Chemical Freeze-out from Hadron Resonance Gas

Sumana Bhattacharyya

Bose Institute,CAPSS
Saltlake,Sector-V
Kolkata 700091

CBM-India Meeting, 2018

Collaborators: *Deeptak Biswas, Sanjay K. Ghosh, Rajarshi Ray, Pracheta Singha*
(manuscript under preparation)

February 15, 2018

Heavy Ion Collisions : :

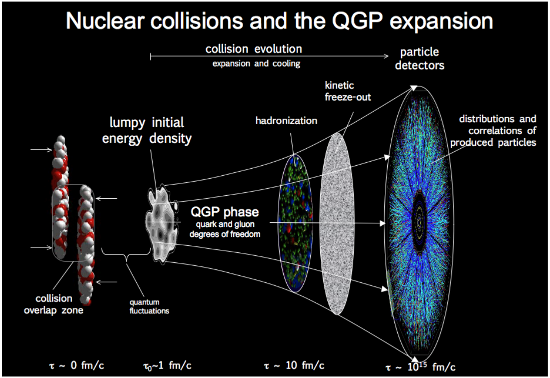


Figure: Evolution of fireball

Fundamental issues: :

- Fireball produced in high energy nucleus-nucleus collision is in thermal equilbrium or not.

- Produced fireball achieved chemical equilibrium or not.

- Quark Gluon state is formed or not.

Equilibrium Physics: :

Chemical equilibrium means the equilibriation of conserved charges. For strong interactions Quantum Chromodynamics (QCD) ensures the conservation of baryon number (B), electric charge (Q), and strangeness (S).

Thus, the equilibrium thermodynamic state of QCD matter is completely determined by temperature (T) and the three chemical potentials μ_B, μ_Q, μ_S and corresponding to B ,Q and S, respectively.

Hadron Resonance Gas Model : :

The grand canonical partition function ($\mathcal{Z}$) for ideal Hadron Resonance Gas (HRG) model can be written as,

$$\boxed{ln\mathcal{Z}^{id} = \sum_i ln\mathcal{Z}_i^{id}}$$

Where, the sum is over all hadrons and their resonances.

Hadron Resonance Gas Model : :

The grand canonical partition function ($\mathcal{Z}$) for ideal Hadron Resonance Gas (HRG) model can be written as,

$$\boxed{ln\mathcal{Z}^{id} = \sum_i ln\mathcal{Z}_i^{id}}$$

Where, the sum is over all hadrons and their resonances.

$$\boxed{ln\mathcal{Z}^{id} = \pm \sum_i \frac{Vg_i}{2\pi^2} \int_0^\infty p^2 \, dp \, ln\Big[1 \pm exp\Big\{ - \frac{(\mathcal{E}_i - \mu_i)}{T} \Big\}\Big]}$$

Thermodynmic observables : :

From partition fuction, we can derive different thermodynamical quantities.

Number density can be calculated according to :

$$n^{id} = \frac{T}{V}\sum_i \Big(\frac{\partial ln\mathcal{Z}_i}{\partial \mu_i}\Big)_{V,T} = \sum_i \frac{g_i}{2\pi^2}\int_0^\infty \frac{p^2\ dp}{[exp\{(\mathcal{E}_i - \mu_i)/T\} \pm 1]}$$

Thermodynamic observables : :

At vanishing chemical potential, various thermodynamic observables like pressure, energy density, number density and even different susceptibilities of conserved charges are in good agreement with lattice results in low temperature phase.

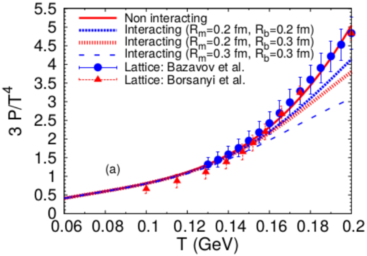


Figure: Pressure with temperature[1]

[1] Phys.Rev.C 90, 034909 (2014);

Freeze-out : :

- **Chemical freeze-out (CFO)** surface is determined by analysing the measured hadron yields [2-3].

[2] Physics Letters B, vol. 365, pp. 1-6, 1996 ; [3] Physical Review C, vol. 48, pp. 2462-2475, 1993;

Freeze-out : :

• **Chemical freeze-out (CFO)** surface is determined by analysing the measured hadron yields [2-3].

• **Kinetic freeze-out (KFO)** surface can be determined by studying the data of transverse momentum (p_T) distribution of produced particles [4].

[2] Physics Letters B, vol. 365, pp. 1-6, 1996 ; [3] Physical Review C, vol. 48, pp. 2462-2475, 1993; [4] Physics Letters B, vol. 503, no. 1-2, pp. 58-64, 2001;

Freeze-out parameters : :

Systematics of Chemical Freeze-out are thermodynamic parameters : T, μ_B, μ_Q, μ_S and normalization factor volume V.

Freeze-out parameters : :

Systematics of Chemical Freeze-out are thermodynamic parameters : T, μ_B, μ_Q, μ_S and normalization factor volume V.

Hadron rapidity density can be written as :

$$\langle \frac{dN}{dy} \rangle = \frac{dV}{dy} n(T, \mu_Q, \mu_B, \mu_S)$$

Freeze-out parameters : :

Systematics of Chemical Freeze-out are thermodynamic parameters : T, μ_B, μ_Q, μ_S and normalization factor volume V.

Hadron rapidity density can be written as :

$$\langle\frac{dN}{dy}\rangle = \frac{dV}{dy}n(T, \mu_Q, \mu_B, \mu_S)$$

Previous literatures incorporated Particle ratios as those erase out many of the systematics including volume.

Common approach to determine CFO parameters : :

• The traditional picture of Chemical Freeze-out is where all the hadrons chemically freeze-out together and to extract the parameters of the model one perform fits of experimental data with model calculations.

Common approach to determine CFO parameters : :

- The traditional picture of Chemical Freeze-out is where all the hadrons chemically freeze-out together and to extract the parameters of the model one perform fits of experimental data with model calculations.

- The equation to fit the experimental data with thermal yield is,

$$\frac{n_i(T, \mu_B, \mu_Q, \mu_S)}{n_j(T, \mu_B, \mu_Q, \mu_S)} = \frac{\frac{dN_i}{dY}}{\frac{dN_j}{dY}}$$

Common approach to χ^2 Method : :

Out of the three chemical potentials it is a common approach to fix μ_Q and μ_S from the following constraints :

$$\frac{\sum_i n_i B_i}{\sum_i n_i Q_i} = 2.5 \qquad \text{and} \qquad \sum_i n_i S_i = 0$$

With this two constraint equations the problem is reduced to a two dimensional problem.

The best fit is obtained by minimizing the distribution of χ^2.

$$\chi^2 = \sum_i \frac{(R_i^{exp} - R_i^{therm})^2}{\sigma_i^2}$$

Our approach to χ^2 Method : :

Here we are trying to give a more general approach to fit the thermal model using χ^2 method.
Four equations we have used from the definition of χ^2 ,

$$\frac{d\chi^2}{dT} = 0,$$

$$\frac{d\chi^2}{d\mu_k} = 0, \quad \text{where}, k = B, Q, S$$

We did not use any constraint relations to reproduce the ratios for $\pi^+, \pi^-, k^+, k^-, p, \bar{p},$

Few important informations : :

- We have used the mid rapidity data of most central collision of Au-Au nuclei for $\sqrt{S}$ of AGS,SPS,RHIC,LHC.

- σ is the uncertainity and to derive σ we have quadratically add statistical and systematic errors of measured yields.

- Error of ratios has been calculated from error propagation method.

Result with four parameters : :

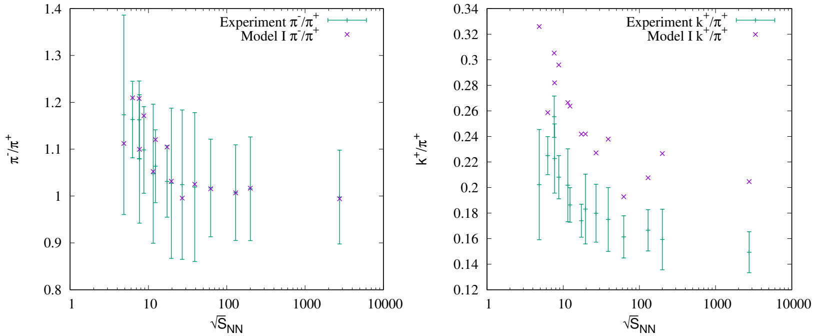


Figure: $\pi^-/\pi+$, k^+/π^+ ratios $\sqrt{S}$.

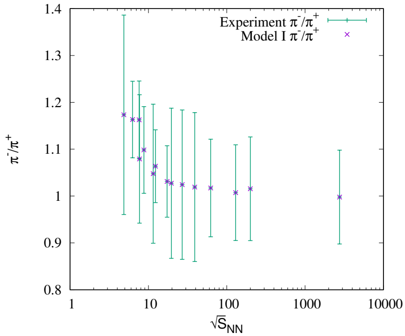
Our approach to χ^2 Method : :

However, an additional fifth parameter, γ_s, called the "*strangeness suppression factor*", which accounts for any out of equilibrium production of strangeness, is often used in thermal model to fit the model predicted value with experimental data.

Thus the fifth equation we have used is,

$$\frac{d\chi^2}{d\gamma_s} = 0,$$

Result with five parameters : :



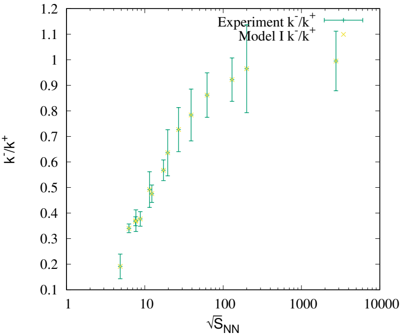


Figure: π^-/π^+ , k^-/k^+ with $\sqrt{S}$.

Result with five parameters : :

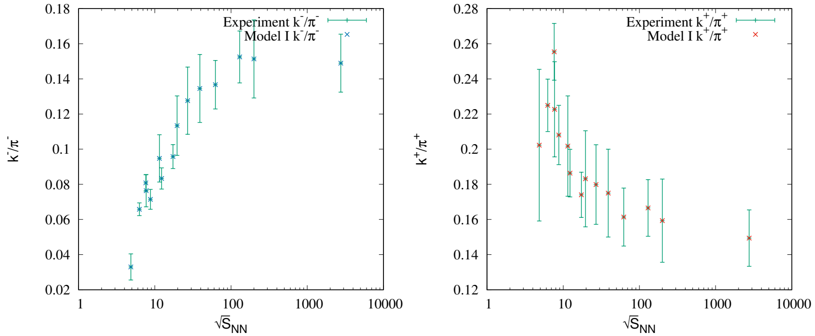


Figure: k^-/π^- , k^+/π^+ with $\sqrt{S}$.

Result with five parameters : :

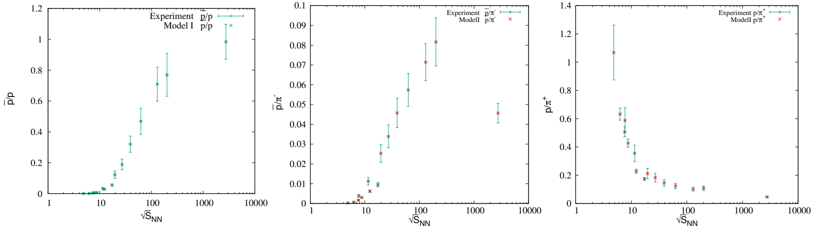


Figure: $\bar{p}/p$, $\bar{p}/\pi^-$ and p/π^+ with $\sqrt{S}$.

Result with five parameters : :

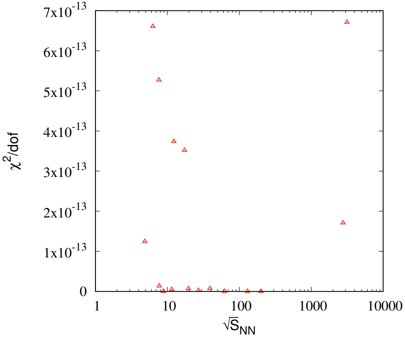


Figure: χ^2/dof with $\sqrt{S}$.

$\sqrt{S}$(GeV)	χ^2/d.o.f
2760	1.7072986125268642E-013
200	1.0911110578905538E-027
130	2.9664564135487808E-023
62.40	2.0582102160215674E-026
39.00	7.1230002851558197E-015
27.00	2.4408937135758199E-015
19.60	6.4712523756302391E-015
11.50	4.6609360702402084E-015
7.70	1.3350001080077253E-014
17.30	3.5181112286718561E-013
12.30	3.7392865786223114E-013
8.76	2.4488899358892493E-026
7.62	5.2719690341529076E-013
6.27	6.6074160291445808E-013
4.85	1.2450338683919042E-013

Prediction of other ratios : :

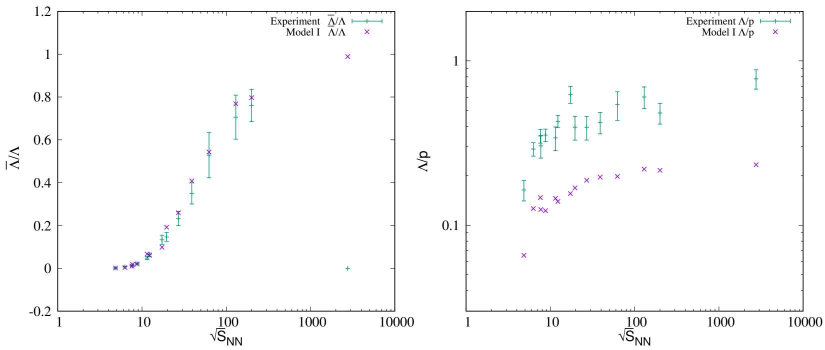


Figure: $\bar{\Lambda}/\Lambda$, Λ/p with $\sqrt{S}$.

Prediction of other ratios : :

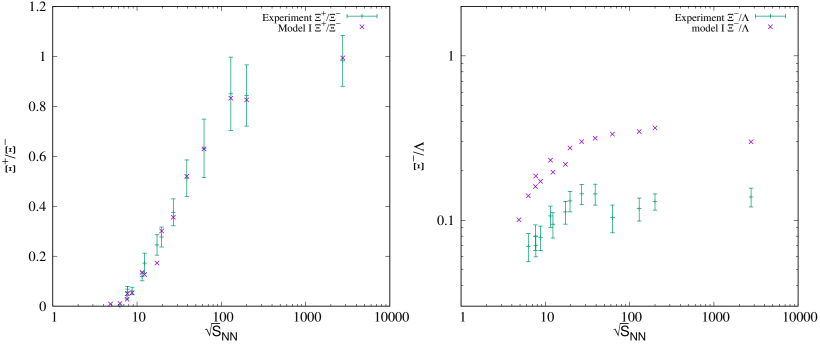


Figure: Ξ^+/Ξ^- , Ξ^-/Λ with $\sqrt{S}$.

Variation of Freeze-out Parameters : :

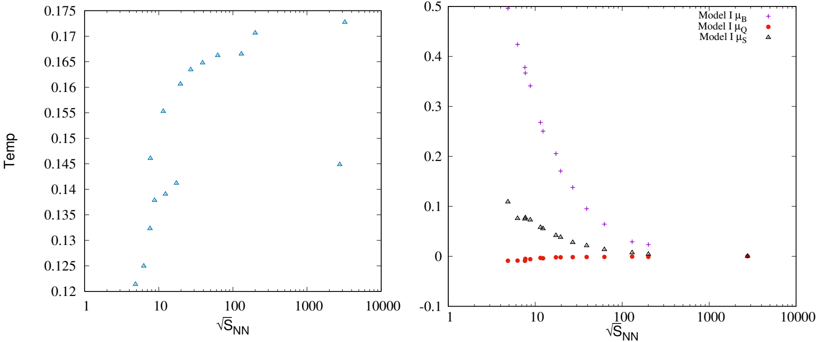


Figure: Variation of freeze-out parameters.

Discussion

- Our model does not show any biasness towards the no. of ratios used for χ^2 minimization.

Discussion

- Our model does not show any biasness towards the no. of ratios used for χ^2 minimization.

- We have solved a multidimensional problem without using any constraint relations.

Discussion

• Our model does not show any biasness towards the no. of ratios used for χ^2 minimization.

• We have solved a multidimensional problem without using any constraint relations.

• The predicted ratios of higher mass particle show deviation for cross ratios where as they are in good agreement with experimental data for particle-antiparticle ratios.


THANK
YOU