New Model for Hadroproduction tested with DIS at HERA

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Shapes of particle spectra observed in pp and $\gamma\gamma$ collisions are quite different as shown recently. This difference could be explained by a newly introduced phenomenological approach. Deep inelastic scattering at HERA is the unique possibility to study the change in hadroproduction dynamics predicted by this model. Therefore, charged particle production is measured in deep inelastic ep scattering at $\sqrt{s} = 225$ GeV with the H1 detector at HERA. The kinematic range of the analysis covers low photon virtualities, $5 < Q^2 < 10$ GeV^2, and medium to high values of inelasticity $y, 0.35 < y < 0.8$. The analysis is performed in the virtual γp centre-of-mass system. The charged particle production cross sections are investigated double-differentially as a function of pseudorapidity η^* and transverse momentum p_T^* in the range $0 < \eta^* < 3.5$ and $p_T^* < 10$ GeV.

1 Introduction

Inclusive charged particle distributions have been studied for a long time to understand the physics of hadron production at high energies. A large amount of experimental data on charge particle production spectra in baryon-baryon, γ-baryon and $\gamma\gamma$ collisions has been accumulated during last forty years. However, the underlying dynamics of hadron production in high energy particle interactions is still not fully understood. A detailed comparative analysis of charged particle spectra measured in different types of collisions could shed light on the hadroproduction mechanisms. Recently, a new unified phenomenological approach to describe the particle production spectra shape was proposed [1]. It was suggested to approximate the charged particle spectra as a function of the particles transverse momentum by a sum of an exponential (Boltzmann-like) and a power-law statistical distributions:

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

where $E_{Tkin} = \sqrt{p_T^2 + M^2} - M$ with M equal to the produced hadron mass. The free parameters A_e, A, T_e, T, N are determined by fits to the data. The detailed arguments for this particular choice are given in [1] and are summarized in section 2. For the charged hadron spectra the mass of the hadrons is assumed to be equal to the pion mass.

The relative contribution of these terms is characterized by ratio R of the power-law term alone to the sum of both contributions integrated over p_T^2:

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

It was found that the exponential contribution dominates the charged particle spectra in baryon-baryon collisions while it is completely absent in $\gamma\gamma$ interactions [1]. Moreover, the exponential contribution is characteristic for charged pion production and is much less pronounced in kaon or proton (antiproton) production spectra [3,4].

2 Phenomenological model

The hadroproduction process in baryon-baryon high energy interactions could be decomposed into at least two distinct parts. These parts are characterized by two different sources of produced hadrons. The first one is associated with the baryon valence quarks and a quark-gluon cloud coupled to the valence quarks. Those partons preexist long time before the interaction and could be considered as being a thermalized statistical ensemble. When a coherence of these partonic systems is destroyed via strong interaction between the two colliding baryons these partons hadronize into particles released from the collision. The hadrons from this source are distributed presumably according to the Boltzmann-like exponential statistical distribution in transverse plane w.r.t. the interaction axis. The second source of hadrons is directly related to the virtual partons exchanged between two colliding partonic systems. In QCD this mechanism is described by the BFKL Pomeron exchange. The radiated partons from this Pomeron have presumably a power-law spectrum typical for perturbative QCD. Figure 1 shows schematically these two mechanisms of particle production in high energy (a) baryonic and (b) $\gamma\gamma$ collisions. Obviously, there are no thermalized partons preexisted long time before the $\gamma\gamma$ interactions. This simplified model explains the observed absence of the Boltzmann-like term in the spectra of hadrons produced in $\gamma\gamma$ collisions [1]. This explanation is qualitative, however.

Figure 1: Two different sources of hadroproduction in high energy (a) baryonic and (b) $\gamma\gamma$ collisions: red arrows - particles produced by the preexisted partons, green - particles produced via the Pomeron exchange.

This simple model is naive, though it allows for making a number of predictions which can be checked experimentally [4].

3 DIS at HERA

At HERA DIS processes are mediated by photon exchange. In the proposed hadroproduction model it is natural to expect that in γp interaction hadron production in the photon hemisphere of event produced at HERA shows similarity with that observed in $\gamma\gamma$ collisions. At the same time hadron production in the proton hemisphere of DIS events at HERA should resemble to what is measured in pp collisions. Therefore a change in the hadron production dynamics is expected at central rapidities of produced particles in γp centre-of-mass system.

Due to the strong asymmetry in the beam energies of electron (27.6 GeV) and proton (920 GeV) beams at HERA the previous inclusive hadron production measurements [5] had only limited access to the central rapidity region in the γp frame and, thus, the change in hadron production dynamics could be hardly observed [1]. However, it is likely to observe a transition in the hadron production dynamics in the rapidity region around central rapidity values where one could observe a smooth transition between two different types of the spectra shapes: one is characteristic to the photon and another to baryon regimes described above. The experimental challenge for such a measurement at HERA is the acceptance limitation for track measurements close to zero rapidity values in the γp centre-of-mass system. Figure 2 shows, that the maximal reach in the rapidity space towards the proton hemisphere at HERA could be obtained using a set of the data collected with reduced proton beam energy. At the same time one should keep a selection of the ep events with high energy of the photon exchanged in these interactions. Thus, high values of inelasticity $0.35 < y < 0.8$ have to be chosen.

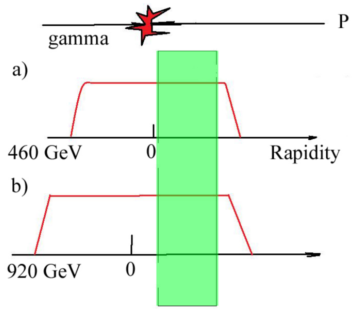

Figure 2: Charge particle rapidity distributions at HERA for (a) reduced ($E_p = 460GeV$) and (b) nominal ($E_p = 920GeV$) beam energies. Green area shows a typical coverage in rapidity space of the central tracking detectors at HERA experiments.

In 2007 the HERA ep-collider was operated at nominal electron beam energy ($E_e = 27.5$ GeV) and reduced proton beam energy ($E_p = 460$ GeV) during three months in which an integrated luminosity of 12.45 pb^{-1} has been collected. These data are used in the present analysis of the charged particle spectra shapes in the virtual γp rest frame as a function of rapidity.

4 Results and Discussions

The measured differential cross sections for central and forward fragmentation (photon direction) regions are shown in figure 3 together with the fit (1) respectively. A clear increase of the exponential contribution is observed at central rapidities.

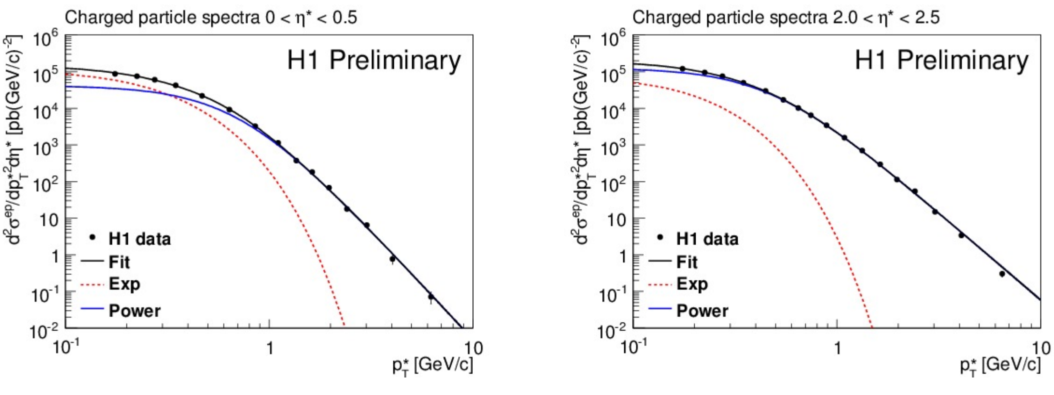

Figure 3: Charged particle double differential cross section together with the fits of the function (1) for central and forward regions respectively. The red line shows the exponential term and the blue one the power-law.

In figure 4 the relative contribution of the power-law type distribution to the charged particle production spectra is shown as function of charged particle rapidity (η^*) in the γp centre-of-mass system. This contribution is calculated according to equation (2) from fits of the function (1) to the H1 data. 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 (Boltzmann-like) contribution for particles produced centrally in the rapidity space. Moreover, the closer particles are produced towards the proton hemisphere the larger the exponential statistical contribution is required to be in order to describe the inclusive charged particle spectrum. Note, that in the pp interaction at about the same collision energy as here for γp at HERA the data require only about 30% of the

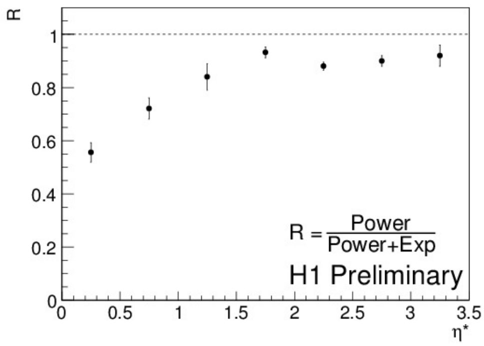

Figure 4: Power-law term contribution of (1) in charged particle spectra as function of pseudorapidity ($\eta*$).

power-law type contribution to the charged particle spectrum measured at central rapidities, while the residual 70% of the particle spectrum is described by the exponential contribution [1]. Thus, the H1 data support the hypothesis of the simple phenomenological model discussed that the particle production dynamics changes when approaching the proton hemisphere.

5 Conclusion

The first measurement of charged particle production spectra in ep collisions at reduced proton beam energy $E_p = 460$ GeV with the H1 detector in the γp centre-of-mass frame was performed. The kinematic range of the analysis covers low photon virtualities, $5 < Q^2 < 10$ GeV^2, and from medium to high values of inelasticity y, $0.35 < y < 0.8$. The differential cross sections of charged particle production are measured in the pseudorapidity region $0 < \eta^* < 3.5$ in seven bins. The shape of the measured transverse momentum distributions changes with η^*.

In order to investigate the change in hadroproduction dynamics with η^* the data are approximated by the recently introduced approach (1). This parameterization provides a much better description of the experimental data than those used traditionally [6]. Moreover, the observed change in the particle production dynamics when particle rapidity values approach the proton hemisphere in the rapidity space of DIS events, is rather well explained by this qualitative model.

Acknowledgments

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