A Program in Medium-Energy Nuclear Physics

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Final Report — October 1, 2014

We report here on the final stages of the Berman grant. In those last stages, the priority was the completion of the Ph.D. thesis work of the two graduate students supported on the grant, namely Nicholas Zachariou and Edwin Munevar. Happily, both of these graduate students finished their work and successfully defended their Ph.D. theses. Some of the details of their work is described below.

The study of the spectrum and properties of the excited states of the nucleon (the N* states) is one of the highest-priority goals of nuclear physics and one of the major programs of Jefferson Lab, especially in Hall B. We have most recently focused our attention on exclusive studies (in both spin and strangeness) of the neutron in the deuteron. Our g13 experiment, "Production of Kaons from the Deuteron with Polarized Photons" [Nadel-Turonski (2006)], was carried out between October 2006 and June 2007. This experiment was done using both linearly and circularly polarized photons, mainly to try to unscramble the multitude of wide and overlapping N* states and to measure their properties by studying in fine detail their decays into strange-particle reaction channels. To this end, one of our students, Edwin Munevar, has analyzed the $\gamma n \rightarrow K^+\Sigma^-$ reaction channel for his Ph.D. topic.

The strangeness-production channels constitute the subject of the original GW group's g13 proposal. But the g13 data set, by virtue of its statistics, polarization, and kinematic coverage, is ideally suited for many other reaction channels as well. Among these is the azimuthal angular asymmetry for deuteron photodisintegration, which was analyzed by another of our students, Nicholas Zachariou, for his Ph.D. topic, with help from Nickolay Ivanov (from the Yerevan Physics Institute in Armenia). This study required a deuterium target and a linearly polarized photon beam.

The group has been admirably led over the years by Barry Berman, up to his untimely death in July 2010. The rest of the group consisted of Assistant Research Professor Anna Micherdzinska, Postdoctoral Research Scientist Rakhsha Nasseripour, and graduate students Edwin Munevar and Nicholas Zachariou.

I. Studies of the Excited States of the Nucleon

A. Exclusive analysis of the $\gamma d \rightarrow K^+ \Sigma^- (p)$ reaction with $\Sigma^- \rightarrow \pi^- n$

E. Munevar

Strangeness channels are important in the experimental search for missing resonances. Due to the scarce experimental data in strangeness photoproduction on the neutron, phenomenological models such as coupled-channels analyses resort to certain approximations that do not allow getting either accuracy or agreement between different analyses when extracting resonance parameters.

Thus, a recent experiment performed at Jefferson Laboratory (CLAS g13 run period) used a liquid deuterium target with linearly and circularly polarized tagged photon beams covering energies from threshold to 2.5 GeV. The experiment provides high-quality data (about 52 billion triggers) with good kinematic coverage and several experimental observables available for each reaction channel.

We have analyzed these data to measure strangeness photo-production on the neutron, in particular, the $\gamma + n \rightarrow K^+ + \Sigma^-$ reaction. The exclusive analysis of this reaction along with the final measurement of the photon beam asymmetry is presented.

In order to perform an exclusive analysis of this reaction, K^+, π^-, and n need to be detected as the proton (p), for the case of a quasi-free reaction, is a low-momentum particle escaping the detection in CLAS. Therefore, the proton (p) and the Σ^- are reconstructed from its missing mass MM(K^+, π^-, n) and its invariant mass M(π^- n), respectively. The final goal of this analysis is to determine the cross section (from the g13a [circularly polarized] data) and the beam asymmetry (from the g13b [linearly polarized] data).

Fig. 1 shows the mass distribution for the proton (p) after PID selection. The small bump on the right (around 1.1 GeV/c^2) is related to π^0 contributions from the reactions $\gamma d \rightarrow K^{+*} \Sigma^- (p)$ and $\gamma d \rightarrow K^+ \Sigma^{-*} (p)$ where K^{+*} and Σ^{-*} decay into $K^+ \pi^0$ and $\Sigma^- \pi^0$, respectively. Such a contribution can be studied by looking at the missing mass of the system (π^- n) as a function of the momentum of K^+ depicted in Fig. 2. By slicing the K^+ momentum into 100-MeV/c pieces and fitting each piece with a double-Gaussian function, the $K^+ \Sigma^-$ (p) contribution (gray histogram in Fig. 1) can be separated from the $K^+ \Sigma^-$ (p) π^0 contribution (dashed histogram in Fig. 1).

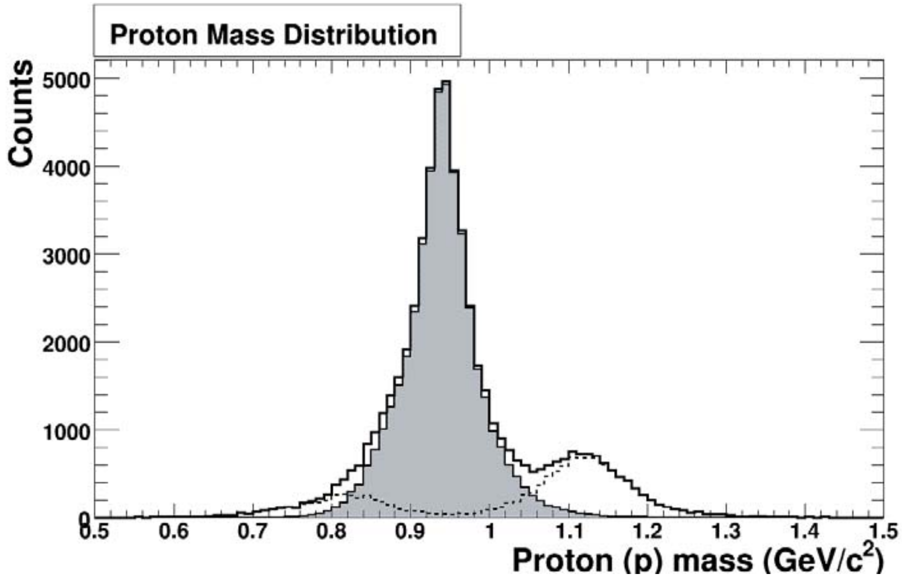

Fig. 1: Missing-mass distribution MM(K^+, π^-, n). The gray histogram represents events for the reaction K^+ Σ^- (p). The dashed histogram represents the contribution of the K^+ Σ^- (p) π^0 channel.

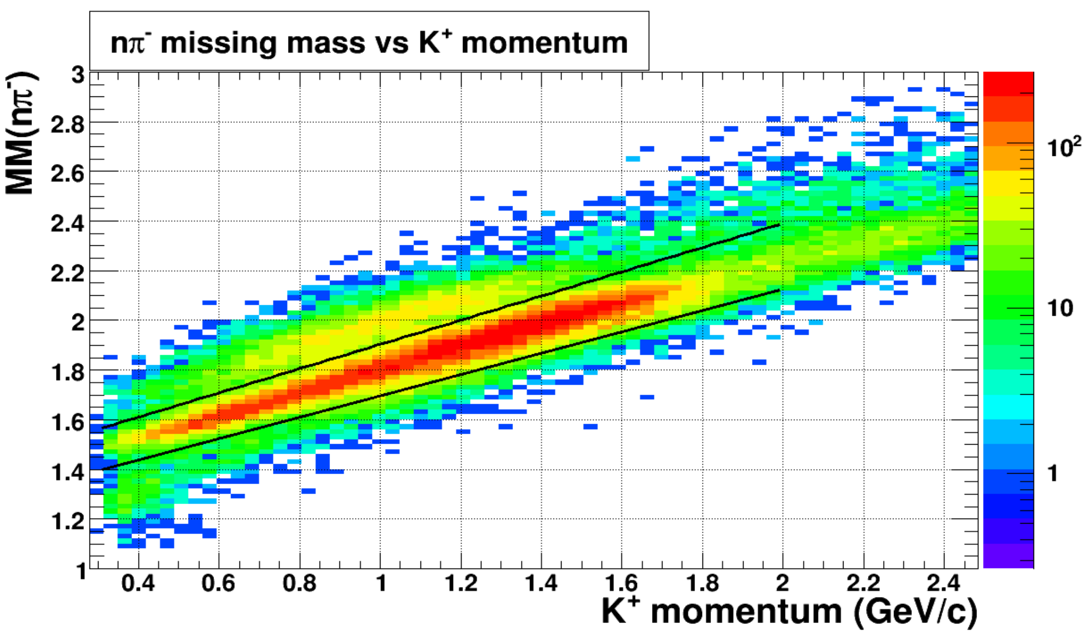

Fig. 2: Missing-mass distribution of the system (π^- n) as a function of the momentum of K^+. A momentum-dependent cut (black lines) allows it to subtract background associated to the reactions $\gamma d \rightarrow K^{+*} \Sigma^-$ (p) and $\gamma d \rightarrow K^+ \Sigma^{-*}$ (p) (events outside the two black lines). Remaining events (within the black lines) represent the reaction K^+ Σ^- (p).

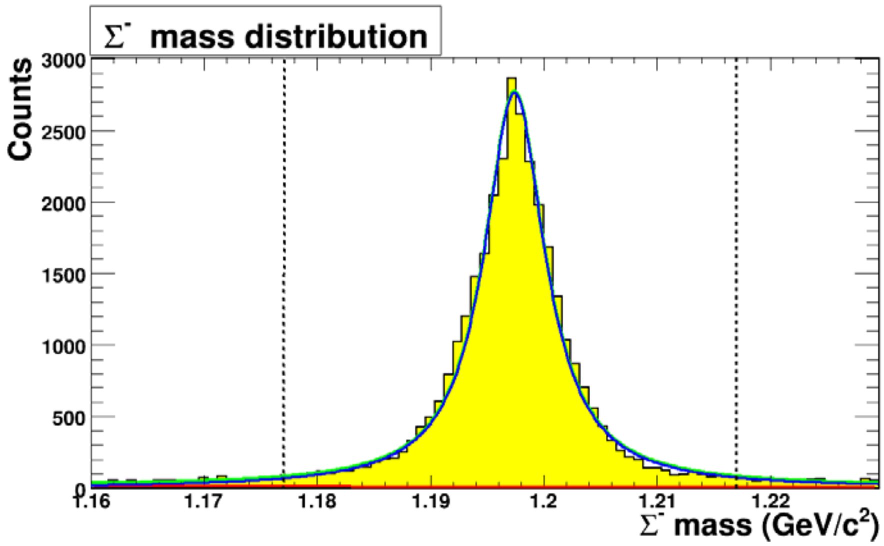

Fig. 3: Invariant-mass distribution $M(\pi^- n)$ fitted with a Breit-Wigner plus a first-order polynomial. Events within the two black dashed lines correspond to roughly 99.3% of the total number of events using g13a data.

Fig. 3 above displays the invariant mass distribution $M(\pi^- n)$ integrated over all angles for E_γ = 2.1-2.3 GeV. Yields are extracted from that distribution by fitting it for each E_γ bin with a Breit-Wigner plus a first order polynomial function. Fig. 4 below depicts the normalized yields for four different photon energy bins. Yields show the cosθ distribution for K^+ in the center-of-mass of the reaction normalized with respect to the photon flux. The next step is to correct these yields for the CLAS acceptance which will produce the differential cross section for the $K^+ \Sigma^-$ reaction.

On the other hand, based on the yields obtained from g13b data, the beam asymmetry can be determined. In order to do so, the linearly polarized data (g13b) were taken with two different photon polarization orientations: horizontal and vertical. The beam asymmetry is extracted from two different methods: the φ-bin method and the method of moments. In the former method, the beam asymmetry is determined by taking the ratio of the flux normalized with horizontal and vertical orientation. For each E_γ and $\cos\theta^*_{K+}$ bin the asymmetry, as a function of the azimuthal distribution φ_{K+}, is fitted by means of a A + B cos(2φ) function where the fitting parameter B is proportional to the beam asymmetry. The second method determines the cos(2φ) moment of the azimuthal distribution and from them, the asymmetry is calculated on an event-by-event basis.

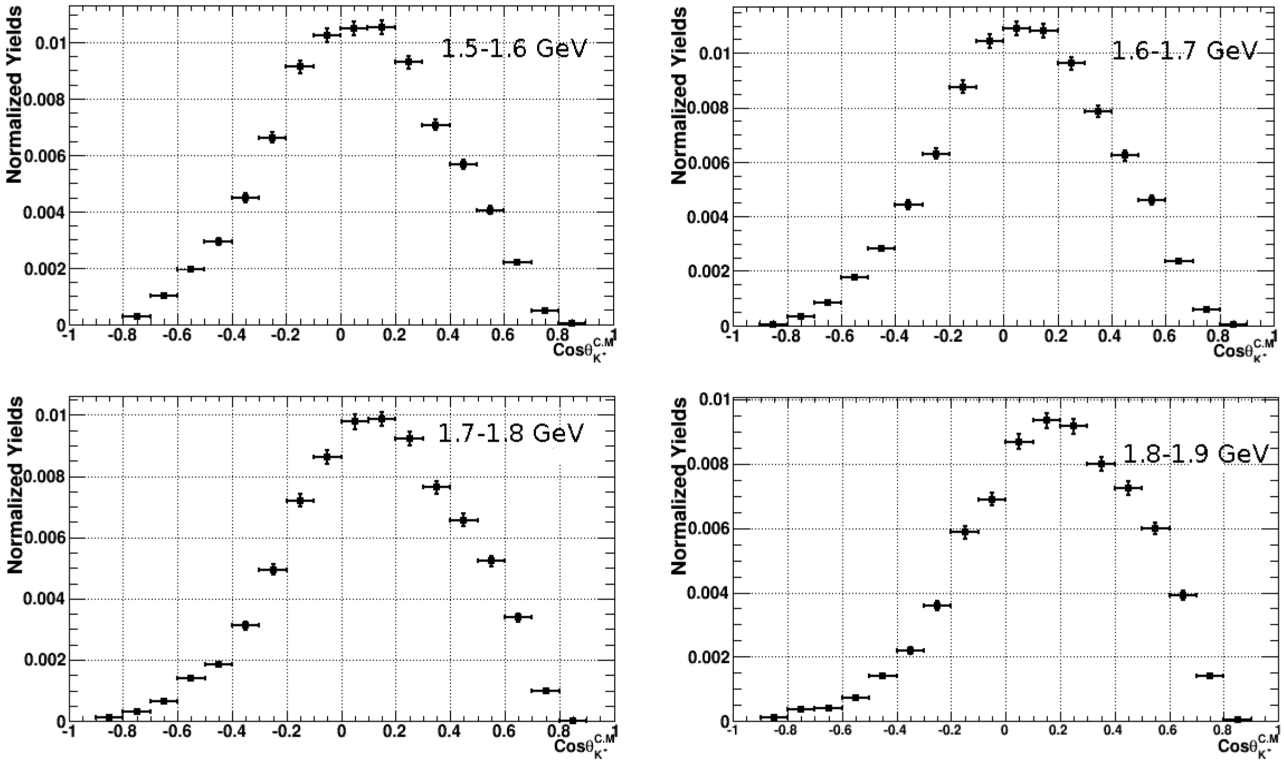

Fig. 4: Yields normalized respect to the photon flux for four energy bins (100-MeV each) between 1.5-1.9 GeV. These yields are not corrected for the CLAS acceptance. Errors shown are only statistical.

Based on the analysis methods to select the Σ^- yields and to determine the photon beam asymmetries, here we show the final results for the photon beam asymmetries as well as their comparison with the current existing asymmetries and predictions found in the literature.

The only published results currently existing on the photon beam asymmetry Σ for the reaction $\gamma n \rightarrow K^+\Sigma^-$ come from the inclusive analysis of data from the SPring-8/LEPS facility. Figs. 5 and 6 show the comparison as a function of $\cos\theta^*_{K+}$ between the photon beam asymmetry determined in this work (using the method of moments) for the 1.9-2.1 GeV and 2.1-2.3 GeV photon energy settings and those determined in from LEPS data. Since the two detectors complement each other, there are only two experimental points to compare with, the points centered at 0.6 and 0.7 in $\cos\theta^*_{K+}$. The asymmetries obtained in this work (red points in Figs. 5 and 6) were determined with a photon energy width of 200 MeV and cover an angular range from about 38° to 155° in the center of mass of the reaction; the results from LEPS correspond (black triangles for 2.05 GeV and magenta triangles for 2.15 GeV in Figs. 5 and 6) were obtained with a photon energy width of 100 MeV and cover a 5° to 55° angular range in the center of mass frame. It is evident then that the results determined in this work represent a significant increment in the kinematic coverage of the data currently existing in the literature for the beam asymmetry of $K^+\Sigma^-$.

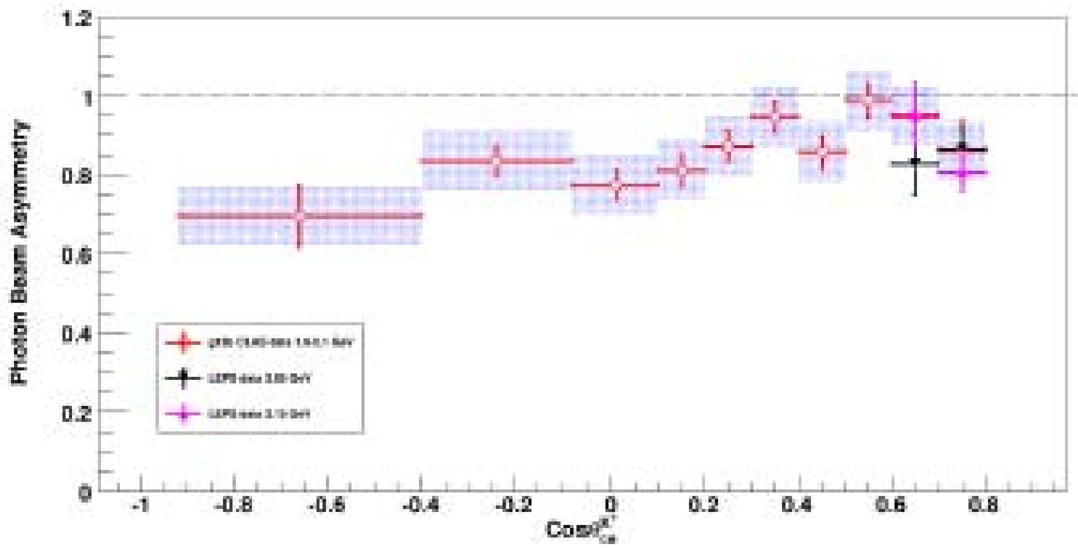

Fig. 5: Comparison of the photon beam asymmetry (open red circles) for the 1.9-2.1 GeV photon energy setting. LEPS results are shown for the 2.05 GeV (black triangles) and the 2.15 GeV (magenta triangles) photon-energy bins. Both statistical (red points) and systematics (blue shadow regions) uncertainties for the asymmetries determined in this work are shown.

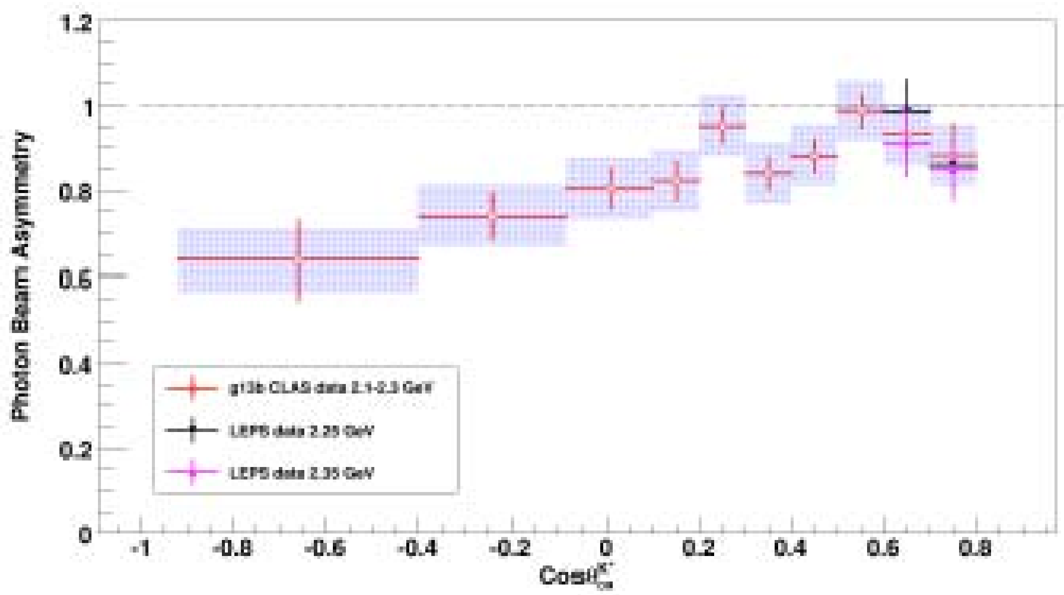

Fig. 6: Comparison of the photon beam asymmetry (open red circles) for the 2.1-2.3 GeV photon energy setting. LEPS results are shown for the 2.25 GeV (black triangles) and the 2.35 GeV (magenta triangles) photon-energy bins. Both statistical (red points) and systematics (blue shadow regions) uncertainties for the asymmetries determined in this work are shown.

The photon beam asymmetry Σ is seen to be positive at all angles and at both photon energy bins, showing a mild polar angle dependence and reaching a maximum value of about 0.99 at $\cos\theta^*_{K+}$ ≈ 56°). The results from both data sets (CLAS and LEPS) agree well within the error bars at the photon energy bins studied. For CLAS data both statistical and systematics errors are shown. The statistical errors are in general smaller than the systematic errors except at the very backward and the very forward angles where the statistics is low and the systematic error bars are smaller by about 10%. For LEPS data only the statistical errors are shown. When comparing both data sets, the statistical error bars are of the same magnitude.

Kaon photoproduction is usually described theoretically from the scheme of hadron ex-changes. In the s-channel, N, N* and Δ* are the exchanged particles; ground-state and excited hyperons are exchanged in the u-channel while K and K* mesons are the ones contributing in the t-channel, being this last meson-exchange contribution expected to be dominant at forward angles. At this point, the photon beam asymmetry Σ plays a key role to identify the type of meson exchanged since at small values of |t| and at high energies, Σ tends to reach the value +1 or -1 depending on whether it is the K* or the K meson being exchanged. The kaon-MAID model assumes the dominance of the K meson in the t-channel leading then to predictions of negative beam asymmetries for the $K^+\Sigma^-$ channel. On the contrary, the data obtained in this analysis show that the beam asymmetries have positive values indicating the t-channel should be dominated by the exchange of the K* meson. Fig. 7 below shows the comparison between the kaon-MAID predictions and the CLAS results determined in this work for the photon beam asymmetry of $K^+\Sigma^-$ at the 2.1 GeV photon energy bin. Predictions from kaon-MAID at higher photon energies are not available. These experimental results indicate therefore the need for an improvement in the current kaon-MAID-like phenomenological models.

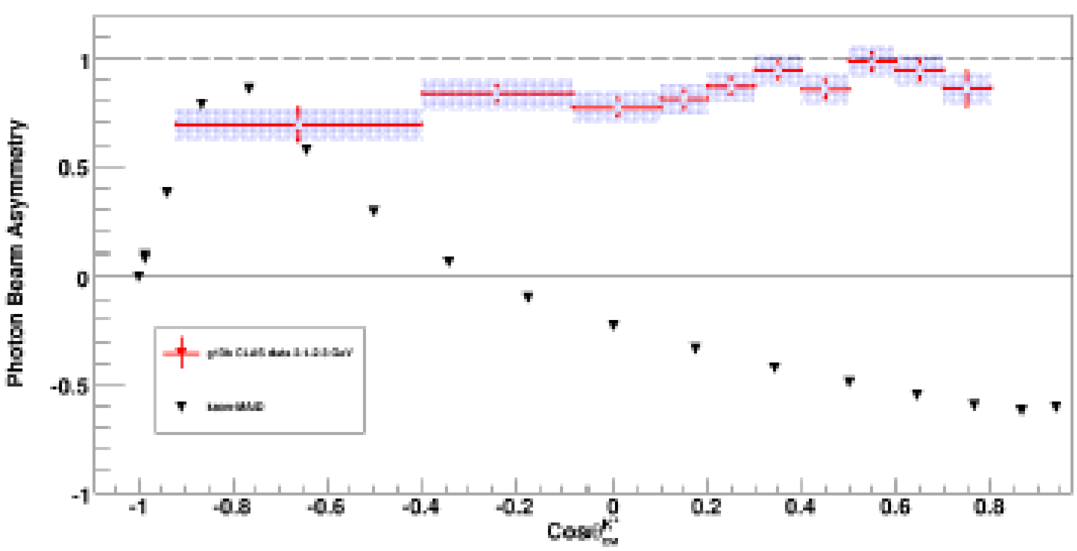

Fig. 7: Comparison of the photon beam asymmetry as a function of $\cos\theta^*_{K+}$ determined in this work (open red circles) for the 2.1-2.3 GeV photon energy setting. Kaon-MAID predictions (black triangles) are shown for the 2.1 GeV photon-energy bin. Both statistical (red points) and systematic (blue shadow regions) uncertainties for the asymmetries from this work are shown.

In summary, the azimuthal photon beam asymmetry Σ has been determined in this work for the quasi-free reaction $\gamma n \rightarrow K^+\Sigma^-$ for two different photon energy bins: E_γ = 1.9-2.1 GeV with E_e = 5.057 GeV, and E_γ = 2.1-2.3 GeV with E_e = 5.157 GeV using CLAS data from the g13b run period. The determination of Σ was carried out by doing an exclusive analysis of the reaction $\gamma d \rightarrow K^+\Sigma^-K^+$ (p) where the K+ as well as the decaying products of the Σ^- , π^- and n, were detected. The quasi-free reaction $\gamma n \rightarrow K^+\Sigma^-$ was defined by requiring the momentum of the proton (p) to be less than 150 MeV. The results obtained in this work provide the only data of Σ available for the reaction $\gamma n \rightarrow K^+\Sigma^-$ in the 1.9-2.3 energy region and in an angular range between roughly 55° and 155°. Therefore, these results can be used to motivate improvement and development on phenomenological models aimed at resolving the “missing resonance” issue.

II. Studies of Few-Body Nuclei

A. Determination of the Azimuthal Asymmetry for Deuteron Disintegration by Linearly Polarized Photons of E_γ = 1.1-2.3 GeV

N. Zachariou

Deuteron photodisintegration is a benchmark process for the investigation of the role of quarks and gluons in nuclei. Existing theoretical models of this process describe the available cross sections with the same degree of success. Therefore, spin-dependent observables are crucial for a better understanding of the underlying dynamical mechanisms. However, data on the induced polarization (P_y), along with the polarization transfers ($C_{x'}$ and $C_{z'}$), have been shown to be insensitive to differences between theoretical models. On the other hand, the beam-spin asymmetry (Σ) is predicted to have a large sensitivity and is expected to help in identifying the energy at which the transition from the hadronic picture of the deuteron to the quark-gluon picture takes place.

In this work, we determined the experimental values of the beam-spin asymmetry for photodisintegration of the deuteron in the photon energy range E_γ = 1.1–2.3 GeV and proton center-of-mass angles θ_p = 20°–160°. The data were taken with the CLAS detector at Jefferson Lab during the g13 experiment. Photons with linear polarization of ~80% were produced using the coherent bremsstrahlung facility in Hall B. Our work shows that the collected data provide the kinematic coverage and statistics to test the QCD-based models at hand. In fact, the results of this study show that the available theoretical models in their current state do not adequately predict the azimuthal asymmetry in this energy region.

Previous measurements for the azimuthal asymmetry only exist for 90° (from Yerevan). The present results are shown below in Fig. 8 compared to those earlier results. Our new results significantly increase the kinematic coverage of the previous data set. We also see that, in the region of overlap, the current results agree well with the Yerevan data.

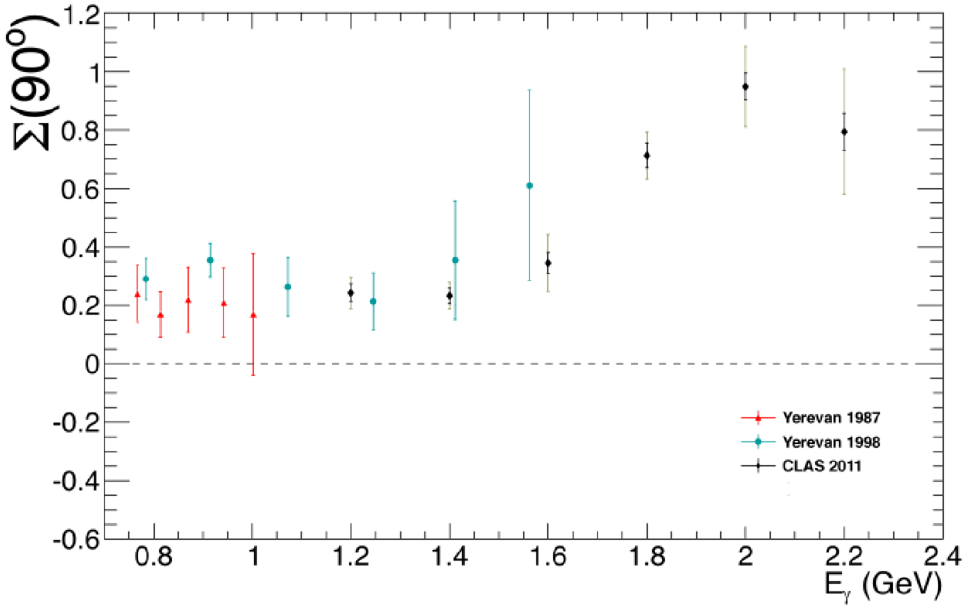

Fig. 8: Azimuthal asymmetry as a function of the incident photon energy, for $\theta_{cm} = 90°$. The red and cyan points correspond to results from Yerevan, whereas the black points correspond to the results from this work.

Figs. 9 and 10 show the results for the azimuthal asymmetry determined from this work. Specifically, Fig. 9 shows the angular dependence of the asymmetry for the six different photon-energy bins (between 1.1–2.3 GeV), whereas Fig. 10 shows the energy dependence of the asymmetry for five angles in the center-of-mass frame. At the lowest photon-energy bin, the azimuthal asymmetry exhibits a minimum at $\theta_{cm} = 90°$. This minimum shifts to larger angles as photon energy increases and vanishes for $E \geq 1.8$ GeV, where the asymmetry exhibits a maximum at $\theta_{cm} = 90°$. The azimuthal asymmetry for all photon-energy bins also changes sign, being negative for small angles and positive for intermediate angles. In addition, the asymmetry at backward angles, and specifically for $\theta_{cm} > 120$, is positive for $E \leq 1.7$GeV and changes sign, becoming negative, for $E \geq 1.7$ GeV. The energy dependence of the azimuthal asymmetry indicates a peak around 2 GeV for all five proton angles. Fig. 10 shows that the azimuthal asymmetry has a maximum for $\theta_{cm} = 35°, 60°, 90°$, and $120°$, and a minimum for $\theta_{cm} = 145°$. As mentioned before, the data for the azimuthal asymmetry of deuteron photodisintegration are the only polarization data available that cover photon energies $E = 1.1 - 2.3$ GeV and all angles.

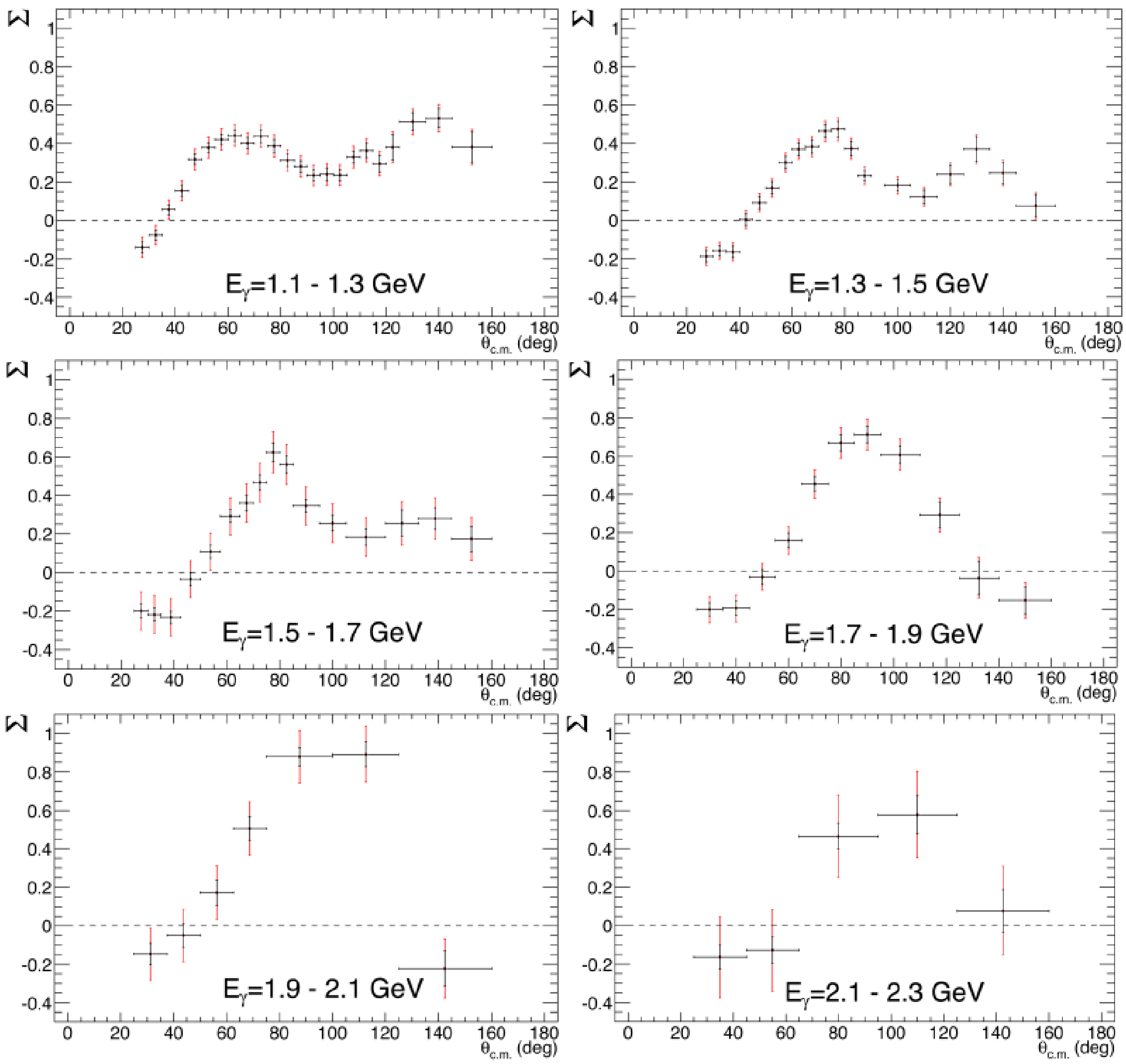

Fig. 9: Azimuthal asymmetry as a function of the proton angle in the center-of-mass frame for six photon energy bins.

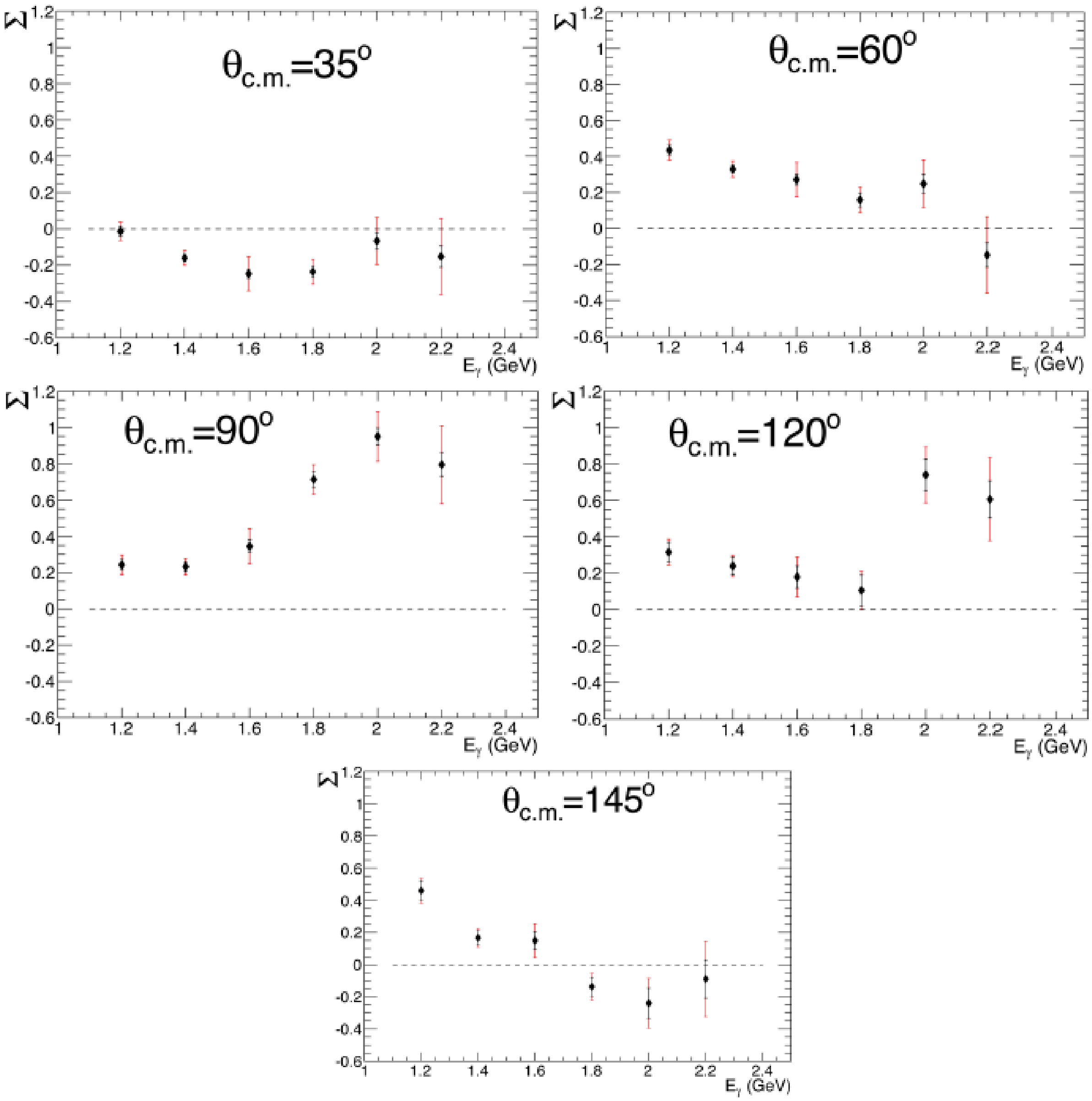

Fig. 10: Azimuthal asymmetry as a function of photon energy for five different angles in the center-of-mass frame.

Theoretical calculations are compared to the data in the following plots. Fig. 11 shows the azimuthal asymmetry as a function of proton angle in the center-of-mass fame for six different photon-energy bins between E =1.1 − 2.3 GeV. The red dashed-dotted line shows the predictions of the QGSM, whereas the blue lines correspond to predictions of the HRM model. The thick and thin solid curves correspond to the "on-shell" version of the model and represent predictions based on large and small helicity non-conservation, respectively. The dashed and dotted blue lines represent two versions of the "off-shell" approximation.

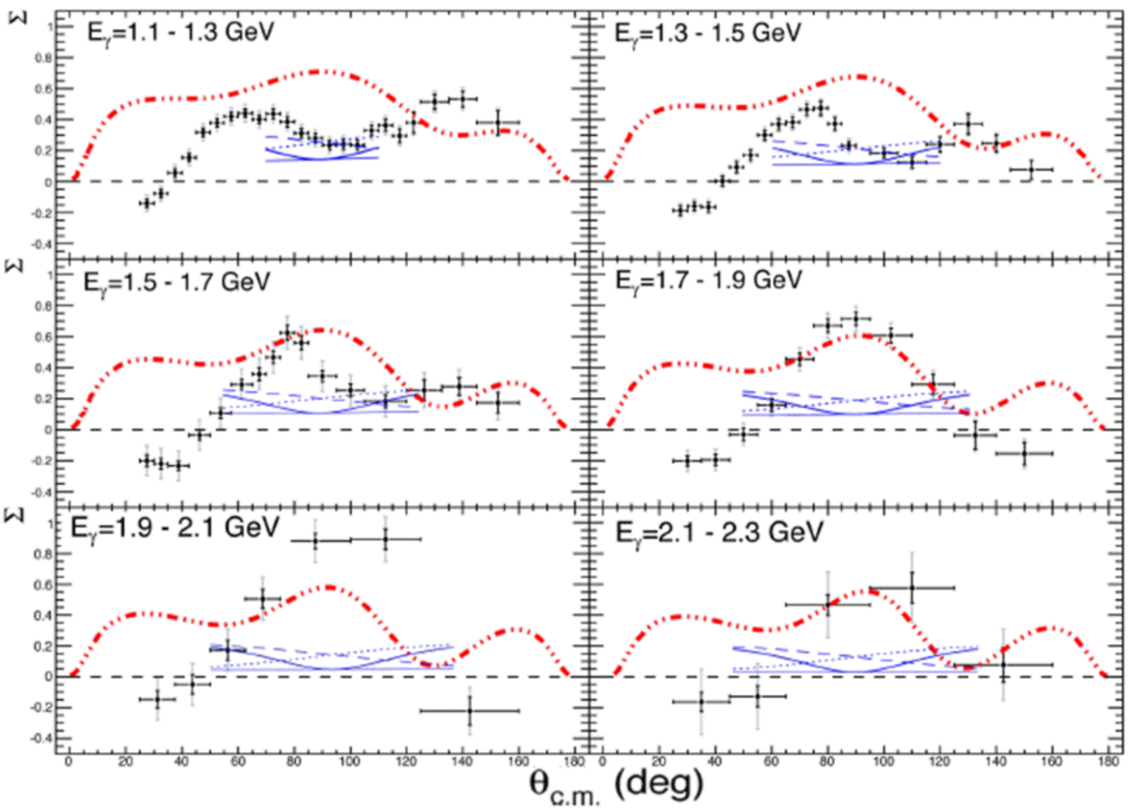

Fig. 11: Azimuthal asymmetry as a function of the proton angle in the center-of-mass frame, for the six photon-energy bins between E =1.1−2.3 GeV. The error bars show the statistical (black) and the systematic (grey) uncertainties. The red dashed-dotted line shows the predictions of the QGSM, whereas the blue lines correspond to predictions of the HRM model (see text).

The angular dependence of the azimuthal asymmetry at fixed E is not well represented by the two models. The QGSM predicts a maximum of the asymmetry at $\theta_{cm} = 90°$, which is observed at the higher photon-energy bins, however, its functional form does not coincide with what is observed from the data. On the other hand the HRM predicts the behavior of the asymmetry at the low photon energy bins (minimum at $\theta_{cm} = 90°$), but fails to do so at the higher energies. In the energy range E =1.1−1.7 GeV, the angular distributions of the azimuthal asymmetry show rich structure (two peaks) which very qualitatively supports the QGSM, which also exhibits rich structure (although three peaks). The cross-section data show a smooth decrease with angle, therefore, this rich structure may be due to strong interference effects.

Fig. 12 shows the energy dependence of the azimuthal asymmetry for $\theta_{cm} = 90°$ compared to the two models. In general, the data rule out the HRM model calculations. It is interesting, however, that the HRM model reproduces the minimum at E =1.2 GeV and $\theta_{cm} = 90°$, given that it is typically expected to be valid at higher energies. The fact that the HRM calculation does not reproduce the peak at 2 GeV may mean that modeling the process as a factorization of pn elastic scattering, the deuteron wave function, and hard scattering is not applicable to the azimuthal asymmetry Σ. It might be the case that any structures in the energy dependence of the azimuthal asymmetry arise from structures in the underlying $pn \rightarrow pn$ amplitude. If this is the case, the factorization to include the $pn \rightarrow pn$ amplitude is not sufficient to explain the peak at 2 GeV, or the extrapolation of this amplitude misses some important physics.

The QGSM does not predict any structure in the energy dependence of Σ at $\theta_{cm} = 90°$. In fact, it predicts asymmetries that decrease at a constant rate as the photon energy increases. Even though this model is expected to be valid for typically higher energies, it does not predict the maximum observed in the asymmetry at $\theta_{cm} = 90°$ around E = 2 GeV.

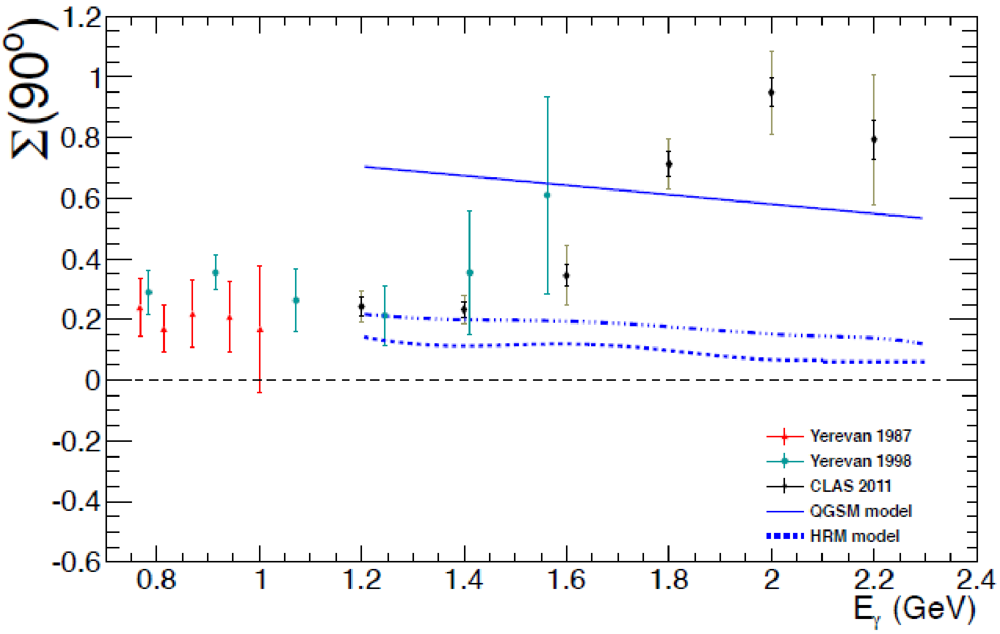

Fig. 12: Azimuthal asymmetry as a function of the incident photon energy, for $\theta_{cm} = 90°$. The blue lines correspond to the predictions of the QGSM (solid line), and HRM (dotted lines). The red and cyan points correspond to results from Yerevan, whereas the black points to the results of this work.

Publications

Papers in Refereed Journals

1. N. Zachariou, Y. Ilieva, M.M. Sargsian, B.L. Berman, G. Feldman *et al*., Determination of the Beam-Spin Asymmetry of Deuteron Photodisintegration in the Energy Region E_γ = 1.1-2.3 GeV, (to be submitted to Phys. Rev. C).
2. I. Pomerantz *et al*., Hard Two-Body Photodisintegration of ^{3}He, Phys. Rev. Lett. **110**, 242301, (2013).
3. S.P. Malace *et al*., Precise Extraction of the Induced Polarization in the ^{4}He(e,$e'p$)^{3}H Reaction, Phys. Rev. Lett. **106**, 052501, (2011).
4. G. Ron *et al*., Low-Q^2 Measurements of the Proton Form Factor Ratio $\mu_p G_E/G_M$, Phys. Rev. **C84**, 055204, (2011).
5. R. Nasseripour *et al*., Coherent Photoproduction of π^+ from ^{3}He, Phys. Rev. **C83**, 034001, (2011).
6. H. Baghdasaryan *et al*., Tensor Correlations Measured in ^{3}He(e,$e'pp$)n, Phys. Rev. Lett. **105**, 222501, (2010).
7. B. Dey *et al*., Differential Cross Sections and Recoil Polarizations for the Reaction $\gamma p \to K^+\Sigma^0$, Phys. Rev. **C82**, 025202, (2010).
8. A. Androic *et al*., Strange Quark Contribution to Parity-Violating Asymmetries in the Backward Angle G0 Electron Scattering Experiment, Phys. Rev. Lett. 104, 012001, (2010).
9. C. D. Bass *et al*., A Liquid Helium Target System for a Measurement of Parity Violation in Neutron Spin Rotation, Nucl. Inst. and Methods in Physics Research A 612, (2009).
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12. A. Micherdzinska *et al*., Measurements of Polarized Neutron Beam Phase Space Properties for Parity-Violating Neutron Spin Rotation Experiments (to be submitted to Phys. Rev. C).
13. A. Micherdzinska *et al*., Polarized neutron beam properties for measuring parity-violating spin rotation in liquid ^{4}He, Nucl. Inst. and Methods in Physics Research A (submitted, manuscript NIMA-D-10-00341).
14. R. Nasseripour *et al.,* Photodisintegration of ^{4}He into p+t, Phys. Rev. C **80,** 044603 (2009).

15. M. Paolone *et al*., Polarization Transfer in the ^{4}He(e,$\acute{e}p$)^{3}H Reaction at Q^2 = 0.8 and 1.3 (GeV/c)^2, Phys. Rev. Lett. **105**, 072001 (2010).
16. I. Pomerantz *et al.,* Hard Photodisintegration of a Proton Pair, Phys. Rev. Lett. (submitted, 2009).
17. E. Stephan *et al.,* Precise set of tensor analyzing power T_{20} data for the deuteron-proton breakup at 130 MeV, European Physics J. A **42,** 13 (2009).
18. E. Stephan *et al.,* Vector and tensor analyzing powers in deuteron-proton breakup at 130 MeV, Phys. Rev. C **82,** 014003 (2010).
19. M.H. Wood, C. Djalali, R. Nasseripour and D. Weygand (CLAS Collaboration), Medium Modifications of Light Vector Mesons in Photoproduction Reactions, Int. J. Mod. Phys. A 24, 309 (2009).
20. M.H. Wood, R. Nasseripour, M. Paolone, D. Weygand and C. Djalali, Absorption of the ω and ϕ Mesons in Nuclei, Phys. Rev. Lett. 105, 112301 (2010).

Conference Proceedings and Presentations

1. R. Nasseripour and B.L. Berman, Isobar Configurations in the ^{3}He Ground State, APS Spring Meeting, Atlanta, GA (2012).
2. N. Zachariou, Y. Ilieva and B.L. Berman, Determination of the Azimuthal Asymmetry for Deuteron Photodisintegration at E_γ = 1.1-2.3 GeV, APS Spring Meeting, Atlanta, GA (2012).
3. A. Micherdzinska and N. Zachariou, Photoproduction of φ Mesons, APS DNP Fall Meeting, Waikoloa, HI (2009); Bull. Am. Phys. Soc. **54**, #10
4. A. Micherdzinska and B.L Berman, ϕ(1020) Photoproduction on the Neutron, APS/AAPT Joint Meeting, Washington DC (2010); Bull. Am. Phys. Soc. **55**, #1
5. A. Micherdzinska and B.L Berman, ϕ(1020) Photoproduction Analysis, International Nuclear Physics Conference INPC 2010 (Vancouver, BC, 2010).
6. E. Munevar and B.L. Berman, Exclusive Analysis of the $\gamma\ n \rightarrow K^+\ \Sigma^-$ Reaction at E_γ = 1.1-2.3 GeV, 2010 APS/AAPT Joint Meeting, Washington, DC (2010); Bull. Am. Phys. Soc. **55**, #1
7. E. Munevar and B.L. Berman, Beam Asymmetry for the $\gamma\ n \rightarrow K^+\ \Sigma^-$ Reaction, APS DNP Fall Meeting, Waikoloa, HI (2009); Bull. Am. Phys. Soc. **54**, #10
8. E. Munevar and B.L. Berman, Exclusive Analysis of the $\gamma\ n \rightarrow K^+\ \Sigma^-$ Reaction at E_γ = 0.8-2.3 GeV, International Nuclear Physics Conference INPC 2010 (Vancouver, 2010)
9. R. Nasseripour and B.L. Berman, π^+ Photoproduction on ^{3}He, APS DNP Fall Meeting, Waikoloa, HI (2009); Bull. Am. Phys. Soc. **54**, #10

10. R. Nasseripour and B.L. Berman, Coherent Photoproduction of π^+ on ^{3}He, 2010 APS/AAPT Joint Meeting, Washington, DC (2010); Bull. Am. Phys. Soc. **55**, #1
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12. R. Nasseripour and B.L. Berman, Coherent Photoproduction of π^+ on ^{3}He with CLAS at Jefferson Laboratory, International Nuclear Physics Conference INPC 2010 (Vancouver, BC, 2010).
13. R. Nasseripour, Photoexcitation of Vector Mesons off Nuclei (JLab G7-CLAS), invited talk at the Workshop on Electromagnetic Probes of Strongly Interacting Matter (ECT, Trento, Italy, 2010).
14. M. Paolone, R. Nasseripour, C. Djalali, D. Weygand and M. Wood, Light Vector Meson Photoproduction from ^{1}H at Jefferson Laboratory, APS DNP Fall Meeting, Waikoloa, HI (2009); Bull. Am. Phys. Soc. **54**, #10
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16. N. Zachariou, B.L. Berman and N. Ivanov, Determination of Azimuthal Asymmetry of Deuteron Disintegration by Linearly Polarized Photons of E_γ = 1.1-2.3 GeV, Gordon Research Conference on Photonuclear Reactions (Tilton, NH, Aug. 2010).

CLAS Analysis Notes

1. R. Nasseripour and B.L. Berman, Coherent Photoproduction of π^+ on ^{3}He, CLAS Analysis Note 2010-103 (2010).
2. M. Wood, R. Nasseripour, M. Paolone, D. Weygand and C. Djalali, Absorption of the ω and ϕ Mesons in Nuclei, CLAS Analysis Note 2009-103 (2009).