Study of Identified Charged Hadron Spectra in Au+Au Collisions at s_{NN}=200 GeV measured by RHIC-PHENIX Experiment

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for the PHENIX Collaboration

JPS meeting at Rikkyo University
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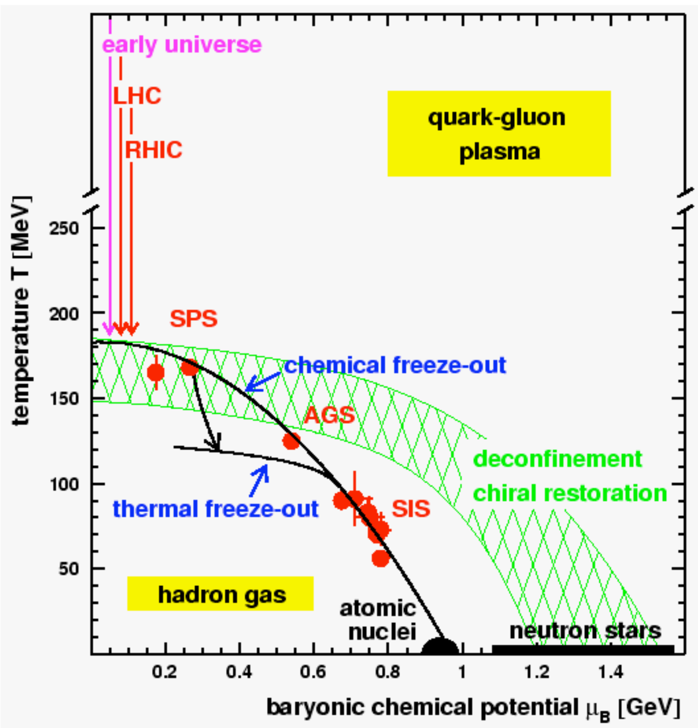
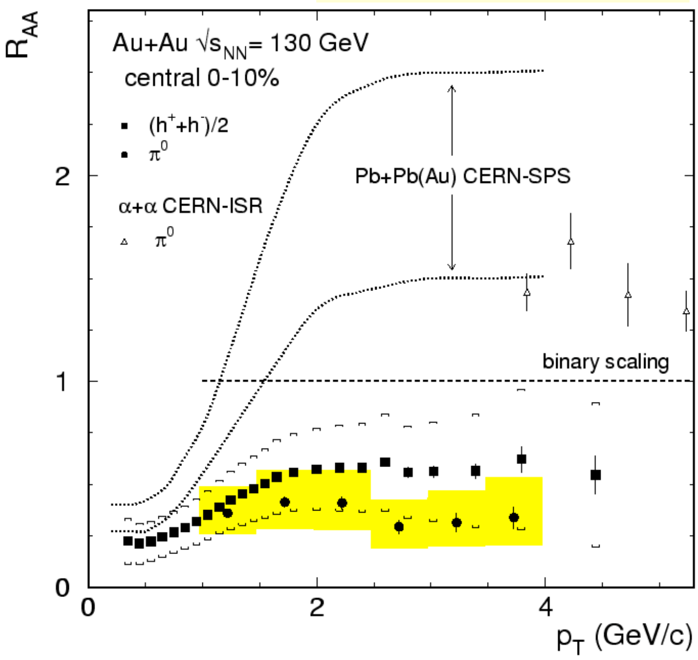
Motivation

What do we learn from hadron measurement

- **Soft process** (Characterize freeze-out)
  - p_T spectra
    - Hydrodynamic Collective Expansion
    - Thermal freeze-out temperature
    - Radial flow velocity
  - Particle ratio
    - Chemical freeze-out temperature
    - Chemical potential
      - **RHIC: T_{ch} ~ 174MeV, μ_B ~ 46MeV (s_{NN}=130 GeV)**
      - **SPS : T_{ch} ~ 170MeV, μ_B ~ 270MeV**
      - **AGS : T_{ch} ~ 130MeV, μ_B ~ 500MeV**
- **Hard process** (Contain earliest stage of collision)
  - Suppression of hadron yield at high p_T
    - Parton energy loss in hot and dense matter.
    - Baryon number transport



PHENIX published
[PRL88, 022301(2002)]

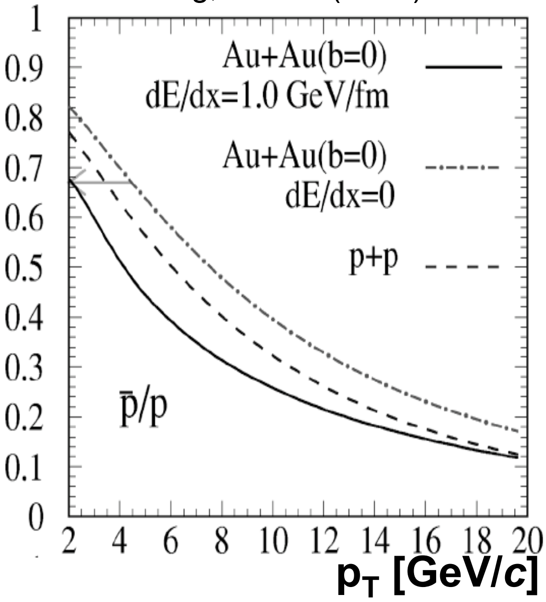


Motivation (Hard process)

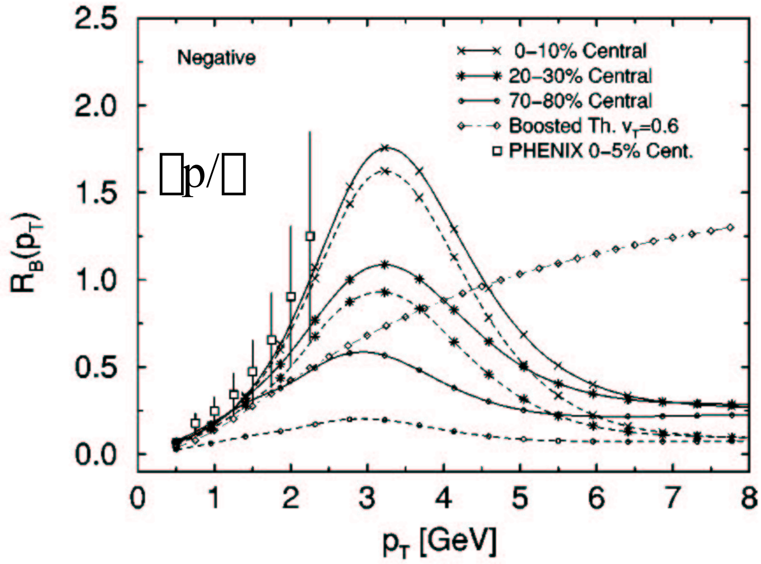
Theory prediction

- Jets will loose its energy in the dense matter.
  - (u,d) quark jets likely produce a leading proton than antiproton.
    - Ratio decreases with pt.
  - Gluon jets produce the same number of proton and antiproton with softer distribution.
    - At high p_T, most of antiproton from gluons, while proton from both valence quark and gluon fragmentation.
    - If gluon jets lose more energy, then ratio behavior modified.
- Baryon number will be transported via gluon junction
  - Baryon/meson ratio will give an information on baryon number transport.
  - π^+, π^-, π^0 strong suppression? $\bar{p}$, p enhance?

X.N.Wang, PRC58(1998)2321



I. Vitev and M. Gyulassy, PRC65(2002)041902



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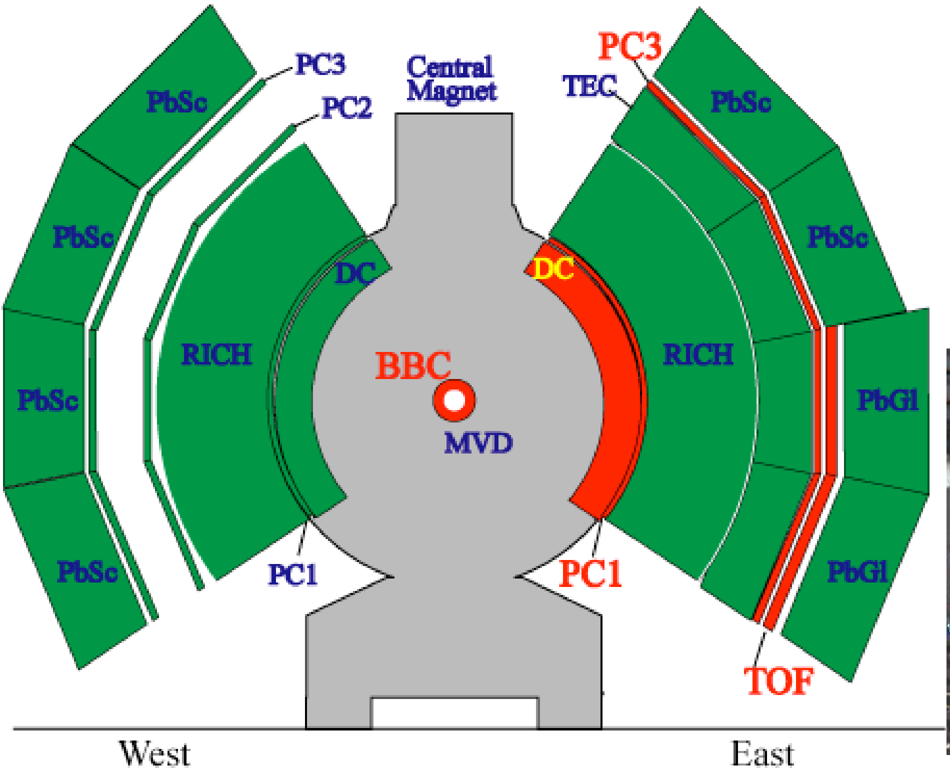
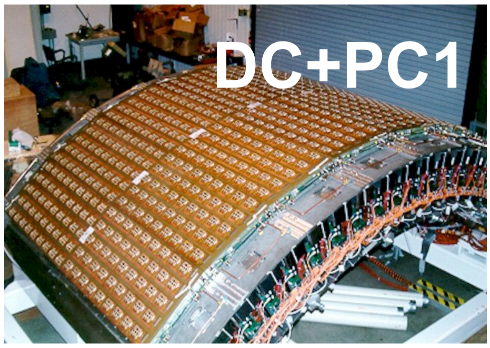
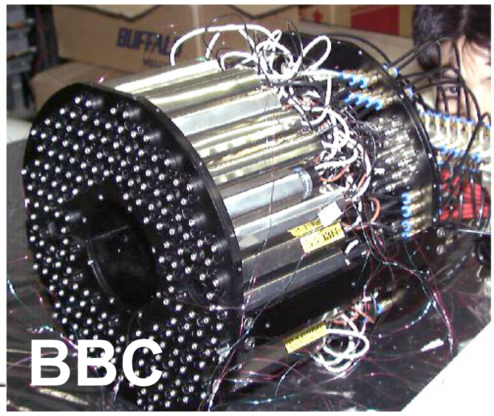
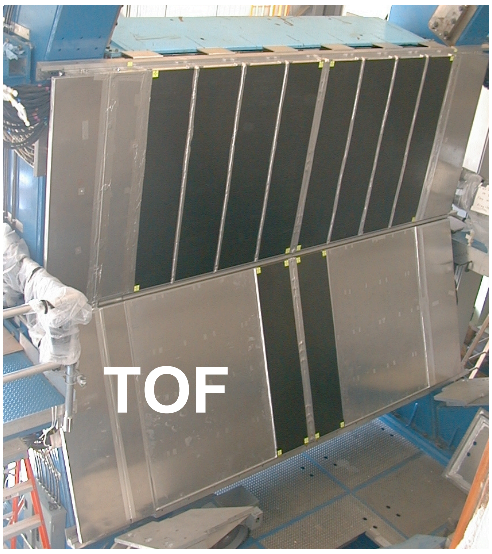
PHENIX Detectors









- **Au + Au at s_{NN}=200 GeV**
- **p + p at s_{NN}=200 GeV**
- Acceptance:
  - **□□ = 45 deg, □□ = 0.7 (±0.35)**
- Detectors used in this analysis
  - Tracking Systems
    - **Drift Chamber (DC)**
    - **Pad Chamber 1 (PC1)**
  - PID Device
    - **Beam-Beam Counter (BBC)**
    - **Time-of-Flight (TOF)**
    - **T0 counter (TZR) for pp run.**

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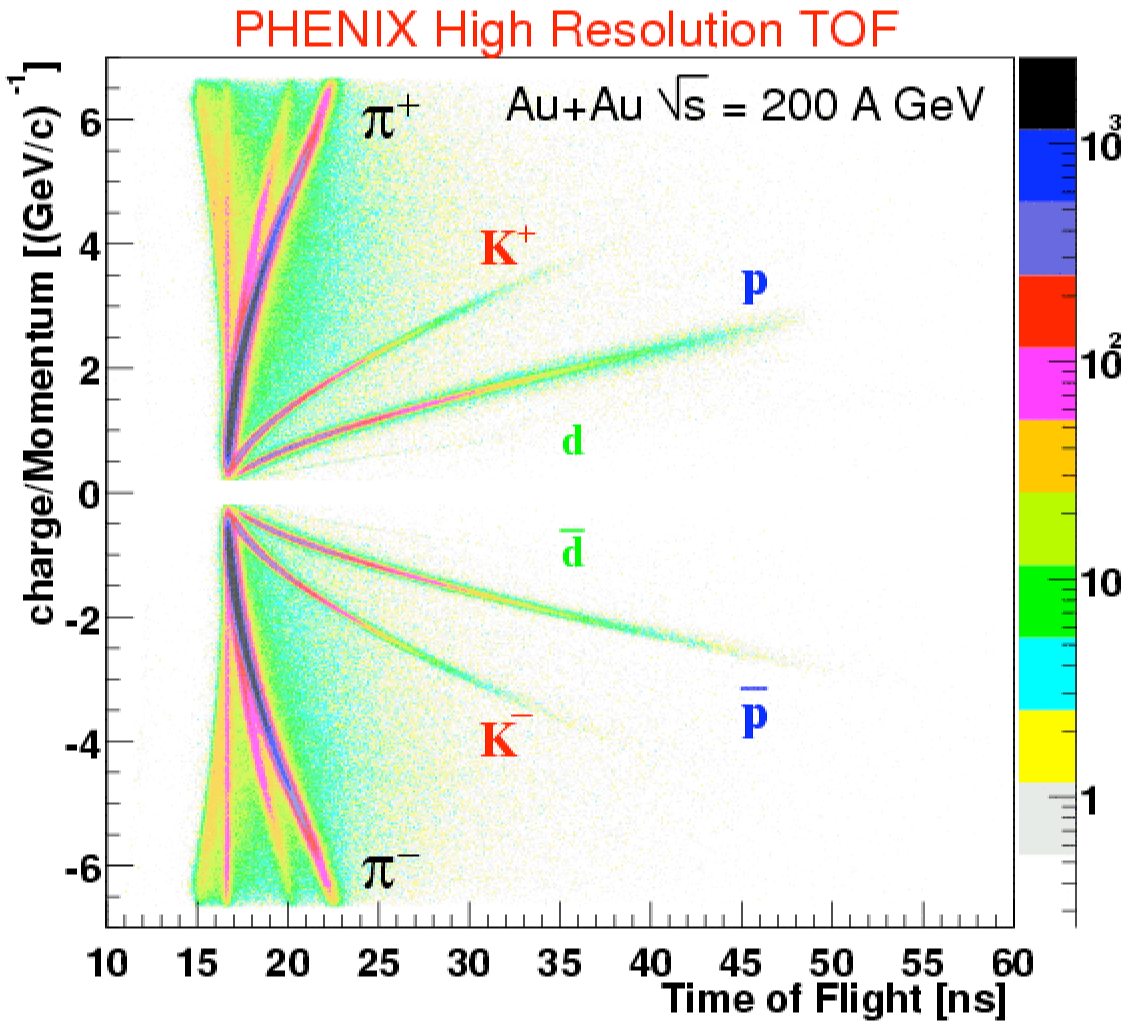
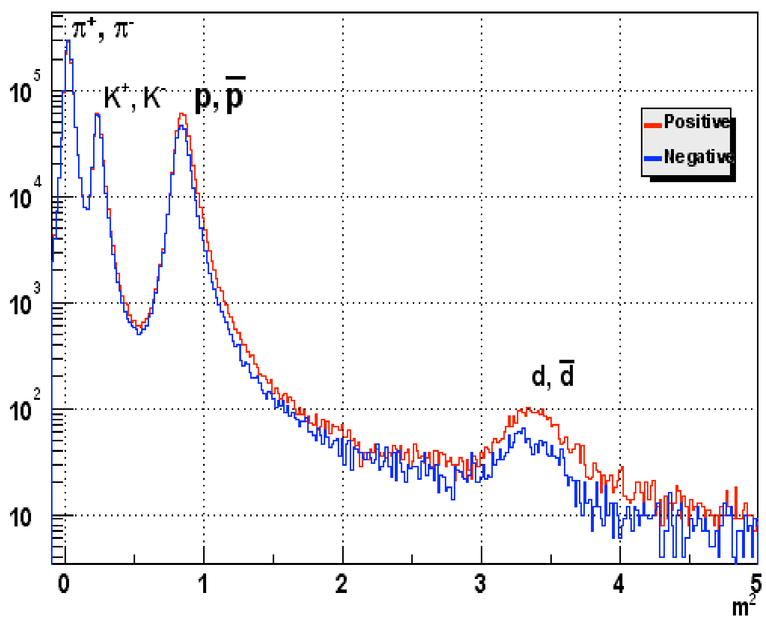
Particle Identification by TOF





- We can see clear □,K,p separation.
- Particle separation
  - □/K < 2.0GeV/c
  - proton < 4.0GeV/c
- Observed d,□d.

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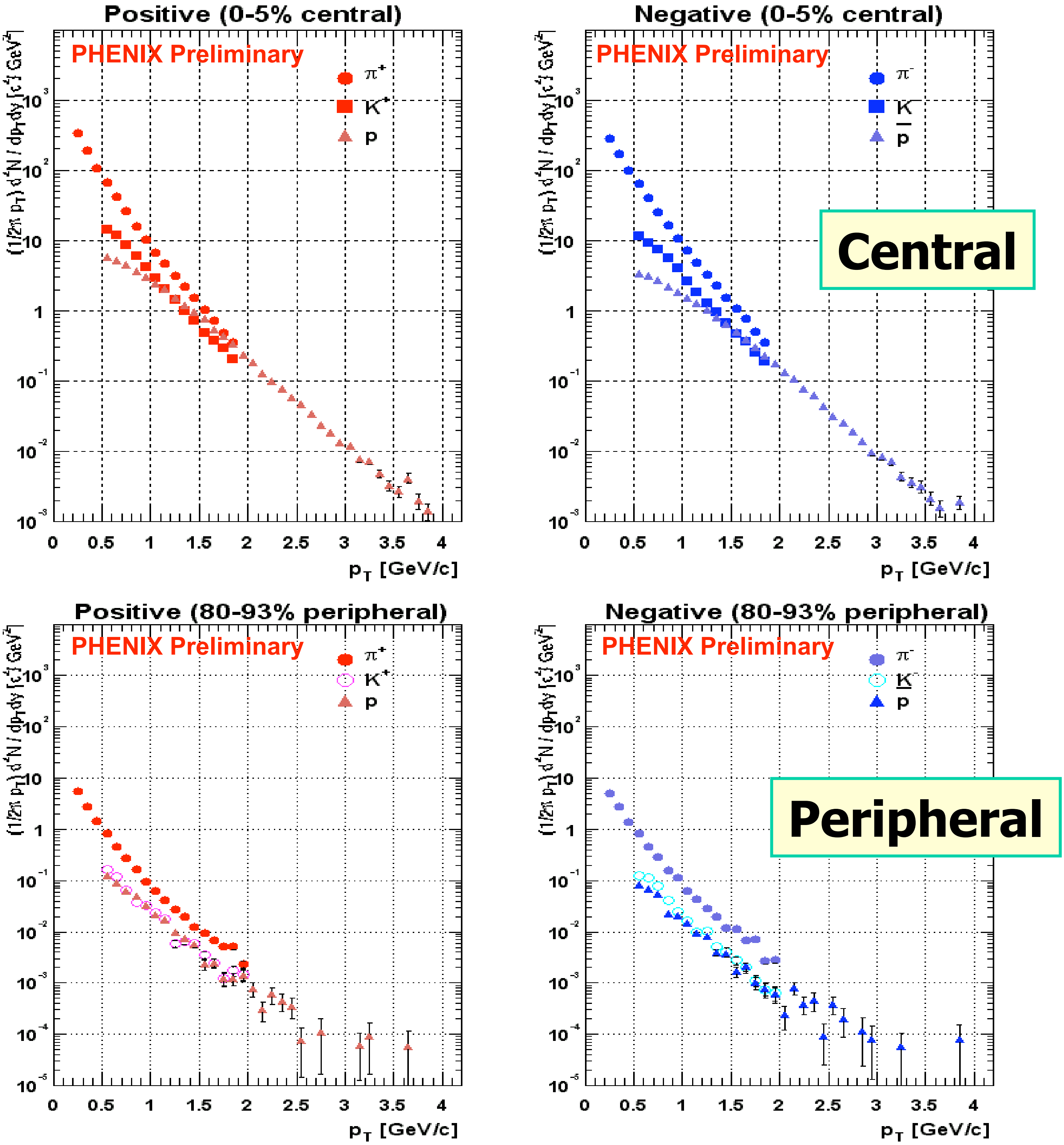
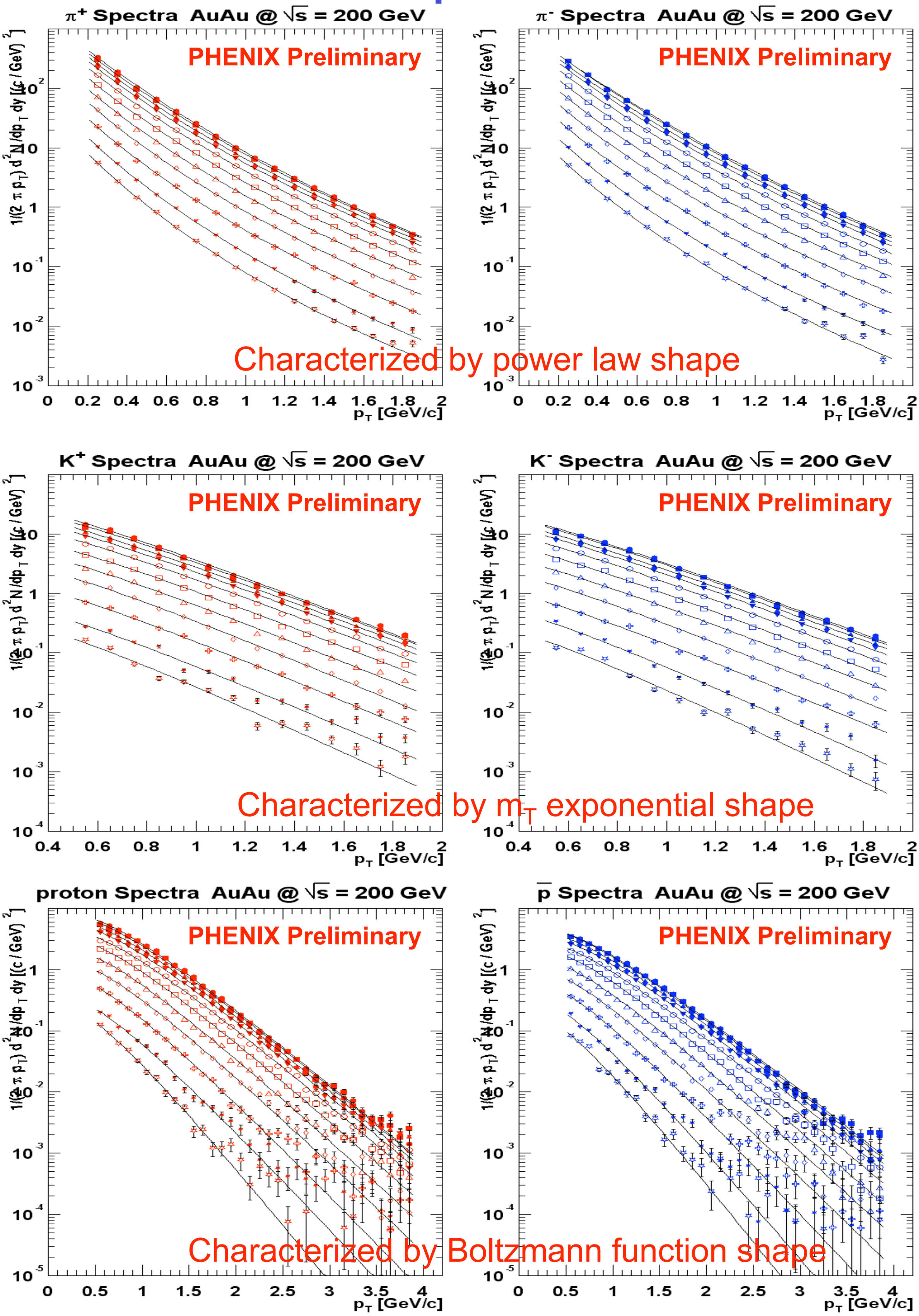
Single Particle Spectra



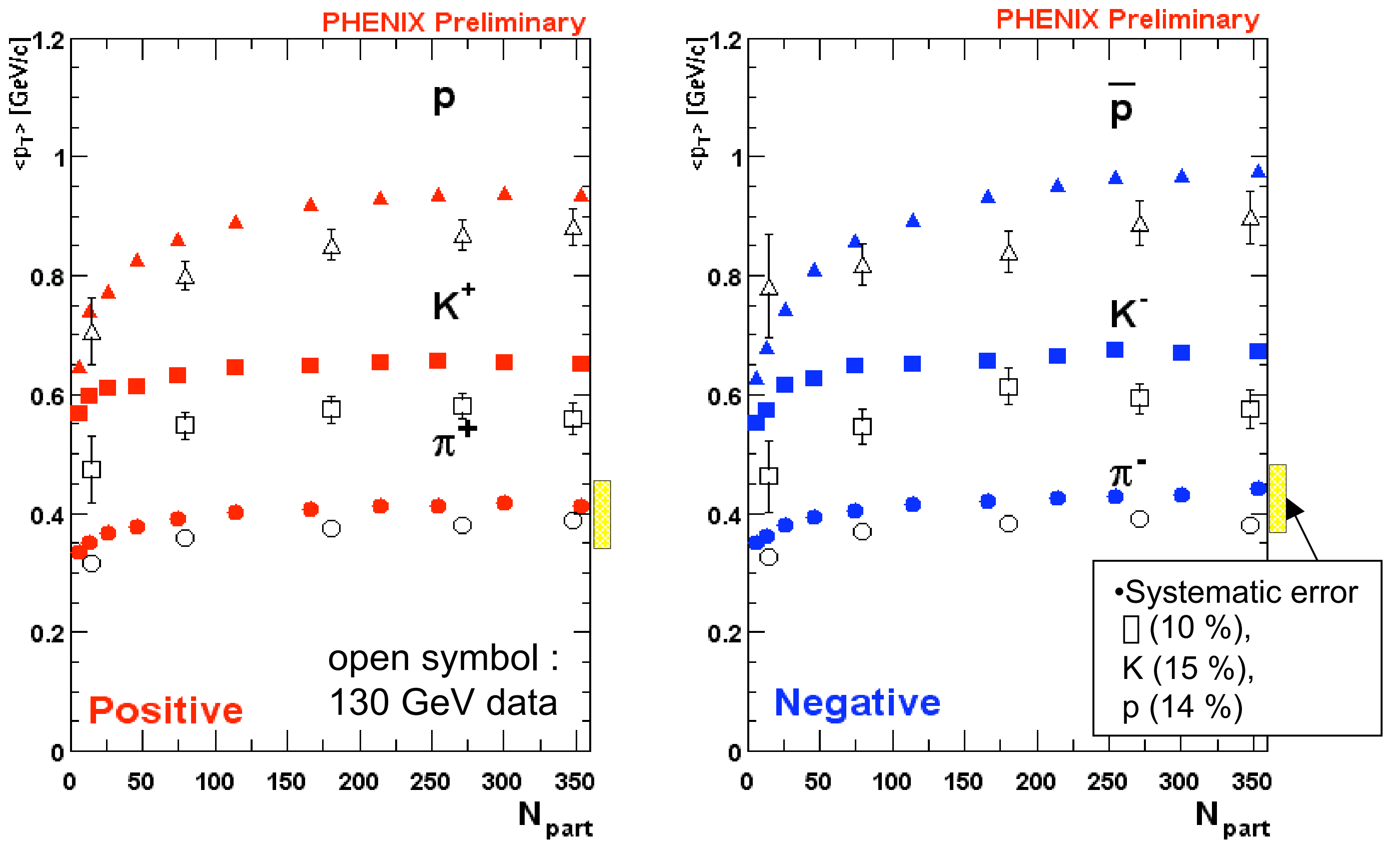
- proton yield ~ pion yield at 2GeV for central.

Spectra



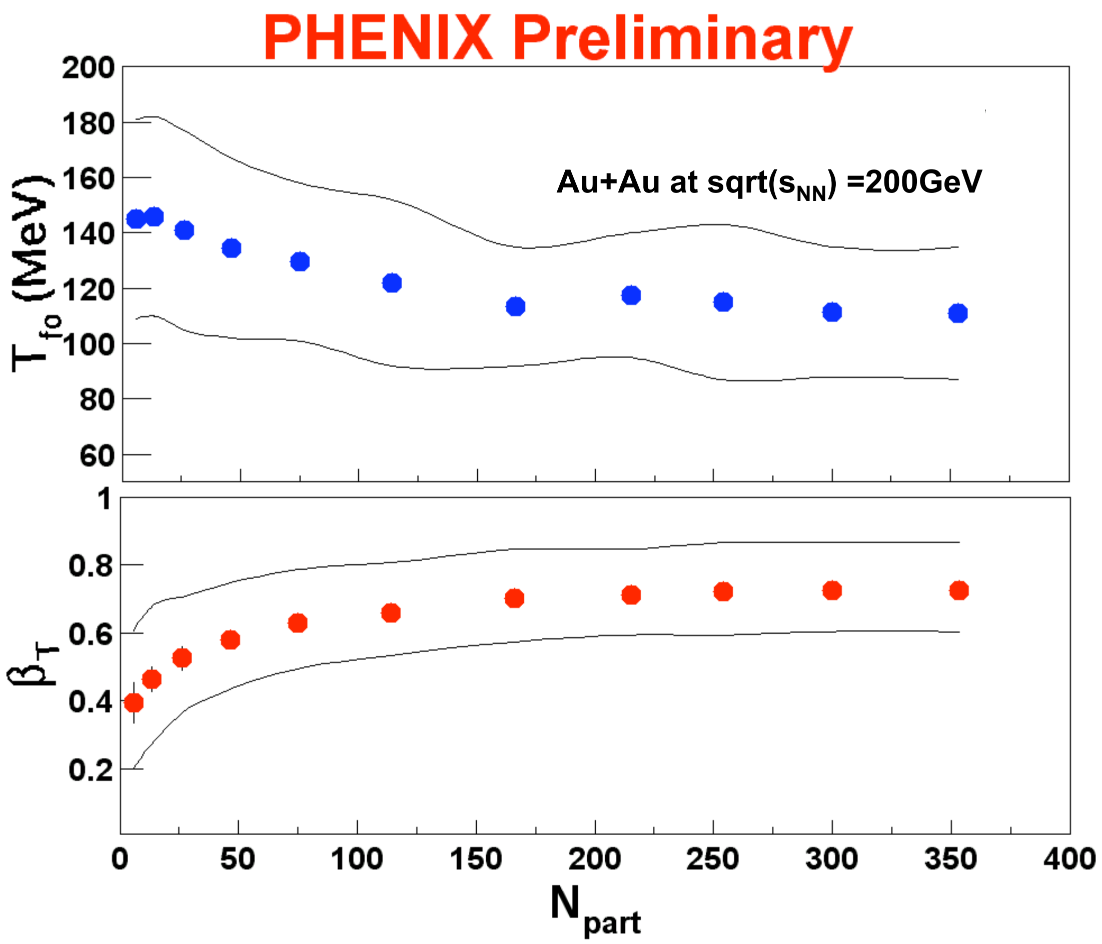
0 – 5 %
5 – 10 %
10 – 15 %
15 – 20 %
20 – 30 %
30 – 40 %
40 – 50 %
50 – 60 %
60 – 70 %
70 – 80 %
80 – 93 %

Centrality dependence of $<p_T>$



- $<p_T>$ increases with N_{part} and mass
  - Consistence with radial expansion picture.
- Relative increase from peripheral to central greater for proton than for pion, kaon.

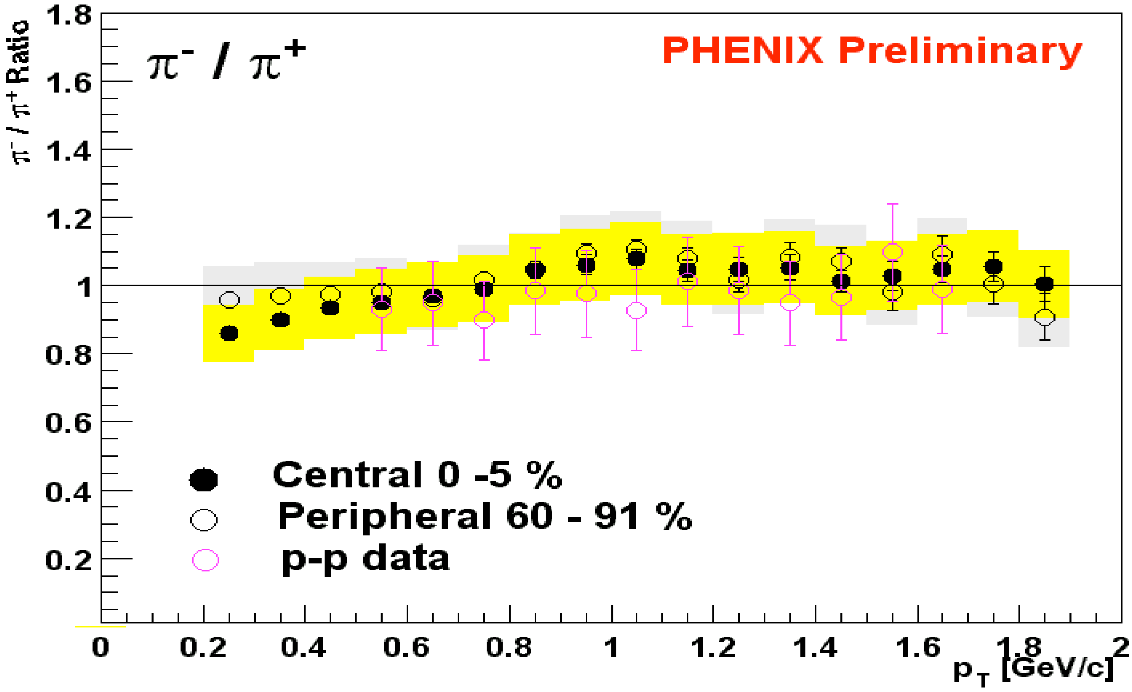
Hydrodynamic Model Fit

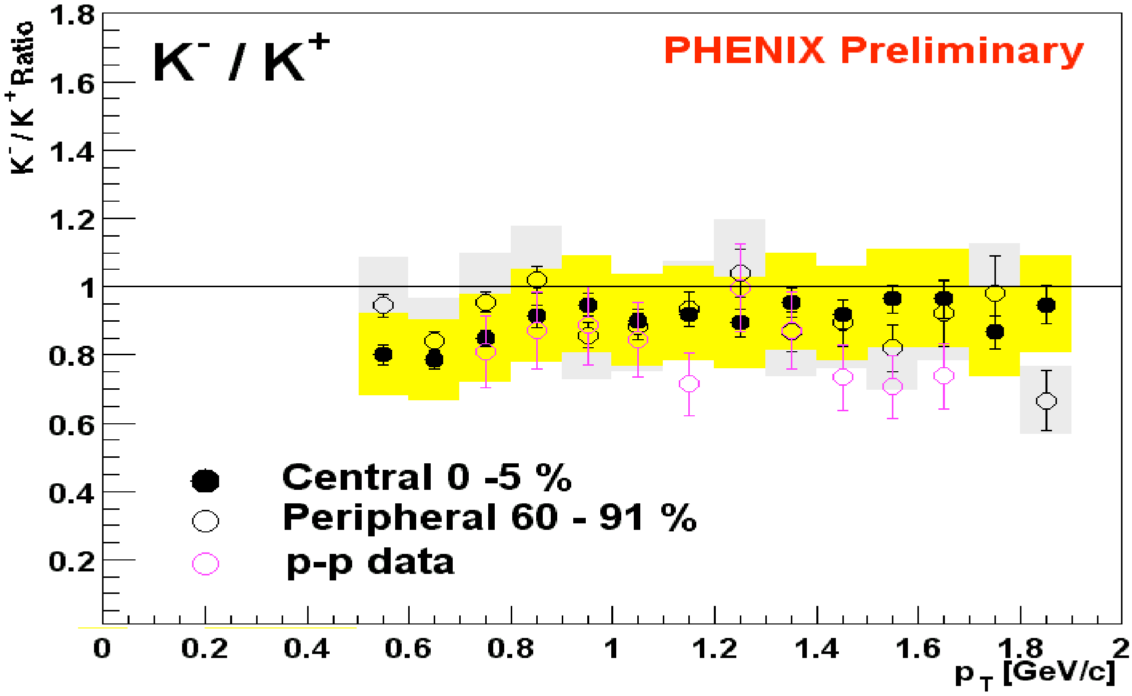


- Simultaneous fit in range (mT - m0)<1GeV
- β_T increases from peripheral to mid-central (N_{part} < 150) and tends to saturate for central collisions.

Most central collision
- **Freeze-out Temperature** T_{fo} = 110 ± 23 MeV
- **Transverse flow velocity** β_T = 0.7 ± 0.2

Particle Ratio (π^-/π^+, K^-/K^+)





- No clear centrality and p_T dependence.

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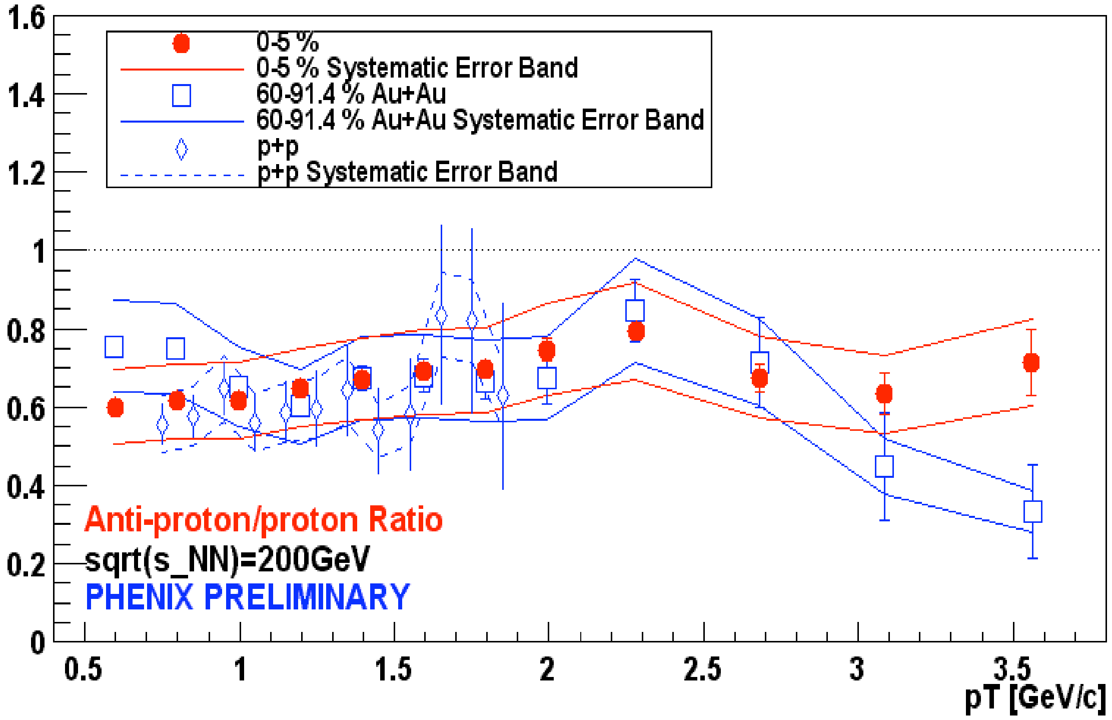
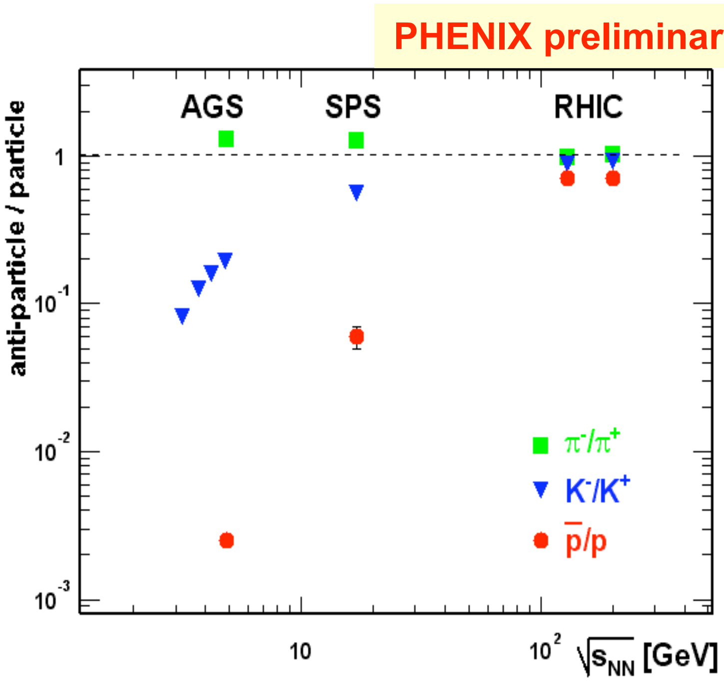
Particle Ratio ($\bar{p}/p$)

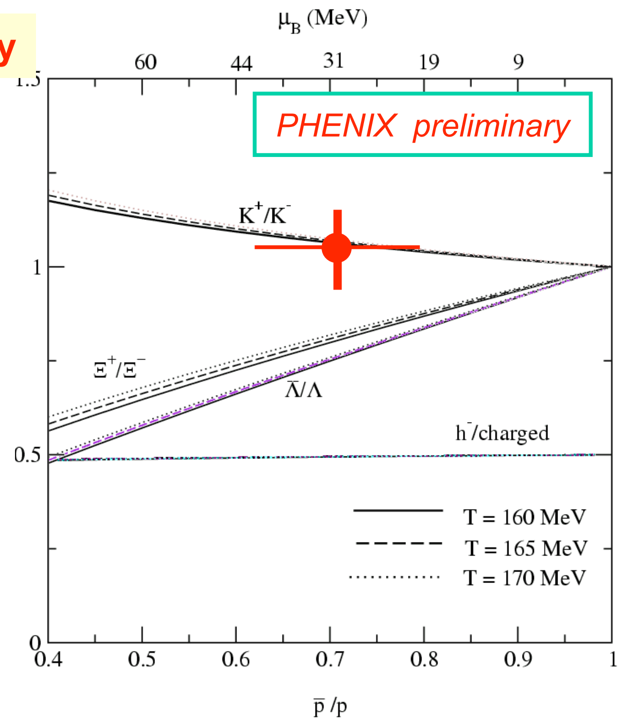


- No clear p_T dependence for central.
- Decreasing for peripheral at p_T>3GeV/c ?

Particle ratio for 0-5% central collision
- π^-/π^+ = 1.02 ± 0.02 (stat) ± 0.1 (sys)
- K^-/K^+= 0.92 ± 0.03 (stat) ± 0.1(sys)
- $\bar{p}/p$ = 0.70 ± 0.04 (stat) ± 0.1(sys)

Beam energy dependence

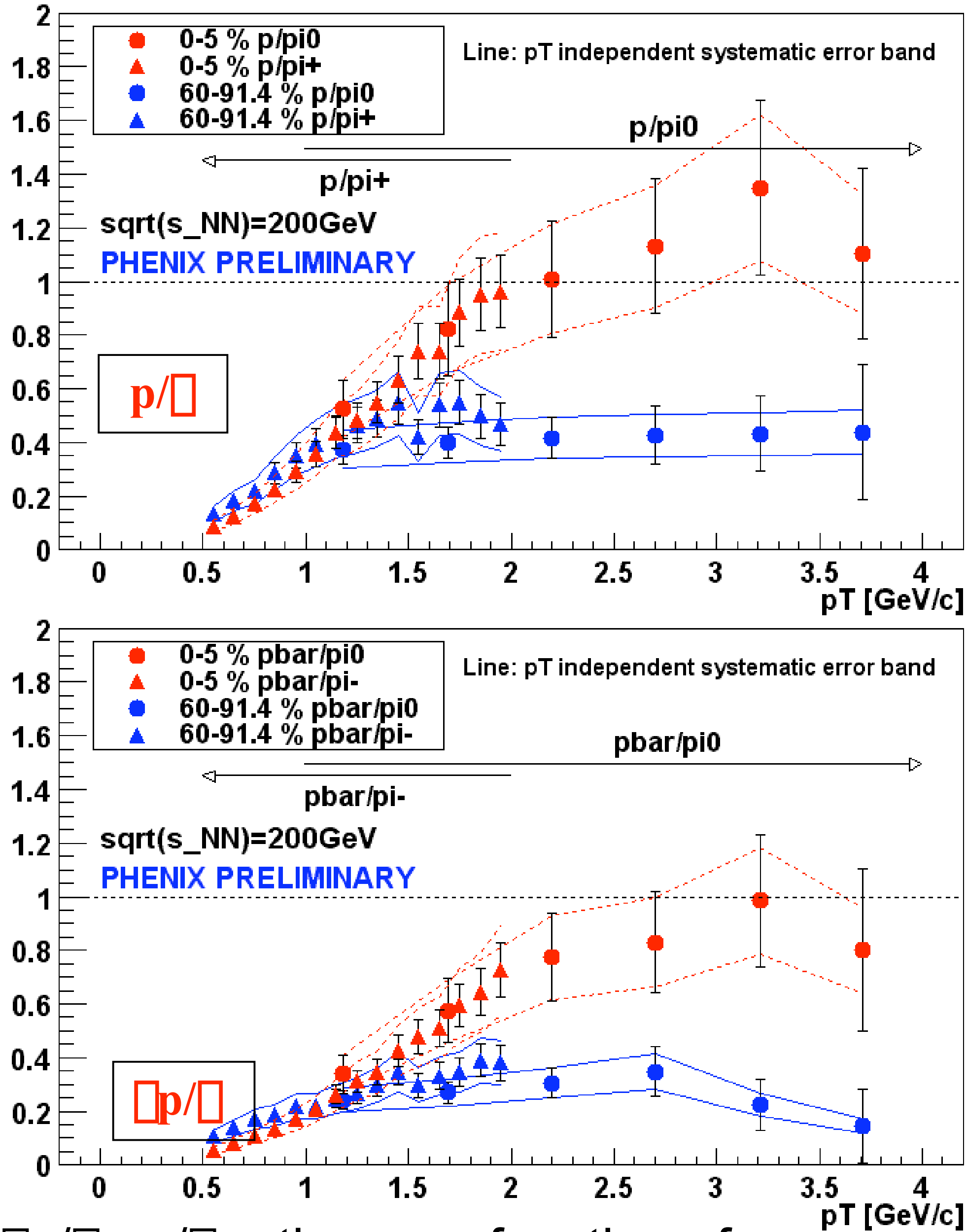




F.Becattini et al. Phys.Rev.**C60**,024901(2001)

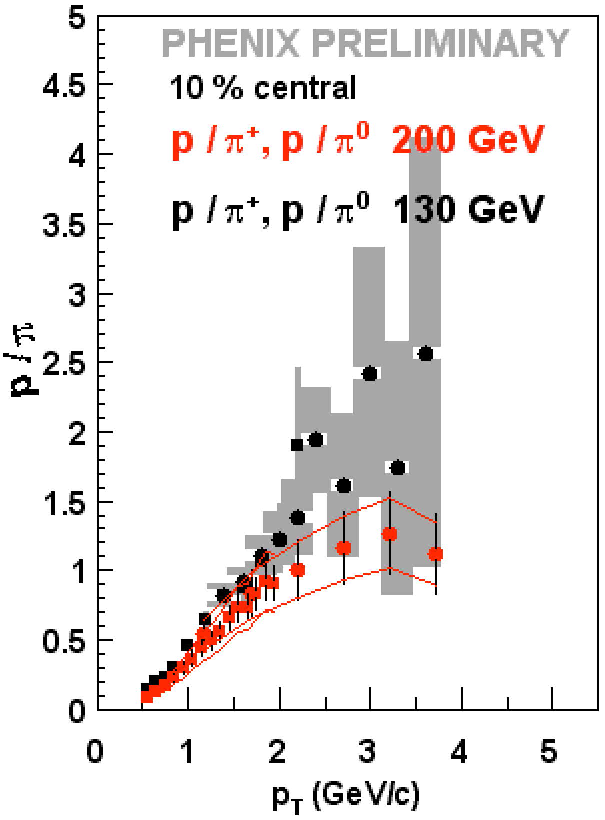
- No strong energy dependence in π^-/π^+ ratio.
- K^-/K^+ and $\bar{p}/p$ ratios increase from SPS and AGS.
- Comparison with Thermal model:
  - Baryon chemical potential: μ_B **~ 30MeV**
  - not baryon free at mid rapidity.

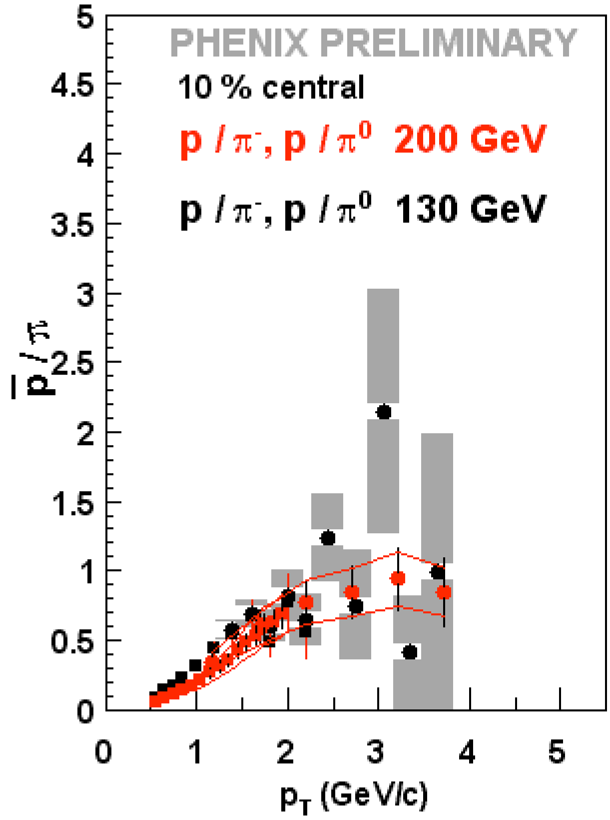
p/π and $\bar{p}$/π ratio



- $\bar{p}$/π , p/π ratios as a function of p_T
  - π^-, π^+ *up to 2GeV/c*, $\bar{p}$,p *up to 4GeV/c*
  - use π^0 at p_T>1GeV
- proton yield is comparable with pion at 2GeV/c in central collision, less in peripheral.

Comparison with s_{NN}=130GeV





- Data compared to Year-1 PHENIX data.
- Similar behavior has been observed.
- Consistent within systematic errors.

Conclusion

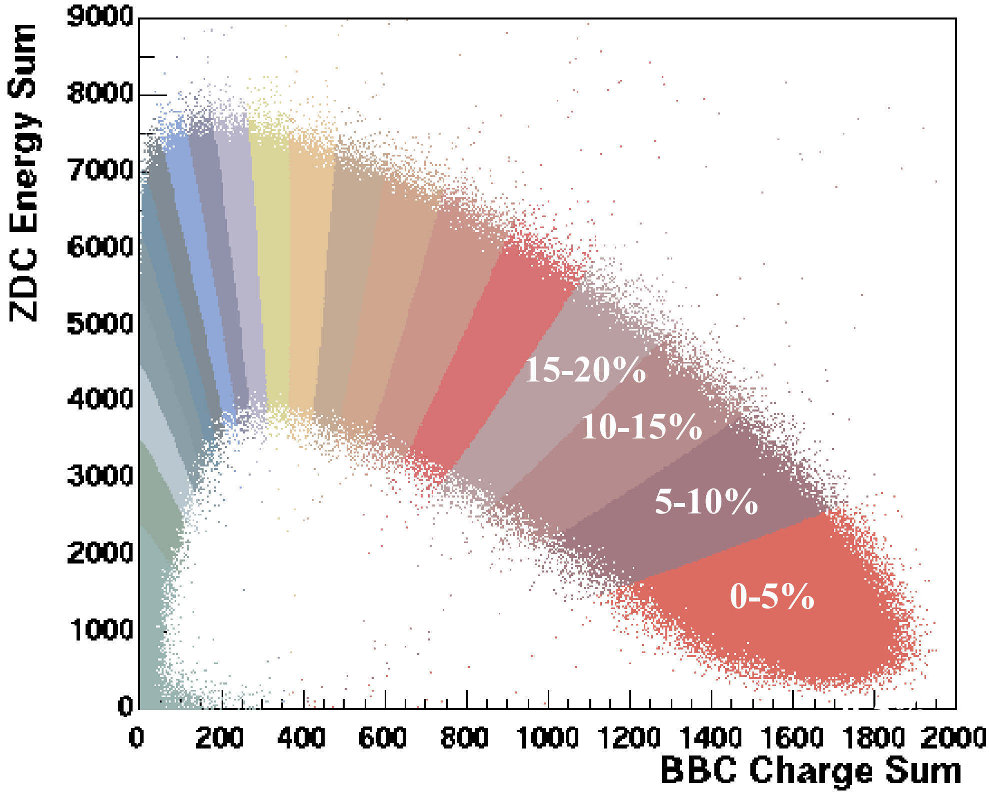
1. Hydrodynamic Collective expansion
   - Indicate a strong collective expansion at central collisions.
   - $<p_T>$ increases with N_{part} and mass
     - Consistence with radial expansion picture.
   - Hydro-dynamical model fit to the spectra
     - T_{fo} = 110 ± 23 MeV, β_T = 0.7 ± 0.2
2. Chemical composition
   - Particle ratios in Au+Au collisions at 200GeV
   - No clear centrality and p_T dependence.
   - Particle ratio at 5% most central event
     - π^-/π^+ = 1.02 ± 0.02(stat.) ± 0.1(syst.)
     - K^-/K^+ = 0.92 ± 0.03(stat.) ± 0.1(syst.)
     - $\bar{p}/p$ = 0.70 ± 0.04(stat.) ± 0.1(syst.)
   - Baryon chemical potential **μ_B ~ 30MeV**
3. Identified hadron yield at high p_T
   - $\bar{p}/p$ ratio is almost flat up to 4GeV/c for central collision, decreasing for peripheral at p_T > 3GeV/c.
   - proton yield is comparable with pion at 2GeV/c for central collision.
   - Hints on the effect of dense matter.

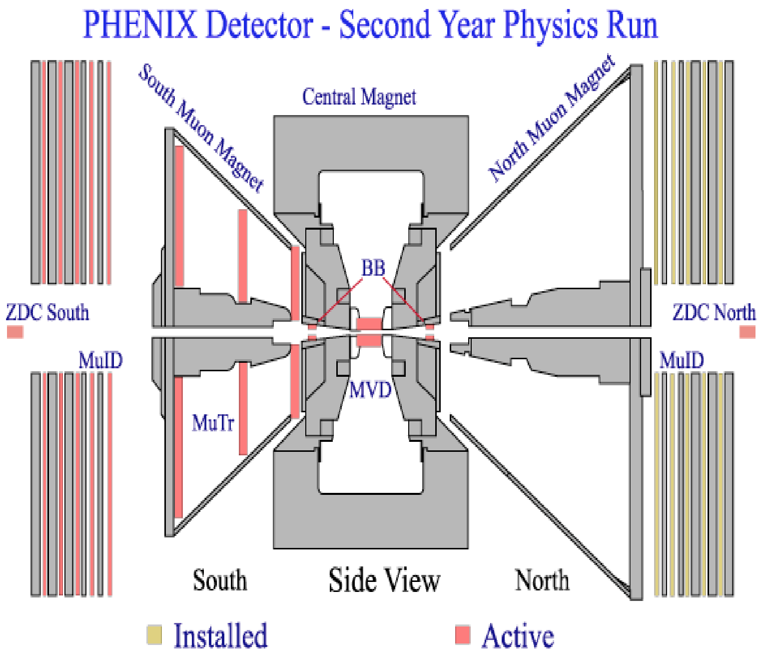
- Outlook
  - Minimize systematic uncertainty.
  - Comparison with p+p data.

Backup Slides

Spare

Event Selection

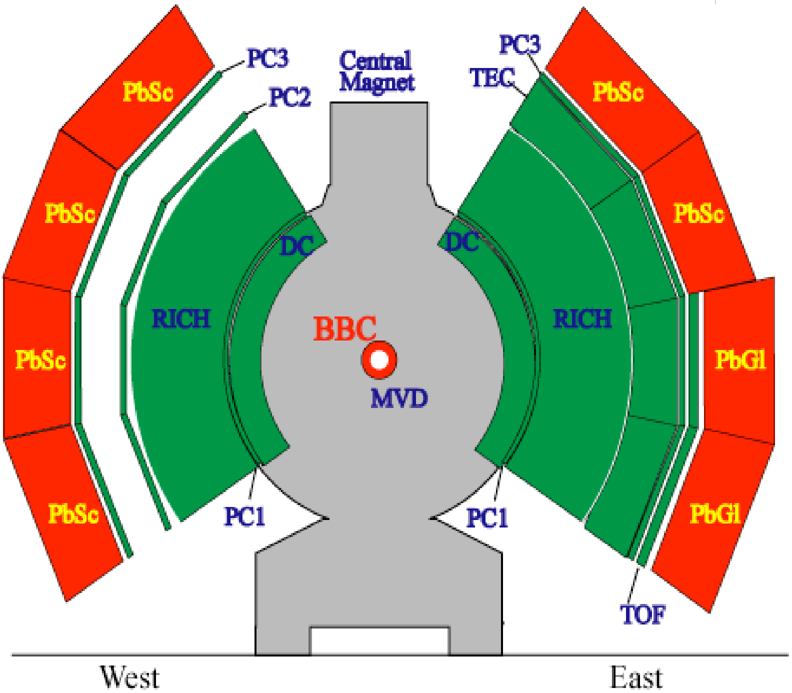


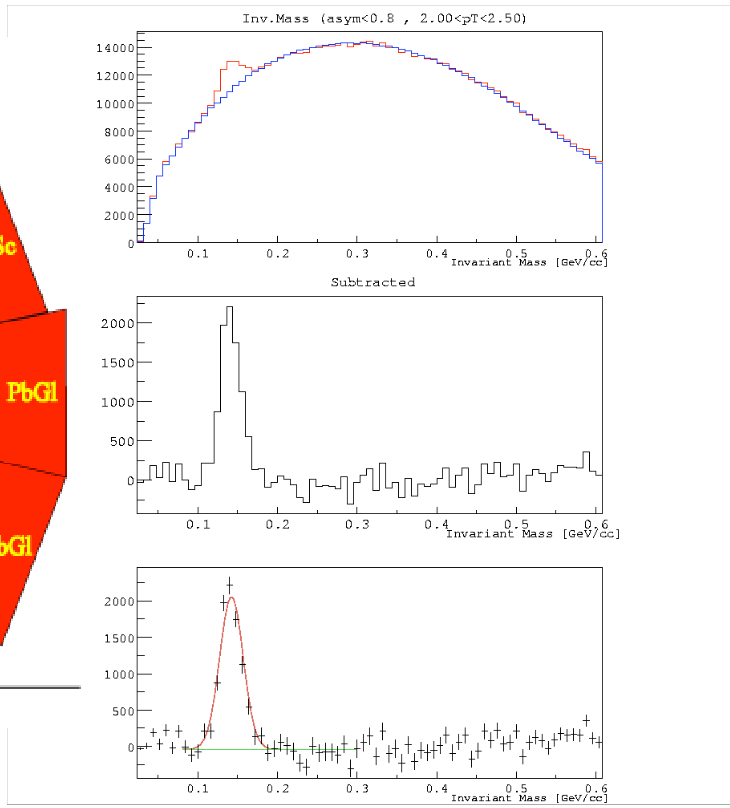


- Centrality selection :
  Used charge sum of BBC ($|\eta|$=3~4) and energy of ZDC in minimum bias events.

- Extracted N_{part} based on Glauber model.

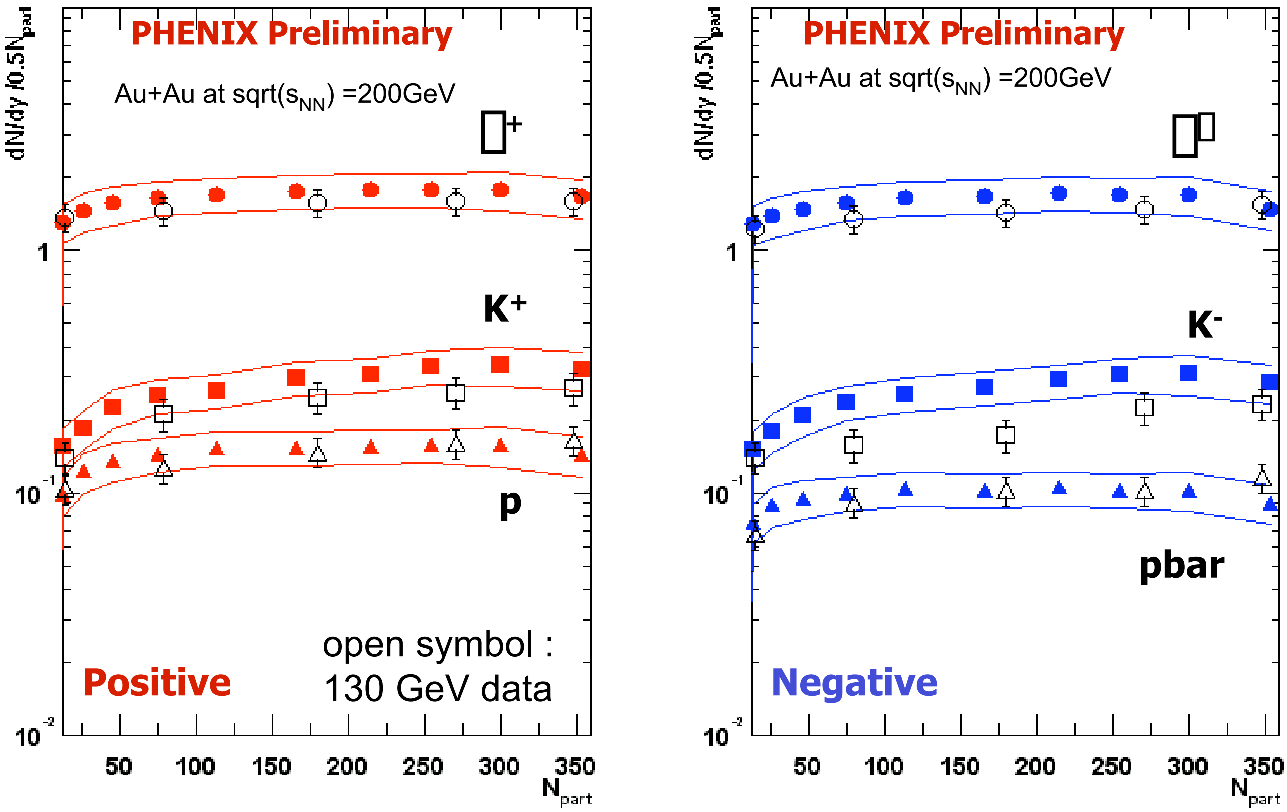
π^0 measurement





- Using Electro-magnetic Calorimeter
  - 1GeV/c<p_T<10GeV/c for π^0
- Calculate $\gamma\gamma$ invariant mass spectra and subtract combinatorial background
- Efficiency is evaluated by embedding simulated π^0 into real event.
- Systematic Error
  - p_T independent: 9%
  - Overall: 20-30%

Centrality Dependence of Particle Yield



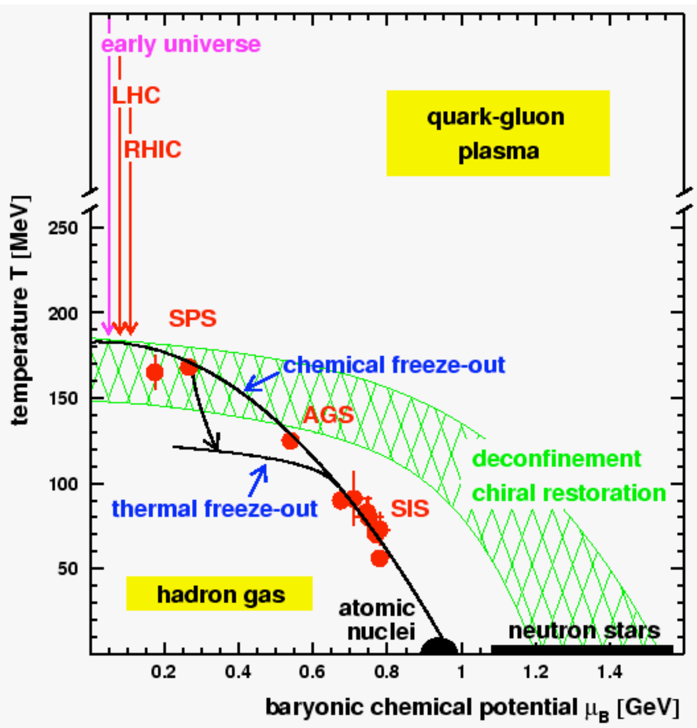
- Yield per pair N_{part} increases with N_{part} and mass
- Linear dependence on N_{part}
- Similar behavior 130GeV and 200 GeV

Motivation

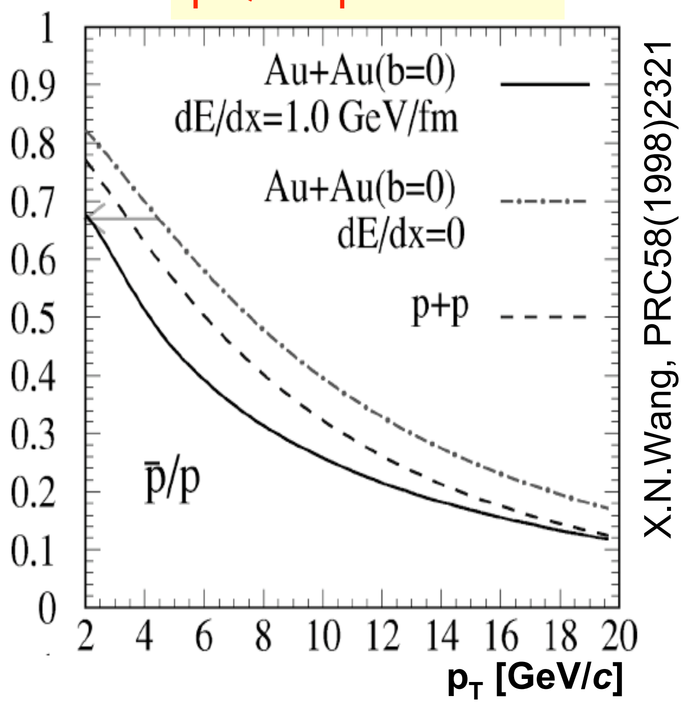
What do we learn from particle ratio?

- **Soft process**
  - Chemical freeze-out Temperature T_{ch}
  - Chemical potential □$_B$, □$_s$
    - SPS : T_{ch} **~ 170MeV, □$_B$ ~ 270MeV**
    - AGS : T_{ch} **~ 130MeV, □$_B$ ~ 500MeV**
  - Degree of baryon stopping power.

- **Hard process**
  - Contain earliest stage of collision.
  - Parton energy loss in hot and dense matter.
    - pbar/p ratio decreases with p_T.
    - Jet quenching moves the pbar/p ratio even below the pp value.



pQCD prediction



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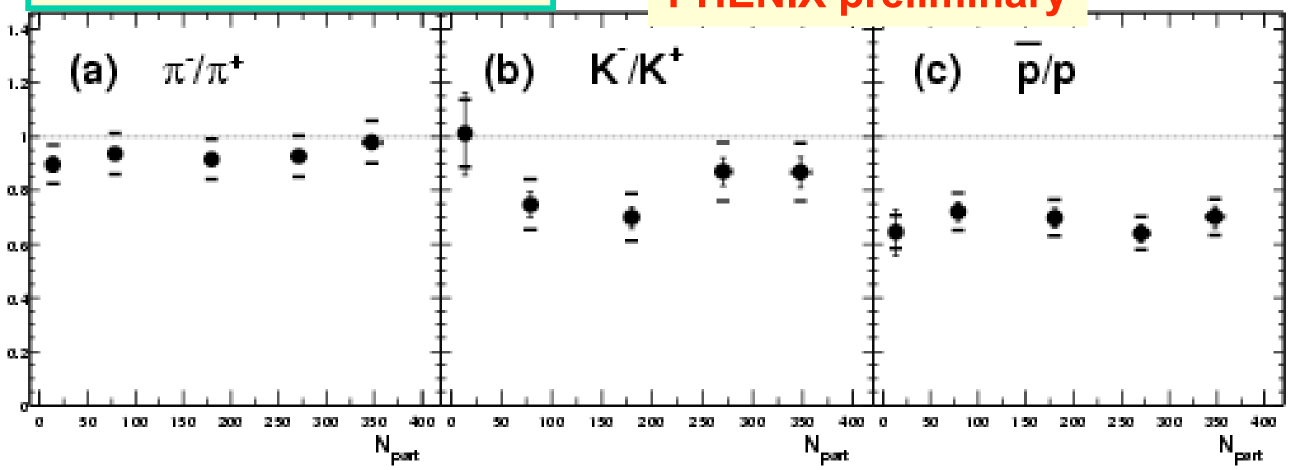
Anti-particle/particle ratios at $\sqrt{s_{NN}} = 130\text{GeV}$

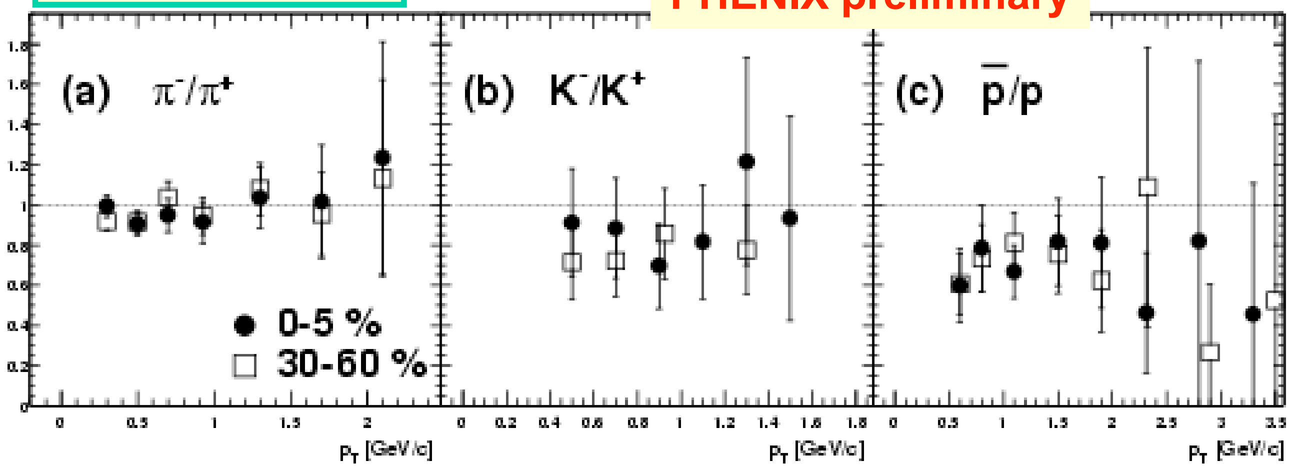
Centrality dependence

PHENIX preliminary



p_T dependence

PHENIX preliminary



- No clear dependence as a function of centrality and p_T.

- π^-/π^+ @5%central = 0.98 ±0.02(stat.) ±0.08(syst.)
- K^-/K^+@5%central = 0.87 ±0.06(stat.) ±0.11(syst.)
- $\bar{p}/p$ @5%central = 0.70 ±0.04(stat.) ±0.07(syst.)

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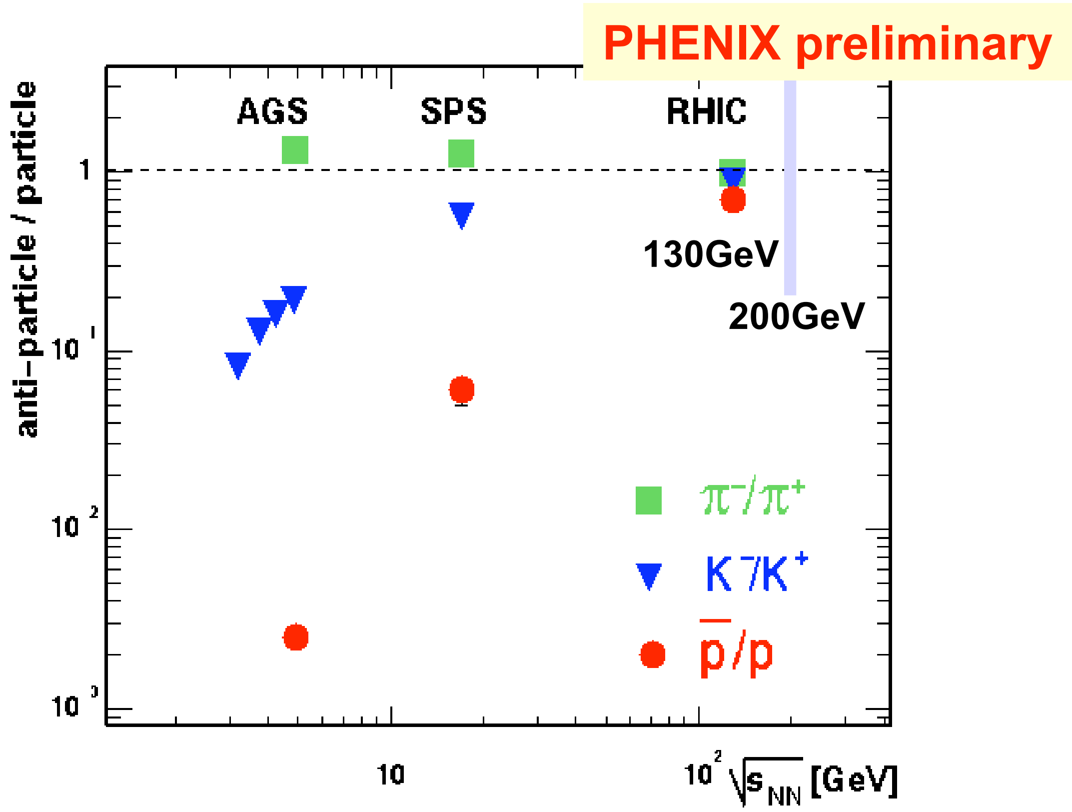
Beam energy dependence



- No strong energy dependence in π^-/π^+ ratio.
- K^-/K^+ and $\bar{p}/p$ ratios increase from SPS and AGS.
- Baryon density at RHIC is much less than AGS and SPS, but not baryon free at mid rapidity.

- Thermal Model calculation
  - P.Braun-Munzinger et al. Phys.Lett.B.518 41(2001)
  - **T_{ch} ~ 174MeV, μ_B ~ 46MeV**
  - Use result from RHIC four experiments.
- How about Au+Au 200GeV → analysis is on going
  - Close to baryon free? Temperature?