Beam energy dependences of baryon productions and hadron freeze-out properties at RHIC-PHENIX

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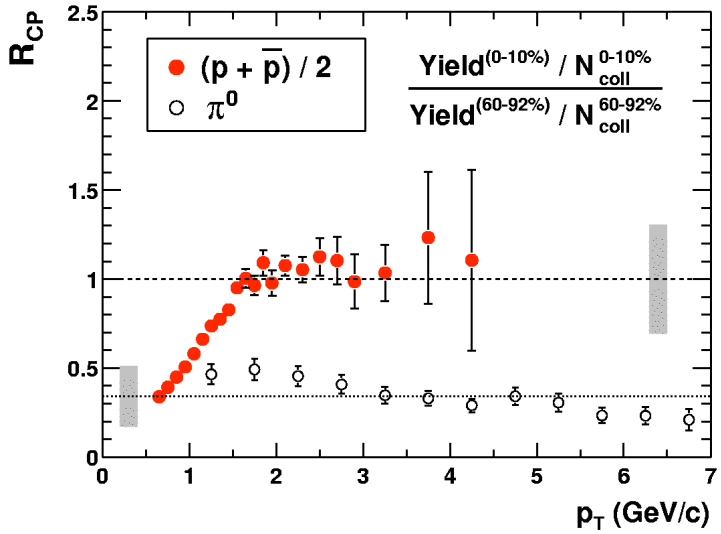
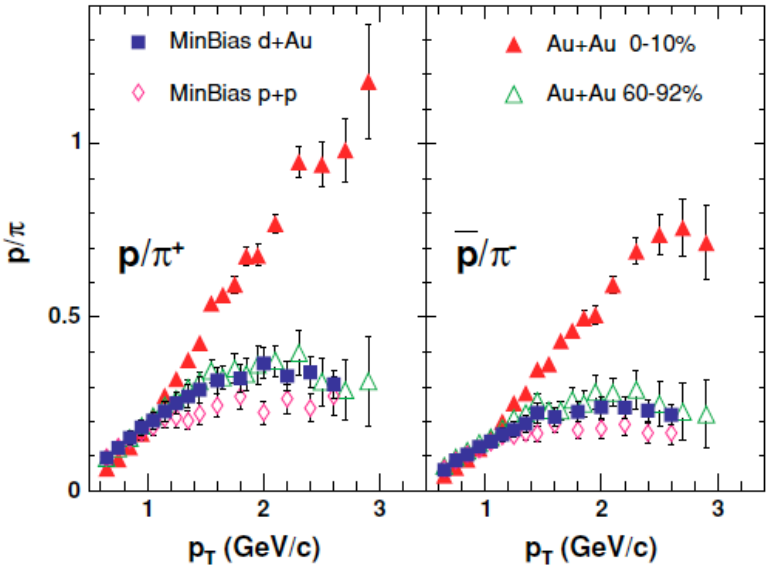
Baryon/Meson anomaly at RHIC

PHENIX: PRL 91, 172301 (2003), PRC 69, 034909 (2004), PRC 74, 024904 (2006)



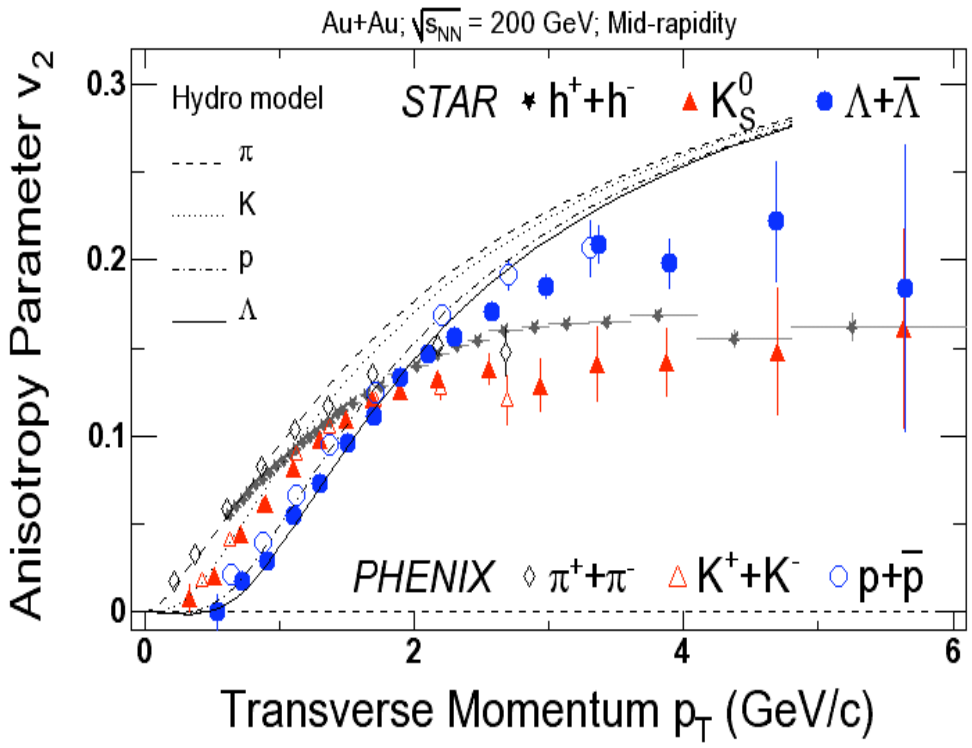


"Baryon anomaly (or enhancement) at RHIC".

- In Au+Au $\sqrt{s_{NN}}$ = 200 GeV central collisions:
- R_{CP} (or R_{AA})
  - Pions: Strong suppression of yields above p_T ~ 2 GeV/c, due to jet quenching.
  - Protons: No suppression at intermediate p_T (2-5 GeV/c).
- p/π and $\bar{p}/\pi$ ratios
  - More (anti) baryons than pions at intermediate p_T (2-5 GeV/c).
  - Strong centrality dependence.

Inspired extensive theoretical works to explain the data.

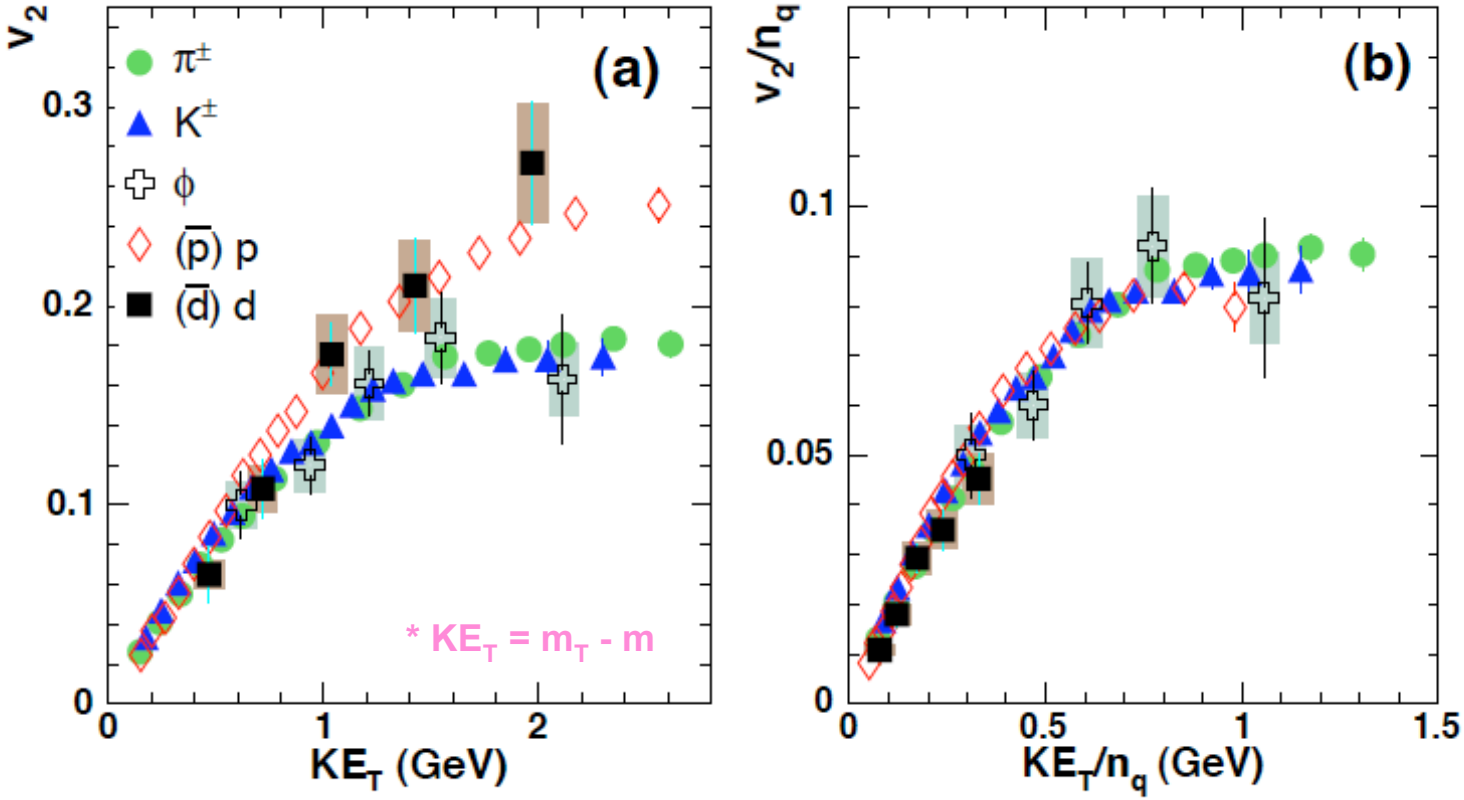
Particle type dep. of elliptic flow (v_2)



- Complicated particle type dependent structure at low p_T (< 1.5 GeV/c) is well described by the hydro model.
- How about at the intermediate p_T?

Quark Number Scaling of v_2

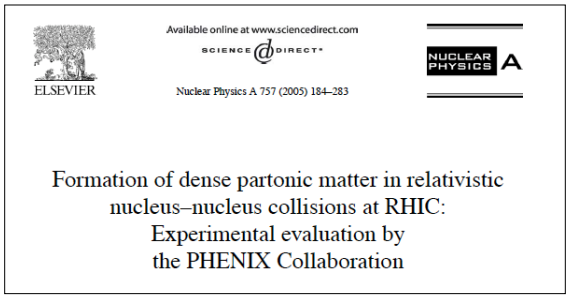
nucl-ex/0703024 (PHENIX)



- Shown a clear **Baryon / Meson splitting** at the intermediate p_T region.
- ϕ meson's v_2 follows the meson data points.
- **Number of constituent quark scaling** (n =2 for mesons, n =3 for baryons) works, suggested the **pressure developed at quark level**, not hadronic level.

PHENIX White Paper (WP) says…

Nucl. Phys. A 757 (2005) 184-283, PHENIX Collaboration



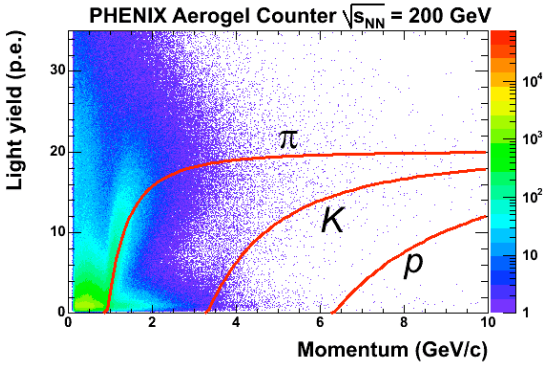
8.1. High-p_T suppression and jet physics

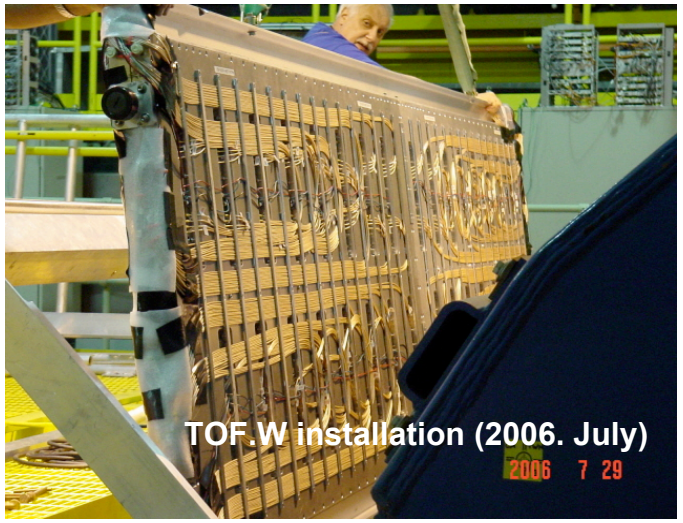
The most exciting results to date at RHIC are the discovery of high-p_T suppression of mesons, interpreted in terms of energy loss of quarks in a high-density medium, and the nonsuppression of baryons or equivalently, the anomalously high p/π ratio which still awaits a clear explanation. These two topics were extensively discussed in Sections 6 and 7, respectively.

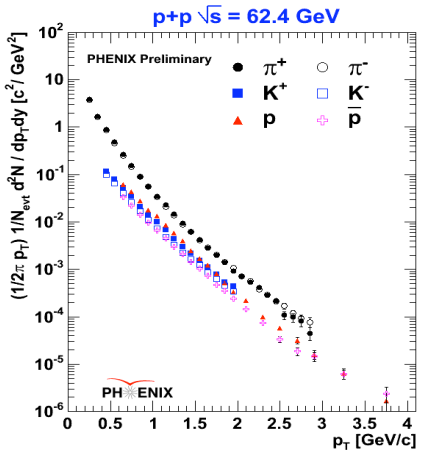
To further elucidate the baryon puzzle, additional data is required with better separation between baryons and mesons. An upgrade consisting of an aerogel Cerenkov counter and a high-resolution TOF detector is expected to be completed in time for the year 2006. A portion of this aerogel counter was already installed prior of the year 2004 run and performed according to expectations. Once completed, this high-p_T detector will allow identification of π, K/p to beyond 8 GeV/c in p_T.

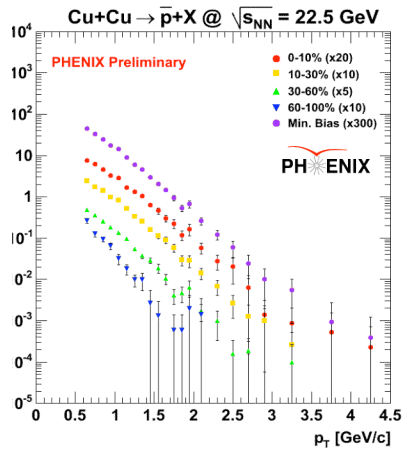
After the publication of WP…

- **PHENIX high p_T PID detector upgrades:**
  - Aerogel Cherenkov
    - Fully installed in 2005, working.
  - TOF West (MRPC)
    - installed in 2006, started data taking in 2007.
- **New data sets:**
  - **High statistics data:**
    - Au+Au 200 GeV (2004)
    - Cu+Cu 200 GeV (2005)
    - p+p 200 GeV (2005,2006)
  - **Lower beam energy data:**
    - Au+Au 62 GeV (2004)
    - Cu+Cu 22, 62 GeV (2005)
    - p+p 62 GeV (2006)









Exploring the QCD phase diagram by changing √s at RHIC

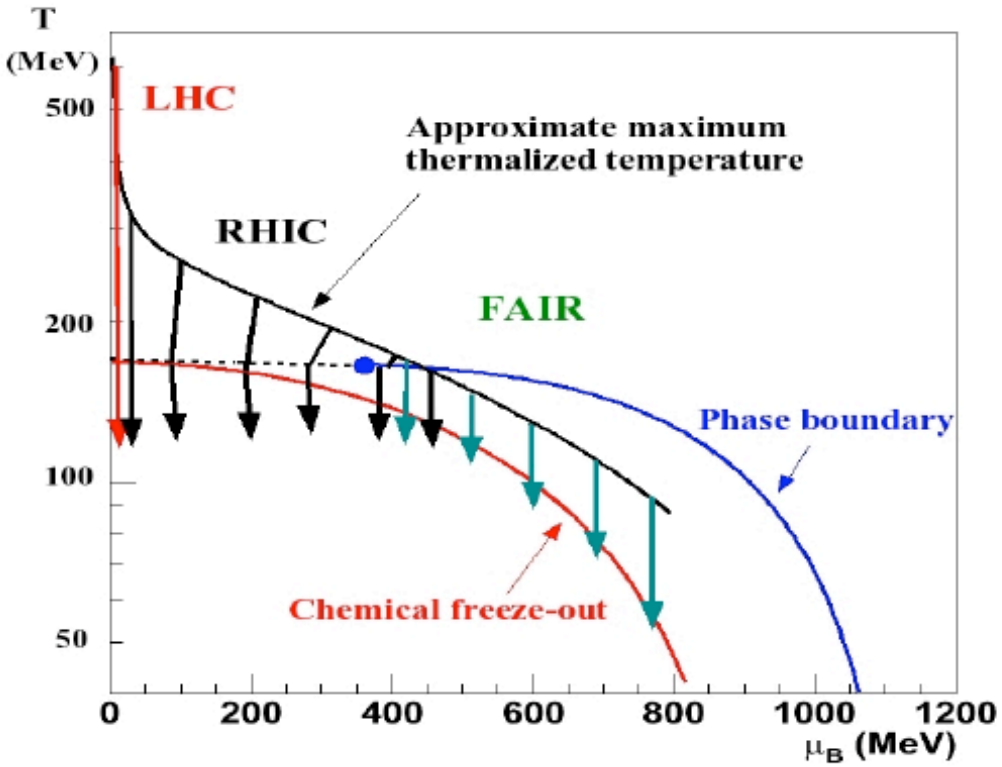
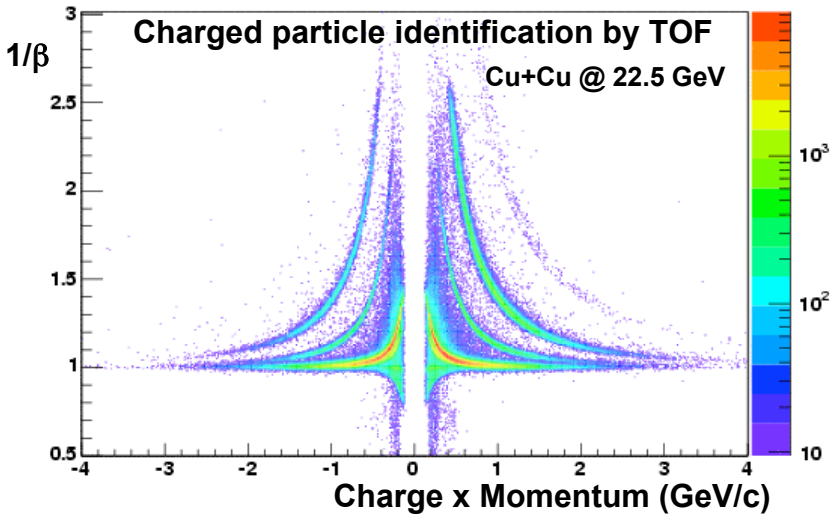


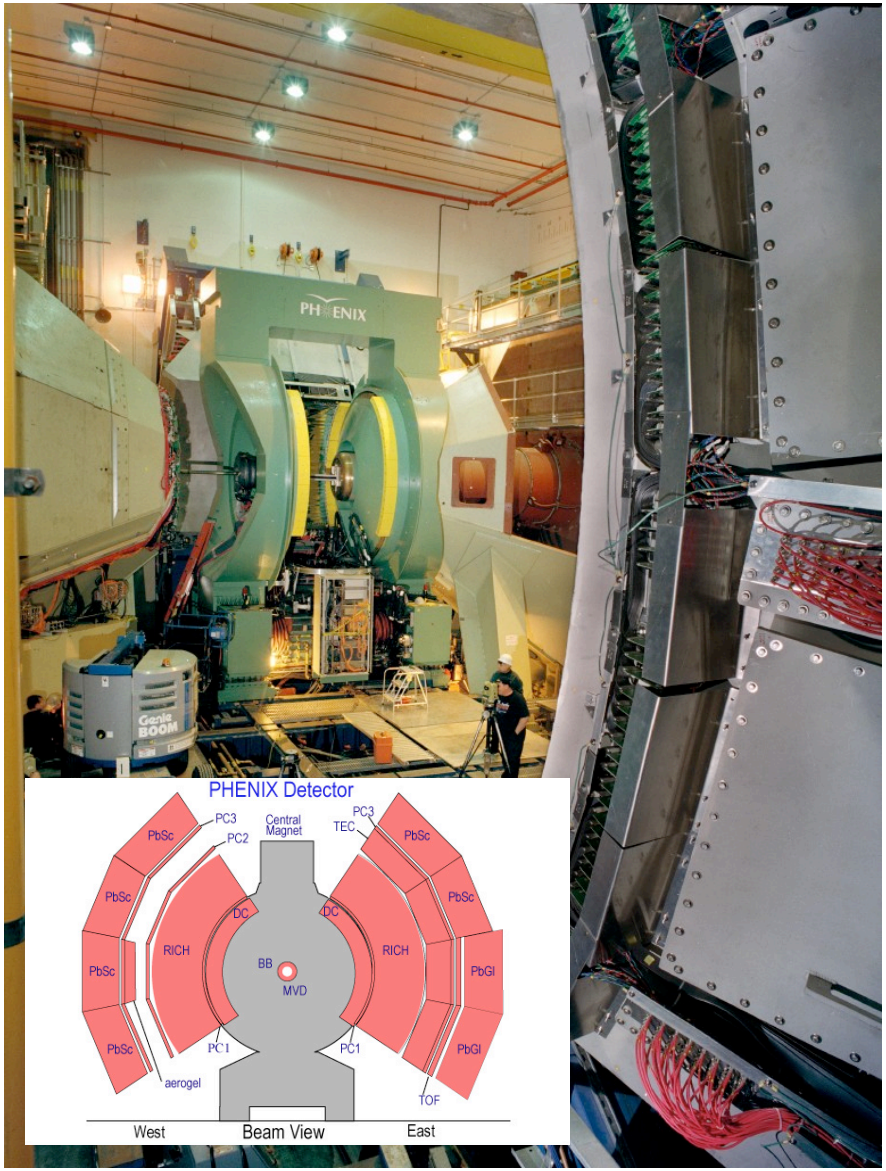
Figure from "Future Science at the Relativistic heavy ion Collider (Aug. 25, 2006 version)", by RHIC II Science Working Groups

- Where is the onset of baryon anomaly at RHIC?
- How p/π^+ and $\bar{p}/\pi^-$ ratios and R_{AA} evolve as a function of √s (or μ_B) and colliding system?
- **The lower beam energy data taken at RHIC so far can provide the excitation function of baryon productions.**

PID charged p_T spectra analysis in PHENIX

- **PHENIX detector:**
  - Drift Chamber, Pad Chamber 1 (PC1), Beam-Beam Counter (BBC) and TOF for PID charged analysis.
- **Collision centrality:**
  - Subdivided minimum bias triggered events, based on BBC charge (62 GeV), or the number of PC1 hit (22 GeV).
- **Corrections:**
  - Geometrical acceptance, in flight decay.
  - No weak decay feed-down correction applied.

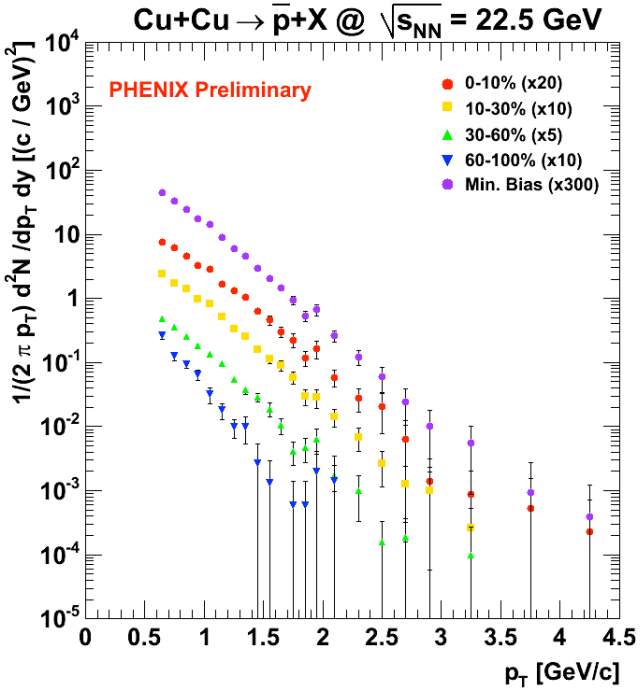


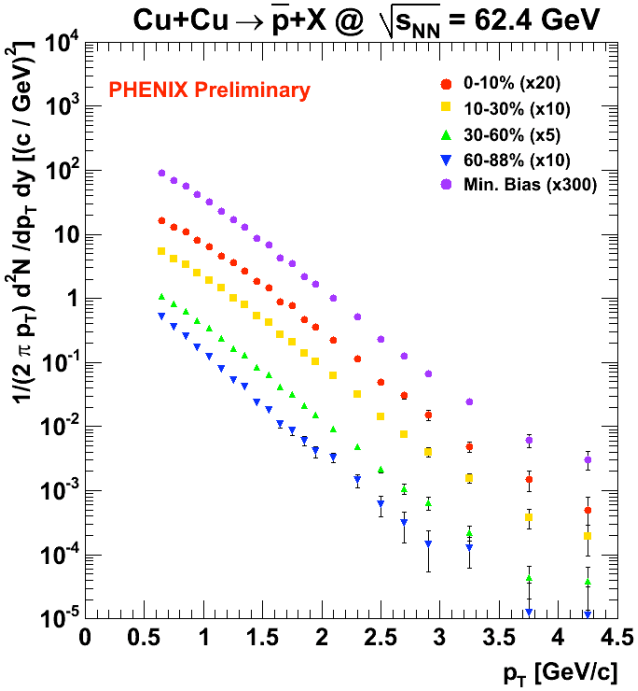


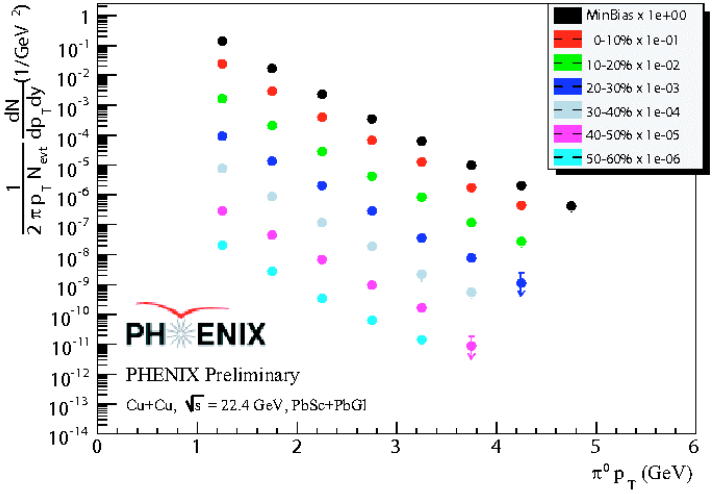
Experimental Results:

$\sqrt{s}$ dependence of baryon productions

PID spectra at lower $\sqrt{s_{NN}}$



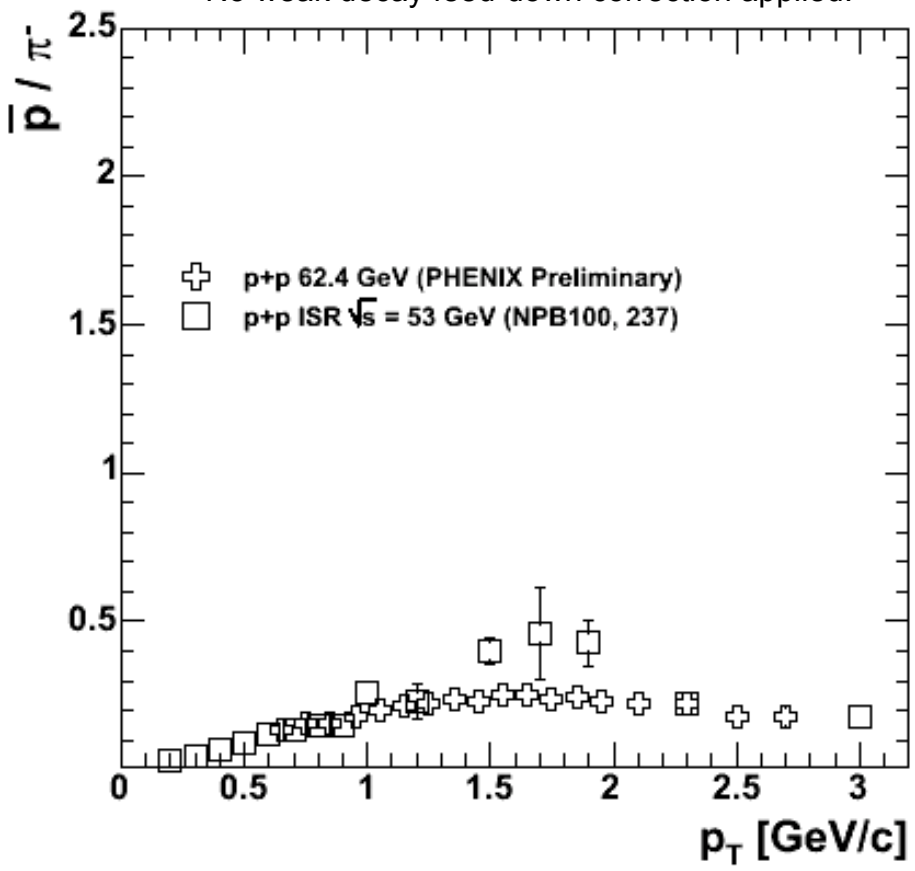




π^0 p_T spectra
in Cu+Cu 22.5 GeV

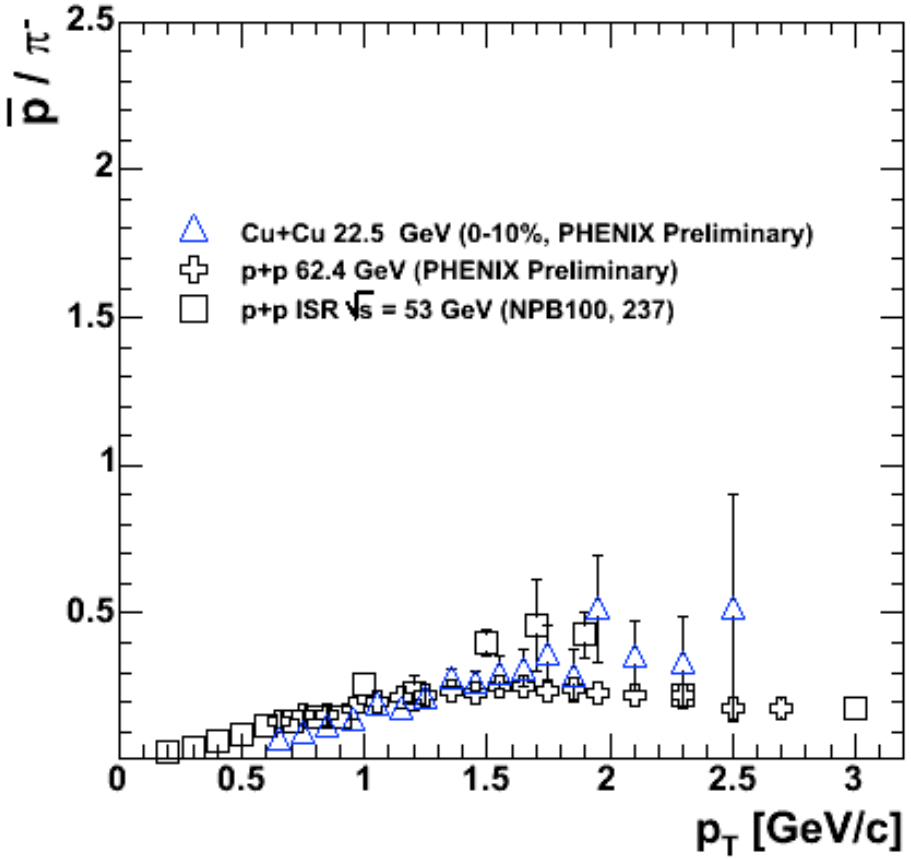
√s dep. of $\bar{p}/\pi^-$ ratio (central)

* No weak decay feed-down correction applied.



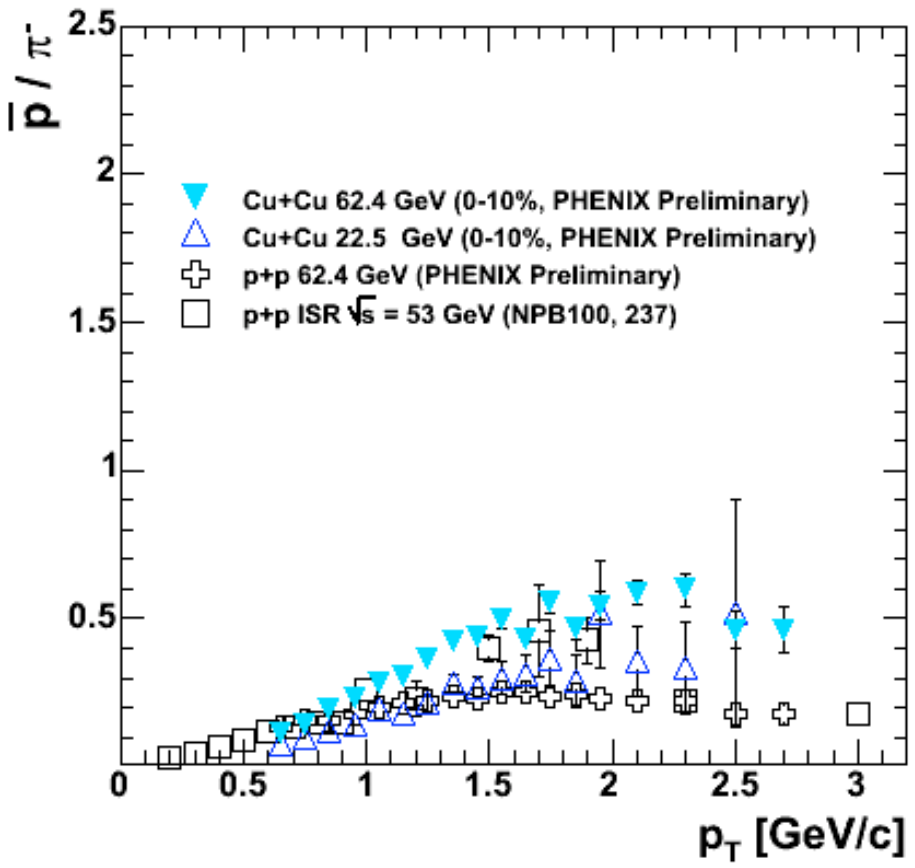
p+p 62.4 GeV, set the baseline for HI data. New PHENIX data agrees with ISR data.

√s dep. of $\bar{p}/\pi^-$ ratio (central)



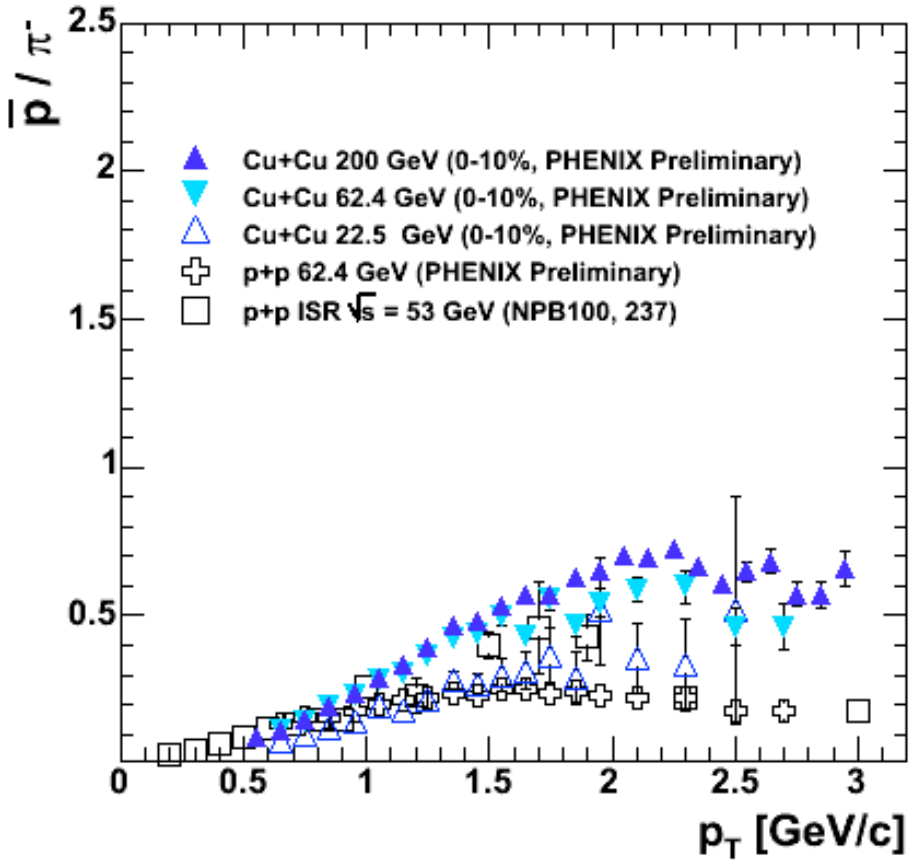
Cu+Cu 22.5 GeV, $\bar{p}/\pi^-$ ratio in central agrees with p+p.

√s dep. of $\bar{p}/\pi^-$ ratio (central)



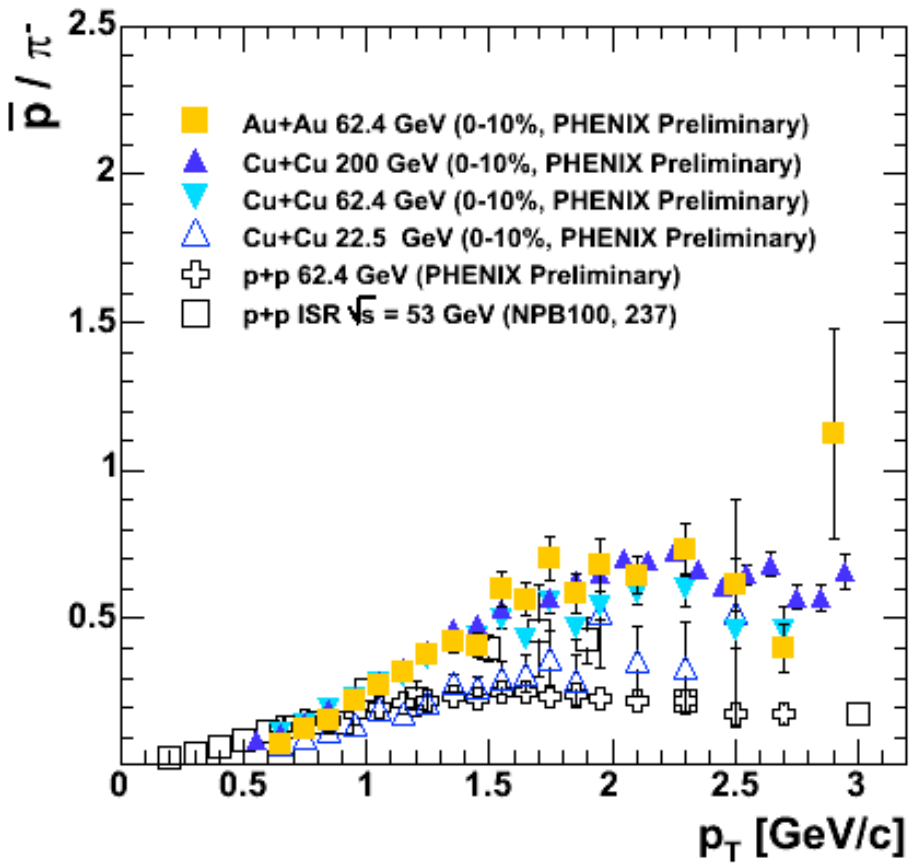
Cu+Cu 62.4 GeV, $\bar{p}/\pi^-$ ratio larger than those in p+p and Cu+Cu 22.5 GeV.

√s dep. of $\bar{p}/\pi^-$ ratio (central)



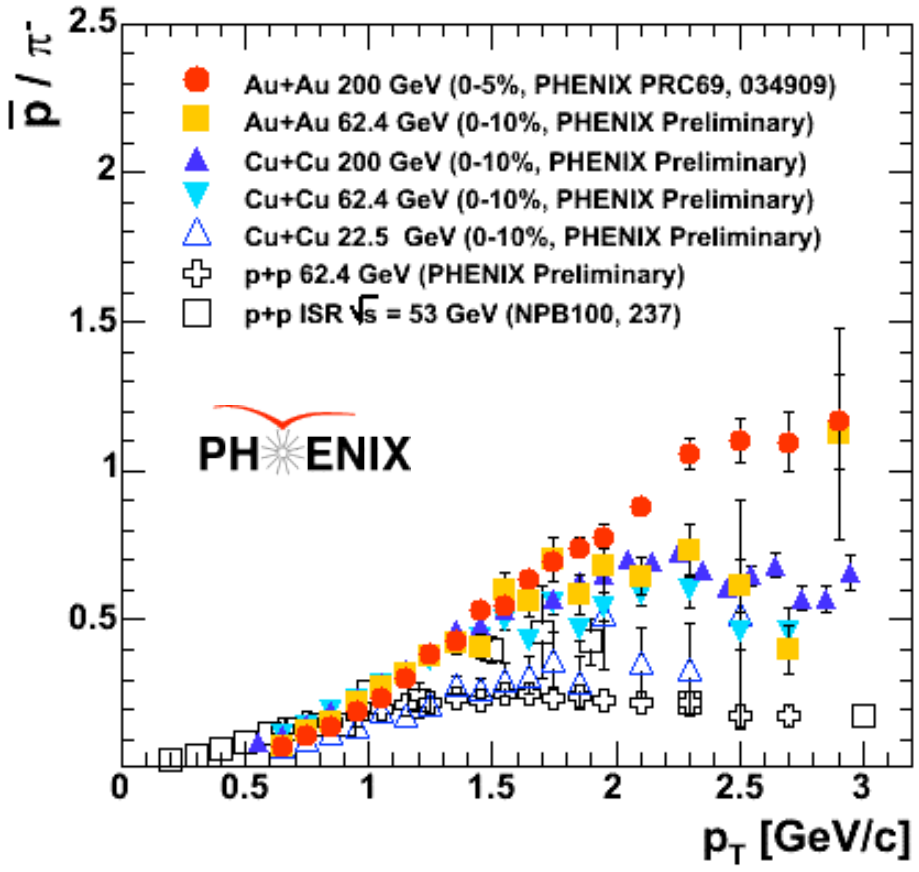
Cu+Cu 200 GeV, similar to those in Cu+Cu 62.4 GeV.

√s dep. of $\bar{p}/\pi^-$ ratio (central)



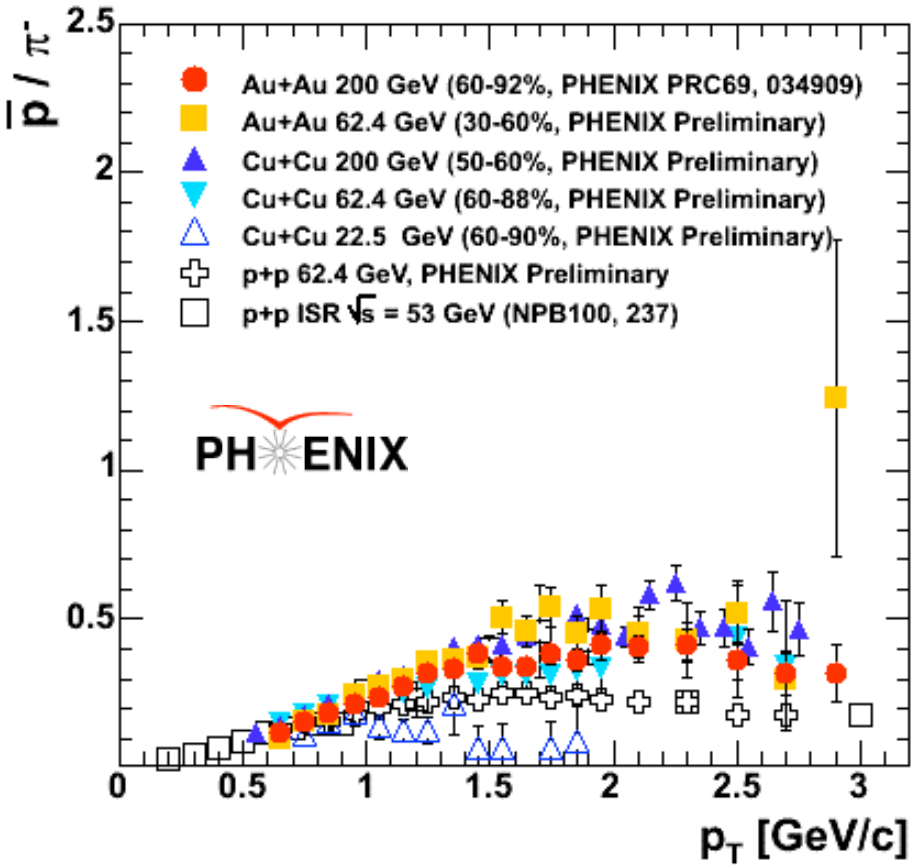
Au+Au 62 GeV, $\bar{p}/\pi^-$ is unchanged from Cu+Cu 200 GeV

√s dep. of $\bar{p}/\pi^-$ ratio (central)



Au+Au 200 GeV, $\bar{p}/\pi^-$ is enhanced.

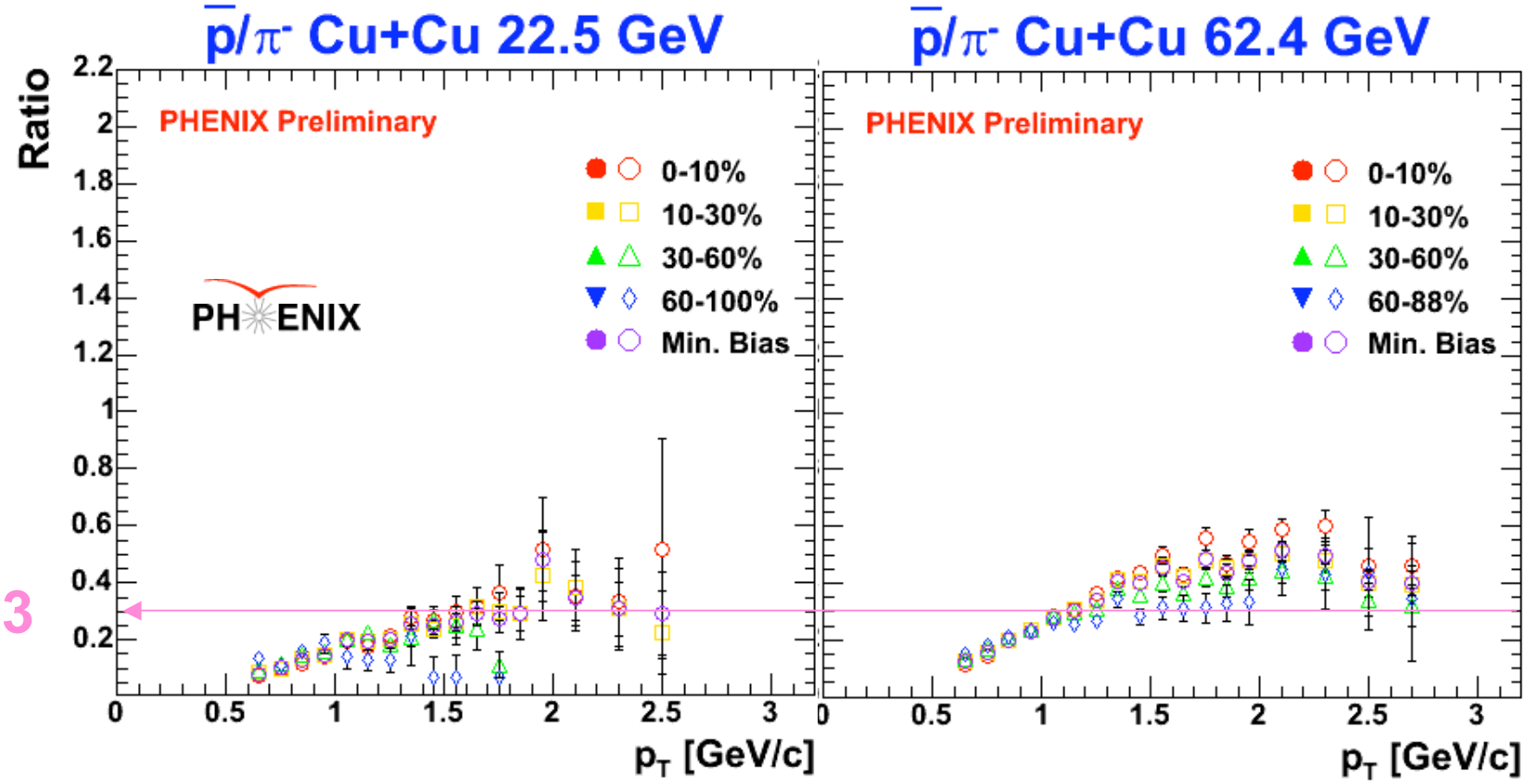
√s dep. of $\bar{p}/\pi^-$ ratio (peripheral)



Peripheral collisions for all systems

Conversing to the same line

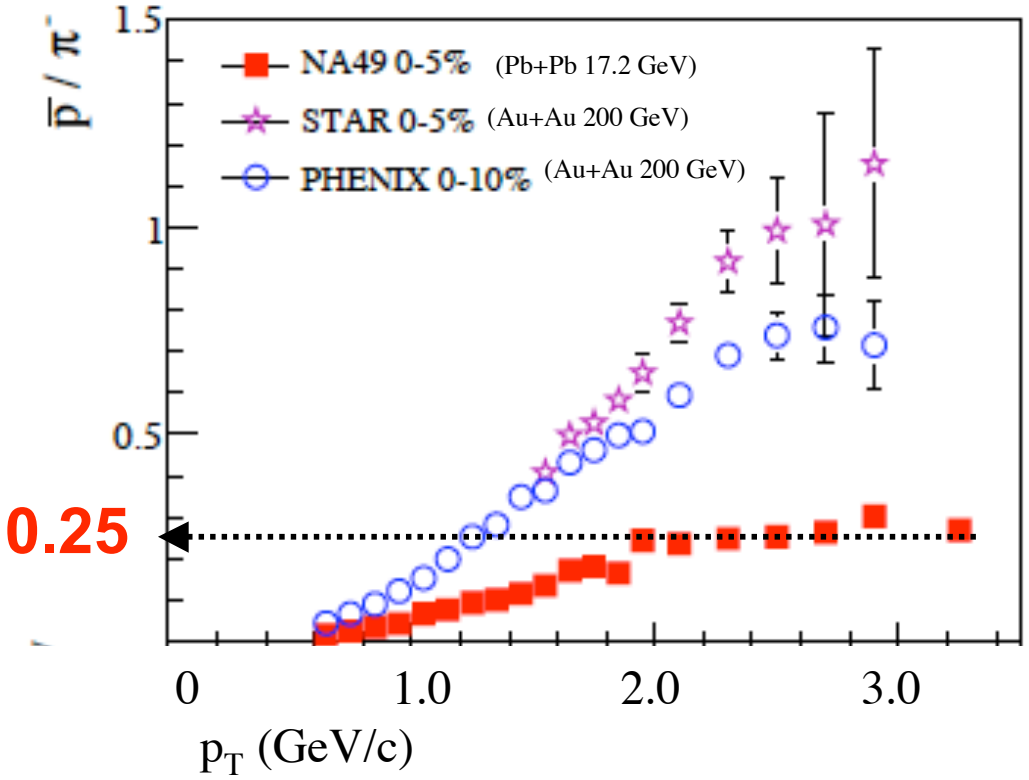
Centrality dep. of $\bar{p}/\pi^-$ (22 GeV vs. 62 GeV)



* No weak decay feed-down correction applied.

- **In 22.5 GeV Cu+Cu: weak centrality dependence, $\bar{p}/\pi^-$ ratios are ~0.3-0.4 at p_T = 2 GeV/c,** which is close to the value in p+p.
- **In 62.4 GeV Cu+Cu: $\bar{p}/\pi^-$ ratio in central collisions reaches R=~0.6 at p_T = 2 GeV/c, decreasing towards the peripheral events.**

Comparison with SPS data

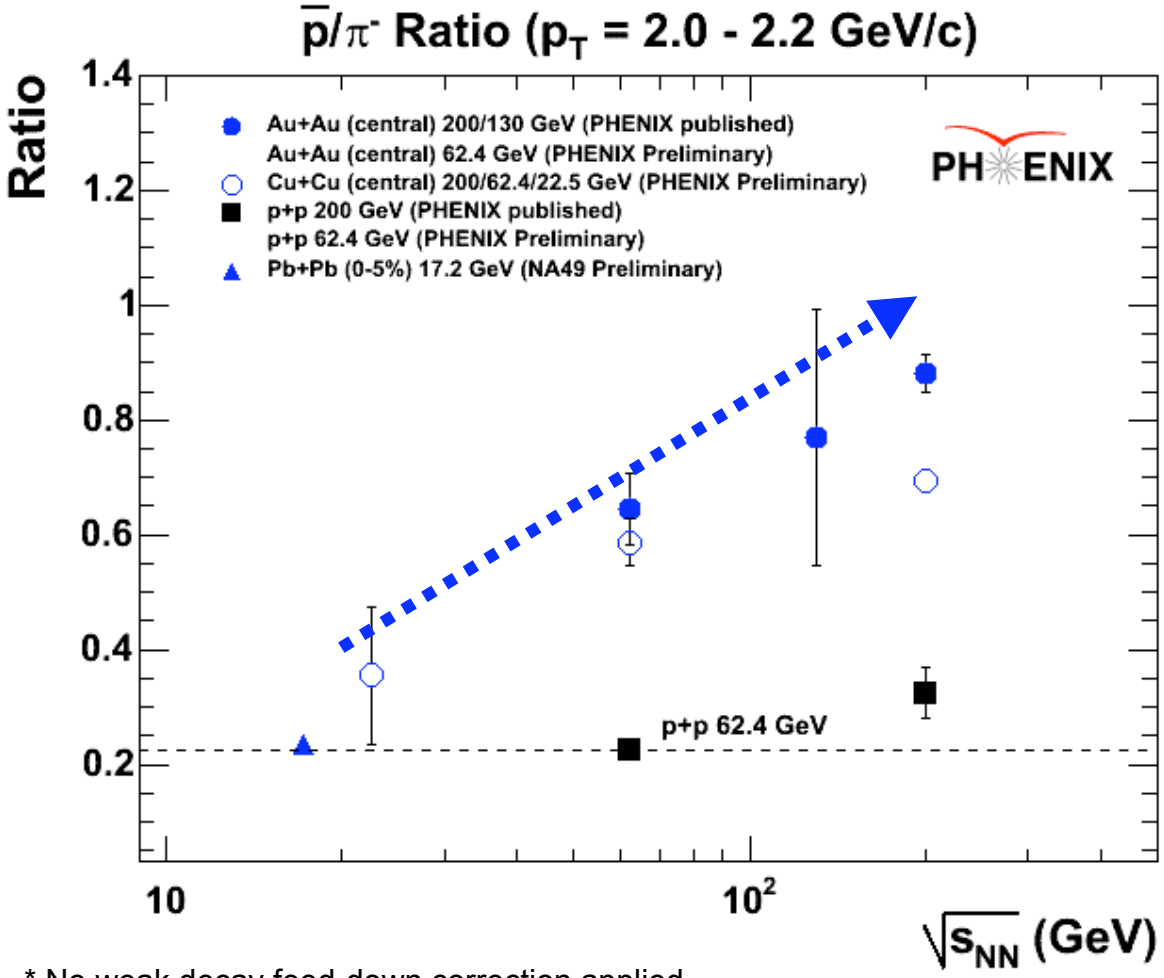


T. Schuster, A. Laszlo (NA49)
nucl-ex/0606005

Pb+Pb 17.2 GeV (central)

SPS Pb+Pb: consistent with Cu+Cu 22.5 GeV $\bar{p}/\pi$.

$\bar{p}/\pi^-$ ratio (central): summary



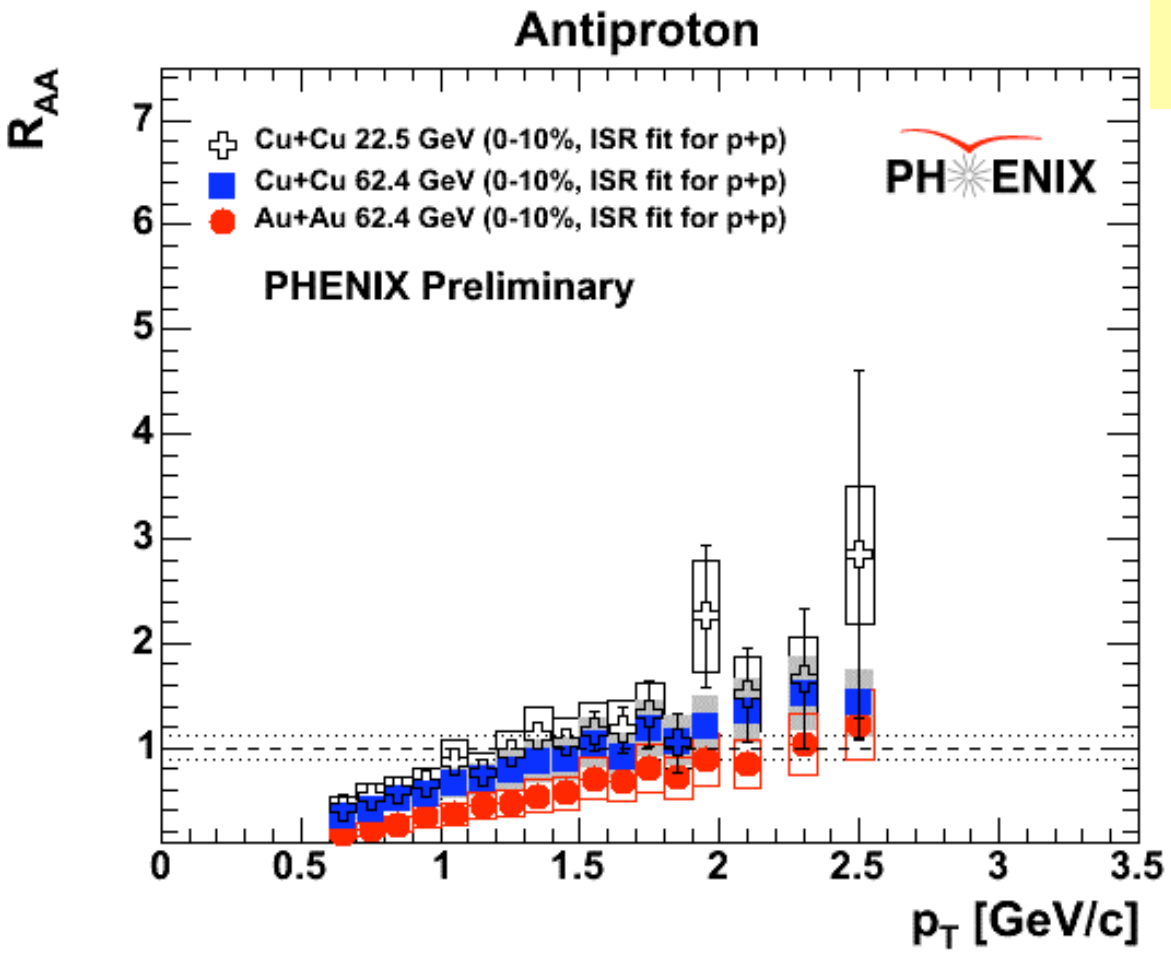
* No weak decay feed-down correction applied.

- Increasing as a function of √s.
- Indicates the onset of baryon enhancement is in between 22 GeV and 62 GeV.

$\sqrt{s_{NN}}$ dep. R_{AA} for antiprotons (by ISR fit)

Nuclear Modification Factor

$$R_{AA}(p_T) = \frac{yield(AuAu)/N_{coll}}{yield(pp)}$$

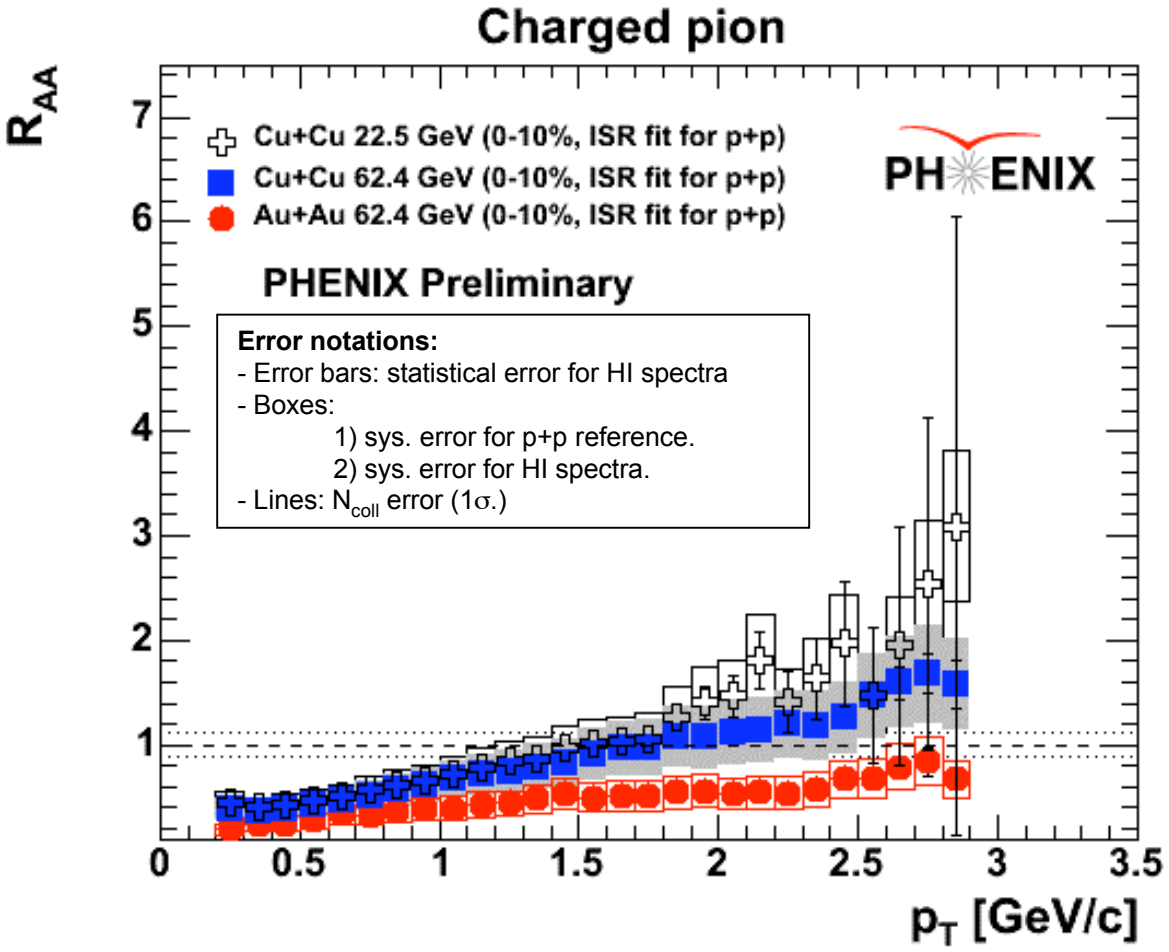


* No weak decay feed-down correction applied.

- Used ISR data at 23 GeV and 63 GeV (Alper. NPB 100, 237) for p+p reference.
- Similar R_{AA} for all three systems.

** Note:*
p+p 62.4 GeV p+p data has been measured by PHENIX, still working on the trigger bias and cross section seen in the detector. Here we use ISR fit to obtain R_{AA}.

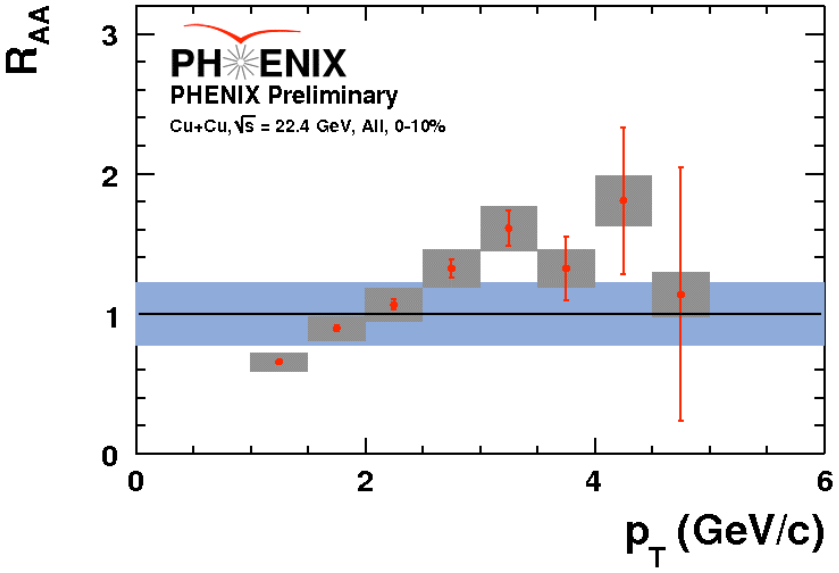
$\sqrt{s_{NN}}$ dep. R_{AA} for charged pions (by ISR fit)

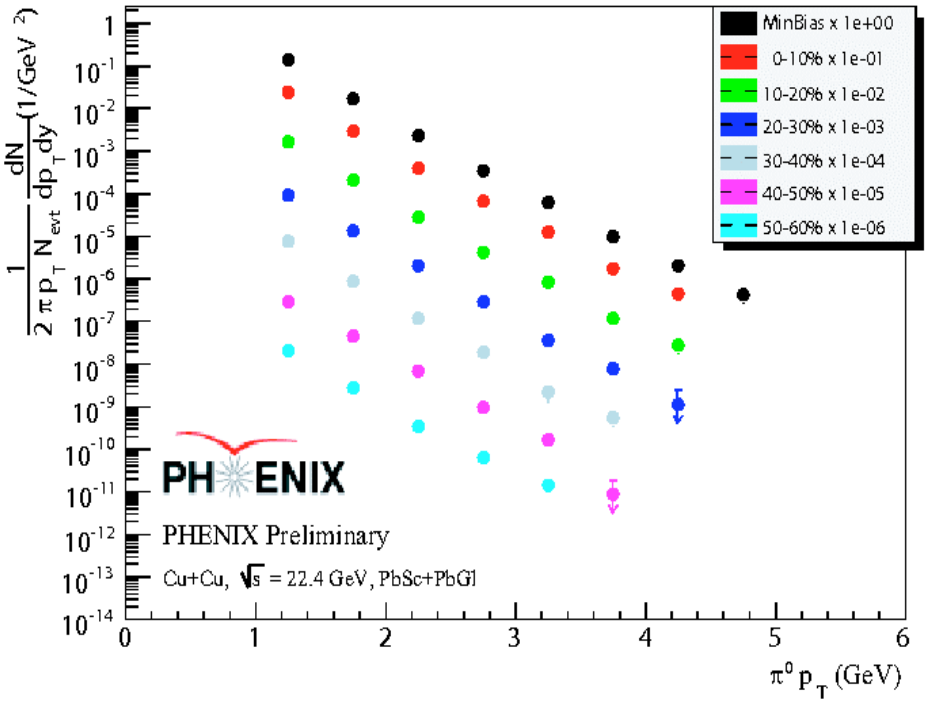


* No weak decay feed-down correction applied.

- Used ISR fit (nucl-ex/0411049, D. d'Enteria) for p+p parameterization.
- Moderate suppression for Au+Au 62.4 GeV.
- Greater than unity for Cu+Cu 62/22 GeV (p_T > 2.0 GeV/c).

π^0 at 22.5 GeV (centrality dep.)



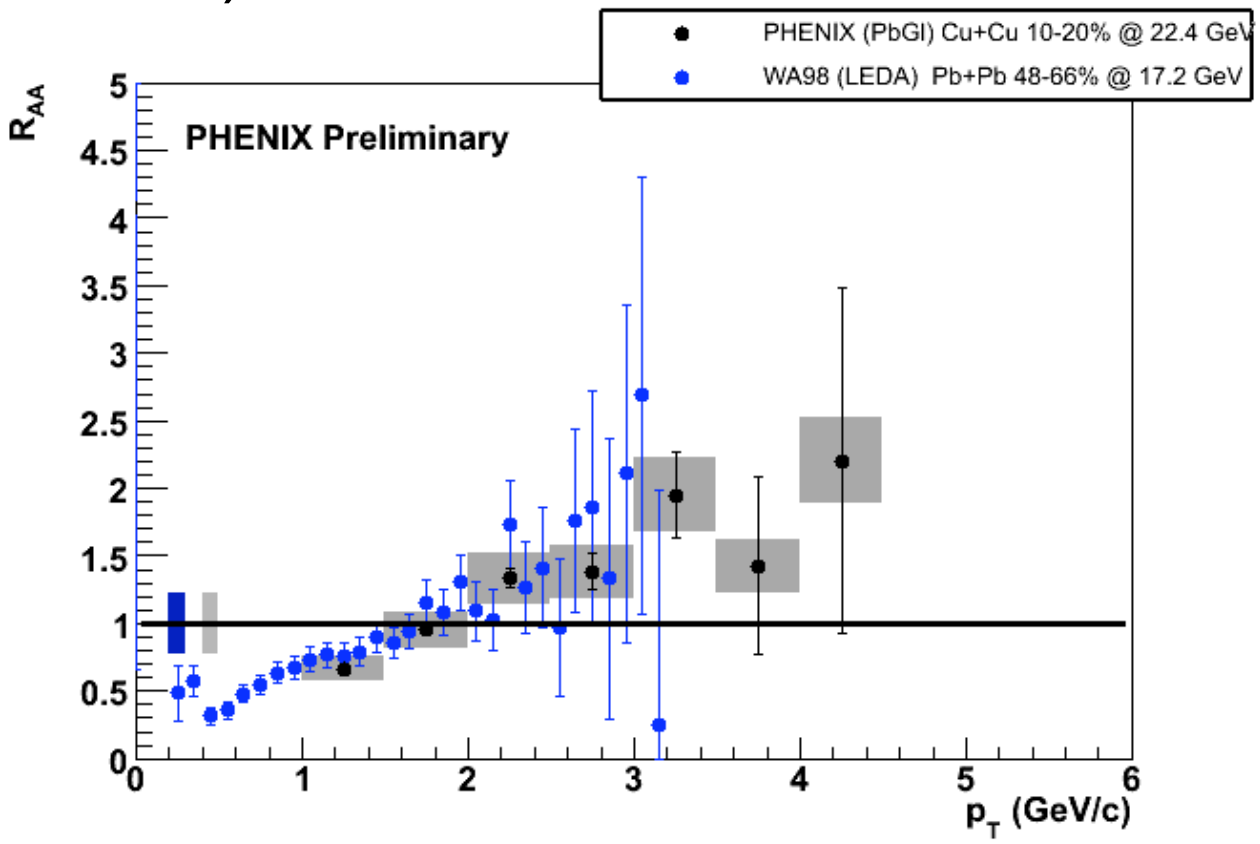


Little centrality dependence

Baldo Sahlmüller (QM06)

SPS (17 GeV) vs. RHIC (22 GeV)

- Same behavior for similar N_{part} (63 at WA98, 67.8 at PHENIX)



Blattnig parameterization used for WA98 data (S. Blattnig et. al., Phys.Rev. D62 (2000) 094030 / D. D'Enterria, Phys. Lett. B 596 (2004) 32))

Baldo Sahlmüller (QM06)

Conclusions

- p_T spectra for antiproton and pions at $\sqrt{s_{NN}}$ = 22.5 and 62.4 GeV in Au+Au (Cu+Cu) have been studied to search for the onset of baryon enhancement at RHIC.
- **Only antiprotons in Cu+Cu 22.5 GeV system seems to be different from others:**
  - Little centrality dependence in $\bar{p}/\pi^-$ ratio at the intermediate p_T.
  - Central 0-10% $\bar{p}/\pi^-$ ratio agrees with the value in p+p collisions.
  - Neutral pion's R_{AA} : no suppression and consistent with SPS data. Little centrality dependence.

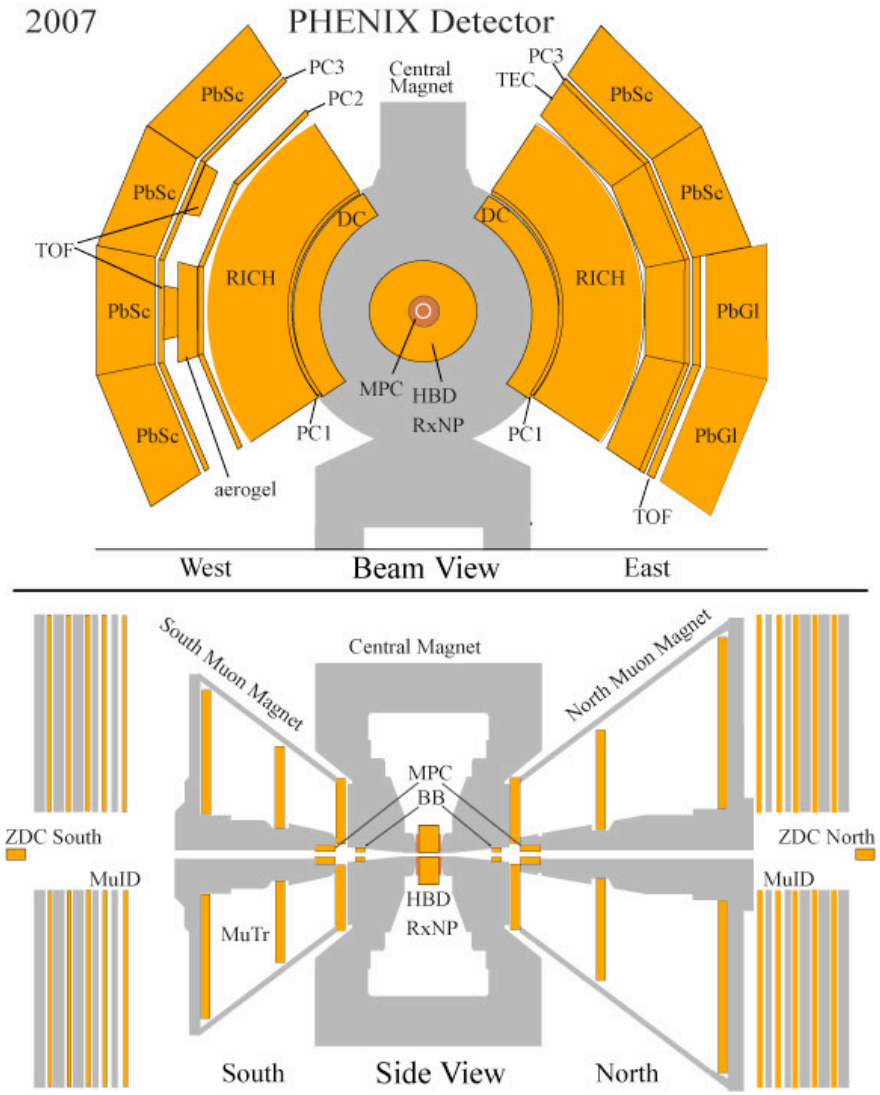
- 62 GeV Cu+Cu/Au+Au data:
  - $\bar{p}/\pi^-$ ratio: baryon enhancement still exists in central Au+Au 62 GeV and Cu+Cu 62 GeV.
  - R_{AA} (by ISR fit, limited p_T < 2.5 ~ 3.0 GeV/c)
    - π: moderate suppression in Au+Au 62 GeV, unity for Cu+Cu 62 GeV.
    - $\bar{p}$: small differences between Cu+Cu and Au+Au, close to one.

- **Data indicates that an onset of baryon anomaly at RHIC is in between 22 GeV and 62 GeV.**

Outlook

- **PHENIX high p_T PID upgrade (Physics):**
  - Jet correlations of PID particles, to study the origin of the baryon enhancement.
  - Detailed study of fragmentation mechanisms of p, $\bar{p}$ at high p_T (> 5 GeV/c).
  - Λ, $\bar{\Lambda}$ spectra and v_2 high p_T (> 5 GeV/c).

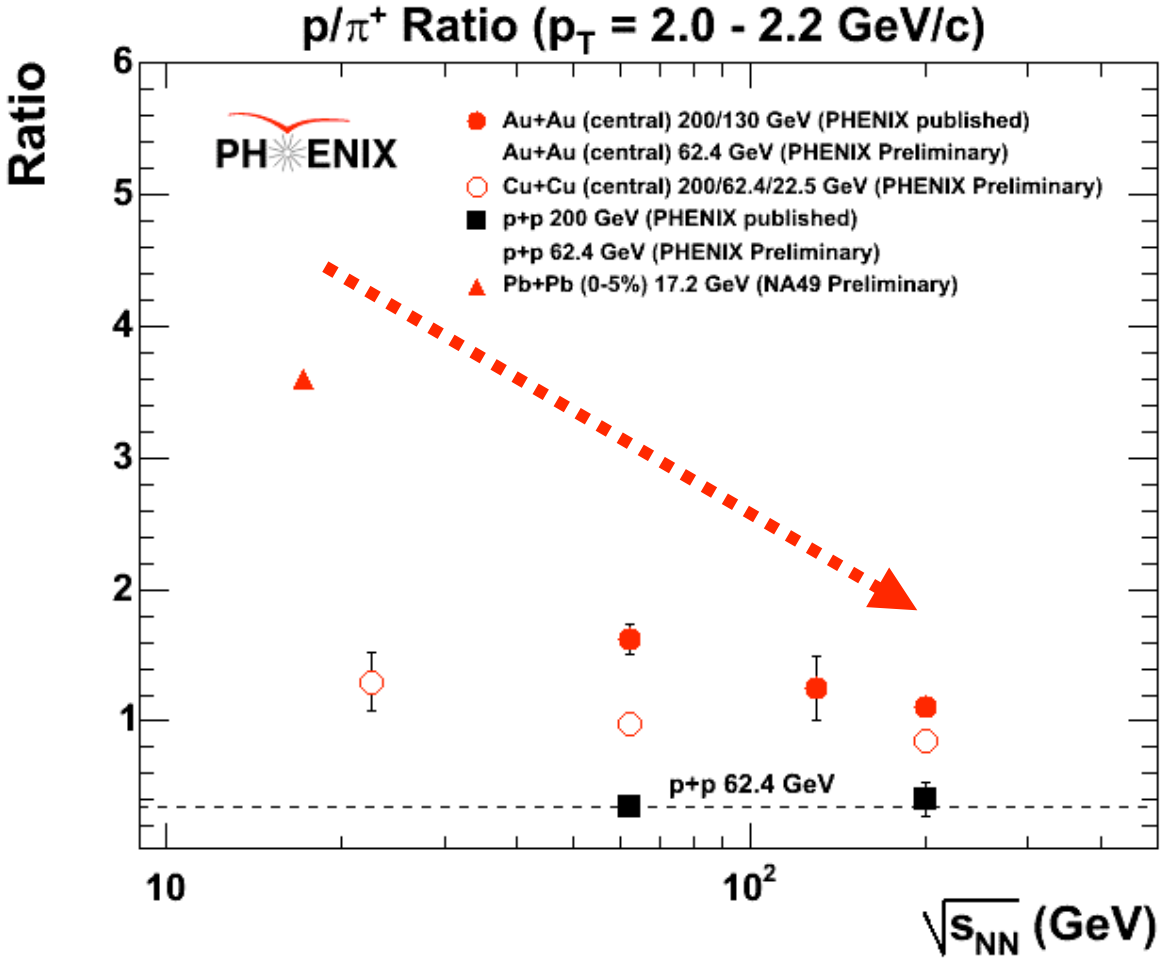
- **RHIC-II program:**
  - Exploring QCD phase diagram in detail by **the beam energy scan($\sqrt{s_{NN}}$ = 5 - 65 GeV) and species scan**, to study the bulk properties of produced QCD matter, **near the critical end point**, which maybe accessible in RHIC-II.




PHENIX
Map No. 3833 Rev. 2 UNITED NATIONS
August 1998
Department of Public Information
Cartographic Section

Backup Slides

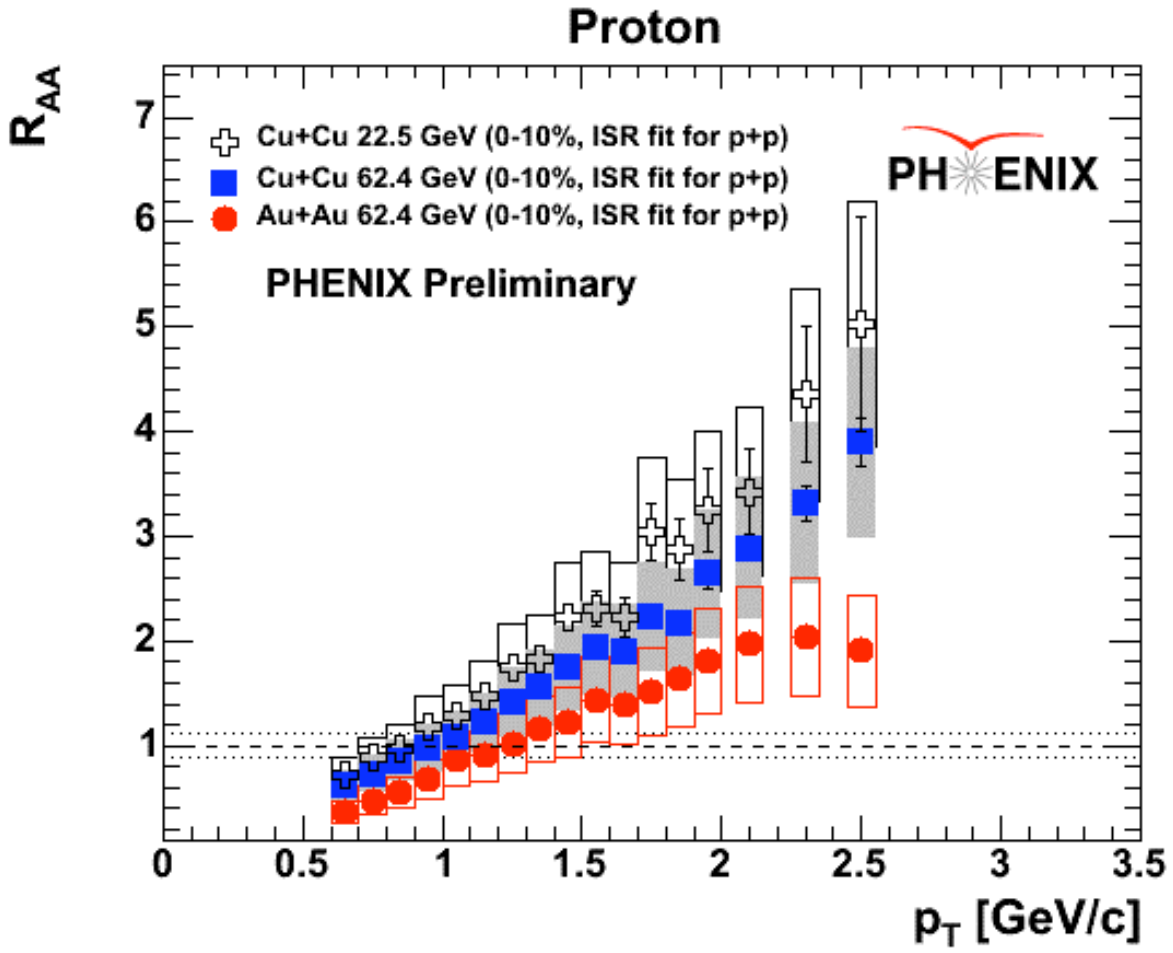
$\sqrt{s_{NN}}$ dep. of p/π^+ ratio (central)



- **decreasing as a function of √s.**

* No weak decay feed-down correction applied.

R_{AA} for protons (by ISR fit)

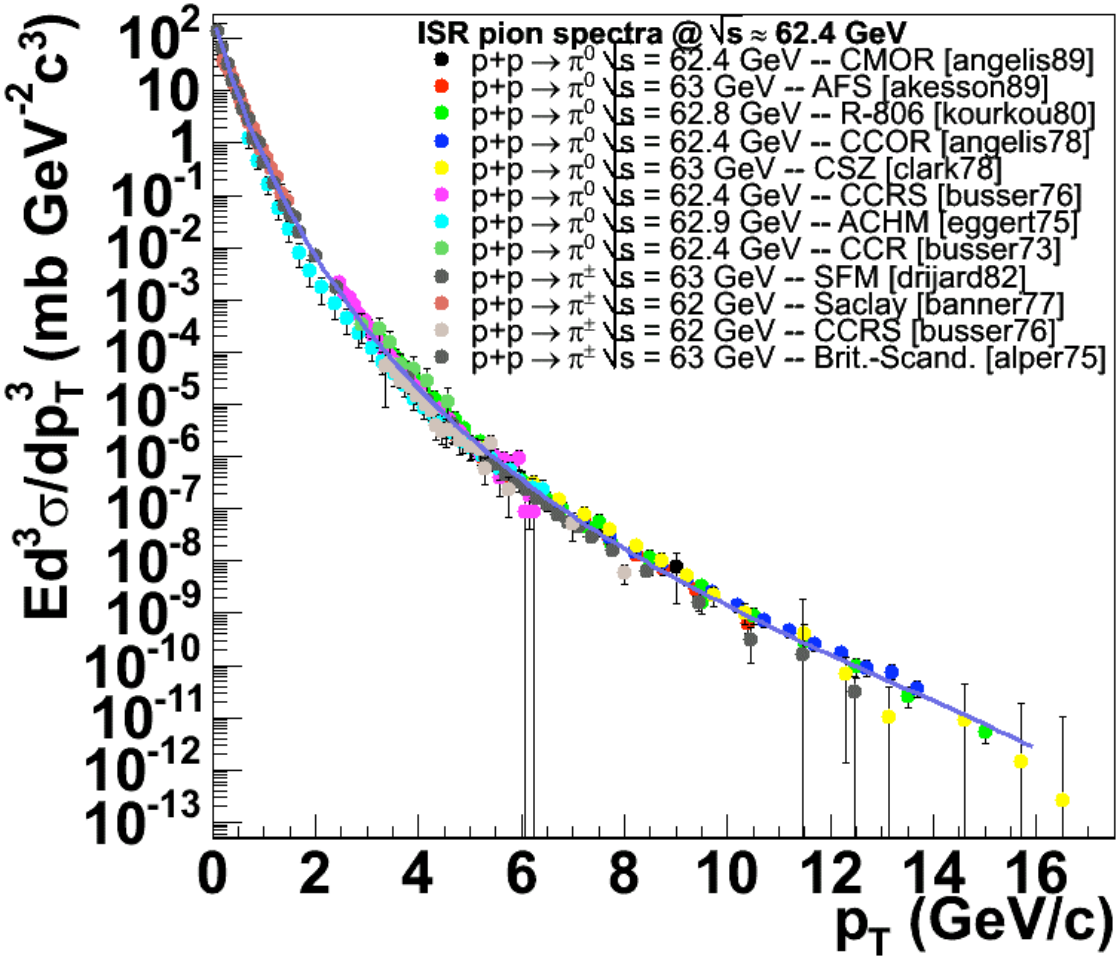


* No weak decay feed-down correction applied.

- Used ISR data at 63 GeV (Alper. NPB 100, 237) for p+p reference.
- Largest R_{AA} for Cu+Cu 22.5 GeV.
- R_{AA} for Au+Au 62.4 GeV is smaller than that in Cu+Cu 62.4 GeV.

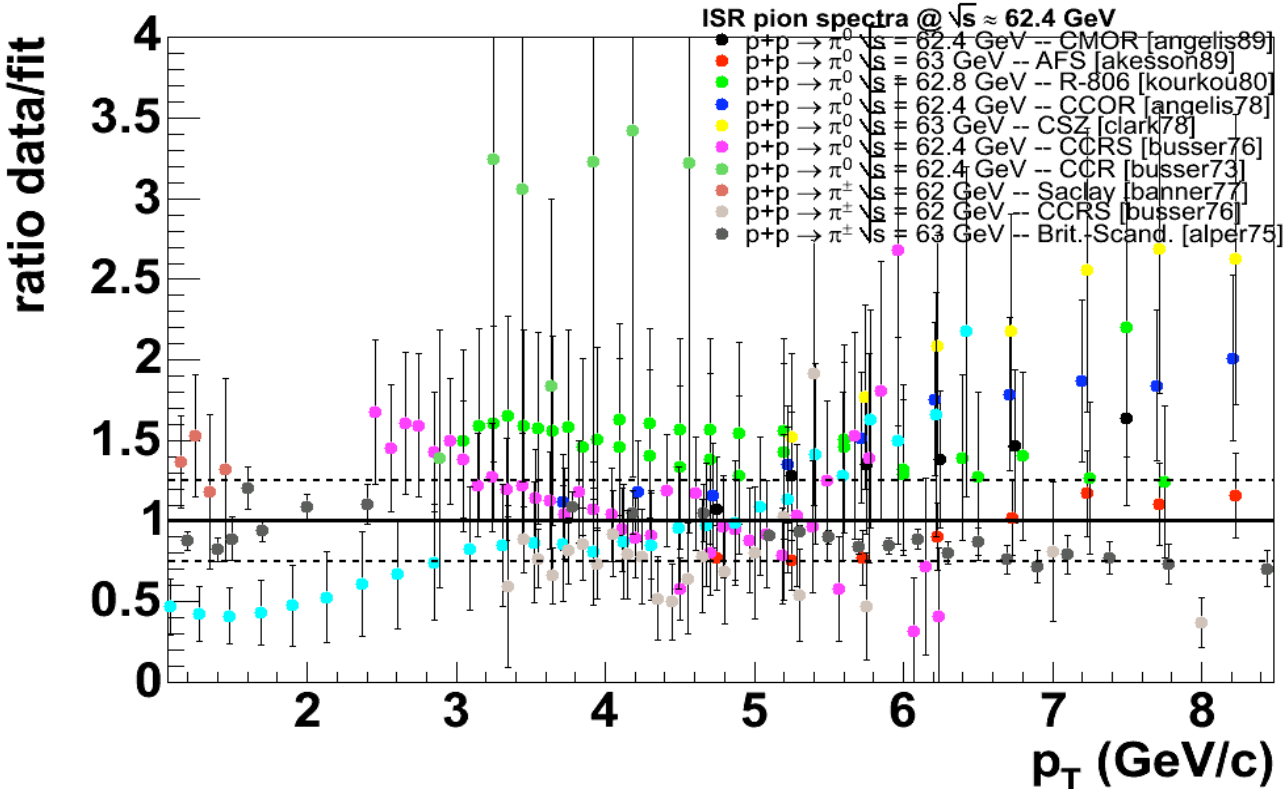
Reference data (p+p 62.4 GeV)

- p+p parameterization at 62.4 GeV: Fit to existing (ISR) data at similar energies (D.d'Enterria. J.Phys.G31, S491 (2005))



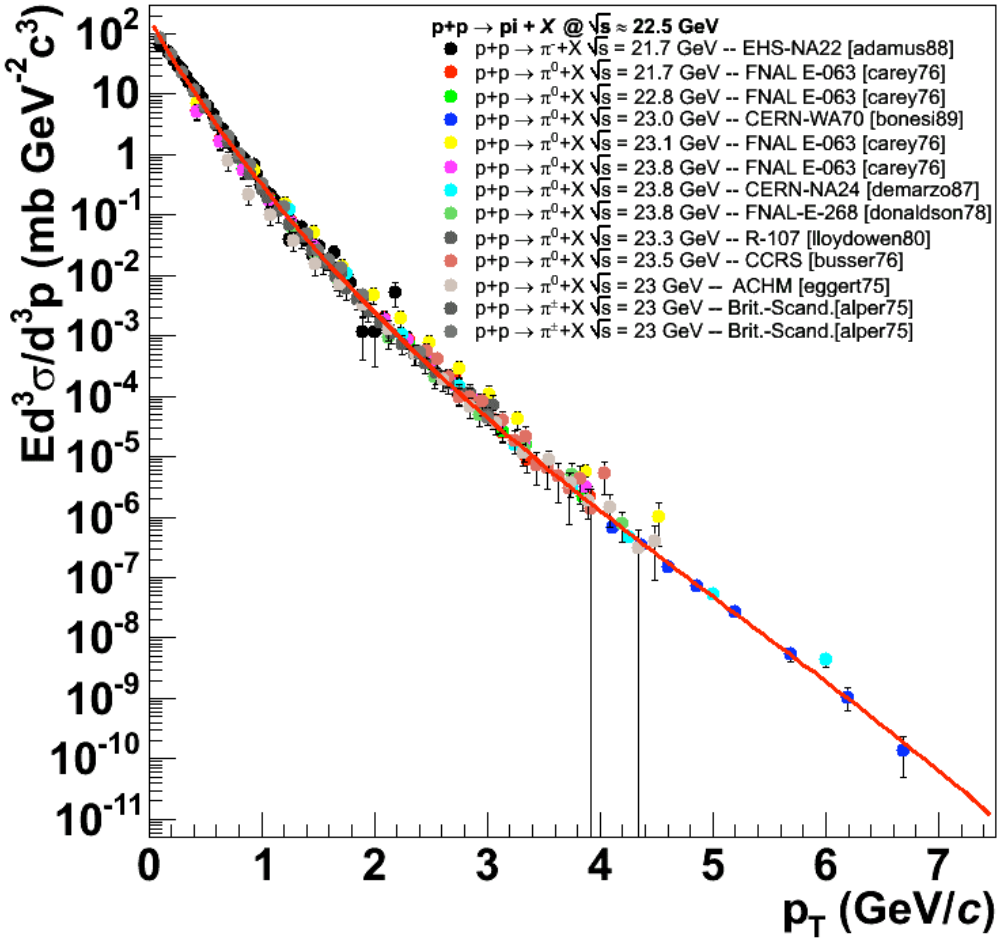
Reference data (p+p 62.4 GeV)

- Problem: data sets inconsistent => large error

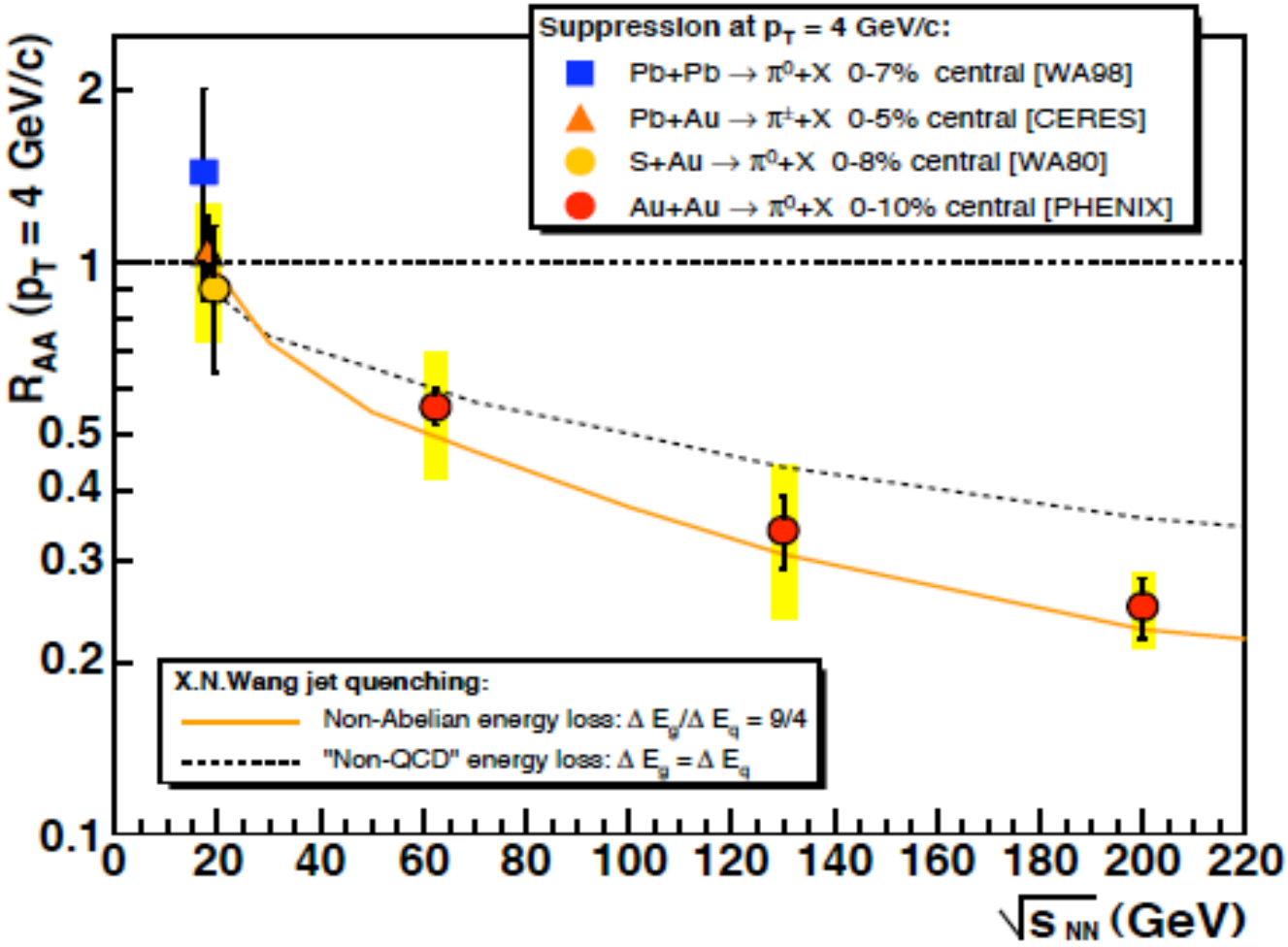


Reference data (p+p 22.5 GeV)

- p+p parameterization at 22.4 GeV: Fit to existing data at similar energies (D.d'Enterria. J.Phys.G31, S491 (2005))



π^0 R_{AA} vs. $\sqrt{s_{NN}}$



D. d'Enterria, nucl-ex/0504001