Helicity Beam Asymmetry $I^{\odot}$ in Two Neutral Pseudoscalar Photoproduction Reactions at the Crystal Barrel Experiment

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Abstract. A method for measuring the helicity beam asymmetry ($I_{\odot}$) is shown and demonstrated using the reaction $\gamma p \rightarrow p\pi^0\eta$. The very preliminary results for this channel are presented and suggest that the helicity beam asymmetry is small. The statistics for this channel in this analysis are limited making an analysis of angular dependencies difficult.

Keywords: photoproduction, polarization observables, baryon spectroscopy

INTRODUCTION

Baryon spectroscopy has historically been explored via π-proton scattering experiments and more recently γ-proton scattering. In each of these scattering cases, the overwhelming majority of the analyses have been done on two-body final states. When these analyses are compared to the known photoproduction cross sections for a variety of final states, we find at a high enough energies the contributions to the total from non-two body final states are significant. In Figure 1, the total hadronic cross section for the γp initial state (photoproduction) is plotted along with some of the known final states. In the figure, at around 1 GeV photon energy, the cross sections for $\pi^+\pi^-$ and $\pi^0\pi^0$ are of the same order of magnitude as some of the single meson reactions. This means that the three body finals states (two meson final states) can not be ignored.

These energy ranges, where the three body final states are important, are also the energy regions where the mass entanglement is the worst. In order to facilitate the separation of the signals from each of these resonances and unambiguously determine states, polarization observables must be measured [1]. Of these polarization observables,

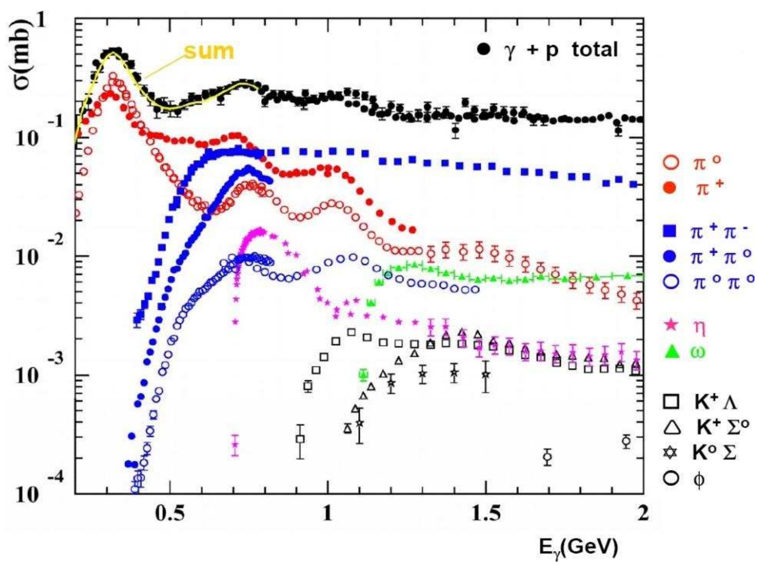

FIGURE 1. γp Total Hadronic Cross Sections

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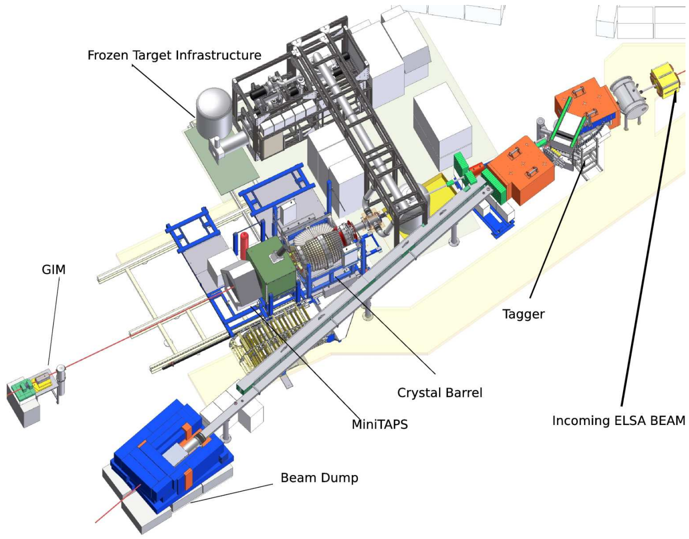

FIGURE 2. Crystal Barrel Detector Assembly (November 2008)

the helicity beam asymmetry ($I_{\odot}$) is one of the easiest technically to measure. The only polarization needed for this observable is the switching of the polarization of the incoming photon beam from a positive helicity state to a negative one.

The two meson final state of p$\pi^0\eta$ will be used as an example of the analysis of the data. This channel is very interesting due to its relatively low threshold energy and the possibility of using the η meson as an isospin filter to further pin down the quantum numbers of the Δ resonances that decay to pπ^0.

The p$\pi^0\eta$ reaction that is studied here has been measured at the CBELSA-TR16 Experiment in Bonn, Germany [2, 3], where the requisite calorimeters detectors like the Crystal Barrel detector and the switching beam polarization can be found. The methods in this work can and have been applied to p$\pi^0\pi^0$ and p$\pi^0\eta$ final states that decay to four photons and a proton at the CBELSA-TR16 Experiment.

CBELSA-TR16 EXPERIMENT

The CBELSA-TR16 Experiment can be supplied longitudinally polarized 2.4 GeV electron by the ELSA accelerator and is optimized to measure the final state photons that neutral mesons most likely decay to. These polarized electrons can be converted via Bremsstrahlung into circularly polarized photons and are energy tagged using a magnetic feild and a set of scintillation counters. Once the photons are tagged, these photons are allowed to interact with protons at the center of the detector assembly. If neutral mesons are created, they usually decay to photons that are detected in the nearly 4π angular coverage calorimeter detector assembly (Crystal Barrel, Mini-TAPS, Forward Plug). If charged particles are present, they are detected via scintillators that are located in front of the calorimeter crystals. An overall schematic of the detector assembly and supporting equipment is provided in Figure 2.

The detector systems are designed to achieve two main goals: measure the energy and direction of photons and detect the presence and direction of charged particles. To measure photons, the Crystal Barrel detector (1230 CsI crystals in a barrel shape covering most of the angular area), Forward Plug (90 CsI crystals extending the crystal barrel in the forward beam direction) and Mini-TAPS (216 BaF_2 crystals in a wall covering the forward angles closest to the outgoing beam direction) have been designed to give good resolution of energy and position of photons. To detect charged particles, the Inner Detector is made of scintillator fibers and covers the angular range of the Crystal Barrel detector. The Forward Plug and Mini-TAPS detectors have scintillators covering the crystals, that detect the passage of charged particles.

To create the circularly polarized photons that are needed to measure the helicity beam asymmetry, the longitudinally polarized electrons are used in a Bremsstrahlung reaction to produce circularly polarized photons. To determine the energy of these photons, a magnetic field and scintillators are used to determine the energy of the final state electron

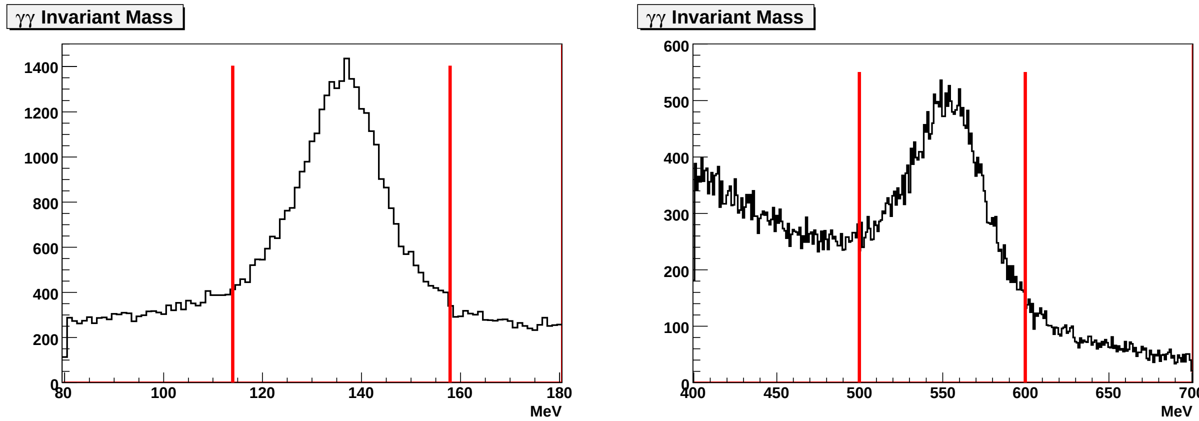

FIGURE 3. Meson $\gamma\gamma$ Invariant Mass. Both figures come from the invariant masses of pairs of photons detected in an event. The left figure is the region of the π^0 meson and the right figure is in the region of the η meson. Data cuts are shown. Estimated background: 30% for π^0, 54% for η.

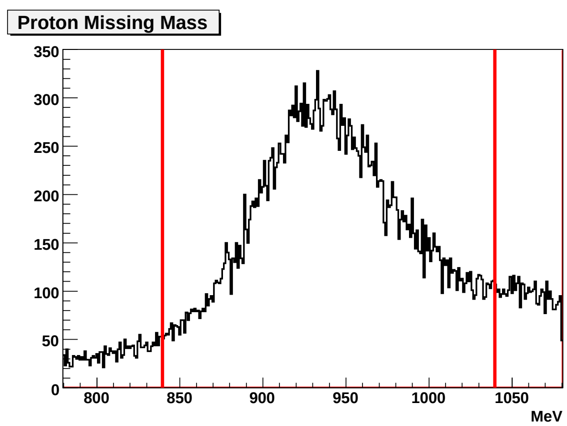

FIGURE 4. Proton Missing Mass. Using energy and momentum conservation, an invariant mass is calculated for a possible missing particle. The data cuts are shown and are used to identify protons that cannot be detected directly. Estimated background: 37%

and in turn is used to determine the energy of the photon using energy conservation. To determine the polarization probability of each photon, the polarization probability of the electron is used in

$$P_\gamma = P_e \frac{4\frac{E_\gamma}{E_{el}} - \frac{E_\gamma}{E_{el}}^2}{4 - 4\frac{E_\gamma}{E_{el}} + 3\frac{E_\gamma}{E_{el}}^2}. \quad (1)$$

DATA SELECTION

The data used in this analysis were selected by using the data taken from November 4, 2008 to November 17, 2008. This data was taken with a circularly polarized photon beam incident on liquid hydrogen. The data selection starts by requiring the identification of four uncharged energy deposits (four photons, a possible final state of one π^0 and one η) and one or zero charged particle (proton). For each event passing this requirement, the four photons are combined in pairs to form invariant masses. The combination that produces one invariant mass between 114 MeV and 158 MeV (π^0) and one invariant mass between 500 MeV and 600 MeV (η) is used in the analysis. In Figure 3, these values are plotted along with the corresponding cut used in the data selection.

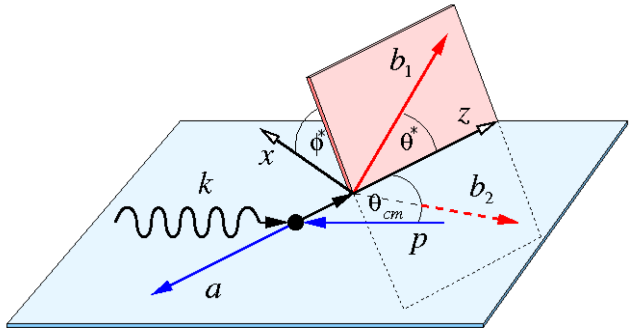

FIGURE 5. Kinematic Variables in the Three-Body Decay. a is the final state proton. b_1 and b_2 are the two final state mesons.

The surviving events are also required to have an incoming photon at the tagging detector at the appropriate time. The time of the detection particles in the detectors are used to calculate at what time the initial state photon must have been at the tagging detector. Only events that had a photon at the tagger at the correct time $\pm$ 5 ns where used in the analysis.

Finally, the charged particle in the reaction is required to have the invariant mass of the proton. Due to the fact that the detector systems can not detect the energy or momentum of a charged particle very well, the invariant mass of the proton must be calculated from the four-vectors of the other particles that are known. The resulting "missing" invariant mass of the event is shown in Figure 4 and was required to have an invariant mass between 840 MeV and 1040 MeV.

To reduce the background in the data where a charged particle was detected, one more cut was applied. The resulting particles are required to conserve momentum in the plane perpendicular to the beam direction. This is done by adding the momenta of the uncharged particles and comparing that to the charged particle detection. If the charged particle hit was more than 20° from the calculated position using momentum conservation, the event is cut from the analysis.

The total number of events passing these requirements is 32,488 events.

The resulting dataset is now subjected to a background subtraction. The background was estimated in each kinematic bin by plotting the proton invariant mass for each of the events in the bin and not requiring the proton missing mass cut. From these plots, the bins just outside the cut region can be summed and properly subtracted from the number of events in the peak region to get a more accurate value for the yield.

DATA ANALYSIS

In order to calculate the helicity beam asymmetry, the equation

$$I^{\odot} = \frac{\frac{N_{\rightarrow}}{\delta_{\odot}^{\rightarrow}} - \frac{N_{\leftarrow}}{\delta_{\odot}^{\leftarrow}}}{N_{\rightarrow} + N_{\leftarrow}} \tag{2}$$

is used, where $I^{\odot}$ is the helicity beam asymmetry, $\delta_{\odot}$ is the degree of polarization, N is the yield in each kinematic bin and $_{\rightarrow}$ is the direction of beam polarization. The simplicity of this formula is made possible because the data taken under each polarization was taken under the same experimental conditions with the same incoming photon flux. The photon beam continuously alternated the polarization direction every 8 seconds over a period of several days. The kinematic variables that are used in this scattering process are diagrammed in Figure 5. In this work, due to statistics, all kinematic variables are integrated over except for ϕ^* but is also binned in center of mass energy (E). ϕ^* is the angle between the plane defined by the initial state particles and the recoiling proton (reaction plane) and the plane defined by the two final state mesons (decay plane).

RESULTS

The resulting helicity beam asymmetry is shown in Figure 6. Each plot in Figure 6 is a different center of mass energy range, while the horizontal axis is the kinematic variable ϕ^*. All other kinematic variables in the process have been integrated over.

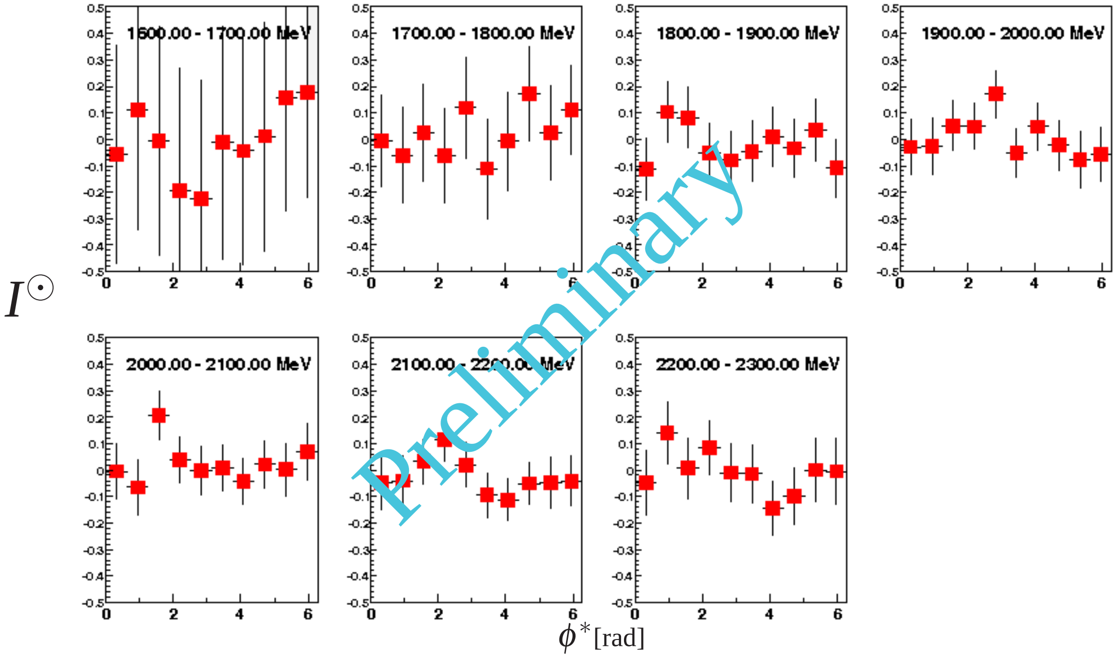

FIGURE 6. Helicity Beam Assemetry for $\gamma p \rightarrow p\pi^0\eta$ (Very Preliminary) Each plot is labeled with the center of mass energy. The vertical axis is the helicity beam assemetry. The horizontal axis is the kinematic variable ϕ^*

CONCLUSIONS

In this work, a general method for selecting and analyzing the data for helicity beam asymmetry for the photoproduction of two pseudoscalar mesons at the CBELSA-TR16 Experiment has been presented. To demonstrate the method, the helicity beam asymmetry for the reaction $\gamma p \rightarrow p\pi^0\eta$ was calculated using data taken at the CBELSA-TR16 Experiment in Bonn, Germany in November 2008.

The $\gamma p \rightarrow p\pi^0\eta$ analysis shows that the helicity beam asymmetry for this reaction is small. In order to perform a more complete analysis of this angular dependencies, a larger number of events must be used.

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