JET PRODUCTION IN DIS AT HERA

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Data on jet production in deep inelastic e^+p scattering are presented. The results are compared with pQCD calculations. At low Q^2 no consistent description of the data over all the phase space is available yet. At high Q^2 ($\gtrsim$150 GeV^2) the data are well described by pQCD in NLO.

1 Introduction

Inclusive deep inelastic lepton nucleon scattering, where only the scattered lepton is detected, played an important role in establishing QCD and continues to provide a well defined testing ground of perturbative QCD (pQCD). The aim of measurements of final state jets is to relate them to final state quarks and gluons and thereby to gain additional insight in the dynamics of lepton nucleon scattering.

The data presented in this talk[a] were recorded in the years 1995 to 1997 at HERA with the H1 and ZEUS detectors where positrons of 27.5 GeV collided with protons of 820 GeV.

1.1 Kinematics

The basic Feynman diagrams describing jet production in deep inelastic scattering are shown in Fig. 1.

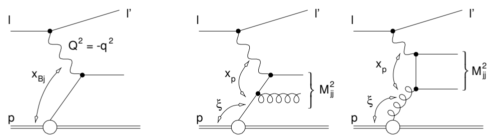

Figure 1. Processes in DIS: Born process; QCD-Compton process; and boson-gluon fusion (left to right).

Standard kinematic quantities[b] are $Q^2 = -q^2 = -(l - l')^2$, the virtuality of the boson exchange and the Bjorken variable $x_{Bj} = Q^2/2pq$. The momentum fraction entering the hard process of jet production with a jet-jet mass M_{jj} (see Fig. 1) is given by $\xi = x_{Bj}(1 + M_{jj}^2/Q^2)$ of which the fraction $x_p = x_{Bj}/\xi$ interacts with the exchanged boson.

In most cases the data are analysed in the Breit frame defined by the condition $2x_{Bj}\vec{p} + \vec{q} = 0$. Quark parton model like events (Fig. 1, left) exhibit no p_t in this frame apart from effects of fragmentation and decays. Jet finding is performed mostly using the inclusive k_t algorithm [1].

1.2 Multi-Jet Production in pQCD

Calculations at the parton level are available up to order α_s^2, i.e. to next to leading order (NLO) (Fig. 1 shows diagrams up to leading order (LO)). They can be compared with data after corrections for hadronisation are applied. DISENT [2] and DISASTER++ [3] have been shown [4] to agree in the kinematic range of interest here. MEPJET [5] is the only program implementing also charged current reactions and JetVip [6] allows resolved photon processes to be included.

A common ambiguity in these fixed order calculations is the choice of the renormalization scale μ_R^2. Typical quantities characterizing the process are Q^2 and E_t^2 and the agreement with the data for these hard scales and

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[b] Polar angles θ are measured with respect to the incident proton direction, the pseudo rapidity is given by $\eta = -\ln(\tan\theta/2)$.

the sensitivity to scale variations is studied.

Forward jets, i.e. jets close to the proton remnant, are of special interest, because they are expected [7] to be sensitive probes of the evolution of parton densities. In particular in $\alpha_s \log(1/x)$ resummation (BFKL approach) one expects jets with larger p_t ("k_t") close to the proton remnant than in the standard $\alpha_s \log(Q^2)$ resummation (DGLAP approach), due to the strong k_t ordering in the latter case.

2 ϕ Asymmetries

A measurement of the ϕ distribution of charged particle tracks has been presented by the ZEUS [8] collaboration, for different transverse momentum cuts. Here ϕ is the azimuthal angle of the hadron production plane with respect to the positron scattering plane in the hadronic centre of mass system. Finite terms $B < 0$ and $C > 0$ were measured in the angular distribution $d\sigma/d\phi = A + B\cos(\phi) + C\cos(2\phi)$ as expected in QCD-based calculations.

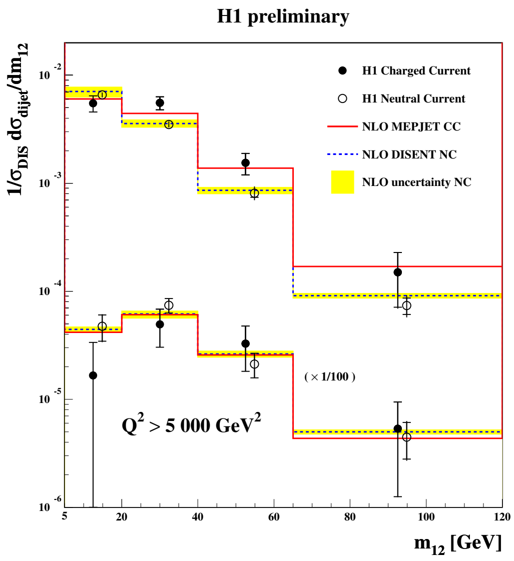

Figure 2. Distribution of jet-jet mass m_{12} (not including the proton remnant jet) for CC and NC interactions. $p_t^{lepton} > 25$ GeV, $Q^2 > 640$ GeV^2 and $Q^2 > 5000$ GeV^2 (the latter scaled by 1/100).

3 Jets in CC Interactions

Jet distributions in charged current (CC) interactions at high Q^2 are consistent with pQCD expectations (see Fig. 2). The differences to neutral current (NC) jets are mainly due to the different boson propagators [9].

4 Jets at Low and High Q^2

The E_T distribution in the Breit frame of single-inclusive jets is shown in Fig. 3 in different regions of η_{lab}. The discrepancies visible in the forward region, where the NLO corrections are huge, originate predominantly from small Q^2. The x_{Bj} dependence in the

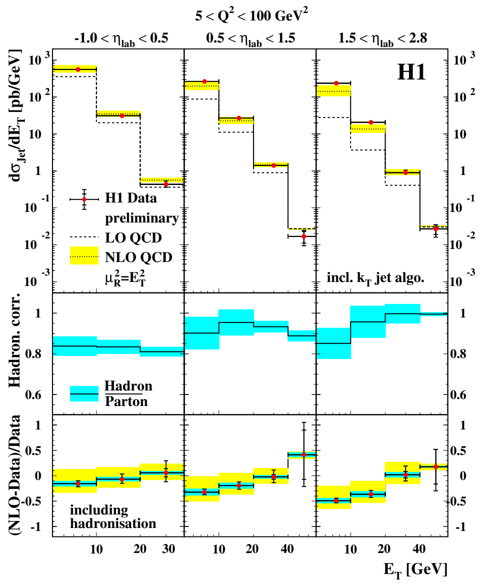

Figure 3. $d\sigma_{Jet}/dE_T$ compared to LO (dashed) and NLO (dotted) pQCD (DISENT) predictions using $\mu_R^2 = E_T^2$. The shaded band shows the sensitivity to scale variations by a factor 4. Also shown are the hadronization corrections and the relative deviations after their application.

forward and central region (Fig. 4) cannot be described with the scale $\mu_R^2 = E_T^2$. A consistent description is possible with $\mu_R^2 = Q^2$, but the susceptibility to scale variations is vastly increased (shaded band in Fig. 4) [10].

Such forward cross sections can be de-

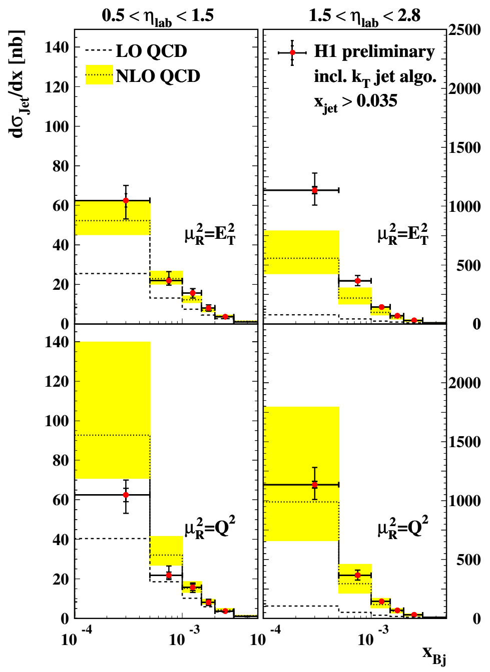

Figure 4. $d\sigma_{Jet}/dx$ for $Q^2 > 5\mathrm{GeV}^2$ in two regions of η_{lab}. NLO calculation in upper plots with $\mu_R^2 = E_T^2$, in lower with $\mu_R^2 = Q^2$.

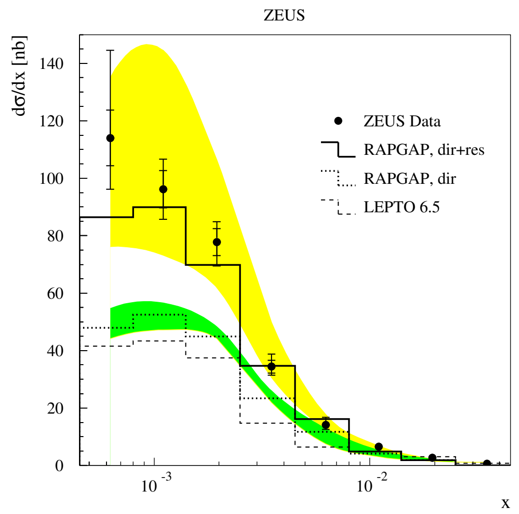

Figure 5. $d\sigma_{Jet}/dx$ for $p_z^{Breit} > 0$, $Q^2 > 10$ GeV^2 , $0.5 < E_T^2/Q^2 < 2$. Comparisons with models of direct (LEPTO, RAPGAP,dir) and direct and resolved photon interactions (RAPGAP, dir+res).

scribed by the NLO program JetVip and by DGLAP-based QCD Monte Carlo models if the hadronic structure of the interacting virtual photon is resolved (RAPGAP [11], dir+res in Fig. 5), whereas inclusion of direct photon interactions only (RAPGAP, dir and LEPTO [12]) is insufficient [13]. In the case of resolved photons, the strong k_t ordering is effectively lost, leading to larger jet E_T close to the proton remnant. However, there are ambiguities in JetVip in the treatment of parton masses and no general solution has been found which is consistent with the H1 data in a large range of rapidities η_{lab} [10].

For detailed discussions of di-jet production at low Q^2 see the contributions [14,15].

At high Q^2 there are precise high statistics data available from H1 and ZEUS which agree with NLO calculations on the 10% level in detailed comparisons (see Fig. 6) [16]. For inclusive jets ZEUS reports [17] at $Q^2 < 250$ GeV^2 some disagreement on the 15% level for E_T^2 and Q^2 scales (see Fig. 7), but otherwise the agreement of data and NLO calculations (DISENT) is very good [18].

5 Conclusion

The description of the available jet data is considerably improved in going from LO to NLO ($\sim \alpha_s^2$) pQCD. However some definite discrepancies remain to be resolved. They are more pronounced choosing E_T^2 as renormalization scale than for Q^2. In the latter case the effects of scale variations are large. Forward jets are better described if the hadronic structure of the virtual photon is taken into account. At high Q^2 ($\gtrsim$150 GeV^2) the data are well described by NLO pQCD, the NLO corrections are moderate and hadronization corrections $\lesssim$10%. These data are well suited for quantitative QCD analyses [19].

Acknowledgments

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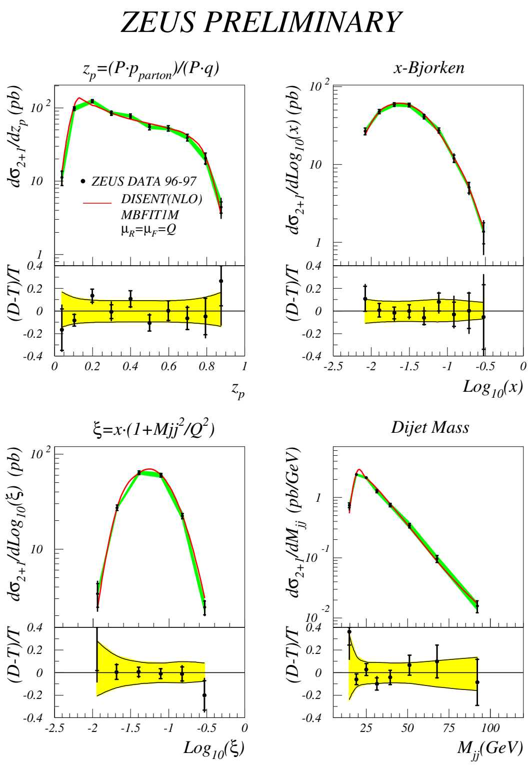

Figure 6. Di-jet distributions for 470 $<Q^2 < 20000$ GeV^2, $-1 < \eta_{jet}^{lab} < 2$, $E_T^{jet1} > 8$ GeV and $E_T^{jet2} > 5$ GeV. The upper band shows the experimental energy scale uncertainty, the lower the uncertainty of the NLO calculation.

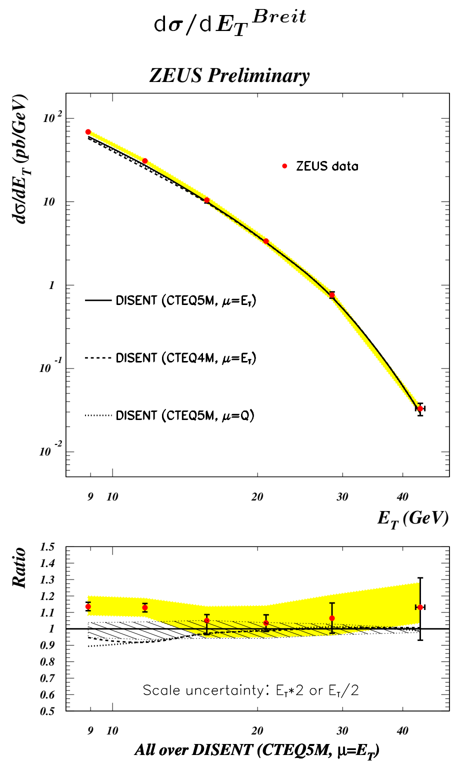

Figure 7. Inclusive jets, $Q^2 > 125$ GeV^2, $-2 < \eta_{jet}^{Breit} < 1.8$

References

1. S.D. Ellis and D.E.Soper, *Phys. Rev.* D **48**, 3160 (1993); S. Catani et al., *Nucl. Phys.* B **406**, 187 (1993).
2. S. Catani, M.H. Seymour, *Nucl. Phys.* B **485**, 291 (1997), Erratum-ibid. B **510**, 503 (1997).
3. D. Graudenz, hep-ph/9710244.
4. C. Duprel et al., Proc. on the Workshop *Monte Carlo Generators for HERA physics*, p. 142 (1999).
5. E. Mirkes and D. Zeppenfeld, *Phys. Lett.* B **380**, 205 (1996); E. Mirkes, TTP-97-39, hep-ph/9711224.
6. B. Pötter, *Comp. Phys. Commun.* **119**, 45 (1999).
7. A.H. Mueller, *Nucl. Phys. B (Proc. Suppl.)* C **18**, 125 (1990); J. Phys. G **17**, 1443 (1991).
8. ZEUS Collab., Contributed Paper 430; *Phys. Lett.* B **481**, 199 (2000).
9. H1 Collab., Contributed Paper 316.
10. H1 Collab., Contributed Paper 318.
11. H. Jung, Comp. Phys. Commun. **86**,147 (1995); http://www-h1.desy.de/~jung/rapgap.html.
12. G. Ingelman, Proc. of the Workshop *Physics at HERA*, Vol 3 (1992).
13. ZEUS Collab., Contributed Paper 429; Phys. Lett. B **474**, 223 (2000).
14. H1 Collab., Contributed Paper 317.
15. ZEUS Collab., Contributed Paper 417.
16. ZEUS Collab., Contributed Paper 420.
17. ZEUS Collab., Contributed Paper 419.
18. H1 Collab., Contributed Paper 319 and references there in.
19. E. Tassi, these proceedings.