# Measurement of High-$p_T$ Identified Charged Hadrons in $\sqrt{s_{NN}}$ = 200 GeV Au+Au Collisions at RHIC-PHENIX

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1

## Outline

1. Physics Motivation
2. PHENIX detector
3. Data Analysis
   - $p_T$ spectra measurement
   - Particle Identification (PID)
   - Background subtraction
4. Results
   - $p_T$ spectra (proton, antiproton)
   - pbar/p ratio vs. $p_T$
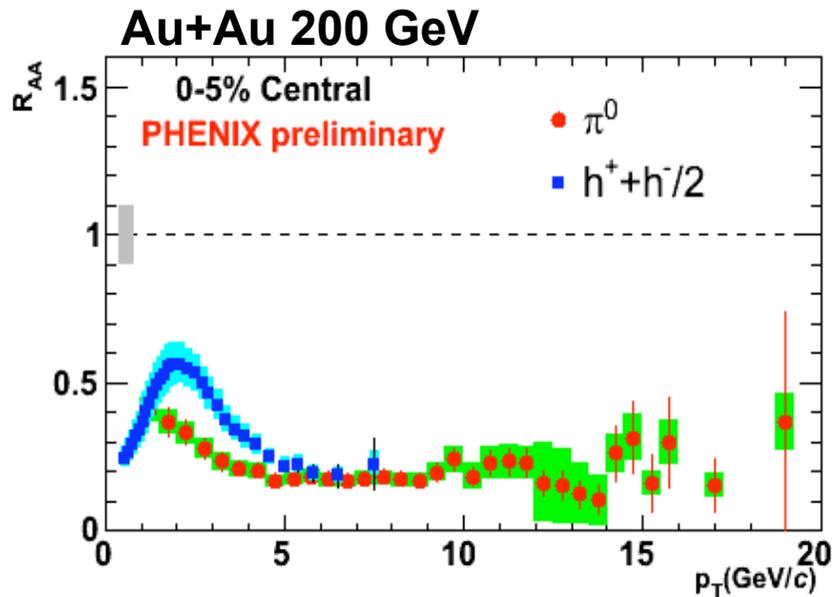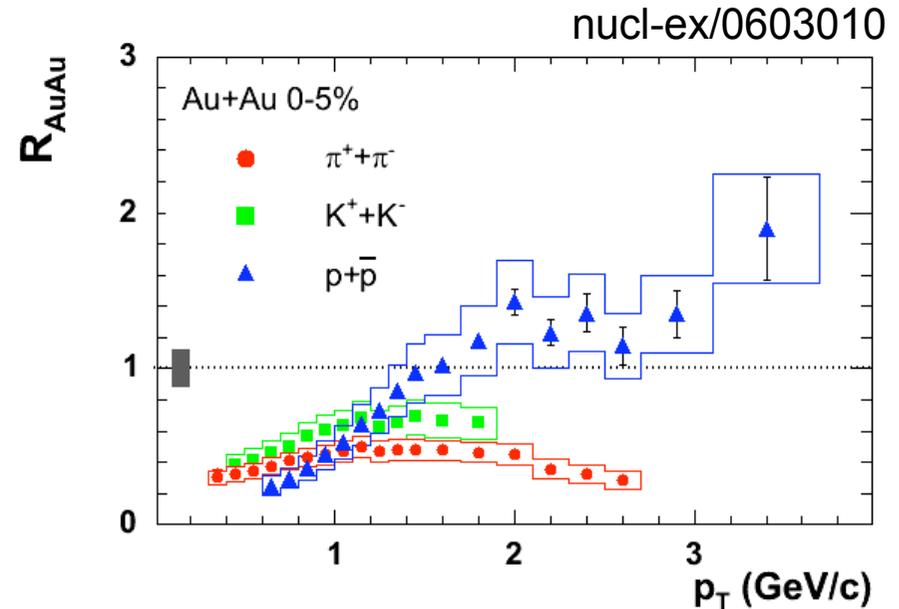   - p/$\pi$ ratio vs. $p_T$
5. Comparison with models
6. Summary

# Physics Motivation

## Nuclear Modification Factor $R_{AA}$

$$R_{AA}(p_T) = \frac{d^2 N^{AA}/dp_T d\eta}{T_{AA} d^2 \sigma^{NN}/dp_T d\eta}$$

nucl-ex/0603010



**Au+Au 200 GeV**

0-5% Central
PHENIX preliminary
- $\pi^0$
- $h^+ + h^-/2$

Au+Au 0-5%
- $\pi^+ + \pi^-$
- $K^+ + K^-$
- $p + \bar{p}$

High-$p_T$ suppression due to parton energy loss in the medium (jet quenching).
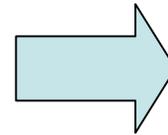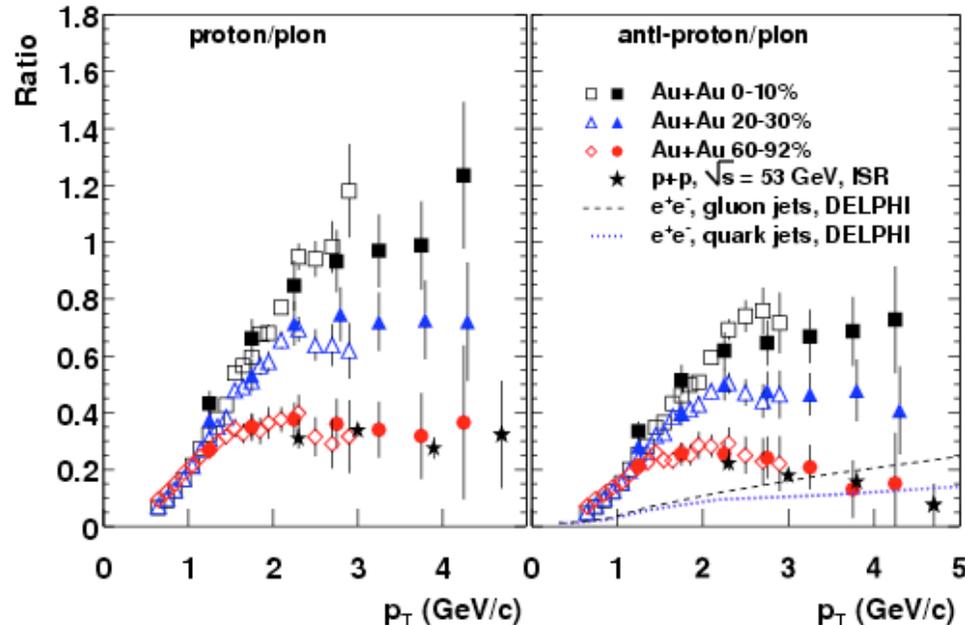
The suppression patterns depend on particle type. Protons are enhanced, while pions and kaons are suppressed.

# Physics Motivation

## Baryon Enhancement

Motivations:

PRL 91, 172301 (2003)



What is the origin of (anti-)proton enhancement at intermediate $p_T$?

To distinguish the different production mechanism for protons and pions at intermediate and higher $p_T$.

Possible sources (medium effect) :
- Strong radial flow
- Recombination
- Baryon junction

- $p/\pi$ ratio ~1 for central Au+Au at intermediate $p_T$ (2-4 GeV/c).
- Larger than expected from fragmentation (measured in pp, $e^+e^-$).
- Baryon / Meson difference at intermediate $p_T$.
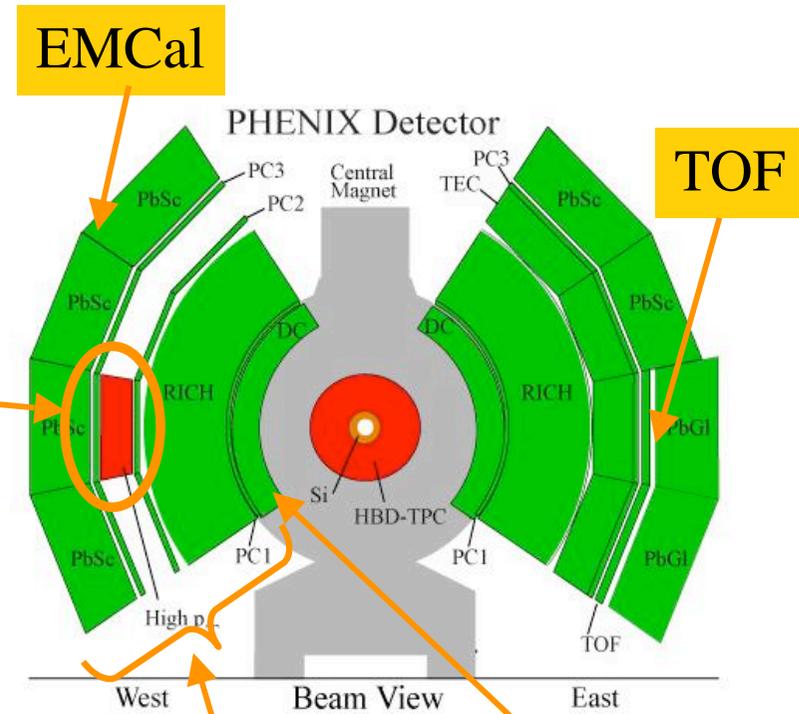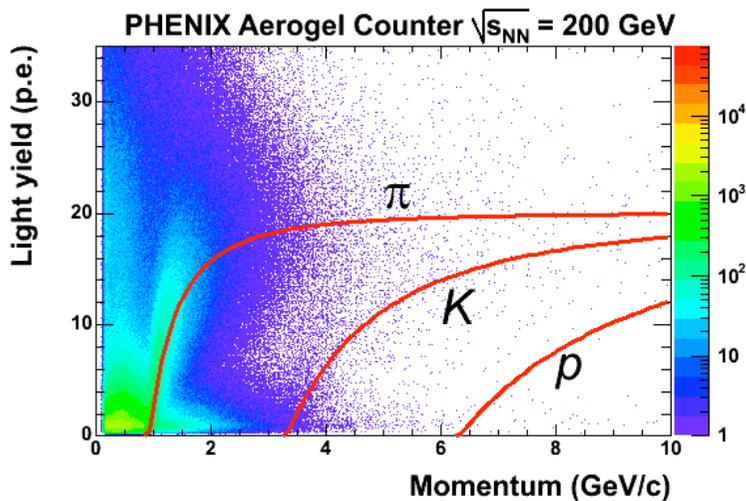  (on $R_{AA}$ (nuclear modification factor) , $v_2$ (elliptic flow) etc.)

4

# PHENIX detector

- Central Arm Detectors
  (magnetic spectrometer)
- Event Characterization detectors

**EMCal**

**TOF**

**Aerogel Cherenkov Counter**

## Hadron Identification at High $p_T$

- n = 1.0113.
- Full installation in 2004.
- Proton separation from $\pi$ /K
  up to 8 GeV/c.



PHENIX Detector

PC3
Central Magnet
PC3
TEC
PbSc
PC2
PbSc
DC
DC
RICH
RICH
PbSc
Si
HBD-TPC
PbGl
PbSc
PC1
PC1
PbGl
High p
TOF
West        Beam View        East

**Drift Chamber
(momentum meas.)**

**Tracking detectors
(PC1,PC2,PC3)**



PHENIX Aerogel Counter $\sqrt{s_{NN}}$ = 200 GeV

Light yield (p.e.)

$\pi$

K

p

Momentum (GeV/c)



5

# Data Analysis

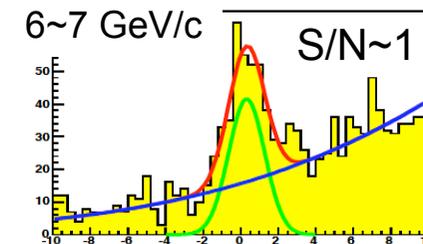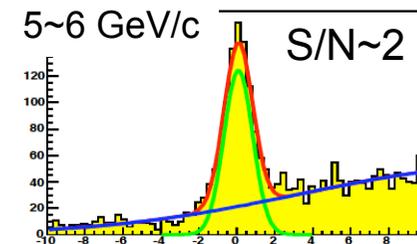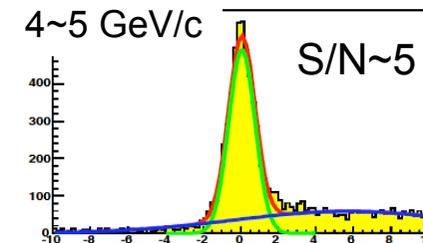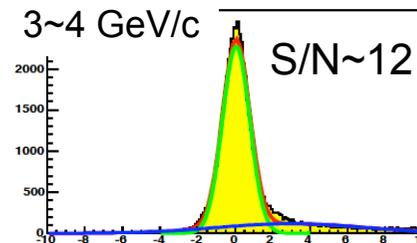- Data set: Au+Au 200 GeV (taken in Run4, 2003-2004)
- High statistics (440M events used)
- Charged Hadron PID:
    - TOF
    - Aerogel (for PID extension toward high $p_T$, Run4-)
- MC Simulations:
    - Acceptance, efficiency (occupancy) corrections
- No feed-down correction.

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## BG Subtraction

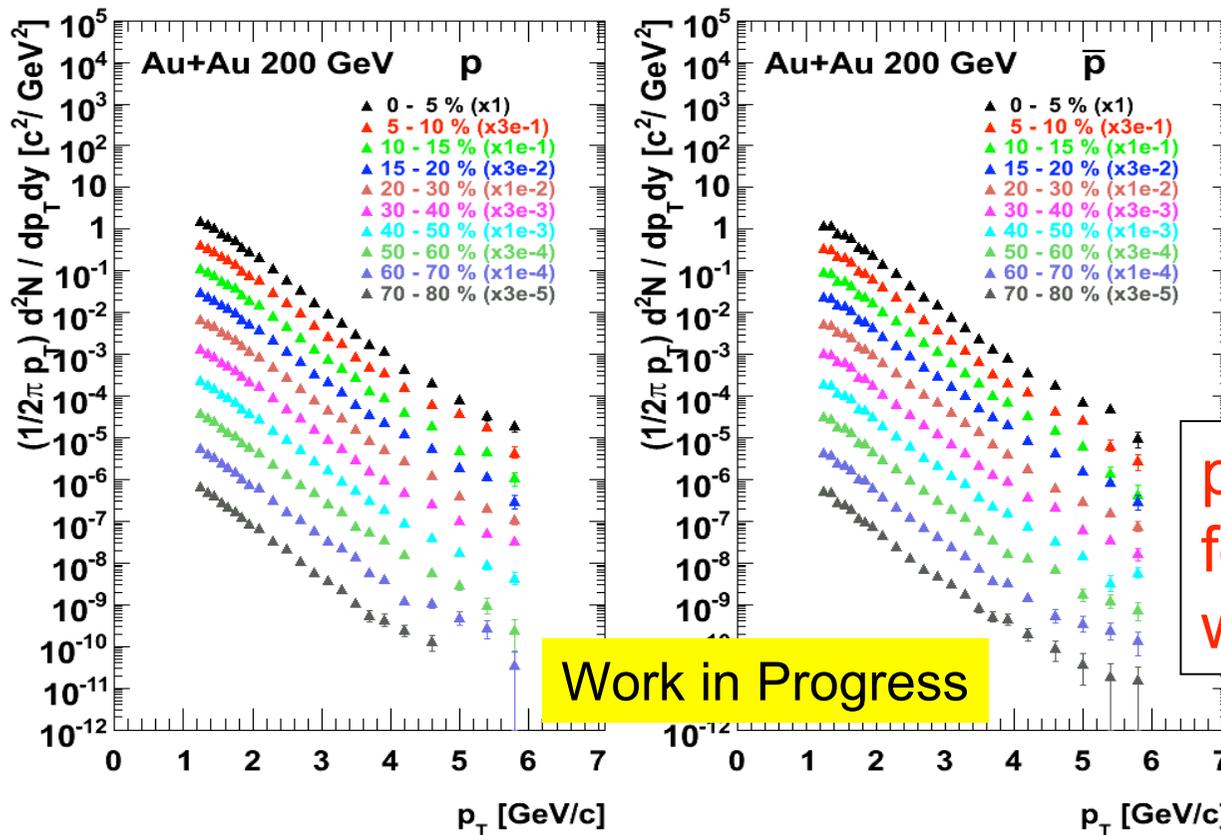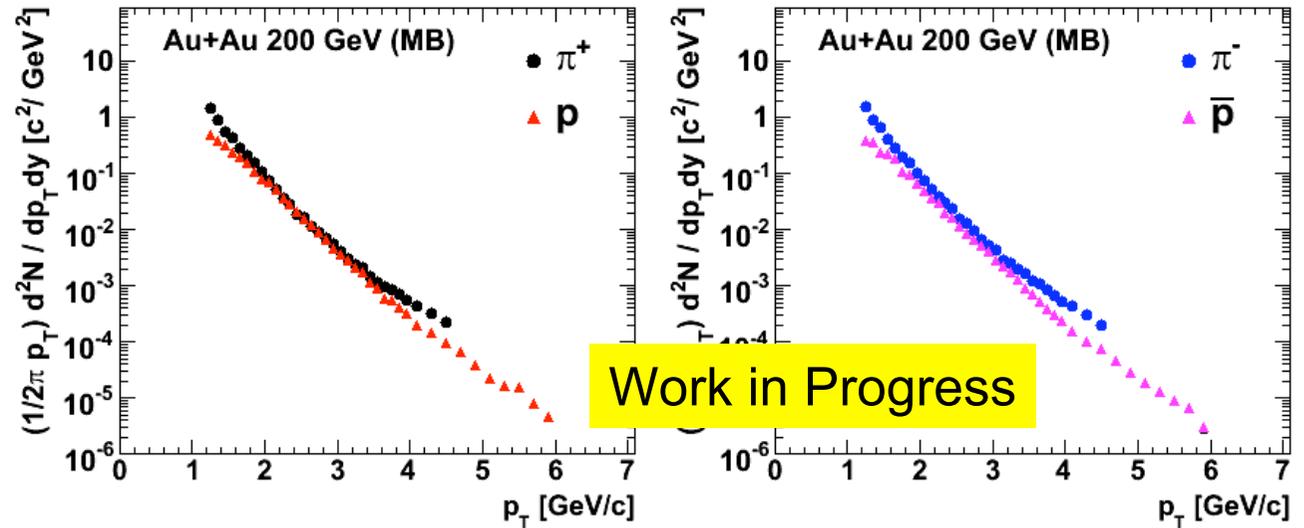Using residual bending
in $\phi$ direction.

Backgrounds:
- random association
- electrons from photon conversion
- decayed products



3~4 GeV/c    S/N~12

4~5 GeV/c    S/N~5

5~6 GeV/c    S/N~2

6~7 GeV/c    S/N~1

track matching residual (a.u.)

# Results

JPS 2006 Spring (Ehime University, 3/27/2006)        M. Konno

## $p_T$ spectra of (anti-)protons



Au+Au 200 GeV (MB)  $\pi^+$  p

Au+Au 200 GeV (MB)  $\pi^-$  $\bar{p}$

$(1/2\pi\,p_T)\,d^2N/dp_T\,dy\;[c^2/GeV^2]$

$p_T\;[GeV/c]$

Work in Progress

Au+Au 200 GeV  p

Au+Au 200 GeV  $\bar{p}$

- 0 - 5 % (x1)
- 5 - 10 % (x3e-1)
- 10 - 15 % (x1e-1)
- 15 - 20 % (x3e-2)
- 20 - 30 % (x1e-2)
- 30 - 40 % (x3e-3)
- 40 - 50 % (x1e-3)
- 50 - 60 % (x3e-4)
- 60 - 70 % (x1e-4)
- 70 - 80 % (x3e-5)

$p_T$ reach extended for (anti-)protons with fine centrality bins.

Work in Progress

8

# pbar/p vs. $p_T$

Central

Peripheral
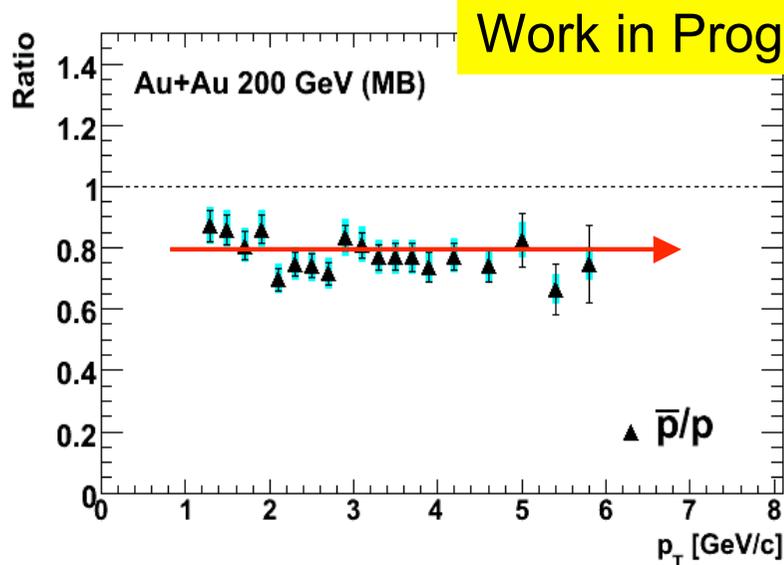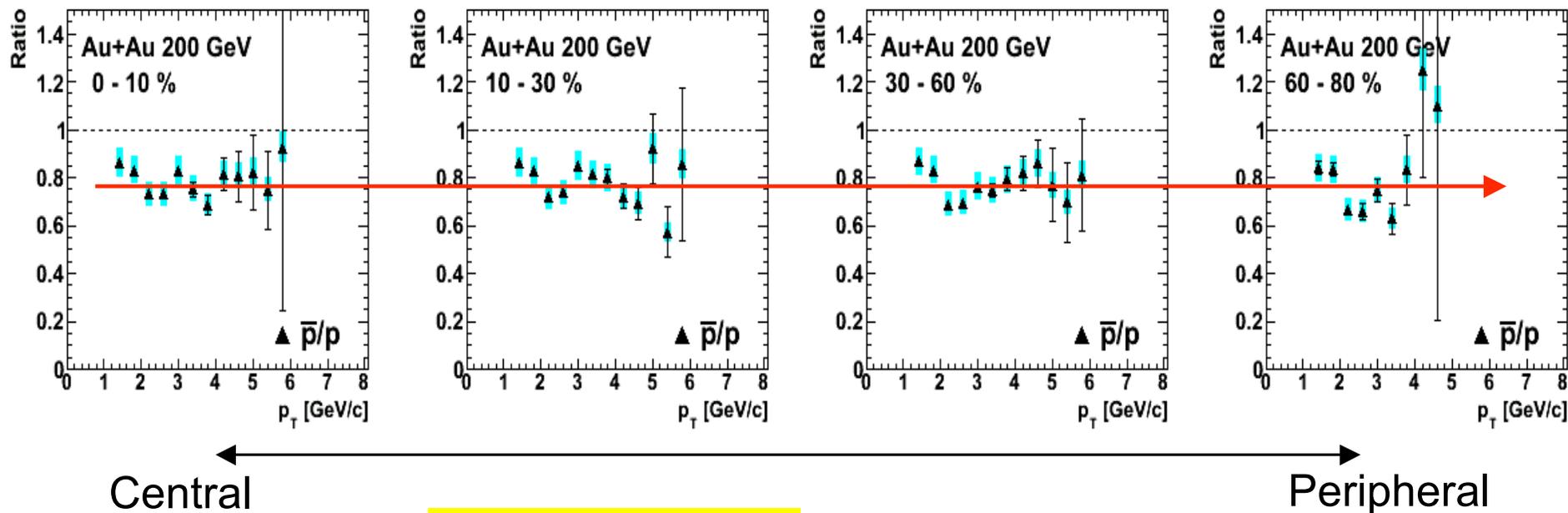
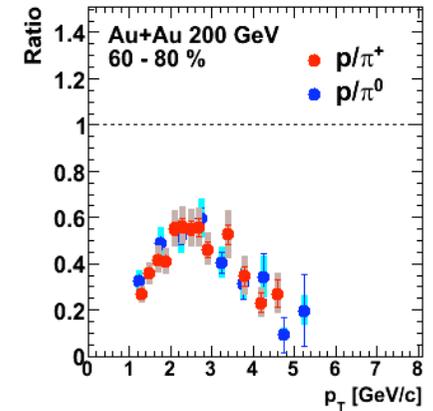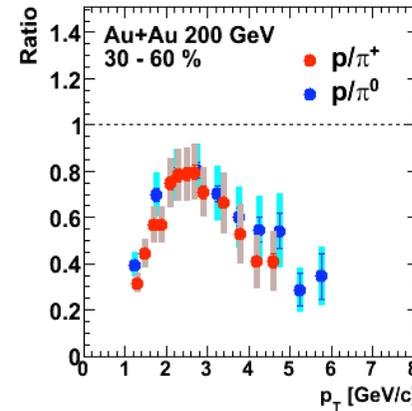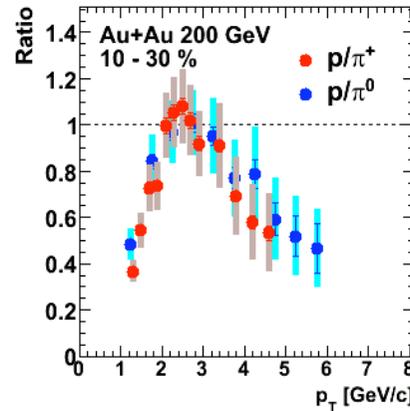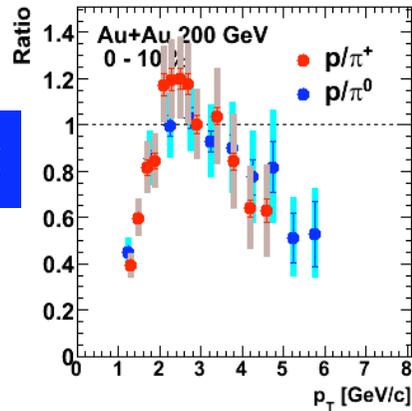No significant centrality or $p_T$ dependence (up to 6 GeV/c).

9

# p/π vs. p$_T$
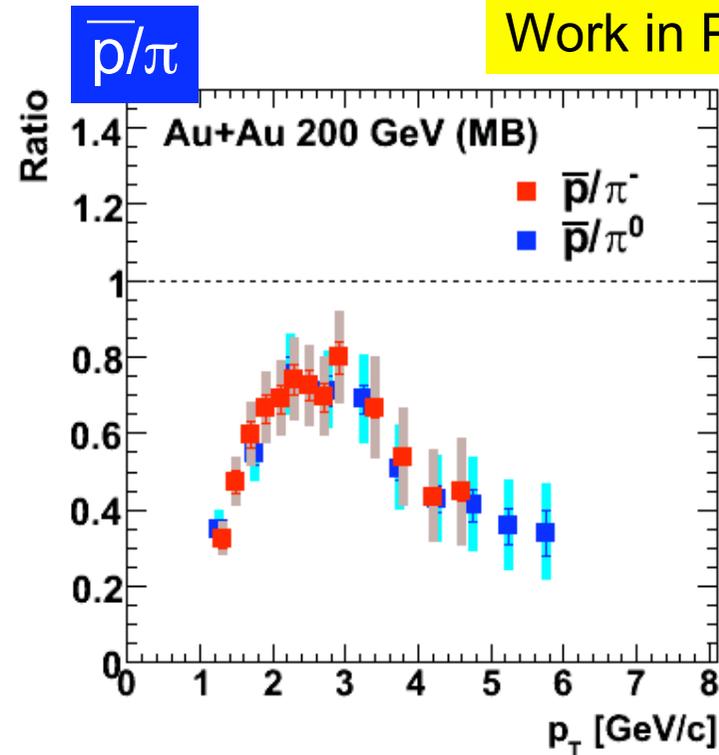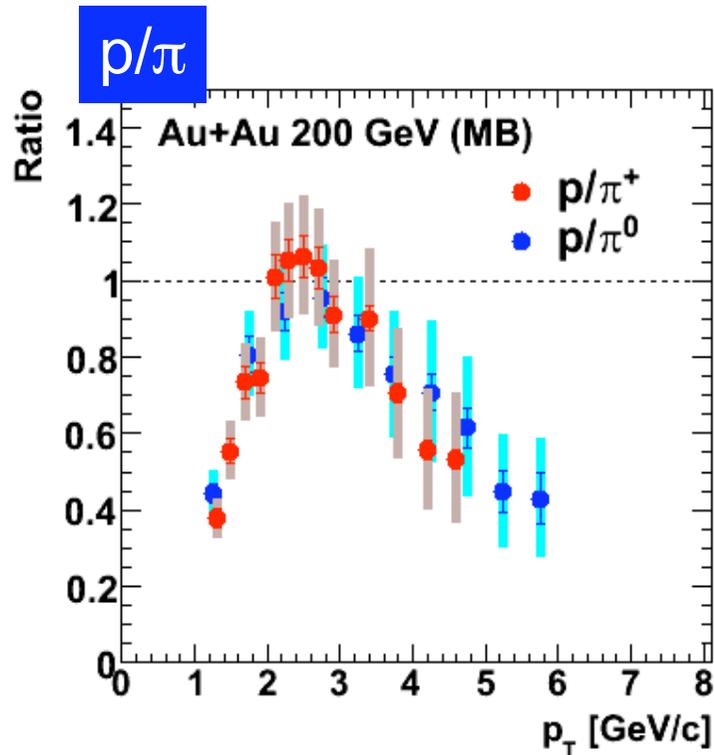


- p/π (pbar/π) ratios seem to turn over at intermediate p$_T$, and close to the value of fragmentation at higher p$_T$.
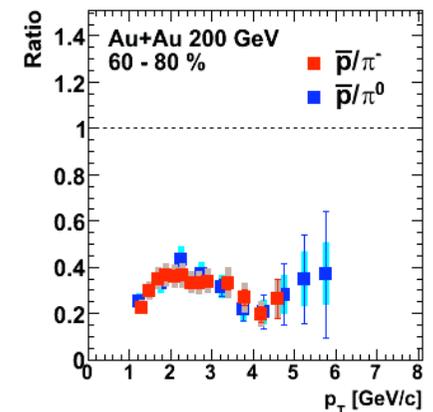- Still large systematic errors.
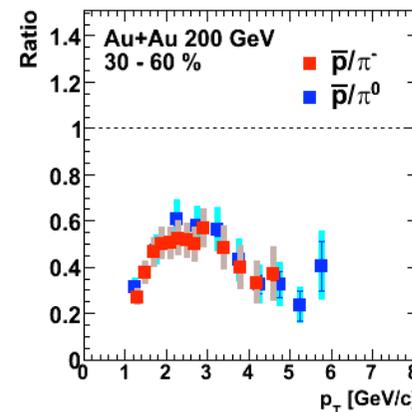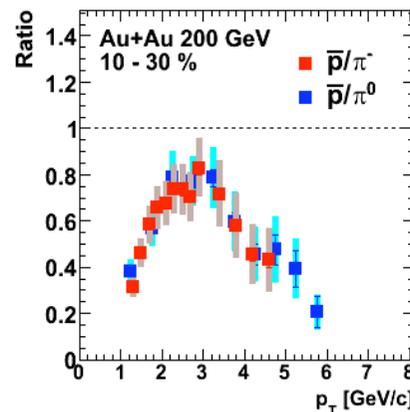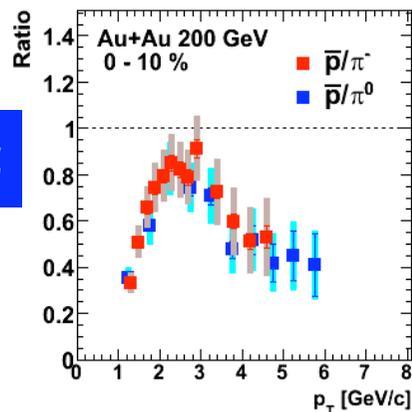
# $p/\pi$ vs. $p_T$ (centrality dep.)

Work in Progress
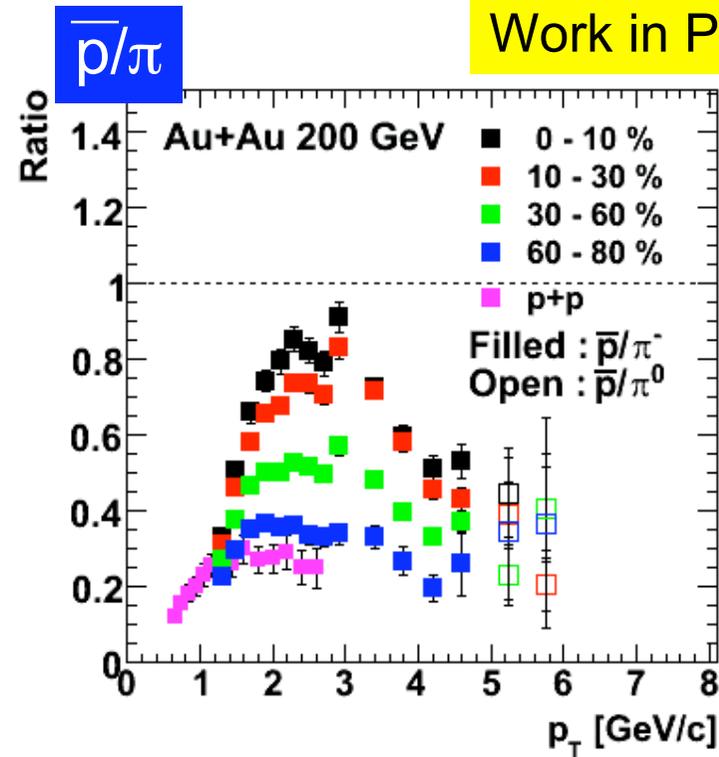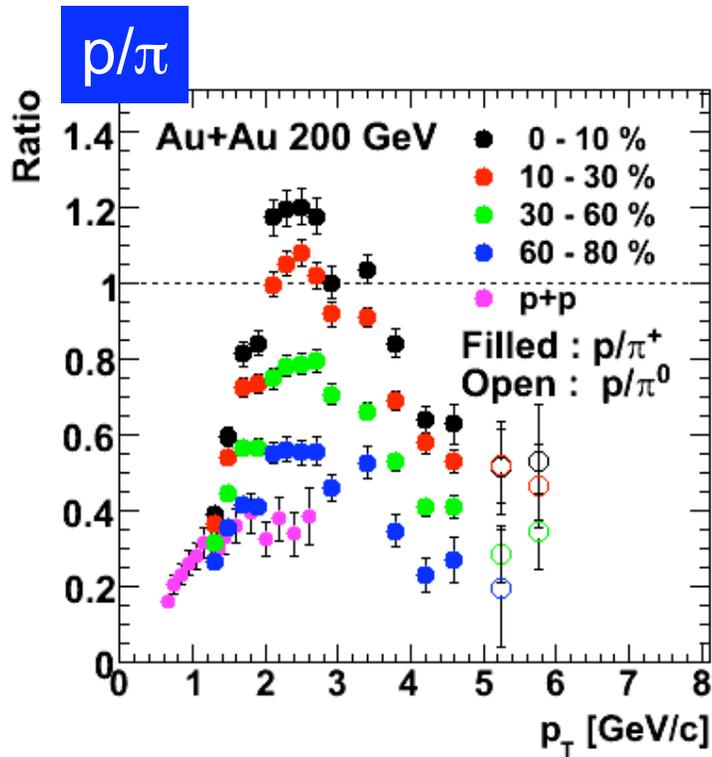
\* No feed-down correction.



Central ⟷ Peripheral

- $p/\pi$ ratios look to have a peak at intermediate $p_T$ (2-4 GeV/c).
- Clear peak in central events than that in peripheral.
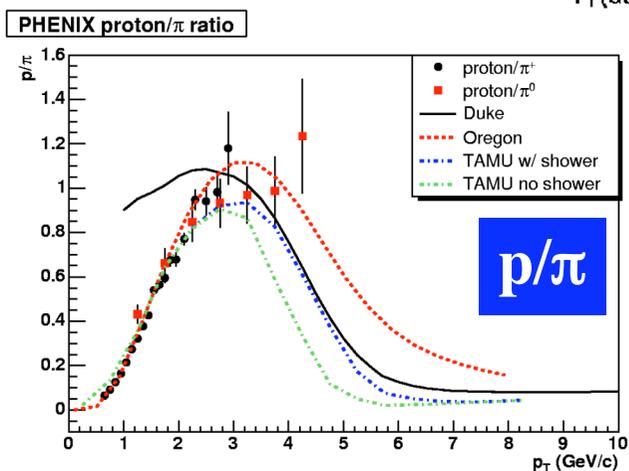
11

# p/π vs. p$_T$ (centrality dep.)



p/π

$\overline{p}$/π

Work in Progress

* No feed-down correction.
* p+p data (nucl-ex/0603010)

- Centrality dependence seen in the magnitude.
- p/π ratio in peripheral lies slightly above the p+p ratio.

# Comparison with Models

PRC 68, 044902 (2003)

PRC 69, 034908 (2004)

PRC 67, 034902 (2003)

**p/π**

PRL 90, 202302 (2003)

**p/π**

PHENIX proton/π ratio
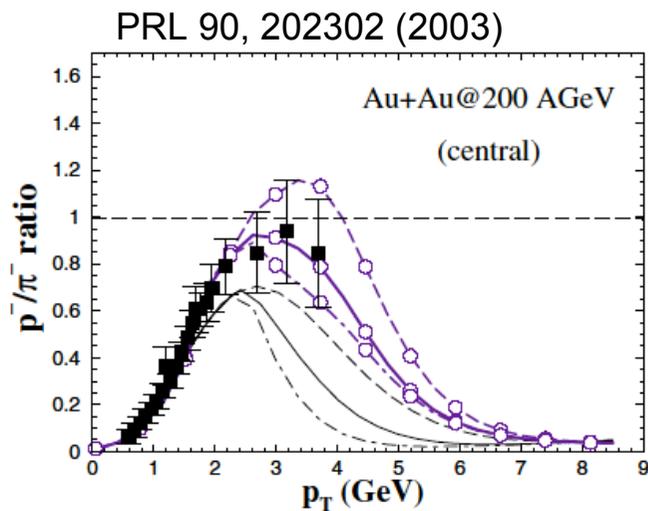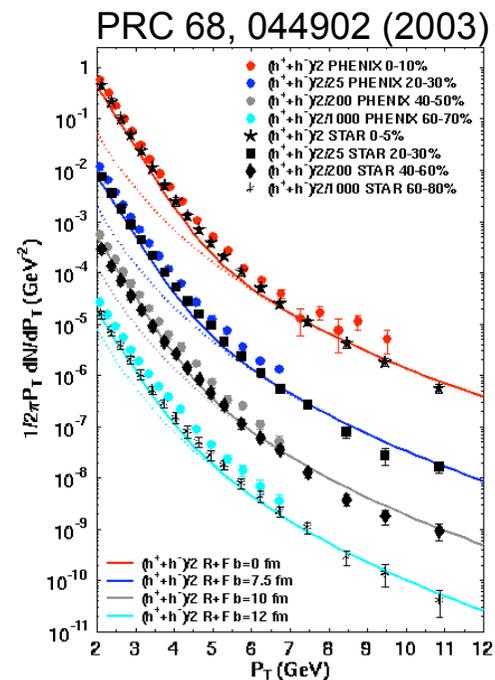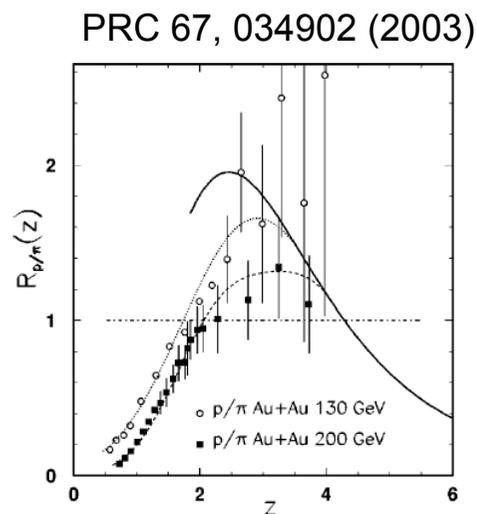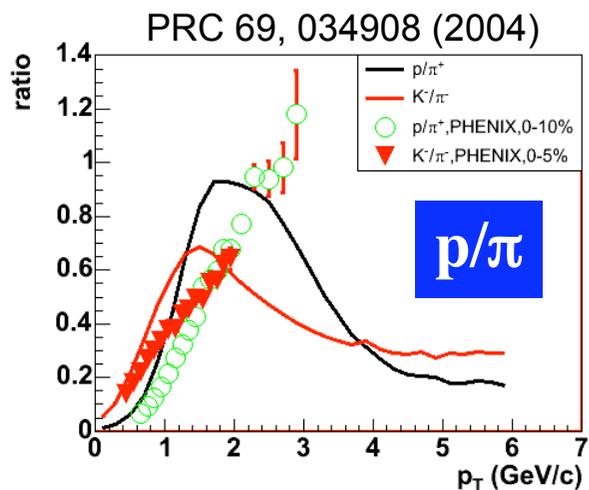
- Only look through several models (recombination, hydro+jet, …).
- Novel mechanism of hadron production at intermediate $p_T$.

## Summary

- $p_T$ reach of PID (especially for p, pbar) extended with:
  - (1) High statistics Au+Au data
  - (2) New PID detector (Aerogel)

- Results are still work-in-progress.
  - pbar/p ratio:
    - No centrality or $p_T$ dependence.
  - p/$\pi$ ratio:
    - Centrality dependence seen in the magnitude.
    - Indicating transition from soft to hard at intermediate $p_T$.

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## Next

- Improve data analysis, reduce sys. errors for PID at high $p_T$.
- Analyze Run5 p+p (abundant) data to make $R_{AA}$ at higher $p_T$.
- MRPC-TOF ($\sigma_{TOF}$~100ps) to be installed for PID upgrade.

14

# Backup slides

JPS 2006 Spring (Ehime University, 3/27/2006)　　　M. Konno
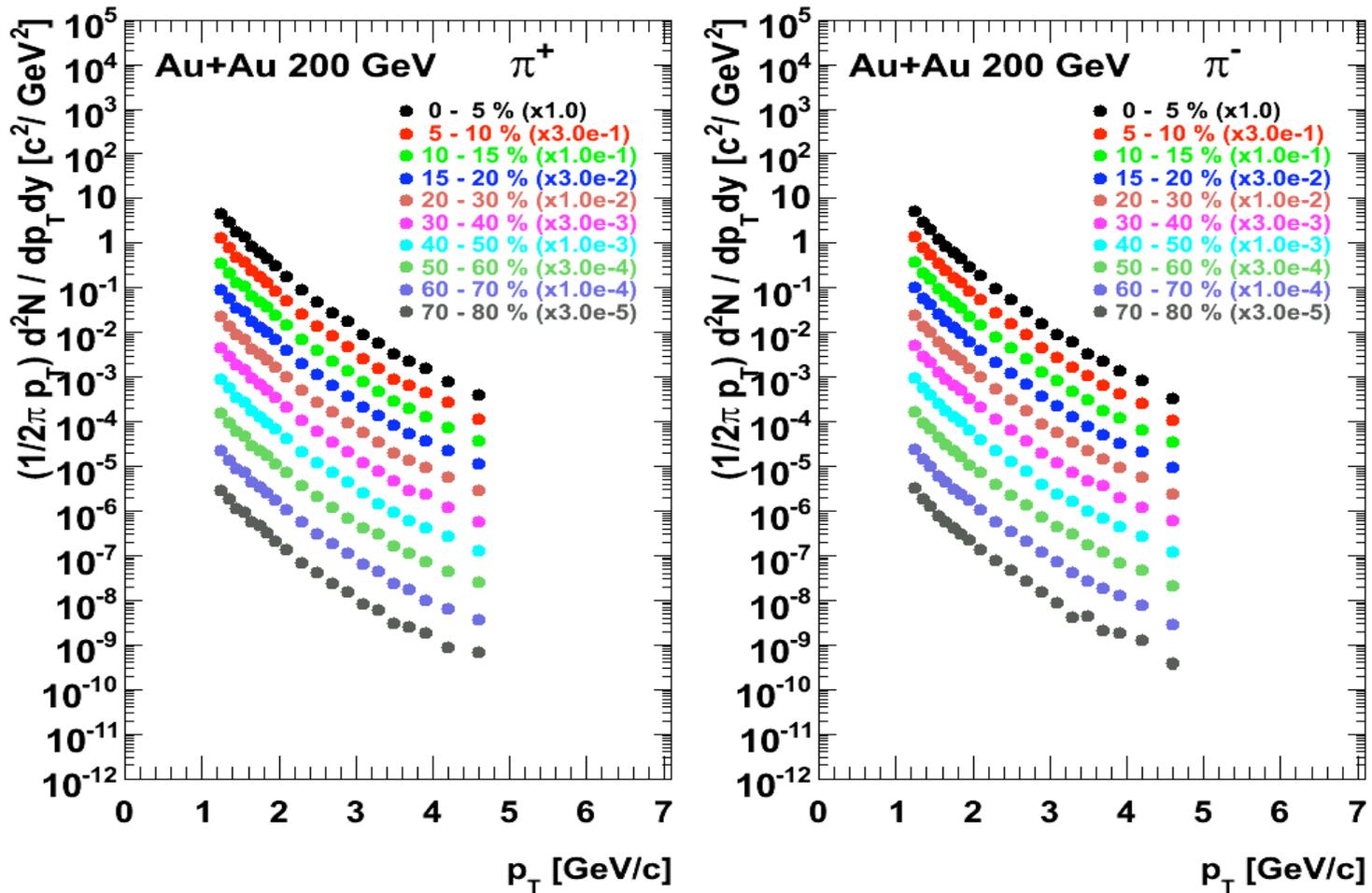
# PID demonstration
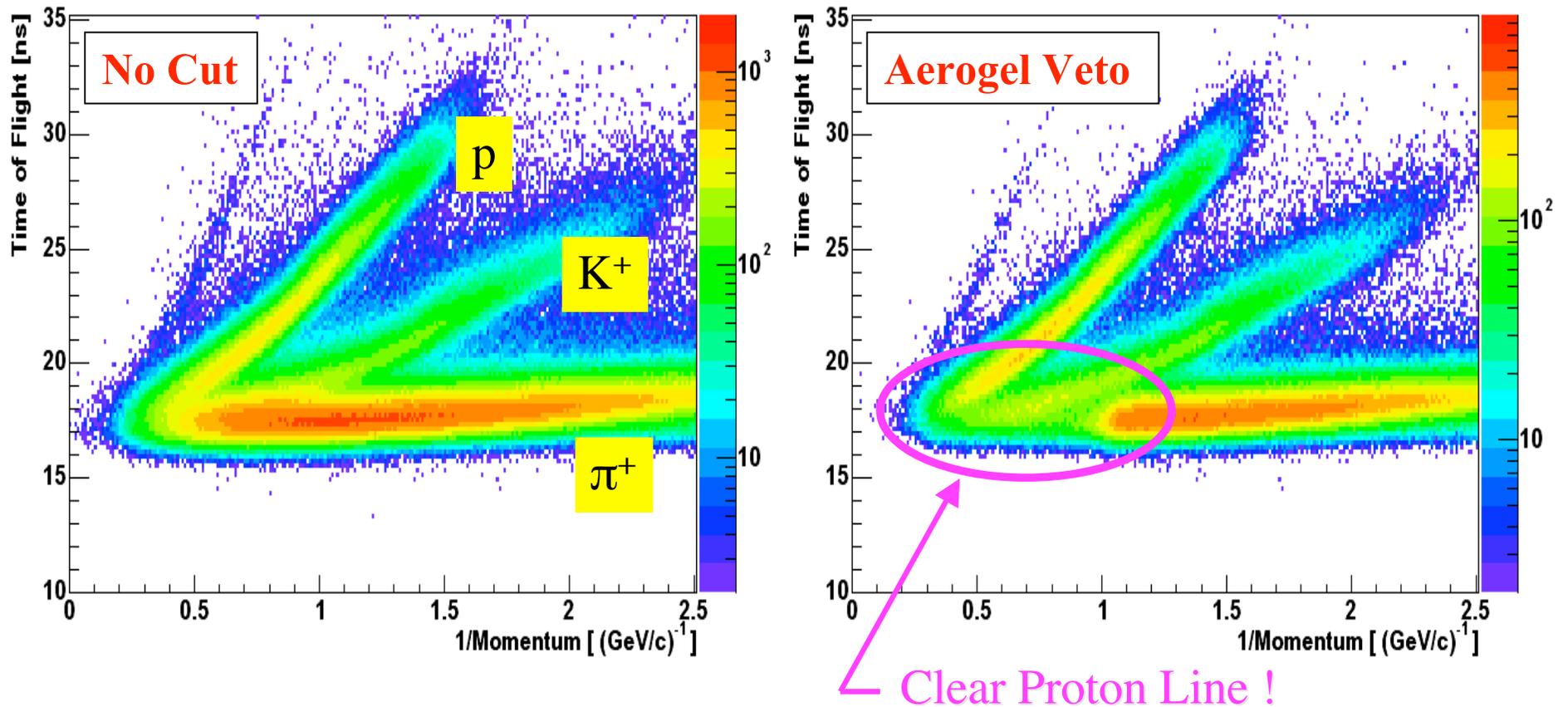


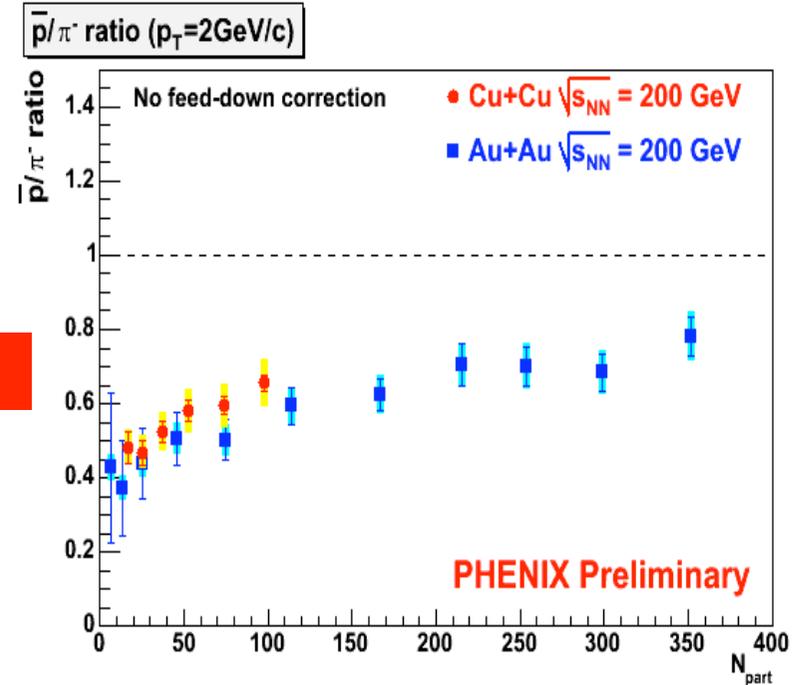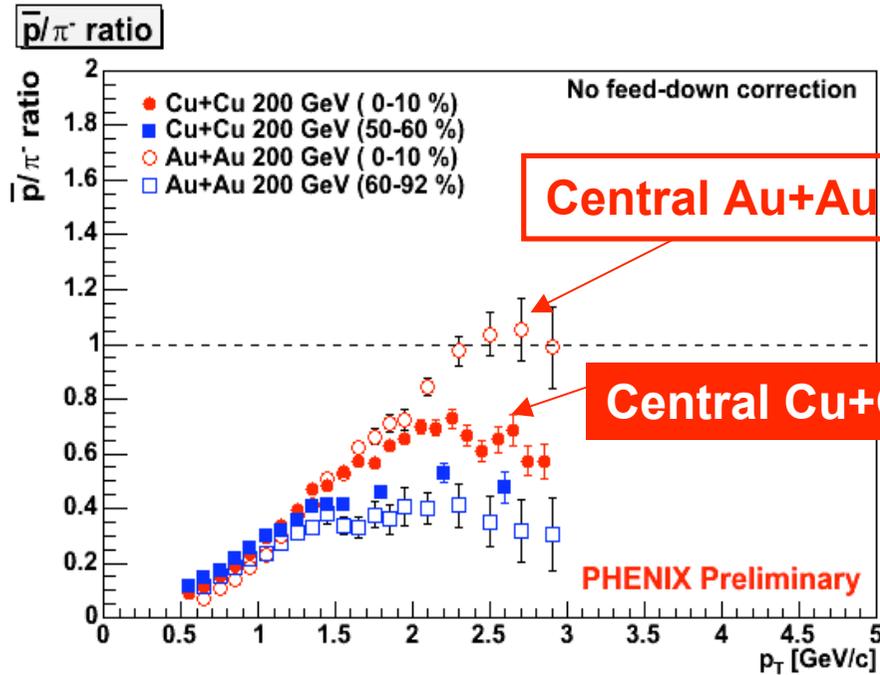- Mass square cut 2σ selection on EMCal-TOF.
- With (without) requiring Cherenkov light from Aerogel
    * Clear pion signal above the threshold (~1 GeV/c).
    * Proton separation up to ~7 GeV/c.

16

# Charged pion spectra
## identified with ACC

## p/π ratio in Cu+Cu / Au+Au

$\overline{p}/\pi^-$ ratio

Cu+Cu 200 GeV ( 0-10 %)
Cu+Cu 200 GeV (50-60 %)
Au+Au 200 GeV ( 0-10 %)
Au+Au 200 GeV (60-92 %)

No feed-down correction

**Central Au+Au**

**Central Cu+Cu**

PHENIX Preliminary

$p_T$ [GeV/c]

$\overline{p}/\pi^-$ ratio ($p_T$=2GeV/c)

No feed-down correction

Cu+Cu $\sqrt{s_{NN}}$ = 200 GeV
Au+Au $\sqrt{s_{NN}}$ = 200 GeV

PHENIX Preliminary

$N_{part}$

* No feed-down correction.

- Observed a large p,pbar contribution at intermediate $p_T$, as seen in 200 GeV data.
- $N_{part}$ dependences on particle ratios have similar trend as in Au+Au ($N_{part}$ scaling).
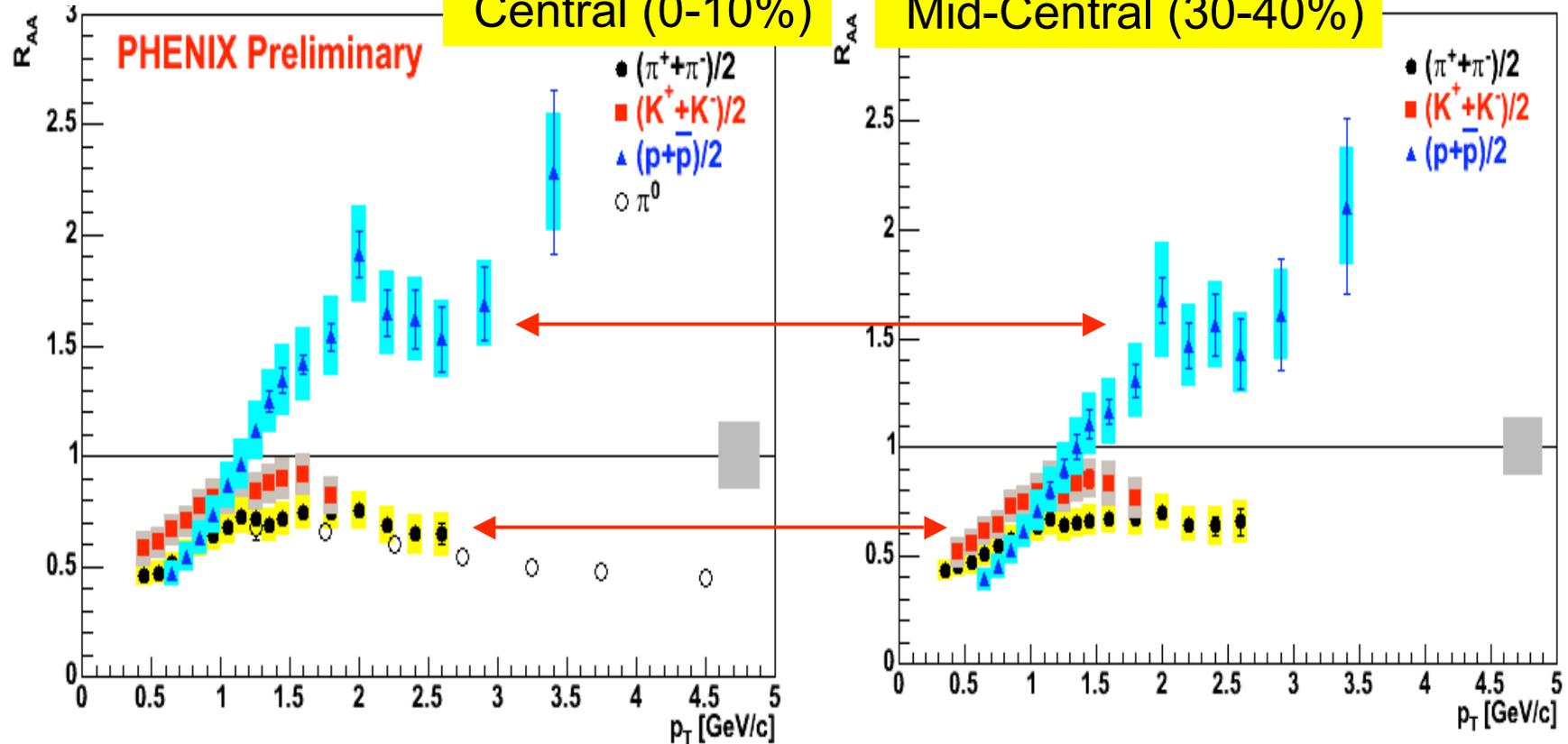
JPS 2006 Spring (Ehime University, 3/27/2006)     M. Konno

# $R_{AA}$ vs. $p_T$

$N_{part} \sim 98$

$N_{part} \sim 114$

Cu+Cu 200 GeV
Central (0-10%)

Au+Au 200 GeV
Mid-Central (30-40%)



PHENIX Preliminary

- $(\pi^+ + \pi^-)/2$
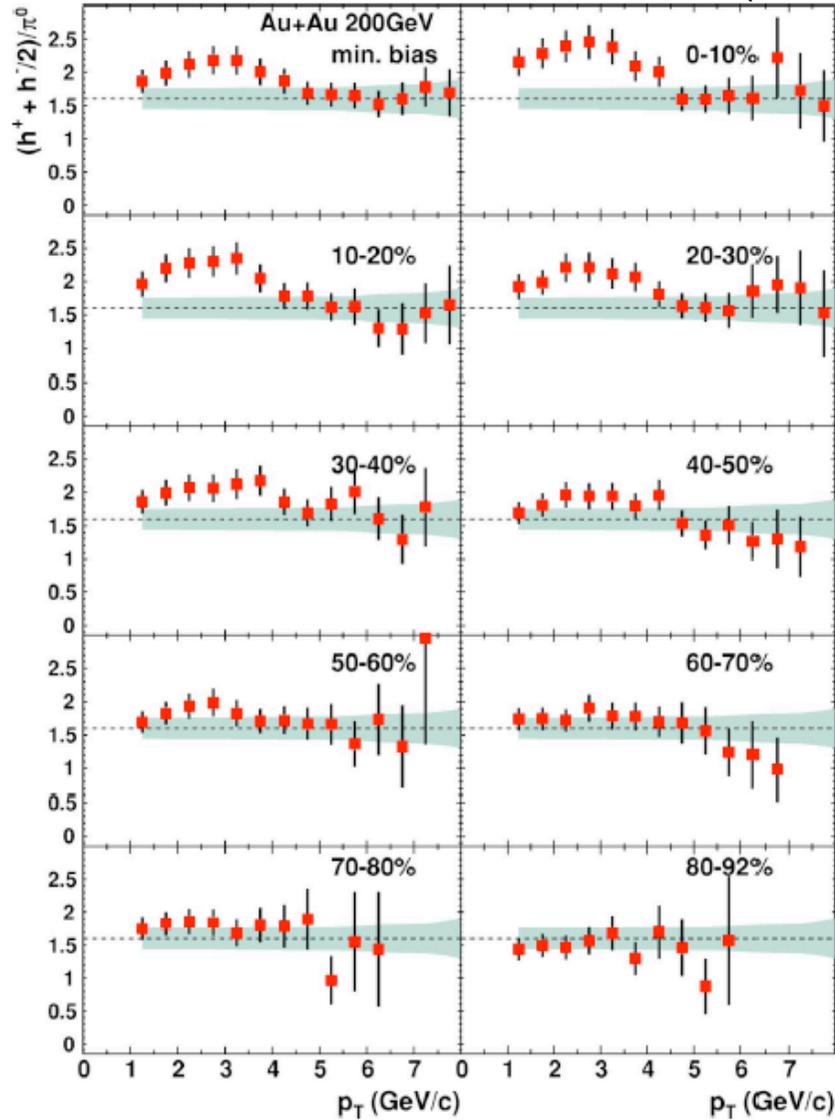- $(K^+ + K^-)/2$
- $(p + \bar{p})/2$
- $\pi^0$

* No feed-down correction.

- Similarity on $R_{AA}$ seen in Cu+Cu and Au+Au:
    - The magnitude of enhancement/suppression
    - Particle type dependence

19

# Bump in the h/π ratios

- Expectation (pp,e⁺e⁻): ~1.6
- Above 5 GeV/c and in peripheral events: recover normal fragmentation.