Rapidity distributions and transverse mass spectra of hadrons in excluded-volume model

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Introduction

The ultimate goal of ultra-relativistic heavy-ion collisions is to study highly excited and dense matter created in the collision and possibly the transition from hot, dense hadron gas to deconfined quark matter called quark-gluon plasma (QGP) [1]. It is very important to understand the dynamics of collisions to predict the formation of QGP. The global properties and dynamics of later stages can be best studied via hadronic observables like hadrons yields, ratios, rapidity distributions and transverse mass spectrum etc [2]. In this paper we study the rapidity distributions and transverse mass spectra of hadrons using the recently proposed equation of state (EOS) for hot, dense Hadron Gas (HG) [3]. We deduce the full rapidity distributions of various particles at fixed centre-of-mass energies and we find that our results are in good fit with the experimental data at mid-rapidity but at other rapidities, the data do not fit well, thus necessity of a flow-term is warranted. Incorporation of the collective flow velocity in our model describes the experimental data quite well. In this analysis, we have chosen the experimental data for the most central case at upper RHIC energies. We assume a similar freeze-out volume for every hadron species in the system which essentially means we consider that every species of particles freezes-out at the same hypersurface.

Formulation of model

Transforming the expression for number density of baryons [3,4] into the terms of rapidity (y) and transverse mass(m_T), $m_T = \sqrt{m^2 + p_T^2}$, the thermal distribution of baryons can be written as follows [5,6]: :

$$\left(\frac{dN}{dy}\right)_{th} = \frac{g_i V \lambda_i}{2\pi^2}\left[(1-R) - \lambda_i \frac{\partial R}{\partial \lambda_i}\right] exp\left(\frac{-m_i\, coshy}{T}\right)\left[m_i^2 T + \frac{2 m_i T^2}{coshy} + \frac{2T^3}{cosh^2 y}\right]. \tag{1}$$

where m_i is the mass of the ith species.V is the freeze-out volume of the system. Eq. 1 gives the rapidity distribution of baryons due to stationary thermal source. In the same fashion, we can get the transverse mass spectra due to stationary thermal source as follows [5] :

$$\frac{dN}{m_T\, dm_T} = \frac{g_i V \lambda_i}{(2\pi)^3}\left[(1-R) - \lambda_i \frac{\partial R}{\partial \lambda_i}\right] m_T\, K_1\Big(\frac{m_T}{T}\Big), \tag{2}$$

where $K_1\Big(\frac{m_T}{T}\Big)$ is a modified Bessel's function. The rapidity spectra after incorporation of flow velocity can be written as follows [5] :

$$\frac{dN}{dy} = \int_{-\eta_{max.}}^{\eta_{max.}} \left(\frac{dN}{dy}\right)_{th} (y-\eta)\, d\eta. \tag{3}$$

where $\eta_{max.}$ is the boost velocity in the longitudinal direction [5].

Similarly, the transverse mass spectra after incorporation of the flow velocity in longitudinal as well as in the transverse direction can be written as [5] :

$$\frac{dN}{m_T dm_T} = \frac{g_i V \lambda_i}{(2\pi)^3}\left[(1-R) - \lambda_i \frac{\partial R}{\partial \lambda_i}\right] \int_0^\infty r\, dr\, K_1\Big(\frac{m_T\, cosh\rho}{T}\Big) I_0\Big(\frac{k_T\, sinh\rho}{T}\Big). \tag{4}$$

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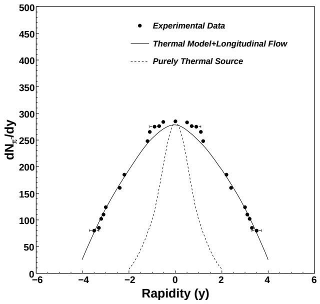

FIG. 1: Rapidity distribution of π^- at $\sqrt{S_{NN}} = 200 GeV$. Dotted Line shows the rapidity distribution due to purely thermal source and solid line shows the result after incorporating longitudinal flow in the thermal model. Points are the experimental data [7].

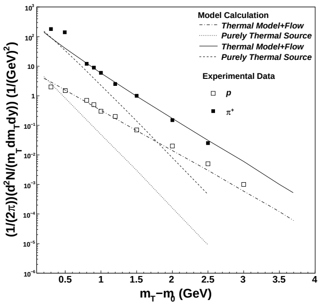

FIG. 2: Transverse mass spectra of π^+ and proton for the most central collisions at $\sqrt{S_{NN}}$= 200 GeV. Dashed and dotted lines are the transverse mass spectra due to purely thermal source of π^+ and proton, respectively. Solid and dash-dotted lines are the results for π^+ and proton, respectively obtained after incorporation of flow in thermal model. Points are the experimental data [8].

Where $K_1\Big(\dfrac{m_T\ cosh\rho}{T}\Big)$ and $I_0\Big(\dfrac{k_T\ sinh\rho}{T}\Big)$ are modified Bessel's functions and ρ is the flow velocity in the transverse direction [5].

Results and Discussions

In FIG. 1, we present the rapidity distributions of π^- for central Au+Au collisions at $\sqrt{S_{NN}} = 200\ GeV$ over full rapidity range. Dotted line shows the distribution of π^- due to stationary thermal source and Solid line shows the rapidity distributions of π^- after incorporation of longitudinal flow in our thermal model. After fitting the experimental data [7], we get the value of $\eta_{max.} = 3.20$ and hence $\beta_L = 0.922$ at $\sqrt{S_{NN}} = 200\ GeV$.

In FIG. 2, we have shown the transverse mass spectra of π^+ and proton for the most central collisions of $Au + Au$ at $\sqrt{S_{NN}}$= 200 GeV. From this figure it is clear that the spectra due to stationary thermal source do not satisfy the experimental data [8] at higher m_T while after incorporation of flow in thermal sorce it is able to describe the experimental data.

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References

[1] C. P. Singh, Phys. Rep. 236, 147 (1993); Int.J. Mod. Phys. A7, 7185 (1992); E. V. Shuryak, Phys. Rept. 61, 71 (1980).
[2] J. Letessier and J. Rafelski, Hadrons and Quark-Gluon Plasma, Cambridge University Press, U.K. (2004).
[3] C. P. Singh, P. K. Srivastava and S. K. Tiwari, Phys. Rev. D 80, 114508 (2009), see also Erratum-Phys. Rev. D 83: 039904 (2011).
[4] M. Mishra and C. P. Singh, Phys. Rev. C 78, 024910 (2008).
[5] E. Schnedermann, J.Sollfrank, U.Heinz, Phys. Rev. C 48, 5:2462-2475 (1993).
[6] P.Braun-Munzinger, J.Stachel, J.P.Wessels, N.Xu., Phys.Lett.B, 43-48, 344 (1995).
[7] I.G. Bearden et al., Phys. Rev. Lett. 94, 162301 (2005).
[8] S.S.Adler et al., Phys. Rev. C 69, 034909 (2004).