# Parton dynamics and identified particles at HERA

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Multi-particle production in the central and forward (proton) rapidity region is studied in photoproduction and deep inelastic scattering (DIS). The measurements in the forward region are a factor of $\sim 2$ larger than QCD predictions based on the DGLAP evolution equations. The central rapidity region is rather well described. Searches for instanton induced processes in DIS are presented.

## 1. Introduction

The production and emission of partons in *ep* interactions at high energies is extremely difficult to describe when there are more than 3 partons in the final state. In particular at high energies (small $x$) and in the rapidity region close to the outgoing proton the effects of new parton dynamics (BFKL [1]) beyond the standard DGLAP approach [2] are expected to become important. The measurements of multi-parton final states can be compared to hadron level Monte Carlo programs like PYTHIA [3], HERWIG [4] and RAPGAP [5] which implement the DGLAP approach. The Lund Color Dipole Model, as implemented in ARIADNE [6], reproduces some of the features of the BFKL [1] evolution equation. The CCFM evolution equation [7], as implemented in CASCADE [8], is based on the concept of color coherence,and reproduces the BFKL and DGLAP evolution equation in their asymptotic limits.

One of the long standing questions in high energy collisions is whether significant deviations from the successful DGLAP evolution equation can be observed at HERA energies.

To answer this question, we first study particle production in the central region of rapidity (in the laboratory frame) in photoproduction, where the DGLAP evolution equation is believed to be valid. Then we study jet and $\pi^0$ production in a region of phase space, in which the effects of evolution according to the BFKL equation are expected to be large, but contributions from DGLAP evolution are suppressed. In a further step, multi-particle production is studied, again in the central rapidity region, with the aim of searching for signatures of parton scattering in the background of an instanton field.

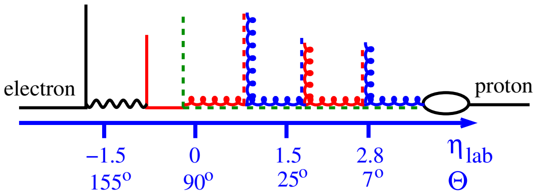


Figure 1. *Schematic diagram of an ep interaction indicating the angular and rapidity ranges in the HERA laboratory frame.*

## 2. Multi-particle and Jet production

The production of $K_s^0$ mesons in photoproduction has been studied by ZEUS [9] in events containing at least two jets with transverse energies of $E_T > 10(9)$ GeV (with $-2.4 < \eta^{jets} < 2$, cf. Fig. 1). In Fig. 2 the differential cross section $d\sigma(ep \to dijet + K_s^0 + X)/d\eta_{K_s^0}$ is shown. Both Monte Carlo Programs, PYTHIA and HERWIG, based on DGLAP, provide a good description of the data in a rapidity range not too far away from the scattered electron (central rapidities).

However, new effects are expected to become visible in a region of rapidity closer to the proton. H1 [10] has measured the cross section for a class of deep inelastic events ($5 < Q^2 < 75$ GeV$^2$) with a jet with $p_t > 3.5$ GeV close to the proton direction ($7^o < \Theta_{jet} < 20^o$) carrying a large fraction of the protons momentum $x_{jet} = E_{jet}/E_p > 0.035$. In addi-

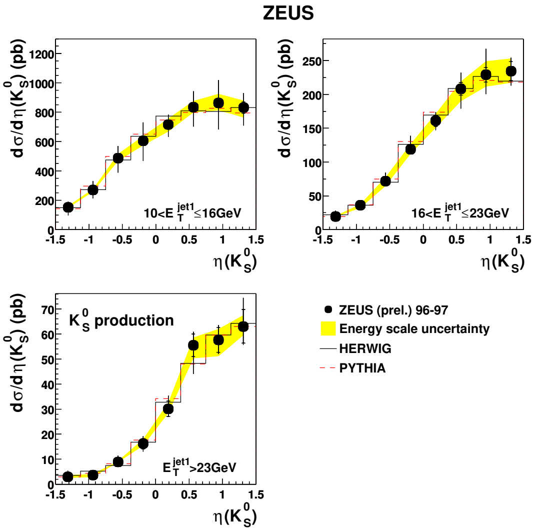


Figure 2. *The differential cross section $d\sigma/d\eta_{K^0}$ for $p_t(K^0) > 0.3$ GeV in different regions of the transverse energy of the leading jet. Also shown are Monte Carlo predictions which have been normalized to the measured cross section*

tion, $0.5 < p_{t\ jet}^2/Q^2 < 2$ is required to suppress contributions from DGLAP type evolution where the phase space for BFKL type evolution in $x$, from the large $x_{jet}$ to the small $x_{Bj}$, is enhanced. This cross section for forward jet production as a function of $x_{Bj}$ and $p_{t\ jet}$ is shown in Fig. 3 and 4. The measurements are up to a factor of two larger than the prediction based on $\mathcal{O}(\alpha_s)$ (and also $\mathcal{O}(\alpha_s^2)$) QCD calculations in the DGLAP approach. Using a hadron level Monte Carlo model incorporating resolved virtual photon processes [5] in addition to the usual direct photon processes allows a reasonable description of the data. ARIADNE [6], which simulates higher order QCD radiation without strong ordering of the transverse momenta of the emitted partons, also describes the measurements well. CASCADE [8], which is based on angular ordering coming from color coherence (CCFM), predicts a rate of forward jet events which is a little too high.

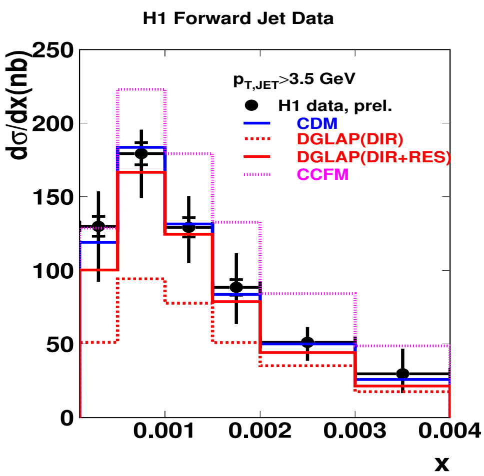


Figure 3. *The cross section for forward jet production at the hadron level, as a function of $x_{Bj}$ for $p_{t\ jet} > 3.5$ GeV. Also shown are the predictions from various Monte Carlo calculations.*

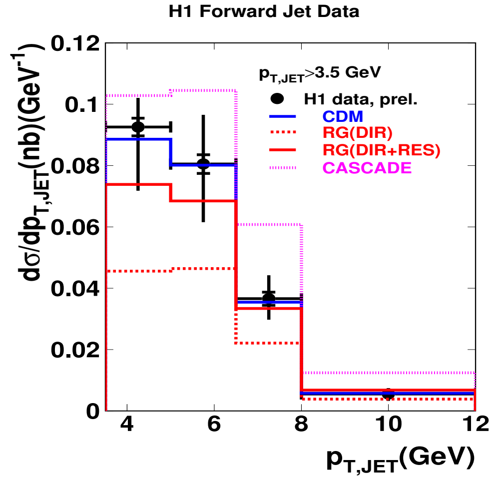


Figure 4. *The cross section for forward jet production at the hadron level, as a function of $p_{t\ jet} > 3.5$ GeV. Also shown are the predictions from various Monte Carlo calculations.*

H1 [11] also measured single particles ($\pi^0$) as opposed to jets, allowing to reach angles closer to the proton direction to be investigated. The analysis is restricted to the kinematic range $2 < Q^2 < 70$ GeV$^2$, $5^o < \Theta_\pi < 25^o$, $x_\pi = E_\pi/E_p > 0.01$ and $p_{T,\pi}^* > 2.5$ GeV, defined in the hadronic center of mass system. The differential cross section as a function of $x_{Bj}$ for different regions in $Q^2$ is shown in Fig. 5. The prediction of DGLAP based Monte Carlos is well below the data, whereas a reasonable description is obtained in an approach with an additional resolved virtual photon contribution. CASCADE is below the data at small values of $x_{Bj}$ and, as in the case of the forward jets, above the measurement for $x_{Bj} > 0.001$.

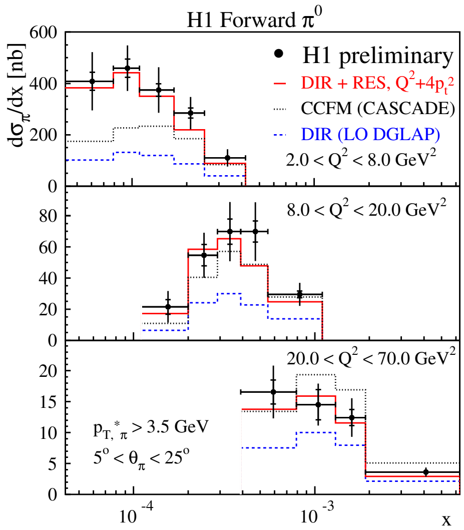


Figure 5. *Inclusive $\pi^0$ production cross section as a function of $x_{Bj}$ in 3 different regions of $Q^2$.*

Since the deviations of the measurements from the DGLAP predictions are related to the non-Abelian structure of QCD and the gluon splitting function at small $x$, it is interesting to search also for signatures coming from the complicated QCD - vacuum, e.g. instantons [12]. If a boson-gluon fusion process happens in DIS in the background of the instanton field, as simulated in the QCDINS program [13], many partons are produced in the central rapidity region. H1 [14] has performed an involved search for such processes using various methods to "control" the standard QCD background. Monte Carlo predictions for particle production in the signal region still differ, thus only upper limits on instanton production could be derived, consistent with calculations coming from lattice QCD.

## References


[1] E. Kuraev, L. Lipatov, V. Fadin, *Sov. Phys. JETP* **44** (1976) 443; E. Kuraev, L. Lipatov, V. Fadin, *Sov. Phys. JETP* **45** (1977) 199; Y. Balitskii, L. Lipatov, *Sov. J. Nucl. Phys.* **28** (1978) 822.

[2] V. Gribov, L. Lipatov, *Sov. J. Nucl. Phys.* **15** (1972) 438 and 675; L. Lipatov, *Sov. J. Nucl. Phys.* **20** (1975) 94; G. Altarelli, G. Parisi, *Nucl. Phys.* **B 126** (1977) 298; Y. Dokshitser, *Sov. Phys. JETP* **46** (1977) 641.

[3] T. Sjöstrand, *Comp. Phys. Comm.* **135** (2001) 238.

[4] G. Marchesini et al., *Comp. Phys. Comm.* **76** (1992) 465, hep-ph/9912396.

[5] H. Jung, *The RAPGAP Monte Carlo for Deep Inelastic Scattering, version 2.08*, Lund University, 2002, `www.quark.lu.se/~hannes/rapgap/`.

[6] L. Lönnblad, *Comp. Phys. Comm.* **71** (1992) 15.

[7] M. Ciafaloni, *Nucl. Phys.* **B 296** (1988) 49. S. Catani, F. Fiorani, G. Marchesini, *Phys. Lett.* **B 234** (1990) 339. S. Catani, F. Fiorani, G. Marchesini, *Nucl. Phys.* **B 336** (1990) 18. G. Marchesini, *Nucl. Phys.* **B 445** (1995) 49.

[8] H. Jung, G. Salam, *Eur. Phys. J.* **C 19** (2001) 351, hep-ph/0012143. H. Jung, *Comp. Phys. Comm.* **143** (2002) 100, hep-ph/0109102, DESY 01-114

[9] ZEUS Collaboration, M. Derrick et al., $K_s^0$ and $\Lambda$ Production in Photoproduction at HERA, 2002, contributed paper to ICHEP 2002.

[10] H1 Collaboration, C. Adloff et al., Forward Jet production at HERA, 2002, contributed paper to ICHEP 2002.

[11] H1 Collaboration, C. Adloff et al., Forward $\pi^0$ Production in DIS at HERA, 1999, contributed paper to ICHEP 2002.

[12] A. Ringwald, F. Schrempp, (1999), hep-ph/9909338.

[13] A. Ringwald, F. Schrempp, *Comput. Phys. Commun.* **132** (2000) 267, hep-ph/9911516.

[14] H1 Collaboration, C. Adloff et al., (2002), hep-ex/0205078.