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Tevatron and HERA Forward Physics Results and Implications for the LHC

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The H1 and Zeus collaborations have measured the dijet and inclusive diffractive DIS cross sections. Diffractive parton density functions (DPDFs) have been extracted from NLO QCD fits to the inclusive data and the predictions of these DPDFs compare well with measurements of diffractive dijets in DIS, proving the validity of the factorisation approximations used in their extraction. The inclusive and dijet data are then used in a combined fit to constrain the diffractive singlet and gluon with good precision over the full phase space. The measurement of the diffractive longitudinal structure function agrees well with the predictions based on NLO QCD fits to the inclusive data. The predictions of DPDFs are compared to diffractive dijets in photoproduction where the issue of survival probability in a hadron-hadron environment can be studied. While these studies at HERA remain inconclusive for the time being, exclusive measurements made at the Tevatron bolster confidence in calculations for survival probabilities at hadron-hadron machines. Exclusive diffractive vector meson production and deeply virtual Compton scattering have also been studied at HERA; the results compare reasonably well with the expectations of QCD and in particular with GPD models. Finally, measurements of the double parton scattering cross-section show that this will need to be understood as a background to rare processes.

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1. Inclusive Diffraction at HERA

It has been shown by Collins [1] that the NC diffractive DIS process $ep \rightarrow eXp$ at HERA factorises; a useful additional assumption is often made whereby the proton vertex dynamics factorise from the vertex of the hard scatter - proton vertex factorisation. The kinematic variables used to describe inclusive DIS are the virtuality of the exchanged boson Q^2, the Bjorken scaling variable x and y the inelasticity. In addition, the kinematic variables x_{IP} and β are useful in describing the diffractive DIS interaction, where x_{IP} is the longitudinal fractional momentum of the proton carried by the diffractive exchange and β is the longitudinal momentum fraction of the struck parton with respect to the diffractive exchange; $x = x_{IP}\beta$. The data are discussed in terms of a reduced diffractive cross-section, $\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$, which is related to the measured differential cross section by:

$$\frac{d^3\sigma_{ep\rightarrow eXp}}{d\beta dQ^2 dx_{IP}} = \frac{4\pi\alpha_{em}^2}{\beta Q^4}(1-y+\frac{y^2}{2})\sigma_r^{D(3)}(\beta, Q^2, x_{IP}). \tag{1.1}$$

In the proton vertex factorisation scheme, the Q^2 and β dependences of the reduced cross section factorise from the x_{IP} dependence. Measurements of the reduced diffractive cross section from both H1 and Zeus are shown in Figure 1, where the new Zeus preliminary measurement has been scaled by a factor of 0.87, a factor consistent with the normalisation uncertainties of the two analyses. The measurements agree rather well.

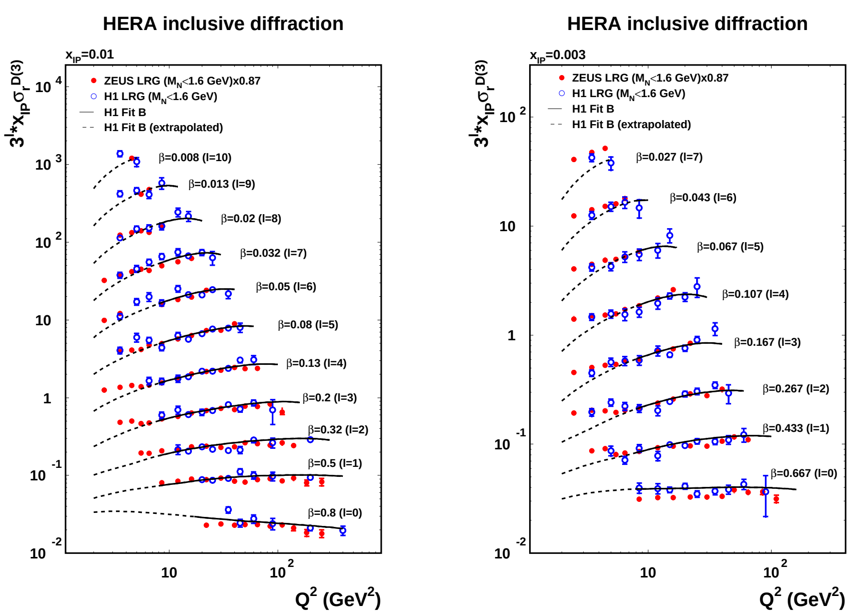

Figure 1: The reduced diffractive cross section as measured by the H1 and Zeus collaborations.

1.1 Diffractive PDFs

Using the approximation of proton vertex factorisation, the H1 [2] and Zeus [3] collaborations have extracted DPDFs using NLO QCD fits to the β and Q^2 dependencies of the reduced cross section. Both H1 and Zeus obtained two fits of approximately equal quality, differing only in the number of terms used to parameterise the gluon. H1 Fit A is very similar to Zeus Fit S; likewise H1 Fit B is similar to Zeus Fit C. The fits, while fully consistent at low fractional momentum, yield very different results for the diffractive gluon at high fractional momentum. This is due to quark-driven evolution dominating the logarithmic Q^2 derivative of the reduced cross section at high β, which in turn greatly reduces the sensitivity of this quantity to the gluon.

Diffractive dijets in DIS provide a sensitive experimental probe of the diffractive gluon, as the dominant production mechanism is boson-gluon fusion. The sensitive variable is $z_{IP} = \frac{Q^2+M_{12}^2}{Q^2+M_X^2}$, where M_{12} is the invariant mass of the dijet system and M_X is the invariant mass of the total hadronic final state X. Both H1 [4] and Zeus [6] have measured the diffractive dijet cross section in DIS. Both collaborations find that, at low z_{IP}, where the inclusive data have sensitivity to the diffractive gluon, the results of the predictions are very similar and agree well with the data. This supports the use of the proton vertex factorisation approximation needed to make the NLO QCD fits. At high z_{IP} the data clearly prefer the predictions of H1 Fit B and Zeus Fit C.

Having shown the sensitivity of the diffractive dijets in DIS data, H1 and Zeus have included their data in a combined fit with the inclusive diffractive DIS data [4, 5]. The resulting fits are indistinguishable from the inclusive-only fits in their description of the inclusive data and produce a better description of the diffractive dijet data, consistent with those of H1 Fit B and Zeus Fit C. The resulting DPDFs from the Zeus combined fit, are shown in Figure 2. Both singlet and gluon are constrained with similarly good precision across the whole kinematic range.

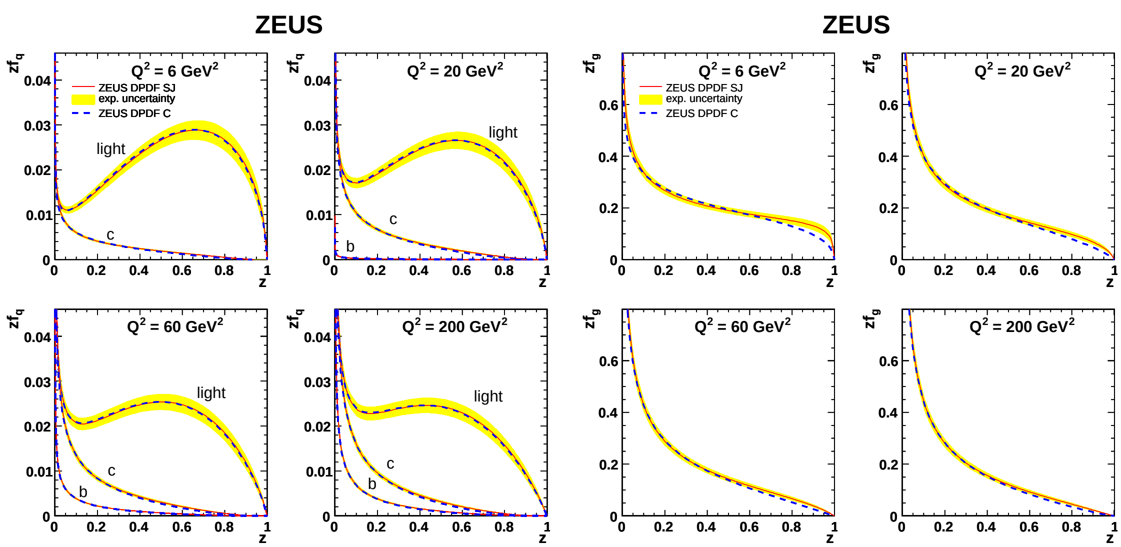

Figure 2: The Zeus DPDFs resulting from the combined fit to the inclusive and dijet diffractive DIS data.

1.2 The Diffractive Longitudinal Structure Function

At high y, the reduced cross-section $\sigma_r^{D(3)}(\beta, Q^2, x_{IP})$, defined in equation 1.1 has a significant contribution from the diffractive longitudinal structure function, F_L^D. The H1 collaboration have measured this quantity using measurements of the reduced cross-section at different beam energies

PoS(HCP2009)025

[7], using an analogous method to that used to extract the inclusive longitudinal structure function [8]. The result, shown in figure 3 is in good agreement with the predictions of NLO QCD fits to inclusive data.

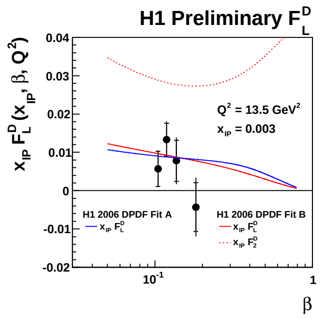

Figure 3: The diffractive longitudinal structure function F_L^D multiplied by $x_{I\!P}$. The data are compared to predictions from two NLO QCD fits to previous H1 data, Fit A (blue line) and Fit B (red line). The data are consistent with both predictions. Also shown is the value of F_2^D as a dashed red line.

1.3 Diffractive dijets in photoproduction

Despite the success of factorisation in diffractive DIS at the HERA experiments, there is a long-standing issue that the predictions obtained with HERA DPDFs grossly overshoot the diffractive dijet cross section at the Tevatron. At HERA, photoproduction events, where $Q^2 \sim 0$, provides an environment similar to a hadron-hadron collider. The variable x_γ is the fraction of the four momentum of the photon transferred to the hard interaction; the lower the value of x_γ the more hadron-like the photon. Both H1 [9] and Zeus [10] have measured diffractive dijets in photoproduction. The latest preliminary results from H1 [11] show a suppression of the cross section with respect to the predictions and this suppression is independent of x_γ. There is also a suggestion that this suppression is dependent on the E_T of the jet. This would be consistent with the Zeus analysis at higher E_T where less suppression is observed. It should be noted in addition that the current measurements have large experimental and theoretical uncertainties. Measurements of the diffractive to inclusive cross-section ratio from H1 [12] show the same features as the previous H1 preliminary results. In priciple, the ratio would provide improved sensitivity compared to direct measurements of the diffractive cross-section, with several large systematic effects cancelling. However, at the low E_T considered in the analysis, the effects of multiple interactions can be large and prohibit strong conclusions being made.

2. Exclusive production, DVCS and double parton scattering

The CDF collaboration has measured the exclusive dijet production cross-section [13] by using the variable R_{JJ} to discriminate between signal events, expected to appear around $R_{JJ} = 1$, and the inclusive background predicted from measurements at HERA. The exclusive signal agrees well with theoretical predictions [14]. The CDF collaboration have also observed exclusive χ_c production and again the measured cross-section is in agreement with theoretical predictions [15]. Both of these results indicate that, while the HERA results on factorisation breaking are dominated by systematic uncertainties, the theoretical understanding of exclusive production and survival probabilities at hadron machines is in good shape.

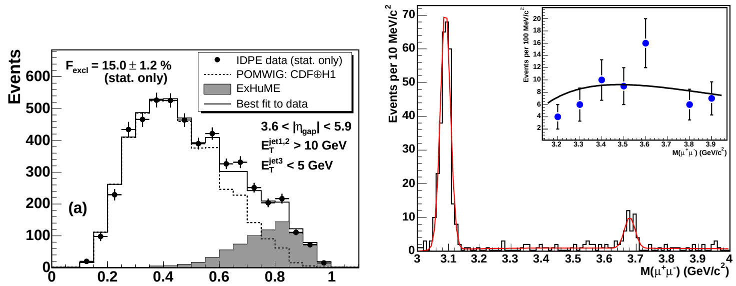

Figure 4: Exclusive dijet production (left) and (right) exclusive χ_c production (see text).

Exclusive vector meson production provides an ideal experimental testing ground for QCD, as the experimental signature is clean and the theoretical calculations are often simplified. Measured at H1 [16], the exclusive production of photons at high momentum transfer t at the proton vertex allows comparison of the experimental results with BFKL calculations which do not suffer from uncertainty on the final state vector meson wave function. The W dependence of the high-t photon cross-section is shown in figure 5 (left); this is certainly one of the hardest diffractive processes yet measured and is consistent with the BFKL predictions, although the precision of the data is limited.

Deeply virtual Compton scattering is a process with sensitivity to the transverse correlations of partons in the proton and thus has sensitivity to models of Generalised Parton Densities (GPDs) [17]. Figure 5 (right) shows the Q^2 dependence of (top) a dimensionless variable S related to the amplitude for the process with the t-dependence removed; (bottom) the Q^2 dependence of a variable R related to the ratio of GPD to PDF. The data can discriminate between GPD models and favour a full GPD model rather than one with only kinematical skewing.

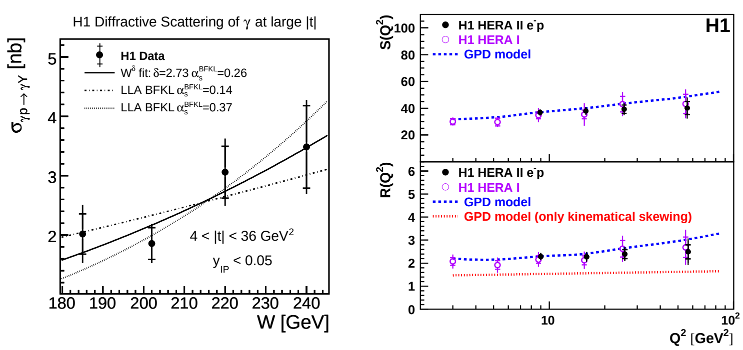

Figure 5: The W dependence of the high-t photon cross-section (left) and (right) the Q^2 dependence of quantities sensitive to GPD models (see text).

The double parton scattering cross section has been measured by the D0 collaboration using events with 3 jets and a photon in the final state [18]. The result of $\sigma_{eff}^{aver.} = 15.1 \pm 1.9$mb is consistent with previous measurement by the CDF collaboration and confirms that double parton scattering will need to be understood as a background to rare processes.

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