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ELECTROPRODUCTION OF EXCLUSIVE $\pi^+\pi^-$ AT HERMES

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Hard exclusive electroproduction of $\pi^+\pi^-$ pairs off hydrogen and deuterium targets has been studied by the HERMES experiment at DESY. Legendre moments $\langle P_1 \rangle$ and $\langle P_3 \rangle$ of the angular distributions of π^+ mesons in the center-of-mass frame of the pair have been measured for the first time. Their dependence on the $\pi^+\pi^-$ invariant mass can be understood as being due to the interference between relative P-wave (isovector) and S, D-wave (isoscalar) states of the two pions. The increase in magnitude of $\langle P_1 \rangle$ as Bjorken x increases is interpreted in the framework of Generalized Parton Distributions as an enhancement of flavour non-singlet $q\bar{q}$ exchange for larger values of x, which leads to a sizable admixture of isoscalar and isovector pion pairs. In addition, the interference between P-wave and D-wave states separately for transverse and longitudinal pion pairs has been studied. The data indicate that in the $f_2(1270)$ region at $\langle Q^2 \rangle = 3$ GeV^2 higher-twist effects can be as large as the leading-twist longitudinal component.

1 Introduction

This analysis reports the first experimental data for hard exclusive $\pi^+\pi^-$ pair production [1,2]

$$e^+p \to e^+p\ \pi^+\pi^- \text{ and } \ e^+d \to e^+d\ \pi^+\pi^-\ . \tag{1}$$

Recent theoretical studies [3,4,5] have shown that the analyzed exclusive process can be described in the framework of Generalized Parton Distributions (*GPD*s) [6,7,8]. The diagrams relevant for this reaction at leading twist are shown in Fig. 1. The pion pairs may be produced through two-gluon or quark-antiquark ($q\bar{q}$) exchange with the target, and either from quark (Fig. 1a,b,c) or from gluon fragmentation

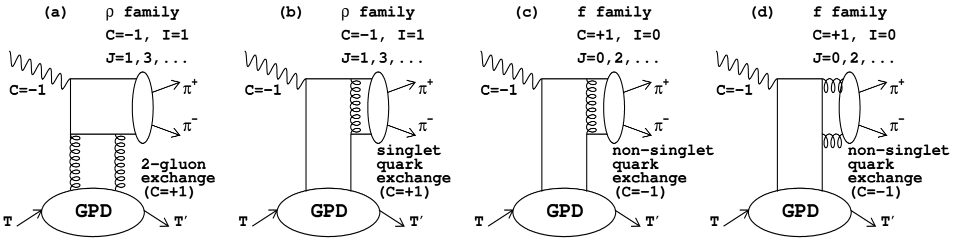

Figure 1. Leading twist diagrams for the hard exclusive reaction $e^+T \to e^+T\ \pi^+\pi^-$. Gluon exchange *(a)* gives rise to pions in the isovector state only, while the quark exchange mechanism *(b,c,d)* gives rise to pions in both isoscalar and isovector states.

(Fig. 1d). In the range of the considered $\pi^+\pi^-$ invariant mass ($m_{\pi\pi}$), both resonant and non-resonant contributions are present.

For the purpose of studying the interference between $\pi^+\pi^-$ production in P-wave ($I=1$) and S,D-wave states ($I=0$), the Legendre moments $\langle P_1(\cos\theta)\rangle$ and $\langle P_3(\cos\theta)\rangle$ are particularly useful because they are sensitive only to such interference. The Legendre moment of order n is given by

$$\langle P_n(\cos\theta)\rangle^{\pi^+\pi^-} = \frac{\int_{-1}^{1} d\cos\theta\, P_n(\cos\theta)\, \frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta}}{\int_{-1}^{1} d\cos\theta\, \frac{d\sigma^{\pi^+\pi^-}}{d\cos\theta}} \,, \tag{2}$$

where θ is the polar angle of the π^+ meson with respect to the direction of the momentum of the $\pi^+\pi^-$ pair in the center-of-momentum frame of the virtual photon and target nucleon. In particular, $\langle P_1\rangle$ is sensitive to P-wave interference with S and D-waves, whereas $\langle P_3\rangle$ is sensitive to only P-wave interference with a D-wave.

In order to study the contribution of the $f_2(1270)$ resonance to the Legendre moments in more detail, the $m_{\pi\pi}$-dependence of the purely longitudinal combination $\langle P_1 + \frac{7}{3}\cdot P_3\rangle$, and of the combination $\langle P_1 - \frac{14}{9}\cdot P_3\rangle$ which is believed to be dominated by the higher-twist transverse contribution to the excitation of the f_2 resonance [9], have been also measured in the f_2 domain.

2 Data analysis

The data have been accumulated with the HERMES forward spectrometer [10] during the running period 1996-2000 of HERA. The 27.6 GeV positron beam was scattered off hydrogen and deuterium targets, respectively. Events have been selected with exactly one positron track and two oppositely charged hadron tracks. The exclusivity of these events was ensured by imposing a further cut on the inelasticity $\Delta E = \frac{M_X^2 - M_P^2}{2M_P}$, where M_X^2 is the missing mass square, and M_p is the proton mass. As explained above, to enhance the isoscalar production and consequently the interference between the isovector and isoscalar channel, it was also required that Bjorken $x > 0.1$. Moreover, in order to enter the *hard* regime of the process, the constraints $Q^2 > 1$ GeV^2 and $W > 2$ GeV were imposed, where W is the invariant mass of the virtual-photon nucleon system.

The most important source of background to the exclusive channel comes from fragmentation of partons in semi-inclusive deep inelastic scattering (*SIDIS*) at low ΔE. Due to the instrumental resolution, those events may contaminate the exclusive sample. The ΔE shape of the *SIDIS* background is well reproduced by a *Monte Carlo* simulation (*MC*) based on the *LEPTO* generator.

The exclusive ΔE region chosen in this analysis is $\Delta E < 0.625$ GeV for both targets. In each of the analyzed bins, $\langle P_n\rangle_{data}$ was evaluated within the chosen exclusive ΔE region, with no background subtraction. The values of $\langle P_n\rangle_{SIDIS}$ for the background events were extracted from the data for $\Delta E > 2$ GeV, where SIDIS events dominate, and then subtracted according to the ratio of integrated exclusive data to background Monte Carlo events for chosen exclusive ΔE region in the analyzed bin.

The systematic uncertainties have been evaluated considering all hadrons as pions, using different exclusive cuts and applying various procedures for the normalization of the *MC* generated background to the data. Effects due to the acceptance, and radiative corrections to the measured Legendre moments were found to be negligible.

3 Results

The $m_{\pi\pi}$-dependence of $\langle P_1 \rangle$ and $\langle P_3 \rangle$ for exclusive $\pi^+\pi^-$ production off hydrogen and deuterium is presented in Fig. 2, for $x > 0.1$. The Legendre moment $\langle P_1 \rangle$ shows a clear dependence on $m_{\pi\pi}$. At low $m_{\pi\pi}$ ($m_{\pi\pi} < 0.6$ GeV) this non-zero moment is interpreted as originating from the interference between the lower tail of the ρ^0 meson and the non-resonant $\pi^+\pi^-$ S-wave production ($I = 1$ and $I = 0$ interference). This interference is present over the entire invariant mass region considered. At $m_{\pi\pi} > 1.0$ GeV, additionally, an interference between the upper tail of the ρ^0 meson and the f-type mesons arises and is superimposed. In particular, the possible change of sign of the asymmetry at $m_{\pi\pi} \approx 1.3$ GeV may be understood as being caused by the interference of the broad ρ^0 tail and the $f_2(1270)$ resonance.

The Legendre moment $\langle P_3 \rangle$ is sensitive only to the interference of P-wave and D-wave states in $\pi^+\pi^-$ production. Consistent with the expectation that no resonance decay into $\pi^+\pi^-$ pairs in D-wave states occurs for $m_{\pi\pi} \leq 1$ GeV, no interference is observed in this invariant mass region. The $\langle P_3 \rangle$ moment for deuterium

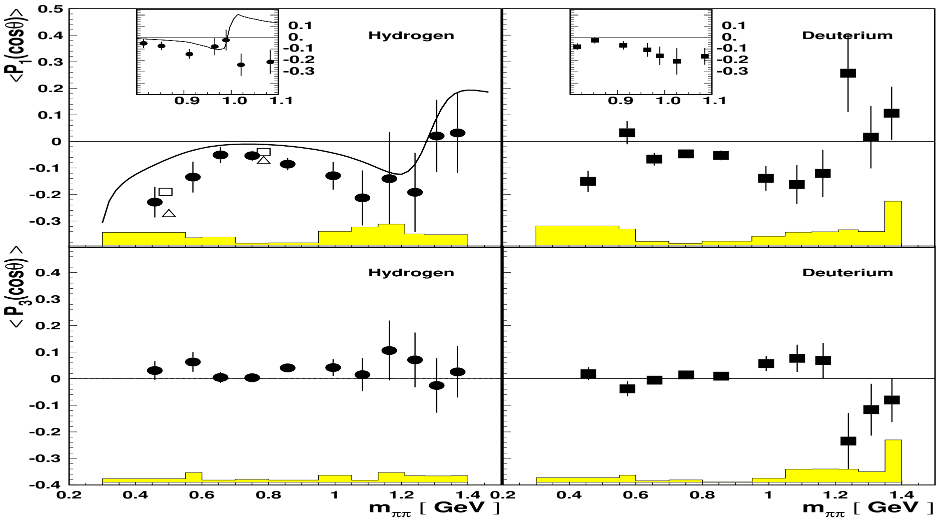

Figure 2. The $m_{\pi\pi}$-dependence of the Legendre moments $\langle P_1 \rangle$ (upper panels) and $\langle P_3 \rangle$ (lower panels) for hydrogen (left panels) and deuterium (right panels), for $x > 0.1$. The region $0.8 < m_{\pi\pi} < 1.1$ GeV is presented with finer bins to better investigate possible contributions from the narrow $f_0(980)$ resonance, as shown in the insert. In the upper panels, leading twist predictions for the hydrogen target including the two-gluon exchange mechanism contribution, LSPG [5,11] (solid curve) at $x = 0.16$ are shown. A calculation without the gluon exchange contribution is shown for limited $m_{\pi\pi}$ values, LPPSG [4] (open squares at $x = 0.1$, open triangles at $x = 0.2$). In these calculations, the contribution from f_0 meson decay was not considered. Instead, the inset panel for the hydrogen target shows the prediction from [12], which includes the f_0 meson contribution. All experimental data have $\langle x \rangle = 0.16$, $\langle Q^2 \rangle = 3.2$ (3.3) GeV^2, and $\langle -t \rangle = 0.43$ (0.29) GeV^2 for hydrogen (deuterium). The systematic uncertainty is represented by the error band.

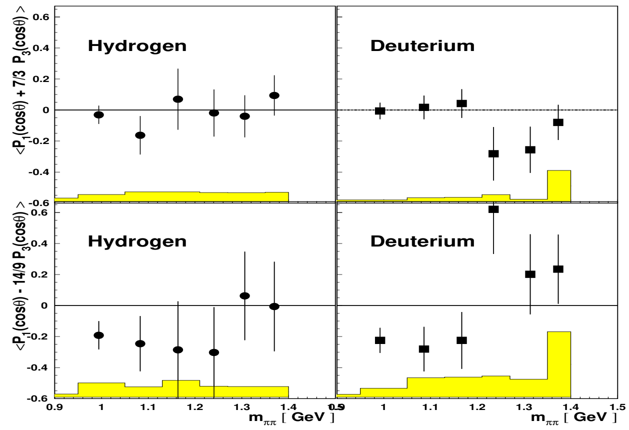

Figure 3.
The $m_{\pi\pi}$-dependence of $\langle P_1 + 7/3 \cdot P_3 \rangle$ (upper panels) and $\langle P_1 - 14/9 \cdot P_3 \rangle$ (lower panels) for hydrogen (left panels) and deuterium (right panels). The data have $\langle x \rangle = 0.16$, $\langle Q^2 \rangle = 3.2$ (3.3) GeV^2, and $\langle -t \rangle = 0.43$ (0.29) GeV^2 for for hydrogen (deuterium). The systematic uncertainty is represented by the error band.

increases in magnitude in the $f_2(1270)$ meson region. A sign change is also prominently visible, reflecting the interference of the P-wave and D-wave resonant $\pi^+\pi^-$ channels. On the other hand, no such signature is evident in the hydrogen data.

In Fig. 2 the $m_{\pi\pi}$-dependence of $\langle P_1 \rangle$ for hydrogen is compared with theoretical calculations based on the GPD framework [4,5,11]. A possible contribution from the f_0 meson was not considered in the calculations. To date, the f_0 contribution is taken into account only by Ref. [12]. The comparison with those predictions for $\langle P_1 \rangle$ on hydrogen is shown in the panel insert of Fig. 2.

The $m_{\pi\pi}$-dependence of the purely longitudinal combination $\langle P_1 + \frac{7}{3} \cdot P_3 \rangle$ is presented in Fig. 3, upper panels, for both hydrogen and deuterium. For comparison, this figure also shows (bottom panels) the combination $\langle P_1 - \frac{14}{9} \cdot P_3 \rangle$ which is believed to be dominated by the higher-twist transverse contribution to the excitation of the f_2 resonance. The comparison between these two distributions suggests that the higher-twist transverse contribution to the Legendre moments in the $f_2(1270)$ region is possibly as large as the longitudinal leading-twist production.

The x-dependence of $\langle P_1 \rangle$ is shown in Fig. 4 for both targets in two regions of $m_{\pi\pi}$: $0.30 < m_{\pi\pi} < 0.60$ GeV and $0.60 < m_{\pi\pi} < 0.95$ GeV. The statistical precision at larger values of $m_{\pi\pi}$ is insufficient for such a presentation. The size of the $\langle P_1 \rangle$ increases with x, in agreement with theoretical expectations according to which at increasing x the $\pi^+\pi^-$ production becomes increasingly dominated by $q\bar{q}$ exchange, leading to a sizable admixture of isoscalar and isovector pion pairs. As explained above this leads to an enhancement of the interference term. The comparison with the theoretical predictions [4] for the proton target is promising.

4 Conclusions

In summary, the Legendre moments $\langle P_1(\cos\theta) \rangle$ and $\langle P_3(\cos\theta) \rangle$ for exclusive electroproduction of $\pi^+\pi^-$ pairs have been measured for the first time for hydrogen and deuterium targets. The data show signatures of the interference between the dominant isospin state $I = 1$ (P-wave) and $I = 0$ (S, D-wave) of these pion pairs. The interference of the ρ^0 amplitude with the non-resonant S-wave and resonant D-wave states appears to be larger than the interference with the resonant f_0 S-wave. In the f_2 region, the combinations $\langle P_1 + 7/3 \cdot P_3 \rangle$ and $\langle P_1 - 14/9 \cdot P_3 \rangle$

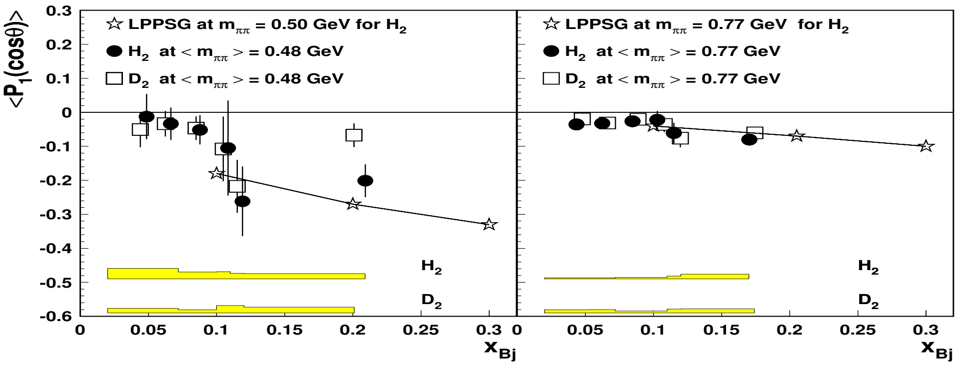

Figure 4. The x-dependence of the Legendre moments $\langle P_1 \rangle$ for both targets separately, in the regions $0.30 < m_{\pi\pi} < 0.60$ GeV (left panel) and $0.60 < m_{\pi\pi} < 0.95$ GeV (right panel). The systematic uncertainty is given by the error band. Theoretical predictions (stars) from LPPSG [4] for hydrogen, which neglect two-gluon exchange mechanism, are compared with the data.

are sensitive to the longitudinal and the transverse states of a D-wave $\pi^+\pi^-$ pair, respectively. Comparison of these combinations suggests that, at $\langle Q^2 \rangle = 3$ GeV^2, the higher-twist transverse contribution to the Legendre moments in the f_2 domain can be as large as the leading-twist longitudinal contribution.

These results constrain the models for Generalized Parton Distributions. Future data of improved statistical significance, when compared to accurate next-to-leading order predictions with and without the inclusion of the two-gluon mechanism, may allow the separation of the contributions of two-gluon and $q\bar{q}$ exchange mechanisms. These mechanisms are connected to the quark and gluon content of the nucleon.

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