Extracting chemical freeze out parameters in Heavy Ion Collision

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THE MYRIAD COLORFUL WAYS OF UNDERSTANDING EXTREME QCD MATTER

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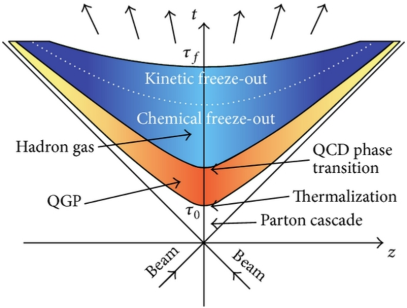
Studying a new state of matter



- RHIC experiments→free quarks, gluons
- Frequent collision → Thermalization
- Rapid expansion and T decreases
- For $T < T_c$ → Hadronization
- Energetic hadrons→Inelastic collision
- Further expansion→No inelastic collision
- Chemical composition becomes fixed
- Chemical Freezeout (CFO)

- We can extract information about this last scattering surface (CFO) from experimentally detected hadron yield.
- A strongly interacting system in equilibrium can be described by thermodynamic parameters T, μ_Q, μ_B, μ_S.
- Extracted T vs μ_B for various experiments is expected to carry information about the phase diagram.

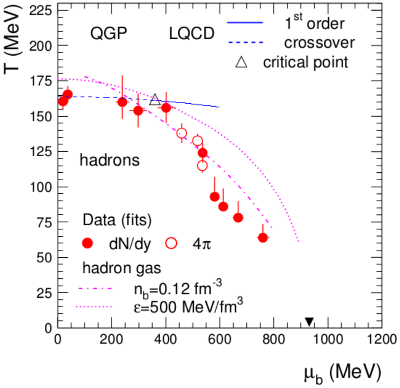


Figure : T vs μ_B[1]

[1] Andronic et. al Nucl.Phys.A772:167-199:2006;

Parameters and model for equilibrium

- One can model HRG like picture with T and μ's to understand CFO surface.
- Thermal density of i'th Hadron can be given as,

$$\boxed{\mathrm{n}_i = \frac{g_i}{(2\pi)^3} \int \frac{d^3p}{\exp[(E_i - \mu_i)/T] \pm 1}.}$$

- $\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$ is total chemical potential, g_i is the degeneracy factor.

Connection with observable

- We observe dN/dy in experiments.
- One can write $dN = ndV$
- Detected i'th primary hadron's rapidity density,

$$\boxed{\frac{dN_i}{dy} = \frac{dV}{dy} n_i(T, \mu_Q, \mu_B, \mu_S)}$$

- Information of the volume can be avoided by constructing ratios out of yields i.e

$$\boxed{\frac{dN_i/dy}{dN_j/dy} = \frac{n_i}{n_j}}$$

Extracting Parameter From Data

- We need four independent equations to extract these four thermal parameters.
- μ_Q and μ_S can be determined by imposing the constraints relations,

$$\boxed{\frac{\sum_i n_i(T, \mu_B, \mu_S, \mu_Q) Q_i}{\sum_i n_i(T, \mu_B, \mu_S, \mu_Q) B_i} = r}$$

$$\boxed{\sum_i n_i(T, \mu_B, \mu_S, \mu_Q) S_i = 0}$$

Extracting Parameter From Data

- To fit temperature T and the baryon chemical potential μ_B one can perform contemporary χ^2 minimization method with multiple ratios.
- We tried to fit constructed ratios numerically.
- We observed that extracted parameters were highly dependent on the ratios we choose.
- Is there an alternate way to extract model parameters?

An Alternate Approach

- For μ_B we have constructed a ratio of net baryon yield to total baryons.

$$\boxed{\frac{\sum_i B_i n_i}{\sum_i \mid B_i \mid n_i} = \frac{\sum_i B_i \frac{dN_i}{dY}}{\sum_i \mid B_i \mid \frac{dN_i}{dY}}}$$

- To extract T, we look at the antiparticles to particles ratio.

$$\boxed{\frac{\sum_i B_i \frac{dN_i}{dY}}{\sum_i \frac{dN_i}{dY}} = \frac{\sum_i B_i n_i^{Tot}}{\sum_i n_i^{Tot}}}$$

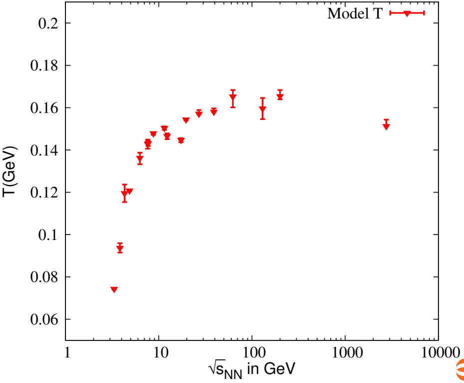
- These two equations have been constructed only out of detected hadrons.

Dataset Used

- We numerically solve these equations to extract all four equilibrium parameters.
- AGS, SPS, RHIC and LHC (2.76 TeV) data have been used.
- Study has been performed for mid-rapidity data of most central collision of these $\sqrt{s}$.
- We have used yield of all available mesons and baryons ($\pi^{\pm}$, $k^{\pm}$ and p, $\bar{p}$,Λ, $\bar{\Lambda}$, $\Xi^{\pm}$) for fitting.
- We have not used $\Omega^{\pm}$ yield as it is not available for most of the $\sqrt{s}$.

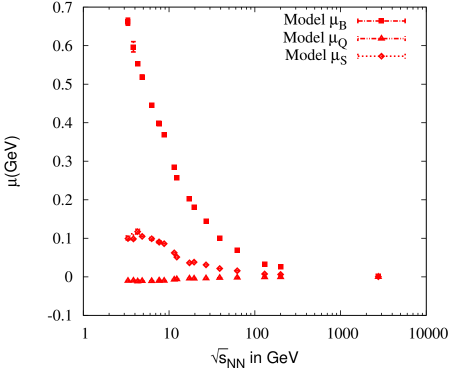
Variation of T with $\sqrt{s}$

- There is a trend of saturation after $\sqrt{s} = 19.6 AGeV$.
- It approaches the flat region of the proposed phase diagram of hadron to QGP transition near $\mu_B = 0$.



Variation of μ with $\sqrt{s}$

- μ_B increases due to higher rate of baryon stopping in lower collision energy.
- The difference between μ's decrease with increaseing $\sqrt{s}$ and converges to zero at very high $\sqrt{s}$.
- At low $\sqrt{s}$, μ_Q becomes negative though both μ_B and μ_S remain positive for all the values of $\sqrt{s}$.



Pion, kaon to pion ratio and proton to pion

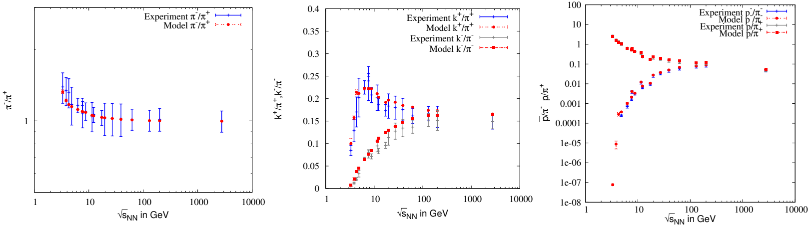


Figure : π^-/π^+, $k^\pm/\pi^\pm$ and p/π

Strange baryon to non-strange baryon ratio

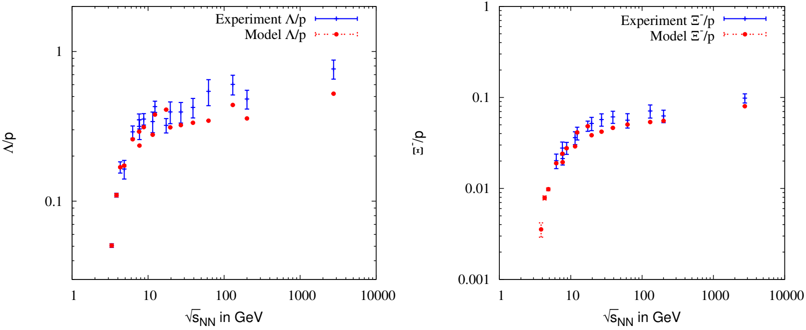


Figure : Variation of Λ/p and Ξ^-/p with $\sqrt{s}$

Predicted ratios

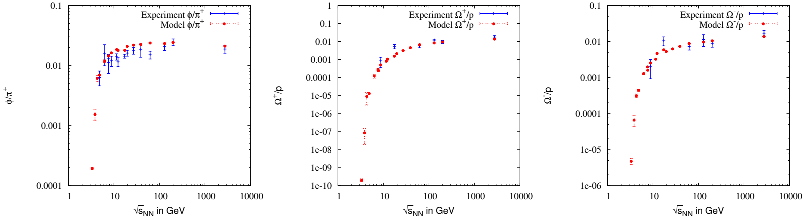


Figure : Variation of ϕ/π^+, Ω/p and Ω^+/p

Summary

- A new mechanism for freeze out parameter extraction has been proposed rather than the standard χ^2 method.
- The extracted parameters have suitably reproduced various ratios.
- Parameters value are in good agreement with that of standard literature.
- It is quite independent prediction as it does not involve any individual particle ratios like one needs in case of χ^2.