Dijets in Diffractive Deep Inelastic Scattering and Photoproduction

W. Słomiński
on behalf of the ZEUS collaboration

M. Smoluchowski Institute of Physics,
Jagellonian University, ul. Reymonta 4, 30-059 Kraków, Poland

The recent ZEUS collaboration measurements of the diffractive dijet production in the Deep Inelastic Scattering and Photoproduction regimes are summarised and confronted with the NLO QCD predictions. Signatures of the factorisation breaking in the diffractive dijet photoproduction are discussed.

1 Introduction

Diffractive electron-proton interactions studied with the HERA collider allow us to investigate the proton diffractive structure. A characteristic feature of this type of interactions is that the proton remains (in principle) intact, and the photon dissociates into a hadronic final state, $\gamma^* p \to Xp$. The actual beam particles are electrons or positrons which emit photons in a wide range of virtualities, $Q^2 \in [0, 100]$ GeV^2. In general, the cross-sections depend both on the proton and photon structure.

For a highly virtual photon, i.e. the one we can consider point-like, the factorisation theorem holds [2] stating that the cross-section is given in terms of universal diffractive parton distributions (DPDFs) and hard partonic cross-sections. A generic formula reads

$$d\sigma = \sum_{j=g,q,\bar{q}} f_j^{\rm D}\left(x_{\mathbb{P}}, z_{\mathbb{P}}, Q^2\right)\, \hat{\sigma}^{\gamma j}\left(x_{\mathbb{P}} z_{\mathbb{P}}, Q^2\right)\, dx_{\mathbb{P}}\, dz_{\mathbb{P}}\,, \tag{1}$$

where $x_{\mathbb{P}}$ is the momentum fraction lost by the proton, $z_{\mathbb{P}}$ is the parton momentum fraction wrt. the diffractive exchange (Pomeron) and Q^2 is the photon virtuality.

The 'diffractive exchange' is basically Pomeron but usually the diffractive structure functions are modelled with more types of diffractive exchanges — secondary Reggeon, multi-component Pomeron (*cf.* [3]).

The factorisation (1) applied to the inclusive DDIS allows us to extract proton DPDFs from the data, see [4, 5, 3]. With these at hand, we can study some less inclusive interactions.

2 Dijet production

In the following we will discuss the inclusive dijet production

$$\gamma^* p \to j_1 j_2 X p\,. \tag{2}$$

where j_1, j_2 denote jets.

The interest in this reaction is two-fold. First, in the DDIS regime we learn about gluons in the Pomeron, as the cross-section is directly sensitive to that. Second, the DPHP regime provides us with information on the factorisation breaking (see below).

The recent results from the ZEUS collaboration correspond to two, qualitatively different, kinematical regions — diffractive Deep Inelastic Scattering (DDIS) [6] and diffractive Photoproduction (DPHP) [7]. Both data samples were collected in 1999–2000 and correspond to luminosities of 61 pb^{-1} and 77.2 pb^{-1} for DDIS and DPHP, respectively. The jets were identified using the inclusive k_{T} algorithm and the two jets, j_1 and j_2, with highest transverse energy were required to have E_{T} above some minimum.

The most important kinematic parameters read

- DDIS: $Q^2 \in [5, 100]$ GeV^2, $E_{\mathrm{T}1} > 5$ GeV, $E_{\mathrm{T}2} > 4$ GeV;
- DPHP: $Q^2 < 1$ GeV^2 with median $= 0.001$ GeV^2, $E_{\mathrm{T}1} > 7.5$ GeV, $E_{\mathrm{T}2} > 6.5$ GeV.

Thus DDIS is dominated by the point-like photon interactions, where the factorization (1) should hold. In the DPHP case the nearly real photon reveals its hadronic structure which results in the factorization breaking. The physical reason for this are the rescattering processes, often described in terms of screening or rapidity gap fill-up, which result in a cross-section decrease. In order to measure the amount of this suppression we first calculate the cross-section assuming that the factorization holds

$$d\sigma = \sum_{i,j=g,q,\bar{q}} f_i^{\gamma}\left(x_{\gamma}, Q^2\right) f_j^{\mathrm{D}}\left(x_{\mathbb{P}}, z_{\mathbb{P}}, Q^2\right) \hat{\sigma}^{ij}\left(x_{\gamma}, x_{\mathbb{P}} z_{\mathbb{P}}, Q^2\right) dx_{\gamma}\, dx_{\mathbb{P}}\, dz_{\mathbb{P}}\,, \tag{3}$$

where x_{γ} is the parton in photon fractional momentum and f_i^{γ} are the photon PDFs. Comparing this prediction with the data we see how big the suppression is.

The CDF collaboration observed a big suppression (by factor ~ 10) in diffractive dijet production in $p\bar{p}$ collisions [8]. In the case of photoproduction much smaller suppression is expected, based on phenomenological considerations [9, 10].

In the next section we present the experimental results confronted with NLO QCD predictions and discuss possible signatures of suppression in DPHP.

3 Results

Let us first discuss the DDIS dijet production. Two representative plots[a] are shown in Figure 1. Also shown are NLO QCD predictions obtained with DISENT [11] for several DPDFs parametrizations. The best agreement with the data is obtained for the H1 2006-B [4] and Martin-Ryskin-Watt [3] parametrizations. (The latter also uses the H1 data.) In general the theoretical predictions tend to overshoot the data. Depending on kinematic region this disagreement varies from 0 to $\sim 25\%$.

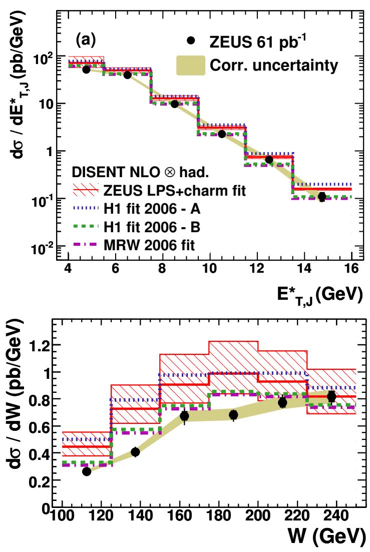

Figure 1: DDIS vs. NLO predictions for: ZEUS-LPS (continuous line), H1 2006-A (dotted), H1 2006-B (dashed), MRW (dashed-dotted).

[a]For more plots and details see [6]

There are several known sources of uncertainties in these predictions, namely

- **Strong scale dependence of the NLO predictions,** which means that higher orders of QCD are important. In particular the factorisation scale used in the DISENT calculation is $\mu_{\rm F} = Q$. Changing it *e.g.* to $\mu_{\rm F} = E_{\rm T1}$ could significantly decrease the cross-section value.
- **Flavour Scheme dependence**. DPDFs are fitted to the inclusive DDIS data using the Fixed Flavour Number scheme with 3 massless and two heavy, c and b, quarks. The dijet production is calculated within the massless Variable Flavour Number scheme. A few percent effect can be expected, *cf.* [12].
- **Gluon content of the Pomeron** is poorly constrained by the fit to the inclusive DDIS data. H1 estimates the uncertainty to be 15% at low $z_{\mathbb{P}}$, and growing with $z_{\mathbb{P}}$.
- **Proton dissociation** has to be corrected for. Its share is estimated via MC simulation within $\sim$10% accuracy.

All the above mentioned uncertainties can easily account for the data vs. theory discrepancies.

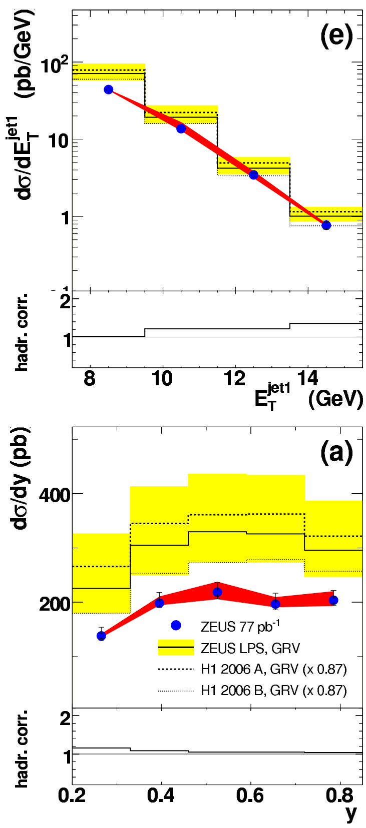

Figure 2: DPHP vs. NLO predictions for: ZEUS-LPS (continuous line), H1 2006-A (dashed), H1 2006-B (dotted).

Let us now turn to the DPHP data. Two selected[b] cross-sections are shown in Figure 2 together with NLO QCD predictions obtained with the Klasen-Kramer computer code [13] for several DPDFs parametrizations and GRV-HO [14] photon PDFs. Again the best agreement with the data is obtained for the H1 2006-B parametrization and the NLO predictions are typically above the data. The data vs. theory discrepancies are comparable to the DDIS case.

Additional uncertainties, apart from these known for DDIS, come from the photon structure. First, we observe that the NLO predictions are sensitive to the choice of the factorisation scheme used at the photon side. The two commonly used schemes are $\overline{\rm MS}$ and DISγ. Changing the scheme is actually reordering of the perturbation series, which at finite order leads to a different result. This behaviour is entirely analogous to changing the value of the factorisation scale. We have checked that for our kinematic region the results differ only for x_γ close to 1 and the DISγ scheme gives 10% lower cross-section than the $\overline{\rm MS}$ one. Another possible uncertainty comes from the photon PDFs. Looking at the contributions from different parton-parton subprocesses we observed that the dominant contribution comes from the gluonic DPDF and quark content of the photon. As the latter is well established experimentally, the choice of the photon parametrization is not a crucial point. (For detailed plots see [1].)

[b] For more plots and details see [7]

Taking into account all the uncertainties discussed so far, we could state that we do not have a firm signal of the suppression, however the suppression of up to ca. 20% is not excluded by the data. This should be confronted with the ca. 50% suppression observed by the H1 collaboration. The crucial difference in the kinematics of the H1 and ZEUS experiments is the jets E_T range. $E_{T1} > 5$ GeV, $E_{T2} > 4$ GeV for H1 as compared to 7.5 and 6.5 for ZEUS. We could thus conclude that the suppression depends on E_T. Such behaviour is actually suggested by a general argument that the size of dissociating photon grows with decreasing E_T [9, 10]. Looking at the cross-sections vs. E_T in Figures 1 and 2 we see that the data go below NLO predictions for DPHP at low E_T. A plot of the suppression factor vs. E_T is shown in Figure 3. We observe the factor of ca. 0.8 at $E_T = 8$ GeV with a tendency to go down for smaller E_T.

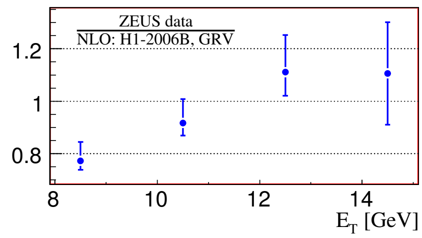

Figure 3: Data to NLO ratio vs. E_T for the diffractive dijet photoproduction.

4 Summary

The diffractive dijet production at HERA has been measured by the ZEUS collaboration in both DIS and PHP regions. The experimental errors are much below the theoretical and model dependent calculational uncertainties. In this note we have discussed these uncertainties from the point of view of possible observation of factorisation breaking in photoproduction. We have observed that the suppression of 0–20% is compatible with the data. Moreover we claim that the suppression depends on jet transverse energy, E_T, and grows with decreasing E_T. The latter observation is suggested by a higher suppression value measured at lower E_T by H1 collaboration.

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