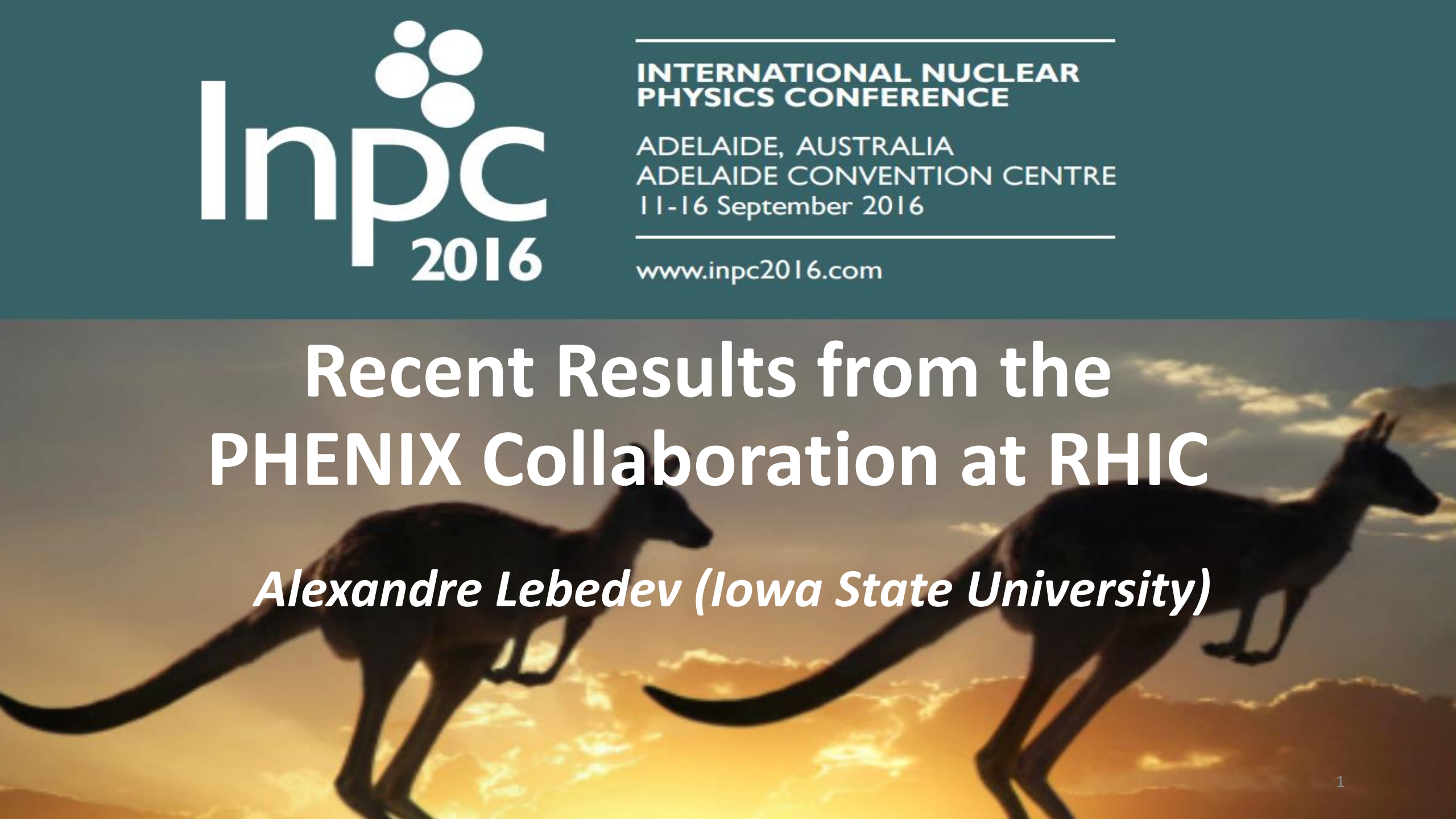



# Recent Results from the PHENIX Collaboration at RHIC

*Alexandre Lebedev (Iowa State University)*

# Outline

**Jets in PHENIX**

- d+Au
- Cu+Au

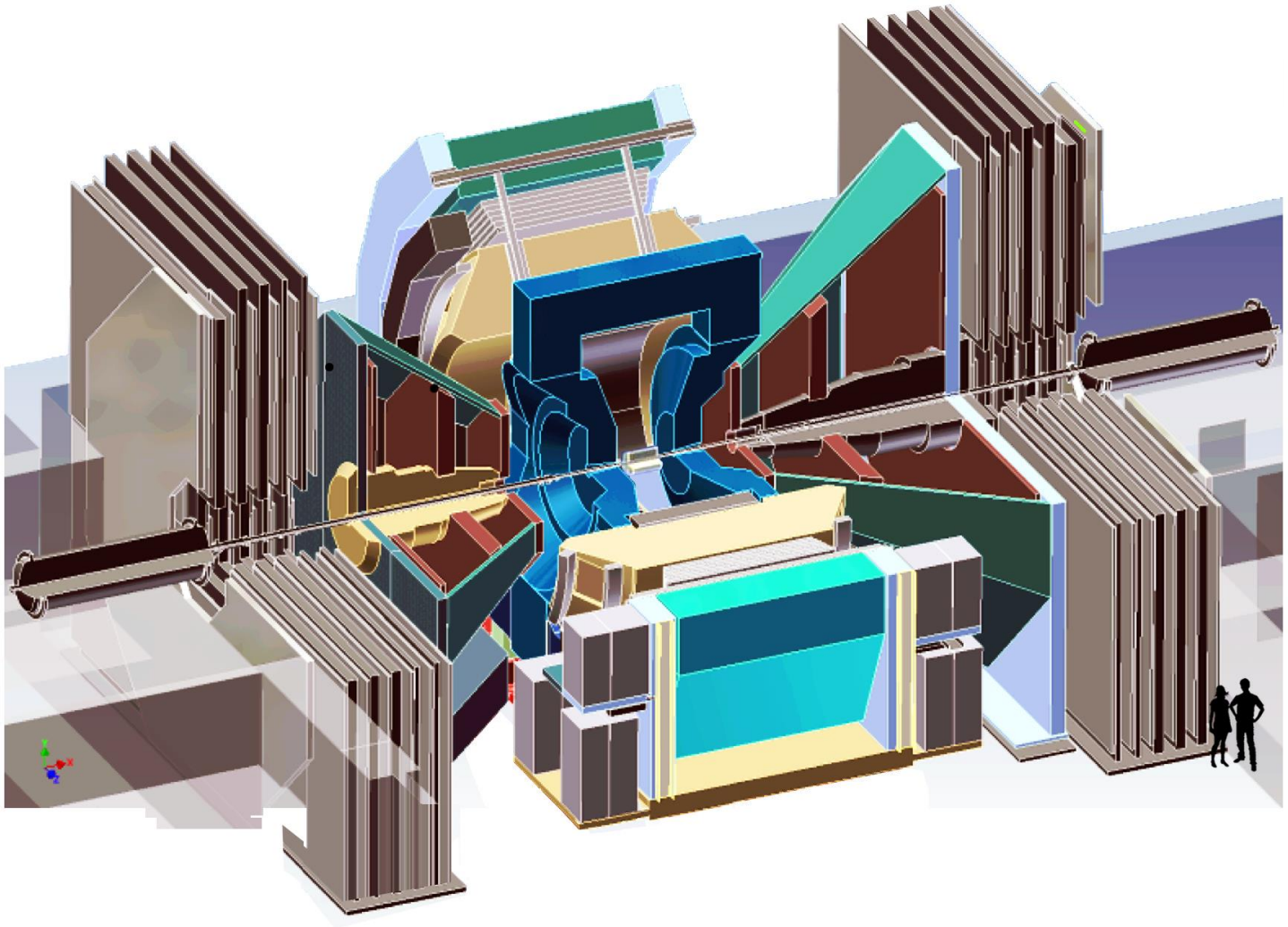
**Quarkonia in PHENIX**

- $\psi'$ / J/$\psi$ ratio in p+Au
- B → J/$\psi$ in p+p and Cu+Au

**Direct photons**

*See also PHENIX talks about open heavy flavor (Takashi Hachiya) and collective behavior in small systems (Julia Velkovska)*

# The PHENIX Detector



**Central Arms**

$|\eta| < 0.35$ $\Delta\phi = 2 \times \pi/2$

Tracking chambers for hadrons

EMCal for photons.

**Muon Arms**

$1.2 < |\eta| < 2.2$ $\Delta\phi = 2\pi$

$P > 2$ GeV

**Central and forward silicon vertex detectors**

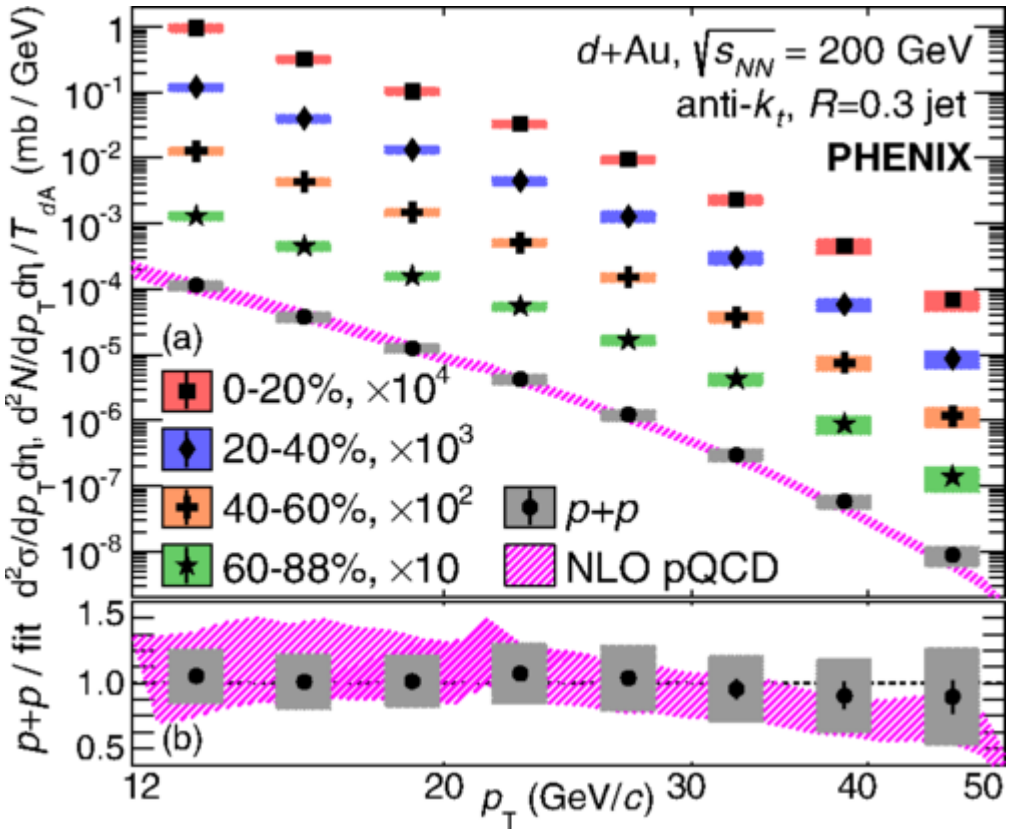
for precise vertex measurement.

# Jets in PHENIX

# Jets in p+p and d+Au

Jets are measured with anti-$k_T$ algorithm (R=0.3) using track $p_T$ and EMCal cluster energy.

Phys. Rev. Lett. 116 (2016) 122301




p + p consistent with NLOJET++ with NNPDF2.3 and hadronization corrections from Pythia.

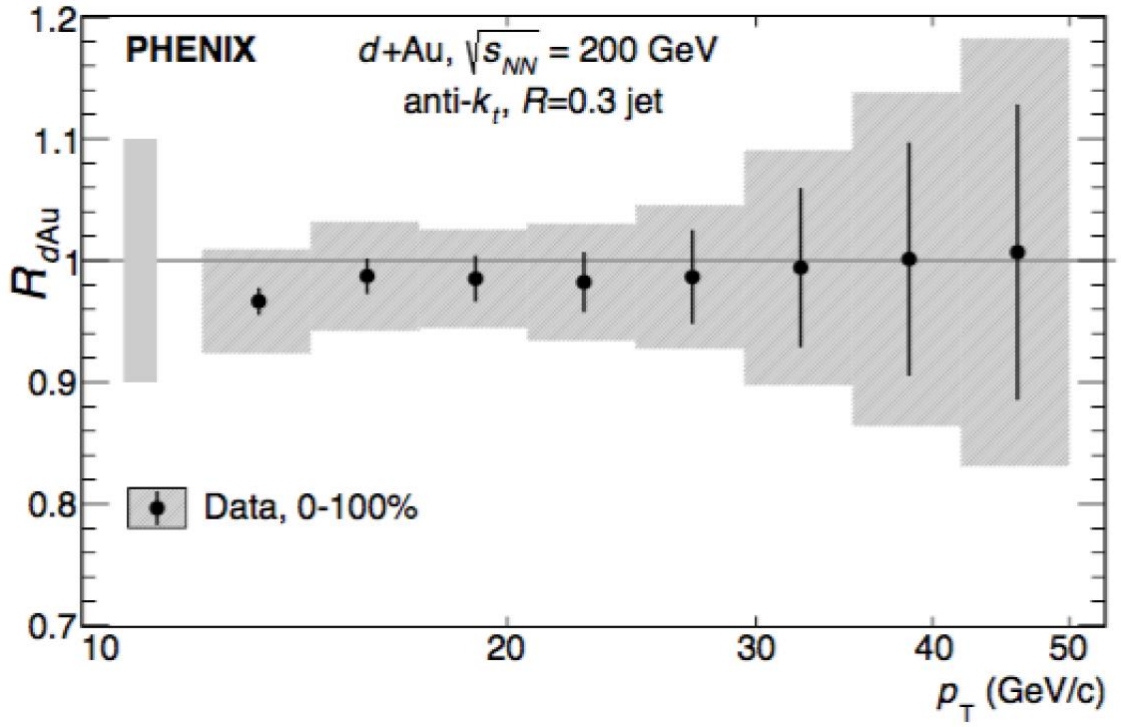
$$R_{AA} = \frac{dN_{AA}^{J/\psi}/dy}{N_{coll}\, dN_{pp}^{J/\psi}/dy}$$

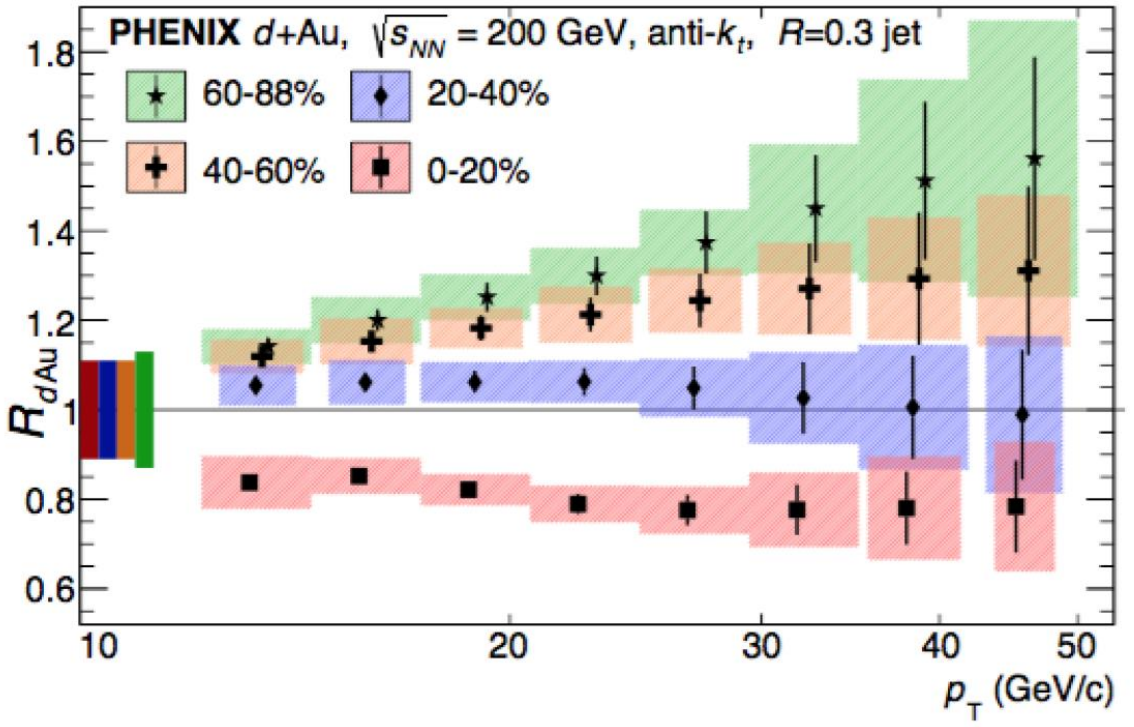
Nuclear modification factor is yield in nucleus-nucleus collisions divided by yield in p+p collisions scaled by number of binary collisions calculated using Glauber model.

# Jet $R_{dAu}$

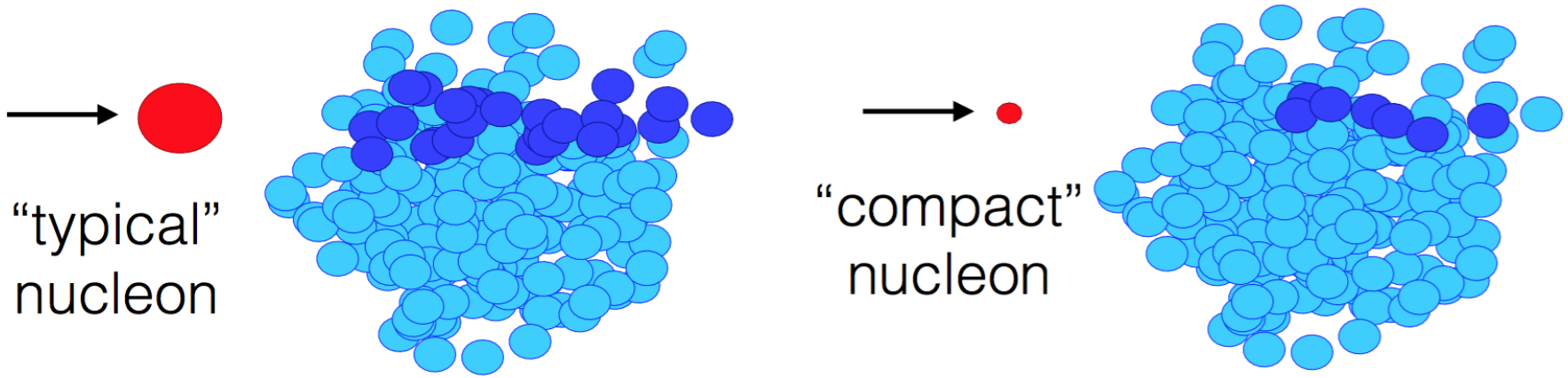
For minimum bias d+Au collisions jets scale as $N_{COLL}$

…but centrality dependence is surprising:
in peripheral collisions jets are enhanced!
Similar observation in ATLAS [PLB 748 (2015) 392] where it is explained as $R_{CP}$ scaling with proton x.



# Nucleus is probing nucleon?



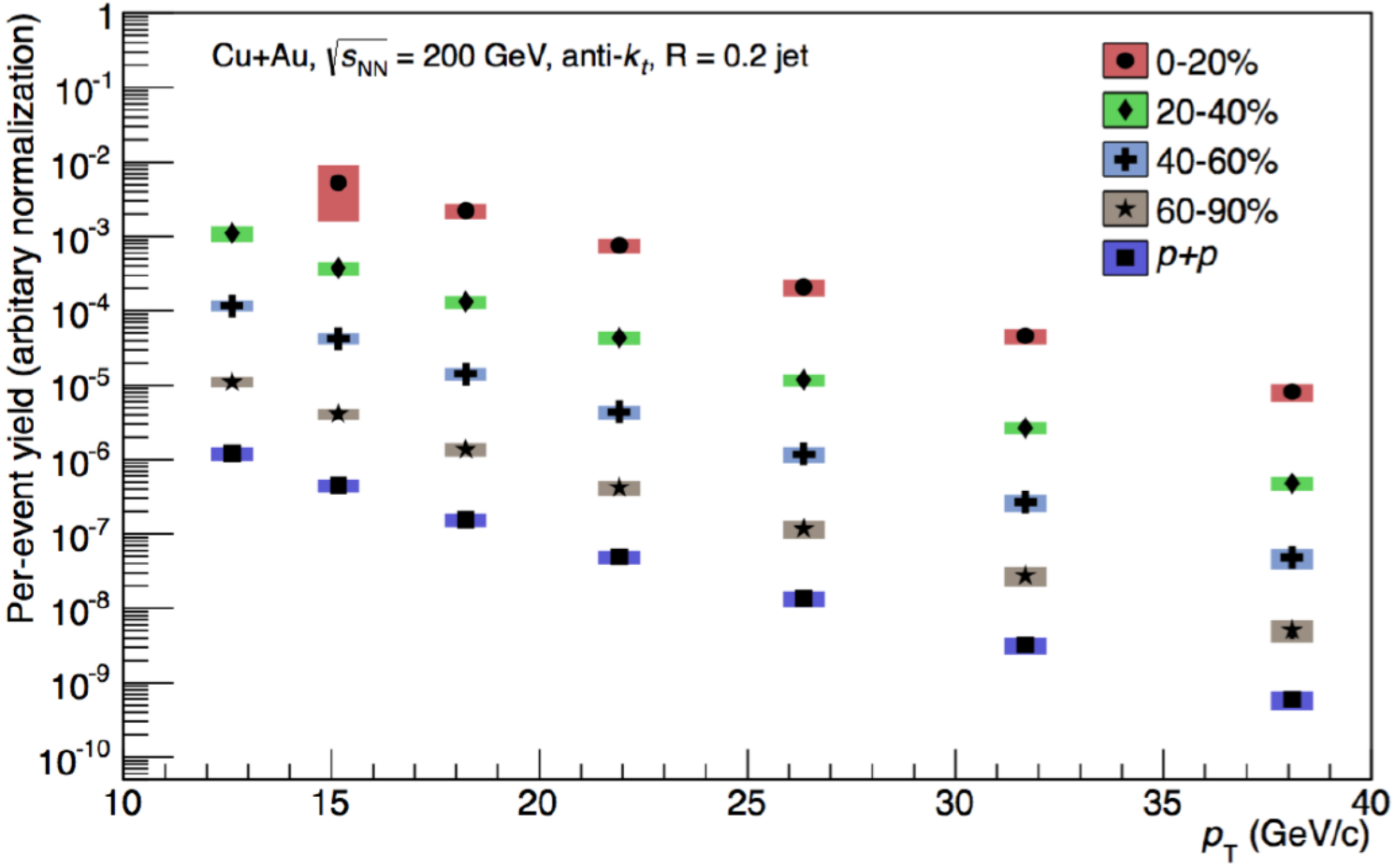

A proton with a high-x parton will be "smaller" than average and strike fewer protons.

Smaller than average $N_{COLL}$ causing $R_{dA}$ to be greater than 1.

Several theoretical efforts in this area: Perepelitsa, Cole and Strickman (PRC 93 (2016) 011902), Bzdak et al. hep-ph/1408.3156, Armesto et al. PLB 747 (2015) 441

# Jets in Cu+Au

Problem: large underlying event background




Anti-$k_T$ R=0.2 to reduce underlying event background

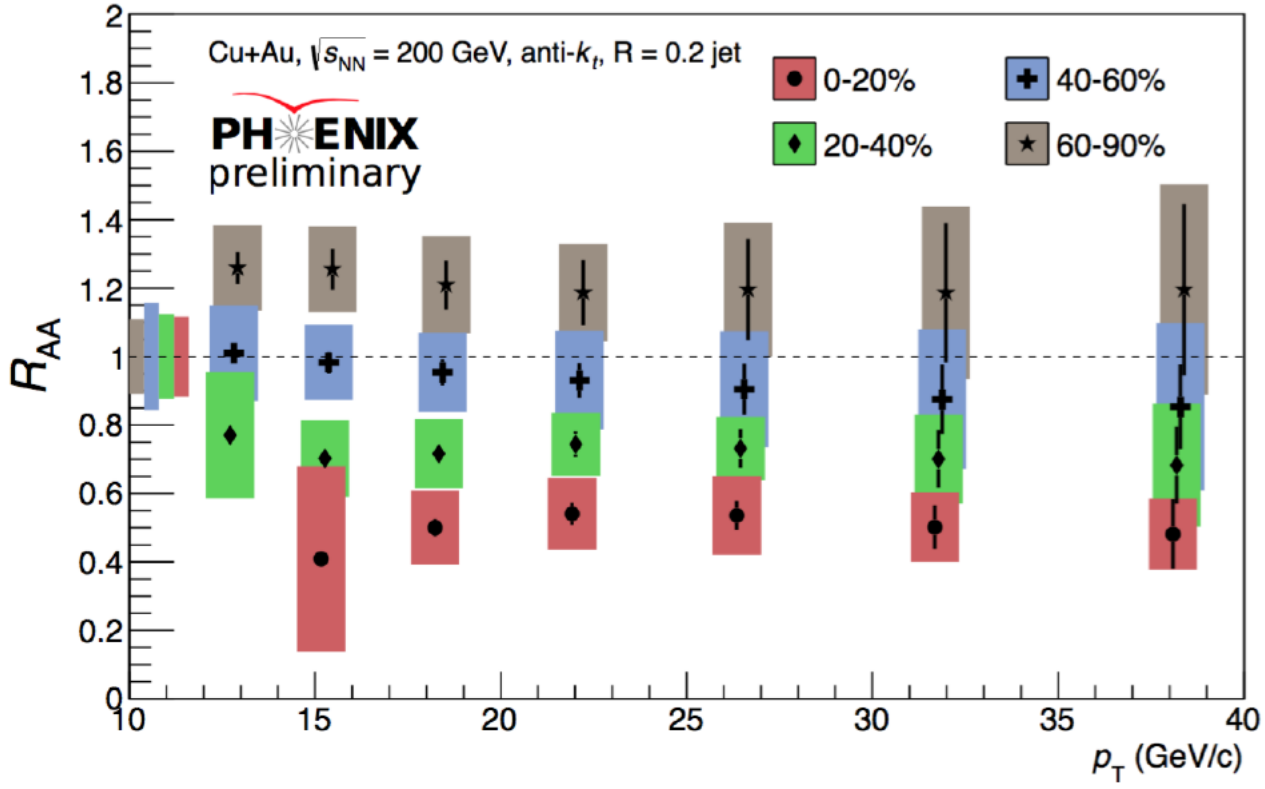
Data-driven underlying event determination:

- Reconstruct jets from randomly shuffled tracks and clusters.
- Fake rate ~30% at 15 GeV and drops to 5% by 25 GeV.

# Jet $R_{CuAu}$

Suppression by factor of ~2 in most central collisions.

Hint of enhancement in most peripheral.



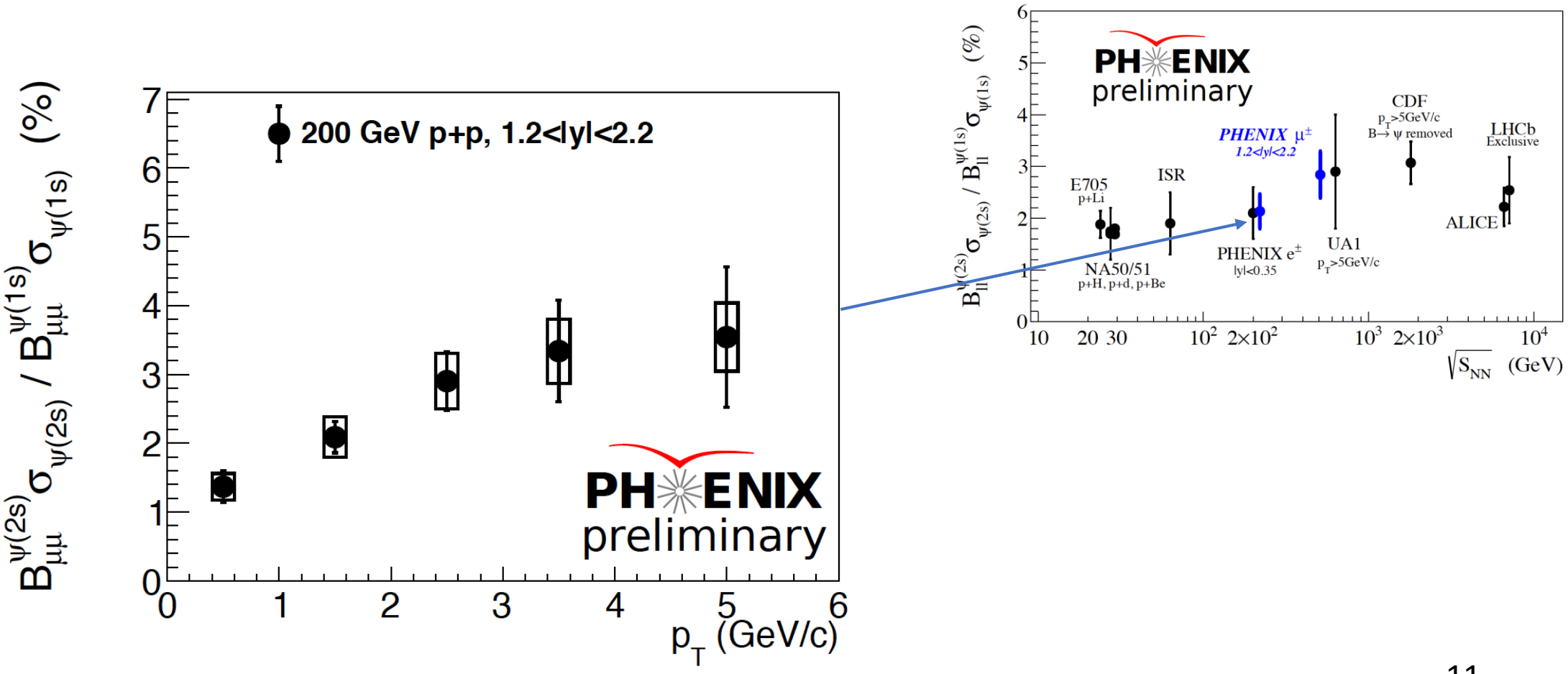
# $\psi'$ / J/$\psi$ ratio

Heavy charm quarks are produced in initial hard scattering, production can be calculated in perturbatve QCD approach.

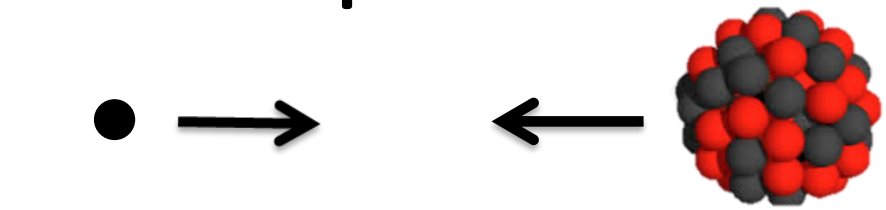
$c\bar{c}$ pairs form J/$\psi$ and $\psi'$ at the later stages of the collision, with very different binding energies (640 and 50 MeV).
Differences between J/$\psi$ and $\psi'$ help to understand final state effects.

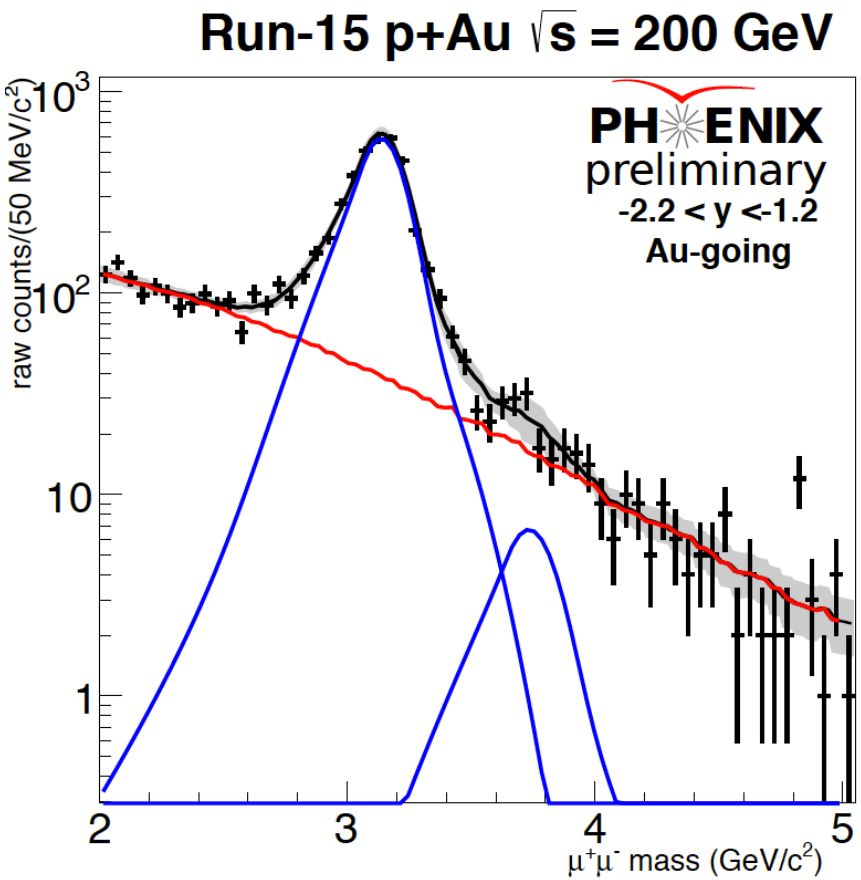
# ψ’ measurement in p+p at forward rapidity

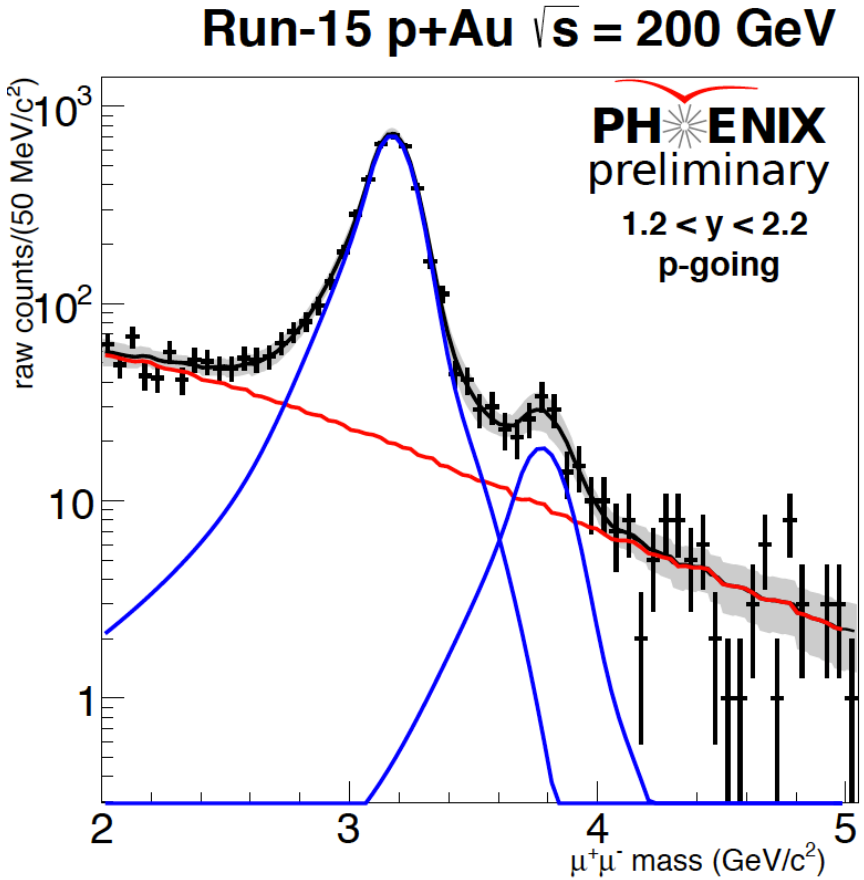
Measurement in Muon Arms, at forward/backward rapidity
Baseline for suppression measurement in p+Au and p+Al



# Di-muon mass in p+Au at forward rapidity

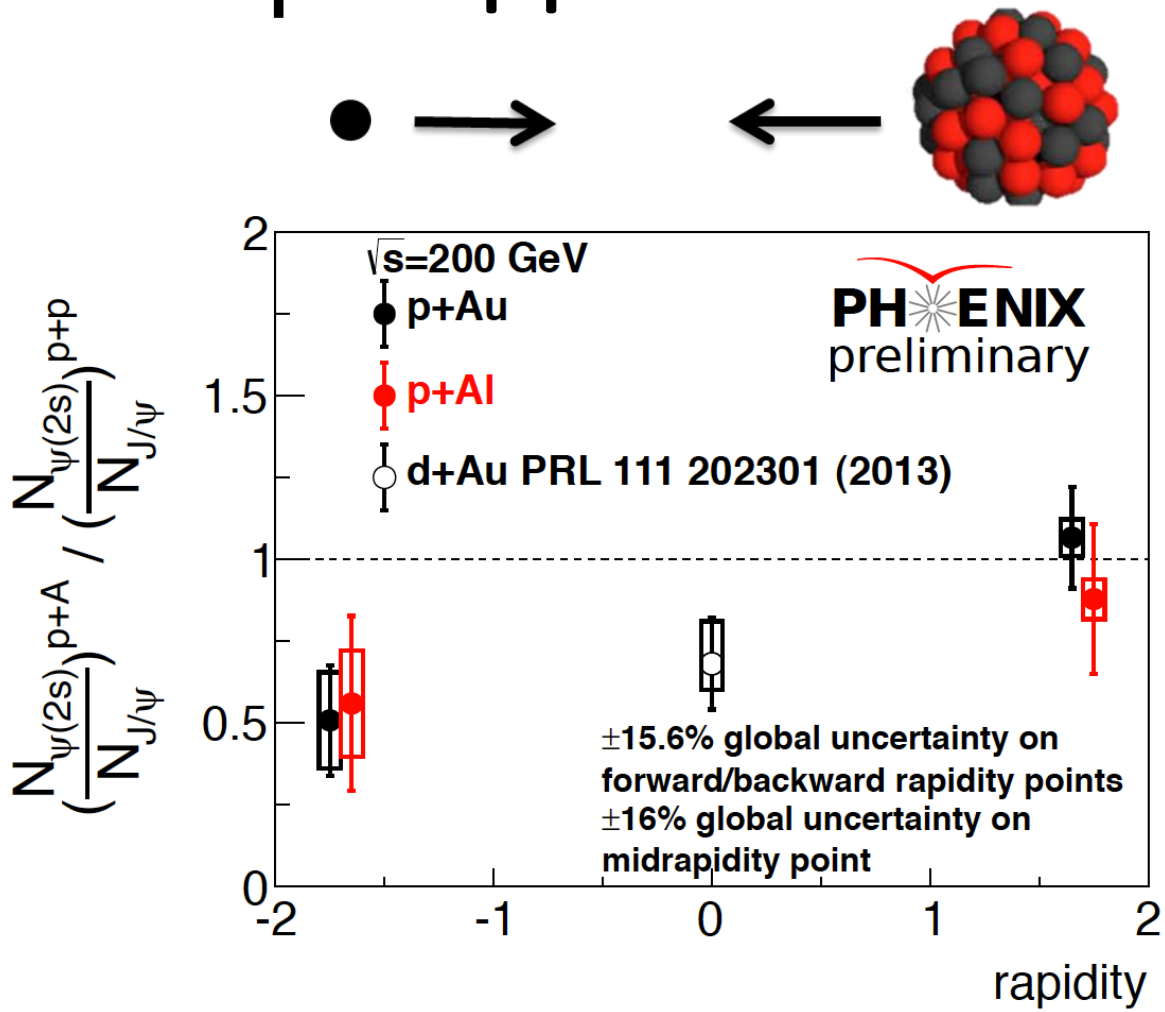




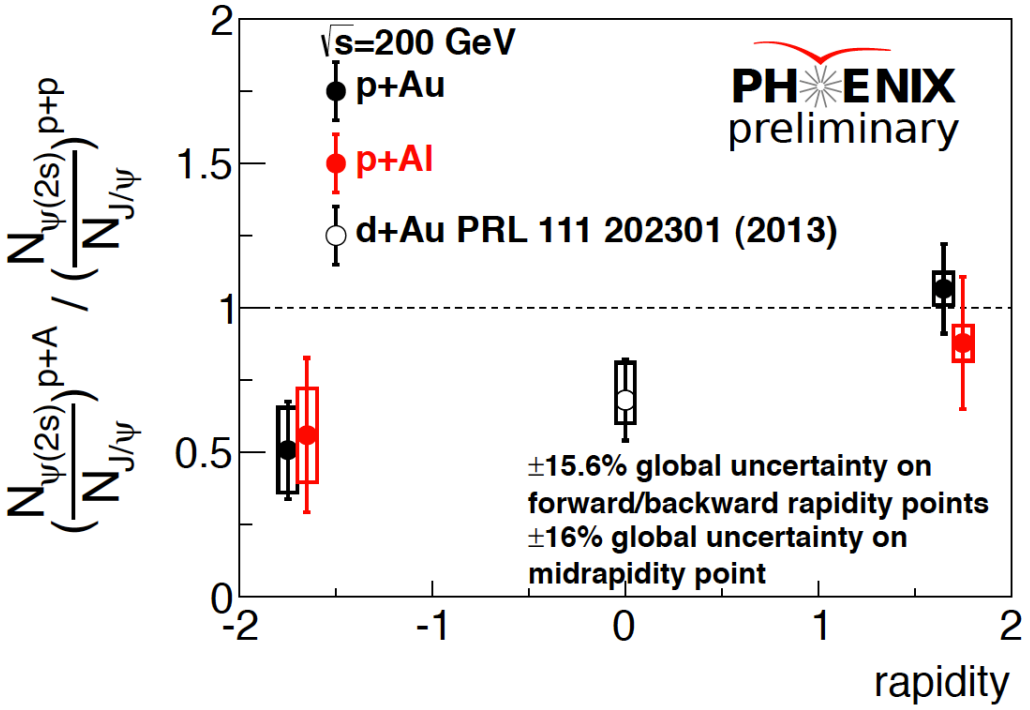

Clearly seen suppression in Au-going direction.

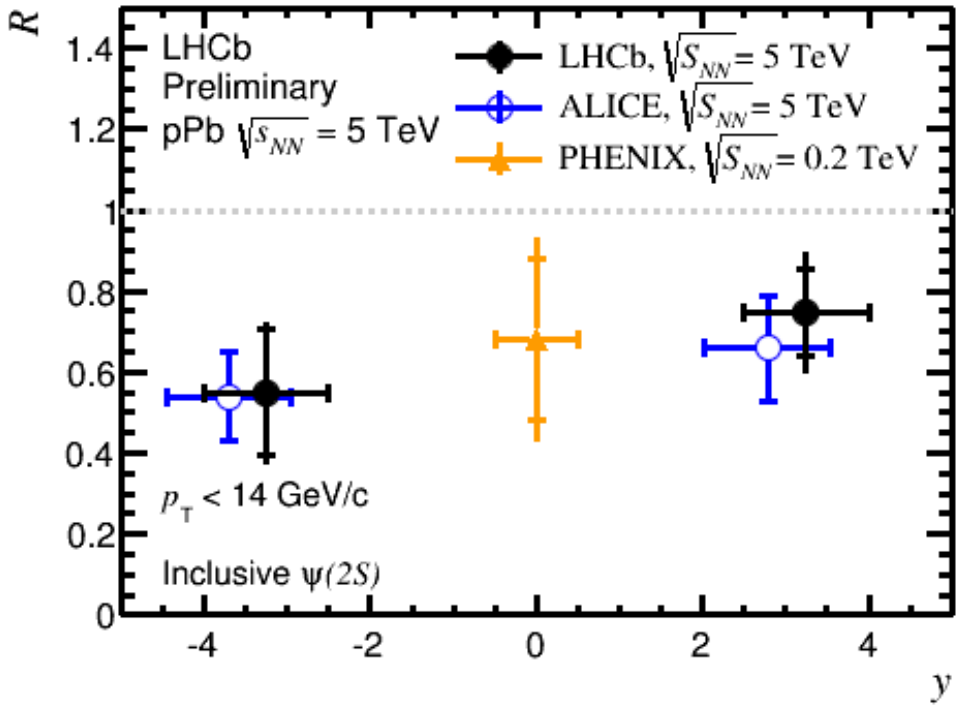
# Relative ψ' suppression vs. rapidity




Strong relative suppression in Au-going direction, no difference in p-going direction.
Indicates importance of quarkonia breakup by co-movers?

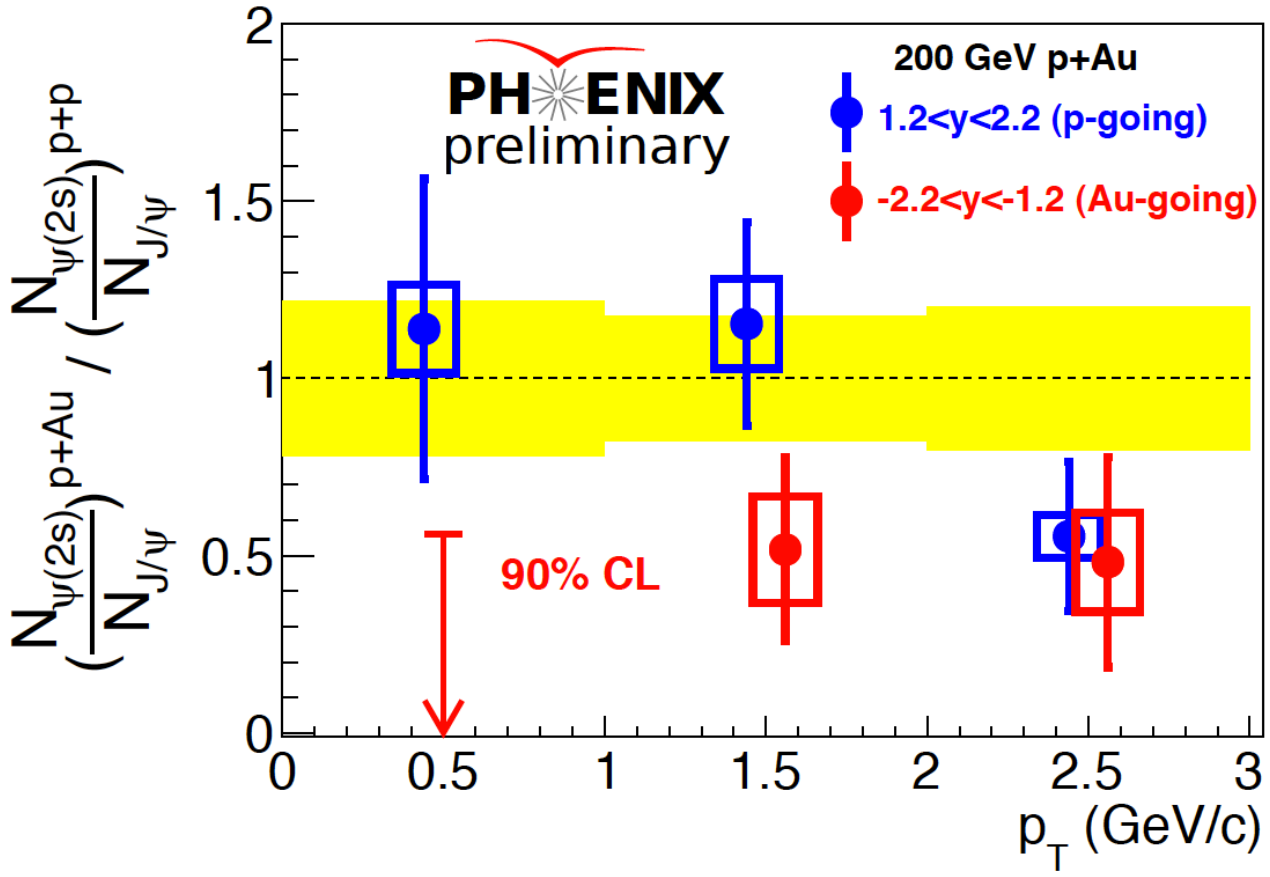
# Comparison with LHC



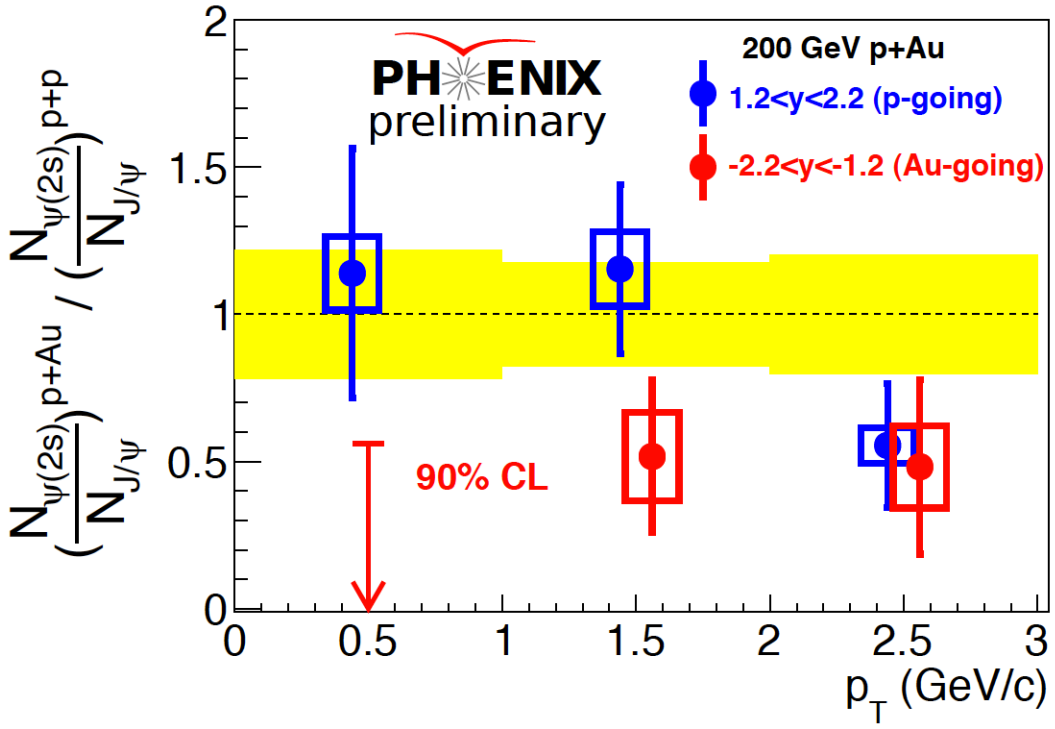

While relative suppression in heavy-ion-going direction is similar at RHIC and LHC, in p-going direction at LHC there is also rather strong suppression.
A hint that co-movers or breakup in nucleus are unlikely explanation at LHC?
However, the difference in p-going direction is within experimental uncertainty.

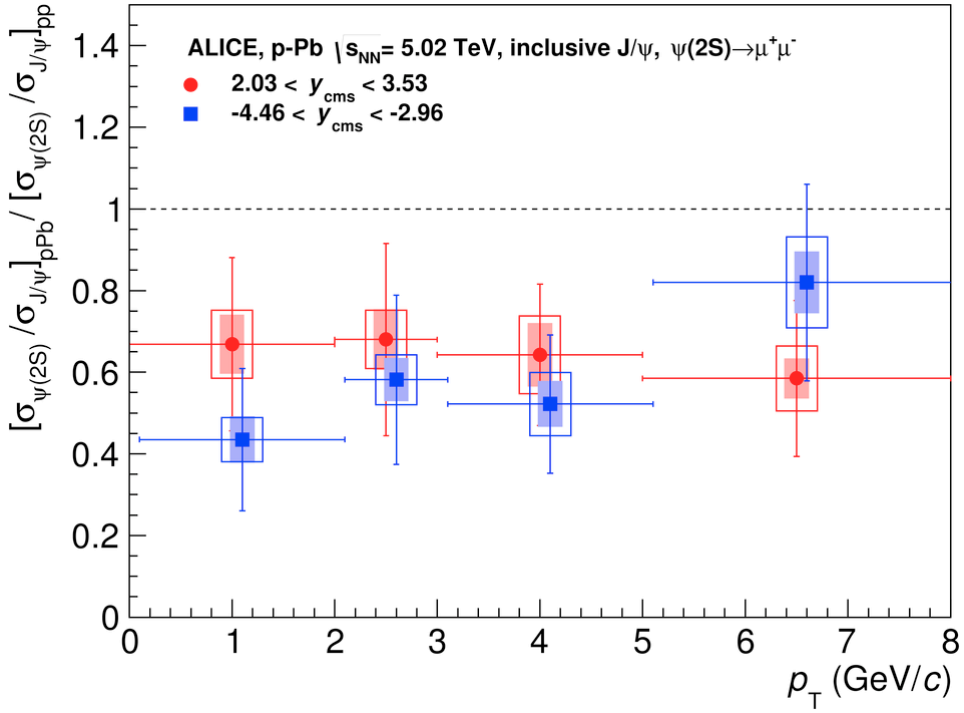
# $p_T$ dependence of relative suppression




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?

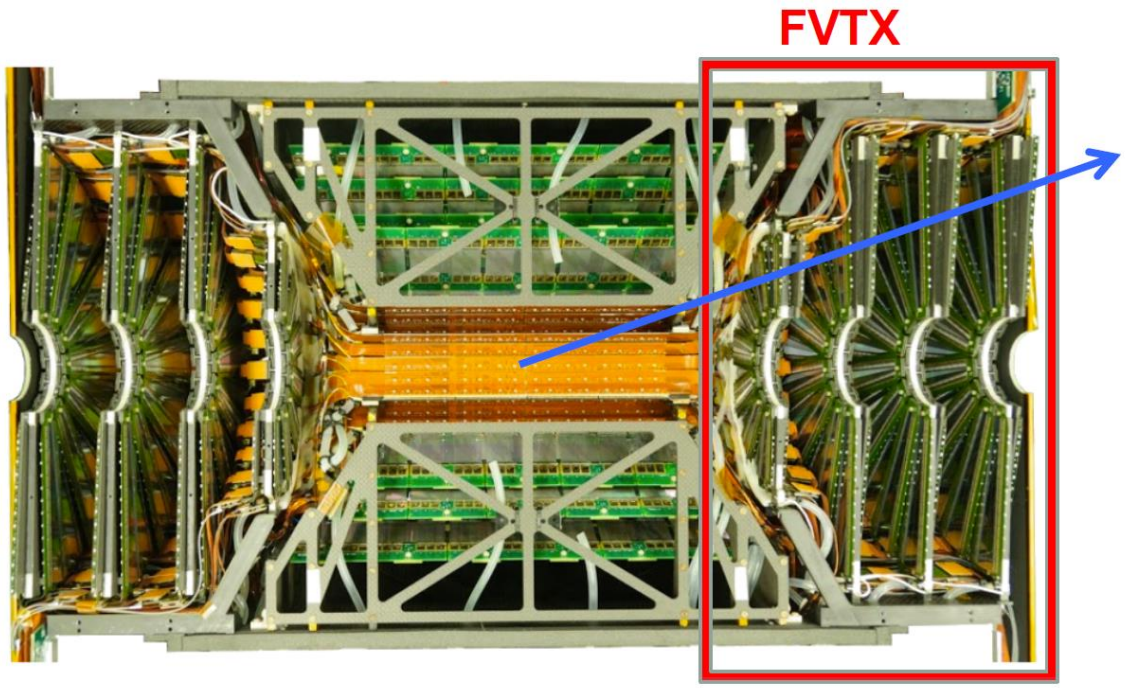
# $B \rightarrow J/\psi$

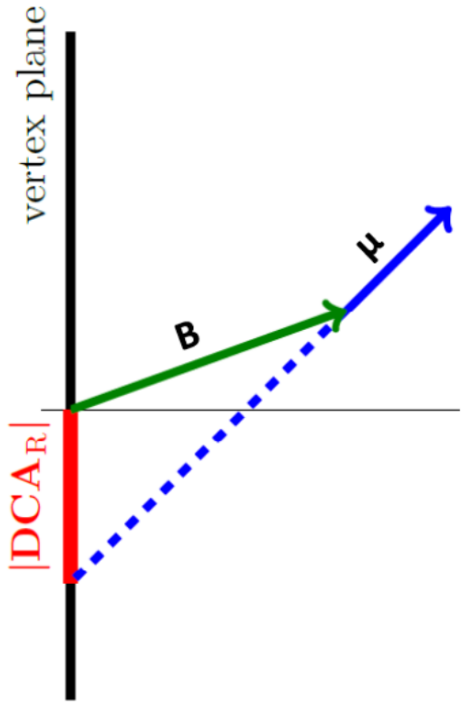
J/ψ produced from B decay are sensitive to different initial state and final state effects than J/ψ produced directly in heavy ion collisions.

In p+p the measurement of $B \rightarrow J/\psi$ helps constrain gluon PDFs in different regions of x and $Q^2$.

# B → J/ψ measurement

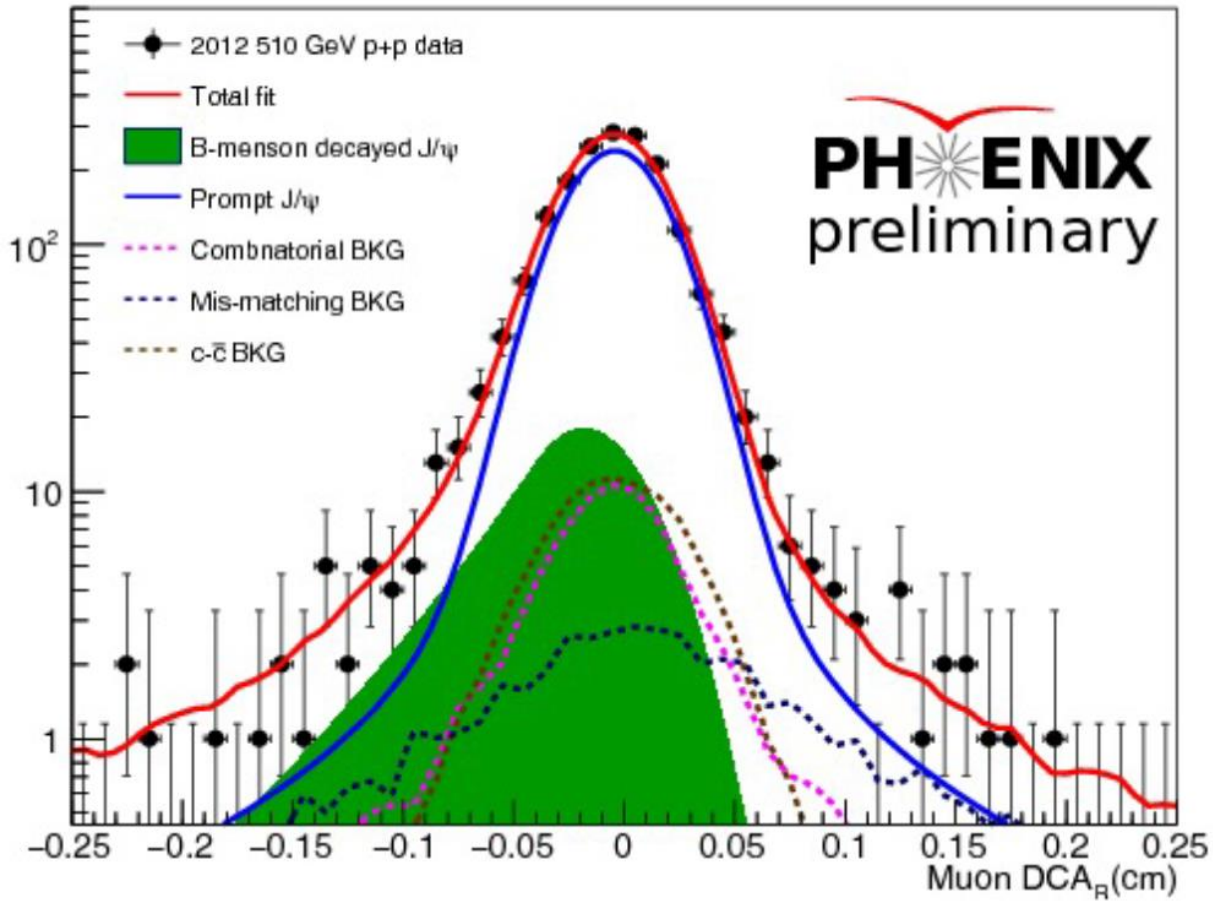
B → J/ψ fraction was measured by precise measurement of distance of closest approach in the plane perpendicular to the beam ($DCA_R$) using forward silicon vertex detector (FVTX).



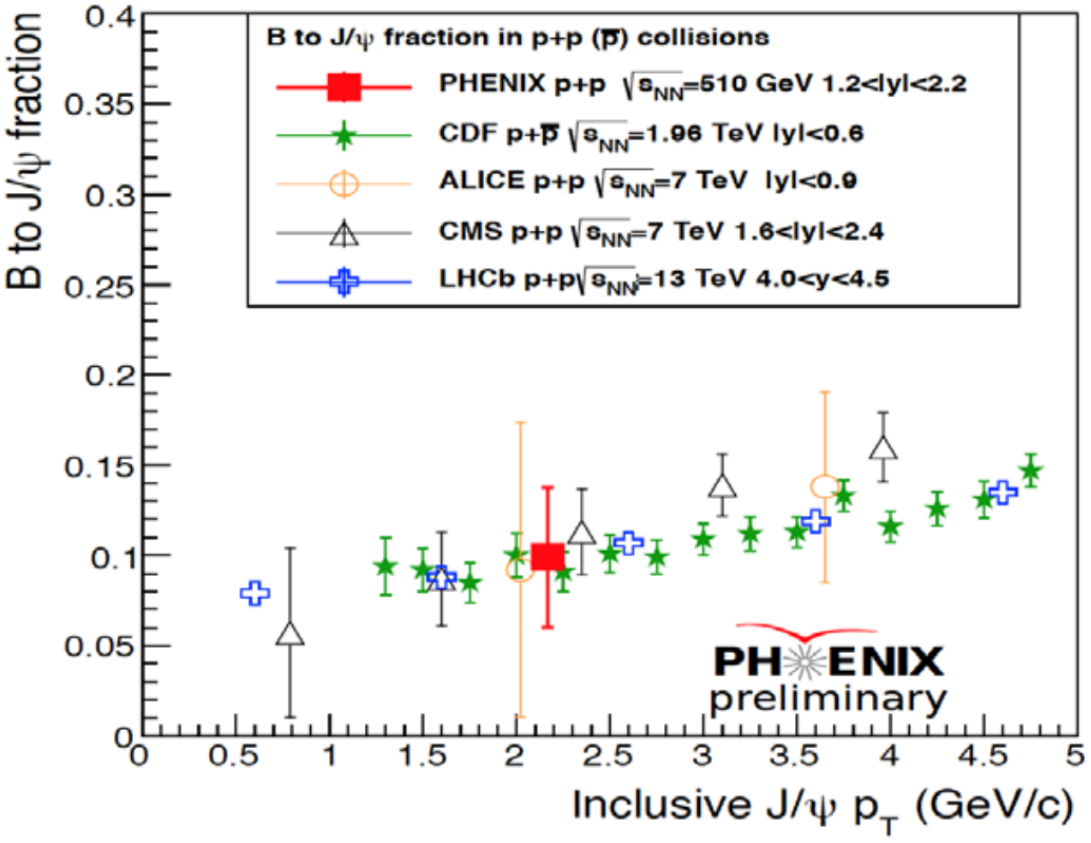



# B → J/ψ in p+p at 510GeV

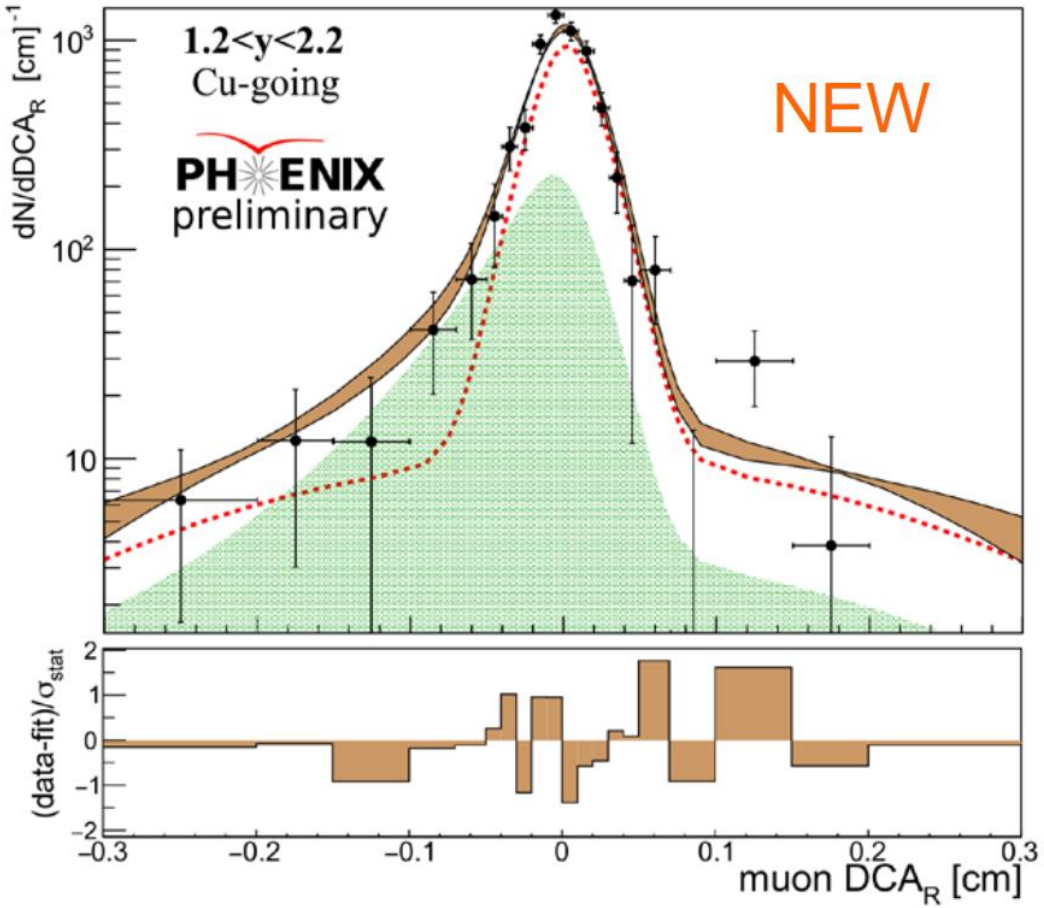
measure and unfold all components




fraction consistent with other measurements at different energies

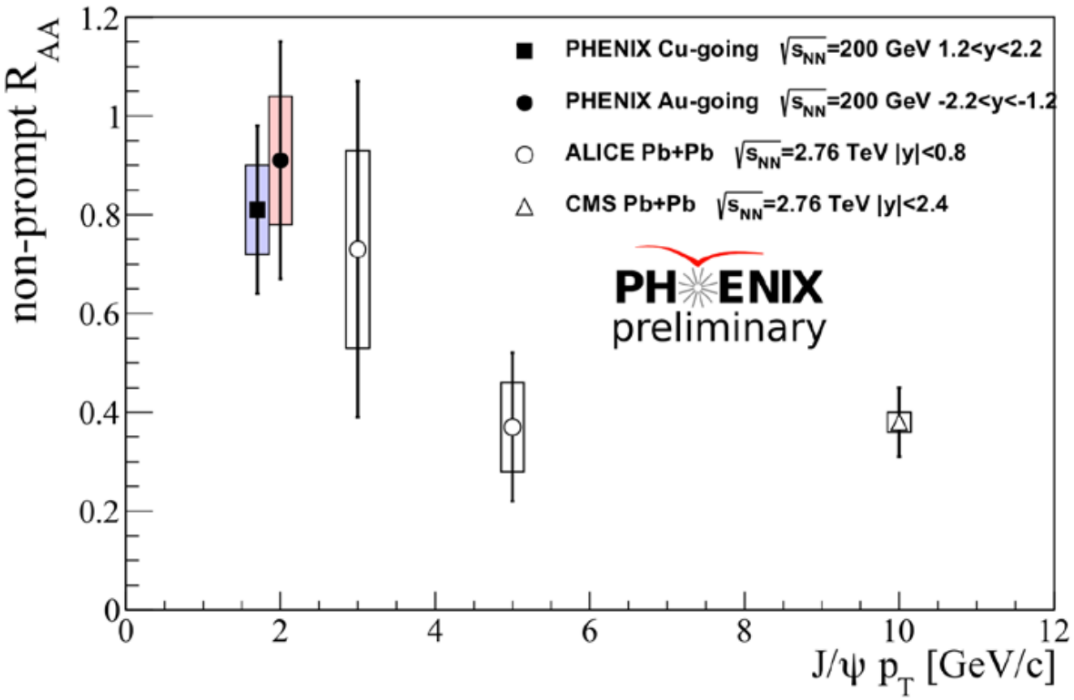


# B → J/ψ in Cu+Au at 200 GeV




Calculate $R_{AA}$ by dividing B → J/ψ fractions in Cu+Au and p+p

$$R_{AA}^{B\to J/\psi} = \frac{F_{B\to j/\psi}^{AA}}{F_{B\to j/\psi}^{pp}} R_{AA}^{J/\psi} = \frac{F_{B\to j/\psi}^{AA}}{0.1} R_{AA}^{J/\psi}$$




B-mesons is less suppressed than J/ψ?

# Direct photons in Au+Au

Direct photons don’t interact.

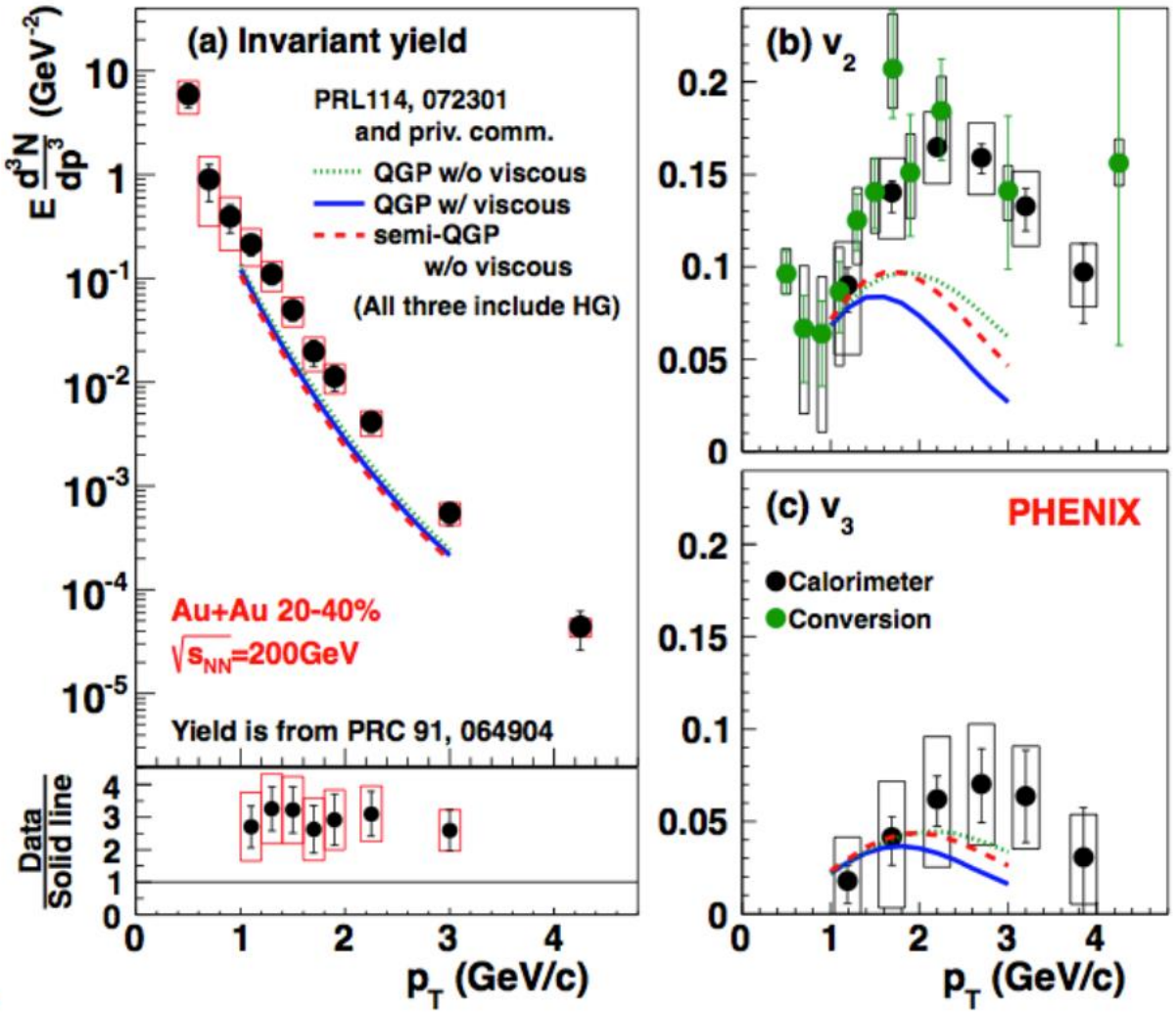
Provide signal from whole event evolution,
from the  the earliest time to the final stages of the collision.

Measurement is challenging due to large background.
PHENIX uses two different methods of direct (and inclusive) photon measurement for consistency check:

- conversion-based method (from di-electron invariant mass)
- EMCal-based method (clusters with CPV and shower shape cuts)

# Direct photon flow and yield

arXiv:1509.07758




Yield and $v_2$ is large compared to prediction of hydrodynamic models

Simultaneous description of large yield and large flow is difficult.

Many more photons need to come from late stages of the collision, when flow has developed.

# Conclusions

- The PHENIX experiment has measured jets in p+p, d+Au, and Cu+Au collisions at $\sqrt{s}$ = 200 GeV.
  - Significant enhancement of jets in peripheral d+Au collisions is observed. Can be interpreted as “nucleus probing a nucleon”.
  - In central Cu+Au collisions jets are suppressed by a factor of ~2. A hint of enhancement in most peripheral?
- In p+A $\psi'$ suppression is larger than that of J/$\psi$ in Au-going direction, and same in p-going direction. Very strong $\psi'$ suppression at low $p_T$. Indicates importance of quarkonia breakup by co-movers.
- Measured B → J/$\psi$ fraction in p+p collisions is consistent with that at different $\sqrt{s}$ Small modification in Cu+Au.
- Direct photons yield and flow are larger than expected from models.