Overview of PHENIX Open Heavy Flavor Research

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For the PHENIX Collaboration

Outline

- Physics Motivations
  - Charm/Bottom Cross Sections
  - Nuclear Modification Factor
  - Collective Flow Effects
- Current Measurements
  - Non-photonic Single Electrons
  - Single Muons
  - Charm/Bottom Separation
- Future/Current Analyses
  - The PHENIX VTX and FVTX detectors
  - Geometric Reconstruction of Heavy Flavor Decays

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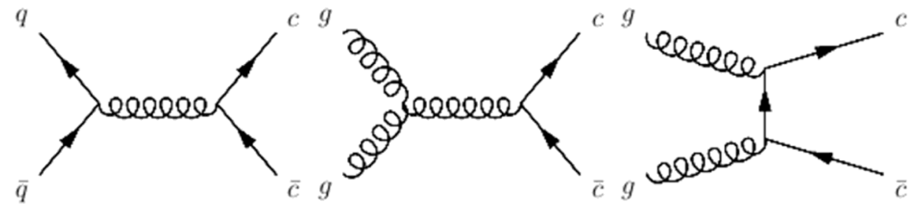
Prediction of Open Charm and Bottom Cross-Sections using Perturbative Quantum Chromodynamics (pQCD)

Production in initial gluon fusion ⇨ Binary Scaling of Charm Cross-Section



Method 1:

- use dp_t slices, then integrate final result
- treat heavy quarks as active flavor
- FONLL Calculation

Charm and Bottom Cross Sections Predicted for 200 GeV Collisions:

$$\sigma_{c\bar{c}}^{\mathrm{NLO}_{\mathrm{n1f+1}}} = 244^{+381}_{-134}\,\mu b \qquad \sigma_{b\bar{b}}^{\mathrm{FONLL}_{\mathrm{n1f+1}}} = 1.87^{+0.99}_{-0.67}\,\mu b$$

$$\sigma_{c\bar{c}}^{\mathrm{FONLL}_{\mathrm{n1f+1}}} = 256^{+400}_{-146}\,\mu b$$

Method 2:

- calculate on full p_t range in one step
- treat heavy quarks as NOT active flavors (heavy quark considered massive)
- NLO Calculation

Charm and Bottom Cross Sections Predicted for 200 GeV Collisions:

$$\sigma_{c\bar{c}}^{\mathrm{NLO}_{\mathrm{n1f}}} = 301^{+1000}_{-210}\,\mu b \qquad \sigma_{b\bar{b}}^{\mathrm{NLO}_{\mathrm{n1f}}} = 2.06^{+1.25}_{-0.81}\,\mu b$$

Ref: R. Vogt, arXiv:0709.2531v1 [hep-ph]

Experiment can help constrain these theoretical predictions.

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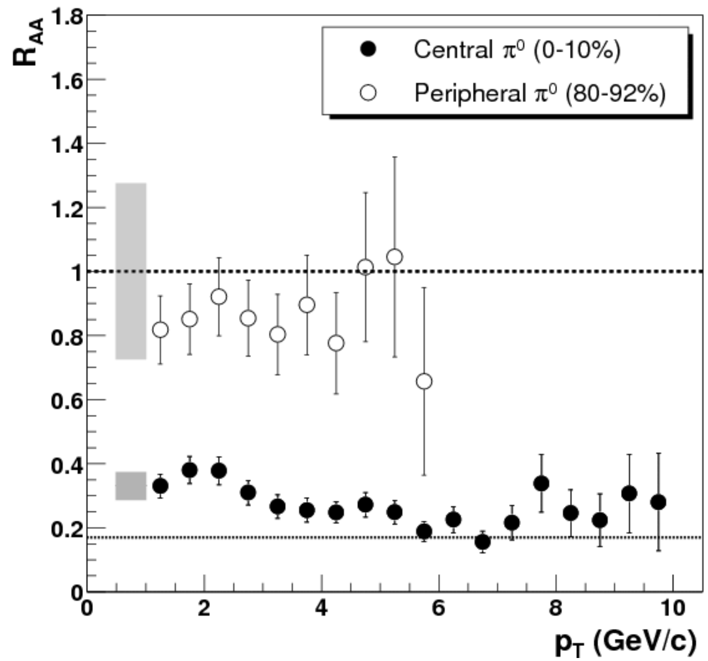
Nuclear Modification Factor

- Nuclear Modification of charm and bottom shows the degree of interaction of these heavy quarks with the medium.
- Heavy suppression seen in pion R_{AuAu} (figure) due to opaque medium.
- Heavy flavor was expected to exhibit less suppression due to dead-cone effect.

$$R_{AB} \equiv \frac{1}{N_{coll}^{AB}} \times \frac{dN^{AB}/dy}{dN^{pp}/dy}$$



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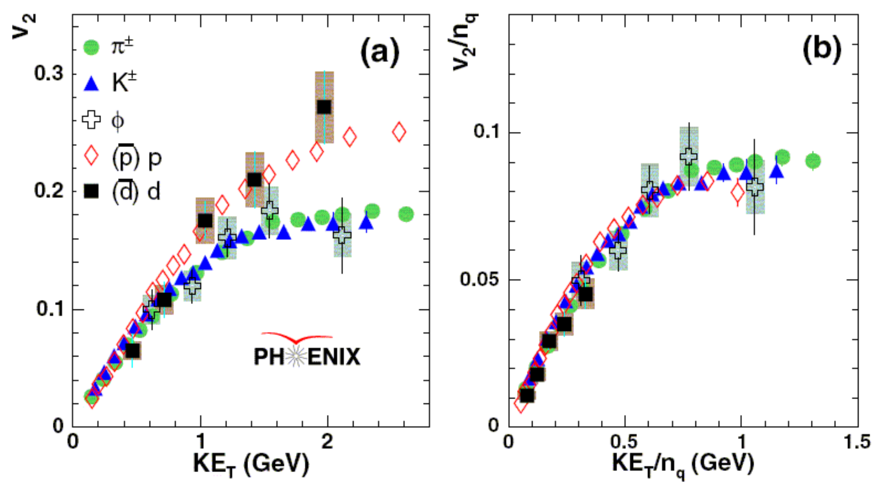
Elliptic Flow Effects

- Azimuthal Aniostropy (v_2) is measured to determine elliptic flow.
- Lights quarks exhibit this elliptic flow, showing a hydrodynamical system.
- If heavy flavor does not interact strongly with the medium, their v_2 should be strongly suppressed.



$$E\frac{d^3N}{d^3p} = \frac{1}{2\pi}\frac{d^2N}{p_t dp_t dy}\left(1+\sum_{n=1}^{\infty} 2v_n \cos[n(\phi-\Psi_r)]\right)$$

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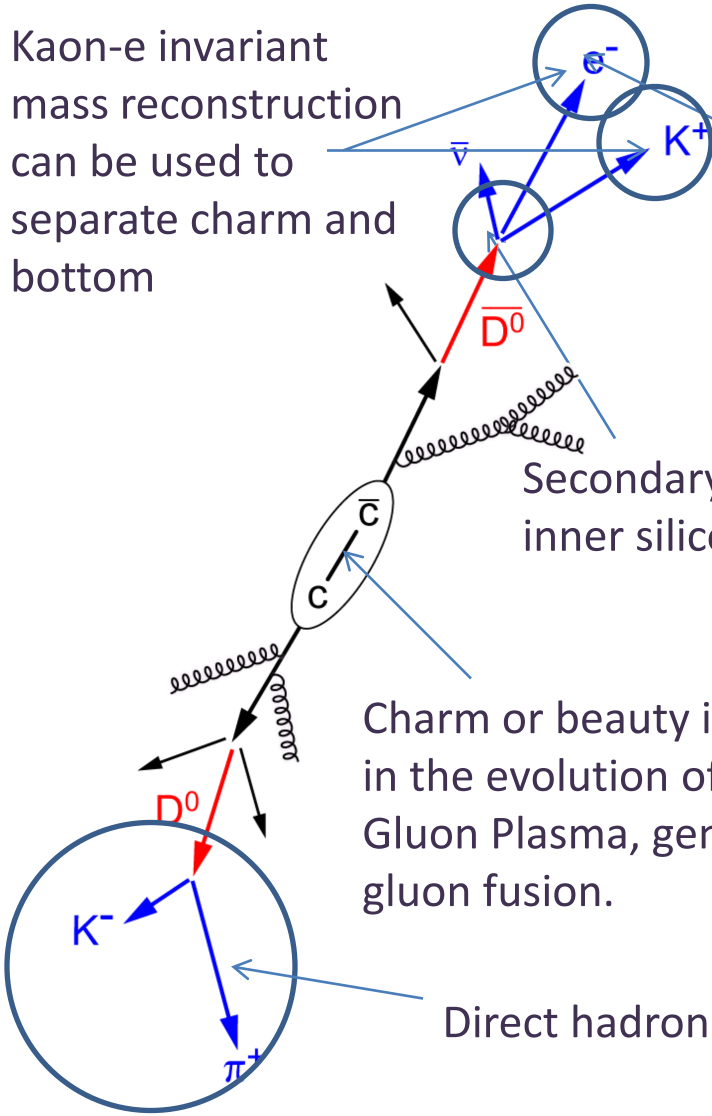
Measuring Heavy Flavor via Single Electrons in PHENIX

Kaon-e invariant mass reconstruction can be used to separate charm and bottom

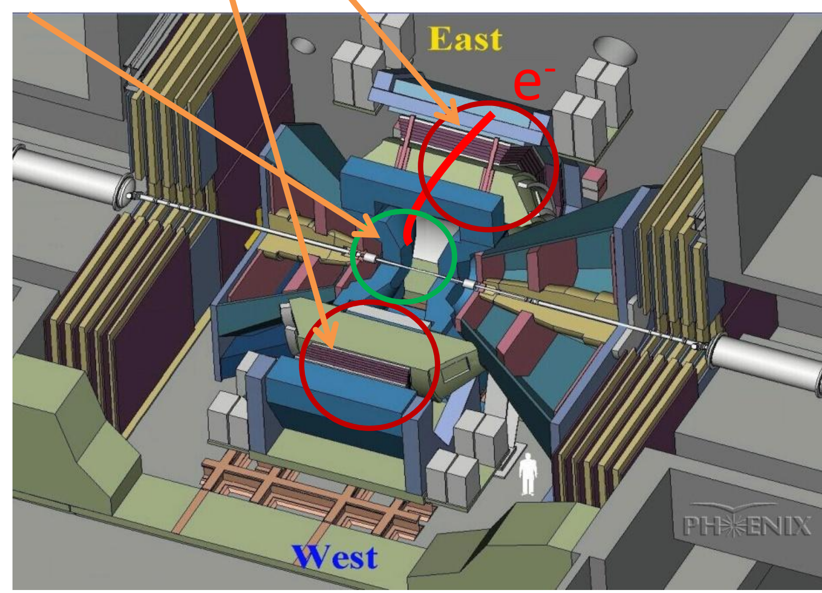


Electrons measured in central spectrometer arms (identification by electro-magnetic calorimeter and ring imaging Cerenkov detectors).

Secondary vertex to be located by inner silicon VTX detector

Charm or beauty is created early in the evolution of the Quark Gluon Plasma, generally from gluon fusion.

Direct hadronic reconstruction



The PHENIX Detector

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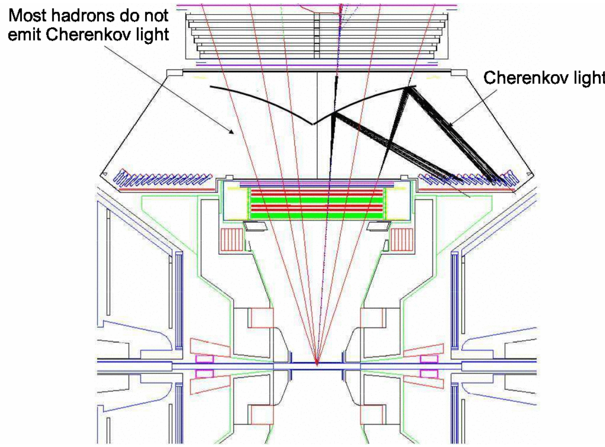
Electron Identification Techniques

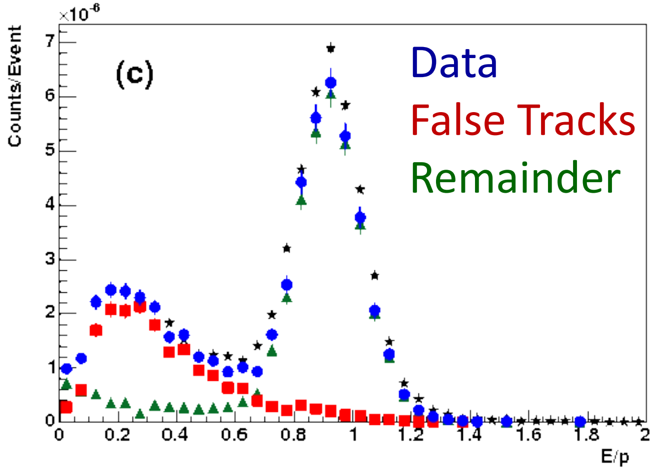
RICH

- Primary electron identifier
- A minimum number of hits for a track is required in analysis to identify an electron
- Same coverage as DC
- Swapped coordinate technique to remove bad tracks



EMCAL

•Because of the light mass of electron, E/P should be centered on ~1. Hadrons generally fall lower in the distribution.
•Secondary tracks also have E/p values differing from 1 due to bad reconstruction of p.



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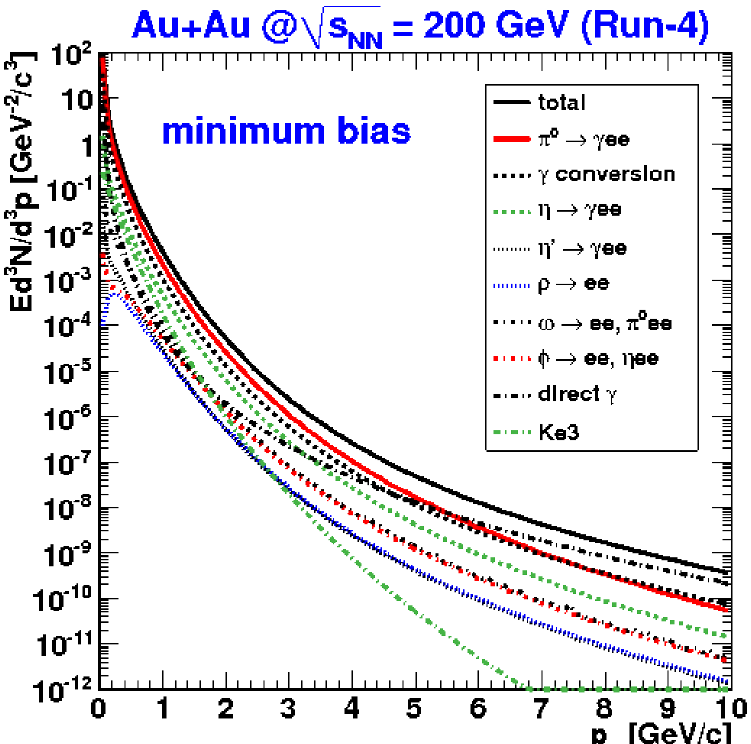
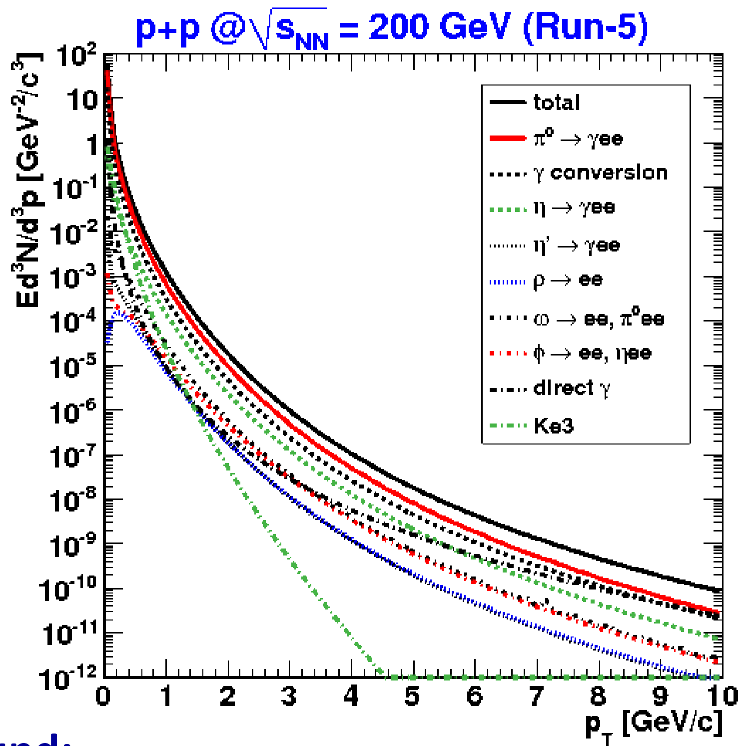
The Single Electron Cocktail





Major Contributors to Single Electron Background:

- **Light Meson Decays** calculated by fitting pion spectra and interpolating other species. Electron decay spectra found in simulation.
- **Photonic Conversions** found in a full detector simulation. Verified by comparing to converter results (later slide)
- **Direct Virtual Photons**, spectra found via fitting to data and then simulation
- **Ke3** decays which are reconstructed with incorrect p due to having displaced vertex. Eliminated through cut on E/p and remainder by simulation.

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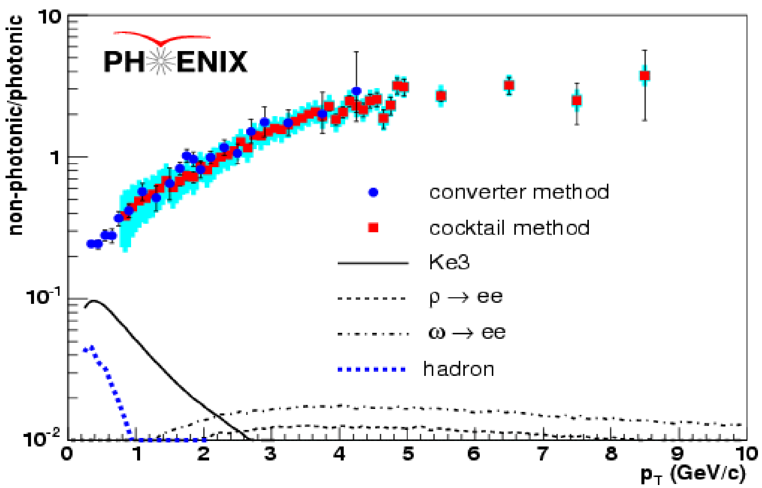
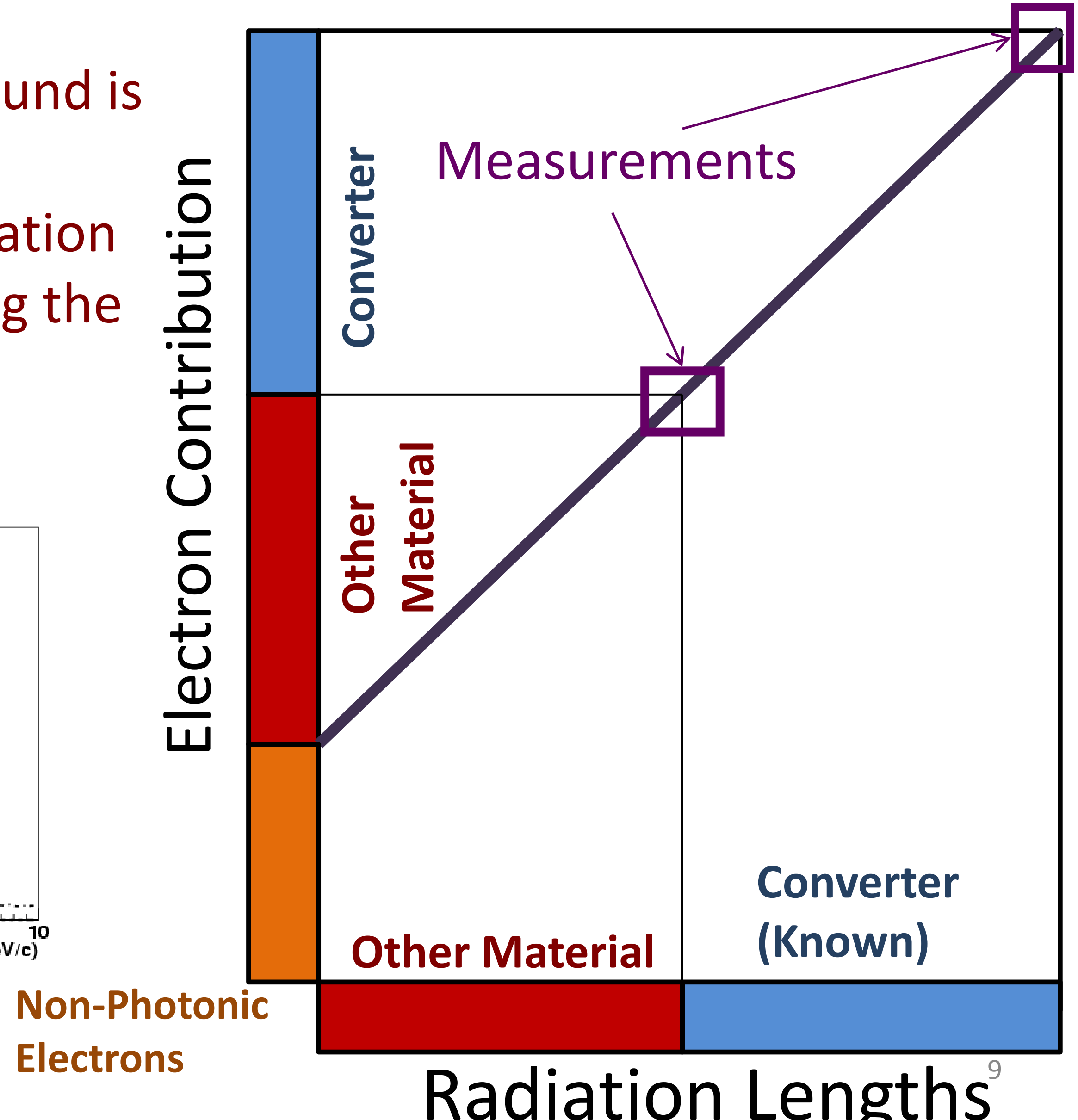
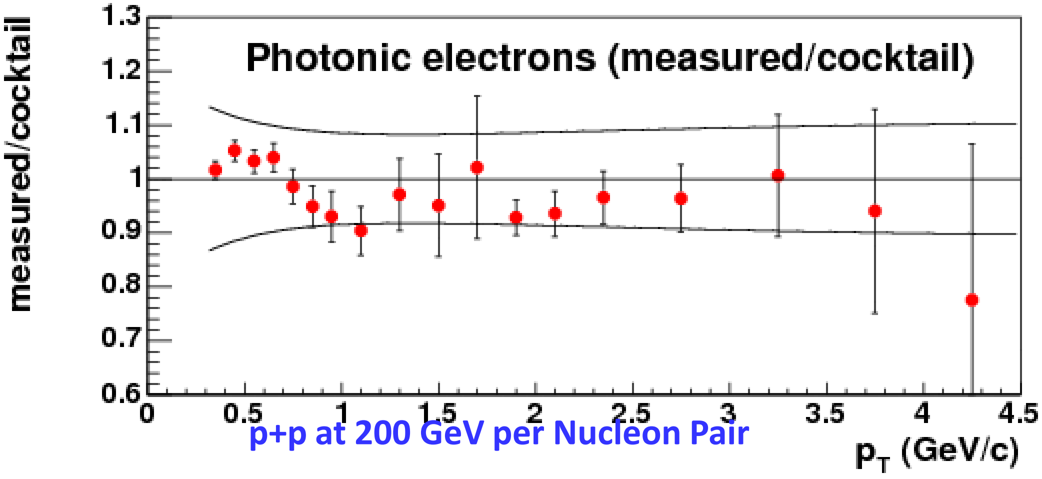
The Converter Method

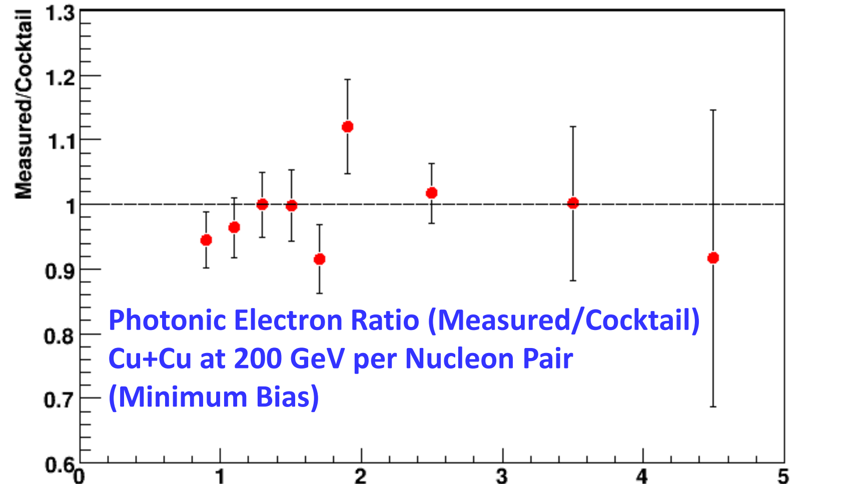
- Photonic Electron Background is a serious problem.
- A converter of known radiation length is placed surrounding the beam pipe to extrapolate photonic background.

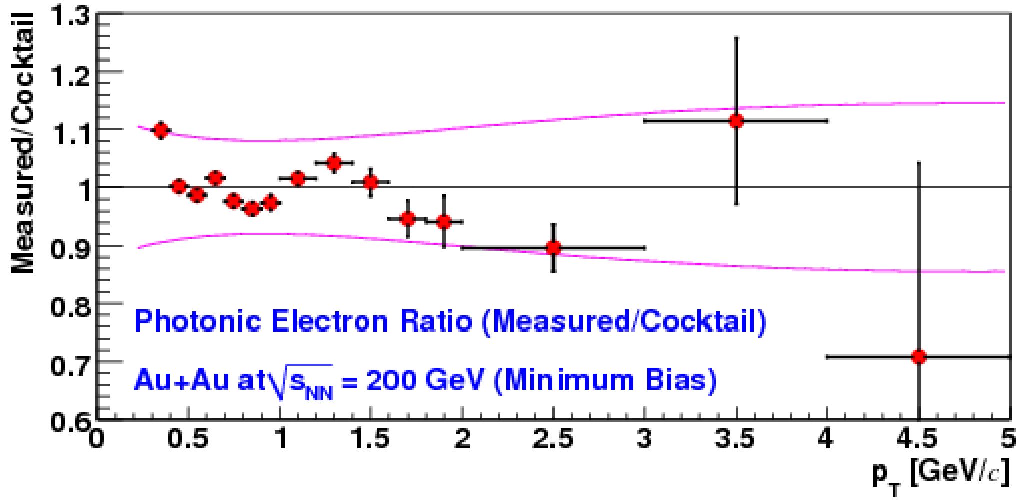


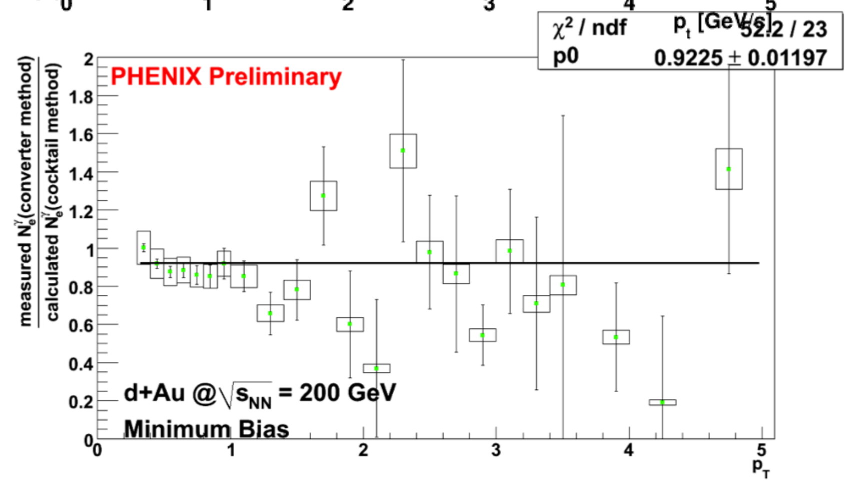


Agreement Between Cocktail/ Converter in Multiple Systems!









Excellent Agreement in photonic electron estimates from two alternate methods!

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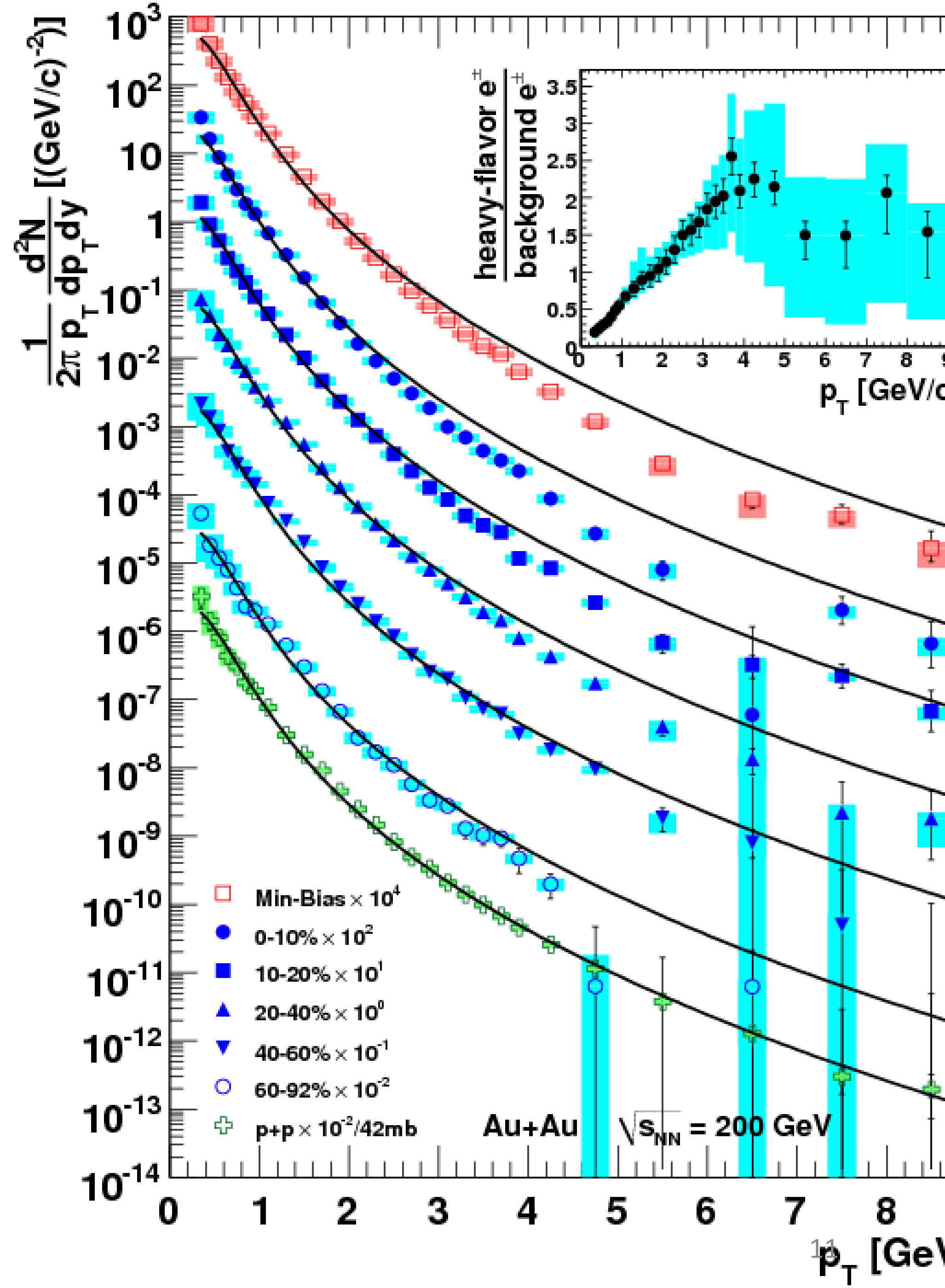
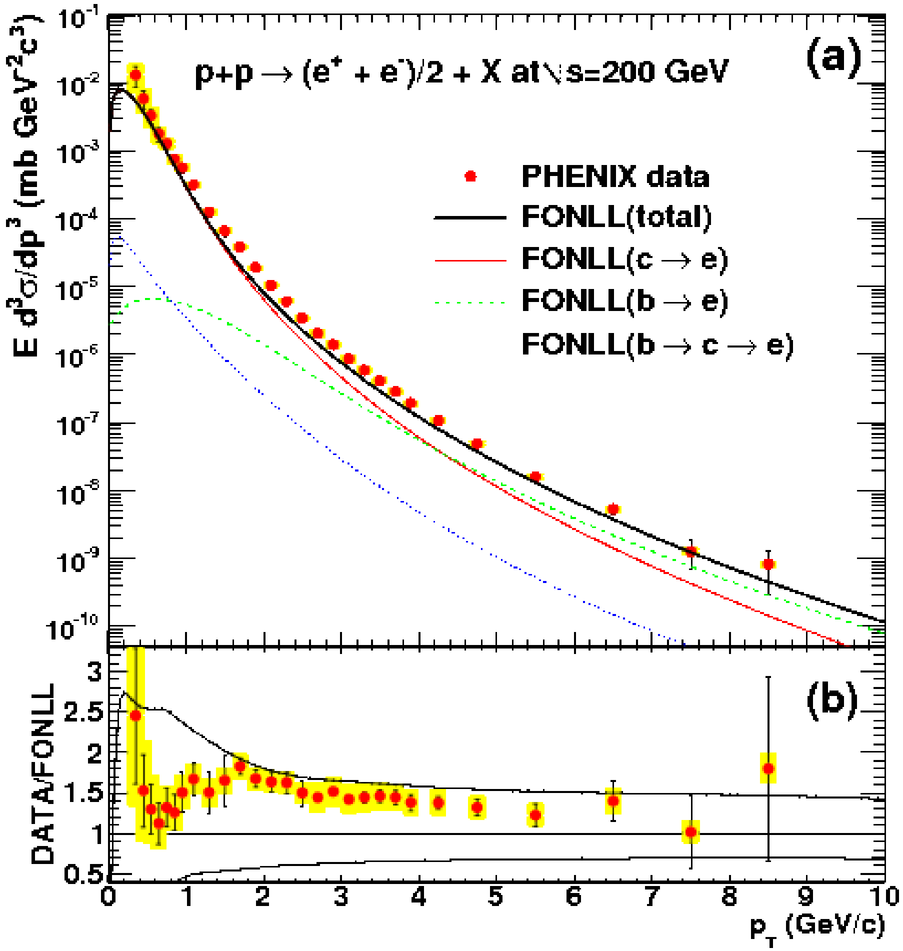
Non-Photonic Electron Spectra

- After subtraction of background, electrons from heavy flavor remain.
- Spectra can be used to calculate cross-section and R_{AA}



Charm Cross-Sections



- PHENIX charm cross-section results sit within upper limit of FONLL prediction.
- Binary scaling between p+p and Au+Au.

$$\sigma_{c\bar{c}}\Big|_{pp(y=0)} = 551 \pm 57(stat.) \pm 195(sys.)\ \mu b$$

$$\sigma_{c\bar{c}}\Big|_{Au+Au(y=0)} = 568 \pm 8(stat.) \pm 150(sys.)\ \mu b$$

Compare:

$$\sigma_{c\bar{c}}^{\mathrm{FONLL}_{\mathrm{n1f+1}}} = 256^{+400}_{-146}\mu b$$

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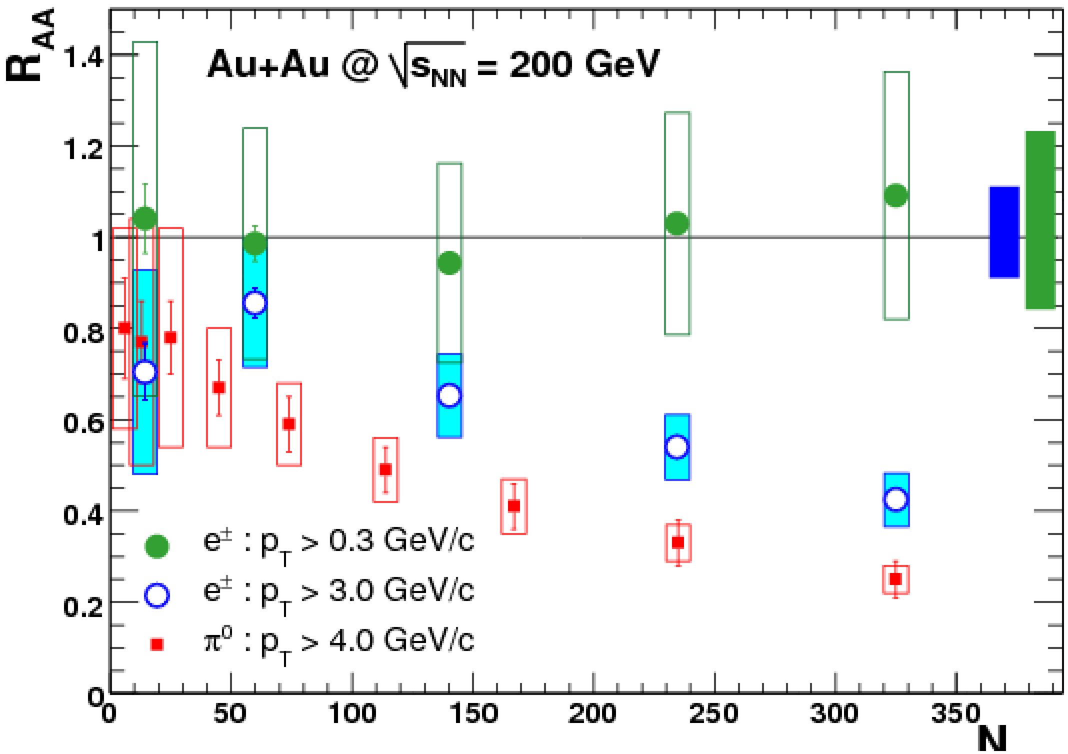
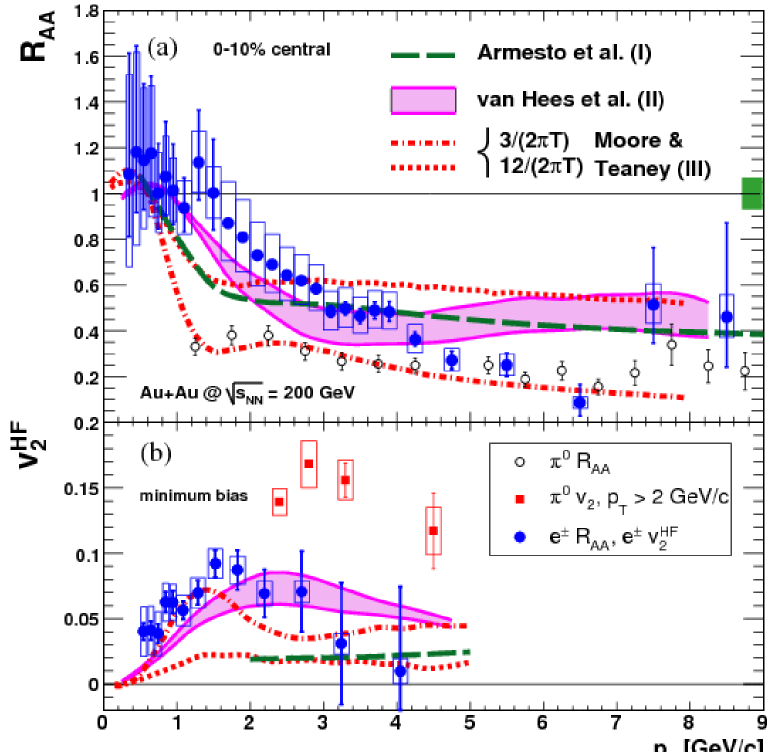
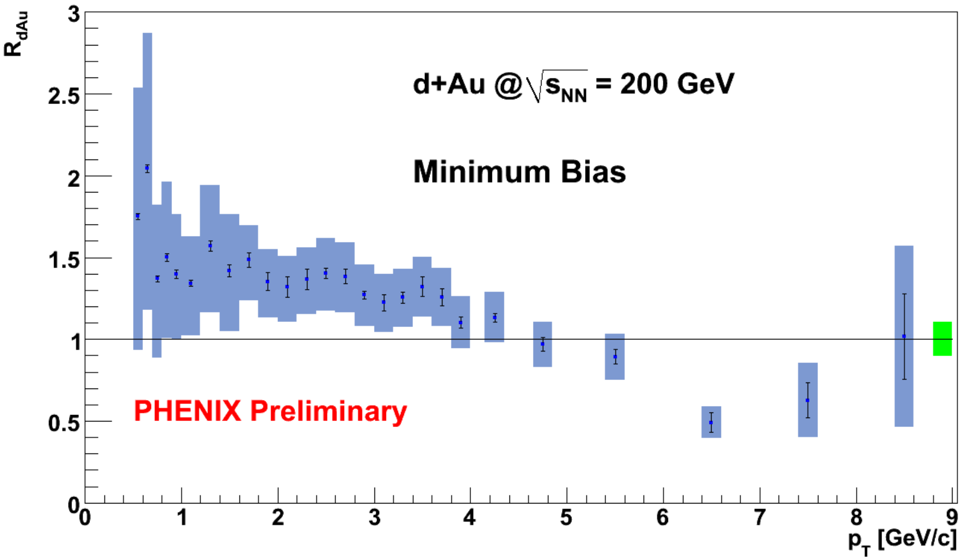
Nuclear Modification Factor in Au+Au

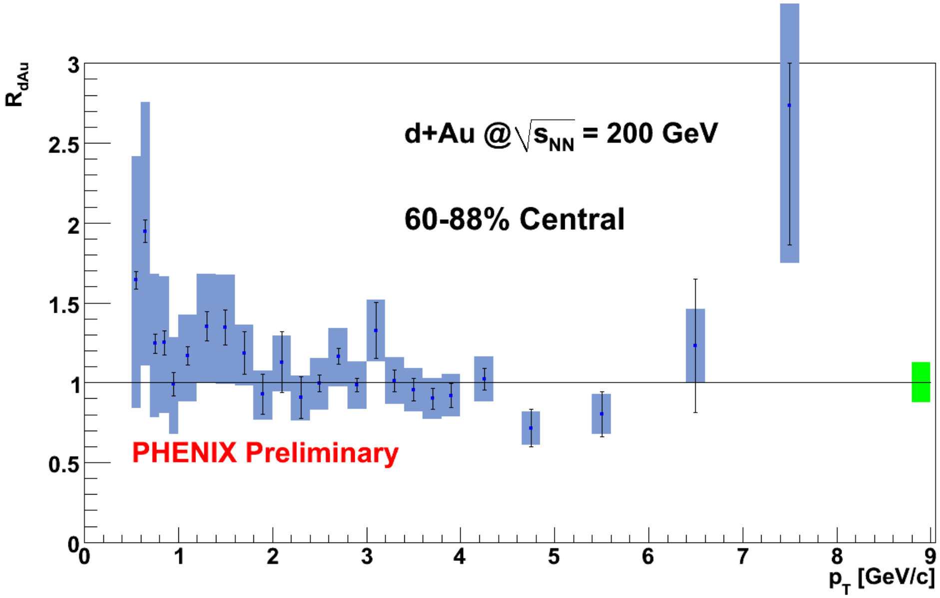




- Significant Suppression seen for electrons from heavy flavor
- At high p_t, the degree of suppression is comparable to pions.

Nuclear Modification in d+Au





- Enhancement seen in minimum bias events
- Enhancement in more central d+Au due to a Cronin type-effect
- Enhancements mostly disappears in peripheral collisions such that d+Au is as p+p

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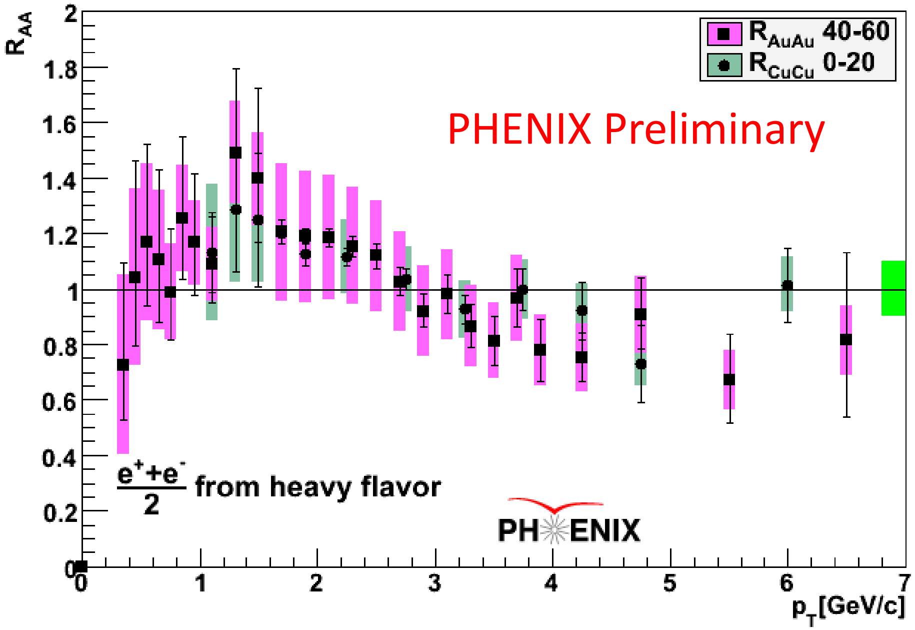
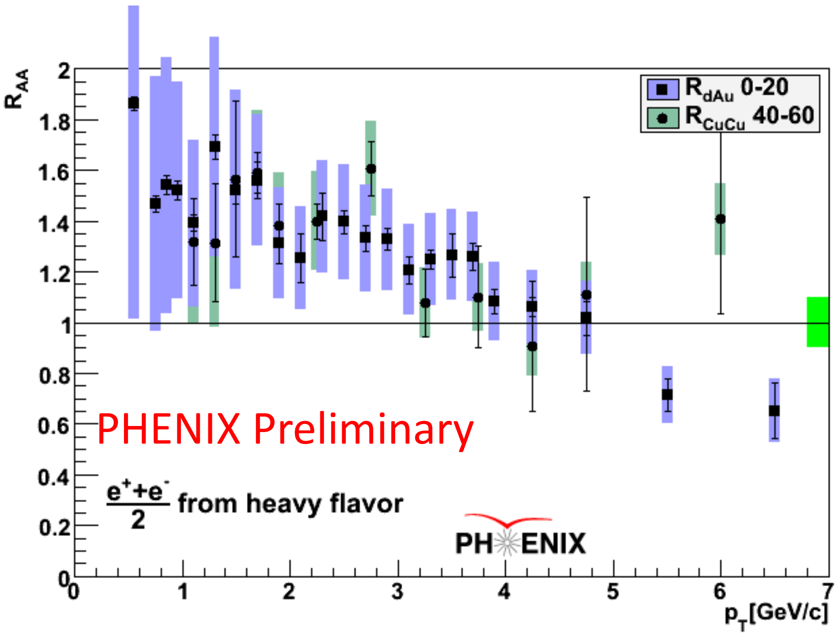
Nuclear Modification Factor in Cu+Cu

200 GeV Cu+Cu (0 to 20% Centrality, N_{coll}= 151.8)
200 GeV Au+Au (40 to 60% Centrality, N_{coll}= 90.65)

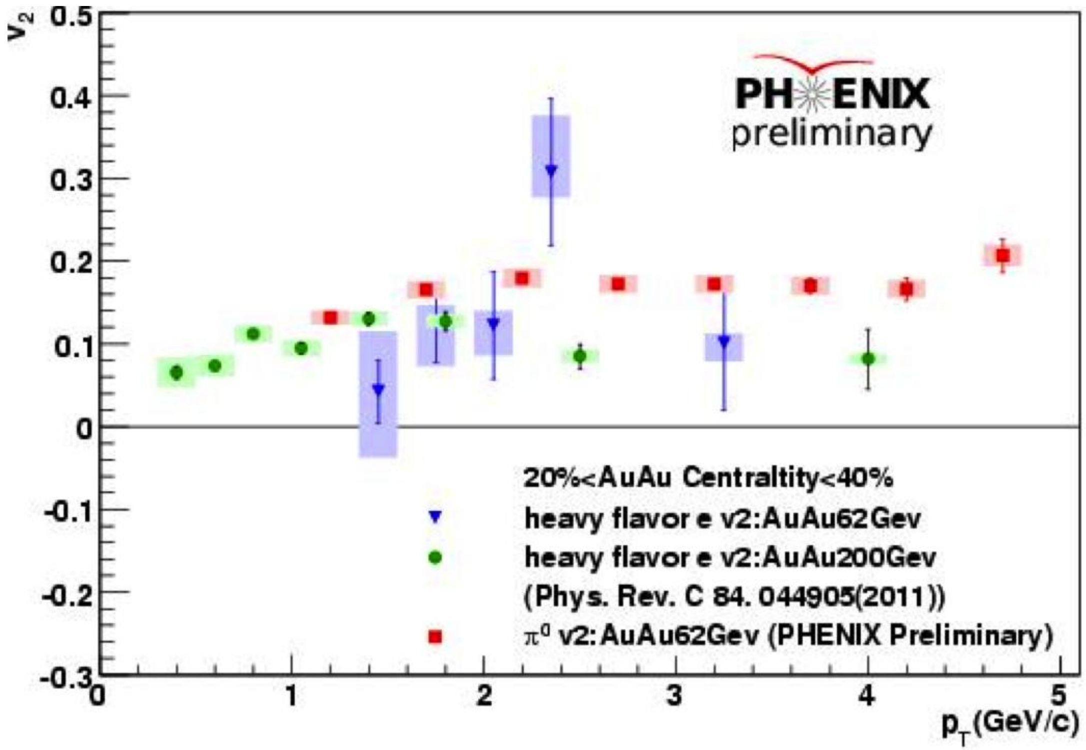


200 GeV Cu+Cu (40 to 60% Centrality, N_{coll}= 22.3)
200 GeV d+Au (0 to 20% Centrality , N_{coll}= 15.1)



- No significant suppression in Cu+Cu 0 to 20% central events.
- Enhancement in more peripheral collisions, similar to d+Au.

Collective Flow Effects



- v_2 calculated via:

$$v_2^{inc} = \langle \cos[2(\phi - \Phi_R)] \rangle / \sigma_R$$

$$\Phi_R = \text{measure reaction plane}$$

- v_2 of photonic electrons then subtracted.
- Result indicates heavy flavor coupled strongly to medium

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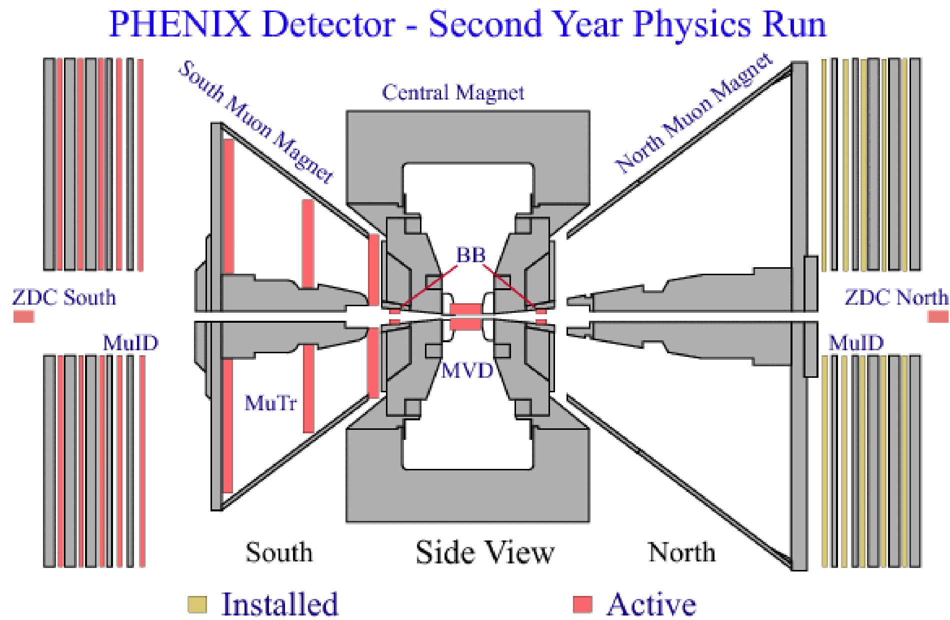
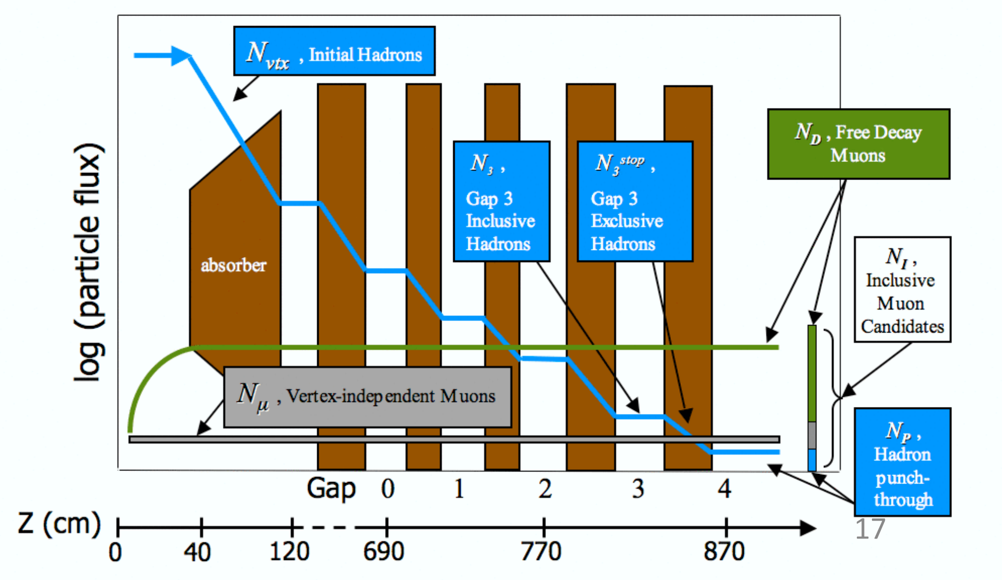
Single Muon Measurements

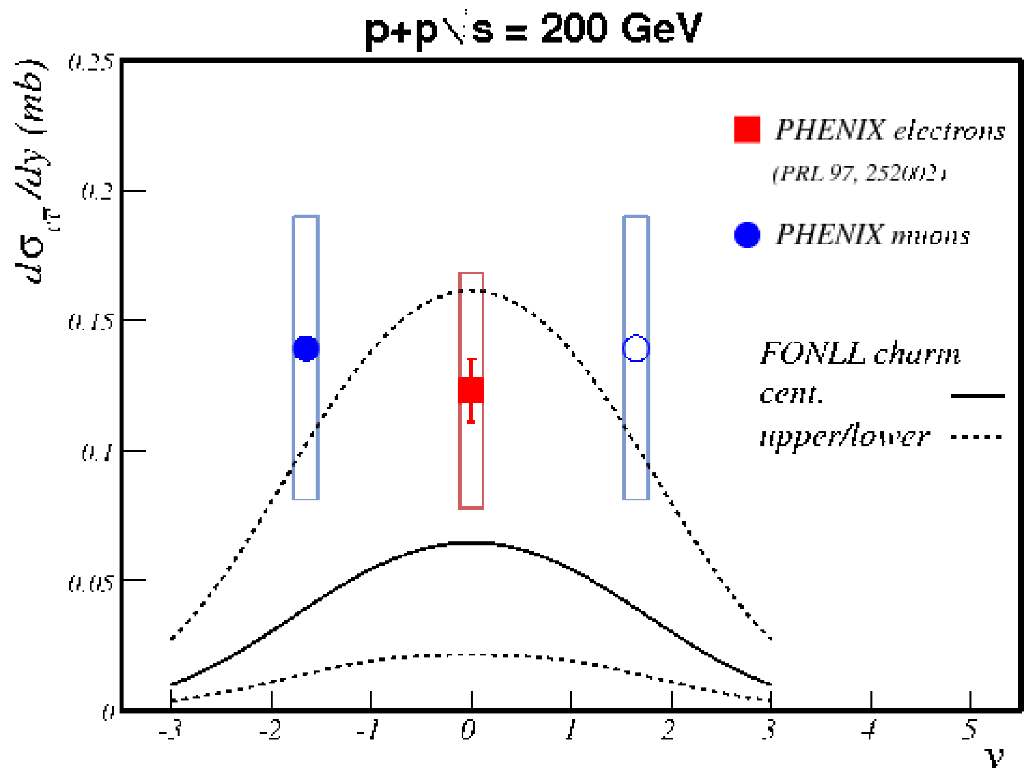
- Yield Components:
  1. Primary vertex decays (mainly HF)
  2. Muon background from secondary decays after MuTR (not contaminating)
  3. Muons from decay of π and K
  4. Hadrons misIDed as muons

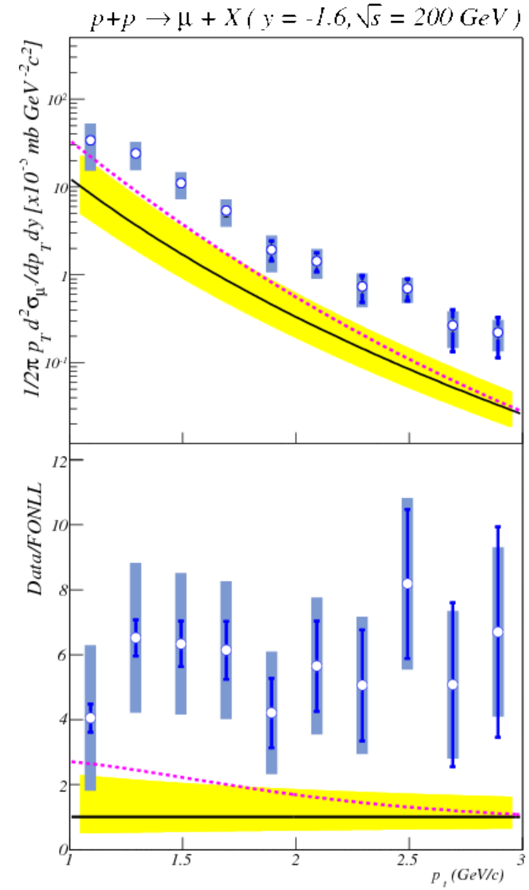


- Hadron generator used with π, K, and p datasets to calculate mis-IDed hadrons and secondary decays
- Charm Cross-Section Extracted via Pythia



Forward Rapidity Charm Cross-Section





- Forward rapidity charm-section calculated using muons
- Consistent with FONLL upper limit

$$\left.\frac{d\sigma_{c\bar{c}}}{dy}\right|_{pp,\langle y\rangle=1.65} = 139 \pm 29(stat.) + 51(sys.) - 58(sys.)\ \text{ub}$$

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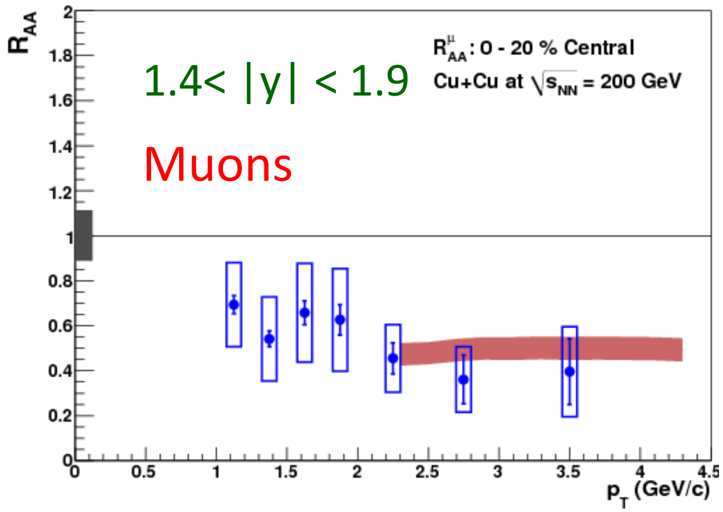
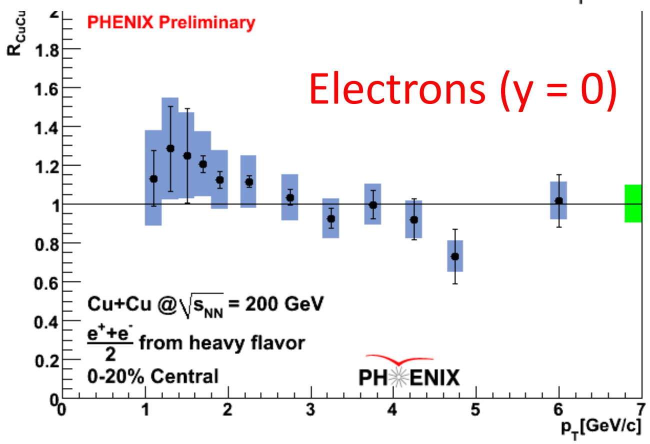
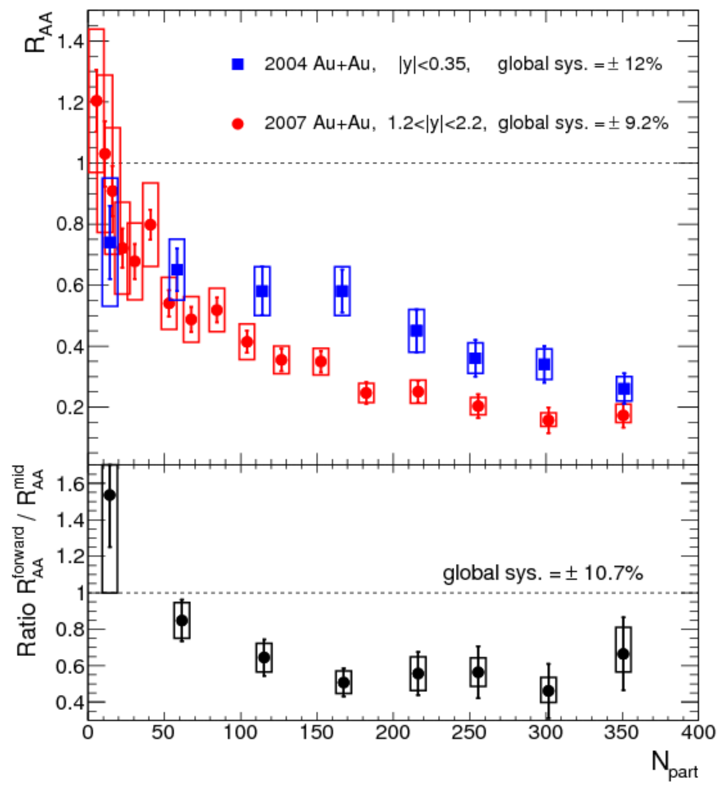
Forward Rapidity Cu+Cu R_{AA} from muons

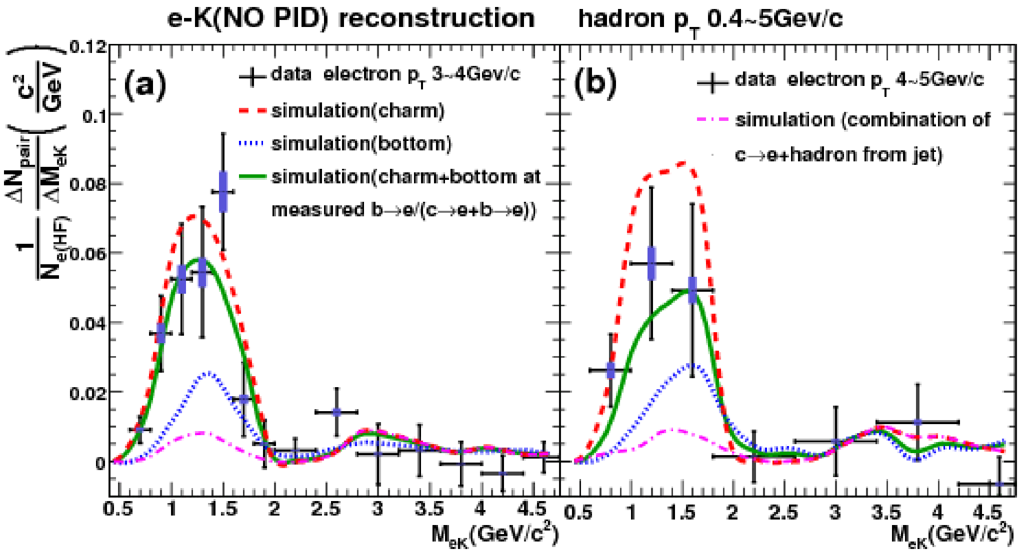


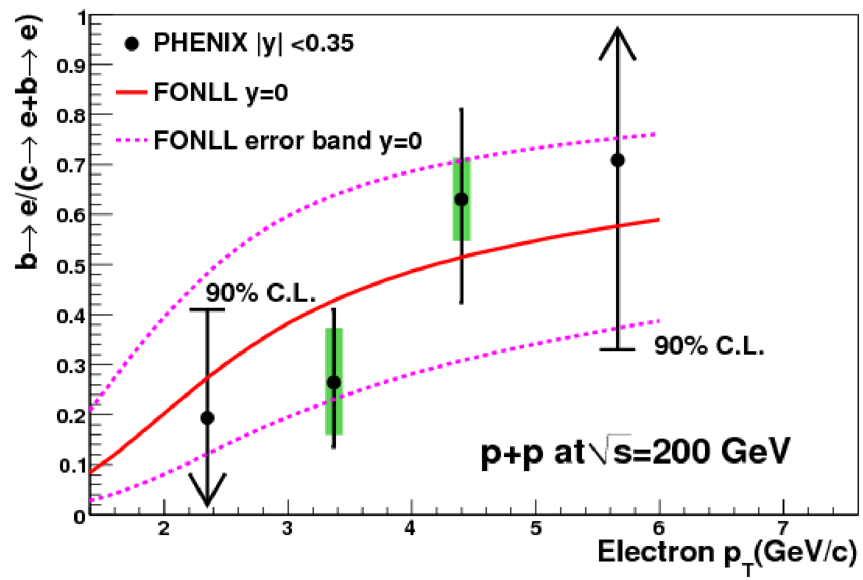




- Factor of ~2 suppression seen in Cu+Cu (Compare with electrons)
- Similar to J/ψ
- Effect present for both open and hidden heavy flavor

Charm/Bottom Separation via Electron-Hadron Correlations





- Previous measurements had no means of separating charm and bottom.
- Partial reconstruction of D/D-bar -> $e^{+/-}$ $K^{-/+}$ X used
- Comparison of invariant mass distribution allows bottom/charm ratio to be estimated
- Assumption of no bottom suppression inconsistent with R_{AA} measurement.

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Future Analyses: The VTX Detector

- Silicon Vertex Detector (4 cylindrical layers)

- Inner 2 layers

  Pixed-type detectors

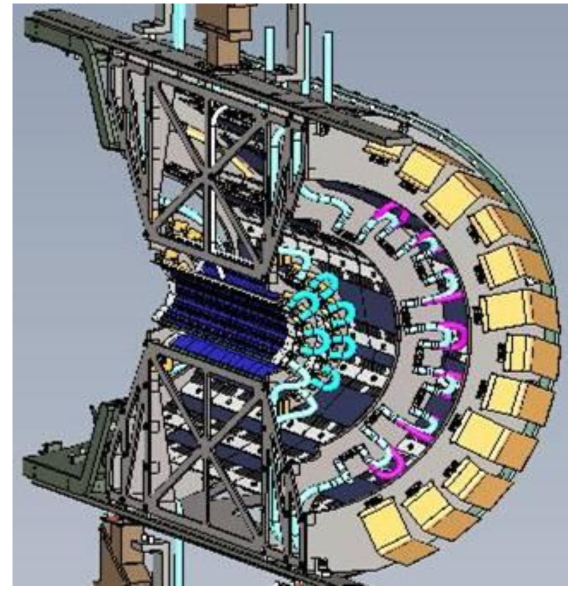
  Layers 3 and 4

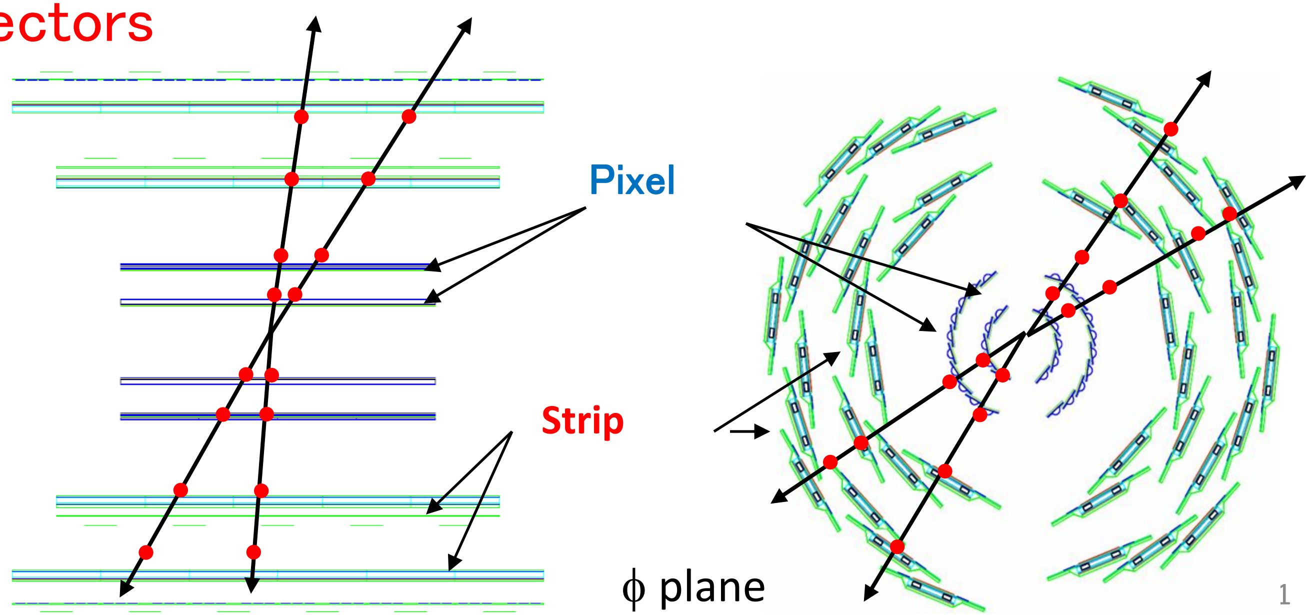
  Strip-pixel detectors

- Radii of Layers

  Pixel 2.5, 5.0 cm

  Strip-pixel 11.6, 16.5 cm





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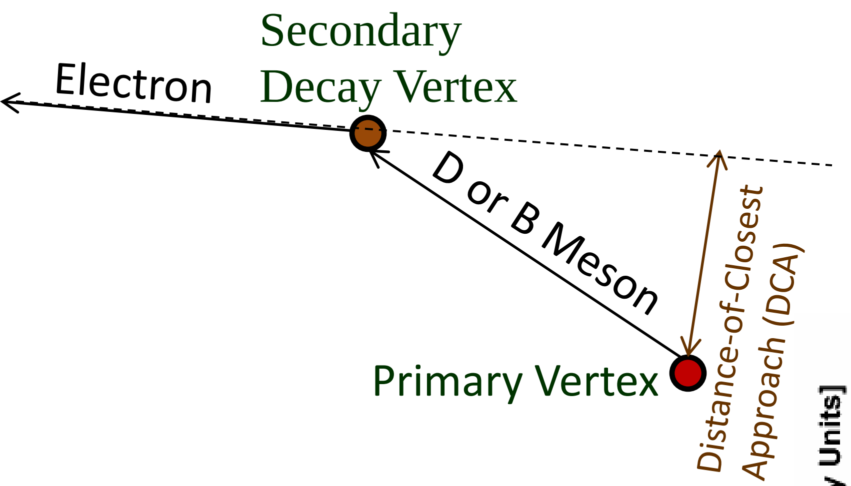
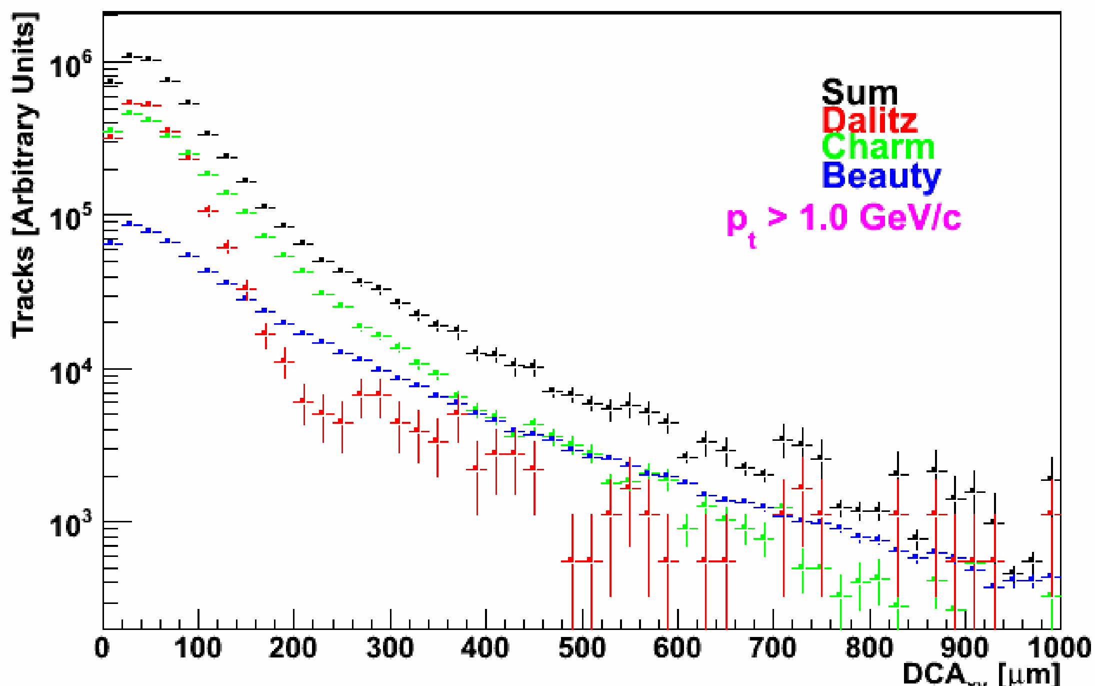
Charm and Bottom Identification Using the VTX



•Charm and bottom have different decay geometries which allow reconstruction

•DCA resolution of ~50 μm

•The shape of the electron distribution as a function of R_{AA} can be compared to simulation in order to extract charm and bottom yields.



•Data now being analyzed

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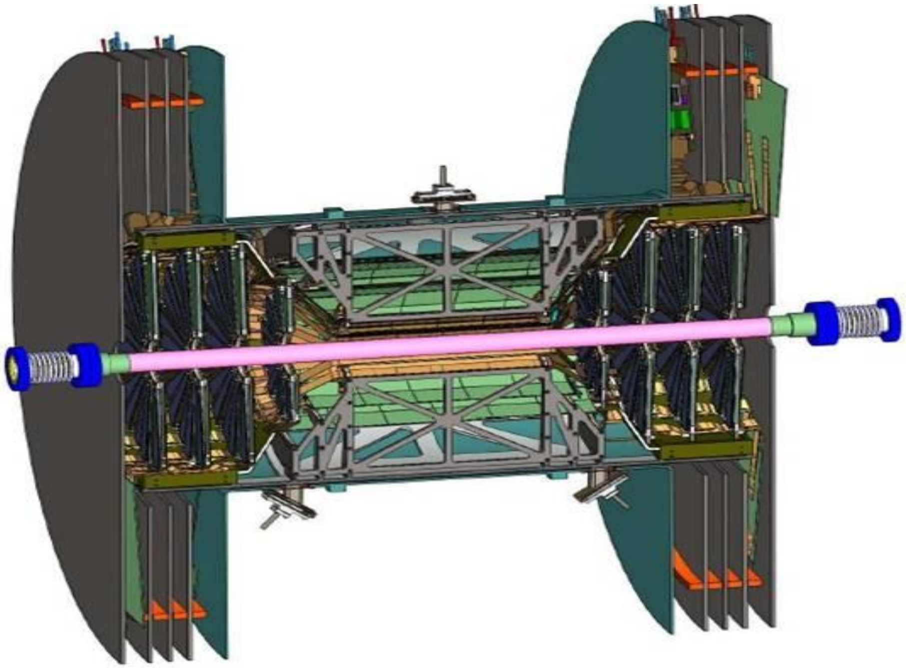
FVTX

- Signal of muons from HF (forward rapidity) is strongly contaminated by π and K decays.
- Resolving decay vertices allows background to be cut.
- Allows D/B decay separation via manner similar to VTX.



The FVTX consist of 4 silicon pixel disks on both sides of the VTX.

The DCA resolution is ~40 μm

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Direct Hadronic Reconstruction of Heavy Flavor Decays

- It may be possible to use the VTX detector to cut background enough to directly reconstruct heavy flavor decays.
- D^0s, for example, can be reconstruction from the $D^0 \rightarrow K\pi$ decay
- Background is subtracted using either a rotational method or event mixing.
- The $D \rightarrow eKX$ channel can be used.

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Conclusions and Outlook

- PHENIX measurement of Charm cross-section within FONLL upper limit.
- Strong suppression of heavy flavor R_{AA} measured
- Collective flow of heavy flavor detected; indicates coupling with medium
- Charm cross-section measured in forward rapidity higher than FONLL prediction
- VTX and FVTX will improve D and B identification capabilities through geometric reconstruction of decays.

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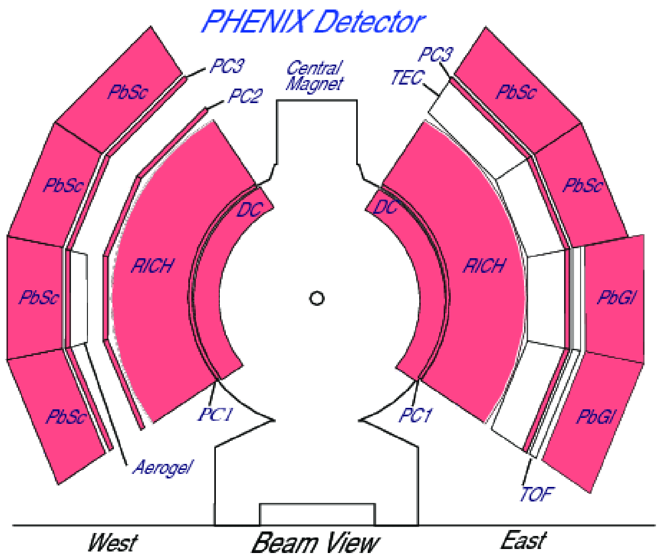
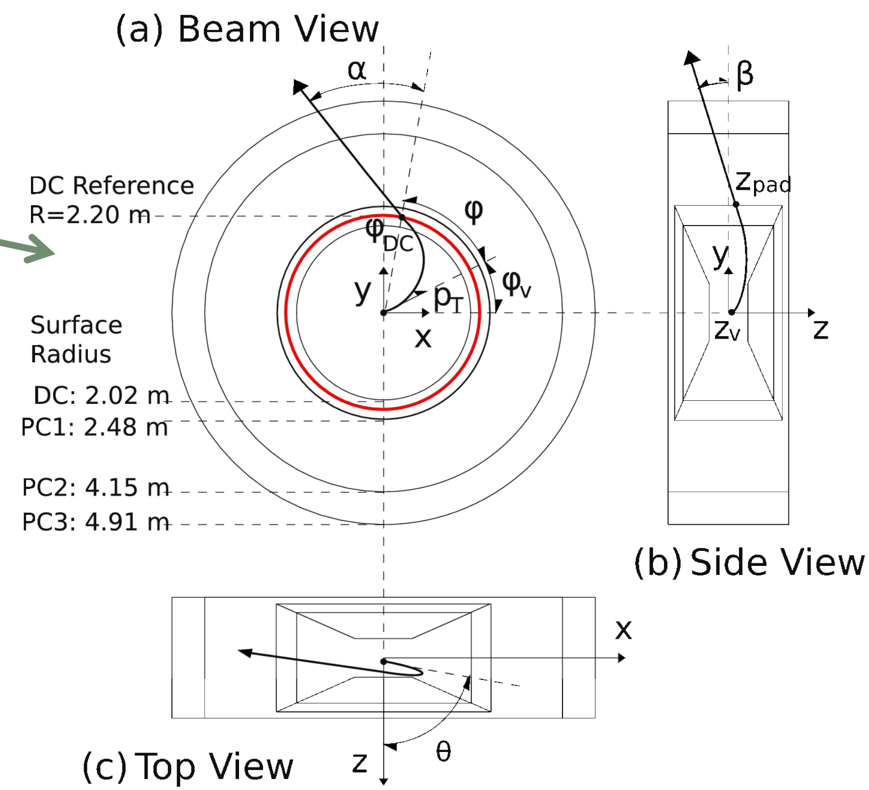
Backup

Electron Track Reconstruction





- The Drift Chambers (DC) and Pad Chambers (PC) in the PHENIX central arms are used to reconstruct track's momenta.

- The DC has a coverage of $|\eta| < 0.35$ and $|\phi| < \pi/2$

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