# FORWARD JET PRODUCTION IN DEEP INELASTIC SCATTERING AT HERA

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The production of forward jets in deep inelastic *ep* collisions has been measured with the H1 detector at HERA. Cross sections are compared with fixed order QCD calculations and QCD-based model predictions. Also events with a forward jet and an additional di-jet system are investigated.

## 1. Introduction

A measurement of forward jets in deep inelastic *ep* scattering (DIS) at low $Q^2$ and low $x_{bj}$ is presented[1]. At small $x_{bj}$ the phase space for cascades of emissions from the interacting parton between the proton and the photon becomes large. Close to the proton direction the emissions as described by DGLAP evolution are soft due to the strong ordering in virtuality, while emissions within BFKL evolution can produce large transverse momenta in this region. Therefore an inclusive measurement of jets from rapidity regions close to the proton remnant, the so-called forward region, can be seen as a test of perturbative parton dynamics. The measurement of a more exclusive final state consisting of the forward jet and an additional di-jet system, provides an additional handle to control the parton dynamics.

## 2. Forward Jet Production in DIS

The analysed data were collected with the H1 detector in the year 1997 and correspond to an integrated luminosity of 13.7 pb$^{-1}$. A detailed description of the H1 detector can be found elsewhere[2]. DIS events with $E_e > 10$ GeV, $156° < \theta_e < 175°$, $0.1 < y < 0.7$ and $5 < Q^2 < 85$ GeV$^2$ are selected, where $E_e$ and $\theta_e$ are the energy and polar angle of the scattered electron and $y$ is the inelasticity of the exchanged virtual photon. Jets are defined in the Breit-frame using the inclusive $k_t$-algorithm. The forward jets are required

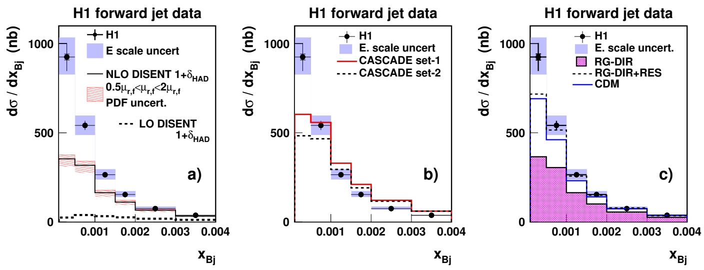


Figure 1. Inclusive forward jet cross section as function of $x_{bj}$ at hadron level compared with predictions from DISENT (a), CASCADE (b), RAPGAP and CDM (c).

to be in the angular range $7^\circ < \theta_{jet} < 20^\circ$ and to have $p_{t,jet} > 3.5$ GeV in the laboratory frame. In order to suppress the phase space for parton cascades ordered in virtuality, as described by DGLAP evolution, forward jets with transverse momenta similar to the photon virtuality are selected by requiring that $0.5 < p_t^2/Q^2 < 5$. This cut is only applied for the single differential cross sections. The phase space for emissions ordered in $x_{bj}$, as described by BFKL evolution, is enhanced by requiring that the forward jet takes a large fraction of the proton momentum, $x_{jet} = E_{jet}/E_p > 0.035$, such that $x_{jet} \gg x_{bj}$.

In Fig.1 the measured single differential forward jet cross sections on hadron level as function of $x_{bj}$ are compared with $\mathcal{O}(\alpha_S)$ and $\mathcal{O}(\alpha_S^2)$ di-jet cross section calculations from the DISENT program and with predictions from the following Monte Carlo event generators: with CASCADE, incorporating the CCFM evolution scheme using two different unintegrated gluon densities (set-1 and set-2), with the DGLAP model with direct (RG-DIR) photon interactions and with additional resolved photon contributions (RG-DIR+RES) using the RAPGAP event generator and with the colour dipole model (CDM) as implemented in ARIADNE. At small $x_{bj}$ the predictions from the $\mathcal{O}(\alpha_S^2)$ di-jet calculation are significantly larger than those at $\mathcal{O}(\alpha_S)$, reflecting the fact that $\mathcal{O}(\alpha_S)$ contributions to the forward jet cross section are highly suppressed in the selected phase space and that the $\mathcal{O}(\alpha_S^2)$ terms effectively represent the contribution at leading order. The $\mathcal{O}(\alpha_S^2)$ calculation gives an improved description of the data at large $x_{bj}$ but undershoots the data at small $x_{bj}$ by a factor of 2. Also the predictions by CASCADE and the direct photon model (RG-DIR) undershoot the data at low $x_{bj}$ and CASCADE overshoots them at high $x_{bj}$. The resolved photon model (RG-DIR+RES) significantly improves the description of the data, but still gives a too low cross section at lowest $x_{bj}$. CDM, with emissions

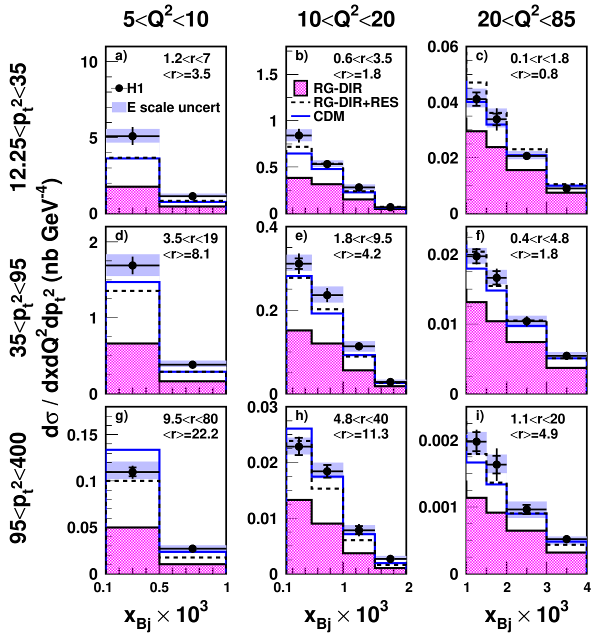


Figure 2. Inclusive forward jet cross section as function of $x_{bj}$, $p_t^2$ and $Q^2$ at hadron level compared with RAPGAP and CDM.

non-ordered in transverse momentum, shows a very similar behaviour as the RG-DIR+RES model. The triple differential forward jet cross section as function of $x_{bj}$, $Q^2$ and $p_t^2$, shown in Fig.2 are also studied and found to be well described by RG-DIR+RES. The comparison with DISENT calculations (not shown) is similar to that for the single differential cross section i.e. the fixed order $\mathcal{O}(\alpha_S^2)$ calculation gives an improved description with increasing $x_{bj}$ and also with increasing $Q^2$ or $p_t^2$.

The measurement of inclusive forward jets is complemented by a subsample of events containing a forward jet and an additional high transverse momentum di-jet system in the polar angular region between the forward jet and the scattered electron, in the following called '2+forward jet' sample. All jets are required to have $p_{t,jet} > 6$ GeV and all cuts given above with exception of the cut on $p_t^2/Q^2$ are applied to the forward jet. The jets are ordered according to pseudorapidity, $\eta_{fwdjet} > \eta_{jet1} > \eta_{jet2} > \eta_e$. In order to obtain further information on the parton dynamics, the cross sections are measured in two intervals of $\Delta\eta_1 = \eta_{jet1} - \eta_{jet2}$ as function of $\Delta\eta_2 = \eta_{fwdjet} - \eta_{jet1}$. In the case that e.g. both $\Delta\eta_1$ and $\Delta\eta_2$ are small, all

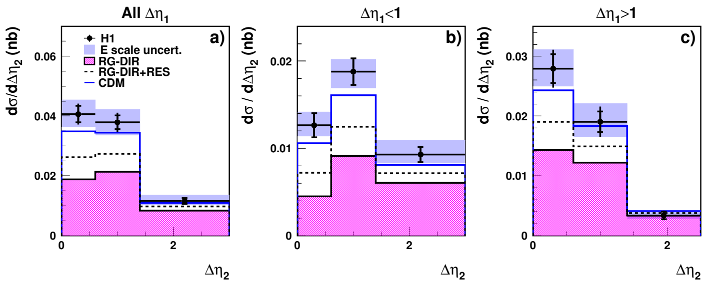


Figure 3. The cross section for the '2+forward jet' sample (see text) as function of the rapidity separation $\Delta\eta_1$ and $\Delta\eta_2$ compared with predictions by RAPGAP and CDM.

jets are produced in the forward region and it is possible that one or both of the additional jets originate from gluon emissions, which is a signature of breaking of ordering in transverse momentum. In Fig. 3 the measured cross sections are compared with the predictions by RG-DIR, RG-DIR+RES and CDM. CDM gives good agreement in all cases, whereas the DGLAP models predict cross sections that are too low except when both $\Delta\eta_1$ and $\Delta\eta_2$ are large. It is notable that while for the inclusive forward jet sample, where CDM and RG-DIR+RES give very similar description of the data, the more exclusive '2+forward jet' sample differentiates CDM and DGLAP-resolved model, with CDM giving the best description of the data.

## 3. Conclusions

An investigation of DIS events containing a jet in the forward direction or a forward jet and an additional hard di-jet system is presented. Various constraints are applied, in order to suppress contributions from parton evolutions described by DGLAP and enhance sensitivity to other parton dynamics. The single and triple differential forward jet cross sections and cross sections for events with an additional reconstructed di-jet system as function of the rapidity separation are confronted with fixed-order calculations and QCD-based models. The data are best described by models that include at least one order of parton emissions with breaking of virtuality ordering, such as the colour dipole model and the resolved photon model.

## References

1. H1 Collab., A. Aktas et al., *Eur. Phys. J.* **C46**,27 (2006) and references herein.
2. I. Abt *et al.* [H1 Collaboration], Nucl. Inst. Meth. **A386** (1997) 310;
   I. Abt *et al.* [H1 Collaboration], Nucl. Inst. Meth. **A386** (1997) 348.