Heavy Flavor Results in Cold Nuclear Matter from PHENIX

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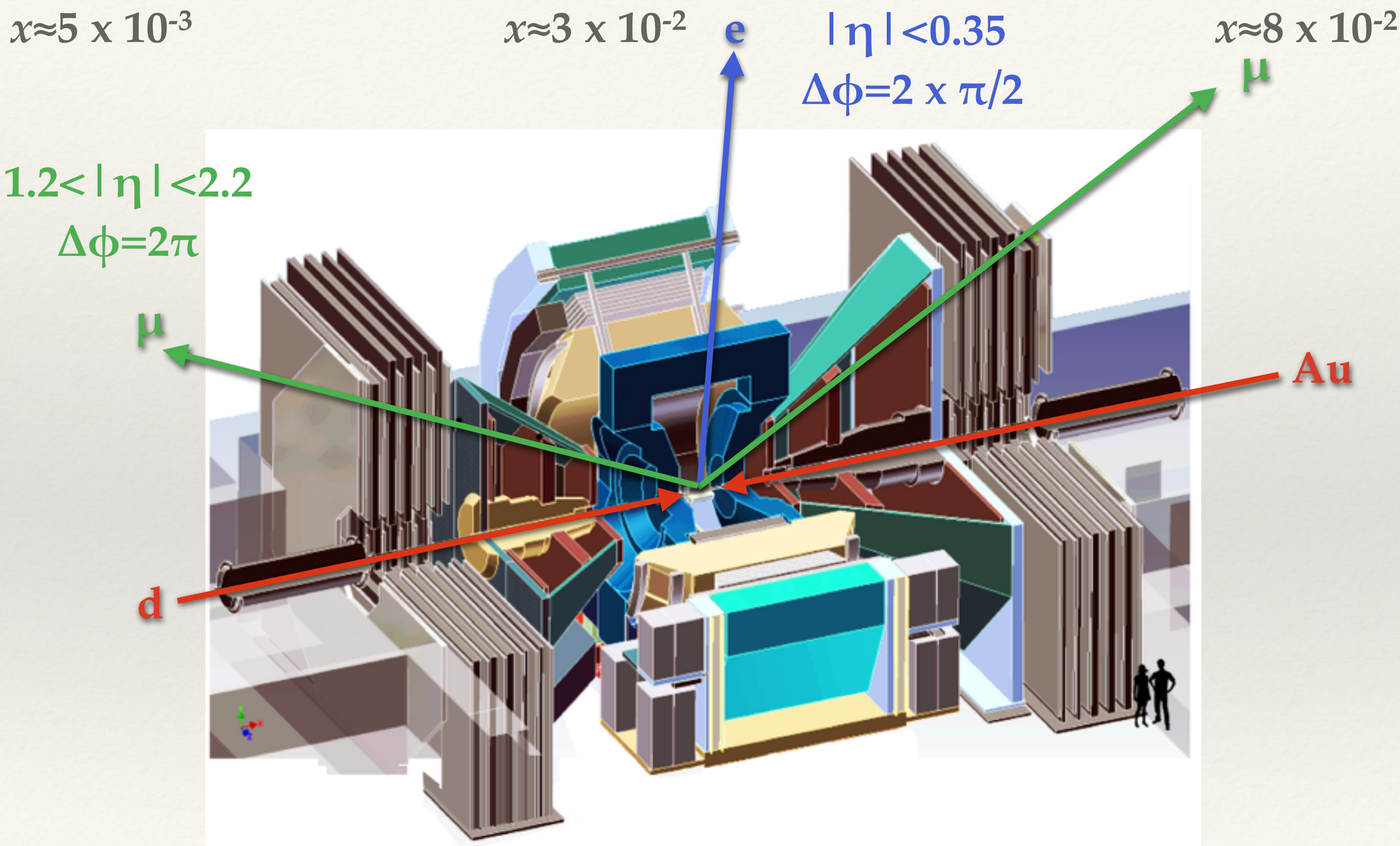
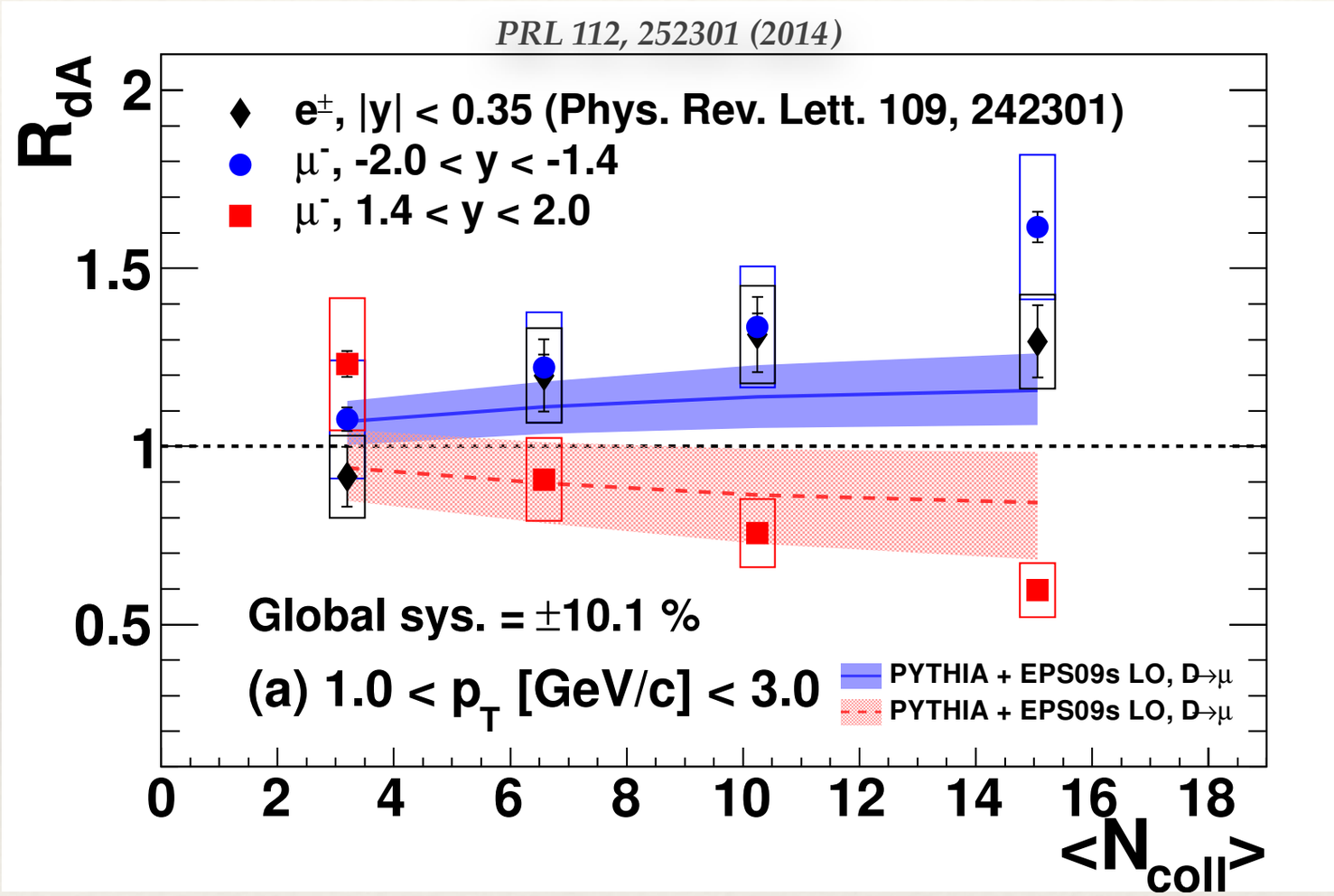
For the PHENIX Collaboration
IS 2014

PHENIX


$x \approx 5 \times 10^{-3}$
$x \approx 3 \times 10^{-2}$
e
$|\eta| < 0.35$
$\Delta\phi = 2 \times \pi/2$
$x \approx 8 \times 10^{-2}$
μ
$1.2 < |\eta| < 2.2$
$\Delta\phi = 2\pi$
μ
Au
d

Open Heavy Flavor in d+Au



Leptonic Decays of HF Hadrons

μ, -2.0 < y < -1.4

$x \approx 5 \times 10^{-3}$

anti-shadowing region

e, |y|<0.5

$x \approx 3 \times 10^{-2}$

shadowing/anti-shadowing transition

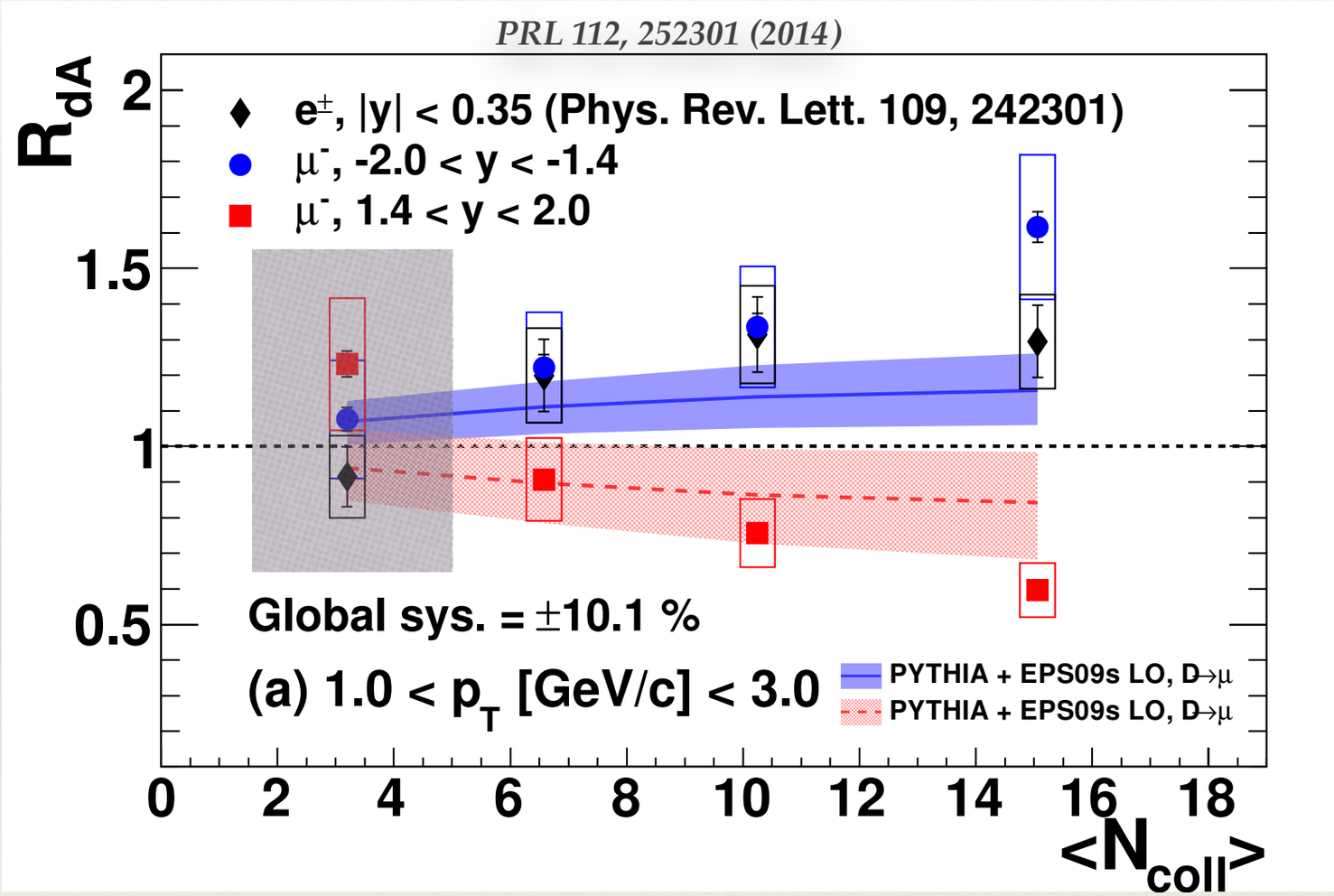
μ, 1.4 < y < 2.0

$x \approx 8 \times 10^{-2}$

shadowing region

NOTE: J/ψ decay contribution subtracted

Open Heavy Flavor in d+Au



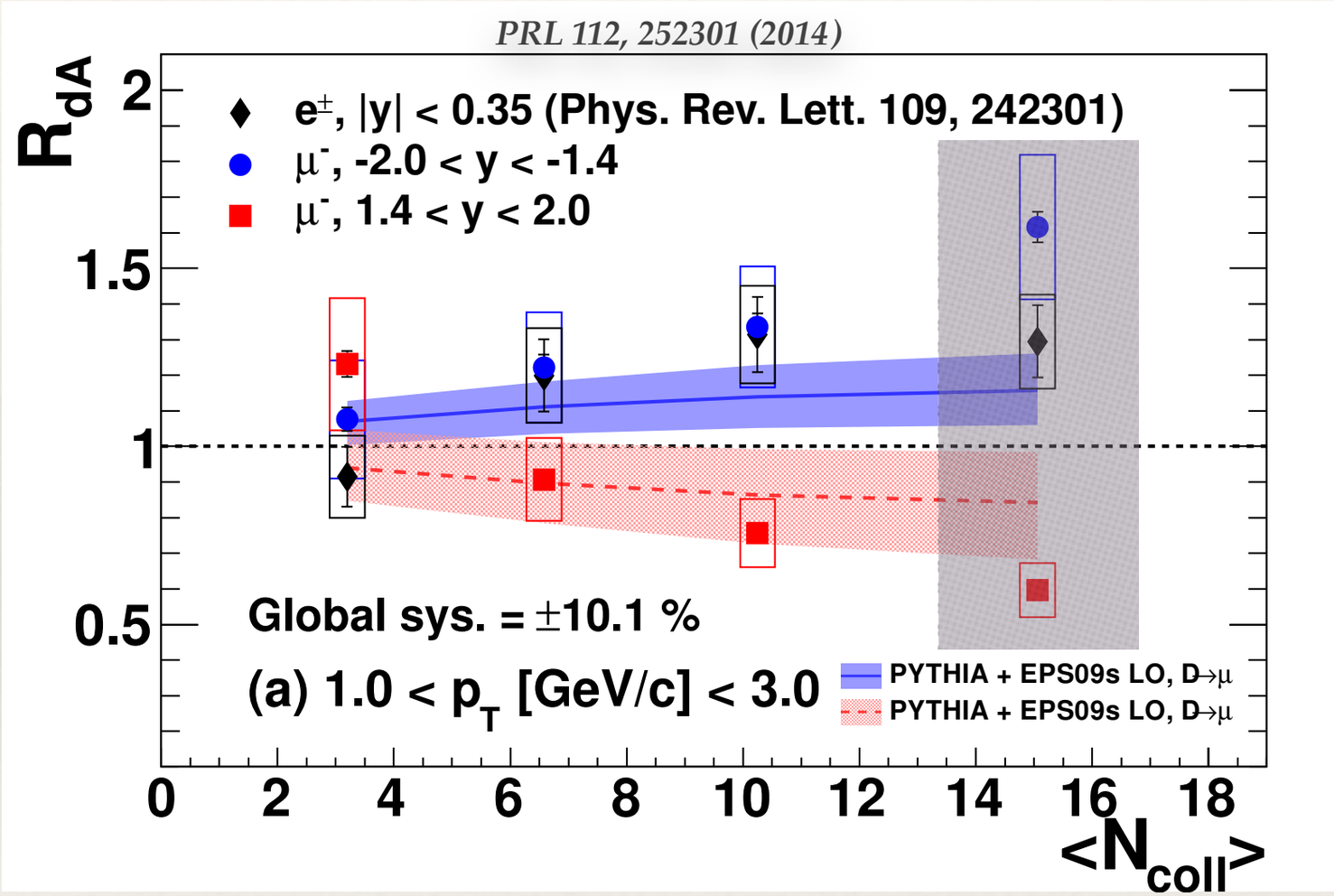
Peripheral Collisions

$R_{dA} \approx 1$

All rapidities!

NOTE: J/ψ decay contribution subtracted

Open Heavy Flavor in d+Au



Peripheral Collisions

$R_{dA} \approx 1$
All rapidities!

Central Collisions

$R_{dA} < 1$: Forward-y
consistent with nPDF modification

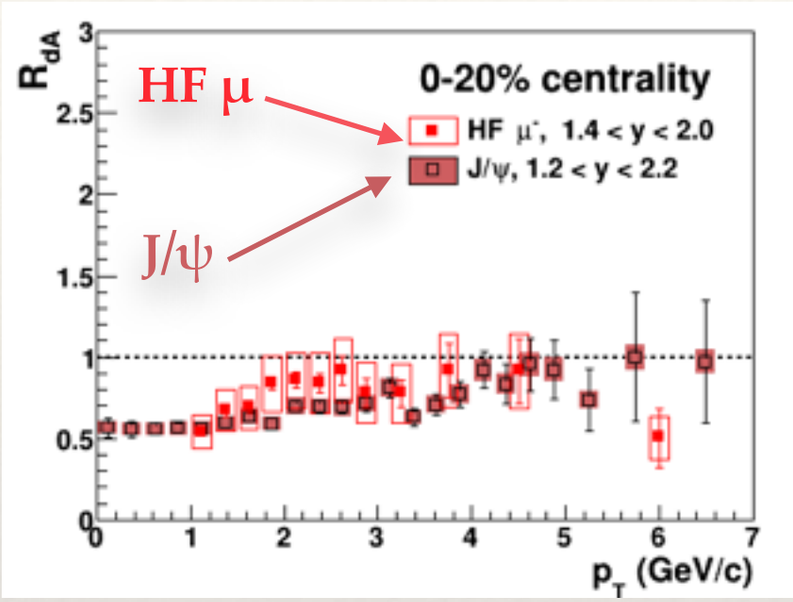
$R_{dA} > 1$: **Mid**/Backward-y
enhancement beyond nPDF modification

NOTE: J/ψ decay contribution subtracted

What about the J/ψ?

**Note different decay kinematics for single charm quark vs fully reconstructed cc state*

PRL 112, 252301 (2014) + PRL 111, 202301 (2013)



Forward Rapidity

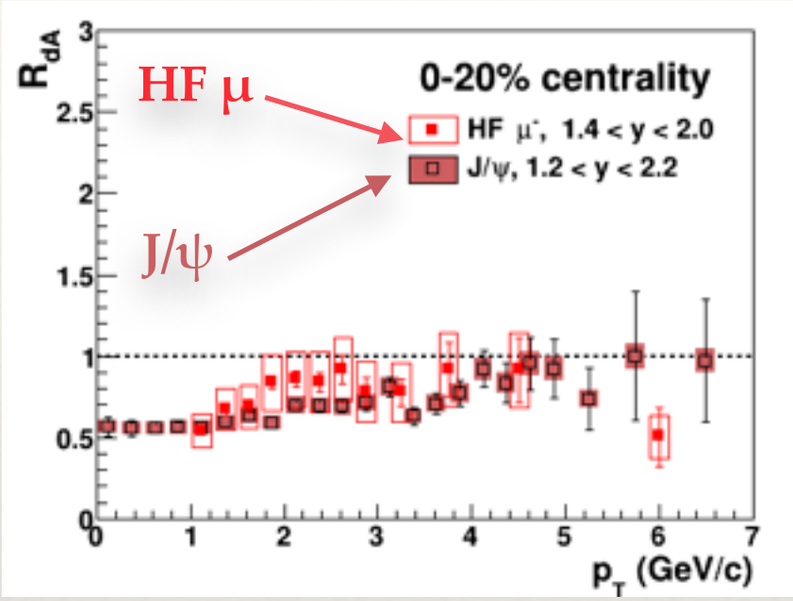
- SIMILAR behavior
- Short time traversing nuclei
- low co-mover density

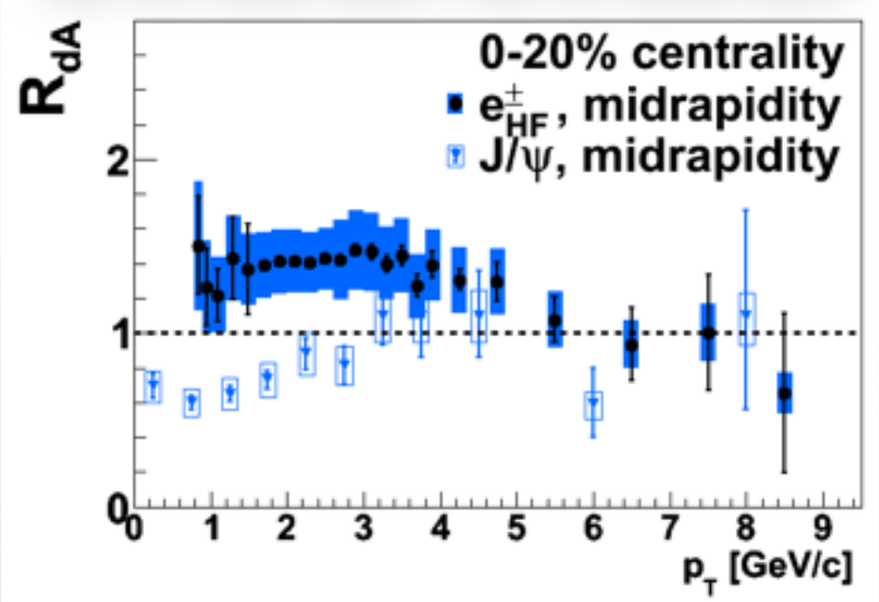
Same mechanism responsible for suppression

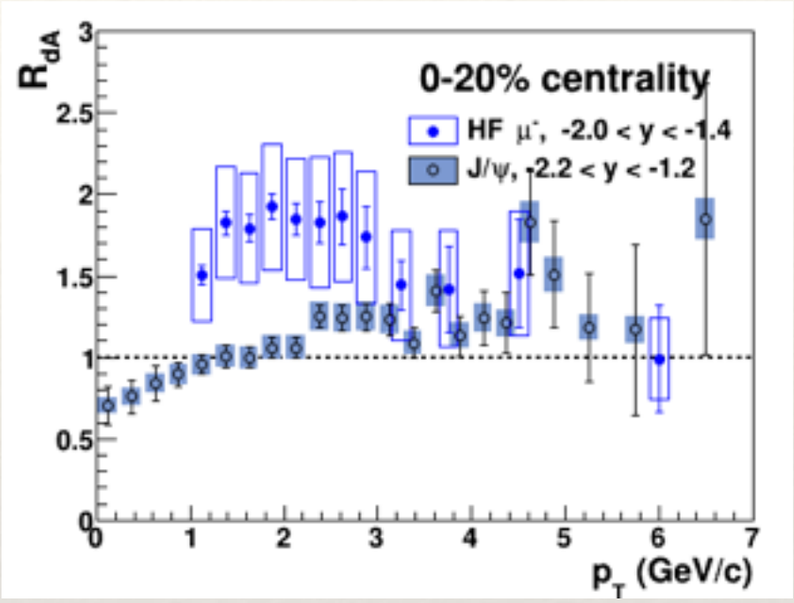
What about the J/ψ?

**Note different decay kinematics for single charm quark vs fully reconstructed cc state*

PRL 112, 252301 (2014) + PRL 111, 202301 (2013)







Forward Rapidity

- SIMILAR behavior
- Short time traversing nuclei
- low co-mover density

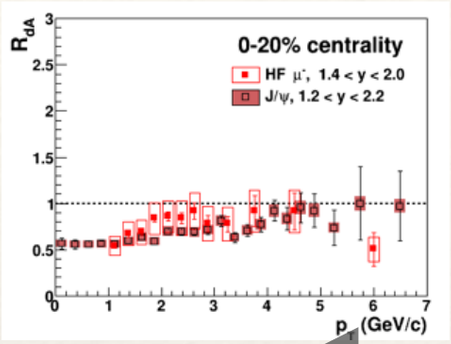
Same mechanism responsible for suppression

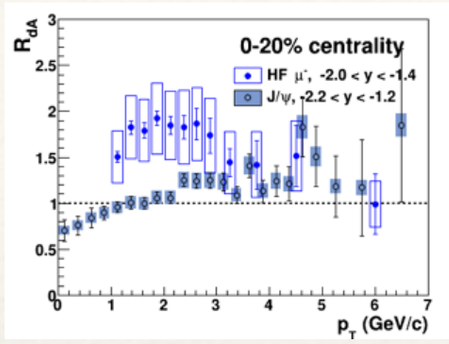
Backward & Mid Rapidity

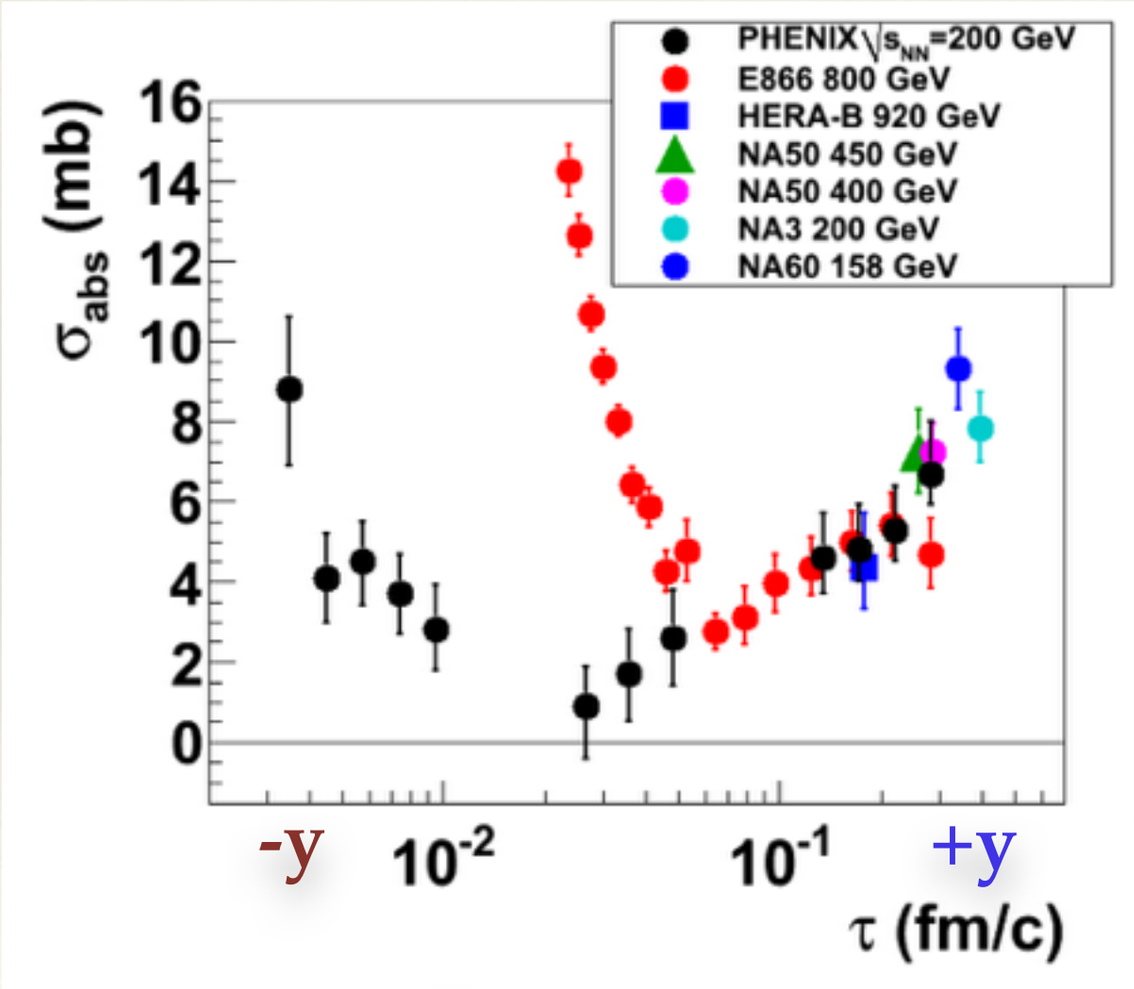
- DIFFERENT behavior
- **enhancement** in OHF **suppression** in J/ψ

Evidence for cc breakup effects!

J/ψ Nuclear Break-up







PRC 87, 054910 (2013)

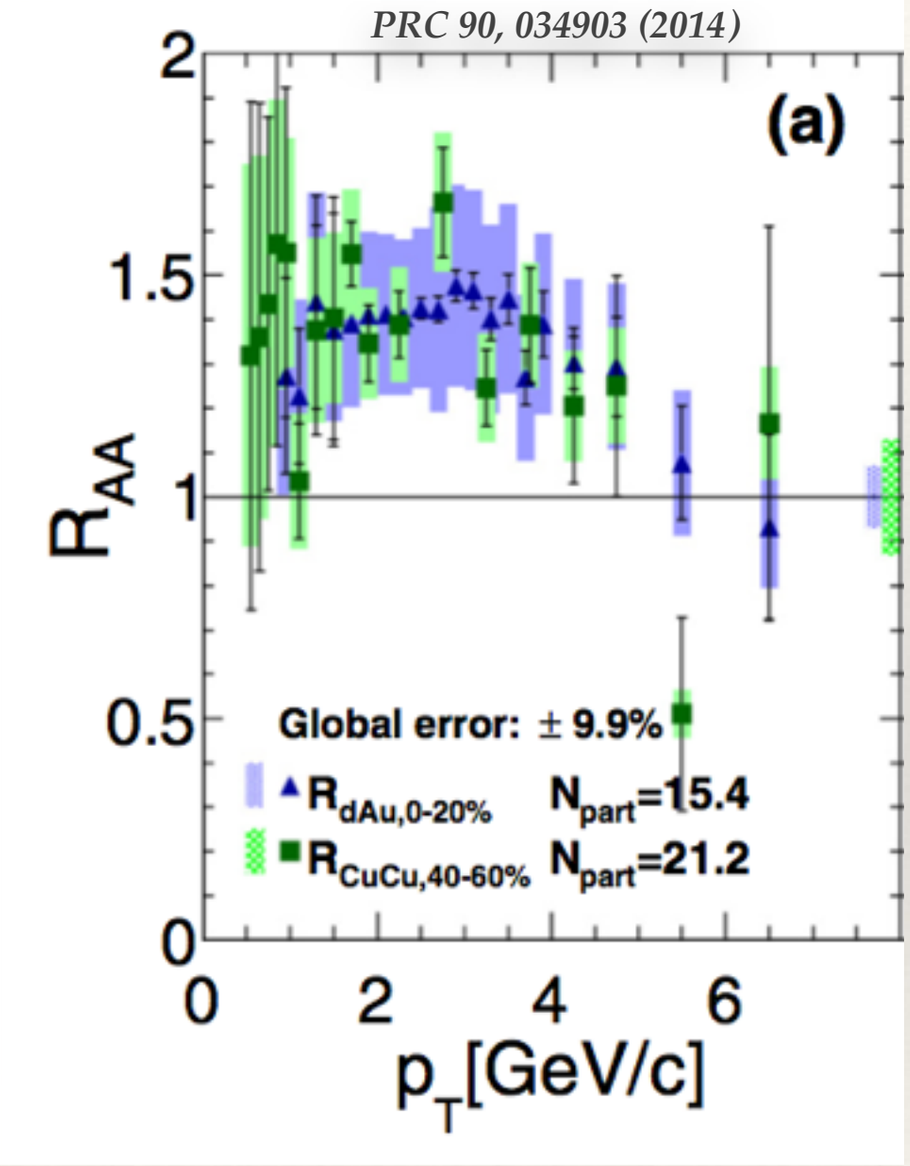
Extract break-up cross section from shadowing corrected data.

observe τ scaling for backward rapidity at RHIC

breaks down at forward rapidity

Further indication of different mechanisms at forward/ backward rapidity

What about different systems?



HF decay e measured in Cu+Cu @ |y|<0.5

Central d+Au

&

Peripheral Cu+Cu

- Different system
- Similar N_{part}
- Same enhancement pattern

Remarkable agreement!

What does theory have to say?

Forward Rapidity

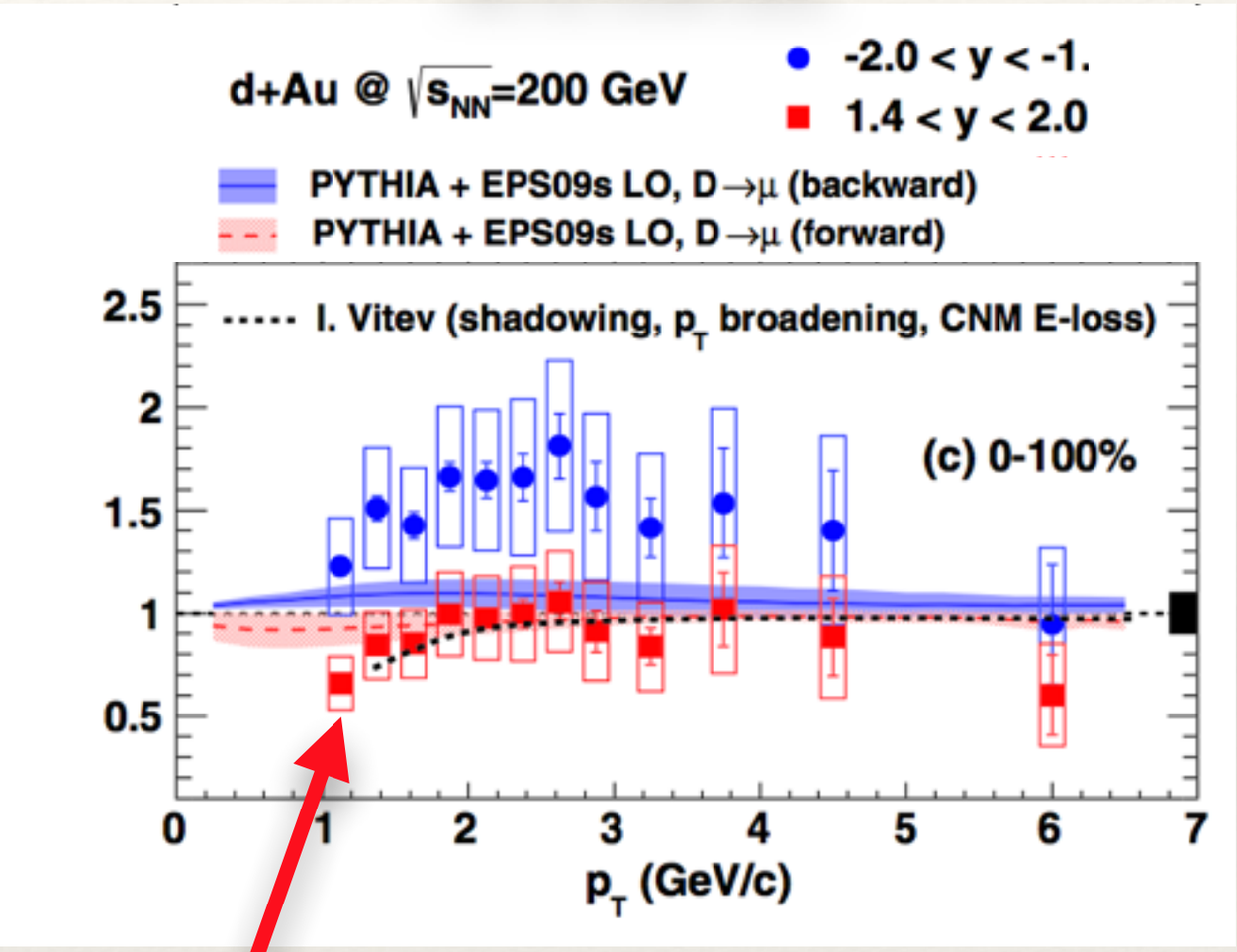
PRL 112, 252301 (2014)

PYTHIA + EPS09s LO

- Small suppression (shadowing)
- Good agreement w/ data

Vitev - shadowing + pT broadening + Initial State E-loss

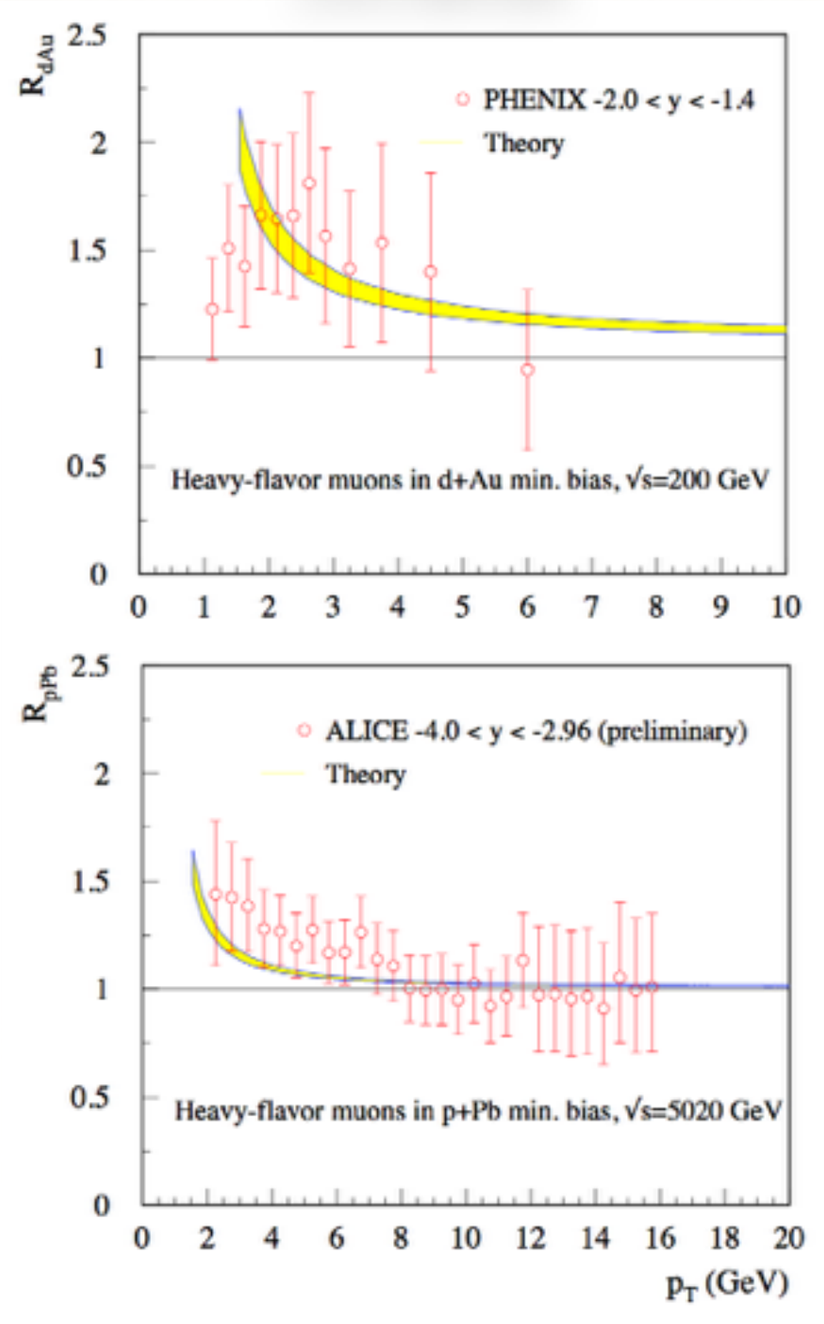
- Increasing suppression @ low-pT
- Better reproduces low-pT behavior seen in data



What does theory have to say?

Backward Rapidity

arXiv:1409.2494



Recent calculations from Kang *et al.*

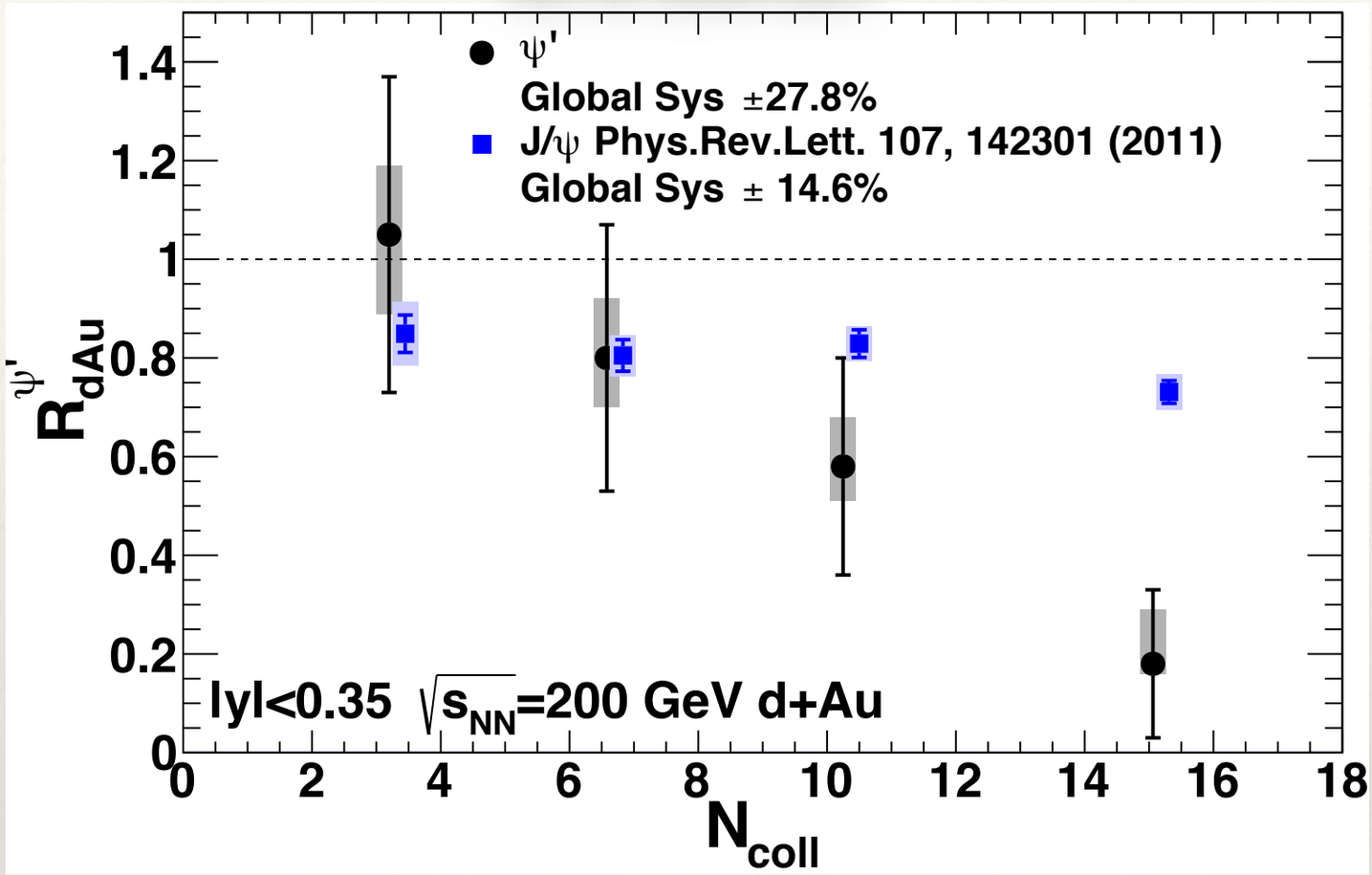
- *incoherent* multiple scattering at backward rapidity.
- In agreement w/ d+Au data
  - Increasing trend at low-pT not observed
  - Large uncertainties in data
- Also consistent w/ ALICE p+Pb data

What does theory have to say?

- Different behavior observed at different rapidities
- Different theories only applicable/effective in certain rapidity regions
  - nPDF modification, Gluon saturation, CNM E-loss at forward rapidity
  - HF decay lepton coherent E-loss as in J/ψ from Arleo *et al*?
  - Multiple scattering at backward rapidity
  - nPDF modification not strong enough at backward rapidity
  - Unsatisfying - makes predictions difficult
  - *Doesn't mean it's wrong.*
- Great similarity in trends observed at RHIC & LHC
  - Similar magnitude, but vastly different multiplicities.

ψ(2S) in d+Au

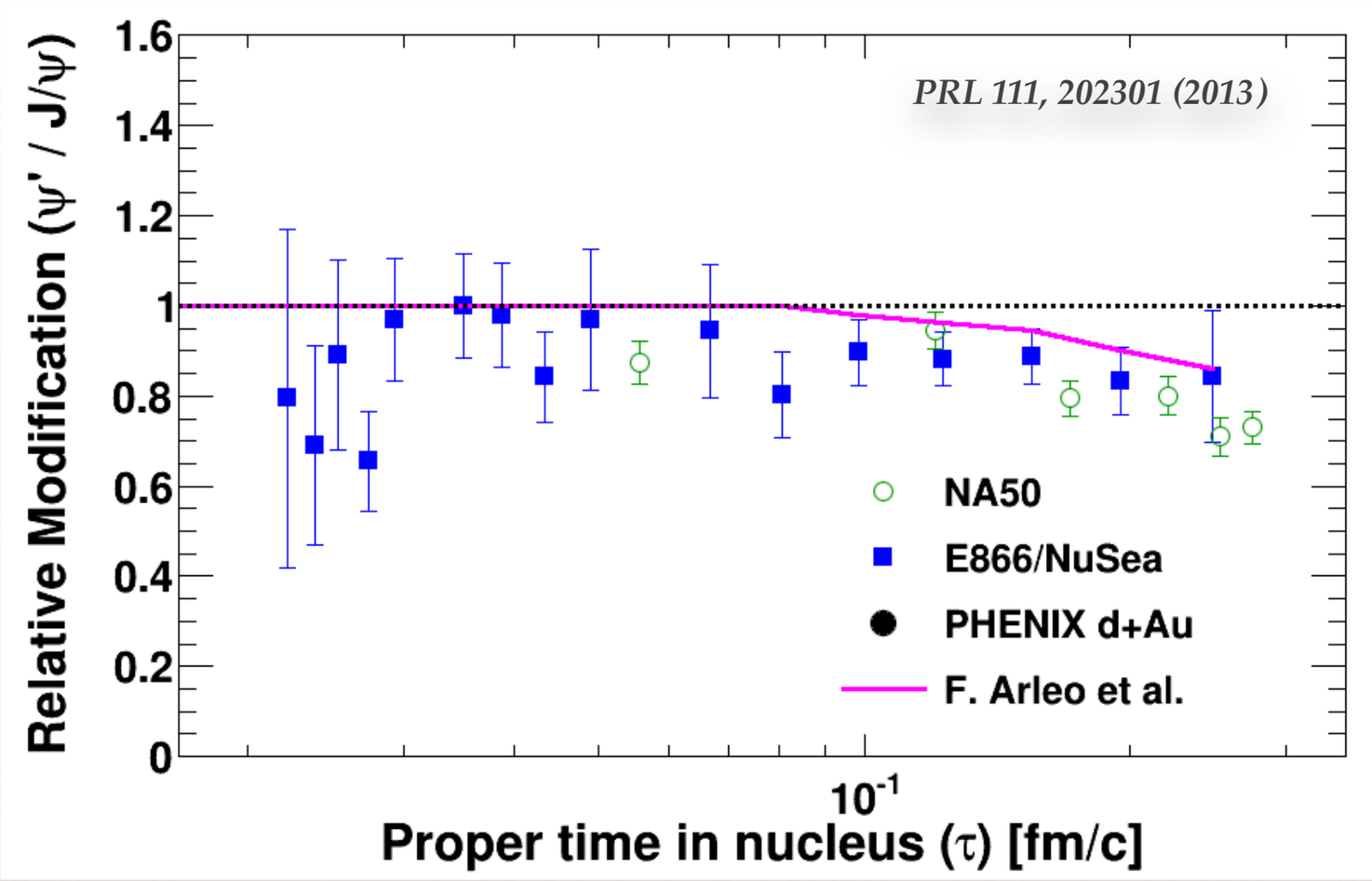
PRL 111, 202301 (2013)



ψ(2S) behaves differently than **J/ψ**

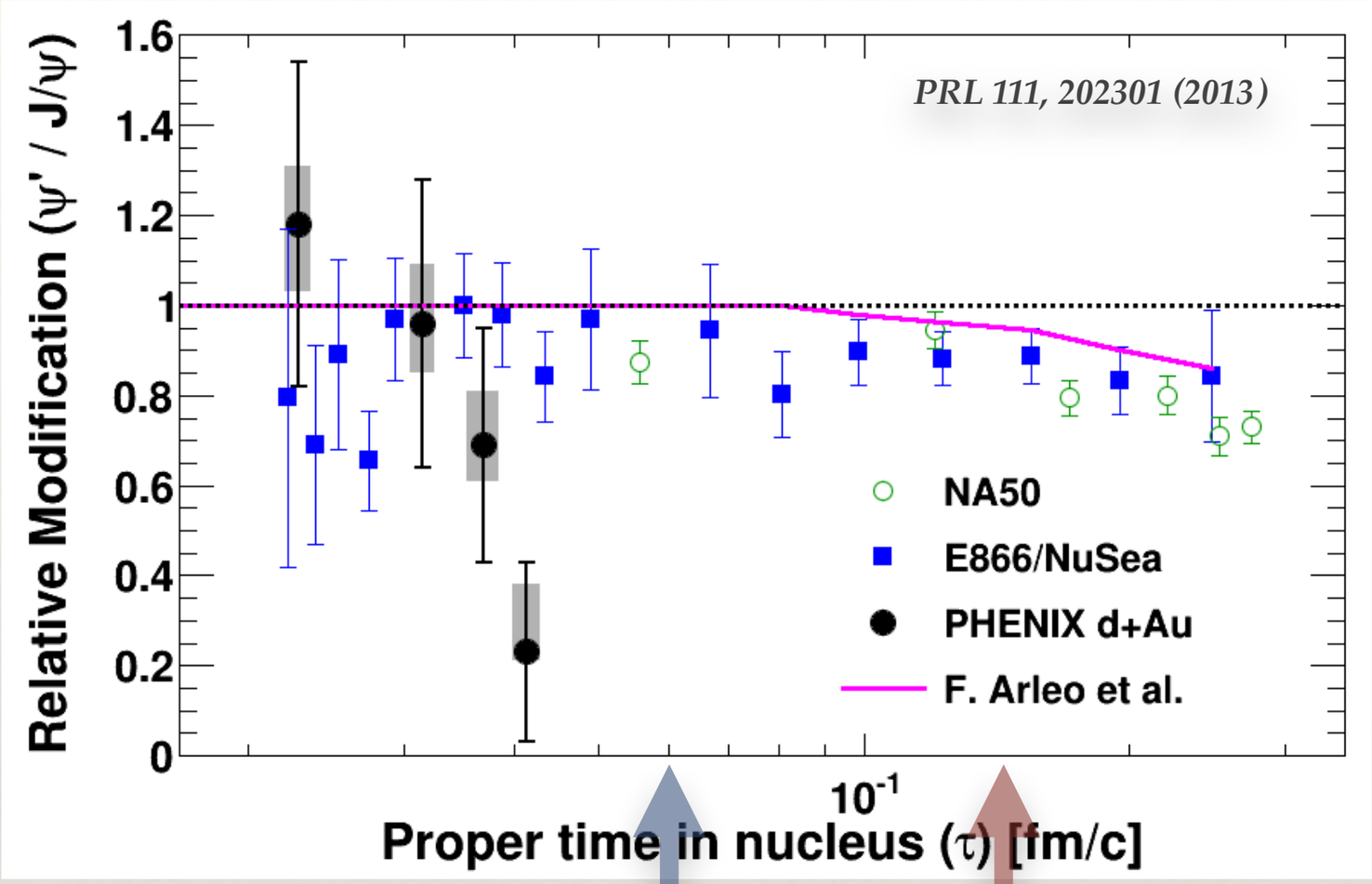
Would have expected similar contributions from shadowing.
Nuclear breakup?

ψ(2S) in d+Au



Low energy results from NA50 and E866 described by increased nuclear breakup due to expanding cc pair.

ψ(2S) in d+Au



cc formation time ≈ 0.05 fm/c

J/ψ formation time ≈ 0.15 fm/c

Low energy results from NA50 and E866 described by increased nuclear breakup due to expanding cc pair.

Increased nuclear breakup can not explain RHIC results.

The cc crosses the nucleus too quickly!

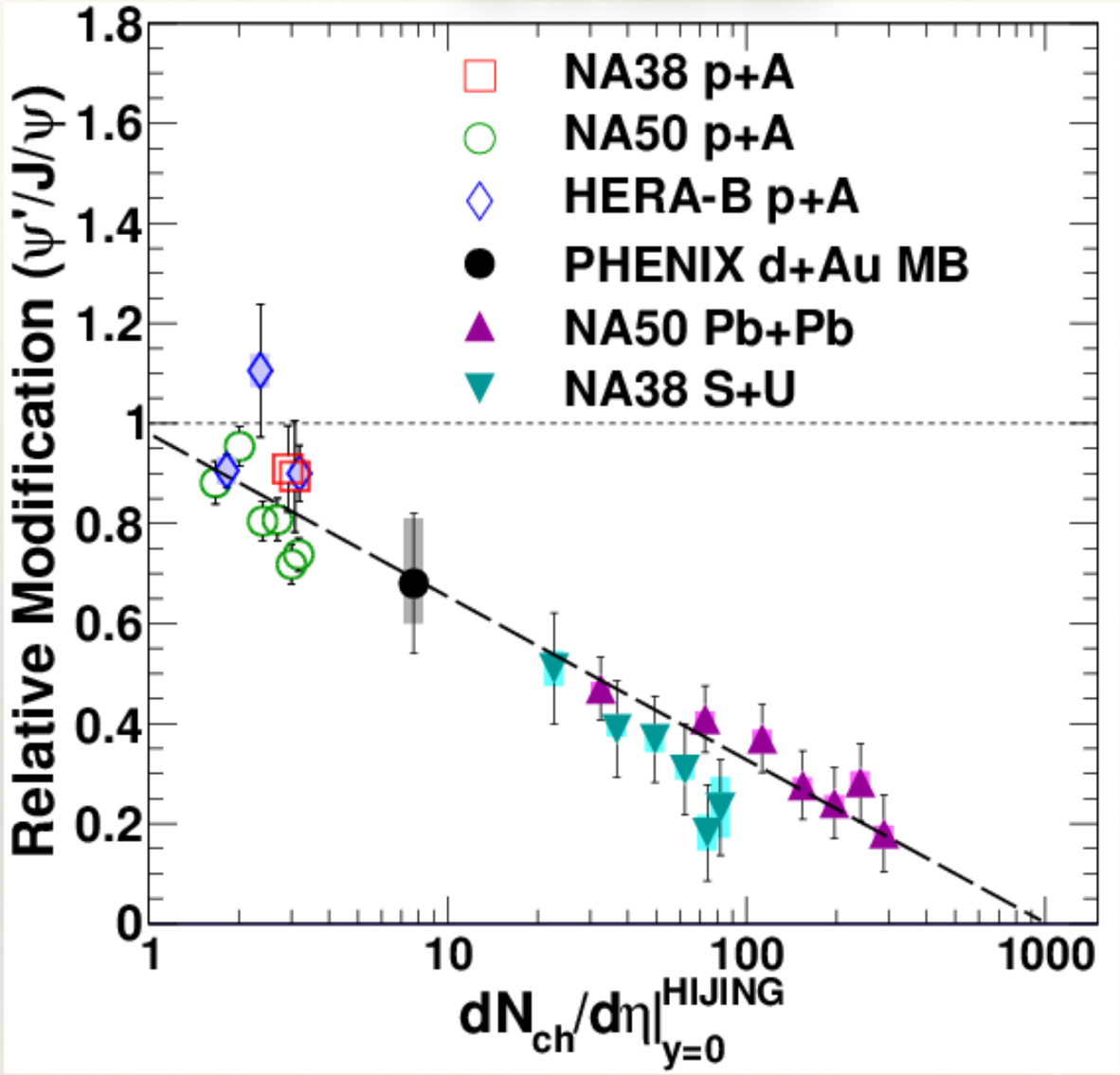
ψ(2S) in d+Au

Additional suppression not from "initial" state effect?

Possibly due to "final" state effect.

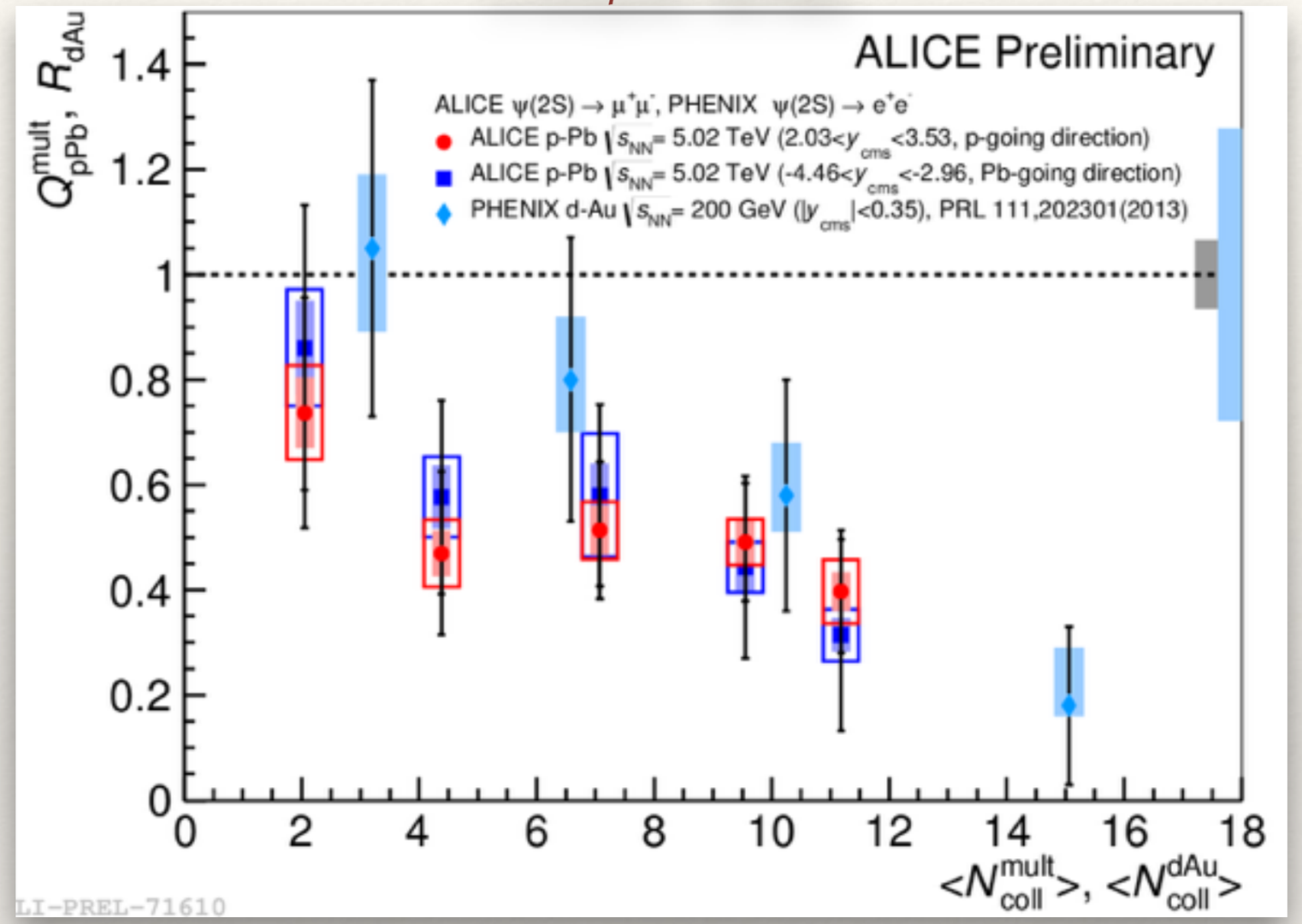
co-movers?
medium in d+Au?

PRL 111, 202301 (2013)



Confirmation at the LHC!

E. Scomparin - INT 2014



Similar trend & magnitude at LHC!

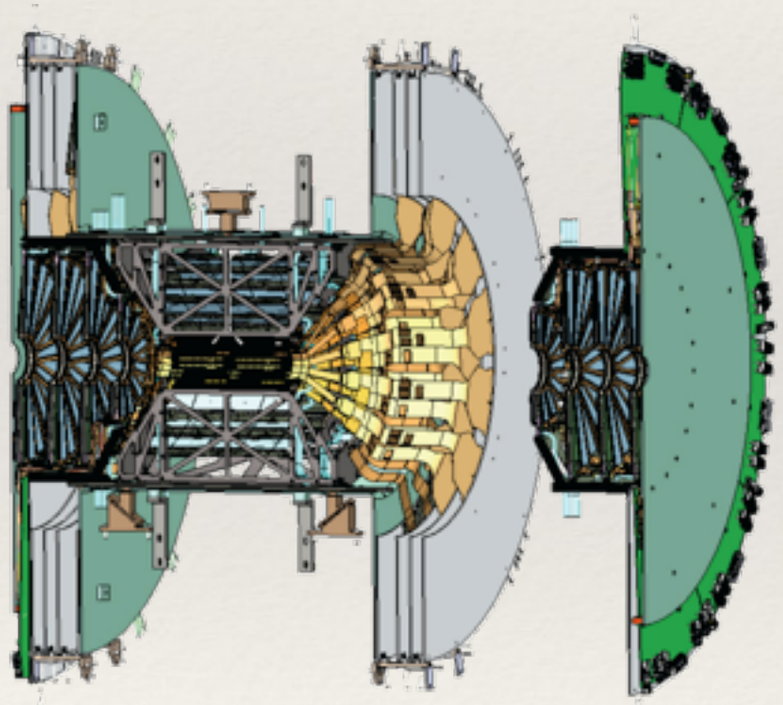
Measured over very different rapidity ranges.

Future Prospects

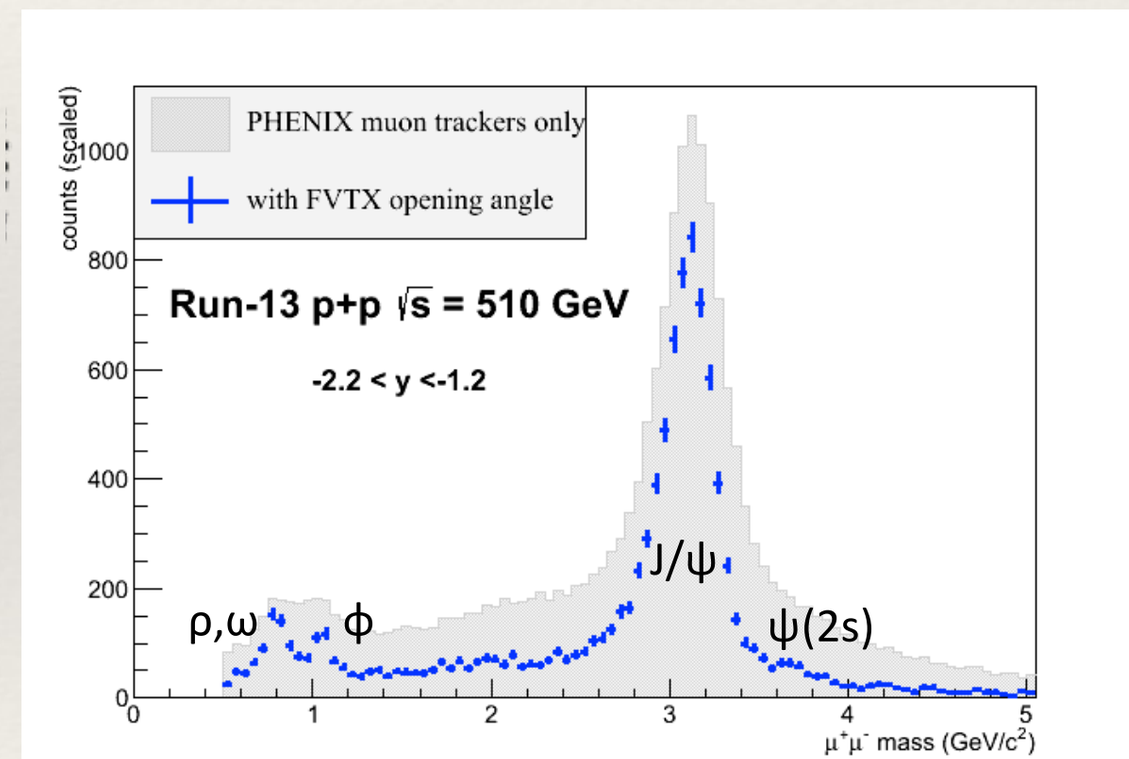
2015 RHIC run will include p+Au & p+Al

- FVTX will allow ψ(2S) at forward/backward rapidity
- p+Au won't have complication of **d** - easier comparison to LHC
- Including **p+Al** will study **A** dependence

Forward Silicon Vertex Detector



NIM A 755 (2014) 44



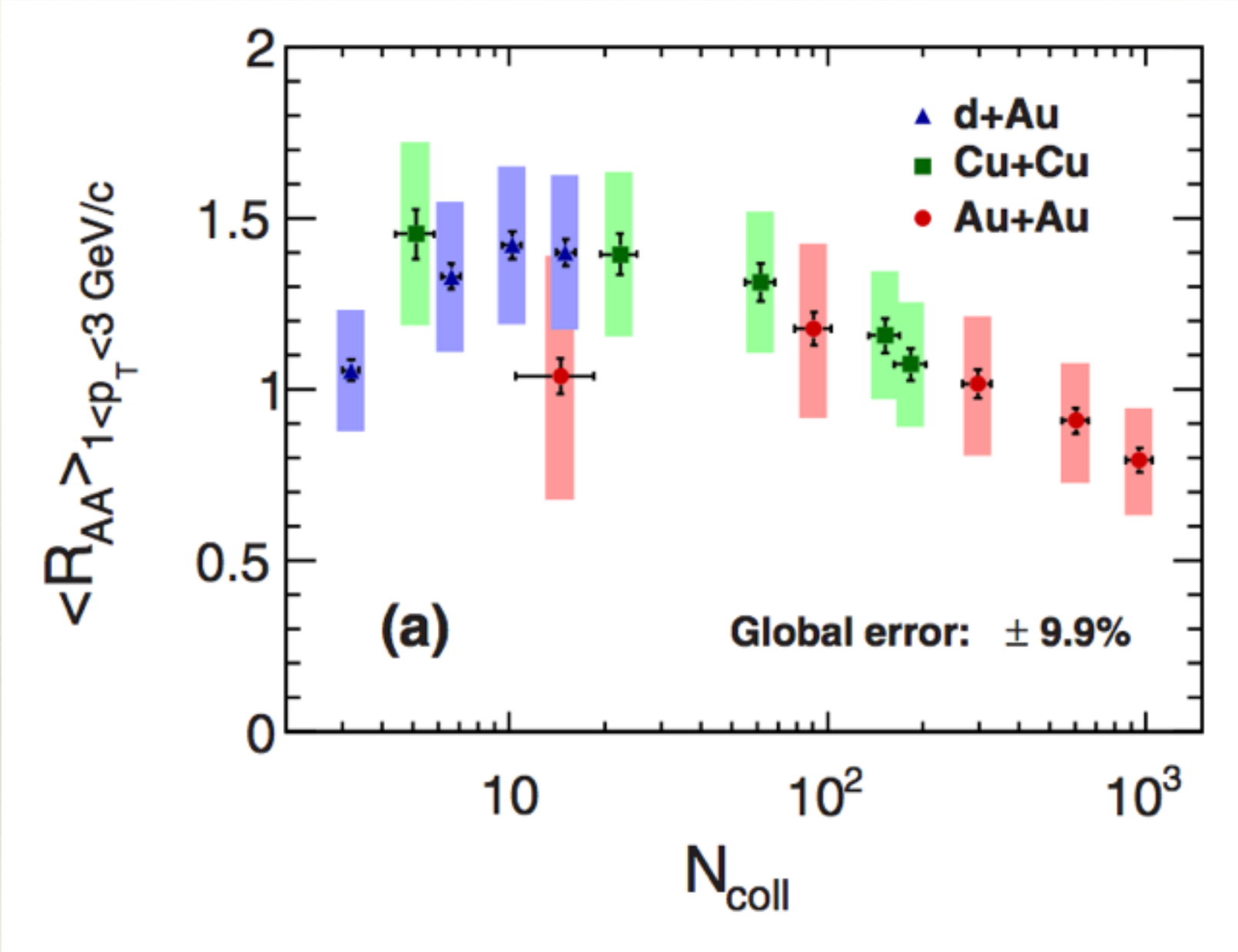
Opening angle in front of absorber: Greatly improved mass resolution and background rejection

Summary

- Open heavy flavor in d+Au:
  - Suppression at +y - *Consistent with nPDF modification, E-loss*
  - Enhancement at mid-y - B*eyond nPDF expectations. Cronin? Multiple scattering?*
  - Enhancement at -y - *Beyond nPDF expectations. Consistent with incoherent multiple scattering.*
- Quarkonia in d+Au:
  - J/ψ Suppression at +y - *Similar behavior to μ from open HF.*
  - J/ψ Small enhancement at -y - *Evidence for extra mechanism → nuclear break-up.*
  - ψ(2S) Suppression - *Unexplained by shadowing or break-up. "Final" state effect?*
- Will be taking p+A data this year.
  - Multiple species - Al, Au
  - Should help distinguish between effects by measuring A dependence.
  - FVTX will allow ψ(2S) measurement at forward/backward rapidities.

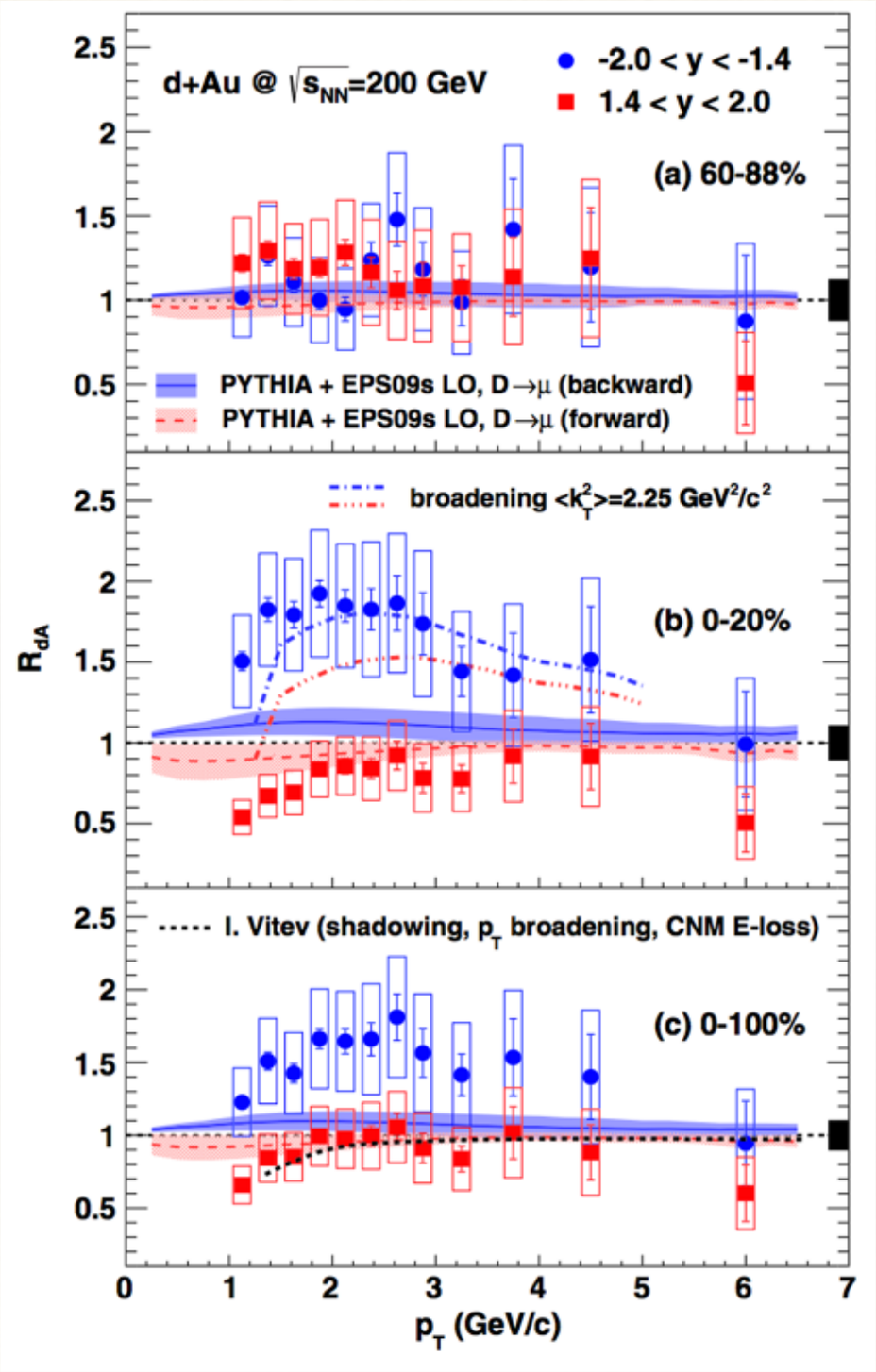
Thank You!

Collision System Evolution



Smooth evolution from enhancement to suppression

Open Heavy Flavor in d+Au



Consistent with 1

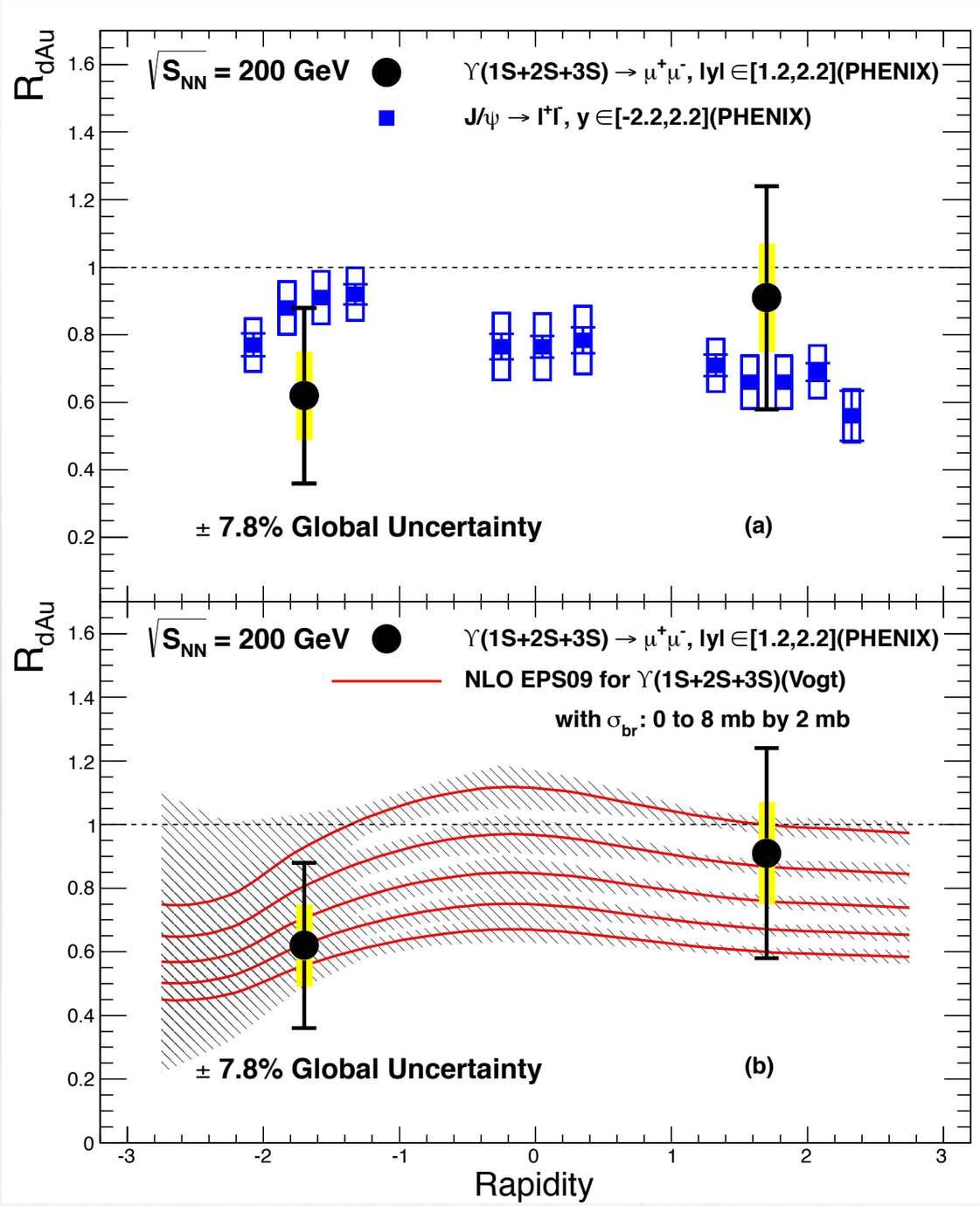
$<k_T^2>$ can't simultaneously reproduce forward/backward rapidity data

EPS09s & I. Vitev calculations reproduce forward rapidity data

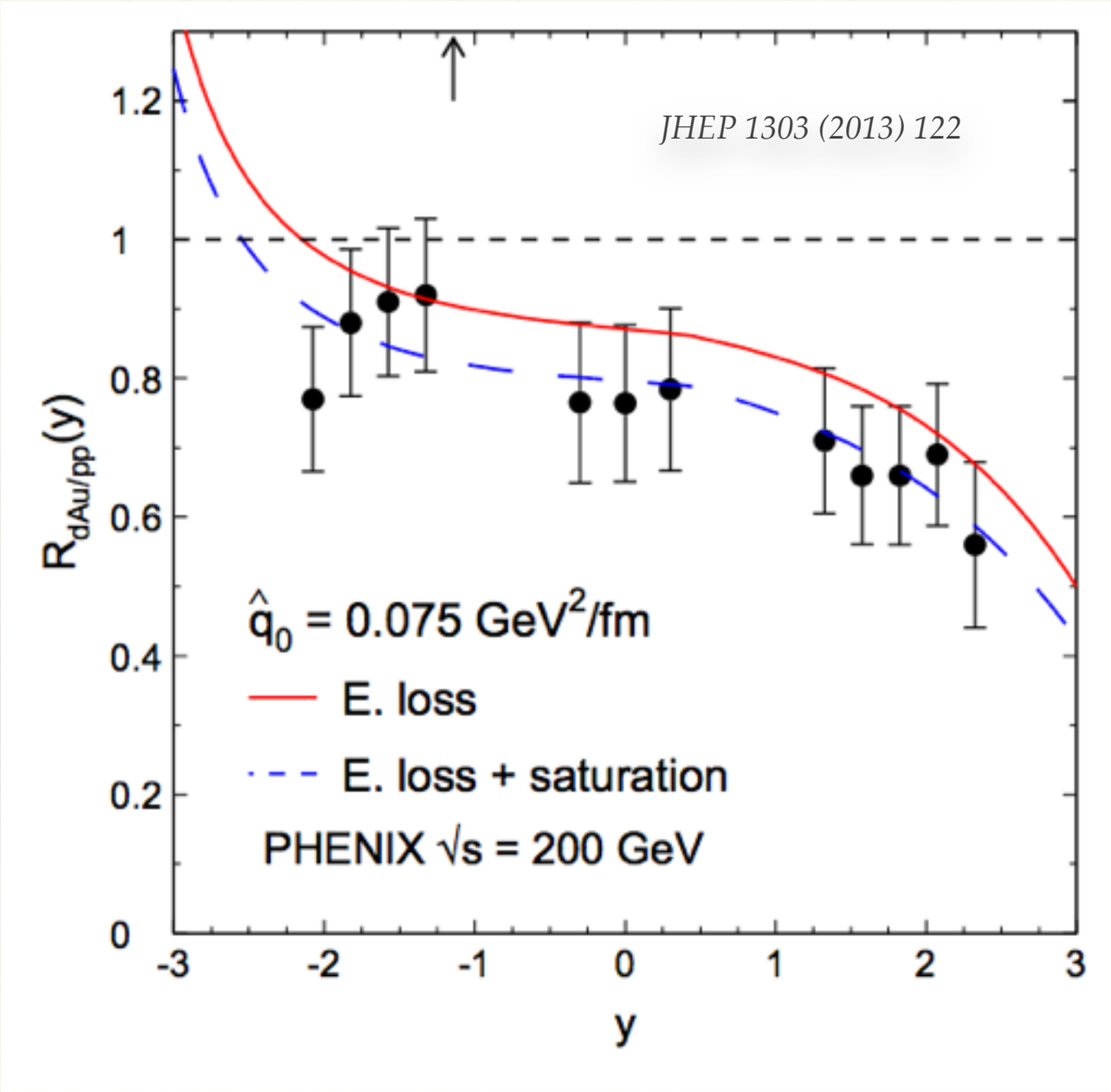
Υ(1S+2S+3S) in d+Au

Large uncertainties

Consistent with NLO EPS09



E-loss - Quarkonia



parton energy loss calculations from Arleo, Peigne able to describe J/ψ, ϒ data from SPS->LHC