Abstract. Recent measurements by the H1 and ZEUS experiments at the HERA ep collider are discussed. The exclusive diffractive production of \( \rho^0 \) and \( \Upsilon \) and the deeply virtual Compton scattering (DVCS) process, measured in a wide range of the photon-proton centre of mass energy, \( W \), of the photon virtuality, \( Q^2 \), and of the vector meson mass, \( M_V \), are the main topic of this report.

1. Introduction

The data collected at the ep collider HERA by the H1 and ZEUS experiments are briefly discussed with main focus on exclusive processes of the type \( ep \rightarrow eVp \), where \( V = \gamma, \rho^0, \omega, \phi, J/\psi, \psi' \), and \( \Upsilon \).

The HERA facility can be viewed as a \( \gamma^*p \) collider, which allows measurements within a single experiment to be made over a wide range of the \( \gamma-p \) centre of mass energy, \( W \), of the photon virtuality, \( Q^2 \), of the four momentum transfer squared, \( t \), and of the vector meson mass, \( M_V \).

Exclusive diffractive vector meson production in \( ep \) collisions was initially considered as a soft process and described within the framework of Regge phenomenology with the Pomeron trajectory derived from hadron-hadron interactions [1]. In this framework, the \( W \) and \( t \) dependence of the cross section can be parameterised as \( \sigma(W) \propto W^\delta \), and \( d\sigma/dt \propto e^{-b|t|} \), where \( b \) shows the transverse size of the interaction (\( b \propto R_p^2 + R_{\gamma}^2 \), where \( R_p^2 \) is the effective radius of the proton and \( R_{\gamma}^2 \) is the effective size of the \( \gamma \)-induced state scattering on the proton).

However, in the presence of a hard scale \( \mu^2 \), provided by large \( Q^2 \) values or large vector meson masses, perturbative QCD (pQCD) is expected to apply [2, 3, 4]. Diffractive vector meson production can then be seen in the nucleon rest frame as a sequence of three subprocesses well separated in time: the fluctuation of the exchanged photon in a \( q\bar{q} \) pair, the hard interaction of the \( q\bar{q} \) pair with the nucleon via the exchange of (at least) two gluons in a color singlet state, and the \( q\bar{q} \) recombination into a real vector meson. Furthermore, to take into account the skewing effect, i.e. the difference in the proton momentum fractions carried by the exchanged partons, one has to consider generalized parton distributions (GPDs).

The following behaviour of \( b \) and \( \delta \) with increasing scale can be expected: \( \delta \) rises from \( \sim 0.2 \) (for ‘soft Pomeron’) to \( \sim 0.8 \) (reflecting the strong rise at small \( x \propto \mu^2/W^2 \) of the gluon density in the proton), and \( b \) decreases from \( \approx 10 \text{ GeV}^{-2} \) to \( \approx 5 \text{ GeV}^{-2} \) [5, 6].

Exclusive diffractive measurements contribute to the understanding of the nature of diffraction in terms of QCD, through access to the gluon density at small \( x \) and access to transverse momentum parton distributions.
2. \( Q^2 + M^2 \) as the hard scale

The exclusive photoproduction of vector mesons at HERA can be used to study the effect of the mass as a hard scale, as \( Q^2 = 0 \). The measurements presented in Fig. 1 show the transition from a soft to a hard production process by the steeper rise of the cross section for heavy vector mesons (\( J/\psi, \psi', \Upsilon \)) compared to light vector mesons (\( \rho^0, \omega, \phi \)). The new measurement of the exclusive photoproduction of \( \Upsilon \) by ZEUS is consistent with a recent NLO calculation \cite{7} and confirms the increase of \( \delta \) with the increase of the hard scale.

A similar steeper rise of the cross section with \( W \) is seen also for all vector mesons and DVCS when the \( Q^2 \) of the process increases. The combined plot of \( \delta \) values extracted from the corresponding measurements (left-hand side of Fig. 2) shows a distinct rise of \( \delta \) as the process becomes ‘harder’. The right-hand side of Fig. 2 shows the decrease of the value of \( b \) with increasing scale, as expected in pQCD. Both plots (Fig. 2) contain new high precision measurements of \( \rho^0 \) meson production in DIS.

![Figure 1](image1.png)

**Figure 1.** A compilation of light(\( \rho^0, \omega, \phi \)) and heavy(\( J/\psi, \psi', \Upsilon \)) exclusive vector meson photoproduction cross sections at HERA.

![Figure 2](image2.png)

**Figure 2.** (Left) A compilation of \( \delta \) from \( \sigma \sim W^2 \) for \( \rho^0, \phi, J/\psi \), DVCS. (Right) A compilation of the \( t \)-slope \( b \) for \( \rho^0, \phi, J/\psi \), DVCS.

3. Deeply virtual Compton scattering

Deeply virtual Compton scattering, \( \gamma^* p \rightarrow \gamma p \), is a process closely related to the exclusive vector meson production and allows more direct tests of existing GPDs to be made, since it is free from ambiguities implied by the vector meson wave-function uncertainties. A new result was obtained by ZEUS with the use of a forward proton tagging detector, which allows a background free elastic cross section measurement. The parameters of the DVCS cross section comply with the parameters which are typical of the heavy vector meson production (Fig. 2).

The only background process for DVCS is Bethe-Heitler, which is a pure QED process. One can derive from the measured cross section a measurable interference term which is directly
connected to the GPDs. The interference term is measured via the beam charge asymmetry
\[ BCA = \left( \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \right) = p_1 \cos(\Phi) \ldots \]
where the differential cross sections are measured for the lepton beam with positive(\(\sigma^+\)) and negative(\(\sigma^-\)) charge, and \(p_1 \propto \text{GPD}\) (left-hand side of Fig. 3). One should keep in mind that being integrated over \(\Phi\) the interference term contribution to the cross section is zero.

**Figure 3.** (Left) Beam charge asymmetry. (Right) The ratio \(r_{04}^{00}\) as a function of \(W\) for different values of \(Q^2\) for the \(\rho^0\) electroproduction.

4. \(\gamma^*_L\) vs \(\gamma^*_T\) cross sections

When the scale becomes harder the longitudinal component of the cross section becomes dominant as expected and also confirmed by the new \(\rho^0\) measurements. No dependence of the ratio \(r_{04}^{00}=\sigma_L/\sigma_{\text{tot}}\) on \(W\) (right-hand side of Fig. 3) and \(|t|\) has been observed [9], which leads to the conclusion that the large-configuration component in the longitudinal cross section is suppressed.

5. Conclusions

New HERA measurements of exclusive \(\rho^0\) in deep inelastic scattering, \(\Upsilon\) in photoproduction and DVCS are presented. The exclusive diffractive vector meson production cross section rises with \(W\) and its logarithmic derivative with respect to \(W\) increases with the hard scale, \(Q^2+M_V^2\). The exponential slope of the \(|t|\) distribution decreases with the hard scale and levels off at \(b \approx 4.5\) GeV\(^{-2}\). The ratio of the cross sections induced by the longitudinally and transversely polarised virtual photons increases with \(Q^2\) but is independent of \(W\) and \(|t|\). All these features are well consistent with general expectations of perturbative QCD. A DVCS beam charge asymmetry measurement contributes to obtaining information about GPDs.

References

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