Recent open bottom measurements at RHIC

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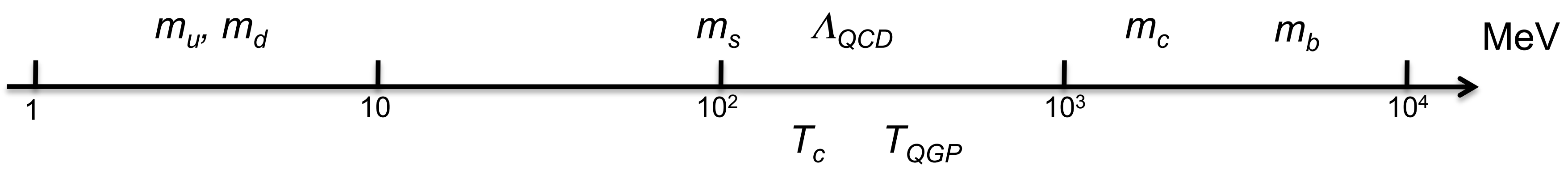
QCD Workshop
Weihai, Jul. 18 – 25, 2019

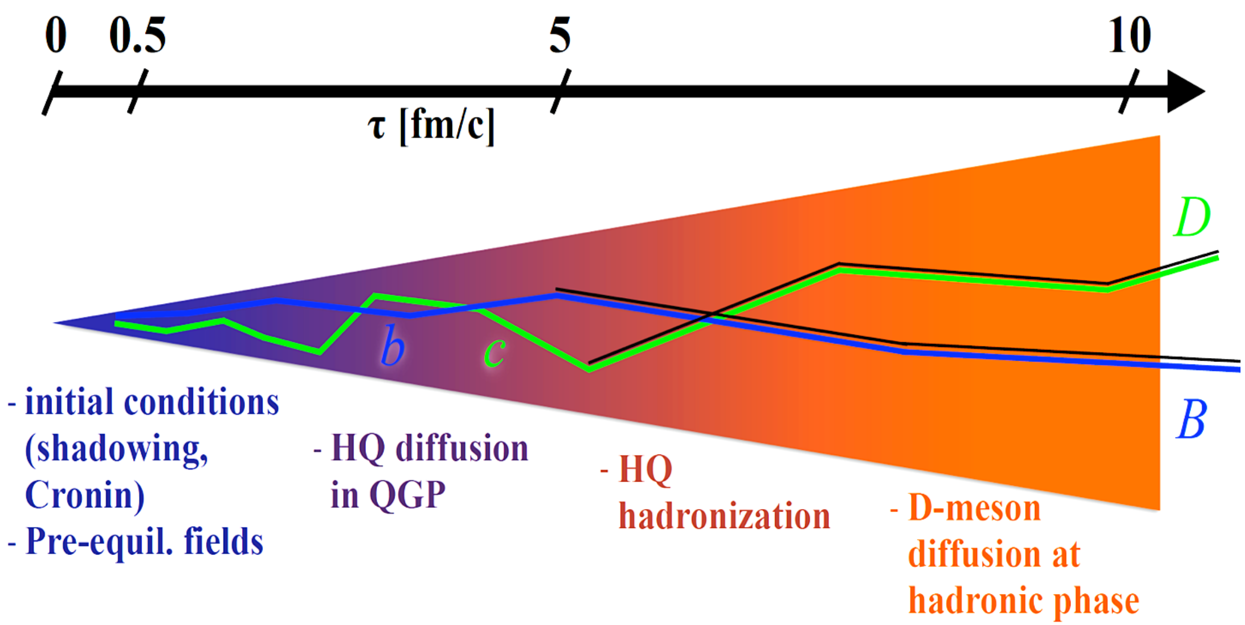
Outline

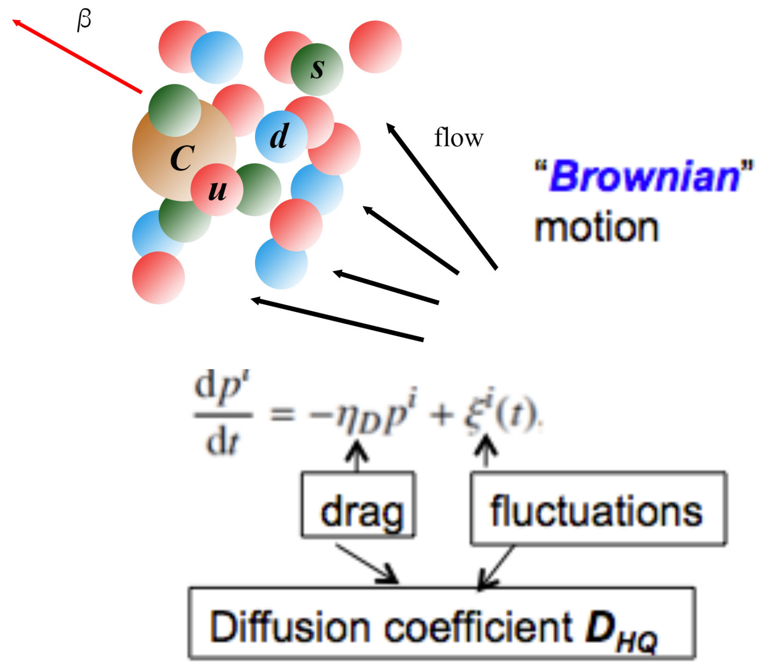
- Introduction
- Methods
- Experiment results
- Summary

Why are heavy quarks important?

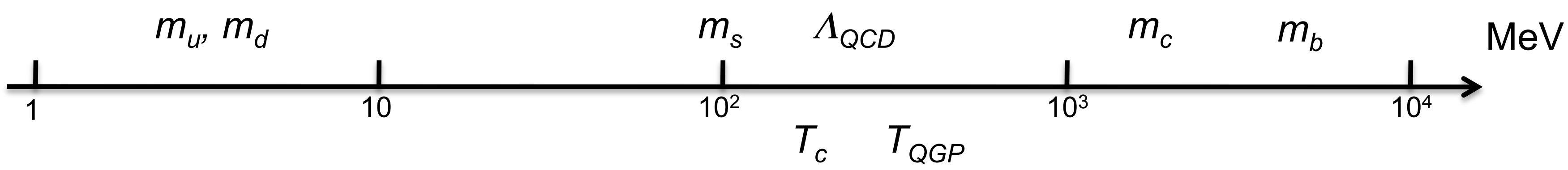


- Produced early in the history of heavy-ion collisions.
- Experience most of the stages of the system evolution.
- Sensitive to the medium properties: diffusion, η/s, temperature etc.





Why are heavy quarks important?



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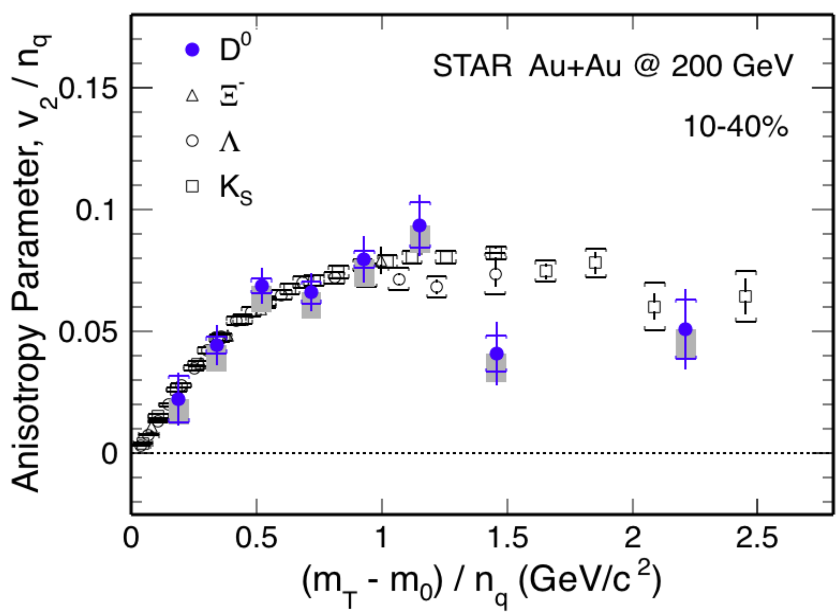
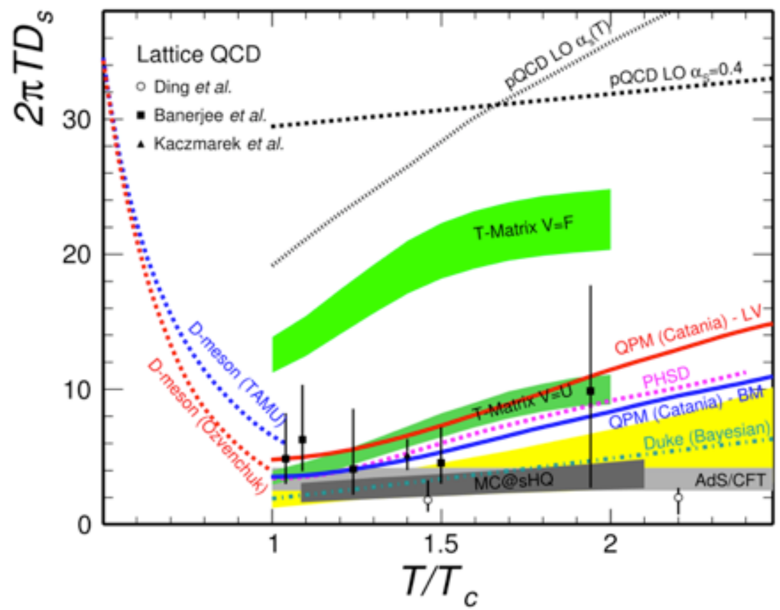


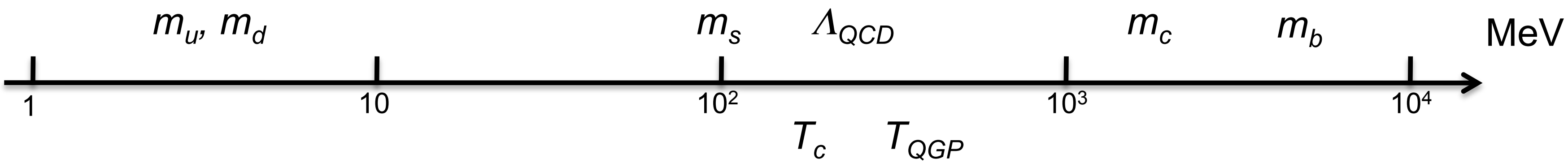
STAR, PRL 118 (2017) 212301



arXiv:1903.07709

Charm is as ordinary as light quarks!

Why are heavy quarks important?



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- Experience most of the stages of the system evolution.
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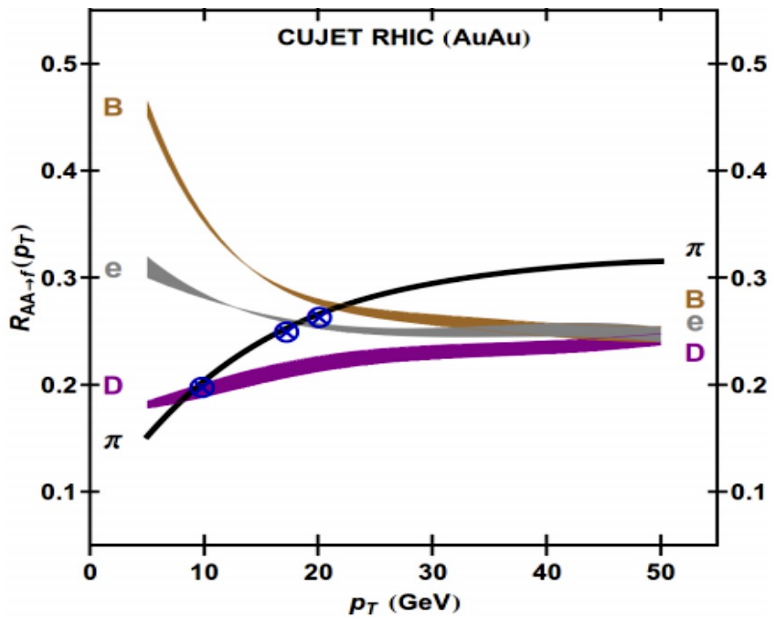
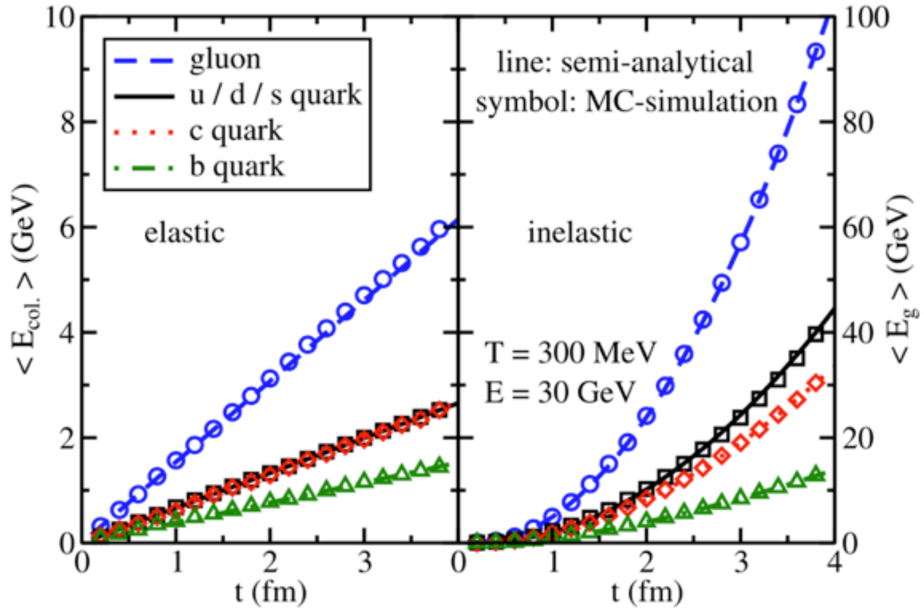
- Theory prediction: $\Delta E_{u,d,s} > \Delta E_c > \Delta E_b$.

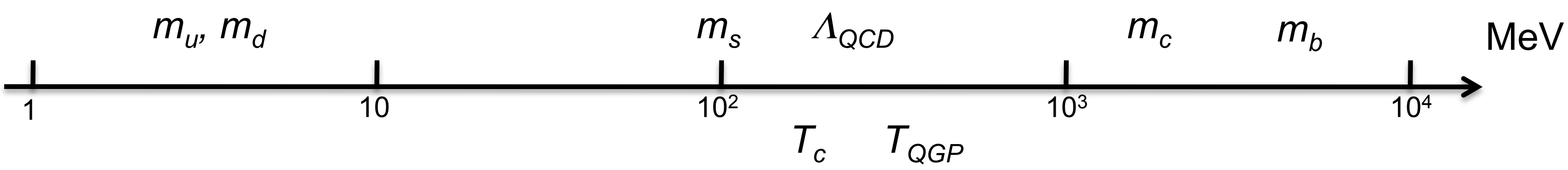


PRL 108 (2012) 022301



PLB 777 (2018) 255-259

Why are heavy quarks important?



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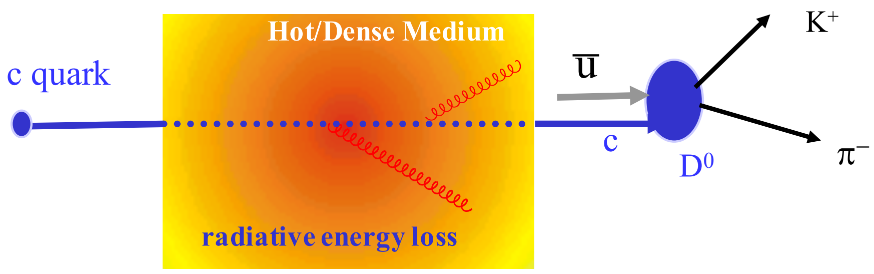
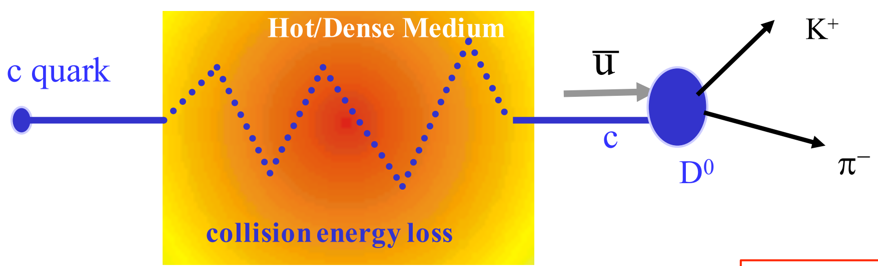
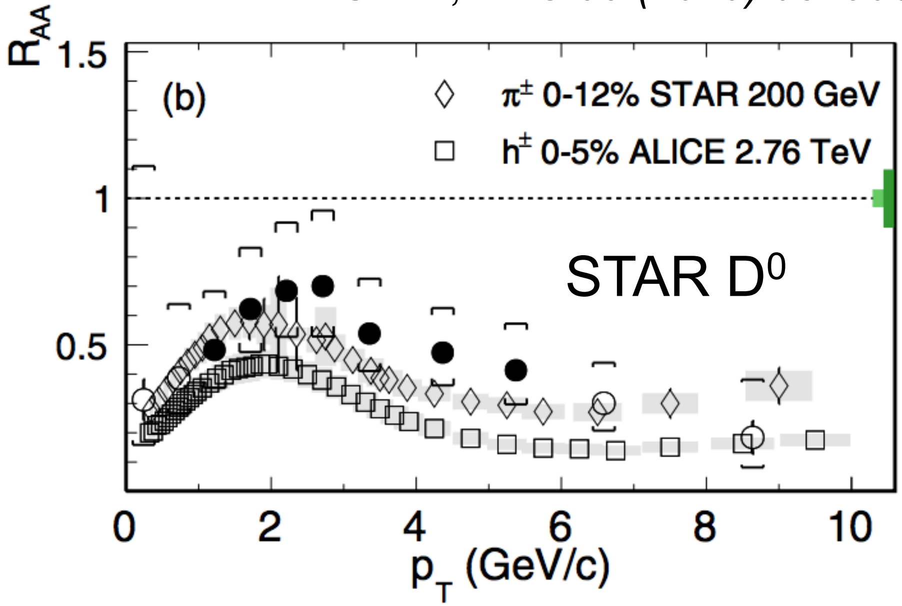


(Baier *et al*, Kharzeev *et al*, Djordjevic *et al*, Wiedemann *et al*.)



(Teaney *et al*, Rapp *et al*, Molnar *et al*, Gossiaux *et al.*)

STAR, PRC 99 (2019) 034908



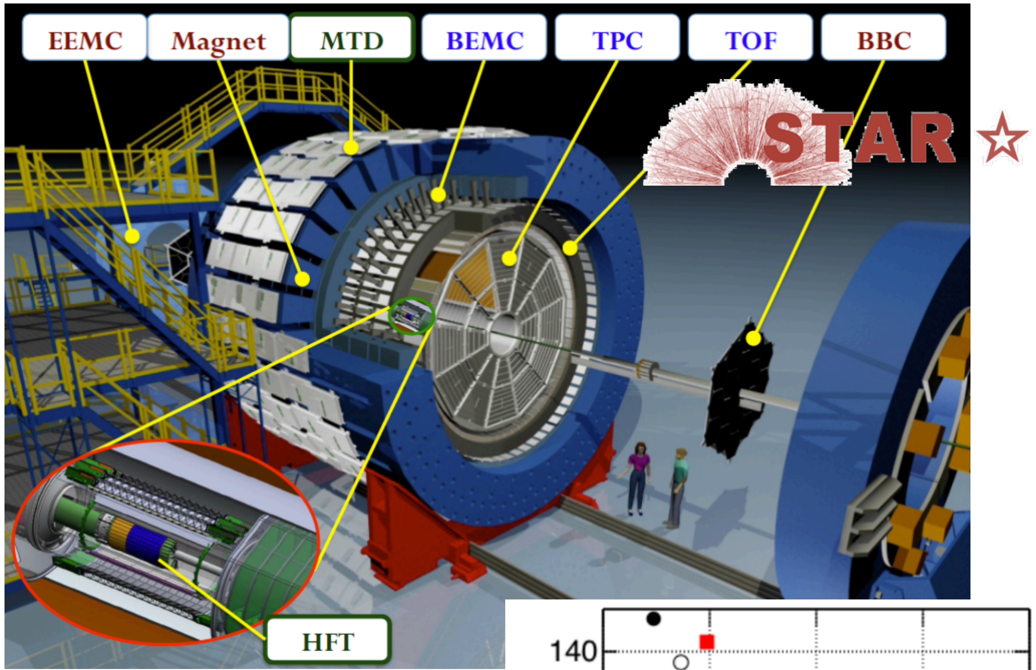
Charm is as ordinary as light quarks!

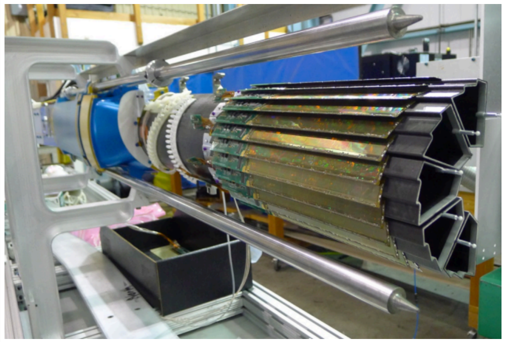
Is there a particle very different from others?

Is there a “big stone” too heavy to be moved in QGP storm?

Moeraki boulders were moved to the beach by storm waves in Austrilia.

RHIC detectors to measure HQ



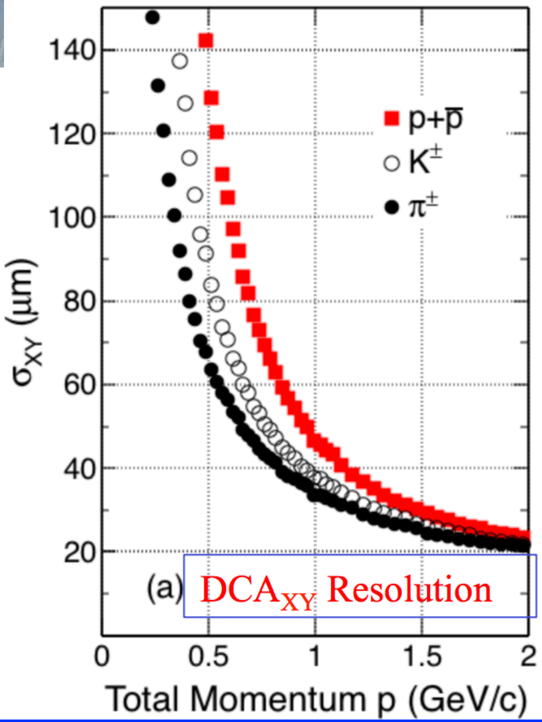


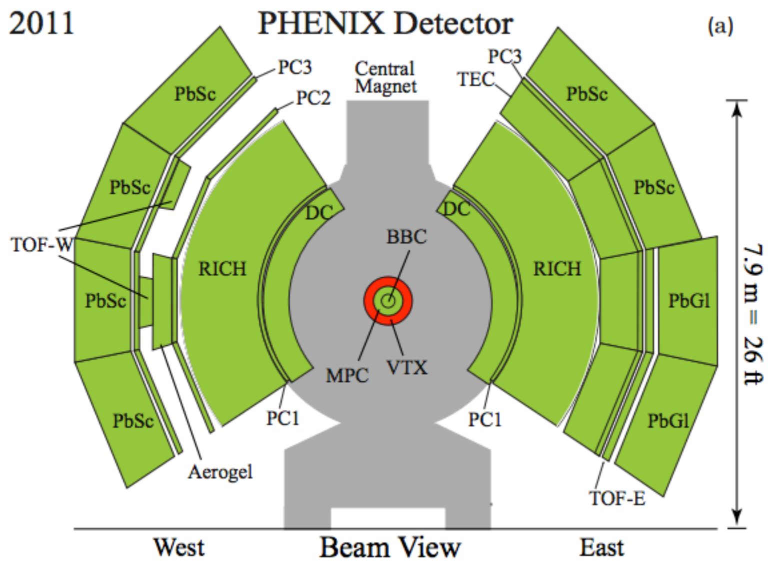
Large acceptance:

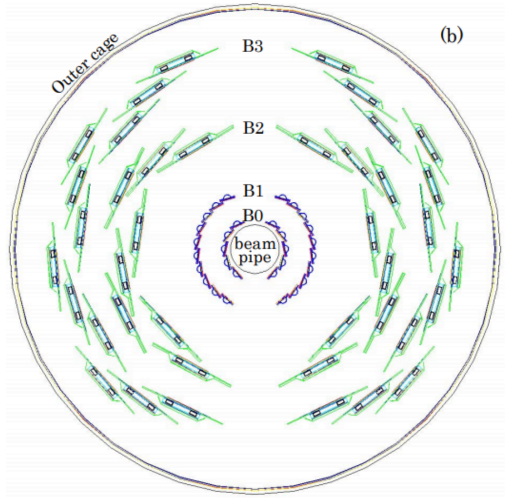
$|\eta| < 1$, $0 < \phi < 2\pi$

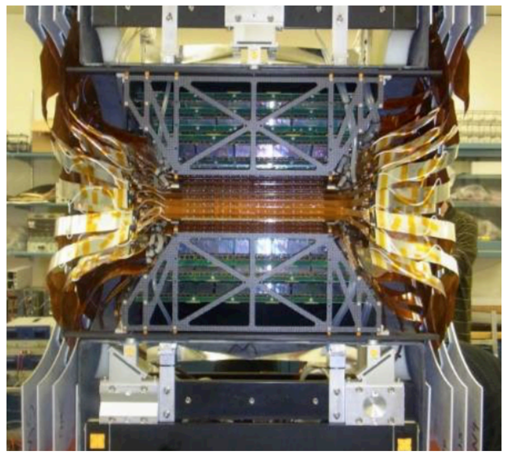
Heavy Flavor Tracker

– track pointing resolution ~30 μm @ p_T ~1 GeV/c



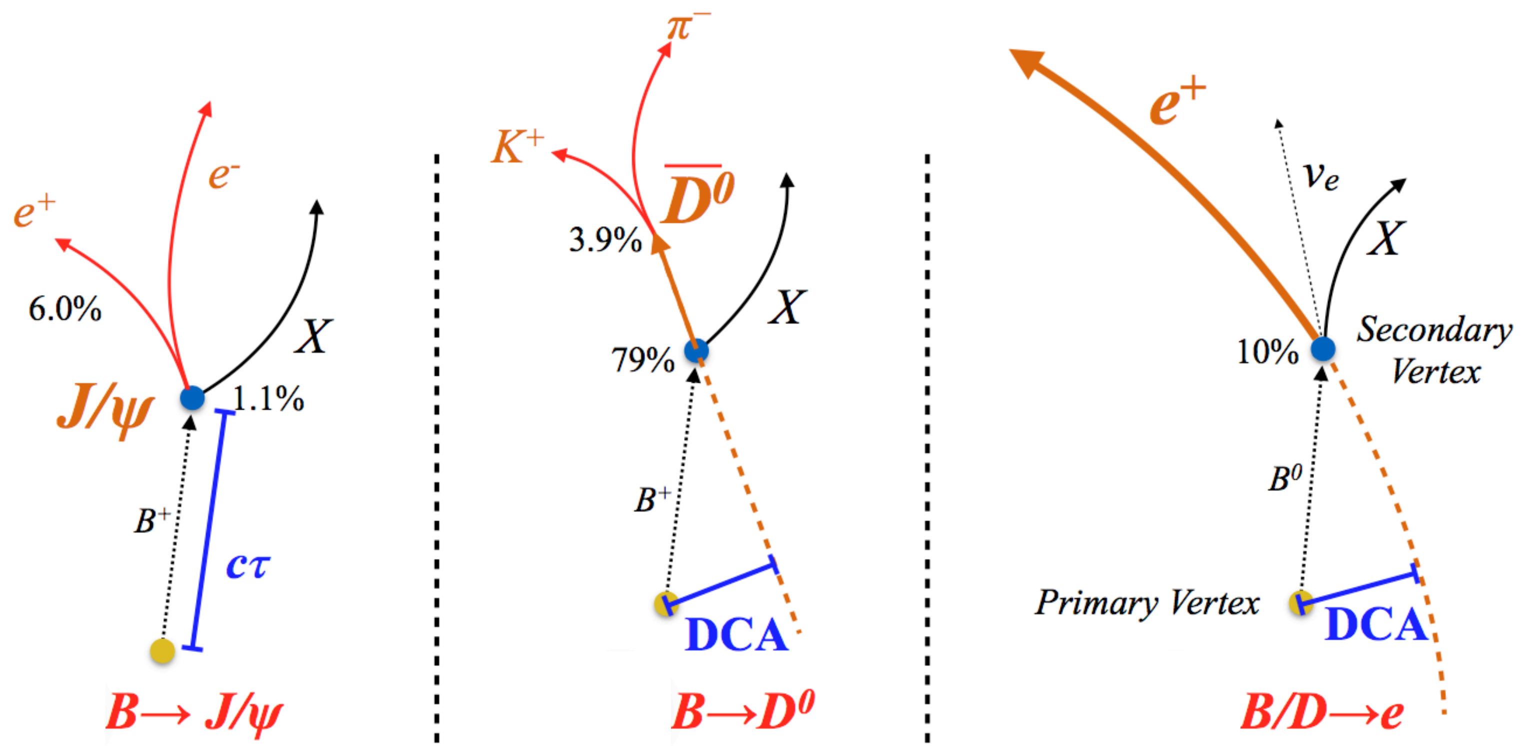






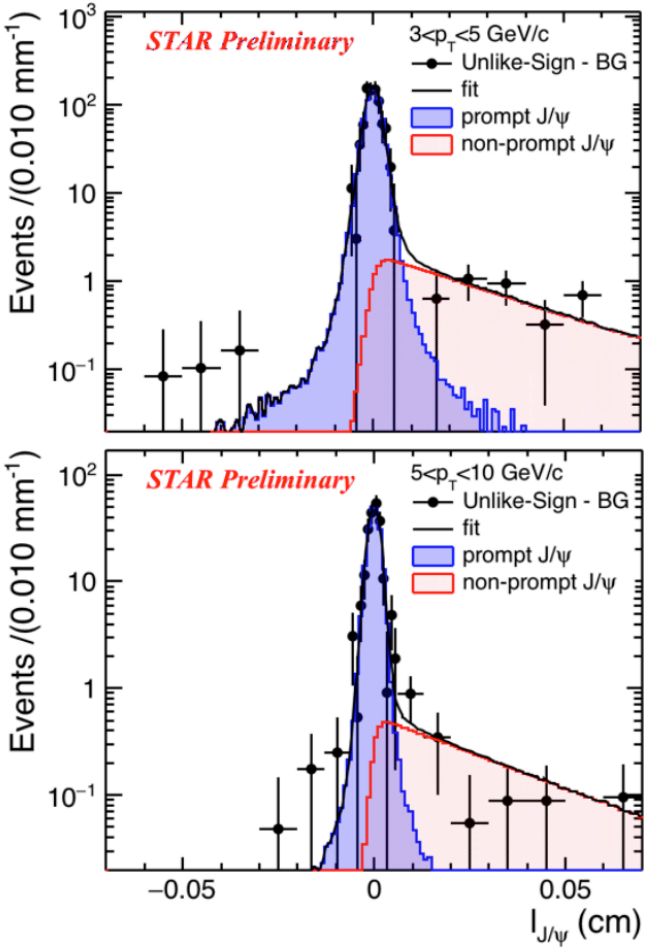
$\sigma_{r\phi}$ = 14.4 (23) um

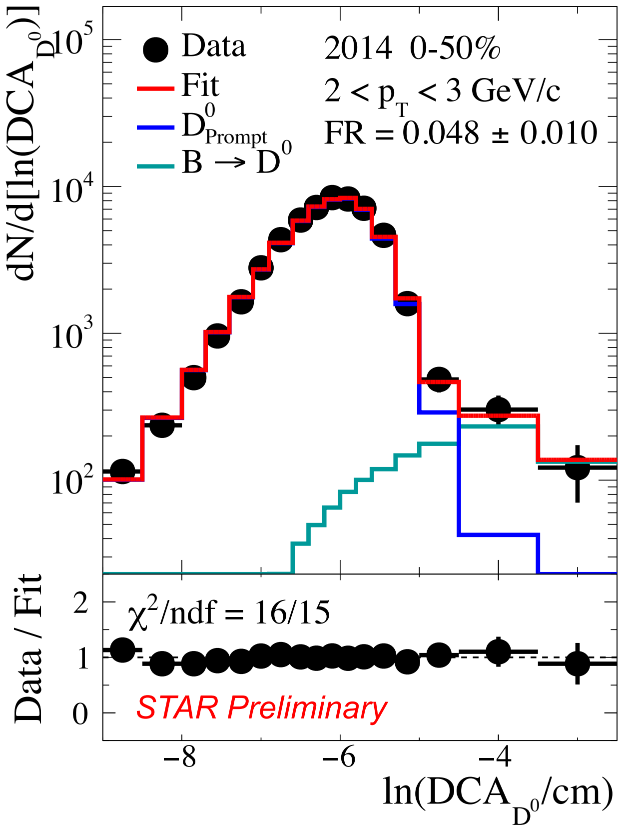
Impact parameter (template) method



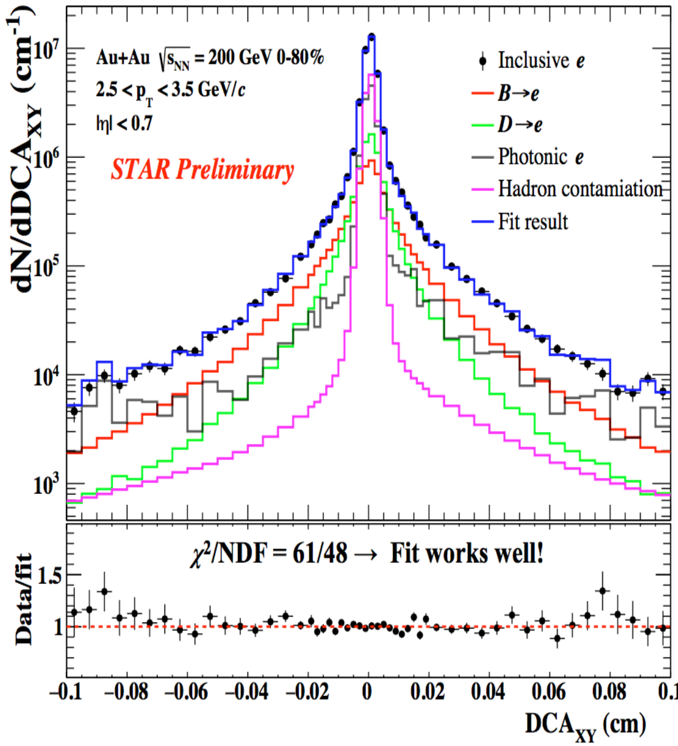
Particle	$c\tau$ (μm)	mass (GeV/c^2)	F.R. ($c/b \to D/B$)	B.R. ($B \to D^0/\overline{D}^0$)
D^0	123	1.865	0.61	-
B^0	459	5.279	0.40	0.081 + 0.474
B^+	491	5.279	0.40	0.086 + 0.790

Impact parameter method from STAR





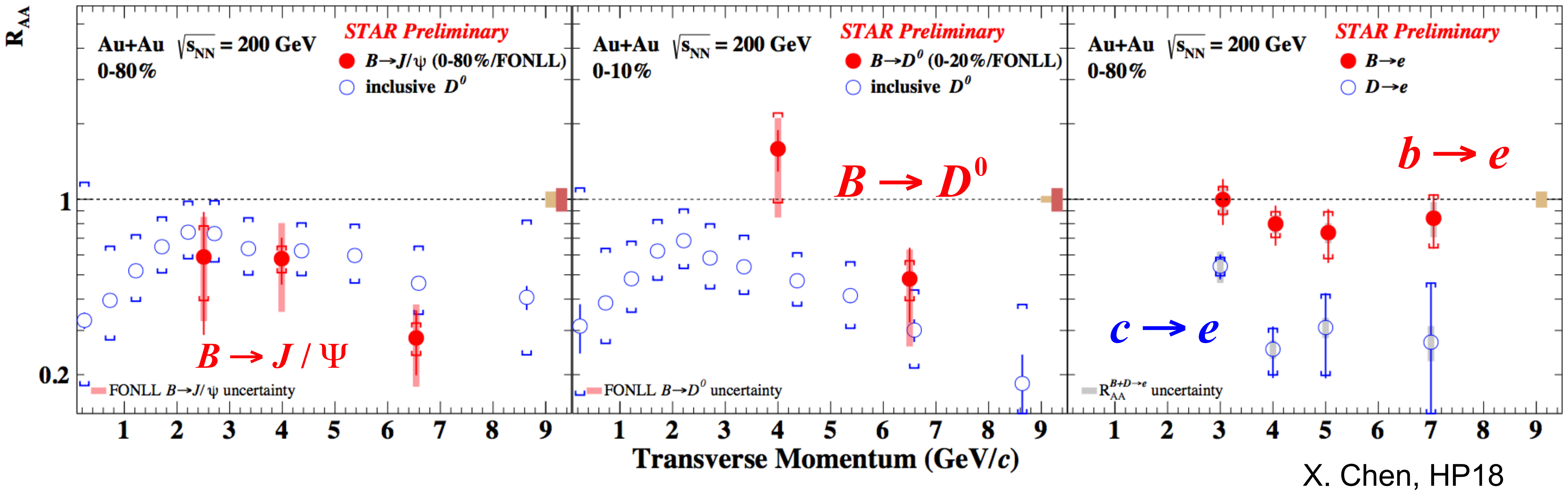
Xiaolong Chen HP18



Kunsu Oh QM17

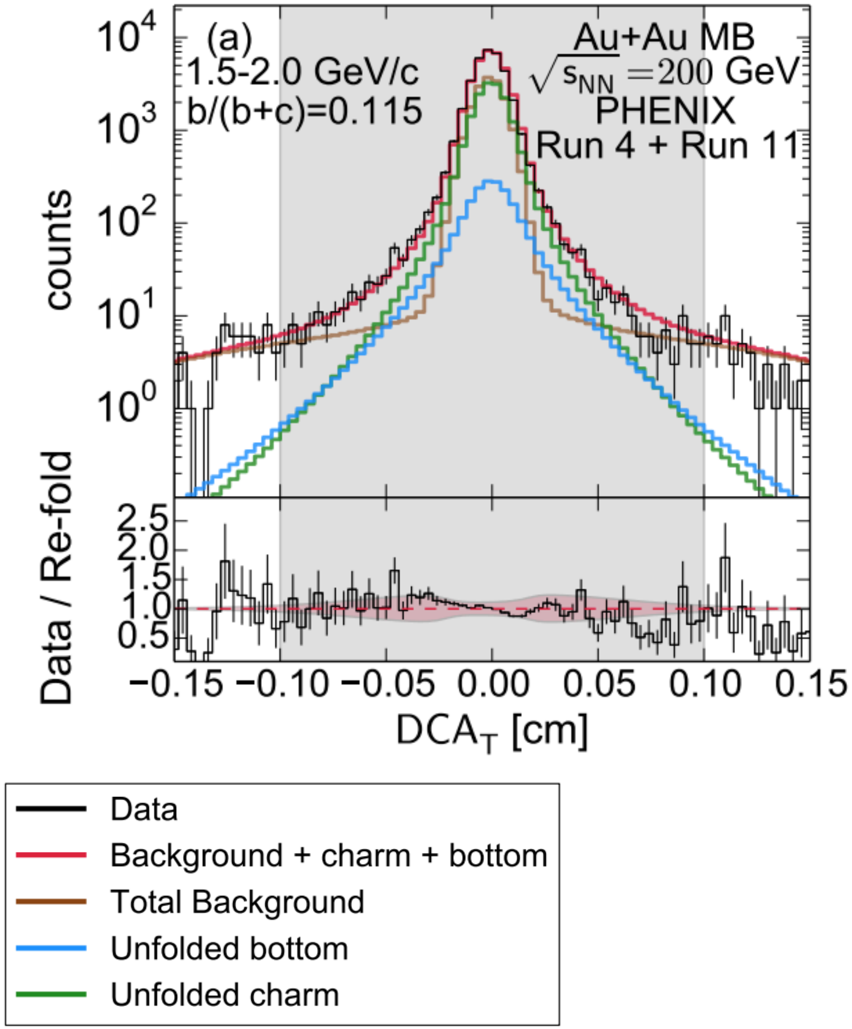
J/ψ D^0 e

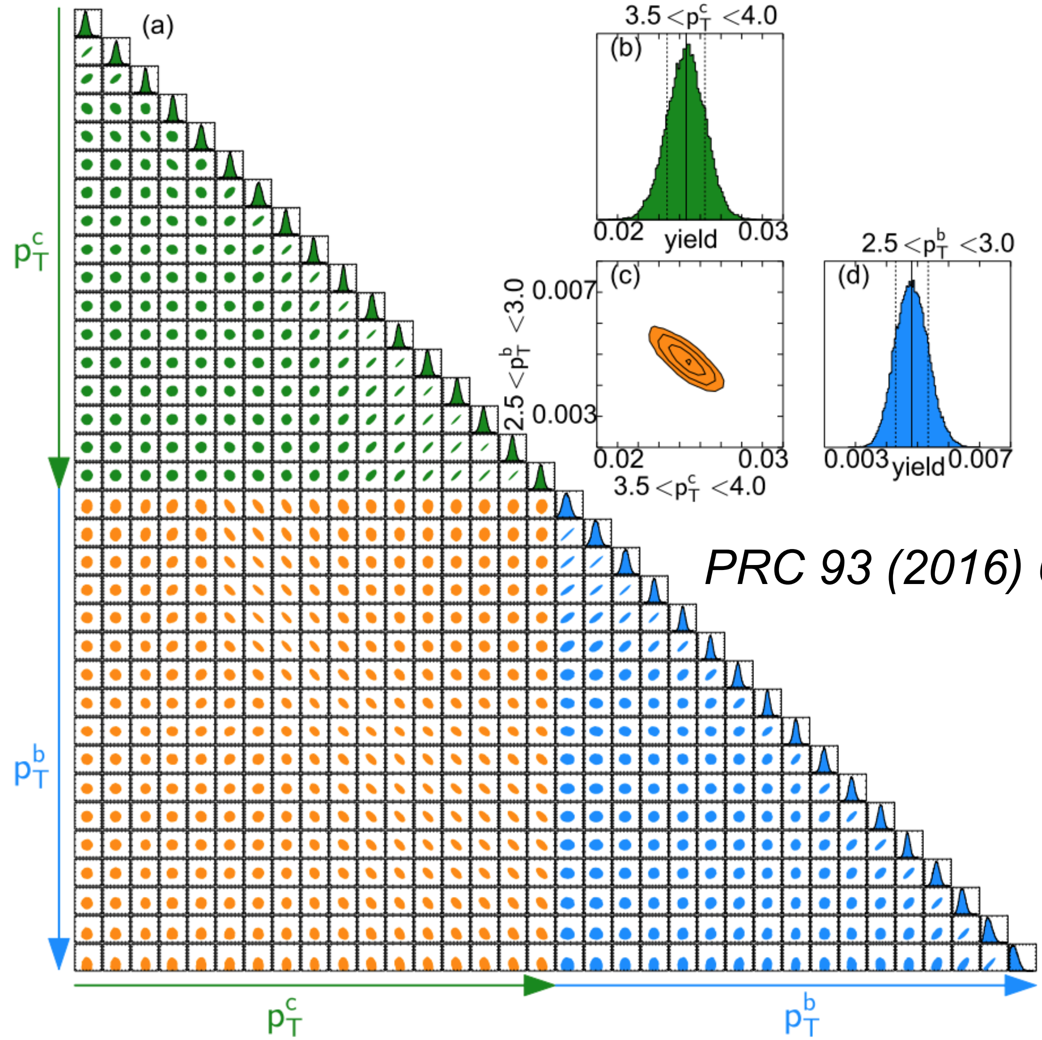
Bottom measurement from STAR



- Strong suppression for B->J/Ψ and B->D^0 at high p_T => Bottom interacts with QGP?
- Less suppression for b->e than c->e (~2σ), consistent with $\Delta E_c > \Delta E_b$.
- Less suppression for non-prompt D^0 at p_T ~ 4 GeV/c, consistent with $\Delta E_c > \Delta E_b$.

Impact parameter method + unfolding from PHENIX

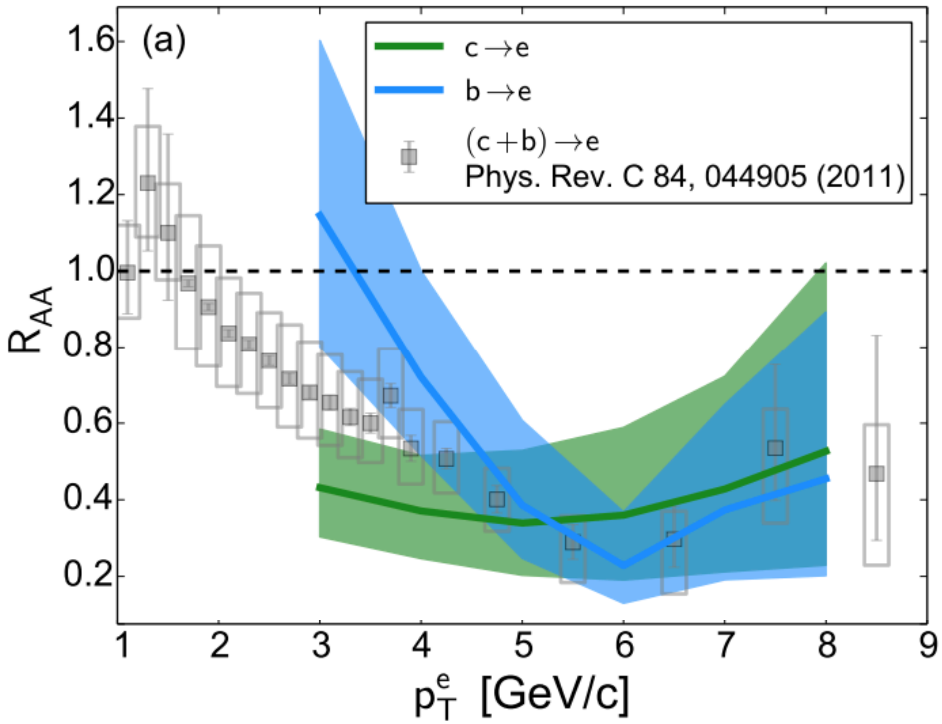




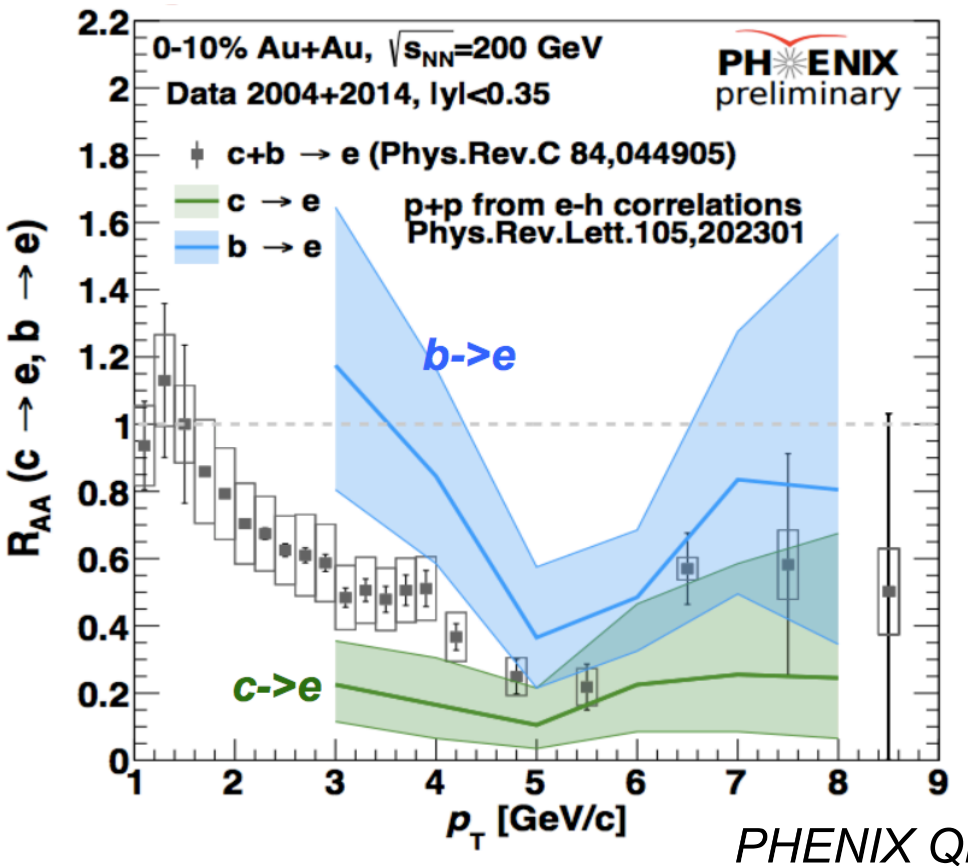
PRC 93 (2016) 034904

- Displaced tracking with VTX for electron DCA$_T$.
- Complicated Bayesian inference techniques (unfolding).

e^{HF} R_{AA} from PHENIX



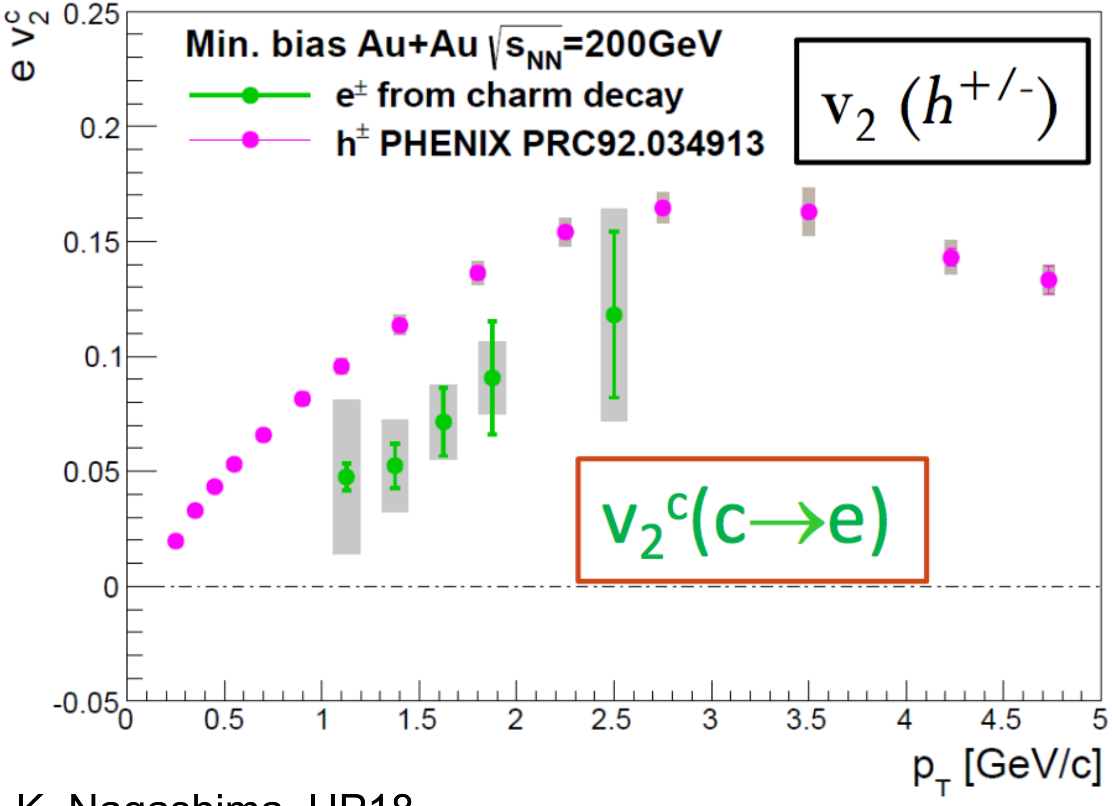
PRC 93 (2016) 034904

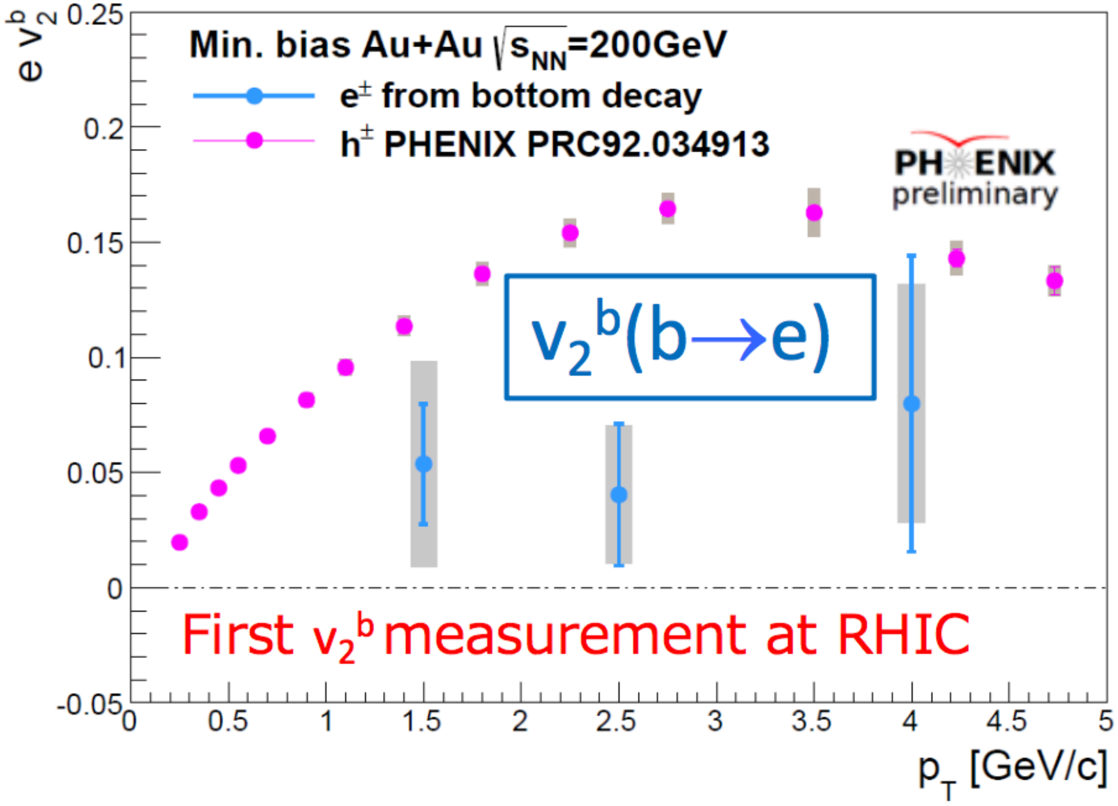


PHENIX QM17

- Electron from charm quarks are more suppressed.
- Hint for less bottom suppression at low p_T compared to charm.
- Large uncertainties due to limited constraints.

e^{HF} v_2 from PHENIX

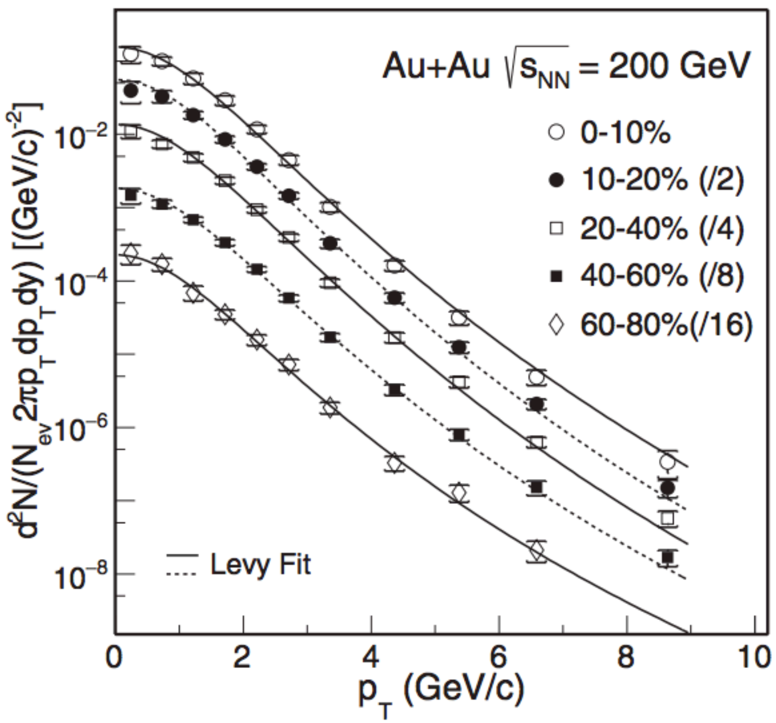




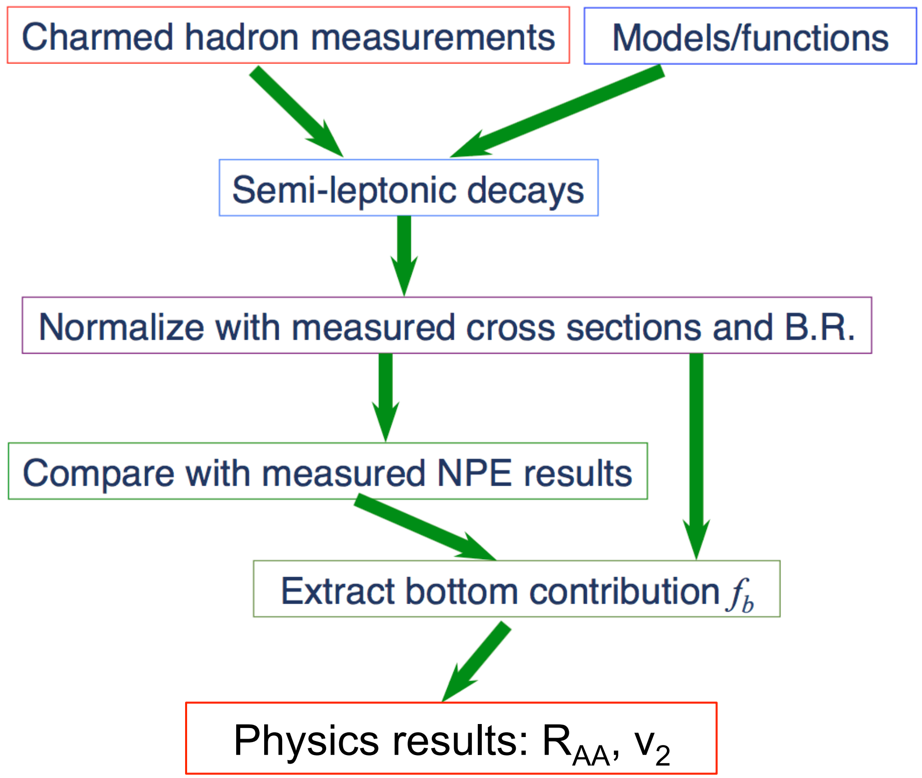
K. Nagashima, HP18

- Flows of electron from charms and bottoms in Au+Au are separated.
- Charm flows less than light-flavor hadrons, hydro mass ordering.
- Hint of bottom flow at RHIC with large uncertainties.

Data driven method (DDM)



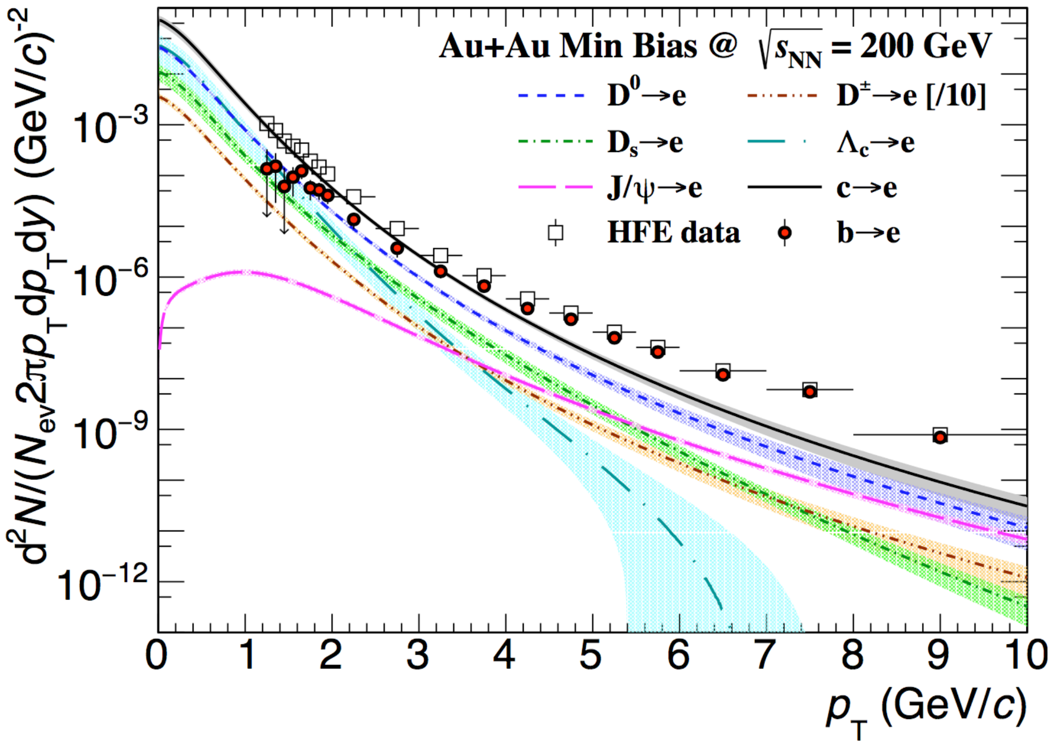
STAR, PRC 99 (2019) 034908

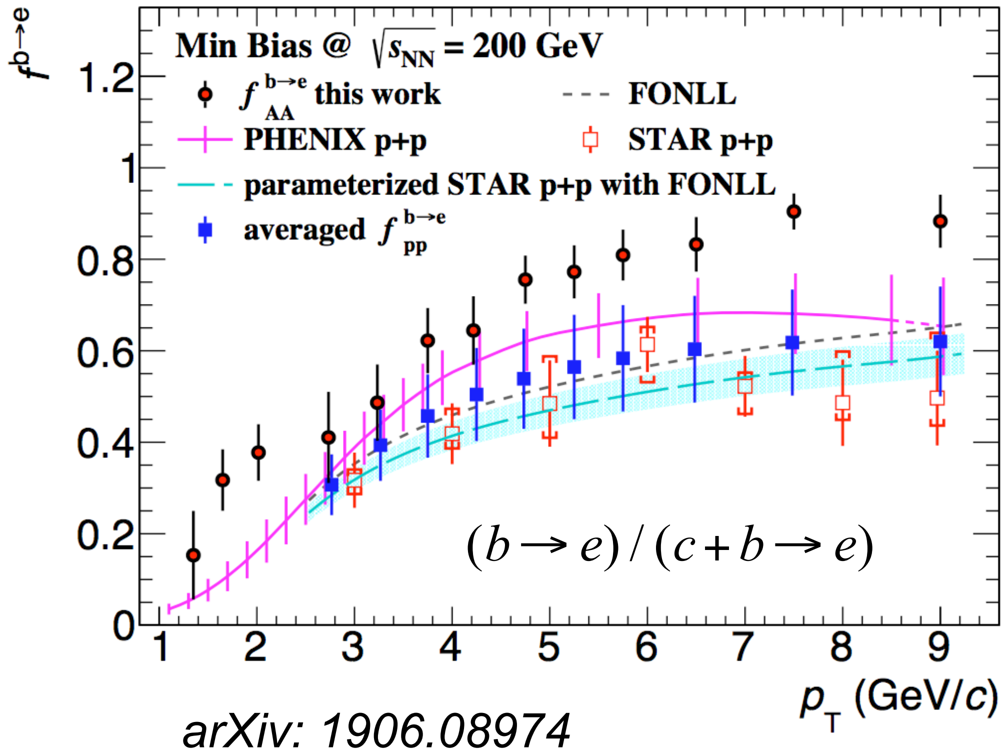


See Zhenyu and Shusu ‘s talks for open charm measurements.

- Largest statistics of Au+Au 200 GeV minimum bias data cumulated so far.
- Taking advantage of precision measurements of open charm hadrons with vertex detectors.
- Minimize the model dependence.

Bottom isolation from DDM





arXiv: 1906.08974

- All charm components are scaled by measured cross sections and B.R.
- Extracted b->e with good uncertainties from DDM.
- Bottom fraction extracted in Au+Au is systematically higher than that in p+p collisions, consistent with less bottom suppression compared to charm in HI collisions.

Bottom NMR from DDM

$$R_{AA}^{c\to e} = \frac{1 - f_{AA}^{b\to e}}{1 - f_{pp}^{b\to e}} R_{AA}^{ince},$$

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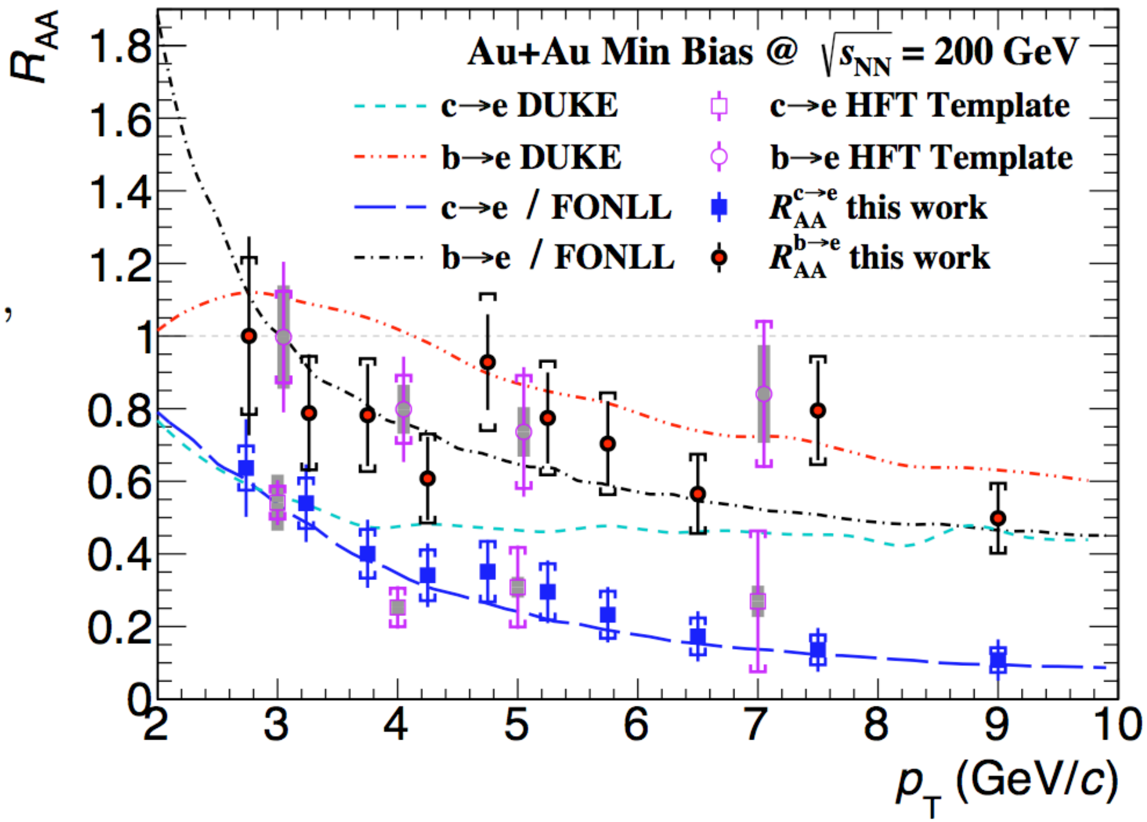
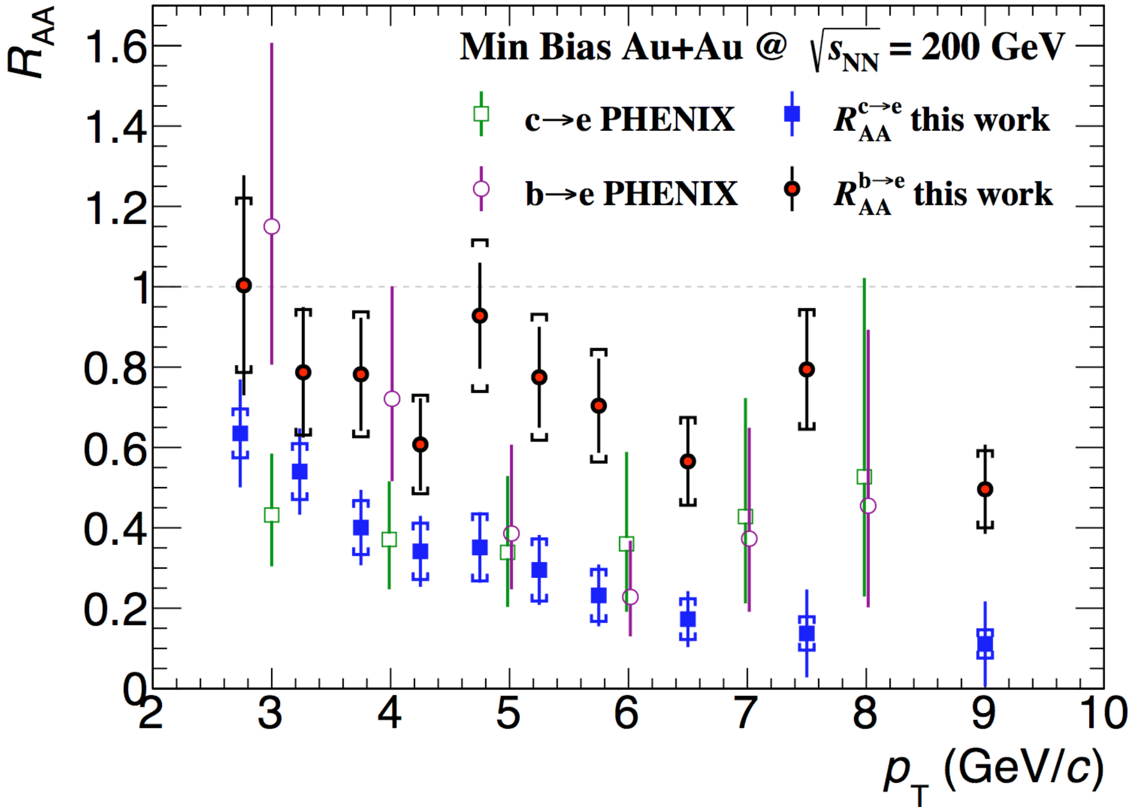


arXiv: 1906.08974

- Consistent with template method but improved precision.
- Clear mass dependence of c/b e-loss shown. Bottom lose less energy.
- b->e is roughly consistent with DUKE model, but c->e shows stronger suppression at p_T > 4 GeV/c.
- Good agreement with c(b)->e / FONLL.

Bottom NMR compared with PHENIX

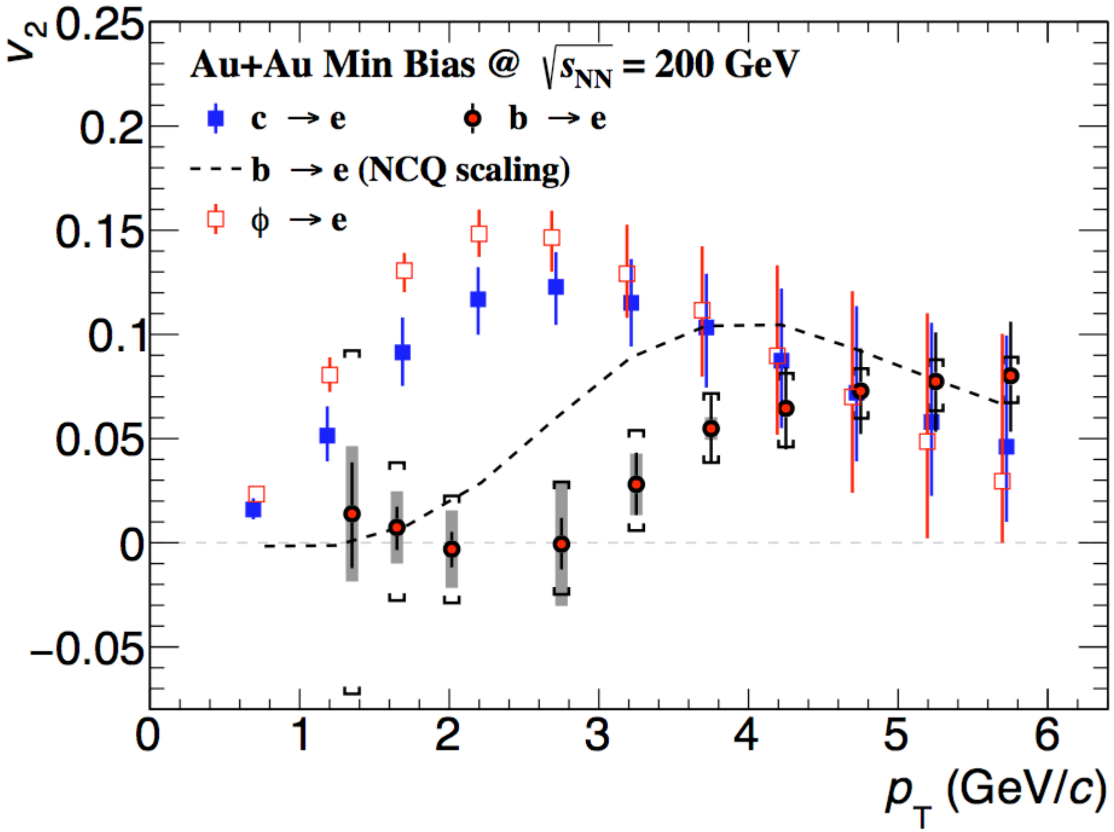


Our work:
arXiv: 1906.08974

PHENIX:
PRC 93 (2016) 034904

- Within uncertainties our result is consistent with PHENIX data.
- PHENIX result has no precision to tell the difference between c and b.
- Our result shows clear mass dependence of heavy quark energy loss.

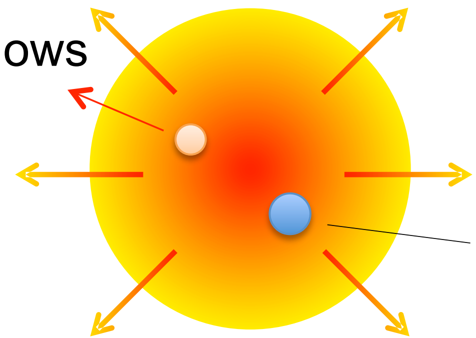
Too heavy to be moved



arXiv: 1906.08974

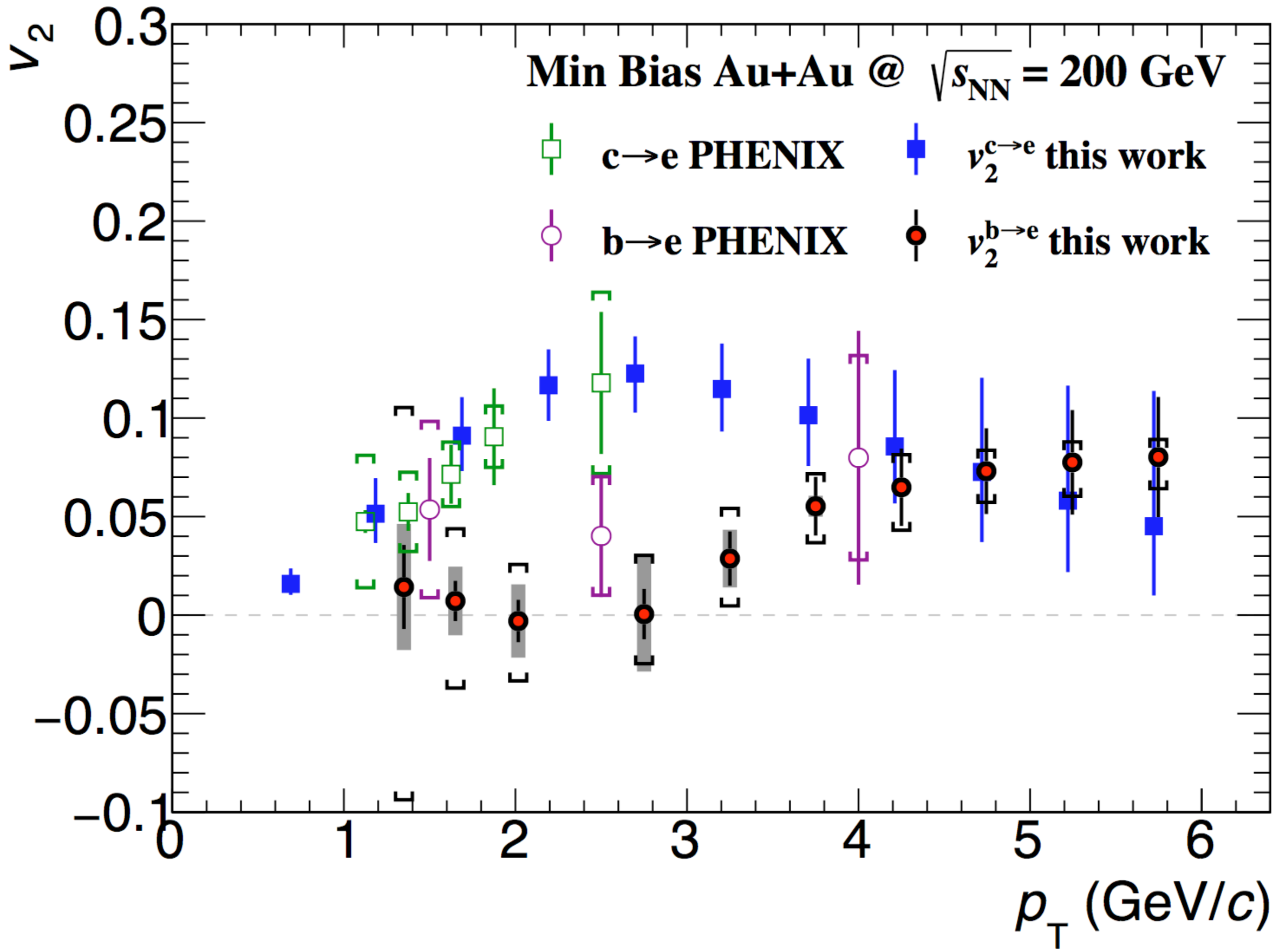
$$v_2(p_T) = \frac{p_0 n}{1+\exp\left(\frac{p_1 - \frac{p_T}{n}}{p_2}\right)} - \frac{p_0 n}{1+\exp\left(\frac{p_1}{p_2}\right)} - p_3 n p_T,$$

$$v_2^{b\to e} = \frac{v_2^{ince} - \left(1 - f_{AA}^{b\to e}\right) v_2^{c\to e}}{f_{AA}^{b\to e}},$$



- Non-zero b->e v_2 observed at p_T > 3 GeV/c.
- Much smaller v_2 compared with c->e at p_T < 4 GeV/c.
- Less flow compared with NCQ scaling hypothesis at 2.5 < p_T < 4.5 GeV/c assuming only mass effect, indicating bottom is unlikely thermalized at RHIC.

Bottom v_2 compared with PHENIX



Our work:
arXiv: 1906.08974

PHENIX:
T. Hachiya NPA 982 (2019) 663

- PHENIX results are consistent with ours within uncertainties but have no precision to tell the difference between charm and bottom.

Summary

- Heaviest quark (bottom) measured at RHIC via multiple decay channels of open bottom hadrons -> J/ψ, D^0 and electron.
- Both R_{AA} results from STAR and PHENIX show hint of mass dependence of heavy quark energy loss via impact parameter methods.
- Non-zero b->e v_2 observed by PHENIX but no precision to tell difference between charm and bottom.
- Improved results are obtained via a data driven method taking advantage of highest statistics accumulated and best precision of open charm measurements.
  - R_{AA} of c->e and b->e show clear suppression but b->e is less suppressed compared with c->e in Au+Au collisions at 200 GeV.
  - Non-zero b->e v_2 observed at p_T > 3 GeV/c.
  - Much smaller b->e v_2 compared with c->e at p_T < 4 GeV/c, which can not be explained by mass effect only (NCQ scaling), indicating that bottom is unlikely thermalized at RHIC energy.

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Thank you for your attention!