Freeze out conditions in Au+Au collision at $\sqrt{s}_{NN} = 200$ GeV

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Introduction

Quantum Chromodynamics predicts a phase transition from normal hadronic matter to a deconfined phase of quarks and gluons (QGP) at very high temperature or very large baryon density. Matter under such extreme conditons can be created in laboratory by colliding heavy ions at relativistic speeds. The space time evolution of QGP is followed by hadronization and freeze-out. The level of equilibrium of the system produced can be tested by analyzing the particle abundances (reflects the chemical composition) or their momentum spectra (reflects their dynamical evolution). Hadron multiplicities and their correlations are the observables which can provide information on the nature, composition and size of the medium from where they are originating. The study of particle (antiparticle) ratios as a function of $\sqrt{s}_{NN}$ give information regarding the matter-antimatter asymmetry, production of new quarks (s, $\bar{s}$, $\bar{u}$ etc.) freeze-out temperature, baryo-chemical potential etc.

After the chemical and kinetic freeze-out the particles reach detectors where their yields are measured. Considering that the particles come out from the fire-ball, the freeze-out temperature and baryo-chemical potential can be obtained by fitting the experimentally measured particle ratios with the statistical thermal model. The measured yield contains particles originating from the fire-ball as well as those coming from weak-decays of particles (feed-down). These secondary particles would not follow the thermal distributions and have to be removed from the total measured yield. In this work, we study the effect of the feed-down contribution on the fitted temperature and baryo-chemical potential.

Thermal Model

According to the statistical model when the system is in thermal equilibrium [1] , the partition function for species i can be given as

$$\ln Z_i = \frac{V g_i}{2\pi^2}\int_0^\infty \pm p^2 dp \ln\left[1 \pm \exp\left(-\frac{E_i-\mu_i}{T}\right)\right] \quad (1)$$

where

$$\mu_i = \mu_b B_i + \mu_{I3} I_3 + \mu_S S_i + \mu_C C_i \quad (2)$$

T is the freeze-out temperature, μ_b is the baryon chemical potential, μ_S is the chemical potential due to strangeness and μ_{I_3} is the chemical potential due to third component of isospin. In equation (1), g_i is the degeneracy $= (2J_i + 1)$ and $E_i = \sqrt{p^2 + m_i^2}$. In equation (2), B, I_3, S and C are the baryon number, total isospin, strangeness and charmness respectively. Partition function contains the contributions from all mesons and baryons. This model is formulated in grand canonical ensemble with some constraints which ensure the conservation of the respective quantum numbers. The constraints are :
$V\sum_i n_i B_i = N_B$, $V\sum_i n_i I_{3i} = I_3^{tot}$ and
$V\sum_i n_i S_i = 0$,
where N_B is the net baryon number and I_3^{tot} is the total isospin of the system.

Now the mumber density of particles are given as :

$$n_i = -\frac{T}{V}\frac{\partial \ln Z}{\partial \mu} = \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2 dp}{\exp\left(\frac{E_i-\mu_i}{T}\right) \pm 1} \quad (3)$$

In equation (3) + is for fermions and - is for bosons. Looking at the constraints it is clear that equation (3) has only two free parameter

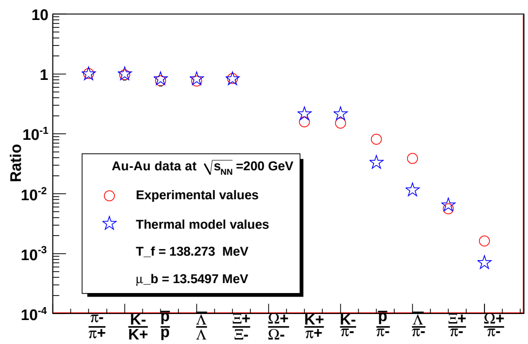

FIG. 1: Comparsion of the hadronic ratios from the experimental yield and from Thermal model.

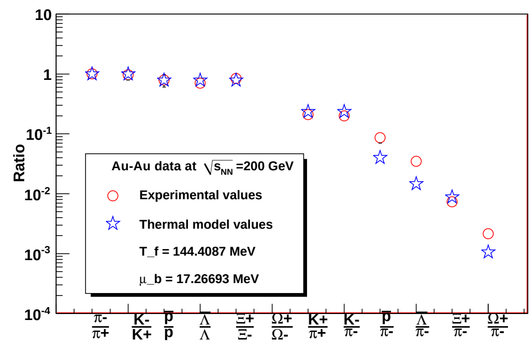

FIG. 2: Comparsion of the hadronic ratios from the experimental yield and from Thermal model after the feed-down corrections.

T and μ_b, which will be obtained from the fitting of experimental data.

Results

For our study we take the data from STAR collaboration for Au+Au system at $\sqrt{s}_{NN}$ = 200 GeV. The yields from the top 5 % most central collisions are used. The particles which are chosen for this study are proton (P), kaon (K), pion (π) [2], lambda (Λ), cascade (Ξ), omega (Ω) [3] and their antiparticles. These ratios are then fitted by equation (3) to obtain the values of T_f (freeze-out temperature) and μ_b. We have put μ_S and μ_{I_3} as zero.

The comparison of the experimental ratios and thermal model estimates are shown in Fig 1. The open circles are the ratios obtained from the experimental yields and the open stars are the points corresponding to the thermal model. The fitted values of T_f and μ_b are 138.27 MeV and 13.55 MeV respectively. From Fig.1 it is seen that the thermal model reproduces the ratios of antiparticle by particle better than the ratio of different type of particles. One of the reasons for this is the experimental yields of P, Λ and π also contain feed-down contributions. The main weak deacys which contribute to feed down are listed below:

$\Lambda \rightarrow$ p + $\pi-$ (63.9%)
$\Xi- \rightarrow \Lambda + \pi-$ (99.887%)
$\Omega- \rightarrow \Lambda + K^-$ (67.8%)
$\Omega- \rightarrow \Xi- + \pi$ (8.6%)
$\Omega- \rightarrow \Xi^0 + \pi^-$ (23.0%)
$K_S^0 \rightarrow \pi^+ + \pi^-$ (69.20%)

We find that the approximate feed-down contribution to proton is 22%, π is 24% and to Λ is 30%. After that we correct the ratios after removing the feed-down contributions and then do the fitting again. The corresponding plot is shown in Fig 2. The new values of T_f and μ_b are 144.41 MeV and 17.27 MeV respectively which is a substantial change.

Conclusions

In this work, we study the effect of the feed-down contribution on the fitted temperature and baryo-chemical potential obtained from thermal model fit to the particle ratios. We find that there is large feed-down contribution to protons, π and Λ. The effect of feeddown on the freeze out parameters is noticeable.

References

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