Open Heavy Flavor Measurements at PHENIX

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Quarkonia in Deconfined Matter
Acitrezza, Italy

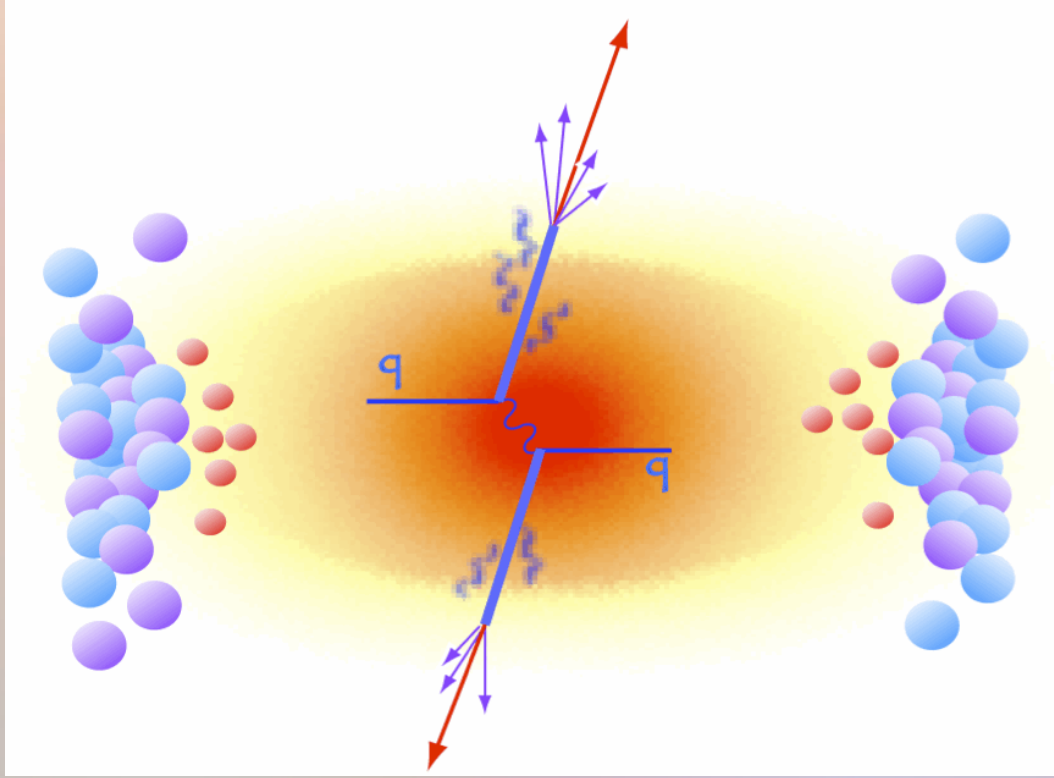
Motivation for Studying Open Heavy Flavor

Why open heavy flavor?

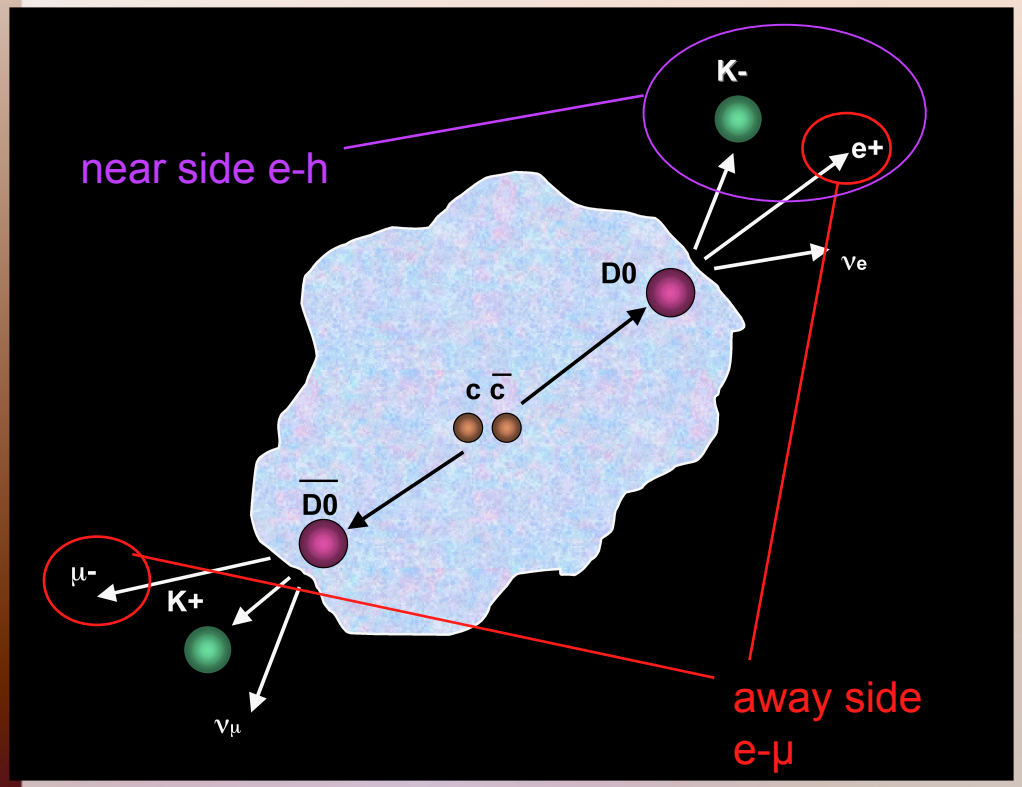
•Help to interpret charmonium suppression/recombination effects: probes initial state effects.

•Measurements in p+p and d+Au serve as a baseline for heavy ion. p+p helps us understand heavy production mechanisms, compare to NLO. In d+Au, understand CNM effects.

•In heavy ion, understand heavy flavor thermalization, energy loss.



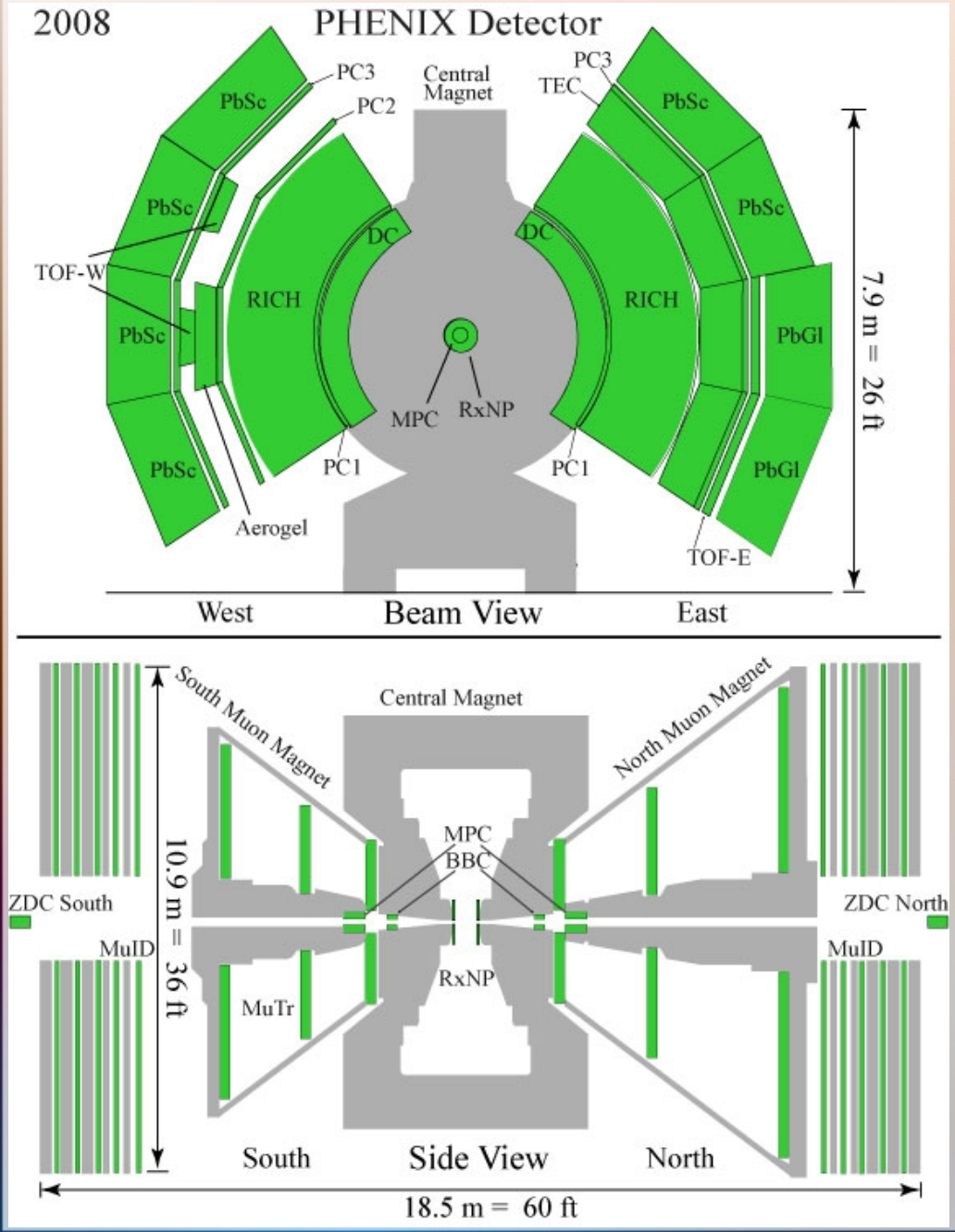
How to Measure Heavy Flavor in PHENIX



D+/- -> e + X	16.0%
D0 -> e+X	6.53%
D+/- -> μ + X	16.0%
D0 -> μ+ X	6.7%

- **Single electrons, muons**.
- **Near side e-h mass correlations:** partial reconstruction of heavy flavor decays, measure c/b ratio.
- **Away side e-h angular correlations:** charm correlations probing jet shape.
- **Opposite sign e- azimuthal correlations**: double semi-leptonic heavy flavor decay.

PHENIX Detector



Central Arms detect electrons

- $|\eta| < 0.35$
- 2 x π/2 in azimuth
- $p_e > 0.2$ GeV/c
- Electron identification:
  - Ring Imaging Cerenkov detector (RICH)
  - Electromagnetic Calorimeter (EMCal)

Forward Arms detect muons

- $-2.2 < |\eta| < -1.2$ and $1.2 < |\eta| < 2.4$
- Muon Tracker reconstructs trajectories and determines momentum
- Muon magnets and Muon Identifier steel absorb hadrons, pion rejection of 250 to 1.
- Muon candidates reach the last gap of the Muon Identifier.

Single Electrons

Single Electron Measurements

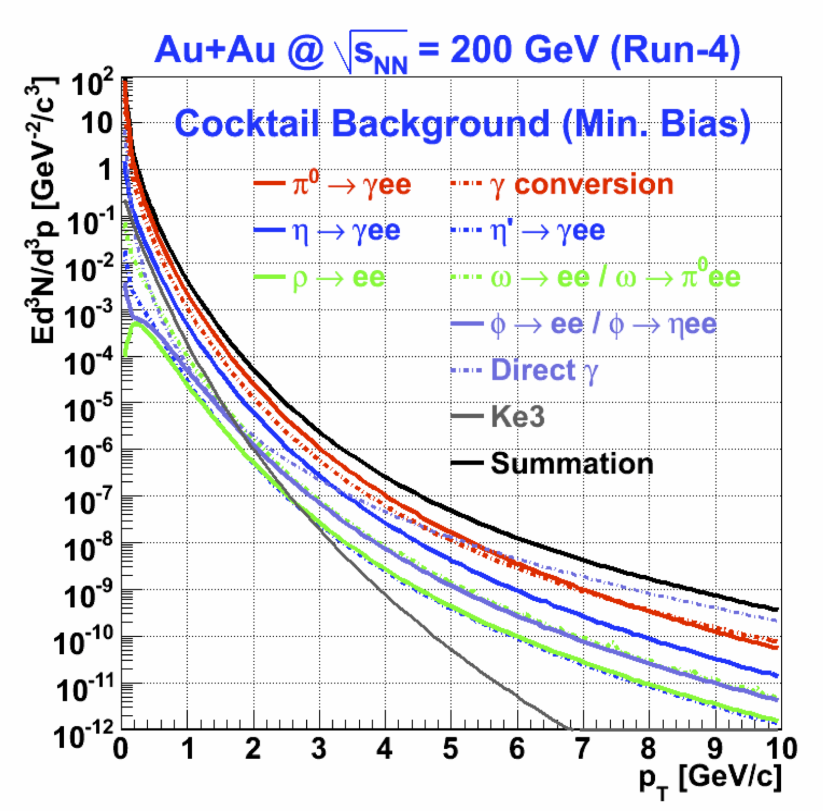
Single electrons measured at central rapidity.

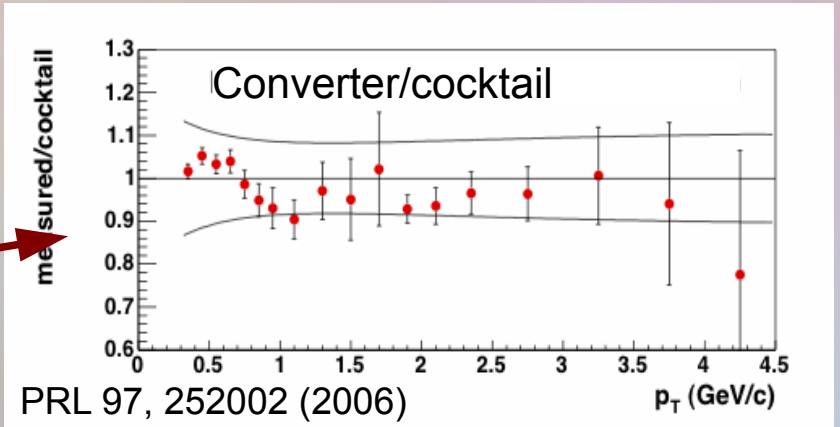
Background subtracted using background **cocktail** composed of electron sources measured at PHENIX:

- photonic sources (light meson Dalitz decay + conversions)
- heavy quarkonia
- Ke3 (K -> e π ν)

Converter subtraction method: adds material of known thickness around beam pipe, measures conversion electrons by extra yield produced. Used at lower p_T where cocktail less accurate.

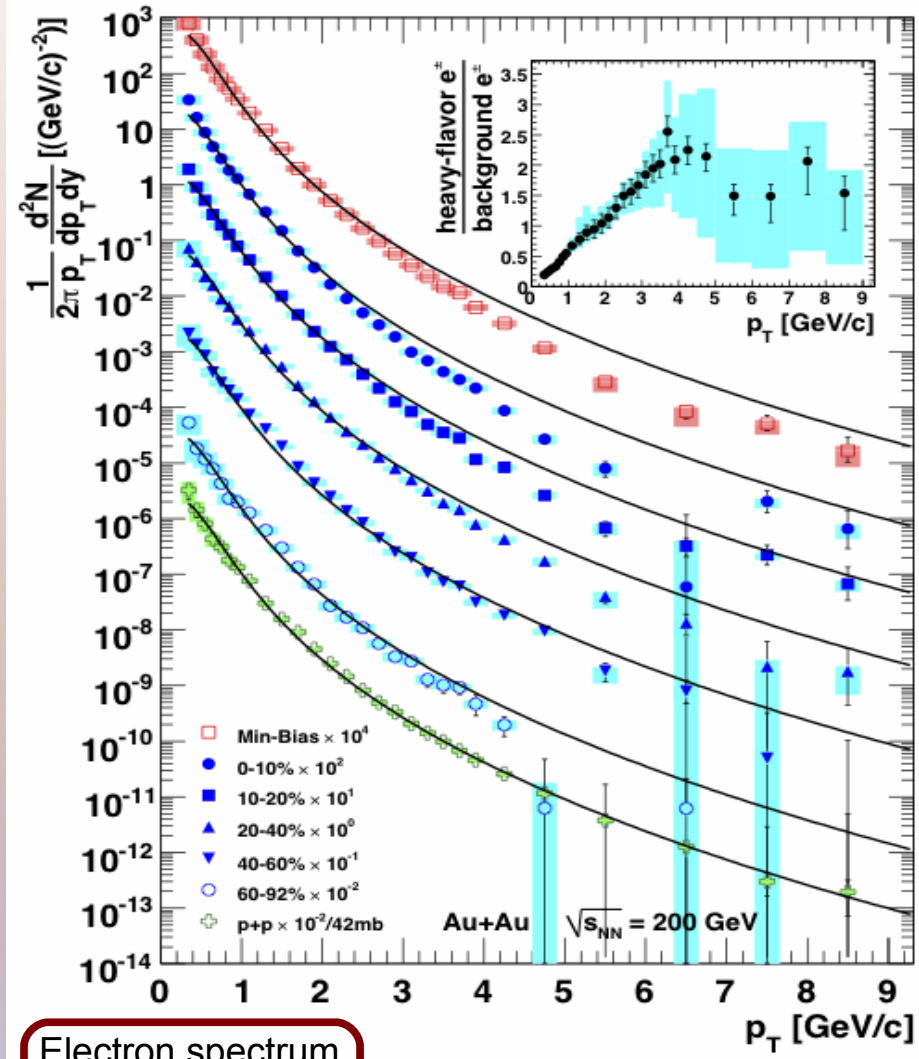
Both cocktail and converter methods agree.



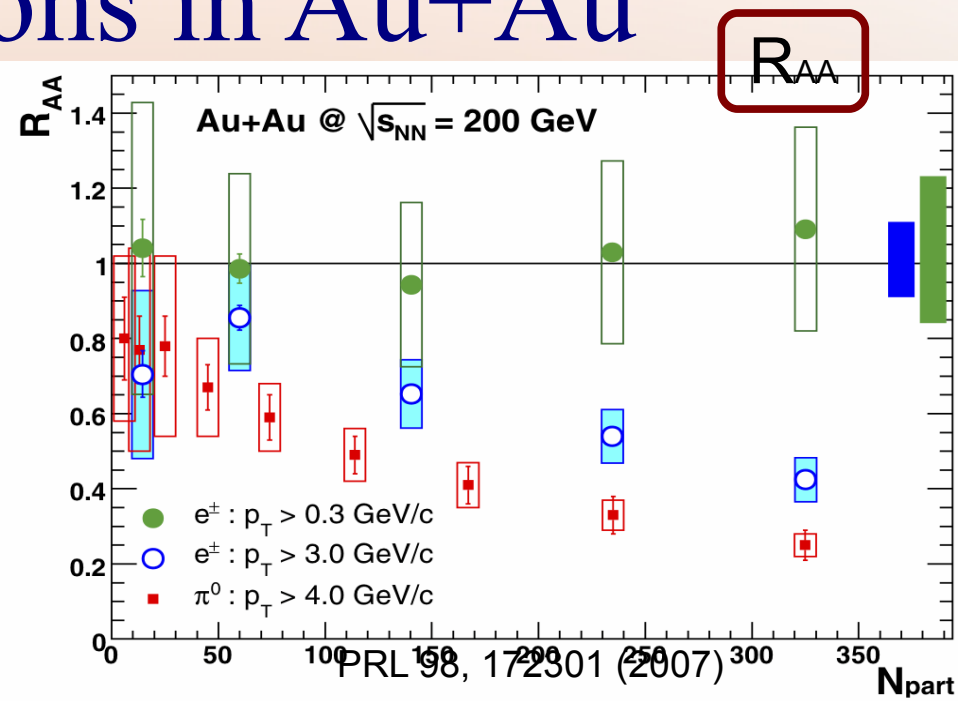


PRL 97, 252002 (2006)

Single Electrons in Au+Au



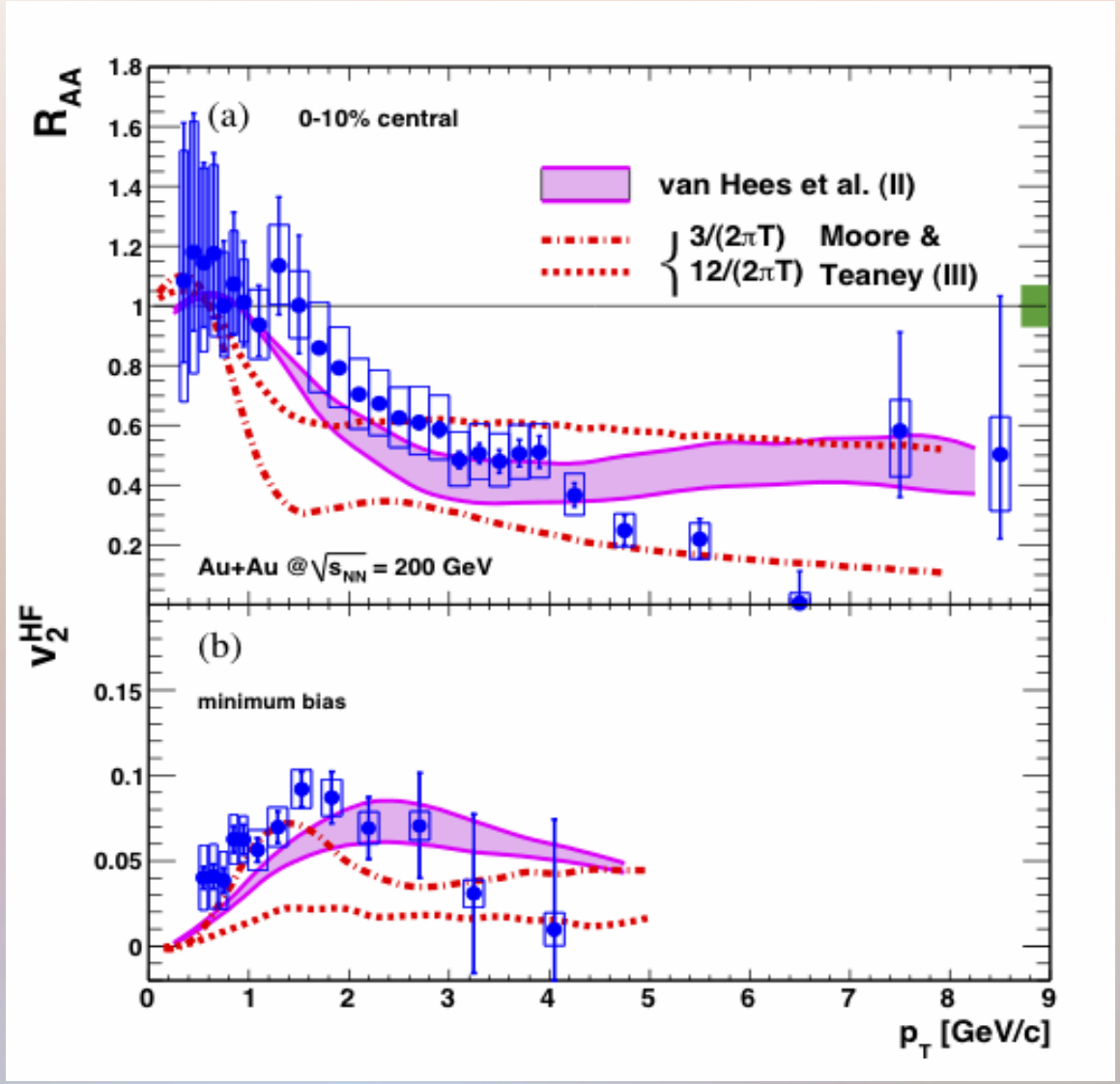
Electron spectrum in Au+Au compared with scaled p+p



PRL 98, 172301 (2007)

Significant suppression of high p_T electrons by amount almost comparable to that of pions.

Single Electrons in Au+Au



Elliptic flow found to be significant.

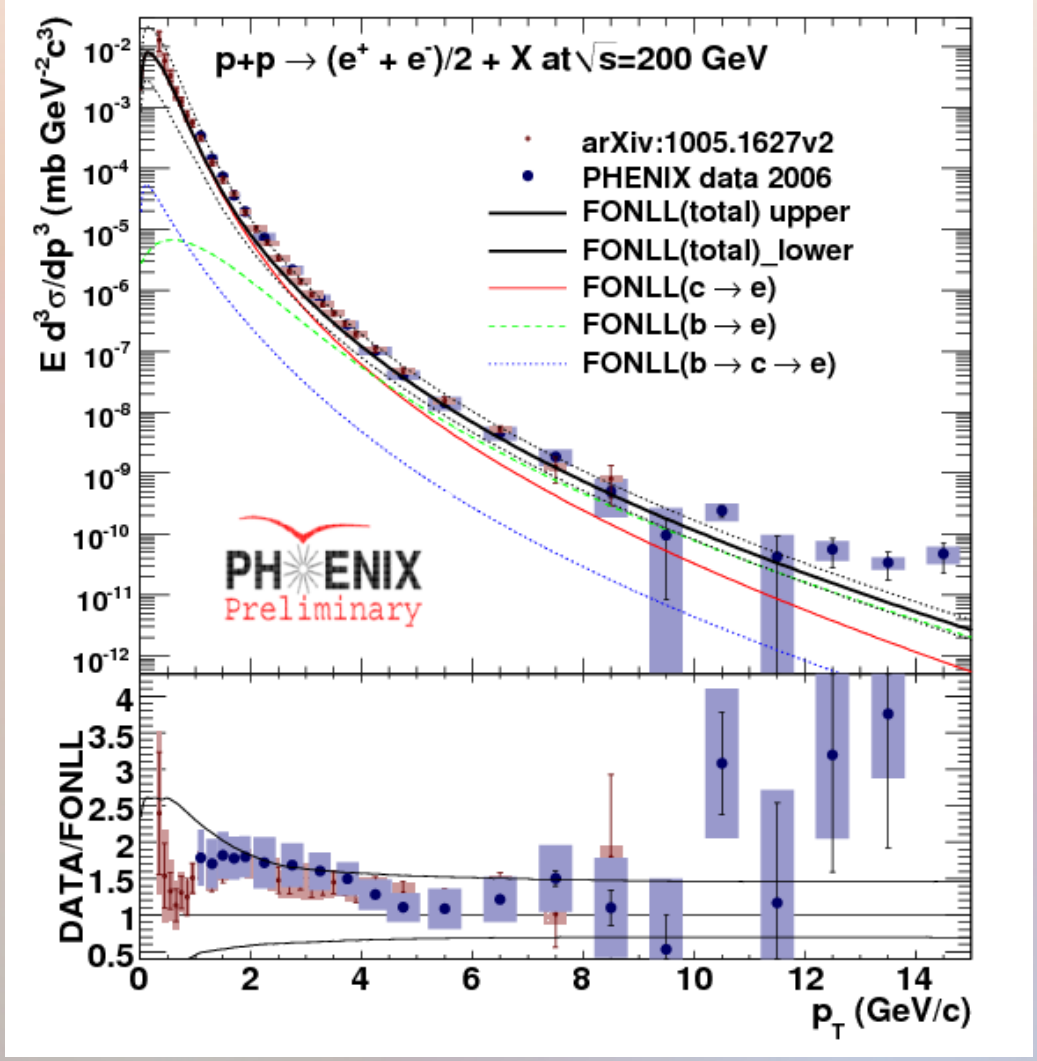
Need p+p and d+Au baseline to understand effects . . .

Single Electrons in p+p

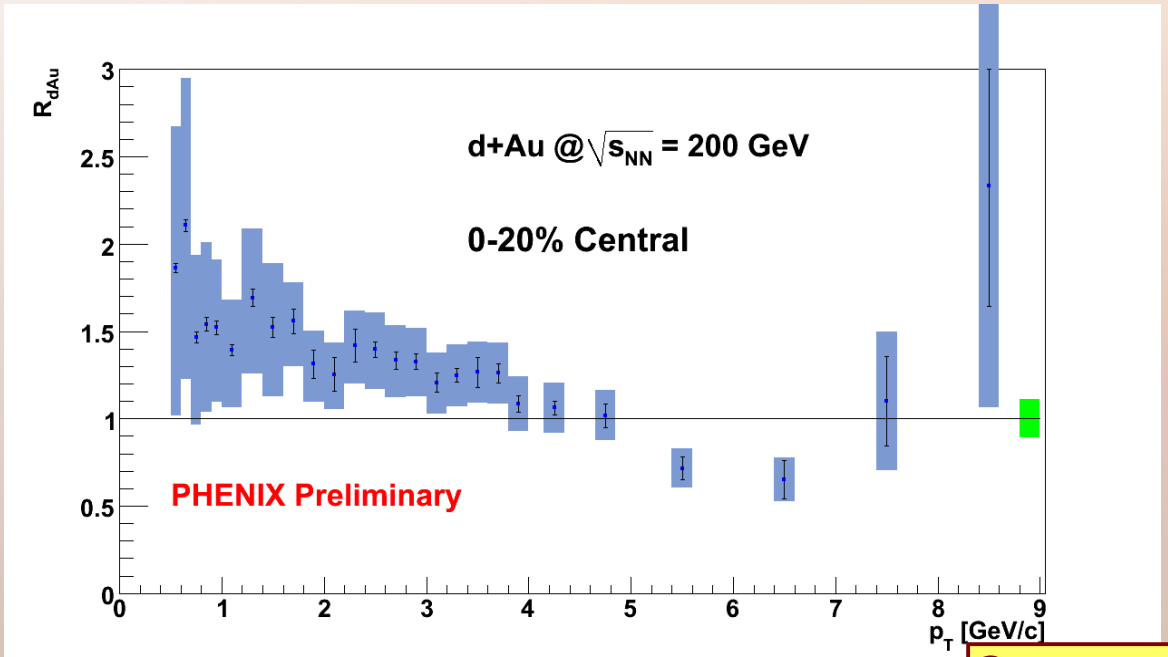
New results, combined Run 5 + Run 6 pp.

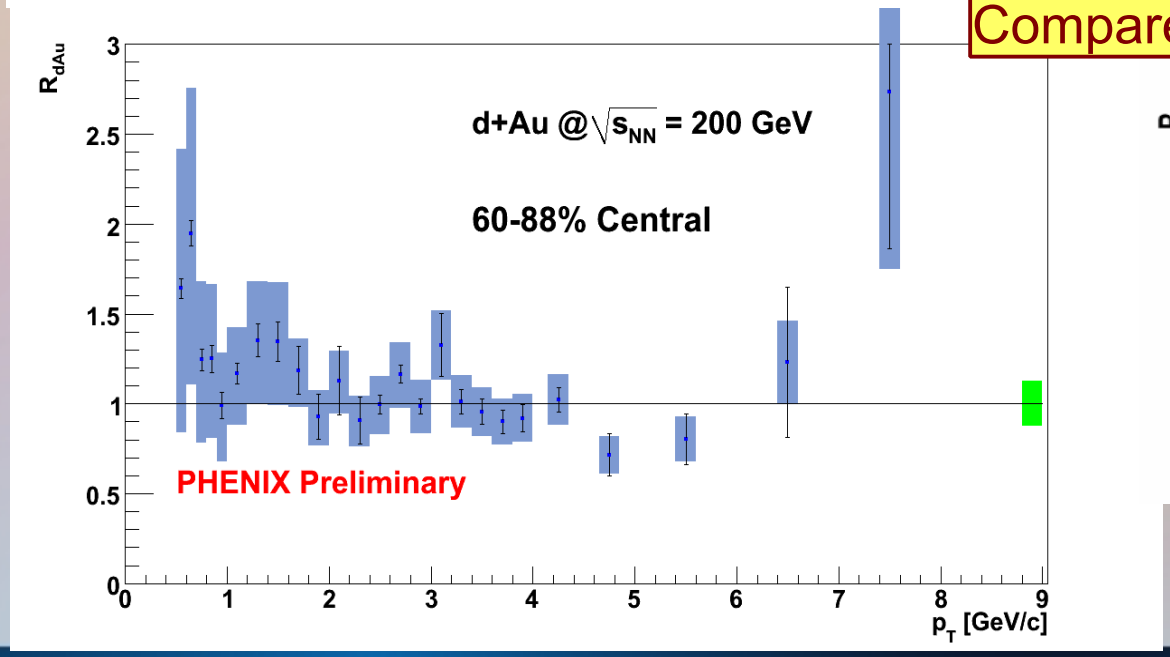
Increased p_T range compared with previous published results.

Consistent with FONLL predictions.



Single Electrons in d+Au



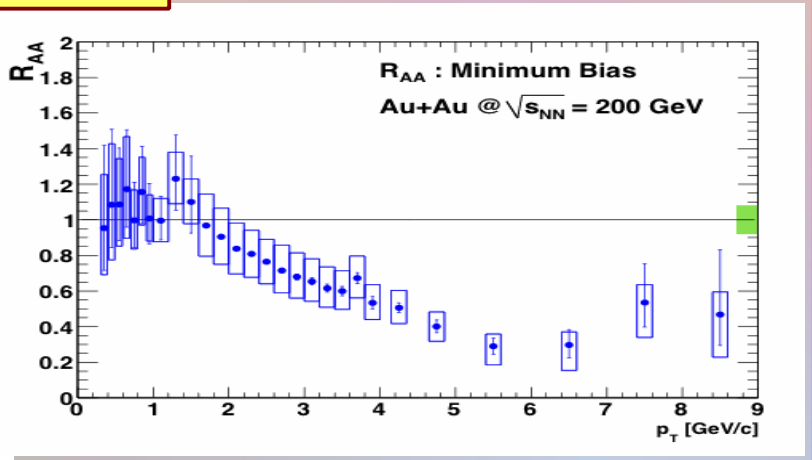


Peripheral R_{dA} consistent with pp.

Hints of CNM effects at lower p_T.

CNM effects cannot explain suppression seen in central Au+Au.

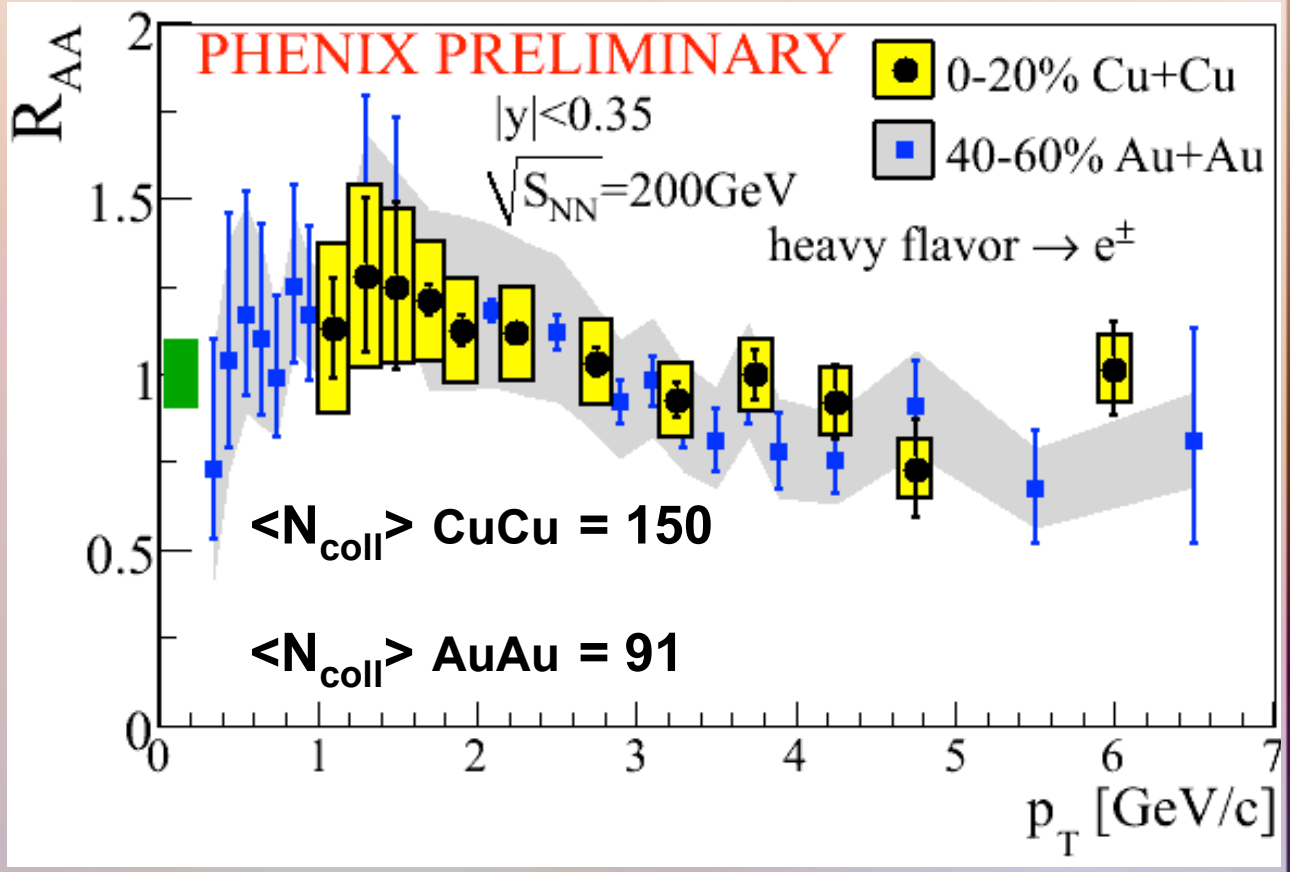
Compare with:



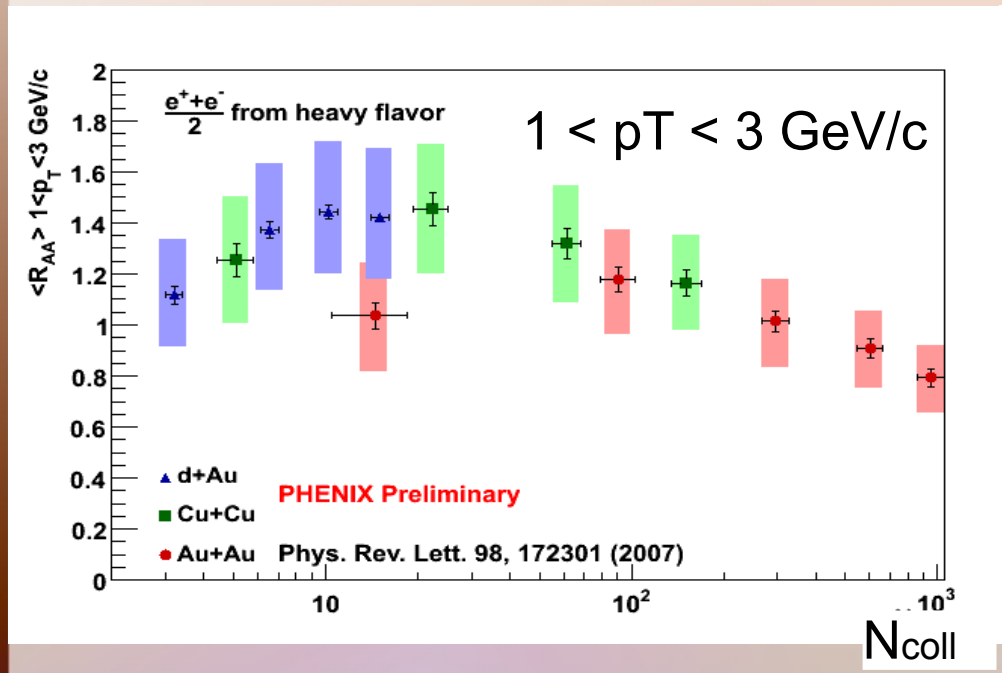
Single Electrons in Cu+Cu

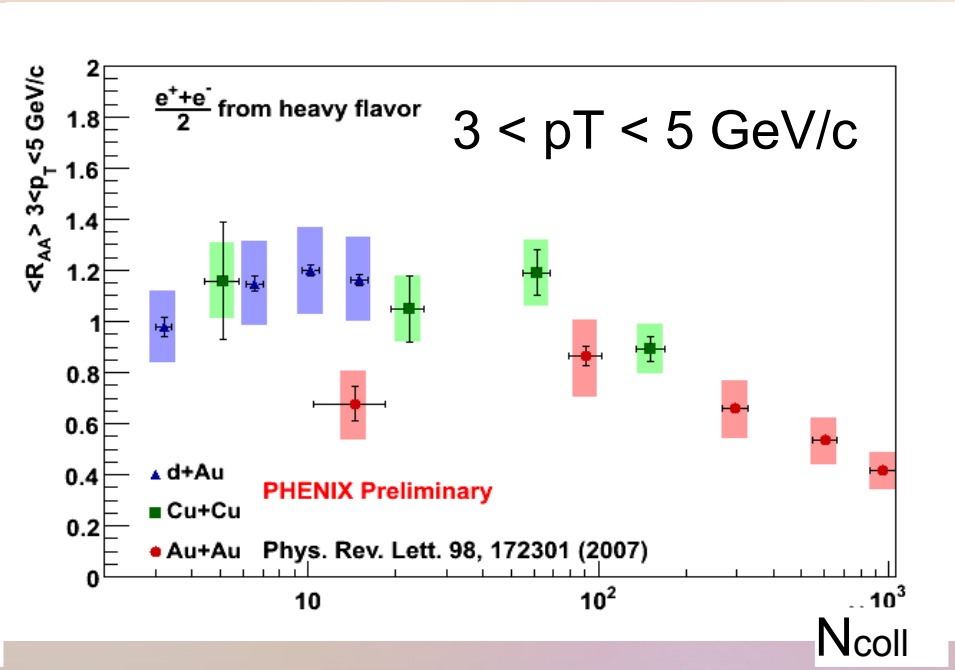
Comparison of central Cu+Cu with semi-peripheral Au+Au shows good agreement.

No suppression is evident.



Single Electron Trends with <N_{coll}>





R_{AA} consistent across systems as a function of centrality for dA, CuCu, and AuAu.

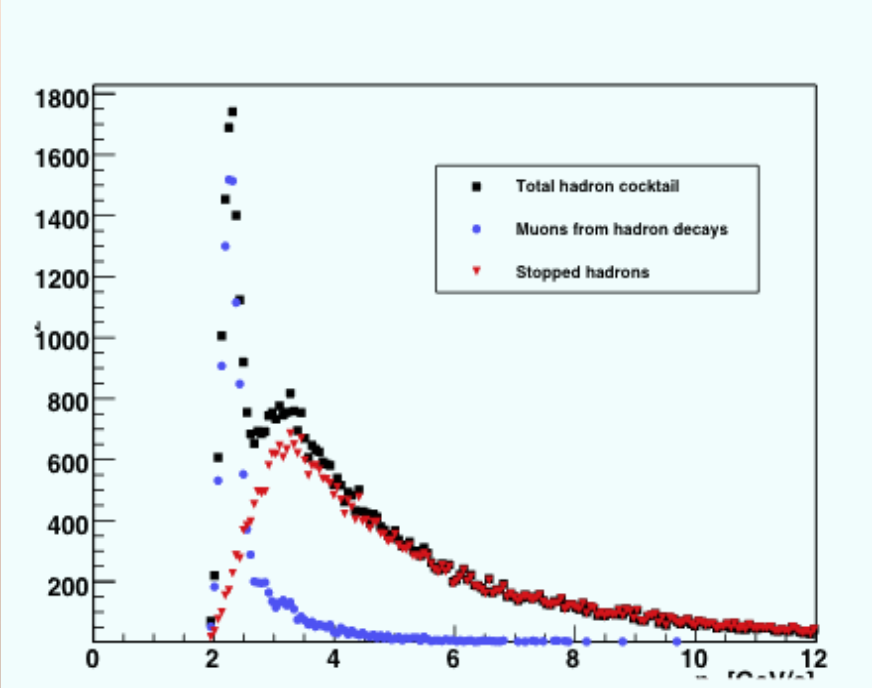
Single Muons

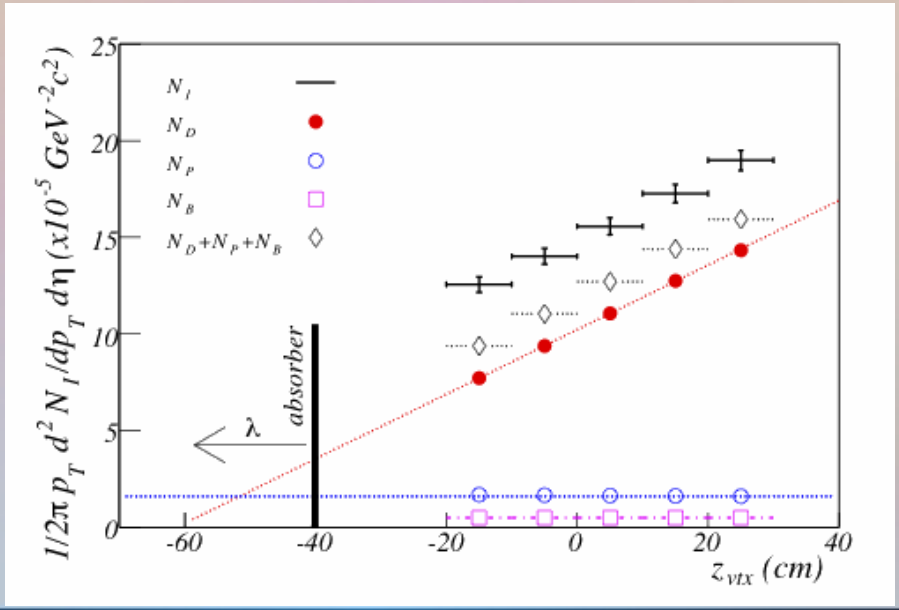
Single Muons at PHENIX

Heavy flavor single muons measured at <y> = 1.65, background removed through hadronic cocktail subtraction. Backgrounds include:

Decay muons: resulting from light hadron decay.

Punchthrough hadrons: hadrons that are not absorbed in steel absorber, look identical to muons.

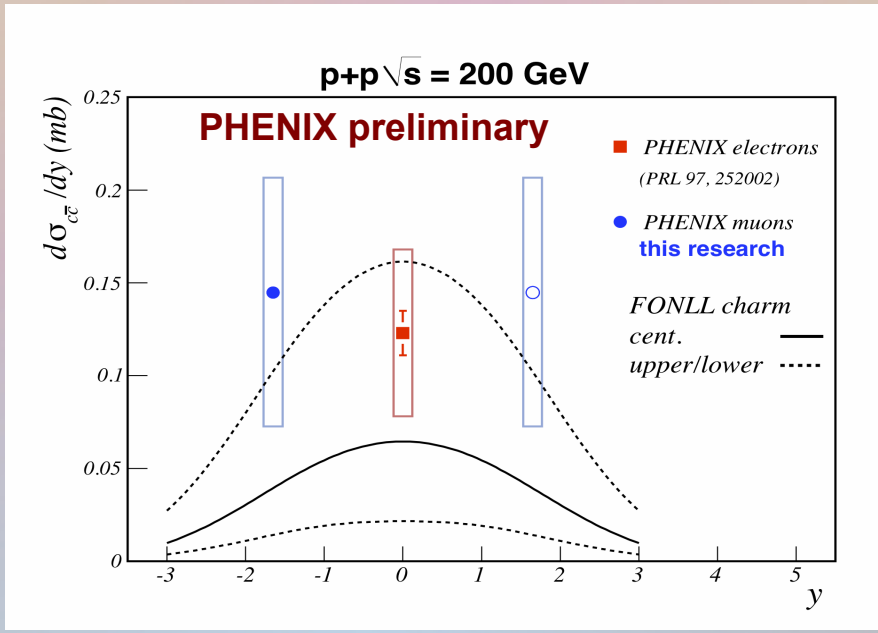


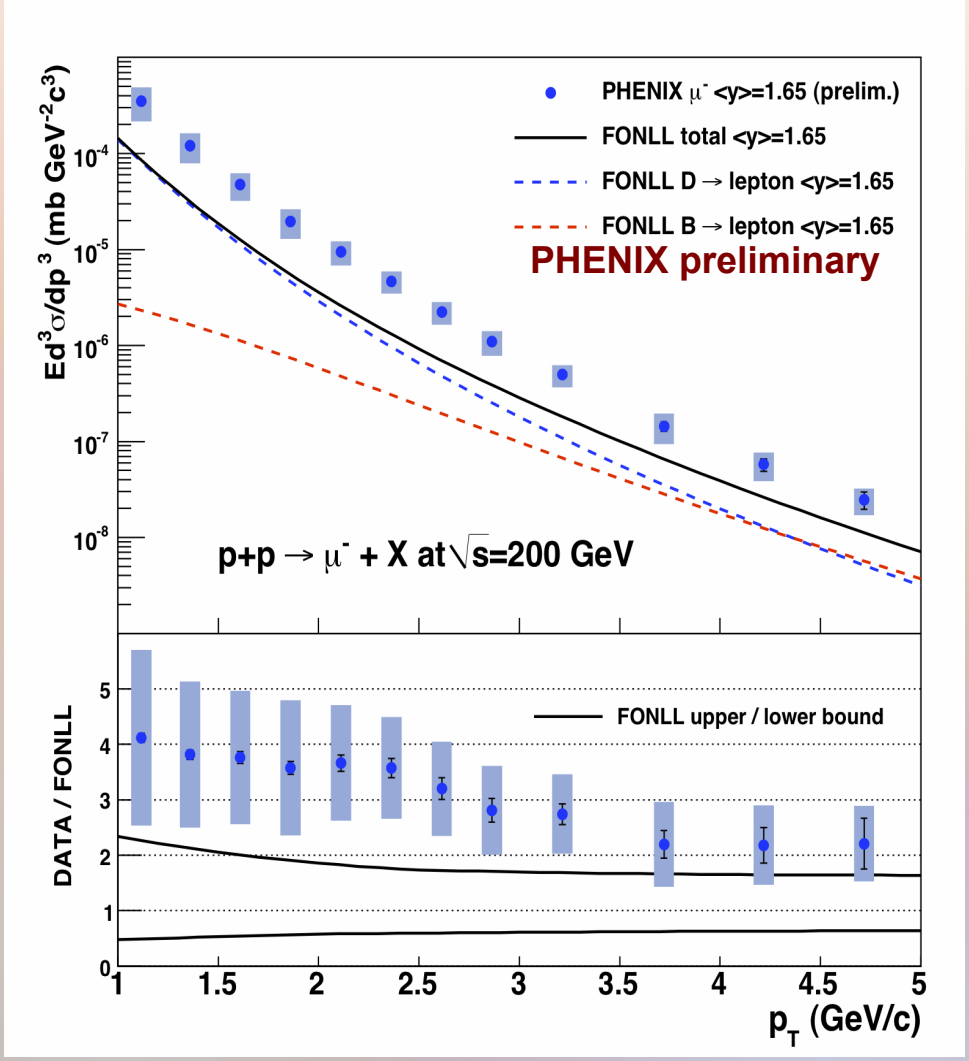


Identify hadrons with tracks stopped in absorbers, decay muons through linear vertex dependence: use to normalize hadronic cocktail.

Single Muons in p+p

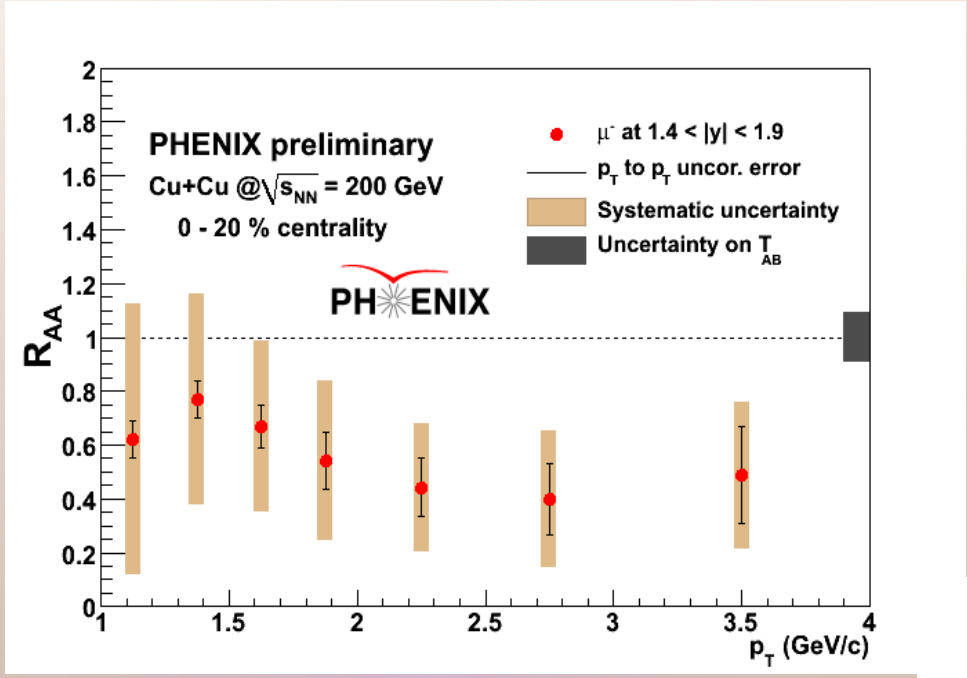
Yield slightly higher than expected using FONLL calculations.





Integrated charm cross section agrees with measurement using single electrons at PHENIX.

Single Muons in Cu+Cu

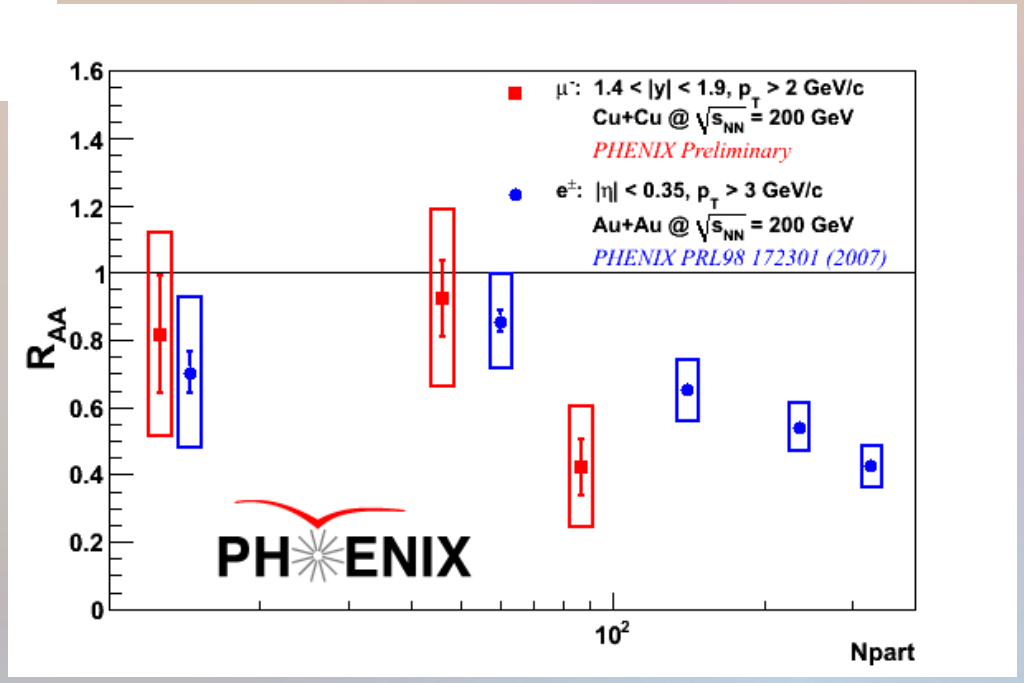


Similar methods to p+p, now single muon cocktail embedded in Cu+Cu events.

Found large suppression at forward rapidity comparable to central Au+Au.

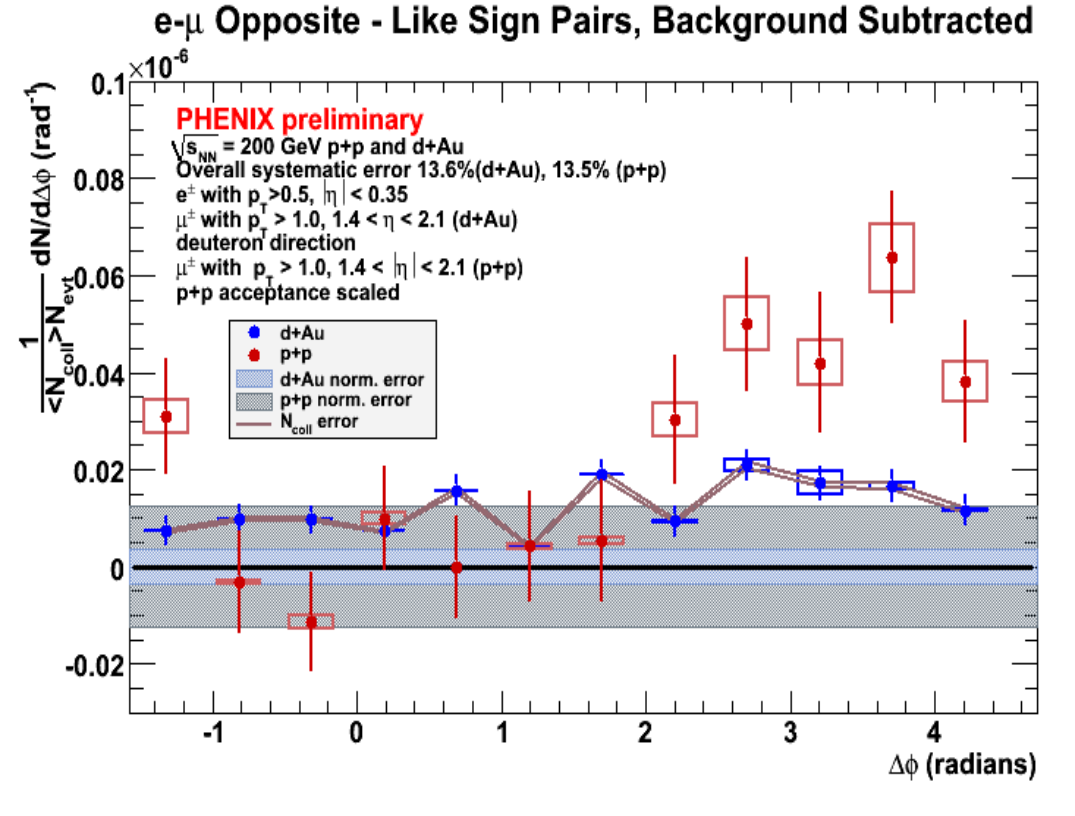
Medium less dense at forward rapidity than central (by 20-25%), also less dense in Cu+Cu than in Au+Au (~ factor of 2).

Hints at importance of initial state effects in forward region (though none in central region).



Heavy Flavor Correlations

e - μ Correlations in p+p and d+Au



•Signal: opposite sign e-μ pairs with $\Delta\varphi \approx \pi$. Product of back-to-back charm pairs produced via gluon fusion and higher order processes.

•Pure signal, few sources of physics background

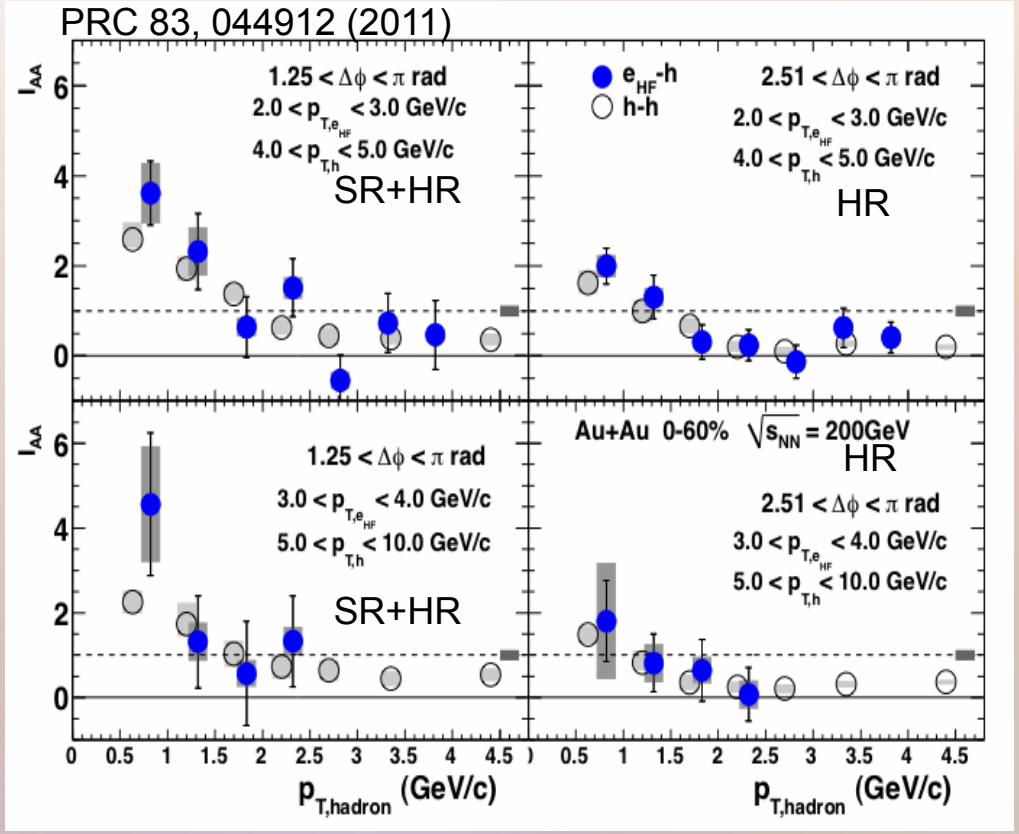
- No contribution from Drell-Yan, thermal production, resonance decays.
- Like-sign subtraction removes combinatoric background, e-μ pairs from dijets.

• Measurement in p+p proves method, found consistent with predicted NLO charm jet shape.

• d+Au measurement shows suppression/decorrelation relative to p+p.

•Still need correction factor to extract RdA.

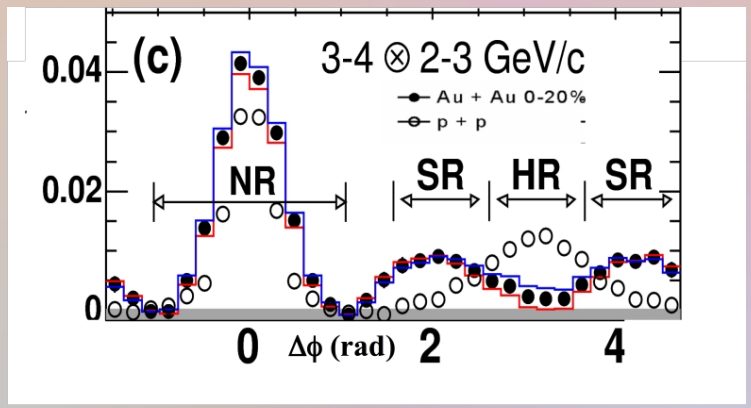
e-h Angular Correlations in p+p and Au+Au



Correlations of heavy flavor electrons with hadrons, photonic electrons removed by subtracting weighted γ-h pairs. Analyze jet shape using I_{AA}:

$$I_{AA}(p_T^a, p_T^b) = \frac{Y^{A+A}_{jet\_ind}(p_T^a, p_T^b)}{Y^{p+p}_{jet\_ind}(p_T^a, p_T^b)}.$$

Away side modification similar to that of dihadron correlations seen.

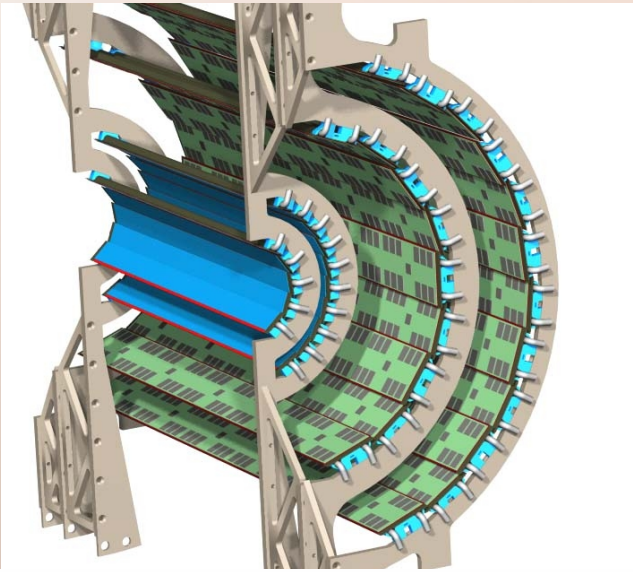


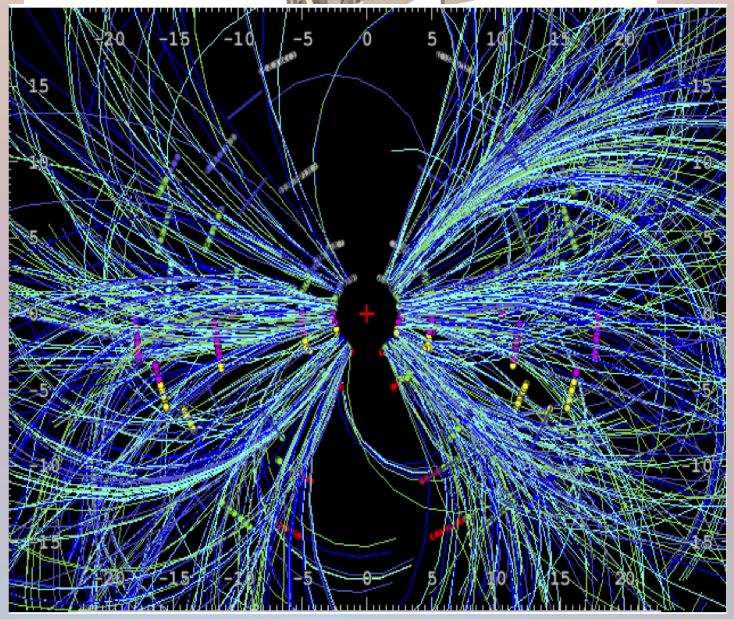
Caution: only v_2 is subtracted, not higher order v_n!

Definitions for head region (HR), shoulder region (SR), and near region (NR)

Recent Upgrades

PHENIX Silicon Vertex Detector





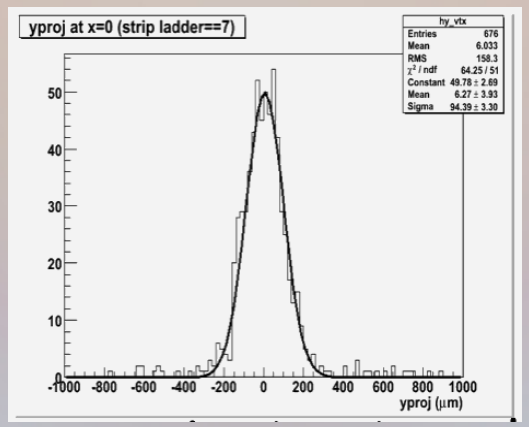
Designed to measure displaced vertices of electrons at central rapidity to separate R_{AA} and v_2 of c->e from b->e.

Acceptance of $|\eta| < 1.2$, full 2π in azimuth.

Consists of 4 layers of silicon detectors:

- 2 inner between 2.5 cm < R < 5 cm using pixel sensors measuring 40 μm by 80 μm.
- 2 outer detectors between 10 cm < R < 14 cm using strip pixels, measuring 80 μm by 1000 μm.

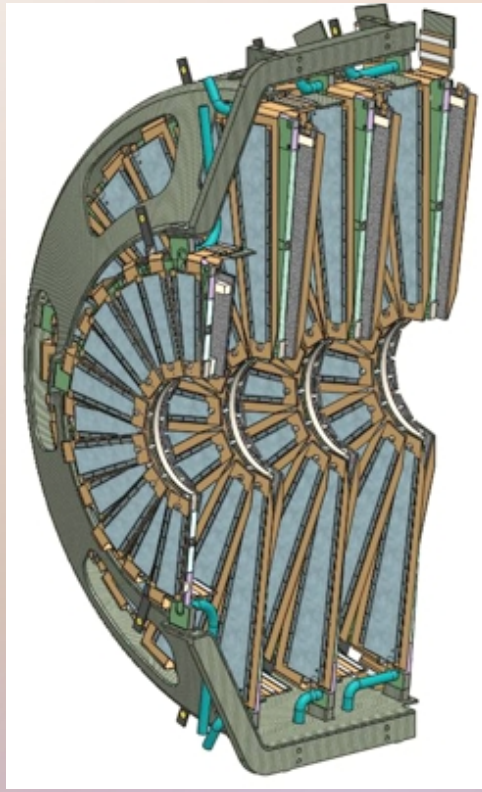
Installed in 2010 for last year's run.



Beam profile $\sigma \sim 100$ μm

Achieved projected vertex resolution ~ 50 μm.

PHENIX Forward Vertex Detector



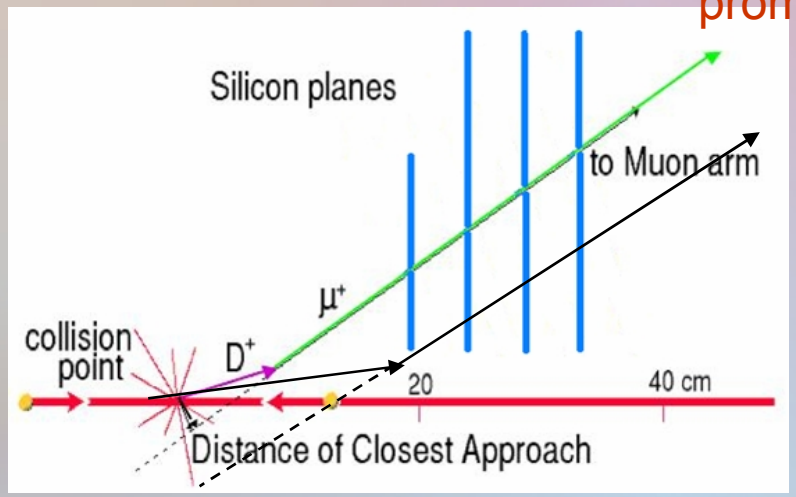
Designed to measure displaced vertices of muons detected by PHENIX muon detectors.

Current vertex resolution = 2 cm. Projected resolution with FVTX = 100 μm.

Two detectors at forward and backward rapidity with 4 stations each, covering $1.2 < |\eta| < 2.4$ and 2π in azimuth (φ), $18.5\text{ cm} < z < 38\text{ cm}$.

Silicon strip detectors with 75 μm wide strips along φ direction.

Is being commissioned for Run 12.



Conclusions

- In p+p collisions, yields have been measured and compared with FONLL.
- Open heavy flavor shows medium effects similar to those of light hadrons in central Au+Au collisions.
  - Elliptic flow
  - Suppression
- Initial state effects do not appear to explain single electron suppression in Au+Au.
- However, initial state effects apparent at forward rapidity.
- New silicon upgrades offer chance to make cleaner, more precise measurements of open heavy favor in the next couple of runs.

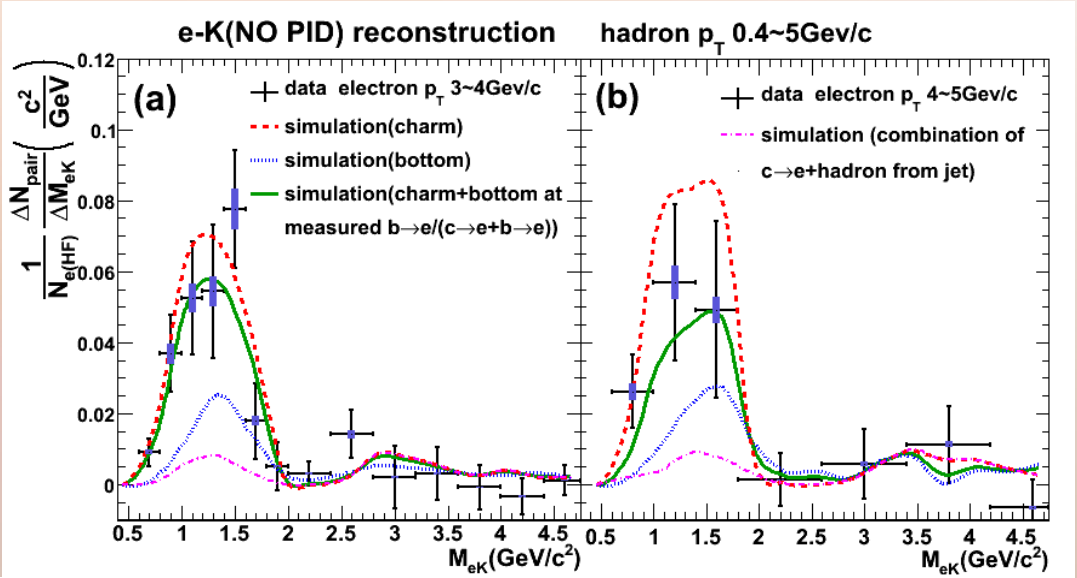
Backup

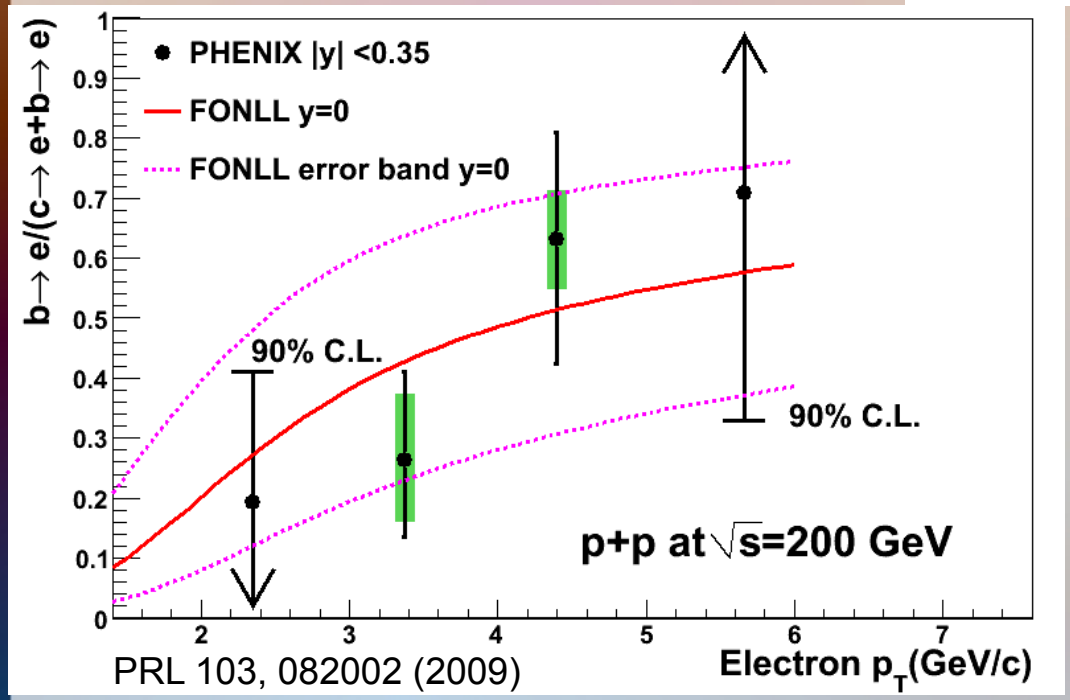
e-h Mass Correlations

Near side electron-hadron correlations to study charm to bottom ratio.

Use unlike sign e-K pairs, like sign subtraction to remove combinatoric background.

Pythia used to find charm and bottom tagging efficiencies.





PRL 103, 082002 (2009)

Mass correlation peak fit to simulated Pythia mass peak of electrons due to bottom along with electrons due to charm.

c-b ratio determined from fit.

c-b ratio found to agree with FONLL predictions.

Motivation for Studying Open Heavy Flavor

High p_T heavy quarks probe jet quenching, lower p_T heavy quarks probe collective flow.

Jet quenching quantified by:

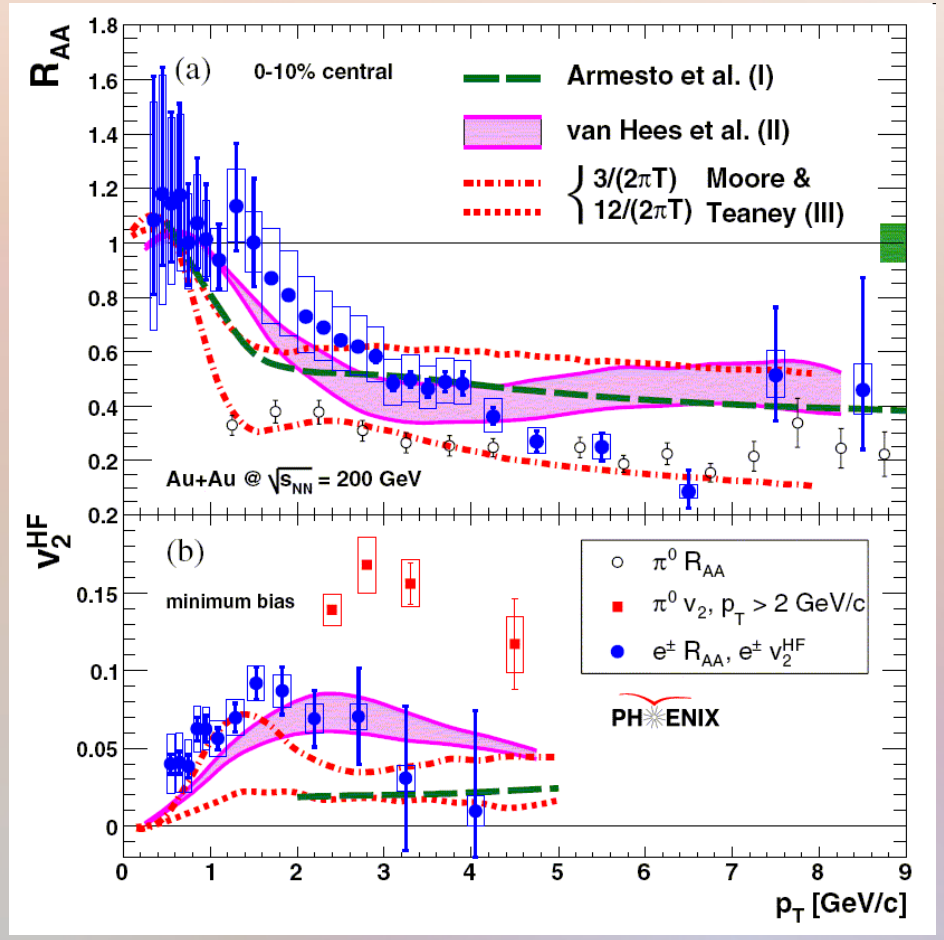
$$R_{AB} = \frac{dN^P_{AB}}{\langle T_{AB}\rangle_f \times d\sigma^P_{NN}} = \frac{dN^P_{AB}}{\langle N_{coll}\rangle_f \times dN^P_{NN}}$$

Elliptic flow quantified by v_2, where:

$$\frac{d^2N}{d\phi dp_T} = N_0(1 + 2v_2(p_T)\cos(2\phi))$$

Single particle measurements provide yields, R_{AA} and v_2 values.

Correlations probe heavy flavor jet structure modified by medium.



Trend with $<N_{coll}>$