Phenomenon of Longitudinal Scaling at LHC in a Thermal Model with Flow

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Introduction

The distribution of multi-particle production in the rest frame of one of the colliding nuclei shows scaling in the fragmentation region independent of center-of-mass energy, ($\sqrt{s_{NN}}$). Such scaling is called longitudinal scaling. Experimentally, longitudinal scaling, also termed as limiting fragmentation, is a well studied phenomenon due to its occurrence for various colliding systems *e. g.* $e^+ + e^-$, $p + p(\bar{p})$, d+Au, Au+Au etc. [1]. Benecke *et al.*, Feynman, and Hagedorn proposed that as $\sqrt{s_{NN}} \to \infty$, the multiplicity distribution becomes independent of $\sqrt{s_{NN}}$ [1]. Recently, Cleymans *et al.* [2] studied the phenomenon of extended longitudinal scaling for dN/dy of pions using statistical thermal model. They assume a Gaussian distribution of fireballs centered at zero rapidity in their model and by extrapolating the fit parameters they predict the rapidity distributions of pions at LHC energies. They claim that the property of extended longitudinal scaling is consistent up to highest RHIC energies and it is violated at LHC.

Microscopically, the perturbative QCD (pQCD) can be applied to the system of very high mean free path while statistical-thermal and hydrodynamical models refer to the system with small mean free path. The hypothesis of longitudinal scaling appears as a coincidence in a system described by Landau hydrodynamics, where the particle multiplicity distribution follows a Gaussian (pseudo)rapidity profile. Thus, the use of the dynamical thermal model inherits the microscopic ingredient of a hydrodynamic evolution of the system to look into the phenomenon of longitudinal scaling. Macroscopically, the Lorentz contracted volume $Vm_p/\sqrt{s}$, controls the $dN/d\eta(y)$, the entropy of the system at freeze-out. Hence the final state (pseudo)rapidity distribution is a reflection of the Lorentz contraction factor [1].

In this article, we propose to study the phenomenon of longitudinal scaling for the rapidity distributions of π^+ over a broad energy range starting from Super Proton Synchrotron (SPS) to Large Hadron Collider (LHC) energies. For this purpose we use our statistical-thermal model with the effect of flow. Since, experimental data for the rapidity distributions of π^+ are not available at LHC energies hence it is important to study longitudinal scaling at this energies theoretically. Also our recently proposed dynamical model with flow parameter is used to quantify the longitudinal flow velocity at LHC energies.

Formulation of the Model

The rapidity distributions of mesons can be calculated by using our thermal model as follows [3] :

$$\left(\frac{dN_m}{dy}\right)_{th} = \frac{g_m V \lambda_m}{(2\pi^2)} \int \frac{m_T^2 \; coshy \; dm_T}{\left[exp\left(\frac{m_T \; coshy}{T}\right)\right]}. \tag{1}$$

Here g_m, λ_m are the degeneracy factor and fugacity of the meson m, respectively. The above equation gives the rapidity spectra arising from stationary thermal source which is not able to describe the experimental data completely. Thus, we incorporate the collective flow in above equation in the longitudinal direction as follows [1]:

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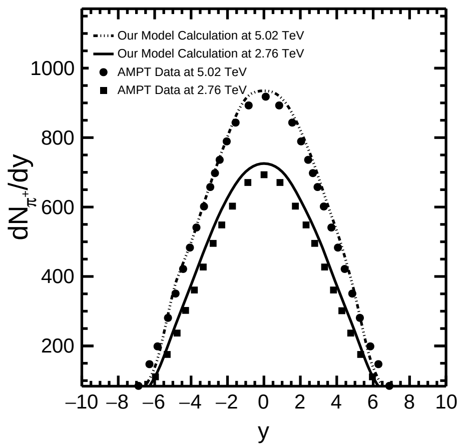

FIG. 1: Rapidity distributions of π^+ at LHC energies. Lines are our model calculations and symbols are the AMPT model results [4].

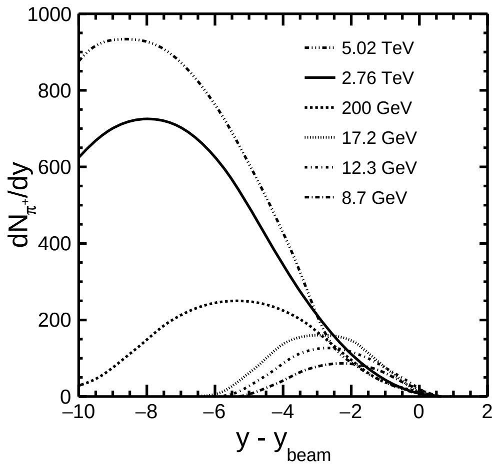

FIG. 2: The rapidity distributions of pions shifted with beam rapidity at various center-of-mass energies.

$$\frac{dN_i}{dy} = \int_{-\eta_{max.}}^{\eta_{max.}} \left(\frac{dN_m}{dy}\right)_{th} (y-\eta)\, d\eta, \qquad (2)$$

where $\left(\frac{dN_m}{dy}\right)_{th}$ can be calculated by using eq. (1). The average longitudinal velocity is given as [1, 3] :

$$\langle \beta_L \rangle = tanh\left(\frac{\eta_{max.}}{2}\right). \qquad (3)$$

Here $\eta_{max.}$ is an important parameter used to determine the upper rapidity limit for the longitudinal flow velocity at particular $\sqrt{s_{NN}}$.

Results and Discussions

In figure 1, we present the rapidity distributions of π^+ at LHC energies. We have compared the results obtained in our thermal model with flow parameter and the AMPT data [4]. We found a very good agreement between these two models. This comparison validates the suitability of our model and the flow parameter used in it. It also predicts the value of longitudinal flow velocity as $\beta_L = 0.99c$ at LHC energies.

Figure 2 shows the rapidity distributions for π^+ shifted with beam rapidity (y_{beam}) ($\equiv y_{beam} = ln(\frac{\sqrt{s_{NN}}}{m_p})$, m_p is the mass of the proton.) at various $\sqrt{s_{NN}}$ from 8.7 GeV to 5.02 TeV. We observe that the phenomenon of longitudinal scaling is violated at upper RHIC and LHC energies.

Conclusions

We calculate the rapidity distributions of π^+ in a thermal model with flow at LHC energies which agrees well with the AMPT data. We shift the rapidity distributions with $(y - y_{beam})$ and find that the longitudinal scaling is violated at upper RHIC and LHC energies. For the details of the work see ref. [1]

References

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