Latest Heavy Flavor Results from the PHENIX Experiment at RHIC

Alexandre Lebedev (Iowa State University)

for the PHENIX Collaboration

32nd Winter Workshop on Nuclear Dynamics – WWND2016

In this talk…

ψ'/ J/ψ ratios in p+Au and p+Al at forward/backward rapidity

J/ψ suppression in U+U

$b\bar{b}$ production in p+p

at $\sqrt{s}$ = 200 GeV at mid-rapidity via opposite sign electron pairs.

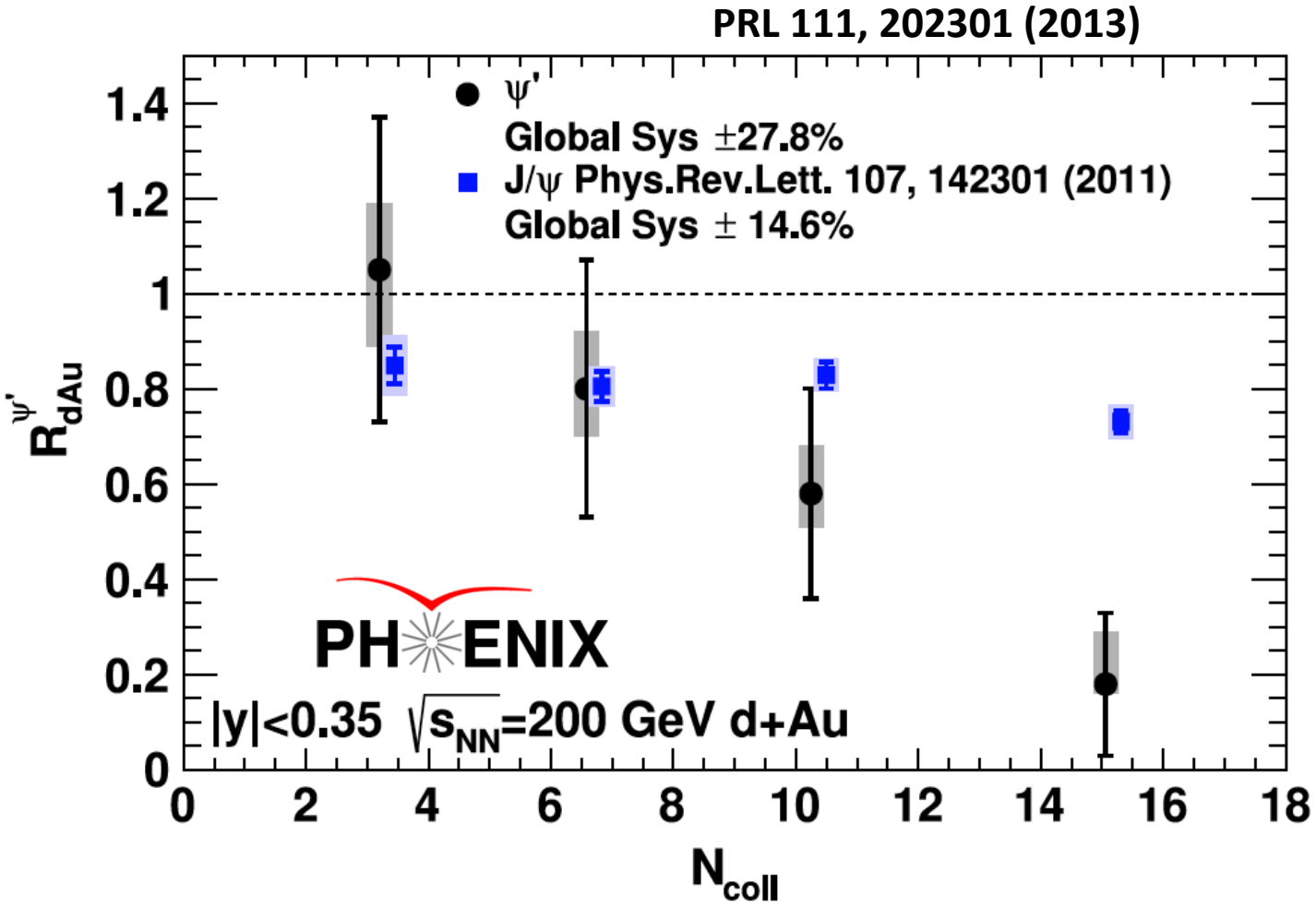
at $\sqrt{s}$ = 510 GeV at forward/backward rapidity via same sign muons.

(brief mention) Single electrons at mid-rapidity

See Takashi Hachiya's talk later today for details.

ψ' at forward rapidity

Existing ψ' measurement in d+Au at mid-rapidity

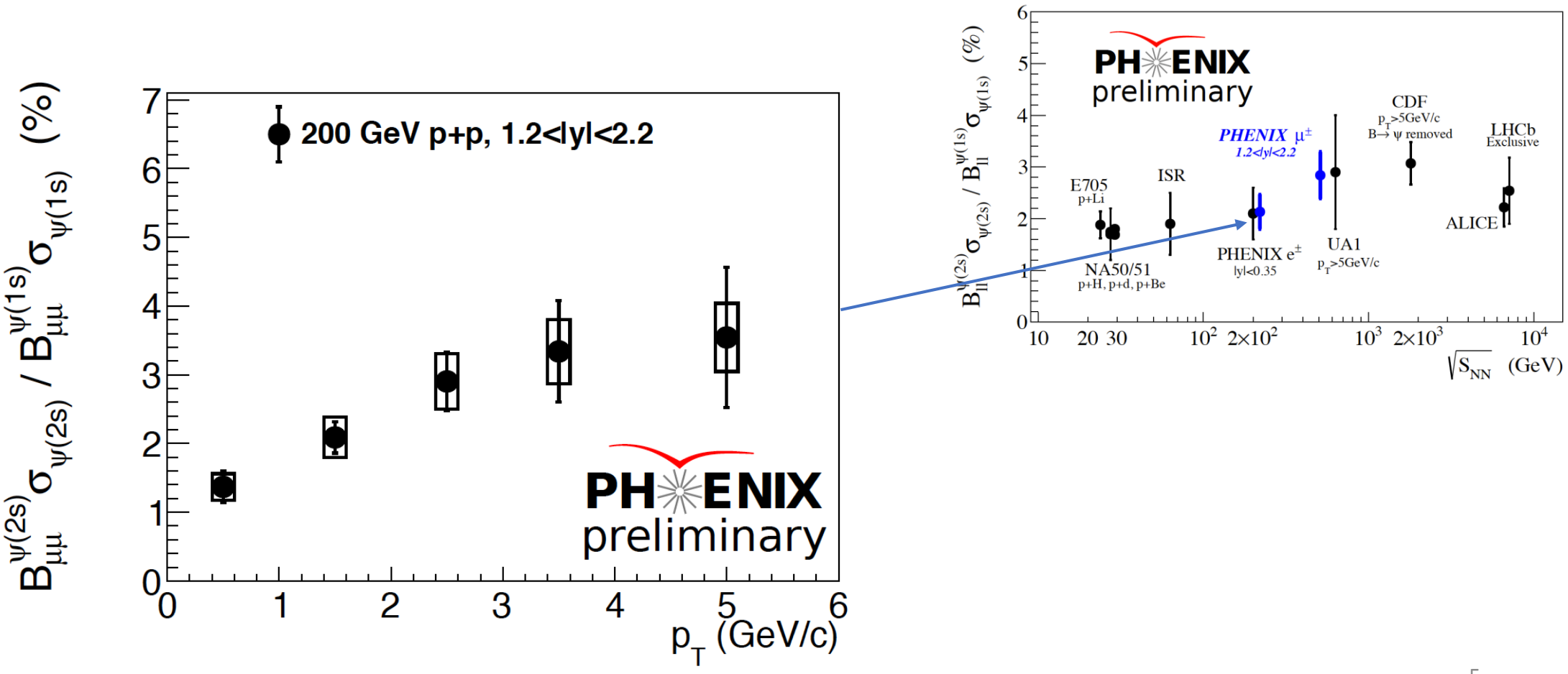


Different trend and magnitude of suppression with increasing centrality for ψ' and J/ψ.

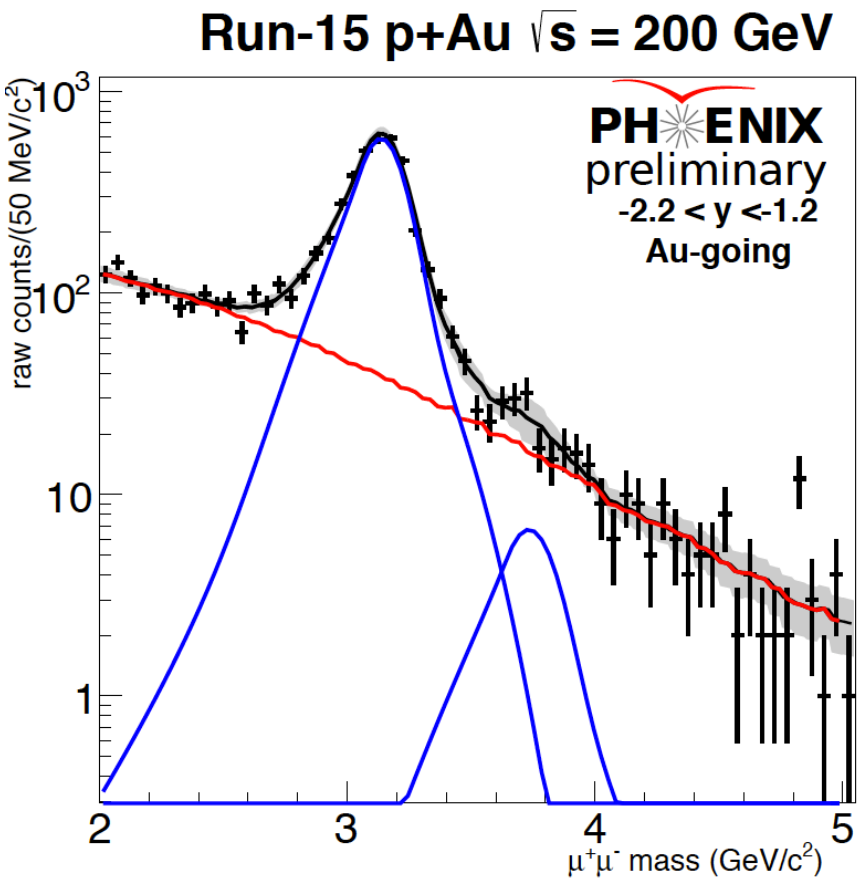
Shadowing, energy loss, etc. for $c\bar{c}$ precursor pairs in nucleus are very similar – something must happen at later stages.

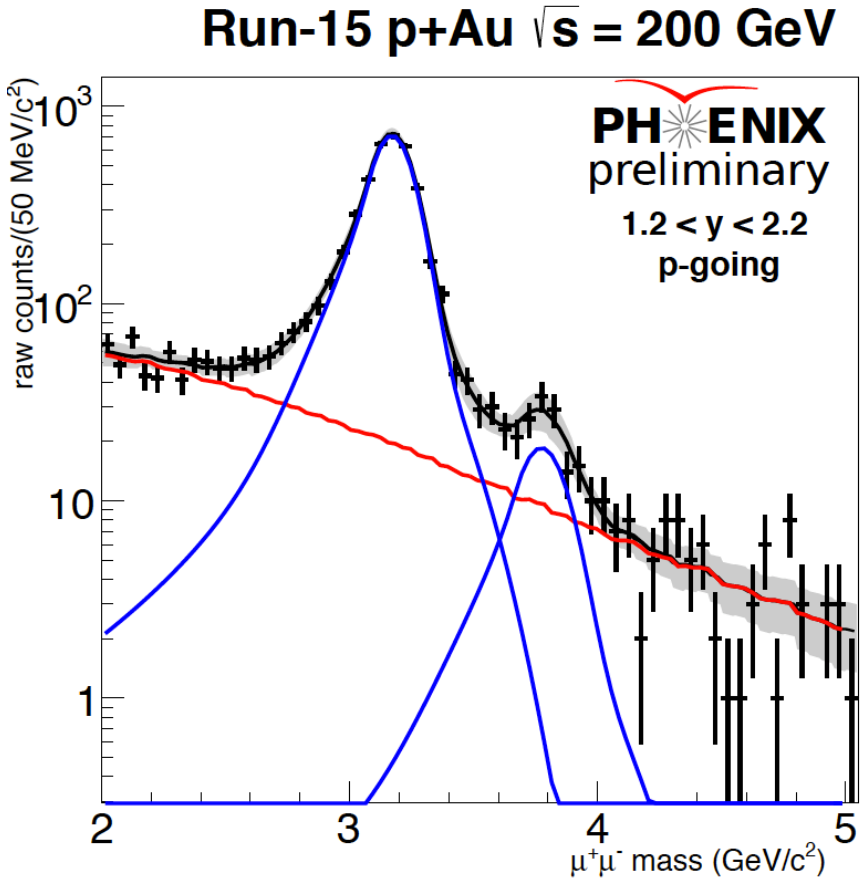
ψ’ measurement in p+p at forward rapidity

Baseline for suppression measurement in p+Au and p+Al



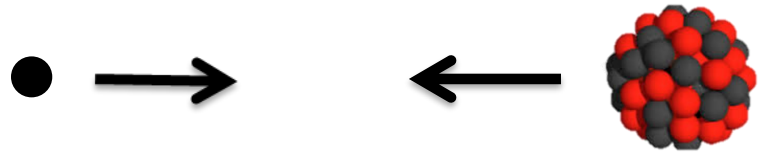
Di-muon mass in p+Au at forward rapidity

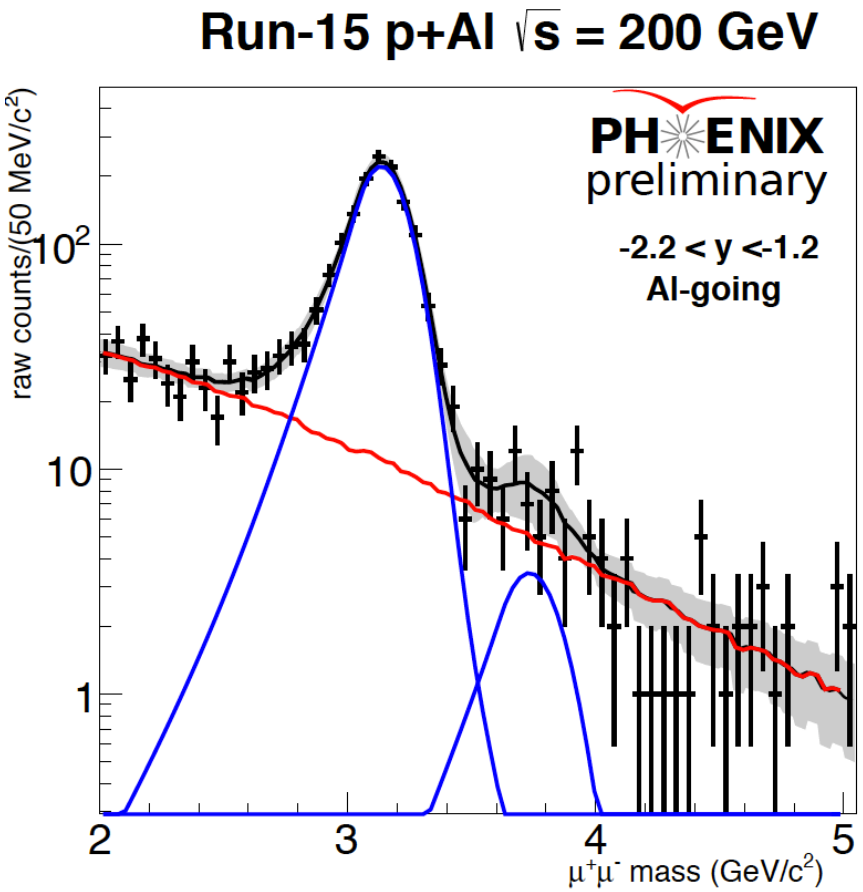


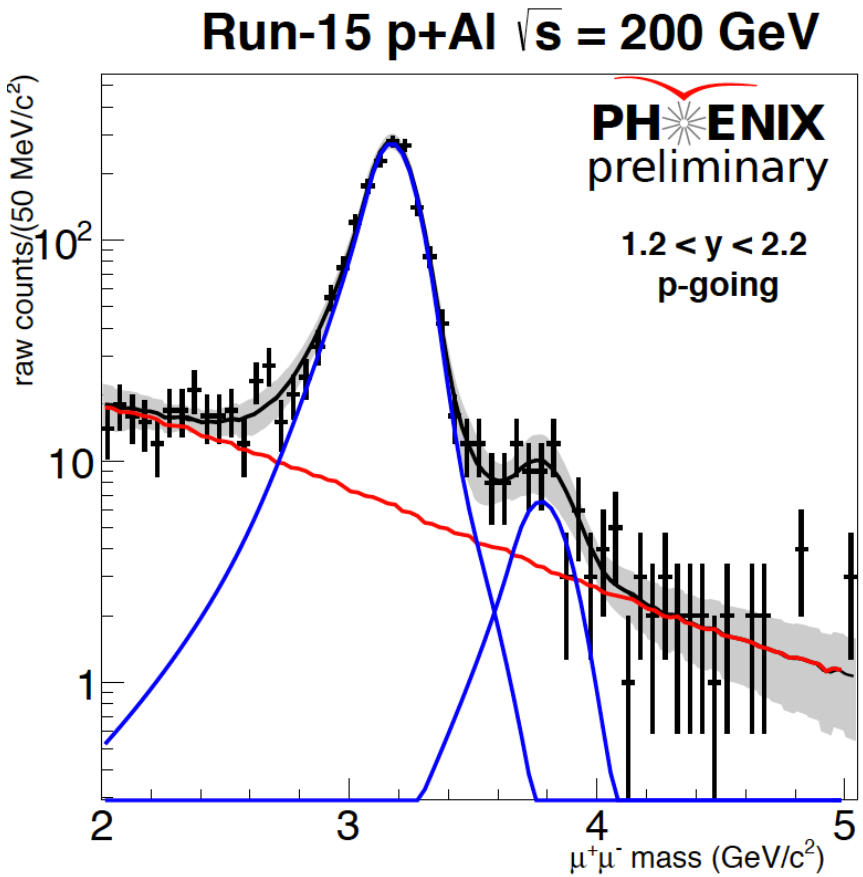


Clearly seen suppression in Au-going direction.

Di-muon mass in p+Al at forward rapidity

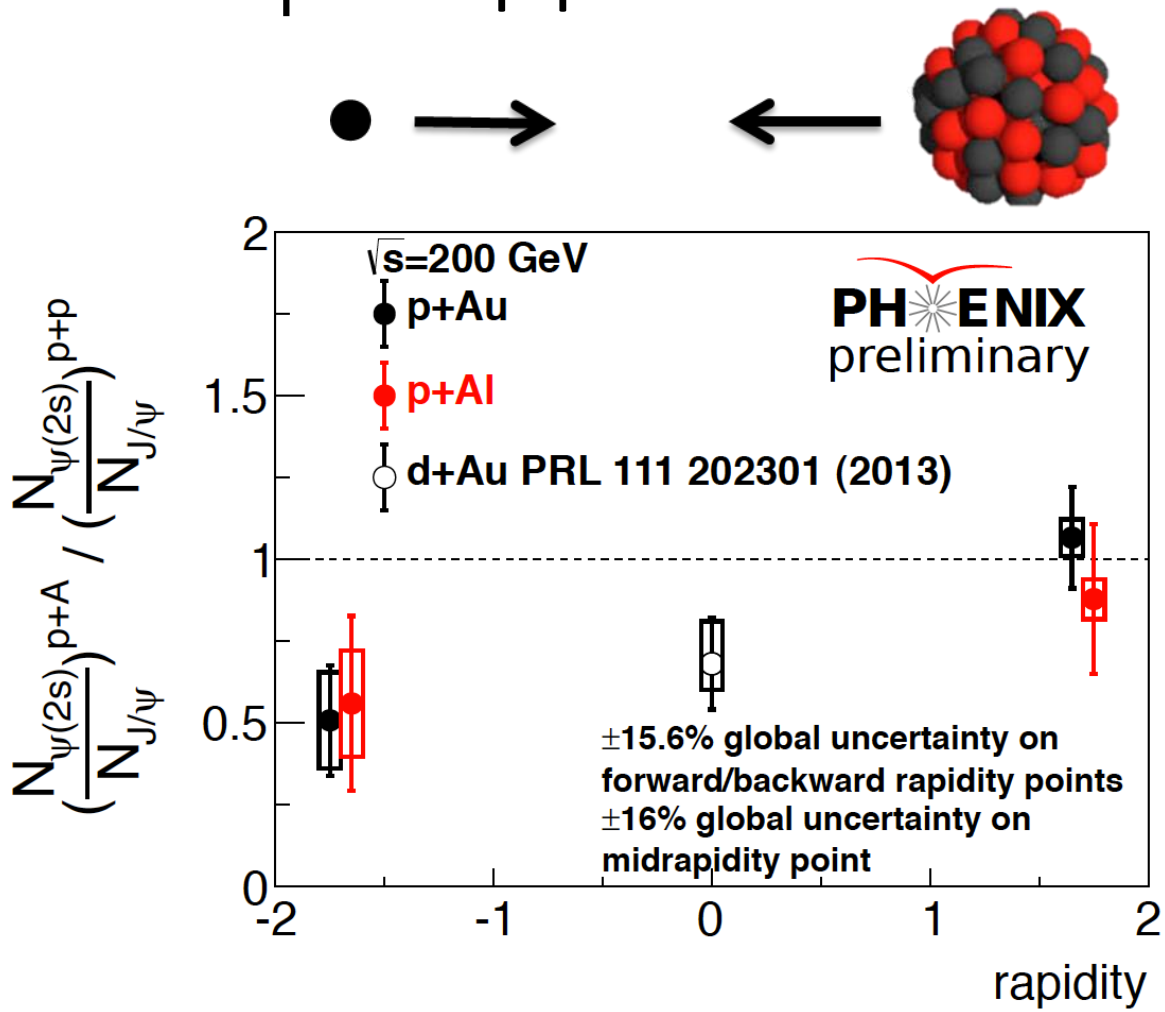






Similar observation in p+Al.

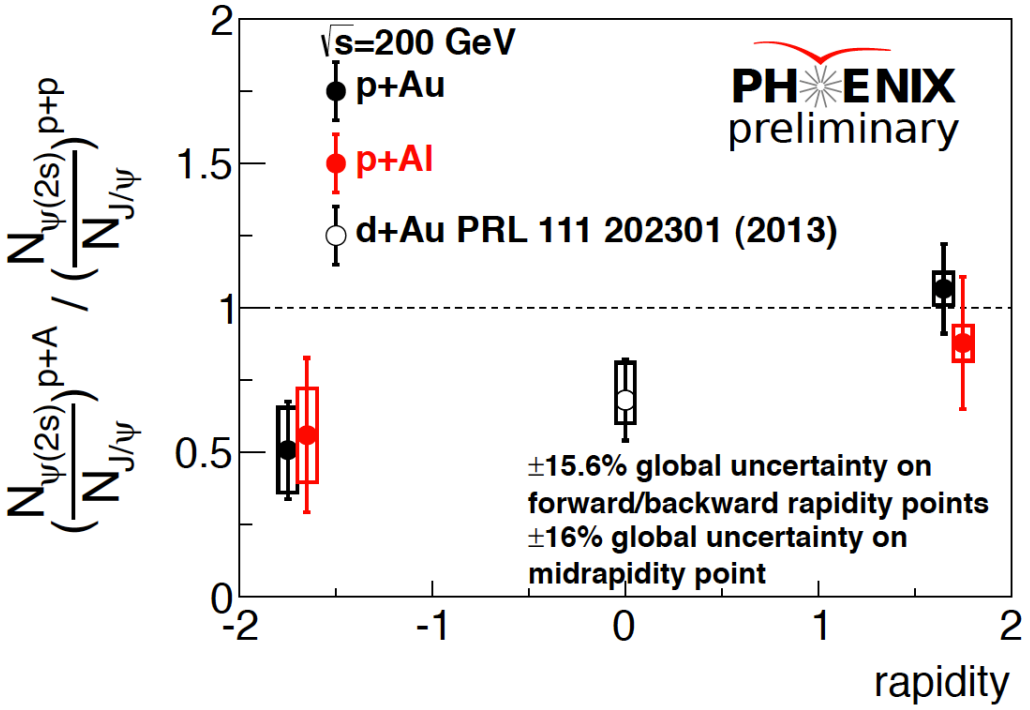
Relative ψ' suppression vs. rapidity

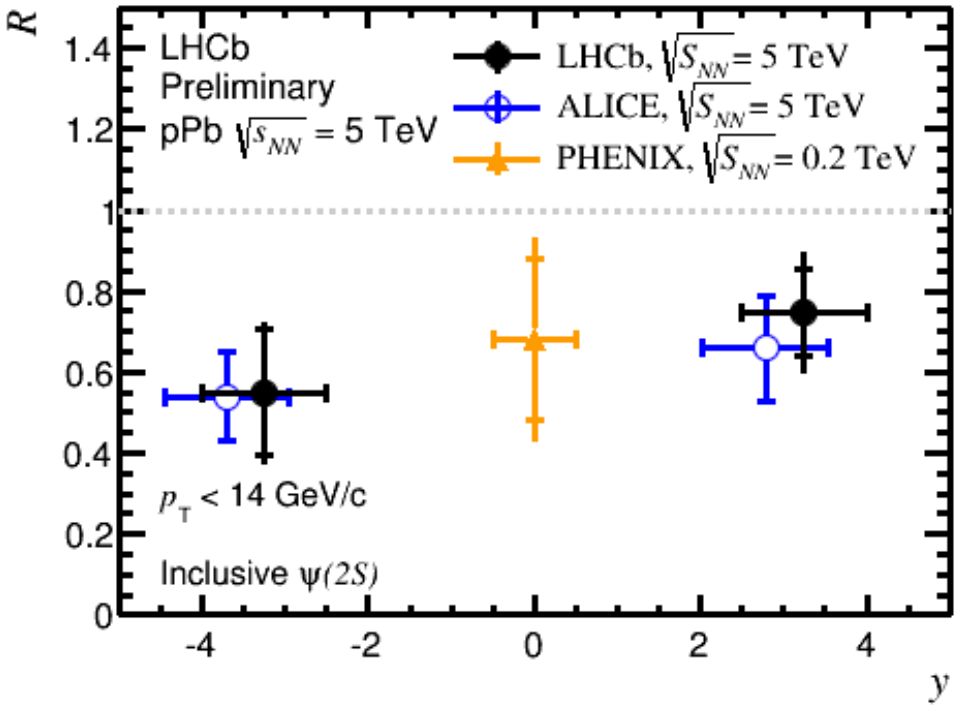


Strong relative suppression in Au-going direction, no difference in p-going direction.

ψ' are strongly suppressed in both directions, while J/ψ are strongly suppressed in p-going direction and moderately in Au-going direction.

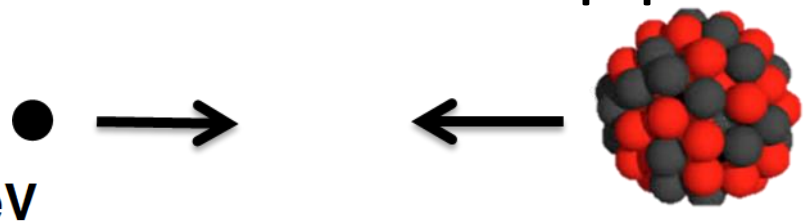
Comparison with LHC

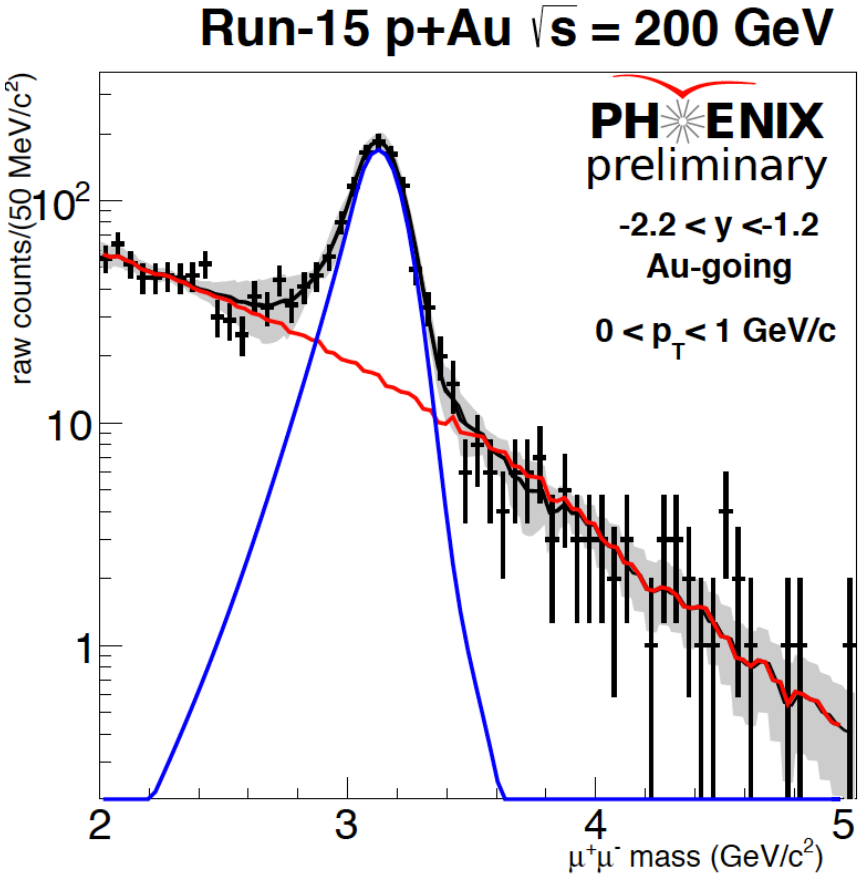


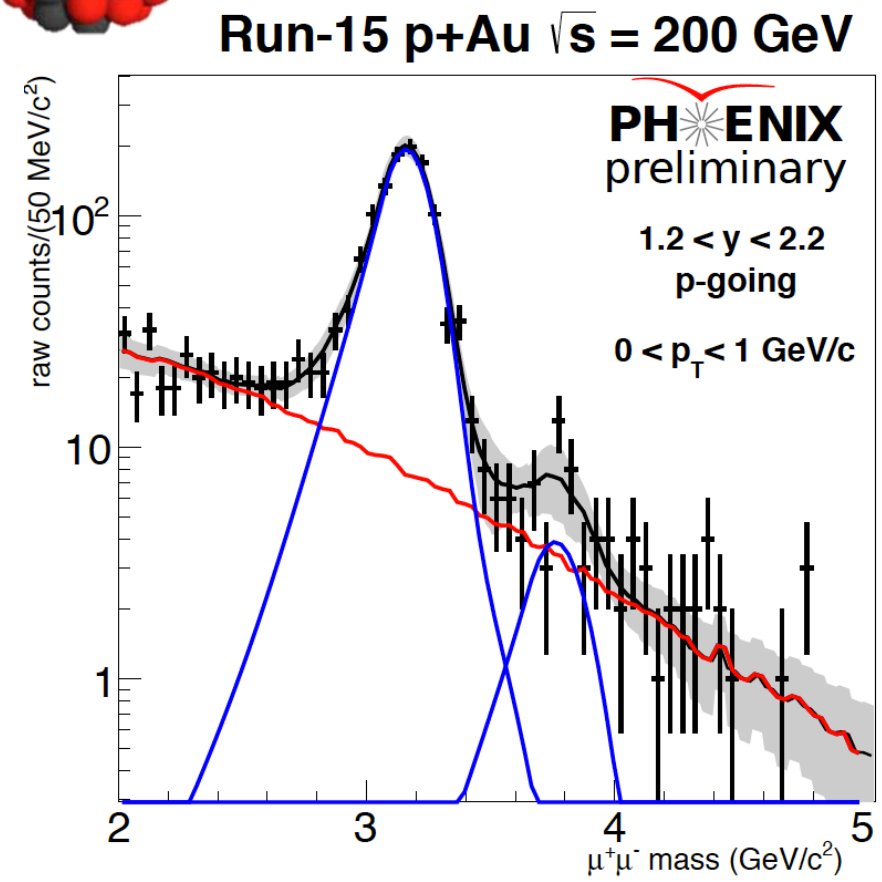


While relative suppression in heavy-ion-going direction is similar at RHIC and LHC, in p-going direction at LHC there is also rather strong suppression.
This difference in p-going direction is within experimental uncertainty.
A hint that co-movers or breakup in nucleus are unlikely explanation at LHC?

p_T dependence of relative suppression (p_T<1GeV/c)

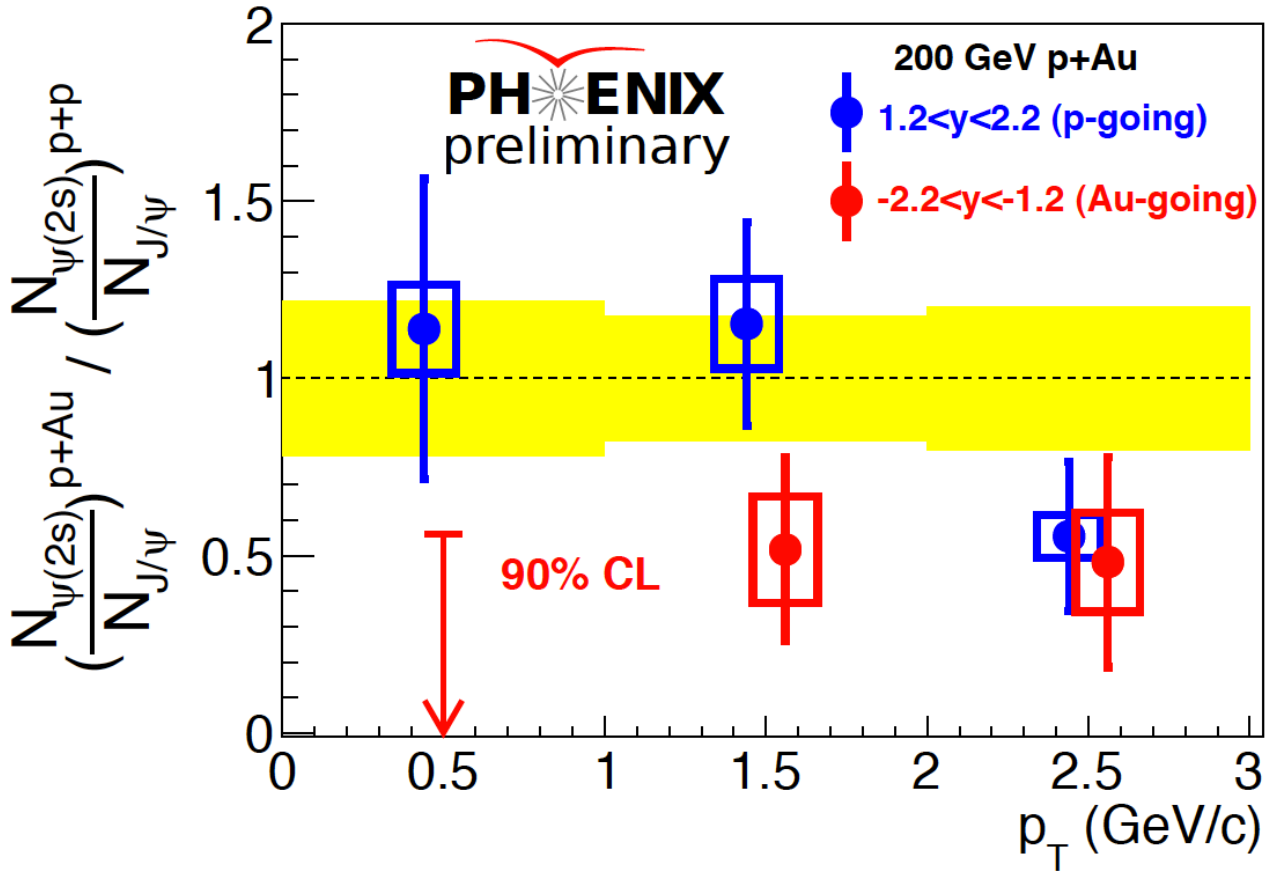






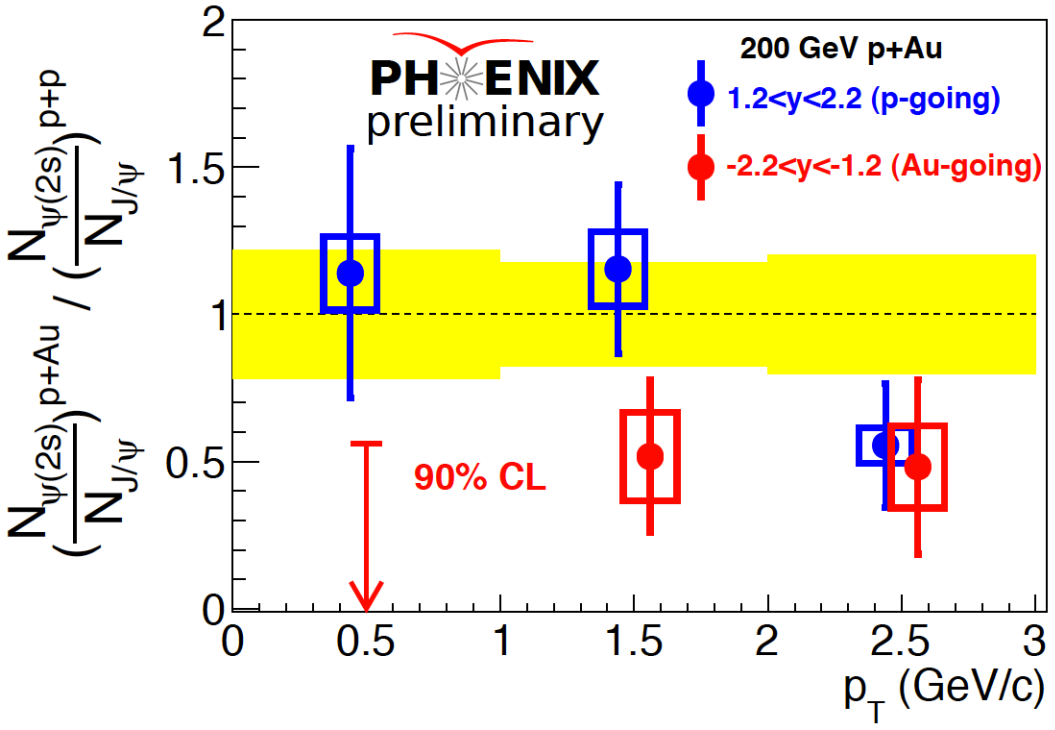
At low p_T ψ's are gone in Au going direction.

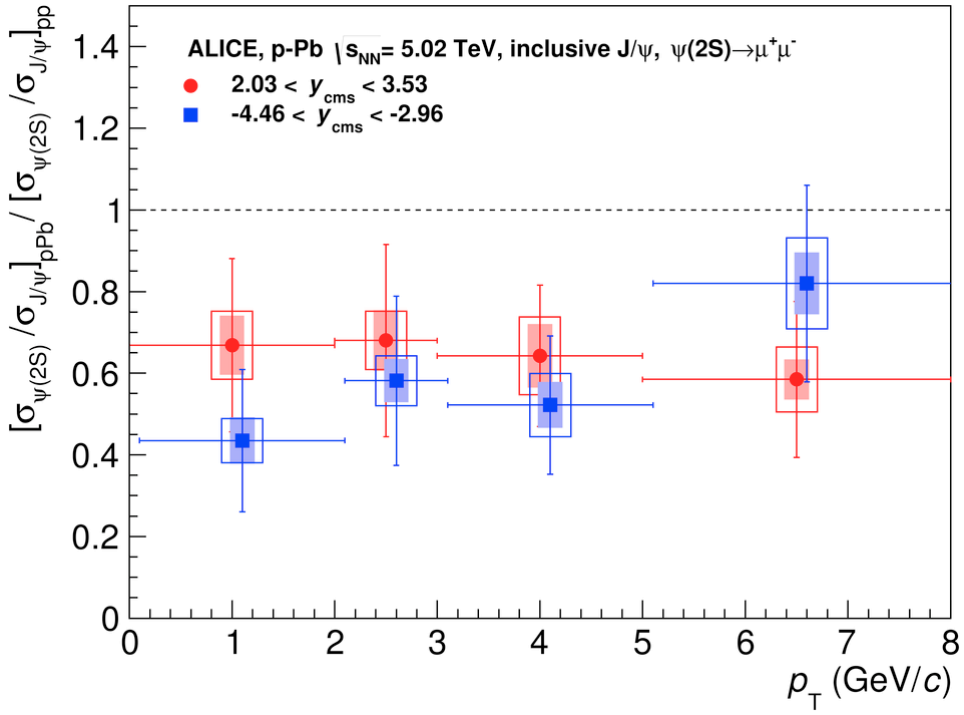
p_T dependence of relative suppression



Slowest ψ's (spend most time with soft co-movers) are gone!

Comparison with LHC





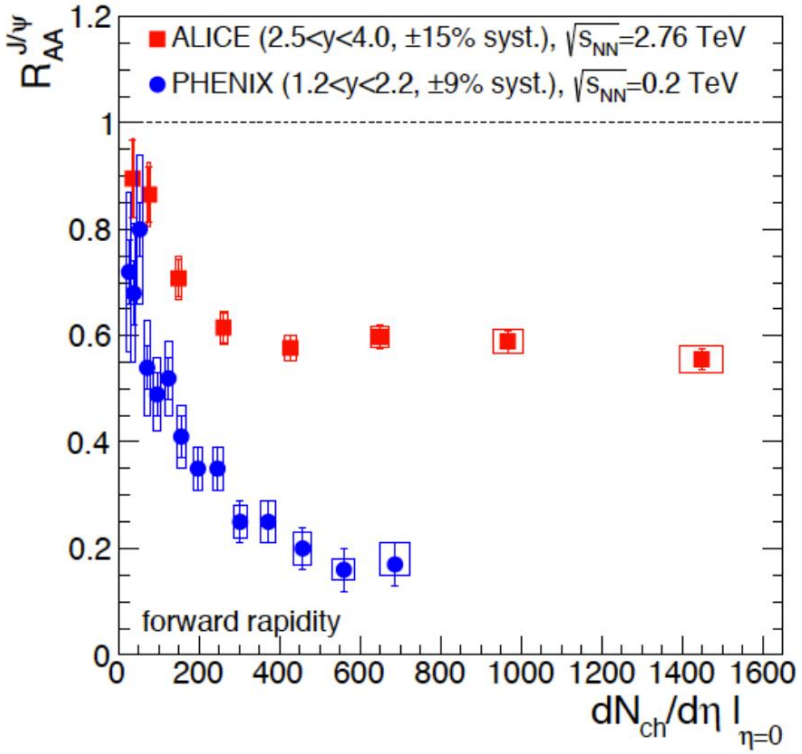
Again, little difference between forward/backward at LHC.

And again, although the plots look qualitatively different, the difference is within experimental uncertainty.

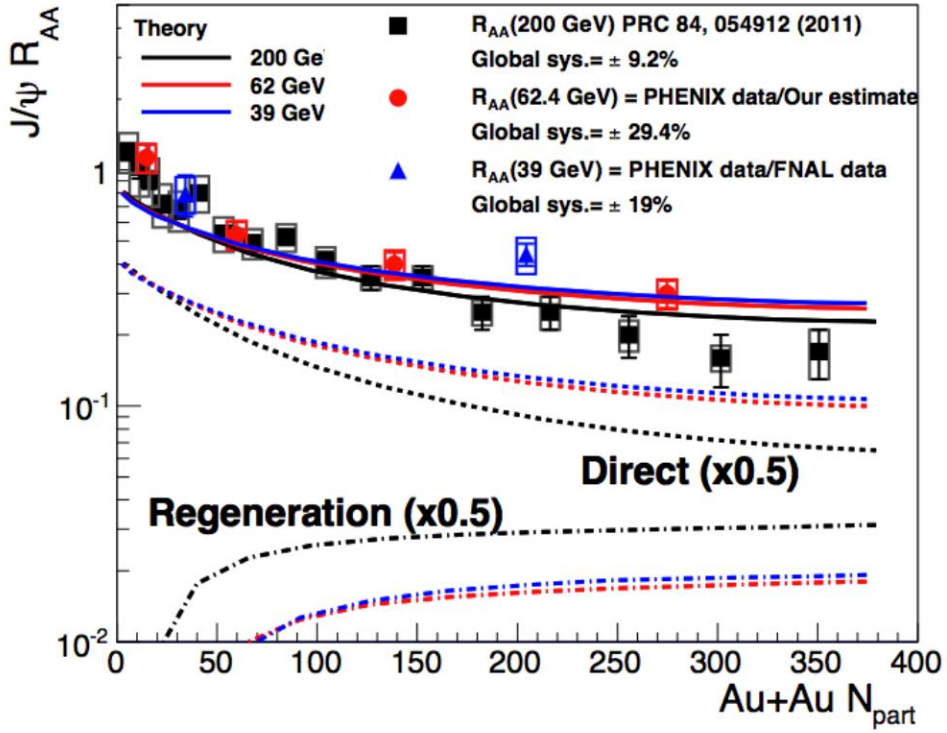
Could this imply that co-mover breakup is not the dominant effect at LHC energies?

J/ψ in U+U

When does coalescence becomes important?



J/ψ suppression much stronger at 200 GeV (RHIC) than 2.76 TeV (LHC) for similar energy density – strong coalescence.



At RHIC 39 GeV, 62 GeV, 200 GeV all show similar suppression, perhaps strongest at 200 GeV. *PRC82, (2010) 064905* explains this as a balance between color screening and coalescence.

U+U at RHIC

U+U collisions allow us to go to higher energy density at RHIC
Central U+U collisions should have:

- 15-20% higher energy density than Au+Au collisions: stronger color screening
- Increased charm production from ~ 25% larger N_{coll} values: stronger coalescence

N_{coll} calculation for U+U is complicated by uranium nucleus deformation

Two shapes:
Set 1 (Phys. Lett. B 679, 440 (2009)) - "conventional" description of the U deformation

- The mean radius and diffuseness are taken from electron scattering

Set 2 (Phys. Lett. B 749, 215 (2015)) differs in 2 ways:

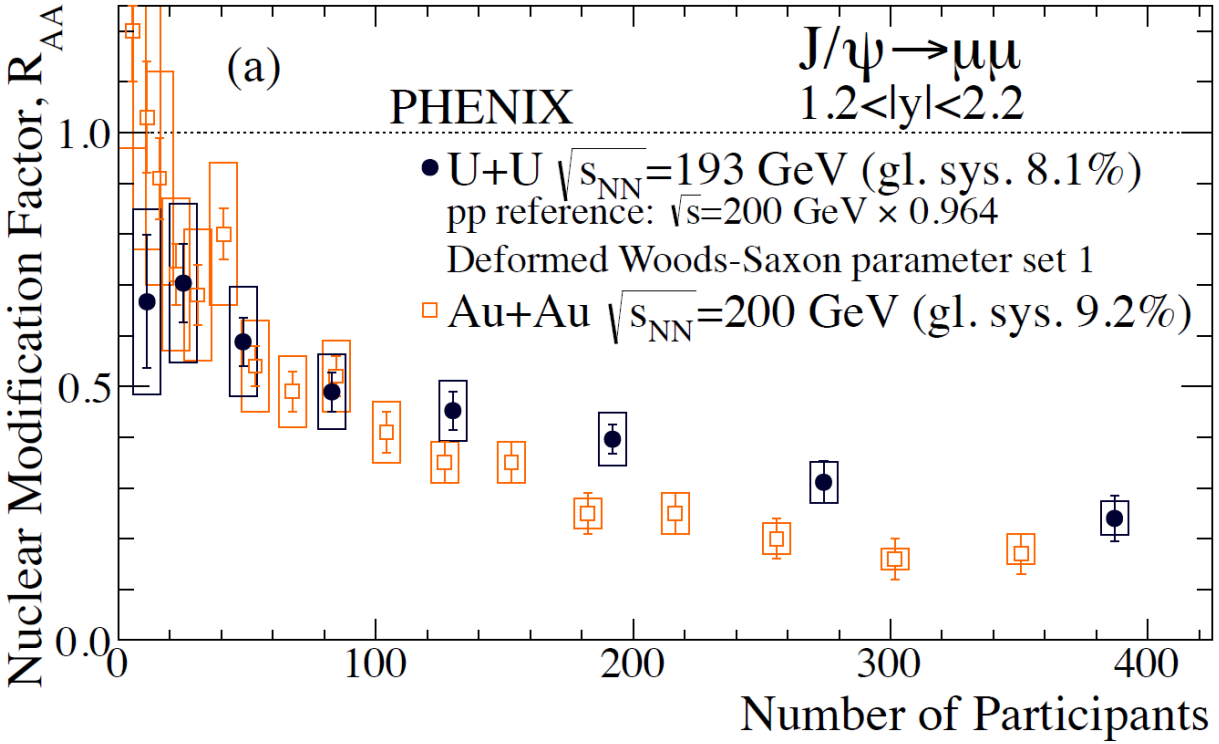
- Takes into account the finite radius of a nucleon
- Averages over all orientations of axis-of-symmetry
  - average radius and diffuseness matches values from electron scattering

U+U R_{AA}

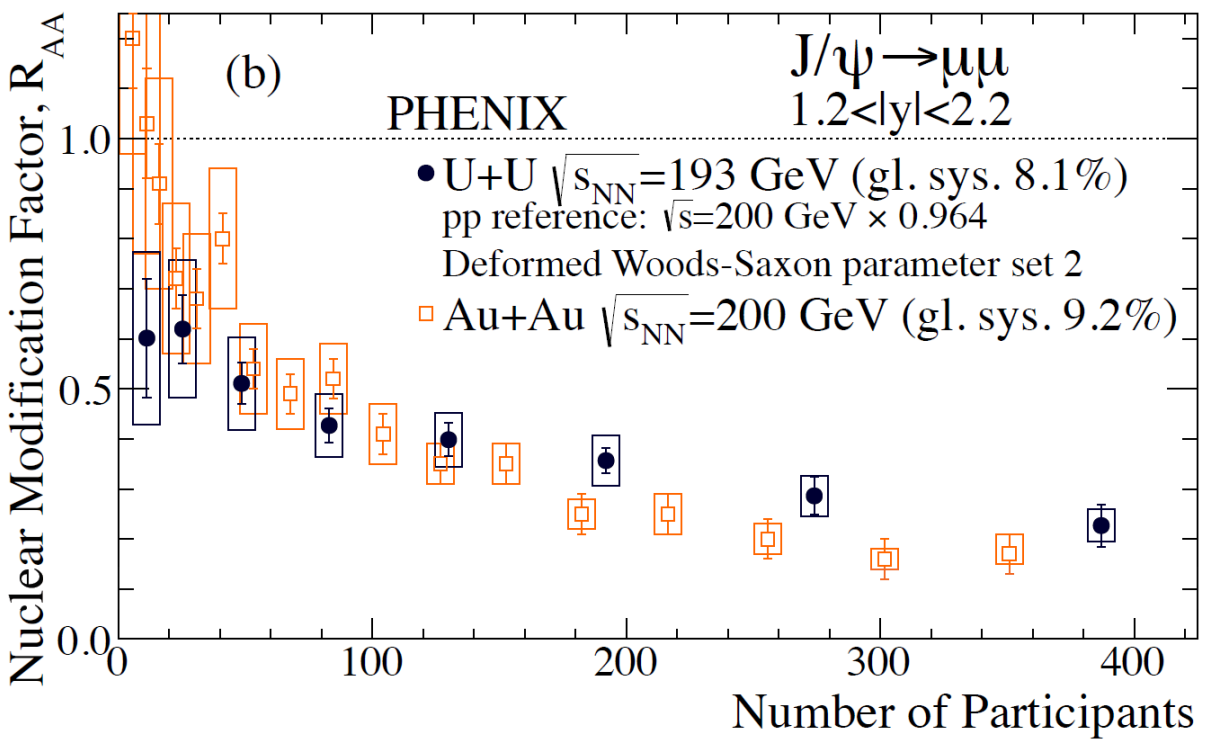
Set 1 has larger surface diffuseness

⇨ less compact nucleus, larger cross section (by 12%), smaller N_{coll} values (by 6-15%)

Set 1



Set 2



Ratio of $dN_{J/\psi}/dy$ for U+U and Au+Au

The measured ratio does not depend on N_{coll}

But we can *predict* how this ratio would change if J/ψ production only depended on N_{coll}

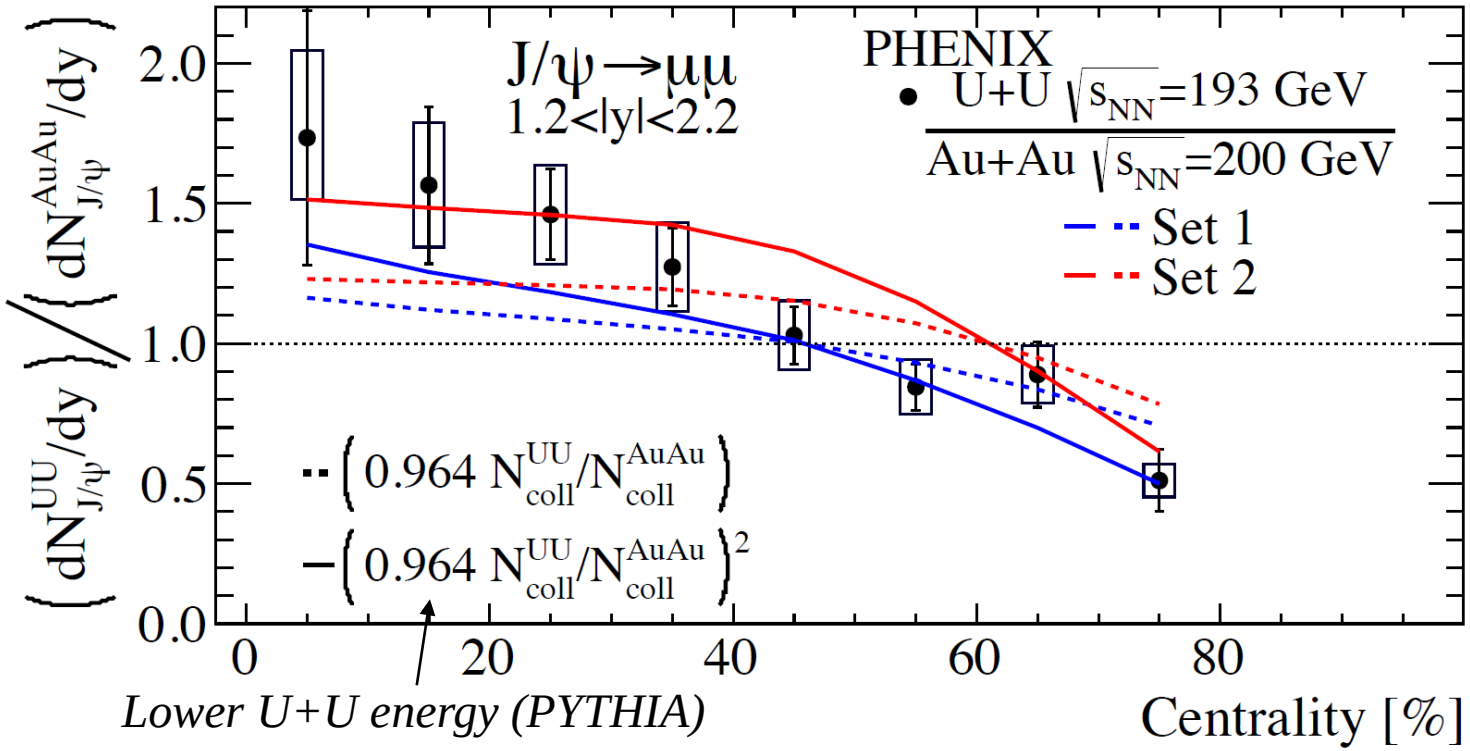
Color curves show how the ratio would change if J/ψ production scaled with

N_{coll} - dashed curves

N_{coll}^2 - solid curves

Set 2 favors N_{coll}^2 dependence

Set 1 consistent with both, slightly favoring N_{coll}^2 at most central collisions.



Consistent with a picture in which the increase in charm coalescence becomes more important than the increased color screening when going from Au+Au to U+U

$b\bar{b}$ production in p+p via di-leptons

at $\sqrt{s}$ = 200 GeV at mid-rapidity via opposite sign electron pairs.
at $\sqrt{s}$ = 510 GeV at forward/backward rapidity via same sign muons.

Opposite sign di-electron spectra

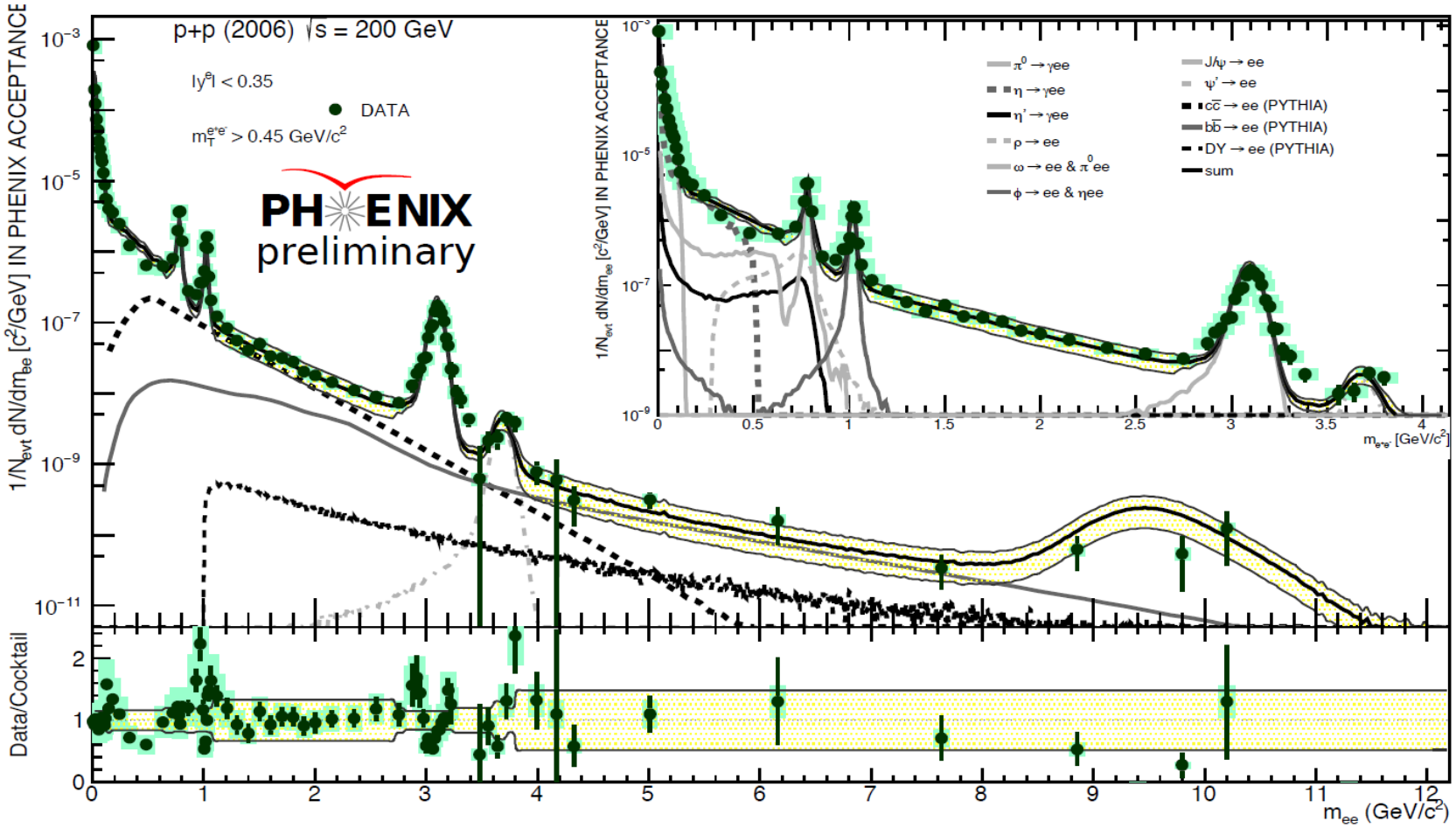
p+p collisions at $\sqrt{s}$ = 200 GeV at mid-rapidity

Very well understood spectrum:

- *Hadronic cocktail at low mass*
- *DY, charm and bottom at high mass*

Subtract yield of vector and pseudo-scalar mesons, and Drell-Yan.

Left with di-electrons from semi-leptonic charm and bottom decays.



Charm/bottom separation

Use technique described in PRC 91, 2015, 014907:

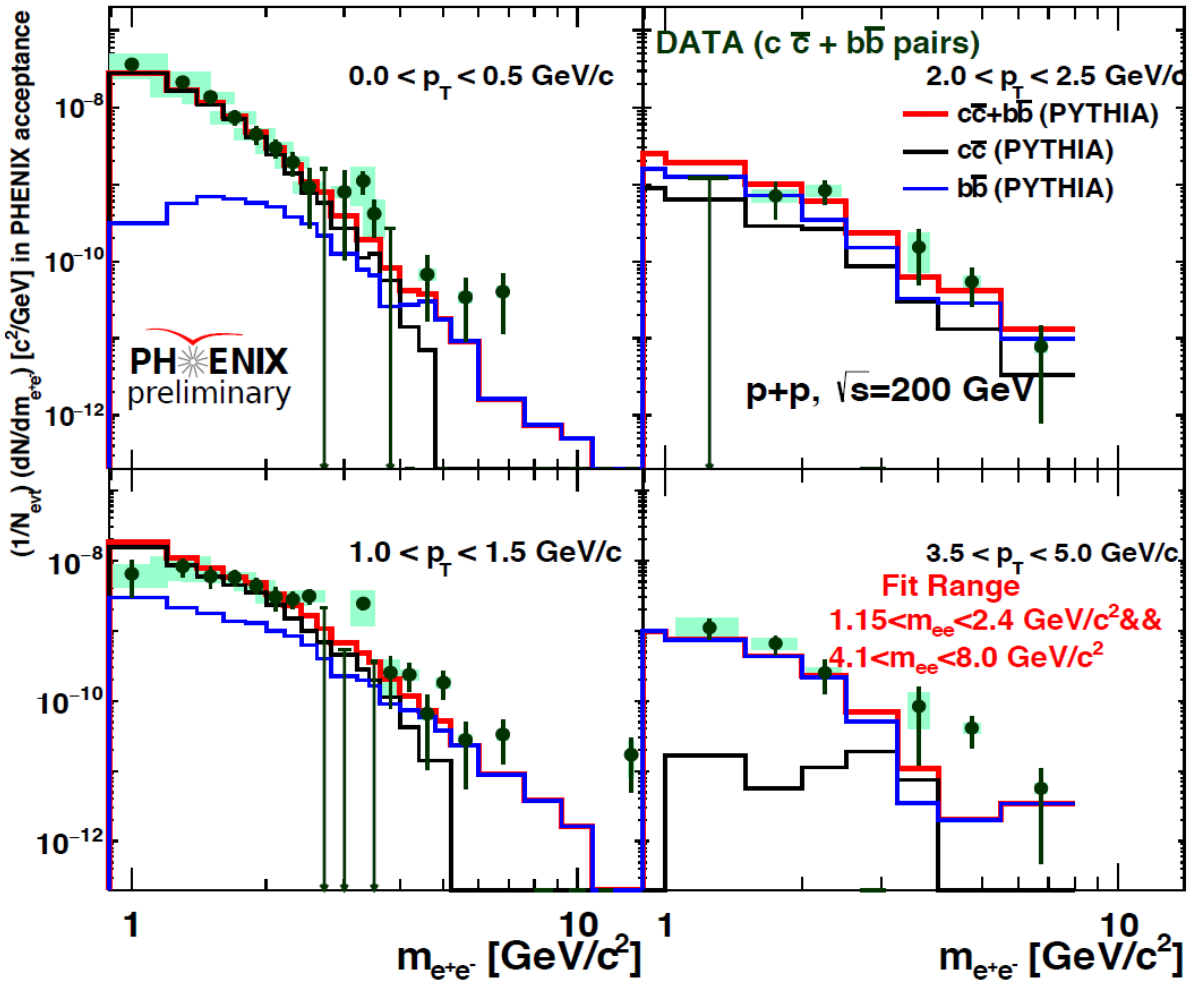
Fit mass and p_T distributions simultaneously:

charm: low mass, low p_T

bottom: high mass low p_T or low mass high p_T

Use PYTHIA and MC@NLO as a crosscheck.

di-electrons from heavy flavor

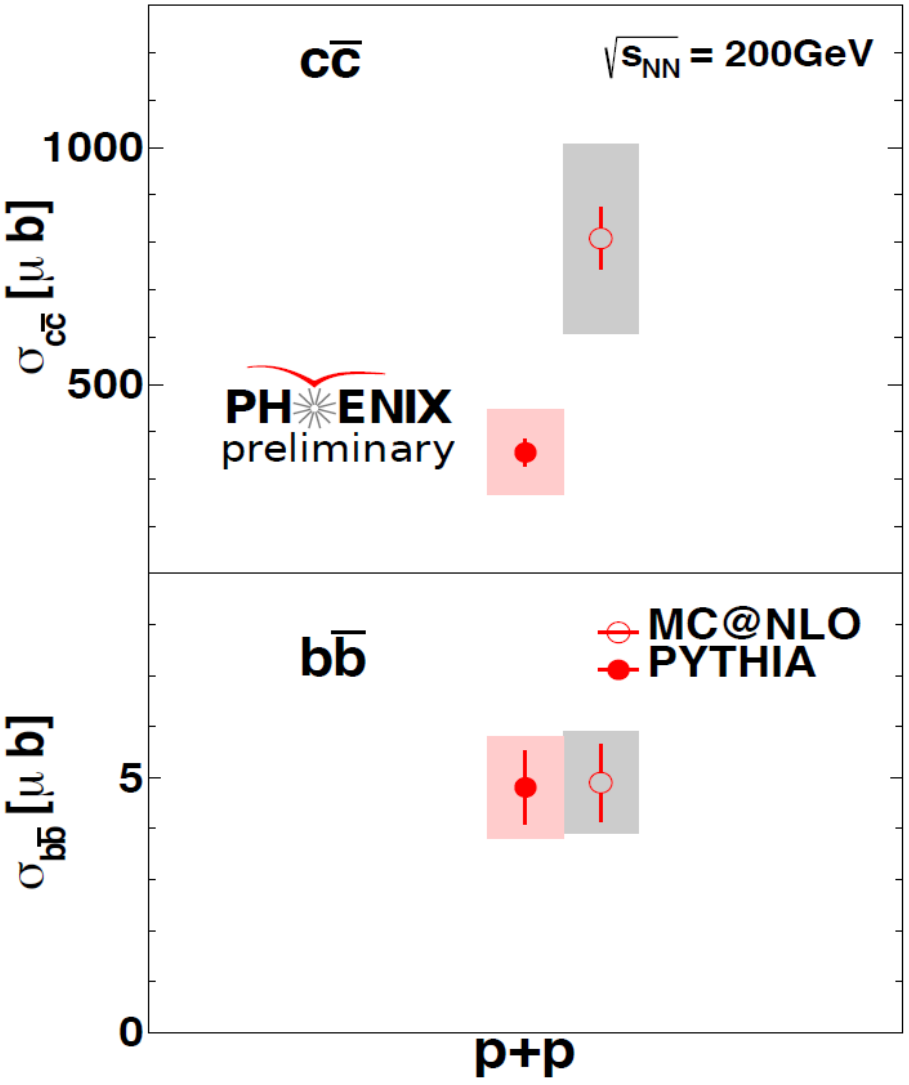


Total cross-section at $\sqrt{s}$ = 200 GeV at mid-rapidity

Bottom result is model-independent, charm is not.

For lighter quarks the distribution of decay electrons depends on the quark distributions.
For heavier quarks the effect of quark distribution get smeared by the decay kinematics.

Rapidity shapes in PYTHIA and MC@NLO are different, thus larger dependence of charm results on model.

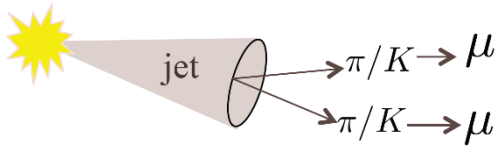


Same sign muons at forward rapidity ($\sqrt{s}$ = 510GeV)

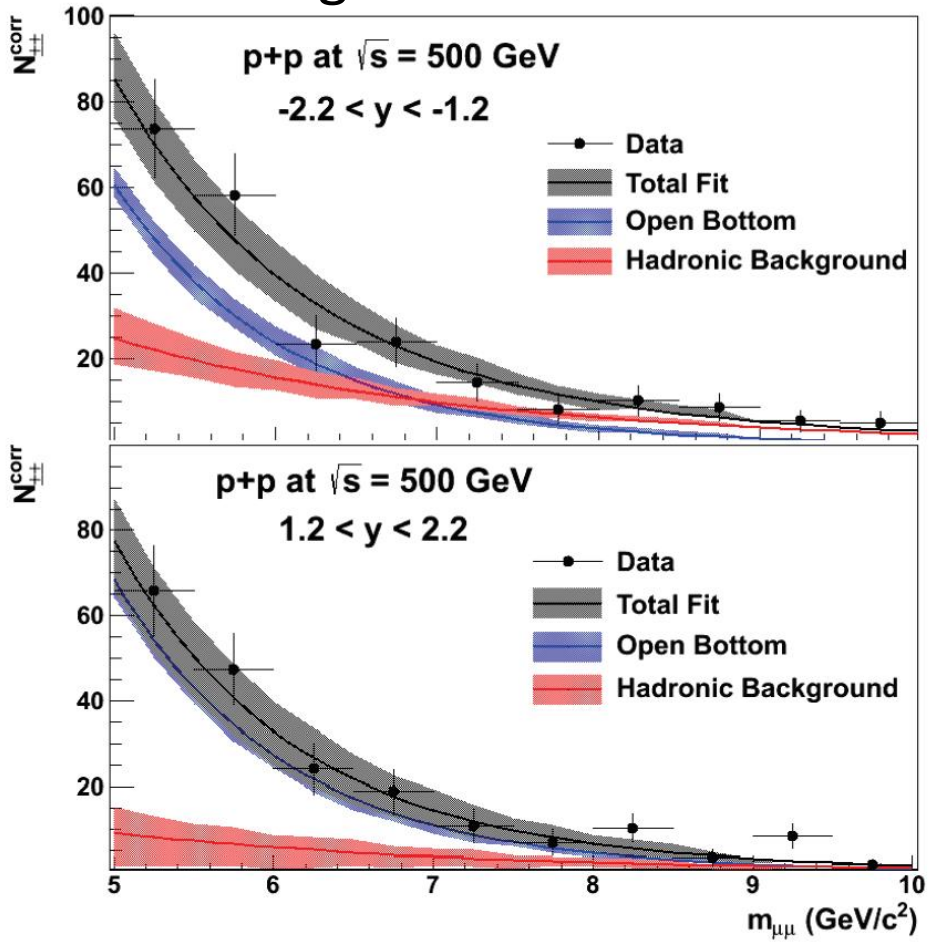
Advantage of using same sign muons (B-meson oscillations):
low background: no contamination from Drell-Yan,
quarkonia or vector mesons.

Same sign pairs consist of:

- Combinatorial background (calculated using mixed events)
- Correlated pairs:
  - charm pairs (negligible in PHENIX acceptance at high mass)
  - bottom pairs
  - jets (estimated from hadronic simulations)

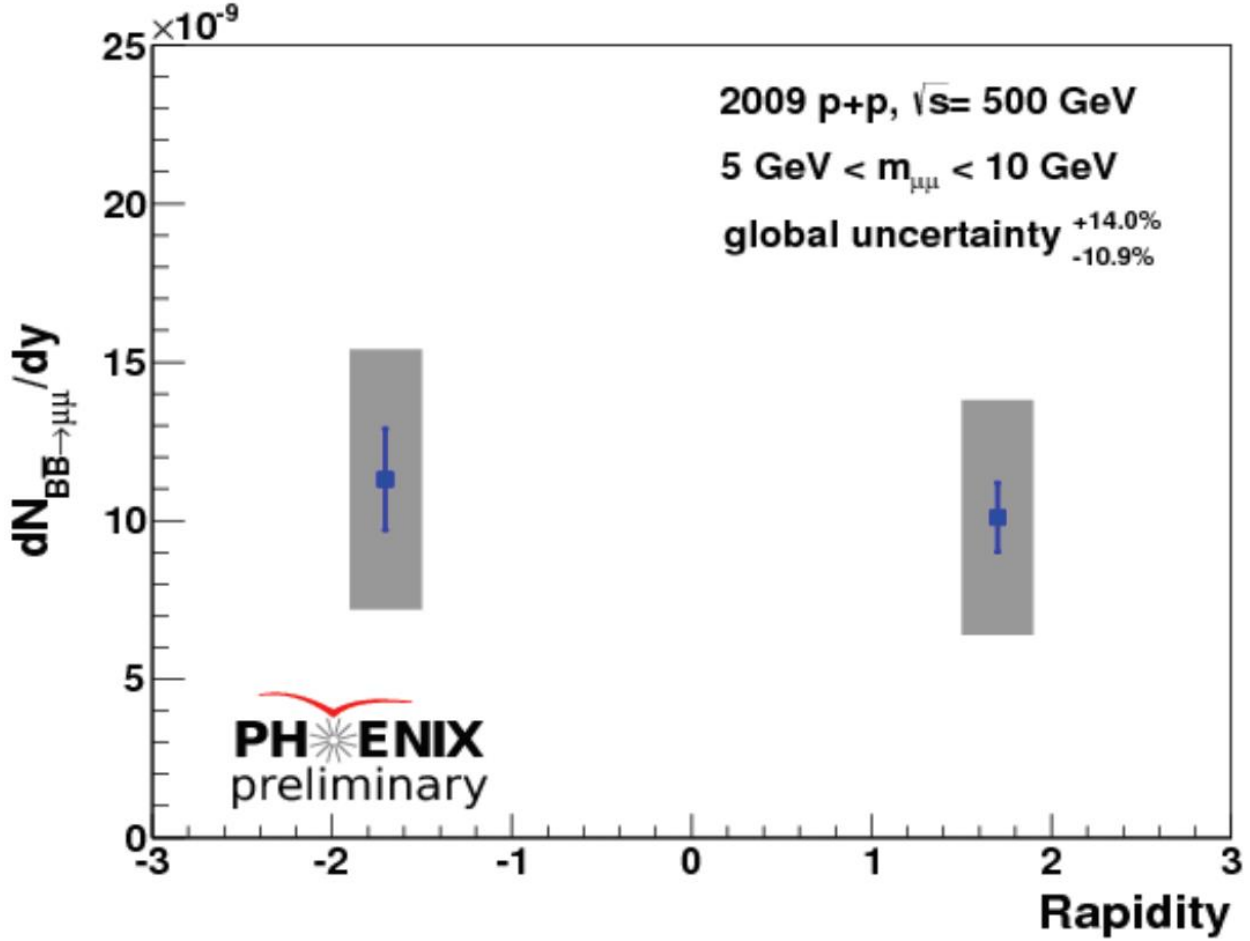


After combinatorial background subtraction

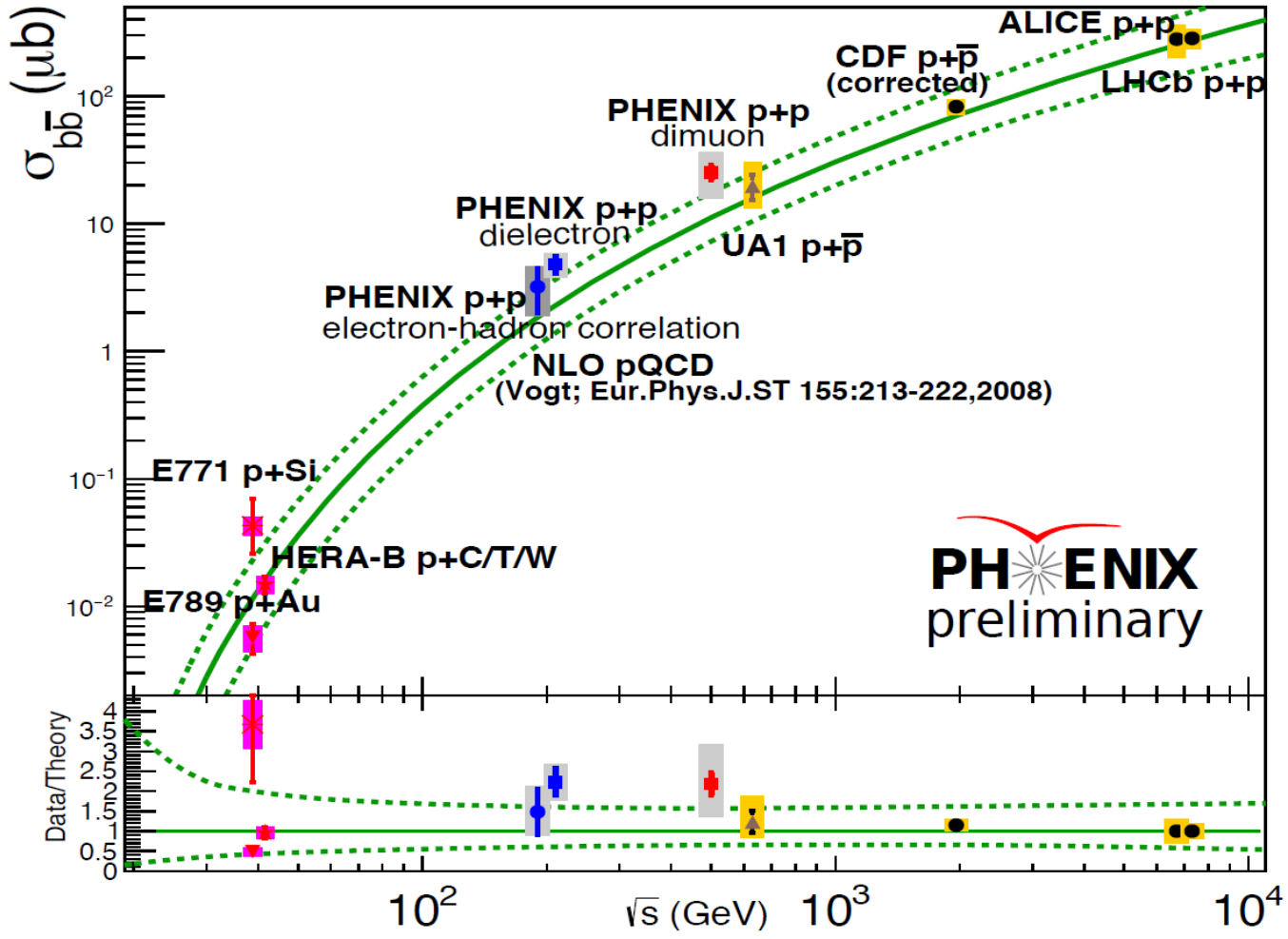


Total cross-section at $\sqrt{s}$ = 510 GeV at forward rapidity

Total cross-section is calculated using PYTHIA extrapolation (scale~0.2%).



Comparison to existing results



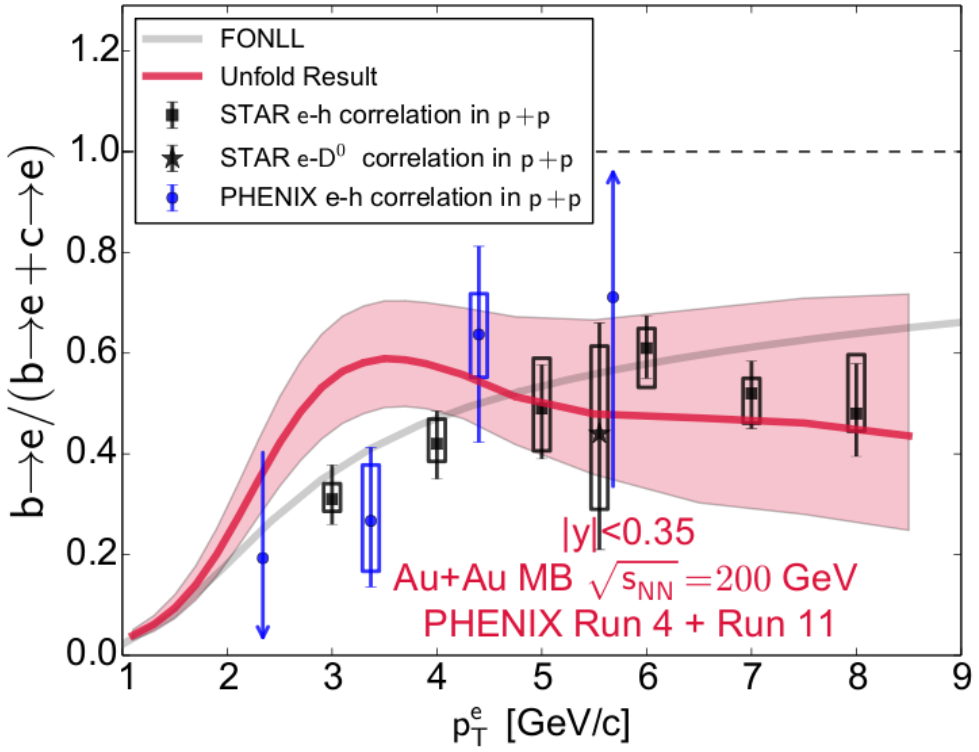
Results consistent with the NLO pQCD calculation within uncertainties.

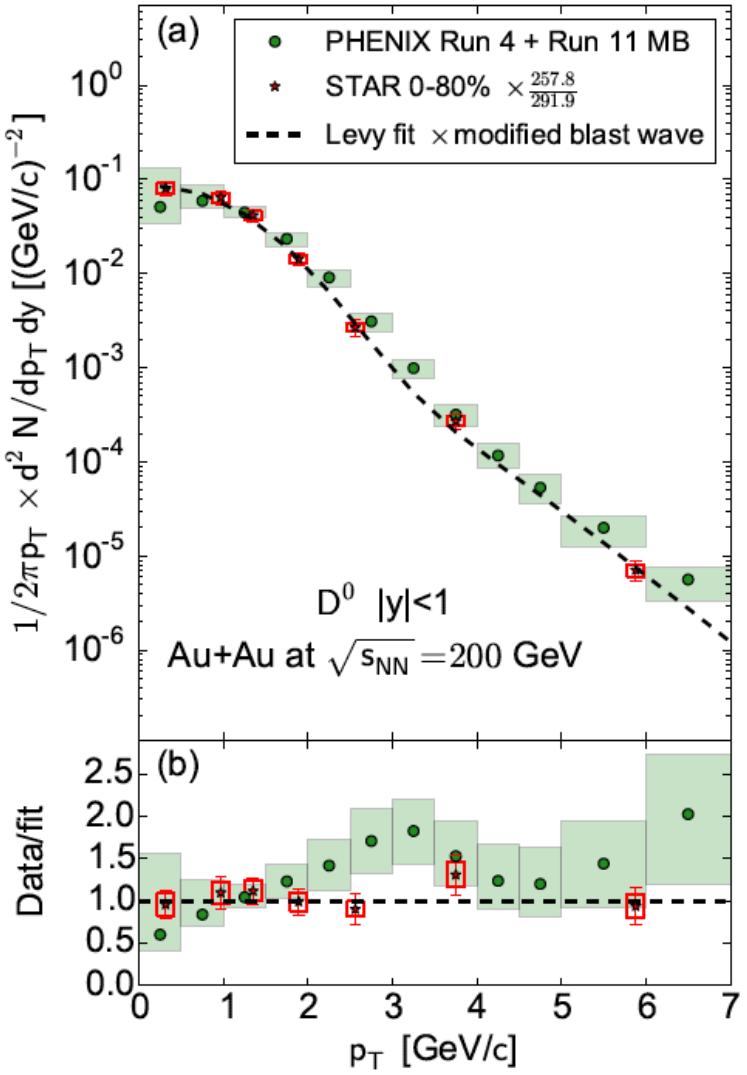
Open charm/bottom at mid-rapidity

Single electrons at mid-rapidity

See Takashi Hachiya talk later today for details!

arXiv:1509.04662 (2015) PRC accepted





Conclusions

In p+A ψ' suppression is larger than that of J/ψ in Au-going direction, and same in p-going direction

- *qualitatively unlike what happens at LHC, but the difference is within experimental uncertainty.*

Very strong ψ' suppression at low p_T.

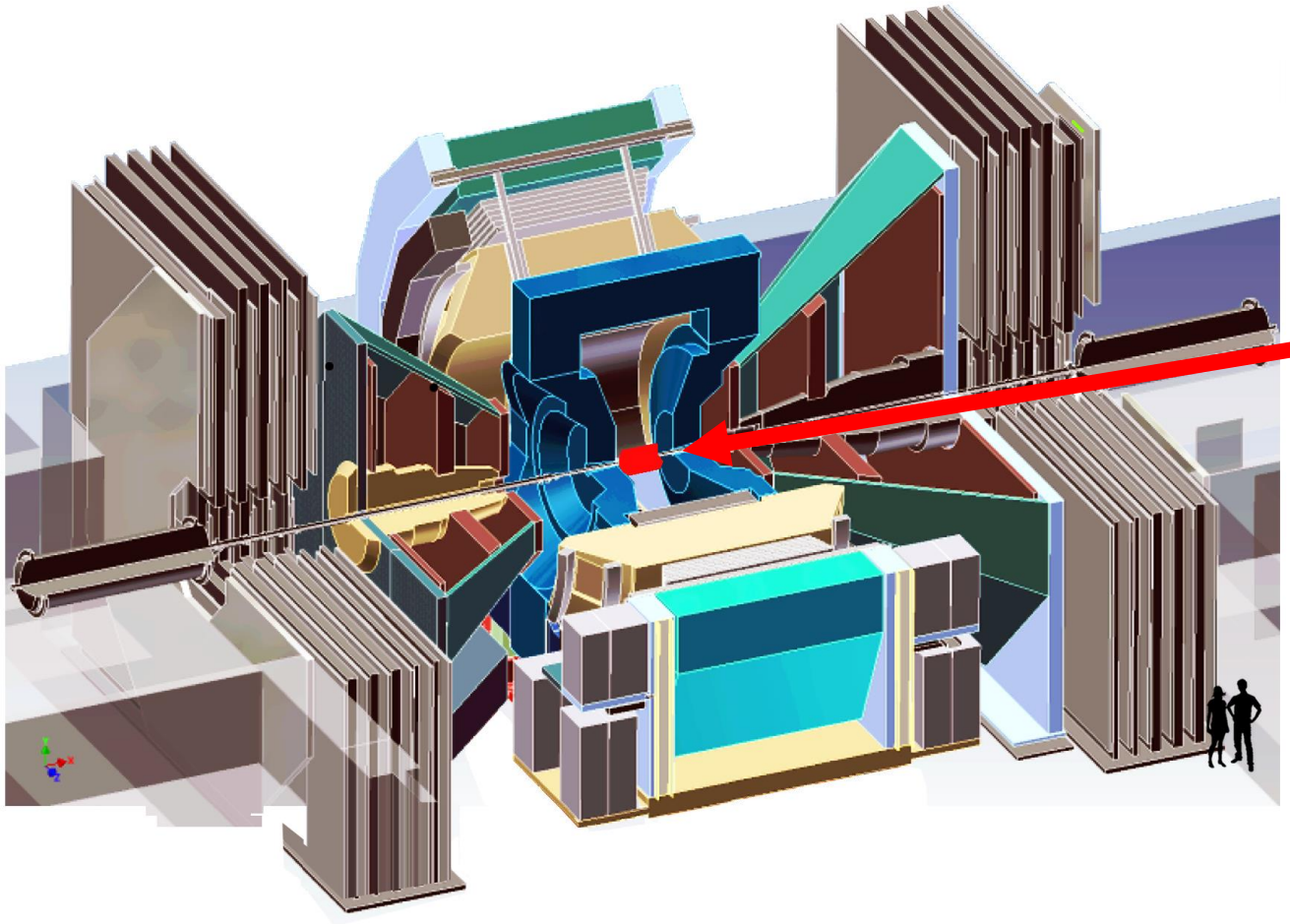
In U+U J/ψ suppression is weaker than that for Au+Au
Consistent with dominance of coalescence over color screening.
Centrality dependence of U+U/Au+Au ratio also consistent with importance of coalescence.

PHENIX measured $b\bar{b}$ production using opposite sign electrons at $\sqrt{s}$ = 200GeV
and same sign muons at $\sqrt{s}$ =510GeV.
Both results are somewhat higher than NLO pQCD calculation, but agree with it within uncertainty.

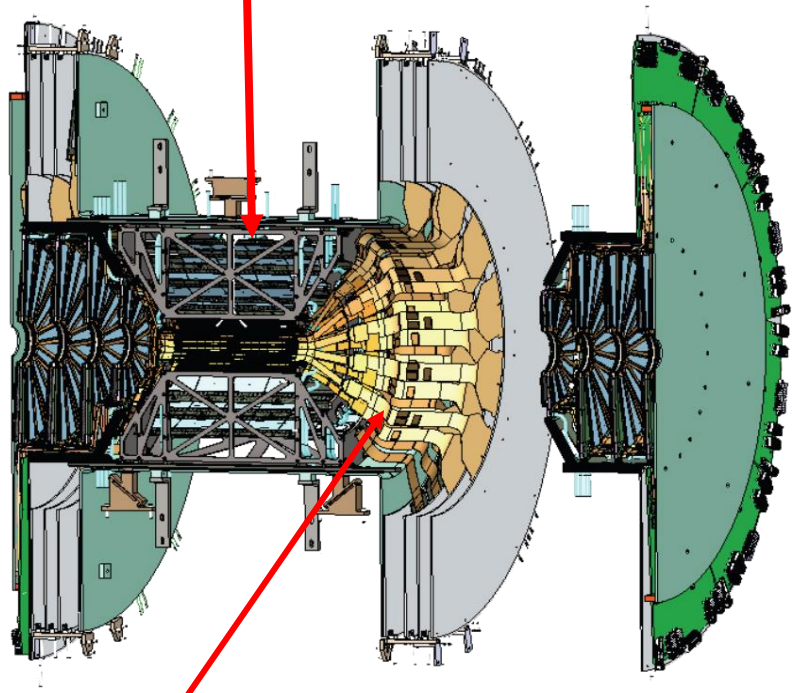
BACKUPS

New Silicon Vertex Detectors at PHENIX

Two out of these new measurements became possible due to new PHENIX vertex detectors.



Mid-rapidity (since 2011) VTX provides precise DCA and vertex measurement



Forward rapidity (since 2012)
FVTX provides improved di-muon mass resolution and precise DCA measurement