to nuclear astrophysics. For the P2 experiment, an external beamline will provide spin-polarized electrons. An integrating magnetic spectrometer/detector apparatus will be used to perform sensitive tests of the Standard Model using parity-violating electron scattering. In particular, a precision measurement of the weak mixing angle is to be performed. Finally, the DarkMESA beam dump experiment, located behind P2, will search for light dark matter particles.

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New insights into the quark model from lattice QCD

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Co-authors: Anthony Thomas [2]; Curtis Abell [1]; Finn Stokes [3]; Jia-Jun Wu [4]; Liam Hockley [1]; Waseem Kamleh [1]; Zhan-Wei Liu [5]

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The idea of dressing quark-model states in a coupled-channel analysis to describe scattering data has been around for decades. What's new are formalisms able to bring these descriptions to the finite-volume of lattice QCD where calculations of the excitation spectrum provide new constraints. This combination of lattice QCD and experiment demands that we reconsider our preconceived notions about the quark-model and its excitation spectrum.

This presentation will focus on recent advances in understanding the structure of baryons and their low-lying excitations. The results are founded on the first-principles approach of Lattice QCD, complemented by Hamiltonian effective field theory (HEFT), a nonperturbative extension of effective field theory incorporating the Luscher formalism.

After presenting the formalism in the context of the Delta resonance, we'll explore the low-lying odd-parity nucleon resonances where two nearby quark-model like states introduce new challenges in mixing multiple bare basis states. The formalism is then applied to the Lambda(1405) where evidence of a molecular meson-baryon state is apparent.

The results lead to a consideration of the even-parity Roper resonance and its isospin-3/2 Delta-resonance partner. Lattice QCD calculations indicate the first radial excitation of the nucleon lies at 1900 MeV, well above the resonance position of 1440 MeV. Using HEFT, experimental scattering data are brought to the finite volume of the lattice where lattice QCD results determine the nature of the Roper resonance. Finally, these techniques can be extended to the Delta-resonance spectrum providing new insight into the structure of the low-lying even-parity Delta(1600) resonance.

Parallel 2 / **108**

Diquarks on the Lattice

Authors: Anthony Francis[None]; Kim Maltman[None]; Philippe de Forcrand[None]; Randy Lewis[None]

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Diquarks are often used as QCD effective degrees of freedom to describe nucleons and other baryons as well as exotic hadrons. Phenomenologically the splittings of the four possible diquark operators, grouped into three channels dubbed "good", "bad" and "not-even-bad", can be estimated from the experimentally observed spectrum in principle. Yet, despite the concept of diquarks being very old and successful in describing many of these low lying QCD states they have remained elusive.
One issue for ab initio, lattice calculations has been their colored nature in the past. Here we present a study that resolves this issue and report on the properties of diquarks in a gauge-invariant formalism with quark masses down to almost physical pion masses in full QCD. We broadly confirm the diquark-diquark as well as diquark-quark mass splittings. Going further we find attractive quark-quark spatial correlations only in the good scalar channel with $\overline{3}_F$, $\bar{3}_c$, $J^P = 0^+$ quantum numbers and we observe that the good diquark shape is spherical. From the spatial correlations in the good diquark channel we extract a diquark size of $\sim$ 0.6 fm. Our results provide quantitative support for modelling the low-lying baryon spectrum using good light diquark effective degrees of freedom.

Parallel 2 / **109**

Role of a triangular singularity in the $\gamma p \to p\pi^0\eta$ reaction

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Recently structures in invariant mass distributions and excitation energy spectra have been attributed to triangular singularities as discussed in e.g., [1,2] and in the review by Guo et al. [3]. These singularities emerge under specific kinematic conditions when new reaction channels open up. It will be shown that a triangular singularity associated with the opening of the $\gamma p \to pa_0 \to p\pi^0\eta$ channel can explain the observation of a structure in the $M_{p\eta}$ invariant mass distribution near 1700 MeV/c^2 in the $\gamma p \to p\pi^0\eta$ reaction [4].\newline
\noindent
[1] G.~D.~Alexeev \textit{et al.}, The COMPASS Collaboration, Phys. Rev. Lett \textbf{127}, 082501 (2021)\newline
[2] M.~Mikhasenko, B.~Ketzer and A.~Sarantsev, Phys. Rev. D \textbf{91}, 094015 (2015).\newline
[3] F.~K.~Guo \textit{et al.}, Rev. Mod. Phys. D \textbf{90}, 015004 (2018).\newline
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In memoriam Bernd Krusche

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Bernd Krusche, professor for nuclear and particle physics at the University of Basel, died on June 1st, 2022 at the age of 66. In this talk his service to the community, his achievements and most relevant contributions to hadron physics will be described. His experiments at the electron accelerators ELSA in Bonn and MAMI in Mainz focused on the photo-production of mesons off nucleons and nuclei. In more than 300 publications he obtained valuable information on the interaction of mesons with nucleons, the excitation of nucleon resonances and the interaction of mesons with nuclei, in particular on meson absorption and the search for meson-nucleus bound states.\newline

Parallel 3 / 111

Dynamical diquarks in baryon transitions

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We shall present a recent calculation of \gamma^{(*)}p->N(1535) transition form factors, based upon a continuum Schwinger method approach which employs a Poincaré-covariant Faddeev equation to describe baryons as composite states. Although limited to a symmetry-preserving contact interaction model of QCD, the results herein shown serve as benchmarks for future more sophisticated calculations; furthermore, the nucleon electromagnetic transition under examination serves as an illustration to address the role and impact of dynamical diquark correlations that appear within the baryon bound state, owing largely to the mechanisms responsible for the emergence of hadron mass in the Standard Model.

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Results of hadron spectroscopy at LHCb

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Hadron spectroscopy is a field of considerable interest for validating predictions of the Heavy Quark effective theory and calculations of Lattice QCD at low energies. LHCb has been the main player in the field, having observed more than 50 new hadrons, both conventional and exotic. This talk will present new exciting results released by LHCb recently. On the one hand, for conventional spectroscopy, results from excited states of Ξ_b and Ξ_c and the first searches for hadrons containing bc quarks will be discussed. On the other hand, for exotic spectroscopy, results about new tetraquark and pentaquark candidates will be presented, notably the observation of the doubly charmed $T_{cc}(3875)^+$ tetraquark, the first tetraquark doublet, $T_{cs0}(2900)^{0/++}$, and, finally, the first pentaquark with strangeness, $P^{\Lambda}_{\psi s}(4338)^0$.

Parallel 1 / 113

Cascade spectroscopy at the CLAS12 Very Strange Experiment

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Although many more cascade resonances than established are expected from quark models and QCD calculations, experimental evidence of most of them have been rather weak. With increased beam energy and luminosity now available at CLAS12, it is possible to search for excited cascades using quasi-real photoproduction as well as electroproduction using the CLAS12 spectrometer and probe their production mechanisms. The CLAS12 Very strange experiment focus on the investigation of $S = -2$ and $S = -3$ hyperons. Most recent results from the reaction of $ep \to eK^+K^+K-(\Lambda/\Sigma)$ and $ep \to eK^+K^+(\Xi^{-(*)})$ will be shown

Parallel 2 / 114

Study of hyperons production and dynamics in heavy ion collisions

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In this contribution a summary of the highlights of the recent experimental findings on strangeness production and dynamics will be presented.
Results obtained by different experimental collaborations spanning in
a large range in centre-of-mass energy and a variety of collision systems will be discussed. The talk does not aim at being a complete review, but rather at connecting the experimental highlights of the different collaborations and at pointing towards questions which should be addressed by these experiments in future.
A comparison of the experimental results with the available theoretical predictions will be also presented and discussed.

Parallel 1 / 115

Parity-violating pion-nucleon coupling from Lattice QCD

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I report on a pilot lattice simulation to study hadronic parity violation with lattice QCD, in particular to calculate the P-odd long-range pion-nucleon coupling h_π^1.
I discuss the implementation of a recently proposed new approach, where the parity-violating Lagrangian
is mapped to a P-conserving one, based on the PCAC relation, and the coupling h_π^1
is extracted from nucleon matrix elements of P-conserving 4-quark operators. Barring
renormalization and fermion loop diagrams, we estimate $h_\pi^1 = 2.31\,(32)\,10^{-7}$
at 260 MeV pion mass, already in

fairly good agreement with the recent experimental determination by the NPDGamma collaboration.

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Towards the determination of excited nucleon matrix elements with lattice QCD

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The observation that neutrinos can oscillate from one flavour to another suggests that these elementary particles have a very small but non-zero mass. The weak cross sections that occur in the neutrino oscillation experiments are parametrized among other things by the nucleon axial and vector form factors, which can be computed via lattice QCD simulations. In this talk, I will highlight the need to determine the structure of nucleon excitations from an experimental and a theoretical perspective. In particular, since the relevant excited nucleons decay into a nucleon and pions, I report on a first step towards the determination of nucleon form factors including those associated with nucleon-pion states.

Parallel 3 / 117

Data-driven pole determination of overlapping resonances

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We describe the application of a model-independent reconstruction method to experimental data in order to identify complex poles of overlapping resonances. The algorithm is based on the Schlessinger Point Method where data points are interpolated using a continued-fraction expression. Statistical uncertainties of the experimental data are propagated with resampling. In order to demonstrate the feasibility of this method, we apply it to the S-wave $J/\psi \to \gamma\pi^0\pi^0$ decay, and perform the pole extraction from BESIII data, to identify identify the $f_0(1500)$, $f_0(1710)$, and $f_0(2020)$ scalar states.

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Baryon and Strangeness Physics with PANDA at FAIR

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With its unique combination of antiproton-proton reactions and an almost full 4π coverage, PANDA (antiProton ANihilations at DArmstadt) at FAIR (Facility for Antiproton and Ion Research) will take

precision tests of QCD to a new level. It is designed to explore QCD at intermediate energies between the high energy perturbative QCD and the low energy region where phenomenological approaches such as χPt or advanced calculations from Lattice QCD are used to describe systems. The reactions offer a gluon-rich environment, ideal for searching for exotic states with gluonic degrees of freedom. In addition, it offers abundant production rates of strange baryons, suitable for precision measurements where strangeness production in the confinement region can be studied. The reactions are also suitable to investigate interactions that may help to constrain theories describing the equation of state of neutron stars. The baryon spectrum will also be explored as well as the baryon structure, *e.g.* in terms of electromagnetic form factors in the reactions pbarp->e+e- and pbarp->μ+μ- PANDA is complementary to current experiments utilizing electron, proton or kaon beams and is expected to improve previous studies of antiproton-proton collisions, *e.g.* from PS185 at LEAR by going to higher energies and increasing the resolution and luminosity. This talk will give an overview of the baryon and strangeness physics program and show some highlights from previously published simulation study results from PANDA.