Exclusive meson production at HERMES

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Abstract. Generalized Parton Distributions (GPDs) provide a new level of insight into the quark structure of the nucleon. Experimentally they can be probed by hard exclusive electroproduction of both scalar and vector mesons. Results for the cross section for the reaction $ep \to en\pi^+$, and a first result for the asymmetry A_{UT} for exclusive ρ^0 production are presented.

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INTRODUCTION

It has been shown [1, 2] that in the case of large Q^2 and for longitudinally polarised virtual photons a factorization theorem can be applied to exclusive meson production. The theorem states that the meson production amplitude can be written as a product of a hard part, describing the interaction of the virtual photon, a meson wave function, and a soft part. The latter can be expressed in terms of Generalised Parton Distribution functions, describing the nucleon. These are related to the unknown quark orbital angular momentum L_q.

For every quark flavor q there are four GPD's, two of them are polarized ($\tilde{E}^q$ and $\tilde{H}^q$), whereas the other two are unpolarized (E^q and H^q). Pseudoscalar (vector) meson production is sensitive to the polarized (unpolarized) GPD's. Different observables like cross-sections, or single-spin asymmetries select different combinations of GPD's. The experimental separation between γ_L^* and γ_T^* is in principle possible for vector mesons, for pseudoscalar mesons this separation will be tested by the overall Q^2 dependence.

In this paper, the cross section for exclusive π^+ production, and the target related single spin asymmetry A_{UT} for exclusive ρ^0 production will be covered. The data is coming from the HERMES experiment at the HERA storage ring at DESY. Only the scattered lepton and the produced meson are detected in the HERMES spectrometer [3], however, by putting constraints to missing mass or missing energy, exclusive reactions can be selected.

CROSS SECTION FOR EXCLUSIVE π^+ PRODUCTION

The cross section for exclusive pion leptoproduction on a proton target can be related to $(\tilde{H}+\tilde{E})^2$. The selection of exclusive π^+ candidates in the reaction $e+p \to e'+\pi^+ +X$ was done by calculating the missing mass $M_X^2 = (P_e + P_p - (P_{e'} + P_{\pi^+}))^2$, and applying a missing mass cut M_X^2 around the squared proton mass. Unfortunately the M_X^2 resolution

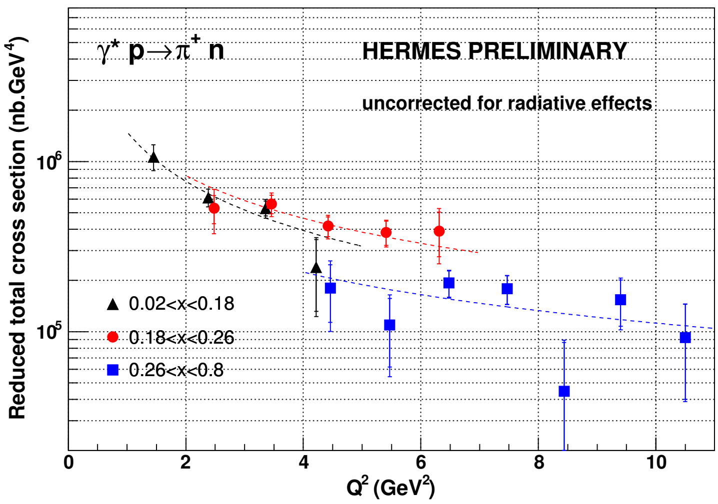

FIGURE 1. Reduced cross section for exclusive π^+ production as a function of Q^2 in different x bins. A polynomial of the order $\frac{1}{Q^2}$ has been fit to every bin.

doesn't allow the separation of the exclusive events from the non-exclusive background. One can however use the normalised π^- yield as an estimate for the background, as there's no exclusive channel in π^- production on the proton with the creation of a nucleon. Applying this background subtraction yields a peak in the M_X^2 spectrum around the squared nucleon mass, whose width and mean could be reproduced by a Monte Carlo based on a GPD model.

The exclusive π^+ cross section was determined by analysing HERMES data sets from 1996 up to 2000. Out of these, approximately 3500 exclusive π^+ events were selected. The cross section was evaluated by applying the following formula:

$$\sigma^{\gamma^* p \to n + \pi^+}(x, Q^2) = \frac{N_{\text{excl}}^{\pi^+}}{L \cdot \Delta x \Delta Q^2 \cdot \kappa(x, Q^2) \cdot \Gamma(<x>, <Q^2>)}, \tag{1}$$

where L is the integrated luminosity, κ the probability to detect the scattered lepton and the produced π^+, and Γ the virtual photon flux factor, calculated following the description described in [4]. The detection probability has been determined using two different Monte Carlo samples based on GPD calculations [5, 6]. The agreement between data and Monte Carlo was good. More details can be found in [7]

The factorization theorem predicts a $\frac{1}{Q^6}$ dependence for σ_L at fixed x and t. We can write σ_L as:

$$\frac{d\sigma_L}{dt} = \frac{1}{16\pi} \frac{x^2}{1-x} \frac{1}{Q^4} \frac{1}{\sqrt{1 + \frac{4m^2 x^2}{Q^2}}} \sum_{\text{spin}} |\mathbf{A}(\gamma^* p \to pM)|^2, \tag{2}$$

where the sum term is the so-called *reduced* cross section, which is independent of x and should have a $\frac{1}{Q^2}$ behavior. The reduced cross section for exclusive π^+ production is shown in figure 1. The remaining x-dependence as seen in that figure can be explained by the finite size of the x-bins. For every x-bin a function $\frac{1}{Q^p}$ has been fitted to the spectrum. The fit parameters $p = 1.9 \pm 0.5$ (triangles), $p = 1.7 \pm 0.6$ (circles), and $p = 1.5 \pm 1.0$ (squares) agree with the predicted Q^2 dependence.

A_{UT} FOR EXCLUSIVE ρ^0 PRODUCTION

Since 2002 HERMES is running with a transversely polarized proton target. The transverse target spin asymmetry for exclusive ρ^0 production is directly related to the GPD E, and is the most direct probe of that GPD. The asymmetry is sensitive to the total angular momentum of quarks as shown in [8].

For the study of A_{UT}, ρ^0's are reconstructed from h^+h^- pairs. Exclusivity is achieved by requiring the missing energy ΔE to be zero. Subtracting the non-exclusive background as described by Monte Carlo from the ΔE spectrum leaves a clear peak around $\Delta E = 0$, which is evidence for exclusive ρ^0 production on a proton target.

Generally, a single spin asymmetry $\mathrm{A_{UT}}$ is measured by subtracting the number of observed events when the target is in one state from the number of events when the target is in the other state. The subtraction occurs in every bin $(\phi - \phi_S)$:

$$\mathrm{A_{UT}}(\phi - \phi_S) = \frac{1}{|P|}\frac{N^{\uparrow} - N^{\downarrow}}{N^{\uparrow} + N^{\downarrow}}.$$

ϕ (ϕ_S) is the angle betweeen the lepton scattering plane and the hadron production plane (target spin), as shown in figure 2. The average polarization $< |P| >$ over the combined 2002-2004 data sample was 0.755 ± 0.049.

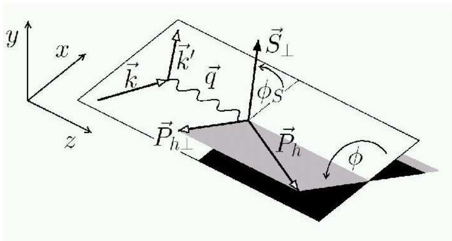

FIGURE 2. Definition of the angles ϕ and ϕ_S.

The relevant observable is the $\sin(\phi - \phi_s)$ amplitude of the asymmetry and is depicted in figure 3 as a function of x and t', the latter variable being the difference of t and t_0, where t_0 is the maximum kinematically allowed value of t. Despite the large error bars a large asymmetry is visible for low x and high t'.

HERMES will run with a transversely polarized proton target up to November 2005. Statistics thus are expected to increase, allowing for a full $\sigma_L - \sigma_T$ separation in the future.

OUTLOOK

Analysis of exclusive processes with HERMES data is still continuing. The transverse target spin asymmetry for exclusive π^+ production for example is an interesting ob-

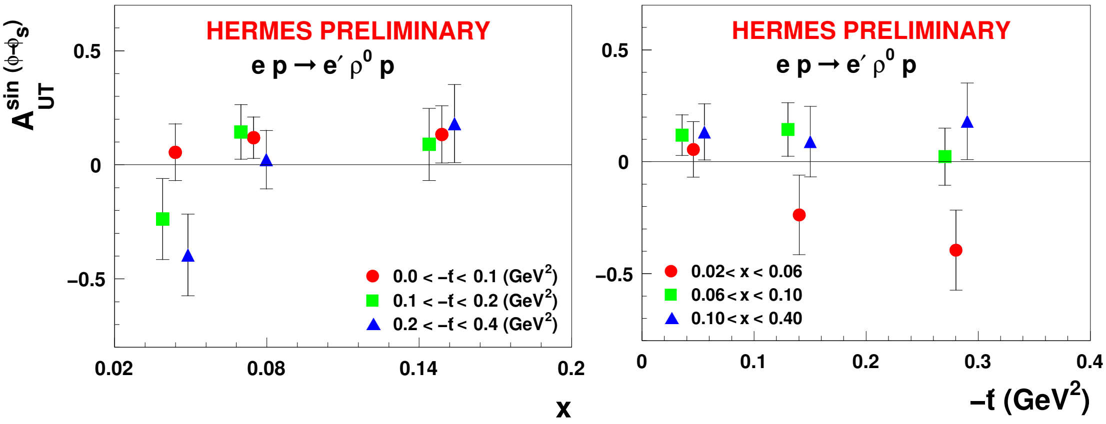

FIGURE 3. A_{UT} for exclusive ρ^0 production on a proton target. Left (right) as a function of x (-t').

servable. The asymmetry is related to $\tilde{E} \cdot \tilde{H}$, and can be used together with the cross section information to disentangle $\tilde{E}$ and $\tilde{H}$. Moreover the scaling region is expected to be reached at lower Q^2 in the case of asymmetries. In [9] the sensitivity of A_{UT} to the pion form factor is shown.

Looking at π^+-electroproduction we see that the pseudoscalar contribution $\tilde{E}$ is dominated by the pion-pole exchange, and therefore is related to the pion form factor. In the case of exclusive π^0 production there's no pion-pole contribution. The production ratio of π^+ to π^0 mesons thus promises to be an interesting observable in the quest for the understanding of the nucleon's structure.

CONCLUSIONS

Exclusive meson production is related to GPDs and can be used to explore the structure of the nucleon. It was shown that the Q^2 dependence of the reduced cross section for exclusive π^+ production on a proton target is in agreement with theoretical predictions.

The exclusive ρ^0 production shows target spin asymmetries which are related th the GPD E. First results for this asymmetry were presented. HERMES is continuing to take data and more results from a refined analysis are expected soon.

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