Hadron Spectra and Yields
Experimental Overview

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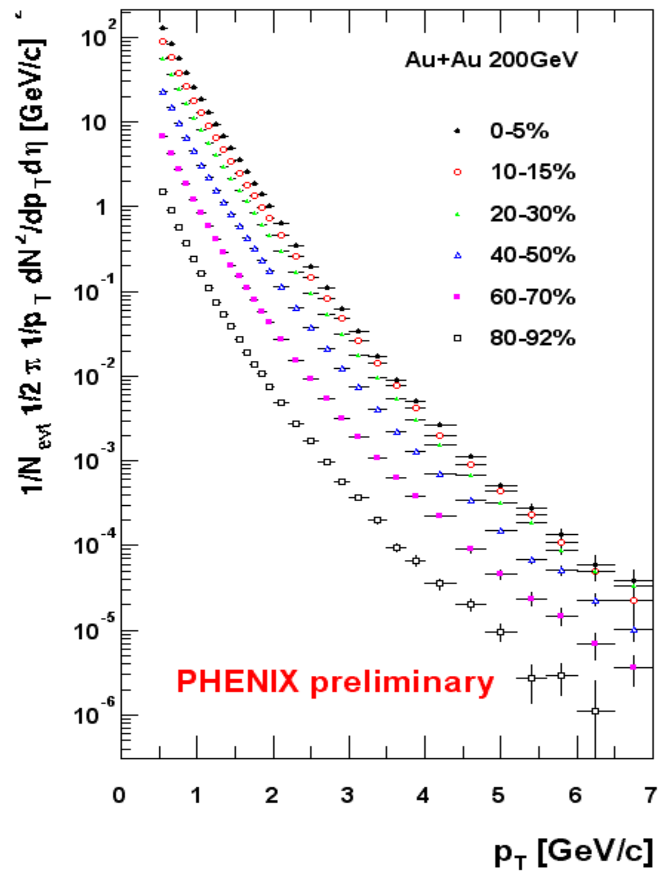
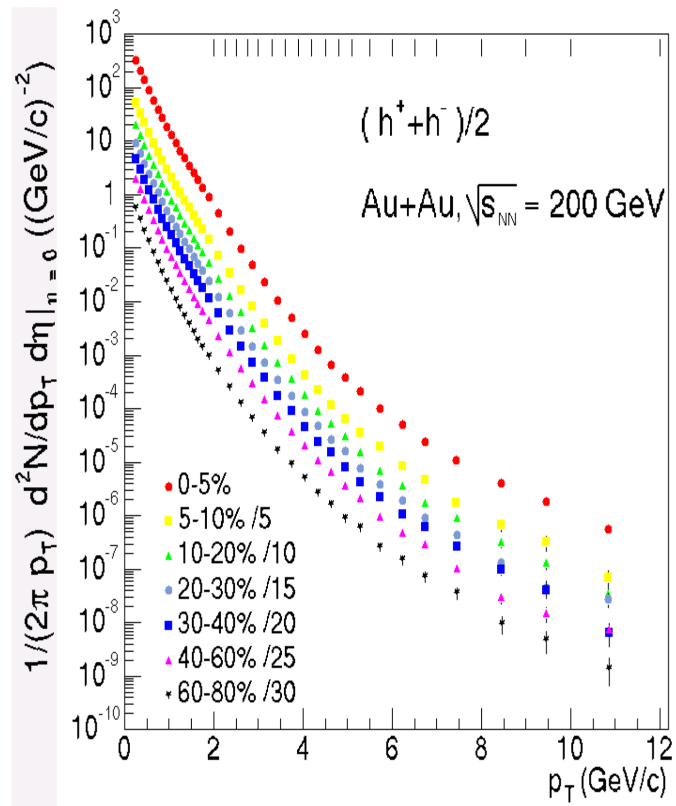
Outline

- Spectra
  - Radial flow
  - Does every particle flow ?
  - What are the freeze-out conditions ?
- Yields and Ratios
  - Chemical properties of the system
  - Is $T_{ch} > T_{fo}$?
- How far in p_T do soft processes dominate ?
- Conclusions

Charged hadron spectra at 200 GeV



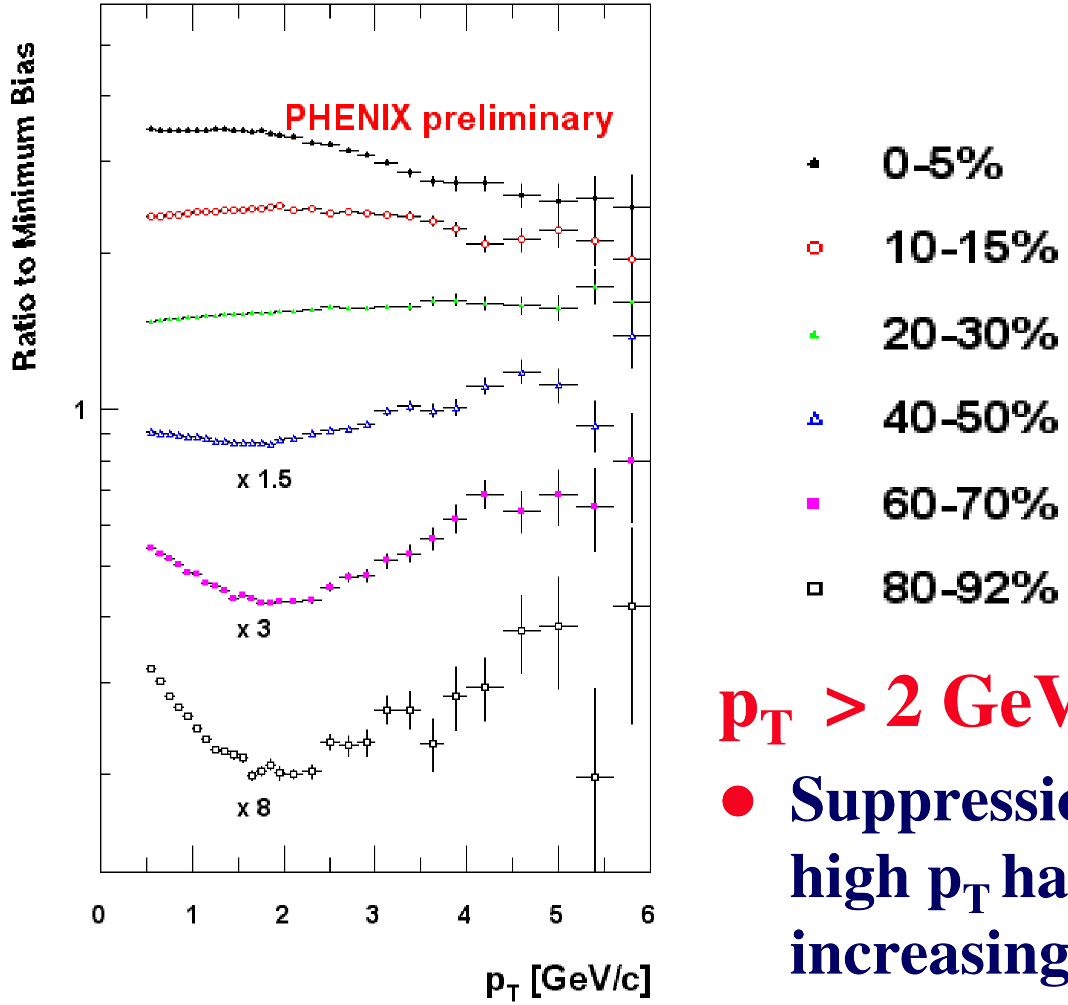


- Exponential at low $p_T < 2$ GeV/c
- Power-low at high $p_T > 2$ GeV/c

Spectral shape evolution with centrality

p_T < 2 GeV/c

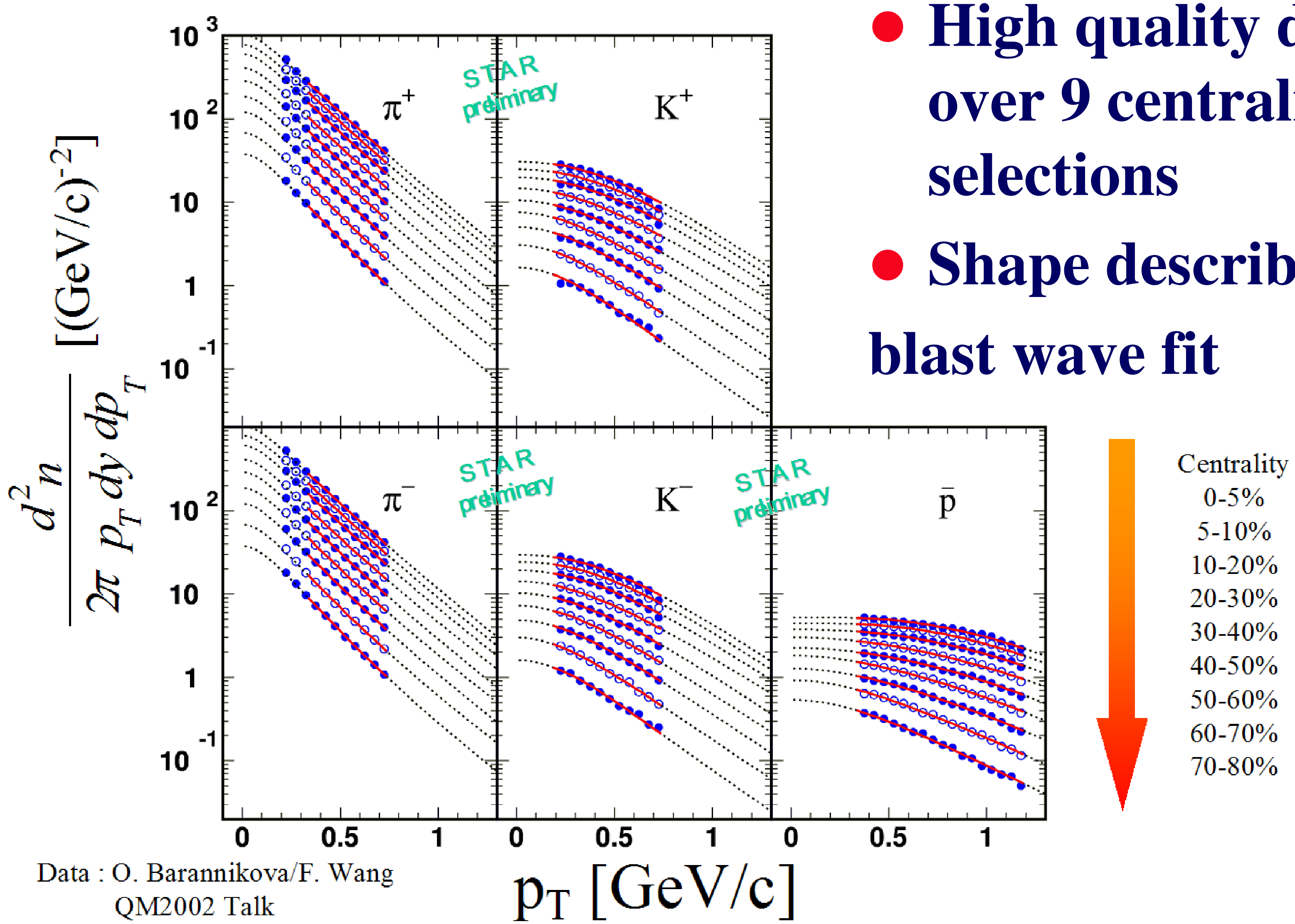
- Inverse slope increases with centrality due to radial flow
- Relatively little change from 0 – 50 %



p_T > 2 GeV/c

- Suppression of high p_T hadrons increasing with centrality

π, K, P spectra from Star

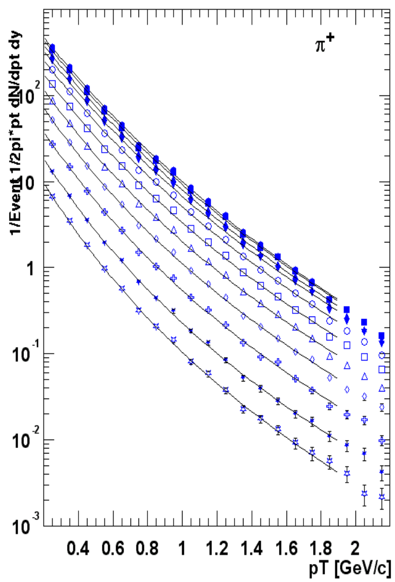


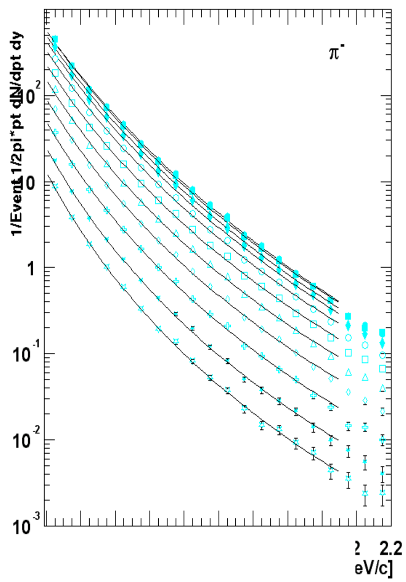
Data : O. Barannikova/F. Wang
QM2002 Talk

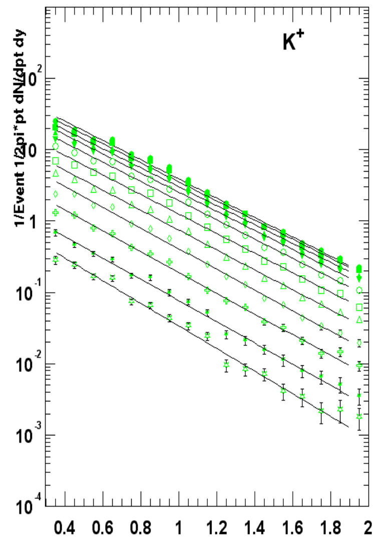
- **High quality data over 9 centrality selections**
- **Shape described by blast wave fit**

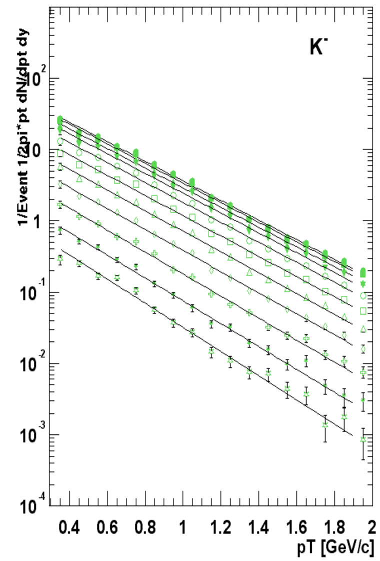
Spectra with broad momentum range from PHENIX

Au+Au at √s = 200 GeV PHENIX preliminary

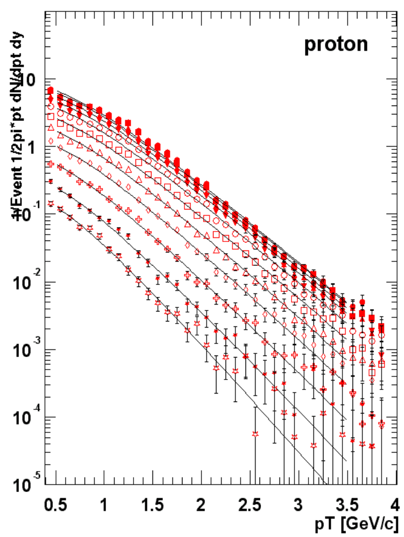


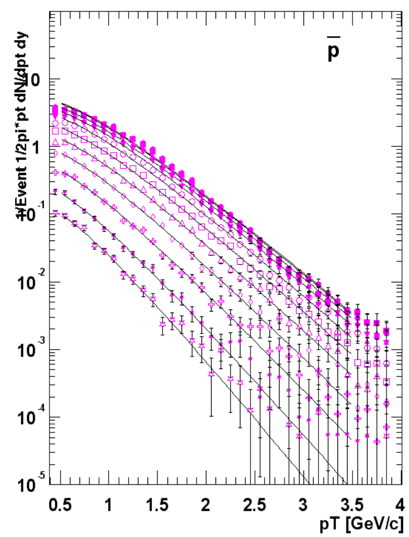






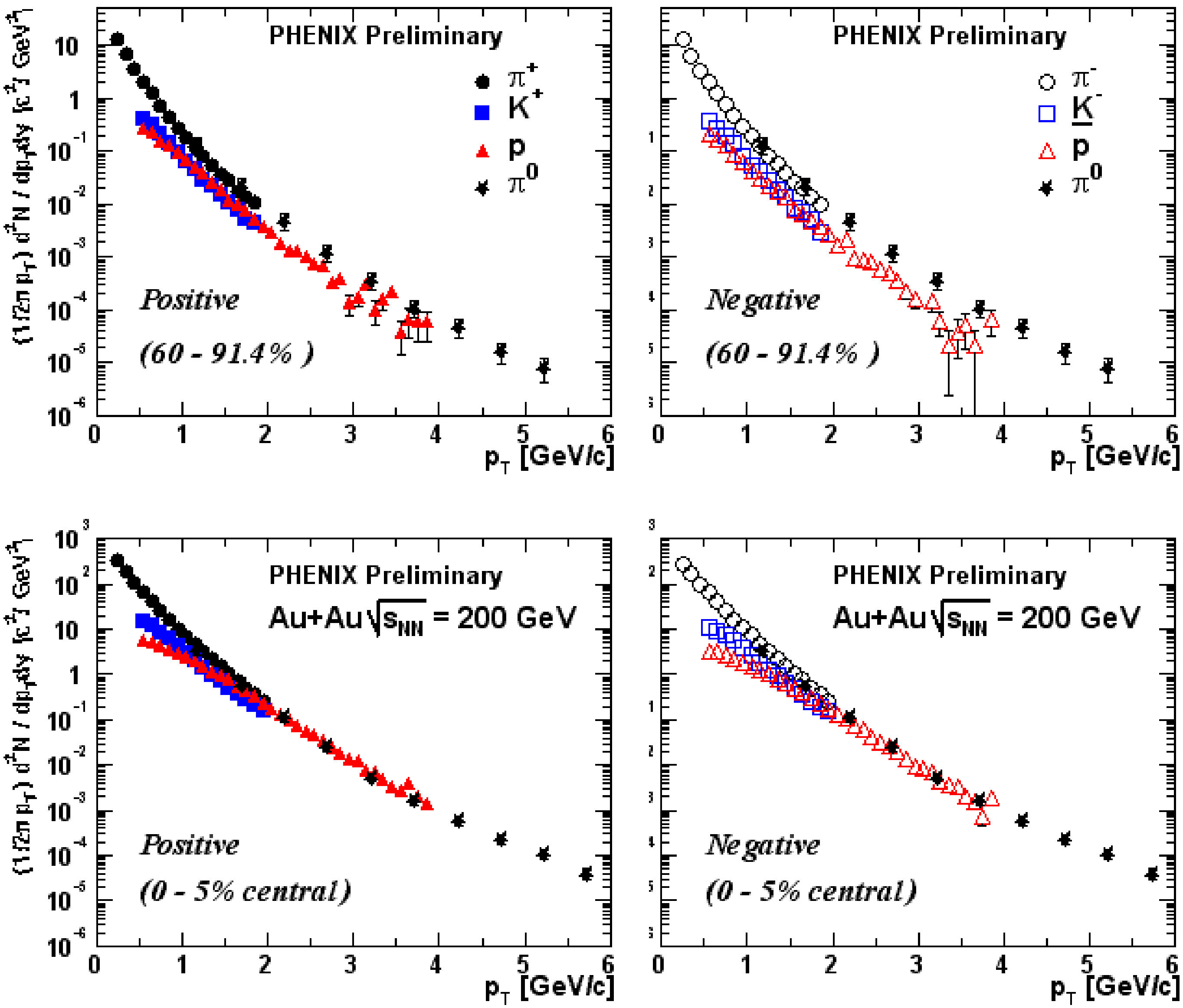
0 – 5 %
5 -10 %
10- 15 %
15 – 20 %
20 – 30 %
30 – 40 %
40 – 50 %
50 – 60 %
60 – 70 %
70 – 80 %
80 – 93 %





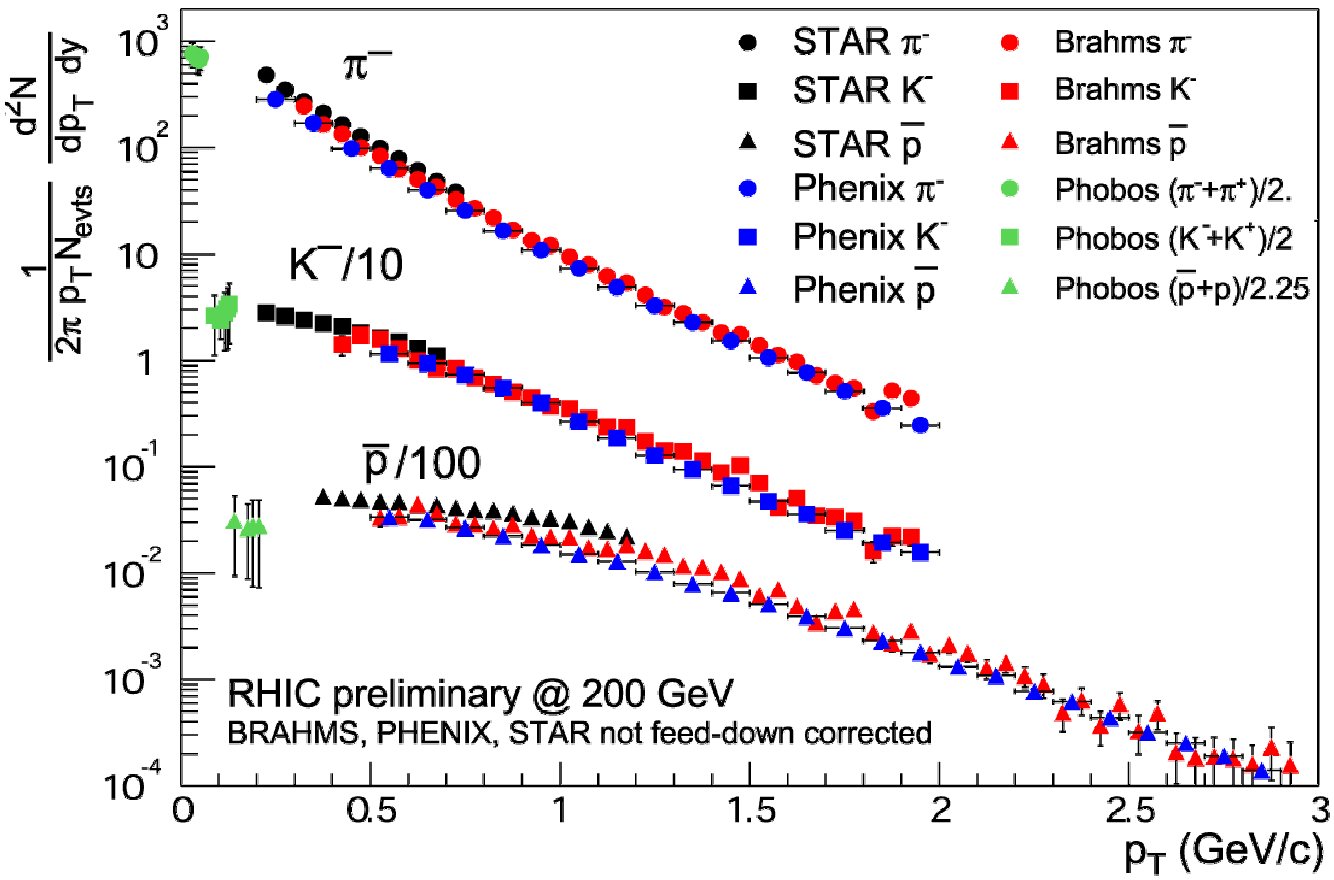
The general features

- **Peripheral :**
  - ~ equal slopes
  - Pions dominate over (anti)protons at all p_T



- **Central**
  - low-pt slopes increase with particle mass
  - proton and anti-proton yields equal the pion yield at high p_T

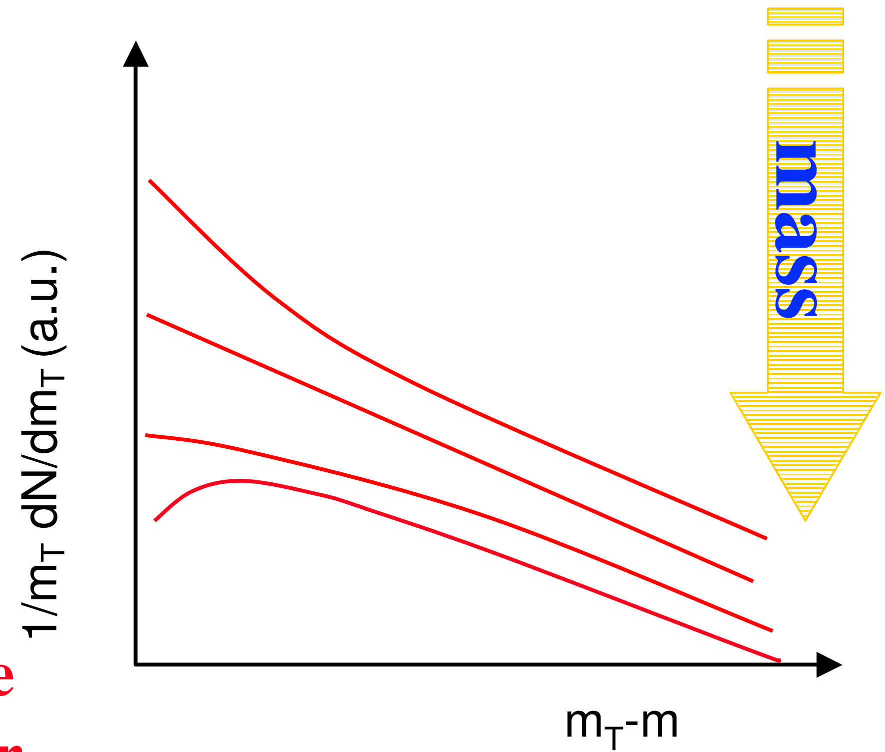
Comparison for 200 GeV central data from all RHIC experiments



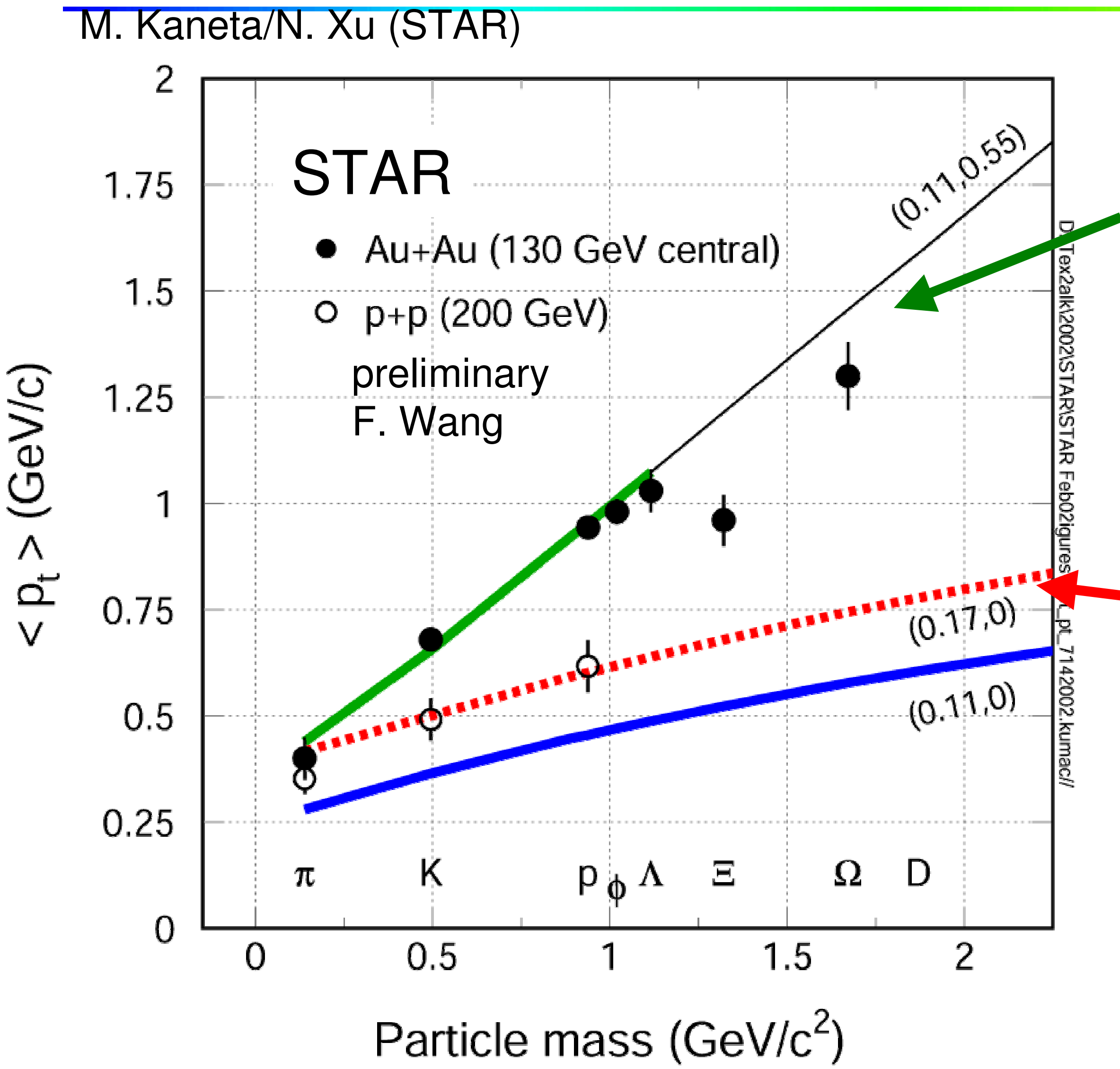
- **Relatively good agreement on preliminary data**
- **Low p_T data from PHOBOS will help constrain extrapolations to $p_T = 0$ GeV/c**

Characterizing the expansion

- **Strong radial flow:**
  - **Spectra are NOT exponential in m_T**
  - **Inverse slopes depend on fitted (measured) range**
  - **Curvature increases with particle mass**
  - **At high m_T all spectra converge to the same slope**
  - **$< p_T >$ versus mass – better than T_{eff} versus mass, but still depends on fit function – very low p_T data helps**



$\langle p_T \rangle$ versus mass



$\langle p_T \rangle$ prediction with T_{th} and $\langle\beta\rangle$ obtained from blastwave fit (green line)

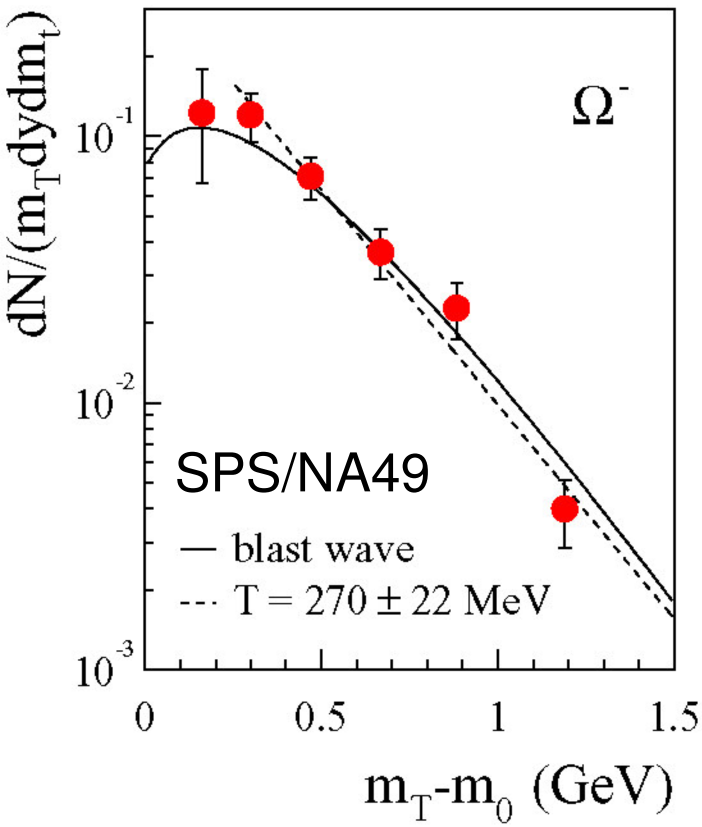
$\langle p_T \rangle$ of Ξ and Ω from exponential fits in m_T Do they flow ? Or is $\langle p_T \rangle$ lower due to different fit function?

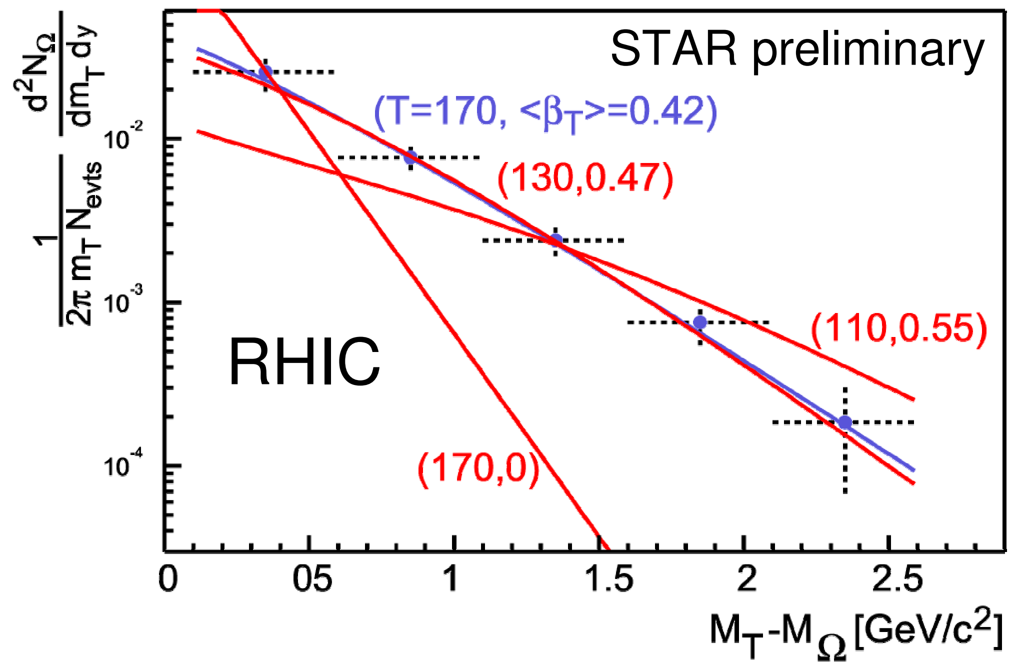
$\langle p_T \rangle$ prediction for T_{ch} = 170 MeV and $\langle\beta\rangle$=0
pp no rescattering, no flow no thermal equilibrium

Fits to Omega m_T spectra

M. van Leeuwen (NA49)

C. Suire (STAR)

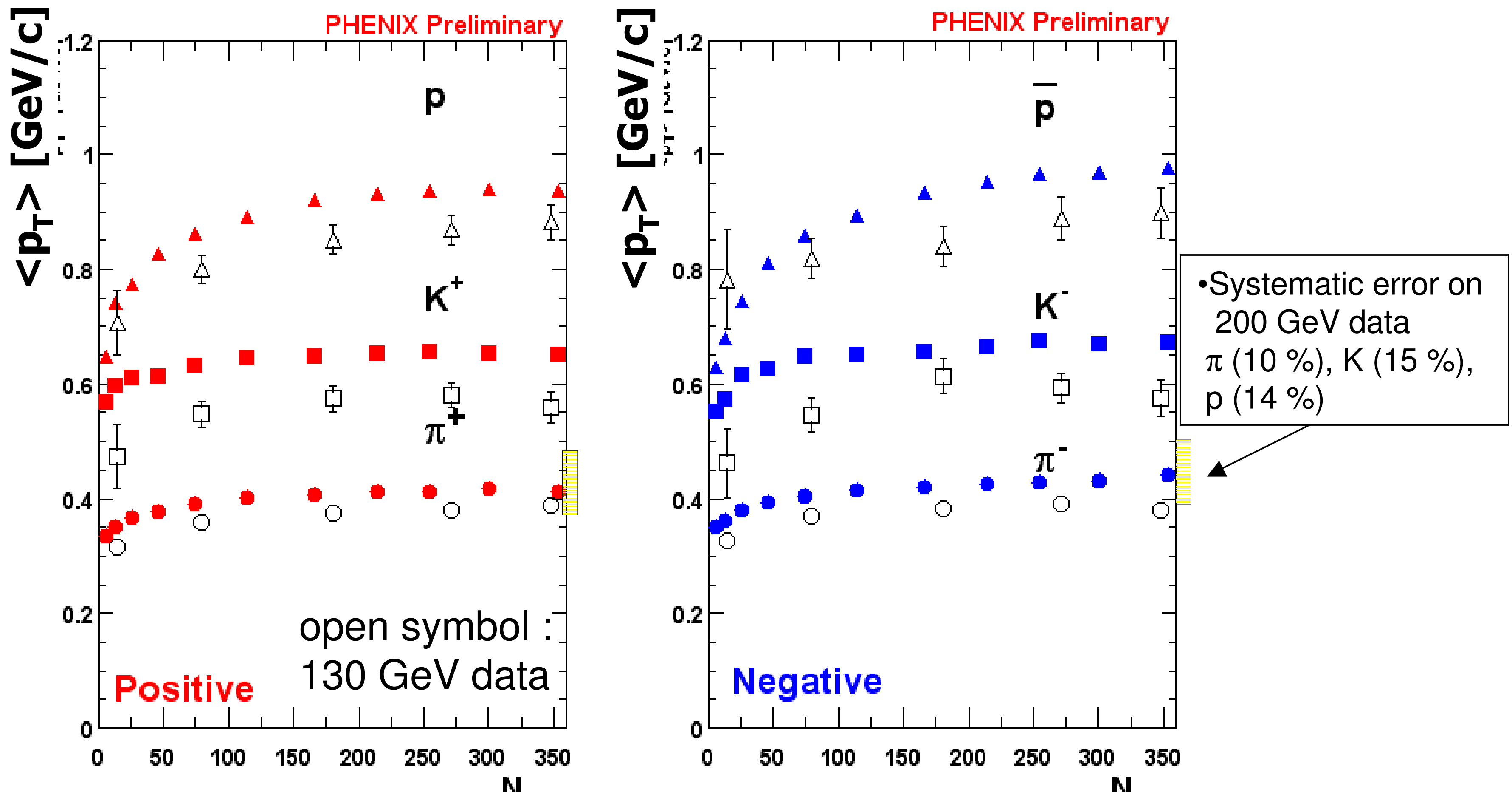




β_T is not well constrained !

- At SPS Ω and Ξ are now found to be consistent with common freeze-out
- Maybe Ω and Ξ are consistent with a blastwave fit at RHIC
- Need to constrain further $\Rightarrow$ more data & much more for v_2 of Ω

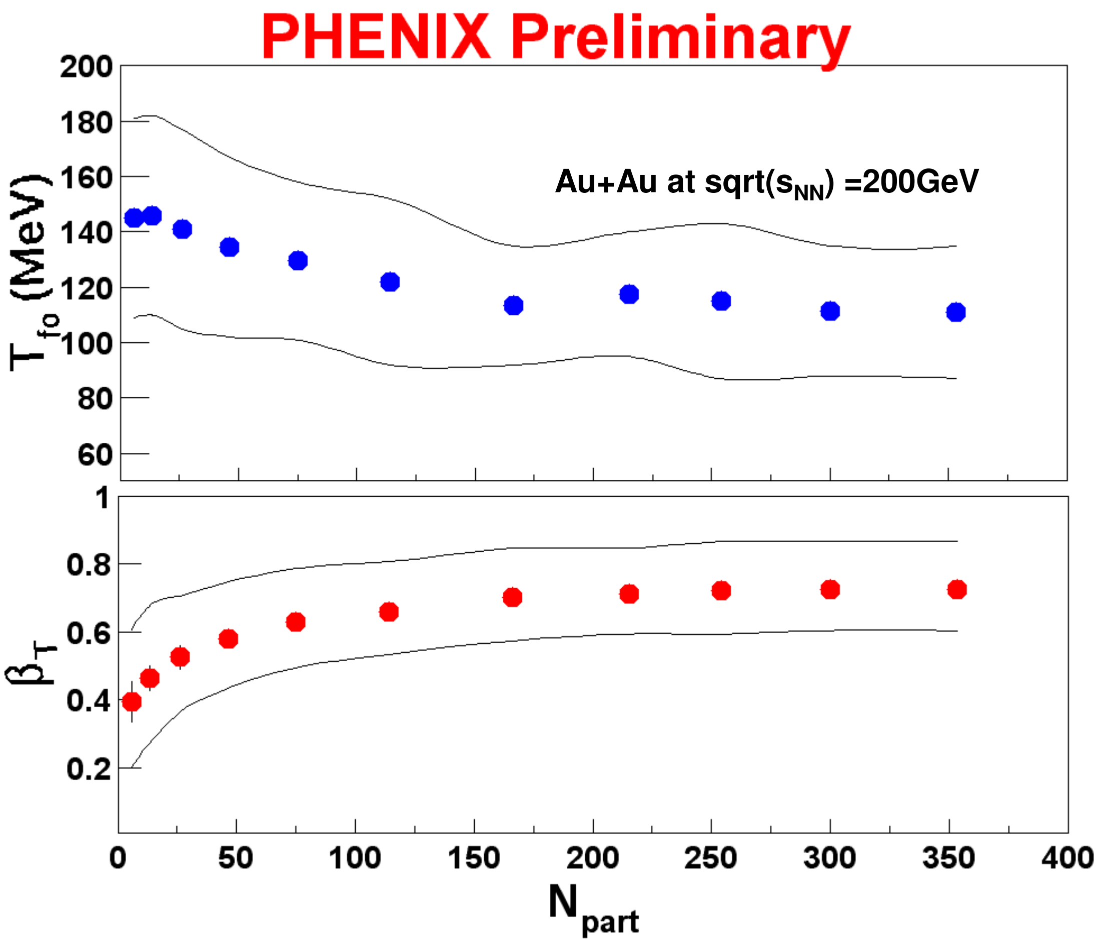
$\langle p_T \rangle$ systematics: centrality and beam energy



- Increase of $\langle p_T \rangle$ as a function of N_{part} and tends to saturate
  π < K < proton (pbar)
- Consistent with radial flow increasing with beam energy and centrality
- But also can come from initial state multiple scattering or gluon saturation.

Kinetic freeze out parameters

- **From hydrodynamics fit**



Top 5% centrality:

STAR:

T_{fo} ~ 100 MeV

$\langle\beta_T\rangle$ ~ 0.55c (130) & 0.6c (200)

PHENIX:

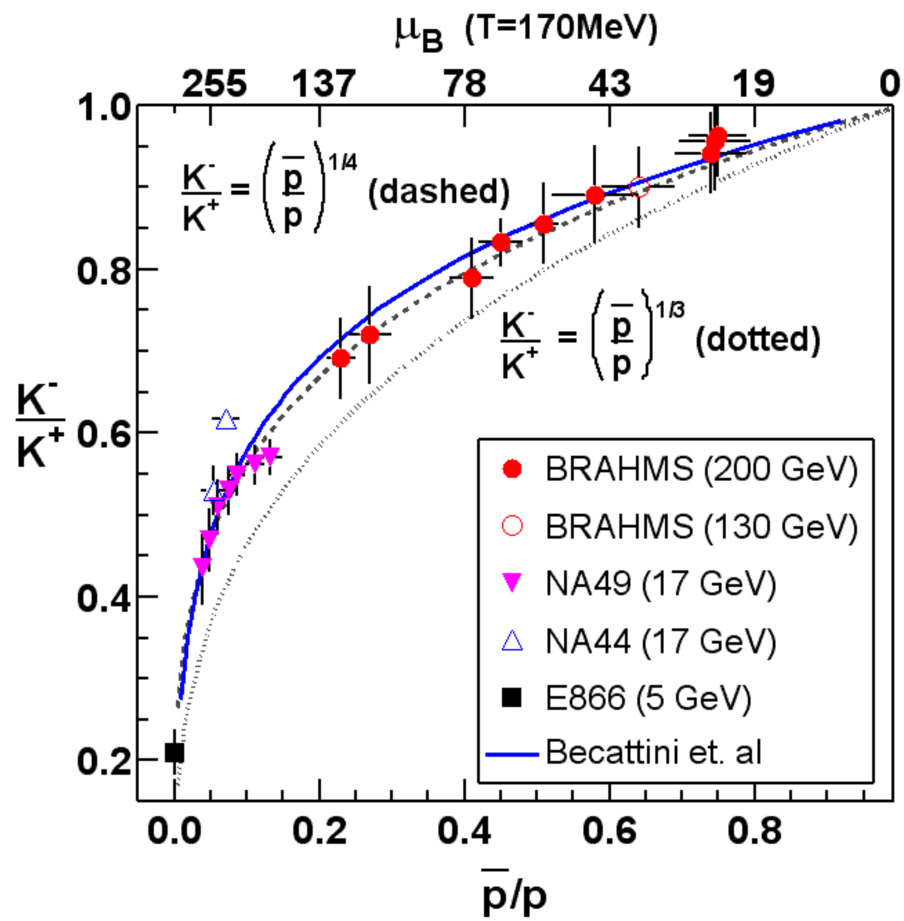
T_{fo} ~ 121MeV(130) &110 MeV(200)

$\langle\beta_T\rangle$ ~ 0.47c (200)

Full model calculations give similar results

Thermal parameters

from K^-/K and pbar/p ratios



Becattini: T=170, γ_s=1

PBM (PhysLettB518 (2000)41) predicts y=0 ratios almost exactly

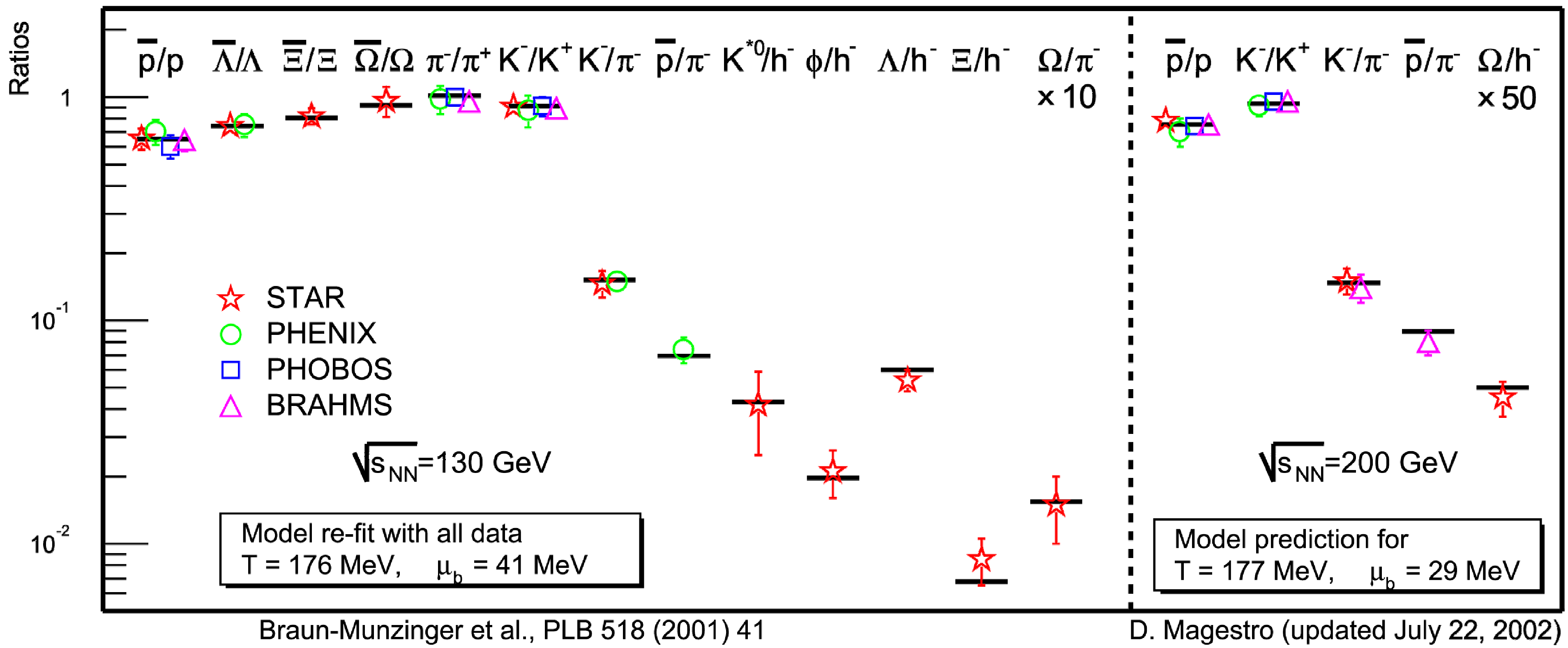
$K^-/K^+ = \exp(2\mu s/T)(\text{pbar}/p)^{1/3}$

$K^-/K^+ = (\text{pbar}/p)^{1/4}$ is a fit to the data points

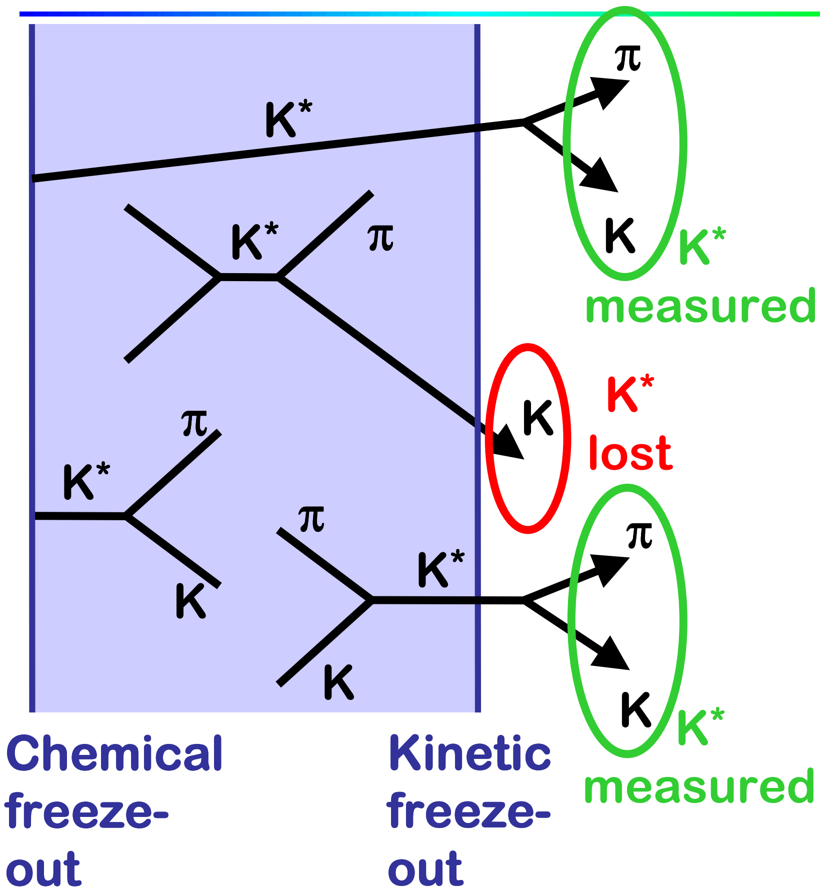
BRAHMS, submitted to PRL 12/07/02 nucl-ex/0207006

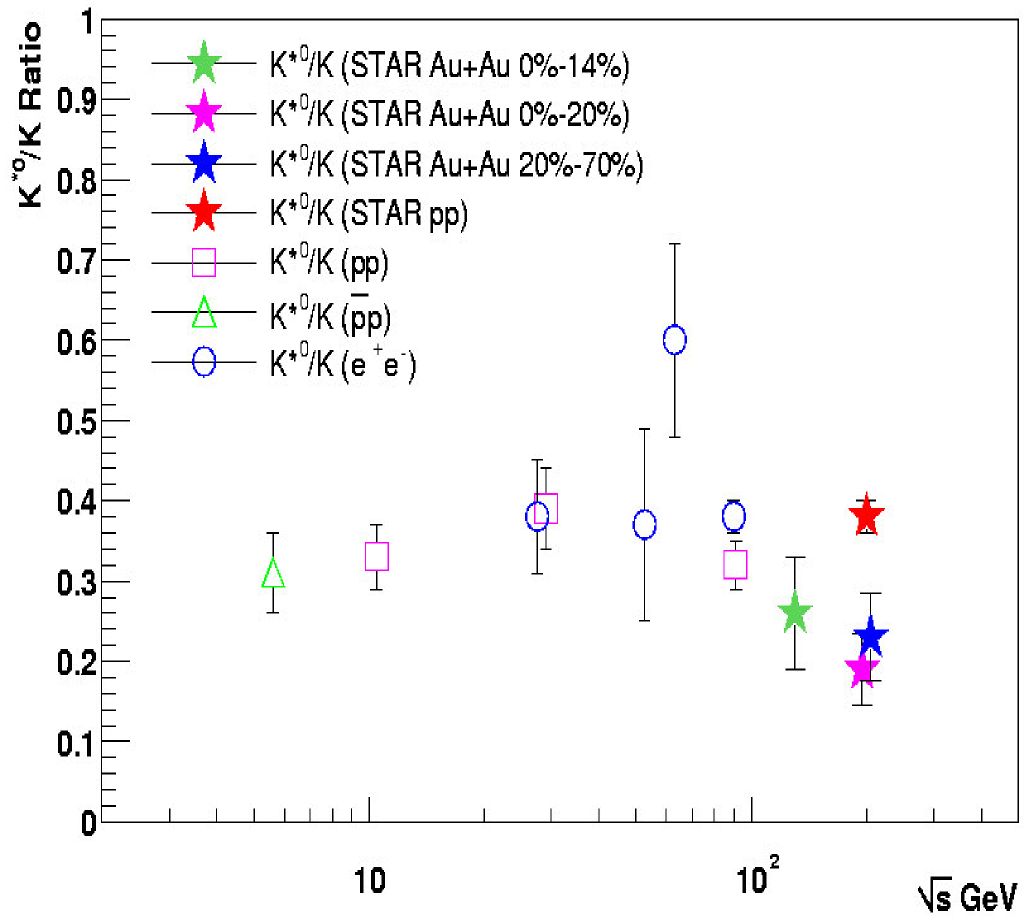
The chemistry of the collisions

- **Thermal models work well in describing particle ratios, even for the multi-strange particles : T_{ch} = 177 MeV – close to critical temperature**



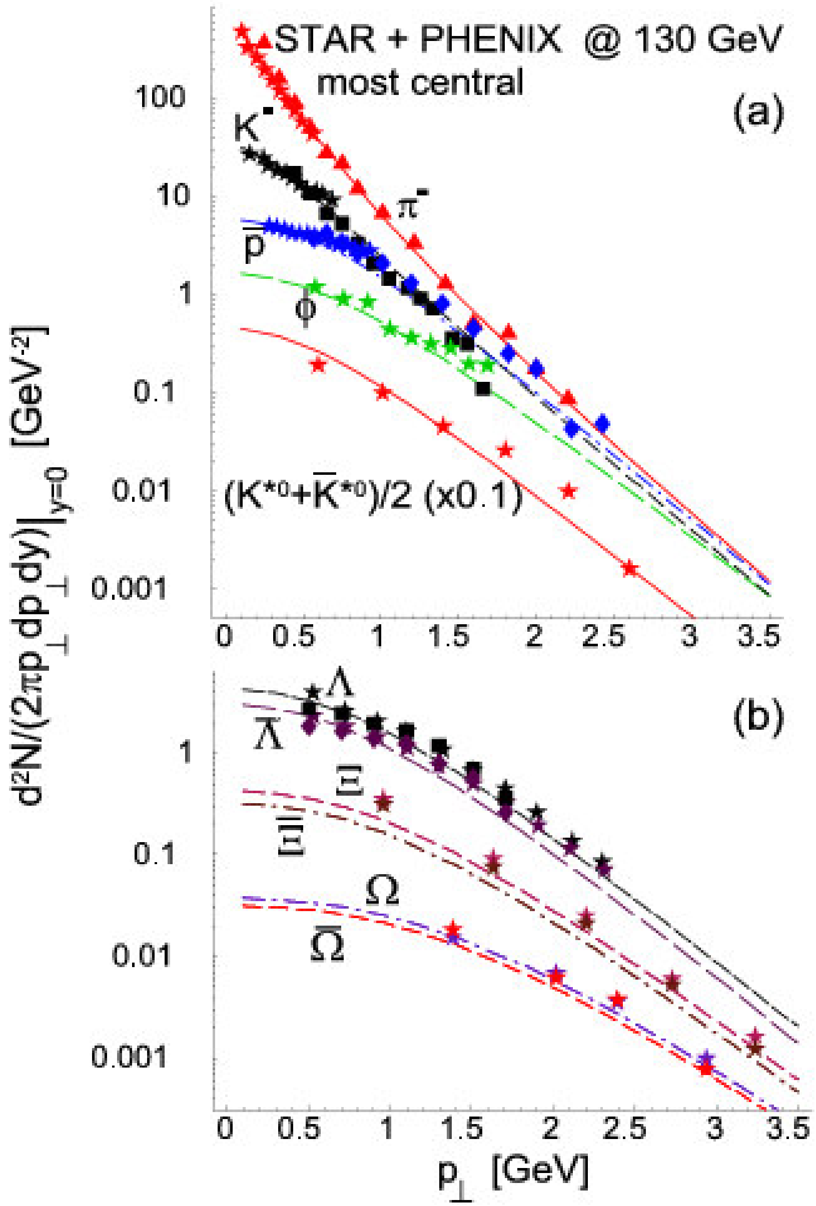
Short-lived resonances : a measure for rescattering timescale





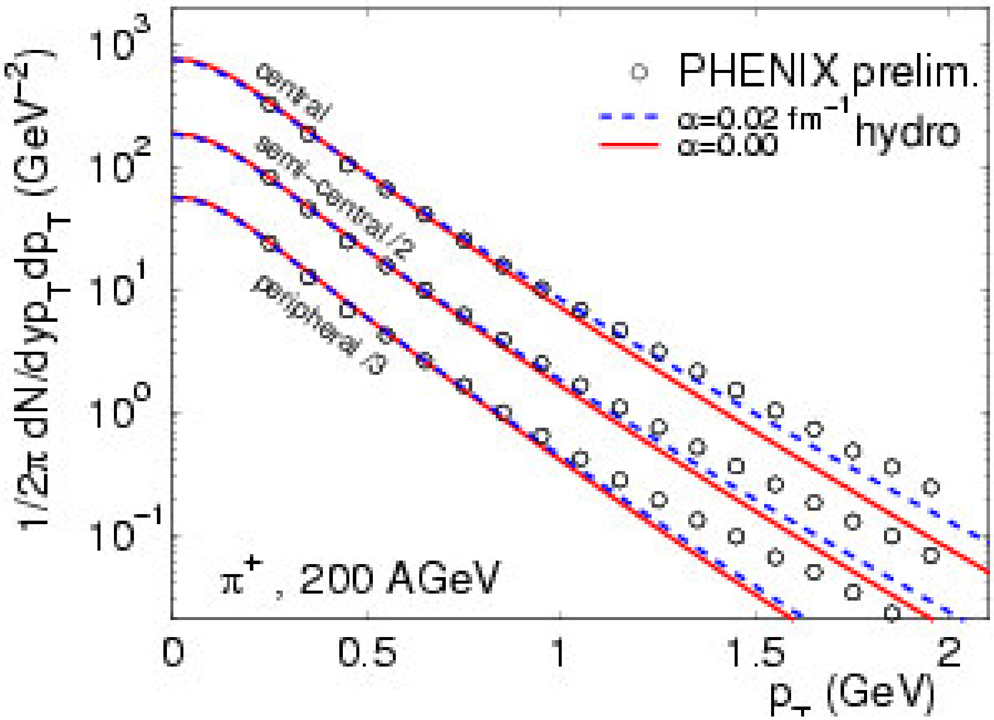
Consistent with sudden freeze-out

Is $T_{ch} > T_{fo}$?

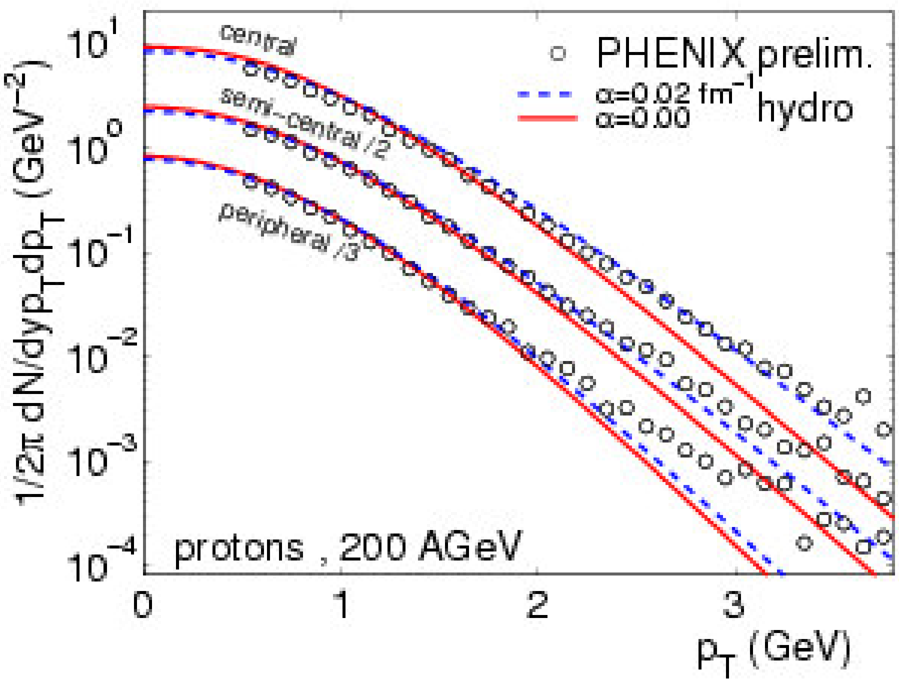


- **Single freeze-out model: Broniowski,Florkowski hep-ph/0209286**
- **2 thermal and 2 geometric (flow) parameters describe all central data including K^{*0} (892)**
  - **How good is the agreement really ?**
  - **Plots of theory/experiment on a linear scale ?**
  - **Comparison to other observables?**

When does the flow start ?



centrality
0-5%
20-30%
40-50%

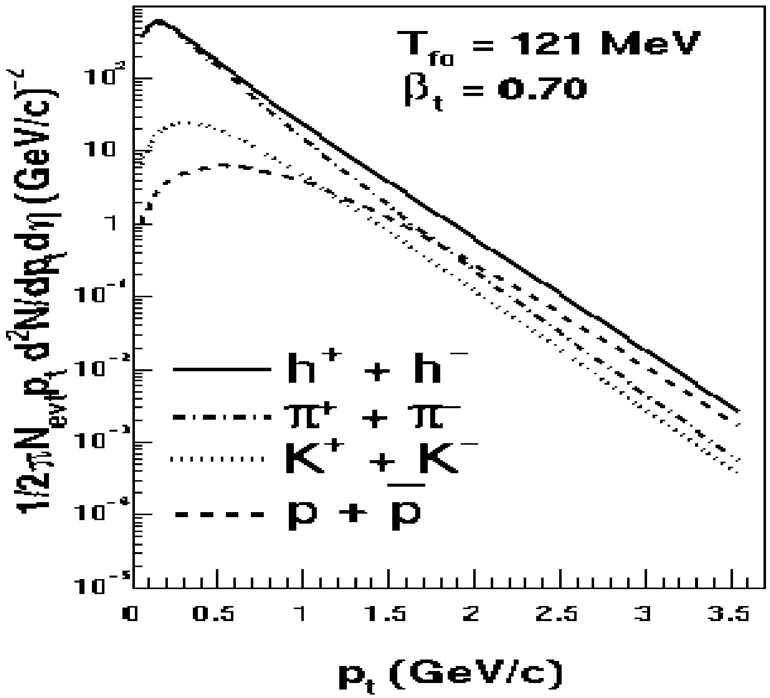


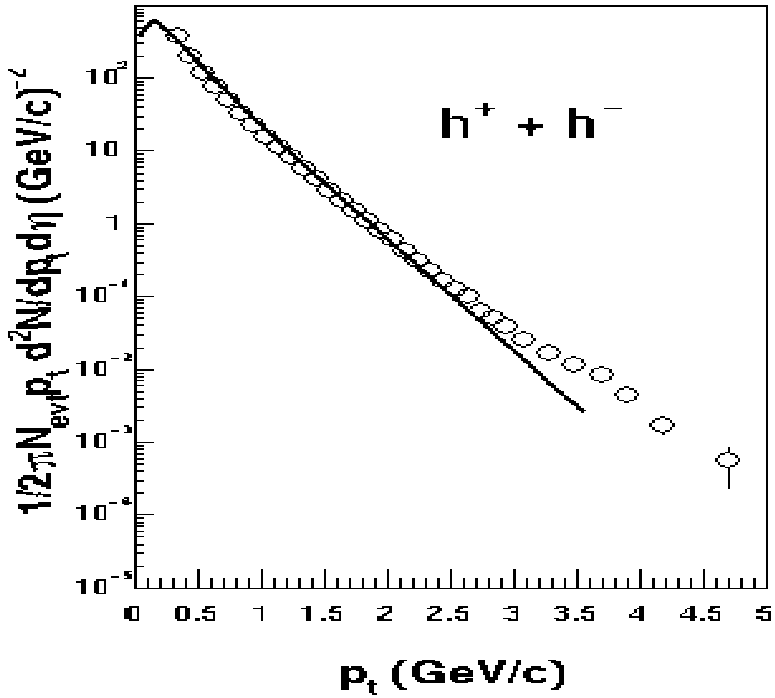
P.Kolb and R. Rapp
hep-ph/0210222

- **Including pre-equilibrium transverse flow field improves agreement with the data**

And how far in p_T does flow dominate?

130 GeV PHENIX

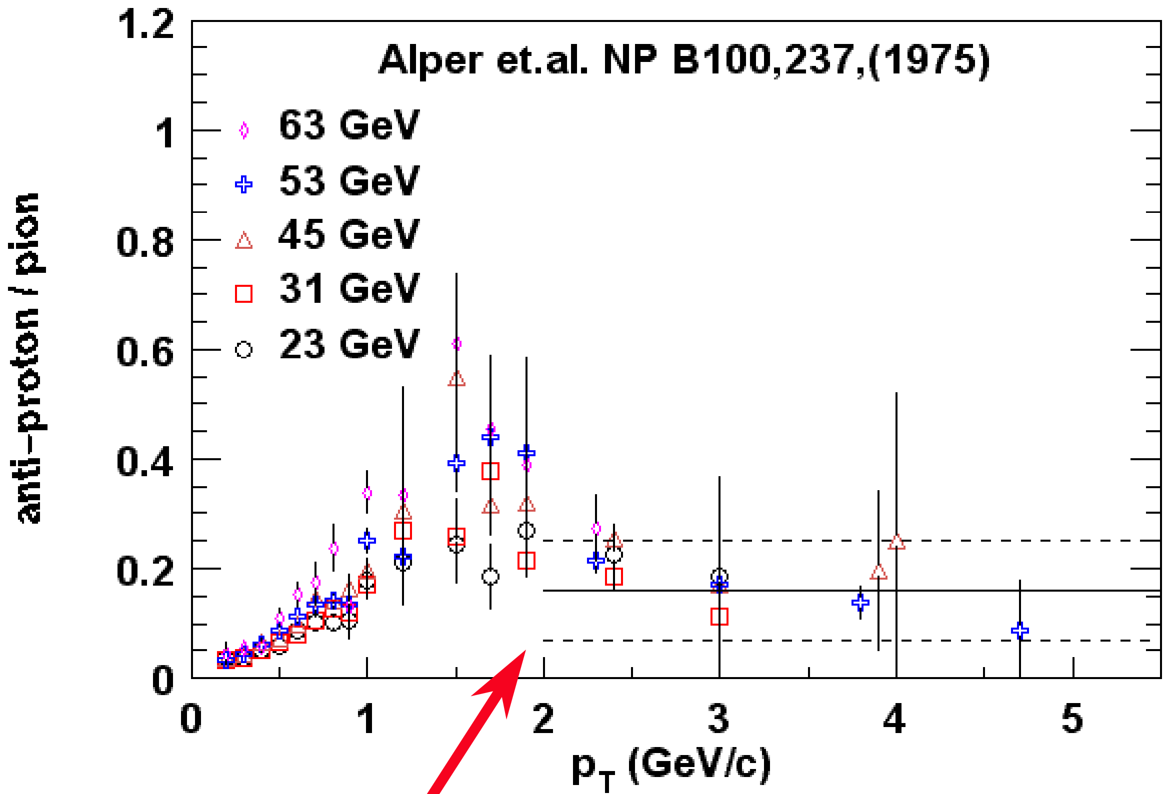




- **Fit the soft part of** π, K,p **spectra using hydrodynamics expression**
- $h^+ + h^- = \Sigma\, \pi, K, p$
- **Compare to measured non-identified charged data**
- **Significant soft component up to 2.5 – 3 GeV/c**

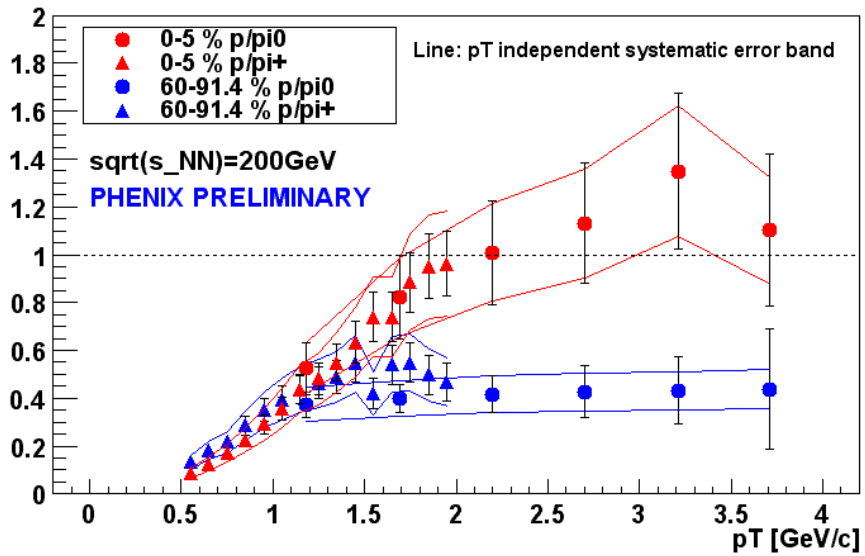
Another approach: look for jet fragmentation ratios as seen in pp data

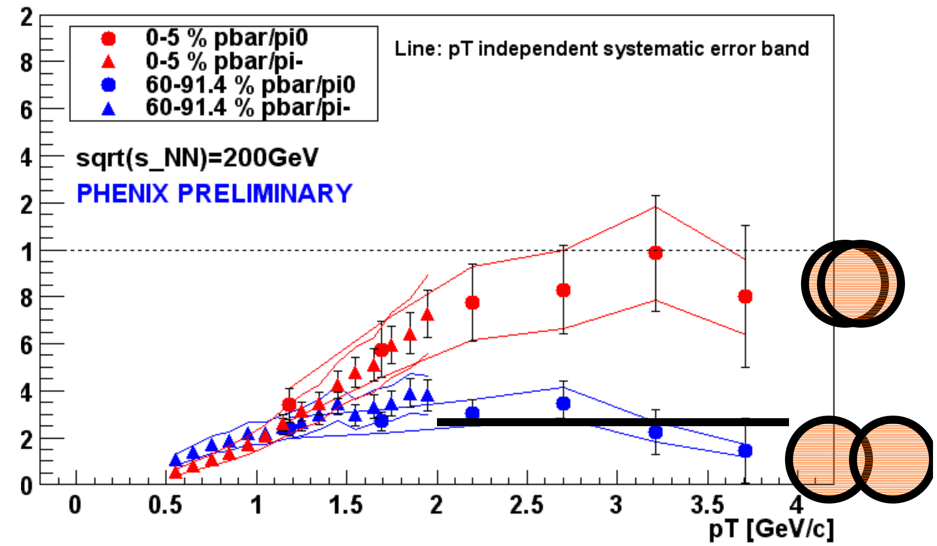
- **Experimentally observed: above pt=2 GeV/c particles are fragments of jets**
- **Characteristic particle composition determined by fragmentation function**



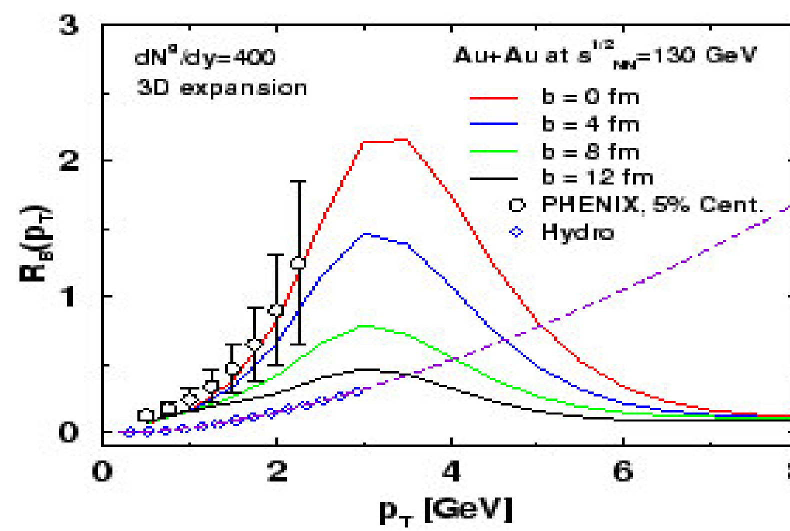
Soft to hard transition in $\bar{p}/\pi$ ratio

(anti)proton/pion ratio: Can we determine soft to hard transition?





- Ratios steeply rising to p_T ~ 2 GeV/c
- Above p_T = 2 GeV/c – flat
  - ~ 1 for central Au+Au
  - ~ 0.3 – 0.4 for peripheral Au+Au
- Is there a peak ? At what p_T do we get to the pQCD ratios ?

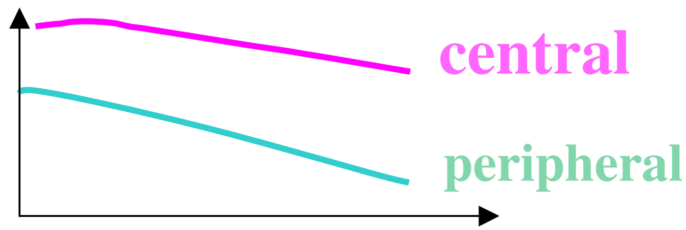


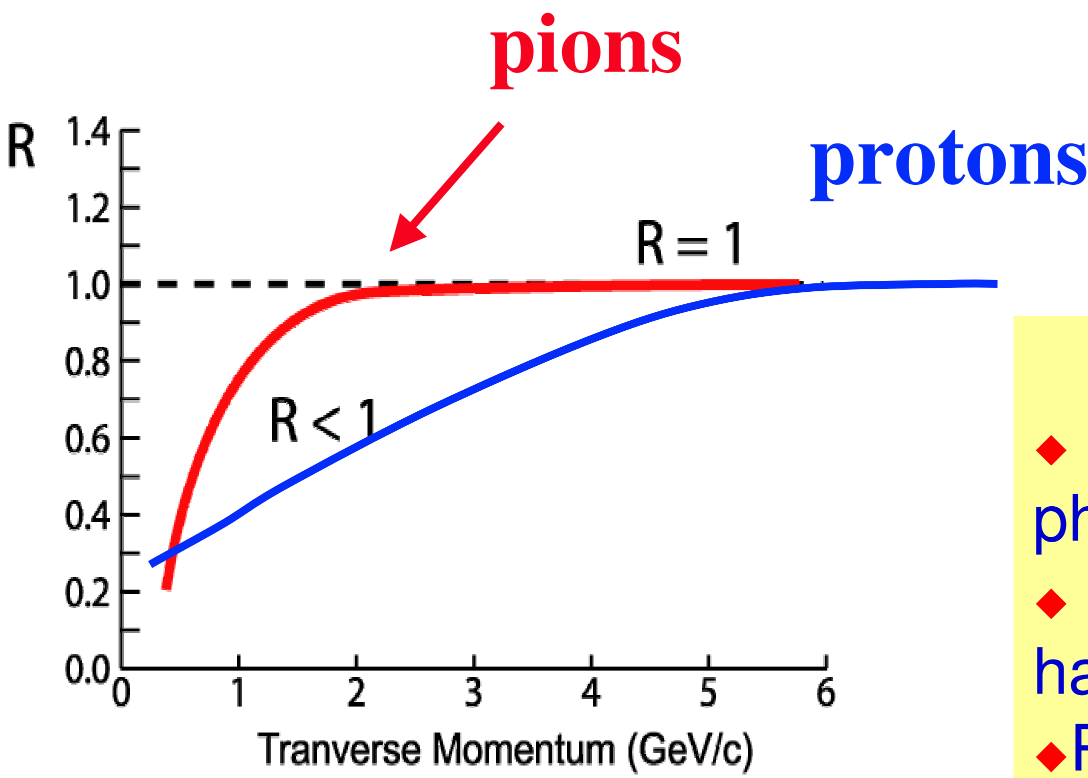
If protons are soft up to 4 Gev/c

$$R = \frac{\text{Yield}_{central} / \langle N_{binary} \rangle_{central}}{\text{Yield}_{pp}}$$

$T_{slope} \sim \text{sqrt}\,[\,(1+\langle\beta_\tau\rangle)/(1-\langle\beta_\tau\rangle)]$

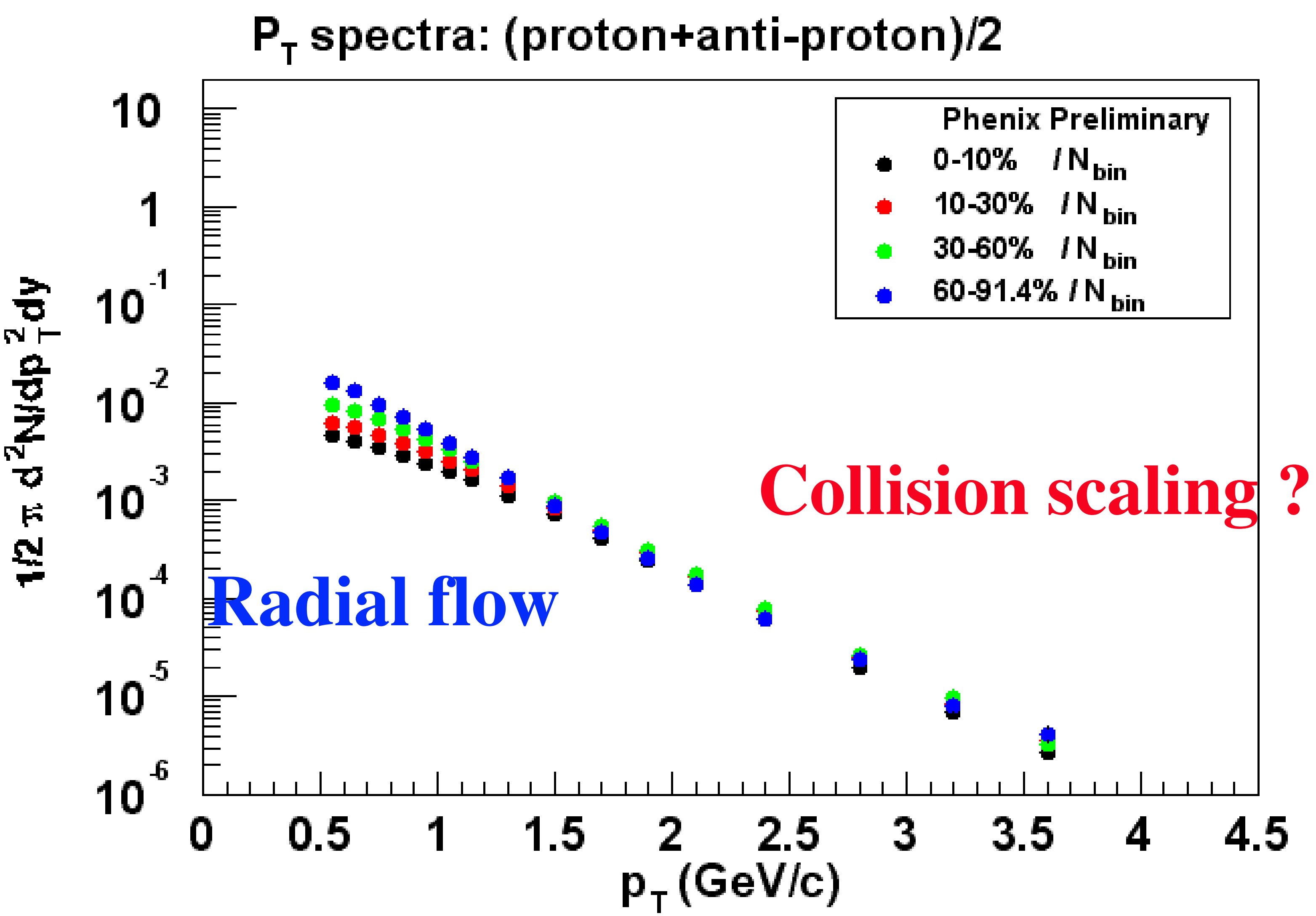
For $m_T > 2\,m_0$





- R < 1 in regime of soft physics
- R = 1 at high-p_T where hard scattering dominates
- R< 1 at high-p_T suppression

Scaling the proton+anti-proton spectra



N_{bin}
975
422
135
14.8

How does the ratio Central/peripheral look ?

…. and more details

- See PHENIX talk by Jiangyoung Jia
- And overview talk by David d'Enterria

Conclusions

- **A wealth of spectra, yields, ratios measurements from the first 2 years of RHIC**
- **Spectral shapes consistent with strong radial expansion**
- **Success of thermal chemical models**
  - **Almost net baryon free system with T_{ch} close to critical temperature**
- **Resonance studies show time-scale for emission is short , T_{ch} close to T_{fo}**
- **Abundant protons+anti-protons at intermediate/high p_T . How do they get there ?**