Forward π°-Meson and Charged Particle Production in Deep Inelastic Scattering at low Bjorken-x

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H1 Collaboration

High transverse momentum π°-mesons and charged particles are measured in deep inelastic e-p scattering events at low Bjorken-x taken with the H1 detector at HERA. The production of high p_t particles is strongly correlated to the emission of hard partons in QCD and is therefore sensitive to the dynamics of the strong interaction. For the first time the measurement of single particles has been extended to the region of small angles w.r.t. the proton remnant (forward region). This region is expected to be particularly sensitive to QCD evolution effects in final states. Results are presented as a function of Bjorken-x and x_i, the fraction of the incident proton's energy carried by the particle, and are compared to different QCD models.

1 Introduction

The positron-proton collider HERA has significantly increased the available kinematical region for the study of Deep Inelastic Scattering (DIS) towards large four-momentum transfer Q^2 (up to $Q^2 \approx 10^4$ GeV^2) and small Bjorken-x ($x \approx 10^{-4}$). The hadronic final state in such events has been suggested to be a very sensitive environment to disentangle different QCD processes and to test the validity of various approximations. In particular the region towards the proton remnant (forward region) is considered to be among the most promising areas to gain new insights into dynamical features of QCD at low Bjorken-x [1] since it provides a large phase space for parton emissions. Several prescriptions for the QCD evolution of the dynamics of such emissions have been proposed. The DGLAP (Dokshitzer-Gribov-Lipatov-Altarelli-Parisi) [2] evolution, where the relevant evolution parameter is $\log(Q^2/Q_0^2)$, has been successfully tested over wide ranges in Q^2, and provides, for instance, a good description of the structure function scaling violations. The BFKL (Balitsky-Fadin-Kuraev-Lipatov) [3] evolution equation, where the relevant evolution parameter is $\log(1/x)$, is expected to become applicable at small enough x where the $\log(1/x)$ terms dominate the evolution. The CCFM (Ciafaloni-Catani-Fiorani-Marchesini) [4] evolution, where the parton emissions obey angular ordering, is expected to be valid for both low and high Bjorken-x, thereby forming a bridge between the BFKL and DGLAP approaches. Hadronic final state calculations for all three prescriptions are, for the first time, becoming available [5].

In this analysis data from the H1 experiment are used to study high energetic π°-meson and charged particle production in the forward region at small Bjorken-x. High p_t particles are strongly correlated to the production of hard partons. They can therefore be used to penetrate screening hadronization effects. Previous measurements [6] exploiting this feature have been limited by experimental acceptance mostly to the central region of the detector. The study of forward going jets has also been suggested [1] to study parton dynamics at low Bjorken-x. The integrating nature of jet algorithms and the spatial extension of jets thus defined however make such observables liable to contributions from the proton remnant. The measurement of single particles provides complementary observables independent of jet algorithms while taking full advantage of the detector acceptance. Another interesting feature of single particle observables is that they can be directly compared to analytical calculations by employing fragmentation functions. In particular the π°-mesons can be measured to high $x_\pi = E_\pi/E_{proton}$ (see below). For these values of x_π the parton density functions in the proton are well known from the global QCD analyses and small Bjorken-x dynamics can be exposed free from the ambiguities associated with the choice of the non-perturbative parton input [7].

2 Data Selection

Experimental data for this analysis were collected by the H1 experiment during the 1994 running period, in which HERA collided 27.5 GeV positrons on 820 GeV protons. Integrated luminosities of the data samples used for the π°-meson and charged particle measurements are 1.9 pb^{-1} and 1.0 pb^{-1} respectively. DIS events are selected in the region of Bjorken-x $2 \cdot 10^{-4} < x < 2.36 \cdot 10^{-3}$ via the scattered positron satisfying $E_e > 12$ GeV, $156^\circ < \Theta_e < 173^\circ$ and $y > 0.1$. All results quoted here are corrected to this range.

3 Forward π°-mesons

The π°-mesons are measured in the dominant decay channel $\pi^\circ \rightarrow 2\gamma$. The π° candidates are selected in the region of $5^\circ < \Theta_\pi < 25^\circ$ using the finely segmented H1 Liquid Argon (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 photons cannot be separated, but appear as one object (cluster) in the calorimetric response. Photon induced showers are selected by measuring the shower

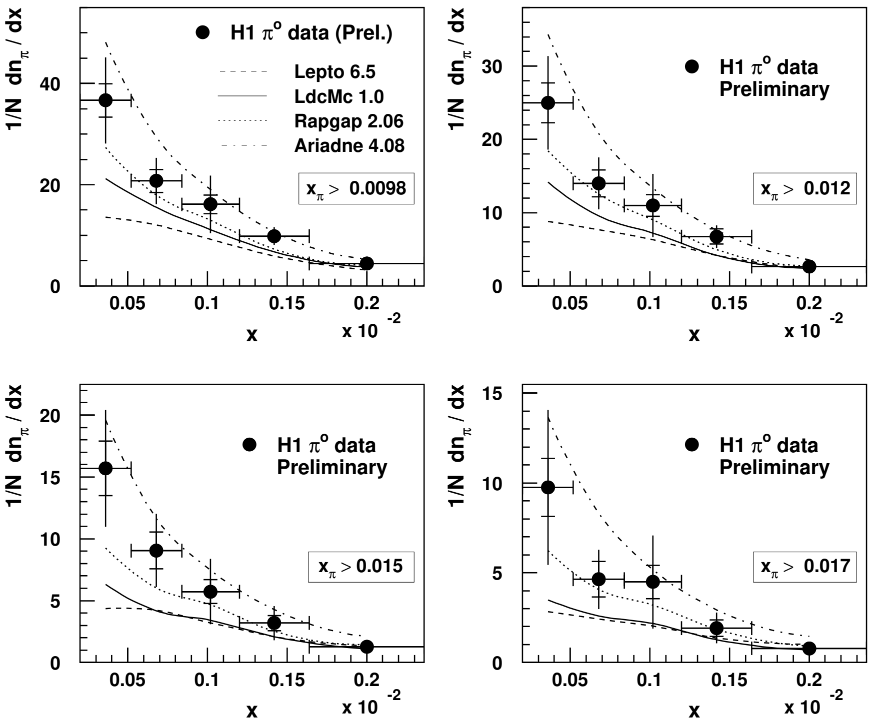

Figure 1: The forward π^0 spectra in Bjorken-x for $p_{t,\pi} > 1$ GeV and $5^\circ < \Theta_\pi < 25^\circ$ are shown for four different values of the lower threshold $x_\pi = E_\pi / E_{proton}$. Here n_π is the number of π^0-mesons and N is the number of events that enter the distribution. For comparison, the predictions of four different QCD models are overlaid.

shapes of candidate clusters. The selection criteria are based on the compact nature of electromagnetic showers as opposed to those of hadronic origin. The very fine segments ($\sim$ 44000 cells in total, with a cell size of 3.5 x 3.5 cm^2 and four-fold longitudinal segmentation in the forward region) of the H1 LAr calorimeter allow for a detailed study of the transverse and longitudinal spread and the energy distribution of each cluster. The main challenge of the analysis is the high particle density in the forward direction leading to overlapping showers of electromagnetic and hadronic origin. Candidates of this type are mostly rejected. The same high multiplicity of particles makes the use of track information as a rejection criterion infeasible for the π^0 selection. Monte Carlo studies using a detailed simulation of the H1 detector nevertheless show the detection efficiency for π°-mesons in the region specified before to be above 40% and predict that more than 75% of the selected candidate showers stem from π°-mesons. The contribution of candidates not associated to the primary vertex is below 10%. All distributions shown are corrected bin-by-bin for these detector effects and QED radiation.

Results are presented as spectra in Bjorken-x of π°-mesons with $5^\circ < \Theta_\pi < 25^\circ$ and $p_{t,\pi} > 1$ GeV. The data is shown in Fig. 1 for the four different lower thresholds of $x_\pi > [\ 0.0098,\ 0.012,\ 0.015,\ 0.017\ ]$ to illustrate the dependence on $x_\pi = E_\pi / E_{proton}$. The full errors are the quadratic sum of the statistical (inner error bars) and systematic errors. All distributions are normalized to the number of DIS events N that fall into the kinematic range specified before. The data clearly rise with decreasing Bjorken-x, giving evidence of much more hard partonic radiation than predicted by DGLAP type QCD models as represented by LEPTO [10]. A better description of the data can be obtained by adding contributions from processes in which the photon is not point-like but acts as an resolved object as implemented in RAPGAP [11]. The choices of scales [14] are however somewhat arbitrary here and introduce large uncertainties. For the first time, the data can also be compared to a MC model based on the CCFM approach (LDCMC [5]). Although it is closer to the data for lower cutoffs in x_π it becomes increasingly similar to the DGLAP based model towards higher π° energies. The Color Dipole Model as implemented in ARIADNE[12] tends to overshoot the data in most of the measured distributions.

4 Forward Charged Particles

Charged particles (cp) are selected using the forward (FT) and central (CT) tracking chambers. Basic quality criteria are used to select well measured tracks originating from the primary interaction point. For tracks restricted to the kinematic range used in this analysis: $p_{cp} > 8$ GeV, $p_{t,cp} > 1$ GeV, $5^\circ < \Theta_{cp} < 25^\circ$, over 90% are reconstructed in the FT. For this measurement, as for the π°-mesons, the high particle multiplicity in the forward direction constitutes the main challenge. It gives rise to a large flux of soft particles produced in secondary interactions in passive material within the detector leading to a degradation of detection efficiency and resolution. Since the curvature of the tracks is used to measure their momentum then the resolution also decreases with increasing momentum. The measurement of charged particles in this analysis is therefore only currently feasible for the lowest threshold of $x_{cp} = E_{cp}/E_{proton} > 0.0098$ used in the π°-meson analysis. The efficiency of reconstructing a central track and associating it to the primary event vertex is over 95% [8]. The equivalent forward track efficiency is over 40% [9] for tracks well

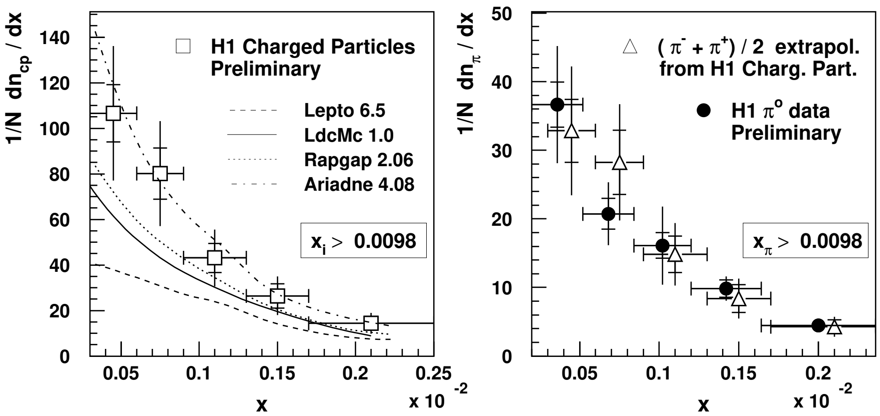

Figure 2: The forward charged particle spectra in Bjorken-x are shown for $x_{cp} = E_{cp}/E_{proton} > 0.0098$ and $p_{t,cp} > 1$ GeV in the polar angular range $5° < \Theta_{cp} < 25°$. Here n_{cp} is the number of charged particles and N is the number of events that enter the distribution. For comparison, the predictions of four different QCD models are overlaid.

contained within the FT. For tracks produced at low values of Θ_{cp} ($\Theta_{cp} < 10°$), a lower efficiency of 25% is obtained. The proportion of these selected charged particles produced in secondary interactions in passive material is negligible for central tracks but is estimated to be maximally 10% for the forward sample used here. The data have been corrected bin-by-bin for the influence of the detector and QED radiation.

The charged particle results are shown as spectra in Bjorken-x in Fig. 2 (left) for the region defined above. Both the data and the QCD models show the same Bjorken-x behavior as the $\pi°$-meson spectra. To further check the consistency of both measurements JETSET [13] has been used to estimate the contribution of charged pions to the charged particle data. The results divided by two are compared to the $\pi°$ measurement in Fig. 2 (right) and show good agreement as expected from isospin symmetry.

5 Summary

Two measurements have been presented which for the first time access the experimentally difficult region close to the proton remnant for the study of high p_t $\pi°$-meson and charged particle production. The data is presented as spectra in Bjorken-x. The two analysis can be compared and are in good agreement. In both cases the data clearly rise with decreasing Bjorken-x, giving evidence of much more hard partonic radiation than predicted by DGLAP type QCD models. The π° measurement can access higher values of x_π and the discrepancy can be seen to increase there. Additional contributions from processes with a resolved photon as implemented in RAPGAP lead to a better description of both π°-mesons and charged particles but here large uncertainties are introduced since one is forced to make a best guess of a reasonable scale [14]. For the first time, predictions for the hadronic final state from a QCD model based on the CCFM approach (LDCMC) are available. Although they are closer to the data for lower cutoffs in x_π they become increasingly similar to the DGLAP based model towards higher π° energies. The Color Dipole Model as implemented in ARIADNE tends to overshoot the data in most distributions.

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