PROCEEDINGS OF SCIENCE

DVCS on Polarized Nucleons with the CLAS12 experiment at Jefferson Lab

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Deeply Virtual Compton Scattering is the most direct channel to access Generalized Partons Distributions (GPDs) and understand more about the 3D structure of the nucleon, the origin of its spin, and the forces at play within it. The complete extraction of GPDs requires using polarized electron beams and polarized nucleon targets in DVCS measurements. The first polarized target experiment of the CLAS12 program at JLab took place between 2022 and 2023, scattering 10.6 GeV electrons on longitudinally polarized protons and neutrons in hydrogen and deuterium targets. It is of high interest for DVCS measurements as it will allow the target-spin and double-spin asymmetries to be measured for neutrons for the first time. These results will allow the extraction of neutron Compton Form Factors over a large phase space and access the H and E GPDs for the neutron. Combining results on the proton and the neutron will allow for the flavor decomposition of GPDs. Analysis from the experiment is ongoing and preliminary, raw asymmetries have been extracted for protons in a hydrogen target using a dataset that represents around 5% of the total RGC data. The target polarization can be extracted by analysis of (quasi)-elastic events. Contamination from N in the molecular NH_3 and ND_3 targets can be quantified with sufficient precision. The extracted raw asymmetries show the expected behavior in their Φ and t-dependencies. These results demonstrate the readiness of the analysis tools specifically developed to work with a polarized nuclear target to be applied to the data with protons and neutrons in deuterium, which will soon be available.

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1. Introduction

Generalized Partons Distributions (GPDs) describe the structure of nucleons in three dimensions by providing information on the distribution of partons in terms of longitudinal momentum, transverse position, and their correlations. They can be accessed in the Deeply Virtual Compton Scattering (DVCS) reaction. The dominant diagram at leading order and leading twist (Fig. 1) leverages QCD factorization to separate the scattering of an incoming electron on a single quark from the nucleon from the non-perturbative QCD processes describing the nucleon structure, encoded in GPDs.

This reaction allows access to four helicity-conserving GPDs for each quark flavor, which are defined depending on the relative orientation of the quark and nucleon spins. These combinations can be explored with measurements combining polarized electron beams scattering on polarized nucleon targets. The measurement of DVCS single- and double-spin asymmetries as an experimental path to GPDs is one of the main goals of the Run Group C (RGC) experiment that ran between June 2022 and March 2023 using the CLAS12 spectrometer [1] at Thomas Jefferson National Accelerator Facility (JLab). A 10.6 GeV polarized electron beam is scattered on dynamically-polarized solid NH_3 and ND_3 targets [2] to measure DVCS for protons and neutrons. The target-spin and double-spin asymmetries will be accessed for polarized neutrons for the first time. A crucial interest for this measurement is obtaining a flavor decomposition of GPDs comparing p and n data in D. Comparing p data in H and D, medium effects will be assessed to interpret the neutron measurement (since a free neutron target is unavailable).

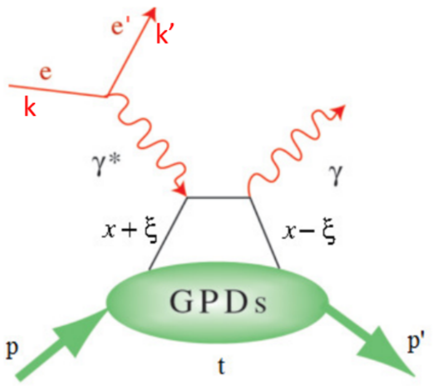

Figure 1: The DVCS process at leading order and leading twist where the incoming electron interacts via the exchange of a virtual photon with a single quark of the nucleon that then emits a real photon.

2. Target Polarization Extraction

Before extracting DVCS asymmetries, the fractions of beam electrons and target nucleons that were effectively polarized during the experiment must be accounted for. A Moller Polarimeter allowed to measure a beam polarization of $P_b = 83.5\% \pm 1.4\%$ while the experiment ran. The target polarization P_t is extracted from data analysis of elastic events by comparing the measured double-spin asymmetry to the theoretical asymmetry (A_{th}), which is computed using the ratio of the electric and magnetic form factors of the proton ($G = \frac{G_M}{G_E}$) [3]:

$$A_{th} = \frac{2\tau G[\frac{M}{E} + G(\tau\frac{M}{E} + (1+\tau)\tan(\frac{\theta}{2})^2)]}{1 + G^2\frac{\tau}{\epsilon}}. \tag{1}$$

E is the beam energy, M the proton mass, θ the polar angle of the scattered electron, $\tau = \frac{Q^2}{4M^2}$, and $\epsilon = \frac{1}{1+2(1+\tau)tan(\theta/2)^2}$. The asymmetry is measured from the yields $N^{\pm}$ for $\pm$ electron helicities and compared to A_{th} using maximum likelihood estimation in N_{bins} Q^2 bins.

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$$P_b P_t = \frac{\sum_{i=0}^{N_{bins}} f_i A_{th,i}(N_i^+ - N_i^-)}{\sum_{i=0}^{N_{bins}} f_i^2 A_{th,i}^2 (N_i^+ + N_i^-)}, \tag{2}$$

The proportion of unpolarized N background is accounted for with the dilution factor f_i that is estimated by comparing the measured yields in NH_3 and a C target: $f_i = 1 - \frac{C_i}{NH_{3i}}$.

Elastic events are measured from the $ep \to e'p'$ reaction, where the final proton and electron are detected. Channel-selection cuts are applied (Fig. 2) using W^2 (square of the missing mass of X in the reaction $ep \to eX$), the square of the missing mass of X in the reaction $ep \to epX$, the coplanarity $\Delta\phi$ (the difference between the azimuthal angles of the detected proton and electron) and the beam energy estimated from the proton and electron polar angles.

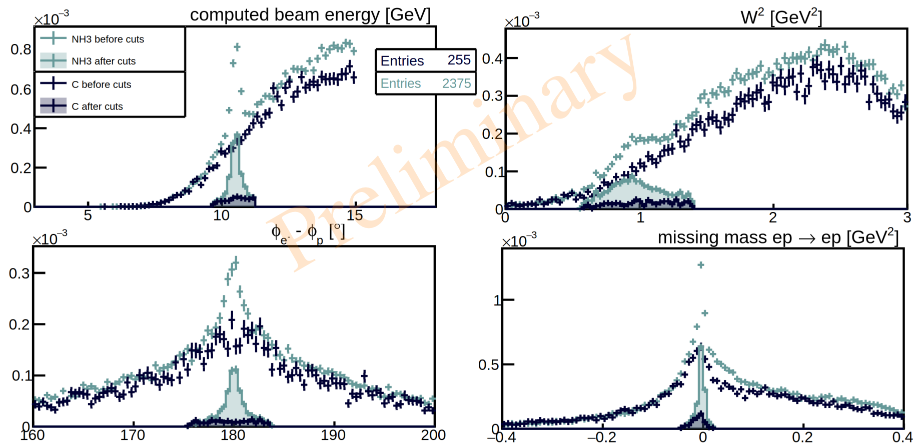

Figure 2: Elastic exclusivity variables for NH_3 (in green) and C (in black) data, before (simple points) and after (filled distribution) cuts. The C target is used to mimic the unpolarized N background.

The target polarization of the positively and negatively polarized NH3 samples, shown in Fig. 3, is $P_b \times P_t = 0.692 \pm 0.085$ and $P_b \times P_t = -0.664 \pm 0.056$, respectively.

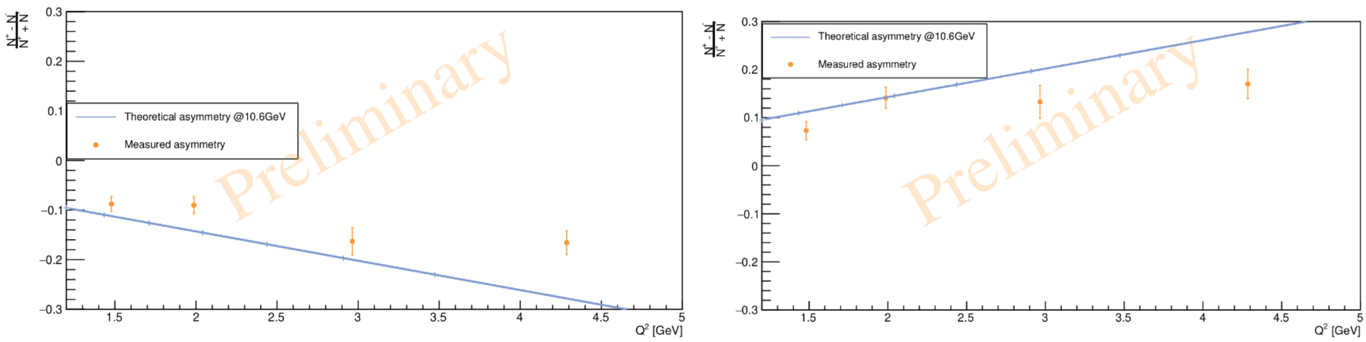

Figure 3: Elastic double spin asymmetry and target polarization for the negative (left) and positive (right) NH3 samples.

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3. DVCS analysis

The DVCS channel is selected from events with at least one proton, one electron, and one photon in the final state. A first set of cuts is applied to select the region in which the GPD formalism can be applied: $Q^2 >= 1$ GeV^2 and $W >= 2$ GeV^2. Further selection cuts are detailed in Fig. 5, based on the square of the missing mass of X in the reaction $ep \rightarrow ep\gamma X$ or $ep \rightarrow eX\gamma$ or $ep \rightarrow epX$; the difference between two ways of computing the momentum transfer t between the initial and final state protons; and the difference between two ways of computing the angle Φ between the leptonic and hadronic planes. The Beam-Spin, Target-Spin, and Double-Spin Asymmetries (BSA, TSA, and DSA) are defined from the measured yields $N^{b,t}$ for each beam (b) helicity and target (t) polarisation orientations:

$$A_{LU} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))} \quad (3)$$

$$A_{UL} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))} \quad (4)$$

$$A_{LL} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_b \times Df \times (P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))} \quad (5)$$

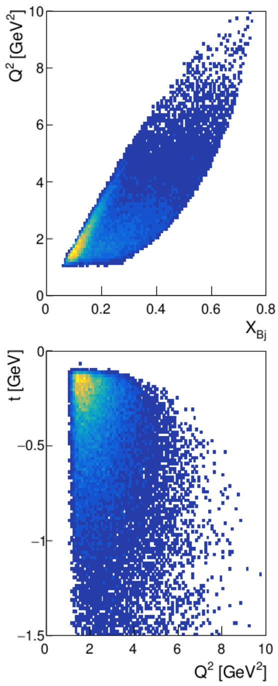

Figure 4: $Q^2 - x_{Bj}$ and $t - Q^2$ coverage for the DVCS events.

As with the elastic analysis, the dilution factor D_f is computed using C data.Figure 6 shows the BSA, TSA, and DSA in Φ and t bins. They are integrated over a wide kinematic range (Fig. 4) and are contaminated by π_0 production, so the amplitudes can not yet be used for physics conclusions. The BSA is lower than measurements for DVCS in H [4] since the N background is not accounted for. All asymmetries show the expected signs, sinusoidal shapes, and t-dependence of the amplitudes, indicating a healthy state of the data and the ongoing analysis. The tools are validated and will be applied to data on ND_3 that will soon be released for the neutron DVCS measurements in particular.

References

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[4] G. Christiaens et al., CLAS Collaboration (2022) *First CLAS12 measurement of DVCS beam-spin asymmetries in the extended valence region*, Phys. Rev. C

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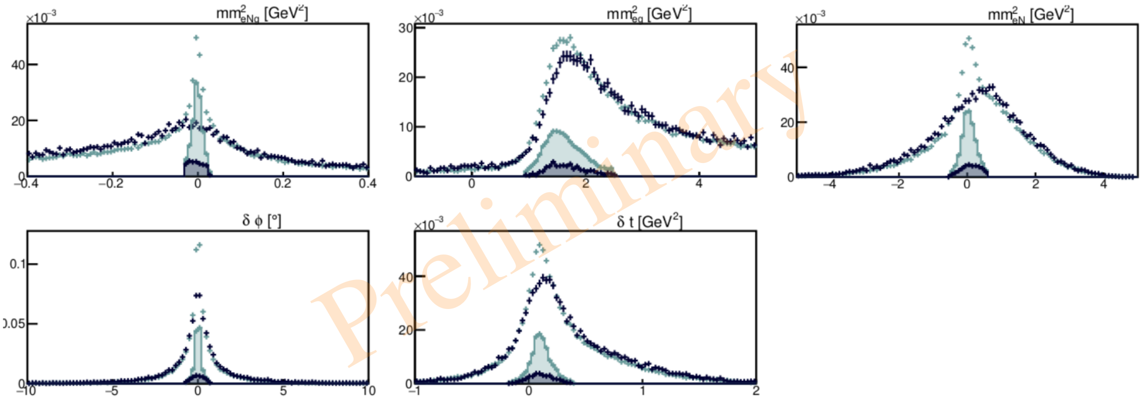

Figure 5: DVCS exclusivity variables for NH_3 (in green) and C (in black) data, before (simple points) and after (filled distribution) cuts.

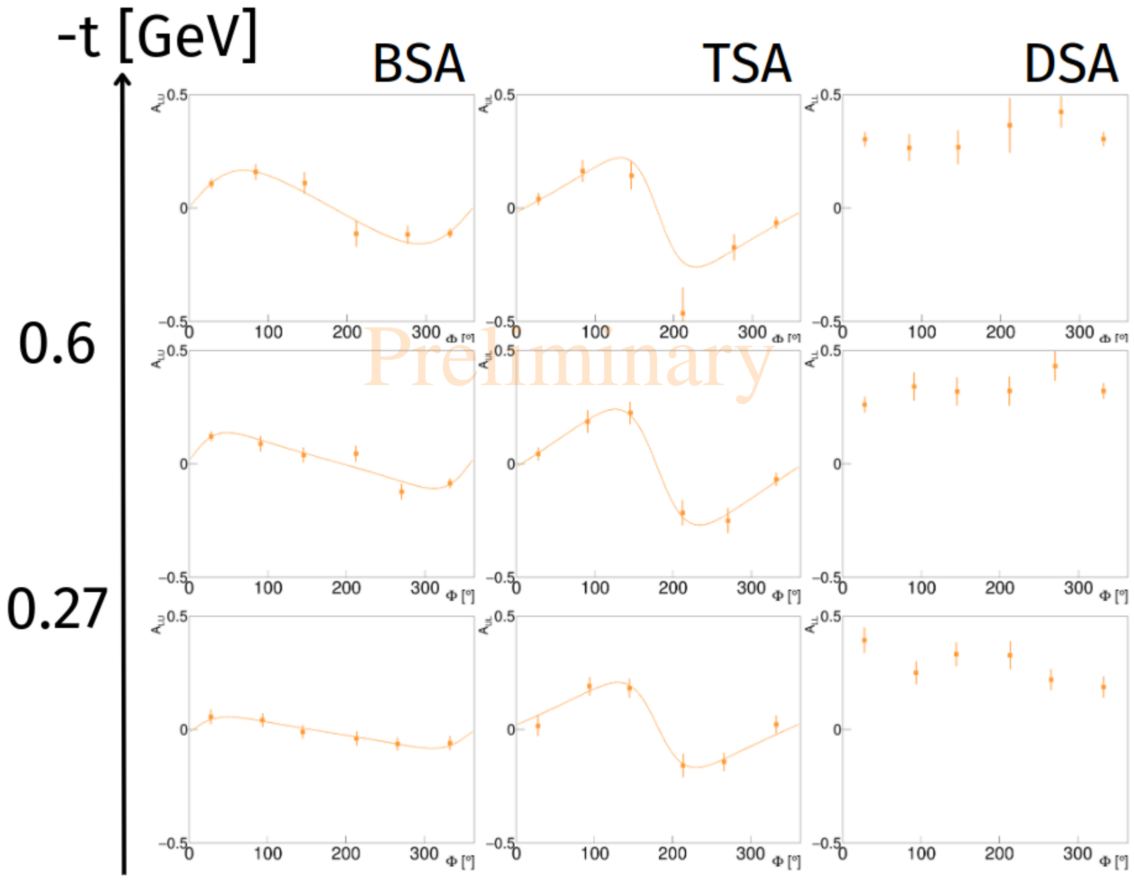

Figure 6: Preliminary raw asymmetries for pDVCS in H in bins of $-t$.

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