PROCEEDINGS OF SCIENCE

Deeply virtual Compton scattering beam spin asymmetries with CLAS

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The Generalized Parton Distributions (GPDs) parameterize the non-pertubative structure of the nucleon and can be used to reveal the correlations between the momentum and position of partons in the nucleon. They appear in the amplitudes of hard-exclusive electroproduction reactions such as DVCS on the nucleon ($ep \to ep\gamma$). The GPD formalism can be extended to more general final states with the introduction of the so-called transition GPDs. Such GPDs permit the description of reactions where the recoil nucleon is replaced by a nucleon resonance (a Δ^+ resonance for instance). In this communication, the recent results of the beam spin asymmetry obtained for DVCS with the CEBAF Large Acceptance Spectrometer (at Jefferson Lab), as well as preliminary results for the ΔVCS ($ep \to e\Delta^+\gamma$), the simplest process for accessing transition GPDs, are shown.

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1. Generalized Parton Distributions and deeply virtual Compton scattering processes

Since the early 1990's, the description of the nucleon evolved with the introduction of Generalized Parton Distributions [1] [2] [3]. GPDs promise a more complete description of the nucleon: in particular they unify the former descriptions of the nucleon (based on form factors and parton distributions) allowing in some configurations the correlation between space and momentum information within it. There are, at leading twist QCD, four quark helicity-conserving GPDs (H, $\widetilde{H}$, E, $\widetilde{E}$) which depend on three kinematical variables: x (reflecting the longitudinal momentum fraction of the probed quark), ξ (reflecting the longitudinal momentum fraction transfered to the probed quark) and t (square of the momentum transfered to the nucleon). The simplest process used to access these functions is Deeply Virtual Compton Scattering (DVCS) described hereafter.

1.1 DVCS ($ep \to ep\gamma$)

DVCS involves the scattering of a lepton (in our case an electron) off the proton with the production in the final state of a hard photon ($ep \to ep\gamma$). At small t and in the Bjorken limit, the DVCS amplitude factorizes into two parts: a *hard* part, exactly calculable and purely electromagnetic and a *soft* part describing the non-perturbative structure of the nucleon (see figure 1, left). This limit is defined as: large $Q^2 = -(k-k')^2$ and fixed $x_{Bj} = Q^2/2(p.q)$, with k, k', p, q, the four-vector of the incoming electron, the outgoing electron, the proton target, the virtual photon respectively.

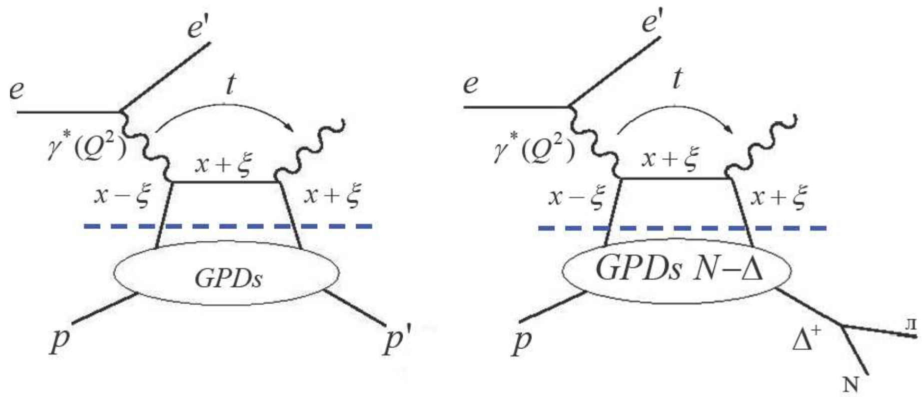

Figure 1: On the left-hand side: DVCS handbag diagram. On the right-hand side ΔVCS handbag diagram. The dashed blue line symbolizes the factorization between the *soft* part (lower part of the diagram) and the *hard* part (upper part of the diagram).

Two main processes contribute to the $ep \to ep\gamma$ reaction: DVCS and Bethe-Heitler (where the produced photon is emitted by the incoming or the outgoing electron). The two processes interfere and when using a polarized lepton beam this produces an asymmetry between positive and negative helicity states. This beam spin asymmetry (BSA) can be parameterized as a function of Φ, the angle between the leptonic plane (defined by the incoming and the outgoing electron) and the hadronic plane (defined by the produced photon and the recoil hadron): $A \simeq \alpha sin\phi/(1+\beta cos\phi)$. The parameters α and β are related to GPDs. Therefore, measuring the beam spin asymmetry for the DVCS process is a way of accessing GPDs.

1.2 ΔVCS ($ep \to e\Delta^+\gamma$)

The electroproduction of a hard photon and a Δ^+ resonance, at small t and in the Bjorken limit, can also be factorized. The corresponding diagram (see figure 1, right) is almost the same as in the DVCS case, the main differences being that the outgoing proton is excited into a Δ^+ resonance (that decays into a nucleon-pion pair: $\Delta^+ \to N\pi$) and that the non-perturbative part is parameterized through transition GPDs (also called N-Δ GPDs [4]). The N-Δ GPDs are extensions of nucleon GPDs to baryonic final states where the recoil particle is a Δ. Intuitively, they reflect the superposition (interference) of the nucleon and Δ wave-functions. This is the main motivation for studying ΔVCS: it may provide information about the N-Δ transition at a partonic level. Also, within the *large* N_C approximation (where the number of colors tends to infinity and which gives predictions with a 30% accuracy), N-Δ GPDs can be expressed in terms of nucleon GPDs. So studying ΔVCS provides another way of accessing nucleon GPDs. Within this limit the nucleon and the Δ are rotational excitations of the same object; thus the only non-zero N-Δ GPDs are related to nucleon GPDs through:

$$H_M(x,\xi,\Delta^2) = \frac{2}{\sqrt{3}}[E^u(x,\xi,\Delta^2) - E^d(x,\xi,\Delta^2)] \tag{1.1}$$

$$C_1(x,\xi,\Delta^2) = \sqrt{3}[\widetilde{H}^u(x,\xi,\Delta^2) - \widetilde{H}^d(x,\xi,\Delta^2)] \tag{1.2}$$

$$C_2(x,\xi,\Delta^2) = \frac{2}{\sqrt{3}}[\widetilde{E}^u(x,\xi,\Delta^2) - \widetilde{E}^d(x,\xi,\Delta^2)] \tag{1.3}$$

As in the DVCS case, the cross section of the reaction $ep \to e\Delta^+\gamma$ is the sum of two processes: the ΔVCS and the associated Bethe-Heitler contribution. Again, the two processes interfere and the resulting calculated asymmetries [4] are shown figure 2. These calculations take into account the contribution from non-resonant channels.

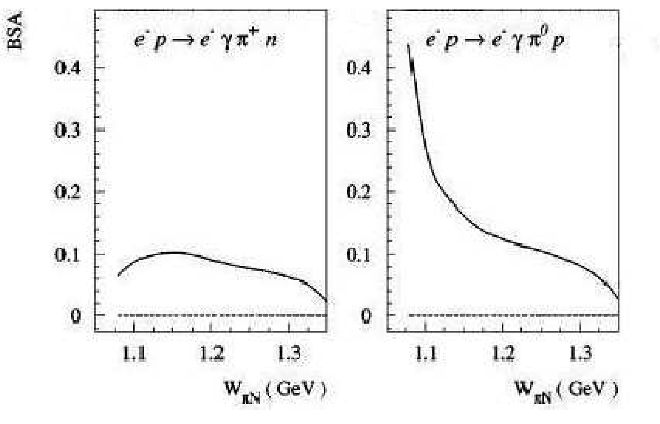

Figure 2: Theoretical (model-dependent) beam spin asymmetry according to reference [4] for $ep \to eN\pi\gamma$ as a function of the invariant mass of the πN system $W_{\pi N}$ for typical Jlab kinematics : $E_e = 6$ GeV, $Q^2 = 2.5$ GeV^2, $x_B = 0.3$, $t = -0.5$ GeV^2, $\Phi = 90^o$ (Φ being the angle between the leptonic and hadronic planes).

2. Data taking and analyses

2.1 The experiment

It was carried out at the Thomas Jefferson Laboratory (USA, VA) using the CEBAF accelerator which delivers a continuous electron beam. It was held in Hall B and used the CEBAF Large Acceptance Spectrometer CLAS [5]. CLAS was used in its standard configuration along with a new electromagnetic calorimeter for the detection of photons at very forward angles, where the majority of DVCS photons are emitted. The experiment ran from March to May 2005 using a 5.77 GeV polarized electron beam and was the first dedicated DVCS experiment conducted in Hall B [6].

2.2 DVCS ($ep \to ep\gamma$)

2.2.1 Event selection

All final state particles are required to be detected. Then, selection cuts are applied to several quantities, such as the transverse missing momentum of the $ep \to ep\gamma X$ system (P_x^T). Even though the selection is of a high quality, there is still some background after applying cuts: it comes from partially measured π^0 electroproduction (where only one of the two decay photons is detected). This background is calculated and then subtracted using Monte-Carlo simulations and exclusive π^0 electroproduction data. It amounts to an average of 5 % and varies with the kinematics. For more details on the analysis see [7] and [8].

2.2.2 Results

The DVCS beam spin asymmetry has been measured over a wide kinematical range. The asymmetries were fitted with the following function: $A = \alpha sin\phi/(1+\beta cos\phi)$. The extracted α parameter (the asymmetry at $\Phi = 90^o$) is shown in figure 3 (black points) for each (Q^2, x_B) bin, as a function of t. The comparison between data and the GPD parameterizations of the VGG code [9] [10] shows a qualitative agreement: the decrease of α is reasonably well reproduced (large $-t$), however the parameterization exceeds the data at small $-t$ (in almost all kinematics). This behaviour is not yet understood [8] and is the subject of ongoing studies.

2.3 ΔVCS ($ep \to e\Delta^+\gamma$)

2.3.1 Event selection

The ΔVCS process leads to two different final states depending on the decay channel of the Δ^+: $ep \to e\Delta^+\gamma \to ep\pi^0\gamma$, referred to as ΔVCS ($\pi^0$) and $ep \to e\Delta^+\gamma \to en\pi^+\gamma$, referred to as ΔVCS ($\pi^+$). The identification procedure of exclusive ΔVCS (π^0) and ΔVCS (π^+) events is almost the same. First it is required that all final states particles be detected. Then, selection cuts are applied to several quantities, such as missing masses. The use of a sideband subtraction method (a detailed example of which can be found in [11]) is required for ΔVCS (π^0) to unambiguously identify the π^0. The Δ^+ is identified by requiring the invariant mass of the nucleon-pion system to be less than 1.35 GeV. As in the DVCS case, there is still, after applying the selection procedure described above, some remaining background. This background arises from double pion electroproduction: $ep \to ep\pi^0\pi^0$ for the ΔVCS (π^0) channel, $ep \to en\rho^+ \to en\pi^+\pi^0$ and $ep \to en\pi^+\pi^0$

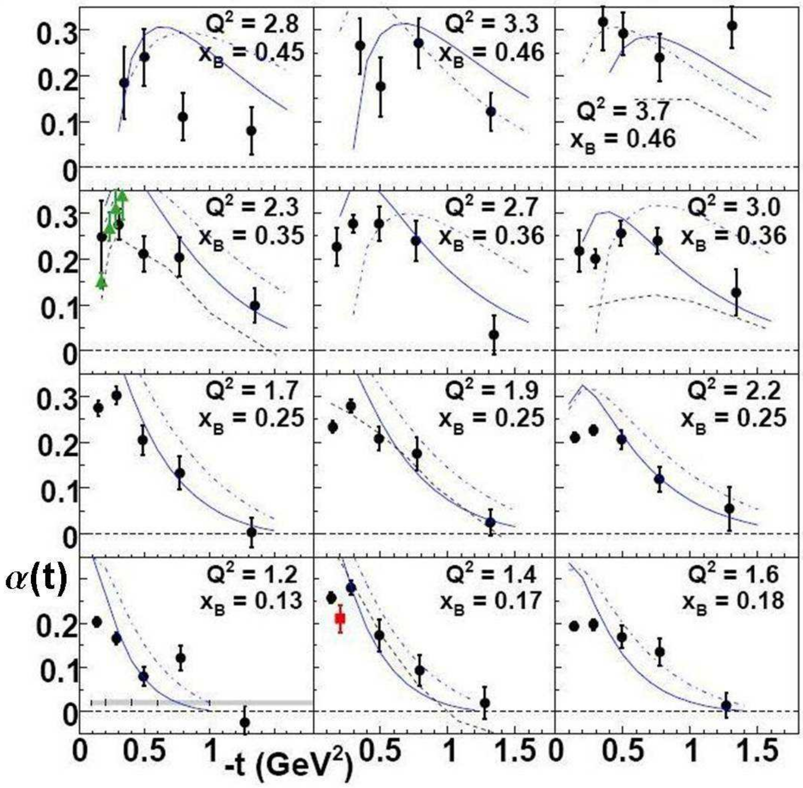

Figure 3: Extracted parameter α for the DVCS beam spin asymmetry. The red point corresponds to a previous CLAS result [12] while the green ones correspond to previous Hall A data [13]. The blue curves are GPD parameterizations using the VGG code with twist-2 [9] (solid) and twist-3 [10] (dashed) approximations. The dashed black line is the result of a simple Regge-model calculation [14].

for the ΔVCS (π^+) channel. The subtraction of these background contributions is work in progress, and the general method used is the same as for the DVCS case.

2.3.2 Results

The ratio $R = \frac{1}{P}\frac{N^+ - N^-}{N^+ + N^-}$ for both ΔVCS analyses are shown figure 4 (P being the beam polarization and N^+ and N^- the number of identified events with positive and negative beam helicities, respectively). They are not background subtracted but give, nonetheless, a first glimpse at the uncertainties and the Φ dependence. In both cases the signal is not constant: it varies from positive to negative for the ΔVCS (π^0) channel (figure 4, left plot) and from negative to positive for the ΔVCS (π^+) channel (figure 4, right plot). It is clear, with regard to the uncertainties, that the statistics is a major issue for these analyses (in particular for the ΔVCS (π^0)). To complete the analyses, the remaining step is to subtract the double pion backgrounds, and this is currently being done.

3. Conclusions

Recent beam spin asymmetry results obtained in Hall B at JLab for DVCS have been presented. They cover the widest phase space for this reaction. Comparison with a GPD parameterization

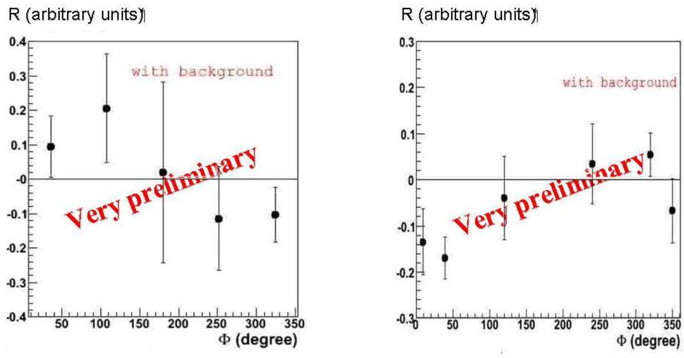

Figure 4: Ratio $R = \frac{1}{P}\frac{N^+ - N^-}{N^+ + N^-}$ as a function of Φ: on the left-hand side for identified $ep \to ep\pi^0\gamma X$ events, on the right-hand side for identified $ep \to en\pi^+\gamma X$ events in the Δ region ($W_{\pi N} < 1.35$ GeV). The error bars are statistical only.

shows a qualitative agreement but more theoretical work is needed to fully described the data. Also, very preliminary results of the pioneering investigation for ΔVCS beam spin asymmetries were shown. Analyses are still underway with the double pion background subtraction to be completed. Concerning future plans: there will be a new DVCS data taking run with CLAS, to be carried out at the end of 2008. This will increase the statistics for the ΔVCS study. Another DVCS experiment is also expected to run in early 2009 with a longitudinally polarized target [15].

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