Pion Electroproduction with JLab at 12 GeV

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The recently developed formalism of "Generalized Parton Distributions" (GPDs) [1], for the first time provides us a rigorous map of the entire set of fundamental quantities of hadronic structure, such as: form factors, polarized and unpolarized parton distributions and components of the spin content of the nucleon due to orbital excitations. Thus, GPD's hold the promise of a complete determination of the nucleon wave function. These GPDs can are probed in processes where the nucleon target recoils elastically. One promising class of reactions sensitive to GPDs are the hard exclusive leptoproduction of mesons [2]. This is based on a factorization theorem which states that for longitudinally polarized photons the meson production amplitudes can be factorized into two part. One part which is exactly calculable in pQCD and describes the interaction of the virtual photon with the quark and gluons of the target, and another part with information about the long-distance and non-perturbative components in the meson and the nucleon target, which can be parametrized in terms of the GPDs. The factorization theorem has recently been proven [3] for lepto-production of mesons at large photon virtuality ($\mathrm{Q}^2 >> \Lambda^2_{QCD}$) and $|t| < \Lambda^2_{QCD}$. It is well known that the GPDs come in two forms "polarized" ($\tilde{\mathrm{H}}$, $\tilde{\mathrm{E}}$) and "unpolarized" (H, E). The polarized GPDs can be separated from the unpolarized ones by measuring pseudo-scalar meson production and vector-meson production respectively. However, GPD's are related to cross-sections through integrals and hence they require deconvolution procedures. This implies that cross-sections alone are not sufficient, but it is also important to measure spin observables. Moreover, the extraction of GPDs cannot be achieved just by a single experiment but it entails measurements of a variety of channels and observables. The single target spin asymmetries in single pion electroproduction is one such observable. These asymmetries depend on the imaginary part of the product of the polarized GPDs, $\tilde{\mathrm{H}}$ and $\tilde{\mathrm{E}}$.

A measurement of the single target spin asymmetry in the reaction $en \to e^{'}\pi^{-}p$ with a transversely polarized ^{3}He target is a feasible option to access the polarized GPDs. The polarized ^{3}He target acts as an effective polarized neutron target in these experiments. A transversely polarized target is advantageous because the differential cross-section for production of pions off a polarized nucleon is proportional to the transverse projection of the polarization vector of the initial nucleon ($S_\perp$) and the angle between $S_\perp$ and the transverse component of the momentum of the outgoing nucleon ($p^{'}_{\perp}$). These asymmetry measurements can be done with a 11 GeV electron beam on a transversely polarized ^{3}He target and the SHMS and the HMS used to detect the scattered electron and π^- in coincidence. The high momentum and small angle capability of SHMS give a significantly larger coverage of the relevant kinematic variables Q^2, x_{Bj} and t compared to the other Halls. The kinematic coverage of Hall C spectrometers, relevant to extracting GPDs from single target spin asymmetry is shown in Fig. 1. It is important to stress that for extracting GPDs the region of interest is $-t < 1.0$ (GeV/c)^2, because the factorization theorem holds only for low t. Thus the forward angle capabilities of the SHMS is a key advantage for Hall C.

Recently, calculations of the single target asymmetry for electroproduction of pions from nucleon targets [4] have become available. Using these calculations as a guide we have investigated the feasibility of measuring the target asymmetry in electroproduction of pions from a transversely polarized ^{3}He target (an effective polarized neutron target). It has been shown that the upgraded Hall B can perform these measurements [5] with a polarized 1H target up to Q^2 = 4.0 (GeV/c)^2. As shown in Fig. 1, Hall C can extend these measurements to much higher Q^{2}s. The rates for electroproduction from a neutron target were estimated from the photoproduction cross-section data [6] and the virtual photon flux using Eq. 1.

$$\frac{d\sigma}{d\Omega_{e'} d\Omega_\pi dE_{e'}} = \Gamma \frac{d\sigma}{d\Omega_{\mathrm{CM}}}, \tag{1}$$

Where, Γ is the virtual photon flux and is given by,

$$\Gamma = \frac{\alpha E_{e'}^2 K_q}{2\pi^2 E_e Q^2 (1-\epsilon)}, \tag{2}$$

and $K_q = \frac{W^2 - M_t^2}{2M_t}$ and $\epsilon = (\frac{1+2(Q^2+(E-E')^2)}{Q^2(\tan(\theta_e/2.))^2})^{-1}$. W^2 is the C.M. energy and M_t is the target mass and ϵ is the degree of longitudinal polarization of virtual photons. Using these rates we find that single target asymmetry measurements with reasonable statistical uncertainties can be achieved in the Q^2 interval of 4.0 - 7.0 GeV^2/c^2 and in the x_{Bj} interval of 0.25 - 0.5 corresponding to $W > 2.5$ GeV. In these estimates we have used a 11 GeV, 15μA electron beam incident on a polarized ^{3}He target with a thickness of 10^{22}/cm^2 (luminosity $\sim$ 9.0x10^{35}) and target polarizations of 45%. The final particles are detected with SHMS and HMS in coincidence. Fig. 2 show the projected results with statistical uncertainty along with the theoretical expectations for t = -0.1, -0.3 and -0.5 GeV^2 at Q^2 = 4.0, 6.0 and 7.0 GeV^2/c^2. According to our estimates 400 hours of beam time is required at each Q^2 for the projected results shown in Fig. 2.

One must also remember that the QCD factorization theorem must hold for the processes under consideration in order to have access to the GPDs. However, the momentum transfer at which one reaches the factorization limit is completely unknown. It is a little realized fact that the onset of Color Transparency (CT) [7] is a necessary but not sufficient condition for factorization. Color transparency, first conjectured by Mueller and Brodsky [8] refers to the suppression of final (and initial) state interactions of hadrons with the nuclear medium in exclusive processes at high momentum transfers. At Hall C CT searches have concentrated on the quasi-elastic A(e,e'p) reaction which has several advantages in the search for CT. However, A(e,e'p) experiments at SLAC [9] and JLab [10] have found no evidence for the onset of CT effect at momentum transfers up to 8.1 $(\mathrm{GeV/c})^2$. It has been suggested that onset of CT is expected to be sooner in a $q\bar{q}$ system than in a three-quark system. Thus the next best reaction in the search for CT at Hall C is the A(e,e'π) reaction. Current theoretical calculations suggest that most of the CT effect should be seen around $Q^2 = 10$ GeV^2/c^2. It is feasible to extend the measurements of A(e,e'π) to these high Q^2 using SHMS and HMS in Hall C. Projected results on a ^{63}Cu target can be found in the paper on transparency in this CDR.

References

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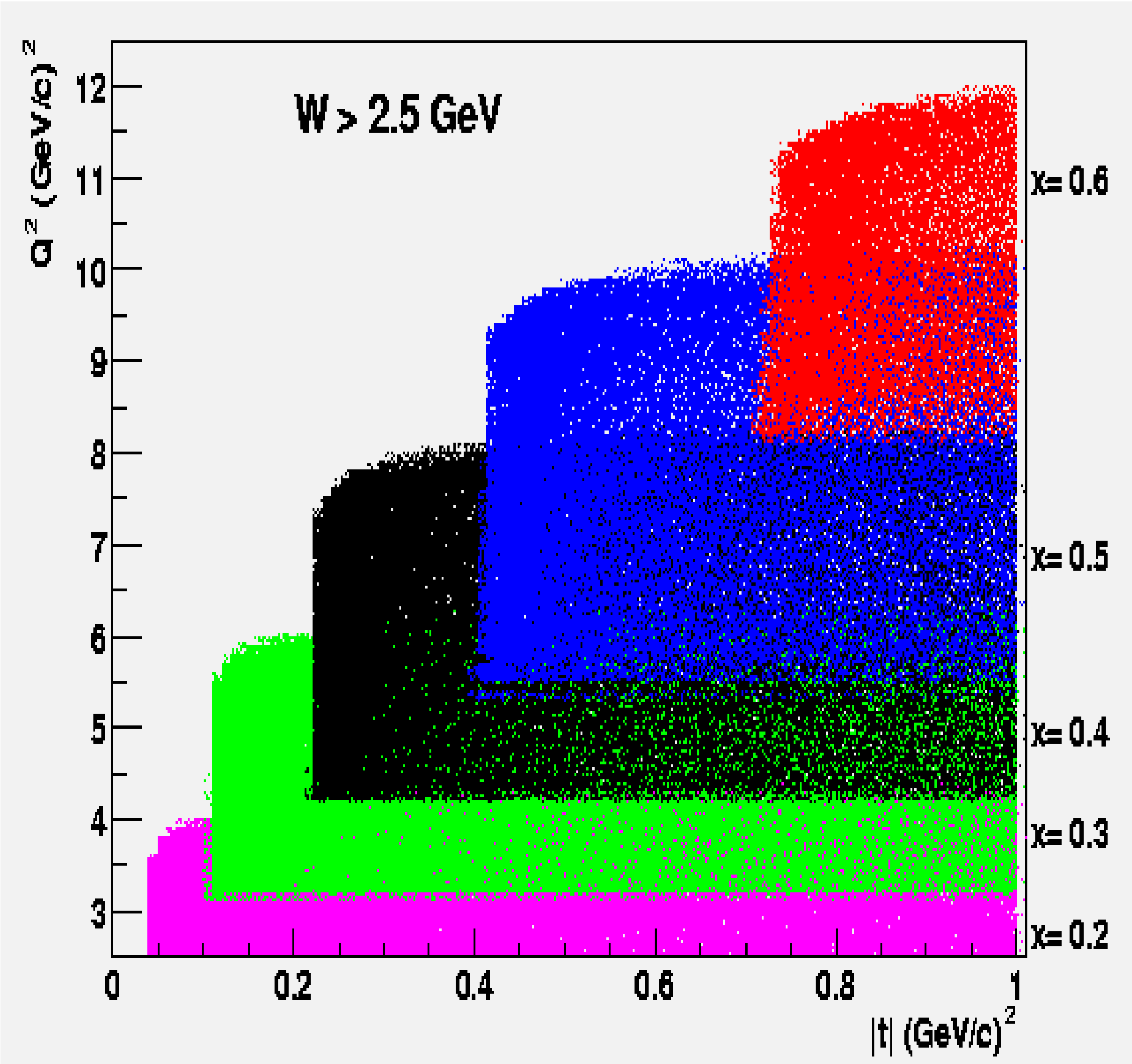

Figure 1: The kinematic range in $-t$, x_{Bj} and Q^2 which can be covered with the Hall C spectrometers HMS and SHMS using a 11.0 GeV electron beam. The range in $-t$ and x_{Bj} relevant for the extraction of GPDs is shown here.

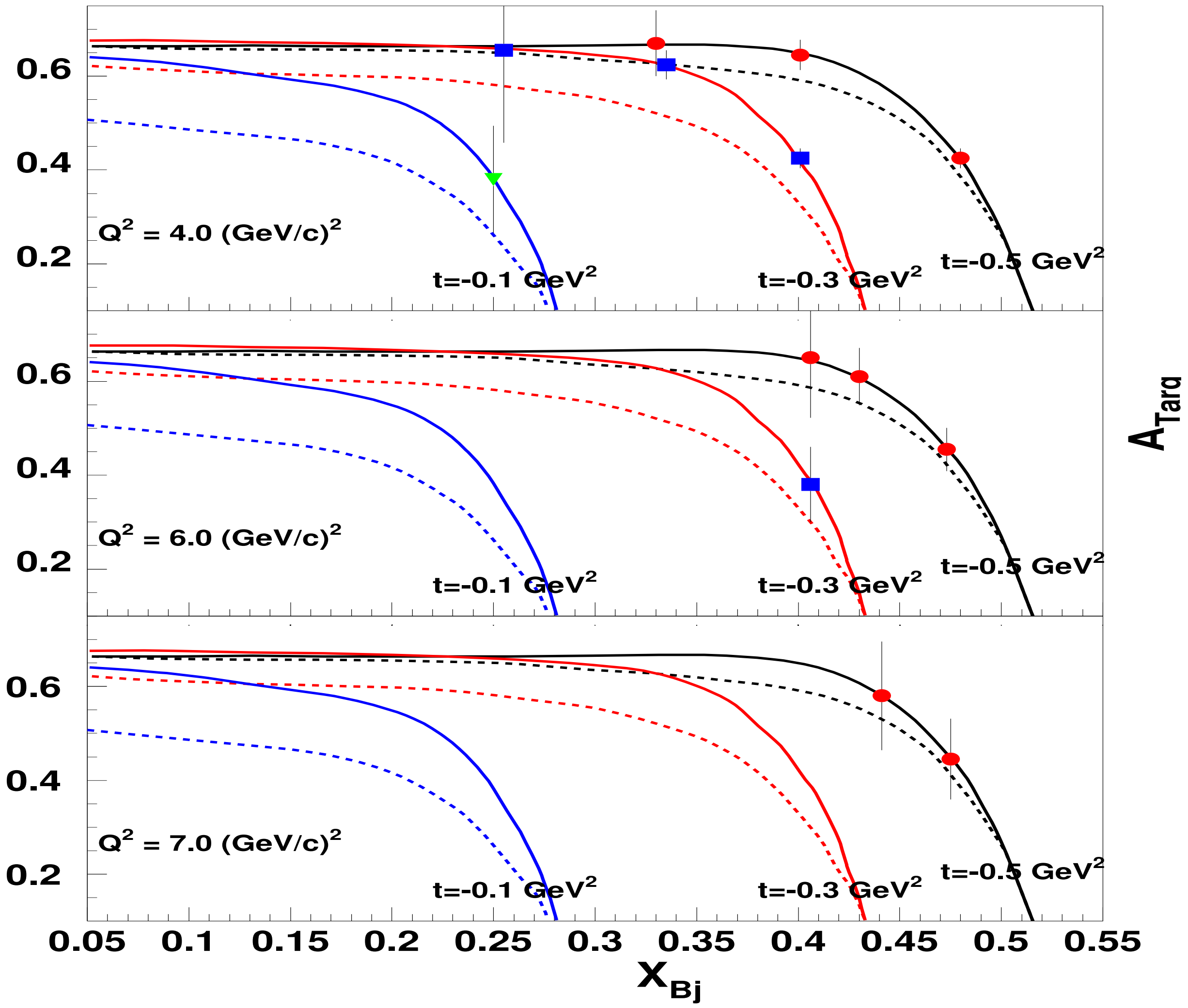

Figure 2: The projected results for target asymmetry in the process $en \to e^{'}\pi^{-}p$ with a transversely polarized ^{3}He target. The solid and dashed lines are the calculations from Ref. [4] and represent different model assumptions regarding the GPDs.