Study of Freeze-out Dynamics in STAR at RHIC Beam Energy Scan Program

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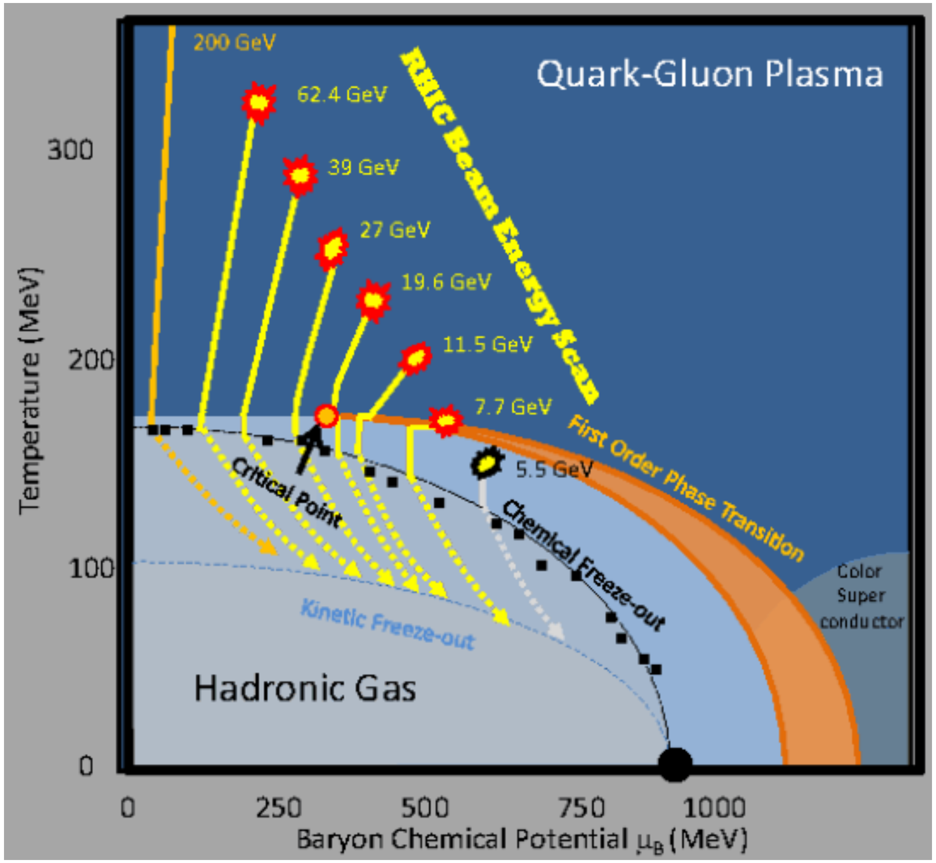
Outline

- Motivation
  Beam Energy Scan (BES) program in STAR at RHIC
- Experimental setup – STAR
- Particle identification method – TPC+TOF
- Transverse momentum spectra
- Energy and centrality dependence of identified particle ratios
- Results on chemical freeze-out parameters
- Summary

Motivation



QCD Phase Diagram

STAR BES proposal: arXiv:1007.2613

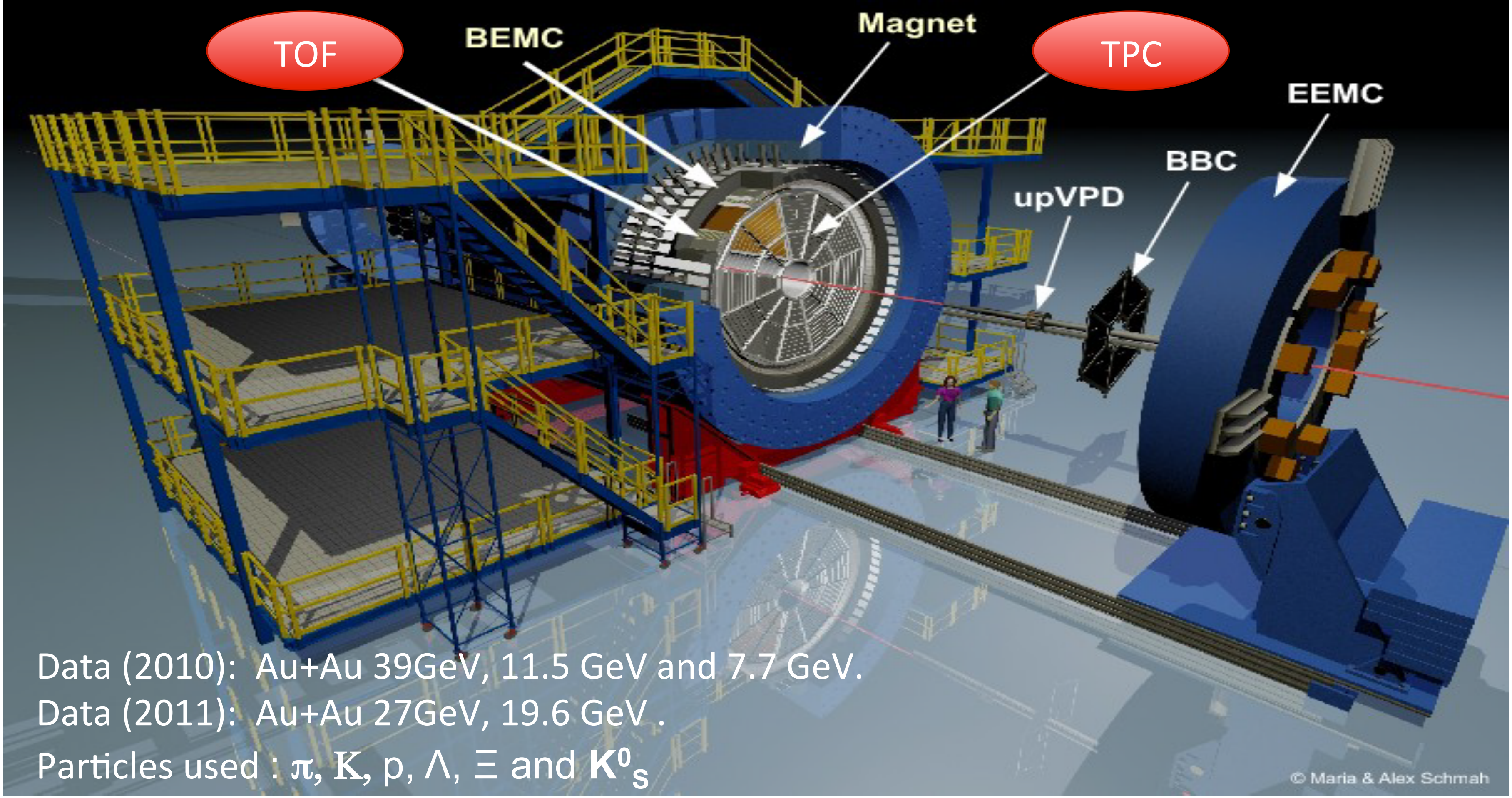
- The main goals of RHIC BES program
  - **To search the possible QCD phase boundary**
  - **To search the possible QCD critical point**

Year	$\sqrt{s_{NN}}$ (GeV)	Minimum bias events (Million)
2010	7.7	~ 4 M
2010	11.5	~ 12 M
2010	39	~ 130 M
2011	27	~ 70 M
2011	19.6	~ 36 M

- The STAR data from BES are used to extract the freeze-out parameters **T and μ_B** from particle ratios to map the QCD phase diagram

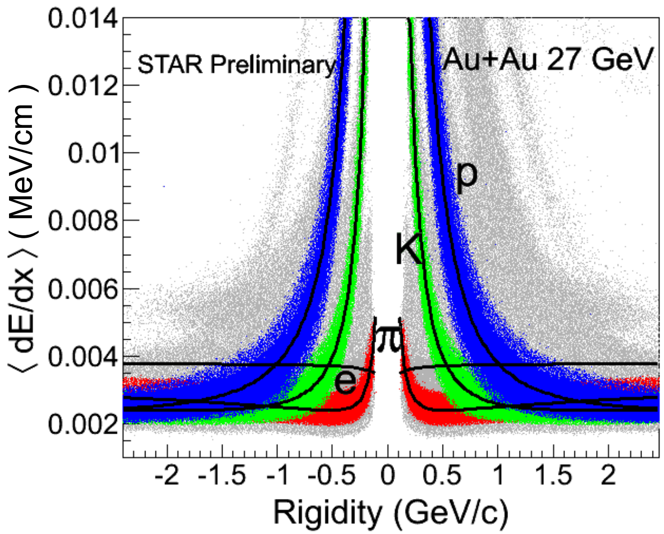
The Solenoidal Tracker At RHIC (STAR)

Full azimuthal particle identification.



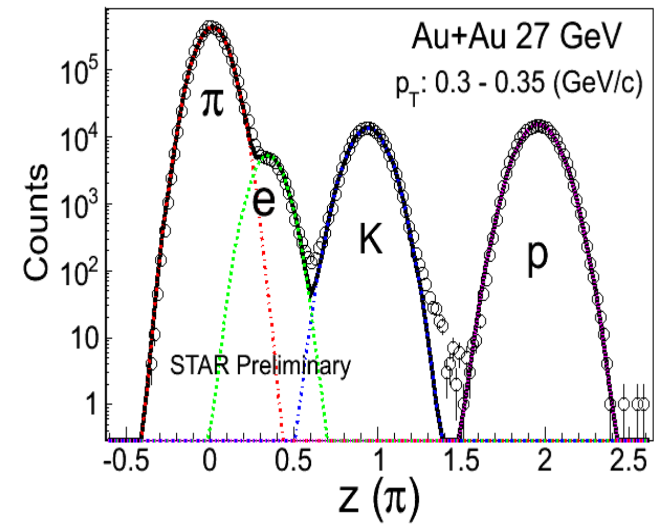
Data (2010): Au+Au 39GeV, 11.5 GeV and 7.7 GeV.
Data (2011): Au+Au 27GeV, 19.6 GeV .
Particles used : π, K, p, Λ, Ξ and K^0_S

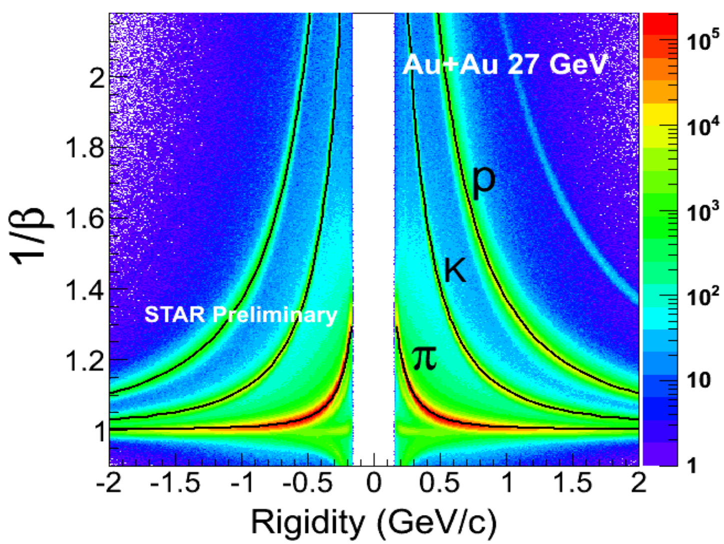
Particle Identification



TPC

$$z = \log\left(\frac{(dE/dx)_{meas.}}{(dE/dx)_{theory}}\right)$$

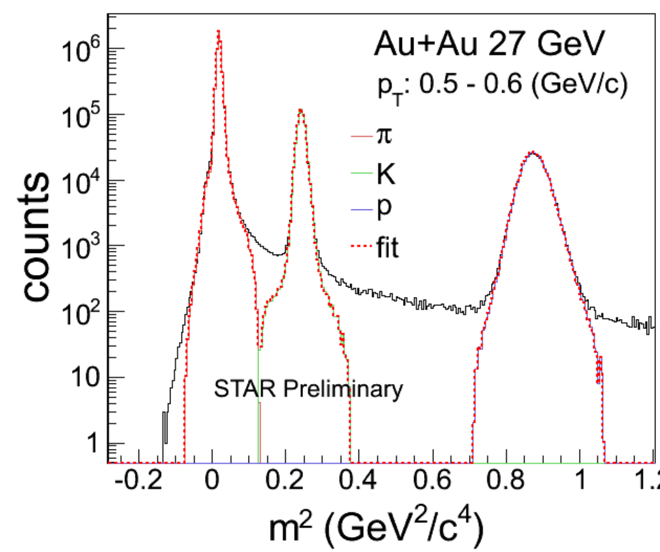




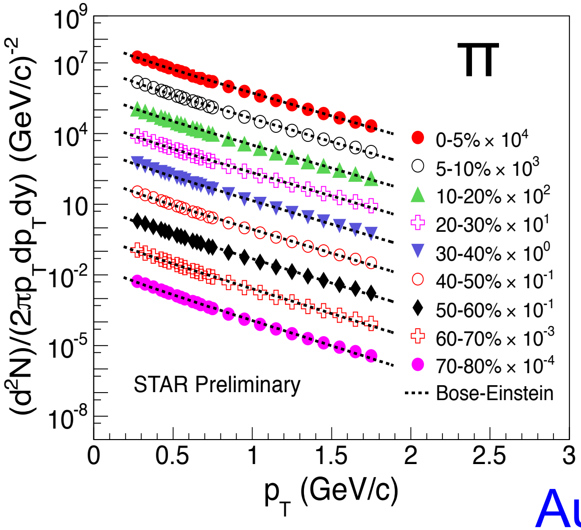
TPC+TOF

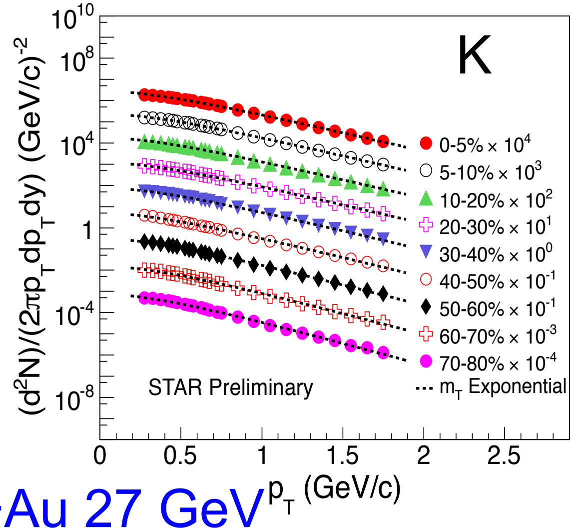
$$m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

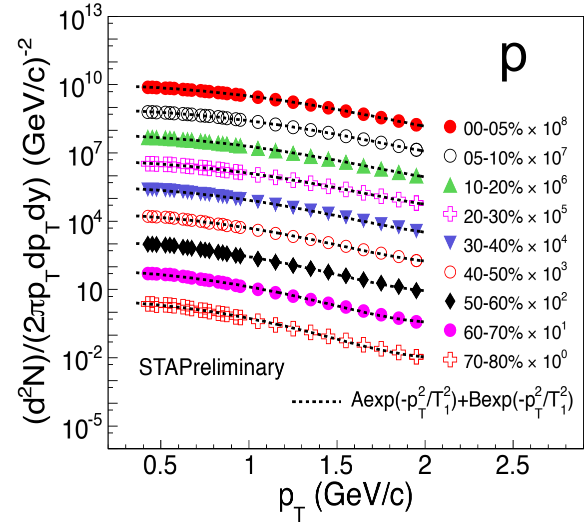
p = momentum
t = time-of-flight
c = velocity of light
L = path length



Transverse Momentum Particle Spectra

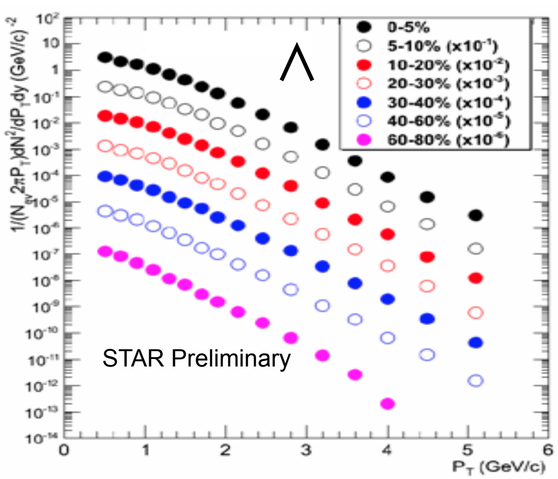




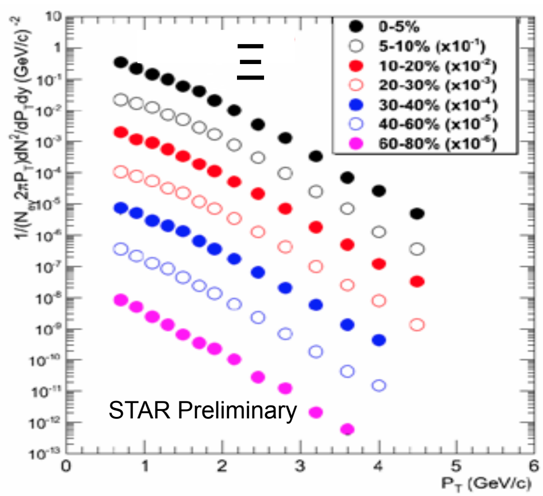


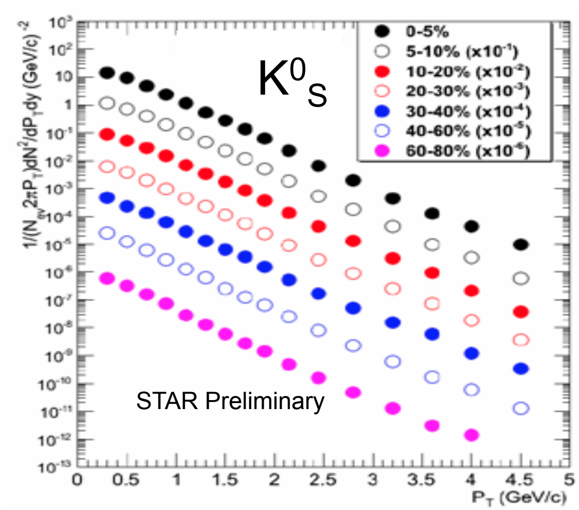
Au+Au 27 GeV

Proton is not feed-down corrected

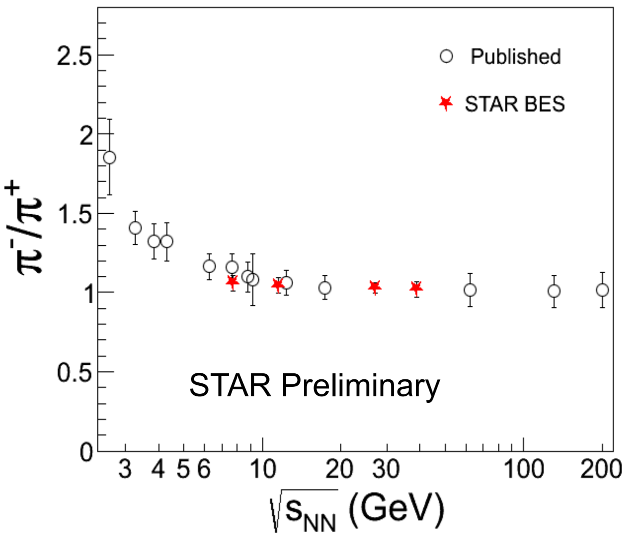


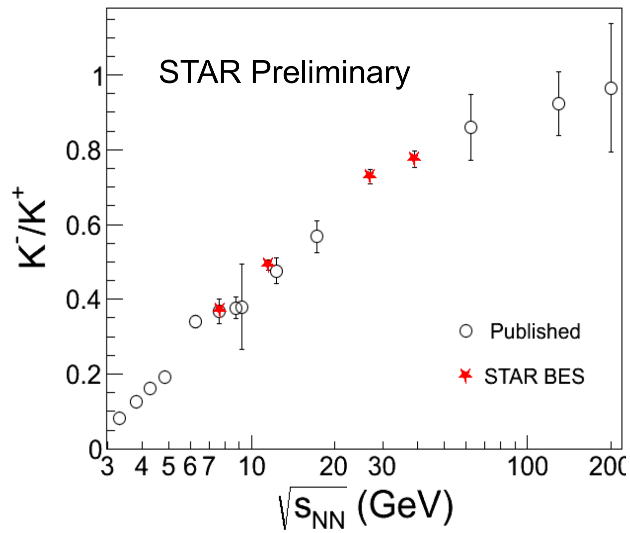
Λ is feed-down corrected

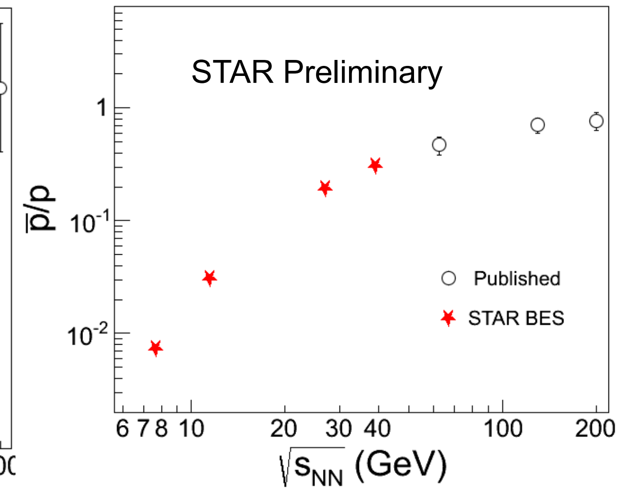




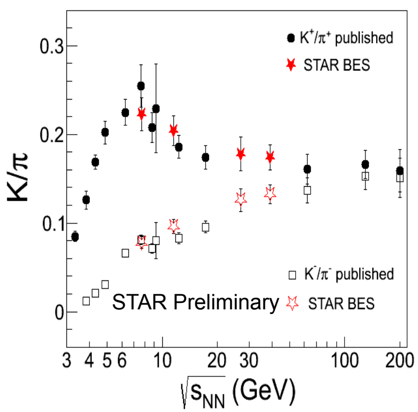
Energy Dependence of Particle Ratios

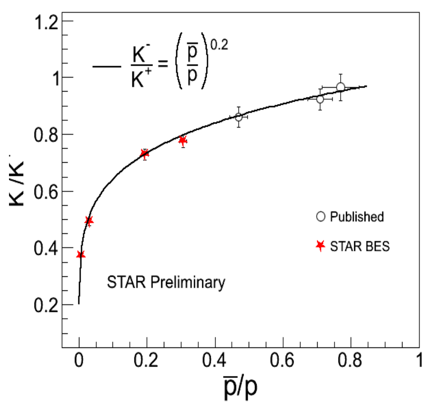






STAR Preliminary



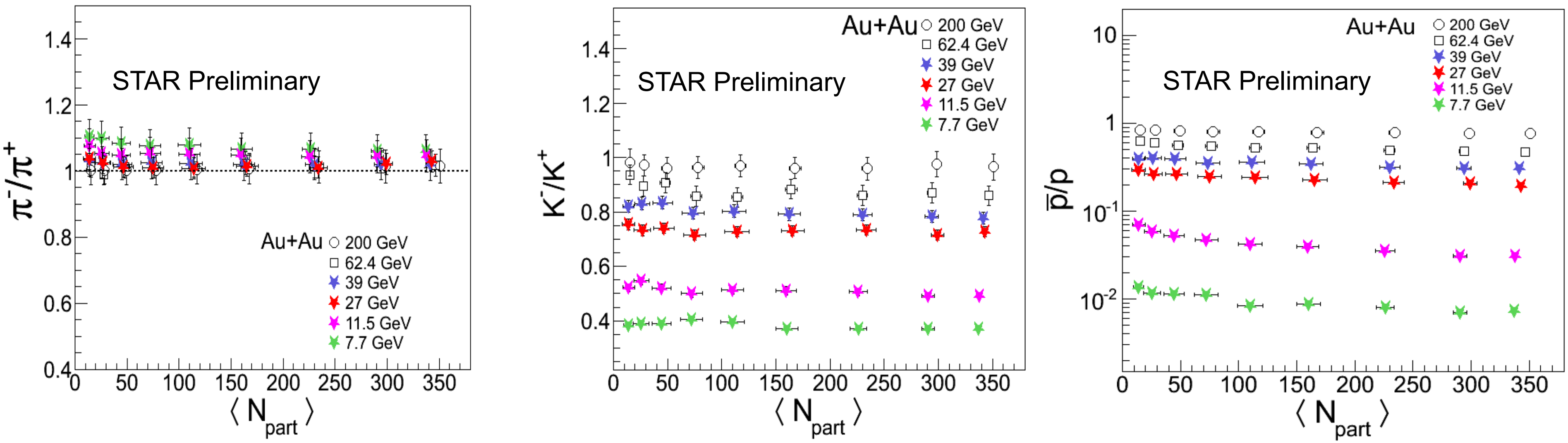


BRAHMS: PRL 90, 102301 (2003)
Becattini et al. PRC 64, 024901 (2001)

Statistical and systematic errors added in quadrature

- Particle ratios at BES energies follows a systematic trend with beam energy
- Correlation between kaon and baryon ratio follows a power law behavior

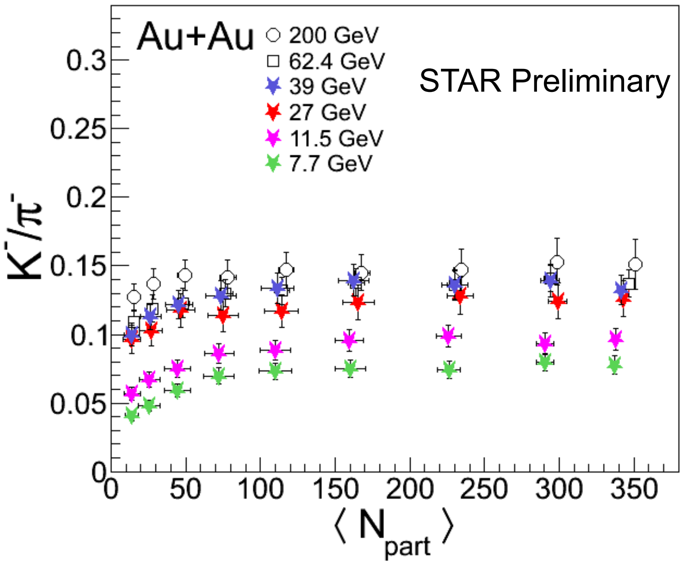
Centrality Dependence of Particle Ratios

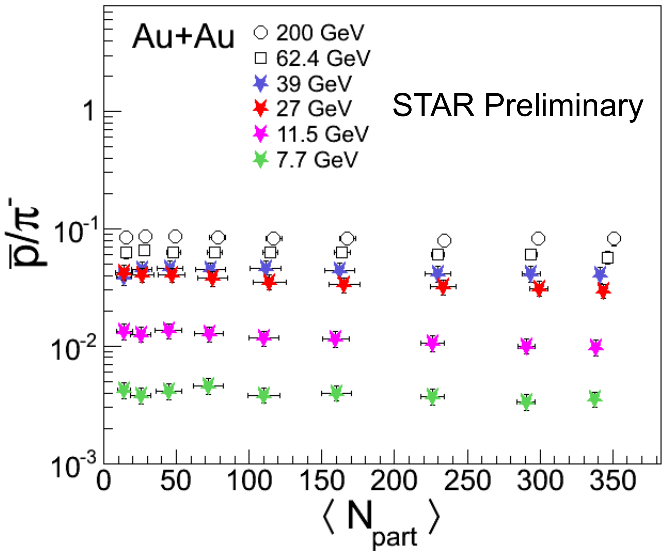


Statistical and systematic errors added in quadrature

- π^-/π^+ ratio is consistent with unity for energies above 11.5 GeV and it slightly increases with decrease in energy below 27 GeV
- $\bar{p}/p$ and K^-/K^+ increases with increase in energy
- $\bar{p}/p$ ratios decreases from peripheral to central bins at all energies

Centrality Dependence of Particle Ratios





Statistical and systematic errors are added in quadrature

- K^-/π^- ratio increases with increase in energy and also it increases from peripheral to central bins

- $\bar{p}/\pi^-$ ratio increases with increase in energy

Chemical Freeze-out

Chemical Freeze-out : Inelastic collision ceases
Particle ratios get fixed

★**THERMUS** : Statistical thermal model
Ensemble used – Grand Canonical and Strangeness Canonical

For Grand Canonical: Quantum numbers (*B, S, Q*) conserved on average

$$n_i = \frac{Tm_i^2 g_i}{2\pi^2} \sum_{k=1}^{\infty} \frac{(\pm 1)^{k+1}}{k} \left(e^{\frac{k\mu_i}{T}} \right) K_2\left(\frac{km_i}{T} \right)$$

To consider incomplete strangeness equilibration:

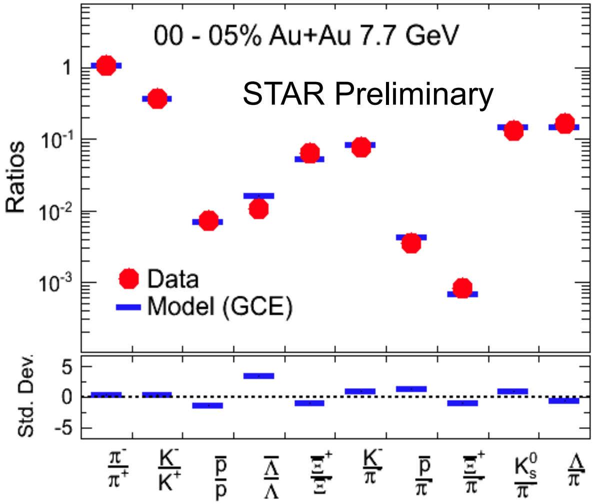
$$n_i \rightarrow n_i \gamma_S^{|S_i|}$$

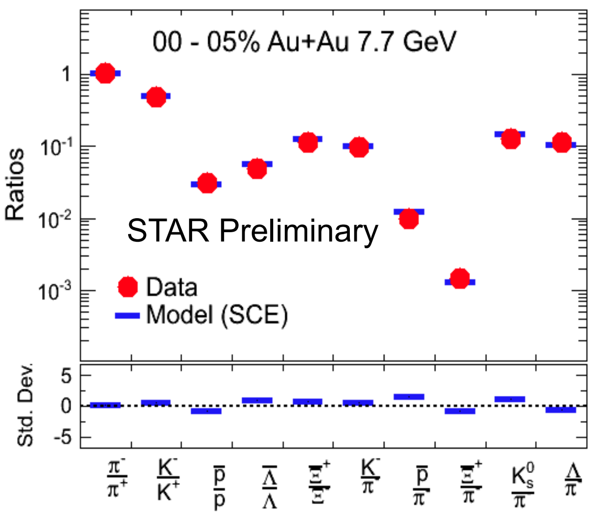
For Strangeness Canonical: Strangeness quantum number (*S*) conserved exactly

Extracted thermodynamic quantities: T_{ch}, μ_B, μ_S and γ_S (strangeness saturation factor)

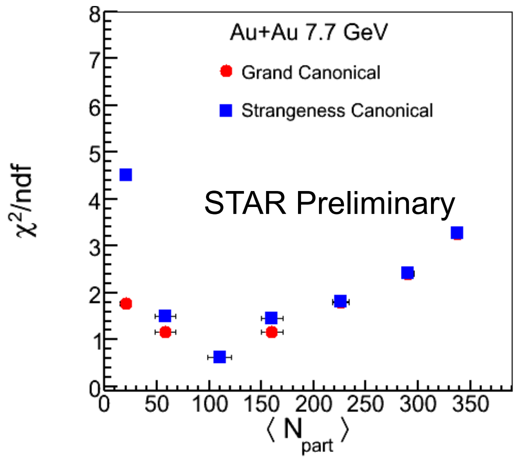
•Thermus, S. Wheaton & Cleymans, Comput. Phys. Commun. 180: 84-106, 2009.

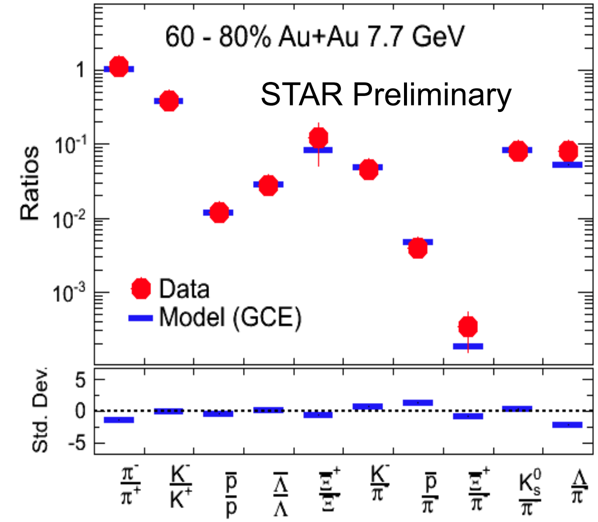
Chemical Freeze-out

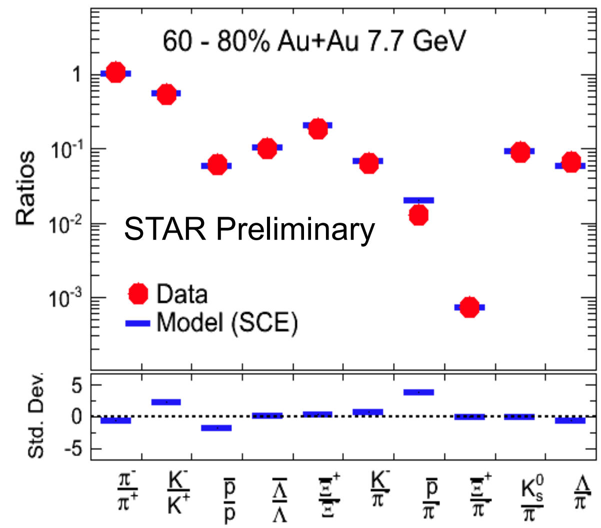




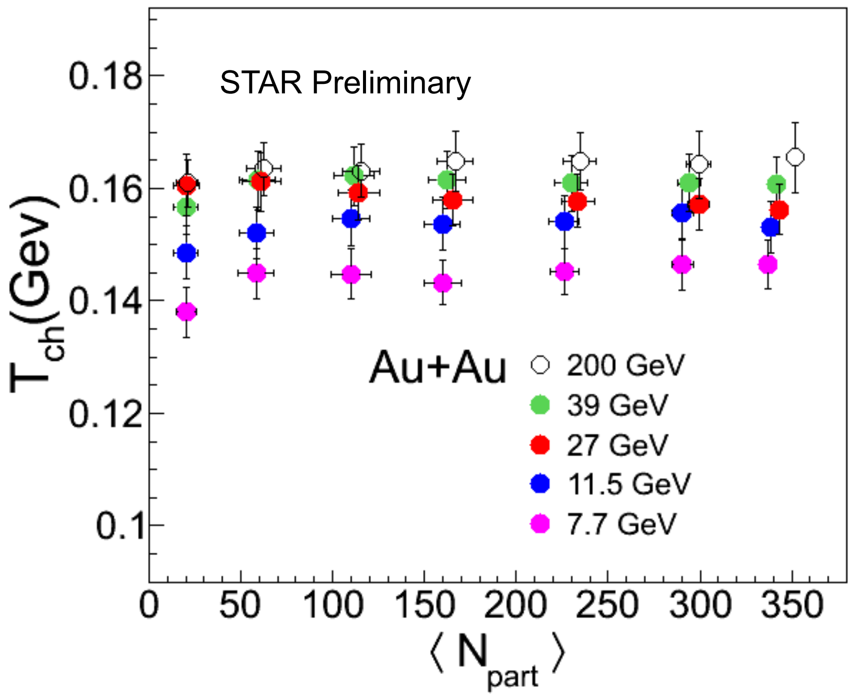
- ✓ Particles used :
  π, K, p, Λ , Ξ , and K^0_s
- ✓ Ensemble used:
  Grand canonical and
  Strangeness canonical
- ✓ Fit parameters:
  T_{ch}, μ_B, μ_s and γ_s
- ✓ BES energies used:
  39, 27, 11.5, and 7.7 GeV

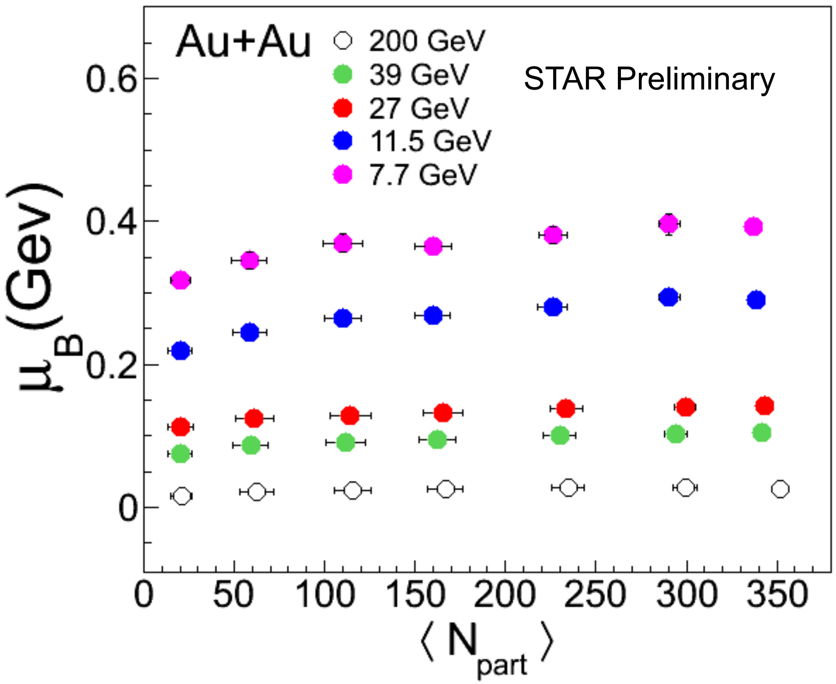






Chemical Freeze-out

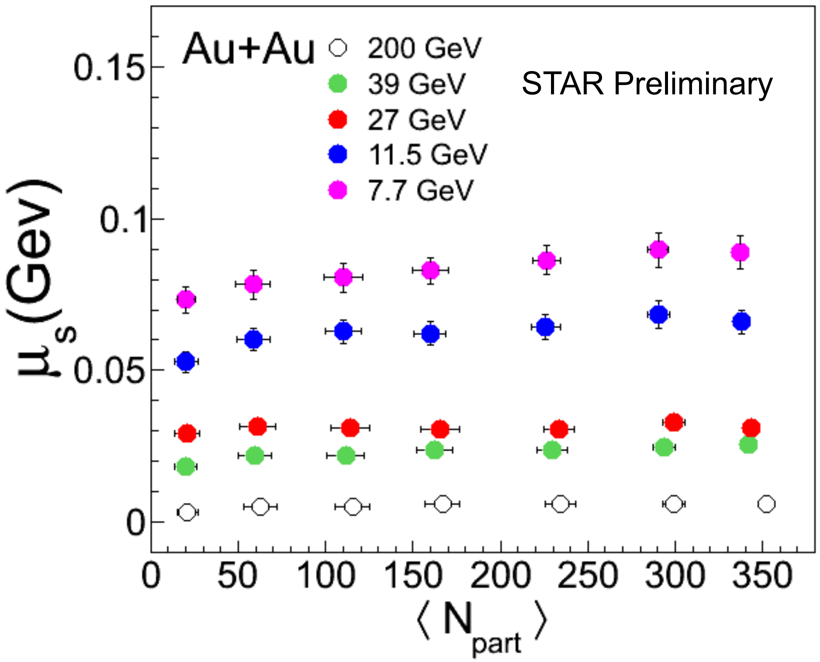


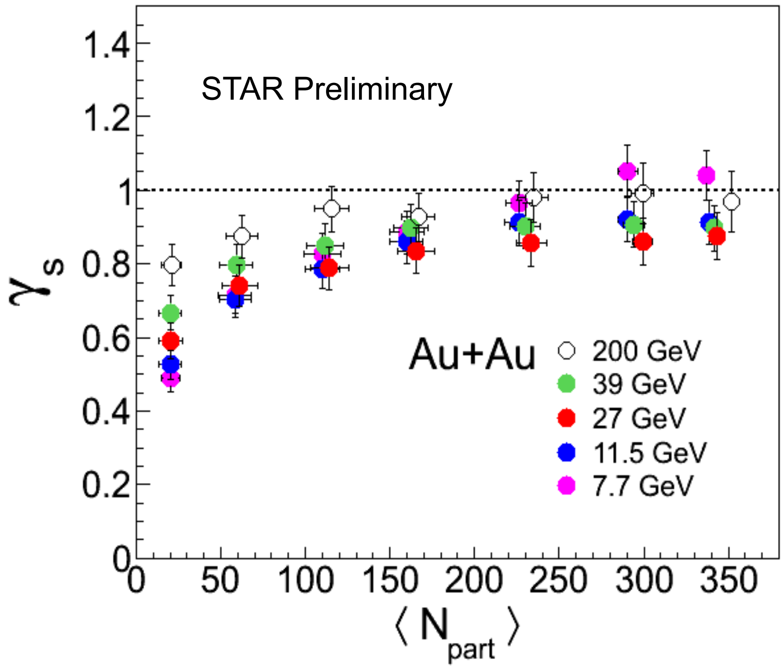


Au+Au 200 GeV : Phys. Rev. C **83** (2011) 24901

- Particles used in the fit: **π, K, p, Λ , Ξ** and **K^0_s**
- Freeze-out results shown from : Grand canonical ensemble
- As collision energy increases chemical freeze-out temperature increases
- Baryon chemical potential decreases with increase in collision energy.

Chemical Freeze-out

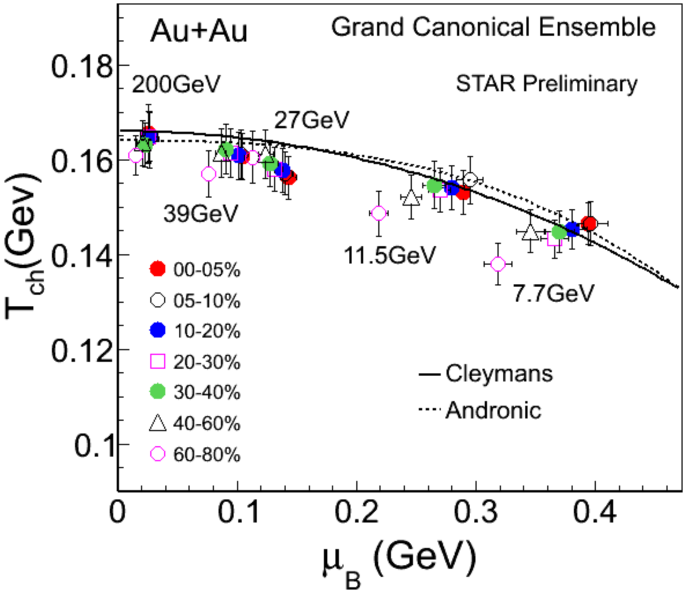




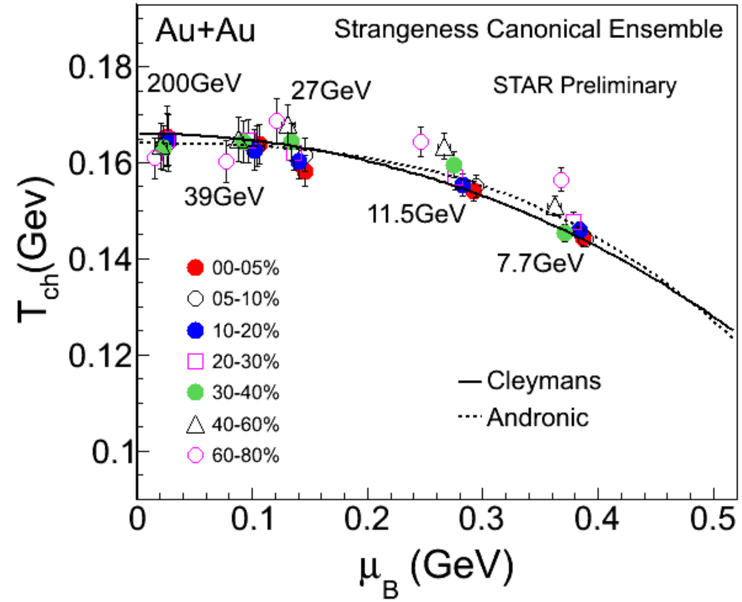
Au+Au 200 GeV : Phys. Rev. C **83** (2011) 24901

- Particles used in the fit : **π, K, p, Λ , Ξ** and **K^0_s**
- Freeze-out results shown from : Grand canonical ensemble
- Strangeness chemical potential decreases with increase in collision energy
- Strangeness saturation factor increases from peripheral to central collisions for all energies

Chemical Freeze-out: T_{ch} vs. μ_B



- ✓ Particles used : π, K, p, Λ , Ξ and K^0_s
- ✓ Ensemble used: **Grand Canonical** and **Strangeness Canonical**
- ✓ Fit parameters: T_{ch}, μ_B, μ_S and γ_S (strangeness saturation factor)



Andronic: NPA 834 (2010) 237
Cleymans: PRC 73 (2006) 034905
Au+Au 200 GeV : Phys. Rev. C **83** (2011) 24901

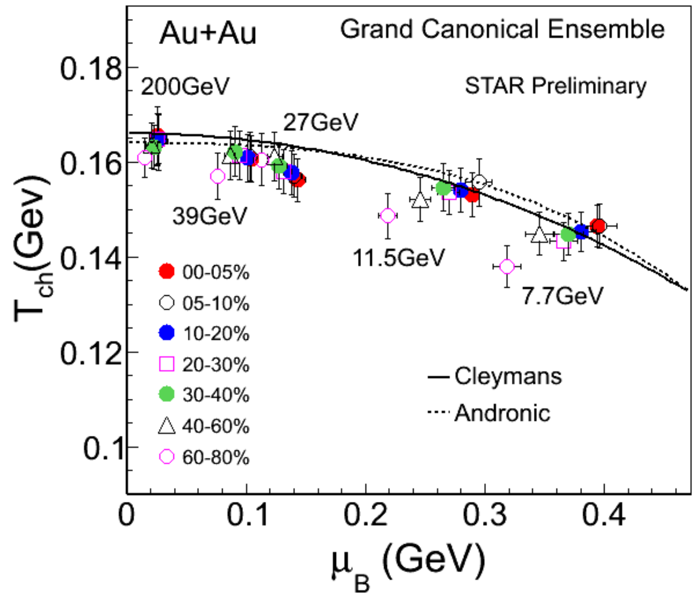
- ➢ We observe a centrality dependence of chemical freeze-out parameters (T_{ch}, μ_B) at lower energies.
- ➢ We are investigating the difference in peripheral region between GCE and SCE and work is going on using particle yields.

Summary

✓ Particle ratios are used to extract the chemical freeze-out parameters which can be used to map the QCD phase diagram

✓ The energy and centrality dependence of particle ratios at BES energies have been presented

✓ New measurements for BES energies (39, 27, 11.5 and 7.7 GeV) at RHIC extend μ_B range from 20 - 400 MeV of the QCD phase diagram



✓ Chemical Freeze-out: Thermus model and particle ratios

Observation of centrality dependence of chemical freeze-out parameters at lower energies

- Central collisions: T_{ch} is comparable in GCE and SCE
- Peripheral collisions: T_{ch} shows disagreement between GCE and SCE. More detailed study is going on.

Thank you