DIFFRACTIVE DIJET AND CHARM PRODUCTION AT HERA

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Jet and charm quark production in diffractive interactions is sensitive to the partonic structure of the diffractive exchange. This article reviews recent cross section measurements of such processes in both deep-inelastic scattering (DIS) regime and photoproduction (PHP) from the HERA *ep* collider experiments. The cross sections are compared to next-to-leading order QCD calculations based on factorisation theorem.

1 Introduction

A diffractive process in hadron-hadron collisions is a scattering through a t-channel exchange, which has quantum numbers of vacuum. In ep collisions, this corresponds to a process with the diffractive exchange between the proton and a photon emitted from the electron. These processes are further classified to diffractive photoproduction and diffractive DIS (DDIS). The virtuality Q^2 of the photon is close to zero for the photoproduction, while $Q^2 \gg \Lambda_{\rm QCD}$ for the DDIS.

The cross sections of DDIS can be described in terms of a diffractive structure function, $F_2^{D(4)}(\beta, Q^2, x_{\mathbb{P}}, t)$, defined as a structure function under the condition that the reaction is a diffractive process. Here t is the four-momentum squared of the exchange at the proton vertex, $x_{\mathbb{P}}$ is the longitudinal momentum fraction of the diffractive exchange to the proton and β is defined as $\beta = x/x_{\mathbb{P}}$, where x is the Bjorken variable in DIS. Like in inclusive DIS, a DGLAP analysis on $F_2^{D(4)}$ allows to extract diffractive parton densities, $f_i^{D(4)}(z, \mu^2, x_{\mathbb{P}}, t)$, which are defined as the parton densities of the proton, again under the condition that diffractive exchange occurs at $(x_{\mathbb{P}}, t)$. Here z is the longitudinal momentum fraction of the parton in the diffractive exchange and μ is the factorisation scale. In many mesurements t cannot be reconstructed experimentally and the structure function integrated over t, $F_2^{D(3)}$, is measured and correspondingly the parton densities $f_i^{D(3)}$ are extracted. These parton densities are well constrained for quarks only since the virtual photon in DDIS can couple directly only to quarks. The gluon density was

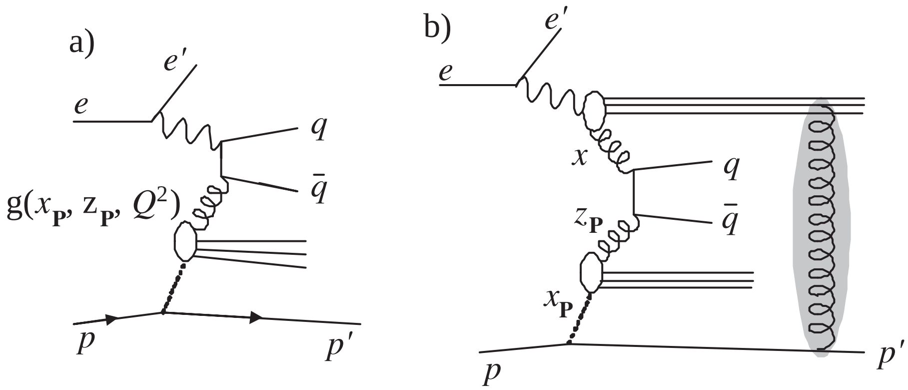

Figure 1: a) An example of diagrams for dijet production through a (virtual-)photon-gluon fusion in diffractive processes. b) An example of diagrams for dijet production in resolved photon processes in diffraction where the photon remnant has exchanged a gluon with the scattered proton.

obtained through the scaling violation of $F_2^{D(3)}$ with much larger uncertainties (see for example [1]).

The perturbative QCD predicts that the cross sections of hard scatterings in DDIS, such as jet and heavy quark production, can be calculated using QCD factorisation[2]. Namely, a cross section at given $x_{\mathbb{P}}$ can be factorised into a product of hard scattering matrix elements and the diffractive parton densities. For example, the jet cross section $d\sigma/dE_T^{\rm jet}$ is given by

$$\left.\frac{d\sigma}{dE_T^{\rm jet}}\right|_{x_{\mathbb{P}}} = \sum_i \int_t dt \int_x^{x_{\mathbb{P}}} d\xi \frac{d\hat{\sigma}^{i\gamma^*}(x, \mu^2, \xi)}{dE_T^{\rm jet}} f_i^D(\xi, \mu^2, x_{\mathbb{P}}, t), \quad (1)$$

where $\hat{\sigma}^{i\gamma^*}$ is the parton level cross section of the photon and the i-th parton. The main diagram of the jet production in DDIS and diffractive PHP are from $\gamma^* g \to q\bar{q}$ ($\gamma^* g \to Q\bar{Q}$ for heavy quark production) as shown in Fig. 1 a). Therefore cross sections for these processes are sensitive the diffractive parton density of gluons.

2 Factorisation tests in diffraction processes at HERA

All the above discussions assume that QCD factorisation holds. The measurements of D^* meson[3] and jet[4] production in DDIS show that the cross sections are well reproduced by next-to-leading order (NLO) calculations using the parton densities obtained from the HERA $F_2^{D(3)}$ data. This can be interpreted in two manners; either the factorisation indeed holds in DDIS assuming the parton densities used in the NLO calculations are correct, or the data give further constraint to the parton densities assuming the factorisation.

It has been known, however, that diffractive jet production in high-energy proton-antiproton collisions at the Tevatron is lower by factor 3–10 than perturbative QCD predictions using the HERA diffractive parton densities as shown in Fig. 2. Such deficit of the cross sections is an indication of factorisation breaking. A popular explanation of the suppression is multiple scattering in one crossing of two hadrons. Since the total hadron-hadron cross section becomes larger with energy, the probability to have more than one scatterings in one crossing becomes also larger. Therefore, a hard scattering would often be accompanied with peripheral scatterings, which are mostly colour-octet. This destroys the colour-singlet state of the diffractive scattering.

Assuming that this hypothesis is correct, this should happen for all combination of hadrons, including the hadronic component of the photon in photoproduction processes at HERA. That is, the resolved photon process, where the photon resolves into more than one partons (see Fig. 1 b)),

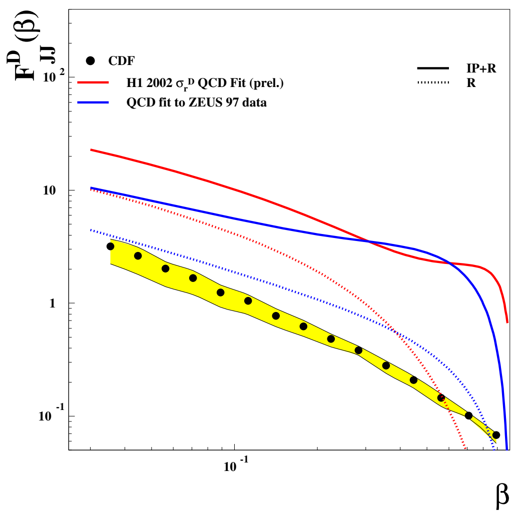

Figure 2: A combination of parton densities $F_{jj}^D = g(x) + (4/9)q(x)$, extracted from diffractive dijet cross sections measured by CDF[5]. The curves[6] are the prediction using the parton densities determined by the H1 and ZEUS data.

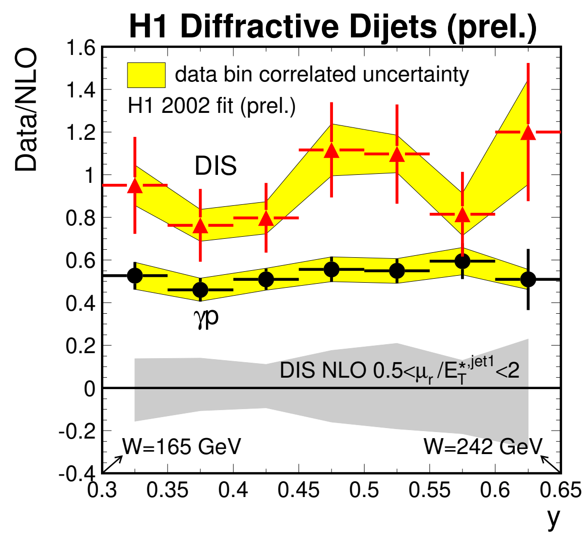

Figure 3: The ratio of dijet cross sections to the NLO calculations, in photoproduction and DIS diffraction[8] as a function of y. The NLO uses the H1 diffractive parton density set[1].

should be suppressed. The direct photon process is expected to be unsuppressed as the photon couples directly to the hard scattering (Fig. 1 a). Using a model explaining the suppression at the Tevatron, Kaidalov et al. have predicted[7] that the resolved processes at HERA should be suppressed by a factor 0.34. The direct and resolved processes can be separated using $x_\gamma^{\rm OBS}$, an estimator of the longitudinal momentum fraction of the parton in the photon involved in the hard scattering, defined as $x_\gamma^{\rm OBS} = \sum(E - P_Z)_{\rm jets}/(E - P_Z)_{\rm hadrons}$. The resolved processes are dominated in $x_\gamma^{\rm OBS} < 0.75$ while direct processes are enriched in $x_\gamma^{\rm OBS} > 0.75$.

The jet production in DDIS is expected to be unsuppressed, since the photon is point-like. This is consistent with the experimental observation described above.

3 Recent measurements of diffractive dijet production at HERA

The photoproduction jet cross sections have been measured recently by both the H1[8] and the ZEUS[9] collaborations. They are again compared to the NLO calculations using the parton densities extracted from the HERA data. The NLO calculations reproduced the shape of the cross section very well. The normalisation of the observed cross sections were, however, a factor 0.5-0.6 lower than the NLO predictions. Two examples of these measurements are discussed below.

The H1 collaboration has measured the jet cross sections in DIS with a re-defined kinematical range close to the photoproduction measurement[8], in order to compare the cross sections of the DDIS and diffractive photoproduction as directly as possible. The measured jet cross sections for both DDIS and diffractive photoproduction are shown as ratio to the NLO calculations using the same diffractive parton densities (Fig. 3). The ratio for DDIS is around 1, confirming that the factorisation holds using the parton densities used in the calculation. The ratio of the photoproduction cross sections is about 0.5. This demonstrates clearly that the photoproduction cross section is suppressed with respect to the DIS ones.

Figure 4 shows the $x_\gamma^{\rm OBS}$ dependence of the jet cross sections measured by ZEUS. The ratio of the data to the NLO calculation is flat in $x_\gamma^{\rm OBS}$ at about 0.6, outside of the quoted theoretical

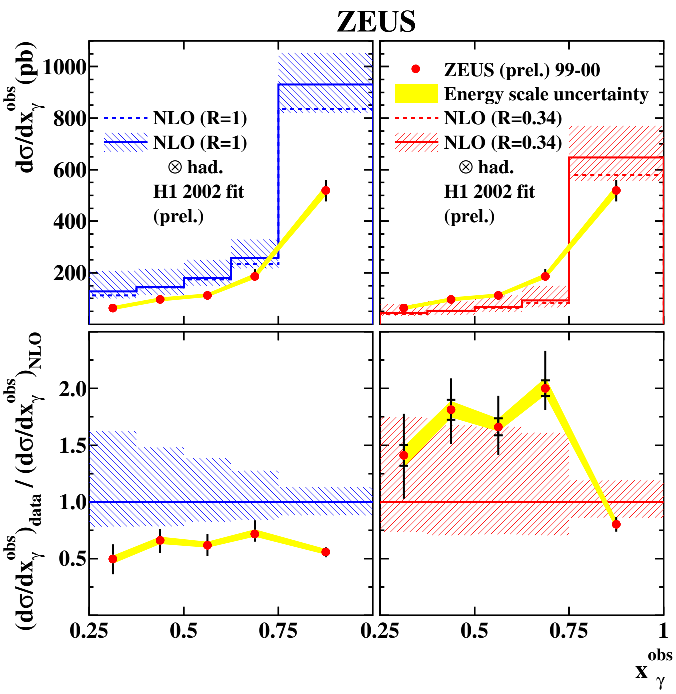

Figure 4: The x_γ^{OBS} dependence of the dijet cross sections in photoproduction by ZEUS[9]. The data are compared with the NLO calculation by Klasen et al. using the diffractive parton densities obtained by H1[1], without (left) and with (right) the resolved suppression factor ('R' in the figure) by Kaidalov et al[7].

uncertainties. The cross section was also compared with the NLO calculations including the resolved-only suppression by Kaidalov et al.[7] The measurement excludes this model where the cross section prediction is too sharply increasing with x_γ^{OBS}. It is noted that similar observation was made in the H1 dijet measurement mentioned above.

4 Summary

The measurements of jets and heavy quark production in the diffractive processes at HERA shows that the photoproduction cross sections are lower by 0.5-0.6 with respect to the NLO calculations, using the diffractive parton densities which describe the jet production in DDIS. The suppression factor is uniform as a function of x_γ^{OBS}, indicating that there is no evidence of suppression for the resolved process only, in conflict with existing theoretical expectations. These measurements, therefore, cast a serious question to the current theoretical framework of the factorisation breaking in the diffractive hadron-hadron collisions.

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