Chemical freeze-out parameters from Au+Au collisions at $\sqrt{s_{NN}}$ = 7.7, 11.5 and 39 GeV

Sabita Das (for the STAR Collaboration)
Institute of physics, Bhubaneswar - 751005, INDIA

Introduction

The main goal of ultra-relativistic heavy-ion collisions is to study the properties of strongly interacting matter at high energy density. If we assume the matter formed in heavy-ion collision is thermalised, the yields or ratios of produced particles can be described within the framework of statistical thermodynamics. This statistical (thermal) model use the experimental particle ratios as input and calculates the corresponding chemical freeze-out parameters. In this work we have used grand-canonical ensemble (GCE) approach of statistical THERMUS model [1] and the related parameters, for fitting the experimental RHIC data at $\sqrt{s_{NN}}$= 7.7 GeV, 11.5 GeV and 39 GeV to compare the model predicted ratios with the measured ratios. We have studied the centrality dependence of the extracted chemical freeze-out parameters [2].

Statistical Thermal Model

The calculations can be carried out using three ensembles such as grand-canonical, canonical and strangeness-canonical. A GCE, in which the quantum numbers are conserved on average is used to describe large systems such as Au + Au collisions due to large number of particle production. We have used GCE for our analysis where the logarithm of the partition function of species i is defined as

$$\ln Z_i = \frac{V g_i}{2\pi^2} \int p^2 dp \ln(1 \pm e^{-\beta(E_i-\mu_i)})^{\pm 1} \quad (1)$$

where V is fireball volume, p is momentum, g_i and μ_i are respectively the degeneracy and chemical potential of hadron species i, $\beta \equiv \frac{1}{T}$, T is chemical freeze-out temperature, $E_i = \sqrt{p^2 + m_i^2}$, m_i is the particle mass. The plus sign is for fermions and the minus sign is for bosons. The chemical pontential for particle species i is given by
$\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$
where B_i, S_i and Q_i are the baryon number, strangeness and charge, respectively, of species i and μ_B , μ_S and μ_Q are the corresponding chemical potentials. From Eq. (1) the particle density is calculated as

$$n_i = \frac{T m_i^2 g_i}{2\pi^2} \sum_{k=1}^{\infty} \frac{(\pm 1)^{k+1}}{k} \exp(\beta k \mu_i) K_2\left(\frac{k m_i}{T}\right) \quad (2)$$

where K_2 is the second order Bessel function. The plus sign is for bosons and the minus sign is for fermions. An additional factor $\gamma_s^{|S_i|}$ is used to account for the lack strangeness chemical equilibration observed in heavy-ion collisions, where $\gamma_s$is strangeness saturation factor and $|S_i|$ is the number of strange and anti-strange quarks in species i. So, the particle density is modified in GCE by,
$n_i \rightarrow \gamma_s^{|S_i|} n_i$

Analysis details

A GCE is used with quantum statistics and resonance widths are included for all particles upto mass 2.6 GeV. The measured particle ratios used for calculation include pion, kaon, proton and the corresponding anti-particles at $\sqrt{s_{NN}}$= 7.7 GeV, 11.5 GeV and 39 GeV and the errors are the quadratic sum of statistical and systematic uncertainties [4]. The final yields or ratios calculated in model include both a primordial and a decay contributions. The parameters used in GCE for fitting are T, μ_B, μ_S, μ_Q, γ_S and R. The errors on freeze-out parameters are obtained from Thermus model using TMinuit class. Here the fire ball radius is extracted by fitting the particle yields and the extracted radius value is fixed while obtaining the other chemical freeze-out

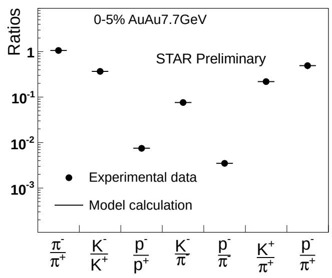

FIG. 1: Comparison of experimental particle ratios from Au+Au colisions at $\sqrt{s_{NN}}$ = 7.7 GeV with the model predicted ratios.

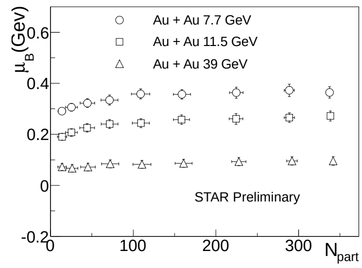

FIG. 3: Variation of μ_B with system size for Au+Au colisions at $\sqrt{s_{NN}}$ = 7.7 GeV, 11.5 GeV and 39 GeV.

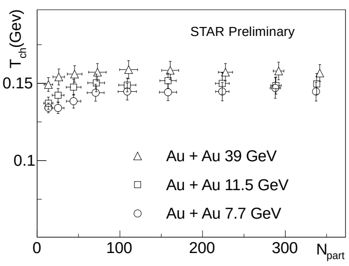

FIG. 2: Variation of temperature with system size for Au+Au colisions at $\sqrt{s_{NN}}$ = 7.7 GeV, 11.5 GeV and 39 GeV.

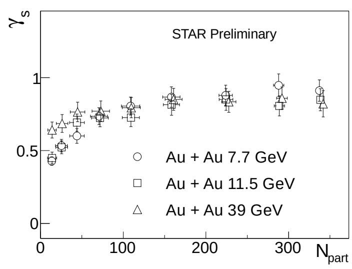

FIG. 4: Variation of γ_S with system size for Au+Au colisions at $\sqrt{s_{NN}}$ = 7.7 GeV, 11.5 GeV and 39 GeV.

parameters using particle ratios.

Results

Figure 1 shows a representative comparison plot of model predicted and experimentaly measured particle ratios in central Au+Au collision at $\sqrt{s_{NN}}$ = 7.7 GeV. Model results are in good agreement with the experiment data for all centrality bins and energies 7.7 GeV, 11.5 GeV and 39 GeV. Figures 2 and 3 , respectively, show the temperature and baryon chemical potential variation with system size in all the energies studied.As the collision energy increases, the temperature increases and the baryon chemical potential decreases. Strangeness chemical potential seems to decrease with the increase of collision energy whereas charge chemical potential is equal to zero for all the energies studied (not shown in figure). Figure 4 shows the strangeness saturation factor variation with system size and it increases from peripheral to central and saturates around 0.8 for all the energies studied. Inclusion of other strange particles like Λ, Ξ and Ω could improve the precision in determining the γ_S [3]. Finally the fireball radius having values ranging between 2 - 7 fm increases from peripheral to central in all energies studies and it also increases as collision energy increases (not shown in figure). The details of the analysis will be discussed.

References

[1] S. Wheaton*et al.*, hep-ph/0407174.
[2] J. Cleymans*et al.*, PRC **71**, 054901 (2005).
[3] J. Takahashi*et al.* (STAR Collaboration), arXiv:nucl-ex/0812.4157
[4] L. Kumar (for the STAR Collaboration), arXiv:nucl-ex/1106.6071.