Freeze-out Conditions in proton-proton Collisions From SPS to LHC Energies

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Introduction

Chemical freeze-out dynamics of the particles produced in high-energy heavy-ion collisions (HICs) can be studied from the particle multiplicities. At chemical freeze-out, inelastic collision cease and the particle yields get fixed. The statistical model of non-interacting gas of hadrons and resonances at some volume V, temperature T and conserved charge chemical potentials μ_B, μ_S and μ_Q corresponding to three conserved charges namely baryon number B, strangeness S and electric charge Q have been remarkably successful in providing a good qualitative description of the mean hadron yields in heavy-ion collisions[1] as well as in p+p collisions[2].

Here we will present the application of thermal model to p+p collisions at $\sqrt{s_{NN}}$ =17.3 (SPS), 200 (RHIC), and to new data from LHC at 900 and 7000 GeV. We will study the systematics of the extracted thermal parameters by employing different ensembles and freeze-out schemes. We have analysed the data in three different ensembles - Grand Canonical Ensemble (GCE), Strangeness Canonical Ensemble (SCE) and Canonical Ensemble (CE). Two different freeze-out schemes have also been studied. One is single freeze-out (1CFO) where all hadrons freeze-out together. The other is double freeze-out (2CFO) where strange and non-strange hadrons freeze-out separately[3]. A comparison with the corresponding results from heavy ion collisions have also been done.

Thermal Model

In 1CFO scheme, the particle multiplicity within GCE can be written as:

$$N_i = \frac{g_i V}{2\pi^2} \sum_{k=1}^{\infty} (\pm 1)^{k+1} \frac{m_i T^2}{k} K_2\left(\frac{k m_i}{T}\right) \times \exp(\beta k \mu_i) \gamma_S^{k|S_i|} \quad (1)$$

Where V is the fireball volume, g_i is the degeneracy, m_i is the particle mass, K_2 is the second order Bessel function. $\beta = \frac{1}{T}$, where T is the chemical freeze-out temperature. The hadron chemical potential μ_i can be written as

$$\mu_i = B_i \mu_B + S_i \mu_S + Q \mu_Q \quad (2)$$

It is a standard practice to extract μ_S and μ_Q from the following constraints: (1) Net S = 0, (2) Net B/Net Q = 1. The remaining parameters (V, T, μ_B) are extracted from fits to hadron yields. The total hadron yield N_i^{tot} of the *ith* hadron include primordial yields N_i^{prim} and secondary yields, which are the feed-down from decays of heavier resonances and can be written as :

$$N_i^{tot} = N_i^{prim} + \sum_{\text{states}_j} N_j^{prim} \text{B.R.}(j \to i), \quad (3)$$

where B.R. is the branching ratio of j to i through all possible channels. We have used the publicly available THERMUS[4] code for 1CFO analysis.

Results

The upper left plot of Fig. 1 shows chemical freeze-out temperature T_{ch} as a function

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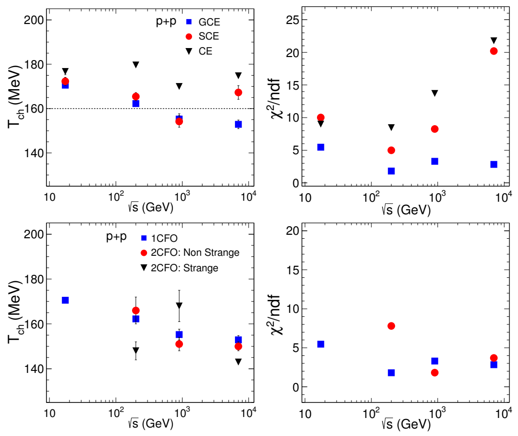

FIG. 1: T_{ch} and χ^2/ndf vs $\sqrt{s}$ extracted from a statistical fit using particle yields in different ensembles(upper panel) and compared between 1CFO and 2CFO schemes in GCE(lower panel).

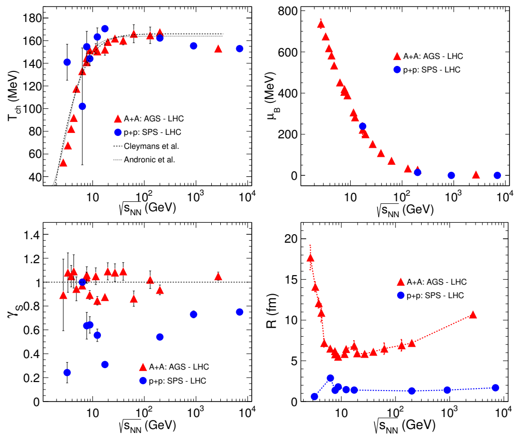

FIG. 2: A compilation of T_{ch}(top left), μ_B(top right), γ_S(bottom left), R(bottom right) vs $\sqrt{s_{NN}}$ in p+p collision and compared with A+A collisions in GCE.

of center of mass energy $\sqrt{s}$ obtained from 3 different ensembles in 1CFO approach. The freeze-out T_{ch} decreases monotonically from SPS to LHC energies. Also we have observed from the χ^2/ndf(upper right plot) of the fits that, GCE describes data best at all the energies with a comparatively lower value of χ^2/ndf.

The comparison between temperatures of 2CFO and 1CFO scheme as a function of $\sqrt{s}$ is shown in the lower left plot of Fig. 1. The 1CFO temperature almost agree with that of non-strange 2CFO temperature. Unlike A+A collisions where 2CFO scheme describes the data better than 1CFO, in p+p the improvement is not significant as the χ^2/ndf(lower right plot) is similar in both 1CFO and 2CFO.

Finally, we have also compared the freeze-out parameters extracted in heavy-ion collision with that of p+p in 1CFO as shown in Fig. 2. At lower energies the p+p freeze-out T_{ch} is higher than A+A, whereas at higher energies it is in agreement with HICs. μ_B observed in p+p is similar to that of A+A. Whereas the radius is 5-10 times smaller compared to HICs. Also in contrast to HICs, the value of γ_S is consistently lower in p+p. Which indicates a significant strangeness suppression in p+p as compared to heavy ion even at LHC energies.

Summary

The chemical freeze-out conditions for p+p collisions have been studied at $\sqrt{s_{NN}} = 17.3$, 200, 900, 7000 GeV in three different ensembles and two freeze-out schemes. We have also compared the results with that of A+A collisions. The main difference arises in the freeze-out of strange hadrons in p+p collisions with a lower value of strangeness suppression factor as compared to HICs. Which could be due to the expected shorter lifetime of the fireball in p+p collisions.

Acknowledgments

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