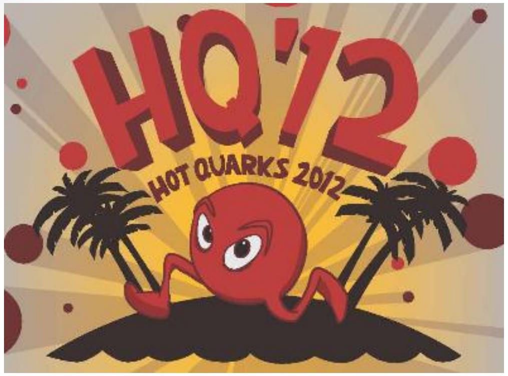


New Measurement of Heavy Flavor Electron v_2 and Bottom Charm Separation Using VTX in PHENIX

Lei Ding

Iowa State University

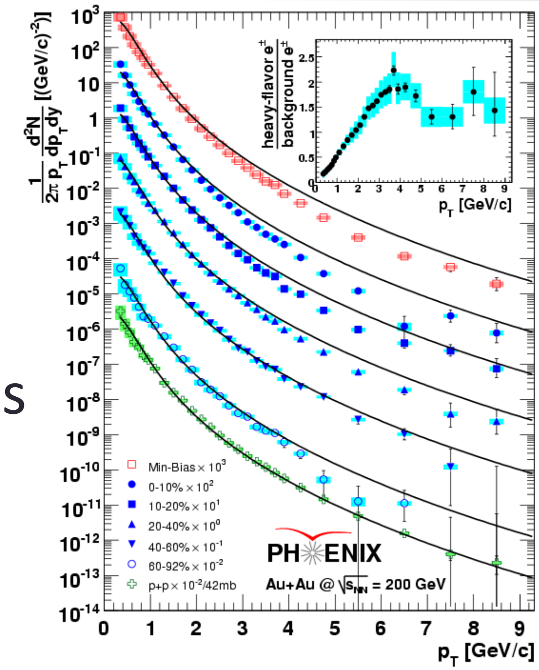
- Motivation
- Measurement of heavy flavor electron v_2 at PHENIX (Au+Au,62.4GeV)
- Measurement of b/(b+c) ratio at PHENIX using VTX (p+p 200GeV)
- Summary

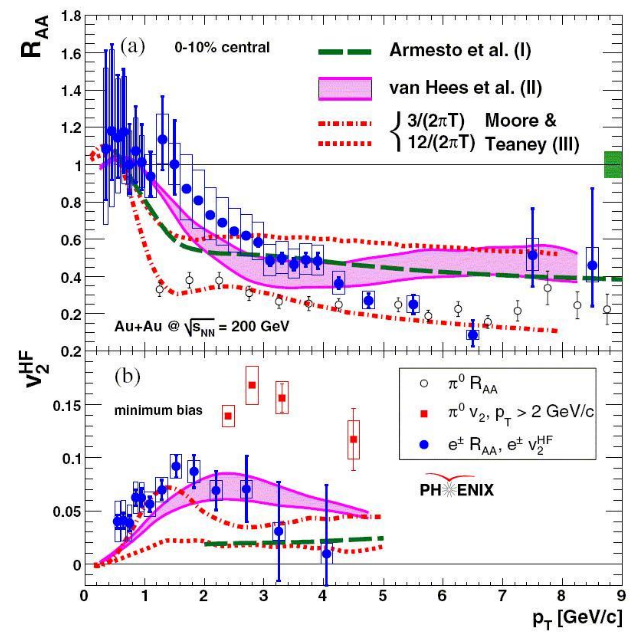
PHENIX

Motivation

- Heavy quarks are hard probe of QGP:
  - produce at the early stage of collisions
  - interact with the medium
- Heavy quarks are "heavy"!

  → expect to lose less energy by gluon radiation compared to light quarks .
- In Au+Au 200GeV collision, PHENIX measurement shows that heavy flaver electrons have unexpected large flow and suppressed similarly in Au+Au collisions as light quarks! Why?





R. Averbeck et al.
Phys. Rv. Lett. 08. 172301(2007)

Motivation

- What is the energy loss mechanism of heavy quarks?
- Do heavy quarks flow at lower beam energy?
- Is charm and bottom suppressed in the same way in QGP?
- ……

- To answer them:
  - Measure heavy flavor electron v_2 in Au+Au collision at $\sqrt{S\_NN}$=62.4GeV
  - Measure electrons from D and B decays separately at $\sqrt{S\_NN}$=200GeV

PHENIX

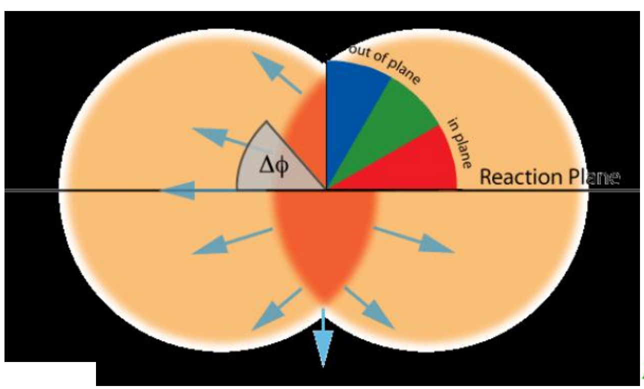
Azimuthal Anisotropy v_2

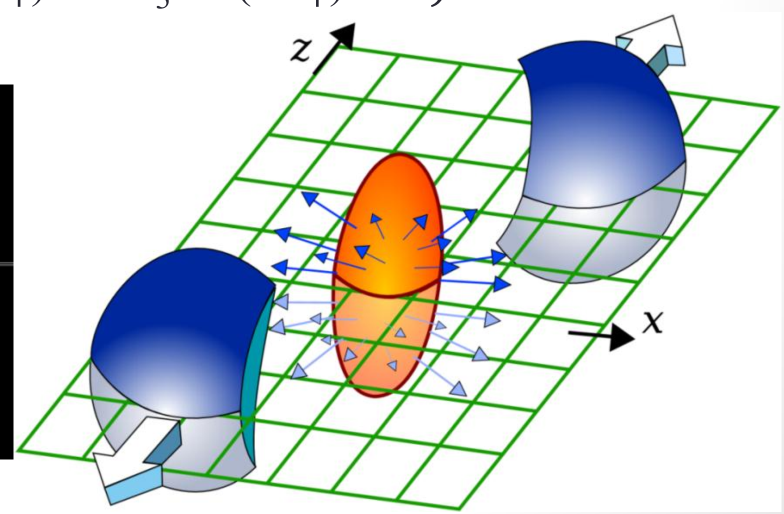
- The collision area of nuclei is not azimuthally symmetric in non-central collisions

→ cause a pressure gradients and azimuthal anisotropy of the particle distribution in the thermodynamic limit.

- v_2 is the second Fourier coefficient of the azimuthal distribution of particle yield w.r.t. the reaction plane.

$$\frac{dN}{d\Delta\phi} = N_0 \quad (1 + 2v_1\cos(\Delta\phi) + 2v_2\cos(2\Delta\phi) + 2v_3\cos(3\Delta\phi) + \cdots)$$

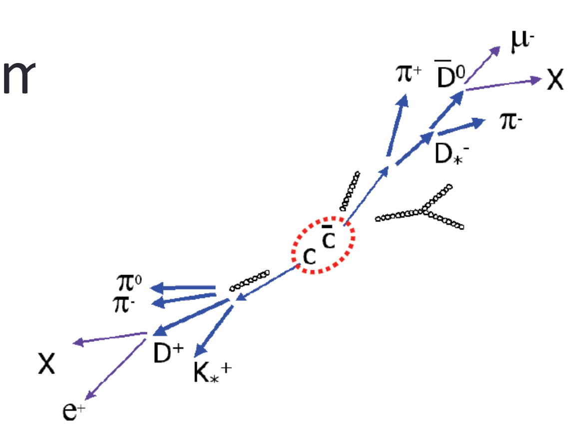


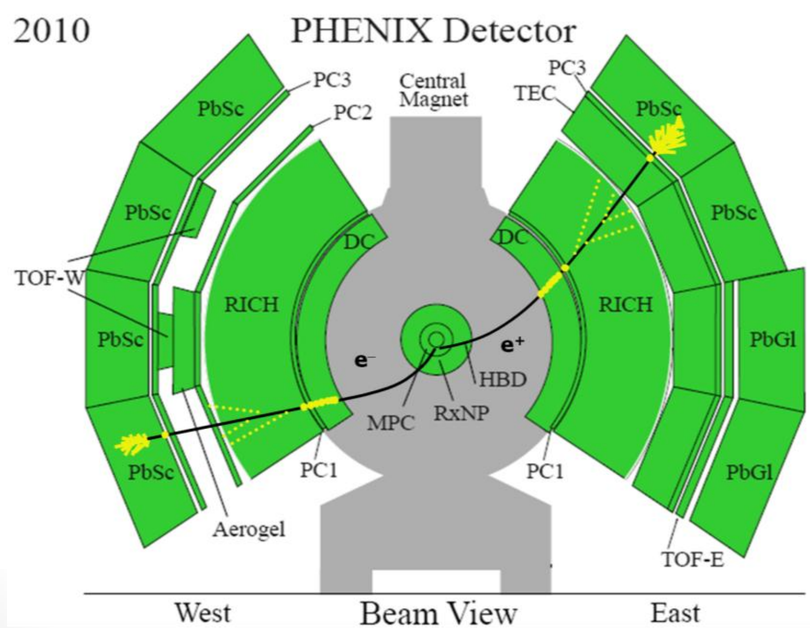


PHENIX

Measure heavy quarks in PHENIX

- Measure heavy quarks indirectly from electrons (Central Arm) or muons (Muon Arm) of heavy flavor meson semi-leptonic decays in PHENIX





- Tracking: DC, EMCal,
- Electron identification: RICH and E/p distribution
- Hadron Blinder Detector (HBD) for additional electron ID and background rejection

Strategy to find heavy flavor electrons

Identify inclusive electrons in the data, and calculate inclusive e v_2 as a function of p_T

Estimate photonic electron background:

- Cocktail method is used. Photonic electron v_2 is simulated with reaction plane dependent cocktail.

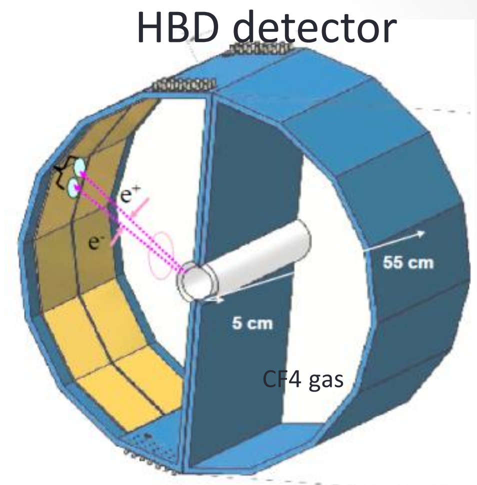
Subtract photonic background from inclusive electrons to obtain the heavy flavor electron yield and v_2

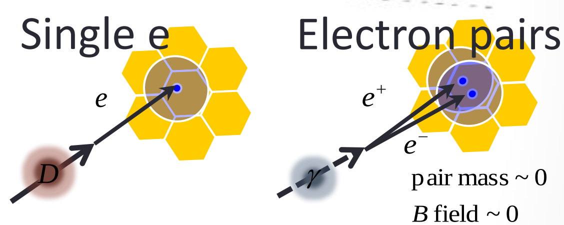
PHENIX

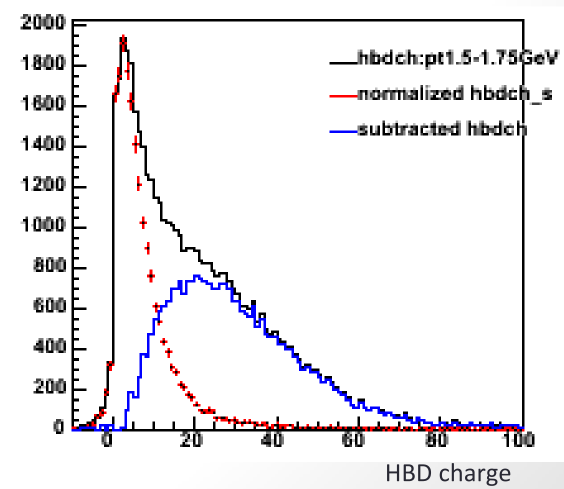
eID and background rejection using HBD

- Hadron Blinder Detector (HBD)
- Challenges in Run10 analysis:
  - ➢ A lot of photon conversions happened at HBD backplane
  - ➢ Random matching with HBD clusters in Au+Au collision
- Solution:

Require HBD cuts and HBD swapping to subtract hadron background and conversion electrons including HBD backplane conversion







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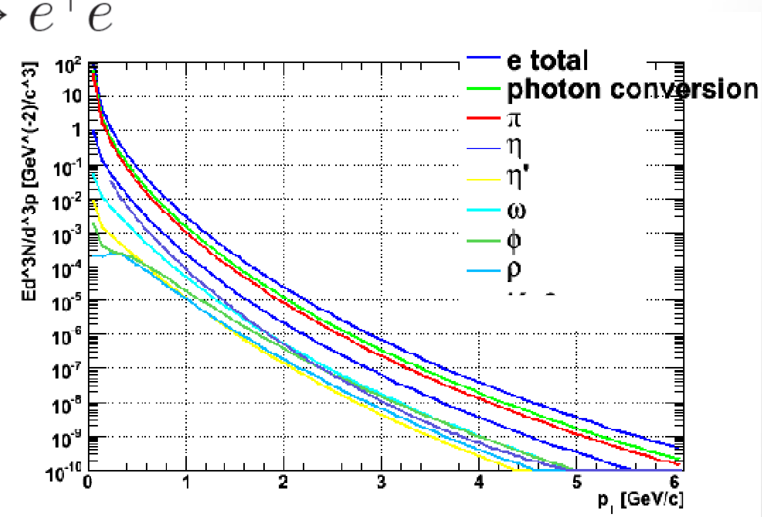
Subtract photonic background from inclusive electrons to obtain the heavy flavor electron yield and v_2

PHENIX

Photonic electron background

- Inclusive electron spectra include:
  - Electrons from heavy flavor meson semi-leptonic decays
  - Photonic electrons
- Photonic electron sources:
  - Dalitz decay: $\pi^0, \eta, \eta', \omega, \phi \longrightarrow \gamma e^+ e^-$
  - Photonic conversions in the material $\gamma \longrightarrow e^+ e^-$

  (HBD backplane, HBD entrance and gas, beampipe)
  - Ke3 decays: $K^\pm \longrightarrow \pi^0 e^\pm \nu_e$
  - Vector meson decays $\rho, \omega, \phi \longrightarrow e^+ e^-$
  - Direct photon conversions
- Using cocktail method to estimate the electrons from photonic background.



Strategy to find heavy flavor electrons

Identify inclusive electrons in the data, and calculate inclusive e v_2 as a function of p_T

Estimate photonic electron background:

- Cocktail method is used. Photonic electron v_2 is simulated with reaction plane dependent cocktail.

Subtract photonic background from inclusive electrons to obtain the heavy flavor electron yield and v_2

$$\frac{dN_{\text{inc}}}{d(\phi-\Psi)} = \frac{dN_{\text{hf}}}{d(\phi-\Psi)} + \frac{dN_{\text{pho}}}{d(\phi-\Psi)} \Rightarrow v_2^{hf} = v_2^{inc} * (1+\frac{1}{S}) - v_2^{pho} * \frac{1}{S}$$

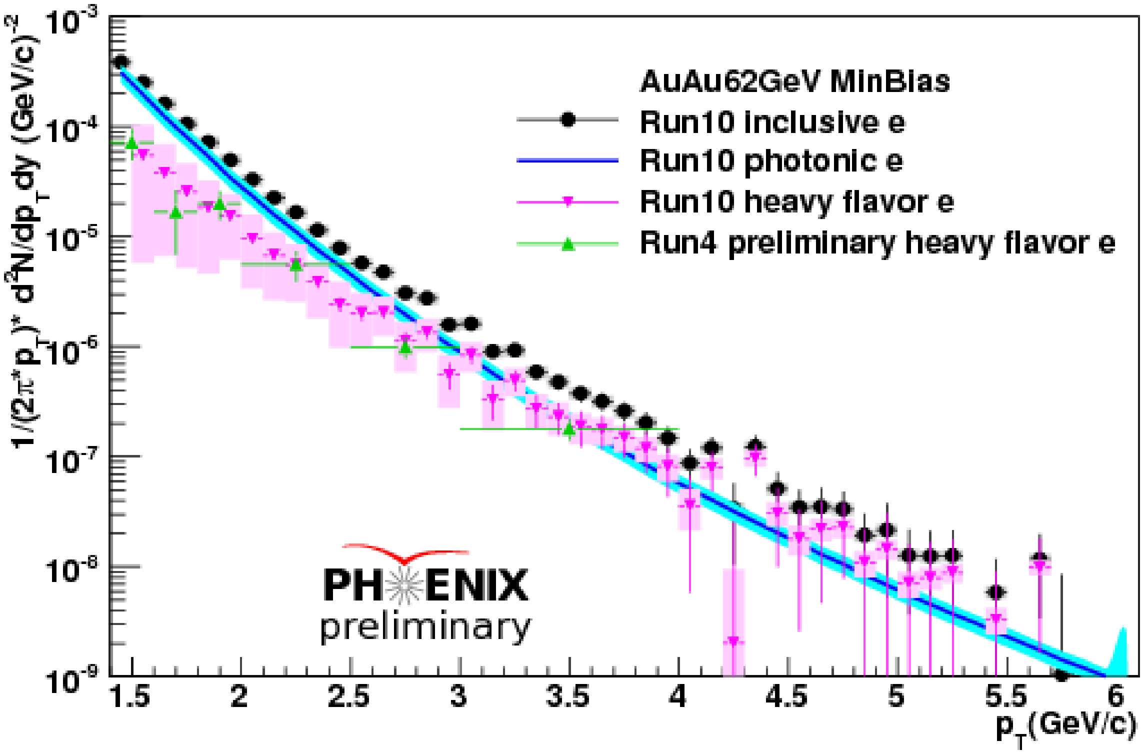
S is heavy flavor electron to photonic electron ratio

PHENIX

Heavy flavor e spectra (Au+Au 62.4GeV, MB)

- Inclusive, photonic and heavy flavor e spectra in Au+Au 62.4 GeV collision (MinBias data)
- HBD works well on the background rejection

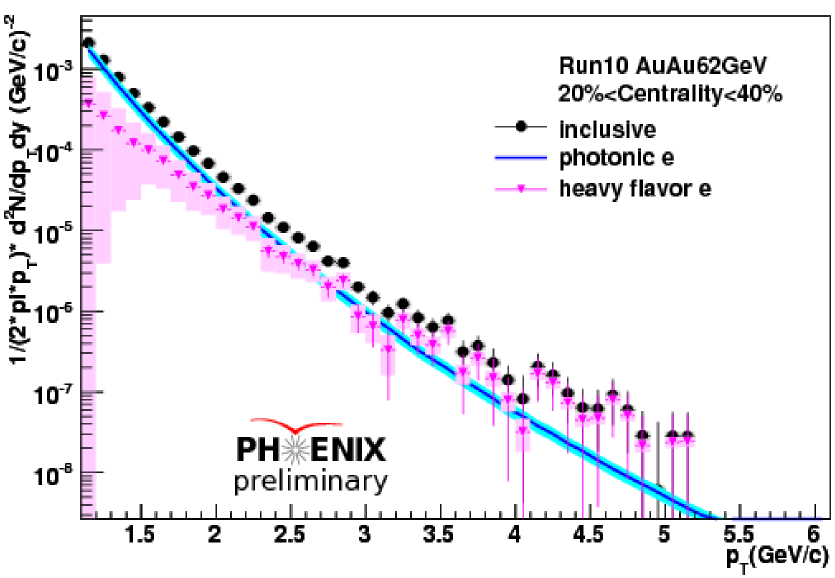
Run10 hf e spectrum agrees with the PHENIX run4 preliminary



PHENIX

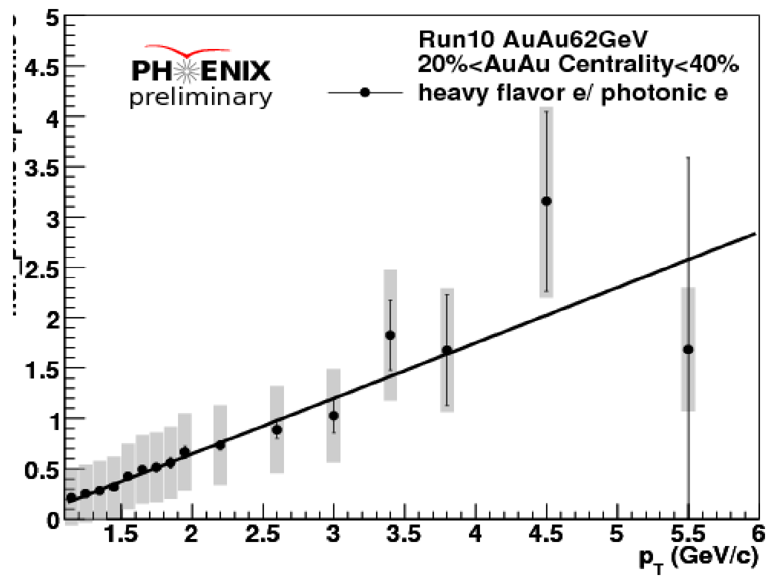
Heavy flavor e spectra (Au+Au 62.4GeV, 20-40% centrality)

Inclusive, photonic and heavy flavor e spectra in Au+Au 62.4 GeV collision (20%<centrality<40%)



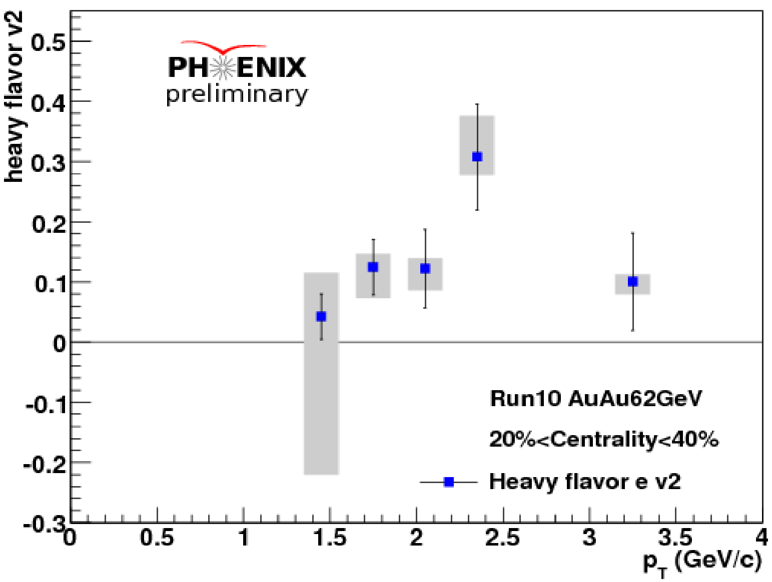
Heavy flavor electron to photonic electron ratio (S/B)

in Au+Au 62.4 GeV collision (20%<centrality<40%)

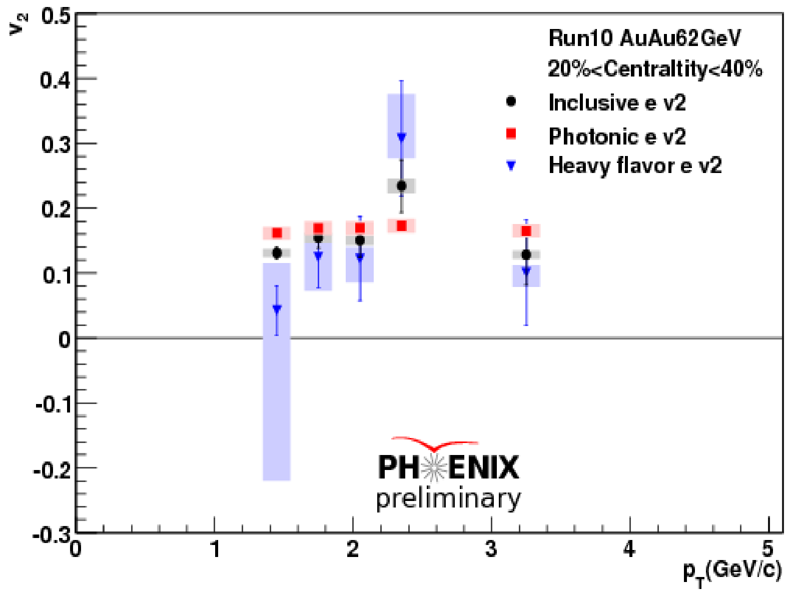


Heavy flavor electron v_2 (Au+Au 62.4GeV, 20-40% centrality)

Heavy flavor electron v_2 at Au+Au 62.4GeV (20-40% centrality)



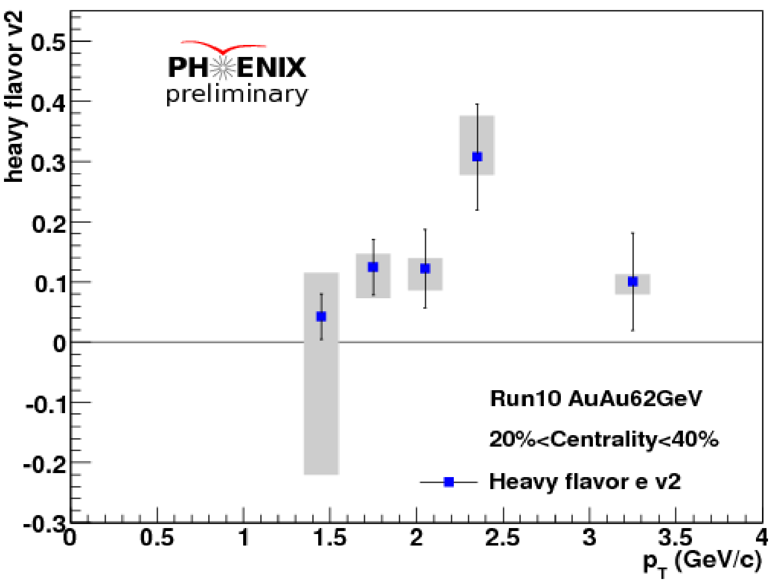
Inclusive, photonic and heavy flavor electron v_2 at Au+Au 62.4GeV (20-40% centrality)



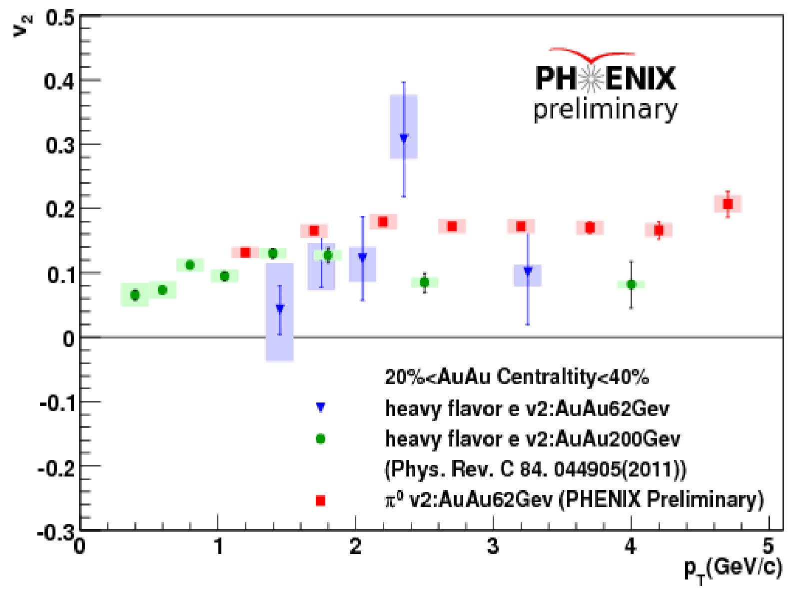
Heavy flavor electron v_2 (Au+Au 62.4GeV, 20-40% centrality)

Heavy flavor electron v_2 at Au+Au 62.4GeV

(20-40% centrality)



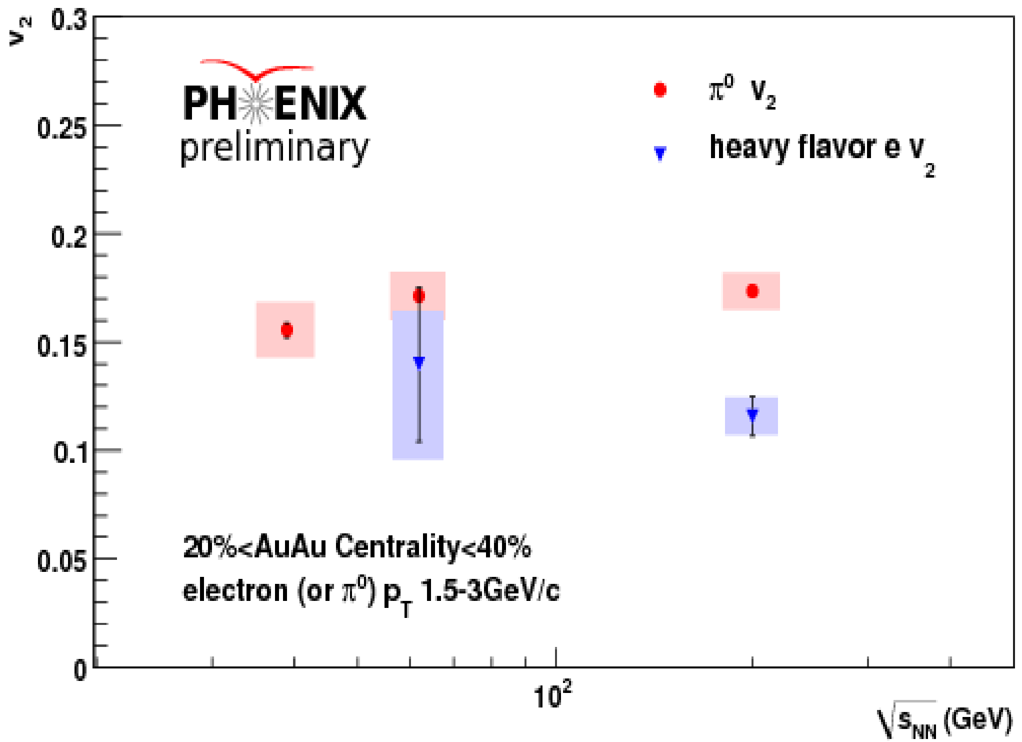
Heavy flavor e v_2 at 62.4GeV compare to heavy flavor e v_2 at 200GeV and π^0 v_2 at Au+Au 62.4GeV



PHENIX

Excitation function

- Heavy flavor e v_2 and π^0 v_2 as a function of beam energy at p_T 1.5-3GeV in Au+Au collision
- The 62.4GeV heavy flavor electron v_2 is consistent with the 200GeV result, given the stated statistical and systematic uncertainties



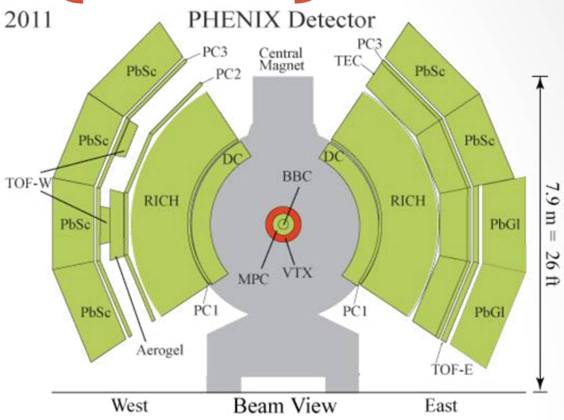
Charm and bottom separation

- All previous PHENIX heavy flavor electron measurements are a mixture of electrons from D and B meson decays.
- charm mass < bottom mass, they may suppress differently in the QGP
- How to separate c and b?
  - D and B meson have different life time
  - Require an accurate measurement of secondary vertex or distance of closest approach (DCA)

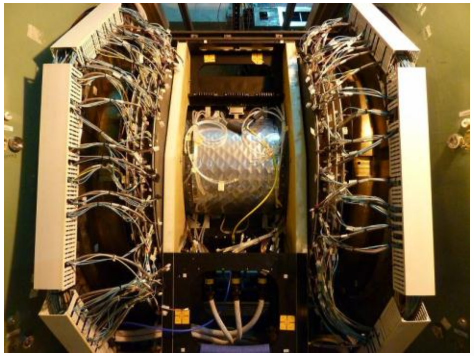
PHENIX

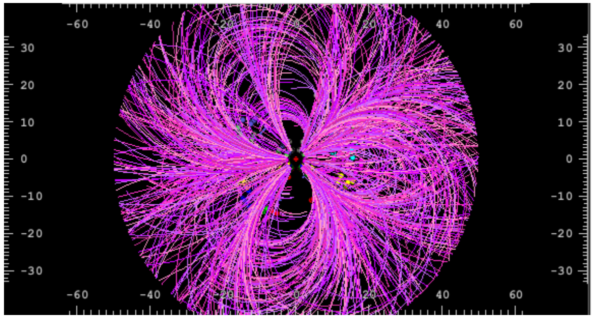
Silicon Vertex Tracker (VTX)

- Installed in PHENIX since Run11
  - Spatial resolution→σ~77μm
  - Large acceptance→$|\eta|<1.2$, $\Delta\phi\sim2\pi$

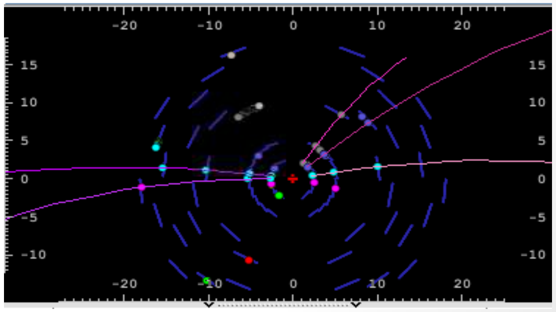


- VTX provides the capability to measure distance of closest approach to separate charm and bottom components of heavy flavor spectra





VTX in **Run 2011: Au+Au** at 200 GeV

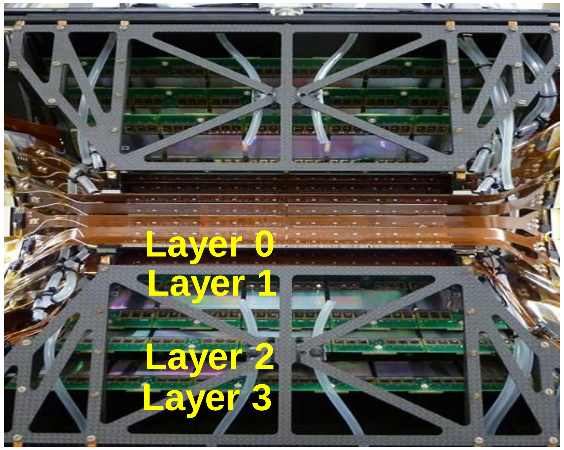


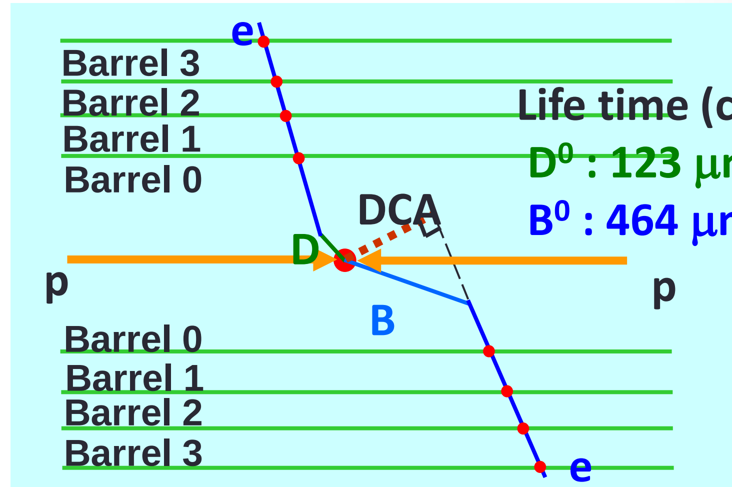
VTX in **Run 2012: p+p** at 200 GeV

PHENIX

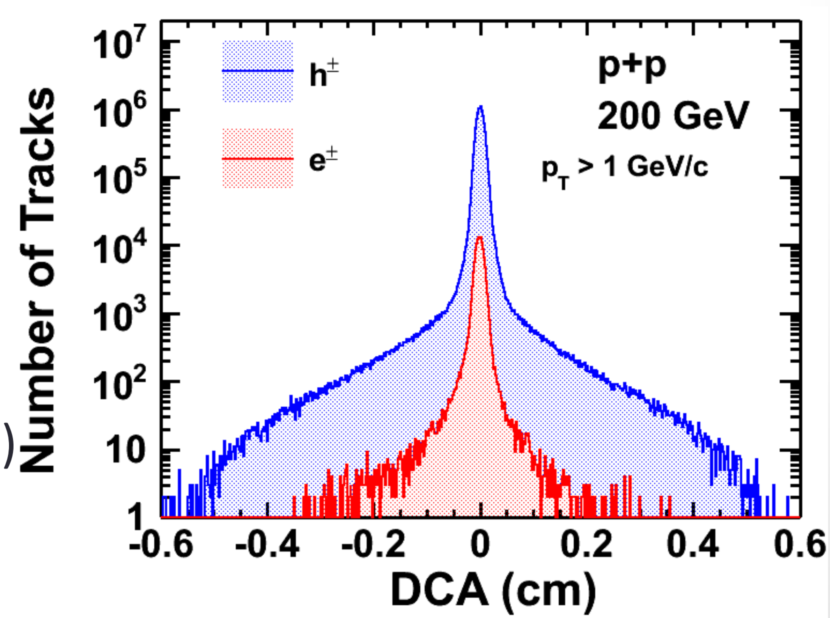
Lei Ding, Iowa State University, 2012/10/19

Distance of closest approach (DCA)





Depends on distance from vertex where decay occurs and opening angle of electron relative to parent trajectory.

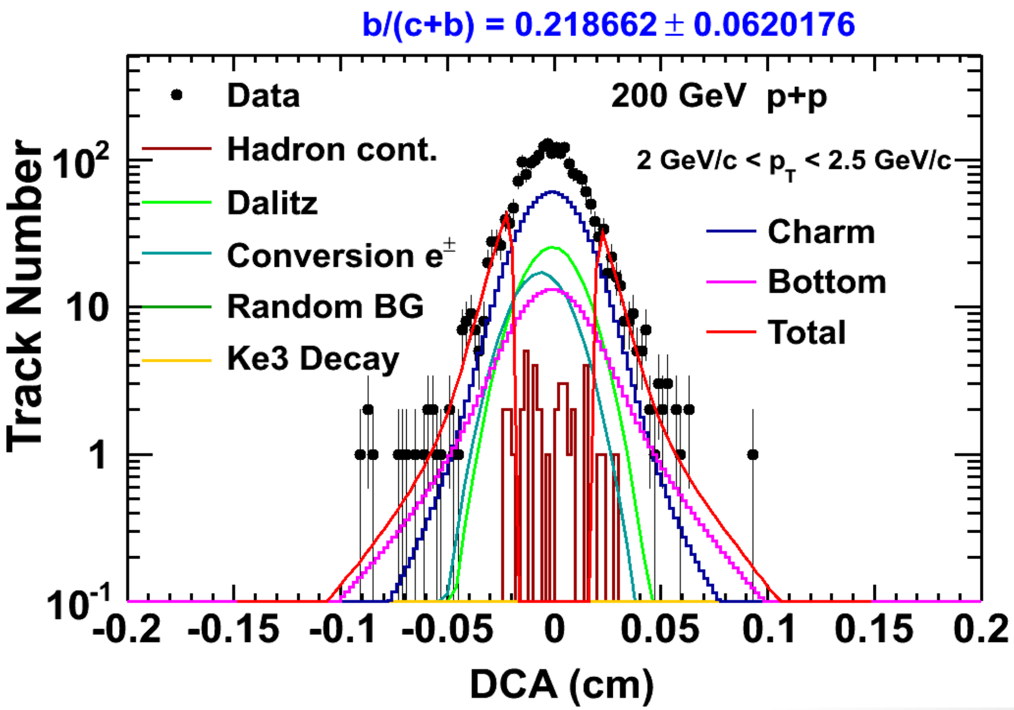


Raw DCA distributions for charged hadrons and electrons (p+p at 200 GeV)

PHENIX

DCA decomposition

- DCA data are fit by
  - Background components (left column)
  - Signal components: c→e **and** b→e (right column)
- The c->e and b->e DCA shape assumes the **PYTHIA** parent (e.g. D, B) p_T distribution and decay kinematics

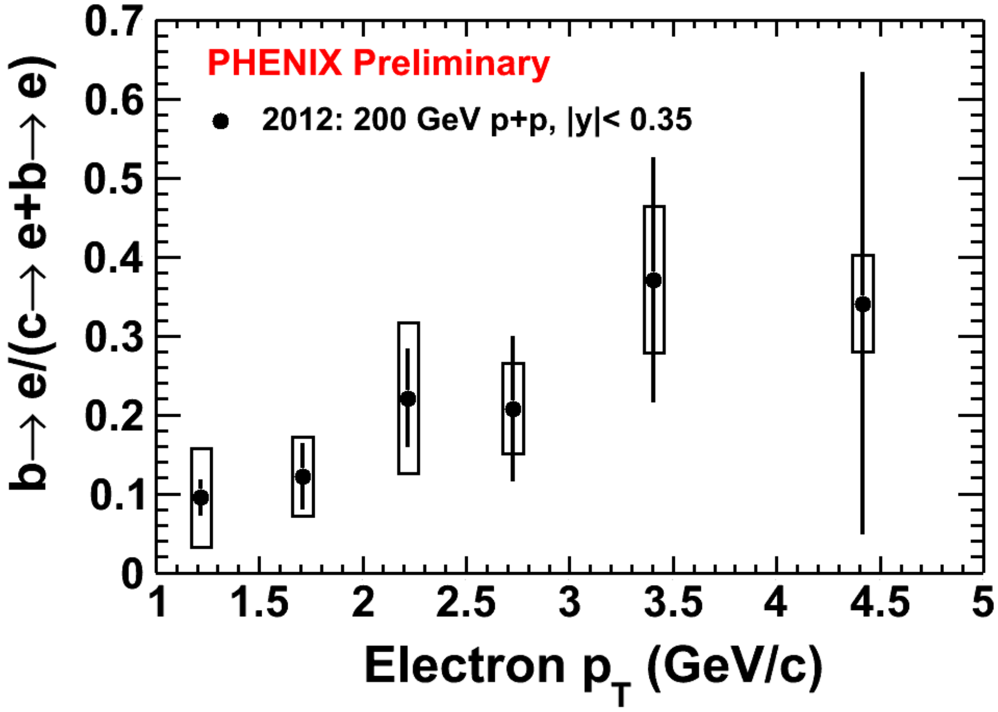


- p_T : 2-2.5GeV
- Fitting region: 0.2<|DCA|<1.5mm
- b/(b+c)=0.22+-0.06

Lei Ding, Iowa State University, 2012/10/19

First direct measurement of bottom production at RHIC : p+p

- From the fit of DCA distribution: $\dfrac{b \rightarrow e}{c \rightarrow e + b \rightarrow e}$



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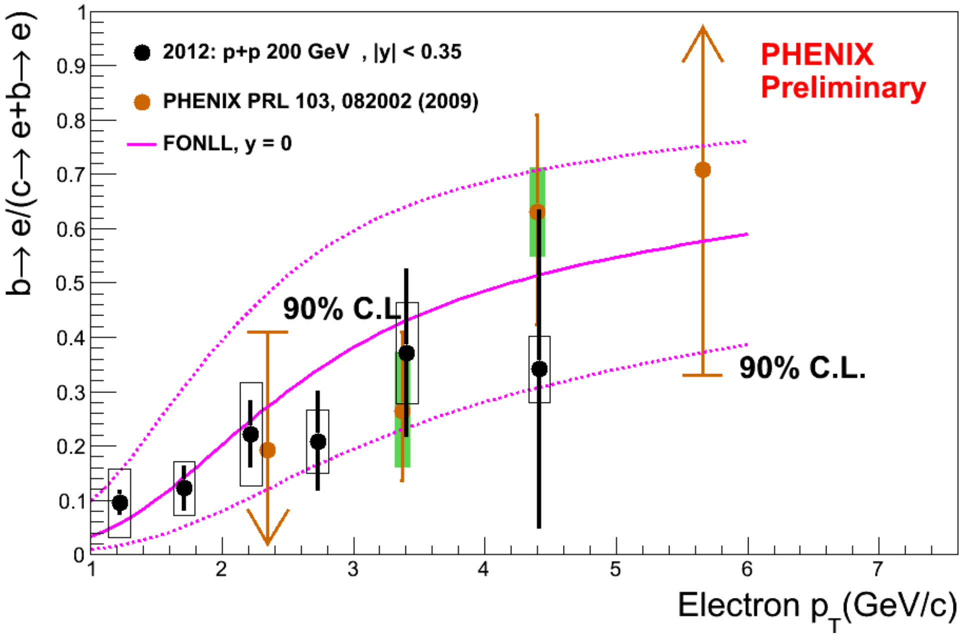

PHENIX Published data agree with new data

FONLL agree with data

First direct measurement of bottom production at RHIC : p+p

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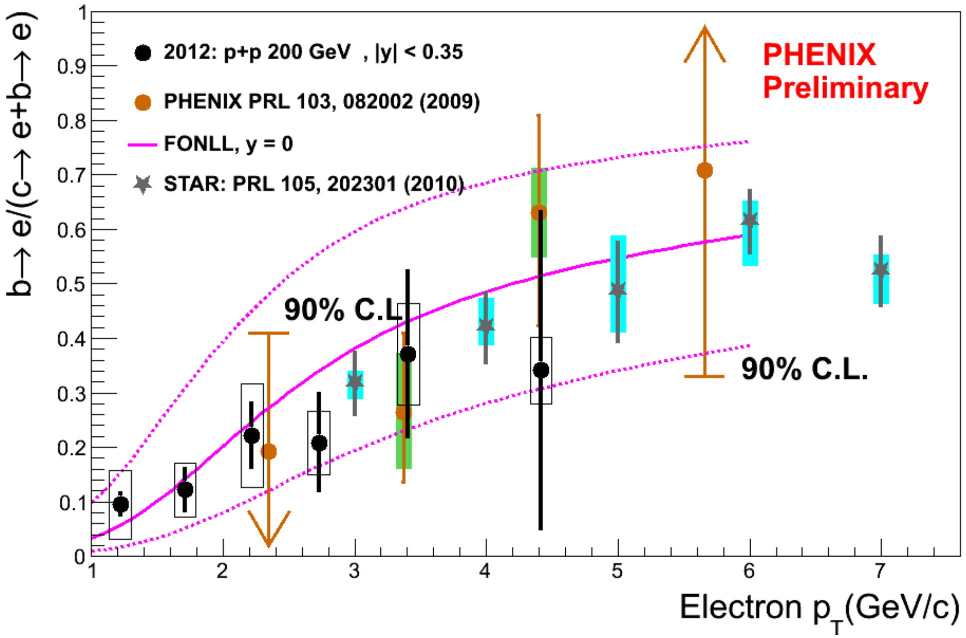

PHENIX Published data agree with new data
FONLL agree with data
STAR indirect measurement consistent with our data

First direct measurement of bottom production at RHIC : p+p

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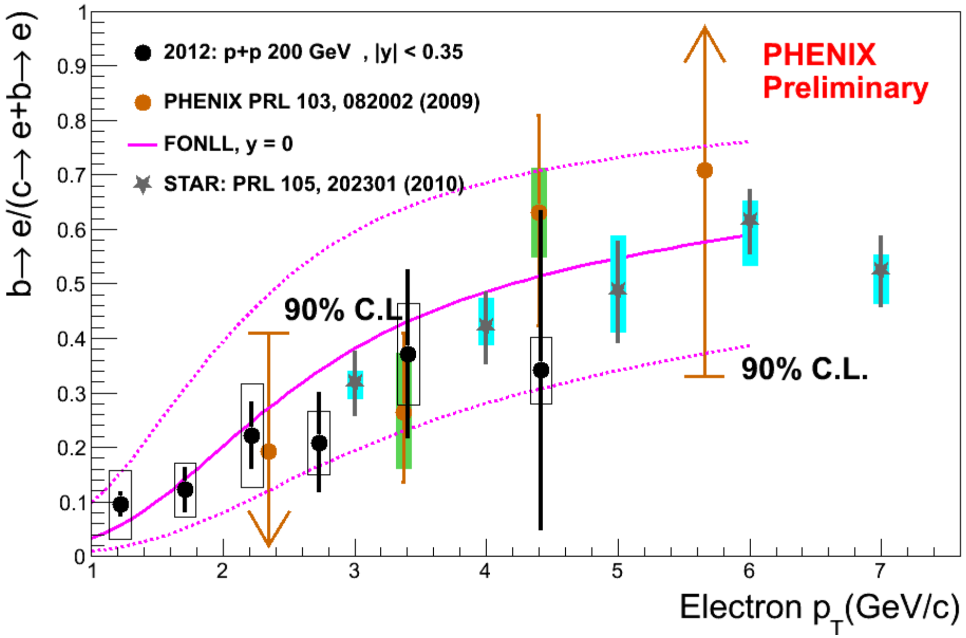


PHENIX Published data agree with new data
FONLL agree with data
STAR indirect measurement consistent with our data

- Au+Au template fits being reviewed after QM12
  - Include modification of B and D meson p_T spectra

PHENIX

Summary

- Heavy flavor electron flow is measured in Au+Au collision at beam energy 62.4 GeV in PHENIX
- The 62.4GeV heavy flavor electron v_2 is consistent with the 200GeV result, given the stated statistical and systematic uncertainties

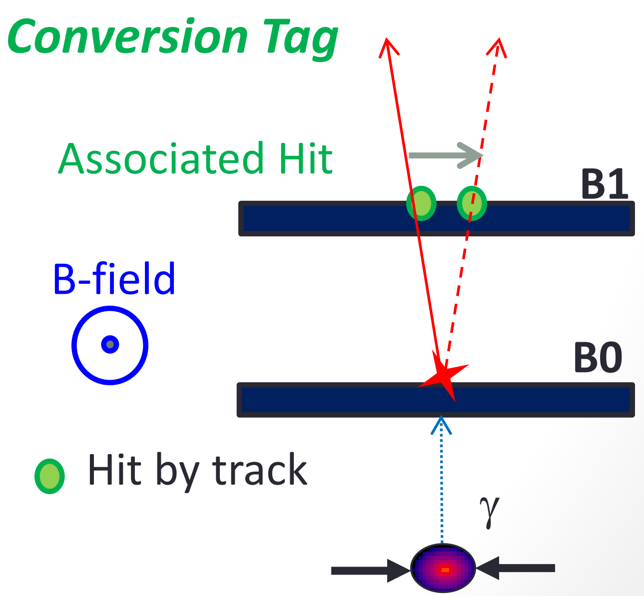
- First direct measurement of charm and bottom separately in p+p collision at RHIC achieved
- FONLL prediction of b/(b+c) agrees with the data.

PHENIX

Backup

Conversion tagging

- Challenge in the DCA measurement of single electrons is the Conversion Electron Background (CEB).
- Most conversions happen in the outer layers (total radiation length = 12 % (B0: 1.3%, B1: 1.3%, B2:4.7% and B3: 4.7%). They are suppressed by requiring a hit in inner silicon layer B0.
- Conversions in the beam pipe and B0, and Dalitz are suppressed by rejecting electron tracks with a nearby hit : Conversion Tag and Veto.
-



PHENIX

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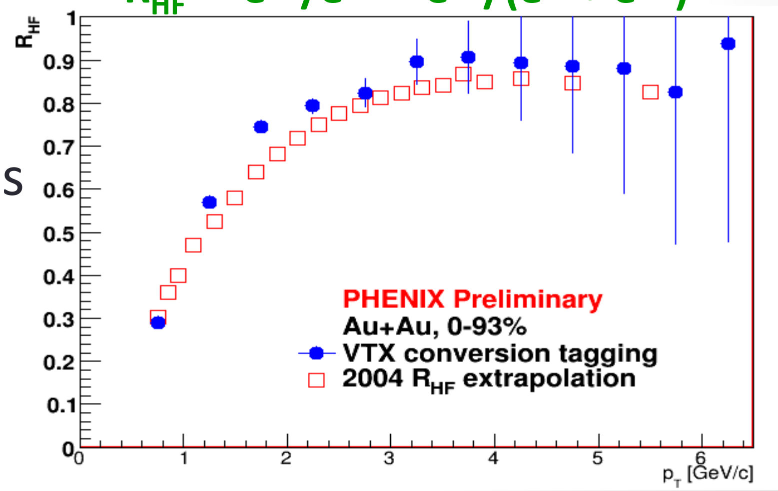
- Most conversions happen in the outer layers (total radiation length = 12 % (B0: 1.3%, B1: 1.3%, B2:4.7% and B3: 4.7%). They are suppressed by requiring a hit in inner silicon layer B0.
- Conversions in the beam pipe and B0, and Dalitz are suppressed by rejecting electron tracks with a nearby hit : Conversion Tag and Veto.
- Yield of the remaining conversions and Dalitz are estimated using the veto efficiency.

Fraction of HF electron after conversion Veto

$$R_{HF} = e^{HF}/e^{inc} = e^{HF}/(e^{HF} + e^{PH})$$



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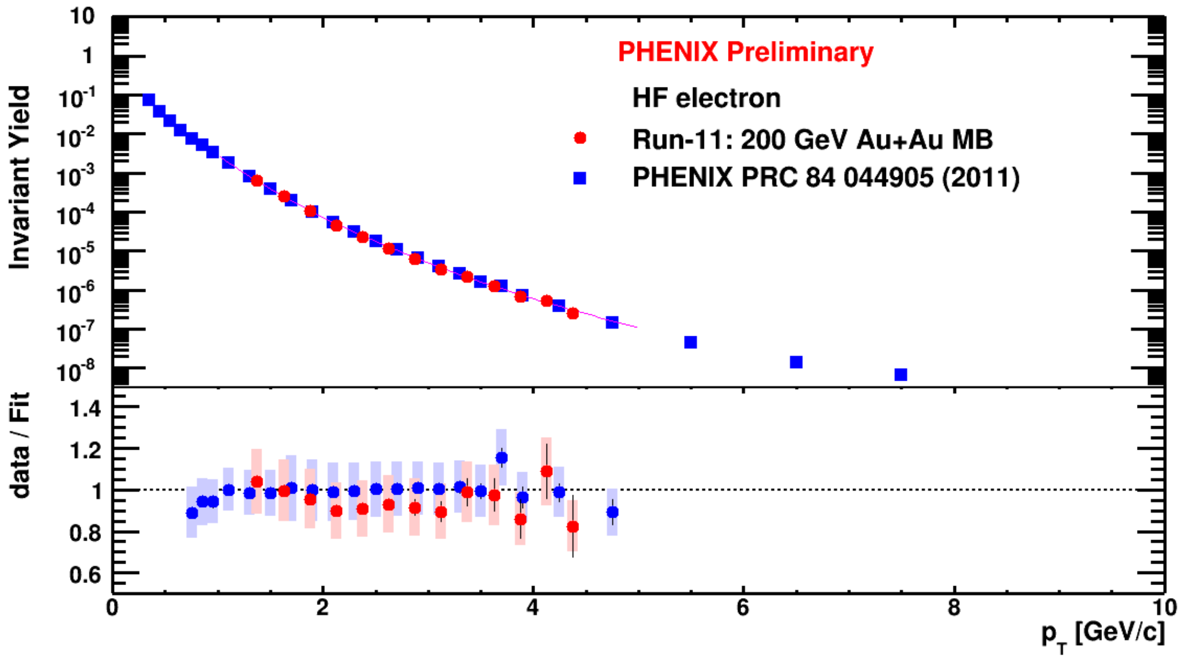
Heavy flavor e (by VTX in run11)

- Using the photonic electron estimated by the VTX, we measure the heavy flavor (HF) electron spectra

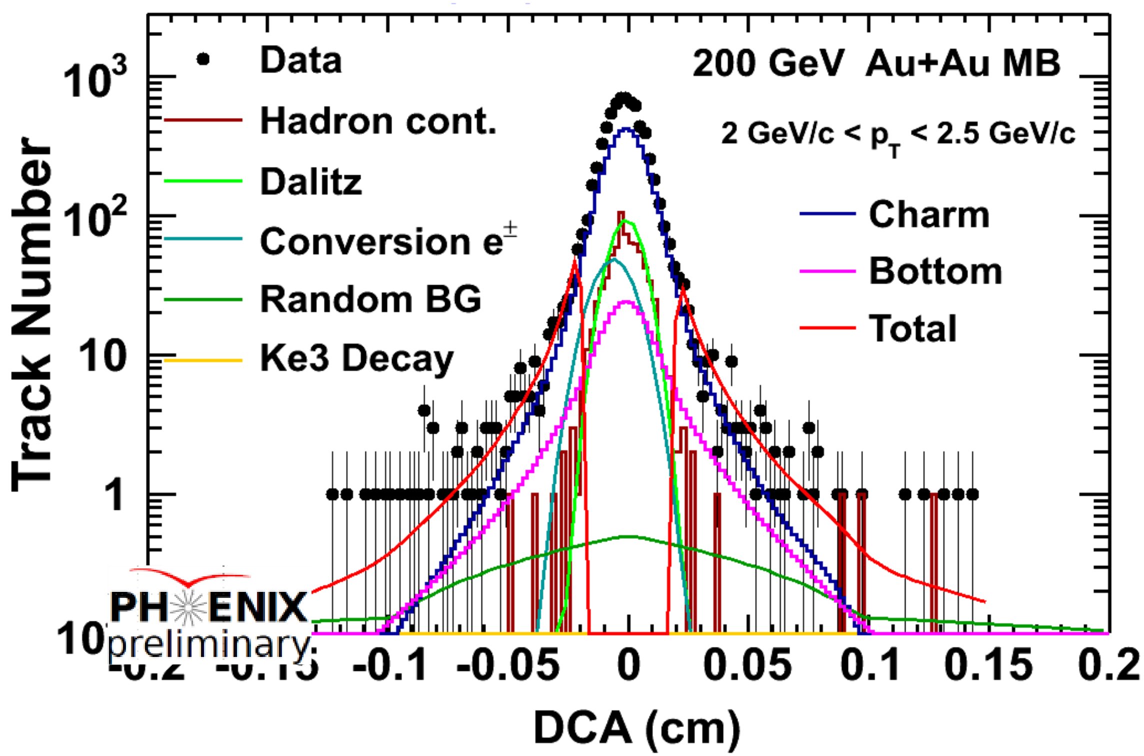


Run 2011 HF spectra consistent with previously published HF by PHENIX

PHENIX

How were the DCA measurement used?

- DCA data are fit by background components (left column) and c→e **and b→e "expected DCA"** (right column)
- The fit produces relative c→e to b→e fractions
- Where did the "expected DCA" distributions come from?



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Lei Ding, Iowa State University, 2012/10/19

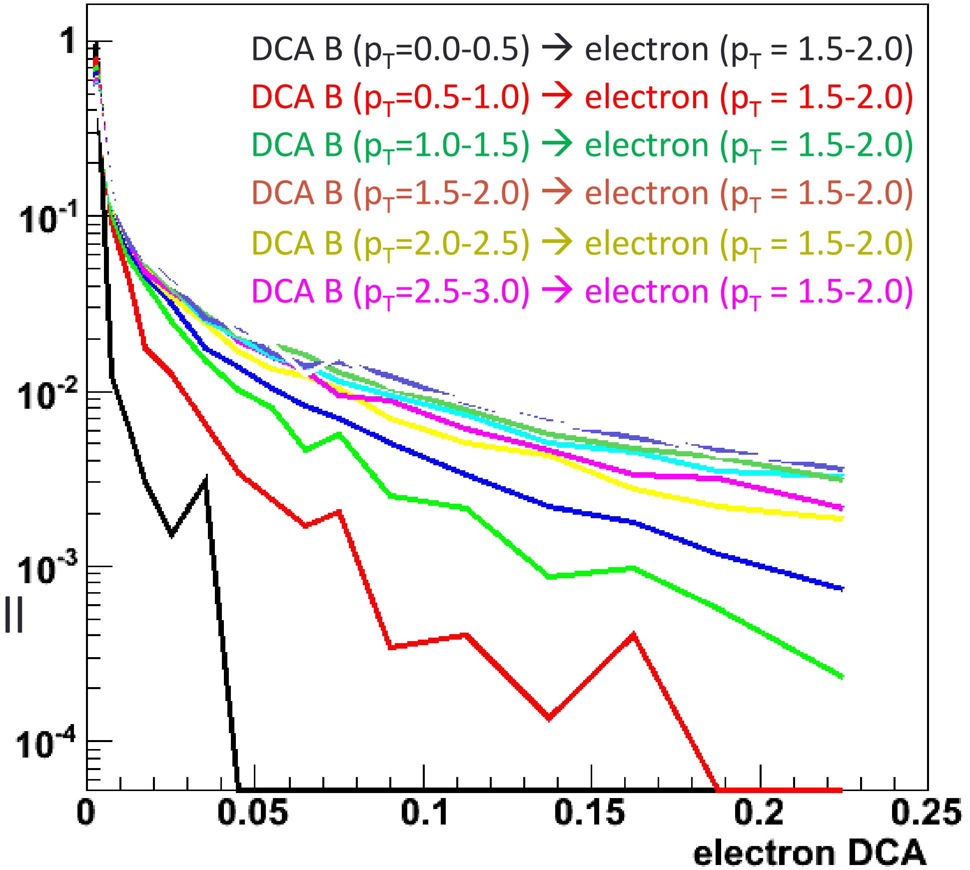
Where did the "expected DCA" distributions come from?

Simple Answer: For the QM Preliminary result, the analysis just used the PYTHIA output. That assumes the **PYTHIA** parent (e.g. D, B) p_T distribution and decay kinematics

The "expected DCA" b→e is a convolution of the B meson parent p_T spectrum with the electron decay kinematics and corresponding DCA

For these p_T electrons, if the parent B meson p_T distribution is significantly modified from PYTHIA, the "expected DCA" from PYTHIA will be wrong

All curves normalized to same integral for shape comparison



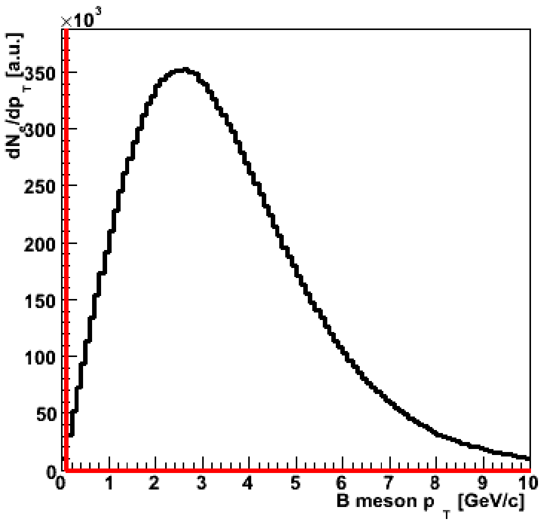
PHENIX

An Extreme Example Just to Demonstrate the Point

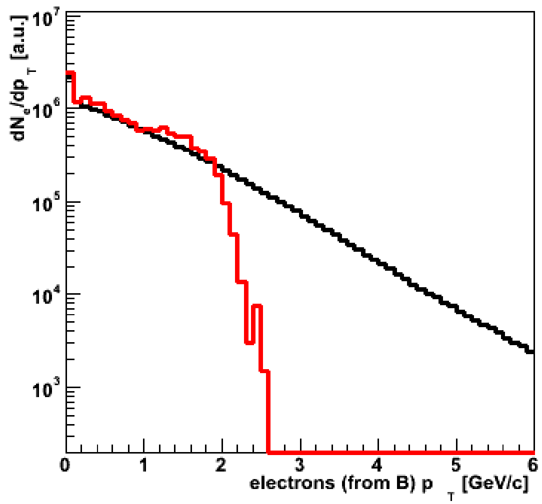
Compare **PYTHIA B meson p_T distribution (Black)** and a **Scenario with all B mesons at p_T = 0 (Red)**

We said it was extreme…

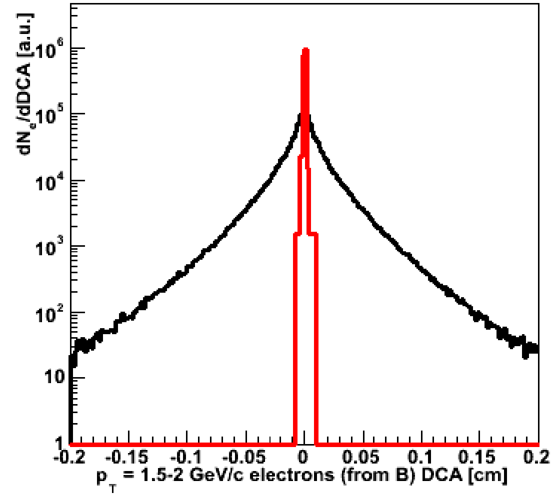
B meson Parents



B→X→electron Daughters

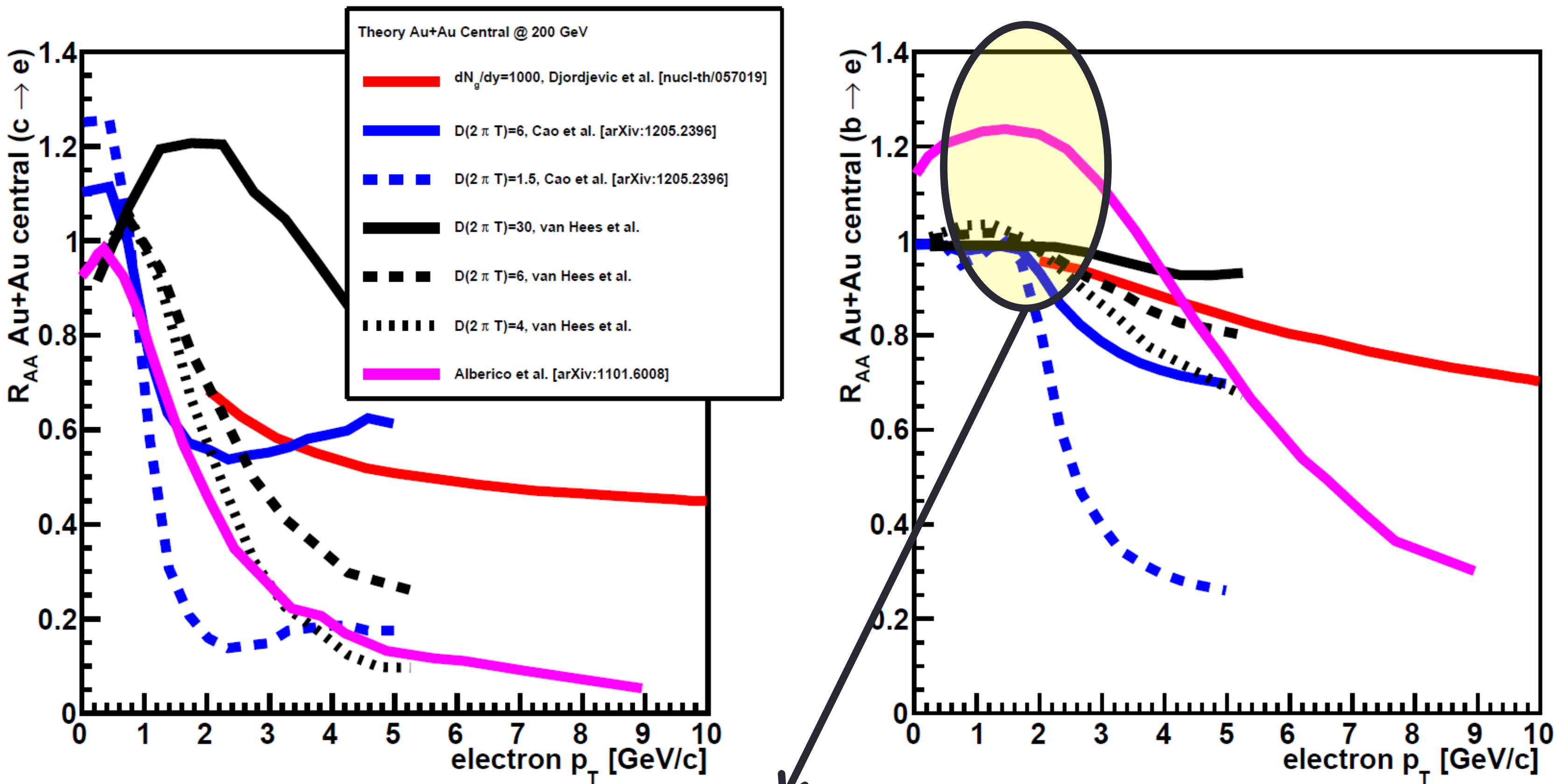


B→X→electron DCA



Because of decay kinematics, even in the Red Scenario, one will have B→X→e all the way out beyond electron $p_T \approx 2$ GeV/c.

However, these electrons will all have DCA = 0 (since the B is at rest) and thus would **not** be properly extracted using the PYTHIA DCA template.



These theory calculations all have b→e R_{AA} ~ 1 out to p_T ~ 2 GeV/c due to the decay kinematics. They likely have very modified DCA distributions relative to PYTHIA.
Thus our QM preliminary fit method would not pick them out as b→e and cannot be properly compared.

PHENIX

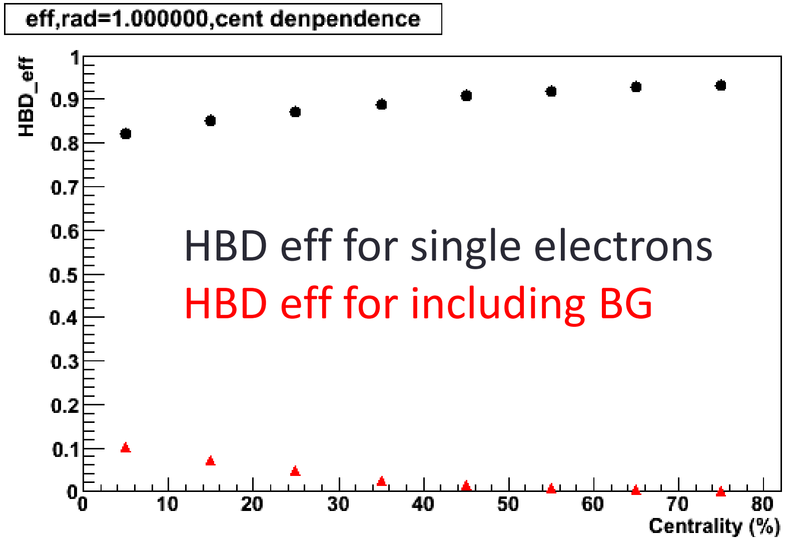
Efficiency correction

- Single electron simulation shows that the Central Arm acceptance and efficiency is about 14% in Run10.
- Multiplicity dependent efficiency.
  - Simulated single electrons are embedded into real data, reconstructed and applied the same eID cuts as data.
  - 0-20% centrality: 77%;   60-86% centrality: 97%
- HBD efficiency is calculated separately from CA efficiency

If require hbdcharge>10,

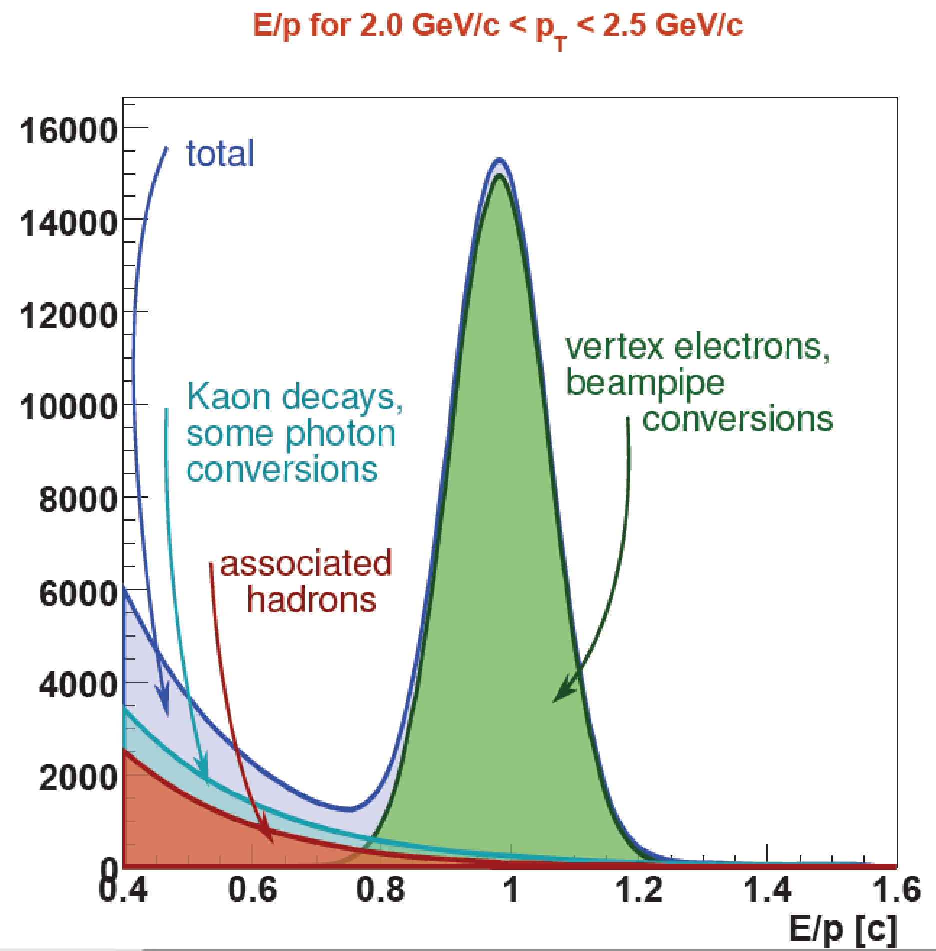
in most central events:

- Single e efficiency ~ 80%
- Efficiency for including background ~ 10%



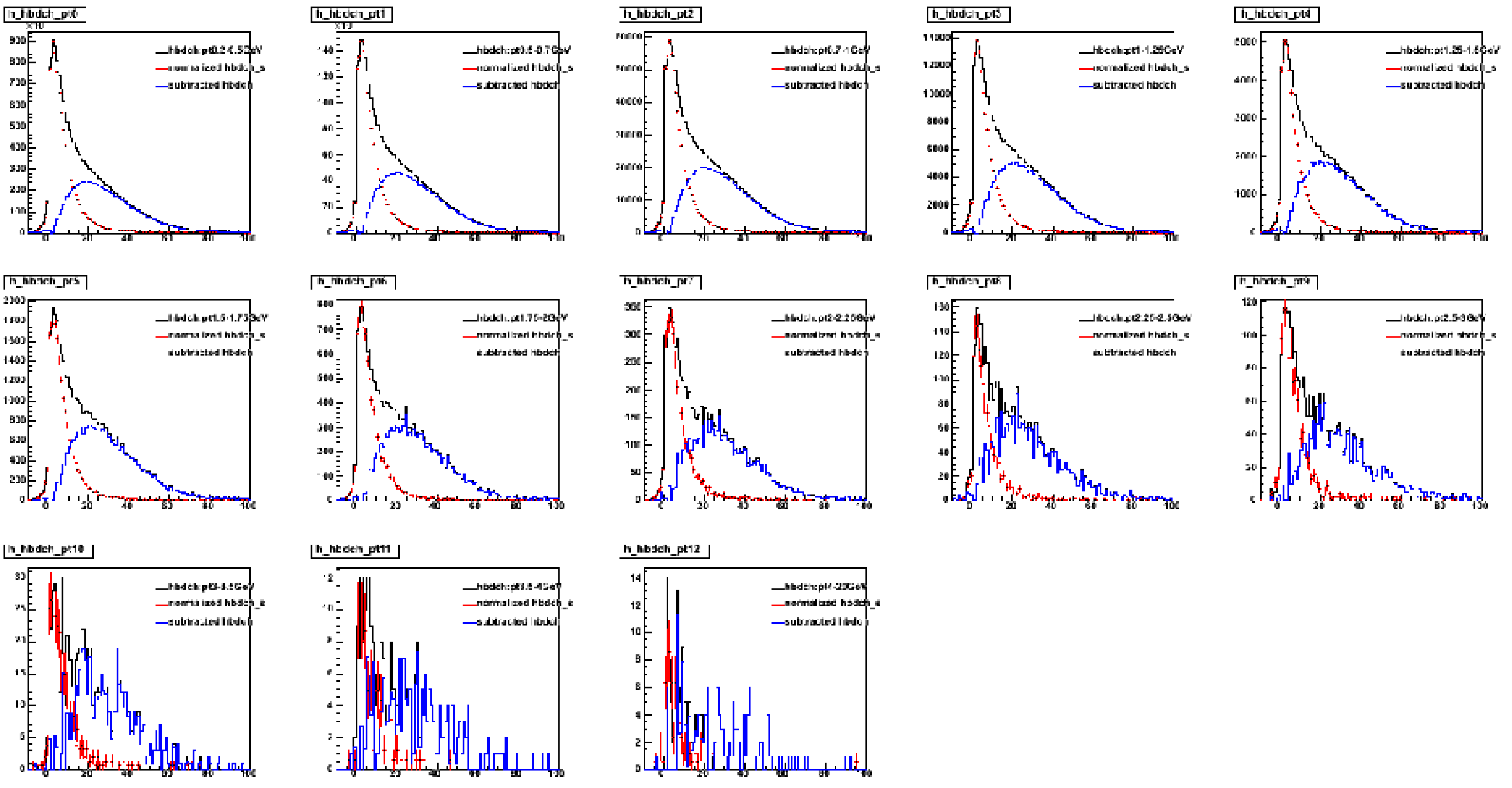
PHENIX

E/p distribution



PHENIX

HBD charge



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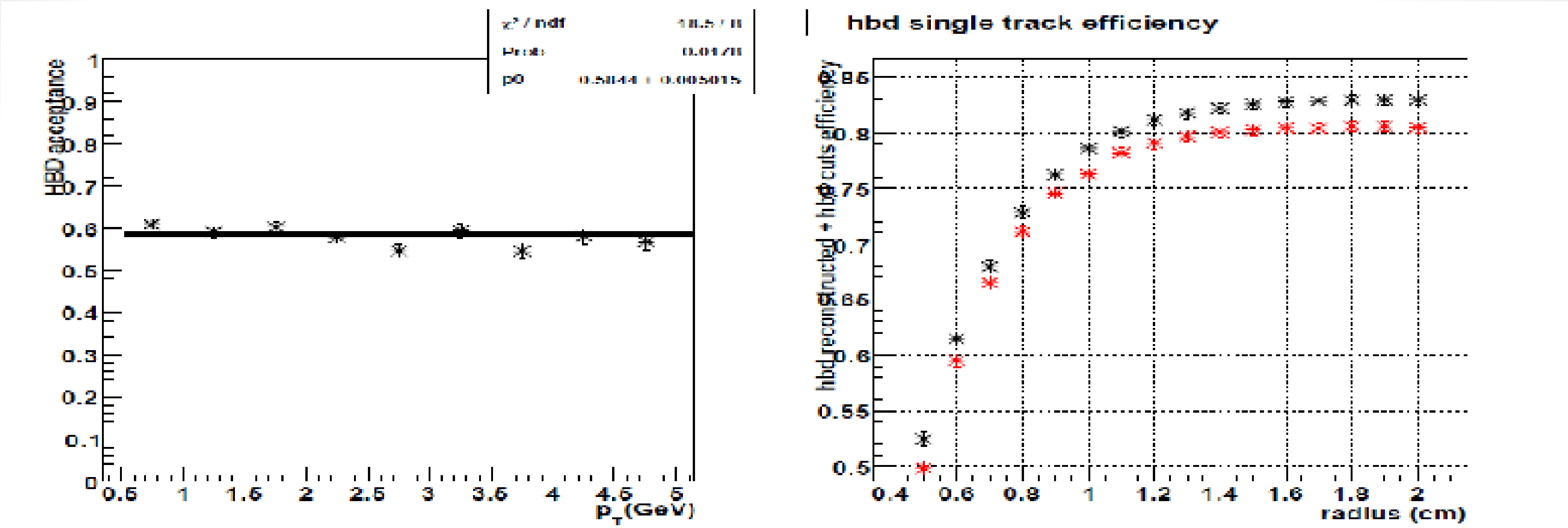
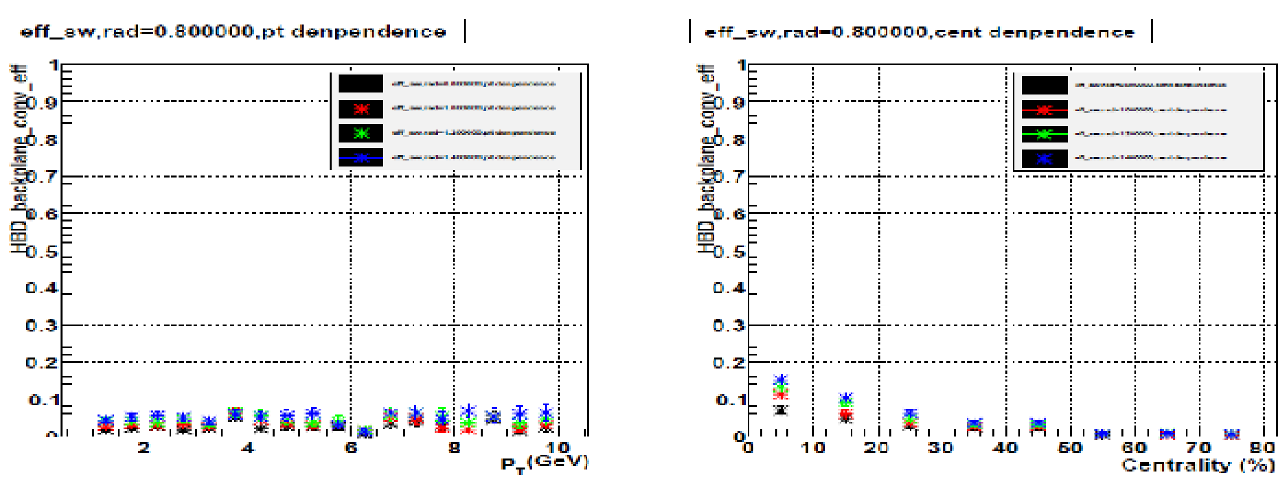
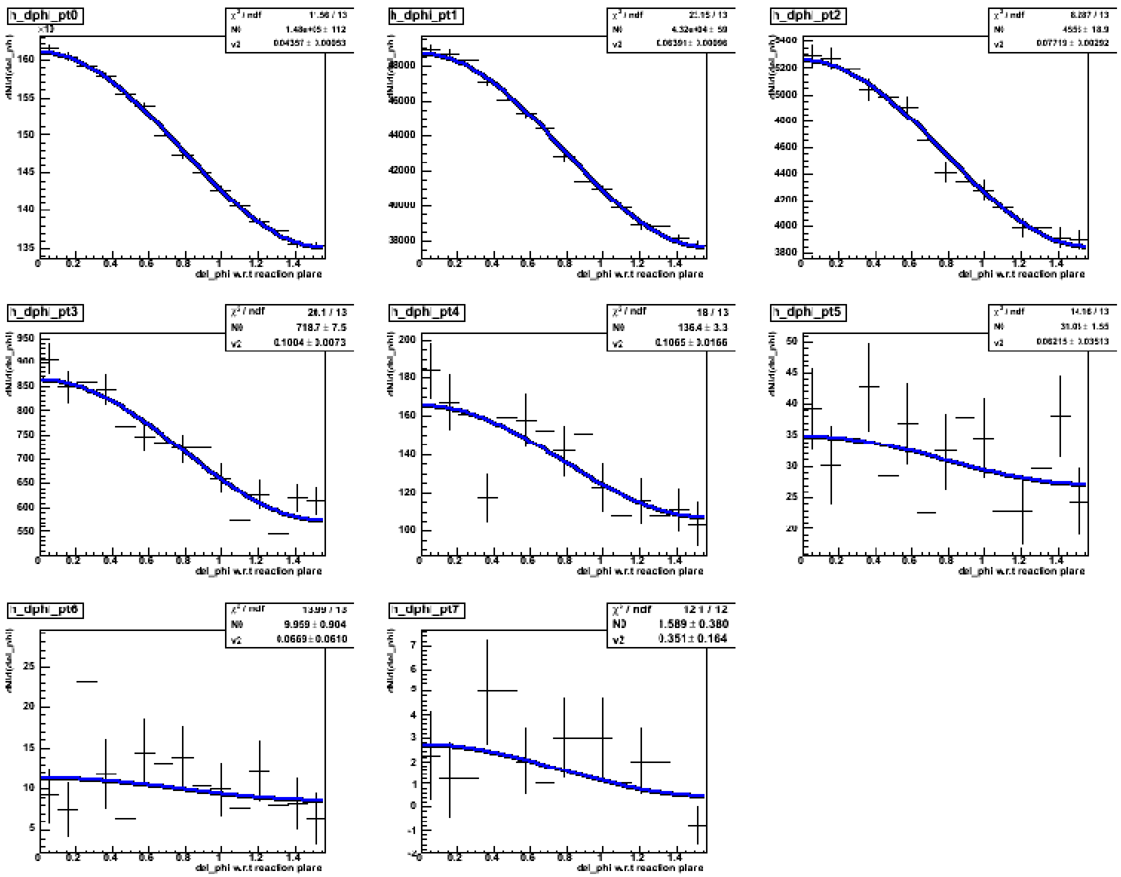


Figure 37: Left plot is HBD acceptance vs p_T, Right plot is HBD efficiency in MinBias data as a function of radius.



40: HBD reconstruct efficiency * embedding efficiency for hbd back plane conversion is vs centrality

Inclusive e flow (20-40%)



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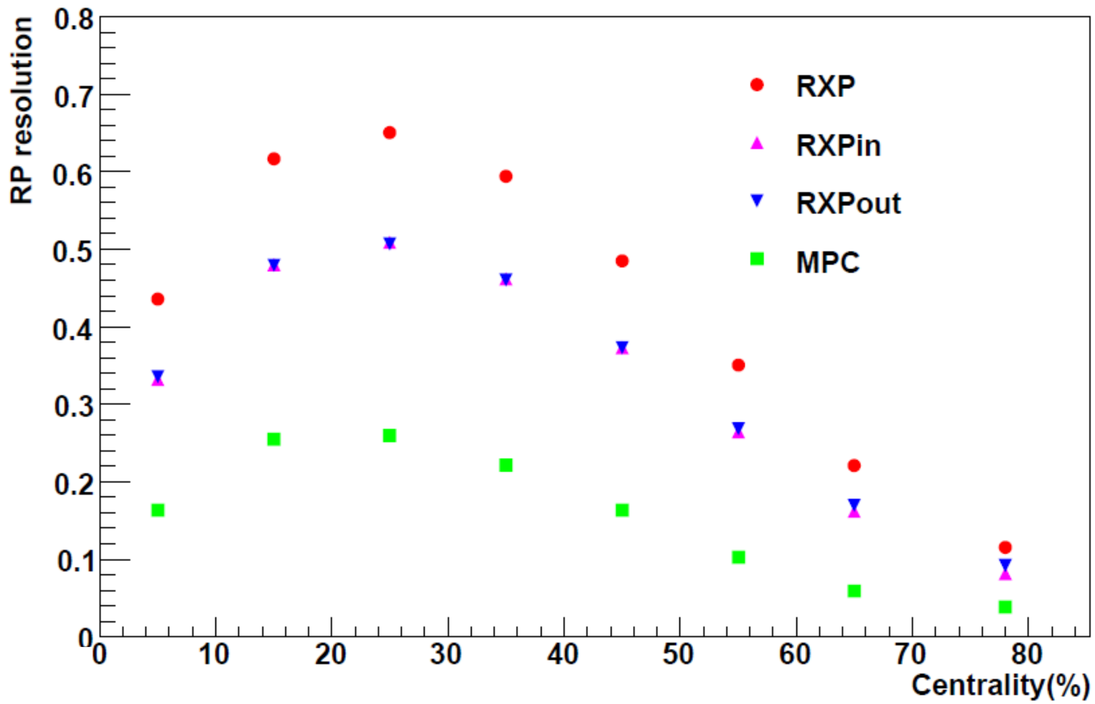
Reaction plane resolution

- In this run10 analysis, reaction plane detector is used to calculate event by event reaction plane
- $v_2 = \frac{v^{raw}{}_2}{reaction\ plane\ resolution}$



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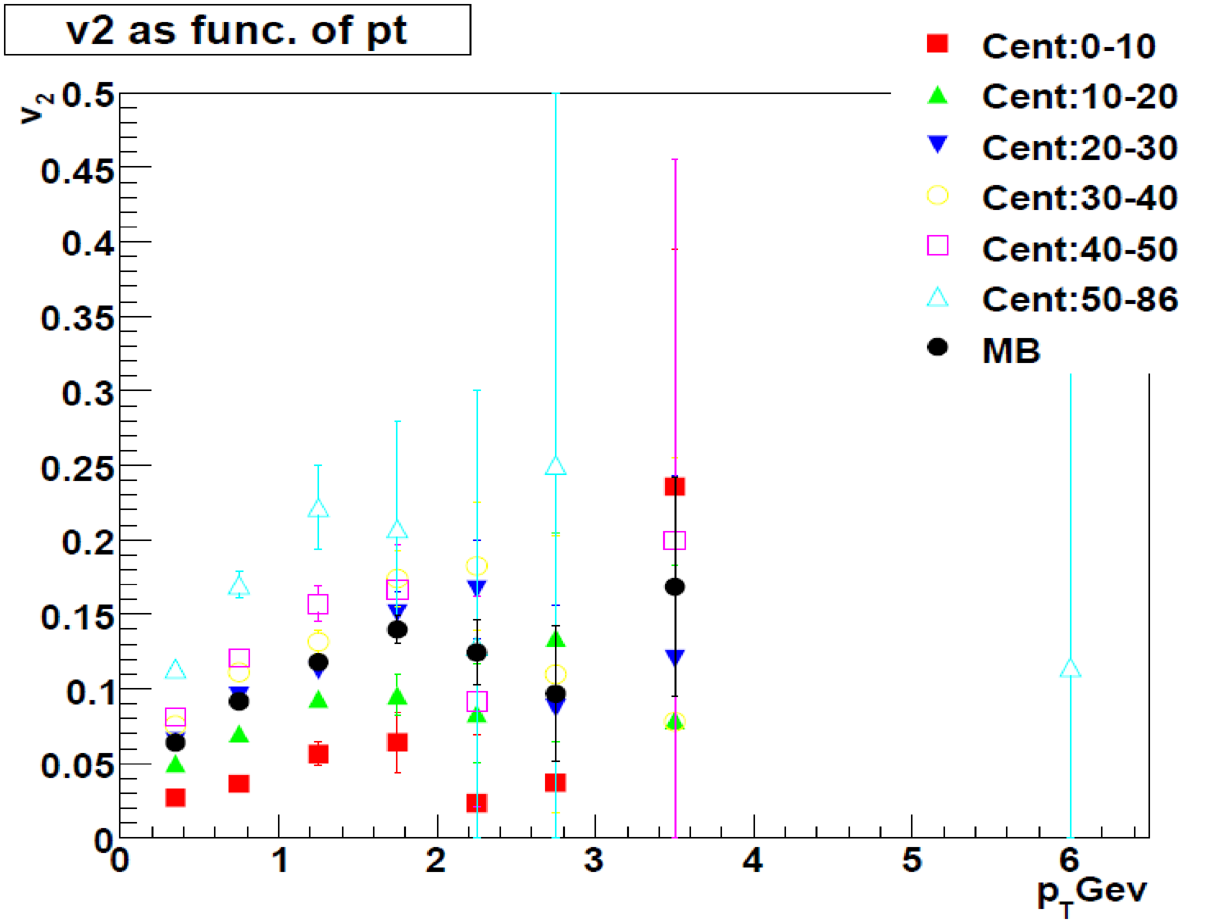
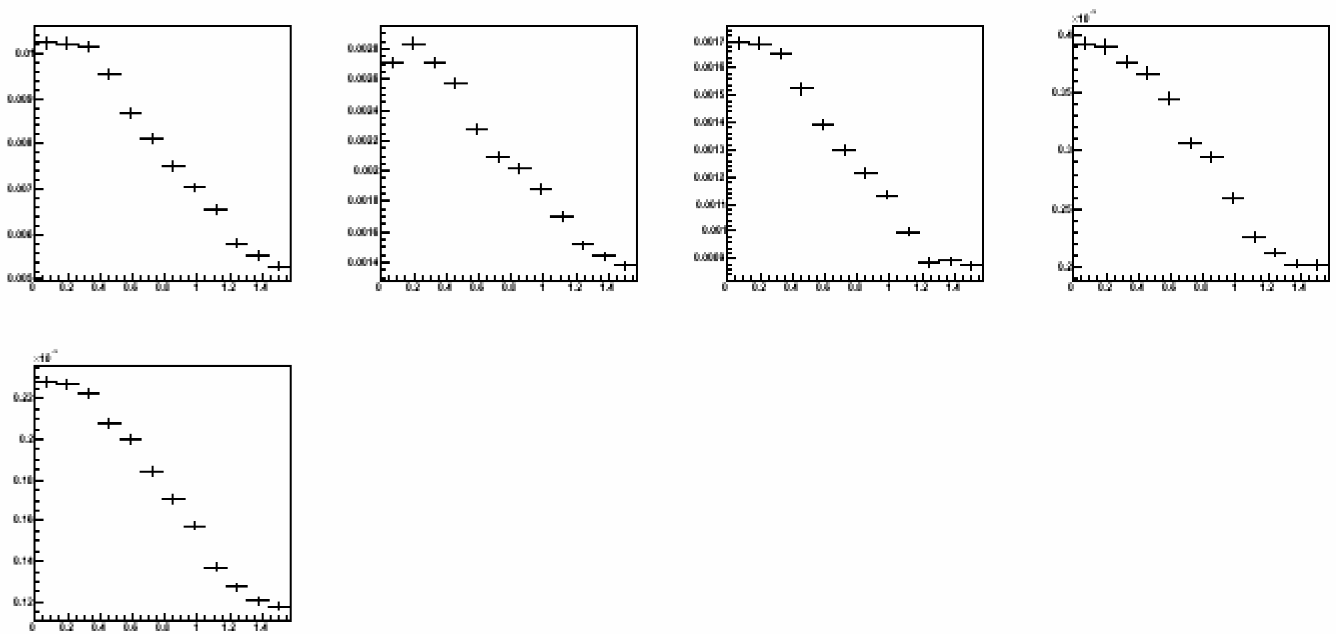
Reaction plane resolution vs centrality measured by MPC,RXPin,RXPout and RXP

Inclusive electron v_2



Photonic e flow



Heavy flavor e v2 error propagation

- Hf v2 is calculated by:

$$v_2^{hf} = v_2^{inc} * (1 + \frac{1}{S}) - v_2^{pho} * \frac{1}{S}$$

- If error in each term is relatively small:

$$(\Delta v_2^{hf})^2 = (\Delta v_2^{inc})^2 * (1 + \frac{1}{S})^2 + (\Delta v_2^{pho})^2 * \frac{1}{S^2} + \frac{(\Delta S)^2}{S^4} * (v_2^{inc} - v_2^{pho})^2$$

- If signal to background error is large:

$$(\Delta v_2^{hf})^2 = (\Delta v_2^{inc})^2 * (1 + \frac{1}{S})^2 + (\Delta v_2^{pho})^2 * \frac{1}{S^2} + (\sum_{n=1}^{\infty} \frac{(-\Delta S)^n}{S^{n+1}})^2 * (v_2^{inc} - v_2^{pho})^2$$

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Reference

- [1] Phys. Rev. C 84, 044905 (2011)
- [2] Phys. Rev. Lett. 98, 172301 (2007)
- [3] **Alan Dion**: "Heavy Flavor at PHENIX", QM2008
- [4] **Mariza Rosati**: “Heavy Flavor at PHENIX”, QM2012
- [5] **Rachid Nouicer**: “Probing Hot and Dense Matter with Charm and Bottom Measurements with PHENIX VTX Tracker”, QM2012