Exclusive Diffraction and Leading baryons at HERA

D. Wegener *
Institute of Physics, TU Dortmund
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Abstract
Recent results on elastic vector meson production are presented and compared to QCD based model predictions. M_V, Q^2, t provide a hard scale. The processes can be described by dipole and 2–gluon exchange models. Leading neutron and proton production data have been measured and are compared to model predictions. Moreover the conditional structure function $F_2^{LN(3)}$ is derived from the neutron data.

1 Exclusive diffraction

1.1 Exclusive vector meson production – predictions

The production of vector mesons in the process $ep \to eVp$ according to the factorization theorem can be described as a three step process, if a hard scale exists: the photon fluctuates into a $q\bar{q}$ pair, carrying the fractional longitudinal momenta z and 1–z respectively. It is followed by the interaction of the dipole with the proton parametrized by the dipole cross section σ_{dip} and finally the recombination into a vector meson. The amplitude for the process is given by the expression $A = \Psi_\gamma \bigotimes \sigma_{dip} \bigotimes \Psi_V$. While Ψ_γ is calculable in QED, Ψ_V is defined by models or parton–hadron duality [1].
The dipole cross section is assumed to be universal in the sense that it permits to describe with the same parameter set the processes $ep \to eX, epX, eVp$. For the latter process $\bar{Q}^2 = z(z-1)(Q^2+M_V^2)$ provides a universal scale. While for longitudinal photons $q\bar{q}-$pairs with fractional longitudinal momenta $z \approx (1-z) \approx \frac{1}{2}$ dominate, i.e. the extension of the dipole is $r^{-2} \approx \frac{1}{4}(Q^2+M_V^2)$, transverse photons contribute up to $z = 0, 1$, hence reliable pQCD calculations of A_T are only possible at higher Q^2 [1]. Vertex factorization holds in the sense that at fixed t elastic and inelastic diffraction display the same Q^2 and W dependence.
In pQCD, σ_{dip} can be modelled in LO by the exchange of two gluons and as a gluon ladder in LL $\frac{1}{x}$ respectively [3, 4]. Hence the vector meson production cross section depends on the gluon distribution according to $\sigma_{VM} \sim [xg(x)]^2 \sim W^\delta$ since $x \approx \frac{Q^2}{W^2}$. Because of the steep rise of g(x) for decreasing x, δ is expected to increase for large Q^2. At low Q^2 the Regge model predicts $\delta \approx 0.2$.

1.2 Hard scales

The measured cross section for the process $\gamma p \to Vp$ as a function of the total energy W is shown in fig.1a. The $\rho^0-, \omega-$ and $\phi-$meson cross sections increase with W with an exponent δ comparable with the total cross section, for the heavy quarkonium states $\psi(1S), \psi(2S)$ and $\Upsilon(1S)$ as predicted by pQCD [1] the increase is steeper. The dipole model ascribes the steeper

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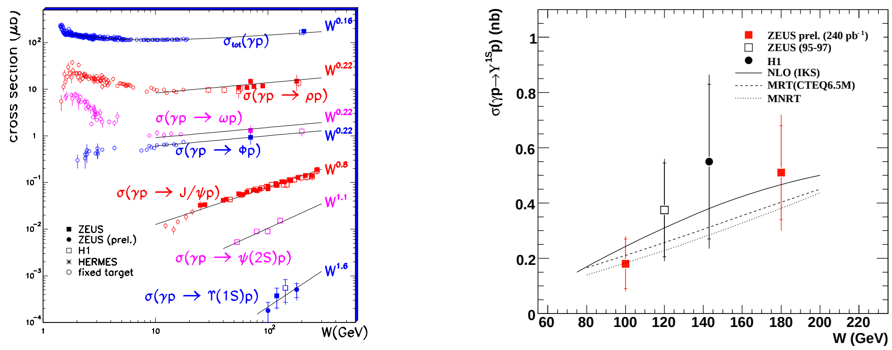

Fig. 1: Photoproduction cross section of vector mesons as function of cms energy W (a) and for $\Upsilon(1S)$ compared with model predictions(b) [2]

rise of the $\psi(2S)$ cross section to the zero of the wave function and correspondingly a smaller dipole. In summary the mass of the heavy quarkonium states provides a hard scale; indeed, as demonstrated by fig.1b, pQCD models reproduce the W–dependence of $\sigma(\gamma p \to \Upsilon(1S)p)$.
If flavour factors are taken into account [5], the cross section for the process $ep \to eVp$ displays an universal dependence on $Q^2 + M_V^2$. This is predicted by the dipole model [1] since the cross sections are expected to depend only on the dipole size. The t–dependence of the cross section at low t can be parametrized by an exponential $\frac{d\sigma}{dt} \sim exp(b \cdot t)$, where b is an universal function of $Q^2 + M_V^2$ (fig.2a); moreover the slope levels off for $Q^2 + M_V^2 \approx 5\ GeV^2$ as predicted by the dipole model [1], where $b = b_{dip} \bigoplus b_{nucl}$ and $b_{dip} \to 0$ for large Q^2. The point like photon probes the gluon distribution of the proton which turns out to be smaller than the proton radius.
Measuring the W–dependence of the production cross section for different Q^2 intervals, $\delta(Q^2)$ can be determined. It increases with Q^2 (fig.2b) as expected for a hard process. The data are compatible with predictions based on 2–gluon exchange and the dipole model respectively [7]. Figs.1–2 demonstrate that $Q^2 + M_V^2$ provides an universal hard scale.
Moreover the momentum transfer t at the proton vertex supplies a hard scale as shown in fig.3a, where the t dependence of $\frac{d\sigma}{dt}$ for the process $\gamma p \to \rho Y$ is plotted. At large t the data are described by a power law with a power characteristic for a hard process [9]. This result can be generalized, since factorization of the processes at the two vertices have been shown to hold for a plethora of elastic and inelastic diffractive reactions [6, 10].
Measurements of the DVCS process $\gamma^* p \to \gamma p$ are less sensitive to model assumptions since the final state is calculable. The measured values of $\delta(Q^2) \approx 0.8$ [11] are compatible with the expectations for a hard process. The dimensionless variable $S(Q^2) = \sqrt{\frac{\sigma_{DVCS} \cdot Q^4 \cdot b(q^2)}{1+\rho^2}}$ allows the study of the Q^2–dependence and $R(Q^2) = \frac{ImA(\gamma^* p \to \gamma p)}{ImA(\gamma^* p \to \gamma^* p)} = \frac{\sqrt{\pi \cdot \sigma_{DVCS} \cdot b(Q^2)}}{\sigma_T(\gamma^* p \to X) \cdot \sqrt{1+\rho^2}}$ provides direct information on the general parton distributions (GPD). ρ is the ratio of the real to imaginary part of the DVCS scattering amplitude. Recent results [11] are shown in fig.3b and compared to model calculations based on GPD's [12]. The expected skewing effect of 2–gluon exchange is observed (fig. 3b).

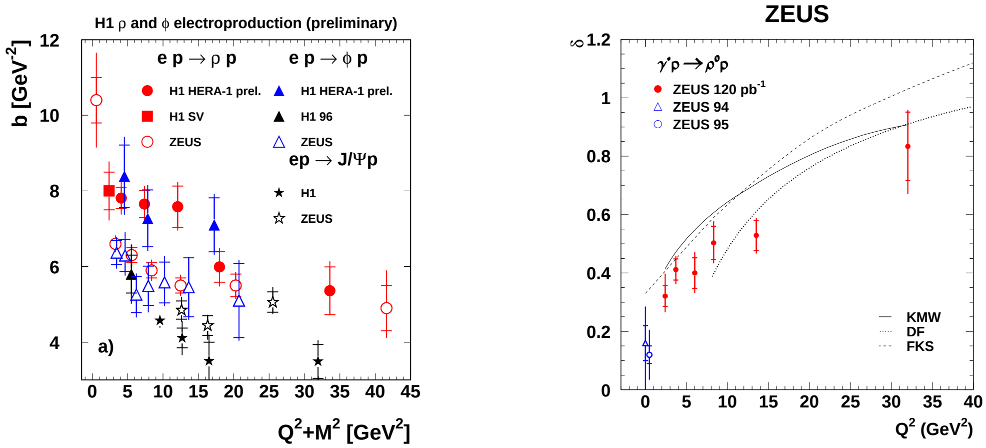

Fig. 2: (a) Slope b of the t-distribution for the process $ep \to epV$ as function of Q^2 [6] and (b) Q^2 dependence of $\delta(Q^2)$ [7]

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1.3 Helicity amplitudes

The analysis of the angular distribution for the processes $ep \to e\rho^0 p, e\Phi p$ allows to determine 15 spin density matrix elements (SDME) and 6 helicity amplitudes $T_{\lambda_\gamma \lambda_V}$ respectively [13]. If the helicity of the virtual photon is transfered to the vector meson, single as well as double flip amplitudes should vanish and only 5 SDME should contibute. Moreover pQCD predicts $T_{00} > T_{11} > T_{01} > T_{10}, T_{1-1}$. Recent results are shown in fig.4 [6]. The five SDME expected to be nonzero,if SCHC holds, are indeed so; they agree with the predictions of a pQCD based model [14]. Except for $r^5_{00} \sim T_{10}\dot{T}^*_{00}$, all other spin–flip SDME are compatible with zero as predicted by SCHC. The SDME $r^4_{00} = \frac{\sigma_L}{\sigma tot}$, where $\sigma_{tot}(\sigma_L)$ are the total production cross section for unpolarized and longitudinal photons respectively, is shown in fig.4 (left upper corner) as function of Q^2. A leveling off is observed for $Q^2 \approx 10\ GeV^2$.

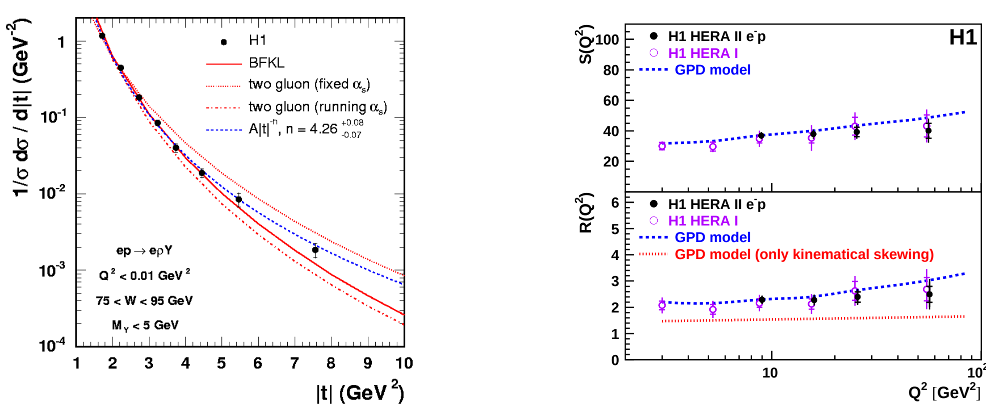

Fig. 3: (a) t-distribution for the process $\gamma p \to \rho X$ [8] and (b) plot of dimensionless variables S and R as function of Q^2 [11]

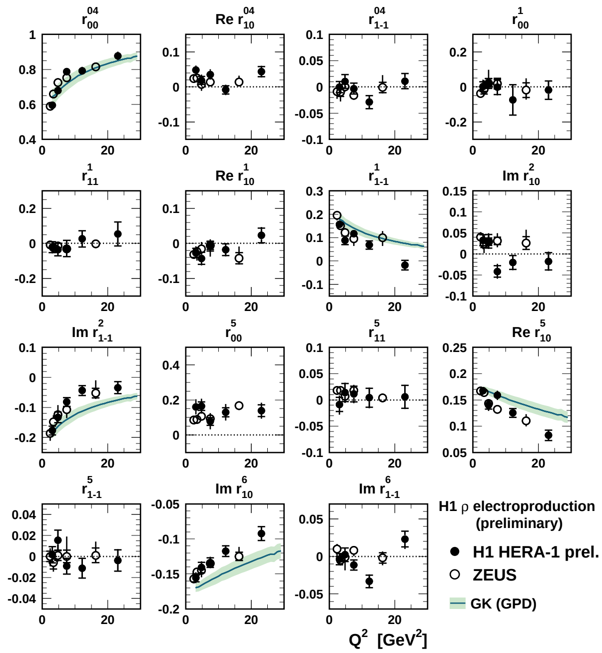

Fig. 4: Q^2-dependence of SDME [6] compared to pQCD predictions [14]

2 Leading baryons in $ep \to eNX$

Studying this process allows a test of the applicability of standard fragmentation models to the semi-inclusive process; moreover the principle of limiting fragmentation [15], postulating the factorization of the photon and proton vertex, can be checked by comparing baryon production in the process $\gamma p \to NX$ and $\gamma^* p \to NX$. The interpretation of the data in the spirit of Regge exchange allows the $\pi-$flux to be factorized from the inclusive scattering of the electron on the $\pi-$meson: $\frac{d^2\sigma}{dx_L dt} = f_{\pi/p}(x_L, t) \cdot \sigma_{\gamma^*\pi}((1-x_L)W, Q^2)$. Moreover the influence of absorption and migration due to rescattering effects can be studied, being of interest for models describing the gap survival probability in diffractive processes at LHC [16].

In fig.5a data [18] for the process $ep \to enX$ are compared with the prediction of different fragmentation models. None describes the data (see also fig. 5b), only the RAPGAP Monte Carlo with $\pi-$exchange reproduces their shape [18]. As demonstrated by fig.5b, a mixture of DJANGO and RAPGAP with $\pi-$exchange allows to reproduce the data. In the interval $0.5 < x_L < 0.9$ $\pi-$exchange dominates. Note, however, that the ratio $r = \frac{\sigma(ep\to epX)}{\sigma(ep\to enX)} \approx 2$ while for $\pi-$exchange $r = \frac{1}{2}$ is expected [18], hence the Regge model with isospin 1 exchange only is not sufficient.

The cross sections for the processes $\gamma p \to n + X$ are suppressed in comparison to those of the reaction $ep \to enX$ (fig.5a), indicating absorption and migration. In the interval $x_L > 0.5$ absorption models [16, 17], based on multi–Pomeron exchange, describe this suppression reasonably, if one considers the different W-dependence of the processes. Kaidalov et al. [16] have shown that migration processes are of importance for $x_L < 0.5$.

Finally H1 [19] has derived the ratio of structure functions $F_2^{LN(3)}(x, Q^2, x_L)/F_2(x, Q^2)$ (fig.5c). This ratio turns out to be constant over a broad interval of x and Q^2 for $0.37 < x_L < 0.82$, which

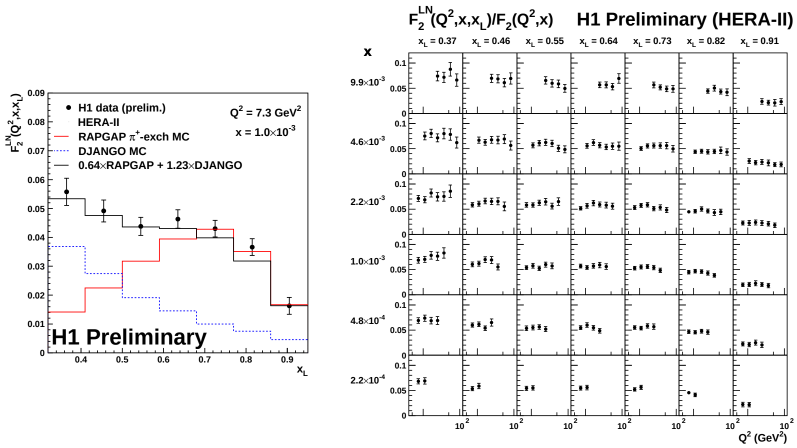

Fig. 5: (a) Ratio of normalized cross sections of photo– and electroproduction of leading neutrons as function of x_L [18], (b) conditional structure function $F_2^{LN(3)}$ as function of x_L [19] and (c) ratio of $F_2^{LN(3)}(x, Q^2, x_L)/F_2(x, Q^2)$ as function of the kinematical variables [19]

nourishes the hope that the structure function $F_2^{\pi}(x, Q^2)$ can be constrained by these data.

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