Diffraction at HERA

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The latest results on the diffractive program at the H1 and ZEUS experiments are presented. The new precision measurements of inclusive diffraction as well as diffractive jet production in both deep-inelastic scattering and photoproduction are discussed. The first measurements of diffractive longitudinal structure function F_L^D and diffractive forward jets are described.

1 Inclusive Diffraction

In high-energy electron[1]-proton collisions at HERA in the low x_{Bj} region of the deep-inelastic scattering (DIS), approximately 10% of all events are of type $ep \to eXY$, where the final state consists of two systems X and Y. The X system, which contains the products of the interaction with the photon emitted by the electron, and the system Y, which contains the outgoing proton (elastic process) or its low mass excitations (proton dissociation), are clearly separated by a region without any energy flow (*Large Rapidity Gap*). These events are called diffractive. According to the Regge phenomenology, the event topology is described in terms of the exchange of a colourless object which carries the quantum numbers of the vacuum, the so-called *Pomeron*. Extensive measurements of inclusive diffractive DIS have been performed at HERA using two experimental methods of detecting diffraction - the *Large Rapidity Gap (LRG)* method [1] and the tagging of the outgoing proton with dedicated detectors (*FPS* and *VFPS* for the H1 experiment, *LPS* for the ZEUS experiment) [2],[3],[4].

For diffraction, in addition to the standard DIS variables Q^2 (the photon virtuality) and x_{Bj} (the momentum fraction of the interacting parton with respect to the incoming proton), the following variables are used to describe the kinematics: the longitudinal proton momentum energy loss $x_{I\!P} = 1 - E'_p/E_p$, the momentum fraction of the interacting parton with respect to the Pomeron β, defined similar to x_{Bj}, and the squared energy transfer at the proton vertex t.

The inclusive cross section measurements are presented in the form of the diffractive reduced cross section defined as $\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)} F_L^{D(4)}$, where $F_2^{D(4)}$ is the diffractive structure function depending on Q^2, β, $x_{I\!P}$ and t, and $F_L^{D(4)}$ is the longitudinal diffractive structure function. The contribution of the $F_L^{D(4)}$ is negligible in the low and medium y regions of the phase space. For the comparison between the two experimental methods the integration over t is performed, since with the *LRG* method t cannot be measured.

[1]The term "electron" is used here to denote both electron and positron.

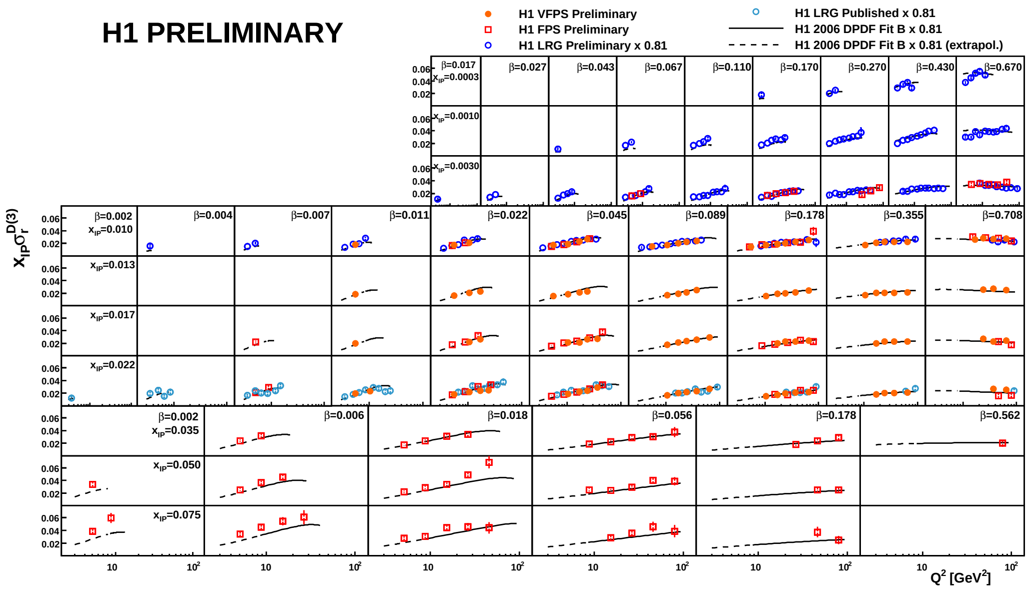

Figure 1: Comparison of the diffractive reduced cross section as measured with the *FPS*, *VFPS* and the *LRG* methods.

Fig. 1 presents the comparison of the two different experimental methods of the diffractive reduced cross section for measurements with the H1 detector. The *LRG* data are multiplied by a factor of 0.81 to account for the proton dissociation that is present only in the *LRG* measurement. The data show a good agreement and are consistent over a wide kinematical range.

The comparison of the H1 *FPS* and ZEUS *LPS* measurements is presented in the Fig. 2 left. The measurements are in agreement within 15%, which is consistent with the overall normalisation uncertainties. Fig. 2 right shows the ratio of the *LPS* to the *LRG* method as measured by the ZEUS Collaboration. The measured value is $0.76 \pm 0.01 \pm 0.03 \pm 0.08$ for ZEUS *LPS*/*LRG*, compared to $1.18 \pm 0.01 \pm 0.06 \pm 0.1$ for H1 *LRG*/*FPS*. The values are compatible within errors.

2 Factorisation in Diffraction

It has been proved by Collins [5], that the diffractive DIS cross section can be factorised into a hard process (denoted as $d\hat{\sigma}^{ei}$) calculable within the pQCD framework and the diffractive parton distribution functions f_i^D (DPDF) which have to be determined experimentally:

$$d\sigma^{ep\to e'XY}(Q^2, |t|, M_Y, \beta, x_{I\!P}) = \sum_i f_i^D(Q^2, |t|, M_Y, \beta, x_{I\!P}) \otimes d\hat{\sigma}^{ei}(Q^2, x_{Bj} = x_{I\!P} \cdot \beta), \quad (1)$$

where the sum runs over all partons. In addition, usually Regge factorisation (also called proton vertex factorisation) is assumed, where the dependence on the variables characterising the proton vertex ($x_{I\!P}$ and t) factorises from the hard interaction depending on β and Q^2:

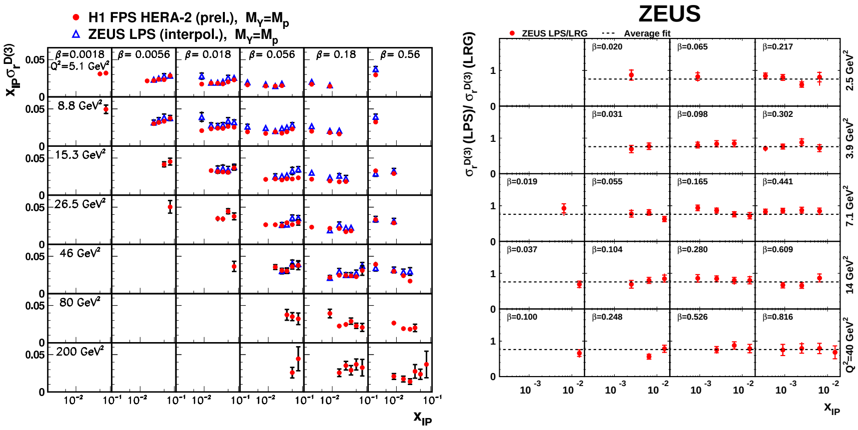

Figure 2: Comparison of the H1 *FPS* and the ZEUS *LPS* methods (left), the ratio of the *LPS* to the *LRG* method (right)

$$f_i^D(Q^2, |t|, M_Y, \beta, x_{I\!P}) = f_{I\!P/p}(x_{I\!P}, t) \cdot f_i(\beta, Q^2), \tag{2}$$

where the $f_{I\!P/p}$ stands for the probability of finding a Pomeron inside the proton (called also Pomeron flux) and f_i is the probability of finding a parton i in the Pomeron. The Pomeron flux is usually parameterised as $f_{I\!P/p}(x_{I\!P}, t) = e^{B_{I\!P} t}/x_{I\!P}^{2\alpha_{I\!P}(t)-1}$ with $\alpha_{I\!P}(t) = \alpha_{I\!P}(0) + \alpha'_{I\!P} \cdot t$.

Proton vertex factorisation has been tested by a determination of the parameters of the Pomeron flux and their dependence on kinematical variables (Fig. 3). The measurements show no significant dependence on Q^2, consistent with the proton vertex factorisation assumption.

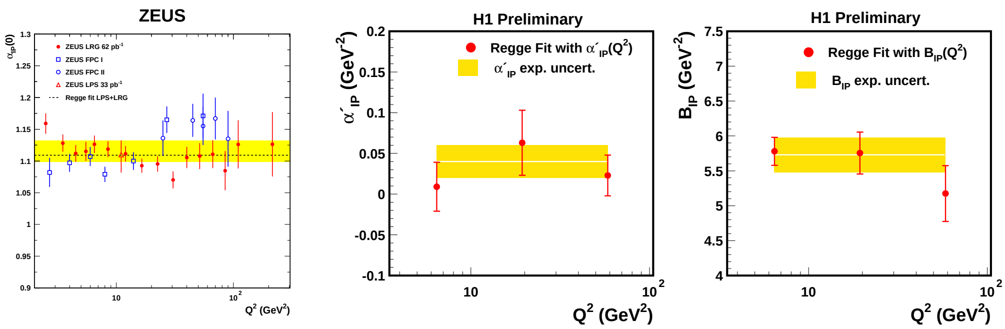

Figure 3: Measurement of the $\alpha_{I\!P}(0)$ (left), $\alpha'_{I\!P}(0)$ (middle) and $B_{I\!P}$ as a function of Q^2

Using the assumption of proton vertex factorisation diffractive parton distribution functions of the Poemeron, depending on β and Q^2, are extracted. The DPDFs are parametrised at starting scale Q_0^2 and evolved using next-to-leading order DGLAP [6, 7]. The quark component of the pomeron is well constrained by the inclusive cross section measurement. Diffractive jet cross sections provide further constraints on the gluon density. Recent measurements of diffractive dijets at H1 and ZEUS are consistent with the factorisation assumption. THey have been included in QCD fits in order to obtain the DPDF sets H1 2007 Jets [8] and ZEUS SJ [9]. Fig. 4 presents the dijet cross sections measured by H1 compared tho the NLO predictions based on the H1 2006 Fit B [10], the ZEUS DPDF fits with (SJ) and without (C) jets and the comparison of the ZEUS data to the ZEUS DPDF SJ prediction.

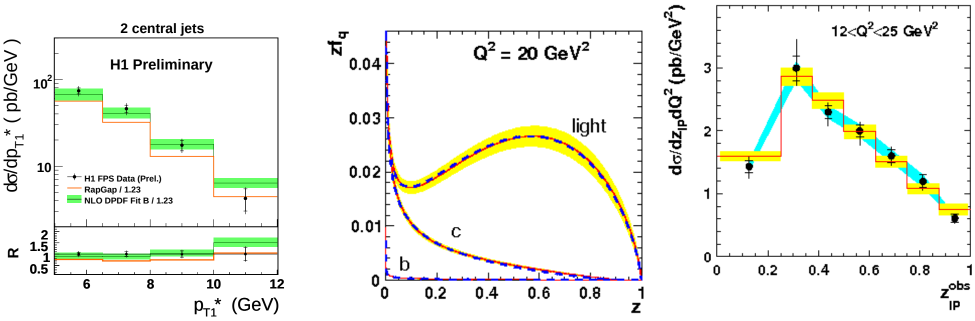

Figure 4: Differential cross section in transverse momentum on the leading jet in the hadronic centre-of-mass system measured with the FPS method compared to the NLO based on H1 2006 Fit B (left), the extracted DPDFs for the quark component of the pomeron, the blue line stands for the ZEUS DPDF C [9], which is performed on inclusive LRG and LPS data, the red line for the ZEUS DPDF SJ, which is performed on inclusive LRG,FPS and dijet data, the yellow band stands for the experimental uncertainties (middle), the comparison of the differential cross section in the fraction of the energy contained in the jets with respect to the whole system M_X ($z_{\mathbb{P}}$) to the ZEUS DPDF SJ (right).

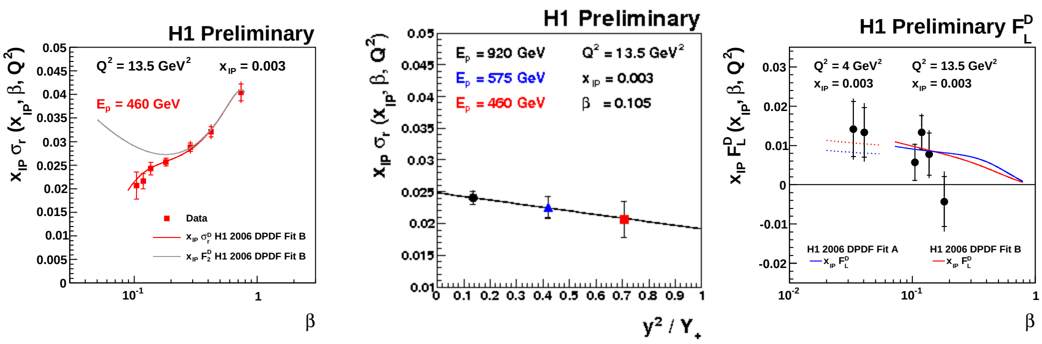

Figure 5: The σ_r for the low energy run compared to the H1 2006 Fit B (grey) and with the extracted F_L^D (red) on the left, the Rosenbluth plot with the F_L^D as the slope of the linear fit (middle), F_L^D as a function of β (right).

Another observable that depends mainly on the gluon component is the longitudinal diffractive structure function F_L^D. Thus its measuerement provides an independent test of the QCD factorisation. Due to the relation $Q^2 = x_{\mathbb{P}}\beta ys$ the centre-of-mass energy of the collision s has to be changed in order to obtain different values of y for fixed Q^2,$x_{\mathbb{P}}$ and β. Special runs with medium ($E_p = 575\ GeV$) and low ($E_p = 460\ GeV$) proton beam energies have been dedicated to the measurement of F_L and F_L^D. Inclusive diffractive DIS reduced cross sections have been measured (Fig 5 left) and the Rosenbluth plot (Fig 5 middle) has been used to obtain F_L^D (Fig. 5 right).

A unique measurement of forward jets in diffraction has been performed in order to test the validity of the DGLAP evolution equations. The phase space, defined by a hard jet close to the outgoing proton direction with a transverse momentum squared of the same order as the photon virtuality, suppresses strongly the DGLAP evolution. Diffractive jet production with a tagged elastic proton allows the reconstruction of forward jets close to the outgoing proton. Within the phase space accessible by the H1 detector and the *FPS*, the DGLAP evolution gives a good description of the production of one central and one forward jet, see Fig. 6.

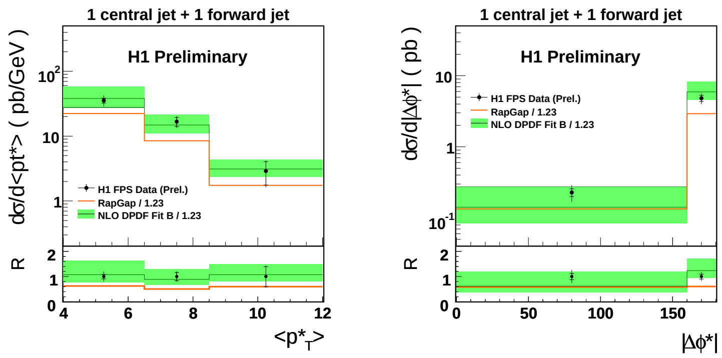

Figure 6: The differential cross section in the mean transverse momenta of the central and forward diffractive jets (left), the deforrelation measured in the difference of the azimuthal angle (right).

Further tests of factorisation in the photoproduction regime ($Q^2 \approx 0\ GeV^2$) have been performed by H1 and ZEUS. Two classes of processes contribute to the photoproduction of dijets: resolved and direct processes. In the resolved processes, the photon is considered as a hadron with a partonic structure, and in addition to the interacting parton a soft remnant is present. In the direct process the photon is treated as structureless. The observable $x_\gamma = \sum(E - p_Z)_{jets} / \sum(E - p_Z)_{hadrons}$ is defined to distinguish the direct ($x_\gamma \approx 1$) from the resolved ($x_\gamma < 1$) processes. According to theoretical calculations, in diffraction the resolved processes are expected to be suppressed by the *Gap Survival Probability* factor, whereas the direct processes remain unsuppressed [11]. The measured cross sections and ratios to the NLO predictions (based on H1 2006 Fit B and ZEUS SJ) show no suppression in the whole x_γ range for the ZEUS measurement, while a constant suppression of 0.58 ± 0.21 for both resolved and direct processes is found for the H1 measurement ([12, 9]). The two measurements cover different regions of phase space, especially for the transverse momentum of the jets.

The recent calculations of Kadialov-Khoze-Martin-Ryskin (KKMR) revise the model of survival probability for *ep* interactions. The ratio of the H1 data to the revised theory is presented in Fig. 7. The agreement between data and NLO calculation is improved, but the description of the x_γ dependence remains unsatisfactory. Therefore the question about factorisation breaking in photoproduction is still not fully answered and needs more investigation.

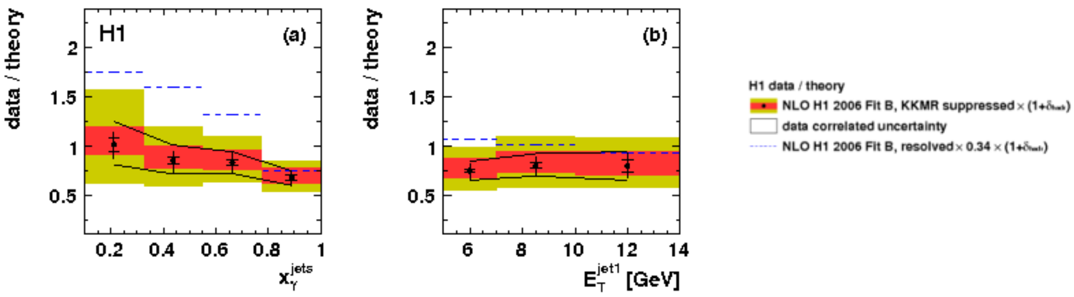

Figure 7: The comparison of the H1 measured data to the revised KKMR theory in the x_γ and transverse momentum of the hardest jet.

Further measurements of diffraction at HERA include the production of vector mesons and the measurement of inclusive processes with a leading neutron. The measurements of vector meson productionare consistent with a smooth interplay between the soft and hard physics [13] Recent measurements with a tagged leading neutron are consistent with Monte Carlo predictions [14] and provide information relevant for fragmentation models [15].

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