Diffractive Heavy Vector Meson Production at HERA

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Abstract

In order to shed further light on the production mechanism of heavy vector mesons at HERA energies new results from the HERA experiments H1 and ZEUS on diffractive J/ψ and Υ photoproduction in ep collisions are reviewed. The dependences on the hadronic final state mass, $W_{\gamma p}$, the momentum transfer at the proton vertex, t, and the exchanged Regge trajectory are measured in order to distinguish between perturbative and non-perturbative effects.

1. Elastic J/ψ Photoproduction

The H1 collaboration reported on a new measurement of elastic J/ψ photoproduction [1]. The data correspond to an integrated luminosity of $\int\mathcal{L}\mathrm{d}t \simeq 21$ pb^{-1} and cover the following kinematic region:

$$40 < W_{\gamma p} < 150\,\mathrm{GeV} \quad \text{and} \quad Q^2 < 1\,\mathrm{GeV}^2.$$

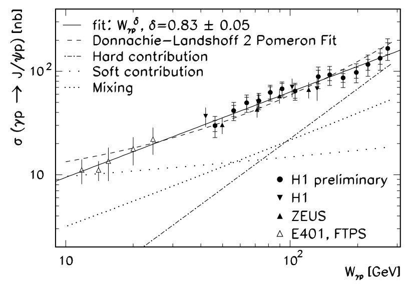
Elastic J/ψ mesons are reconstructed via their muonic decay mode. The selection resembles closely the procedure described in detail in [2]. The data are corrected for backgrounds from proton dissociation ($14\,\%$), non-resonant QED two-photon processes ($12\,\%$) and from the process $\psi(2S) \to J/\psi +$ neutrals (3 %). The systematic error amounts to about $12\,\%$ on average.

1.1. $\boldsymbol{W_{\gamma p}}$ Dependence

The total γp cross section for the entire $W_{\gamma p}$ range is shown from this analysis together with previous HERA results [2, 3, 4] and fixed target data [5, 6] in figure 1a). A fit $\propto W_{\gamma p}^{\delta}$ to all data is performed yielding $\delta = 0.83 \pm 0.05$. A fit according to the two-pomeron model by Donnachie and Landshoff [7] adjusting only the contributions of the two pomerons is also shown. The dashed curves represent the *soft* and the *hard* pomeron contribution as well as their mixing. In figure 1b) the HERA data are compared to predictions by Frankfurt et al. [8] which use different parameterisations of the gluon density in the proton. The normalisation of the curves has been adjusted to the data.

The rise with energy is found to be much steeper than in the prediction of the Donnachie-Landshoff model using the soft pomeron only [9] ($\delta = 0.22$–0.32). The description of the data is improved taking into account a second hard pomeron [7]. The important prediction of the perturbative QCD calculations by Frankfurt et al. [8] concerns mainly the slope of the cross section while the absolute magnitude depends critically on the mass of the charm quark. The slope of the data is described using the gluon density CTEQ4M or MRSR2 while GRV-HO is slightly too steep.

a)



b)

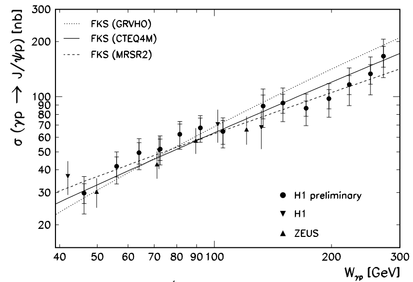


Figure 1. *Total elastic J/ψ cross section $\sigma_{\gamma p}$ as a function of $W_{\gamma p}$ compared to different models. The inner error bars show the statistical uncertainty, whereas the outer bars give the systematic and the statistical errors added in quadrature.*

1.2. Elastic Slope Parameter $\boldsymbol{b}$

The momentum transfer t at the proton vertex can be approximated by p_t^2 of the J/ψ in photoproduction. The differential cross section can be fitted by an exponential

† For the H1 and ZEUS collaborations.

for low values of $|t|$: $\sigma_{\gamma p} \propto e^{-b|t|}$. Within the soft pomeron model [9] a logarithmic increase of the elastic slope parameter b with energy is predicted (shrinkage of the diffractive peak):

$$b = b_0 + 4\alpha' \ln(W_{\gamma p}/W_0) \,, \qquad (1)$$

with $\alpha' = 0.25$. The hard pomeron is expected to show much less shrinkage ($\alpha' = 0.1$ [7]). In predictions derived in the context of pQCD there is also little or no shrinkage.

Fits to the corrected t distributions with an exponential up to $|t| = 0.8$ GeV^2 are performed. The resulting b values are shown as a function of $W_{\gamma p}$ in figure 2a). In figure 2b) in addition previous HERA data and one fixed target result (re-fitted with a single exponential in order to be consistent with the HERA data) are presented. Fits are shown both for equation 1 as well as for a straight line (no shrinkage). For both data sets the χ^2 are compatible for the two different assumptions, favouring slightly the shrinkage hypothesis (on a 2 s.d. level).

The fit to all data (figure 2b) allowing for shrinkage yields:

$$b_0 = (4.5 \pm 0.2)\ \text{GeV}^{-2}, \alpha' = (0.18 \pm 0.09)\ \text{GeV}^{-2},$$

with $W_0 = 90$ GeV. Assuming no energy dependence yields an average $b = 4.3 \pm 0.2$ GeV^{-2}. The data are clearly compatible with being independent of $W_{\gamma p}$. Shrinkage can however not be excluded in view of the errors.

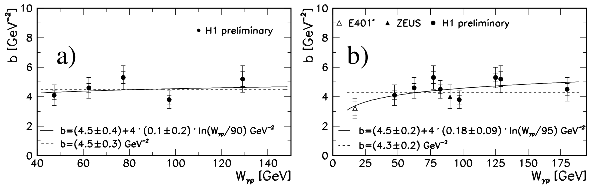


Figure 2. *The results for b in five $W_{\gamma p}$ bins. The inner error bars are the statistical errors only, while the outer bars are the statistical and the systematic errors added in quadrature.*

1.3. Regge Trajectory

A more direct way of determining the properties of the exchange in diffractive J/ψ production is proposed in [10]. The differential cross section $d\sigma/dt$ at fixed t is determined as a function of $W_{\gamma p}$ as shown in figure 3. The data are fitted with the function:

$$\frac{d\sigma}{dt_i}(W_{\gamma p}) = N_i \cdot (W_{\gamma p}/90\,\text{GeV})^{4\alpha(t_i)-4} \qquad (2)$$

in five bins of $t_i (i = 1...5)$ using N_i and $\alpha(t_i)$ as free parameters. The resulting values for $\alpha(t_i)$ are then fitted to the linear form $\alpha_0 + \alpha' \cdot t$, yielding:

$$\alpha(t) = (1.26 \pm 0.05) + (0.05 \pm 0.15) \cdot t \,.$$

The result of this fit is shown in figure 4 as a band reflecting the 1 s.d. contour taking into account correlations. It favours the absence of shrinkage of the diffractive peak, but the data are not yet precise enough to allow a final judgment. The measured trajectory lies in between the soft and the hard pomeron by Donnachie and Landshoff and close to the pomeron derived in the context of the BFKL equation [11].

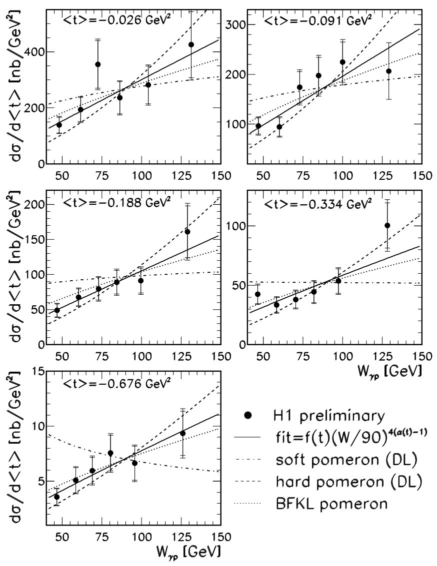


Figure 3. *The differential γp cross section $d\sigma/dt$ as a function of $W_{\gamma p}$ in five bins of t together with a fit of the form $\frac{d\sigma}{dt} = N \cdot (W_{\gamma p}/90\ GeV)^{4\alpha(t)-4}$ in each bin. The average t values are indicated in the plots.*

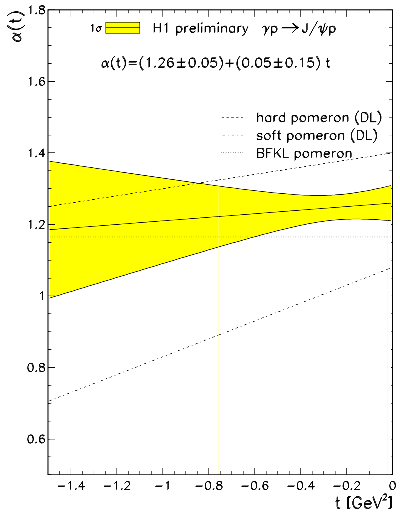


Figure 4. *The measured Regge trajectory $\alpha(t) = \alpha_0 + \alpha' \cdot t$ for the process $\gamma p \to J/\psi p$. The data are given by the 1 s.d. band from the fit.*

2. Proton Dissociative J/ψ Production

The ZEUS collaboration measured the J/ψ photoproduction cross section with proton dissociation at high $-t$. The measurement is shown in figure 5 together with a prediction within the BFKL framework by Bartels et al. [12]. A good description by the BFKL calculations is achieved. However, it has to be stressed that this is only a leading order calculation and that a large uncertainty is introduced due to the choice of α_s. The measurement is found to be in good agreement with a similar measurement by the H1 collaboration [13].

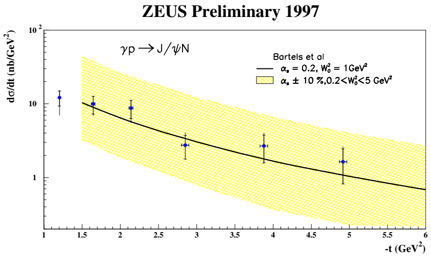


Figure 5. *J/ψ photoproduction cross section with proton dissociation at high momentum transfer $-t$ together with a LO BFKL prediction [12].*

The high $-t$ J/ψ data are also used to measure the cross section ratio of J/ψ to ρ mesons as shown in figure 6 (lower plot). The ratio which is expected from flavour independence is only reached at high values of $-t$, while it is significantly lower at low $-t$. This can be compared to the light vector mesons, σ_ϕ/σ_ρ (upper plot), for which this ratio is already measured at lower $-t$.

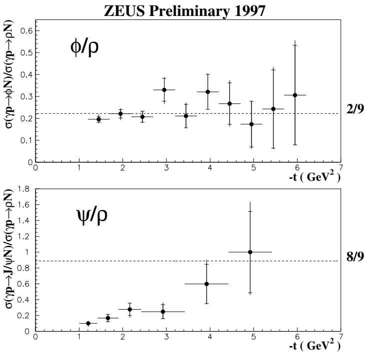


Figure 6. *The cross section ratios of ϕ and ρ and of J/ψ and ρ as a function of $-t$ compared to the expectation from flavour independence.*

3. Elastic Υ Production

An update of the measurement of the elastic Υ photoproduction from the ZEUS collaboration is presented in figure 7. The published result [14] based on the muonic decay is improved by new data from the decay $\Upsilon \rightarrow ee$. It is shown together with the preliminary H1 measurement [15] and several theoretical calculations. While the prediction based on the same assumptions as for the J/ψ (curve labelled 'FKS') is by about 2 s.d. too low, recalculations taking into account especially the real part of the amplitude and skewed parton dentsities (curves labelled 'MRT(1)', 'MRT(2)' and 'FSM') agree quite well with the data. The difference between the curves labelled 'FSM' and 'FSM(only Im)' allows an estimate for the contribution from the real part of the amplitude.

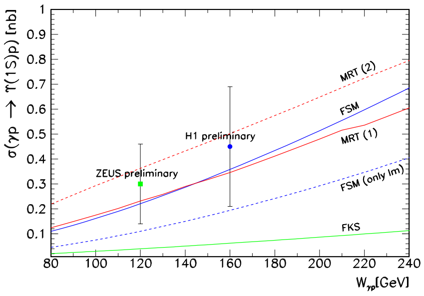


Figure 7. *The measured $\Upsilon(1S)$ photoproduction cross section compared to several theoretical predictions by Frankfurt et al. (FKS [8] and FSM [16]) and by Martin et al. (MRT [17]).*

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