Forward jet production at HERA in NLO QCD

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We discuss a comparison between forward jet production data recently published by the H1 and ZEUS collaborations at HERA and NLO calculations based on the resolved photon approach. We point out that our approach is an approximation to DIS jet cross sections in NNLO.

1. INTRODUCTION

The cross section for forward jet production in deep inelastic scattering (DIS) has been proposed as a particularly sensitive means to investigate the parton dynamics at small x [1]. Analytic calculations based on the BFKL equation [2] in the leading-logarithmic approximation show a strong rise of this cross section with decreasing x [3] and were found in reasonable agreement [4] with the first data from the H1 collaboration at HERA [5]. More recent measurements of the forward cross section, based on an order of magnitude increased statistics compared to [5], have been presented recently by the ZEUS [6] and the H1 [7] collaborations confirming the earlier findings [5]. Monte Carlo generators based on direct photon interactions calculated from LO $O(\alpha\alpha_s)$ matrix elements together with leading-logarithm parton showers disagree with the measured jet cross section [6,7] by an appreciable factor. Also NLO, i.e., $O(\alpha\alpha_s^2)$, calculations predict too small forward cross sections at small x as already shown by Mirkes and Zeppenfeld [8] using their `MEPJET` program [9] when comparing to the data in [5]. This has been confirmed also with the new data in [6,7]. Recently the forward jet cross section has been calculated in NLO QCD within the resolved virtual photon approach [10]. In this paper we summarize the details of this calculation and compare to the new H1 and ZEUS data [6,7].

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2. RESOLVED PHOTON APPROACH

The calculation of jet cross sections in NLO including not only direct, but also resolved virtual photons includes three steps. First the pure DIS direct cross section of $\mathcal{O}(\alpha\alpha_s^2)$ has to be calculated. Second, the subtraction of terms proportional to $P_{q\gamma}\ln(Q^2/s)$, where $\sqrt{s}$ is the partonic cms energy, from the direct cross section has to be performed, to avoid double counting. Third, the resolved component can be included by convoluting the virtual photon PDF with the resolved matrix elements up to $\mathcal{O}(\alpha_s^3)$.

In [10] we performed a test of how large the resolved photon contribution is in the forward region. We chose for this test the cuts used by Mirkes and Zeppenfeld [8], which differ somewhat from the cuts used in the ZEUS [6] and H1 [7] analyses. By including the resolved photon component, the cross section was enhanced by nearly a factor of 2 with respect to the DIS result. We believe that the NLO resolved contribution supplies higher order terms in two ways, which largely enhances the forward jet cross section. One way is through the NLO corrections in the hard scattering cross section and second by evolving the PDF's of the virtual photon to the chosen factorization scale, which, however, in the considered kinematical region, is not an important effect numerically [10]. The enhancement of the NLO direct cross section through inclusion of resolved processes in NLO is mainly due to the convolution of the point-like term in the photon PDF with the NLO resolved matrix elements, which gives an approximation to the NNLO direct cross section without resolved contributions.

3. COMPARISON TO DATA

The H1 and ZEUS collaborations have measured forward jet cross sections at small x under slightly different kinematical conditions, shown in Tab. 1.

Our results for the forward jet cross section under the ZEUS kinematical conditions are shown in Fig. 1 a,b. In Fig. 1 a we plotted the full $\mathcal{O}(\alpha_s^2)$ inclusive two-jet cross section (DIS) as a function of x for three different scales $\mu^2 = \mu_R^2 = 3M^2 + Q^2, M^2 + Q^2$ and $M^2/3 + Q^2$ with a fixed $M^2 = 50$ GeV^2 related to the mean E_T^2 of the forward jet and compared them with the measured points from ZEUS [6]. The choice $\mu_F^2 > Q^2$ is mandatory if we want to include a resolved contribution. As to be expected the calculated NLO direct cross section is by a factor 2 to 4 too small compared to the data. The variation inside the assumed range of scales is small, so that also with a reasonable change of scales we can not get agreement with the data. In Fig. 1 b we show the corresponding forward jet cross sections with the NLO resolved contribution included, labeled DIR$_S$+RES, again for the three different scales μ as in Fig. 1 a. Now we find good agreement with the ZEUS data. The scale dependence is not so large that we must fear our results not to be trustworthy.

Table 1
Forward jet selection criteria by H1 and ZEUS

H1 cuts	ZEUS cuts
$E'_e > 11$ GeV	$E'_e > 10$ GeV
$y_e > 0.1$	$y_e > 0.1$
$E_{jT} > 3.5$ (5) GeV	$E_{jT} > 5$ GeV
$1.7 < \eta_{jet} < 2.8$	$\eta_{jet} < 2.6$
$0.5 < E^2_{T,jet}/Q^2 < 2$	$0.5 < E^2_{T,jet}/Q^2 < 2$
$x_{jet} > 0.035$	$x_{jet} > 0.036$

In Fig. 1 c,d we show the results compared to the H1 data [7] obtained with $E_T > 3.5$ GeV in the HERA system. In the plot on the left the data are compared with the pure NLO direct prediction, which turns out to be too small by a similar factor as observed in the comparison with the ZEUS data. In Fig. 1 d the forward jet cross section is plotted with the NLO resolved contribution included in the way described above. We find good agreement with the H1 data inside the scale variation window $M^2/3 + Q^2 < \mu^2 < 3M^2 + Q^2$. We have also compared the predictions with the data from the larger E_T cut, namely $E_T > 5.0$ GeV, and found similar good agreement [10].

In [7] the H1 forward jet data are also successfully described with the RAPGAP model [11,12] which includes a direct and a resolved component, both in LO, and with a similar scale μ as we have used. In addition this model has leading logarithm parton showers in the initial and final state built in. We think that these parton shower contributions produce the higher order effects which we found necessary to account for the correct normalization and the x dependence of the forward jet cross section data. Very recently a calculation based on the BFKL approach, incorporating NLO effects through higher order consistency conditions, also showed good agreement with the forward jet data [13].

4. CONCLUSIONS

We conclude that the NLO theory with a resolved virtual photon contribution as an approximation of the NNLO DIS cross section, which is presently not available, gives a good description of the forward jet data.

REFERENCES

1. A. Mueller, Nucl. Phys. (Proc. Suppl.) **18C** (1990) 125; J. Phys. **G17** (1991) 1443.

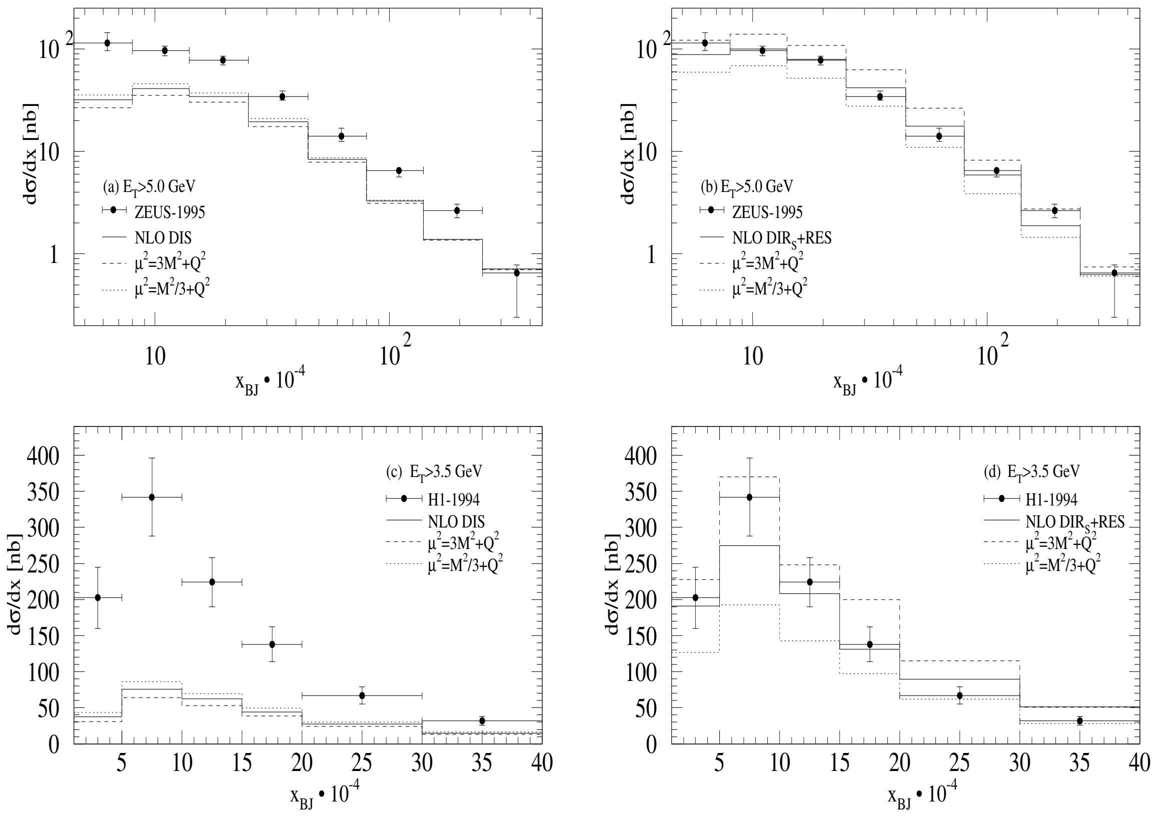

Figure 1. Dijet cross section in the forward region compared to HERA data: (a) and (b) ZEUS; (c) and (d) H1. (a) NLO DIS, $E_T > 5$ GeV; (b) NLO DIR$_S$+RES, $E_T > 5$ GeV; (c) NLO DIS, $E_T > 3.5$ GeV; (d) NLO DIR$_S$+RES, $E_T > 3.5$ GeV.

2. E.A. Kuraev, L.N. Lipatov, and Y.S. Fadin, Sov. Phys. JETP **45** (1977) 199; Ya.Ya. Balitzky and L.N. Lipatov, Sov. J. Nucl. Phys. **28** (1978) 288.
3. J. Kwieciński, A.D. Martin, and J.P. Sutton, Phys. Rev. **D46** (1992) 921; J. Bartels, A. De Roeck, and M. Loewe, Z. Phys. **C54** (1992) 635; W.K. Tang, Phys. Lett. **B278** (1992) 363.
4. J. Bartels, V. Del Duca, A. De Roeck, D. Graudenz, and M. Wüsthoff, Phys. Lett. **B384** (1996) 300.
5. S. Aid et al., H1 Collaboration, Phys. Lett. **B356** (1995) 118.
6. J. Breitweg et al., ZEUS Collaboration, Eur. Phys. J. **C6** (1999) 239.
7. C. Adloff et al., H1 Collaboration, Nucl. Phys. **B538** (1999) 3.
8. E. Mirkes and D. Zeppenfeld, Phys. Rev. Lett. **78** (1997) 428.
9. E. Mirkes and D. Zeppenfeld, Phys. Lett. **B380** (1996) 205.
10. G. Kramer and B. Pötter, DESY-99-004, MPI–PhT 99-01, hep-ph/9901314, Phys. Lett **B** (to appear).
11. H. Jung, proceedings of the 'Madrid low x Workshop', Miraflores de la Sierra, Spain, 1997, hep-ph/9709425; H. Jung, L. Jönsson, and H. Küster, DESY 98-51, hep-ph/9805396 (unpublished).
12. H. Jung, Comp. Phys. Comm. **86** (1995) 147.
13. J. Kwieciński, A.D. Martin, and J.J Outhwaite, DTP/99/28, hep-ph/9903439.