On Scaling of Inclusive Spectra of Charged Particles in Ultra-Relativistic Heavy Ion Collisions

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Abstract

The inclusive spectra of charged particles produced in ultra-relativistic heavy ion collisions at the Relativistic Heavy-Ion Collider (RHIC) are examined for scaling behavior.

1. Introduction

The pseudorapidity distributions of secondary charged particles produced in high energy nucleus-nucleus interactions at relativistic heavy ion collider (RHIC) have been measured recently over a broad range of pseudorapidity $\left(\eta \equiv \frac{1}{2} ln \frac{p+p_l}{p-p_l}\right)$ by the PHOBOS experiment for a range of collision centralities covering a span of a factor of ten in collision energy ($\sqrt{s_{NN}}$) [1]. The measurements show that near mid rapidity the particle density increases approximately logarithmically with energy [2] and is independent of collision centrality whereas in the forward region the limiting fragmentation hypothesis [3] appears to hold [1] and in this region the shape of the distribution depends on centrality. These features constrain the initial conditions of such reactions and thus differentiate different perturbative QCD based phenomenological models (see for example [4-5]).
The overall particle production scenario in nucleus-nucleus collision is expected to follow from that of pp (or $p\bar{p}$) collision. In case of pp collision also, particle density in the central region is found to increase with Centre-of-mass energy ($\sqrt{s}$) [6]. Such a feature of the interaction can be represented well by the Wdowczyk and Wolfendale (WW) scaling (or scale breaking) law [7]. In fact the analysis made by the UA5 collaboration [6] shows that the law works well from the central to fragmentation region in the Centre-of-mass energy range 56 GeV to 900 GeV. It is thus of considerable interest to examine whether the pseudorapidity distributions in nucleus-nucleus collision can be expressed by the WW scaling law.
In the present work we shall study the WW scaling behavior of nucleus-nucleus collisions using the PHOBOS data.

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2. WW scale breaking model

Feynman predicted the so called 'scaling' character of longitudinal momentum distribution of secondary pions produced in hadron collisions at extreme energies [8]. The study of hadron-hadron collision at the collider energies, however, shows clear violation of the scaling law in the central region [6,9] which seemed to be valid at ISR energies [10]. Based on the statistical model, Wdowczyk and Wolfendale (WW) proposed [7] a new scaling (or scale breaking) law for hadron production replacing the Feynman scaling variable x ($x \equiv \frac{p_l}{p_{max}}$) by the new scaling variable $x(s/s_o)^\alpha$ where the parameter α measures the degree of scaling violation and showed that their model can explain the rise of particle density with the Centre-of-mass energy in the central region.
Mathematically the WW scaling law is given by [7]

$$\frac{2E}{\sqrt{s}}\frac{1}{\sigma_{in}}\frac{d^2\sigma}{dxdp_t^2} = k(s,s_o)(s/s_o)^\alpha F(x(s/s_o)^\alpha, p_t) \tag{1}$$

where $k(s,s_o) \equiv k_{\pi^\pm}(s)/k_{\pi^\pm}(s_o)$, k is the inelasticity. For $\alpha = 0$ and $k(s,s_o) = 1$ it coincides with the Feynman scaling law and for $\alpha = .25$ it resembles with Fermi's statistical model. Since the pseudorapidity is the experimentally more easily measured ($\eta \equiv -ln(tan\frac{\theta}{2})$) quantity and the particle distribution in pseudorapidity space is invariant under Lorentz transformation, the collider data are usually given in the form of the secondary particle energy spectra versus pseudorapidity. So to compare with experimental data usually one has to express scaling law (1) in terms of η (or *viz versa*). Assuming $k(s,s_o)(s/s_o)^\alpha = (s/s_o)^\beta$ and transforming Eq. (1) into dependence on the pseudorapidity variable using the relation

$$x = \frac{2p_t}{\sqrt{s}}sinh(\eta) \ . \tag{2}$$

which is valid at high energies, one gets [11]

$$\frac{1}{\sigma_{in}}\frac{d^2\sigma}{d\eta dp_t^2} = (s/s_o)^\beta f_1\left(< p_t > sinh(\eta)\left(\frac{s}{s_o}\right)^{\alpha-1/2}\right) \tag{3}$$

Thus the WW scaling law suggests that $\frac{1}{\sigma_{in}}\frac{d\sigma}{d\eta}(s/s_o)^{-\beta}$ is independent of $\sqrt{s}$ when expressed as a function of $< p_t > sinh(\eta)\left(\frac{s}{s_o}\right)^{\alpha-1/2}$. In the following section we will compare Eq.(3) with the PHOBOS data.

3. Scaling behavior of the PHOBOS inclusive spectra

The PHOBOS experiment measured pseudorapidity distribution of charged particle in the range $-5.3 \leq \eta \geq 5.3$ for Au + Au collision at a verity of collision centralities for three energies $\sqrt{s_{NN}} = 19.6, 130$ and 200 GeV [1]. For $< p_t >$

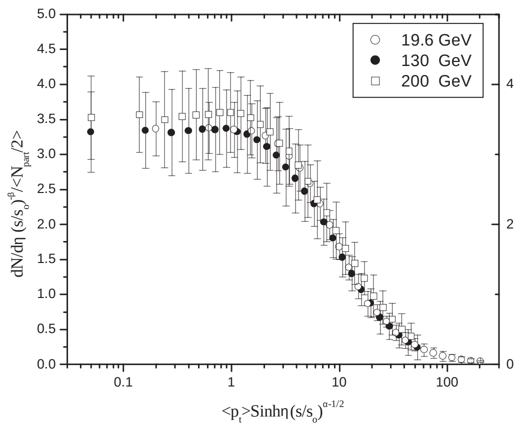

Fig. 1. Variation of $\frac{dN}{d\eta}\frac{2}{N_{part}}\left(\frac{s}{s_o}\right)^{-\beta}$ with $< p_t > sinh(\eta)\left(\frac{s}{s_o}\right)^{\alpha-1/2}$ for the PHOBOS data over the energy range 19.6 -200 GeV when $\alpha = .13$, $\beta = \alpha$.

there is only one measurement in Au-Au collision by the PHENIX experiment [12] with a value $< p_t >= 523$ MeV/c at $\sqrt{s_{NN}} = 130$ GeV which is substantially higher than that in the pp interaction at the same Centre-of-mass energy. Assuming the energy dependence of $< p_t >$ in nucleus-nucleus collision is same of that in the pp collision [13] and ignoring its dependence on η, we have compared the PHOBOS data with the Eq. (3) and found that the WW scaling represents the data well for $\alpha = \beta = .13$. Figure 1 shows the plot of $\frac{dN}{d\eta}\frac{2}{N_{part}}(s/s_o)^{-\beta}$ as a function of $< p_t > sinh(\eta)\left(\frac{s}{s_o}\right)^{\alpha-1/2}$ for the PHOBOS most central data (0-6%) with $\alpha = \beta = .13$ (the measured distributions are folded about midrapidity). However, for $\alpha = .25$ and $\beta = .11$, the values adopted by the UA5 collaboration for representation of p$\bar{p}$ collision data [6], the Eq.(3) does not represent the data well.

4. Discussion

We study the scaling behavior of the pseudorapidity distributions in Au + Au collisions at RHIC. It is observed that the distributions are scaled according to the WW scaling prescription with $\alpha = .13$. Such a value of α is also required to describe pp reaction data in the similar energy range [7].
The present analysis is restricted only to the central region. The fragmentation region is obviously more important in view of cosmic ray air shower studies. But to study the scaling behavior in the fragmentation region knowledge on η dependence of $< p_t >$ is a *priori* required [11] which is not available yet.

Acknowledgment: I am grateful to the LOC of the 28th ICRC for partial assistance towards conference registration fee.

5. References

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