Strangeness in PHENIX

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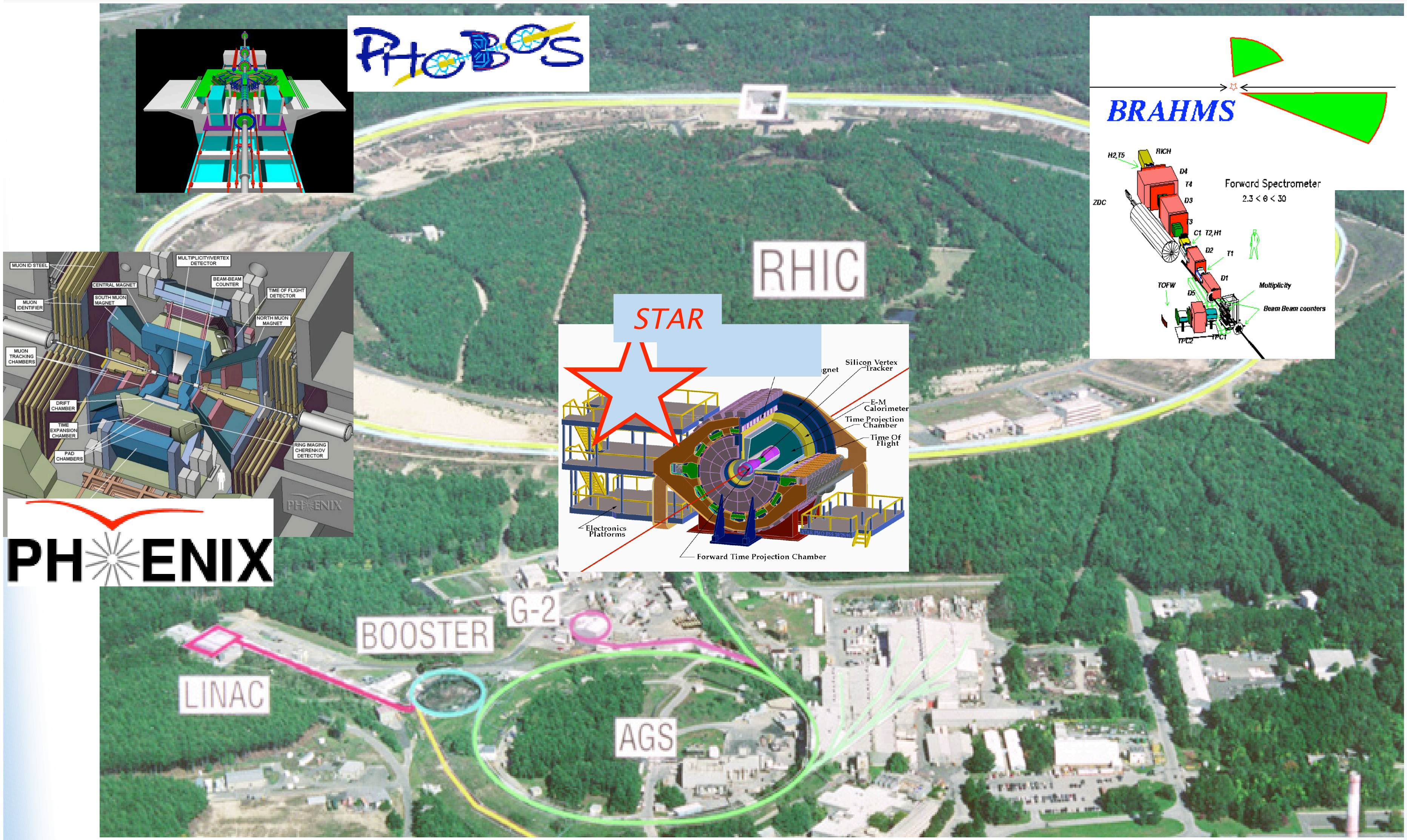
Vanderbilt University
for the PHENIX Collaboration

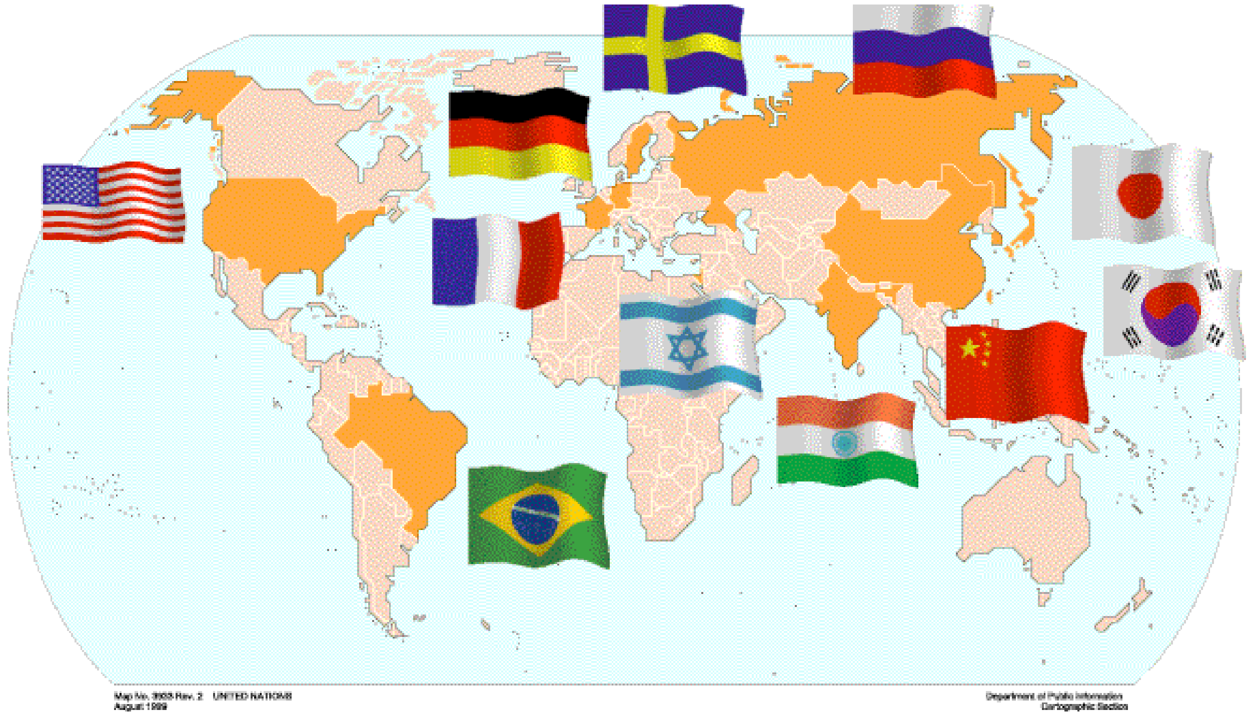
Presentation Outline

- Description of RHIC and PHENIX
- Results from Inclusive Identified Hadrons
  - Temperature and Flow Velocity
  - Chemistry
- The □ in PHENIX

The Four RHIC Experiments



PHENIX



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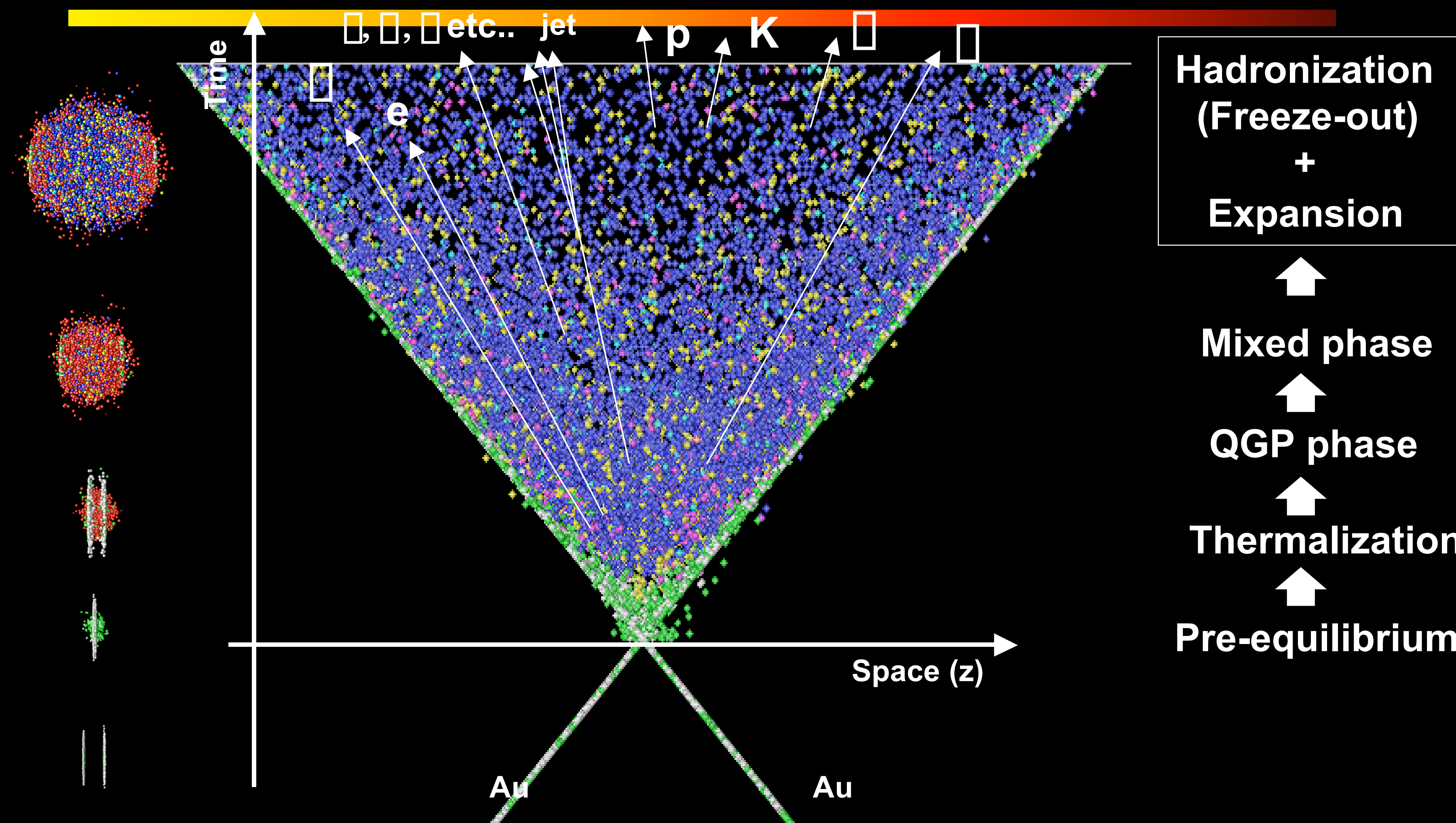
Space-time Evolution of System at RHIC



- Can we learn about the final state freeze out temperature and expansion velocity?
- Do the early hard collisions survive as signature jets at high p_t?
- Will the decay of the [illegible] meson be affected by the medium?

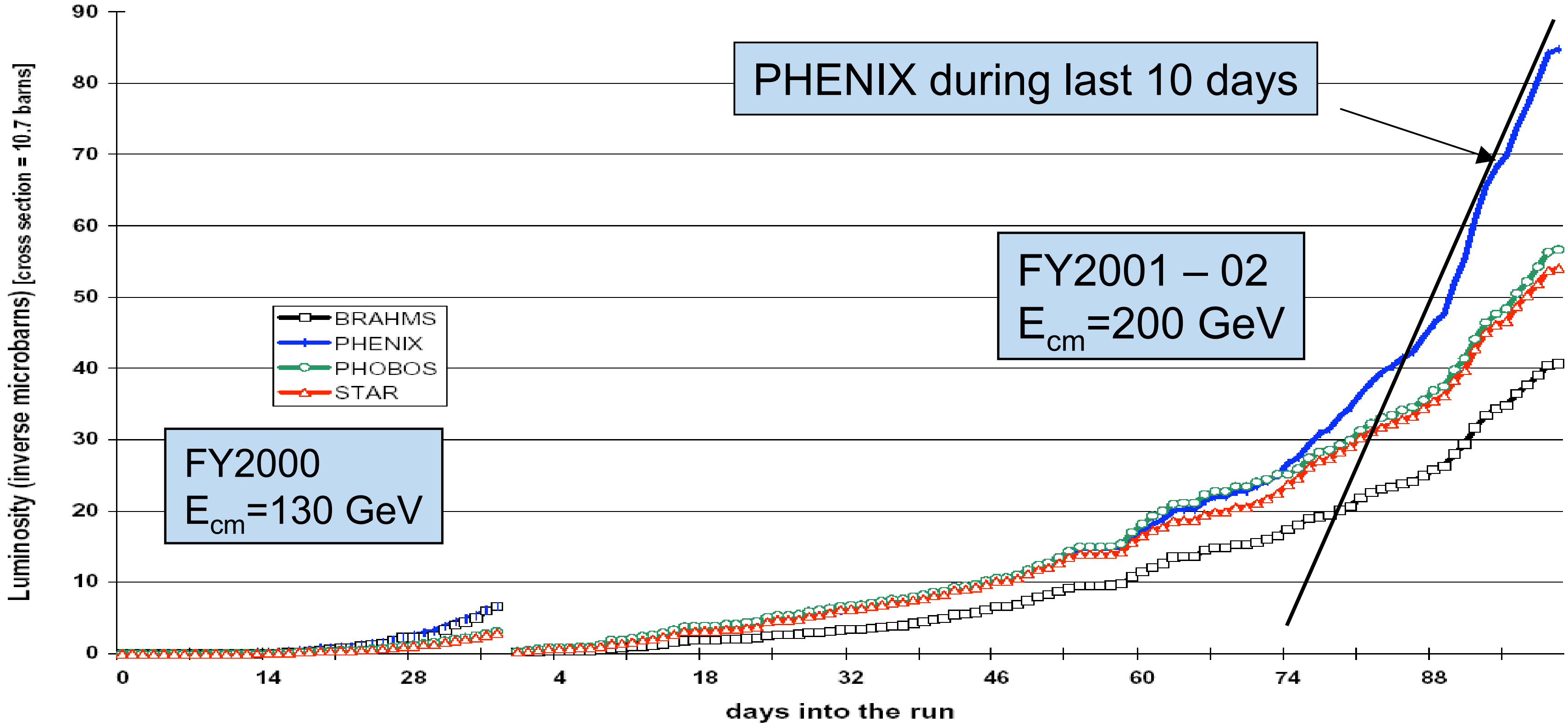
PHENIX - Run II

Au-Au running at E_{cm} = 200 GeV

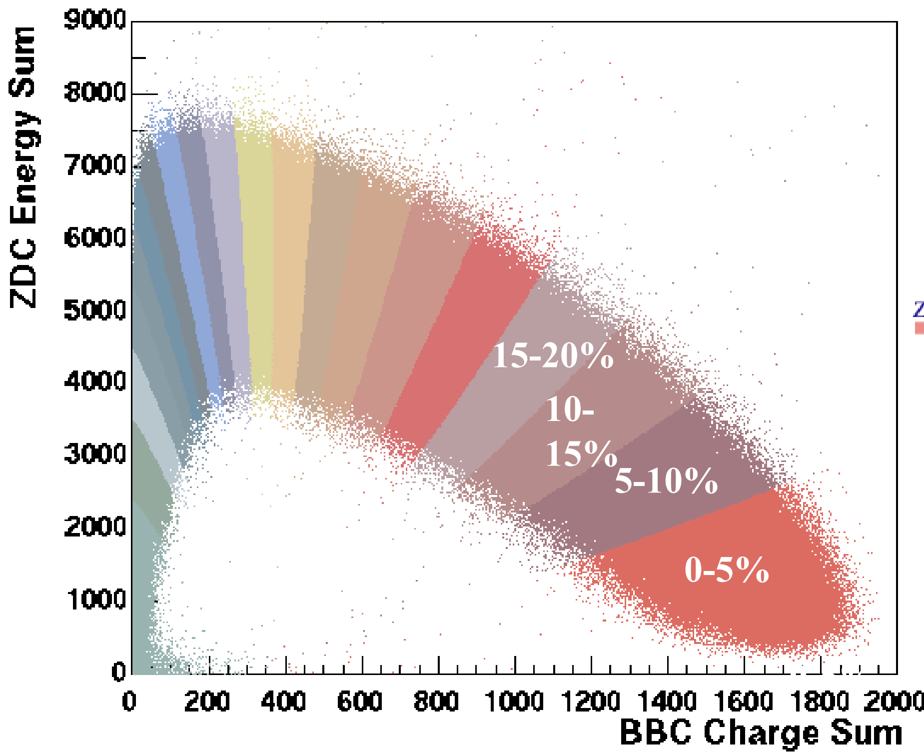
RHIC delivered 42 □b^{-1} |z|<45 cm to PHENIX

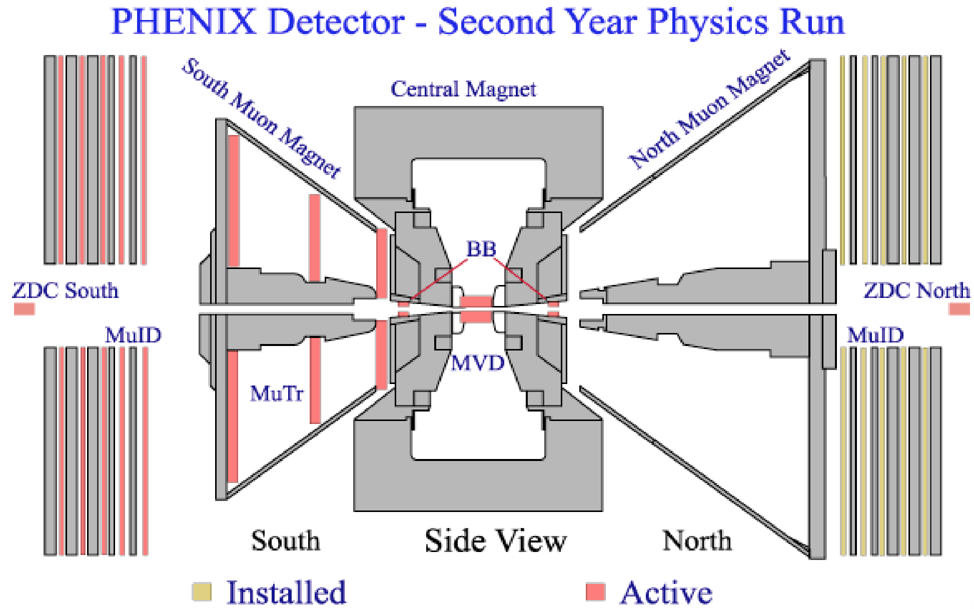
We sampled with “minimum bias” and Level-2 triggers 24 □b^{-1}

Over 50% of that in the last two weeks of the AuAu run.



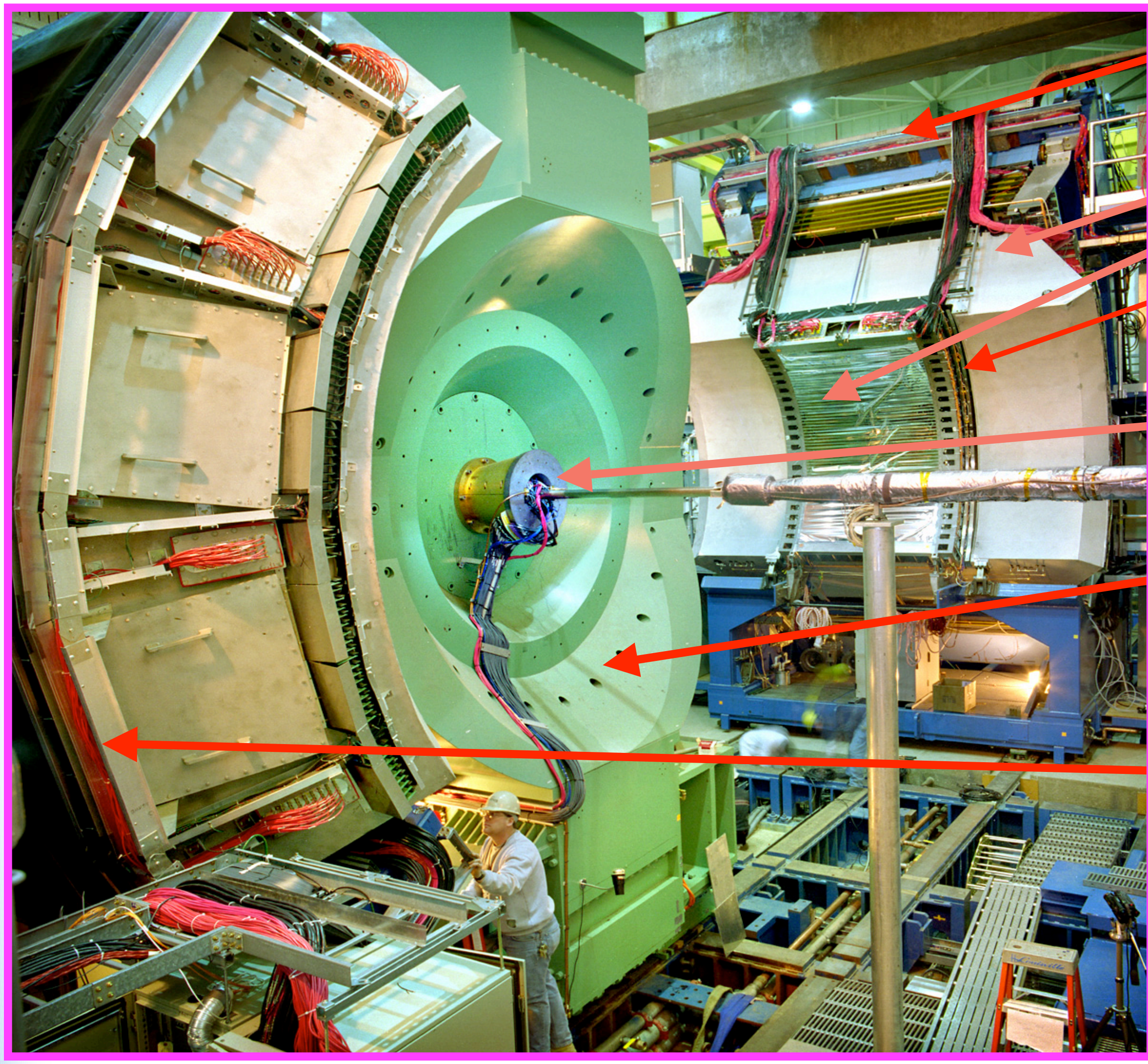
Global Event Selection





- Centrality selection : Used charge sum of Beam-Beam Counter (BBC, $|\eta|=3\sim4$) and energy of Zero-degree calorimeter (ZDC) in minimum bias events.
- Extracted N_{part} based on Glauber model.

PHENIX Central Spectrometers



East Carriage

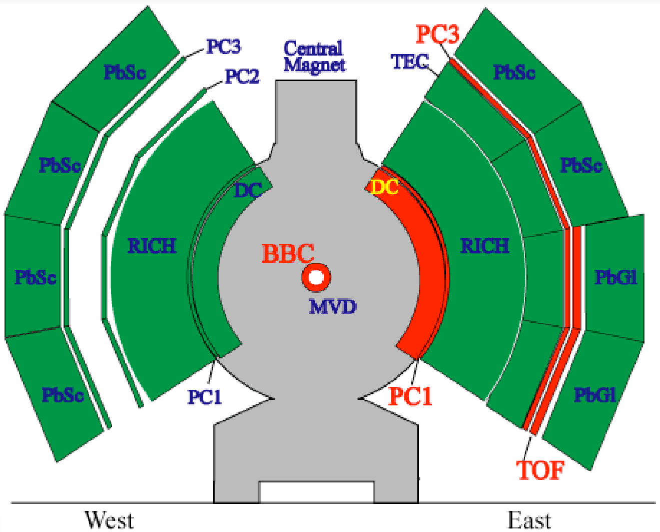
Ring Imaging Cerenkov
Drift Chamber (East)
Pad Chamber (PC1, East)

Beam-Beam Counter (N)

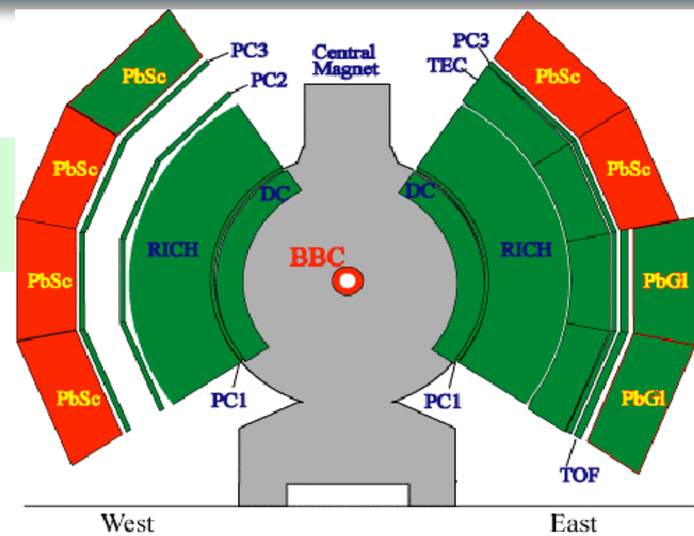
Central Magnet (N)

West Carriage

Detecting □±, K±, p± in PHENIX



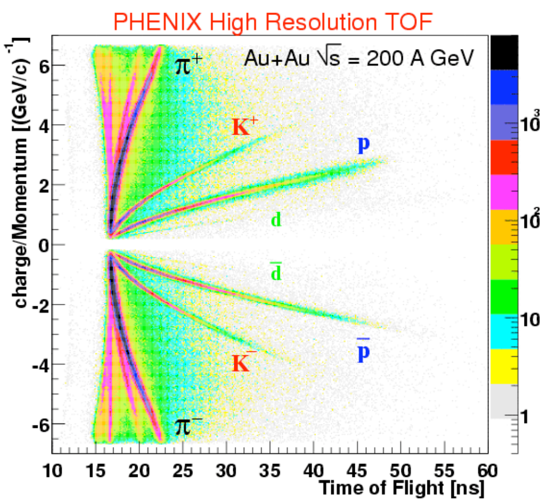
momentum resolution
$□_p/p \sim 1\% \oplus 1\%\, p$



TOF resolution 120 ps

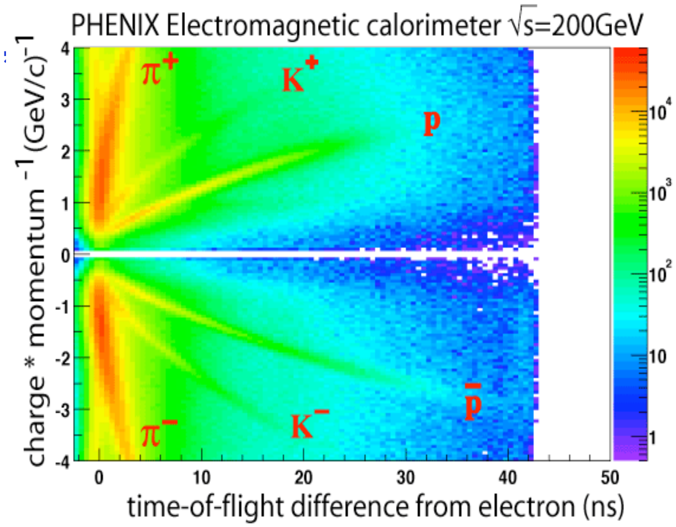
Inclusive identified hadron spectra use TOF in East Arm

EMCal resolution 450 ps

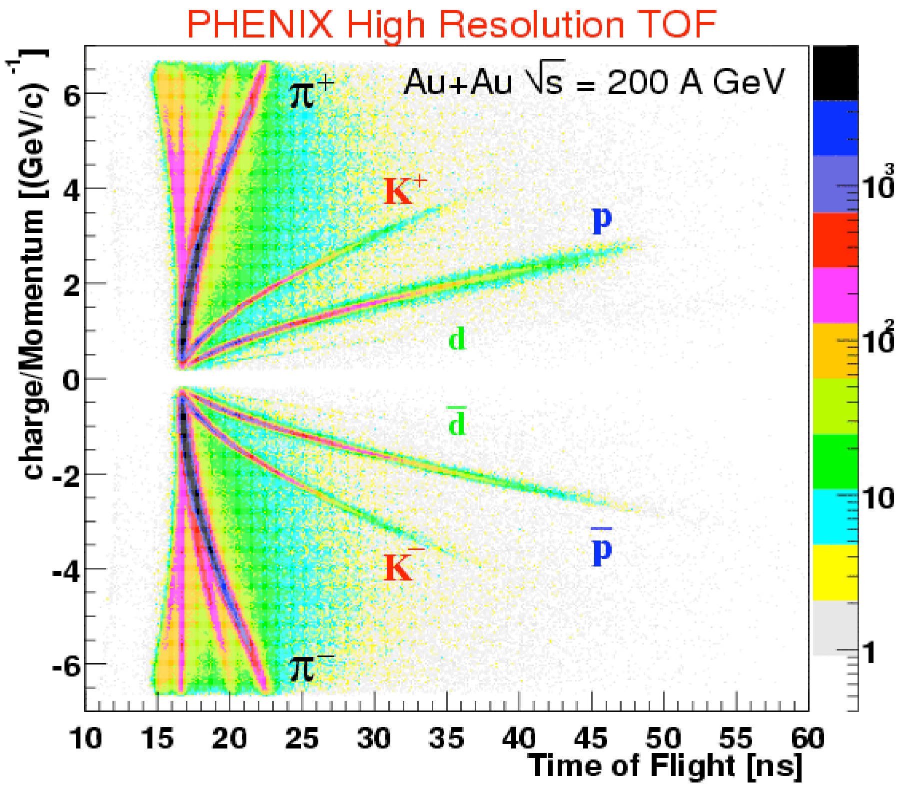


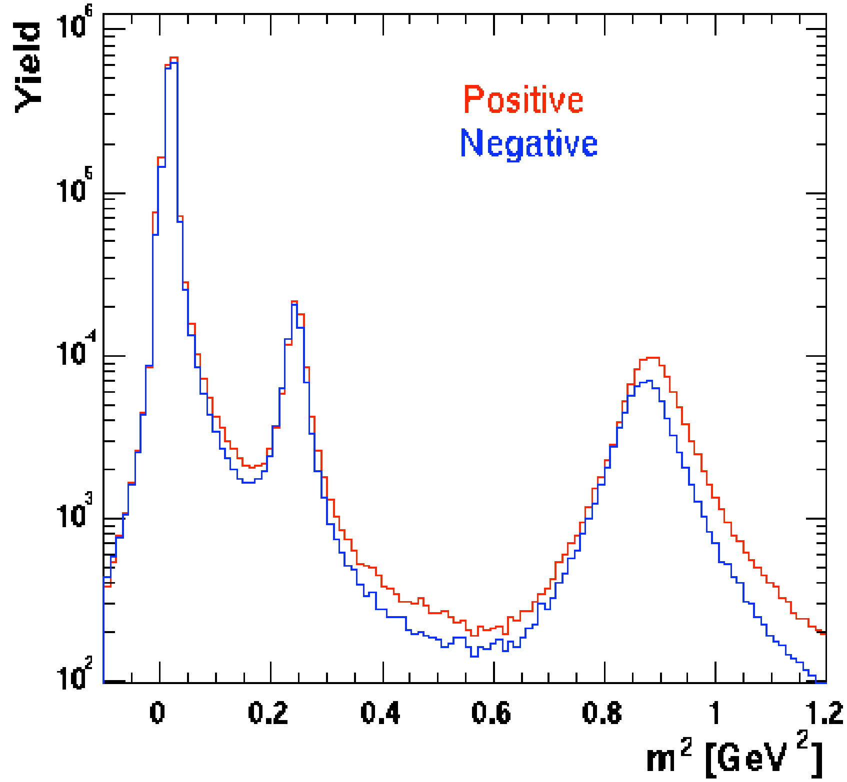
□->K+K- uses TOF-TOF, EMCal-EMCal, and TOF-EMCal in East

□->e+e- uses RICH, EMCal-EMCal in East-West, East-East, and West-West



Particle Identification in High Resolution TOF

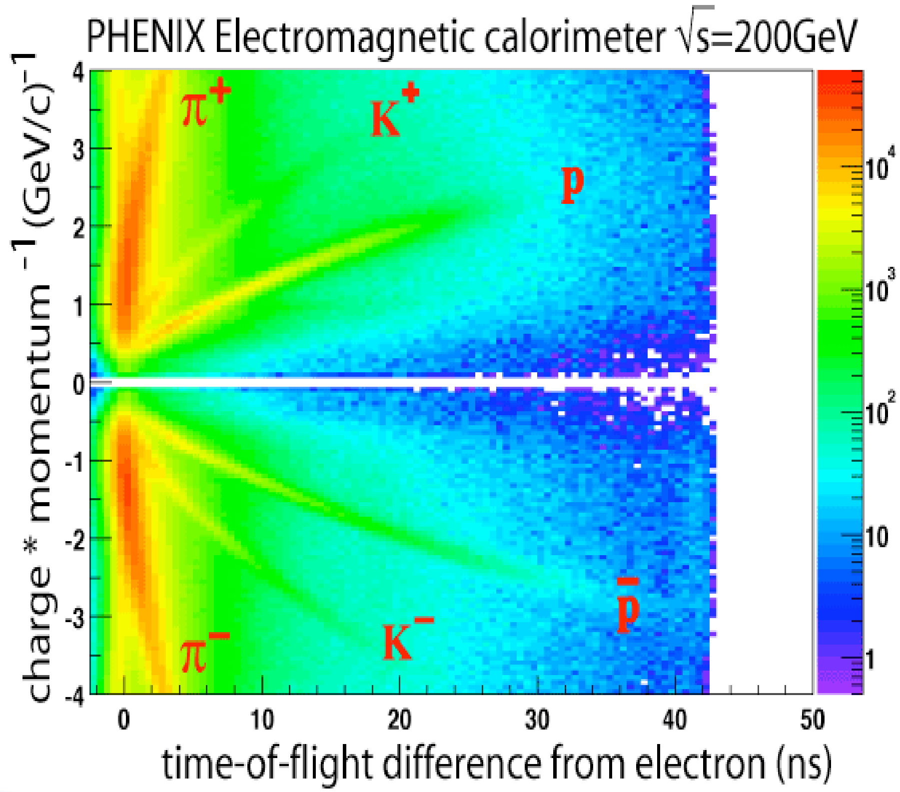


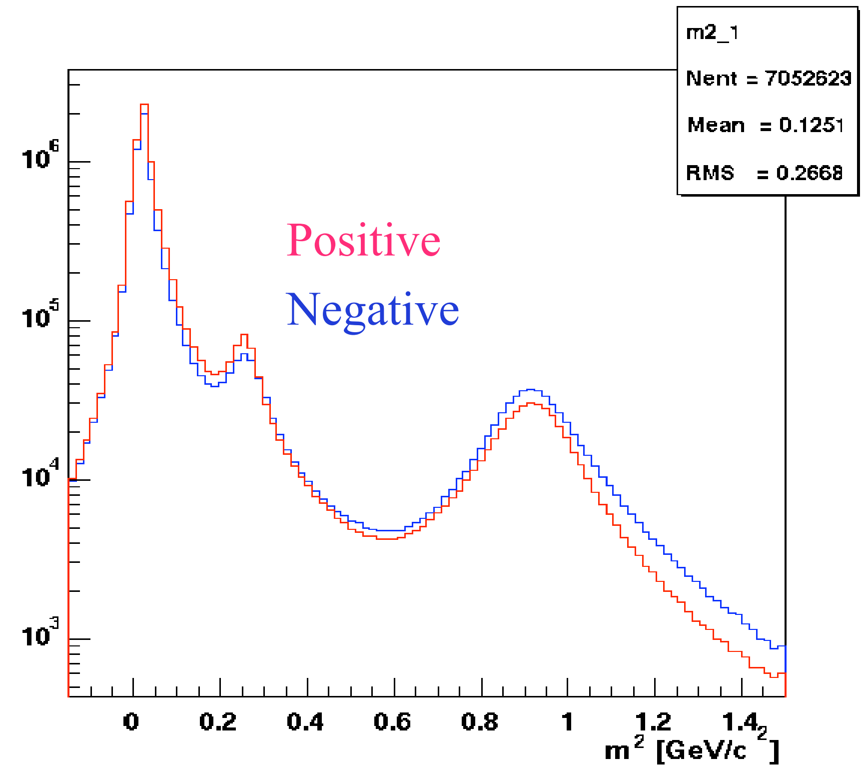


TOF timing resolution: □$_t$ ~ 120 ps

K/□ separation up to 2.0 GeV/c

EMCal Particle Identification

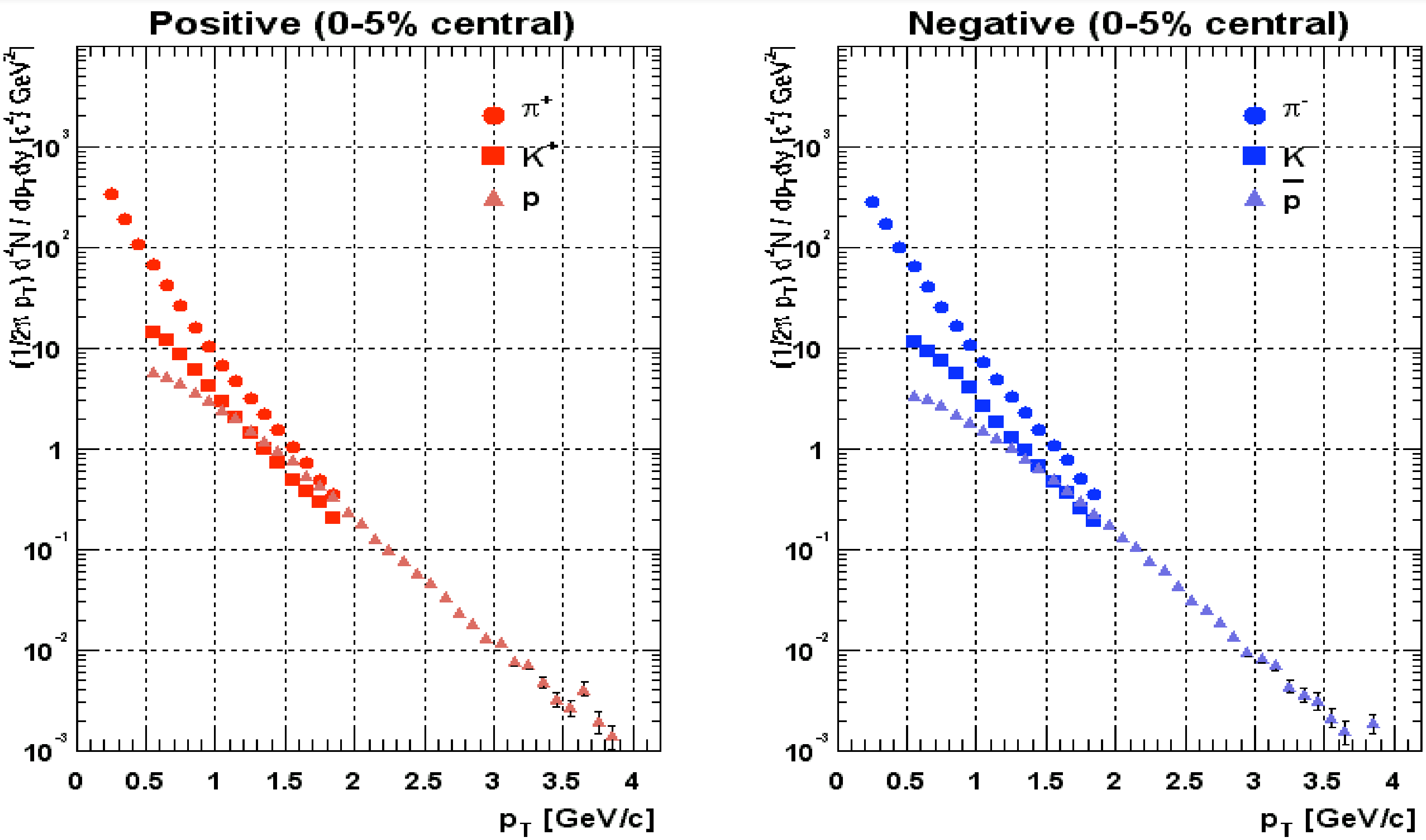




EMCAL resolution: σ_t ~ 450 ps

K/π well separated for 0.3 < p [GeV/c] < 1.0

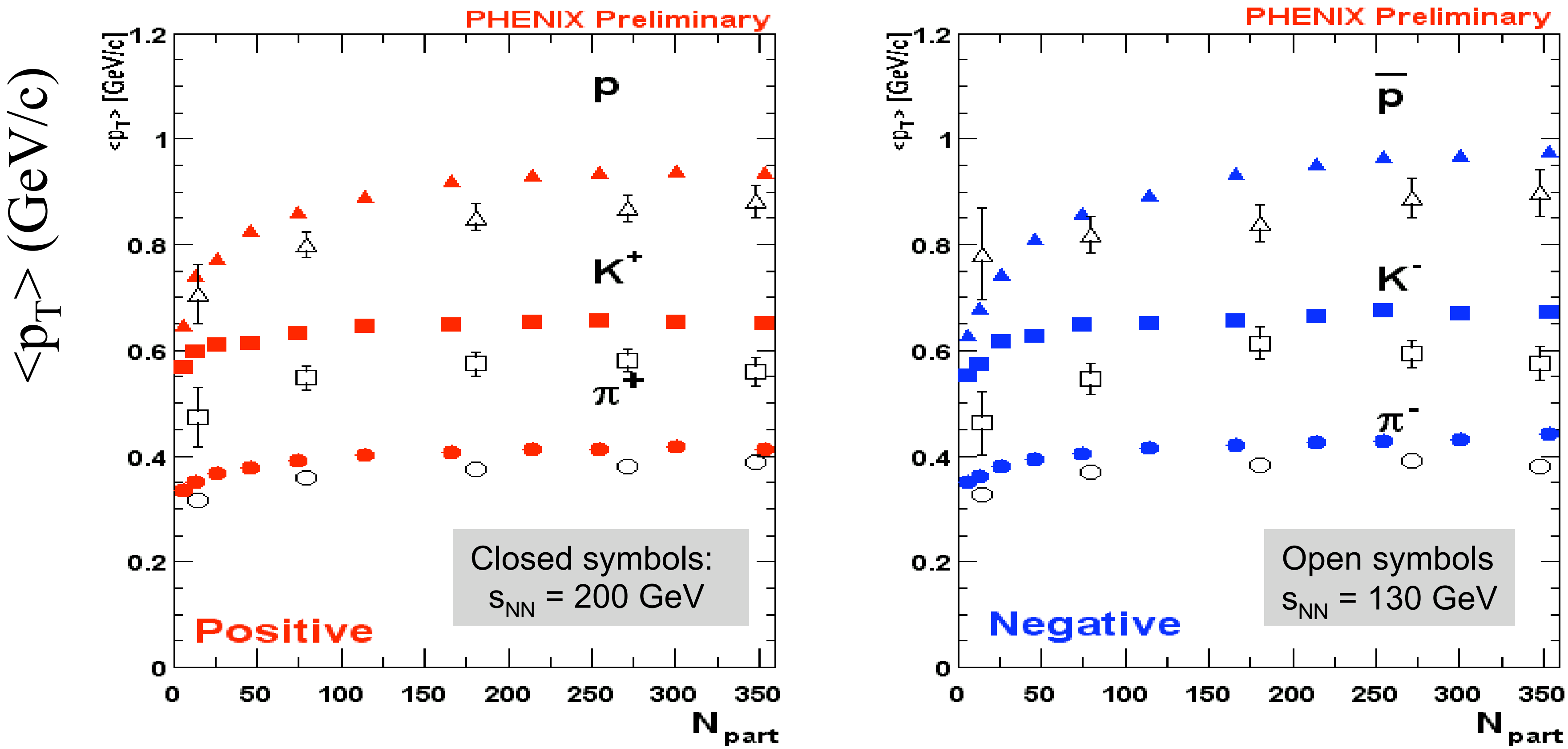
Transverse Momentum Spectra at s_{NN} = 200 GeV



Proton yield ~ pion yield @ p_t = 2 GeV

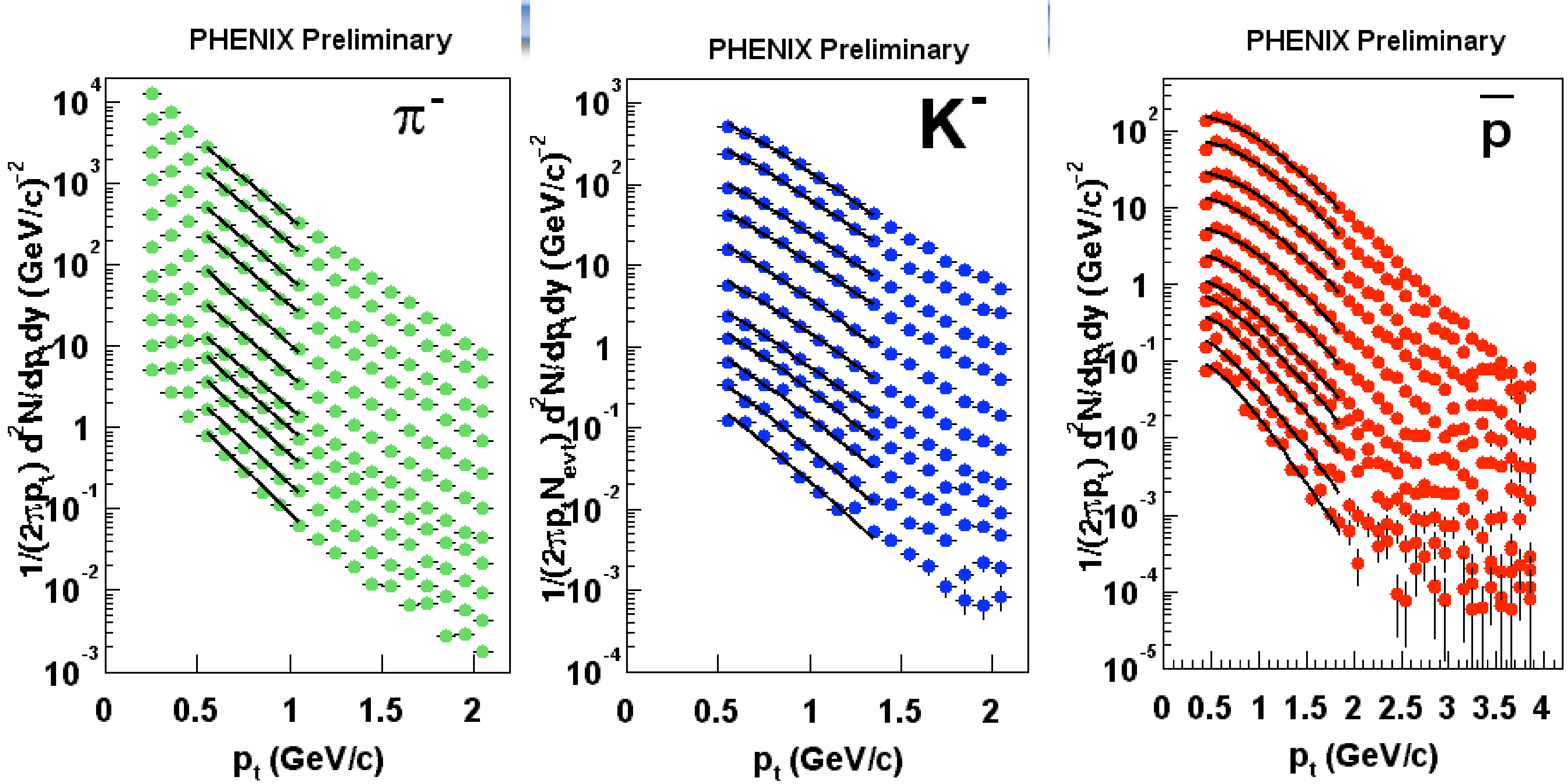
High p_t protons not suppressed -- a mysterious result

Mean Transverse Momentum
Compare Run1 and Run2 Data



- Mean p_t increases with N_{part} and m_0, indicative of radial expansion.
- Relative increase from peripheral to central greater for (anti)p than for π, K.
- Systematic uncertainties: π 10%, K 15%, and (anti-)p 14%

Hydrodynamic Model Fit



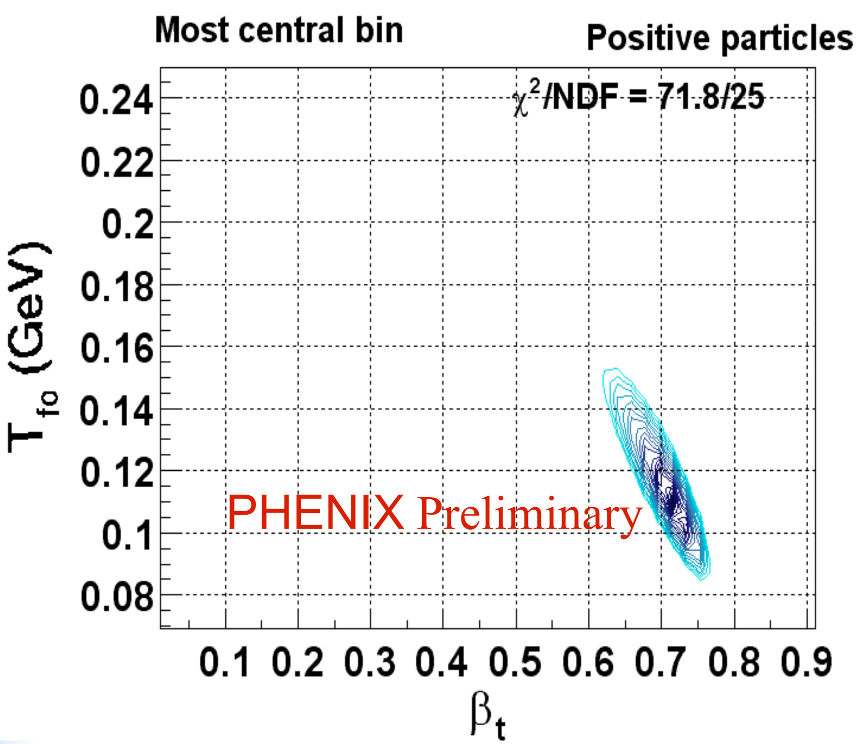
Simultaneous fit in range $(m_t - m_0) < 1$ GeV/c
The top 5 centralities are scaled for visual clarity.
Similar fits for positive particles.

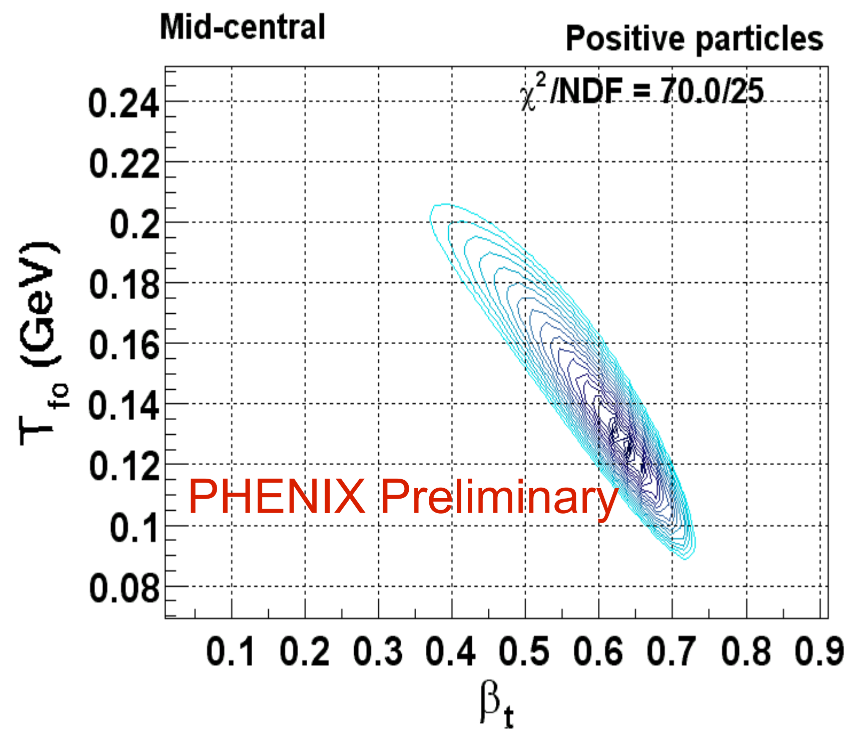
Ref: E. Schnedermann, J. Sollfrank, and U. Heinz, Phys. Rev. C 48, 2462 (1993)

Fit All Centralities: χ^2 Contours in Parameter Space T_{FO} and β_T

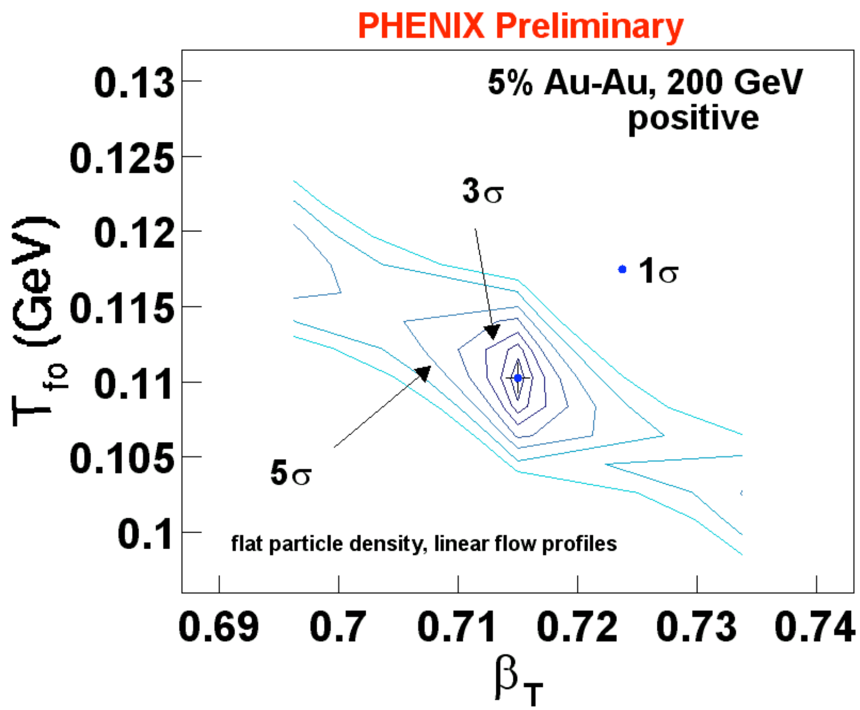
In each centrality, the first 20 n-σ contour levels are shown.

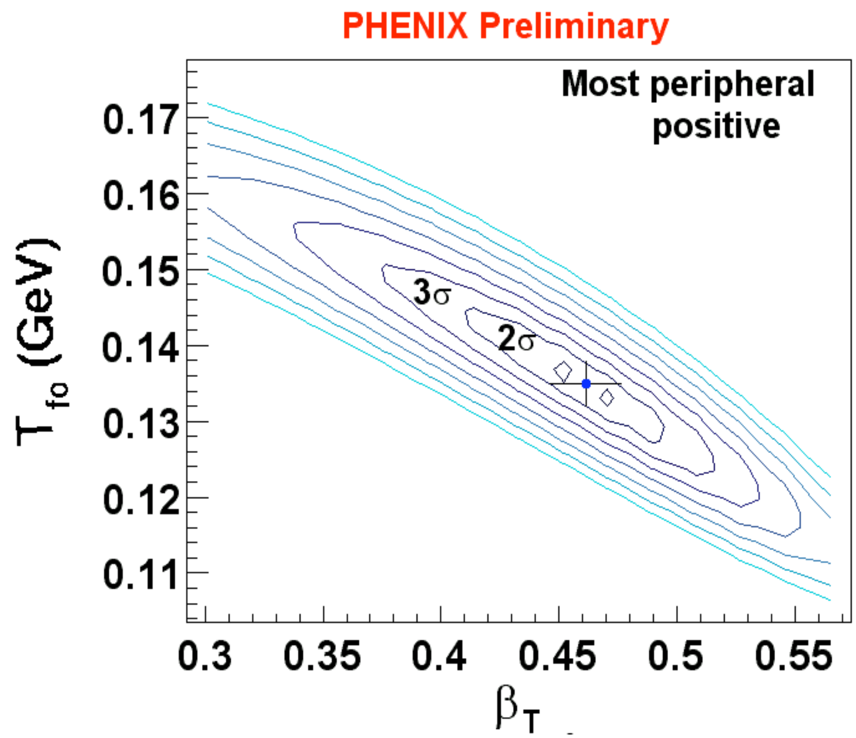
From the most peripheral to the most central data, the single particle spectra are fit simultaneously for all pions, kaons, and protons.





Most Central and Most Peripheral Compared



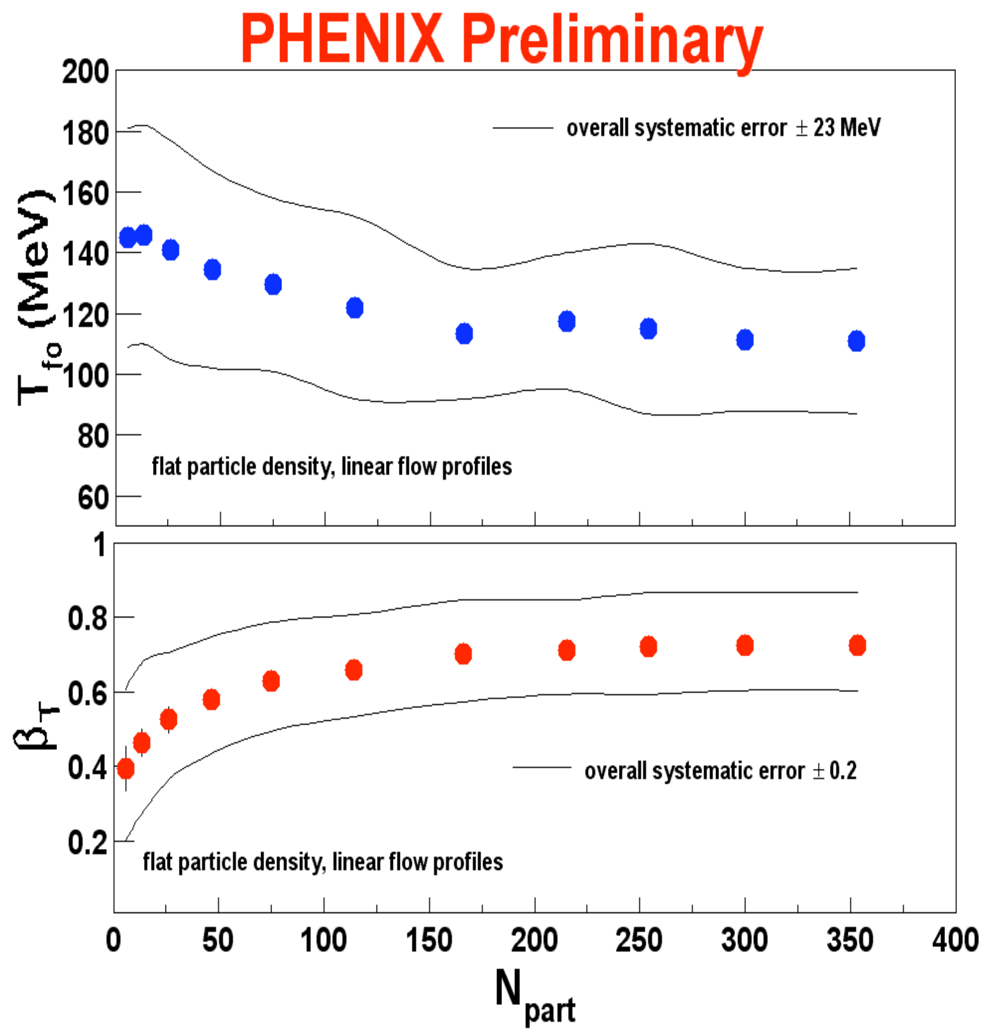


For the 5% spectra
β_T = 0.7 ± 0.2 syst.
T_{fo} = (110 ± 23 syst.) MeV

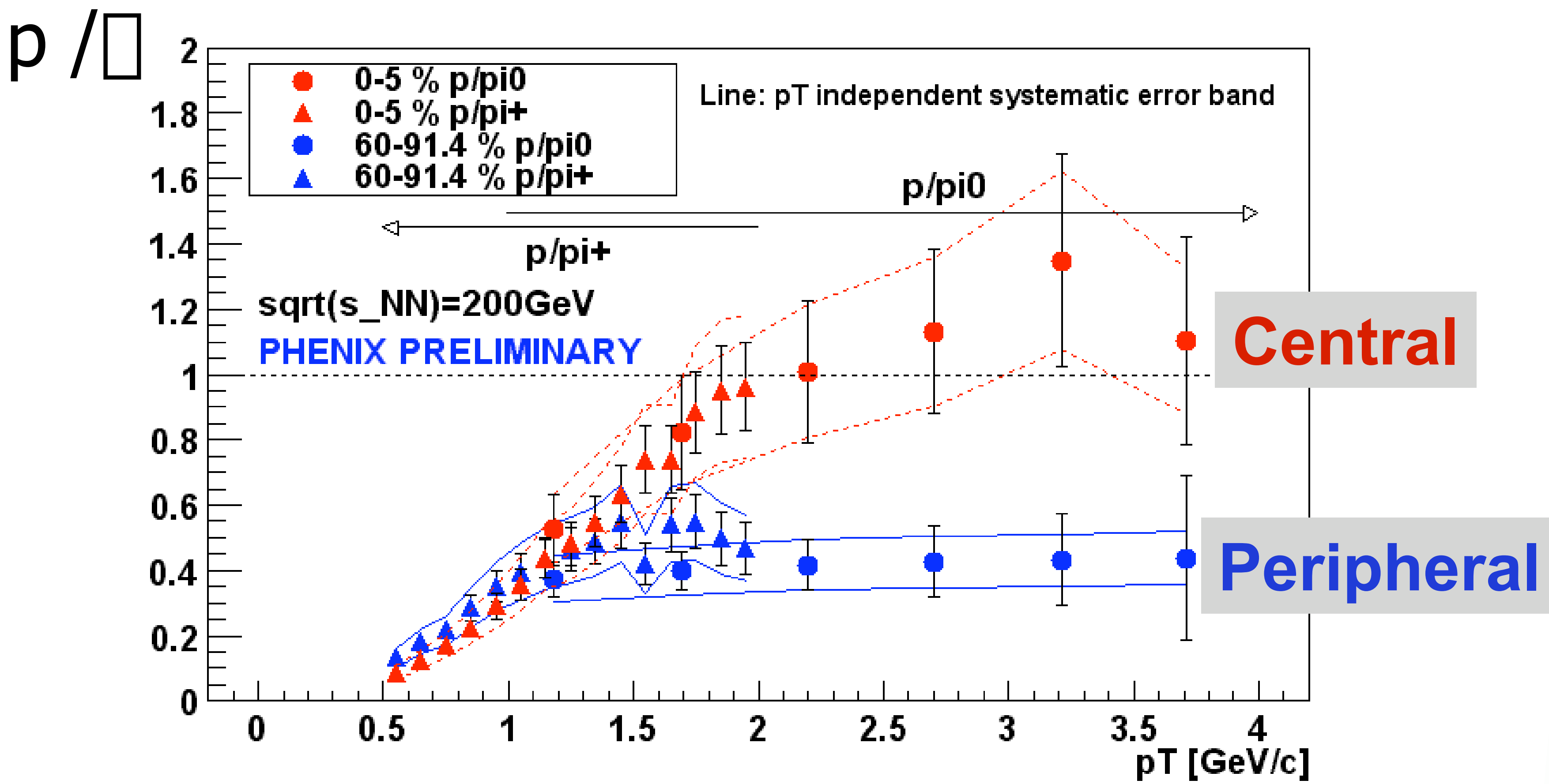
For the most peripheral spectra:
β_T = 0.46 ± 0.02 stat. ±0.2 syst.
T_{fo} = 135 ± 3 stat. ± 23 syst. MeV

The Parameters T_{FO} and β_T vs. N_{part}

- Expansion parameters in each centrality
- Overall systematic uncertainty is shown
- A trend with increasing N_{part} is observed:
  - T_{FO} decreases
  - β_T increases
- Saturation at mid-centrality



An intriguing mystery: p/



proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral.

Baryon - Meson Ratio

1. Strong flow effect from expansion for protons but less for pions

2. Enhancement of p and pbar yield at high p_T.

3. Pion suppression at high $p_{T.}$

□ Flow may cause the observed comparable yield of p and □ at 2 GeV/c in spectra for central Au + Au collisions

or

□ Final state quark recombination may introduce difference between protons and pions, or …

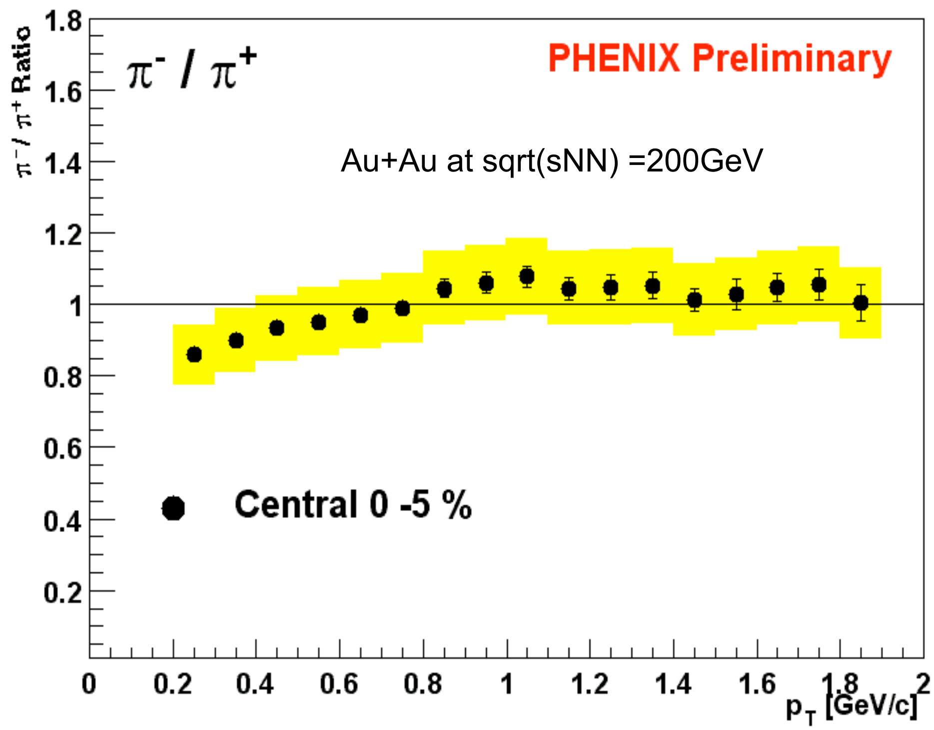
Identified Hadron Summary

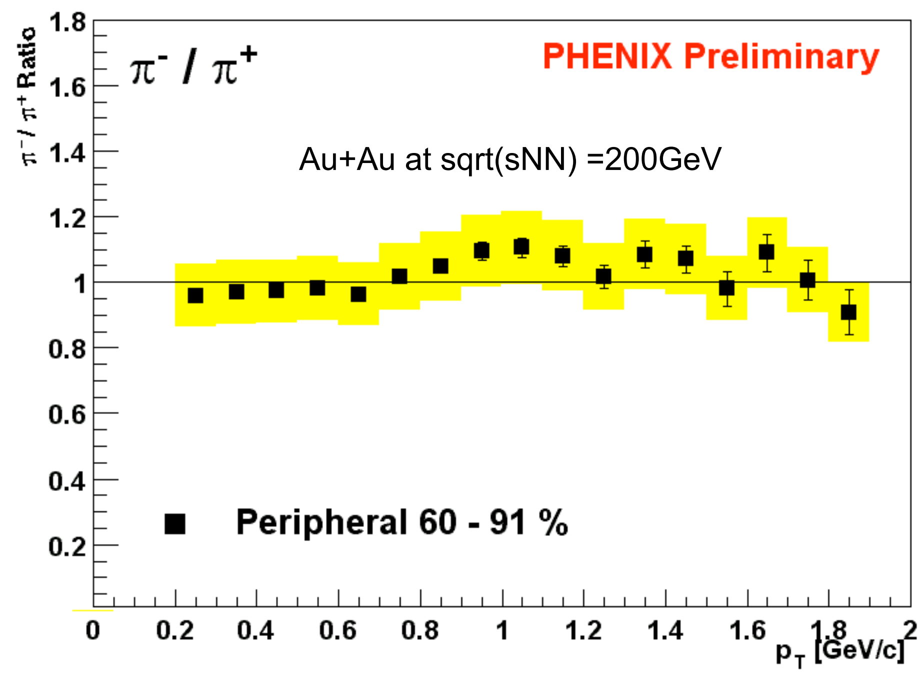
PHENIX results for identified charged particles spectra at 200 GeV in Au + Au at RHIC.

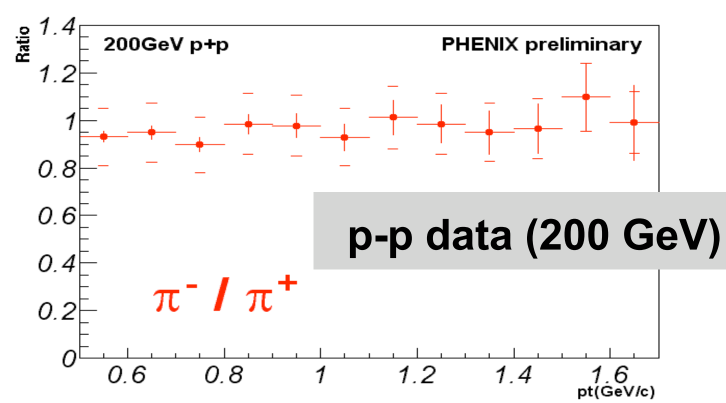
- **Identified Charged Hadron Spectra**
  - indication of a strong collective expansion at central collisions.
  - $\langle p_T \rangle$ vs. mass : the heavier mass, the larger $\langle p_T \rangle$.
  - $\langle p_T \rangle$ vs. centrality : steep rise at peripheral to mid-central collisions.
  - Hydro-dynamical model fit to the spectra
    □ $\square_T = 0.7$, $T_{FO} = 110$ MeV

- **High p_T Hadron Production**
  - proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral
  - □ may be due to
    1) high p_T pion suppression, and
    2) hydrodynamic flow effect for proton, or
    final state quark recombination, or … ??

Central and Peripheral π^- / π^+ ratios vs. p_T



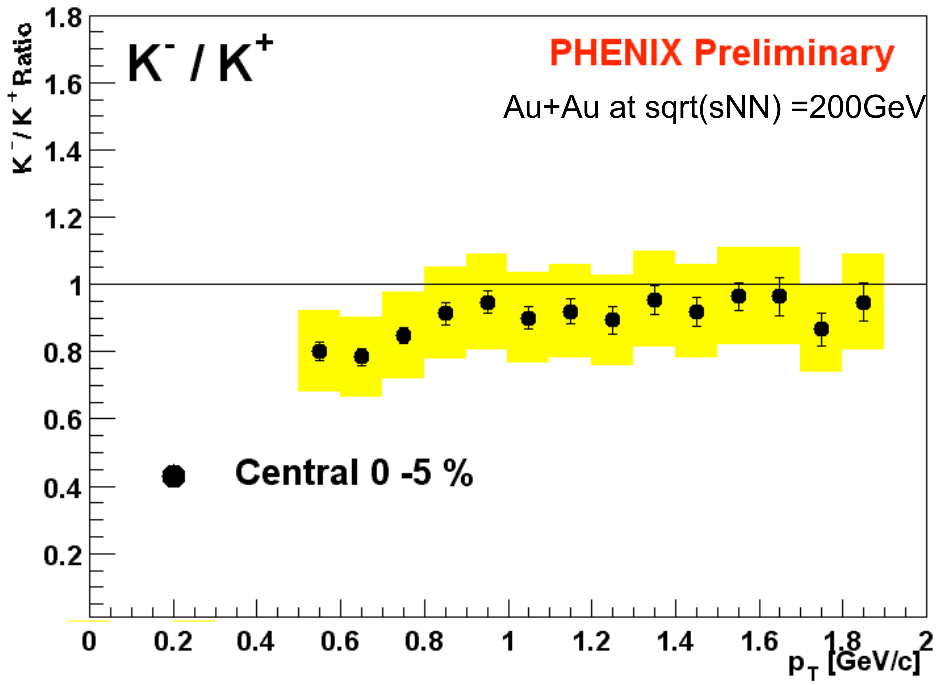


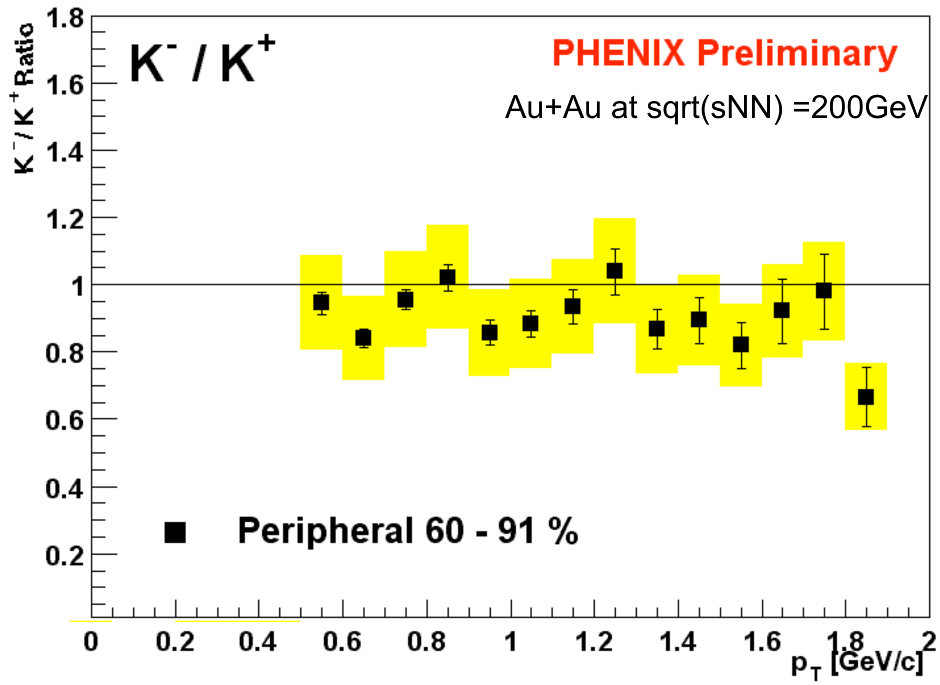


Flat p_T dependence

No centrality dependence

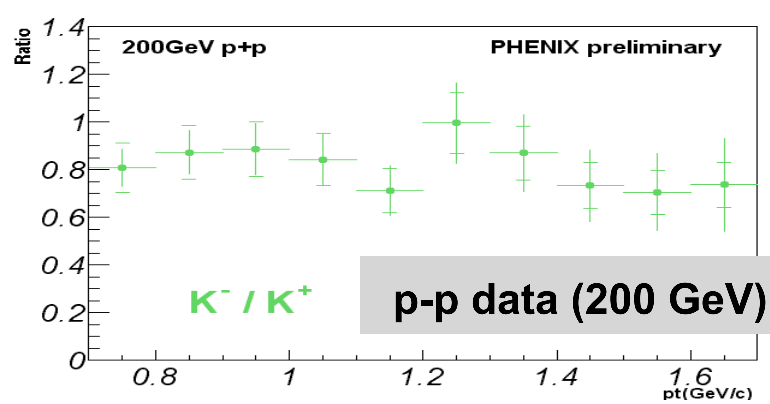
Central and Peripheral K^-/K^+ ratios vs. p_T





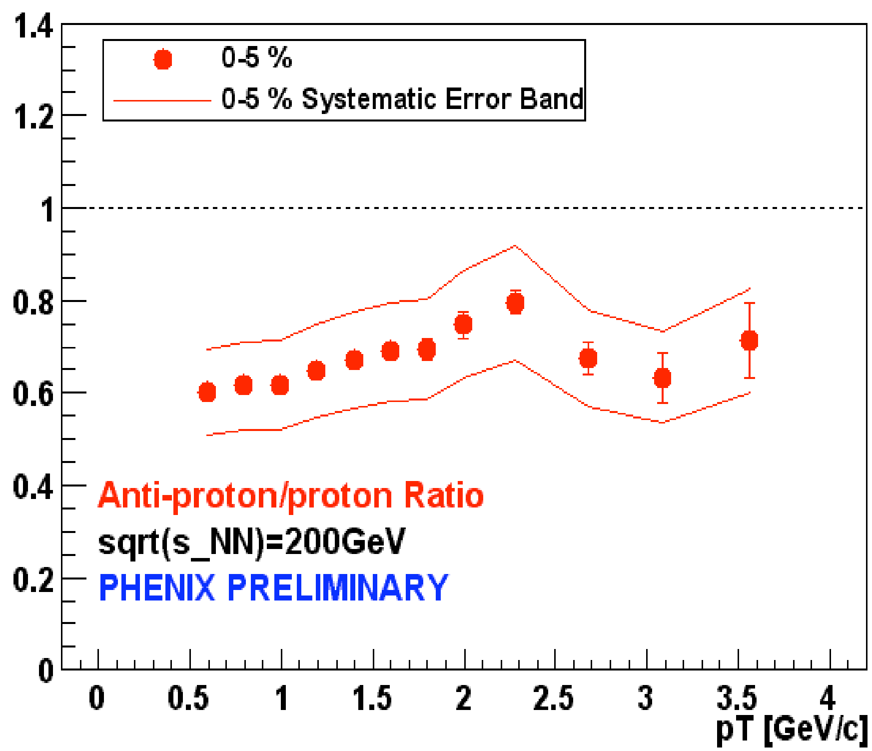
Flat p_T dependence

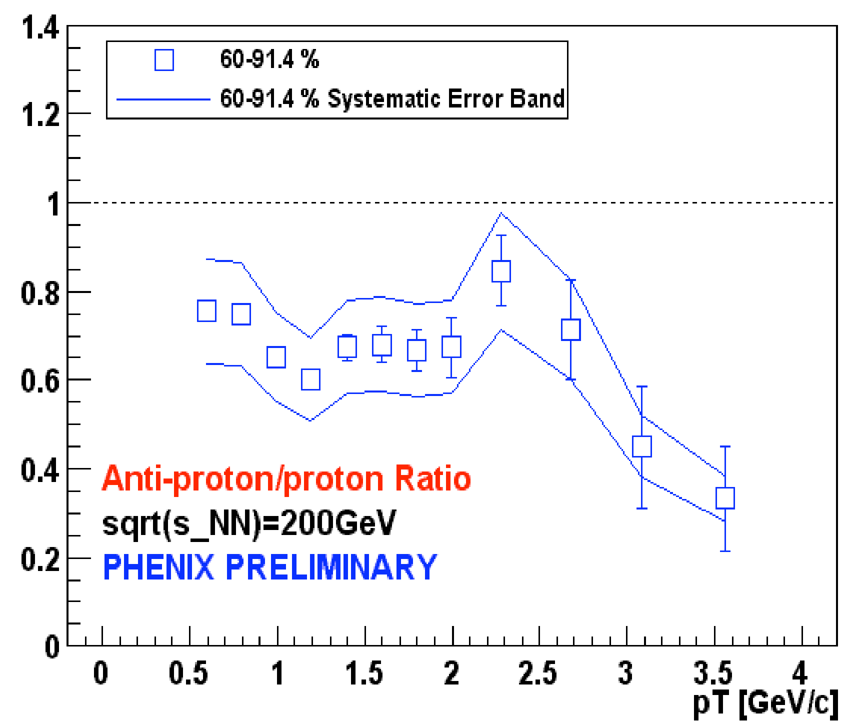
No centrality dependence



p-p data (200 GeV)

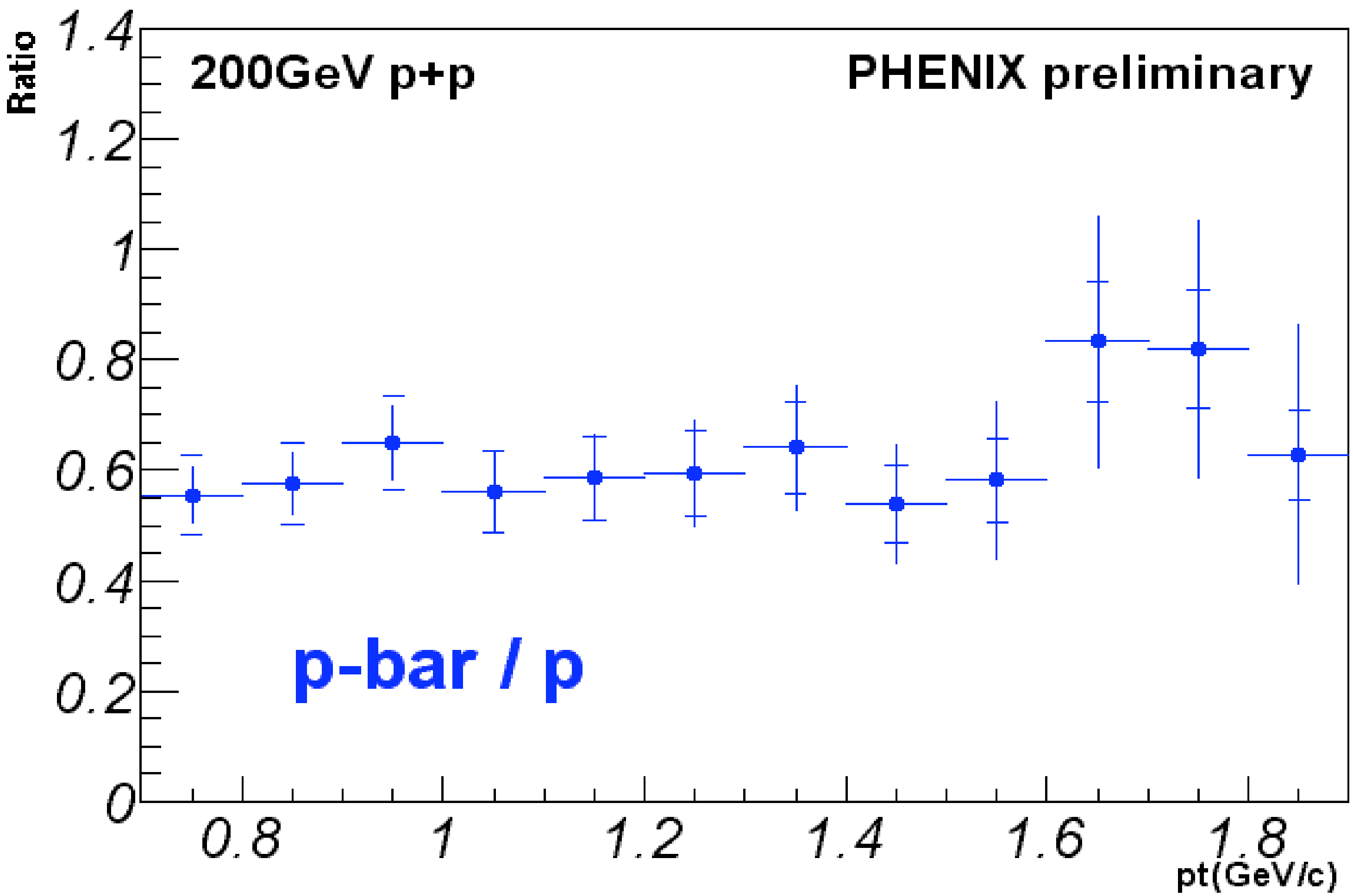
Central and Peripheral pbar/p ratios for Au+Au vs. p_T



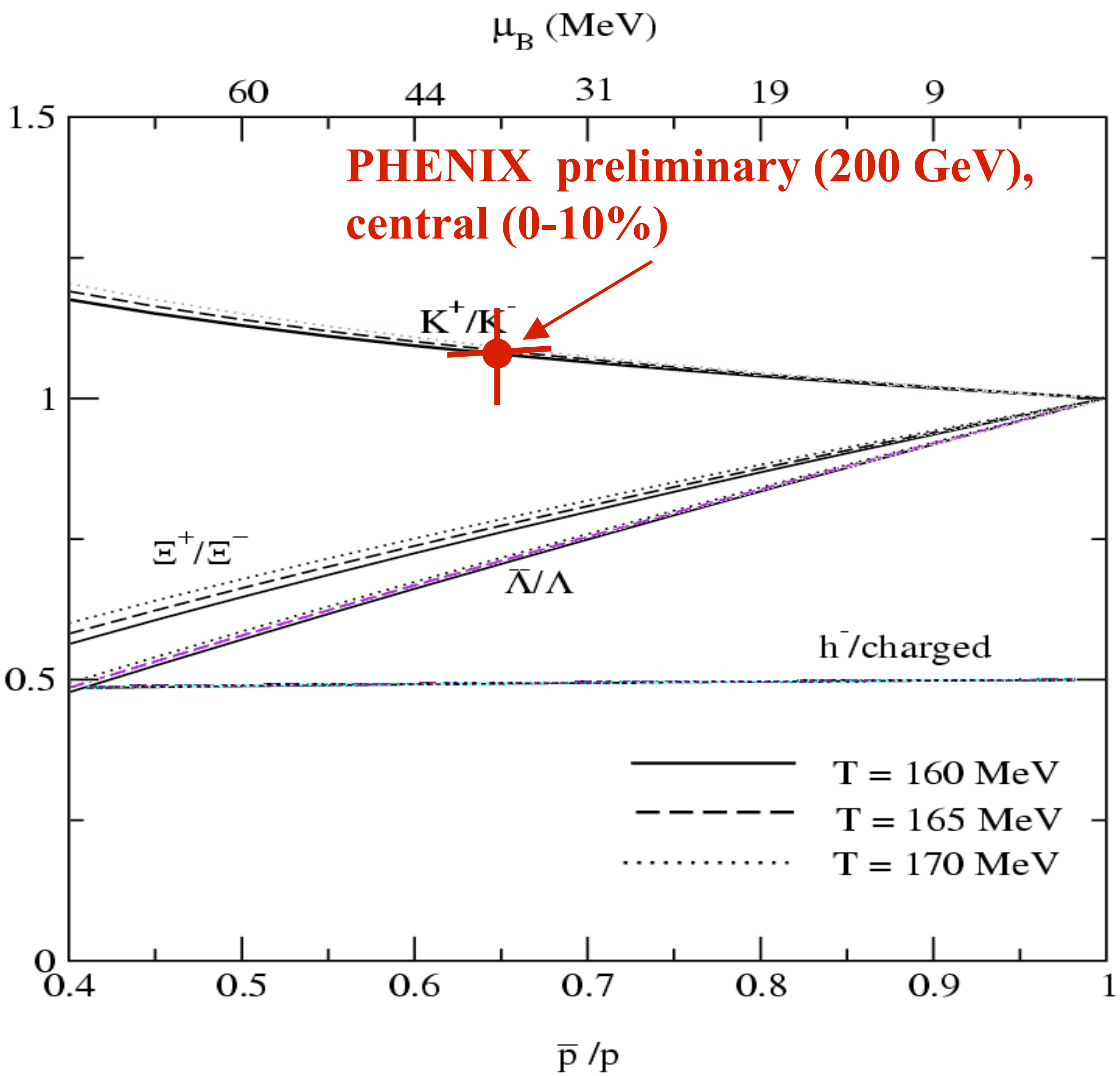


Flat p_T dependence for central.
Decreasing for peripheral > 3 GeV?

pbar/p in proton-proton



Estimate of Baryon Potential



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

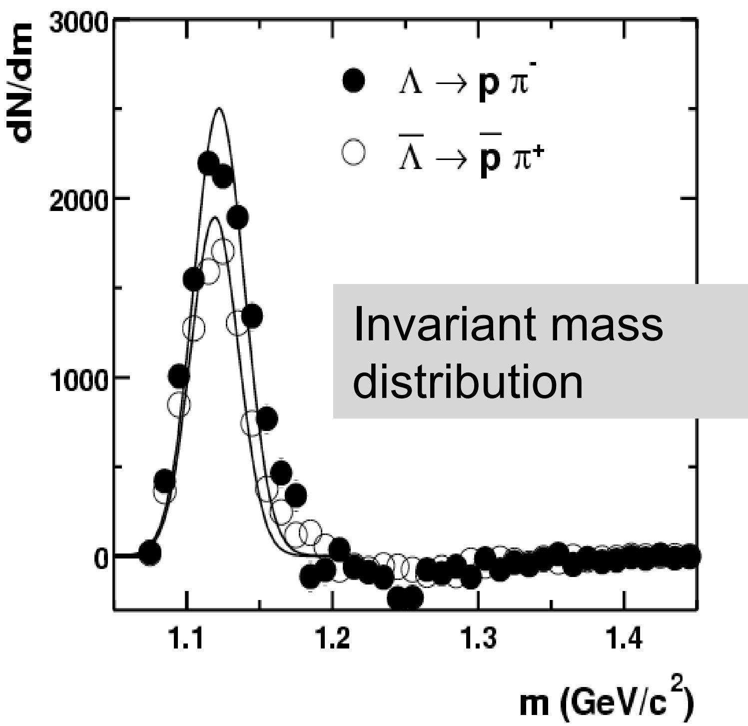
$\square^- / \square^+ = 1.02 \pm 0.02$ (stat) $\pm$ 0.1 (sys)
$K^- / K^+ = 0.92 \pm 0.03$ (stat) $\pm$ 0.1(sys)
pbar / p = 0.70 $\pm$ 0.04 (stat) $\pm$ 0.1(sys)

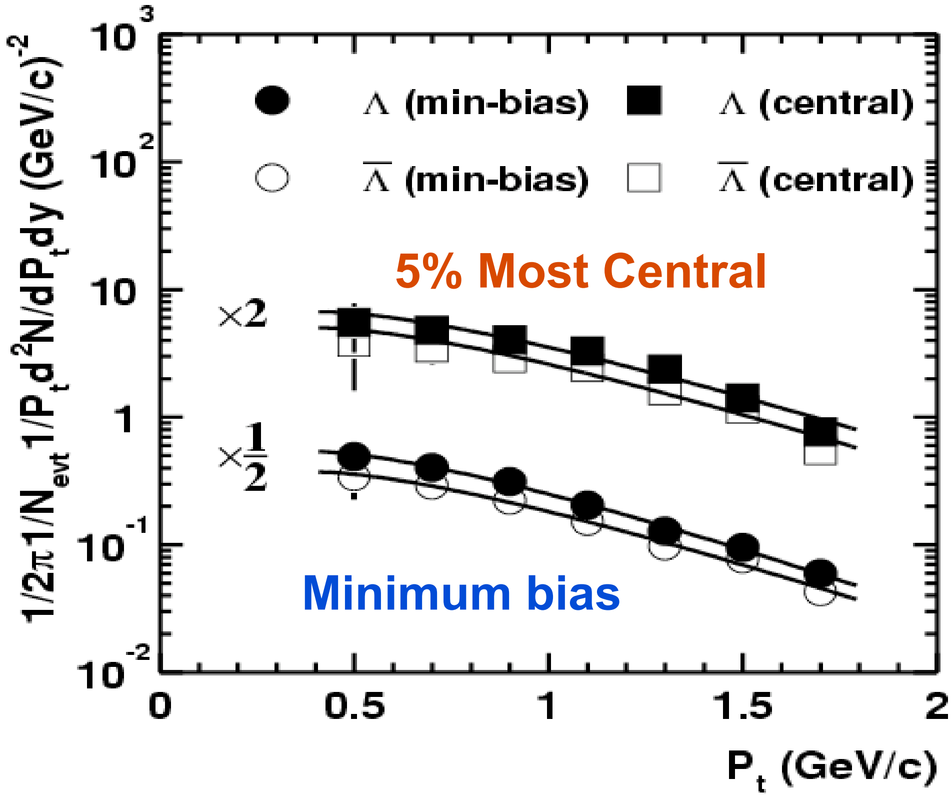
Baryon chemical potential m_B~ 30MeV

Λ’s via combinatorial method

Au+Au at sqrt(s_{NN}) = 130GeV

K. Adcox et al., Phys. Rev. Lett. 89, 092302 (2002)





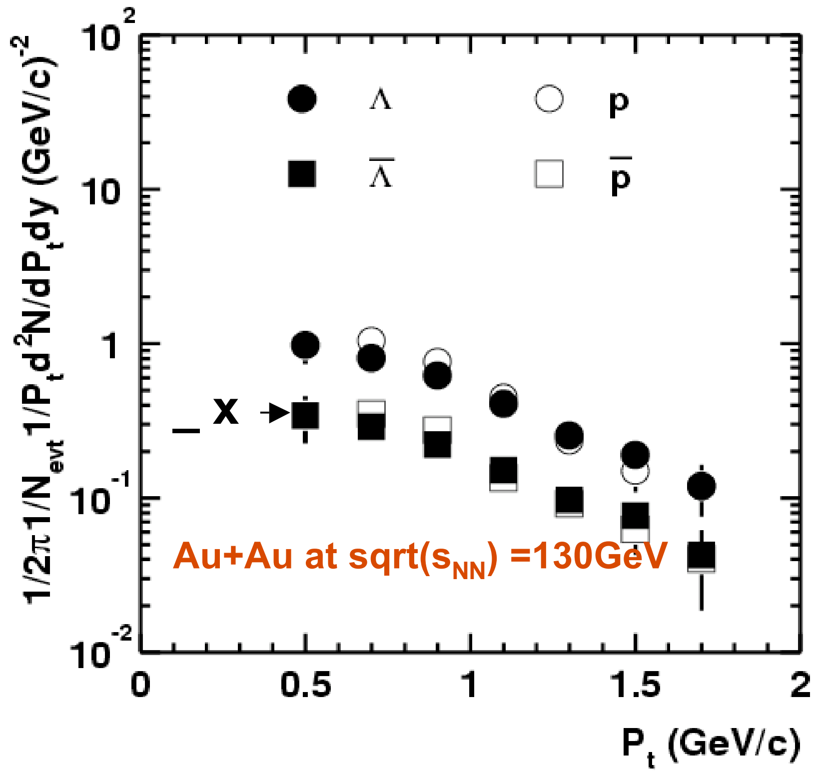
The data are well described by a Boltzmann function ($0.4 < p_T < 1.8$ GeV/c) for central 0-5% and for minimum bias spectra.

Feed-down corrected p, pbar spectra

- Ratios (130 GeV data) **K. Adcox et al., Phys. Rev. Lett. 89, 092302 (2002)**

Λ/p	= 0.89 ± 0.07(stat)
(anti-Λ)/(anti-proton)	= 0.95 ± 0.09(stat)
(anti-Λ)/Λ	= 0.75 ± 0.09(stat)

Net baryon number	Data (PHENIX, central 5%)	HIJING	HIJING/B
(Λ – anti–Λ)	4.6 ± 2.5	0.8	3.2
(p – anti–p)	5.6 ± 0.9	4.7	7.1



Reasonable agreement in net Λ and proton yield by HIJING/B model (non perturbative gluon junction mechanism)

See contribution of T. Arkadij

Ratios and □ Analysis Summary

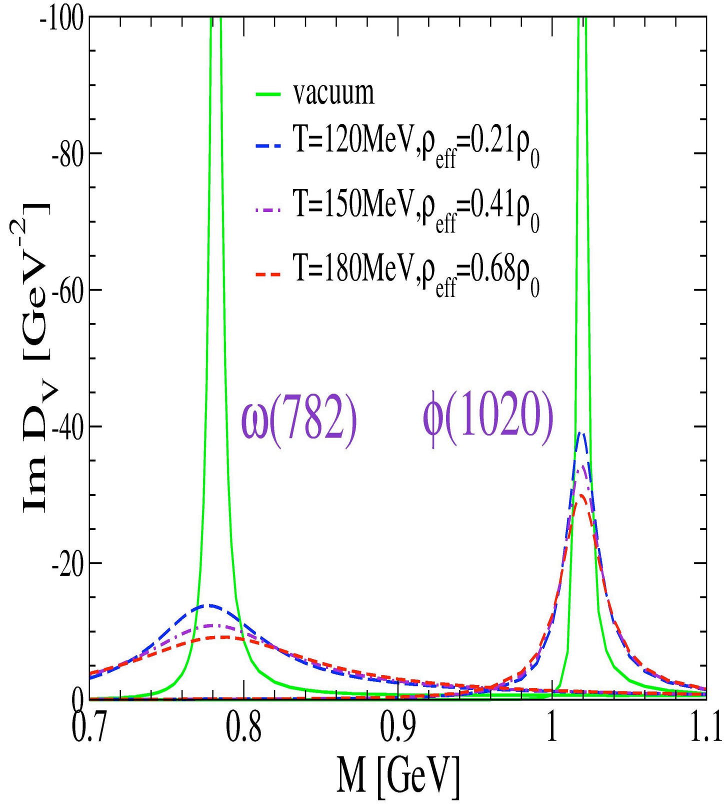
Chemistry

- Baryon chemical potential ~ 30 MeV
- No p_T and centrality dependence for p^{-}/p^{+}, K^{-}/K^{+}, pbar/p ratio.
- Proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral.
- Feed down corrected p, pbar spectra for 200 GeV data can be done soon.

The Interest in the φ(1019.4)
[formerly φ(1020)]

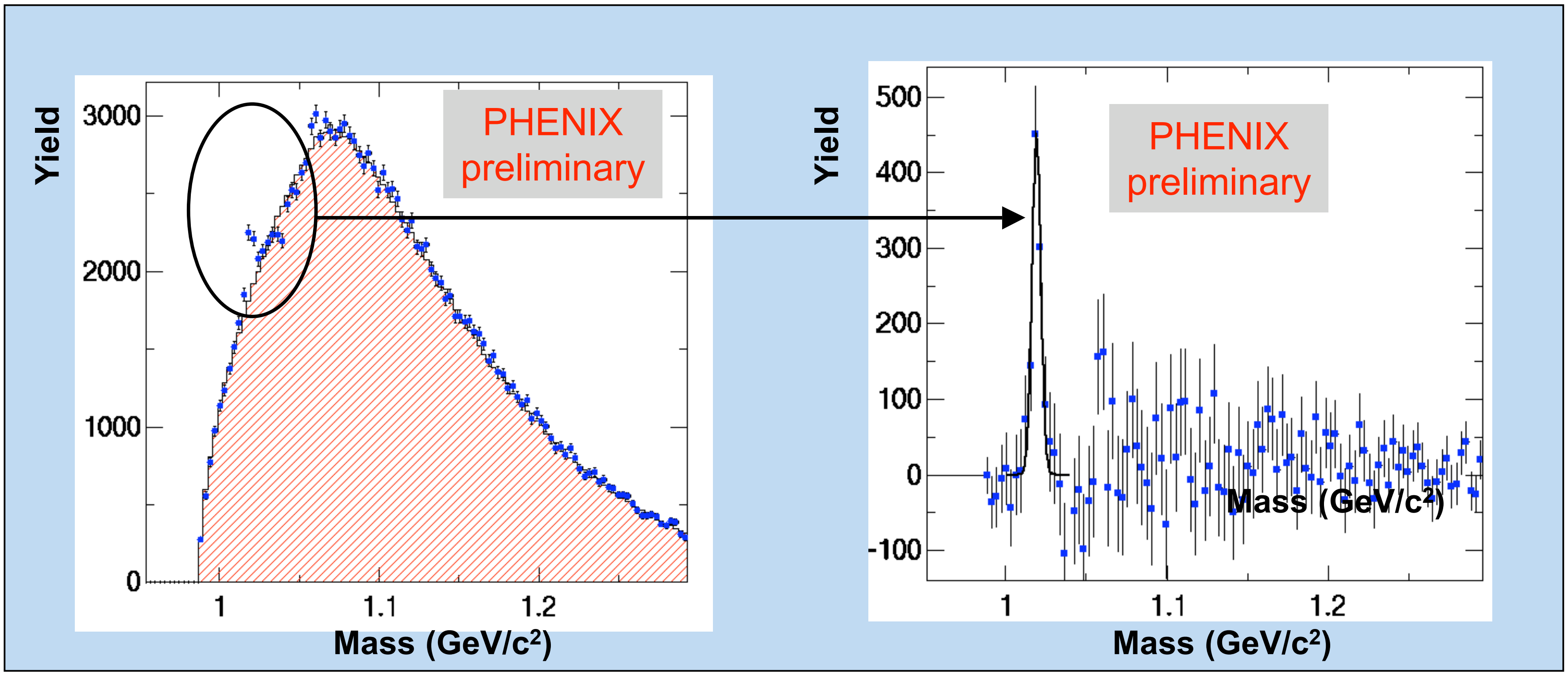
- Restoration of approximate chiral symmetry may modify the φ mass and width in medium
  - Look for variations with centrality
  - Compare to p+p and d+A results
- These modification may result in a change in the branching fraction of φ→ K^+K^- and φ→ e^+e^- when φ decays in medium (t_f ~ 44 fm/c)
  - Compare different pair p_T ranges
- Final state interactions of kaons may lower the apparent measured branching fraction of φ→ K^+K^- relative to φ→ e^+e^-
  - Measure both channels in the same detector

R. Rapp nucl-th/0204003



□□ $K^+ K^-$

Au + Au minimum bias (0-90% central) data at E_{cm}=200 GeV



Signal = 1135 ± 120

Signal / Background = 1 / 12

Mass peak and width agree within errors of PDG values.

$\phi \to K^+ K^-$ Results

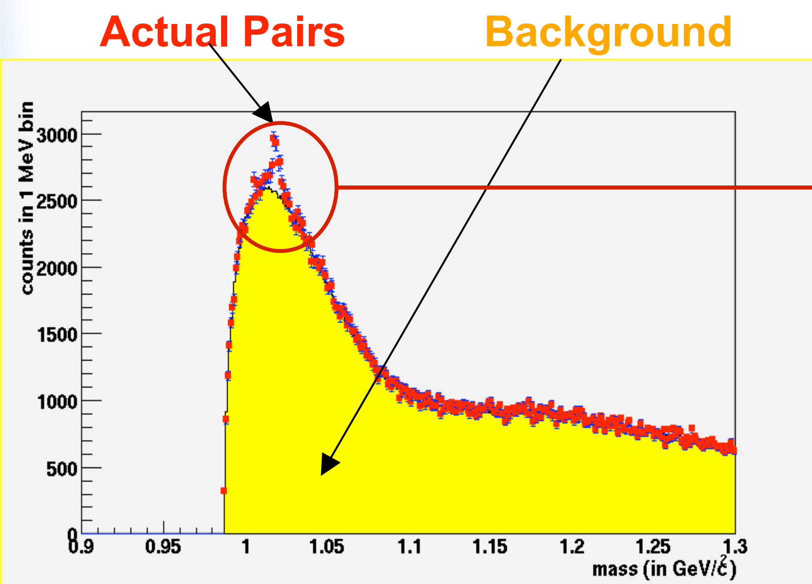
Au + Au minimum bias (0-90% central) at E_{cm}=200 GeV

PHENIX Preliminary at QM'02

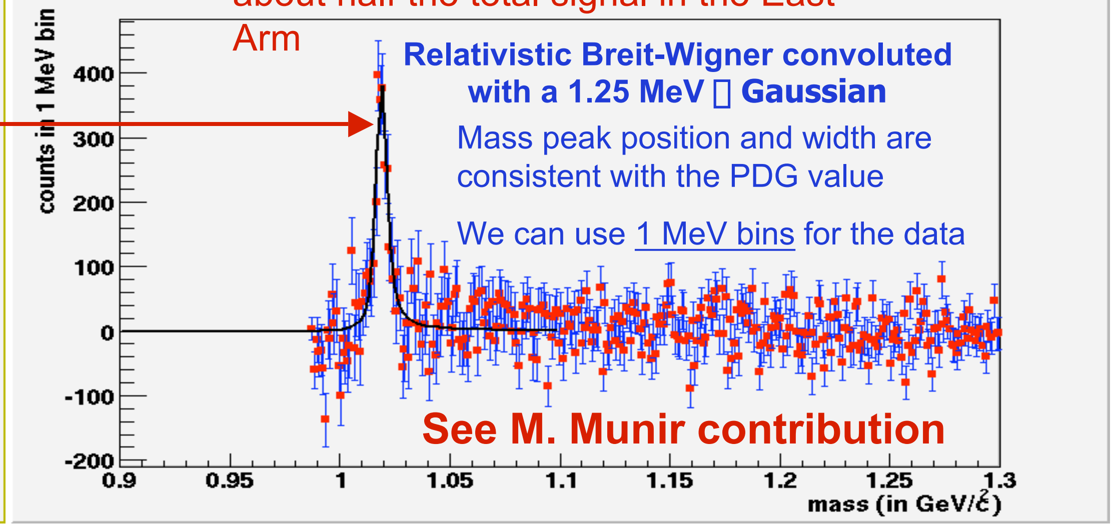
$$\phi \to K^+K^-: \quad \frac{dN}{dy} = 2.01 \pm 0.22(stat)^{+1.01}_{-0.52}(sys)$$

STAR result: Au + Au minimum bias (0-85%) at E_{cm}=130 GeV
dN/dy = 2.01 ± 0.11 (stat)

We now have a factor of 3 higher statistics using our EM Calorimeter PID



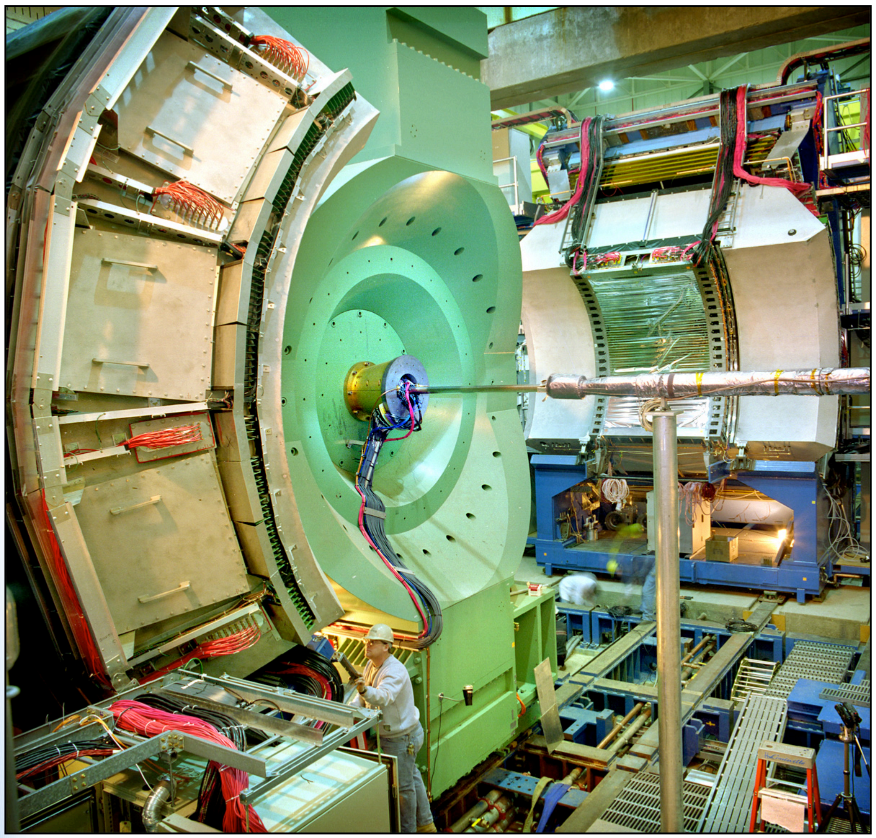
Signal from TOF-EMCal pairs, min bias: about half the total signal in the East Arm

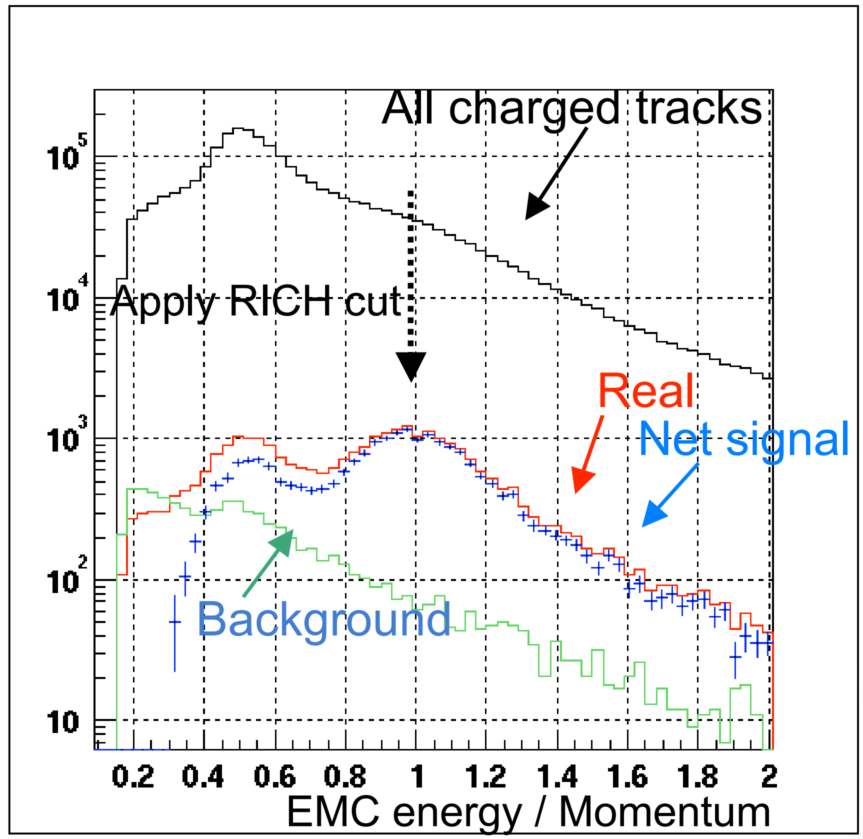


Electron Identification for □ −> e^+e^-

PHENIX has excellent electron identification capabilities.

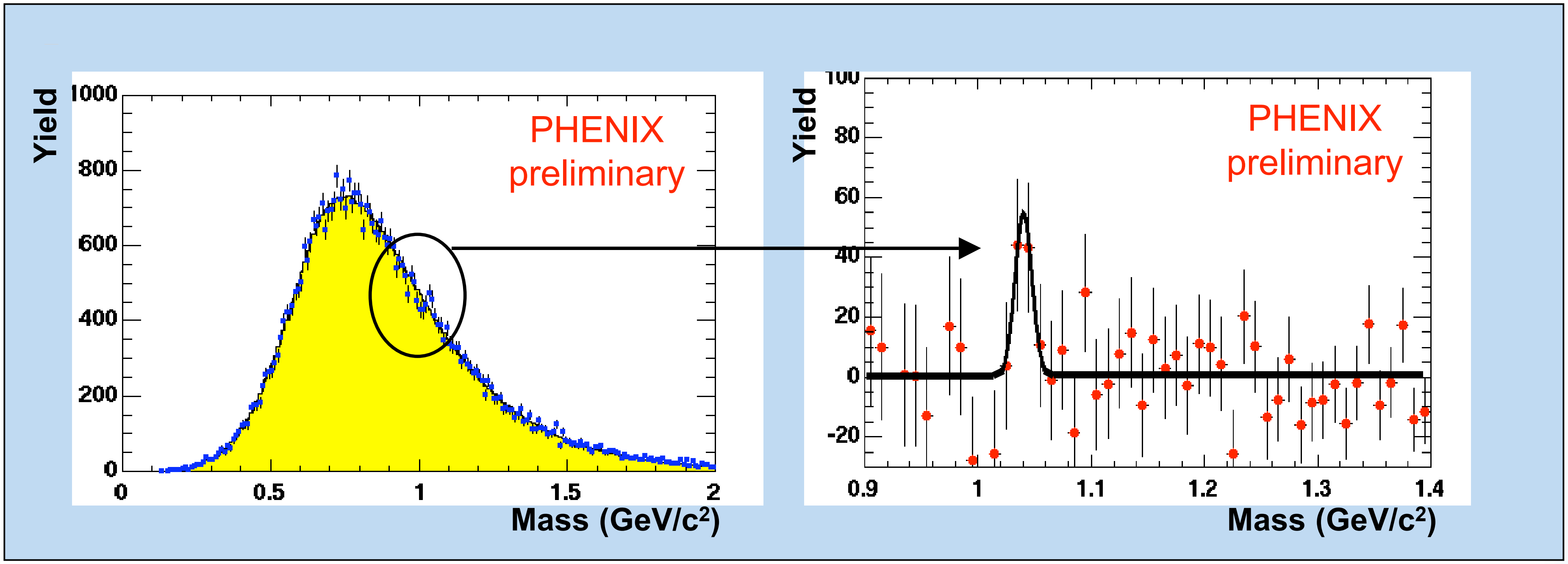
- Ring Imaging Cerenkov Counter - threshold selection
- Time Expansion Chamber - dE/dx measurement
- Electromagnetic Calorimeter - Energy-Momentum match





□□ e^+e^-

Au + Au minimum bias (0-90% central) at E_{cm}=200 GeV



$$\text{Signal} = 101 \pm 47\,(\text{stat})^{+56}_{-20}(\text{sys})$$

Signal / Background = 1 / 20

Mass peak and width agree within errors of PDG values.

□ Comparison

Au + Au minimum bias (0-90% central) at E_{cm}=200 GeV

dN/dy corrected for vacuum PDG branching fraction values.

B.F. □□ e^+e^- = 2.9 x 10^{-4}, B.F. □□ K^+K^- = 0.49

PHENIX Preliminary

$$\square\square\ e^+e^{\square}: \quad \frac{\mathrm{dN}}{\mathrm{dy}} = 5.4 \pm 2.5(stat)^{+3.4}_{\square 2.8}(sys)$$

PHENIX Preliminary

$$\square\square\ K^+K^{\square}: \quad \frac{\mathrm{dN}}{\mathrm{dy}} = 2.01 \pm 0.22(stat)^{+1.01}_{\square 0.52}(sys)$$

Data are consistent with the free vacuum PDG branching fraction values to within 1□ statistical errors.

New □ -> K^+K^- data being analyzed with the use of the EMCal will enable us to set better limits on the dN/dy, the mass centroid, and the width.

Summary

- **Hydrodynamic Collective Expansion**
  - All results of 200 GeV data indicate a strong collective expansion in central collisions
  - $<p_T>$ vs. centrality : the heavier mass, the larger $<p_T>$, steep rise at peripheral to mid-central collisions
  - Hydro-dynamical model fit to the spectra □ $b_T = 0.7$, $T_{fo} = 110$ MeV

- **Chemical Composition**
  - Baryon chemical potential ~ 30 MeV
  - No p_T and centrality dependence for $□^-/□^+$, K^-/K^+, pbar/p ratio
  - proton yield is comparable with pions @ 2 GeV in central collisions, less in peripheral

- **The □ in PHENIX**
  - The □ has been measured in both the K^+K^- and e^+e^- channels
  - Preliminary data values in agreement with PDG
  - A large factor increase in statistics from the EMCal plus a more refined analysis will enable us to set tighter limits on the comparison with PDG