Preliminary

Freeze-Out Conditions at RHIC

Nu XU
Lawrence Berkeley National Laboratory

- Introduction

- Experimental results
  1) particle ratios – chemical freeze-out
  2) m_T distributions – kinetic freeze-out
  3) net-protons – baryon transfer

- Summary and Outlook

Many Thanks To

Conference organizers

I. Bearden (Brahms)
H. Ohnishi, J.Velkovska (Phenix)
N. George (Phobos)
M. Calderon, F. Laue, E. Yamamoto, Z. Xu (STAR)
C. Blume, V. Friese, T. Susa (NA49)
H. Appelshauser (NA45)
P. Bordale (NA50)

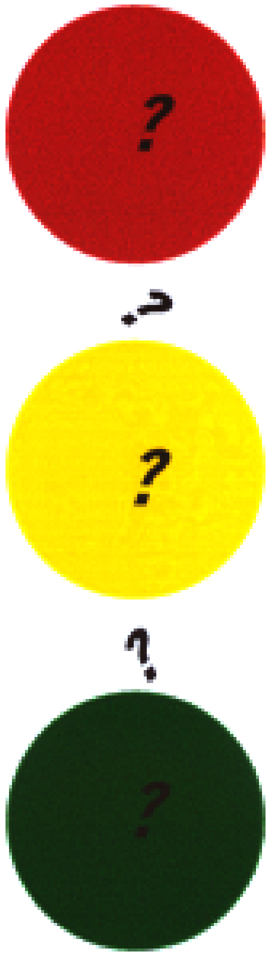
L. Bravina, M. Kaneta, K. Redlich

Introductions

1) Initial condition
- *baryon transfer*
- *energy production*
- *partons produced*

2) System evolve
- *parton/hadron expansion*
- *hydrodynamic with given EOS*

3) Freeze-out
- *hadrons*
- *interactions stop*
- *particles seen at detector*



➢ **Goals:**

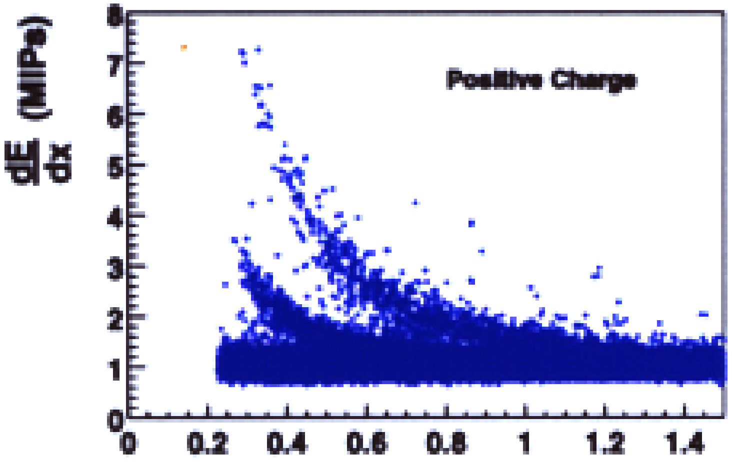
To study the bulk property of matter under the conditions of high energy density and particle density. Both parton and hadron degree of freedoms are important.

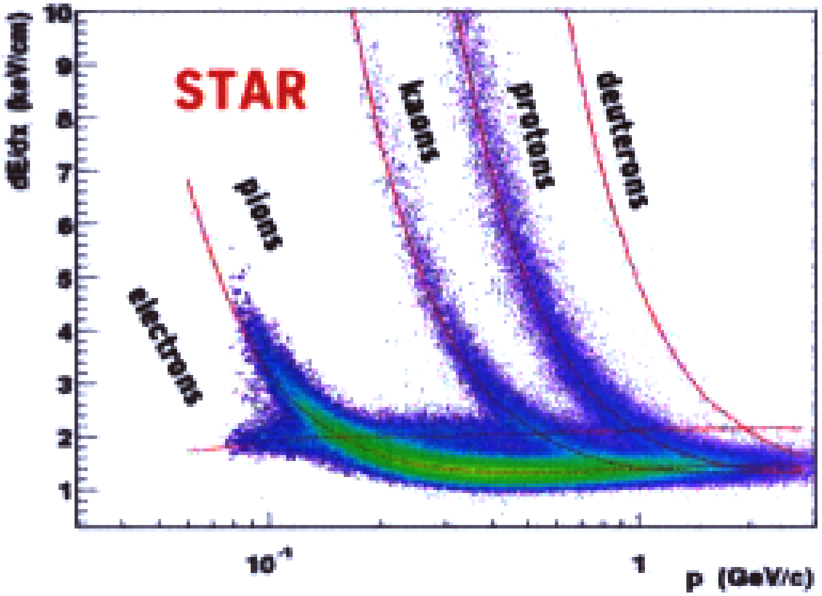
➢ **Focus of this talk:**

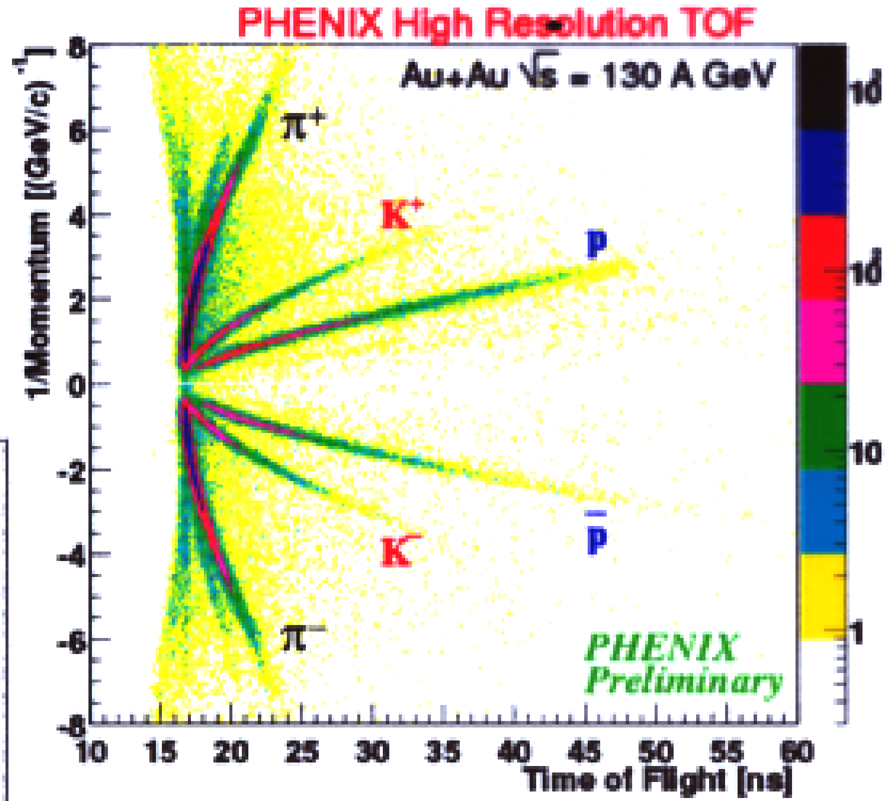
- Freeze-out conditions of low momentum hadrons – low p_t and mid-rapidity;
- Compare to results of collisions at lower energies.

1) Lots of preliminary data, more work needed;
2) More theoretical works needed: pQCD + hadronic models

Particle Identification



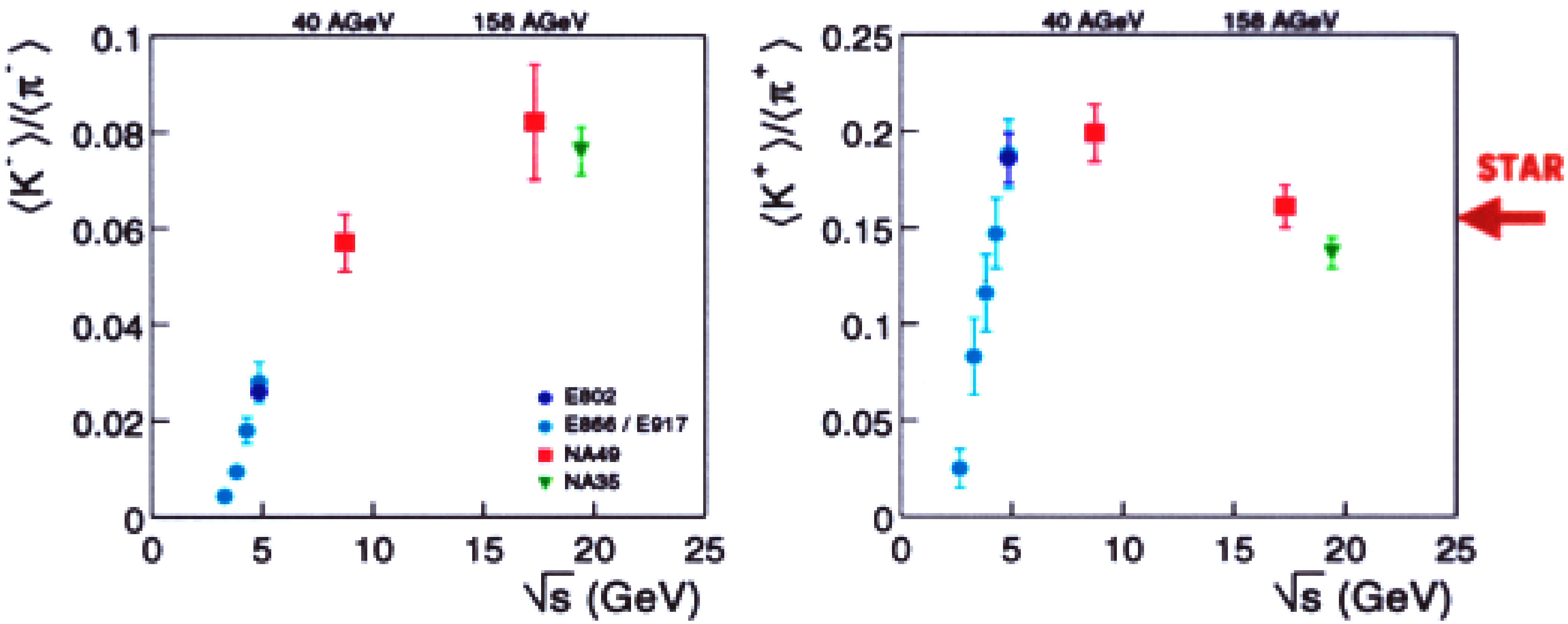




PHOBOS, STAR: large acceptance

BRAHMS, PHENIX: PID up to high pt

Particle ratios (i)

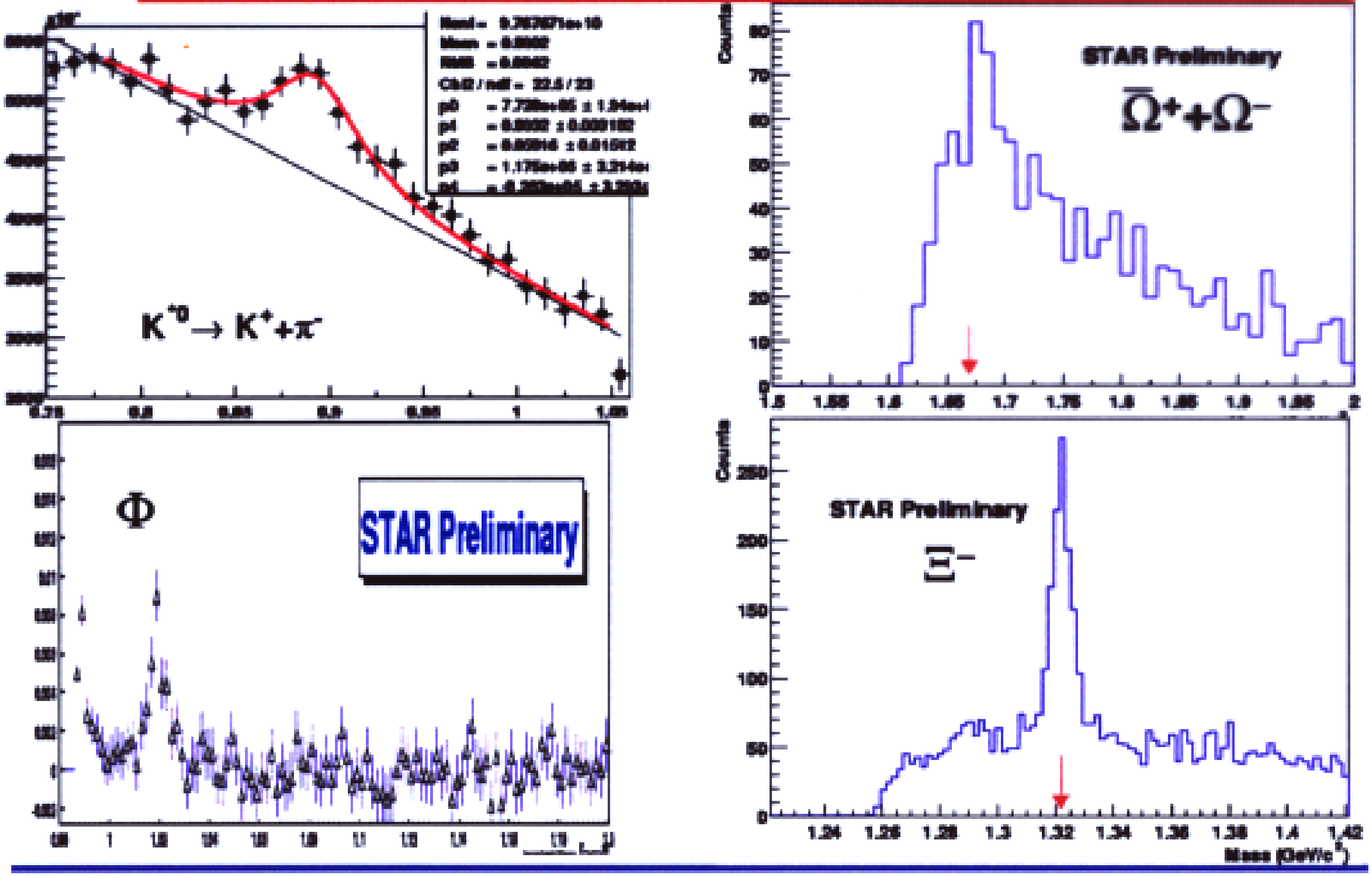


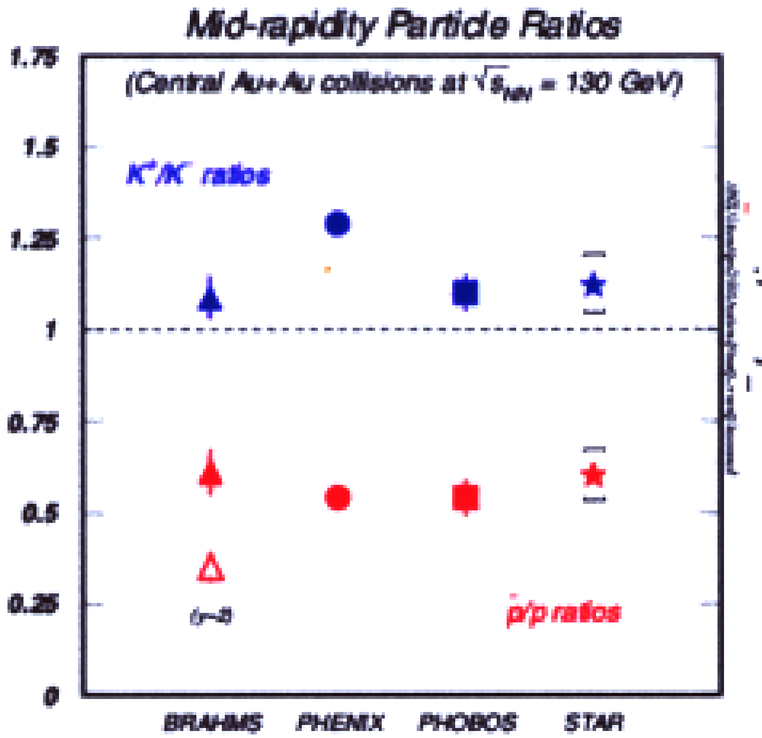
(NA49, C. Blume)

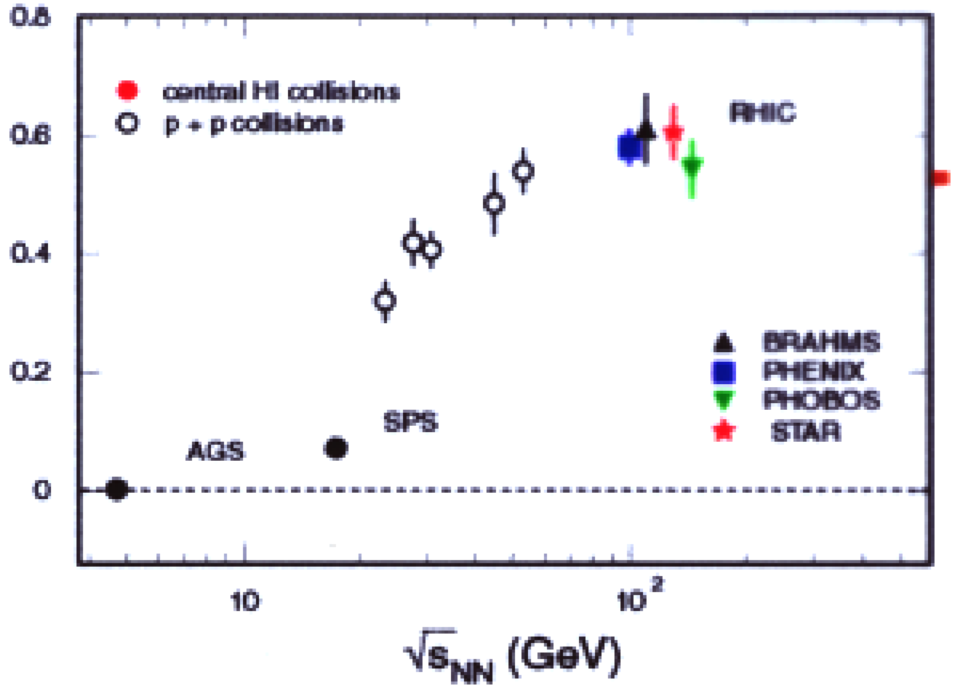
Non-monotonic energy dependence in $\langle K^+ \rangle / \langle \pi^+ \rangle$

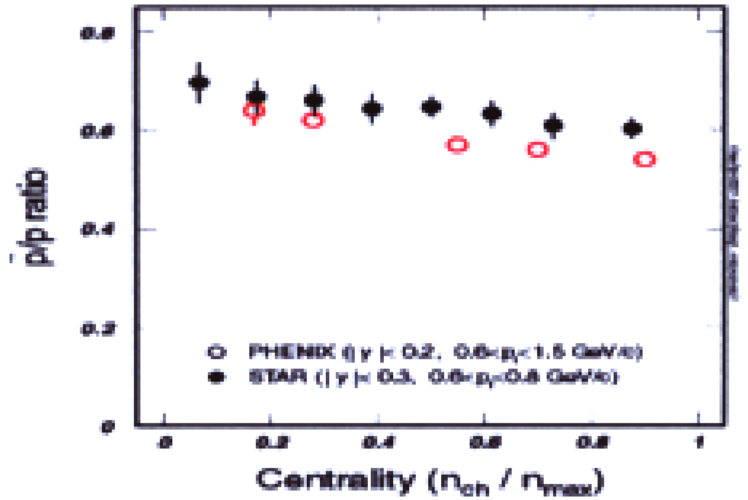
Monotonic energy dependence in $\langle K^- \rangle / \langle \pi^- \rangle$

Strange particles



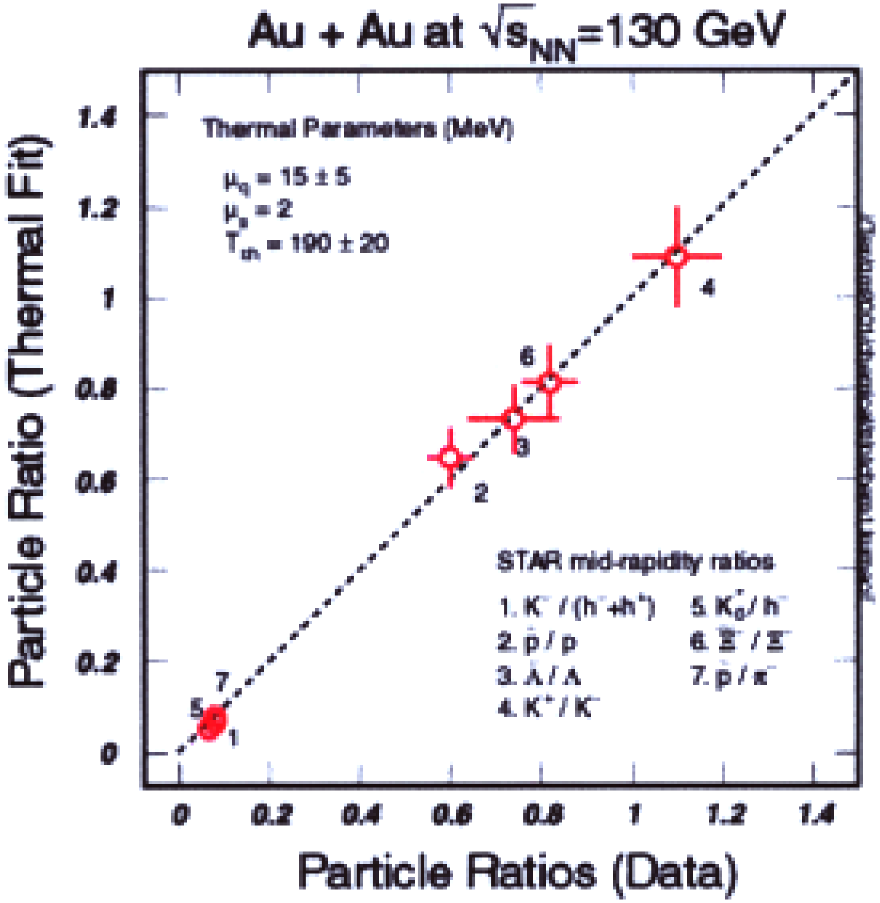






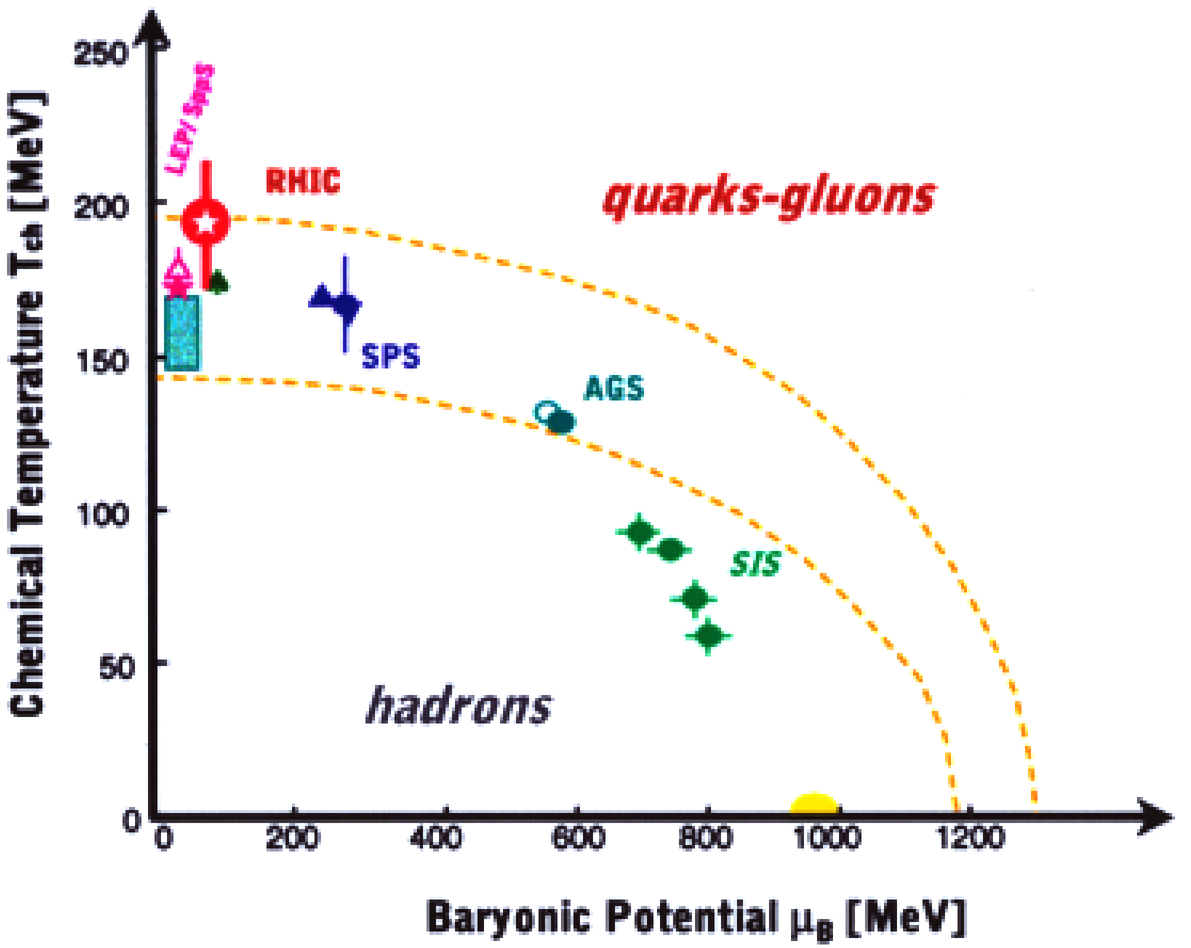
1) Particle ratio data consistent;
2) Constant as a function of p_t and y;
3) Weak centrality dependence;
4) Pbar/p ratio < 1, finite baryon transfer!

Chemical Fit Results



- **Thermal fit to preliminary data:**
  - $T_{ch} = 190$ MeV
  - $\mu_q = 15$ MeV
  - $\mu_s \leq 4$ MeV
- **Not a 4π-yields fit!**
  - $\gamma_s = 1$
  - $\chi^2 = 1.4$

Chemical Freeze-out Systematic

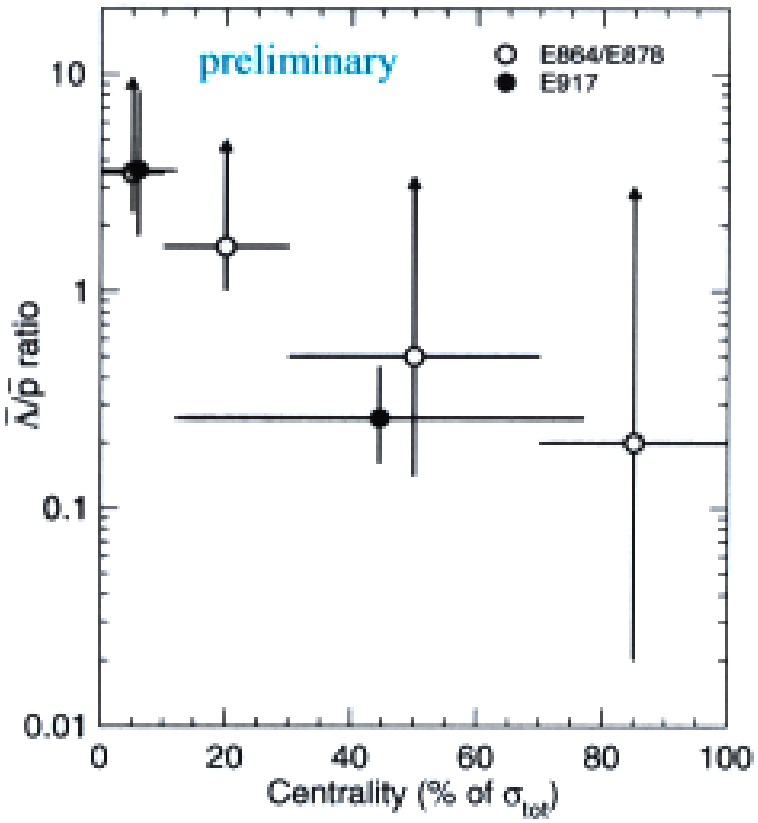


Reference:

1) P. Braun-Munzinger et al, Phys. Lett. B344, 43(1995);

2) ....

$\bar{\Lambda}/\bar{p}$ Yield vs. Centrality



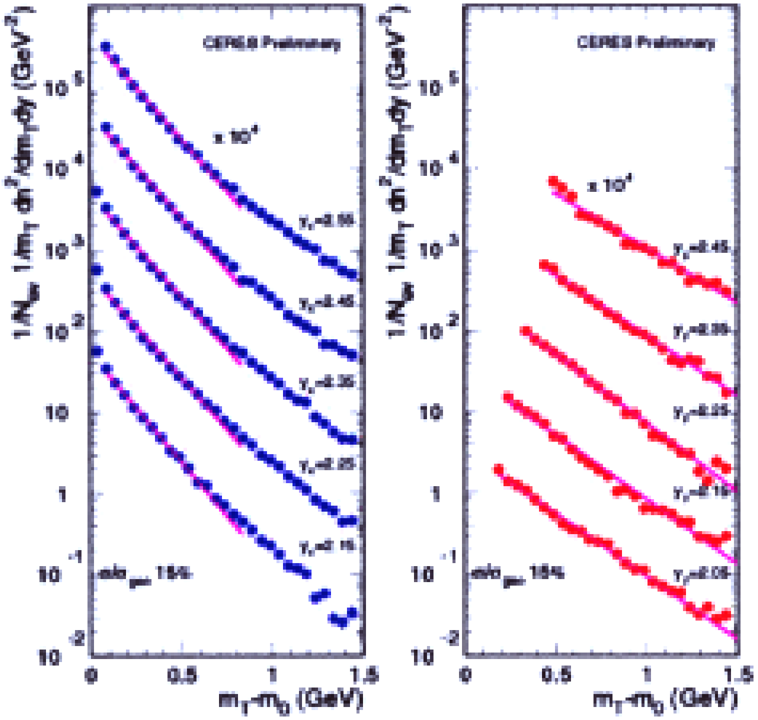
E917, B. Holzman

Centrality	$\bar{\Lambda}/\bar{p}_{direct}$
0-12%	$3.6^{+4.7\ +2.7}_{-1.8\ -1.1}$
12-77%	$.26^{+.19\ +.5}_{-.15\ -.4}$

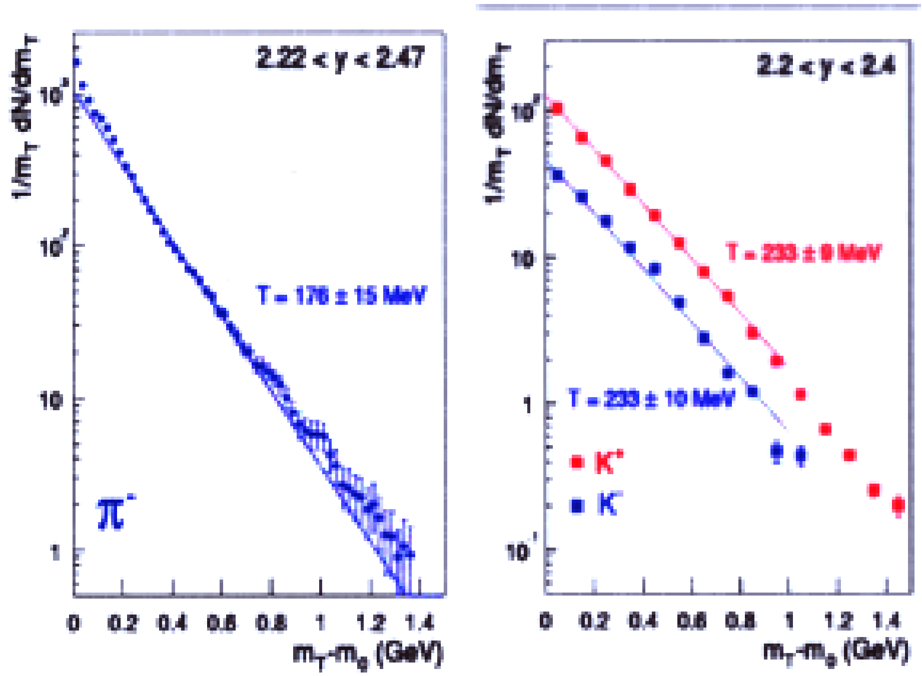
Maximal values from theory:
UrQMD (F. Wang): ~ 1.3
Thermal (J. Cleymans) ~ .9

m_T distributions (i)

NA45 preliminary, Pb+Au @ 40 *A*GeV
(H. Appelshauser, Heidelberg)



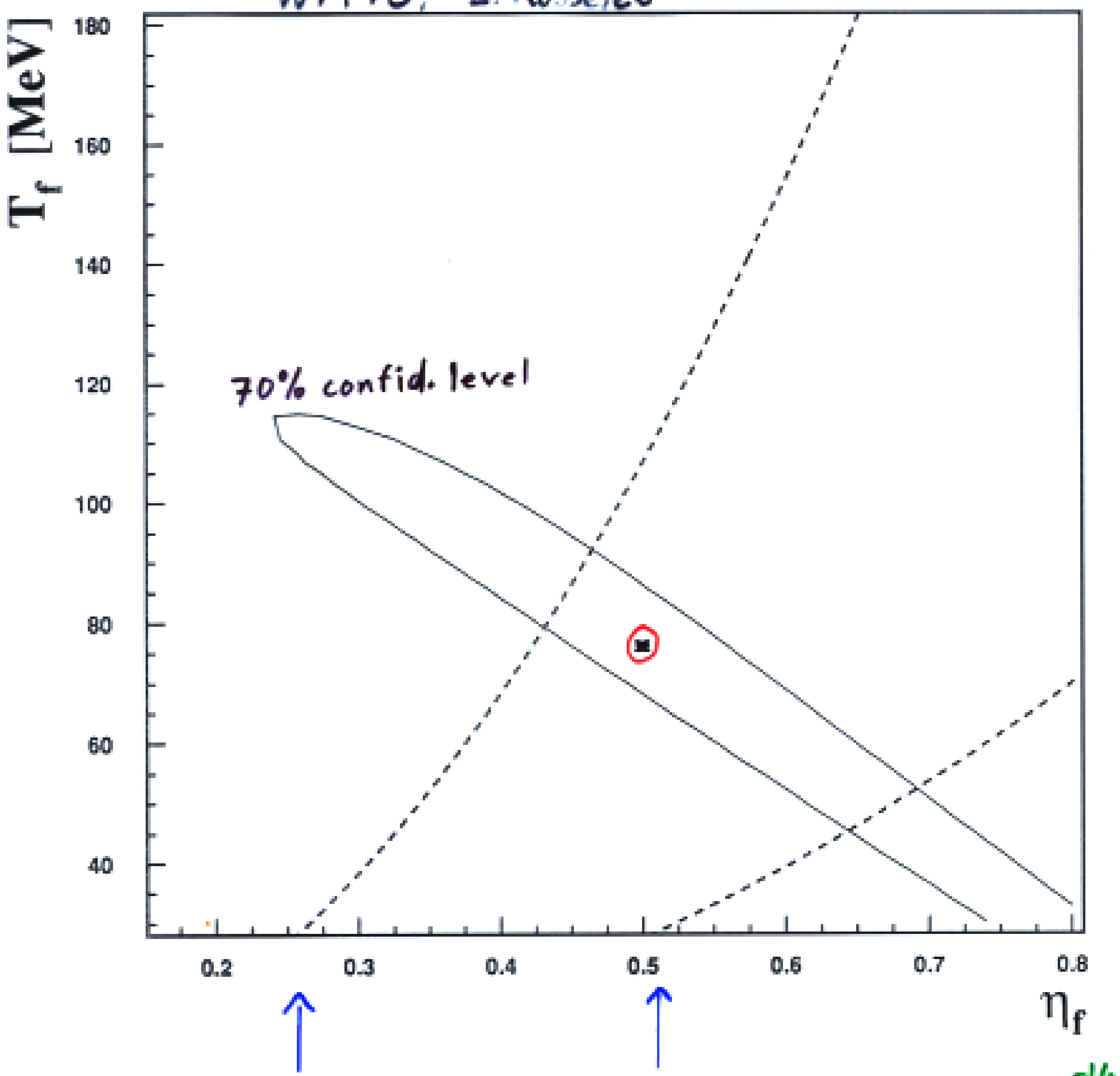
NA49 preliminary, Pb+Pb @ 40 *A*GeV
(Christoph Blume, GSI)



At 40 AGeV, the Ts of π, K, and p are similar to the results from 158AGeV!

QM2001

WA98, L. Rosselet



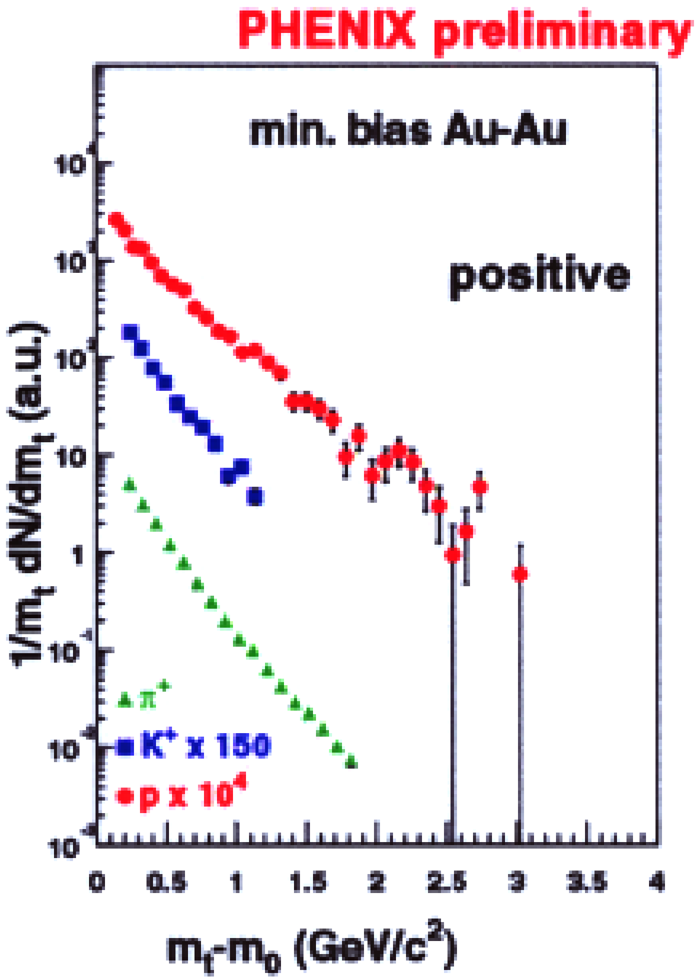
$\pm 1\sigma$ HBT constraint from fit $R_T = R_G \left[1 + m_T \cdot \frac{\eta_f^2}{T_f}\right]^{-1/2}$

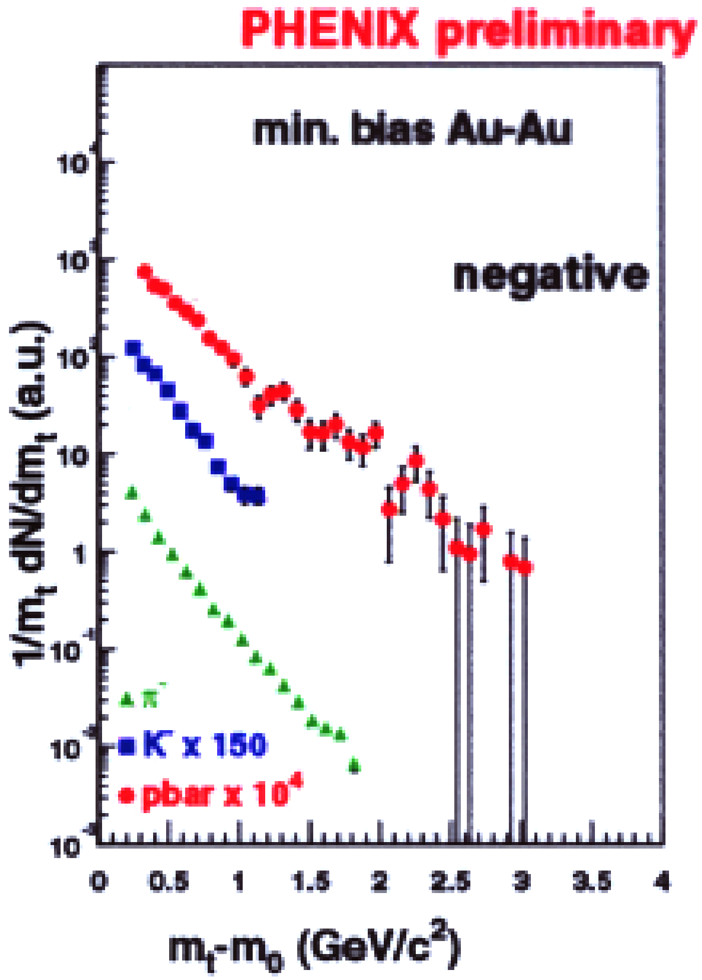
from WA98 - same data

with $m_T = \sqrt{m_\pi^2 + k_T^2}$

. . .

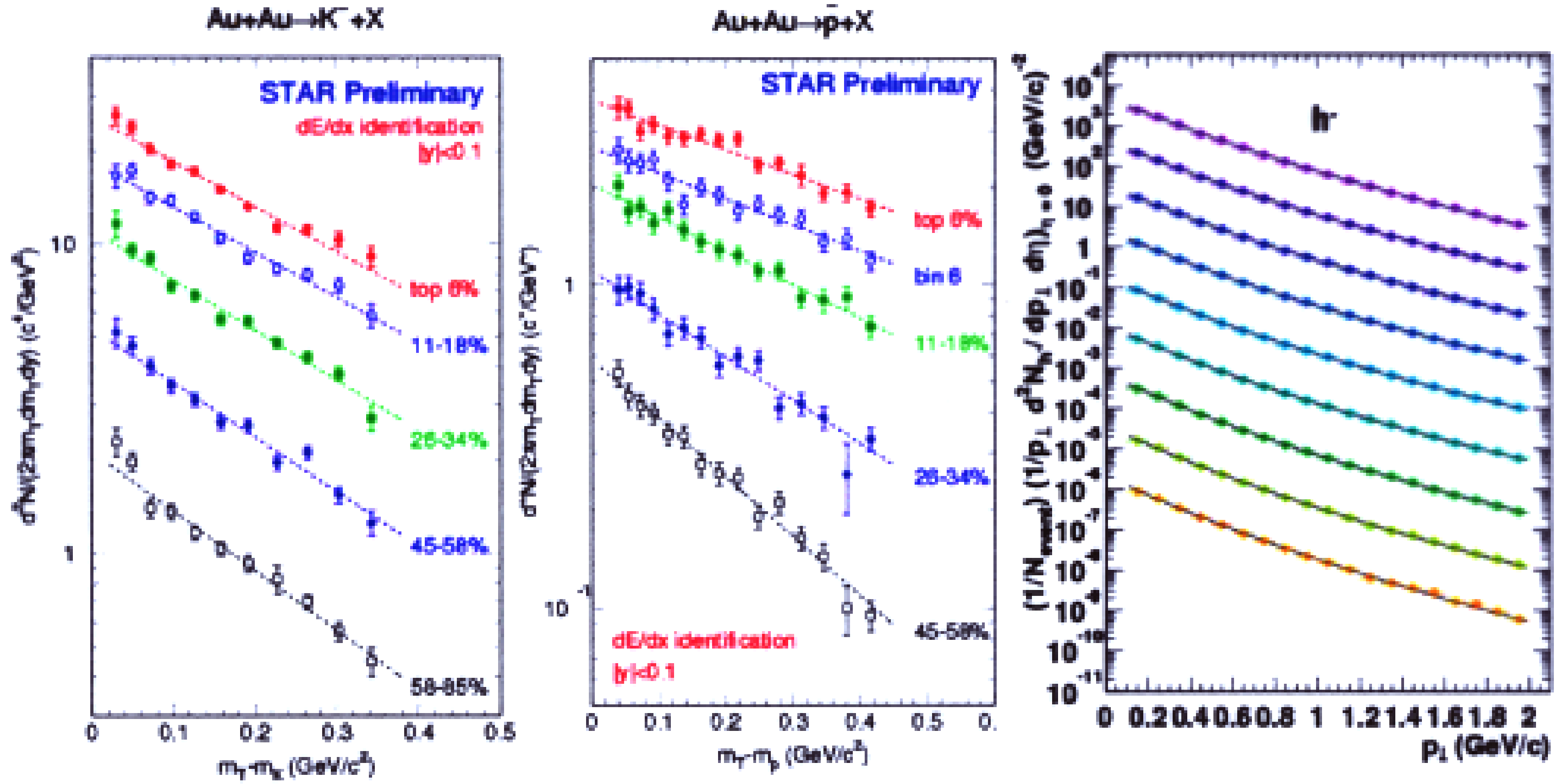
m_T distributions (ii)



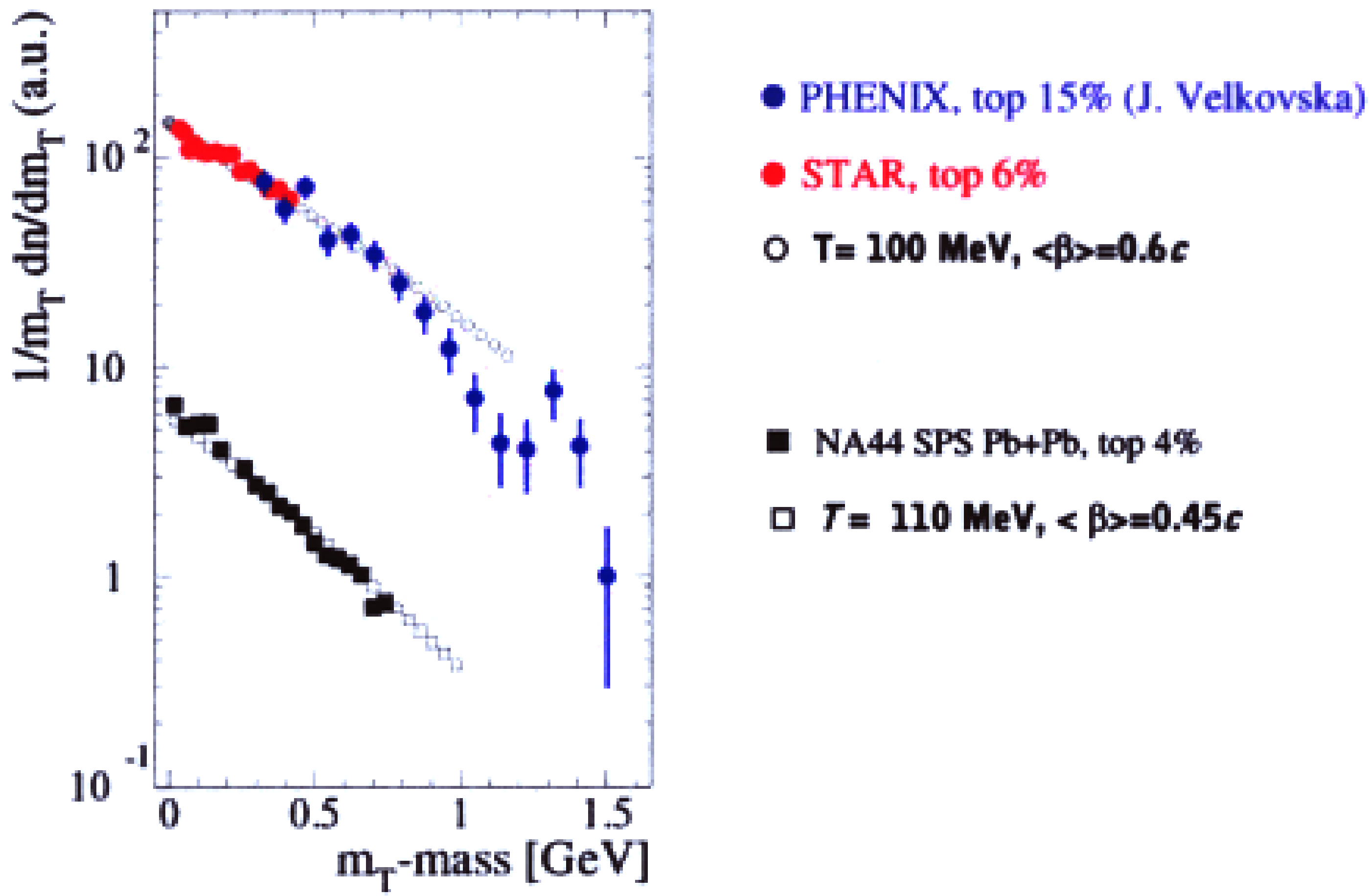


QM2001

m_T distributions (iii)

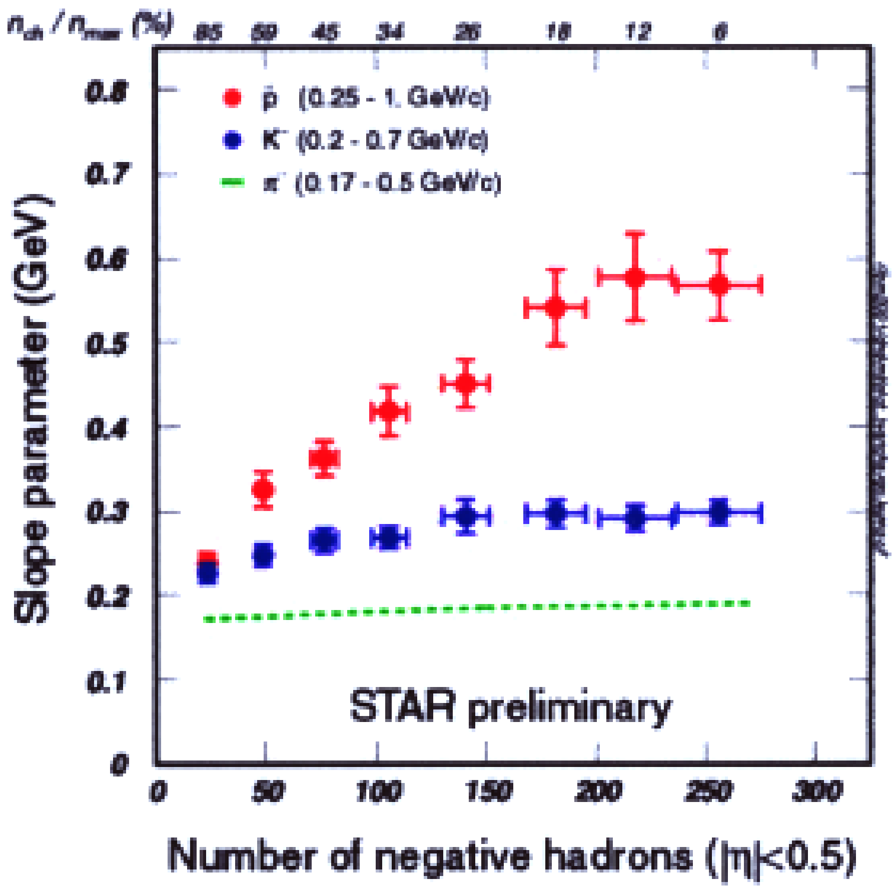


Comparison


1/m_T dn/dm_T (a.u.)
10^2
10
1
10^-1
0
0.5
1
1.5
m_T-mass [GeV]
PHENIX, top 15% (J. Velkovska)
STAR, top 6%
T= 100 MeV, <β>=0.6c
NA44 SPS Pb+Pb, top 4%
T= 110 MeV, < β>=0.45c

Slope Parameters vs. Centrality

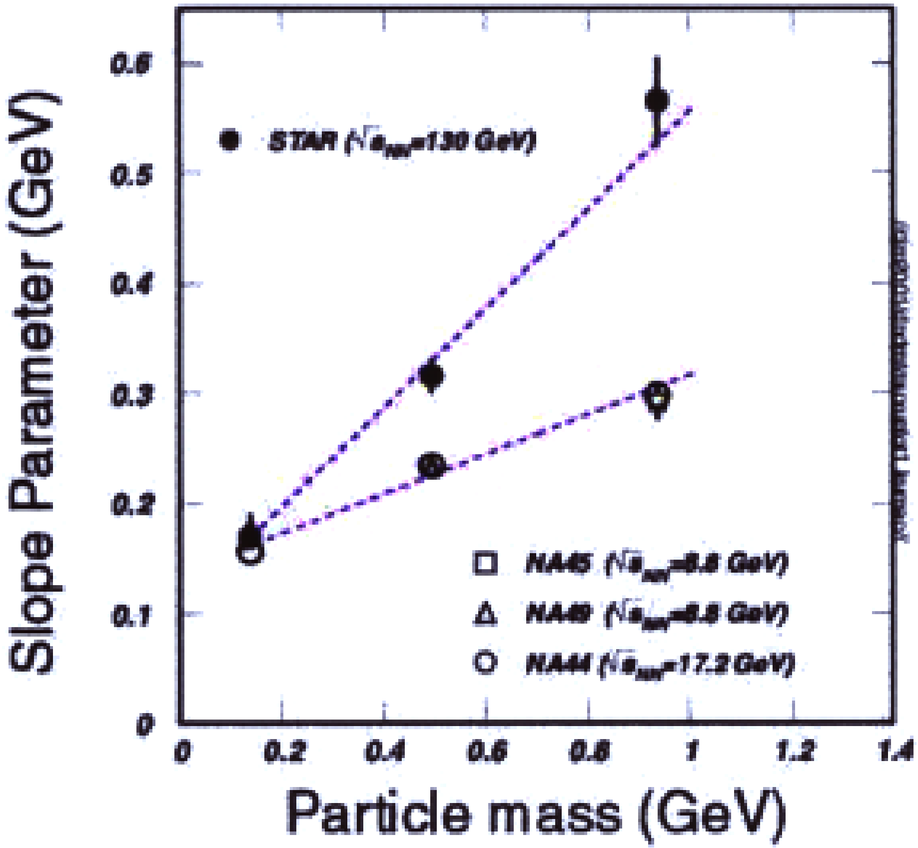
Au + Au at $\sqrt{s_{NN}}$ = 130 (GeV)



M. Calderon (Yale)

- Fits at low p_t region! (kink kaon up to 2 GeV/c, similar slope)
- Slope parameters increase as a function of centrality with mass dependence
  - *- collective flow?*
  - *- annihilation ?*
  - *- parton or/and hadron dof ?*
  - *- others effects?*
- Φ, Ξ, Ω data are needed !

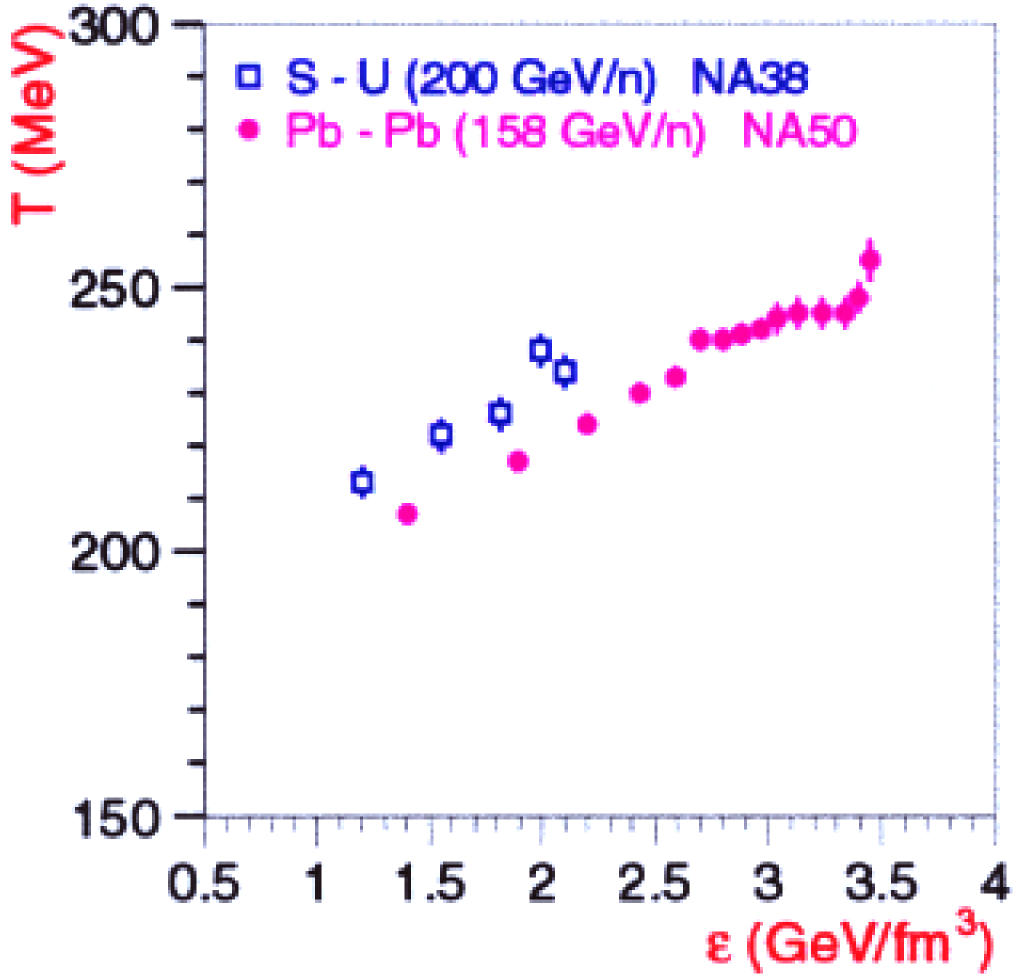
SPS Comparison



- Slope parameters of pion and kaon overlap at 40 and 158 AGeV central collisions
  - *similar strength of flow ?*
- Stronger mass dependence at RHIC than SPS
  - *stronger flow ?*
- *Slope parameter change with fitting region -> strong flow behavior!*
- NA50 J/ψ slope = 233 MeV! (P.Bordalo)

Phenix (0.8 < p_t < 1.75 GeV/c) / STAR (0.2 < p_t < 1 GeV/c)

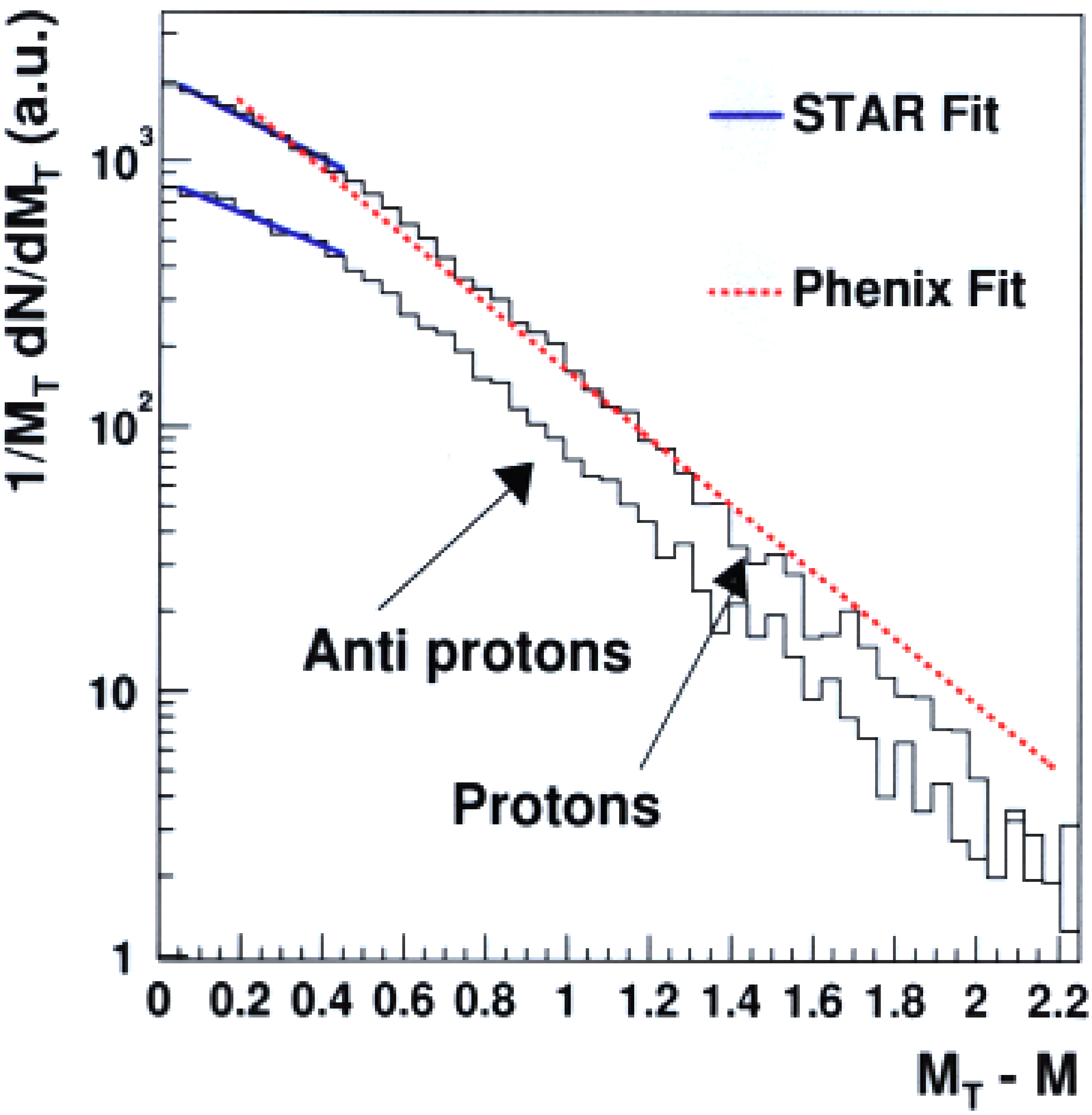
m_T distributions (iv)



NA50, P.Bordalo

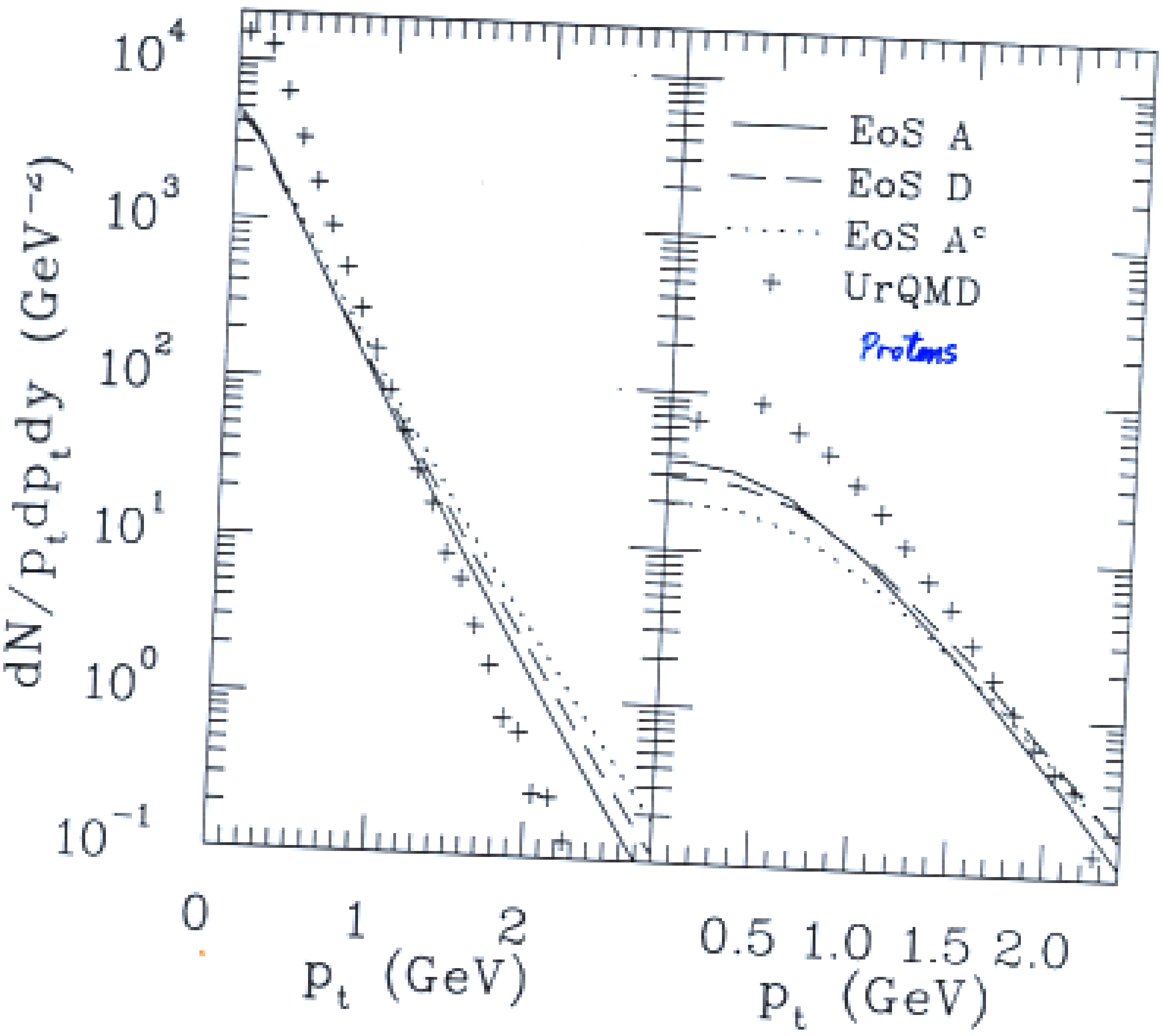
J/Ψ slope parameter as a function of the centrality.

RHIC Radial Flow comparisons



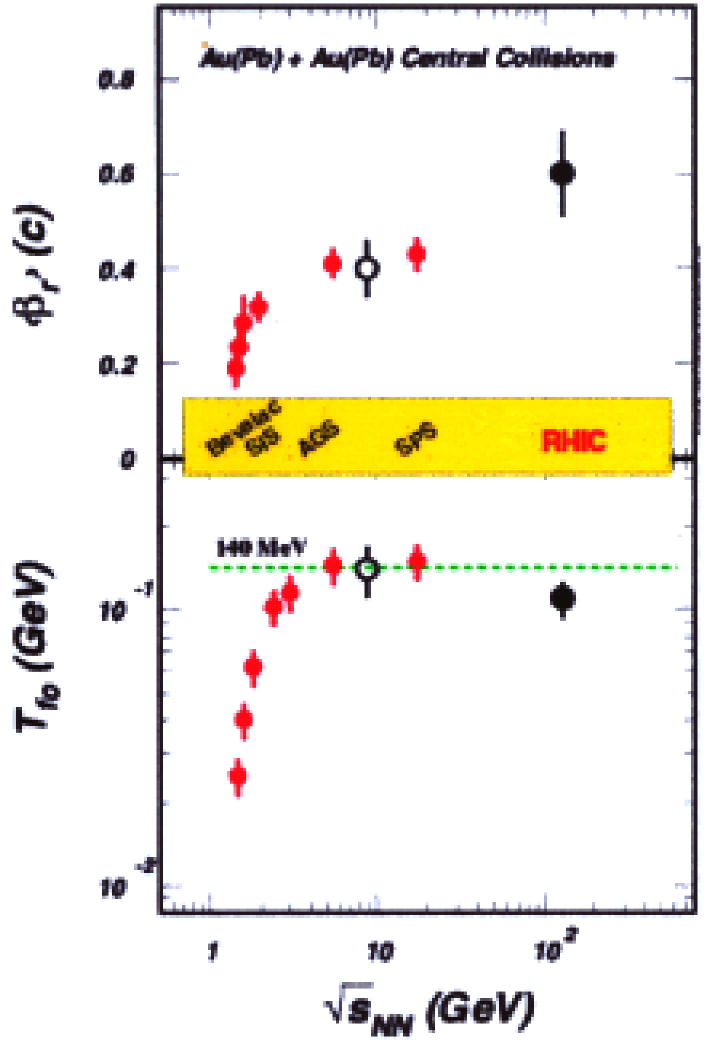
D. Teaney, J. Lauret, E.V. Shuryak nucl-th/0011058

P. Huovinen, P. Kolb, U. Heinz, P. Ruuskanen, S. Voloshin
hep-ph/0101136



$$v_2 = \tanh\left[\frac{1}{2}\left(\frac{\kappa p_t - \lambda m_t}{T} + \mu\right)\right] \quad \begin{cases} \kappa = r_x v_x - r_y v_y \\ \lambda = r_x - r_y \\ \mu = \ln\sqrt{\frac{r_x v_x}{r_y v_y}} \end{cases}$$

Kinetic Freeze-out Systematic



1) At RHIC, in central Au+Au collisions:

$\beta_r \cong 0.6$ c

$T_{fo} \cong 0.1$ GeV

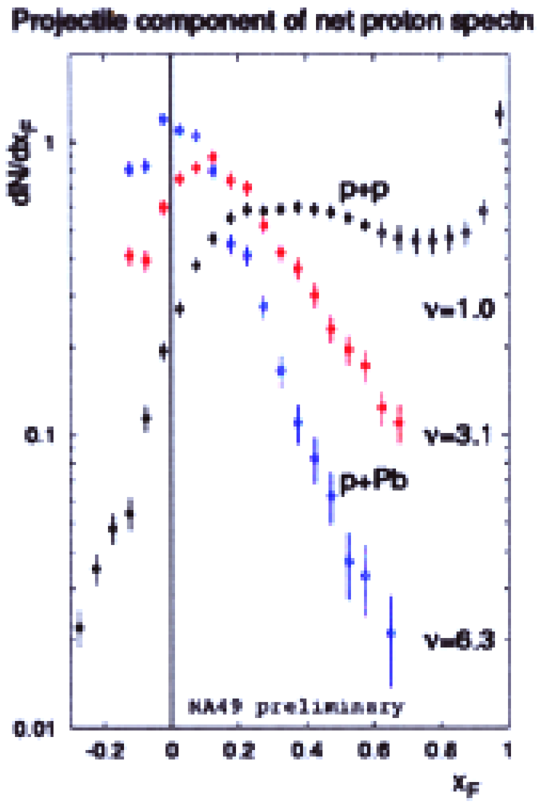
2) A jump(?) in the collective velocity parameter compared to results from lower energy collisions.

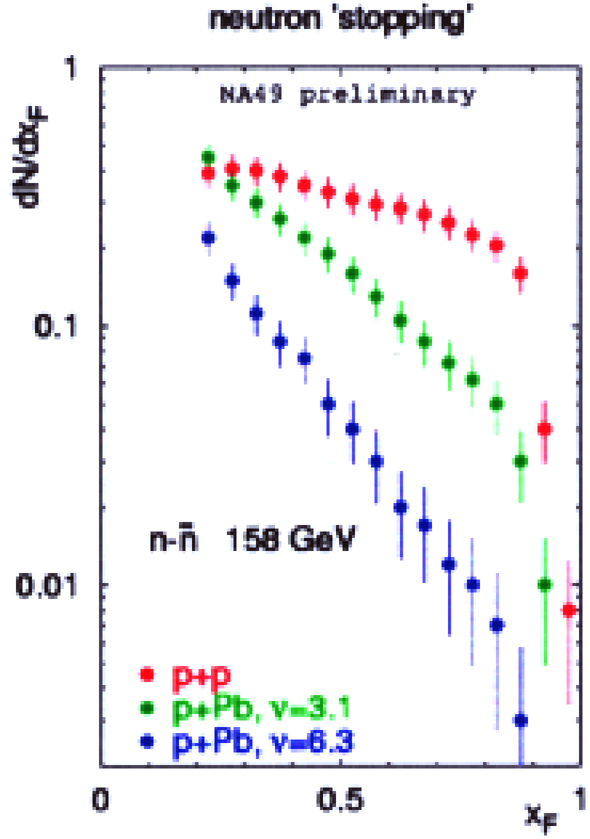
The large value of ßr at RHIC is consistent with the v_2 and the strong m_t-dependence of the π HBT measurements!

3) T_{fo} behavior in (1-10 GeV) predicted by Stocker et al. in 1981;

4) Energy scan need to check if this is a jump or smooth rise.

Baryon transfer

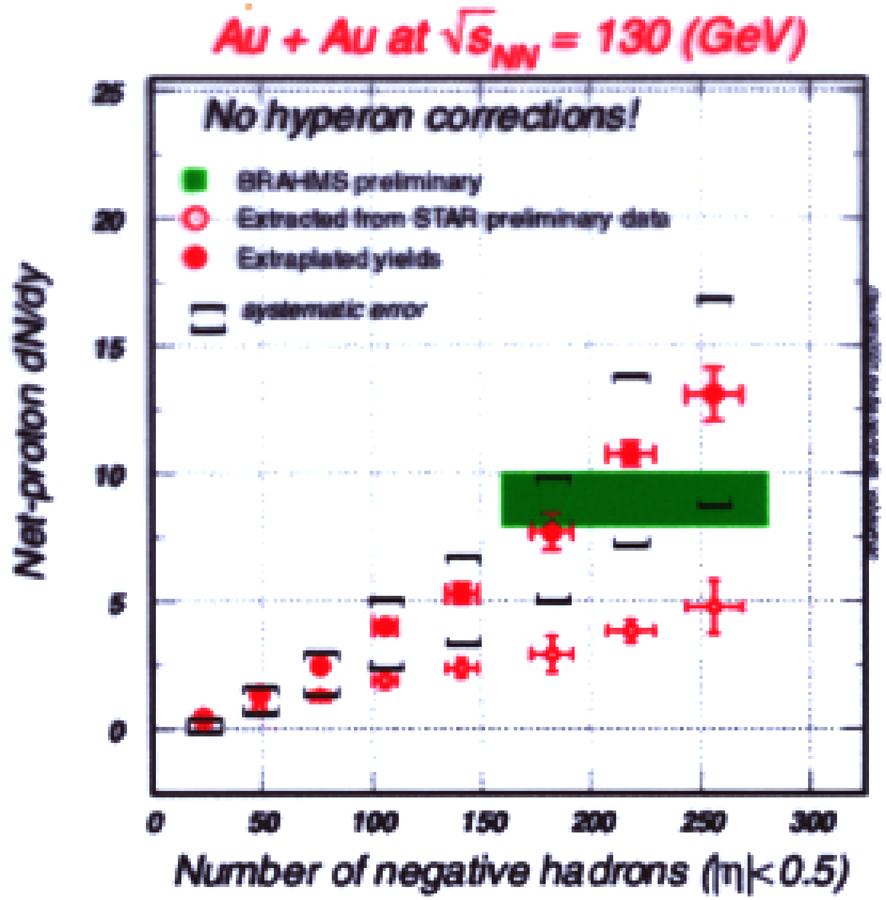




- New data from p+A at AGS/SPS
- Stopped after 3 collisions

1) W.Busza et al, Z. Phys. C48, 167(1990);
2) W. Busza, Acta Phys. Polon. B8, 333(1977);
3) W. Busza and R. Ledoux, Ann. Rev. Nucl. Part., Sci. 38, 119(1988).

Mid-rapidity net-protons



- No hypron corrections in data!
- Net-protons increase as centrality increases ⇒
  - *more stopping at central collisions !*
- Net-protons increase faster than that of the number of the negative hadrons
- Hijing/BB model prediction: 12 for 200 GeV central collisions.

Reference:

1) S. Vance et al, Nucl. Phys. A661, 230.(1999).

Summary

- New RHIC data flows out quickly!

  particle ratios ⇐ dbar/pbar, pbar/p, Λbar/Λ, Ξbar/ Ξ, K/π, ...

  m_t distributions ⇐ π, K, p and anti-particles, ...

  y distributions ⇐ h^-, ...

  resonances ⇐ K^*_0, Φ, Λ, Ξ, Ω, ...

  Most results are consistent!

- Net-baryon ≠ 0 at mid-rapidity! ($\Delta y = y_0 - y_{beam} \sim 5$)

  mid-rapidity net-proton ≥ 10

- Chemical parameters

  T_{ch} (RHIC) = 0.19 GeV ≥ T_{ch} (SPS/AGS) = 0.17 GeV

  μ_q (RHIC) = 0.015 GeV << μ_q (SPS/AGS)

- Kinetic parameters

  β_r (RHIC) = 0.6c > β_r (SPS/AGS) = 0.4-0.5c

  T_{fo} (RHIC) = 0.1-0.12 GeV ≤ T_{fo} (SPS/AGS) = 0.12-0.14 GeV

Outlook

- How do these nucleons shifted from y_{beam} to y_0 ?
- Radial flow developed with parton or hadron rescatterings ?

Fix the bulk properties at freeze-out:

- **Φ, Λ, Ξ, Ω transverse momentum and rapidity spectra**

- **anti-proton, kaon, and Φ spectra vs. collision geometry**
  early or late rescatterings among particles

- **non-identical particle correlations**
  freeze-out sequence in space-time

- **energy scan from 20 – 200 GeV is important!**
  check the possible collective velocity increase
  $\beta_r \Rightarrow \partial P \Rightarrow$ dof, if temperature is fixed!