Chemical Freeze out condition for central Heavy-ion Collisions at AGS, SPS, RHIC and LHC Energies

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Introduction

As a result of ultrarelativistic collision between two heavy ions, a fireball is expected to form that rapidly thermalizes as it expands and hence cools. As the inter-particle separation increases the particles cease to interact. The surface of last scattering is the freeze-out surface. It can be of two types: chemical freeze-out (CFO) where inelastic collisions cease and kinetic freeze-out where elastic collisions cease. But in general freeze-out can be a more complicated process in which different types of particles and reactions switch-off at different times giving rise to a series of freeze-out surfaces. Here we will discuss two CFO schemes: 1CFO, in which all hadrons freeze-out together and 2CFO[1], in which all strange and those with hidden strangeness freeze-out at the same surface and the other non strange hadrons freeze-out at a separate surface.

Model

For the hadron resonance gas (HRG) which is a good low temperature (T) approximation to QCD thermodynamics, at a given $\sqrt{s_{NN}}$, the grand canonical partition function is the summed contribution over single particle partition function (Z_h) for all hadrons whose partial derivative w.r.t μ_h gives the primordial yield of the h^{th} hadron N_h^P given by

$$N_h^P = \frac{V_h T_h}{\pi^2} g_h m_h^2 \sum_{l=1}^{\infty} (-a)^{l+1} l^{-1} K_2(l m_h/T_h) \times \exp(l(B_h\mu_{B_h} + Q_h\mu_{Q_h} + S_h\mu_{s_h})/T_h), \quad (1)$$

where K_2 is the Bessel function of second kind and $a = -1$ for bosons and 1 for fermions, m_h and g_h are mass and deganeracy factor and B_h, Q_h, S_h are the conserved charges of the h^{th} hadron. T_h, μ_h, V_h are the thermal parameters at the time of chemical freeze out. In 1CFO, $T_h(\sqrt{s_{NN}}) = T(\sqrt{s_{NN}})$ for all hadrons as there is single freeze-out surface. In 2CFO there are two surfaces. $T_h = T_{ns}$ for all non strange hadrons while $T_h = T_s$ for all strange and hidden strangeness hadrons. So the particle ratios in the asymptotic limit $m/T >> 1$ is

$$N_i/N_j = \frac{g_i V_i}{g_j V_j}\left(\frac{T_i m_i}{T_j m_j}\right)^{3/2} \exp(m_j/T_j - m_i/T_i) \exp(B_i\mu_{B_i}/T_i - B_j\mu_{B_j}/T_j) \times \exp(Q_i\mu_{Q_i}/T_i - Q_j\mu_{Q_j}/T_j) \exp(S_i\mu_{s_i}/T_i - S_j\mu_{s_j}/T_j). \quad (2)$$

The total multiplicity of the h^{th} hadron N_h^t is the sum of primordial yield as well as that feed-down from the heavier resonances that decay to it.

We have analysed the particle yields as well as ratios in grand canonical ensemble (GCE) and strange canonical ensemble (SCE) for 1CFO and 2CFO schemes and compared between them using the THERMUS[2] code at AGS, SPS, STAR and LHC energies. We have fixed μ_Q and μ_s by the constraints:
(1) Net B/Net Q = 2.5 and (2) Net S = 0. The usual set of free parameters are T_{ch}, μ_B, the overall normalization volume and γ_s called the strangeness under-saturation factor which

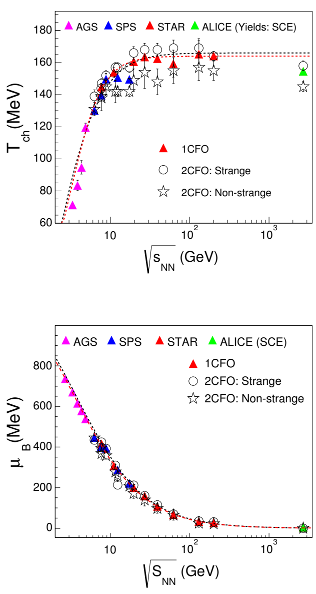

FIG. 1: T_{ch} and μ_B versus center of mass energy in different CFO schemes.

accounts for any out of equilibrium production of strangeness.

Results and Discussions

The extracted thermal parameters from the yields of the particles $\pi^+, \pi^-, k^+, k^-, p, \overline{p}, \Lambda, \overline{\Lambda}, \Xi$ and $\overline{\Xi}$ are found to be insensitive to the choice of ensemble (GCE or SCE) and to the two fitting procedures: one in which γ_s is free with fixed μ_s and the other in which $\gamma_s = 1$ in addition to fixing μ_s by constraint(2). Fig.1 represents the thermal parameters extracted in 1CFO and 2CFO schemes in SCE with $\gamma_s = 1$ and μ_Q solved from constraint(1). At all the energies studied, we found that the temperature T_{ns} is consistently lower than T_s which can be interpreted as an early freeze out for the strange hadrons. The 1CFO thermal parameters lies intermediate to the corresponding 2CFO values for the non strange and strange CFO surfaces with substantial improvement in $\chi^2/N_{\mathbf{df}}$ for 2CFO as compared to 1CFO. For the particle ratios

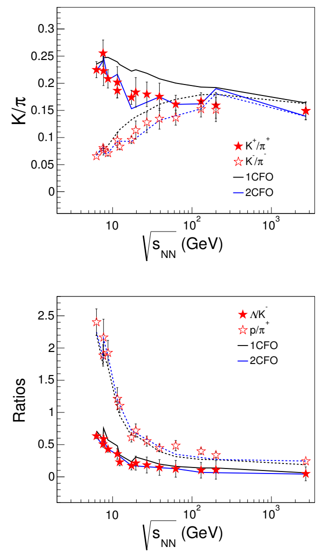

FIG. 2: Different particle ratios versus center of mass energy. Experimental data compared with results from various CFO schemes.

as can be seen from Eq(2), the thermal factor co-efficient $(V_i T_i^{3/2})/(V_j T_j^{3/2})$ do not cancel off for unlike flavor particles while in 1CFO this factor does not arise at all. So the particle ratios of unlike flavor $(K/\pi, \Lambda/p)$ discriminate between the different CFO schemes while those with same flavor $(p/\pi, \Lambda/K)$ appear similar in both the schemes as shown in Fig.2 with 2CFO describing the ratios well.

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