Heavy Quark Production in PHENIX

Hard Probes 2006 Asilomar

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for the PHENIX collaboration

- Created during initial hard scattering $\rightarrow$ it is a hard probe
  - Yield is insensitive to final state effects
  - Yield obeys N_{coll} scaling $\leftarrow$ pQCD
- Heavy quark suppression is sensitive to the initial temperature and gluon density
- Open charm measurement serves as a baseline for J/ψ measurement
- Heavy quark anisotropies provide information about thermalization

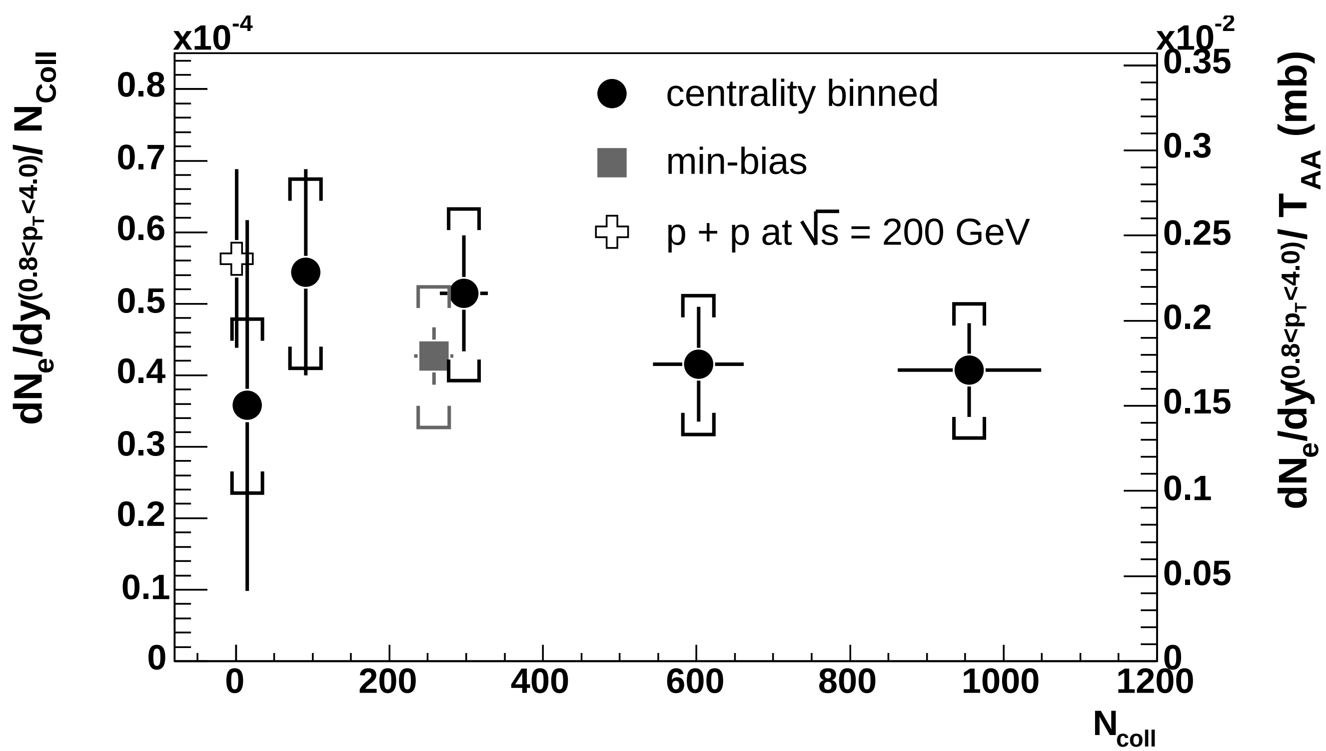

Figure 1: Charm electron yield ($0.8 < p_T < 4.0\ GeV/c$) from Au+Au collisions at 200 GeV/c scaled by N_{coll}

Experimental Approach to Open Charm/Bottom

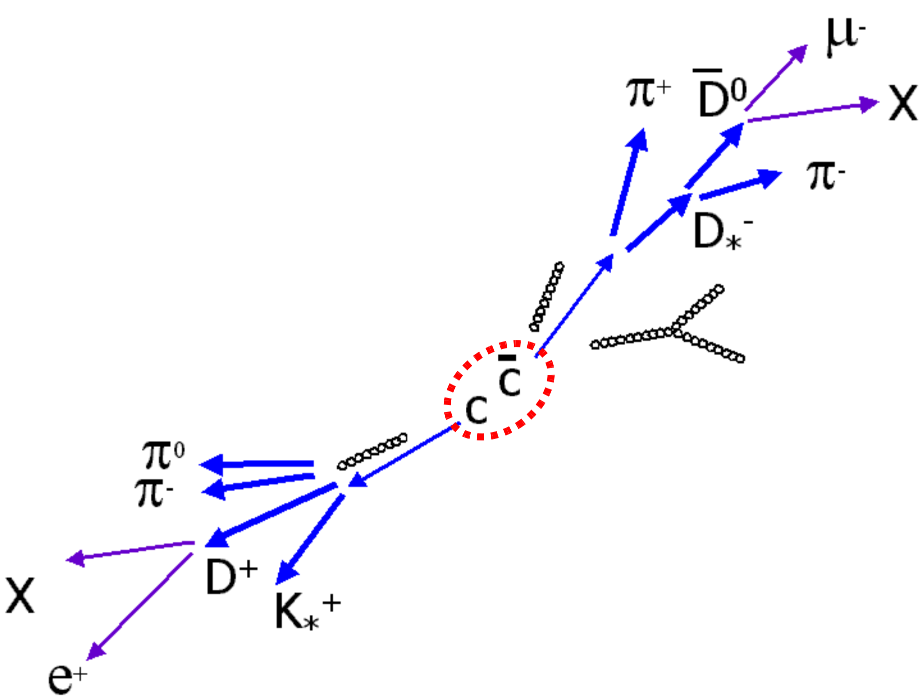

Figure 2: Illustration of charm decay

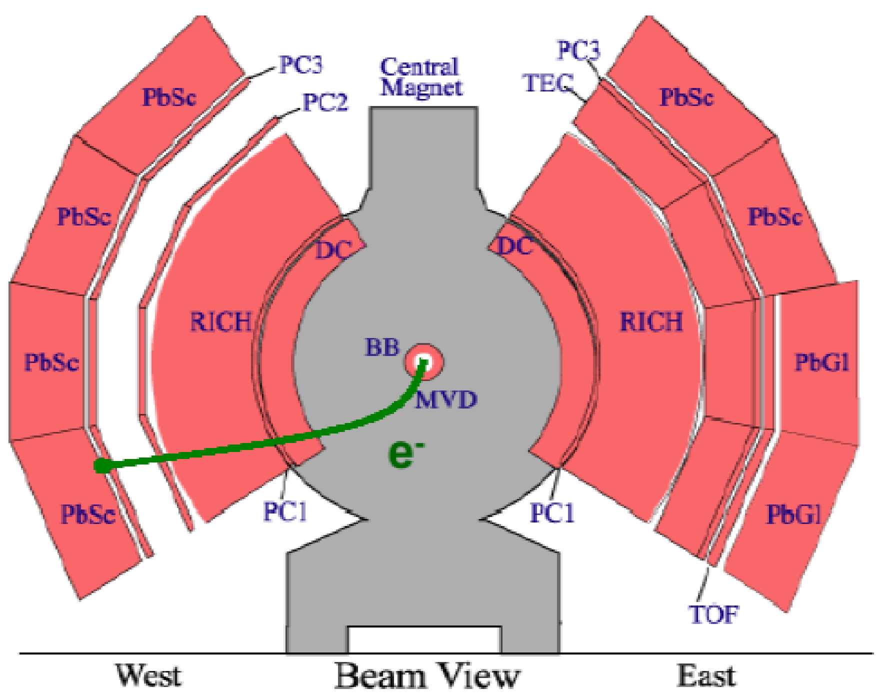

Figure 3: Schematic of PHENIX central arms

- Measure D and B mesons indirectly through electron spectra
  - Can't yet directly reconstruct charm/bottom decays
- Tracking:
  - Drift Chamber
- Electron Identification:
  - Ring-Imaging Cherenkov Detector
  - PbSc and PbGl electromagnetic calorimeters
  - E/p distribution

E/p Distribution

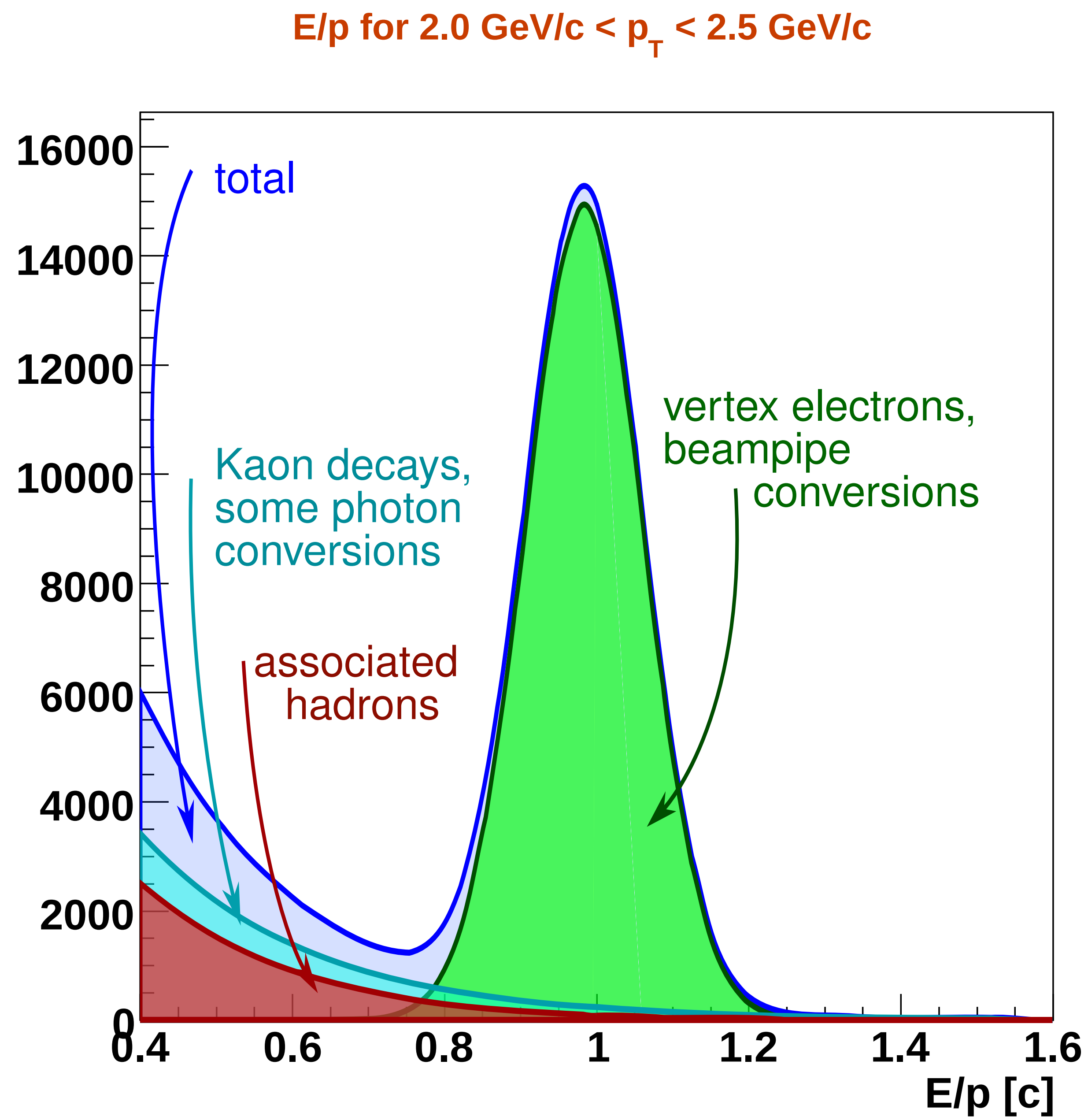

Figure 4: E/p distribution for p_T between 2.0-2.5 GeV/c

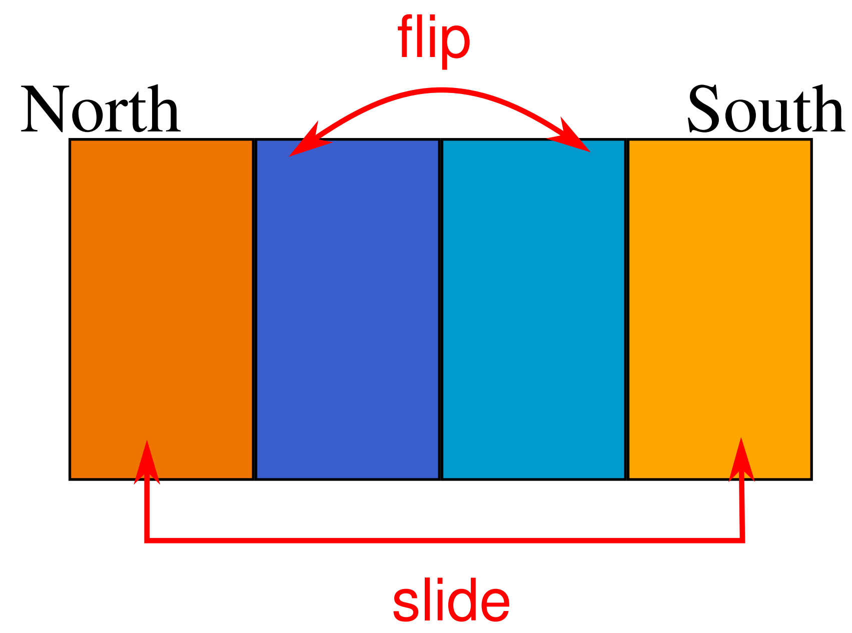

Figure 5: Flip-and-slide method for the RICH detector

Some hadrons are randomly associated with a RICH ring. These are statistically subtracted by "flipping and sliding" the RICH hits in software.

- 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

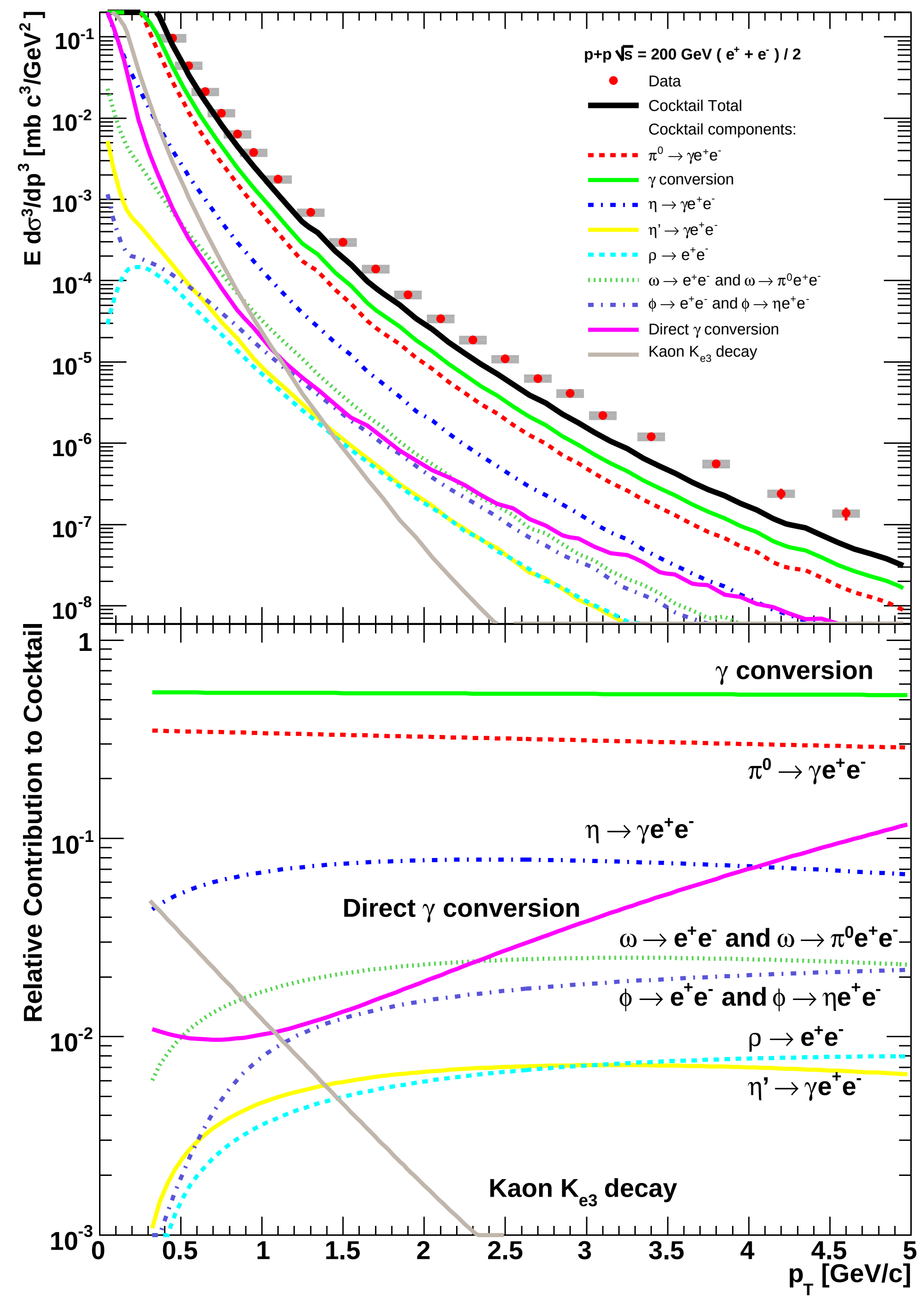

Figure 6: Inclusive electrons and cocktail predictions for run 3 p+p

Extraction of Heavy Flavor Signal

Cocktail subtraction

- Relevant background sources are measured
- Decay kinematics and photon conversion rate are calculated
- Background cocktail is subtracted from the inclusive spectrum
- Performs well at high p_T where signal/background is large
- Not limited by statistics

Converter subtraction

- Add material of known thickness to the experiment and compare the electron spectra with and without the material installed
- works best at low p_T where photonic sources are significant
- Limited by statistics of converter run

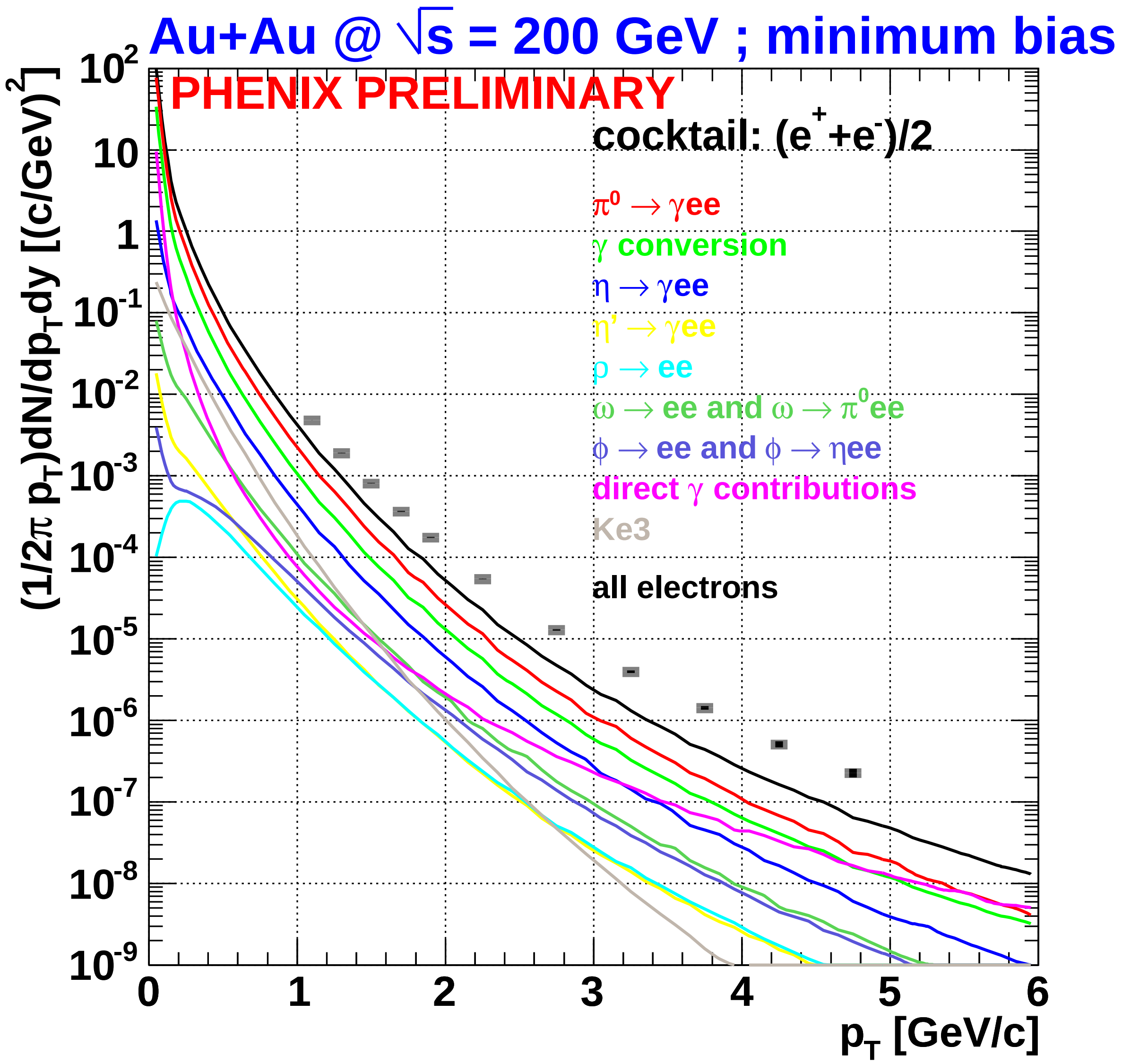

Figure 7: Inclusive electrons and cocktail predictions for Au+Au collisions at $\sqrt{s} = 200\ GeV/c$

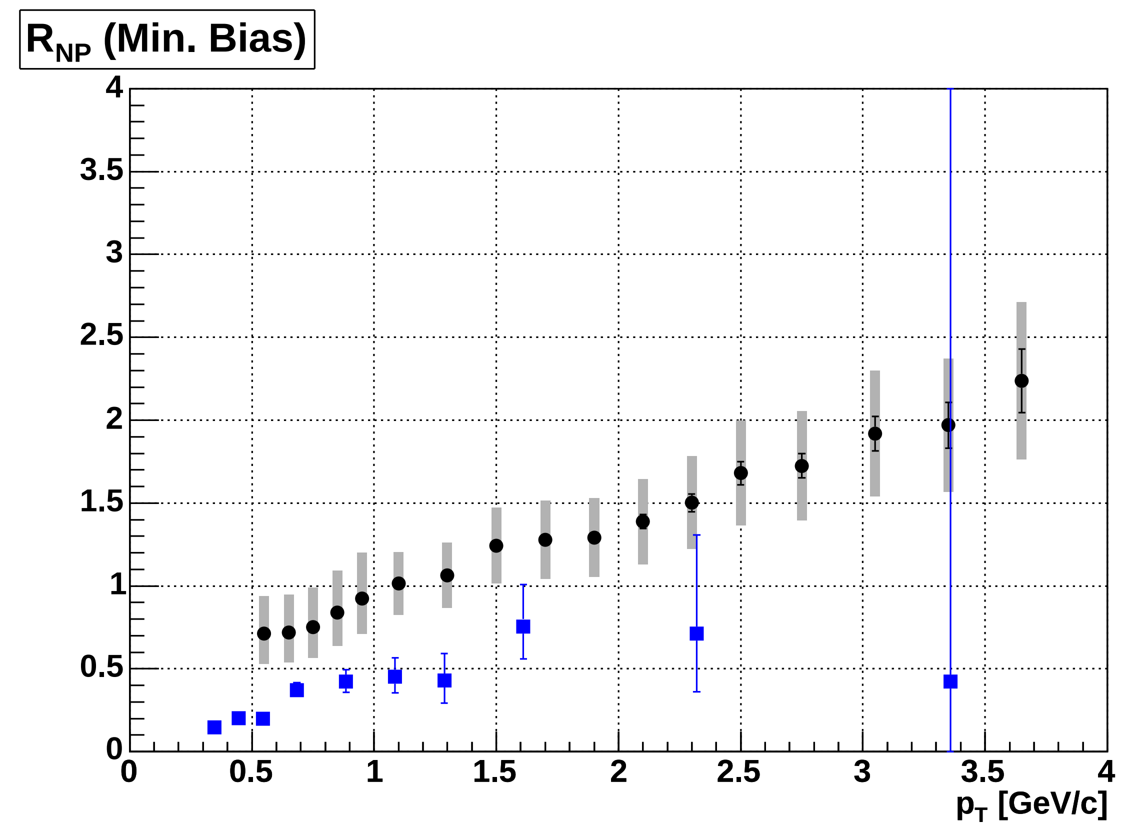

Figure 8: Ratio of non-photonic to photonic electrons from Au+Au collisions in run4 (black) and run2 (blue) converter runs

PHENIX

- FONLL: Fixed Order Next-to-Leading Log pQCD
  - M. Cacciari, P. Nason, R. Vogt PRL95, 122001 (2005)
- Spectra are harder than FONLL
- Open questions
  - Hard fragmentation?
  - Enhanced bottom?
  - Heavy quarks from jet fragmentation?
- Rapidity dependence needed
  - PHENIX μ data ($1.2 < |\eta| < 2.4$)

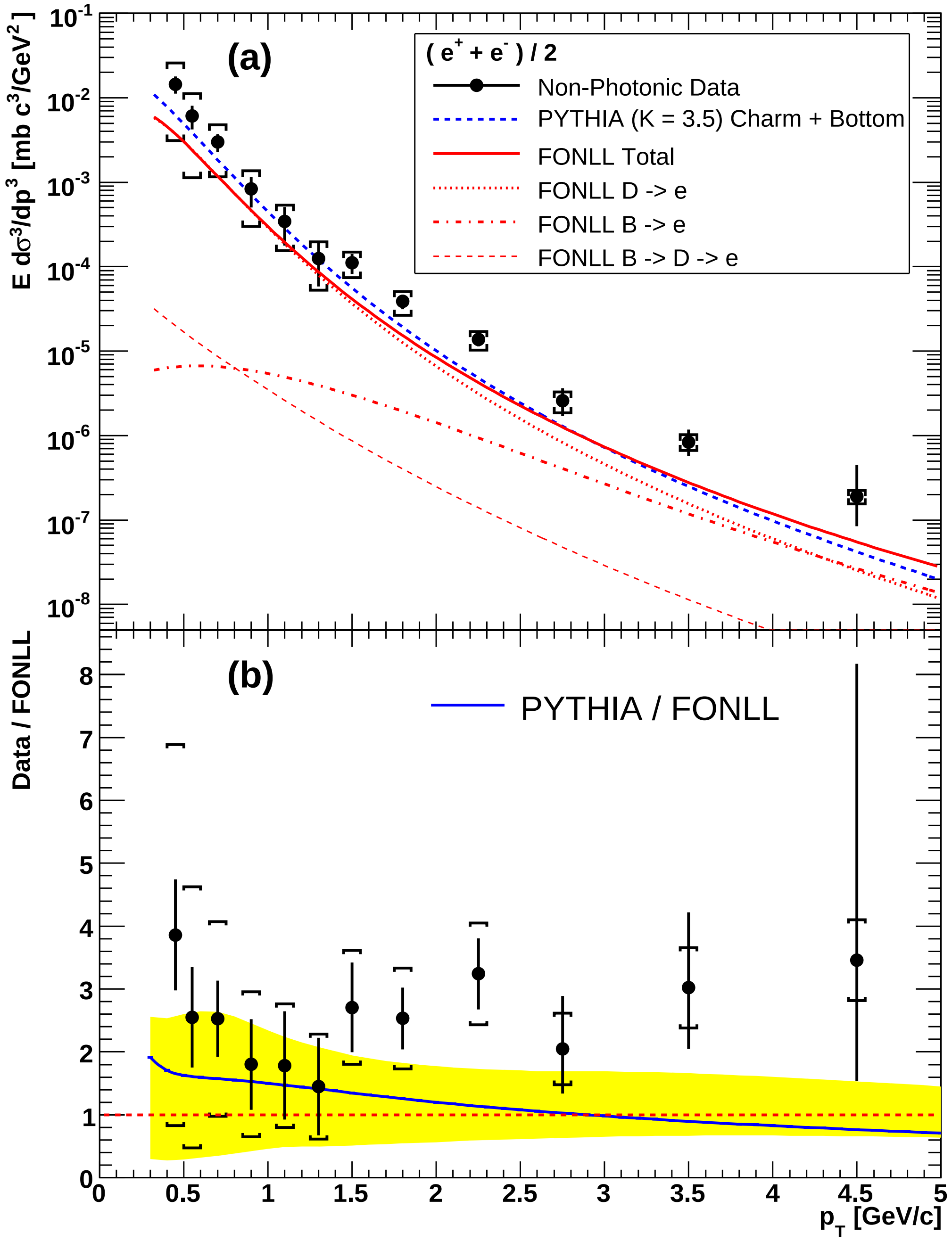

Figure 9: Electrons from heavy flavor decays compared with PYTHIA LO (K=3.5) and FONLL pQCD

PHENIX

- 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

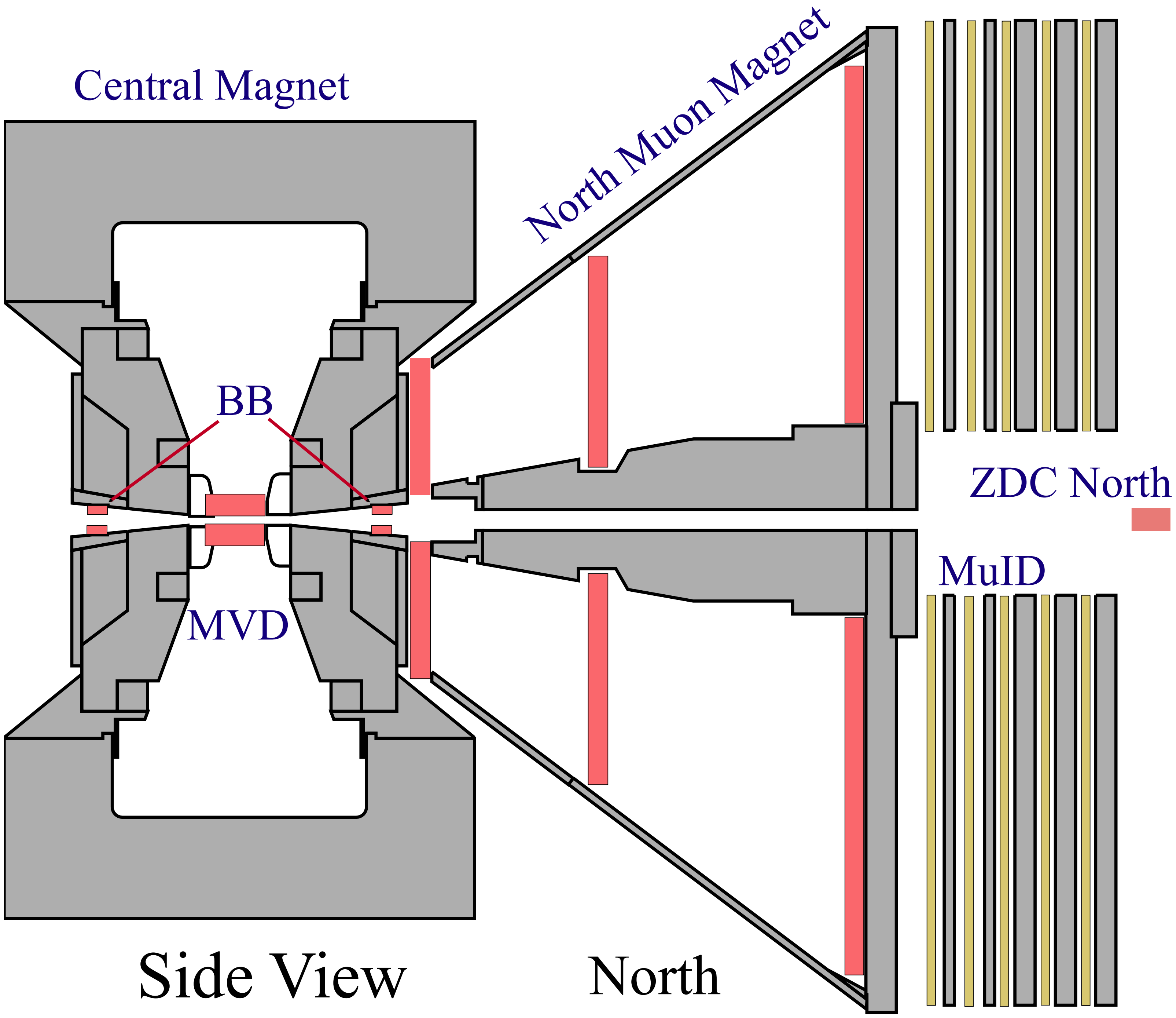

Figure 10: Schematic of PHENIX muon arms

- 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

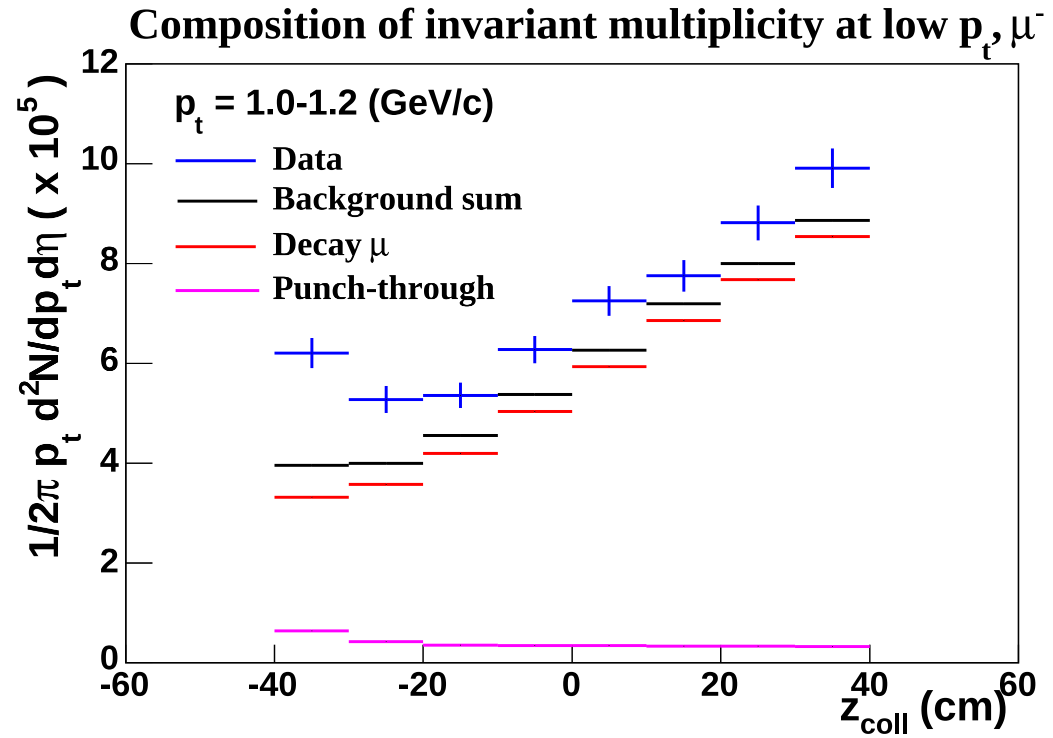

Figure 11: Background composition in muon arms

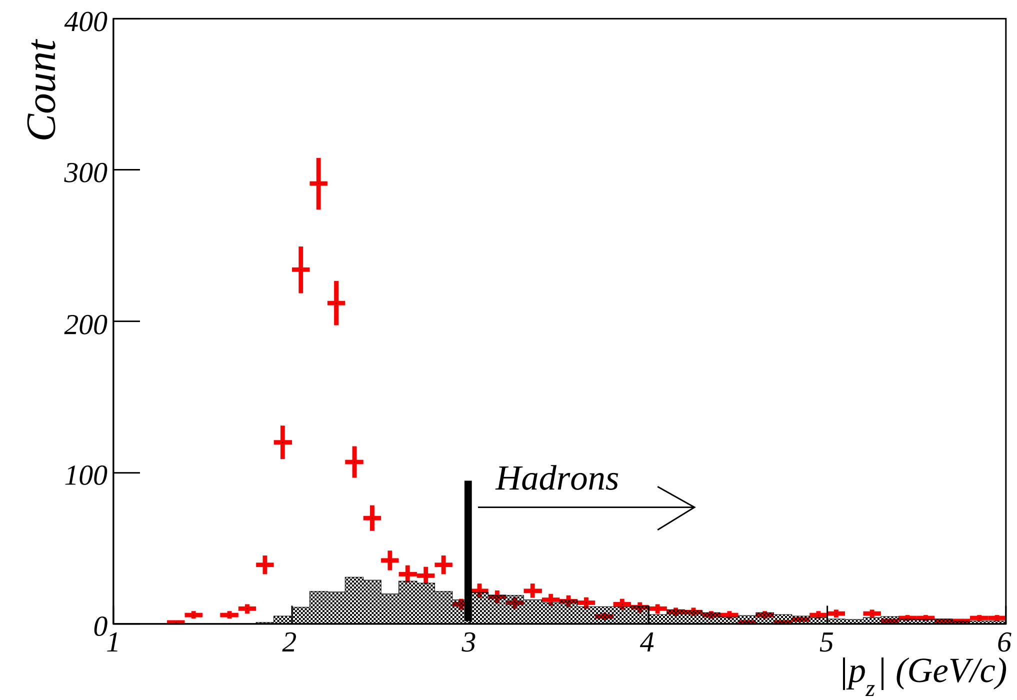

Figure 12: Longitudinal momentum in gap 3

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

- Prompt μ^- spectrum from p+p collisions at $\sqrt{s} = 200$ GeV
- Prompt μ^+ spectrum has much larger uncertainty due to punch-through hadrons

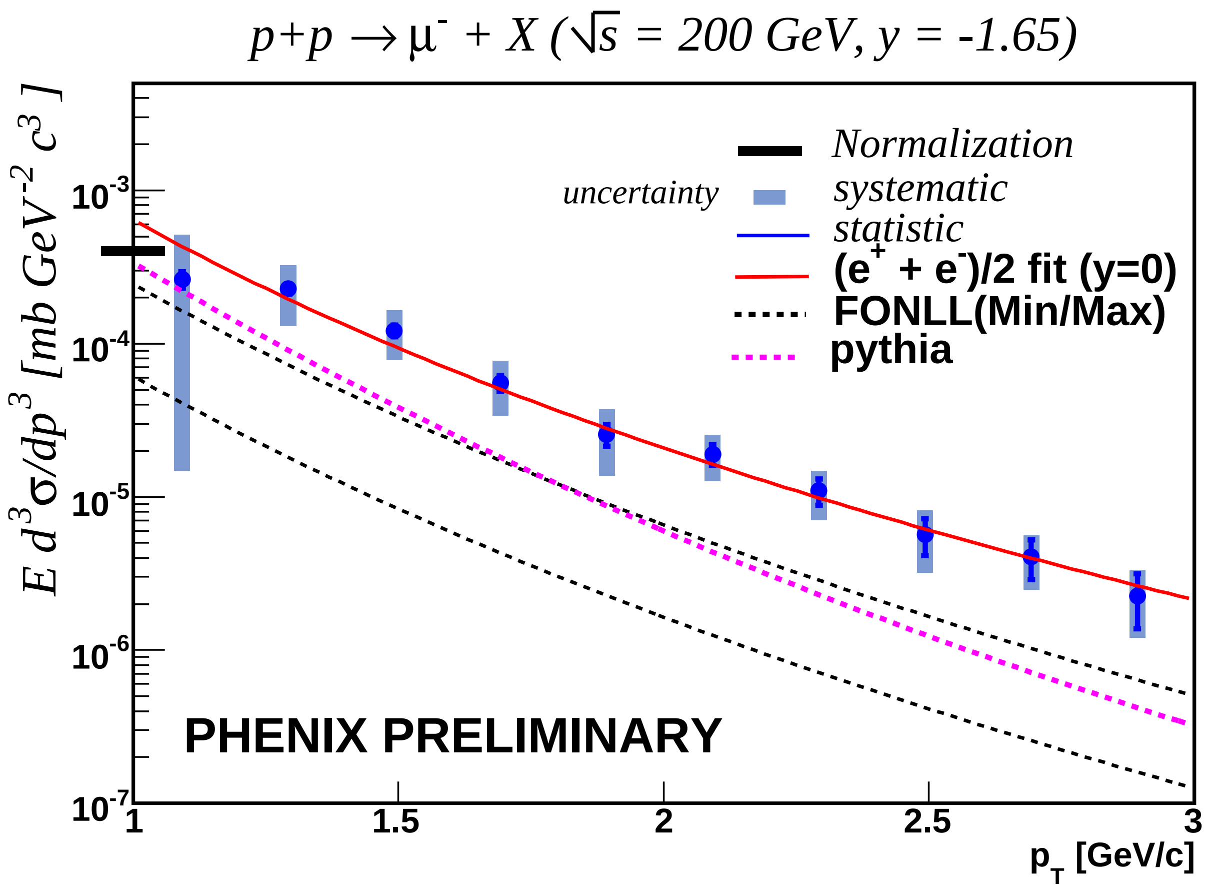

Figure 13: μ^- spectrum vs. FONLL

- 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

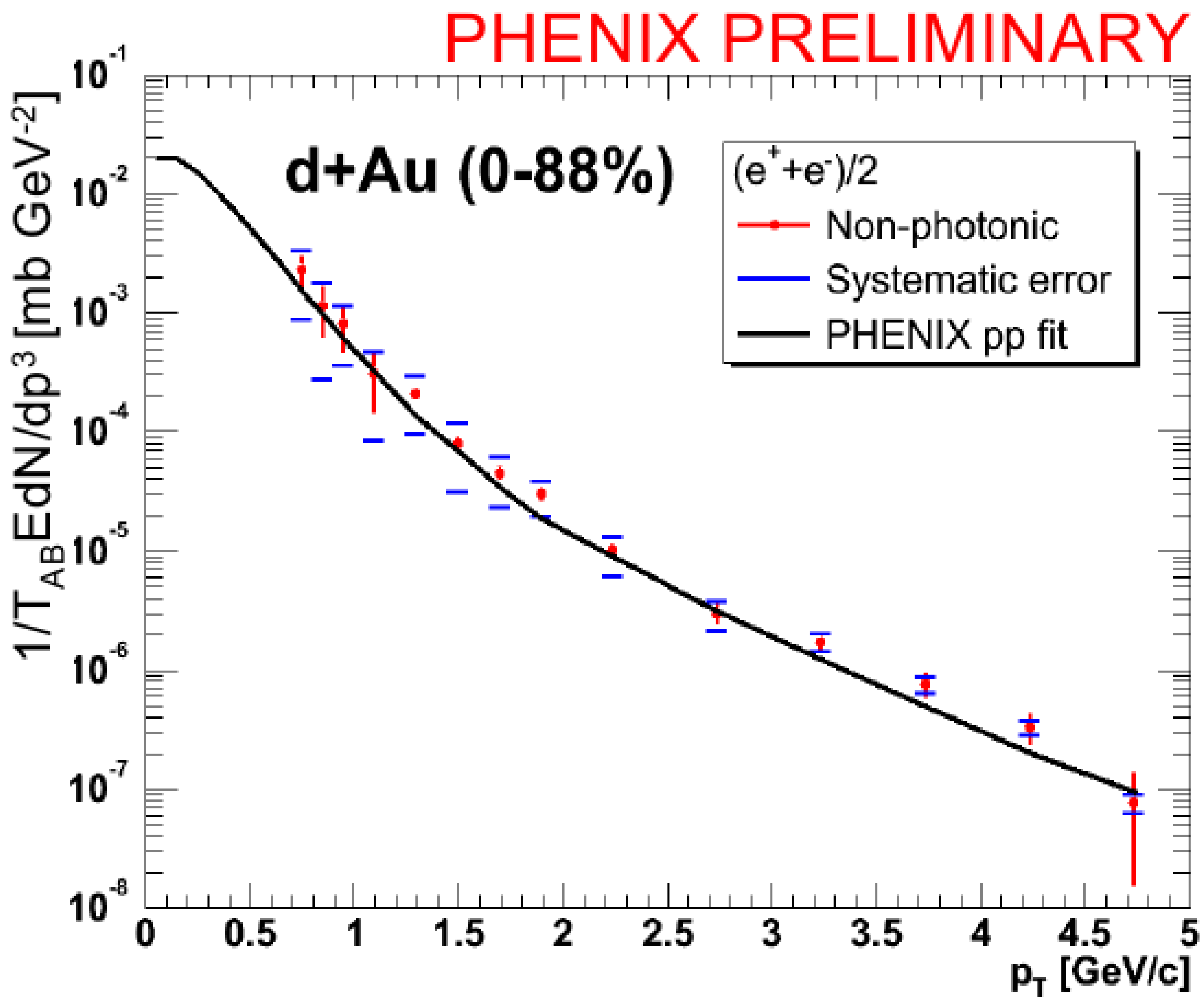

Figure 14: Electrons from heavy flavor from d+Au collisions compared to those from p+p

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

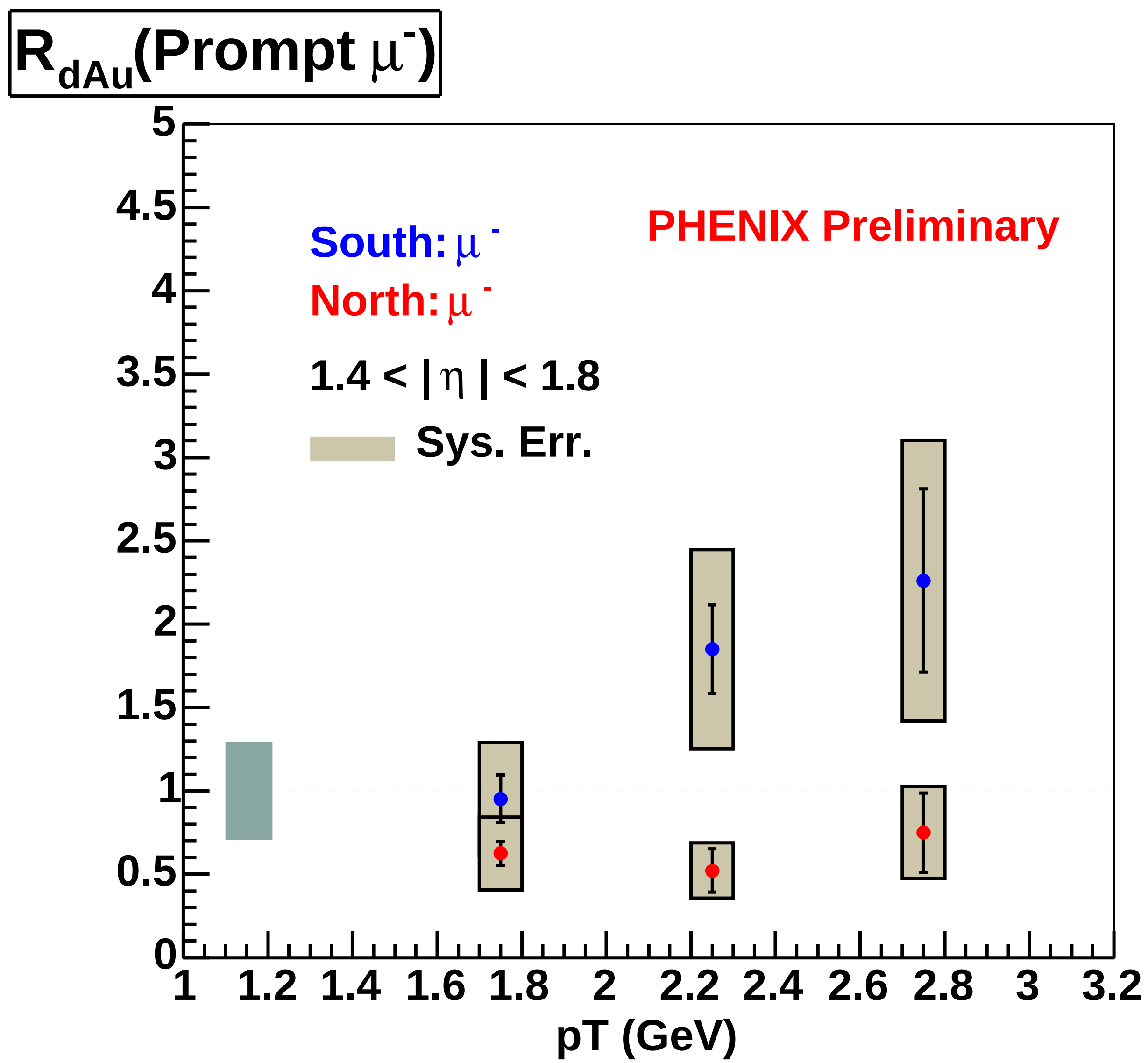

Figure 15: R_{dA} for μ^-

- Suppression in d-going direction $\rightarrow$ CGC?
- Enhancement in Au-going direction $\rightarrow$ anti-shadowing? recombination?

Nuclear Modification of $e^{\pm}$ Spectra

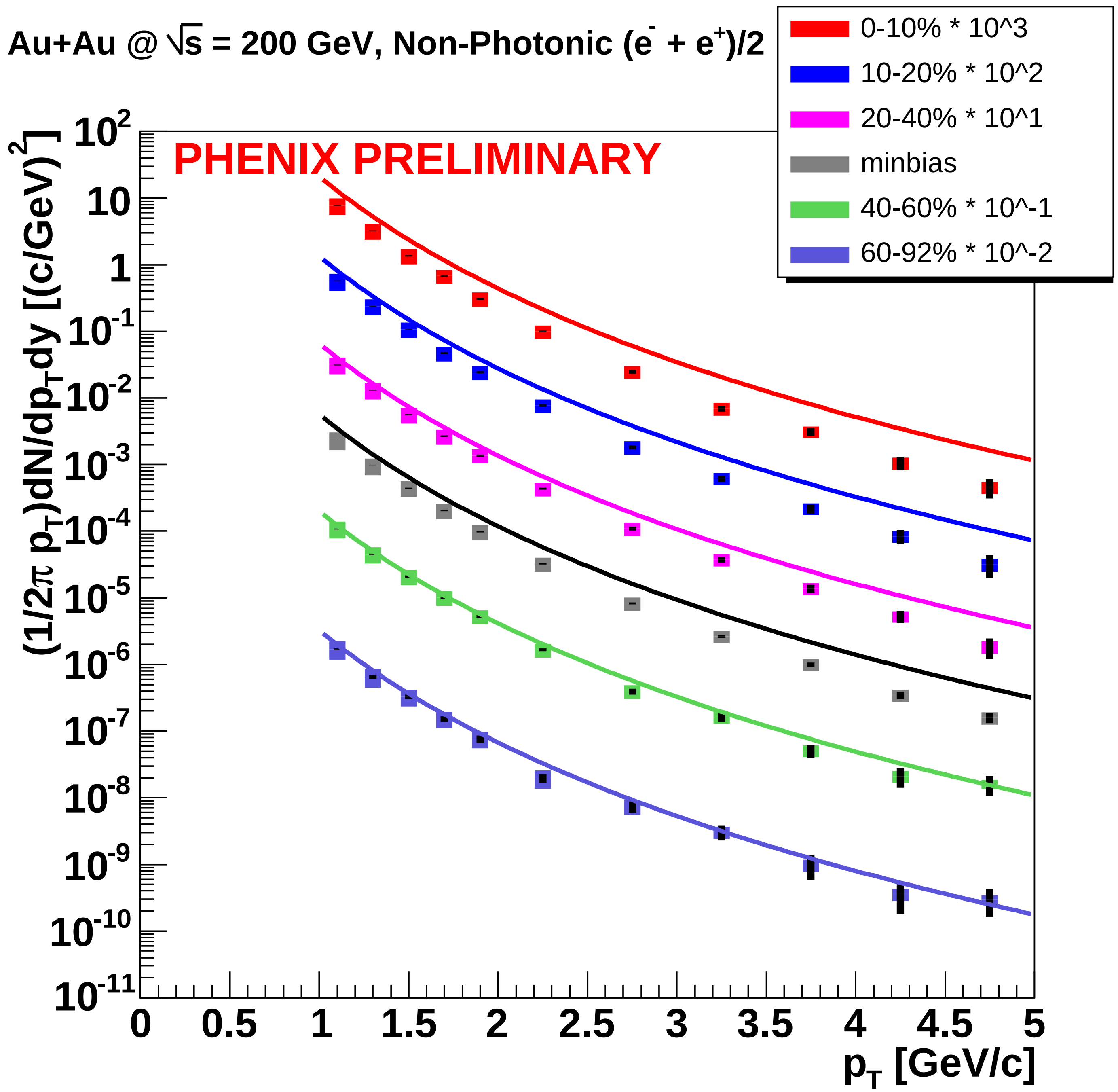

Figure 16: Non-photonic spectra of electrons from run4 Au+Au data comared to scaled p+p fit

- Strong modification of spectra at high p_T

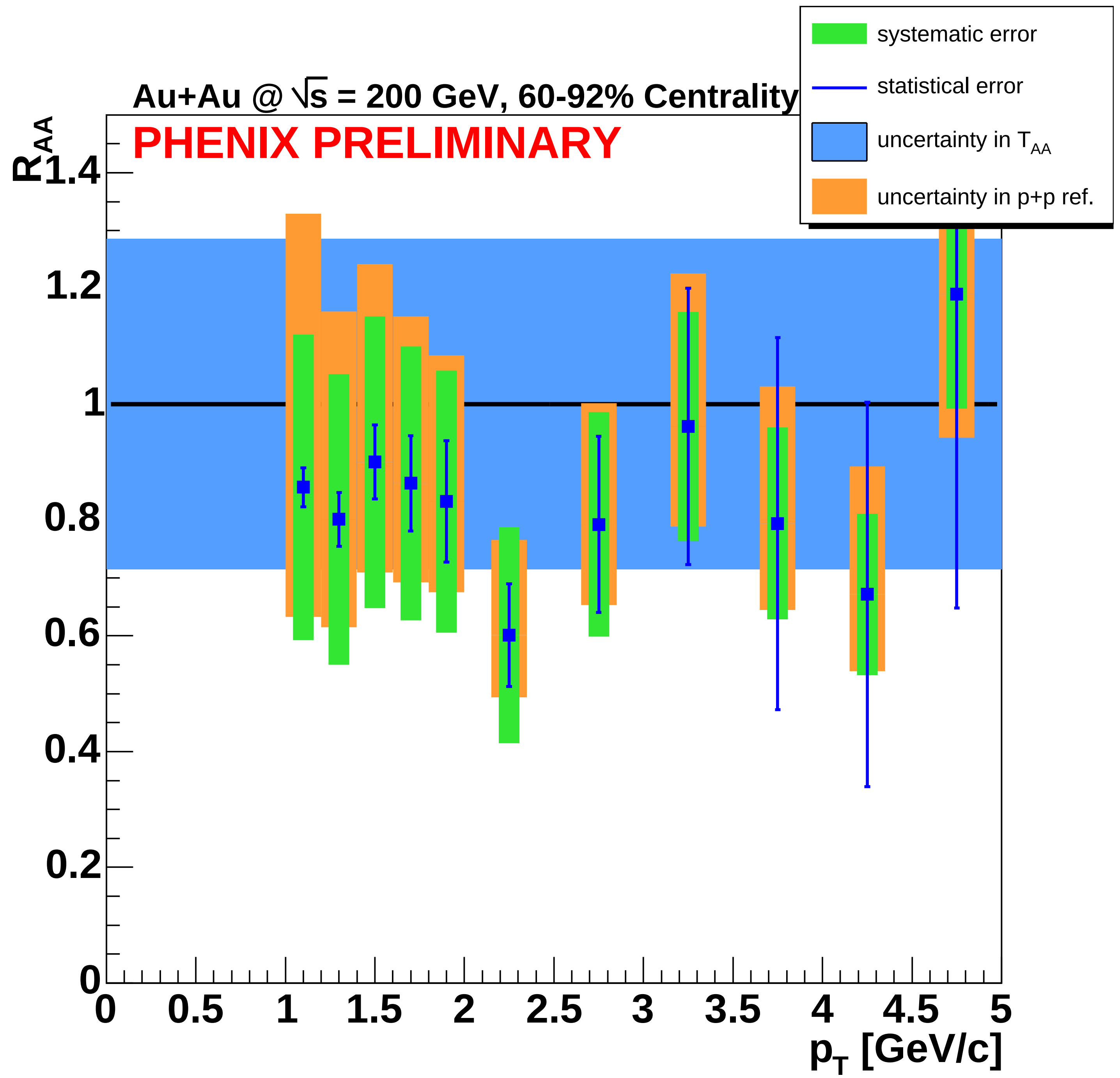

Figure 17: R_{AA} for 60-92% centrality

$$R_{AA} \equiv \frac{dN_{AA}}{\langle T_{AA} \rangle dN_{pp}}$$

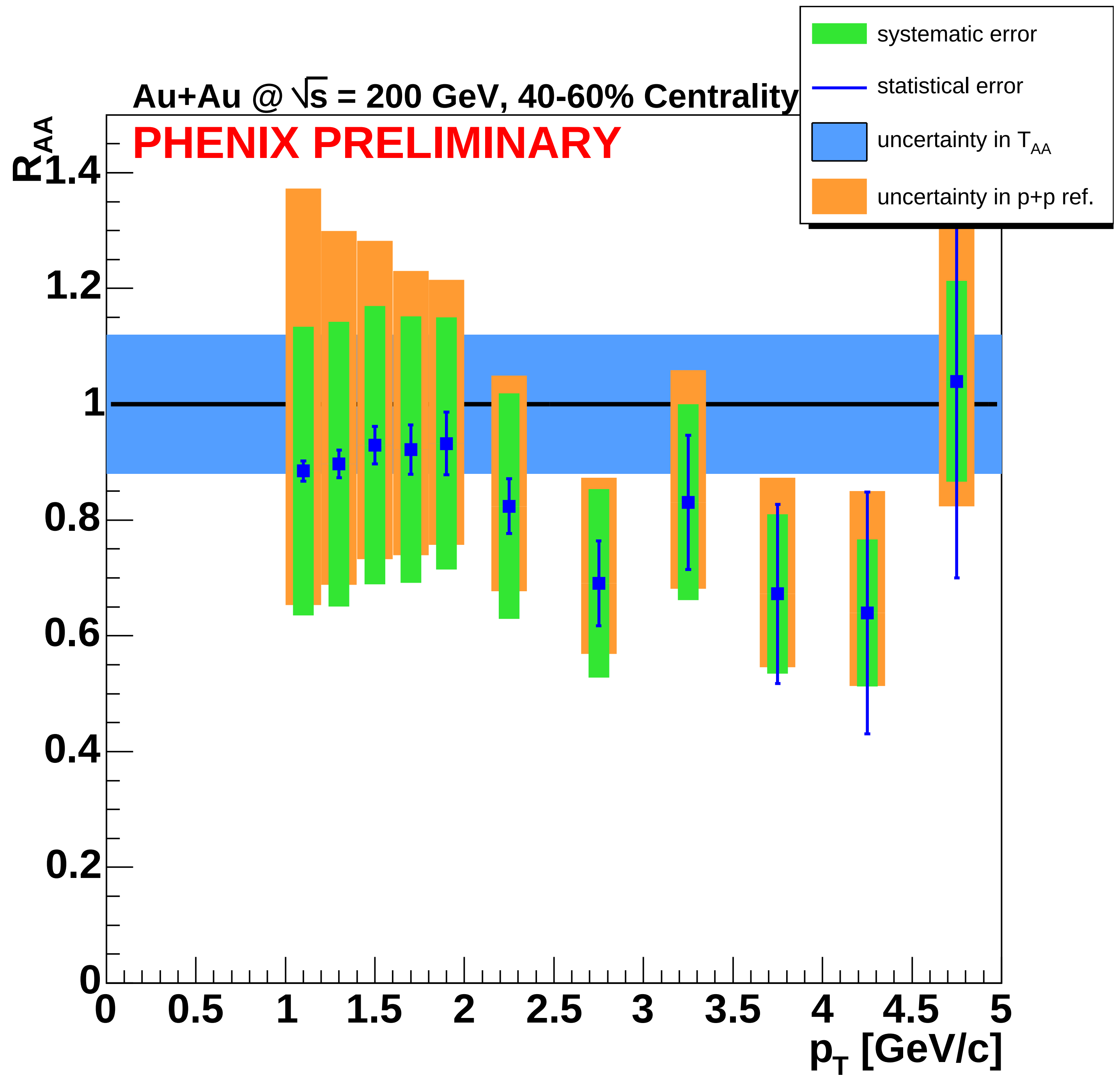

Figure 18: R_{AA} for 40-60% centrality

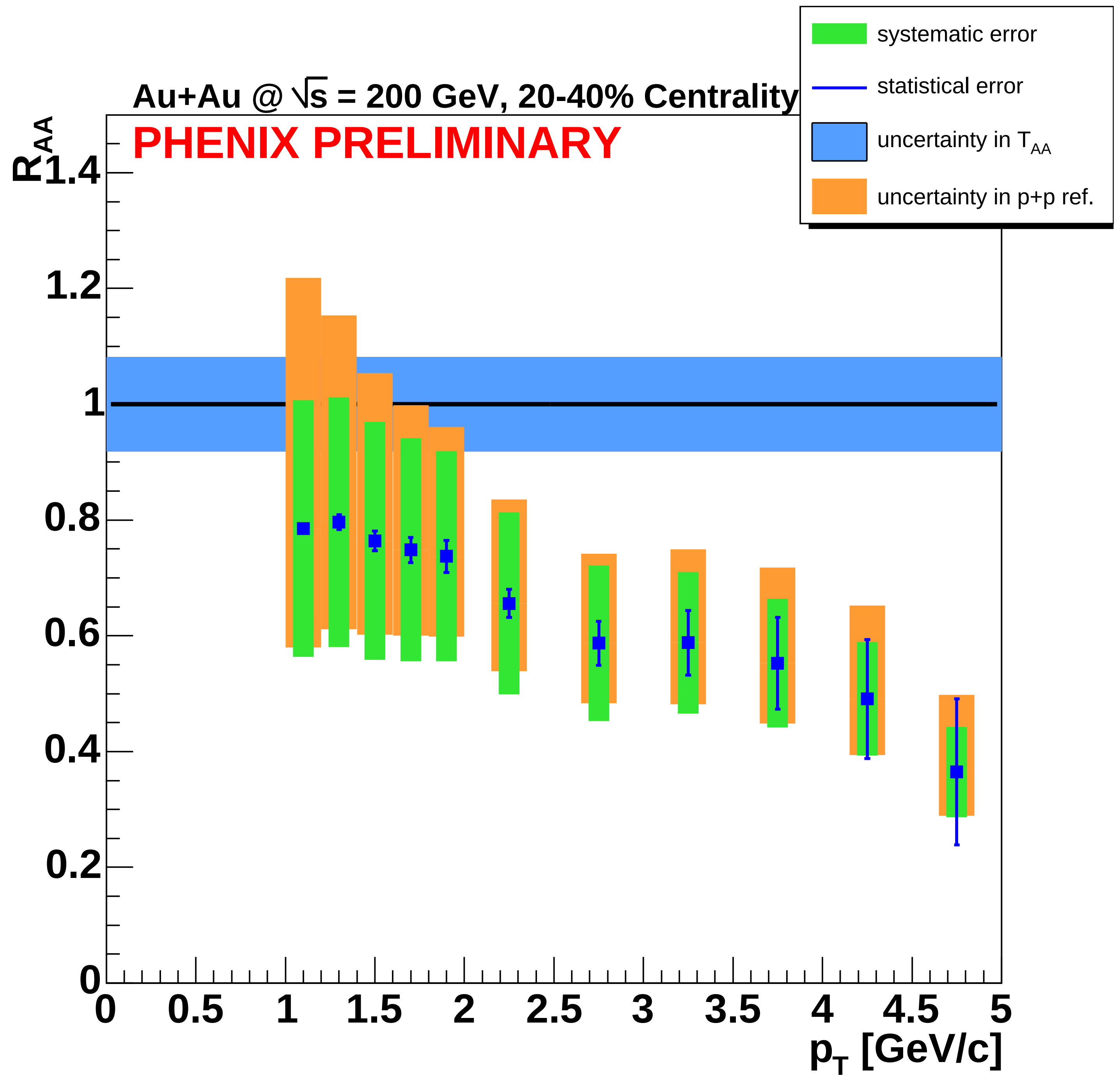

Figure 19: R_{AA} for 20-40% centrality

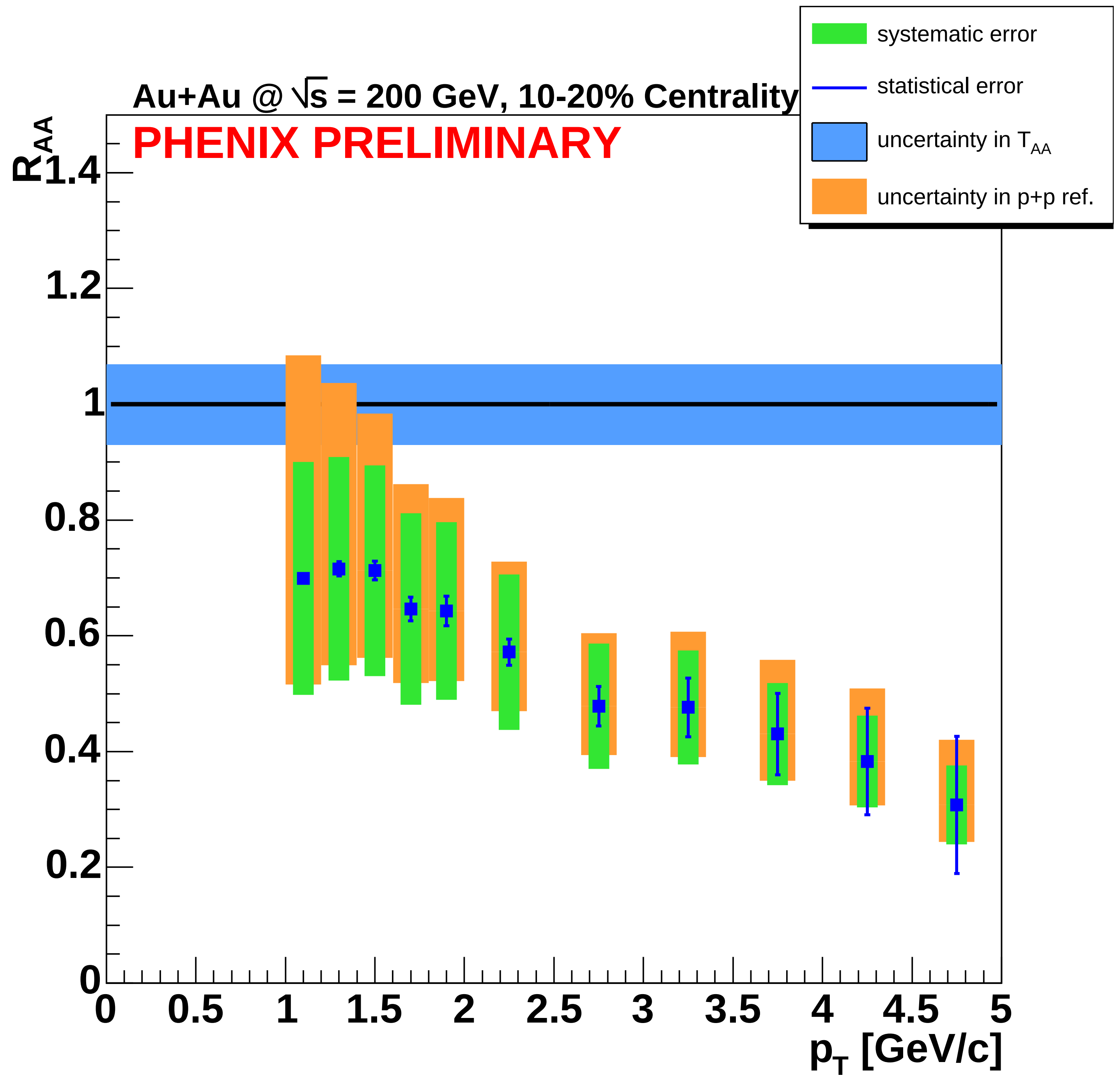

Figure 20: R_{AA} for 10-20% centrality

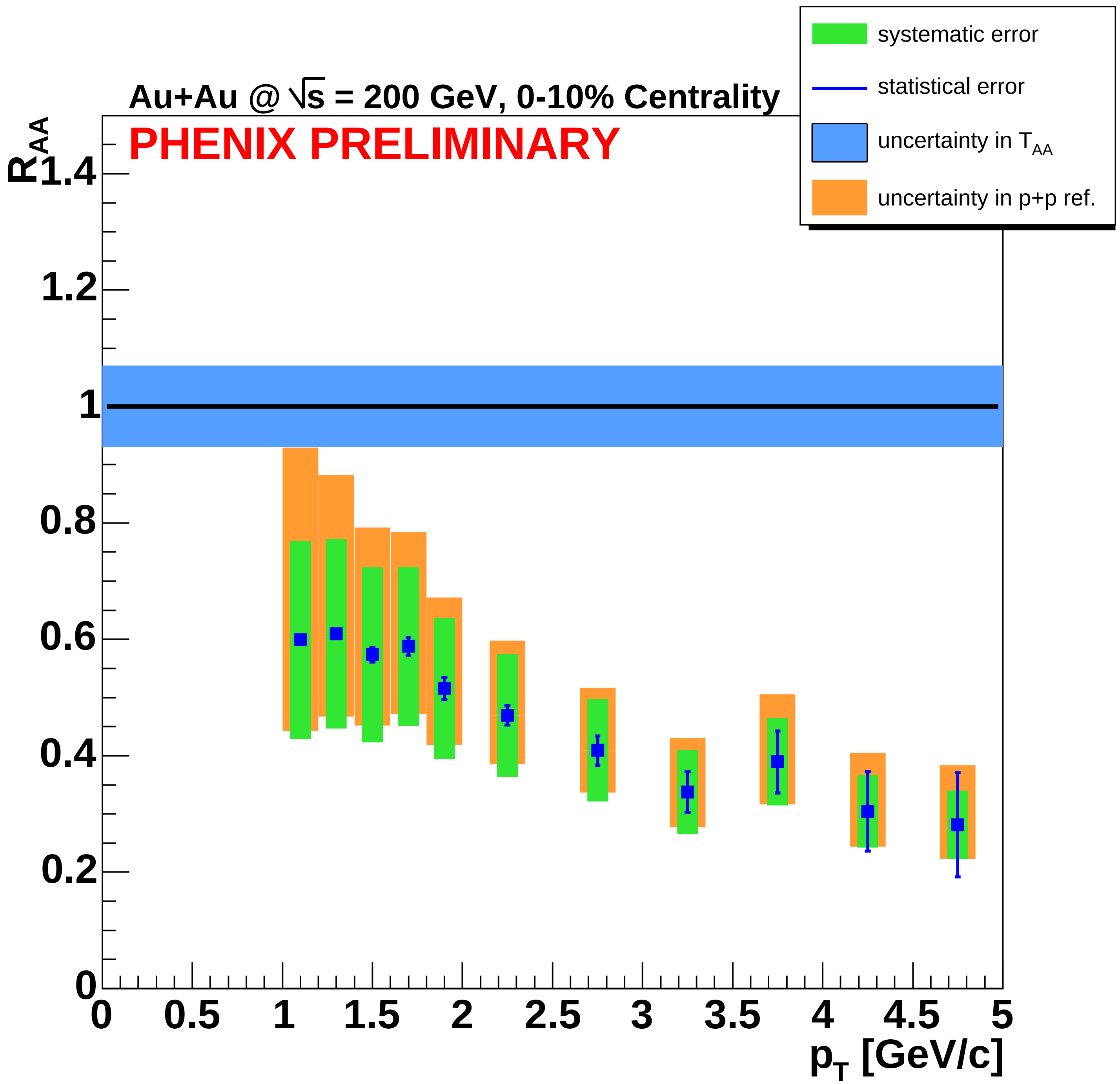

Figure 21: R_{AA} for 0-10% centrality

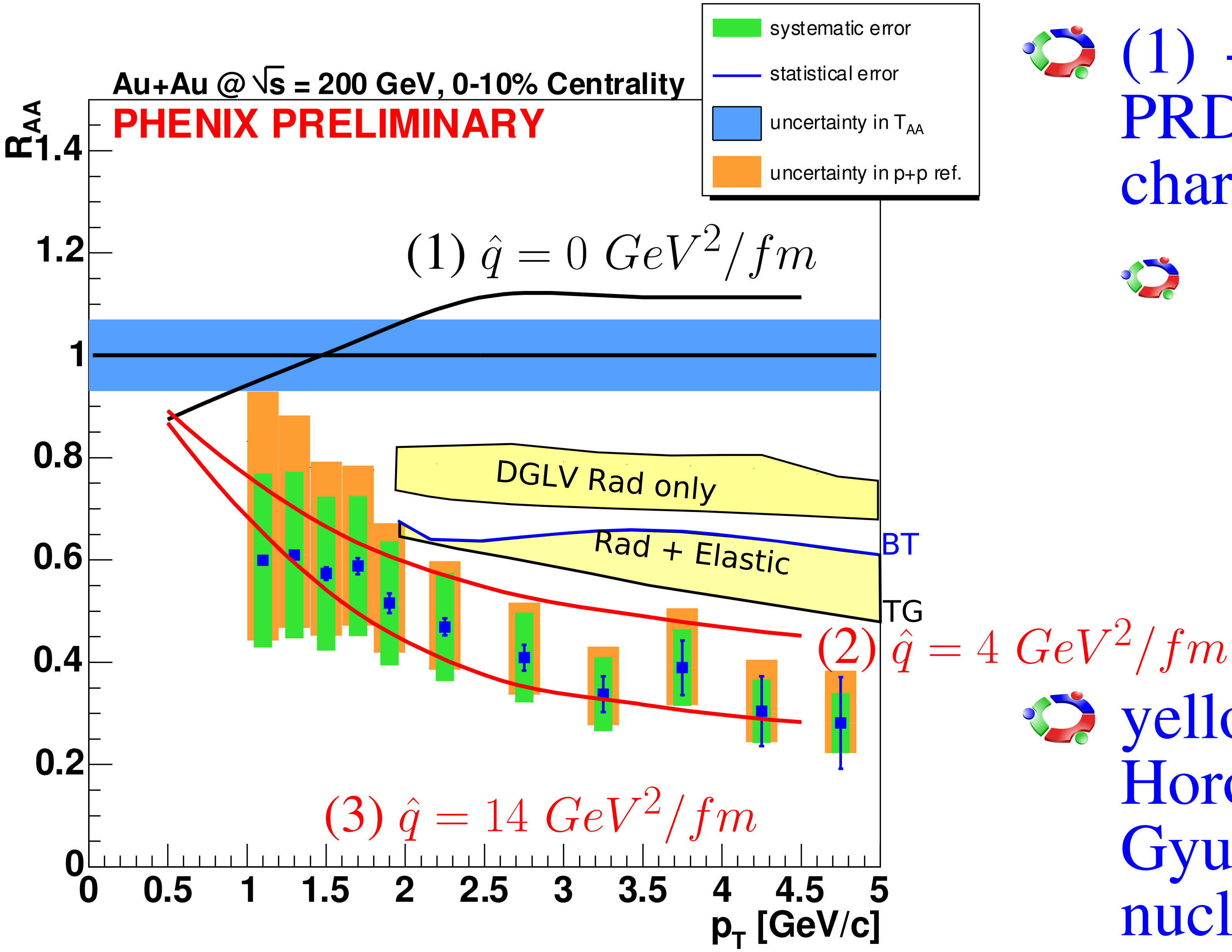

Figure 22: R_{AA} for 0-10% centrality compared to theoretical predictions

- (1) - (3): N Armesto, et al., PRD 71, 054027 only contains charm contribution
  - $\hat{q} \equiv$ transport coefficient $\propto$ density of scattering centers in medium
- yellow bands: S. Wicks, W. Horowitz, M. Djordjevic, M. Gyulassy nucl-th/0512076
  - The lower band contains elastic energy loss in addition to radiative energy loss
  - $\frac{dN_g}{dy} = 1000$

$$\frac{dN}{d\phi} = \frac{dN_{photonic}}{d\phi} + \frac{dN_{non-photonic}}{d\phi} \propto 1 + v_2 cos(2(\phi - \Psi))$$

$$v_{2_{non-\gamma}} = \frac{1+v_2 R_{NP} - v_{2_\gamma}}{R_{NP}}$$

Photonic electron v_2 determination

- Converter method:

  Measure inclusive $e^{\pm}$ v_2 with/without converter

  Separate non-photonic and photonic v_2

- Cocktail method:

  Determine photonic $e^{\pm}$ v_2 with reaction-plane-dependent cocktail

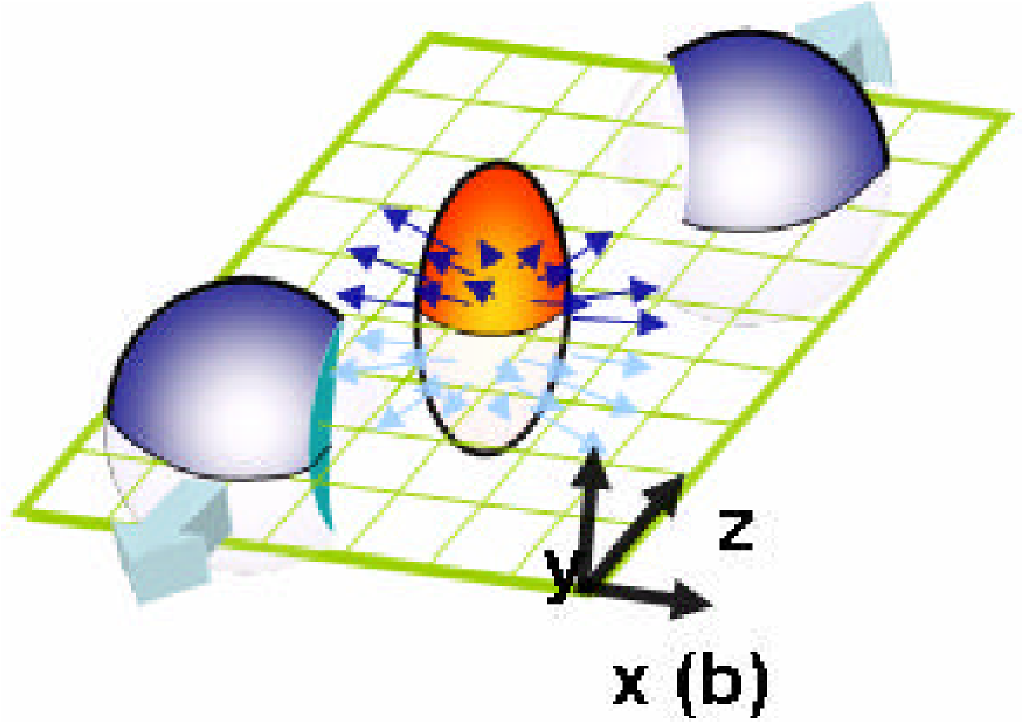

Figure 23: Illustration of elliptic flow

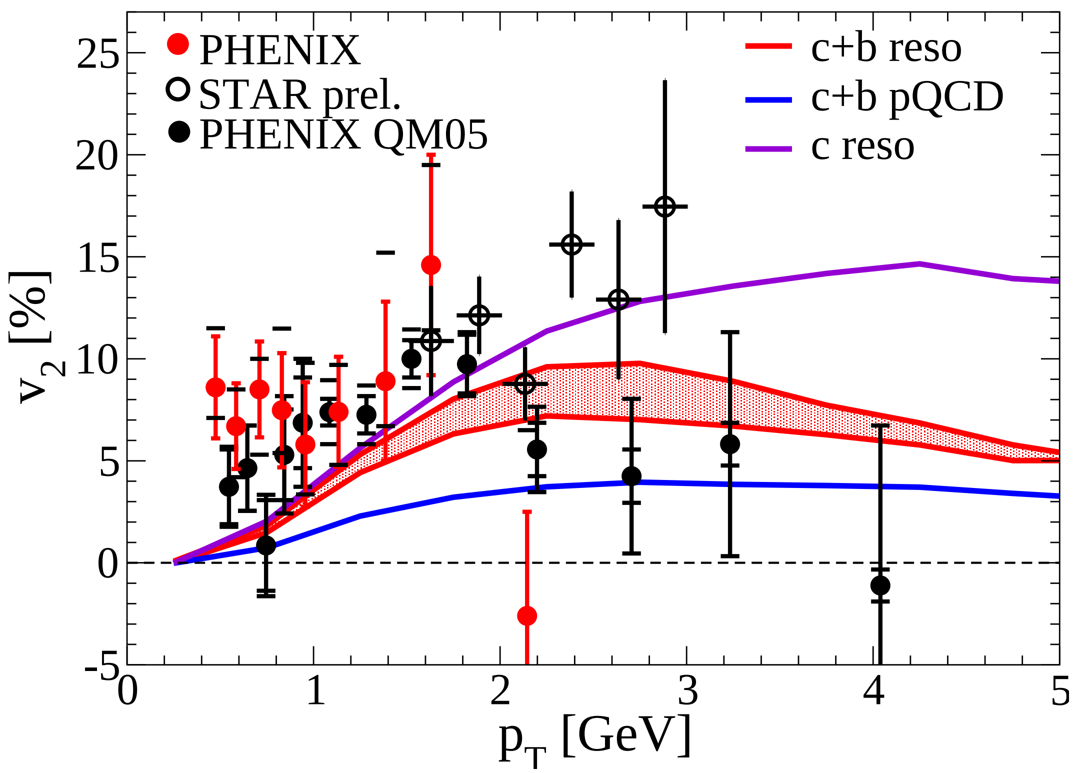

Figure 24: $e^{\pm}$ v_2 compared to model from van Hees et al., PRC73 034913 (2006)

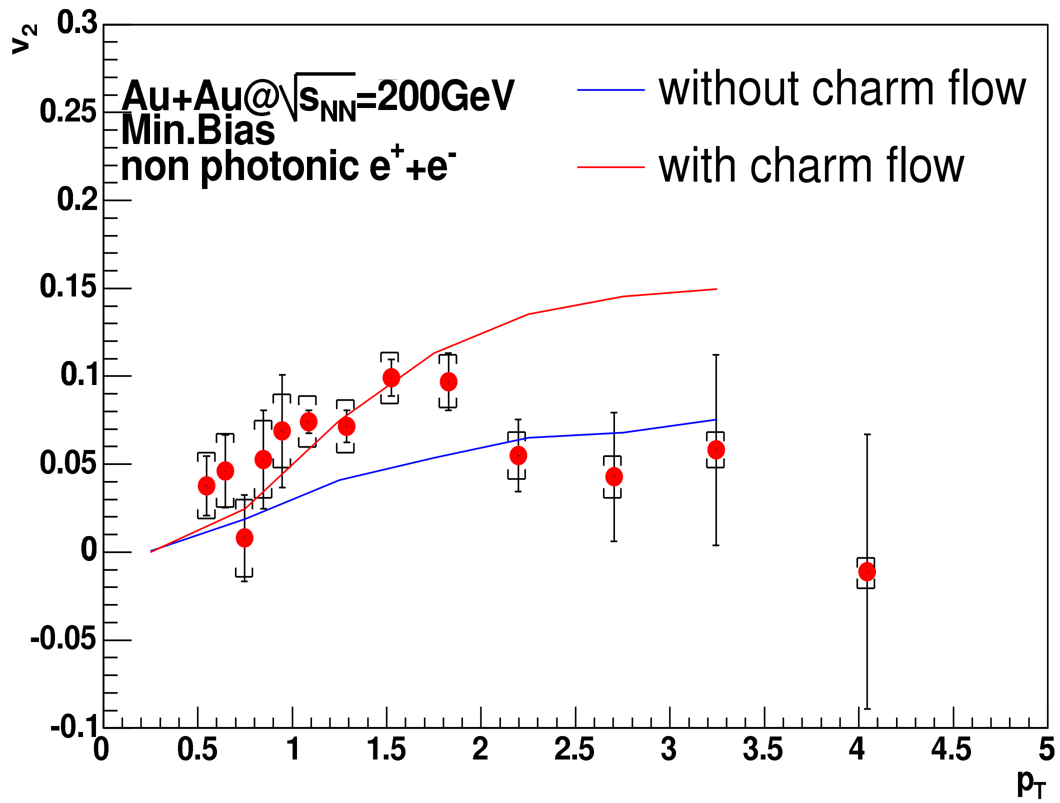

Figure 25: $e^{\pm}$ v_2 compared to model from Greco et al., PLB 595 (2004) 202

PHENIX

- Measurement of electrons at y=0 and muons at η = -1.65 from semileptonic heavy flavor decays
  - p_T spectra harder than FONLL and PYTHIA predictions
  - Rapidity distribution is wider than expected from pQCD
- Improvements from ongoing run 5/6 analyses
  - Extend electron spectra to lower p_T $\rightarrow$ improved charm cross section measurement
  - Extend electron spectra to higher p_T $\rightarrow$ improved estimate of bottom contribution
  - Improved background subtraction for prompt muon measurement

d+Au Summary

- No significant cold nuclear matter effects observed for electrons from heavy flavor decays at y=0
- Indications for cold matter effects for prompt muons at forward/backward rapidity
  - Suppression in d-going direction
  - Enhancement in Au-going direction

Au+Au Summary

- Electrons from heavy flavor at y=0
  - 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's the deal with bottom?

PHENIX

Hadron Blind Detector

- Dalitz/conversion background rejecton for single electrons and electron pairs

Silicon Vertex Tracker

- Direct tagging of charm/bottom decays → distiguish charm from bottom signal and measure v_2 of D meson

New reaction plane detector

- High p_T non-photonic electron v_2