Recent N* results from photoproduction experiments at CLAS

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Abstract. The recent breakthroughs in the technology of polarised targets have enabled a new generation of meson photoproduction experiments to be carried out. A measurement of a full set of polarisation observables off both polarised proton and neutron targets and in a large number of meson-production channels has come within sight. Such a measurement would very significantly reduce model-dependence in the analysis of the data and thus has the potential to resolve long-standing issues, such as the "missing resonance" problem, and shed new light on the nucleon excitation spectrum. This has formed the motivation for the recent N* experimental programme of CLAS.

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1. INTRODUCTION

The nucleon excitation spectrum provides deep insight into the structure of the nucleon. Despite years of study, however, it is still relatively little known. Predictions are primarily from Lattice QCD (Quantum Chromodynamics) and from a variety of phenomenological models, such as the constituent quark model, the di-quark model and others. The plethora of different models predict spectra of different resonances, many more in fact than have so far been observed – a conundrum known as the "missing resonance" problem. Experimentally, the extraction of resonance parameters from the measurable observables is still heavily model-dependent. Thus the question remains – are the missing resonances not there in nature, or are we simply not seeing them?

A powerful technique for the study of the nucleon excitation spectrum is meson photoproduction. Since the first resonance region is above the combined invariant mass of a nucleon and the lowest-mass meson (pion), many resonances preferentially decay via the production of a meson. Sensitivity to different resonances can be observed in different meson-production reactions. Additionally, the electromagnetic (EM) interaction of real photons is well-understood and gives access to the EM properties of the nucleon.

Meson photoproduction can be described in terms of complex reaction amplitudes, which number four in the case of pseudo-scalar mesons. Experimentally, combinations of these yield 16 polarisation observables [1] – measurable quantities in experiments employing polarised photons, polarised targets and the ability to measure recoil polarisation. It has been shown [2] that a measurement of eight carefully chosen polarisation observables (which have to include cross-section and the three single polarisation observables, as well as four chosen from at least two of the groups of double-polarisation experiments: beam-target (BT), beam-recoil (BR) and target-recoil (TR)) is sufficient to remove ambiguities in the partial wave analysis (PWA), one of the main methods used to extract resonance parameters from the data. Additionally, measurements obtained from a variety of reaction channels are very important as input for coupled channel analyses where they enable a choice to be made between the large number of different models and can provide indication of strong quark correlations in the nucleon.

Moreover, since the electromagnetic interaction does not conserve isospin, the multipole amplitudes which feature in PWA contain both isoscalar and isovector contributions of the EM current. Measurements from both isospin partners, the proton and the neutron, are therefore required to study different isospin couplings. Since different meson production channels are sensitive to different resonances, data from a variety of channels and on both proton and neutron targets are required.

The recent experimental programme of the CLAS Collaboration at Jefferson Lab is contributing significantly, both to the quest for a "complete" measurement and in expanding and refining the dataset for coupled channel analyses.

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Due to enormous technological challenges in the construction and use of polarised targets, it is only recently that the beam-target and target-recoil groups of double-polarisation measurements have become accessible.

2. CLAS AT JEFFERSON LABORATORY

Jefferson Lab (JLab) is home to a 1.4 km long race-track accelerator, currently operating at energies up to 6 GeV and about to undergo an upgrade to 12 GeV within the next few years. 200 μA of continuous current is split and delivered simultaneously to three experimental halls, A, B and C. The experiments presented here were carried out in Hall B, where the electron beam is passed through a radiator, emitting, depending on the type of material used and the polarisation of the electron beam, either circularly or linearly polarised photons by the process of bremsstrahlung. Circular polarisations up to 80% and linear polarisations $> 90\%$ are typical. The scattered electrons are momentum-analysed in a tagging spectrometer, which serves to "tag" the photons through a coincidence timing measurement between the deflected electrons and the event time in the detector, thus allowing the exact photon involved in an interaction to be identified. The target cell is positioned at the centre of CLAS, the CEBAF (Continuous Electron Beam Accelerator Facility) Large Acceptance Spectrometer for charged and neutral particles. It consists of near-spherical layers of scintillators, drift-chambers, and calorimeters, providing almost complete angular coverage in the azimuthal direction and from 8° to 140° in the polar angle. Coupled to a toroidal magnetic field from six superconducting coils, CLAS offers particularly excellent sensitivity to charged particles, while still allowing detection of neutral reaction products.

Although no recoil detector is currently installed, measurements of recoil polarisation are still possible for photoproduction channels involving the production of hyperons, such as $\gamma + p \rightarrow K^+ + \Lambda \rightarrow K^+ + p + \pi^-$. The procedure makes use of the "self-analysing" property of hyperons, whose polarisation can be determined from the angular distributions of their weak-decay products (in the case above, p and π^-). As a result, a complete measurement in kaon-photoproduction off the proton has already been possible in CLAS.

3. RECENT EXPERIMENTS

In this paper we present a selection of preliminary results from three recent experiments carried out at Jefferson Lab, which were aimed at expanding measurements of single and double polarisation observables in a number of meson photoproduction channels. The details of the experiments are discussed in the following sections.

3.1. The G8 experiment: Linearly polarised photons, LH_2 target

The G8 experiment, as it is labelled in JLab nomenclature, ran from June to Sept. 2005, using linearly polarised photons, in the range 0.9 - 2.1 GeV, incident on an unpolarised liquid H_2 target. This enabled measurements on the proton of the beam spin asymmetry from the pion (see M. Dugger *et al.* in this publication), η and η' photoproduction channels, and a number of observables from the kaon-production channels. The experiment complements a much earlier run (G1) in which similar measurements were carried out using a circularly polarised photon beam.

Fig. 1 presents a sample of preliminary results from measurement of three observables in the $\gamma(p,\Lambda)K^+$ channel [3]. The two measurements of the beam asymmetry (left) display very good agreement with previous data (GRAAL for photon energies in the range 1.15 - 1.5 GeV (Lleres *et al.*, 2007), and LEPS in the photon energy range 1.5 - 2.1 GeV (Zegers *et al.*, 2003)). The large statistics of the experiment allowed much finer angular binning, with reduced error bars, and at photon energies > 1.5 GeV provided the first measurements at backward angles.

Very good agreement with past results from both CLAS and GRAAL is also observed in a measurement of the recoil polarisation (middle), where the much higher statistics allowed a finer binning and smaller error bars.

Significantly, a first measurement of the O_x beam-recoil observable has been possible, showing large polarisations. The data in the two right columns of Fig. 1 is displayed with a selection of Regge model predictions, calculated by the Gent group [4]. The Regge calculation including only the better-established "core" resonances, S11(1650), P11(1710), P13(1720) and P13(1900), does not appear to be sufficient. A test inclusion of additional "missing" resonances was made into the model and the prediction compared with the data. There is a tentative suggestion of an important role of the D13(1900) resonance, and no clear evidence for the P11(1900) state. Agreement at low energies, however, is poor.

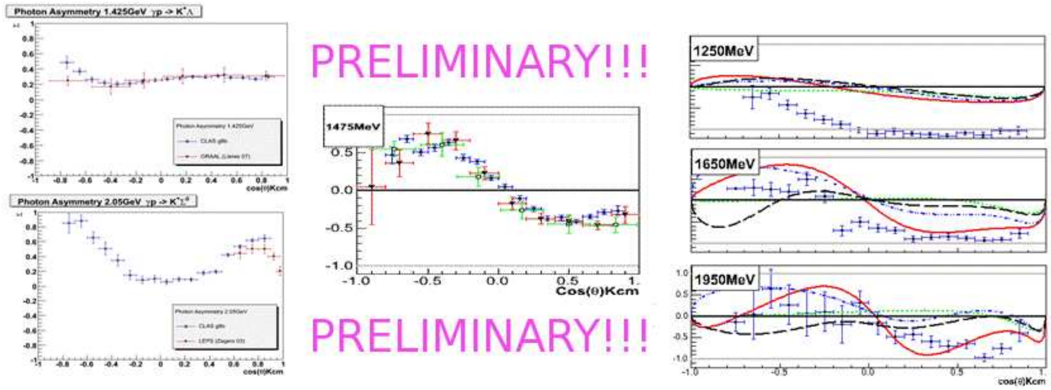

FIGURE 1. Single and double-polarisation measurements in $\gamma + p \rightarrow \Lambda + K^+$. Left: beam asymmetry for $1.40 < E_\gamma < 1.45$ GeV (top) and $2.0 < E_\gamma < 2.1$ GeV (bottom). Middle: recoil polarisation for $1.45 < E_\gamma < 1.5$ GeV, G8 data (blue diamonds) compared to past CLAS data (red down triangle, (McNabb *et al.*, 2004)) and GRAAL data (open green squares, (Lleres *et al.*, 2007)). Right: O_x double polarisation measurement, compared to Regge prediction (dotted green), Regge + core resonances (dot-dash blue), Regge + core + D13(1900) (solid red) and Regge + core + P11(1900) (dashed black) [3], [4].

3.2. The G13 experiment: Polarised photons, LD_2 target

A complementary experiment, G13, took data in autumn 2006 and March - June 2007, using photon beams of both circular (0.4 - 2.5 GeV) and linear polarisations (1.1 - 2.3 GeV) incident on a liquid deuterium target. This gave access to polarisation observable measurements off the neutron.

A comparison of the beam asymmetry measurement in $\gamma(p,\Lambda)K^+$ off the bound proton and a free proton (from the G8 experiment) showed good agreement, indicating that the quasi-free nucleons in deuterium can be assumed to provide a good approximation for free nucleons [5].

Some preliminary results of the first measurement of the beam asymmetry off the neutron in the channels $\gamma(n,\Lambda)K^0$ are shown in Fig. 2, where the data are compared to MAID PWA calculations [6] inclusive of different resonances. It is evident that the PWA fits the data rather badly, suggesting that the description is incomplete. A similar measurement performed for the channel $\gamma(n,\Sigma)K^0$ is also being prepared for publication.

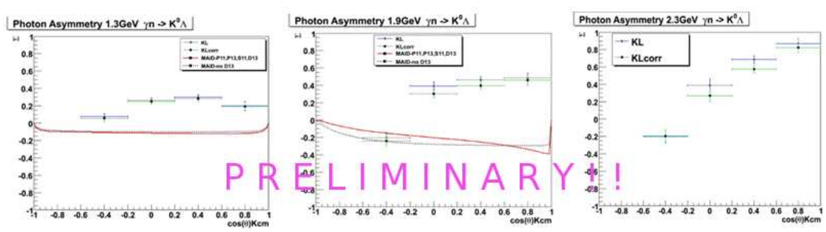

FIGURE 2. Beam asymmetry measurement from $\gamma(n,\Lambda)K^0$, in a sample of three photon energy bins [7]. Curves show MAID predictions [6]. The PWA is not valid for the energy of the third bin.

The preliminary results of a tremendously high statistics measurement of the beam asymmetry in the channel $\gamma(n,p)\pi^-$ are shown in Fig. 3 [8]. The world dataset has been increased from 52 previous data points to 1535. Comparisons to the MAID07 [6] and SAID09 [9] predictions indicate a slightly better agreement with MAID07 at backward angles and SAID09 in the forward direction. At invariant mass > 2 GeV/c^2, however, agreement is poor, indicating that physics previously unobserved in the PWA is at play.

3.3. The FROST experiment - polarised photons and a polarised target

The FROST (Frozen Spin Target) experiment employed a custom-designed dilution refrigerator to hold the spin of the butanol target (C_4H_9OH), aligned via Dynamic Nuclear Polarisation. Data was taken with both linear and circular

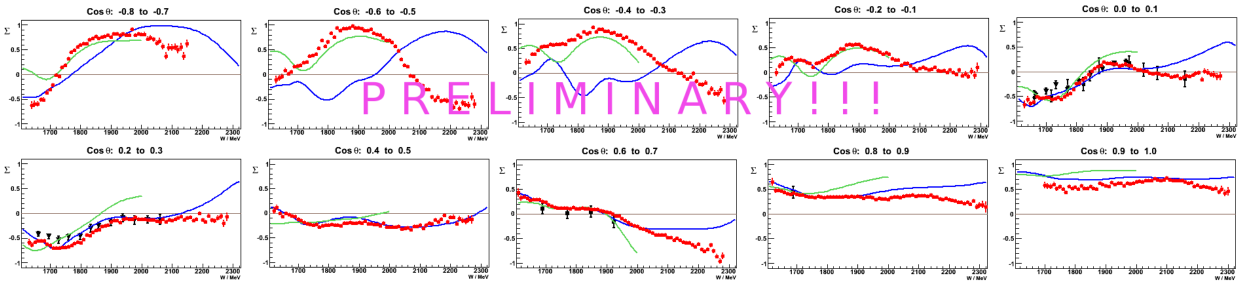

FIGURE 3. Beam asymmetry measurement in the $\gamma(n,p)\pi^-$ channel, overlaid with a MAID07 [6] prediction (short green) and SAID09 [9] (long blue). Previous data are shown in black [8].

photon beam polarisations in the energy range 0.5 - 2.4 GeV, with the target spin aligned parallel to the beam direction (longitudinally polarised, running Nov. '07 - Feb. '08) and perpendicular to it (transverse polarisation, from Mar. - July 2010). A selection of single and double polarisation observables are currently being extracted from the single and double pion, the η and the kaon photoproduction channels.

Very preliminary results from the measurement of the helicity asymmetry in $\gamma(p,n)\pi^-$ can be seen in Fig. 4, compared with predictions of two SAID models (SAID95 and SAID09) and MAID07. In the invariant mass range 1.35 - 1.5 GeV/c^2, SAID05 appears to describe the data best, while in the range 1.5 < W < 1.6 GeV/c^2 the SAID95 and MAID07 offer a better agreement. Most interestingly, above 1.85 GeV/c^2 all three PWAs appear to predict the opposite behaviour, indication that a fit inclusive of the current data may reveal signatures of different resonances.

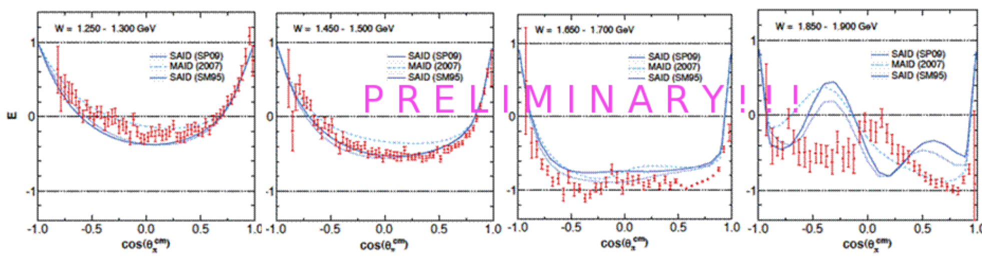

FIGURE 4. Helicity asymmetry measurement in $\gamma(p,n)\pi^-$ [10].

Preparations are currently underway for HDice, an experiment scheduled to run in 2011, which will employ an HD target with polarisation relaxation time on the order of months. This will not only enable the first ever measurements of target double-polarisation observables to be taken off the neutron, but will also allow simultaneous measurements on the proton, thus enabling comparison of proton and neutron data within the same setup.

With experiments on the proton and neutron, using both polarised and unpolarised targets and photon beams, a model-independent analysis of meson photoproduction data is fast approaching, promising greater insight into the nucleon resonance spectrum.

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