Update on results from the triplet polarimeter for the Spring 2015 commissioning run

M. Dugger
Arizona State University, Tempe, AZ 85287-1504

The GlueX experiment in Hall D at Jefferson Lab will utilize a polarized photon beam to help identify exotic meson states. The use of the triplet production process (pair creation off an atomic electron) allows for the determination of average beam photon polarization. A preliminary measurement of the cross section and polarization for triplet production using the triplet polarimeter for two commissioning runs is presented.

I. INTRODUCTION

The GlueX detector located at Jefferson Laboratory's Hall D is designed to search for exotic mesons. The detector will use polarized photons incident on a liquid hydrogen target to produce physics events. To accomplish the goals of the GlueX experiment, the degree of photon beam polarization has to be known to within 0.04 (absolute).

The polarized photons are created by way of coherent bremsstrahlung from an oriented diamond crystal with a coherent peak at approximately 9 GeV. Two methods for the determination of photon beam polarization are being employed. One of the methods is Coherent Bremsstrahlung Spectral Analysis (CBSA), where the energy distribution of post-bremsstrahlung electrons is analyzed using QED. The other method for determination of the photon beam polarization, and the topic of this update, is to use pair creation off an atomic electron (referred to in this document as triplet production), where the beam asymmetry gives the measure that is used to determine the photon beam polarization.

In the triplet photoproduction process, a polarized photon beam interacts with an atomic electron resulting in the production of an electron-positron pair, with the atomic electron recoiling from the atom. Any transverse momentum of the electron-positron pair is compensated for by the recoil electron, which has much less momentum than the pair, and thus can attain large polar angles. The azimuthal angular distribution of the recoil electron yields information on the beam polarization.

For polarized photons the triplet cross section can be written as $\sigma_t = \sigma_0 \left[1 + P\Sigma cos(2\phi)\right]$, where σ_0 is the unpolarized cross section, P is the photon beam polarization, Σ is the beam asymmetry, and ϕ is the azimuthal angle of the recoil electron. For GlueX, the photoproduced pair is detected in the pair spectrometer downstream of the triplet polarimeter. Since QED is a very well understood theory, we take a QED calculation of the beam asymmetry as the analyzing power of the reaction.

To determine the photon beam polarization, the azimuthal distribution of the recoil electrons is recorded and fit to the function $A\left[1 + Bcos(2\phi)\right]$, where the variables A and B are parameters of the fit. Once B has been extracted from the data, we calculate the polarization as $P = B/\Sigma$.

II. DETECTOR

The polarimeter uses an S3, double sided silicon strip detector manufactured by Micron Semiconductor to measure timing, energy deposition, and azimuthal distribution of recoil electrons coming from the atomic electron in the triplet process. As can be seen in Fig. 1, the S3 has 32 azimuthal sectors on the ohmic side and 24 concentric rings on the junction side. The S3 has an outer active diameter of 70 mm and an inner active diameter of 22 mm. The thickness of the silicon is 1034 microns and is fully depleted using a bias potential of 165 V. During normal operation the detector was run with the manufacturers suggested potential of 200 V.

The detector is placed in the beam line and within a vacuum chamber located in the Hall D collimator cave just upstream of the pair spectrometer. Signals are passed from the detector to an electrical feed-through flange that contains two 50-pin D-sub connectors, where one of the D-sub connectors route signals for the sectors, while the other D-sub passes the signal lines for the rings. The air-side of the electrical feed-through flange is contained in a "distribution box" that acts as a Faraday cage, as well as a volume where preamp boxes are contained, with power and signal lines distributed to the preamp boxes.

In the depletion region of the silicon detector, an electron hole pair is created for each 3.6 eV of energy deposited. The electrons are collected on the positive side of the potential (sector side of the detector), while the holes are swept towards the ring side (ground). As of the commissioning run there was no preamplification of the ring side signals, however, the charge exiting the sector side was passed through a charge sensitive preamplifier manufactured by Swan Research.

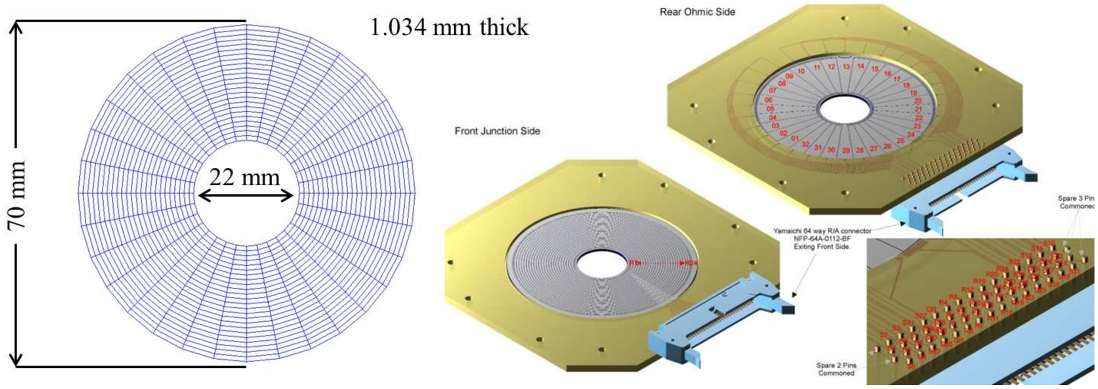

FIG. 1: The S3 double sided silicon strip detector.

A circuit diagram for a simplified and generic charge-sensitive preamplifier can be found in Fig. 2. The Swan preamps used in the polarimeter are more complicated than that shown in Fig. 2, however, the Swan preamps still contains all of the elements shown. Of particular importance is the feedback capacitance (C_f) and resistance (R_f). For our application, we chose $C_f = 0.2$ pF and $R_f = 30$ MΩ. The fall time for the preamplifier is simply $R_f C_f$ and is equal to 6 μs. The rise time for the signal is determined by the charge collection time of the detector and by the response time of the preamplifier. Optimal sensitivity (S_o) of the preamps is determined by the feedback capacitance such that $S_o = 1/C_f$, which leads to $S_o \approx 250$ mV/MeV. However, once the preamps are impedance matched to the other electronics at 50 Ω, the effective sensitivity is about 40% of optimal.

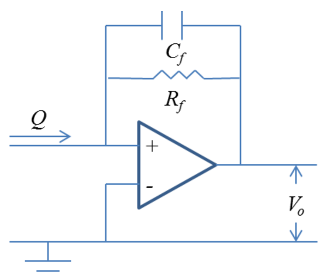

FIG. 2: Circuit diagram of a generic charge-sensitive preamplifier.

III. SIMULATION

The event generator used in simulating the triplet process includes all 8 tree-level diagrams with screening corrections included. The generated events are then sent through a GEANT4 simulation of the triplet polarimeter. A visual representation of the simulation can be found in Fig. 3, where 100 triplet events have been thrown (green lines represent photons, blue represent positrons, and red lines are the electrons). Within Fig. 3, the region shaded in blue is the vacuum chamber with the door set to be invisible. Also, within Fig. 3, there is a shaded green region that represents a removable plate, from which several elements are affixed:

1. Detector stand with detector.
2. Converter tray assembly, capable of holding three different converters, attached to a geared rack.
3. Rack guide that holds, and allows movement of, the geared rack.
4. Radiation-hardened and vacuum-rated stepper motor that positions the converter tray assembly.

Moreover, there is a representation of the 30 AWG kapton wires (red) that carry the signals to the feed-through containing the D-sub connectors (gray).

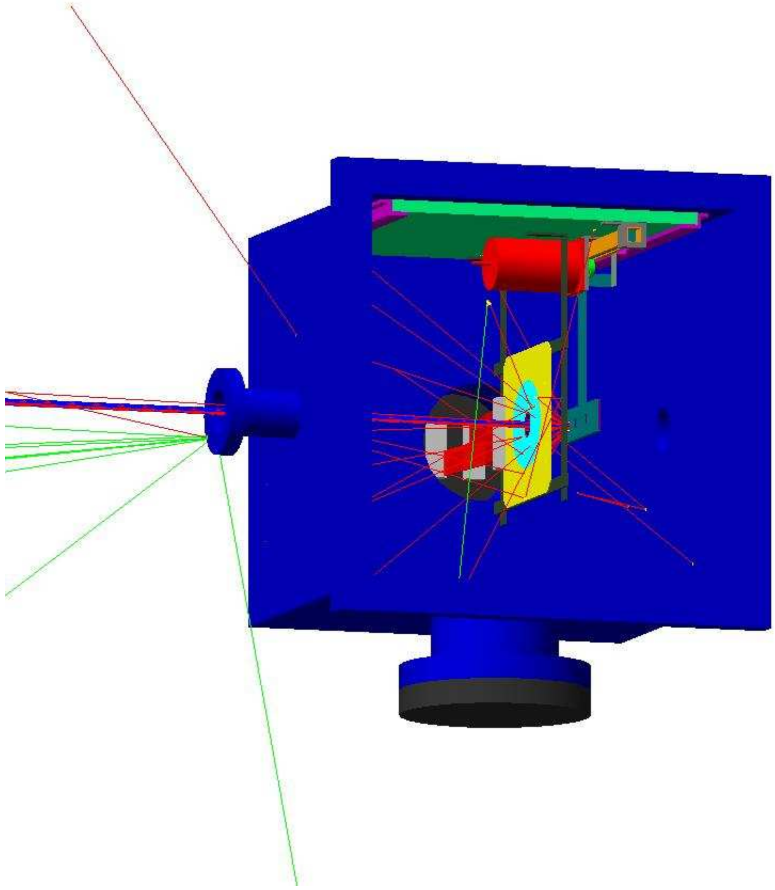

FIG. 3: Simulation of the triplet polarimeter with 100 thrown events.

The converters for the polarimeter are placed 35 mm upstream of the detector. For each generated triplet event the vertex was distributed isotropic in the beam line direction (z) throughout the converter thickness, while the profile of the vertex distribution orthogonal to z was isotropic within a diameter of 5 mm.

For the simulation used in this update, the generator used a coherent bremsstrahlung spectrum with coherent peak located at 3 GeV, an energy range between 2.4 and 3.1 GeV, and a 75 μm thick beryllium converter.

IV. DATA

Data presented in this document are of two runs from the Spring 2015 commissioning data. The relevant information for these runs can be found in table I.

TABLE I: Runs used in this document

Run Number	Tagger radiator type	Electron beam current	Running time (approximate)
3180	Amorphous (10^{-4} rad. length)	70 nA	4 hours
3185	Para oriented diamond (50 micron)	10 nA	2 hours

The triplet polarimeter was read out every time there was a trigger from the GlueX detector or a trigger from the pair spectrometer. When the triplet polarimeter was read out, the raw fADC signals for each of the 32 sectors was written to tape without regard to the information content coming from any of the fADC modules. For the analysis in this document, we are only interested in triplet events that are associated with a pair-hit in the pair spectrometer.

Furthermore, in order to remove data that represents a lack of a sector hit, hits seen in the fADC were ignored if the maximum difference in fADC counts was less than 45.

A. Extraction of time and energy information

For each hit in the triplet polarimeter the fADC counts as a function of time is fit to the function

$$V(t) = H(t - t_0)\frac{\Gamma_r A V_m}{(\Gamma_r - \Gamma_f)}\left[e^{(\Gamma_r t)} - e^{(\Gamma_f t)}\right] + C,$$

where $H(t - t_0)$ is a step function, Γ_r (Γ_f) represent the inverse of rise (fall) time, V_m is the maximum voltage attainable if the fall time were infinite, A is the conversion factor for fADC count to voltage, and C is an overall constant. The fall time was fixed to 6 μs (RC of the feedback loop within the pramplifier circuit), and the variables Γ_r, V_m, t_0, and C are parameters of the fit. An example of the fit for a single fADC hit can be found in Fig. 4.

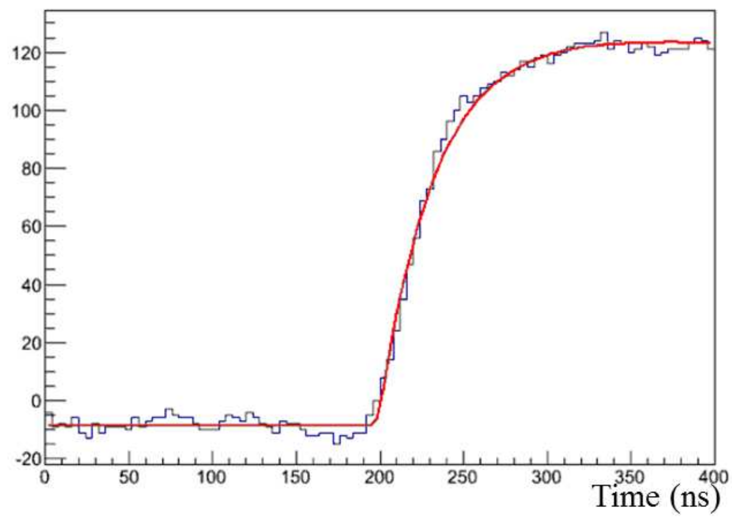

FIG. 4: Example fit to fADC signal versus time (ns) using the function described in the text.

The value of t_0 represents the beginning of the charge transfer from the ionizing track to the preamplifier and is taken as the time of the triplet event. The time difference between the pair spectrometer and the triplet polarimeter is defined as

$$\Delta T = t_0 - t_p - t_{offset},$$

where t_p is the time recorded by the pair spectrometer for a pair-hit, and t_{offset} is taken to be 89.1 ns. A plot of ΔT versus sector number of polarimeter hit is shown in Fig. 5.

In what follows, a timed hit is defined as having a ΔT between -30 ns and 50 ns, and an out-of-time hit is defined as having ΔT between 60 ns and 220 ns.

Initial energy calibrations for each sector of the polarimeter were performed at ASU using a ^{210}Po source. The sensitivity was sector dependent and ranged from 92.5 to 106.4 (mV per MeV). Energy deposition is plotted in Fig. 6 for real data (3185) and monte carlo, where the real-data timed-hits were weighted as unity and out-of-time hits where weighted by -0.5. Included in Fig. 6 are red lines that represents 250 keV and is the minimum energy deposition required for events to be further analyzed.

B. Azimuthal distribution

The following cuts have been applied to the data:

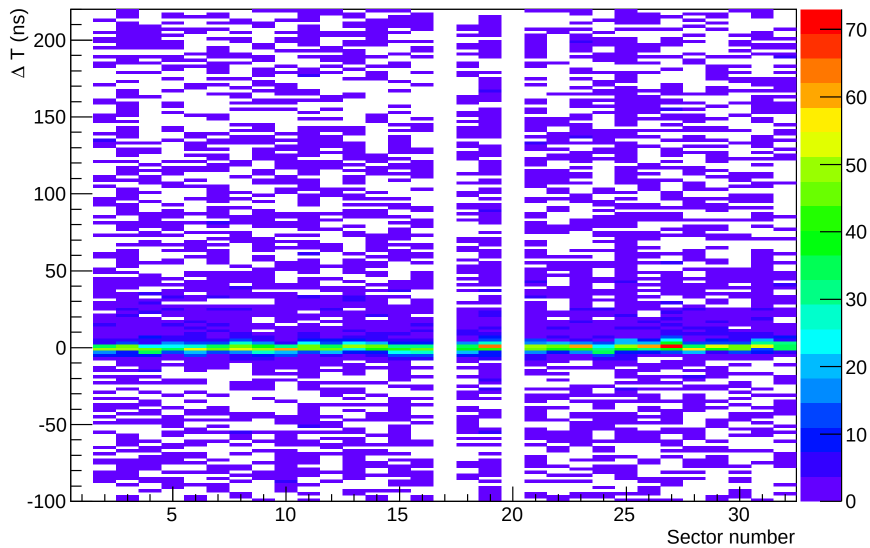

FIG. 5: Time difference between pair spectrometer and triplet polarimeter (ΔT) versus sector number of polarimeter.

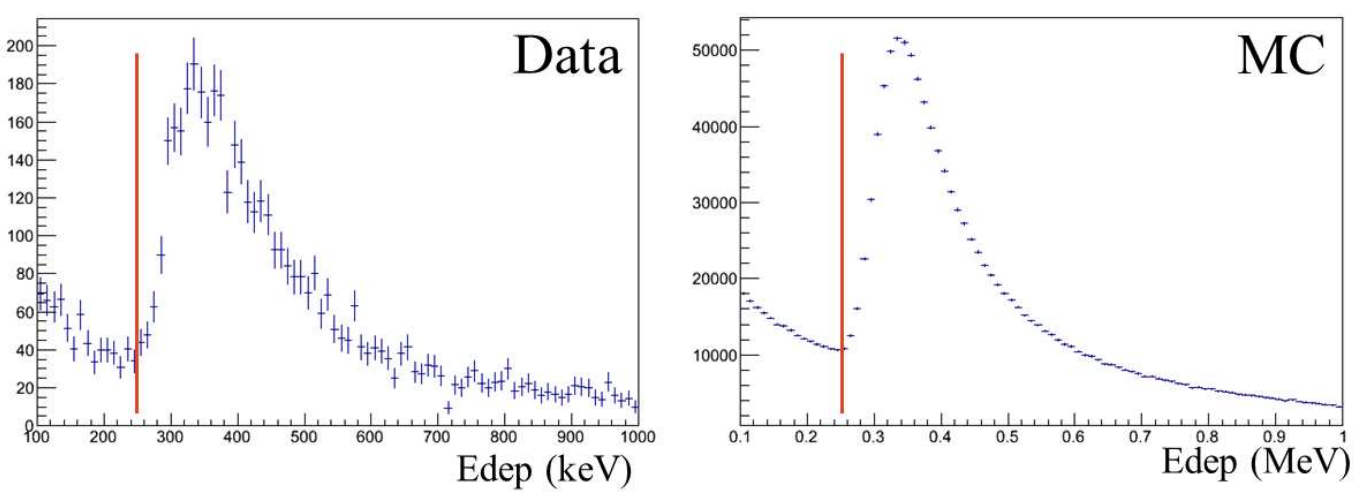

FIG. 6: Energy deposition in the polarimeter. Left panel: Energy deposition for real data (run 3185) where timed hits were weighted as unity and out-of-time hits where weighted by -0.5. Right panel: Energy deposition for Monte Carlo data. The red lines at 250 keV represents the energy cut made in the analysis.

1. A single sector hit seen in the polarimeter.
2. Energy deposition in the sector-hit of the triplet polarimeter is required to be greater than 250 keV.
3. Single pair-hit in the pair spectrometer.
4. The course left and right paddle numbers of the pair spectrometer must add together to be between 11 and 13. This choice corresponds to the electron-positron pair having energy between 2.4 and 3.1 GeV and a maximum energy difference between each of the detected leptons to be 730 MeV.

The azimuthal distribution of the events seen on the triplet polarimeter that have survived the cuts listed above are weighted such that timed-hits were weighted as unity and out-of-time hits where weighted by -0.5. Plots showing the weighted counts can be found in figure 7, where the left panel is for an amorphous-radiator run (3180), the right panel shows the azimuthal distribution for a diamond-radiator run (3185), the function fit to the distributions is $A\left[1 + Bcos(2\phi)\right]$, with A and B being parameters of the fit.

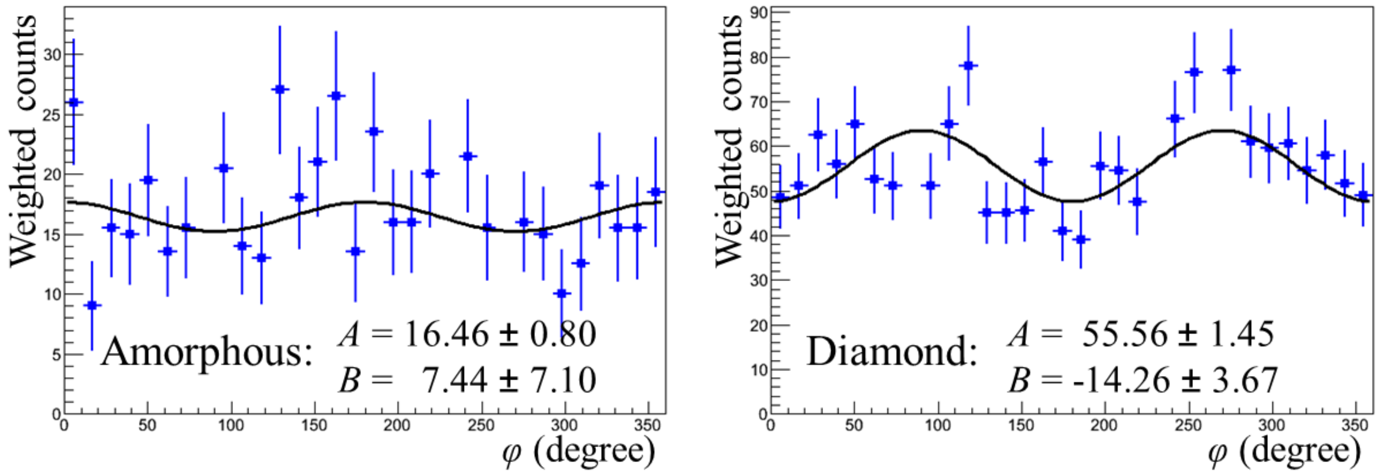

FIG. 7: Azimuthal distribution. Left panel: Azimuthal distribution for amorphous radiator (run 3180). Right panel: Azimuthal distribution for diamond radiator (run 3185). Each of the distributions were fit to the function $A\left[1 + Bcos(2\phi)\right]$, with A and B being parameters of the fit. The weighting of the histograms is described in the text.

C. Consistency of rates between the triplet polarimeter and the pair spectrometer

The converter for the triplet polarimeter is 35 mm upstream of the silicon strip detector and is referred to as converter a in this document. Downstream of the triplet polarimeter and upstream to the pair spectrometer is the main pair-spectrometer converter (converter b).

The pair spectrometer will see pairs created within each converter (a and b). Additionally, the created pairs seen in the pair spectrometer will be created from the nuclei, as well as from the atomic electrons. Of primary interest for the measurement of the triplet process is the number of events seen in the pair spectrometer for events that originate in converter a. Approximately, the number of events seen in the pair spectrometer that originate in converter a is

$$N_{pa} = N_p \frac{R_a}{R_a + R_b}, \tag{1}$$

where R_a (R_b) is the radiation length of converter a (converter b) and N_p is the number of single pair-hits seen in the spectrometer.

The value of N_{pa} is related to cross section by

$$\sigma_{ea} + \sigma_{Na} = \frac{N_{pa}}{E_\gamma \rho_a L_a \epsilon_{pa}}, \tag{2}$$

where E_γ is the number of incident photons, ρ_a is the number of atoms per volume in converter a, L_a is the thickness of converter a, and ϵ_{pa} represents the efficiency and acceptance for the measurement of pairs in the pair spectrometer from events originating in converter a in the energy range of interest.

The Number of single-sector hit events seen in the triplet polarimeter (N_t) is related to the cross section by

$$\sigma_{ea} = \frac{N_t}{E_\gamma \rho_a L_a \epsilon_{pa} \epsilon_t}, \tag{3}$$

where ϵ_t is the efficiency and acceptance for the measurement of the recoil electron.

Equations 2 and 3 can be used to write the triplet cross section in terms of the number of measured events in the pair spectrometer and triplet polarimeter as

$$\sigma_{ea} = \frac{\sigma_{Na} N_t}{N_{pa}\epsilon_{pa} - N_t}, \tag{4}$$

where σ_{Na} has a value of 132 mb (from NIST) and ϵ_{pa} is determined through monte carlo simulation and has value 0.0699.

TABLE II: Cross section for pair production from atomic electron in beryllium

Source	σ_e (mb/atom)
NIST	38.48
Run 3180	40.58 ± 1.98
Run 3185	36.81 ± 0.96
Weighted average (3180 and 3185)	37.53 ± 0.87

Table II gives results for runs 3180 and 3185, as well as the average over the two runs, along with the expected NIST result. The cross section from run 3180 is high and within 1.1 standard deviations, where as run 3185 is low and within 1.8 standard deviations. The weighted average over the two runs is within 1.1 standard deviations of the NIST value.

V. PRELIMINARY BEAM POLARIZATION ESTIMATE

The analyzing power for the reaction is the expected beam asymmetry (Σ_e) after the generated triplet events have been processed through the monte carlo simulation using the same cuts as was used for real data and has a value of 0.197.

To obtain the preliminary beam-polarization estimate, we simply divide the value of B (obtained from fitting the azimuthal distribution to $A\,[1 + Bcos(2\phi)]$), by Σ_e. The results for the two runs used in the analysis can be found in table III

TABLE III: Polarization estimates for two runs

Run Number	Tagger radiator type	Polarization estimate
3180	Amorphous (10^{-4} rad. length)	0.38 ± 0.36
3185	Para oriented diamond (50 micron)	0.72 ± 0.19

As can be seen in table III, the estimated beam polarization for the amorphous run is within 1.06 standard deviations from the desired result of zero, while the diamond run has an estimated beam polarization of 0.72 ± 0.19.

Currently, for the diamond run, there is no way to determine the accuracy of the polarization estimate. There are, however, early indications from the analysis of $\gamma p \rightarrow p\rho$ that suggests that the beam polarization for run 3185 is probably somewhat higher than 50%, which would further suggest that the estimated polarization given in this document might be within a standard deviation of the true value.

VI. ACKNOWLEDGMENTS

This work was supported at Arizona State University by the National Science Foundation award PHY-1306737.