Diffraction at HERA

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The latest results from the H1 and ZEUS experiments at HERA on the measurements of diffractive production are presented. Precision measurements of reduced diffractive cross sections are described, first measurements of longitudinal diffractive structure function and jet cross sections with a tagged leading proton are shown and the results are discussed in terms of diffractive parton densities and Regge factorisation.

1 Inclusive Diffraction

In the ep[b] high-energy collisions at HERA in the low x 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 M_X and M_Y. The M_X system, which contains the products of the interaction with the photon emitted by the electron, is clearly separated from the system M_Y, which contains the outgoing proton or its low mass excitations, by a region without any energy flow (*Large Rapidity Gap*). These events are called diffractive. According to the Regge phenomenology, the event topology is explained in terms of exchange of an colourless object which carries quantum numbers of the vacuum, a *Pomeron*. Extensive measurements of inclusive 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 (*FPS* and *VFPS* for the H1 experiment, *LPS* for the ZEUS experiment) [2,3].

The diffractive kinematics is defined apart from the standard DIS variables Q^2 (the photon virtuality) and x_{bj} (the fraction of the momentum of the parton, which undergoes the interaction with the photon, to the momentum of the incoming proton) with the $x_{I\!P}$, β and t variables. The $x_{I\!P} = 1-E'_p/E_p$ stands for the longitudinal proton momentum energy loss, $\beta(= x_{bj}/x_{I\!P})$, similarly to the X_{bj}, is defined as the momentum fraction of the interacting parton with respect to the Pomeron and t stands for the squared energy transfer at the proton vertex.

The inclusive cross section measurements are presented in form of the diffractive reduced cross section defined as

$$\sigma_r^{D(4)} = F_2^{D(4)} - \frac{y^2}{2(1-y+y^2/2)} F_L^{D(4)}. \tag{1}$$

The $F_2^{D(4)}$ is the diffractive structure function in Q^2, β, $x_{I\!P}$ and t, the $F_L^{D(4)}$ is the longitudinal diffractive structure function. The contribution of the $F_L^{D(4)}$ is assumed to be 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 the *LRG* method is incapable of the t measurement.

Fig. 1 presents the comparison of the two different experimental methods of the diffractive reduced cross section measurements within H1. The data show a good agreement and are consistent over a wide kinematical range.

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[b] The lepton-proton scattering involves electrons as well as positrons, will be referred as electron-proton scattering in the following text

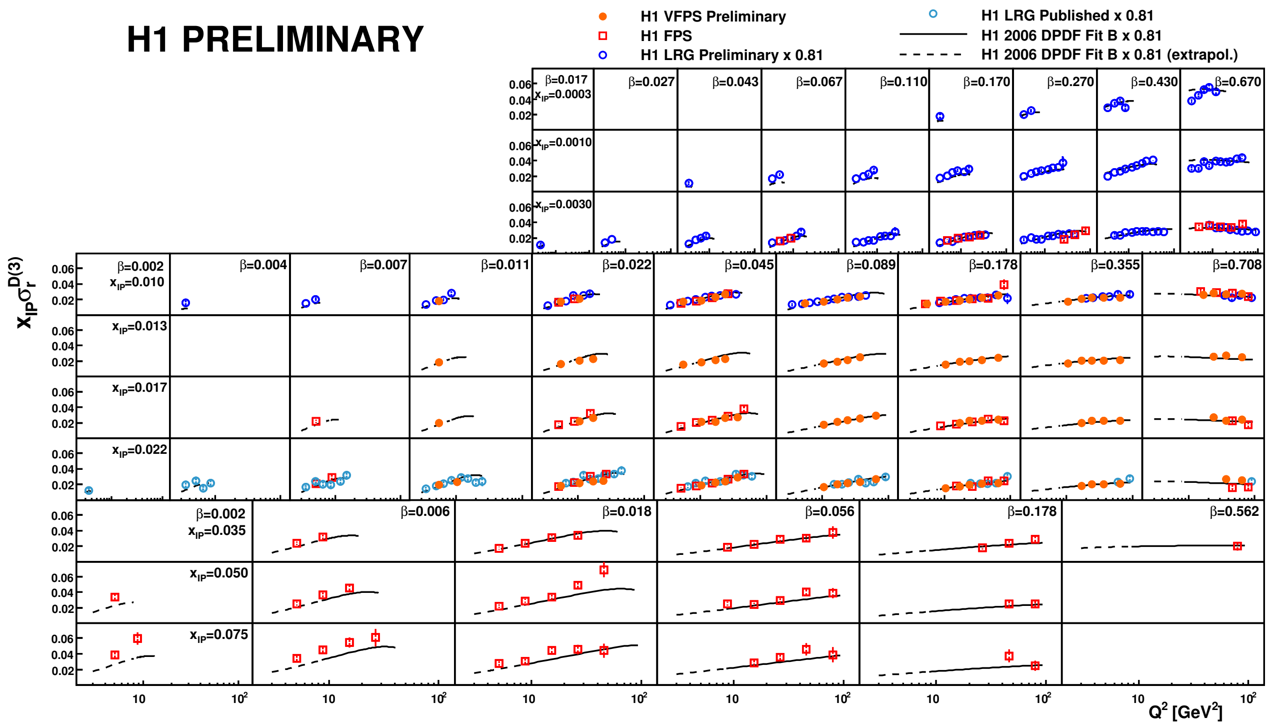

Figure 1: Compilation of diffractive reduced cross section measurements performed with the FPS, $VFPS$ and the LRG methods. The LRG data are corrected for proton dissociation by multiplication by a constant factor of 0.81.

The comparison of the H1 FPS and ZEUS LPS measurements is presented on the left side of Fig. 2 and the results are in agreement within 15% arising from the overall normalisation uncertainties. In order to gain in statistical and systematic precision of the measured data sets, a combination of H1 and ZEUS data was performed in the kinematical range of $|t|$ directly measurable by both detectors: $0.09 < |t| < 0.55$ GeV^2[4]. The Fig. 2 middle shows data sets used for the combination, on the right side of Fig. 2, the result of the combination compared with the individual measurements for bin of $x_{\mathbb{P}} = 0.05$ are presented. The improvement in the reduction of the total error is visible.

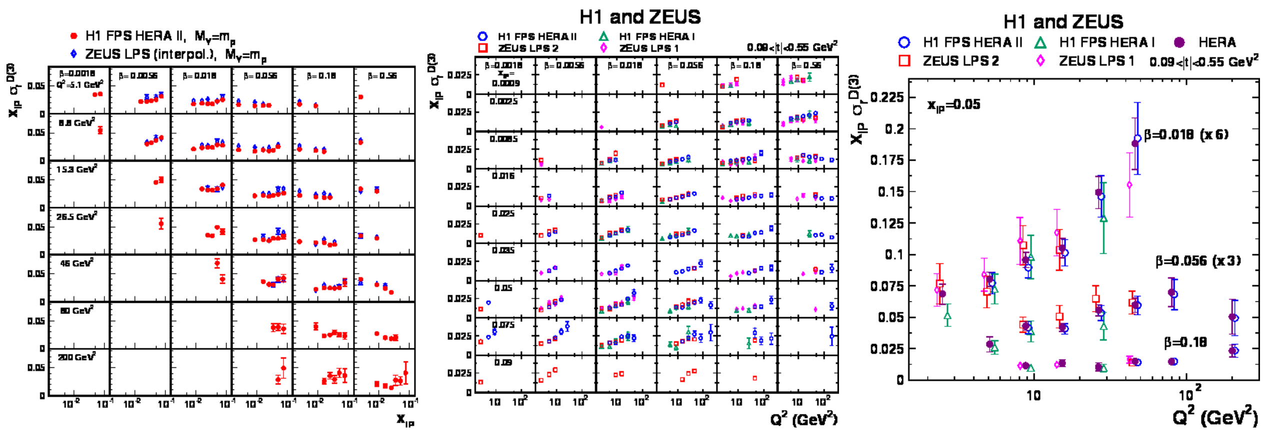

Figure 2: Comparison of the H1 FPS and the ZEUS LPS measurements of reduced diffractive cross sections measured in the kinematical range of $|t| < 1.0$ Gev^2 (left), in the restricted range of $0.09 < |t| < 0.55$ Gev^2 as used for the H1-ZEUS combination (middle) and the comparison of the combined data points with the individual measurements for bin of $x_{\mathbb{P}} = 0.05$.

The measurement of the longitudinal diffractive structure function F_L^D directly investigates the gluonic part of the exchanged object (Pomeron) and has to be perfomed in the kinematical domain of high y (see Eq. 1)[5]. Due to the relation $Q^2 = x_{\mathbb{P}}\beta ys$ in order to obtain different values of y for the fixed Q^2,$x_{\mathbb{P}}$ and β the central mass energy of the collision has to be changed. Special runs with medium ($E_p = 575\ GeV$) and low ($E_p = 460\ GeV$) proton beam energies have been dedicated to the

F_L and F_L^D measurements. Inclusive diffractive DIS reduced cross sections have been measured and the Rosenbluth plot [5] has been constructed in order to obtain the F_L^D (See Fig. 3).

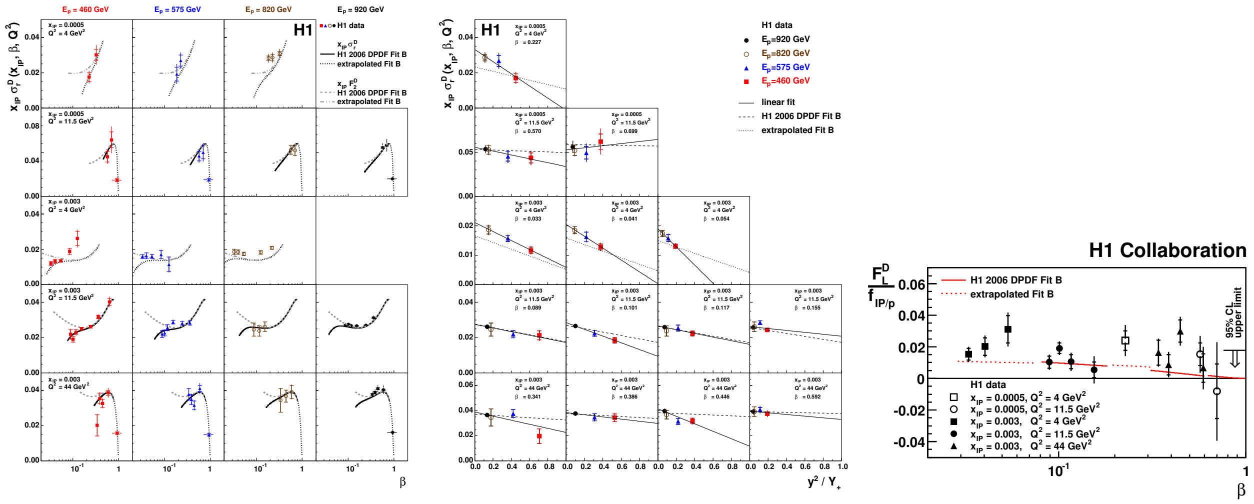

Figure 3: The σ_r for runs with different proton energies compared to the H1 2006 Fit B (grey), the Rosenbluth plots with the F_L^D as the slope of the linear fit (middle), F_L^D as a function of β. - UPDATE

2 Jets in Diffraction

It has been proved[6], that the diffractive cross section can be factorised into a hard process (due to the presence of the photon virtuality or high transverse momentum of the interacting parton, denoted as $d\hat{\sigma}^{ei}$) calculable within the pQCD framework and the diffractive parton distribution function f_i^D (DPDF) which has to be provided by the experiment:

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

here the sum runs over all partons. Regge factorization (also called proton vertex factorization) is usually assumed in addition, where the dependence on the variables characterizing the proton vertex ($x_{I\!P}$ and t) factorizes from the hard interaction depending on β and Q^2: $f_i^D(Q^2,|t|,\beta,x_{I\!P}) = f_{I\!P/p}(x_{I\!P},t)\cdot f_i(\beta,Q^2)$, where the $f_{I\!P/p}$ stands for the Pomeron flux and f_i is the probability of finding a parton i in the Pomeron. The quark densities within the Pomeron are well constrained by the inclusive diffractive DIS measurements ([2]), whereas a better constraint on the gluon density in the Pomeron is provided by measurement of jets in the final state. In addition, dijet measurements allow tests of perturbative QCD calculations, various models for modelling diffractive processes and serve as a tool for studying the parton evolution.

The measurements of central di-jet production with a proton measured in the *FPS*[7] and *VFPS*[8] spectrometers have been performed for the first time at HERA. The cross sections are corrected to the level of stable hadrons with a matrix (*FPS*) and bin by bin (*VFPS*) unfolding. They are compared to pNLO DGLAP QCD calculations, DPDF-based RAPGAP Monte Carlo, two-gluon Pomeron RAPGAP Monte Carlo and soft colour interaction (SCI) model as implemented in the LEPTO Monte Carlo. The left side of Figure 4 presents the comparison of the *VFPS* (data to NLO). The direct comparison of the *FPS* and *LRG* methods and the extension of the phase space for the *FPS* method is presented on the right side of Fig. 4. All methods agree well within errors, the *LRG* measurement is corrected for proton dissociation by a constant factor of 1.2.

A unique measurement of diffractive forward jets has been performed in order to search for the physics beyond DGLAP evolution equations[7]. The phase space defined by hard jet production collinear with the outgoing proton with transverse momentum squared of the same order as the photon virtuality suppress strongly the DGLAP evolution in favour to other models. The diffractive jet production with tagged elastic outgoing proton allows a clear signal of forward jets to be reconstructed. Within the

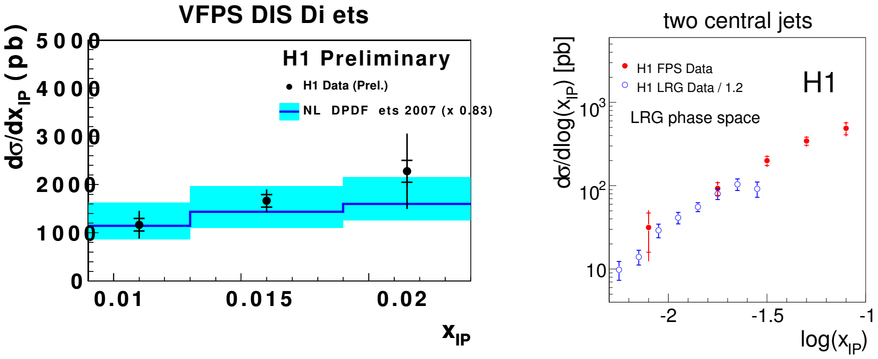

Figure 4: The single differential cross section measured in $x_{I\!P}$ with the VFPS method (left) and FPS and LRG method (right) as a fuction of $\log(x_{I\!P})$ (left). The VFPS data are compared to the hadron level corrected NLO-DGLAP predictions, the LRG dataset was corrected for proton dissociation with a constant factor of 1.2.

phase space accessible by the H1 detector the DGLAP evolution gives a good description of the production of one central and one forward jet as shown in Fig. 5.

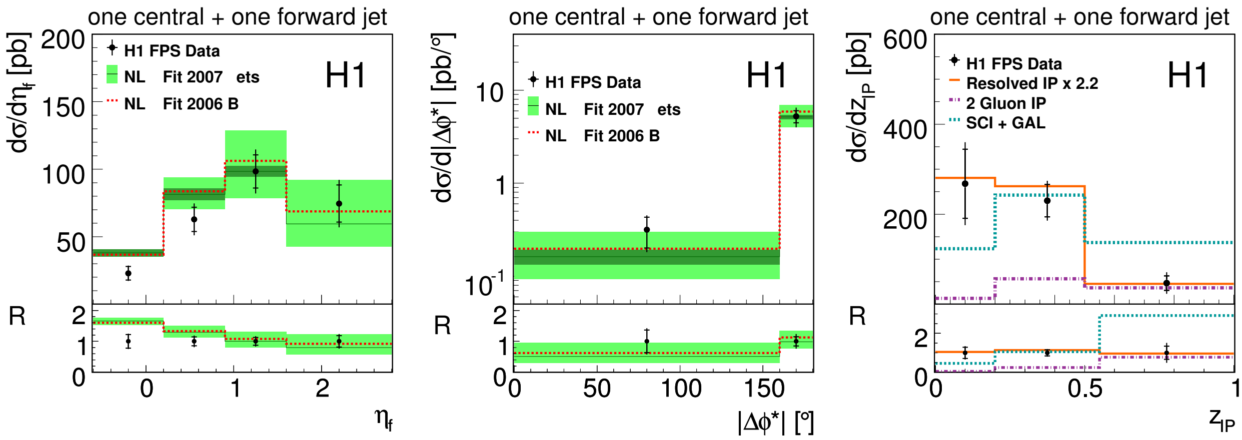

Figure 5: The sinlge differential cross section for the production of one central + one forward jet shown as a function of $z_{I\!P}$ (left) and $|\Delta\phi^*|$ (middle) compared to the NLO QCD DGLAP predictions based on DPDFs H1 2007 Jets and H1 2006 Fit B. Comparison of the cross section measured as a function of $z_{I\!P}$ with several MC models is on the right.

Further new measurements of diffraction at HERA include the production of exclusive vector mesons - J/Ψ by H1 [9] and Υ by ZEUS [10] and provide an interplay between soft and hard physics. They were not discussed due to lack of space.

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