Systematic Study of Identified Particle Spectra with Radial Flow at RHIC and LHC in Tsallis Non-extensive Statistics

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Introduction

The particle spectrum in high energy experiments can reveal the information of particle production mechanism. It is now a common practice to use the Tsallis distribution to fit the invariant transverse momentum spectra of various particle species at high energy and in a very broad range of the transverse momenta. In reference [1], the Tsallis distribution is expanded in Taylor series in power of (q-1), where q is the Tsallis parameter and an analytic result is provided in presence of collective flow. We perform the fitting for the data taken at RHIC and LHC energies for Au+Au $\sqrt{s_{NN}}$=200 GeV, Pb+Pb $\sqrt{s_{NN}}$=2.76 TeV and p+p systems for both energies with this modified function. Then by extracting the fitting parameters like volume, temperature, radial flow and q-parameter, we present a comparative study of these parameters with particle mass.

The Modified Tsallis distribution with flow

The Taylor series expansion of Tsallis distribution is done in the presence of collective flow up to the first order of (q-1) and the modified Tsallis distribution with flow is given by [1],

$$\frac{1}{p_T}\frac{dN}{dp_Tdy} = \frac{gV}{(2\pi)^2}$$

$$\Bigg\{2T[rI_0(s)K_1(r) - sI_1(s)K_0(r)]$$
$$-(q-1)Tr^2I_0(s)[K_0(r)+K_2(r)]$$
$$+4(q-1)\ TrsI_1(s)K_1(r)$$
$$-(q-1)Ts^2K_0(r)[I_0(s)+I_2(s)]$$
$$+\frac{(q-1)}{4}Tr^3I_0(s)[K_3(r)+3K_1(r)]$$
$$-\frac{3(q-1)}{2}Tr^2s[K_2(r)+K_0(r)]I_1(s)$$
$$+\frac{3(q-1)}{2}Ts^2r[I_0(s)+I_2(s)]K_1(r)$$
$$-\frac{(q-1)}{4}Ts^3[I_3(s)+3I_1(s)]K_0(r)\Bigg\} \quad (1)$$

$$s = \frac{\gamma\beta p_T}{T}\ ,\ r = \frac{\gamma m_T}{T}$$

Here $I_n(s)$ and $K_n(r)$ are the modified Bessel functions of the first and second kind. There are four parameters V, T , β , q ; where V is the volume, T is the temperature, β is the radial flow and q is the Tsallis parameter.

Results

We perform the fitting of p_T spectra with different p_T ranges around the mid rapidity. Keeping all four parameters free, we try to fit the spectra with Eq.1 for different kind of particles with different centrality for Pb+Pb and Au+Au collision using TMinuit class available in ROOT library. In this fitting process we have seen that the fitting does not converge for most central collisions but it does for more peripheral collisions. This may be due to ergodicity. As well known, Boltzmann-Gibbs statistics is the correct description of thermostatistically approaching ergodic systems.

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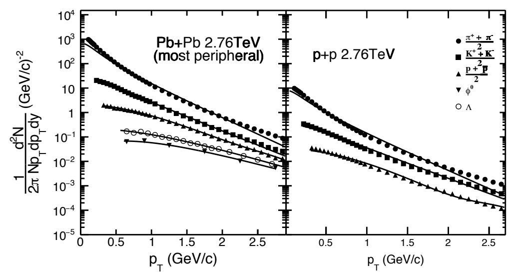

FIG. 1: p_T spectra of different particles using modified Tsallis distributions with radial flow.

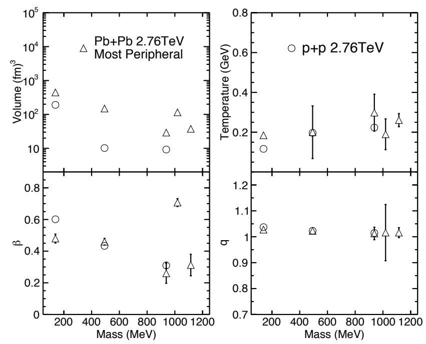

FIG. 2: The Tsallis parameters versus mass for most peripheral Pb+Pb and p+p collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

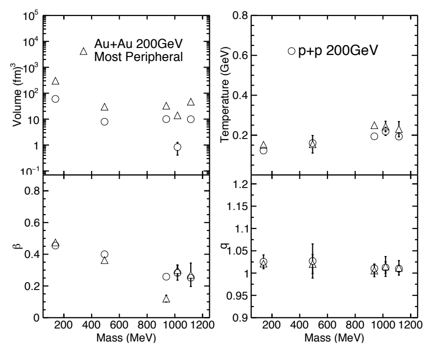

FIG. 3: The Tsallis parameters versus mass for most peripheral Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV.

On the other hand, nontrivial ergodicity breakdown and strong correlations typically drag the system into out-of-equilibrium states where Boltzmann-Gibbs statistics fails. For such systems, the correct approach is to use Tsallis statistics instead. That's why most peripheral Pb+Pb system and Au+Au along with p+p systems are chosen. FIG. 1 demonstrates the fitted spectra for Pb+Pb collisions and p+p collisions at $\sqrt{s_{NN}}$=2.76 TeV collisions as examples. The fitting is good for peripheral Pb+Pb collisions up to p_T~3 GeV and for p+p data up to p_T~2.5 GeV. Similar to FIG. 1 we repeat the same procedure for Au+Au systems.

After fitting the p_T spectra, the parameters of Tsallis distributions are obtained, which are studied as a function of particle mass. It is clearly seen from FIG. 2 and FIG. 3 that the volume parameter decreases from $\pi^{\pm}$ to Λ with increase of mass. Only a slight deviation is observed for ϕ-meson. It physically signifies that heavy particle freezes out early as compared to the lighter particles. It also indicates that the particle production mechanism is similar in p+p and most peripheral heavy ion collisions. Secondly, since the heavier particles are more likely to be produced earlier compared to lighter particles, the freeze-out temperature is observed to increase with increase of mass. Also, it can be seen from FIG. 2 and FIG. 3 that radial flow is high for lighter particles and decreases with increase of mass, which go inline with the observations of mass ordering at RHIC and LHC. Finally we obtain the fourth parameter q, which is almost consistent with mass.

From this systematic study, we conclude that the Tsallis distribution with radial flow can explain the p_T spectra very nicely with additional information regarding the mass dependent radial flow. More details are available in Ref.[3].

References

[1] T. Bhattacharyya et al., arXiv:1507.08434

[2] H. Zheng et al., Adv.High Energy Phys. 2015 (2015) 180491; it contain all data references.

[3] D. Thakur et al. (under preparation).