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The Evolution of Inclusive Charged Particle Spectra with Q^2 in ep interactions at HERA

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Abstract

Using positron-proton collision data taken with the H1 detector at HERA, measurements of the pseudorapidity and transverse momentum spectra of inclusively produced charged tracks in the photon-proton centre-of-mass frame are presented for different photon virtualities Q^2. The Q^2 range extends from $Q^2 \approx 0$ GeV^2 to $Q^2 = 50$ GeV^2. The pseudorapidity range extends from the photon fragmentation region to the central region between the photon and proton fragmentation regions. The results are compared with QCD based models.

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1 Introduction

Electron-proton interactions can proceed via the exchange of virtual photons. For the exchange of quasi-real photons ($Q^2 \sim 0$ GeV^2), these are termed photoproduction interactions and have properties typical of hadron-hadron scattering and can be described by the Vector Meson Dominance picture in which the photon is assumed to fluctuate into a vector meson before interacting with the proton. Direct interactions of the photon with a parton in the proton and a point-like contribution in which the photon splits into a $q\bar{q}$ pair are needed to accommodate the large tail observed in the transverse momentum distribution of produced particles [1]. In contrast, interactions with Q^2 above several GeV^2, which are termed Deep Inelastic Scattering (DIS), can be interpreted as a hard scattering process in which a point-like virtual photon "probes" the structure of the hadronic target. It has been argued that a smooth transition between photoproduction and DIS can be achieved by viewing the photon-proton collision in the proton rest frame and considering the photon to develop as a hadronic object before interacting with a parton from the proton [2]. For values of Bjorken-x of between $10^{-4} < x < 10^{-2}$ the photon is able fluctuate into and stay as a $q\bar{q}$ pair long enough to interact as a hadron [3, 4]. At HERA energies such values of x can be reached for $Q^2 \sim 10$ GeV^2. This approach is complementary to the treatment of DIS as a point-like process [4].

The rapidity distribution of hadrons produced in photon-proton collisions can be sub-divided into three regions: the proton fragmentation region, the photon fragmentation region and a central hadronic plateau between these two regions [5]. The photon fragmentation region is expected to depend strongly on the hadronic nature of the photon, which depends on Q^2, while due to the short range nature of the strong interactions governing hadron production, the central and proton fragmentation regions are expected to be independent of Q^2 and to depend only on the photon-proton centre of mass energy. Recent results on transverse energy flows [2] support this. Transverse energy flows however do not allow the study of the proportion of the energy carried by individual hadrons and the charged particle analysis presented here is more sensitive in this respect.

2 Event Selection and Detector Description

Experimental data for this analysis were collected with the H1 detector [6] 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 1.3 pb^{-1}. DIS events are selected via the scattered positron in the H1 Backward Electromagnetic Calorimeter and are required to have $E_e^{\prime} > 12$ GeV, $156^\circ < \Theta_e < 173^\circ$, $5 < Q^2 < 50$ GeV^2, $0.3 < y_e < 0.5$. Further reduction of photoproduction background from the DIS sample 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 [7], with the sum extending over all tracks and calorimeter clusters, j, in the event, using combined information where available. The kinematic variables are determined using information from the scattered positron: $Q^2 = 4E_eE_e^{\prime}\cos^2(\Theta_e/2)$ and $y = 1 - (E_e/E_e^{\prime})\sin^2(\Theta_e/2)$, where $E_e^{\prime}$ and Θ_e are the energy and polar angle (with respect to the incoming proton direction) of the scattered positron respectively. 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 photoproduction events were triggered by requiring simultaneously a positron candidate in the H1 low angle electron tagger and a track with $p_T > 200$ MeV. The acceptance for such events is high in the region $Q^2 < 0.01$ GeV^2 and $0.3 < y < 0.5$ and the results are corrected to this region.

Charged particles are measured in 2 mechanically distinct devices, the central and forward[1] trackers which are used to select charge particles in the ranges of polar angle, θ, of $22° < \theta < 150°$ and $5° < \theta < 25°$ respectively.

To remove the contributions of low mass diffractive events in photoproduction and DIS processes, the presence was required of at least 500 MeV of energy in the forward region of the liquid argon calorimeter, $4.4° < \theta < 15°$. The remaining samples are termed non-diffractive and all results are quoted with respect to this requirement. After all cuts the mean hadronic centre of mass energy for the DIS and photoproduction samples is $\langle W \rangle$=190 GeV and the average photon virtuality of the DIS sample is $\langle Q^2 \rangle$=16 GeV^2.

3 Results

Figure 1 shows the corrected transverse momentum distribution $\frac{1}{N}\frac{\mathrm{d}n}{\mathrm{d}p_T^*\eta^*}$ of charged particles produced in DIS and photoproduction interactions. Here, p_T^* and η^* denote the transverse momentum and pseudorapidity respectively in the photon-proton centre of mass system, where the photon is taken to be aligned with the $+z^*$ direction. The measurement is presented in the following intervals of η^*: $-0.5 < \eta^* < 0.5$, $0.5 < \eta^* < 1.5$ and $1.5 < \eta^* < 2.5$. In these spectra, the error bars correspond to the quadratic sum of the statistical and systematic errors.

Major sources of systematic errors on these measurements include contributions from the choice of Monte Carlo model used to correct the data which typically contributes a 10% systematic error on the data shown. A further source of systematic error is the uncertainty in the charged track finding efficiency. This varies from 15% in the $-0.5 < \eta^* < 0.5$ interval to 5% for larger η^* values. Systematic errors of 2% were assigned due to uncertainties on the energy scale of the BEMC and electron tagger. Photoproduction background to the DIS sample and electron beam-induced background in the photoproduction sample give systematic errors of less than 2%.

Comparisons are made with the QCD-based Monte Carlo generators LEPTO 6.5 [8] and the Colour Dipole Model (CDM) [9] as implemented in ARIADNE 4.08 [10] for DIS and PHOJET 1.3 [11] for photoproduction. The DIS transverse momentum distribution is seen to be significantly harder than the equivalent photoproduction distribution for large pseudorapidity ($\eta^* > 1.5$), that is in the photon fragmentation region, although the two distributions are seen to converge for the lower pseudorapidity intervals. Within the precision of the measurement no Q^2 dependence is observed for the lower pseudorapidity range $-0.5 < \eta^* < 0.5$, which corresponds to the hadronic plateau region.

The CDM and PHOJET describe well the DIS and photoproduction p_T spectra over the pseudorapidity ranges considered. LEPTO however fails to give a good description of the DIS data and is particularly deficient for the lower pseudorapidity bins. The inclusion of the $-0.5 < \eta^* < 0.5$ interval, made possible by using the H1 Forward Tracker, extends the phase space measured above that covered in a recent charged particle analysis [12] which also found an increasing inability of LEPTO to predict the high transverse momentum tail with decreasing pseudorapidity.

The inclusive charged particle pseudorapidity distribution $\frac{1}{N}\frac{\mathrm{d}n}{\mathrm{d}\eta^*}$ is shown in figure 2 for DIS and photoproduction interactions. Previously published data [13] is shown with new, additional points for $\eta^* < 0.5$. In these spectra the error bars shown correspond to the quadratic sum of the statistical and systematic errors. Over the pseudorapidity range considered, no significant differences in particle density are observed between the photoproduction and DIS data sets and neither PHOJET nor the CDM adequately describe the overall rate of produced charged particles though both provide a reasonable description of the shape of the distributions.

[1]The forward direction is taken to refer to the direction of the incoming proton.

4 Summary

A preliminary measurement of inclusive charged particle transverse momentum and pseudorapidity spectra has been performed in non-diffractive DIS and photoproduction. In the central region of the hadronic cms there is striking agreement in the shape and normalisation of the transverse momentum distributions from the two data samples though the DIS distributions become significantly harder towards the photon fragmentation region. Over the pseudorapidity range measured in this analysis, there are no significant differences in the particle densities of hadrons produced in DIS and photoproduction.

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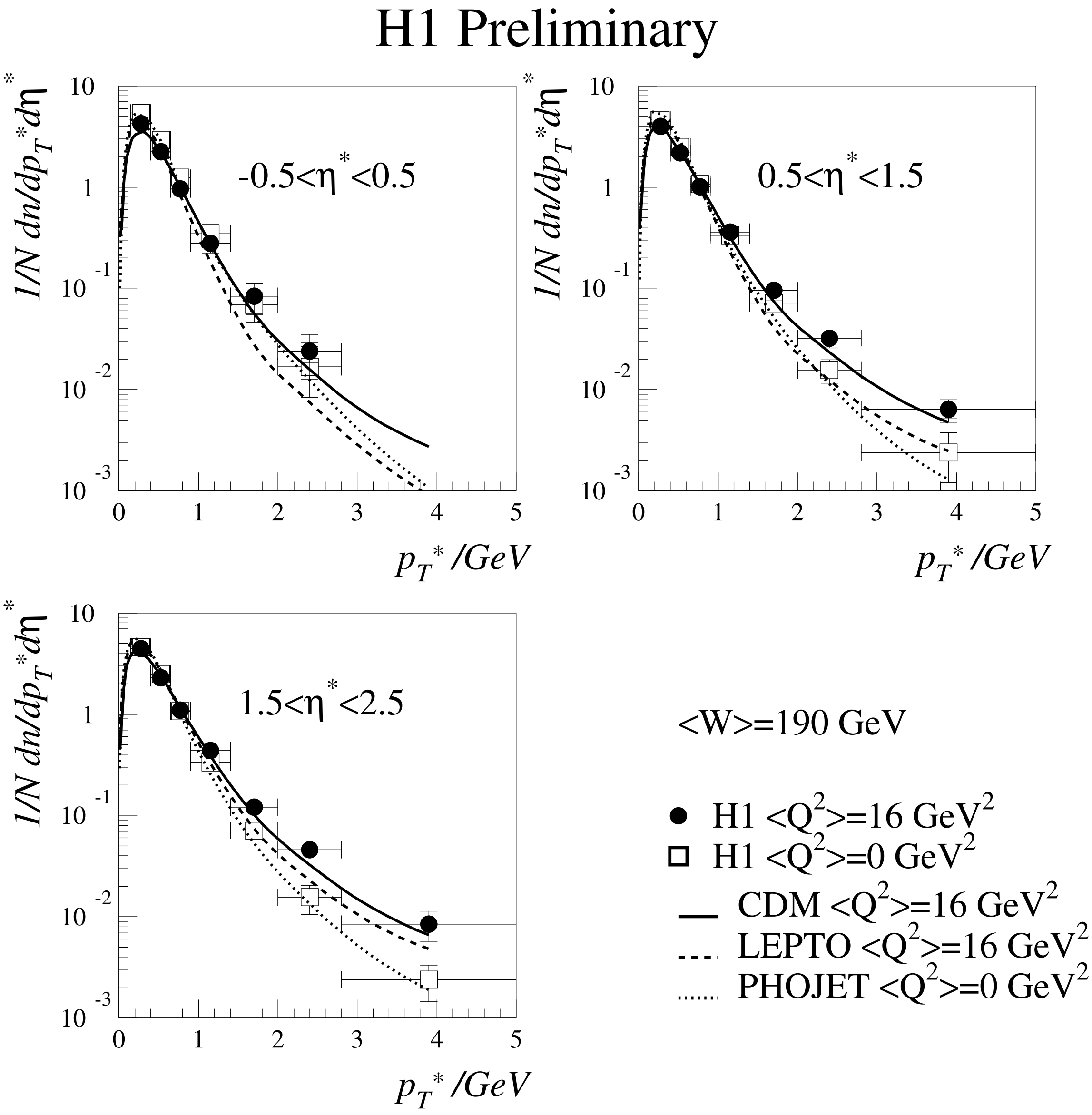

Figure 1: The inclusive charged particle distribution $\frac{1}{N}\frac{\mathrm{d}n}{\mathrm{d}p_T^*\eta^*}$ in the pseudorapidity intervals: $-0.5 < \eta^* < 0.5$, $0.5 < \eta^* < 1.5$ and $1.5 < \eta^* < 2.5$ in photoproduction and DIS. A comparison is made to the predictions of the CDM, LEPTO and PHOJET

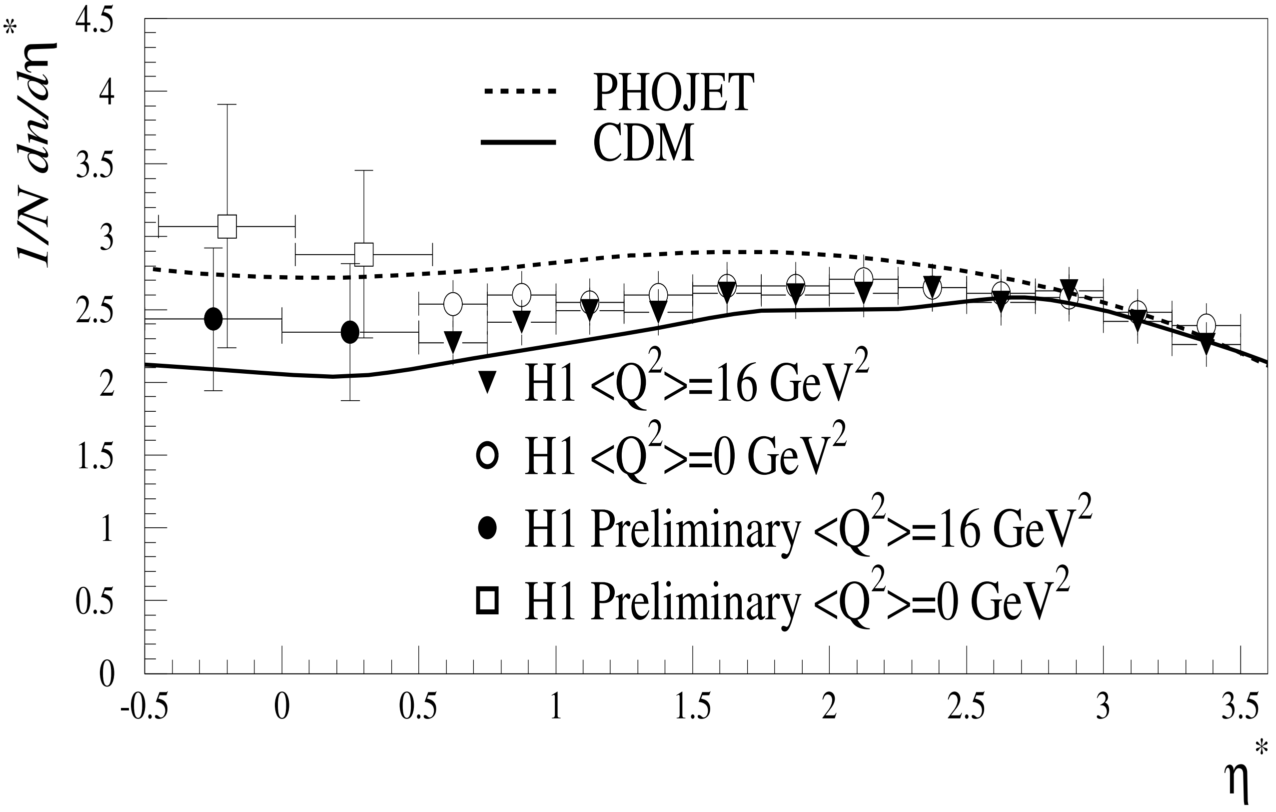

Figure 2: The inclusive charged particle distribution $\frac{1}{N}\frac{\mathrm{d}n}{\mathrm{d}\eta^*}$ in DIS and photoproduction compared to the CDM and PHOJET