Centrality dependence of thermal properties of the medium produced in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV using a thermal model

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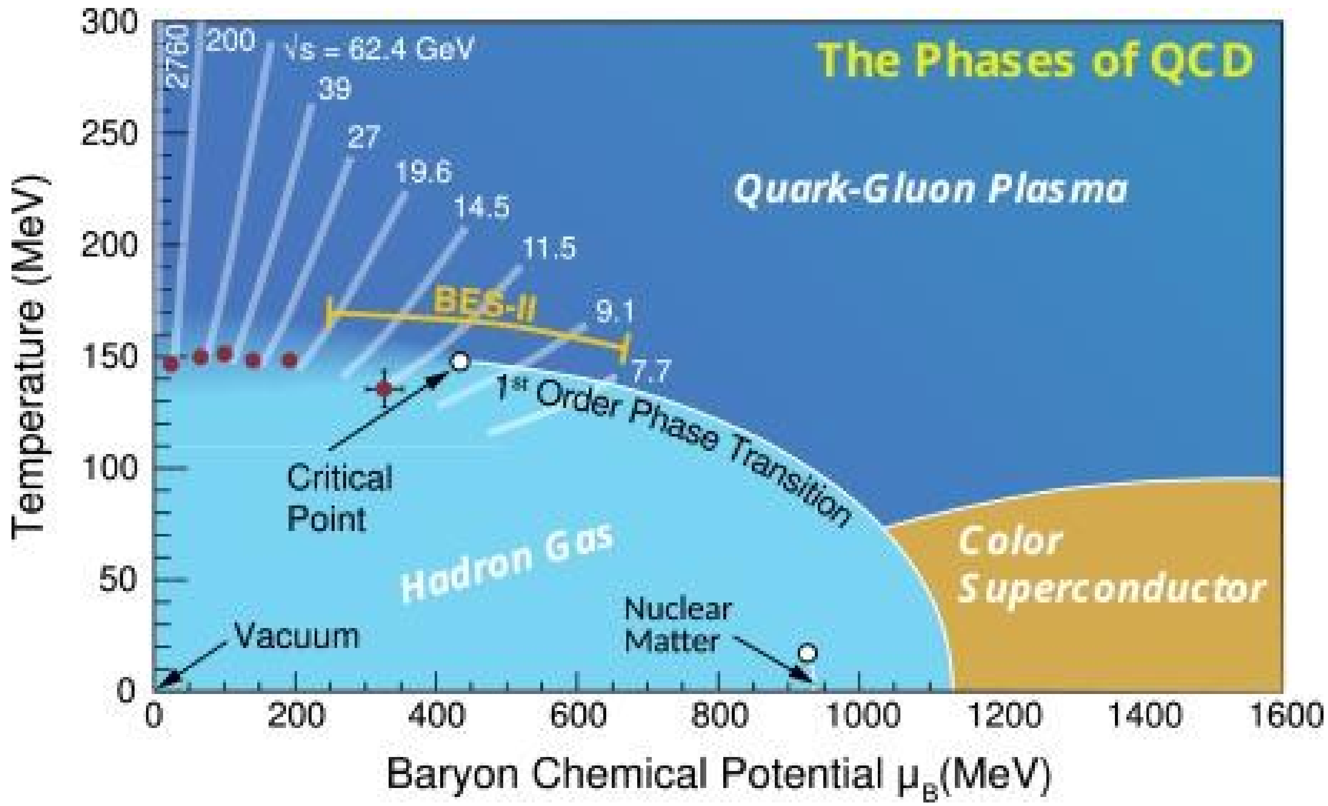
Motivation



- Investigate nuclear matter produced in heavy-ion collisions via the QCD phase diagram.
- At high T and μ_B, the de-confined quarks and gluons, QGP phase is expected to be present, while at low T and μ_B, the quarks and gluons are confined within hadrons.
- Theoretically, these phases are investigated through lattice QCD, which uses numerical simulations in the non-perturbative QCD regime.
- Experimentally, the exploration is done by varying the center of mass energy ($\sqrt{s_{NN}}$) in heavy-ion collisions.

Thermal model

- Thermodynamic models are widely and successfully used to describe identified particle yields and ratios produced in hadronic, especially in heavy ion collisions.
- The equilibrium thermodynamic properties of the QCD matter can be determined by T and the three chemical potentials μ_Q, μ_B, and μ_S.
- We use a grand canonical ensemble (GCE) in this thermal model and assume that particles produced from the collision of particles and nuclei (p+p, p+A, A+A) emerge from a thermal source.
- We then calculate the expected particle ratios for various assumed temperatures and chemical potentials.
- Then, the experimental particle ratios are compared with thermal model predictions to assess the degree of agreement by the χ^2/ndf characterizing the fit.
- In the case of minimum χ^2/ndf, the temperature and chemical potentials of the hypothetic thermal particle source are estimated.

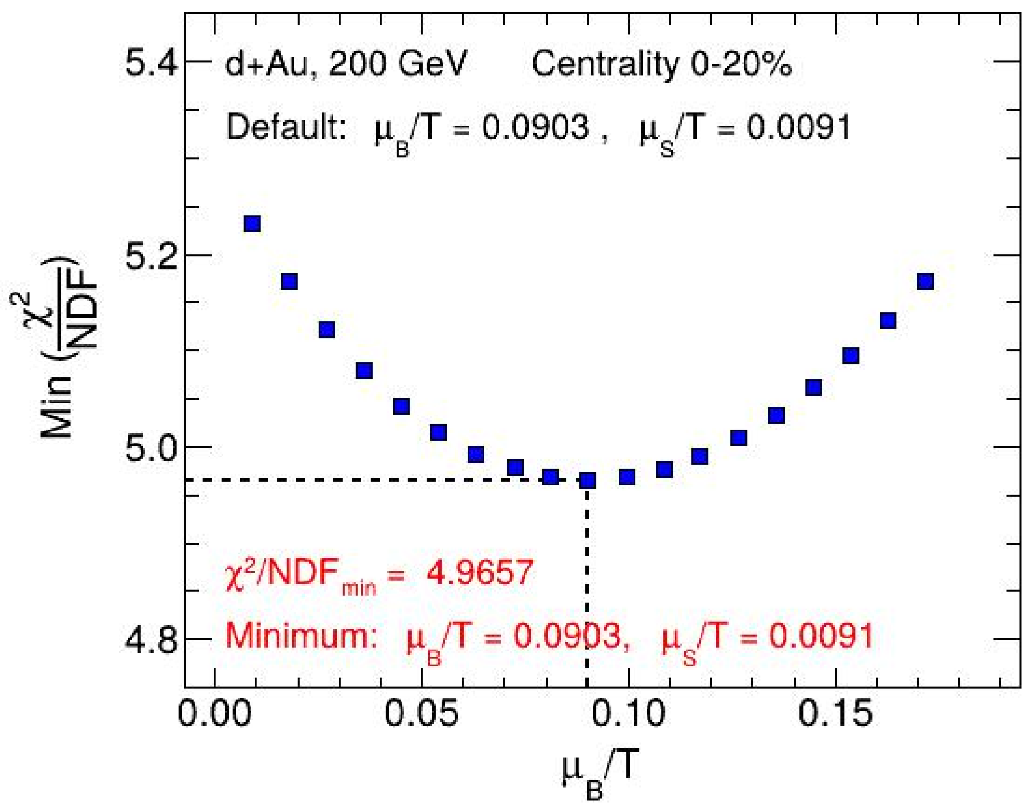
Input parameters μ_B/T and μ_S/T

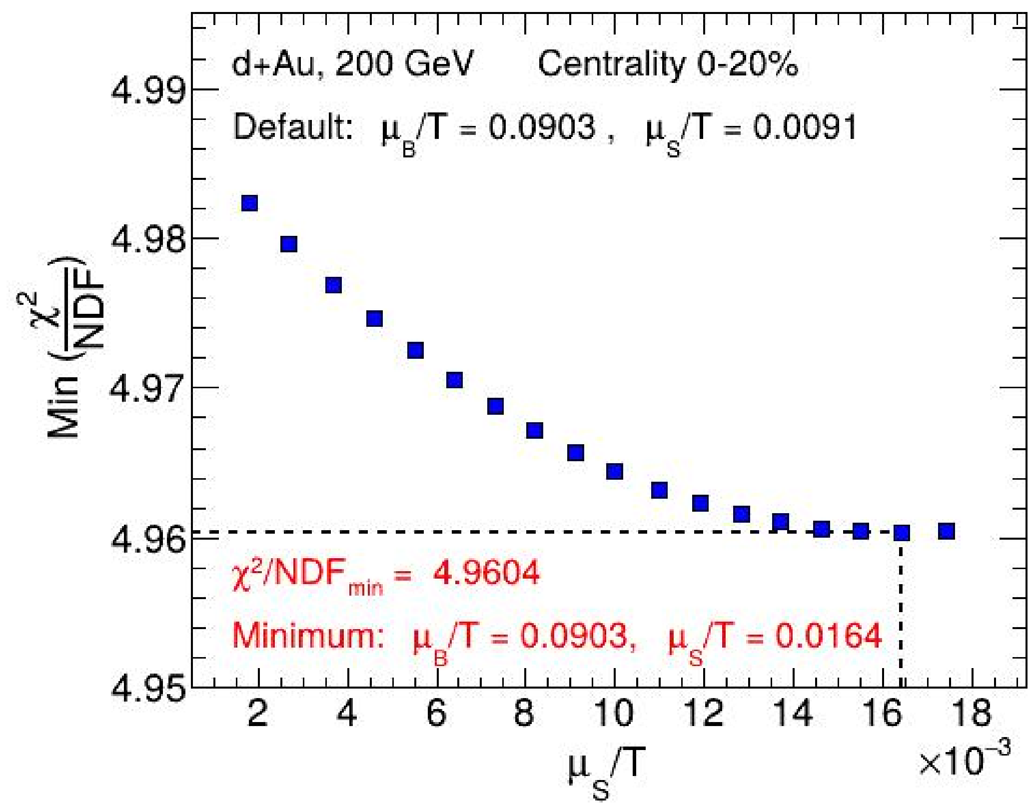
- Initialize with the input parameters:

Preminiary

$$\frac{\bar{p}}{p} = e^{\left(\frac{-2\mu_B}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_B}{T}\right)} = 0.833 \rightarrow \frac{\mu_B}{T} = 0.0903$$

$$\frac{K^-}{K^+} = e^{\left(\frac{-2\mu_S}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_S}{T}\right)} = 0.982 \rightarrow \frac{\mu_S}{T} = 0.0091$$



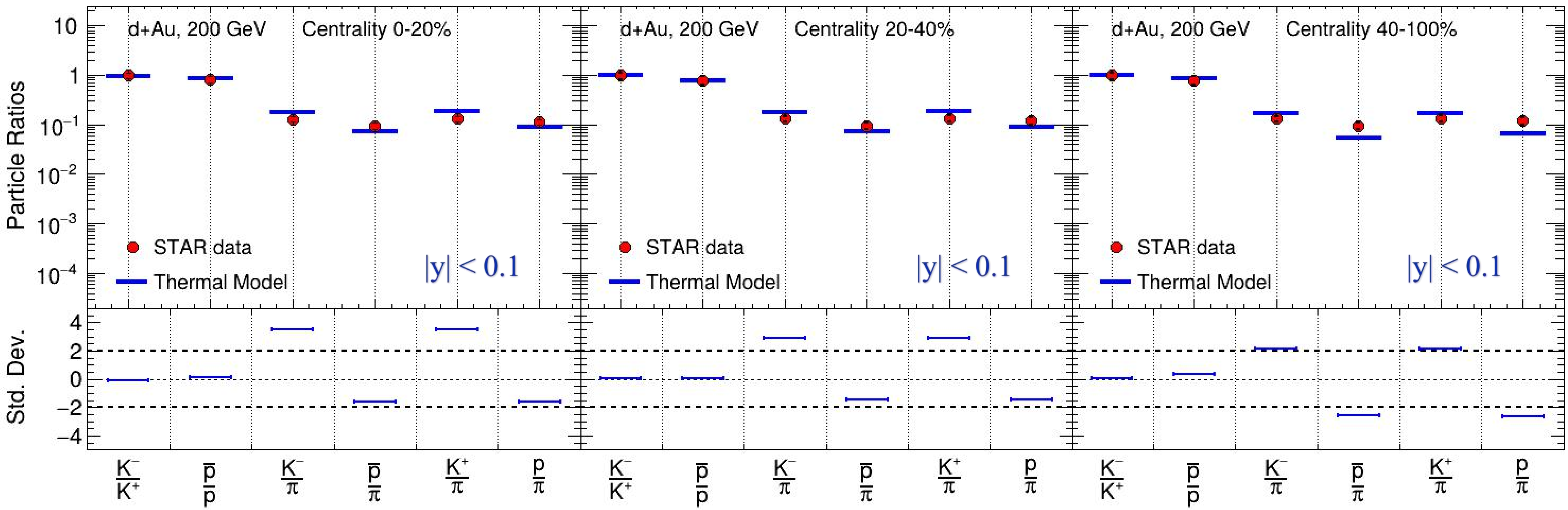


- Varied μ_B/T and μ_S/T in steps of ±90% of the initial value, to get minimum of $\chi 2$/NDF.
- μ_B/T and μ_S/T at minimum $\chi 2$/NDF is used as the default input parameters for the thermal model.

minimum $\chi 2$/NDF = 4.9604 → μ_B/T = 0.0903 and μ_S/T = 0.0164

Particle Ratios

Preminiary



- The comparison of experimental particle ratios with the thermal model calculation is shown for 0-20%, 20-40% and 40-100% central d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.
- Thermal model is successfully predicting the experimental particle ratios within $\pm 4\sigma$ deviation where, Std. dev. (σ) is represented by:

$$\sigma = \frac{Ratio_{Th.} - Ratio_{Exp}}{\sigma_{Exp}}$$

- B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 79, 034909 (2009)

Uncertainties on thermal parameters

Statistical uncertainties:

- Statistical uncertainties are obtained as the maximum deviation of the two cases, i.e adding and subtracting the experimental errors from the experimental ratios.

Systematic uncertainties:

- Systematic uncertainties are obtained as the average of deviation of the results from 100% and 0% of weak decay correction.

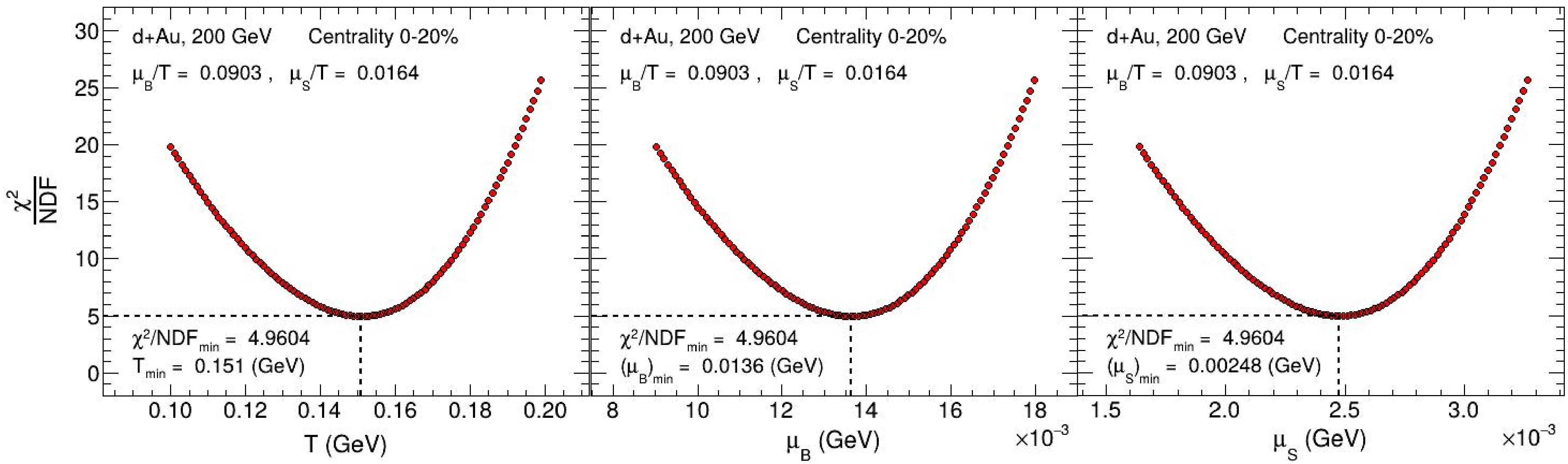
Total uncertainties:

- Total uncertainties on the results are calculated as the square root of quadratic sum of statistical and systematic uncertainties.

Thermal parameters d+Au $\sqrt{s_{NN}}$ 200 GeV (0-20%)

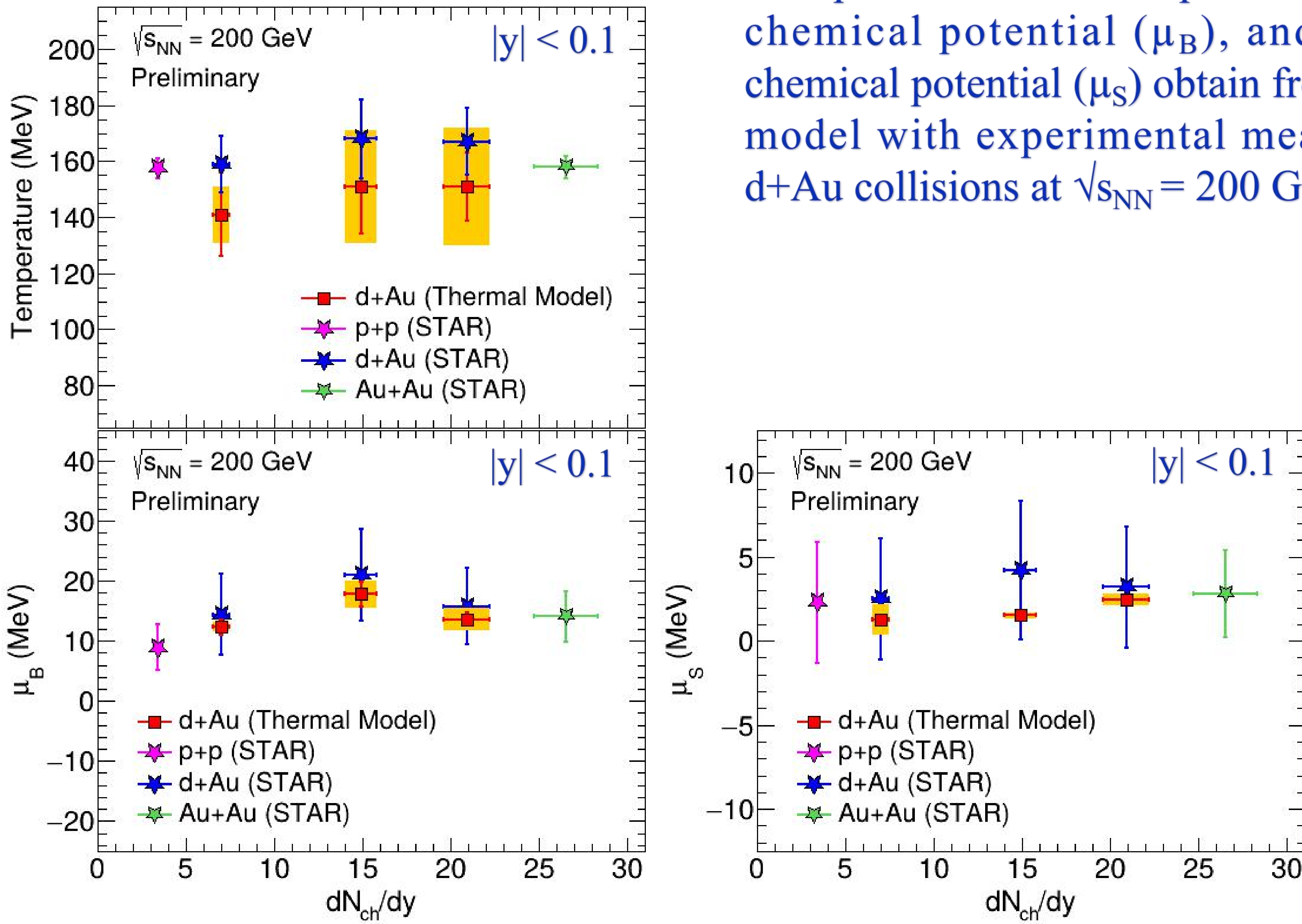
- Fit results from thermal model is plotted to extract the thermal parameters in 0-20% central d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Preminiary



- At the minimum ± of $\chi 2/NDF = 4.9604$:
  - $T = 151 \pm 12$ (stat.) $\pm$ 21 (sys.) MeV
  - $\mu_B = 13.6 \pm 1.1$ (stat.) $\pm$ 1.9 (sys.) MeV
  - $\mu_S = 2.48 \pm 0.20$ (stat.) ± 0.34 (sys.) MeV

Thermal parameters for d+Au at $\sqrt{s_{NN}} = 200$ GeV

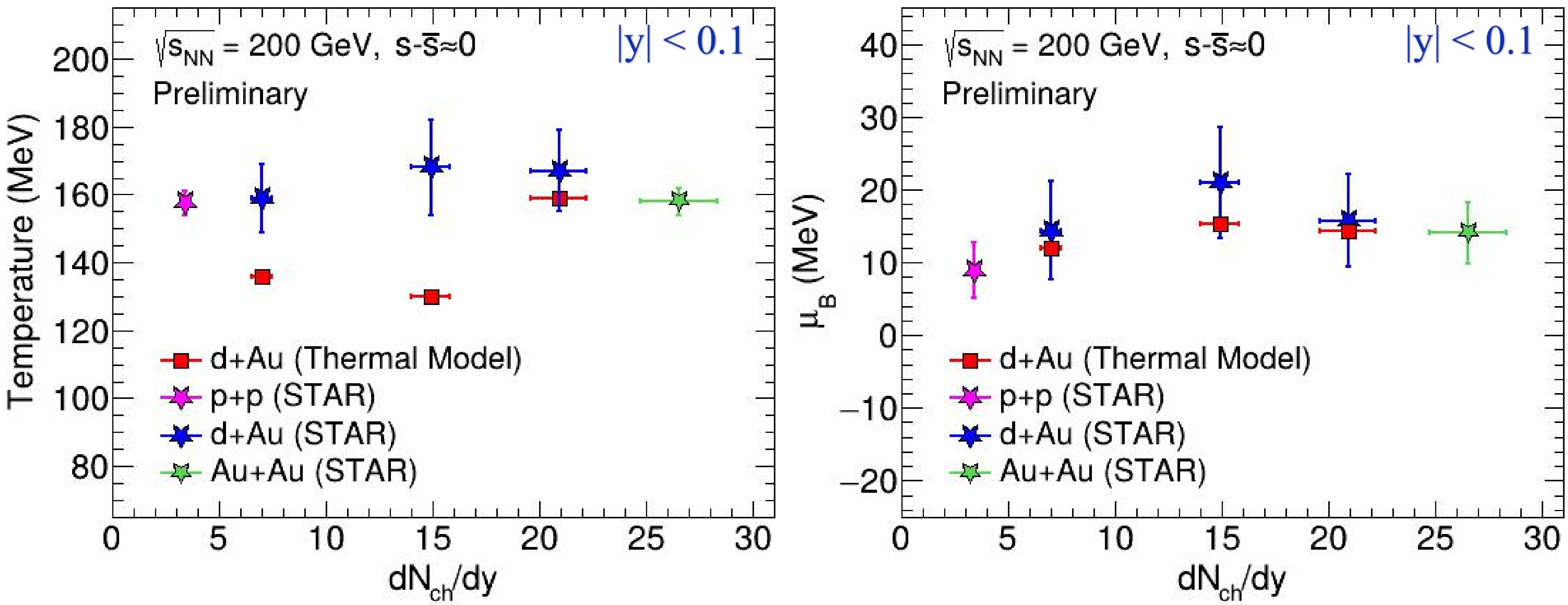


- Comparison of the temperature (T), baryon chemical potential (μ_B), and strangeness chemical potential (μ_S) obtain from the thermal model with experimental measurements in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

- B. I. Abelev et al. (STAR), Phys. Rev. C 79, 034909 (2009), J. Adams et al. (STAR), Phys. Rev. Lett. 92, 112301 (2004)

Thermal parameters ($s-\bar{s} \approx 0$)

- With strangeness conservation condition (**$s-\bar{s} \approx 0$**)
- Comparison of the temperature (T) and baryon chemical potential (μ_B) obtain from the thermal model with experimental measurements in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.



- B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 79, 034909 (2009)
- J. Adams et al. (STAR Collaboration), Phys. Rev. Lett. 92, 112301 (2004)

Summary

- Thermal properties temperature (T), chemical potentials (μ_B and μ_S) are presented for d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV using the thermal model.
- Particle ratios from the experimental particle yields are calculated in order to predict thermal properties of the medium produced in d+Au collisions at at $\sqrt{s_{NN}}$ = 200 GeV.
- The T, μ_B and μ_S are consistent within uncertainties with the results from the thermal model published by the STAR experiment at RHIC.

Centrality dependence of thermal properties:

Chemical freeze-out temperature and chemical potentials (μ_B and μ_S) do not show centrality dependence in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

Thank you for your attention!

Backups

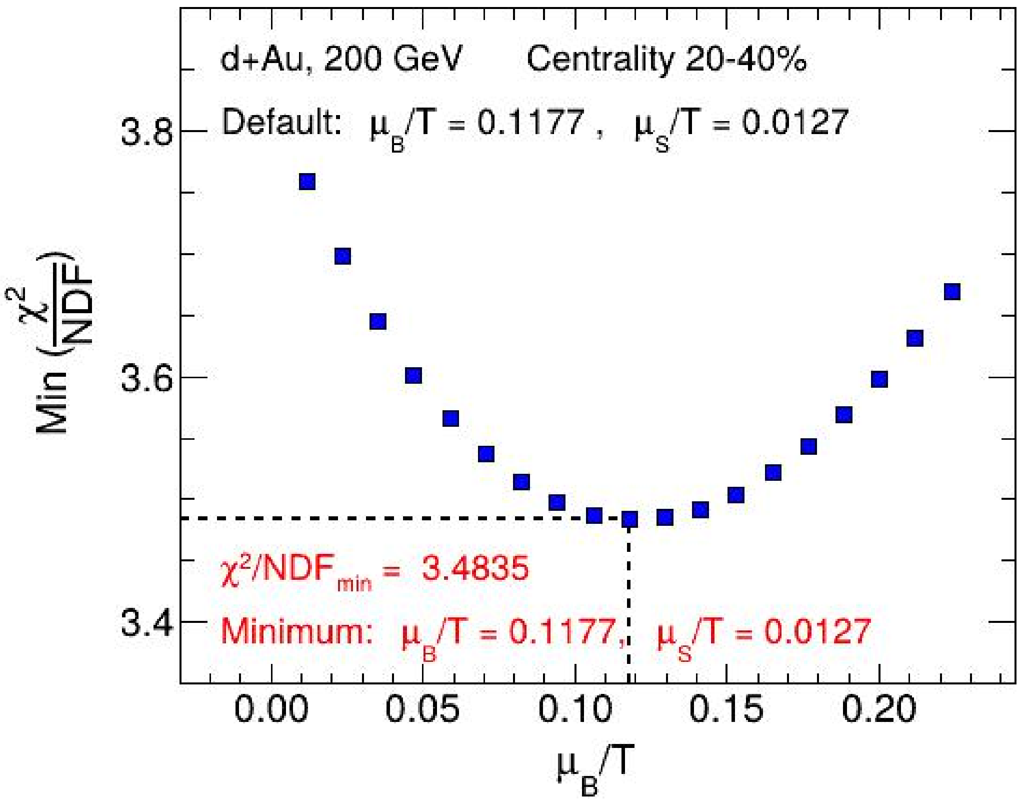
μ_B/T and μ_S/T (20-40% Central)

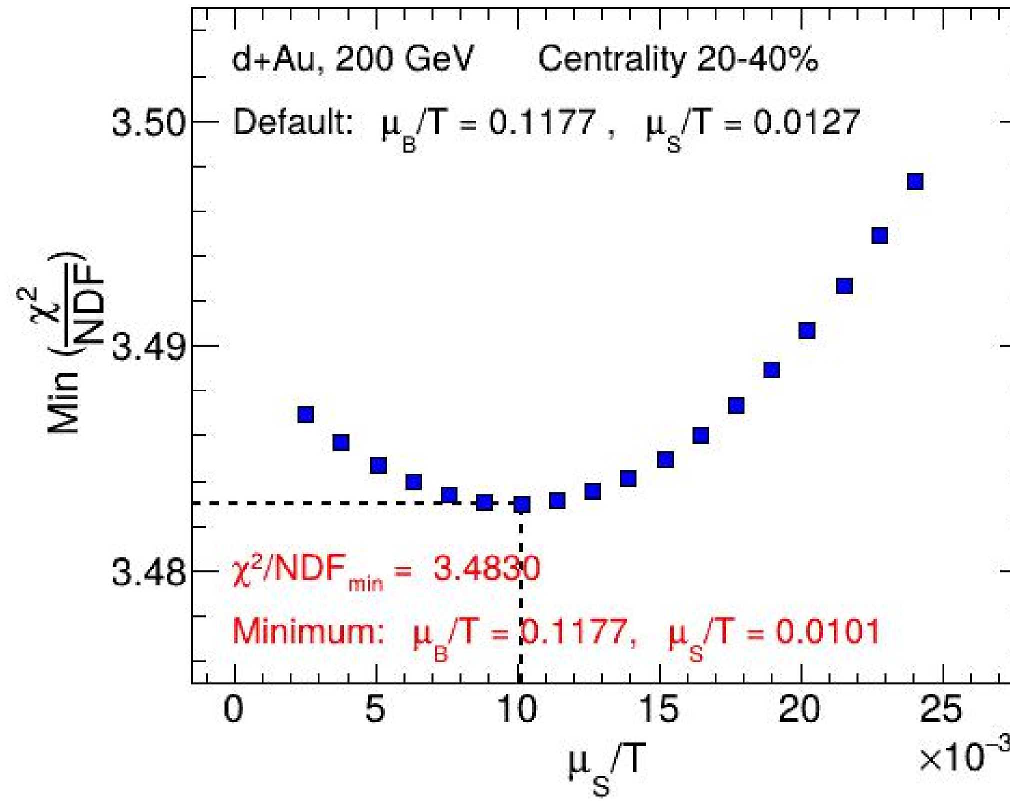
- Initialize with the input parameters:

Preminiary

$$\frac{\overline{p}}{p} = e^{\left(\frac{-2\mu_B}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_B}{T}\right)} = 0.833 \rightarrow \frac{\mu_B}{T} = 0.0903$$

$$\frac{K^-}{K^+} = e^{\left(\frac{-2\mu_S}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_S}{T}\right)} = 0.982 \rightarrow \frac{\mu_S}{T} = 0.0091$$





- Varied μ_B/T and μ_S/T in steps of ±90% of the initial value, to get minimum of $\chi 2$/NDF.
- μ_B/T and μ_S/T at minimum $\chi 2$/NDF is used as the default input parameters for the thermal model.

minimum $\chi 2$/NDF = 3.4830 → μ_B/T = 0.1177 and μ_S/T = 0.0101

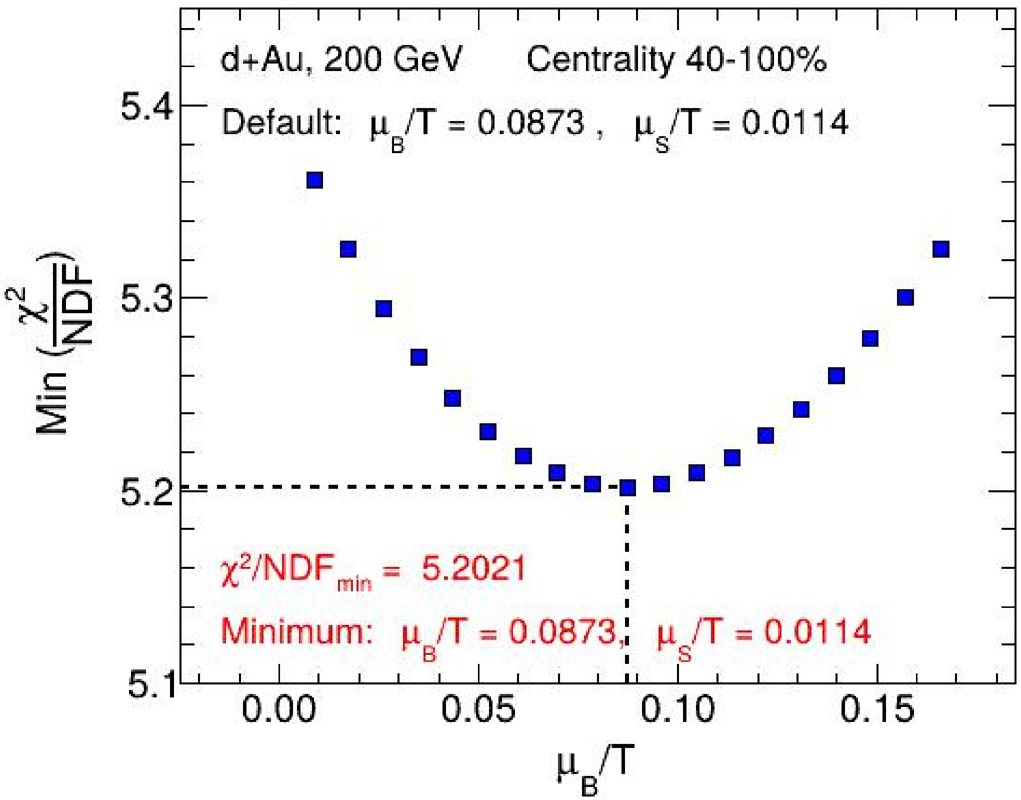
μ_B/T and μ_S/T (40-100% Central)

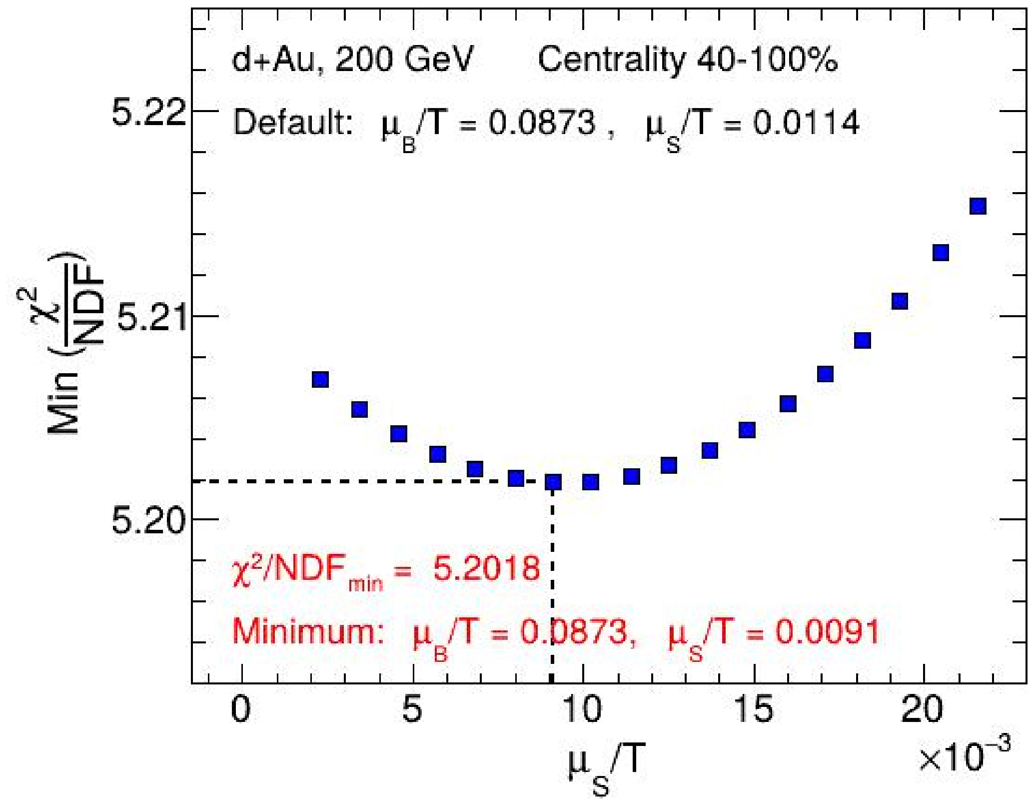
- Initialize with the input parameters:

Preminiary

$$\frac{\bar{p}}{p} = e^{\left(\frac{-2\mu_B}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_B}{T}\right)} = 0.833 \rightarrow \frac{\mu_B}{T} = 0.0903$$

$$\frac{K^-}{K^+} = e^{\left(\frac{-2\mu_S}{T}\right)} \rightarrow e^{\left(\frac{-2\mu_S}{T}\right)} = 0.982 \rightarrow \frac{\mu_S}{T} = 0.0091$$





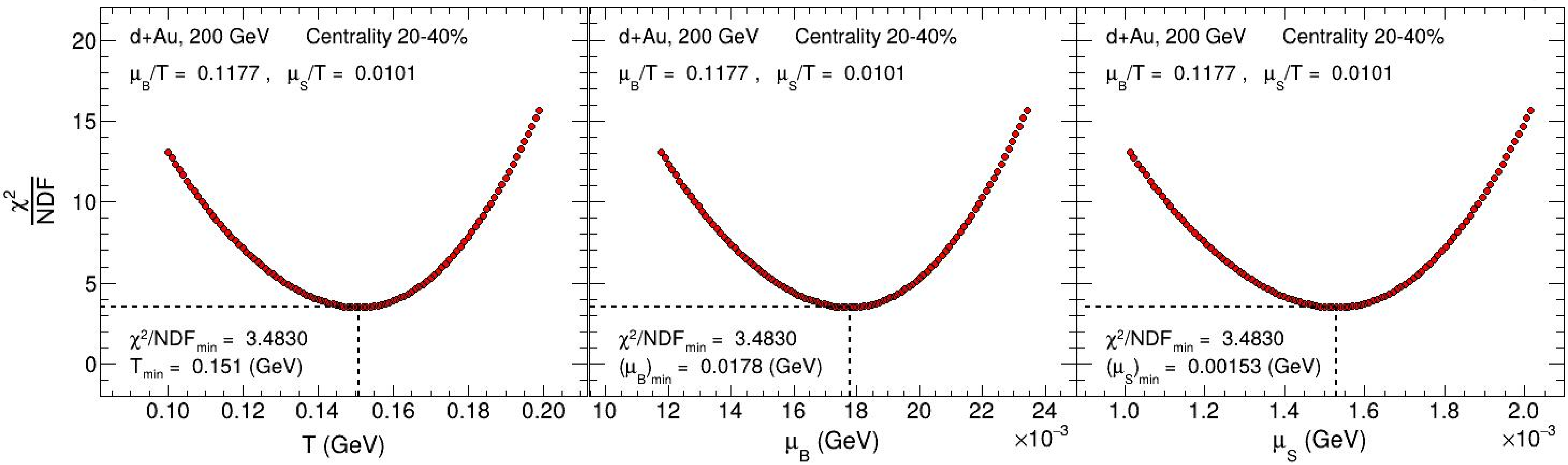
- Varied μ_B/T and μ_S/T in steps of ±90% of the initial value, to get minimum of χ2/NDF.
- μ_B/T and μ_S/T at minimum χ2/NDF is used as the default input parameters for the thermal model.

minimum χ2/NDF = 5.2018 → μ_B/T = 0.0873 and μ_S/T = 0.0091

Thermal parameters d+Au $\sqrt{s_{NN}}$ 200 GeV (20-40%)

- Fit results from thermal model is plotted to extract the thermal parameters in 20-40% central d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Preminiary

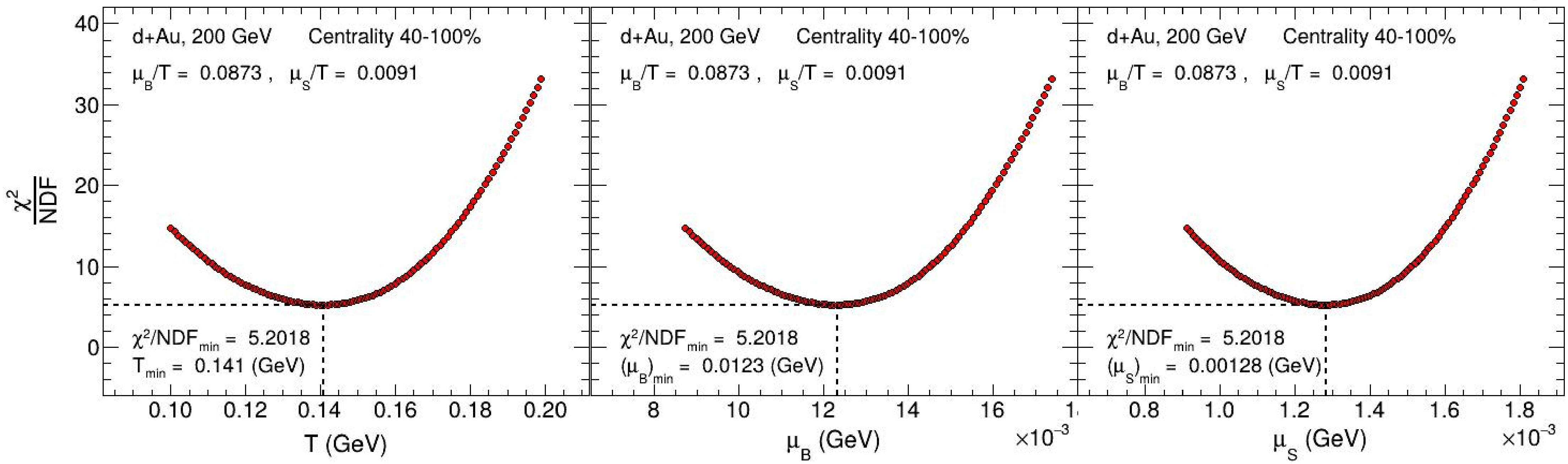


- At the minimum ± of $\chi2/NDF = 3.4830$:
  - $T = 151 \pm 17 \pm 20$ MeV
  - $\mu_B = 17.8 \pm 2.0 \pm 2.3$ MeV
  - $\mu_S = 1.53 \pm 0.18 \pm 0.19$ MeV

Thermal parameters d+Au $\sqrt{s_{NN}}$ 200 GeV (40-100%)

- Fit results from thermal model is plotted to extract the thermal parameters in 40-100% central d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

Preminiary



- At the minimum ± of $\chi2/NDF = 5.2018$:
  - $T = 141 \pm 15 \pm 10$ MeV
  - $\mu_B = 12.3 \pm 1.3 \pm 0.8$ MeV
  - $\mu_S = 1.28 \pm 0.14 \pm 0.09$ MeV

Particle Ratios

- Experimental particle ratios and their error are from mid-rapidity (|y| < 0.1) in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV from the STAR experiment at RHIC.

Particle Ratio	STAR Experiment			Experimental Error (statistical & systematic)			Thermal model		
Centrality	**0-20%**	**20-40%**	**40-100%**	**0-20%**	**20-40%**	**40-100%**	**0-20%**	**20-40%**	**40-100%**
$\frac{K^-}{K^+}$	0.982	0.975	0.978	0.120	0.149	0.128	0.970	0.982	0.985
$\frac{\bar{p}}{p}$	0.835	0.790	0.840	0.133	0.166	0.158	0.848	0.798	0.847
$\frac{K^-}{\pi^-}$	0.129	0.130	0.121	0.014	0.017	0.014	0.178	0.179	0.167
$\frac{\bar{p}}{\pi^-}$	0.094	0.094	0.082	0.012	0.015	0.012	0.074	0.072	0.055
$\frac{K^+}{\pi^+}$	0.131	0.133	0.124	0.015	0.017	0.014	0.183	0.182	0.170
$\frac{p}{\pi^+}$	0.112	0.119	0.098	0.015	0.020	0.015	0.088	0.090	0.065

Preminiary

- Particle ratios calculated from this thermal model is also shown.

- B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 79, 034909 (2009)

Thermal parameters for d+Au at $\sqrt{s_{NN}}$ = 200 GeV

- Comparison of the thermal parameters obtain from the thermal model with experimental measurements at mid-rapidity (|y| < 0.1) in d+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

Parameters	Experimental Results			Thermal model			Thermal model (Strangeness conservation)		
Centrality (%)	**0-20**	**20-40**	**40-100**	**0-20**	**20-40**	**40-100**	**0-20**	**20-40**	**40-100**
$\chi 2$/NDF	0.069	0.068	0.051	4.96	3.48	5.20	4.96	3.48	5.20
T (MeV)	167 ±12	168 ±14	159 ±10	151 ±24	151 ± 26	141 ± 18	159	130	136
μ_B (MeV)	15.8 ±6.3	21.0 ±7.6	14.4 ±6.7	13.6 ±2.2	17.8 ± 3.0	12.3 ± 1.5	14.4	15.3	11.9
μ_S (MeV)	3.2 ±3.6	4.2 ±4.1	2.5 ±3.6	2.48 ±0.39	1.53 ± 0.26	1.28 ± 0.45	2.61	1.31	1.24

Preminiary

- B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 79, 034909 (2009)