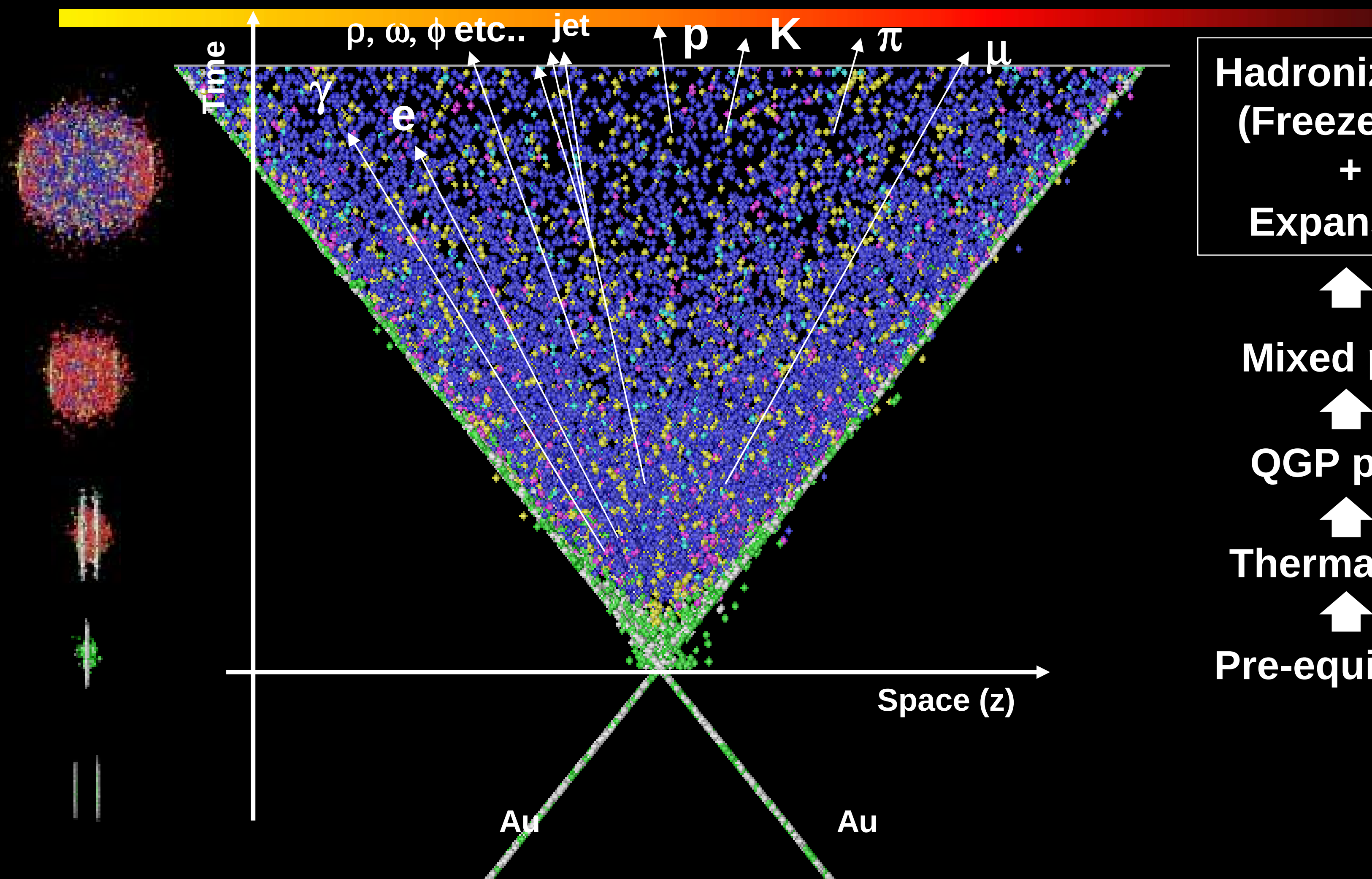
Results on Particle Yields from the PHENIX Experiment at RHIC

Tatsuya Chujo (BNL)
for the PHENIX Collaboration

Space-time Evolution of System at RHIC



Hadronization
(Freeze-out)
+
Expansion

Mixed phase

QGP phase

Thermalization

Pre-equilibrium

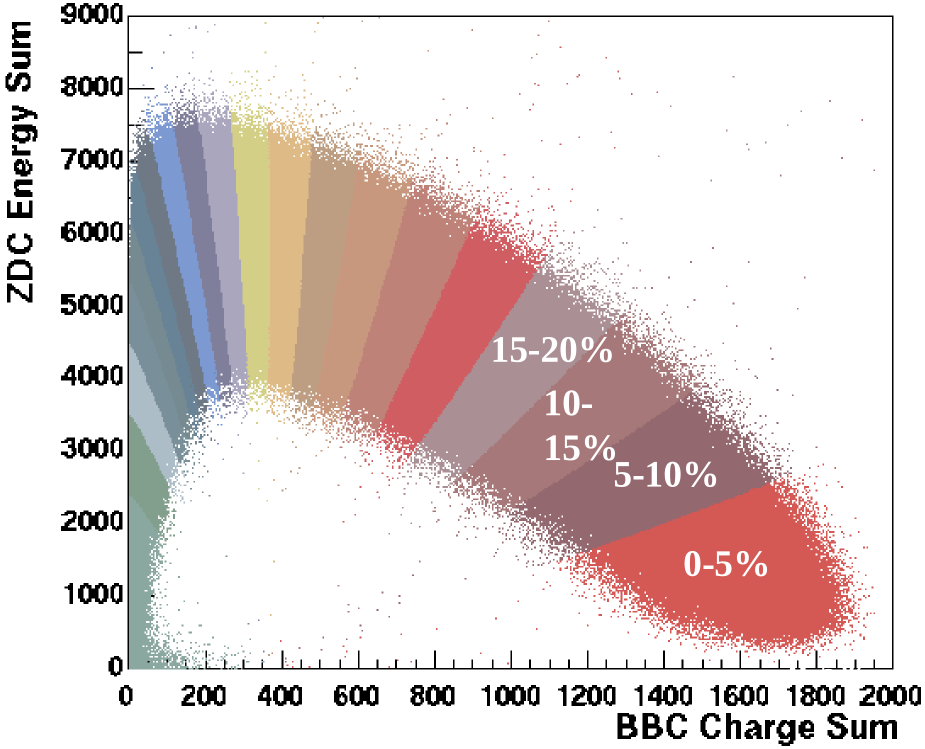
Hadrons reflect the bulk property of created system and its evolution!

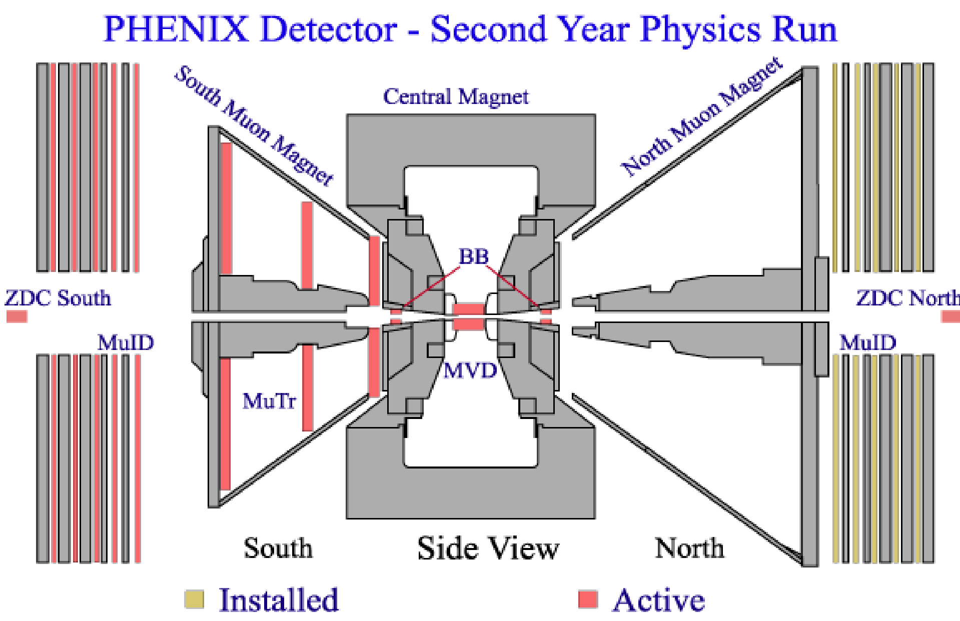
Characterize freeze-out

1. **Hydrodynamic Collective Expansion**
   - Identified charged hadron spectra vs. centrality
   - $<p_T>$ vs. centrality
   - Hydro-dynamical model fit.
   - Elliptic flow (identified particle) vs. hydro. model
2. **Space-time evolution of the System**
   - Pion HBT correlation (k_T and centrality dependence)
   - Deuteron / anti-deuteron spectra and coalescence model
3. **Chemical Composition**
   - Particle ratios for same mass
   - p/ π ratio vs. p_T and centrality
   - dN/dy for π, K, p and anti-proton vs. centrality
   - Λ, Λbar yield

We present the first results of identified charged hadrons in Au+Au @ sqrt(s_{NN}) = 200 GeV at mid-rapidity from the PHENIX experiment.

Event Selection



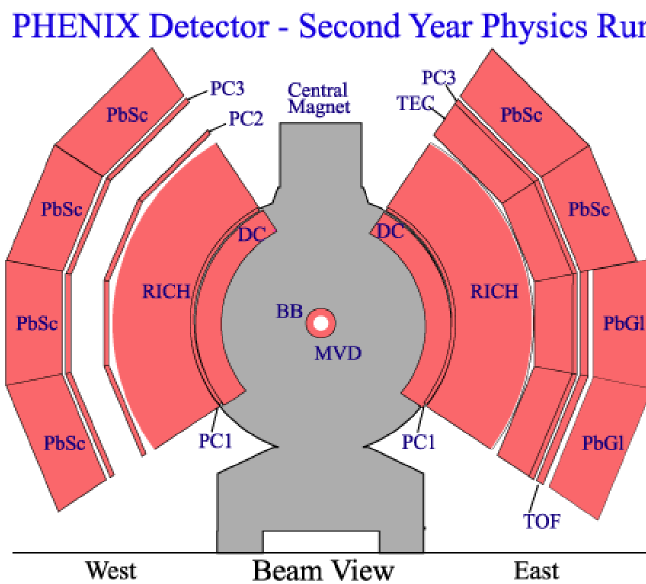


- Centrality selection : Used charge sum of Beam-Beam Counter (BBC, $|\eta|$=3~4) and energy of Zero-degree calorimeter (ZDC) in minimum bias events.
- Extracted N_{part} based on Glauber model.

Charged Particle Identification at PHENIX

HBT analysis
Time-of-Flight
by Calorimeter

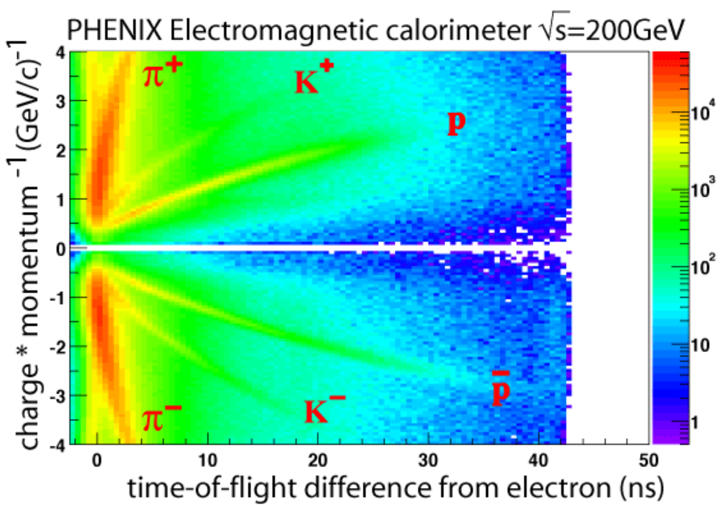
- large acceptance
  ($\Delta\phi = \pi$)

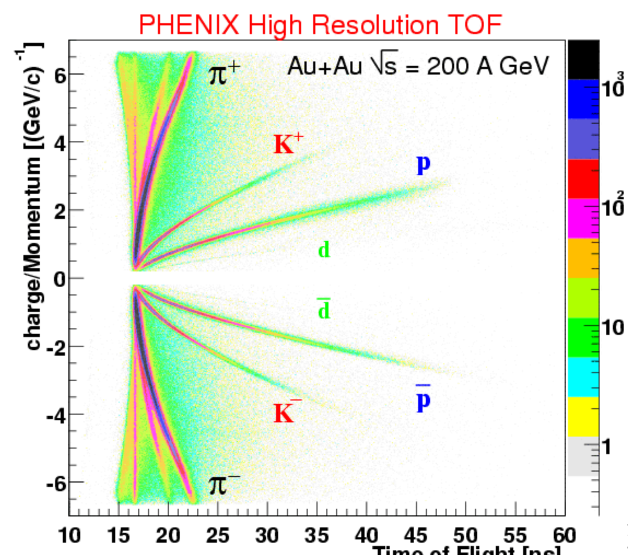


Single particle spectra and elliptic flow w.r.t reaction plane analysis

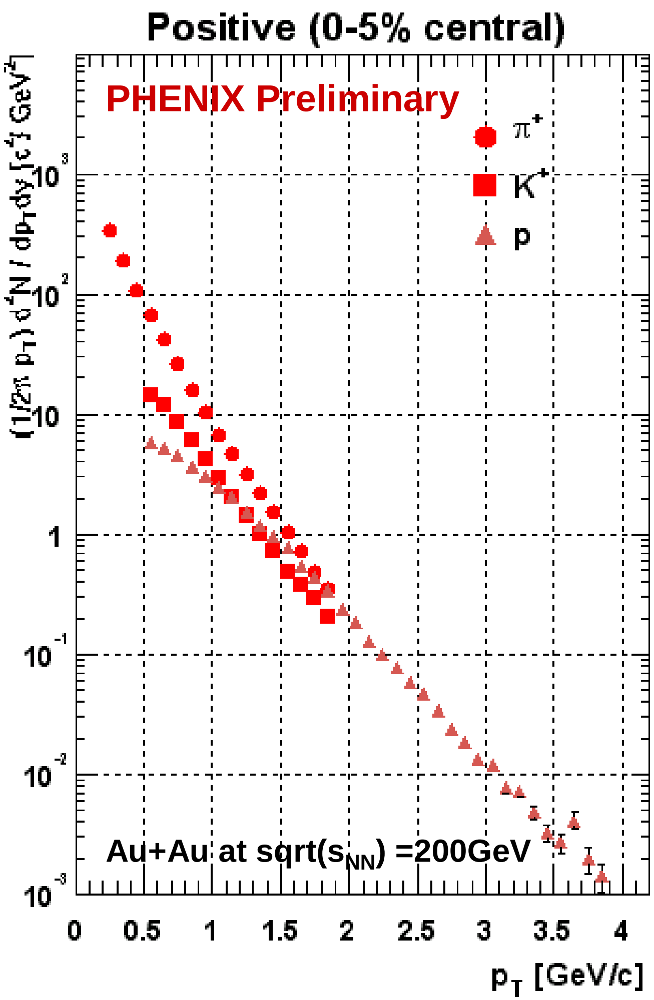
PID by high resolution TOF

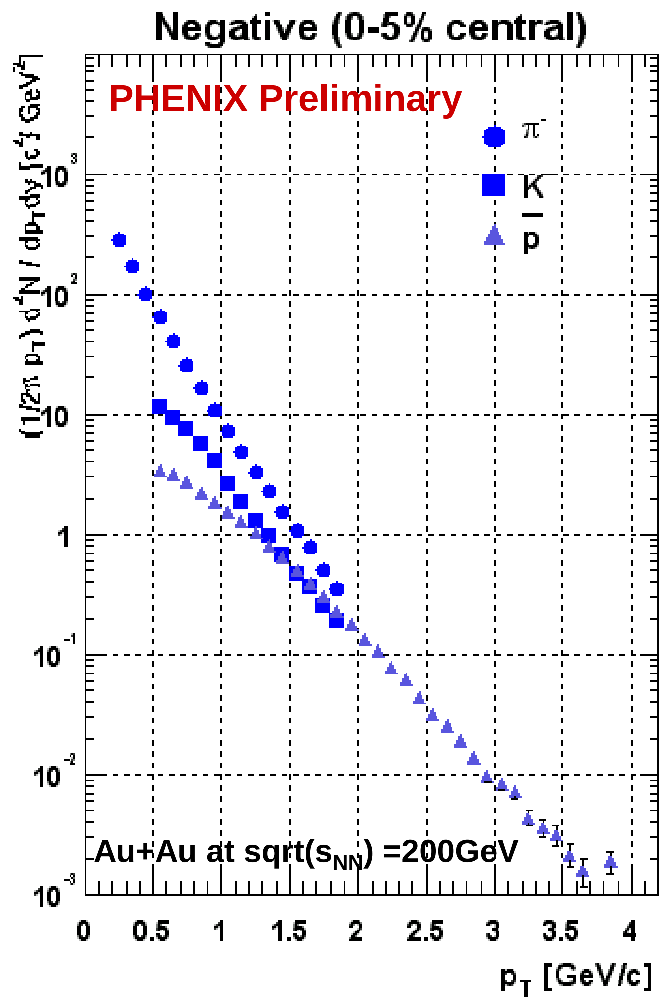
- broad p_T range
  - π, K < 2 GeV
  - proton, anti-proton < 4 GeV
- $\Delta\phi = \pi/4$





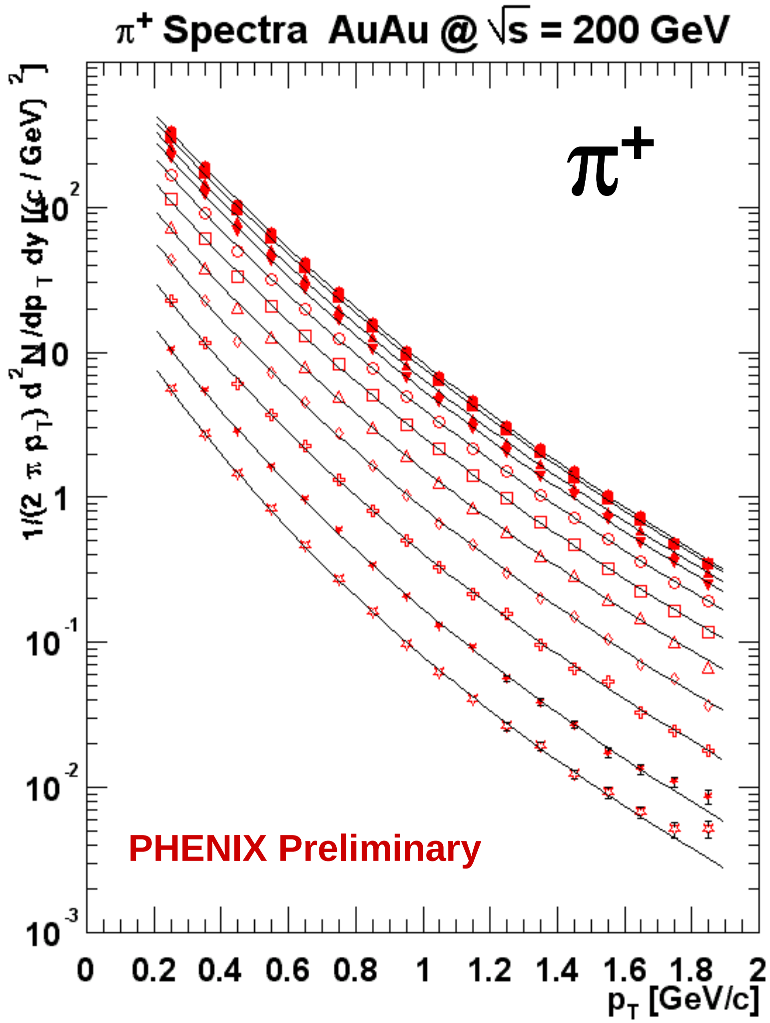
Single Particle Spectra at most central events (0-5 %)

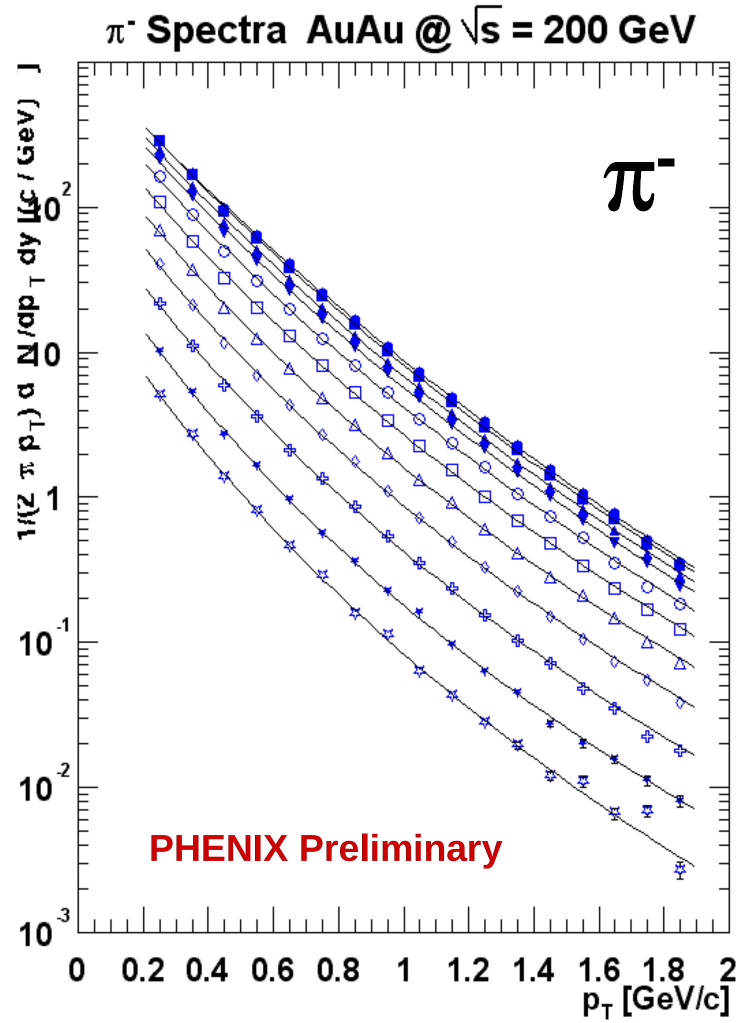




- proton yield ~ pion yield @ 2 GeV

Pion p_T spectra (centrality dependence)

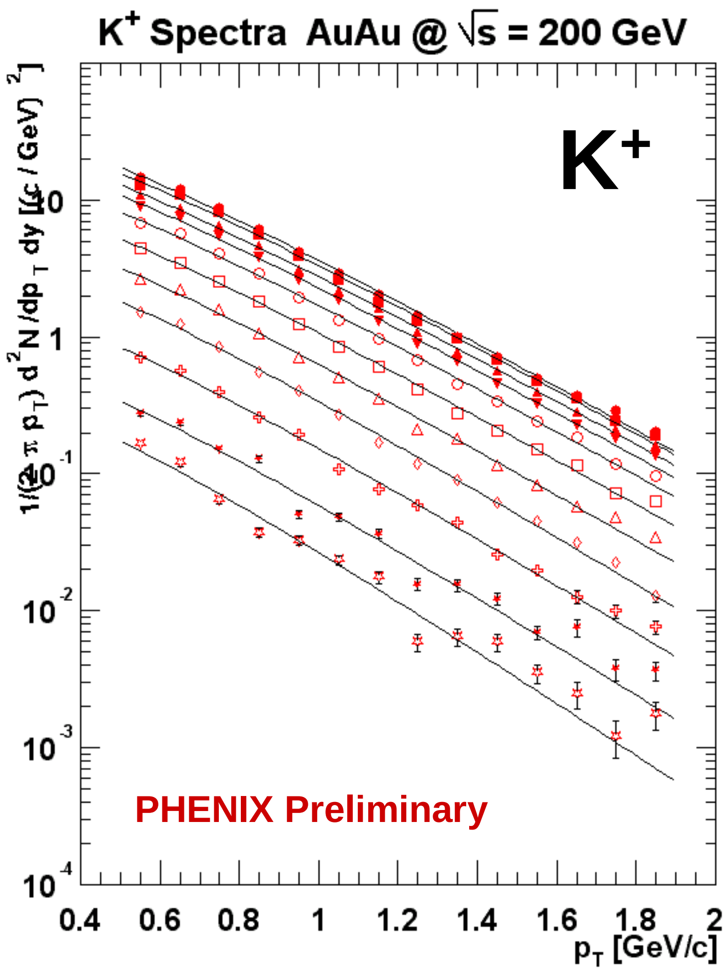


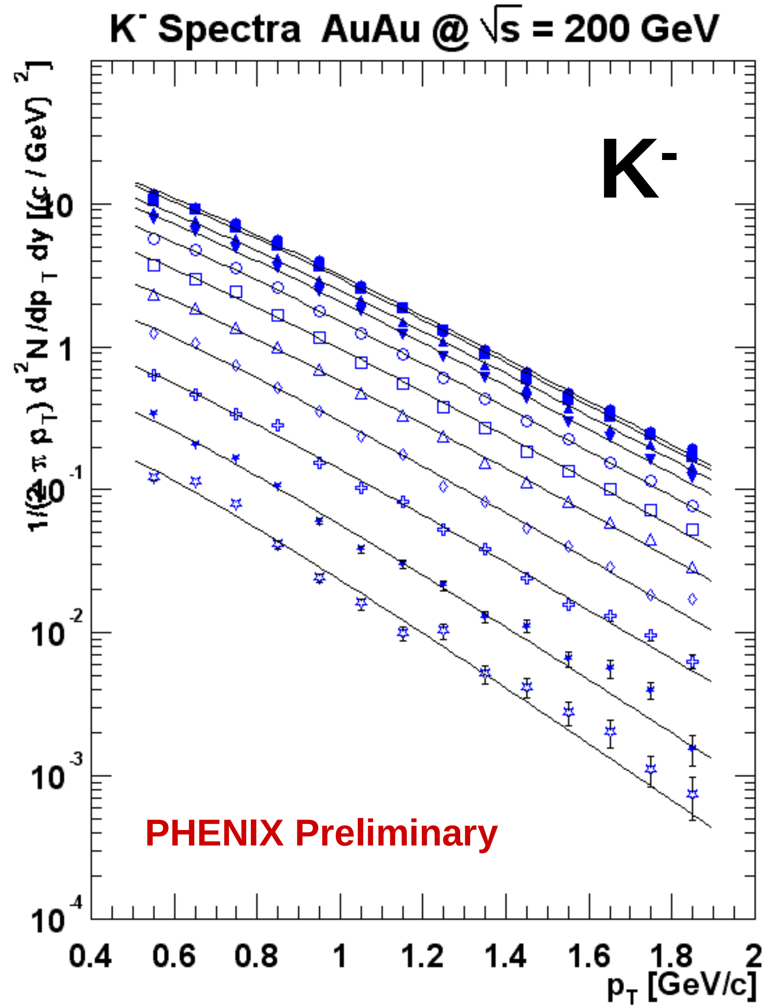


centrality
0 - 5 %
5 - 10 %
10 - 15 %
15 - 20 %
20 - 30 %
30 - 40 %
40 - 50 %
50 - 60 %
60 - 70 %
70 - 80 %
80 - 91 %

Characterized by power law shape for all centralities

Kaon p_T spectra





centrality
0 - 5 %
5 - 10 %
10 - 15 %
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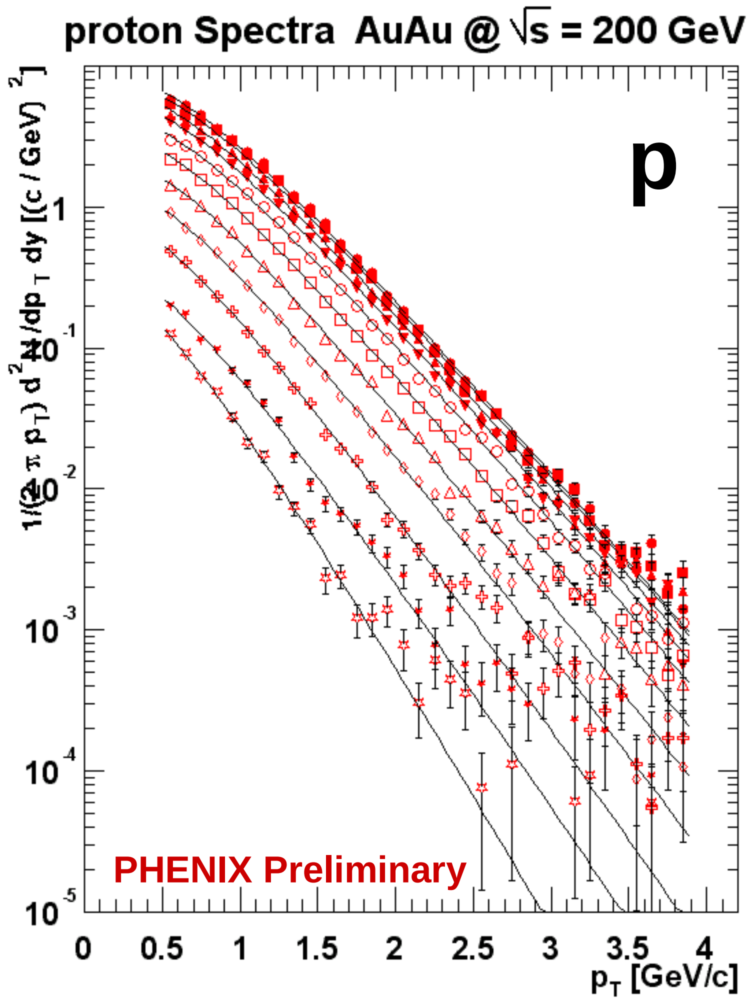
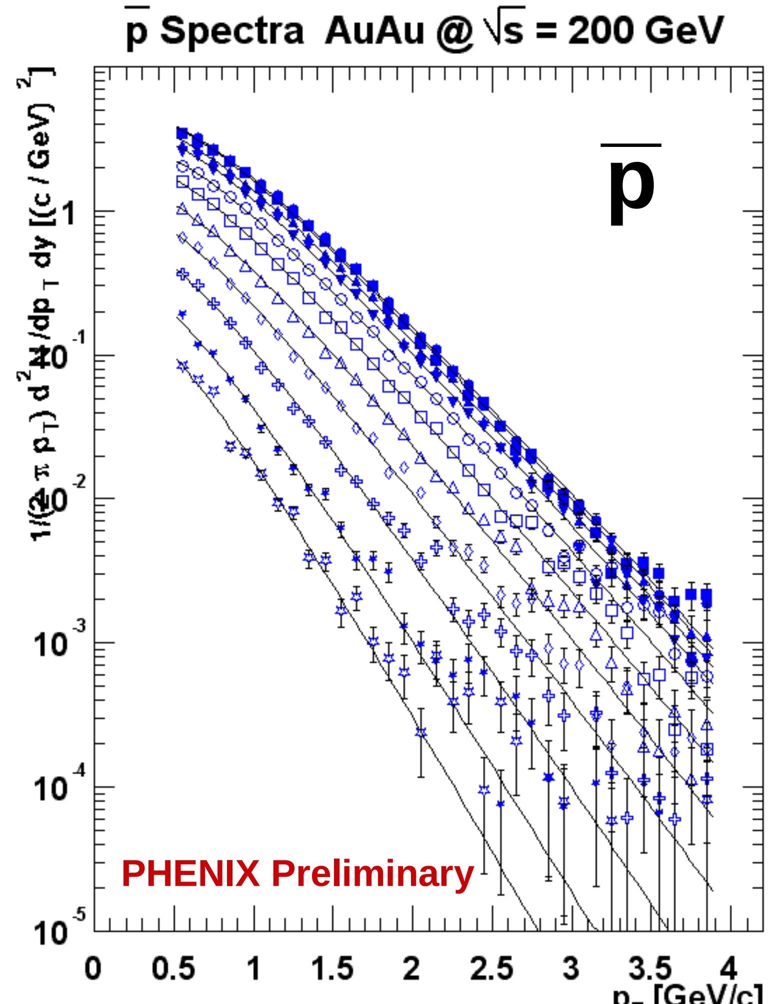
60 - 70 %
70 - 80 %
80 - 91 %

Characterized by m_T exponential shape for all centralities

p, pbar p_T spectra



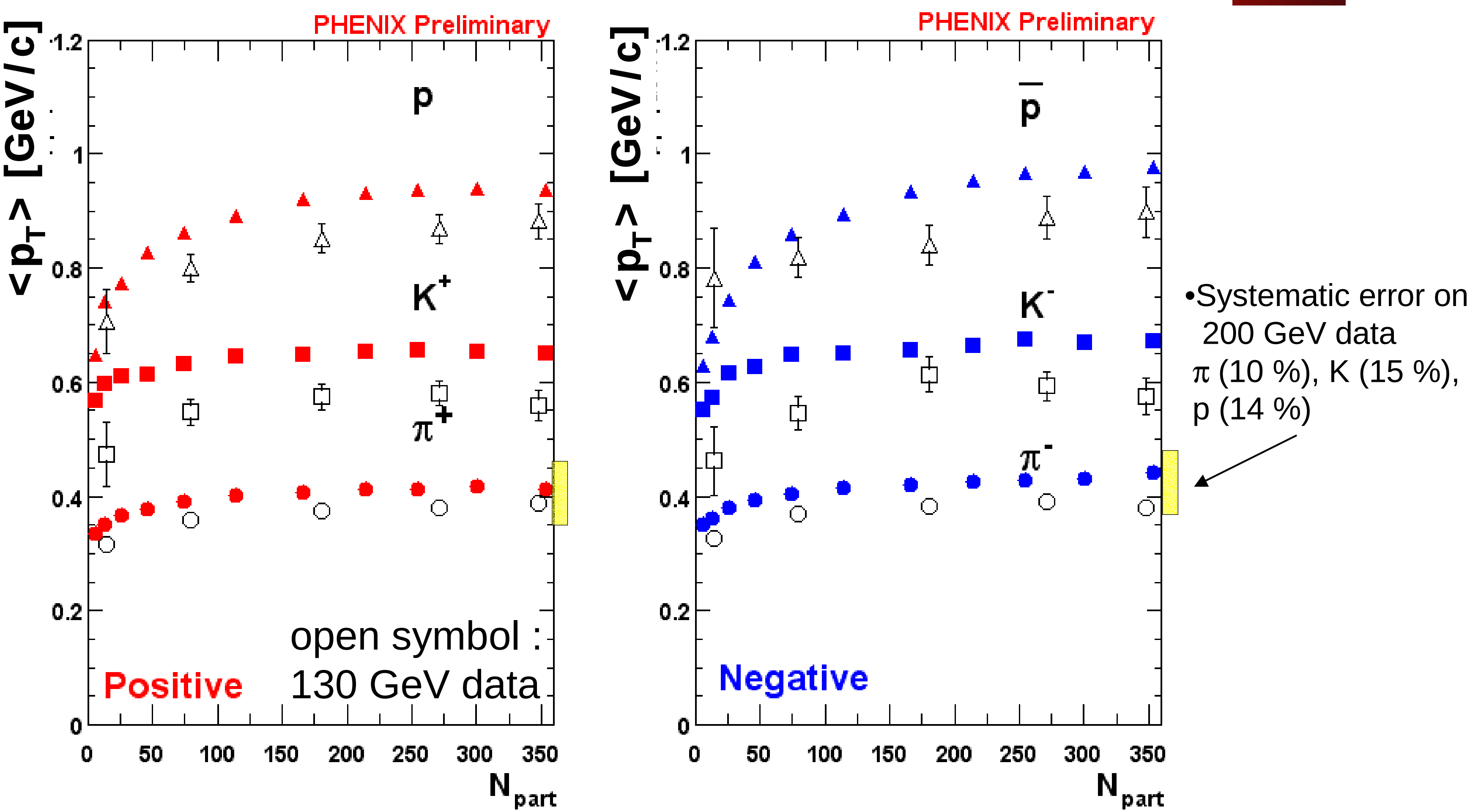


centrality
0 - 5 %
5 - 10 %
10 - 15 %
15 - 20 %
20 - 30 %
30 - 40 %
40 - 50 %
50 - 60 %
60 - 70 %
70 - 80 %
80 - 91 %

Characterized by Boltzmann function shape for all centralities

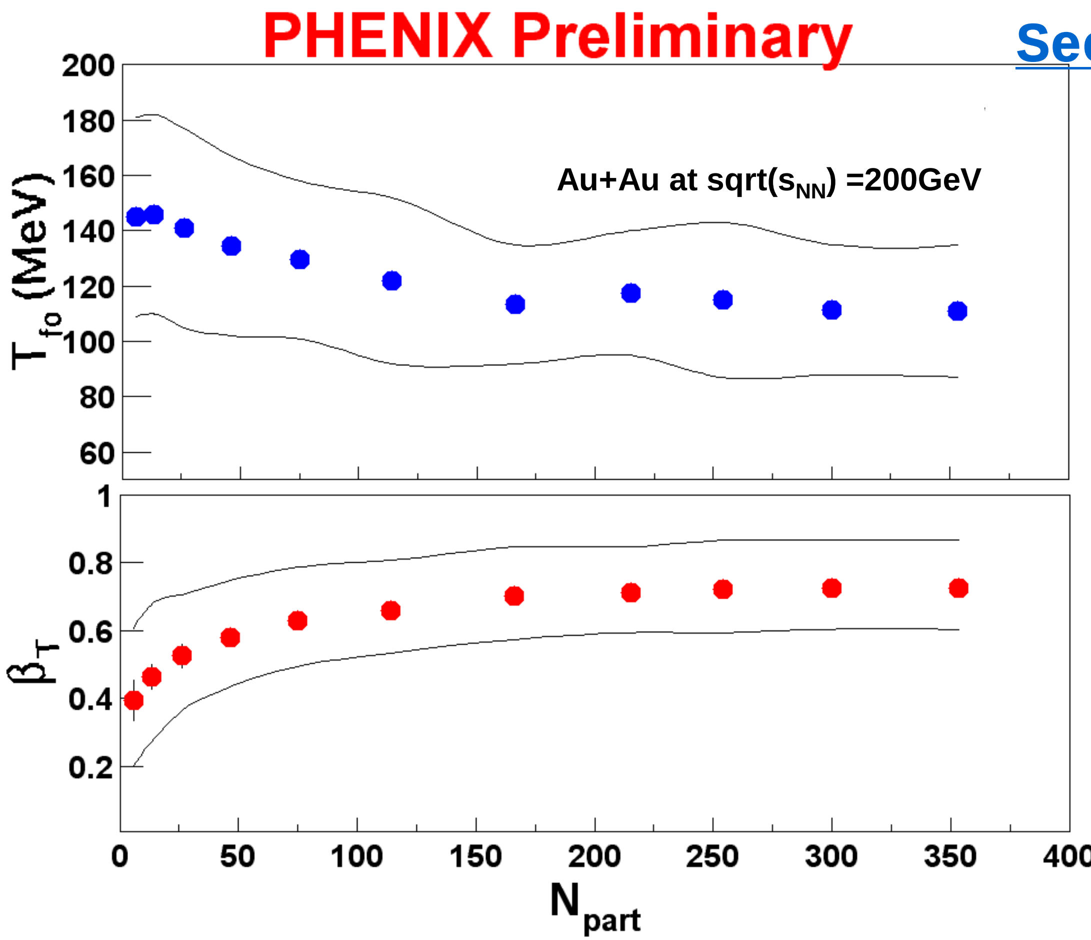
- **One way to characterize expansion is $<p_T>$ vs. centrality.**

$<p_T>$ vs. N_{part}



- Increase of $<p_T>$ as a function of N_{part} and tends to saturate
  π < K < proton (pbar)
- Consistent with hydrodynamic expansion picture.

Hydrodynamic Model Fit to the Spectra



See talk of J.M. Burward-Hoy

Most central collisions for 200 GeV data

Freeze-out Temperature

$T_{fo} = 110 \pm 23$ MeV

Transverse flow velocity

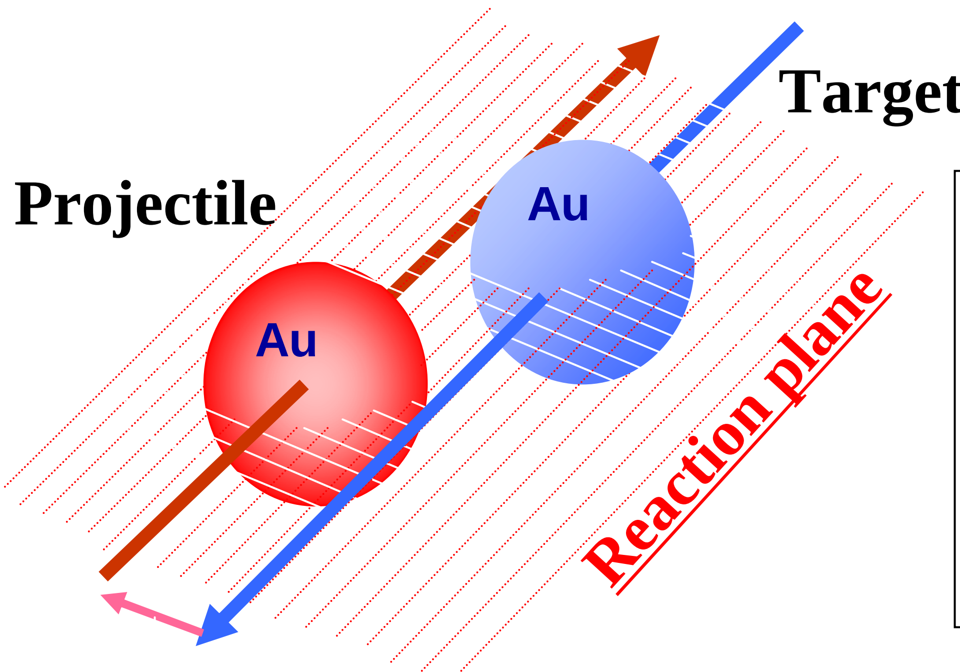
$\beta_T = 0.7 \pm 0.2$

Ref: E. Schnedermann, J. Sollfrank, and U. Heinz, Phys. Rev. C 48, 2462 (1993)

- β_T increases from peripheral to mid-central (N_{part} < 150) and tends to saturate for central collisions.

- **The elliptic flow (azimuthal asymmetries) provides information on pressure at very early stage of the collisions.**

Elliptic Flow Measurements w.r.t reaction



Reaction plane determination
By Beam-beam counter ($|\eta|$=3~4)

⬇

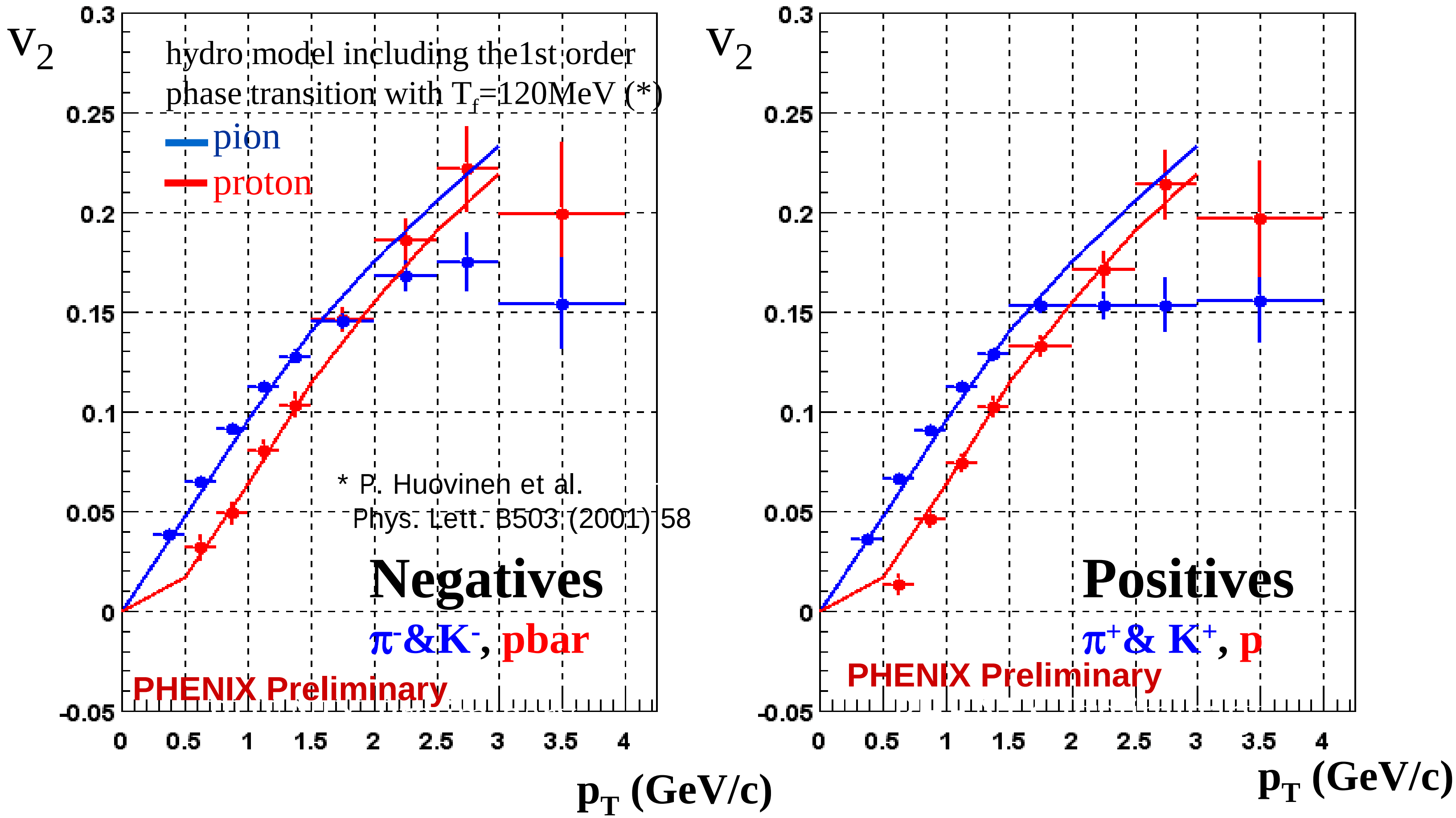
<u>**Less non-flow**</u> **contributions.**

b : Impact parameter

v2 of Identified Hadrons

See talk of S. Esumi

Au+Au at sqrt(s_{NN}) =200GeV, Minimum bias, Reaction Plane | η |=3~4



- Good agreement with hydrodynamic model calculation up to 1.5 GeV.
- Deviation for pions from model at higher p_T?

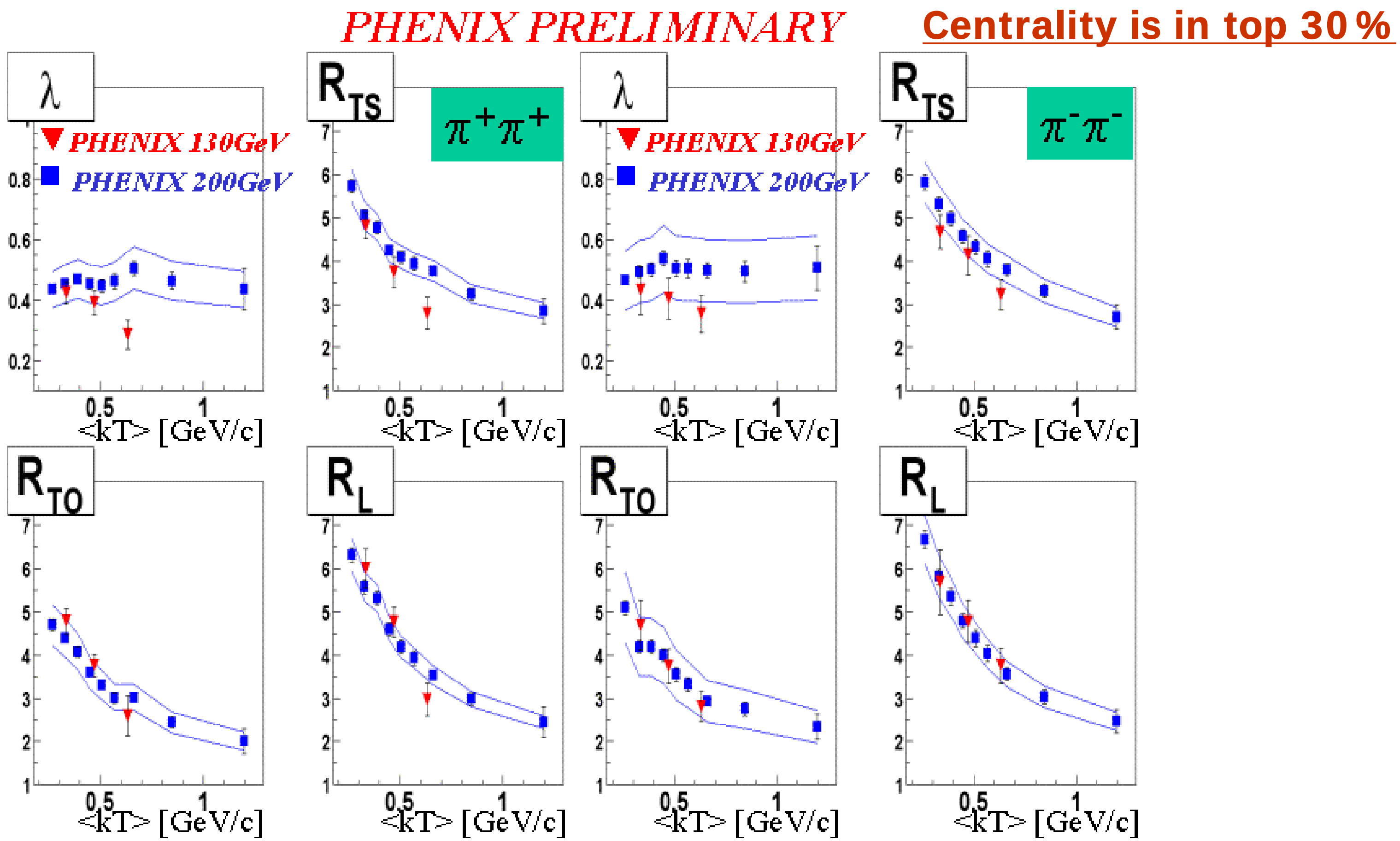
- **Another experimental constraint on expansion:**

HBT vs. momentum

Bertsch-Pratt parameterization

$$C_2 = 1 + \lambda \exp\left(-R_{\mathrm{side}}^2 q_{\mathrm{side}}^2 - R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 - R_{\mathrm{long}}^2 q_{\mathrm{long}}^2\right)$$

k_T dependence of R



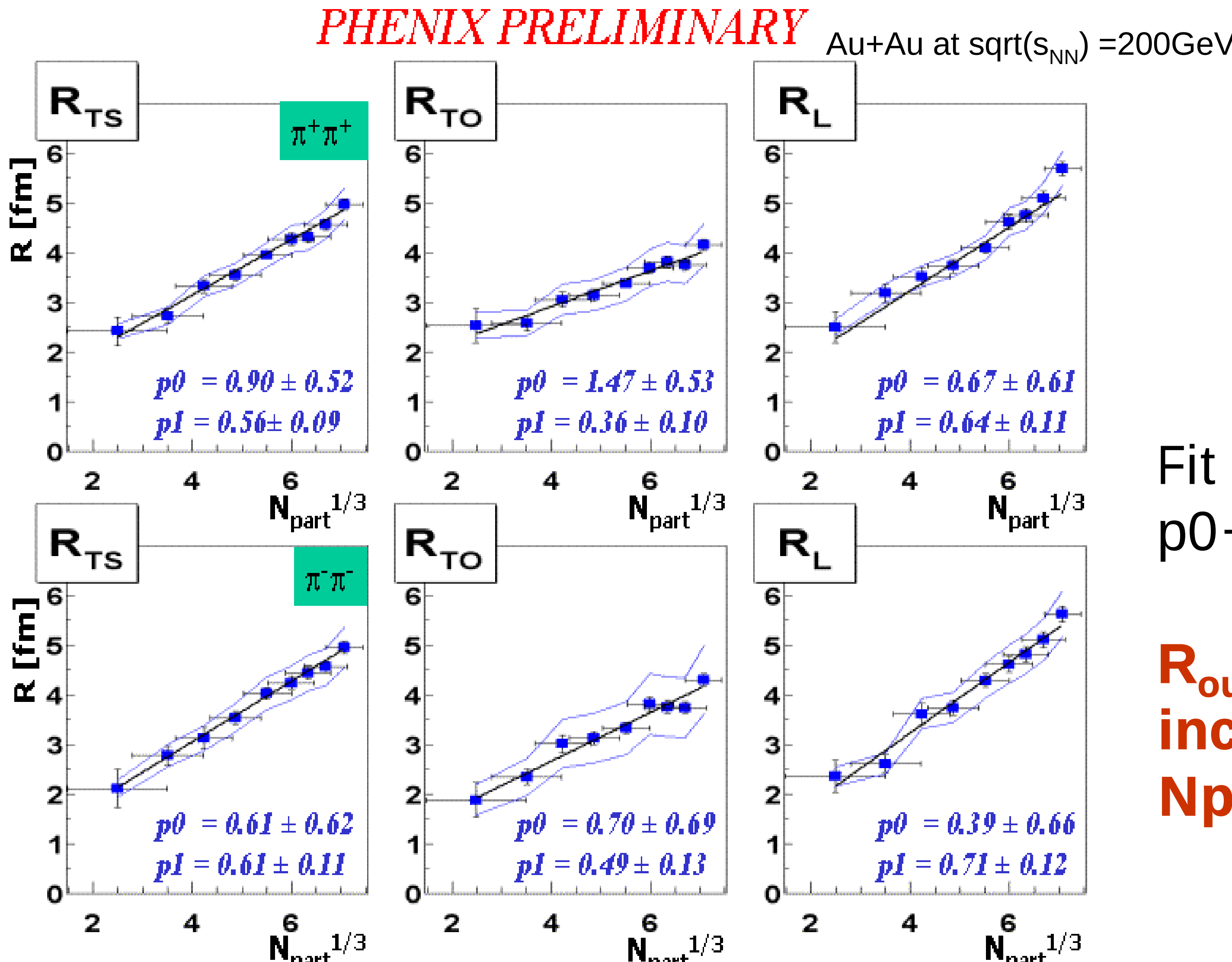
- **Broad $\langle k_T \rangle$ range : 0.2 - 1.2 GeV/c**
- **All R parameters decrease as a function of k_T**

⇒ consistent with collective expansion picture.

- **Stronger k_T dependent in R_{long} have been observed.**

k_T : average momentum of pair

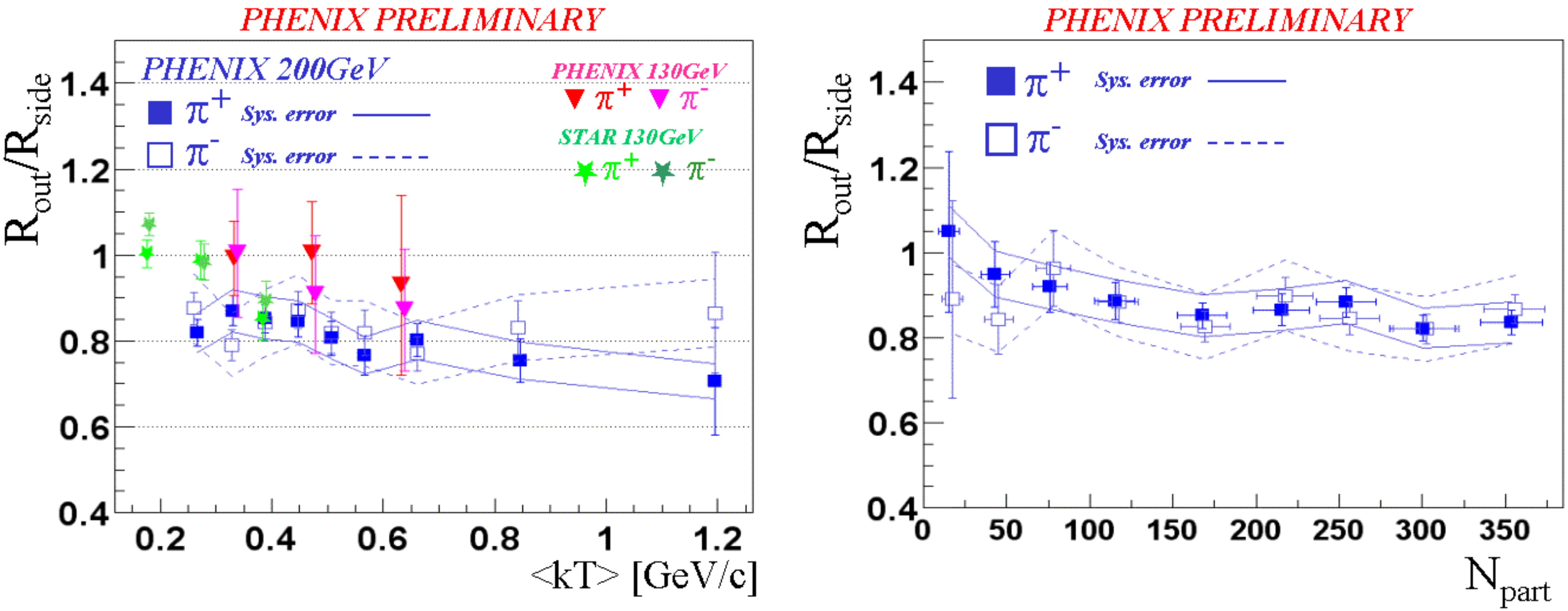
R vs. $N_{part}^{1/3}$



Fit with $p0+p1*N_{part}$^1/3

R_{out} weaker increase with Npart

R_{out}/ R_{side} vs. k_T and N_{part}



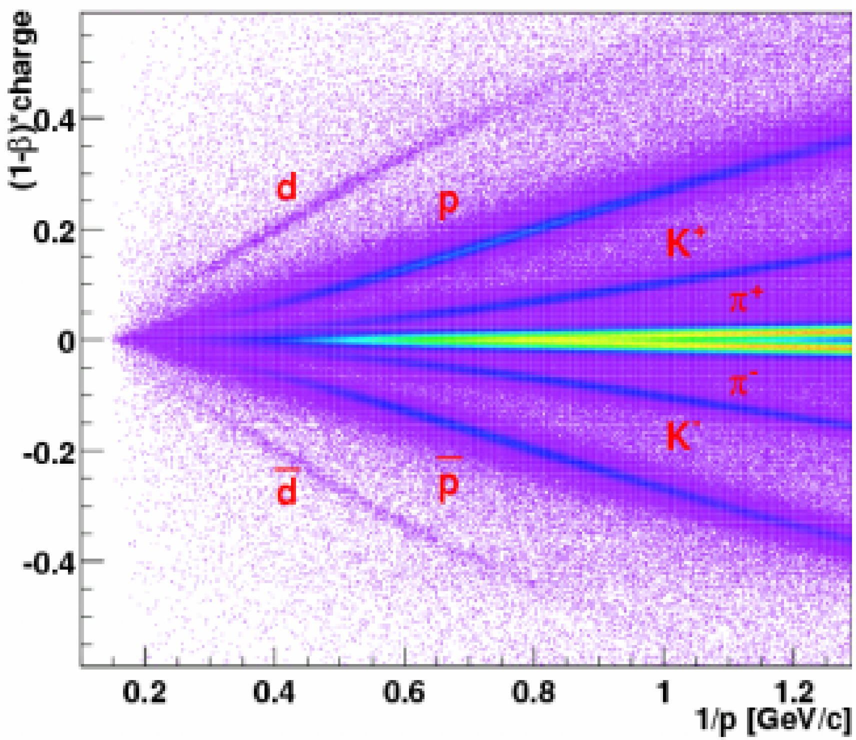
- No dependence of Rout/Rside as a function of $<k_T>$ and N_{part}
- Large k_T range is strong challenge for dynamical models.

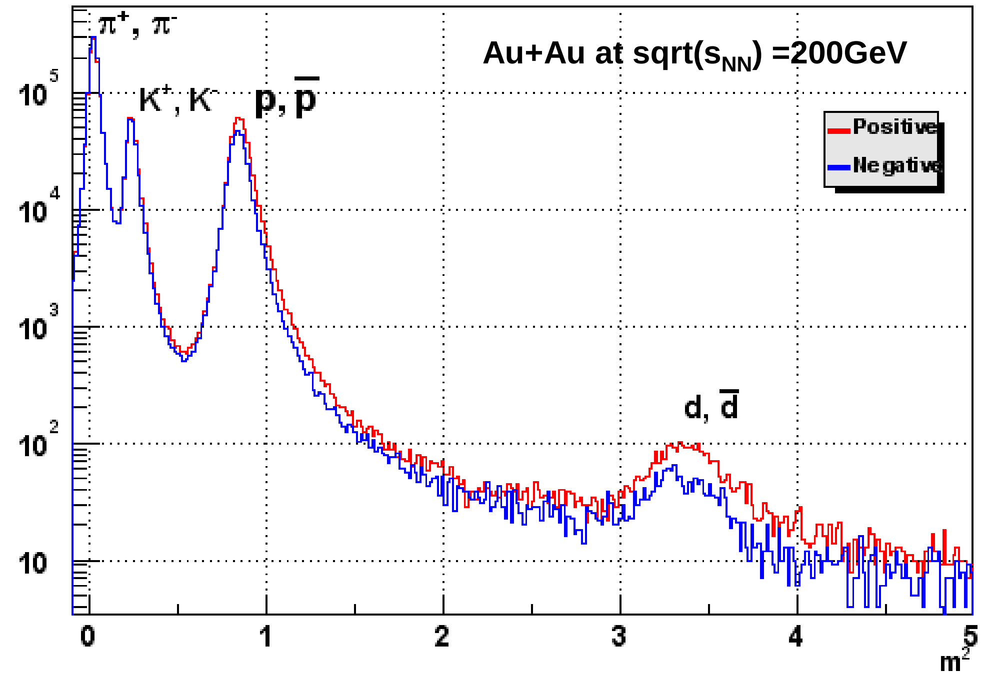
See talk of A. Enokizono (3D ππ, KK)

and poster of M. Heffner (1D KK, pp)

- **Deuteron Coalescence from proton and neutron provides another measure of space-time evolution to be compared to HBT.**

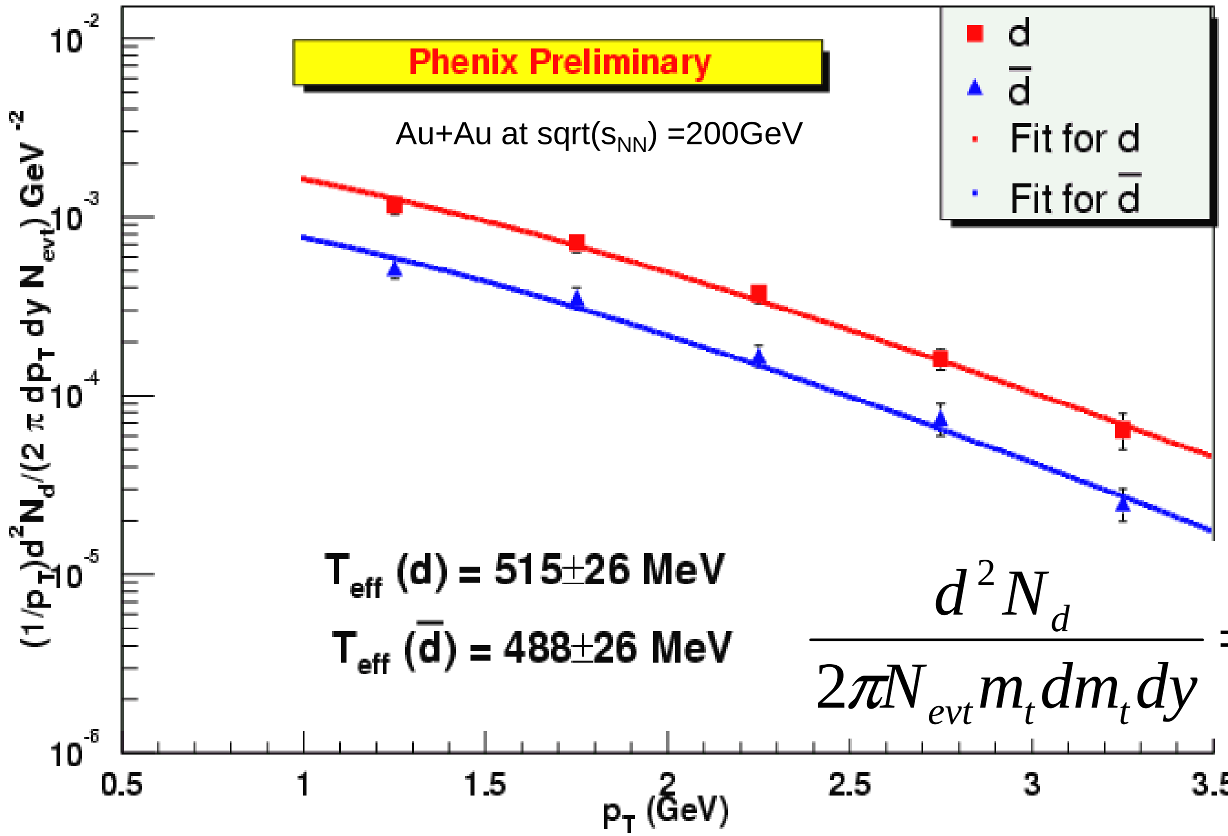
Deuteron Identification by TOF





- Clear deuteron and anti-deuteron signals have been observed in 200 GeV data, using 23 M minimum bias events.

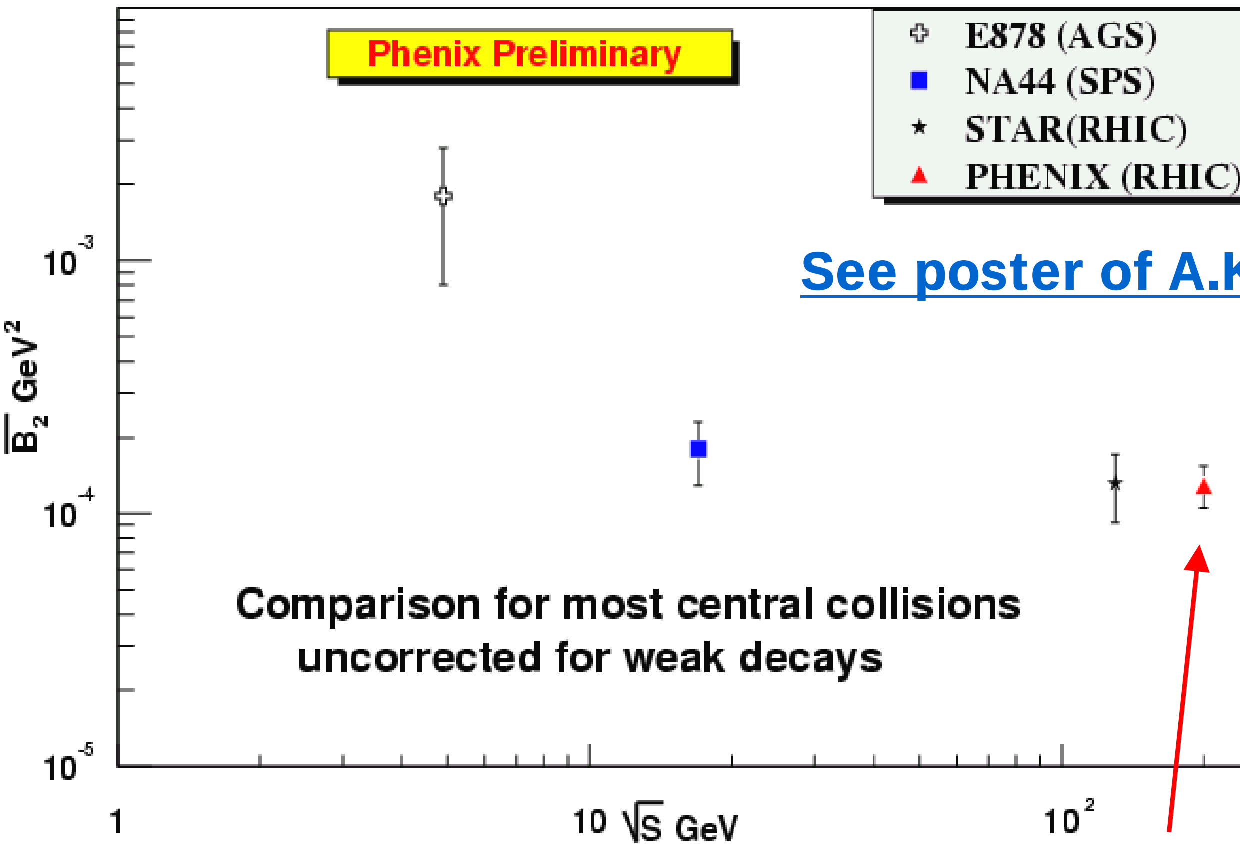
Deuteron and anti-deuteron spectrum



$$\frac{d^2 N_d}{2\pi N_{evt} m_t dm_t dy} = A\exp(-m_t / T_{eff})$$

- PID by TOF detector.
- Fitted by m_T exponential function.

Coalescence model for anti-deuteron



See poster of A.K. Purwar and R. Rietz

Au+Au at sqrt(s_{NN}) =200GeV

$1/B_2 \propto V$

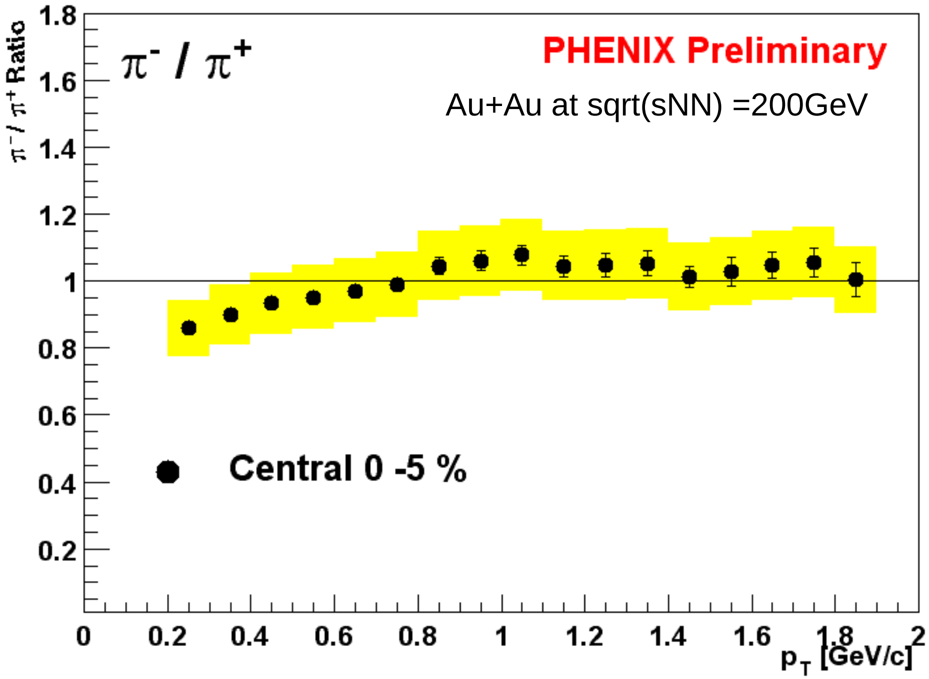
$$E_d \frac{d^3N_d}{dp_d^3} = B_2 (E_p \frac{d^3N_p}{dp_p^3})^2$$

- Weak beam energy dependence from SPS to RHIC.
- Similar behavior has been observed in pion HBT correlations.

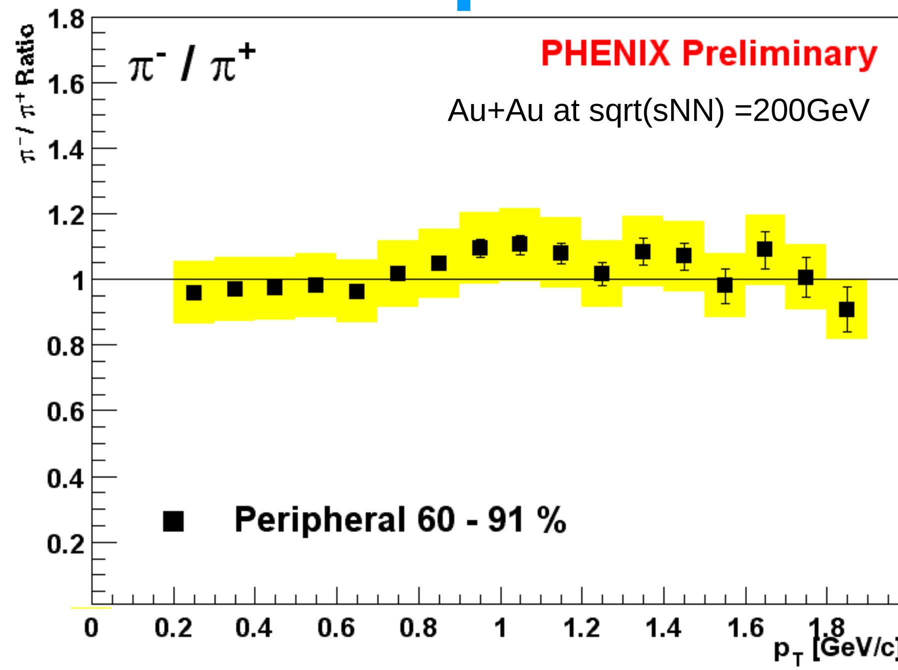
- **Chemical composition at freeze-out can be deduced from particle ratios.**

π^-/π^+ ratio vs. p_T

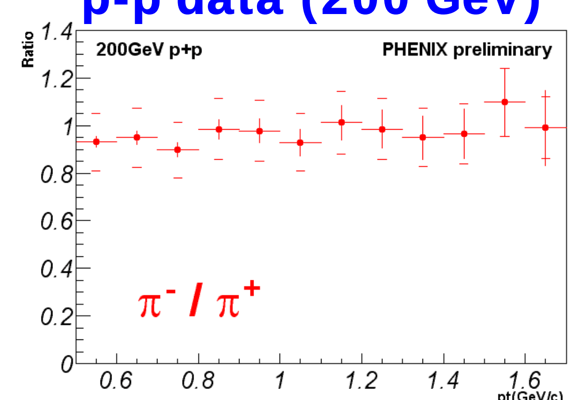
Central



Peripheral



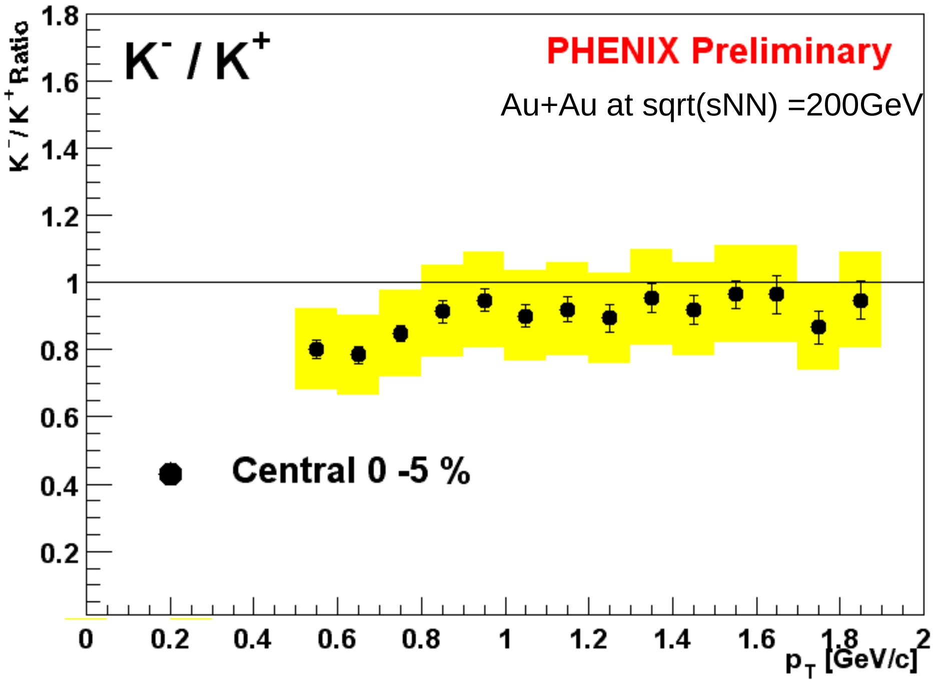
p-p data (200 GeV)



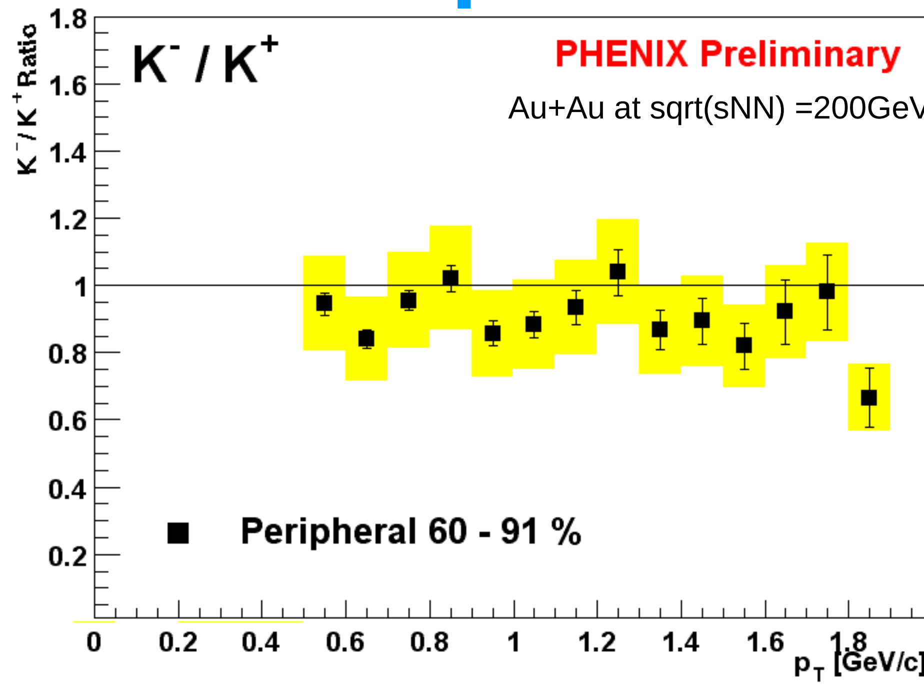
- Flat p_T dependence
- No centrality dependence

K^-/K^+

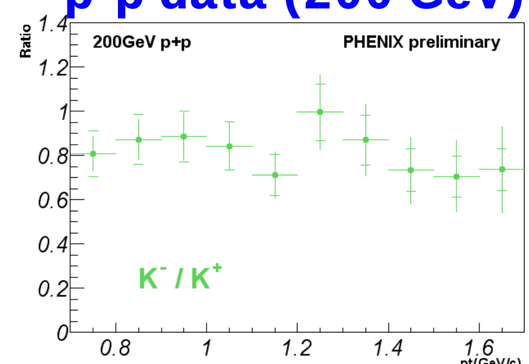
Central



Peripheral



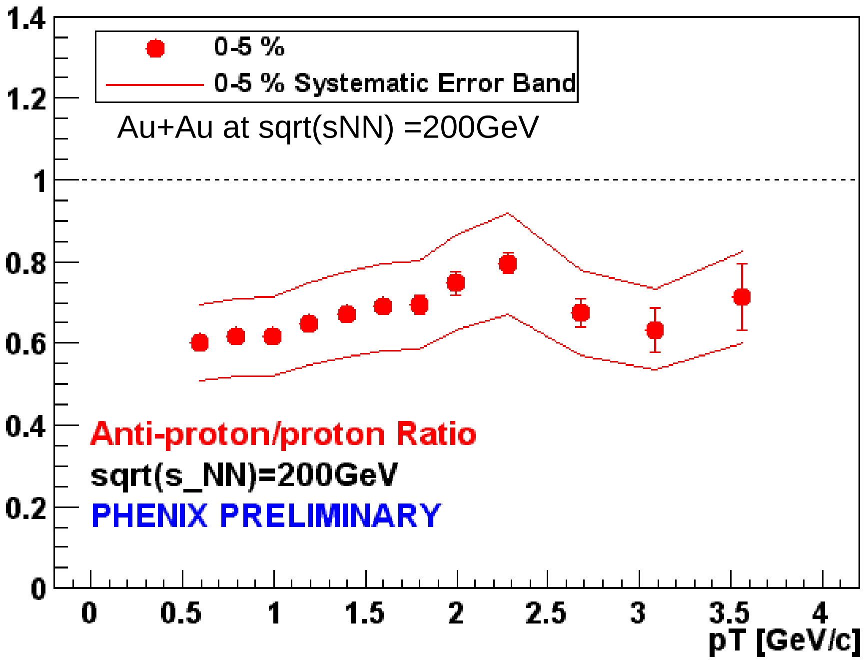
p-p data (200 GeV)



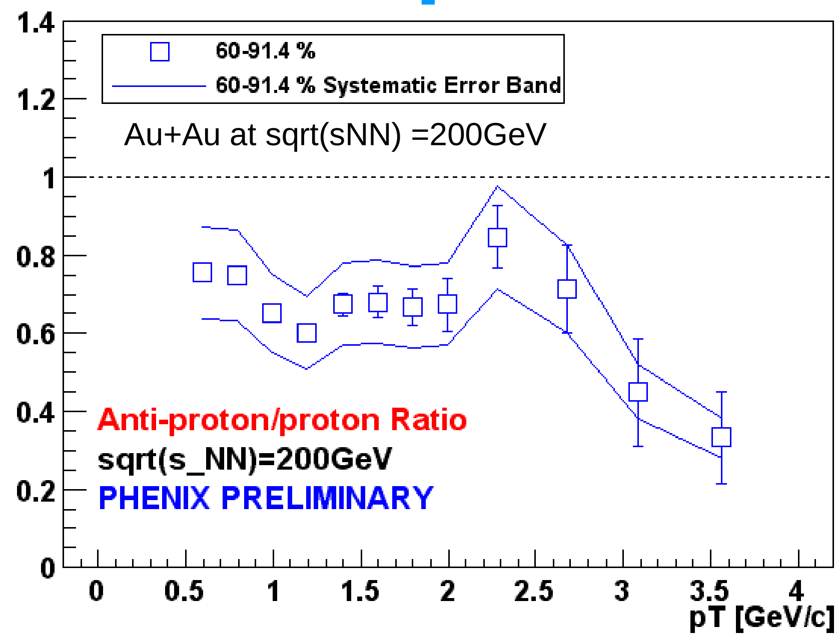
- **Flat p_T dependence**
- **No centrality dependence**

pbar/p

Central



Peripheral

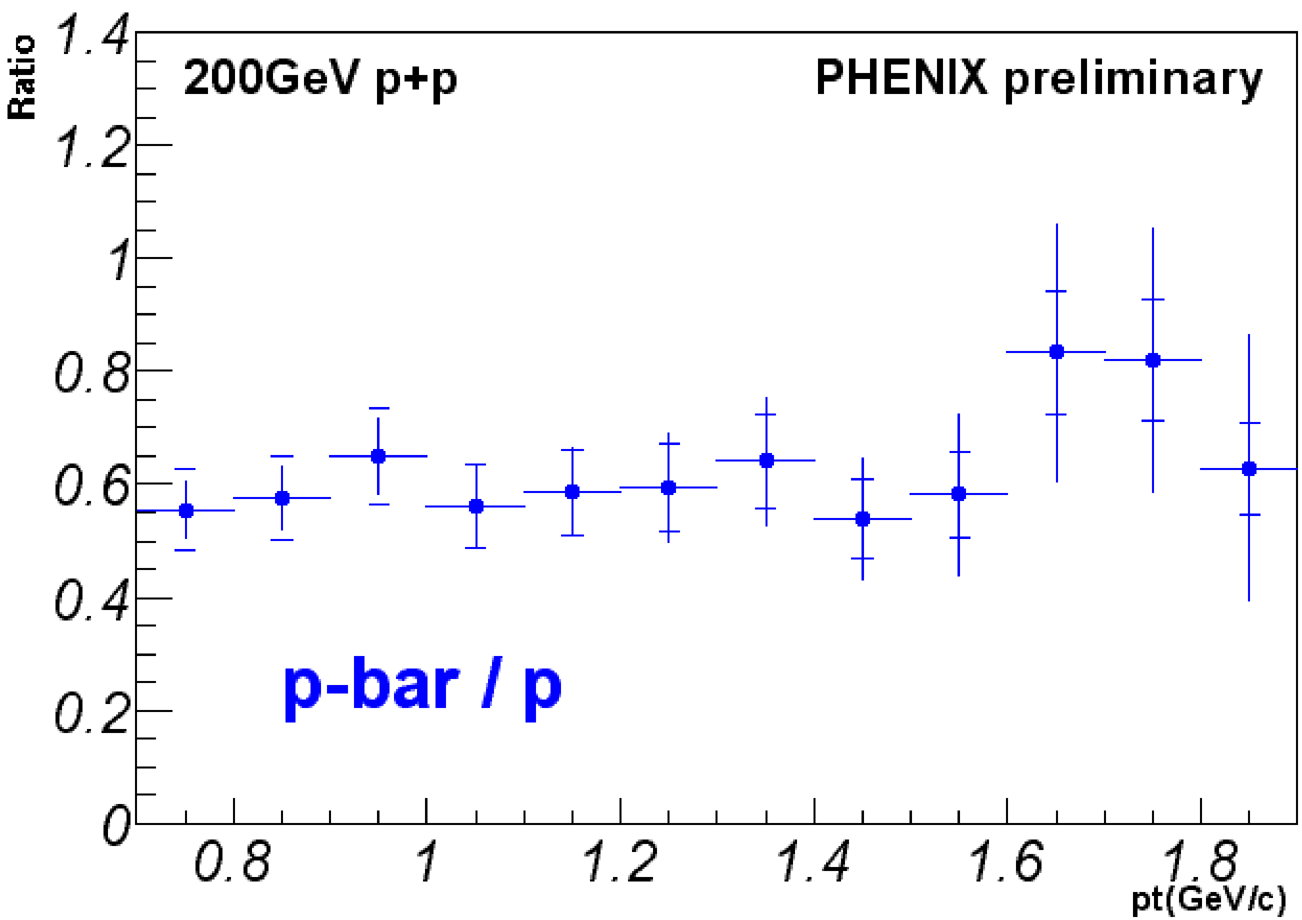


- **Flat p_T dependence for central.**
- **Decreasing for peripheral > 3 GeV?**

See talk of T. Sakaguchi (Au-Au)

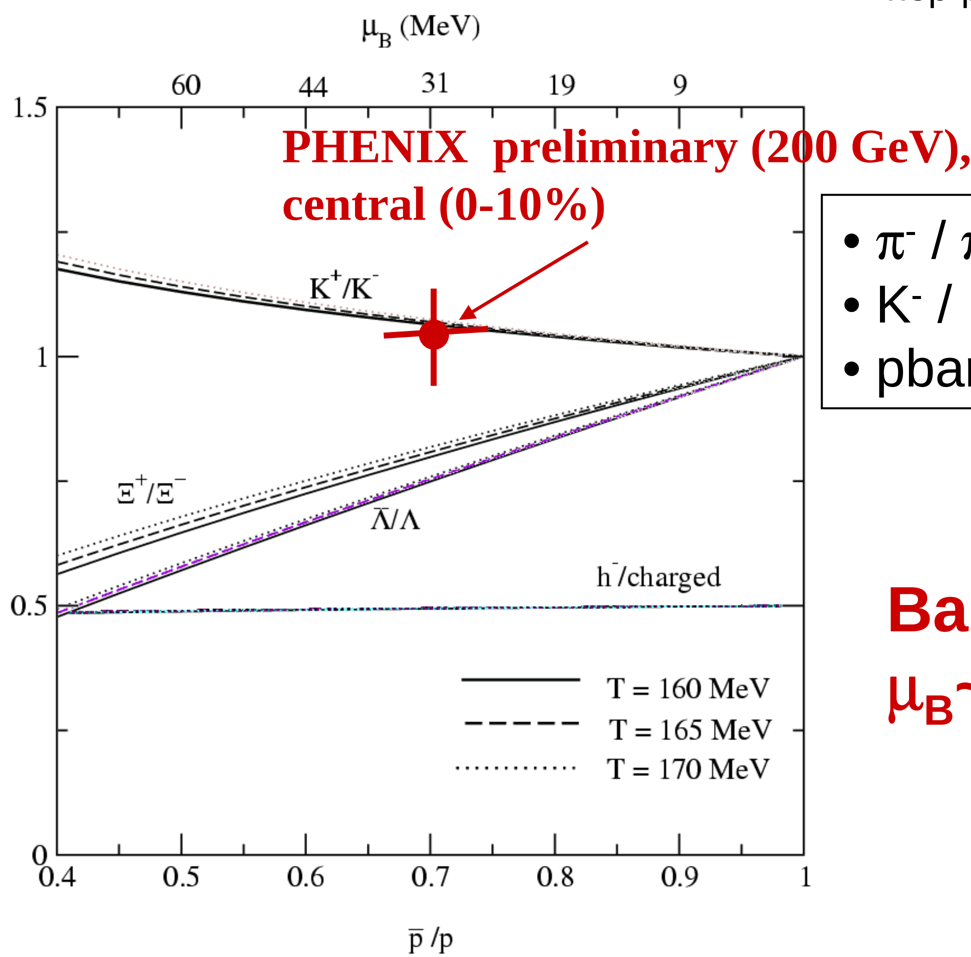
and poster of S. Sato (p-p data)

pbar/p in proton-proton



Estimate of Baryon Potential

Statistical thermal model hep-ph/0002267 F.Becattini et al.

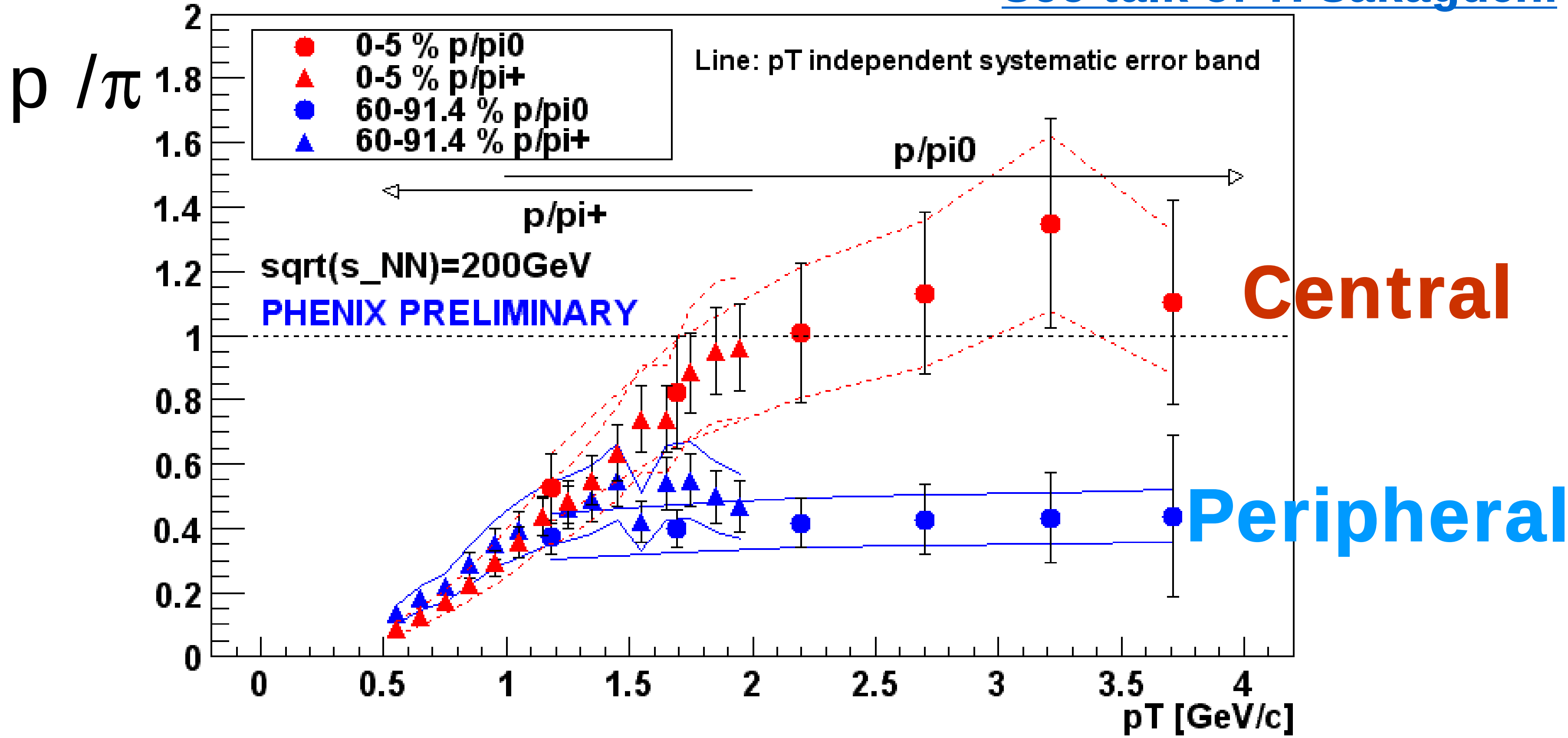


- $\pi^- / \pi^+ = 1.02 \pm 0.02$ (stat) $\pm$ 0.1 (sys)
- $K^- / K^+ = 0.92 \pm 0.03$ (stat) $\pm$ 0.1(sys)
- pbar / p = 0.70 ± 0.04 (stat) $\pm$ 0.1(sys)

Baryon chemical potential
$\mu_B \sim$ 30MeV

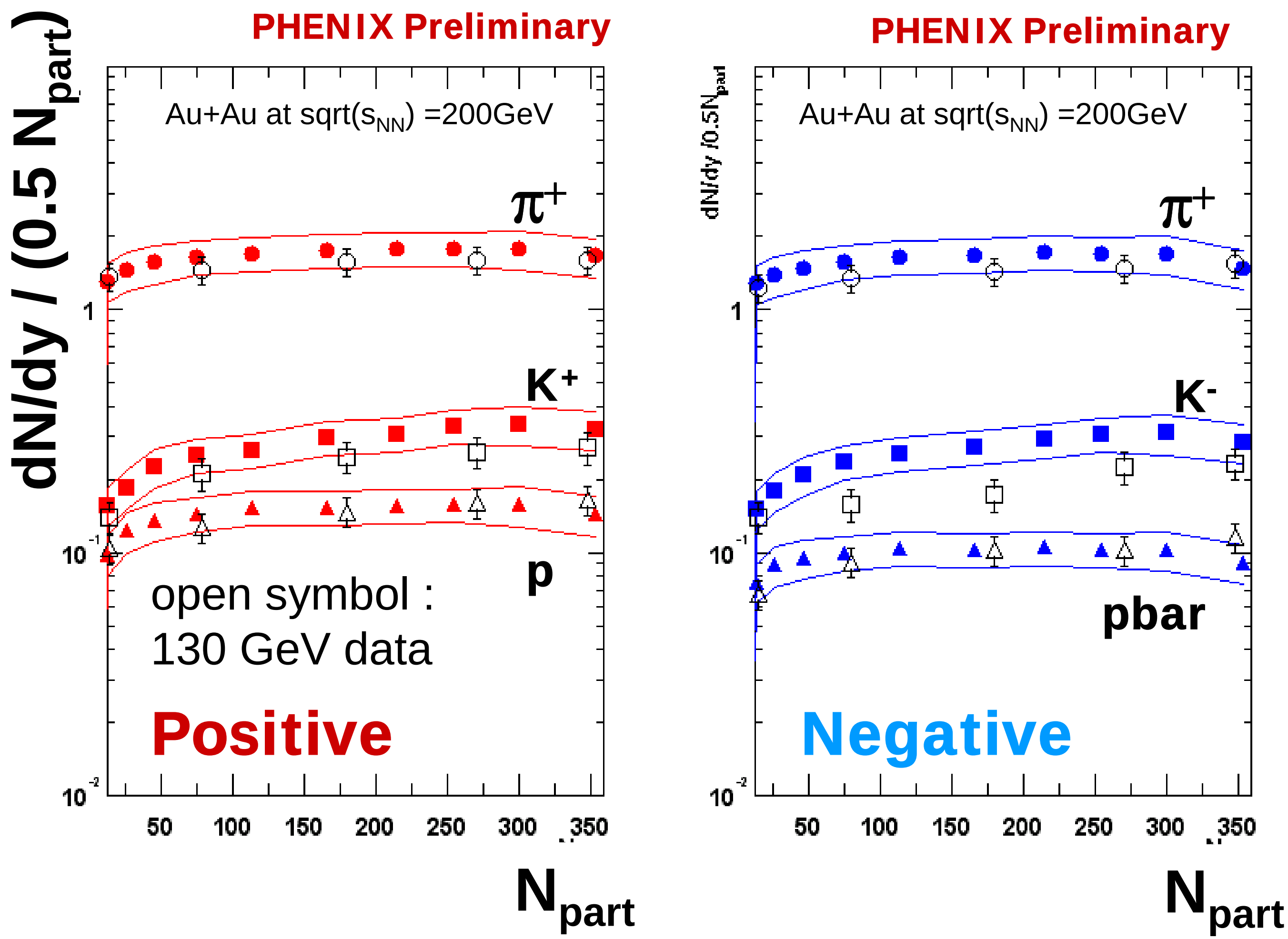
p /π

See talk of T. Sakaguchi



- proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral.

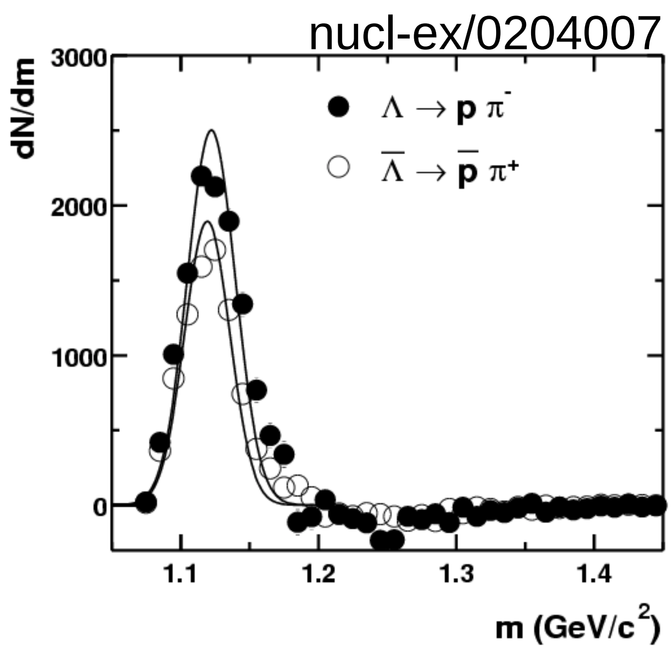
dN/dy



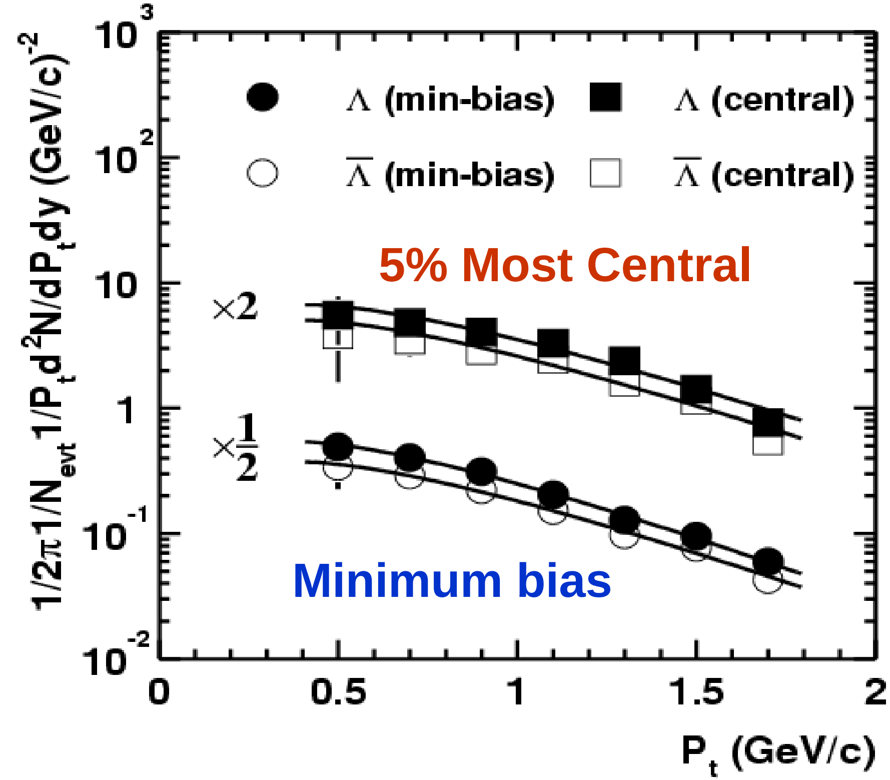
- **Similar centrality dependence 130 GeV and 200 GeV**

Λ's via combinatorial method

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



Invariant mass distribution



Well described by Boltzmann function ($0.4 < p_T < 1.8$ GeV/c) for central 0-5% and minimum bias spectra.

Feed-down corrected p, pbar spectra

See poster of T. Arkadij

- Ratios (130 GeV data)

Λ/p	= 0.89 ± 0.07(stat)
(anti-Λ)/(anti-proton)	= 0.95 ± 0.09(stat)
(anti-Λ)/Λ	= 0.75 ± 0.09(stat)

Net baryon number	Data (PHENIX, central 5%)	HIJING	HIJING/B
(Λ – anti-Λ)	4.6 ± 2.5	0.8	3.2
(p – anti-p)	5.6 ± 0.9	4.7	7.1

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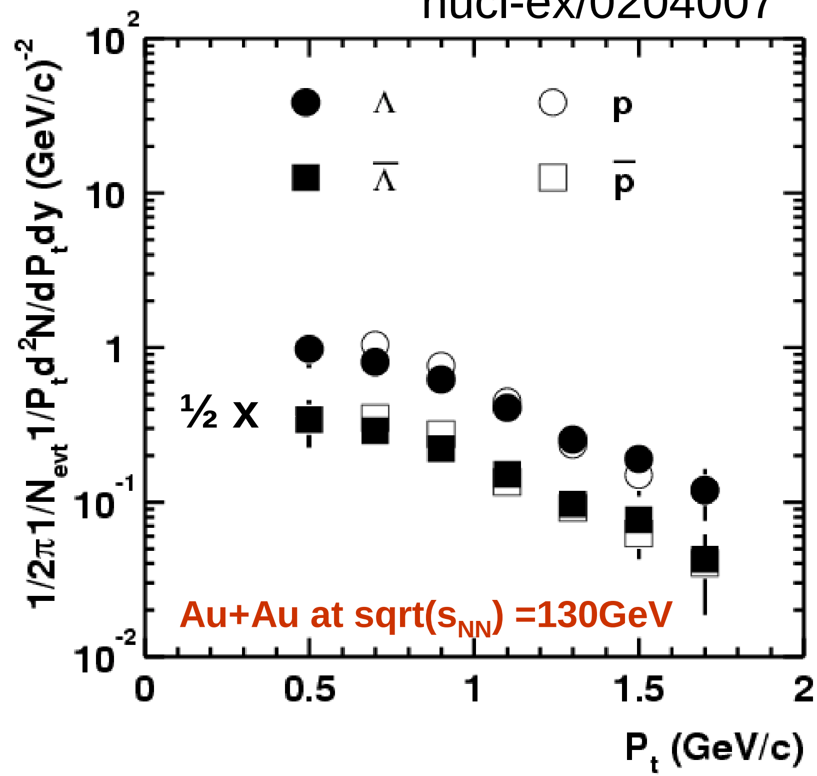


- **Reasonable agreement in net Λ and proton yield by HIJING/B model (non perturbative gluon junction mechanism)**

Summary (I)

We presented the first results of identified charged particle spectra and yields (π, K, p, pbar, d, dbar), azimuthal correlation w.r.t reaction plane for identified hadrons, HBT correlations at sqrt(s_{NN}) = 200 GeV and the Λ results from 130 GeV data.

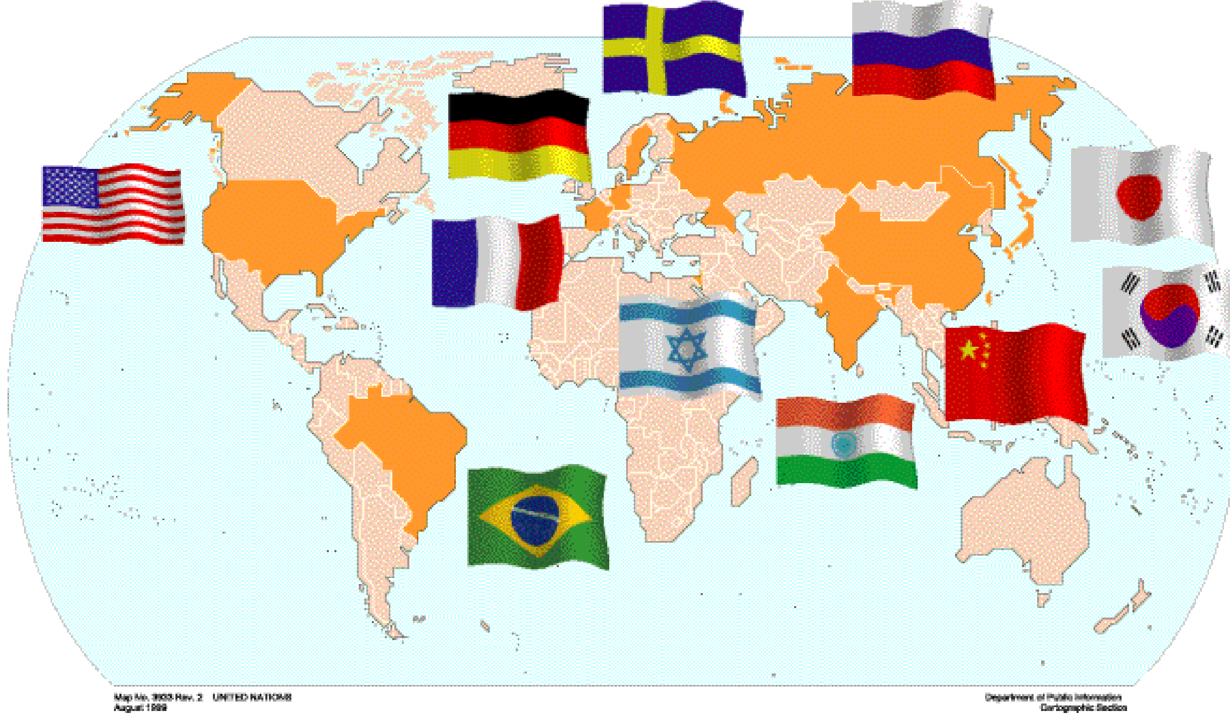
1. **Hydrodynamic Collective Expansion**
   - All results of 200 GeV data indicate a strong collective expansion at central collisions.
   - $<p_T>$ vs. centrality : the heavier mass, the larger $<p_T>$, steep rise at peripheral to mid-central collisions.
   - Hydro-dynamical model fit to the spectra $\Rightarrow$ β_T = 0.7, T_{fo} = 110 MeV
   - Elliptic flow (identified particle) vs. hydro. Model

     $\Rightarrow$ Good agreement with hydro model < 1.5 GeV, deviated from hydro > 2GeV for pions.

Summary (II)

2. **Space-time evolution of the System**
   - R values are very similar to sqrt(s_{NN}) = 130 GeV.
   - Much large k_T range for HBT in 200 GeV data.
   - No dependence of R_{out}/R_{side} on $\langle k_T \rangle$, N_{part}.
   - Deuteron, anti-deuteron B_2 show weak energy dependence from SPS to RHIC, similar to HBT results.
3. **Chemical Composition**
   - Baryon chemical potential ~ 30 MeV.
   - No p_T and centrality dependence for π^- / π^+, K^-/K^+, pbar/p ratio.
   - proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral.
   - Feed down corrected p, pbar spectra for 200 GeV data can be done soon.

PHENIX



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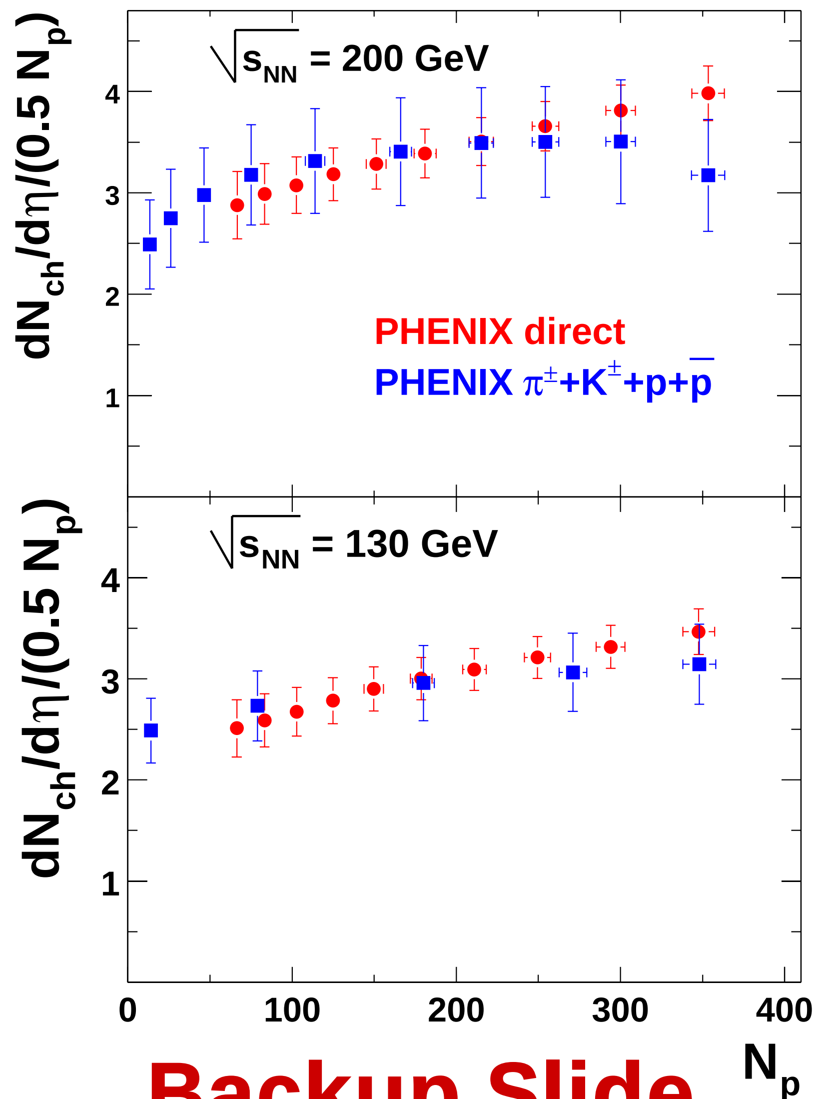
Vanderbilt University, Nashville, TN 37235, USA

dN_{ch} /dy comparison



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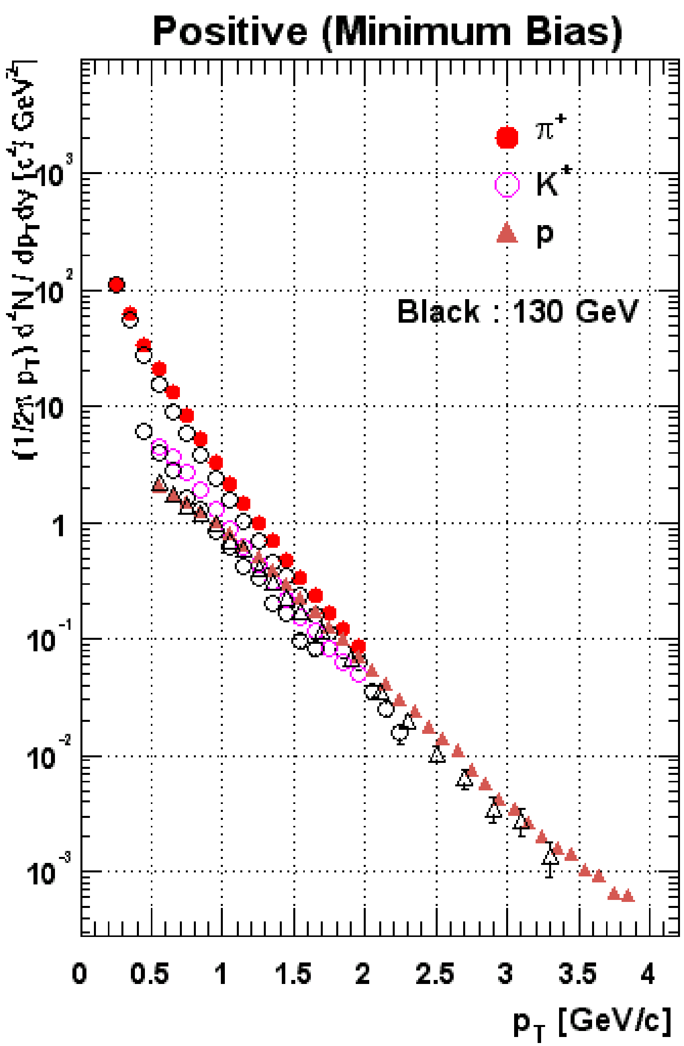
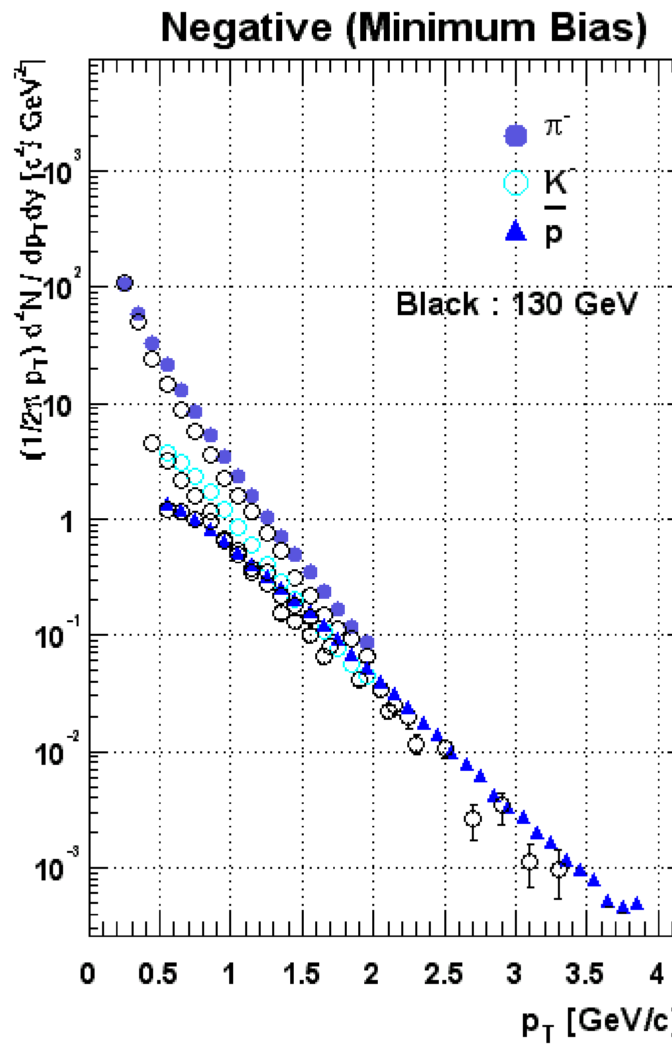
130 GeV vs. 200 GeV (MB)





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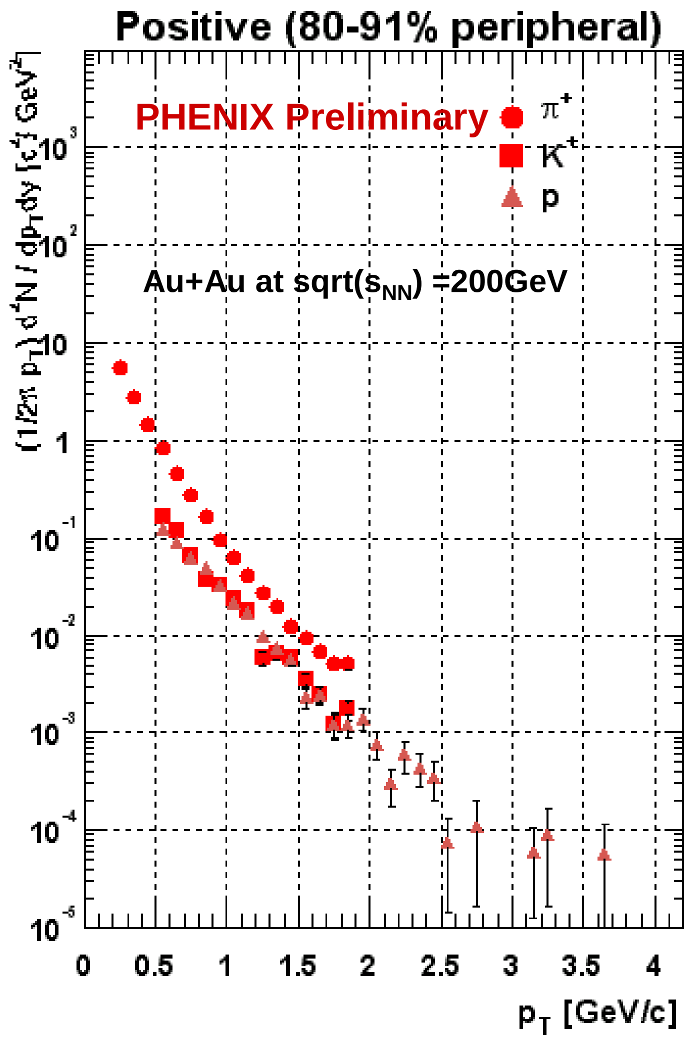
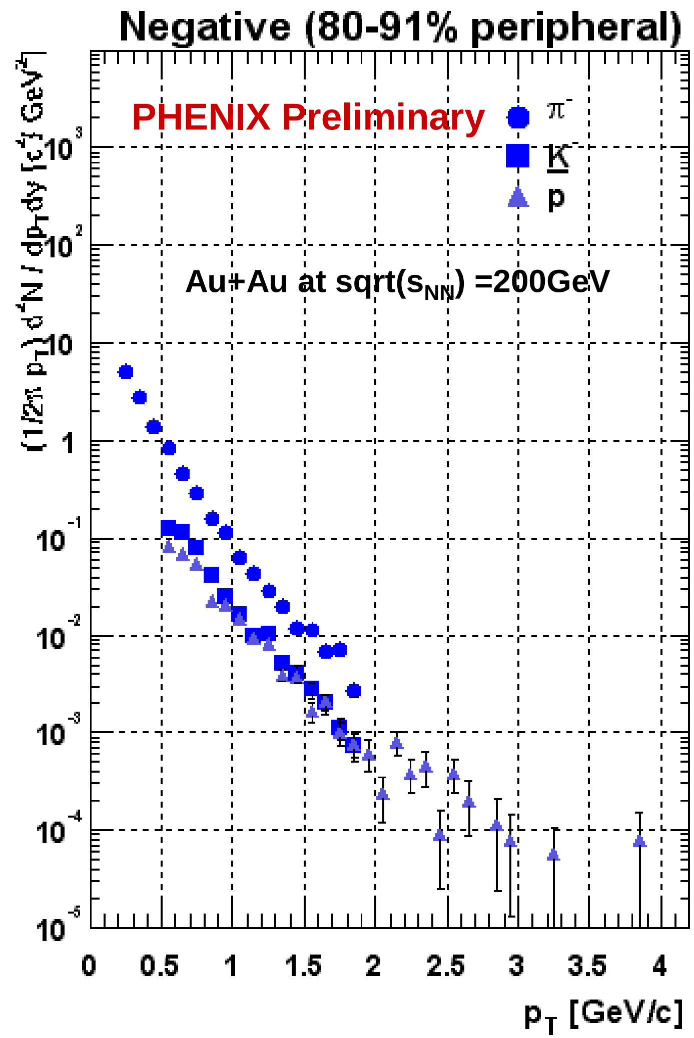
Single Particle Spectra at most peripheral events (80-91 %)





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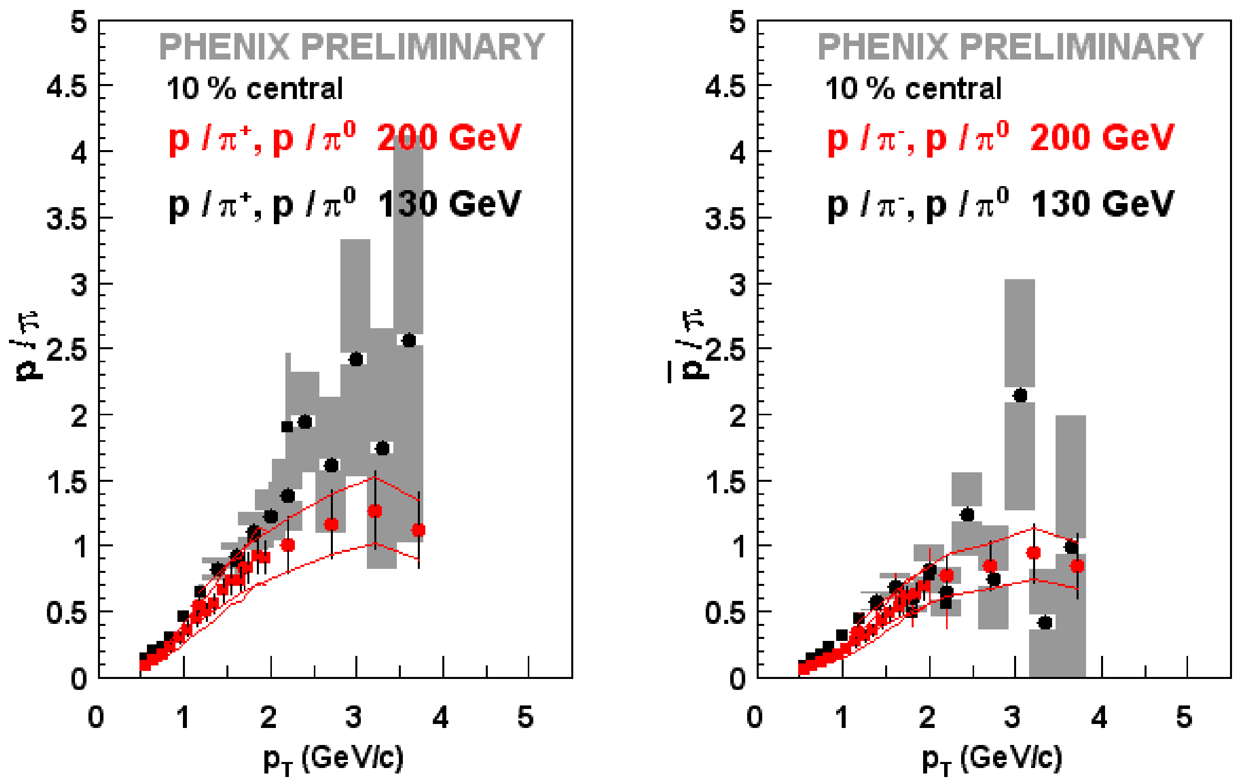
Comparison between 130 GeV and 200 GeV



Less protons in 200 GeV data than 130 GeV data

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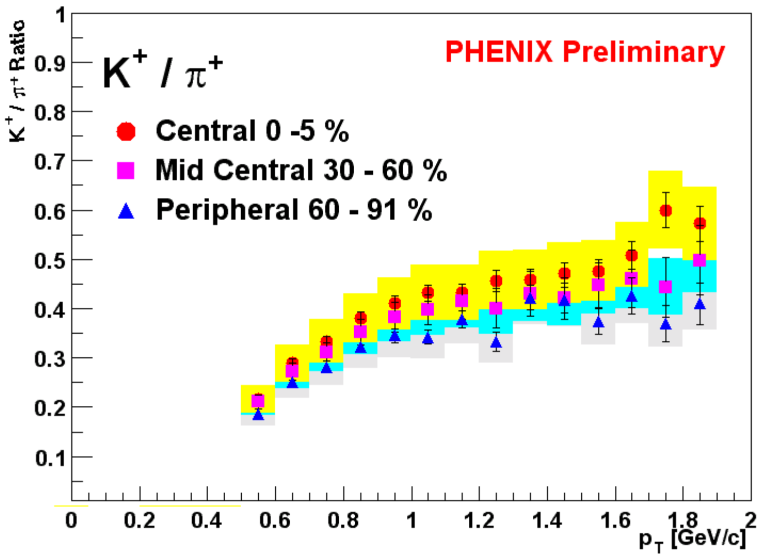
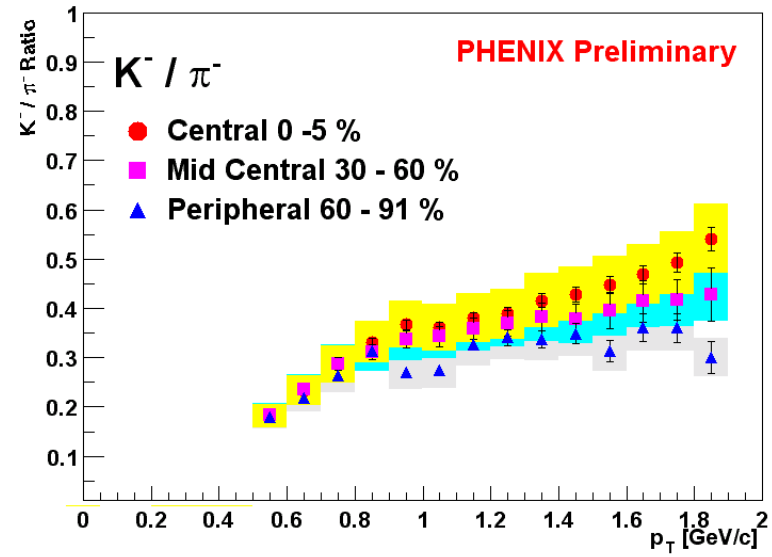
K/π Ratio vs. p_T





K/π ratio above 1.5 GeV : (peripheral) < (mid-central) < (central)

⇒ reflected shape changes as a function centrality

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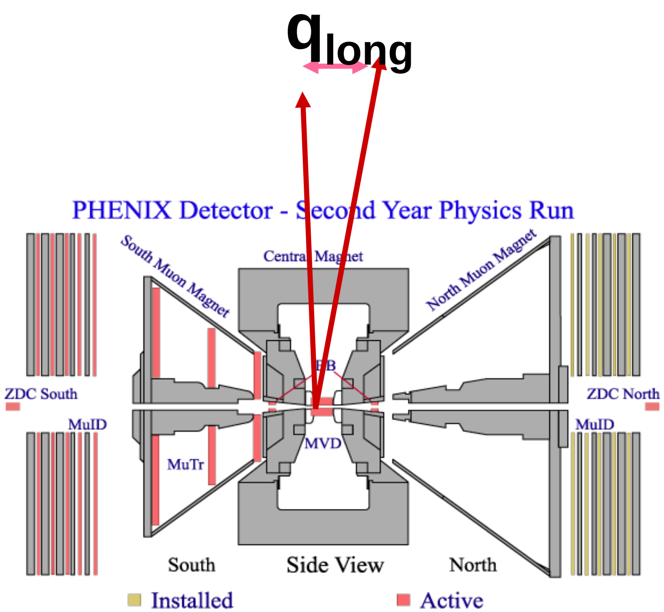
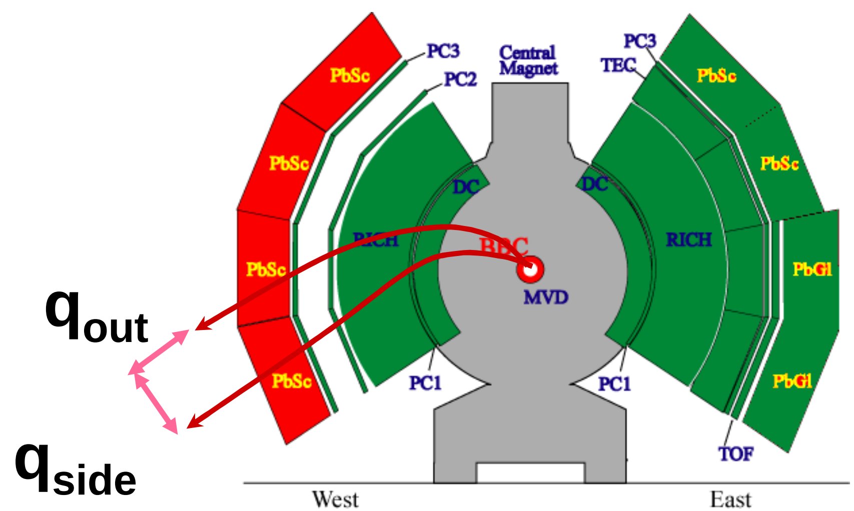
Two Particle Correlations (HBT) for pions





- **Full analytic coulomb corrections.**
- **Taking account two track separations.**
- **50 M Minimum-bias data sample.**

Bertsch-Pratt parameterization

$$C_2 = 1 + \lambda \exp\left(-R_{\mathrm{side}}^2 q_{\mathrm{side}}^2 - R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 - R_{\mathrm{long}}^2 q_{\mathrm{long}}^2\right)$$

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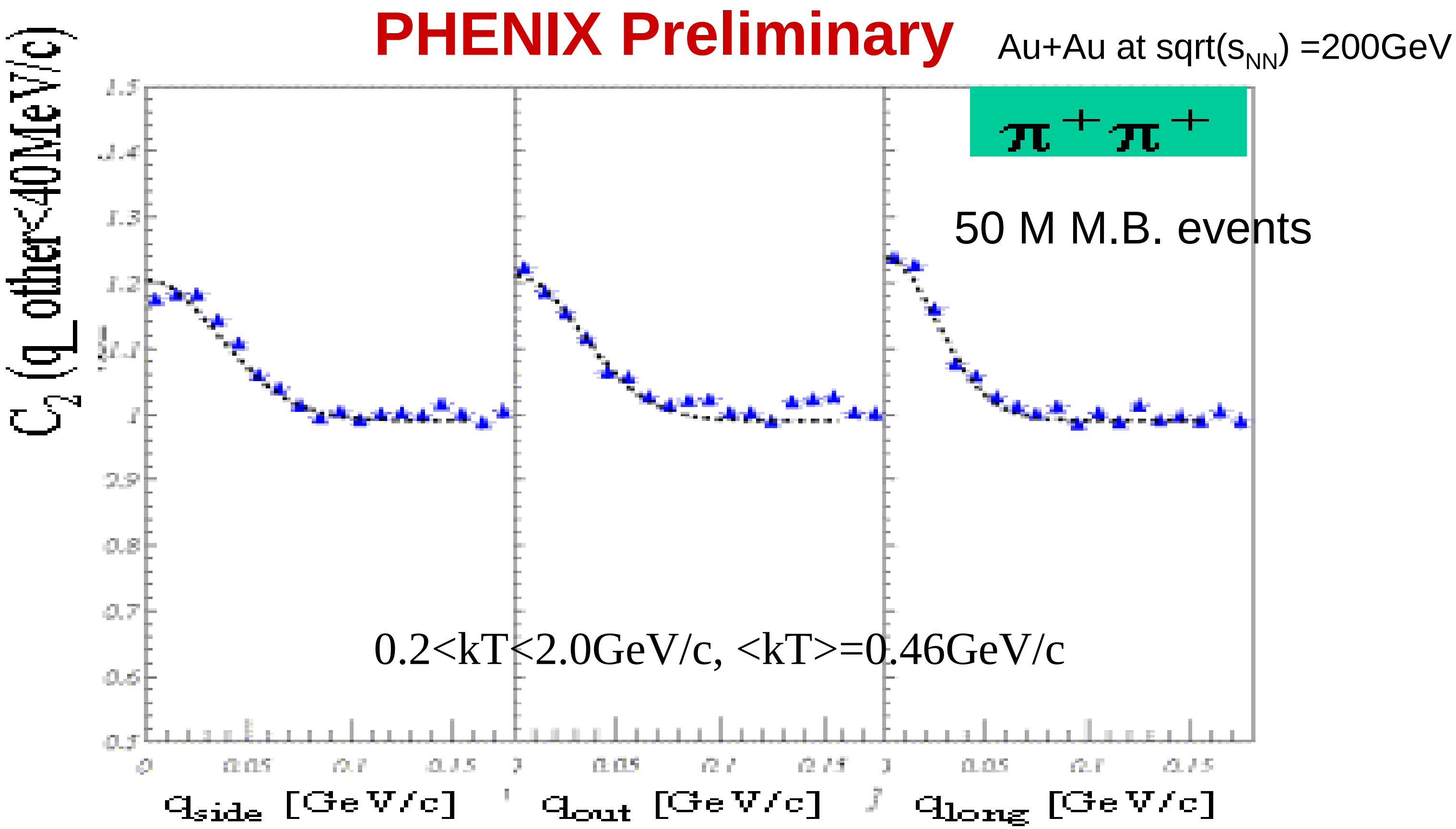
3D HBT Example for pions



Bertsch-Pratt parameterization

$$C_2 = 1 + \lambda \exp\left(-R_{\mathrm{side}}^2 q_{\mathrm{side}}^2 - R_{\mathrm{out}}^2 q_{\mathrm{out}}^2 - R_{\mathrm{long}}^2 q_{\mathrm{long}}^2\right)$$

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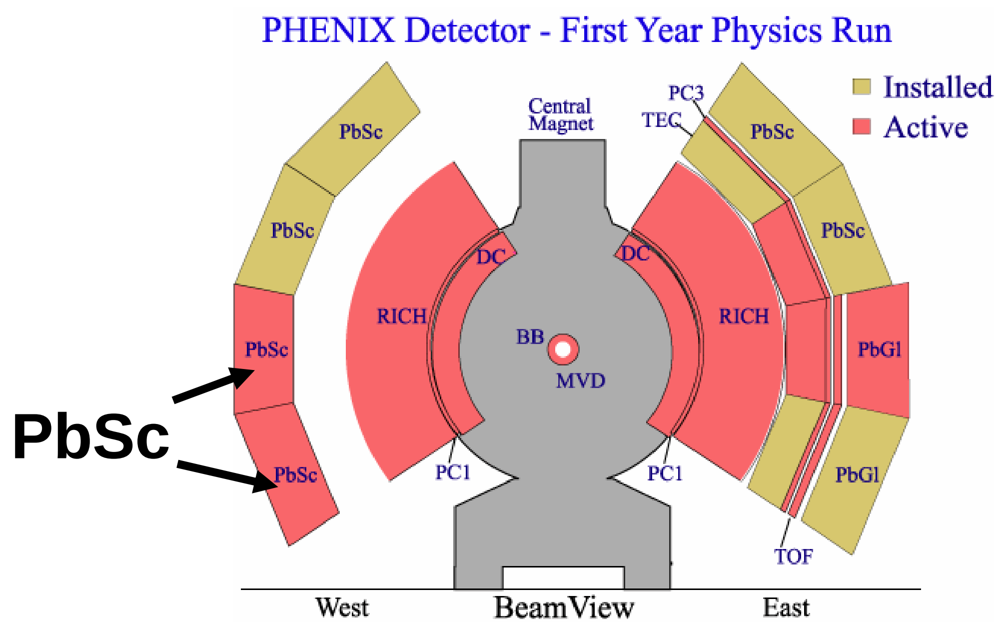
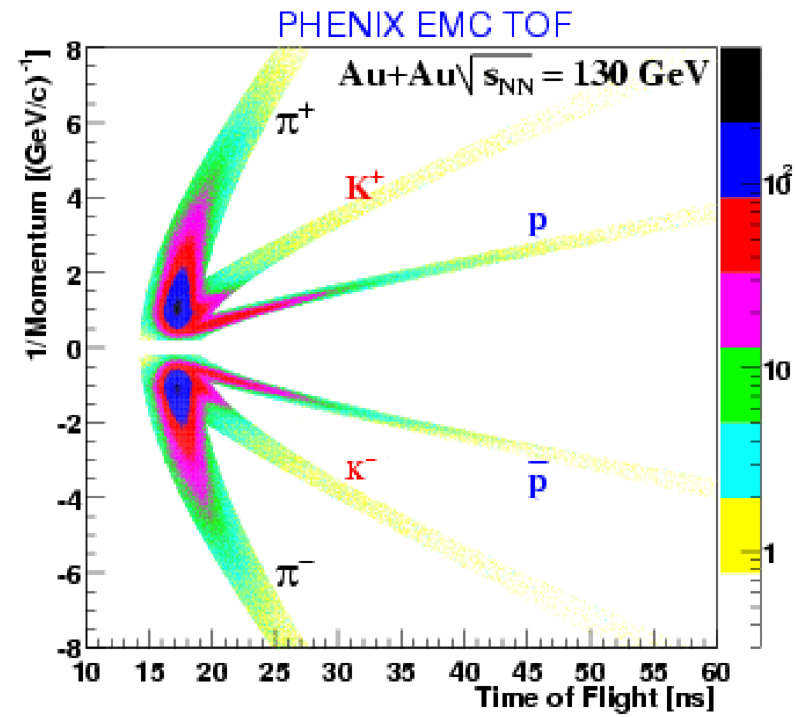
Λ Analysis (130 GeV data)





- Used 1.3 M minimum bias events from 130 GeV data.
- Hadron PID by EMC (PbSc)
  West arm PbSc EMC-TOF (σ_{TOF} ~700 ps in Run1) for PID (2σ cut)
- Pion ID : p_T < 0.6 GeV/c, proton ID : p_T < 1.4 GeV/c
- Used combinatorial method to extract lambda.

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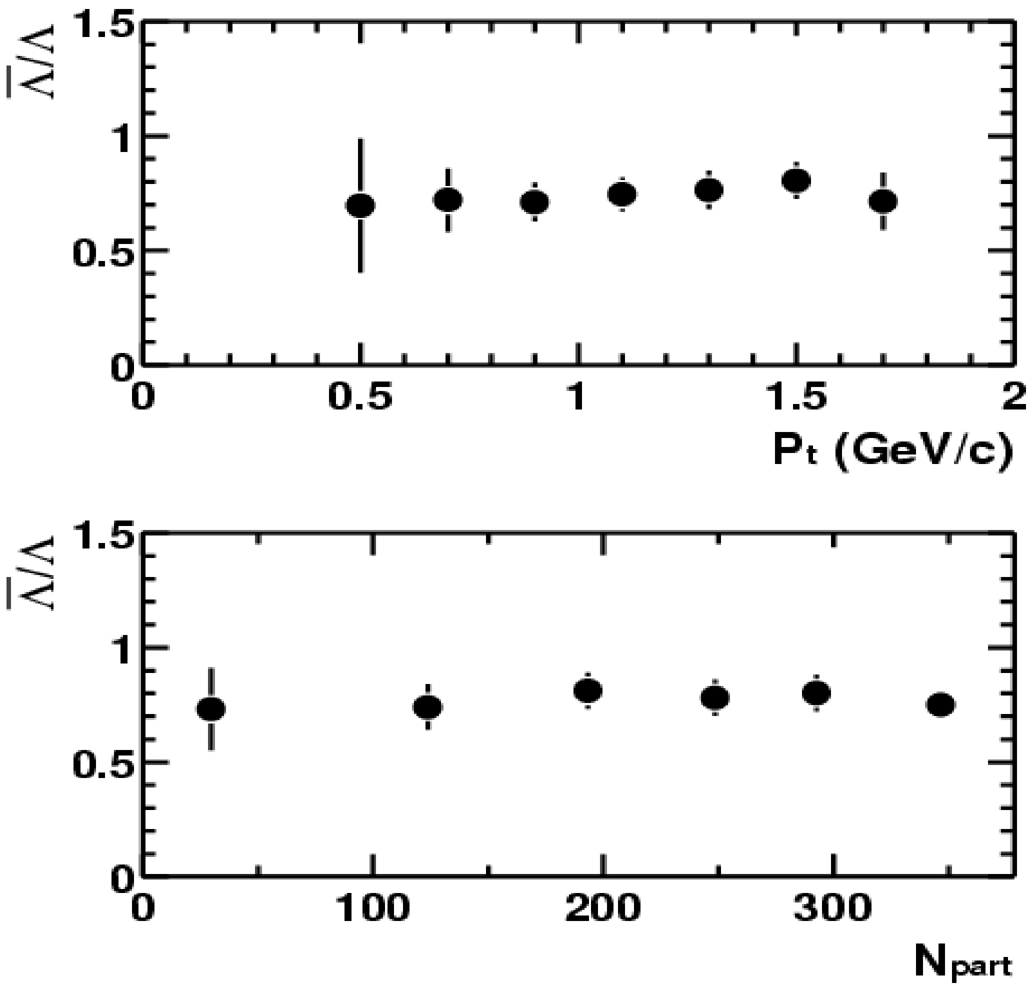
$\bar{\Lambda}/\Lambda$ ratio vs. p_T and N_{part}



- No p_T and N_{part} dependences in anti-Λ/Λ ratio
- Averaged anti-Λ/Λ ratio :
  0.75 $\pm$ 0.09
- No p_T dependence $\Rightarrow$
  Consistent with the statistical thermal model

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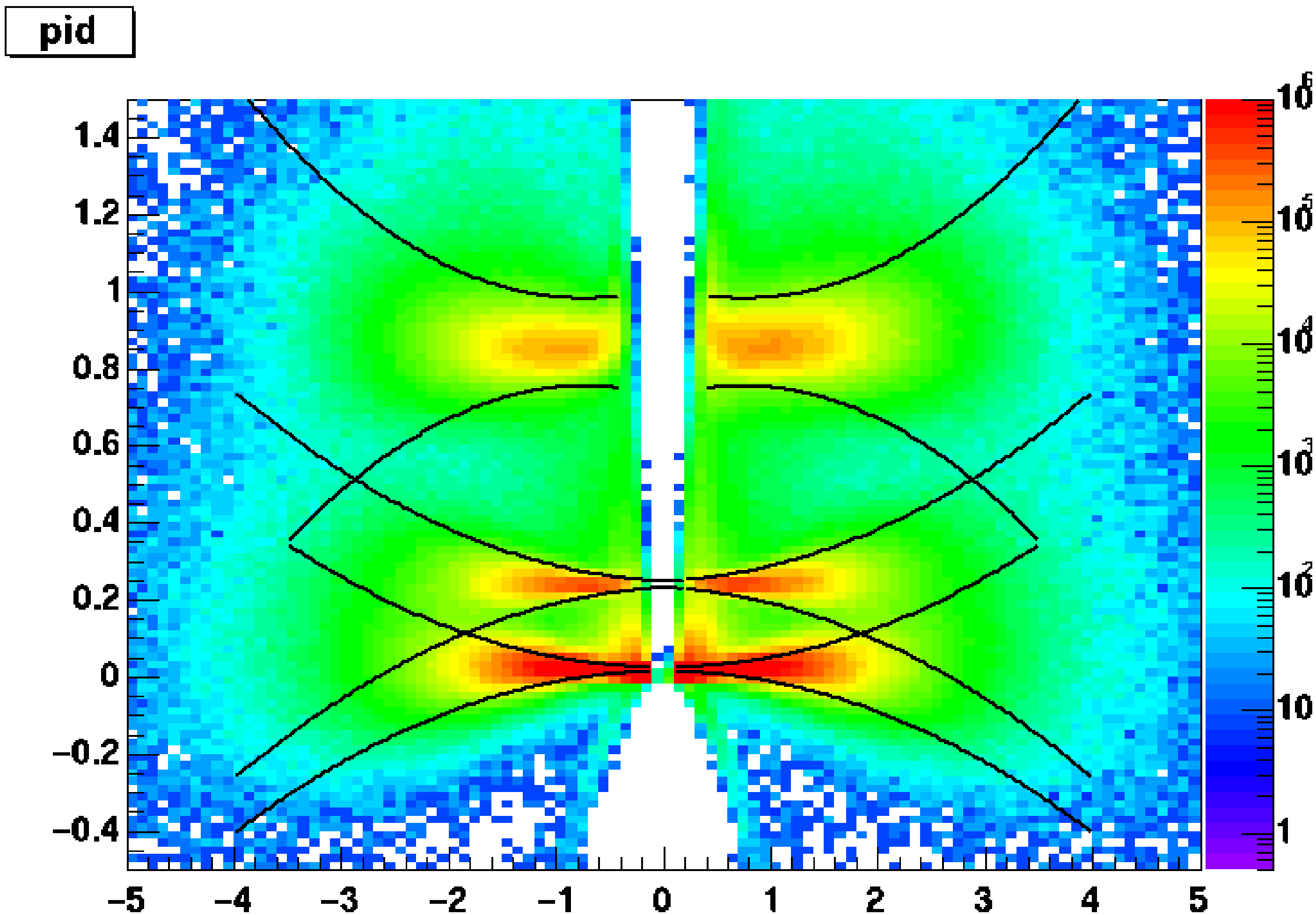
PID plot for reaction plane v2 analysis



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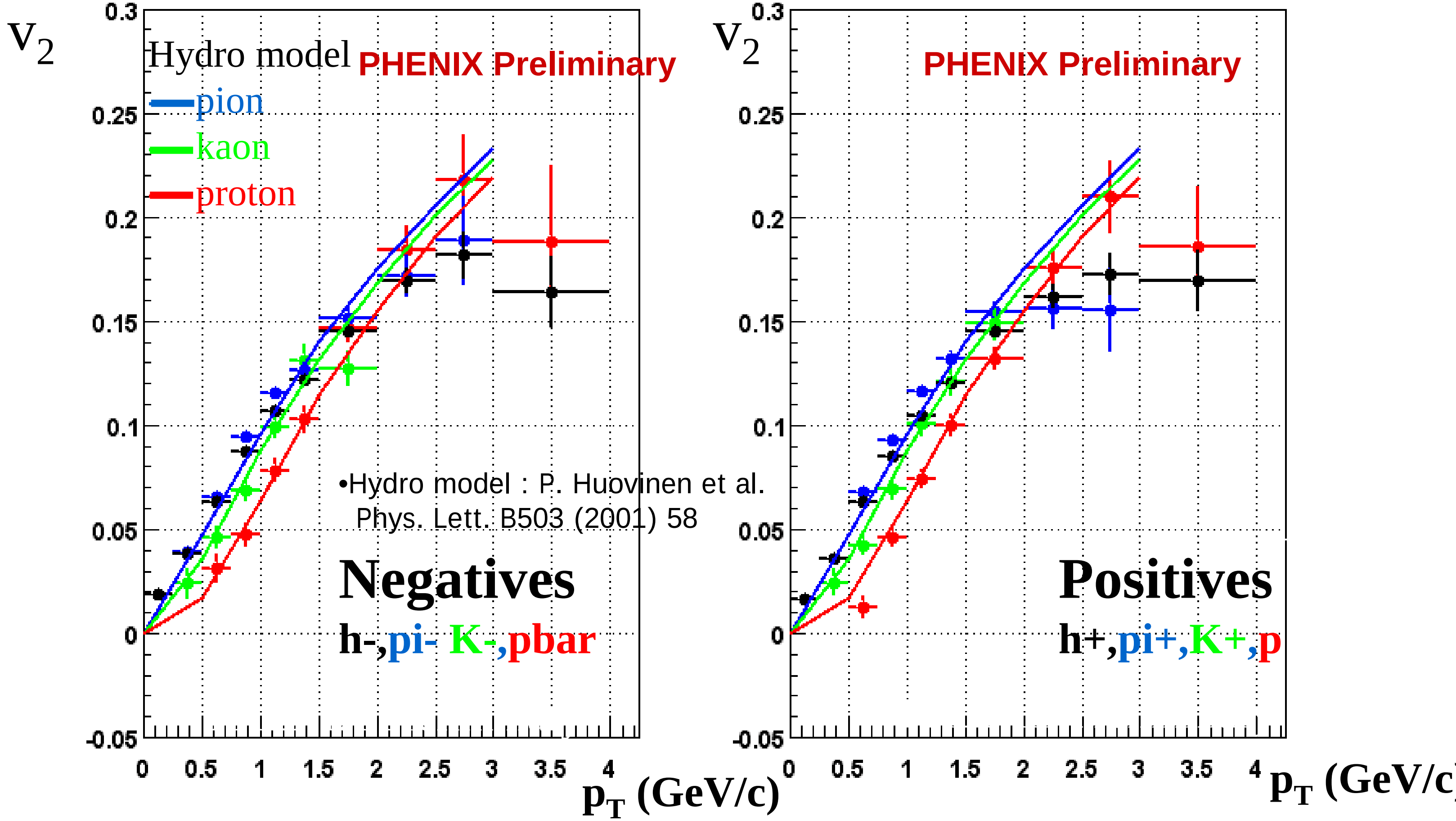
v2 of Identified Hadrons (π, K, p)

Au+Au at sqrt(s_{NN}) =200GeV, Minimum bias, Reaction Plane | η |=3~4



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