THE GENERALIZED PARTON DISTRIBUTIONS PROGRAM AT JEFFERSON LAB

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The Generalized Parton Distributions (GPD) have drawn a lot of interest from the theoretical community since 1997, but also from the experimental community and especially at Jefferson Lab. First, the results for Deeply Virtual Compton Scattering (DVCS) at 4.2 GeV beam energy have recently been extracted from CLAS data. The single spin asymmetry shows a remarkably clean sine wave despite the rather low Q^2 achievable at this energy. Two new dedicated DVCS experiments using 6 GeV beam will run in 2003 and 2004 in Hall A and Hall B respectively. Both experiments will yield very accurate results over a wide range of kinematics, and allow for the first time a precise test of the factorization of the DVCS process. Assuming the Bjorken regime is indeed reached, these experiments will allow the extraction of linear combinations of GPD's and put strong constraints on the available phenomenological models. Upon successful completion of both experiments, a wider experimental program at 6 GeV can be envisioned, using for instance Deuterium targets trying to nail down the neutron and deuteron GPD's. In addition, resonances can be probed using ΔVCS where one produces a resonance in the final state. In a way similar to DVCS, such a process depends on Transition GPD's which describe in a unique way the structure of resonances. Finally, the 12 GeV upgrade of Jefferson Lab extends the available kinematical range, and will allow us to perform a complete, high precision GPD program using various reactions among which, Deeply Virtual Meson Electroproduction (DVMP) and DVCS.

1. Introduction

The understanding of the structure of the nucleon is a fundamental topic. Despite having been studied during the past forty years, there are still many questions left unanswered. An example of such is the extensive debate over the spin structure of the nucleon ground state. Two kinds of electromagnetic observables linked to the nucleon structure have been considered so far. Electromagnetic form factors, first measured on the proton by Hoftstader in the 1950's, then more recently on the neutron. Weak form factors have been measured in parity violating experiments. Another ap-

proach initiated in the late 60's studies parton distribution functions via Deep Inelastic Scattering (DIS), and Drell-Yan processes.

Recently a new theoretical framework has been proposed, namely the Generalized Parton Distributions (GPD) [1,2]. These provide an intimate connection between the ordinary parton distributions and the elastic form factors and therefore contain a wealth of information on the quark and gluon structure of the nucleon. Moreover, not only do they depend on the usual DIS variables, the skewdness ξ (linked to x_B) and Q^2, but also on the average parton momentum fraction in the loop x and the momentum transfer between the initial and recoil protons $t = (p'-p)^2$, giving the GPD's much more degrees of freedom than the regular parton distributions.

In addition, it has been shown recently [3] that the t dependence of the GPD's provide information on the transverse position of partons inside the nucleon. One could imagine the possibility to take "pictures" [4] of the nucleon with a very high definition (fixed by the virtuality of the incoming virtual photon), which would revolutionize our understanding of the nucleon structure and confinement in general. Such a femto-picture applied to the deuteron case for instance would yield a much clearer understanding of where quarks are actually located inside of the deuteron.

2. DVCS with CLAS at 4.2 GeV

The first accurate result on DVCS has come from Jefferson Lab with the CLAS detector in Hall B [5]. We have measured a globally exclusive beam-spin asymmetry in the reaction $\vec{e}p \to ep\gamma$, using a 4.25 GeV longitudinally polarized electron beam on a liquid hydrogen target. As usual with low-energy experiments, the $ep \to ep\gamma$ process is dominated by Bethe-Heitler (BH) where photons are emitted from the incoming or scattered electron lines. While the interesting process is actually DVCS where the photon is emitted by the proton in response to the electromagnetic excitation by the virtual photon, the interference between the BH and DVCS amplitude boosts the effect of DVCS and produces a large cross-section difference for electrons of opposite helicities. In this difference, the large BH contribution drops out and only the helicity dependent interference term remains, parametrized as $\alpha.\sin\phi + \beta.\sin 2\phi$, where ϕ is the angle between the leptonic and hadronic planes. Note that the α coefficient is linear in the leading twist GPD's. Experimentally, the Hall B experiment measured the relative asymmetry $A = (d^4\sigma^+ - d^4\sigma^-)/(d^4\sigma_{tot})$, which has a more complex ϕ dependence than the difference in cross-sections, but is much simpler to measure in a large acceptance spectrometer such as CLAS.

The reaction $ep \to ep\gamma$ was identified by examining $ep \to epX$ events

and requiring the mass of the missing particle to be zero. Unfortunately, CLAS is not able to separate π^0 electroproduction from photon electroproduction using an event-by-event missing mass technique. The number of photon events was determined using a fitting technique that analyzed the shape of the missing mass distribution. The exclusivity of the reaction is therefore demonstrated globally rather than event-by-event. Figure 1 shows the resulting asymmetry A as a function of ϕ. The data points are fitted with the function $A(\phi) = \alpha.\sin\phi + \beta.\sin 2\phi$ where $\alpha = 0.202 \pm 0.028^{stat} \pm 0.013^{syst}$ and $\beta = -0.024 \pm 0.021^{stat} \pm 0.009^{syst}$. Up to the accuracy of the data, β seems to be very small at Q^2 as low as 1.25 GeV^2, indicating that the tranverse part of the process dominates as expected. More accurate data are clearly needed to test the factorization in a systematic way.
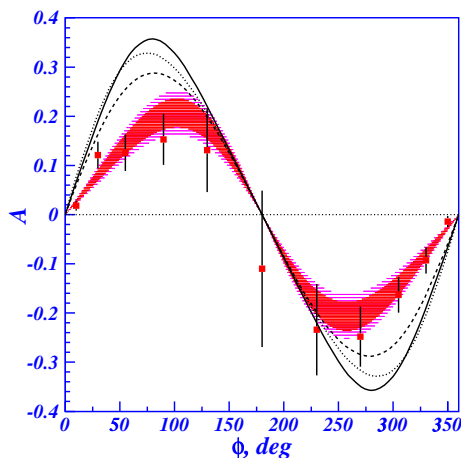

Figure 1. ϕ dependence of the beam spin asymmetry A. The dark shaded region is the range of the fitted function defined by statistical errors only. The kinematics averages to $< Q^2 >= 1.25$ GeV^2, $< x_B >= 0.19$ and $< -t >= 0.19$ GeV^2.

3. DVCS in Hall A at 6 GeV

The Hall A DVCS experiment [6] proposes to check the factorization of the DVCS process by performing an accurate measurement of the (properly) weighted cross-section difference for three values of Q^2 from 1.5 up to 2.5 GeV^2 at fixed $x_B = 0.35$. The high resolution and high luminosity achievable in Hall A allows one to make a very clean interpretation of the data, since the exclusivity will be checked on an event-by-event basis. The

experimental apparatus is composed of a High Resolution Spectrometer for the detection of the scattered electron, a high resolution PbF_2 calorimeter for the detection of the emitted photon and an array of plastic scintillators for the detection of the recoil proton. An example of the quality of the data achievable by this experiment is shown on Figure 2 for the $Q^2 = 2.5$ GeV^2 setting.
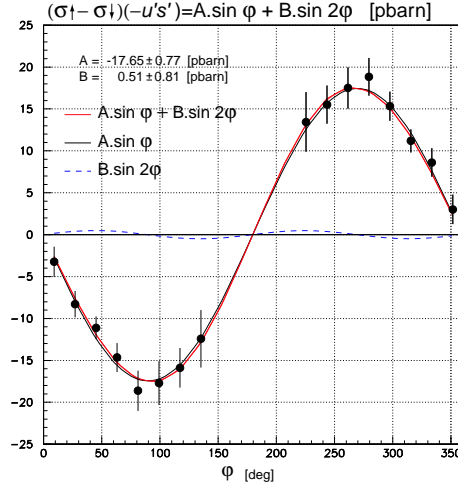

Figure 2. Expected cross-section difference mutiplied by a kinematical factor corresponding to the BH propagators as a function of ϕ for the $Q^2 = 2.5$ GeV^2 setting. Note that the convention for ϕ is different compared to Fig. 1.

4. DVCS in Hall B at 6 GeV

Once the factorization for the DVCS process has been confirmed by the Hall A experiment, DVCS in Hall B will allow one to look at various kinematical dependences of the beam spin asymmetry [7]. Indeed, CLAS with its large acceptance will allow to scan this observable in function of x_B, t and Q^2, for a total of 378 bins with good staticstics. In order to address the issue of the full exclusivity of DVCS events, the CLAS DVCS collaboration is designing a forward $PbWO_4$ calorimeter to detect low angle photons typical of DVCS at small t. In order to achieve a higher luminosity, a Moller shield composed of a superconducting solenoid surrounding the target is also under design. Figure 3 shows the quality of the data which is expected from this experiment.
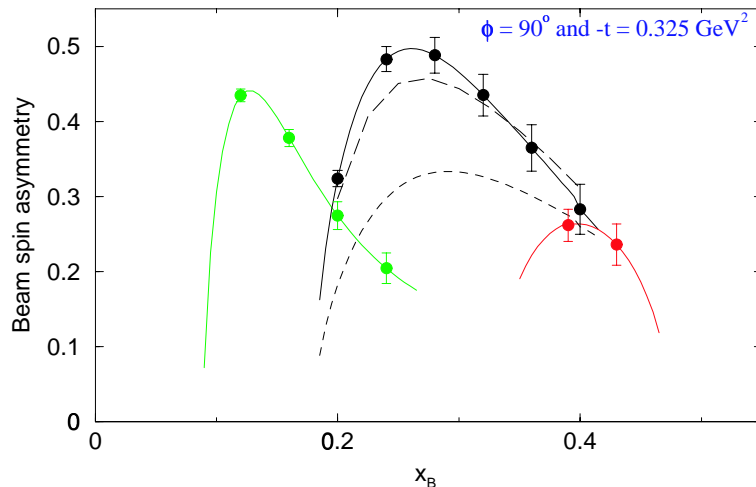
Figure 3. x_B dependence of the single spin asymmetry at $\phi = 90°$ expected in the 6 GeV CLAS DVCS experiment. Three sets of points correspond to three $< Q^2 >$.

5. New experiments at 6 GeV

Although DVCS and Deeply Virtual Meson Production are not easy experiments, one could think of the future of these measurements using 6 GeV beam. DVCS on the Deuterium is of remarkable interest: it allows not only to measure the coherent electroproduction of photons off the deuteron, but also, using deuteron as a quasi-free neutron target, to measure the DVCS reaction on the neutron. This type of experiments is essential if one envisions a full flavor decomposition of the GPD's. However, several difficulties arise. As far as the Deuteron DVCS (D_2VCS) is concerned, the recoil deuteron has to escape the target, which is more difficult than in the proton case. This will contribute to raising the minimum $-t$ achievable by the experiment. The cross-section has been evaluated recently [8]: at low x_B, it is comparable to the proton cross-section. The beam spin asymmetry is also sizeable much like in the proton case. For the neutron case, the experiment is much more difficult. Once again, the cross-section is only 2 to 3 times smaller, but the asymmetry is much smaller than for the proton, of the order of a few %.

The GPD formalism has been extended to transition reactions where the final particle is a nucleon resonance [9]. Just as in the neutron case, the cross-section is smaller, although not too small, and the asymmetry is a few %. Even though ΔVCS is a very difficult experiment, the prospects for a new kind of baryon resonance spectroscopy makes the study worth.

6. The GPD program with 12 GeV beam at Jefferson Lab

The extension of the planned 6 GeV GPD program up to 12 GeV is rather straightforward. Higher energy beam allows one to open up the kinematical coverage: $0.1 \leq x_B \leq 0.6$ and $1 \leq Q^2 \leq 8$ GeV^2. One can therefore imagine a complete GPD program using all kinds of Hard Exclusive reactions ($ep \rightarrow ep\gamma$, $ep \rightarrow ep\rho$, $eD \rightarrow eD\gamma$, $ep \rightarrow en\pi^+$, ...) on different targets, polarized or not, and looking at various observables such as cross-sections, single spin asymmetries or even double spin asymmetries. Both the luminosity and/or the high resolution of the Jefferson Lab equipments will make it possible to perform accurate measurements in a reasonnable amount of time.

7. Conclusion and outlook

Jefferson Lab is in a unique position to make pioneering steps towards a better understanding of the structure of the nucleon. The 4.2 GeV CLAS data has confirmed that the DVCS single spin asymmetry is indeed large and close to a pure sine wave, encouraging us to perform two new experiments at 6 GeV in Hall A and Hall B. These experiments will not only try to justify the factorization of DVCS at moderate Q^2, but will give the first strong contrains to GPD phenomenological models. Additional information can be obtained at 6 GeV using a Deuterium target and looking either at coherent deuteron DVCS, or DVCS on quasi-free neutrons. Finally, the 12 GeV of Jefferson Lab greatly enhances the kinematical coverage of Deeply Exclusive processes, and a complete GPD program can be performed, which undoubtedly, will shed a new light on the understanding of the nucleon.

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