FORWARD π^0 PRODUCTION IN DIS AT HERA*

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The dynamics of QCD evolution at low values of Bjorken-x are studied via the measurement of hard π^0 probes in deeply inelastic positron proton scattering with the H1 experiment. The π^0 mesons are produced close to the fragmented proton direction which is called forward region. Measurements of the forward π^0 cross sections and the accompanying transverse energy flow around the π^0 are presented and used to discriminate between different schemes for QCD evolution.

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1. Introduction

The HERA collider has extended the available kinematic space for Deep-Inelastic Scattering (DIS) to regions of large values of the four momentum transfer Q^2 ($\leq 10^5$) and small Bjorken-x ($x \approx 10^{-5}$). A variety of measured processes has made detailed tests of perturbative QCD possible. In particular, studies at low x could reveal novel features of parton dynamics. At small x it is very probable that the quark struck by the virtual photon originates from a QCD cascade initiated by a parton in the proton. In different regions of the Q^2 and x space different equations are expected to describe the parton evolution: the mostly discussed being DGLAP [1], BFKL [2] and CCFM [3]. At high Q^2 and high x the initial state radiation is described by the conventional DGLAP evolution equations which resum the leading $\alpha_{\rm s} \ln(Q^2/Q_0^2)$ terms. In this scheme a space-like chain of subsequent gluon emissions is characterized by a strong ordering in transverse momenta $k_{\rm T}$.

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However, at small x the contribution of large leading $\ln 1/x$ terms may become important. Resumation of these terms leads to the BFKL evolution equation. No ordering on transverse momenta k_{T} of emitted gluons is imposed here. The CCFM evolution equation based on angular ordering and color coherence interpolates between the BFKL and DGLAP approaches.

An extended parton ladder at low x leads to high k_{T} partonic emission in the forward region to which measurements of jets and leading particles are sensitive. Production of DIS events with a single forward particle is a more refined version of the forward jet production; a forward jet is identified by its single energetic fragmentation product. In analogy to the forward jet analysis, inspired by the proposal of Mueller [4], selection of a single particle with transverse momentum squared of the order of Q^2, ${k_{\mathrm{T}}}^2 \approx Q^2$, suppresses the k_{T} ordered DGLAP evolution and the choice of the fractional momentum $x_\pi = E_\pi/E_p$ (E_p is the proton beam energy) greater than the Bjorken-x enhances the phase space for BFKL effects. An advantage of studying single particles, as opposed to jets, is the potential to reach smaller angles than is possible with jets with broad spatial extension. However, the rate of the process is suppressed in comparison to forward jet production and fragmentation effects are expected to be more significant. Differential cross-sections for inclusive π^0-meson production [5] have been measured by the H1 Collaboration. The BFKL calculation approximating some of the NLO effects [6] was found to be in good agreement with the data, particularly for the shape description, but the absolute normalization remained strongly affected by the scale uncertainty. A reasonable description of the data is also given by the Monte Carlo model RAPGAP [7] based on the DGLAP formalism with inclusion of resolved photon processes.

In this analysis we present new results from the H1 experiment on high transverse momentum forward π^0 production in DIS with statistically increased (by factor 3.5) sample that allows for more differential studies. In addition an investigation of the additional characteristics of the hadronic final state has been performed.

2. Experimental setup and data selection

The data used for this analysis were collected in 1996 and 1997 with the H1 detector at HERA, which collided beams of 27.5 GeV positrons and 820 GeV protons, and correspond to an integrated luminosity of 21 pb^{-1}. A detailed description of the H1 detector can be found elsewhere [8]. DIS events are selected by identification of scattered positrons in the backward lead/scintillating fiber calorimeter with energy resolution for electrons $\sigma_E/E \approx 0.075/\sqrt{E}$. The analysis is restricted to the range $0.1<y<0.6$ and $2.0<Q^2<70.0$ GeV^2, and Bjorken-x extends over two orders of magnitude down to $x\approx 10^{-5}$. The photoproduction background is reduced to a negligible level.

The π^0-mesons are measured in the finely segmented liquid argon (LAr) calorimeter consisting of an electromagnetic section, that provides an energy resolution of $\sigma_E/E \approx 0.12/\sqrt{E}$, and of hadronic section with energy resolution for charged pions $\sigma_E/E \approx 0.50/\sqrt{E}$. The absolute energy scales are known to 3% for electromagnetic section in the forward region relevant for this analysis and to 4% for hadronic section. The π^0-mesons are identified via the dominant decay channel $\pi^0 \to 2\gamma$ using calorimetric information only. The π^0 candidates are selected in the HERA laboratory frame[1] with polar angles in the region $5^\circ < \Theta_\pi < 25^\circ$ and with x_π greater than 0.01. The cut on the minimum transverse momentum of the π^0-meson, $p^*_{\mathrm{T},\pi}$ defined in the photon–proton center of mass system (CMS) is set to 2.5 GeV. At high π^0 energies requested here, the decay photons cannot be separated in the LAr calorimeter and their energy deposits are reconstructed as one calorimetric cluster. Photon induced showers are selected by a detailed analysis of longitudinal and transverse shower shape development in the LAr calorimeter [5]. The efficiency for finding π^0-mesons after all selection cuts is above 45% and the purity of the selected π^0-meson sample is at the level of 80%. Other sources of high energy photons (such as prompt photon production) are at negligible level [9]. The influence of η-meson production is also taken into account in the analysis.

3. Results

Inclusive forward π^0 cross-sections for $p^*_{\mathrm{T},\pi} > 2.5$ GeV are shown as a function of x and $p^*_{\mathrm{T},\pi}$ for different regions of Q^2 in Fig. 1. All cross-sections are corrected for detector effects and for the influence of QED radiation by a bin-by-bin unfolding procedure. Systematic errors are dominated by the model dependence of the correction procedure which gives rise to typically 10–15 % uncertainty. The QCD calculations are presented using the Monte Carlo model RAPGAP based on LO DGLAP parton showers with (DIR+RES) and without (DIR) resolved photon processes. The Monte Carlo model CASCADE [10] has been used as an implementation of the CCFM equation. The prediction of RAPGAP with a point-like photon is well below the data. A reasonable description of the cross-sections is obtained by including in RAPGAP additional resolved photon contribution and using a renormalization and factorization scale of $Q^2 + 4p_{\mathrm{T}}^2$. CASCADE undershoots the data for lower values of Q^2. The fact that CASCADE describes the forward jet cross-section [11] but not the forward π^0 production, may indicate the importance of the quark splitting functions which are not taken into account in CASCADE. Fig. 2 shows the transverse energy flow

[1] H1 uses a a right-handed coordinate system with the z-axis defined by the incident proton beam.

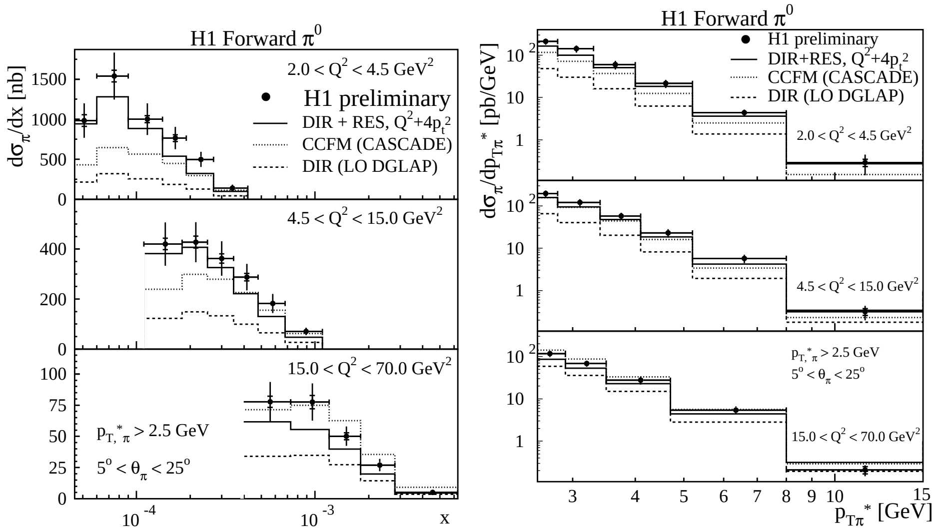

Fig. 1. Inclusive forward π^0-meson production cross-sections in three regions of Q^2. Left: as a function of Bjorken-x and Right: as a function of $p^*_{\mathrm{T},\pi}$. The inner bars are statistical, the outer error bars give the statistical and systematic error added quadratically.

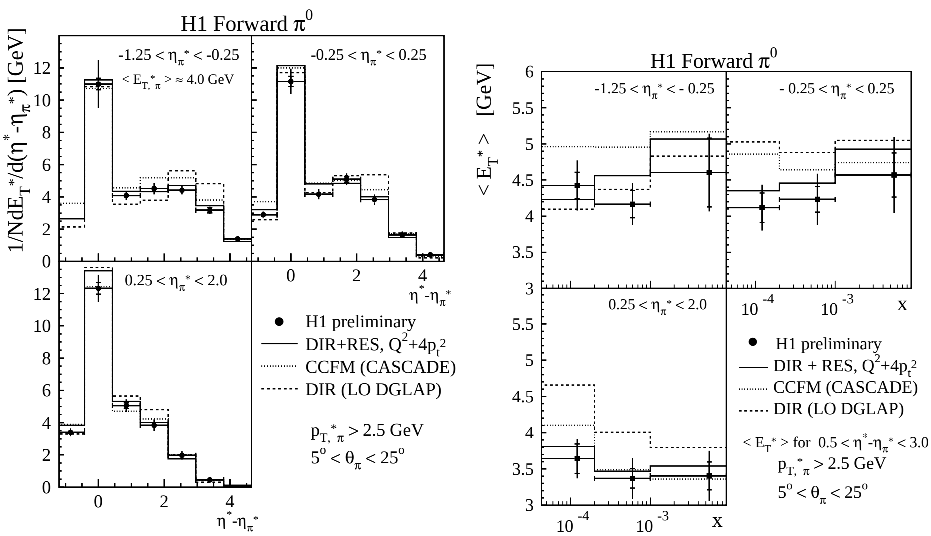

Fig. 2. Left: Transverse energy flow around the forward π^0. Right: Mean transverse energy in the region $0.5 < \eta^* - \eta^*_\pi < 3.0$ as a function of Bjorken x. Distributions are in the hadronic CMS for different ranges of η^*_π.

around the forward π^0 in the hadronic CMS, for different ranges of η^*_π, as a function of the distance from the π^0 direction in units of pseudorapidity. The energy flow is highly collimated around the direction of the π^0, with an average contribution to the bin containing this particle of about 4 GeV. Large amounts of transverse energy are also produced away from the π^0. The QCD models presented here give similar predictions, however the calculations which include resolved processes tend to agree better with the data. The transverse energy flow around the π^0 reflects how the transverse momentum of the jet is compensated along the ladder. It is best seen in the $E_{\rm T}$ flow distribution for the most forward π^0 shown in the left upper plot of Fig. 2. RAPGAP with only direct contribution taken into account predicts less radiation in the vicinity of the π^0 and the $p_{\rm T}$ of the forward particle is mainly compensated far away from the π^0 as expected for $k_{\rm T}$ ordered DGLAP emissions. For the CCFM approach, there is more QCD radiation close to the π^0 direction, while the prediction of RAPGAP with resolved γ component lies between predictions of CASCADE and RAPGAP-DIR. The mean transverse energy along the ladder, in the region $0.5 < \eta^* - \eta^*_\pi < 3.0$, for different ranges of η^*_π in the hadronic CMS as a function of Bjorken x is presented in the right part of Fig. 2. The data,within the presently limited statistical accuracy, show no dependence on x and the best description is given by RAPGAP with resolved photon interactions.

4. Summary

High precision measurements of the forward π^0 cross-sections and their accompanying energy flow were presented. The data allow us to discriminate between different QCD models and are best described by an approach in which partonic substructure of virtual photons is also taken into account.

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