MEASUREMENTS OF THE STRUCTURE OF DIFFRACTION AT HERA

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Measurements of diffraction in ep collisions are presented. All measured processes which occur through the exchange of a virtual photon (DIS) are consistent with a universal structure. For the diffractive photoproduction of dijets, factorisation is broken by a global factor ≈ 0.5 with respect to the DIS processes.

1 Inclusive diffraction at HERA

At the HERA ep collider the diffractive quark structure of the proton is probed with a point-like photon (Fig. 1a). The hard scale of the interaction is given by the photon virtuality Q^2.

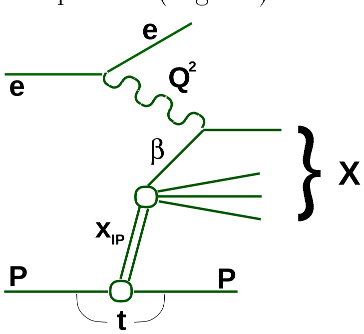

Fig. 1: Diffractive ep scattering.

In diffraction the proton remains intact and loses only a small fraction $x_{I\!P}$ of its initial momentum. Such events can be selected experimentally by requiring an empty area in the detector (rapidity gap) between the outgoing proton and the produced hadronic system X. Since the outgoing proton is not detected, the measured cross section σ^D is integrated over $|t| < 1$ GeV^2, where t is the squared 4-momentum transferred at the proton vertex, and the measured cross sections include $\approx 10\%$ of events where the proton is excited into a system of mass < 1.6 GeV. In a two-step picture, the proton exchanges a diffractive object (often called the pomeron) with momentum fraction $x_{I\!P}$ and the quark struck by the photon carries a fraction β of the momentum of the diffractive exchange. Additional kinematic variables are Bjorken-x $x = \beta\, x_{I\!P}$ and the inelasticity $y = Q^2/(sx)$ where s is the ep centre-of-mass energy squared. The reduced diffractive cross section σ_r^D is given by $\frac{d^3\sigma^D}{dx_{I\!P}\,dx\,dQ^2} = \frac{4\pi\alpha^2}{xQ^4} Y\,\sigma_r^D(x_{I\!P}, x, Q^2)$, with $Y \equiv \left(1 - y + \frac{y^2}{2}\right)$, and is related to the structure functions by $\sigma_r^D = F_2^D - \frac{y^2}{2Y} F_L^D$. The diffractive structure functions have been proven to factorise into diffractive quark densities f_i^D of the proton convoluted with ordinary photon-quark scattering cross sections $\hat{\sigma}^{\gamma^* i}$: $F_2^D = \sum_i f_i^D \otimes \hat{\sigma}^{\gamma^* i}$, where the sum runs over all contributing

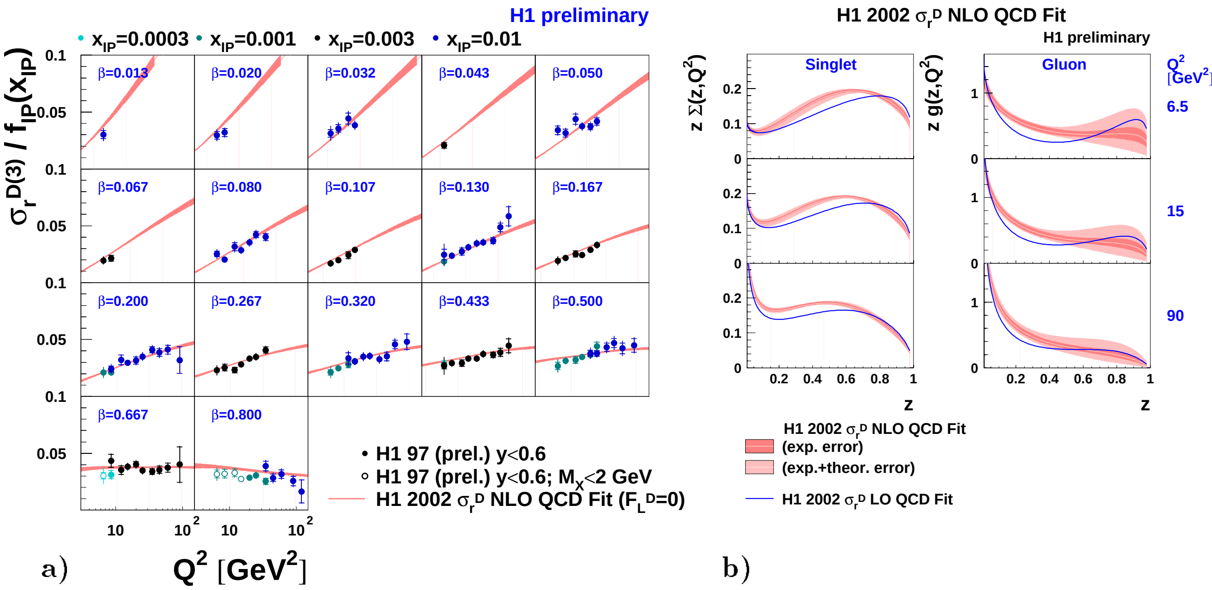

Fig. 2: a) Reduced diffractive cross section divided by the flux factor as a function of Q^2 compared with the H1 2002 NLO fit. b) Diffractive quark ("Singlet") and gluon densities.

quark and anti-quark flavours.[1] This leading twist factorisation formula holds for large enough Q^2 and applies also to F_L^D. Diffractive parton densities (PDFs) which are applicable at fixed $x_{I\!P}$, obey the standard QCD evolution equations and can be determined from fits to structure function data.

2 Inclusive Measurements and Parton Densities

Diffractive structure function measurements have been performed by the H1 and ZEUS Collaborations.[2,3] The H1 Collaboration has extracted diffractive PDFs from their data. The collected event sample statistics do not allow an extraction at fixed values of $x_{I\!P}$. The $x_{I\!P}$ and t dependences of the PDFs are therefore parameterised in a flux factor $f_{I\!P}$: $f_i^D(\beta, Q^2, x_{I\!P}, t) = f_{I\!P}(x_{I\!P}, t)\ f_i^D(\beta, Q^2)$, with $f_{I\!P}(x_{I\!P}, t) = e^{Bt} x_{I\!P}{}^{1-2\alpha_{I\!P}(t)}$ where $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P}\, t$ is the linear pomeron Regge trajectory and $\alpha_{I\!P}(0) = 1.17^{+0.07}_{-0.05}$. The flux factor approach is consistent with the diffractive data within uncertainties for $x_{I\!P} < 0.01$. At larger $x_{I\!P}$ values, a second term has to be introduced which can be interpreted as subleading reggeon exchange. The reduced cross section divided by the flux factor is shown in Fig. 2a as a function of Q^2 for different β values in a kinematic region where to a good approximation $\sigma_r^D = F_2^D$ and the reggeon term is negligible. The cross section exhibits scaling violations with positive $\partial\sigma_r^D/\partial \ln Q^2$ up to $\beta \approx 2/3$ which are driven by the gluon distribution. Also shown is the DGLAP QCD fit and the extracted quark and gluon densities are shown in Fig. 2b. The gluon carries $\approx 75\%$ of the momentum of the diffractive exchange and is poorly known at large fractional momentum z. Diffractive NLO PDFs have also been obtained by Alvero *et al.*[4] in combined fits to H1 and ZEUS diffractive data.

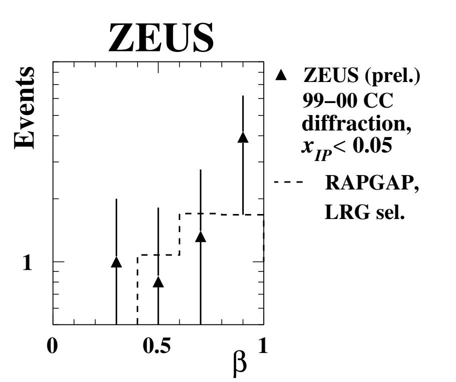

Fig. 3: Diffractive charged current events as a function of β compared with a LO Monte Carlo prediction.

3 Charged current events

Diffractive processes which occur through W boson exchange have been measured by ZEUS and H1 using events with missing transverse energy which is carried away by a neutrino.[5,6] Both experiments find the ratio of the diffractive to the inclusive charged current cross section to be

$\approx 3\% \pm 1\%$ for $x_{I\!P} < 0.05$ and $Q^2 > 200$ GeV^2. The β distribution of the events as measured by the ZEUS Collaboration is shown in Fig. 3. It is well described by a leading order Monte Carlo prediction obtained with the RAPGAP program[7] using an earlier version ("H1 fit 2") of the diffractive PDFs.[8]

4 Final State Measurements

Diffractive dijet and D* meson (heavy quark) production are directly sensitive to the diffractive gluon through the photon-gluon fusion production mechanism (Fig. 4a) and are used to test the universality of the diffractive parton densities.

4.1 Diffractive dijet production in DIS

Cross sections for dijet production in the kinematic range $Q^2 > 4$ GeV^2, $E_T^{\mathrm{jet}}(1,2) > 5, 4$ GeV have been measured by H1[9] using the inclusive k_T cluster algorithm to identify jets. NLO predictions have been obtained by interfacing the H1 diffractive PDFs with the DISENT program.[10] The renormalisation and factorisation scales were set to the transverse energy of the leading parton jet. The NLO parton jet cross sections have been corrected for hadronisation effects using RAPGAP with parton showers and Lund string fragmentation. Comparisons of the DISENT and RAPGAP predictions with the measured cross section differential in $z_{I\!P}^{\mathrm{jets}}$, an estimator for the fraction of the momentum of the diffractive exchange entering the hard scatter, are shown in Fig. 5a. The inner band around the NLO calculation indicates the $\approx 20\%$ uncertainty resulting from a variation of the renormalisation scale by factors 0.5 and 2. The uncertainty in the diffractive PDFs is not shown. Taking this additional uncertainty into account leads to a large increase in the uncertainty at high $z_{I\!P}^{\mathrm{jets}}$, such that the dijet cross section is well described by the NLO calculation based on the diffractive PDFs.

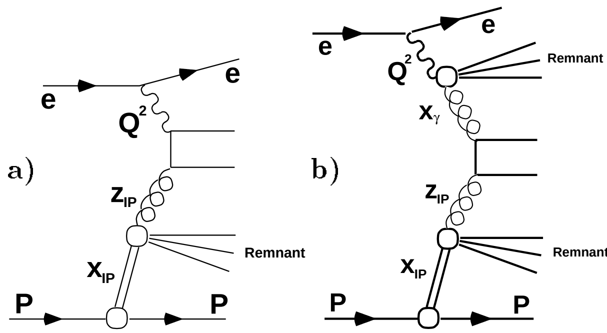

Fig. 4: Example processes for a) direct photon and b) resolved photon interactions.

4.2 Diffractive D^* production in DIS

The diffractive production of D^* mesons has been measured by the ZEUS and H1 Collaborations.[11,12] Fig. 5b shows the ZEUS cross section ($1.5 < Q^2 < 200$ GeV^2, $x_{I\!P} < 0.035$, $p_T^{D*} > 1.5$ GeV/c) as a function of β compared with NLO predictions of a diffractive extension of the HVQDIS program[13] interfaced to the Alvero *et al.* fit B diffractive PDFs. The charm mass is $m_c = 1.45$ GeV, the QCD scales are $\mu = \sqrt{Q^2 + 4m_c^2}$ and the Peterson fragmentation function was used with $\varepsilon = 0.035$. The NLO error band is given by variations of m_c from 1.3 to 1.6 GeV. The cross section is well described by the NLO calculation within errors. The H1 data on diffractive D^* production is well described within errors by the H1 2002 NLO diffractive PDFs.[12]

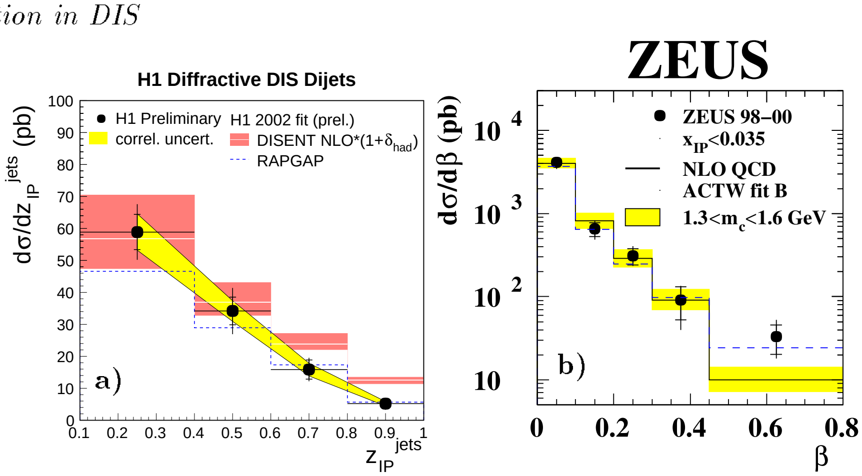

Fig. 5: Diffractive DIS cross section for a) dijet production b) D^* production compared with NLO predictions based on diffractive PDFs.

4.3 Diffractive photoproduction of dijets

Dijet cross sections in diffractive photoproduction ($Q^2 \approx 0$) have been measured by the H1 and ZEUS Collaborations.[9,14] In photoproduction, a sizeable contribution to the cross section is given by resolved photon processes (Fig. 4b) in which only a fraction $x_\gamma < 1$ of the photon momentum enters the hard scatter. The H1 cross section ($Q^2 < 0.01$ GeV^2, $x_{I\!P} < 0.03$, $E_T^{\rm jet}(1,2) > 5, 4$ GeV, inclusive k_T algorithm) is shown in Fig. 6. NLO predictions have been obtained with the Frixione *et al.* program[15] interfaced to the H1 diffractive PDFs. The parton jet calculation is corrected for hadronisation effects using RAPGAP. The calculation lies a factor $\approx$ 2 above the data and factorisation is therefore broken in photoproduction. Fig. 6a shows the NLO predictions scaled down by a global factor 0.5 which gives a good description of the measured cross section. In Fig. 6b, only the "resolved" part for which $x_\gamma^{\rm jets} < 0.9$ at the parton level is scaled by a factor 0.34, as proposed by Kaidalov *et al.*[16] The calculation for $x_\gamma^{\rm jets} > 0.9$ is left unscaled. This approach is clearly disfavoured. The same conclusion is reached by the ZEUS analysis in a comparison with NLO calculations by Klasen and Kramer.

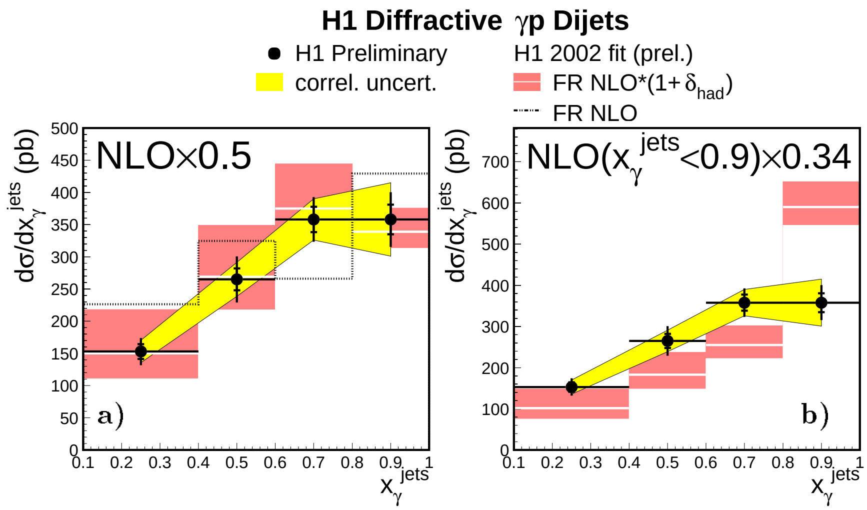

Fig. 6: Diffractive dijet photoproduction cross section. a) NLO calculation scaled by global factor 0.5, b) "resolved" part scaled by 0.34.

5 Conclusions

Diffractive deep-inelastic *ep* scattering is described by universal parton densities. For dijets in diffractive photoproduction, factorisation is broken by a factor ≈ 0.5 with no observed dependence on $x_\gamma^{\rm jets}$ or other kinematic variables.

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