Beam-Spin Asymmetries (Σ) in Charged Pion Photo-Production from Polarized Neutrons at Jefferson Lab

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While the ground state properties of mesons and baryons are described succesfully by QCD, hadron excited state spectra still presents many challanges. There are many resonances that have been predicted by Lattice-QCD and by quark models, but have not been observed experimentally. N^* resonances are generally broad and overlapping, and detailed partial wave analyses (PWA) of reaction amplitudes with polarized beams and targets are needed to isolate resonance contributions. Data are particularly sparse for polarized neutron targets. To address this deficit, the JLab E06-101 experiment was performed at the Thomas Jefferson Accelerator Facility (JLab) during the years 2011-2012 (the *g14* run with the CLAS detector in Hall B), using circularly and linearly polarized photons incident on longitudinally polarized Deuterons in frozen-spin targets of solid Hydrogen-Deuteride (HD). Spin asymmetries from the reaction $\gamma + n(p) \rightarrow \pi^- + p + (p)$ have been used to extract the beam-target E asymmetries with circularly polarized photons, and these have been published recently. Σ and G asymmetries from reactions with linearly polarized beams are presently under analysis. In this paper, preliminary results for the Σ beam asymmetries are discussed.

KEYWORDS: linearly polarized photon, polarized neutron, HD target, CLAS

1. Introduction

The g14 experiment was performed from December 2011 to May 2012, and included data taken with linearly polarized photon beams (3.7 x 10^9 triggered events), whose energies ranged from 1.3 to 2.3 GeV. Linear beam polarization was produced by the coherent bremsstrahlung of electrons in a diamond crystal, which produced an enhanced peak of polarized photons that typically extended about 400 MeV below a sharp *coherent edge*. The energy of this enhanced peak was changed by adjusting the orientation of the diamond crystal, and data were recorded with coherent edges at 1.8, 2.0 and 2.2 GeV. Photon energies and arrival timings were measured by a photon-tagging system with resolutions of 0.1 % and 100 ps, respectively [1]. The degree of photon polarization was determined by fitting the enhanced photon spectrum to a coherent bremsstrahlung calculation using measured photon beam parameters [2]. The uncertainty in the polarization was estimated to be about 5 %. Periods of data collection alternated between incident beams with photon polarizations oriented horizontally (*parallel*) or vertically (*perpendicular*), with respect to the hall floor and the CLAS apparatus.

Frozen-spin Hydrogen Deuteride (HD) targets were used to provide a source of quasi-free longitudinally polarized neutrons at the Thomas Jefferson National Accelerator Facility (JLab). The HD In-Beam Cryostat (IBC) was designed and constructed by the HDice group at JLab. Its dilution refrigerator held targets at 50 mK during the experiment and a thin superconducting magnet maintained a longitudinal holding field of 1 T. The target polarizations were calibrated in a separate production dewar and monitored by Nuclear Magnetic Resonance (NMR) in the IBC. The polarization process and the various cryostats involved are described in refs. [3,4]. During the experiment the target polarization was flipped between orientations parallel and anti-parallel to the beam direction. The average D polarizations in HD was about 21% during experiments with the linearly polarized photon beams and the relaxation time for D was measured to be more than one year for the run periods in this analysis. The background contributions from reaction in the material of the target cells, pCTFE [C_2CIF_3] and thin 5N Aluminum wires, were monitored from the yields in empty target runs.

Proton and π^- pairs were detected and identified in the CEBAF Large Acceptance Spectrometer (CLAS) [5], which covered laboratory polar angles between 8 to 142 degrees, and azimuthal angles spanning almost 360 degrees. The momenta of charged particles were deduced from track measurements in drift chambers within the CLAS Toroidal magnetic field, and a comparison between these momenta and particle velocity, determined by measured flight times and traveled paths [6] was used to provide particle identification.

E asymmetries measured during g14 experiment for this final state using circularly polarized photon beams and longitudinally polarized HD targets have been published recently [7]. Analyses for the double spin asymmetry G with linearly polarized photons and a longitudinally polarized target are ongoing. In this report, we focus on preliminary results for the single-spin beam asymmetry (Σ).

2. Data reduction

To obtain the Σ asymmetries, the following corrections and cuts were applied to select quasi-free neutron reactions for $\gamma + n(p) \rightarrow \pi^- + p(p)$, where (p) represents a spectator proton.

(1) π^- and p pairs were identified using the correlation between the velocity, calculated from the time of flight measurement, and the particle momentum, measured by the drift chamber in the CLAS torus. Events in which only one π^- and one proton were identified were selected.

(2) Three sets of corrections were applied: (i) photon beam energy correction from effects of gravitational sag and various misalignments of Energy counters on the tagger focal plane to improve the energy resolution, (ii) energy loss corrections for charged particles passing through the materials surrounding the target (such as the radiation shields, etc.), and (iii) momenta corrections coming from the imperfections in the drift chamber alignments within the magnetic fields of the CLAS torus.

(3) A missing momentum requirement on the reaction, $\gamma + n(p) \rightarrow \pi^- + p(p)$, to be less than 0.18 GeV, was imposed to avoid perturbations to Σ from final state interactions.

(4) The event selection on the reaction, $\gamma + D \rightarrow \pi^- + p(p_{miss})$, was obtained using the following procedure. The missing momentum of the undetected proton (p_{miss}) was calculated assuming the above reaction. This momentum, equal in strength but opposite in direction, was assigned to the target neutron. The momentum (p_1) of a proton from the two-body process $\gamma n \rightarrow \pi^- p$ was calculated in the center-of-mass (CM) frame of the γ and this moving neutron using the photon beam energy and π^- momentum. Detected protons were boosted into the same CM frame and their momenta identified as p_2. Events were selected by requiring the difference of p_1 and p_2 to be less than the three standard deviations of the quasi-free peak width (45 MeV).

(5) Background contributions to the reaction from the target cells were determined from yields and fluxes during experiments with an empty target. From the flux-normalized yields with and without HD, a dilution factor was estimated to be 1.07 and the asymmetries were corrected by this number.

3. Preliminary results

The differential cross section with linearly polarized photons on a longitudinally polarized neutron target is given by :

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_{unpolarized} \times [1 - P_L \Sigma cos(2\phi) + P_L P_z G sin(2\phi)]. \quad (1)$$

Here, P_L and P_z are the photon beam (parallel or perpendicular) and target (parallel or anti-parallel to the beam axis) polarizations, respectively, and ϕ is the azimuthal angle in right-handed coordinates between the reaction plane and the beam polarization direction (*ie.* the net electric field vector of the ensemble of photons) [8]. From four combinations of target and beam polarization orientations, preliminary Σ asymmetries have been obtained. Figure 1 shows Σ asymmetries from the E06-101 (*g14*) experiment (black points) as a function of cos θ_{π^-} in W bins, where θ_{π^-} is the polar angle for π^- in the CM frame and W is defined as an invariant mass of the final state proton and π^- detected by the CLAS detectors. Σ asymmetries were measured for five energy regions, (a) $1.82 \leq W \leq 1.90$ GeV, (b) $1.90 \leq W \leq 1.98$ GeV, (c) $1.98 \leq W \leq 2.06$ GeV, $2.06 \leq W \leq 2.14$ GeV and (e) $2.14 \leq W \leq 2.22$ GeV. Green shaded areas are the predictions from a PWA solution [TS21] from SAID [9], which have been fitted to all published data including g14's E asymmetries [7] and differential cross section data from the CLAS g13 experiment on the same reaction [10] . (The latter have been performed with a liquid deuterium target and polarized photon beams). Red and blue curves are the SAID predictions for low and high limits of each W bin, respectively. The predictions describe the data well at low W ranges, although some discrepancies are seen at higher W values.

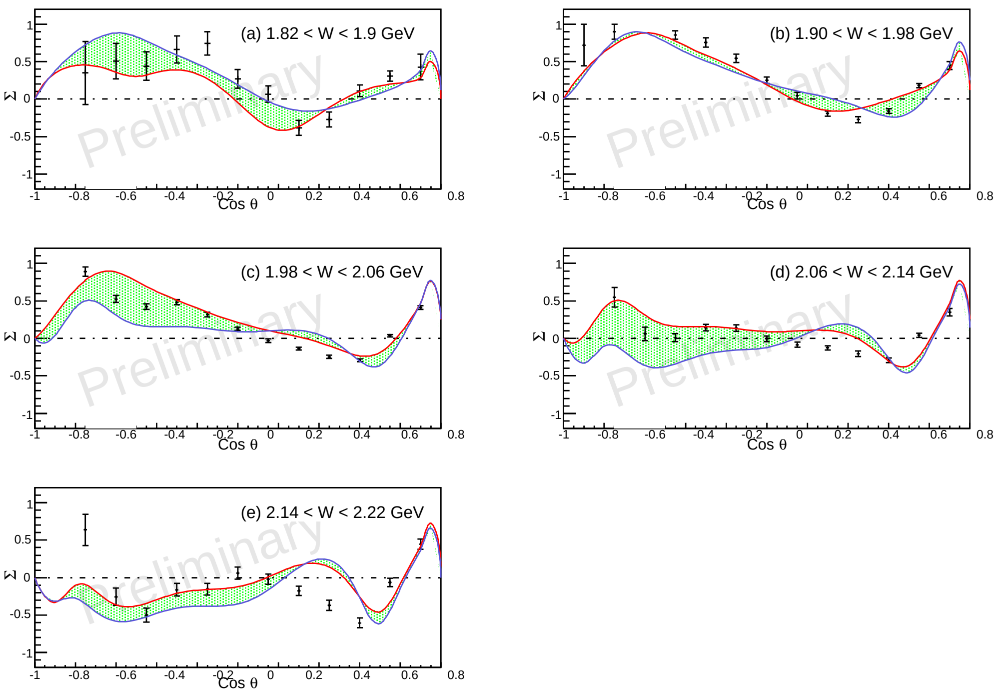

Fig. 1. Preliminary Σ asymmetries from the E06-101 (*g14*) experiment (black points) as a function of cos θ_{π^-}, the π^- polar angle in the CM frame, for five different invariant mass (W) bins. PWA predictions from SAID [TS21], with solutions fitted to all published data including g14's E asymmetries [7] and the g13's differential cross sections [10] are shown as green shaded areas for each W range. Red and blue curves are predictions for the low and high W limits of each invariant mass bin, respectively.

4. Summary

Pseudoscalar meson photoproduction data for neutron targets are quite sparse, particularly for spin asymmetries. Double-spin polarization experiments with polarized photon beams and polarized quasi-free neutrons (in deuterium) have been carried out in Hall B at JLab using frozen spin HD solid targets. Preliminary results for the single-spin beam asymmetries (Σ) have been presented. Analysis for the G double spin asymmetries in this reaction is in progress and results are expected to appear soon.

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