PROCEEDINGS OF SCIENCE

D*(2010) and dijet diffractive cross sections from the ZEUS experiment at HERA

I.A. Korzhavina∗†
Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia
E-mail: irina@mail.desy.de

Recent experimental data from the ZEUS Collaboration at HERA on diffractive dijet and charm production in deep-inelastic scattering and photoproduction are reviewed. The data are compared with predictions from the leading-logarithm parton-shower Monte Carlo models and the next-to-leading order perturbative QCD calculations using available parameterisations of diffractive parton densities.

DIFFRACTION 2006 - International Workshop on Diffraction in High-Energy Physics
September 5-10 2006
Adamantas, Milos island, Greece

∗Speaker.
†On behalf of the ZEUS Collaboration

PoS(DIFF2006)007

1. Introduction

High energy diffraction is thought to occur due to a t-channel diffractive exchange (Fig. 1a), called Pomeron (IP). The exchange has vaccuum quantum numbers, is colourless and transfers a small momentum. These properties of the Pomeron exchange reflect experimentally into a large gap in rapidity (LRG) between the hadronic systems of masses M_X and M_Y (Fig. 1a). One of the hadronic systems (Y) may be the scattered beam particle. The other system (X) may include jets, charmed particles, etc. The squared four momentum transfer t and fractional longitudinal momentum $x_{I\!P}$ of the diffractive exchange are typically small.

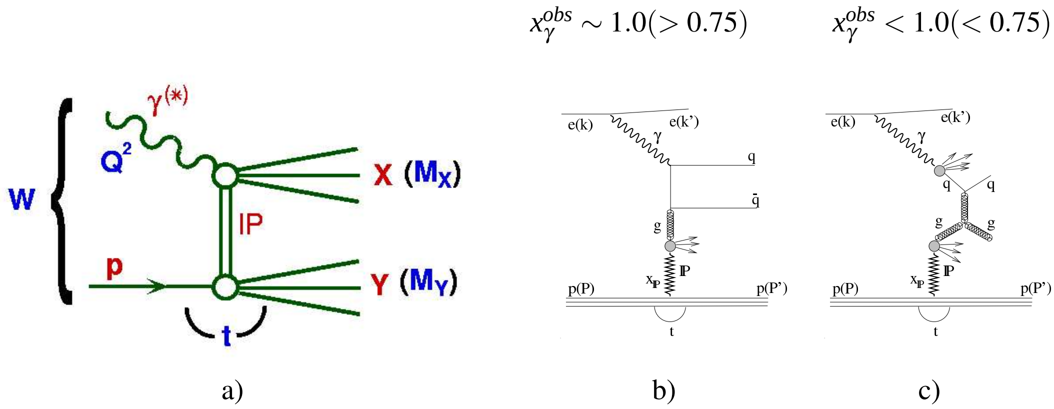

Figure 1: Diffractive scattering process $ep \to e'XY$ with the hadronic systems X and Y separated by the largest rapidity gap in the final state. a) general graph, b) point-like photon process graph and c) hadron-like photon process graph.

In the framework of QCD, the cross section of diffractive scattering can be calculated as a sum of universal partonic cross sections convoluted with universal diffractive parton distribution functions (dPDFs) of the proton (this is the QCD hard diffractive factorisation theorem). Note, that the universal partonic cross sections are known to be process dependent. The universal diffractive parton distribution functions are expected to be process independent. Thus, QCD calculations based on the dPDFs are expected to predict production rates for various diffractive reactions, inclusive or semi-inclusive. The validity of the QCD factorisation was proved [1] for diffractive deep inelastic scattering (dDIS) mediated by a point-like (direct) photon (Fig. 1b). Estimates of the diffractive dijet cross sections for the Tevatron [2] based on the dPDFs measured at HERA are a factor of 5-10 larger than the measurements [3]. This suppression of the observed cross section is ascribed to re-scatterings between the spectator partons from the interacting hadrons. Additional particles created by the re-scatterings partly fill the rapidity gap, suppressing the observed cross section considerably. The ep scattering via photons of low virtualities $Q^2 < 1$ GeV^2 (photoproduction, PhP) involves a hadron-like (resolved) component of the photon (Fig. 1c). Thus for diffractive photoproduction (dPhP), QCD factorisation is not expected to hold like it does not hold for hadron-hadron scattering. An eikonal model [4] predicts a cross section suppression by about a factor of three for resolved photoproduction at HERA. It should be noted that the introduction of a suppression factor for the resolved contribution into the next-to-leading order (NLO) calculations may be not straightforward. The direct and resolved processes are defined uniquely only in leading order (LO). At the

NLO these two processes are related, and relationship between them is factorisation scheme and scale dependent. Only the sum of both contributions can give the physically relevant cross section, which is approximately independent of the factorisation scheme and scale.

Recent experimental data [5, 6, 7] from the ZEUS Collaboration at HERA on diffractive dijet and charm production in deep inelastic scattering and photoproduction are reviewed. Cross sections for diffractive dijet and charm production were measured during the 1998–2000 data taking period, when HERA collided 27.5 GeV electrons[1] with 920 GeV protons. Deep inelastic events were identified by the detection of the scattered lepton. Events without a measured scattered electron were regarded as due to photoproduction. Jets were identified with the k_T algorithm [8]. Charm production was tagged by the detection of a D^* meson. Candidates for D^* mesons were reconstructed with the mass-difference method. Diffractive events were identified by a large gap in pseudorapidity between the produced hadronic-state X and the outgoing proton. The proton dissociative admixture was evaluated to be 16±4 % and subtracted [9]. The diffractive cross sections were measured as functions of the following variables: the photon virtuality Q^2, the photon-proton centre-of-mass energy W, the mass of a diffractively produced hadronic state M_X, the fraction of the proton's momentum $x_{I\!P}$ carried by the Pomeron, the fraction $\beta(z_{I\!P}^{obs})$ of the Pomeron momentum and the fraction x_γ^{obs} of the virtual photon longitudinal momentum, participating in the hard subprocess, the transverse energy E_T or momentum p_T and pseudorapidity η of the jet or the D^* meson.

RAPGAP Monte Carlo [10] leading-logarithm (LL) simulations of diffractive jet and charm production were used for the cross section calculations with the H1 Fit 2 parameterisation of dPDFs [11]. The calculations were performed using leading order matrix elements. Higher order QCD corrections were approximated by the QCD parton shower model MEPS [12], based on the leading logarithm DGLAP [13] splitting functions. The ep interactions at small Q^2 were modeled with both direct and resolved photon processes. The photon structure was parameterised by the GRV-G-LO set of parton densities [14].

The next-to-leading order calculations were performed with the renormalisation and factorisation scales set to the transverse energy of the leading parton jet or the transverse energy of the charm quark. For dijet production, the NLO parton level predictions are corrected to the hadron level using correction factors determined with the Lund string model of hadronisation [15]. The correction factors, calculated with RAPGAP, were found to be ~ 1. For charm production the NLO parton level predictions are corrected to the hadron level using the Peterson fragmentation function [16]. Diffractive dijet and charm production processes are directly sensitive to the gluon content of diffractive exchange (via the dominating process $\gamma g \to q\bar{q}$, Fig. 1b).

2. Comparison of the ZEUS data with theory predictions

2.1 Diffractive deep inelastic production of dijets

The diffractive dijet cross sections have been measured [5] in the range $5 < Q^2 < 100\,\mathrm{GeV}^2$, $100 < W < 200\,\mathrm{GeV}$, $x_{I\!P} < 0.03$ with a data sample of 65 pb^{-1}. The two highest transverse energy jets with $-3.5 < \eta^*_{jet} < 0$, $E_T^{*jet_1} > 5\,\mathrm{GeV}$ and $E_T^{*jet_2} > 4\,\mathrm{GeV}$ were selected. The measured cross

[1] Hereafter, "electron" is used to refer both electron and positron beams.

sections (dots) are compared with the theoretical predictions (histograms) in Figs. 2, 3. The energy scale and the proton dissociation subtraction uncertainties are shown as shaded bands in the figures.

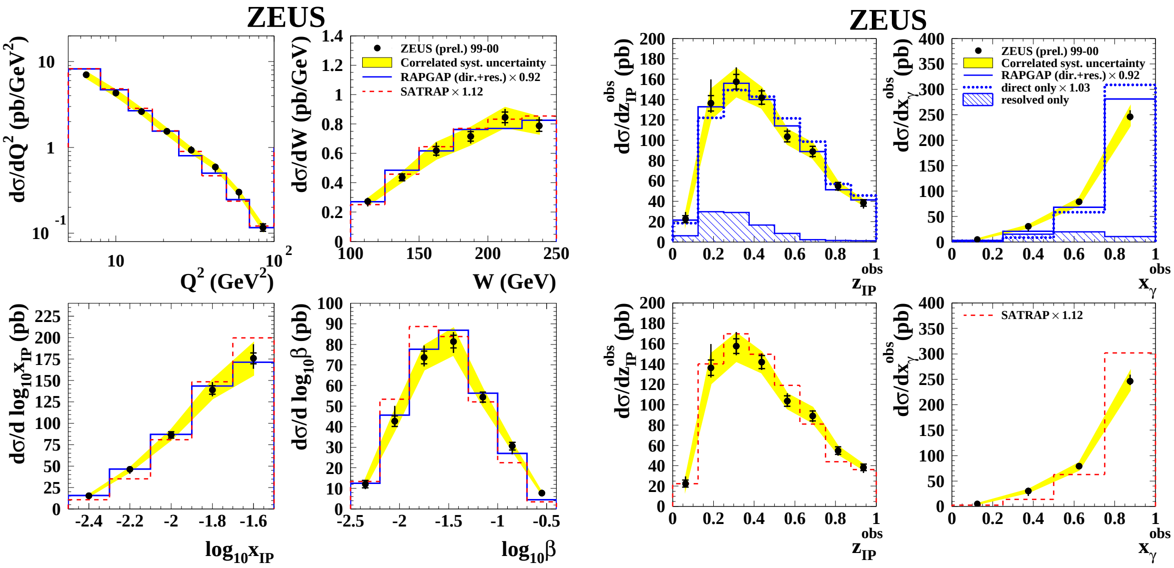

Figure 2: The cross sections for diffractive deep inelastic production of dijets in comparison with LL MC predictions.

The LL Monte Carlo calculations were performed using the generators SATRAP [17] and RAPGAP [10]. SATRAP describes a diffractive process in terms of the saturation model with parton showers modeled in the Colour Dipole Model [18]. The cross sections were calculated using the proton dipole cross section obtained from inclusive DIS data. The contributions from resolved processes are missing in the calculations. RAPGAP MC calculations were performed as described in the introduction. Both sets of LL calculations are consistent with the data in normalization within 10% and reproduce data shapes reasonably well. A small resolved photon admixture (hatched histograms), contributing mainly to low $z_{I\!P}^{obs}$ and x_γ^{obs} range, improves description of the data shapes.

NLO QCD predictions (Fig. 3) have been obtained with the DISENT program [19] for various sets of diffractive PDFs determined from QCD fits to the HERA diffractive DIS data. Within the experimental uncertainties and uncertainties in factorisation and renormalisation scales (30-40%, not shown), the predictions based on the H1 2002 (prel.) [20] and ZEUS LPS [21] dPDFs are compatible with the measured diffractive dijet cross sections in shape and normalization. The normalization of the prediction with the GLP dPDFs [22] is substantially lower than those from the other two sets. The difference observed between the three sets of predictions may be interpreted as an estimate of the uncertainty associated with the diffractive PDFs.

2.2 Diffractive photoproduction of dijets

The diffractive dijet cross sections have been measured [6] with a data sample of 77.6 pb^{-1} in the range $Q^2 < 1$ GeV^2, $0.2 < y < 0.85$, $x_{I\!P} < 0.025$. The two highest transverse-energy jets with $|\eta_{jet}| < 1.5$, $E_T^{*jet_1} > 7.5\,\text{GeV}$ and $E_T^{*jet_2} > 6.5\,\text{GeV}$ were selected. In photoproduction, a sizable contribution to the cross section is given by resolved photon processes (Fig. 1c), in which only a

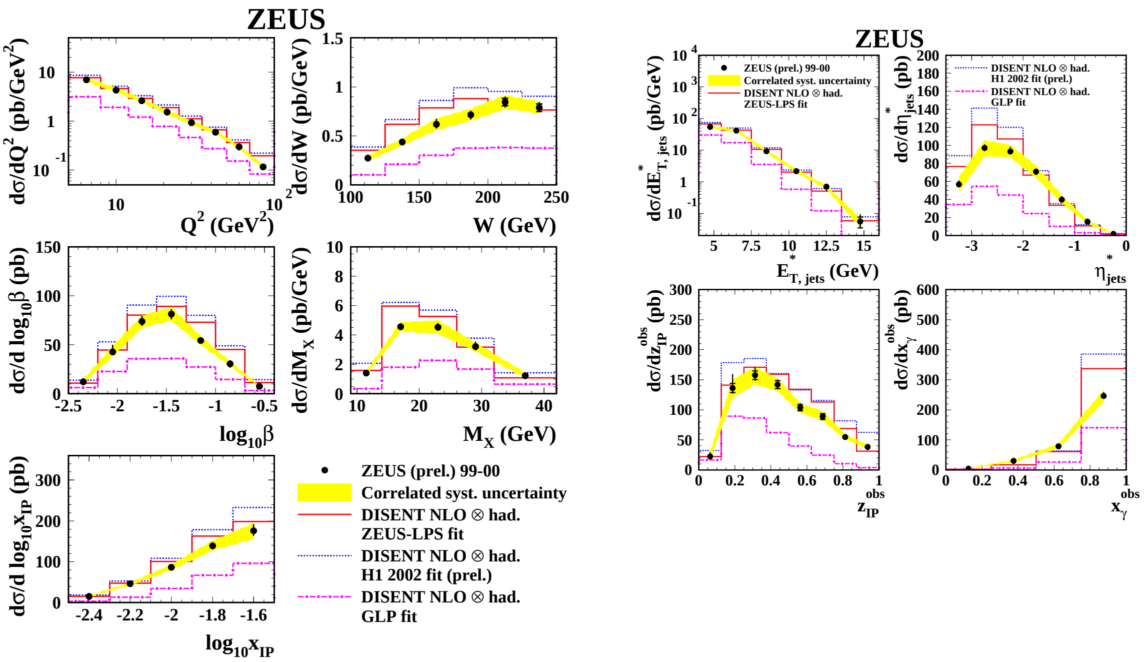

Figure 3: The cross sections for diffractive deep inelastic production of dijets in comparison with the NLO QCD predictions.

fraction x_γ^{obs} of the photon momentum enters the hard scattering. The measured cross sections (dots) are compared with theoretical predictions (histograms) in Figs. 4 and 5 separately for samples enriched in direct ($x_\gamma^{obs} > 0.75$) and resolved ($x_\gamma^{obs} < 0.75$) contributions, respectively. The energy scale and proton dissociation subtraction uncertainties are shown as shaded bands in the figures.

The LL predictions from the Rapgap MC are normalized to the data by a global factor of 0.53. Apart from $z_{I\!P}^{obs}$, which is sensitive to the uncertainties of the diffractive gluon distributions, the LL calculations describe the shapes of all cross sections for both the direct and resolved enriched samples. The ratios of the resolved-enriched to the direct-enriched cross sections were compared to the calculations as well. It is expected that in the ratios uncertainties such as those due to the diffractive PDFs cancel, providing a more reliable comparison with the predictions. The ratios (not shown) are well described as functions of all variables, indicating that the LL MC calculations reproduce both the direct- and resolved-enriched samples alike in various kinematic regions. A suppression of the resolved photoproduction data is expected to be observed from certain theoretical calculations (e.g. [4]), but no such evidence is found.

Two sets of NLO QCD calculations [23] (Fig. 5) are compared to the data: a model with the resolved photon contribution suppressed by a factor of $R = 0.34$ and a model without the suppression ($R = 1$). The diffractive PDFs from H1 2002 Fit (prel.) [20] are used in both cases. Both model predictions (Fig. 5) do not reproduce the normalization of the data. Diffractive dijet photoproduction is overestimated (underestimated) by calculations with $R = 1 (R = 0.34)$, based on dPDFs which give a good description of the diffractive deep inelastic dijet data. The ratios of the resolved-enriched to the direct-enriched cross sections are well reproduced by the NLO predictions with $R = 1$ (not shown), indicating no evidence for a suppression of the resolved photon processes relative to the direct photon processes in any particular kinematic region. An uniform suppression

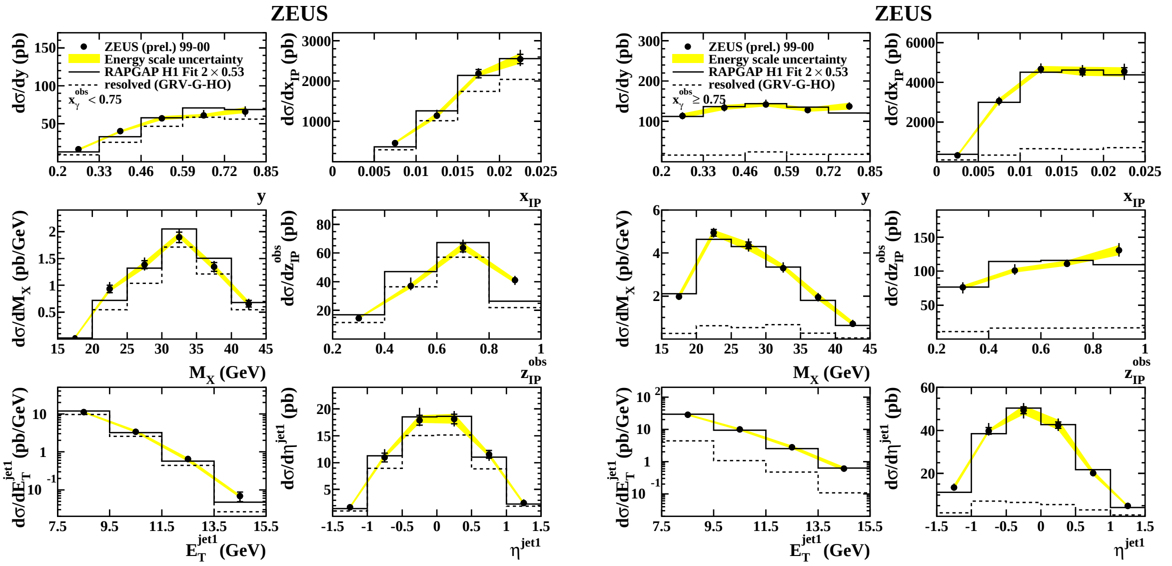

Figure 4: The cross sections for diffractive photoproduction of dijets in comparison with the LL MC predictions.

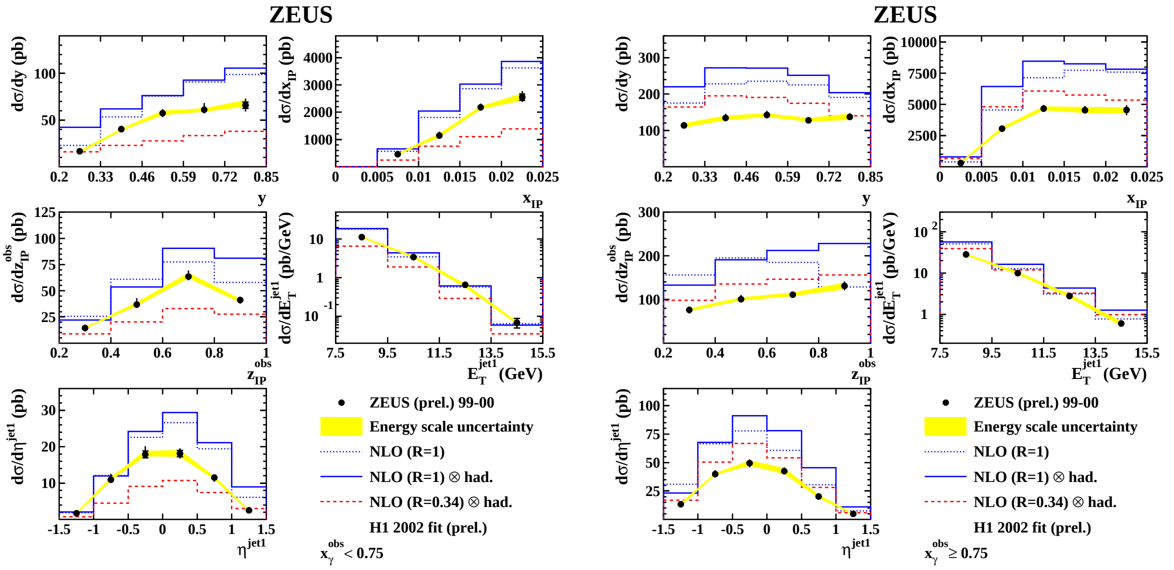

Figure 5: The cross sections for diffractive photoproduction of dijets in comparison with the NLO QCD predictions.

for both resolved and direct processes provides a better description of the data assuming the H1 2002 Fit (prel.) dPDFs.

2.3 Diffractive photoproduction of $D^{*\pm}(2010)$ mesons

Cross sections for diffractive photoproduction of $D^{*\pm}(2010)$ mesons[2] have been measured [7] in the kinematic range $Q^2 < 1\,\mathrm{GeV}^2, 130 < W < 300\,\mathrm{GeV}$, $0.001 < x_{I\!P} < 0.035$ with a data sample of 78.6 pb^{-1}. The D^* candidates with $p_T(D^*) > 1.9\,\mathrm{GeV}$ and $|\eta(D^*)| < 1.6$ were selected in the

[2]From now on, the notation D^* will be used for both D^{*+} and D^{*-}.

decay mode $D^{*+} \to D^0\pi^+$, followed by $D^0 \to K^-\pi^+ + (c.c.)$. A clear signal of 458±30 D^* mesons was observed in the $\Delta M = M(K,\pi,\pi_s) - M(K,\pi)$ distribution (Fig. 6) at the nominal value. After non-diffractive and proton-dissociative backgrounds were subtracted, the cross section, integrated over the above range, was found to be

$$\sigma_{ep\to e'D^*Xp'} = 1.57 \pm 0.12(\text{stat.})^{+0.20}_{-0.22}(\text{syst.}) \pm 0.08(\text{p.d.})\ \text{nb}.$$

The last uncertainty is due to subtraction of the dissociative background. The measured cross section is sizable in comparison to the inclusive D^* photoproduction cross section of $18.9 \pm 1.2^{+1.8}_{-0.8}$ nb, measured by the ZEUS experiment in a similar kinematic range [24]. This observation indicates that diffractive charm production is not suppressed as much as some early models predicted [25].

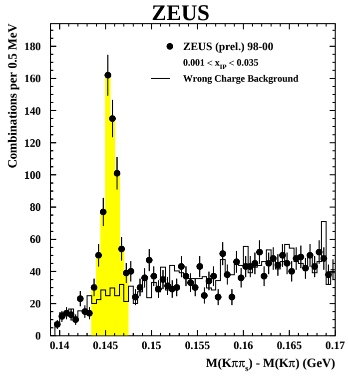

Figure 6: The distribution of the mass difference, $\Delta M = M(K\pi\pi_s) - M(K\pi)$, for the $D^{*\pm}$ candidates (dots) with $p_T > 1.9\,\text{GeV}$ and $-1.6 < \eta < 1.6$, reconstructed in the range $Q^2 < 1\,\text{GeV}^2$, $130 < W < 300\,\text{GeV}$ and $0.001 < x_{I\!P} < 0.035$. The histogram shows the ΔM distribution for the combinatorial background. The shaded band shows the signal range in which the background subtraction was performed. The signal has 458 ± 30 D^* candidates.

The measured differential cross sections (dots in Fig. 7a) are compared to the LL MC expectations from the resolved-Pomeron model [26] (histograms) based on the H1 Fit 2 parton density parameterisation [11]. The calculations were performed with the MC generator RAPGAP [10] in the same kinematic region for both direct and resolved photon mechanisms of charm production, with the resolved component including flavour excitations and amounting to 35% of the total. The expectations overestimate the current measurement by a factor ~ 3 but reasonably reproduce the data shapes. Scaling the resolved component by 0.34 [4] would not give a substantially better description of the data in both shape and normalisation.

The cross sections for diffractive photoproduction of D^* mesons (histograms in Fig. 7b) were compared to the next-to-leading order of QCD predictions calculated with the FMNR code [27] using the H1 2006 Fit A, Fit B [28], the ZEUS LPS [21] and the GLP [22] diffractive PDFs. To account for the proton-dissociative contribution, present in the H1 2006 and GLP fits, the corresponding predictions were scaled down by factors 0.81 and 0.7, respectively [28, 22]. The estimated QCD scale uncertainties are shown as shaded bands for the results with dPDFs from H1 2006 Fit A. The uncertainties for the calculations with other dPDFs are similar and not shown. (Uncertainties of the dPDFs are not included in the calculations.) The differential cross sections calculated with H1 2006 or ZEUS LPS dPDFs are close to each other and reproduce the measurement (Fig. 7b) in shape and normalisation. The calculations with the GLP Fit are systematically lower than the data.

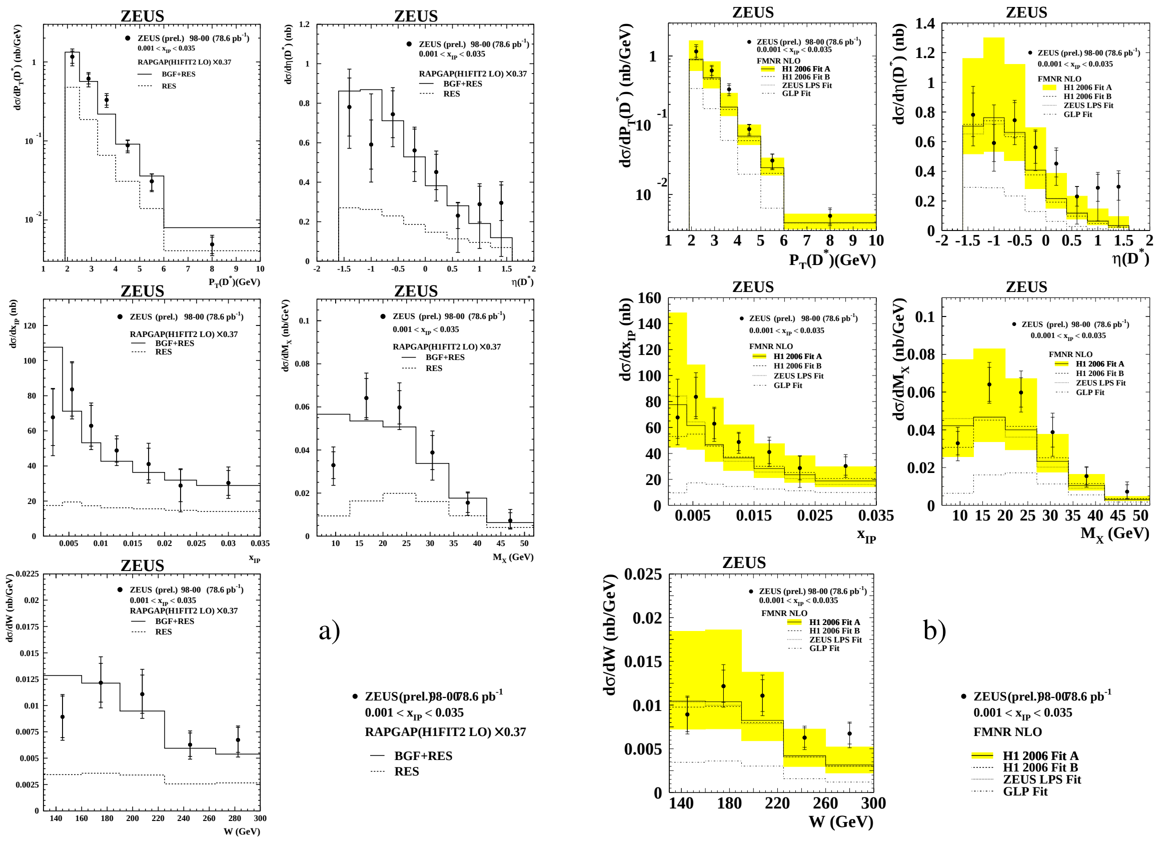

Figure 7: The cross sections for diffractive photoproduction of D^* in comparison with a) the LL MC and b) NLO QCD predictions.

3. Conclusions

Data from the ZEUS Collaboration at HERA on diffractive open charm photoproduction and dijet production in DIS and photoproduction have been compared with LL MC and NLO QCD predictions using various parameterisations of diffractive parton densities.

The LL calculations describe the shapes of the dijet cross sections well for both low and high Q^2. While for DIS production data and calculations are in agreement, the calculations overestimate the photoproduction data.

For the NLO calculations, the agreement between data and predictions depends on the dPDFs chosen. Given the H1 2002 (prel.) diffractive PDFs, the NLO calculations are in good agreement with the diffractive deep inelastic dijet data. The diffractive dijet photoproduction data are overestimated by the NLO predictions, suggesting that factorisation is broken for this process. No evidence is observed for a suppression of resolved photon processes relative to direct photon processes in diffractive dijet photoproduction. A uniform suppression for both resolved and direct processes gives a better description of the data.

The predictions of the LL MC for the differential cross sections of diffractive photoproduction of $D^{*\pm}$ overestimate the data, but reproduce the shapes with the resolved photon contribution acounting for 35% of the total. The NLO predictions based on H1's fits A and B, as well as the

ZEUS LPS fit are consistent with the data. The normalisation of the prediction of the GLP fit is substantially lower than those from the other fits.

The differences observed between the theoretical predictions based on the available dPDF sets may be interpreted as an estimate of the uncertainty associated with the diffractive PDFs. At present it is hard to make a definite statement about the validity of the QCD diffractive factorisation theorem unless a better understanding of the dPDFs and their uncertainties obtained.

References

[1] J. C. Collins, Phys. Rev.D **57**, 3051 (1998) [*Erratum-ibid.* D **61**, 019902 (2000)]; J. C. Collins, J.Phys. G **28**, 1069 (2002).

[2] L. Alvero, J. C. Collins, J. Terron, and J. Whitmore, Phys. Rev. **D 59**, 074022 (1999); R. J. M. Covolan and M. S. Soares, Phys. Rev. D **60**, 054005 (1999); **61**, 019901(E) (2000).

[3] CDF Coll., T. Affolder *et al.*, Phys. Rev. Lett. **84**, 5043 (2000).

[4] A. B. Kaidalov *et al.*, Eur. Phys. J. C **21**, 521 (2001); Phys. Lett. B **567**, 61 (2003).

[5] ZEUS Coll., Paper submitted to the XXXIII International Conference on High Energy Physics ICHEP 2006, Moscow, Russian Federation.

[6] ZEUS Coll., Paper 293 submitted to the International Europhysics Conference on High Energy Physics EPS 2005, Lisboa, Portugal.

[7] ZEUS Coll., Paper 268 submitted to the XXII International Symposium on Lepton-Photon Interactions at High Energy LEPTON-PHOTON 2005, Uppsala, Sweden.

[8] S. Catani *et al.*, Nucl. Phys. B **406**, 187 (1993).

[9] ZEUS Coll., S. Chekanov *et al.*, Nuclear Physics B **672**, 3 (2003).

[10] H. Jung, Comp. Phys. Comm. **86**, 147 (1995).

[11] H1 Coll., C. Adloff *et al.*, Z. Phys. C **76**, 613 (1997).

[12] M. Bengtsson and T. Sjostrand, Z. Phys. C **37**, 465 (1998).

[13] V. Gribov, Sov. J. Nucl. Phys. **15**, 438 and 675 (1972); L. Lipatov, Sov. J. Nucl. Phys. **20**, 94 (1975); G. Altarelli, G. Parisi, Nucl. Phys. B **126**, 298 (1977); Y. Dokshitzer, Sov. Phys. JETP **46**, 641 (1977).

[14] M. Gluck, E. Reya and A. Vogt, Phys. Rev. D **45**, 986 (1992).

[15] M. Bengtsson and T. Sjostrand, Comp. Phys. Comm. **46**, 43 (1987); T. Sjostrand, Comp. Phys. Comm. **82**, 74 (1994).

[16] C. Peterson *et al.*, Phys. Rev. D **27**, 105 (1983).

[17] K. Golec-Biernat and W. Wusthoff, Phys. Rev. D **60**, 114023 (1999).

[18] G. Gustafson and U. Peterson, Nucl. Phys. B **306**, 746 (1988)

[19] S. Catani, M.H. Seymour, Nucl. Phys. B **485**, 291 (1997); erratum ibid. B **510**, 503 (1997).

[20] H1 Coll., paper 980 submitted to XXXI Intl. Conf. on High Energy Physics ICHEP 2002, Amsterdam, and paper 089 submitted to the EPS 2003 Conf., Aachen (unpubl.).

[21] ZEUS Coll., S. Chekanov *et al.*, Eur. Phys. J. C **38**, 43 (2004).

[22] M. Groys, A. Levy and A. Proskuryakov, Proc.of the HERA-LHC Workshop, preprint CERN-2005-014, 499 (2005).

[23] M. Klasen and G. Kramer, Eur. Phys. J. C **38**, 93 (2004).

[24] ZEUS Coll., Paper 786 submitted to the XXXI International Conference on High Energy Physics ICHEP 2002, Amsterdam, the Netherlands.

[25] N.N. Nikolaev and B.G. Zakharov, Z. Phys. C **53**, 331 (1992).

[26] G. Ingelman and P. Schlein, Phys. Lett. B **152**, 256 (1985); A. Donnachie and P.V. Landshoff, Nucl. Phys. B **303**, 634 (1988).

[27] M.L. Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B **373**, 295 (1992); S. Frixione, M.L.Mangano, P. Nason and G. Ridolfi, Nucl. Phys. B **412**, 225 (1994).

[28] H1 Coll., A. Aktas *et al.*, preprint DESY-06-049, accepted by Eur. Phys. J. C, 06/06.