Recent PHENIX Heavy-Flavor Results (incl. c and b flow)

Dan Richford for the PHENIX Collaboration

2024 AGS/RHIC Users Meeting

9:40 a.m., Wednesday, June 12, 2024

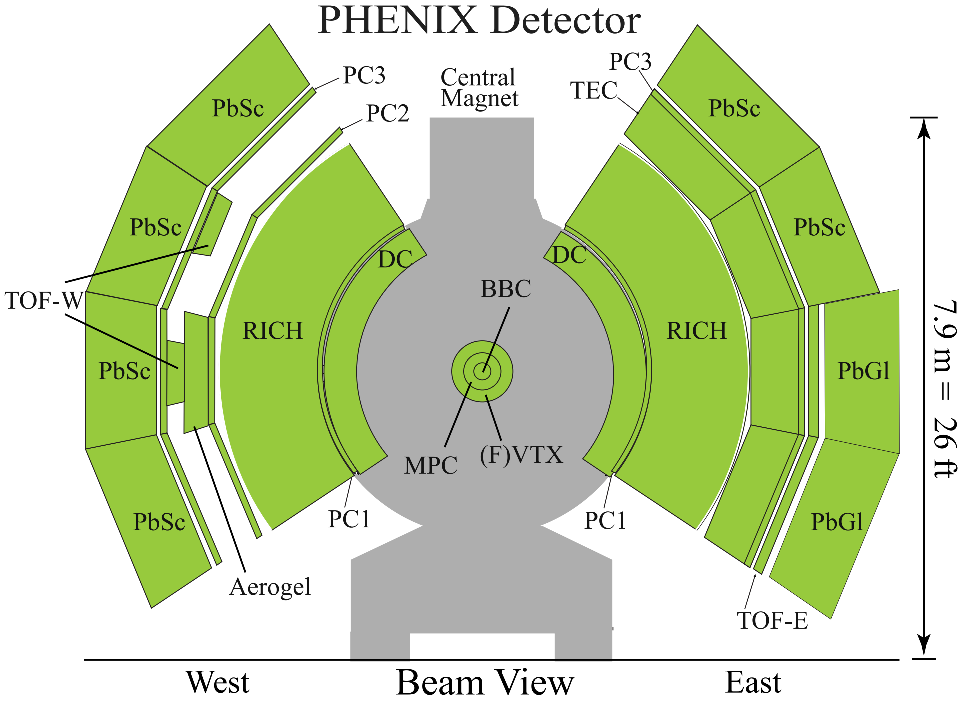
CUNY GRADUATE CENTER

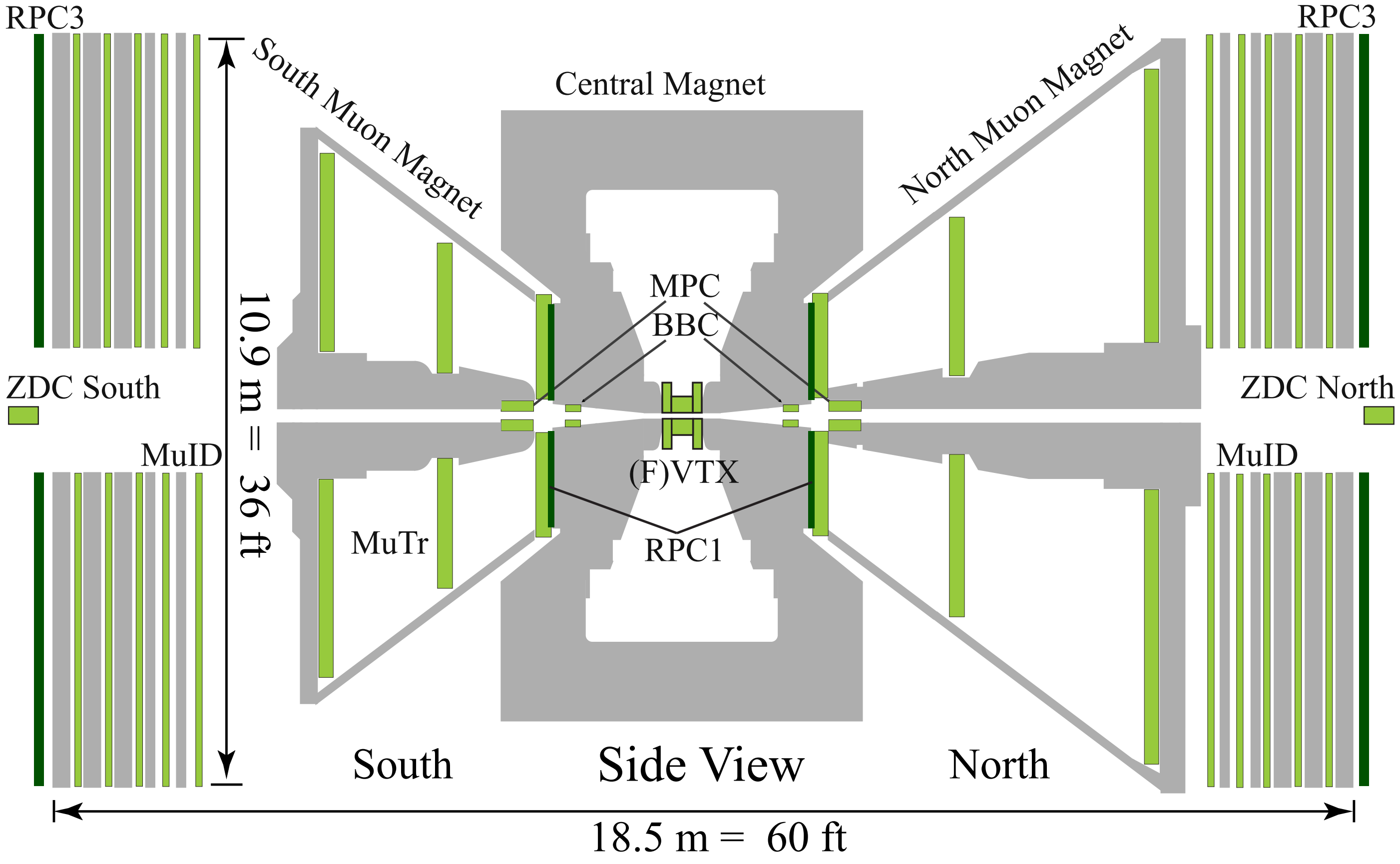
PHENIX

Baruch COLLEGE

Overview

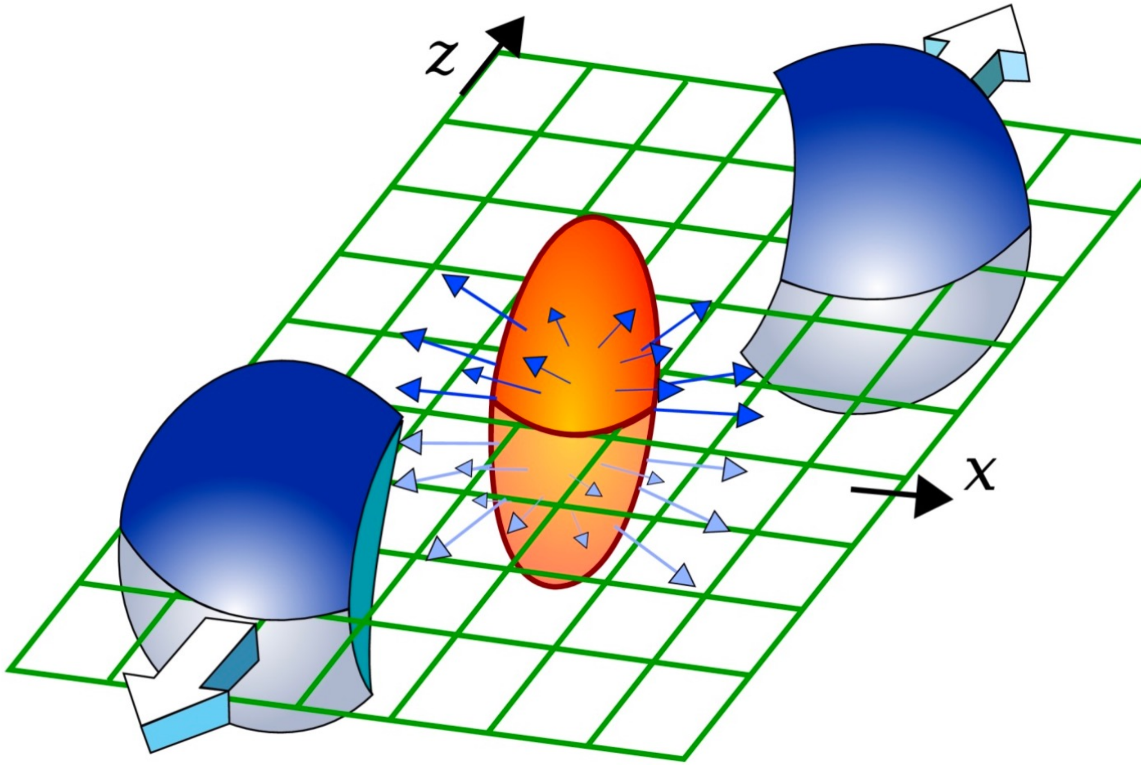
Detector

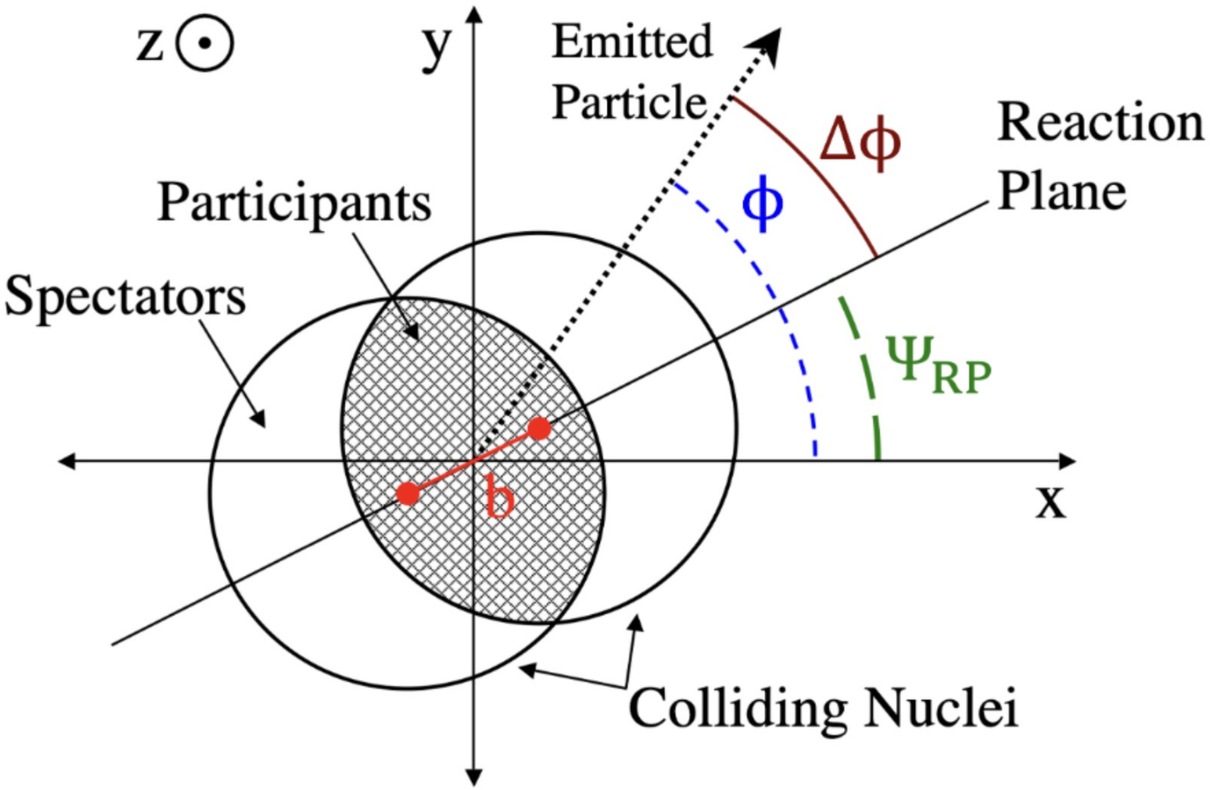

PHENIX Detector
PbSc
PC3
PC2
Central Magnet
PC3
TEC
PbSc
PbSc
PbSc
TOF-W
DC
DC
BBC
RICH
RICH
PbSc
PbGl
MPC
(F)VTX
PC1
PC1
PbSc
PbGl
Aerogel
TOF-E
West
Beam View
East
7.9 m = 26 ft

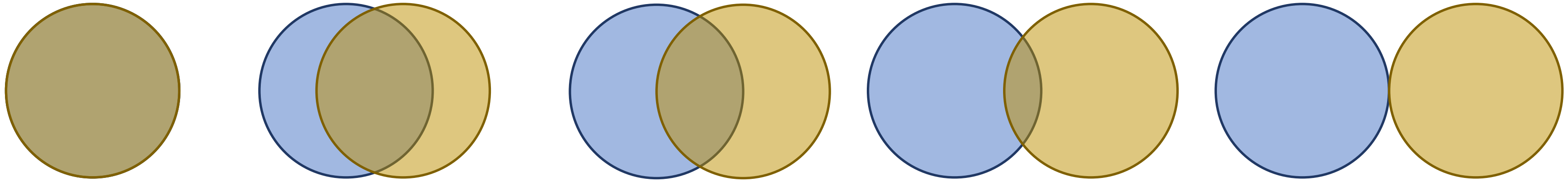

RPC3
South Muon Magnet
Central Magnet
North Muon Magnet
RPC3
MPC
BBC
ZDC South
ZDC North
10.9 m = 36 ft
MuID
MuID
(F)VTX
MuTr
RPC1
South
Side View
North
18.5 m = 60 ft

Centrality in Large Systems

Geometric and Momentum Anisotropy







Broad Study of Light-Flavor Hadrons in Small and Large Systems at Multiple Centrality Classes

&

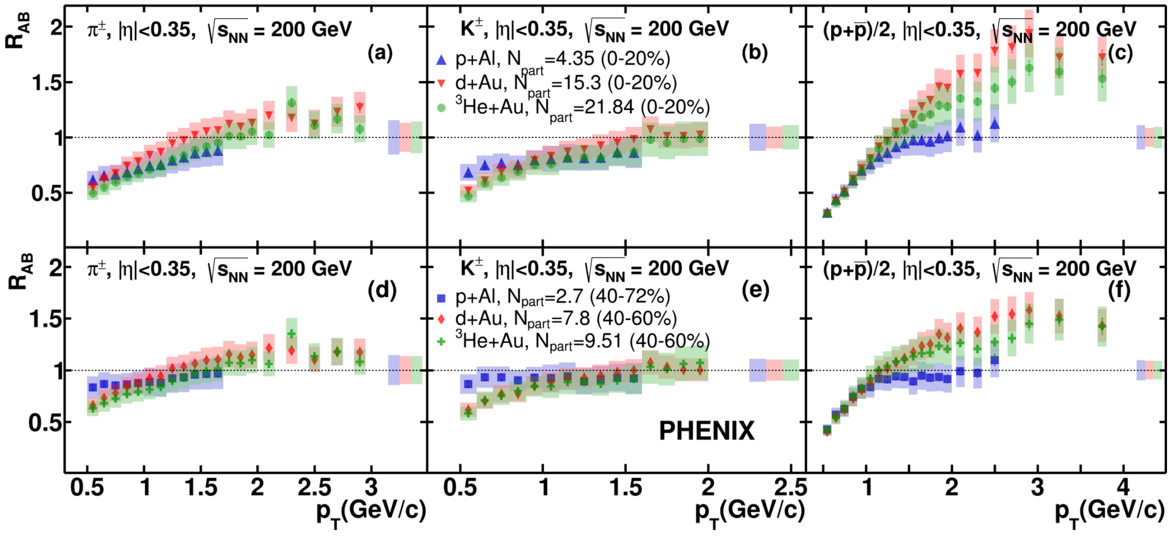
Broad Study of Flow in Small Systems at Multiple Centrality Classes

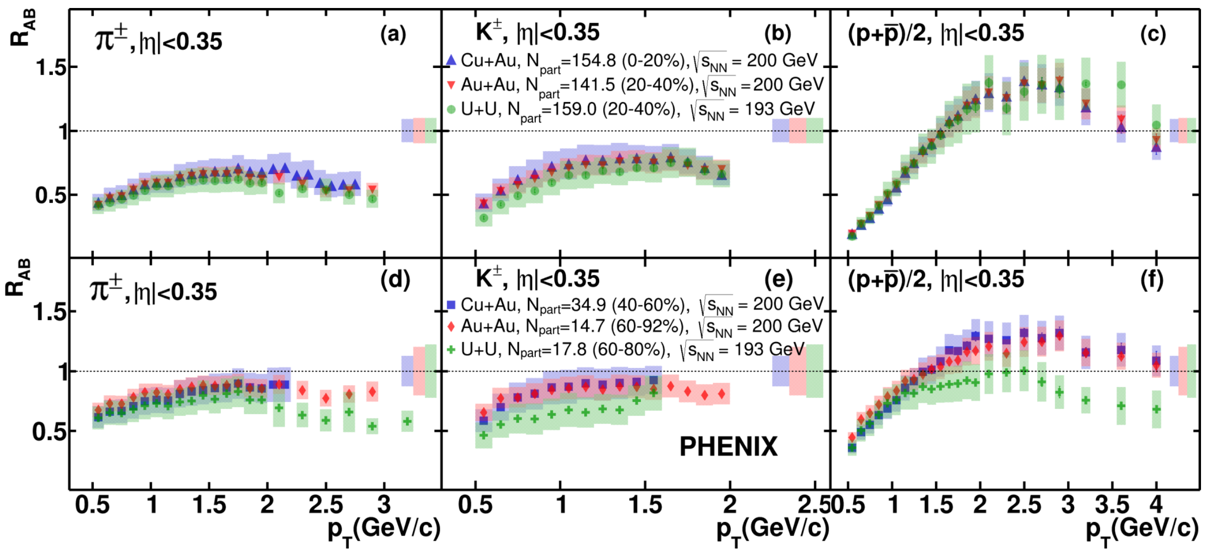
Light Flavor in PHENIX

Charged Hadron Production in p+Al, d+Au, 3He+Au, Cu+Au, Au+Au, U+U (PRC 109 054910 [2024])

Nuclear Modification Factor

- Small systems on left, large on right
- Central on top, peripheral on bottom





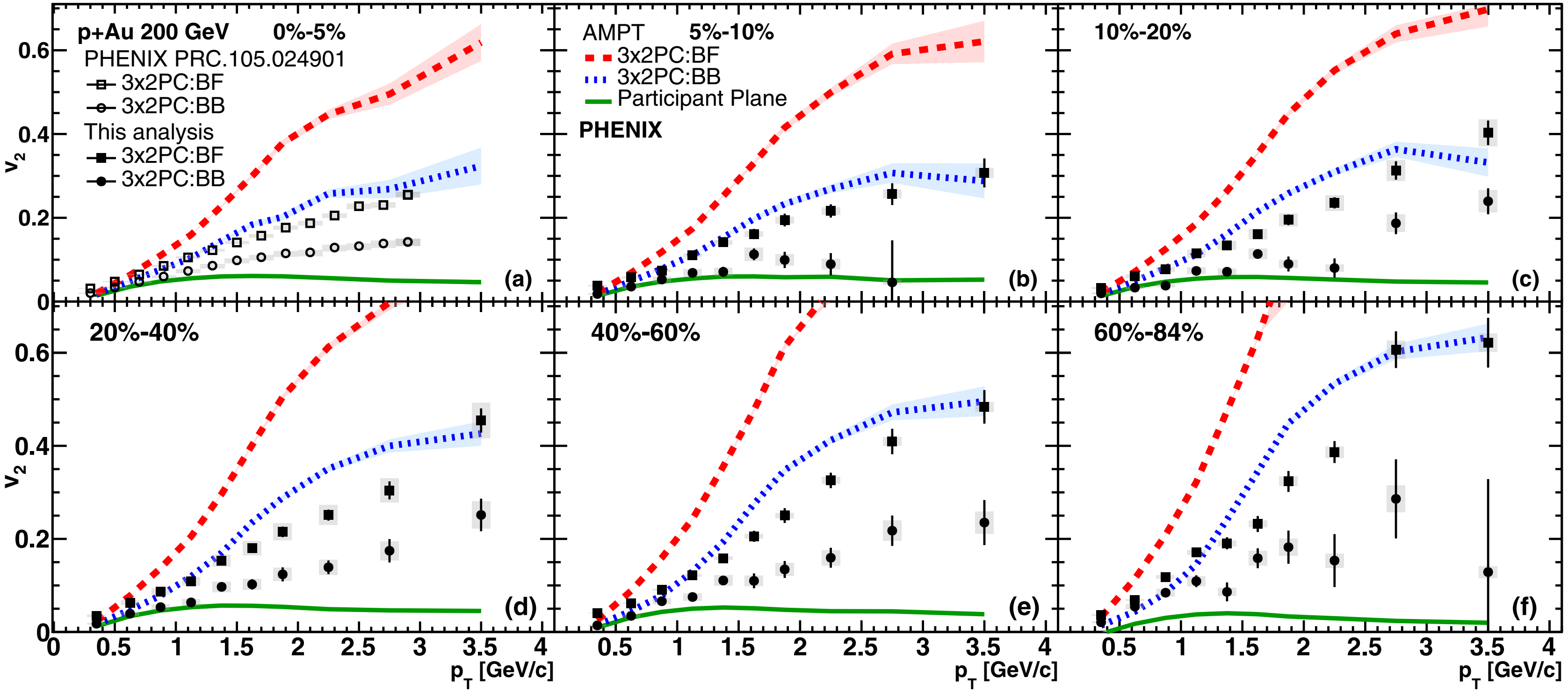
Comprehensive look at PHENIX Data and Analysis

2-Particle Correlation v_2

v_2 in p+Au, d+Au, 3He+Au (PRC 107 024907 [2024])

v_2 in Small Systems

- Extending prior central result (PRC 105 024901)
- greater v_2 for more peripheral collisions



Comprehensive look at PHENIX Data and Analysis

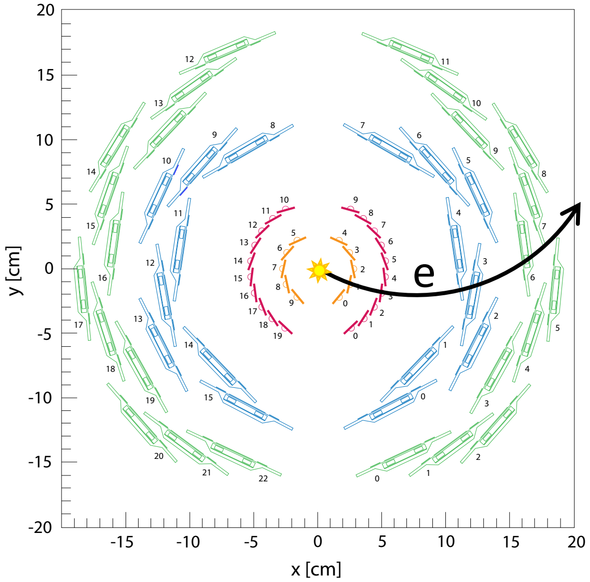
Midrapidity Heavy-Flavor Measurement

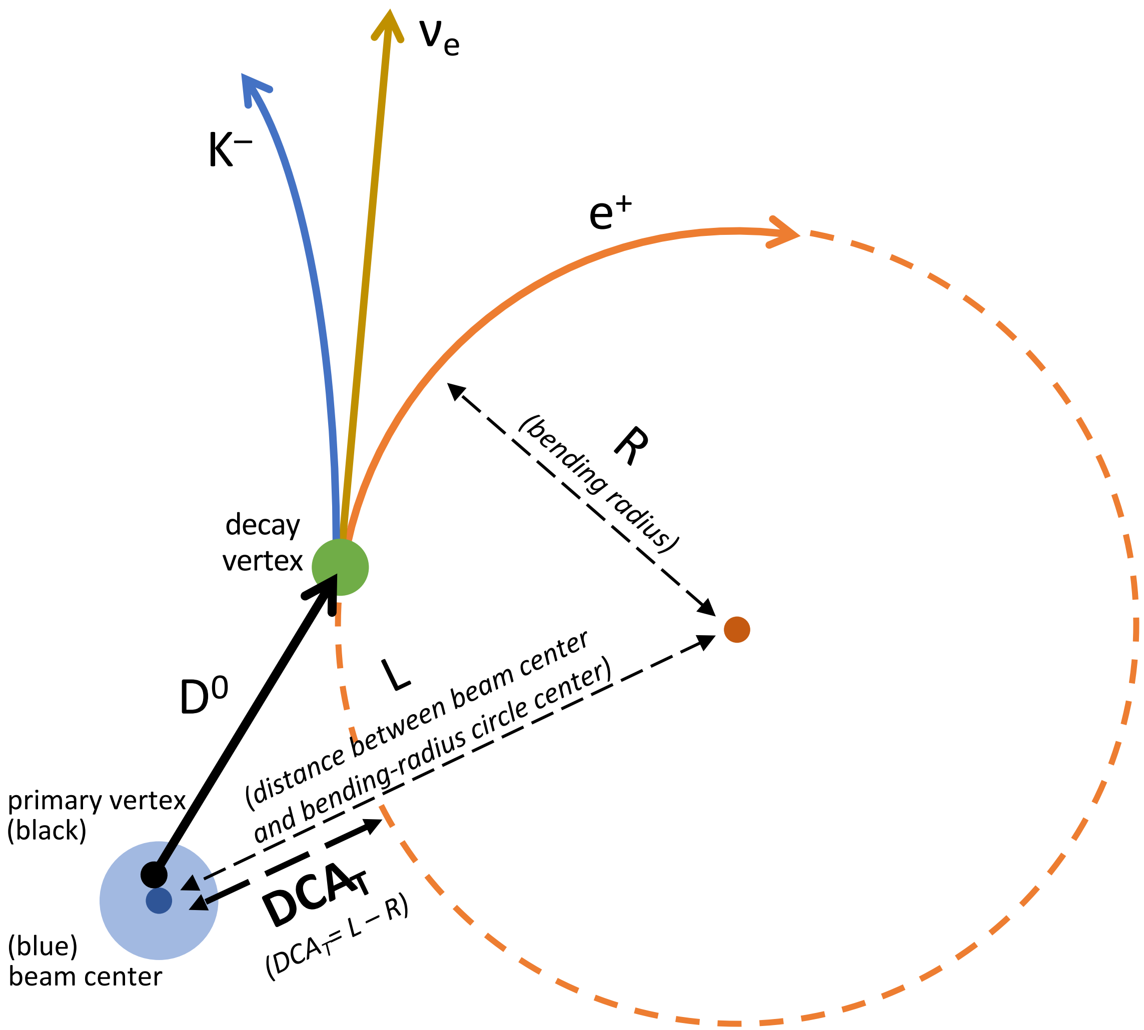
Heavy Flavor in PHENIX

Flavor Determination Using the VTX, DC/PC, RICH, EMCal

- $|\eta| < 0.35$
- $\Delta\phi = \pi$
- Electron-ID: RICH, EMCal
- Track projection of electrons back to the primary vertex
- ID HF electrons based on DCA_T (lifetime)

Particle (Antip.)	*Lifetime* ($c\tau$, μm)
D^0 ($\overline{D}^0$)	122.9
D^+ (D^-)	311.8
D_s^+ (D_s^-)	151.2
Λ_c^+ ($\overline{\Lambda}_c^-$)	60.7
B^0 ($\overline{B}^0$)	455.4
B^+ (B^-)	491.1
B_s^0 ($\overline{B}_s^0$)	454.2
Λ_b^0 ($\overline{\Lambda}_b^0$)	441.0



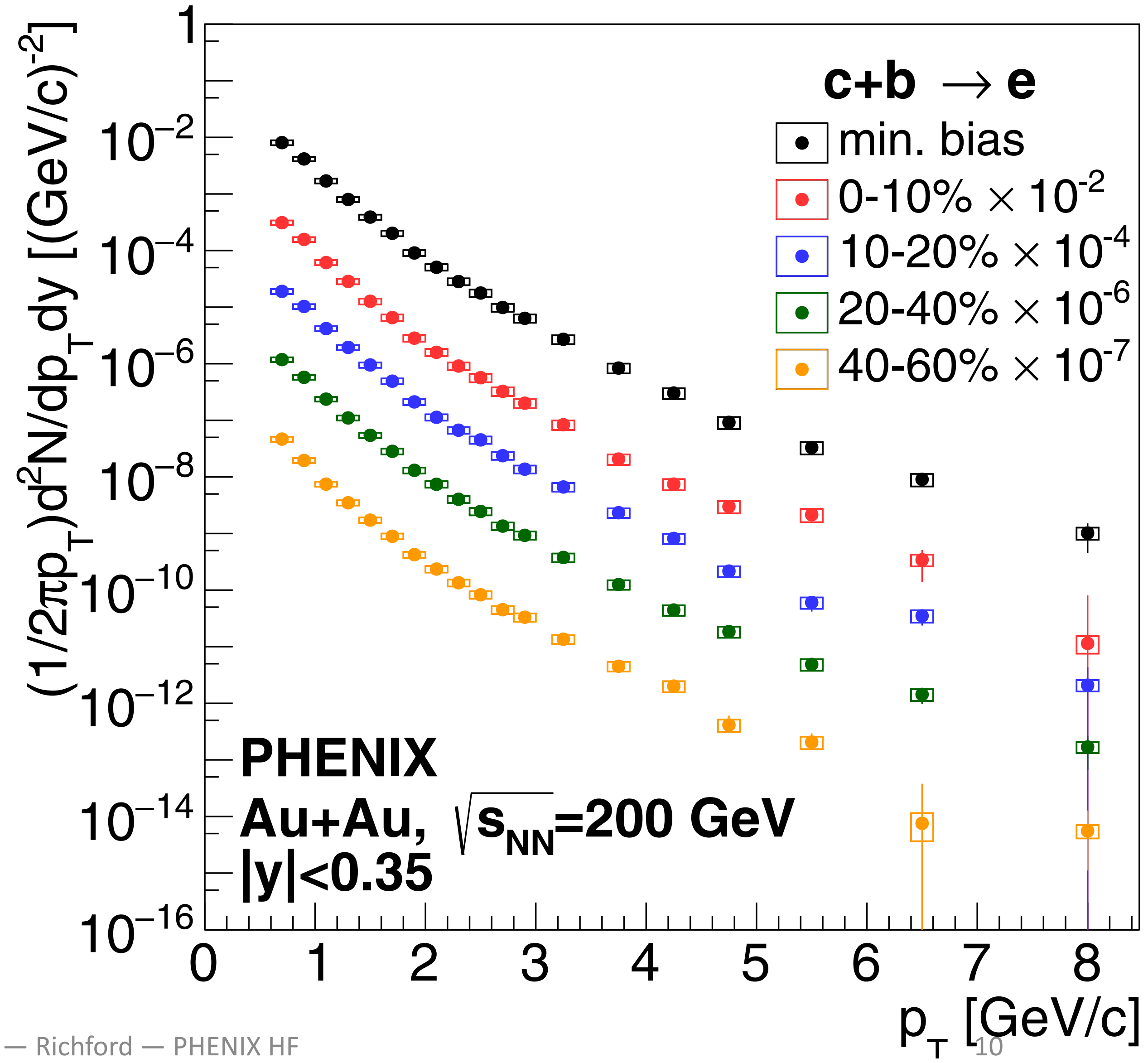


HF IY, *c*- & *b*-hadron separation, RAA for Au + Au 200 Gev @ different centrality (PRC 109 044907 [2024])

Improvement over last analysis:
6x more data!
Larger active VTX area for tracking
Extended p_T results down to 1 GeV/c
Reduced systematic uncertainties

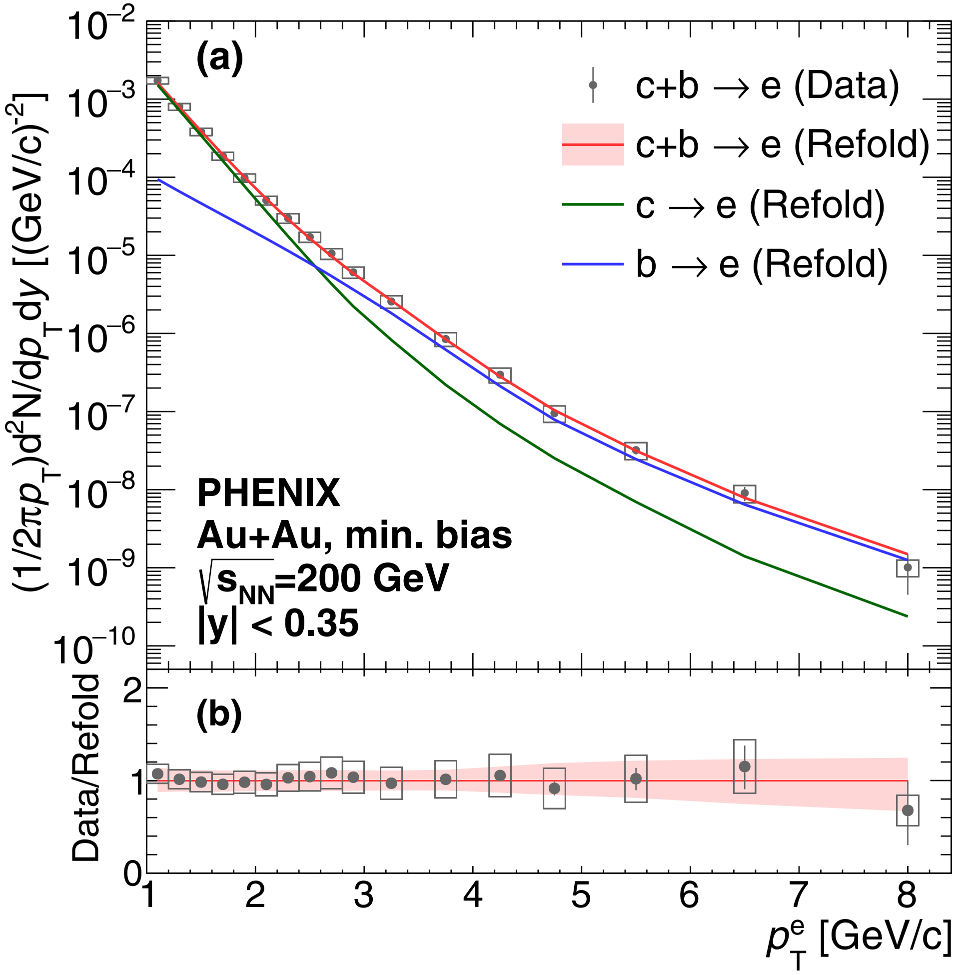
Heavy-Flavor Invariant Yield

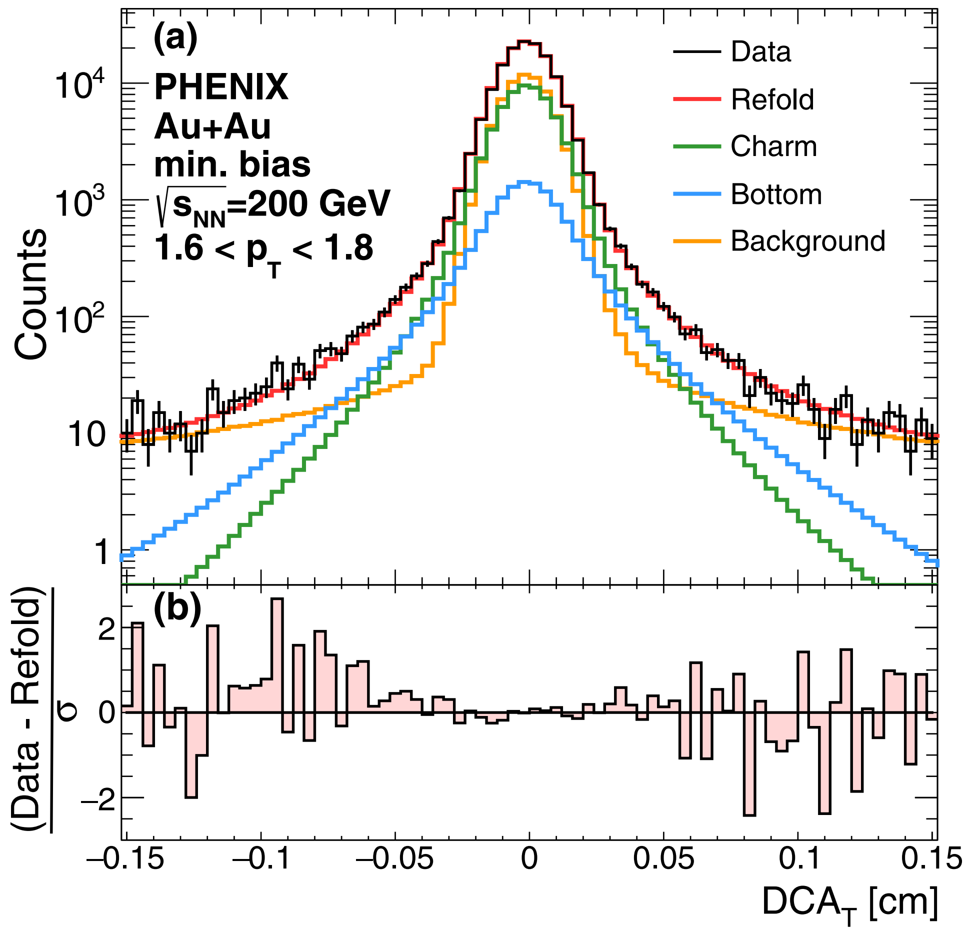
- **Centrality classes scaled for clarity**



AuAu 200 Gev @ different centrality classes (PRC 109 044907)

Unfolding Result





Au+Au HF

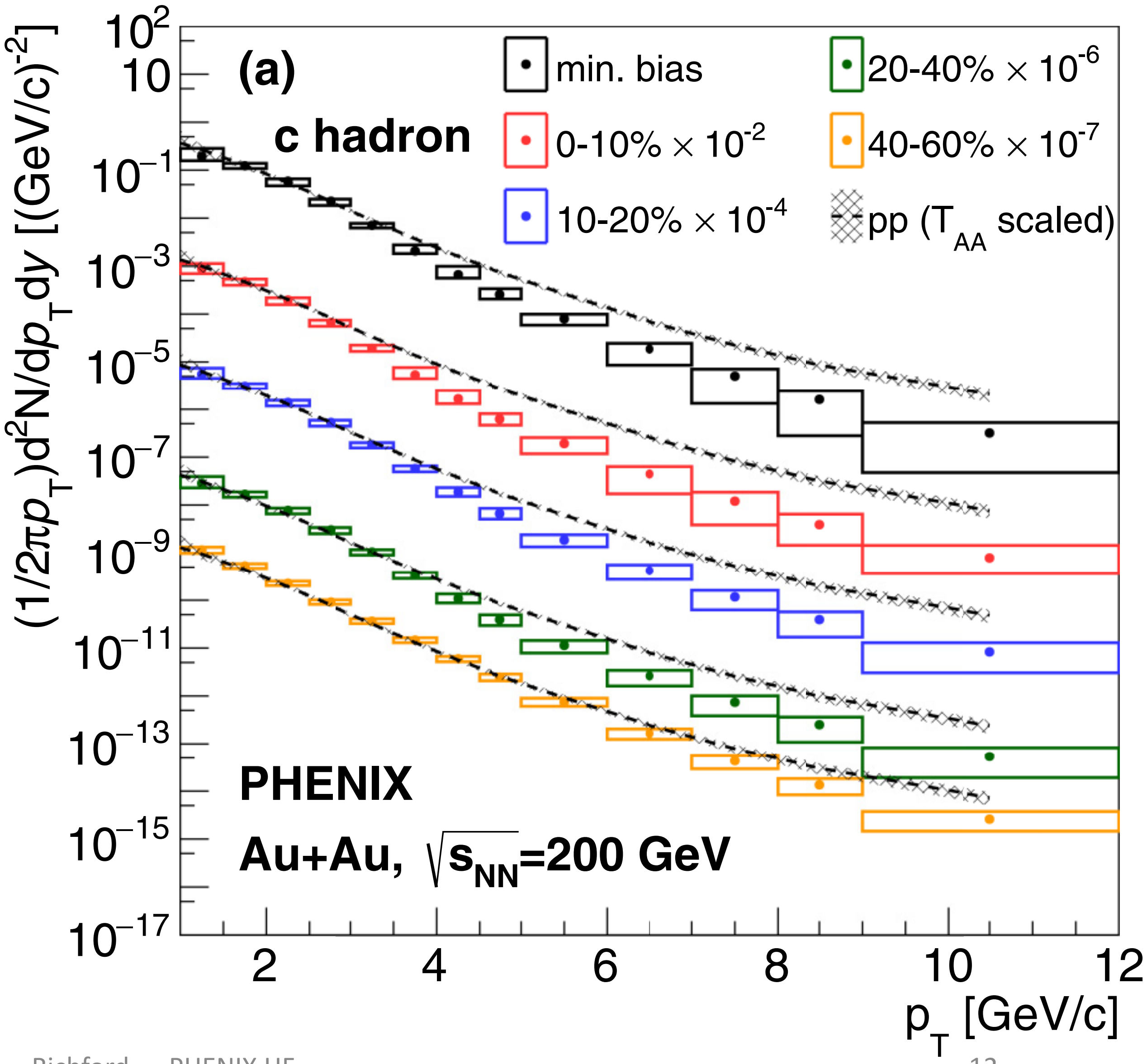
AuAu 200 Gev @ different centrality classes (PRC 109 044907)

Charm-Hadron Invariant Yield

- Centrality classes scaled for clarity
- pp reference scaled by TAA

Suppression for all centrality classes

- Greater for more-central events



Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

Bottom Hadron Invariant Yield

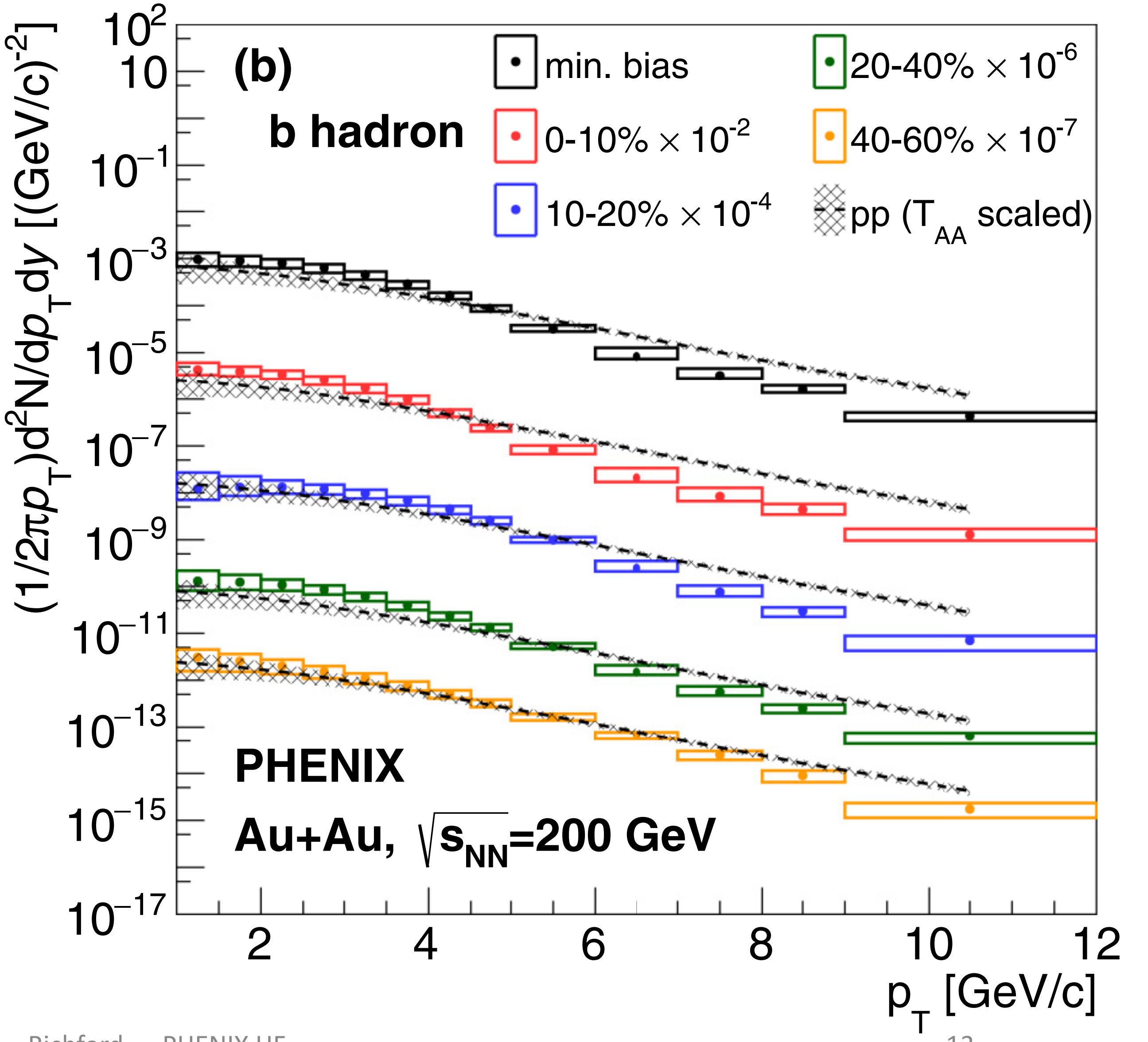
- Centrality classes scaled for clarity
- pp reference scaled by TAA

Mass ordering

- less than charm

Suppression for all centrality classes

- Greater for more-central events



Au+Au HF

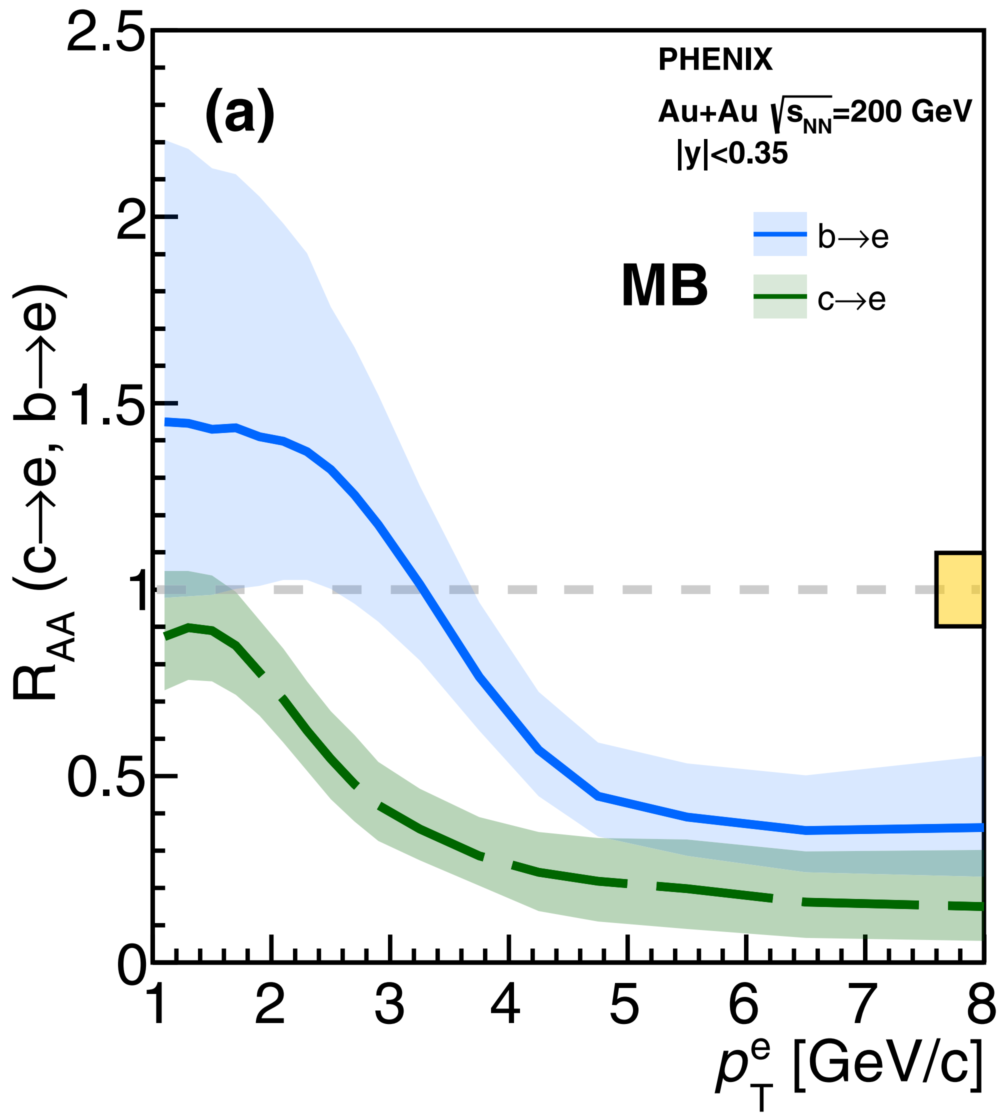
AuAu 200 Gev @ different centrality classes (PRC 109 044907)

$$R_{AA}^{c\to e} = \frac{(1 - F_{\rm AuAu})}{(1 - F_{pp})} R_{AA}^{\rm HF}$$

$$R_{AA}^{b\to e} = \frac{F_{\rm AuAu}}{F_{pp}} R_{AA}^{\rm HF},$$

F_{xx}: *b*-fraction

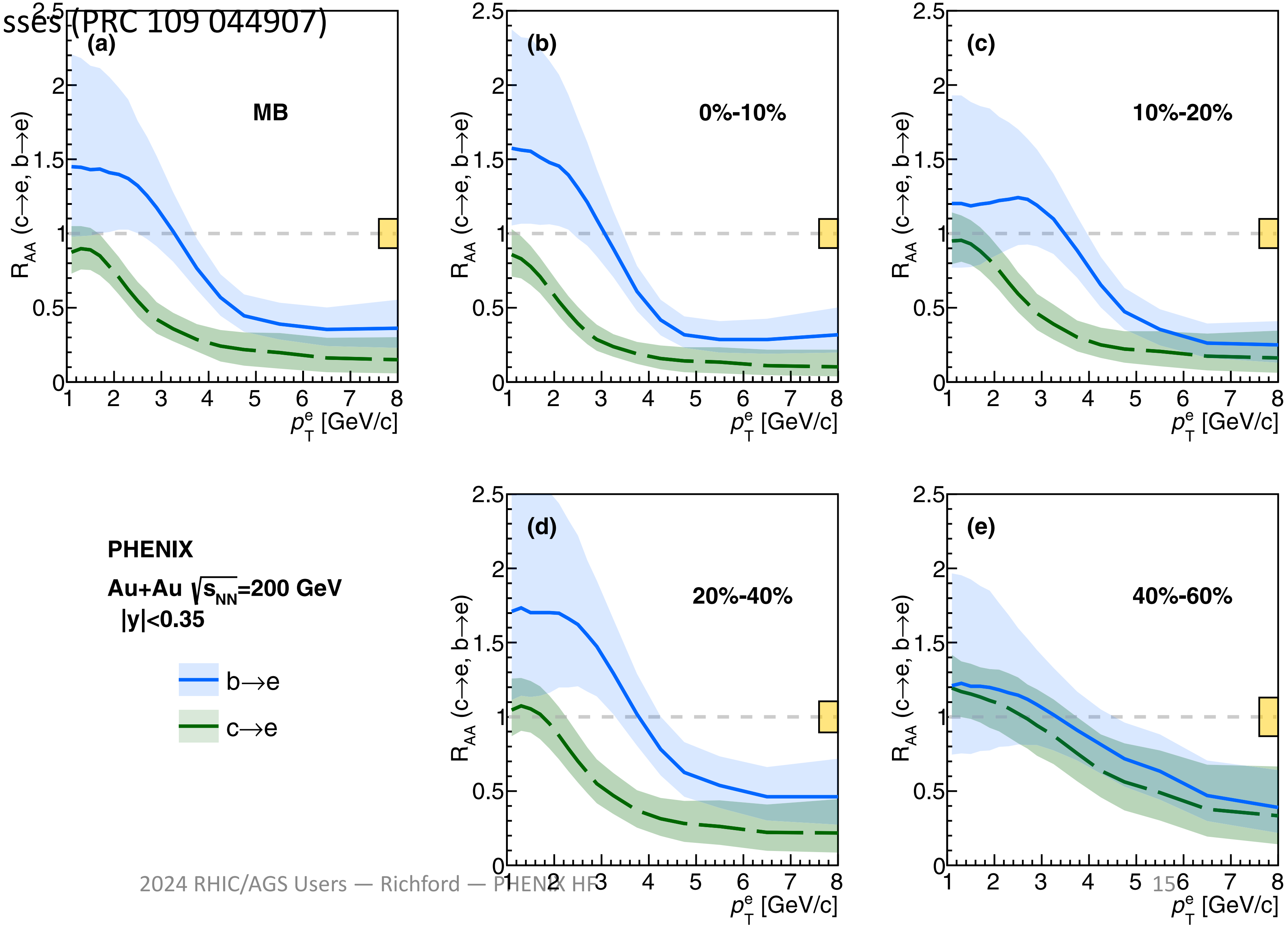
$R_{AA}{}^{HF}$: anticorrelated *c*-, *b*-inclusive HF hadron R_{AA}



Result

- Large charm suppression above 3.5-4 GeV/c
- Bottom suppression above 1-2 GeV/c

AuAu 200 Gev @ different centrality classes (PRC 109 044907)



Result

- Greater HF suppression in central collisions

Heavy-Flavor Flow

HF Electron Flow @ Midrapidity

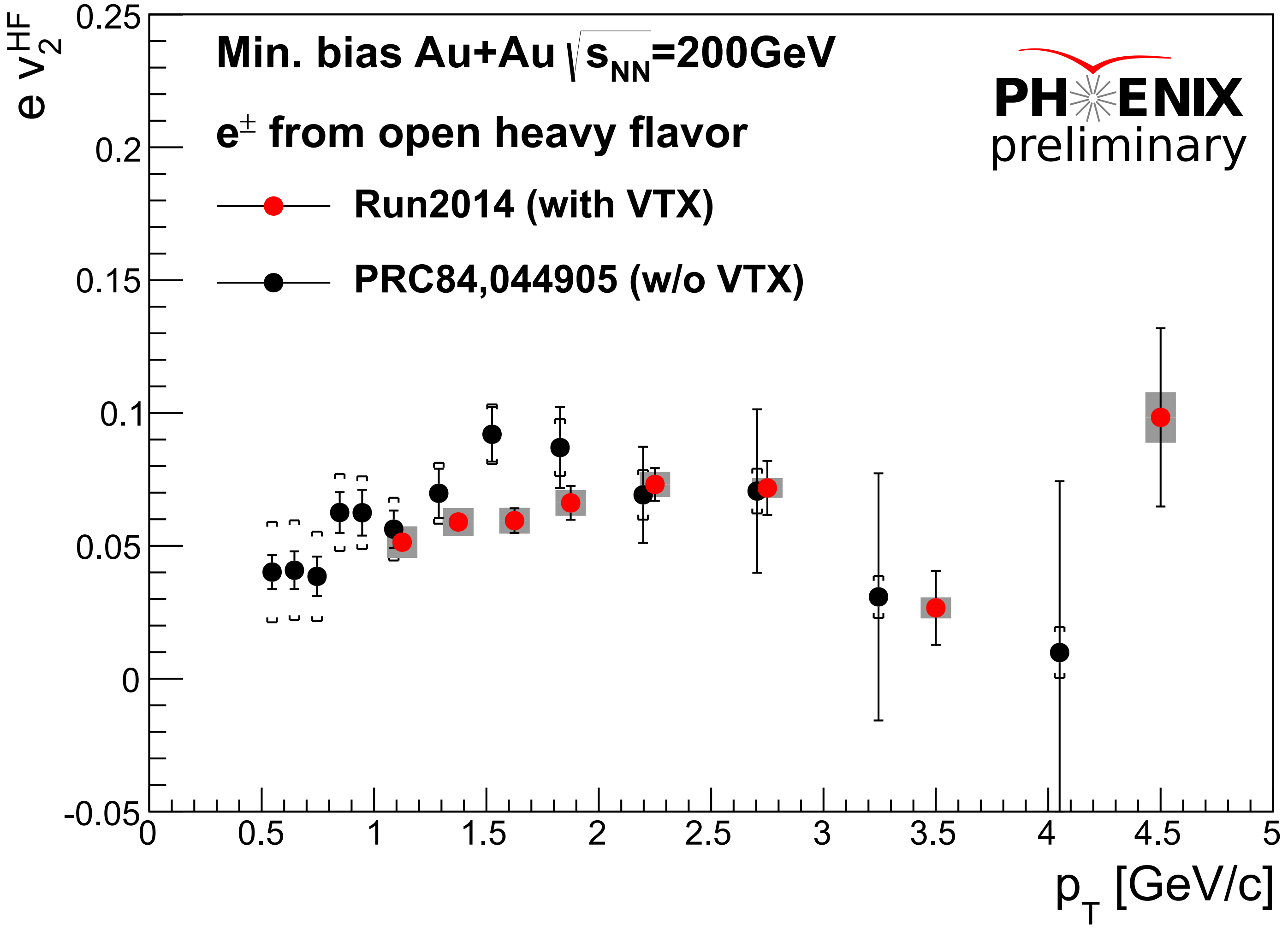
Additional Details: Nuc. Phys. A 982 663

HF v_2 at midrapidity

$$v_2^{meas} = < cos(2 \cdot (\phi_i - \Psi)) >$$

- c + b together
- consistent with prior measurement without Silicon Vertex detector tracking

- Clear collective motion
- Small uncertainty

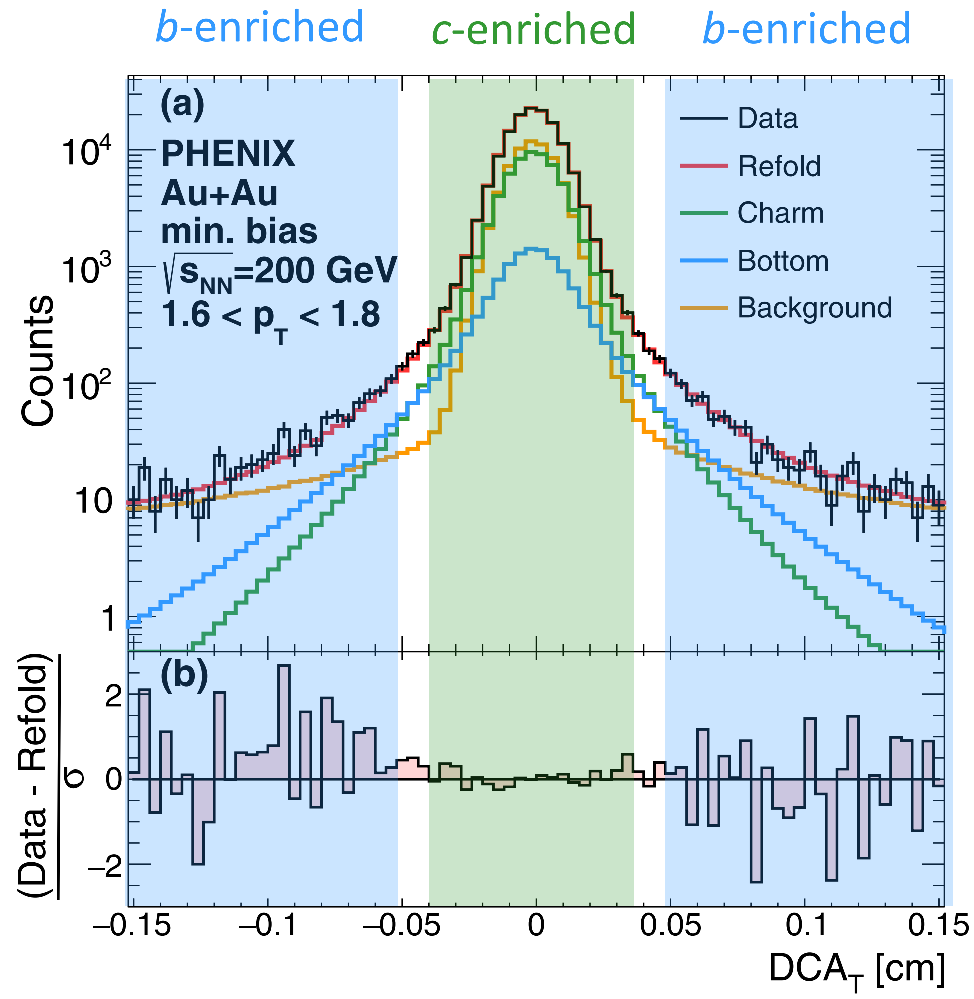


HF Electron Flow

HF Flow @ Midrapidity (electrons) (Conf.: Nuc.Phys.A 982 663)

c-, b-separation from unfolding leads to flow measurement at midrapidity

- measure v_2 in flavor-enriched DCA_T regions

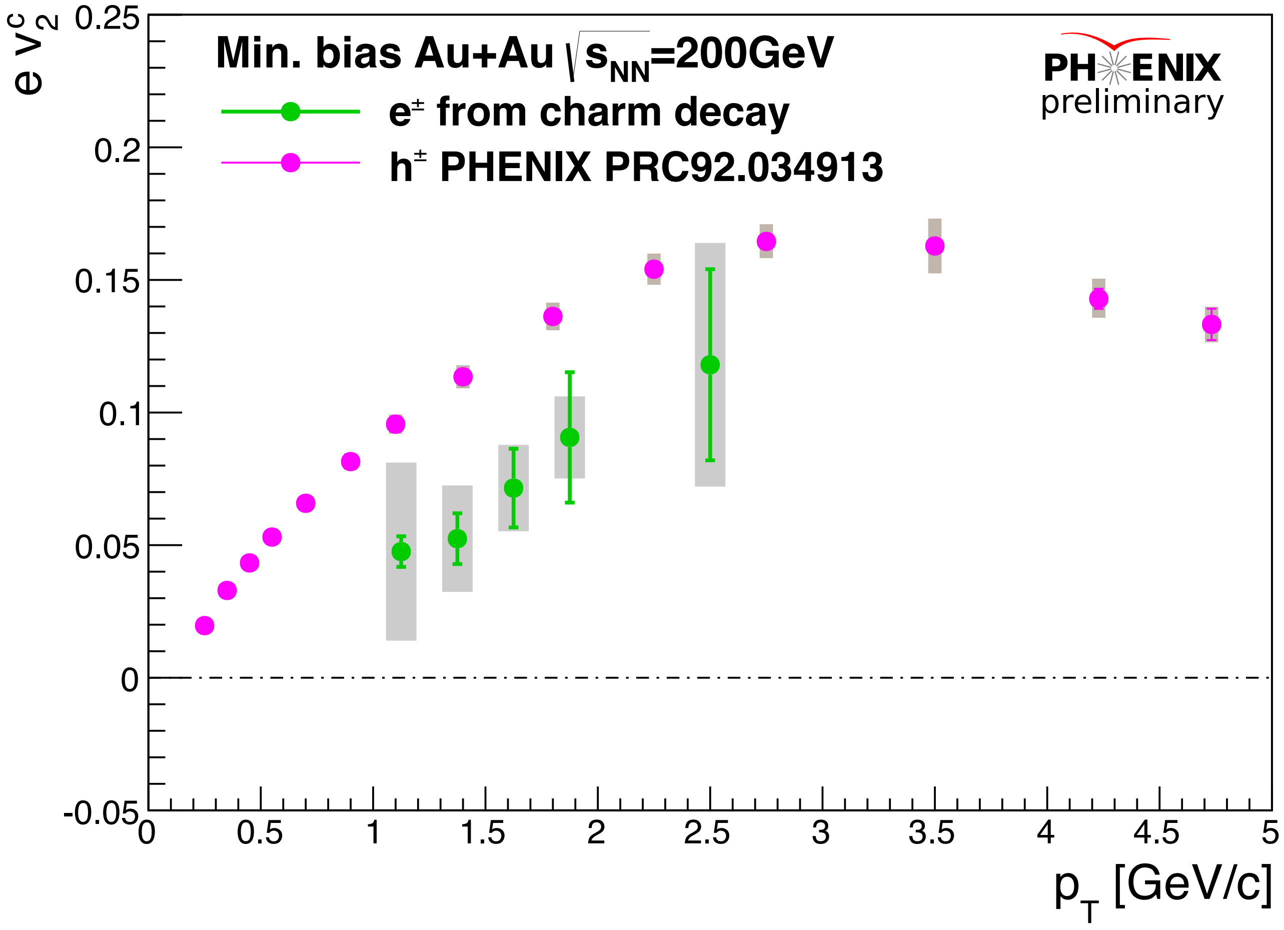


HF Electron Flow

HF Flow @ Midrapidity (electrons) (Conf.: Nuc.Phys.A 982 663)

Charm electron v_2

- Comparison to prior charged hadron measurement
- less elliptic flow below 3 GeV/c

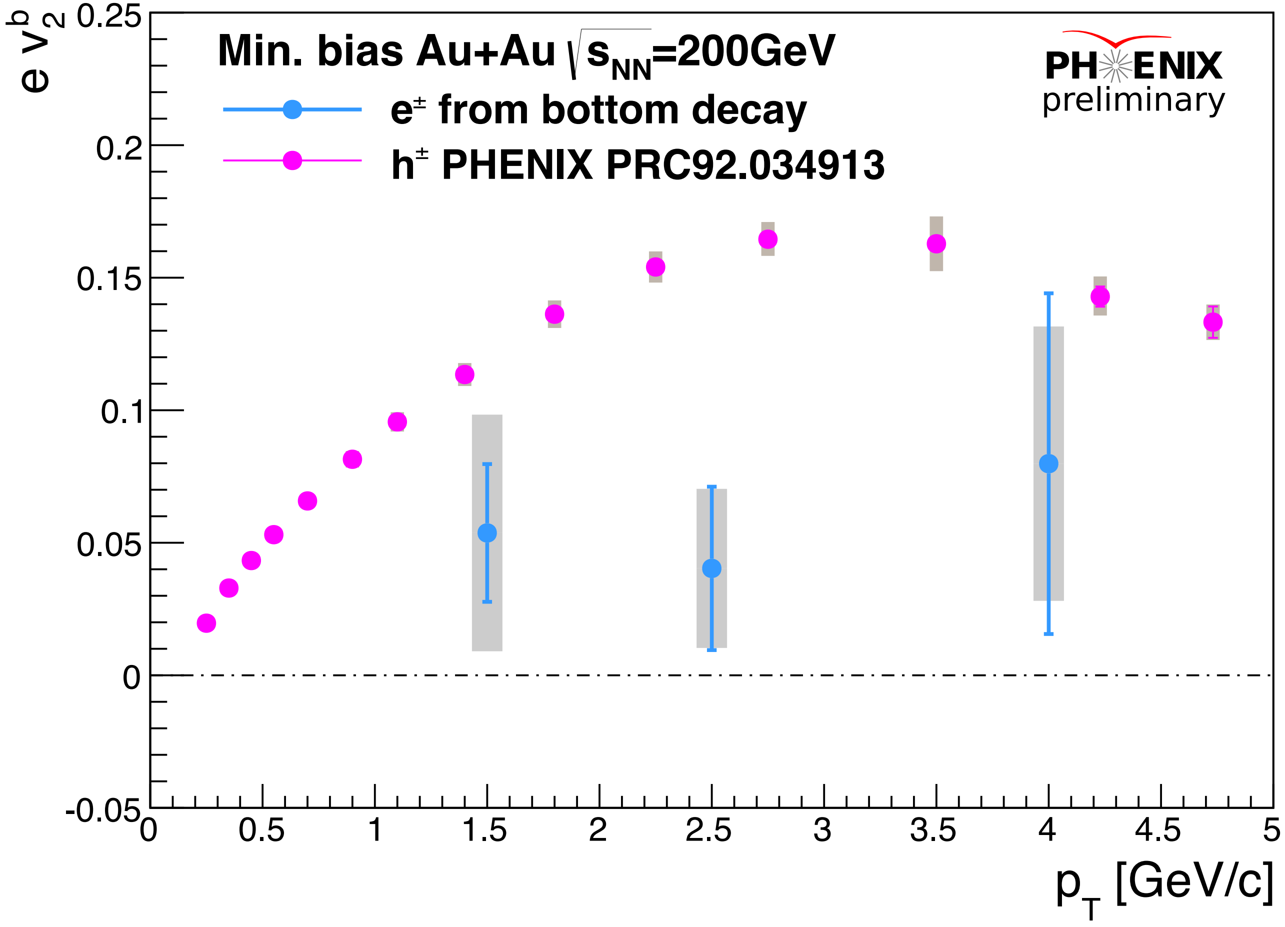


HF Electron Flow

HF Flow @ Midrapidity (electrons) (Conf.: Nuc.Phys.A 982 663)

Bottom electron v_2

- Comparison to prior charged hadron measurement
- less elliptic flow below 4 GeV/c

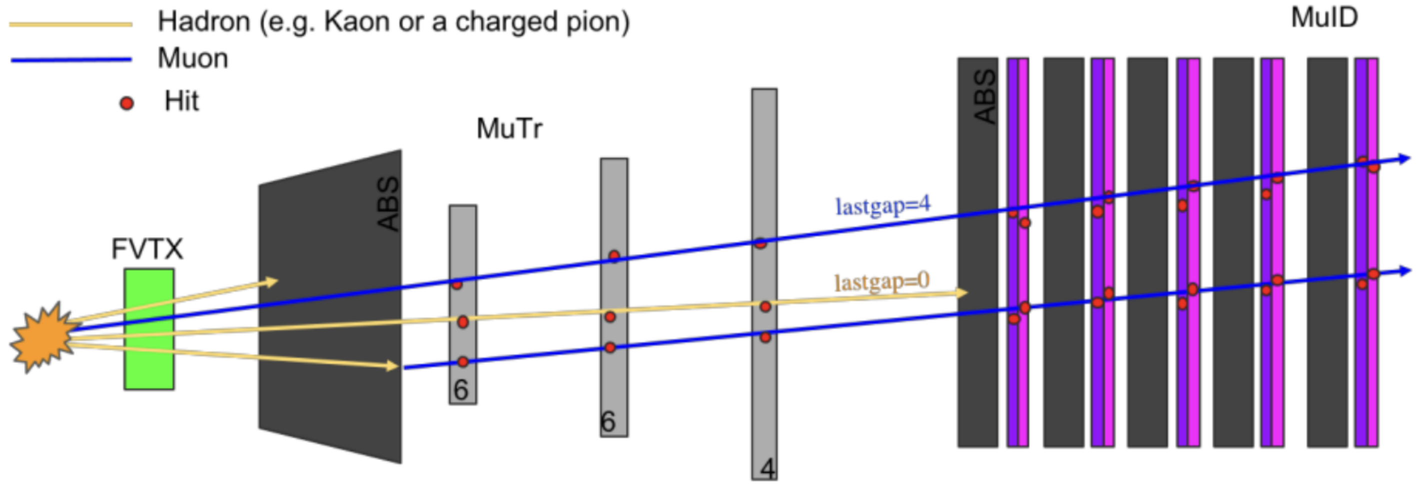


Muon Detectors in PHENIX

HF Muon Flow @ Forward Rapidity

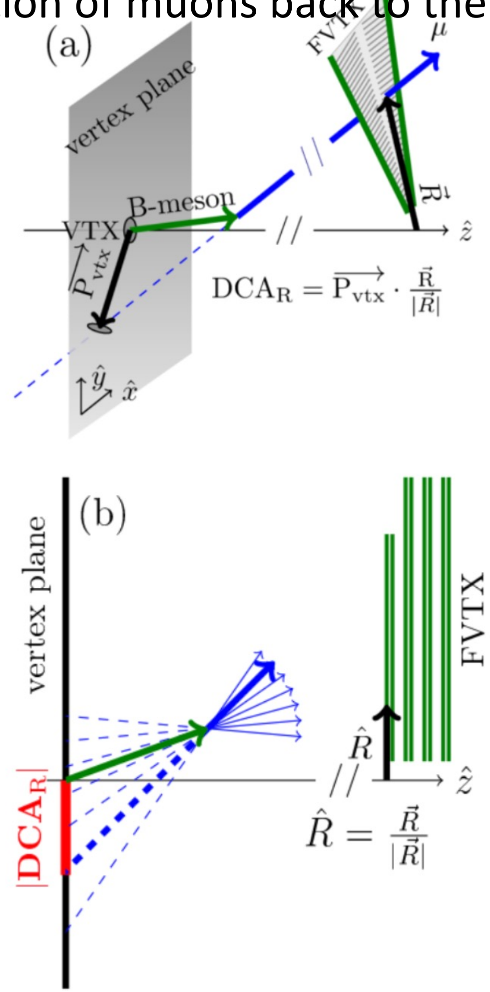
https://indico.cern.ch/event/1139644/contributions/5456502/

$$v_2^{HF} = \frac{1}{F^{HF}}\left(v_2^{\mu} - (1 - F^{HF})v_2^{LF}\right)$$



Flavor Determination Using the FVTX, MuTr

- $1.2 < |\eta| < 2.2$
- $\Delta\phi = 2\pi$
- Muon-ID: MuID
- Track projection of muons back to the primary vertex
- DCA_R

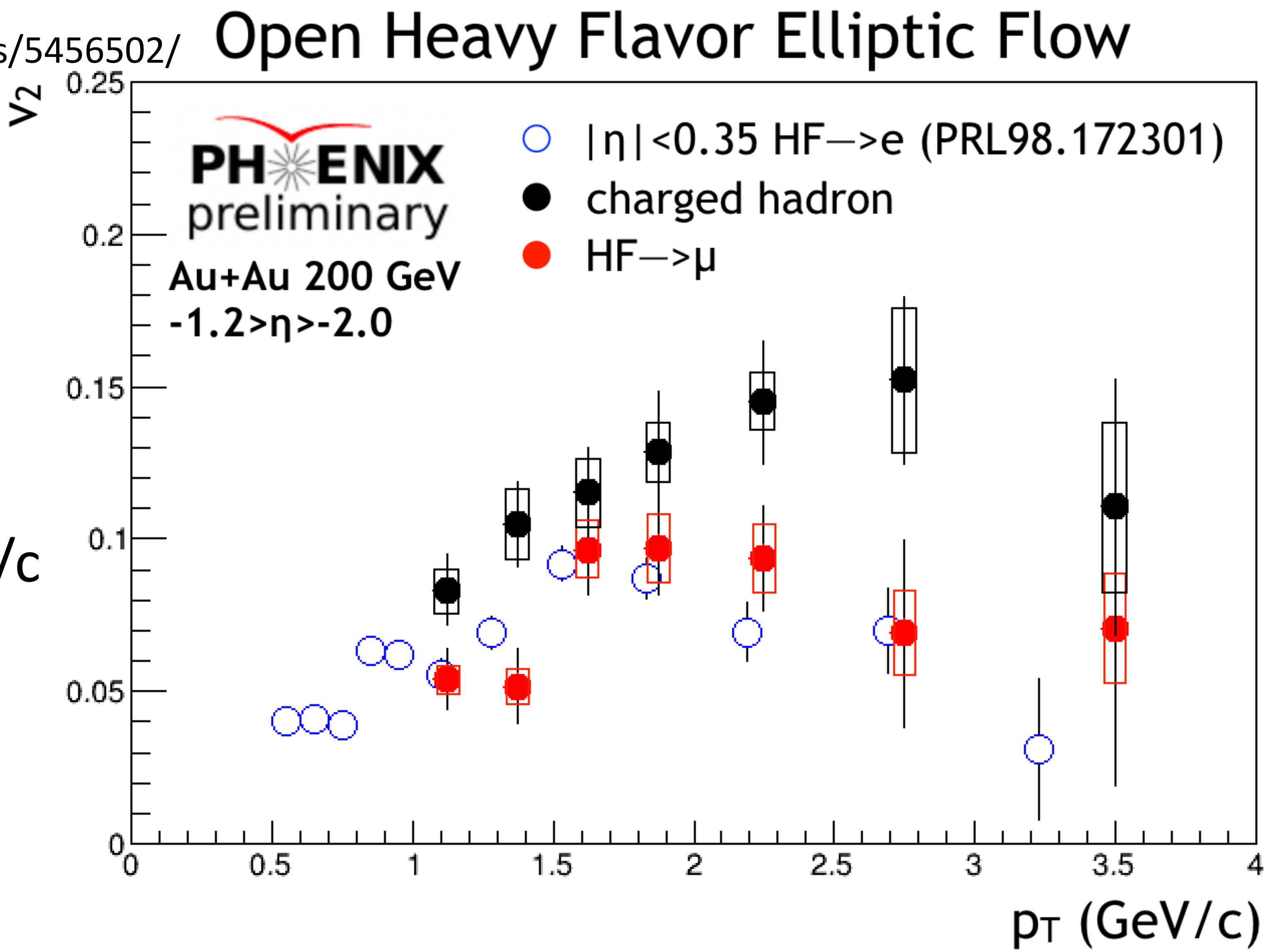


HF Muon Flow

HF Muon Flow @ Forward Rapidity (muons)
https://indico.cern.ch/event/1139644/contributions/5456502/

HF-inclusive muon v_2

- Comparison to prior charged hadron measurement
- less elliptic flow below 4 GeV/c
- Consistent with results at midrapidity!



PHENIX

Summary (the end)

PHENIX data and analysis are comprehensive and sophisticated

- Many reaction types from pp to UU, and mixed

HF Production and c-, b-separation result in Au+Au shows significant improvement from prior result

- More statistics, less uncertainty
- Clear suppression of charm and bottom hadrons in QGP, varying by centrality and n_{Part}

Clear HF v_2 at midrapidity and forward rapidity

- Agreement between the two probes
- Separate c, b v_2 shows mass-ordering

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PHENIX

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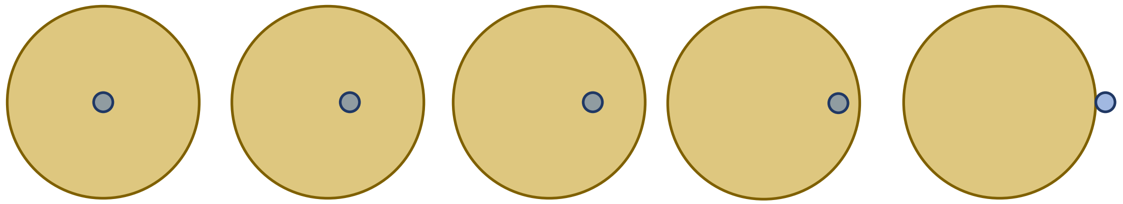
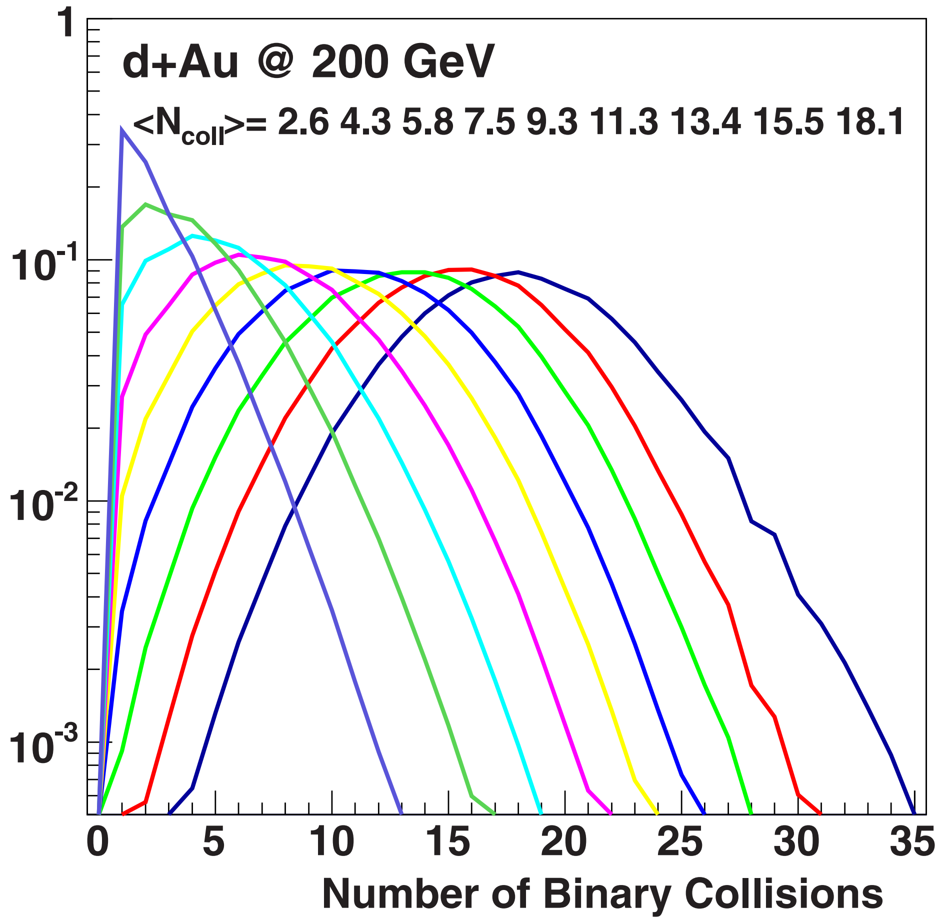
Backup Slides

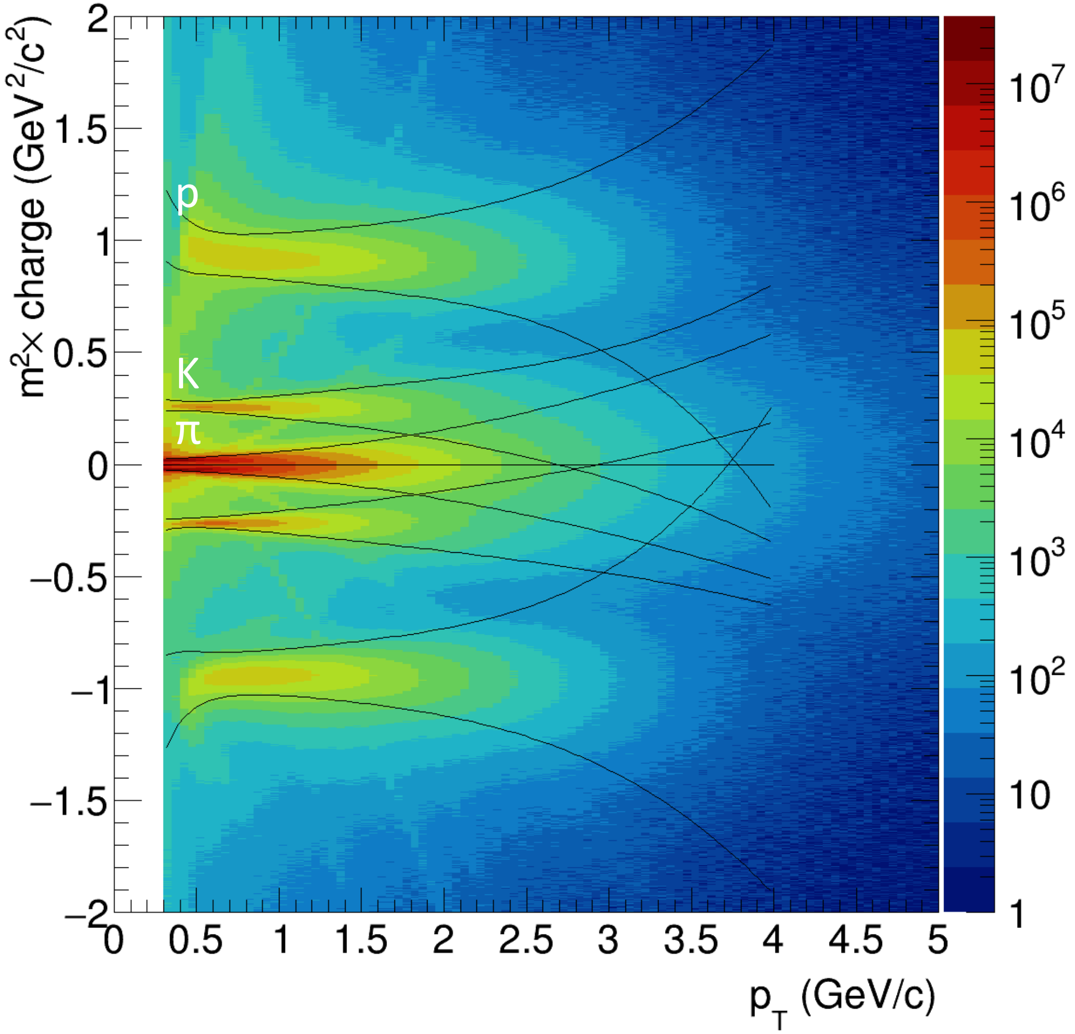
Geometric and Momentum Anisotropy and Measure of Event Activity





TOF Particle ID in PHENIX

Particle-ID Using the TOF, DC



$$m^2 = \frac{p^2}{c^2}\left(\frac{t^2c^2}{L^2} - 1\right)$$

mass squared

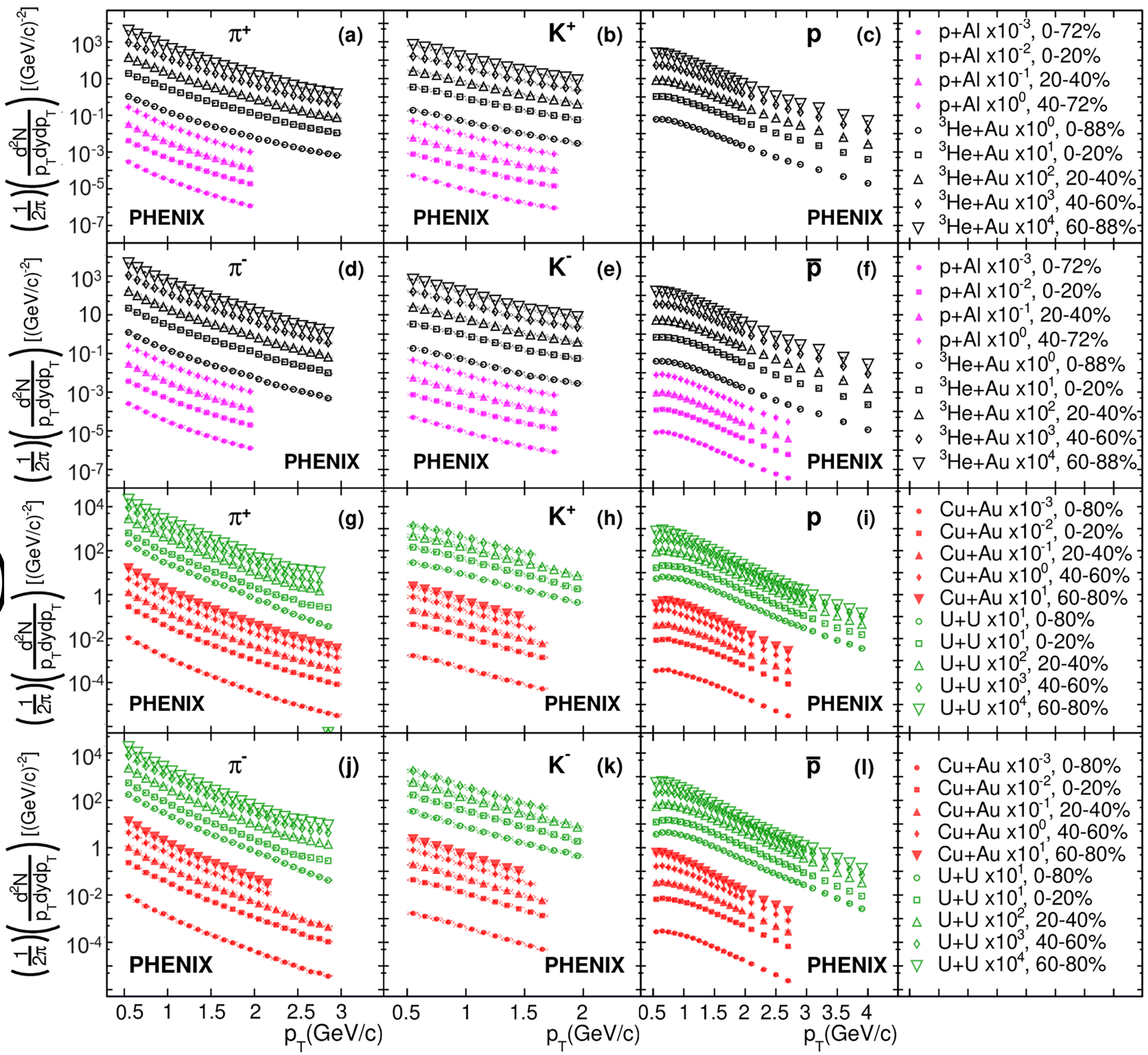
measured momentum

measured time of flight

measured distance from event vertex to TOF detector

Light Flavor in PHENIX

Charged hadrons of different collision systems @ different centrality classes (PRC 109 054910)

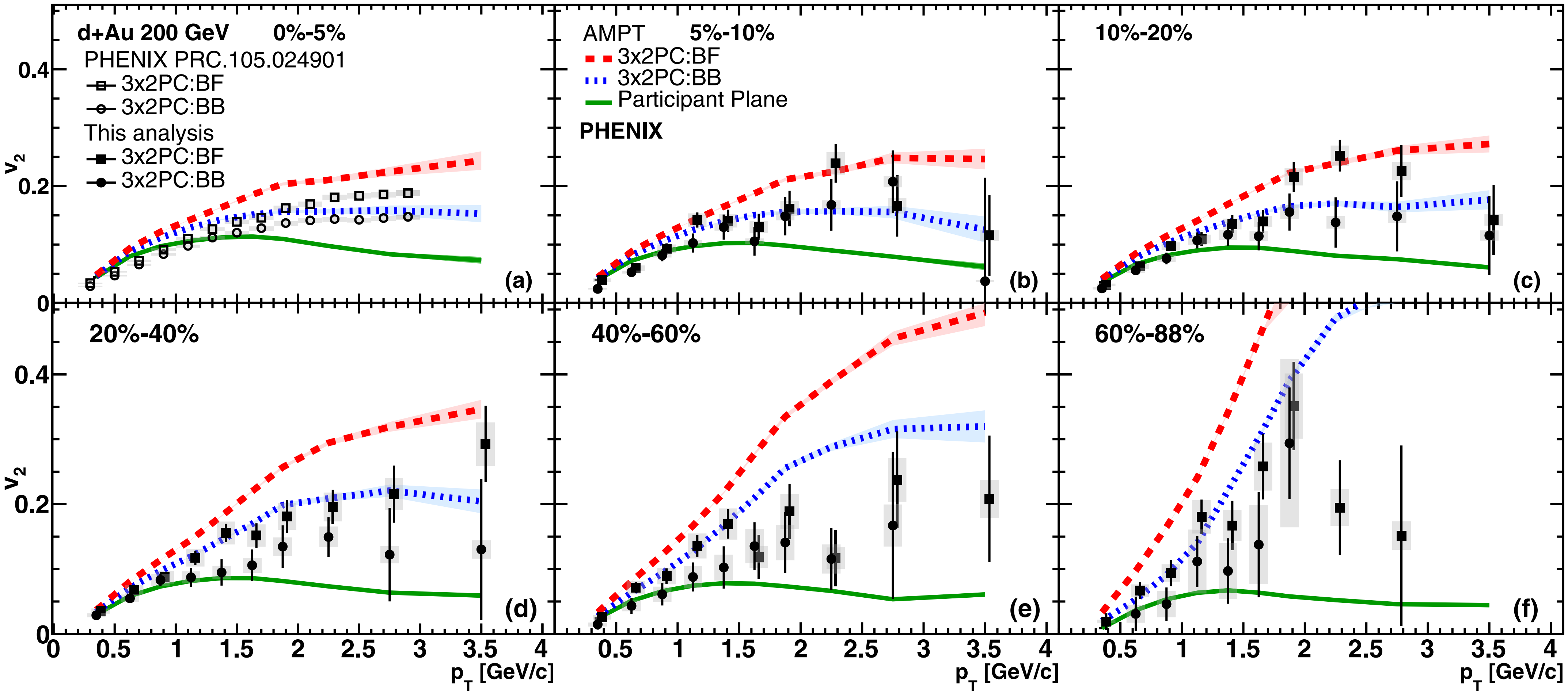


Light-Flavor Invariant Yield

- Small systems (black=pAl, pink=3HeAu)
- Large systems (green=CuAu, red=UU)
- Centrality classes scaled for clarity

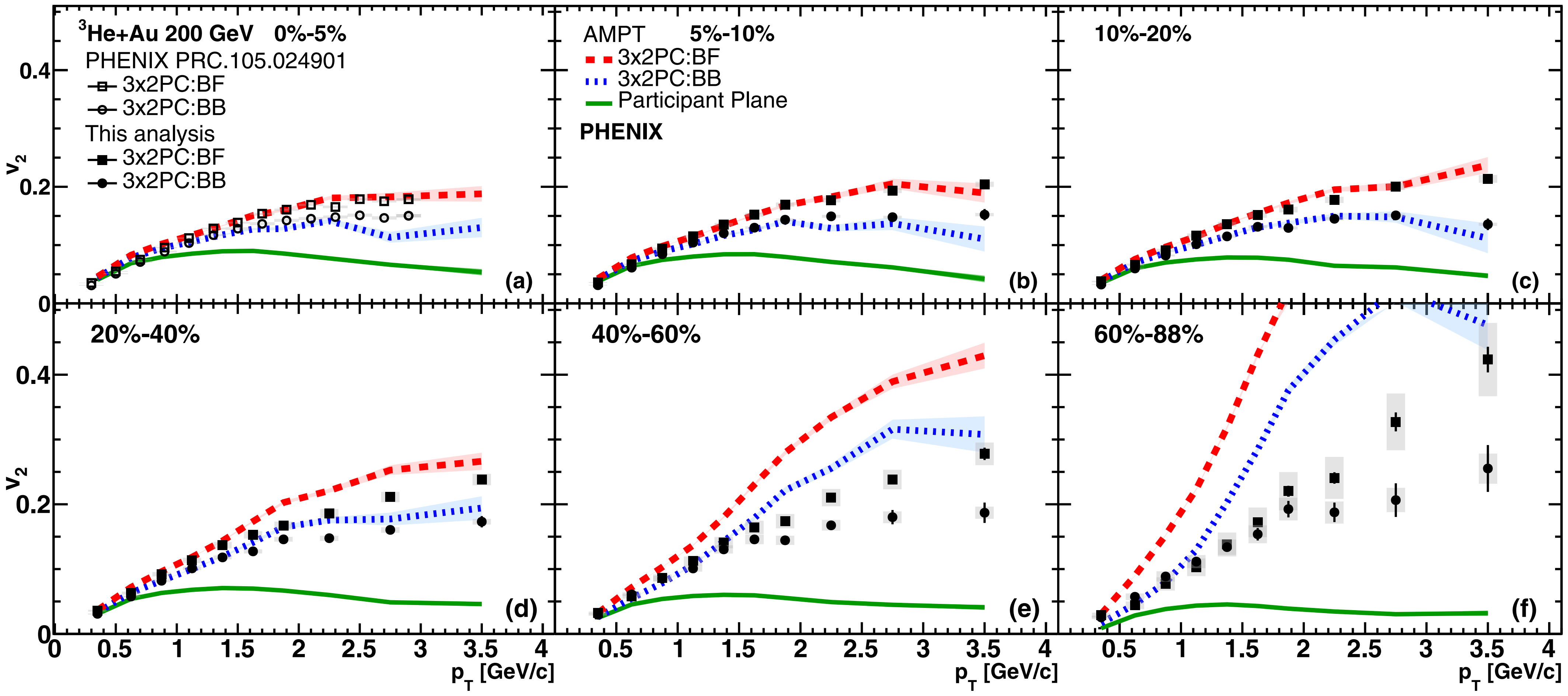
2-Particle Correlation v_2

v2 in small systems @ different centrality classes (PRC 107 024907)



2-Particle Correlation v_2

v2 in small systems @ different centrality classes (PRC 107 024907)

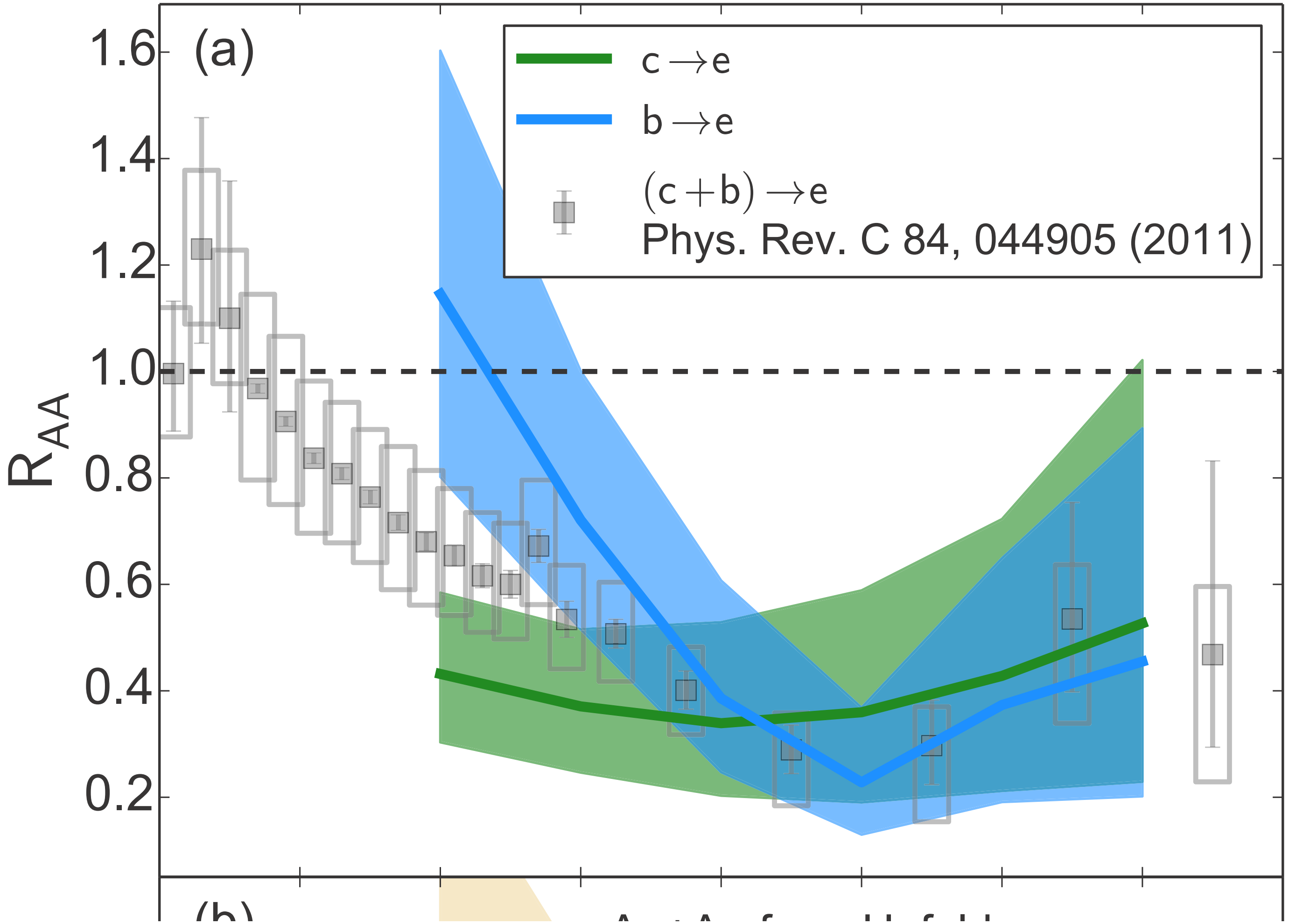


Prior Result: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

Prior Result
PRC 93 034904

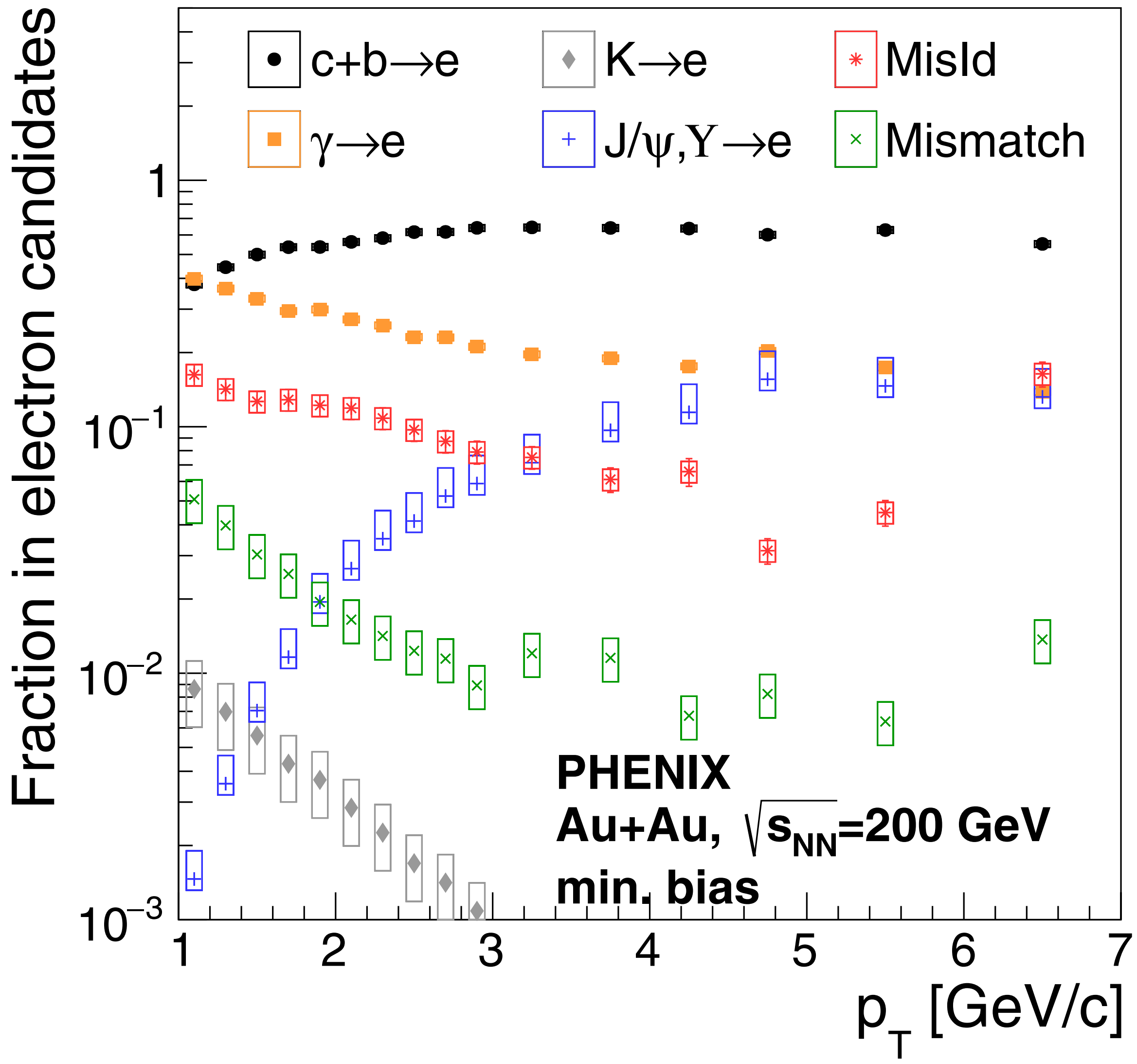
Fig. 19



Background Comp.: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

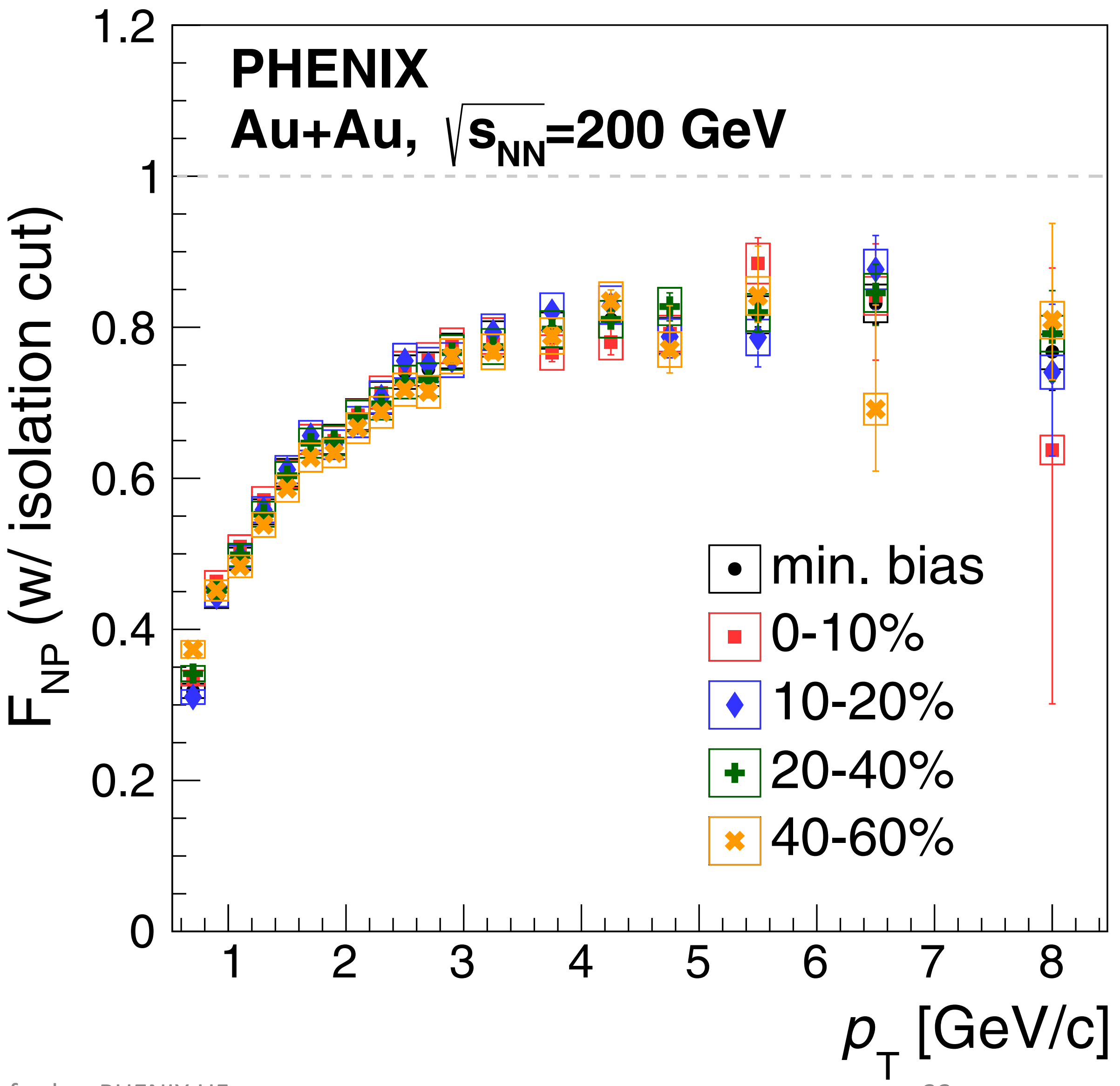
Simulation of background components



Unfolding: F_{NP}: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

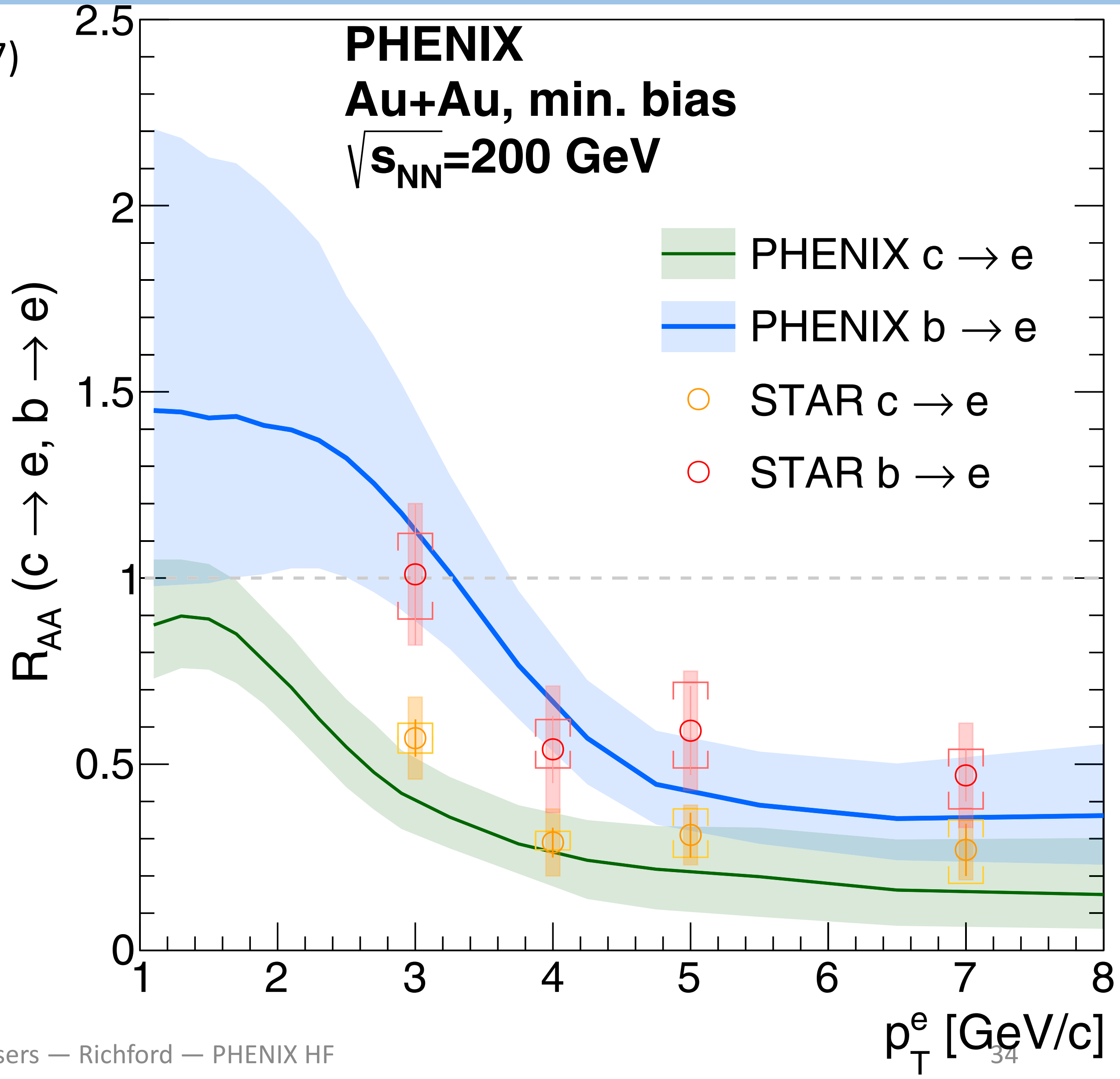
Unfolding constraint: FNP



Comparison to STAR: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

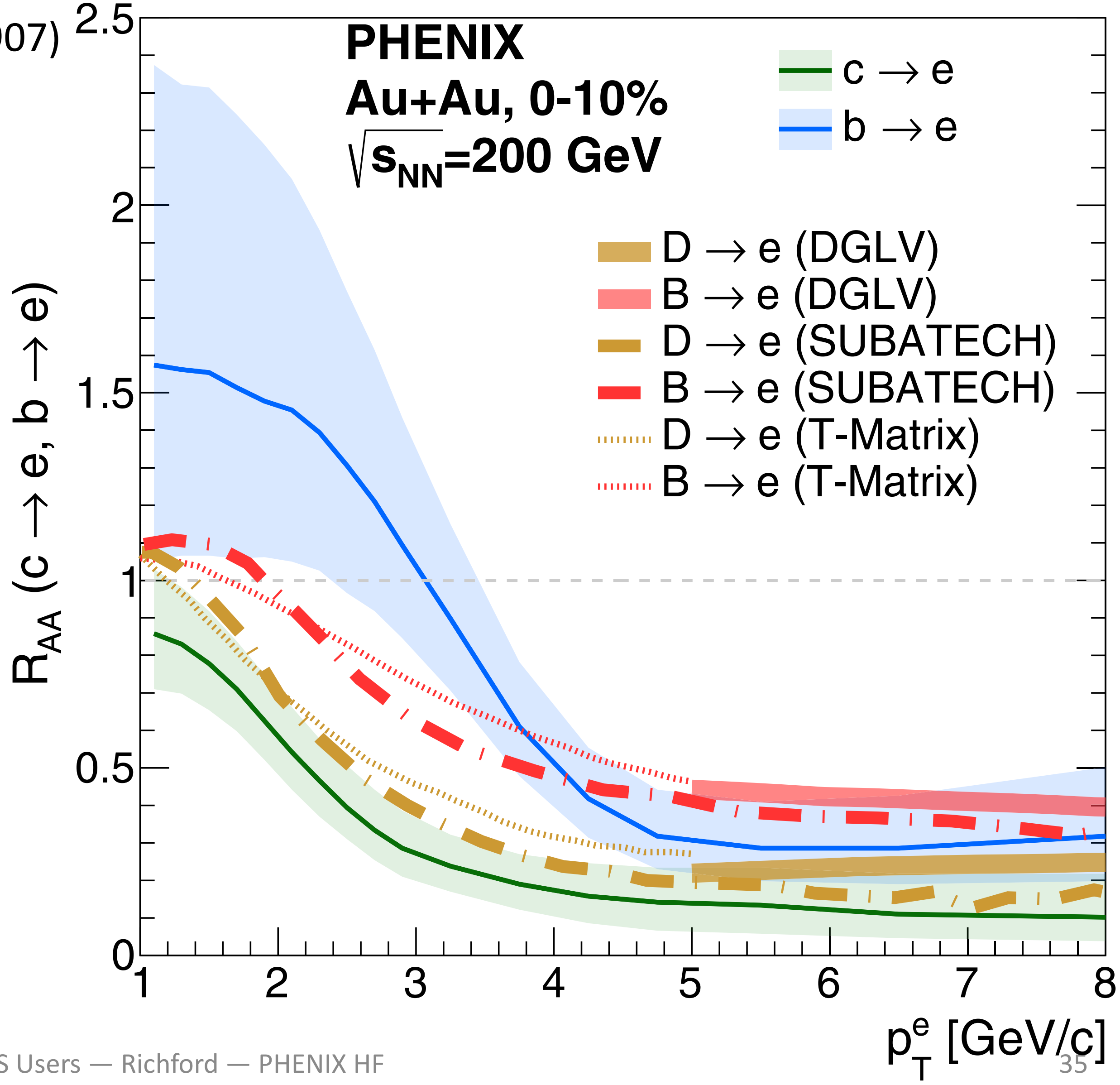
Comparison to Star



Comp'n to Models: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

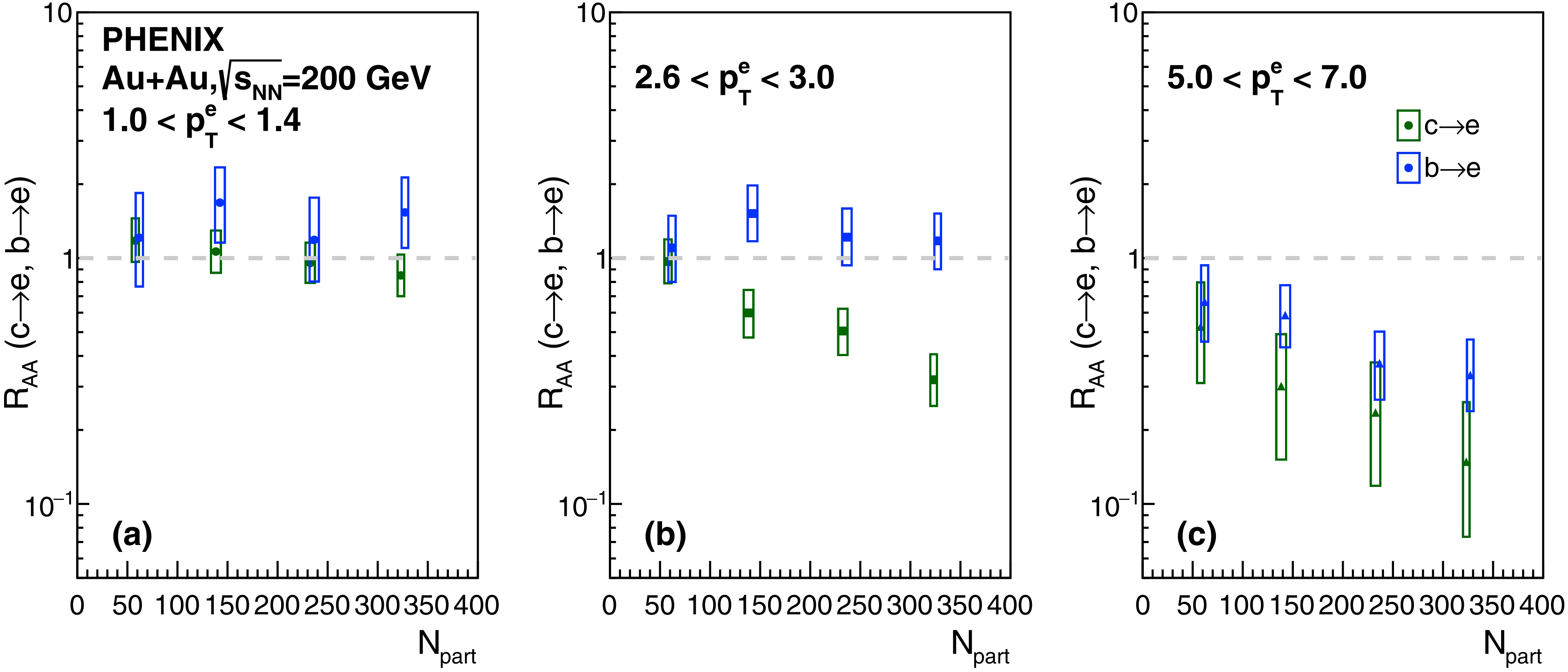
Comparison to Models



n_{Part} scaling: Au+Au HF

AuAu 200 Gev @ different centrality classes (PRC 109 044907)

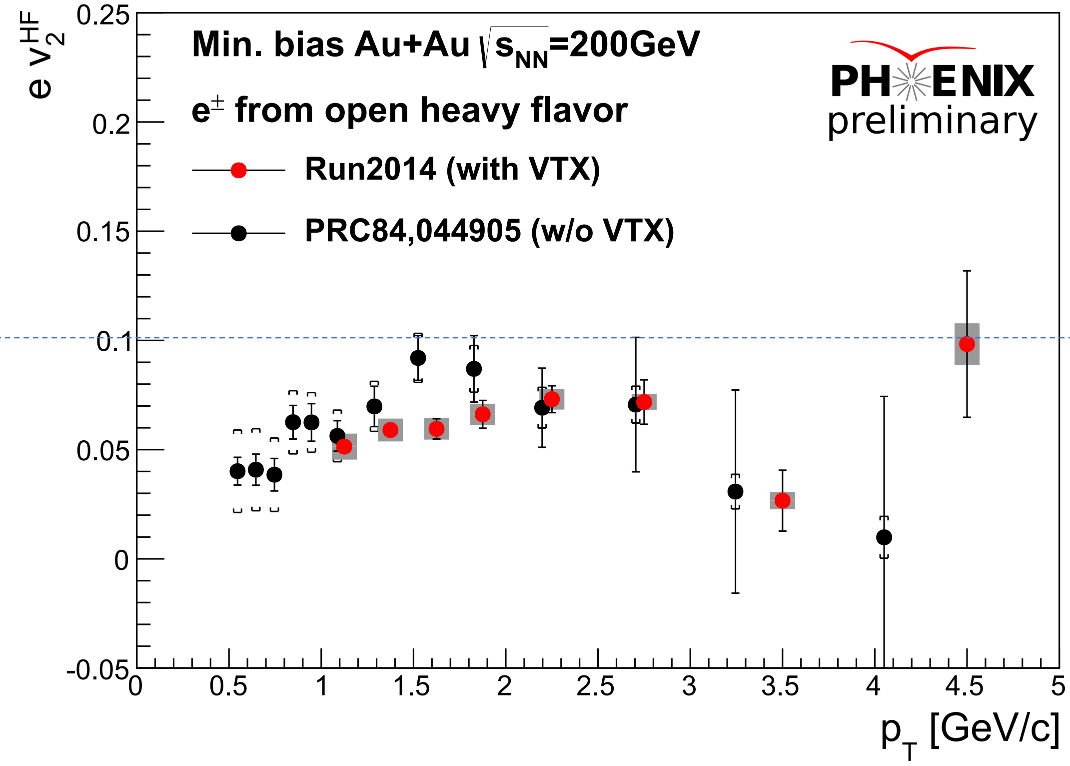
n_{Part} scaling



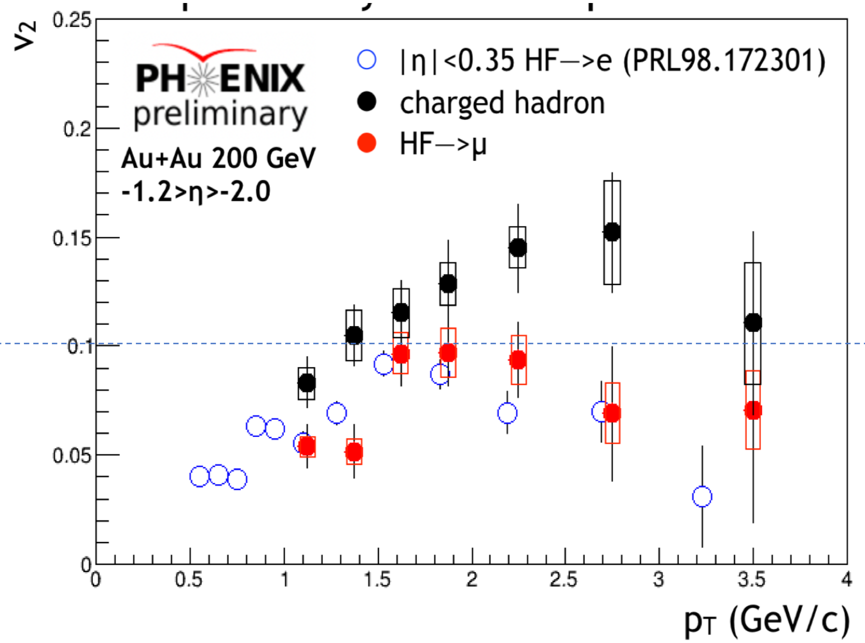
e-vs-μ Comp'n: HF Flow

HF Flow (possible rapidity effect?t)

HF-inclusive Electron v_2 @ Midrapidity



HF-inclusive Muon v_2 @ Forward Rapidity



Muons: F_{LF}: HF Flow

HF Flow: Muons (constituent parts of equation)