DVCS AND VECTOR MESON PRODUCTION AT HERA

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The measurement of exclusive vector meson production and deeply virtual Compton scattering (DVCS) at HERA allows to study the nature of diffractive exchanges. New results from the H1 and ZEUS Collaborations on exclusive J/ψ and ρ production as well as on DVCS are presented and compared to predictions based on Regge theory and perturbative QCD.

1. Introduction

Perturbative Quantum-Chromodynamics (pQCD) successfully describes the strong force between hadrons and between their constituents, the quarks and gluon, in the limit of short distances ("hard" interactions). Hadron scattering cross sections are however dominated by long-range forces ("soft" interactions), where an understanding in the framework of QCD remains a challenge. A large fraction of these soft interactions are mediated by a colourless exchange ("diffractive" interactions) which are described in Regge theory by the t-channel exchange of a trajectory with vacuum quantum numbers called "Pomeron". Both the elastic production of vector mesons and deeply virtual Compton scattering (DVCS) are examples for diffractive processes. In the framework of pQCD diffractive processes in which the proton remains intact after the collision ("elastic" processes) give access to the transverse momentum distributions of the parton in the proton.

The wide range in the photon proton center-of-mass energy W and the photon virtuality Q^2 make the HERA electron-proton collider and its two colliding beam experiments H1 and ZEUS a unique facility to study diffractive processes and especially the transition region between soft and hard regimes.

2. Diffractive Vector Meson Production

Measurements of the elastic production of light vector mesons (ρ,ω,ϕ) in electron-proton collisions at HERA at low Q^2 (called photoproduction regime) as function of $W_{\gamma p}$ have verified the expected Regge behaviour with a Pomeron trajectory depending on the momentum transfer t at the proton vertex ($\sigma \propto W^{4(\alpha(t)-1)}$). A new preliminary H1 measurement[1] of exclusive ρ photoproduction with greatly improved statistics allows the extraction of the Pomeron trajectory from the data of a single experiment (Fig. 1).

A linear fit $\alpha(t) = 1.093 \pm 0.003^{+0.008}_{-0.007} + \big(0.116 \pm 0.027^{+0.036}_{-0.046}\big)\,\mathrm{GeV}^{-2} \cdot t$ to the data differs significantly from the global Pomeron trajectory of Donnachie and Landshoff.[2]

In the measurement of diffractive vector meson photoproduction the momentum tansfer $|t|$ can provide a hard scale ensuring the applicability of pQCD. A stringent test of pQCD based models is given by the helicity structure of exclusive vector meson production, where QCD predicts significant deviations from s-channel helicity conservation (SCHC). Measurements[3] of the spin density matrix elements for ρ production at large $|t|$ are compared to pQCD based models[4,5] in Fig. 2. A violation of SCHC shows up in all three matrix elements, especially in r^{04}_{1-1}

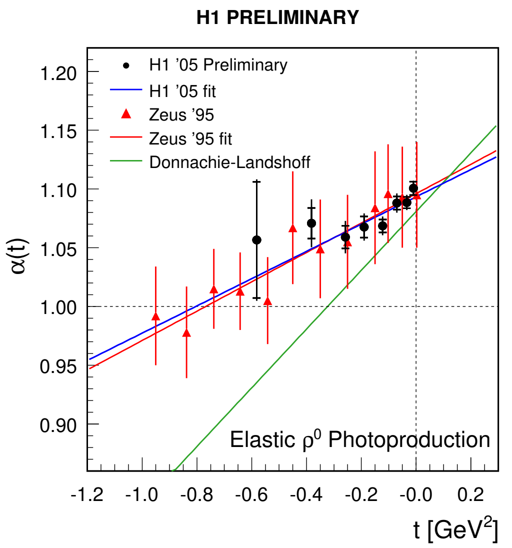

Fig. 1. Pomeron trajectory extracted from photoproduction of ρ mesons

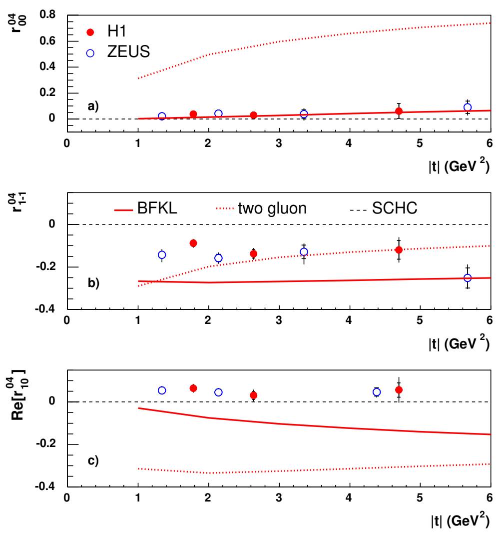

Fig. 2. Spin density matrix elements for ρ photoproduction at large $|t|$

which corresponds to a helicity double-flip. Neither the BFKL nor the two-gluon model can describe all measured spin density matrix elements.

The photoproduction of J/ψ mesons[6,7] shows a much steeper rise with W than observed for light vector mesons, compatible in a simple pQCD two-gluon exchange picture with a steeply rising gluon density towards low fractions of the proton momentum carried by the gluons. The W (Fig. 3) and Q^2 dependence of the J/ψ photoproduction cross section can be compared to pQCD based models.[8,9] The accuracy of the measurements and the shape predictions (calculations giving an absolute normalisation are not yet available) are reaching a level, where vector meson measurements could constrain the gluon density in regions of phase space where it is poorly known from inclusive DIS measurements.

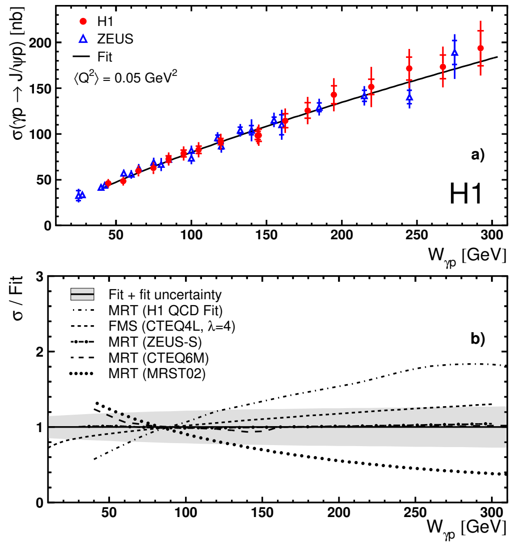

Fig. 3. J/ψ cross section as a function of W for $|t| < 1.2$ GeV^2 compared to a fit W^δ (upper) and ratio of QCD based calculations to the fit (lower).

The new preliminary ZEUS measurement[10] of diffractive J/ψ photoproduction at large $|t|$ allows to distinguish between different evolution equations for the gluon ladder mediating the interaction. The data show an increasing rise of the cross section as a function of W with rising $|t|$. This behaviour is qualitatively described by the BFKL-basel model[11], while the DGLAP-based predictions[12] are too flat.

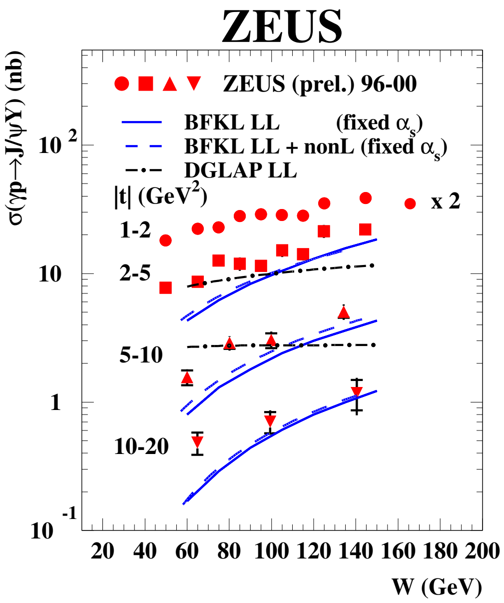

Fig. 4. J/ψ cross sections at large $|t|$ as a function of W compared to pQCD based calculations.

3. Deeply Virtual Compton Scattering

In deeply virtual Compton scattering, a real photon is produced by a virtual photon scattering off the proton. The photon in the final state removes the theoretical uncertainties linked to the vector meson wave-function and make this a particularly clean process to study – in fact DVCS is the first diffractive process fully calculable in pQCD[13,14,15]. The DVCS process is experimentally indistinguishable from the Bethe-Heitler process, where the photon is radiated from the incoming or outgoing electron. The Bethe-Heitler process is calculable in QED and statistically subtracted to obtain the DVCS cross sections[a]. Via the momentum difference between the emitted and absorbed parton, DVCS gives access to the transverse momentum distributions of the parton in the proton that can be expressed by generalised parton distributions (GPDs).

A new preliminary H1 measurement[16] increases the available statistics significantly. The fall of the cross section differential in t (Fig. 5) can be described by the form $e^{-b|t|}$ with $b = 5.83 \pm 0.27 \pm 0.50$ providing a constraint on the normalisation of the theoretical predictions.

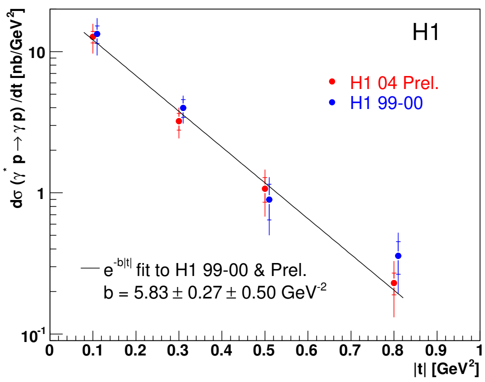

Fig. 5. DVCS cross sections as a function of $|t|$

The W dependence of the combined H1 results (Fig. 6) can be parameterized as $\sigma \propto W^\delta$ with $\delta = 1.00 \pm 0.16 \pm 0.22$ indicating the presence of a hard regime. The data can be described by pQCD based calculations[15] as well as a prediction based on the colour dipole model[17].

4. Conclusion

For exclusive vector meson production and deeply virtual Compton scattering, the experimental accuracy is reaching a level where it starts to constrain theoretical models and the parton distributions in the proton. More results from the HERA II running period will add to this with higher statistics and new measurement capabilities with the upgraded detectors.

[a] The interference between the DVCS and Bethe-Heitler processes gives rise to asymmetries, which however vanish when integrating over the azimuthal angle in unpolarised scattering.

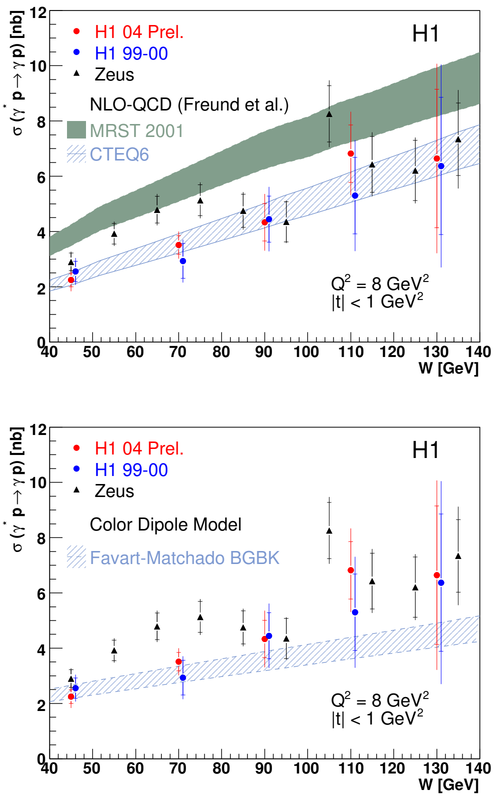

Fig. 6. DVCS cross sections as a function of W compared to NLO QCD calculations (upper) and a prediction based on the color dipole model (lower). The error bands correspond to the uncertainty in the $|t|$ slope measurement.

Acknowledgments

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