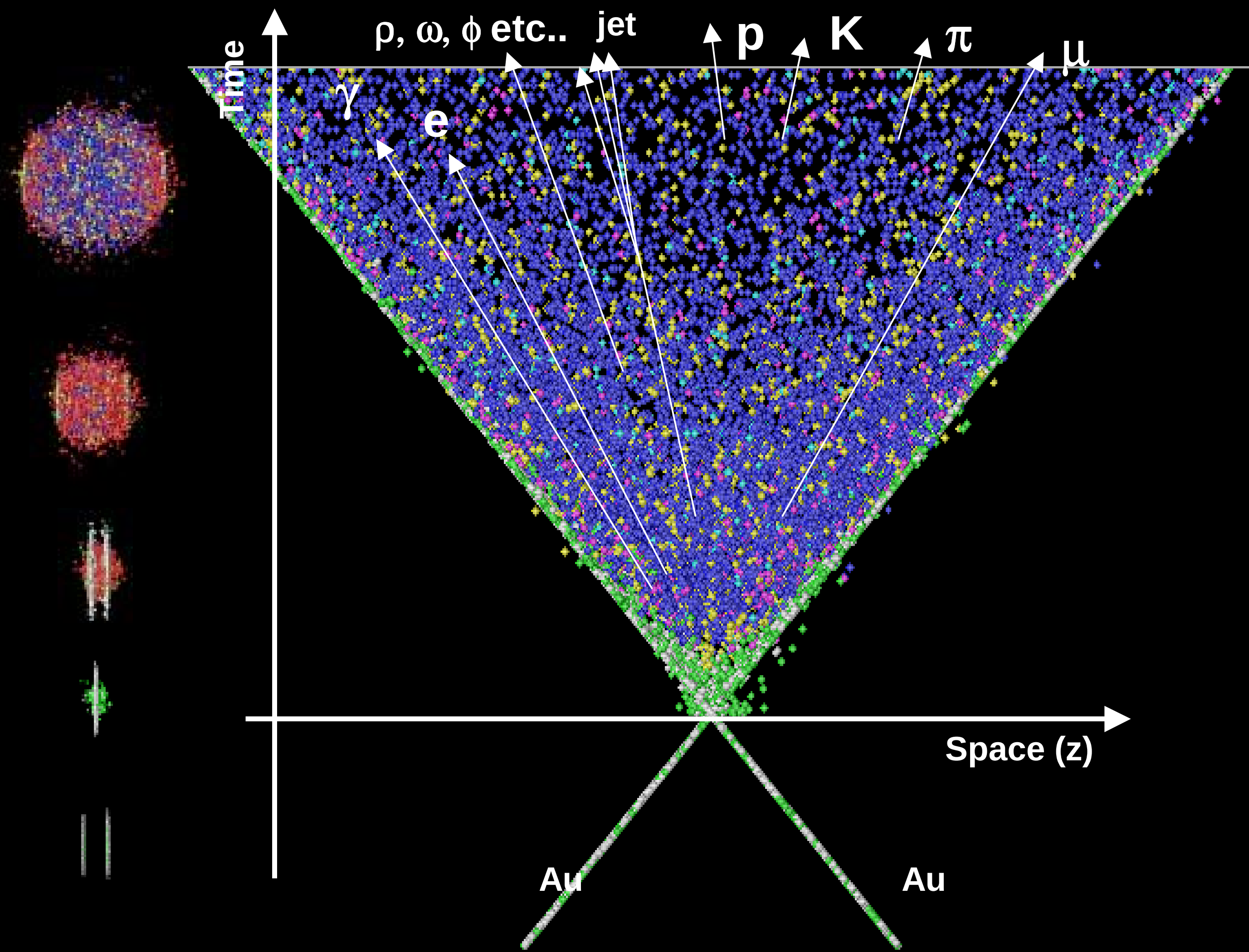
Hadron Production at RHIC-PHENIX

Tatsuya Chujo (BNL)
for the PHENIX Collaboration

managed by Brookhaven Science Associates
for the U.S. Department of Energy

Space-time Evolution in Relativistic Heavy Ion Collisions



Hadronization (Freeze-out) + Expansion

Mixed phase

QGP phase

Thermalization

Pre-equilibrium

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

Physics of Identified Hadron

- Hydro-dynamical collective expansion velocity (β).
- Thermal freeze-out temperature (T_{th}). → **p_T spectra**
- Chemical freeze-out temperature and chemical potential (T_{ch}, μ_B) → **dN/dy**
- Jet quenching effect at high p_T by parton energy loss in medium (dE/dx). → **High p_T spectra**
- Space-time evolution of the system → **HBT correlation**

↓

Shed light on QGP formation at RHIC

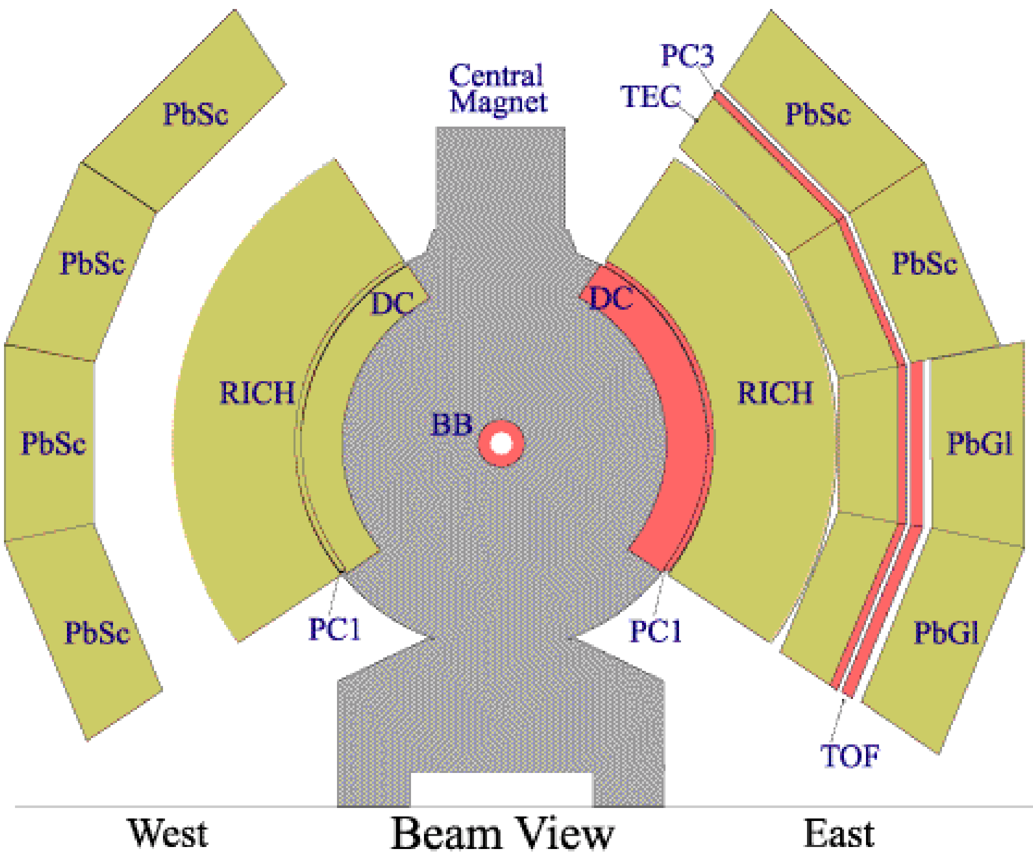
Outline

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

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

1. **Experimental setup and PID by TOF.**
2. **Identified charged hadron spectra.**
   - **Spectra shape**
   - **Inverse slope parameter vs. centrality**
   - **Particle ratios**
3. **HBT $\pi^+\pi^+$, $\pi^-\pi^-$ correlations.**

PHENIX Detector Setup

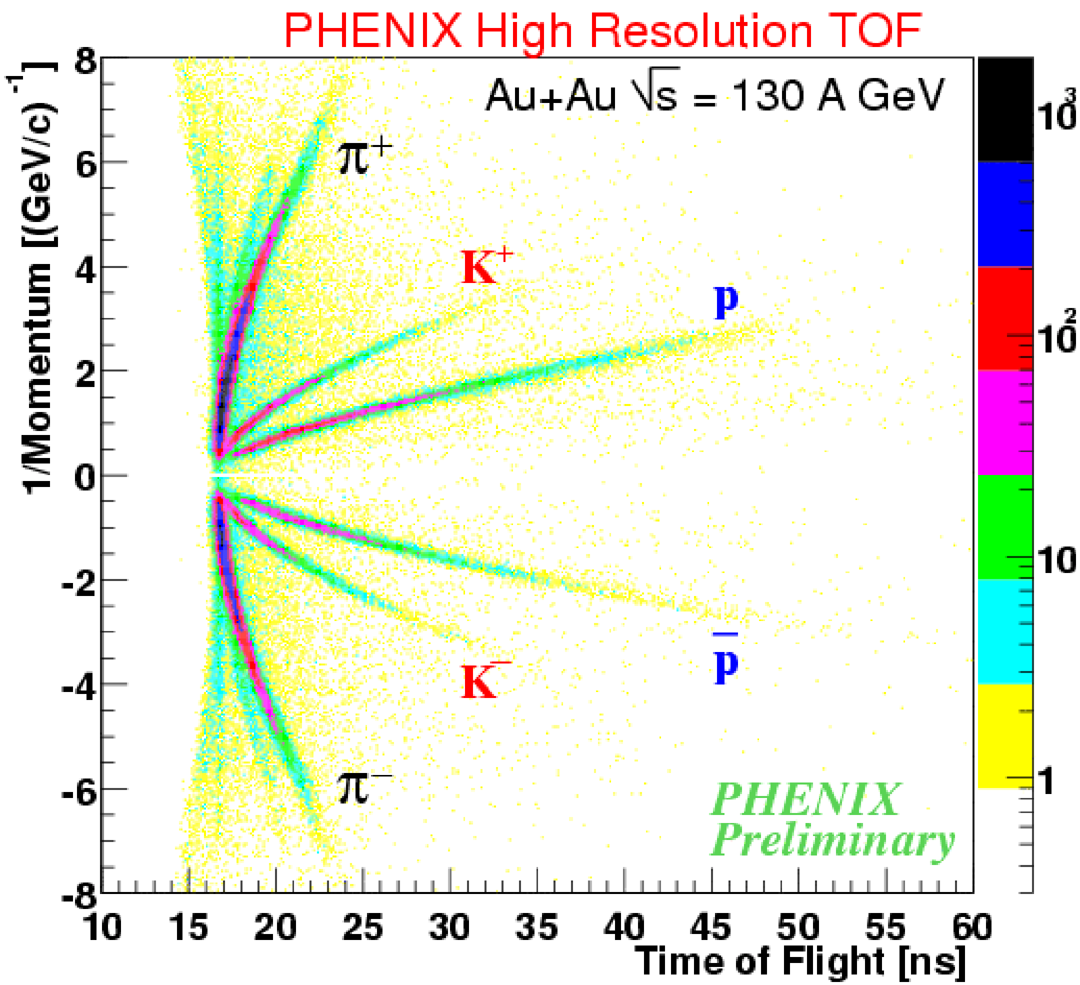


In this analysis, we use

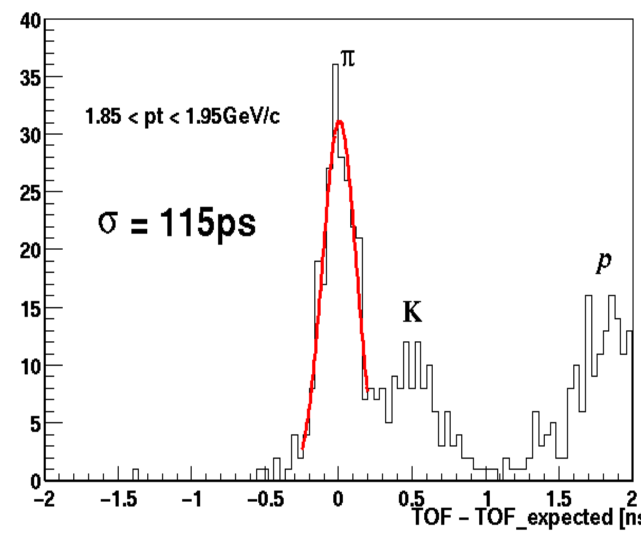
- **Beam-Beam Counter (BBC)**
  z vertex, start timing for TOF
- **Time-of-Flight (TOF)**
  stop timing measurement
- **Drift Chamber (DC)**
  momentum, flight path length
- **Pad Chamber 1 (PC1)**
  additional track z information to Dch

Reality of PHENIX

Particle Identification by TOF

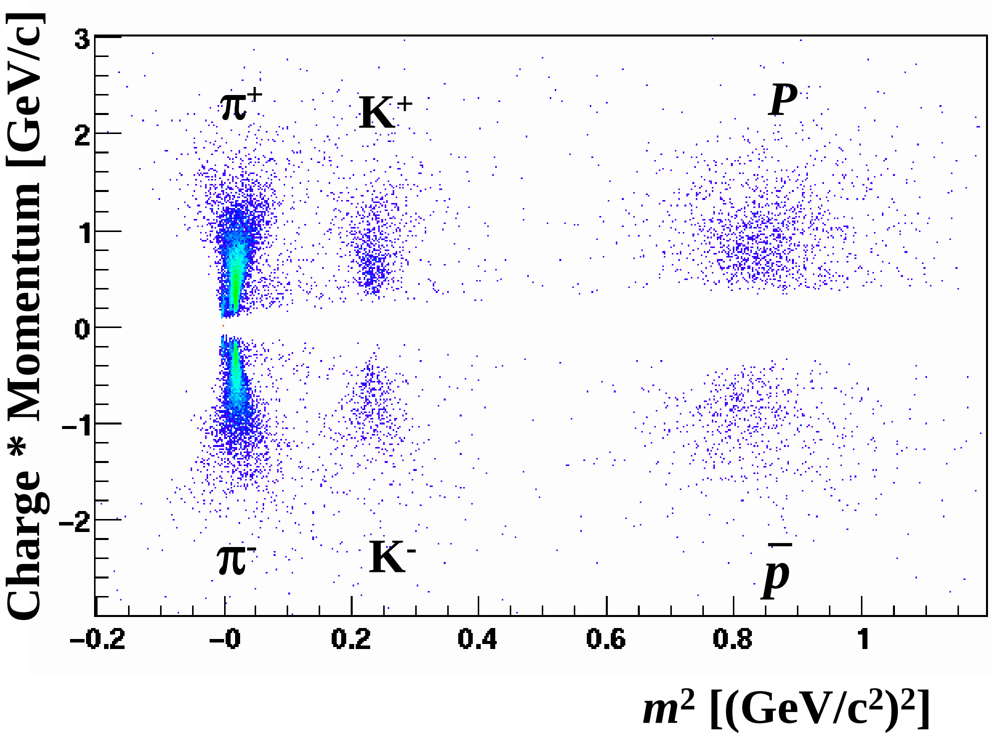


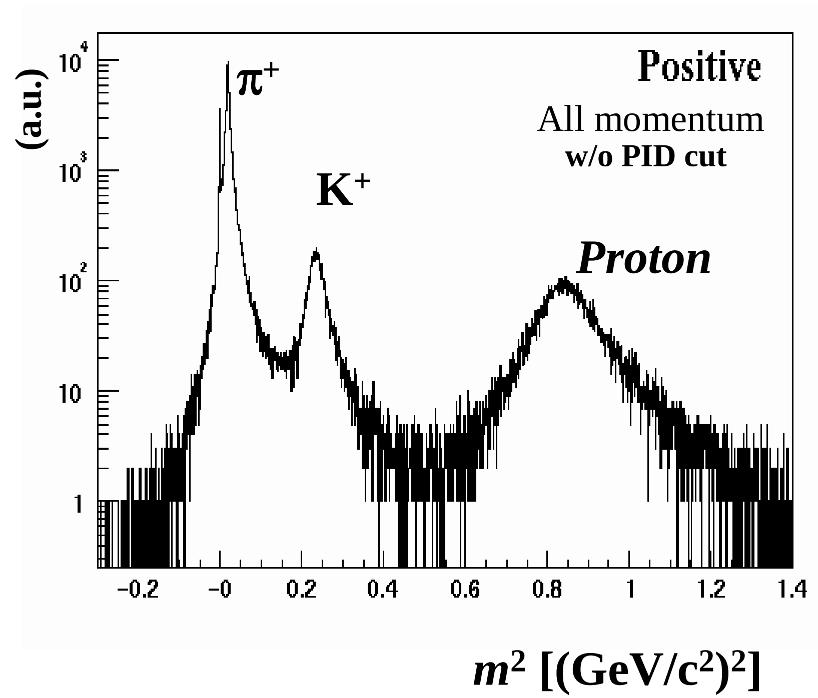
- **Demonstrated clear PID by TOF**
- **Time-of-Flight resolution**
  σ_{TOF} ~ 110-120 ps (@ 3/27/01)
- **Flight path length : ~ 5m**
  - **K/π separation : < 2 GeV/c**
  - **p/K separation : < 4 GeV/c**



TOF – TOF $_{expected}$ [ns]

PID Cut Criteria

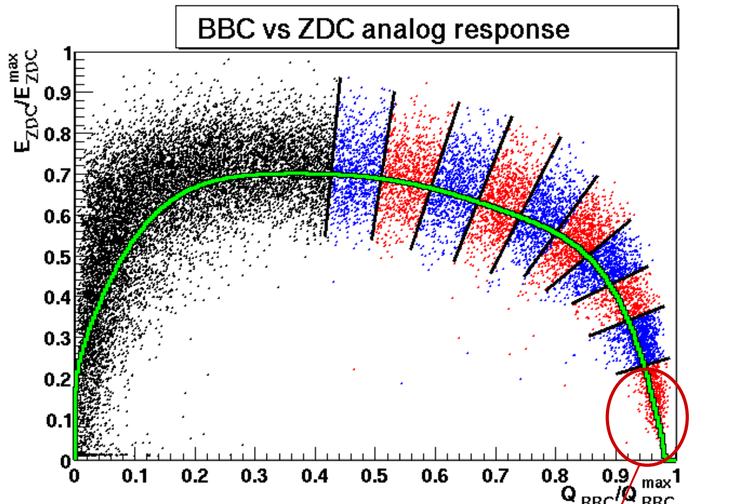




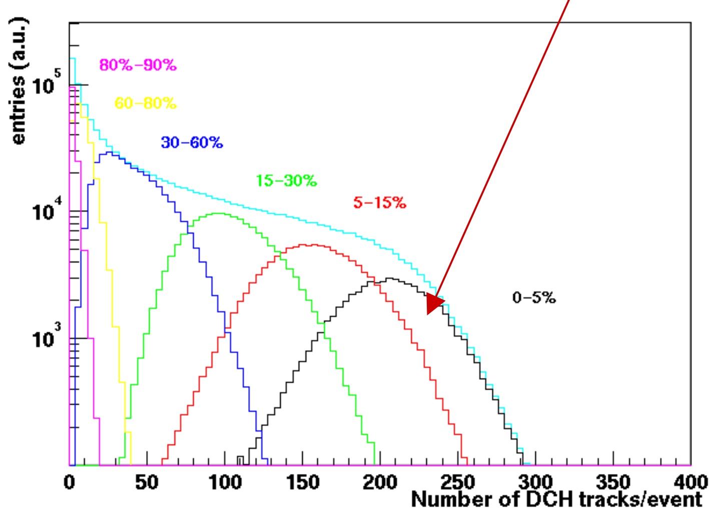
- PID by m^2 vs. momentum space
- $|m^2_{\mathrm{measured}} - m^2_0| < 2.5\,\sigma_m^{\;2}$
- Momentum cutoff

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

Centrality Classes



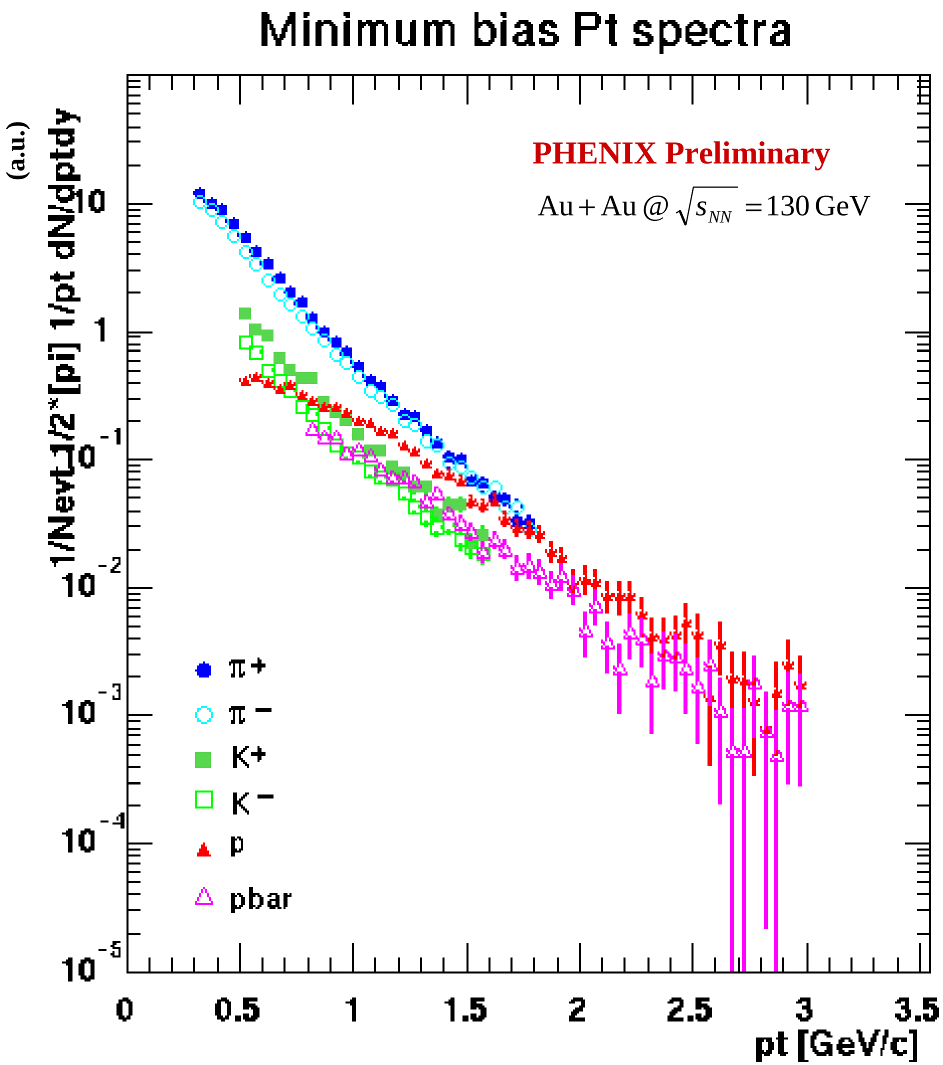
Dch raw multiplicity distributions



- **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%
60-80%	19 ± 60%
80-92%	5 ± 60%

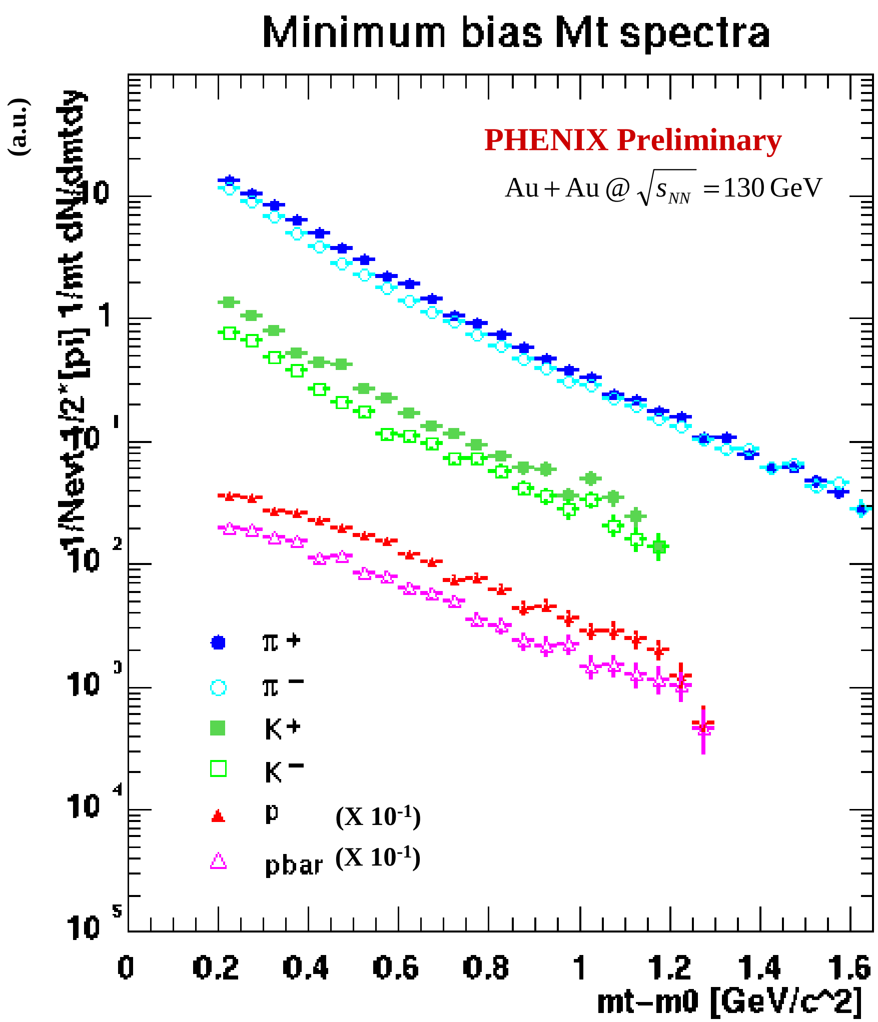
Results : Minimum bias p_T spectra



- pions yield ~ proton/pbar yield @ p_T~ 2 GeV/c.
- How m_T spectra look like? → next slide

particle	p_T range
p	0.3 - 1.8 GeV/c
K	0.5 - 1.6 GeV/c
proton	0.5 - 3.0 GeV/c
pbar	0.8 - 3.0 GeV/c

Minimum bias m_T spectra



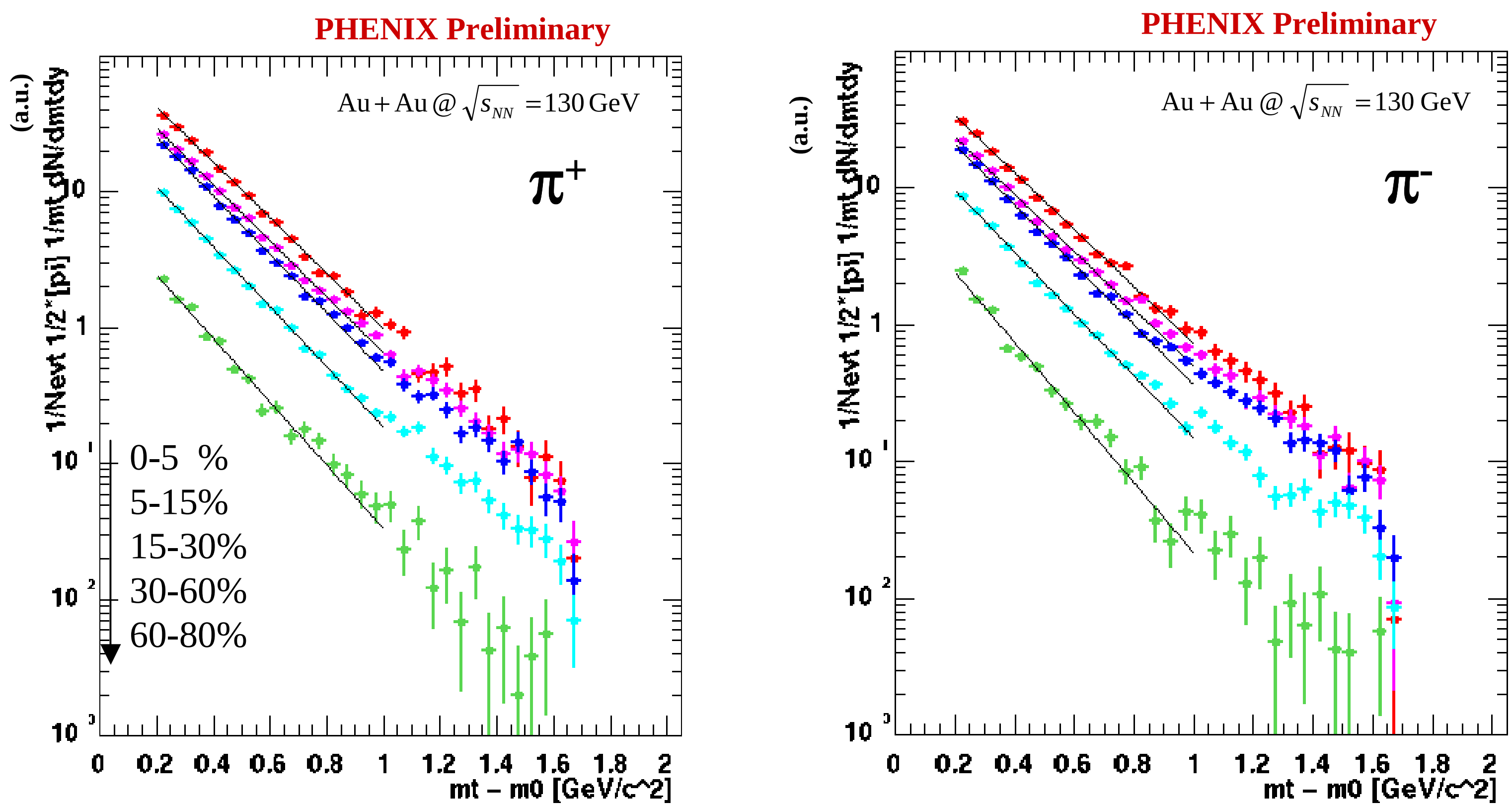
- In $0.2 < m_t - m_0 < 1.2$ [GeV/c^2], spectra for all species scaled by single exp. function.
- Similar inverse slope for π and K.
- $T_{proton} > T_{\pi}$

★ **Fitting results by single exp. function**

$$\frac{1}{m_T}\frac{dN}{dm_T} \propto A\exp\left(-\frac{m_T - m_0}{T}\right)$$

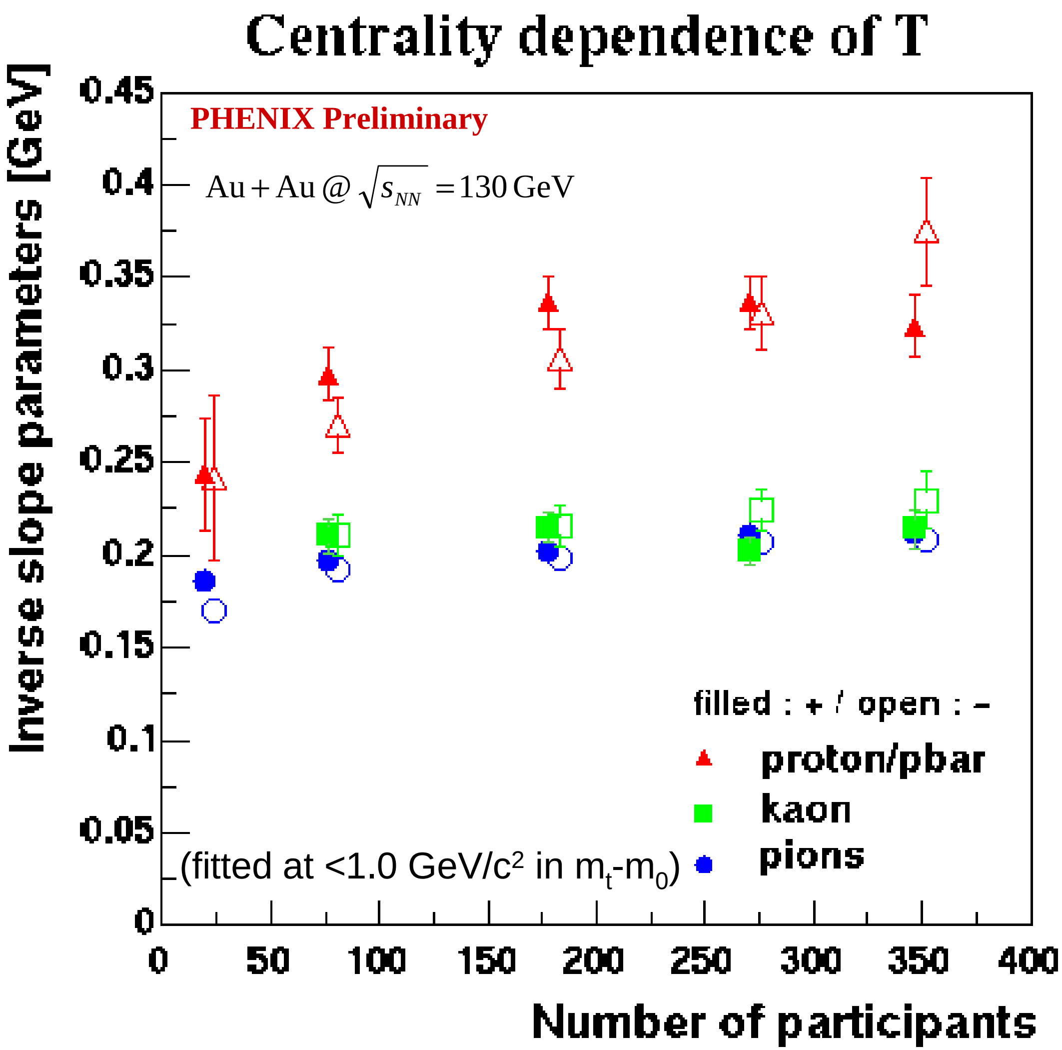
$\pi^{\pm}$	~ 205 ± 5 (stat.)	± 15 (sys.)	MeV
$K^{\pm}$	~ 215 ± 5 (stat.)	± 20 (sys.)	MeV
p, $\bar{p}$	~ 320 ± 10 (stat.)	± 20 (sys.)	MeV

Centrality Dependence of m_T Spectra for π



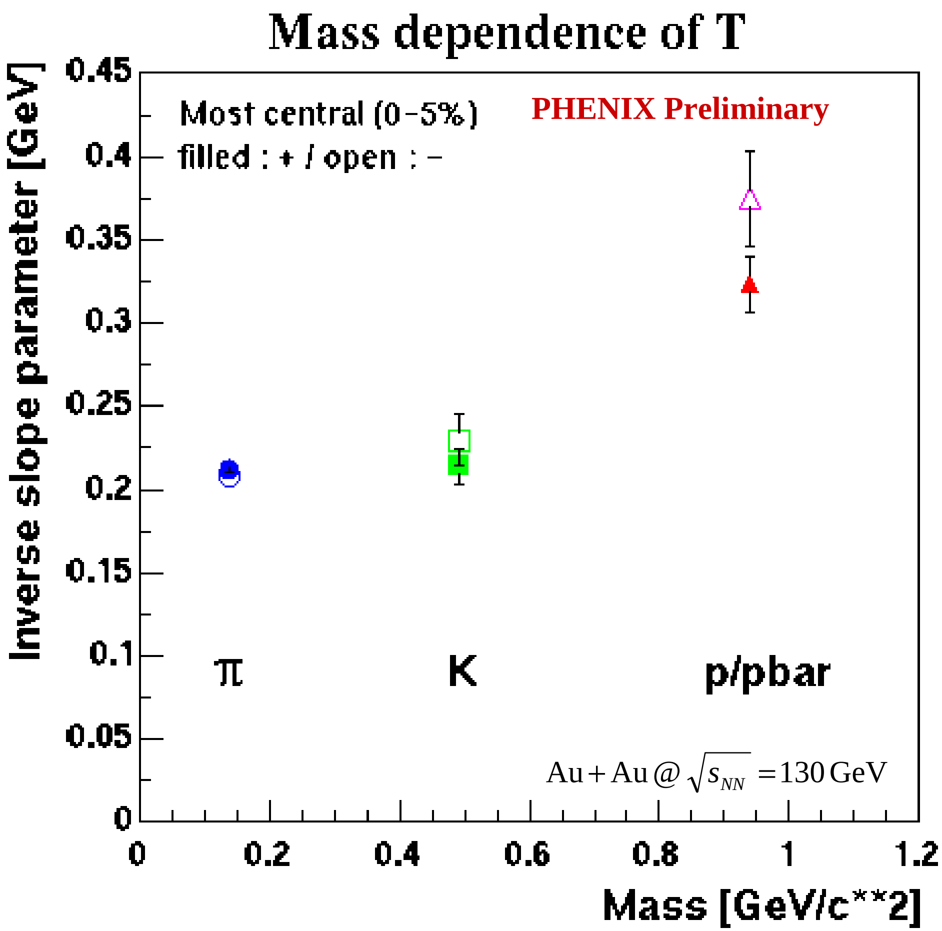
- **Single exponential scaling at 0.2 -1.0 GeV in m_t-m_0 (soft region).**
  (power low shape in most peripheral event ?)
- **T_π (central 0-5%) ~ 210 MeV ±5 (stat.) ±15 (sys.) MeV.**
- **Applied same parameterization for kaons and (anti-) protons.**

Centrality dependence of m_T *slope*



- Weak centrality dependence for T_π and T_K.
- Gradual rise of T_{proton} and T_{pbar} from peripheral to mid-central collisions.
- $T_\pi \cong T_K < T_{proton}$

Mass Dependence of *T*



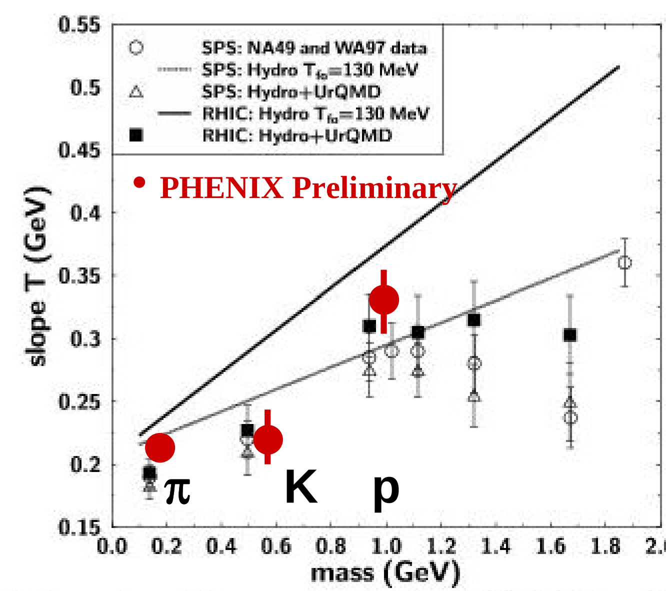
* NOTE: fitted at <1.0 GeV/c^2 in m_t-m_0

★ **Intuitive explanation of mass dependence of *T***

$$T \propto T_{\text{theremal}} + m \cdot < \beta_t >^2$$

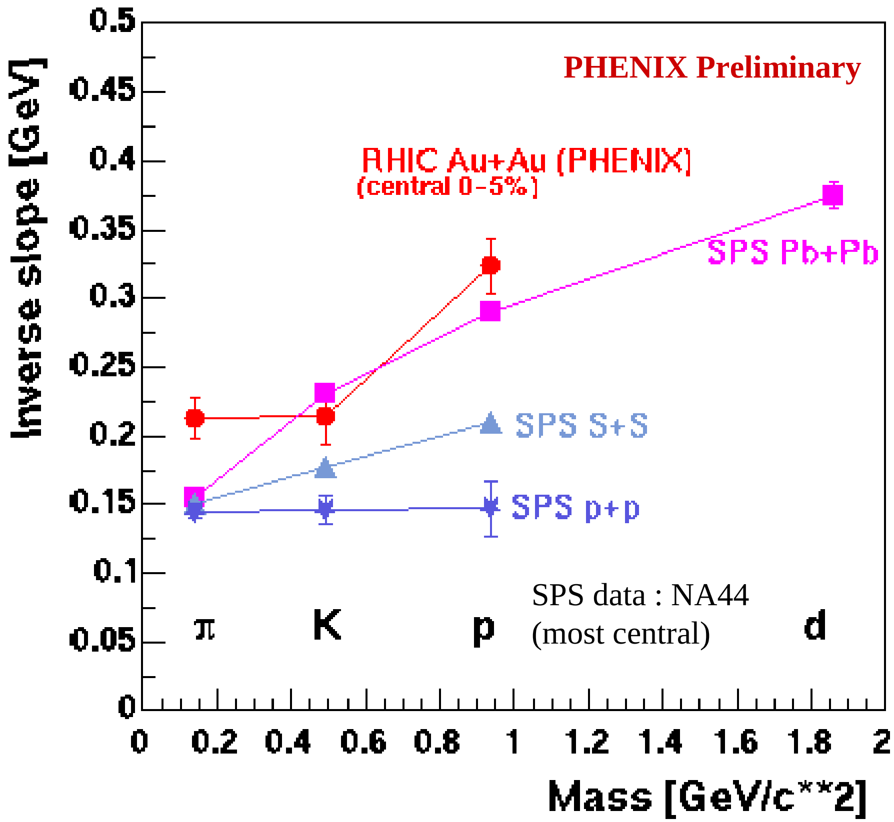
β_t : Transverse expansion velocity

nucl-th/0001033 S. A. Bass et al.



• **Good agreement with Hydro+UrQMD (cascade model).**

Comparison with CERN Energy

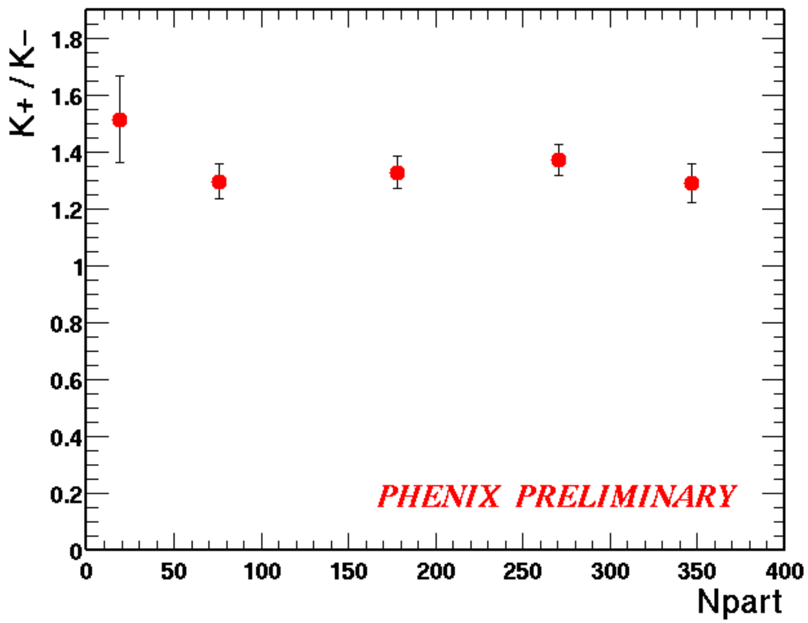


•NOTE: fitted at <1.0 GeV/c^2 in m_t-m_0

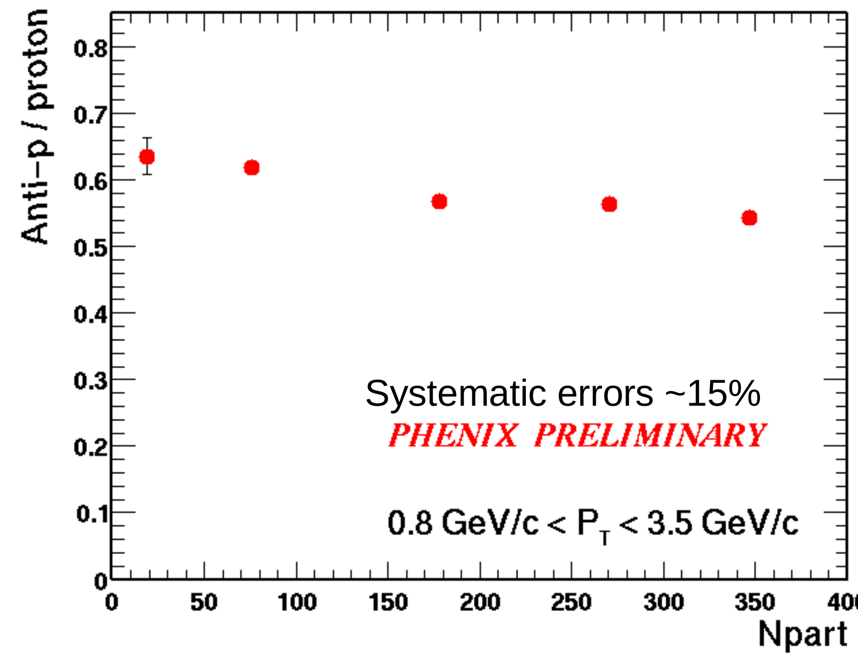
- **The slopes of pions and protons at RHIC are higher than that of Pb+Pb collisions at SPS.**
- **<u>Large transverse flow @ RHIC than SPS?</u>**

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

K^+/K^-



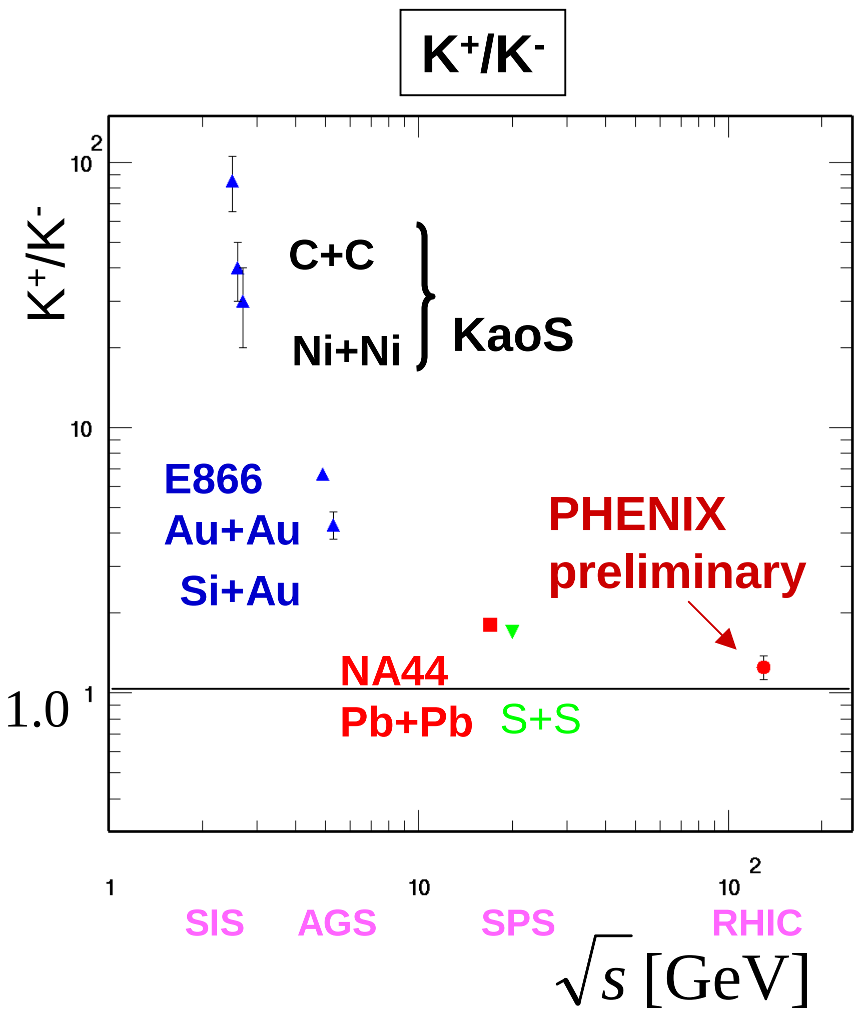
pbar/p

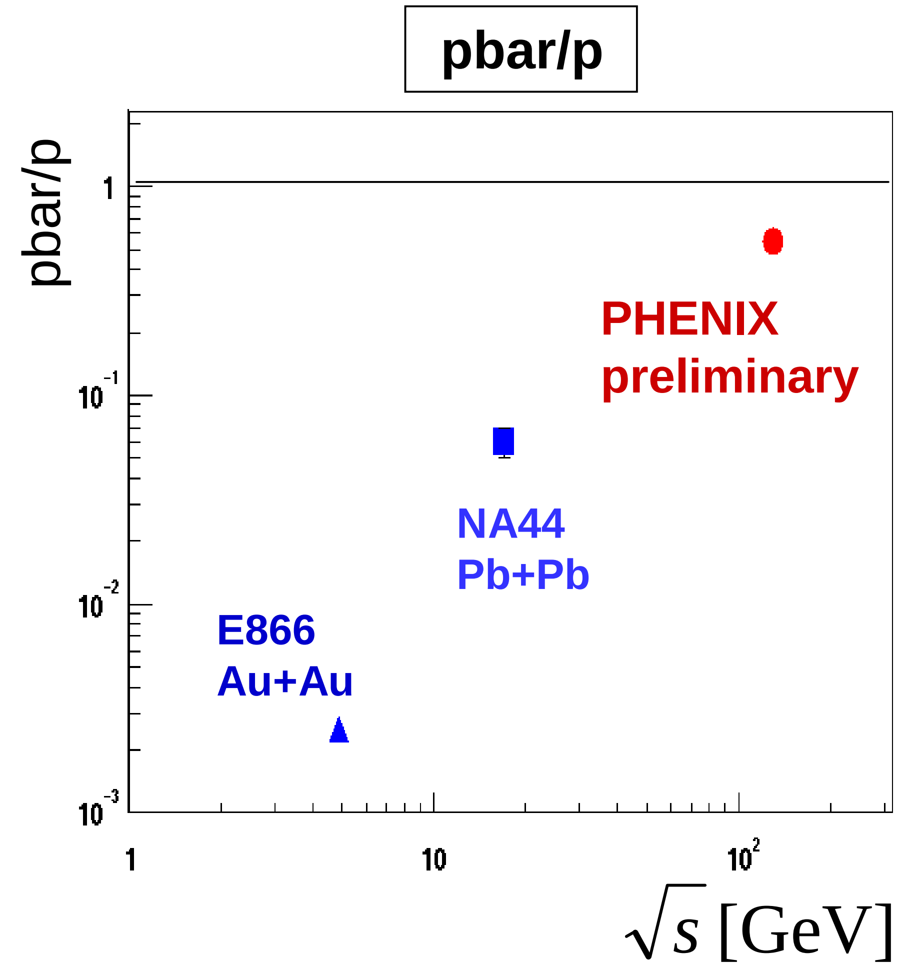


- **No clear dependence as a function of centrality (N_{part}) in both K^+/K^- and pbar/p ratios.**

- **K+/K- @5% central = 1.29±0.07(stat) ±0.19(sys.)**
- **pbar/p = 0.54±0.01(stat.)±0.08(sys.)**

Beam Energy Dependence of ratios

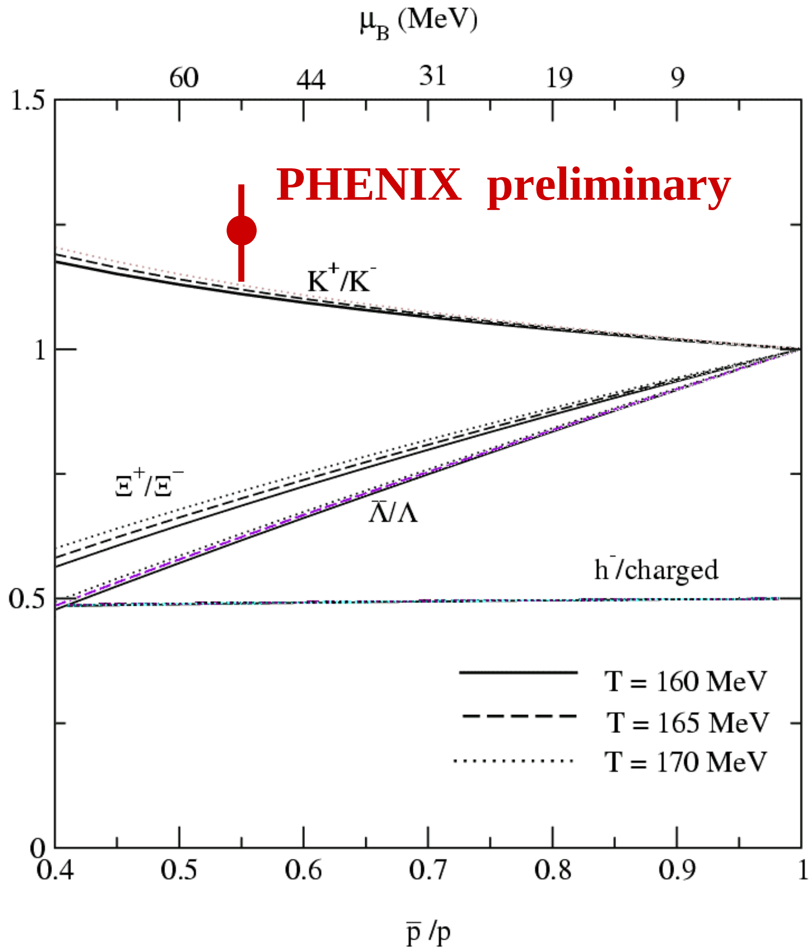


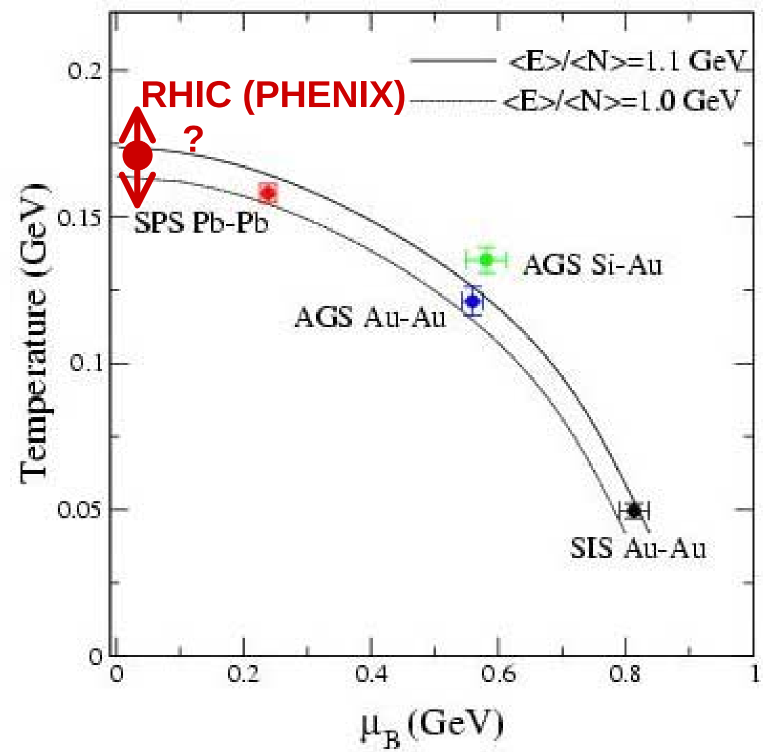


Both ratios are closing to 1.0 from AGS, SPS to RHIC energy.

RHIC data point in μ_B-T plane

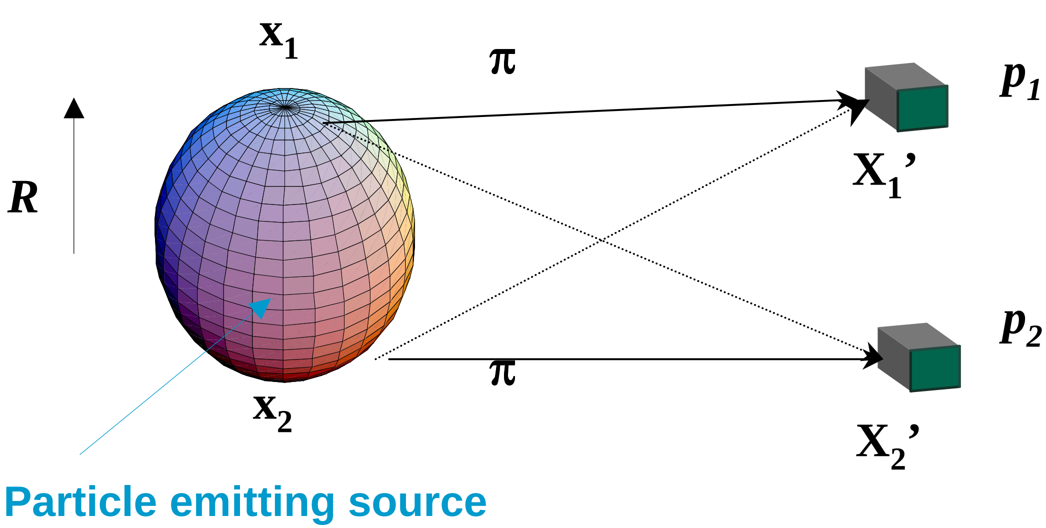
<u>Statistical thermal model</u> hep-ph/0002267 F.Becattini et al.



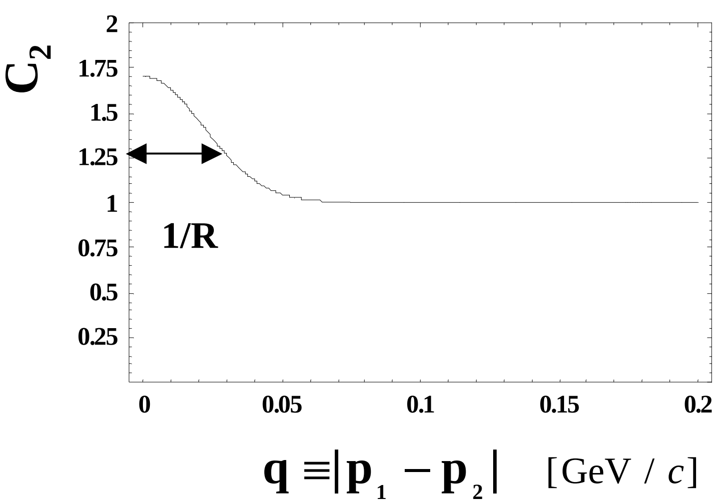


<u>Baryon chemical potential ~ 50MeV, not baryon free(μ_B=0).</u>

HBT correlations



Extraction of source size "R" using quantum interferometry



- **Correlation function C_2**

$$C_2 \equiv \frac{P(p_1, p_2)}{P(p_1)\cdot P(p_2)}$$

Fourier transform of $\rho_{\mathrm{eff}} \rightarrow \tilde{\rho}_{eff}(\mathbf{q})$

$$= 1 + \left|\tilde{\rho}_{eff}(\mathbf{q})\right|^2$$

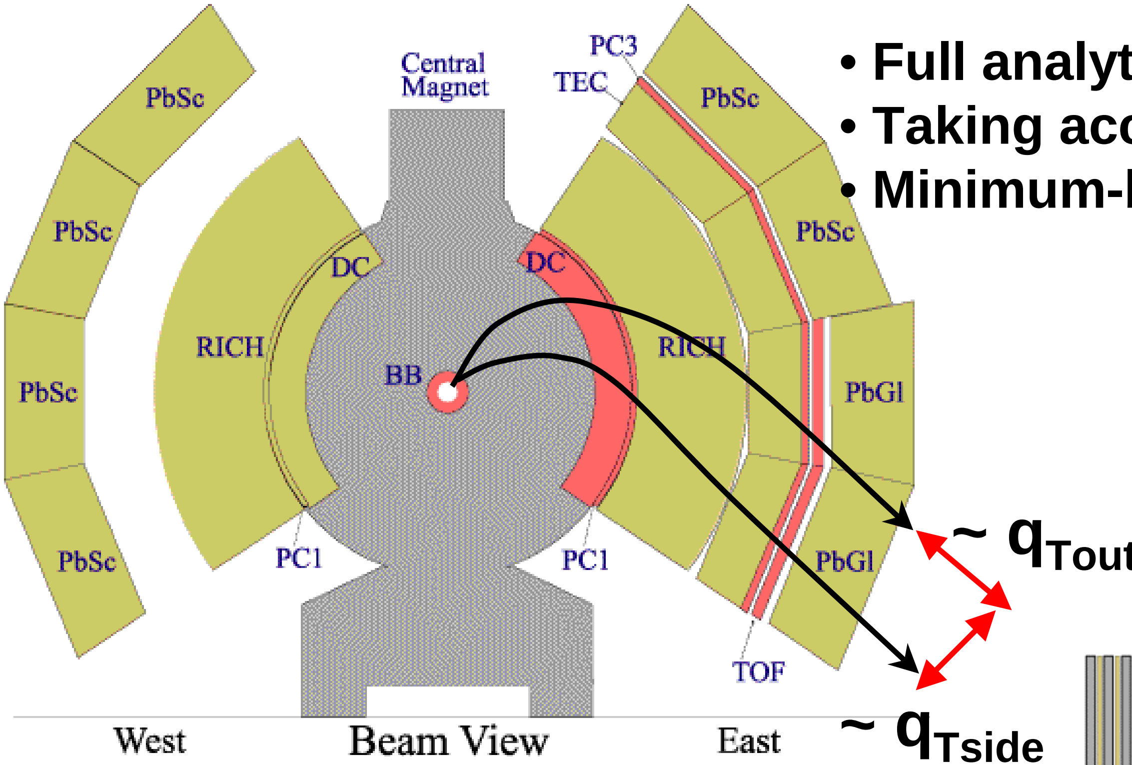
$$\mathbf{q} \equiv \mathbf{p_1} - \mathbf{p_2}$$

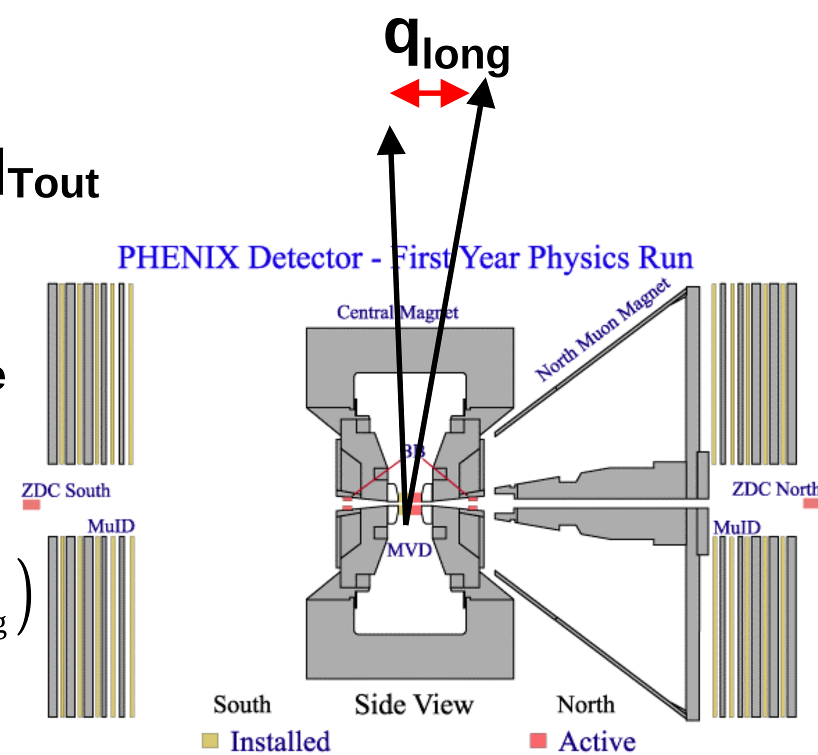
$$= 1 + \lambda \exp(-R^2 \mathbf{q}^2) \longleftarrow$$

Assume Gaussian r_{eff} with width "R"

3D HBT measurement in PHENIX

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

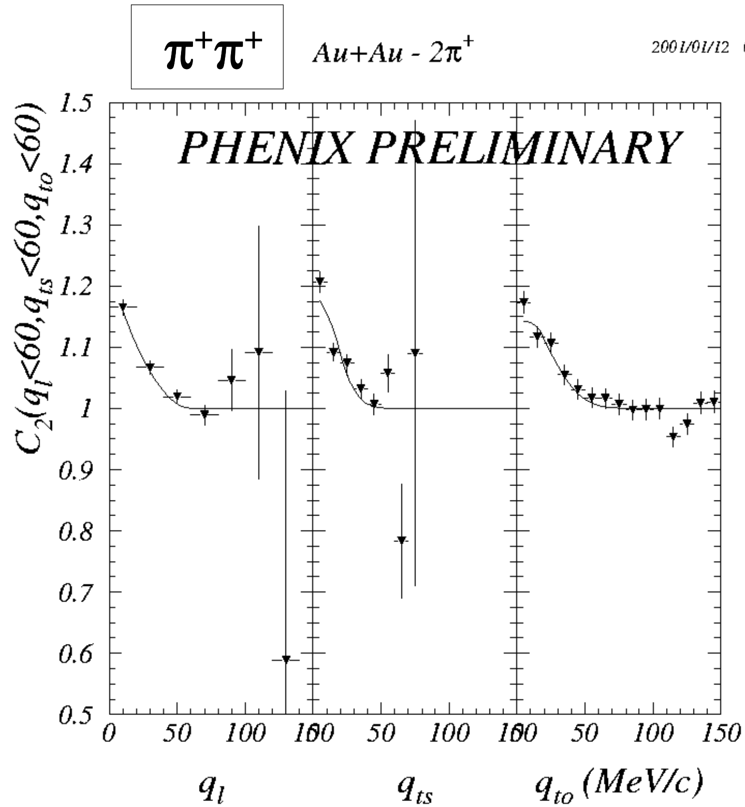


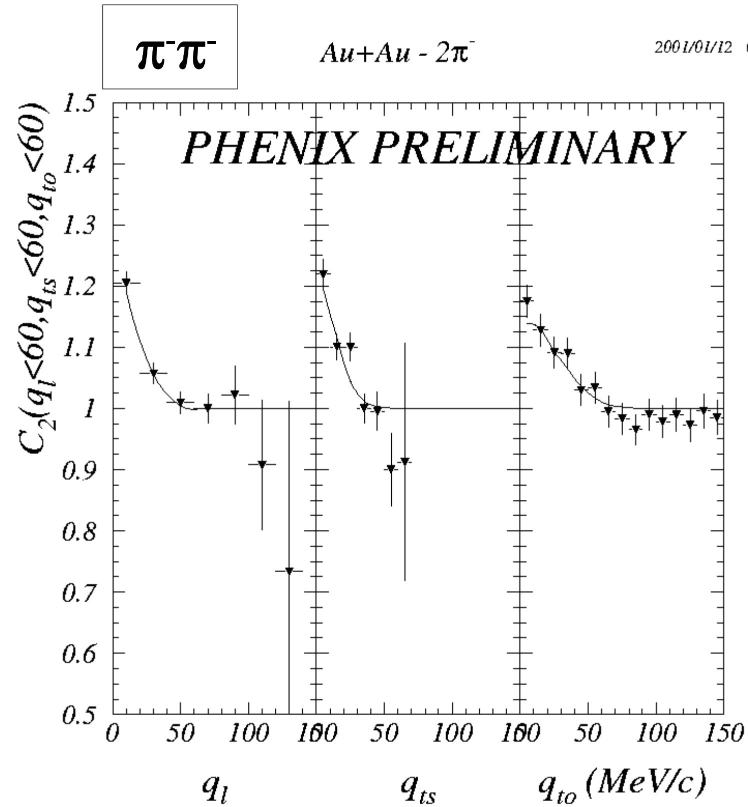


Bertsch-Pratt parameterization

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

Bertsch-Pratt Fit Results (TOF PID)

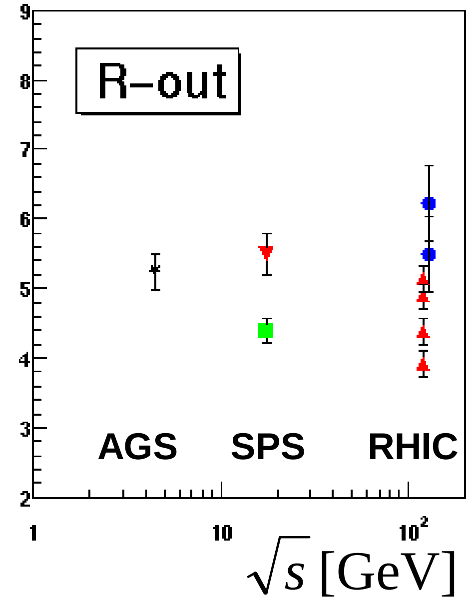


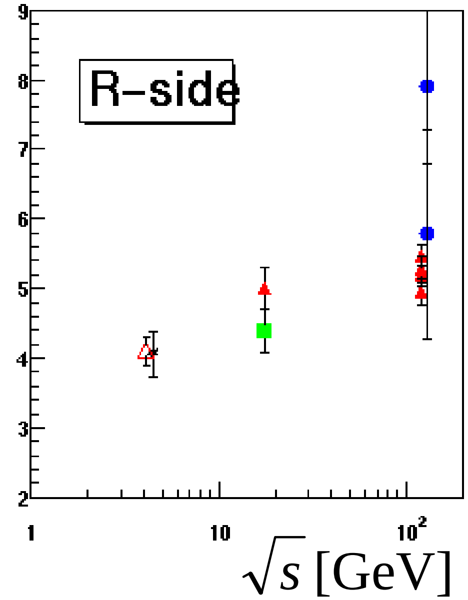


R_{long} = 4.0 ± 1.2
R_{Tside} = 7.9 ± 1.1
R_{Tout} = 6.23 ± 0.54
λ = 0.493 ± 0.050

R_{long} = 6.7 ± 0.9
R_{Tside} = 5.8 ± 1.5
R_{Tout} = 5.49 ± 0.54
λ = 0.493 ± 0.061

Beam energy dependence of R



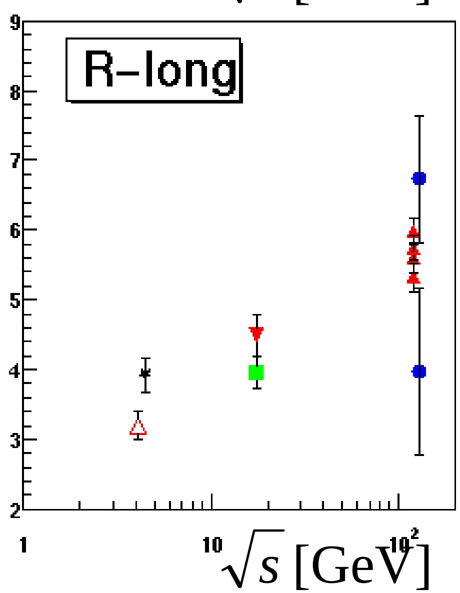


No indication of large volume

$\rightarrow$ No big jump from SPS to RHIC

Due to ….

- **High expansion velocities? (i.e. *x-p* correlation)**
- **Resonance contributions?**



▲ Star Preliminary
■ NA44
▼ NA49
★ E866
△ E895
● PHENIX Preliminary

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 for T_{π} and T_{K}.
- Gradual rise of T_{proton} and T_{pbar} from peripheral to mid-central collisions.
- $T_{\pi} \cong T_{K} < T_{proton}$ at all centrality classes.
- The slope of pions and protons at RHIC are higher than that of Pb+Pb collisions at SPS (indicative of large expansion velocity @ RHIC).
- Weak centrality dependence in both K^{+}/K^{-} (~1.29) and pbar/p (~0.54).
- Baryon chemical potential ~ 50MeV (thermal model), not baryon free(μ_B=0).
- No indication of large source size in 2π HBT measurement.

Start next data taking from May 2001!
$\Rightarrow \times$ ~1000 data will come soon, and more physics

See also

- **28aSG7 : Measurement of hadron spectra at RHIC-PHENIX experiment**
  M. Suzuki (Univ. of Tsukuba)

- **28aSG8 : Study of charged particle ratios at RHIC-PHENIX experiment**
  A. Kiyomichi (Univ. of Tsukuba)