PHOTOPRODUCTION WITH A LEADING PROTON AT HERA

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The semi-inclusive reaction $ep \to e'Xp'$ in photoproduction is investigated by the H1 experiment [1] at the HERA accelerator. To measure the energy and scattering angle of the outgoing proton at the interaction point the Forward Proton Spectrometer (FPS) is used [2]. The FPS consists of fibre hodoscopes, sandwiched between scintillators, residing in movable "Roman pot" housings. The acceptance of the FPS is restricted to polar angles below 0.5 mrad and proton energies between 500 GeV and 780 GeV.

By selecting an electron candidate in the electron calorimeters of the luminosity system, the kinematic range is restricted to values of the photon virtuality $Q^2 < 0.01\,\mathrm{GeV}^2$. The central tracking chambers and the central proportional chambers measure the momentum of tracks. At least one track in the H1 detector was required to have a transverse momentum above 0.5 GeV and a polar angle θ in the range of $20° < \theta < 160°$ in order to guarantee a good trigger and reconstruction efficiency. To reject background from interactions of the beam with the residual gas in the beampipe, the z coordinate of the event vertex was restricted to $|z_{\mathrm{Vtx}}| < 35\,\mathrm{cm}$.

This analysis is based on a data set from the 1996 running period, when HERA collided 820 GeV protons with 27.5 GeV positrons, resulting in an ep centre-of-mass energy $\sqrt{s} = 300\,\mathrm{GeV}$. The integrated luminosity amounts to $3.3\,\mathrm{pb}^{-1}$ corresponding to 23072 events.

The data are corrected for acceptances and efficiencies using the Monte Carlo programmes PHOJET [3] and POMPYT [4]. Corrections are made for the trigger efficiency, the track reconstruction efficiency, the track multiplicity dependent trigger efficiency of the central tracker and the electron tagger acceptances. The acceptance corrections range from 0.27 to 0.90.

The differential cross section $\mathrm{d}\sigma_{\gamma p \to Xp'}(W,z)/\mathrm{d}z$ is determined using the relation

$$\frac{\mathrm{d}^3\sigma_{ep\to eXp'}(W,Q^2,z)}{\mathrm{d}y\mathrm{d}Q^2\mathrm{d}z} = \mathcal{F}_{\gamma/e}(y,Q^2)\frac{\mathrm{d}\sigma_{\gamma p\to Xp'}(W,z)}{\mathrm{d}z}, \tag{1}$$

where $z = E'_p/E_p$ is the fractional proton momentum, W is the center-of-mass energy of the photon-proton system with $W = \sqrt{y \cdot s}$ and $\mathcal{F}_{\gamma/e}(y,Q^2)$ is the photon flux in the Equivalent Photon Approximation [5].

Background contributions from the decay of baryon resonances or proton dissociation processes, proton beam wall or residual gas interactions and Bethe-Heitler events $ep \rightarrow e'p'\gamma$ are at the per cent level and neglected in this analysis. The fraction of background events entering the data sample, where $|z_{\rm Vtx}| <$ 35 cm is required, varies between 2.2% and 3.4% and has been subtracted.

The cross section $\mathrm{d}\sigma_{\gamma p\rightarrow Xp'}(W,z)/\mathrm{d}z$ for $W = 91$, 187 and 231 GeV and five values of z in the range $0.68 \leq z \leq 0.88$ is shown in figure 1. It is observed that for all z and W, the measured cross sections are compatible with an average value of $8.05 \pm 0.06\,(\mathrm{stat}) \pm 0.89\,(\mathrm{syst})\,\mu$b. The restriction in the transverse momentum of the final state proton to $p_T \leq 0.2$ GeV implies that the measured cross section represents $23 \pm 2\,(\mathrm{stat}) \pm 5\,(\mathrm{syst})$% of the full cross section if the t dependence is described by the exponential e^{bt} from the fit below.

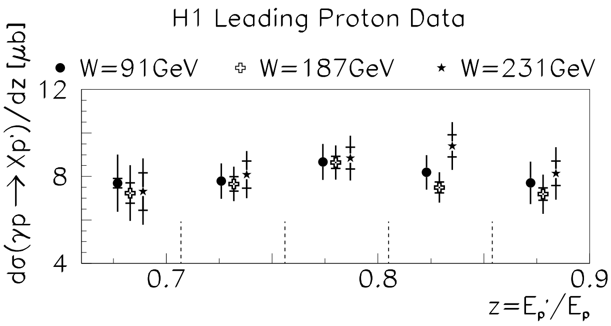

Figure 1: *The cross section $d\sigma_{\gamma p\rightarrow Xp'}/dz$ as a function of z for three values of W. The inner error bar is the statistical and the outer is the total error.*

In Regge phenomenology, the W and z dependences yield information about the exchange mechanisms contributing to leading proton photoproduction. Using the "Triple Regge" ansatz with the Mueller-Regge approach [7] the total cross section at fixed $M_X = W\sqrt{1-z}$ is obtained from a coherent sum of the amplitudes for the exchange of Regge trajectories α_i. If M_X^2 is large and $W^2 \gg M_X^2$, these amplitudes can be expressed as a further sum of Regge trajectories $\alpha_k(0)$. Neglecting interference contributions, the cross section can be expressed as a sum over the contributing Regge trajectories [6]

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}t\mathrm{d}z} = W^2\frac{\mathrm{d}^2\sigma}{\mathrm{d}t\mathrm{d}M_X^2} = \frac{s_0}{W^2}\sum_{i,k} G_{iik}(t)\left(\frac{W^2}{M_X^2}\right)^{2\alpha_i(t)}\left(\frac{M_X^2}{s_0}\right)^{\alpha_k(0)} \qquad (2)$$

where α_i refers to the trajectory exchanged between the photon and the proton, α_k refers to the additional trajectory describing the total cross section between α_i and the photon and $G_{iik}(t)$ represents the product of all couplings. It is further assumed that all t dependent terms can be absorbed into a single exponential e^{bt} and each trajectory has the form $\alpha_i(t) = \alpha_i(0) + \alpha_i' t$.

The observed approximate independence of $\mathrm{d}\sigma/\mathrm{d}z$ of M_X^2 and W implies that $2\alpha_i(0) - 1 \sim 0$ and $\alpha_k(0) - 2\alpha_i(0) \sim 0$, i.e. $\alpha_i(0) \sim 0.5$ and $\alpha_k(0) \sim 1$. A fit to the data gives: $\alpha_i(0) = 0.33 \pm 0.04(stat) \pm 0.04(syst)$ and $\alpha_k(0) = 0.99 \pm 0.01(stat) \pm 0.05(syst)$. The cross section $\mathrm{d}\sigma/\mathrm{d}z$ superimposed by the Triple Regge fit is shown in figure 2.

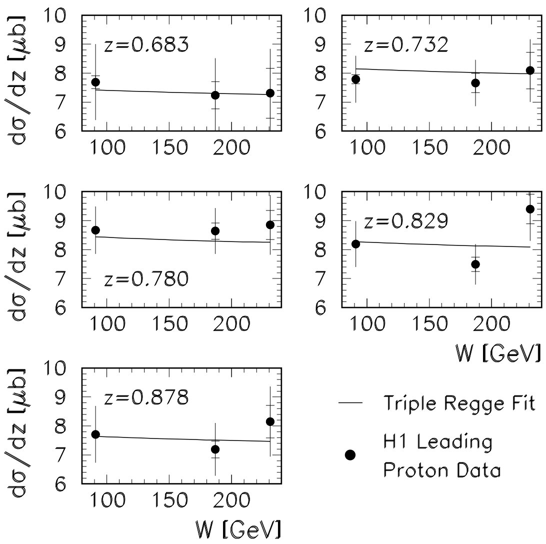

Figure 2: *The Triple Regge fit to the cross section $d\sigma/dz$ as a function of W.*

At the mean value $z = 0.78$, the slope $b = 6.6 \pm 0.7\,(\mathrm{stat}) \pm 1.5\,(\mathrm{syst})\ \mathrm{GeV}^{-2}$ is obtained. The values of $\alpha(0)$ for the π, $I\!R$ and Pomeron trajectories are approximately 0, 0.5 and 1.0, respectively [9]. Hence, within the framework of the applied model, we deduce that the exchange between the photon and the proton can be understood as a mixture of π and $I\!R$ trajectories, consistent with the previous H1 measurement at higher Q^2 [10]. In addition since $\alpha_k(0)$ is close to unity, the total cross section for photon scattering from the mixture of π and $I\!R$ Reggeons is dominated by Pomeron exchange.

The photoproduction cross sections are compared with data from deep inelastic scattering with a leading proton in the range $0.71 < z < 0.90$, published in [10]. The DIS data sample covered the range $2\,\mathrm{GeV}^2 \leq Q^2 \leq 50\,\mathrm{GeV}^2$ and $6 \cdot 10^{-5} \leq x \leq 6 \cdot 10^{-3}$.

A sensitive quantity to study the transition from DIS to photoproduction is the ratio of the semi-inclusive to inclusive cross sections, for photoproduction defined as

$$\mathrm{f_{LP}}(Q^2 \approx 0, W, z) = \frac{\mathrm{d}\sigma_{\gamma p \to X p'}/\mathrm{d}z(Q^2 \approx 0, W, z)}{\sigma_{\gamma p}^{tot,DL}(W)}, \tag{3}$$

where $\sigma_{\gamma p}^{tot,DL}$ is a parametrization taken from [11]. For DIS, the ratio of leading proton production to the inclusive process is obtained from

$$\mathrm{f_{LP}}(Q^2, W, z) = \frac{F_2^{LP(3)}(x, Q^2, z)}{F_2^{\mathrm{H1QCD}}(x, Q^2)}, \tag{4}$$

where $F_2^{\mathrm{H1QCD}}(x, Q^2)$ is a parametrisation of the proton structure function taken from [12].

The ratios $\mathrm{f_{LP}}(Q^2, W, z)$ are shown in figure 3, separately for each z value in four ranges of W. The fraction of leading proton events is found to increase with Q^2 from $\sim 5\%$ in photoproduction to about 10% at $Q^2 \sim 10\,\mathrm{GeV}^2$ at all z and W.

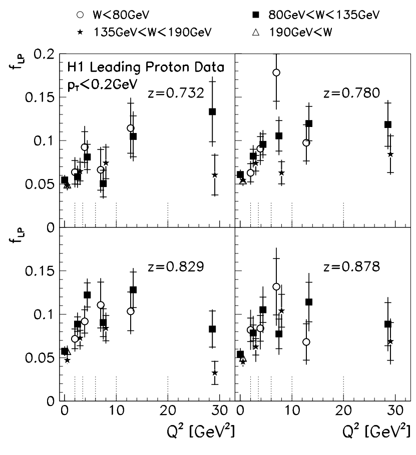

Figure 3: *The ratio* $\mathrm{f_{LP}}$ *of leading proton events to all events as a function of* Q^2.

The observed rise of f_{LP} cannot fully be explained by any reasonable Q^2 dependence of the t slope and thus indicates a breaking of factorisation of the proton from the photon vertex. A similar suppression of the cross section relative to predictions based on vertex factorisation has been observed in diffractive dijet production in regions where the photon is resolved [13] and in the process $pp \to Xp$ at high energy [14].

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