Description of hadron p_T spectra with modified Tsallis function

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Introduction

Transverse momentum (p_T) distributions of identified hadrons are the most common tools used to study the dynamics of heavy ion collisions and quark gluon plasma (QGP). The Tsallis distribution [1] gives very good description of hadron spectra in $p + p$ collisions [2], interpreting the system in terms of temperature T and a parameter q which measures temperature fluctuation. It has been shown [2] that the functional form of Tsallis distribution with thermodynamic origin is same as the form of QCD inspired Hagedorn distribution [3] in terms of power n (related to q). The high p_T hadrons coming from initial hard scattering decide the value of n and the low p_T hadrons form the bulk of the spectra decide T. The Tsallis distribution does not reproduce the hadron spectra in Au+Au collisions at intermediate p_T. Thus, we used a modified Hagedorn formula to describe meson spectra in Au+Au collisions at $\sqrt{s}$=200 GeV in the work [4] and baryon spectra in the work [5]. While the modified Hagedorn formula gives very good description of hadron p_T distributions, its parameters lack physics interpretation. To explain the hadron spectra in heavy ion collisions in wider p_T range we propose a modified Tsallis function by introducing an additional parameter which accounts for collective flow. We make a systematic study of the parameters of modified Tsallis function for pions, kaons, protons, $\Lambda(1115)$, and Ξ^- as a function of system size at $\sqrt{s_{NN}} = 200$ GeV using measured hadron spectra from PHENIX and STAR experiments.

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Tsallis distribution and flow

Tsallis distribution [1] describes a thermal system in terms of two parameters T and n, given as;

$$E\frac{d^3N}{dp^3} = C_n\left(1 + \frac{E}{nT}\right)^{-n}. \qquad (1)$$

Here C_n is the normalization constant, E is the particle energy, T is the temperature and $q = (1 + n)/n$ is the so-called nonextensivity parameter which measures the temperature fluctuations in the system. This form is same as the QCD inspired Hagedorn function [3, 6].

If there is transverse flow with velocity β then one can replace the energy E by, $E = \gamma(m_T - \vec{\beta}.\vec{p_T})$ where the factor $\gamma = 1/\sqrt{1-\beta^2}$. Guided by this we propose a modification of Tsallis function which includes the transverse flow

$$E\frac{d^3N}{dp^3} = C_n\left(\exp\left(\frac{-\gamma\beta p_T}{nT}\right) + \frac{\gamma m_T}{nT}\right)^{-n}. \qquad (2)$$

The low and high p_T limits of this formula are given by

$$E\frac{d^3N}{dp^3} \simeq \left(1 + \frac{\gamma(m_T - \beta p_T)}{nT}\right)^{-n} \quad \text{for } p_T \to 0$$
$$\simeq \left(\frac{\gamma m_T}{nT}\right)^{-n} \quad \text{for } p_T \to \infty. \qquad (3)$$

Thus at low p_T, it represents a thermalized system with collective flow and at high p_T it becomes a power law which mimics "QCD inspired" quark interchange model [6].

Results and Discussions

We test the formula (Eq. 2) using measured transverse momentum spectra of mesons (pions, kaons) and baryons (protons, Λ, Ξ) measured in $p+p$ and Au+Au collisions at $\sqrt{s_{NN}}$

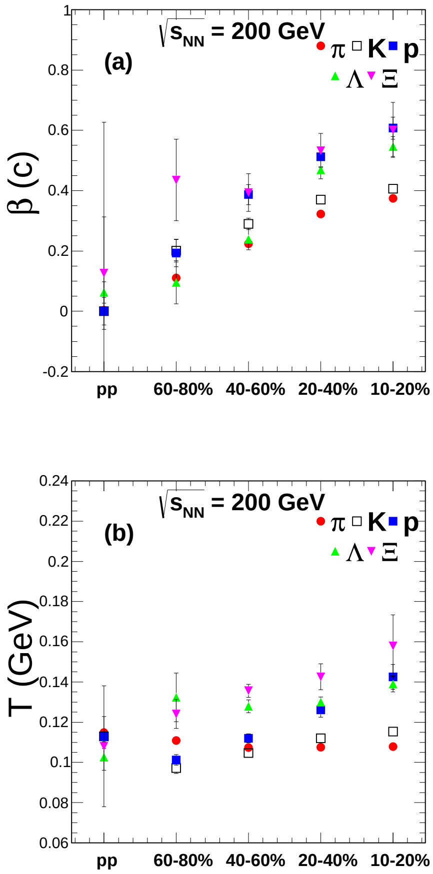

FIG. 1: The parameters, (a) transverse flow velocity β and (b) freeze-out temperature T of Modified Tsallis function as function of system size at $\sqrt{s_{NN}}$ = 200 GeV.

= 200 GeV, which are listed in work [4, 5] along with their references. The particle spectra are studied as a function of system size using p+p collisions and Au+Au collisions of four centralities; 10-20 %, 20-40 %, 40-60 % and 60-80 %.

In our fit procedure first we fit the measured spectra of pions, kaons, protons, Λ and Ξ in $p+p$ collisions using modified Tsallis distribution (Eq. 2) with same temperature to obtain different values of n for different particles. The spectra of different particles in Au+Au collisions for all centralities are fitted to obtain β and T as a function of system size. When going from p+p collisions to Au+Au collisions, the initial hard scattering is assumed to be same and hence the values of n for each particle is kept fixed to values obtained from $p + p$ collisions. The values of β and T as a function of system size is plotted in Fig. 1. We find that β increases with system size and is more for baryons than mesons. The temperature T for baryons increases more rapidly than mesons with increasing centrality in Au+Au system.

Conclusions

In this work we propose a modified Tsallis function which includes a new parameter that accounts for the collective flow of particles. This function describes the hadronic p_T spectra very well both in $p+p$ and Au+Au systems at $\sqrt{s_{NN}}$ = 200 GeV. We observe that flow velocity extracted for all particles increases with centrality in Au+Au collisions. There is a clear separation of flow between mesons and baryons in the most central Au+Au collisions showing a dependence on number of constituent quarks. The behavior of freeze-out temperatures T can also be grouped into mesons and baryons. For baryons the increase of temperature is more rapid as compared to mesons. The baryons in general freezeout earlier than mesons.

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