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A new beam asymmetry measurement from pion photoproduction on the neutron using CLAS

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Abstract We present a preliminary analysis of the photon beam asymmetry observable (Σ) from the photoproduction reaction channel $\gamma n \rightarrow p\pi^-$ in the invariant mass range 1.6—2.3 GeV. The measurement was obtained using the near-4π CEBAF Large Acceptance Spectrometer (CLAS) at Jefferson Laboratory, USA, employing a linearly polarised photon beam with an energy range 1.1—2.3 GeV, incident on a liquid deuterium target. The measurement will provide new data to address the poorly established neutron excitation spectrum and will greatly expand the sparse world data-set both in energy and angle.

Key words beam asymmetry, photonuclear, photoproduction, neutron, pion.

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1 Introduction – the nucleon resonance spectrum

Despite decades of study our knowledge of the fundamental resonance spectrum of the nucleon is still incomplete. The masses, widths, electromagnetic couplings and in some cases even the existence of many resonances are not well established due to inconsistent results from analyses of available data with different techniques. Most theoretical predictions of the resonance spectrum are based on phenomenological models, such as constituent quark, holographic dual and Dyson-Schwinger models but lattice predictions more directly linking to quantum chromodynamics (QCD) are also fast developing. Experimental differentiation between theoretical approaches based on the presently established resonance spectrum is, however, inconclusive due to the many "missing" and poorly established resonances. This situation has arisen largely because of the insufficient accuracy and quantity of experimental observables in the world data-set of meson production and scattering from the nucleon[1].

2 Polarisation observables in meson photoproduction

The new generation of photoproduction measurements from the nucleon is expected to give new, precise information for partial wave analyses (PWA), which will improve our knowledge of the nucleon excitation spectrum. Pion photoproduction is a particularly promising tool as many resonances are expected to couple to the pion decay channel and polarised real photons, with a well-understood electromagnetic interaction, provide a powerful probe. This forms part of a large programme of precision cross-section and polarisation measurements in the pion[2, 3] and the strangeness[4, 5] sectors. The programme is complemented by measurements on other pseudoscalar channels, such as η, and multiple meson production.

Measuring a selection of polarisation observables from experiments employing polarised photon beam and target and recoil baryon polarimetry in single pseudoscalar meson production will allow model independent extraction of reaction amplitudes. This will greatly enhance our capabilities to separate resonant and non-resonant contributions to the nucleon excitation spectrum and aid in determining the reso-

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nance spectrum in a nearly model-independent way[6]. Experiments to this effect are being carried out at various photon beam facilities worldwide.

2.1 Beam asymmetry

The choice of polarisation observables has to include the differential cross section, all three single-polarisation (beam, target, recoil nucleon) and a total of four well chosen double-polarisation observables[7]. One of the three single-polarisation observables – and a crucial one to constrain PWA used to extract resonances from the data – is the beam asymmetry, Σ, from linearly polarised photons. It has the effect of modulating the differential cross-section thus:

$$\frac{d\sigma}{d\Omega} = \sigma_0(1 - P_{\text{lin}}\Sigma\cos 2\phi). \tag{1}$$

where σ_0 is the unpolarised cross-section, P_{lin} is the degree of linear beam polarisation and ϕ is the angle the photon polarisation (electric field vector) makes to the reaction plane.

Data from the neutron is crucial for achieving a determination of the resonance isospin and a reliable extraction of the isoscalar and isovector electromagnetic couplings of the neutron excited states. The world data-set on the neutron, however, is extremely sparse, consisting of only three fixed-angle experiments limited to the 1.70—2.05 GeV range in beam energy and 35°—90° in scattering angle[8—10].

3 The g13 experiment

A new, extensive photoproduction experiment (labelled g13 in the lab nomenclature1)) using a polarised photon beam and a liquid deuterium target has been carried out at Jefferson Laboratory, Virginia, USA, in March - June 2007. The experiment ran with both a circularly and a linearly polarised beam at six photon energy settings, equally spaced between 1.1 and 2.3 GeV. Linearly polarised photons were produced from an electron beam (at energies 3.3—5.2 GeV) by coherent bremsstrahlung in a high purity diamond crystal. To aid in the treatment of detector acceptance, fine rotations of the crystal planes were used to flip the photon polarisation plane frequently between two orthogonal orientations, parallel and perpendicular to the lab floor. A single charged particle trigger was used, yielding a total of 3×10^{10} events recorded. This paper presents a very preliminary measurements of Σ from the analysis of the $\gamma + n \rightarrow p + \pi^-$ channel.

3.1 Experimental facility – Jefferson Lab

Jefferson Laboratory is home to a 1.4 km racetrack electron accelerator operating at energies up to 6 GeV (an upgrade to 12 GeV is currently under way). 200 μA of continuous current is split and delivered simultaneously to three experimental halls. Our experiment was conducted in Hall B, housing the bremsstrahlung facility, tagging spectrometer and CLAS.

After passing through the diamond crystal, the scattered electrons are momentum analysed in the Hall B photon tagging facility[11], which also serves to “tag” the photons through a coincidence timing measurement between the deflected electron and the event time in the detector. The target cell is positioned in the centre of CLAS.

CLAS[12] consists of multiple layers of detectors (drift chambers, scintillators and calorimeters) providing nearly full coverage in the azimuthal angle and from 8° to 140° in scattering angle (lab frame) which, combined with a toroidal magnetic field, offer excellent sensitivity to charged particles.

4 Analysis technique

4.1 Identifying the $\gamma + n \rightarrow p + \pi^-$ channel

Our interest is in photoproduction off the neutron and we therefore need to select the quasi-free reaction, in which the proton in the deuteron nucleus remains a spectator:

$$\gamma + d \rightarrow \pi^- + p + (p_{\text{spectator}}). \tag{2}$$

The following cuts are applied to the data to obtain a first selection of the $\gamma + n \rightarrow \pi^- + p$ channel:

- A momentum-dependent mass-cut selecting two-particle events with particle masses of the π^- and p in the final state.
- A cut on the “missing mass” of the recoiling system, required to be consistent with the mass of a proton (the spectator) (Fig. 1).
- Selection of low “missing momentum” of the spectator – below 0.12 GeV/c, in order to minimise the effect of final state interactions (Fig. 2).
- A cut on the angle between p and π^- momenta, requiring coplanarity in the invariant

1) “Kaon production on the deuteron using polarised photons”, proposed by P. Nadel-Turonski and co-spokespersons B. Berman, Y. Ilieva, D. Ireland and A. Tkabladze.

mass frame of the photon and reconstructed neutron.

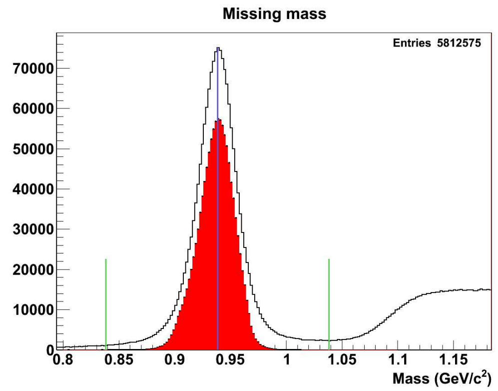

Fig. 1. "Missing mass" distribution before data cuts (vertical lines) to identify the spectator and, shaded, after all cuts have been applied.

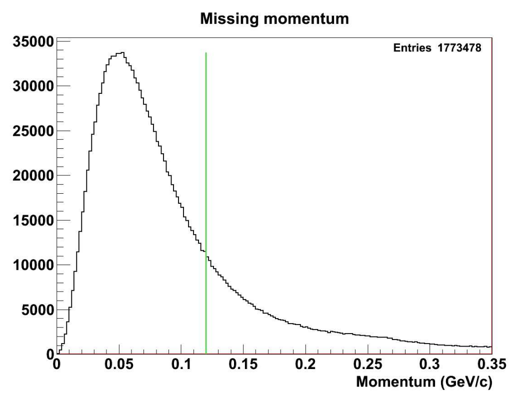

Fig. 2. "Missing momentum", showing cut at 120 MeV.

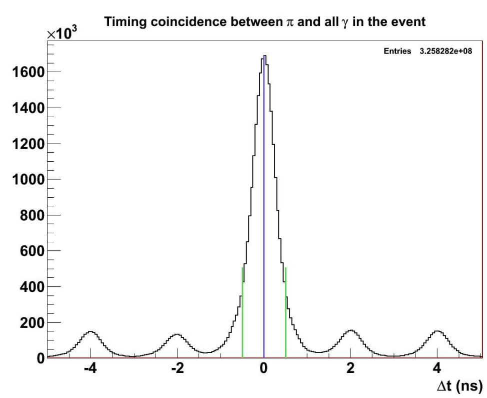

Fig. 3. Timing coincidence, Δt, at the event vertex between all associated photons and the pion. For each event, the photon with the lowest Δt is chosen, then a cut is applied at $\pm$ 0.5 ns, as shown, to remove contamination from neighbouring beam bunches.

The photon was identified through timing coincidence of the reaction in CLAS with the tagger. This is made possible by the bunched nature of the beam which arrives in pico-second bunches at 2 ns intervals (Fig. 3).

4.2 Extracting the beam asymmetry

As can be seen from (1), the beam asymmetry is extracted from a $\cos 2\phi$ fit to the ϕ-distribution. The angle ϕ is, as before, measured between the reaction plane and the photon polarisation plane. In order to reduce systematics, the polarisation plane was rotated between two orthogonal directions during the experiment, with ϕ being always measured from the horizontal polarisation plane, thus simplifying the expression:

$$N_{\parallel} = \sigma_0(1 - P\Sigma\cos 2\phi).$$

$$N_{\perp} = \sigma_0(1 + P\Sigma\cos 2\phi).$$

$$\Sigma P\cos 2\phi = \frac{N_{\perp} - N_{\parallel}}{N_{\perp} + N_{\parallel}}. \tag{3}$$

where $N_{\parallel}$ is the differential cross-section from (1) using a parallel beam polarisation and $N_{\perp}$, consequently, a perpendicular polarisation. The asymmetry is then extracted from a fit to the distribution in Eq. (3), an example of which is shown in Fig. 4. This method was chosen to ensure that acceptance effects, which would be the same for each orientation of the beam polarisation plane, cancel out. We make the assumption that $P_{\parallel} = P_{\perp} = P$ and at this stage, for the purpose of extracting an approximate beam asymmetry, assume that $P = 1$. Final calibrations and a determination of the beam polarisation are nearing completion, but a very preliminary evaluation of $\sim 25\%$ of the data indicates a tiny statistical uncertainty (Fig. 5). It is our goal to reduce systematics, which are currently very large, to $\sim$5%.

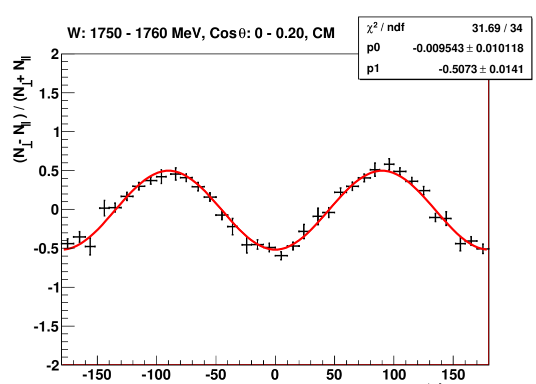

Fig. 4. $\frac{N_{\perp} - N_{\parallel}}{N_{\perp} + N_{\parallel}}$ for a single invariant mass and $\cos\theta$ bin, showing a fit with $p_0 + p_1\cos 2\phi$.

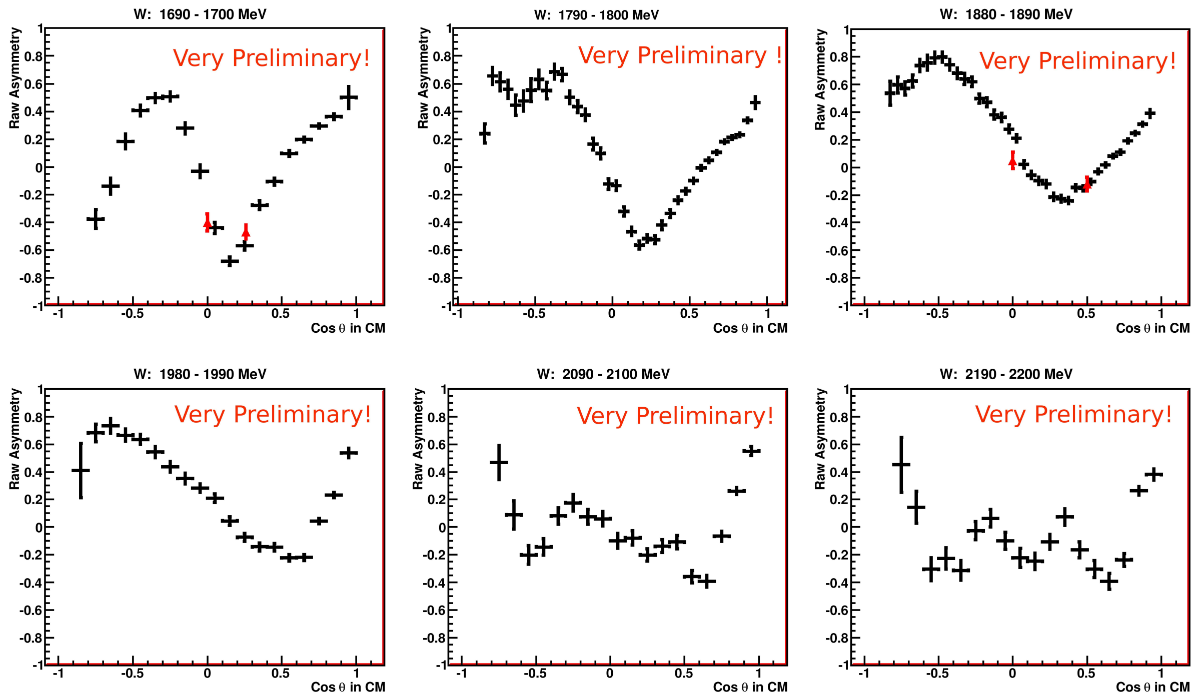

Fig. 5. Raw asymmetry (ΣP) vs. $\cos\theta$ distributions for a selection of invariant masses ~0.1 GeV apart. Only the statistical error is shown here. Triangular points show previous data[10].

5 Prospects

The determination of the Beam Asymmetry, Σ, from a linearly polarised photon beam incident on a neutron (in a liquid deuterium target) is underway. Early analysis shows that the data quality is good, statistical uncertainty is tiny and a sizeable asymmetry changing both with scattering angle and invariant mass can be observed. A full analysis is to follow soon in the entire invariant mass range 1.6—2.3 GeV. The measurement promises to greatly expand the sparse world data-set on the neutron and aid in constraining the determination of the reaction amplitudes in pion photoproduction thus providing strong constraints on the nucleon excitation spectrum.

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