Open Heavy Flavor Results from PHENIX

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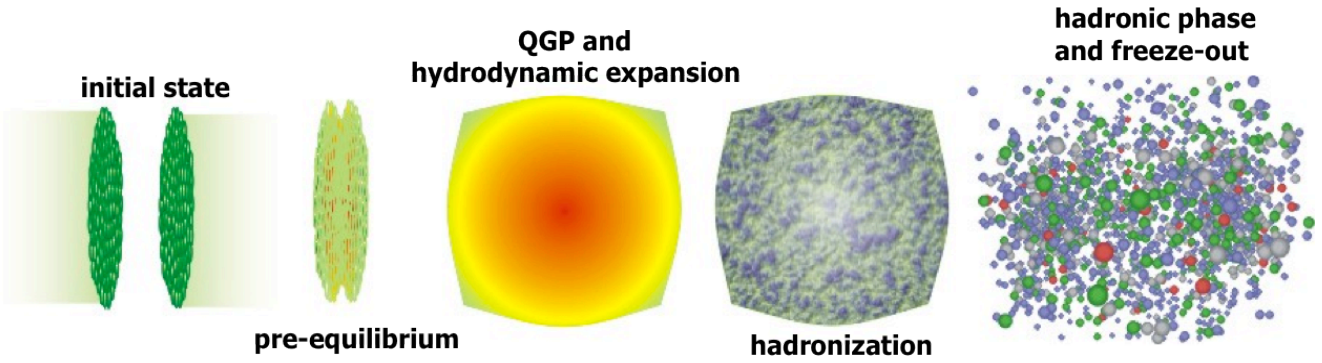
Outline

- Motivation & Background
- PHENIX Heavy Flavor (HF) Results
  - p+p (charm & bottom cross sections)
  - Heavy Ion (Cu+Cu, Au+Au)
  - d+Au
- Summary

Motivation

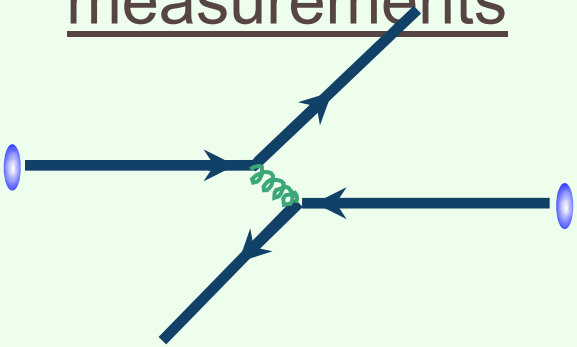
- Heavy quarks can be used to probe medium properties.



- Heavy quarks are produced early in the collision due to their large mass (~4.2 GeV for b and ~1.3 GeV for c).
- Heavy quark production can be used as a test of pQCD theory.

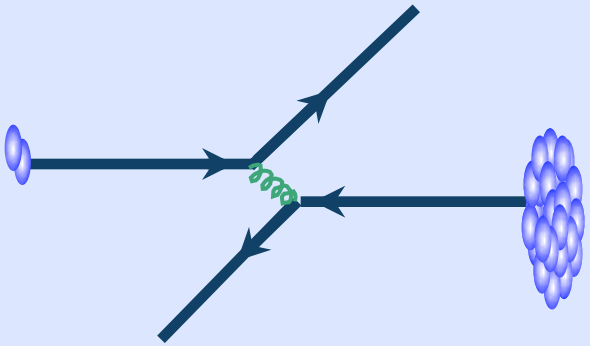
Quantifying Medium Effects

p+p measurements



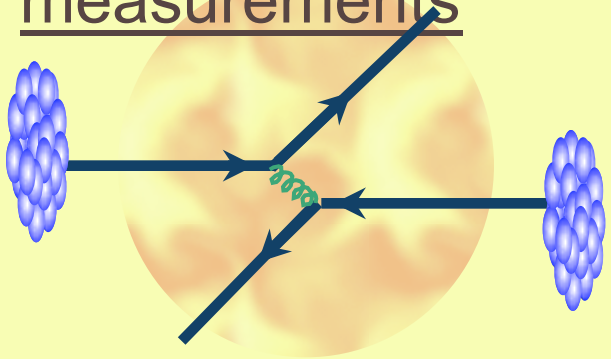
Baseline

d+A measurements



probe CNM effects

A+A measurements



probe HNM+CNM effects

- Nuclear modification factors:

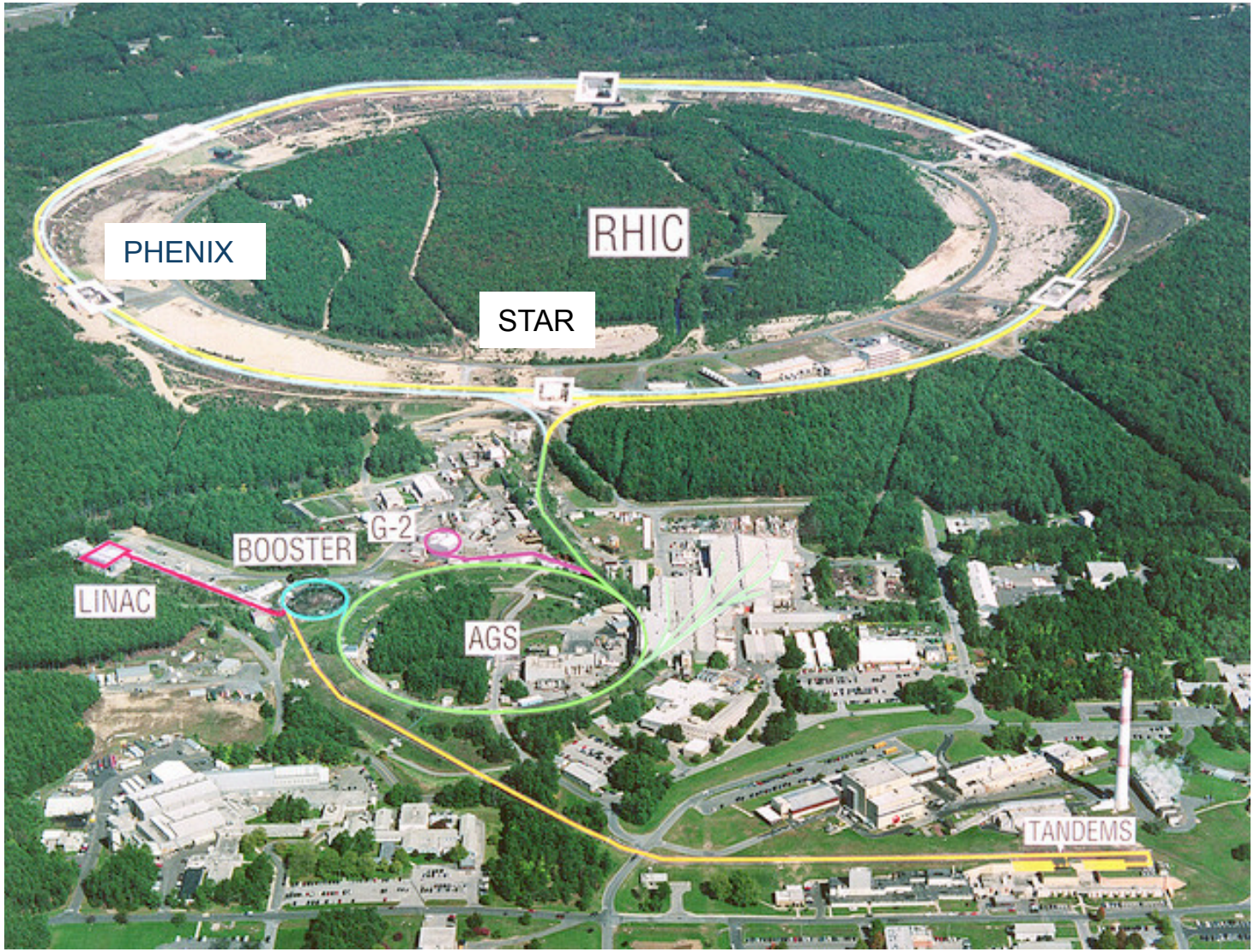
N_{coll} → Averaged number of binary collisions

$$R_{AA} = \frac{dN_{AA}/dp_T}{\langle N_{coll} \rangle \times dN_{pp}/dp_T}$$

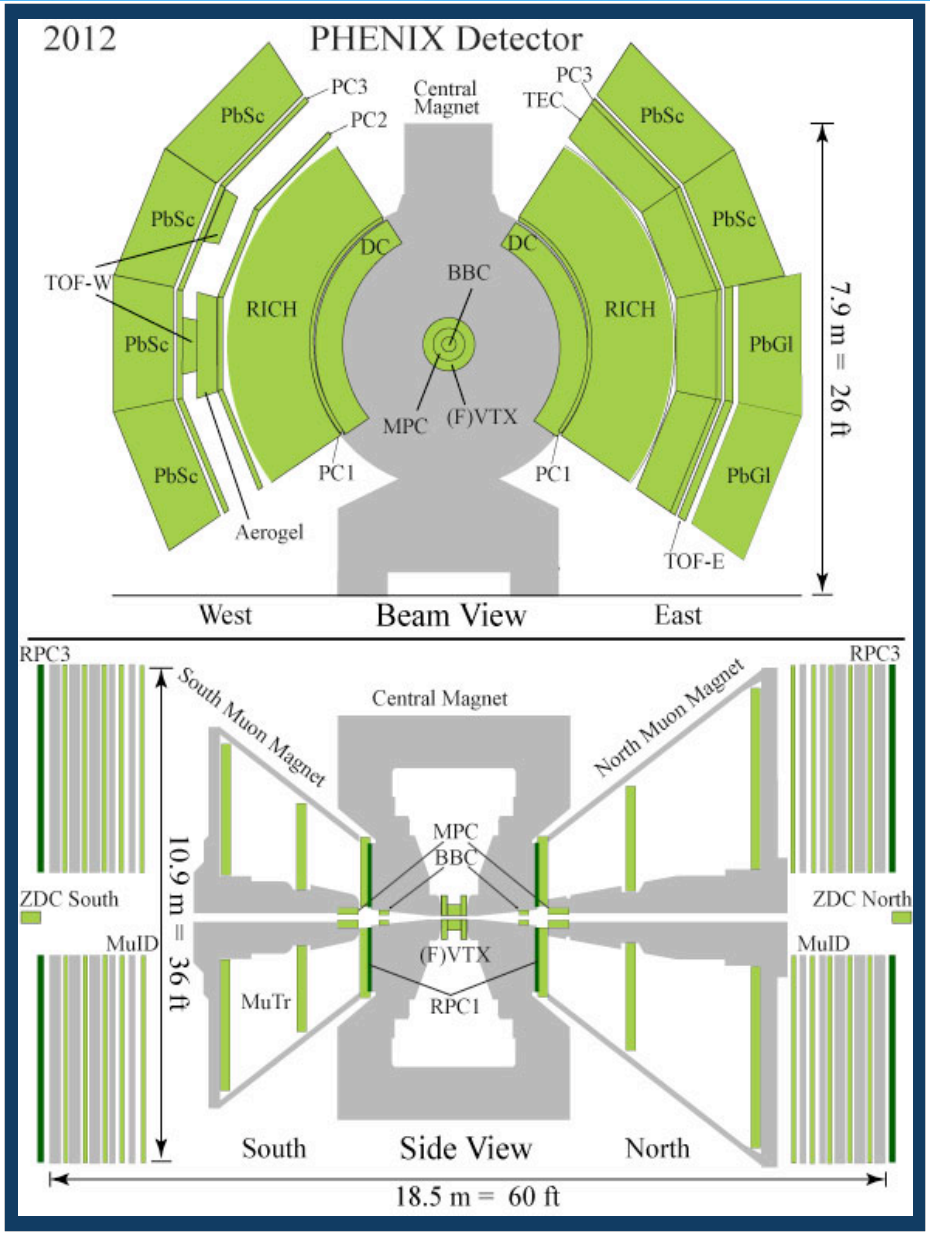
$$R_{CP} = \frac{\frac{dN_{AA}/dp_T}{< N_{coll} >}\ (\text{central})}{\frac{dN_{AA}/dp_T}{< N_{coll} >}\ (\text{peripheral})}$$

R > 1 (enhancement)
R = 1 (no medium effect or balance)
R < 1 (suppression)

Relativistic Heavy Ion Collider



PHENIX



Central arms:

Hadrons, photons, electrons

- $|\eta| < 0.35$
- $p_e > 0.2$ GeV/c
- $\Delta\phi = \pi$ (2 arms x $\pi/2$)

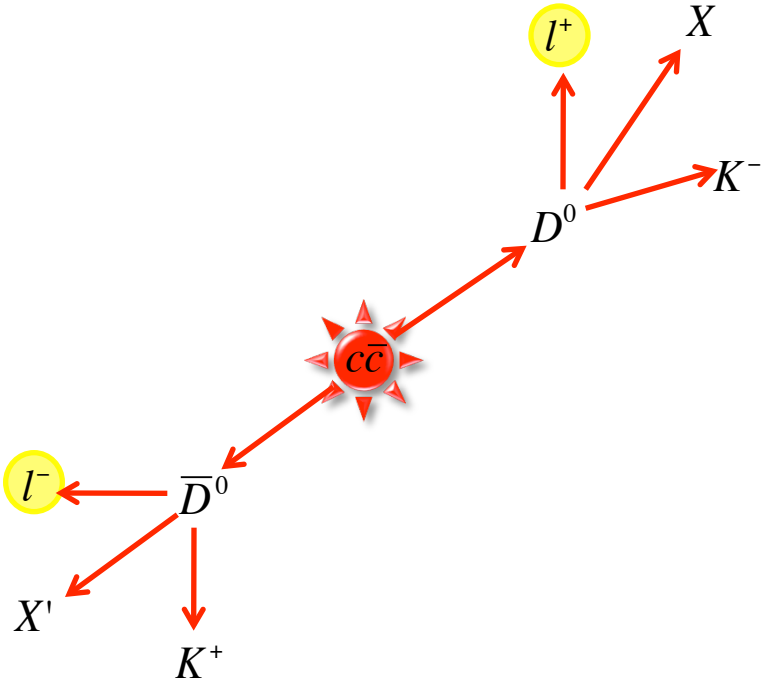
Forward rapidity arms:

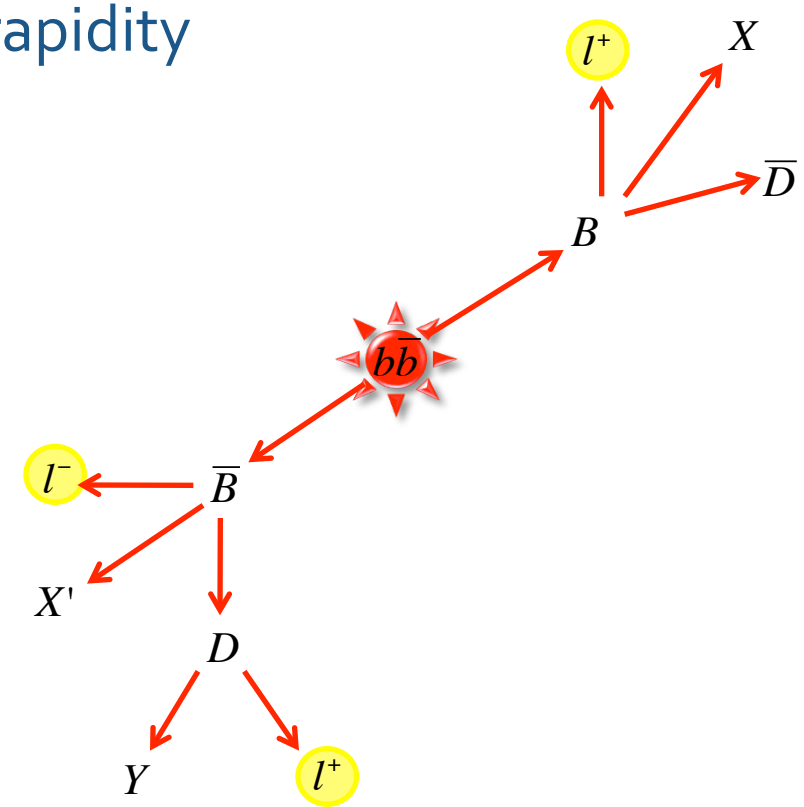
Muons

- $1.2 < |\eta| < 2.2$
- $p_\mu > 1$ GeV/c
- $\Delta\phi = 2\pi$

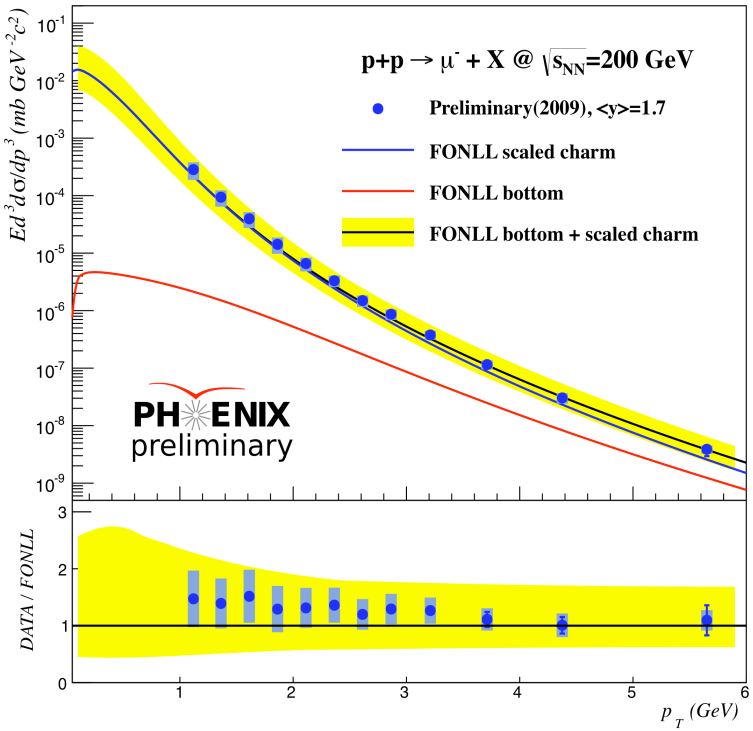
Open Heavy Flavor Measurements

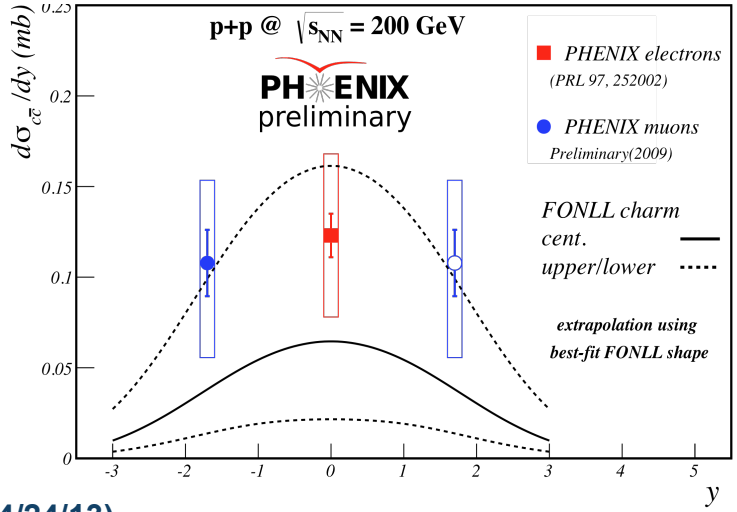
- Indirect measurement of charm and bottom through semi-leptonic decay.
  - Electrons at mid-rapidity
  - Muons at forward/backward rapidity

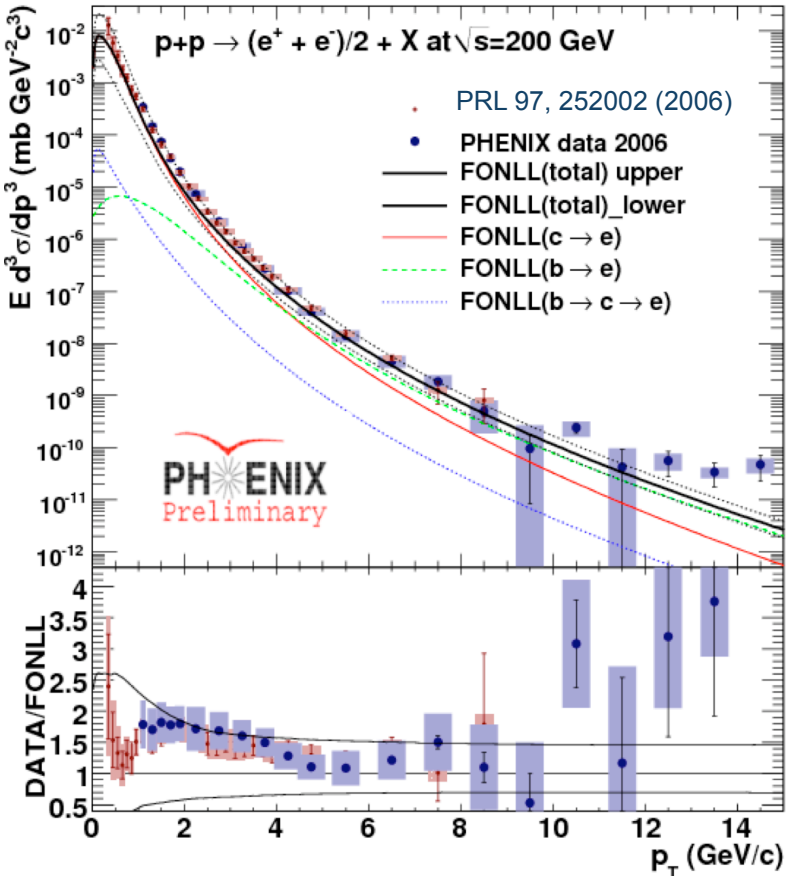




Single Leptons in p+p at 200 GeV



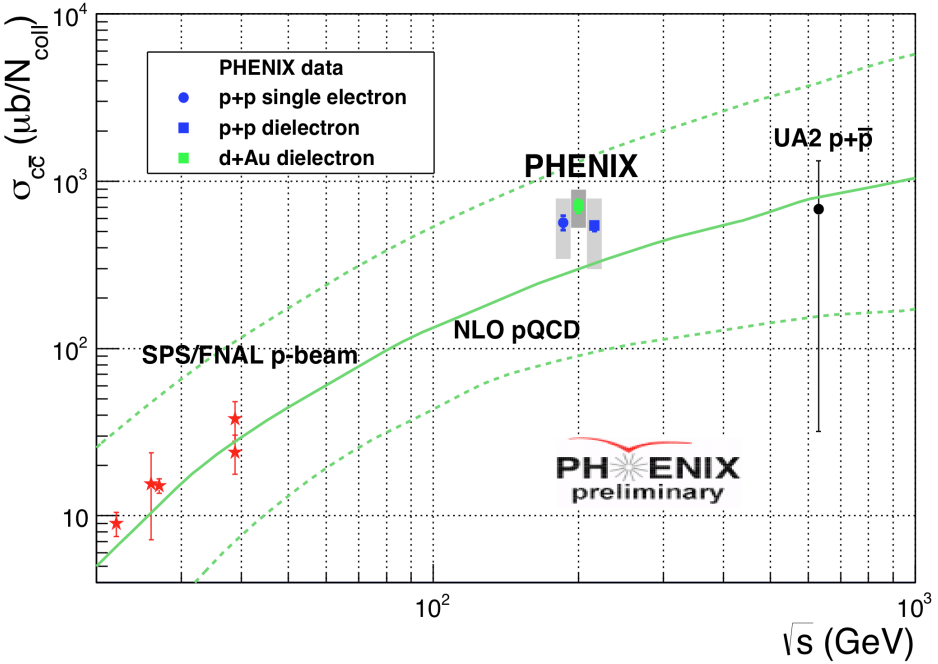


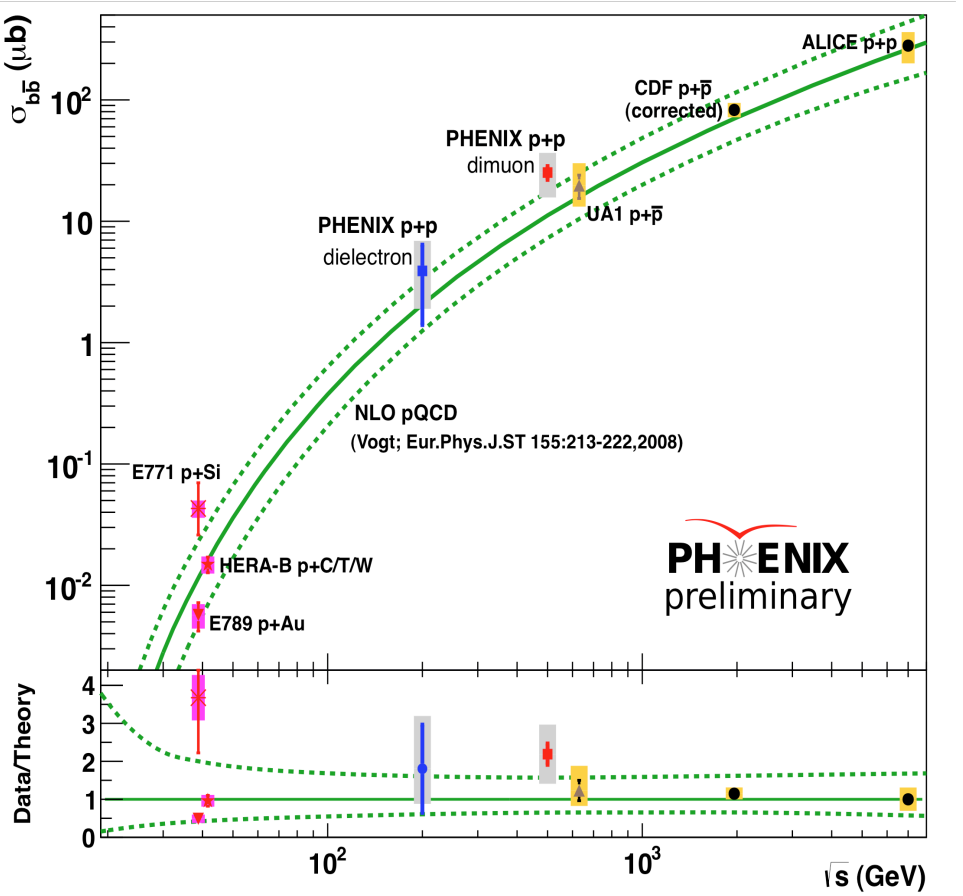


- e and μ baseline measurements in central and forward rapidity
- Consistent with FONLL upper limit

Charm & Bottom Cross Sections

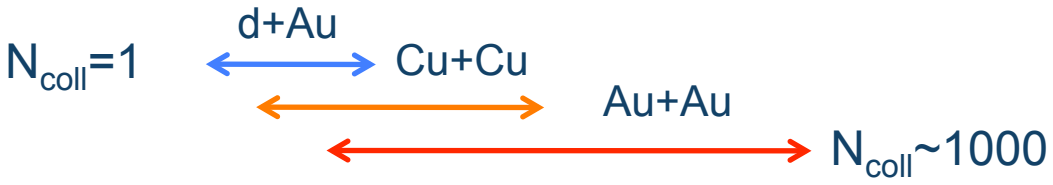
- PHENIX has multiple measurements for charm and bottom production.
  - All are in agreement with pQCD values.



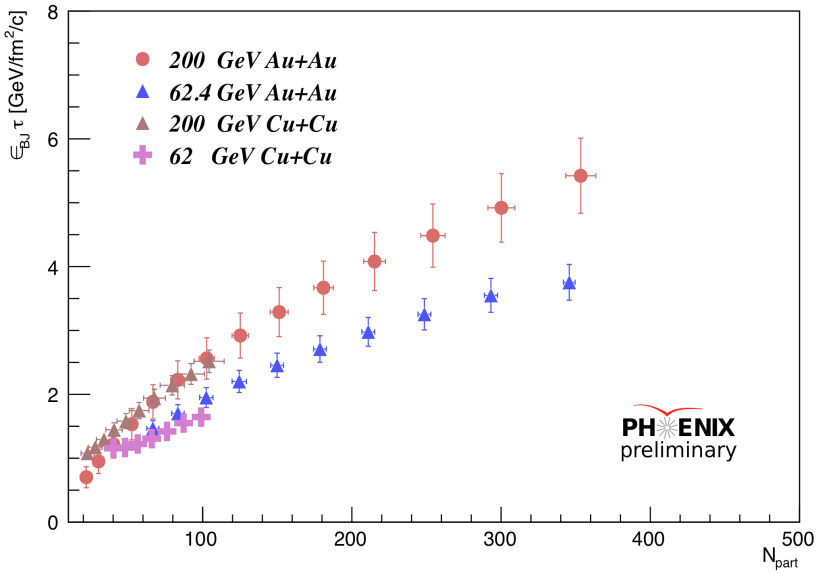


Cu+Cu at 200 GeV

- Cu+Cu collisions provide a cross over between d+Au and Au+Au.

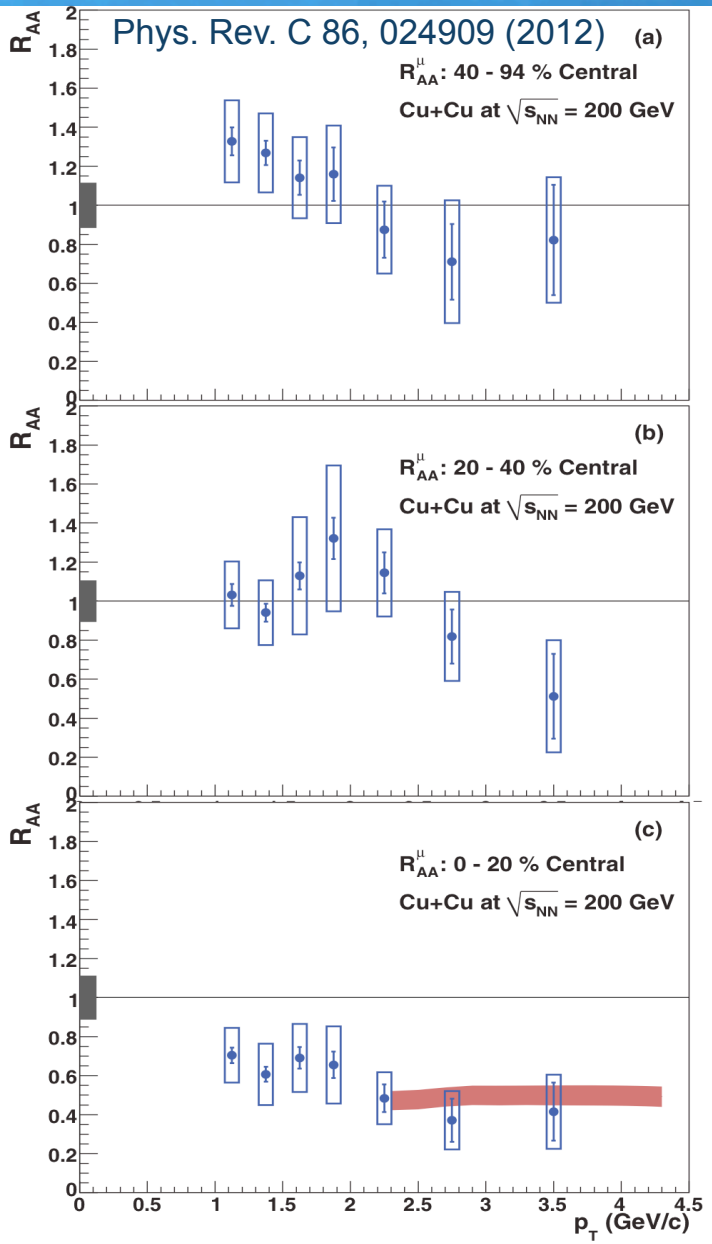


- The medium created in central Cu+Cu collisions has a different density than central Au+Au



Single Leptons in Cu+Cu

- Suppression of muons from HF in most central collisions.



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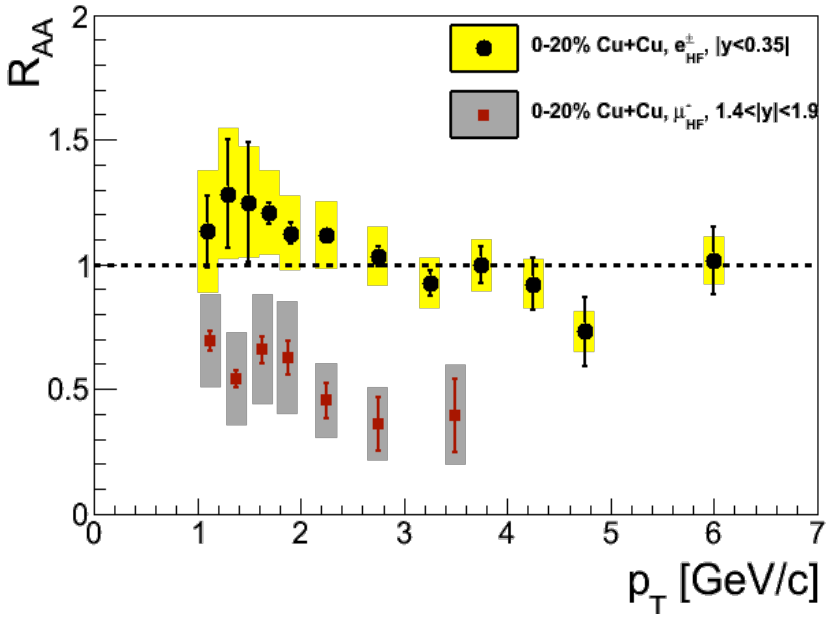
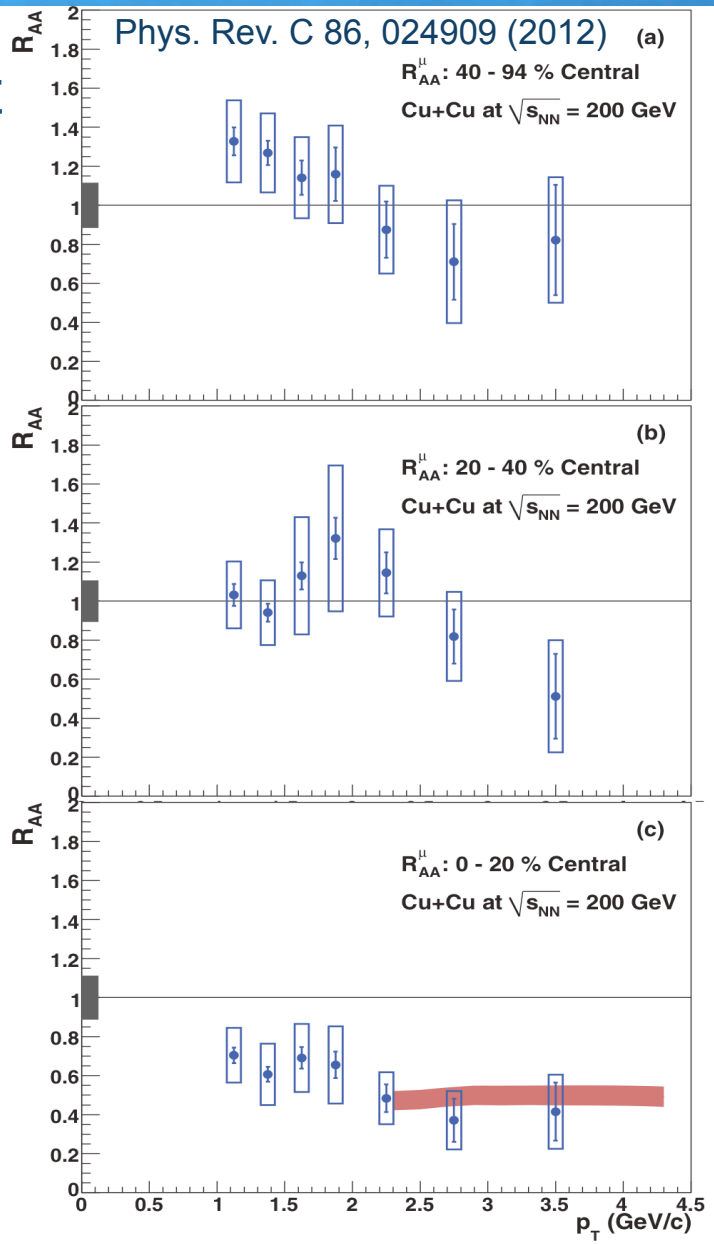


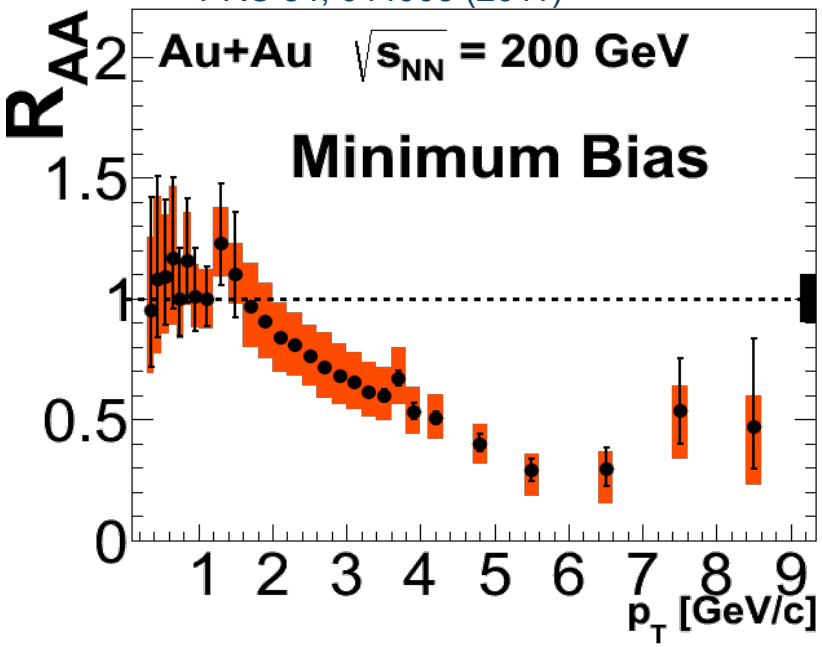
- Larger suppression at forward rapidity.
- Additional CNM effects are expected at forward rapidity.



Single Leptons in Au+Au

- Use single electrons from HF to study the medium.

PRC 84, 044905 (2011)



- Suppression in Au+Au for p_T>1.5 GeV.

Single Leptons in Au+Au

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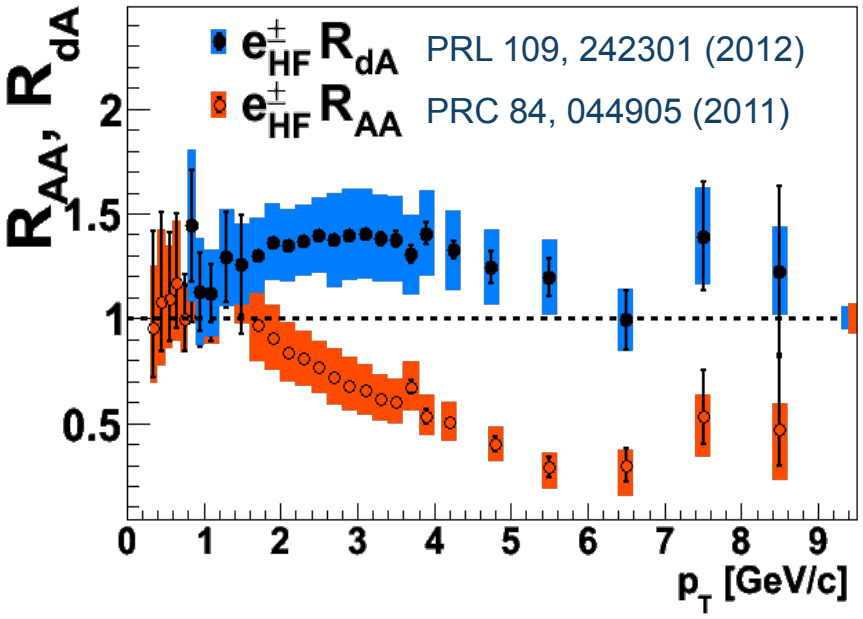


- Suppression in Au+Au for p_T>1.5 GeV.
- No suppression in d+Au
- Suppression in Au+Au must be due to HNM effects.

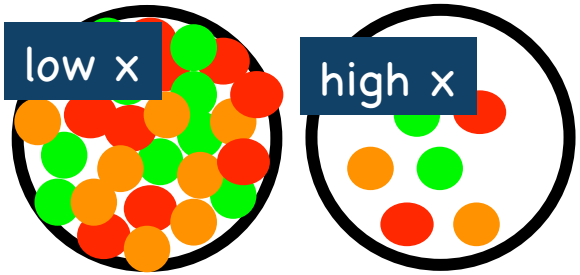
Disentangling Cold Nuclear Matter Effects

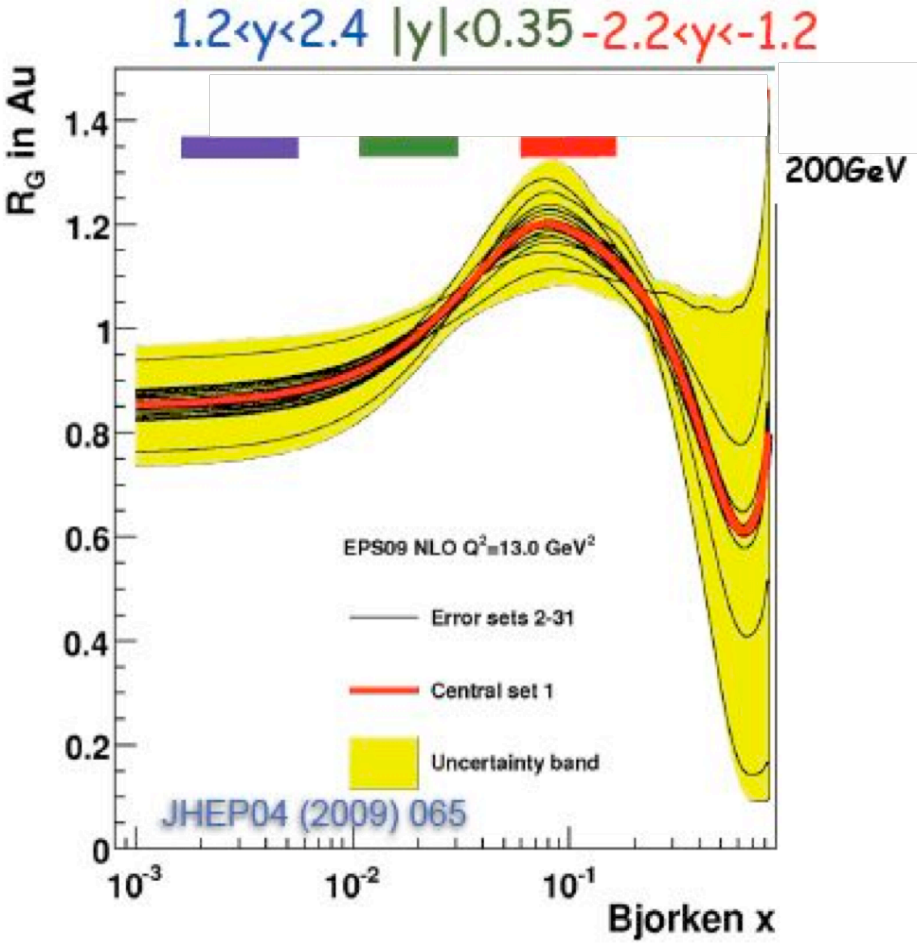
- Difficult to conclude much in heavy ion collisions without a thorough understanding of CNM.
- d+Au collisions provide an environment to probe CNM effects!
  - No QGP is expected to form.

Cold Nuclear Matter Effects

- Nuclear PDF is modified: Shadowing, Anti-shadowing, EMC, Saturation

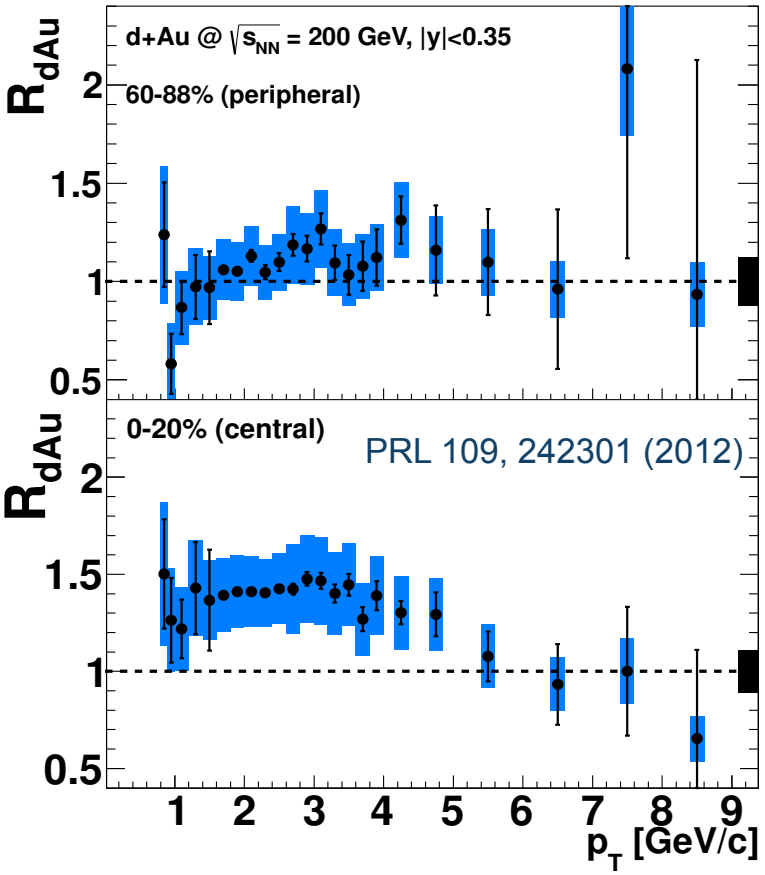
- Gluon saturation





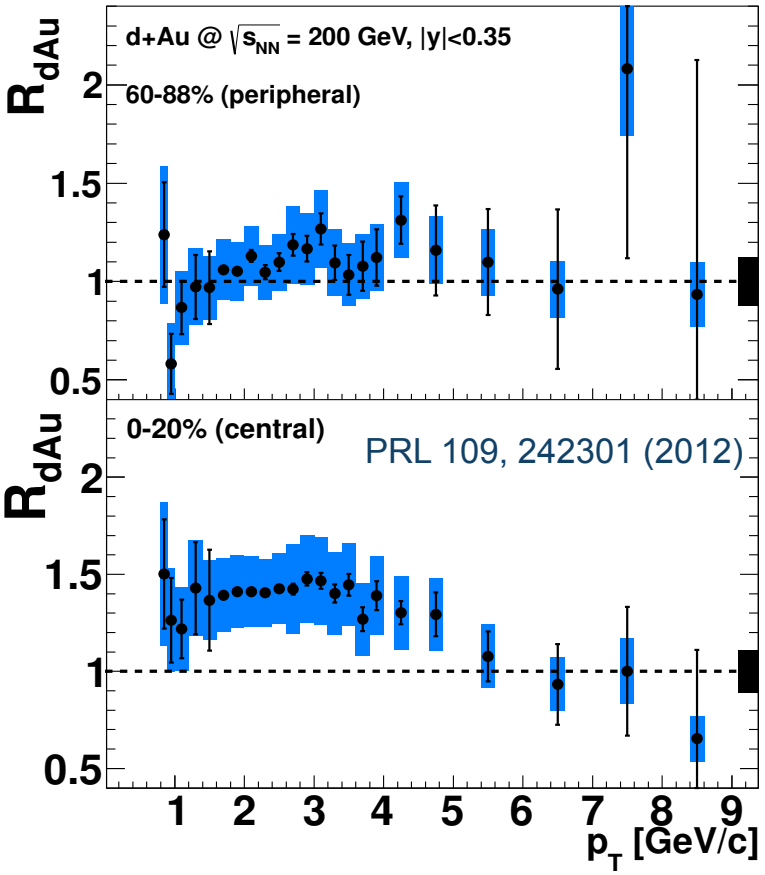
- Unlike quarkonia, there are no final state breakup effects!

Single HF Leptons in d+Au



- R_{dA} ~1 in peripheral collisions
- Enhancement in central collisions

Single HF Leptons in d+Au



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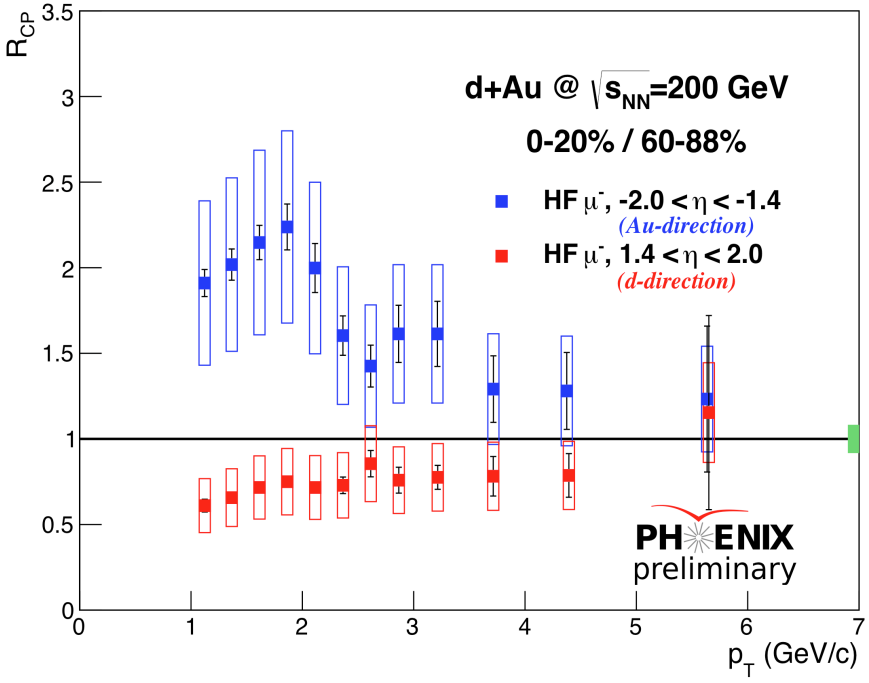
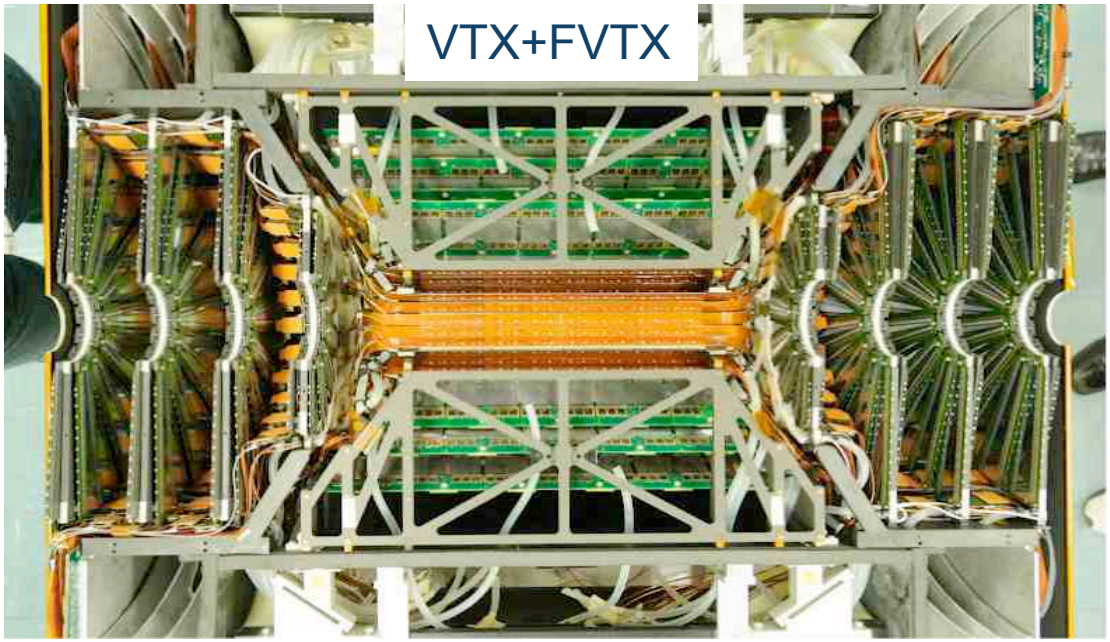


- Suppression in the d-going direction
- Enhancement in the Au-going direction, similar to central region

Future Work

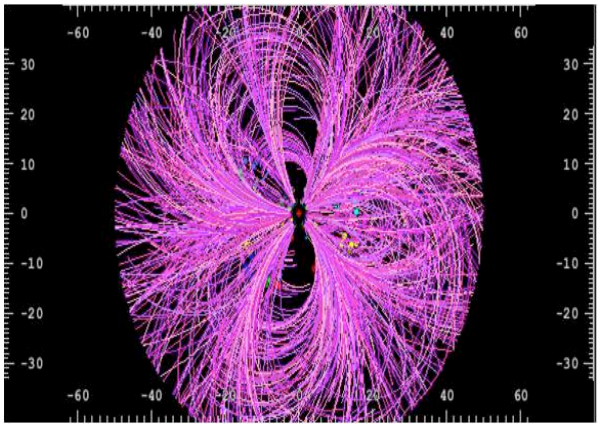
- A more detailed understanding of heavy quark energy loss requires separation of charm and bottom.
- To accomplish, this PHENIX recently installed two silicon vertex tracker detectors.

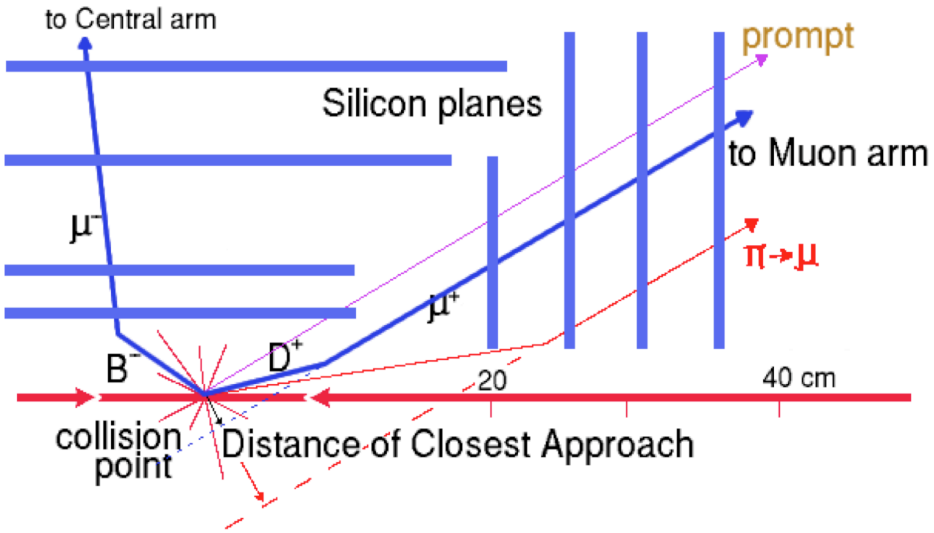


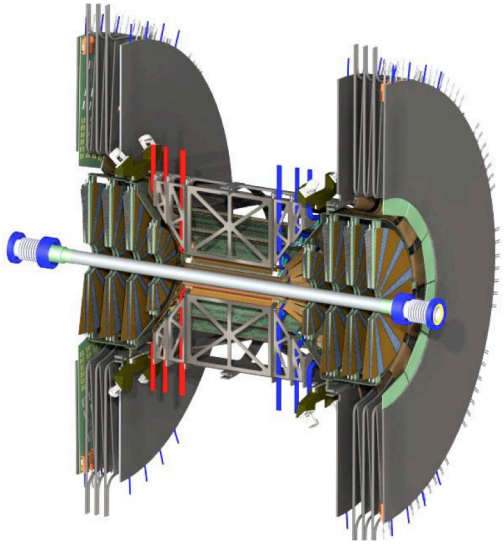
VTX (commissioned in 2011) and FVTX (commissioned 2012)

PHENIX (F)VTX

- VTX installed in Run-11 & FVTX in Run-12.
- Will allow separation of B & D.



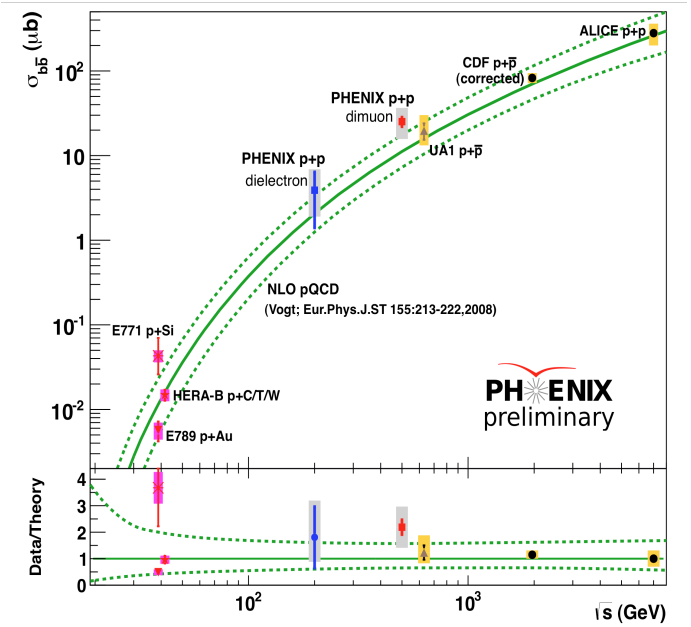


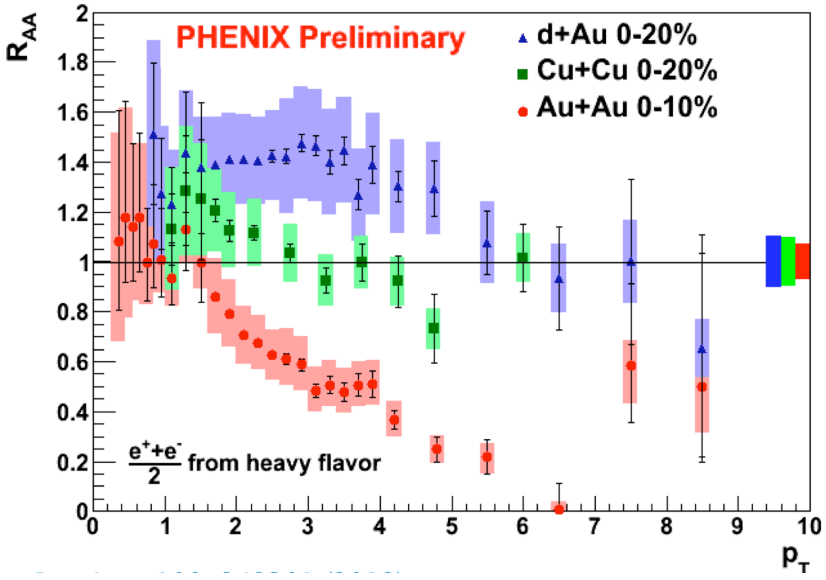


- New results coming soon!

Summary

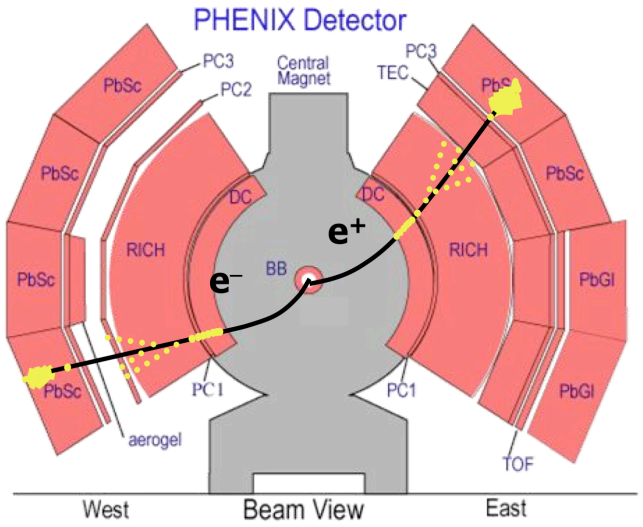
- PHENIX has multiple measurements for heavy flavor cross sections in p+p.
- Heavy ion results show suppression beyond that expected from CNM.
- d+Au results show some some rapidity dependent modification in open heavy flavor.
- Quantifying the HNM effects is an ongoing process.

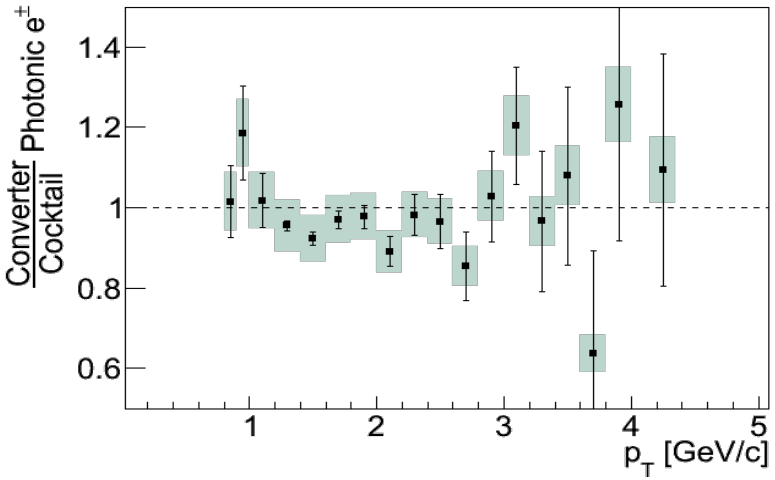




Backup

Single e Signal Extraction





Excellent agreement between two independent methods

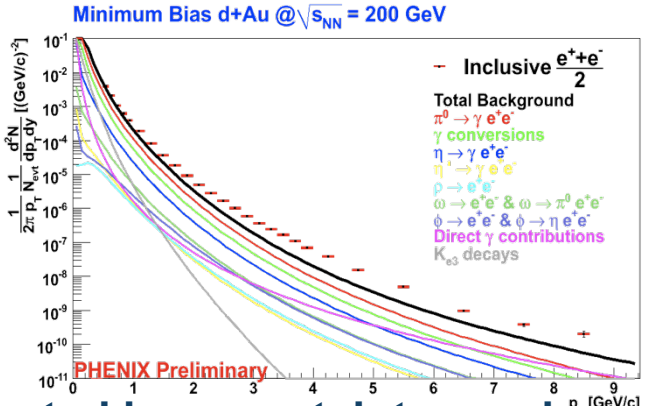
Converter method

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

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

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

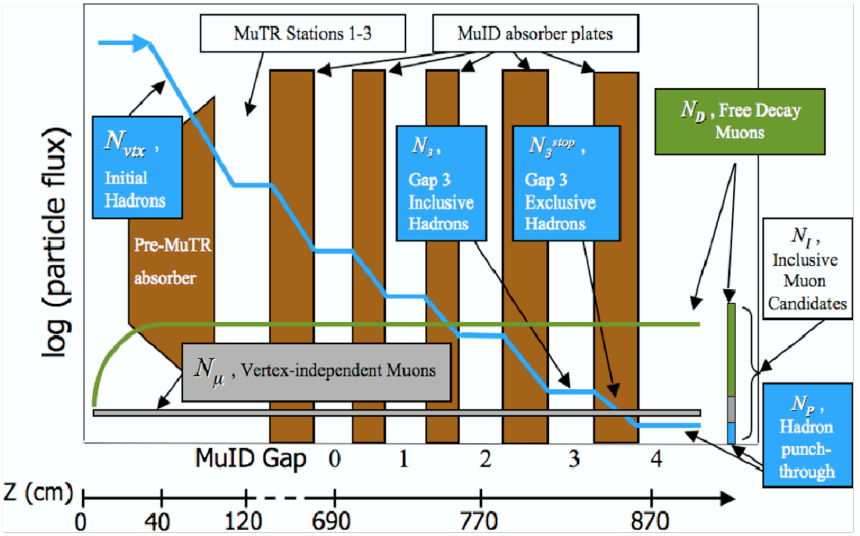
Cocktail method

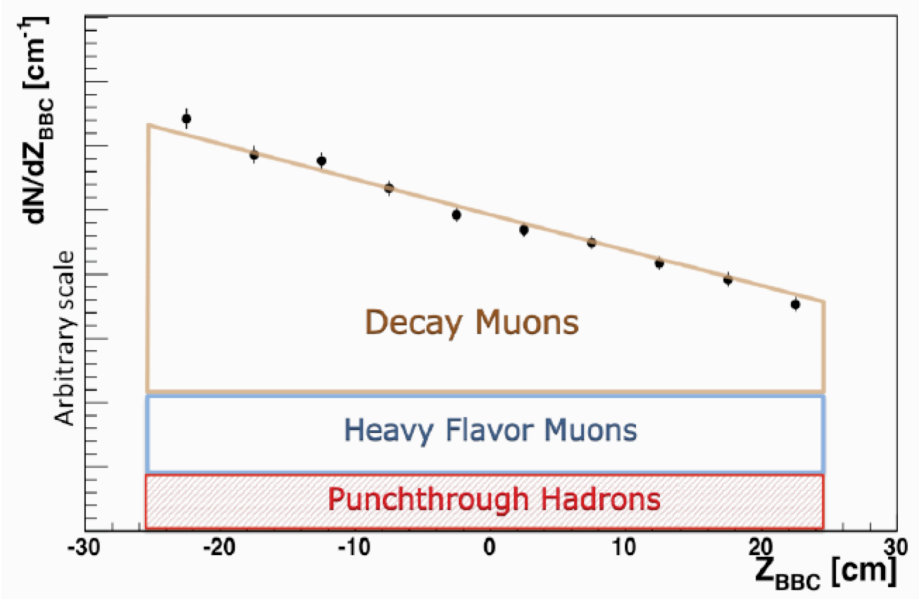


Dominated by uncertainty on pion spectra

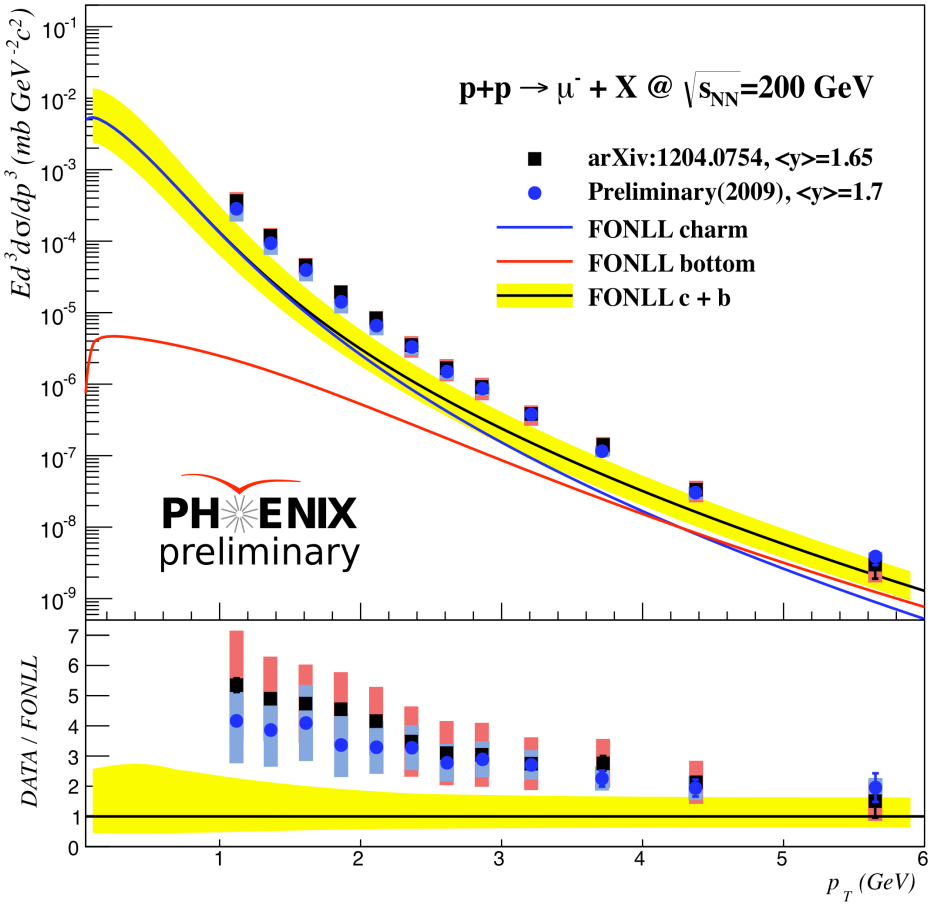
Single Muon Analysis

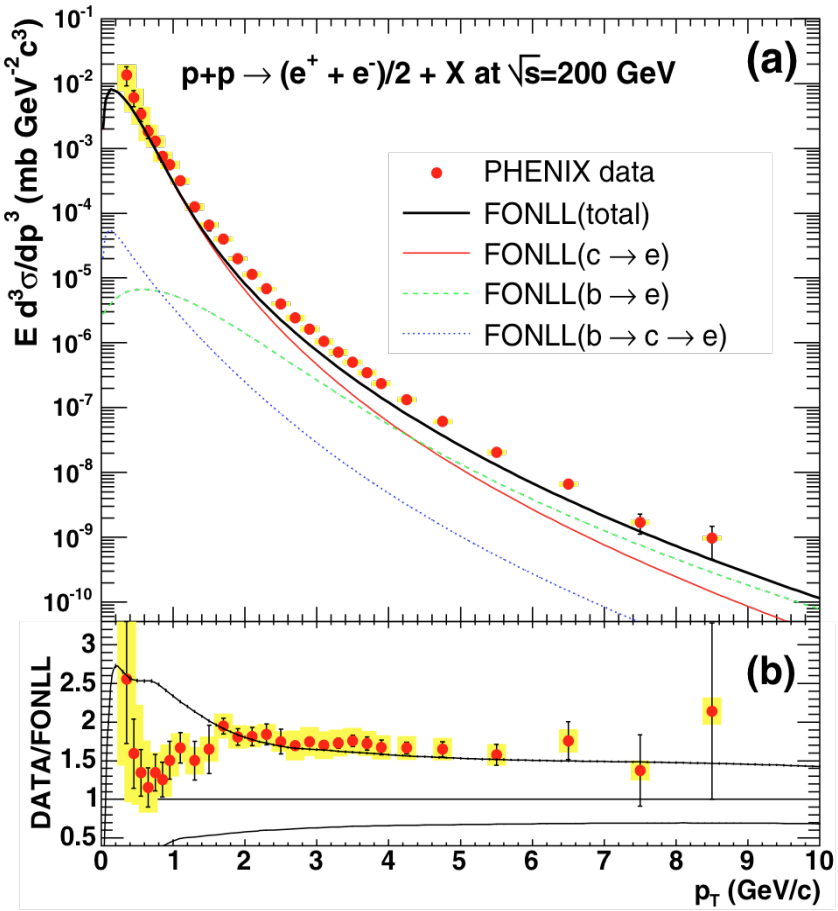
- Background
  - Decay muons from light vector mesons
  - Punch through hadrons
- Hadron cocktail input tuned to match data distributions
  - Decay muon z-vertex dependence
  - "stopped" hadron spectra





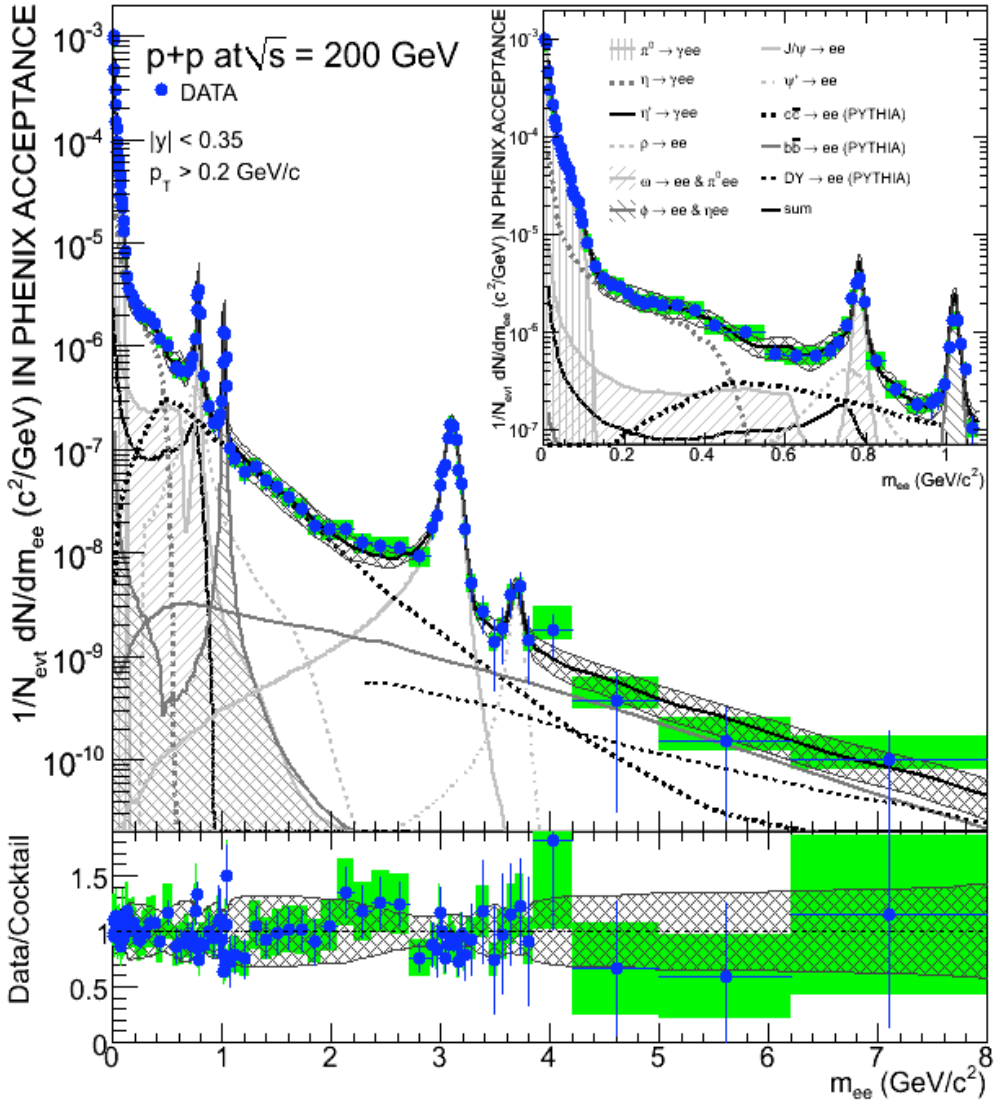
Previous Single Lepton Results in p+p





Dielectron Analysis p+p at 200 GeV

Phys. Lett. B 670, 313 (2009)



- Use simulation for each component.
- Excellent agreement between data and cocktail.

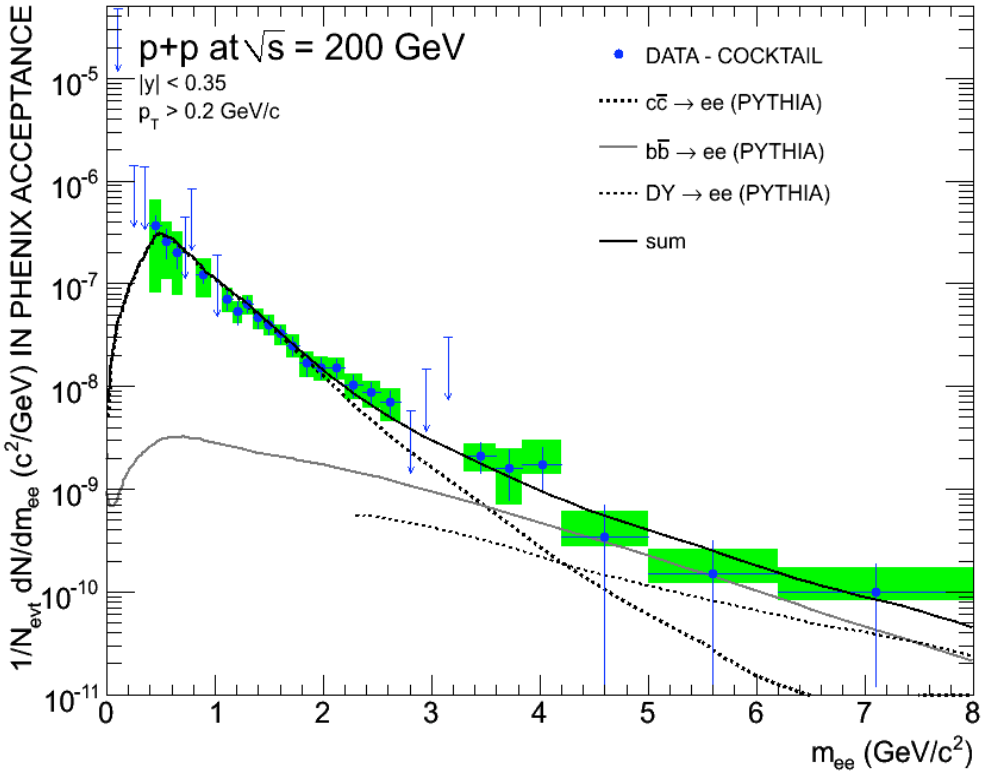
Dielectron Analysis p+p at 200 GeV

- Cocktail subtraction leaves only continuum contributions.
- Simultaneously fit the charm & bottom components. (DY is fixed)
- Use Pythia to extrapolate a total cross section.
- Cross Sections:

$$\sigma_{c\bar{c}} = 544 \pm 39(\text{stat}) \pm 142(\text{sys}) \pm 200(\text{model})\,\mu b$$

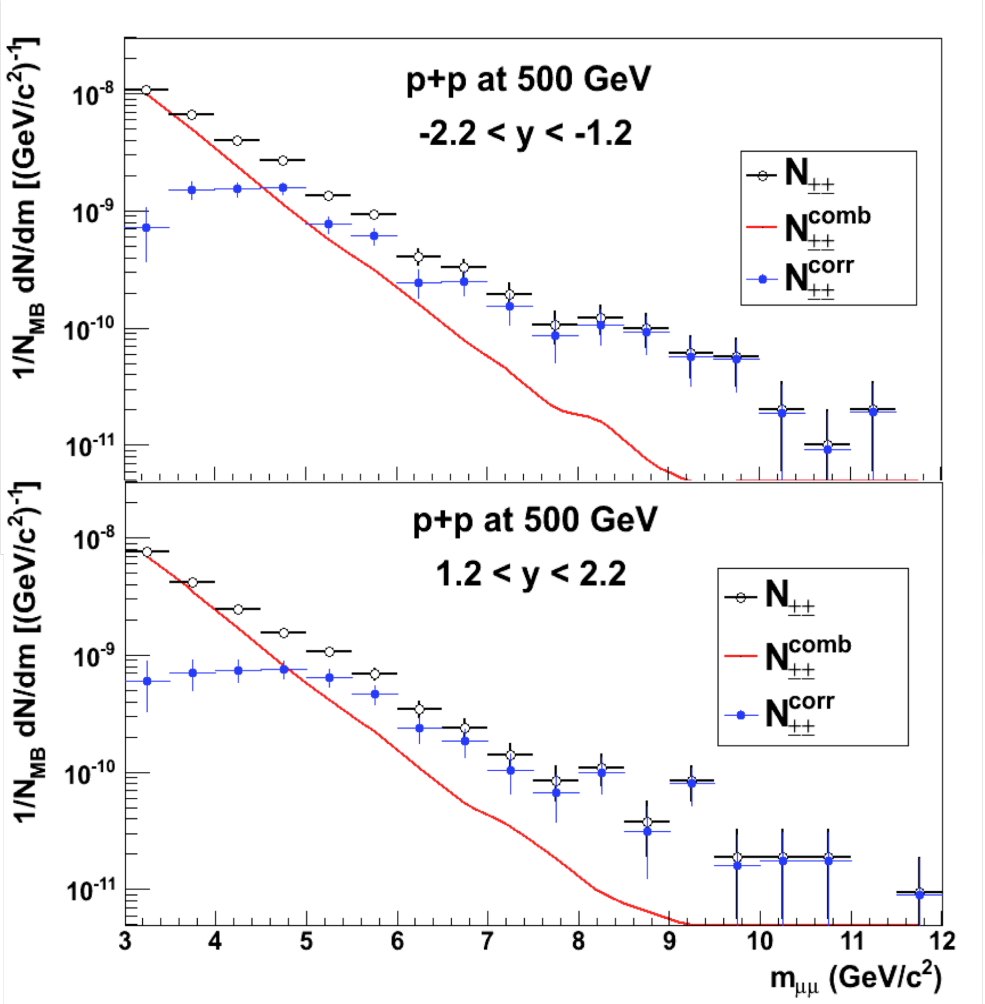
$$\sigma_{b\bar{b}} = 3.9 \pm 2.4(\text{stat})^{+3}_{-2}(\text{sys})\,\mu b$$

Phys. Lett. B 670, 313 (2009)



Like-sign Dimuon Analysis p+p at 500 GeV

- Use like-sign dimuons to calculate total cross section



Correlated Like-Sign Signal

- Like-sign technique: contains combinatorial and correlated signal.
- Event mixing technique: contains only combinatorial signal.

$$N^{corr}_{\pm\pm} = N^{like}_{\pm\pm} - N^{mixed}_{\pm\pm}$$

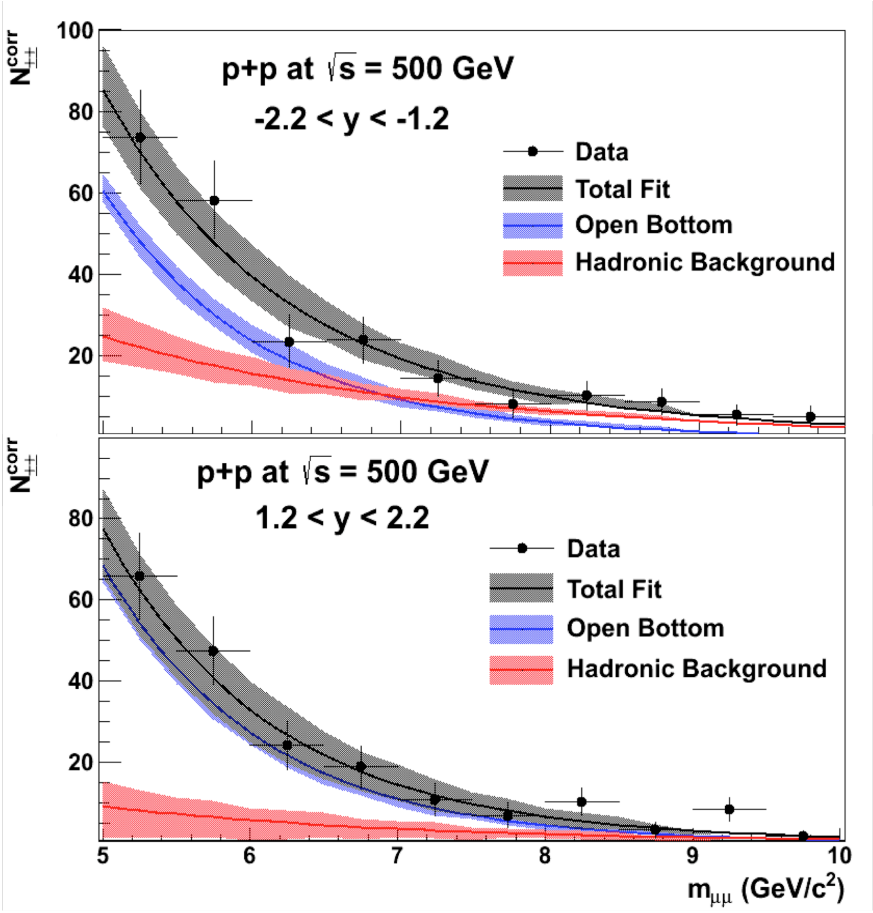
Like-sign Dimuon Analysis p+p at 500 GeV

- Use simulation to get line shapes.
- Simultaneous fit of two components:

$$F(m) = p_0 \exp(-m/p_1) + p_2 \exp(-m/p_3)$$

Hadronic background contribution

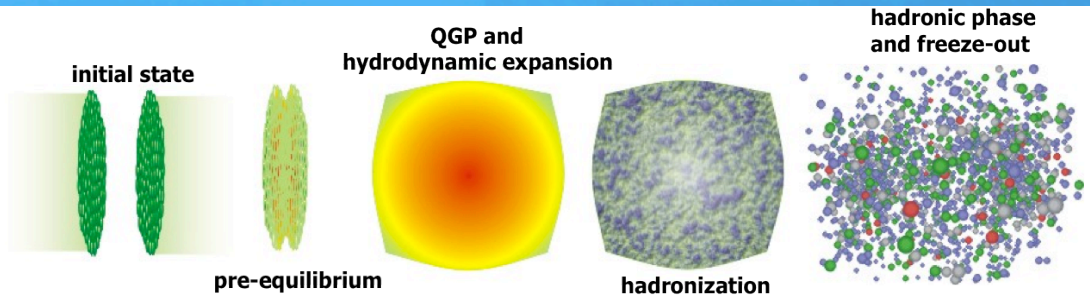
Open Bottom contribution



- Extrapolate to total cross section using Pythia.

Cross Section: $\sigma_{b\bar{b}} = 25.2 \pm 3.2(\text{stat})^{+11.4}_{-9.5}(\text{sys})\mu b$

Heavy Ion Collisions- Mass Spectra



Diverse Physics Signatures

- Low mass: sensitive to chiral symmetry restoration
- Intermediate mass: thermal radiation, modification of open charm & charmonia
- High mass: modification of open bottom & Upsilon