

# J/ $\psi$ and Charm at RHIC

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for the PHENIX Collaboration

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# Outline

## J/ $\psi$ measurements

- p+p baseline, polarization
- d+Au, Cold Nuclear Matter Effects
- Au+Au results

## Open charm measurements

- Suppression in Au+Au
- Flow

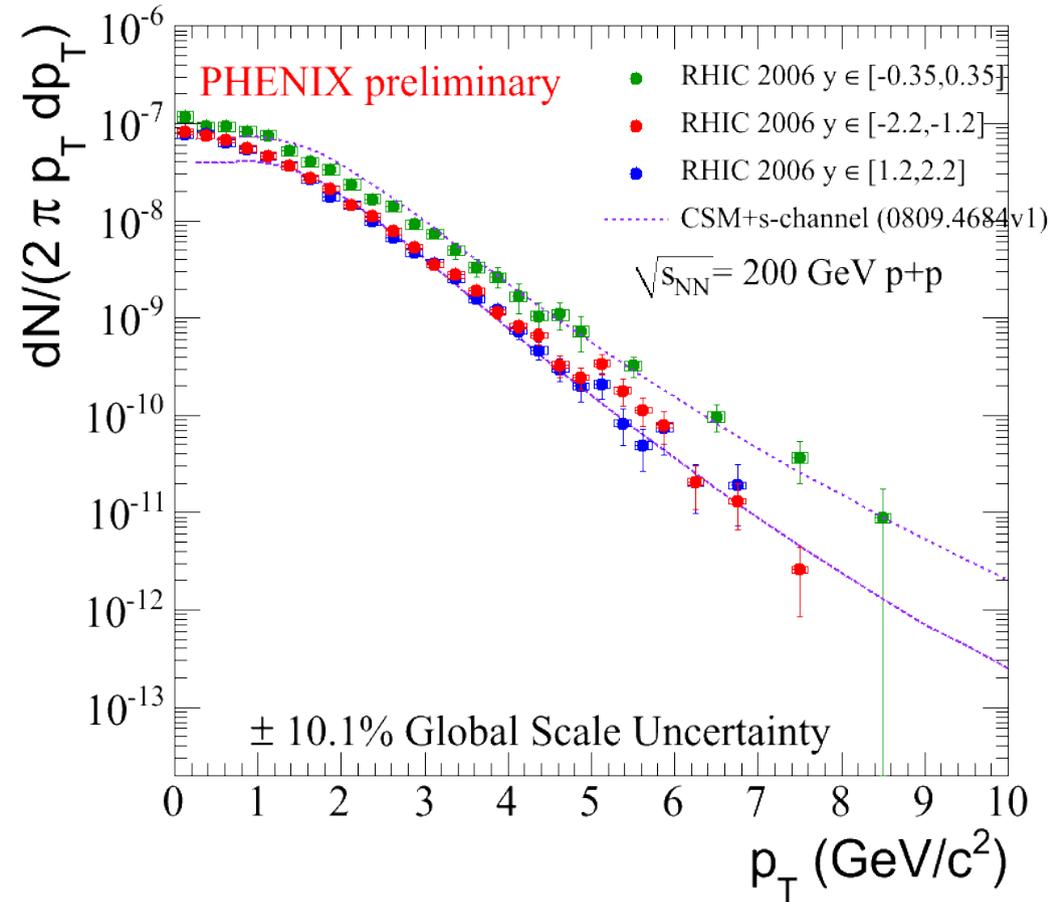
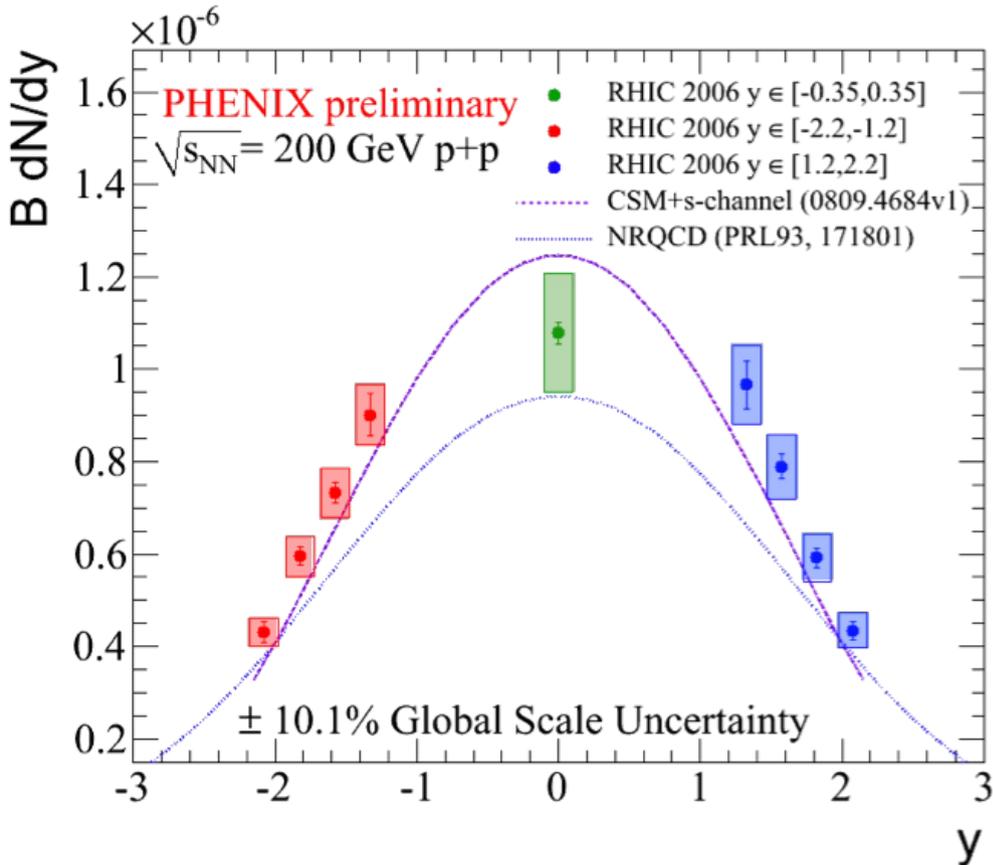
## Future Measurements with VTX/FVTX



**J/ψ**

# J/ψ in p+p

Models have absolute normalization



- “s-channel cut” CSM shows good agreement with the data  
(Haberzettl, Lansberg, PRL 100 (2008) 032006)
- Good baseline for d+Au and Au+Au

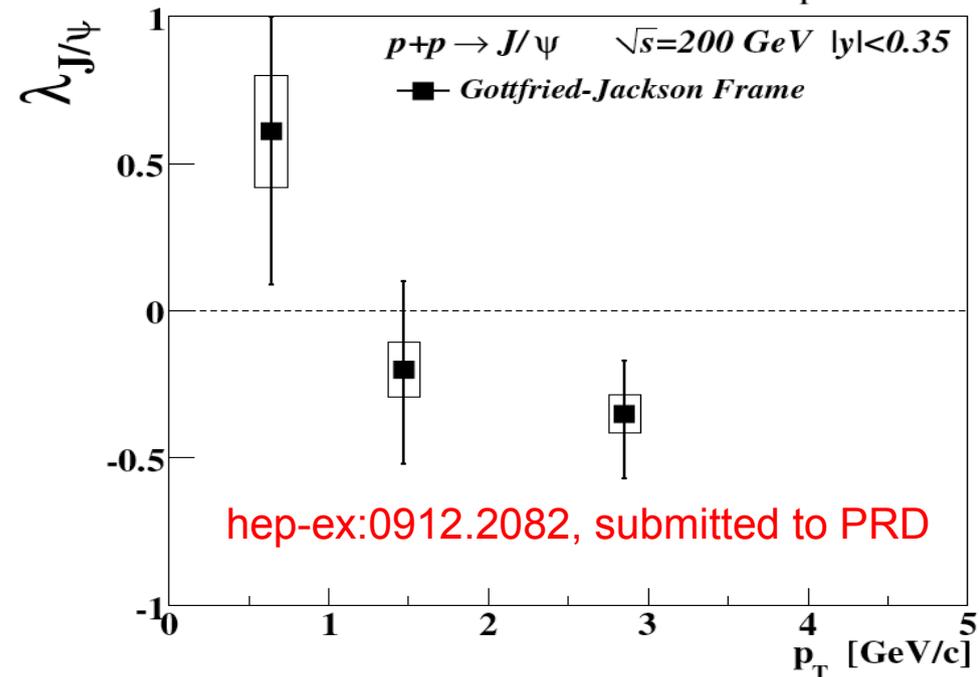
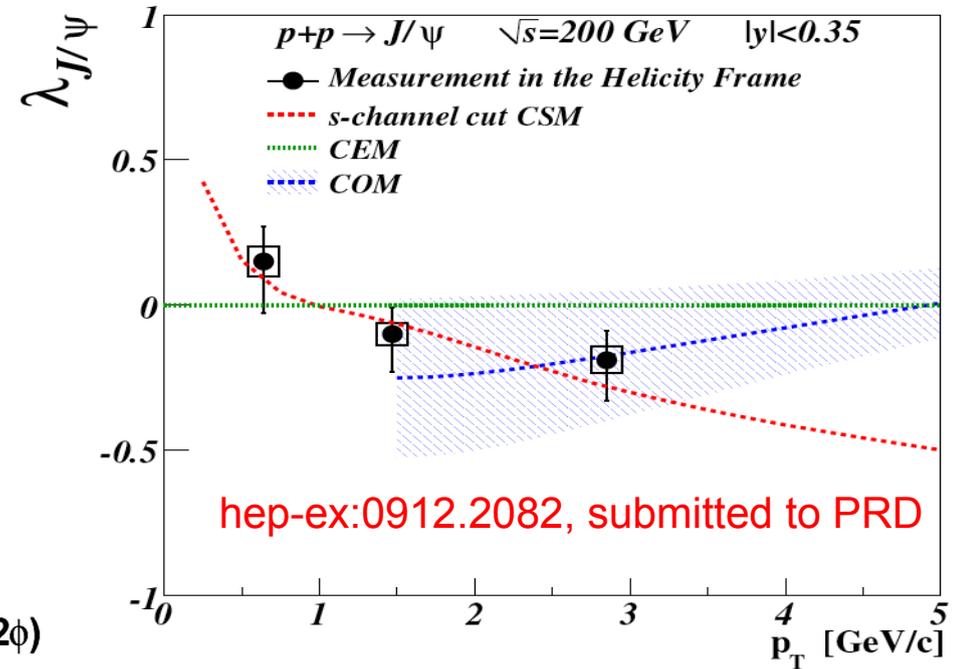
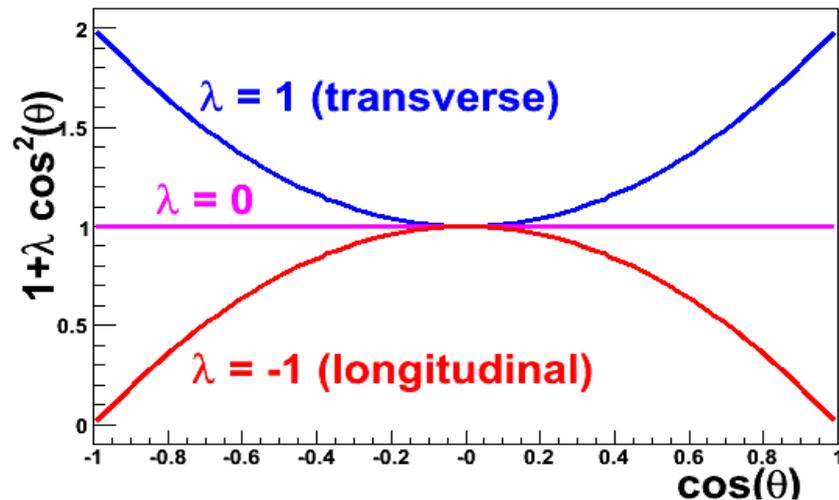
# J/ψ polarization in p+p

Measure decay lepton angle in J/ψ rest frame relative to a polarization axis:

- Helicity frame: J/ψ momentum in lab frame  
(correlation between J/ψ spin and momentum)
- Gottfried-Jackson frame: momentum of the colliding parton.  
(corelation between J/ψ spin and colliding parton momentum)

$$\frac{dN}{d\cos(\theta) d\phi} \propto 1 + \lambda_{\theta} \cos^2(\theta) + \lambda_{\theta\phi} \sin(2\theta)\cos(\phi) + \lambda_{\phi} \sin^2(\theta)\cos(2\phi)$$

$$\frac{dN}{d\cos\theta} = A(1 + \lambda \cos^2\theta)$$



# J/ψ and Cold Nuclear Matter Effects

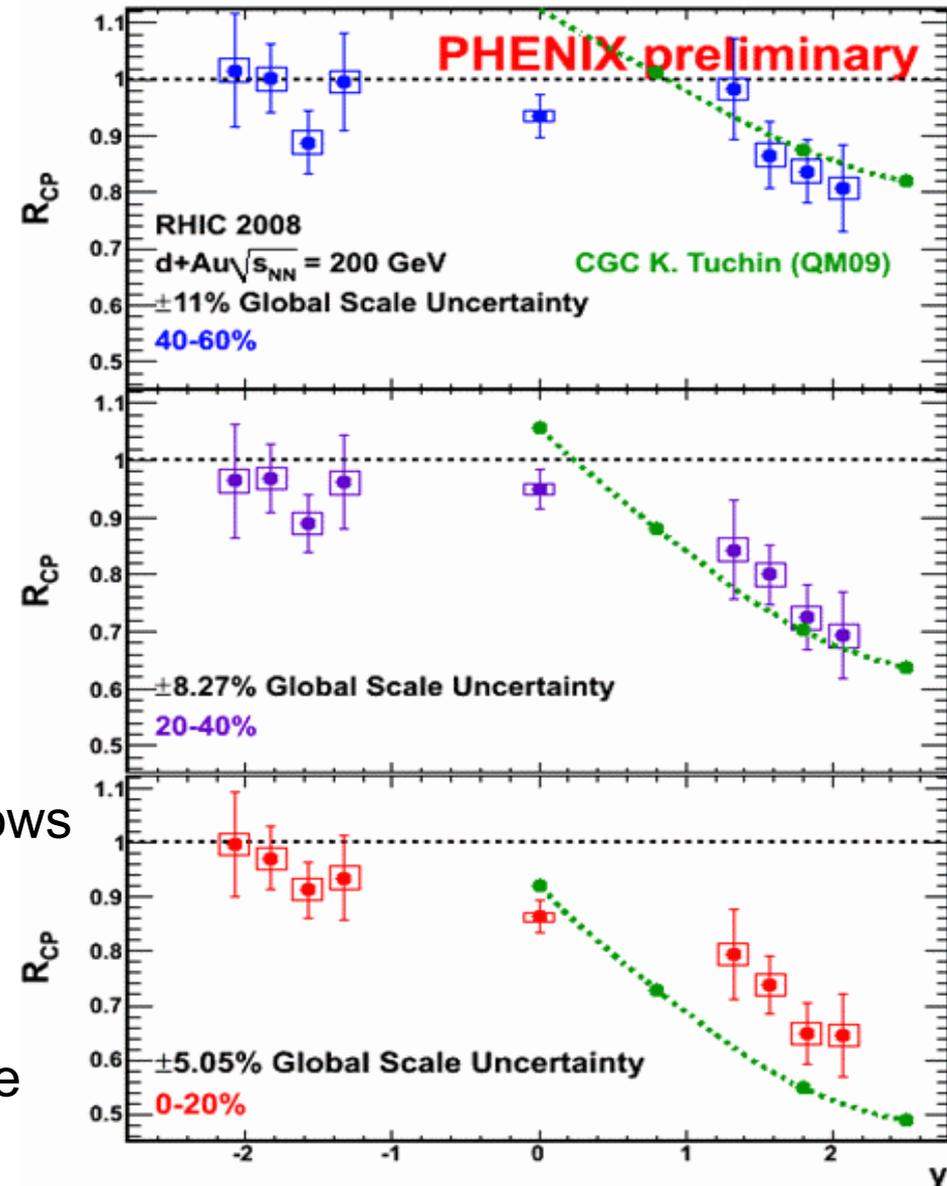
*Before attempting to understand what happens in Au+Au we must understand “cold nuclear matter” effects, including:*

- Pdf modification in nuclei
- Breakup by surrounding hadrons
- Gluon saturation at low  $x$  / CGC
- Initial state energy loss
- Cronin effect

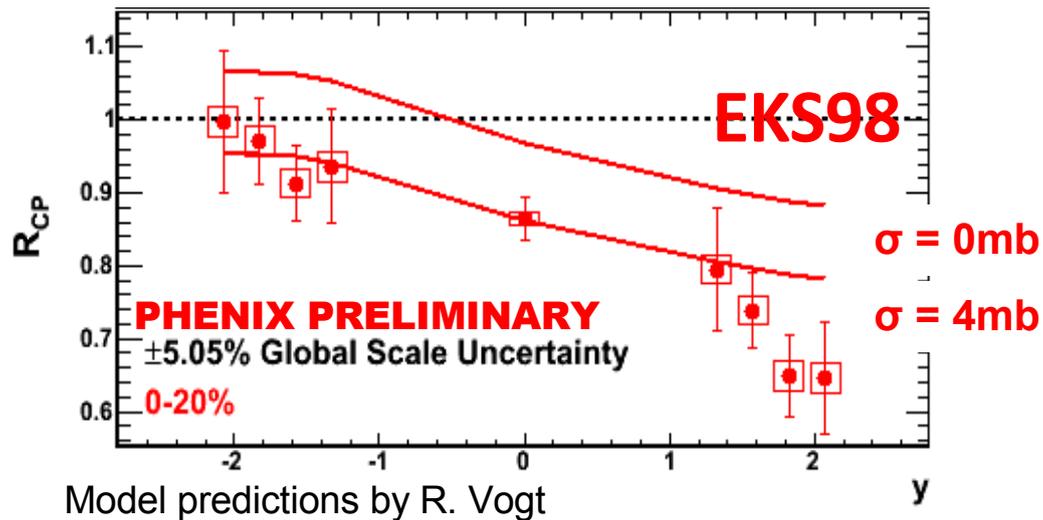
2008 d+Au data sample has ~40 times more statistics than 2003 published results and allows finer rapidity binning.

$R_{CP} \sim 1$  at negative rapidity (Au direction)

$R_{CP} < 1$  and decreases with rapidity at positive rapidity (deuteron direction)



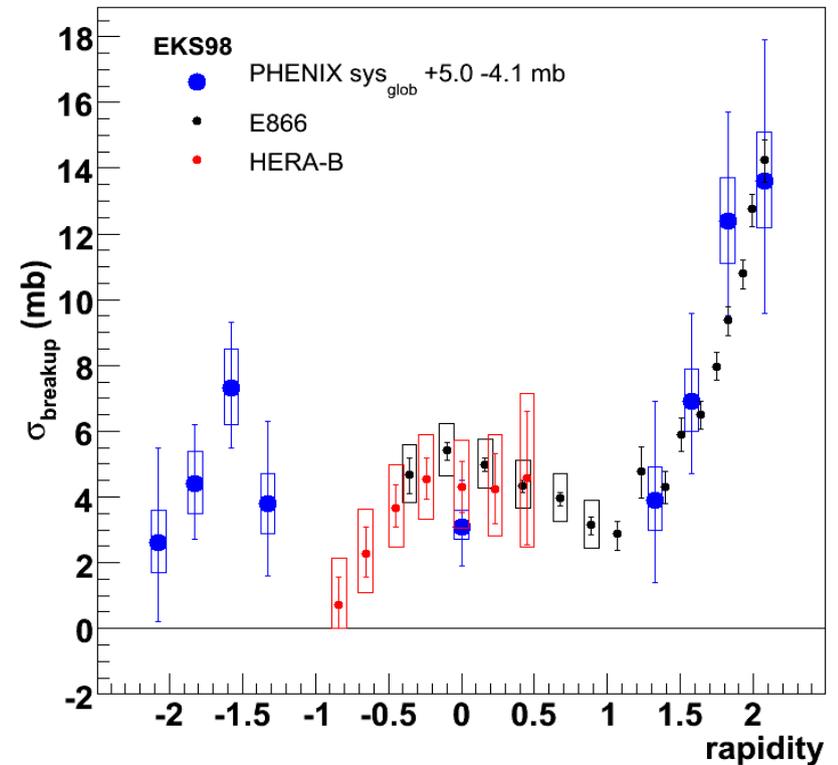
# J/ψ and CNM (2)



Shadowing plus constant breakup cross-section do not match the data.

Instead:  
 Extract effective breakup cross-section vs rapidity. Include in this way all other CNM effects.

Lourenco, Vogt, Woehri - arXiv:0901.3054



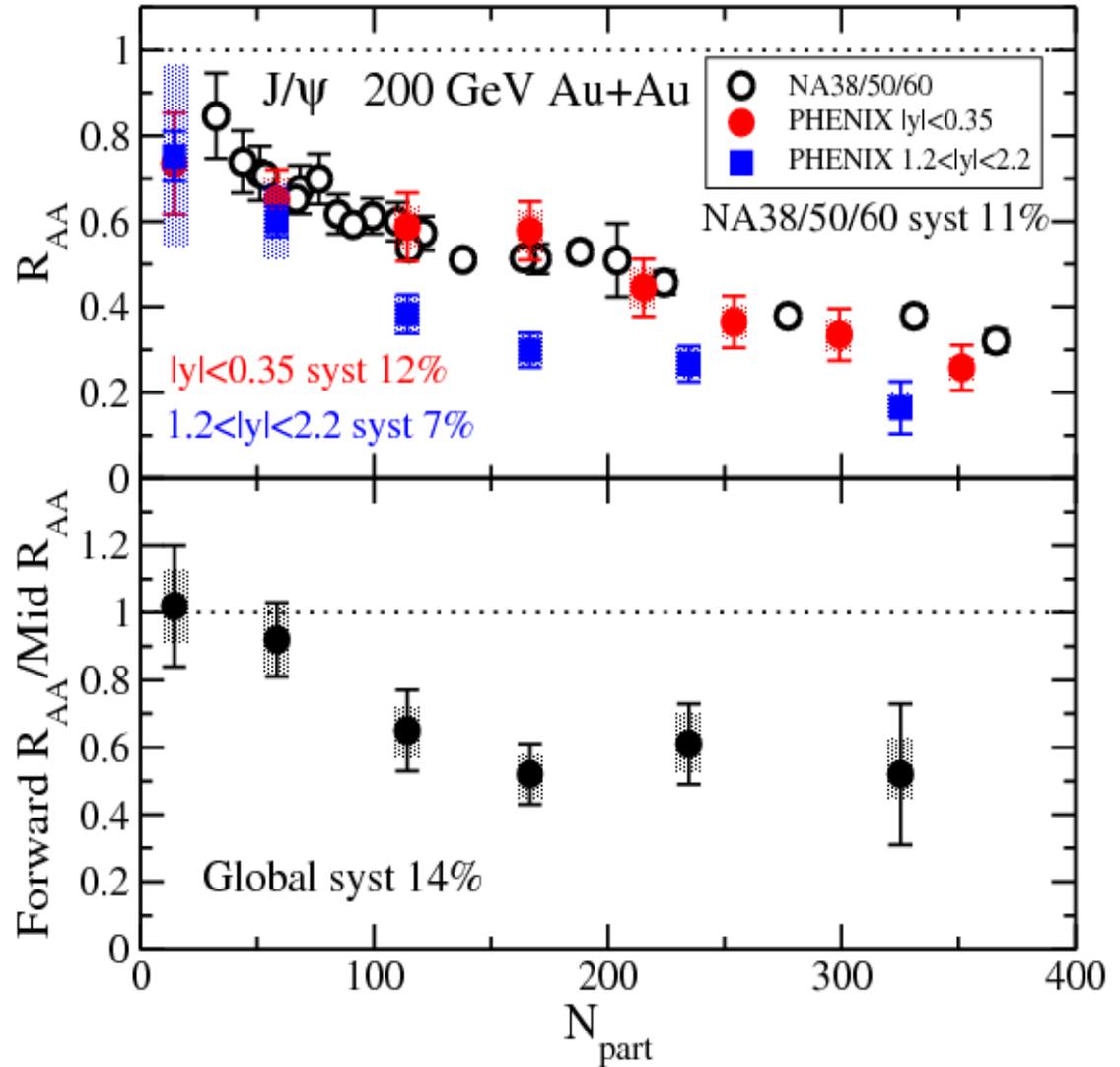
PHENIX results match E866 and HERA-B

# J/ $\psi$ in Au+Au

J/ $\psi$  suppression is similar to open charm suppression

Suppression at RHIC similar to one observed at SPS at mid-rapidity, but stronger at forward rapidity.

Many different interpretations exist (“cold nuclear matter” effects, re-generation, etc.) Exact picture is still unclear.

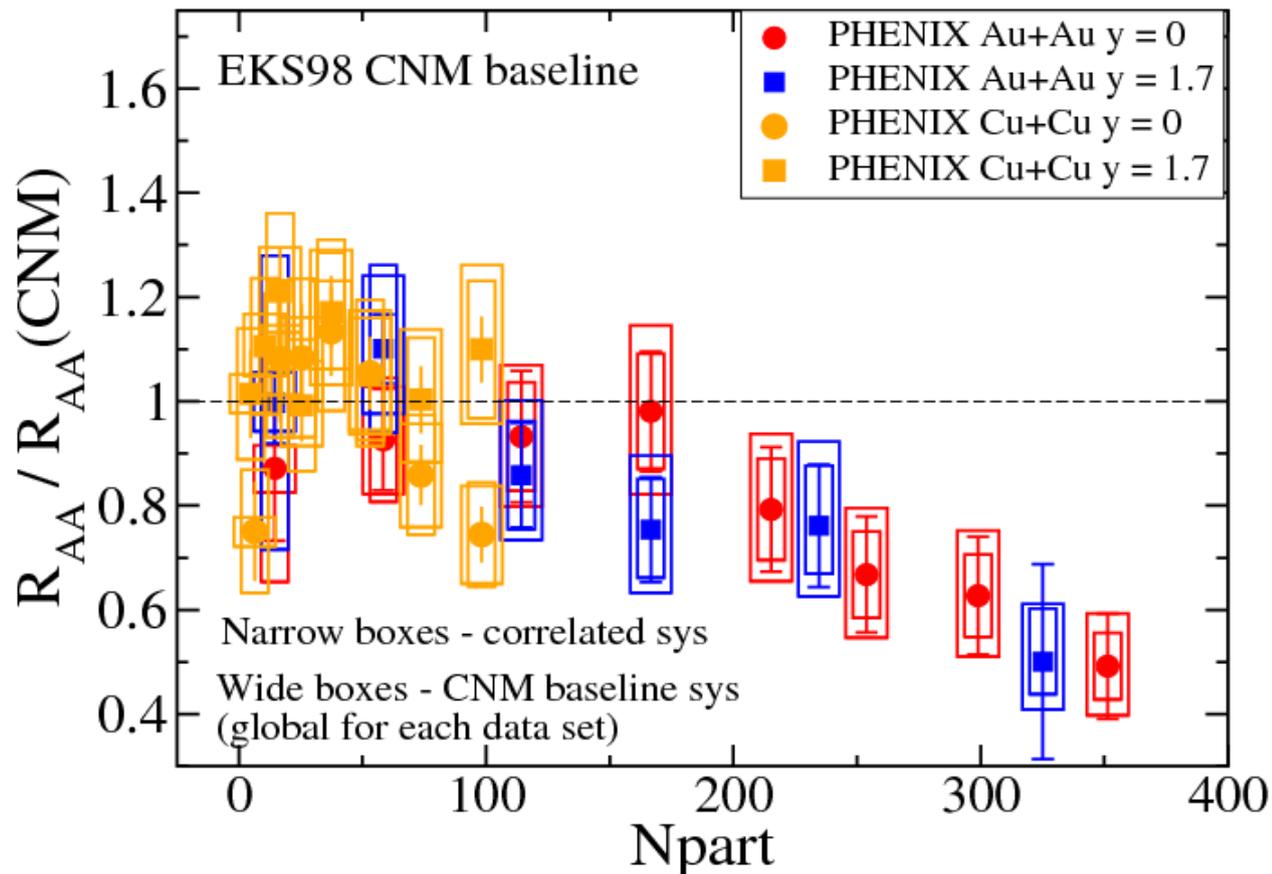


# Can CNM Explain Observed Suppression?

Not a Phenix result, uses Phenix preliminary (QM09)

Calculation by Tony Frawley

CNM with rapidity dependent effective breakup cross-section.

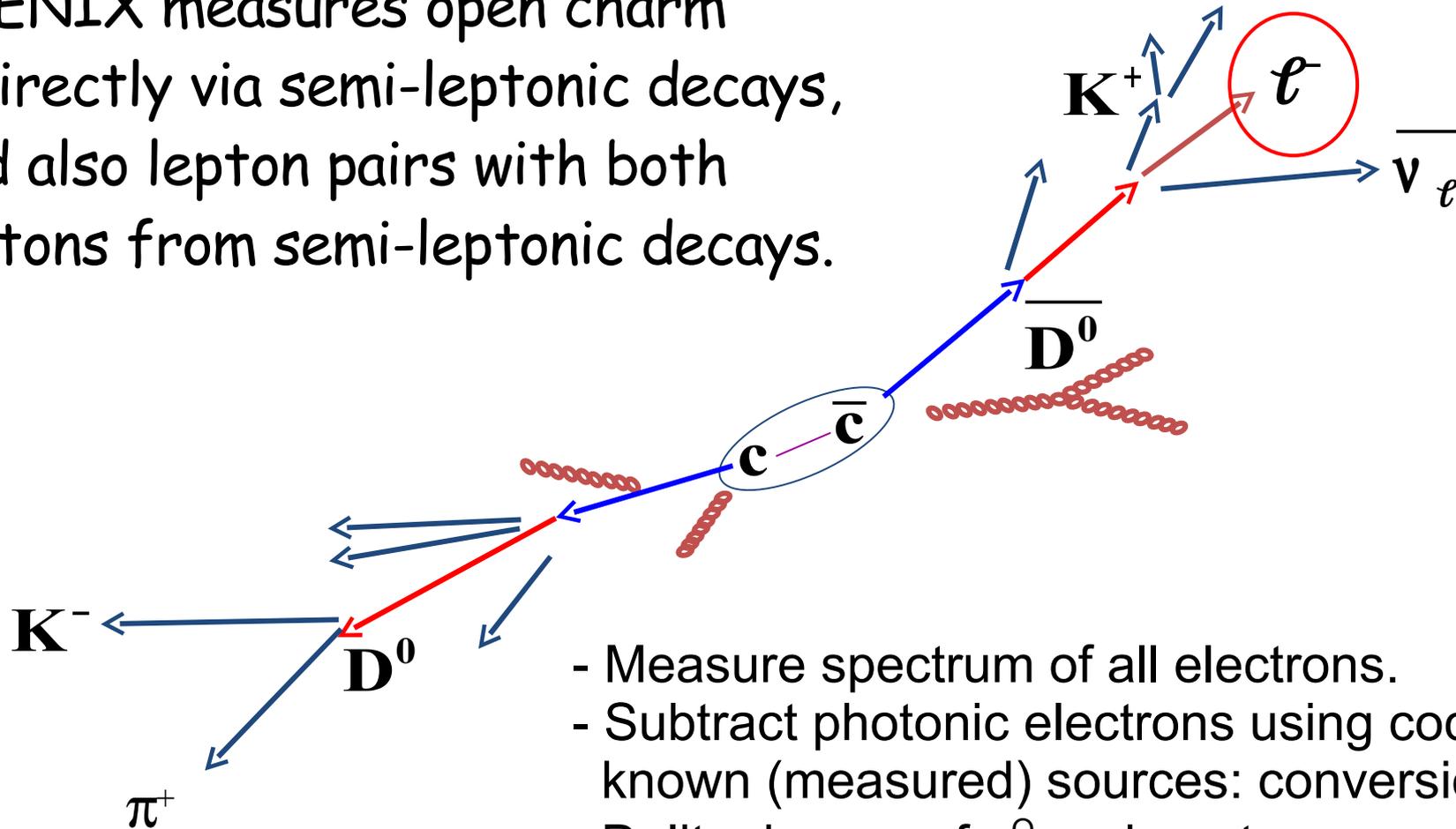


- Forward and central rapidity results become similar.
- Suppression beyond CNM in most central collisions.

# Open Charm

# Open Charm Measurement in PHENIX

PHENIX measures open charm indirectly via semi-leptonic decays, and also lepton pairs with both leptons from semi-leptonic decays.



- Measure spectrum of all electrons.
- Subtract photonic electrons using cocktail of known (measured) sources: conversions, Dalitz decays of  $\pi^0$  and  $\eta$ , etc.
- Additional subtraction of quarkonia contribution.
- Cross-check of photonic contribution by inserting converter.

# Heavy Flavor Electrons in p+p

Good agreement with FONLL

Charm dominates low  $p_T$  region and total cross-section.

Derived charm cross-section:

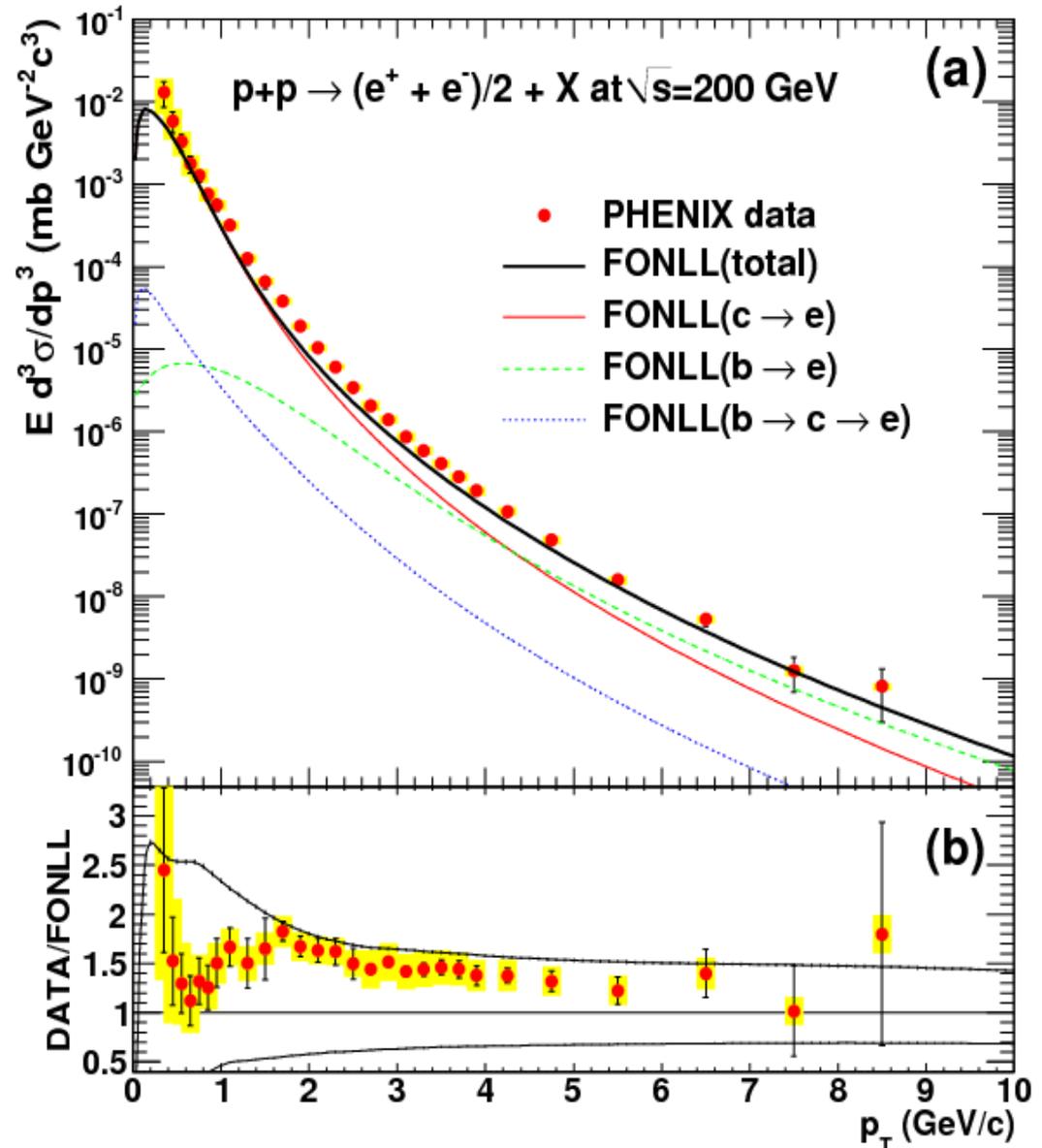
$$\sigma_{c\bar{c}} = 567 \pm 57(\text{stat}) \pm 224(\text{sys}) \mu\text{b}$$

*(PRL97 (2006) 252002)*

Beauty contribution separated using e-h correlations *(PRL 103 (2009) 082002)*

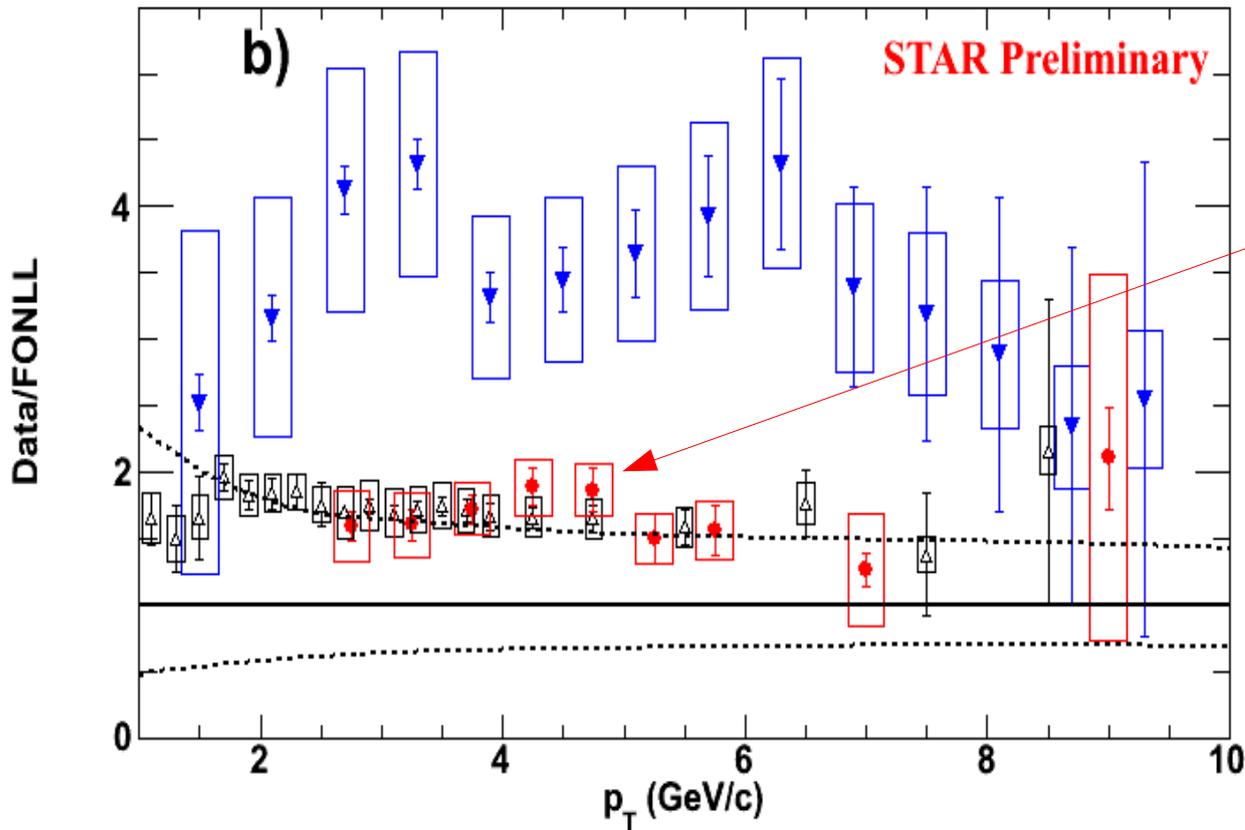
$$\sigma_{b\bar{b}} = 3.2^{+1.2}_{-1.1}(\text{stat})^{+1.4}_{-1.3}(\text{sys}) \mu\text{b}$$

Good baseline for Au+Au



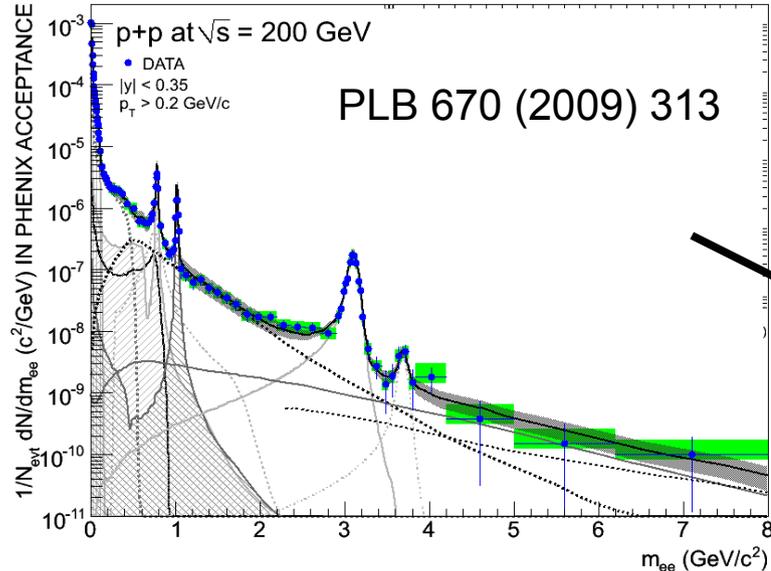
# PHENIX/STAR Disagreement Solved

From Wei Xie's talk at DIS-2010:

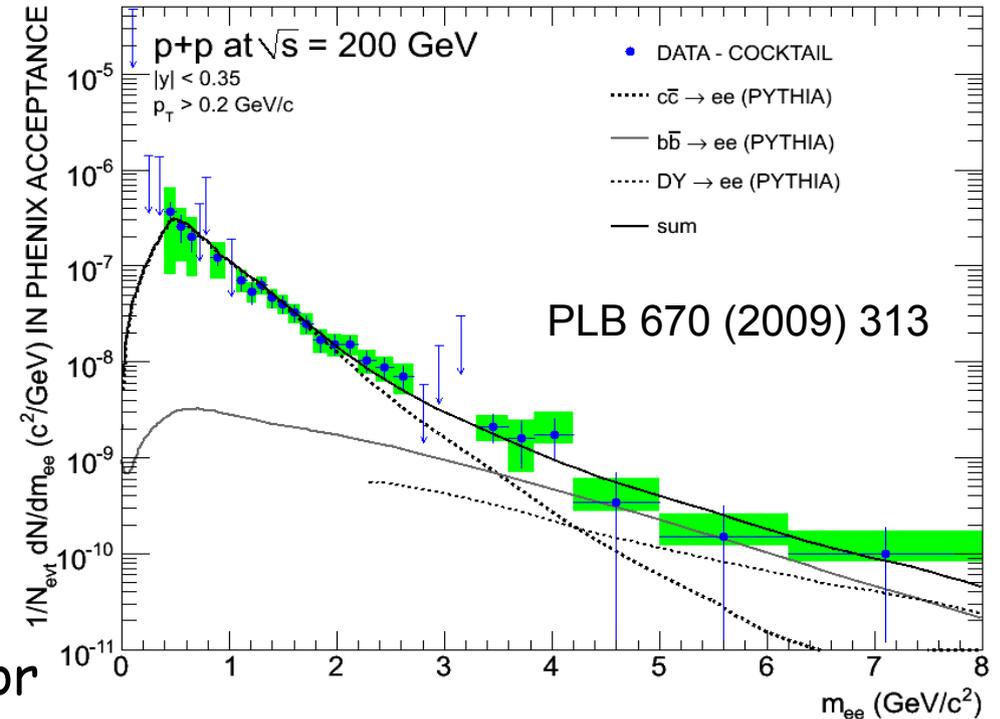


**New STAR preliminary**  
consistent with PHENIX  
result and FONLL

# Charm in p+p from di-electron spectra



After subtraction of all hadronic sources of di-electrons



- A different way to measure heavy flavor
- Agrees well with single electron results
- Charm/beauty separation is model (PYTHIA) dependent

$$\sigma_{c\bar{c}} = 518 \pm 47(\text{stat}) \pm 135(\text{sys}) \pm 190(\text{model}) \mu\text{b}$$

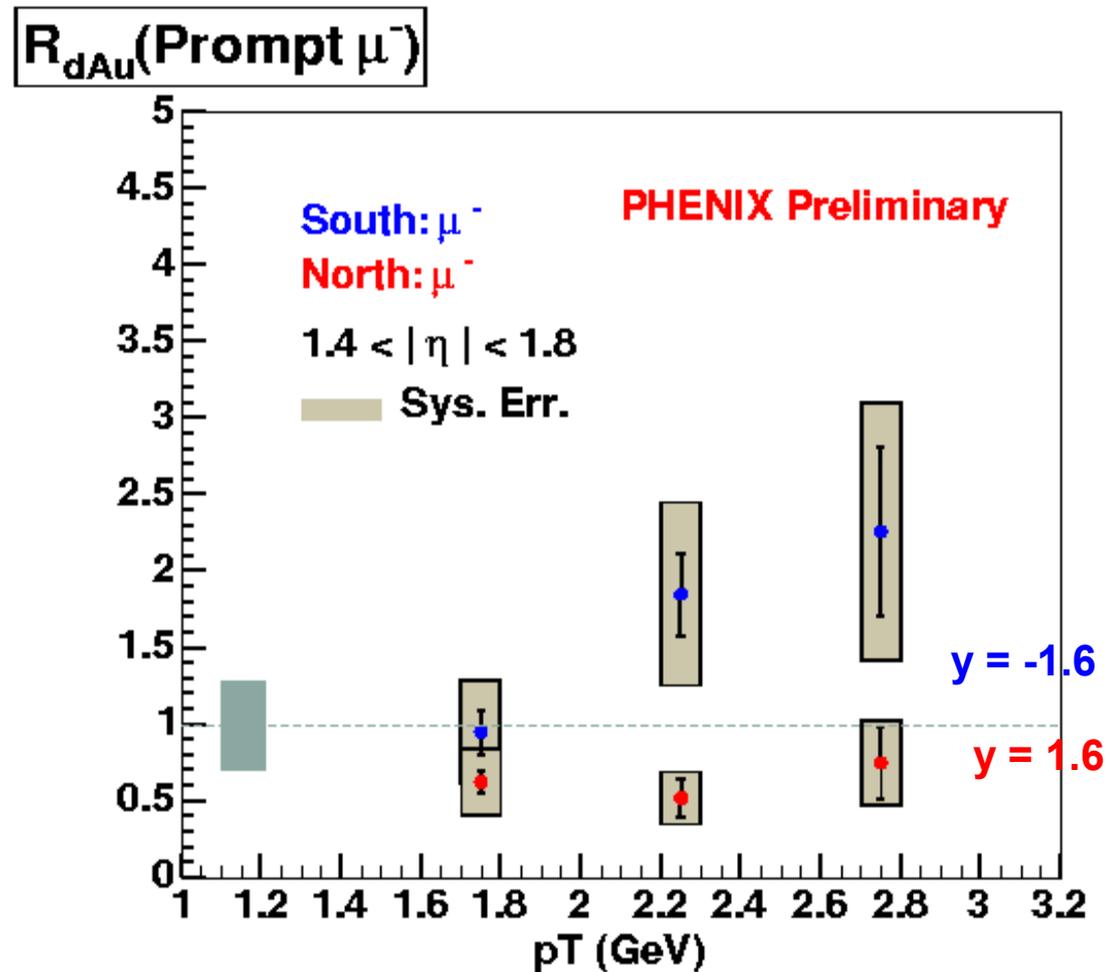
$$\sigma_{b\bar{b}} = 3.9 \pm 2.4 +3/-2 \mu\text{b}$$

(PLB 670 (2009) 313)

# CNM Effects from Open Charm?

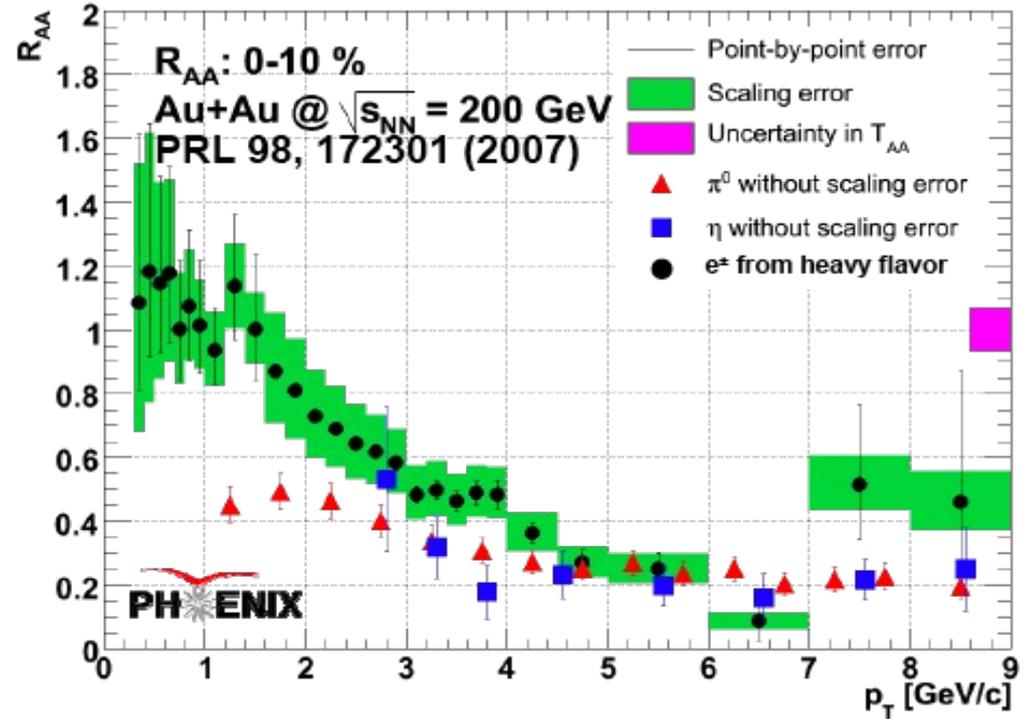
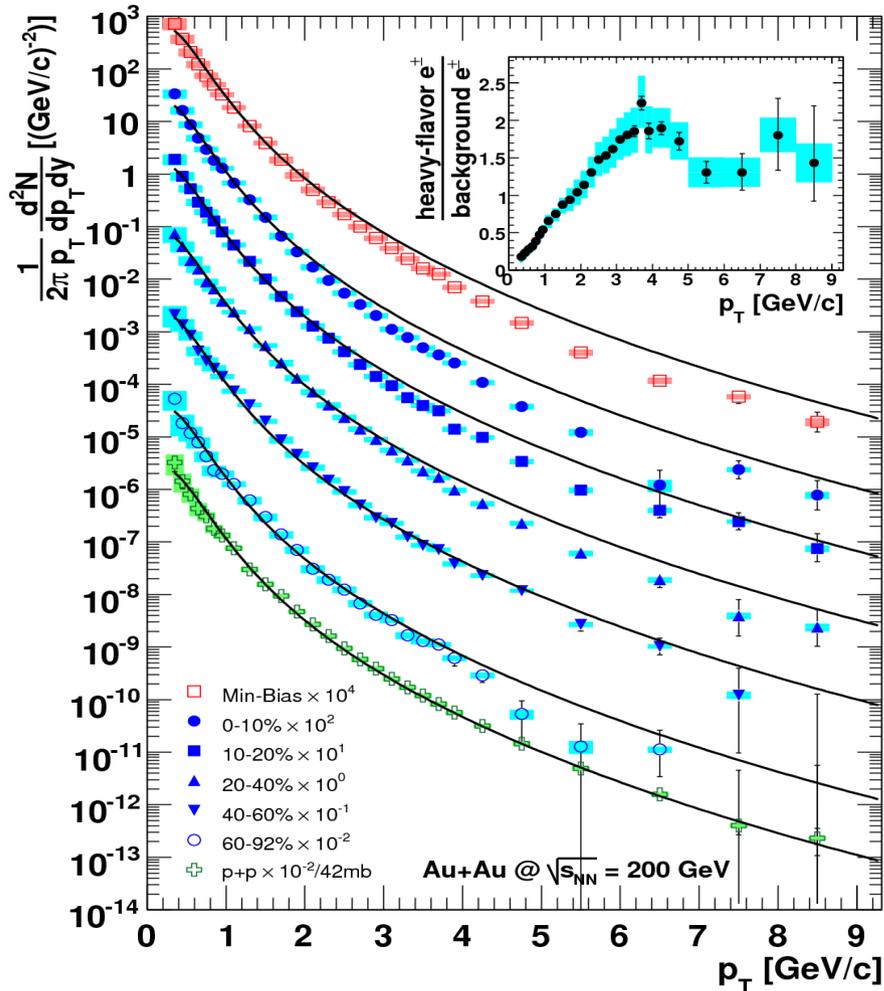
So far we have limited information about CNM from open charm

- Run3 d+Au single muon measurement
- 20% most central collisions
- Suppression at positive rapidity (deuteron direction)
- Enhancement at negative rapidity (Au direction)



# Open Heavy Flavor in Au+Au

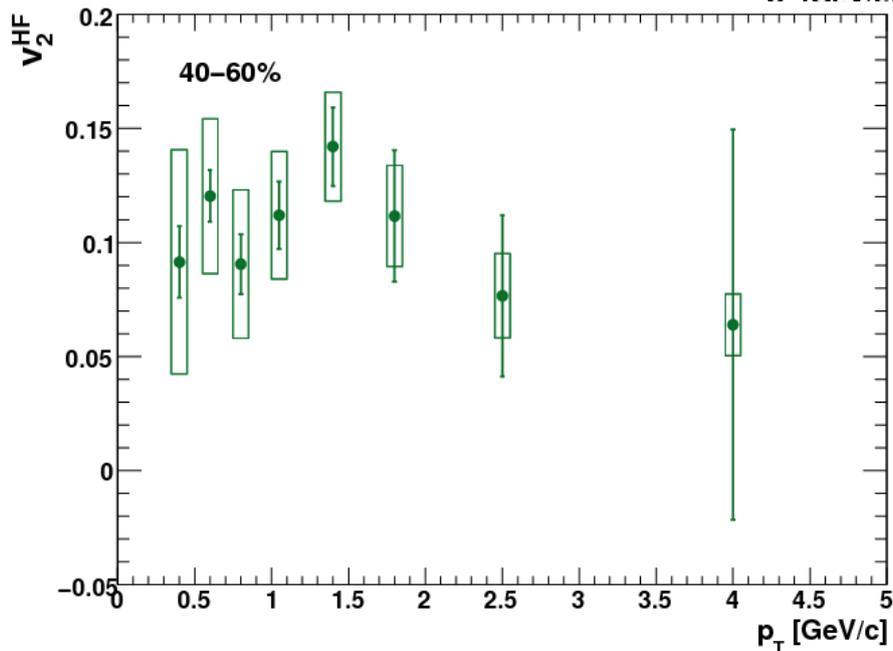
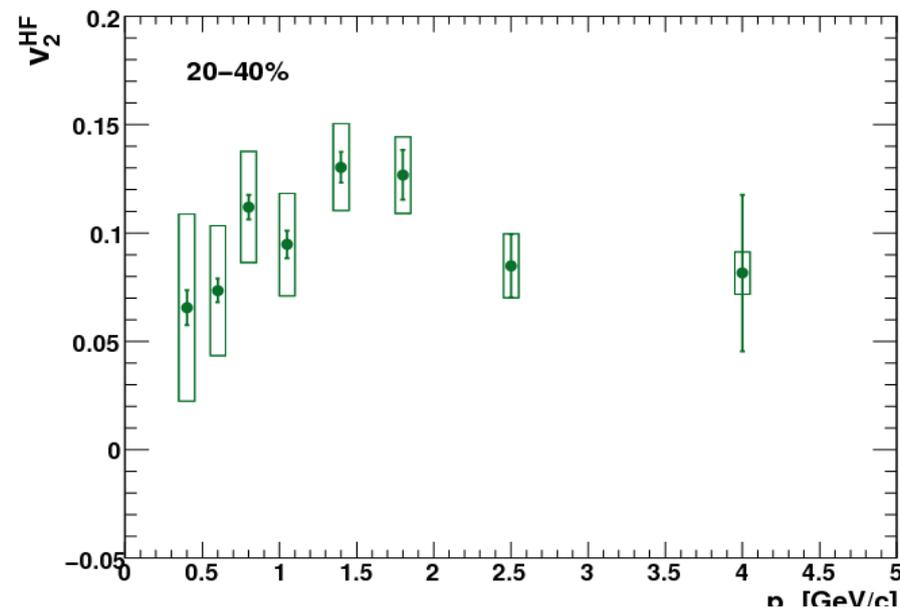
Heavy flavor electrons from Au+Au  
 compared to  $N_{\text{COLL}}$  scaled p+p  
 (FONLL x 1.71)



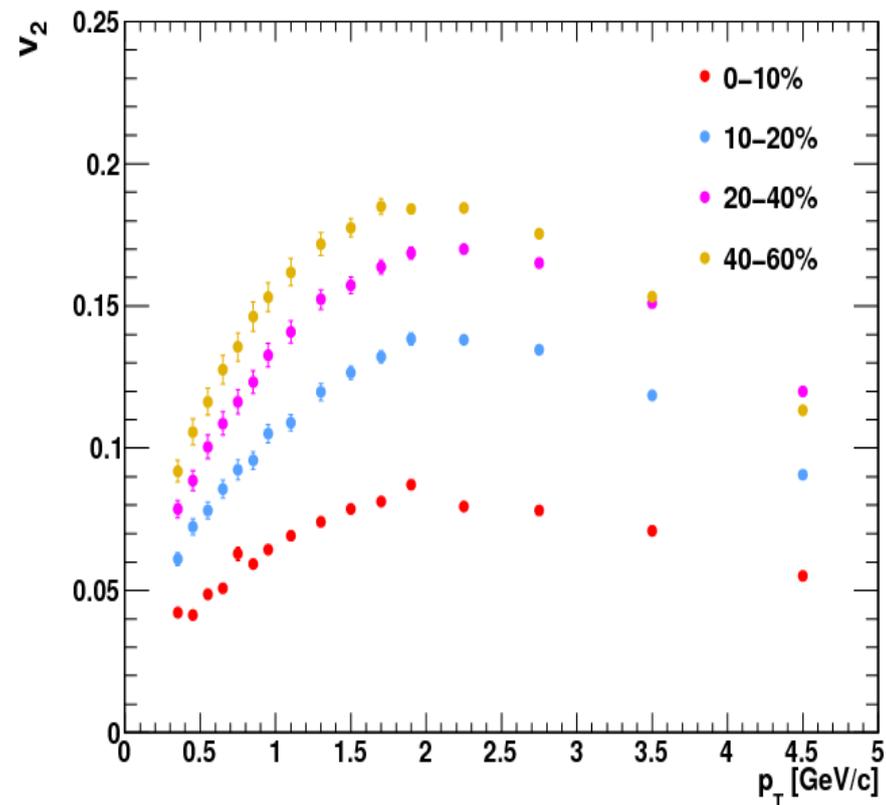
**Charm suppression is almost the same as for light quarks at high  $P_T$ !**

# Open Heavy Flavor Flow

## HF electrons flow



## Photonic electrons flow



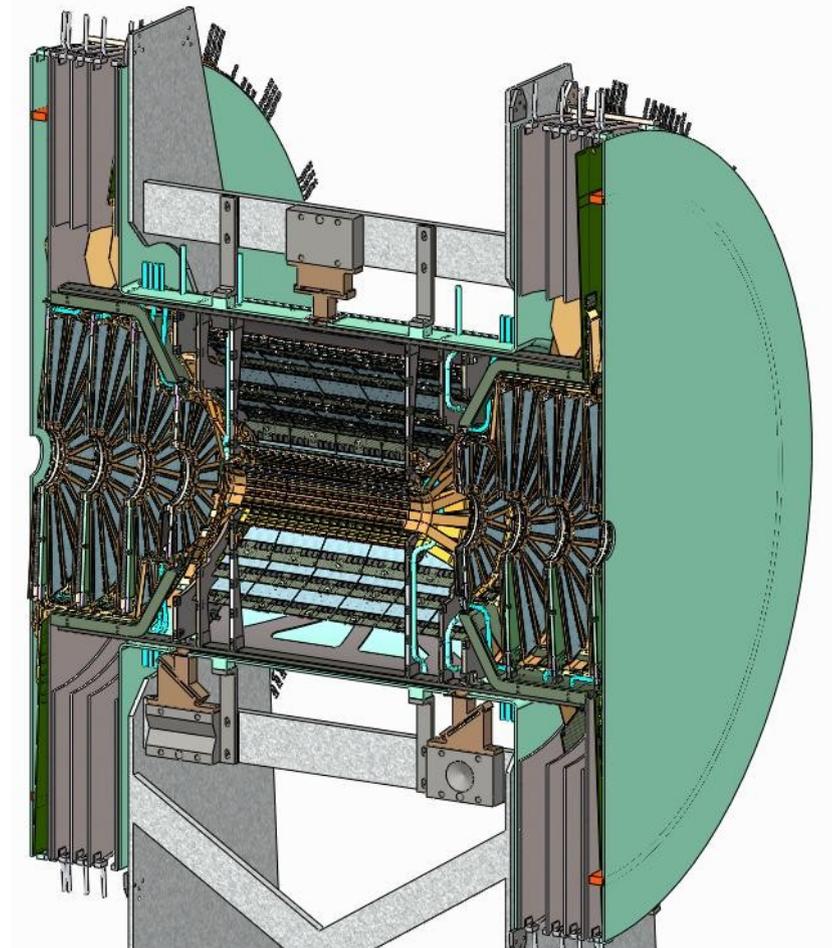
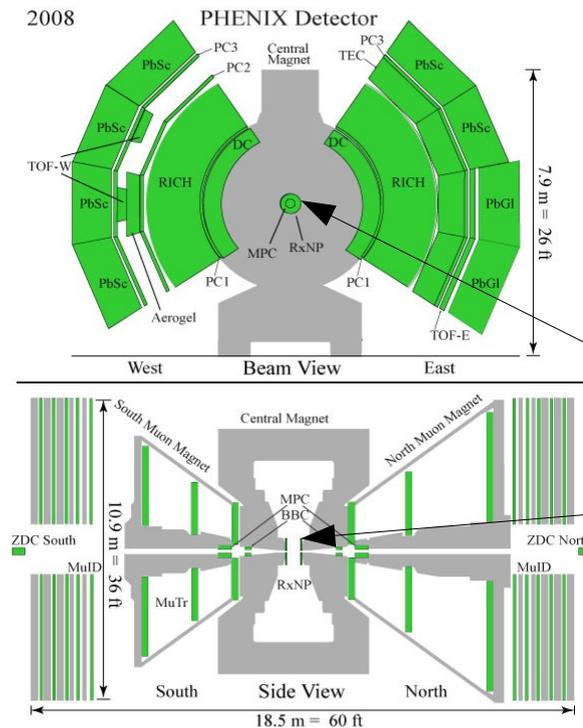
arXiv:1005.1627

Submitted today to PRC

**Heavy flavor (charm) flow is comparable to that of light quarks!**

# Future Upgrades

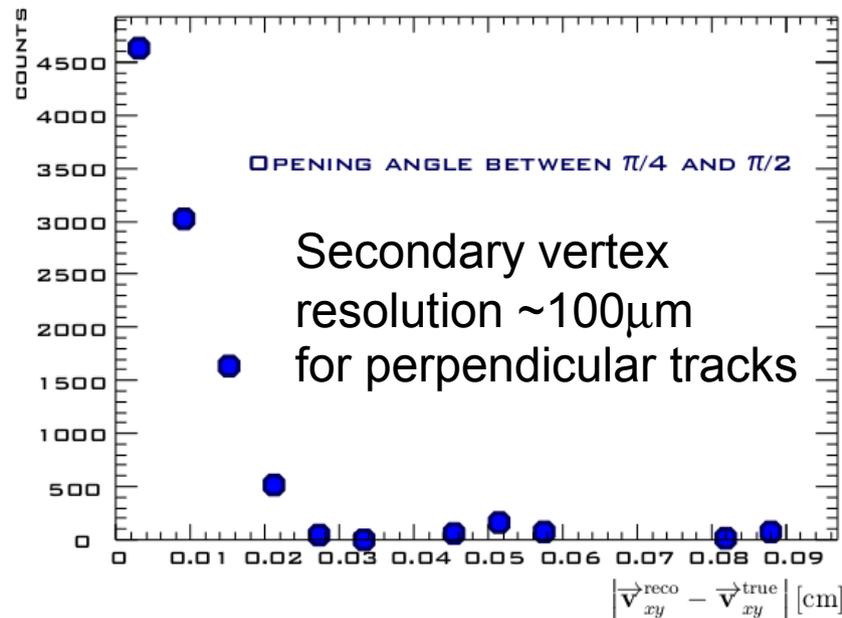
## Silicon vertex detector (VTX/FVTX)



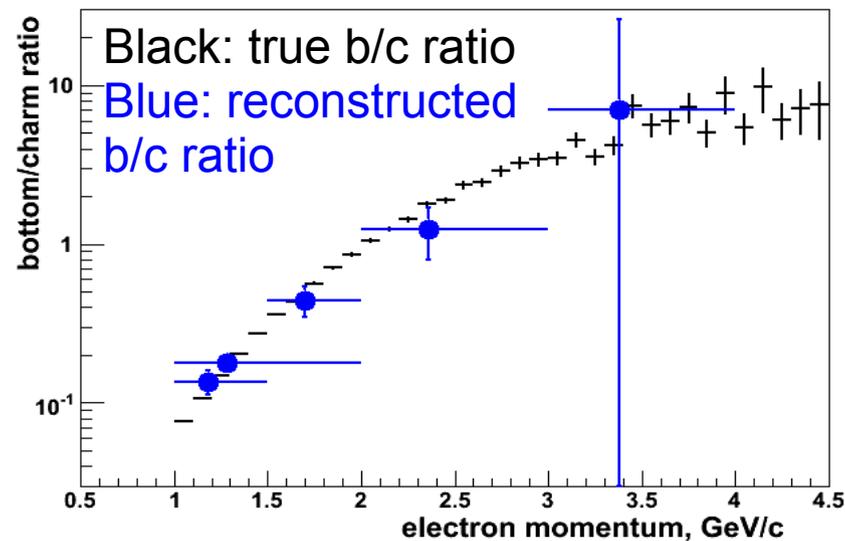
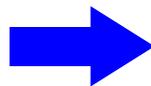
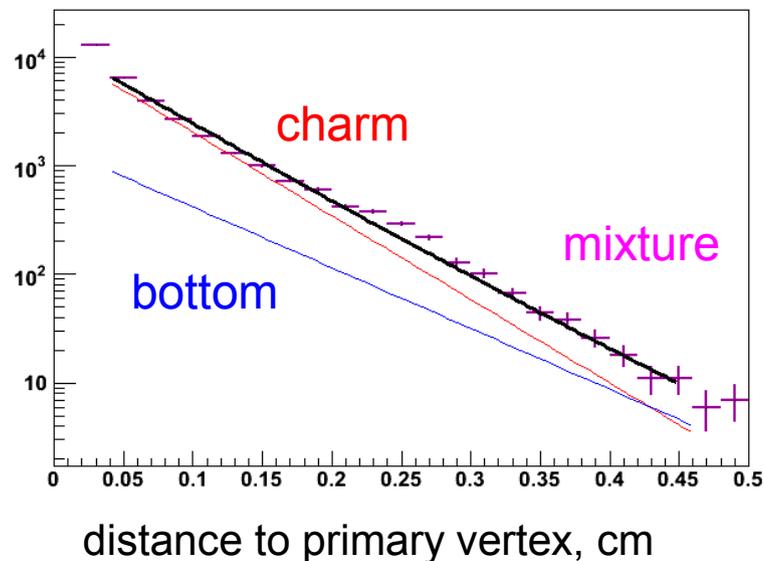
- Barrel (VTX) covering two units of  $\eta$  at mid-rapidity, 4 layers of silicon pixels and strips. To be installed this year.
- Endcaps, covering Muon Arms, to be installed next year.
- Allows accurate secondary vertex reconstruction.

# Future Measurements

- Direct charm measurements in  $D^0 \rightarrow Kp$  channel,
- Direct bottom measurement via  $B \rightarrow J/\psi$



Simulation of open charm/bottom separation using DCA



# Conclusions

- PHENIX has excellent capability to study open charm and charmonium in p+p, p+A, and A+A collisions.
- CNM effects can not be understood in terms of just shadowing and breakup.
- Indication of  $J/\psi$  suppression in most central Au+Au collisions beyond CNM effects.
- Open charm suppression and flow in Au+Au is similar to that of light quarks.
- More results with new PHENIX detector upgrades!