

# **The 12th International Workshop on the Physics of Excited Nucleons**

Monday, 10 June 2019 - Friday, 14 June 2019

Bonn, Campus Poppelsdorf

## **Book of Abstracts**



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# Concluding Remarks

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# Opening

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## Parallel Session A / 7

# $\eta$ Photoproduction in the Jülich-Bonn Model

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The current status of the  $\eta$  photoproduction analysis within the Jülich-Bonn framework is presented. A structure in production on the proton at around  $W \sim 1.68$  GeV is discussed. Furthermore, the extraction of resonance helicity couplings and their correlations from  $\eta$  photoproduction is outlined, and how new experiment could help to further disentangle these quantities. Also, a brief outlook is provided of how machine learning techniques can assist in determining the baryonic resonance spectrum from data.

## Parallel Session A / 18

# $\Lambda(1405)$ and $\Sigma^*$ production in $\Lambda_c \rightarrow \pi \pi \pi \Sigma$ decay

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A  $\Sigma^*$  resonance with spin-parity  $JP=1/2^-$  and mass in the vicinity of the  $K^-N$  threshold has been predicted in the unitary chiral approach and inferred from the analysis of CLAS data on the  $\gamma p \rightarrow K^+ \pi^0 \Sigma^0$  reaction. In this work, based on the dominant Cabibbo favored weak decay mechanism, we perform a study of  $\Lambda_c \rightarrow \pi^+ \pi^0 \Sigma^*$  with the possible  $\Sigma^*$  state decaying into  $\pi^- \Sigma^+$  through a triangle diagram. This process is initiated by  $\Lambda_c \rightarrow \pi^+ K^{*-} N$ , then the  $K^{*-}$  decays into  $K^- \pi$  and  $K^- N$  produce the  $\Sigma^*$

through a triangle loop containing  $K^*NK^-$  which develops a triangle singularity. We show that the  $\pi-\Sigma^+$  state is generated from final state interaction of  $K^-N$  in S-wave and isospin  $I=1$ , and the  $\Lambda+c \rightarrow \pi+\pi^0\pi-\Sigma^+$  decay can be used to study the possible  $\Sigma^*$  state around the  $K^-N$  threshold. The proposed decay mechanism can provide valuable information on the nature of the  $\Sigma^*$  resonance and can in principle be tested by facilities such as LHCb, BelleII and BESIII.

In addition, the decay of  $\Lambda_c$  into  $\pi+\pi^0\Lambda(1405)$  with the  $\Lambda(1405)$  decay into  $\pi^0\Sigma^0$  through a triangle diagram is studied. This process is initiated by  $\Lambda_c \rightarrow \pi+K^*N$ , then the  $K^*$  decays into  $K^-\pi$  and  $K^-N$  produce the  $\Lambda(1405)$  through a triangle loop containing  $K^*NK^-$  which develops a singularity around 1890 MeV. This process is prohibited by the isospin symmetry, but the decay into this channel is enhanced by the contribution of the triangle diagram, which is sensitive to the mass of the internal particles. We find a narrow peak in the  $\pi^0\Sigma^0$  invariant mass distribution, which originates from the  $\Lambda(1405)$  amplitude, but is tied to the mass differences between the charged and neutral  $K^-$  or  $N$  states. The observation of the unavoidable peak of the triangle singularity in the isospin-violating  $\Lambda(1405)$  production would provide further support for hadronic molecular picture of the  $\Lambda(1405)$  and further information on the  $K^-N$  interaction.

Parallel Session A / 26

## $\Lambda(1405)$ with one pole

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Low-energy data on the three charge states in  $\gamma p \rightarrow K^+(\Sigma\pi)$  from CLAS at JLab, on  $K^-p \rightarrow \pi^0\pi^0\Lambda$  and  $\pi^0\pi^0\Sigma$  from the Crystal Ball at BNL, bubble chamber data on  $K^-p \rightarrow \pi^-\pi^+\pi^\pm\Sigma^\mp$ , low-energy  $K^-p$  differential cross sections for elastic and charge exchange scattering, total cross sections on  $K^-$  induced reactions, and data on the  $K^-p$  atom are fitted with the BnGa partial-wave-analysis program. We find that the  $\Lambda(1405)$  region can be fitted well with just one isoscalar spin-1/2 negative-parity pole, the  $\Lambda(1405)$ , and background contributions.

Parallel Session A / 31

## Exotic Nstar: from light quarks to Charm and Beauty

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We explore the photo-production of possible exotic  $N^*$ , which are narrow pentaquark candidates containing light quarks or Charm or Beauty. The latter two are also known as  $P_c$  and  $P_b$  states in literatures. We analyzed the Compton scattering off the proton in the third resonance region in a coupled-channel effective Lagrangian model with K-matrix approximation. The evidence of exotic  $N^*$  with light quarks are found to be weak at present. Motivated by the  $P_c$  observed by LHCb, we discussed the possible signal of  $P_c$  and  $P_b$  states in  $\gamma p \rightarrow J/\psi p$  and  $\gamma p \rightarrow \Upsilon p$ , respectively at an Electron-Ion Collider (EIC) in order to disentangle the nature of these states.

Parallel Session A / 6

## PROBING OF STRONG INTERACTIONS AND HADRON MATTER WITH HIDDEN AND OPEN CHARM RESONANCE STUDIES



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The spectroscopy of charmonium-like states together with the spectroscopy of charmed and strange baryons is discussed. It is a good testing tool for the theories of strong interactions, including: QCD in both the perturbative and non-perturbative regimes, LQCD, potential models and phenomenological models [1, 2, 3]. An understanding of the baryon spectrum is one of the primary goals of non-perturbative QCD. In the nucleon sector, where most of the experimental information is available, the agreement with quark model predictions is astonishingly small, and the situation is even worse in the strange and charmed baryon sector. The experiments with hadron and heavy ion collisions are well suited for a comprehensive spectroscopy program, in particular, the spectroscopy of charmonium-like states and flavour baryons. Charmed and strange baryons can be produced abundantly in both processes, and their properties can be studied in detail [1, 2, 3].

For this purpose an elaborated analysis of charmonium and tetraquark spectrum together with spectrum of charmed and strange baryons is given. The recent experimental data from different collaborations (BaBar, Belle, BES, LHCb) are analyzed. A special attention was given to the recently discovered XYZ-particles. The attempts of their possible interpretation are considered [4 - 7]. The results of physics simulation are obtained. Some of these states can be interpreted as higher lying charmonium and tetraquarks with a hidden charm [5, 6, 7] and strangeness [8, 9]. It has been shown that charge/neutral tetraquarks must have their neutral/charged partners with mass values which differ by few MeV. This hypothesis coincides with that proposed by Maiani and Polosa [10] and need confirmation nowadays. Many heavy baryons with charm and strangeness are expected to exist. But much more data on different decay modes are needed before firmer conclusions can be made. These data can be derived directly from the experiments using a high quality antiproton beam with  $\sqrt{s}$  up to 5.5 GeV planned at FAIR and proton-proton (proton-nuclei) collisions with  $\sqrt{s}$  up to 26 GeV planned at the NICA.

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#### Parallel Session A / 39

### Evidence for a high spin $N^*$ resonance in eta photo-production in the extremely backward angle

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We carried out exclusive measurements of photo-production of an eta meson from a proton target with an egg-shape BGO calorimeter (BGOegg) and forward charged particle detectors at LEPS2/SPRING-8, Japan. The differential cross-section at extreme backward angles were obtained and compared with the prediction from etaMAID2018. Possible evidence for a high spin  $N^*$  resonance with a mass of 2.2 ~ 2.3 GeV will be presented.

## Parallel Session A / 42

### Hybrid Baryon Search at CLAS 12

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The study of baryonic excited states provides fundamental information on the internal structure of the nucleon and on the degrees of freedom that are relevant for QCD at low energies. *Nare composite states and are sensitive to details of the how quark are confined.*

*A program has been approved at JLAB to search for new excited baryon states in the mass range from 1.8 GeV to 3 GeV with CLAS12. For the first time the behavior of resonance electro-couplings over the full spectrum of excited proton states will be studied at very low photon virtualities, approaching the photon point. The experiment will measure  $KY$  and  $\pi^+\pi^-p$  exclusive final states using longitudinally polarized electron beams in the energy range between of 6.5 GeV and 8.8 GeV, to cover the range of invariant masses up to 3 GeV. By studying the  $Q^2$  evolution of electroexcitation amplitudes it will be possible to distinguish between regular  $N$  states and possible additional hybrid baryon states, with the glue as an extra constituent component beyond the three constituent quarks. Very first results from 6.5 GeV and 7.5 GeV electron energy data are reported.*

## Parallel Session A / 52

### Nucleon resonances in Compton scattering

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The nucleon excitation spectrum has traditionally been at the heart of strong interaction studies. Nucleon resonances and their transition form factors are interesting in a variety of processes: In addition to nucleon-pion scattering and meson photo- and electroproduction, from where they are experimentally extracted, nucleon resonances also appear as intermediate states in nucleon Compton scattering. I present a structure analysis of Compton scattering in general kinematics, which allows one to calculate the resonance contributions to the Compton amplitude and the nucleon's polarizabilities. Gauge invariance and analyticity pose constraints on the general form of the transition currents, which we use to construct fits for the experimental data of  $J = 1/2$  and  $3/2$  resonances. The transition form factors also encode information on the nonperturbative substructure of resonances and I will highlight progress with Dyson-Schwinger and Bethe-Salpeter equations in calculating them from the level of quarks and gluons.

**Parallel Session A / 99****NN****Parallel Session A / 61****Determining dominant partial waves in photoproduction via moment analysis****Author:** Yannick Wunderlich<sup>1</sup><sup>1</sup> *University of Bonn***Corresponding Author:** wunderlich@hiskp.uni-bonn.de

Important insights into the excitation spectra of baryons are provided by measurements of polarization observables in reactions that involve particles with spin. The photoproduction of a single pseudoscalar meson constitutes an example-reaction that has been under intense investigation recently.

In this talk, we present the basic method of moment-analysis for pseudoscalar meson photoproduction, in which just the angular distributions are analyzed. Using this method, the total angular momentum quantum number of the dominant partial waves contributing in the data can be extracted quickly. Furthermore, the Legendre-coefficients extracted from the angular distributions show interesting composition-patterns in terms of multipoles and allow for instructive comparisons to models. In the talk, we will show recent results for moment analyses of polarization data for the photoproduction of pions and eta-mesons.

**Parallel Session A / 28****EtaMAID-2019 for  $\eta$  and  $\eta'$  photoproduction on nucleons****Author:** Victor Kashevarov<sup>1</sup><sup>1</sup> *Institut für Kernphysik, Mainz***Corresponding Author:** kashev@kph.uni-mainz.de

Results of the phenomenological analysis of  $\eta$  and  $\eta'$  photoproduction on the protons and the neutrons with updated version of EtaMAID model are presented. The model includes 23 nucleon resonances parameterized with Breit-Wigner shapes,  $t$ -channel exchange of vector and axial-vector mesons with Regge cuts, and Born terms in  $s$  and  $u$  channels.

A new approach is discussed to avoid double counting in the overlap region of Regge and resonances. Parameters of the resonances were obtained from a fit to available experimental data. The model well describes both differential cross sections and polarization observables for photoproduction of  $\eta$  and  $\eta'$  on the nucleons at photon beam energies from the threshold up to 9 GeV.

A comparison is done among four newly updated partial waves analyses for observables and partial waves. The nature of the most interesting specifics in the data is discussed.

**Parallel Session A / 51**

## Bonn-Gatchina analysis of the $\eta$ -photoproduction reactions

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We present the result of the combined analysis of the eta and eta-prime photoproduction data measured by A2,CB-ELSA and CLAS collaborations. The analysis confirms the existence of the  $N(1895)1/2^-$  state and allowed us to define its properties with a good precision.

Parallel Session A / 36

## Measurement of $\pi^0 \pi^{+-}$ photoproduction off the deuteron and D-butanol targets

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The research work of Nuclear and Particle Physics group at University of Basel is centered around Hadron Physics sector. Photoproduction of Mesons provides an efficient tool for the study of decays of nucleon resonances and the excitation spectrum of hadrons tells us about the internal degrees of freedom. Thus to know the internal structural details of nucleons and mesons, investigation of excited nucleon states via photoproduction of mesons and the modification of the properties of nucleon resonances and mesons are being studied quite extensively.

Our group is involved in some international collaborations among which the research works related to photon induced meson production are carried out in Crystal Ball A2 with MAMI(Mainz) and Crystal Barrel ELSA(Bonn) collaborations.

In the presentation, research involved in the Crystal Ball experiment in MAMI as well as my analysis work including few preliminary results in the context of photoproduction of double pions with unpolarized and polarized deuteron targets will mainly be discussed.

Parallel Session A / 73

## Quark Model

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Parallel Session A / 35

## Quark model calculations of transition form factors at high photon virtualities

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We present calculations of  $\gamma^* N \rightarrow N^*$  transition form factors, where  $N$  is the nucleon and  $N^*$  and  $N^*$  is a nucleon resonance, based on a covariant quark model. At high photon virtualities (large  $Q^2$ ) it is expected that the valence quark degrees of freedom dominate the contributions to the transition form factors. In these conditions, the quark model estimates can be compared with the available data, particularly with the Jefferson Lab data at intermediate and large momentum transfer ( $Q^2 > 2 \text{ GeV}^2$ ). The main focus is on the  $\Delta(1232)3/2^+$ ,  $N(1440)1/2^+$ ,  $N(1535)1/2^-$  and  $N(1520)3/2^-$  resonances, but the estimates for other higher mass resonances are also discussed.

**Parallel Session A / 85**

## **The spectrum of hyperon resonances from a partial wave analysis of K-p scattering data**

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**Parallel Session A / 47**

## **Measurement of polarization observables in neutral double pion photoproduction off the proton with the CBELSA/TAPS experiment**

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One important step in understanding the baryon spectrum is a precise knowledge of the excited states and their decays. In order to extract the contributing resonances from experimental data a partial wave analysis needs to be performed. To resolve ambiguities, the measurement of polarization observables is indispensable. In the regime of high mass baryon resonances multi-meson final states are of particular importance. Here sequential decays of resonances are observed. 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. In combination with a longitudinally or transversely polarized target and an energy tagged, linearly or circularly polarized photon beam the experiment allows the measurement of a large set of polarization observables. This talk will focus on preliminary results on neutral double pion production obtained with a linearly polarized photon beam and a transversely polarized target as well as their impact within the Bonn-Gatchina partial wave analysis.

**Parallel Session A / 2**

## **Status of $\Lambda$ (1405)**

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Understanding of the non-trivial pattern of excited states of QCD at low energies is one of the main goals of the modern nuclear physics. One of the most interesting states is the so-called Lambda 1405, which is widely accepted as a dynamically generated state from the meson-baryon interaction.

Recently, high precision data on the energy shift and width of the Kaonic-hydrogen as well as the line-shape measurements in the pi-Sigma photo-production experiment at CLAS have sparked new interest in this interaction channel. Additionally, the “molecular” picture of this state seems also to be supported by the recent Lattice QCD results.

In my talk, I will show the available input from experimental measurements and Lattice QCD calculations. Then, I will review the presently available theoretical models on the meson-baryon scattering and discuss their predictions in comparison to each other.

**Parallel Session A / 82**

## **The XYZ states - status and perspectives**

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In the past decade, lots of hadrons were discovered especially in the heavy quarkonium mass ranges that cannot be fit into the level scheme provided by the traditional quark models. In the talk I will review some of the most popular proposals for the nature of these so-called XYZ states, including hadronic molecules, hadro-quarkonia and tetraquarks, as well as the non-trivial predictions that can be derived from them. Based on these together with the experimental prospects it is fair to expect significant progress towards a deeper understanding of the XYZ states in the near future.

**Parallel Session A / 5**

## **Two Pion Photo- and Electroproduction with CLAS and CLAS12**

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The  $\pi^+\pi^-p$  photo- and electroproduction off proton channel is sensitive to the contributions from most excited nucleon states, offering an effective tool for the exploration of the nucleon resonance spectrum and structure. The data on nine independent one-fold differential  $\pi^+\pi^-p$  photo- and electroproduction cross sections have become available for the first time from the measurements with the CLAS detector at invariant masses of the final state hadrons  $W < 2.0$  GeV and in the range of photon virtualities  $Q^2 < 5.0$  GeV<sup>2</sup>. Phenomenological analysis of these data has allowed us to establish all essential contributing mechanisms and makes possible the credible isolation of the resonant contributions needed for the extraction of the resonance photo-/electroexcitation amplitudes, the so-called resonance photo-/electrocouplings.

In the talk, I will discuss the results on the resonance photo-/electrocouplings obtained from the CLAS  $\pi^+\pi^-p$  photo- and electroproduction data, as well as their impact on understanding resonance structure and the insight gained into the strong QCD mechanisms underlying hadron mass generation. I will also present the evidence for the existence of the new  $N'(1720)3/2^+$  baryon state that has recently become available from the combined analysis of the CLAS  $\pi^+\pi^-p$  photo-/ electroproduction data. The completion of the phenomenological analysis of the CLAS  $\pi^+\pi^-p$  electroproduction data will provide results for the electrocouplings of the most nucleon resonances in the mass range up to 2.0 GeV and at  $Q^2 < 5.0 \text{ GeV}^2$ , shedding light on the evolution of nucleon resonance structure at the distances where the transition to the dominance of quark degrees of freedom takes place. The future prospects for the studies of  $N^*$  structure in the 12 GeV era at Jefferson Laboratory from the  $\pi^+\pi^-p$  electroproduction data foreseen from the CLAS12 detector will be outlined with a focus on the insight into the strong interaction dynamics at distances where the transition from quark-gluon confinement to perturbative QCD is expected, addressing key open problems of the Standard Model on the nature of hadron mass and quark-gluon confinement.

#### Parallel Session A / 9

### From Experiment to Pole Parameters in a Theory-Independent Way (Fixed-t Single-Energy PWA + Laurent-Pietarinen model for pole extraction)

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Pole parameters, as the minimally model dependent link between measurements and QCD approaches, were always extracted from experiment through procedures notably relying on elaborated microscopic theories. Partial waves were obtained by fitting free parameters of a microscopic model to experimental data, and poles were extracted by performing the analytic continuation of the result into the complex energy plane. This introduced important model dependence upon a particular theory, what was quite often very difficult to take into account in order to get a true, theory-independent result. We have shown that this can be bypassed as using only fixed-t analyticity as a constraint produces continuous, unique, single-energy PWA, and Laurent-Pietarinen expansion based only on conformal mapping generated expansion of regular part of Laurent decomposition very precisely extracts poles from such theory-independent set of partial waves. So, combining the two, fixed-t SE PWA and L+P expansion, a theory independent procedure is formulated which obtains pole parameters directly from experimental data using only general features like analyticity and unitarity.

#### Parallel Session B / 11

### S- and p-wave structure of $S=-1$ meson-baryon scattering in the resonance region

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We present a simultaneous analysis of s- and p-waves of the  $S = -1$  meson-baryon scattering amplitude using low-energy experimental data. For the first time differential cross section data are included for chiral unitary coupled-channel models. From this model s- and p-wave amplitudes are extracted and we observe both well-known  $I(J P) = 0(1/2^-)$  s-wave states as well as a new  $I(J P) =$

$1(1/2^+)$  state absent in quark models and lattice QCD results. Multiple statistical and phenomenological tests suggest that, while the data clearly require an  $I = 1$  p-wave resonance, the new state accounts for the absence of the decuplet  $\Sigma(1385)3/2^+$  in the model.

**Parallel Session B / 74**

## 3-particles on the lattice

**Parallel Session B / 59**

## Is there really a narrow nucleon resonance at $W=1700$ MeV?

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The reaction  $\gamma p \rightarrow p\pi^0\eta$  has been studied with the Crystal Barrel/MiniTAPS detector system at the electron stretcher accelerator ELSA in Bonn for incident photon energies from threshold up to 3.1 GeV. This work has been motivated by the recently claimed observation of a narrow structure around an excitation energy of 1678 MeV [1]. Invariant mass distributions and angular distributions of the final state particles have been analysed for the incident photon energy range  $E_\gamma = 1400 - 1600$  MeV. A structure in the  $M(p\eta)$  mass distribution near 1700 MeV has been indeed observed, but is found to be much broader in energy. This structure has been quantitatively studied in comparison to a partial wave analysis based on previous studies of the  $\gamma p \rightarrow p\pi^0\eta$  reaction. The observed excess yield with a cross section of about  $0.1 \mu b$  is tentatively attributed to a so far unobserved cascade decay of the  $N(1900)3/2^+$  resonance which decays via  $\pi^0$  emission to the  $N(1710)1/2^+$  resonance with subsequent  $\eta$  decay to the nucleon ground state. This interpretation needs to be confirmed in an updated partial wave analysis.

[1] V. Kuznetsov *et al.*, *JETP Letters* **106** (2017) 693

**Parallel Session B / 57**

## Low-energy pion-nucleon scattering and the Delta resonance in lattice QCD

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We report on our investigation of low-energy pion-nucleon scattering from lattice QCD with Wilson-type fermions.

Our focus is on the isospin  $I = 3/2$  channel, which couples to the Delta resonance.

We discuss our calculations aiming at the extraction of the Delta resonance mass, width and effective coupling at pion mass

250 MeV and the physical point, using the Lüscher finite-volume method to extract the phase shift  $\delta_{J=3/2, l=1}$ .



## Parallel Session B / 1

**Non-strange dibaryons studied in coherent double neutral-meson photoproduction on the deuteron****Author:** Takatsugu Ishikawa<sup>1</sup><sup>1</sup> *Research Center for Electron Photon Science (ELPH), Tohoku University***Corresponding Author:** ishikawa@lms.tohoku.ac.jp

The search for non-strange  $B = 2$  (dibaryon) bound/resonance states has a long history. The dibaryon state is of interest, which can be a molecule consisting of two baryons or a spatially compact hexaquark object. The  $\gamma d \rightarrow \pi^0 \pi^0 d$  reaction has been experimentally investigated at incident energies ranging from 0.58 to 1.2 GeV to study non-strange dibaryons. The angular distributions of deuteron emission in the  $\gamma d$  center-of-mass cannot be reproduced by quasi-free production of neutral pions followed by deuteron coalescence. Additionally a 2.14-GeV peak is observed in the  $\pi^0 d$  invariant mass distribution. These suggest a sequential process such as  $\gamma d \rightarrow R_{IS} \rightarrow \pi^0 R_{IV} \rightarrow \pi^0 \pi^0 d$ . We discuss the newly observed two isoscalar dibaryons ( $R_{IS}$ ) and an isovector dibaryon ( $R_{IV}$ ) observed in the  $\pi^0 \pi^0 d$  and  $\pi^0 d$  channels, respectively. We also show the  $\gamma d \rightarrow \pi^0 \eta d$  reaction.

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T. Ishikawa et al., Phys. Lett. B 772, 398 (2017); Phys. Lett. B 789, 413 (2019).

## Parallel Session B / 75

**MAID**

## Parallel Session B / 40

**Polarizabilities of the nucleon****Author:** Philippe Martel<sup>1</sup><sup>1</sup> *Johannes Gutenberg-Universität Mainz***Corresponding Author:** martel@uni-mainz.de

What happens when a proton is subjected to an electric field? The simple answer from first-year physics is that it would move. The less simple answer is that it would also deform due to the internal structure of the proton. Such is also the case in a magnetic field, and similarly so for the neutron, which obviously would have otherwise remained at rest. These responses to electric and magnetic fields are described by parameters of the nucleon called polarizabilities. The A2 collaboration at the Mainz Microtron has undertaken a multi-experiment project to extract these polarizabilities. This is done by taking polarized photons, provided from tagged Bremsstrahlung, and Compton scattering them off of either polarized or unpolarized protons. The measurements of various observables from these experiments are then compared with theoretical values from dispersion and chiral perturbation calculations. Values for the proton polarizabilities, some of which had not been experimentally determined previously, have been extracted, and plans to improve these values and continue the program on the neutron are underway.

## Parallel Session B / 16

## Linearly polarized photons and determination of the polarization degree

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Linearly polarized photons are an invaluable tool for disentangling the nucleon spectrum. Used in a number of experiments both past and present, a range of techniques have been developed to determine the polarization degree of the photons. Many recent measurements have revealed the need to have a more accurate measurement of the degree of polarization, the systematic error of which was often insignificant compared to the statistical error.

In the talk, the advantages of each technique are outlined and possible methods to reduce the uncertainties for the future.

**Parallel Session B / 102**

**NN**

**Parallel Session B / 92**

## Photoproduction of mesons off quasifree nucleons

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Photoproduction of mesons off the nucleon is a very efficient tool for the study of the excitation spectrum of the nucleon related to the fundamental properties of the strong interaction. Much progress has been made during the last decade in particular due to the measurements of several polarization observables in particular with polarized beams and polarized targets. Availability of such polarization observables allows for much better constraint model analyses, because they are sensitive to small interference terms in the amplitudes. However, up to now the experimental data base is only much improved for reactions off free protons. The investigation of the isospin degree of freedom requires also measurements with neutron targets. In the absence of free neutron targets experiments must be done with quasifree nucleons bound in light nuclei, in particular in the deuteron. Such experiments are complicated by the effects of nuclear Fermi motion, which smears out all observed structures and by the presence of Final State Interactions (FSI) which may significantly influence the reaction amplitudes in comparison to free nucleons. However, also for this issue significant progress has been achieved during the last few years. In particular at the Bonn CBELSA/TAPS experiment and the Mainz Cball/TAPS experiment such reactions have been systematically investigated. The effects of Fermi motion can be mostly removed when the center-of-mass energy of the photon-participant-nucleon system is reconstructed from the final state kinematics of the reaction products. Several attempts have been made to model in a better way FSI effects, but also phenomenological approaches, which are based on the assumption that FSI

effects in the deuteron are for many reactions similar for recoil protons and neutrons, have been used. For the measurement of polarization observables such effects cancel often to a large extent because they effect different polarization states in the same way. We will discuss recent results for the photoproduction of  $\eta$ - and  $\pi^0$ -mesons and for  $\pi\pi$ - and  $\pi\eta$ -pairs. Reactions like photoproduction of neutral meson pairs off quasifree neutrons are among the technically most difficult ones and can practically only be measured when almost the complete solid angle is covered by an electromagnetic calorimeter. Some results of these experiments, such as the narrow structures observed in the excitation function of the  $n\eta$  final state, where quite surprising and are not yet fully understood.

Such experiments may also profit from production mechanisms which only contribute to photoproduction from light nuclei such as coherent production of mesons or meson pairs. This may partly help to disentangle the isospin structure of the reaction amplitudes, but is also under discussion for example for the possible manifestation of a di-baryon state in coherent photoproduction of  $\pi^0\pi^0$  pairs off the deuteron. Recent results will be discussed.

## Parallel Session B / 105

### The Polarized Target at the CBELSA/TAPS Experiment

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In 2017, the polarized target system from Mainz/Dubna and Bonn were combined for data taking in Bonn. After testing the combined system, the experiment with a polarized frozen-spin target and the upgraded Crystal Barrel detector started in winter 2017. First data with a transversal proton target were already taken. In the meantime, several developments to improve the figure of merit are ongoing. To get a high target polarization and long relaxation times, low temperatures are indispensable. For this, new cryogenic systems are under construction. In Bonn, as an optimizing tool for the construction of dilution refrigerators and to gain detailed information about the different incoming and outgoing fluid streams, several CFD-simulations were done and improvements of the model are ongoing. Other research to reach a higher polarization during the experiment is done for superconducting magnets and target materials. Both can be used to build a continuous polarizing  $4\pi$  solid target. This talk will give an overview about the projects and results of this research.

## Parallel Session B / 91

### Search for the $N(1685)$ in $\eta$ $\pi$ -photoproduction

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The nucleon-like member  $N(1685)$  of the speculative baryon antidecuplet denotes one possible explanation for the narrow peak-structure around  $W = 1.68$  GeV observed in the total cross section of  $\eta$ -photoproduction off the neutron. If this baryon existed, it would likely to be seen in other reactions as well. While the aforementioned peak, whatever its nature is, was confirmed by several experiments, claims for signatures of the  $N(1685)$  in other reactions and observables are mainly made by V. Kuznetsov et al. using GRAAL data. Their latest work suggests signals of both  $N(1685)$

charge states in all isospin channels of  $\eta\pi$ -photoproduction off the proton and neutron. This contribution reports on challenging these claims with data from the A2 at MAMI experiment employing photon beam energies from  $E_\gamma = 1.42 - 1.58$  GeV. The  $\eta\pi^0 p$  and  $\eta\pi^+ n$  final states produced from a hydrogen target were studied and new analysis cuts were tested in order to enhance a possible signal.

Parallel Session B / 46

## Double polarisation observable E and helicity dependent cross section for single $\pi^0$ photoproduction off proton and neutron

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Since the beginning of the 1960's, the internal structure of the nucleon, in particular its spin structure, and the excitation spectra of protons and neutrons have been a central issue for many theoretical models and experiments of nuclear and particle physics.

Photon-induced reactions, like meson photoproduction, allow to excite the nucleon, to have access to many different polarisation observables, and are an essential tool to disentangle the role of the different electromagnetic multipoles due to the change of sign of some contributions and the presence of interference terms between different multipole amplitudes. In addition, the use of polarised beams and/or targets allow to access additional observables which are fundamental in order to accurately determine the nucleon resonance properties.

Up to now, most efforts have been devoted to studying proton excitation but, since the electromagnetic excitations are isospin dependent, also measurements of meson-photoproduction off the neutron are required.

The A2@MAMI collaboration is carrying out a broad and systematic study on this topics, both on the proton and the neutron. The experiments are performed at the tagged photon beam facility of the MAMI accelerator in Mainz, using circularly and longitudinally polarised photons on longitudinally polarised proton and deuteron targets, for energies ranging from the pion production threshold up to 1.6 GeV. Hadronic reaction products are then measured with the large acceptance Crystal Ball spectrometer, complemented by charged particle and vertex detectors for tracking and identification.

In this talk, an overview of the results obtained so far for the double polarisation observable E (circularly polarised photon beam on a longitudinally polarised target) on the single  $\pi^0$  photoproduction off the proton and the neutron will be given.

Furthermore, new results on the helicity-dependent  $d\sigma/d\Omega$   $\pi^0$  cross sections on the proton and the deuteron will be presented.

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

Parallel Session B / 111

## SAID Status

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Parallel Session B / 14

## Undressing the nucleon with photons

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Allowing arbitrary dressing mechanisms for both pions and nucleons, it is shown that combining the respective fully dressed propagators with fully dressed electromagnetic currents in a consistent manner *completely* removes all dressing effects from half-on-shell combinations of the form (propagator)  $\times$  (current). The key to this exact result is the realization that the coupling procedures for the electromagnetic field are necessarily different when applied to the respective scalar dressing functions of Dirac and scalar particles. This means, for example, that the usual gauge-invariant Ball-Chiu current ansatz for spin-1/2 particles suffers from an incomplete coupling procedure. Immediate and direct practical consequences for the descriptions of pion photoproduction off the nucleon and real Compton scattering processes on the pion and on the nucleon are discussed. For the latter processes, in particular, it is found that *all* dressing effects cancel exactly, *except* for contributions where hadrons loop around two photon insertion points.

Parallel Session B / 22

## Partial Wave Analysis of HADES Data for Two-Pion Production in Pion-Nucleon Reactions

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The High Acceptance DiElectron Spectrometer (HADES) [1], installed at GSI Helmholtzzentrum in Darmstadt, was designed to measure emissivity of dense and hot baryonic matter. The microscopic description of the emissivity requires understanding of baryon-virtual photon couplings which can be studied in NN and  $\pi$ -N reactions. The elementary collisions, especially those with pion beams, also offer a great opportunity to unambiguously fix the description of baryonic resonances and their coupling to the light vector mesons rho and omega, which plays an essential role in baryon  $\rightarrow$  N  $\gamma^*$  transitions. Therefore, to understand resonances production mechanisms a systematic energy scan and high precision data are needed.

In 2014 a large dataset of  $\pi$ -p scattering have been obtained at the four pion beam momenta 0.656, 0.69, 0.748 and 0.8 GeV/c [2,3]. Two pion final states,  $\pi^+\pi^-$  and  $\pi^-\pi^0$ , have been selected and investigated by the multichannel Partial Wave Analysis (PWA) developed by the Bonn-Gatchina group [4].

In this talk, total and a set of differential cross-section distributions of the two pion final states in a function of invariant masses, polar scattering, helicity and Gottfried-Jackson angles will be presented and compared to the PWA solutions. Moreover, separations of cross sections into dominant contributions like  $\Delta(1232)\pi$ ,  $N(938)\sigma$ ,  $N(938)\rho$ ,  $N(1440)1/2^+$  and  $N(1520)3/2^-$  will be shown. The special attention will be paid to the role of  $\rho$ -N coupling.

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[4] A.V. Sarantsev, JPS Conf. Proc. 10 (2016) 010005.

## Parallel Session B / 34

## Recent results of charged pion and kaon photoproduction on the proton at SPring-8/LEPS

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We have been carrying out photoproduction experiments by using linearly polarized tagged photon beams with energies of 1.5-2.9 GeV at SPring-8/LEPS. Charged pions and kaons were detected at forward angles. We studied the  $\gamma p \rightarrow \pi^- \Delta^{++}$ ,  $\pi^+ n$ , and  $K^+ \Lambda(\Sigma^0)$  reactions. In the final states of these reactions,  $u\bar{u}$ ,  $d\bar{d}$ , and  $s\bar{s}$  quark-antiquark pairs are produced, respectively. The differential cross sections and photon beam asymmetries were measured. It is interesting that only the  $\pi^- \Delta^{++}$  reaction is found to have negative asymmetries and the other reactions have positive asymmetries. In the  $\pi^- \Delta^{++}$  reaction, a d quark in the proton is replaced with a u quark. In the other reactions, a u quark is replaced with a d or an s quark. The difference in asymmetries might originate from different characteristics between the u and d quarks in the proton. We newly analyzed the data for the  $\gamma p \rightarrow \pi^+ \Delta^0$  reaction. The comparison between the  $\pi^- \Delta^{++}$  and  $\pi^+ \Delta^0$  reactions plays an important role for distinguishing  $N^*$  from  $\Delta^*$  in the s channel. We present preliminary results for the  $\pi^+ \Delta^0$  reaction in the NSTAR2019 workshop.

## Parallel Session B / 48

## $\eta'$ beam asymmetry at threshold using the BGO-OD experiment

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The unexpected nodal structure of the beam asymmetry recently reported by the GRAAL collaboration in  $\eta'$  photoproduction very close to threshold could be explained by a previously unobserved very narrow resonance. Therefore, the measurement is important to be independently confirmed.

This possibility is offered by the BGO-OD experiment. It is well suited for the detection of forward going charged particles which in the threshold region of interest allows the identification of the reaction  $\gamma p \rightarrow \eta' p$  solely based on the proton going in forward direction. This yields unprecedented statistics if in the missing mass analysis of the  $\eta'$  meson the background can be sufficiently well controlled. A linearly polarized photon beam produced via coherent bremsstrahlung off a diamond radiator makes it possible to measure the  $\eta'$  beam asymmetry.

In this talk I will present preliminary results on the determination of the  $\eta'$  beam asymmetry in several energy and angular bins close to threshold.

Supported by DFG (PN 50165297).

## Parallel Session B / 108

## Three-body system in a box

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Lattice QCD calculations provide an ab initial access to hadronic process. These calculations are usually performed in a small cubic volume with periodic boundary conditions. The infinite volume extrapolations for three-body systems are indispensable to understand many systems of high current interest. We derive the three-body quantization condition in a finite volume using an effective field theory in the particle-dimer picture. This work shows a powerful and transparent method to read off three-body physical observables from lattice simulations.

**Parallel Session B / 30**

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

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Two-pion production is a very rich inelastic channel in nucleon-nucleon collisions in the few energy range, as it carries unique information both on  $\pi^+\pi^-$  dynamics and on single and double baryon excitation. Precise data are therefore crucial to improve the description of hadronic or nuclear collisions which is mostly based on one meson production channels. Two pion production channels have been measured in the past over a rather broad energy range. However only a few experiments have provided high statistics data, especially above the  $\rho$  meson production threshold.

The High Acceptance Di-Electron Spectrometer (HADES) [1] installed at GSI in Darmstadt, designed to investigate dielectron production in heavy-ion collisions in the range of kinetic beam energies 1-3 A GeV is also an excellent detector for charged hadron detection. Recently, differential and integrated cross sections for the reactions  $pp \rightarrow pp\pi^0$ ,  $pp \rightarrow pn\pi^+[2-4]$ ,  $pp \rightarrow pp\pi^+\pi^-$ ,  $pn \rightarrow pn\pi^+\pi^-$  [5],  $pn \rightarrow d\pi^+\pi^-$  have been investigated with HADES at kinetic energies 1.25, 2.2 and 3.5 GeV.

This talk will focus on the analysis of the  $pp \rightarrow pp \pi^+ \pi^-$  channel at 3.5 GeV, using results from  $pp \rightarrow pp\pi^0$ ,  $pp \rightarrow pn\pi^+$  [3] and  $pp \rightarrow pK\Lambda$  [6] measured at the same energy by HADES. A consistent description of the different channels is achieved and the contributions of the excitation of one or two baryonic resonances with masses up to 1.9 GeV has been quantified. In addition, using specific kinematical cuts, the total production cross section and angular distribution of the  $\rho$  meson were also extracted. The differential cross sections are compared to theoretical models [7-8] and the resonance contributions are confronted to the inputs of transport models used for the description of nuclear collisions.

The obtained results on single and double baryon resonance contributions as well as  $\rho$  production provide valuable constraints for the interpretation of the dielectron spectra measured by the HADES collaboration. Baryonic resonances and  $\omega$  mesons are indeed important sources of  $e^+e^-$  pairs which are strongly coupled according to the Vector Dominance Model.

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**Parallel Session B / 110****Study of  $\bar{p} p \rightarrow \Xi^+ \Lambda K^-$  with the PANDA Detector****Authors:** Jennifer Pütz<sup>1</sup>; Albrecht Gillitzer<sup>1</sup>; James Ritman<sup>1</sup>; Tobias Stockmanns<sup>1</sup><sup>1</sup> *Forschungszentrum Jülich***Corresponding Author:** j.puetz@fz-juelich.de

For a deeper insight into the mechanisms of non-perturbative QCD it is essential to understand the excitation pattern of baryons. Up to now only the nucleon excitation spectrum has been subject to systematic experimental studies, while very little is known on excited states of double or triple strange baryons.

In studies of antiproton-proton collisions the PANDA experiment is well-suited for a comprehensive baryon spectroscopy program in the multi-strange sector. A large fraction of the inelastic  $\bar{p}p$  cross section is associated to final states with a baryon-antibaryon pair together with additional mesons, giving access to excited states both in the baryon and the antibaryon channel.

For final states containing a  $\Xi^+ \Xi^-$  pair, cross sections up to  $\mu\text{b}$  are expected, corresponding to production rates of  $\sim 10^6/\text{d}$  at a luminosity  $L = 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$ . This study focuses on excited  $\Xi$  states decaying into  $\Lambda K^-$ . A strategy to reconstruct the reaction  $\bar{p}p \rightarrow \Xi^+ \Xi^{*-}$  and its charge conjugate channel with the PANDA detector will be presented.

**Parallel Session C / 15****Radiative pion-photoproduction in covariant chiral EFT****Author:** Jan Rijneveen<sup>1</sup><sup>1</sup> *Ruhr-Universität Bochum***Corresponding Author:** jan.rijneveen@rub.de

Radiative pion-photoproduction is studied in the framework of covariant SU(2) chiral perturbation theory up to loop order. The effects of the delta (1232) resonance are studied in the “ $\epsilon$ ” power-counting scheme. Further, I will give an outlook how the magnetic dipole moment of the delta can be assessed with this reaction.

**Parallel Session C / 8****Towards a combined analysis of inclusive/exclusive electroproduction****Authors:** Astrid Hiller Blin<sup>1</sup>; Victor Mokeev<sup>2</sup>; Adam Szczepaniak<sup>3</sup>; Vincent Mathieu<sup>4</sup>; Cesar Fernandez Ramirez<sup>3</sup>; Volker Burkert<sup>5</sup>; V. V. Chesnokov<sup>6</sup>; Marc Vanderhaeghen<sup>7</sup>; A. A. Golubenko<sup>8</sup><sup>1</sup> *CERN*<sup>2</sup> *Thomas Jefferson National Accelerator Facility*<sup>3</sup> *Syracuse University (US)*<sup>4</sup> *Indiana University*<sup>5</sup> *Jefferson Lab*<sup>6</sup> *Skobeltsyn Nuclear Physics Institute and Moscow State University*<sup>7</sup> *Johannes Gutenberg Universität Mainz*



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The CLAS experiments have achieved major advances in the study of the  $N^*$  region of the electroproduction spectrum, and the data on electrocouplings of the many baryon resonances in the mass range up to 1.8 GeV showed consistency between the different meson channels. We present our theoretical studies of structure functions in view of the CLAS12 experiments planned in the near future, which are to study electron scattering observables at a wide  $Q^2$  range and with high precision in  $x$ .

We model the resonant contributions to inclusive electron scattering, using the electrocoupling data as input. Our results are thus not fitted to the inclusive data: instead, we use the reliable extraction of the separate resonance contributions from exclusive reactions. The combination of the resonance model with a non-resonant background based on Regge models will enable, for the first time, a combined description of the low and high- $x$  regions of the proton structure functions. This is useful for future endeavours on understanding the transition between low and high  $x$  regions, strongly related to tests on quark-hadron duality.

## Parallel Session C / 12

# Exploring the origin of mass using resonance electroproduction

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One of the greatest challenges within the Standard Model is to discover the source of visible mass. Indeed, this is the focus of a “Millennium Problem”, posed in 2000 by the Clay Mathematics Institute. The answer is hidden within quantum chromodynamics; and it is quite likely that revealing the origin of mass will also explain the nature of confinement. In addressing these issues, this presentation will reveal insights that have recently been drawn using contemporary methods to solve the continuum bound-state problem and how they have been informed and enabled by modern experiments on nucleon-to-resonance transition form factors.

## Parallel Session C / 23

# $K^+ \Lambda(1405)$ photoproduction at the BGO-OD experiment

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Since the discovery of the  $\Lambda(1405)$ , it remains poorly described by conventional constituent quark models, and it is a candidate for having an “exotic” meson-baryon or “penta-quark” structure, similar to states recently reported in the hidden charm sector.

The  $\Lambda(1405)$  can be produced in the reaction  $\gamma p \rightarrow K^+ \Lambda(1405)$ . The pure  $I=0$  decay mode into  $\Sigma^0 \pi^0$  is prohibited for the mass-overlapping  $\Sigma(1385)$ . Combining a large aperture forward magnetic spectrometer and a central BGO crystal calorimeter, the BGO-OD experiment is ideally suited to measure this decay with the  $K^+$  in the forward direction. Preliminary results will be presented.

\*Supported by DFG (PN 50165297).

#### Parallel Session C / 19

### The role of the triangle singularity in $\Lambda(1405)$ production in the $\pi^-p \rightarrow K^0 \pi \Sigma$ and $pp \rightarrow p K^+ \pi \Sigma$ processes

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We have investigated the cross section for the  $\pi^-p \rightarrow K^0 \pi \Sigma$  and  $pp \rightarrow p K^+ \pi \Sigma$  reactions paying attention to a mechanism that develops a triangle singularity. The triangle diagram is realized by the decay of a  $N^*$  to  $K^* \Sigma$  and the  $K^*$  decay into  $\pi K$ , and the  $\pi \Sigma$  finally merges into  $\Lambda(1405)$ . The mechanism is expected to produce a peak around 2140 MeV in the  $K\Lambda(1405)$  invariant mass. We found that a clear peak appears around 2100 MeV in the  $K\Lambda(1405)$  invariant mass which is about 40 MeV lower than the expectation, and that is due to the resonance peak of a  $N^*$  resonance which plays a crucial role in the  $K^* \Sigma$  production. The mechanism studied produces the peak of the  $\Lambda(1405)$  around or below 1400 MeV, as is seen in the  $pp \rightarrow p K^+ \pi \Sigma$  HADES experiment.

#### Parallel Session C / 29

### Studying time-like electromagnetic baryonic transitions with HADES in pion induced reactions

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A dedicated programme to study electromagnetic baryonic transitions in the time-like region has started using the pion beam and the HADES (High Acceptance Di-Electron Spectrometer) set-up at GSI [1].

First measurements have been performed in the second resonance region, at a center-of-mass energy of 1.49 GeV, using carbon and polyethylene targets, allowing for an analysis of the inclusive  $e^+e^-$  production and of the exclusive quasi-free  $\pi^-p \rightarrow ne^+e^-$  reaction. The  $e^+e^-$  yield at invariant masses larger than 300 MeV/c<sup>2</sup> strongly exceeds expectations based on real photon couplings, signaling the effect of baryon transition form factors of the Vector Dominance type. A quantitative description of the observed  $e^+e^-$  yield is achieved by estimating the contribution from off-shell  $\rho$ s deduced from a Partial Wave Analysis [2] of the two-pion production channels, which were measured simultaneously in our experiment. The angular distributions for the  $e^+e^-$  production contain additional selective information on the electromagnetic structure of the different transitions. An analysis based on the spin density matrix formalism, providing in particular quantitative information on the contribution of longitudinal virtual photons will be presented. The predictions of several models for the  $\pi^-p \rightarrow ne^+e^-$  reaction [3, 4, 5, 6, 7] will also be discussed.

Finally, the prospects for future experiments focusing on the third resonance region or on hyperon Dalitz decays will also be shortly presented.

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## Parallel Session C / 56

### Baryon Spectrum in Neutrino-induced Reactions

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The precise determination of neutrino properties in current and future accelerator-based oscillation experiments requires a good understanding and realistic modeling of neutrino interactions in the detectors: it is crucial to distinguish signal from background, reconstruct the neutrino energy and minimize systematic uncertainties. A significant fraction of the inelastic-scattering neutrino-nucleon cross section comes from the excitation of baryonic resonances. Pion production mediated by  $\Delta(1232)$  excitation is the most important inelastic process. Nonetheless, at current (NOvA) and future (DUNE) oscillation experiments, with neutrino fluxes in the few-GeV region, heavier baryonic excited states become important, leading to a variety of reaction channels such as multiple-pion, eta or strangeness production. The theoretical description of baryon resonance excitation, and meson production in general, currently relies on the input from their electromagnetic counterparts for the vector part of the interaction, while pion-nucleon scattering constrains the axial current at  $Q^2 = 0$  thanks to PCAC. The  $Q^2$  dependence of the axial current remains poorly known. Although the MINERvA experiment recently obtained valuable data on neutrino-induced pion production, final state interactions in the nuclear target ( $^{12}\text{C}$ ) hinder the extraction of reliable information about the elementary process, so that new measurements on hydrogen and deuterium are needed.

## Parallel Session C / 43

### KY electroproduction at CLAS12

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An experimental program has been approved at the Thomas Jefferson National Accelerator Facility to measure the  $(e, e'K^+)Y$  reactions using the CLAS12 setup in Hall B.

Data have been obtained using electron beams with energies of 6.5, 7.5, and 10.2 GeV, impinging upon a liquid hydrogen target in the CLAS12 center. Scattered electrons have been detected in an angle range of  $2.5^\circ$  to  $4.5^\circ$  by the Forward Tagger (FT) and at angles greater than  $6^\circ$  in the CLAS12 Forward Detector, allowing to measure the KY electro-production differential cross section and to probe the  $Q^2$  evolution of the *Nresonances electro-couplings in the  $Q^2$  range from 0.05 GeV<sup>2</sup> to 3 GeV<sup>2</sup>. The study of the  $Q^2$  dependence of the electro-couplings will provide a crucial tool to investigate the possible hybrid nature of the N resonances.* Preliminary results from CLAS12 data are compared with simulated data using a realistic Gent Regge plus resonance event generator.

## Parallel Session C / 53

### The prospect for studying $\pi\pi^+ \pi^0$ electroproduction off protons

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Investigation of double pion electroproduction channel is a very efficient tool for the study of nucleon resonances.

Many experiments have already provided a lot of data on the cross sections of the reaction  $\gamma_v p \rightarrow p' \pi^+ \pi^-$ . Their subsequent interpretation within the phenomenological model delivered valuable information on nucleon resonances electrocouplings.

Another promising channel with  $n \pi^+ \pi^0$  final state was not yet subject to the investigation with CLAS due to the limited angular coverage of  $\pi^0$  detection. The cross section of this so far unexplored channel benefits from larger relative resonant contribution comparing to the reaction with  $p \pi^+ \pi^-$  final state.

The study of a new channel requires an adaptation of the experimental analysis tools and the phenomenological reaction model which were previously established for  $\gamma_v p \rightarrow p' \pi^+ \pi^-$  channel. The status of this activity will be presented in the talk.

#### Parallel Session C / 45

### Spanning the Space-like and Time-like Divide

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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 have also begun in studying the time-like ( $q^2 > 0$ ) region at GSI. We initiated these discussions at the May 2017 ECT *workshop*, which was entitled *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.

#### Parallel Session C / 96

### NN

#### Parallel Session C / 17

### Spectrum and structure of octet and decuplet baryons and their positive-parity excitations

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A continuum approach to the three valence-quark bound-state problem in quantum field theory is used to compute the spectrum and Poincaré-covariant wave functions for all flavour- $SU(3)$  octet and decuplet baryons and their first positive-parity excitations. Such analyses predict the existence of nonpointlike, dynamical quark-quark (diquark) correlations within all baryons; and a uniformly sound description of the systems studied is obtained by retaining flavour-antitriplet-scalar and flavour-sextet-pseudovector diquarks. Thus constituted, the rest-frame wave function of every system studied is primarily  $S$ -wave in character; and the first positive-parity excitation of each octet or decuplet baryon exhibits the characteristics of a radial excitation. Importantly, every ground-state octet and decuplet baryon possesses a radial excitation. Hence, the analysis predicts the existence of positive-parity excitations of the  $\Xi$ ,  $\Xi^*$ ,  $\Omega$  baryons, with masses, respectively (in GeV): 1.75(12), 1.89(03), 2.05(02). These states have not yet been empirically identified. This body of analysis suggests that the expression of emergent mass generation is the same in all  $u$ ,  $d$ ,  $s$  baryons and, notably, that dynamical quark-quark correlations play an essential role in the structure of each one. It also provides the basis for developing an array of predictions that can be tested in new generation experiments.

Parallel Session C / 25

## The Discussion of $P_c$ states and the prediction of $J/\psi$ Photo-production

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We will provide the theoretical description of  $P_c$  states within coupled channel model. To provide information for the search of nucleon resonances with hidden charm  $P_c$  for the on-going experiments at JLab, we make predictions by including the resonant amplitude of  $\gamma p \rightarrow N_{c\bar{c}}^* \rightarrow J/\psi p$  calculated from all available theoretical models. The background is mainly from Pomeron-exchange model of the  $\gamma p \rightarrow J/\psi p$  reaction. The parameters of the Pomeron-exchange amplitudes are determined by fitting the total cross section data of  $\gamma p \rightarrow J/\psi p$  up to very high energy  $W = 300$  GeV. We then demonstrate that the  $P_c$  can be most easily identified in the differential cross sections at large angles where the contribution of background becomes negligible.

Parallel Session C / 50

## Photoproduction of mesons and Compton scattering on the proton: Selected high-precision results from the A2 Collaboration at MAMI

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The A2 Collaboration performs a manifold research program using real photons in the Crystal Ball/TAPS experiment at the MAMI accelerator facility in Mainz. The experiments take advantage of high-intensity unpolarized, linearly or circularly polarized photon beams, and unpolarized or polarized targets. The detector setup provides almost complete coverage in solid angle and is well suited

for the detection of multi-particle final states. In order to probe the internal structure of the nucleon, the spectrum of baryon resonances is studied via measurements of unpolarized cross-sections and various polarization observables in single and double meson photoproduction. The program aiming to determine the scalar and spin polarizabilities of the nucleons with high precision is performed with the Compton scattering experiments.

In 2018, the focal plane detector used in the tagging system of the Crystal Ball/TAPS experiment was completely renewed, allowing new measurements with unprecedentedly high precision. In this talk, recent results, the current status, and future plans for new experiments at MAMI will be presented.

#### Parallel Session C / 27

### Covariant nucleon-nucleon contact Lagrangian up to order $O(q^4)$

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We adopt a covariant version of the naive dimensional analysis and construct the two-nucleon contact Lagrangian constrained by Lorentz, parity, charge conjugation, and Hermitian conjugation symmetries. We show that at  $O(q^0)$ ,  $O(q^2)$ , and  $O(q^4)$ , where  $q$  denotes a generic small momentum, there are 4, 13, and 23 terms, respectively. We find that by performing  $1/m_N$  expansions, the covariant Lagrangian reduces to the conventional nonrelativistic one, which includes 2, 7, and 15 terms at each corresponding order. We also do some preliminary studies on nucleon-nucleon contact potentials.

#### Parallel Session C / 54

### Studying Isospin breaking and anomalous $\eta$ $\eta'$ - Decay Modes in Photoproduction with GlueX

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The  $\eta/\eta'$ -Meson is a unique tool to study low energy QCD phenomena and test models.

The isospin violating decay  $\eta \rightarrow \pi^+ \pi^- \pi^0$  is driven by the strong force and allows probing of the light quark masses, via measuring the corresponding decay amplitude. This amplitude is accessible either via a Dalitz-Plot or partial wave analysis. The latter one allows for a direct calculation of the quark mass ratio  $Q$  whereas the parameters from the Dalitz Plot analysis give insights into the decay dynamics and can be compared to theoretical calculations.

The decay  $\eta^{(\prime)} \rightarrow \pi^+ \pi^- \gamma^* [\gamma^* \rightarrow e^+ e^-]$  allows study of quantum anomalies, because its decay amplitude is driven by the box anomaly. However, final state interactions between the two charged pions are present and have to be taken into account when modeling the decay amplitude. CP-symmetry breaking effects can be tested by measuring the angle of the decay plane between the lepton and pion pair.

These  $\eta^{(\prime)}$ -decays have been produced and measured in the reaction  $\gamma p \rightarrow p\eta^{(\prime)}$  with the GlueX experiment, located at the Thomas Jefferson National Laboratory. GlueX finished the first phase of data taking in the winter last year. The second phase will start this fall with an upgraded setup including a DIRC-detector.

This talk will discuss the status and prospects of the analysis of the two decay modes within the GlueX data set, as well as the application of partial wave analysis.

#### Parallel Session C / 107

### ”Recent Progress in the Quark Models”

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Recent theoretical results on spectroscopy, helicity amplitudes and strong decays will be reviewed.

#### Parallel Session C / 104

### Meson-baryon Scattering in Extended-on-mass-shell Scheme up to NNLO

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In this present work, we study the scattering of a pseudoscalar meson off one ground state octet baryon in covariant baryon chiral perturbation theory up to the next-to-next-to-leading order. We remove the power counting breaking terms with the extended-on-mass-shell scheme. We perform the first combined study of the pion-nucleon and kaon-nucleon scattering data and show that the covariant baryon Chiral perturbation theory can provide a reasonable description of the experimental data for both channels.

#### Parallel Session C / 33

### Covariant calculations of $N^*$ Dalitz decays

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We present calculations of the electromagnetic transitions of the nucleon, to nucleon resonances  $N^*$ , namely the  $\Delta(1232)_{\frac{3}{2}}^{+}$ ,  $N(1520)_{\frac{3}{2}}^{-}$  and  $N(1535)_{\frac{1}{2}}^{-}$ . Our results for these  $\gamma^* N \rightarrow N^*$  reactions are based on a covariant quark model. In this contribution, we focus on the timelike regime — where the square momentum transfer is positive ( $q^2 > 0$ ) — which is the kinematic region of interest for heavy ion collisions experiments at intermediate energies.

In addition to effects from the valence quark degrees of freedom, we find parametrizations for meson cloud effects at low  $q^2$  values, which are determined by the dominant meson decay channels, and are also constrained by the empirical data in the spacelike region ( $q^2 < 0$ ).

The obtained theoretical transition form factors are used to calculate the Dalitz decay rates  $d\Gamma_{e^+e^-N}/dq$  for the resonances  $\Delta(1232)_{\frac{3}{2}}^{+}$ ,  $N(1520)_{\frac{3}{2}}^{-}$  and  $N(1535)_{\frac{1}{2}}^{-}$ , as well as the corresponding Dalitz decay widths  $\Gamma_{e^+e^-N}$ . The results from HADES suggest that the  $\Delta(1232)$  resonance dominate the Dalitz decay rates for the kinetic energies near 1 GeV. For larger kinetic energies, the impact of the  $N(1520)$  and  $N(1535)$  resonances are expected to increase.

Our theoretical results are compared with recent di-electron production data from the HADES Collaboration at GSI, on proton-proton ( $pp$ ),  $pA$  or  $\pi p$  scattering, where creation and propagation of intermediate  $N^*$  states occur ( $N^* \rightarrow \gamma^* N \rightarrow e^+e^-N$ ). We present results for the two isospin cases, i.e., for reactions with proton or neutron targets, for which experimental data from HADES can also be provided.

**Parallel Session C / 13**

## Nucleon-to-Roper electromagnetic transition form factors at large $Q^2$

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High-precision nucleon-resonance electroproduction data on a large kinematic domain of energy and momentum transfer have proven crucial in revealing novel features of strong interactions within the Standard Model and unfolding structural details of baryon excited states. Thus, in anticipation



of new data reaching to unprecedented photon virtuality, we employ a quark-diquark approximation to the three-valence-quark bound-state problem to compute  $\gamma p \rightarrow R^+$  and  $\gamma n \rightarrow R^0$  transition form factors on  $Q^2/mN^2 \in [0, 12]$ , where  $mN$  is the nucleon mass. Having simultaneously analyzed both charged and neutral channels, we also provide a quark-flavor separation of the transition form factors. The results should be useful in planning new-generation experiments.

Parallel Session C / 44

## Dilepton production and anisotropy in pion-nucleon collisions

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The study of virtual photon polarisation in time-like baryon electromagnetic transitions allows for the extraction of crucial information about the nature of particles and interactions at a fundamental level. Recent research has considered the transition  $\pi^- p \rightarrow n e^+ e^-$  with respect to the polarisation of the virtual photon, which has an impact on the angular distribution of the emerging lepton pair at a center of mass energy of  $\sqrt{s} = 1.49$  GeV [1], which matches the experiment at HADES (High Acceptance Di-Electron Spectrometer) at GSI [2]. A phenomenological model is used, based on effective Lagrangians [3] including the vector meson dominance model [4], which allows to split up the process into a production part  $\pi N \rightarrow N \gamma^*$  and a decay part  $\gamma^* \rightarrow e^+ e^-$ . We can calculate cross sections, analyse the angular distribution in terms of anisotropy coefficients and furthermore make predictions for the spin density matrix elements of the production process, which then can be compared to the experimental data. We have extended the abovementioned calculations to include the Born terms. Also, with new information on branching ratios of the intermediate nucleon resonances such as N1440, N1520, N1535,  $\Delta$ 1600 available, we are able to give an updated view on existing calculations. Furthermore we include higher mass resonances to provide calculations for higher beam energies at  $\sqrt{s} = 1.7$  GeV, which matches future experiments at HADES[2].

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Parallel Session C / 24

## $K^0 \Sigma^0$ photoproduction at the BGO-OD experiment

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The BGO-OD experiment at the ELSA accelerator facility uses an energy tagged bremsstrahlung photon beam to investigate the excitation structure of the nucleon in meson photoproduction.

The setup with a BGO calorimeter surrounding the target and an open dipole spectrometer covering the forward region is ideally suited for investigating low momentum transfer processes, in particular in strangeness photoproduction.

The associated photoproduction of  $K_S^0$  and hyperons is essential to understand the role of  $K^*$  exchange mechanisms.

A cusp-like structure observed in the  $\gamma p \rightarrow K_S^0 \Sigma^+$  reaction at the  $K^*$  threshold is described by models including dynamically generated resonances from vector meson-baryon interactions.

Such interactions are predicted to give a peak like structure in  $K_S^0 \Sigma^0$  photoproduction off the neutron.

This talk presents a preliminary analysis of the reaction  $\gamma n \rightarrow K_S^0 \Sigma^0$  from a new deuterium target dataset taken in 2018.

\*Supported by DFG (PN 50165297).

## Parallel Session C / 10

### Role of the $N(1535)$ in the $\Lambda_c \rightarrow \bar{K}^0 \eta p$ decay

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

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The nonleptonic weak decay of  $\Lambda_c \rightarrow \bar{K}^0 \eta p$  is analyzed from the viewpoint of probing the  $N(1535)$  resonance, which has a big decay branching ratio to  $\eta N$ . Up to an arbitrary normalization, the invariant mass distribution of  $\eta p$  is calculated with both the chiral unitary approach and an effective Lagrangian model. Within the chiral unitary approach, the  $N(1535)$  resonance is dynamically generated from the final-state interaction of mesons and baryons in the strangeness zero sector. For the effective Lagrangian model, we take a Breit-Wigner formula to describe the distribution of the  $N(1535)$  resonance. It is found that the behavior of the  $N(1535)$  resonance in the  $\Lambda_c \rightarrow \bar{K}^0 \eta p$  decay within the two approaches is different. The proposed  $\Lambda_c$  decay mechanism can provide valuable information on the properties of the  $N(1535)$  and can in principle be tested by facilities such as BEPC II and SuperKEKB.

## Plenary Session 1 / 37

### Strangeness photoproduction at the BGO-OD experiment

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Hadron spectroscopy has for many years been used to explore the excitation spectrum of the nucleon and the relevant degrees of freedom of the constituents. Despite the wealth of data there remain many “missing resonances” which are predicted by both quark models and Lattice QCD calculations, but are not observed experimentally.

Since the conception of the quark model, there have been descriptions of baryons and mesons of more than three and two constituent quarks respectively, giving rise to multi-quark entities often referred to as penta- and tetraquarks. These could manifest as single colour bound objects, or evolve from meson-baryon and meson-meson interactions, opening a possibility of molecular systems and meson re-scattering effects near production thresholds. Indeed, models including meson-baryon interactions have had improved success in describing both strange and non-strange resonance spectra. Similar models have also been used to describe the pentaquark baryon candidates and the XYZ

mesons in the “heavy” charmed quark sector. Intriguingly, there are early indications that similar configurations may manifest in the “light” strange quark sector.

To study such effects experimentally, access to a low momentum exchange region is crucial. The BGO-OD experiment at ELSA, comprised of a forward spectrometer and central calorimeter, is uniquely suited for the study of strangeness photoproduction in this region of forward meson angles. First key results at low  $t$  include line shapes and differential cross sections for  $\gamma p \rightarrow K^+ \Lambda(1405) \rightarrow K^+ \Sigma^0 \pi^0$ , and observation of a cusp-like structure in  $\gamma p \rightarrow K^+ \Sigma^0$  cross section at the  $\Lambda(1405)$  threshold.

## Plenary Session 1 / 62

### Recent highlights with baryons from lattice QCD

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Highlights of recent progress in baryon calculations in lattice QCD are presented.

## Plenary Session 1 / 65

### Theory of Baryon Resonances

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## Plenary Session 1 / 41

### Production of baryons, bound baryon systems and exotica with ALICE at the LHC

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The high energy pp, p-Pb, and Pb-Pb collisions at the LHC offer a unique opportunity to study with ALICE the production of baryons, baryon bound systems, exotica and the corresponding anti-particle states.

Their production yields can be well described within a statistical-thermal model approach, in which the yields depend only the mass and quantum numbers of the state and a single temperature describing the system formed in the collision. This can then be used to make robust predictions for exotic states production at LHC, allowing their existence to be probed.

The technique of femtoscopy studies the source size and dynamics through the correlations of commonly produced hadron pairs, with low relative momenta. It provides a complementary tool to determine the nature of the short-range interactions involving baryon pairs such as  $\Lambda$ ,  $\Sigma$ ,  $\Xi$ , and  $\Omega$  which are not accessible with ordinary scattering experiments.

Plans for the future LHC Run 3, scheduled to start in 2021, taking into account the expected improvements in terms of statistics and precision will also be presented.

**Plenary Session 1 / 69****Baryon decays and spectroscopy at BESIII****Corresponding Author:** fangss@ihep.ac.cn

Based on the world's largest samples of  $J/\psi$  and  $\psi'$  events accumulated at the BESIII detector, the recent results on baryon decays and spectroscopy will be presented. Also the perspectives on the baryon spectroscopy at BESIII will be discussed.

**Plenary Session 1 / 49****Baryon spectra and properties from functional methods****Author:** Christian Fischer<sup>1</sup><sup>1</sup> *JLU Gießen***Corresponding Author:** christian.fischer@physik.uni-giessen.de

In this talk I will give a general overview on recent results from several groups on the spectrum and properties of baryons as obtained in the framework of Dyson-Schwinger and Bethe-Salpeter equations.

I will discuss the spectrum of light baryons with focus on the comparison with quark model expectations, the impact of dynamical mass generation and explain the importance of relativistic components in the wave functions of baryons.

If time permits I will also discuss selected form factors.

Baryons do also have an impact on the QCD phase diagram at finite temperature and chemical potential. I will briefly explain their influence on the location of the critical end point of QCD.

Recent reviews on these topics can be found in

G. Eichmann, H. Sanchis-Alepuz, R. Williams, R. Alkofer and C. S. Fischer,

Prog. Part. Nucl. Phys. 91 (2016) 1

C. S. Fischer, Prog. Part. Nucl. Phys. 105 (2019) 1

**Plenary Session 1 / 77****Nucleon Electroexcitations and their Structure****Corresponding Author:** gothe@sc.edu**Plenary Session 1 / 89****COMPASS II****Corresponding Author:** bgrube@ph.tum.de**Plenary Session 1 / 88**

## Hyperon physics with PANDA at FAIR

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Plenary Session 1 / 94

## Precision Hadron Physics at MESA

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At Johannes Gutenberg University of Mainz, the new electron accelerator MESA (Mainz Energy-Recovering Superconducting Accelerator) for a new generation of fixed-target experiments, is currently under construction. In this talk we report on the status and the science case of MAGIX, which will be operated as an internal target experiment during the energy-recovery operation mode of MESA. The detector will consist of two high-resolution spectrometers.

Key experiments to be performed at MAGIX range from the measurement of electromagnetic form factors of the nucleon (proton radius puzzle) and of light nuclei to searches for low-mass particles of the dark sector. Furthermore, we also discuss the possibilities for a beam dump experiment at MESA, which opens the avenue for competitive searches for light dark matter particles.

Plenary Session 1 / 64

## N\* Experiments and their Impact on Strong QCD

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Plenary Session 2 / 103

## New Results in Strangeness Production with Polarization Observables

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Photoproduction of kaons can be regarded as the “golden channel” in the resonance region because of the opportunity to measure combinations of beam, target and recoil polarization. This talk will look at the impact of the recent results from CLAS and elsewhere, and in particular will describe the possibility of determining the weak decay parameter of the  $\Lambda$ . This study complements a recent result from BES, which measured a significantly different number to the value quoted in the PDG. Such a discrepancy has several consequences for hadron physics studies.

Plenary Session 2 / 60

## Probing the nucleon and strongly interacting matter at MAMI

**Authors:** Daniel Watts<sup>1</sup>; Crystal Ball at MAMI collaboration<sup>None</sup>

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The talk will give an overview of the current and planned research program of the A2@MAMI collaboration. Our research program utilises the intense energy-tagged real photon beam provided by the Mainz/Glasgow tagger in conjunction with the Crystal Ball/TAPS calorimeters, ancillary charged particle detector systems and a range of polarised and unpolarised cryogenic target systems. This infrastructure enables a broad scientific program relating to the structure of nucleons, nuclei and hadronic matter in general.

The talk will include preliminary results from our ongoing program aiming to better establish the nature and electromagnetic coupling of the  $d(2380)$  resonance, *whose existence has been evidenced in a range of nucleon-nucleon scattering reactions. The latest results from measurements of deuterium photodisintegration in the region of the  $d(2380)$*  with polarised photon beams and a large acceptance neutron recoil polarimeter will be presented.

Plenary Session 2 / 58

## Recent results from the CBELSA/TAPS experiment at ELSA

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In order to gain a better understanding of the dynamics inside the nucleon and of the non-perturbative regime of QCD, the nucleon excitation spectra and the properties of nucleon resonances are investigated. An essential experimental tool to achieve this goal is the study of different photoproduction reactions. Partial wave analyses are performed in order to obtain information about the contributing resonances. A complete experiment is needed to extract the underlying amplitudes unambiguously, which requires the measurement of carefully chosen single and double polarization observables in addition to the unpolarized cross section. The CBELSA/TAPS experiment in Bonn offers the possibility to measure several polarization observables using a linearly or circularly polarized photon beam and with a longitudinally or transversely polarized target. This talk gives an overview of recently measured polarization observables in different final states. The impact of the new data is discussed.

Plenary Session 2 / 70

## Overview PWA

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Plenary Session 2 / 72

## Theoretical Review of Pentaquark Structures

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Plenary Session 2 / 71

## Heavy Flavor Baryon Spectroscopy at LHCb

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Plenary Session 2 / 81

## Nuclear Femtography with CLAS12

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Plenary Session 2 / 106

## Different partial-wave analysis tools and recent results of the Jülich-Bonn model

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We give an overview of (some of) the different analysis tools and PWA approaches used to extract the spectrum of nucleon and Delta states from experimental data. Differences and similarities, e.g. in the construction of the amplitude or the data base, will be illustrated.

In addition, we show recent results of the Jülich-Bonn model, a unitary dynamical coupled-channel approach, and discuss the influence of kaon photoproduction on the resonance spectrum.

Plenary Session 2 / 93

## Non-strange baryons (CLAS)

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Baryon spectroscopy is an essential tool in the study of nucleon resonances. The spectrum of broad and overlapping nucleon excitations can be greatly clarified by use of polarization observables. The N\* program at Jefferson Lab with the CEBAF Large Acceptance Spectrometer (CLAS) includes experimental studies with linearly- and circularly-polarized tagged-photon beams, longitudinally- and

transversely-polarized nucleon targets, and recoil polarizations. An overview of these experimental studies and recent results will be presented.

## Plenary Session 2 / 32

# Exploring time like transitions in $pp$ , $\pi^- p$ heavy ion reactions with HADES

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Exploring time like transitions in  $pp$  and  $\pi p$  reactions with HADES

Piotr Salabura for the HADES collaboration

Radiative transition of an excited baryon to a nucleon with emission of a virtual massive photon decaying to electron-positron pair ( $R \rightarrow N + e^+e^-$  Dalitz decays) provides important insight into baryon-photon vertex at low  $q^2 = (m_{e^+e^-})^2$  in time-like region. A prominent enhancement in the respective electromagnetic Transition Form-Factors (eTFF) at  $q^2$  near the vector meson ( $\rho/\omega$ ) poles has been predicted by various calculations reflecting strong baryon-vector meson couplings (see for example [1]). The understanding of these couplings is also of great importance for the interpretation of the emissivity of QCD matter studied in heavy ion collisions via dilepton emission [2]. Indeed, model interpretations of thermal radiation rates measured below the vector meson poles show that the dominant contribution originate from  $\rho$  meson with a spectral function strongly modified by interactions with baryons in the fireball. Both aspects are studied by the HADES collaboration at GSI/FAIR by means of dedicated measurements performed with proton-proton, pion-proton and heavy-ion reactions.

The first measurements of the Dalitz decay of  $\Delta(1232)$  and of higher mass resonances in  $p+p$  collisions have been recently concluded [3, 4], indicating the important role played by  $\rho$  meson. Two-pion and, for the first time, dielectron production were studied in pion induced reactions on polyethylene and carbon targets in the second resonance region. The two-pion data have been analysed using the Bonn-Gatchina PWA together with results of other experiments allowing for the separation of resonance contributions and their decay channels. In particular the off-shell  $\rho$  meson contribution has been extracted providing an important constraint for the interpretation of dielectron invariant mass spectra measured in the same reaction. Angular distributions of emitted electrons have been also analysed allowing for the estimation of hadronic spin density matrix elements as a function of virtual photon emission angle, as suggested in [5]. They provide independent information about spin and parity of the involved resonances and about virtual photon polarization. This presentation will summarize most important results obtained in proton and pion induced reactions measured with HADES.

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