Centrality Dependence of Freeze-out Parameters From the Beam Energy Scan at STAR

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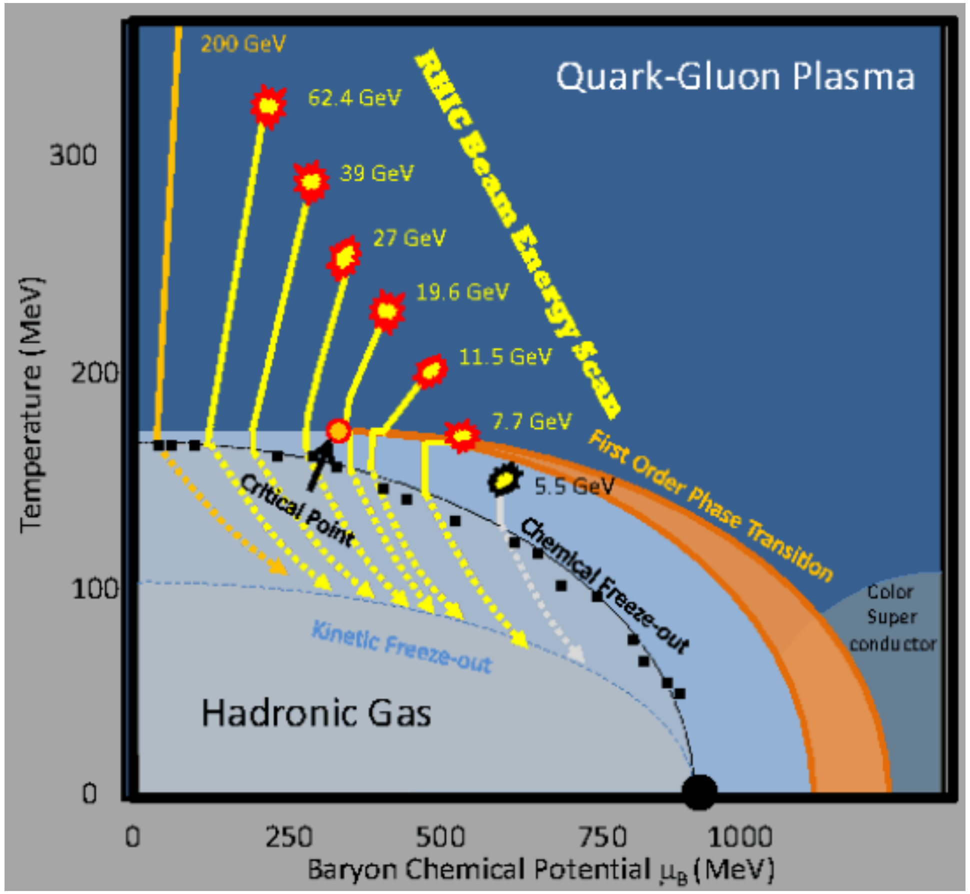
Outline

- Motivation
- Introduction
  - Chemical freeze-out
  - Kinetic freeze-out
- Experimental set-up
- Particle Identification method
- Results on freeze-out parameters
- Summary

Motivation



QCD Phase Diagram

STAR BES proposal: arXiv:1007.2613

- The main goals of RHIC BES program

- To map the QCD phase diagram
- To search the possible QCD phase boundary
- To search the possible QCD critical point

- The STAR data from BES are used to extract the freeze-out parameters T, μ_B and $<\beta>$ from identified particle spectra and ratios

Introduction

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

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

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

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

Introduction

Kinetic Freeze-out : Elastic collision ceases
Transverse momentum spectra get fixed

Blast Wave : Hydrodynamic inspired model

$$\frac{dN}{p_T dp_T} \propto \int_0^R r dr m_T I_0\left(\frac{p_T \sinh \rho(r)}{T_{kin}}\right) \times K_1\left(\frac{m_T \cosh \rho(r)}{T_{kin}}\right)$$

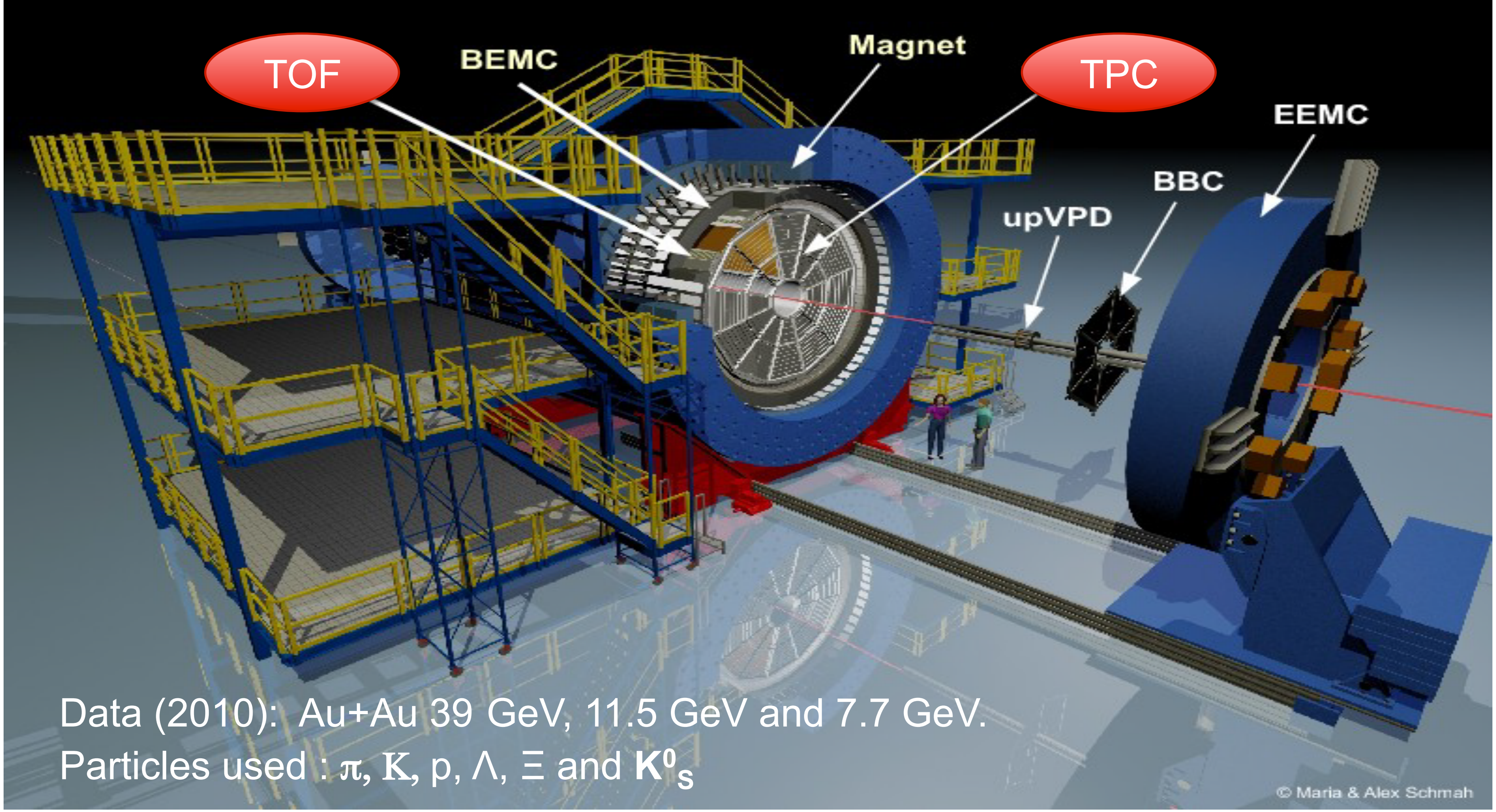
E. Schnedermann et al., Phys. Rev. C 48, 2462 (1993)

Particle spectra are fitted simultaneously

Extracted thermodynamic quantities: T_{kin} and **<β>**

The Solenoid Tracker At RHIC (STAR)

Full azimuthal particle identification.

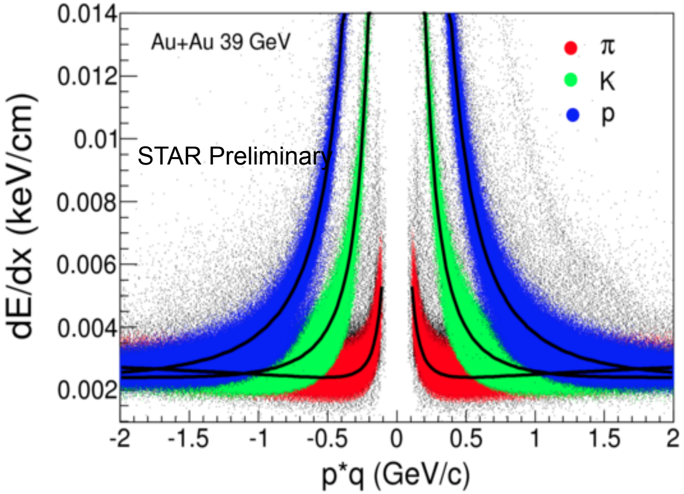


Data (2010): Au+Au 39 GeV, 11.5 GeV and 7.7 GeV.

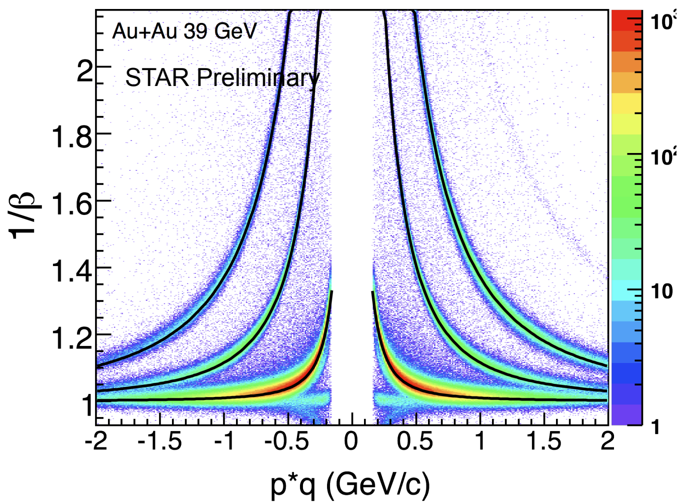
Particles used : π, K, p, Λ, Ξ and K^0_S

Particle Identification

TPC



TPC+TOF

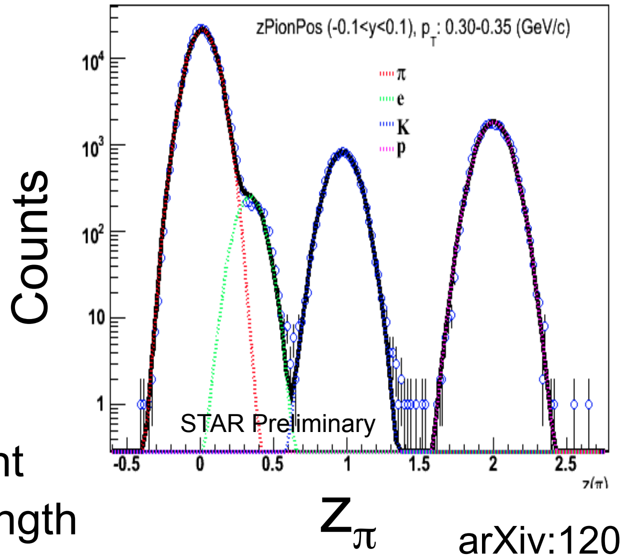


$$z = \log\left(\frac{(dE/dx)_{meas.}}{(dE/dx)_{theory}}\right)$$

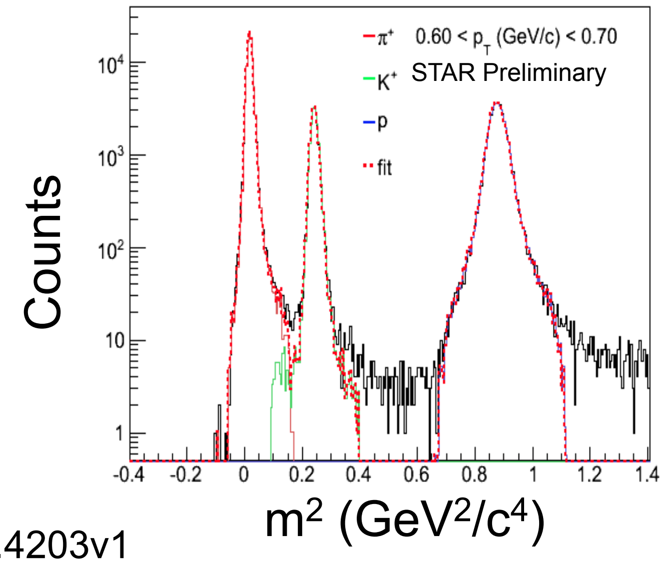
$$m^2 = p^2\left(\frac{c^2t^2}{L^2} - 1\right)$$

p = momentum, t = time-of-flight

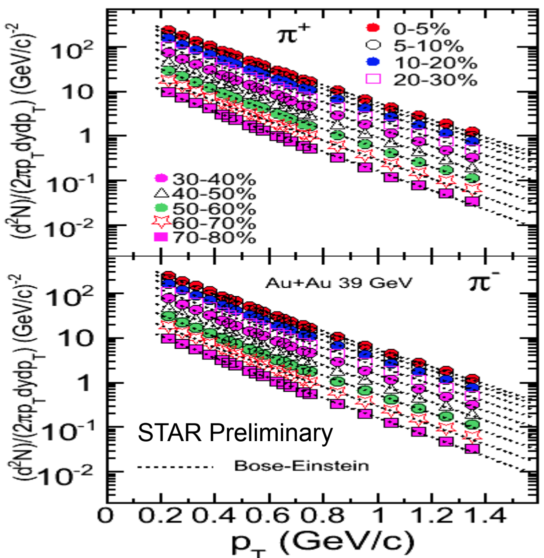
c = velocity of light, L = path length

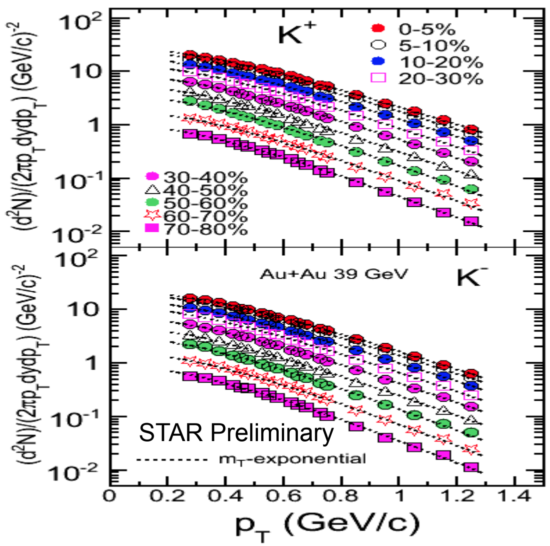


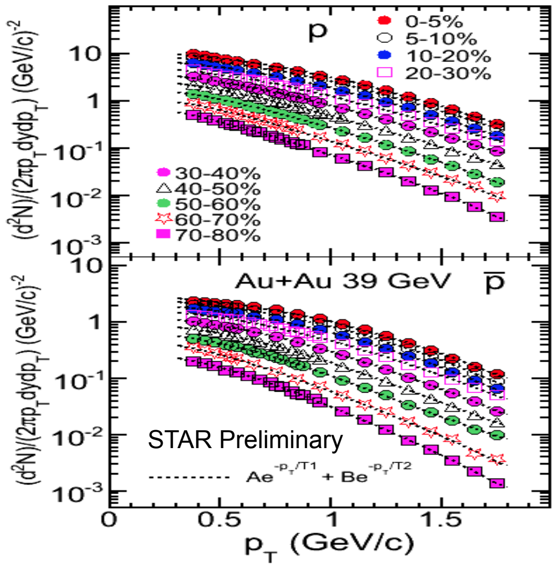
arXiv:1201.4203v1



Particle Spectra



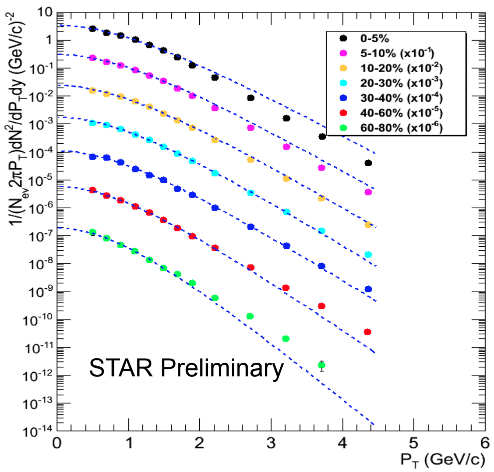




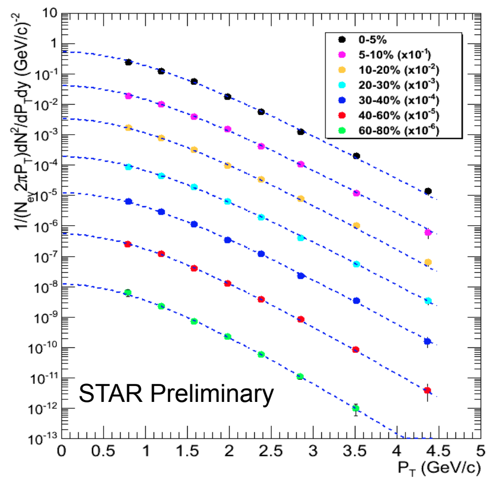
arXiv:1201.4203v1

arXiv:1203.5183

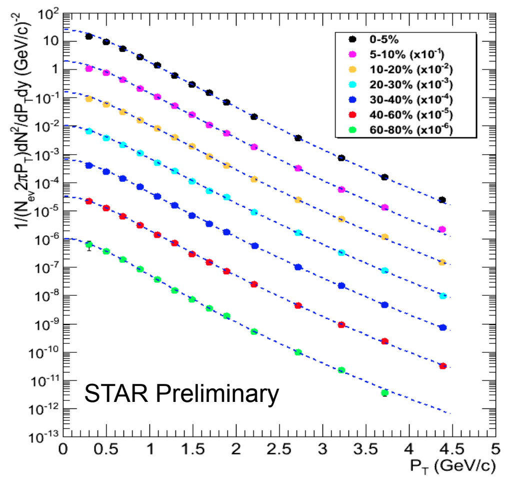
Λ spectra, Au+Au 39 GeV



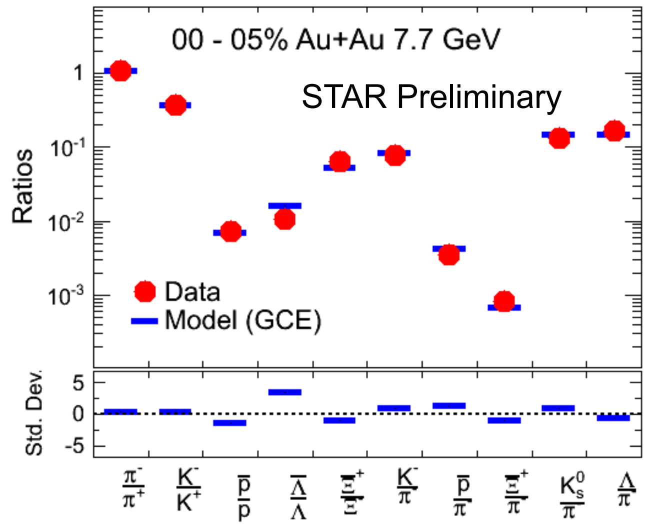
Ξ^- spectra, Au+Au 39 GeV

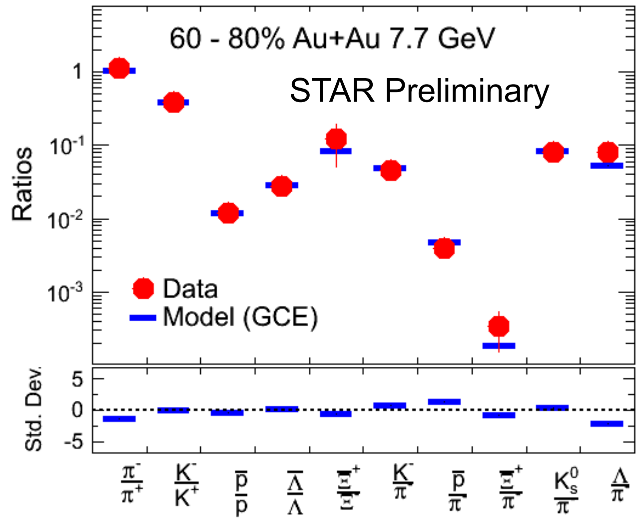


K^0_S spectra, Au+Au 39 GeV

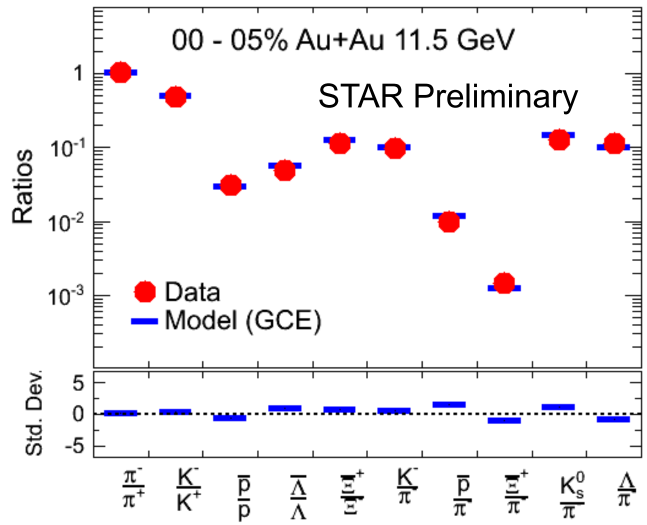


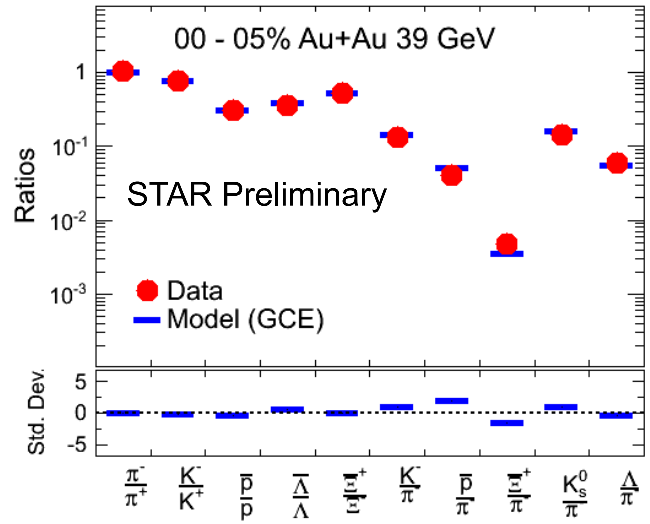
Chemical Freeze-out



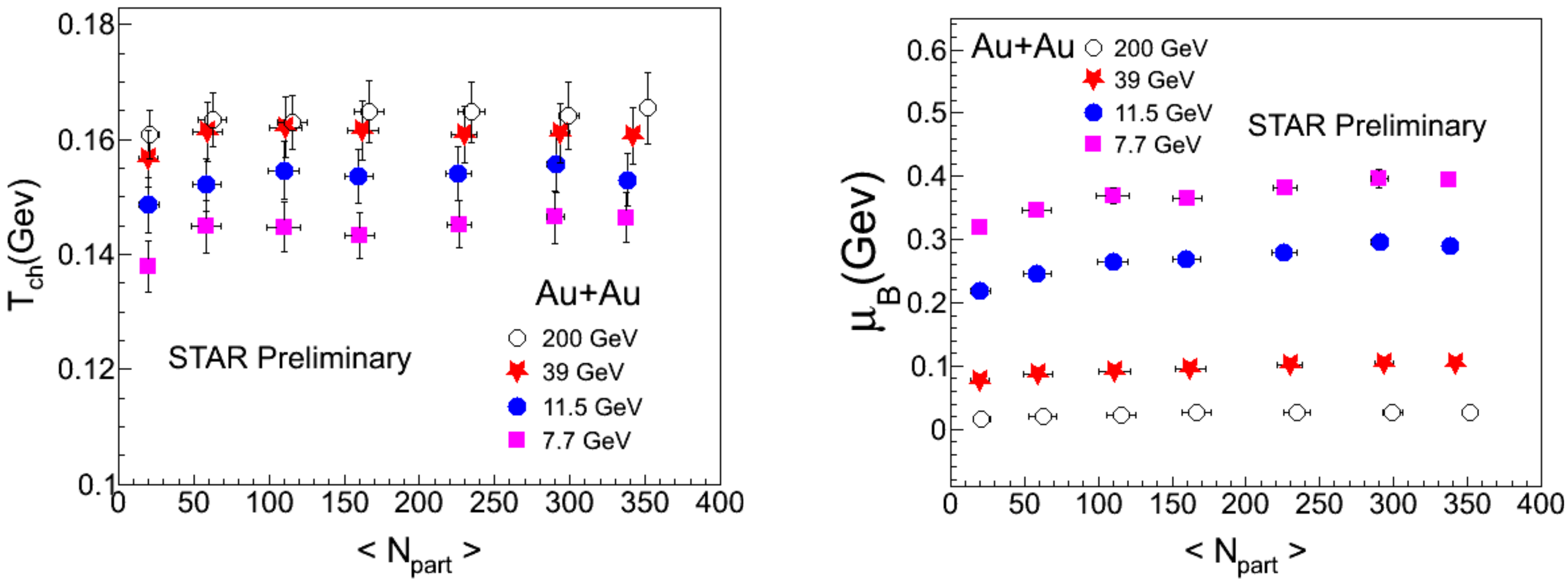


- ✓ Particles used : π, **K, p**, Λ , Ξ and K^0_s
- ✓ Ensemble used: **Grand Canonical**
- ✓ Fit parameters: T_{ch}, μ_B, μ_s and γ_S (strangeness saturation factor)





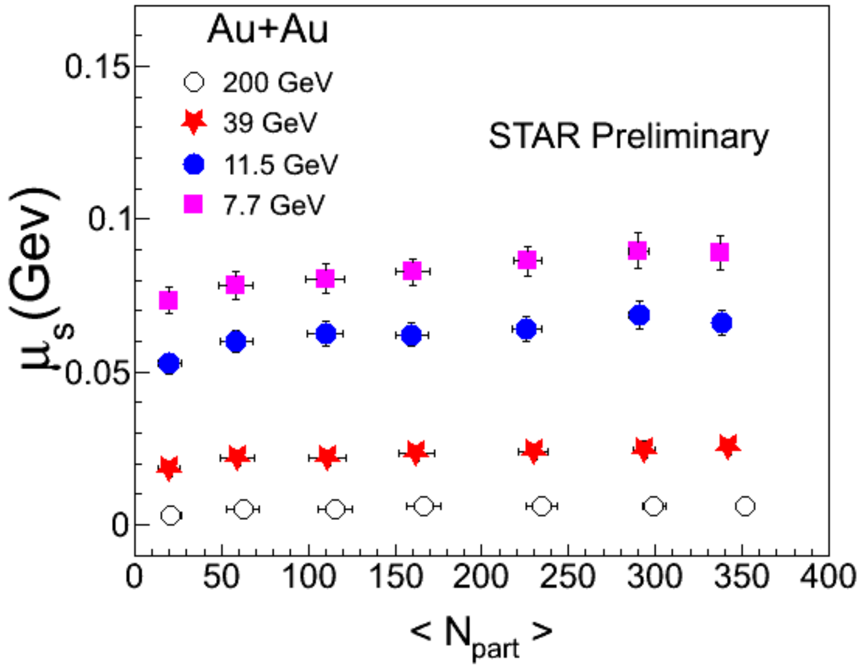
Chemical Freeze-out

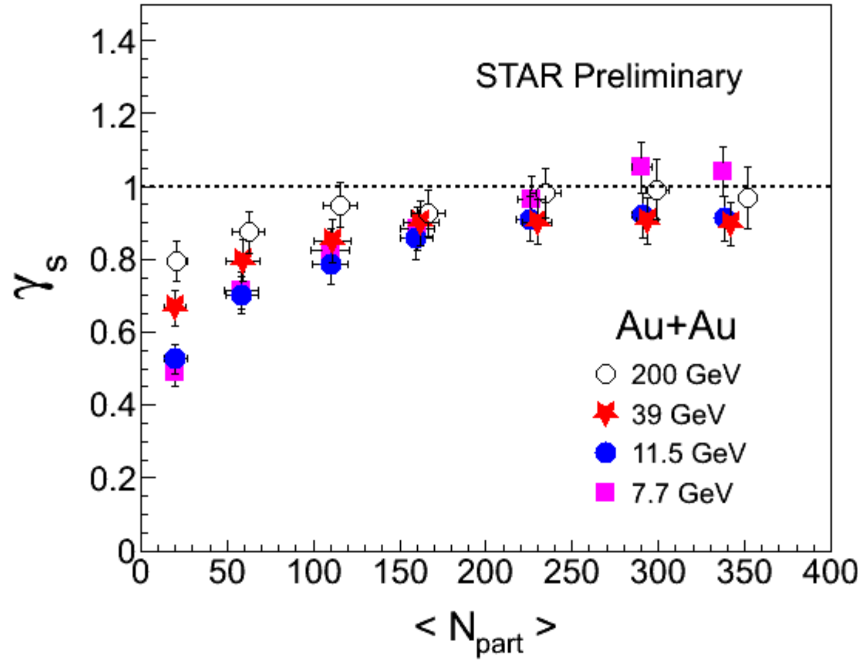


Au+Au 200 GeV : Phys. Rev. C **83** (2011) 24901

- Particles used in the fit: **π, K, p, Λ , Ξ** and **K^0_s**
- Chemical freeze-out temperature increases with increase in collision energy.
- Baryon chemical potential decreases with increase in collision energy.

Chemical Freeze-out

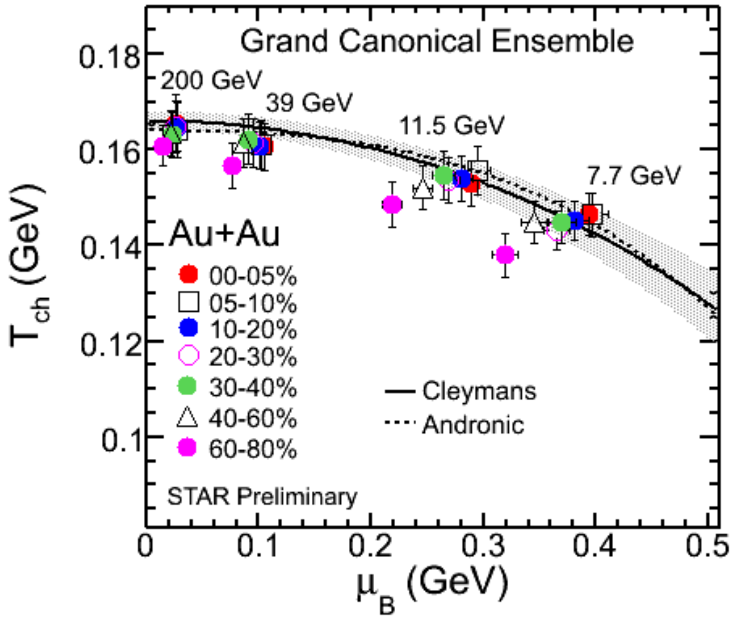




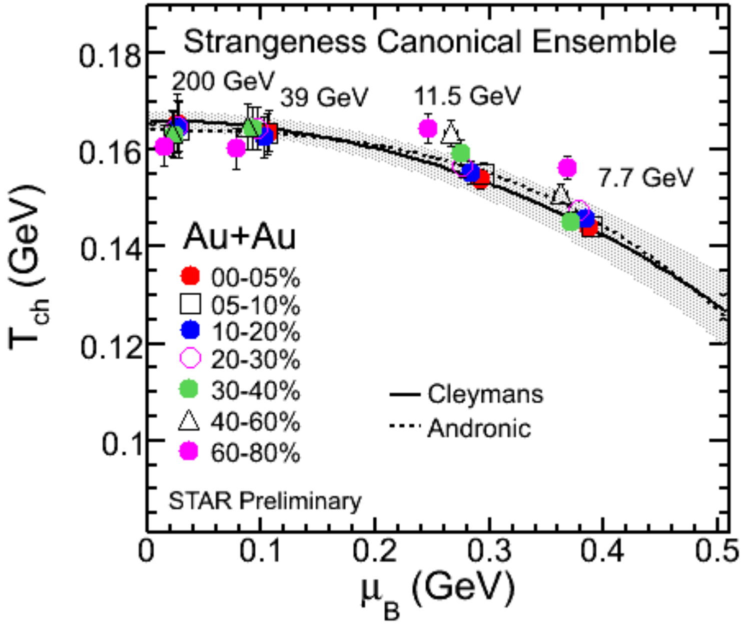
Au+Au 200 GeV : Phys. Rev. C **83** (2011) 24901

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

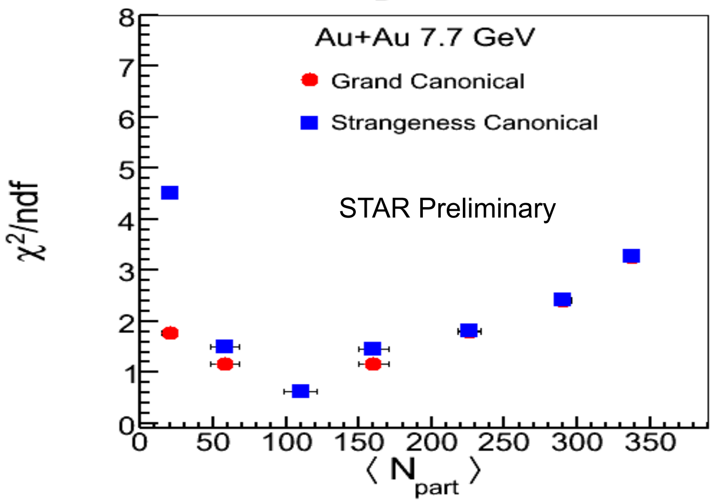
Chemical Freeze-out: T_{ch} vs. μ_B



- ✓ 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

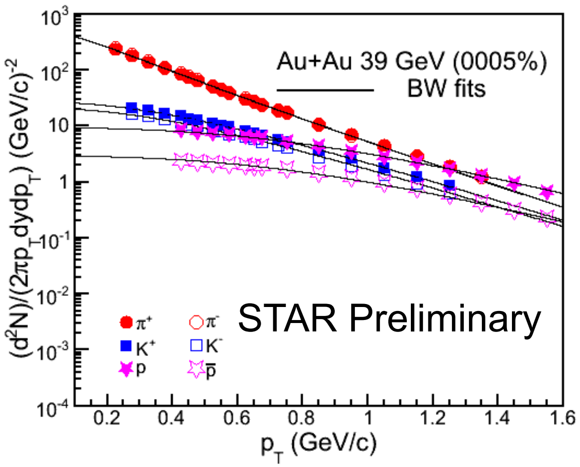


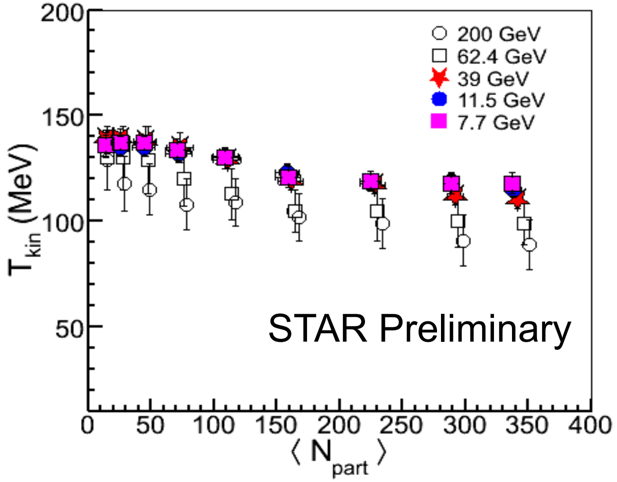
- ➢ We observe a centrality dependence of chemical freeze-out parameters (T_{ch}, μ_B) at lower energies.
- ➢ For peripheral collisions: T_{ch} (SCE) > T_{ch} (GCE)

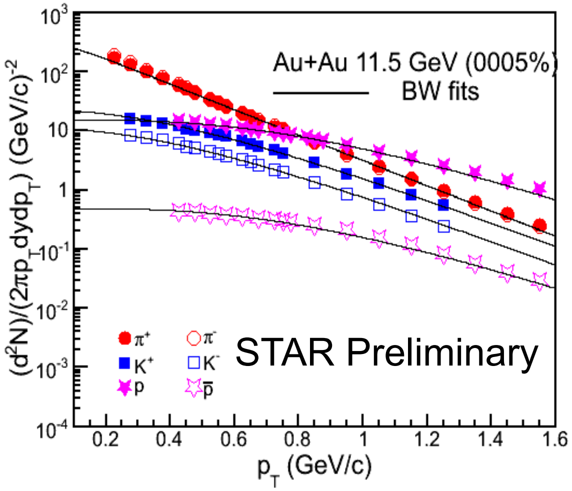
Kinetic Freeze-out: Blast-Wave

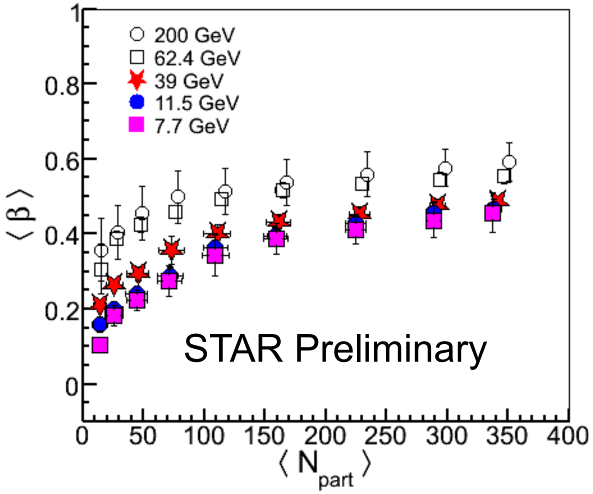
✓ **Blast-Wave Model** is used to fit the spectra

✓ Two main parameters T_{kin} and $< \beta >$



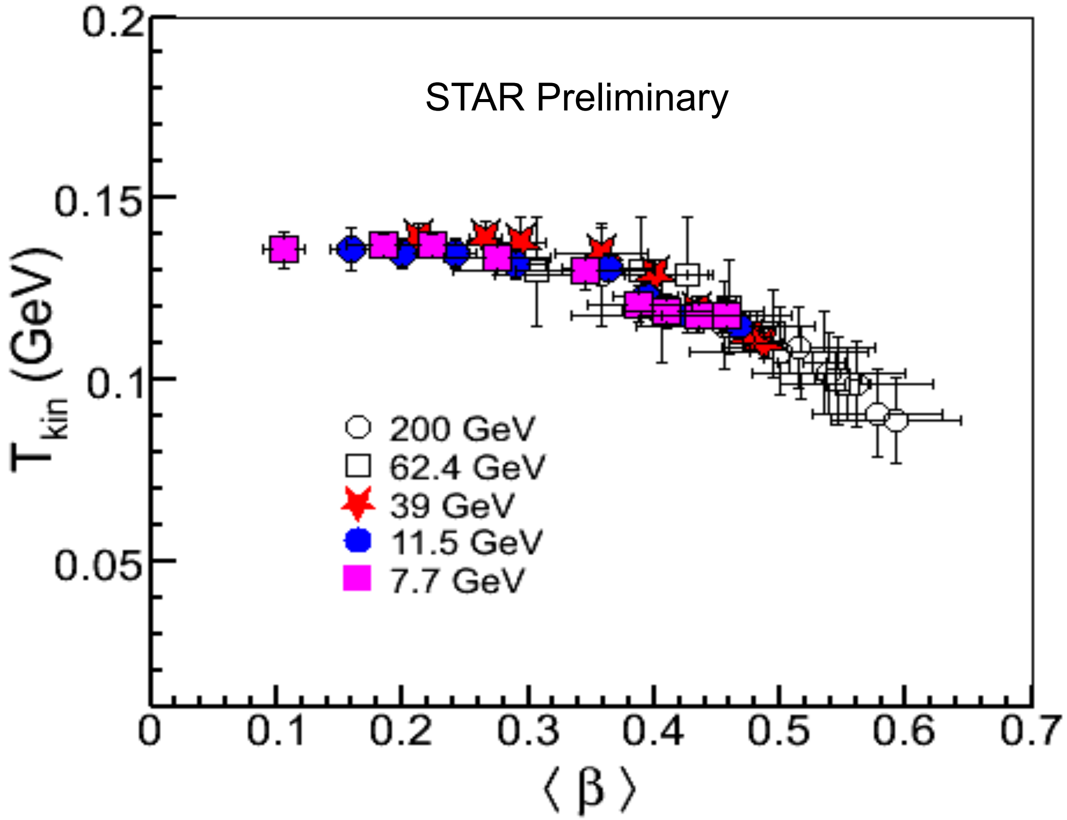






- For central collisions: Low temperature and high flow velocity
- For peripheral collisions: High temperature and low flow velocity

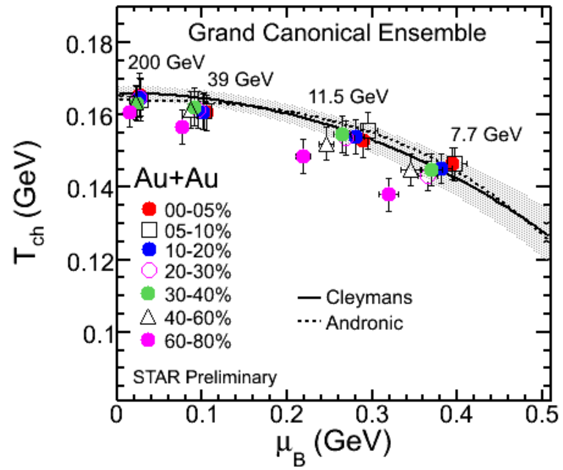
Kinetic Freeze-out: T_{kin} vs. $<\beta>$



- Blast-Wave: Higher kinetic temperature corresponds to lower value of average flow velocity and vice-versa.

Summary

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

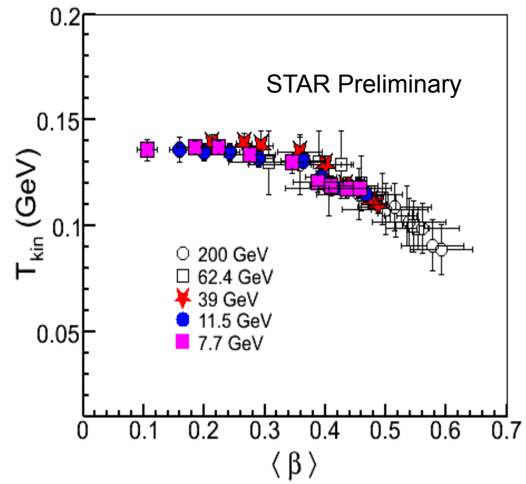


✓ Chemical Freeze-out: Thermus model and particle ratios

First observation of centrality dependence of chemical freeze-out parameters at lower energies
- Central collisions: GCE and SCE ~ T_{ch}
- Peripheral collisions: T_{ch} (SCE) > T_{ch} (GCE) and χ^2/ndf (SCE) > χ^2/ndf (GCE) at low energies

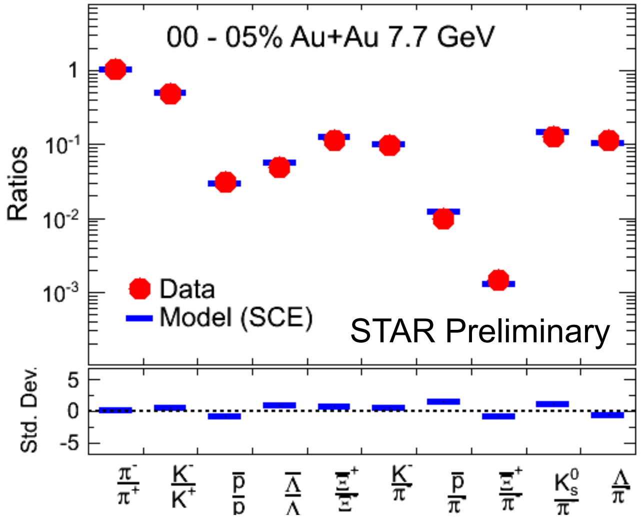
✓ Kinetic Freeze-out: Blast-Wave model and Particle p_T spectra

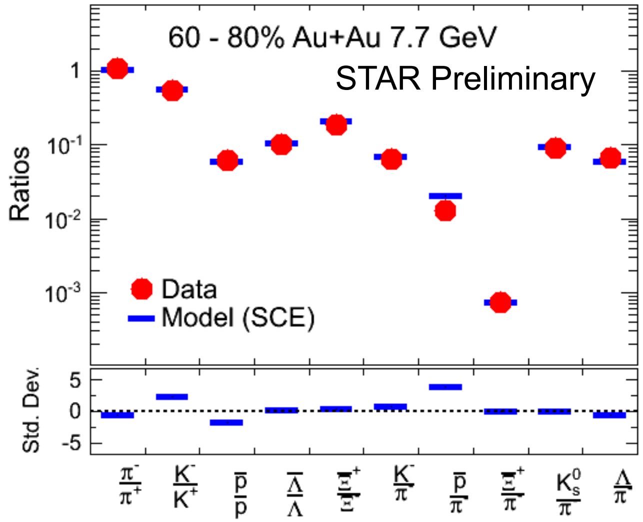
- Central collisions: Low T_{kin} and high $<\beta>$
- Peripheral collisions: High T_{kin} and low $<\beta>$

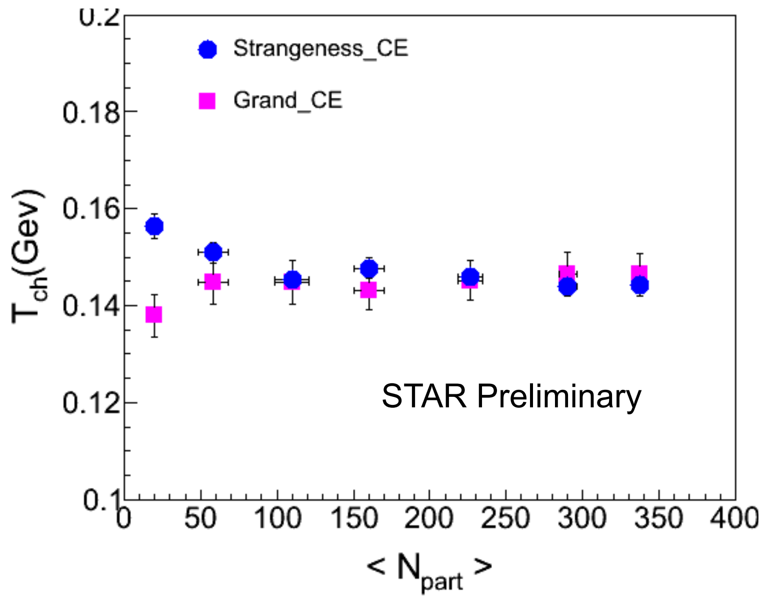


THANK YOU

Back up


00 - 05% Au+Au 7.7 GeV
Ratios
Data
Model (SCE)
STAR Preliminary
Std. Dev.


60 - 80% Au+Au 7.7 GeV
STAR Preliminary
Ratios
Data
Model (SCE)
Std. Dev.


Strangeness_CE
Grand_CE
T_{ch}(Gev)
STAR Preliminary
< N_{part} >