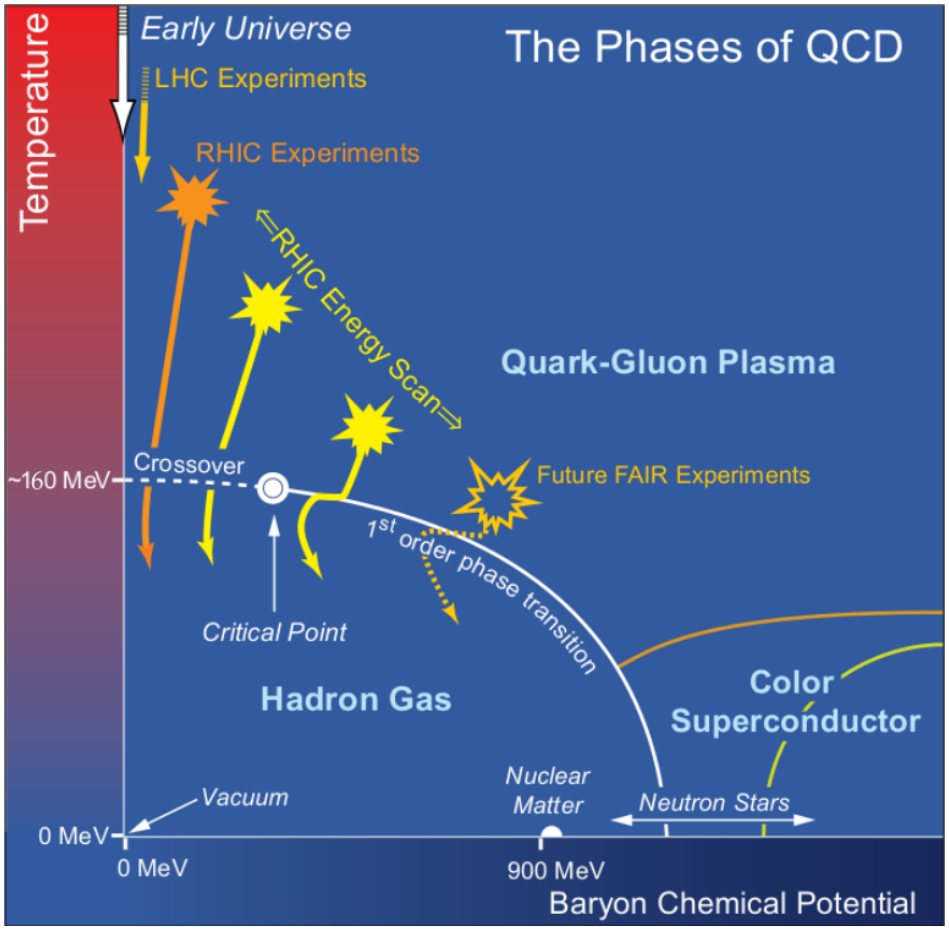
Extraction of chemical freeze-out parameters considering Baryon charge conservation

Deeptak Biswas

Department of Physics, Bose Institute, Kolkata, India

Contemporary and Emerging Topics in High Energy Nuclear Physics 2019

Scanning T and μ_B



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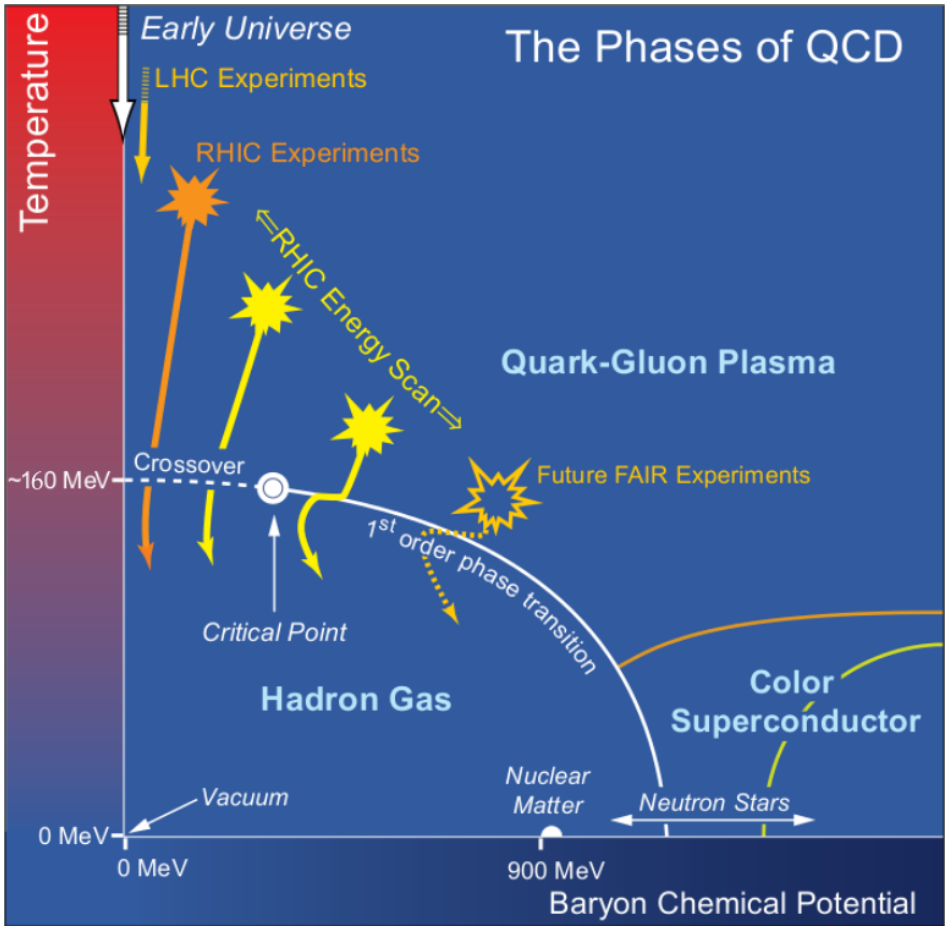

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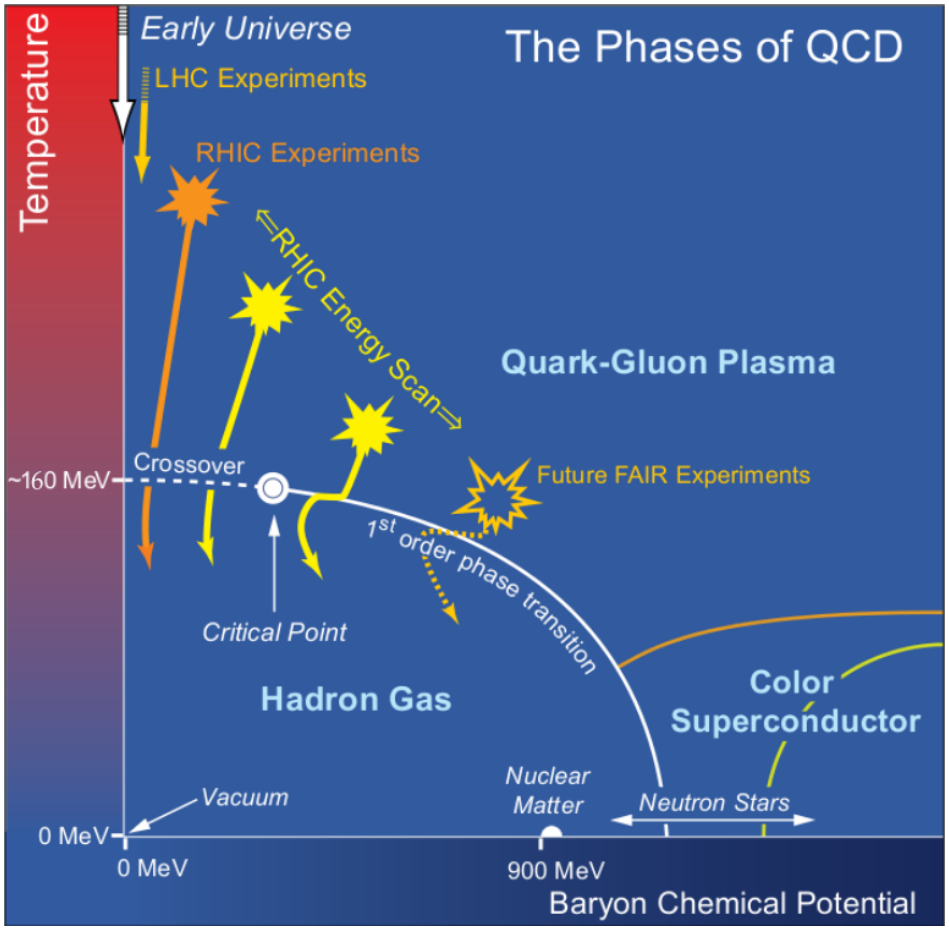

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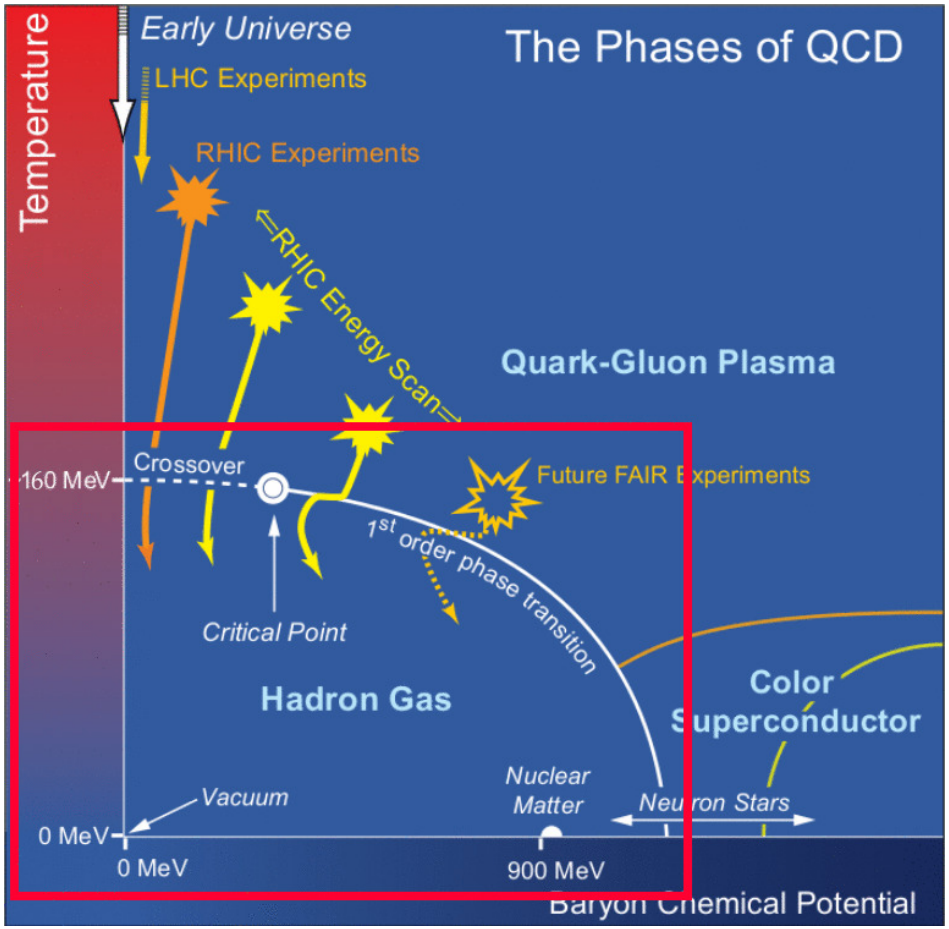

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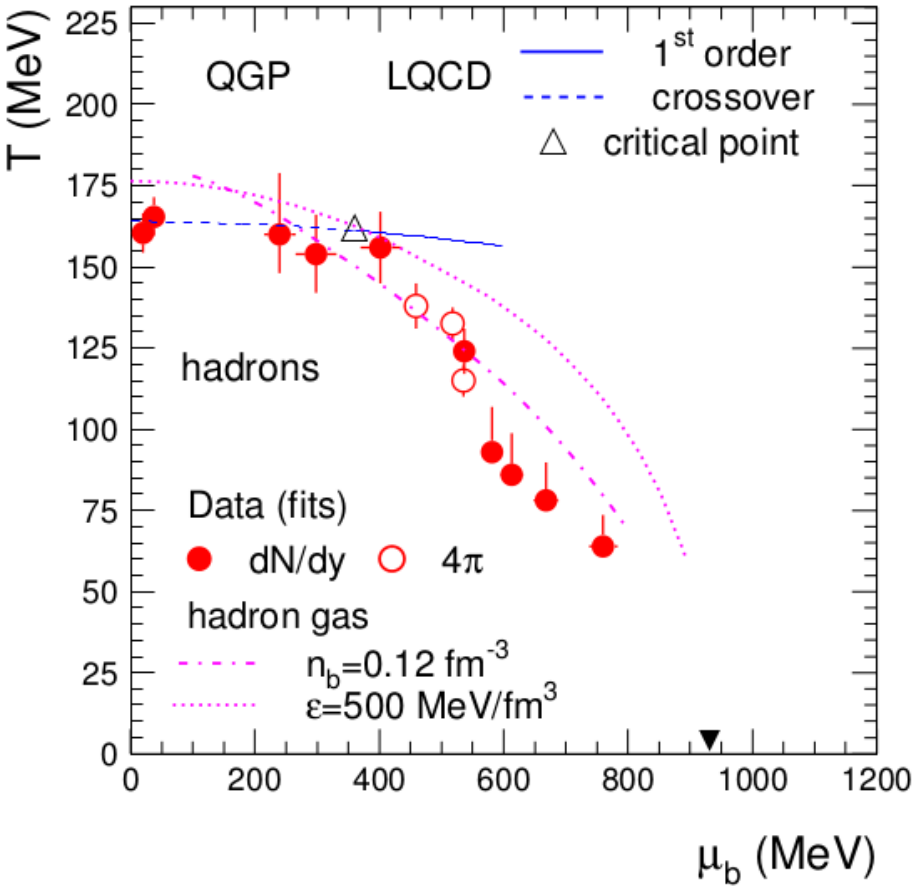
Let's collide nuclei and collect the data.

Data comes after freeze-out



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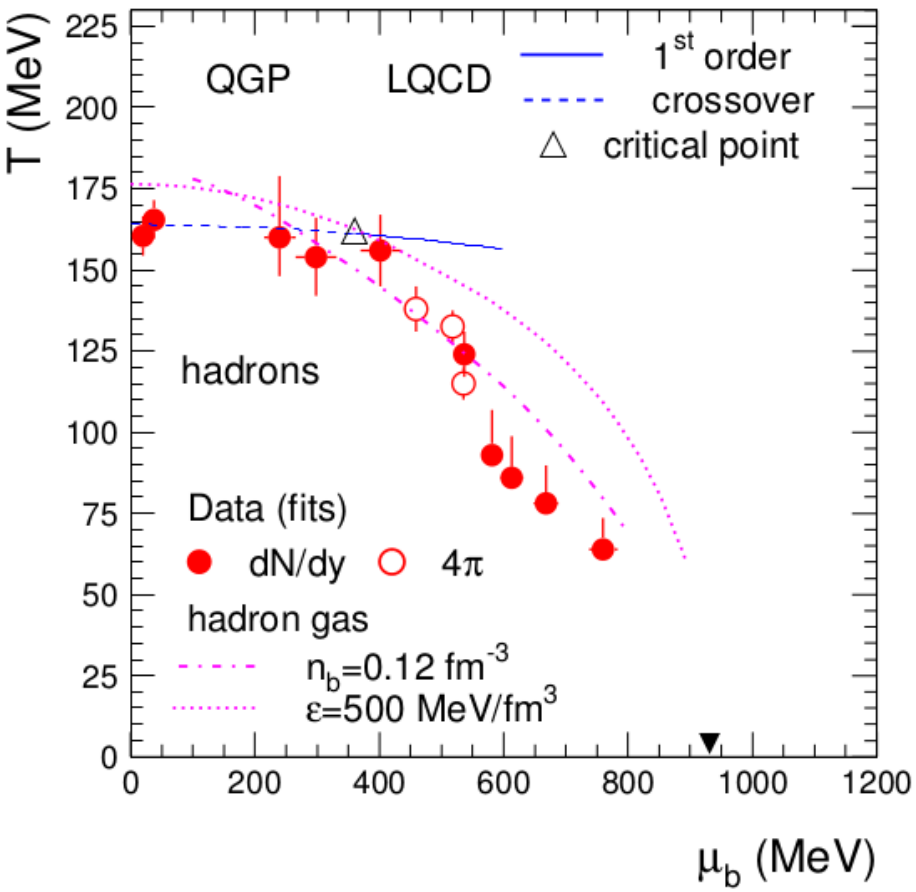

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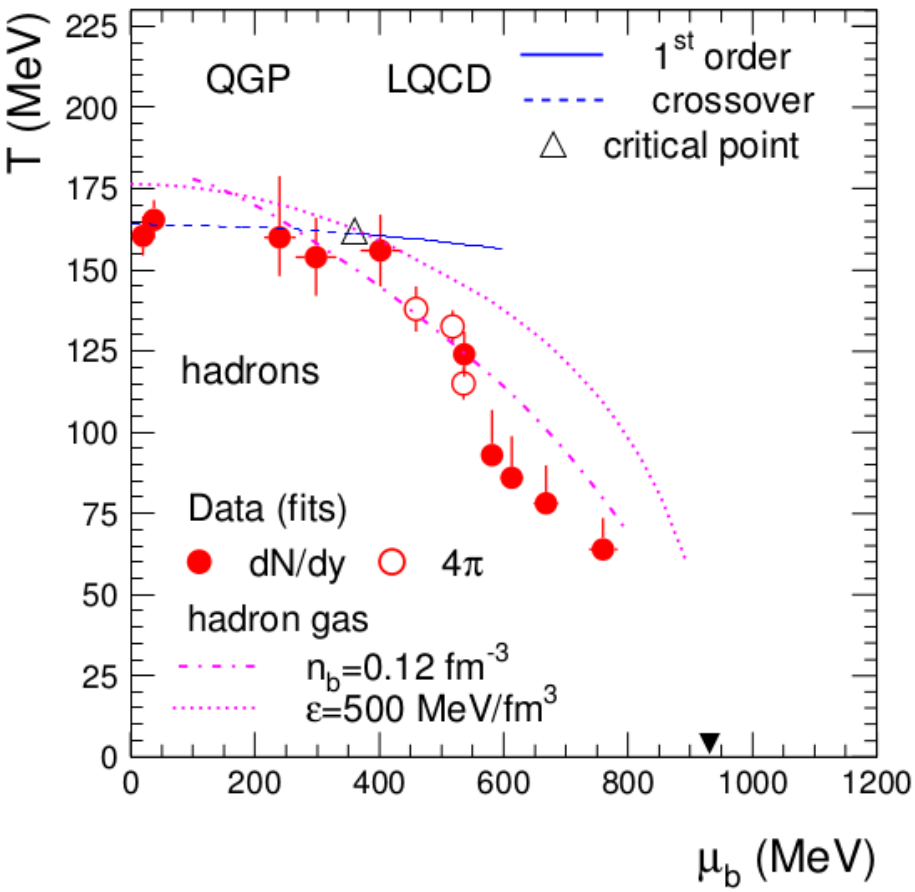

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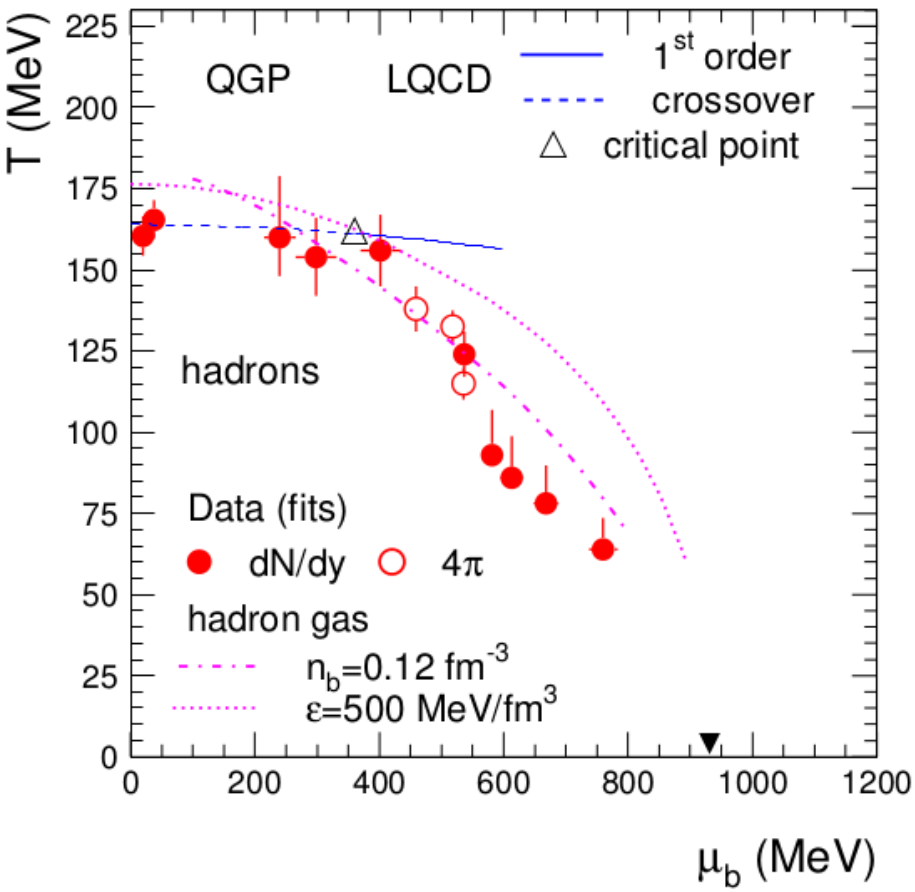

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These T and μ_B are guideline to locate phase transition.

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,

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

- $\mu_i = B_i\mu_B + S_i\mu_S + Q_i\mu_Q$ is total chemical potential, g_i is the degeneracy factor.
- Decay of parents to daughter particles has been included via,

$$\begin{aligned} n_i^{Tot} &= n_i(T,\mu_B,\mu_Q,\mu_S) \; + \\ \textstyle\sum_j & \; n_j(T,\mu_B,\mu_Q,\mu_S) \times \textit{Branching Ratio}(j \to i) \end{aligned}$$

Connection with observable

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

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

- 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,

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

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

- Above equations contain information of the incident nuclei. For Au-Au and Pb-Pb, $r \sim 2.50$.

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.
- Several standard codes are available like *THERMUS*, *SHARE*.
- We observed that extracted parameters were dependent on the ratios we choose and systematics of the analysis. *arxiv-1911.04828, talk by Sumana*

Uncertainities in χ^2 minimization approach

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- One can use additional parametrs, different freeze-out description depending on flavour etc. for better accuracy.
- Rather than incorporating numerous parameters, here we try to use minimum number of parameters as a most general approach.

Can there be an alternate way to extract thermodynamic parameters

Can there be an alternate way to extract thermodynamic parameters other than χ^2 ?

Let the conserved charges guide us

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- In this way one can maximally utilize yield data of all baryons and No Bias will be induced.
-

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

continuing...

- We need one more equation to close our system of equations.
- To extract T, we look at the net baryon to total particles ratio.

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

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

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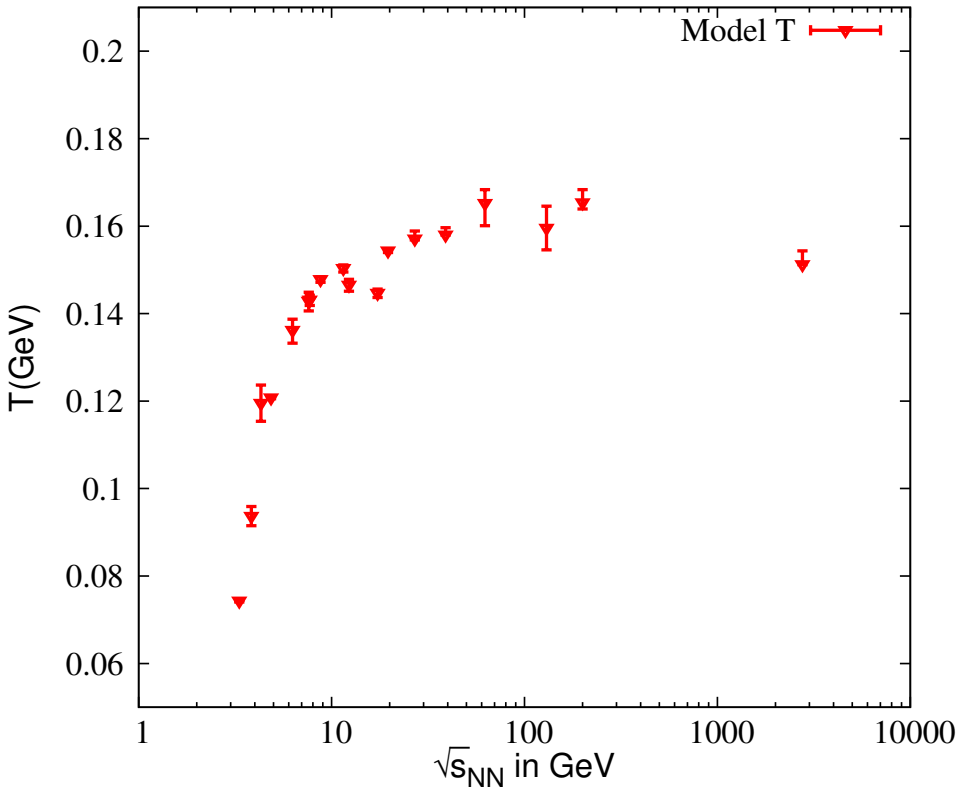
- To solve $\Longrightarrow$ Two new equations + Two constraints.

Dataset Used

- 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 $p, \bar{p}, \Lambda, \bar{\Lambda}, \Xi^{\pm}$) for fitting.
- We have not used $\Omega^{\pm}$ yield, it is not available for most of the $\sqrt{s}$.
- *Feed-down corrections* are taken care of, according to the corresponding experiment.
- Error has been calculated using extremum values of data.

Variation of T with $\sqrt{s}$

- There is 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 $\mu_B = 0$.



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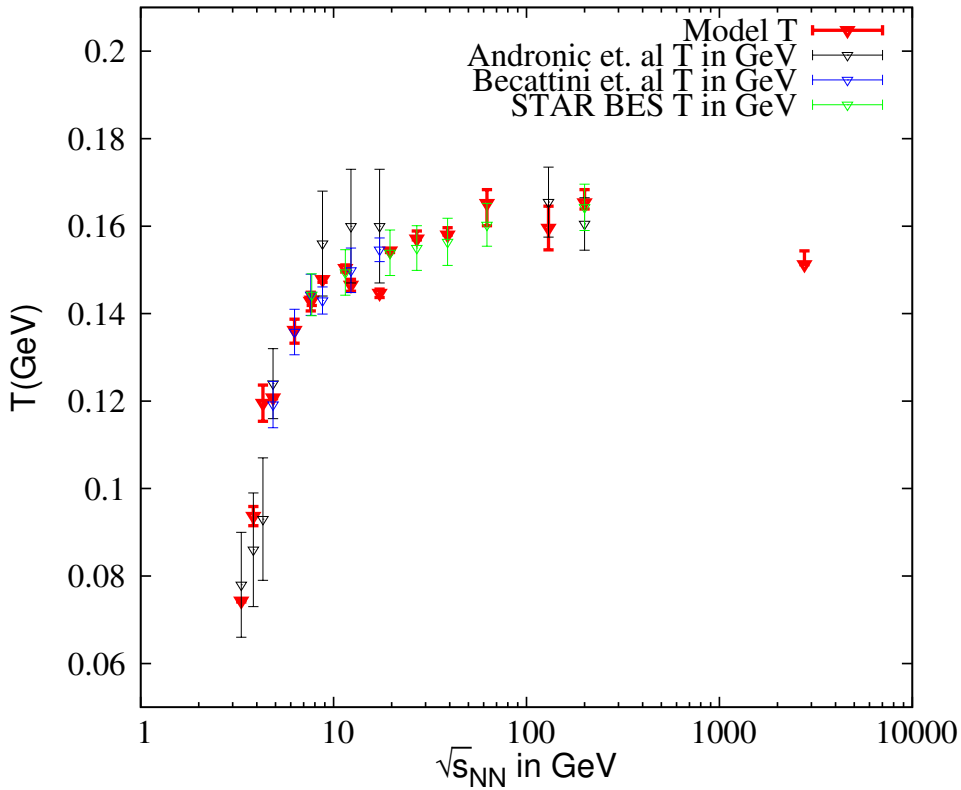
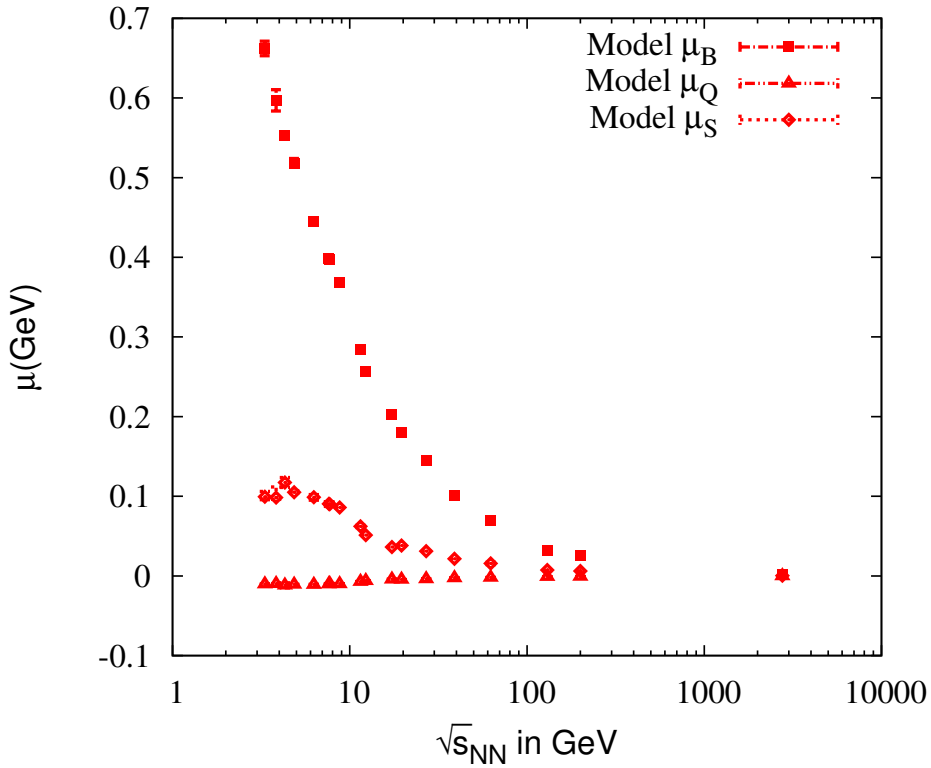
- We have compared our extracted T with *Andronic et.al* and BES.



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 $\sqrt{s}$.



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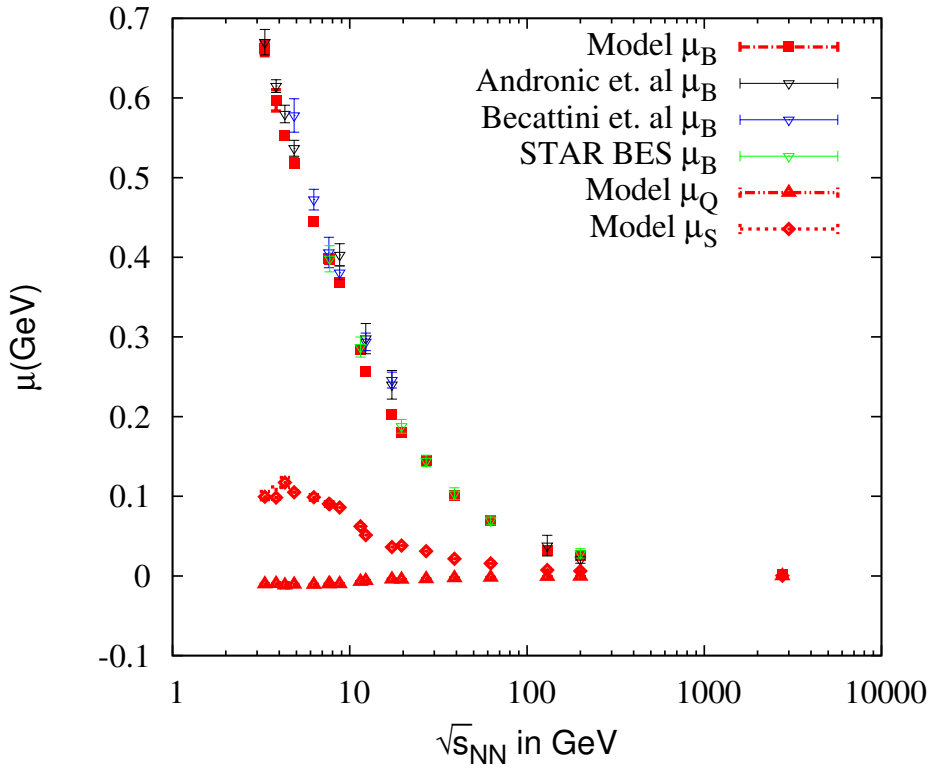


Pion, kaon to pion ratio and proton to pion

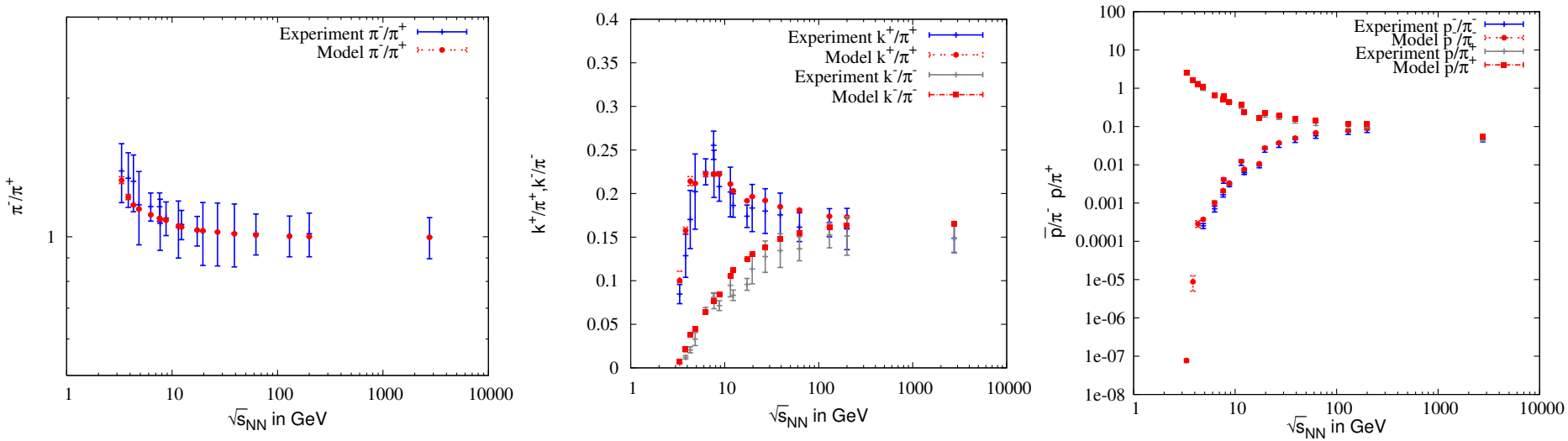
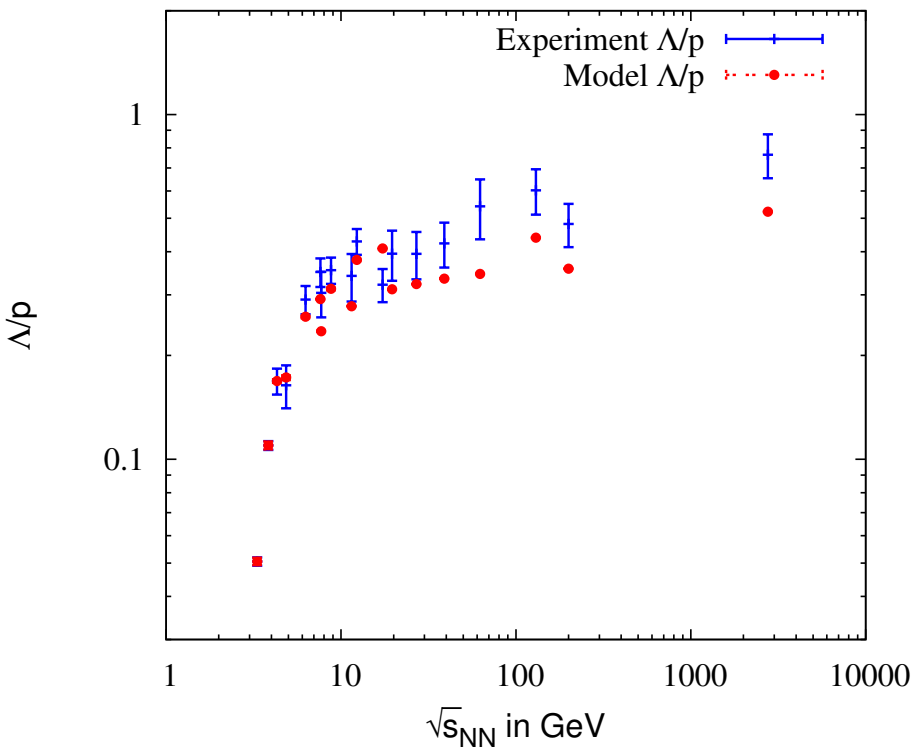


Figure: π^-/π^+, $k^\pm/\pi^\pm$ and p/π

Strange baryon to non-strange baryon ratio



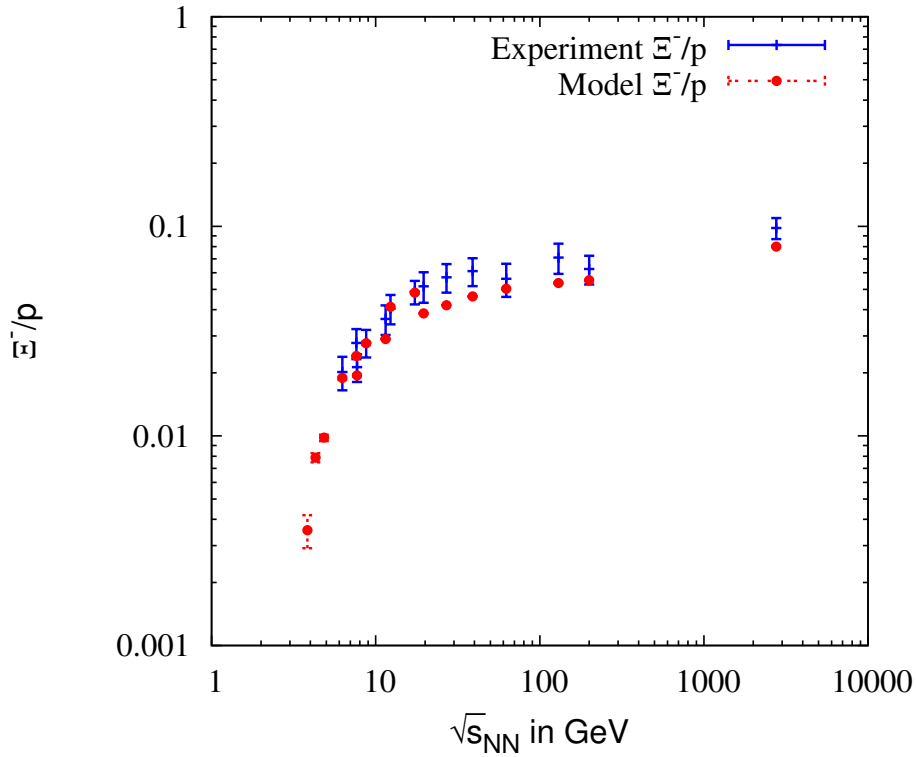


Figure: Variation of Λ/p and Ξ^-/p with $\sqrt{s}$

Predicted ratios

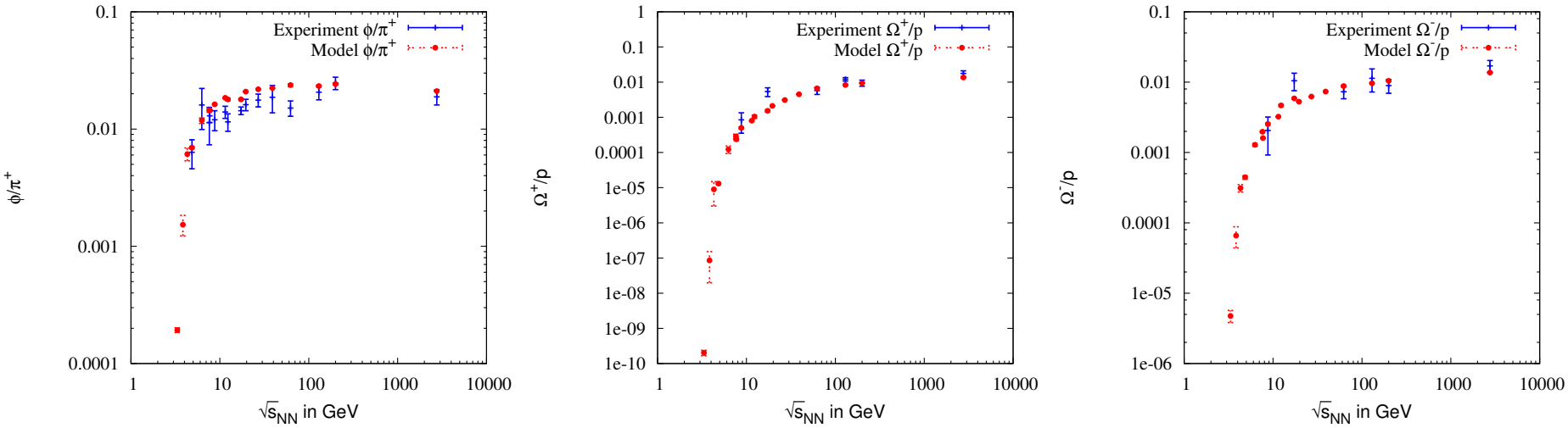
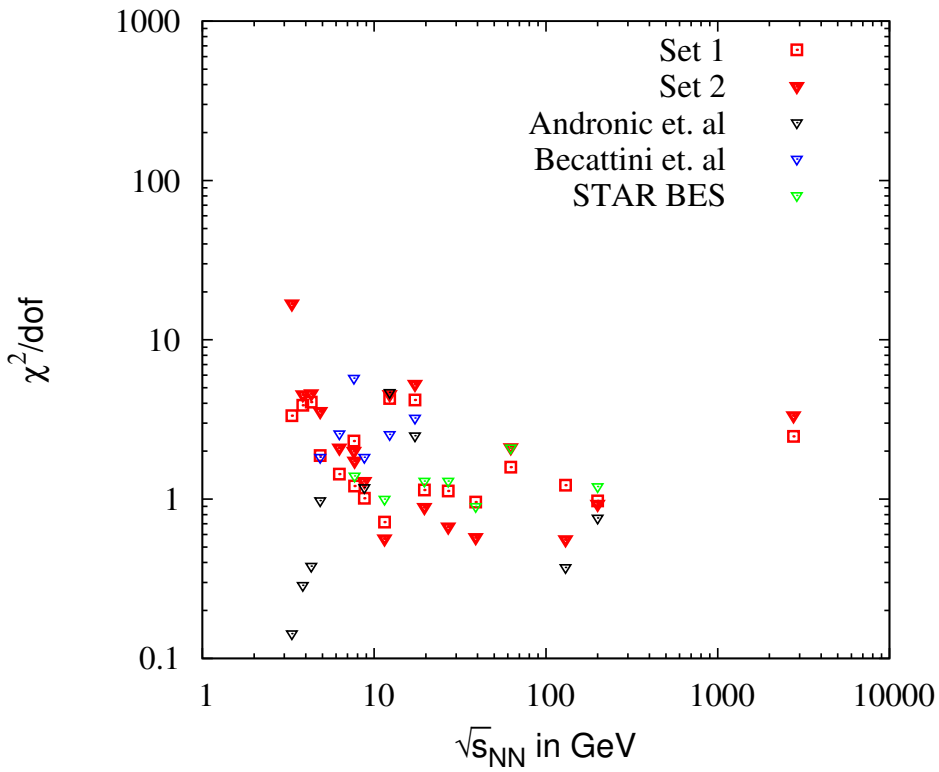


Figure: Variation of ϕ/π^+, Ω^-/p and Ω^+/p

Do we have a better χ^2 per degrees of freedom ?

- $\chi^2/d.o.f$ are better at RHIC and BES and worse at *AGS* energy range.
- Lack of hyperon data at these $\sqrt{S}$ plays a significant role. Only Λ data are available.
- Though there is good agreements between data and model predictions, $\chi^2/d.o.f$ is quite large.



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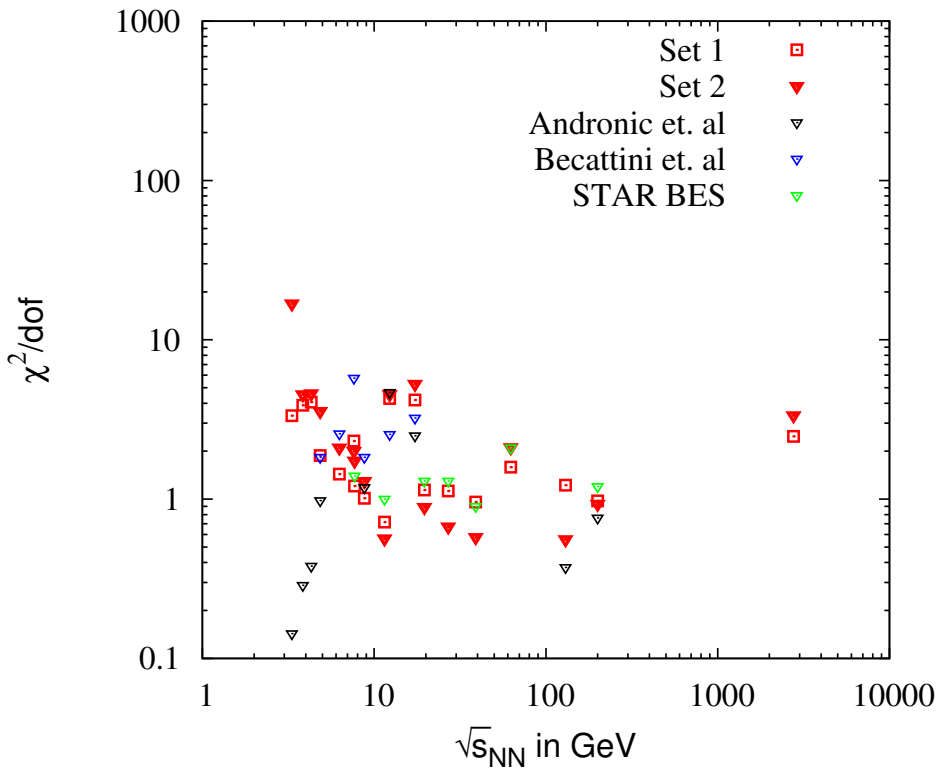

It is not a minimization routine, χ^2 can be a misleading measure!

Summary

- A new mechanism for freeze out parameter extraction has been proposed depending on net baryon charge.
- The extracted parameters have suitably reproduced various ratios.
- Chemical equilibrium at freeze-out under the umbrella of various charges.
- Parameters value are in good agreement with that of standard literature.
- Ratios are quite independent prediction as our process does not involve any individual particle ratios like one uses in case of χ^2 minimization.
- Precise data at lower $\sqrt{S}$ can improve our prediction.

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This method can be a good alternative to investigate chemical equilibrium at freeze-out in Heavy-Ion collision.

Collaborators

Sumana Bhattacharyya
Sanjay K. Ghosh
Rajarshi Ray
Pracheta Singha