Cold Nuclear Matter Effects on Heavy Quark Production from PHENIX

J. Matthew Durham

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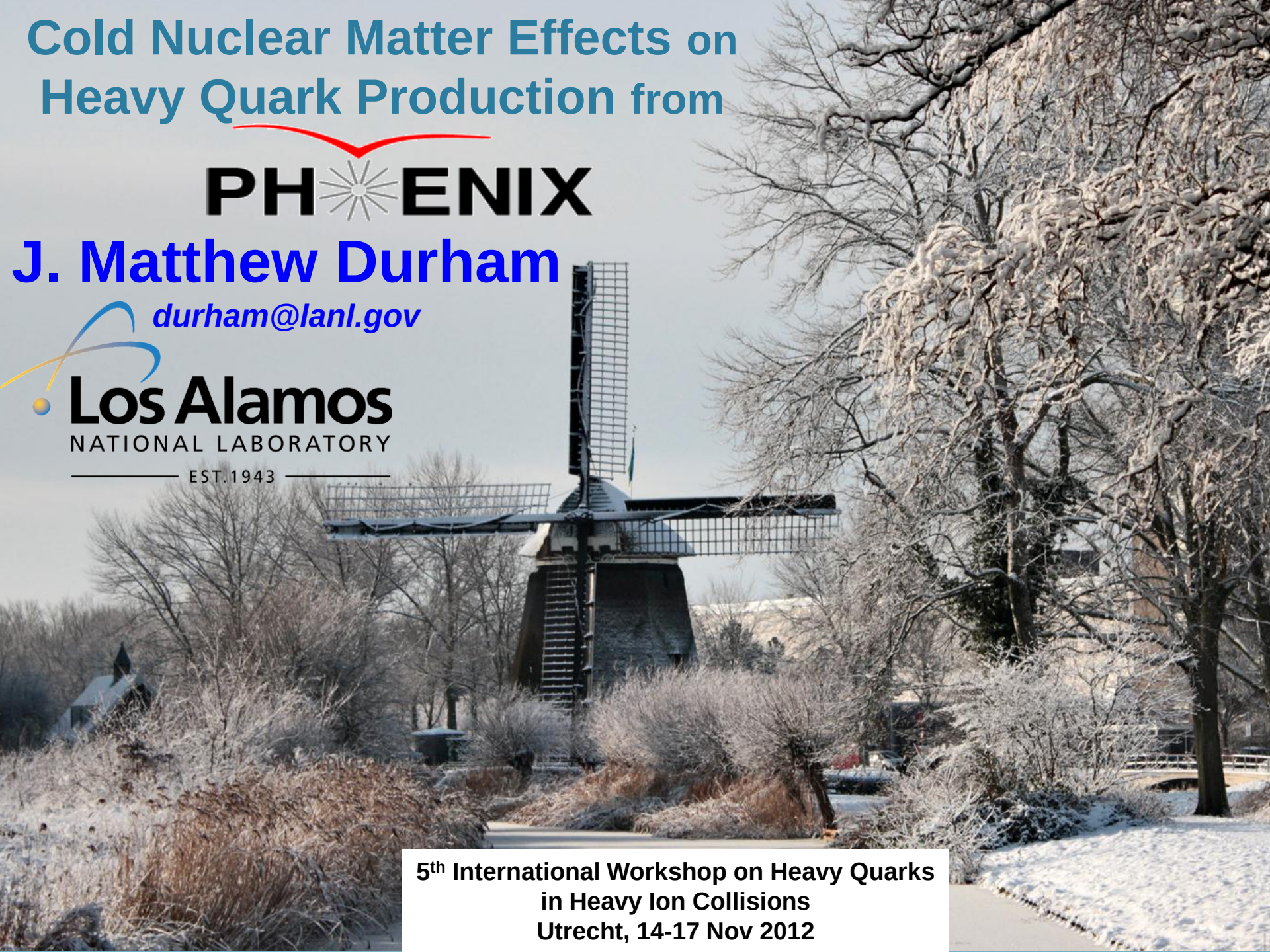


5th International Workshop on Heavy Quarks in Heavy Ion Collisions
Utrecht, 14-17 Nov 2012

Open HF in A+A

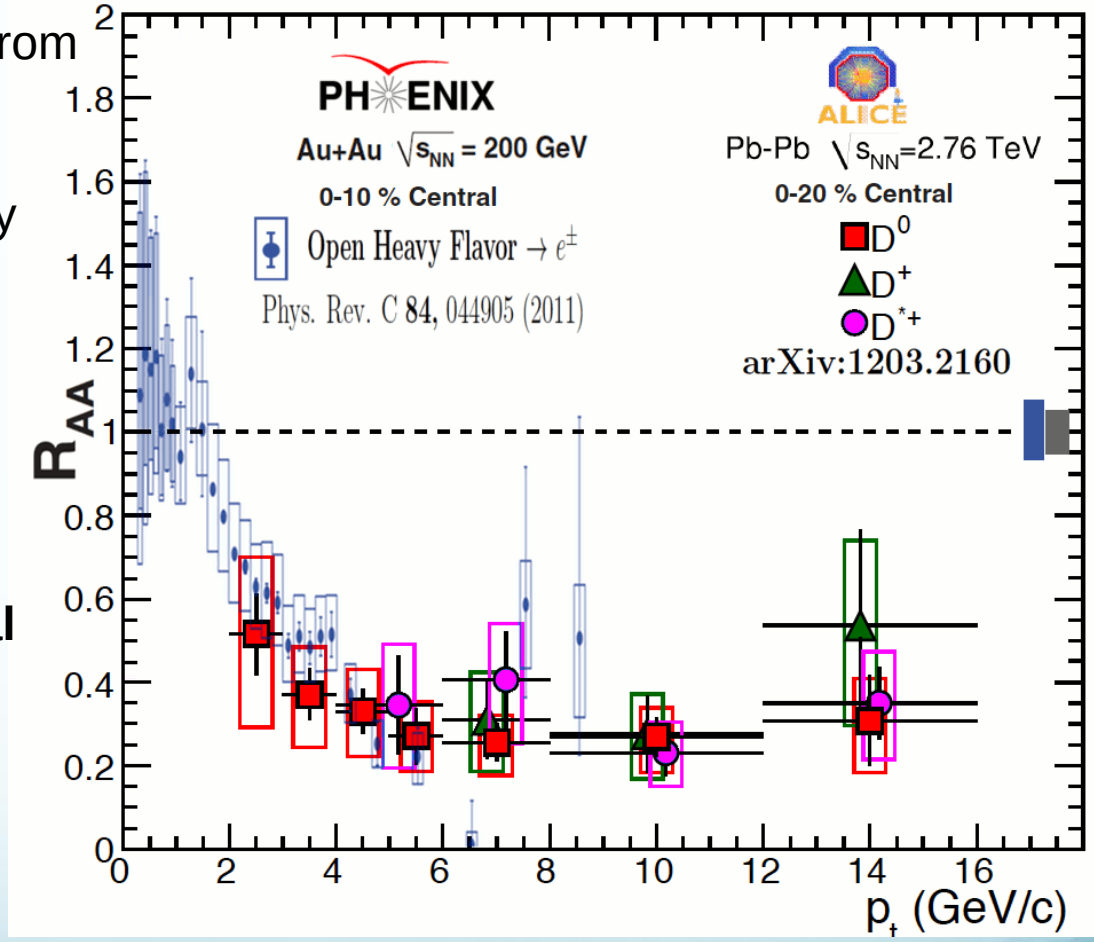
One of the most striking results from RHIC:

Large suppression of open heavy flavor mesons!

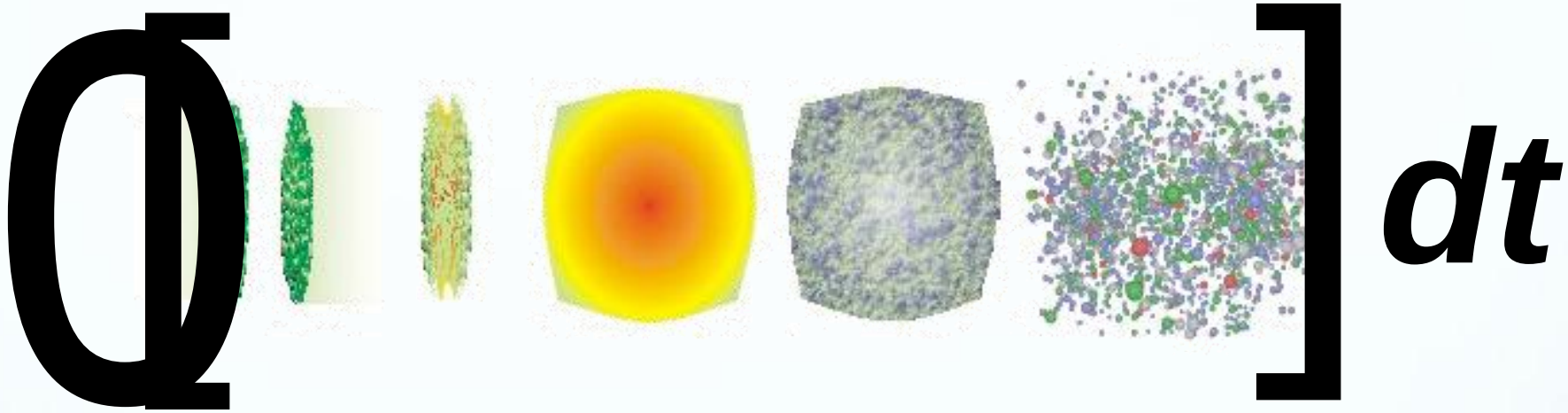
$$m_{c,b} > T, \Lambda_{QCD}$$

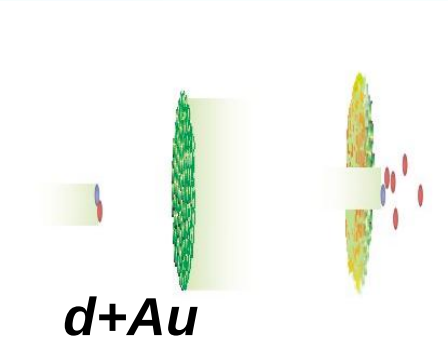
Heavy quarks produced in initial hard scattering

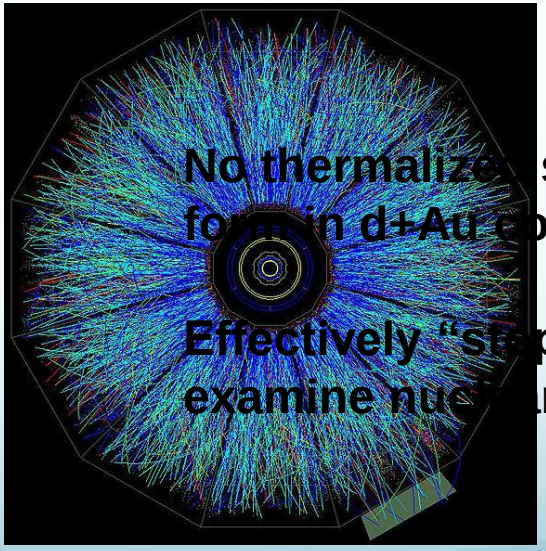
Perturbative QCD techniques applicable



“Timeline” of a HI collision







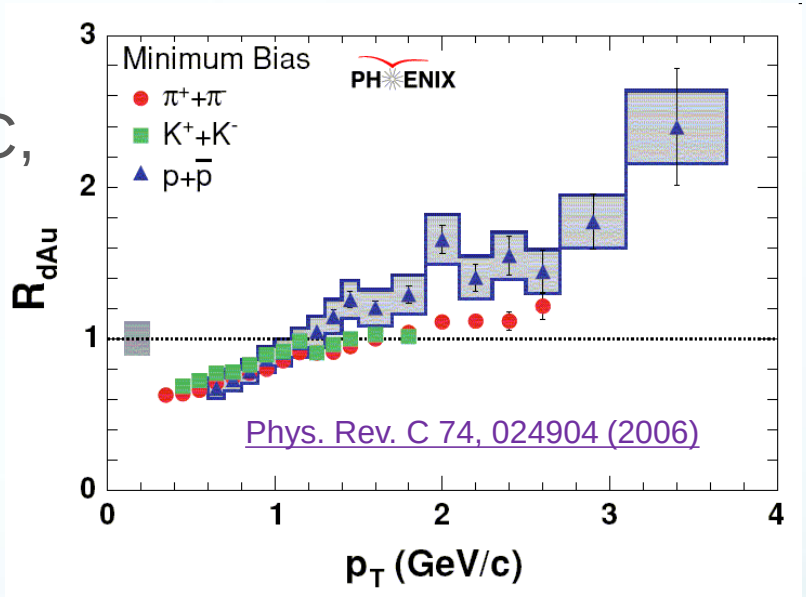
No thermalized system expected to form in d+Au collisions

Effectively “stops the clock” to examine nuclear initial state only

Cold Nuclear Matter Effects

Collisions of nuclei are *inherently different* from collisions of bare nucleons

- Nuclear PDF is modified: S, AS, EMC, saturation?
- Partons can interact with nucleons while passing by
  - kT kicks ("traditional" explanation of Cronin, but mass dependence?)
  - Energy loss in nucleus?
- For cc and bb states, breakup effects



Phys. Rev. C 74, 024904 (2006)

None of these effects are present in p+p

PHENIX Results on CNM

Charged Hadrons
Phys. Rev. Lett. 91, 072303 (2003)

Forward/backward hadrons
Phys. Rev. Lett. 94, 082302 (2005)

Pion, kaon, proton
Phys. Rev. C 74, 024904 (2006)

J/ψ R_{dA}
Phys. Rev. Lett. 96, 012304 (2006)
Phys. Rev. C 77, 024912 (2008)

Dihadron correlations
Phys. Rev. C 73, 054903 (2006)

ω R_{dA}
Phys. Rev. C 75, 051902 (2007)

Neutral pion, η
Phys. Rev. Lett. 98, 172302 (2007)

Hadrons in p/n+Au
Phys. Rev. C 77, 014905 (2008)

Φ R_{dA}
Phys. Rev. C83 , 024909 (2011)

J/ψ R_{dA}
Phys. Rev. Lett. 107, 142301 (2011)
arXiv:1204.0777

Forward/backward dihadrons
Phys. Rev. Lett. 107, 172301 (2011)

Forward Open Heavy Flavor (Cu+Cu)
Phys. Rev. C 86, 024909 (2012)

Direct photons
arXiv:1208.1234

Open Heavy Flavor
arXiv:1208.1293 **(accepted by PRL)**

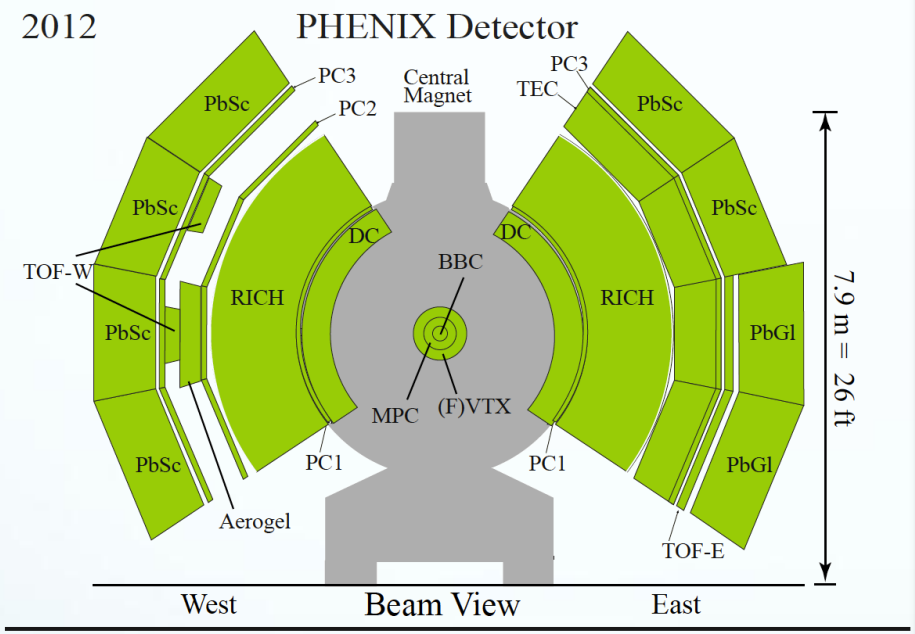
Preliminary results on:

χ_c R_{dA}
ψ' R_{dA}

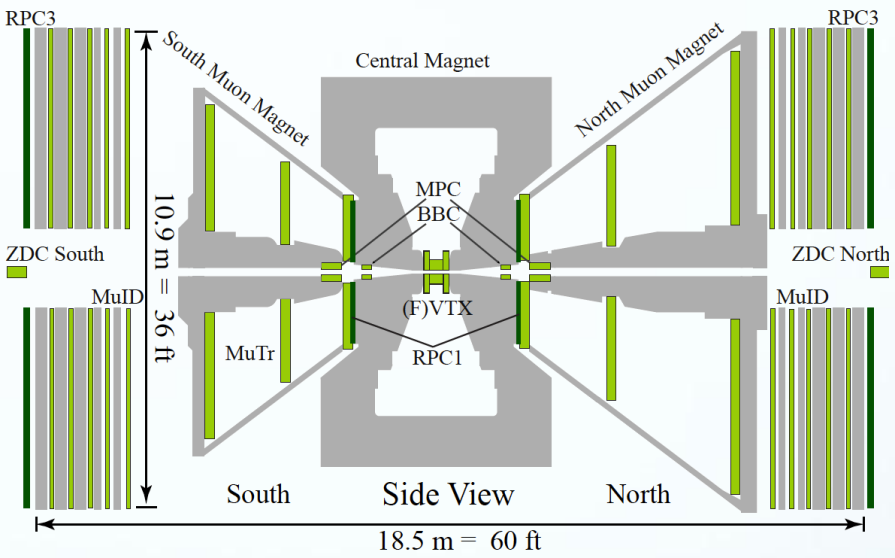
Open Heavy Flavor (Cu+Cu)

High pT pion, eta
Dielectron continuum
Reconstructed jets

HF leptons at PHENIX



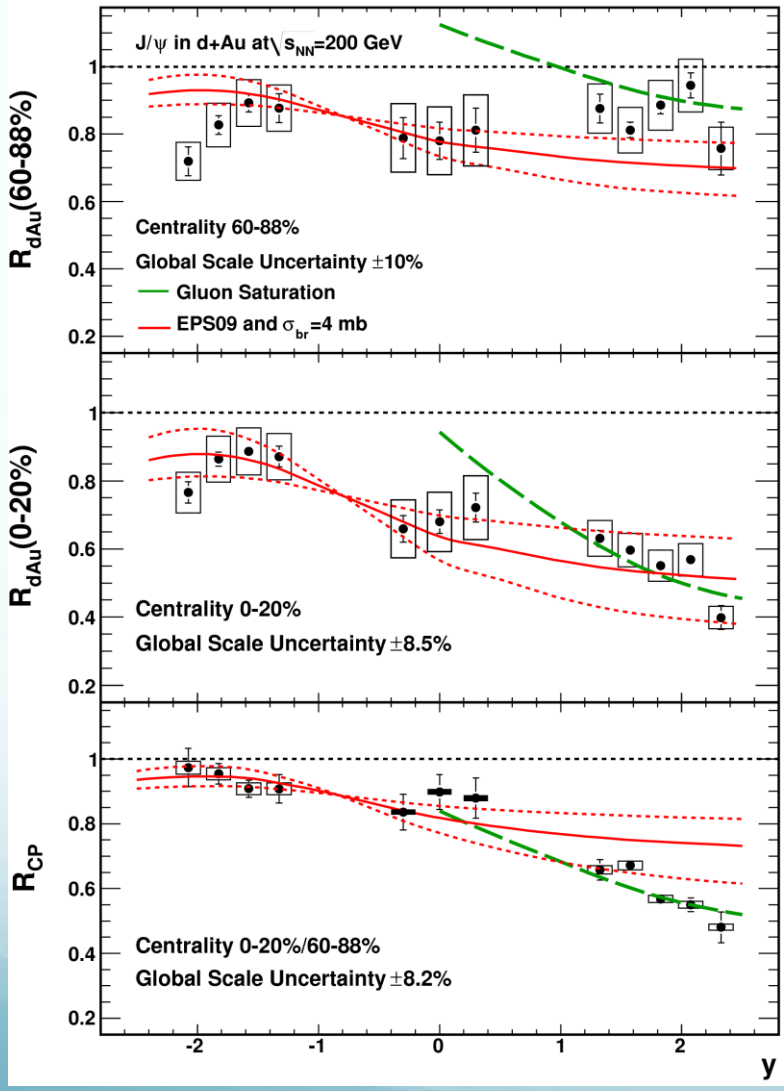
Midrapidity: electrons
|y| < 0.35
Tracking from DC/PC
Electron ID from RICH
Energy from EMCal
Low material



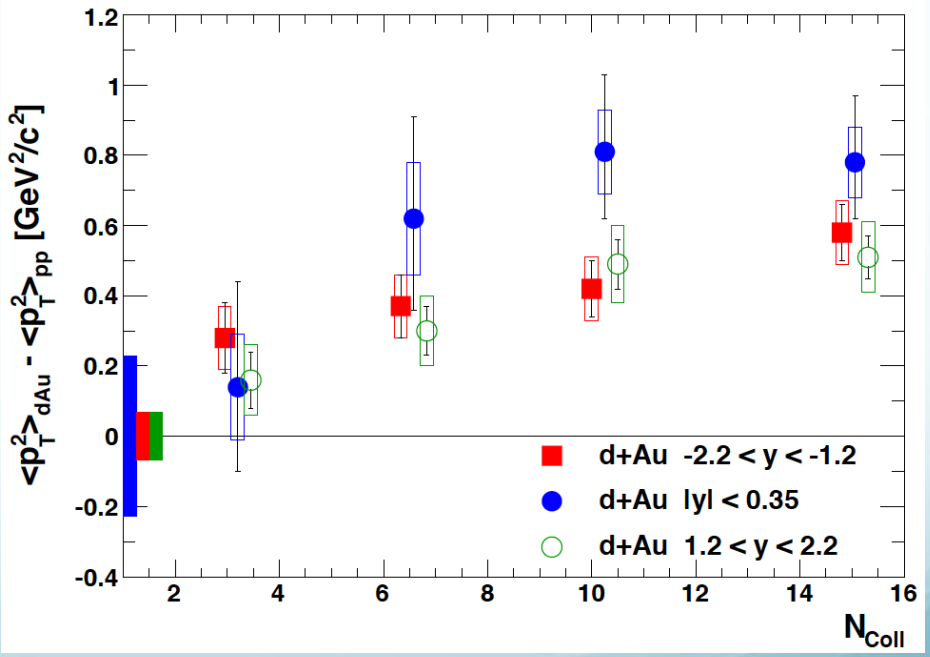
Forward/backward rapidity: muons
1.1 <|y| < 1.9
Wire chambers for tracking
Absorbers limit hadron range
Iarocci tubes/steel for muon ID

J/Ψ in d+Au

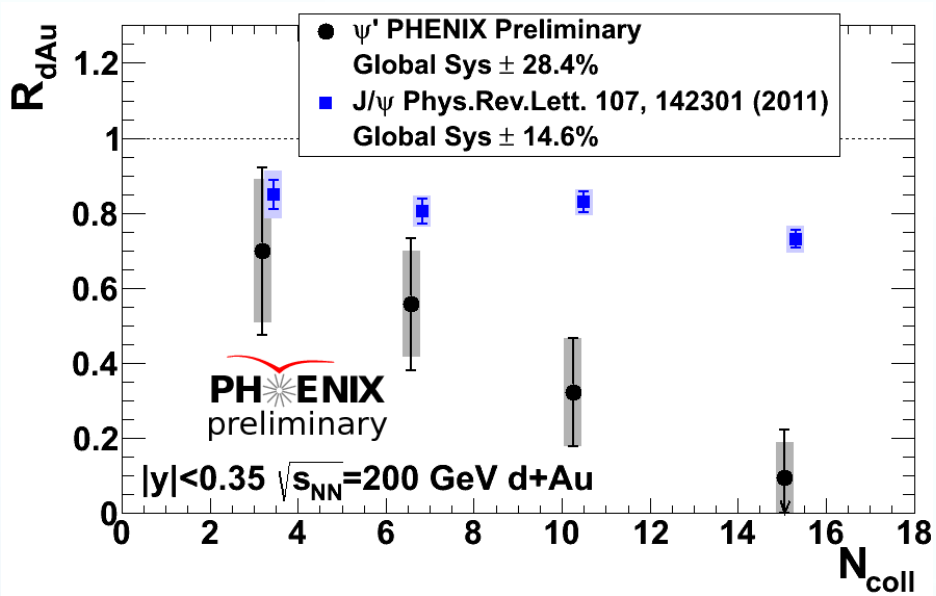
PRL 107, 14230 (2011)

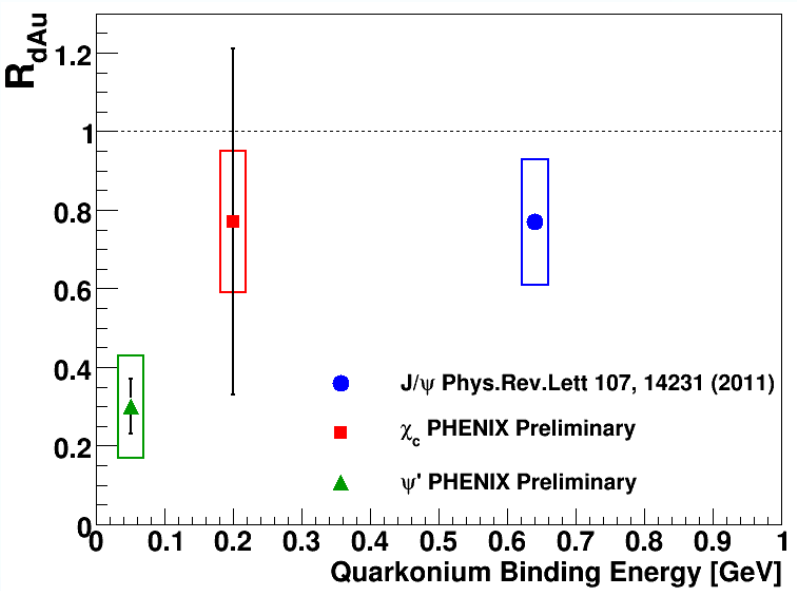


- Low pT suppression
- Significantly hardened spectrum (AKA Cronin)



Higher charmonium states



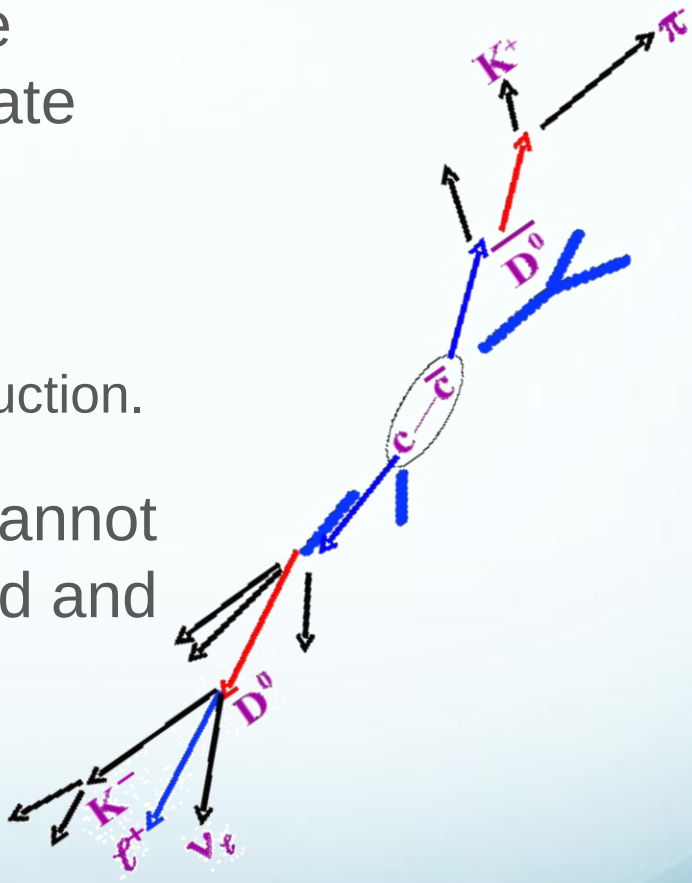


Initial state of all charmonia sensitive to exact same CNM effects

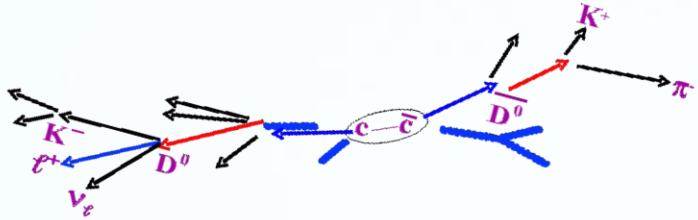
***Something* must be affected by presence of nucleus**
-Precursor state quantum numbers?
-Hadronization in the nucleus?

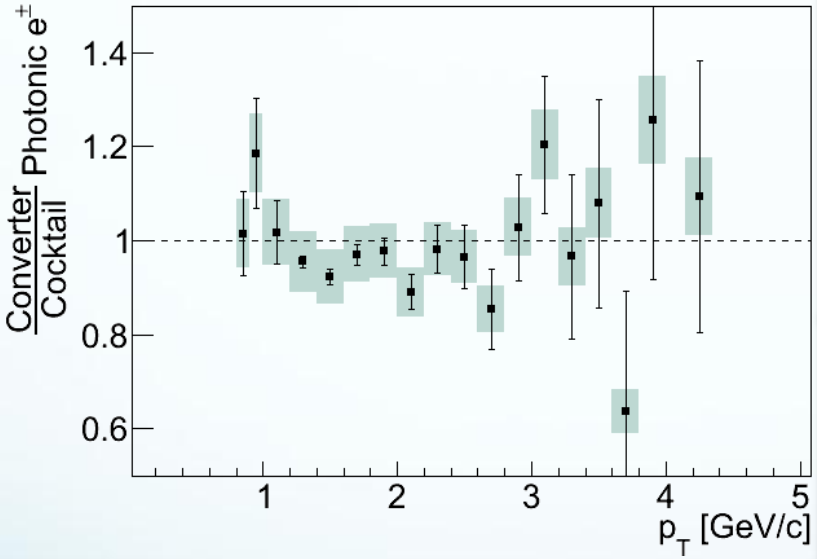
Open Heavy Flavor

- Open charm and bottom hadrons are sensitive to same primordial initial state effects as charmonia, bottomonia.
- No breakup effects!
  - Cleaner probe of baseline charm production.
- Without precise vertex information, cannot fully separate electrons from charmed and bottom hadrons



Methodology





Excellent agreement between two independent methods
-No low mass thermal photon* excess in d+Au to worry about

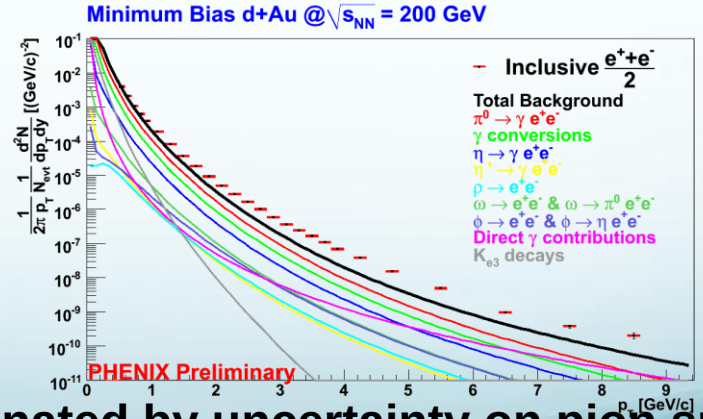
Converter method

$$N^{conv-out} = N^{\gamma} + N^{non-\gamma}$$

$$N^{conv-in} = R_{\gamma} N^{\gamma} + (1-\varepsilon) N^{non-\gamma}$$

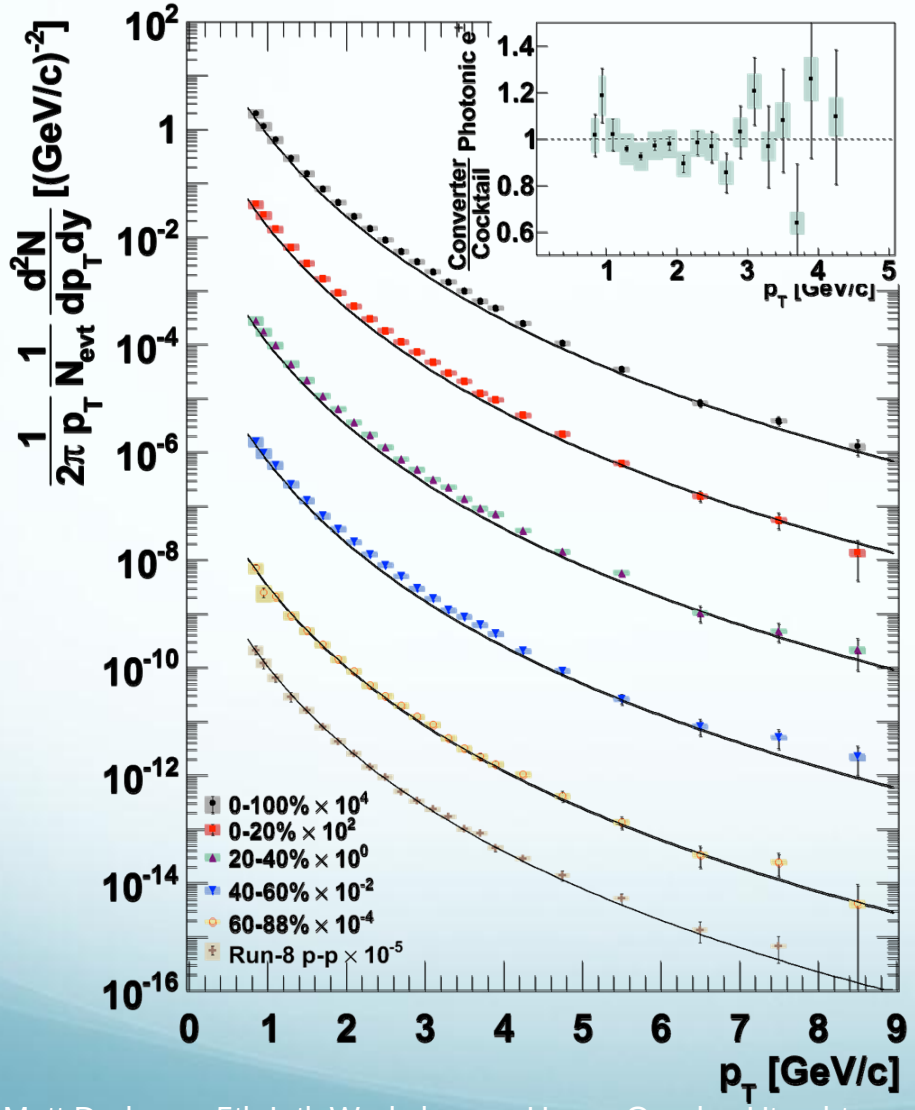
Dominated by low stats of conv-in data (1 day)

Cocktail method



Dominated by uncertainty on pion spectra

Run-8: d+Au and p+p



arXiv:1208.1293
(Accepted by PRL)

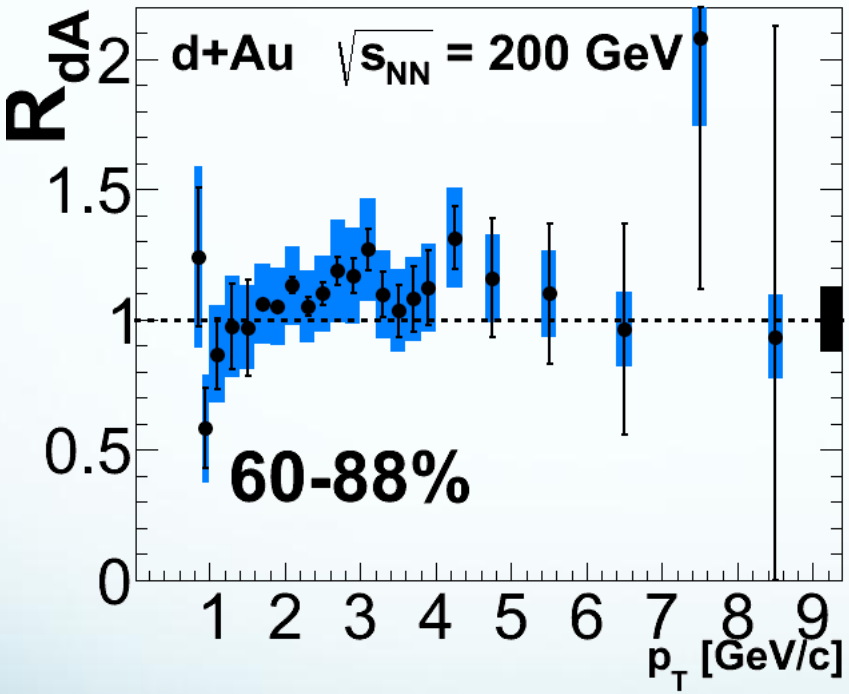
p+p data prepared with identical cuts, techniques, codes, etc as d+Au data

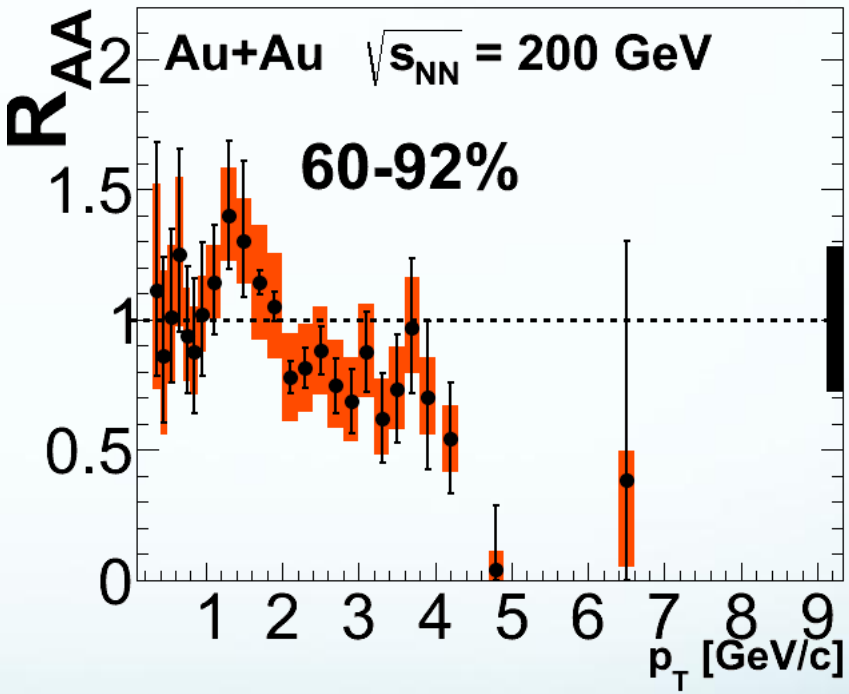
Consistent with previous p+p data from Run-5

Rigorous cross-check of techniques

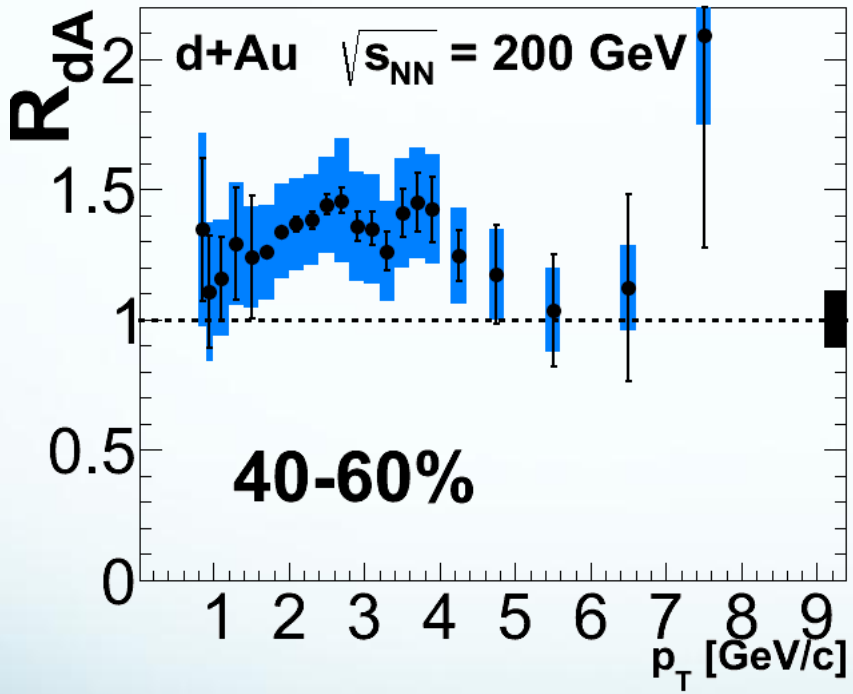
Forward/backward rapidity open HF results coming soon!

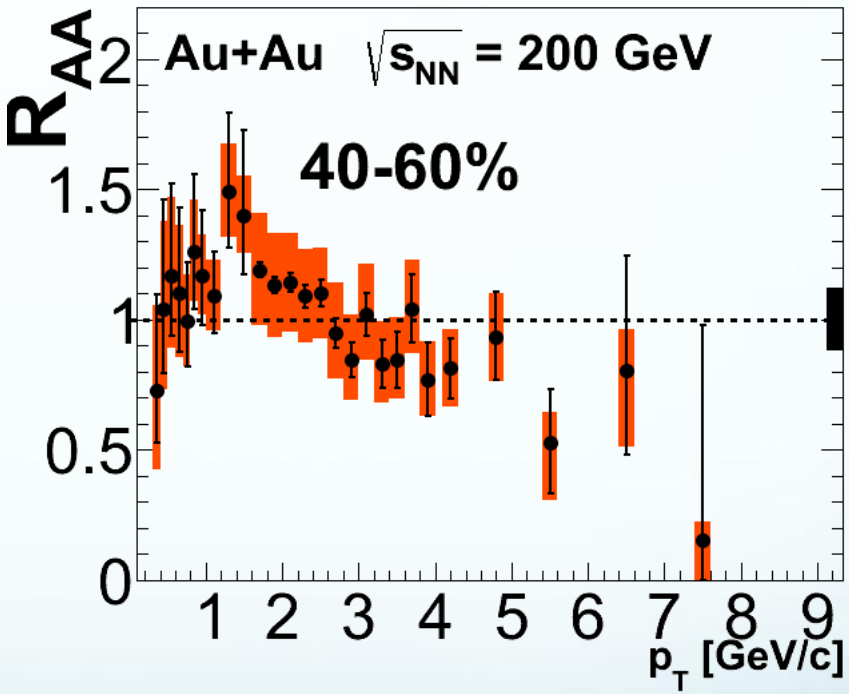
R_{dA} – Peripheral



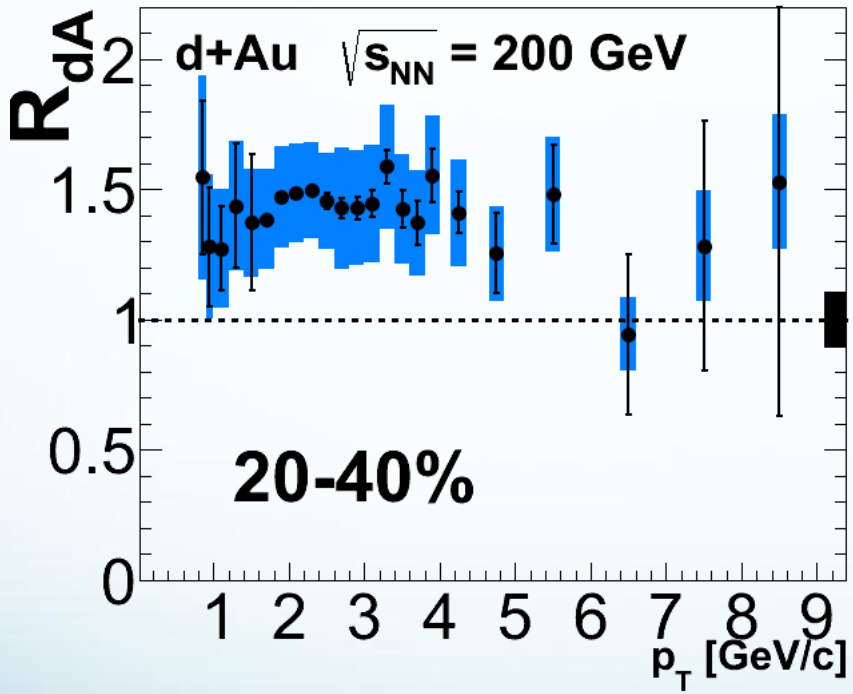


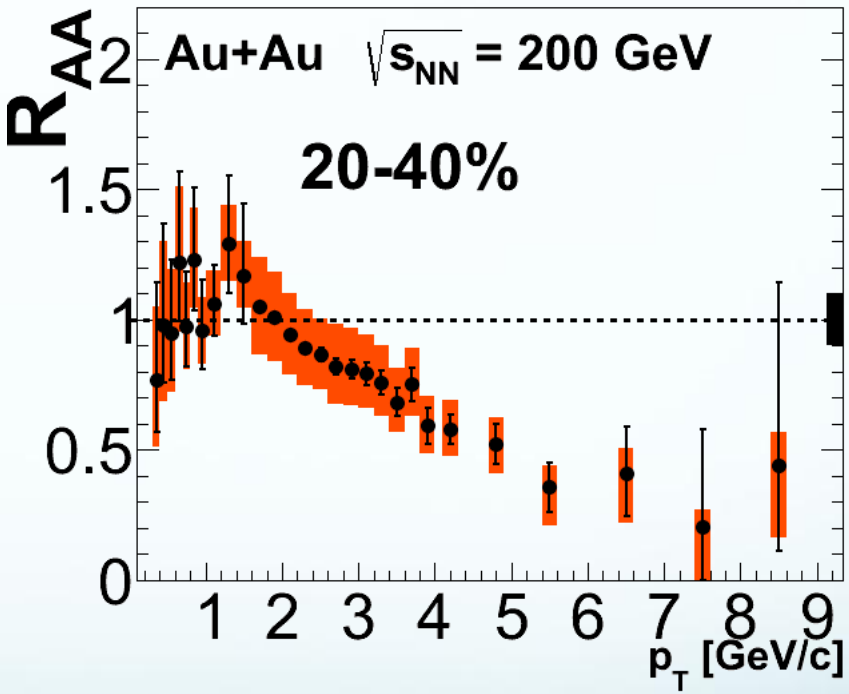
R_{dA} – Semi-peripheral



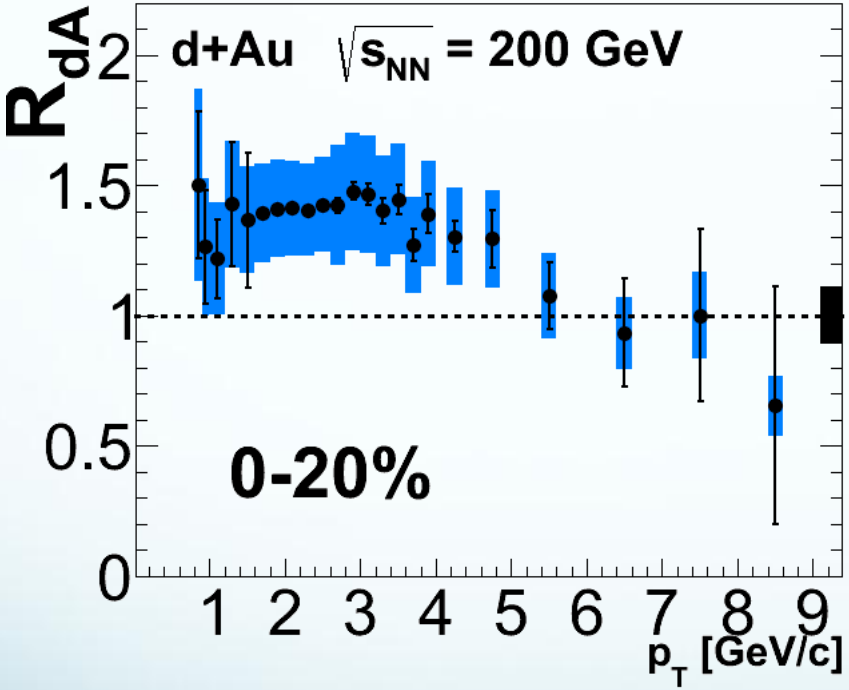


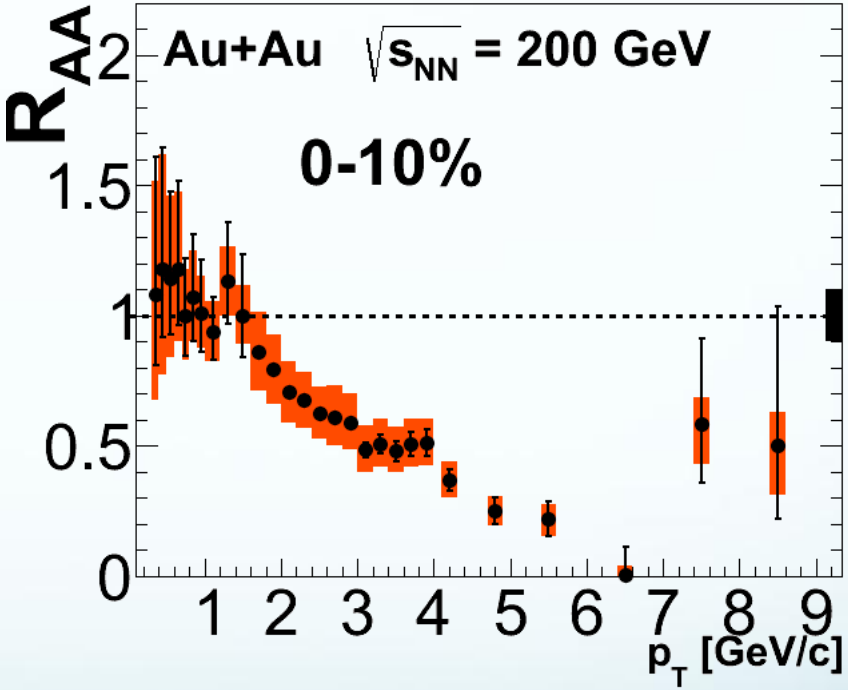
R_{dA} – Semi-central



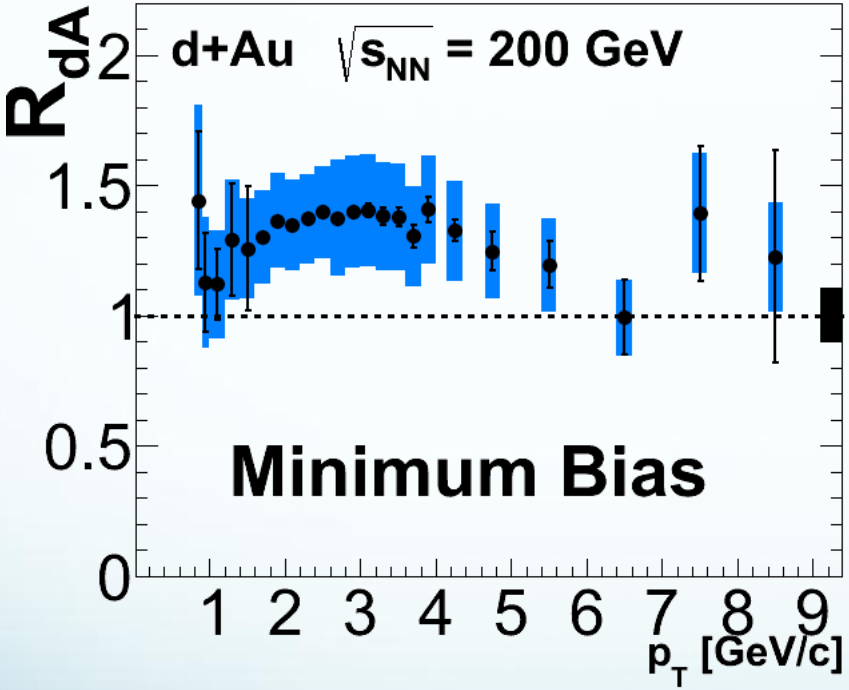


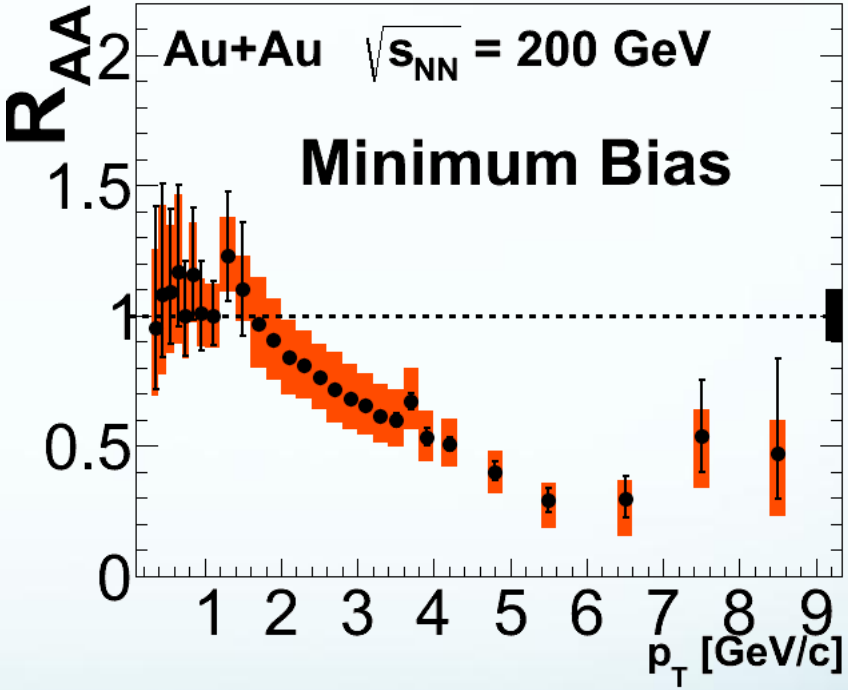
R_{dA} – Central


R_{dA}
d+Au $\sqrt{s_{NN}}$ = 200 GeV
0-20%
p_T [GeV/c]

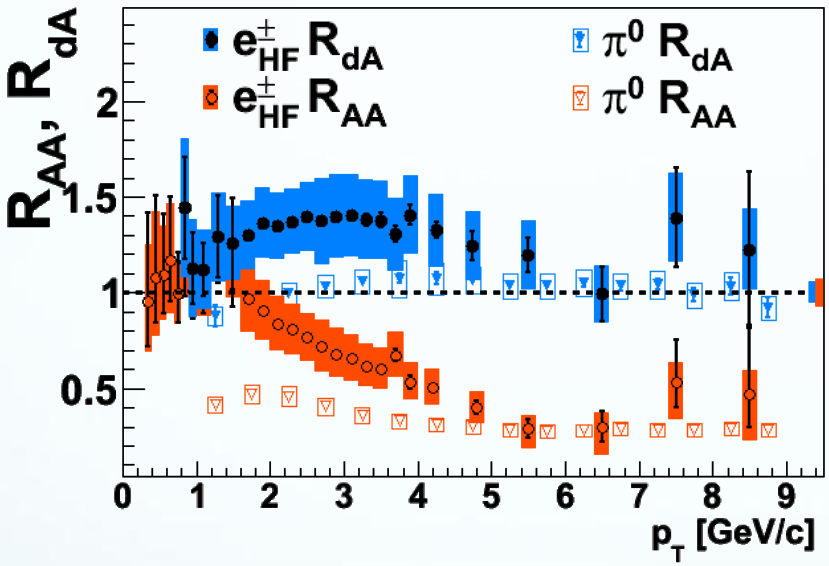

R_{AA}
Au+Au $\sqrt{s_{NN}}$ = 200 GeV
0-10%
p_T [GeV/c]

R_{dA} – Min Bias


R_{dA}
d+Au $\sqrt{s_{NN}}$ = 200 GeV
Minimum Bias
0
0.5
1
1.5
2
1 2 3 4 5 6 7 8 9
p_T [GeV/c]


R_{AA}
Au+Au $\sqrt{s_{NN}}$ = 200 GeV
Minimum Bias
0
0.5
1
1.5
2
1 2 3 4 5 6 7 8 9
p_T [GeV/c]

R_{dA} – Min Bias



No suppression observed for open heavy flavor in d+Au (within uncertainty)

-Suppression therefore attributed to hot matter phase in Au+Au

Effect decreases at higher electron pT

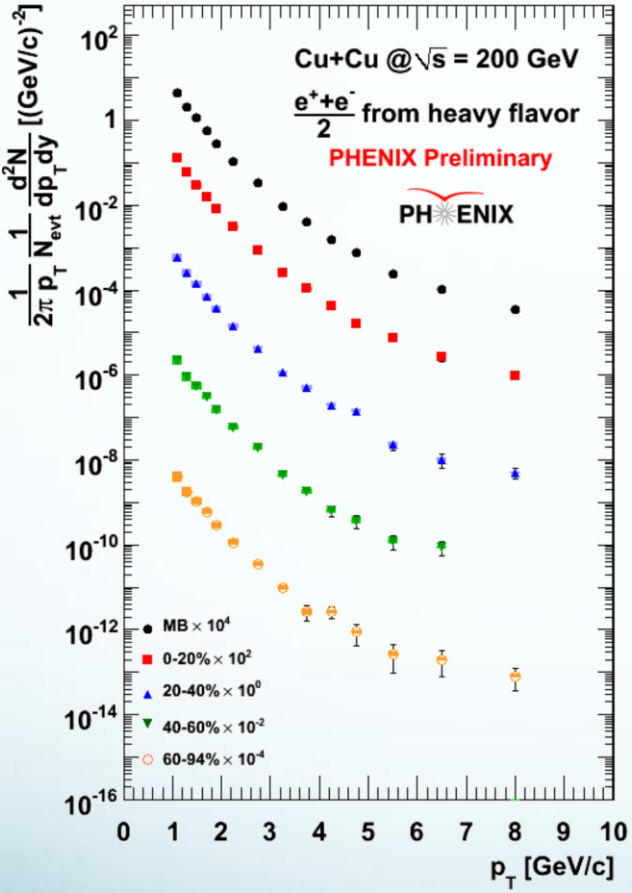
-Does bottom experience different effects? Need vertex info to be sure.

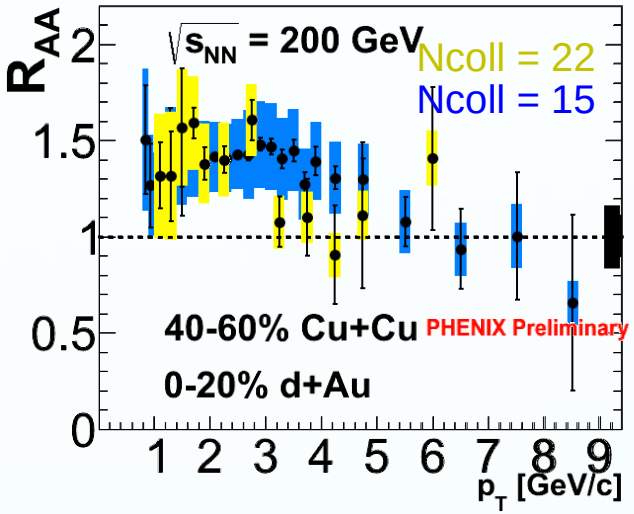
CNM effects on heavy flavor significantly larger than pion

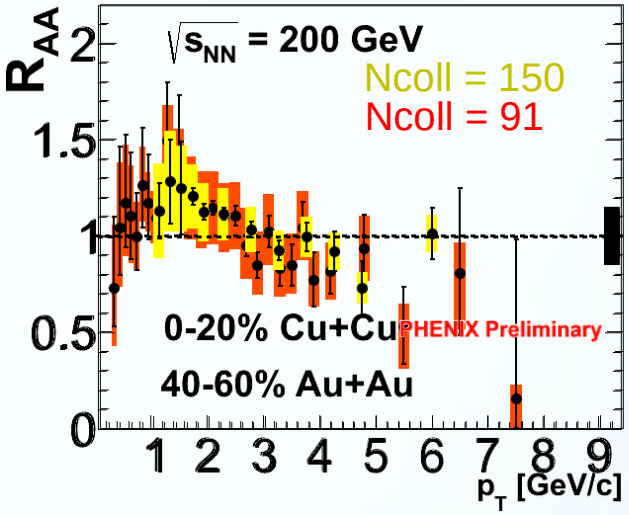
- Mass dependence of Cronin enhancement carries over to charm

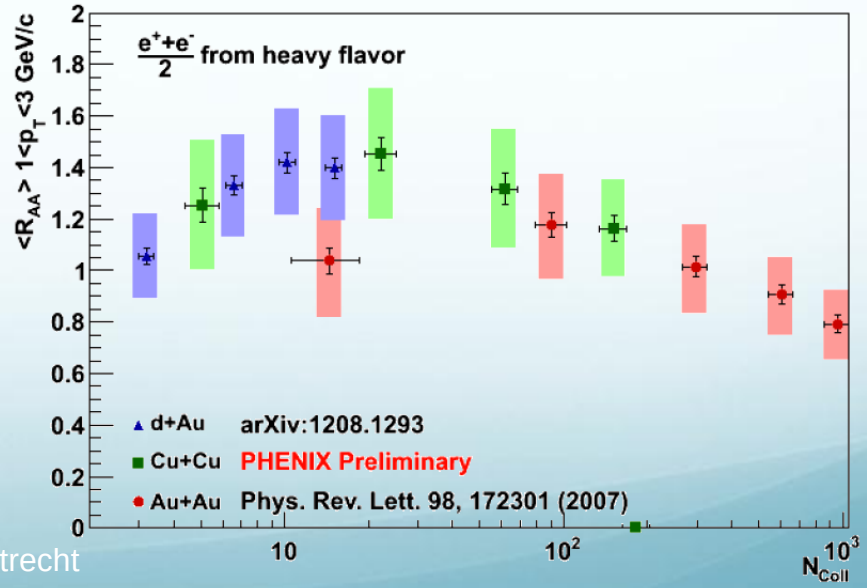
Biggest difference in HFe and pion RAA in pT range where CNM effects are largest and different.

HF in Cu+Cu – Mid rapidity



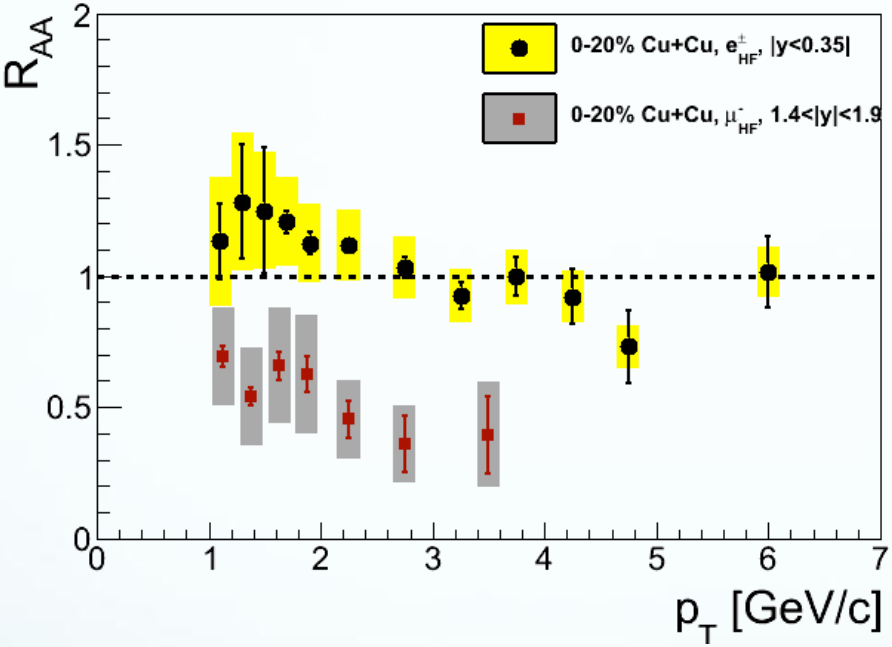


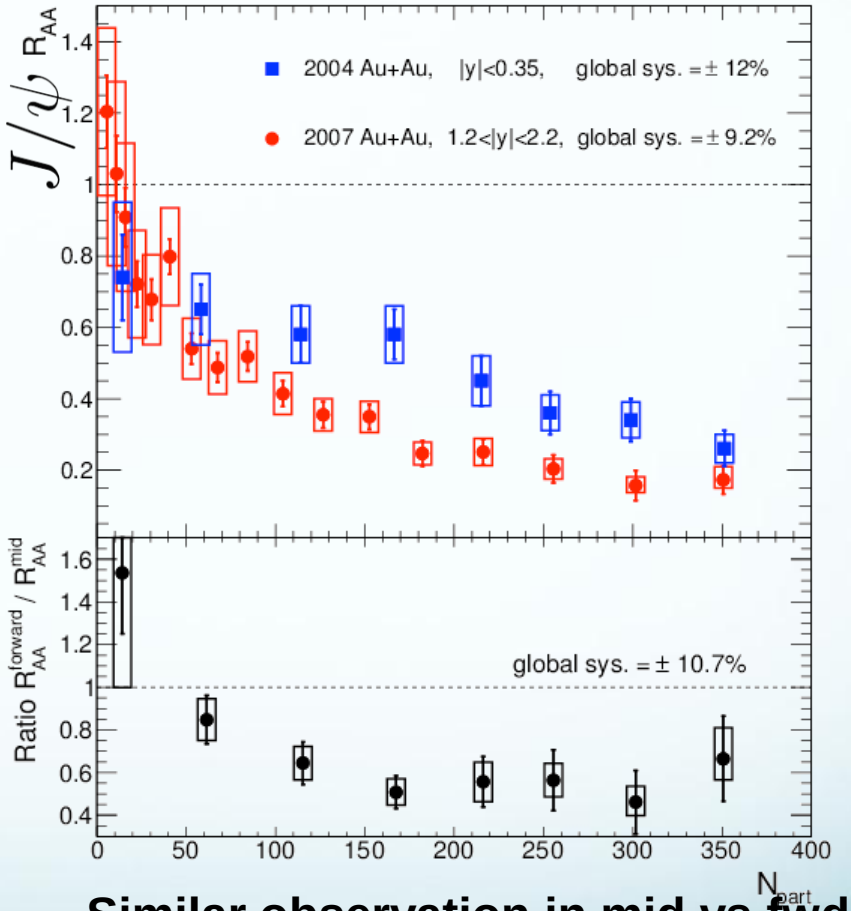




Finalized Cu+Cu results out soon

HF in Cu+Cu – Forward



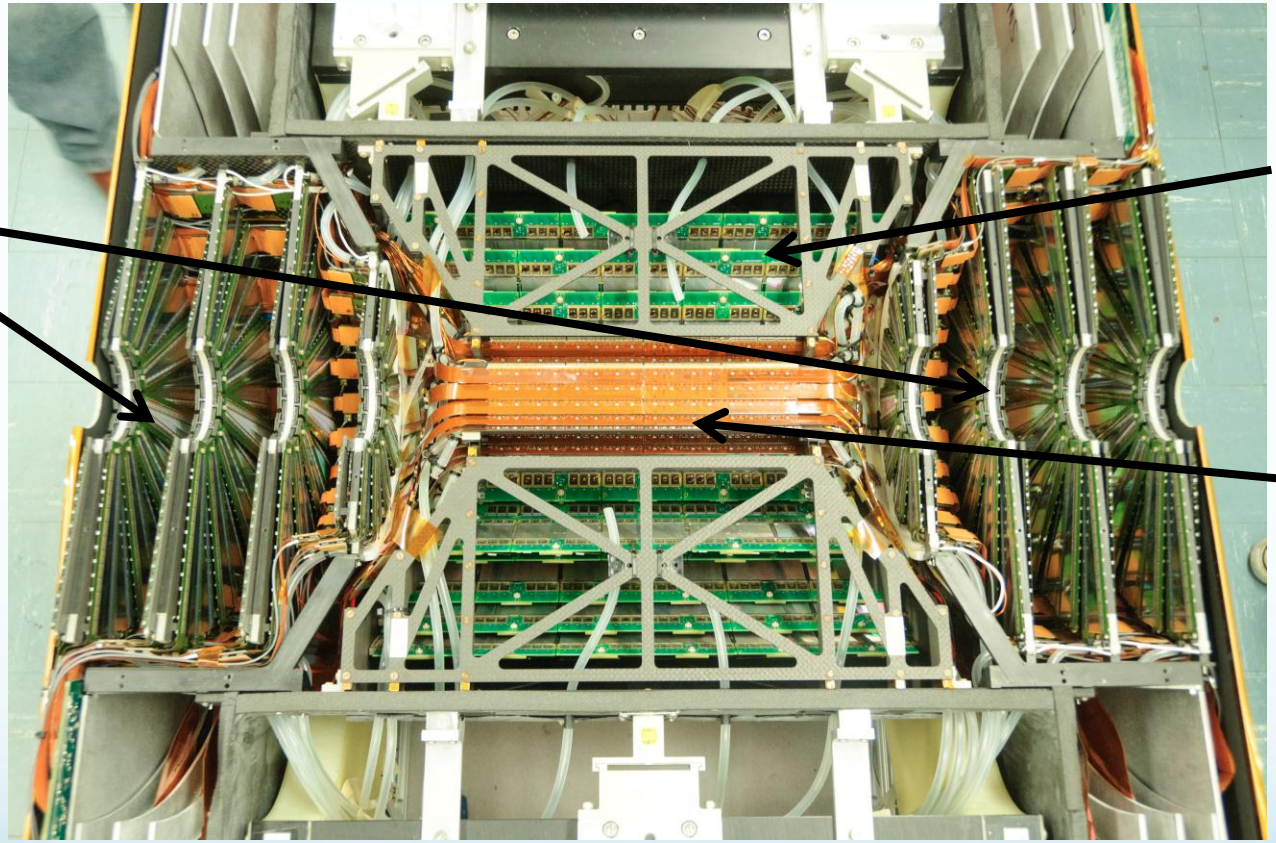


Unexpected: Significantly larger suppression at forward rapidity
-Lower energy density…

Suggests additional CNM effects:
Energy loss?
Shadowing?

Similar observation in mid vs fwd J/psi: Same mechanism?
Depletion of primordial charm?

Precise Vertexing at RHIC

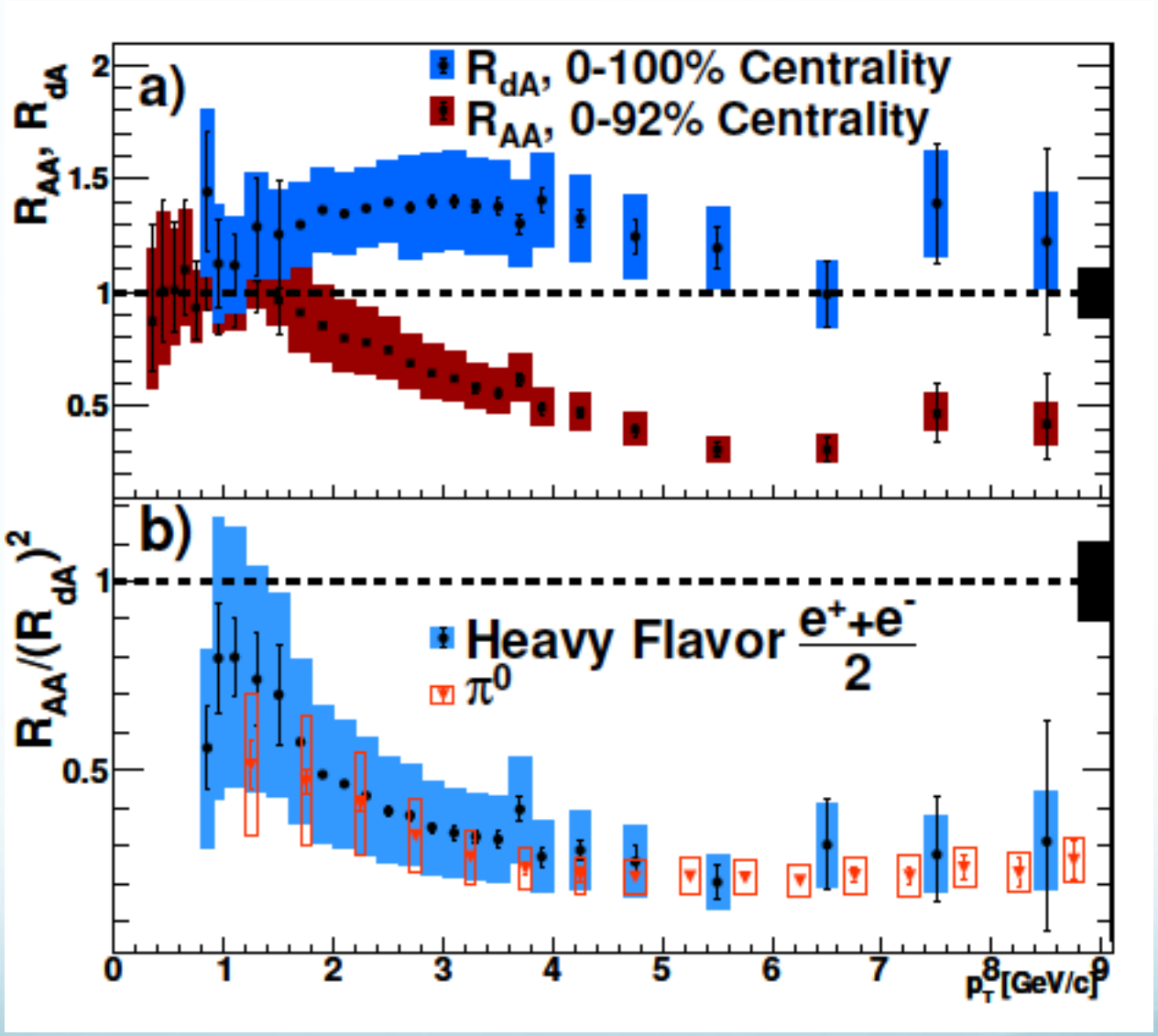


A new era of precision heavy flavor measurements at RHIC

Summary

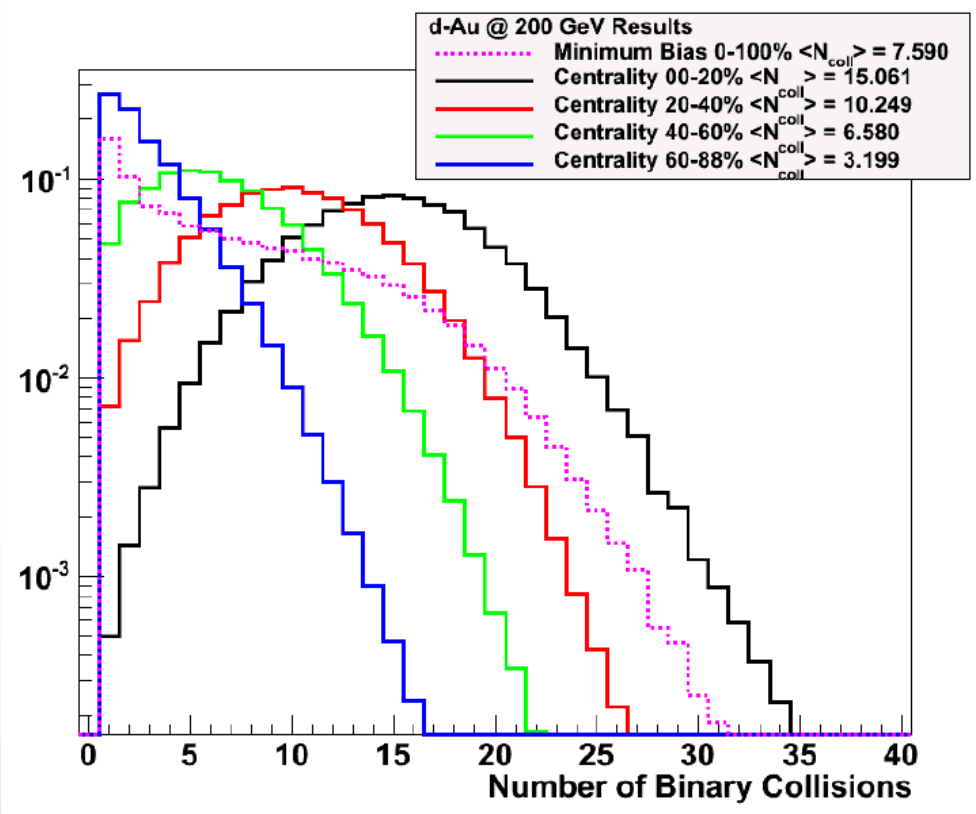
- PHENIX has observed significant CNM effects on hidden and open heavy flavor
  - Initial state of heavy flavor in A+A collisions is **highly modified**
  - A reference from p+p data does not reflect these modifications
- It is possible (even *likely*) that open charm and open bottom hadrons experience a different magnitude of CNM effects
- LOTS of quality d+Au data! Waiting for full treatment from theory.
  - Light flavors, photons at midrapidity.
  - Open HF baseline at midrapidity (forward rapidity coming soon).
  - Charmonia at mid and forward rapidity.
- We are all eagerly awaiting HF data from p+Pb
- Heavy flavor is even more interesting that we ever thought!

BACKUPS


a)
R_{dA}, 0-100% Centrality
R_{AA}, 0-92% Centrality
R_{AA}, R_{dA}
b)
Heavy Flavor $\frac{e^+ + e^-}{2}$
π^0
$R_{AA}/(R_{dA})^2$
p_T [GeV/c]

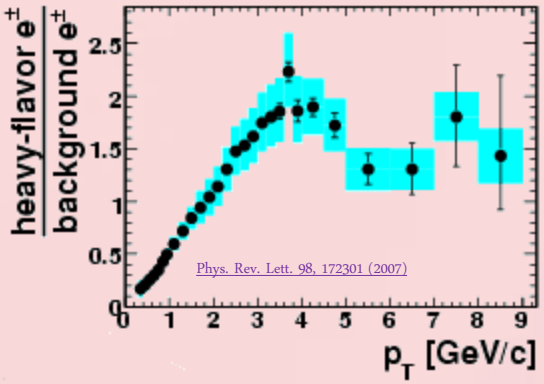
Centrality in d+Au

Centrality	<Ncoll>
0-100%	7.590 ± 0.427
00-20%	15.061 ± 1.013
20-40%	10.248 ± 0.704
40-60%	6.579 ± 0.444
60-88%	3.198 ± 0.193



Electron Sources

- Dalitz decays
  - Mostly $\pi^0 \to \gamma e^+ e^-$
  - Also from $\eta, \omega, \eta', \phi$
- Conversions in material
  - Photons predominantly from $\pi^0 \to \gamma\gamma$
- Kaon decays
  - $K^\pm \to \pi^0 e^\pm \nu_e$
- Dielectron decays of vector mesons
  - $\rho, \omega, \phi, J/\psi \to e^+ e^-$
- Thermal/direct radiation
  - Small but significant at high pt



BACKGROUND

- **Heavy Flavor Decays**

SIGNAL