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Measurement of Charged Particle Spectra in Deep-Inelastic ep Scattering at HERA

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Charged particle production is measured in deep inelastic ep scattering with the H1 detector at HERA at ep centre-of-mass energies of $\sqrt{s} = 319$ GeV and $\sqrt{s} = 225$ GeV centre-of-mass energies. The kinematic range of these analyses covers low photon virtualities, $5 < Q^2 < 100$ GeV^2 and $5 < Q^2 < 10$ GeV^2, respectively, and small values of Bjorken-x. The analyses are performed in the virtual photon-proton centre-of-mass system. The charged particle spectra are investigated as a function of pseudorapidity η^* and transverse momentum p_T^*. The data are compared to different Monte Carlo generators implementing various options for parton evolutions and hadronization. In addition, the data measured at $\sqrt{s} = 225$ GeV are used for testing a phenomenological model.

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1. Intorduction

Deep-inelastic scattering (DIS) processes at the ep collider HERA can access small values of Bjorken-x at low four momentum transfers squared Q^2 of a few GeV^2. In the region of low x, characterised by high densities of gluons and sea quarks in the proton, the parton interaction with the virtual photon may originate from a cascade of partons emitted prior to the interaction. In perturbative Quantum Chromodynamics (QCD) such multi-parton emissions are described only within certain approximations valid in restricted phase space regions. In [1] it has been proposed that a measurement of the transverse momentum spectra of charged particles will allow testing different approaches for parton evolution dynamics. In addition, such measurement can serve as a test for various phenomenological models.

Results on charged particle production in DIS from two different analyses based on data collected with the H1 detector at ep centre-of-mass energies of $\sqrt{s} = 319$ GeV [2] and $\sqrt{s} = 225$ GeV [3] are presented. The analyses are performed in the hadronic center of mass system (HCM), i.e. in the proton-photon rest frame. Monte Carlo generators using different approaches to simulate the parton cascade are studied in present analysis: RAPGAP generator [4] based on leading log DGLAP parton showers; DJANGOH generator [5] based on Color Dipole Model (CDM), a description of parton emission which is similar to that of the BFKL evolution; CASCADE generator [6] based on the CCFM model, which unifies the BFKL and DGLAP approaches and requires angular ordering of the emitted quanta w.r.t. the proton beam. In the CDM and the CCFM approaches the p_T of the emitted partons in a parton shower is not ordered in x. All generators use the Lund string model [7] for hadronisation as it is implemented in PYTHIA, with parameters tuned by the ALEPH collaboration to fit LEP data [8].

In addition, it is interesting to test the phenomenological approach which has been proposed recently [9] for DIS data. This approach suggests that the particle production p_T spectrum can be described by the sum of an exponential (Boltzmann-like) and a power-law statistical distributions:

$$\frac{d\sigma}{dp_T^2} = A_e \exp\left(-E_{Tkin}/T_e\right) + \frac{A}{(1 + \frac{p_T^2}{T^2 \cdot N})^N}, \tag{1.1}$$

where $E_{Tkin} = \sqrt{p_T^2 + M^2} - M$ with M equal to the produced hadron mass. A_e, A, T_e, T, N are free parameters to be determined by fit to the data. The detailed arguments for this particular choice are given in [9].

2. Results

The p_T dependence of charged particle densities (at $\sqrt{s} = 319$ GeV) is studied in two different pseudorapidity intervals, $0 < \eta^* < 1.5$ and $1.5 < \eta^* < 5$, referred to as the "central region" and "current region", respectively. Such division separates the regions of sensitivity to the hard scattering process (current region), from the region of parton showering (central region). The measurement at reduced proton beam energies ($\sqrt{s} = 225$ GeV) allows for a more precise measurement of the "central region", therefore, the p_T spectra are measured in seven bins in the pseudorapidity region $0 < \eta^* < 3.5$. The target region, $\eta^* < 0$, is not accessible in the analyses.

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2.1 Rapidity distributions

The charged particle densities as a function of pseudorapidity are shown in Fig. 1 for two different regions in p_T^*. Details in the fragmentation process mainly influence the low p_T^*-region (Fig. 1a) while the large p_T^* region is rather insensitive to fragmentation (Fig. 1d). Conversely the low p_T^*-region shows only little dependence on the parton cascade (Fig. 1c) while the differences due to parton showering are clearly visible at large p_T^*. The CASCADE MC is failing in describing the data in general in both regions.

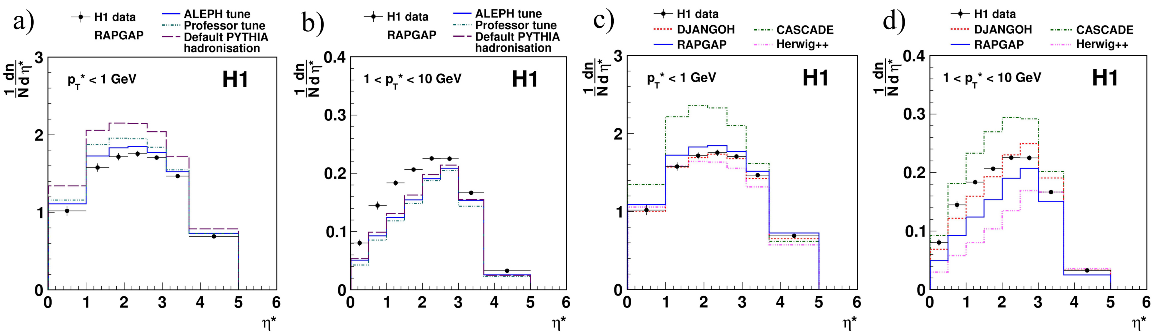

Figure 1: .Charge particle densities as function of pseudorapidity measured for $p_T^* < 1$ GeV (a, c) and for $p_T^* > 1$ GeV (b, d) separately and shown together with prediction for different hadronisation (a, b) parameters and parton evolution models (c, d).

2.2 Transverse momenta of charged particle

The transverse momentum spectra (p_T^*) of charged particles are presented in Fig. 2. DJANGOH describes the data fairy well for the whole p_T^* range, whereas RAPGAP is significantly below the data for $p_T^* > 1$ GeV. CASCADE is above the data for almost the whole p_T^* range.

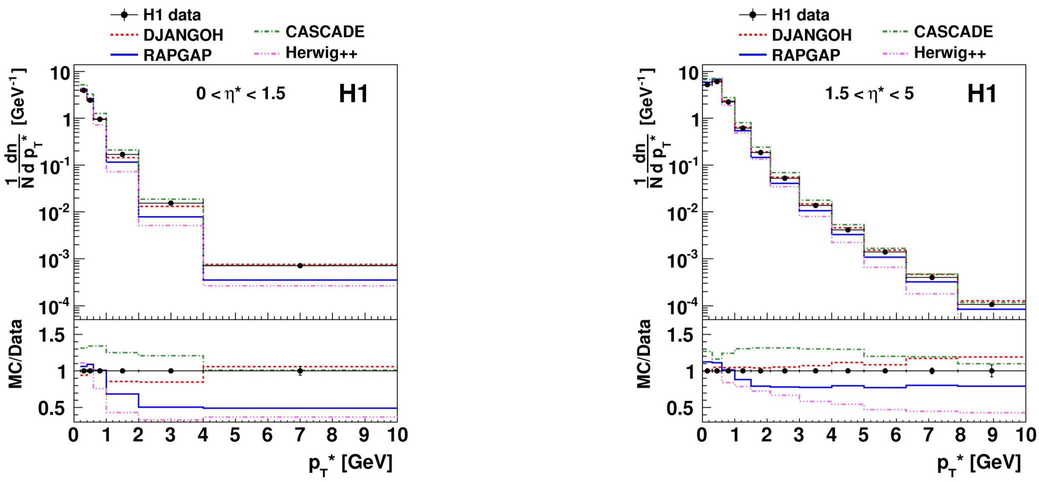

Figure 2: The measured transverse momentum spectra of charged particles together with different Monte Carlo prediction and the ratios Monte Carlo over data shown for central and current regions respectively.

However, if one look at the ratios Monte Carlo over data (Fig. 3) measured at $\sqrt{s} = 225$ GeV as function of p_T^* with better resolution, it can be seen that both RAPGAP and DJANGOH fail to describe the data in the central region.

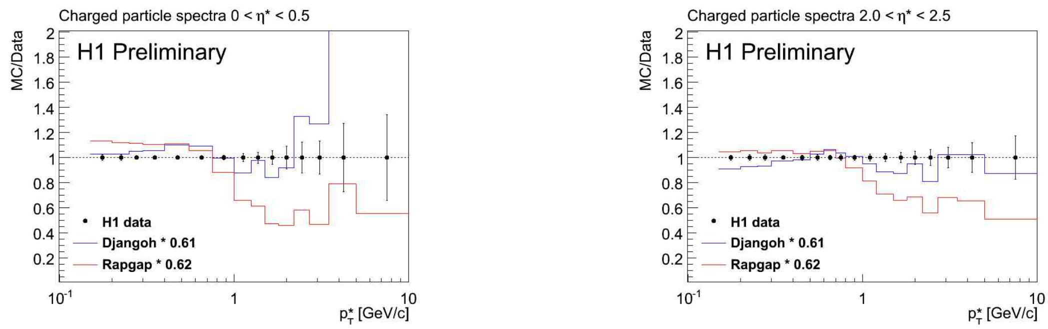

Figure 3: Ratios Monte Carlo over data for charged particle p_T^* spectra measured at $\sqrt{s} = 225$ GeV shown for central and current regions respectively.

2.3 Phenomenological studies

The particle densities measured at $\sqrt{s} = 225$ GeV are used for a phenomenological analysis using the parameterisation (1.1). By integrating over p_T^2 the relative contribution of the exponential and power-law terms, the ratio R of the power-law term to the sum of both terms is given by

$$R = \frac{ANT^2}{ANT^2 + A_e(2MT_e + 2T_e^2)(N-1)} \tag{2.1}$$

In [9] it was shown that charged particle spectra measured in $\gamma\gamma$ collisions can be described by the power-law term of (1.1) alone while spectra measured in pp-collisions require a large ($\approx 70\%$) exponential contribution. Qualitatively such behavior was explained in [10]. Therefore, it is expected that at HERA the transition between these two regimes of hadron production dynamics should be visible. The double differential cross sections for central and current regions are shown in figure 4 together with the fit (1.1), respectively. A clear increase of the exponential contribution is observed at central rapidities. In figure 4 the relative contribution of the power-law type distribution

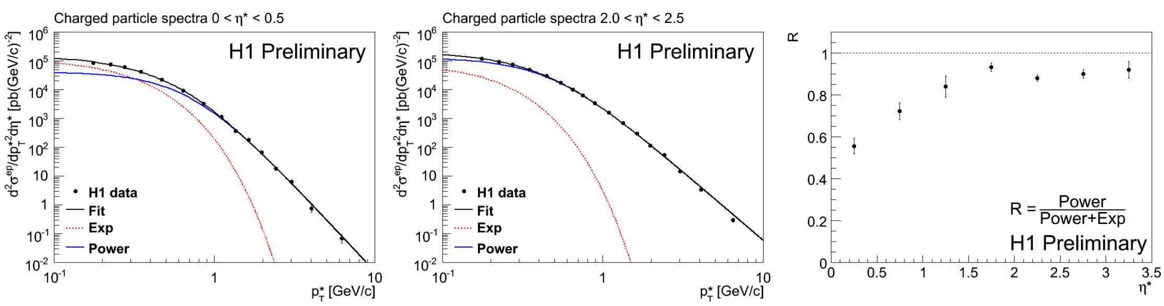

Figure 4: Charged particle double differential cross section together with the fits of the function (1.1) for central and forward regions respectively and power-law term contribution of (1.1) as function of pseudorapidity.

to the charged particle production spectra is also shown as function of charged particle rapidity

(η^*) in the γp centre-of-mass system. One could observe that the particles produced in the photon fragmentation region at high rapidity values are described by the power-law statistical distribution only. However, the data require a significant exponential contribution for particles produced in the "central" region. Thus, the expected change in hadroproduction dynamics is observed.

3. Conclusion

Cherged particle production in DIS has been studied by measuring the transverse momentum and rapidity spectra with the H1 detector at HERA at ep centre-of-mass energies of $\sqrt{s} = 319$ GeV and $\sqrt{s} = 225$ GeV. The transverse momentum spectra are compared to predictions from different parton dynamics models (DGLAP, CDM and CCFM). The data are shown to be in favour of CDM, while the DGLAP models are below the data in hard momentum region ($p_T^* > 1$ GeV). However, when testing the models with higher resolution at $\sqrt{s} = 225$ GeV none of the models describes the data well. The data are also used to test a phenomenological model recently introduced. Within this model the data show a change in particle production dynamics when moving from the current to the central rapidity region.

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