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Overview of the two component model for hadroproduction

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Transverse momentum spectra, $d^2\sigma/(d\eta dp_T^2)$, of charged hadron production in pp-collisions are considered in terms of a recently introduced two component model. The shapes of the particle distributions vary as a function of c.m.s. energy in the collision and the measured pseudorapidity interval. In order to extract predictions on the double-differential cross-sections $d^2\sigma/(d\eta dp_T^2)$ of hadron production for future LHC-measurements the different sets of available experimental data have been used in this study.

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1. Introduction

Recently a qualitative model considering two sources of hadroproduction has been introduced [1]. It was suggested to parametrize charged particle spectra by a sum of an exponential (Boltzmann-like) and a power-law p_T distributions:

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

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 a fit to the data. The detailed arguments for this particular choice are given in [1]. The exponential term in this model is associated with thermalized production of hadrons by valence quarks and a quark-gluon cloud coupled to them. The power-law term is related to the mini-jet fragmentation of the virtual partons (pomerons in pQCD) exchanged between two colliding partonic systems.

A typical charged particle spectrum as a function of transverse momentum fitted with this function (1.1) is shown in figure 1. As one can see, the exponential term dominates the particle spectrum at low p_T values.

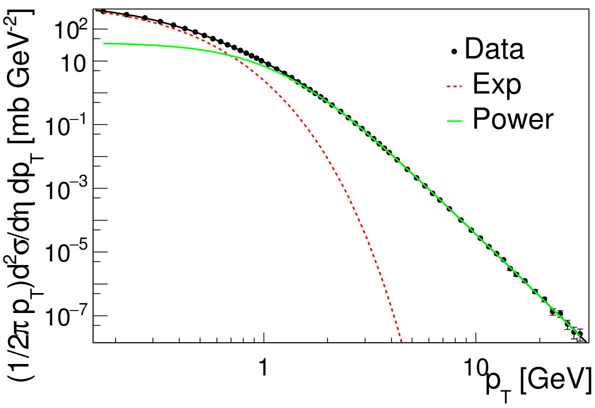

Figure 1: Charge particle differential cross section: the red (dashed) line shows the exponential term and the green (solid) line shows the power law term.

Separating "soft" and "hard" contributions with this model allowed to calculate the predictions on the mean $< p_T >$ values as a function of multiplicity in a collision [2] and pseudorapidity distributions of charged particles [3]. However, the major interest of many studies in QCD is the transverse momentum spectrum itself. Therefore, in this article it is discussed how its shape varies in different experiments under various conditions. In [1] it was shown that the parameters of the fit (1.1) show a strong dependence on the collision energy. Unfortunately, due to the fact that different collaborations measure charged particle production in their own phase space and under various experimental configurations, the dependences observed in [1] were smeared and did not allow to make strong predictions for further measurements. Thus, an approach to correct the measurements in order to allow an accurate combination of different experimental data is proposed here.

2. Parameter variations

In [3] it was shown that two sources of hadroproduction described above contribute to different pseudorapidity regions: while the power-law term of (1.1) prevails in the mid-rapidity region($\eta \sim 0$), the exponential term dominates at high values of η. Since each collaboration presents measurements on transverse momentum spectra in various pseudorapidity intervals, these variations might explain the smearing of the dependences in [1]. The idea to study parameter variations as a function of both collision energy and pseudorapidity region has already been successfully tested in [4].

To further study the variations of the spectra shape as a function of pseudorapidity we use the data published by the UA1 experiment [5] which present charged particle spectra in five pseudorapidity bins, covering the total rapidity interval $|\eta| < 3.0$. Figure 2 shows how the parameter N varies with pseudorapidity together with a power-law fit of this variation. Note, that the parameter shows a growth with pseudorapidity [3], that is explained by higher thermalization of the spectra, as found in [3].

Since the variations of the parameter as function of pseudorapidity have been found, it is desirable to exclude its influence when studying the dependences of N on the c.m.s. energy in a collision. This is possible, if one combines only those data that have been measured in more or less the same pseudorapidity intervals. Hence, it is prudent to look at the combined data taken by the ISR [6], PHENIX [7] and ALICE [8] that were measured in $|\eta| < 0.8$ pseudorapidity region.

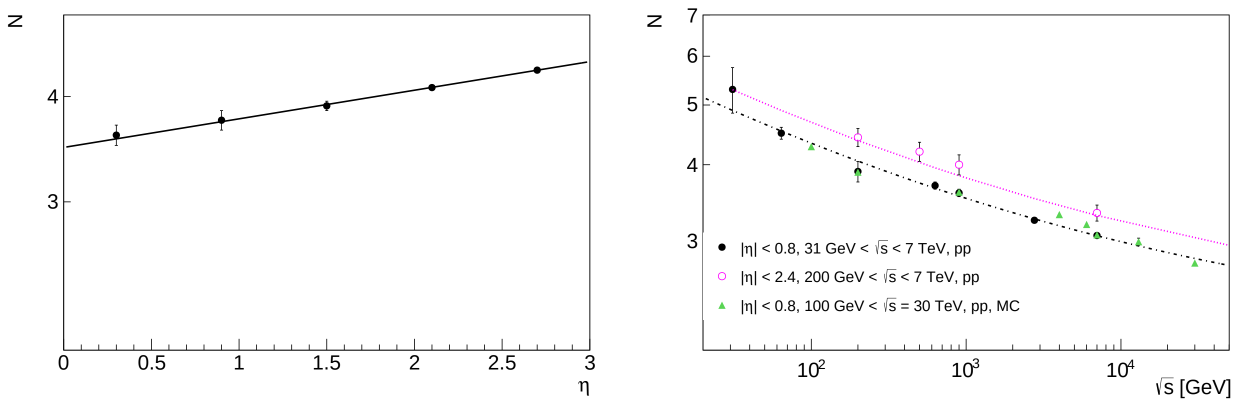

Figure 2: Variation of the N parameter obtained from the fits to the experimental dataas a function of c.m.s. energy $\sqrt{s}$ in a collision and measured pseudorapidity interval.

Figure 2 shows the parameter N variation as a function of c.m.s. energy in a collision. One can notice that it can be characterized by the falling N-value. It is related to the fact that the probability to produce a high-p_T mini-jet should grow with $\sqrt{s}$. Notably, this behaviour correlates with the fact that N decreases when the rapidity interval between the secondary hadron and the initial proton increases.

Let us now check this correlation explicitly and calculate the rapidity interval in the moving proton rest frame according to a simple formula:

$$\eta' = |\eta| - log(\sqrt{s}/2m_p), \tag{2.1}$$

where m_p is the mass of the incoming proton. The results of this procedure are shown in figure 3. Surprisingly, all the points came to a single line in this interpretation. To understand the origin of this universality one might use Monte Carlo(MC) generators: hard processes at large p_T are known to be described by MC generators pretty well, thus it is expected to get the value of the N-parameter from the fits of the MC-generated spectra rather close to the real data, but with a higher accuracy and in a wider collision energy range. To check this universality, we have produced the Monte Carlo samples for proton-proton collisions at different energies for inelastic(INEL) events with the PYTHIA 8.2 generator [9]. Indeed, the values of the parameter N extracted from the fits to the MC-generated spectra are nicely placed at the same line. Thus, a universal parameter describing the shape of the transverse momentum spectra in pp-collisions has been found.

$$N = 5.04 + 0.27\eta' \tag{2.2}$$

Remarkably, similarly to N, the T and T_e also show dependences as a function of both the collisions energy $\sqrt{s}$ and the measured pseudorapidity interval η. The variations of the T and T_e parameters were studied in [4]. In [4] the possible theoretical explanation of the thermalized particle production was presented and the following proportionalities were established:

$$T = 409 \cdot (\sqrt{s})^{0.06} \cdot \exp(0.06|\eta|)\ MeV \tag{2.3}$$

$$T_e = 98 \cdot (\sqrt{s})^{0.06} \cdot \exp(0.06|\eta|)\ MeV \tag{2.4}$$

The parametrizations for T and T_e differ only by a constant factor. However, both the T and T_e parameters reflect the thermalization which is stronger at higher energies and when closer to the valence quarks. Therefore, the (2.3,2.4) parametrizations which are functions of the center of mass energy and rapidity interval can be rewritten in a form with only one universal parameter. This universal parameter is the rapidity distance η'' from the farther incoming proton.

$$\eta'' = |\eta| + \log(\sqrt{s}/2m_p) \tag{2.5}$$

Using (2.3,2.4) we get the universal dependence[1]:

$$T = 409 \cdot \exp(0.06\eta'') \cdot (2m_p)^{0.06}\ MeV, \tag{2.6}$$

$$T = 98 \cdot \exp(0.06\eta'') \cdot (2m_p)^{0.06}\ MeV. \tag{2.7}$$

The dependences are shown on figure 3.

3. Prediction for further measurements

In [3] it was shown, that the introduced approach is able to give predictions on the pseudo-rapidity distributions in high energy collisions for non-single diffractive events (NSD). Using the parameterizations from [3] in addition with (2.2)-(2.7) one can provide a formula that describes the shapes of charged particle spectra, being a function only of the center of mass energy and a measured pseudorapidity region. Let us now summarize all the equations to obtain the final result:

$$\sigma_{power} = 0.217 + 0.235 \cdot \ln\sqrt{s}, \tag{3.1}$$

[1] In the (2.6,2.7) m_p is given in units of 1 GeV/c^2.

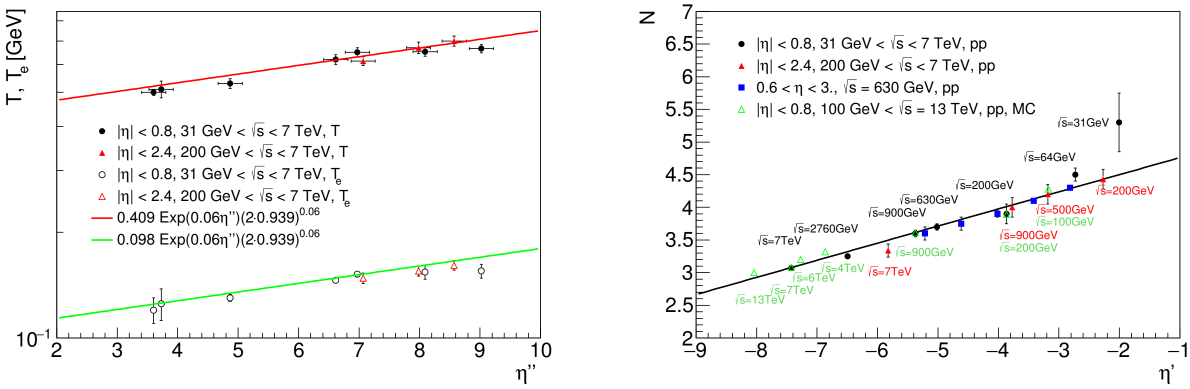

Figure 3: The dependence of the parameters on the pseudorapidity of the secondary hadron in the moving opposite side proton rest frame. The data points from different experiments [5, 6, 7, 8, 10, 11] are shown.

$$\eta_{exp} = 0.692 + 0.293 \cdot \ln\sqrt{s}, \tag{3.2}$$

$$\sigma_{exp} = 0.896 + 0.136 \cdot \ln\sqrt{s}, \tag{3.3}$$

$$A_{power} = 0.13 \cdot s^{0.175}, \tag{3.4}$$

$$A_{exp} = 0.76 \cdot s^{0.106}, \tag{3.5}$$

Now, one can calculate double differential cross sections $d^2\sigma/(d\eta dp_T^2)$ of charged particle production in high energy collisions at different energies for NSD events. These predictions are shown in figure 4 for $|\eta| < 0.8$ and $|\eta| < 2.4$ pseudorapidity intervals together with the experimental data measured by CMS [11] and ALICE [12]. A good agreement of the prediction with the data can be observed. Thus, these results give us a powerful tool for predicting the spectral shapes in NSD events.

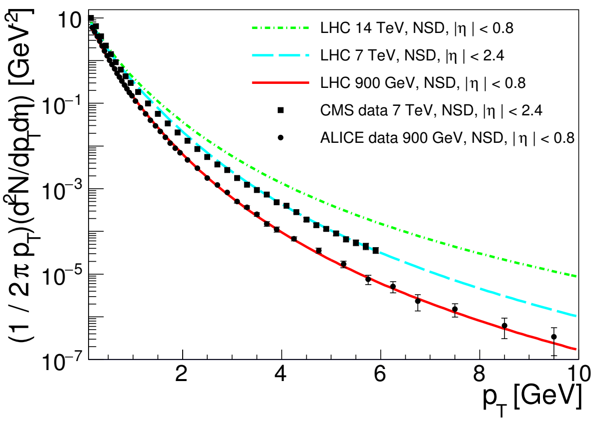

Figure 4: Predictions of the yield of charged particles $(1/2\pi p_T)d^2N/(d\eta dp_T)$ in high energy collisions in NSD events together with data points from the ALICE [12] and CMS [11] experiments.

4. Conclusion

In conclusion, transverse momentum spectra in pp-collisions have been considered using a two component model. Variations of the parameters obtained from the fit have been studied as a function of pseudorapidity η and c.m.s. energy $\sqrt{s}$ in the collision. A universal parameter describing a shape of the spectra in pp-collisions was found to be a preudorapidity of a secondary hadron in the moving proton rest frame. Finally, the observed dependences, together with previous investigations allowed to make predictions on double differential spectra $d^2\sigma/(dp_T^2 d\eta)$ at higher energies, successfully tested on the available experimental data.

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