Jets and Diffraction Results from HERA

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The latest results on precision measurements of jet and diffractive cross sections obtained by the H1 and ZEUS experiments at HERA are reported. The inclusive jet and multi-jet cross sections are used in QCD calculations at next-to-leading order (NLO) to determine the strong coupling α_s. The cross section measurements for diffractive inclusive DIS processes with a leading proton in the final state are combined for the H1 and ZEUS experiments in order to improve the precision and extend the kinematic range. The dijet cross sections are measured in diffractive DIS with a leading proton and compared with QCD predictions based on diffractive parton densities in the proton. The cross sections for exclusive heavy vector meson photoproduction are studied in terms of the momentum transfer at the proton vertex and of the photon-proton centre-of-mass energy.

1 Jets in DIS and Photoproduction

The strong coupling, α_s, is the fundamental parameter of perturbative QCD (pQCD). The running of α_s is predicted by the pQCD. The absolute normalisation, however, must be determined by experiment. The H1 and ZEUS Collaborations performed extensive studies of the jet production processes in the different kinematic regimes. These measurements allowed the determinations of α_s at HERA with an unprecedented level of precision.

In *ep* collisions at HERA one distinguishes two processes according to the virtuality Q^2 of the exchanged boson, the Deep Inelastic Scattering (DIS) and photoproduction. In DIS a highly virtual boson ($Q^2 > 1$ GeV^2) interacts with a parton carrying a momentum fraction of the proton. In photoproduction a quasi-real photon ($Q^2 < 1$ GeV^2) interacts with a parton from the proton either directly or via its constituent. In the pQCD, a jet cross section is expressed as the convolution of the parton distribution functions (PDFs) in the proton (and in the photon for the photoproduction) with the matrix elements. In regions where the PDFs are well constrained, the jet data allow testing of the general aspects of pQCD. In regions where the PDFs are not so well constrained, jet cross sections can be incorporated into global QCD fits, which would lead to the reduction of the PDF uncertainties.

Jet production in *ep* collisions proceeds via the Born, boson-gluon fusion and QCD Compton processes. In the Breit frame, where the virtual boson and the proton collide head on, the significant transverse momenta P_T are produced at leading order (LO) in α_s by the boson-gluon fusion and QCD Compton processes. Jet production with P_T in the Breit frame is thus directly sensitive to α_s. In the analyses presented here the jets are defined using the k_T clustering algorithm, which is applied in the Breit frame for DIS and in the photon-proton collinear frame for photoproduction. The associated cross sections are collinear and infrared safe and therefore are well suited for comparison with the predictions from the fixed order QCD calculations.

The H1 Collaboration reported new measurement [1] of inclusive jet, 2-jet and 3-jet production at high Q^2 Neutral Current (NC) DIS ($150 < Q^2 < 15000$ GeV^2). The measured differential cross sections as a function of transverse momenta of the jets $P_{T,jet}$ (or the average transverse momentum of two or three leading jets $\langle P_T \rangle_{jet}$ in the 2-jet and 3-jet events) in the regions of Q^2 normalised to the inclusive DIS cross section are shown in the left side of Figure 1. The right side of Figure 1 shows the measured cross sections of inclusive jet photoproduction published by the ZEUS Collaboration [2] for jets with transverse energies $E_T^{jet} > 17$ GeV as a function of E_T^{jet} in the different ranges of jet pseudorapidity η^{jet}. For both measurements the ultimate 1% jet energy scale uncertainty is achieved.

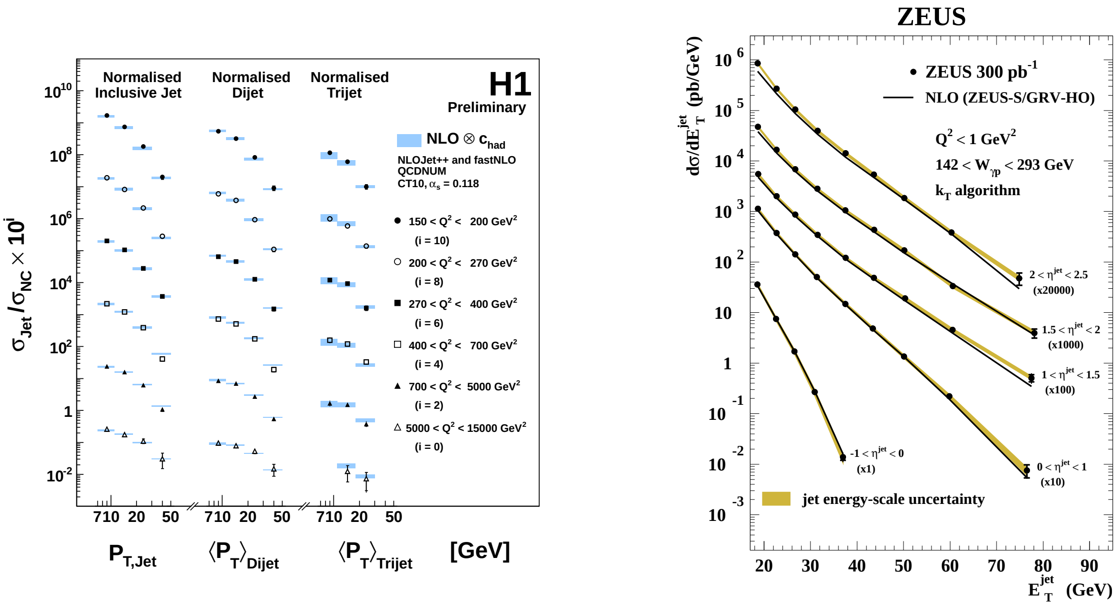

Figure 1: Left: The inclusive jet, dijet and trijet production cross sections in DIS normalised to the DIS cross section as a function of jet transverse momentum in the Breit frame $P_{T,jet}$ or the average transverse momentum of two or three leading jets $P_{T,jet}$, measured in the regions of Q^2. Right: The measured differential cross sections for inclusive jet photoproduction with transverse energy $E_T^{jet} > 17$ GeV in different regions of η^{jet}. The NLO QCD calculations, corrected for hadronisation effects are compared to the measurements

The NLO QCD calculations provide a good description of the jet measurements, both in the DIS and the photoproduction regimes. The NLO QCD fitting technique is applied to these measurements in order to extract the strong coupling α_s. The values $\alpha_s(M_Z) = 0.1183 \pm 0.0011(exp.) \pm 0.0014(PDF) \pm 0.0008(had.) \pm 0.0039(theory)$ for H1 DIS jet measurement and $\alpha_s(M_Z) = 0.1206^{+0.0023}_{-0.0022}(exp.)^{+0.0042}_{-0.0033}(theory)$ for ZEUS photoproduction jet measurement are obtained. Within uncertainties, which are dominated by the uncertainties of theory calculations due to missing higher orders, the obtained values of α_s agree with each other and with the world average [3].

2 Diffraction at HERA

2.1 Measurement of Inclusive Diffractive DIS

About 10% of the DIS cross section measured at low Bjorken-x at HERA are due to diffractive processes, such as $ep \to eXp$. Diffractive DIS can be viewed as process in which the virtual photon probes a net colour singlet combination of exchanged partons. In processes of diffractive production of jets and heavy vector mesons, the P_T of the jet and the mass of heavy quark provide a hard scale for perturbative calculations.

The diffractive interactions at HERA are identified employing two different methods: by requirement of the absence of hadronic activity in the direction of proton (*large rapidity gap* or LRG method) or by a direct measurement of scattered proton in the dedicated forward proton spectrometers (*leading proton* or FPS method). The accuracy of the LRG method is limited by the systematics related to the missing leading proton and by the contribution from the proton dissociation, while the FPS method is limited by low acceptance of proton spectrometers and by the proton tagging systematics.

The H1 and ZEUS Collaborations performed the combination of the diffractive DIS cross sections measured using their proton spectrometers in the range $0.09 < |t| < 0.55$ GeV^2 in squared four-momentum transfer at the proton vertex[4]. The H1 and ZEUS diffractive DIS cross sections are combined using χ^2 minimisation procedure[5]. The result of the combination is shown in the left side of Figure 2. Also shown are the uncombined data. Due to the cross calibration of the correlated systematic uncertainties of both experiments the combined data are more precise than each measurement alone. The cross sections indicate strong rise with Q^2, which implies the scaling violation and large contribution from the gluons to the diffractive interactions.

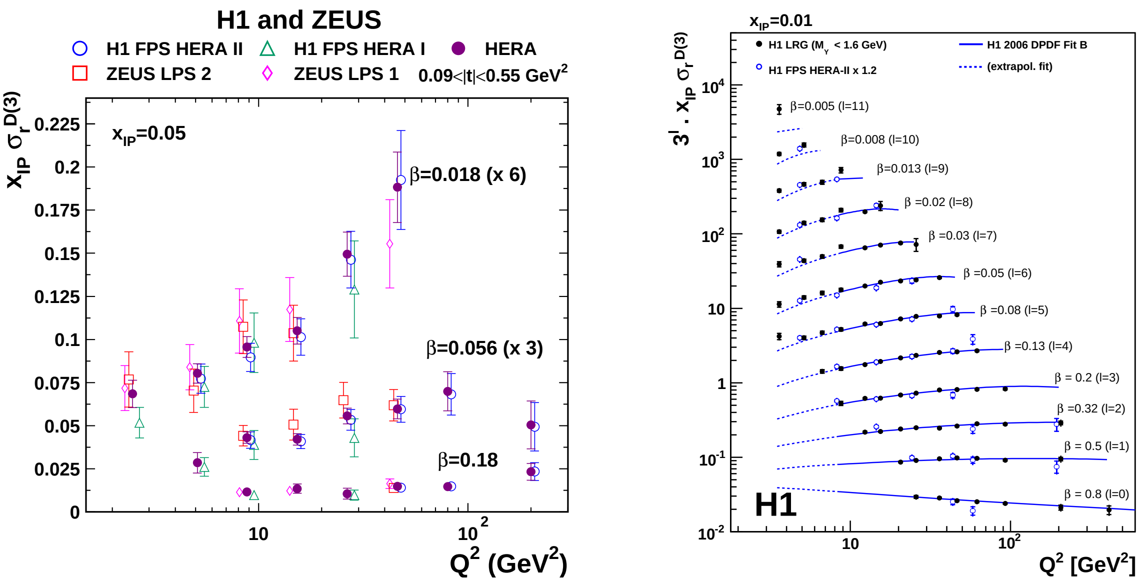

Figure 2: Left: Reduced diffractive cross section $x_{I\!P}\sigma_r^{D(3)}(\beta, Q^2, x_{I\!P})$ for $0.09 < |t| < 0.55$ GeV^2 as a function of Q^2 for different values of β at $x_{I\!P} = 0.05$. The combined data are compared to the H1 and ZEUS data input to the averaging procedure. Right: Reduced diffractive cross section from combined H1 LRG data $x_{I\!P}\sigma_r^{D(3)}$ at $x_{I\!P} = 0.01$. The LRG data are compared with the H1 FPS results [7]

In the right side of Figure 2 the diffractive reduced cross section $\sigma_r^{D(3)}$ from H1 as measured by the LRG method based on the full HERA statistics[6] is compared with the pQCD predictions using the diffractive parton distribution functions (DPDFs) H1 2006 Fit B set[8]. The data are well described for $Q^2 > 10$ GeV^2. Also shown are the FPS measurement from H1, scaled by a factor 1.2, which accounts for the contribution of proton dissociation to the LRG data. The cross section measurements agree well with each other.

2.2 Measurement of Diffractive Dijets in DIS

According to the QCD factorisation theorem[9], the parton distribution functions extracted from the QCD fits to diffractive structure functions can be used to describe hadronic final states in diffractive DIS. Of particular interest are measurements of diffractive dijet production since the boson–gluon fusion process provides a direct probe of the gluon content of the diffractive exchange, in contrast to inclusive measurements which are mainly sensitive to the quarks. The

NLO QCD analyses of inclusive diffractive DIS cross sections do not constrain well the diffractive gluon density, providing different solutions for the DPDFs. Therefore the jet measurements can distinguish between the different DPDFs and reduce the uncertainties on diffractive gluon density. The H1 Collaboration has recently published the measurements of the diffractive dijet production with a leading proton detected in the FPS and VFPS spectrometers [10,11]. The differential cross section as a function of the longitudinal momentum fraction of the diffractive exchange carried by the parton entering the hard scatter, $z_{I\!P}$, is presented in Figure 3 together with NLO QCD predictions based on H1 2006 Fit B and on the H1 2007 Jets [12] DPDF sets. Good agreement is observed between the theory and the data. The proton detection also allows a direct measurement of t and a determination of the exponential t slope parameter B. The measured slope B from diffractive dijets agrees with a value measured from inclusive diffractive DIS, as expected from the proton vertex factorisation.

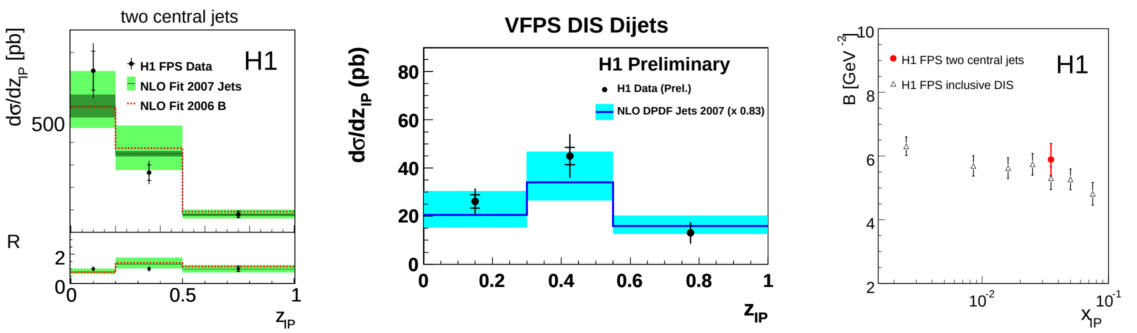

Figure 3: The differential cross section for the diffractive production of dijets in DIS, with the leading proton measured in the proton spectrometers FPS and VFPS, as a function of $z_{I\!P}$. The NLO calculations are compared to the measurements. The rightmost figure shows the t-slope parameter B from the diffractive dijet data and from the inclusive diffractive DIS data.

2.3 Exclusive Heavy Vector Meson (VM) Photoproduction

The exclusive production of heavy vector mesons J/ψ and Υ has been studied at HERA in the photoproduction regime.

The H1 Collaboration performed a simultaneous measurement of J/ψ photoproduction in elastic and proton dissociation processes [13]. The cross section is measured as a function of t and the γp centre-of-mass energy, $W_{\gamma p}$. The cross section for elastic J/ψ photoproduction is shown in the left side of Figure 4. The cross section as a function of $W_{\gamma p}$ exhibits a fast rise as $\propto W^{0.8}$, which can be explained by the rapid increase of the gluon density with decreasing of the fractional momentum x, where $x \propto 1/W^2$.

In an optical model approach the exponential slope b of the t-dependence of the exclusive VM production is related to the sum of squared radii of the $\gamma \to q\bar{q}$ dipole and that of the proton, and thus is a measure of transverse size of interaction region. At high values of the VM mass M_{VM} or photon virtuality Q^2 the $q\bar{q}$ contribution decreases as $b_{q\bar{q}} \propto 1/(Q^2 + M_{VM}^2)$ and the slope of the t-dependence saturates at $b \sim 5$ GeV^{-2}, which corresponds to the gluonic radii of the proton. The b slope measurements for J/ψ and for the recently published ZEUS measurements of $\Upsilon(1S)$ photoproduction [14] are consistent with this approach, as is demonstrated in the right side of Figure 4.

3 Conclusions

Numerous measurements of jet production and diffractive interactions in *ep* collisions have been made over a wide kinematic range at HERA. In this report only few recent results could be given.

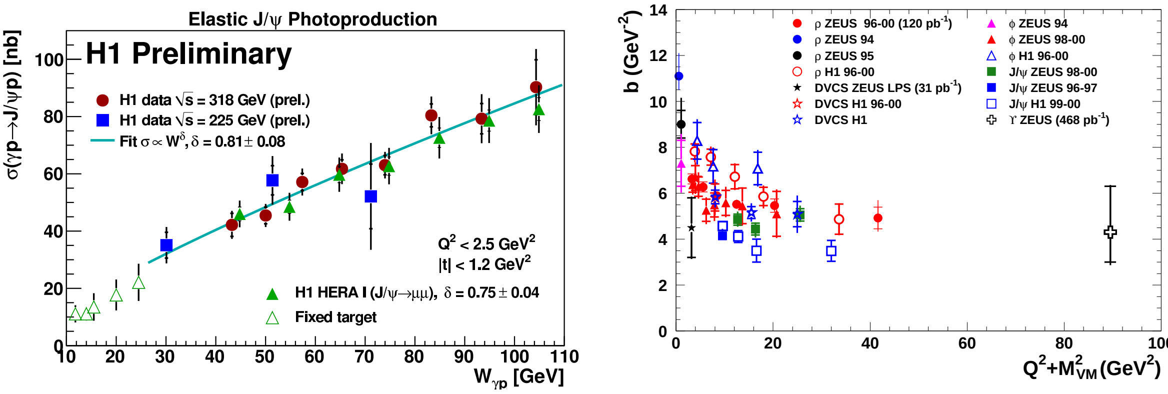

Figure 4: Left: Cross section for J/ψ photoproduction as a function of γp centre-of-mass energy $W_{\gamma p}$. Right: Comparison of the HERA measurements of the slope parameter b as a function of the scale $Q^2 + M_{VM}^2$ for exclusive VM production including the latest ZEUS measurement of exclusive $\Upsilon(1S)$ production and for deeply virtual Compton scattering (DVCS).

In general, the jet data are well described by NLO QCD predictions, and the small experimental uncertainties allow the extraction of strong coupling α_s with high experimental precision, which is not yet matched by the theory error. The measurements of the inclusive diffraction and the jet production in diffractive DIS can be described within a consistent picture. The results support QCD factorisation with diffractive parton densities which are dominated by the gluon contribution.

Acknowledgements

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