Final Report: May 1, 1999 - May 31, 2015

Data Analysis Center for Electromagnetic and Hadronic Scattering Processes

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I. TASK I: DATA ANALYSIS CENTER

1. Abstract

The GW Data Analysis Center (DAC) has made significant progress in its program to enhance and expand the partial-wave and multipole analyses of fundamental reactions, while maintaining and expanding each associated database. These efforts provide guidance to national and international experimental and theoretical efforts, and are an important link between theory and experiment. Our principal goals are focused on baryon and meson physics programs and related topics.

2. GW Personnel

The senior personnel associated with Task I are:
Professor W.J. Briscoe (The PI for this project)
Research Professor I.I. Strakovsky (Co-PI)
Associate Research Professor R.L. Workman (Co-PI)

Postdoctoral Researcher: Dr. D.M. Schott

The following are not paid via this grant, but are working closely with us:
Assistant Professor M. Döring (GW after January 2nd, 2014)
Research Professor: A.E. Kudryavtsev (ITEP/GW)

3. Project Goals

Task I of the project is intended to enhance and continue research conducted within The George Washington University Institute for Nuclear Studies (GWINS) and Data Analysis Center (DAC). Research accomplishments, continuing activities, and new initiatives are presented within the context of a larger program of Hadronic Physics. DAC research is focused on five principal topics:

- *PWA:* Partial-wave analysis of fundamental two- and three-body reactions.
- *Experimental Program Support:* Analysis of final and preliminary data, and studies of systematics and sensitivities required for the refinement of experimental proposals.
- *Phenomenological and Theoretical Investigations:* Studies which bridge the gap between theory and experiment, including the methodology used in PWA.
- *Databases:* Development of databases associated with these fundamental reactions.
- *Development of the SAID Facility:* Creation of new software, including graphical representations, to disseminate our results (and the results of competing analyses which have often employed different methods).

Tracking the SAID facility on-line activity, through the web interface, `http://gwdac.phys.gwu.edu` reveals on the order of 300 hits per month, on average. About 40% of these are of US origin, the next highest user being Germany, at 20% of the total.

4. Recent Accomplishments

A majority of DAC research is aimed at the direct support of existing, continuing, and planned experimental programs. We update the SAID databases, develop and study partial-wave analyses, and keep numerous versions of phenomenological and theoretical models, both those of the GWINS/DAC and other research groups, relevant to two- and three-body reactions of interest. These are made available to the nuclear and particle physics communities through a web-based interface to the SAID Facility. When possible and appropriate, we submit the results of GWINS/DAC investigations to peer-reviewed journals. However, given the large number of fits generated, much of this work has been published "on-line", rather than in paper form. Below, we list our work on research topics, published both in journal and on-line form, beyond that required to maintain the on-line facility, though this task requires significant effort.

- Pole Structure from Energy-dependent and Single-energy Fits to GWU-SAID πN Elastic Scattering Data:

  The pole structure of the current GWU-SAID partial-wave analysis of elastic πN scattering and ηN production data was studied [1] in a collaboration between RLW and groups from Zagreb and Tuzla. Pole positions and residues were extracted from both the energydependent and single-energy fits, using two different methods. For the energy-dependent fits, both contour integration and a Laurent-Pietarinen approach were used. In the case of single-energy fits, the Laurent-Pietarinen approach was used. Errors were estimated and the two sets of results were compared to other recent and older fits to data.

- High-precision Measurements of πp Elastic Differential Cross Sections with EPECUR:

  In cooperation of EPECUR Collaboration and DAC group, we reported cross sections for $\pi \pm p$ elastic scattering which have been measured to high precision, for beam momenta between 800 and 1240 MeV/c (2638 π^+p and 4277 π^-p data points), using the ITEP proton synchrotron. Special attention was addressed to the systematics. These comparisons of new data with updated (RLW) and previous PWA results imply that over the covered energy range, the Carnegie-Mellon-Berkeley (CMB) analysis is significantly more predictive when compared to versions of the Karlsruhe-Helsinki (KH) analyses [2].

- First Measurement of the Polarization Observable E in the $\vec{\gamma}\vec{p} \to \pi + n$ Reaction with FROST:

  DAC group is heavily involved in the FROST activity, in particular, WJB and IIS are co-spokespersons of the pion photoproduction from a polarized target, FROST project [3].

  First results from the longitudinally polarized frozen-spin target (FROST) program was reported recently. 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 [4]. The final-state pions were detected with the CLAS facility in Hall B at JLab. These polarization data agree fairly well with previous PWAs 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 resulting in updated nucleon resonance parameters. The paper reports updated fits from the SAID (RLW), Bonn-Gatchina, and Jülich (MD) groups [4].

- Precision measurement of the $ep \to \pi^0 e'p$ near threshold:

  New results were reported from a measurement of π^0 electroproduction near threshold using the $ep \to \pi^0 e'p$ reaction [5]. The experiment was designed using DAC help to precisely determine the energy dependence of s- and p-wave electromagnetic multipoles as a stringent test of the predictions of Chiral Perturbation Theory (ChPT). The data were taken with an electron beam energy of 1192 MeV using a two-spectrometer setup in Hall A at JLab. For the first time, complete coverage of the azimuthal and polar pion production angles in $p\pi^0$ CM was obtained for invariant energies above threshold from 0.5 MeV up to 15 MeV. A simple phenomenological analysis of new data shows significant disagreement with p-wave predictions from ChPT for $Q^2 > 0.07\ (GeV/c)^2$, while the s-wave predictions are in reasonable agreement.

- π^0 Photoproduction on the Proton from MAMI-C:

  Differential cross sections for the $\gamma p \to \pi^0 p$ reaction have been measured with the A2 tagged-photon facilities at the Mainz Microtron, MAMI-C, up to a center-of-mass energy W = 1.9 GeV [6]. The new results, obtained with a fine energy and angular binning, increase the existing quantity of π^0 photoproduction data by $\sim 47\%$. Owing to the unprecedented statistical accuracy and the full angular coverage, the results are sensitive to high partial-wave amplitudes. Our special attention was addressed to study systematics and energy calibration. This is demonstrated by the decomposition of the differential cross sections in terms of Legendre polynomials and by further comparison to model predictions. A new solution of the SAID PWA (RLW), obtained after adding the new data into the fit, shows that these 8,000 new measurements can be fitted with a relatively low $\chi 2/dp = 1.2$ [6]. IIS reported the final results to the A2 Collaboration in March of 2015.

- Poles in the SAID NN analyses:

New WASA at COSY data for quasifree polarized np scattering, in the region of the recently observed d^*-resonance structure, have been obtained by exclusive and kinematically complete high-statistics measurements [7]. A modified PWA (RLW), including these new data, suggests a resonance pole in the $^3D_3 -^3 G_3$ coupled partial waves at $(2380 \pm 10, -i40 \pm 5)\ MeV$ - in accordance with the d^*-dibaryon resonance hypothesis. The effect of the new partial-wave solution on the description of total and differential cross section data and specific combinations of spin-correlation and spin-transfer observables was presented by RLW at MESON 2014, Krakow, Poland, May, 2014.

- Three-body Final State Interaction in $\eta \to 3\pi$:

  The JPAC Collaboration and our post-doc, DMS, have studied a unitary dispersive model for the $\eta \to 3\pi$ decay process based upon the Khuri Treiman equations which are solved by means of the Pasquier inversion method. The description of the hadronic final-state interactions for the $\eta \to 3\pi$ decay is essential to reproduce the available data and to understand the existing discrepancies between Dalitz plot parameters from experiment and chiral perturbation theory [8]. In particular, DMS was able to take the amplitude from Peng Guo (JPAC) and fit CLAS data from the g12 run period. The amplitude and the fitter have been packaged for anyone who wants to use it in the future. Results were presented by DMS at MESON 2014, Krakow, Poland, May, 2014.

- Double-Regge Exchange Limit for the $\gamma p \to K^+K^-p$ Reaction:

  The JPAC Collaboration has applied the generalized Veneziano model in the double-Regge exchange limit to the $\gamma p \to K^+K^-p$ reaction. Four different cases defined by the possible combinations of the signature factors of leading Regge exchanges have been simulated through the Monte Carlo method. Suitable event candidates for the double Regge exchange high-energy limit were selected employing Van Hove plots as a better alternative to kinematical cuts in the K^+K^-p Dalitz plot [9]. Our post-doc, DMS, is heavily involved in this project. During this period, she has worked with Meng Shi on the pKK system to fit CLAS data with a double regge limit amplitude written by Meng Shi (JPAC).

- Physics Opportunities with Meson Beams:

  Over the past two decades, meson photo- and electroproduction data of unprecedented quality and quantity have been measured at electromagnetic facilities worldwide. By contrast, the meson-beam data for the same hadronic final states are mostly outdated and largely of poor quality, or even nonexistent, and thus provide inadequate input to help interpret, analyze, and exploit the full potential of the new electromagnetic data. To reap the full benefit of the high-precision electromagnetic data, new high-statistics data from measurements with meson beams, with good angle and energy coverage for a wide range of reactions, are critically needed to advance our knowledge in baryon andmeson spectroscopy and other related areas of hadron physics. To address this situation, a state of-the-art meson-beam facility needs to be constructed. The recent review summarizes unresolved issues in hadron physics and outlines the vast opportunities and advances that only become possible with such a facility [10].

  Our white paper [10] was distributed worldwide to a large (about 500) scientists and that almost 140 agreed to be listed as endorsers.

  This task was reported by one of members of DAC, IIS, at 6th Workshop of the APS Topical Group on Hadronic Physic, Baltimore, MD, April 2015 and at APS DNP: 2014 Long-range plan Joint Town Meetings on QCD, Temple University, Philadelphia, PA, USA, Sept. 2014.

- PDG Progress:

  Work on the Review of Particle Physics continues, with a paper version last published in the summer of 2014 and off-year updates posted on the PDG website [11]. One of the DAC members, RLW, is heavily involved a overseer of the Unstable Baryons section of the Review of Particle Physics.

  The most recent version of the Review featured a significant overhaul of the non-strange baryon section (including the naming scheme, the larger role of pole parameters, and star ratings for established and new baryon candidates). A current project is ongoing to quantify the elements of error estimation required for new fits to be included in averages of resonance quantities. This work has been done in collaboration with Eberhard Klempt, Lothar Tiator, Volker Burkert, and Michael Pennington - members of the N* group in the PDG.

- SAID Database:

  IIS continues to update the full DAC (SAID) database as new data become available. The greatest activity has been in meson photoproduction on both proton and "neutron" targets included double polarized measurements and electroproduction. Relatively few NN and πN experiments are new being performed. Some new EPECUR data are precise but cover a narrow energy range. NN data from WASA at COSY have been added to the database and included in fits DAC.

- Contribution to Geant4:

  One of the medium-energy hadron-nucleus interaction models in the Geant4 simulation toolkit is based partly on the Bertini intranuclear cascade model. Since its initial appearance in the toolkit, this model has been largely rewritten in order to extend its physics capabilities and to reduce its memory footprint. Physics improvements include extensions in applicable energy range and incident particle types, and improved hadron-nucleon cross sections and angular distributions. That is the GW responsibility [Two DAC members, WJB and IIS, are members of the Geant4 Collaboration (Hadronic Working Group)] and the DAC group contribution to the Geant4 simulation toolkit is essential [12].

II. TASK II: EXPERIMENTAL PROGRAM

1. *Abstract*

Task II is the experimental component of the GWINS DAC program. Its primary goal is the enhancement of the body of data necessary for our analyses of fundamental $\gamma - N$ reactions. We propose and perform experiments that study the dynamics responsible for the internal structure of the nucleon and its excitations, and the fundamental properties of hadrons. Our principal focus is on the N^* programs at JLab and MAMI. At JLab, we study spin-polarization observables using polarized photons, protons and neutrons and yielding charged final states. Similarly, at MAMI, we study neutral meson photoproduction off polarized protons and neutrons. Our program emphasizing neutral final states at Mainz complements our program emphasizing charged final states at JLab. We are also heavily involved in a renewed effort to study neutral pion photoproduction close to threshold at Mainz. In addition to the programs underway, we are contributing to the future by participation in preparations for the coming JLab 12 GeV upgrade by supplying students to work on the CTOF detection system in Hall B.

2. *Personnel*

The senior personnel associated with Task II are:
Professor W.J. Briscoe (The PI for this project)
Research Professor I.I. Strakovsky (Co-PI)
Associate Research Professor R.L. Workman (Co-PI)

Postdoctoral Researcher: Dr. Schott

Undergraduate Students: Oliver Berroteran, Joseph Crandall, Antonia Keutze, Cynthia Trinh, Zachary West

The following are not paid via this grant, but are working closely with us:
Research Professor: A.E. Kudryavtsev (ITEP/GW)
Research Professor M.F. Taragin (Weismann/GW-ret)

3. *Project Goals*

Task II of the proposal continues, enhances, and expands the experimental nuclear physics research conducted by The George Washington University Institute for Nuclear Studies (GWINS). The physics objectives, recent research accomplishments, continuing activity, and new initiatives, are presented within the context of a larger program of Hadronic Physics. Our research will be focused on two principal facilities around the world.

In the following sections, we will outline recent accomplishments of the GW group, divided along the labs indicated above. New research opportunities are then described together with their relevance to the goals of the nuclear physics community.

4. *Recent Accomplishments*

Much of our research is motivated by a baryon spectroscopy program that has spanned nearly forty years. Of interest to this proposal is that work which was accomplished over the lifetime of the DOE support being continued here. One proposal for JLab Hall C submitted to JLab PAC42 was approved and one LoI for the GlueX Collaboration was submitted for PAC43 as well.

- *GW Activity at JLab*

  While JLab Hall B has been shut down for upgrades, we have worked on analysis and equipment upgrades. We extended our Hall B experience and focusing on physics with Halls C and D.

– FROST Project with CLAS [$g9a/g9b$]:

The second generation of CLAS photoproduction experiments used the FROST polarized target, which allowed double-polarization measurements on hydrogen. (Although FROST was shown to work well as a polarized deuteron target, the lab administration would not allow this use because of their internal political backing of the HD-ICE target, which in the end did not work well at all as polarized deuterium target.) With the FROST target, we measure all beam-target double-polarization observables for single pseudoscalar meson photoproduction and for two (charged) pion production as well. For hyperon photoproduction, in addition to polarization observables with polarized beam and target, one can extract polarization observables that include recoil polarization. This makes possible *the complete experiment*, which measures enough observables for unambiguous reconstruction of the reaction amplitude. CLAS collected linearly and circularly polarized beam and longitudinally and transverse polarized target data. Many of the observables in this experiment were measured for the first time. One of our students, Hideko Iwamoto (WJB – adviser) worked toward the analysis of the E observable ($\pi^0 p$ final state) as part of her 2011 Ph.D. Thesis [13]. WJB and IIS are among the co-spokespersons of the FROST experiment E–03–105 [3]. Over the past year, our post-doc, DMS, has worked with WJB to complete this project.

The entire data set is invaluable for a multi-channel analysis. The value of these data is more than just its broad coverage for different reaction channels and observables. The real strength of this program is its measurement of everything under the same controlled conditions with the same systematic uncertainty. This provides much stronger constraints for subsequent analyses of the properties of contributing nucleon resonances.

– $\gamma n \to \pi^- p$ from CLAS

Our knowledge of the neutral resonance couplings is less precise as compared to the charged values [11]. Here we focus on the single-pion production and note that a complete solution requires couplings from both charged and neutral baryon resonances, the latter requiring π^- and π^0 photoproduction off a neutron target, typically a neutron bound in a deuteron target. Extraction of the two-body ($\gamma n \to \pi^- p$ and $\gamma n \to \pi^0 n$) cross sections requires the use of a model-dependent nuclear correction, which mainly comes from final-state interactions (FSI). A large body of new measurements for $\gamma n \to \pi^- p$, 11,000 new differential cross sections for E $= 395 - 2510$ MeV is coming from CLAS $g13$ [14].

Using our FSI code [15], IIS calculated FSI correction factor for each data-point coming from $g13$. The GW undergrad, Joseph Crandall, during summer of 2014 worked with IIS to do sistematic study of FSI code and its contribution to the overal systematics of the experimental data.

– Wide Angle, Exclusive Photoproduction of π^0 Meson at Hall C:

Hard exclusive reactions provide an excellent opportunity to study the complicated hadronic dynamics of underlying subprocesses at partonic level. Existing world data on photoproduction of neutral pions on proton $\gamma p \to \pi^0 p$ have very large systematic errors and do not have suficient accuracy to perform comprehensive phenomenological analysis. Preliminary expermimental data from CLAS $g12$ on π^0 photoproduction extend existing world experential cross section up to $s \sim 11\ GeV^2$ [16].

There is disagreement between CLAS ($g1c$) [17] and CB-ELSA [18] forward measurements for $\gamma p \to \pi^0 p$. New CLAS $g12$ data from Moskov Amaryan's (ODU) graduate student, Michael Kunkel, prove that previous CLAS data from $g1c$ are good as they are while CB-ELSA measurements have systematic uncertainties. This ODU analysis detected π^0 via decay to $e^+e^-\gamma$. The branching $\pi^0 \to e^+e^-\gamma$ is small (~ 0.012) but the π^0 signal is clean and statistics from the CLAS $g12$ is extraordinary. Special attention was addressed to the study of systematics in the analysis of $g12$ data and the interpretation of these measurements covered both resonance and Regge energy range.

We proposed to measure the differential cross section of the $\gamma p \to \pi^0 p$ reaction in the range of $10\ GeV^2 < s < 20\ GeV^2$ at large pion center-of-mass angles and around 90° deg with Hall C facility. This allows an extension of the CLAS energy range to study dynamics of π^0 photoproduction above the resonance range. Our proposal E12-14-005 for JLab Hall C, submitted to JLab PAC42, was approved [19] (IIS is a co-spokesperson of this roposal).

– Physics Opportunities with a Secondary K_L^0 Beam at Hall D:

We expressed our interest in creating a secondary K_L^0 beam in Hall D to be used with the GlueX experimental setup for spectroscopy of excited hyperons through formation as well as production processes. This program would operate in Hall D for 5+ years. We submitted our LoI to JLab PAC43 [20] and are waiting for permission to prepare a full proposal for the next PAC44.

We estimated the flux of K_L^0 beam on the GlueX physics target in the range of few times $10^3/s$ up to $10^4/s$, to be compared to about $10^3\ K_L^0/s$ used at SLAC in LASS experiment, almost comparable to charged kaon rates obtained at AGS and elsewhere in the past. Momenta of neutral kaons will be measured using time-of-flight technique. Our studies show $\Delta p/p \sim 0.5\%$ of K_L^0 momenta can be achieved.

These measurements will allow studies of very poorly known multiplets of Λ, Σ, Ξ, and Ω hyperons with unprecedented statistical precision, and have a potential to observe dozens of predicted (but heretofore unobserved) states and to establish the quantum numbers of already observed hyperons listed in PDG [11]. Unfortunately, the information about pole positions of hyperons is poorly known. We determine a pole position for $\Lambda(1520)$ on the base of the analysis of Kaon electroproduction at JLab Hall A, the first time for a hyperon [21].

The possibility to run with polarized target (e.g., FROST), and measure recoil polarization of hyperons will open up a new avenue to the complete experiment.

– Photoproduction of the Very Strangest Baryons on a Proton Target in CLAS12:

The JLab12 energy upgrade, with the new CLAS12, will provide an ideal tool for extensive studies of both baryon resonances and heavier baryons (hyperons). In consideration of this, we submitted a CAA proposal [22] to JLab PAC40 that was approved. This project was initiated by IIS, a co-spokesperson of the experiment.

Experimentally, there are many data for photoproduction of final states with a nucleon. A set of data with final hyperons Σ or Λ, though more meager, also exists. But data on Ξ production is definitely insufficient, and the photoproduction of the "very strange" hyperon, Ω^-, is unknown (there is only an upper limit of 17 nb at 20 GeV reported by SLAC). Meanwhile, its distinct feature is given by the fact that the Ω is the most strange of possible non-exotic baryons, S = -3, and, thus, contains no constituent quark that could be common with the initial nucleon. The approved beam time for E12–11–005a (80 days) should be just sufficient to achieve physics.

The CLAS12 detector is being constructed at JLab and one of its detector components is the Central Time-Of-Flight barrel (CTOF). The CTOF system is the primary tool for hadron identification at mid- to backward angles for the CLAS12 spectrometer, including the strangeness baryon photoproduction experiment where the GW nuclear physics group is heavily involved. The final stages of CTOF assembly and testing are now underway. Several GW undergraduate students under IIS advisering spent several summers at JLab to help to develop the CTOF system for the CLAS12. During the summer of 2014, two GW undegrads, Antonia Keutze and Zachary West are testing of stabilized PMT voltage dividers and transmittance tests for the CTOF barrel. Then GW students reported results at the Annual Conference Experience for Undergraduates (CEU14) at APS DNP fall Meeting [23].

- *GW Activity at MAMI-C*

The Program of double-polarization measurements – linearly and circularly polarized beam and transversely polarized target – began in the fall of 2009. These measurements use the Crystal Ball and TAPS, and center on the detection of neutral final states, complementing the JLab FROST measurements. However, with the Edinburgh particle identification detector (PID) and Pavia cylindrical wire chambers, we can also measure and identify charged final states. The installation of a new focal plane, and upgrades that allow the Glasgow Photon Tagger to be used at the higher MAMI-C energies are complete. We now routinely use MIAMI-C to provide 1604 MeV electrons, with a corresponding increase in tagged-photon energies.

– The Analysis of new A2 Data for $\gamma p \to \pi^0 p$.

In 2013–2014, we collected differential cross section for π^0 photoproduction in the energy range of 220 through 1570 MeV ($\Delta E \sim 2\ MeV$ and $\theta = 15$ through 165° ($\Delta\theta \sim 6^\circ$). There are 8k data - almost a quarter of the world database. IIS evaluated systematics and energy calibration; RLW performed a multipole analysis of the new A2 Collaboration data vs. the world database obtaining a $\chi^2/dp = 1.2$ [6].

As expected for such a fit using orthogonal polynomials, the Legendre coefficients A_j decrease markedly for large j. At our energies and precision, a maximum value of j = 10 was found to be sufficient to describe the data. IIS used a truncated series accordingly, using the relation

$$d\sigma/d\Omega(W,\cos\theta) = \sum_{j=0}^{10}(2j+1)\ A_j(W)\ P_j(\cos\theta),$$

where $P_j(\cos\theta)$ are Legendre polynomials, j = 0,..., 10.

IIS reported the final results to the A2 Collaboration in March of 2015.

– Photoproduction of the ω-meson on the proton near threshold

An experimental study of ω photoproduction on the proton was conducted by using the Crystal Ball and TAPS multiphoton spectrometers together with the photon tagging facility at the Mainz Microtron MAMI. The $\gamma p \to \omega p$ differential cross sections are measured from threshold to the incident-photon energy E = 1.40 GeV (W = 1.87 GeV for the center-of-mass energy) with 15-MeV binning in E and full production-angle coverage [24]. The quality of the present data near threshold gives access to a variety of interesting physics aspects. As an example, an estimation of the ωN scattering length $\alpha_{\omega p}$ is provided.

– $\gamma d \to \pi NN$ below and above 800 MeV

For the second stage of the A2 Collaboration N^* neutron program, we proposed to perform a precision measurement of the differential cross section in the reactions $\gamma d \to \pi^- pp$ and $\gamma d \to \pi^0 pn$ in the tagged-photon energy region from 800 up to 1500 MeV in order to determine the neutron EM couplings of the low-lying baryon resonances using the PWA techniques developed by our SAID group [25]. The analysis of the MAMI-A2-02/12 data below 800 MeV [26], which we collected in March of 2013 is in progress. WJB and IIS are co-spokespersons of these experiments. IIS reported the first results to the A2 Collaboration in March of 2015.

The differential cross section for the processes $\gamma n \to \pi^- p$ and $\gamma n \to \pi^0 n$ will be extracted from these MAMI-C measurements accounting for Fermi motion effects in the impulse approximation (IA) as well as NN- and πN-FSI effects beyond the IA. The FSI code developed by the GW-ITEP Collaboration for the $\gamma n \to \pi^- p$ works well [15] and continued development for $\gamma n \to \pi^0 n$ [27] which is in progress.

For analysis of the pion photoproduction on the deuteron target, the knowledge on the neutron detection efficiency is a critical factor. A new measurement of the neutron detection efficiency for the NaI Crystal Ball detector was published recently [28].

– Extended FSI Code for $\gamma d \to \pi N p$:

In recent studies [29, 30], we have applied the FSI code to extract $\gamma n \to \pi^- p$ cross sections from $\gamma d \to \pi^- pp$ data [15]. We extend our effort and develop new FSI code to extract $\gamma n \to \pi^0 n$ cross sections from $\gamma d \to \pi^0 np$ measurements. Collaborators from ITEP are heavily involved in this project as well. The realization of this proposed program will result in the addition of new high-quality data for reactions on a neutron. These will provide critical constraints for PWA determining neutron multipoles and the couplings of neutral baryon resonances.

In a collaboration with the ITEP theorists, Alexander Kudryavtsev and his group, and Basel Univ. experimentalist, Bernd Krusche, we discuss the procedure for extracting photoproduction cross sections with neutral pseudoscalar mesons off the neutron using deuteron data. We are seeing that the FSI corrections for the π^0/η photoproduction cross sections off the proton and neutron are not equal in a general case. However, in a special case of the $\Delta(1232)3/2^+$ energy region, the FSI corrections for $\gamma p \to \pi^0 p$ and $\gamma n \to \pi^0 n$ cross sections are equal due to the isospin structure of the $\gamma N \to \pi N$ amplitude [27].

- *GW Activity at MAX-lab*

While MAX-lab is shut down for upgrade and building up MAX IV, we use this chance to collect data following to our Proposal aproved by MAX-lab PAC [31].

– Near-Threshold Photoproduction of π^-:

It is a difficult task to measure $\pi^- p$ final state for meson photoproduction close to the threshold. One of the critical factors is that π^-s are captured before they can decay. Instead, we intend to investigate the fundamental $\gamma n \to \pi^- p$ process using a deuterium target via a "two-step" process. The second step in the process involves the capture of the photoproduced π^- in the target deuterium [31].

We collected new data in April of 2015. WJB and IIS are involved in MAX-lab activity. The GW undergrad, Oliver Berroteran, during summer of 2015 worked with IIS to calculate FSI corrections to the threshold MAX-lab $\gamma n \to \pi^- p$ total cross sections using our FSI code [15]. Then Oliver made systematic study for the FSI contribution to the overall systematics of the experimental data.

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I. APPENDICES - RECENT ACTIVITY OF THE DAC MEMBERS SINCE LAST PROGRESS REPORT

A. Books

[A.01] *NN and N3 Interactions*, edited by L.D. Blokhintsev and I.I. Strakovsky, (Nova Science, 2014).

B. Refereed Journal Publications and Submissions

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[B.03] M. McCracken, M. Bellis *et al.* (CLAS Collaboration), *A search for baryon- and lepton-number violating decays of Λ hyperon using the CLAS detector at Jefferson Laboratory*, submitted to Phys. Rev. C .

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[B.05] I. Senderovich *et al.* (CLAS Collaboration), *First measurement of the helicity asymmetry E in η photoproduction on the proton*, submitted to Phys. Rev. C arXiv:1507.00325 [nucl–ex].

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D. Technical Reports

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E. New Proposals for JLab

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F. International Conference Service

[F.01] R.L. Workman, Member, *International Advisory Committee of the the 10th International Workshop on the Physics of Excited Nucleons (NSTAR2015)*, Osaka, Japan, May 2015.

[F.02] W.J. Briscoe, Member, *Local Organizing Committee of the PWA8/ATHOS3 Workshop*, GW VSTC Ashburn, VA, USA, April, 2015.

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G. Invited Talks

[G.01] I.I. Strakovsky, *GlueX physics plans at The George Washington University. GlueX Collaboration Meeting*, Newport News, VA, May 2015.

[G.02] D.M. Schott, *Hadron Spectroscopy: providing the link between experiment and theory in the intermediate energy region at JLab*, *6th Workshop of the APS Topical Group on Hadronic Physic*, Baltimore, MD, April 2015.

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[G.04] D.M. Schott, *Hadron Spectroscopy: providing the link between experiment and theory in the intermediate energy region at JLab*, *4th Joint Meeting of the APS DNP and the Physical Society of Japan, APS Division of Nuclear Physics Annual Meeting*, Waikoloa, HI, USA, Oct. 2014.

[G.05] I.I. Strakovsky, *Radiative decay width of neutral non-strange baryons from PWA*, *Dark Matter, Hadron Physics and Fusion Physics Workshop*, Messina, Italy, Sept. 2014.

[G.06] R.L. Workman, *The SAID analysis program*, *Photonuclear Gordon Conference*, Holderness, NH, Aug. 2014.

[G.07] I.I. Strakovsky, *Why we need neutron data*, *Exciting Baryons: Design and Analysis of Complete Experiments for Meson Photoproduction Workshop*, ECT*, Trento, Italy, June 2014.

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[G.10] D.M. Schott, *CLAS Results on Meson Spectroscopy*, *13th International Workshop on Meson Production, Properties and Interaction (MESON2014)*, Krakow, Poland, May, 2014.

H. Talks

[H.01] I.I. Strakovsky, *Physics opportunities with meson beams*, *6th Workshop of the APS Topical Group on Hadronic Physic*, Baltimore, MD, April 2015.

[H.02] I.I. Strakovsky, *Measurement of π^0 photoproduction on the proton at the MAMI-C energy range*, *A2 Collaboration Meeting*, Mainz, Germany, March 2015.

[H.03] I.I. Strakovsky, *Neutral pion photoproduction off the bounded neutron: Status*, *A2 Collaboration Meeting*, Mainz, Germany, March 2015.

[H.04] A. Keutzer, Z. West, V. Baturin, and G. Asryan, *Time resolution study for CLAS12 central time-of-flight detector*, *4th Joint Meeting of the APS DNP and the Physical Society of Japan*, *Conference Experience for Undergraduates (CEU14) of APS Division of Nuclear Physics Annual Meeting*, Waikoloa, HI, USA, Oct. 2014.

[H.05] I.I. Strakovsky, *Why we need meson beams*, *APS Division of Nuclear Physics: 2014 Long-range plan Joint Town Meetings on QCD*, Temple University, Philadelphia, PA, USA, Sept. 2014.