VECTOR MESONS AND pQCD AT HERA

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An overview of recent results from the H1 and ZEUS collaborations on vector meson production in electron-proton collisions at HERA is given. For diffractive vector meson production, the energy dependence is discussed. The dependences on different scales, $M_{VM}$, $Q^2$, and $|t|$, are investigated. The data are compared to pQCD theoretical calculations. In addition, new results on inelastic $J/\psi$ electroproduction in a kinematical range $2 < Q^2 < 100$ GeV$^2$ and $50 < W_{\gamma p} < 225$ GeV are shown. Differential cross sections are compared to theoretical predictions for color singlet and color octet contributions as well as to calculations for color singlet contributions alone.
proton breaks up. In the absence of a hard scale the colorless exchange can be modeled by a soft pomeron trajectory using the Regge approach. In this case the cross section is predicted to rise slowly with \(W_{\gamma p}\). In the presence of a hard scale vector meson production can be calculated in the framework of perturbative QCD. In this case the colorless exchange is modeled by a pair of gluons or gluon ladder (with the quantum numbers of the vacuum). Therefore the cross section is proportional to the square of the proton gluon density and a steep rise with increasing \(W_{\gamma p}\) is predicted.

1.2 Inelastic vector meson production

Inelastic vector meson production is dominated by the process of photon gluon fusion where a photon emitted by the incoming positron and a gluon as parton of the proton produce a \(q\bar{q}\) pair. This \(q\bar{q}\) pair can either be produced in a color singlet state by emission of a hard gluon or in a color octet state. The color singlet state can directly evolve into a real vector meson, while in the case of color octet states additional emission of soft gluons is necessary. Here the data for \(J/\psi\) production are compared to two theoretical predictions performed in non-relativistic QCD (NRQCD). The color singlet model (CS) includes only color singlet states, while the full calculation (CS+CO) takes in addition color octet contributions into account.

2 Results on diffractive production

HERA offers the unique possibility to study the dependence of diffractive processes on \(Q^2\), the mass of the vector mesons \(M_{VM}^2\) and \(|t|\). The results presented cover a range up to 100 GeV\(^2\) in \(Q^2\), \(20 < W_{\gamma p} < 290\) GeV and up to 20 GeV\(^2\) in \(|t|\). The production of \(\rho, \omega, \phi, J/\psi\) and \(\Upsilon\) mesons is studied.

The \(W_{\gamma p}\) dependence for elastic vector meson photoproduction is shown in figure 1(a). The lines indicate a behaviour of the cross section following a power law \(W_{\gamma p}^\delta\). The light vector mesons \(\rho, \phi\) and \(\omega\) show a slow \(W_{\gamma p}\) dependence with a value for \(\delta \approx 0.22\), similar to the value that describes the total photoproduction cross section and well in agreement with predictions in the Regge approach. For the heavier vector meson \(J/\psi\), a harder \(W_{\gamma p}\) dependence is observed with a value \(\delta \approx 0.8\) as expected within pQCD predictions, that describe the \(J/\psi\) production data very well (figure 1(b)). Improved statistics are required before firm conclusions can be drawn.
for the Υ meson. Figure 1c) shows the development of the $W_{γp}$ dependence with increasing mean values of $Q^2$ for ρ meson production. Here the transition from a soft behaviour in photoproduction to a hard dependence in electroproduction is seen.

In addition to $Q^2$ and $M^2_{V M}$, it is possible that $|t|$ may provide a hard scale. At high $|t|$ proton dissociative production dominates the diffractive cross section. Within Regge approaches an exponential decrease of the differential cross section in $|t|$ is expected. However, calculations using pQCD predict a decrease that follows a power law $|t|^{-n}$. In figure 2a) the differential photoproduction cross sections as a function of $|t|$ for the light vector mesons $ρ$ and $φ$ are presented. A fit to $|t|^{-n}$ is shown which agrees with the expectation of pQCD. Figure 2b) presents the proton dissociative cross section of $J/ψ$ photoproduction compared to a pQCD calculation. Good agreement is found. Both observations indicate that $|t|$ provides a hard scale in diffractive vector meson production such that pQCD can be applied at large $|t|$.

3 Results on inelastic production

New results on inelastic $J/ψ$ electroproduction in the kinematic range of $2 < Q^2 < 100 \text{GeV}^2$, $50 < W_{γp} < 225 \text{GeV}$, $0.3 < z < 0.9$ and $p_t^{J/ψ} > 1 \text{GeV}^2$ are presented in figure 3. Differential $ep$ cross sections as a function of $Q^2$ (a) and the squared transverse momentum of the $J/ψ$ meson in the $γ^*p$ system $p_t^{J/ψ}$ (b) are shown as well as the normalized differential cross section in $z$ (c). The data are compared to two theoretical predictions in leading order performed in the framework of NRQCD. With the light grey band the calculation for color singlet contributions (CS) alone is shown, while the dark band represents the full prediction including color singlet and color octet contributions (CS+CO). The CS prediction falls below the data by almost a factor of three and has a too steep $p_t^{J/ψ}$ dependence. Note, however, that higher order processes are expected to contribute significantly at high values of $p_t^{J/ψ}$ as observed in next-to-leading order calculations for CS contributions in the photoproduction limit. On the other hand the behaviour of the cross section in $z$ is well described. The calculation including both CS and CO contributions shows the right dependence and magnitude of the cross section at high $Q^2$ and $p_t^{J/ψ}$, while it fails to describe the data at high values of $z$. This discrepancy may be due to phase space limitations at high $z$ for the emission of soft gluons in the transition from the color octet $c\bar{c}$ pair to the $J/ψ$ meson, which are not taken into account in the calculation.
Conclusions

HERA offers the unique possibility to study the transition region from soft to hard diffraction in vector meson production. The $W_{\gamma p}$ dependence of the cross section for different vector mesons and at different values of $Q^2$ as well as the $|t|$ dependence of the cross section were presented. A clear indication that $Q^2$, $M_{V,M}^2$ and $|t|$ provide a hard scale is found. In the presence of a hard scale perturbative QCD calculations describe the data well.

In addition new results on inelastic $J/\psi$ electroproduction were shown and compared to leading order theoretical predictions in NRQCD for color singlet contributions alone and the full calculation including color singlet and color octet contributions. The CS calculation falls below the data by a factor of 3, while the CO+CS prediction is in good agreement with the data at high $Q^2$ and $p_t^2$.

Acknowledgments

It is a pleasure to thank the organizers for this interesting and well prepared conference. I would like to thank my colleagues in H1 and ZEUS for providing the figures shown in this report.

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