Open Heavy Flavor at PHENIX

Alan Dion

STONY BROOK STATE UNIVERSITY OF NEW YORK

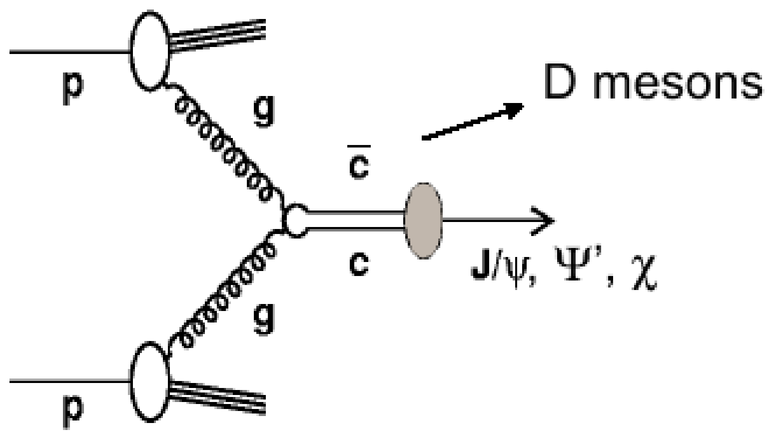
PHENIX

HEP 2007, July 19, 2007

$c\bar{c}$, $b\bar{b}$ from hadronic collisions

hard process

quark-antiquark annihilation
gluon fusion (dominates at large energy)
higher-order processes? (small at large energy)



General strategy to study heavy quarks

Calibrate the heavy quark production in p+p collisions

Probe the medium from A(d)(p)+A collisions, using known initial yield

Theoretical Expectation

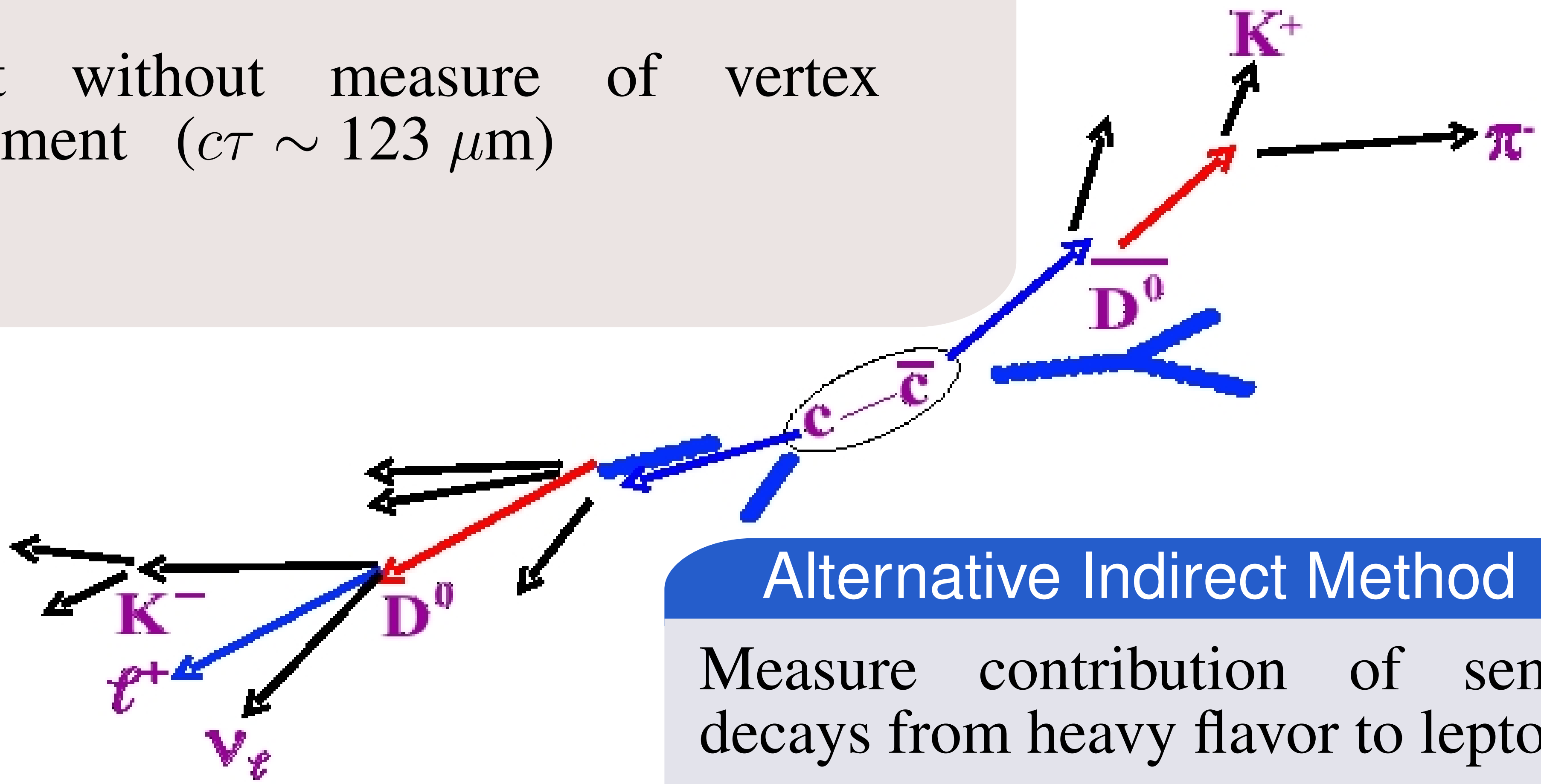
Large mass ⇒ less E-loss from gluon radiation ("Dead-cone" effect)

Some medium-induced radiation
Elastic scattering? (depends on α_s)

Direct Reconstruction

$\overline{D^0} \rightarrow K^+\pi^-$

Difficult without measure of vertex displacement $(c\tau \sim 123\ \mu\text{m})$

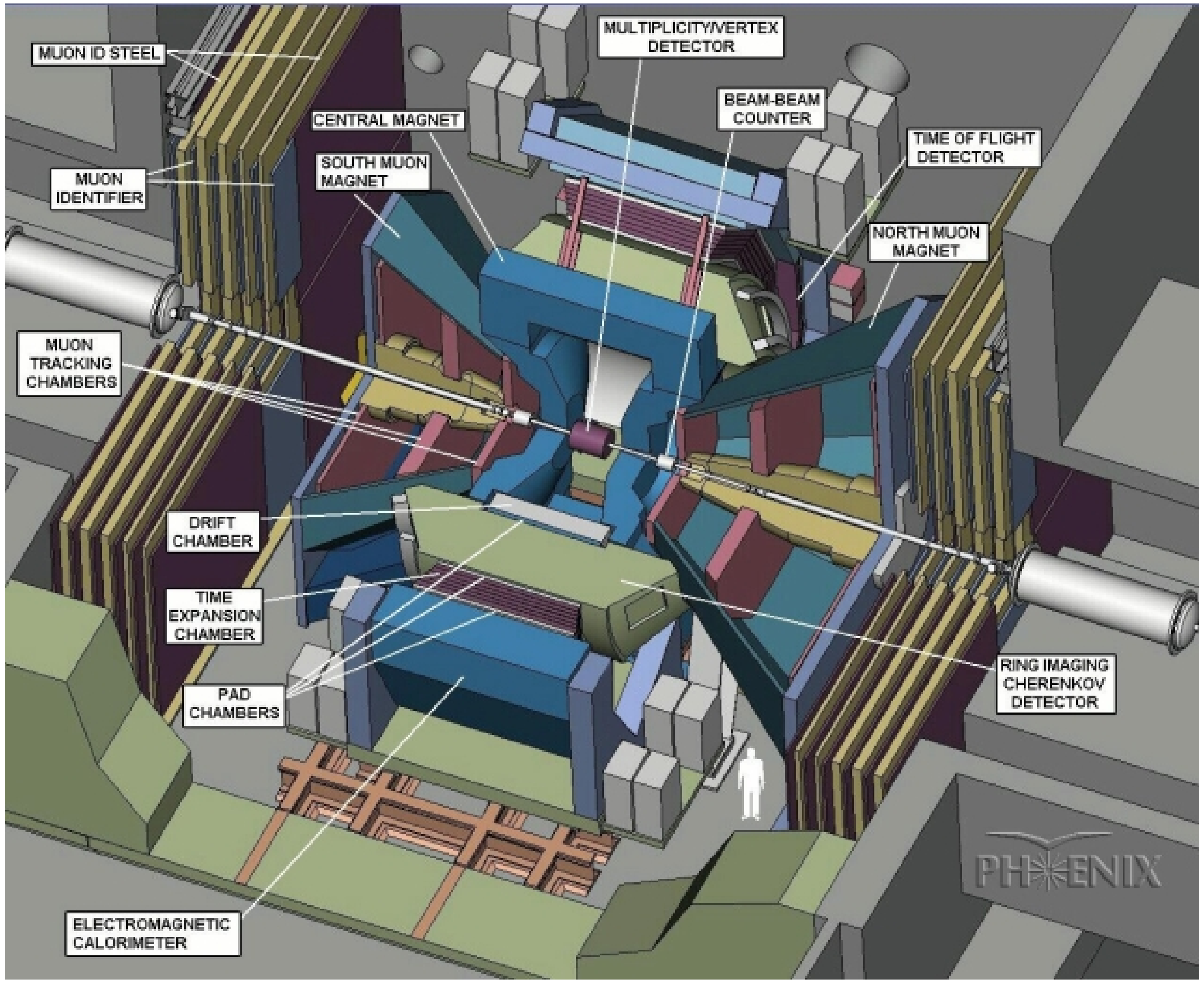


Alternative Indirect Method

Measure contribution of semileptonic decays from heavy flavor to lepton spectra

Both single and pair spectra

PHENIX Detector



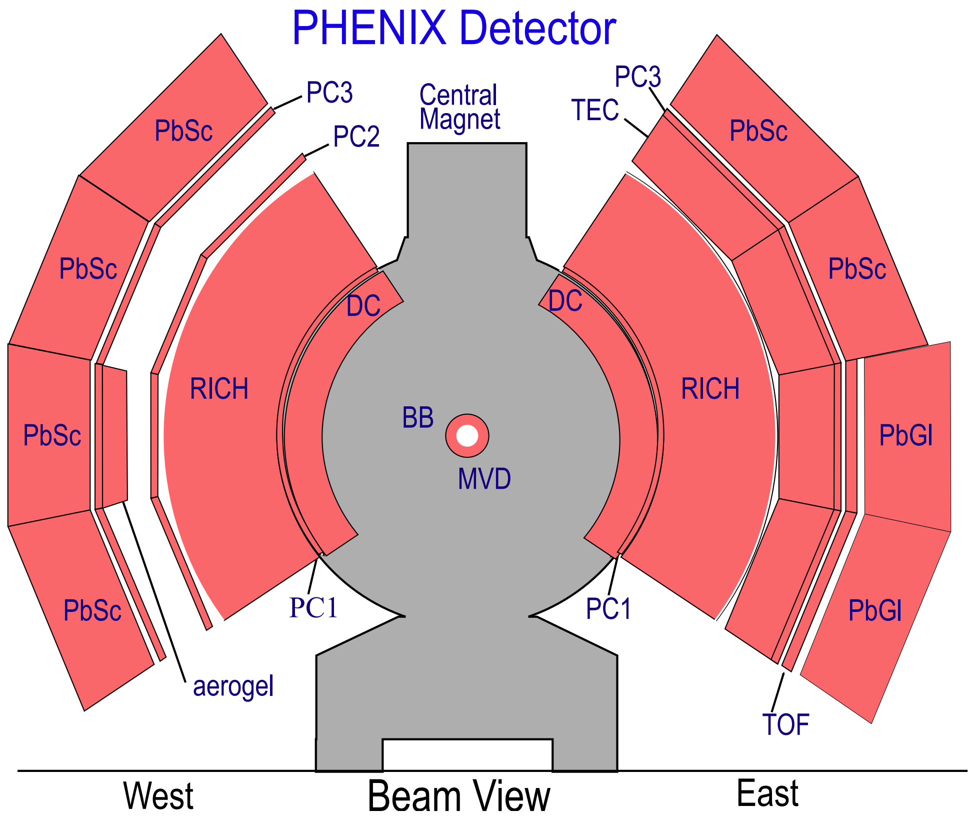
PHENIX

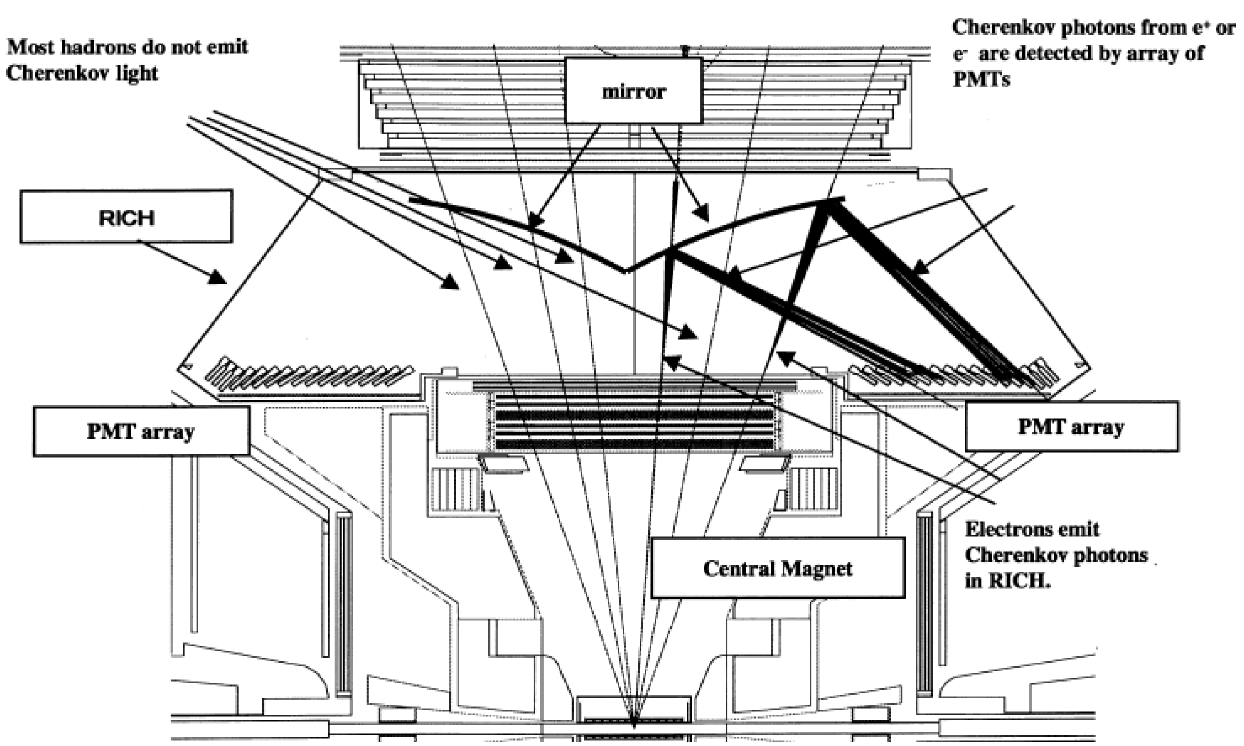
electrons in central arms:
tracking, eID with RICH, EMC

muons in forward arms:
tracking, μID with absorber

Electron Identification in PHENIX

PHENIX



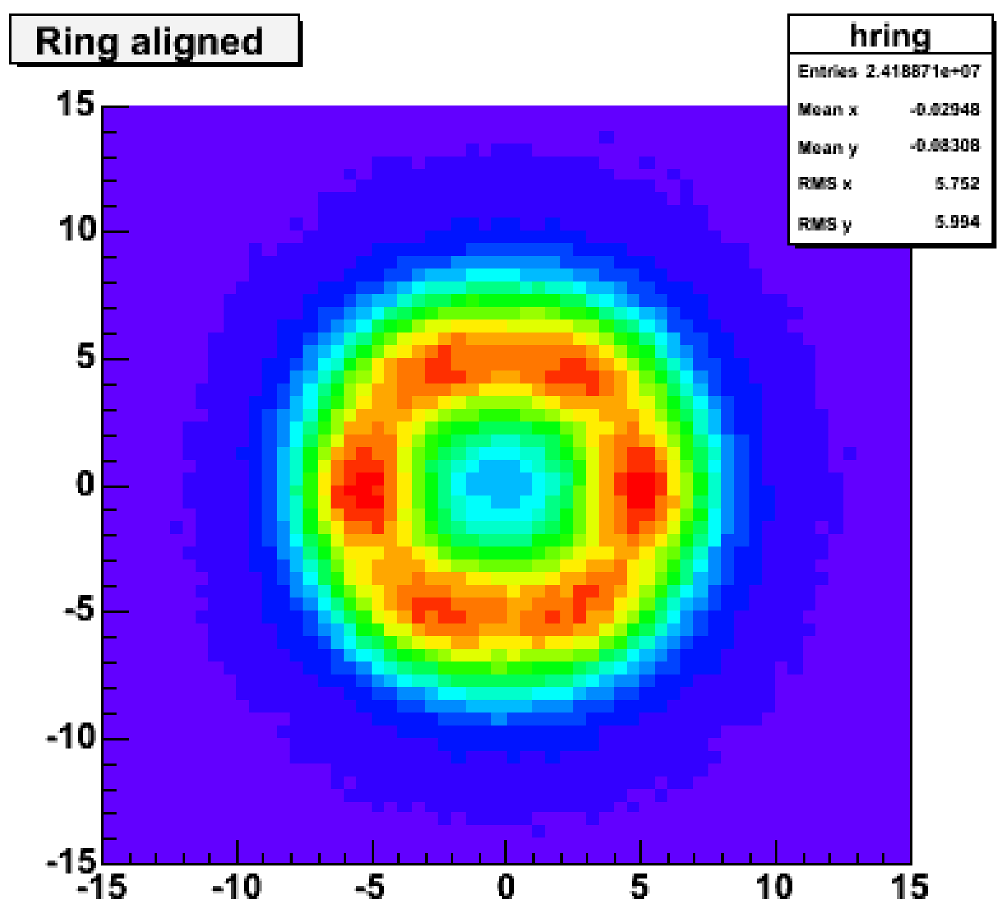


Detectors

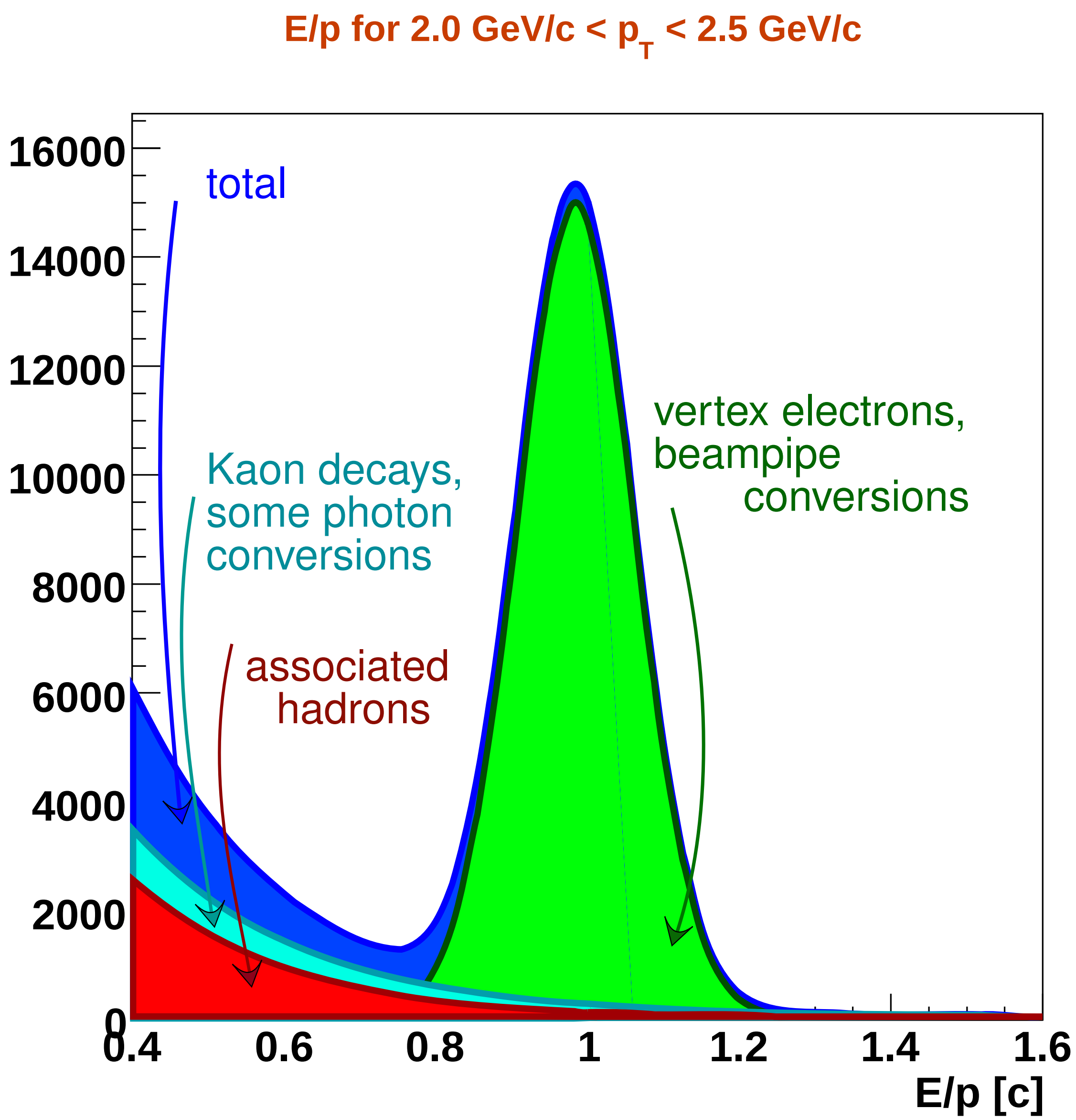
Tracking in drift chamber. Track matching to RICH & EMC.

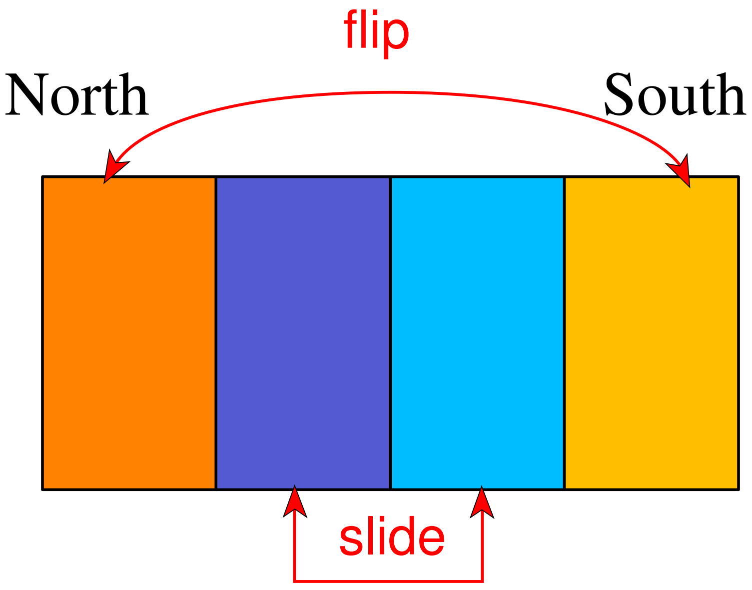
Ring size/shape in RICH

E/p distribution from the EMC and DC.



Electron Identification in PHENIX





Hadronic Background

Some hadronic tracks are randomly associated with a ring in the RICH. These are statistically subtracted by swapping the north and south sides of the RICH in software.

Energy/momentum distribution

The E/p distribution gives strong evidence that we understand our eID. Kaons which decay far from the collision have mis-reconstructed momentum. Most tracks passing eID cuts form a gaussian centered at 0.98 (EMC calibrated for photons)

Electron sources

- Dalitz decay of light neutral mesons
  - $\pi^0 \rightarrow \gamma e^+ e^-$
  - also from $\eta, \omega, \eta^{'}, \phi$
- $\gamma \rightarrow e^+ e^-$ in material
  - main photon source: $\pi^0 \rightarrow \gamma\gamma$
  - beampipe, detector material, air
- Weak kaon decays
  - $K^{\pm} \rightarrow \pi^0 e^{\pm} \nu_e$
- Di-electron decays of vector mesons
  - $\rho, \omega, \phi \rightarrow e^+ e^-$
- Direct/thermal radiation

- Heavy flavor decays

Cocktail Method

PHENIX

Method

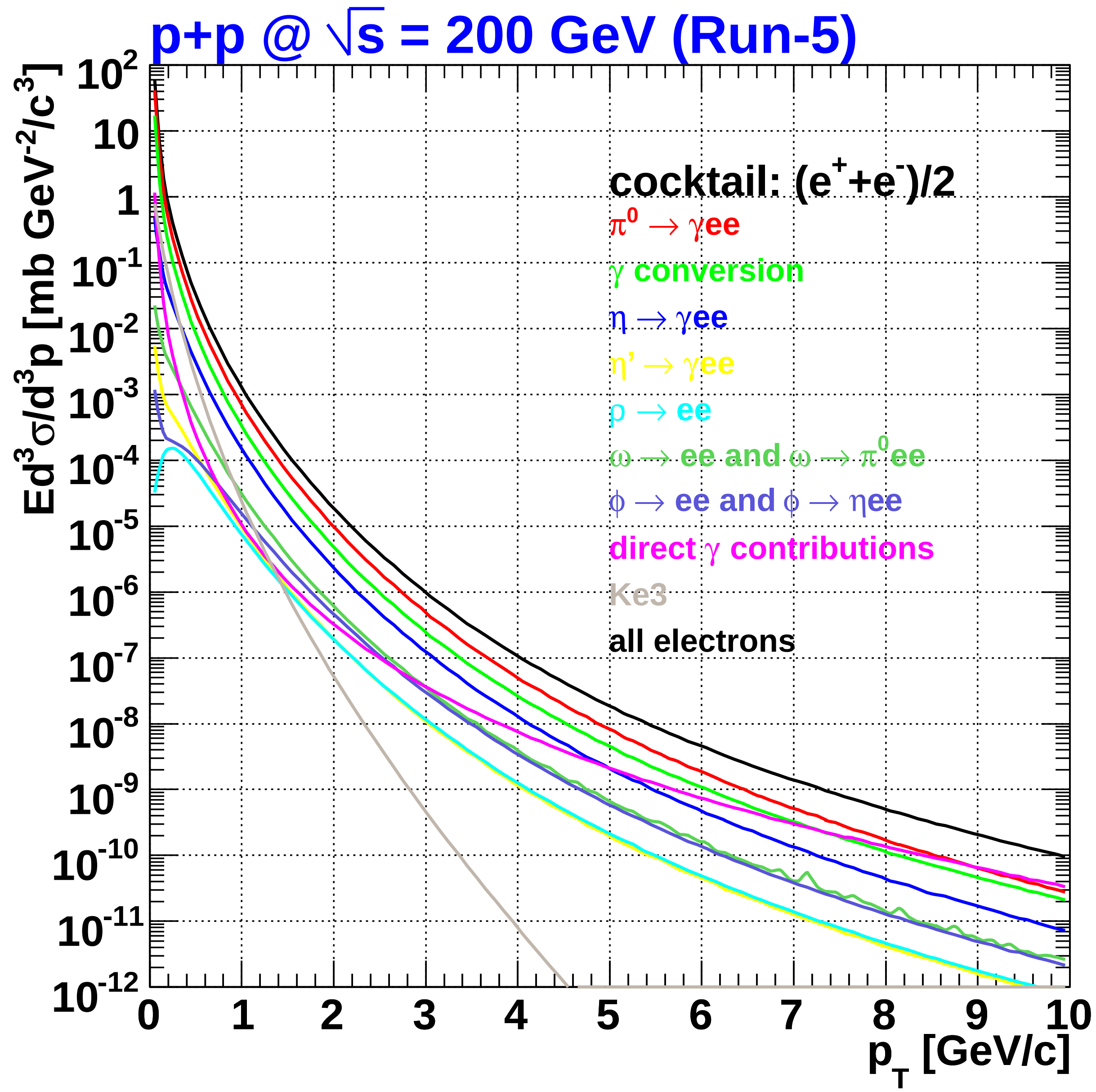
All relevant background sources are <u>measured</u>

Decay kinematics and photon conversion rate are calculated (simulated)

Background cocktail is subtracted from inclusive spectrum

Performs well at high p_T where signal/background is large

Not limited by statistics



Converter Method

Method

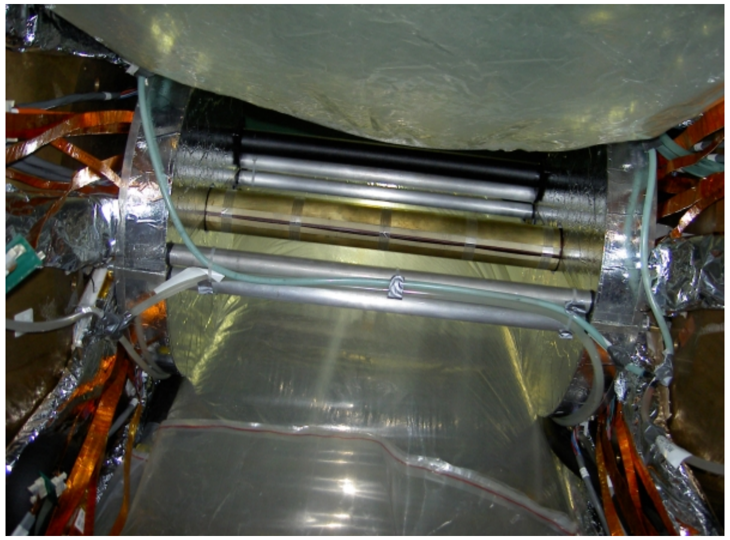
Add material of known thickness around the beampipe and compare the electron spectra with and without the material installed

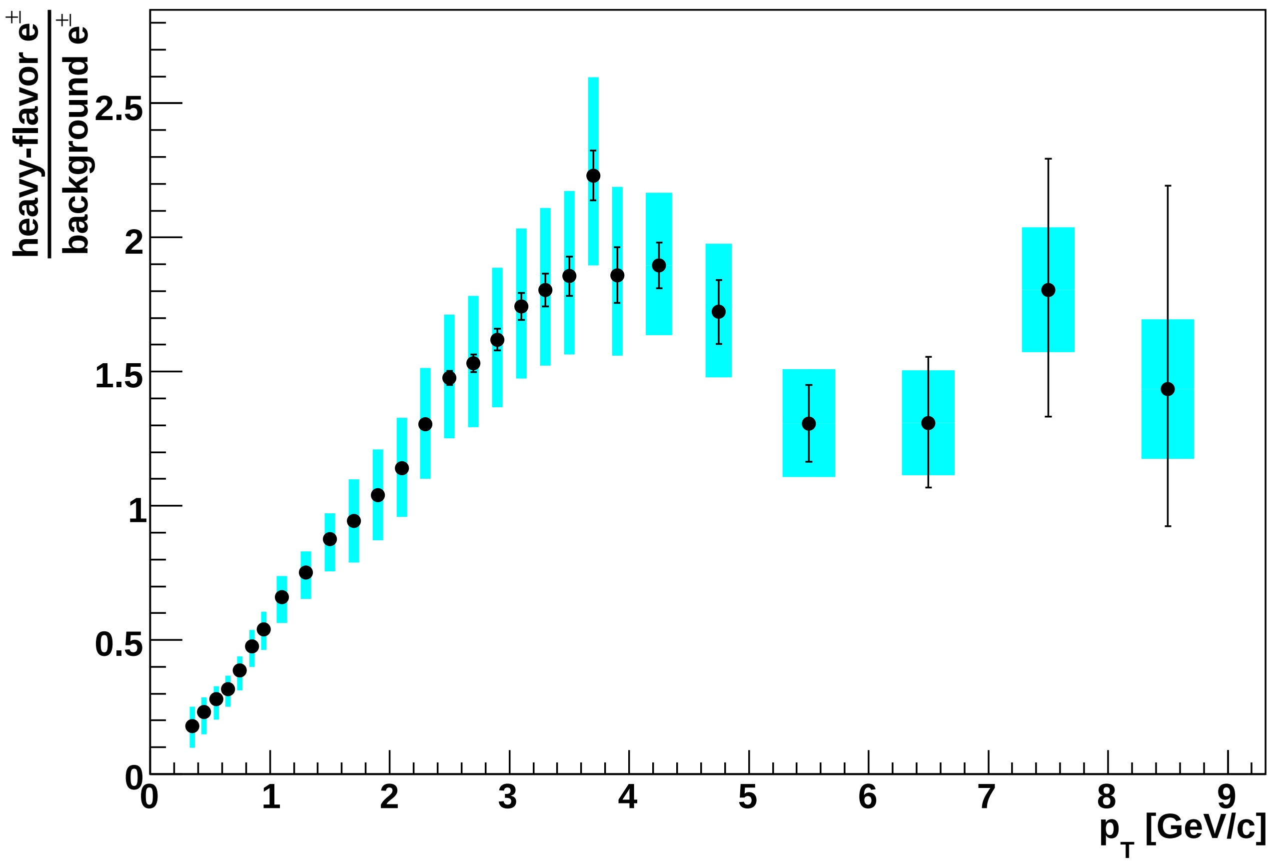
$$N_{non-photonic} = \frac{R_\gamma N_{inclusive} - N^{converter}_{inclusive}}{R_\gamma - 1}$$

Works best at low p_T where photonic sources are significant

Limited by statistics of converter run

Converter method is used to normalize the cocktail method





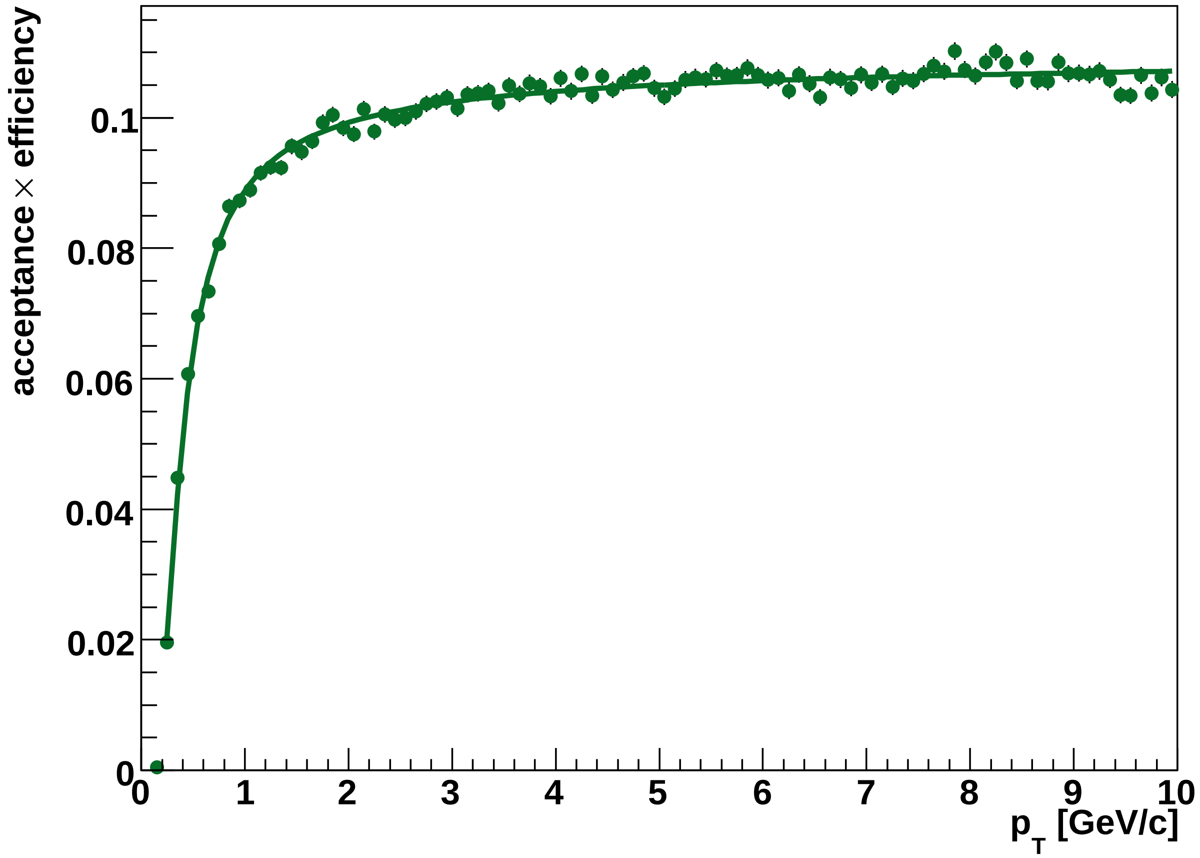
Efficiency Correction

Acceptance × Efficiency

Simulate single electrons/positrons in full azimuth and PHENIX rapidity

run through GEANT

make eID cuts



Multiplicity Dependence

Simulate single electrons/positrons in full azimuth and PHENIX rapidity

embed into real data

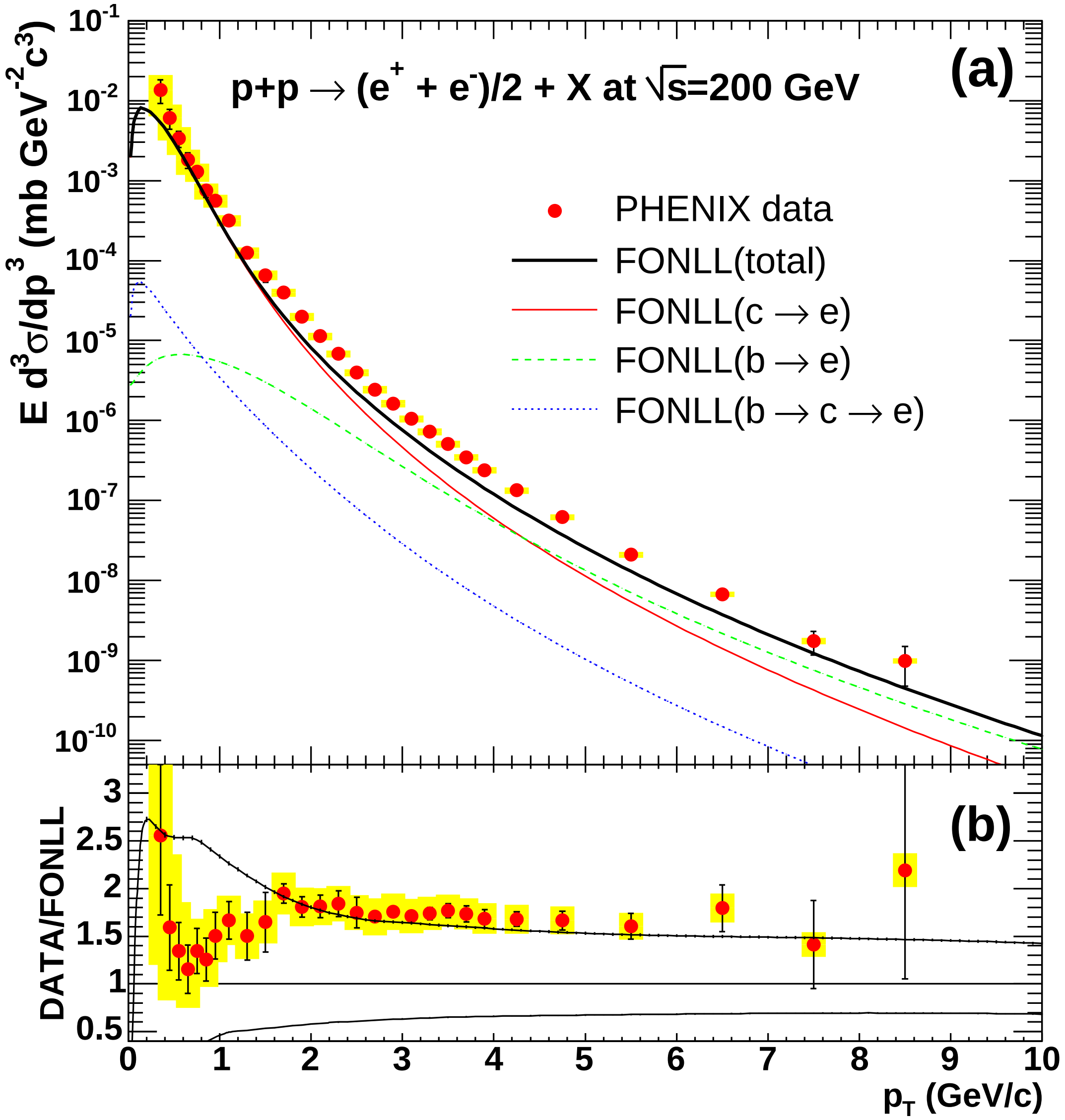
run reconstruction software

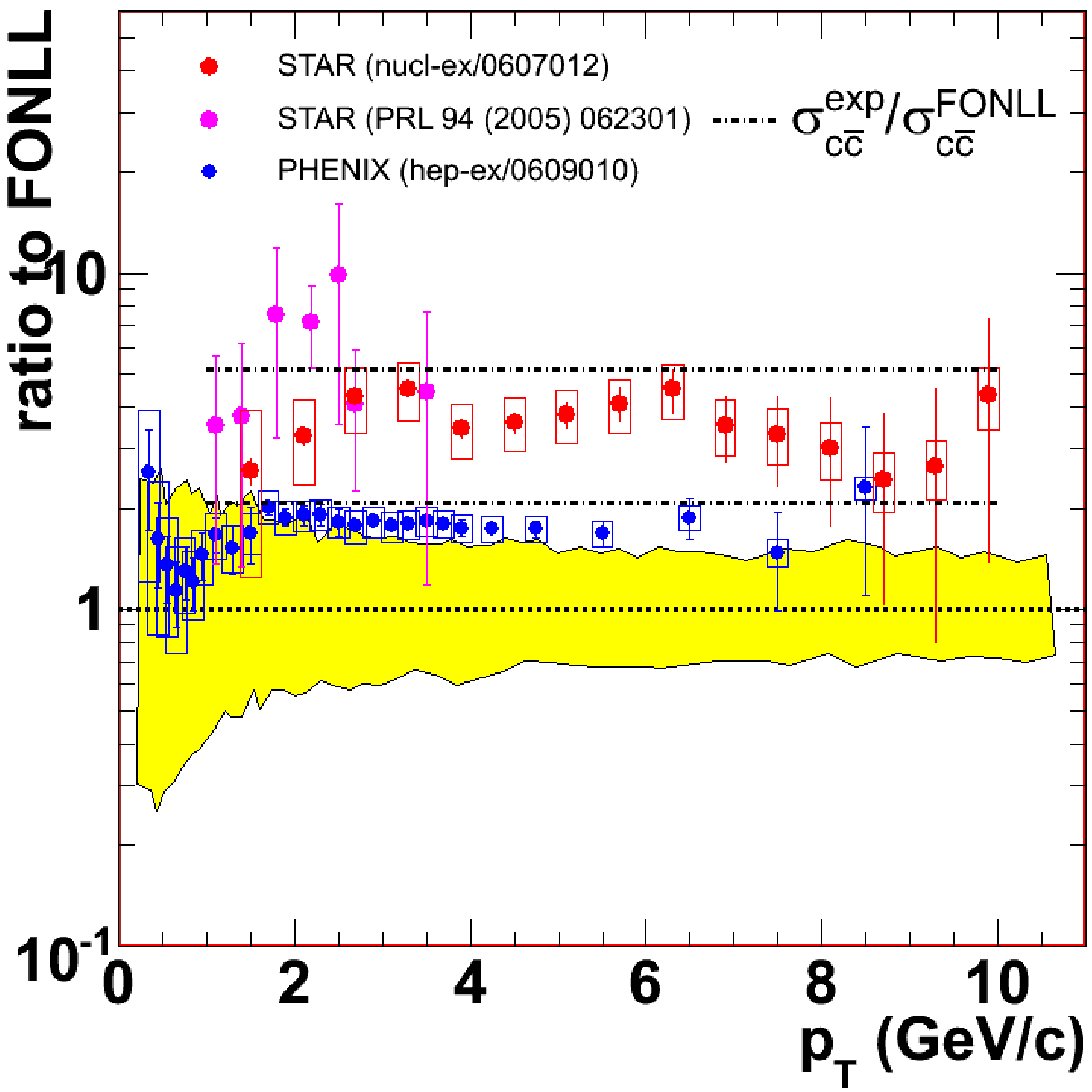
make eID cuts

Centrality	Efficiency
0-10%	0.751
10-20%	0.810
20-40%	0.874
40-60%	0.935
60-93%	0.976

Charm Cross Section

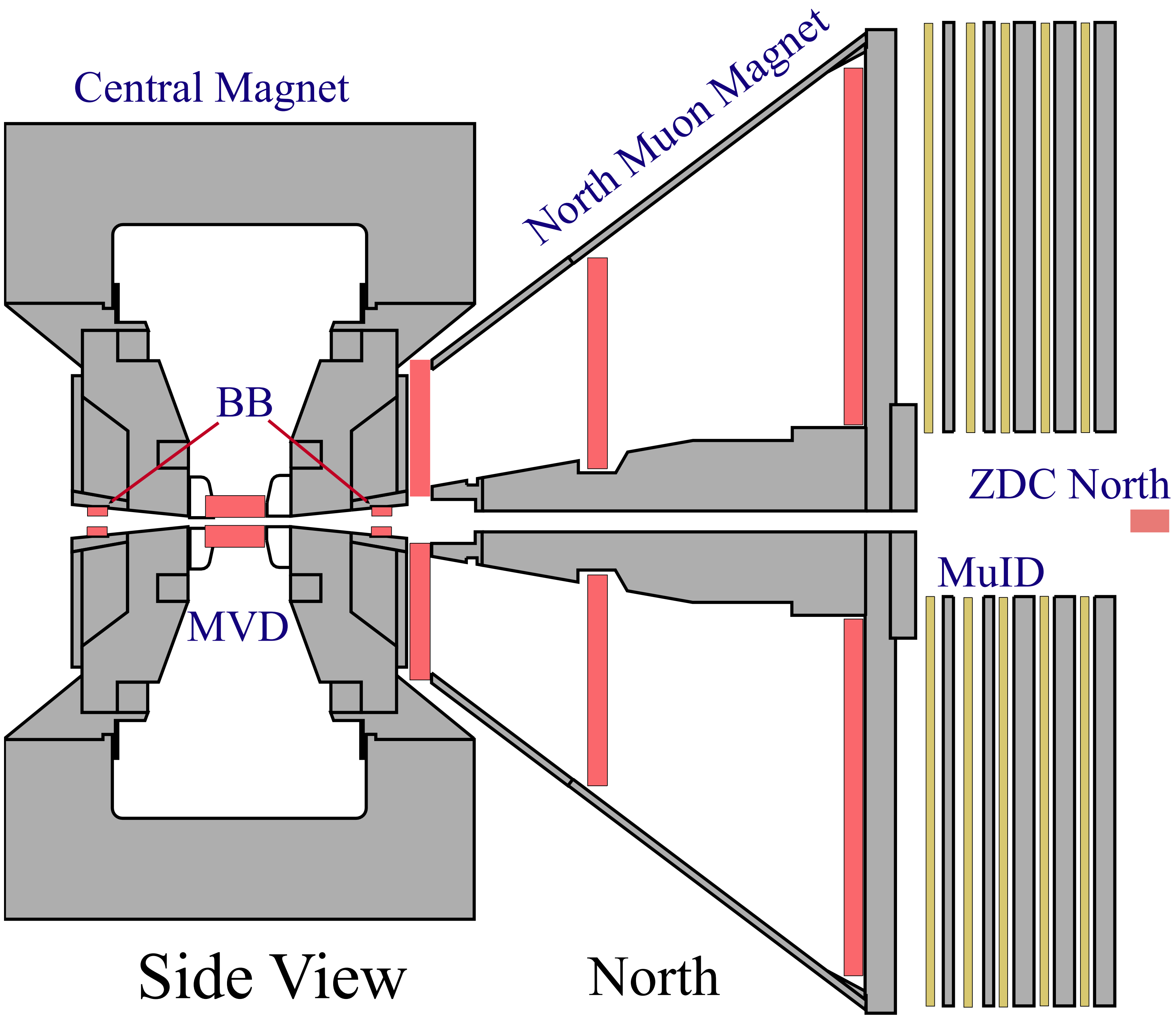
- PHENIX $e^{\pm}$ consistent with FONLL
- STAR $e^{\pm}$ above FONLL



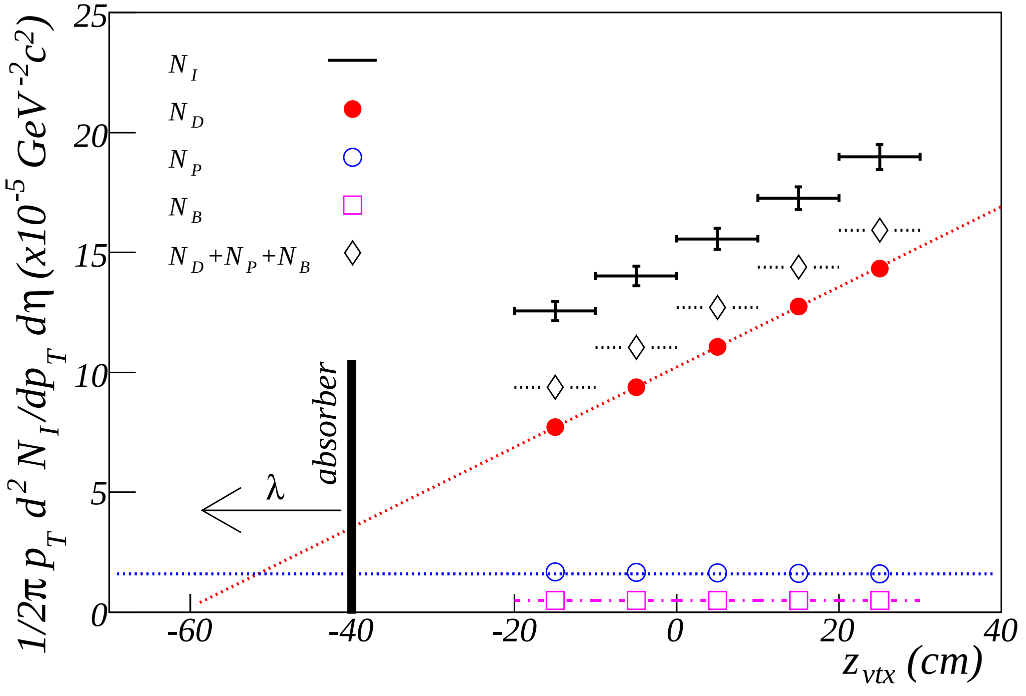


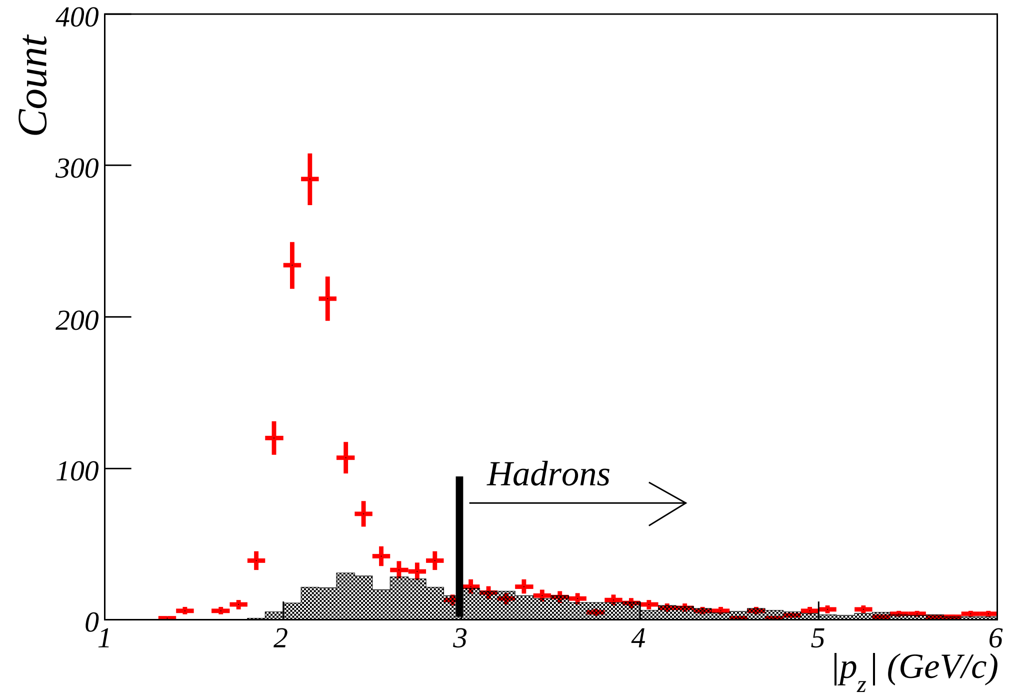
Muon Sources

- Prompt muons
  - mainly from c, b
  - PYTHIA: <15% from $\rho, \omega, \phi \rightarrow \mu^+\mu^-$ for p_T > 0.9 GeV/c
- Decay muons
  - From π, K
  - Important at all p_T
- Punch-through hadrons
  - small, uncertain contribution
- Stopped hadrons



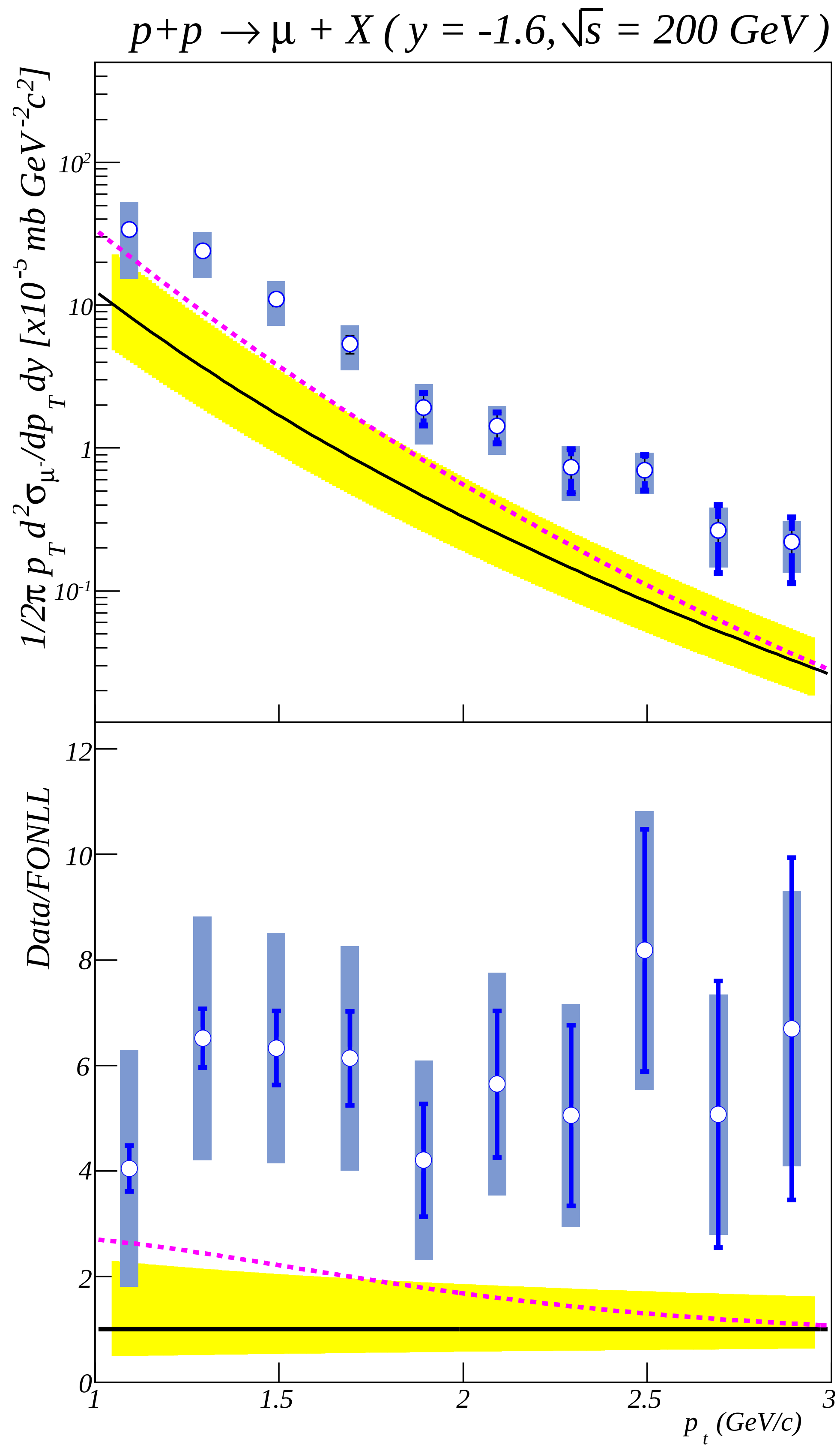
- Decay muons obtained from vertex distribution
  - Yield of decay muons increases linearly with distance between collision vertex and absorber
- Punch-through hadrons calculated from a data-driven absorption model:
  - Tracks reaching gap 2 (3), but not gap 3(4)
  - Tracks reaching gap 4
  - Nuclear interaction lengths (FLUKA, GHEISHA)
- Decay muons obtained from vertex distribution
  - Subtract decay muons and punch-through hadrons from inclusive yield at gap 4

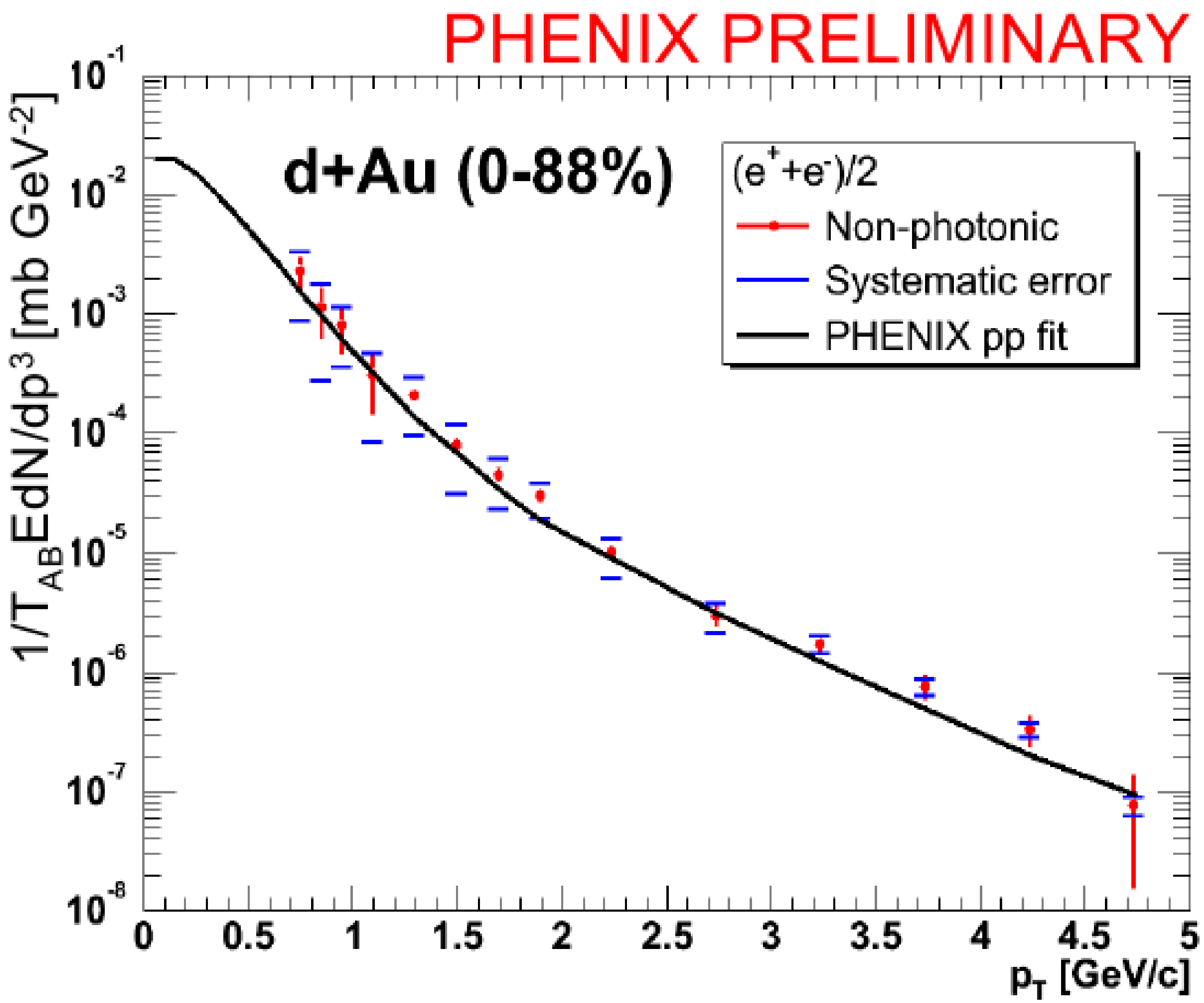




Comparison of $\mu^{\pm}$ with FONLL

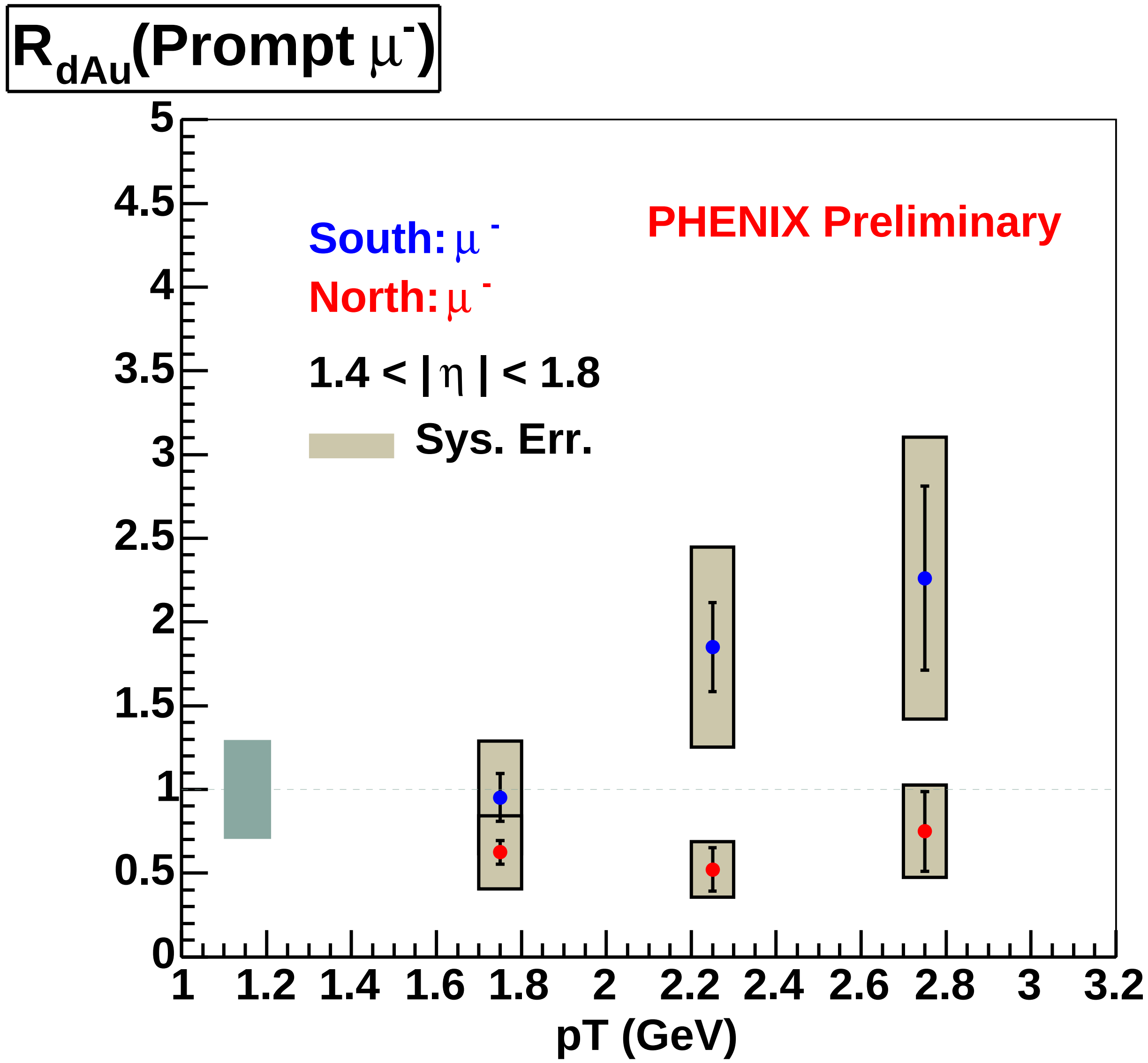
- Prompt μ^{-} spectrum from p+p collisions at $\sqrt{s} = 200$ GeV
- Prompt μ^{+} spectrum has much larger uncerntainty due to punch-through hadrons
- Prompt μ^{-} spectrum at η = -1.65 is comparable to heavy flavor $e^{\pm}$ spectrum at y=0
- Excess over PYTHIA and FONLL
- Heavy flavor rapidity distribution wider than expected from pQCD





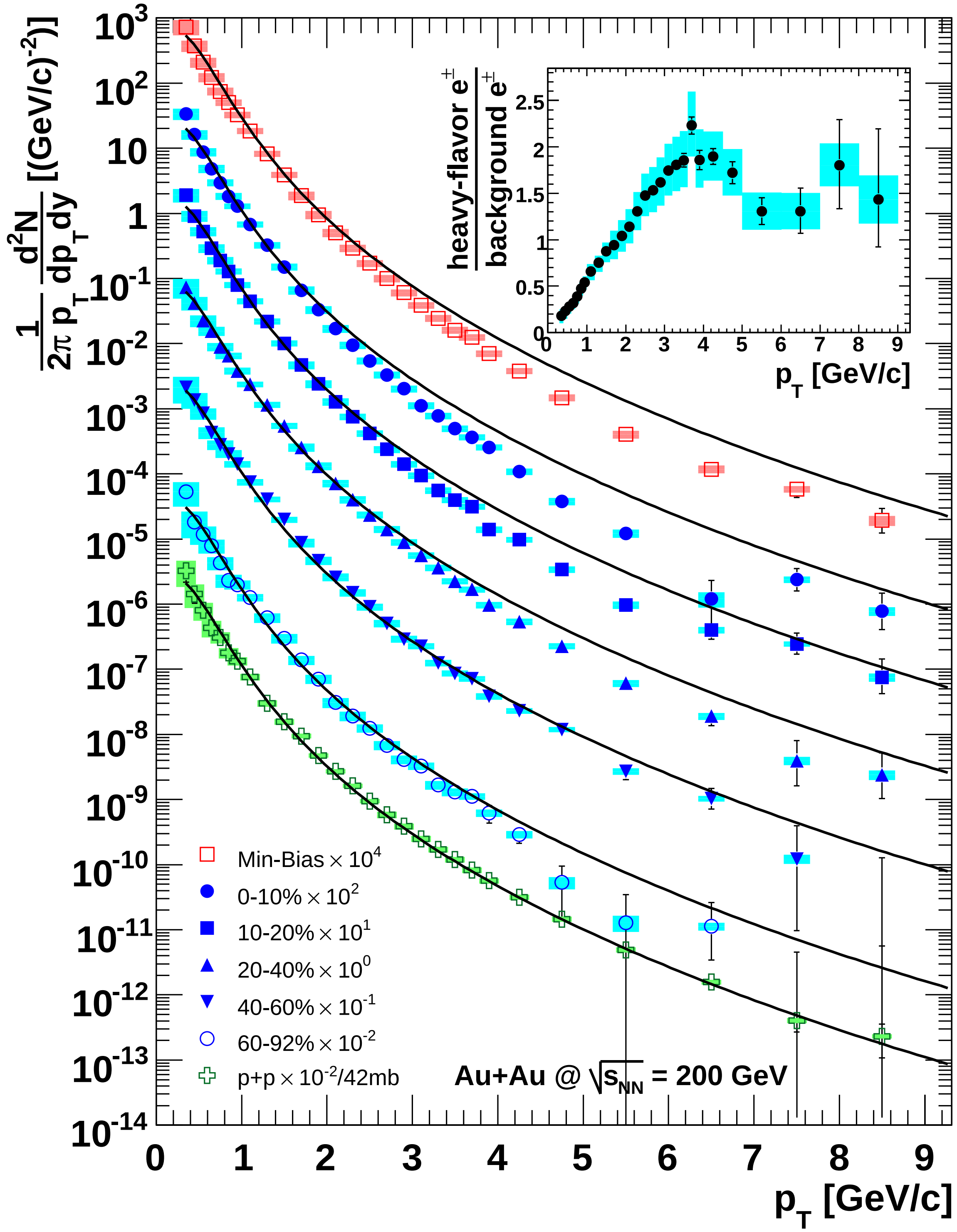
- No significant cold nuclear matter effects of heavy flavor at y=0

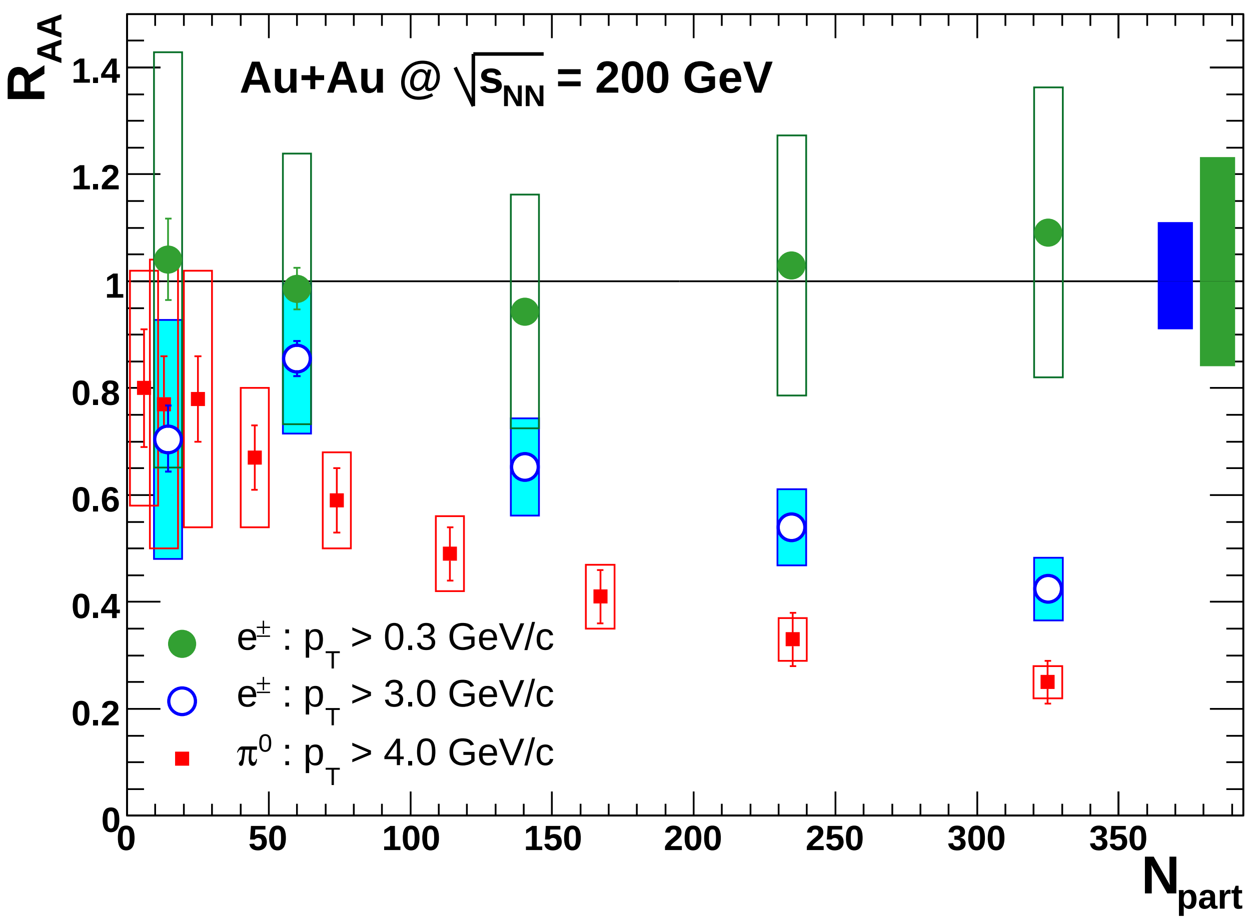
μ^- from d+Au Collisions



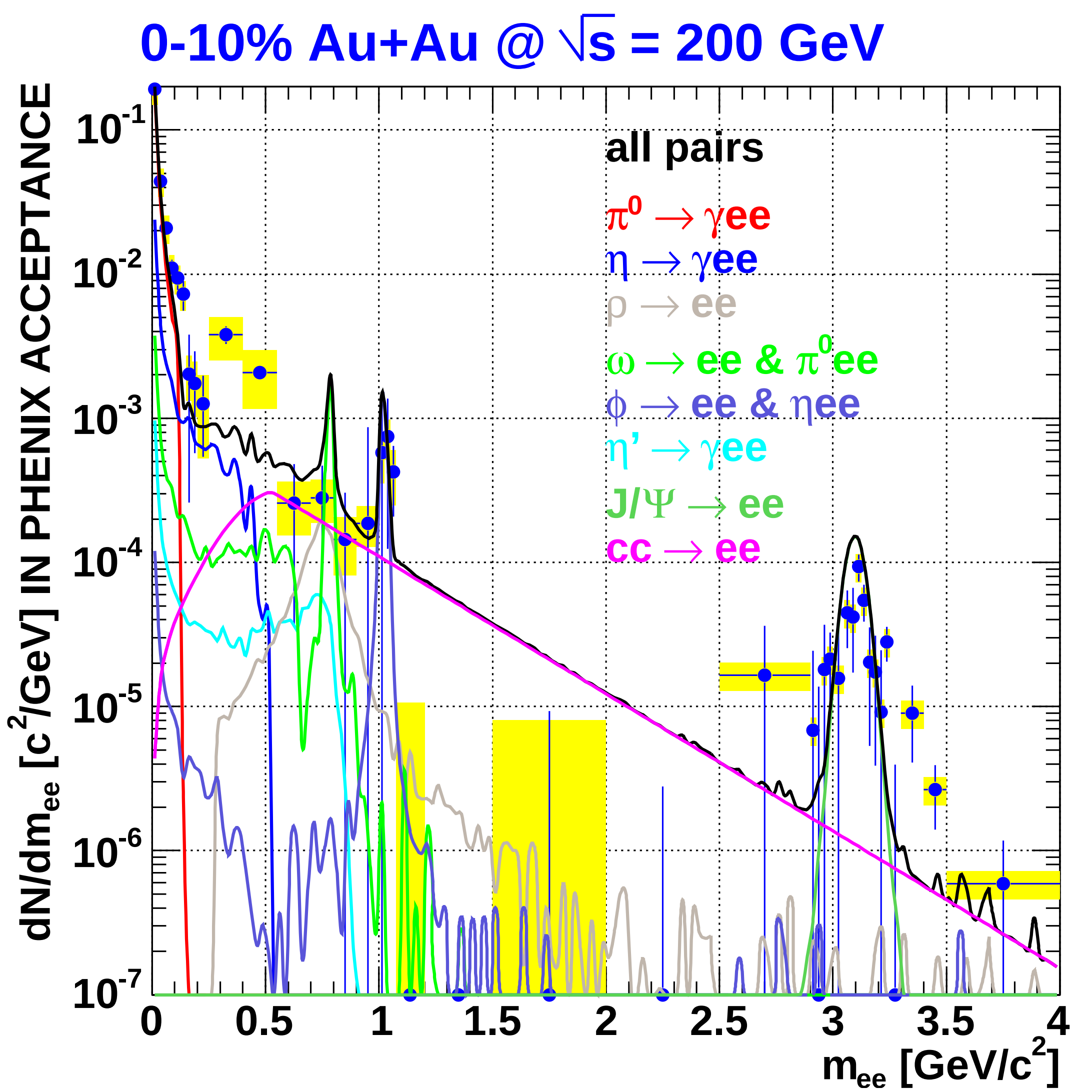
- Suppression in d-going direction → CGC?
- Enhancement in Au-going direction → anti-shadowing? recombination?

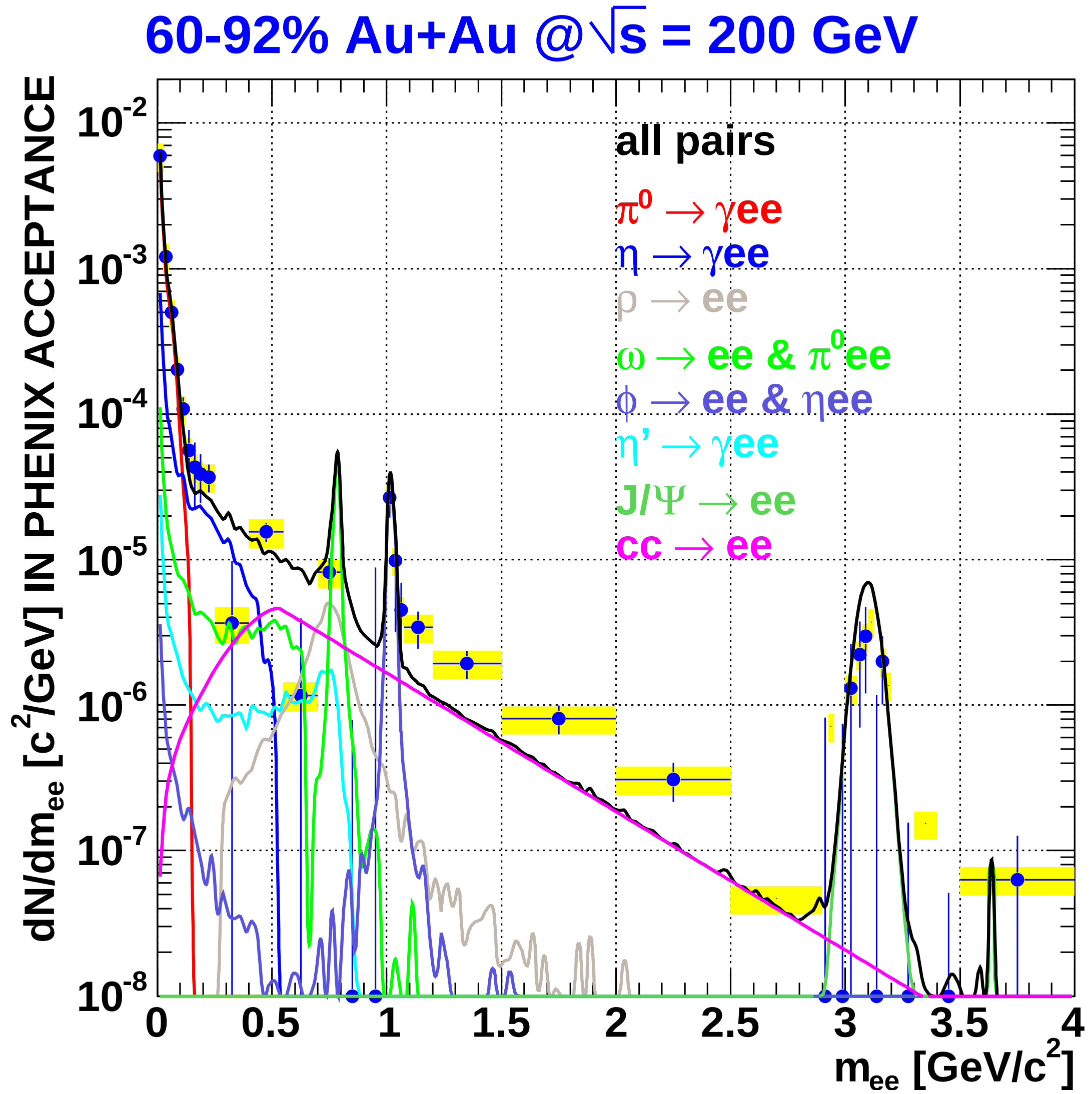
Hot Nuclear Matter





Di-leptons at PHENIX



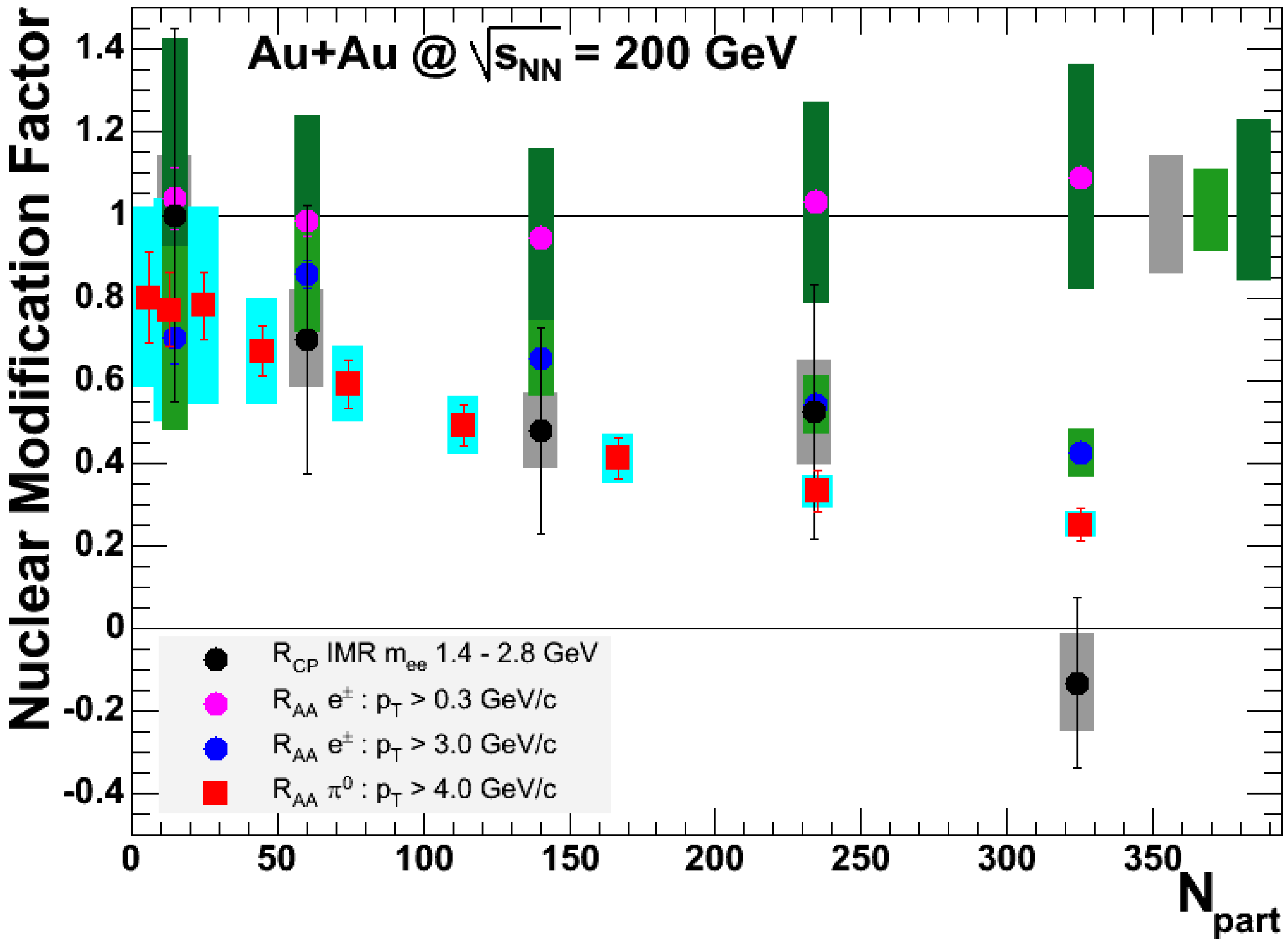


Intermediate-mass di-electrons

mostly come from charm...perhaps a significant thermal radiation contribution

what can the di-electrons tell us about the medium properties and heavy quark energy loss?

Di-leptons at PHENIX



apparent mass shift

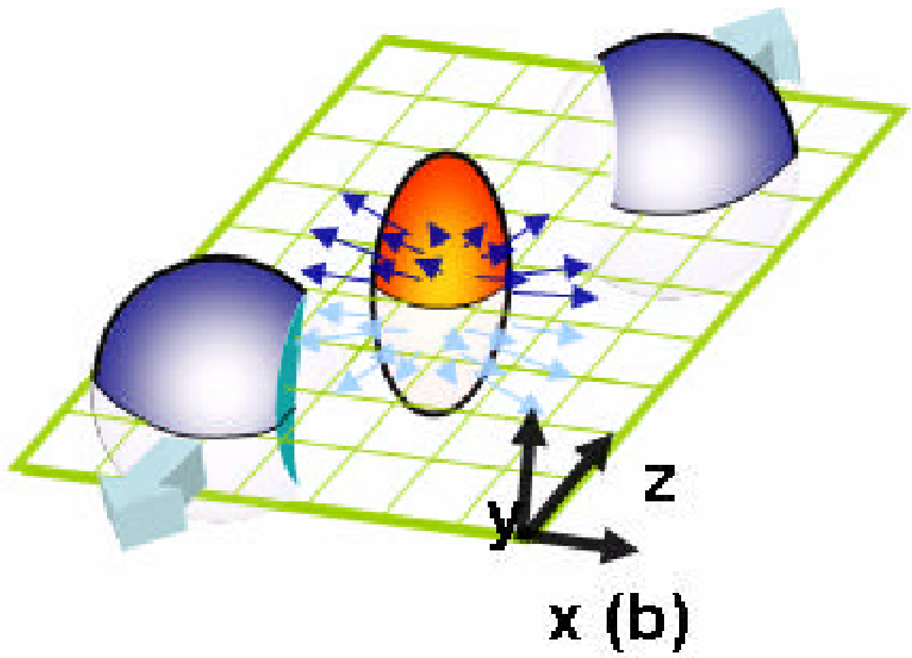
"suppression" similar to that of single electrons

the medium changes the opening angle of e^+e^- pairs

low-mass enhancement hidden by PHENIX acceptance

this effect will be more dramatic for energy loss through many small scatters, than for one large scatter

Azimuthal Anisotropy



the measurement

Measure reaction plane with BBC at forward and backward rapidity

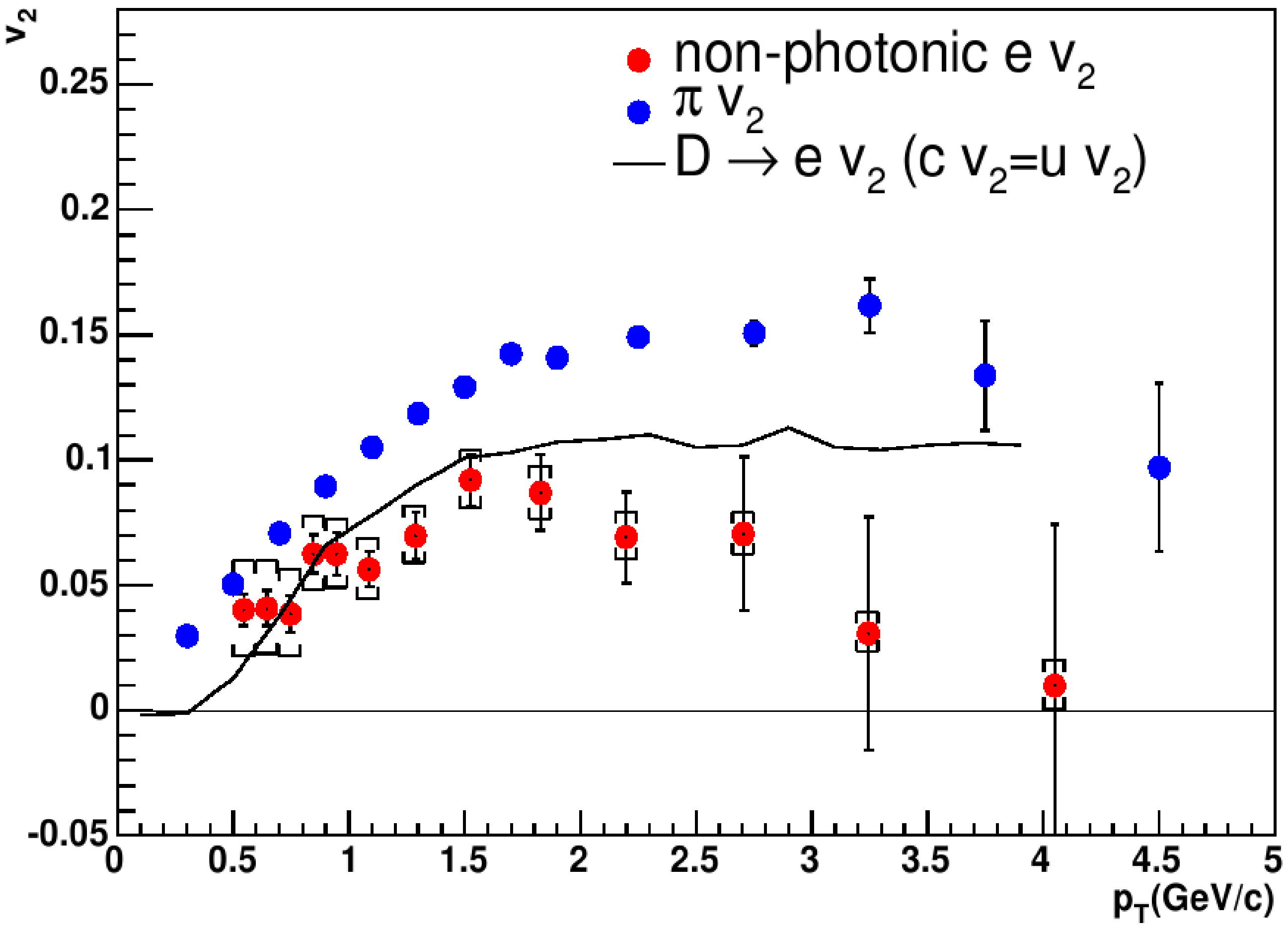
Measure electrons in similar way as the singles sprectra, with "cocktail" and "converter" method.

the observable

quantify azimuthal dependence of observed particles with respect to the reaction plane of the collision by the Fourier expansion

$$\frac{dN}{d\phi} \propto 1 + \sum_i v_i \cos(i(\phi - \Psi))$$

We are mostly interested in v_2, as the other coefficients will either be small or masked by the reaction plane resolution.



coalescence

There is some evidence for a valence quark recombination model

we can extract the charm v_2 from such a model

Heavy Quark Flow

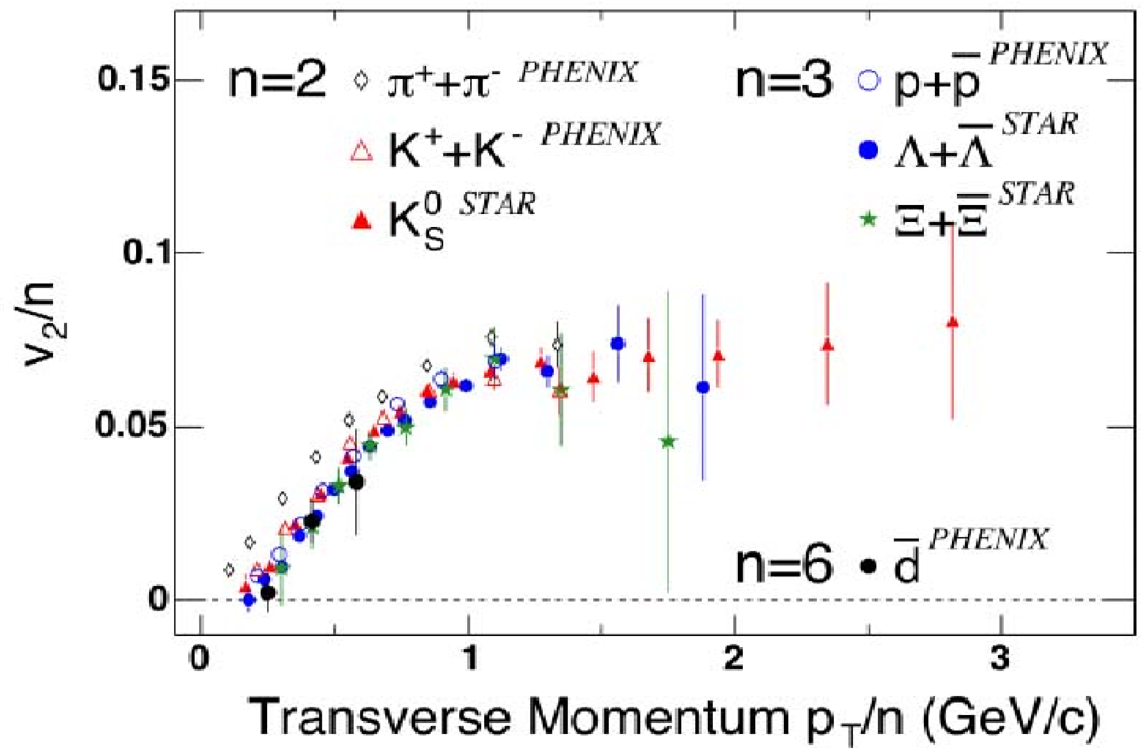
PHENIX measures anisotropy of electrons from heavy flavor decays

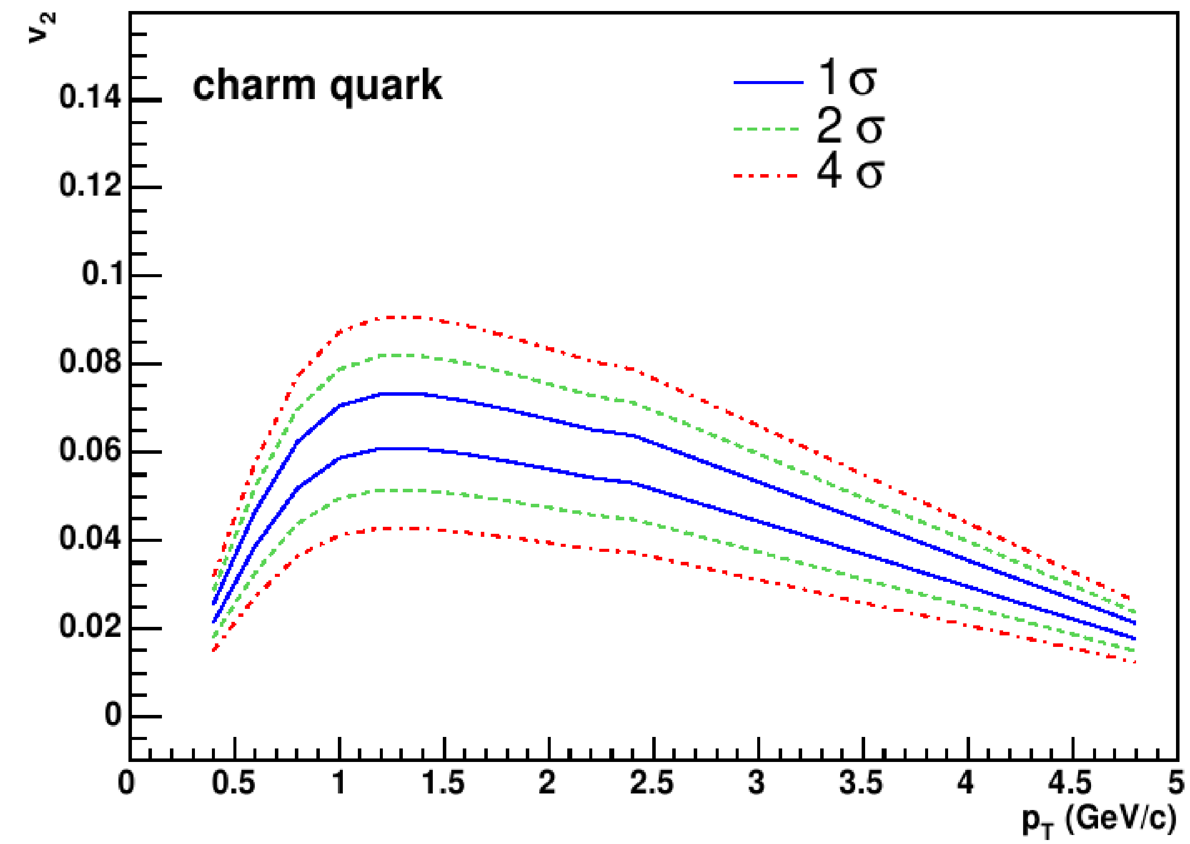
Decay kinematics lower the electron v_2

We want to estimate the flow of the charm quark from the electron anisotropy

Universal v_2

PHENIX





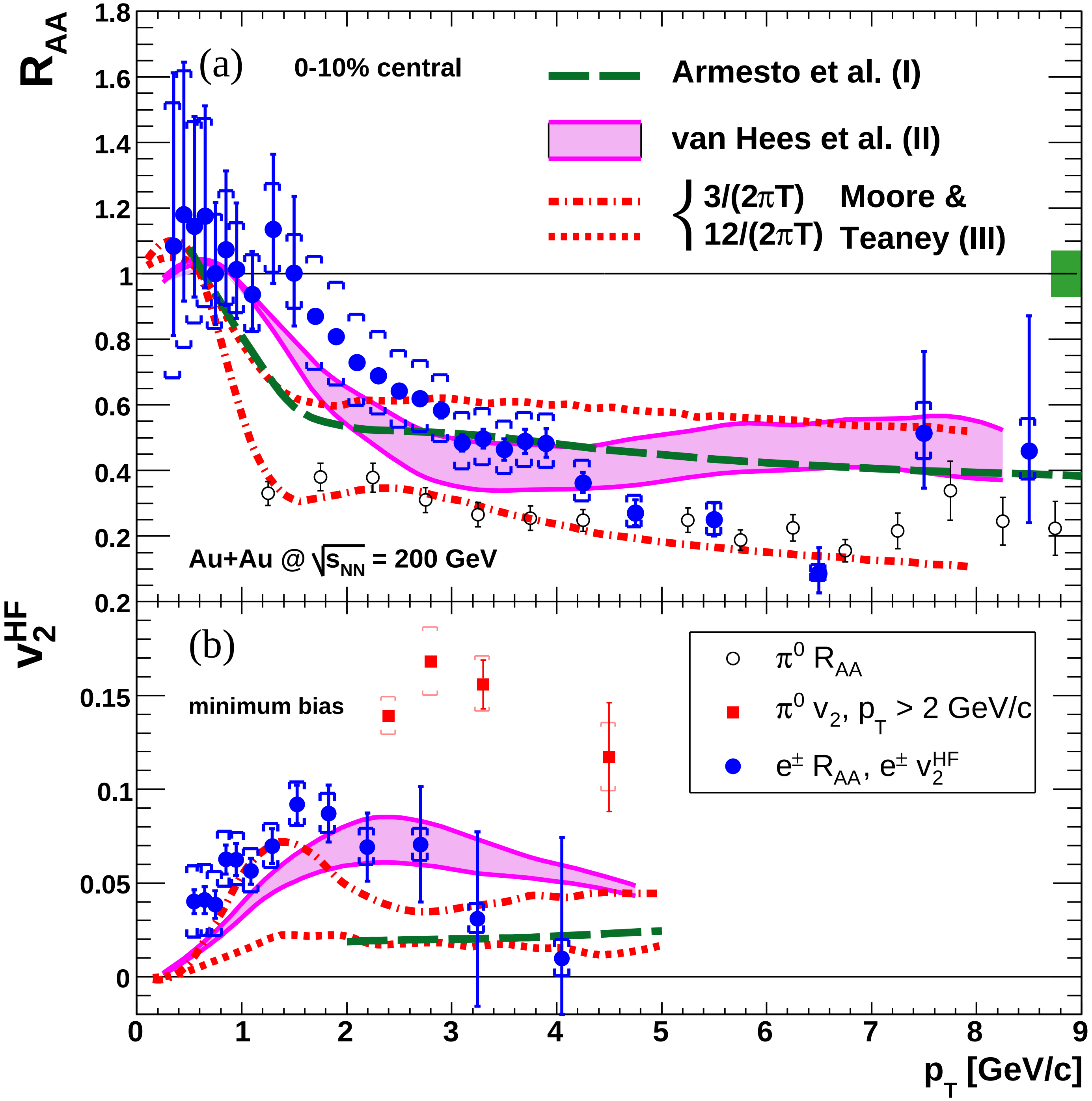
charm appears to flow

The v_2 of hadrons scales with the number of valence quarks. This, and the pion/proton ratio, give evidence for recombination models.

When the decay kinematics of the D-meson decays are unfolded, the electron v_2 measurement suggests that charm quarks flow similarly to light quarks

But what is going on at high p_T?

Comparison to $e^{\pm}$ Data



Caveats

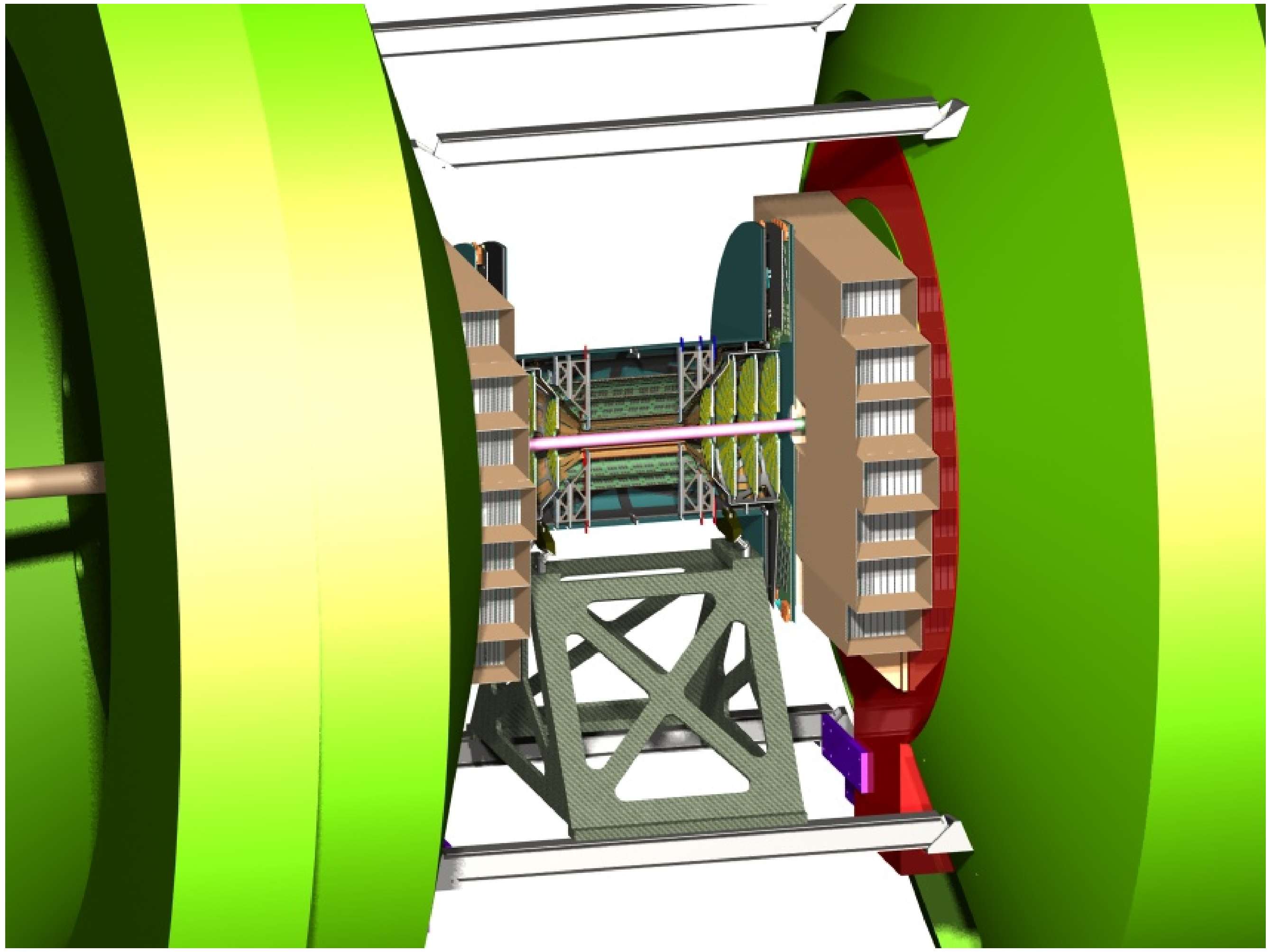
The Rapp/van Hees model seems to do pretty well, but it is missing a few things:

radiative energy loss
more realistic geometry/density

Also, the model uses a given impact parameter for "0-10%" and "minimum-bias". Averaging over impact parameters is needed.

More evidence for resonances?

Silicon Vertex Detector



The detector

2 pixel layers, 2-strip layers at mid-rapidity
4 pixel layers at forward rapidity

accurate primary and secondary vertex reconstruction

stand-alone tracking: momentum reconstruction

The impact

direct D,B meson reconstruction

disentangle charm and bottom signals

increase rapidity coverage for jet reconstruction

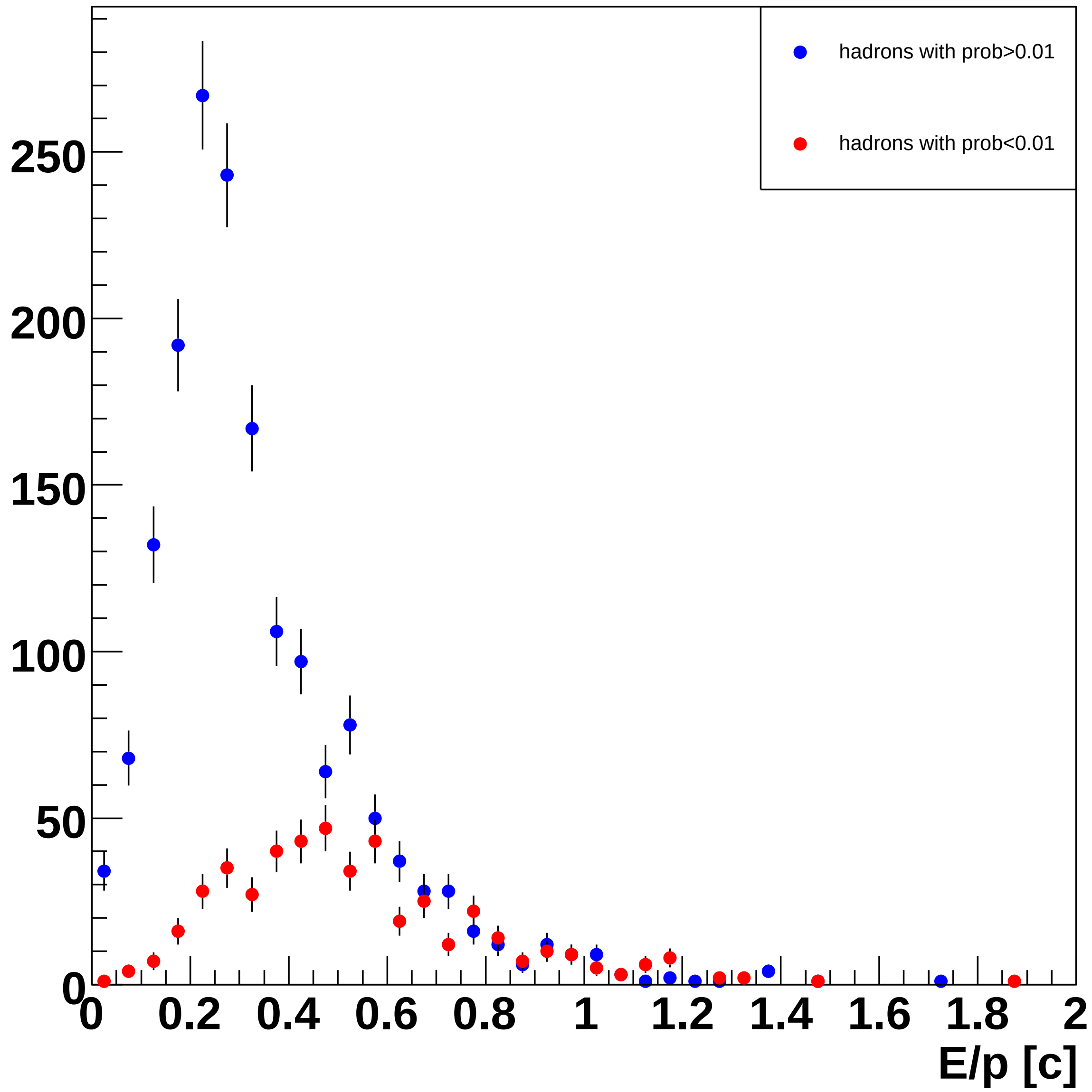
Summary

PHENIX

- Measurement of electrons at y=0 and muons at η = -1.65 from semileptonic heavy flavor decays from p+p collisions
  - p_T spectra harder than FONLL and PYTHIA predictions
  - Rapidity distribution is wider than expected from pQCD
  - PHENIX/STAR yield discrepancy needs to be worked out
- Electrons from heavy flavor at y=0 from Au+Au collisions
  - Yield follows binary scaling (hard probe)
  - p_T spectra stronly modified by the medium
  - v_2 indicates charm flow
- Charm quarks seem to interact with the medium similarly to light quarks
- What is the bottom quark distribution?
- Stay tuned for e-h correlation and D meson measurement in the near future.

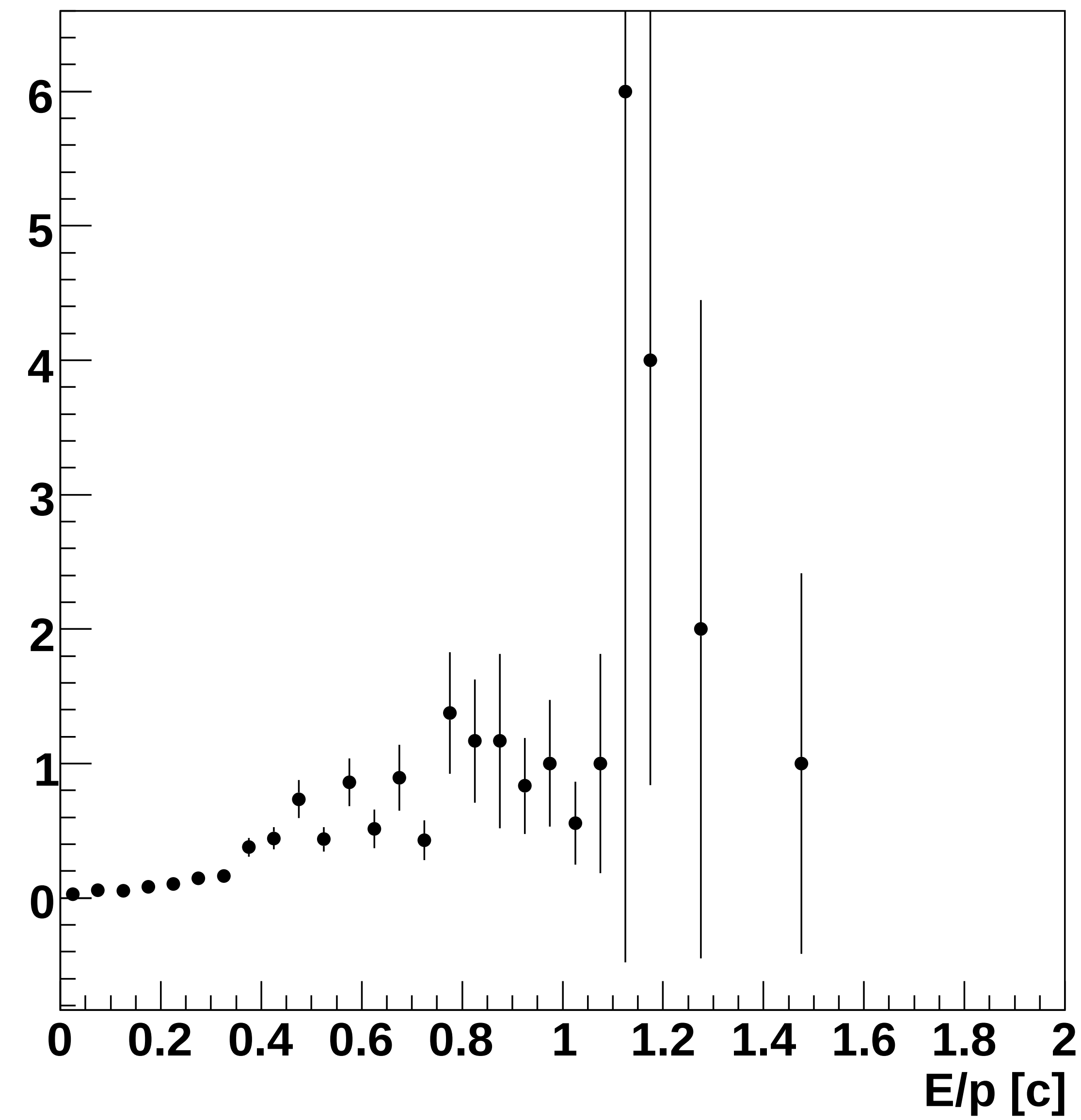
Backup Slides

Hadrons from RICH veto with 1 GeV/c < p_T < 4 GeV/c



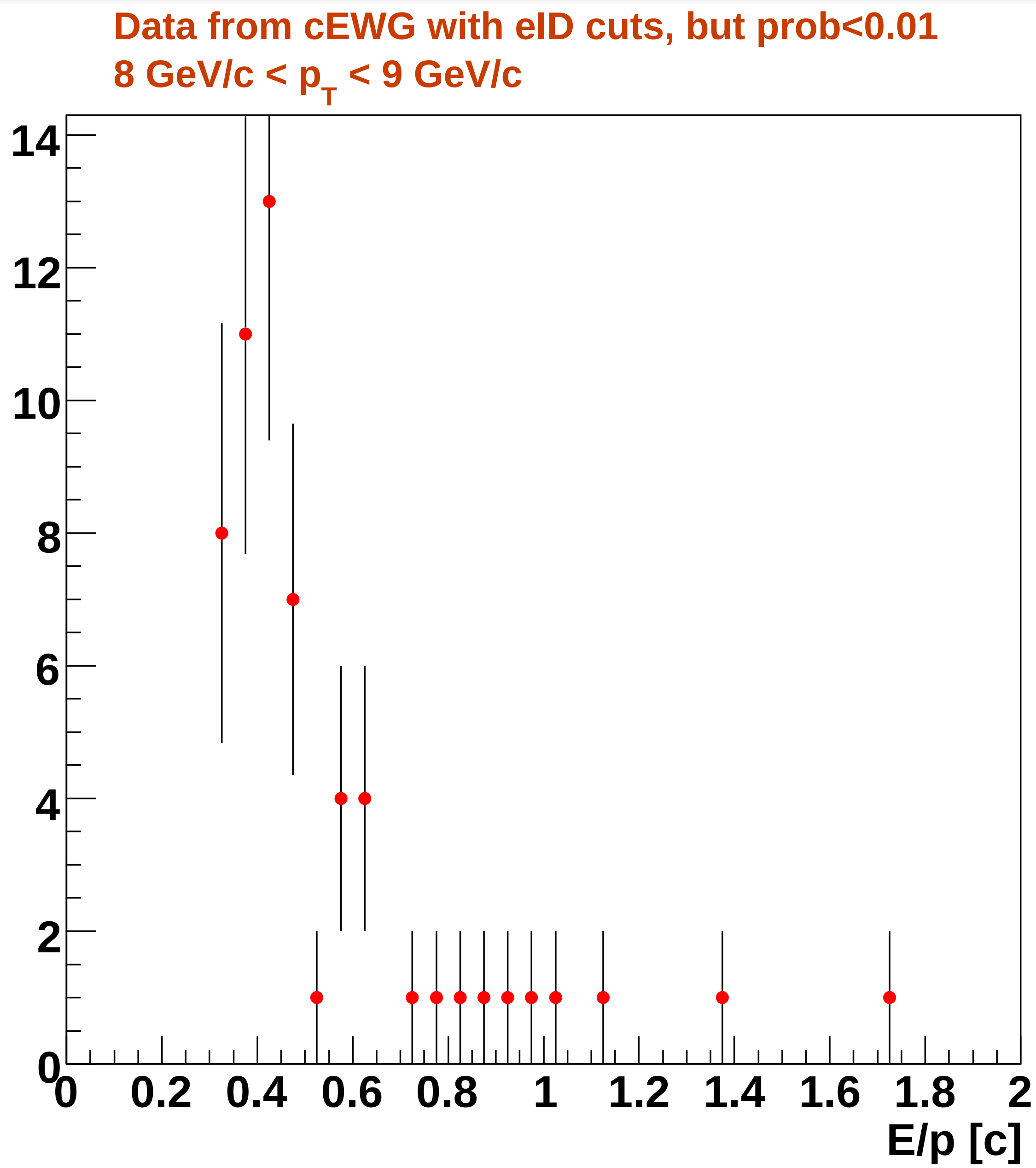
- get a hadron sample from CNT's by a RICH veto

Ratio of hadrons with prob<0.01 to those with prob>0.01

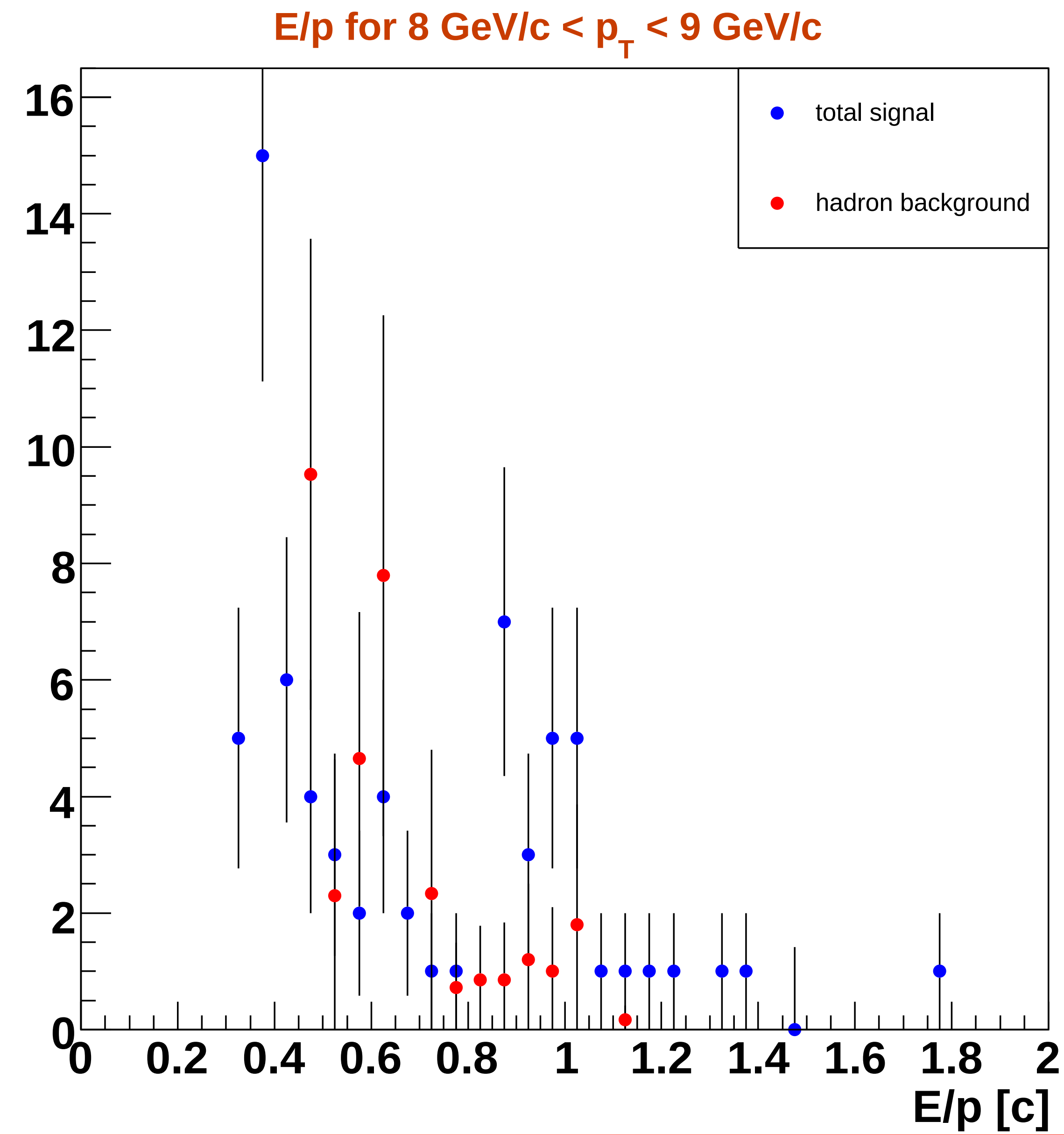


- eID cuts are the same as electron analysis except for inverse prob and RICH veto

Hadrons with inverse prob cut



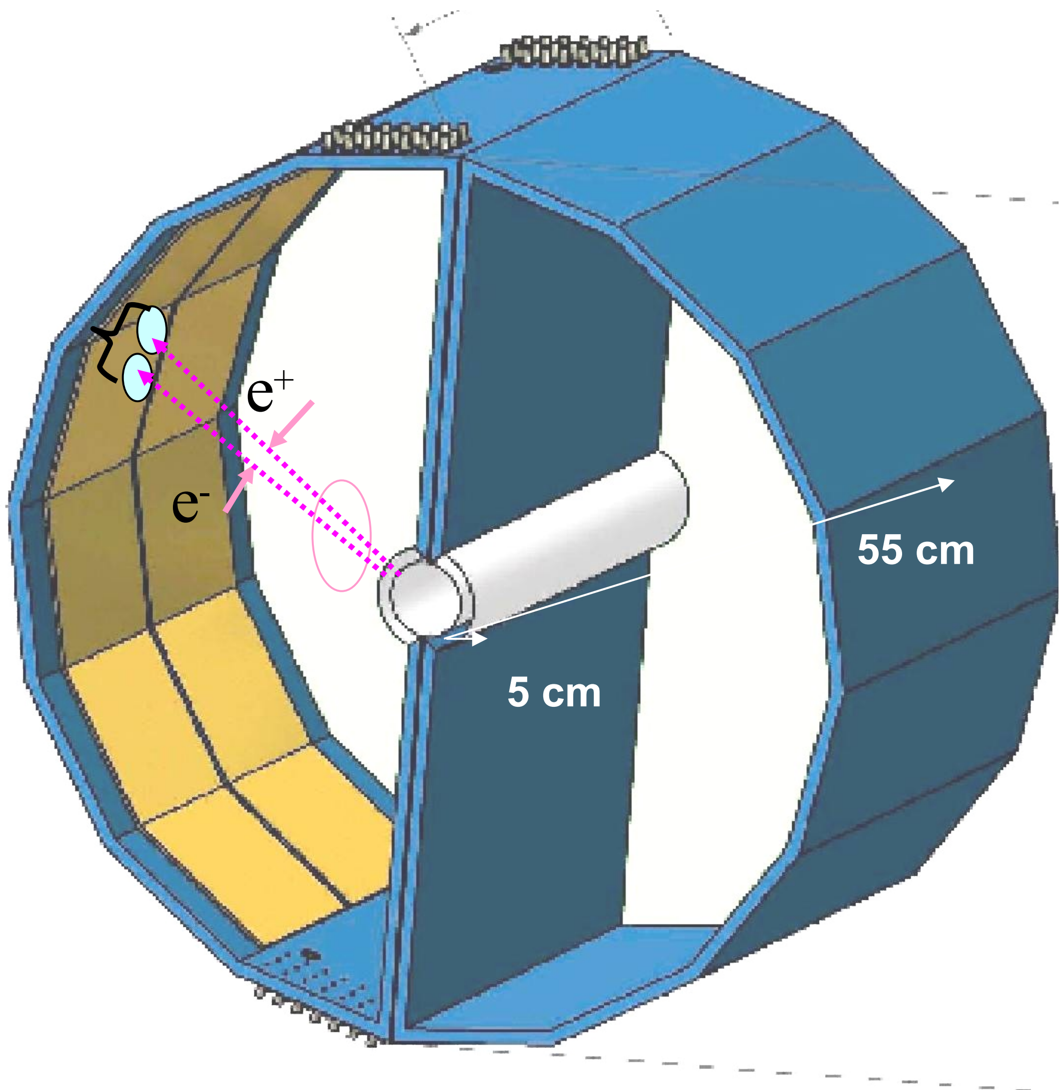
- Blue points are the E/p of tracks which pass normal eID cuts. Red points are the E/p of tracks which pass eID cuts with the inverse prob cut, divided by the ratio shown on slide 1.



- eID cuts are the same as electron analysis except for inverse prob

Hadron-Blind Detector

PHENIX



The detector

windowless Cherenkov detector

GEM detector

"blind" to ionizing hadrons

rejects $e^{\pm}$ pairs with small opening angle

The impact

greatly reduces background in di-electron measurements

improved measurement in the charm mass region will give important information on the relation between R_{AA} and v_2

Reaction Plane Detector

The detector

Current reaction plane resolution limited by BBC eta range

Scintillating paddle counter on the nose cone

very inexpensive ☺

The impact

improves reaction plane resolution

reduced errors on v_2. Will give a measurement at much higher p_T

disentangle charm/bottom v_2?