Baryons 2016

Monday 16 May 2016 - Friday 20 May 2016

Florida State University Alumni Center

Book of Abstracts
This book contains only abstracts which have been reviewed and accepted by the organizers. You can check the status of your pending abstract(s) on the conference website.
### Contents

- Baryon Spectroscopy at LHCb .................................................. 1
- \( \Lambda \)-baryon decays at LHCb ............................................. 1
- Baryonic \( B \) decays at LHCb ................................................. 1
- Wide Angle Compton Scattering using a Compact Photon Source .......... 1
- Photoproduction of mesons off the neutron .................................. 2
- Study of Nucleon’s Spin and parsonic dynamics with the Electron Ion Collider .......... 2
- Perspectives on baryons: from the inside out ................................ 3
- Baryon Chiral Perturbation Theory with 1/\( N_c \) expansion: masses and form factors of the baryon octet and decuplet ........................................ 3
- Forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions ................................................. 3
- First Rosenbluth separation of \( \pi^0 \) and photon electroproduction cross sections at Jefferson Laboratory-Hall A .................................................. 4
- Deeply virtual Compton scattering with CLAS12 ................................ 4
- The Charged Life of HDice at Jefferson Lab ................................... 4
- Impact of ATLAS measurements on the knowledge of the Proton structure .......... 5
- Methods of the Constituent Quark and Gluon Model to Calculate Hybrid Baryon States ........... 5
- Heavy flavour production and spectroscopy at ATLAS .................. 5
- Elastic form factors and the proton radius .................................. 5
- Measuring e/m transition form factors of light mesons with the A2 setup at MAMI .................................. 6
- Hadron-hadron scattering and hadron spectroscopy from lattice QCD .......... 6
- An overview of light meson decays ......................................... 6
- Probes of CP-violation and rare decays in the heavy flavour sector at ATLAS .......... 6
- An update on JPAC activities ............................................... 7
New results on nucleon resonance analysis of the $\gamma p \rightarrow \pi^+ \pi^- p$ cross sections in the
second and third resonance regions ........................................... 7

Baryon spectroscopy at BESIII .................................................... 8

Recent results from the Crystal Ball/TAPS experiment at MAMI .................... 8

Polarization Observables in Vector-Meson Photoproduction off Transversely-Polarized
Protons at CLAS (On behalf of the CLAS Collaboration) ........................... 9

Antibaryon Photoproduction using CLAS at Jefferson Lab .......................... 9

Toward a $K_L$ beam in Hall D at Jefferson Lab .................................. 9

Search for the $H$-dibaryon in the $(K^-, K^+)$ reaction ............................ 10

Interference effect between $\phi$ and $\Lambda(1520)$ production channels in the $\gamma p \rightarrow K^+ K^- p$
reaction near threshold .............................................................. 10

Exclusive Single Pion Electroproduction off the Proton: Recent Results from CLAS .................. 10

Form factors and decay width of $\Lambda_c$ semileptonic decay in constituent quark model ........ 11

Baryons from the chiral Lagrangian with three light flavors .......................... 11

Meson Spectroscopy of the $3\pi$ decay channel in $g12$ run of CLAS .................... 11

A search for supersymmetry at CMS with two photons and missing transverse energy at
$\sqrt{s} = 13$ TeV ................................................................. 11

Resonance production and decay in pion induced collisions with HADES .................... 12

Spectroscopy of Strange Baryons: Future Perspectives .................................. 13

Recent progress on TMD study and future perspective at the EIC ......................... 13

Physics with nuclei at an electron-ion collider ........................................ 13

Electroexcitation of Nucleon Resonances ............................................. 14

First Rosenbluth separation on $\pi^0$ at Jefferson Laboratory-Hall A ................... 14

Angular distribution of exclusive dielectron production in pion-nucleon collisions .......... 14

Strangeness photoproduction at the BGO-OD experiment ................................ 15

Photon electroproduction at Jefferson Laboratory-Hall A ............................ 15

Conversion Decays of Light Mesons .................................................. 16

Meson and Baryon Spectroscopy at GlueX ............................................ 16

Studies of Strange Sea distribution functions using Kaons with CLAS12 .................. 16

Tensor Polarized Deuteron at Jefferson Lab ........................................... 17

The Structure of the Neutron and the BoNuS Experiment ............................... 17
The international project FAIR: A status overview .................................................. 17
Physics with polarized beams at the EIC and detector designs ............................... 17
Hadron Physics at KLOE/KLOE-2 .............................................................................. 18
Photoproduction of \( \omega \) Mesons Using CLAS at Jefferson Laboratory ............... 18
Measurement of polarization transferred to a proton bound in nuclei ................... 18
Status and Future of PWA in Baryon Spectroscopy ............................................... 19
Cascade and Omega Spectroscopy at Jefferson Lab ............................................... 19
Understanding the basic features of cascade photoproduction ......................... 19
Determination of the Spin Triplet p\( A \) Scattering Length from the Reaction p\( A \) \( p \) \( K^+ \Lambda \) ................................................................. 20
Measurement of the double polarization observables E and G at the Crystal Ball experiment at MAMI ................................................................. 20
Collins asymmetry and proton form factors at BESIII ....................................... 20
Basis Light-Front Quantization Approach to Heavy Quarkonium ....................... 21
Recent Belle Results on Charmed Baryon Spectroscopy and Decays ................... 21
Three-flavor chiral effective model with four baryonic multiplets ......................... 21
Nucleon tomography in momentum space: TMDs .............................................. 22
A Solution to the Proton Radius "Puzzle" ............................................................... 22
Baryonic forces from SU(3) chiral effective field theory .................................... 22
\( \Delta(1232) \) resonance in the \( \gamma p \rightarrow p\pi^0 \) reaction at threshold .............. 23
Searching for d* Dibaryons with CLAS ................................................................. 23
\( \gamma n \rightarrow p\pi^- \) Cross Section Measurement at CLAS .................................. 23
Hyperon forward spin polarizability \( \gamma_0 \) in baryon chiral perturbation theory .... 24
Partial-Wave Analysis of the Reactions \( \gamma p \rightarrow \eta p, \gamma n \rightarrow \eta n, \) and \( \gamma p \rightarrow K^+\Lambda \) in a Multichannel Framework ...................... 24
\( b \)-baryon decays at LHCb .................................................................................... 24
Understanding the Nucleon as a Borromean Bound-State .................................... 25
Model discrimination in pseudoscalar-meson photoproduction .......................... 25
Superconformal baryon-meson symmetry and light front holographic QCD .......... 25
The Observation of a Di-Baryon in the Proton-Neutron System - Hexaquark or Molecule? .......................... 26

vii
Complete Experiments in pseudoscalar meson photoproduction

The Lambda(1405) and new non ordinary baryons

Measurement of the triple-differential cross section for photon + jet production at $\sqrt{s} = 8$ TeV with the CMS detector

A Dalitz plot analysis of the $\omega \rightarrow 3\pi$ decay

The Qweak Experiment: Direct Measurement of the Proton's Weak Charge

Proton Form Factor Ratio $G_E/G_M$ from the Double Spin Asymmetry

A Measurement of Proton Spin Structure Function $g_2$ at Low $Q^2$

XYZ exotic states at COMPASS

Measuring nucleon TMD spin-momentum correlations via Drell-Yan at Fermilab E906/E1039 SeaQuest Experiment

Light-cone QCD sum rules for soft contribution to exclusive Drell-Yan process $\pi^- p \rightarrow \mu^+ \mu^- n$

Baryon spectroscopy at BESIII

$\Lambda_c$ decays at BESIII

Collins FF and proton form factors at BESIII

Photoproduction of $\pi^- \Delta^{++}$ and $\pi^+ \Delta^0$ on the proton for comparing $\bar{u}u$ and $\bar{d}d$ productions at LEPS/SPring-8

Spectroscopy of Exotic Baryons at LHCb

Hadronic Physics in the NSAC Long Range Plan

Exotic baryons: past and future

Parity Violation in Deep Inelastic Scattering at Jefferson Lab

Cascade Baryon Spectroscopy with Kaon Beams

Search for Hybrid Baryons with CLAS12 at JLAB

Radiative and Hadronic Decay modes of the $\eta$-Meson with CLAS and WASA-at-COSY

Determination of $I^*$ and $F$ observables in $\eta$ photoproduction on the CLAS Frozen Spin Target (FROST)

Inclusive cross section and double-helicity asymmetry for $\pi^+$ production at midrapidity in $p+p$ collisions at $\sqrt{s}=510$ GeV

Polarization observables in double-pion photo-production with circularly polarized photons off transversely polarized protons

The GlueX/JEF program in Hall D at Jefferson Lab

Baryon Spectroscopy in Photonuclear Reactions
New results on nucleon resonance analysis of the $\gamma p \to \pi^+ \pi^- p$ cross sections in the second and third resonance regions .................................................. 45

Probes of CP-violation and rare decays in the heavy flavour sector at ATLAS .................. 46

$\Lambda_c$ decays at BESIII .................................................................................. 46

Form factors and decay width of $\Lambda_c$ semileptonic decay in constituent quark model .......... 46

Interference effect between $\phi$ and $\Lambda(1520)$ production channels in the $\gamma p \to K^+ K^- p$ reaction near threshold ................................................................. 46

$\bar{b}$-baryon decays at LHCb ...................................................................... 47

First Rosenbluth separation on $\pi^0$ at Jefferson Laboratory-Hall A ................................ 47

Studies of Strange Sea distribution functions using Kaons with CLAS12 ................................ 47

A Measurement of Proton Spin Structure Function $g_2$ at Low $Q^2$ ....................... 48

Proton Form Factor Ratio $G_E/G_M$ from the Double Spin Asymmetry ....................... 48

Photoproduction of $\pi^- \Delta^{++}$ and $\pi^+ \Delta^0$ on the proton for comparing $\bar{u}u$ and $dd$ productions at LEPS/SPring-8 ......................................................... 48

Polarization observables in double-pion photo-production with circularly polarized photons off transversely polarized protons ......................................................... 49

Determination of the Spin Triplet $p \Lambda$ Scattering Length from the Reaction $p \to pK^+ \Lambda$ .............................................................. 49

Measurement of Polarization Observables for the recoil hyperon $\Lambda$ in the reaction $\gamma p \to K^+ \Lambda$ for energies up to 5.45 GeV ......................................................... 49

Forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions ......................................................... 50

Baryonic forces from SU(3) chiral effective field theory ............................................. 50

Spectroscopy of Strange Baryons: Future Perspectives .............................................. 50

Photoproduction of Hyperons with Linear Polarised Photons at CLAS .......................... 51

The Spectrum and Structure of Baryon Excitations from Lattice QCD .......................... 51

Proton spin structure in phase space .................................................................. 52

Nucleon tomography in momentum space: TMDs ................................................. 52

Study of Nucleon’s Spin and parsonic dynamics with the Electron Ion Collider ............... 52

The Structure of the Neutron and the BoNuS Experiment ............................................. 52

Physics with polarized beams at the EIC and detector designs .................................... 53

Recent progress on TMD study and future perspective at the EIC ......................... 53

Physics with nuclei at an electron-ion collider ..................................................... 53
<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Productions of hyperons and charmed baryons</td>
<td>54</td>
</tr>
<tr>
<td>Toward a $K_L$ beam in Hall D at Jefferson Lab</td>
<td>54</td>
</tr>
<tr>
<td>Cascade Baryon Spectroscopy with Kaon Beams</td>
<td>54</td>
</tr>
<tr>
<td>Understanding the basic features of cascade photoproduction</td>
<td>55</td>
</tr>
<tr>
<td>Cascade and Omega Spectroscopy at Jefferson Lab</td>
<td>55</td>
</tr>
<tr>
<td>An overview of light meson decays</td>
<td>55</td>
</tr>
<tr>
<td>Hadron Physics at KLOE/KLOE-2</td>
<td>55</td>
</tr>
<tr>
<td>Measuring e/m transition form factors of light mesons with the A2 setup at MAMI.</td>
<td>56</td>
</tr>
<tr>
<td>Radiative and Hadronic Decay modes of the $\eta$-Meson with CLAS and WASA-at-COSY</td>
<td>56</td>
</tr>
<tr>
<td>The GlueX/JEF program in Hall D at Jefferson Lab</td>
<td>56</td>
</tr>
<tr>
<td>Conversion Decays of Light Mesons</td>
<td>57</td>
</tr>
<tr>
<td>Heavy Baryons on the Lattice</td>
<td>57</td>
</tr>
<tr>
<td>Baryon Spectroscopy at LHCb</td>
<td>57</td>
</tr>
<tr>
<td>Perspectives on baryons: from the inside out</td>
<td>57</td>
</tr>
<tr>
<td>Understanding the Nucleon as a Borromean Bound-State</td>
<td>58</td>
</tr>
<tr>
<td>Strangeness photoproduction at the BGO-OD experiment</td>
<td>58</td>
</tr>
<tr>
<td>Partial-Wave Analysis of the Reactions $\gamma p \rightarrow \eta p$, $\gamma n \rightarrow \eta n$, and $\gamma p \rightarrow K^+\Lambda$ in a Multichannel Framework</td>
<td>59</td>
</tr>
<tr>
<td>$\gamma n \rightarrow p\pi^-$ Cross Section Measurement at CLAS</td>
<td>59</td>
</tr>
<tr>
<td>Impact of ATLAS measurements on the knowledge of the Proton structure.</td>
<td>59</td>
</tr>
<tr>
<td>Light-cone QCD sum rules for soft contribution to exclusive Drell-Yan process $\pi^- p \rightarrow \mu^- \mu^+ n$</td>
<td>60</td>
</tr>
<tr>
<td>Measuring nucleon TMD spin-momentum correlations via Drell-Yan at Fermilab E906/E1039 SeaQuest Experiment</td>
<td>60</td>
</tr>
<tr>
<td>A Solution to the Proton Radius &quot;Puzzle&quot;</td>
<td>61</td>
</tr>
<tr>
<td>Hadron-hadron scattering and hadron spectroscopy from lattice QCD</td>
<td>61</td>
</tr>
<tr>
<td>Three-flavor chiral effective model with four baryonic multiplets</td>
<td>61</td>
</tr>
<tr>
<td>Methods of the Constituent Quark and Gluon Model to Calculate Hybrid Baryon States</td>
<td>62</td>
</tr>
<tr>
<td>$\Delta(1232)$ resonance in the $\gamma p \rightarrow p n^0$ reaction at threshold</td>
<td>62</td>
</tr>
<tr>
<td>Spectroscopy of Exotic Baryons at LHCb</td>
<td>62</td>
</tr>
<tr>
<td>Exotic baryons: past and future</td>
<td>62</td>
</tr>
</tbody>
</table>
Meson and Baryon Spectroscopy at GlueX ........................................ 62
Recent results from the Crystal Ball/TAPS experiment at MAMI .......... 63
Hyperon forward spin polarizability $\gamma_0$ in baryon chiral perturbation theory ........................................ 63
Hadron Spectroscopy with COMPASS ............................................. 64
Meson Spectroscopy of the $3\pi$ decay channel in $g_{12}$ run of CLAS .......... 64
$\Lambda(1405)$ Photoproduction at MAMI ........................................... 64
The international project FAIR: A status overview ......................... 65
The Charged Life of HDice at Jefferson Lab ........................................ 65
Tensor Polarized Deuteron at Jefferson Lab ......................................... 65
Searching for $d^*$ Dibaryons with CLAS ......................................... 65
The Observation of a Di-Baryon in the Proton-Neutron System - Hexaquark or Molecule? .......................... 66
Search for the $H$-dibaryon in the $(K^-, K^+)$ reaction ...................... 66
Search for Hybrid Baryons with CLAS12 at JLAB .............................. 67
Measurement of polarization transferred to a proton bound in nuclei .......... 67
New results on spin structure functions at very low momentum transfers from Jefferson Lab ........................................... 67
Collins asymmetry and proton form factors at BESIII ......................... 68
Deeply virtual Compton scattering with CLAS12 ............................... 68
Model discrimination in pseudoscalar-meson photoproduction ............... 68
An update on JPAC activities .......................................................... 69
Determination of $T$ and $F$ observables in $\eta$ photoproduction on the CLAS Frozen Spin Target (FROST) ........................................... 69
Measurement of the double polarization observables E and G at the Crystal Ball experiment at MAMI ......................... 70
Baryon spectroscopy at BESIII ....................................................... 70
Resonance production and decay in pion induced collisions with HADES ........................................... 70
Angular distribution of exclusive dielectron production in pion-nucleon collisions ........................................... 71
Antibaryon Photoproduction using CLAS at Jefferson Lab ..................... 71
Recent Belle Results on Charmed Baryon Spectroscopy and Decays ........... 72
Basis Light-Front Quantization Approach to Heavy Quarkonium ............. 72
Heavy flavour production and spectroscopy at ATLAS ............................................ 72
XYZ exotic states at COMPASS ................................................................. 73
Superfast quarks in collider experiments and QCD evolution ......................... 73
Measurement of the triple-differential cross section for photon + jet production at $\sqrt{s} = 8$ TeV with the CMS detector .......................................................... 73
Inclusive cross section and double-helicity asymmetry for $\pi^0$ production at midrapidity in p+p collisions at $\sqrt{s}=510$ GeV .......................................................... 74
A search for supersymmetry at CMS with two photons and missing transverse energy at $\sqrt{s} = 13$ TeV ............................................................................ 74
Superconformal baryon-meson symmetry and light front holographic QCD ........ 74
Parity Violation in Deep Inelastic Scattering at Jefferson Lab .......................... 75
Elastic form factors and the proton radius .......................................................... 75
The Lambda(1405) and new non ordinary baryons ............................................ 75
The Qweak Experiment: Direct Measurement of the Proton’s Weak Charge ....... 76
Baryon Spectroscopy at LHCb

Dr. SPRADLIN, Patrick

1 University of Glasgow

The LHCb experiment at the CERN Large Hadron Collider is collecting the world’s largest sample of charm and beauty hadrons with a detector that is tailored for precision measurements of their properties. LHCb is actively exploiting its unique data set to investigate the relatively unexplored field of the physics of heavy baryons. This talk will present selected recent results from the LHCb experiment with a focus on the spectroscopy and properties of beauty baryons.

b-baryon decays at LHCb

VECCHI, stefania

1 INFN - Ferrara

The decays of b-baryons to charmless final states proceed via suppressed b → u tree and b → s, d penguin diagrams and thus are sensitive to physics beyond the Standard Model. Relevant observables to study are branching fractions, CP asymmetries, triple-product asymmetries. Unexpected values of these observables have the potential to reveal New Physics. Moreover the sector is almost unexplored and peculiar to LHCb. In this work we present the latest results in the study of b-baryon decays performed by LHCb using the data sample collected during the first run of the LHC.

Baryonic B decays at LHCb

VECCHI, stefania

1 INFN - Ferrara

The mechanisms behind baryon production in decays of heavy flavoured particles remain mysterious and challenging to describe theoretically. Among the interesting features observed by previous experiments are the suppression of branching fractions to two-body final states and threshold enhancements in higher multiplicity decays. The large data sample accumulated by the LHCb experiment enables studies of all types of B mesons. The latest results on baryonic B decays are reviewed.

Wide Angle Compton Scattering using a Compact Photon Source

Author(s): Dr. NICULESCU, Gabriel
Co-author(s): Dr. WOJTSEKHOWSKI, Bogdan

1 James Madison University
2 Jefferson Lab

Testing of the QCD-based calculations of the fundamental exclusive reactions is the subject of large interest in hadron physics. Wide Angle Compton Scattering (WACS) of photons off a polarized proton target constitutes an excellent opportunity to carry out such tests. Recently concluded data analyses based on two Jefferson Lab experiments (E99-114 and E07-002) have demonstrated the validity of the experimental technique of using untagged photon beams on a proton target, and provided high accuracy cross-section and polarization observable results.
(KLL) at modest values of s, u, and t. This presentation will focus on a proposal to extend these precision measurements to much larger energies. The photons will be detected by the Neutral Particle Spectrometer and the protons by the Super Bigbite Spectrometer. The experiment will use the 11 GeV JLab electron beam and a novel high intensity untagged photon source. Projected results and their impact, as well as other potential uses for the photon source developed for this experiment will be discussed.

**Photoproduction of mesons off the neutron**

Prof. KRUSCHE, Bernd

1 University of Basel

Photoproduction of mesons has recently dominated the spectroscopy of of excited nucleon states. In particular, the accessibility of single and double polarization observables has given much momentum to this field. Results from the major facilities (CLAS at Jlab, ELSA in Bonn, and MAMI in Mainz) had large impact on the partial wave analyses of many different reactions and thus on our knowledge of the nucleon excitation spectrum. The vast majority of the experiments studied photoproduction off free protons. However, results from reactions off the neutron target are also required to fix the isospin structure of the photonuclear couplings. The experimental setups at the MAMI (Mainz) and ELSA (Bonn) accelerators based on almost 4π covering electromagnetic calorimeters are particularly well suited for the study of such reactions. The detectors allow to detect and identify photons from the decay of neutral mesons, charged pions, and also recoil protons and neutrons. In contrast to experiments based on magnetic spectrometry they are thus capable to identify also reactions with purely neutral final states such as γn → nπ^0, nη, nπ^0π^0, nπ^0π^0, nπ^0η,... Reactions with neutral mesons in the final state are of particular interest because non-resonant background contributions are much smaller than for charged mesons. During the last few years from both facilities results for total and differential cross sections and some results for beam-helicity asymmetries for three-body final states have been reported for the above mentioned reactions. The recently published data on the nπ^0 and nη final states demonstrate clearly the importance of measurements with neutron targets. In case of single pion production cross section data for all other isospin channels (pπ^0, pπ^−, nπ^+) were already available and since only three independent isospin amplitudes are involved this should be sufficient to fix the isospin structure completely. Nevertheless, different partial wave analyses predicted much different results for the nπ^0 state and actually none of them agreed with the new γn → nπ^0 data, which had significant impact on the isospin decomposition. The data for η production off the neutron revealed a prominent, narrow (less than 50 MeV wide) structure in the excitation function around incident photon energies of 1 GeV (statistical significance beyond any doubts), which does not exist for the proton. Many different scenarios have been discussed for it. Very recently, a second narrow structure around W=1720 MeV (which had been previously identified in Compton scattering off the proton) was identified. Currently, these measurements have reached a new level of sophistication with the measurement of double polarization observables for reactions off the quasi-free neutron. Most recent results for such observables will be reported from experiments using circularly polarized photon beams and longitudinally and transversely polarized targets. Among the results are the first split of the cross section of the γn → nη reaction into its helicity-1/2 and 3/2 parts (clearly demonstrating that the prominent narrow structure is in helicity 1/2), helicity contributions to single and double π^0 production (all in preparation for publication) and preliminary results for the T and F asymmetries for nη, nπ^0, and nπ^0π^0 final states.

**Study of Nucleon’s Spin and parsonic dynamics with the Electron Ion Collider**

Prof. DESHPANDE, Abhay

1 Stony Brook University

The Electron Ion Collider (EIC) was recently recommended by the US Nuclear Science Advisory Committee (NSAC) in its 2015 Long Range Planning, as the next major facility to be constructed

Page 2
in the US after the FRIB (the Facility for Radioactive Beams, currently under construction). The EIC will enable high-energy, high-luminosity polarized electron-polarized nucleon and unpolarized electron-nuclear collisions over a wide range in center of mass energy and nuclear species. In this talk I will focus on the potential for frontier QCD research at the EIC using its polarized beams, and elucidate how we could explore the nucleon’s spin structure as well as the partonic dynamics, potentially leading to 2+1 dimensional tomographic images of the nucleon. Complementarity of the EIC with current & future facilities around the world will be discussed, while highlighting the uniqueness of EIC’s abilities for this physics.

Plenary Session V - Wednesday / 21

Perspectives on baryons: from the inside out
Dr. ROBERTS, Craig¹

¹ Argonne

The last three years have seen significant developments in our understanding of the internal structure of ground- and excited-state baryons and the influence this has on their interactions with electromagnetic probes. That progress has been driven by feedback between experiment and theory, and constructive interactions between diverse theoretical methods. In particular, an accumulation of evidence suggests that many features of the baryon spectrum and interactions can be explained by the existence of tight but nonpointlike diquark correlations within baryons, whose formation is driven by the same mechanism that produces both an unnaturally light pion and simultaneously a heavy constituent-quark. This presentation will provide a snapshot of contemporary theory relating to these themes.

Recent Approaches to Non-Perturbative QCD I / 22

Baryon Chiral Perturbation Theory with 1/Nc expansion: masses and form factors of the baryon octet and decuplet

Author(s): Mr. FERNANDO, Ishara¹
Co-author(s): Prof. GOITY, Jose ¹

¹ Hampton University and Jefferson Lab

Work in progress on calculating masses, and vector and axial-vector current form factors for the low lying octet and decuplet baryons is presented. The framework used is heavy baryon ChPT supplemented with the constraints imposed by consistency with a 1/Nc power counting. The calculations are carried out in the power counting scheme where both M π,K,η and 1/Nc are considered to be quantities of O(ξ). In that scheme, the mentioned observables are evaluated to include sub-leading terms suppressed up to O(ξ³). The improvement of the expansion resulting from implementing the consistency with the 1/Nc power counting is discussed. Possible applications to recent results obtained in lattice QCD will be discussed.

Hadron-Hadron Interactions I / 23

Forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions

Prof. HOENEISEN, Bruce¹

¹ Universidad San Francisco de Quito

We present measurements of the forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions at sqrt(s) = 1.96 TeV recorded by the DO detector at the Fermilab Tevatron Collider. The data also confirm that the anti-lambda/lambda production ratio, measured by several experiments with various targets and a wide range of energies, is a universal function of “rapidity loss”, i.e., the rapidity difference of the beam proton and the lambda.
First Rosenbluth separation of $\pi^0$ and photon electroproduction cross sections at Jefferson Laboratory-Hall A
Dr. DEFURNE, Maxime

$^1$ CEA Saclay

We will present new results of $\pi^0$ and photon electroproduction cross sections in the valence region ($x_{Bj}=0.36$) at three $Q^2$-values (1.5, 1.75 and 2 GeV$^2$). Unlike the previous data sets, each kinematical setting was run with two beam energies. It allows to perform, for the first time, a Rosenbluth separation of the two processes. These new results bring new information about the generalized parton distributions and their contributions.

Deeply virtual Compton scattering with CLAS12
Dr. BISELLI, Angela

$^1$ Fairfield University

The Generalized Parton Distributions (GPDs) have emerged as a universal tool to describe hadrons in terms of their elementary constituents, the quarks and the gluons. Deeply Virtual Compton Scattering (DVCS) on a proton or neutron ($N$), $eN \rightarrow e'N'\gamma$, is one of the simplest processes that can be described in terms of GPDs. The amplitudes of DVCS and Bethe-Heitler, process where a photon is emitted by the incident or scattered electron, can be accessed via cross section measurements or exploiting their interference which give rise to spin asymmetries. Spin asymmetries, cross sections and cross-section differences can be connected to different combinations of the four leading order GPDs ($H$, $E$, $\tilde{H}$, $\tilde{E}$) for the two quark flavors depending on the observable and the type of target. This talk focuses on recent CLAS results and gives an overview of the upcoming experimental program on DVCS in Hall B at 12 GeV. Several experiments have been proposed to extend and improve the current measurements on polarized and unpolarized proton and as well as new measurements on neutron target. This program, once completed, will bring us a step closer to fully reveal the 3D quark structure of the nucleon.

The Charged Life of HDice at Jefferson Lab
Dr. HANRETTY, Charles

$^1$ Jefferson Lab

Polarized targets, especially of the frozen-spin variety, are highly valuable tools in the study of nucleon structure and the interaction mechanisms of its constituents. One such target, HDice, is a “next generation” target system operated at Jefferson Lab in Newport News, VA. This unique target is a quantum crystal of molecular HD in its solid phase. Both H and D can be polarized in true frozen-spin states, and spin can be transferred between H and D to optimize conditions for specific fixed-target experiments. Recently, the target has been used for the E06-101 N* run in Hall B (CLAS-6) using photon beams, with in-beam polarization lifetimes of years. Its potential for use with electron beams in CLAS-12 would open a window to a plethora of experiments; three A-rated experiments with transversely polarized HD have already been approved and designated as “high-impact” for Hall B. However, new polarization loss-mechanisms become active with charged-particle beams. Since the energy deposition in HD is nearly independent of the electron beam energy, polarization lifetimes can be studied with MeV-scale beams. A new 10 MeV accelerator is under construction at JLab and will be used to optimize the performance of the HDice target system with electrons. The principles of this complex target system, the aforementioned eHD test program, as well as HDice’s future use with CLAS-12 will be discussed.
**Impact of ATLAS measurements on the knowledge of the Proton structure**

CLAIRE, Gwenlan

1 Oxford

Several measurements performed by the ATLAS collaboration can be used to constrain the proton structure. Measurements of the $W^+c$ production and the inclusive $W$ and $Z$ differential cross sections are found to constrain the poorly known strange-quark density at low $x$. Similarly, the ratio of $W^+/W^-$ production is found to constrain the valence quarks at low $x$. New results will be presented using $W,Z$ production at 13 TeV. New precise measurements of Drell-Yan cross section measurements performed above the $Z$ peak region have a different sensitivity to parton flavour, parton momentum fraction $x$ and scale $Q$ compared to measurements on the $Z$ peak. A large impact is found on the photon content of the proton as well as high $x$ quarks. Measurements of the inclusive jet and photon cross sections are standard candles and constrain the medium and high $x$ gluon densities. New precise measurements of inclusive photon and jet cross sections at 8 TeV are presented and compared to various PDF predictions.

**Methods of the Constituent Quark and Gluon Model to Calculate Hybrid Baryon States**

Author(s): Mr. GROSS, Johnathan

1 Florida State University

Hybrid baryons are composite states composed of three quarks and at least one gluon. These states are allowed by quantum chromodynamics, but have so far not been detected. Lattice quantum field theory has proven extremely useful in calculating these states but are computationally intensive. The constituent quark model has been useful in calculating non-hybrid baryon states and should be just as useful for hybrid baryons. Methods of the constituent quark model and how they can be applied to hybrid baryons will be discussed.

**Heavy flavour production and spectroscopy at ATLAS**

Prof. ABBOTT, Brad

1 University of Oklahoma

ATLAS has a wide programme to study the production properties of conventional and exotic quarkonium, beauty, and charm bound states. This presentation will cover the latest results on $J/\psi$, $\psi2s$ and $\Upsilon$ production at 7, 8, and 13 TeV, $D$ meson production with Run-1 data, and $B^+$ production at 13 TeV. The latest results in the ATLAS programme of heavy hadron production and spectroscopy are also presented, including studies of $B_c$ and $\Lambda_b$ decays, and measurement of $b$-quark fragmentation functions.

**Elastic form factors and the proton radius**

Dr. ARRINGTON, John

1 Argonne National Laboratory
A new generation of measurements utilizing polarization degrees of freedom in electron scattering has dramatically improved our picture of the nucleon form factors, providing clearer pictures of the short-distance structure of the proton and neutron. In more recent years, there has been renewed interest in low-$Q^2$ measurements which focus on the nucleon’s large-scale structure including the charge and magnetic radii of the proton. Differences between these results and new measurements of the atomic levels in muonic hydrogen, have given us the proton radius puzzle, which is attracted intense interest. I will give an overview of the new insight that has been gained from these measurements, present an update on recent results, and discuss future plans to further improve our detailed understanding of nucleon structure and to resolve the proton radius puzzle. This work was supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH11357.

Light-Meson Decays / 124

**Measuring e/m transition form factors of light mesons with the A2 setup at MAMI.**

Dr. PRAKHOV, Sergey

1 UCLA

Electromagnetic transition form factors (e/m TFFs) for the $\eta \rightarrow e^+e^-\gamma$ and $\omega \rightarrow \pi^0 e^+e^-$ Dalitz decays have been measured in the $\gamma p \rightarrow \eta p$ and $\gamma p \rightarrow \omega p$ reactions, respectively, with the A2 tagged-photon facilities at MAMI. The results for the $\omega\pi^0$ TFF are in better agreement with phenomenological calculations compared to earlier experiments. The analyses of the $\pi^0 \rightarrow e^+e^-\gamma$ and $\eta' \rightarrow e^+e^-\gamma$ decays are in progress. New higher-statistics experiments for measuring the $\pi^0$ and $\omega\pi^0$ TFFs have been planned by the A2 Collaboration.

Recent Approaches to Non-Perturbative QCD I / 125

**Hadron-hadron scattering and hadron spectroscopy from lattice QCD**

Dr. BULAVA, John

1 Trinity College Dublin

Recent algorithmic advances in the treatment of quark propagation have enabled the precise determination of hadron-hadron scattering amplitudes directly from large-volume lattice QCD simulations for the first time. I will review current progress in the calculation of these amplitudes as well as the extraction of resonance parameters from lattice QCD data. As an illustrative example, a recent calculation of the pion-pion scattering amplitude in the rho resonance channel will be discussed. Finally, I will report on preliminary efforts toward the lattice calculation of resonance photoproduction amplitudes, in particular the timelike pion form factor.

Light-Meson Decays / 126

**An overview of light meson decays**

KAMPF, Karol

1 Charles University Prague

The light mesons play a prominent role in hadronic processes at low energies. In my talk I will focus on theoretical calculations within Chiral Perturbation Theory and Resonance Chiral Theory. I will for example discuss the importance of the decay constant $F_{\pi}$ and cover all decay modes of the lightest hadron: neutral pi.
EM and Weak Interactions I / 127

Probes of CP-violation and rare decays in the heavy flavour sector at ATLAS
Prof. PRELL, Soeren

1 Iowa State University

We present the results on CP-violation searches in the Bs system, studied in the decay into J/psi phi, and the Bd system through the comparison of the decay time distributions in the flavour specific state J/psi K* and in the CP eigenstate J/psi KS, both using the Run-1 LHC dataset. We additionally present new results in the search for the rare decays of Bs and Bd into mu+mu-. Such processes involve FCNC transitions in b-hadron decays, suppressed in the standard model, and are sensitive to new physics contributions. These searches are based on the full sample of data collected by ATLAS at 7 and 8 TeV collision energy. The consistency with the SM and with other available measurements is discussed.

Hadron Spectroscopy VI / 129

An update on JPAC activities

Author(s): Dr. PAUK, Vladislav
Co-author(s): Dr. MATHIEU, Vincent

1 JLab
2 Indiana University

The Joint Physics Analysis Center (JPAC) between Indiana University and Jefferson Lab is a theory group aimed for developing analysis tools for hadron spectroscopy. In this talk I’ll summarize recent activities of JPAC in hadron structure and spectroscopy. First, I’ll present a new method of experimental analysis of the proton electric form factor. The suggested approach is aimed for adding a missing puzzle in the proton radius problem. In particular, we propose to measure the proton form factor in the photo production of lepton pairs on a proton target. The comparison of the production rates for the electron versus muon pairs gives a direct access for testing the lepton universality and comparison of the proton radius extraction from the electron versus muon scattering type experiments. Furthermore, I’ll summarize recent JPAC efforts on hyperon spectrum and hidden charm pentaquark searches.

Hadron Structure I / 59

New results on nucleon resonance analysis of the $\gamma_vp \rightarrow \pi^+\pi^-p$ cross sections in the second and third resonance regions

Author(s): FEDOTOV, Gleb
Co-author(s): Dr. GOTHE, Ralf; Dr. MOKEEV, Victor; Dr. BURKERT, Volker

1 Moscow State University
2 University of South Carolina
3 Jefferson Lab

The studies of the $N^*$ electroexcitation amplitudes, the so-called $\gamma_vp\bar{N}^*$ electrocouplings, at photon virtualities $Q^2 < 5.0$ GeV$^2$ represent an important direction in the $N^*$ Program with the CLAS detector at Jefferson Lab. We report new results on nine one-fold differential cross sections of the $\pi^+\pi^-$ electroproduction off protons measured in the invariant mass range of the final hadron system $W$ from 1.3 GeV to 1.8 GeV and at photon virtualities from 0.4 GeV$^2$ to 1.0 GeV$^2$. Due to the high statistics, the cross sections have been extracted in 0.05 GeV$^2$ fine $Q^2$-bins, which is a factor of six narrower than previously achieved [1]. Furthermore, our measurements expand the range of covered photon virtualities towards smaller values in comparison to the previous
CLAS experiment [1]. These data on nine one-fold differential cross sections make it possible to establish all essential mechanisms contributing to the \( \pi^+\pi^-p \) exclusive channel from their manifestations in different observables, offering a credible separation between the resonant/non-resonant contributions, which allows for a reliable extraction of the \( \gamma_{\nu}pN^* \) electrocouplings as well as the \( N^* \) partial hadronic decay widths to the \( \pi\Delta \) and \( pp \) final states. We expect that the ongoing phenomenological analysis of our data within the framework of the meson-baryon reaction model JM [2,3] will improve the knowledge on \( \gamma_{\nu}pN^* \) electrocouplings for states with masses above 1.6 GeV, since many of them decay preferentially to the \( N\pi\pi \) final states. Resonance electrocouplings obtained from our data will offer a valuable cross-check of the resonance parameters determined from \( N\pi \) electroproduction channels confronting them with the results of an independent extraction from data of another major exclusive channel. Further evidence of the existence of the new \( N'(1720)3/2^+ \) state was recently obtained from a combined analysis of the CLAS \( \pi^+\pi^-p \) photoproduction and electroproduction data [4]. The electrocouplings of the \( \gamma_{\nu}pN'(1720)3/2^+ \) transition will be obtained from the precise electroproduction data set, which will help elucidate the internal structure of the new baryon state.


### Hadron Spectroscopy VIII / 58

#### Baryon spectroscopy at BESIII

**Dr. DE STEFANIS, Marco**

1 Università degli Studi di Torino and INFN

The BESIII experiment, hosted at the IHEP of Beijing, has collected the world largest data sample in the charmonium energy region. One of the most important physics goals of BESIII is the investigation of the QCD prediction. QCD can be accessed in a unique way by means of hadron spectroscopy. Charmonium decays provide an excellent scenario for studying nucleons, hyperons and their excited states, such as the \( N^* \), \( \Lambda^* \), \( \Sigma^* \) and \( \Xi^* \) resonances, as well as threshold production. The most recent results for baryon spectroscopy from BESIII will be discussed.

### Hadron Structure V / 55

#### Recent results from the Crystal Ball/TAPS experiment at MAMI

**Dr. SOKHOYAN, Vahe**

1 Institut für Kernphysik, University of Mainz

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. The long-term research programs performed with the Crystal Ball/TAPS experiment are diverse. 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. Studying the properties and decays of light mesons also represents an important part of the effort of the collaboration. Furthermore, experiments with light and heavy nuclear targets are carried out.
to search for the modifications of hadrons in the nuclear medium, using a novel experimental

The upcoming upgrade of the tagging system of the Crystal Ball/TAPS experiment will allow us to perform new measurements with unprecedentedly high precision. In this talk, recent results, the current status, and future plans for new high-precision experiments at MAMI will be presented.

**Hadron Spectroscopy I / 54**

**Polarization Observables in Vector-Meson Photoproduction off Transversely-Polarized Protons at CLAS (On behalf of the CLAS Collaboration)**

ROY, Priyashree

*Florida State University*

Studying the baryon spectrum is essential to understand the theory of the strong force, Quantum Chromodynamics (QCD), in the non-perturbative regime and to answer elementary questions such as what are the effective degrees of freedom inside baryons. Lately, photoproduction experiments have played a vital role in the understanding of the light baryon spectrum. But the spectrum is inadequately understood, particularly above 1.7 GeV c.m. energies where many resonances have been predicted by the constituent quark model as well as Lattice QCD calculations but have not yet been experimentally confirmed. It is anticipated that these resonances may predominantly couple to vector-mesons (ω, ρ, φ) and two-pion final states. These decay modes have been poorly explored in the past. The FROST (FROzen Spin butanol Target) experiment conducted in 2010 at Jefferson Lab using the CLAS detector, with center-of-mass energies between 1.5 and 2.3 GeV, has provided a good opportunity to study these decay modes. Here we report on preliminary results from the FROST experiment on the polarization observables for $\gamma p \rightarrow p\omega \rightarrow p\pi^+\pi^- (\pi^0)$ using transversely-polarized protons. Furthermore, preliminary results on the polarization observables for $\pi^+\pi^-$ photoproduction using linearly-polarized photons and transversely-polarized protons will be discussed. The latter reaction will give important information on the intermediate resonances that are involved in sequential decays to multipion final states as well as on the decay modes of the resonances to the $\rho$ vector-meson. Many observables presented here are first-time measurements and are expected to provide further constraints to identify the contributing baryon resonances to these final states.

**Hadron Spectroscopy VIII / 57**

**Antibaryon Photoproduction using CLAS at Jefferson Lab**

PHELPS, William

*Florida International University*

There is little known about the baryon-antibaryon photoproduction mechanism. Three reactions, $\gamma p \rightarrow pp\bar{p}$, $\gamma p \rightarrow pp\bar{p}\pi^-$, and $\gamma p \rightarrow pp\bar{p}\pi^+$ have been investigated for the photon energy range of 4.4-5.45 GeV. The data were from the g12 experiment taken with the CLAS detector using a liquid hydrogen target in Hall B at Thomas Jefferson National Accelerator Facility. This experiment had high statistics, with an integrated luminosity of 68 pb$^{-1}$. General features of the data and preliminary cross sections for the $pp\bar{p}$ system will be discussed.

**Physics of Hyperons / 56**

**Toward a $K_L$ beam in Hall D at Jefferson Lab**

TAYLOR, Simon

*Jefferson Lab*

Few baryons containing strange quarks have been observed experimentally in spite of the rich spectrum of hyperons predicted by quark models. In particular, the doubly-strange $\Xi$ states
are sparse with only a few with well-established mass, width and $J^P$ assignments and only the ground state $\Omega^-$ has firmly established quantum numbers. The field has largely stagnated for decades with some renewed interest in recent years. A $K_L$ beam has the advantage that it contains one unit of strangeness/anti-strangeness, thereby opening up new opportunities to study hyperon production. A plan is evolving to take advantage of the existing photon beam line and experimental hall in the Hall-D complex at Jefferson Lab to deliver a beam of $K_L$ particles onto a physics cryo-target within the GlueX detector. The recently constructed GlueX detector in Hall-D is a large acceptance spectrometer with good coverage for both charged and neutral particles that can be adapted to this purpose with a change to the size of the physics target. A preliminary conceptual design for production of a $K_L$ beam in Hall-D and simulations of interactions of the $K_L$ beam with a liquid hydrogen target inside the GlueX detector will be presented.

**Hadron Spectroscopy V / 51**

**Search for the $H$-dibaryon in the ($K^-, K^+$) reaction**

Prof. AHN, Jung Keun

1 Korea University

A recent claim from the LHCb collaboration on the observation of two hidden-charm pentaquark states revives hopes for experimental discoveries of other multiquark baryonic states such as the $H$-dibaryon with a 6-quark $(uuddss)$ configuration. Recent theoretical predictions for the mass of $H$-dibaryon pointing to the mass region near $\Lambda\Lambda$ threshold also encourage experimental searches. A dedicated experiment (J-PARC E42) has been proposed to search for the $H$-dibaryon in the bound and unbound mass regions near $\Lambda\Lambda$ threshold. The experiment is designed to measure production of $\Lambda p\pi^-$, $\Lambda\Lambda$ and $\Xi^- p$ systems in the $^{12}C(K^-, K^+)$ reaction with a 1-MeV mass resolution. A new large-acceptance spectrometer (Hyperon Spectrometer) is now under construction, consisting of a superconducting dipole magnet and a time projection chamber. The current status of the J-PARC E42 experiment will be presented. On the other hand, the $H$-dibaryon can be produced through $\Xi^- p$ fusion in the elementary $K^-(pp) \rightarrow K^+ \Xi^- p \rightarrow K^+ H$ reaction from $^{12}C$. Therefore, a fraction of di-proton pairs in relative $S$-wave state in $^{12}C$ is very interesting. A preliminary idea on the di-proton measurement via the $(p,p'2He)$ reaction will also be discussed.

**EM and Weak Interactions I / 50**

**Interference effect between $\phi$ and $\Lambda(1520)$ production channels in the $\gamma p \rightarrow K^+ K^- p$ reaction near threshold**

Author(s): Dr. RYU, Sun Young

Co-author(s): LEPS COLLABORATION

1 RCNP, Osaka University

The $\phi - \Lambda(1520)$ interference effect in the $\gamma p \rightarrow K^+ K^- p$ reaction has been measured for the first time in the energy range from 1.673 to 2.173 GeV at LEPS/SPring-8. The relative phases between $\phi$ and $\Lambda(1520)$ production amplitudes were obtained in the kinematic region where the two resonances overlap. The measurement results support strong constructive interference when $K^+ K^-$ pairs are observed at forward angles, but destructive interference for proton emission at forward angles. Furthermore, the observed interference effect does not account for the $\sqrt{s} = 2.1$ GeV bump structure in forward differential cross sections for $\phi$ photoproduction. This fact suggests possible exotic structures such a hidden-strangeness pentaquark state, a new Pomeron exchange and rescattering processes via other hyperon states.

**Hadron Structure I / 53**

**Exclusive Single Pion Electroproduction off the Proton: Recent Results from CLAS**
A probing the effective degrees of freedom in excited nucleon states at the varying distance scale is essential to understand the transition from the contributions of both quark core and meson-baryon cloud to the quark core dominance. Exclusive meson electroproduction off protons has been used extensively as a powerful tool. During the decade, the CLAS collaboration has executed a broad experimental program to study the excited states of the proton using polarized electron beam and both polarized and unpolarized proton targets with a broad kinematic range. In particular, several dedicated CLAS analyses using $\gamma^*p \rightarrow n\pi^+$ reaction have been utilized for the first time to explore the nucleon resonances with full range of invariant mass $W$ from near threshold to deep inelastic scattering. As results, several low-lying nucleon resonance states have been explored including $\Delta(1232)^{3/2+}$, $N(1440)^{1/2+}$, $N(1520)^{3/2-}$, and $N(1535)^{1/2-}$ states. In addition, the recent publication showed the differential cross sections for higher $W$ (1.6 to 2.0 GeV) and allowed to extract the $N(1675)^{5/2-}$, $N(1680)^{3/2+}$, and $N(1710)^{1/2+}$ states due to sensitivity of isospin $3/2$ within the same spin-parity assignments. In this talk, I will briefly discuss these states from CLAS results and future CLAS12 $N^*$ physics program.

Form factors and decay width of $\Lambda_c$ semileptonic decay in constituent quark model

Hussain, Md Mozammel

The form factors for semileptonic decay, $\Lambda_c \rightarrow \Lambda^*l\nu_l$ has been calculated in constituent quark model. Different excited states of $\Lambda^*$ has been studied. The heavy quark effective theory has been employed to compare numerical results for form factors. The decay width and branching fraction of the decay, $\Lambda_c \rightarrow \Lambda^*l\nu_l \rightarrow \Sigma\pi l\nu_l$ has been calculated for various excited states of $\Lambda$.

Baryons from the chiral Lagrangian with three light flavors

Author(s): Prof. Lutz, Matthias
Co-author(s): Dr. HEO, Yonggoo

In this talk I will review applications of the three-flavor chiral Lagrangian with the baryon octet and decuplet fields. On the one hand coupled-channel approaches are known to successfully grasp some baryon resonance properties with $J^P = 1/2^-$ and $3/2^-$ quantum numbers. On the other hand the quark-mass dependence of the baryon ground-state masses with $J^P = 1/2^+$ and $3/2^+$ can be computed and compared to QCD lattice simulations. It is argued that the two issues are intimately related and reliable computations should rest on a universal parameter set. An accurate reproduction of the available QCD lattice data on the ground-state baryon masses is achieved. The number of unknown parameters is reduced significantly by sum rules that follow from QCD in the limit of a large number of colors.

Meson Spectroscopy of the $3\pi$ decay channel in g12 run of CLAS

In this talk I will review applications of the three-flavor chiral Lagrangian with the baryon octet and decuplet fields. On the one hand coupled-channel approaches are known to successfully grasp some baryon resonance properties with $J^P = 1/2^-$ and $3/2^-$ quantum numbers. On the other hand the quark-mass dependence of the baryon ground-state masses with $J^P = 1/2^+$ and $3/2^+$ can be computed and compared to QCD lattice simulations. It is argued that the two issues are intimately related and reliable computations should rest on a universal parameter set. An accurate reproduction of the available QCD lattice data on the ground-state baryon masses is achieved. The number of unknown parameters is reduced significantly by sum rules that follow from QCD in the limit of a large number of colors.
Hadron-Hadron Interactions II / 88

A search for supersymmetry at CMS with two photons and missing transverse energy at $\sqrt{s} = 13$ TeV

**Author(s):** Mr. SANTRA, Arka
**Co-author(s):** Dr. ASKEW, Andrew $^1$; Dr. WEINBERG, Marc $^1$; Ms. REINSVOLD, Allison $^2$; Mr. TOPSIS-GIOTIS, Iasonas $^3$; Prof. HILDRETH, Michael $^2$

$^1$ Florida State University  
$^2$ University of Notre Dame  
$^3$ National Center for Scientific Research Demokritos

The missing transverse energy, potentially a sign of new physics, is a measure of the imbalance in the observed energy of an event. The Standard Model background prediction for the missing transverse energy in the two photon final state was determined using a data-driven technique, where different components of the background were estimated from different side-bands to the candidate two photon sample. This background was compared with the observed missing transverse energy distribution produced in proton-proton collisions, collected by the CMS Experiment at the CERN LHC at $\sqrt{s} = 13$ TeV. The results were then interpreted using simplified supersymmetry models.

Hadron Spectroscopy VIII / 89

Resonance production and decay in pion induced collisions with HADES

Dr. PRZYGODA, Witold$^1$

$^1$ Jagiellonian University in Krakow

Witold Przygoda for the HADES Collaboration

Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-348 Krakow, Poland

A major goal of the High Acceptance Di-Electron experiment (HADES) [1] at GSI is to study the electromagnetic properties of hadronic matter in the 1-3.5 GeV/nucleon incident energy range. The present interpretation of dilepton spectra measured in heavy-ion reactions at various energies is based on hadronic models, which predict in-medium modifications of the $\rho$ meson spectral function due to its coupling to resonance-hole states [2]. In the energy range of the HADES experiments, the $\rho$ meson is mainly produced in primary $NN$ or secondary $\pi N$ collisions, which opens the possibility to constrain the interpretation of medium effects by measuring dielectron emission in elementary reactions and better understand the relation between the couplings of the baryonic resonances to the $\rho$ meson and the electromagnetic structure of the corresponding baryonic transitions. Recently, HADES collected data in $\pi^- - N$ reactions at four different pion beam momenta (0.656, 0.69, 0.748 and 0.8 GeV/c) [3]. In this measurement two targets (polyethylene and carbon) were used with the aim to subtract events from scattering on carbon and identify pure contribution from scattering on protons. Exclusive channels with one pion ($\pi^- p$), two pions ($n\pi^+\pi^-$ and $p\pi^-\pi^0$) and dileptons ($ne^+e^-$) in the final state were identified. The normalization was done based on the elastic scattering ($\pi^- p$) channel with the cross sections taken from the SAID database [4]. Results for exclusive channels with two pions in the final state have been included in a combined partial wave analysis (PWA) of the Bonn-Gatchina group [5]. The obtained solution provides the excitation function of two-pion production around the pole of the $N\,(1520)D_{13}$ resonance with the decomposition into contributing channels, in particular coupling to the intermediate $\rho$ meson. The $\rho$ spectral distribution obtained from the partial wave analysis is used to compute the respective contribution to the exclusive $ne^+e^-$ channel, assuming strict Vector Meson Dominance. The results of this analysis will be presented.

References
Plenary Session III - Tuesday / 111

Spectroscopy of Strange Baryons: Future Perspectives

GILLITZER, Albrecht

1 IKP, Forschungszentrum Jülich

Understanding the excitation pattern of baryons is a prerequisite for a deeper insight in the properties of the strong interaction in the non-perturbative regime. The baryon spectroscopy programs at various laboratories based on photo-induced reactions in the recent years was very successful in enlarging our knowledge of the nucleon and Δ excitation spectrum, after, for many years, the data base had been essentially determined by results obtained in inelastic pion-nucleon collisions. On the other hand, in the sector of strange (Λ, Σ) and multi-strange (Ξ, Ω) baryons, the last decades have not seen any substantial experimental progress. Looking at the data base of excited Ξ and Ω states, we find that very little (in case of Ξ) or almost nothing is known (in case of Ω). In a constituent quark model picture, however, according to approximate SU(3) flavor symmetry, one would expect corresponding partner states of the known N and Δ states in the Ξ spectrum (and of the Δ states in the Ω spectrum). Proving or excluding the existence of these states will be important for understanding which degrees of freedom - three-quark, quark-diquark, or meson-baryon dynamics - are relevant for the baryonic excitation pattern. The presentation will give an overview showing the current knowledge of strange baryon resonances, and discuss different approaches to access in particular Ξ and Ω excited states in current and in planned experiments.

Spin Physics and Future Opportunities at the EIC / 110

Recent progress on TMD study and future perspective at the EIC

Dr. KANG, Zhongbo

1 Los Alamos National Laboratory

Transverse momentum dependent (TMD) parton distribution and fragmentation functions are novel theoretical concept, which provide information on the parton's intrinsic transverse motion, and thus present a path to three-dimensional nucleon tomography. In this talk, I will first review recent theoretical advances in TMD study. In particular, we discuss the current efforts and status in determining the TMD parton distributions and fragmentation functions from semi-inclusive deep inelastic scattering, e+e-, as well as p+p collisions. We then outline the future perspective at the future electron ion collider (EIC).

Spin Physics and Future Opportunities at the EIC / 113

Physics with nuclei at an electron-ion collider

Dr. EYSER, Oleg

1 Brookhaven Nat. Lab.

Experiments in the past decades have revealed an unexpected richness of nature as described by quarks and gluons in QCD. Nucleons exhibit a complex substructure that remains challenging for theory and requires precision measurements that disentangle the dynamics and contributions from different degrees of freedom, including spin and orbital angular momentum. At the same time, nucleons that are bound inside nuclei reveal a collective behaviour that under extreme
conditions leads to its own QCD substructure. Observations of a quark gluon plasma at the highest temperatures and densities in heavy ion collisions, where the relevant degrees of freedom are quarks and gluons, have lead to studies of condensed matter of the strong force and the self interaction of gluons. Similarly, high energy deep inelastic scattering has pointed towards a dominance of gluons towards low partonic momenta in the nucleon, where it is expected that the gluon density has to reach a non-linear region and saturate in order to not violate unitarity. This so called color glass condensate is supposed to be universal and well within the reach of an electron-ion collider, where the nucleus serves as an amplifier for the gluon density. The short range structure of nuclei can be analyzed over a wide range of partonic momenta and momentum transfer for a variety of light and heavy ion species.

Plenary Session I - Monday / 112

Electroexcitation of Nucleon Resonances
GOTHE, Ralf

1 University of South Carolina

Meson-photoproduction measurements and their reaction-amplitude analyses can establish more sensitively, and in some cases in an almost model-independent way, the nucleon excitations and non-resonant reaction amplitudes. However, to investigate the strong interaction from explored – where meson-cloud degrees of freedom contribute substantially to the baryon structure – to still unexplored distance scales – where quark degrees of freedom dominate and the transition from dressed to current quarks occurs – we depend on experiments that allow us to measure observables that are probing this evolving non-perturbative QCD regime over its full range. Transition form factors are uniquely suited to trace this evolution by measuring exclusive single-meson and double-pion electroproduction cross sections of the free proton. Recent efforts try to include their isospin dependence by analyzing the cross sections of the quasi-free neutron and proton in Deuterium. In the near future, these exclusive measurements will be extended to higher momentum transfers with the energy-upgraded CEBAF beam and CLAS12 to study the quark degrees of freedom, where their strong interaction is responsible for the ground and excited nucleon state formations. Recent and preliminary results will highlight the status of the analyses and of their theoretical descriptions, and an experimental and theoretical outlook will outline what shall and may be achieved in the new era of the 12-GeV upgraded transition form factor program.

This work is supported in part by the National Science Foundation under Grant PHY 1505615.

Hadron Structure II / 82

First Rosenbluth separation on \( \pi^0 \) at Jefferson Laboratory-Hall A
Dr. DEFURNE, Maxime

1 CEA Saclay

Although being a higher-twist contribution, the transverse response was assumed to be responsible of the large \( \pi^0 \) electroproduction cross sections measured by the Hall A and CLAS collaboration. However no Rosenbluth separation has been performed yet to verify this assumption. We will present new results of \( \pi^0 \) electroproduction cross sections in the valence region (\( x_{Bj} = 0.36 \)) at three \( Q^2 \)-values (1.5, 1.75 and 2.0 GeV\(^2\)). Unlike the previous data sets, each kinematical setting was run with two beam energies. It allows to perform, for the first time, the separation of the longitudinal and transverse contributions.

Hadron Spectroscopy VIII / 83

Angular distribution of exclusive dielectron production in pion-nucleon collisions
A study of the angular distribution of the dilepton produced in the reaction $\pi N \rightarrow Ne^+e^-$ is presented [1]. Effective interactions describing only the physical degrees of freedom for baryon resonances up to spin-5/2 are employed to compute the spin-anisotropy coefficient for isolated intermediate baryon resonances. It is shown that a given spin-parity state of the intermediate resonance exhibits a characteristic angular dependence of the spin-anisotropy coefficient. Furthermore, the spin-anisotropy coefficient resulting from the interference between resonances with different spin and parity is presented. Our results show that the spin-anisotropy coefficient can help disentangle the resonance contributions to the process [2]. Moreover, it is argued that the study of polarization observables can provide information on the production process and equilibration mechanism in heavy-ion collisions.


Hadron Spectroscopy III / 80

Strangeness photoproduction at the BGO-OD experiment

Dr. JuDe, Thomas

1 University of Bonn

The BGO-OD experiment at the ELSA accelerator facility uses an energy tagged bremsstrahlung photon beam to investigate the excitation structure of the nucleon. The setup consists of a highly segmented BGO calorimeter surrounding the target, with a particle tracking magnetic spectrometer at forward angles. Compared to constituent quark models (CQMs), models including pseudoscalar meson-baryon interactions have had improved success in describing baryon excitation spectra. Vector-meson baryon interactions have also been predicted to dynamically generate states, which may have been observed in photoproduction reactions. BGO-OD is ideal for investigating low momentum transfer processes due to the acceptance and high momentum resolution at forward angles. This enables the investigation of degrees of freedom not derived from CQMs, and in particular, strangeness photoproduction where $t$-channel exchange mechanisms play an important role. The ability of the BGO-OD to reconstruct final states of mixed charge also renders the experiment ideal for the investigation of higher lying hyperon states, for example $\Lambda(1405)$. With the first major data taking periods for BGO-OD complete, an extensive programme for the investigation of associated strangeness photoproduction has begun. This includes final states with charged and neutral kaons, for the investigation of ground level and excited hyperons. Data has also been taken with a deuterium target for the investigation of neutral channels such as $K^0\Lambda$ and $K^0\Sigma^0$. The current status of analysis and perspectives will be presented. Supported by DFG (SFB/TR-16).

Hadron Structure I / 81

Photon electroproduction at Jefferson Laboratory-Hall A

Dr. Defurne, Maxime

1 CEA Saclay

We will review the experimental program dedicated to photon electroproduction running in the Hall A of Jefferson Laboratory. First we will talk about the latest results of the E00-110
experiment running in 2004, published in Phys.Rev.C last year. Then we will present new results of photon electroproduction cross sections in the valence region ($x_{Bj} = 0.36$) at three $Q^2$-values (1.5, 1.75 and 2 GeV$^2$) from the E07-007 experiment which was running in 2010. Unlike the E00-110 experiment, each kinematical setting was run with two beam energies. It allows, for the first time, to perform a Rosenbluth separation on the photon electroproduction. These new results bring new information about the generalized parton distributions and their contributions.

**Light-Meson Decays / 119**

**Conversion Decays of Light Mesons**  
SCHADMAND, Susan$^1$

$^1$ Forschungszentrum Juelich

We focus on the Dalitz decays of eta and omega mesons used for the experimental determination of electromagnetic transition form factors. The analyses are using data obtained with the WASA-at-COSY and the CLAS detectors.

---

**Plenary Session VI - Thursday / 118**

**Meson and Baryon Spectroscopy at GlueX**  
CHUDAKOV, Eugene$^1$

$^1$ Jefferson Lab

The commissioning of the GlueX experiment in Hall D at Jefferson Lab has been completed and the the first physics run is scheduled for the Fall of 2016. The primary goal of the experiment is a search for gluonic excitation in the spectra of light mesons. Recent theoretical developments using Lattice QCD predict hybrid states, including those with exotic quantum numbers. Such states, if established, would provide a laboratory for testing QCD in the confinement regime. The experiment is using a beam of linearly polarized photons produced by the electron beam from the linear accelerator. A new, solenoid-based, hermetic detector is collecting data on meson production and decays. At the second stage of running, after 2018, the spectrometer will be equipped with an additional detector for particle identification. This will allow also to study the spectroscopy of strange baryons. For a more distant future, a possibility to build a beam of K-long mesons in the same beam line is being discussed. Such a beam would add new capabilities for doing strange-baryon spectroscopy. A description of the research program, the apparatus, and the commissioning results will be presented.

---

**Hadron Structure II / 84**

**Studies of Strange Sea distribution functions using Kaons with CLAS12**  
**Author(s):** Prof. BENMOKHTAR, Fatiha$^1$  
**Co-author(s):** Mr. TROTTA, Richard $^1$ ; Mr. TORISKY, Benjamin $^1$

$^1$ Duquesne University

The understanding of the spin structure of the nucleon in terms of quarks and gluons has been the goal of intense investigations during the last decades. The techniques of inclusive and semi-inclusive polarized deep-inelastic scattering employed at CERN, SLAC, DESY, and Jefferson Lab have provided a wealth of information about the spin structure of the nucleon. The determination of strangeness is challenging and the only way of determining the strange distribution accurately from data is to include semi-inclusive information. This talk is focused on the determination of the strange sea contribution to the nucleon spin through the pseudo-scalar using semi-inclusive Kaon detection technique with CLAS12 at Jefferson Lab. The method will be explained and the expected precision of the measurements will be presented.
Tensor Polarized Deuteron at Jefferson Lab
Dr. LONG, Elena

1 University of New Hampshire

With the development of a new solid DNP spin-1 tensor-polarized target, interest has been growing to explore physics that can be extracted using such a target. In the DIS region, HERMES data measured the b1 structure function at a surprising large, negative value that cannot be explained using conventional models but only with novel physics such as 6-quark hidden color effects. A new experiment at JLab will confirm the HERMES data as well as map out the region of zero-crossing. Additionally, in the quasi-elastic region, tensor polarization experiments can be used to better understand the deuteron’s S/D wavefunction ratio, probe the tensor force that’s expected to be the source of short range correlations, and provide a crucial test of relativistic light-cone and virtual-nucleon models. A second experiment at JLab will probe this quasi-elastic tensor structure of the deuteron. An overview of this emerging tensor program will be discussed.

The Structure of the Neutron and the BoNuS Experiment
Dr. NICULESCU, Gabriel

1 James Madison University

Since the late 60’s inclusive electron-nucleon scattering has proven a rich source of information on the internal structure of nucleons and nuclei. While both electron-proton and electron-neutron interactions are equally important, as they provide access to different linear combinations of the underlying quark distributions, the latter type of studies have been hindered by the lack of a neutron target. The existing neutron results have been obtained by subtracting suitably smeared proton data from deuteron/light nuclei distributions, which are prone to uncertainties due to nuclear binding effects. The Jefferson Lab BONuS experiment addresses this problem using a detector capable of detecting spectator protons stemming from e+d interaction down to 70 MeV/c. F2 structure function results (and moments thereof) obtained during the 6 GeV era of Jefferson Lab using this technique will be presented. Progress on follow-on experiment BoNuS12, identified as one of the top priority experiments in the 12 GeV era, will also be discussed, as well.

The international project FAIR: A status overview
Dr. NICMORUS, Diana

1 FAIR

The new international accelerator facility FAIR under construction in Darmstadt aims at studying matter at atomic, nuclear and hadronic levels. I will review several important aspects towards the realization of the Facility for Antiproton and Ion Research, and discuss recent developments. I will present the focus of the experimental programmes - hadron physics, nuclear structure and compressed nuclear matter physics, plasma and atomic physics, as well as related applications.

Physics with polarized beams at the EIC and detector designs
Dr. FEEGE, Nils

1 Stony Brook University
The Electron Ion Collider (EIC, arXiv:1212.1701.v3) will allow for precision measurements of the partonic and spin structure of nucleons and the partonic structure of nuclear matter using high energy, high luminosity electron-proton and electron-ion collisions, respectively. The electron, proton, and light ion beams at the EIC will be polarized. Together with recent advances in theoretical frameworks achieved for transverse momentum dependent parton distributions (TMDs) and generalized parton distributions (GPDs), these measurements promise to yield multi-dimensional maps of the momentum and spatial distribution of partons inside hadrons. Furthermore, the EIC will provide new insights into how quarks and gluons give rise to overall nucleon properties like spin. Well designed experiments integrated into the interaction region are the key to unlock this physics potential. In this talk, I will present the physics addressed with polarized beams at the EIC and detector concepts currently being evaluated for this facility.

Light-Meson Decays / 100

Hadron Physics at KLOE/KLOE-2
Dr. PEREZ DEL RIO, Elena

1 LNF-INFN Laboratori di Frascati

The KLOE experiment, operating at the Phi-factory DAFNE in Frascati, has a large statistical sample, consisting of 2.5 fb$^{-1}$ and 250 pb$^{-1}$ on- and off- the Phi meson peak respectively. The large data sample of light meson available allows for precise measurements on decay dynamics, transition from factors and searches of new physics. Furthermore, the KLOE2 experiment, with an improved detector, has started operation by the end of 2014 with the aim of collecting up to 5 fb$^{-1}$ in the next year. Recent results on the KLOE data will be presented.

Hadron Spectroscopy I / 101

Photoproduction of $\omega$ Mesons Using CLAS at Jefferson Laboratory

AKBAR, zulkaida

1 Florida State University

The spectrum and properties of the excited states of baryons reveal the dynamics and degrees of freedom of the interaction within them. Higher-lying excited states are generally predicted to have strong couplings to a heavier meson, e.g. one of the vector mesons, $\rho$, $\omega$, $\phi$. Therefore, vector-meson studies are important to search for the so-called missing baryon resonances. Photoproduction of $\omega$ mesons was studied using the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab. Two observables have been measured from the reaction $\gamma p \rightarrow p \omega$: The differential cross section and the double-polarization observable E. The differential cross section measurement was performed using circularly-polarized photons produced from bremsstrahlung of longitudinally-polarized electrons with energies of 5.7 GeV, incident on an unpolarized liquid hydrogen target. The double-polarization observable E was measured using circularly-polarized photons for an energy range up to 2.4 GeV and a longitudinally-polarized frozen-spin butanol target. The differential cross section as well as the polarization observable allow us to find $N^*$ resonances decaying to $p\omega$ through multi-channel Partial Wave Analysis (PWA) that has been developed for the omega channel. The observables also provide a probe to test theoretical models on the production mechanism of $\omega$ mesons and also the scaling behaviour of the cross section. We found that the $\gamma p \rightarrow p\omega$ differential cross section at higher energies exhibits a scaling behavior as predicted by pQCD.

Measurement of polarization transfered to a proton bound in nuclei

Prof. PIASETZKY, Eli
Possible differences between free and bound protons may be observed in the ratio of polarization-transfer components. We report the measurement of this ratio on deuteron at low and high missing momenta. Observed increasing deviation of the measured ratio from that of a free proton as a function of the virtuality, similar to that observed in $^4\text{He}$, indicates that the effect in nuclei is due to the virtuality of the knock-out proton and not due to the average nuclear density. The measured differences from calculations assuming free-proton form factors (about 10%), may indicate in-medium modifications. Preliminary data on proton removed from carbon will also be presented.

**Plenary Session II - Monday / 104**

**Status and Future of PWA in Baryon Spectroscopy**

**Author(s):** Prof. DORING, Michael$^1$

**Co-author(s):** Dr. RÖNCHEN, Deborah $^2$ ; Prof. WORKMAN, Ron $^3$

1. George Washington U and Jefferson Lab
2. HISKP, Bonn University
3. George Washington University

Light baryonic resonances are generally broad and overlap which makes their identification difficult. Furthermore, many resonances couple only weakly to the $\pi N$ state that was traditionally the prime channel for spectroscopy. Photoproduction of one or more mesons provides access to new resonances predicted in QCD simulations, in particular through polarized measurements. The impact of new data from Jefferson Lab and other facilities will be discussed. Obtaining conclusive answers in baryon spectroscopy is a long-sought goal requiring improved statistical analysis techniques as the era of precision spectroscopy has begun.

**Cascade and Omega Spectroscopy at Jefferson Lab**

Dr. GUO, Lei$^1$

1. Florida International University

Compared to the tremendous experimental progress made in the nucleon resonances, the advances in cascade and Omega spectroscopy have been scarce. The large amount of photoproduction data that have been collected in the past decade by the CLAS collaboration, and the next generation of experiments to be performed at the upgraded facilities at Jefferson Lab, will make it possible to investigate the photoproduction mechanisms of these baryon states with multiple strange quarks with unprecedented statistics in terms of both cross section and polarization measurements. It could also be possible to discover the missing $S=-2$ and $S=-3$ states as expected by various quark model predictions and Lattice QCD calculations. The incoming Very Strange Experiment at CLAS12 using the Forward Tagger, and the cascade spectroscopy program at GlueX will be discussed.

**Understanding the basic features of cascade photoproduction**

Prof. NAKAYAMA, Kanzo$^1$

1. University of Georgia

The photoproduction of cascade baryons off nucleons is discussed. It is a part of our theoretical effort in connection to the cascade baryon spectroscopy program at the Thomas Jefferson National
Accelerator Facility (JLab). Specifically, the reaction $\gamma N \rightarrow K K \Xi$ is investigated, in conjunction with the $K$-induced reaction $\bar{K} + N \rightarrow K \Xi$, within a relativistic hadron exchange model of strong interactions. The latter reaction is planned to be studied at J-PARC; it can also be studied at JLab if the secondary $K_L$ beam becomes available. The basic features of these reactions and their manifestations in some of the observables will be discussed.

Hadron Spectroscopy II / 38

Determination of the Spin Triplet $p\Lambda$ Scattering Length from the Reaction $p[U+20D7] p \rightarrow pK+ \Lambda$

HAUENSTEIN, Florian$^1$

$^1$ IKP, Forschungszentrum Juelich

The $\bar{p}p \rightarrow pK^+\Lambda$ reaction was measured with the COSY-TOF detector using a polarized proton beam of 2.7 GeV/c. From these data the $p\Lambda$ scattering length can be extracted from the final state interaction in the $p\Lambda$ invariant mass spectrum. Furthermore, it is possible to determine not only the spin averaged scattering length but also the spin triplet $p\Lambda$ scattering length utilizing the dependence of the Kaon analyzing power on the $p\Lambda$ invariant mass. The obtained spin triplet $p\Lambda$ scattering length set constraints for theoretical calculations of light hypernuclei and neutron stars. In this talk the extraction method as well as the results on the spin effective and spin triplet $p\Lambda$ scattering length and the Kaon analyzing power will be shown. The systematic errors of the extracted values will be discussed.

Hadron Spectroscopy VI / 33

Measurement of the double polarization observables $E$ and $G$ at the Crystal Ball experiment at MAMI

Ms. AFZAL, Farah Noreen$^1$

$^1$ HISKP, University of Bonn

For a better understanding of the nucleon excitation spectra and hence QCD at the non-perturbative regime, meson photoproduction reactions are studied at facilities like MAMI in Mainz where the Crystal Ball experiment is located. To be able to describe the photoproduction processes, polarization observables need to be measured in addition to the unpolarized cross section. The A2 collaboration has measured the double polarization observables $E$ and $G$ for the first time simultaneously using a longitudinally polarized electron beam together with a diamond radiator resulting in an elliptically polarized photon beam. Additionally a longitudinally polarized butanol target was utilized. Preliminary results for the photoproduction reaction $\gamma\bar{p} \rightarrow p\pi^0$ will be presented in this talk.

Hadron Structure VI / 32

Collins asymmetry and proton form factors at BESIII

Dr. DBEYSSI, Alaa$^1$

$^1$ Helmholtz-Institut Mainz

We report on the measurement of the $e^+e^- \rightarrow \bar{p}p$ cross section using the data collected by the BESIII detector at 12 c.m. energies in the range between 2.23 to 3.67 GeV. The proton electromagnetic form factor in the time-like region is measured. BESIII also collected data from the $\Lambda_c$-pair mass threshold to 4.6 GeV. Based on this data set, the $\Lambda_c$ form factor can be studied for the first time. In addition, based on $\sim 65$ pb data collected at 3.65 GeV, we explore Double Collins asymmetries by looking at the two back-to-back charged pions, which has similar energy coverage with the SIDIS experiments. The results of the first measurement of Collins asymmetry at low $Q$ will be reported.
Basis Light-Front Quantization Approach to Heavy Quarkonium

Author(s): Dr. LI, Yang
Co-author(s): Prof. MARIS, Pieter; Prof. VARY, James; Prof. ZHAO, Xingbo; Dr. ADHIKARI, Lekha; Dr. CHEN, Guangyao

1 Iowa State University
2 Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou

We present the properties of heavy quarkonium obtained within the Basis Light-Front Quantization approach [1]. An effective Hamiltonian is developed based on the Light-Front Holographic QCD plus the one-gluon exchange interaction. The produced mass spectra of charmonium and bottomonium agree with experiments to within a root mean square (r.m.s.) deviation of 40 MeV in the masses of the known states below open flavor thresholds. The resulting light-front wavefunctions grant access to hadronic observables relevant for experiments. We evaluate the decay constants, the form factors and the r.m.s. radii, and compare with experiments and other established approaches. We discuss our progress for evaluating additional observables including the generalized parton distributions (GPDs) of quarkonium (cf. [2]). We also apply the light-front wavefunctions to diffractive vector meson production in Deep Inelastic Scattering (DIS). Our predictions for these observables can be tested at current and forthcoming experimental facilities, e.g., LHC, RHIC and EIC. We will also discuss the prospect of extending the Basis Light-Front Quantization approach to the baryon sector. We acknowledge DOE Grants DE-FG02-87ER40371 & DESC0008485. X. Zhao is supported by the new faculty startup funding by the Institute of Modern Physics, Chinese Academy of Sciences.


Recent Belle Results on Charmed Baryon Spectroscopy and Decays

Dr. YELTON, John

1 University of Florida

Electron-Positron annihilations in the Upsilon resonance region have for many years proved a wonderful source of charmed baryon data. In this talk I review recent results on charmed baryons using data from the Belle experiment, which has collected the world’s largest dataset in this energy range.

Three-flavor chiral effective model with four baryonic multiplets

Dr. ZÉTÉNYI, Miklós; OLBRICH, Lisa; Prof. GIACOSA, Francesco; Prof. RISCHKE, Dirk

1 Wigner Research Center for Physics, Budapest, Hungary
2 Institute for Theoretical Physics, Goethe University, Frankfurt am Main, Germany
3 Institute of Physics, Jan Kochanowski University, Kielce, Poland

We present a version of the so-called extended linear sigma model that contains four multiplets of spin-1/2 baryons. Two of these multiplets transform in a “mirror” way under chiral transformations, which allows for chirally invariant mass terms. The model is constructed in the case of three
quark flavors and then reduced to the two-flavor case. In this way, four nucleonic states are obtained which mix to produce the nucleon and the three nucleon resonances, N(1440), N(1535), and N(1650). We determine the parameters of the nucleonic part of the Lagrangian from a fit to masses and decay properties of these states. We study the limit of vanishing quark condensate and identify the chiral partners.

Plenary Session IV - Tuesday / 36

Nucleon tomography in momentum space: TMDs
Prof. GAO, Haiyan

1 Duke University/Duke Kunshan University

Transverse momentum dependent parton distributions (TMDs) provide new insight about the structure of the nucleon, especially those associated with the transverse structure of the nucleon, and transverse spin. They also uncover the rich QCD dynamics, and the orbital motion and orbital angular momentum of the quarks inside the nucleon. Semi-inclusive deep-inelastic scattering (SIDIS) has proven to be an effective process to access TMDs. Such experiments have been successfully carried out at JLab during the 6-GeV era. In this talk, I will focus on the 12-GeV SoLID SIDIS program following a brief review of the 6-GeV results. This work is supported in part by the US Department of Energy under contract number DE-FG02-03ER41231.

Hadron Structure III / 35

A Solution to the Proton Radius "Puzzle"

Author(s): Prof. NORUM, Blaine
Co-author(s): Dr. HIGINBOTHAM, Douglas ; Dr. MEEKINS, David ; Dr. SAWATZKY, Bradley

1 University of Virginia
2 Jefferson Lab

The reported large discrepancy between the proton charge radius measured using the muonic atom Lamb shift \(0.84087(39) \text{ fm}\) and that extracted from elastic electron scattering measurements \(0.879(8) \text{ fm}\) has generated a great deal of interest. To examine possible origins of this discrepancy we reanalyzed the published electron scattering data from Saskatchewan (1974), Mainz (1980), and Mainz (2014) using standard statistical methods. We found that these data are actually in very good statistical agreement with the muonic atom results. While strictly speaking not germane to the extraction of the charge radius, we also found that a simple dipole function with its single parameter fixed to the muonic atom value of the proton radius reproduces \(GE_p\) within \(\approx 1\%\) up to momentum transfers of \(q^2 = 30 \text{ fm}^{-2}\).

Hadron-Hadron Interactions I / 34

Baryonic forces from SU(3) chiral effective field theory

Author(s): Dr. PETSCHAUER, Stefan
Co-author(s): Prof. KAIser, Norbert ; Prof. WEISE, Wolfram ; Dr. HAIDENBAUER, Johann ; Dr. NOGGA, Andreas ; Prof. MEßNER, UlF-G.

1 Technische Universität München
2 TU München
3 Forschungszentrum Jülich
4 Universität Bonn, Forschungszentrum Jülich

Results for the hyperon-nucleon interaction at next-to-leading order in chiral effective field theory are presented. These potentials include one- and two-meson exchange diagrams as well as contact interactions.
terms with SU(3) symmetric low-energy constants and are found to lead to a good description of the experimental scattering data. Furthermore, the properties of hyperons in nuclear matter are investigated using the chiral baryon-baryon potentials within the Brueckner-Hartree-Fock approach. We calculate the single-particle potentials of Λ and Σ hyperons in symmetric and asymmetric nuclear matter, and find good agreement with the empirical information. In particular, our calculation gives a repulsive Σ-nuclear potential and a weak Λ-nuclear spin-orbit force. Finally, we present potentials for the leading-order three-baryon interactions, which involve contact terms and irreducible one- and two-meson exchange diagrams. The pertinent low-energy constants are estimated by including decuplet baryons as explicit degrees of freedom. With these potentials one can study systematically the role of three-baryon forces, especially the ΛNN interaction, for hypernuclei and neutron star matter. Work supported in part by DFG and NSFC (CRC110).

Recent Approaches to Non-Perturbative QCD I / 60

Δ(1232) resonance in the \( \gamma p \rightarrow p\pi^0 \) reaction at threshold

**Author(s):** Mrs. HILLER BLIN, Astrid

**Co-author(s):** Dr. VICENTE VACAS, Manuel; Dr. LEDWIG, Tim

1 IFIC/CSIC/Universidad de Valencia

We calculate the neutral pion photoproduction on the proton near threshold in covariant baryon chiral perturbation theory, including the Δ(1232) resonance as an explicit degree of freedom, up to chiral order \( p^7/2 \) in the delta counting. We compare our results with recent low-energy data from the Mainz Microtron for angular distributions and photon asymmetries. The convergence of the chiral series of the covariant approach is found to improve substantially with the inclusion of the \( \Delta(1232) \) resonance.

Hadron Spectroscopy V / 61

Searching for d* Dibaryons with CLAS

Dr. MATTIONE, Paul

1 Jefferson Science Associates

Over the past several decades, a number of groups have reported evidence of dibaryons, bound states of two baryons. However, only one unambiguous dibaryon state is known to exist: the deuteron, which has a binding energy of only 2.2 MeV. Recently, the WASA-at-COSY collaboration has reported evidence for a \( d^*(2380) \) ΔΔ bound state in \( pN \rightarrow d\pi\pi \). Studying dibaryon resonances is important for understanding the properties of the strong force in nuclear systems. A study of the \( \gamma d \rightarrow d\pi\pi^+ \) reaction is shown using data from the Jefferson Lab CLAS g13 experiment. Strong, resonance-like \( d\pi \) structures are seen in Dalitz plots of this system, indicating potential NΔ bound states. Preliminary fits of this data to Breit-Wigner line-shapes will be shown. However, in the long-run, an amplitude analysis of this data needs to be performed to study the interference between these potential NΔ bound states, the \( \rho \), and other potential backgrounds. With over 3 million events and a detected dibaryon in the final state, these CLAS data are a promising place to search for dibaryon resonances.

Hadron Spectroscopy III / 62

\( \gamma n \rightarrow p\pi^- \) Cross Section Measurement at CLAS

Dr. MATTIONE, Paul

1 Jefferson Science Associates

Measuring the spectrum of \( N^* \) resonances will provide valuable information on the degrees of freedom within the nucleon, shedding light on whether there is a significant contribution from a correlated quark-pair, or diquark, in the nucleon. To extract these states, measurements of both \( \gamma p \)
and γn cross sections are necessary to disentangle the isospin components of the photoproduction amplitudes. The γn world data set is much smaller than that for γp, and the N* amplitudes on the neutron have very large uncertainties due to low statistics. A preliminary measurement of the γn → pπ− differential cross section will be shown using data from the Jefferson Lab CLAS g13 experiment. These results were determined by first measuring the cross section for γd → pπ−(p), and then performing a model-dependent correction for final-state interactions in the target deuteron. These data are a factor of 2.5x more than the world data set for this channel, providing much needed statistics to improve the amplitude extraction for coupling to the N* resonances.

Hadron Structure V / 63

Hyperon forward spin polarizability γ₀ in baryon chiral perturbation theory

Author(s): Mrs. HILLER BLIN, Astrid
Co-author(s): Dr. LEDWIG, Tim ; Prof. GUTSCHE, Thomas ; Dr. LYUBOVITSKIJ, Valery

IFIC/CSIC/Universidad de Valencia
Eberhard-Karls Universitaet Tuebingen

We present the calculation of the hyperon forward spin polarizability γ₀ using manifestly Lorentz-covariant baryon chiral perturbation theory including the intermediate contribution of the spin-3/2 states. As at the considered order the extraction of γ₀ is a pure prediction of chiral perturbation theory, the obtained values are a good test for this theory. After including explicitly the decuplet states, our SU(2) results have a very good agreement with the experimental data and we extend our framework to SU(3) to give predictions for the hyperons' γ₀ values. Prominent are the Σ− and Ξ− baryons as their photon transition to the decuplet is forbidden in SU(3) symmetry and therefore they are not sensitive to the explicit inclusion of the decuplet in the theory.

Hadron Spectroscopy III / 64

Partial-Wave Analysis of the Reactions γp → ηp, γn → ηn, and γp → K+Λ in a Multichannel Framework

Author(s): HUNT, Brian
Co-author(s): Dr. MANLEY, D. Mark

Kent State University

The goal of our research is to determine the properties of nucleon resonances using a multichannel partial-wave analysis. Currently, many predicted resonances have not been found, while the properties of several known resonances are relatively uncertain. This is changing with the recent experimental emphasis on photoproduction reactions. High-quality data for a number of spin observables is helping us solve the question of the “missing resonances”, and is allowing us to obtain nearly model-independent solutions for these reactions. This work focuses on analyzing the world database for the photoproduction reactions γp → ηp, γn → ηn, and γp → K+Λ by model-independent single-energy fits. Our single-energy amplitudes are then included in the multichannel energy-dependent fits, which are used to determine resonance parameters. We will present preliminary results for our single-energy solutions, the corresponding energy-dependent solution, and some resonance parameters.

EM and Weak Interactions I / 65

b-baryon decays at LHCb

Dr. FU, Jinlin

INFN and University of Milan
The decays of $b$-baryons to charmless final states proceed via suppressed $b \rightarrow u$ tree and $b \rightarrow s, d$ penguin diagrams and thus are sensitive to physics beyond the Standard Model. Relevant observables to study are branching fractions, CP asymmetries, triple-product asymmetries. Unexpected values of these observables have the potential to reveal New Physics. Moreover, the sector is almost unexplored and peculiar to LHCb. In this work we present the latest results in the study of $b$-baryon decays performed by LHCb using the data sample collected during the first run of the LHC.

Hadron Spectroscopy III / 66

Understanding the Nucleon as a Borromean Bound-State

**Author(s):** Dr. SEGOVIA, Jorge

**Co-author(s):** Dr. ROBERTS, Craig

1 Technische Universität München

2 Argonne

We explain how the emergent phenomenon of dynamical chiral symmetry breaking ensures that Poincaré covariant analyses of the three valence-quark scattering problem in continuum quantum field theory yield a picture of the nucleon as a Borromean bound-state, in which binding arises primarily through the sum of two separate contributions. One involves aspects of the non-Abelian character of QCD that are expressed in the strong running coupling and generate tight, dynamical color-antitriplet quark-quark correlations in the scalar-isoscalar and pseudovector-isotriplet channels. This attraction is magnified by quark exchange associated with diquark breakup and reformation, which is required in order to ensure that each valence-quark participates in all diquark correlations to the complete extent allowed by its quantum numbers. Combining these effects, we arrive at a properly antisymmetrised Faddeev wave function for the nucleon and calculate, e.g., the flavor-separated versions of the Dirac and Pauli form factors and conclude that available data and planned experiments are capable of validating the proposed picture.

Hadron Spectroscopy VI / 67

Model discrimination in pseudoscalar-meson photoproduction

**Author(s):** Prof. RYCKEBUSCH, Jan

**Co-author(s):** Mr. NYS, Jannes; Prof. IRELAND, David; Dr. GLAZIER, Derek

1 Ghent University

2 University of Glasgow

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

Plenary Session VII - Friday / 68

Superconformal baryon-meson symmetry and light front holographic QCD

Prof. DOSCH, Hans Guenter
An effective QCD light front Hamiltonian for all light hadrons is constructed by embedding superconformal quantum mechanics into AdS space. The specific breaking of conformal symmetry inside the graded algebra determines uniquely the effective confinement potential. The generalized supercharges connect the meson and baryon light front wave functions and reproduce the characteristic features of the spectra. All light hadron masses are reproduced with an accuracy better than 10 percent.

Hadron Spectroscopy V / 69

The Observation of a Di-Baryon in the Proton-Neutron System - Hexaquark or Molecule?

Dr. BASHKANOV, Mikhail

Several new findings in the four and five quark systems reheat the interest in the field of multiquark states (beyond trivial $qq$ and $qqq$). A lot of progress is made in the 6$q$ sector on both the baryonium and di-baryon sides. A resonance like structure observed in double-pionic fusion to deuteron, at $M = 2.38$ GeV with $\Gamma = 70$ MeV and $I(J^P) = 0(3^+)$ has been consistently observed in a wealth of reaction channels, supporting the existence of a resonant dibaryon state - the $d^*(2380)$. These studies include measurement of all the principle decay channels in $pd$ and $dp$ collisions in the quasi-free mode by the WASA-at-COSY and HADES collaborations. Recently the $d^*$ has been observed in two-body reactions, which are amenable to simpler interpretation through partial wave analysis. The $pn$ decay channel was measured by use of polarized deuterons on a proton target in inverse kinematics. These new $np$ analyzing power data exhibit a pronounced resonance effect in their energy dependence. The SAID partial-wave analysis with inclusion of these data reveals a pole in the complex plane of the $^3D_1$ partial wave at $(2380 \pm 10)\text{MeV} - i(40 \pm 5)\text{MeV}$ in accordance with the $d^*(2380)$ resonance hypothesis. The internal structure of the $d^*(2380)$ is largely unknown. It can contain various hidden color $6q$ configurations and $\Delta\Delta$ molecular structures with angular momentum $L=0,2,4,6$. A large set of already available experimental data constrains the internal structure of the $d^*(2380)$ dibaryon. Future plans to improve our understanding of the $d^*$ will be presented as well as the exciting possibilities for investigation of SU(3) multiplet companions and mirror partners of the $d^*$.

Hadron Spectroscopy I / 99

Complete Experiments in pseudoscalar meson photoproduction

Mr. WUNDERLICH, Yannick

The determination of the nucleon excitation spectrum remains one of the long standing challenges towards an understanding of non-perturbative QCD. The reaction of pseudoscalar meson photoproduction, $\gamma N \rightarrow MB$, poses an interesting field of study since it can potentially open a window to new baryon resonances, which have escaped observation in pion induced reactions. The spin structure of photoproduction results in 16 accessible polarization observables. The so-called ‘Complete Experiment’ problem investigates which subsets of the 16 observables are sufficient in order to determine the underlying amplitudes (e.g. 4 helicity amplitudes $H_i$) up to an overall phase. Chiang and Tabakin have found a mathematical solution to this problem, stating that generally 8 observables can fulfil this purpose. The Complete Experiment refers here to an investigation in each kinematic bin, energy and angle ($W, \theta$), individually. If a truncated partial wave analysis is done with the goal of determining multipoles, the $\theta$-distributions of the observables are utilized. In this case, less than 8 observables can already be sufficient to uniquely determine the multipoles (this is deducible from work done by Omelaenko in the 80s). The presentation will first treat the completeness problem for truncated partial wave analyses and then show preliminary results for an analysis of the process $\gamma p \rightarrow \pi^0 p$, using as input 7
Polarization observables measured in the second resonance region. Supported by the Deutsche Forschungsgemeinschaft (SFB/TR16).

**Plenary Session VIII - Friday / 98**

**The Lambda(1405) and new non ordinary baryons**

Prof. OSET, Eulogio

1 *IFIC, University of Valencia*

I shall give an overview of past and recent work on the Lambda(1405) to show its “extraordinary” nature, beyond the qqq picture, and the present status. Then will show results for the Lambda_b -> J/psi K^- p reaction comparing with LHCb data and how the complementary Lambda_b -> J/psi pi Sigma reaction filters isospin zero and is a good tool to provide extra information on the Lambda(1405). This issue will connect with the recent pentaquarks discovered by the LHCb collaboration and I shall elaborate on them from the theoretical point of view, making predictions for new pentaquark states of meson-baryon molecular nature.

**Hadron-Hadron Interactions II / 91**

**Measurement of the triple-differential cross section for photon + jet production at \( \sqrt{s} = 8 \text{ TeV} \) with the CMS detector**

*Author(s):* Ms. KHATIWADA, Ajeeta

*Co-author(s):* Prof. ASKEW, Andrew

1 *Florida State University*

We measure the triple differential cross section for photon plus jet as a function of photon transverse momentum \( (p_\gamma^T) \), photon pseudorapidity \( (\eta_\gamma) \), and jet pseudorapidity \( (\eta_{jet}) \). The production of photons in association with jets can be used to understand gluon distribution functions as well as to test perturbative Quantum Chromodynamics (QCD). The measurement is made using data collected by the Compact Muon Solenoid detector in proton-proton collisions at the center-of-mass energy of 8TeV. For each bin, a signal fraction is extracted by fitting a Multivariate Analysis distribution of single photon triggered data candidates with Monte Carlo signal template and data-driven background template. The background template is obtained by optimizing the data sideband region to reduce bias and systematics. The final value of triple differential cross sections at various kinematic regions are compared to theoretical predictions at leading and next-to-leading order.

**Light-Meson Decays / 90**

**A Dalitz plot analysis of the \( \omega \to 3\pi \) decay**

Mr. ZEOLI, Christopher

1 *Florida State University*

During the CLAS-g12 experiment at Jefferson National Laboratory (JLab), vector-mesons were photoproduced off an unpolarized liquid-hydrogen target, \( \gamma p \to p\omega \), using a circularly polarized photon beam ranging in tagged energies from 1.1 to 5.4 GeV. Originally devised to study strong interactions via \( N^* \) resonance production and decay dynamics, the 2009 run-period was a concerted effort to exploit the nearly 4\pi detector, CLAS, for high acceptance detection of meson decays. With only charged final-state particles detected for this experiment, a high statistics data sample was sought from the reaction \( \gamma p \to p\omega \to \pi^+ \pi^- (\pi^0) \), which exhibits an 89% branching ratio. Analyses of both the photoproduction and the decay dynamics of the \( \omega \) vector-meson are underway at Florida State University (FSU). With the high statistics CLAS-g12 data sample and measured differential cross section procured, a Dalitz Plot (DP) analysis of the \( \omega \to 3\pi \) decay dynamics in close cooperation with the Joint Physics Analysis Center (JPAC) at JLab is being conducted. Spin Density Matrix Elements (SDMEs) for an unpolarized beam and unmeasured recoil-proton-spin
have been extracted. Also, in addition to fitting Dalitz Plot Expansion parameters (e.g. $\alpha$, $\beta$, $\gamma$, and $\delta$), a first-time, real data fit to an Isobar and Unitarity based decay model, JPAC decay amplitude, is being made. As a consequence of unitarity, this amplitude also accounts for both elastic (i.e. $\pi-\pi$) and inelastic (e.g. $K-\bar{K}$) rescattering effects. The novel separation and parameterization of these latter contributions are unique features of this model which set it apart from alike models. Finally, a comparison between experiment and theory is sought via a one-to-one correspondence of the DP Expansion parameter $\alpha$ and the sole JPAC amplitude parameter $a_1/a_0$.

**Plenary Session VIII - Friday / 93**

**The Qweak Experiment: Direct Measurement of the Proton’s Weak Charge**

**Author(s):** Ms. LEE, Anna Lee

**Co-author(s):** QWEAK COLLABORATION

1 Virginia Tech

The Standard Model makes a definite prediction for the neutral weak charge of the proton; any deviation from this value would be a signature of physics beyond the Standard Model. The Qweak experiment, performed over the course of 2.5 years at Jefferson Lab, will obtain a precision measurement of the weak charge by determining the magnitude of the parity-violating asymmetry in elastic scattering of the 1.1 GeV longitudinally polarized electron beam with a low momentum transfer of $Q^2 = 0.025 (\text{GeV/c})^2$. The experimental apparatus and technical challenges will be explained and the process of extracting the weak charge will be described. The result from a small subset of the data has been published and will be discussed. There will also be an update on the status of the current analysis of the full dataset, and descriptions of several ancillary measurements taken during the experimental run.

**Hadron Structure II / 92**

**Proton Form Factor Ratio $G_E/G_M$ from the Double Spin Asymmetry**

**Dr. LIYANAGE, Anusha**

1 Hampton University

Experiment E07-003 (SANE, Spin Asymmetries of the Nucleon Experiment) was carried out in Hall C at Jefferson Lab in 2009 to study the proton spin structure functions with a dynamically polarized ammonia target and longitudinally polarized electron beam. In the main experiment, scattered electrons were detected in a large acceptance non-magnetic detector array (BETA). In parallel, elastic measurements were carried out by detecting elastically scattered electrons from the polarized ammonia target in the High Momentum Spectrometer (HMS) which was on the opposite side of the beam. The elastic double spin asymmetry allows to extract the proton electric to magnetic form factor ratio $G_E/G_M$ at $Q^2 = 2.2 (\text{GeV/c})^2$. To reach higher $Q^2$ than that of the inclusive data, elastically scattered protons were detected in the HMS in coincidence with electrons detected in the BETA. The beam-target asymmetry for elastic kinematics was measured to extract $G_E/G_M$ at $Q^2 = 5.25 (\text{GeV/c})^2$ and $Q^2 = 6.25 (\text{GeV/c})^2$. This alternative measurement of $G_E/G_M$ aimed to independently verify the dramatic discrepancy at high $Q^2$ between the Rosenbluth and the recoil polarization transfer method. The experiment and the results will be presented in detail.

**Hadron Structure II / 95**

**A Measurement of Proton Spin Structure Function $g_2$ at Low $Q^2$**

LIU, Jie
Jefferson Lab has been at the forefront of a program to measure the spin-dependent structure functions over the past few decades. Measurements of these nucleon spin structure functions have been proven to be powerful tools in testing the validity of effective theories of Quantum Chromodynamics. The proton spin structure function $g_1^p$ has been measured to very high precision over a very wide kinematic range, while the second proton spin structure function $g_2^p$ remains largely unmeasured. The recent Jefferson Lab Hall A $g_2^p$ experiment is an inclusive measurement of the proton $g_2$ structure function in the low $Q^2$ region ($0.02 < Q^2 < 0.2$ GeV$^2$). The measured data will provide an unambiguous benchmark test of Chiral Perturbation Theory ($\chi$PT) calculations by extracting the generalized longitudinal-transverse polarizability $\delta_{LT}$, and these data will also help test the Burkhardt-Cottingham Sum Rule at low $Q^2$. This talk will present the details of the experiment, the analysis status and preliminary results.

Hadron Spectroscopy VII / 94

XYZ exotic states at COMPASS
Dr. BERNHARD, Johannes$^1$

$^1$ CERN

The COMPASS experiment at CERN contributes to the understanding of the structure and the dynamics of hadrons. With large acceptance over a wide kinematic range for both charged and neutral particles, COMPASS is well suited for detailed studies of inelastic reactions of hadrons or muons with target nucleons with a focus on the extraction of hadron resonance parameters. We present an overview of current activities in the search for XYZ exotic states with muon-beam induced photo-production at beam energies from 160 GeV to 200 GeV. As a first result, an upper limit for the exclusive production of the charged $Z_c(3900)$ was established as well as an upper limit for the partial width of its decay $Z_c(3900) \rightarrow J/\Psi \pi^\pm$. In addition, we will explore future possibilities within the COMPASS-II program, such as a study of neutral $Z_c(3900)$ production in the $J/\Psi \pi^0$ channel as well as a study of $X(3872)$ production in the $J/\Psi \pi^+\pi^-\pi^\pm$ channel.

Hadron Structure III / 97

Measuring nucleon TMD spin-momentum correlations via Drell-Yan at Fermilab E906/E1039 SeaQuest Experiment
Dr. DAVID, Kleinjan$^1$

$^1$ Los Alamos National Laboratory

The Drell-Yan process is an ideal probe to measure the naive T-odd Boer-Mulders and Sivers transverse momentum dependent parton distribution functions (TMDs), both of which describe spin-momentum correlations in the nucleon. Previous experimental results of $\cos(2\phi)$ modulations in dilepton azimuthal distributions suggest significant non-perturbative effects, including a non-zero Boer-Mulders TMD. The Boer-Mulders TMD has been confirmed non-zero by semi-inclusive deep-inelastic scattering experiments. Presently, E906/SeaQuest experiment at Fermilab can measure Drell-Yan produced from a 120 GeV unpolarized proton beam directed on unpolarized nucleon targets. The $\cos(2\phi)$ modulations will be measured to greater precision and at higher-$x$ than previous experiments, deepening our understanding of the role the (anti)quark Boer-Mulders TMD plays the structure of the nucleon. In the future, the E1039/Seaquest experiment will introduce the beam onto a transversely polarized nucleon target. The transverse single spin asymmetry of Drell-Yan production will directly measure the sign and magnitude of sea quark Sivers TMD, which may probe the role sea quark OAM plays in the spin of the nucleon. Much remains to be learned about sea quarks in the nucleon. Measurement of spin-momentum correlations probes parton dynamics, providing insight beyond static quantities and shedding further light on the dynamical origins of the nucleon sea.
Light-cone QCD sum rules for soft contribution to exclusive Drell-Yan process $\pi^- p \to \mu^+ \mu^- n$

TANAKA, Kazuhiro

1 Juntendo University

Exclusive Drell-Yan process, $\pi^- p \to \mu^+ \mu^- n$, may be measured using the high-intensity pion beams at J-PARC, and its QCD description is complementary to that for the deeply virtual meson production, $\gamma^* p \to \pi N$, at e.g., JLAB. The leading hard exclusive amplitude for exclusive Drell-Yan process was obtained by E.R. Berger, M. Diehl, and B. Pire [Phys. Lett. B 523 (2001) 265] in terms of the partonic subprocess convoluted with the relevant nonperturbative functions, the nucleon generalized parton distributions (GPDs) and the pion distribution amplitudes, and, recently, subleading amplitudes, suppressed by the inverse powers of the dilepton mass $Q$, have also been calculated by S. V. Goloskokov and P. Kroll [Phys. Lett. B 748 (2015) 323]. However, those predictions based on the QCD factorization approach still seem to have large uncertainties that originate from the treatment of the pion pole contribution arising in the relevant GPDs in the ERBL region, the parton transverse momentum to regularize the endpoint singularities, the so-called soft-overlap mechanism, etc. These effects related to “soft contribution” important at J-PARC kinematics are not directly accessible in the usual framework for QCD factorization of the hard exclusive amplitudes. We study the exclusive Drell-Yan process constructing the light-cone QCD sum rules for the corresponding exclusive amplitudes, which allow us to estimate the relevant soft contributions making use of dispersion relations and quark-hadron duality.

13

Baryon spectroscopy at BESIII

Dr. FANG, shuangshi

1 Institute of High Energy Physics

The BESIII experiment has accumulated a large sample of $J/\psi$ and $\psi(2S)$ events. Through these charmonium radiative and hadronic decays, we can explore the baryon spectroscopy. In this talk, we will report our recent results on the study of the baryon spectroscopy.

15

$\Lambda_c$ decays at BESIII

Dr. FANG, shuangshi

1 Institute of High Energy Physics

The BESIII detector accumulated 567 pb$^{-1}$ data at the center-of-mass energy of 4.599 GeV, which is the world’s largest $e^+e^-$ collision sample at the $\Lambda_c^+$ pair threshold. By analyzing this data sample, we report the determinations of the absolute branching fractions of the $\Lambda_c^+$ semi-leptonic decay into $\Lambda_c e^+\nu$, and 12 hadronic decays of $pK$, $pK^-\pi^+$, $pK_0\pi^0$, $pK_+\pi^-$, $\Lambda\pi^+$, $\Lambda\pi^+\pi^0$, $\Lambda\pi^+\pi^+\pi^-$, $pK^-\pi^+\pi^0$, $\Sigma_0\pi^+$, $\Sigma^+\pi^0$, $\Sigma^+\pi^+\pi^-$ and $\Sigma^+\omega$. The precisions of these absolute branching fractions for these decays are improved significantly.

14

Collins FF and proton form factors at BESIII

Dr. FANG, shuangshi

1 Institute of High Energy Physics

We report cross section measurement of $e^+e^- \to p\bar{p}$ at 12 c.m. energies in the range of 2.23 to 3.67 GeV using BESIII data. The electromagnetic form factor of the proton is measured. BESIII also collected data from the $\Lambda_c$-pair mass threshold to 4.6 GeV. Based on this data set, the $\Lambda_c$
form factor can be studied for the first time. In addition, based on ~65/pb data at 3.65 GeV, we explore Double Collins Asymmetries by looking at the two back-to-back charged pions, which has similar energy coverage with the SIDIS experiments. The results of the first measurement of Collins asymmetry at low Q will be reported.

Hadron Spectroscopy II / 17

Photoproduction of $\pi^-\Delta^{++}$ and $\pi^+\Delta^0$ on the proton for comparing $\bar{u}u$ and $\bar{d}d$ productions at LEPS/SPring-8
Dr. KOHRI, Hideki

$^1$ RCNP, Osaka University

Photoproduction reactions are dominated by isospin rules. In the case of $\pi\Delta$ photoproduction on the proton at forward $\pi$ angles, the exchange of isospin=1 meson ($\pi$ or $\rho$) in the $t$-channel is the most dominant reaction mechanism, which is considered to give a cross section ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ of 1/3. The cross section ratio has not been measured precisely experimentally. We present cross section ratios at $E_\gamma=1.5$-3.0 GeV for the first time. Larger ratios than 1/3 measured by our experiment at LEPS suggest that the $\bar{d}d$ productions are enhanced compared with the $\bar{u}u$ productions in the photoproduction reactions on the proton. We also present recent developments for future LEPS and LEPS2 experiments at SPring-8.

Plenary Session VI - Thursday / 16

Spectroscopy of Exotic Baryons at LHCb
Dr. NEUBERT, Sebastian

$^1$ Heidelberg University

The LHCb experiment is designed to study the decays and properties of heavy flavoured hadrons produced in the forward region from pp collisions at the CERN Large Hadron Collider. During Run1, it has recorded the world's largest data sample of beauty and charm hadrons, enabling precise studies into the spectroscopy of such particles. The unique sample of $\Lambda_b$ baryon decays has led to the discovery of a new class of exotic resonances in the $J/\psi p$ system. The status and latest results of the investigations into these pentaquark states will be presented.

Plenary Session I - Monday / 19

Hadronic Physics in the NSAC Long Range Plan
GEESAMAN, Donald

$^1$ Argonne National Laboratory

Hadronic Physics figures prominently in the 2015 Nuclear Science Advisory Committee’s Long Range Plan, Reaching for the Horizon. In this talk I will summarize the goals we have set for ourselves and the vision we have to realize them in both hadronic physics and related areas.

Plenary Session VI - Thursday / 18

Exotic baryons: past and future
Prof. RICHARD, Jean-Marc

$^1$ Institut de Physique Nucleaire de Lyon and Universite Claude Bernard
A review of exotic baryons is presented, from the early speculations on Z-baryons in the 60s to the recent pentaquarks with hidden-charm. The phenomenological pictures are compared and commented. Some suggestions will be given for further experimental and theoretical studies.

Plenary Session VII - Friday / 117
Parity Violation in Deep Inelastic Scattering at Jefferson Lab
Dr. ZHENG, Xiaochao¹

¹ University of Virginia

Sixty years after the first discovery of parity violation in electroweak interactions, parity-violating electron scattering (PVES) has become a tool not only in establishing the Standard Model of electroweak physics and studying the subatomic structure of the nucleon, but also in exploring possible new physics beyond the Standard Model. In this talk, I will present the physics of Parity Violation in Deep Inelastic Scattering (PVDIS), focusing on recent results from Jefferson Lab using the 6 GeV electron beam. I will also give a brief outlook of the PVDIS program using the 12 GeV Jefferson Lab and the Solenoid Large Intensity Device (SoLID). At the end of the talk I’d like to keep the perspective that as we progress more and more towards a thorough understanding of electroweak physics, we may also want to investigate how parity violation could affect our everyday life.

Physics of Hyperons / 116
Cascade Baryon Spectroscopy with Kaon Beams
Prof. NARUKI, Megumi¹

¹ Kyoto University

Properties of cascade baryons are not well determined, especially for excited states. Only the members of ground-state octet and decuplet are listed as well-established states in the PDG summary table. Our experiences and knowledge of cascades have been mainly obtained by bubble-chamber experiments performed in the ’60 to ’70s. The new secondary beam lines at J-PARC provides us with an opportunity to investigate cascade baryons systematically. It enable us to use beam kaons to form multi-strange systems in the mid-energy region. The future possibilities of cascade baryon spectroscopy at J-PARC will be presented.

Hadron Spectroscopy V / 48
Search for Hybrid Baryons with CLAS12 at JLAB
Dr. LANZA, Lucilla¹

¹ Dip. Fisica Universita’ di Roma Tor Vergata and INFN Roma Tor Vergata

Hybrid baryons are hypothetical three-quark states with dominant gluonic admixtures. Their existence is allowed by QCD, and lattice QCD calculations now predict several baryon states with dominant gluonic admixture to the wave function, and with the lowest mass hybrids approximately 1.3 GeV above the nucleon ground state of 0.94 GeV, i.e. in the range W = 2.2-2.3 GeV. An experimental program is under development to analyze the mass range up to 3.5 GeV with the CLAS12 setup in HallB at Jefferson Laboratories exploiting the process $e+p \rightarrow e'+ K^+ + \Lambda$. Electron beams with energies of 6.6, 8.8, and 11 GeV impinging upon a liquid hydrogen target in the CLAS12 center may be employed. Scattered electrons may be detected in an angle range of 2.5° to 4.5° in the Forward Tagger (FT) and for angles greater than 6° in the CLAS12 Forward Detector. FT allows to probe the crucial $Q^2$ range where hybrid baryons may be identified due to the fast dropping of their $A_{1/2}(Q^2)$ electro-coupling and to the suppression of $S_{1/2}(Q^2)$. The Gent Regge plus Resonance model has been used to include a realistic hybrid resonance contribution
at the amplitude level to determine the sensitivity of the CLAS12 apparatus to a hybrid baryon signature.

Light-Meson Decays / 49

Radiative and Hadronic Decay modes of the $\eta$-Meson with CLAS and WASA-at-COSY

LERSCH, Daniel$^1$

$^1$ Forschungszentrum Jülich

The radiative decay $\eta \rightarrow \pi^+ \pi^- \gamma$ allows to explore the anomalous sector of QCD via the box anomaly, which is part of the Wess-Zumino-Witten Lagrangian. However, interactions between the final state pions have a considerable contribution to the decay amplitude and therefore need to be taken into account. Existing theoretical models can be tested by investigating the energy distribution of the final state photon. The amplitude of the isospin violating decay $\eta \rightarrow \pi^+ \pi^- \pi^0$ is sensitive to the ratio of the light quark masses $Q$. This ratio is investigated via a Dalitz plot or partial wave analysis, whereas the latter one allows an explicit calculation of $Q$. The measurement of those $\eta$ decays have been done with the CLAS detector at Jefferson Lab and with the WASA-at-COSY detector at Forschungszentrum Jülich. The $\eta$-mesons were produced at CLAS using the photoproduction reaction $\gamma p \rightarrow p \eta$, whereas hadronic reactions $pd \rightarrow ^3$He$\eta$ and $pp \rightarrow pp\eta$ were used at WASA. Both experiments comprise large acceptance spectrometer with the capability to reconstruct all initial and final state particles. This talk will give an overview about the analysis status of those three data sets with respect to the decay modes $\eta \rightarrow \pi^+ \pi^- \pi^0$ and $\eta \rightarrow \pi^+ \pi^- \gamma$.

Determination of $T$ and $F$ observables in $\eta$ photoproduction on the CLAS Frozen Spin Target (FROST)

Mr. TUCKER, Ross$^1$

$^1$ Arizona State University

Polarization observables are an important tool for understanding and clarifying baryon resonance spectra. In 2010, experiments were conducted at Jefferson Lab using a polarized photon beam incident on a polarized frozen spin target (FROST). We present preliminary data of the $T$ and $F$ asymmetries for $\eta$ photoproduction from the proton, along with comparisons to theoretical predictions. The data used in the present analysis were taken during the second running period of FROST using the CLAS detector at Jefferson Lab, with transversely-polarized protons in a butanol target or circularly-polarized incident tagged photons with energies between 0.62 and 2.93 GeV.

Work at Arizona State University is supported by the U.S. National Science Foundation award PHY-1306737.

Inclusive cross section and double-helicity asymmetry for $\pi^0$ production at midrapidity in p+p collisions at $\sqrt{s}=510$ GeV

Dr. GURAGAIN, HARI$^1$

$^1$ GEORGIA STATE UNIVERSITY

One of the major objectives of the RHIC spin program at BNL is the measurement of the gluon helicity contribution, $\Delta G$, to the proton spin via measuring the double longitudinal spin...
asymmetry ($A_{LL}$) in various channels. In PHENIX (Pioneering High Energy Nuclear Interaction Experiment) the $A_{LL}$ in $\pi^0$, $\eta$, $J/\psi$ etc. are measured in wide rapidity range. In this talk, $A_{LL}$ in $\pi^0$ production in central rapidity and $J/\psi$ production in forward rapidity will be discussed. The $\pi^0$ is reconstructed through its diphoton decay channel within the rapidity range of $|\eta| < 0.35$ and azimuthal angle of 180°. Similarly, $J/\psi$ is reconstructed via dimuon decay channel within the rapidity range of $1.2 < |\eta| < 2.2$. Results for $A_{LL}$ in $\pi^0$ and $J/\psi$ production from the data collected in the year 2013 at center of mass energy ($\sqrt{s}$) = 510 GeV will be presented. Also, their impact on $\Delta G$ constraint will be discussed. In year 2013, the total integrated luminosity was 150 $pb^{-1}$ which is almost ten times the total luminosity recorded in the year 2009 at $\sqrt{s}$ = 200 GeV. Due to increase in the center of mass energy and integrated luminosity, the new measurements cover the Bjorken x range down to 0.01 for $\pi^0$ and 0.002 for $J/\psi$.

Hadron Spectroscopy II / 44

Polarization observables in double-pion photo-production with circularly polarized photons off transversely polarized protons

NET, Lelia

1 University of South Carolina

The study of multi-meson decay of baryon resonances serves as an important tool in understanding better the properties of nucleon excited states. Double pion photo-production is studied using transversely-polarized protons and circularly-polarized photons, with center-of-mass energies between 1.4 GeV and 2.3 GeV. Polarization observables $I^{\odot}$, $P_x^{\odot}$, $P_y^{\odot}$, $P_x$, $P_y$ are measured for the $\vec{\gamma}\vec{p} \rightarrow p\pi^+\pi^-$ reaction, using the data provided by the g9b (FROST) experiment at Jefferson Lab. Preliminary results will be reported and they will be compared with the calculations of an effective Lagrangian model. The data will help deepen our knowledge of hadronic resonance decays and possibly assist in identifying new baryon resonances.

*Work supported by the U.S. National Science Foundation: NSF PHY-1505615

Light-Meson Decays / 45

The GlueX/JEF program in Hall D at Jefferson Lab

TAYLOR, Simon

1 Jefferson Lab

As part of the 12 GeV upgrade to CEBAF, the GlueX detector is a large acceptance spectrometer based on a solenoidal design with good coverage for both charged and neutral particles. The apparatus was designed for the flagship program to search for exotic (hybrid) mesons. The Jefferson Lab Eta Factory (JEF) program seeks to extend the physics reach of the GlueX experiment by focusing on rare decays of the $\eta$ meson. In particular, the $\eta \rightarrow \pi^0\gamma\gamma$ decay allows access to the dark matter sector. A putative lepto-phobic dark boson $B$ is predicted to manifest itself in the non-dark sector through the $B \rightarrow \pi^0\gamma$ transition. The JEF experiment will search for the $B$-boson in the mass range of 140-550 MeV, with sensitivity to the baryonic fine structure constant as low as $10^{-7}$. The JEF search for a dark gauge boson is complementary to other accelerator-based searches for invisible decays; it is also complementary to the ongoing worldwide effort to search for a dark photon focusing mainly on signatures involving leptons. Because good photon reconstruction is essential for this challenging experiment, we plan to upgrade the inner region of the existing forward calorimeter (FCAL) in the GlueX detector with Lead Tungstate crystals, which will improve the position and energy resolution each by a factor of two relative to the lead glass blocks currently in the FCAL. The status of preparations for the JEF program will be presented. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177.
Baryon Spectroscopy in Photonuclear Reactions

Mr. HARTMANN, Jan

University of Bonn

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

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

Measurement of Polarization Observables for the recoil hyperon $\Lambda$ in the reaction $\gamma p \to K^+ \Lambda$ for energies up to 5.45 GeV.

ADHIKARI, Shankar

Florida International University

Polarization observables are important to understand the photoproduction mechanisms of intermediate baryon resonances. Photoproduction of $\Lambda$ hyperon through the reaction $\gamma + P \to K^+ + \Lambda$ has been studied to measure polarization of recoil $\Lambda$, which is ultimately comes from circularly polarized photon beam. This analysis is performed on the data obtained using the CLAS detector at Jefferson lab for beam energy 1.117 - 5.45 GeV. This work concentrate on extracting transfer polarization coefficient $C_x$ and $C_z$, and induced polarization $P$ for beam energy higher than 3 GeV upto 5.45 GeV, where previous measurements are lacking. The goal of choosing beam energy higher than resonance production region is to extract t channel background that would eventually helps us to constrain the production models of the nucleon resonances.

Polarization Observable $E$ in $\pi^+$ Photoproduction from FROST

Prof. STRAUCH, Steffen

University of South Carolina

The spectrum of nucleon excitations is dominated by broad and overlapping resonances. Polarization observables in photoproduction reactions are key in the study of these excitations. They give indispensable constraints to partial-wave analyses and help clarify the spectrum. First results from the longitudinally-polarized frozen-spin target (FROST) program are reported. The double-polarization observable $E$, for the reaction $\vec{\gamma} \vec{p} \to \pi^+ n$, has been measured using a circularly-polarized tagged-photon beam, with energies from 0.35 to 2.37 GeV. The final-state pions were detected with the CEBAF Large Acceptance Spectrometer in Hall B at the Thomas Jefferson National Accelerator Facility. These polarization data agree fairly well with previous partial-wave analyses at low photon energies. Over much of the covered energy range, however, significant deviations are observed, particularly in the high-energy region where high-$L$ multipoles...
contribute. The data have been included in new multipole analyses from the Bonn-Gatchina, Jülich-Bonn, and SAID groups.

Hadron Spectroscopy IV / 41

Hadron Spectroscopy with COMPASS

Dr. BERNHARD, Johannes

1 CERN

The COMPASS experiment at CERN aims to contribute to the understanding of the structure and the dynamics of hadrons. With its large acceptance over a wide kinematic range for both charged and neutral particles, COMPASS is well suited for a detailed study of final states produced in inelastic interactions of hadrons or polarized muons with target nucleons. We present an overview of current activities in hadron spectroscopy of light mesons at a beam momentum of 190 GeV/c with an emphasis on the $\pi^+\pi^-\pi^+$ final state for which COMPASS recorded the world’s largest data sample. This allows us to measure the properties of known resonances with unprecedented precision and opens the door for new discoveries such as the recently observed axial-vector meson $a_1(1420)$. Additionally, the findings are crosschecked with the analysis of the $\pi^+\pi^0\pi^0$ channel and found to be well compatible. Furthermore, amplitudes of the $\pi^+\pi^-$ subsystems are extracted from data as a function of the $3\pi$ mass. Other studies in COMPASS include Primakoff reactions on nuclear targets, central production of pions and kaons, as well as diffractive production of final states with $\eta$ and $\eta'$. 

Plenary Session III - Tuesday / 77

Photoproduction of Hyperons with Linear Polarised Photons at CLAS

Dr. MCKINNON, Bryan

1 University of Glasgow

The discrepancy between quark model predictions of nucleon excited states and those observed by experiment is further highlighted by recent Lattice QCD calculations. Searches for such missing resonances require detailed partial wave analysis, which in turn require high statistics polarisation observable measurements over a large kinematic range. As part of the N* programme with CLAS at Jefferson Lab, KY photoproduction plays an important role towards the extraction of the complete set of such observables with sufficient precision. This talk will highlight some recent CLAS measurements from experiments utilising linear polarised photon beams. Particular emphasis will be placed upon the reactions $\gamma p \rightarrow K\Lambda$ and $\gamma p \rightarrow K\Sigma$ from which the photon beam asymmetry $\Sigma$, target asymmetry $T$ and the double polarisation observables $O_x$ and $O_z$ were extracted.

Hadron Structure VI / 76

New results on spin structure functions at very low momentum transfers from Jefferson Lab

ADHIKARI, Krishna

1 Mississippi State University

Several experiments in Jefferson Lab have collected a large amount of data on the spin structure of nucleons using polarized electron beam directed on various polarized targets ($NH_3$ and $ND_3$, $^3He$). In these double polarization experiments, either the double spin asymmetries $A_{||}$ and $A_{\perp}$ or the polarized cross section differences $\Delta\sigma_||$ and $\Delta\sigma_\perp$ are measured with high precision over a wide kinematic range, with $0.02 \, GeV^2 < Q^2 < 5.0 \, GeV^2$ and $1.08 \, GeV < W < 3.0 \, GeV$ and from these measurements, the spin structure functions and their moments are extracted. These data help us shed more light on the nucleon spin structure in the region of quark-confinement as well
as in the transition region between hadronic and partonic degrees of freedom. With these data, it is possible to put constraints on quark-hadron duality, test pQCD predictions for the quark polarization at large x, and test various predictions for moments of structure functions from sum rules and QCD based effective theories such as Chiral Perturbation Theory (χPT) as well as from phenomenological models. Additionally, these data make it possible to perform more precise calculations of higher-twist matrix elements in the framework of the Operator Product Expansion. At very low momentum transfers (Q^2 \to 0), the first moment (\Gamma_1) of structure function g_1 is constrained by the GDH sum rule and its χPT extensions, which makes measurements of g_1 in this region uniquely interesting. In this talk, I will present new results on spin structure functions from various experiments at Jefferson Lab with an emphasis on low Q^2 measurements. In particular, I will present new results from the EG4 experiment with CLAS, which measured the double polarized cross section difference on NH_3 and ND_3 (with both electron beam and targets longitudinally polarized) down to Q^2 = 0.02 GeV^2.

Plenary Session IV - Tuesday / 74

Proton spin structure in phase space
Author(s): Dr. LORCE, Cedric
Co-author(s): Prof. PASQUINI, Barbara

1 Ecole polytechnique, Palaiseau
2 Università di Pavia and INFN

The internal structure of hadron can be probed in many different ways, from elastic scattering to semi-inclusive deep-inelastic scattering. Each observable reveals particular aspects of this internal structure. Relativistic phase-space distributions allow one to gather all this information in a single coherent picture, and provide a natural definition of orbital angular momentum and spin-orbit correlation. We present a short introduction to relativistic phase-space distributions and show how one can reveal the rich spin structure of the proton. As a by-product, we identified the physical meaning of all the measurable leading-twist parton distributions.

Plenary Session III - Tuesday / 73

The Spectrum and Structure of Baryon Excitations from Lattice QCD
Prof. LEINWEBER, Derek

1 University of Adelaide

This presentation will focus on the low-lying even- and odd-parity excitations of the nucleon and the Λ(1405) as obtained in today’s lattice QCD calculations. Commencing with a survey of the literature we’ll review how results for the first even-parity nucleon excitation energy have differed by as much as 1 GeV, a rather unsatisfactory situation. Following a brief review of the methods used to isolate excitations of the nucleon in lattice QCD, and drawing on recent advances, we’ll see how a consensus on the low-lying spectrum has emerged among many different lattice groups. To provide insight into the nature of these states we’ll explore the wave functions and electromagnetic form factors that are available for a few of these states. Here the strange magnetic form factor of the Λ(1405) is of particular interest, signaling an internal structure dominated by a \bar{K}N molecular bound state. Having reviewed the status of lattice QCD calculations, we’ll turn our attention to connecting the finite-volume results of lattice QCD to the infinite-volume results of Nature. Drawing on a simple description of the Λ(1405) resonance, the Matrix Hamiltonian implementation of chiral effective field theory will be introduced. Consistent with the Luscher formalism for extracting phase shifts from finite volume spectra, the Hamiltonian approach can provide guidance on the manner in which physical quantities manifest themselves in the finite volume of the lattice. With this insight, we will answer the question; Have we seen the Roper in lattice QCD?
Productions of hyperons and charmed baryons
Prof. HOSAKA, Atsushi

1 RCNP, Osaka University

We would like to discuss hadron induced hyperon and charmed baryon productions for the study of resonance structures. At sufficient high energies, we expect either forward or backward dominance corresponding to t and u channel dynamics. We discuss the production rates of these cross sections and characteristic features which are useful to extract the information of the internal structure.

Hadron Spectroscopy IV / 71

Λ(1405) Photoproduction at MAMI
Dr. WERTHMUELLER, Dominik

1 University of Glasgow

Despite being classified as a 4-star state by the PDG the nature of the Λ(1405) is still not well understood. The picture of a p-wave excitation of the uds ground state within the classic quark model fails at describing its low mass. Alternative models involving exotic structures, such as pentaquarks or hybrids, have been proposed but it is becoming widely accepted that the Λ(1405) emerges as a dynamically generated resonance from the antikaon-nucleon interaction. Since the early calculations of Dalitz and Tuan new insights have been gained, especially using unitary chiral perturbation theory frameworks, which for example, found evidence for a two-pole structure of the Λ(1405). On the experimental side, the recent high quality data obtained from photoproduction measurements at the CLAS experiment set new standards for future experiments, which are still required to progress in understanding the Λ(1405). The high quality and intensity electron beam at the MAMI accelerator facility in Mainz is used by the A2 collaboration to produce a real photon beam via the tagged bremsstrahlung technique. Using an electron beam energy of 1.6 GeV allows the photoproduction of the Λ(1405) near threshold from a proton target in the reaction \( \gamma p \rightarrow K^+\Lambda(1405) \). The excellent photon detection capabilities of the electromagnetic calorimeters Crystal Ball and TAPS will enable a precise measurement of the \( \Sigma^0\pi^0 \) final state. In addition, the A2 setup would be ideally suited for the very challenging measurements of the radiative decays of the Λ(1405), which have never been directly measured before but can provide crucial information about the internal structure of the state. A report on the status of the data analysis and planned activities will be presented.

Plenary Session V - Wednesday / 70

Heavy Baryons on the Lattice
Prof. MEINEL, Stefan

1 University of Arizona / RIKEN BNL Research Center

Baryons containing charm or bottom quarks are interesting systems in QCD because their dynamics is constrained by approximate heavy-quark symmetries. Furthermore, weak decays of heavy baryons play an increasingly important role for flavor physics. I will present recent lattice QCD results for the spectrum, structure, and decays of charm and bottom baryons.

EM and Weak Interactions I / 79

Λ_c decays at BESIII
Author(s): LI, Lei¹ ; LI, Peirong²
Co-author(s): Mr. DONG, Xiao ¹

1 IHEP
Λc is a charmed baryon which is interesting and can produce many chances to test the Standard Model or find new physics. The BESIII detector has accumulated 567 pb\(^{-1}\) data at the center-of-mass energy of 4.599 GeV, which is the world’s largest \(e^+e^-\) collision sample at the \(\Lambda_c\) pair threshold. By analyzing this data sample, we report the determinations of the absolute branching fractions of \(\Lambda^+_c\) semi-leptonic decay into \(\Lambda^+e^+\nu_e\), and 12 hadronic decays of \(pK_s, pK^-\pi^+, pK_s\pi^0, pK^-\pi^+, \Lambda\pi^+, \Lambda\pi^+\pi^0, \Lambda\pi^+\pi^-\), \(pK^-\pi^+\pi^0\), \(\Sigma^0\pi^+, \Sigma^+\pi^0\), \(\Sigma^+\pi^+\pi^-\) and \(\Sigma^+\omega\). The precisions of these absolute branching fractions for these decays are improved significantly.

**Hadron Structure I / 78**

Two-photon exchange in proton elastic scattering

Dr. BERNAUER, Jan Christopher\(^1\)

\(^1\) MIT

Recent interest in the proton electromagnetic form factors is partly motivated by the discrepancy found in the determination of the electric-to-magnetic form factor ratio using different techniques. Results from scattering experiments using the Rosenbluth technique indicate that the form factor ratio is approximately constant as a function of \(Q^2\) while experiments employing polarization show a clear, roughly linear, decline of the ratio. A possible explanation is the typically unaccounted for contribution of hard two-photon exchange to the scattering process. Theoretical calculations show large variations, many indicating an effect of the right sign and magnitude. Direct verification was sought by experiments at VEPP-3, Jefferson Lab and by the OLYMPUS collaboration at DESY. In the talk, I will discuss the OLYMPUS experiment and the current state of experimental and theoretical results.

**Hadron-Hadron Interactions II / 47**

Superfast quarks in collider experiments and QCD evolution

Author(s): FREESE, Adam\(^1\)
Co-author(s): Dr. SARGSIAN, Misak \(^1\); Dr. STRIKMAN, Mark \(^2\)

\(^1\) Florida International University
\(^2\) Pennsylvania State University

Quantum chromodynamics has been extremely successful in describing many high-energy experiments with the use of universal parton distribution functions. PDFs of the free proton are well-constrained by experimental data, but nuclear PDFs require further elaboration. One of the unique aspects of nuclear QCD is the possibility of superfast partons with Bjorken \(x > 1\), which are indicative of short range correlations between bound nucleons. We present investigations of superfast quarks at energy scales relevant to both the LHC and EIC that take into account not only the latest phenomenology of nuclear SRCs, but also parton-level modifications of nucleons within the nuclear medium. An account will additionally be given for QCD evolution of superfast quarks, with corrections due to finite target mass and higher-twist effects.

**Plenary Session I - Monday / 19**

Hadronic Physics in the NSAC Long Range Plan

GEESAMAN, Donald\(^1\)

\(^1\) Argonne National Laboratory

Hadronic Physics figures prominently in the 2015 Nuclear Science Advisory Committee’s Long Range Plan, *Reaching for the Horizon*. In this talk I will summarize the goals we have set for ourselves and the vision we have to realize them in both hadronic physics and related areas.
Plenary Session I - Monday / 112

Electroexcitation of Nucleon Resonances
GOTHE, Ralf

1 University of South Carolina

Meson-photoproduction measurements and their reaction-amplitude analyses can establish more sensitively, and in some cases in an almost model-independent way, the nucleon excitations and non-resonant reaction amplitudes. However, to investigate the strong interaction from explored – where meson-cloud degrees of freedom contribute substantially to the baryon structure – to still unexplored distance scales – where quark degrees of freedom dominate and the transition from dressed to current quarks occurs – we depend on experiments that allow us to measure observables that are probing this evolving non-perturbative QCD regime over its full range. Transition form factors are uniquely suited to trace this evolution by measuring exclusive single-meson and double-pion electroproduction cross sections of the free proton. Recent efforts try to include their isospin dependence by analyzing the cross sections of the quasi-free neutron and proton in Deuterium. In the near future, these exclusive measurements will be extended to higher momentum transfers with the energy-upgraded CEBAF beam and CLAS12 to study the quark degrees of freedom, where their strong interaction is responsible for the ground and excited nucleon state formations. Recent and preliminary results will highlight the status of the analyses and of their theoretical descriptions, and an experimental and theoretical outlook will outline what shall and may be achieved in the new era of the 12-GeV upgraded transition form factor program.

This work is supported in part by the National Science Foundation under Grant PHY 1505615.

Plenary Session II - Monday / 104

Status and Future of PWA in Baryon Spectroscopy

Author(s): Prof. DORING, Michael
Co-author(s): Dr. RÖNCHEN, Deborah; Prof. WORKMAN, Ron

1 George Washington U and Jefferson Lab
2 HISKP, Bonn University
3 George Washington University

Light baryonic resonances are generally broad and overlap which makes their identification difficult. Furthermore, many resonances couple only weakly to the $\pi N$ state that was traditionally the prime channel for spectroscopy. Photoproduction of one or more mesons provides access to new resonances predicted in QCD simulations, in particular through polarized measurements. The impact of new data from Jefferson Lab and other facilities will be discussed. Obtaining conclusive answers in baryon spectroscopy is a long-sought goal requiring improved statistical analysis techniques as the era of precision spectroscopy has begun.

Plenary Session II - Monday / 42

Baryon Spectroscopy in Photonuclear Reactions

Mr. HARTMANN, Jan

1 University of Bonn

One of the remaining challenges within the standard model is to gain a good understanding of QCD in the non-perturbative regime. A key step towards this aim is baryon spectroscopy, investigating the spectrum and the properties of baryon resonances. To gain access to resonances with small $\pi N$ partial width, photoproduction experiments provide essential information. Partial wave analyses need to be performed to extract the contributing resonances. Here, a complete
experiment is required to unambiguously determine the contributing amplitudes. This involves
the measurement of carefully chosen single and double polarization observables.
In a joint endeavor by JLab, MAMI in Mainz, and ELSA in Bonn, a new generation of experiments
with polarized beams, polarized proton and neutron targets, and $4\pi$ particle detection have been
started in recent years. Many results of unprecedented quality were recently published by all
three experiments, and included by the various partial wave analysis groups in their analyses,
leading to substantial improvements, e.g. a more precise determination of resonance parameters.
In this talk, an overview of recent results in non-strange reactions is given, and their impact on
our understanding of the nucleon excitation spectrum is discussed.

Plenary Session II - Monday / 115

Baryons from the chiral Lagrangian with three light flavors

**Author(s):** Prof. LUTZ, Matthias ¹
**Co-author(s):** Dr. HEO, Yonggoo ²

¹ GSI and TU Darmstadt
² GSI

In this talk I will review applications of the three-flavor chiral Lagrangian with the baryon octet
and decuplet fields. On the one hand coupled-channel approaches are known to successfully grasp
some baryon resonance properties with $J^P = 1/2^-$ and $3/2^-$ quantum numbers. On the other
hand the quark-mass dependence of the baryon ground-state masses with $J^P = 1/2^+$ and $3/2^+$
can be computed and compared to QCD lattice simulations. It is argued that the two issues
are intimately related and reliable computations should rest on a universal parameter set. An
accurate reproduction of the available QCD lattice data on the ground-state baryon masses is
achieved. The number of unknown parameters is reduced significantly by sum rules that follow
from QCD in the limit of a large number of colors.

Hadron Spectroscopy I / 54

Polarization Observables in Vector-Meson Photoproduction
off Transversely-Polarized Protons at CLAS (On behalf of
the CLAS Collaboration)

ROY, Priyashree ³

³ Florida State University

Studying the baryon spectrum is essential to understand the theory of the strong force, Quantum
Chromodynamics (QCD), in the non-perturbative regime and to answer elementary questions such
as what are the effective degrees of freedom inside baryons. Lately, photoproduction experiments
have played a vital role in the understanding of the light baryon spectrum. But the spectrum is
inadequately understood, particularly above 1.7 GeV c.m. energies where many resonances have
been predicted by the constituent quark model as well as Lattice QCD calculations but have not
yet been experimentally confirmed. It is anticipated that these resonances may predominantly
couple to vector-mesons ($\omega, \rho, \phi$) and two-pion final states. These decay modes have been poorly
explored in the past. The FROST (FROzen Spin butanol Target) experiment conducted in 2010 at
Jefferson Lab using the CLAS detector, with center-of-mass energies between 1.5 and 2.3 GeV, has
provided a good opportunity to study these decay modes. Here we report on preliminary results
from the FROST experiment on the polarization observables for $\bar{\gamma}p \rightarrow p\omega \rightarrow p\pi^+\pi^- (\pi^0)$ using
transversely-polarized protons. Furthermore, preliminary results on the polarization observables
for $\pi^+\pi^-$ photoproduction using linearly-polarized photons and transversely-polarized protons will
be discussed. The latter reaction will give important information on the intermediate resonances
that are involved in sequential decays to multipion final states as well as on the decay modes of the
resonances to the $\rho$ vector-meson. Many observables presented here are first-time measurements
and are expected to provide further constraints to identify the contributing baryon resonances to
these final states.
Hadron Spectroscopy I / 99

Complete Experiments in pseudoscalar meson photoproduction

Mr. WUNDERLICH, Yannick

1 HISKP, University of Bonn

The determination of the nucleon excitation spectrum remains one of the long standing challenges towards an understanding of non-perturbative QCD. The reaction of pseudoscalar meson photoproduction, $\gamma N \rightarrow MB$, poses an interesting field of study since it can potentially open a window to new baryon resonances, which have escaped observation in pion induced reactions. The spin structure of photoproduction results in 16 accessible polarization observables. The so-called ‘Complete Experiment’ problem investigates which subsets of the 16 observables are sufficient in order to determine the underlying amplitudes (e.g. 4 helicity amplitudes $H_i$) up to an overall phase. Chiang and Tabakin have found a mathematical solution to this problem, stating that generally 8 observables can fulfill this purpose. The Complete Experiment refers here to an investigation in each kinematic bin, energy and angle ($W, \theta$), individually. If a truncated partial wave analysis is done with the goal of determining multipoles, the $\theta$-distributions of the observables are utilized. In this case, less than 8 observables can already be sufficient to uniquely determine the multipoles (this is deducible from work done by Omelaenko in the 80s). The presentation will first treat the completeness problem for truncated partial wave analyses and then show preliminary results for an analysis of the process $\gamma p \rightarrow \pi^0 p$, using as input 7 polarization observables measured in the second resonance region. Supported by the Deutsche Forschungsgemeinschaft (SFB/TR16).

Photoproduction of mesons off the neutron

Prof. KRUSCHE, Bernd

1 University of Basel

Photoproduction of mesons has recently dominated the spectroscopy of of excited nucleon states. In particular, the accessibility of single and double polarization observables has given much momentum to this field. Results from the major facilities (CLAS at Jlab, ELSA in Bonn, and MAMI in Mainz) had large impact on the partial wave analyses of many different reactions and thus on our knowledge of the nucleon excitation spectrum. The vast majority of the experiments studied photoproduction off free protons. However, results from reactions off the neutron target are also required to fix the isospin structure of the photonuclear couplings. The experimental setups at the MAMI (Mainz) and ELSA (Bonn) accelerators based on almost $4\pi$ covering electromagnetic calorimeters are particularly well suited for the study of such reactions. The detectors allow to detect and identify photons from the decay of neutral mesons, charged pions, and also recoil protons and neutrons. In contrast to experiments based on magnetic spectrometry they are thus capable to identify also reactions with purely neutral final states such as $\gamma n \rightarrow n\pi^0, n\eta, n\pi^0\pi^0, n\pi^0\eta,...$. Reactions with neutral mesons in the final state are of particular interest because non-resonant background contributions are much smaller than for charged mesons. During the last few years from both facilities results for total and differential cross sections and some results for beam-helicity asymmetries for three-body final states have been reported for the above mentioned reactions. The recently published data on the $n\pi^0$ and $n\eta$ final states demonstrate clearly the importance of measurements with neutron targets. In case of single pion production cross section data for all other isospin channels ($p\pi^0, p\pi^-, n\pi^+$) were already available and since only three independent isospin amplitudes are involved this should be sufficient to fix the isospin structure completely. Nevertheless, different partial wave analyses predicted much different results for the $n\pi^0$ state and actually none of them agreed with the new $\gamma n \rightarrow n\pi^0$ data, which had significant impact on the isospin decomposition. The data for $\eta$ production off the neutron revealed a prominent, narrow (less than 50 MeV wide) structure in the excitation function around incident photon energies of 1 GeV (statistical significance beyond any doubts), which does not exist for the proton. Many different scenarios have been discussed for it. Very recently, a second narrow structure around $W=1720$ MeV (which had been previously identified in Compton scattering off the proton) was identified. Currently, these measurements
have reached a new level of sophistication with the measurement of double polarization observables for reactions off the quasi-free neutron. Most recent results for such observables will be reported from experiments using circularly polarized photon beams and longitudinally and transversely polarized targets. Among the results are the first split of the cross section of the $\gamma n \rightarrow n\eta$ reaction into its helicity-1/2 and 3/2 parts (clearly demonstrating that the prominent narrow structure is in helicity 1/2), helicity contributions to single and double $\pi^0$ production (all in preparation for publication) and preliminary results for the $T$ and $F$ asymmetries for $n\eta$, $n\pi^0$, and $n\pi^0\pi^0$ final states.

Hadron Spectroscopy I / 40

Polarization Observable $E$ in $\pi^+$ Photoproduction from FROST

Prof. STRAUCH, Steffen

1 University of South Carolina

The spectrum of nucleon excitations is dominated by broad and overlapping resonances. Polarization observables in photoproduction reactions are key in the study of these excitations. They give indispensable constraints to partial-wave analyses and help clarify the spectrum. First results from the longitudinally-polarized frozen-spin target (FROST) program are reported. The double-polarization observable $E$, for the reaction $\vec{\gamma}\vec{p} \rightarrow \pi^+n$, has been measured using a circularly-polarized tagged-photon beam, with energies from 0.35 to 2.37 GeV. The final-state pions were detected with the CEBAF Large Acceptance Spectrometer in Hall B at the Thomas Jefferson National Accelerator Facility. These polarization data agree fairly well with previous partial-wave analyses at low photon energies. Over much of the covered energy range, however, significant deviations are observed, particularly in the high-energy region where high-$L$ multipoles contribute. The data have been included in new multipole analyses from the Bonn-Gatchina, Jülich-Bonn, and SAID groups.

Hadron Spectroscopy I / 101

Photoproduction of $\omega$ Mesons Using CLAS at Jefferson Laboratory

AKBAR, zulkaida

1 Florida State University

The spectrum and properties of the excited states of baryons reveal the dynamics and degrees of freedom of the interaction within them. Higher-lying excited states are generally predicted to have strong couplings to a heavier meson, e.g. one of the vector mesons, $\rho$, $\omega$, $\phi$. Therefore, vector-meson studies are important to search for the so-called \textit{missing baryon resonances}. Photoproduction of $\omega$ mesons was studied using the CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Lab. Two observables have been measured from the reaction $\gamma p \rightarrow p\omega$: The differential cross section and the double-polarization observable $E$. The differential cross section as well as the polarization observable allow us to find $N^*$ resonances decaying to $p\omega$ through multi-channel Partial Wave Analysis (PWA) that has been developed for the omega channel. The observables also provide a probe to test theoretical models on the production mechanism of $\omega$ mesons and also the scaling behaviour of the cross section. We found that the $\gamma p \rightarrow p\omega$ differential cross section at higher energies exhibits a scaling behavior as predicted by pQCD.

Hadron Structure I / 78
Two-photon exchange in proton elastic scattering
Dr. BERNAUER, Jan Christopher

1 MIT

Recent interest in the proton electromagnetic form factors is partly motivated by the discrepancy found in the determination of the electric-to-magnetic form factor ratio using different techniques. Results from scattering experiments using the Rosenbluth technique indicate that the form factor ratio is approximately constant as a function of $Q^2$ while experiments employing polarization show a clear, roughly linear, decline of the ratio. A possible explanation is the typically unaccounted for contribution of hard two-photon exchange to the scattering process. Theoretical calculations show large variations, many indicating an effect of the right sign and magnitude. Direct verification was sought by experiments at VEPP-3, Jefferson Lab and by the OLYMPUS collaboration at DESY. In the talk, I will discuss the OLYMPUS experiment and the current state of experimental and theoretical results.

Photon electroproduction at Jefferson Laboratory-Hall A
Dr. DEFURNE, Maxime

1 CEA Saclay

We will review the experimental program dedicated to photon electroproduction running in the Hall A of Jefferson Laboratory. First we will talk about the latest results of the E00-110 experiment running in 2004, published in Phys.Rev.C last year. Then we will present new results of photon electroproduction cross sections in the valence region ($x_{FJ} = 0.36$) at three $Q^2$-values (1.5, 1.75 and 2 GeV$^2$) from the E07-007 experiment which was running in 2010. Unlike the E00-110 experiment, each kinematical setting was run with two beam energies. It allows, for the first time, to perform a Rosenbluth separation on the photon electroproduction. These new results bring new information about the generalized parton distributions and their contributions.

Exclusive Single Pion Electroproduction off the Proton: Recent Results from CLAS
Dr. PARK, Kijun

1 JLab

A probing the effective degrees of freedom in excited nucleon states at the varying distance scale is essential to understand the transition from the contributions of both quark core and meson-baryon cloud to the quark core dominance. Exclusive meson electroproduction off protons has been used extensively as a powerful tool. During the decade, the CLAS collaboration has executed a broad experimental program to study the excited states of the proton using polarized electron beam and both polarized and unpolarized proton targets with a broad kinematic range. In particular, several dedicated CLAS analyses using $\gamma^* p \rightarrow n\pi^+$ reaction have been utilized for the first time to explore the nucleon resonances with full range of invariant mass $W$ from near threshold to deep inelastic scattering. As results, several low-lying nucleon resonance states have been explored including $\Delta(1232)^{1+}$, $N(1440)^{1+}$, $N(1520)^{3-}$, and $N(1535)^{3-}$ states. In addition, the recent publication showed the differential cross sections for higher $W$ (1.6 to 2.0 GeV) and allowed to extract the $N(1675)^{3-}$, $N(1680)^{5+}$, and $N(1710)^{1+}$ states due to sensitivity of isospin 3/2 within the same spin-parity assignments. In this talk, I will briefly discuss these states from CLAS results and future CLAS12 $N^*$ physics program.
Wide Angle Compton Scattering using a Compact Photon Source

Author(s): Dr. NICULESCU, Gabriel
Co-author(s): Dr. WOJTSEKHOWSKI, Bogdan

Testing of the QCD-based calculations of the fundamental exclusive reactions is the subject of large interest in hadron physics. Wide Angle Compton Scattering (WACS) of photons off a polarized proton target constitutes an excellent opportunity to carry out such tests. Recently concluded data analyses based on two Jefferson Lab experiments (E99-114 and E07-002) have demonstrated the validity of the experimental technique of using untagged photon beams on a proton target, and provided high accuracy cross—section and polarization observable results (KLL) at modest values of s, u, and t. This presentation will focus on a proposal to extend these precision measurements to much larger energies. The photons will be detected by the Neutral Particle Spectrometer and the protons by the Super Bigbite Spectrometer. The experiment will use the 11 GeV JLab electron beam and a novel high intensity untagged photon source. Projected results and their impact, as well as other potential uses for the photon source developed for this experiment will be discussed.

New results on nucleon resonance analysis of the $\gamma_{\nu}p \rightarrow \pi^+\pi^-p$ cross sections in the second and third resonance regions

Author(s): FEDOTOV, Gleb
Co-author(s): Dr. GOTHE, Ralf; Dr. MOKEEV, Victor; Dr. BURKERT, Volker

The studies of the $N^*$ electroexcitation amplitudes, the so-called $\gamma_{\nu}pN^*$ electrocouplings, at photon virtualities $Q^2 < 5.0$ GeV$^2$ represent an important direction in the $N^*$ Program with the CLAS detector at Jefferson Lab. We report new results on nine one-fold differential cross sections of the $\pi^+\pi^-$ electroproduction off protons measured in the invariant mass range of the final hadron system $W$ from 1.3 GeV to 1.8 GeV and at photon virtualities from 0.4 GeV$^2$ to 1.0 GeV$^2$. Due to the high statistics, the cross sections have been extracted in 0.05 GeV$^2$-bins, which is a factor of six narrower than previously achieved [1]. Furthermore, our measurements expand the range of covered photon virtualities towards smaller values in comparison to the previous CLAS experiment [1]. These data on nine one-fold differential cross sections make it possible to establish all essential mechanisms contributing to the $\pi^+\pi^-p$ exclusive channel from their manifestations in different observables, offering a credible separation between the resonant/non-resonant contributions, which allows for a reliable extraction of the $\gamma_{\nu}pN^*$ electrocouplings as well as the $N^*$ partial hadronic decay widths to the $\pi\Delta$ and $pp$ final states. We expect that the ongoing phenomenological analysis of our data within the framework of the meson-baryon reaction model JM [2,3] will improve the knowledge on $\gamma_{\nu}pN^*$ electrocouplings for states with masses above 1.6 GeV, since many of them decay preferentially to the $N\pi\pi$ final states. Resonance electrocouplings obtained from our data will offer a valuable cross-check of the resonance parameters determined from $N\pi$ electroproduction channels confronting them with the results of an independent extraction from data of another major exclusive channel. Further evidence of the existence of the new $N'(1720)3/2^+$ state was recently obtained from a combined analysis of the CLAS $\pi^+\pi^-p$ photoproduction and electroproduction data [4]. The electrocouplings of the $\gamma_{\nu}pN'(1720)3/2^+$ transition will be obtained from the precise electroproduction data set, which will help elucidate the internal structure of the new baryon state.

EM and Weak Interactions I / 127

Probes of CP-violation and rare decays in the heavy flavour sector at ATLAS

Prof. PRELL, Soeren

1 Iowa State University

We present the results on CP-violation searches in the Bs system, studied in the decay into J/psi phi, and the Bd system through the comparison of the decay time distributions in the flavour specific state J/psi K* and in the CP eigenstate J/psi KS, both using the Run-1 LHC dataset. We additionally present new results in the search for the rare decays of Bs and Bd into mu+mu-. Such processes involve FCNC transitions in b-hadron decays, suppressed in the standard model, and are sensitive to new physics contributions. These searches are based on the full sample of data collected by ATLAS at 7 and 8 TeV collision energy. The consistency with the SM and with other available measurements is discussed.

EM and Weak Interactions I / 79

Λc decays at BESIII

Author(s): LI, Lei; LI, Peirong

Co-author(s): Mr. DONG, Xiao

1 IHEP
2 UCAS

Λc is a charmed baryon which is interesting and can produce many chances to test the Standard Model or find new physics. The BESIII detector has accumulated 567 pb^{-1} data at the center-of-mass energy of 4.599 GeV, which is the world’s largest e^+e^- collision sample at the Λc pair threshold. By analyzing this data sample, we report the determinations of the absolute branching fractions for these decays are improved significantly.

EM and Weak Interactions I / 52

Form factors and decay width of Λc semileptonic decay in constituent quark model

HUSSAIN, Md Mozammel

1 Florida State University

The form factors for semileptonic decay, Λ_c → Λ^*ν_τ has been calculated in constituent quark model. Different excited states of Λ^* has been studied. The heavy quark effective theory has been employed to compare numerical results for form factors. The decay width and branching fraction of the decay, Λ_c → Λ^*ν_τ → Σπν_τ has been calculated for various excited states of Λ.
Interference effect between $\phi$ and $\Lambda(1520)$ production channels in the $\gamma p \to K^+K^-p$ reaction near threshold

Author(s): Dr. RYU, Sun Young
Co-author(s): LEPS COLLABORATION

The $\phi - \Lambda(1520)$ interference effect in the $\gamma p \to K^+K^-p$ reaction has been measured for the first time in the energy range from 1.673 to 2.173 GeV at LEPS/SPring-8. The relative phases between $\phi$ and $\Lambda(1520)$ production amplitudes were obtained in the kinematic region where the two resonances overlap. The measurement results support strong constructive interference when $K^+K^-$ pairs are observed at forward angles, but destructive interference for proton emission at forward angles. Furthermore, the observed interference effect does not account for the $\sqrt{s} = 2.1$ GeV bump structure in forward differential cross sections for $\phi$ photoproduction. This fact suggests possible exotic structures such a hidden-strangeness pentaquark state, a new Pomeron exchange and rescattering processes via other hyperon states.

b-baryon decays at LHCb

Dr. FU, Jinlin

The decays of $b$-baryons to charmless final states proceed via suppressed $b \to u$ tree and $b \to s,d$ penguin diagrams and thus are sensitive to physics beyond the Standard Model. Relevant observables to study are branching fractions, CP asymmetries triple-product asymmetries. Unexpected values of these observables have the potential to reveal New Physics. Moreover the sector is almost unexplored and peculiar to LHCb. In this work we present the latest results in the study of $b$-baryon decays performed by LHCb using the data sample collected during the first run of the LHC.

First Rosenbluth separation on $\pi^0$ at Jefferson Laboratory-Hall A

Dr. DEFURNE, Maxime

Although being a higher-twist contribution, the transverse response was assumed to be responsible of the large $\pi^0$ electroproduction cross sections measured by the Hall A and CLAS collaboration. However no Rosenbluth separation has been performed yet to verify this assumption. We will present new results of $\pi^0$ electroproduction cross sections in the valence region ($x_{Bj}=0.36$) at three $Q^2$-values (1.5, 1.75 and 2 GeV$^2$). Unlike the previous data sets, each kinematical setting was run with two beam energies. It allows to perform, for the first time, the separation of the longitudinal and transverse contributions.

Studies of Strange Sea distribution functions using Kaons with CLAS12

Author(s): Prof. BENMOKHTAR, Fatiha
Co-author(s): Mr. TROTTA, Richard; Mr. TORISKY, Benjamin

Duquesne University
The understanding of the spin structure of the nucleon in terms of quarks and gluons has been the goal of intense investigations during the last decades. The techniques of inclusive and semi-inclusive polarized deep-inelastic scattering employed at CERN, SLAC, DESY, and Jefferson Lab have provided a wealth of information about the spin structure of the nucleon. The determination of strangeness is challenging and the only way of determining the strange distribution accurately from data is to include semi-inclusive information. This talk is focused on the determination of the strange sea contribution to the nucleon spin through the pseudo-scalar using semi-inclusive Kaon detection technique with CLAS12 at Jefferson Lab. The method will be explained and the expected precision of the measurements will be presented.

**Hadron Structure II / 95**

**A Measurement of Proton Spin Structure Function $g_2$ at Low $Q^2$**

LIU, Jie

1 University of Virginia

Jefferson Lab has been at the forefront of a program to measure the spin-dependent structure functions over the past few decades. Measurements of these nucleon spin structure functions have been proven to be powerful tools in testing the validity of effective theories of Quantum Chromodynamics. The proton spin structure function $g_1^p$ has been measured to very high precision over a very wide kinematic range, while the second proton spin structure function $g_2^p$ remains largely unmeasured. The recent Jefferson Lab Hall A $g_2^p$ experiment is an inclusive measurement of the proton $g_2$ structure function in the low $Q^2$ region ($0.02 < Q^2 < 0.2$ GeV$^2$). The measured data will provide an unambiguous benchmark test of Chiral Perturbation Theory ($\chi$PT) calculations by extracting the generalized longitudinal-transverse polarizability $\delta_{LT}$, and these data will also help test the Burkhardt-Cottingham Sum Rule at low $Q^2$. This talk will present the details of the experiment, the analysis status and preliminary results.

**Hadron Structure II / 92**

**Proton Form Factor Ratio $G_E/G_M$ from the Double Spin Asymmetry**

Dr. LIYANAGE, Anusha

1 Hampton University

Experiment E07-003 (SANE, Spin Asymmetries of the Nucleon Experiment) was carried out in Hall C at Jefferson Lab in 2009 to study the proton spin structure functions with a dynamically polarized ammonia target and longitudinally polarized electron beam. In the main experiment, scattered electrons were detected in a large acceptance non-magnetic detector array (BETA). In parallel, elastic measurements were carried out by detecting elastically scattered electrons from the polarized ammonia target in the High Momentum Spectrometer (HMS) which was on the opposite side of the beam. The elastic double spin asymmetry allows to extract the proton electric to magnetic form factor ratio $G_E/G_M$ at $Q^2 = 2.2$ (GeV/c)$^2$. To reach higher $Q^2$ than that of the inclusive data, elastically scattered protons were detected in the HMS in coincidence with electrons detected in the BETA. The beam-target asymmetry for elastic kinematics was measured to extract $G_E/G_M$ at $Q^2 = 5.25$ (GeV/c)$^2$ and $Q^2 = 6.25$ (GeV/c)$^2$. This alternative measurement of $G_E/G_M$ aimed to independently verify the dramatic discrepancy at high $Q^2$ between the Rosenbluth and the recoil polarization transfer method. The experiment and the results will be presented in detail.

**Hadron Spectroscopy II / 17**

**Photoproduction of $\pi^-\Delta^{++}$ and $\pi^+\Delta^0$ on the proton for comparing $\bar{u}u$ and $dd$ productions at LEPS/SPring-8**
Dr. KOHRI, Hideki

RCNP, Osaka University

Photoproduction reactions are dominated by isospin rules. In the case of $\pi\Delta$ photoproduction on the proton at forward $\pi$ angles, the exchange of isospin=1 meson ($\pi$ or $\rho$) in the $t$-channel is the most dominant reaction mechanism, which is considered to give a cross section ratio $\sigma(\pi^+\Delta^0)/\sigma(\pi^-\Delta^{++})$ of 1/3. The cross section ratio has not been measured precisely experimentally. We present cross section ratios at $E_\gamma=1.5-3.0$ GeV for the first time. Larger ratios than 1/3 measured by our experiment at LEPS suggest that the $\bar{d}d$ productions are enhanced compared with the $\bar{u}u$ productions in the photoproduction reactions on the proton. We also present recent developments for future LEPS and LEPS2 experiments at SPring-8.

Hadron Spectroscopy II / 44

Polarization observables in double-pion photo-production with circularly polarized photons off transversely polarized protons

NET, Lelia

University of South Carolina

The study of multi-meson decay of baryon resonances serves as an important tool in understanding better the properties of nucleon excited states. Double pion photo-production is studied using transversely-polarized protons and circularly-polarized photons, with center-of-mass energies between 1.4 GeV and 2.3 GeV. Polarization observables $I^\circ, P_x^\circ, P_y^\circ, P_x, P_y$ are measured for the $\vec{\gamma}\vec{p}\to p\pi^+\pi^-$ reaction, using the data provided by the g9b (FROST) experiment at Jefferson Lab. Preliminary results will be reported and they will be compared with the calculations of an effective Lagrangian model. The data will help deepen our knowledge of hadronic resonance decays and possibly assist in identifying new baryon resonances.

*Work supported by the U.S. National Science Foundation: NSF PHY-1505615

Hadron Spectroscopy II / 38

Determination of the Spin Triplet $p\Lambda$ Scattering Length from the Reaction $p[U+20D7] p \to pK^+ \Lambda$

HAUENSTEIN, Florian

IKP, Forschungszentrum Juelich

The $\vec{p}\vec{p}\to pK^+\Lambda$ reaction was measured with the COSY-TOF detector using a polarized proton beam of 2.7 GeV/c. From these data the $p\Lambda$ scattering length can be extracted from the final state interaction in the $p\Lambda$ invariant mass spectrum. Furthermore, it is possible to determine not only the spin averaged scattering length but also the spin triplet $p\Lambda$ scattering length utilizing the dependence of the Kaon analyzing power on the $p\Lambda$ invariant mass. The obtained spin triplet $p\Lambda$ scattering length set constraints for theoretical calculations of light hypernuclei and neutron stars. In this talk the extraction method as well as the results on the spin effective and spin triplet $p\Lambda$ scattering length and the Kaon analyzing power will be shown. The systematic errors of the extracted values will be discussed.

Hadron Spectroscopy II / 43

Measurement of Polarization Observables for the recoil hyperon $\Lambda$ in the reaction $\gamma p \to K^+\Lambda$ for energies up to 5.45 GeV.

ADHIKARI, Shankar
Polarization observables are important to understand the photoproduction mechanisms of intermediate baryon resonances. Photoproduction of $\Lambda$ hyperon through the reaction $\gamma + P \to K^+ + \Lambda$ has been studied to measure polarization of recoil $\Lambda$, which is ultimately comes from circularly polarized photon beam. This analysis is performed on the data obtained using the CLAS detector at Jefferson lab for beam energy 1.117 - 5.45 GeV. This work concentrate on extracting transfer polarization coefficient $C_x$ and $C_z$, and induced polarization $P$ for beam energy higher than 3 GeV upto 5.45 GeV, where previous measurements are lacking. The goal of choosing beam energy higher than resonance production region is to extract t channel background that would eventually helps us to constrain the production models of the nucleon resonances.

Forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions

Prof. HOENEISEN, Bruce

We present measurements of the forward-backward asymmetries in the production of lambda, cascade and omega baryons in proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV recorded by the DO detector at the Fermilab Tevatron Collider. The data also confirm that the anti-lambda/lambda production ratio, measured by several experiments with various targets and a wide range of energies, is a universal function of “rapidity loss”, i.e., the rapidity difference of the beam proton and the lambda.

Baryonic forces from SU(3) chiral effective field theory

Author(s): Dr. PETSCHAUER, Stefan
Co-author(s): Prof. KAISER, Norbert; Prof. WEISE, Wolfram; Dr. HAIDENBAUER, Johann; Dr. NOGGA, Andreas; Prof. MEIßNER, Ulf-G.

Results for the hyperon-nucleon interaction at next-to-leading order in chiral effective field theory are presented. These potentials include one- and two-meson exchange diagrams as well as contact terms with SU(3) symmetric low-energy constants and are found to lead to a good description of the experimental scattering data. Furthermore the properties of hyperons in nuclear matter are investigated using the chiral baryon-baryon potentials within the Brueckner-Hartree-Fock approach. We calculate the single-particle potentials of $\Lambda$ and $\Sigma$ hyperons in symmetric and asymmetric nuclear matter, and find good agreement with the empirical information. In particular, our calculation gives a repulsive $\Sigma$-nuclear potential and a weak $\Lambda$-nuclear spin-orbit force. Finally, we present potentials for the leading-order three-baryon interactions, which involve contact terms and irreducible one- and two-meson exchange diagrams. The pertinent low-energy constants are estimated by including decuplet baryons as explicit degrees of freedom. With these potentials one can study systematically the role of three-baryon forces, especially the $\Lambda NN$ interaction, for hypernuclei and neutron star matter. Work supported in part by DFG and NSFC (CRC110).
Understanding the excitation pattern of baryons is a prerequisite for a deeper insight in the properties of the strong interaction in the non-perturbative regime. The baryon spectroscopy programs at various laboratories based on photo-induced reactions in the recent years was very successful in enlarging our knowledge of the nucleon and $\Delta$ excitation spectrum, after, for many years, the data base had been essentially determined by results obtained in inelastic pion-nucleon collisions. On the other hand, in the sector of strange ($\Lambda, \Sigma$) and multi-strange ($\Xi, \Omega$) baryons, the last decades have not seen any substantial experimental progress. Looking at the data base of excited $\Xi$ and $\Omega$ states, we find that very little (in case of $\Xi$) or almost nothing is known (in case of $\Omega$). In a constituent quark model picture, however, according to approximate SU(3) flavor symmetry, one would expect corresponding partner states of the known $N$ and $\Delta$ states in the $\Xi$ spectrum (and of the $\Delta$ states in the $\Omega$ spectrum). Proving or excluding the existence of these states will be important for understanding which degrees of freedom - three-quark, quark-diquark, or meson-baryon dynamics - are relevant for the baryonic excitation pattern. The presentation will give an overview showing the current knowledge of strange baryon resonances, and discuss different approaches to access in particular $\Xi$ and $\Omega$ excited states in current and in planned experiments.

Plenary Session III - Tuesday / 77

Photoproduction of Hyperons with Linear Polarised Photons at CLAS

Dr. MCKINNON, Bryan$^1$

$^1$ University of Glasgow

The discrepancy between quark model predictions of nucleon excited states and those observed by experiment is further highlighted by recent Lattice QCD calculations. Searches for such missing resonances require detailed partial wave analysis, which in turn require high statistics polarisation observable measurements over a large kinematic range. As part of the N* programme with CLAS at Jefferson Lab, $\gamma p \rightarrow K\Lambda$ and $\gamma p \rightarrow K\Sigma$ from which the photon beam asymmetry $\Sigma$, target asymmetry $T$ and the double polarisation observables $O_x$ and $O_z$ were extracted.

Plenary Session III - Tuesday / 73

The Spectrum and Structure of Baryon Excitations from Lattice QCD

Prof. LEINWEBER, Derek$^1$

$^1$ University of Adelaide

This presentation will focus on the low-lying even- and odd-parity excitations of the nucleon and the $\Lambda(1405)$ as obtained in today’s lattice QCD calculations. Commencing with a survey of the literature we’ll review how results for the first even-parity nucleon excitation energy have differed by as much as 1 GeV, a rather unsatisfactory situation. Following a brief review of the methods used to isolate excitations of the nucleon in lattice QCD, and drawing on recent advances, we’ll see how a consensus on the low-lying spectrum has emerged among many different lattice groups. To provide insight into the nature of these states we’ll explore the wave functions and electromagnetic form factors that are available for a few of these states. Here the strange magnetic form factor of the $\Lambda(1405)$ is of particular interest, signaling an internal structure dominated by a $KN$ molecular bound state. Having reviewed the status of lattice QCD calculations, we’ll turn our attention to connecting the finite-volume results of lattice QCD to the infinite-volume results of Nature. Drawing on a simple description of the $\Lambda(1405)$ resonance, the Matrix Hamiltonian implementation of chiral effective field theory will be introduced. Consistent with the Luscher formalism for extracting phase shifts from finite volume spectra, the Hamiltonian approach can
provide guidance on the manner in which physical quantities manifest themselves in the finite volume of the lattice. With this insight, we will answer the question; Have we seen the Roper in lattice QCD?

**Plenary Session IV - Tuesday / 74**

**Proton spin structure in phase space**

*Author(s):* Dr. LORCE, Cedric \(^1\)

*Co-author(s):* Prof. PASQUINI, Barbara \(^2\)

\(^1\) Ecole polytechnique, Palaiseau

\(^2\) Università di Pavia and INFN

The internal structure of hadron can be probed in many different ways, from elastic scattering to semi-inclusive deep-inelastic scattering. Each observable reveals particular aspects of this internal structure. Relativistic phase-space distributions allow one to gather all this information in a single coherent picture, and provide a natural definition of orbital angular momentum and spin-orbit correlation. We present a short introduction to relativistic phase-space distributions and show how one can reveal the rich spin structure of the proton. As a by-product, we identified the physical meaning of all the measurable leading-twist parton distributions.

**Plenary Session IV - Tuesday / 36**

**Nucleon tomography in momentum space: TMDs**

Prof. GAO, Haiyan \(^1\)

\(^1\) Duke University/Duke Kunshan University

Transverse momentum dependent parton distributions (TMDs) provide new insight about the structure of the nucleon, especially those associated with the transverse structure of the nucleon, and transverse spin. They also uncover the rich QCD dynamics, and the orbital motion and orbital angular momentum of the quarks inside the nucleon. Semi-inclusive deep-inelastic scattering (SIDIS) has proven to be an effective process to access TMDs. Such experiments have been successfully carried out at JLab during the 6-GeV era. In this talk, I will focus on the 12-GeV SoLID SIDIS program following a brief review of the 6-GeV results. This work is supported in part by the US Department of Energy under contract number DE-FG02-03ER41231.

**Plenary Session IV - Tuesday / 20**

**Study of Nucleon’s Spin and parsonic dynamics with the Electron Ion Collider**

Prof. DESHPANDE, Abhay \(^1\)

\(^1\) Stony Brook University

The Electron Ion Collider (EIC) was recently recommended by the US Nuclear Science Advisory Committee (NSAC) in its 2015 Long Range Planning, as the next major facility to be constructed in the US after the FRIB (the Facility for Radioactive Beams, currently under construction). The EIC will enable high-energy, high-luminosity polarized electron-polarized nucleon and unpolarized electron-nuclear collisions over a wide range in center of mass energy and nuclear species. In this talk I will focus on the potential for frontier QCD research at the EIC using its polarized beams, and elucidate how we could explore the nucleon’s spin structure as well as the partonic dynamics, potentially leading to 2+1 dimensional tomographic images of the nucleon. Complementarity of the EIC with current & future facilities around the world will be discussed, while highlighting the uniqueness of EIC’s abilities for this physics.
Spin Physics and Future Opportunities at the EIC / 109

The Structure of the Neutron and the BoNuS Experiment
Dr. NICULESCU, Gabriel

1 James Madison University

Since the late 60’s inclusive electron-nucleon scattering has proven a rich source of information on the internal structure of nucleons and nuclei. While both electron-proton and electron-neutron interactions are equally important, as they provide access to different linear combinations of the underlying quark distributions, the latter type of studies have been hindered by the lack of a neutron target. The existing neutron results have been obtained by subtracting suitably smeared proton data from deuteron/light nuclei distributions, which are prone to uncertainties due to nuclear binding effects. The Jefferson Lab BONuS experiment addresses this problem using a detector capable of detecting spectator protons stemming from e+d interaction down to 70 MeV/c. F2 structure function results (and moments thereof) obtained during the 6 GeV era of Jefferson Lab using this technique will be presented. Progress on follow-on experiment BoNuS12, identified as one of the top priority experiments in the 12 GeV era, will also be discussed, as well.

Spin Physics and Future Opportunities at the EIC / 103

Physics with polarized beams at the EIC and detector designs
Dr. FEEGE, Nils

1 Stony Brook University

The Electron Ion Collider (EIC, arXiv:1212.1701.v3) will allow for precision measurements of the partonic and spin structure of nucleons and the partonic structure of nuclear matter using high energy, high luminosity electron-proton and electron-ion collisions, respectively. The electron, proton, and light ion beams at the EIC will be polarized. Together with recent advances in theoretical frameworks achieved for transverse momentum dependent parton distributions (TMDs) and generalized parton distributions (GPDs), these measurements promise to yield multi-dimensional maps of the momentum and spatial distribution of partons inside hadrons. Furthermore, the EIC will provide new insights into how quarks and gluons give rise to overall nucleon properties like spin. Well designed experiments integrated into the interaction region are the key to unlock this physics potential. In this talk, I will present the physics addressed with polarized beams at the EIC and detector concepts currently being evaluated for this facility.

Spin Physics and Future Opportunities at the EIC / 110

Recent progress on TMD study and future perspective at the EIC
Dr. KANG, Zhongbo

1 Los Alamos National Laboratory

Transverse momentum dependent (TMD) parton distribution and fragmentation functions are novel theoretical concept, which provide information on the parton’s intrinsic transverse motion, and thus present a path to three-dimensional nucleon tomography. In this talk, I will first review recent theoretical advances in TMD study. In particular, we discuss the current efforts and status in determining the TMD parton distributions and fragmentation functions from semi-inclusive deep inelastic scattering, e+e-, as well as p+p collisions. We then outline the future perspective at the future electron ion collider (EIC).

Spin Physics and Future Opportunities at the EIC / 113

Physics with nuclei at an electron-ion collider
Experiments in the past decades have revealed an unexpected richness of nature as described by quarks and gluons in QCD. Nucleons exhibit a complex substructure that remains challenging for theory and requires precision measurements that disentangle the dynamics and contributions from different degrees of freedom, including spin and orbital angular momentum. At the same time, nucleons that are bound inside nuclei reveal a collective behaviour that under extreme conditions leads to its own QCD substructure. Observations of a quark gluon plasma at the highest temperatures and densities in heavy ion collisions, where the relevant degrees of freedom are quarks and gluons, have lead to studies of condensed matter of the strong force and the self interaction of gluons. Similarly, high energy deep inelastic scattering has pointed towards a dominance of gluons towards low partonic momenta in the nucleon, where it is expected that the gluon density has to reach a non-linear region and saturate in order to not violate unitarity. This so called color glass condensate is supposed to be universal and well within the reach of an electron-ion collider, where the nucleus serves as an amplifier for the gluon density. The short range structure of nuclei can be analyzed over a wide range of partonic momenta and momentum transfer for a variety of light and heavy ion species.

**Physics of Hyperons / 72**

**Productions of hyperons and charmed baryons**

Prof. HOSAKA, Atsushi

\(^1\) RCNP, Osaka University

We would like to discuss hadron induced hyperon and charmed baryon productions for the study of resonance structures. At sufficient high energies, we expect either forward or backward dominance corresponding to t and u channel dynamics. We discuss the production rates of these cross sections and characteristic features which are useful to extract the information of the internal structure.

**Physics of Hyperons / 56**

**Toward a \(K_L\) beam in Hall D at Jefferson Lab**

TAYLOR, Simon

\(^1\) Jefferson Lab

Few baryons containing strange quarks have been observed experimentally in spite of the rich spectrum of hyperons predicted by quark models. In particular, the doubly-strange \(\Xi\) states are sparse with only a few with well-established mass, width and \(J^P\) assignments and only the ground state \(\Omega^-\) has firmly established quantum numbers. The field has largely stagnated for decades with some renewed interest in recent years. A \(K_L\) beam has the advantage that it contains one unit of strangeness/anti-strangeness, thereby opening up new opportunities to study hyperon production. A plan is evolving to take advantage of the existing photon beam line and experimental hall in the Hall-D complex at Jefferson Lab to deliver a beam of \(K_L\) particles onto a physics cryo-target within the GlueX detector. The recently constructed GlueX detector in Hall-D is a large acceptance spectrometer with good coverage for both charged and neutral particles that can be adapted to this purpose with a change to the size of the physics target. A preliminary conceptual design for production of a \(K_L\) beam in Hall-D and simulations of interactions of the \(K_L\) beam with a liquid hydrogen target inside the GlueX detector will be presented.

**Physics of Hyperons / 116**

**Cascade Baryon Spectroscopy with Kaon Beams**

Prof. NARUKI, Megumi

\(^1\) Page 54
Properties of cascade baryons are not well determined, especially for excited states. Only the members of ground-state octet and decuplet are listed as well-established states in the PDG summary table. Our experiences and knowledge of cascades have been mainly obtained by bubble-chamber experiments performed in the ‘60 to ‘70s. The new secondary beam lines at J-PARC provides us with an opportunity to investigate cascade baryons systematically. It enable us to use beam kaons to form multi-strange systems in the mid-energy region. The future possibilities of cascade baryon spectroscopy at J-PARC will be presented.

Physics of Hyperons / 39

Understanding the basic features of cascade photoproduction

Prof. NAKAYAMA, Kanzo

1 University of Georgia

The photoproduction of cascade baryons off nucleons is discussed. It is a part of our theoretical effort in connection to the cascade baryon spectroscopy program at the Thomas Jefferson National Accelerator Facility (JLab). Specifically, the reaction $\gamma N \rightarrow KK\Xi$ is investigated, in conjunction with the $\bar{K}$-induced reaction $\bar{K} + N \rightarrow K\Xi$, within a relativistic hadron exchange model of strong interactions. The latter reaction is planned to be studied at J-PARC; it can also be studied at JLab if the secondary $K_L$ beam becomes available. The basic features of these reactions and their manifestations in some of the observables will be discussed.

Physics of Hyperons / 105

Cascade and Omega Spectroscopy at Jefferson Lab

Dr. GUO, Lei

1 Florida International University

Compared to the tremendous experimental progress made in the nucleon resonances, the advances in cascade and Omega spectroscopy have been scarce. The large amount of photoproduction data that have been collected in the past decade by the CLAS collaboration, and the next generation of experiments to be performed at the upgraded facilities at Jefferson Lab, will make it possible to investigate the photoproduction mechanisms of these baryon states with multiple strange quarks with unprecedented statistics in terms of both cross section and polarization measurements. It could also be possible to discover the missing S=−2 and S=−3 states as expected by various quark model predictions and Lattice QCD calculations. The incoming Very Strange Experiment at CLAS12 using the Forward Tagger, and the cascade spectroscopy program at GlueX will be discussed.

Light-Meson Decays / 126

An overview of light meson decays

KAMPF, Karol

1 Charles University Prague

The light mesons play a prominent role in hadronic processes at low energies. In my talk I will focus on theoretical calculations within Chiral Perturbation Theory and Resonance Chiral Theory. I will for example discuss the importance of the decay constant $F_{\pi}$ and cover all decay modes of the lightest hadron: neutral $\pi$. 
Hadron Physics at KLOE/KLOE-2
Dr. PEREZ DEL RIO, Elena

1 LNF-INFN Laboratori di Frascati

The KLOE experiment, operating at the Phi-factory DAFNE in Frascati, has a large statistical sample, consisting of 2.5 fb\(^{-1}\) and 250 pb\(^{-1}\) on- and off- the Phi meson peak respectively. The large data sample of light meson available allows for precise measurements on decay dynamics, transition from factors and searches of new physics. Furthermore, the KLOE2 experiment, with an improved detector, has started operation by the end of 2014 with the aim of collecting up to 5 fb\(^{-1}\) in the next year. Recent results on the KLOE data will be presented.

Measuring e/m transition form factors of light mesons with the A2 setup at MAMI.
Dr. PRAKHOV, Sergey

1 UCLA

Electromagnetic transition form factors (e/m TFFs) for the \(\eta \to e^+e^-\gamma\) and \(\omega \to \pi^0 e^+e^-\) Dalitz decays have been measured in the \(\gamma p \to \eta p\) and \(\gamma p \to \omega p\) reactions, respectively, with the A2 tagged-photon facilities at MAMI. The results for the \(\omega\pi^0\) TFF are in better agreement with phenomenological calculations compared to earlier experiments. The analyses of the \(\pi^0 \to e^+e^-\gamma\) and \(\eta' \to e^+e^-\gamma\) decays are in progress. New higher-statistics experiments for measuring the \(\pi^0\) and \(\omega\pi^0\) TFFs have been planned by the A2 Collaboration.

Radiative and Hadronic Decay modes of the \(\eta\)-Meson with CLAS and WASA-at-COSY
LERSCH, Daniel

1 Forschungszentrum Jülich

The radiative decay \(\eta \to \pi^+\pi^-\gamma\) allows to explore the anomalous sector of QCD via the box anomaly, which is part of the Wess-Zumino-Witten Lagrangian. However, interactions between the final state pions have a considerable contribution to the decay amplitude and therefore need to be taken into account. Existing theoretical models can be tested by investigating the energy distribution of the final state photon. The amplitude of the isospin violating decay \(\eta \to \pi^+\pi^-\pi^0\) is sensitive to the ratio of the light quark masses \(Q\). This ratio is investigated via a Dalitz plot or partial wave analysis, whereas the latter one allows an explicit calculation of \(Q\). The measurement of those \(\eta\) decays have been done with the CLAS detector at Jefferson Lab and with the WASA-at-COSY detector at Forschungszentrum Jülich. The \(\eta\)-mesons were produced at CLAS using the photoproduction reaction \(\gamma p \to \eta n\), whereas hadronic reactions \(pd \to ^3He\eta\) and \(pp \to \eta n\) were used at WASA. Both experiments comprise large acceptance spectrometer with the capability to reconstruct all initial and final state particles. This talk will give an overview about the analysis status of those three data sets with respect to the decay modes \(\eta \to \pi^+\pi^-\pi^0\) and \(\eta \to \pi^+\pi^-\gamma\).

The GlueX/JEF program in Hall D at Jefferson Lab
TAYLOR, Simon
Jefferson Lab

As part of the 12 GeV upgrade to CEBAF, the GlueX detector is a large acceptance spectrometer based on a solenoidal design with good coverage for both charged and neutral particles. The apparatus was designed for the flagship program to search for exotic (hybrid) mesons. The Jefferson Lab Eta Factory (JEF) program seeks to extend the physics reach of the GlueX experiment by focusing on rare decays of the η meson. In particular, the $\eta \rightarrow \pi^0 \gamma \gamma$ decay allows access to the dark matter sector. A putative lepto-phobic dark boson $B$ is predicted to manifest itself in the non-dark sector through the $B \rightarrow \pi^0 \gamma$ transition. The JEF experiment will search for the $B$-boson in the mass range of 140-550 MeV, with sensitivity to the baryonic fine structure constant as low as $10^{-7}$. Because good photon reconstruction is essential for this challenging experiment, we plan to upgrade the inner region of the existing forward calorimeter (FCAL) in the GlueX detector with Lead Tungstate crystals, which will improve the position and energy resolution each by a factor of two relative to the lead glass blocks currently in the FCAL. The status of preparations for the JEF program will be presented. This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics under contract DE-AC05-06OR23177.

Light-Meson Decays / 119

Conversion Decays of Light Mesons

SCHADMAND, Susan

1 Forschungszentrum Juelich

We focus on the Dalitz decays of eta and omega mesons used for the experimental determination of electromagnetic transition form factors. The analyses are using data obtained with the WASA-at-COSY and the CLAS detectors.

Plenary Session V - Wednesday / 70

Heavy Baryons on the Lattice

Prof. MEINEL, Stefan

1 University of Arizona / RIKEN BNL Research Center

Baryons containing charm or bottom quarks are interesting systems in QCD because their dynamics is constrained by approximate heavy-quark symmetries. Furthermore, weak decays of heavy baryons play an increasingly important role for flavor physics. I will present recent lattice QCD results for the spectrum, structure, and decays of charm and bottom baryons.

Plenary Session V - Wednesday / 130

Baryon Spectroscopy at LHCb

Dr. SPRADLIN, Patrick

1 University of Glasgow

The LHCb experiment at the CERN Large Hadron Collider is collecting the world’s largest sample of charm and beauty hadrons with a detector that is tailored for precision measurements of their properties. LHCb is actively exploiting its unique data set to investigate the relatively unexplored field of the physics of heavy baryons. This talk will present selected recent results from the LHCb experiment with a focus on the spectroscopy and properties of beauty baryons.
Perspectives on baryons: from the inside out
Dr. ROBERTS, Craig

1 Argonne

The last three years have seen significant developments in our understanding of the internal structure of ground- and excited-state baryons and the influence this has on their interactions with electromagnetic probes. That progress has been driven by feedback between experiment and theory, and constructive interactions between diverse theoretical methods. In particular, an accumulation of evidence suggests that many features of the baryon spectrum and interactions can be explained by the existence of tight but nonpointlike diquark correlations within baryons, whose formation is driven by the same mechanism that produces both an unnaturally light pion and simultaneously a heavy constituent-quark. This presentation will provide a snapshot of contemporary theory relating to these themes.

Understanding the Nucleon as a Borromean Bound-State
Author(s): Dr. SEGOVIA, Jorge
Co-author(s): Dr. ROBERTS, Craig

1 Technische Universität München
2 Argonne

We explain how the emergent phenomenon of dynamical chiral symmetry breaking ensures that Poincaré covariant analyses of the three valence-quark scattering problem in continuum quantum field theory yield a picture of the nucleon as a Borromean bound-state, in which binding arises primarily through the sum of two separate contributions. One involves aspects of the non-Abelian character of QCD that are expressed in the strong running coupling and generate tight, dynamical color-antitriplet quark-quark correlations in the scalar-isoscalar and pseudovector-isotriplet channels. This attraction is magnified by quark exchange associated with diquark breakup and reformation, which is required in order to ensure that each valence-quark participates in all diquark correlations to the complete extent allowed by its quantum numbers. Combining these effects, we arrive at a properly antisymmetrised Faddeev wave function for the nucleon and calculate, e.g., the flavor-separated versions of the Dirac and Pauli form factors and conclude that available data and planned experiments are capable of validating the proposed picture.

Strangeness photoproduction at the BGO-OD experiment
Dr. JUDE, Thomas

1 University of Bonn

The BGO-OD experiment at the ELSA accelerator facility uses an energy tagged bremstrahlung photon beam to investigate the excitation structure of the nucleon. The setup consists of a highly segmented BGO calorimeter surrounding the target, with a particle tracking magnetic spectrometer at forward angles. Compared to constituent quark models (CQMs), models including pseudoscalar meson-baryon interactions have had improved success in describing baryon excitation spectra. Vector-meson baryon interactions have also been predicted to dynamically generate states, which may have been observed in photoproduction reactions. BGO-OD is ideal for investigating low momentum transfer processes due to the acceptance and high momentum resolution at forward angles. This enables the investigation of degrees of freedom not derived from CQMs, and in particular, strangeness photoproduction where t-channel exchange mechanisms play an important role. The ability of the BGO-OD to reconstruct final states of mixed charge also renders
the experiment ideal for the investigation of higher lying hyperon states, for example \( \Lambda(1405) \). With the first major data taking periods for BGO-OD complete, an extensive programme for the investigation of associated strangeness photoproduction has begun. This includes final states with charged and neutral kaons, for the investigation of ground level and excited hyperons. Data has also been taken with a deuterium target for the investigation of neutral channels such as \( K^0\Lambda \) and \( K^0\Sigma^0 \). The current status of analysis and perspectives will be presented. Supported by DFG (SFB/TR-16).

**Hadron Spectroscopy III / 64**

**Partial-Wave Analysis of the Reactions** \( \gamma p \rightarrow \eta p, \gamma n \rightarrow \eta n, \) and \( \gamma p \rightarrow K^+\Lambda \) **in a Multichannel Framework**

**Author(s):** HUNT, Brian

**Co-author(s):** Dr. MANLEY, D. Mark

1 Kent State University

The goal of our research is to determine the properties of nucleon resonances using a multichannel partial-wave analysis. Currently, many predicted resonances have not been found, while the properties of several known resonances are relatively uncertain. This is changing with the recent experimental emphasis on photoproduction reactions. High-quality data for a number of spin observables is helping us solve the question of the “missing resonances”, and is allowing us to obtain nearly model-independent solutions for these reactions. This work focuses on analyzing the world database for the photoproduction reactions \( \gamma p \rightarrow \eta p, \gamma n \rightarrow \eta n, \) and \( \gamma p \rightarrow K^+\Lambda \) by model-independent single-energy fits. Our single-energy amplitudes are then included in the multichannel energy-dependent fits, which are used to determine resonance parameters. We will present preliminary results for our single-energy solutions, the corresponding energy-dependent solution, and some resonance parameters.

**Hadron Spectroscopy III / 62**

**\( \gamma n \rightarrow p\pi^- \) Cross Section Measurement at CLAS**

Dr. MATTIONE, Paul

1 Jefferson Science Associates

Measuring the spectrum of \( N^* \) resonances will provide valuable information on the degrees of freedom within the nucleon, shedding light on whether there is a significant contribution from a correlated quark-pair, or diquark, in the nucleon. To extract these states, measurements of both \( \gamma p \) and \( \gamma n \) cross sections are necessary to disentangle the isospin components of the photoproduction amplitudes. The \( \gamma n \) world data set is much smaller than that for \( \gamma p \), and the \( N^* \) amplitudes on the neutron have very large uncertainties due to low statistics. A preliminary measurement of the \( \gamma n \rightarrow p\pi^- \) differential cross section will be shown using data from the Jefferson Lab CLAS g13 experiment. These results were determined by first measuring the cross section for \( \gamma d \rightarrow p\pi^- (p) \), and then performing a model-dependent correction for final-state interactions in the target deuteron. These data are a factor of 2.5x more than the world data set for this channel, providing much needed statistics to improve the amplitude extraction for coupling to the \( N^* \) resonances.

**Hadron Structure III / 120**

**Impact of ATLAS measurements on the knowledge of the Proton structure**

CLAIRE, Gwenlan

1 Oxford
Several measurements performed by the ATLAS collaboration can be used to constrain the proton structure. Measurements of the W^+c production and the inclusive W and Z differential cross sections are found to constrain the poorly known strange-quark density at low x. Similarly, the ratio of W^+/W^- production is found to constrain the valence quarks at low x. New results will be presented using W,Z production at 13 TeV. New precise measurements of Drell-Yan cross section measurements performed above the Z peak region have a different sensitivity to parton flavour, parton momentum fraction x and scale Q compared to measurements on the Z peak. A large impact is found on the photon content of the proton as well as high x quarks. Measurements of the inclusive jet and photon cross sections are standard candles and constrain the medium and high x gluon densities. New precise measurements of inclusive photon and jet cross sections at 8 TeV are presented and compared to various PDF predictions.

### Hadron Structure III / 96

**Light-cone QCD sum rules for soft contribution to exclusive Drell-Yan process** $\pi^- p \rightarrow \mu^+ \mu^- n$

TANAKA, Kazuhiro

1 Juntendo University

Exclusive Drell-Yan process, $\pi^- p \rightarrow \mu^+ \mu^- n$, may be measured using the high-intensity pion beams at J-PARC, and its QCD description is complementary to that for the deeply virtual meson production, $\gamma^* p \rightarrow \pi N$, at e.g., JLAB. The leading hard exclusive amplitude for exclusive Drell-Yan process was obtained by E.R. Berger, M. Diehl, and B. Pire [Phys. Lett. B 523 (2001) 265] in terms of the partonic subprocess convoluted with the relevant nonperturbative functions, the nucleon generalized parton distributions (GPDs) and the pion distribution amplitudes, and, recently, subleading amplitudes, suppressed by the inverse powers of the dilepton mass Q, have also been calculated by S. V. Goloskokov and P. Kroll [Phys. Lett. B748 (2015) 323]. However, those predictions based on the QCD factorization approach still seem to have large uncertainties that originate from the treatment of the pion pole contribution arising in the relevant GPDs in the ERBL region, the parton transverse momentum to regularize the endpoint singularities, the so-called soft-overlap mechanism, etc. These effects related to “soft contribution” important at J-PARC kinematics are not directly accessible in the usual framework for QCD factorization of the hard exclusive amplitudes. We study the exclusive Drell-Yan process constructing the light-cone QCD sum rules for the corresponding exclusive amplitudes, which allow us to estimate the relevant soft contributions making use of dispersion relations and quark-hadron duality.

### Hadron Structure III / 97

**Measuring nucleon TMD spin-momentum correlations via Drell-Yan at Fermilab E906/E1039 SeaQuest Experiment**

Dr. DAVID, Kleinjan

1 Los Alamos National Laboratory

The Drell-Yan process is an ideal probe to measure the naive T-odd Boer-Mulders and Sivers transverse momentum dependent parton distribution functions (TMDs), both of which describe spin-momentum correlations in the nucleon. Previous experimental results of $\cos(2\phi)$ modulations in dilepton azimuthal distributions suggest significant non-perturbative effects, including a non-zero Boer-Mulders TMD. The Boer-Mulders TMD has been confirmed non-zero by semi-inclusive deep-inelastic scattering experiments. Presently, E906/SeaQuest experiment at Fermilab can measure Drell-Yan produced from a 120 GeV unpolarized proton beam directed on unpolarized nucleon targets. The $\cos(2\phi)$ modulations will be measured to greater precision and at higher-x than previous experiments, deepening our understanding of the role the (anti)quark Boer-Mulders TMD plays the structure of the nucleon. In the future, the E1039/Seaquest experiment will introduce the beam onto a transversely polarized nucleon target. The transverse single spin asymmetry of Drell-Yan production will directly measure the sign and magnitude of sea quark Sivers TMD, which may probe the role sea quark OAM plays in the spin of the nucleon. Much remains to be learned about sea quarks in the nucleon. Measurement of spin-momentum correlations probes
parton dynamics, providing insight beyond static quantities and shedding further light on the dynamical origins of the nucleon sea.

Hadron Structure III / 35

A Solution to the Proton Radius "Puzzle"

**Author(s):** Prof. NORUM, Blaine

**Co-author(s):** Dr. HIGINBOTHAM, Douglas; Dr. MEEKINS, David; Dr. SAWATZKY, Bradley

1 University of Virginia
2 Jefferson Lab

The reported large discrepancy between the proton charge radius measured using the muonic atom Lamb shift \([0.84087(39) \text{ fm}]\) and that extracted from elastic electron scattering measurements \([0.879(8) \text{ fm}]\) has generated a great deal of interest. To examine possible origins of this discrepancy we reanalyzed the published electron scattering data from Saskatchewan (1974), Mainz (1980), and Mainz (2014) using standard statistical methods. We found that these data are actually in very good statistical agreement with the muonic atom results. While strictly speaking not germane to the extraction of the charge radius, we also found that a simple dipole function with its single parameter fixed to the muonic atom value of the proton radius reproduces \(G_E p\) within \(\approx 1\%\) up to momentum transfers of \(q^2 = 30 \text{ fm}^{-2}\).

Recent Approaches to Non-Perturbative QCD I / 125

Hadron-hadron scattering and hadron spectroscopy from lattice QCD

**Dr. BULAVA, John**

1 Trinity College Dublin

Recent algorithmic advances in the treatment of quark propagation have enabled the precise determination of hadron-hadron scattering amplitudes directly from large-volume lattice QCD simulations for the first time. I will review current progress in the calculation of these amplitudes as well as the extraction of resonance parameters from lattice QCD data. As an illustrative example, a recent calculation of the pion-pion scattering amplitude in the rho resonance channel will be discussed. Finally, I will report on preliminary efforts toward the lattice calculation of resonance photoproduction amplitudes, in particular the timelike pion form factor.

Recent Approaches to Non-Perturbative QCD I / 37

Three-flavor chiral effective model with four baryonic multiplets

**Dr. ZÉTÉNYI, Miklós**; OLBRICH, Lisa; Prof. GIACOSA, Francesco; Prof. RISCHKE, Dirk

1 Wigner Research Center for Physics, Budapest, Hungary
2 Institute for Theoretical Physics, Goethe University, Frankfurt am Main, Germany
3 Institute of Physics, Jan Kochanowski University, Kielce, Poland

We present a version of the so-called extended linear sigma model that contains four multiplets of spin-1/2 baryons. Two of these multiplets transform in a “mirror” way under chiral transformations, which allows for chirally invariant mass terms. The model is constructed in the case of three quark flavors and then reduced to the two-flavor case. In this way, four nucleonic states are obtained which mix to produce the nucleon and the three nucleon resonances, N(1440), N(1535), and N(1650). We determine the parameters of the nucleonic part of the Lagrangian from a fit to masses and decay properties of these states. We study the limit of vanishing quark condensate and identify the chiral partners.
Recent Approaches to Non-Perturbative QCD I / 121

Methods of the Constituent Quark and Gluon Model to Calculate Hybrid Baryon States

Author(s): Mr. GROSS, Johnathan 1
Co-author(s): Prof. CAPSTICK, Simon 1

1 Florida State University

Hybrid baryons are composite states composed of three quarks and at least one gluon. These states are allowed by quantum chromodynamics, but have so far not been detected. Lattice quantum field theory has proven extremely useful in calculating these states but are computationally intensive. The constituent quark model has been useful in calculating non-hybrid baryon states and should be just as useful for hybrid baryons. Methods of the constituent quark model and how they can be applied to hybrid baryons will be discussed.

Recent Approaches to Non-Perturbative QCD I / 60

$\Delta(1232)$ resonance in the $\gamma p \rightarrow p \pi^0$ reaction at threshold

Author(s): Mrs. HILLER BLIN, Astrid 1
Co-author(s): Dr. VICENTE VACAS, Manuel 1; Dr. LEDWIG, Tim 1

1 IFIC/CSIC/Universidad de Valencia

We calculate the neutral pion photoproduction on the proton near threshold in covariant baryon chiral perturbation theory, including the $\Delta(1232)$ resonance as an explicit degree of freedom, up to chiral order $p^{7/2}$ in the delta counting. We compare our results with recent low-energy data from the Mainz Microtron for angular distributions and photon asymmetries. The convergence of the chiral series of the covariant approach is found to improve substantially with the inclusion of the $\Delta(1232)$ resonance.

Plenary Session VI - Thursday / 16

Spectroscopy of Exotic Baryons at LHCb

Dr. NEUBERT, Sebastian 1

1 Heidelberg University

The LHCb experiment is designed to study the decays and properties of heavy flavoured hadrons produced in the forward region from pp collisions at the CERN Large Hadron Collider. During Run1, it has recorded the world’s largest data sample of beauty and charm hadrons, enabling precise studies into the spectroscopy of such particles. The unique sample of $\Lambda_b$ baryon decays has led to the discovery of a new class of exotic resonances in the $J/\psi p$ system. The status and latest results of the investigations into these pentaquark states will be presented.

Plenary Session VI - Thursday / 18

Exotic baryons: past and future

Prof. RICHARD, Jean-Marc 1

1 Institut de Physique Nucléaire de Lyon and Universite Claude Bernard

A review of exotic baryons is presented, from the early speculations on Z-baryons in the 60s to the recent pentaquarks with hidden-charm. The phenomenological pictures are compared and commented. Some suggestions will be given for further experimental and theoretical studies.
Meson and Baryon Spectroscopy at GlueX

CHUDAKOV, Eugene

1 Jefferson Lab

The commissioning of the GlueX experiment in Hall D at Jefferson Lab has been completed and the first physics run is scheduled for the Fall of 2016. The primary goal of the experiment is a search for gluonic excitation in the spectra of light mesons. Recent theoretical developments using Lattice QCD predict hybrid states, including those with exotic quantum numbers. Such states, if established, would provide a laboratory for testing QCD in the confinement regime. The experiment is using a beam of linearly polarized photons produced by the electron beam from the linear accelerator. A new, solenoid-based, hermetic detector is collecting data on meson production and decays. At the second stage of running, after 2018, the spectrometer will be equipped with an additional detector for particle identification. This will allow also to study the spectroscopy of strange baryons. For a more distant future, a possibility to build a beam of K-long mesons in the same beam line is being discussed. Such a beam would add new capabilities for doing strange-baryon spectroscopy. A description of the research program, the apparatus, and the commissioning results will be presented.

Recent results from the Crystal Ball/TAPS experiment at MAMI

Dr. SOKHOYAN, Vahe

1 Institut für Kernphysik, University of Mainz

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. The long-term research programs performed with the Crystal Ball/TAPS experiment are diverse. 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. Studying the properties and decays of light mesons also represents an important part of the effort of the collaboration. Furthermore, experiments with light and heavy nuclear targets are carried out to search for the modifications of hadrons in the nuclear medium, using a novel experimental technique. The upcoming upgrade of the tagging system of the Crystal Ball/TAPS experiment will allow us to perform new measurements with unprecedentedly high precision. In this talk, recent results, the current status, and future plans for new high-precision experiments at MAMI will be presented.

Hyperon forward spin polarizability $\gamma_0$ in baryon chiral perturbation theory

Author(s): Mrs. HILLER BLIN, Astrid
Co-author(s): Dr. LEDWIG, Tim 1 ; Prof. GUTSCHE, Thomas 2 ; Dr. LYUBOVITSKIJ, Valery 2

1 IFIC/CSIC/Universidad de Valencia
2 Eberhard-Karls Universität Tübingen

We present the calculation of the hyperon forward spin polarizability $\gamma_0$ using manifestly Lorentz-covariant baryon chiral perturbation theory including the intermediate contribution of the spin-3/2
states. As at the considered order the extraction of $\gamma_0$ is a pure prediction of chiral perturbation theory, the obtained values are a good test for this theory. After including explicitly the decuplet states, our SU(2) results have a very good agreement with the experimental data and we extend our framework to SU(3) to give predictions for the hyperons' $\gamma_0$ values. Prominent are the $\Sigma^-$ and $\Xi^-$ baryons as their photon transition to the decuplet is forbidden in SU(3) symmetry and therefore they are not sensitive to the explicit inclusion of the decuplet in the theory.

**Hadron Spectroscopy IV / 41**

**Hadron Spectroscopy with COMPASS**

Dr. BERNHARD, Johannes

1 CERN

The COMPASS experiment at CERN aims to contribute to the understanding of the structure and the dynamics of hadrons. With its large acceptance over a wide kinematic range for both charged and neutral particles, COMPASS is well suited for a detailed study of final states produced in inelastic interactions of hadrons or polarized muons with target nucleons. We present an overview of current activities in hadron spectroscopy of light mesons at a beam momentum of 190 GeV/c with an emphasis on the $\pi^-\pi^+\pi^-$ final state for which COMPASS recorded the world’s largest data sample. This allows us to measure the properties of known resonances with unprecedented precision and opens the door for new discoveries such as the recently observed axial-vector meson $a_1(1420)$. Additionally, the findings are crosschecked with the analysis of the $\pi^-\pi^0\pi^0$ channel and found to be well compatible. Furthermore, amplitudes of the $\pi^+\pi^-$ subsystems are extracted from data as a function of the $3\pi$ mass. Other studies in COMPASS include Primakoff reactions on nuclear targets, central production of pions and kaons, as well as diffractive production of final states with $\eta$ and $\eta'$.

**Hadron Spectroscopy IV / 114**

**Meson Spectroscopy of the 3$\pi$ decay channel in g12 run of CLAS**

**Hadron Spectroscopy IV / 71**

**$\Lambda(1405)$ Photoproduction at MAMI**

Dr. WERTHMUELLER, Dominik

1 University of Glasgow

Despite being classified as a 4-star state by the PDG the nature of the $\Lambda(1405)$ is still not well understood. The picture of a p-wave excitation of the uds ground state within the classic quark model fails at describing its low mass. Alternative models involving exotic structures, such as pentaquarks or hybrids, have been proposed but it is becoming widely accepted that the $\Lambda(1405)$ emerges as a dynamically generated resonance from the antikaon-nucleon interaction. Since the early calculations of Dalitz and Tuan new insights have been gained, especially using unitary chiral perturbation theory frameworks, which for example, found evidence for a two-pole structure of the $\Lambda(1405)$. On the experimental side, the recent high quality data obtained from photoproduction measurements at the CLAS experiment set new standards for future experiments, which are still required to ensure progress in understanding the $\Lambda(1405)$. The high quality and intensity electron beam at the MAMI accelerator facility in Mainz is used by the A2 collaboration to produce a real photon beam via the tagged bremsstrahlung technique. Using an electron beam energy of 1.6 GeV allows the photoproduction of the $\Lambda(1405)$ near threshold from a proton target in the reaction $\gamma p \rightarrow K^+\Lambda(1405)$. The excellent photon detection capabilities of the electromagnetic calorimeters Crystal Ball and TAPS will enable a precise measurement of the $\Sigma^0\pi^0$ final state. In addition, the A2 setup would be ideally suited for the very challenging measurements of the radiative decays of the $\Lambda(1405)$, which have never been directly measured before but can provide...
crucial information about the internal structure of the state. A report on the status of the data analysis and planned activities will be presented.

**Hadron Structure IV / 102**

**The international project FAIR: A status overview**

Dr. NICMORUS, Diana

1 FAIR

The new international accelerator facility FAIR under construction in Darmstadt aims at studying matter at atomic, nuclear and hadronic levels. I will review several important aspects towards the realization of the Facility for Antiproton and Ion Research, and discuss recent developments. I will present the focus of the experimental programmes - hadron physics, nuclear structure and compressed nuclear matter physics, plasma and atomic physics, as well as related applications.

**Hadron Structure IV / 87**

**The Charged Life of HDice at Jefferson Lab**

Dr. HANRETTY, Charles

1 Jefferson Lab

Polarized targets, especially of the frozen-spin variety, are highly valuable tools in the study of nucleon structure and the interaction mechanisms of its constituents. One such target, HDice, is a “next generation” target system operated at Jefferson Lab in Newport News, VA. This unique target is a quantum crystal of molecular HD in its solid phase. Both H and D can be polarized in true frozen-spin states, and spin can be transferred between H and D to optimize conditions for specific fixed-target experiments. Recently, the target has been used for the E06-101 N* run in Hall B (CLAS-6) using photon beams, with in-beam polarization lifetimes of years. Its potential for use with electron beams in CLAS-12 would open a window to a plethora of experiments; three A-rated experiments with transversely polarized HD have already been approved and designated as “high-impact” for Hall B. However, new polarization loss-mechanisms become active with charged-particle beams. Since the energy deposition in HD is nearly independent of the electron beam energy, polarization lifetimes can be studied with MeV-scale beams. A new 10 MeV accelerator is under construction at JLab and will be used to optimize the performance of the HDice target system with electrons. The principles of this complex target system, the aforementioned eHD test program, as well as HDice's future use with CLAS-12 will be discussed.

**Hadron Structure IV / 85**

**Tensor Polarized Deuteron at Jefferson Lab**

Dr. LONG, Elena

1 University of New Hampshire

With the development of a new solid DNP spin-1 tensor-polarized target, interest has been growing to explore physics that can be extracted using such a target. In the DIS region, HERMES data measured the b1 structure function at a surprising large, negative value that cannot be explained using conventional models but only with novel physics such as 6-quark hidden color effects. A new experiment at JLab will confirm the HERMES data as well as map out the region of zero-crossing. Additionally, in the quasi-elastic region, tensor polarization experiments can be used to better understand the deuteron’s S/D wavefunction ratio, probe the tensor force that’s expected to be the source of short range correlations, and provide a crucial test of relativistic light-cone and virtual-nucleon models. A second experiment at JLab will probe this quasi-elastic tensor structure of the deuteron. An overview of this emerging tensor program will be discussed.
Searching for $d^*$ Dibaryons with CLAS

Dr. MATTIONE, Paul

Over the past several decades, a number of groups have reported evidence of dibaryons, bound states of two baryons. However, only one unambiguous dibaryon state is known to exist: the deuteron, which has a binding energy of only $2.2\text{ MeV}$. Recently, the WASA-at-COSY collaboration has reported evidence for a $d^*(2380)\Delta\Delta$ bound state in $pN\rightarrow d\pi\pi$. Studying dibaryon resonances is important for understanding the properties of the strong force in nuclear systems. A study of the $\gamma d\rightarrow d\pi\pi^-$ reaction is shown using data from the Jefferson Lab CLAS g13 experiment. Strong, resonance-like $d\pi$ structures are seen in Dalitz plots of this system, indicating potential $N\Delta$ bound states. Preliminary fits of this data to Breit-Wigner line-shapes will be shown. However, in the long-run, an amplitude analysis of this data needs to be performed to study the interference between these potential $N\Delta$ bound states, the $\varphi$, and other potential backgrounds. With over $3\text{ million events}$ and a detected dibaryon in the final state, these CLAS data are a promising place to search for dibaryon resonances.

The Observation of a Di-Baryon in the Proton-Neutron System - Hexaquark or Molecule?

Dr. BASHKANOV, Mikhail

Several new findings in the four and five quark systems reheat the interest in the field of multiquark states (beyond trivial $q\bar{q}$ and $qqq$). A lot of progress is made in the $6q$ sector on both the baryonium and di-baryon sides. A resonance like structure observed in double-pionic fusion to deuteron, at $M = 2.38\text{ GeV}$ with $\Gamma = 70\text{ MeV}$ and $I(J^P) = 0(3^+)$ has been consistently observed in a wealth of reaction channels, supporting the existence of a resonant dibaryon state - the $d^*(2380)$. These studies include measurement of all the principle decay channels in $pd$ and $dp$ collisions in the quasi-free mode by the WASA-at-COSY and HADES collaborations. Recently the $d^*$ has been observed in two-body reactions, which are amenable to simpler interpretation through partial wave analysis. The $pn$ decay channel was measured by use of polarized deuterons on a proton target in inverse kinematics. These new $np$ analyzing power data exhibit a pronounced resonance effect in their energy dependence. The SAID partial-wave analysis with inclusion of these data reveals a pole in the complex plane of the $^3D_3$ partial wave at $(2380 \pm 10)\text{MeV} - i(40 \pm 5)\text{MeV}$ in accordance with the $d^*(2380)$ resonance hypothesis. The internal structure of the $d^*(2380)$ is largely unknown. It can contain various hidden color $6q$ configurations and $\Delta\Delta$ molecular structures with angular momentum L=$0,2,4,6$. A large set of already available experimental data constrains the internal structure of the $d^*(2380)$ dibaryon. Future plans to improve our understanding of the $d^*$ will be presented as well as the exciting possibilities for investigation of SU(3) multiplet companions and mirror partners of the $d^*$.

Search for the $H$-dibaryon in the $(K^-, K^+)$ reaction

Prof. AHN, Jung Keun

A recent claim from the LHCb collaboration on the observation of two hidden-charm pentaquark states revives hopes for experimental discoveries of other multiquark baryonic states such as the $H$-dibaryon with a 6-quark ($uuddss$) configuration. Recent theoretical predictions for the mass of $H$-dibaryon pointing to the mass region near $\Lambda\Lambda$ threshold also encourage experimental searches. A dedicated experiment (J-PARC E42) has been proposed to search for the $H$-dibaryon.
in the bound and unbound mass regions near \( \Lambda \Lambda \) threshold. The experiment is designed to measure production of \( \Delta p\pi^- \), \( \Lambda \Lambda \) and \( \Xi^- p \) systems in the \( 12C(K^-, K^+ \) reaction with a 1-MeV mass resolution. A new large-acceptance spectrometer (Hyperon Spectrometer) is now under construction, consisting of a superconducting dipole magnet and a time projection chamber. The current status of the J-PARC E42 experiment will be presented. On the other hand, the \( H \)-dibaryon can be produced through \( \Xi^- p \) fusion in the elementary \( K^- (pp) \rightarrow K^+ \Xi^- p \rightarrow K^+ H \) reaction from \( 12C \). Therefore, a fraction of di-proton pairs in relative \( S \)-wave state in \( 12C \) is very interesting. A preliminary idea on the di-proton measurement via the \( (p, p' 2He) \) reaction will also be discussed.

**Hadron Spectroscopy V / 48**

**Search for Hybrid Baryons with CLAS12 at JLAB**

Dr. LANZA, Lucilla

1 Dip. Fisica Universita’ di Roma Tor Vergata and INFN Roma Tor Vergata

Hybrid baryons are hypothetical three-quark states with dominant gluonic admixtures. Their existence is allowed by QCD, and lattice QCD calculations now predict several baryon states with dominant gluonic admixture to the wave function, and with the lowest mass hybrids approximately 1.3 GeV above the nucleon ground state of 0.94 GeV, i.e. in the range \( W = 2.2-2.3 \) GeV. An experimental program is under development to analyze the mass range up to 3.5 GeV with the CLAS12 setup in HallB at Jefferson Laboratories exploiting the process \( e+p \rightarrow e' K^+ + \Lambda \). Electron beams with energies of 6.6, 8.8, and 11 GeV impinging upon a liquid hydrogen target in the CLAS12 center may be employed. Scattered electrons may be detected in an angle range of 2.5° to 4.5° in the Forward Tagger(FT) and for angles greater than 6° in the CLAS12 Forward Detector. FT allows to probe the crucial \( Q^2 \) range where hybrid baryons may be identified due to the fast dropping of their \( A_{1/2}(Q^2) \) electro-coupling and to the suppression of \( S_{1/2}(Q^2) \). The Gent Regge plus Resonance model has been used to include a realistic hybrid resonance contribution at the amplitude level to determine the sensitivity of the CLAS12 apparatus to a hybrid baryon signature.

**Hadron Structure VI / 106**

**Measurement of polarization transferred to a proton bound in nuclei**

Prof. PIASETZKY, Eli

1 Tel Aviv University

Possible differences between free and bound protons may be observed in the ratio of polarization-transfer components. We report the measurement of this ratio on deuteron at low and high missing momenta. Observed increasing deviation of the measured ratio from that of a free proton a function of the virtuality, similar to that observed in 4He, indicates that the effect in nuclei is due to the virtuality of the knock-out proton and not due to the average nuclear density. The measured differences from calculations assuming free-proton form factors (about 10%), may indicate in-medium modifications. Preliminary data on proton removed from carbon will also be presented.

**Hadron Structure VI / 76**

**New results on spin structure functions at very low momentum transfers from Jefferson Lab**

ADHIKARI, Krishna

1 Mississippi State University
Several experiments in Jefferson Lab have collected a large amount of data on the spin structure of nucleons using polarized electron beam directed on various polarized targets ($NH_3$ and $ND_3$, $^3He$). In these double polarization experiments, either the double spin asymmetries $A_{||}$ and $A_{\perp}$ or the polarized cross section differences $\Delta \sigma_{||}$ and $\Delta \sigma_{\perp}$ are measured with high precision over a wide kinematic range, with $0.02 \text{GeV}^2 < Q^2 < 5.0 \text{GeV}^2$ and $1.08 \text{GeV} < W < 3.0 \text{GeV}$ and from these measurements, the spin structure functions and their moments are extracted. These data help us shed more light on the nucleon spin structure in the region of quark-confinement as well as in the transition region between hadronic and partonic degrees of freedom. With these data, it is possible to put constraints on quark-hadron duality, test pQCD predictions for the quark polarization at large $x$, and test various predictions for moments of structure functions from sum rules and QCD based effective theories such as Chiral Perturbation Theory ($\chi$PT) as well as from phenomenological models. Additionally, these data make it possible to perform more precise calculations of higher-twist matrix elements in the framework of the Operator Product Expansion. At very low momentum transfers ($Q^2 \to 0$), the first moment ($\Gamma_1$) of structure function $g_1$ is constrained by the GDH sum rule and its $\chi$PT extensions, which makes measurements of $g_1$ in this region uniquely interesting. In this talk, I will present new results on spin structure functions from various experiments at Jefferson Lab with an emphasis on low $Q^2$ measurements. In particular, I will present new results from the EG4 experiment with CLAS, which measured the double polarized cross section difference on $NH_3$ and $ND_3$ (with both electron beam and targets longitudinally polarized) down to $Q^2 = 0.02 \text{GeV}^2$.

Hadron Structure VI / 32

Collins asymmetry and proton form factors at BESIII
Dr. DBEYSSI, Alaa$^1$

$^1$ Helmholtz-Institut Mainz

We report on the measurement of the $e^+e^- \to \bar{p}p$ cross section using the data collected by the BESIII detector at 12 c.m. energies in the range between 2.23 to 3.67 GeV. The proton electromagnetic form factor in the time-like region is measured. BESIII also collected data from the $\Lambda_c$-pair mass threshold to 4.6 GeV. Based on this data set, the $\Lambda_c$ form factor can be studied for the first time. In addition, based on $\sim 65/pb$ data collected at 3.65 GeV, we explore Double Collins asymmetries by looking at the two back-to-back charged pions, which has similar energy coverage with the SIDIS experiments. The results of the first measurement of Collins asymmetry at low Q will be reported.

Hadron Structure VI / 29

Deeply virtual Compton scattering with CLAS12
Dr. BISELLI, Angela$^1$

$^1$ Fairfield University

The Generalized Parton Distributions (GPDs) have emerged as a universal tool to describe hadrons in terms of their elementary constituents, the quarks and the gluons. Deeply Virtual Compton Scattering (DVCS) on a proton or neutron ($N$), $eN \to e'N'\gamma$, is one of the simplest processes that can be described in terms of GPDs. The amplitudes of DVCS and Bethe-Heitler, process where a photon is emitted by the incident or scattered electron, can be accessed via cross section measurements or exploiting their interference which give rise to spin asymmetries. Spin asymmetries, cross sections and cross-section differences can be connected to different combinations of the four leading order GPDs ($H, E, \tilde{H}, \tilde{E}$) for the two quark flavors depending on the observable and the type of target. This talk focuses on recent CLAS results and gives an overview of the upcoming experimental program on DVCS in Hall B at 12 GeV. Several experiments have been proposed to extend and improve the current measurements on polarized and unpolarized proton and as well as new measurements on neutron target. This program, once completed, will bring us a step closer to fully reveal the 3D quark structure of the nucleon.
Model discrimination in pseudoscalar-meson photoproduction

Author(s): Prof. RYCKEBUSCH, Jan¹
Co-author(s): Mr. NYS, Jannes ¹ ; Prof. IRELAND, David ² ; Dr. GLAZIER, Derek ²

¹ Ghent University  
² University of Glasgow

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

An update on JPAC activities

Author(s): Dr. PAUK, Vladislav¹  
Co-author(s): Dr. MATHIEU, Vincent ²

¹ JLab  
² Indiana University

The Joint Physics Analysis Center (JPAC) between Indiana University and Jefferson Lab is a theory group aimed for developing analysis tools for hadron spectroscopy. In this talk I’ll summarize recent activities of JPAC in hadron structure and spectroscopy. First, I’ll present a new method of experimental analysis of the proton electric form factor. The suggested approach is aimed for adding a missing puzzle in the proton radius problem. In particular, we propose to measure the proton form factor in the photo production of lepton pairs on a proton target. The comparison of the production rates for the electron versus muon pairs gives a direct access for testing the lepton universality and comparison of the proton radius extraction from the electron versus muon scattering type experiments. Furthermore, I’ll summarize recent JPAC efforts on hyperon spectrum and hidden charm pentaquark searches.

Determination of $T$ and $F$ observables in $\eta$ photoproduction on the CLAS Frozen Spin Target (FROST)

Mr. TUCKER, Ross¹

¹ Arizona State University

Polarization observables are an important tool for understanding and clarifying baryon resonance spectra. In 2010, experiments were conducted at Jefferson Lab using a polarized photon beam incident on a polarized frozen spin target (FROST). We present preliminary data of the $T$ and $F$ asymmetries for $\eta$ photoproduction from the proton, along with comparisons to theoretical predictions. The data used in the present analysis were taken during the second running period of FROST using the CLAS detector at Jefferson Lab, with transversely-polarized protons in a butanol target or circularly-polarized incident tagged photons with energies between 0.62 and 2.93 GeV.
Measurement of the double polarization observables E and G at the Crystal Ball experiment at MAMI

Ms. AFZAL, Farah Noreen

1 HISKP, University of Bonn

For a better understanding of the nucleon excitation spectra and hence QCD at the non-perturbative regime, meson photoproduction reactions are studied at facilities like MAMI in Mainz where the Crystal Ball experiment is located. To be able to describe the photoproduction processes, polarization observables need to be measured in addition to the unpolarized cross section. The A2 collaboration has measured the double polarization observables E and G for the first time simultaneously using a longitudinally polarized electron beam together with a diamond radiator resulting in an elliptically polarized photon beam. Additionally a longitudinally polarized butanol target was utilized. Preliminary results for the photoproduction reaction $\vec{\gamma}\vec{p} \rightarrow p\pi^0$ will be presented in this talk.

Baryon spectroscopy at BESIII

Dr. DESTEFANIS, Marco

1 Università degli Studi di Torino and INFN

The BESIII experiment, hosted at the IHEP of Beijing, has collected the world largest data sample in the charmonium energy region. One of the most important physics goals of BESIII is the investigation of the QCD prediction. QCD can be accessed in a unique way by means of hadron spectroscopy. Charmonium decays provide an excellent scenario for studying nucleons, hyperons and their excited states, such as the N*, Λ*, Σ* and Ξ* resonances, as well as threshold production. The most recent results for baryon spectroscopy from BESIII will be discussed.

Resonance production and decay in pion induced collisions with HADES

Dr. PRZYGODA, Witold

1 Jagiellonian University in Krakow

Witold Przygoda for the HADES Collaboration

Smoluchowski Institute of Physics, Jagiellonian University of Cracow, 30-348 Krakow, Poland

A major goal of the High Acceptance Di-Electron experiment (HADES) [1] at GSI is to study the electromagnetic properties of hadronic matter in the 1-3.5 GeV/nucleon incident energy range. The present interpretation of dilepton spectra measured in heavy-ion reactions at various energies is based on hadronic models, which predict in-medium modifications of the $\rho$ meson spectral function due to its coupling to resonance-hole states [2]. In the energy range of the HADES experiments, the $\rho$ meson is mainly produced in primary $NN$ or secondary $\pi N$ collisions, which opens the possibility to constrain the interpretation of medium effects by measuring dielectron emission in elementary reactions and better understand the relation between the couplings of the baryonic resonances to the $\rho$ meson and the electromagnetic structure of the corresponding baryonic transitions. Recently, HADES collected data in $\pi^- - N$ reactions at four different
pion beam momenta (0.656, 0.69, 0.748 and 0.8 GeV/c) [3]. In this measurement two targets (polyethylene and carbon) were used with the aim to subtract events from scattering on carbon and identify pure contribution from scattering on protons. Exclusive channels with one pion ($\pi^-$p), two pions ($n\pi^+\pi^-$ and $p\pi^-\pi^0$) and dileptons ($\nu e^+e^-$) in the final state were identified. The normalization was done based on the elastic scattering ($\pi^-p$) channel with the cross sections taken from the SAID database [4]. Results for exclusive channels with two pions in the final state have been included in a combined partial wave analysis (PWA) of the Bonn-Gatchina group [5]. The obtained solution provides the excitation function of two-pion production around the pole of the $N(1520)D_{13}$ resonance with the decomposition into contributing channels, in particular coupling to the intermediate $\rho$ meson. The $\rho$ spectral distribution obtained from the partial wave analysis is used to compute the respective contribution to the exclusive $\nu e^+e^-$ channel, assuming strict Vector Meson Dominance. The results of this analysis will be presented.

References

Hadron Spectroscopy VIII / 83

Angular distribution of exclusive dielectron production in pion-nucleon collisions

Mr. SPERANZA, Enrico1 ; Dr. ZETÉNYI, Miklós2 ; Mr. FRIMAN, Bengt3

1 GSI Helmholtzzentrum für Schwerionenforschung and Technische Universität Darmstadt, Darmstadt, Germany
2 Wigner Research Center for Physics, Budapest, Hungary
3 GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

A study of the angular distribution of the dilepton produced in the reaction $\pi N \rightarrow Ne^+e^-$ is presented [1]. Effective interactions describing only the physical degrees of freedom for baryon resonances up to spin-5/2 are employed to compute the spin-anisotropy coefficient for isolated intermediate baryon resonances. It is shown that a given spin-parity state of the intermediate resonance exhibits a characteristic angular dependence of the spin-anisotropy coefficient. Furthermore, the spin-anisotropy coefficient resulting from the interference between resonances with different spin and parity is presented. Our results show that the spin-anisotropy coefficient can help disentangle the resonance contributions to the process [2]. Moreover, it is argued that the study of polarization observables can provide information on the production process and equilibration mechanism in heavy-ion collisions.


Hadron Spectroscopy VIII / 57

Antibaryon Photoproduction using CLAS at Jefferson Lab

PHELPS, William1

1 Florida International University

There is little known about the baryon-antibaryon photoproduction mechanism. Three reactions, $\gamma p \rightarrow pp\bar{p}$, $\gamma p \rightarrow pp\pi^-$, and $\gamma p \rightarrow pm\pi^+$ have been investigated for the photon energy range of 4.4-5.45 GeV. The data were from the g12 experiment taken with the CLAS detector using a liquid
hydrogen target in Hall B at Thomas Jefferson National Accelerator Facility. This experiment had high statistics, with an integrated luminosity of $68 \text{ pb}^{-1}$. General features of the data and preliminary cross sections for the $p\bar{p}$ system will be discussed.

**Hadron Spectroscopy VII / 30**

**Recent Belle Results on Charmed Baryon Spectroscopy and Decays**

Dr. YELTON, John$^1$

$^1$ University of Florida

Electron-Positron annihilations in the Upsilon resonance region have for many years proved a wonderful source of charmed baryon data. In this talk I review recent results on charmed baryons using data from the Belle experiment, which has collected the world’s largest dataset in this energy range.

**Hadron Spectroscopy VII / 31**

**Basis Light-Front Quantization Approach to Heavy Quarkonium**

**Author(s):** Dr. LI, Yang$^1$

**Co-author(s):** Prof. MARIS, Pieter $^1$; Prof. VARY, James $^1$; Prof. ZHAO, Xingbo $^2$; Dr. ADHIKARI, Lekha $^1$; Dr. CHEN, Guangyao $^1$

$^1$ Iowa State University

$^2$ Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou

We present the properties of heavy quarkonium obtained within the Basis Light-Front Quantization approach [1]. An effective Hamiltonian is developed based on the Light-Front Holographic QCD plus the one-gluon exchange interaction. The produced mass spectra of charmonium and bottomonium agree with experiments to within a root mean square (r.m.s.) deviation of 40 MeV in the masses of the known states below open flavor thresholds. The resulting light-front wavefunctions grant access to hadronic observables relevant for experiments. We evaluate the decay constants, the form factors and the r.m.s. radii, and compare with experiments and other established approaches. We discuss our progress for evaluating additional observables including the generalized parton distributions (GPDs) of quarkonium (cf. [2]). We also apply the light-front wavefunctions to diffractive vector meson production in Deep Inelastic Scattering (DIS). Our predictions for these observables can be tested at current and forthcoming experimental facilities, e.g., LHC, RHIC and EIC. We will also discuss the prospect of extending the Basis Light-Front Quantization approach to the baryon sector. We acknowledge DOE Grants DE-FG02-87ER40371 & DESC0008485. X. Zhao is supported by the new faculty startup funding by the Institute of Modern Physics, Chinese Academy of Sciences.


**Hadron Spectroscopy VII / 122**

**Heavy flavour production and spectroscopy at ATLAS**

Prof. ABBOTT, Brad$^1$

$^1$ University of Oklahoma

ATLAS has a wide programme to study the production properties of conventional and exotic quarkonium, beauty, and charm bound states. This presentation will cover the latest results on
J/psi, psi2s and Upsilon production at 7, 8, and 13 TeV, D meson production with Run-1 data, and B+ production at 13 TeV. The latest results in the ATLAS programme of heavy hadron production and spectroscopy are also presented, including studies of B_c and Lambda_b decays, and measurement of b-quark fragmentation functions.

Hadron Spectroscopy VII / 94

XYZ exotic states at COMPASS
Dr. BERNHARD, Johannes

The COMPASS experiment at CERN contributes to the understanding of the structure and the dynamics of hadrons. With large acceptance over a wide kinematic range for both charged and neutral particles, COMPASS is well suited for detailed studies of inelastic reactions of hadrons or muons with target nucleons with a focus on the extraction of hadron resonance parameters. We present an overview of current activities in the search for XYZ exotic states with muon-beam induced photo-production at beam energies from 160 GeV to 200 GeV. As a first result, an upper limit for the exclusive production of the charged \( Z_c(3900) \) was established as well as an upper limit for the partial width of its decay \( Z_c(3900) \to J/\Psi \pi^{\pm} \). In addition, we will explore future possibilities within the COMPASS-II program, such as a study of neutral \( Z_c(3900) \) production in the \( J/\Psi \pi^0 \) channel as well as a study of \( X(3872) \) production in the \( J/\Psi \pi^+ \pi^- \pi^{\pm} \) channel.

Superfast quarks in collider experiments and QCD evolution

Author(s): FRESE, Adam
Co-author(s): Dr. SARGSIAN, Misak; Dr. STRIKMAN, Mark

Quantum chromodynamics has been extremely successful in describing many high-energy experiments with the use of universal parton distribution functions. PDFs of the free proton are well-constrained by experimental data, but nuclear PDFs require further elaboration. One of the unique aspects of nuclear QCD is the possibility of superfast partons with Bjorken \( x > 1 \), which are indicative of short range correlations between bound nucleons. We present investigations of superfast quarks at energy scales relevant to both the LHC and EIC that take into account not only the latest phenomenology of nuclear SRCs, but also parton-level modifications of nucleons within the nuclear medium. An account will additionally be given for QCD evolution of superfast quarks, with corrections due to finite target mass and higher-twist effects.

Measurement of the triple-differential cross section for photon + jet production at \( \sqrt{s} = 8 \) TeV with the CMS detector

Author(s): Ms. KHATIWADA, Ajeeta
Co-author(s): Prof. ASKEW, Andrew

We measure the triple differential cross section for photon plus jet as a function of photon transverse momentum \( (p_T^\gamma) \), photon pseudorapidity \( (\eta^\gamma) \), and jet pseudorapidity \( (\eta^{jet}) \). The production of photons in association with jets can be used to understand gluon distribution functions as well as to test perturbative Quantum Chromodynamics (QCD). The measurement is made using data collected by the Compact Muon Solenoid detector in proton-proton collisions.
at the center-of-mass energy of 8TeV. For each bin, a signal fraction is extracted by fitting a Multivariate Analysis distribution of single photon triggered data candidates with Monte Carlo signal template and data-driven background template. The background template is obtained by optimizing the data sideband region to reduce bias and systematics. The final value of triple differential cross sections at various kinematic regions are compared to theoretical predictions at leading and next-to-leading order.

Hadron-Hadron Interactions II / 86

Inclusive cross section and double-helicity asymmetry for $\pi^0$ production at midrapidity in p+p collisions at $\sqrt{s}$=510 GeV

Dr. GURAGAIN, HARI

1 GEORGIA STATE UNIVERSITY

One of the major objectives of the RHIC spin program at BNL is the measurement of the gluon helicity contribution, $\Delta G$, to the proton spin via measuring the double longitudinal spin asymmetry ($A_{LL}$) in various channels. In PHENIX (Pioneering High Energy Nuclear Interaction eXperiment) the $A_{LL}$ in $\pi^0$, $\eta$, $J/\psi$ etc. are measured in wide rapidity range. In this talk, $A_{LL}$ in $\pi^0$ production in central rapidity and $J/\psi$ production in forward rapidity will be discussed. The $\pi^0$ is reconstructed through its diphoton decay channel within the rapidity range of $|\eta| < 0.35$ and azimuthal angle of 180°. Similarly, $J/\psi$ is reconstructed via dimuon decay channel within the rapidity range of 1.2 < $|\eta|$ < 2.2. Results for $A_{LL}$ in $\pi^0$ and $J/\psi$ production from the data collected in the year 2013 at center of mass energy ($\sqrt{s}$) = 510 GeV will be presented. Also, their impact on $\Delta G$ constraint will be discussed. In year 2013, the total integrated luminosity was 150 $pb^{-1}$ which is almost ten times the total luminosity recorded in the year 2009 at $\sqrt{s}$ = 200 GeV. Due to increase in the center of mass energy and integrated luminosity, the new measurements cover the Bjorken x range down to 0.01 for $\pi^0$ and 0.002 for $J/\psi$.

Hadron-Hadron Interactions II / 88

A search for supersymmetry at CMS with two photons and missing transverse energy at $\sqrt{s} = 13$ TeV

Author(s): Mr. SANTRA, Arka
Co-author(s): Dr. ASKEW, Andrew ; Dr. WEINBERG, Marc ; Ms. REINSVOLD, Allison ; Mr. TOPSIS-GIOTIS, Iasonas ; Prof. HILDRETH, Michael

1 Florida State University
2 University of Notre Dame
3 National Center for Scientific Research Demokritos

The missing transverse energy, potentially a sign of new physics, is a measure of the imbalance in the observed energy of an event. The Standard Model background prediction for the missing transverse energy in the two photon final state was determined using a data-driven technique, where different components of the background were estimated from different side- bands to the candidate two photon sample. This background was compared with the observed missing transverse energy distribution produced in proton- proton collisions, collected by the CMS Experiment at the CERN LHC at $\sqrt{s} = 13$ TeV. The results were then interpreted using simplified supersymmetry models.
An effective QCD light front Hamiltonian for all light hadrons is constructed by embedding superconformal quantum mechanics into AdS space. The specific breaking of conformal symmetry inside the graded algebra determines uniquely the effective confinement potential. The generalized supercharges connect the meson and baryon light front wave functions and reproduce the characteristic features of the spectra. All light hadron masses are reproduced with an accuracy better than 10 percent.

Plenary Session VII - Friday / 117

Parity Violation in Deep Inelastic Scattering at Jefferson Lab
Dr. ZHENG, Xiaochao

University of Virginia

Sixty years after the first discovery of parity violation in electroweak interactions, parity-violating electron scattering (PVES) has become a tool not only in establishing the Standard Model of electroweak physics and studying the subatomic structure of the nucleon, but also in exploring possible new physics beyond the Standard Model. In this talk, I will present the physics of Parity Violation in Deep Inelastic Scattering (PVDIS), focusing on recent results from Jefferson Lab using the 6 GeV electron beam. I will also give a brief outlook of the PVDIS program using the 12 GeV Jefferson Lab and the Solenoid Large Intensity Device (SoLID). At the end of the talk I’d like to keep the perspective that as we progress more and more towards a thorough understanding of electroweak physics, we may also want to investigate how parity violation could affect our everyday life.

Plenary Session VII - Friday / 123

Elastic form factors and the proton radius
Dr. ARRINGTON, John

Argonne National Laboratory

A new generation of measurements utilizing polarization degrees of freedom in electron scattering has dramatically improved our picture of the nucleon form factors, providing clearer pictures of the short-distance structure of the proton and neutron. In more recent years, there has been renewed interest in low-Q^2 measurements which focus on the nucleon’s large-scale structure including the charge and magnetic radii of the proton. Differences between these results and new measurements of the atomic levels in muonic hydrogen, have given us the proton radius puzzle, which is attracted intense interest. I will give an overview of the new insight that has been gained from these measurements, present an update on recent results, and discuss future plans to further improve our detailed understanding of nucleon structure and to resolve the proton radius puzzle. This work was supported by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH11357.

Plenary Session VIII - Friday / 98

The Lambda(1405) and new non ordinary baryons
Prof. OSET, Eulogio

IFIC, University of Valencia

I shall give an overview of past and recent work on the Lambda(1405) to show its “extraordinary” nature, beyond the qqq picture, and the present status. Then will show results for the Lambda_b -> J/psi K^- p reaction comparing with LHCb data and how the complementary Lambda_b
-> J/psi pi Sigma reaction filters isospin zero and is a good tool to provide extra information on the Lambda(1405). This issue will connect with the recent pentaquarks discovered by the LHCb collaboration and I shall elaborate on them from the theoretical point of view, making predictions for new pentaquark states of meson-baryon molecular nature.

Plenary Session VIII - Friday / 93

The Qweak Experiment: Direct Measurement of the Proton’s Weak Charge

Author(s): Ms. LEE, Anna Lee
Co-author(s): QWEAK COLLABORATION

Virginia Tech

The Standard Model makes a definite prediction for the neutral weak charge of the proton; any deviation from this value would be a signature of physics beyond the Standard Model. The Qweak experiment, performed over the course of 2.5 years at Jefferson Lab, will obtain a precision measurement of the weak charge by determining the magnitude of the parity-violating asymmetry in elastic scattering of the 1.1 GeV longitudinally polarized electron beam with a low momentum transfer of $Q^2 = 0.025 \ (GeV/c)^2$. The experimental apparatus and technical challenges will be explained and the process of extracting the weak charge will be described. The result from a small subset of the data has been published and will be discussed. There will also be an update on the status of the current analysis of the full dataset, and descriptions of several ancillary measurements taken during the experimental run.