Heavy Flavor and Quarkonia in PHENIX

Brandon Blankenship (Vanderbilt University)
for the PHENIX collaboration

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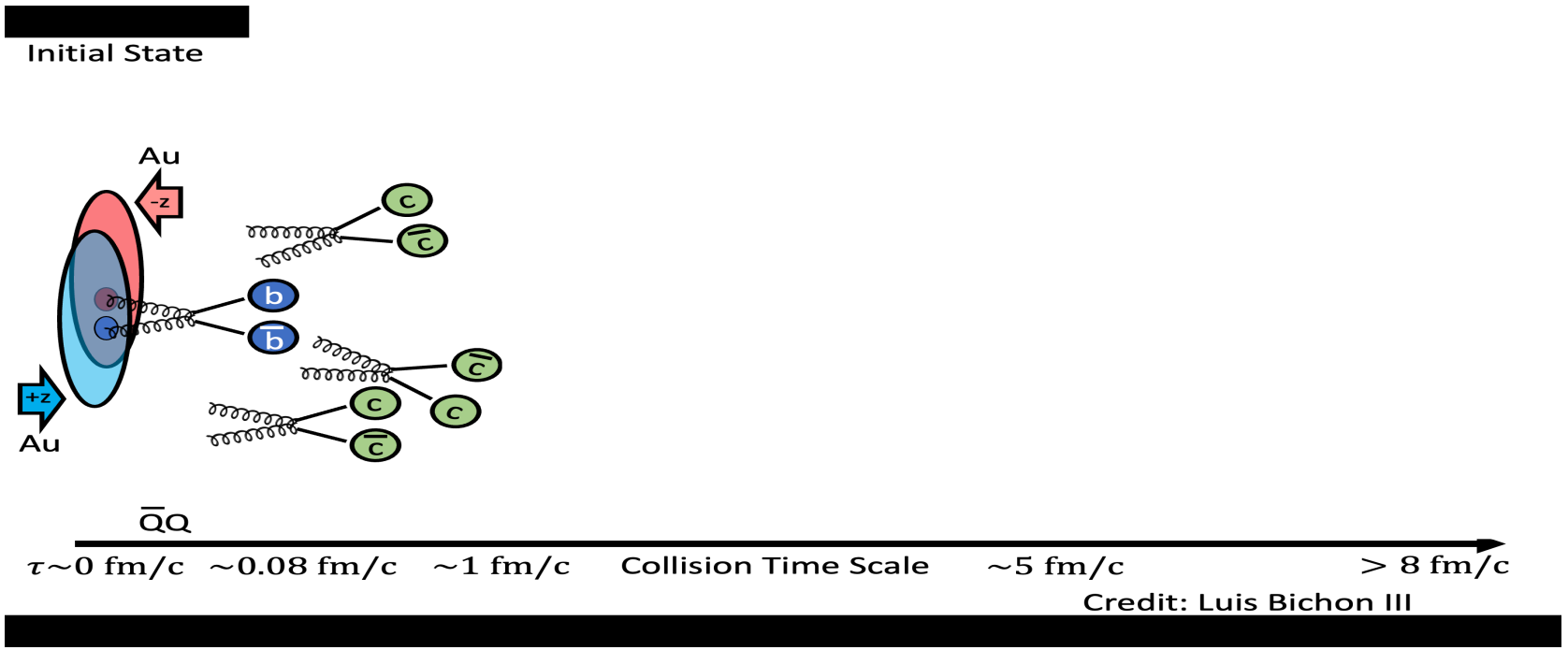
Outline

- Why heavy flavor and why study rapidity dependence?
- PHENIX detector
- Overview of current results
- Ongoing analyses
- Summary and outlook

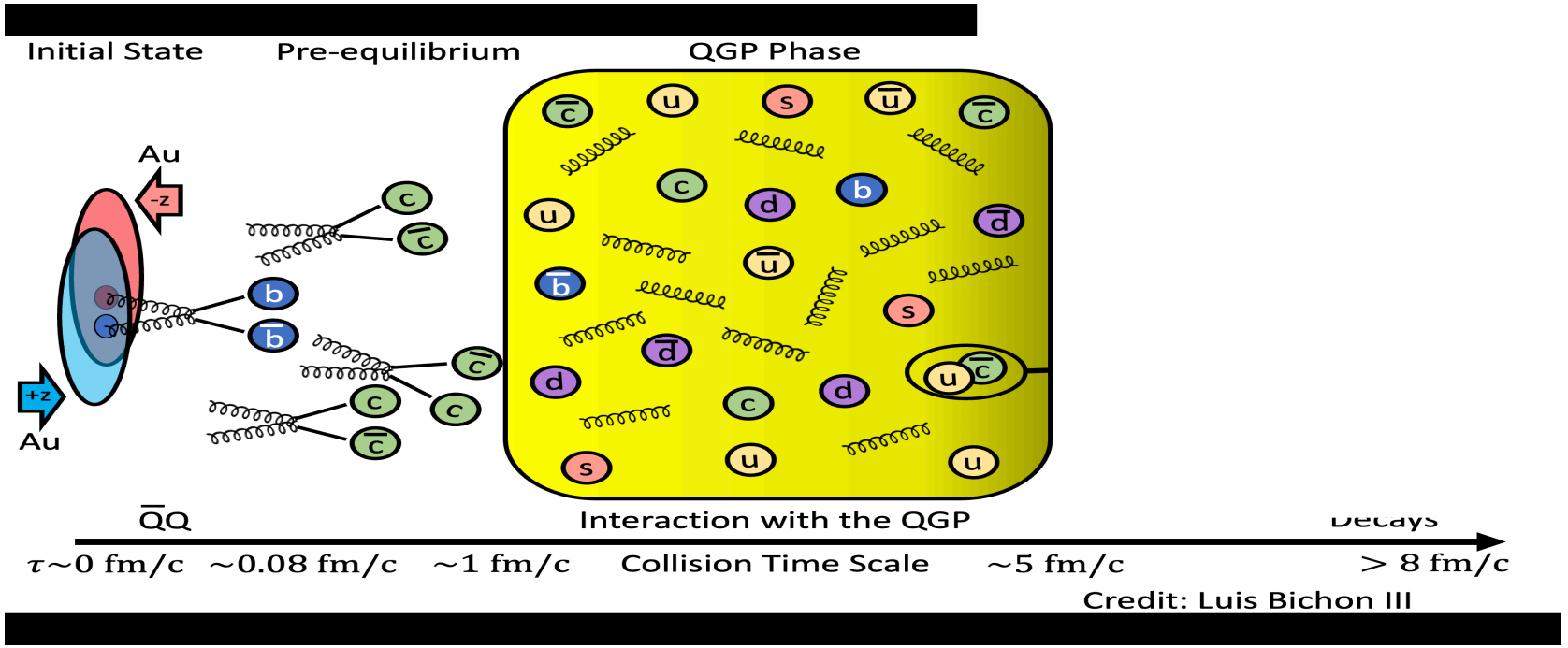
Heavy flavor as a probe of the QGP

- Large mass of heavy quarks —> only produced in initial hard scatterings



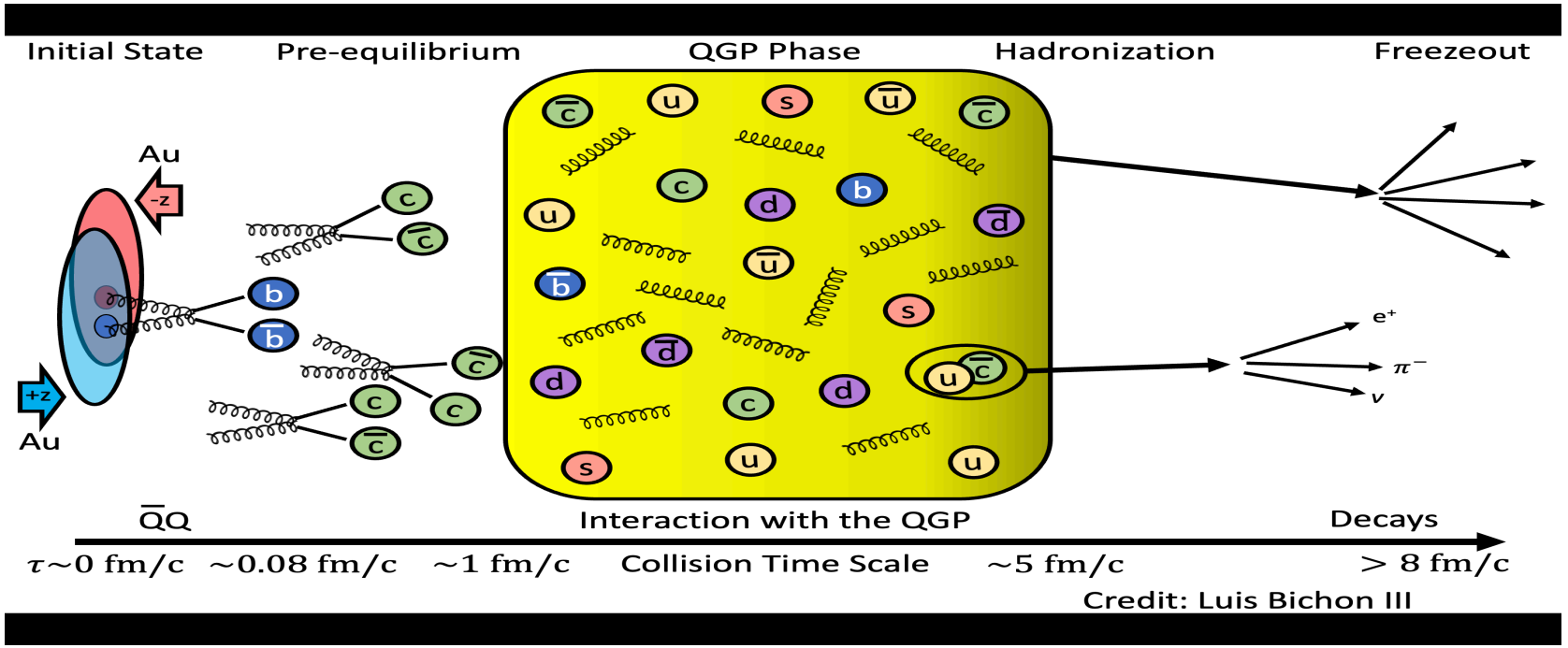
Heavy flavor as a probe of the QGP

- Large mass of heavy quarks —> only produced in initial hard scatterings
- Energy loss and flow effects as they pass through QGP —> particle yields and angular distributions can be modified by interaction with the QGP

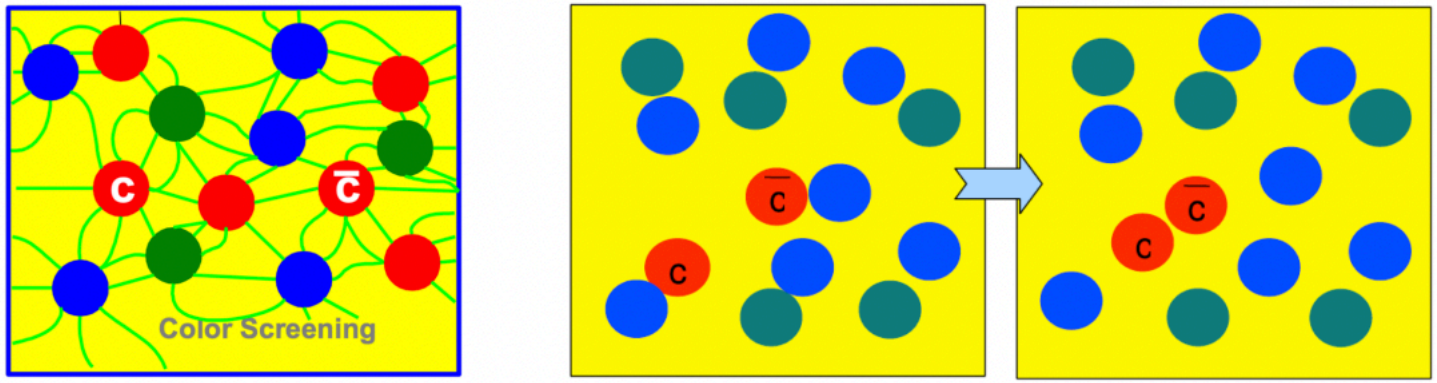


Heavy flavor particles as a probe of the QGP

- Large mass of heavy quarks —> only produced in initial hard scatterings
- Energy loss and flow effects as they pass through QGP —> particle yields and angular distributions can be modified by interaction with the QGP
- Heavy flavor particles reconstructed or their semi-leptonic decays —> understanding of heavy quark interaction with QGP medium

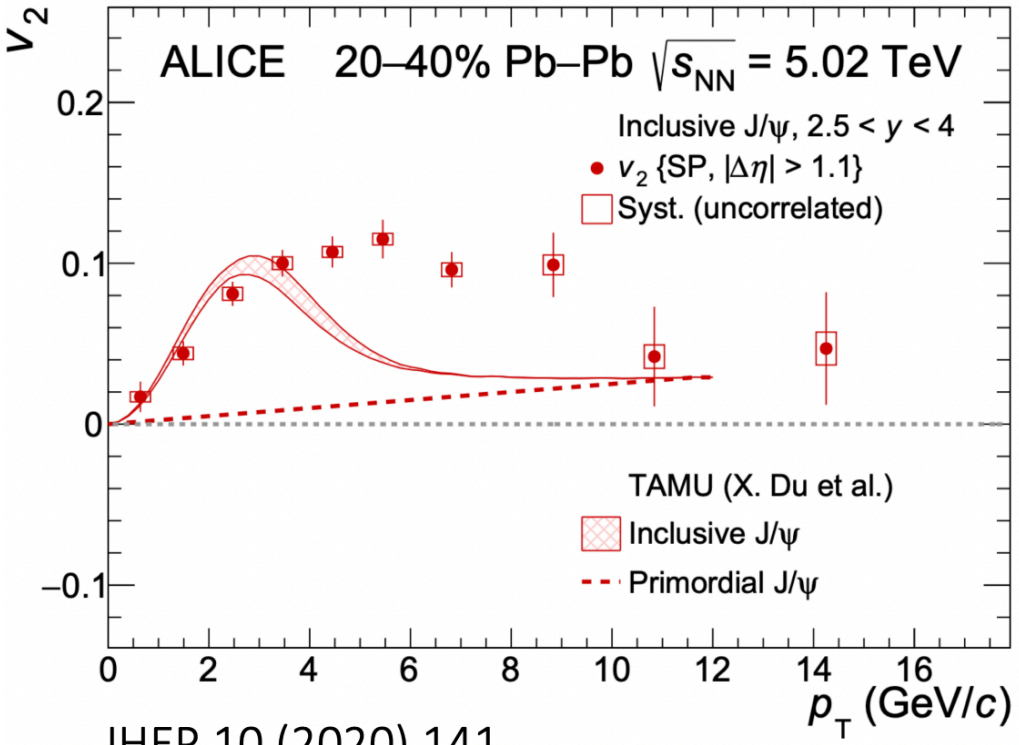


J/Ψ R_{AA} and v_2 as probes of QGP



- Quarkonium suppression probes T and density of QGP

- Multiple mechanisms for J/Ψ flow
  - Path length dependent dissociation
  - Charm equilibration and J/Ψ regeneration
  - Primordial J/Ψ equilibration – small effect



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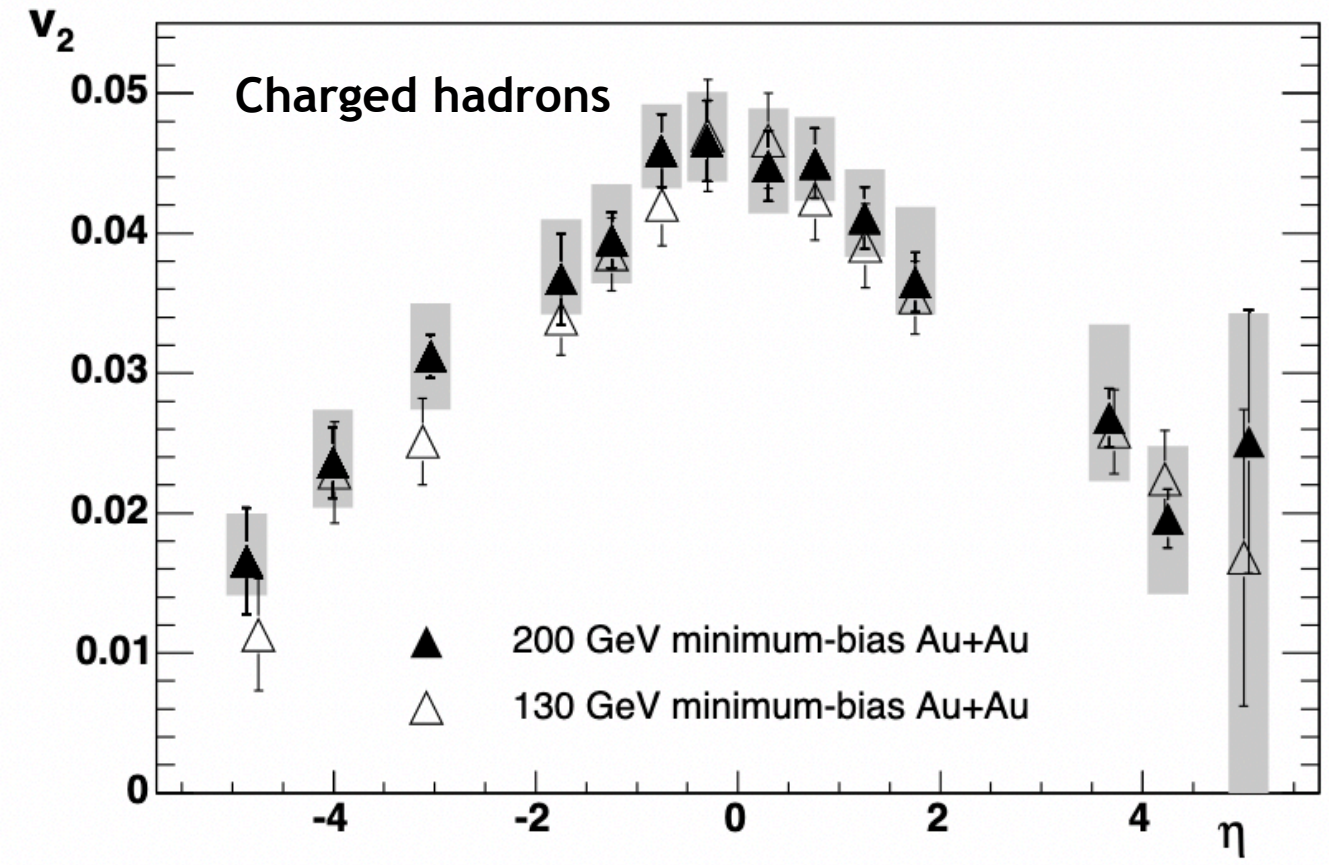
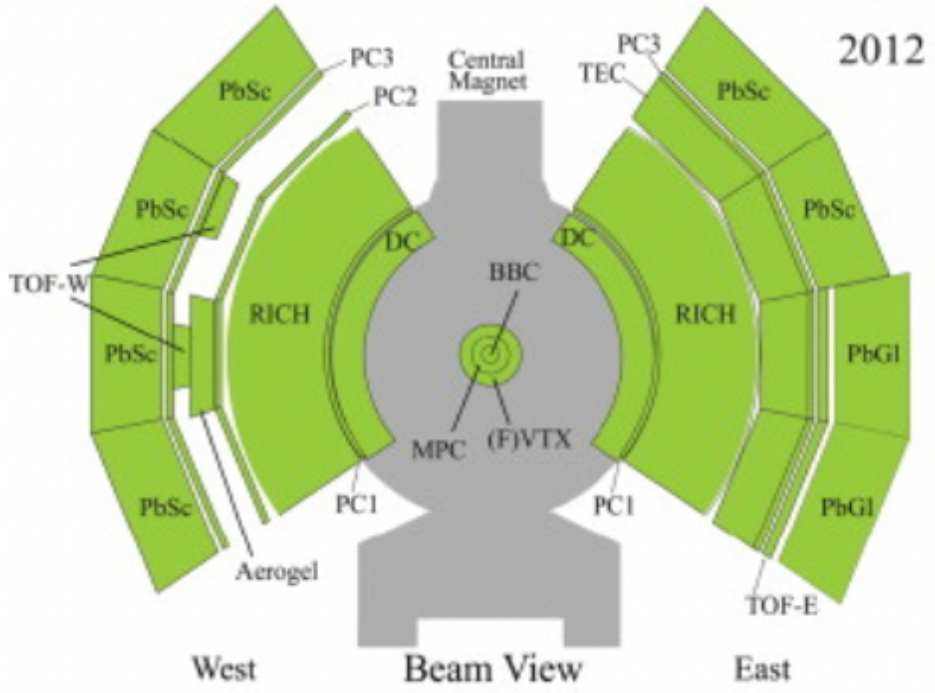
Rapidity dependence of QGP interactions

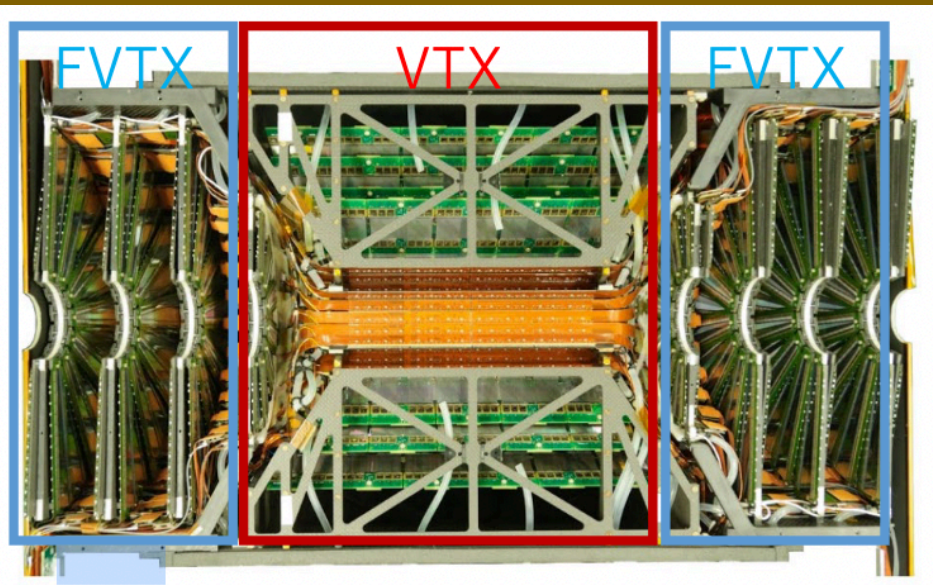
- Rapidity dependence of flow gives access to the longitudinal dynamics of QGP
- Heavy flavor and quarkonia dynamics have rapidity-dependent initial state effects
- PHENIX has unique capabilities at RHIC for separating charm and beauty with decay vertex determination at forward rapidity

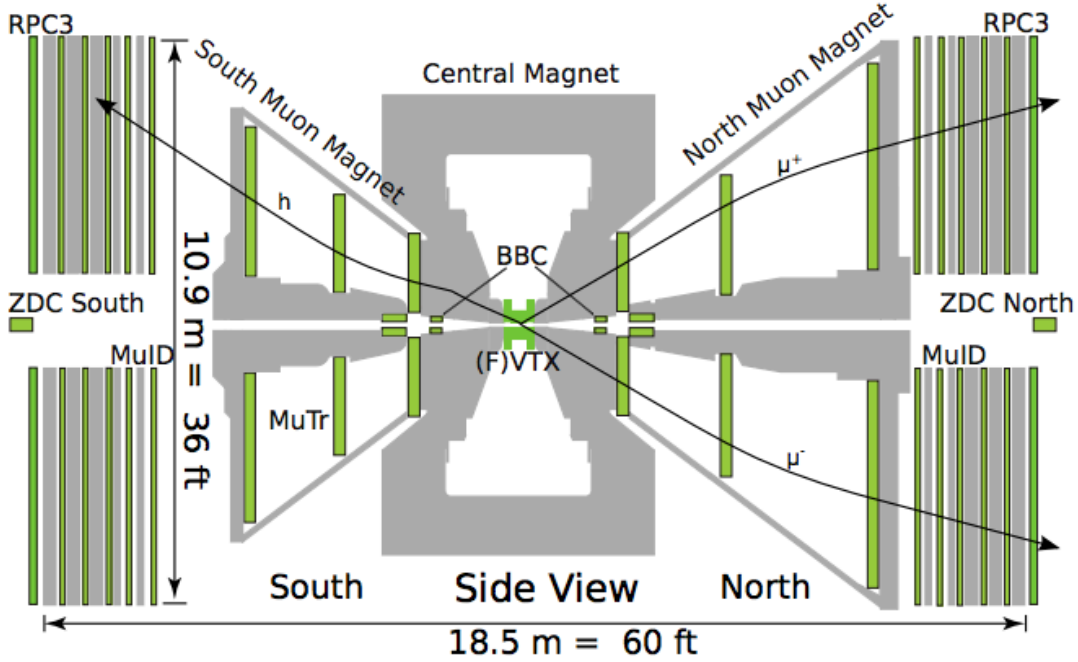
PHOBOS, PRL 89 (2002), 222301



PHENIX detector

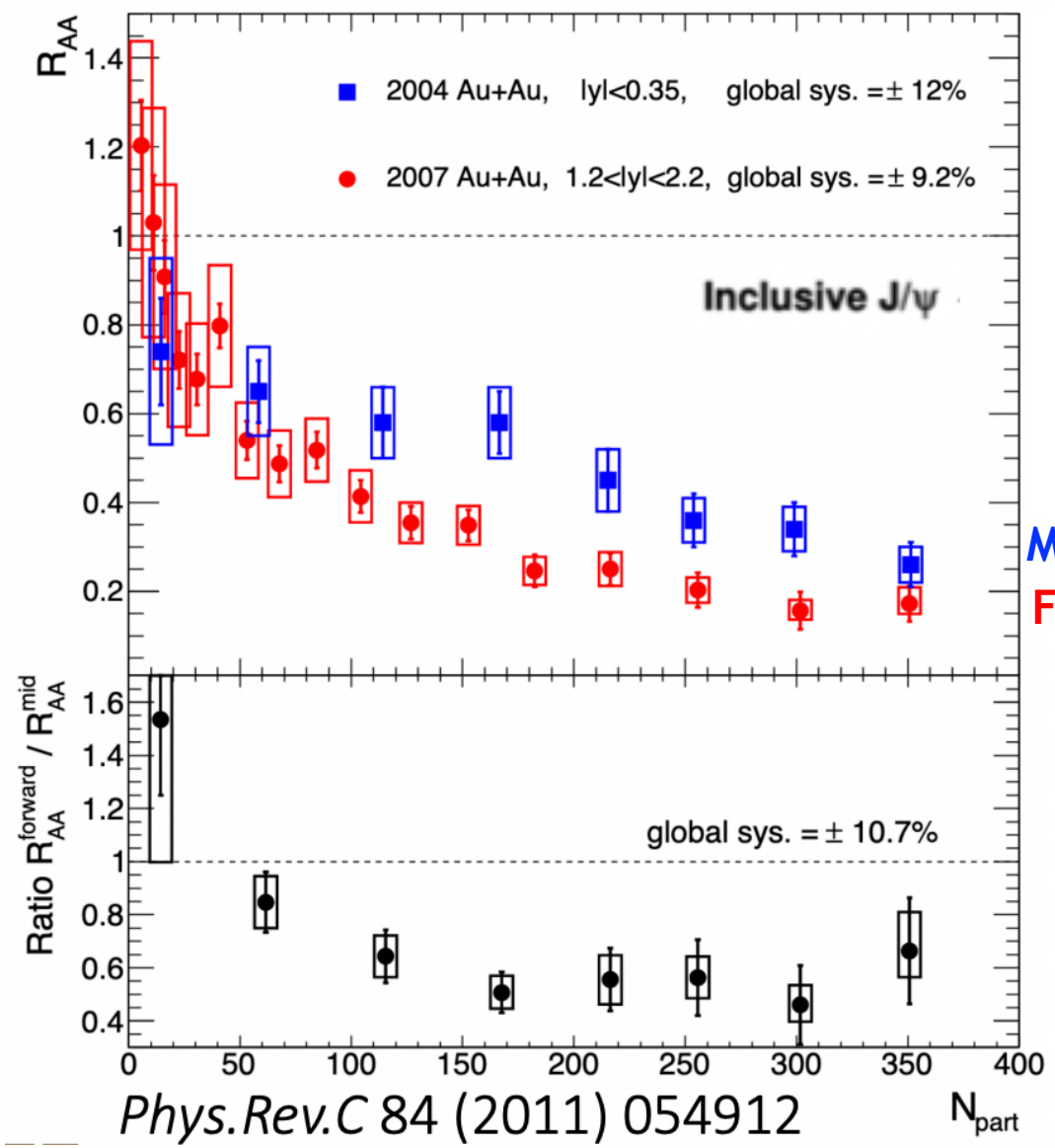






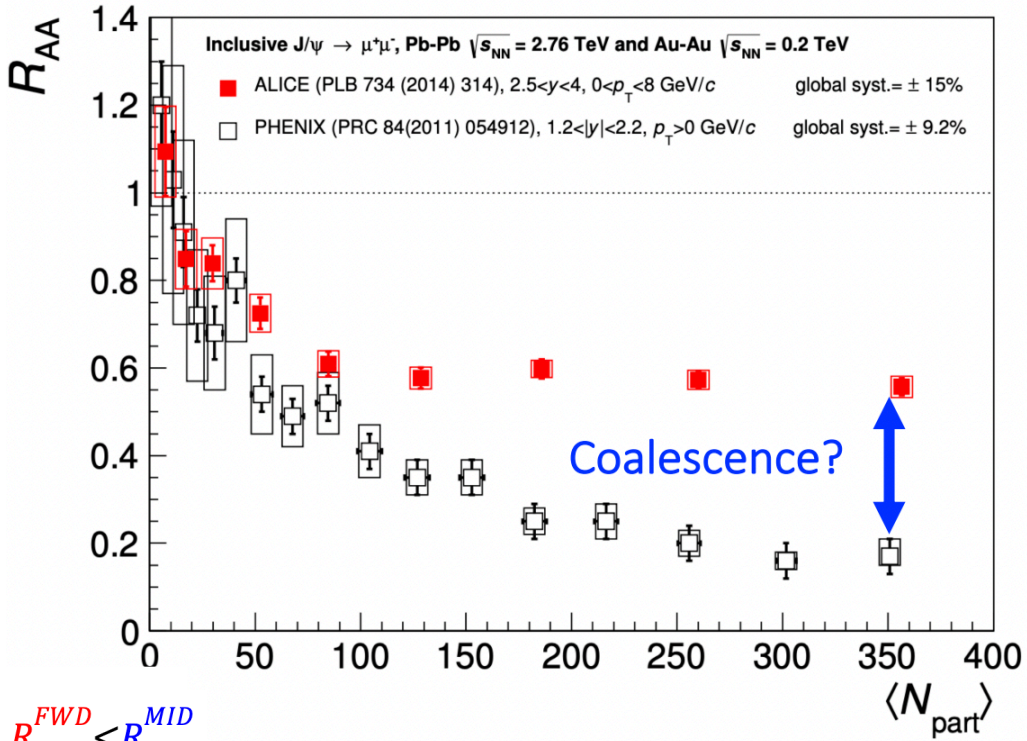
- **Central arms:** |y|<0.35
  - electrons, hadrons, and photons
- **Muon arms:** 1.2<|y|<2.2
  - muons and hadrons
- **VTX-FVTX:** Precise HF tracking and ID over full PHENIX rapidity range

J/Ψ R_{AA} and coalescence



Mid-rapidity

Forward



- At RHIC: $R_{AA}^{FWD} < R_{AA}^{MID}$
- LHC vs RHIC: $R_{AA}^{RHIC} < R_{AA}^{LHC}$

➢ Both contrary to expectations of how medium density and temperature influence suppression

- Coalescence can explain these results as at RHIC energies most $c\bar{c}$ pairs are produced at mid-rapidity and ~10x more $c\bar{c}$ pairs are produced at LHC energies compared to RHIC

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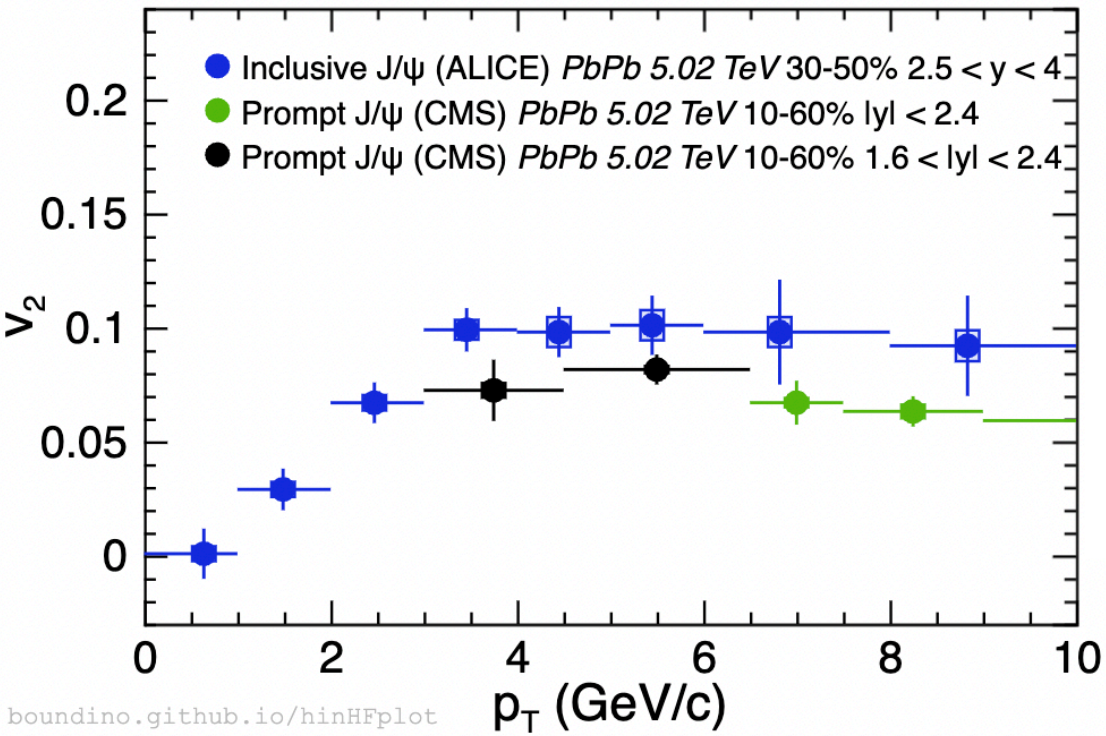
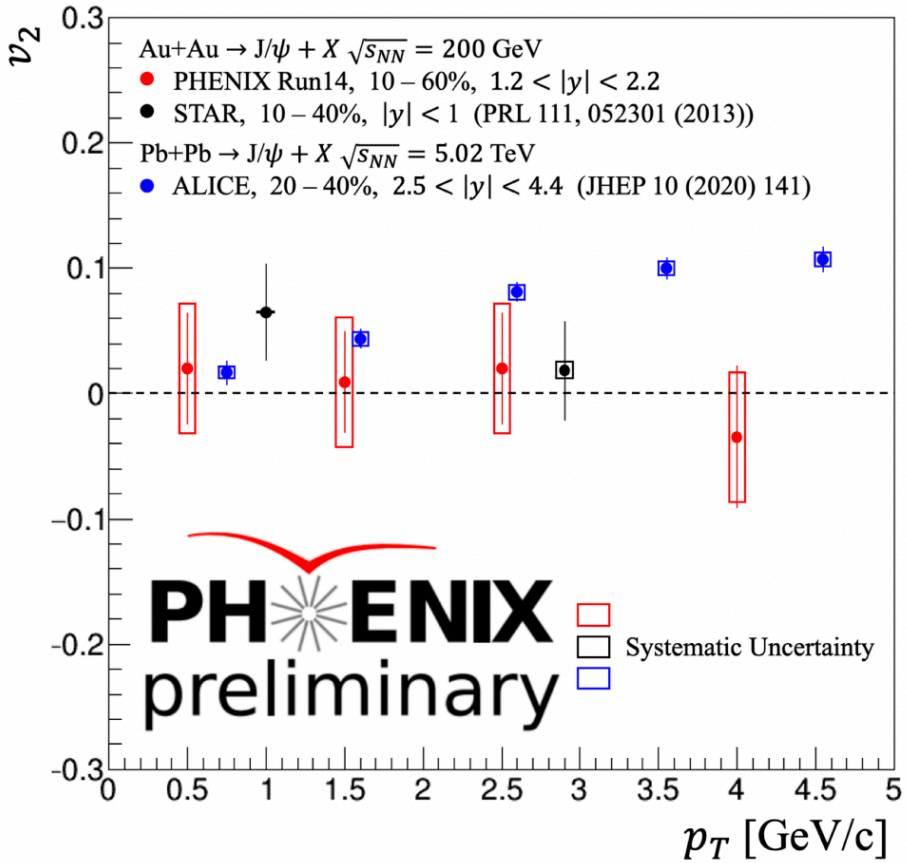
PHENIX

v_2 of J/Ψ at RHIC and LHC



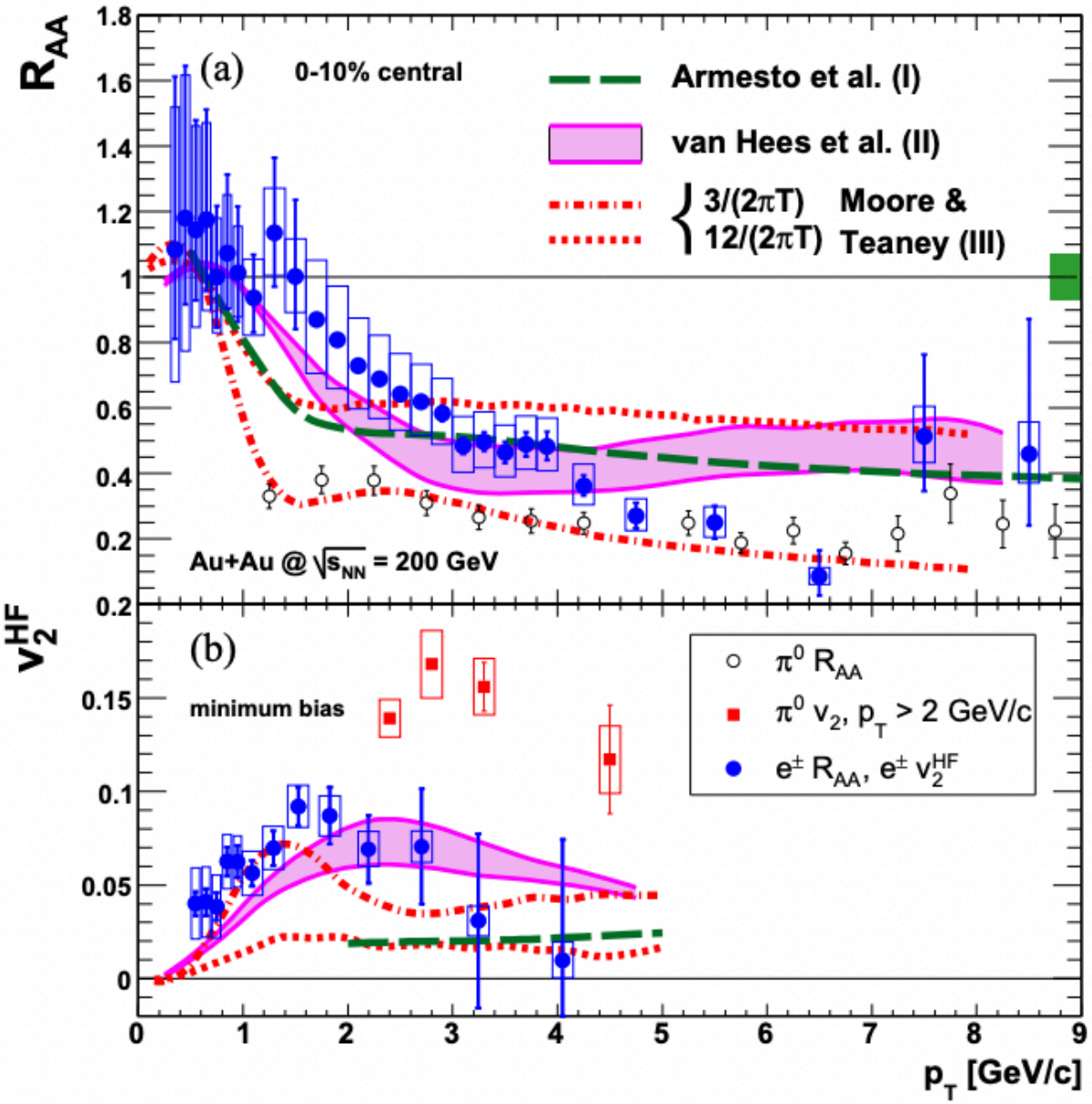


- At LHC energies, J/Ψ has significant v_2 across rapidity
- At RHIC , v_2 of J/Ψ is consistent with zero both at mid- and forward rapidity

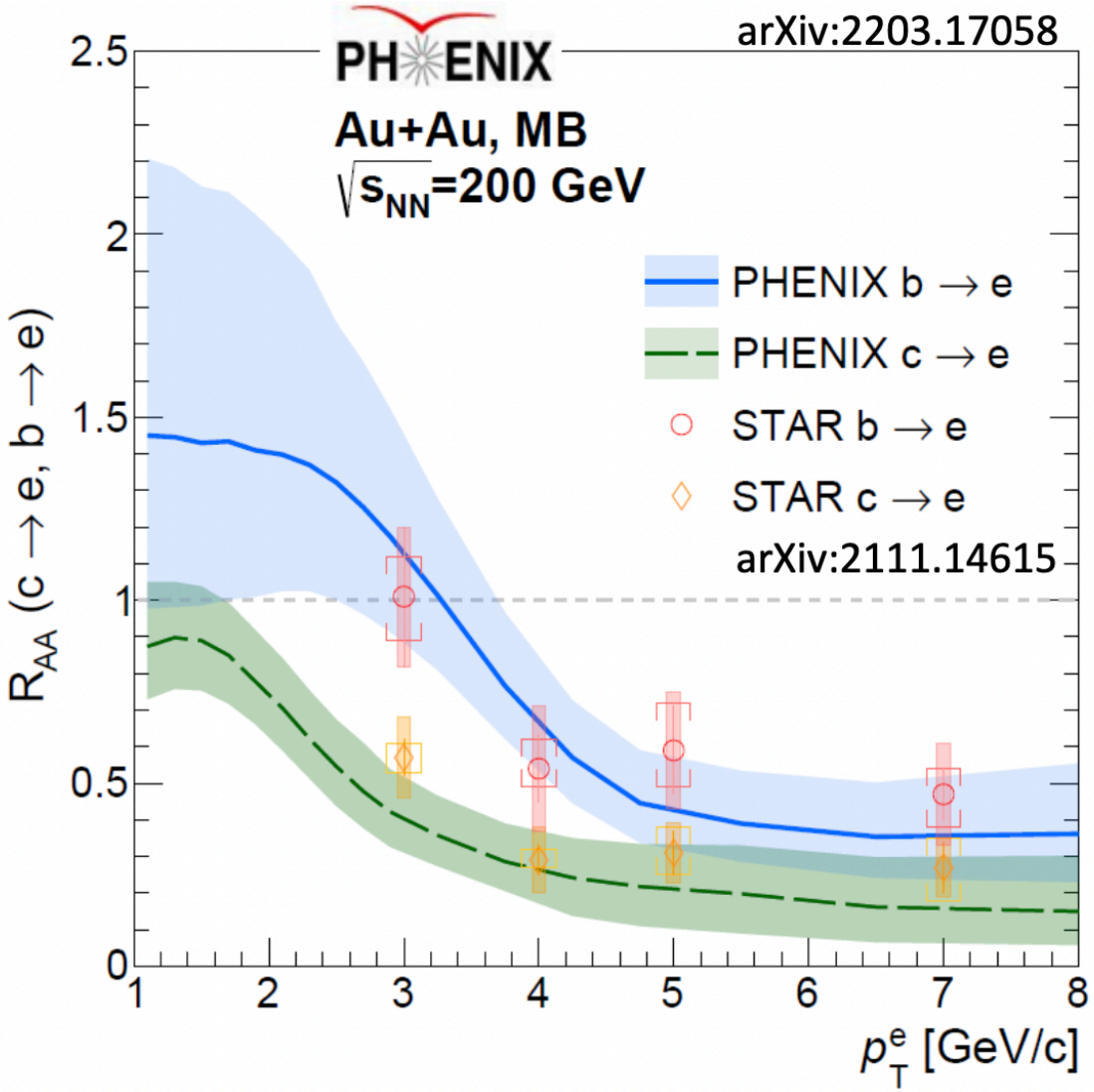
➢ Improvement needed for RHIC results to assess the role of coalescence

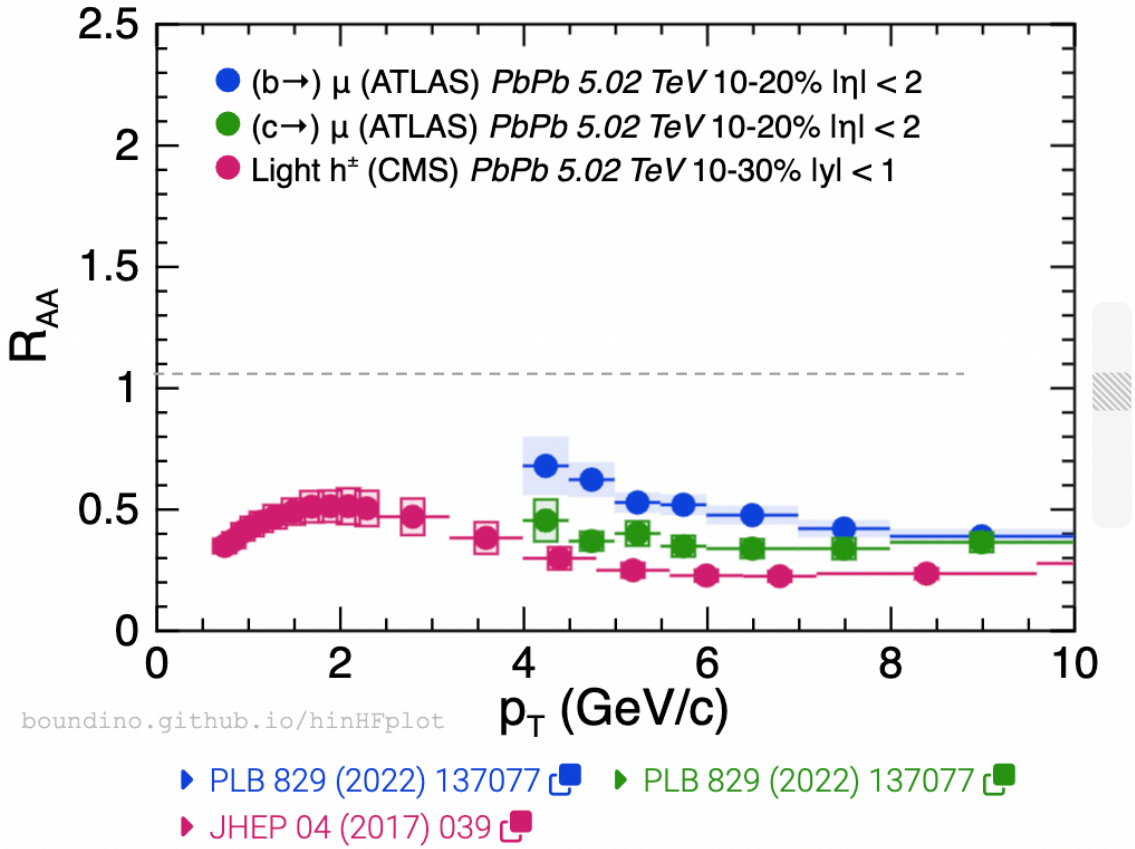
Inclusive heavy flavor v_2 and R_{AA}

- Electrons from inclusive heavy flavor show significant R_{AA} suppression and non-zero v_2
- Both measurements show significant differences compared to neutral pions
  - Indicates mass ordering of particle interactions with QGP
- Do separated *c* and *b* exhibit the same mass ordering behavior?



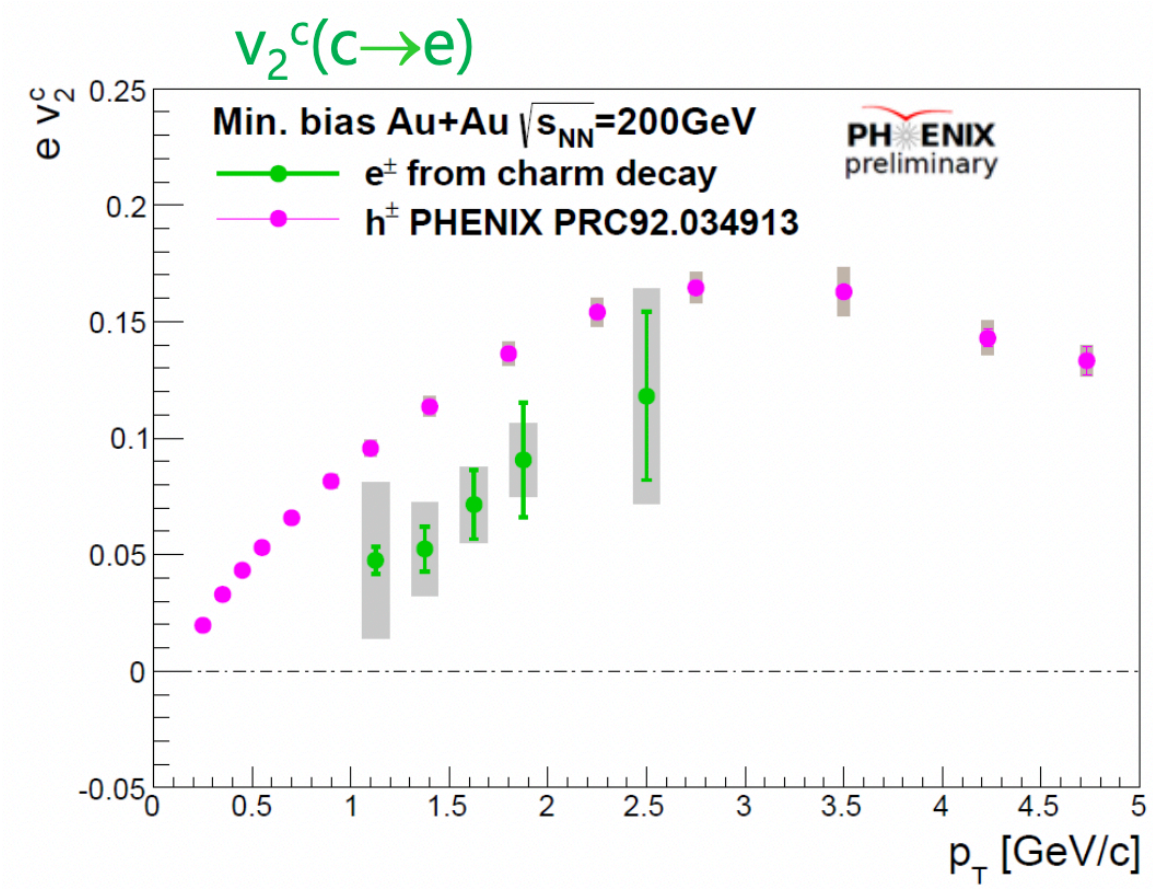
R_{AA} of separated *charm* and *beauty*

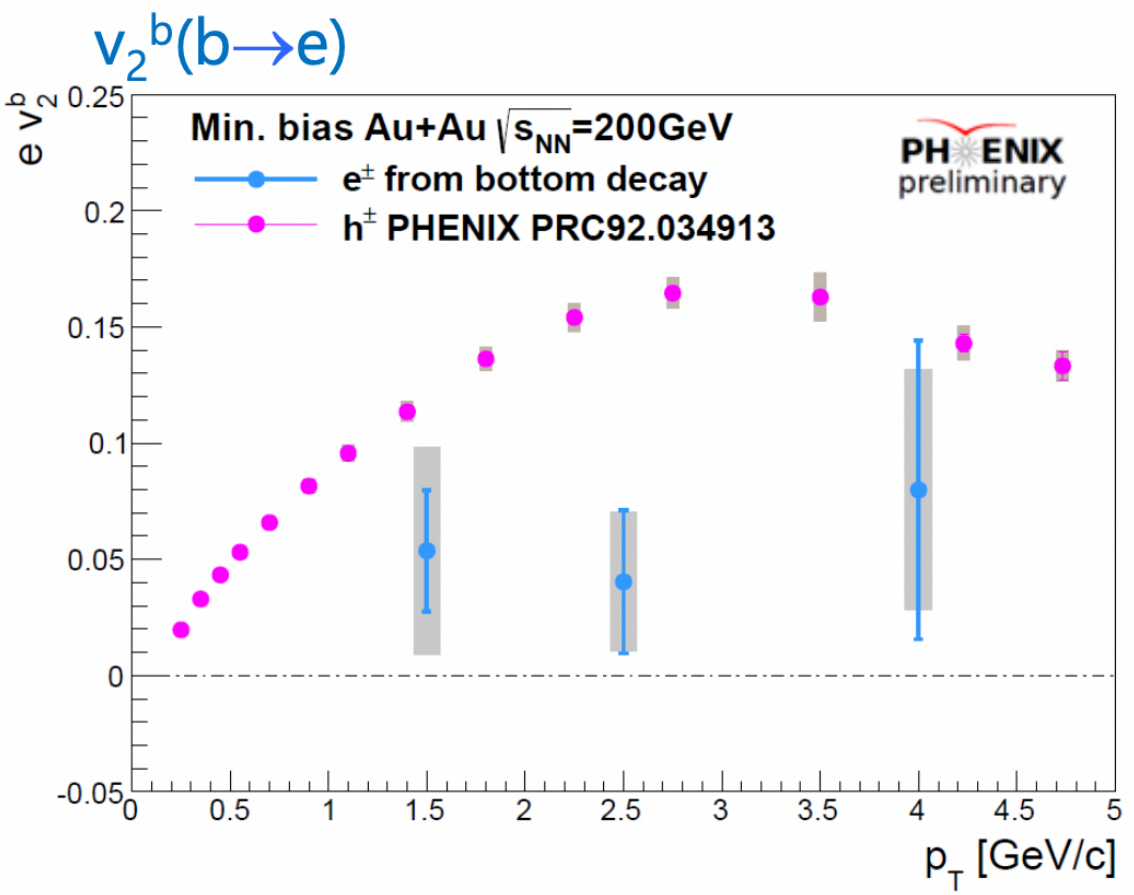




- Clear mass ordering between b->*l* and c->*l* at RHIC and LHC energies
- R_{AA} measurement of open heavy flavor at forward rapidity will provide further insights

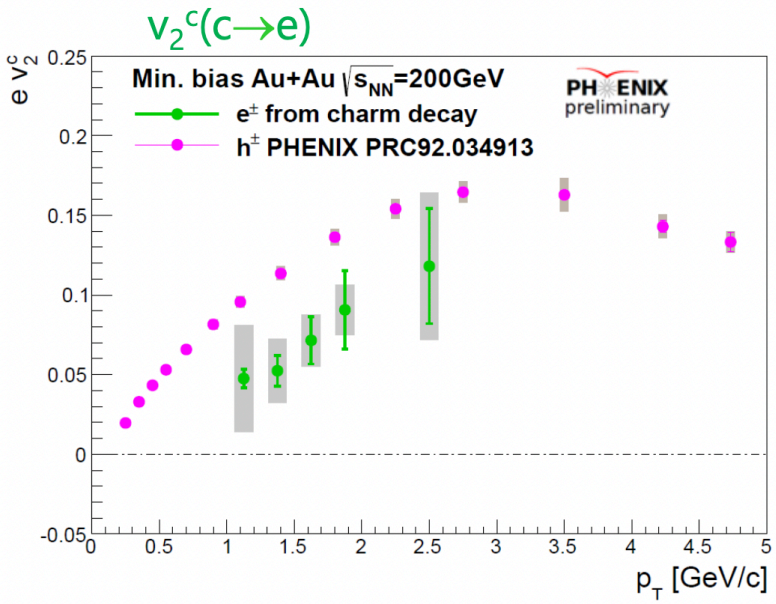
PHENIX separated *c* and *b* v_2

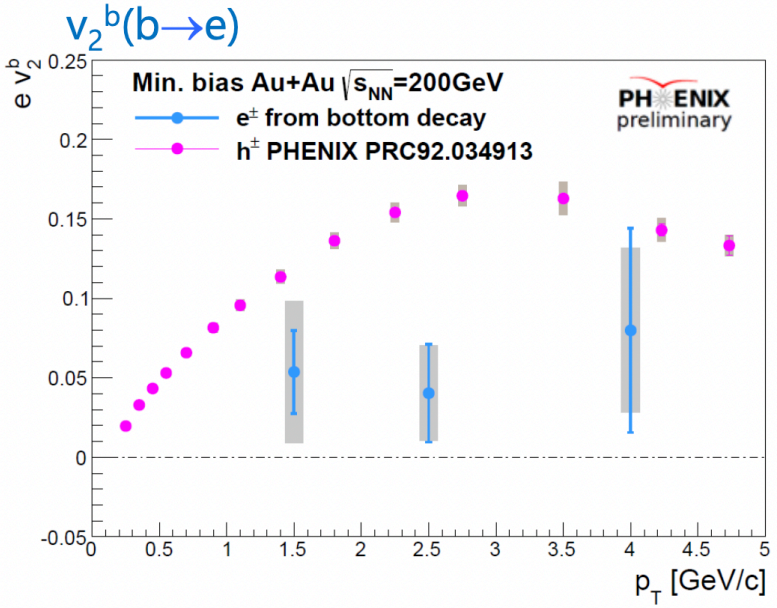


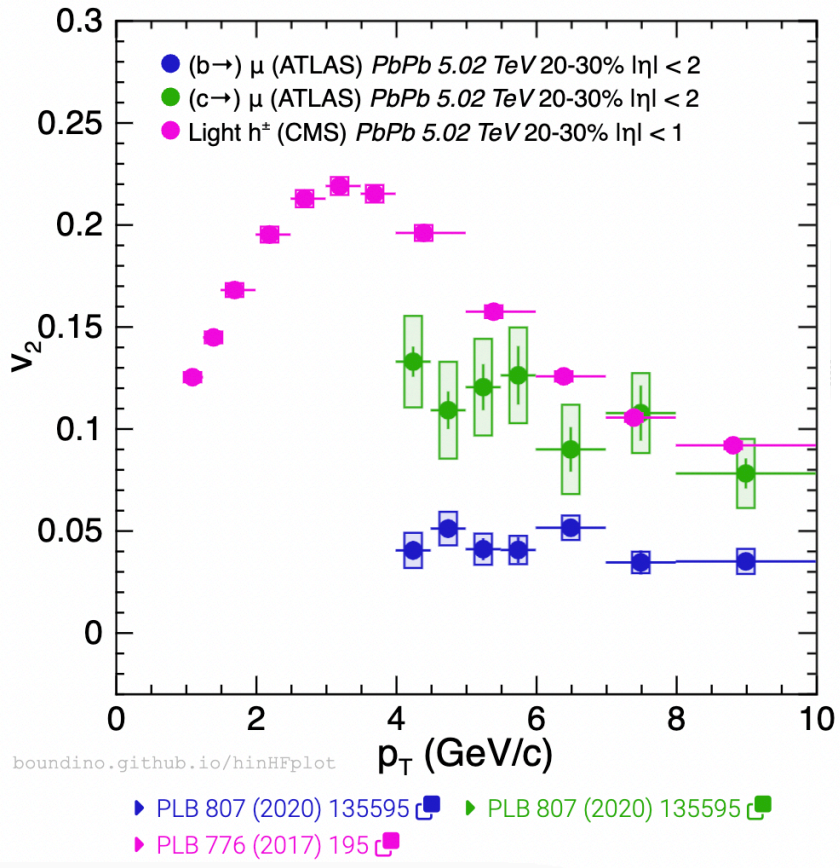


- v_2(c—>e) is positive with ~3.5 sigma and follows trend of charged hadron v_2
- v_2(b—>e) indicates positive with 1.1 sigma
- Mass ordering is seen, as in R_{AA}

v_2 of separated *c* and *b*

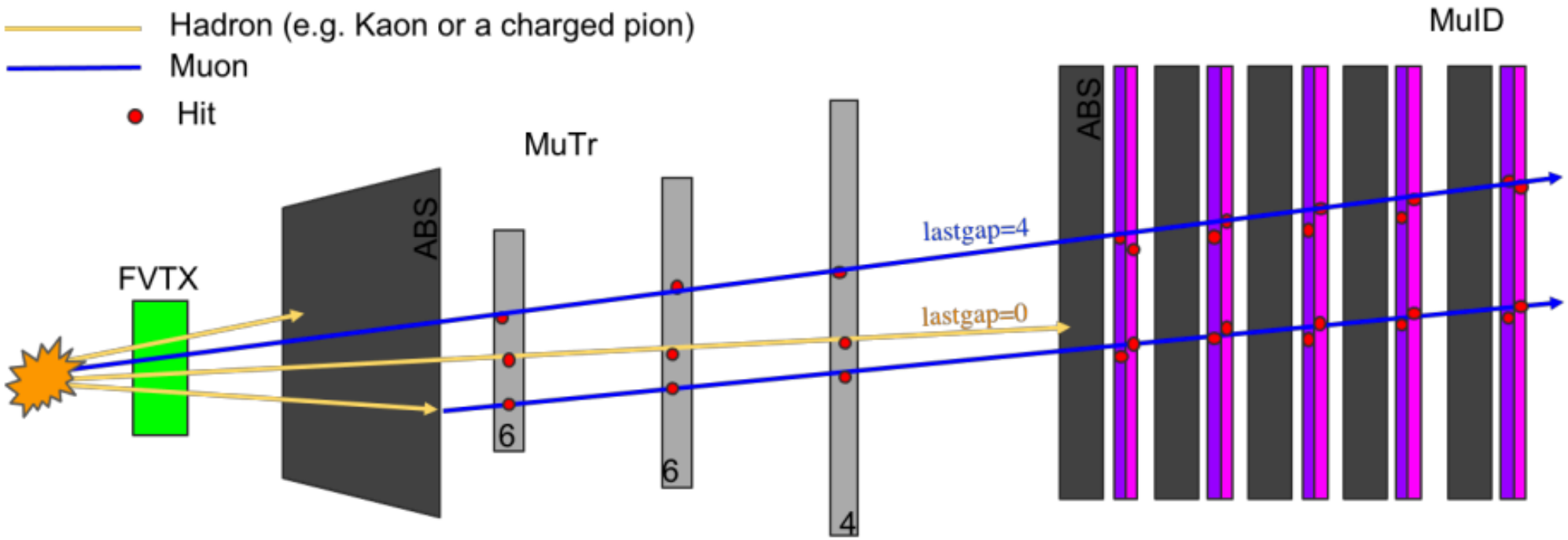






- v_2 of *c* and *b* are different at both RHIC and LHC
- Extending the PHENIX measurement to forward rapidity is necessary for a more complete understanding of heavy flavor interactions with QGP

Analysis in PHENIX muon arms



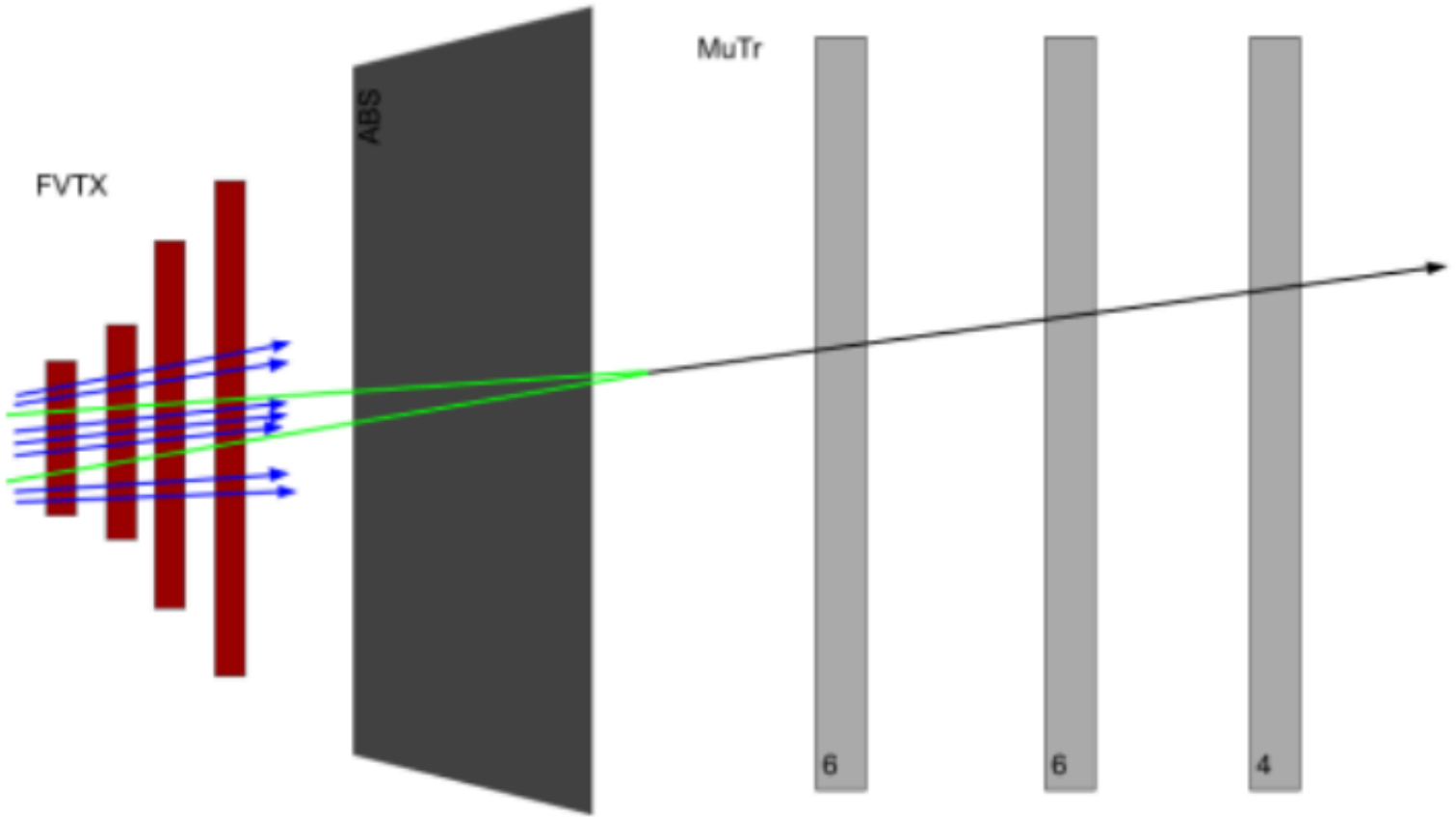
- PHENIX muon arms consist of forward vertex detector (FVTX), absorber, muon tracker (MuTr) and muon identification (MuID)
  - FVTX: precise decay vertex measurement
  - MuTr: tracking and momentum info for particles that make it past absorber
  - MuID: layers of Iarocci tubes and absorber to filter out remaining hadrons

Track matching and background subtraction in Au+Au

- Due to particles scattering in absorber material a single MuTr track can match to multiple tracks in the FVTX

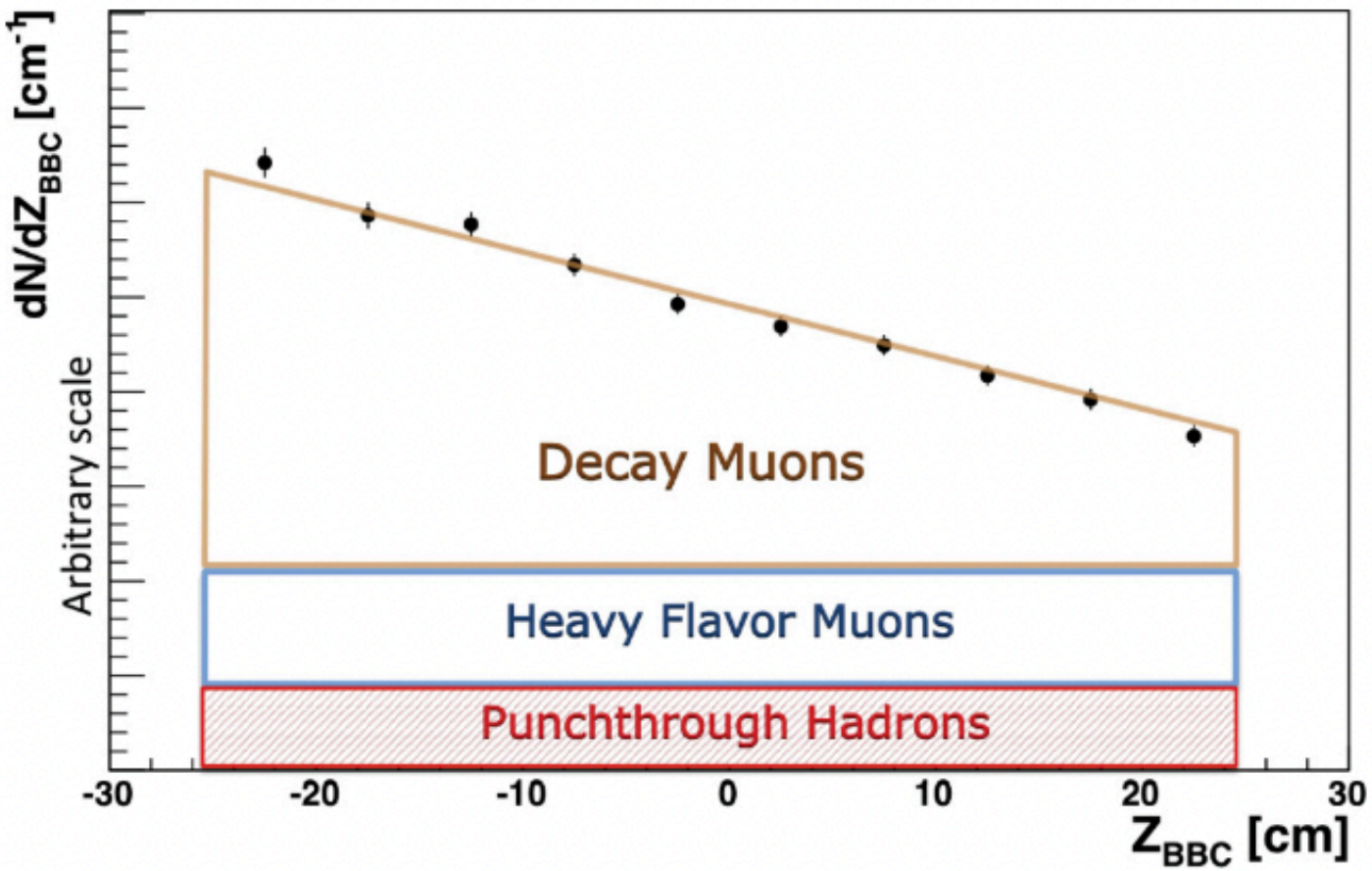
- Because of this we combine a single MuTr track with all matched FVTX tracks and with tracks from 5 mixed events with similar Z vertex and multiplicity

- By normalizing the mixed event data and subtracting it out we resolve mismatching issues between detectors



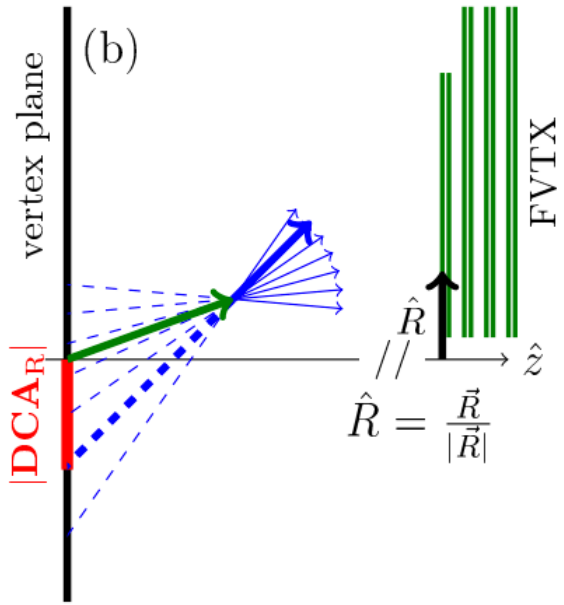
Z vertex dependence of hadron decay

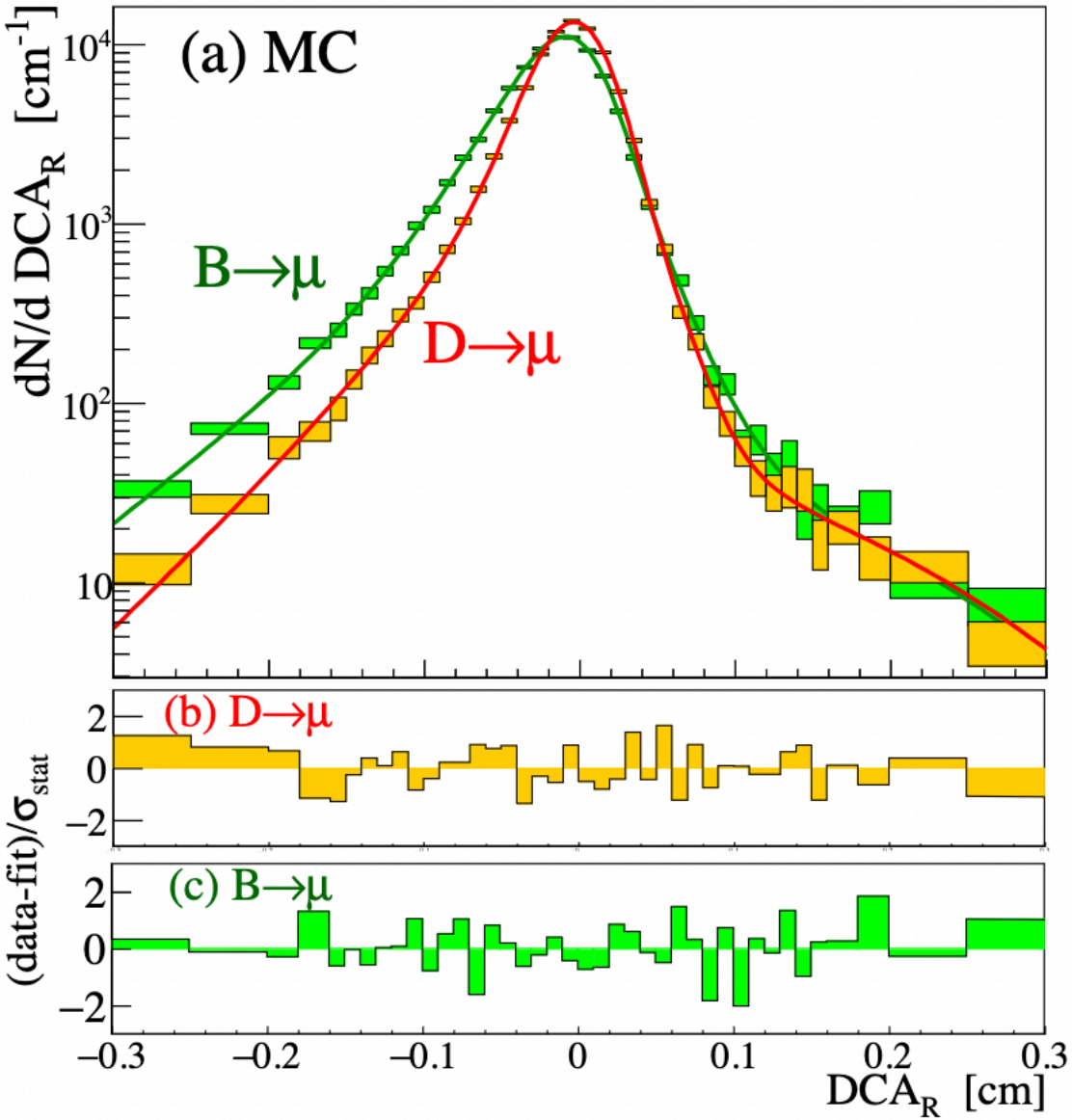
- Long decay length of kaons and pions —> yield of muons from light hadron decays is Z vertex dependent
- Use this to separate inclusive muon yield into light and heavy flavor decay components —> Measure HF v_2



Using DCA_R to separate *c* and *b*

- Measure secondary vertex of decay muons with FVTX —> statistically separate B—>μ and D—>μ decays
- DCA_R measurements provide means to separate *b* and *c*





Summary

- PHENIX has measurements of open and closed heavy flavor v_2 and R_{AA}
- Coalescence of *cc* pairs could explain the difference between forward and mid-rapidity J/Ψ R_{AA} results
  - J/Ψ v_2 at RHIC has no rapidity dependence, but the results are not yet conclusive

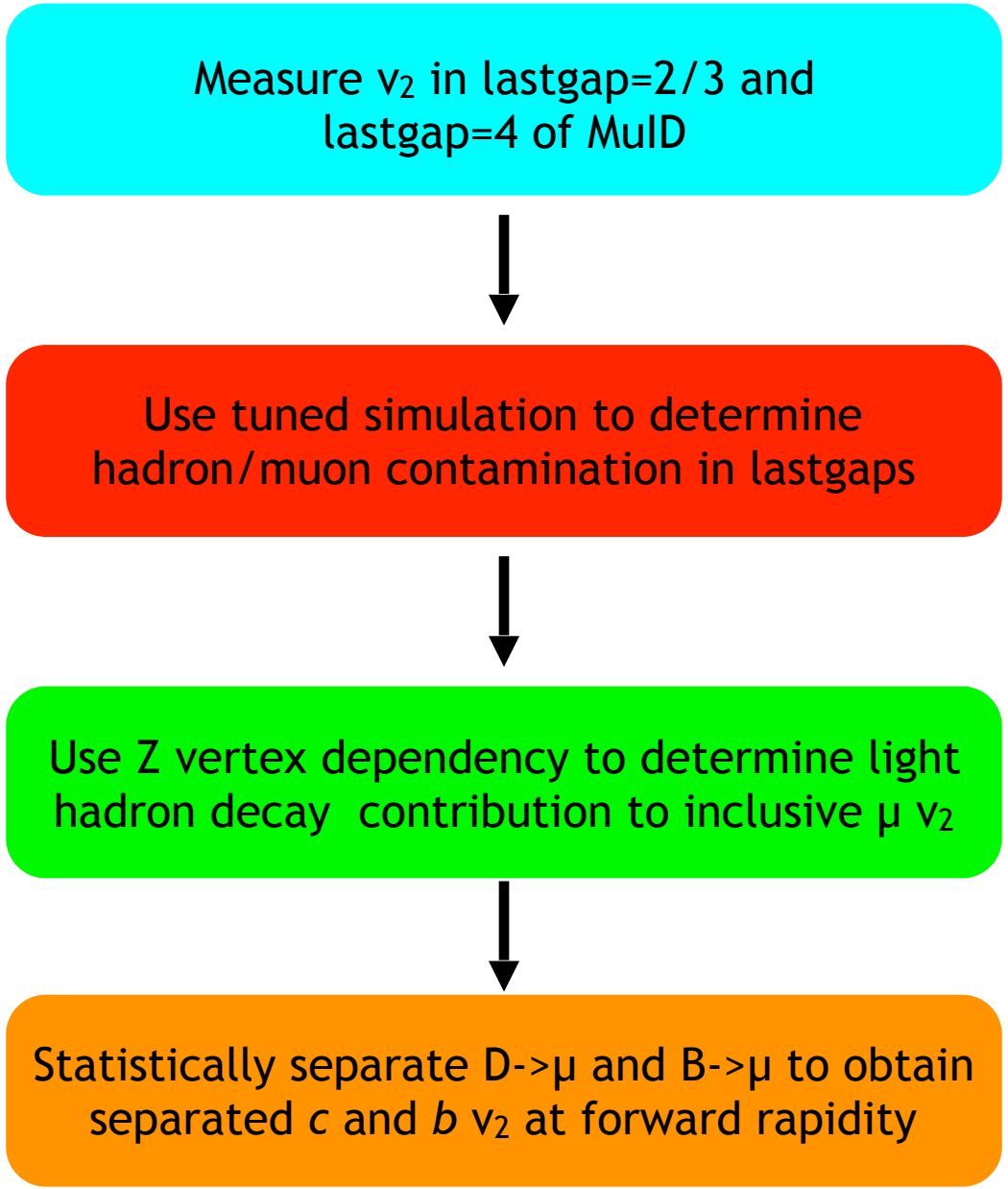
- v_2 and R_{AA} light and heavy flavor (*c* and *b)* show mass ordering at mid-rapidity
  - Measurements will be extended to forward rapidity to get a more complete understanding of heavy flavor interactions with QGP

- Inclusion of the Run16 Au+Au 200 GeV dataset will double statistics for ongoing PHENIX heavy flavor analyses

Stay tuned !

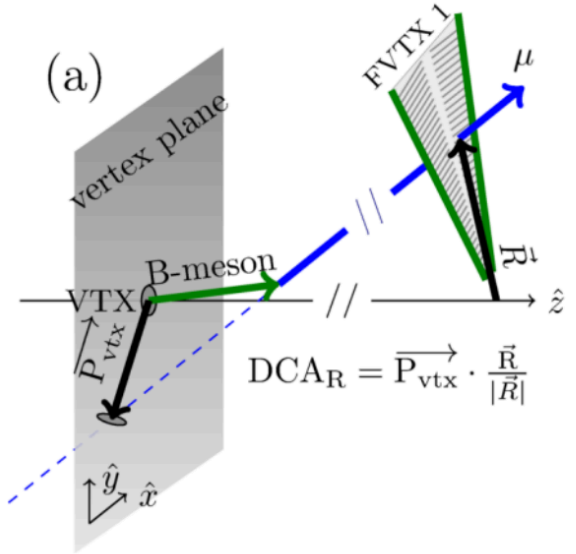
Back-ups

Ongoing PHENIX muon arm analysis

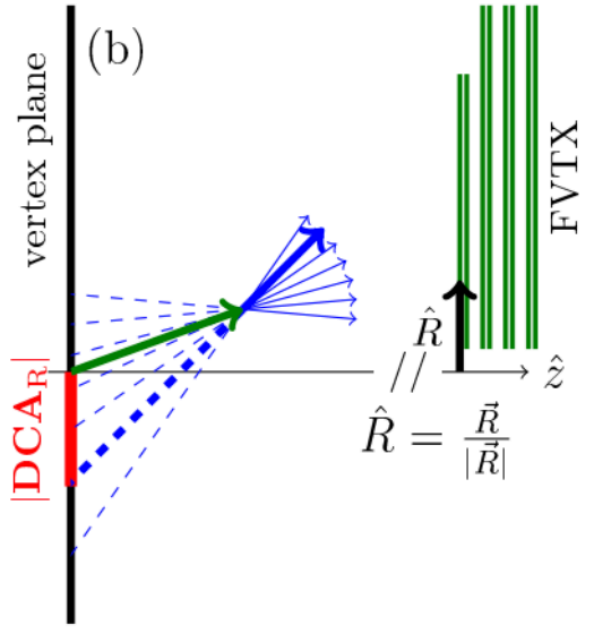


Radial distance of closest approach (DCA_r)

- DCA_r is determined by projecting the particle track determined by the FVTX onto a plane in the z-axis located at the initial collision point
- Essentially this is a measurement of the distance from the primary vertex at which a particle was produced, i.e. for a prompt particle $DCA_r = 0$
- With a precise measurement you can separate detected muons according the particle from which they decayed



3D visualization of DCA_r



r-*z* plane visualization of DCA_r