The Longitudinal Photon, Transverse Nucleon, Single-Spin Asymmetry in Exclusive Pion Electroproduction

In recent years, much progress has been made in the theory of generalized parton distributions (GPDs). Unifying the concepts of parton distributions and of hadronic form factors, they contain a wealth of information about how quarks and gluons make up hadrons. While the usual parton distributions are obtained from the squared hadron wavefunction representing the probability to find a parton with specified polarization and longitudinal momentum fraction x in a fast moving hadron, GPDs represent the interference of different wavefunctions, one where the parton has momentum fraction $x+\xi$ and one where this fraction is $x-\xi$.

A special kinematic regime is probed in deep exclusive meson production, where the initial hadron emits a quark-antiquark or gluon pair. This has no counterpart in the usual parton distributions and carries information about $q\bar{q}$ and gg-components in the hadron wavefunction which is unlikely to be available from any other source. In particular, almost no data constrain the spin-flip GPD $\tilde{E}$, since it cannot be related to already known parton distributions. Its only constraint comes from the pseudoscalar nucleon form factor, which is highly uncertain because it is negligible at the momentum transfer of β-decay. The most promising way to probe $\tilde{E}$ is believed [1] to be the single-spin asymmetry in exclusive π^+ production, $\vec{p}(e,e'\pi^+)n$, from a transversely polarized target, defined [2] as

$$A_L^\perp = \left(\int_0^\pi d\beta \frac{d\sigma_L^{\pi^+}}{d\beta} - \int_\pi^{2\pi} d\beta \frac{d\sigma_L^{\pi^+}}{d\beta}\right)\left(\int_0^{2\pi} d\beta \frac{d\sigma_L^{\pi^+}}{d\beta}\right)^{-1}, \tag{1}$$

where $d\sigma_L^{\pi^+}$ is the exclusive electroproduction cross section using longitudinally polarized photons and β is the angle between the target polarization vector and the reaction plane. L.L. Frankfurt et al. [3] have shown that this asymmetry must vanish if $\tilde{E}$ is zero.

The GPD formalism is restricted to the hard scattering regime, where one can factorize the reaction into perturbative and non-perturbative contributions. Hard exclusive meson electroproduction was first shown to be factorizable in Ref. [4]. This factorization applies when the virtual photon is longitudinally polarized, which corresponds to a small size configuration compared to a transversely polarized photon. The transverse spin asymmetry $A_L^\perp$ is especially interesting in this regard, because it seems likely that the factorization of the meson production amplitude will lead to a precocious scaling of $A_L^\perp$ as a function of Q^2 at moderate $Q^2 \sim 2-4$ GeV^2 [3]. This precocious scaling arises from the fact that higher order corrections, which may be significant at low Q^2, will likely cancel when one examines the ratio of two cross sections. In contrast, the onset of scaling for the absolute cross section is only expected for much larger values of $Q^2 \geq 10$ GeV^2.

Renormalon model calculations [5] of both the asymmetry and the longitudinal cross section at $Q^2 = 4$ GeV^2 are shown in Fig. 1. While the magnitude of the cross section changes significantly when taking into account the twist-four corrections, the transverse spin asymmetry is essentially

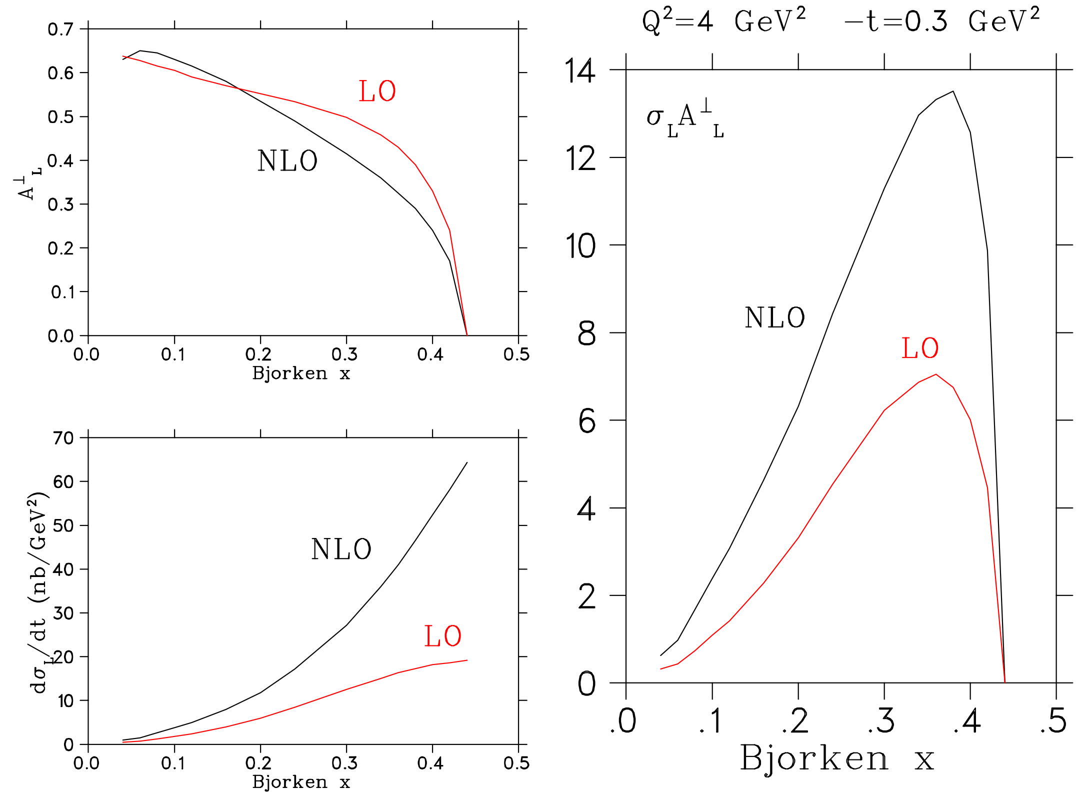

Figure 1: Calculation of the transverse single-spin asymmetry including twist-four corrections by A. Belitsky [5] at $-t = 0.3$ GeV^2, $Q^2 = 4$ GeV^2. The red curves are the leading order calculation, while the black curves have twist-four power effects taken into account. While the cross section is very sensitive to these corrections, the transverse spin asymmetry is stable. The figure of merit $\sigma_L A_L^{\perp}$ maximum at $x = 0.37$ corresponds to $W = 2.8$ GeV, and yields particle angles and momenta which are compatible with a Hall C measurement.

insensitive to them and displays the expected precocious scaling. The relatively low value of Q^2 for the expected onset of precocious scaling is important, because it will be experimentally accessible after the JLab 12 GeV upgrade.

There are five chief experimental requirements for a measurement of the transverse spin asymmetry.

1. A Rosenbluth separation is crucial, because in hard meson electroproduction, factorization can only be applied to longitudinal photons. The unique contribution of JLab will be its ability to take measurements at multiple beam energies and unambiguously isolate the longitudinal component of the asymmetry.

2. The π^+ must be detected in non-parallel kinematics. It is the component of the target polarization parallel to $\hat{q} \times \hat{p_\pi}$ that is relevant, and this direction is uniquely defined only in

non-parallel kinematics.

3. The luminosity requirements are dictated by the fact that the longitudinal cross section is largest in parallel kinematics, where the asymmetry vanishes, and is small where the asymmetry is maximal. The right panel of Fig. 1 shows the figure of merit $\sigma_L A_L^{\perp}$ from the A. Belitsky calculation. At the figure of merit maximum, the longitudinal cross section is approximately 40 nb/GeV^2, so a luminosity of about 10^{35}/cm^2/sec is required to complete the measurement in 100 days of beam.

4. A target with good polarization, and a holding-field geometry that does not occlude the measurement, is required.

5. Sufficient resolution to assure the exclusive final state, or at minimum, place significant constraints upon a semi-exclusive measurement, is highly desired.

Table 1: Kinematic settings for the $\vec{p}(e, e'\pi^+)n$ reaction at $Q^2 = 4.0$ GeV^2, $W = 2.8$ GeV. The scattered electron is to be detected in the HMS, and the π^+ in the SHMS. $\Theta_{\pi q}$ indicates the lab angle of the π^+ with respect to $\vec{q}$, above or below the (non-horizontal) scattering plane. Deflection in the target magnetic field will introduce a small correction to these settings.

$E_{e'}$ (GeV)	$\theta_{e'}$ (deg)	θ_π (deg)	$\Theta_{\pi q}$ (deg)	p_π (GeV)	$-t$ (GeV^2)	x	z
High $\epsilon = 0.745$ setting, $E_e = 11.00$ GeV							
5.160	15.25	-12.70	0.0	5.744	0.175	0.365	0.984
5.160	15.25	-12.70	± 3.0	5.666	0.322	0.365	0.970
5.160	15.25	-12.70	± 5.0	5.531	0.576	0.365	0.947
Low $\epsilon = 0.200$ setting, $E_e = 6.70$ GeV							
0.860	49.23	-6.06	0.0	5.744	0.175	0.365	0.984
0.860	49.23	-6.06	± 3.0	5.666	0.322	0.365	0.970
0.860	49.23	-6.06	± 5.0	5.531	0.576	0.365	0.947

An upgraded Hall C, using the HMS in coincidence with the proposed SHMS, meets all four requirements, and can yield a measurement of $A_L^{\perp}$ squarely within the kinematic region accessible to theorists.

1. For the optimum kinematics of $x = 0.37$ indicated in the right panel of Fig. 1, the use of 6.7 and 11 GeV electron beam provides a $\Delta\epsilon$ range of about 0.55, which provides acceptable error bars for the L/T separation. Angle and momentum settings for the two spectrometers are listed in Table 1. The 5.5^o minimum angle capability of the SHMS greatly benefits the measurement, as it allows a much larger $\Delta\epsilon$ range than otherwise possible.

2. The HMS and SHMS have their largest acceptances in the vertical direction, and with the intense focussing of the pion cone at $Q^2 = 4$ GeV^2, these vertical acceptances allow measurements up to $|t| = 0.75$ GeV^2. In this case, the scattered electron is detected at some vertical position in the HMS, which forces the scattering plane and the q-vector to be non-horizontal. The π^+ is detected in the SHMS, either above or below $\vec{q}$, depending on whether the scattered electron was detected at above or below the horizontal plane.

3. The target polarization is therefore horizontal, parallel to $\hat{q} \times \hat{p_\pi}$, and is nearly transverse to $\vec{q}$ for all angles between the scattering and reaction planes. The vertical bending spectrometers thus allow the use of proven horizontally-polarized target technology to perform the measurement, with an efficient use of beam time. In addition to the refurbished target, this measurement requires a beam deflection magnet installed downstream of the target, to keep the electron beam from hitting the SHMS Q1.

4. Since proven polarized target technology can be used, the required luminosity is obtained with 85 nA of beam on a 3 cm polarized NH_3 target. 90% target polarization has been achieved in such a configuration.

5. Finally, the use of the HMS and SHMS magnetic spectrometers guarantee the ability to distinguish the exclusive $\vec{p}(e, e'\pi^+)n$ final state, and provide the systematic error control necessary for a high-quality L/T separation.

An extension of this program could be to measure the polarized single spin asymmetry in π^- production from the neutron. At high $|t|$, the π^-/π^+ ratio is expected to be sensitive to differences in the $u\bar{d}$ and $d\bar{u}$ parton distributions. This would necessite the use of a transversely polarized deuterium target and a measurement of the exclusive $\vec{d}(e, e'\pi^-)p[p]$ reaction, where the second proton is a spectator.

References

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