Results on soft physics:Flow, spectra and flavor composition from PHENIX

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for the U.S. Department of Energy

Physics of Soft Hadron

Soft hadrons contain the bulk property of created system and its dynamical evolution!

- **Hydro-dynamical collective expansion velocity (β) and thermal freeze-out temperature (T_{th}).** → **p_T spectra**; → **K_T dependence of HBT correlation radius**
- **Chemical freeze-out temperature and chemical potential (T_{ch}, μ_B, μ_S)** → **dN/dy, ratio**
- **Space-time evolution of the system** → **HBT correlation**

↓

Shed light on QGP formation at RHIC

Outline

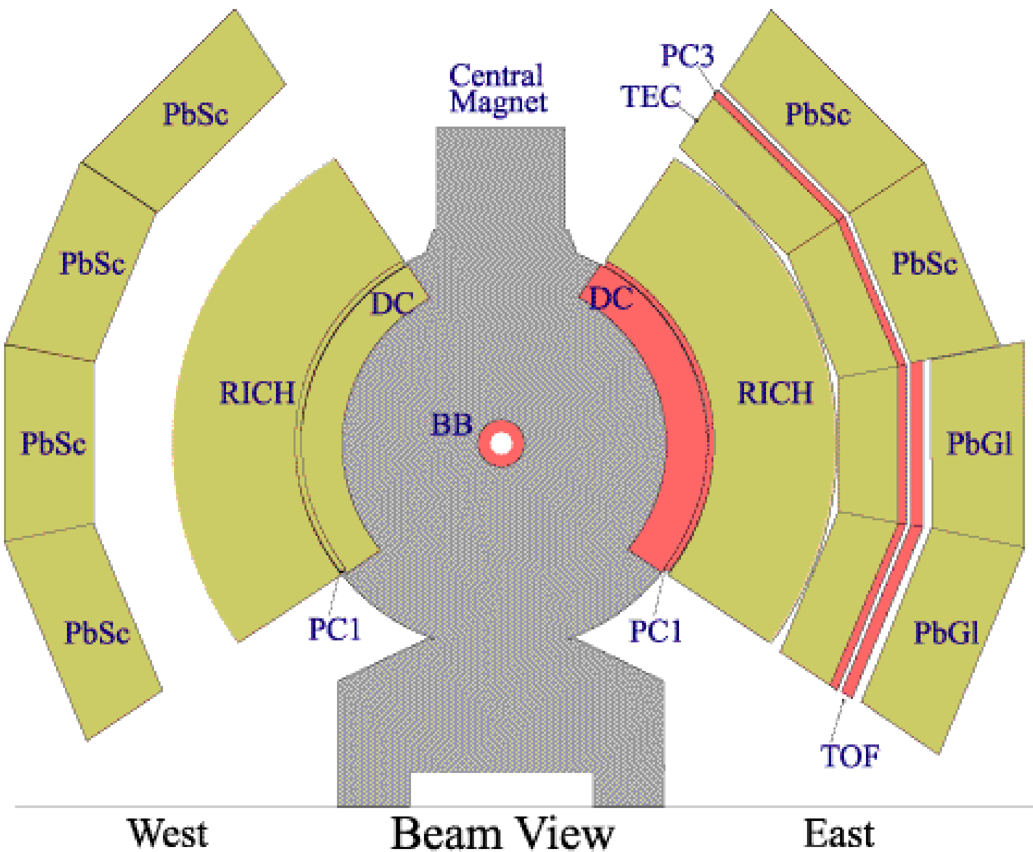
<u>In this presentation, we present the recent preliminary results in</u>

Au+Au collisions, $\sqrt{s_{NN}}$ = 130 GeV @ mid-rapidity $|\eta| < 0.35$, Measured at RHIC-PHENIX.

1. **Experimental setup and hadron PID by TOF.**
2. **Identified charged hadron spectra.**
   - **Spectra shape**
   - **Inverse slope, $\langle p_T \rangle$ vs. centrality**
   - **Particle ratios (pbar/p, K^+/K^-)**
3. **HBT $\pi^+\pi^+$, $\pi^-\pi^-$ correlations (TOF, EMC analysis).**

- **Based on the post QM01 analysis (to be published in the QM proceedings).**
- **Due to the time restriction, I will skip the results of elliptic flow analysis.**

PHENIX Detector Setup



In this presentation, we use

- **Beam-Beam Counter (BBC)**

  z vertex, start timing for TOF
- **Time-of-Flight (TOF)**

  stop timing measurement
- **Drift Chamber (DC)**

  momentum, flight path length
- **Pad Chamber 1 (PC1)**

  additional track z information to Dch

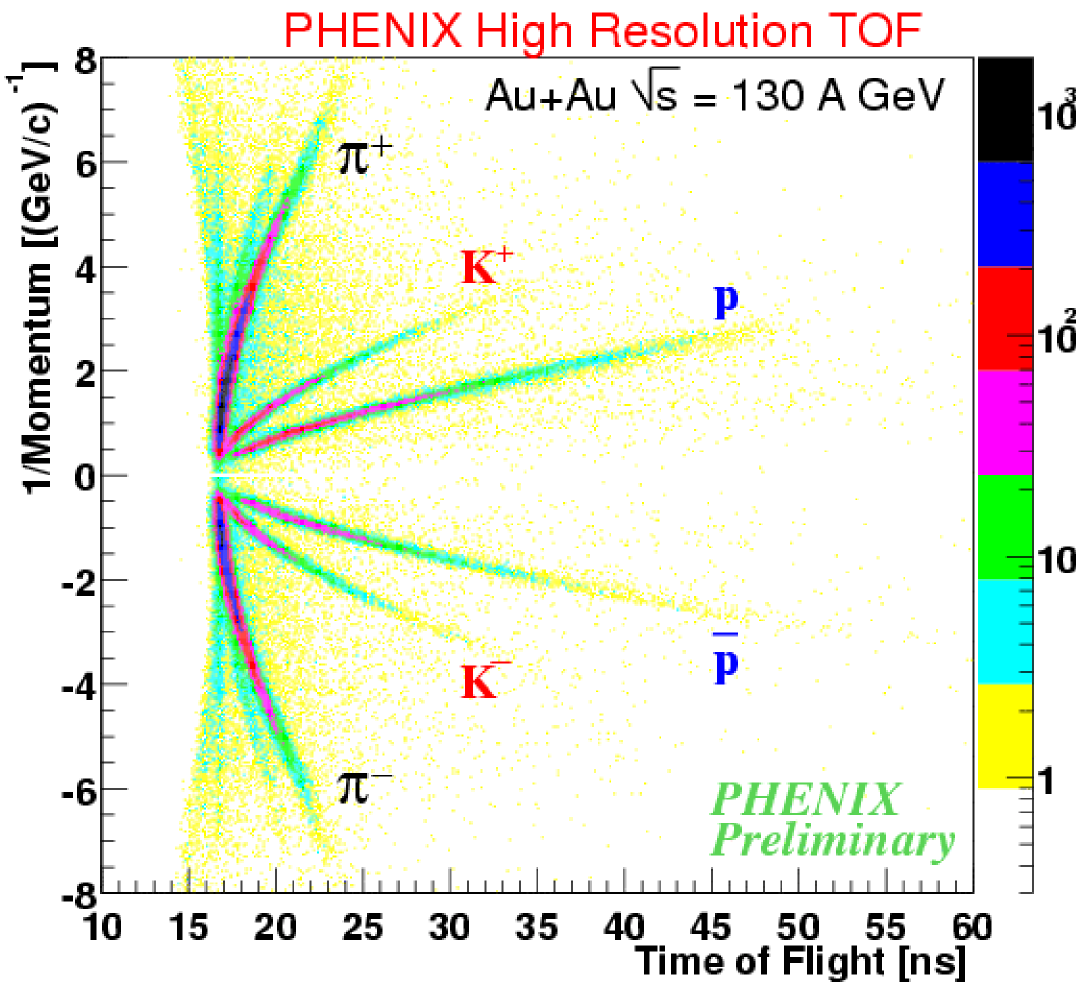
+

- **PbSc EMCal (EMC)**

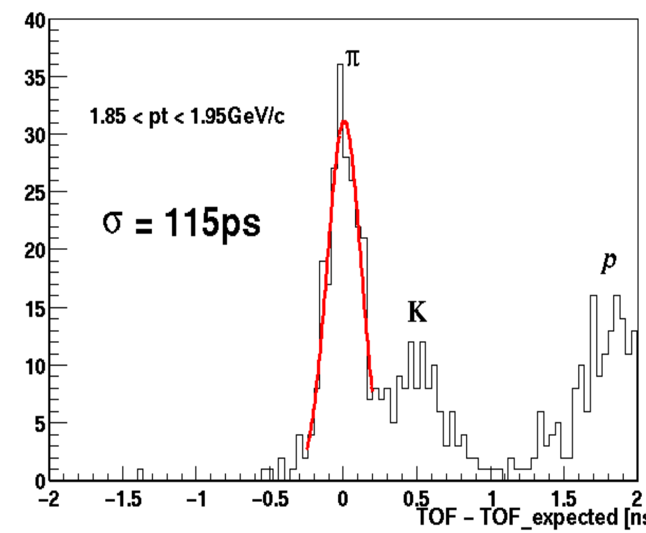
  as TOF detector for HBT analysis

Reality of PHENIX

Particle Identification by TOF

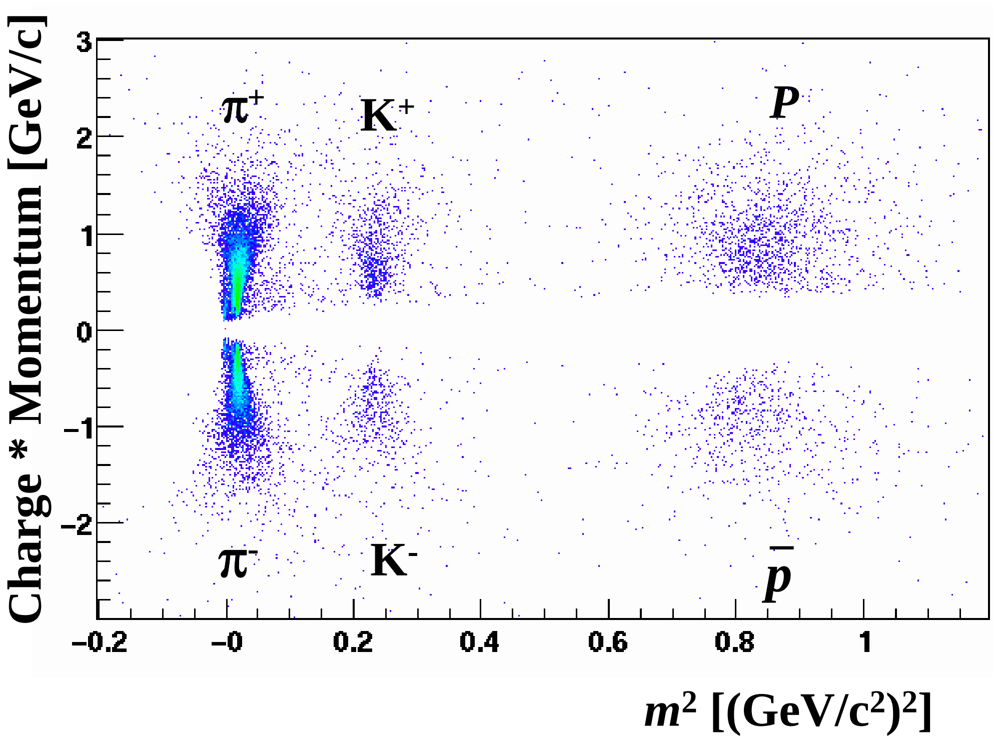


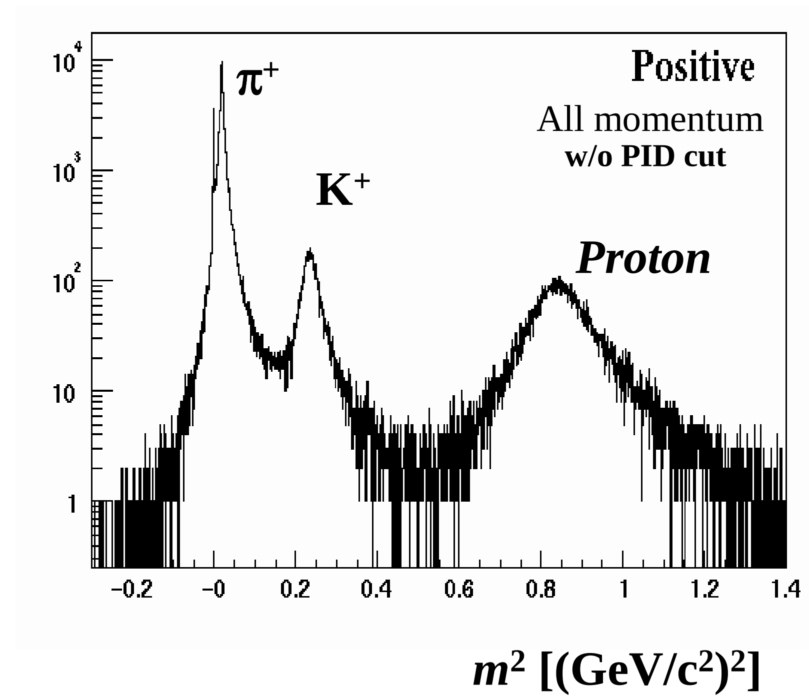
- **Demonstrated clear PID by TOF**
- **Time-of-Flight resolution**
  σ_{TOF} ~ 110-120 ps (@ 3/27/01)
- **Flight path length : ~ 5m**
  - **K/π separation : < 1.6 GeV/c**
  - **p/K separation : < 3.5 GeV/c**



TOF – $TOF_{expected}$ [ns]

PID Cut Criteria

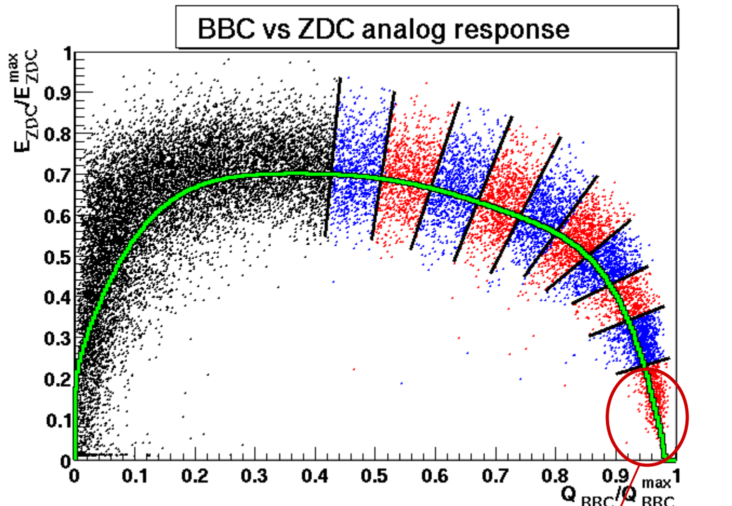




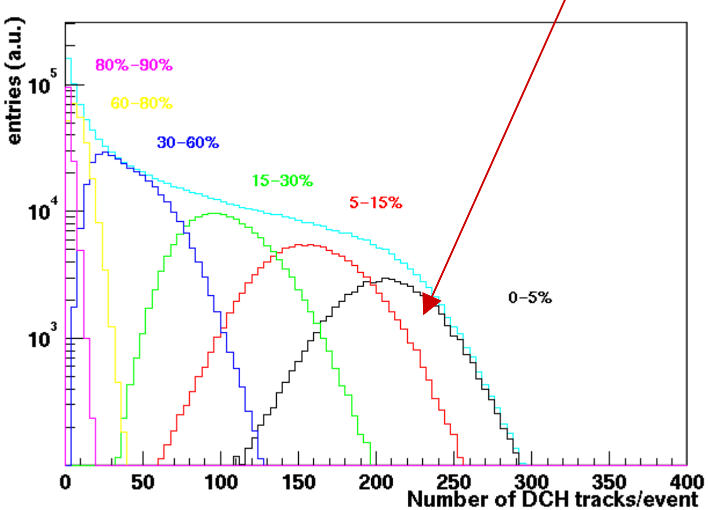
- PID by m^2 vs. momentum space
- $|m^2_{measured} - m^2_0| < 2\ \sigma_m{}^2$
- Momentum cutoff

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

Centrality Classes



Dch raw multiplicity distributions

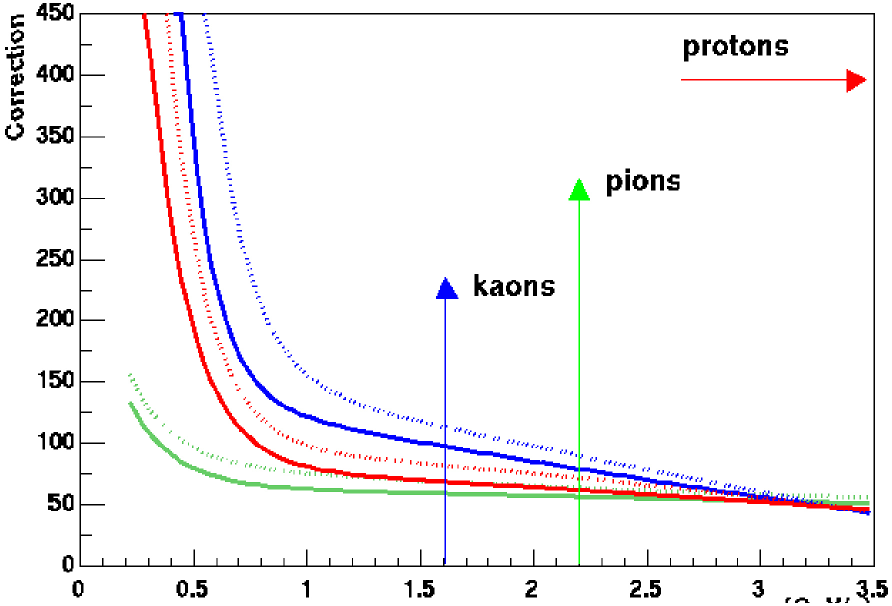


- **Used correlation between BBC charge and ZDC energy to define centrality.**
- **Extracted N_{part} based on Glauber model.**

Centrality	Participants
0-5%	347 ± 15%
5-15%	271 ± 15%
15-30%	178 ± 15%
30-60%	76 ± 15%
60-92%	12 ± 60%

Corrections for raw p_T spectra

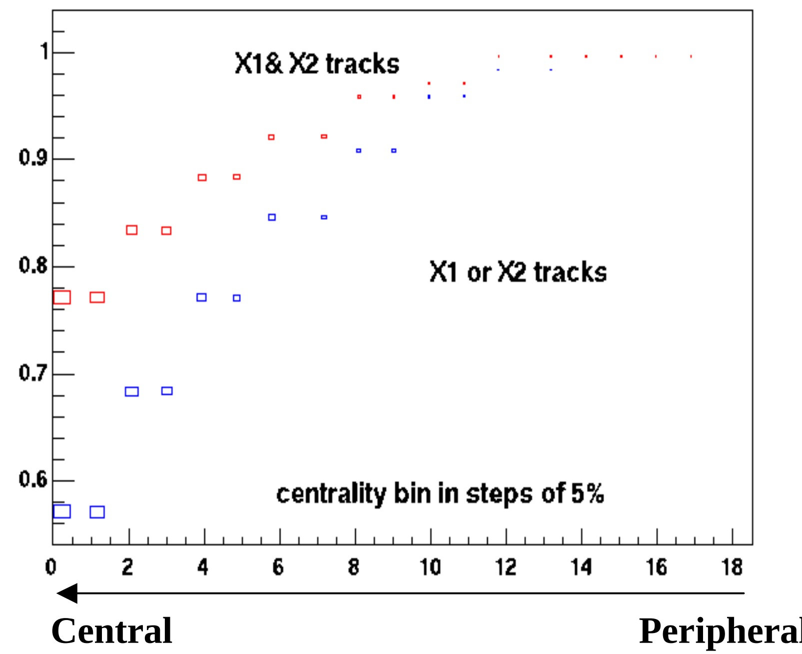
Correction functions



* Arrows indicate the upper limit of pt region

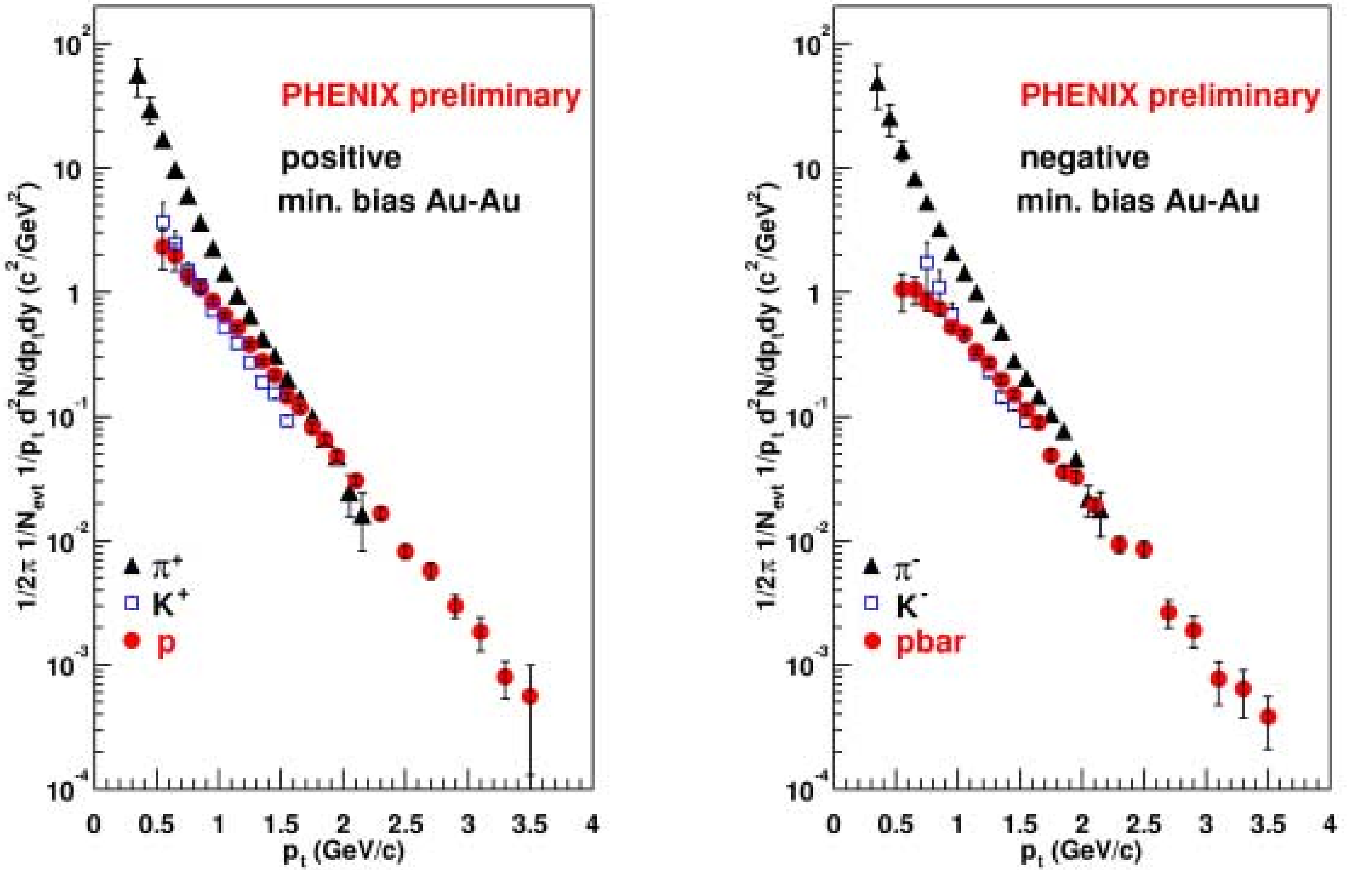
p_T [GeV/c]

Track reconstruction efficiency



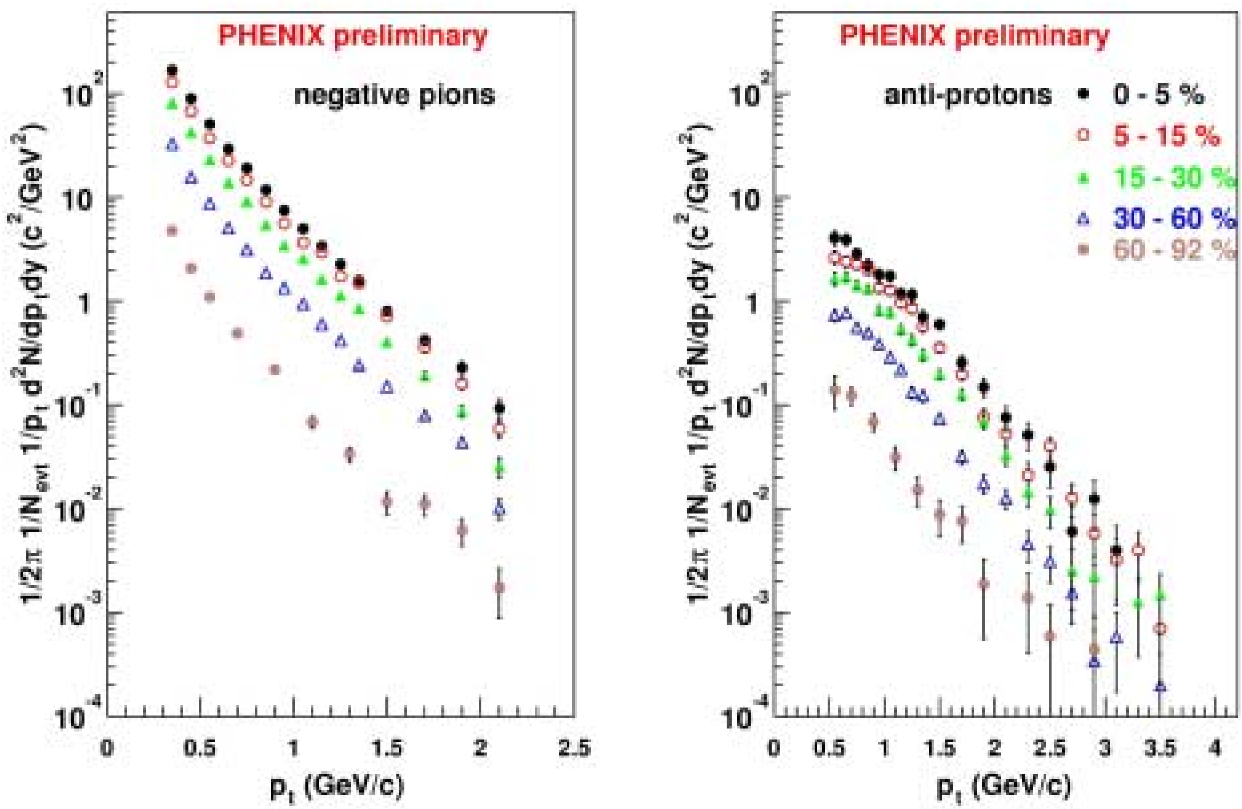
- Correction factor based on the single particle MC simulation for each particle species.
  ☆ Including geometrical acceptance and decay effect.
- Taking into account track reconstruction efficiency in each centrality bin by using the embedding method.

Results : Minimum bias p_T spectra



- **pions yield ~ proton and pbar yield @ p_T~ 2 GeV/c,**
- **Indicated that p/pbar is dominant at high p_T region.**

Centrality Dependence of p_T Spectra for π^- and anti-proton

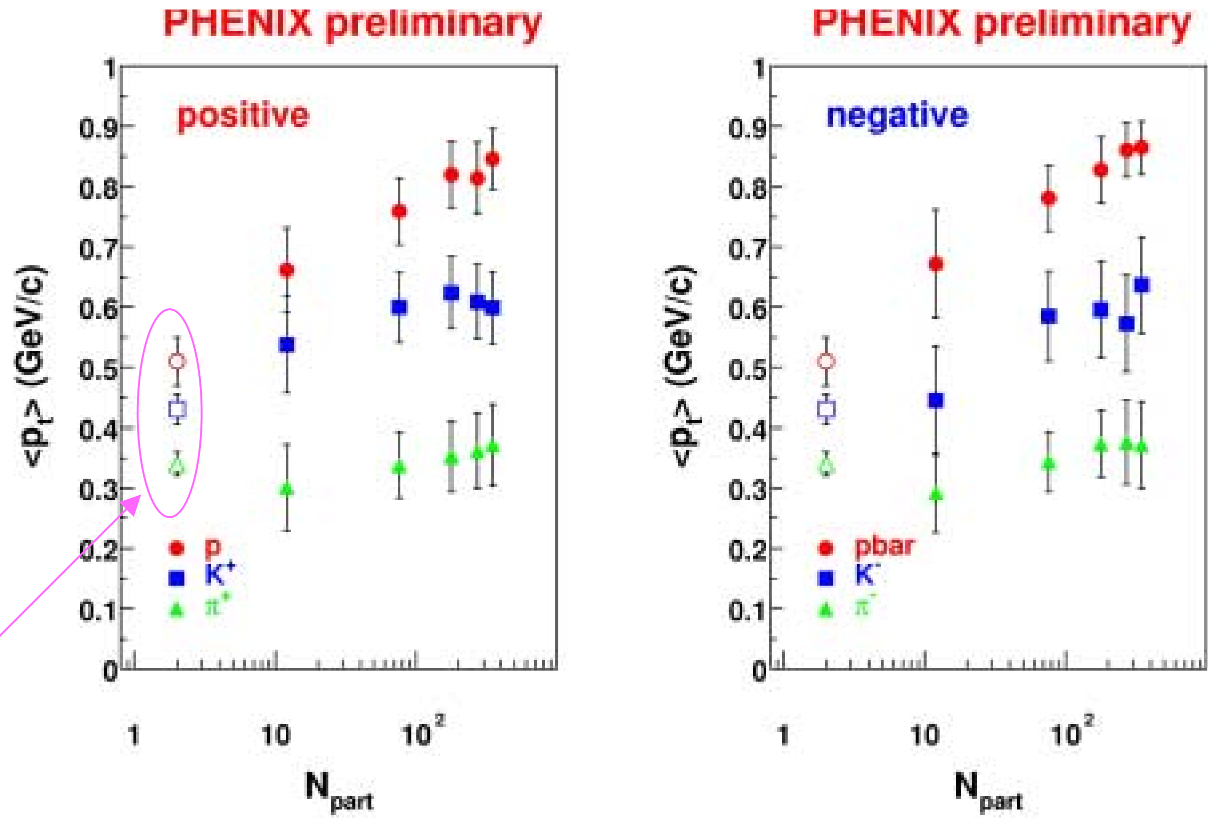


- Power law shape is prominent in peripheral event for pions.
- <p_T> are extracted by fitting the each spectra in whole p_T range.

  π : power law function,

  p/K, : single exponential function.

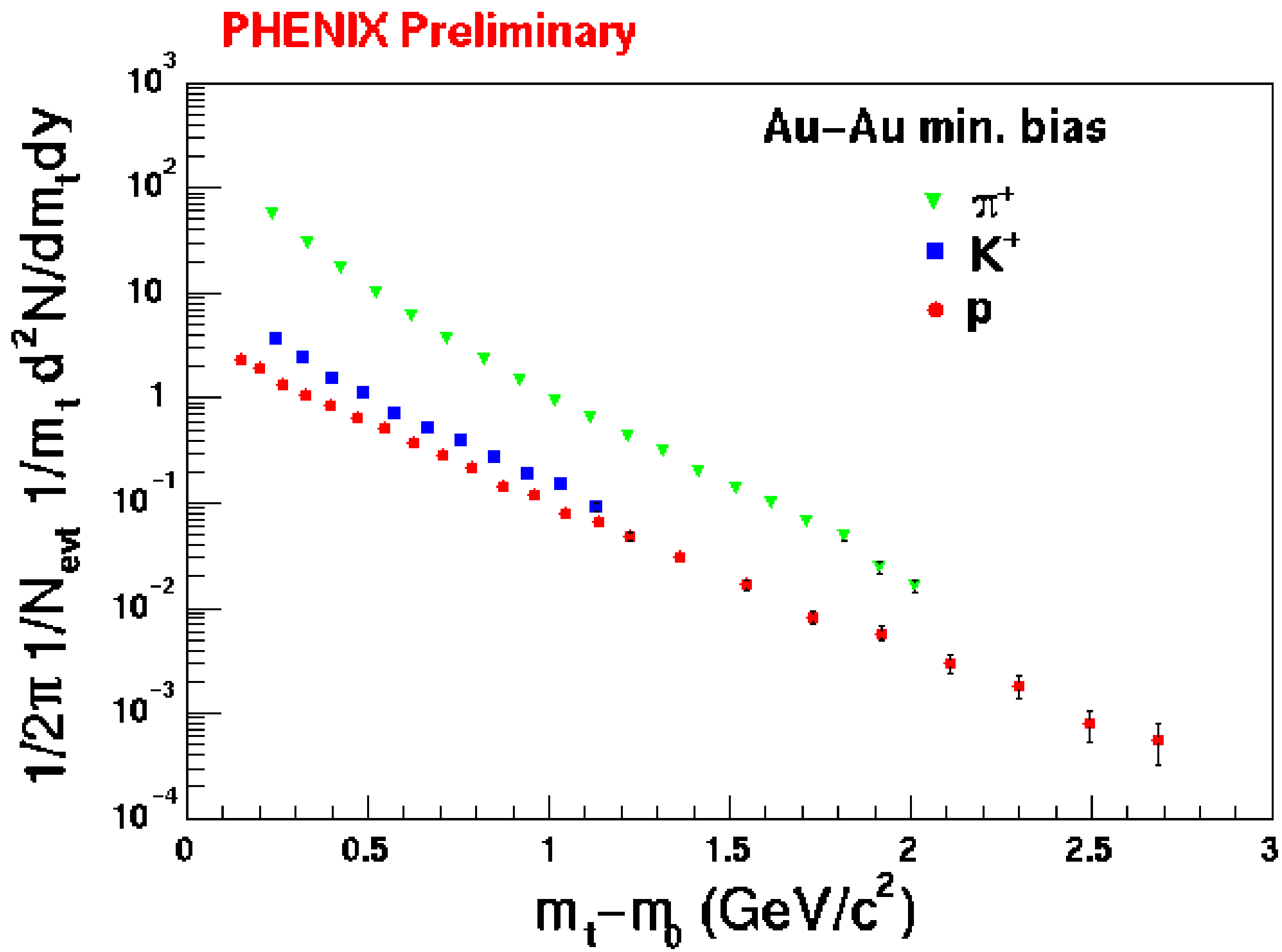
$\langle p_T \rangle$ vs. centrality



Interpolation to sqrt(s)=130 GeV
From $p\bar{p}$ collisions

- The heavier mass, the larger $\langle p_T \rangle$.
- Continuous rise for proton, anti-proton (K), rather flat distribution for π.

Minimum bias m_T spectra

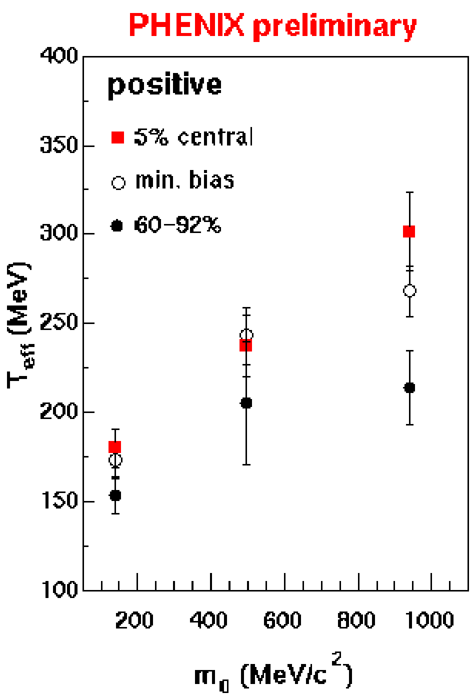


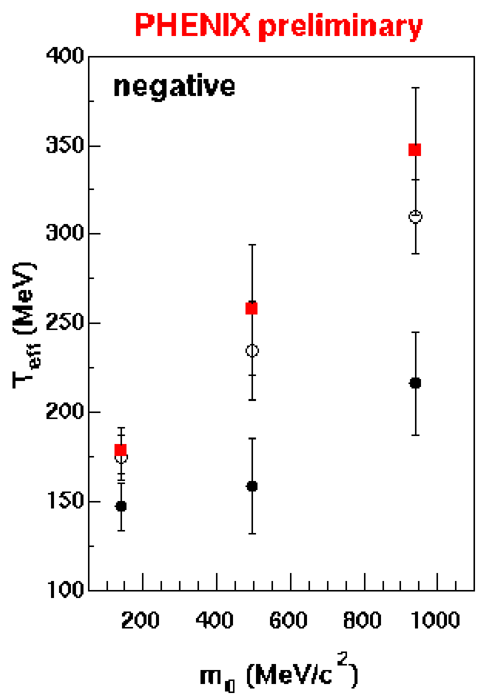
- For protons and kaons, single exponential shape up to 1.0 GeV/c^2.
- For pions, power law like behavior.

Mass dependence of m_T slope

- Fitted to exponential in $m_T - m_0$

$$\frac{1}{m_T}\frac{dN}{dm_T} \propto A\exp\left(-\frac{m_T}{T}\right)$$





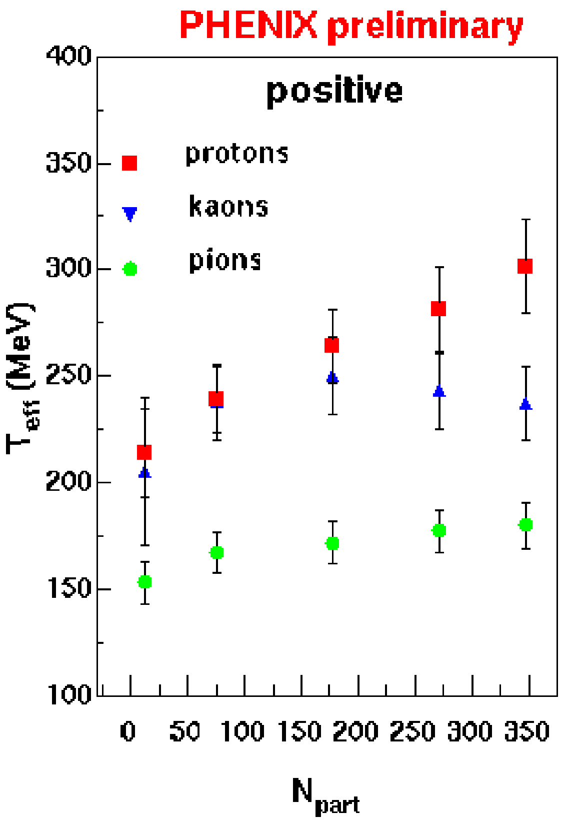
particle	Fitting range in p_T
π	0.3 - 0.9 GeV/c
K	0.55 - 1.6 GeV/c
proton	0.55 - 1.6 GeV/c

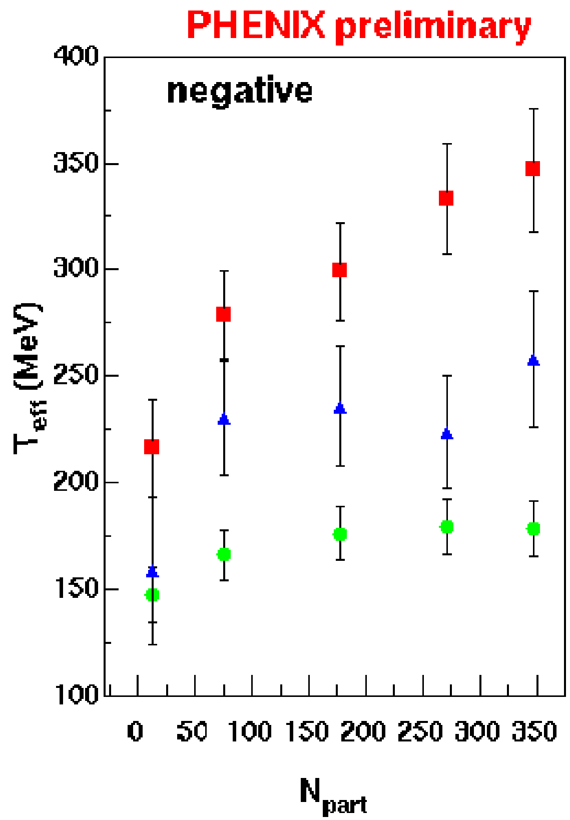
- **Clear mass dependence of *T*.**
- **$T_\pi < T_K < T_{proton}$, especially for nost central collisions.**

- **Inverse slope @ 5% central**

π^+ = 180 ± 11 MeV	, π^- = 179 ± 13 MeV
K^+ = 237 ± 17 MeV	, K^- = 258 ± 37 MeV
p = 302 ± 22 MeV	, $\bar{p}$ = 347 ± 36 MeV

Centrality Dependence of *T*





Simultaneous fitting by hydrodynamic model to the data @ 5% central.

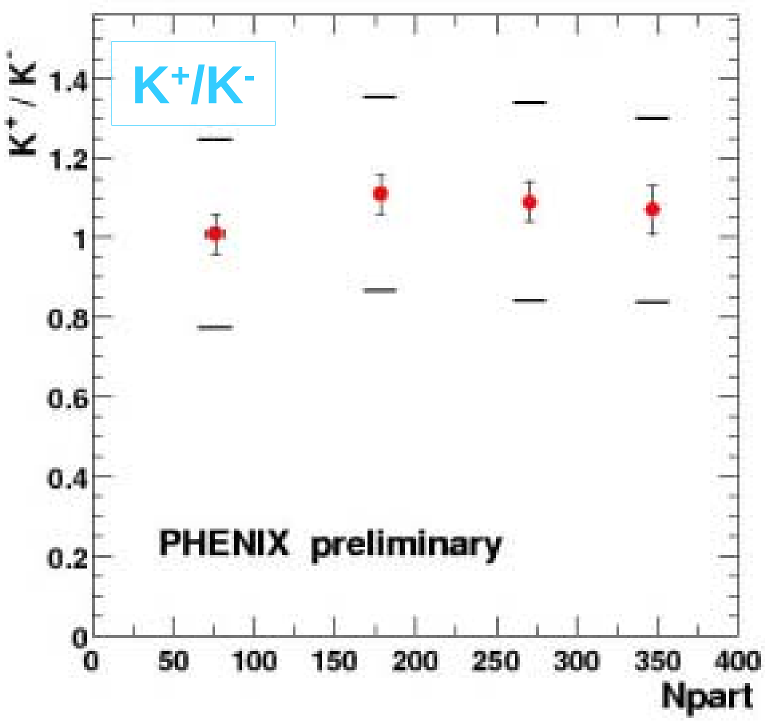
T_{fo}~ 125 - 83 MeV ± 8% (sys)

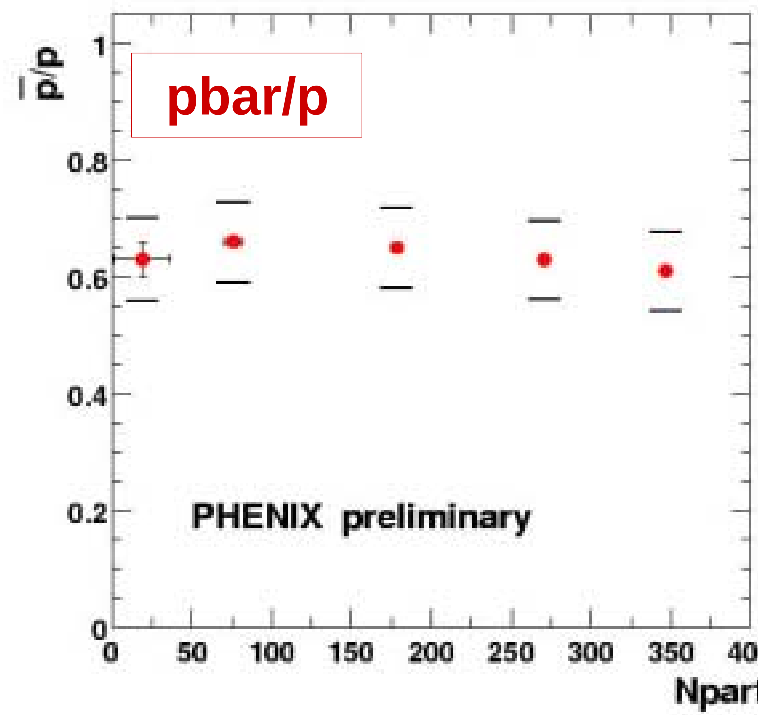
β_t ~ 0.6 - 0.8 ± 5% (sys)

(calculated by J. B Burward-Hoy, SUNY)

- **Continuous rise of T_{proton}, T_{pbar} as a function of N_{part}, while rather flat for T_π, T_K .**
- **$T_\pi < T_K < T_{proton}$ @ most central collision consistent with expansion picture.**

K^+/K^- and pbar/p ratios vs. centrality

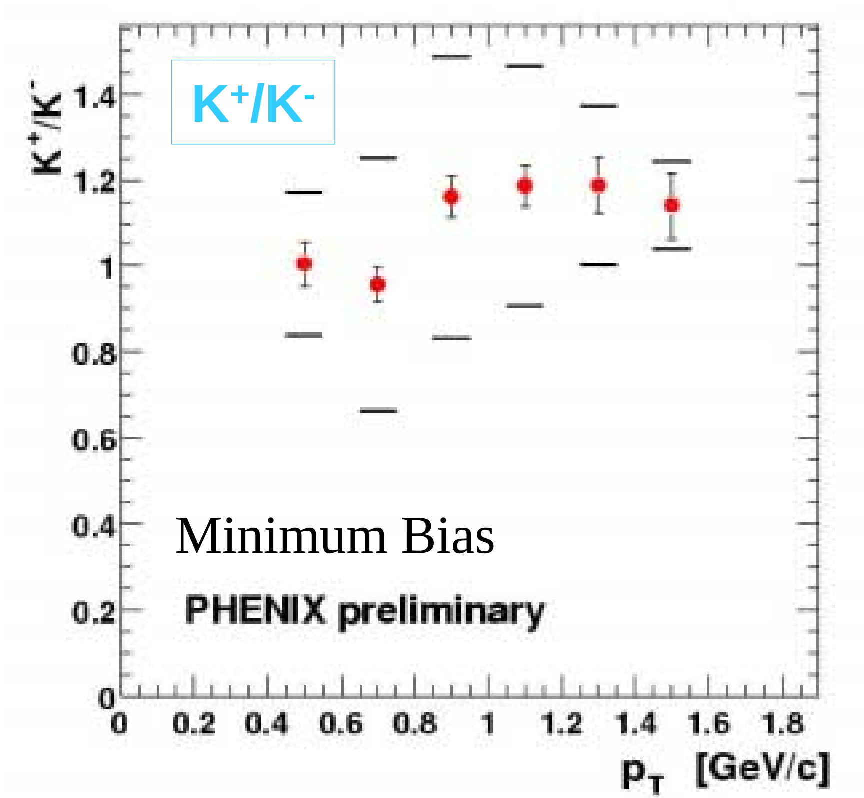


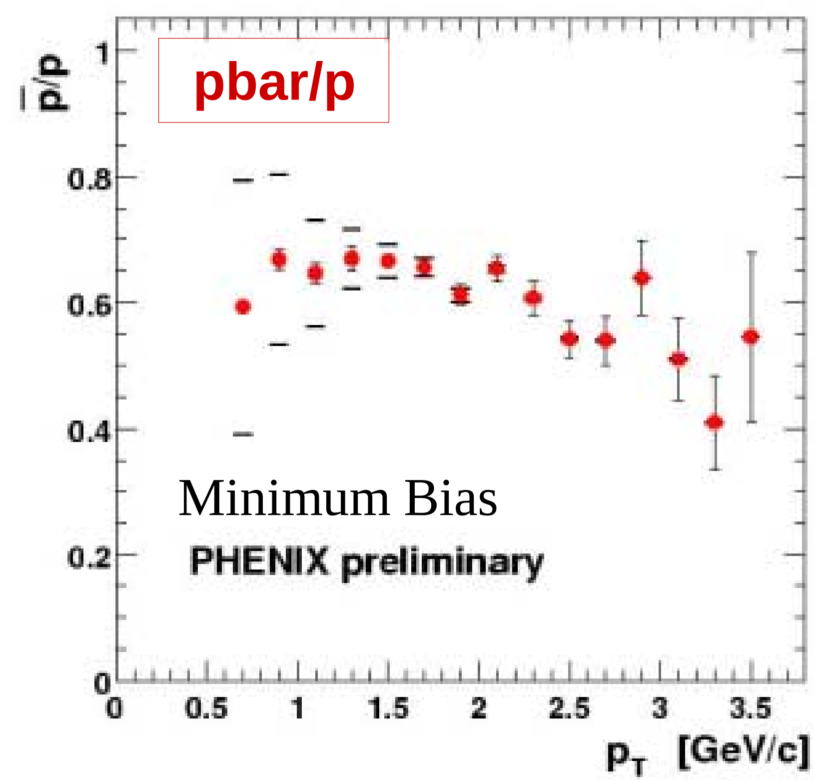


- No clear dependence as a function of N_{part} in both K^+/K^- and pbar/p ratios.

- K^+/K^- (Min. Bias) = 1.08±0.03(stat) ±0.22(sys.)
- pbar/p (Min. Bias) = 0.64±0.01(stat.)±0.07(sys.)

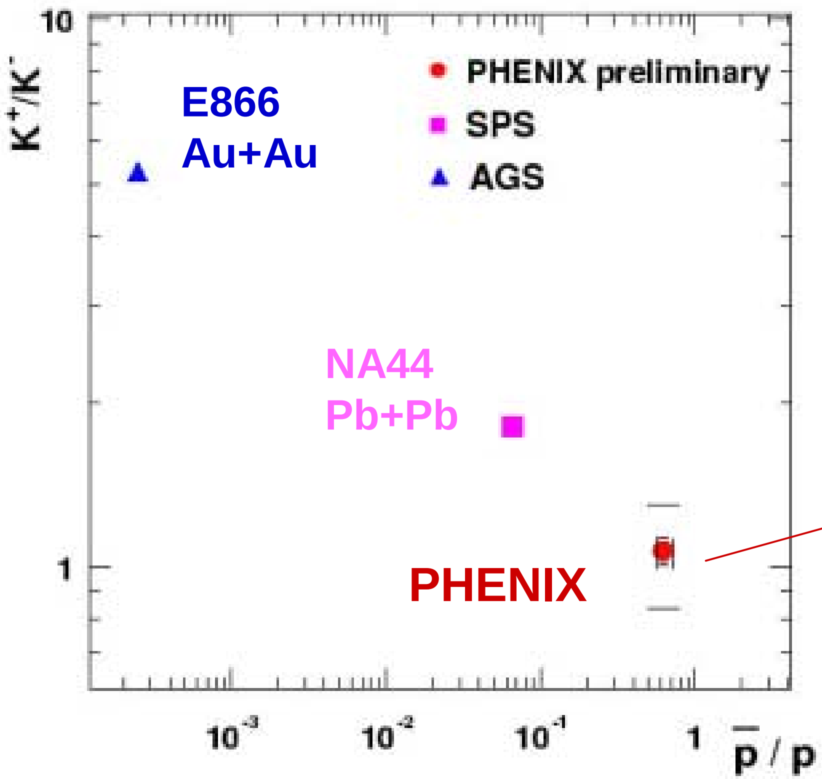
K^+/K^- and pbar/p ratios vs. p_T





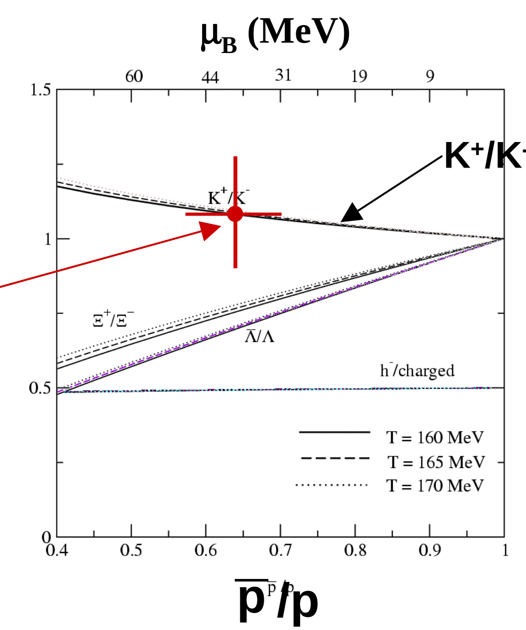
- **Within the systematic errors, No clear p_T dependence in both K^+/K^- and pbar/p ratios.**

Beam Energy Dependence of ratios



Statistical thermal model

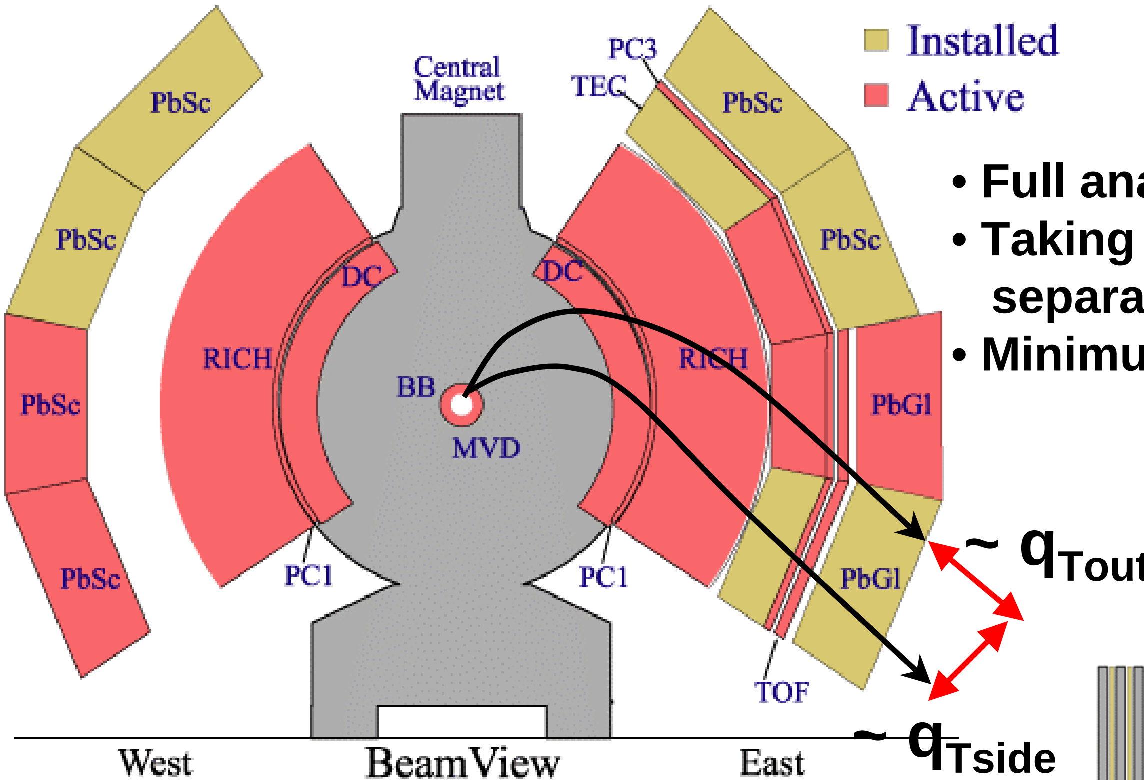
hep-ph/0002267 F.Becattini et al.

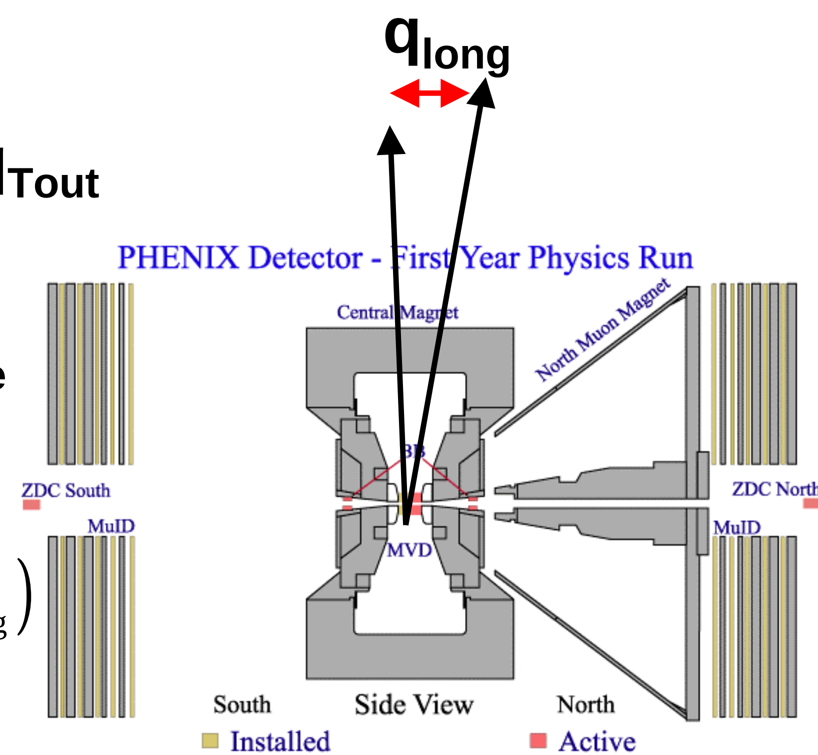


- Both ratios are closing to 1.0 from AGS, SPS to RHIC energy.
- Baryon chemical potential ~ 40MeV, not baryon free (μ_B!=0).

3D HBT measurement in PHENIX

- Full analytic coulomb corrections.
- Taking into account two track separations.
- Minimum-bias data sample.

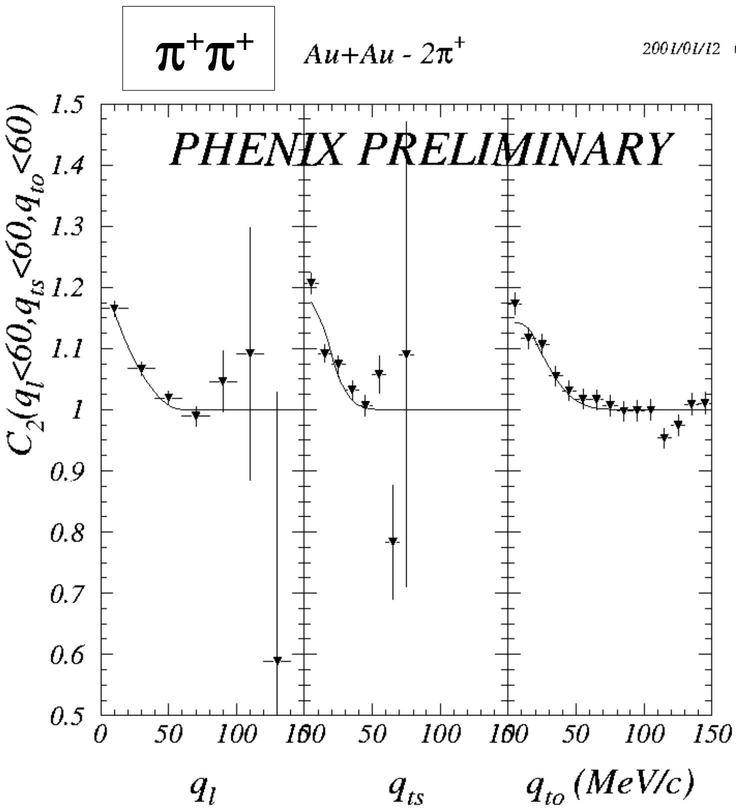




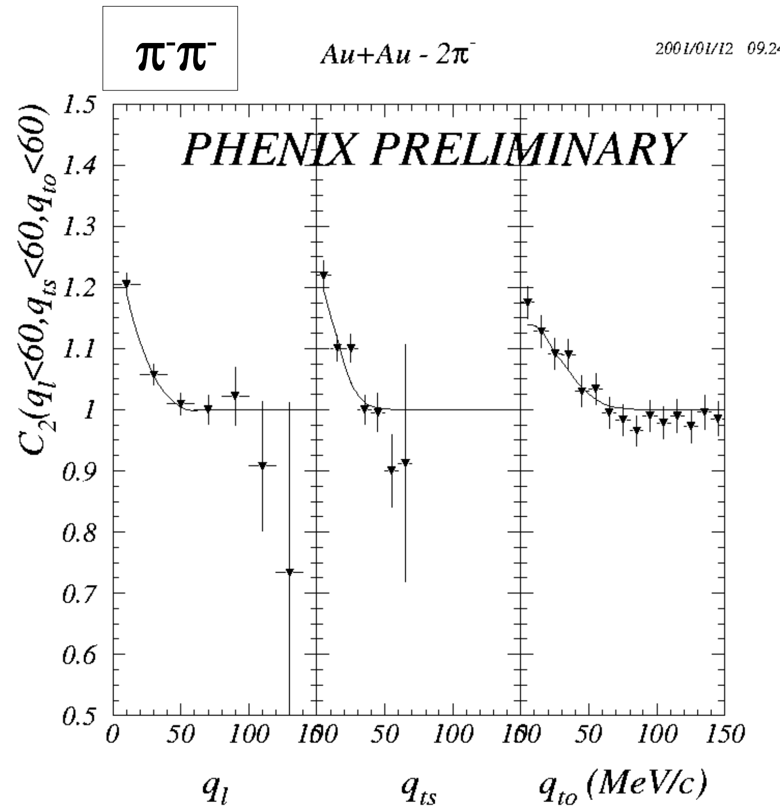
Bertsch-Pratt parameterization

$$C_2 = 1 + \lambda \exp\left(-R^2_{\rm Tside} q^2_{\rm Tside} - R^2_{\rm Tout} q^2_{\rm Tout} - R^2_{\rm long} q^2_{\rm long}\right)$$

Bertsch-Pratt Fit Results I (TOF PID)



R_{long} = 4.0 ± 1.2 fm
R_{Tside} = 7.9 ± 1.1 fm
R_{Tout} = 6.2 ± 0.5 fm
λ = 0.49 ± 0.05

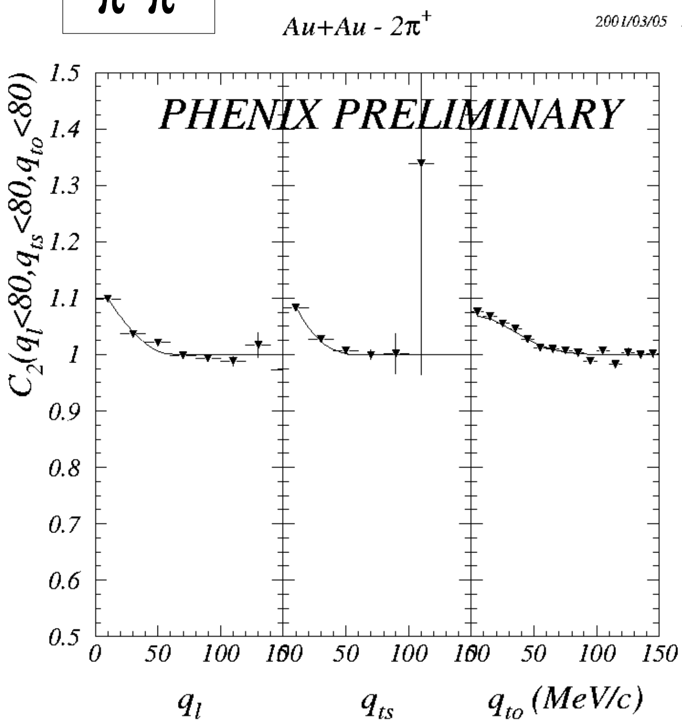


R_{long} = 6.7 ± 0.9 fm
R_{Tside} = 5.8 ± 1.5 fm
R_{Tout} = 5.5 ± 0.5 fm
λ = 0.49 ± 0.06

* Correlation functions have been fully Coulomb corrected in TOF, EMC analysis

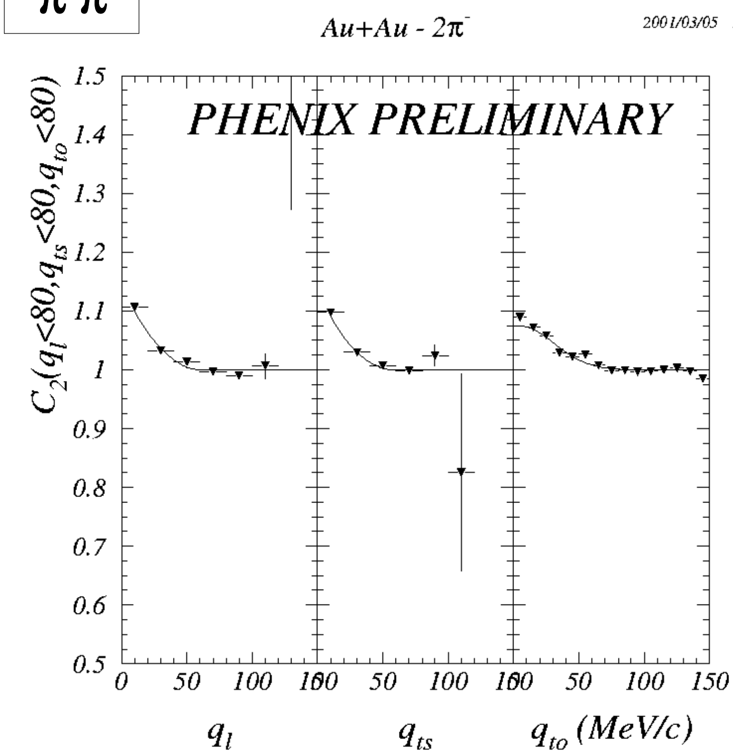
Bertsch-Pratt Fit Results II (EMC PID)

$\pi^+\pi^+$



R_{long} = 5.9 ± 0.4 fm
R_{Tside} = 5.1 ± 0.6 fm
R_{Tout} = 4.4 ± 0.2 fm
λ = 0.27 ± 0.02

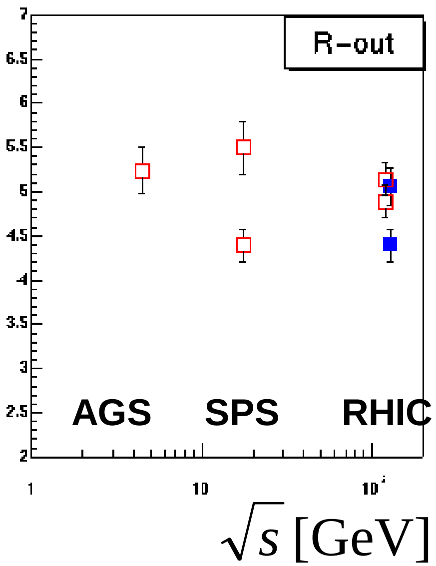
$\pi^-\pi^-$

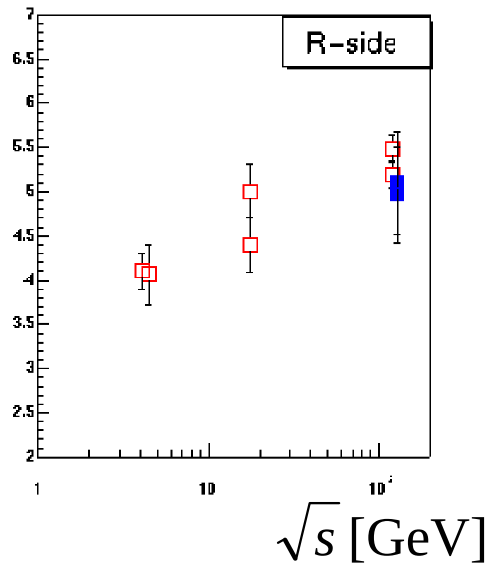


R_{long} = 5.9 ± 0.4 fm
R_{Tside} = 5.0 ± 0.6 fm
R_{Tout} = 5.1 ± 0.2 fm
λ = 0.30 ± 0.02

- Note 1 : EMC radii are consistent with TOF results within error bars.
- Note 2 : λ are different, but it's understood in terms of different S/B between the two analysis.

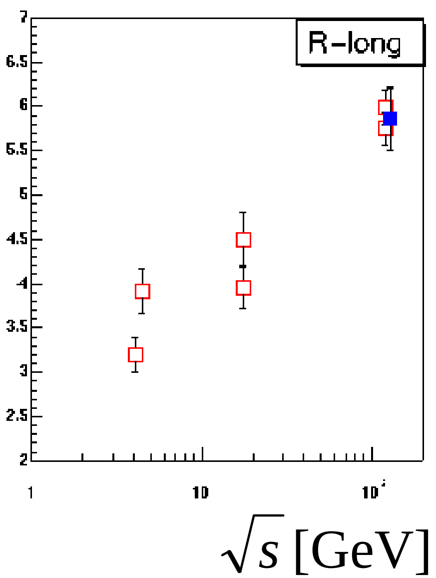
Beam energy dependence of R





Moderately larger source size compared with SPS.

→ No big jump from SPS to RHIC

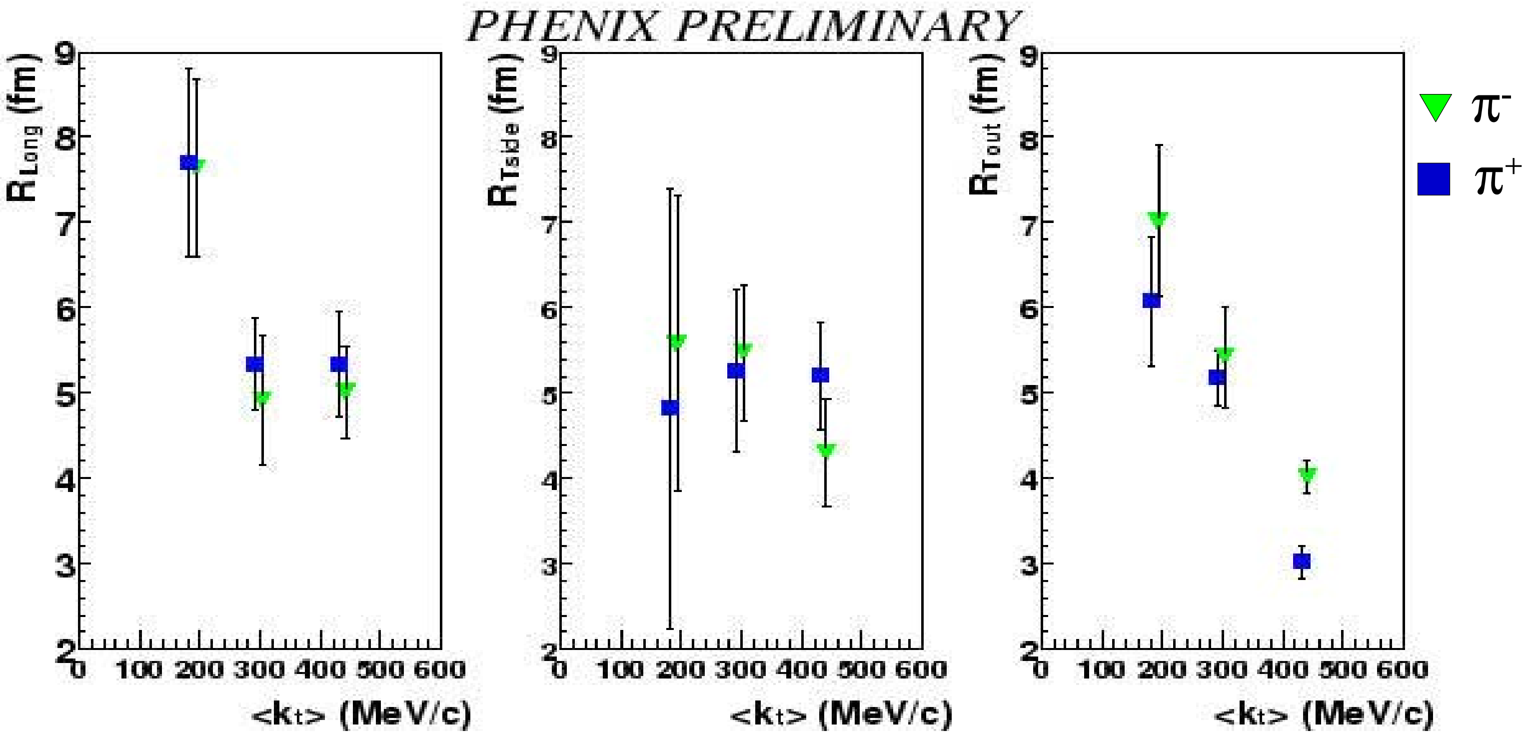


- □ **STAR Preliminary**
- **NA49**
- **E895**
- **E866**
- **NA44**
- ■ **PHENIX Preliminary (EMC analysis)**

- **R_L, R_{TS} ; increase**
- **R_{TO} ; flat**

as a function of beam energy

k_T dependence of HBT radii



* From EMC analysis

$$R_{\perp}^{2} \approx \frac{R^{2}}{1+\eta_{f}^{2}\left(M_{\perp}/T\right)}$$

Related to degree of collective motion

- **Consistent with expanding source picture.**

Conclusions from Year-1 data

Single particle spectra for $\pi^{\pm}$, $K^{\pm}$, protons and anti-protons in each centrality class and 2π HBT correlations are studied.

- Weak centrality dependence of slopes and $\langle p_T \rangle$ for pions.
- For protons and anti-protons, continuous rise of slopes and $\langle p_T \rangle$ from peripheral to central collisions are observed.
- $T_{\pi} < T_{K} < T_{proton}$ at all centrality classes, which is consistent with expanding source picture @ RHIC energy.
- No clear centrality and p_T dependence in both K^+/K^- (~1.08) and pbar/p (~0.64) ratios.
- Baryon chemical potential ~ 40MeV (thermal model); indicative of not baryon free(μ_B=0) system in Au+Au at $\sqrt{s_{NN}}$ = 130 GeV.
- In 2π HBT measurements, moderately larger source radii are observed.
- k_T dependence of radii suggests the larger collective motion, which is consistent with the observation of single particle analysis.

PHENIX

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