Exclusive pion cross section and asymmetry at HERMES

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Exclusive electroproduction of π^+ mesons was studied by scattering 27.6 GeV positrons or electrons off a gaseous hydrogen target. The spin-averaged cross section and the single-spin azimuthal asymmetry with respect to transverse target polarisation were measured as a function of the Mandelstam variable t, the Bjorken scaling variable x_B, and the virtuality Q^2 of the exchanged photon. The results are compared to recent theoretical models.

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1. Introduction

The possibility to interpret hard exclusive processes in the framework of Generalised Parton Distributions (GPDs) [1] and to gather new information on the nucleon structure has lead to growing interest in the study of exclusive processes. In the description of exclusive production of π^+ mesons on protons by longitudinal virtual photons at leading twist (see Fig. 1), only the two GPDs $\widetilde{H}$ and $\widetilde{E}$ appear. Spin-averaged and spin-dependent cross sections are sensitive to different combinations of $\widetilde{H}$ and $\widetilde{E}$. Unlike the spin-averaged cross section, the azimuthal asymmetry with respect to transverse target polarisation is directly proportional to the sine of the relative phase between $\widetilde{H}$ and $\widetilde{E}$. HERMES has previously performed measurements of the single-spin azimuthal asymmetry in exclusive π^+ electroproduction on longitudinally polarised protons [2]. Recently, results on the spin-averaged cross section [3] and the single-spin azimuthal asymmetry for the hard exclusive reaction $ep^{\uparrow} \rightarrow en\pi^+$ on transversely polarised protons [4] have been reported (see Sections 2, 3 below). Recent theoretical analyses of hard exclusive pion production are presented in [5, 6, 7].

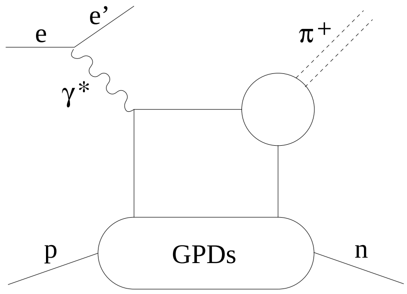

Figure 1: Leading-order diagram for exclusive π^+ electroproduction.

2. Cross section

The data used for this measurement were collected in 1996-2005 with the HERMES spectrometer in the HERA storage ring at DESY. The average target polarisation was zero. Events with one lepton and one pion in the momentum range between 7 GeV and 15 GeV were accepted. The following requirements were imposed: $W^2 > 10\,\mathrm{GeV}^2$, $y < 0.85$, $Q^2 > 1\,\mathrm{GeV}^2$. The quantity $-t' = -(t - t_0)$, with $-t_0$ the minimum value of $-t$, was used in the analysis.

The exclusive channel $ep \rightarrow en\pi^+$ was separated from background channels using the missing mass (M_X) technique. The exclusive π^+ yield was obtained by subtracting the yield difference $(N_{\pi^+} - N_{\pi^-})$ of a PYTHIA Monte Carlo simulation from that of the data, with both differences being independently absolutely normalized: $N^{\mathrm{excl}}_{\pi^+} = (N_{\pi^+} - N_{\pi^-})^{\mathrm{data}} - (N_{\pi^+} - N_{\pi^-})^{\mathrm{PYTHIA}}$. An upper cut on M_X^2 of $1.2\,\mathrm{GeV}^2$ was set in order to optimise the (quadratically) combined statistical and systematic uncertainty of $N^{\mathrm{excl}}_{\pi^+}$; 4510 events are obtained after background subtraction.

The differential cross section is extracted from data using the relation [3]

$$\frac{d\sigma^{\gamma^* p \rightarrow n\pi^+}(x_\mathrm{B}, Q^2, t')}{dt'} = \frac{1}{\Gamma_V(\langle x_\mathrm{B}\rangle, \langle Q^2\rangle)} \frac{N^{\mathrm{excl}}_{\pi^+}}{\Delta x_\mathrm{B}\, \Delta Q^2\, \Delta t'\, \kappa(x_\mathrm{B}, Q^2)\, \eta}, \tag{2.1}$$

where the virtual-photon flux factor Γ_V, the detection probability κ, and the radiative correction factor η are all determined for each kinematic bin with bin sizes Δx_B, ΔQ^2, and $\Delta t'$.

Figure 2 shows the t' dependence of the differential cross section for four Q^2 bins. The data are compared with calculations of $\frac{d\sigma}{dt'}$ using a GPD model: with a Regge-inspired t' dependence for $\widetilde{E}$ and neglecting $\widetilde{H}$. While the leading-order calculation underestimates the data, the calculations including power corrections agree with the data for $-t' < 0.3\,\mathrm{GeV}^2$. The calculation of $\frac{d\sigma}{dt'}$ using

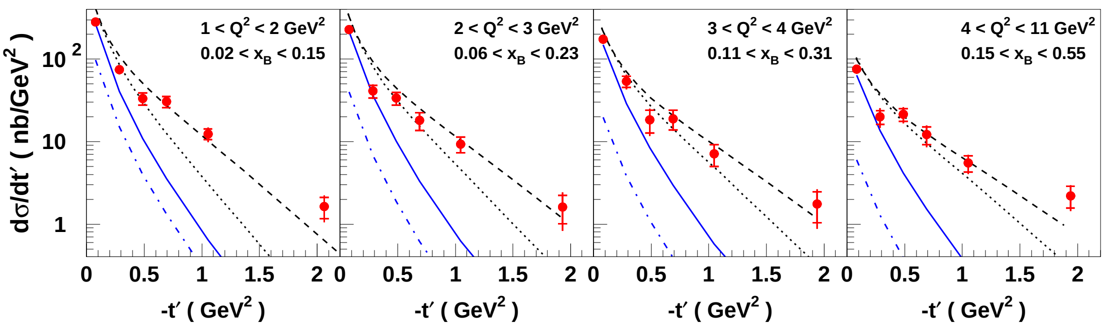

Figure 2: Differential cross sections as a function of $-t'$ for four Q^2 bins [3].

a Regge model describes the data well. More recent calculations of other models that are able to describe the data are presented in [5, 6, 7].

3. Spin asymmetry

The asymmetry for the reaction $ep^{\uparrow} \rightarrow en\pi^{+}$ is extracted from a subset of the data used for the cross section measurement presented above, which was taken in 2002-2005 with a transversely polarised hydrogen target. The average value of the transverse proton polarisation $|P_T|$ was 0.72 ± 0.06. The azimuthal angles ϕ and ϕ_S of the pion and of the target polarisation vector, respectively, are defined around the virtual-photon three-momentum vector relative to the lepton scattering plane in the target rest frame. After applying the same cuts as for the cross section analysis, the number of observed π^{+} events is 3425, of which half are background events.

The single-spin asymmetry for exclusive π^{+} production with unpolarized (U) beam and target polarization transverse (T) to the lepton (ℓ) beam direction is defined as

$$A_{\mathrm{UT},\ell}(\phi,\phi_S) = \frac{1}{|P_{\mathrm{T}}|}\frac{\mathrm{d}\sigma^{\uparrow}(\phi,\phi_S) - \mathrm{d}\sigma^{\downarrow}(\phi,\phi_S)}{\mathrm{d}\sigma^{\uparrow}(\phi,\phi_S) + \mathrm{d}\sigma^{\downarrow}(\phi,\phi_S)}, \tag{3.1}$$

where $\mathrm{d}\sigma^{\uparrow(\downarrow)}(\phi,\phi_S) = \mathrm{d}\sigma_{\mathrm{UU}}(\phi) + P_{\mathrm{T}}\,\mathrm{d}\sigma_{\mathrm{UT},\ell}(\phi,\phi_S)$ is a sum of the spin-averaged and spin-dependent cross sections, with $P_{\mathrm{T}}/|P_{\mathrm{T}}|$ equal to 1 (-1) for the $\uparrow$ $(\downarrow)$ orientations of the transverse target polarization vector P_{T}. The asymmetry (3.1) can be Fourier-decomposed as [8]

$$\begin{aligned}\mathscr{A}_{\mathrm{UT},\ell}(\phi,\phi_S) &= A_{\mathrm{UT},\ell}^{\sin(\phi-\phi_S)}\sin(\phi-\phi_S) + A_{\mathrm{UT},\ell}^{\sin(\phi+\phi_S)}\sin(\phi+\phi_S) + A_{\mathrm{UT},\ell}^{\sin\phi_S}\sin\phi_S \\ &+ A_{\mathrm{UT},\ell}^{\sin(2\phi-\phi_S)}\sin(2\phi-\phi_S) + A_{\mathrm{UT},\ell}^{\sin(3\phi-\phi_S)}\sin(3\phi-\phi_S) + A_{\mathrm{UT},\ell}^{\sin(2\phi+\phi_S)}\sin(2\phi+\phi_S).\end{aligned} \tag{3.2}$$

The set of six Fourier amplitudes of the sine-modulation terms in (3.2) were extracted from the observed π^{+} event sample using a maximum likelihood fit.

Each extracted Fourier amplitude was corrected for background contributions in order to estimate its true value for exclusive π^{+} production, $A_{\mathrm{t}} = \frac{A_{\mathrm{r}} - bA_{\mathrm{b}}}{1-b}$. Here, A_{r} denotes the raw value obtained from the maximum likelihood fit, and b and A_{b} stand for the fractional contribution and Fourier amplitude of the background. The background fraction $b = \frac{N_{\pi^+} - N_{\pi^+}^{\mathrm{excl}}}{N_{\pi^+}}$ with N_{π^+} and $N_{\pi^+}^{\mathrm{excl}}$ being the number of observed π^{+} events in the selected data sample and after background subtraction described above, respectively. As the background originates from resolution smearing of events occuring at higher missing mass, A_b was assumed to be equal to the Fourier amplitude measured in the M_X^2 region between $1.9\,\mathrm{GeV}^2$ and $2.6\,\mathrm{GeV}^2$ where the contribution of exclusive π^+ events is negligible.

Figure 3 shows the extracted Fourier amplitudes as a function of $-t'$, x_B, and Q^2. The average values of the kinematic variables are $\langle -t' \rangle = 0.18\,\mathrm{GeV}^2$, $\langle x_B \rangle = 0.13$, and $\langle Q^2 \rangle$=$2.38\,\mathrm{GeV}^2$. The background fraction b varies between $(54 \pm 6)\%$ and $(62 \pm 5)\%$ in the various kinematic bins. The values of A_b are smaller than ± 0.1, except for the $\sin \phi_S$ modulation for which they amount on average to (0.25 ± 0.04). The leading $\sin(\phi - \phi_S)$ amplitude appears to change sign from negative to positive as a function of $-t'$, but it is also consistent with zero. This result is interesting in view of the large value initially predicted for this amplitude [7] using GPD models. The measured $\sin \phi_S$ amplitude is surprisingly large implying a significant contribution from the transverse-to-longitudinal virtual-photon helicity transition. An attempt to evaluate the complete set of Fourier amplitudes (3.2), and in particular the value of $A_{\mathrm{UT},\ell}^{\sin(\phi-\phi_S)}$, is presented in [6]. Comparisons of model calculations with data are also presented in [7].

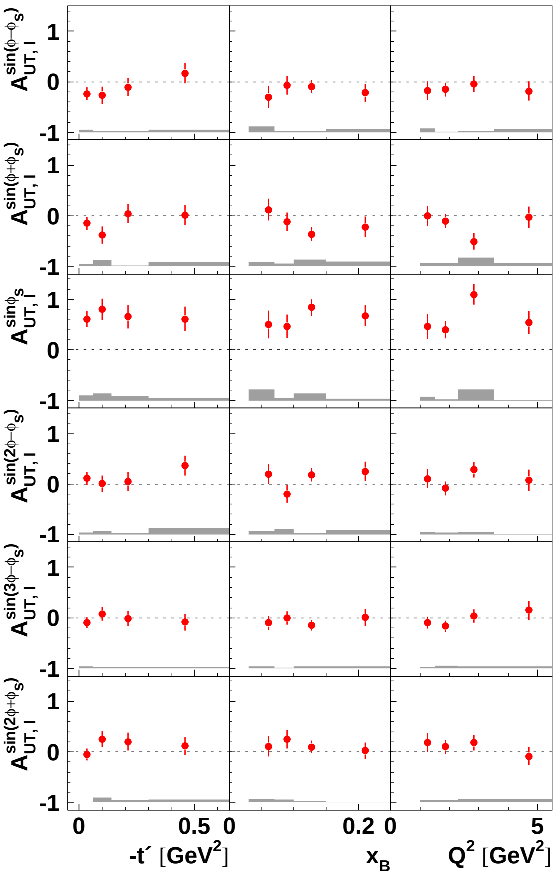

Figure 3: Amplitudes of the sine modulations of the single-spin azimuthal asymmetry [4].

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