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Diffractive production of vector mesons at HERA

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Abstract. An extended study of vector meson production has been performed by the ZEUS collaboration over a large kinematical phase space. Precision data test various QCD based predictions at high energies in a region that maps the transition between soft and hard dynamics. This report covers recent results on exclusive ρ and J/ψ and proton dissociative J/ψ photoproduction at high $|t|$.

1 Introduction

HERA collider offers a unique opportunity to study the diffractive production of vector mesons $ep \to eVY$ where $V = \rho, \omega, \phi, J/\psi, \psi'$ or Υ and Y being either a scattered proton or a low mass hadronic system.

A consistent picture of vector meson production can be expressed simply in the rest frame of the proton. The production is viewed as a sequence of processes: the virtual photon fluctuates into a $q\bar{q}$ pair which scatters from the proton and eventually forms a meson bound state. At high energies these processes are well separated in time. At high photon virtualities Q^2, or a heavy quark mass squared the transverse size of the dipole is relatively small compared to the size of the proton and pQCD [1,2] becomes applicable. For light vector mesons and low Q^2, large dipoles dominate and the interaction is expected to be described by Regge Phenomenology [3] and the Vector Meson Dominance model (VMD) [4].

The dependence of the cross-section on several variables has been measured: the mass of the vector meson m_{VM}, the photon virtuality $0 \leq Q^2 < 100\ GeV^2$, the center-of-mass energy of the γp system $20 < W < 290\ GeV$ and the four-momentum transfer squared at the proton vertex $-12 < t < 0\ GeV^2$.

2 W dependence of the $\gamma^* p$ cross-section

The dependence of the $\sigma(\gamma^* p \to \phi p)$ on the photon-proton center of mass energy W is expected to be $\sigma \propto W^{\delta(Q^2)}$. For the soft processes $\delta \sim 0.2$, while in pQCD the prediction is related to the gluon density: $\sigma \sim |xG(x,Q^2)|^2 \sim x^{-2\lambda} \sim W^{2\lambda}$ which leads to $\delta \approx 0.8$.

The results for the ρ and J/ψ are shown in Figs. 1 and 2. For ρ production, δ rises smoothly with Q^2 showing the transition from soft to hard physics. In the case of the J/ψ no Q^2 dependence is observed and $\delta \approx 0.7$ in agreement with pQCD since the large charm quark mass provides a hard scale for all Q^2.

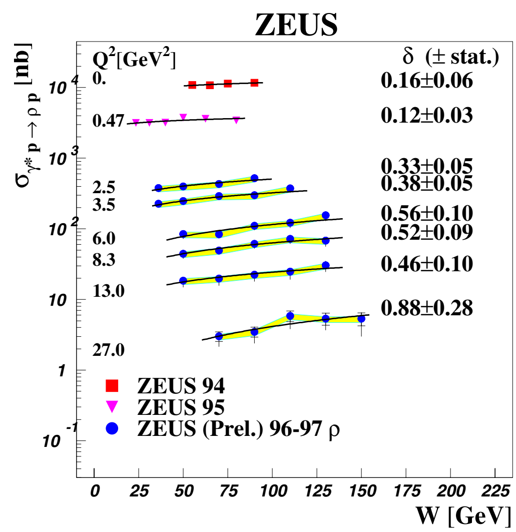

Fig. 1. W dependence of the $\sigma(\gamma^* p \to \rho p)$ for various Q^2 values [5]. The *lines* represent the results of a fit $\sigma \sim W^\delta$ for fixed value of Q^2 and the results of the fit are shown in figure

3 Q^2 dependence of the $\gamma^* p$ cross-section

The dependence of the J/ψ cross-section can be described by a simple function $\sigma \sim \frac{1}{(Q^2+M_{VM}^2)^n}$ with $n = 2.7 \pm 0.08$ [7]. On the other hand the same fit to the ρ data [6] suggests that the parameter n increases with Q^2. The physical interpretation of this fact is the subject of debate. In the framework of the dipole model, the effect can be attributed to the $x \approx Q^2/W^2$ dependence of the gluon density in the proton or to other Q^2-dependent effects.

4 Ratio of the longitudinal and transverse cross-sections for ρ production

The ratio of the ρ production cross-sections for longitudinally and transversely polarized photons can be extracted

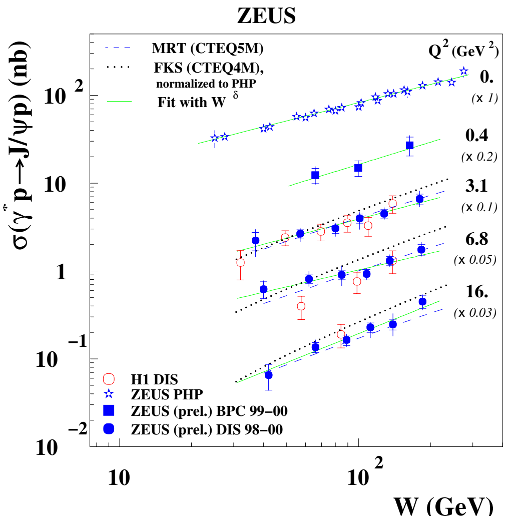

Fig. 2. W dependence of the $\sigma(\gamma^* p \to J/\psi p)$ for several values of Q^2 [7]. The *lines* show the results of a fit to the form $\sigma \sim W^\delta$ as well as two pQCD predictions [1,2]

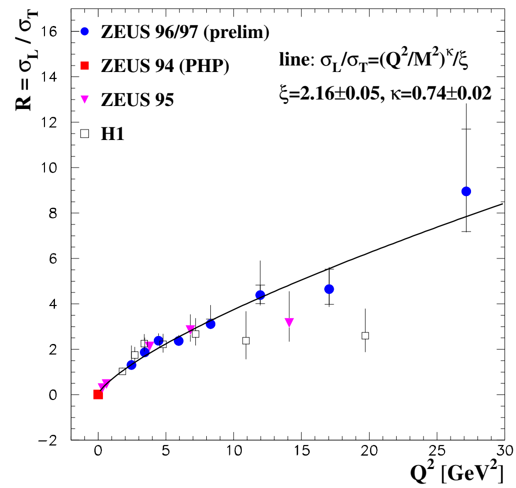

Fig. 3. The value of R as a function of Q^2 for ρ production. The *full line* is a result of fit to the function described in Sect. 4

from the measurement of the spin density matrix through the angular distributions of decay products and the scattered electron [9].

The $q\bar{q}$ dipole sizes for transversely polarized photons are expected to be larger than for those with longitudinal polarization. This means that the predictions of pQCD become applicable at lower Q^2 for the longitudinally polarized photons while for transverse photons the soft physics processes still dominate. For these reasons it is expected that R should rise with W at fixed Q^2. The ratio of the cross-sections thus represents a powerful test for models of VM production.

The dependence of R on Q^2 is shown in Fig. 3. R first rises steeply with Q^2 and this rise softenes for large values of Q^2. The formula $R(Q^2) = (Q^2/M_{VM}^2)^\kappa/\xi$ leads to a good description of the data with $\xi = 2.16 \pm 0.05$ and $\kappa = 0.74 \pm 0.02$.

Within the errors R doesn't depend on W [5]. This is in contradiction with the naive expectation described above. This is an indication that despite the large differences in expected dipole sizes for transversely and longitudinally polarized photons the interaction of large dipoles sizes is suppressed so that dipoles of similar sizes contribute to the production of ρ.

5 Pomeron trajectory for the J/ψ electroproduction

In the context of Regge theory [3], elastic and diffractive processes are described by the exchange of the Pomeron trajectory. The predicted energy dependence takes the form $\sigma \sim W^{4(\alpha_P(t)-1)}$, where $\alpha_P(t) = \alpha_P(t) + \alpha' t$. At ZEUS the pomeron trajectory can be extracted through the measurement of the W-dependence of the cross-section for different values of t. The measured value at $< Q^2 >= 6.7\ GeV^2$ of $\alpha_P(t) = (1.21 \pm 0.03) + (0.1 + 0.05) \times t$ is consistent with the previous results measured at $< Q^2 >=$

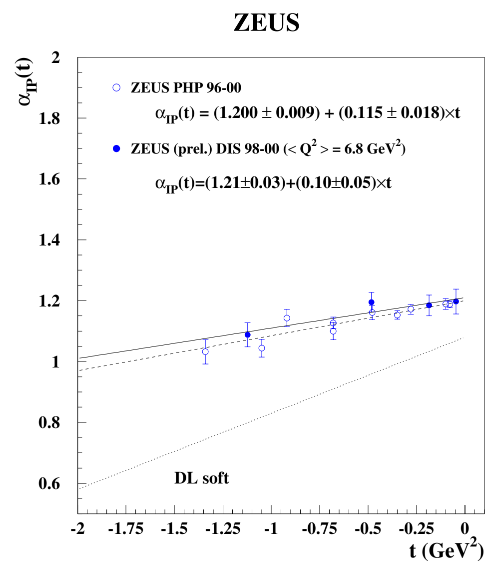

Fig. 4. The t dependence of the pomeron trajectory, α_P for J/ψ measured for two values of Q^2, $< Q^2 >= 0\ GeV^2$ and $< Q^2 >= 6.7\ GeV^2$

$0\ GeV^2$ [8] where $\alpha_P(t) = (1.2 \pm 0.009) + (0.115 + 0.018) \times t$. The measurement is consistent with prediction [10].

6 Proton dissociative photoproduction at high $|t|$

Photoproduction of ρ, ω, ϕ and J/ψ mesons has been studied [11] at $W = 100\ GeV$ for $|t| < 12\ GeV^2$. The t dependence of the differential cross-section is described by a power-like behaviour $d\sigma/dt \propto |t|^{-n}$ with n decreasing with increasing mass of the vector meson as shown in Fig. 5. The data are well described by a BFKL-like behaviour [14] and [15].

The W dependence of J/ψ photoproduction has also been investigated [12]. The results, shown in Fig. 6, should be compared with the predictions given by models based

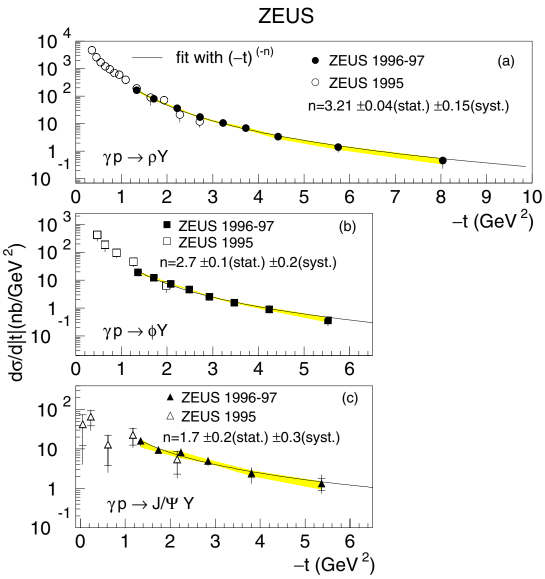

Fig. 5. The differential cross-section $d\sigma/d|t|$ for ρ^0, ϕ and J/ψ.The *lines* are results of the fit to the function $|t|^{-n}$

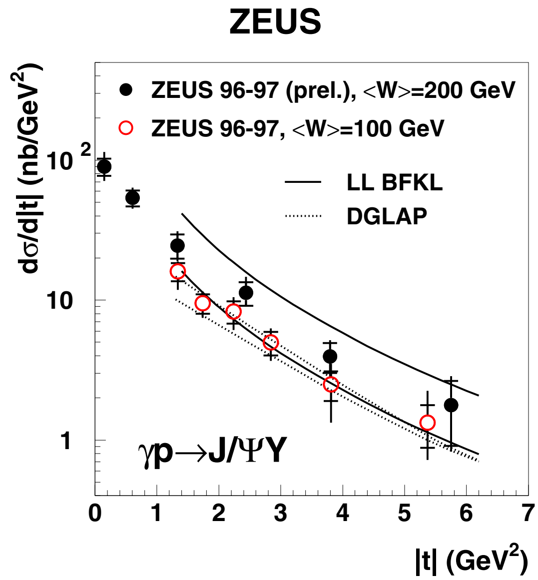

Fig. 6. The differential cross-section $d\sigma/d|t|$ for the process $\gamma p \rightarrow J/\psi p$ at $W \simeq 200\,GeV$ (*full circles*) and at $W \simeq 100\,GeV$ (*open circles*). The *solid lines* represent the result of the BFKL calculations [16] and the *dashed* ones the result of DGLAP calculations [13] at two energies

on 2-gluon exchange (DGLAP) [13] and those assuming the exchange of BFKL gluon ladder [14,15]. Both models predict a relatively hard t dependence as compared to exlusive VM photoproduction. The two classes of models differ, however, in the predicted energy dependence of $d\sigma/dt$: two-gluon exchange yields energy independent cross-sections whereas BFKL exchange leads to cross-sections that rise with increasing energy.

The observed increase of the cross-section with W favours the gluon-ladder exchange models over two-gluon exchange. However, further improvements on the theory side - mainly the treatment of non-leading terms into the BFKL calculations - are needed in order to make a more definitive conclusion [16].

7 Conclusions

The data on the exclusive production of vector mesons are consistent with expectations from the dipole model. J/ψ production shows all signs of a hard process while for the ρ a smooth transition from the soft to the hard regime is observed.
Photoproduction of vector mesons with proton dissociation shows that $|t|$ can serve as a hard scale as well. The energy dependence of the cross-section observed for the J/ψ photoproduction is in agreement with the BFKL predictions.

Quantitative understanding of vector meson production at HERA requires further developements of the theory and would benefit from measurements of increased precision.

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