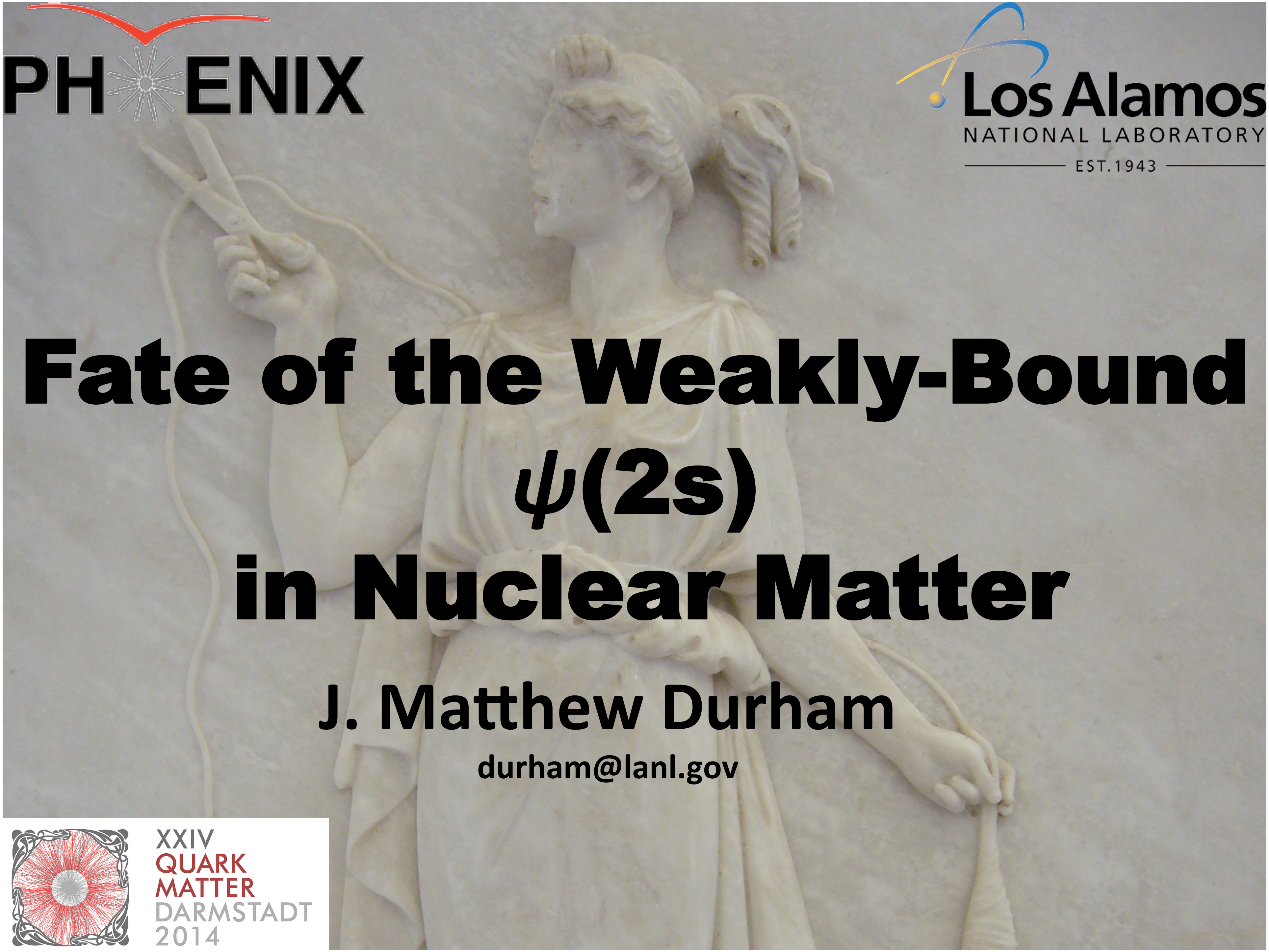

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NATIONAL LABORATORY
EST. 1943

Fate of the Weakly-Bound ψ(2s) in Nuclear Matter

J. Matthew Durham

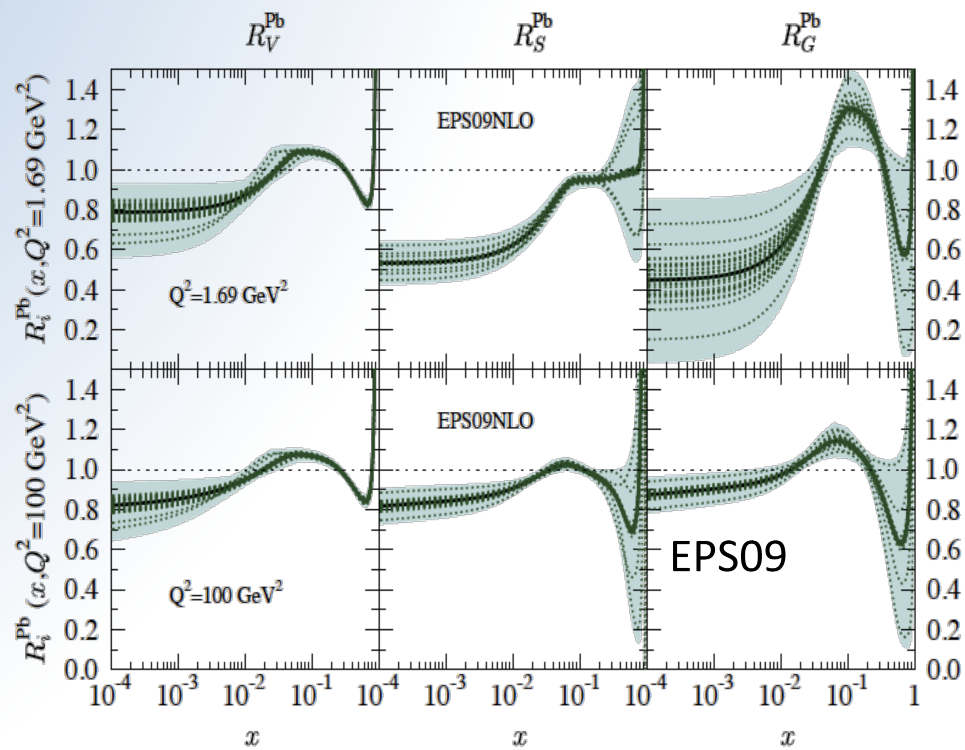
durham@lanl.gov

XXIV
QUARK
MATTER
DARMSTADT
2014

Effects in Nuclear Collisions-nPDF

Collisions of nuclei are *inherently different* from collisions of bare nucleons

- Nuclear PDF is modified: S,AS, EMC, saturation?
  - RHIC probes a unique crossover region in *x,* both shadowing and anti-shadowing regions easily accessible
  - Heavy quarks especially sensitive to gluon nPDF



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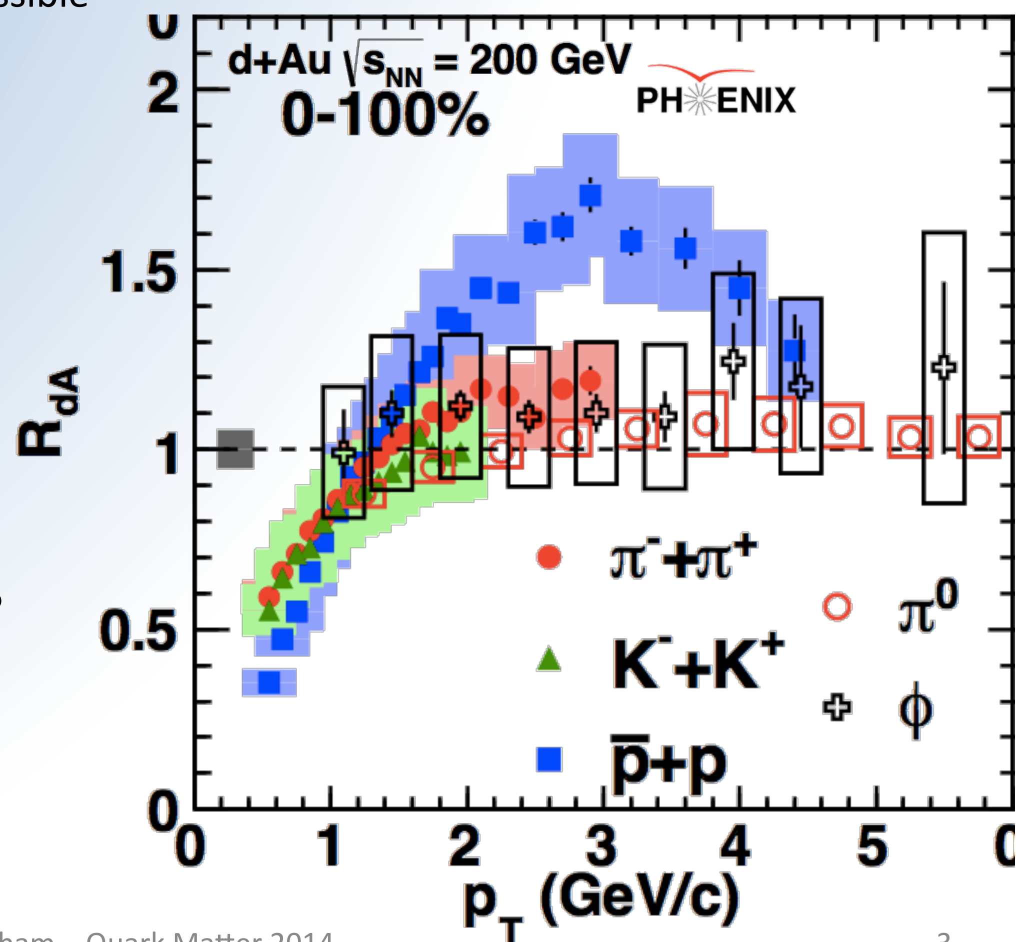
Effects in Nuclear Collisions-Cronin

Collisions of nuclei are *inherently different* from collisions of bare nucleons

- Nuclear PDF is modified: S,AS, EMC, saturation?
  - RHIC probes a unique crossover region in *x,* both shadowing and anti-shadowing regions easily accessible
  - Heavy quarks especially sensitive to gluon nPDF
- Partonic interactions in nucleus
  - Energy loss in CNM
  - kT kicks ("traditional" explanation of Cronin, but mass dependence?)
- Baryon enhancement, recombination?
- Possible hydrodynamic phenomena in d+A?

PRC 88 024906 (2013)

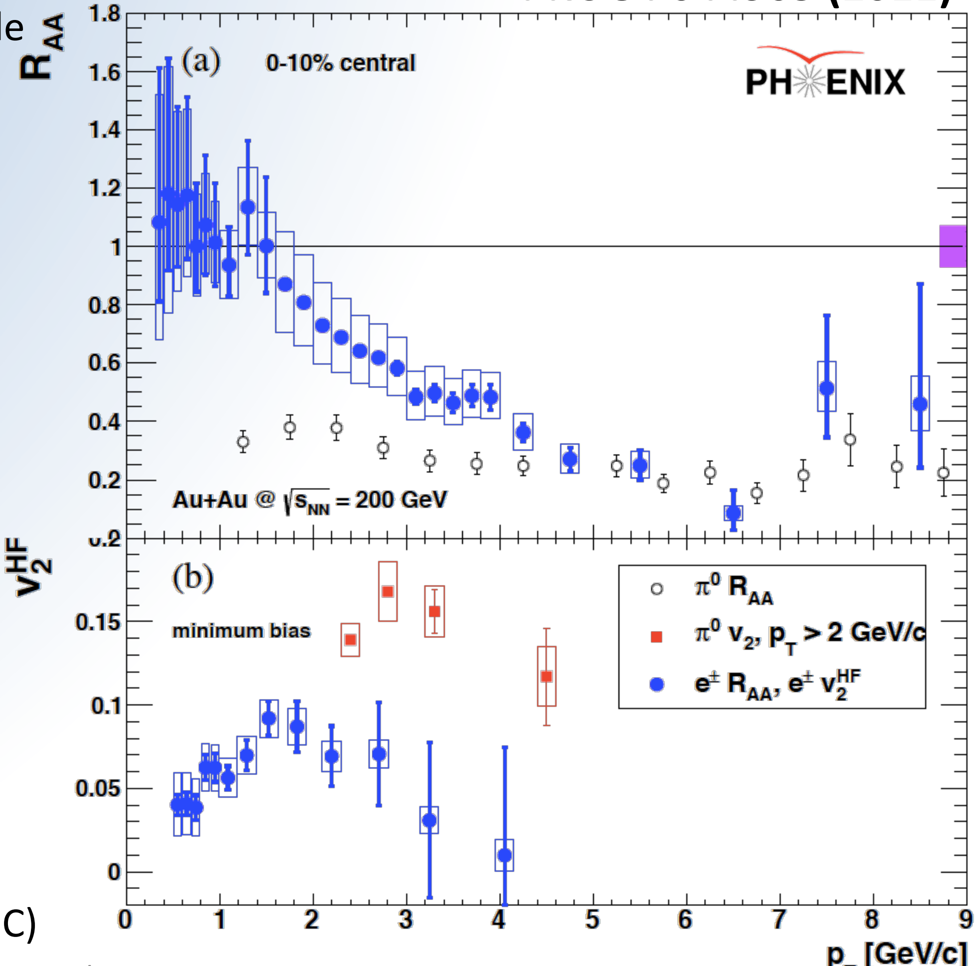


Effects in Nuclear Collisions-QGP

Collisions of nuclei are *inherently different* from collisions of bare nucleons

- Nuclear PDF is modified: S,AS, EMC, saturation?
  - RHIC probes a unique crossover region in *x,* both shadowing and anti-shadowing regions easily accessible
  - Heavy quarks especially sensitive to gluon nPDF
- Partonic interactions in nucleus
  - Energy loss in CNM
  - kT kicks ("traditional" explanation of Cronin, but mass dependence?)
- Baryon enhancement, recombination?
- Possible hydrodynamic phenomena in d+A?
- In A+A collisions, all of the above effects plus:
  - Strong charm flow and energy loss
  - Color screening in deconfined medium
  - Recombination (likely at LHC, maybe at RHIC)

PRC 84 044905 (2011)



Quarkonia at PHENIX

PHENIX

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Designed to measure quarkonia down to pT = 0 through dilepton decays at mid and forward rapidity:

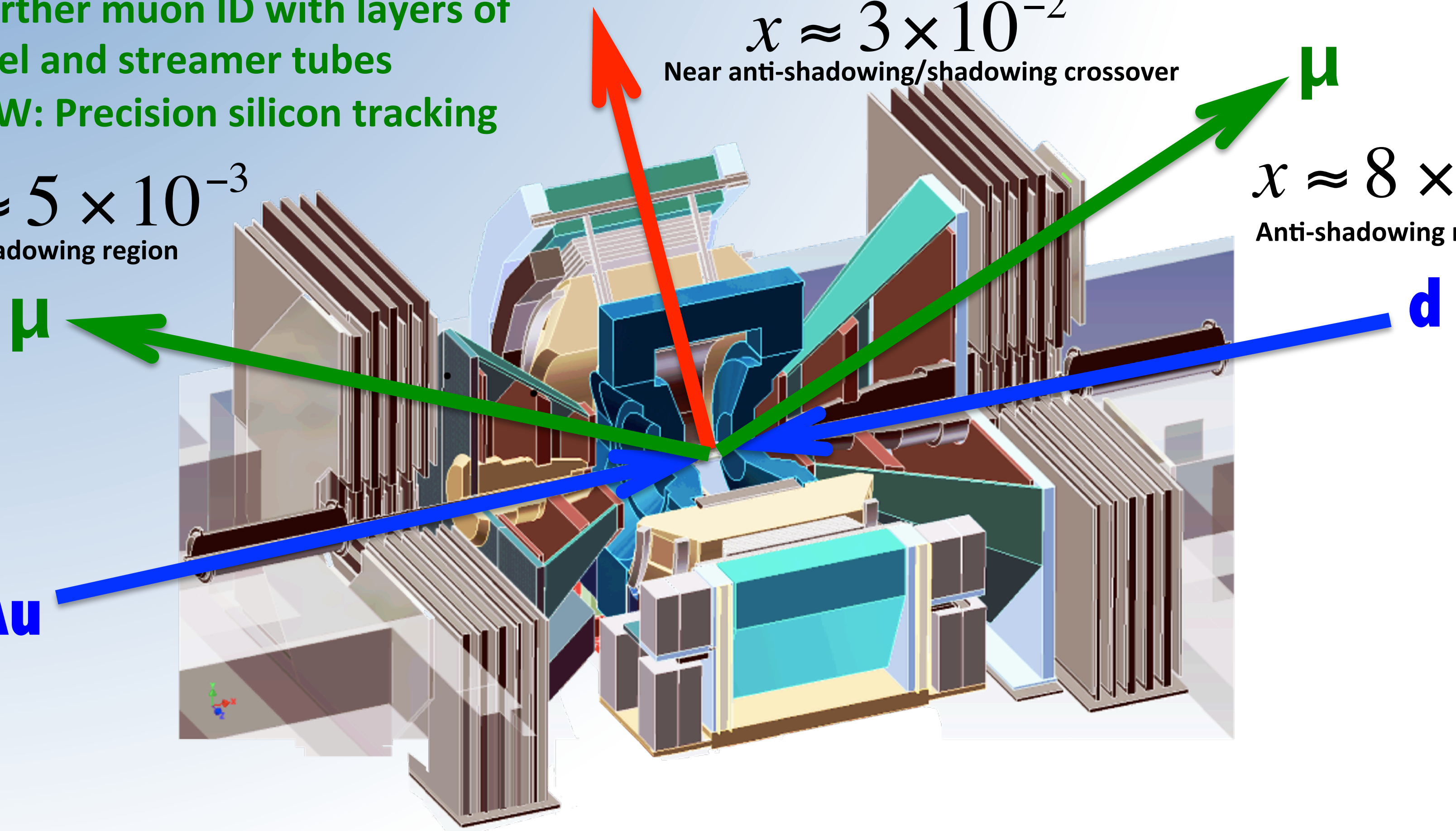
Muons: $1.2 < |y| < 2.2$,
-Tracked with wire chambers
-Further muon ID with layers of steel and streamer tubes
NEW: Precision silicon tracking

Electrons: $|y| < 0.35$,
-Tracked with DC,PC
-ID with RICH, EmCal

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

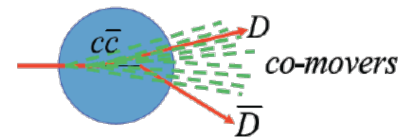
$x \approx 3 \times 10^{-2}$
Near anti-shadowing/shadowing crossover

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



Open HF versus J/ψ

Sensitive to same initial state effects: gluon shadowing, kT broadening, partonic energy loss in nucleus (details on open HF in S. Lim's talk)
BIG difference: nuclear breakup of charmonia bound states



*Keep in mind different kinematics for decay leptons from single charm quark versus fully reconstructed *cc* state

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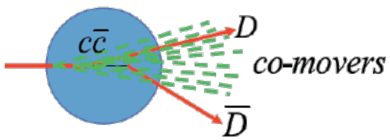

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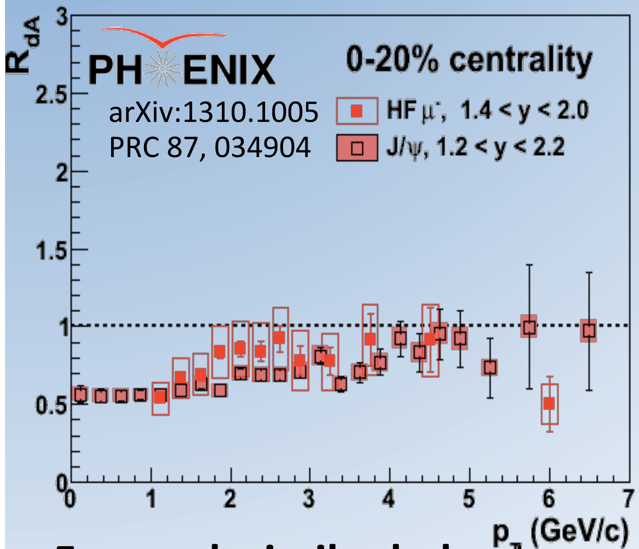

Forward: similar behavior
-Short time in nucleus
-Low co-mover density

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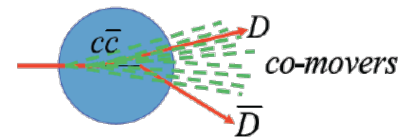

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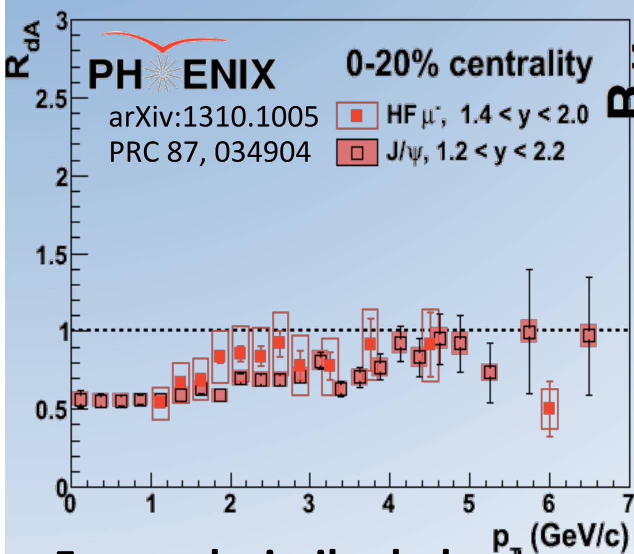

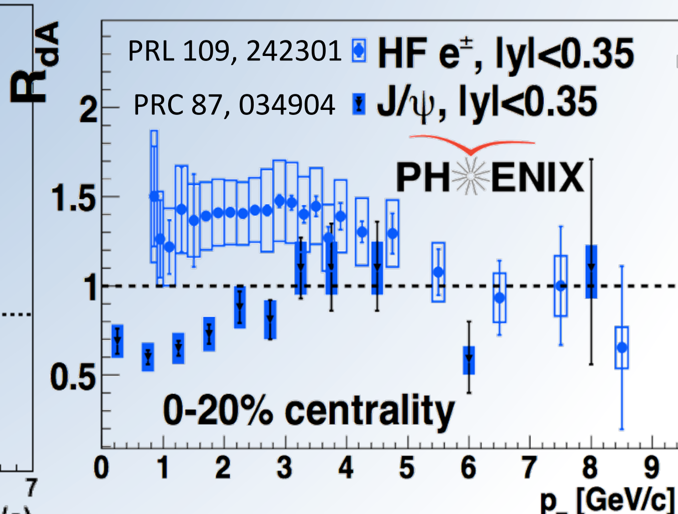

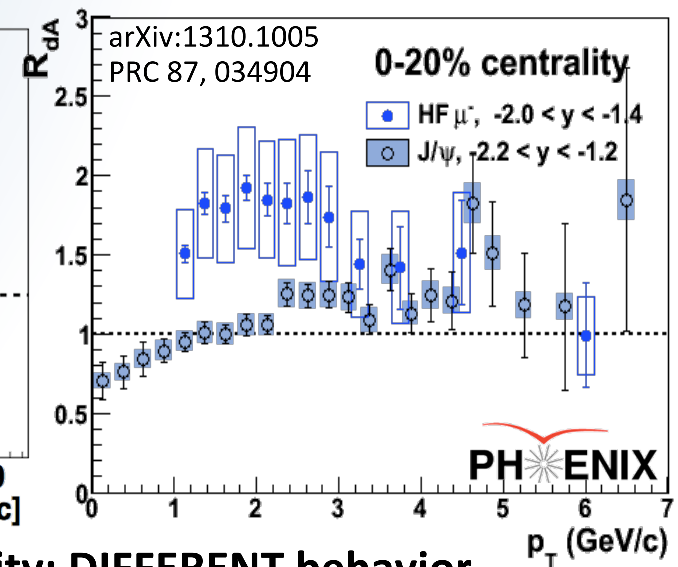

Forward: similar behavior
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Mid- and backwards rapidity: DIFFERENT behavior
enhanced open HF versus suppressed J/ψ

Open HF versus J/ψ

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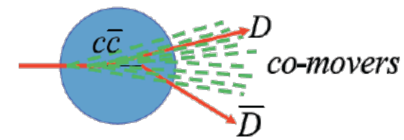
BIG difference: nuclear breakup of charmonia bound states



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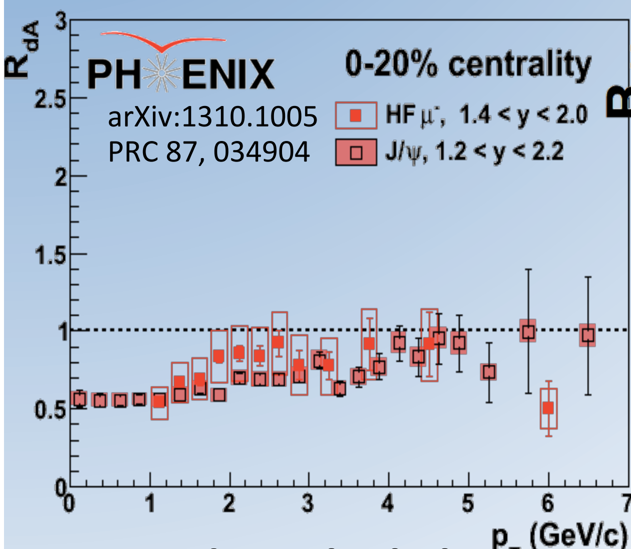

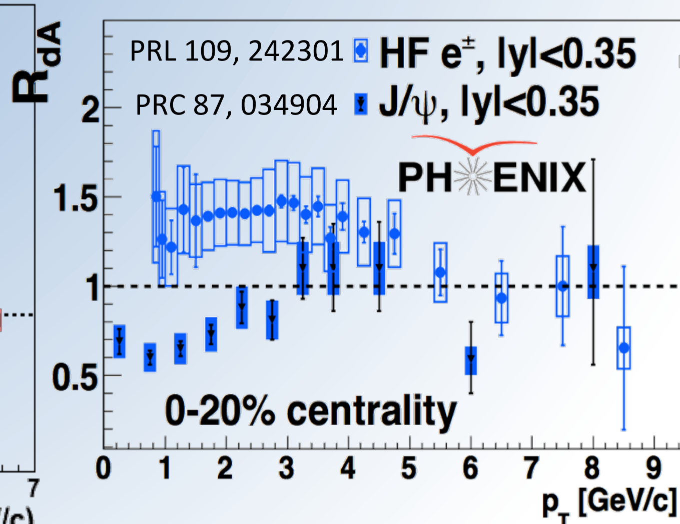

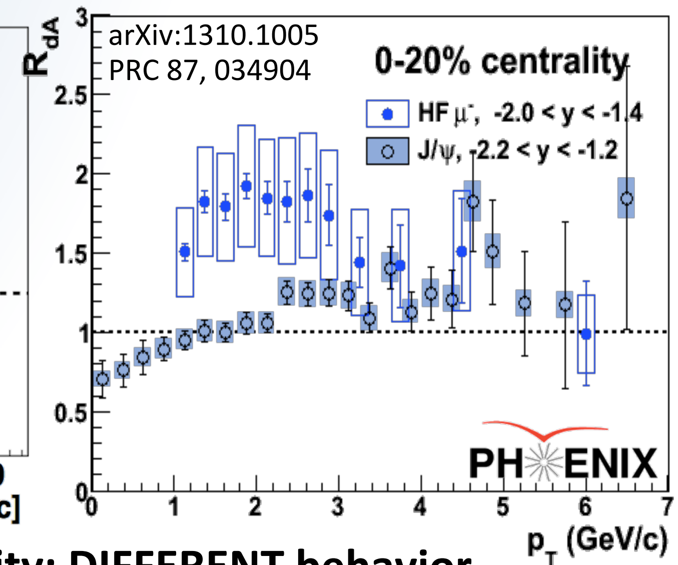

Forward: similar behavior
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Mid- and backwards rapidity: DIFFERENT behavior
enhanced open HF versus suppressed J/ψ

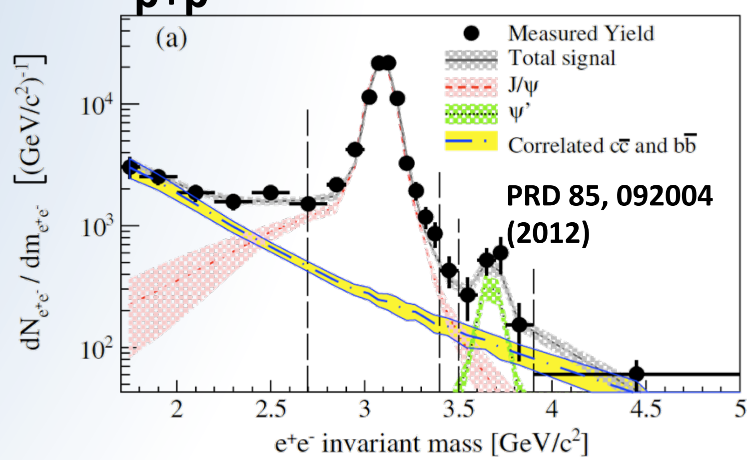
Compelling evidence for significant *cc* breakup effects

Excited charmonia: ψ(2s)

Very weakly bound: E_b ~50 MeV

PHENIX ee measurements at midrapidity in p+p:
$\psi(2s) / \psi(1s) = 2.1 \pm 0.5$ %

p+p



PRD 85, 092004 (2012)

Excited charmonia: $\psi(2s)$

Very weakly bound: E_b ~50 MeV

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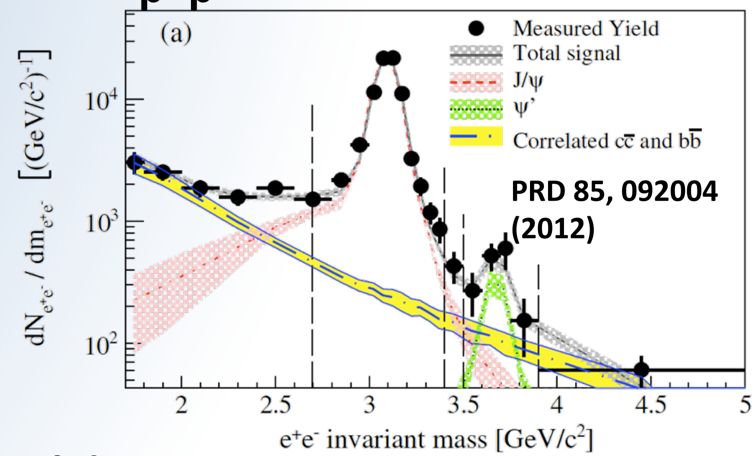
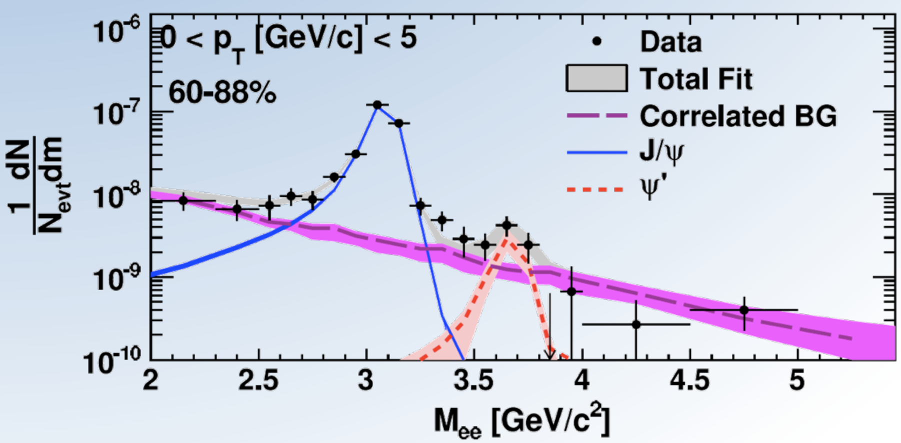
Finalized measurement in d+Au:
PRL 111, 202301 (2013)

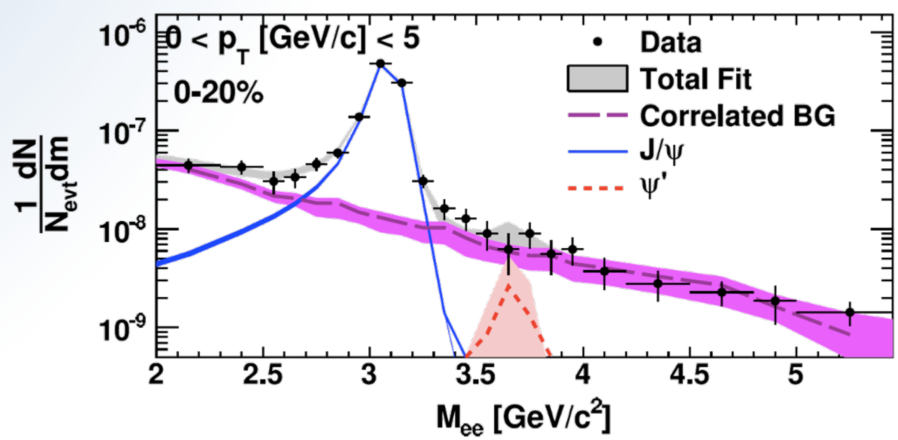
p+p



Peripheral d+Au



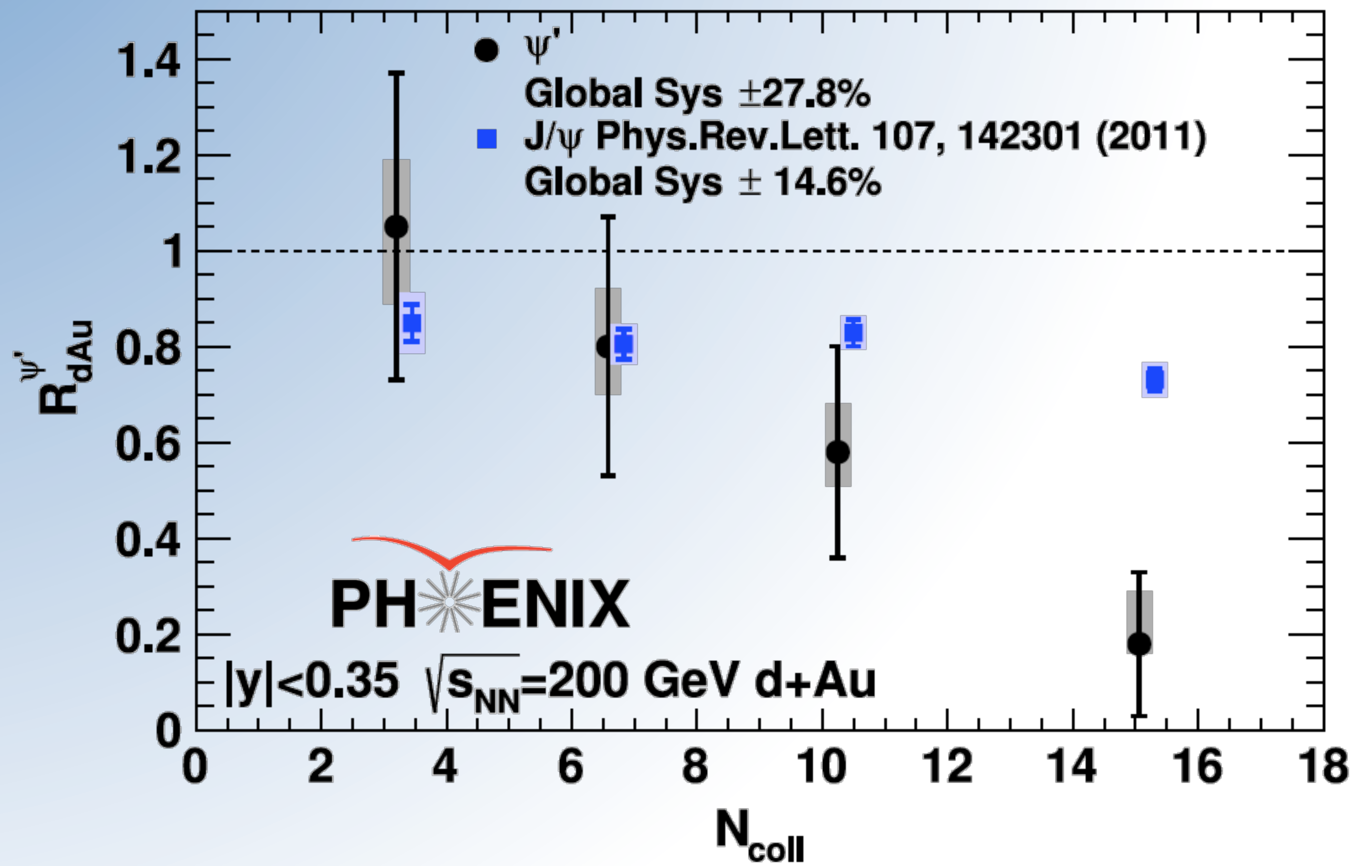
Central d+Au



By eye, clear difference in peaks between peripheral and central d +Au

Nuclear Modification R_{dA}

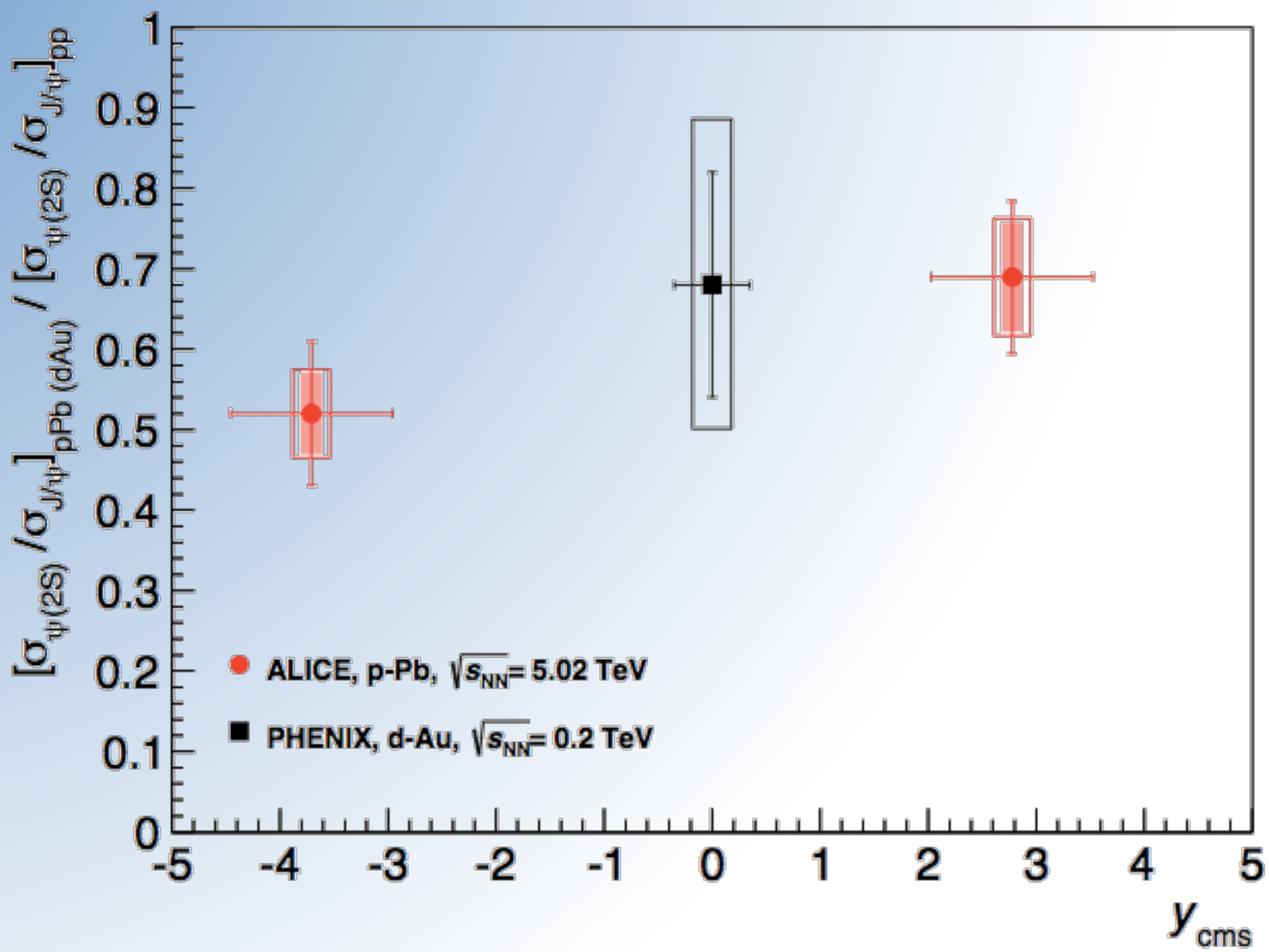
PRL 111, 202301 (2013)



ψ(2s) more suppressed by a factor of ~3 in central collisions

Very different trend than ψ(1s)

Confirmation at LHC

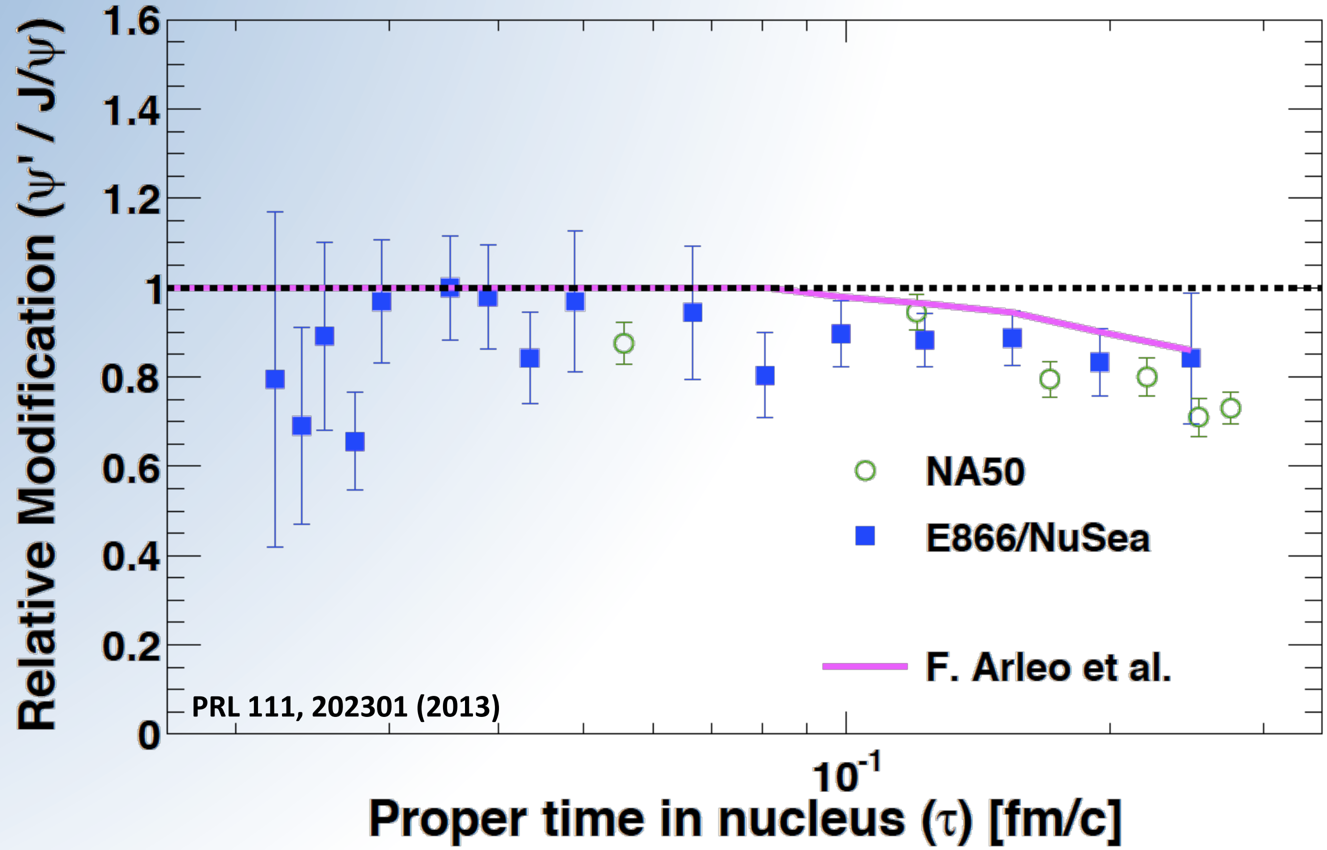


Similar effect observed by ALICE in Min Bias p+Pb
arXiv:1405.3796

Relative Modification of $\psi(2s)/\psi(1s)$ – time in nucleus

After *cc* formation, the pair expands as it crosses nucleus

$\psi(1s)$ formation time ~0.15 fm



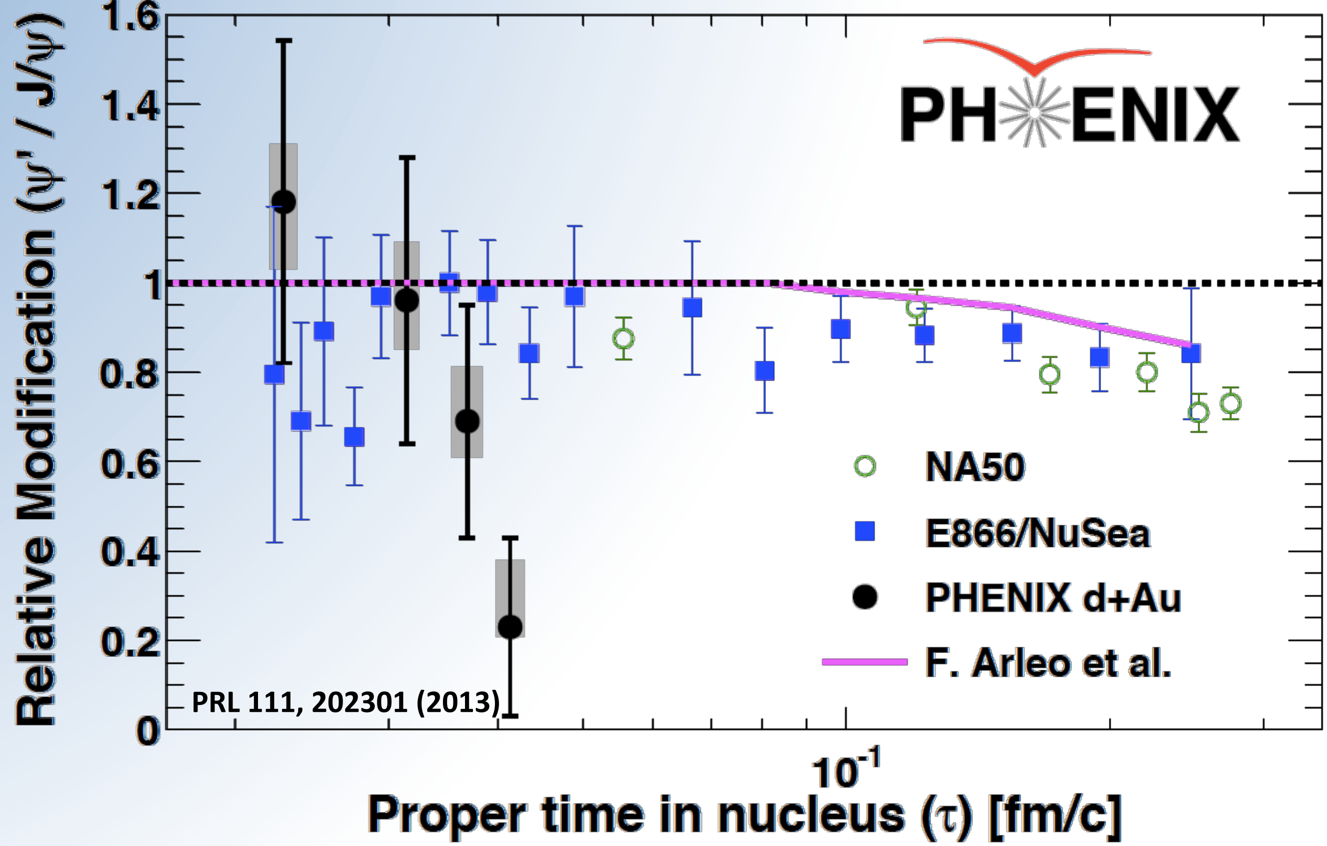
Relative Modification of $\psi(2s)/\psi(1s)$ – time in nucleus

After *cc* formation, the pair expands as it crosses nucleus

$\psi(1s)$ formation time ~0.15 fm

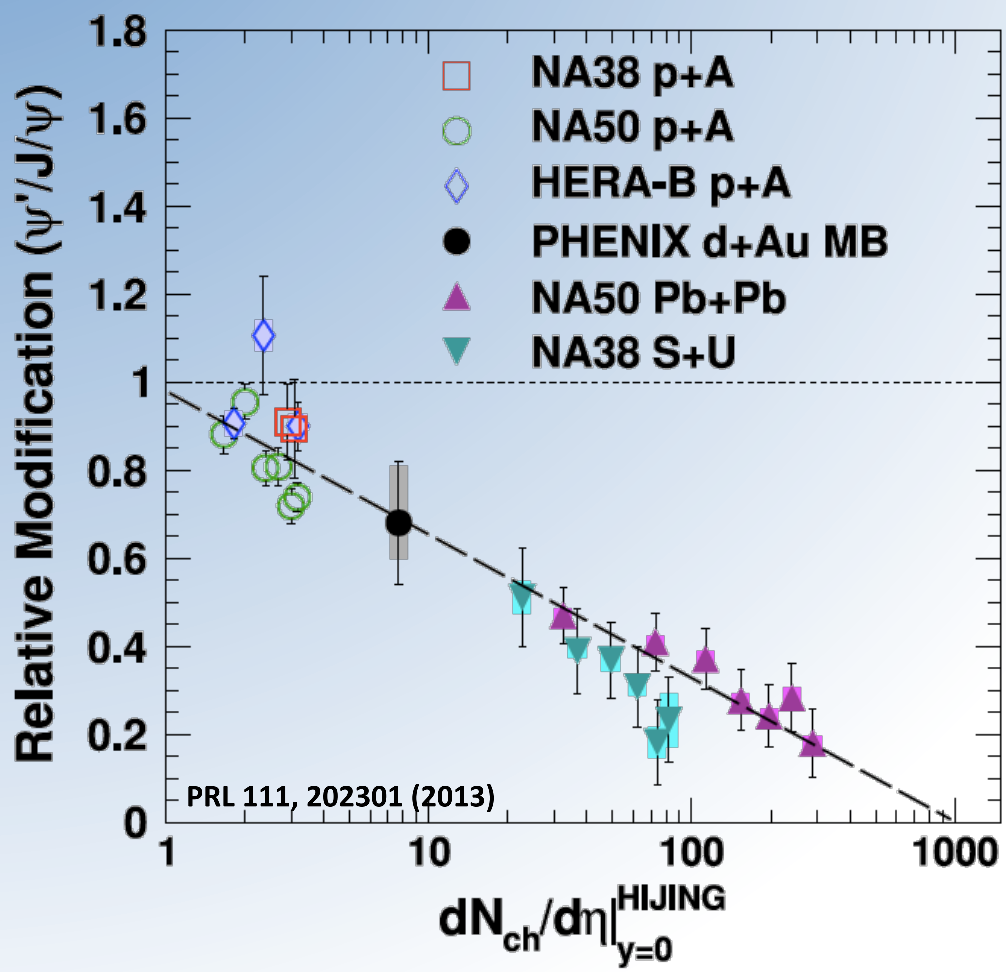
At RHIC, τ ~ 0.05 fm

Precursor state crosses nucleus before final state meson forms



Increased suppression NOT due to same breakup mechanism while inside nucleus.
Breakup *outside* nucleus (co-mover interactions)?
Or is there an altogether *different* mechanism at RHIC energies?

Relative Modification of $\psi(2s)/\psi(1s)$ – particle density



Relative modification in *all* systems follows common trend with increasing produced particle density.

Co-mover (or medium?) density seems to be the relevant quantity.

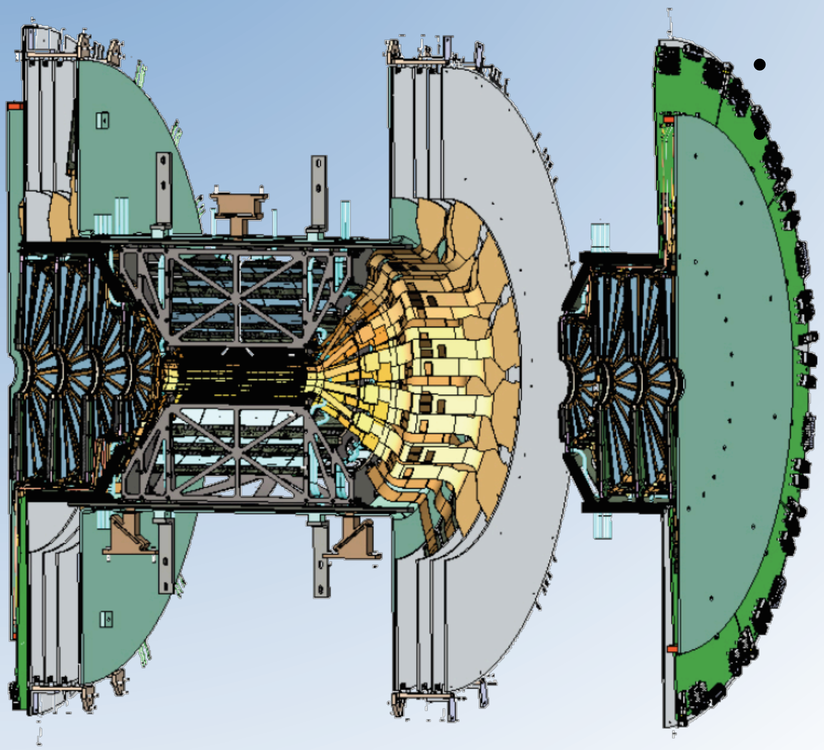
Mini-summary

- Charmonia production in the nucleus suppressed beyond open charm – breakup effects are significant
- The magnitude and trend of ψ(2s) suppression in nuclear collisions is quite different from J/ψ
- Very short crossing time: effect likely to occur outside the nucleus
- Approximate scaling with produced particle density

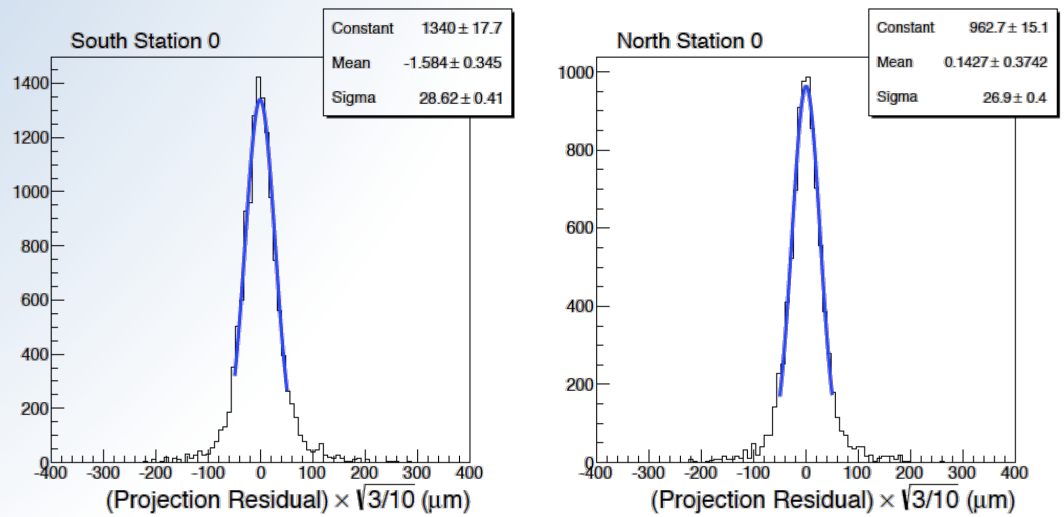
- Measurements at different rapidities at same CM energy would:
  - Effectively vary produced particle density, proper time in nucleus
  - Increased discrimination between models

Precision Tracking at Forward Rapidity: the FVTX

Forward Silicon Vertex Tracker



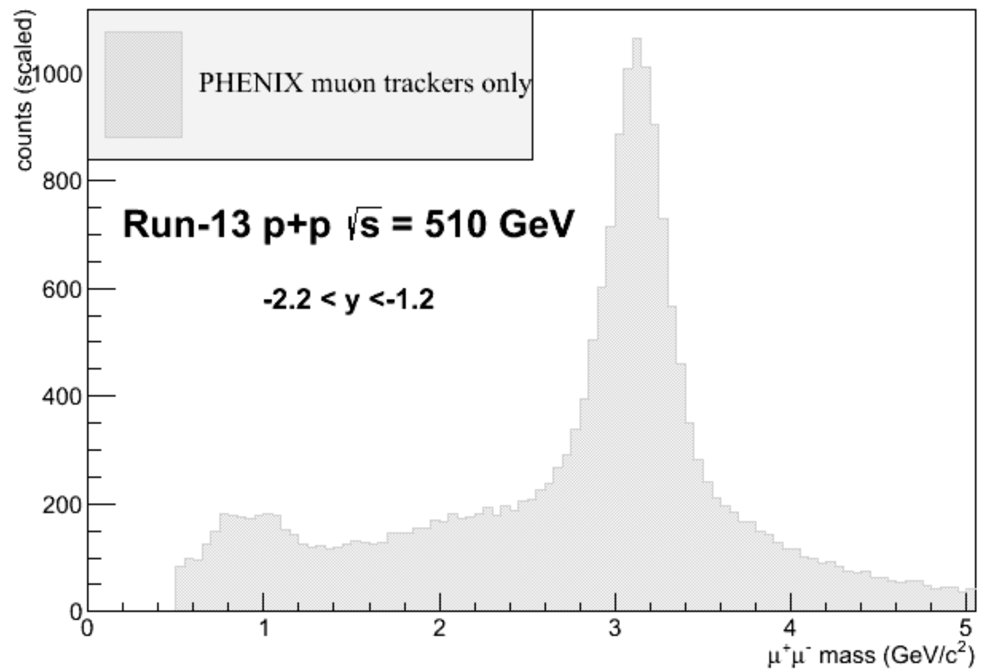
- Four layers of silicon sensors in each end of central rapidity silicon
- 75um pitch in r, 3.75 deg in phi
- Full azimuthal coverage at forward and backward rapidity

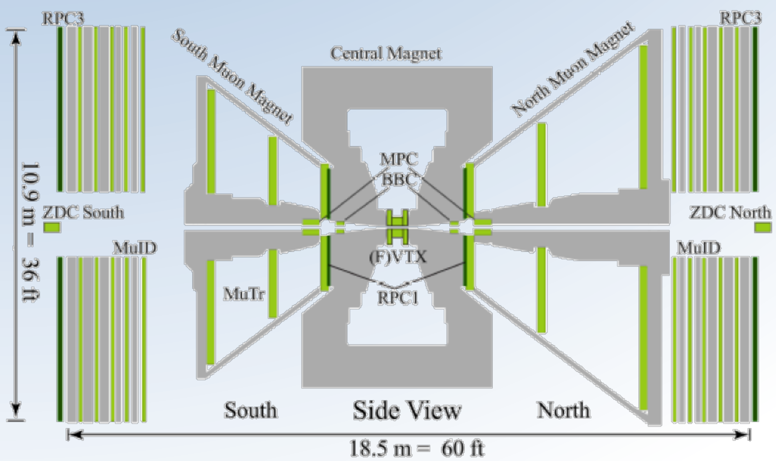


- Position resolution better than 30 um in each station
- Single hit efficiency >95%

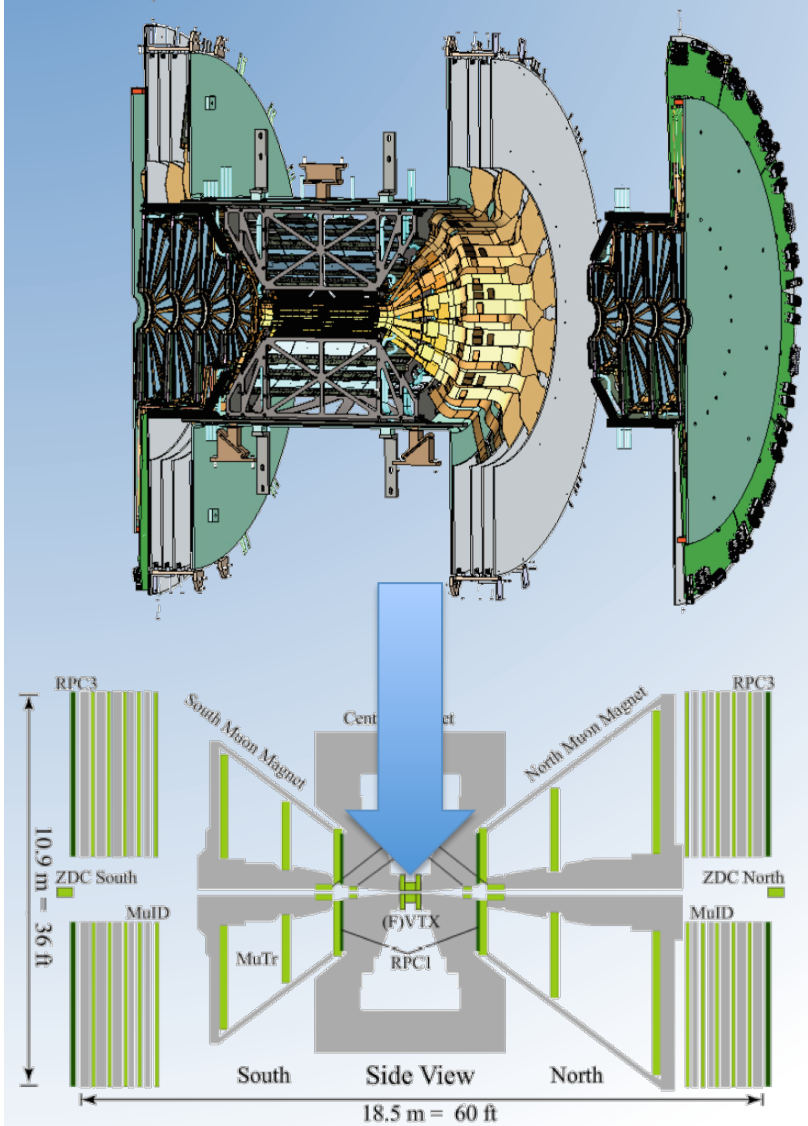
Details just published: NIM A 755 (2014) 44

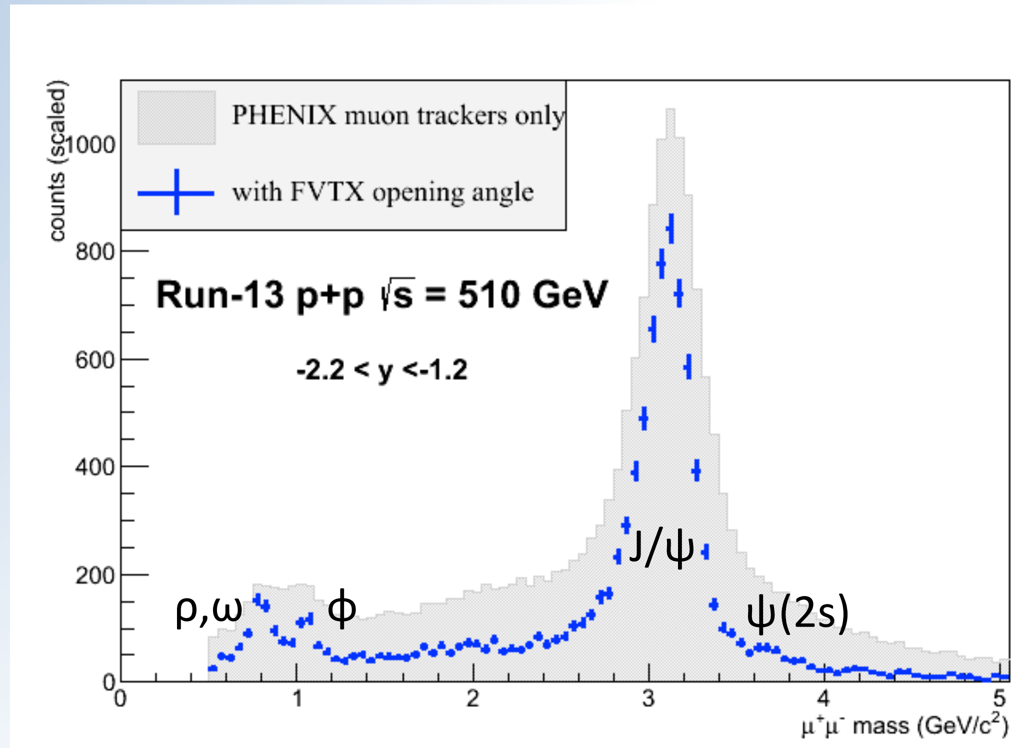
FVTX in PHENIX





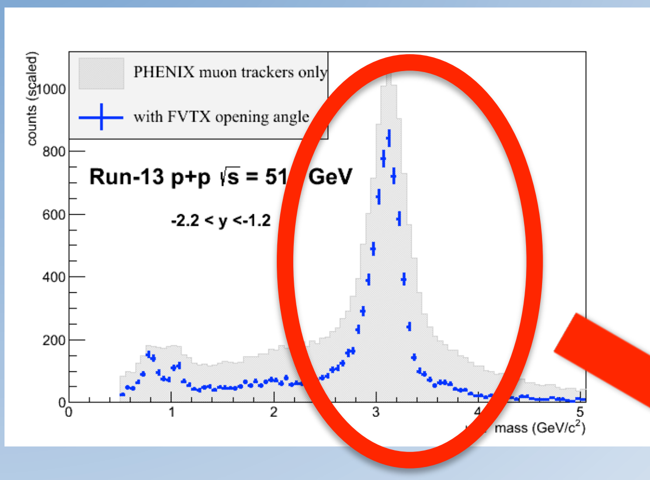
FVTX in PHENIX

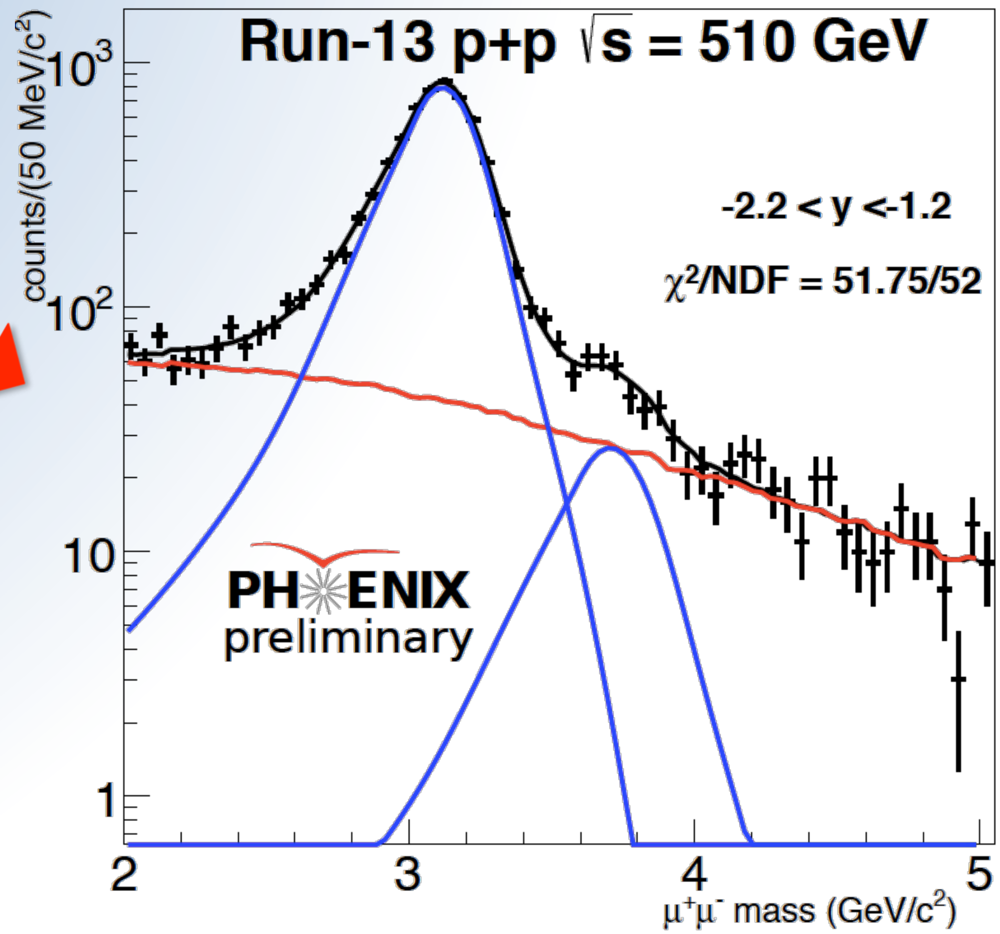




Opening angle in front of absorber: Greatly improved mass resolution and background rejection

Extracting the ψ(2s) peak

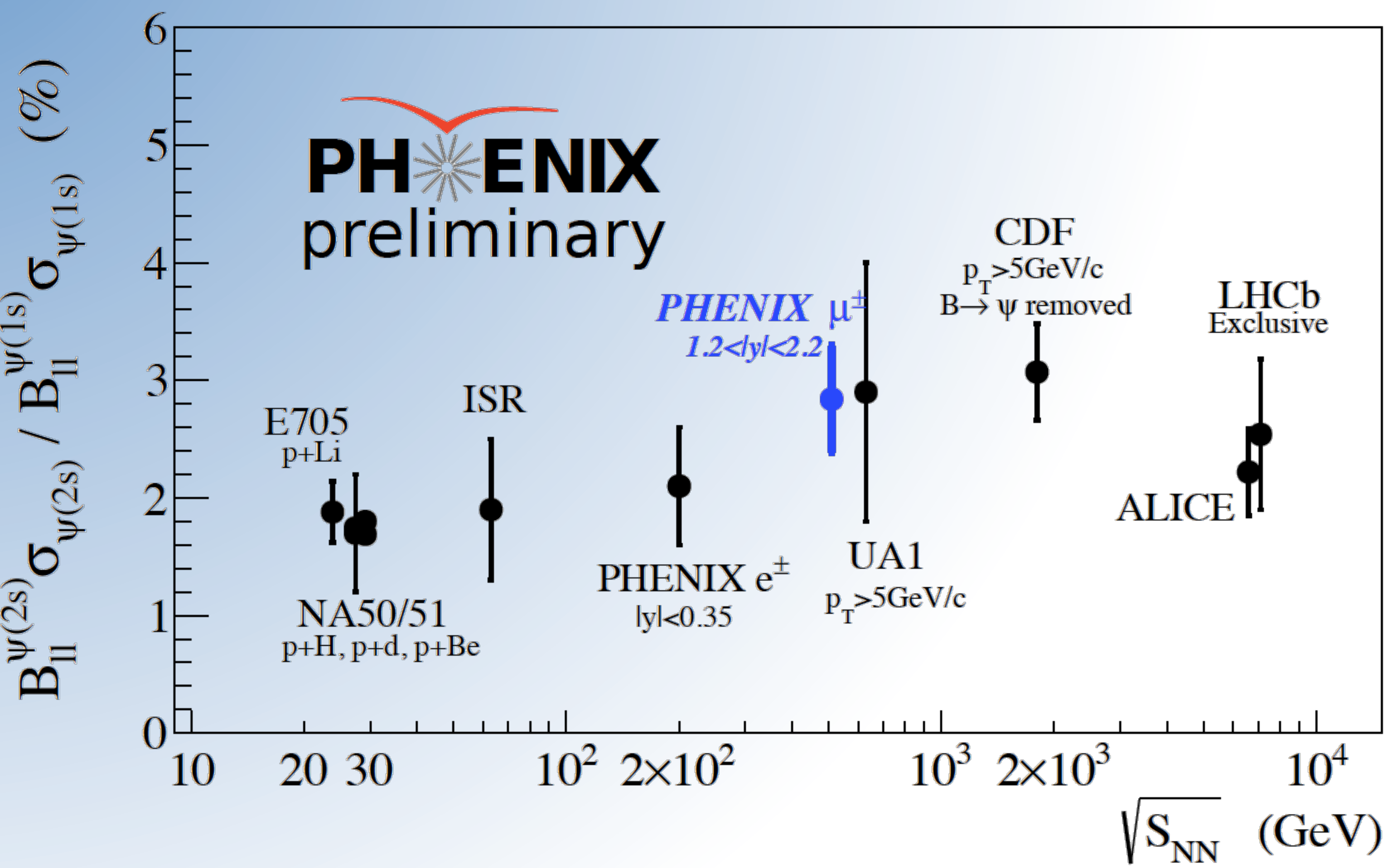




Signal peaks: Crystal Ball + gaussian

Bg: mixed event combinatorial + exponential continuum

ψ(2s) production vs √s



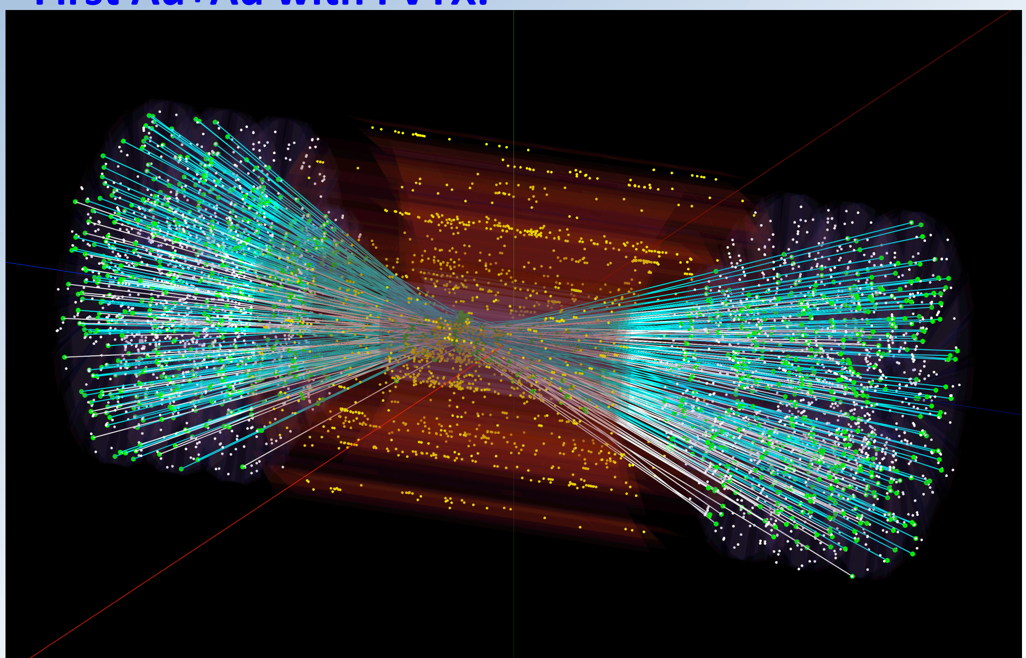
First measurement at 510 GeV. First measurement at forward rapidity at RHIC.
Consistent with world data.
➔p+p baseline well understood experimentally.

Near Future Plans

Run-14: 200 GeV Au+Au:

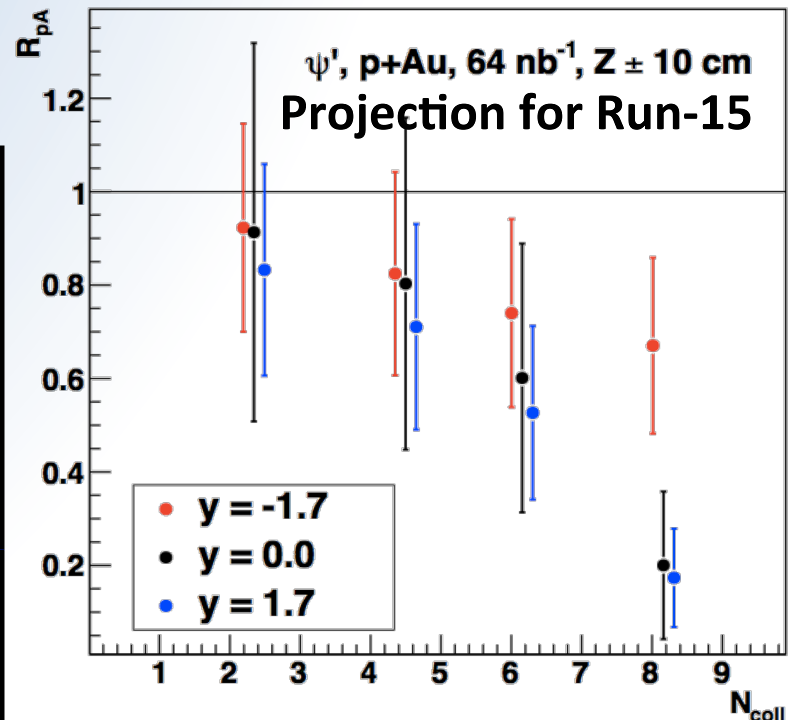
PHENIX luminosity goals reached, still 7 weeks to go in run.

Our BEST Au+Au dataset ever.
First Au+Au with FVTX.



Reconstructed FVTX tracks in a typical Au+Au event

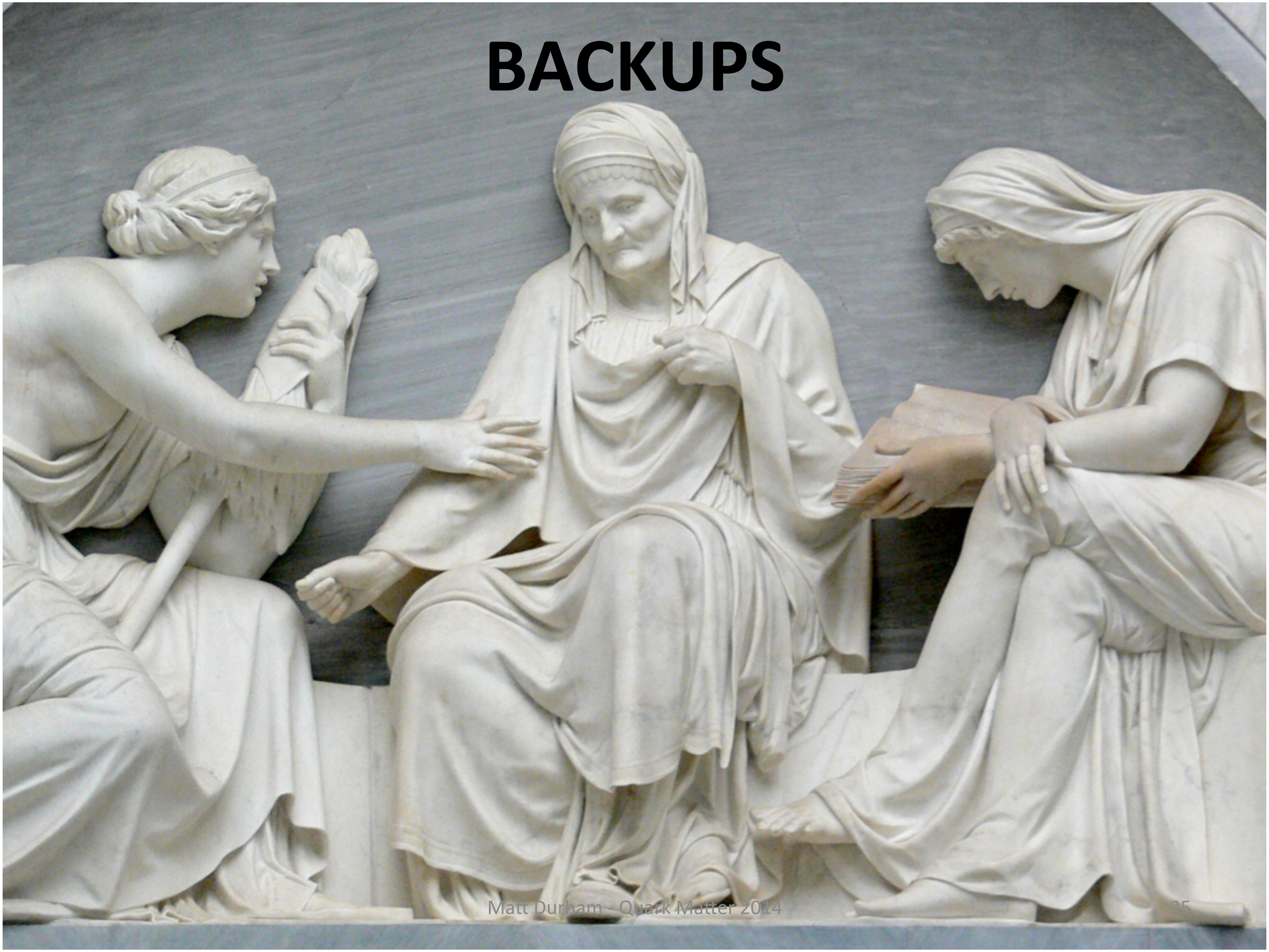
Run-15: 200 GeV p+Au
First p+Au at RHIC



Summary

- The difference between suppression of charmonia states in d+Au collisions at RHIC indicates late stage breakup that occurs outside the nucleus
- PHENIX is actively exploring this topic with greatly enhanced capabilities at forward rapidity
- Looking forward to Run-15: p+A at RHIC

BACKUPS



Centrality in dA