Final Technical Report

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Project Summary

This report summarizes a program of low-energy photonuclear studies at MAX-Lab in Lund (Sweden) and at the High Intensity Gamma Source (HIGS) at Duke University. A major emphasis has been on Compton scattering from deuterium in order to determine the electric and magnetic polarizabilities of the neutron. The studies at Lund utilized unpolarized photons at E_γ = 62-115 MeV to measure differential cross sections. The studies at HIGS utilized polarized and unpolarized photon beams (both linear and circular) at $E_\gamma < 90$ MeV. Polarization observables will be exploited to improve our understanding of the electric and magnetic polarizabilities, and in particular, double-polarization observables (using polarized targets) will be measured in the future to provide new information about the spin polarizabilities of the nucleon.

The MAX-Lab experiments (using unpolarized photons) focused on an approved PAC proposal for Compton scattering on the deuteron aimed at making a precise determination of the electromagnetic polarizabilities of the neutron. At MAX-Lab we had three of the largest NaI detectors in the world, each capable of ~2% energy resolution. We have completed our measurements in two separate tagged photon energy ranges which overlap each other (62-97 MeV and 90-115 MeV) and the results of these experiments have been published.

The photon beam at the High Intensity Gamma Source (HIGS) has several distinct advantages that make it unique: (1) ultra-high photon flux, ultimately reaching 10^8 Hz, (2) 100% linearly polarized photon beam, as well as circular polarization, (3) monoenergetic beam, with ~2% energy resolution, and (4) extremely low-background beam environment. Exploiting the high flux and polarization capabilities of the HIGS photon beam is central in the series of experiments being performed at this facility.

Very little data exist on Compton scattering using polarized photons. We will exploit clear sensitivities in the polarization observables to the electric and magnetic polarizabilities of the nucleon, and we will ultimately extend these studies to the investigation of the spin polarizabilities. To accomplish these objectives, a liquid hydrogen/deuterium/helium cryotarget has been constructed at HIGS, and an array of NaI detectors has been commissioned for Compton studies.

I. Experimental Program at Lund

The Compton scattering program on deuterium at MAX-Lab in Lund is motivated by the necessity of obtaining an improved determination of the neutron electromagnetic polarizabilities. In this case, we utilize a cryogenic liquid deuterium target, and the experiment involves the simultaneous operation of three large-volume NaI detectors to measure the scattered photons – the CATS detector from Mainz, the BUNI detector from Boston University and the DIANA detector from the University of Kentucky. The major data-taking period ended in 2010, and we have covered the tagged photon energy ranges 62-97 MeV and 90-115 MeV (including an overlap region between the two). All of these measurements were taken with our NaI detectors at fixed scattering angles of 60° (CATS), 120° (BUNI) and 150° (DIANA).

In each running period, we would begin the experiment with a calibration run using a solid carbon target. This was done to provide an important cross-check of our overall normalization by comparing our carbon Compton scattering cross section with the literature. Our carbon data was of sufficiently high quality that we published these carbon results separately, and the energy-dependent cross sections are shown in Fig. 1 below. As seen in the figure, we have achieved good agreement with the previous carbon data, and this provides the confirmation that our absolute cross sections have been reliably extracted. These carbon data have been published in the following reference:

Compton Scattering from ^{12}C Using Tagged Photons in the Energy Range 65-115 MeV
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration), Phys. Rev. **C89**, 035202 (2014).

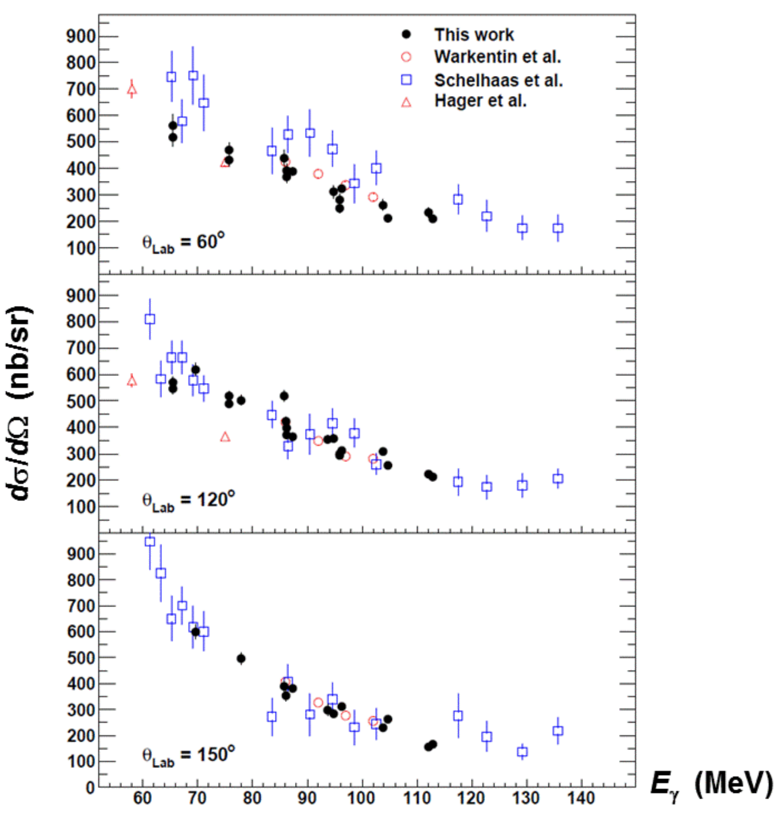

Fig. 1: Energy dependence of the cross section for Compton scattering on ^{12}C at three angles. The current data (black dots) are compared to several previous measurements on the same reaction.

The analysis of our deuterium data is also complete, and the results are presented below. The energy dependence of the cross section is shown in Fig. 2, and the angular distributions at our various tagger energy bins are shown in Fig. 3. Comparisons with the few previous measurements of this reaction by Lundin, Lucas and Hornidge are also shown in both figures. The theory curves are based on an Effective Field Theory (EFT) treatment by Griesshammer. These data were published initially in Physical Review Letters, and then subsequently a longer, more detailed article was published in Physical Review C. The references to these articles are given below:

Compton Scattering from the Deuteron Below Pion-Production Threshold
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration), Phys. Rev. **C92**, 025203 (2015).

Measurement of Compton Scattering from the Deuteron and an Improved Extraction of the Neutron Polarizabilities
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration), Phys. Rev. Lett. **113**, 262506 (2014).

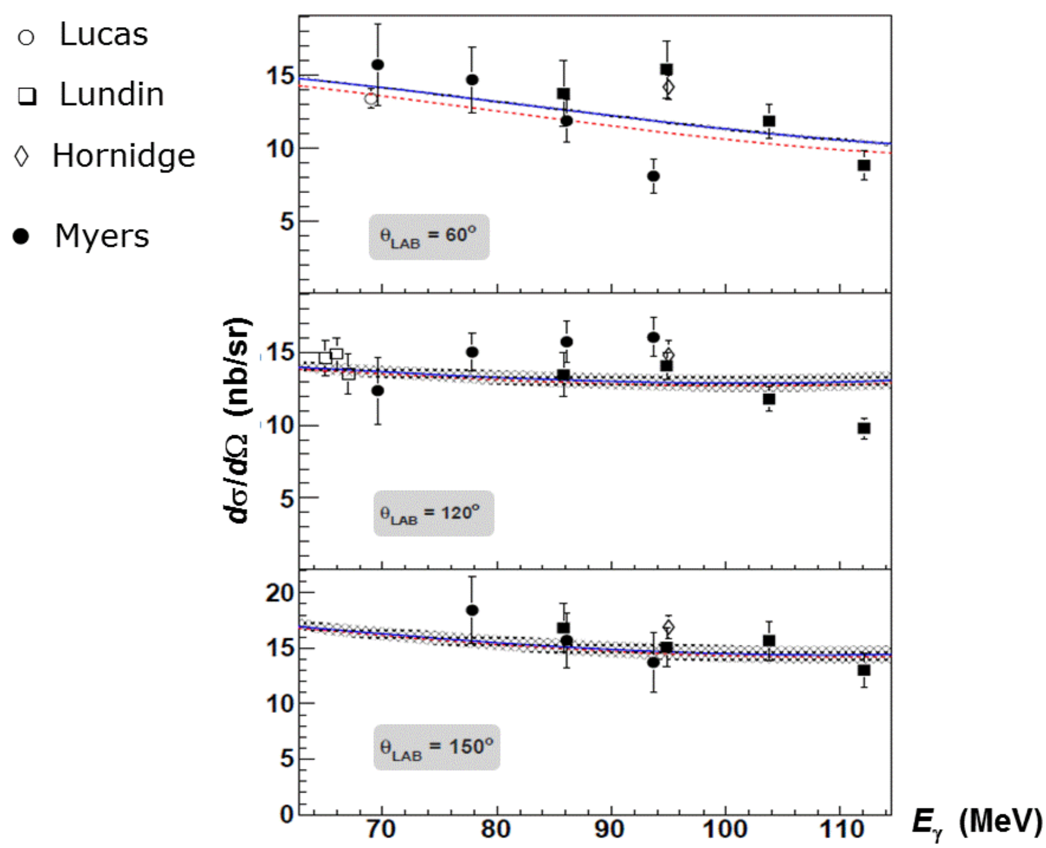

Fig. 2: Energy dependence of the cross section for Compton scattering on deuterium at three angles. The current data (solid black circles and squares) are compared to several previous measurements (open symbols) on the same reaction. The curves are EFT fits to the global data set.

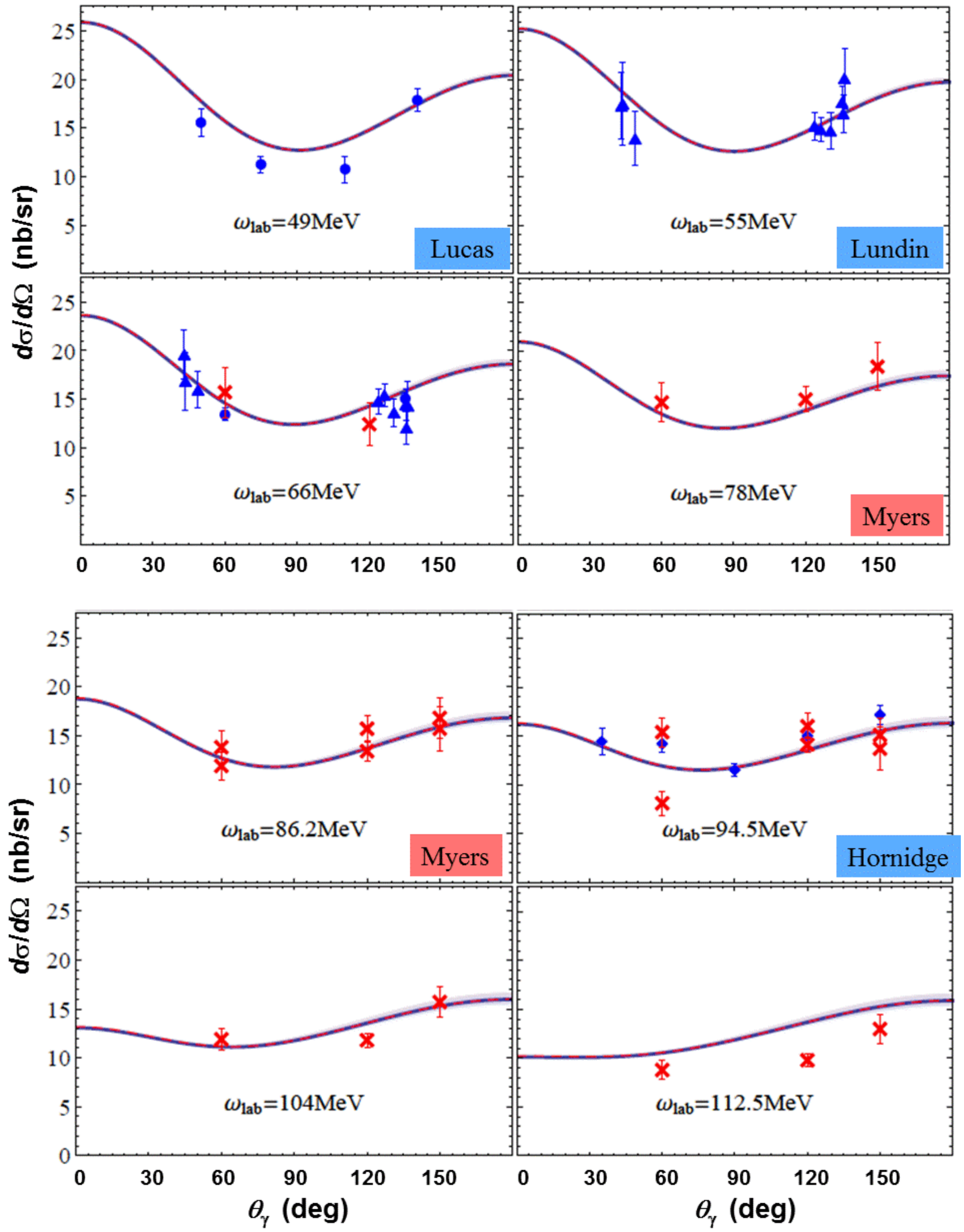

Fig. 3: Angular distributions of the cross section for Compton scattering on deuterium at various energies. The current data (red crosses) are compared to several previous measurements (blue symbols) on the same reaction. The curves are EFT fits to the global data set.

II. Experimental Program at HIGS

The focus of the work at HIGS has been on commissioning the HIGS NaI Detector Array (HINDA) which forms the backbone of the Compton scattering efforts there. The array consists of eight 10”×12” NaI detectors, each surrounded by a 2” thick NaI annulus. The annulus can serve for rejection of cosmic rays and escape radiation, or can be used to add back the energy of escape radiation in order to enhance the overall energy resolution. The NaI detectors can be mounted independently to a large frame so that they can be positioned separately – they will also be able to be oriented parallel to the plane of the floor or out of plane.

A. Systematic study of the IVGQR

The primary work on polarization has actually taken place at lower energies, where we had begun investigating the isovector giant quadrupole resonance (IVGQR) using linearly polarized photons. In 2010, a Compton scattering test run on ^{209}Bi was the first of these efforts, primarily intended to test the HINDA array. NaI detectors were located in-plane and out-of-plane, as shown in Fig. 4 below. The nucleus ^{209}Bi was chosen because it is readily available as a thick metallic target and also due to the fact that the high-Z nucleus has a large Compton scattering cross section.

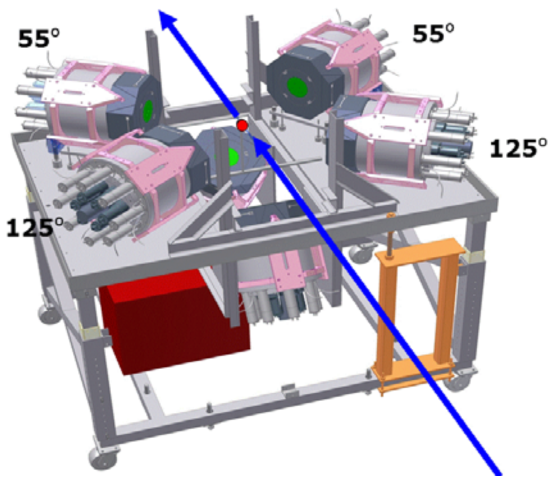

Fig. 4: Configuration of NaI detectors in the HINDA array for IVGQR experiments. In the scattering plane, four detectors are arranged as left/right symmetric pairs at 55° and 125°. Below the scattering plane, two detectors are at 55° and 125°. The two NaI detectors above the plane are not shown.

In Fig. 5 below, two gamma-ray spectra are depicted in the left panel, at a forward angle and a backward angle. The lineshape fits to the data are also shown, where the forward-angle spectrum includes an exponential background. The asymmetry determined from the horizontal and vertical yields is plotted in the right panel of Fig. 5. The impact of the IVGQR is clearly observed as a signature of E1/E2 interference in the photon beam asymmetry. The forward- and backward-angle asymmetries are nearly mirror images of each other, reflected about the E1-only line (*i.e.* no E2 IVGQR strength) shown as a dotted line. By fitting the energy dependence of the asymmetry with the parameters of the IVGQR (energy, width, strength), it is possible to extract these values for the case of the ^{209}Bi nucleus. The publication is given here:

New Method for Precise Determination of the Isovector Giant Quadrupole Resonance in Nuclei
S.S. Henshaw, M.W. Ahmed, G. Feldman, A.M. Nathan and H.R. Weller,
Phys. Rev. Lett. **107**, 222501 (2011).

The success of this effort to characterize the IVGQR prompted a new proposal to be submitted to the HIGS PAC to conduct a systematic study of the IVGQR parameters (energy, width, strength) over a range of masses across the periodic table. Thus far, new data have been taken on ^{89}Y in December 2012 and on ^{124}Sn in June 2013. Data were taken over the photon energy range E_γ = 20-35 MeV with the eight HINDA detectors located at scattering angles of 55° and 125° in the plane of photon polarization and perpendicular to the plane.

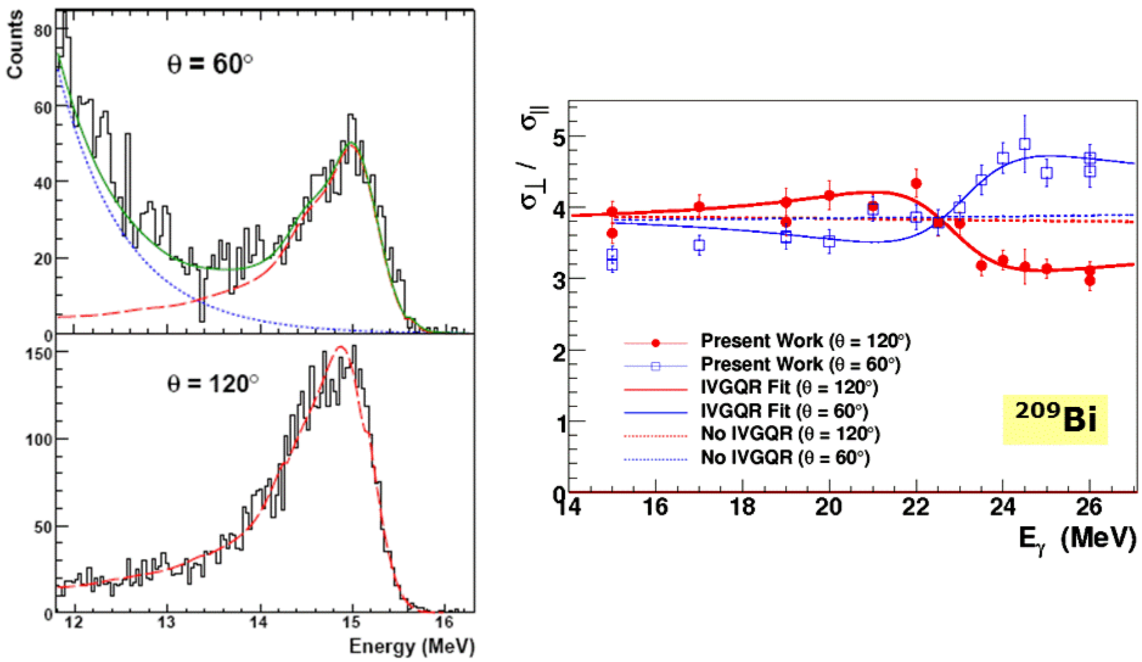

Fig. 5: Left panel: scattered photon spectra at two angles from the ^{209}Bi(γ,γ)^{209}Bi reaction, also showing the lineshape fits to the data. Right panel: energy dependence of the asymmetry for the Compton scattering reaction. Fits to the data are based on a phenomenological model.

The energy dependence of the photon asymmetry in these experiments on ^{89}Y and ^{124}Sn is shown in Fig. 6 below. The ratio of the perpendicular to parallel yields ($\sigma_{perp}/\sigma_{para}$) for the forward and backward angles is depicted along with a phenomenological model fit to the data used in determining the IVGQR parameters (energy E, width Γ and strength S). The effect of the existence of the IVGQR is again clearly visible in this case – the curves that exclude the IVGQR (*i.e.* purely E1) are shown as the dotted green (nearly flat) lines at a ratio of approximately 3.0 and are obviously not in agreement with the trend of the data. The trends of the data at the forward and backward angles are almost mirror images of each other reflected about the pure E1 line, and the crossover point is very close to the resonance energy.

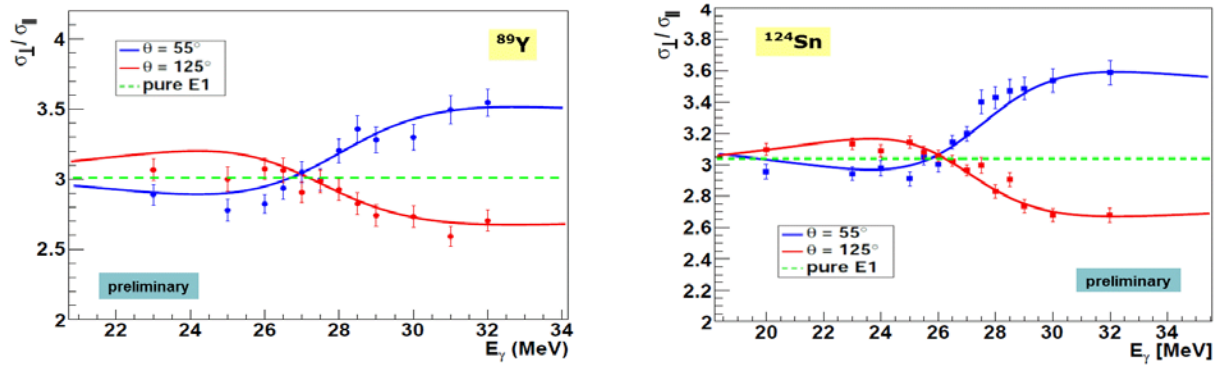

Fig. 6: Energy dependence of the photon asymmetry for ^{89}Y (left panel) and ^{124}Sn (right panel). The curves represent a phenomenological model fit to the data.

The extracted resonance parameters have been compared to the global IVGQR systematics as a function of mass number in Fig. 7. In this plot, the recent HIGS results for ^{209}Bi, ^{89}Y and ^{124}Sn are shown for the resonance energy, width and strength (as a fraction of the energy-weighted sum rule). It is apparent that the precision of the current results is much greater than previous experimental data (at least, for the energy and strength). The dotted lines indicate possible future targets that we would investigate as part of this systematic study.

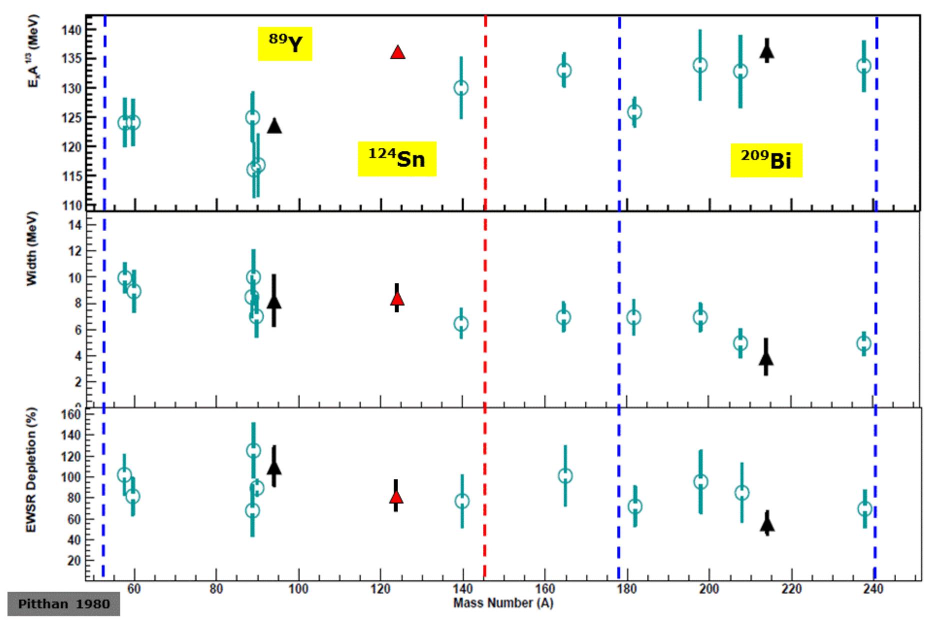

Fig. 7: IVGQR parameters from the current experiment (red or black triangles) compared to general IVGQR systematics as a function of mass number obtained from the review article by Pitthan *et al*. The three panels represent the resonance energy (top), resonance width (middle) and resonance strength (bottom).

B. Compton scattering on ^{6}Li

We have also undertaken a new experiment to use a ^{6}Li target to study polarizability effects. The idea is to measure a careful angular distribution of the cross section for unpolarized Compton scattering on ^{6}Li to be compared with phenomenological calculations in order to extract nucleon polarizabilities. The higher Z of the target increases the cross section significantly over lighter targets such as deuterium or helium. We have also attracted the attention of the theory group at Trento (Orlandini and Leidemann) who will be able to perform a realistic calculation based on the Lorentz integral transform (LIT) technique.

Data have been taken at 60 and 86 MeV over a range of 8 angles (40°-160°). In this case, using an unpolarized photon beam, the NaI detectors of the HINDA array are all arranged in a horizontal plane, parallel to the floor. This configuration is shown in Fig. 8 below.

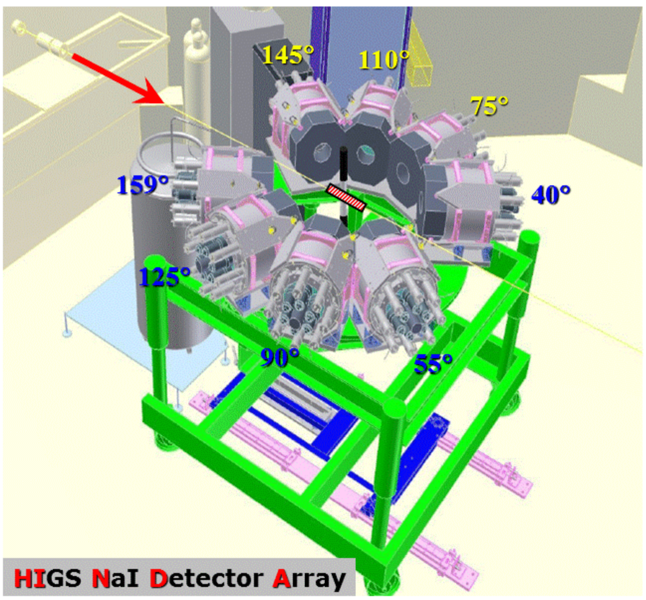

Fig. 8: Configuration of NaI detectors in the HINDA array for the ^{6}Li experiment using an unpolarized photon beam. All detectors are oriented in a plane, with 4 detectors on each side, covering a range of 8 distinct scattering angles (as labeled in the figure).

The cross sections for the 60 MeV and 86 MeV data are shown in Fig. 9 below. The blue curve is a fit to the data using a phenomenological model, and the dashed lines indicate the sensitivity of the fit to variations in the polarizability values by ±2. It should be mentioned that this is not intended to be an extraction of the values of α and β, but rather it is a demonstration of the sensitivity of the data. We see an increased sensitivity to the polarizability values in the higher-energy case, since it is apparent at back angles that the theoretical curves (black dotted lines) span a larger cross-section range. These data have been published in Physical Review C as two separate articles which are referenced below:

Compton Scattering from ^{6}Li at 86 MeV
L.S. Myers, M.W. Ahmed, G. Feldman, A. Kafkarkou, D.P. Kendellen, I. Mazumdar, J.M. Mueller, M.H. Sikora, H.R. Weller and W.R. Zimmerman, Phys. Rev. **C90**, 027603 (2014).

Compton scattering from ^{6}Li at 60 MeV
L.S. Myers, M.W. Ahmed, G. Feldman, S.S. Henshaw, M.A. Kovash, J.M. Mueller, and H.R. Weller, Phys. Rev. **C86**, 044614 (2012).

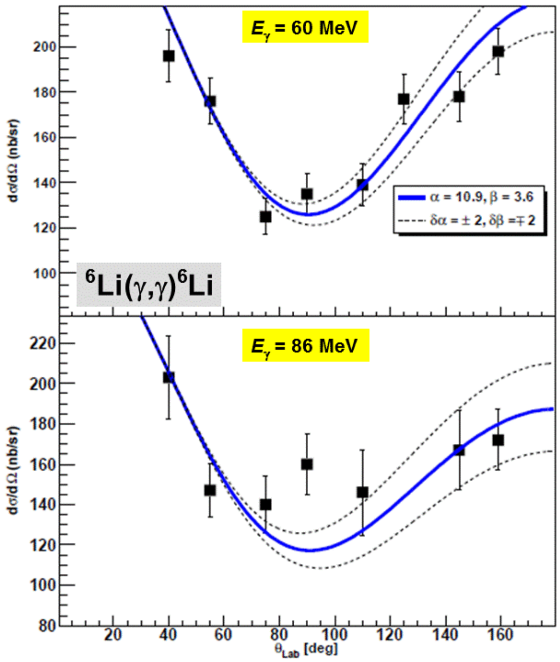

Fig. 9: Angular distributions for ^{6}Li Compton scattering at 60 MeV (top) and 86 MeV (bottom). The blue curve is a phenomenological fit, and the black dotted lines indicate variations in the values of α and β by ±2.

C. Development of cryogenic target system

One of the reasons to pursue the lithium measurements was a desire to conduct polarizability experiments in the absence of a hydrogen or deuterium target at HIGS. This problem has now been alleviated with the development of a state-of-the-art cryogenic target system at HIGS. This project was initiated in the early part of 2013, and the construction of the cryotarget was essentially completed by the beginning of 2015. The target is shown in Fig. 10 below, both in a schematic view and an actual photograph of the cryostat.

After a series of bench tests (cooling down, emptying the target, etc.), the first in-beam test run with the cryotarget took place in September 2015 using liquid helium. The results of this first experiment will be discussed below. The target has a temperature range of 3.5-24 K, and it is capable of liquefying hydrogen, deuterium and helium. In the latter case, we are referring primarily to ^{4}He, but there are efforts underway to explore the prospects of using the current target system to also liquefy ^{3}He. If modifications are needed to accomplish this, then contingency plans are being made to implement an upgrade of the target system in order to liquefy ^{3}He.

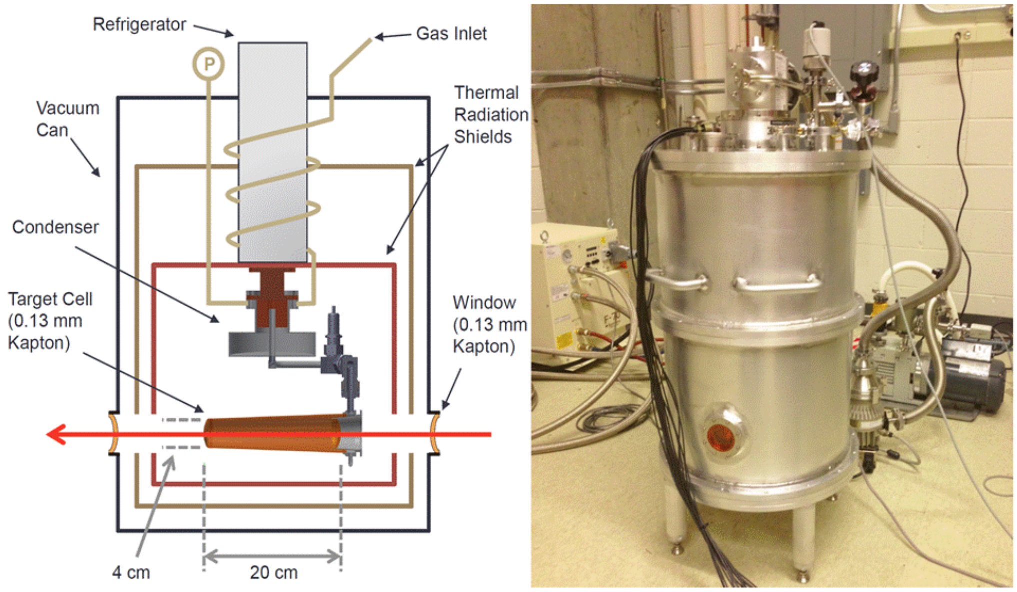

Fig. 10: Left panel: schematic of the cryogenic target system.
Right panel: photograph of the cryostat.

D. Compton scattering on ^{4}He

As mentioned above, we have performed a commissioning test run with our new cryogenic target using ^{4}He in September 2015. In this experiment, we obtained Compton scattering data on ^{4}He at an incident photon energy of 61 MeV using the HINDA NaI array covering 8 angles in the range 40°-160°. Sample gamma-ray spectra are shown in the left panel of Fig. 11 below, along with lineshape fits to the data. The resulting cross sections (shown in the right panel of Fig. 11) have low statistical error bars, owing to the high flux of the HIGS beam and also to the larger cross section (relative to deuterium, for example) for the A = 4 nucleus. These data are consistent with an older (and much more sparse) data set from Illinois on Compton scattering from ^{4}He. We have applied a crude phenomenological model to fit these data points, although the approximate nature of this "toy model" does not enable us to extract any definitive results for the electromagnetic polarizabilities of the nucleon. In that sense, the experiment is more or less a "proof of principle" to show the value of Compton scattering on a "heavier" nuclei (*i.e.* relative to deuterium), and it also serves as an incentive for the Effective Field Theory (EFT) community to work on treatments of data relating to targets with A > 2.

At the present time, the data analysis is essentially complete for this experiment, and a publication is being prepared for submission to Physical Review C. This would constitute the first published HIGS data obtained with our new cryotarget.

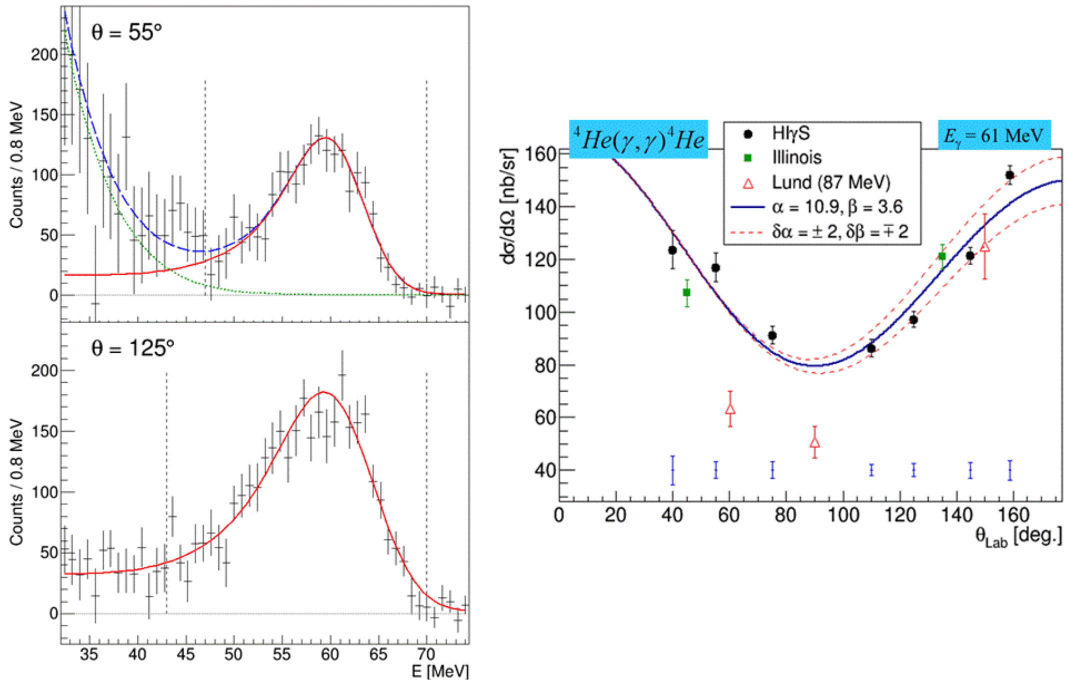

Fig. 11: Left panel: scattered photon spectra at two angles from the $^4He(\gamma,\gamma)^4He$ reaction, also showing the lineshape fits to the data. Right panel: angular distribution for the Compton scattering reaction at 61 MeV. The curves are based on a phenomenological model.

E. Compton scattering on deuterium

After the successful commissioning run on ^4He, we proceeded with our plan to take Compton scattering data on deuterium. In the spring and summer of 2016, we obtained Compton data on deuterium at 65 and 85 MeV covering the same angular range as in the ^4He case. The cross sections for these two energies are shown in Fig. 12 below. While the statistics are better for the lower-energy measurement (due to higher beam fluxes available at lower energies at HIGS), both sets of data have better statistics (and wider angular coverage) than the recent deuterium data taken at MAX-Lab in Lund.

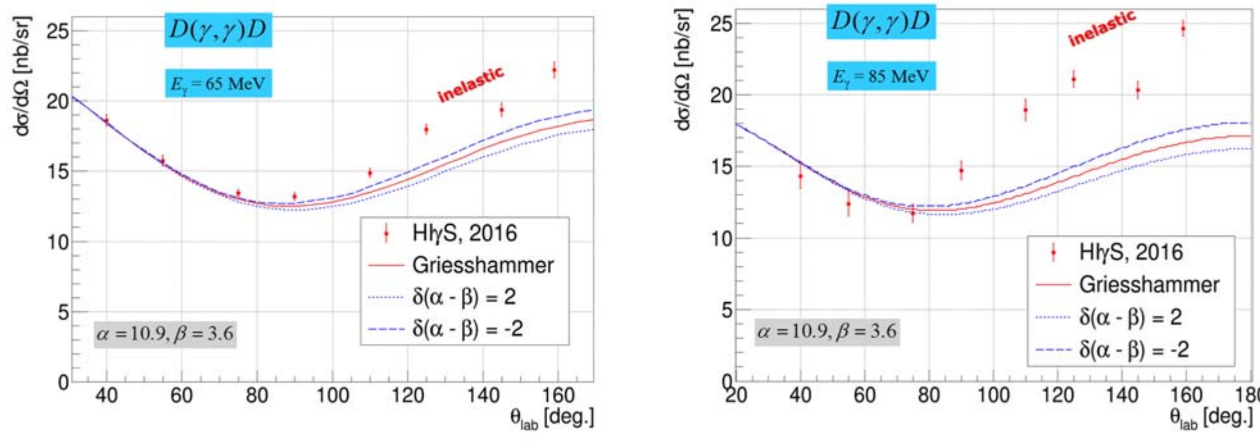

Fig. 12: Angular distributions for the $^2H(\gamma,\gamma)^2H$ reaction at 65 and 85 MeV. The curves are EFT calculations using the existing best values for the nucleon isoscalar polarizabilities. The discrepancy between the data and the curves at back angles is due to inelastic strength which has not been resolved in the current experiment.

There is one problem remaining with the analysis of these data sets which is apparent from the plots, and that is the contribution from inelastic scattering (*i.e.* breakup of the deuterium target) in our Compton data. In order to achieve reasonable beam fluxes for the deuterium experiment, a photon beam collimator was used which did not provide a tight beam energy resolution. As a consequence, the inelastic strength (which comes at 2.2 MeV lower than the elastic peak) is not able to be cleanly resolved from the elastic strength. This is evident in the data by a back-angle measured cross section that exceeds the theoretical EFT curves by 10-20% or so. This excess is actually greater in the 85 MeV data, which is consistent with the assertion that this additional strength is arising from an inelastic process.

At the moment, we are discussing various methods of accounting for or eliminating this inelastic background. In one case, we could possibly use a simple model to estimate this contribution and then subtract it from the data. Another option would be to leave the data as it is, and then utilize a more detailed theoretical treatment (based on EFT) to account for the total data set (elastic plus inelastic) and then hope to isolate the elastic contribution. Finally, an experimental option is to use another NaI detector with much better resolution (for example, the DIANA detector from Kentucky) to run the same experiment with the objective of being able to resolve the elastic peak directly from the data.

III. <u>Publications and Conference Presentations</u>

A. Articles in refereed journals

Compton Scattering from the Deuteron Below Pion-Production Threshold
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration),
Physical Review **C92**, 025203 (2015).

Measurement of Compton Scattering from the Deuteron and an Improved Extraction of the Neutron Polarizabilities
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration),
Physical Review Letters **113**, 262506 (2014).

Compton Scattering from ^{6}Li at 86 MeV
L.S. Myers, M.W. Ahmed, G. Feldman, A. Kafkarkou, D.P. Kendellen, I. Mazumdar, J.M. Mueller, M.H. Sikora, H.R. Weller and W.R. Zimmerman,
Physical Review **C90**, 027603 (2014).

Compton Scattering from ^{12}C Using Tagged Photons in the Energy Range 65-115 MeV
L.S. Myers *et al*. (Compton@MAX-Lab Collaboration),
Physical Review **C89**, 035202 (2014).

Monte Carlo simulation of the photon-tagger focal-plane electronics at the MAX IV Laboratory
L.S. Myers, G. Feldman, K.G. Fissum, L. Isaksson, M.A. Kovash, A.M. Nathan, R.E. Pywell and B. Schroder,
Nuclear Instruments and Methods in Physics Research **A729**, 707 (2013).

The upgraded photon tagging facility at the MAX IV Laboratory
J.-O. Adler *et al*.,
Nuclear Instruments and Methods in Physics Research **A715**, 1 (2013).

Compton scattering from ^{6}Li at 60 MeV
L.S. Myers, M.W. Ahmed, G. Feldman, S.S. Henshaw, M.A. Kovash, J.M. Mueller, H.R. Weller
Physical Review **C86**, 044614 (2012).

Using Effective Field Theory to analyse low-energy Compton scattering data from protons and light nuclei
H.W. Griesshammer, J.A. McGovern, D.R. Phillips and G. Feldman
Progress in Particle and Nuclear Physics **67**, 841 (2012).

New Method for Precise Determination of the Isovector Giant Quadrupole Resonance in Nuclei
S.S. Henshaw, M.W. Ahmed, G. Feldman, A.M. Nathan and H.R. Weller,
Physical Review Letters **107**, 222501 (2011).

B. Invited talks

Compton Scattering at HIGS with Polarized Photons
G. Feldman,
ECT* Workshop on Compton Scattering off Protons and Light Nuclei
Trento, Italy (July/August 2013).

Compton Scattering at HIGS: from Giant Resonances to Spin Polarizabilities
G. Feldman,
INT Workshop on Electroweak Properties of Light Nuclei
Seattle, Washington (November 2012).

First Look at Compton Scattering on Lithium
G. Feldman,
ECT* Workshop on Electroweak Probes from Low-Energy Nuclear Physics to Astrophysics
Trento, Italy (June 2012).

Compton Scattering from the Deuteron and the Polarizability of the Neutron
G. Feldman,
INT Workshop on Soft Photons and Light Nuclei,
Seattle, Washington (June, 2008).

Summary Talk — Working Group on Hadron Structure and Meson-Baryon Interactions
G. Feldman and T.R. Hemmert,
5th International Workshop on Chiral Dynamics
Chapel Hill, North Carolina (September, 2006).

C. Conference proceedings

Program of Compton Scattering Studies on Light Nuclei at HIGS
G. Feldman and Compton@MAX-Lab Collaboration,
23rd European Conference on Few-Body Problems in Physics,
Aarhus, Denmark (August 2016).

New Results for Compton Scattering on Deuterium: A Better Determination of the Neutron Electromagnetic Polarizabilities
G. Feldman and Compton@MAX-Lab Collaboration,
8th International Workshop on Chiral Dynamics,
Pisa, Italy (July 2015).

Compton Scattering from Light Nuclei at MAX-Lab
L. Myers,
INT Workshop on Electroweak Properties of Light Nuclei
Seattle, Washington (November 2012).

Compton Scattering with Tagged Photons at MAX-Lab
L. Myers, G. Feldman, K. Fissum, L. Isaksson, M. Kovash, A. Nathan, B. Schröder, K. Shoniyozov,
7th International Workshop on Chiral Dynamics
Newport News, VA (August 2012).

Compton Scattering at the HIGS Facility
H. Weller, M. Ahmed, G. Feldman, J. Mueller, L. Myers, M. Sikora and W. Zimmerman,
7th International Workshop on Chiral Dynamics
Newport News, VA (August 2012).

Compton Scattering from Deuterium and the Polarizabilities of the Neutron
L. Myers, J. Brudvik, J.I. Capone, G. Feldman, K. Fissum, K. Hansen, L. Isaksson, M.A. Kovash,
K. Lewis, M. Lundin, A.M. Nathan, B. Schröder, K. Shoniyozov and S. Stave,
International Nuclear Physics Conference (INPC 2010),
Vancouver, Canada (July 2010).

Compton Scattering from Deuterium and the Electromagnetic Polarizabilities of the Neutron
G. Feldman, M. Andersson, J.R.M. Annand, R. Codling, K. Fissum, K. Hansen,
S. Henshaw, L. Isaksson, M.A. Kovash, M. Lundin, D.E. Mittelberger, L. Myers,
A.M. Nathan, B. Schröder, S. Stave and H.R. Weller,
20th European Conference on Few-Body Problems in Physics,
Pisa, Italy (September 2007).

D. Contributed talks

Compton Scattering from Deuterium and the Electromagnetic Polarizabilities of the Neutron
G. Feldman and Compton@MAX-Lab Collaboration,
Spring Meeting of the American Physical Society
Baltimore, MD (April 2015).

A Cryogenic Target for Compton Scattering Experiments at HIGS
D. Kendellen, M. Ahmed, H. Weller and G. Feldman,
Spring Meeting of the American Physical Society
Baltimore, MD (April 2015).

Measurement of the Isovector Giant Quadrupole Resonance in ^{124}Sn at HIGS
M. Sikora, G. Feldman, J. Park, H. Scheit, M. Ahmed, J. Mueller, L. Myers and H. Weller,
Fall Meeting of the APS Division of Nuclear Physics
Newport News, VA (October 2013).

Measurement of the Isovector Giant Quadrupole Resonance in ^{124}Sn Using Polarized Photon Scattering
J. Park, G. Feldman, M. Sikora, M. Ahmed, J. Mueller, L. Myers, H. Weller and H. Scheit,
Fall Meeting of the APS Division of Nuclear Physics
Newport News, VA (October 2013).

Compton Scattering from Deuterium and Carbon near 100 MeV
K. Shoniyozov, M.A. Kovash, G. Feldman, K. Fissum, K. Hansen, L. Isaksson, M. Lundin,
J. Brudvik, B. Schröder, A.M. Nathan, L. Myers and S. Stave,
Fall Meeting of the APS Division of Nuclear Physics
Newport News, VA (October 2013).

Measurement of the Isovector Giant Quadrupole Resonance in ^{89}Y at HIGS
M. Sikora, G. Feldman, M. Ahmed, J. Mueller, L. Myers, H. Weller and W. Zimmerman,
Fall Meeting of the APS Division of Nuclear Physics
Newport Beach, CA (October 2012).

Compton Scattering on ^{6}Li at 60 MeV
L.S. Myers, M.W. Ahmed, S.S. Henshaw, J.M. Mueller, H.R. Weller, G. Feldman, T. Balint,
K. Sykora and M.A. Kovash,
Fall Meeting of the APS Division of Nuclear Physics
East Lansing, MI (October 2011).

Neutron Emission Asymmetries from Linearly Polarized γ Rays on ^{nat}Cd, ^{nat}Sn and ^{181}Ta
W.C. Smith and G. Feldman,
Annual Meeting of the Southeastern Section of the APS
Roanoke, VA (October 2011).

Enhanced Sensitivity to the Isovector Giant Quadrupole Resonance using Linearly Polarized Photons
S.S. Henshaw, M.W. Ahmed, N. Brown, B.A. Perdue, S. Stave, H.R. Weller, R. Prior,
M. Spraker, R. Pywell, G. Feldman and A. Nathan and S. Whisnant,
Fall Meeting of the APS Division of Nuclear Physics
Santa Fe, NM (November 2010).

Polarized (γ,n) Reaction Studies of ^{nat}Cd, ^{nat}Sn and ^{181}Ta
W.C. Smith and G. Feldman,
Fall Meeting of the APS Division of Nuclear Physics
Santa Fe, NM (November 2010).

A Study of the (γ,n) Reaction on ^{235}U, ^{238}U and ^{nat}Pb between 11 and 15.5 MeV
J.R. Tompkins, H.J. Karwowski, M.W. Ahmed, N. Brown, S.S. Henshaw, J.M. Mueller,
B.A. Perdue, S. Stave, H.R. Weller, B. Davis, D.M. Markoff, G. Feldman and L. Myers,
Fall Meeting of the APS Division of Nuclear Physics
Santa Fe, NM (November 2010).

Program of Compton Scattering Studies on the Deuteron at HIGS
G. Feldman,
Spring Meeting of the American Physical Society
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IV. <u>Personnel</u>

The following is a list of the personnel associated with this project over its duration. Each person is identified by their corresponding position and by the period during which they were supported by the project.

Gerald Feldman: Principal Investigator (2006-16)
Mark Sikora: Post-Doctoral Research Associate (2011-15)
Arman Margaryan: Post-Doctoral Research Associate (Spring/Summer 2016)

Daniel Mittelberger: undergraduate student (2006-07)
Kasey Lewis: undergraduate student (2008-09)
John Capone: undergraduate student (2008-10)
W. Clarke Smith: undergraduate student (2010-12)
James Park: undergraduate student (2013-14)
Shane Roche: undergraduate student (Summer 2013)
Trevor Balint: graduate student (Spring 2011)
Kevin Sykora: graduate student (Spring 2011)