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Forward π° Production at HERA

H1 Collaboration

Abstract

High transverse momentum π°-meson production is studied in deep inelastic scattering data taken with the H1 detector at the positron-proton collider HERA. Results are presented as a function of Bjorken-x and x_{π}, the fraction of the incident proton's energy carried by the pion. The rate of high p_T particle production is strongly correlated to the underlying parton dynamics. Different models for parton radiation thus lead to differing predictions for π^0 production, particularly at low Bjorken-x and large x_{π}.

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1 Introduction

The electron-proton collider HERA has significantly increased the available kinematical region for the study of Deep Inelastic Scattering (DIS). Large values of the four-momentum transfer Q^2 ($\leq 10^5$ GeV^2) can be reached as well as very small Bjorken-x ($x \approx 10^{-4}$). It has been suggested that the region of small Bjorken-x is sensitive to new dynamic features of QCD.

Several recent measurements by the H1 and ZEUS collaborations [1, 2, 3, 4] have caused much debate as to whether the HERA data has reached a region were the description of the QCD evolution of the parton densities by the DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) evolution equations [5] ceases to be a good approximation. The DGLAP equation sums all leading double logarithms in ln (Q^2/Q_0^2) ln (x^{-1}) along with single logarithms in ln Q^2/Q_0^2 but misses single logarithms in ln x^{-1}. For a series of gluon emissions as illustrated in Fig. 1 it correctly treats the region $Q_0^2 \ll k_{T_1}^2 \ll ... \ll k_{T_i}^2 \ll ... \ll Q^2$. For large $1/x \sim s/Q^2$ one must resum the leading ln x^{-1} contributions along with the leading double logarithms in x and Q^2 as above. In leading order this is accomplished by the BFKL (Balitsky-Fadin-Kuraev-Lipatov) evolution equation [6] where, for essentially the same sequence of gluon emissions, the region $x_1 \ll ... \ll x_i \ll ... \ll x$ with no ordering in k_T is correctly treated.

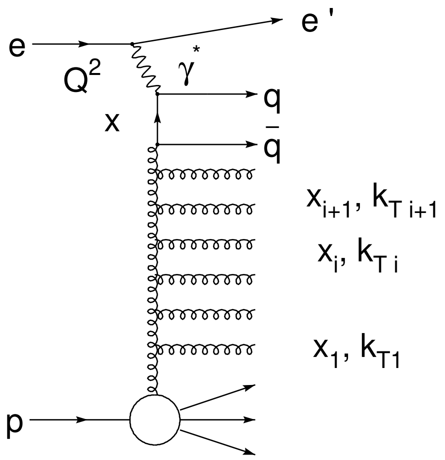

Figure 1: Generic Diagram for parton evolution at low x

The strong rise of the proton structure function F_2 towards small Bjorken-x observed at HERA [2, 3] can be explained in terms of ln x^{-1} contributions. However, an equally good description can be achieved by DGLAP evolution from suitably chosen input parton distributions [7, 8], therefore leaving the main origin of the rise an open question. The measurement of F_2 may thus be too inclusive to be a sensitive discriminator. Rather, the properties of the hadronic final state should be explored. For small values of Bjorken-x the production of hadrons in the region between the current jet and the proton remnant is expected to be sensitive to the underlying parton dynamics [9], which corresponds to the very forward direction (i.e. small angles with respect to the proton beam direction) in the H1 laboratory frame. Furthermore, while different models predict very similar E_T flows, high p_T particles have been shown to be sensitive to the underlying parton dynamics[10, 11, 12].

In this paper the H1 detector is used to study the production of high p_T forward π°-mesons, extending the phase space region previously accessible to single high p_T particle studies [4]. Calculations using the BFKL equations for the distributions shown should be possible using techniques as described in [13].

2 The H1 Detector

A detailed description of the H1 apparatus can be found elsewhere [14]. The following briefly describes the detector components relevant to this analysis.

The π°-mesons are measured with a liquid argon (LAr) calorimeter [15] covering the polar angle range $4^{\circ} < \Theta < 153^{\circ}$ with full azimuthal coverage, where Θ is defined with respect to the proton beam direction ($+z$ axis). It consists of an electro-magnetic section with lead absorbers and a hadronic section with steel absorbers with a combined total depth between 4.5 and 8 interaction length. Both sections are (especially in the forward direction) highly segmented in the transverse and longitudinal direction with about 44000 cells in total. Electromagnetic shower energies are measured with a resolution of $\sigma_E/E \approx 0.12/\sqrt{E\,[\mathrm{GeV}]} \oplus 0.01$. Test beam measurements show an energy resolution of $\sigma_E/E \approx 0.50/\sqrt{E\,[\mathrm{GeV}]} \oplus 0.02$ for charged pions [16]. The absolute energy scales are known to 4% and 5% for electromagnetic and hadronic energies respectively.

A lead scintillator calorimeter (BEMC) [17] covers the backward region of the detector $151^{\circ} < \Theta < 177^{\circ}$ with a depth of 22 radiation length or 1 interaction length. A major task of the BEMC is to trigger and to measure precisely the scattered positron in DIS processes with values of the four momentum transfer Q^2 ranging from 5 to 100 GeV^2. The BEMC resolution is given by $\sigma_E/E = 0.10/\sqrt{E\,[\mathrm{GeV}]} \oplus 0.42/E[\mathrm{GeV}] \oplus 0.03$. Its energy scale for electrons is known to an accuracy of 1%. A backward proportional chamber (BPC), in front of the BEMC as seen from the interaction point, serves to identify the scattered positron and to measure precisely its direction. Using information from the BPC, the BEMC and the reconstructed event vertex the polar angle of the scattered positron is known to about 1 mrad. The calorimeters are surrounded by a superconducting solenoid providing a uniform magnetic field of 1.15 T parallel to the beam axis in the tracking region. Charged particle tracks are measured in a central drift chamber and in the forward tracking system covering the polar angular range $7^{\circ} < \Theta < 165^{\circ}$. The tracking system is used to define the event vertex.

The luminosity is measured with the reaction $ep \rightarrow ep\gamma$ with two TlCl/TlBr crystal calorimeters installed in the HERA tunnel.

3 Event Selection

Experimental data for this analysis were collected by H1 during the 1994 running period, in which HERA collided 27.5 GeV positrons on 820 GeV protons. The data sample used corresponds to an integrated luminosity of 1.9 pb^{-1}. DIS events are selected via the scattered positron satisfying $E_e^{'} > 12$ GeV, $156^{\circ} < \Theta_e < 173^{\circ}$ and $y_e > 0.1$.

The trigger used in the collection of the data is the requirement that there be a localised energy deposit in the BEMC of at least 4 GeV with no associated veto signal from the H1 Time-of-Flight system. This has been shown to be more than 99% efficient for the collection of DIS events in which the scattered positron enters the BEMC and has energy greater than 10 GeV.

Further reduction of photoproduction background and the removal of events in which an energetic photon is radiated off the incoming positron is achieved by requiring $\sum_j (E_j - p_{z,j}) > 35$ GeV [2], with the sum extending over all measured objects, j, in the event using the combined information of the calorimeter and the tracking system. The kinematic variables are determined using information from the scattered positron: $Q^2 = 4E_eE_e^{'}\cos^2(\Theta_e/2)$ and $y = 1 - (E_e/E_e^{'})\sin^2(\Theta_e/2)$. The scaling variable Bjorken-x is related to these quantities via the square of the centre of mass energy s: $x = Q^2/(ys)$.

The π°-mesons are measured via the dominant decay channel $\pi^\circ \to 2\gamma$. The π° candidates are selected in the region of $5^\circ < \Theta_\pi < 25^\circ$ using the LAr calorimeter, where Θ_π is the polar angle of the produced π° with respect to the incoming proton beam direction. Candidates are required to have an energy of $E_\pi > 8$ GeV with a transverse component $E_{T_\pi} = E_\pi \sin\Theta_\pi > 1$ GeV. At the high π° energies considered here, the two gammas cannot be distinguished, but are treated as one object in the calorimetric response. Photon induced showers are selected by measuring the longitudinal and transverse shower shapes of candidate clusters. The clusters are required to have more than 90% of their energy deposited in the electromagnetic part of the LAr calorimeter.

Further selection criteria profit from the compact nature of electromagnetic (e.m.) showers as opposed to those of hadronic origin. A "hot" core consisting of the most energetic group of continuous e.m. calorimeter cells which must include the hottest cell is defined for each candidate [18]. The fraction of the deposited energy in this core is then required to be above 50%. The lateral spread of the shower is quantified in terms of lateral shower moments calculated relative to the shower principal axis [18] and taken to be less then 4 cm. The longitudinal shower shape is used as a selection criterion via the fraction of energy deposited in each layer of cells in the e.m. part of the calorimeter. The precise specifications of these layers can be found in [18]. The value obtained by subtracting the fraction of energy deposited in the fourth layer of cells from that in the second layer as seen from the interaction point is required to be larger than 0.4, thereby selecting showers which start to develop close to the calorimeter surface and are well contained in the e.m. part of the calorimeter, as expected from showers of e.m. origin. After selecting candidates in this way, the efficiency for finding π°-mesons satisfying $5^\circ < \Theta_\pi < 25^\circ$, $E_\pi > 8$ GeV and $p_{T_\pi} > 1$ GeV is above 45%.

Monte Carlo studies using a detailed simulation of the H1 detector predict that more than 67% of the found candidates stem from π°-mesons. Similarly these calculations predict that less than 10% of the candidates originate from the secondary scattering of charged hadrons with passive material in the forward region where the dead material composition is highest. This source of background is predicted not to increase in any way in the restricted p_T range covered by these measurements. The contamination due to it is calculated using the H1 detector simulation and is subtracted bin-by-bin in the analysis procedure outlined in the next section, and is anyway of the order of 25% of the overall systematic errors of the measurements presented.

4 Results

Results are presented as spectra in Bjorken-x of π°-mesons with $5^\circ < \Theta_\pi < 25^\circ$, $p_{T_\pi} > 1$ GeV and four different lower thresholds of $x_\pi = E_\pi / E_{proton} > 0.0098$, 0.012, 0.015 and 0.017. All distributions are normalized to the number of DIS events that fall into the specified kinematic range. The data are corrected bin-by-bin for detector effects, including geometrical acceptance and π° detection efficiency, as well as for QED radiative effects. The corrections are determined using Monte Carlo generated events with a full simulation of the H1 detector response. Systematic errors include the uncertainty of the calorimeter absolute energy scale and the model dependence of the correction for detector effects. Background from photoproduction has been studied with the PHOJET [19] Monte Carlo model, following the procedure and cross-checks made in the recent measurements of F_2 [2], and is found to make no significant contribution to the distributions shown. The error on the π° selection efficiency has been studied by varying the selection cuts used by 10% and the resulting error is typically 10% on each bin in Bjorken-x. The preliminary data are shown for the four thresholds in x_π in Fig. 2. The full errors are the quadratic sum of the statistical (inner error bars) and systematic errors. The data clearly rise with decreasing Bjorken-x, i.e. the production of high p_T π°-mesons increases towards small Bjorken-x.

The measurements are compared to two predictions of Monte Carlo models based on QCD phenomenology. The MEPS model (Matrix Element plus Parton Shower) as implemented in the LEPTO 6.4 generator [20] incorporates the QCD matrix elements up to first order, with additional soft emissions generated by adding leading logarithmic parton showers using the DGLAP equations. The partons thus emitted are strongly ordered in k_T. In the color dipole model (CDM) chromodynamic radiation stems from color dipoles formed by the color charges. Gluons emitted by this mechanism do not obey strong ordering in k_T. The CDM model as implemented in ARIADNE 4.08 [21] is used via the generator DJANGO 6.2 [22]. Both the MEPS and the CDM programs use the Lund string model [23] for hadronization.

While both types of Monte Carlo generators considered here successfully describe the flow of transverse energy as measured by H1 [10, 11], the production of particles with large transverse momentum reveals the different ansätze for modelling the underlying parton dynamics [12]. From the comparison of the data with the Monte Carlo predictions it is evident that the CDM model gives a much better description of the data than the MEPS model. Instead of rising with decreasing Bjorken-x the latter predicts rather flat behavior especially for the larger values of x_π. Thus the data support a larger amount of partonic activity at small Bjorken-x than is compatible with the MEPS model as implemented in LEPTO.

5 Summary

A preliminary measurement of forward high p_T π° spectra as a function of Bjorken-x has been presented for different lower thresholds in $x_\pi = E_\pi/E_{proton}$. The data show a clear rise towards small Bjorken-x. The high p_T π° production is a measure of the partonic activity in the rapidity region between the photon-quark vertex and the proton remnant. The data disfavour the Matrix Element plus Parton Shower model as implemented in LEPTO, while the color dipole approach results in a rather good description of the shown distributions.

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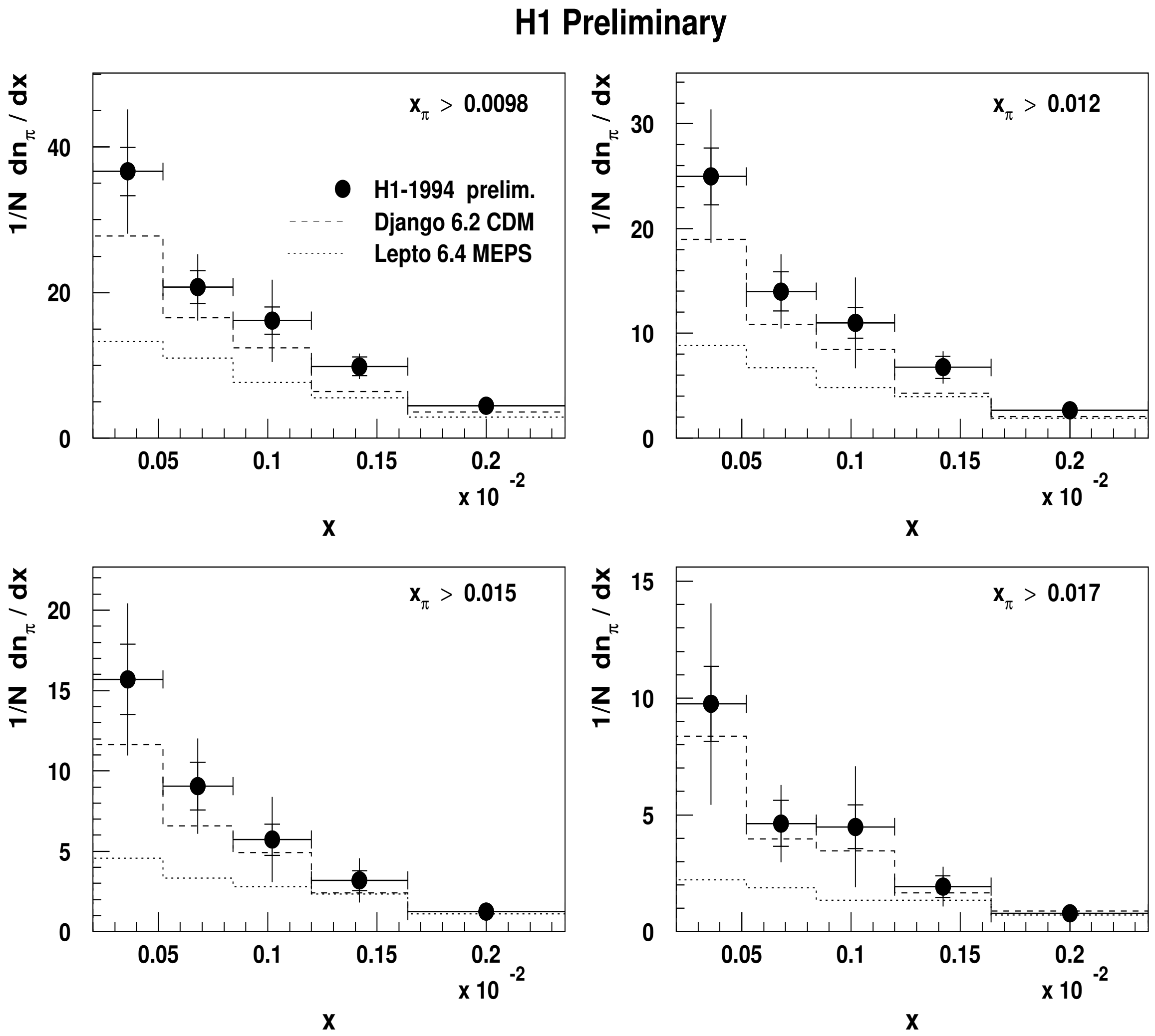

Figure 2: The forward π° spectra in Bjorken-x for four different values of the lower threshold $x_\pi = E_\pi/E_{proton}$ are shown for π° produced in the polar angular range $5^\circ < \Theta_\pi < 25^\circ$. For comparison, the models DJANGO+ARIADNE (CDM, dashed line) and LEPTO (MEPS, dotted line) are overlaid. Here n_π is the number of π°-mesons and N is the number of DIS events that fall into the specified kinematic range.