Inclusive diffraction and factorisation at HERA

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Abstract
In this article, recent measurements of diffraction in deep inelastic scattering are presented along with QCD fits to extract the partonic structure of the exchange. These so-called diffractive parton density functions can then be used in predictions for other processes to test factorisation in diffraction. This is an important verification of QCD and has significance for predicting exotic signals such as diffractive Higgs production at the LHC.

1 Introduction

Diffraction in deep inelastic scattering (DIS) has long been a subject of great interest since the discovery of the first striking events at the beginning of the HERA programme [1, 2]. The final state of a diffractive ep collision at HERA contains a high energy scattered electron measured in the detector and a proton which remains intact and exits through the beam-pipe, sometimes to be detected in proton spectrometers along the proton beam-line. In addition the event consists of hadronic activity in the main detector, but with none in the direction of the proton. This dearth of hadronic activity in the proton direction constitutes the striking experimental signature which caused great surprise in the early years. Along with this so-called large rapidity gap (LRG), the hadronic final state has a very low invariant mass, M_X, compared to non-diffractive DIS. All three signatures are used to isolate diffractive events. The techniques complement each other with detection of the final-state proton providing the cleanest signature but also with much lower statistics and a more restricted kinematic range. The LRG and M_X methods are similar in range and statistics but have different background contaminations.

Such events can be understood in terms of the exchange of a colourless object, sometimes known as the Pomeron, which develops a structure. The virtual photon emitted from the electron collides with a parton in this colourless object producing a hard collision. Figure 1 shows this process along with relevant kinematic variables. The cross section for diffractive processes can be factorised into the convolution of the Pomeron flux, $f_{I\!P}$, as suggested by Regge theory, diffractive parton density functions (dPDFs), $f_{i/I\!P}$, and the hard scatter between one of the partons from the diffractive exchange and the photon, $\sigma_{ep\to eXp} \sim f_{I\!P} \otimes f_{i/I\!P} \otimes \sigma_{i\gamma\to jk}$.

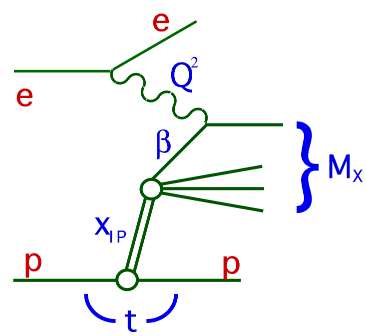

Fig. 1: Schematic of diffraction in DIS.

There are several motivations to study the nature of diffractive processes and learn more about QCD, *viz*: diffractive processes constitute a large fraction of inclusive cross section; the transition from "soft" to "hard" regimes [3]; the applicability of the factorisation approach; and the potential for major discoveries such as the Higgs boson produced in diffractive processes at the LHC which relies on the above understanding.

This article reviews the most recent measurements of inclusive diffraction in DIS and the extraction of dPDFs from such data. Factorisation is then tested through comparison of dPDFs (convoluted with an appropriate programme to calculate the hard scatter) for jet production in DIS and photoproduction as well as at the Tevatron.

2 Inclusive diffraction in DIS

The ZEUS collaboration has recently published results on inclusive diffraction in DIS using all three methods [4,5]. The data from the M_X method extend the previous results [6] to higher photon virtuality, Q^2, and, in the region of overlap, with increased precision. The data using the LRG method is a significant update over previous ZEUS measurements with this method. It covers the same kinematic range as the data from the M_X method and complements the previously released data using the LRG method from the H1 collaboration [7]. Similarly, the data where the proton is tagged using the leading proton spectrometer (LPS) complement previous measurements [8,9].

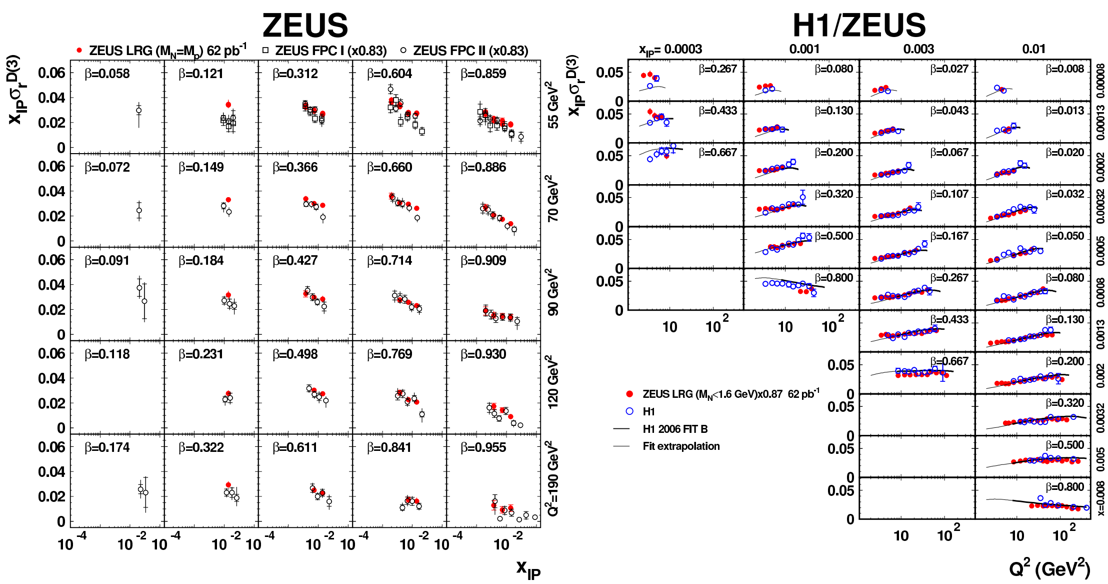

Fig. 2: Comparison of the reduced cross section in inclusive diffractive DIS as a function of (left) $x_{I\!P}$ for fixed β and Q^2 for the LRG and M_X methods and (right) Q^2 for fixed $x_{I\!P}$ and β for H1 and ZEUS data using the LRG method.

A comparison of the ZEUS measurements of the inclusive reduced cross section using the LRG and M_X methods is shown in Fig. 2 (left) for the high-Q^2 data as a function of the Pomeron momentum fraction, $x_{I\!P}$, at fixed Q^2 and fixed Pomeron momentum fraction carried by the parton in the hard scatter, β. The data using the M_X method are scaled to account for the residual background from proton dissociation in which a proton breaks up into a low-mass nucleon. Some differences between the methods (more marked at lower Q^2, not shown) as a function of $x_{I\!P}$ are observed which can be attributed to the suppression of Reggeon and pion trajectories at high $x_{I\!P}$ in the M_X method. Also at lower Q^2, the two measurements have a somewhat different Q^2 dependence with the data from the M_X method decreasing faster with the Q^2 than those from the LRG data. However the overall agreement between the two data sets is reasonable.

The measurements of the reduced cross section from both H1 and ZEUS collaborations using the LRG method are compared in Fig. 2 (right) as a function of Q^2 for fixed $x_{I\!P}$ and β. To enable a comparison in shape, the ZEUS data have been normalised to the H1 data within the uncertainty in the relative normalisation of the two measurements. Overall the (qualitative) agreement is good and work is ongoing to combine the measurements which will give a quantitative measure of their compatibility and possibly lead to a significantly improved determination of the cross section. Already from these data it can be seen that at fixed β, the Q^2 dependence is different for different $x_{I\!P}$ values. This effect, also seen in the results using the M_X method, means that the data cannot be described by a single factorisable Regge contribution, $f_{I\!P}$.

Results in which a forward-going proton was tagged not only provide a clean measure of diffraction, but also as a result allow the determination of the residual background from proton dissociation, which is independent of all kinematic variables, in the other data samples. This and other results of these measurements are discussed in the relevant publications [5, 8, 9].

3 Extraction of dPDFs

The H1 collaboration pioneered fits in next-to-leading-order (NLO) QCD to the dPDFs. The inclusive data presented in the previous section was fit [7] and found to be dominated ($\sim$70%) by the gluon density in the diffractive exchange. However at large longitudinal momentum fraction, $z_{I\!P}$, of the parton relative to the diffractive exchange, the data lack constraining power. Although the quark contribution is stable, the gluon density can vary considerably when choosing different parametrisations. This residual uncertainty (larger than other theoretical and experimental uncertainties) needed further input and was reduced by considering jet production in DIS and simultaneously fitting [10] these and the inclusive data.

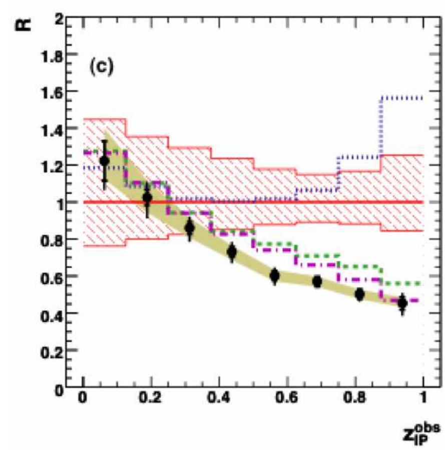

Fig. 3: Ratio of ZEUS data to NLO QCD theory as a function of $z_{I\!P}^{\mathrm{obs}}$ for different dPDFs: a ZEUS fit to LPS and charm data (solid line); a H1 fit to inclusive LRG data, H1 fit 2006 - A (dotted line) and H1 fit 2006 - B (dashed line); and a fit to inclusive data from Martin et al., MRW 2006 (dot-dashed line).

Figure 3 shows data from ZEUS on jet production, similar to that used by H1 in the NLO QCD fit for the dPDFs. The ratio of the measured cross section to NLO QCD predictions with different dPDFs is shown as a function of the experimental estimator of $z_{I\!P}$. The data show clear sensitivity to the choice of dPDF with the theoretical predictions differing by up to a factor of 3 coming from the weak constraints on the gluon density. There is also a clear preference for two of the dPDFs, MRW 2006 and H1 fit 2006 B, where the latter is one of the above two parametrisations derived from fits to inclusive data. The good description of the data by these two parametrisations also demonstrates the applicability of factorisation in diffractive DIS. These results demonstrate that jet data can be used in NLO QCD fits to further constrain the dPDFs.

An NLO QCD fit was performed for the jet data as a function of the variable $z_{I\!P}$ at different scales and in combination with the inclusive data. The resulting parton densities for quark and gluons are shown in Fig. 4 in comparison to the previous fits to the inclusive data only. The new parametrisation of the gluon density follows that of H1 fit 2006 B and is now similarly well constrained in comparison with the quark density over the whole kinematic range.

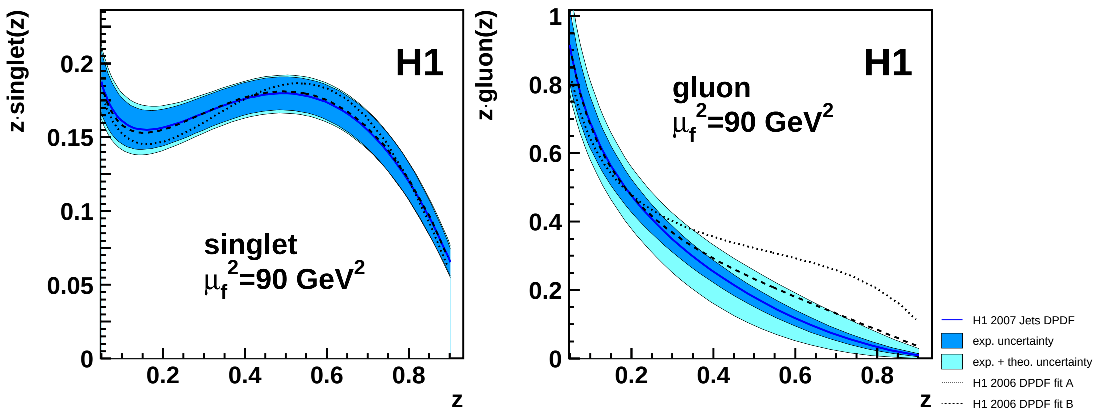

Fig. 4: Comparison of dPDFs for the quark and gluon densities when simultaneously fitting inclusive and jet data (bands) and when fitting inclusive only (lines).

4 Diffractive jet photo/hadroproduction

It has long been observed that when dPDFs are compared to Tevatron data [11], the rate is overestimated by about a factor of 10. Explanations of this factorisation breaking exist [12] which predict secondary (multiple) interactions between the remnants which destroy the rapidity gap signature of diffraction. It might also be expected for this to occur in photoproduction in which the almost-real photon develops a structure and can effect a hadronic collision. A useful variable to isolate such interactions is x_γ which is the fraction of the photon's momentum participating in the hard scatter. High values, the direct process, indicate the photon was point-like whereas lower values, the resolved process, indicate that the photon developed some structure. However, as can be seen in Fig. 5 and also confirmed by ZEUS data [13], no dependence of a suppression factor is seen as a function of x_γ. There are indications of an overall suppression factor which (also) depends on the jet transverse energy.

5 Discussion

At first sight the situation in photoproduction and hadroproduction seems contradictory. However, it should be noted that the nature and rate of secondary interactions in the two processes is almost certainly different. From inclusive jet photoproduction data [14], secondary interactions are expected, but almost certainly not at the same rate as in hadroproduction. It should be remembered that in photoproduction, part of the resolved collisions look like the collision of a structured, vector-meson like, object with a proton. However, there is also the perturbative point-like splitting of the photon, which is fully calculable in QCD [15], in which the photon is not a structured object in the same way as for the vector meson model. This is in contrast the obvious structured objects in hadroproduction.

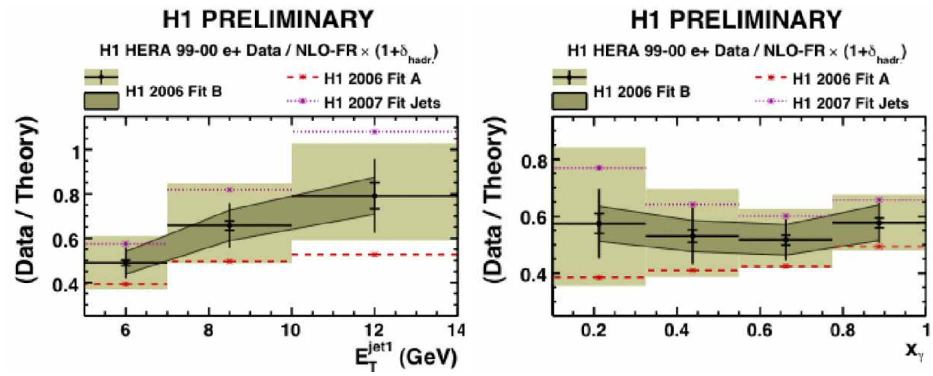

Fig. 5: Ratio of data to theory in jet photoproduction as a function of E_T^{jet1} and x_γ.

In summary, new measurements of inclusive diffraction have been made and new determinations of the partonic structure of the diffractive exchange calculated. These new parton densities demonstrate the applicability of factorisation in deep inelastic scattering, but do not change the situation in hadroproduction where models of secondary interactions are invoked to alleviate this breaking of factorisation. The situation in photoproduction is less clear cut, but also does not contradict the results in DIS or in hadroproduction. Further improvements will be made with the analysis of more inclusive and jet data and combination of data sets from the two collaborations.

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