BERKELEY LAB

Chemical Pro

and Kinetic
perties at

Freeze-out RHIC

STAR

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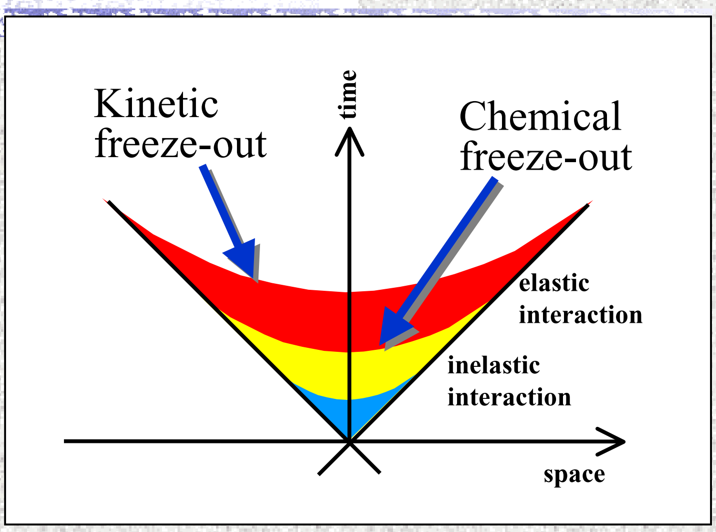
for the STAR Collaboration,

LBNL

Kinetic and Chemical Freeze-out



- Kinetic freeze-out
  - End of elastic interactions
  - Particle momenta are frozen

  ⇔ Transverse momentum distribution

Ref. E. Schnedermann et al., PRC48(1993)2462

- Chemical freeze-out
  - End of inelastic interactions
  - Number of each particle species is frozen

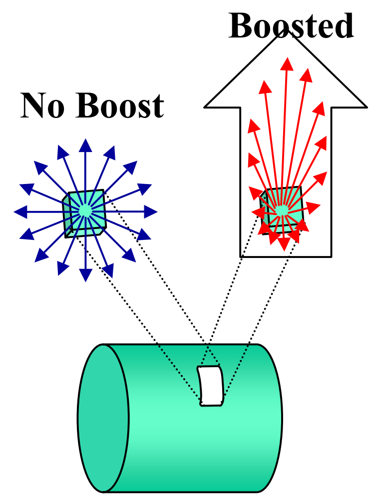
  ⇔ Particle ratios

Refs. J.Rafelski, PLB(1991)333
J.Sollfrank et al., PRC59(1999)1637

Blast Wave Model

E. Schnedermann, J.Sollfrank, U. Heinz, PRC48(1993)2462

- Source is
  - Locally thermally equilibrated
  - Boosted



$$E\frac{d^3n}{dp^3} \propto \int_\sigma e^{-(u^\nu p_\nu)/T_{th}} p^\lambda d\sigma_\lambda$$

$$u^\nu(t,r,z=0) = (\cosh\rho, \vec{e}_r \sinh\rho, 0)$$

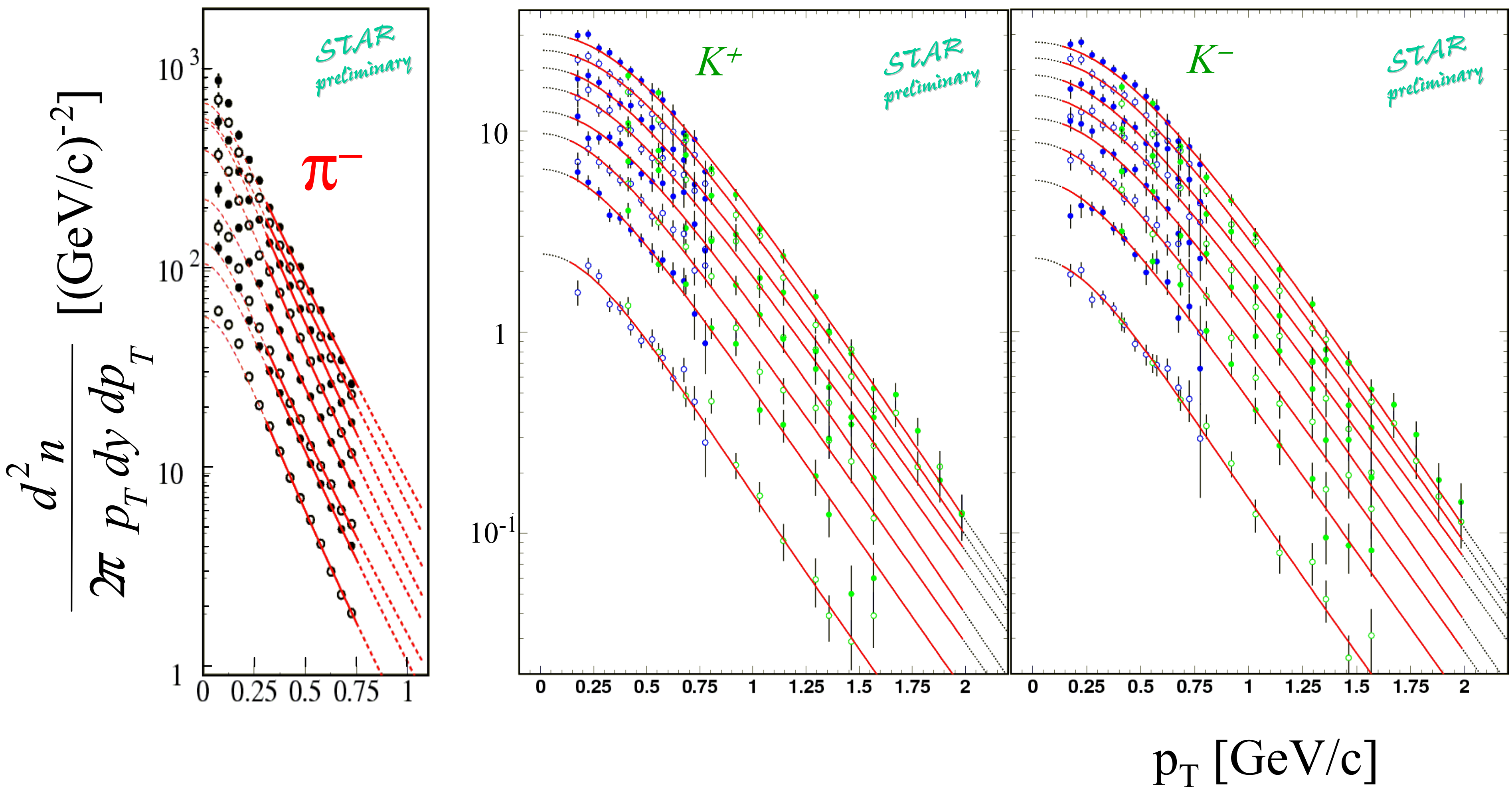
$$\rho = \tanh^{-1}\beta_r$$

$$\beta_r = \beta_s\ f(x,p) = \beta_s (r/R)^n$$

$$\frac{dn}{m_T dm_T} \propto \int_0^R r\,dr\, m_T K_1\left(\frac{m_T\cosh\rho}{T_{th}}\right) I_0\left(\frac{p_T\sinh\rho}{T_{th}}\right)$$

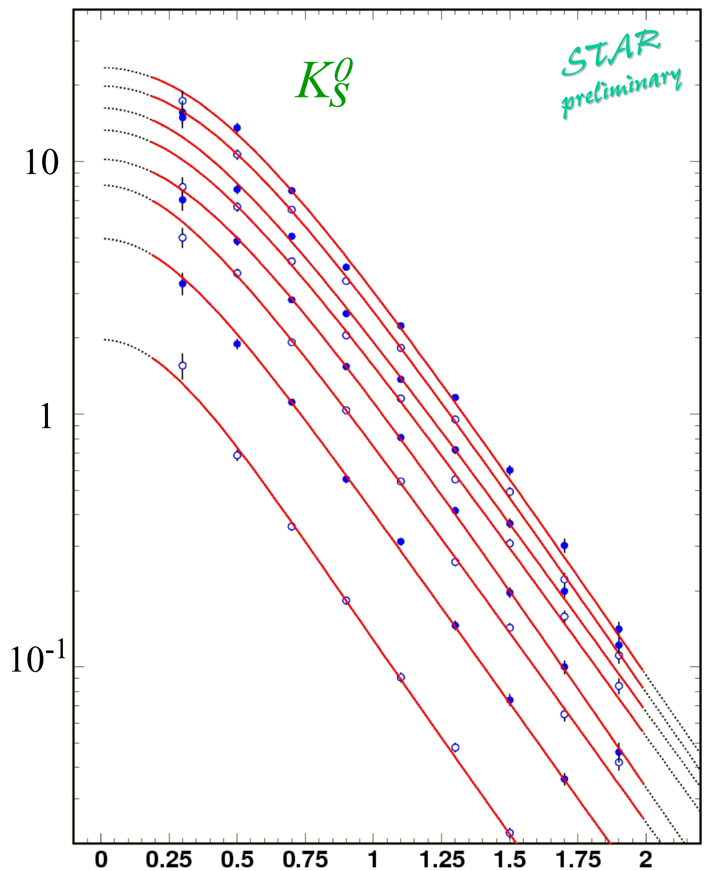
Compare p_T spectra to experimental data

Model Fit to 130

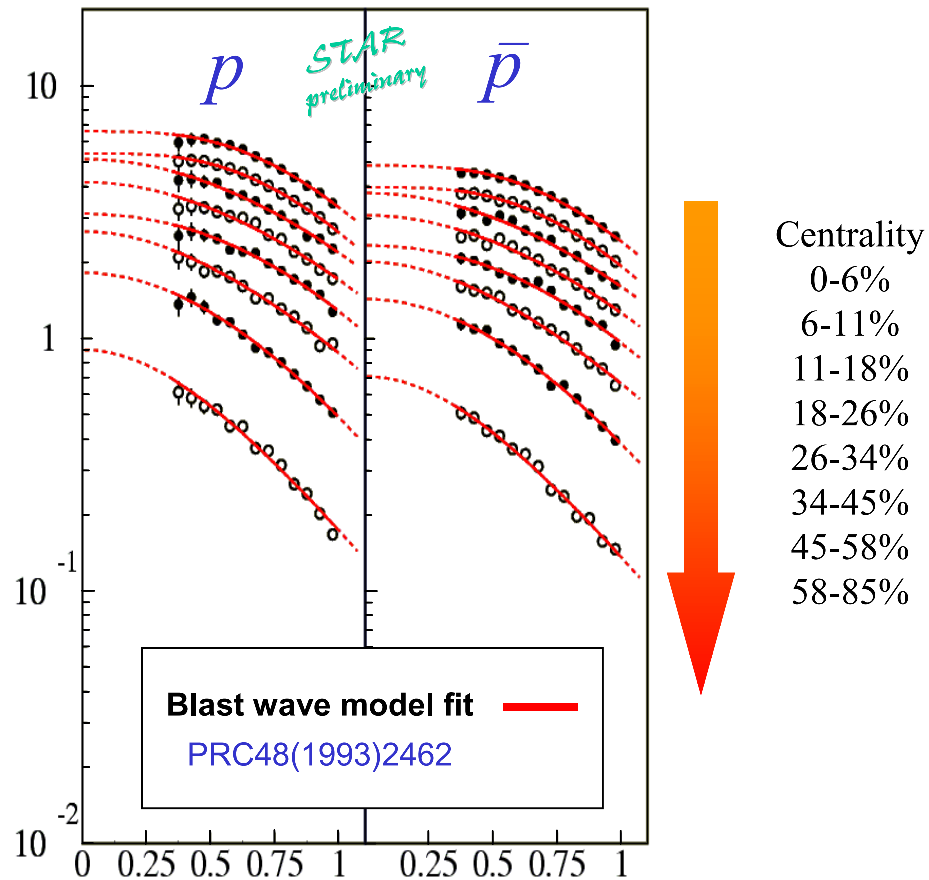


Blast wave model describes data very well

GeV Data

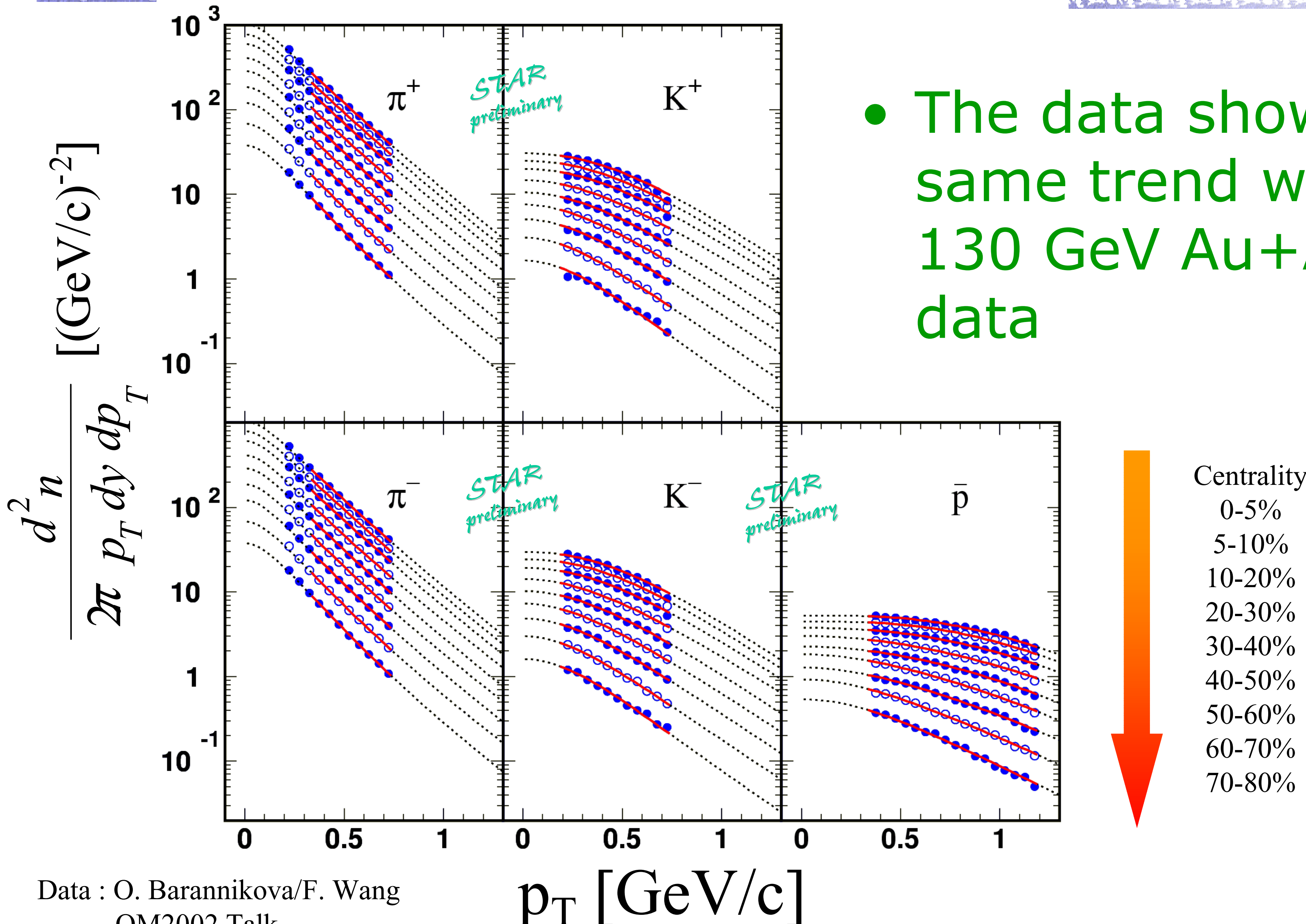


K_S^0
STAR preliminary
10
1
10^-1
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2



p
STAR preliminary
$\bar{p}$
10
1
10^-1
10^-2
0 0.25 0.5 0.75 1
0.25 0.5 0.75 1
Blast wave model fit
PRC48(1993)2462
Centrality
0-6%
6-11%
11-18%
18-26%
26-34%
34-45%
45-58%
58-85%

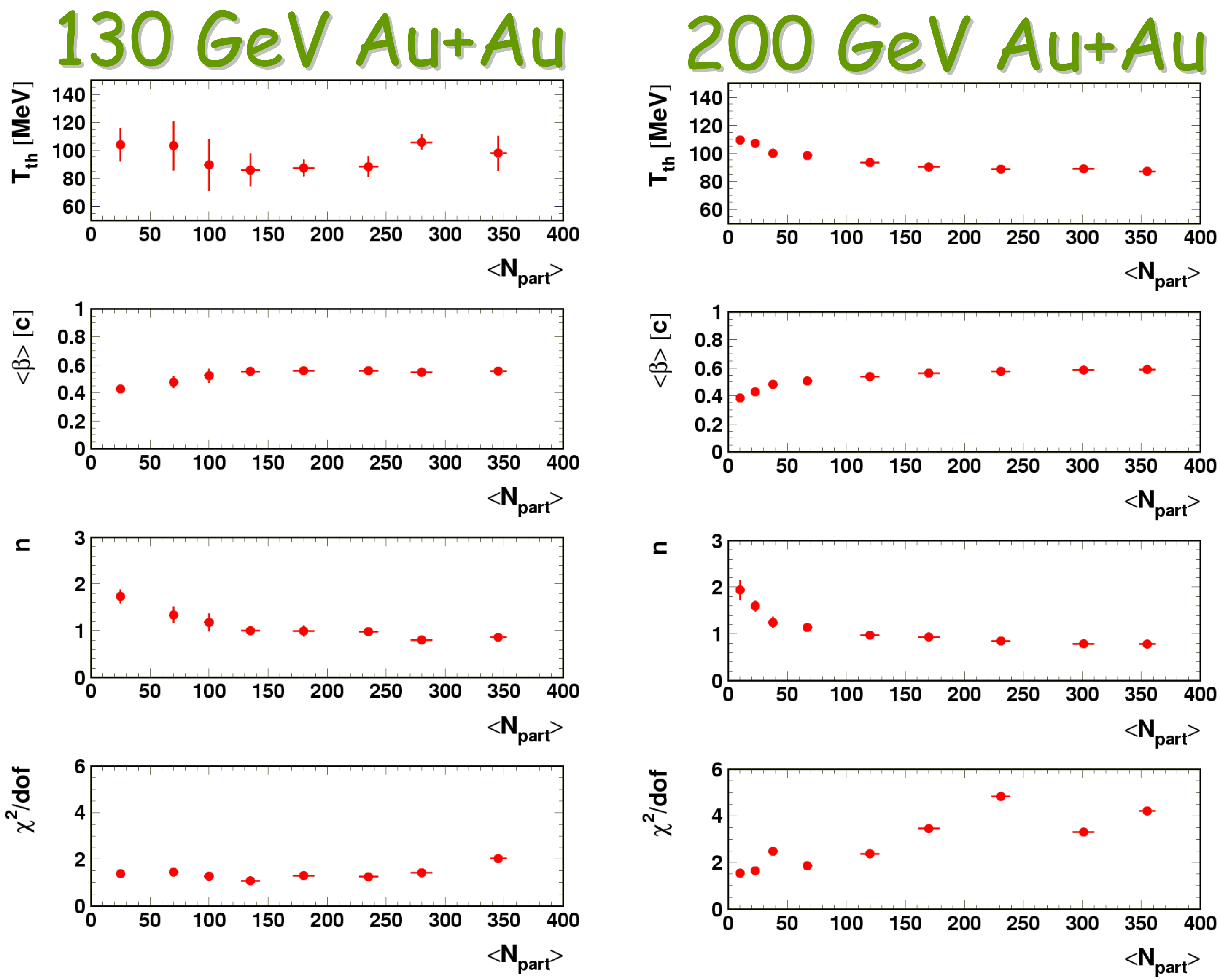
Model Fit to 200 GeV Au+Au Data



- The data show same trend with 130 GeV Au+Au data

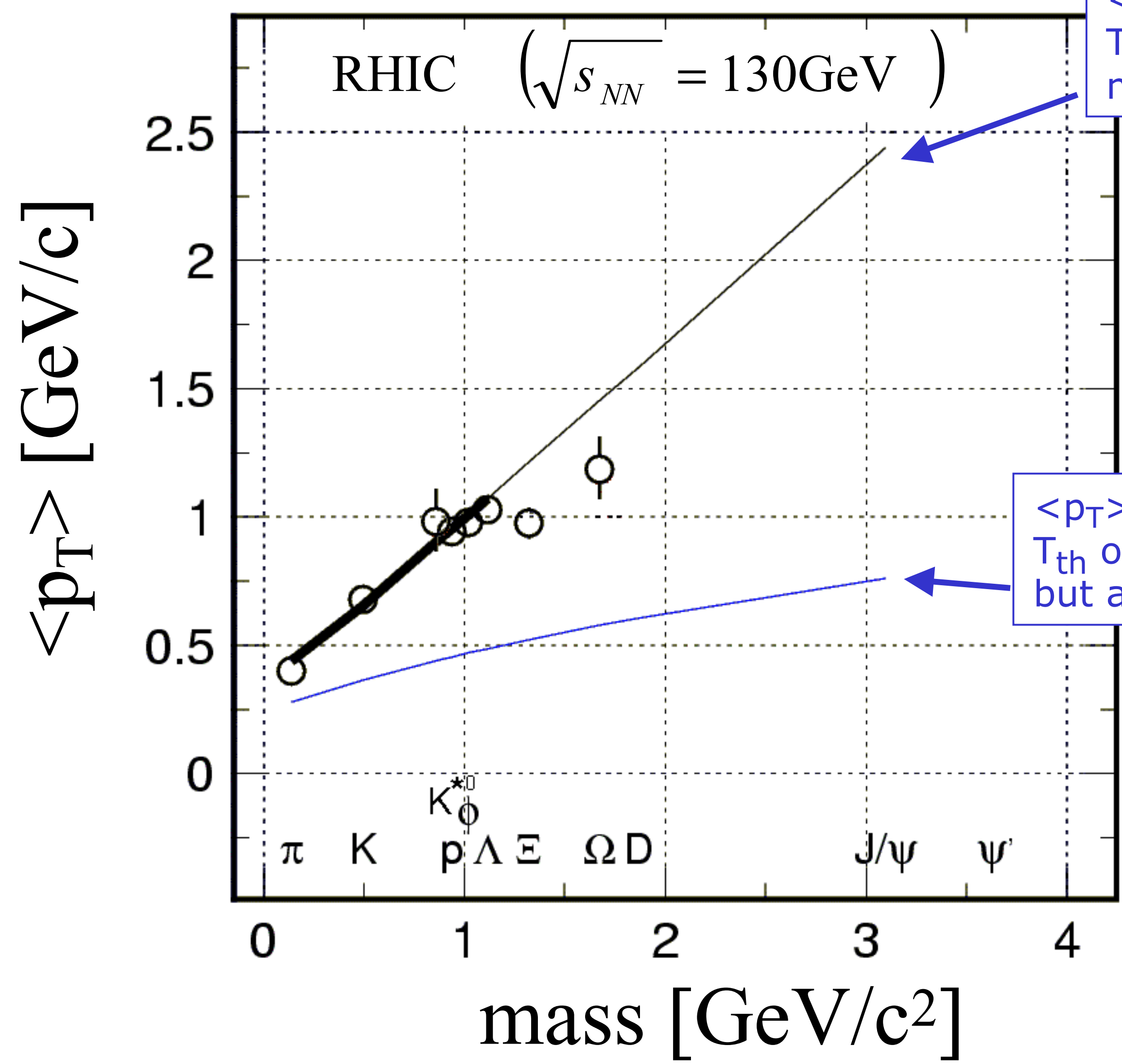
Data : O. Barannikova/F. Wang
QM2002 Talk

Kinetic Freeze-out Parameter vs. Centrality



The blast wave model fit is done for π, K, and p p_T distributions for both 130 GeV and 200 GeV data

Mass Dependence of <p_T> (central data)

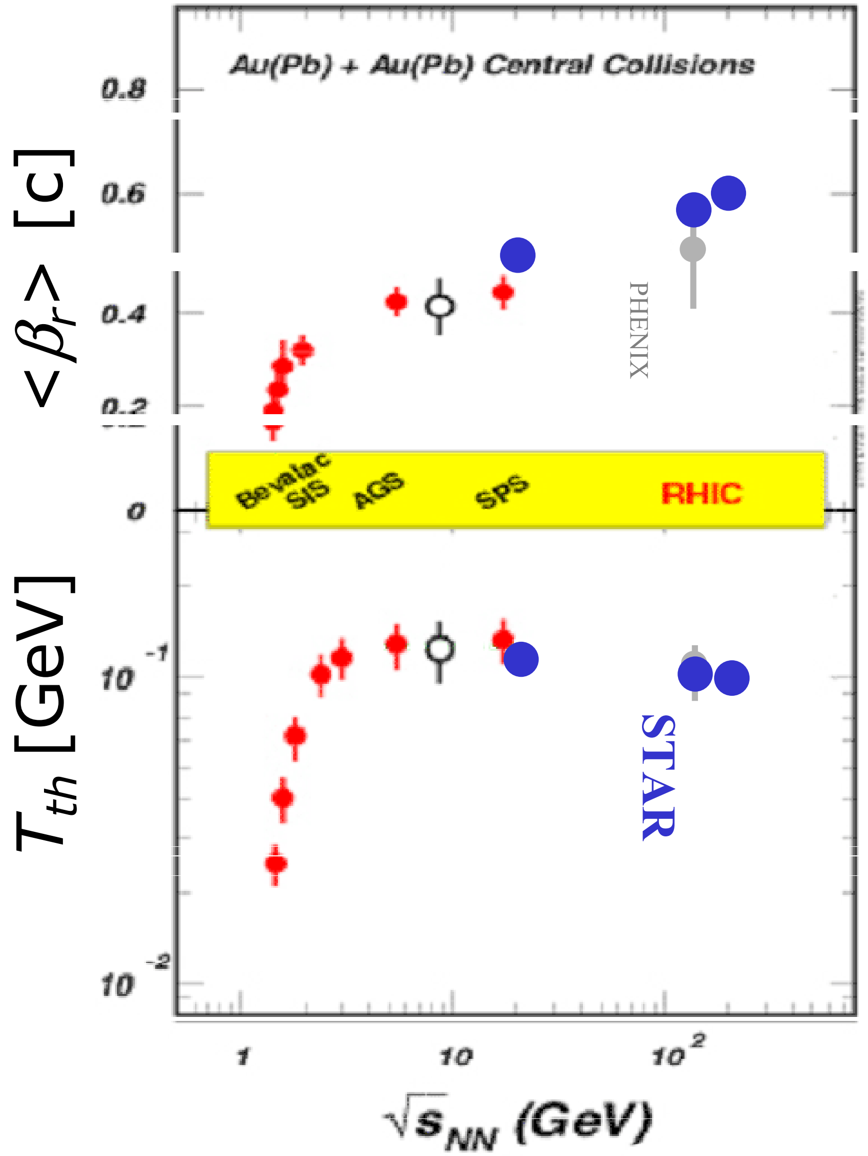


<p_T> prediction with T_{th} and <β> obtained model fit

<p_T> prediction with T_{th} obtained model fit but assuming <β>=0

- Ξ and Ω show a deviation from common thermal freeze-out

Bombarding Energy Dependence



- From SPS to RHIC Energy
  - Increasing flow
  - Saturating temperature

Summary of Kinetic Freeze-out

- The p_T distributions of π, K, and p are obtained as a function of centrality from RHIC-STAR at $\sqrt{s_{NN}}$=130GeV and 200 GeV Au+Au
- The blast wave model describes the data over all of centrality
- Within the blast wave model
  - As a function of centrality at RHIC
    - T_{th} ~ 100 MeV, goes down
    - $\langle \beta_r \rangle$ goes up and saturates (~0.55c (130GeV), 0.60c (200GeV))
    - Indication of change of flow profile
  - Beam energy dependence
    - Increasing flow
    - Saturating temperature

Model of Chemical Freeze-out

- Hadron resonance ideal gas

Refs. J.Rafelski PLB(1991)333
J.Sollfrank et al. PRC59(1999)1637

density of hadron i is

$$\rho_i = \gamma_s{}^{\langle s+\bar{s}\rangle_i} \frac{g_i}{2\pi^2} T_{ch}{}^3 \left(\frac{m_i}{T_{ch}}\right)^2 K_2(m_i/T_{ch})\ \lambda_q{}^{Q_i}\ \lambda_s{}^{s_i}$$

T_{ch} : chemical freeze-out temperature
μ_q : light-quark chemical potential
μ_s : strangeness chemical potential
γ_s : strangeness saturation factor

$$\lambda_s = \exp(\mu_s/T_{ch}) \quad Q_i = \langle u-\bar{u}+d-\bar{d}\rangle_i$$

$$\lambda_q = \exp(\mu_q/T_{ch}) \quad s_i = \langle s-\bar{s}\rangle_i$$

Relation to quantum number:

Baryon $\mu_B = 3\mu_q$
Strangeness $\mu_S = \mu_q - \mu_s$

All resonances and unstable particles are allowed to decayed in the model

Compare particle ratios to experimental data

Common Chemical Freeze-out?

- Multi-Strange particles show earlier kinetic freeze-out
- How about Chemical Freeze-out?
  - Check two combinations of ratios for fit
    - with Ξ
    - without Ξ
- Particle ratios are obtained from recent STAR data
  - published / preprint / conference proceedings
  - some data are interpolated to adjust centrality ($\langle N_{part} \rangle$) to centrality bin of Ξ

Centrality Dependence of Chemical Freeze-out in 130 GeV Au+Au Collisions

From the chemical freeze-out model

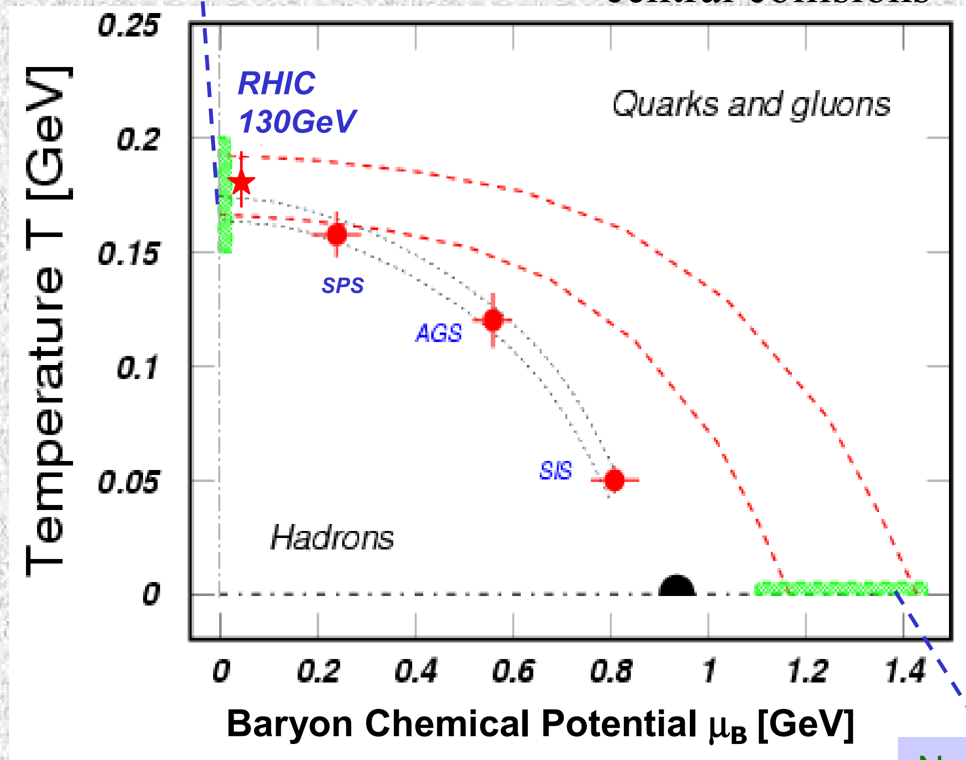
- Tch ~ 175 MeV
- μ_q is increasing with centrality
  - Baryon transfer / Antibaryon absorbed?
- μ_s is close to zero
  - Close to phase boundary

    Refs. PLB262(1991)333. PRC37(1988)1452, RC37(1988)1452
- γ_s is increasing with centrality
  - Fully strangeness equilibration in central collisions
- Deviation of multi-strangeness from non-strange/single-strangeness in peripheral collisions

Summary of Chemical Freeze-out

Lattice QCD predictions

central collisions



Neutron star

parton-hadron phase boundary

<E>/<N>~1GeV, J.Cleymans and K.Redlich, PRC60 (1999) 054908

- Beam energy dependence
  - Temperature increases
  - Baryon chemical potential decreases
- At RHIC
  - Being close to phase boundary
  - Fully strangeness equilibration ($\gamma_s \sim 1$) at central collisions