Measuring neutron polarisation in pn production using CLAS

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Utilising a novel method, an independent measurement of neutron polarisation in deuteron photo-disintegration is determined with CLAS data from Jefferson Lab Hall B, covering previously inaccessible kinetic regimes, including the resonance energy region of the d*(2380). After isolating the reaction of interest, a maximum likelihood technique and bootstrapping technique were used to determine the neutron polarisation transfer $C_{x'}$ and reliable extraction of associated uncertainties, substantially extending the kinematic coverage from previous measurements, most notably to higher energies. The demonstrated success of this technique paves the way for further analyses that can be brought to CLAS12 for other reactions with a neutron in the final state.

1. – Introduction

Polarisation is a property that can be induced or transferred to and from hadrons. Because of this, nucleon-nucleon phenomena such as short-range correlations (SRCs) and dibaryon states can be investigated by measuring the polarisation of product particles resulting from baryon scattering reactions. However, the world dataset of neutron polarisation measurements contains significant gaps in terms of angular coverage and energy ranges, largely because the determination of neutron polarisation requires dedicated equipment and extremely high statistics. Motivated by this problem, this work has explored a novel approach to determine neutron polarisation, which utilises the Start Counter (a component of JLab's CLAS detector) as a neutron polarimeter during a high intensity beamtime. This allows us to measure neutron polarisation in deuteron photo-disintegration, which covers previously inaccessible kinematic regimes, including the resonance energy of the $d^*(2380)$ hexaquark.

2. – Experimental setup

This project uses data from a Jefferson Lab CLAS experiment [1] referred to internally as g13, which ran during 2006-2007 [2]. The nuclear target for this experiment was liquid deuterium (LD_2) in target cell. A polarised photon beam was incident on the target cell, with the reaction products detected by the various subsystems of the CLAS detector. The g13 experiment consists of two parts: g13a, which used a circularly polarised photon beam, and g13b, which used a linearly polarised photon beam. The results shown in this paper are produced using data from the g13a data set.

The Start Counter was a component of the CLAS detector utilised in the determination of the start time of events in photoproduction experiments. It consisted of 24 3-mm-thick BC-408 plastic scintillator paddles arranged into 6 sectors surrounding the target cell [3]. The start counter's role requires it to be close to the target cell, with the paddles running parallel down its length.

The reaction of interest in this analysis is deuteron photo-disintegration ($\gamma d \rightarrow np$), where a photon incident on a deuteron nucleus causes it to disintegrate into its two components, a proton and neutron. This is one of the simplest reactions in which neutron polarisation can potentially be measured, with both the induced polarisation (P_y) and the polarisation transferred from the circularly polarised photon beam ($C_{x'}$ or $C_{z'}$), being accessible. The determination of nucleon polarisations typically requires sophisticated polarimeter equipment. However, in this work, we investigate the utilisation of the Start Counter paddles as an analysing polarimeter, by selecting events that undergo a charge exchange reaction within the Start Counter paddles, e.g. $p(n,p)n$, causing a scattered, secondary proton to be detected by CLAS. This means that two protons in the final state of the reaction were detected and identified. Information from the CLAS detector allows us to fully reconstruct the two-step reaction process. For this reaction, the spin-dependent cross section equation is given by:

$$\frac{d\sigma}{d\Omega} = \left(\frac{d\sigma}{d\Omega}\right)_0 [1 + \alpha(\theta_{sc})(P_y cos\phi_{sc} - C_{x'} P_\gamma^{\odot} sin\phi_{sc})] \tag{1}$$

Where $\left(\frac{d\sigma}{d\Omega}\right)_0$ is the differential cross-section for unpolarised photons, $\alpha(\theta_{sc})$ is the analysing power as a function of polar scattering angle of the charge-exchanged proton, ϕ_{sc} is the azimuthal scattering angle of the charge-exchanged proton, and $P_\gamma^{\odot}$ is the photon polarisation. This azimuthal distribution can then be used to determined the neutron polarisation observables P_y and $C_{x'}$.

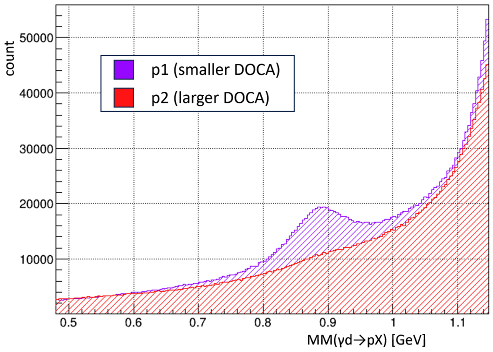

Fig. 1.: Missing neutron mass in the reconstructed deuteron photodisintegration reaction, showing two plots for both cases where either p1 or p2 (defined by DOCA) is chosen to be the proton 4-vector.

3. – Analysis

Events with exactly two detected protons in the final state are selected, eliminating many background contributions. For these events, it is important to establish which proton originated from deuteron photo-disintegration, p_1, and which proton was the result of the charge exchange reaction originating within the start counter paddles, p_2. This distinction can be made by comparing the distance of closest approach (DOCA) of each of the two protons with the incident photon for each event. The DOCA is the shortest distance possible between two trajectories, and is defined by the separation of a pair of points/vertices, one on each trajectory, such that a line connecting these points would be perpendicular to both trajectories. In the reaction of interest, the initial photon, γ, is expected to have a smaller DOCA with p_1 than p_2. The success of this DOCA separation is visualised in Fig. 1. We utilise this to select p_2 and identify the scattering angles θ_{sc} and ϕ_{sc}. This is done by reconstructing the neutron from deuteron photodisintegration via the missing momentum of the $\gamma d \to p_1 X$ reaction. The charge exchange reaction ($p(n,p)n$) is well understood, with the analysing power ($\alpha(\theta_{sc})$) known to a high precision [4]. Values of this analysing power were obtained from the SAID database using the neutron energy and the proton scattering angles. Values of photon polarisation ($P_\gamma^\odot$) are calculated from the tagged electron beam energy and polarisation[5].

In order to isolate and reconstruct the reaction of interest from the many two-proton events in g13, a series of analysis cuts are applied, intended to remove background while preserving as much data as possible. For example, ensuring the region of the target cell is selected using z-vertex cuts, ensuring the correct photon is identified with coincidence time cuts, etc. Figure 1 shows the missing-mass plot of $\gamma d \to p_1 X$ illustrating background reactions that still contribute to the deuteron photodisintegration reaction.

To determine the values of P_y and $C_{x'}$ from this sample of events, an unbinned max-

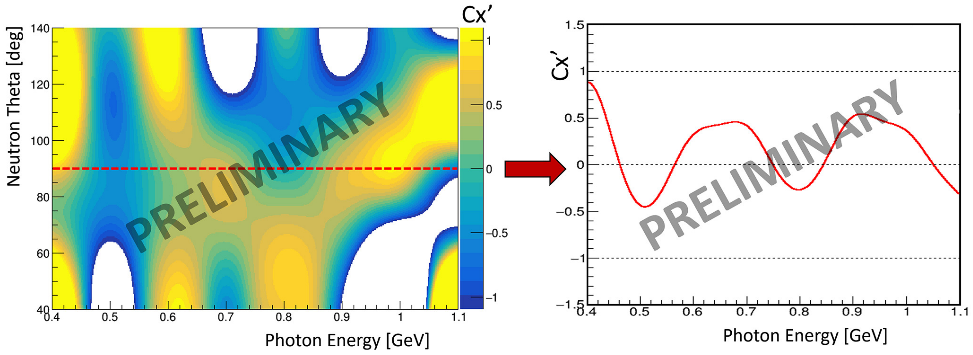

Fig. 2.: Function of $C_{x'}$ values extracted via maximum likelihood. The left panel shows $C_{x'}$ as a function of E_γ and θ_N. The right panel shows a slice of this same function at $\theta_N = 90\,\text{deg}$.

imum likelihood technique was used. The likelihood was determined from the reaction cross sections (see Eq. (2)).

$$\log[L] = \sum_{i=1}^{n} -2\log[1 + \alpha(\theta_{sci})(P_y cos\phi_{sci} - C_{x'} P_\gamma^{\odot}{}_i sin\phi_{sci})] \tag{2}$$

In this work we focus on the determination of $C_{x'}$, as the frequent helicity flips enable a robust determination of this observable. On the other hand, P_y requires detailed knowledge of the detector acceptance and is thus left for future analysis. $C_{x'}$ is parameterised with a function that depends on the photon energy, E_γ, and the neutron scattering angle, θ_N, meaning that the final extraction of $C_{x'}$ is in the form of a 2D surface of values.

4. – Results

A 2D function of $C_{x'}$ is extracted, covering E_γ values between 0.4 GeV and 1.1 GeV, and θ_N values between 40° and 140° as shown in Fig. 2.

The uncertainty in the $C_{x'}$ extraction was determined using a bootstrapping technique [6]. This involves taking the dataset used in the initial $C_{x'}$ likelihood extraction, and randomly resampling to create a new sample of equal size. Performing the same likelihood technique on this new dataset will create a new $C_{x'}$ function with a slight variation from the original. Repeating this multiple times allows us to study the variance of $C_{x'}$ functions and represents the statistical uncertainties (see Fig. 3).

These preliminary results show that $C_{x'}$ has a positive value at lower energies, but has a sign flip at photon energies of 450MeV. This has strong agreement with the published data from M.Bashkanov et. al [7], including rough agreement at higher energies within increasing uncertainties.

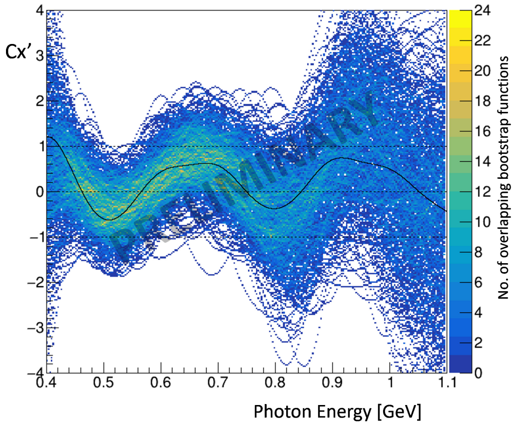

Fig. 3.: Extracted $C_{x'}$ function at $\theta_N = 90\,\mathrm{deg}$ (black), with added overlapping bootstap functions to capture the spread of uncertainty in the extracted function

5. – Summary

In this work, I have explored a novel approach that allows the determination of neutron polarisation without the need of dedicated polarimetery equipment, opening the door to sophisticated analyses on existing CLAS data sets, and additionally, on more recent CLAS12 data sets through utilization of CLAS12's SVT (silicon vertex tracker). The preliminary results shown give $C_{x'}$ measurements in a kinematic regime that exceeds past measurement.

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