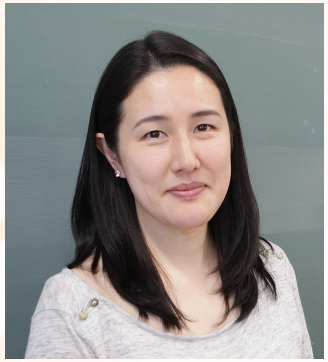
Latest heavy flavor and quarkonia results with PHENIX



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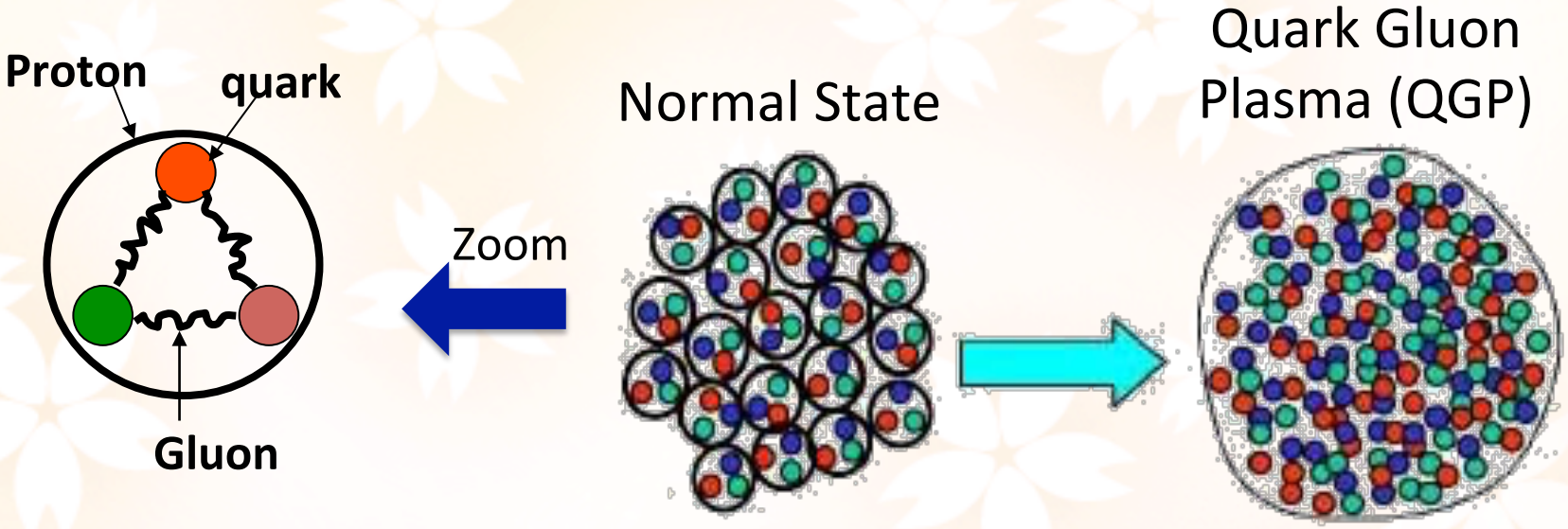
March 25th 2016

Moriond QCD

Why heavy flavor (HF)?

The purpose of our experiment is ..

1. Create "QGP" in Lab. --- Done!



2. Study of the QGP characteristic.
   - Focus on the interaction in QGP.

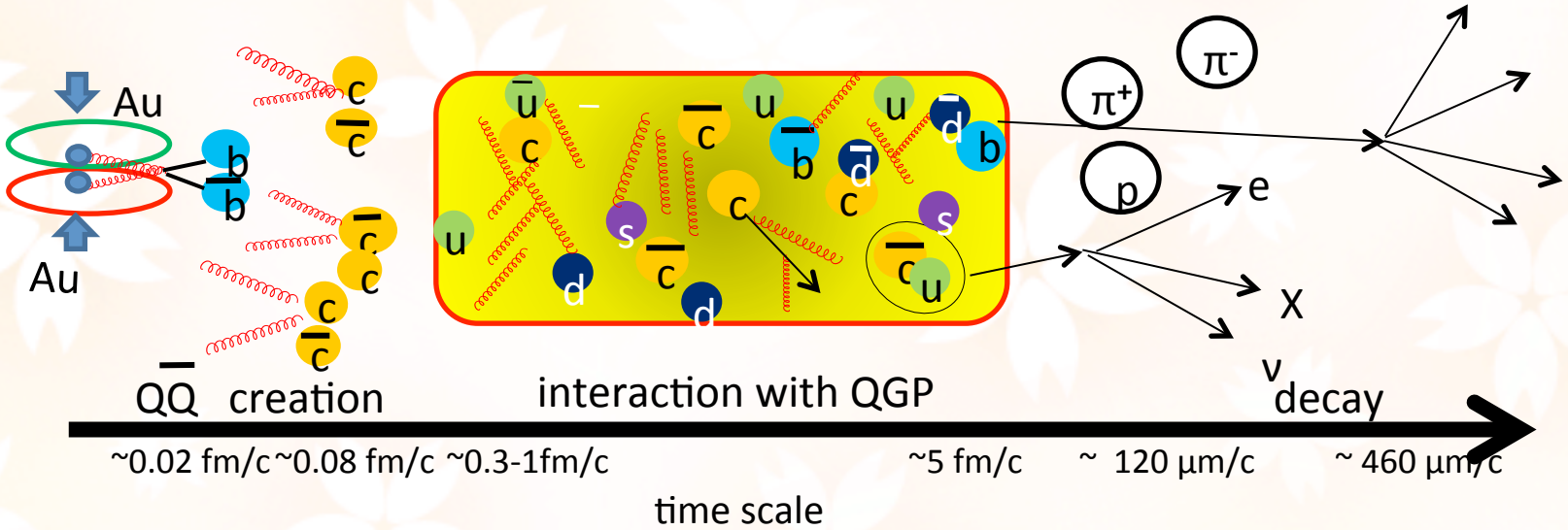
Why HF ?

c- mass 1.3 GeV
b- mass 4.5 GeV **>>** QGP temperature 300~600 MeV

Clean and known!

"HEAVY" quarks (c, b)

- are produced in the initial collision.
- interacted with QGP.
- production can be calculated by p-QCD.



The modification of HF in QGP is the key.

Inclusive(charm & bottom) results

$$R_{AA} = \frac{\text{Yield_Au+Au}}{\text{Ncoll* Yield_p+p}}$$ (1 with no suppression)

Single electrons from inclusive HF decays shows :

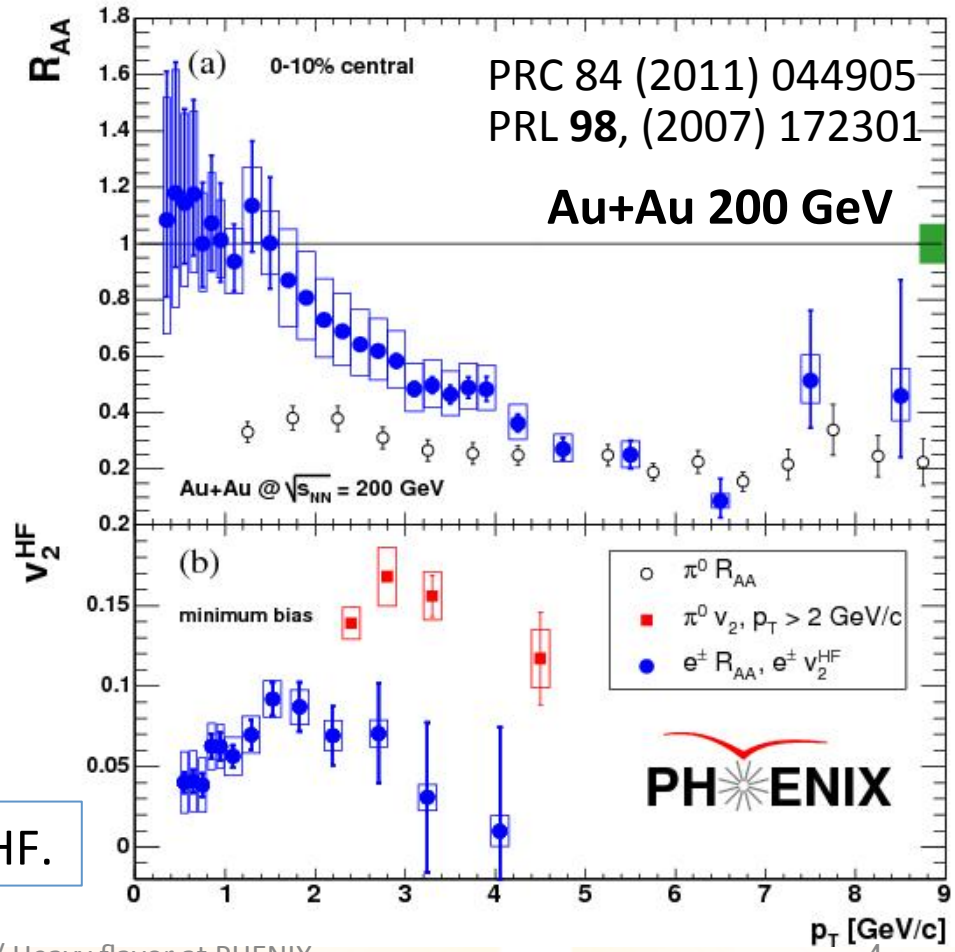
R_{AA}: strong suppression

v_2 : non-zero flow

v_2 : Azimuthal anisotropy (0 with no flow at low p_T) (0 with no suppression at high p_T)

Surprising results

- Questions
  - What is the energy loss mechanism for heavy flavor?
  - Mass dependence of energy loss?

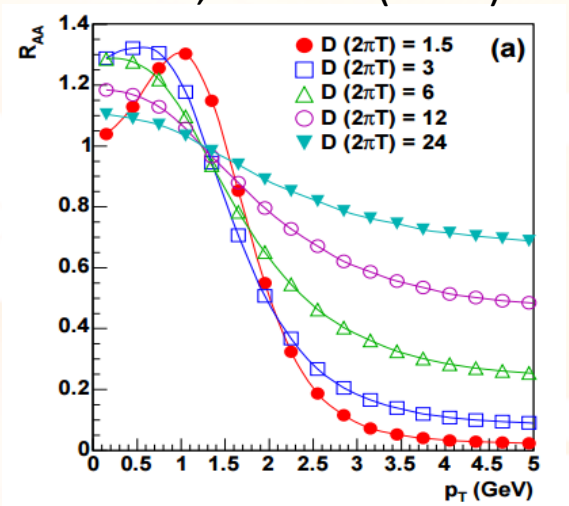


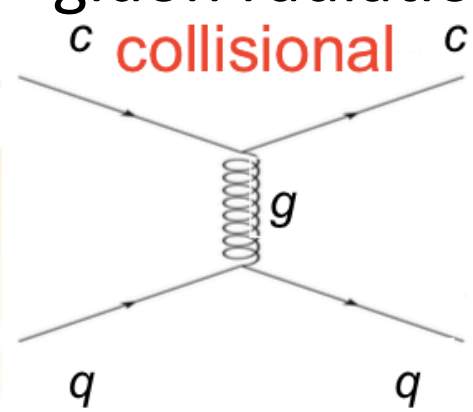
Need more precise measurement for HF.

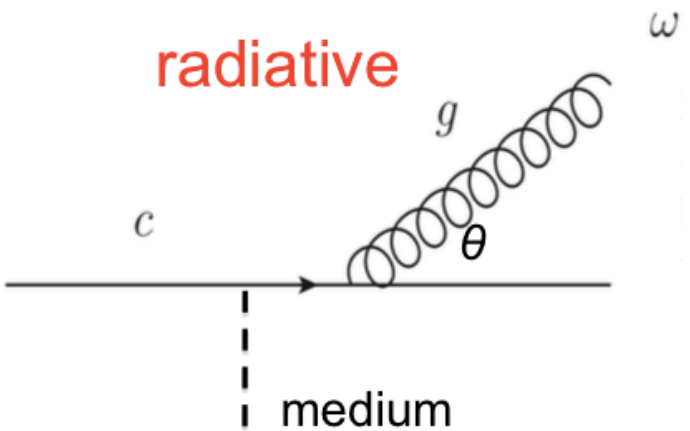
Energy loss mechanism

- Collisional loss (low p_T)
  - multiple scattering
    - Brownian motion
    - Mass dependence
- Radiative loss (high p_T)
  - gluon radiation

Collisional loss of charm quarks
PRC 71, 064904 (2005)



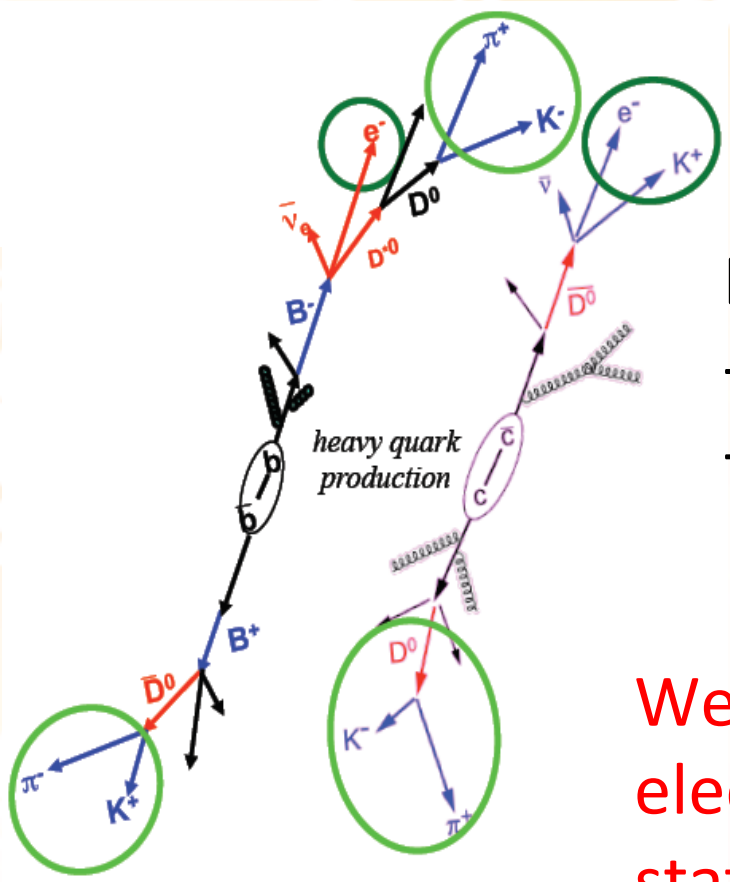




Need to measure bottom and charm separately!

Challenge to separate b and c origin

- Use their different lifetimes and decay kinematics



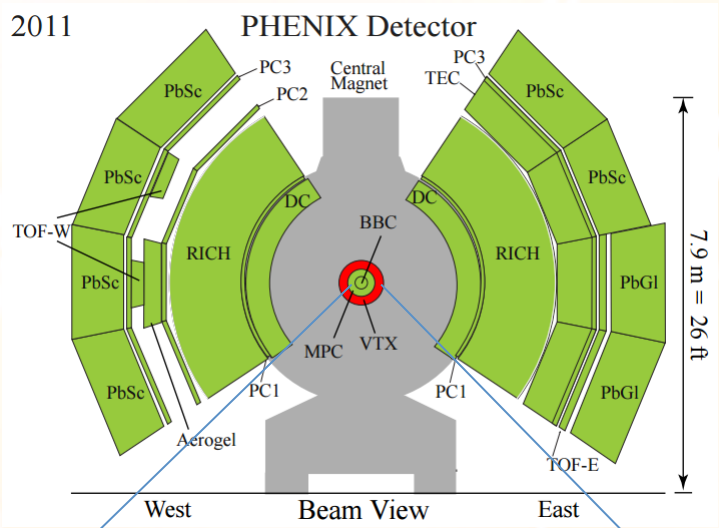
decay length ($c\tau$)

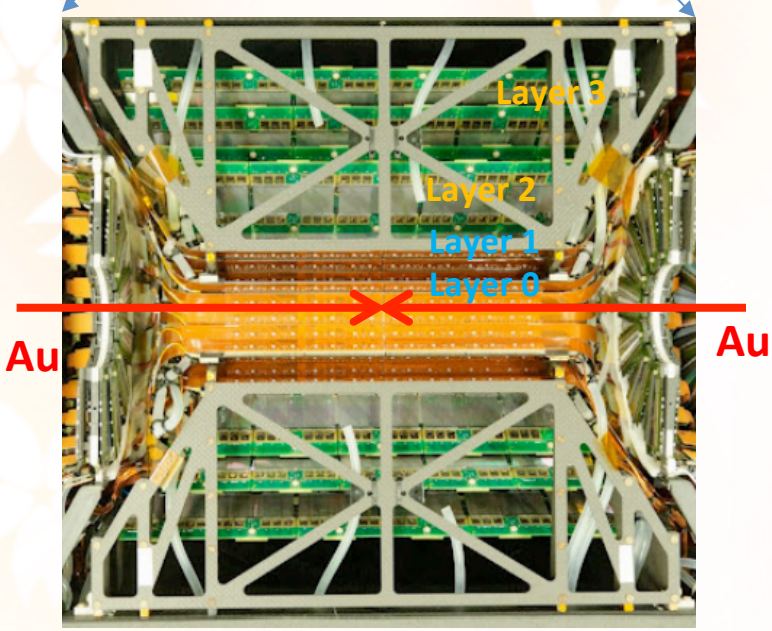
B^+ : 491.1 μm, D^+ : 311.8 μm,

Experimentally if we measure
- Precise displaced tracking
- Precise primary vertex

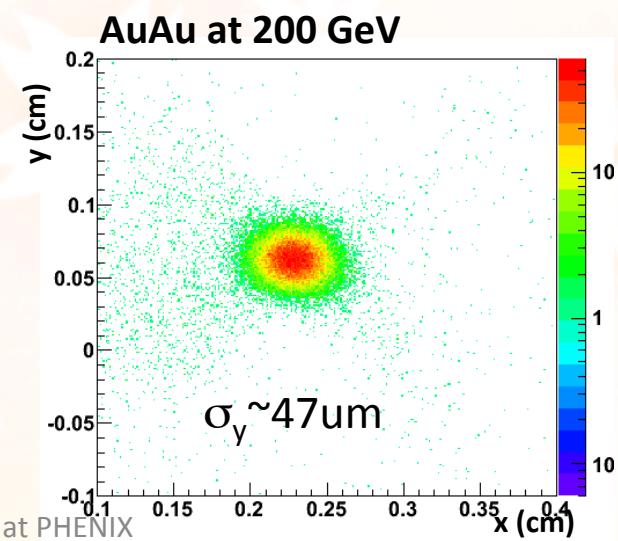
We can separate between c-origin electrons and b-origin electrons statistically!

PHENIX Silicon Vertex Detector(VTX)



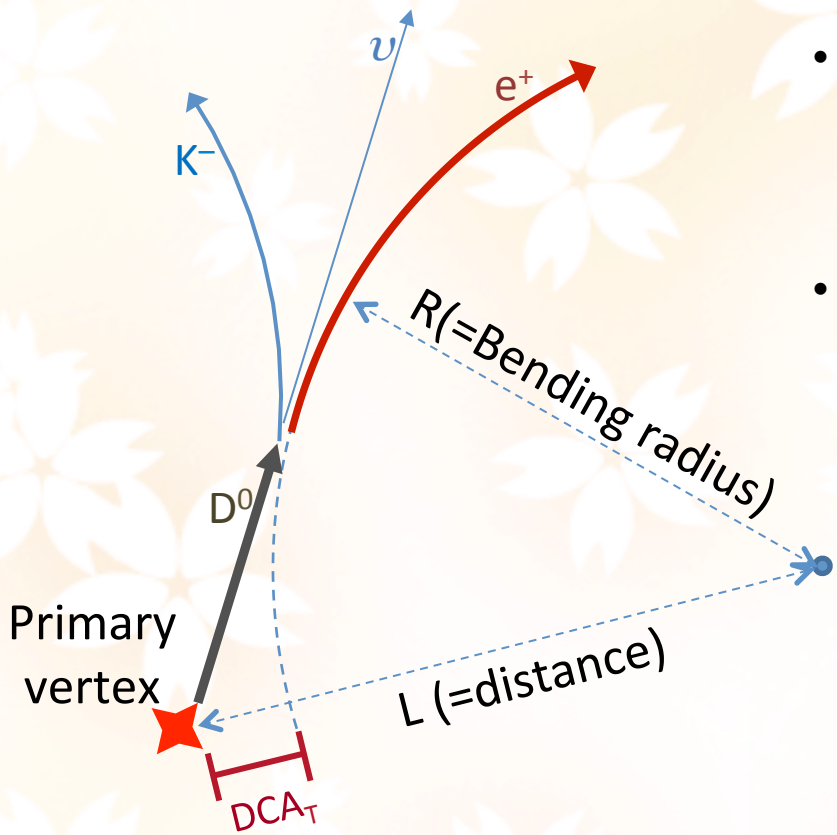


- VTX installed in Run2011
  - Large coverage
    - $|\eta|<1.2$, $\phi \sim 2\pi$
  - 4 layer silicon detectors
    - 2 inner pixel detector
    - 2 outer stripixel detector
- Measure
  - Precise displaced tracking
  - Precise 3D primary vertex

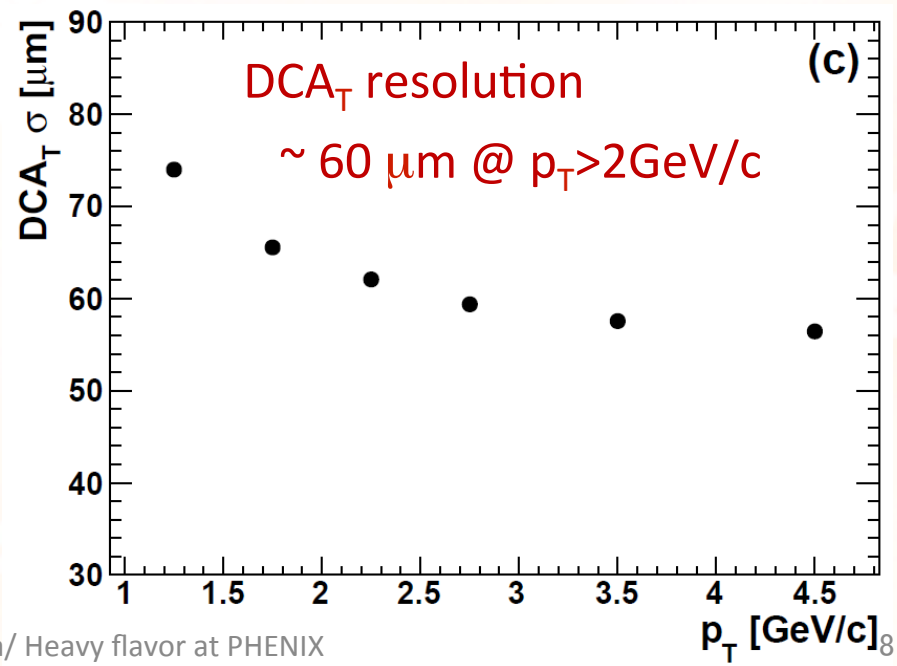


Precise displaced tracking

$DCA_T \equiv L - R$

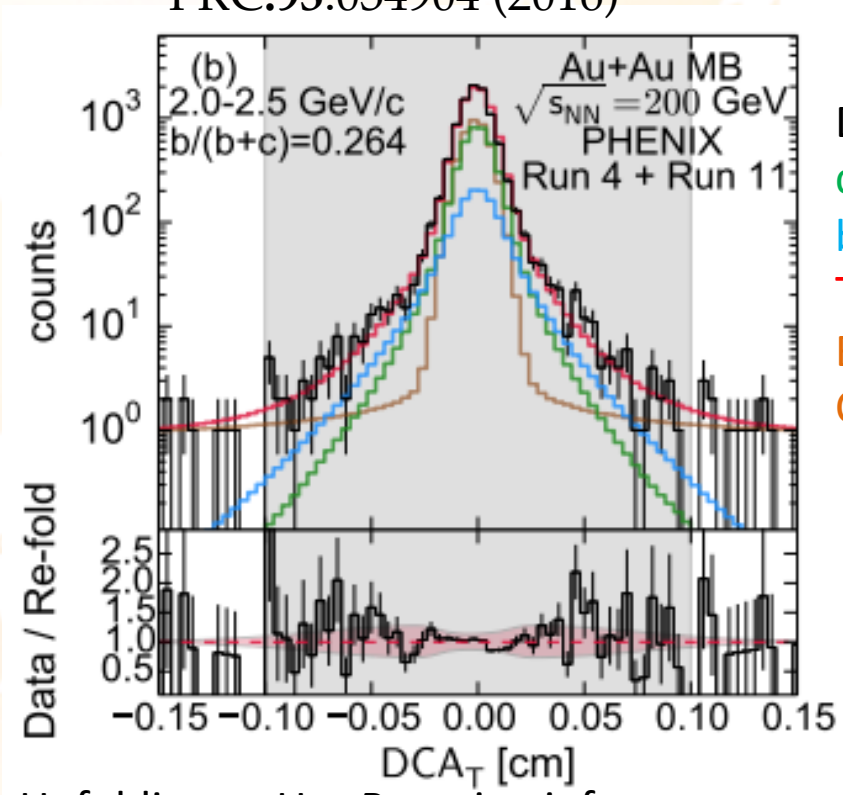


- Calculate Distance of Closest Approach (DCA) of electrons to primary vertex
  - Proxy for decay length
- Calculate separately
  - DCA_T = in transverse plane
  - DCA_L = in longitudinal plane
- DCA_T is better by detector design



Separation of b & c with DCA_T

PRC.**93**.034904 (2016)

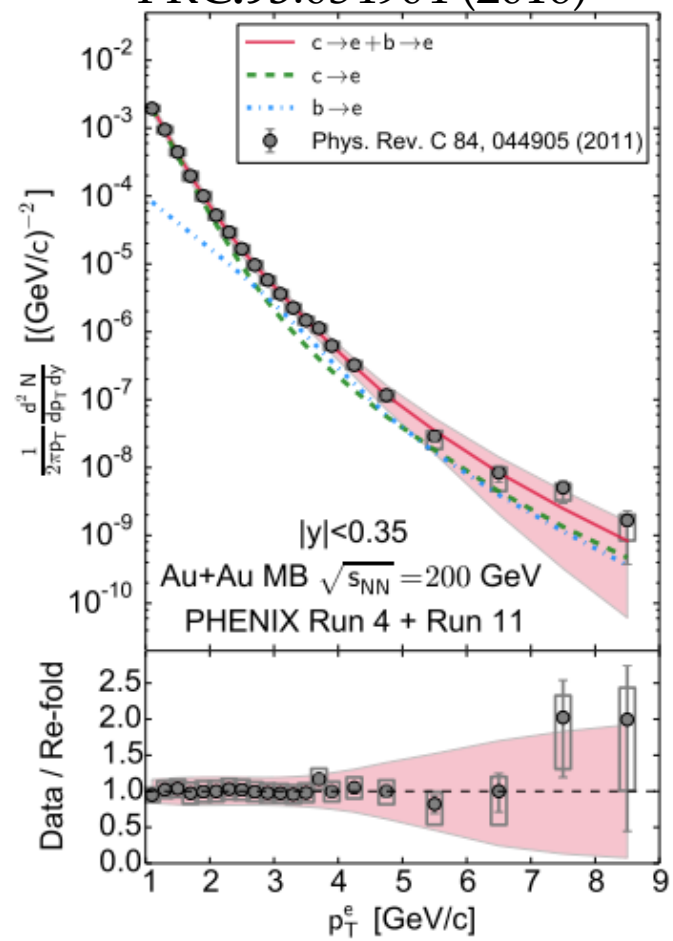


Data
c->e
b->e
Total
Background
Components

Unfolding --- Use Bayesian inference methods to determine parent charm and bottom hadron p_T distributions.

Consistency check !

PRC.**93**.034904 (2016)



Statistically separated bottom and charm!

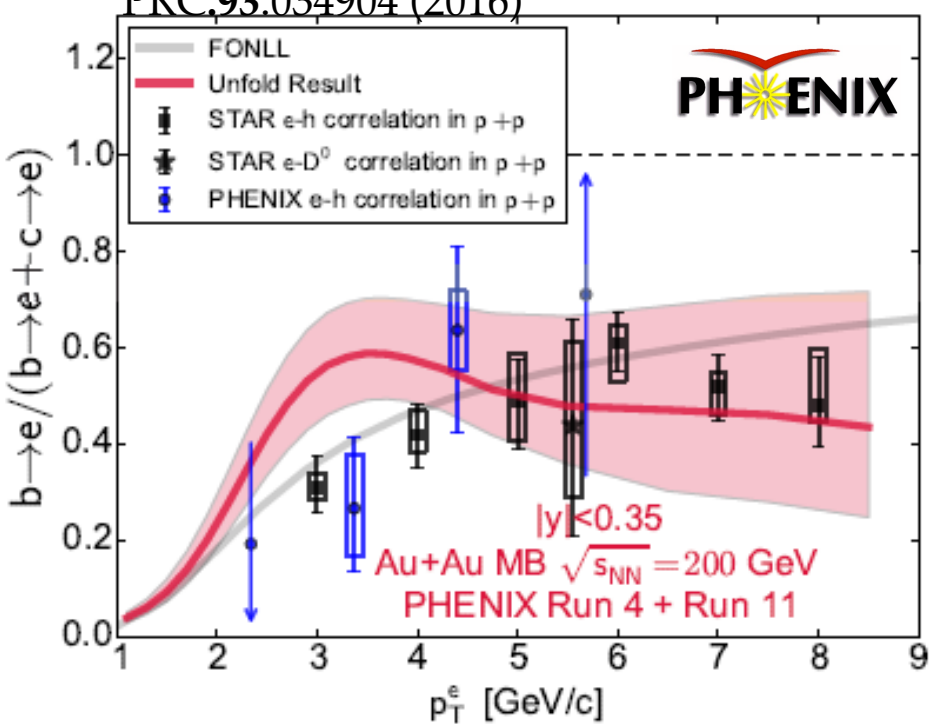
Bottom fraction

In electron's pT space

Fraction of electrons from bottom

$$F = \frac{b \to e}{b \to e + c \to e}$$

PRC,**93**.034904 (2016)



p+p result is consistent with pQCD calculation(FONLL)

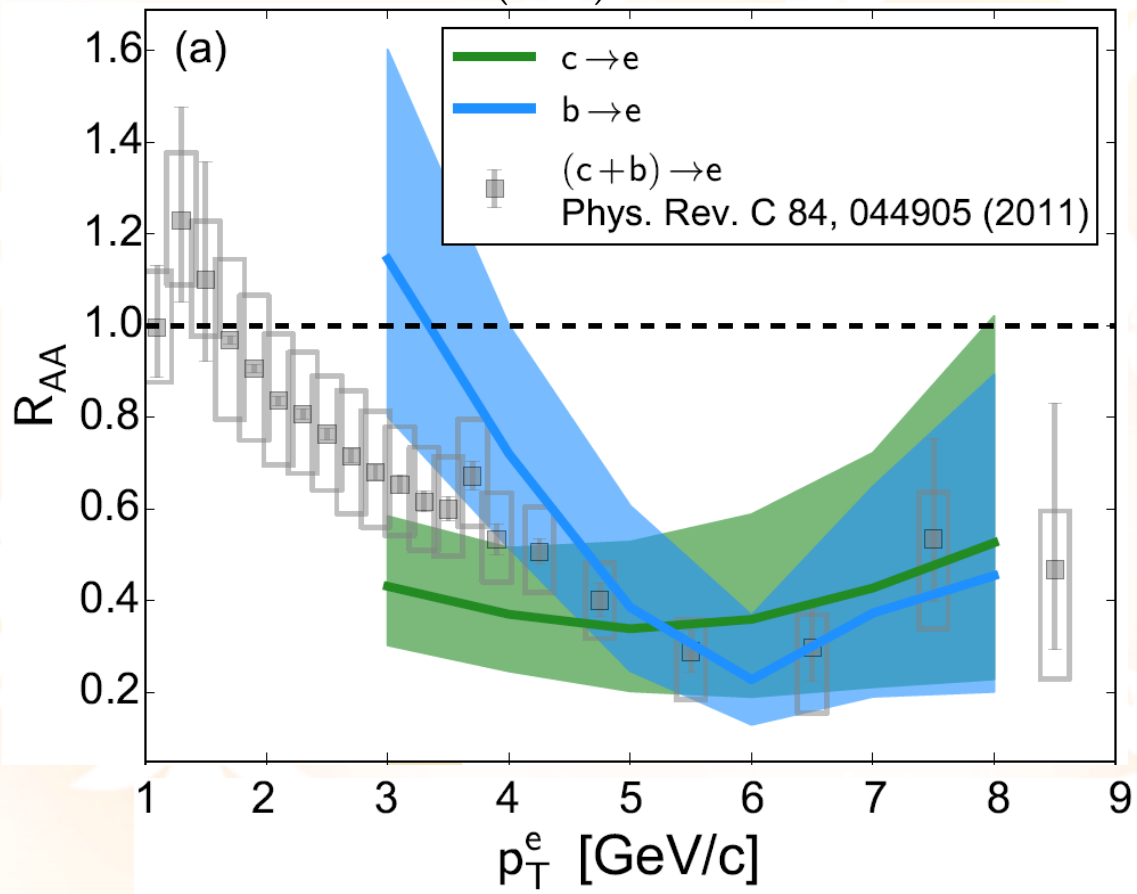
Au+Au result is different! Decreasing at high p_T.

b and c have different suppression pattern as a function of p_T.

HF Result

Bottom & Charm R_{AA}

PRC.**93**.034904 (2016)



F_{AuAu} : fraction of bottom origin electron in Au+Au

F_{pp} : : : fraction of bottom origin electron in p+p

R_{AA}^{HF} : HF electron R_{AA}

$R_{AuAu}^{c\text{->}e} = (1-F_{AuAu})/(1-F_{pp})R_{AA}^{HF}$

$R_{AuAu}^{b\text{->}e} = F_{AuAu}/F_{pp}R_{AA}^{HF}$

R_{AA} = 1 if no suppression

- Bottom and charm have same strong suppression at high p_T.
  - **First measurement** for bottom suppression at RHIC.
- Bottom **suppressed less** than Charm at low p_T

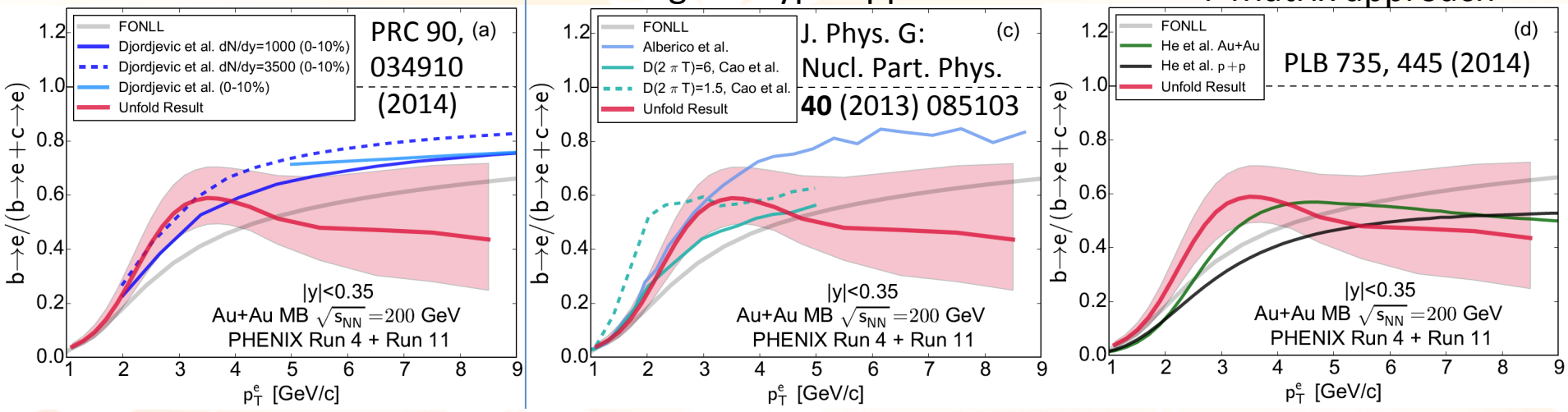
HF Result

Comparison with models

Radiative
DGLV model

Collisional
Langevin type-approach

Collisional
T-Matrix approach



- Data and models show different tendency.
  - Data can constrain models.
- Need to make data uncertainty smaller (especially at high p_T).
  - On going analysis with Run 2014, 10 times larger statistics!

Charmonia at small system (p+Au, p+Al)

Charmonia (c-c)

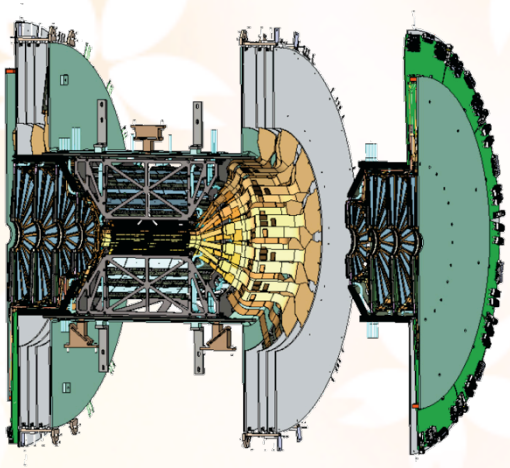
- is created in initial collisions (same as open HF)
- can be broken (different from open HF)

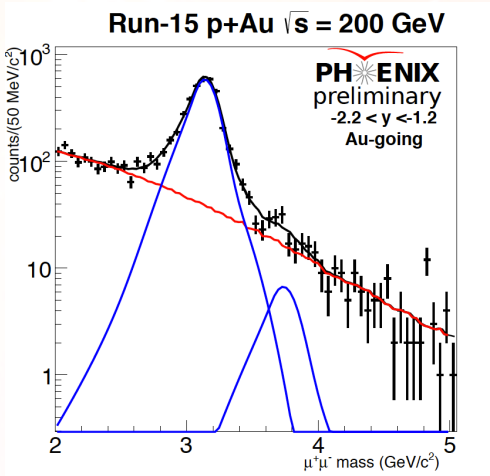
The ψ' is more weakly bound than the J/ψ .
They have different width → different break up cross section.

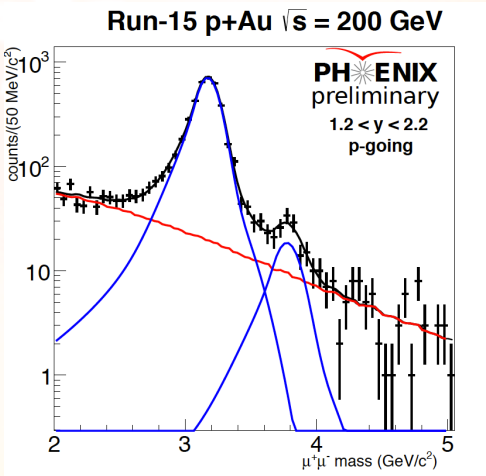
→ **Interesting probe.**

New detector "Forward VTX (FVTX)" separates the J/ψ and the ψ'.

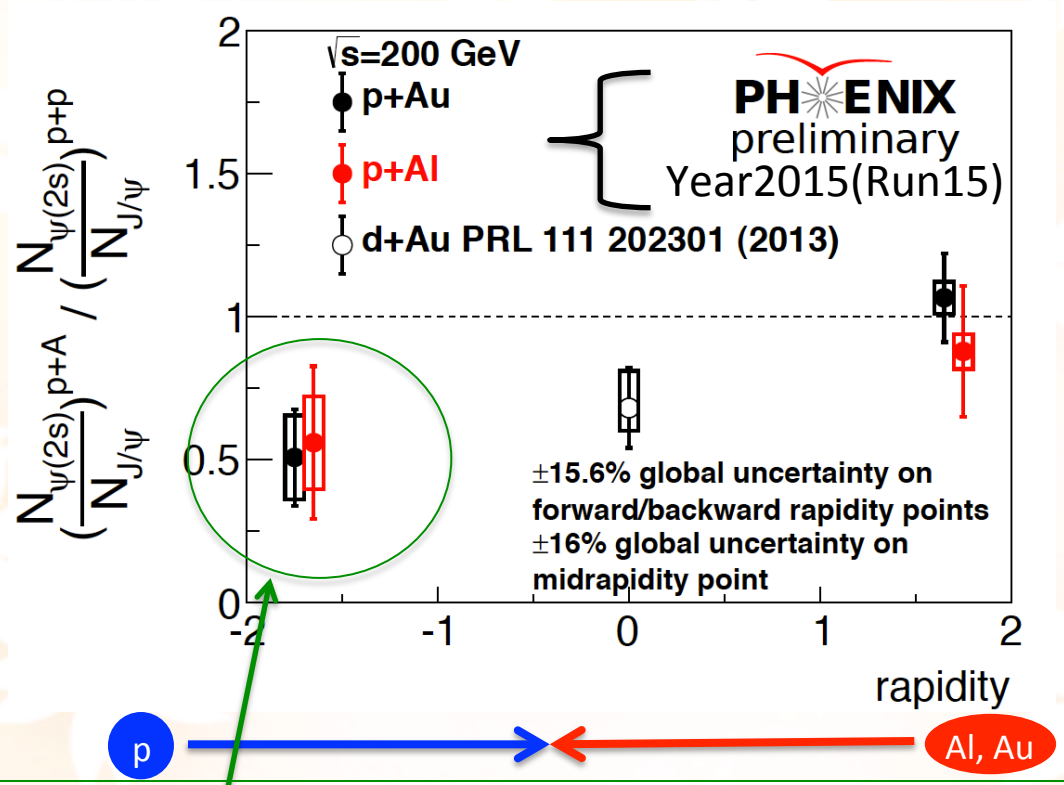
- Greatly improved mass resolution and BG rejection







Forward Rapidity ψ' :J/ψ in p+Al, p+Au



$$\frac{\left(\frac{N_{\psi(2s)}}{N_{J/\psi}}\right)^{p+A}}{\left(\frac{N_{\psi(2s)}}{N_{J/\psi}}\right)^{p+p}}$$

Strong suppression of ψ' in the A-going side but not p-going side.

- Breakup in collisions with nucleons doesn't explain this large suppression. (PRC 87 (2013)54910)
- Neither initial state effect. →other effect ?

Summary & outlook

- PHENIX VTX succeeded in measurement of b-electron and c-electron separately in Au+Au at 200GeV collision.
  - First observation of bottom suppression at RHIC.
  - Bottom suppressed less than charm at $3 < p_T < 4$ GeV/c .
  - Bottom suppressed equal to charm at $p_T > 4$GeV/c.
  - Data has large uncertainty
- VTX new data analyses are ongoing.
  - Au+ Au (Run2014) data has high statistics and will improve uncertainties significantly.
  - p+p (2015) data will give the baseline measurement with same method.

- PHENIX FVTX could separate ψ' and J/ψ in p+Al and p+Au at 200GeV Collision.
  - Stong suppression is observed at A-going side.
  - No initial effect explain this large suppression well yet.