VECTOR MESON CROSS-SECTIONS AT HERA*

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Inelastic and elastic (exclusive) cross-section measurements of vector meson production at HERA are discussed.

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1. Introduction

Vector meson production is an ideal tool for studying the structure of the proton and to investigate the transition from purely soft to hard pQCD processes. Vector mesons can be produced in two different ways in lepton proton scattering, in so-called inelastic processes, where the proton breaks, or elastic (exclusive) processes, where the incoming proton stays intact. The different production mechanisms are shown schematically in Fig. 1. They suggest that the cross-section for inelastic vector meson production behaves like $\sigma_{\rm inel} \sim xG(x,\mu^2)$ whereas for elastic production like $\sigma_{\rm el} \sim \left[xG(x,\mu^2)\right]^2$. Different regions of the available phase space ranging from photoproduction ($Q^2 \sim 0$) to the DIS regime ($Q^2 > 1$ GeV^2) and various vector mesons, including photons can be investigated.

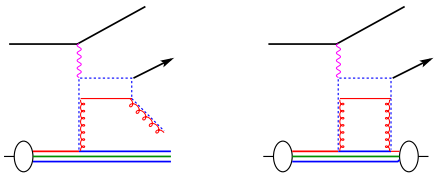

Fig. 1. Schematic picture of inelastic (left) and elastic (right) vector meson leptoproduction.

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2. Inelastic vector meson production

Inelastic J/ψ production (see Fig. 1(a)) has been measured by the H1 and ZEUS experiments both in the photoproduction [1, 2] and DIS [1, 3] regime. The cross-section $\frac{d\sigma}{dp_t^2}$ as measured by H1 [1] for photoproduction is shown in Fig. 2. In Fig. 3 the cross-section $\frac{d\sigma}{dp_t^2}$ in the DIS region [1] ($3.6 < Q^2 < 100$ GeV^2) for different values of the inelasticity

$$z = \frac{p_p . p_{J/\psi}}{p_p . p_\gamma} = \left. \frac{E_{J/\psi}}{E_\gamma} \right|_{\text{p rest}}$$

is shown. The results are in good agreement with the measurements of ZEUS [2, 3] and they agree well in normalization and shape with a QCD calculation [4] using k_t-factorization (implemented in CASCADE [5]). The NLO calculation of [6] applicable for the photoproduction region also agrees well with the measurement.

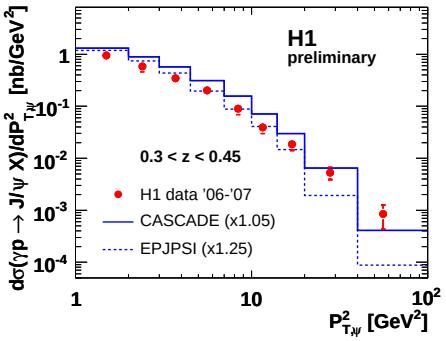

Fig. 2. Cross-section as a function of p_t^2 in photoproduction of J/ψ mesons [1].

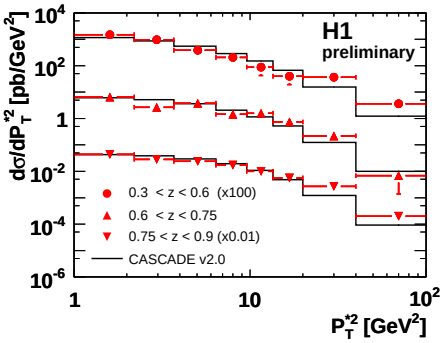

Fig. 3. Cross-section as a function of p_t^2 for J/ψ lepto-production in the range of $3.6 < Q^2 < 100$ GeV^2 [1].

Prompt photon production (the vector meson is replaced by a real photon in Fig. 1) in $Q^2 \sim 0$ and in the DIS region have been measured by H1 and ZEUS [7]. Calculations using leading log parton showers or NLO calculations ($\mathcal{O}(\alpha^3 \alpha_s)$) are able to describe some of the features of the data in DIS but not all. In the photoproduction region the measurements are reasonably well described in shape by NLO calculations but the predicted cross-sections are a factor ~ 2 smaller than the measured ones, indicating that significant contributions (presumably higher order corrections) are still missing in the calculations.

Thus, vector meson production (not prompt photon production) is reasonably well understood and can be used to further investigate the structure of the hadronic final state: the elastic (exclusive) production of vector mesons, where the proton stays intact.

3. Elastic (exclusive) vector meson production

The cross-section for elastic vector meson production as a function of the $\gamma^* p$ center of mass energy W is shown in Fig. 4 [8]. One observes a steep rise of the cross-section with W for heavy vector mesons. A similar behavior is observed for light vector meson production at large Q^2.

As suggested in Fig. 1, elastic vector meson production at large scales should behave like $\left[xg(x,\mu^2)\right]^2 \sim x^{-2\lambda}$, whereas inelastic processes, like inelastic vector meson production or the inclusive cross-section F_2 at small $x \sim 1/W^2$, behave like $xg(x,\mu^2) \sim x^{\lambda}$. Fig. 5 [9] shows a measurement of λ for ρ^0 production at large Q^2 and compared with the one from F_2 showing a similar energy dependence λ, in contrast to the naive expectation coming from 2-gluon exchange. Note, a similar behavior is seen in the energy dependence of diffractive and inclusive cross-sections at large Q^2 [10].

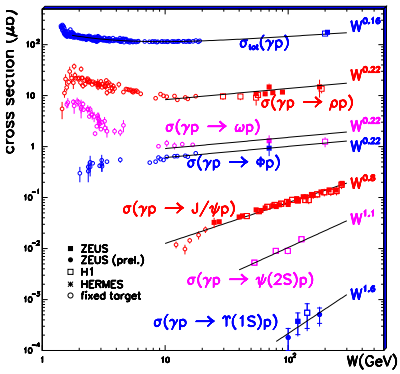

Fig. 4. Cross-section for $\gamma^* p \to Vp$ as a function of W The total γp cross-section is also shown. The lines are results of a fit of the form W^{δ} [8].

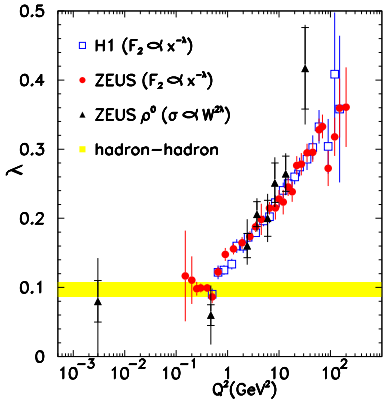

Fig. 5. λ for ρ^0 production at large Q^2 compared with the one from inclusive F_2 [9].

The dependence of the elastic vector meson production cross-section on $t = (p - p')^2$, the momentum transfer at the proton vertex, is often parameterized as $\sigma \sim \exp(-b|t|)$. The measured b-slope obtained from different measurements of vector meson production is shown in Fig. 6 [11] as a function of $Q^2 + M^2$, with M being the mass of the produced vector meson. At large $Q^2 + M^2 \simeq 10$ GeV^2 the b-slope becomes constant at $b \sim 5$ GeV^{-2}.

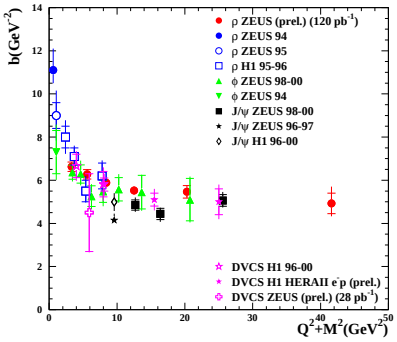

Fig. 6. b-slope as a function of $Q^2 + M^2$ for different vector mesons.

The energy dependence of the cross-section as a function of t can be parameterized with

$$\frac{d\sigma_{\gamma p}(W)}{dt} = \frac{d\sigma_{\gamma p}(W_0)}{dt} \left(\frac{W}{W_0}\right)^{4(\alpha_{I\!P}(t)-1)} .$$

The measurement of $\alpha_{I\!P}(t)$ within a one experiment is shown in Fig. 7 [12] and compared with results of [13]. Even in the photoproduction region the value of $\alpha_{I\!P}(t)$ is smaller than expected from soft hadron–hadron interactions.

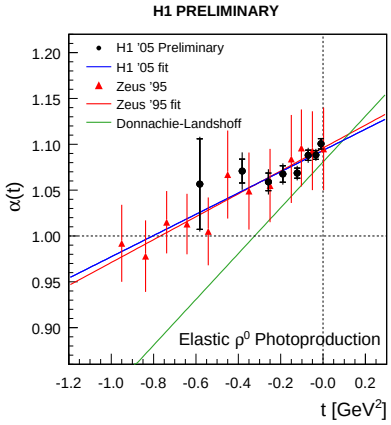

Fig. 7. $\alpha_{I\!P}(t)$ measured in elastic ρ^0 photoproduction.

4. Conclusion

Measurements of inelastic vector meson production in the photoproduction and DIS region can be reasonably well described with higher order QCD calculations. Measurements of elastic ρ^0 vector meson production show a energy dependence, which is similar to the one obtained from inclusive measurements. Even in photoproduction of elastic ρ^0 mesons, the measured $\alpha_{I\!P}$ is smaller than expected from soft hadron–hadron interactions. Thus understanding of elastic vector meson production is still a challenge.

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