

Insights into Hard–Soft QCD Correlations from Multiplicity-Dependent Charmonium Production in $p+p$ and $p+Au$ Collisions

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For the PHENIX Collaboration

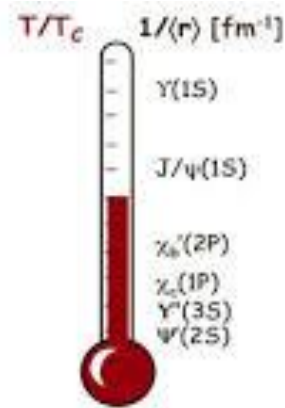
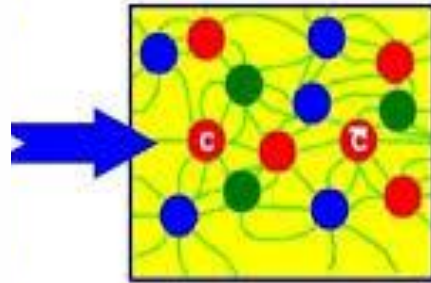
06/27-28, 2026

Jets and Heavy Flavor Physics Workshop @GSU

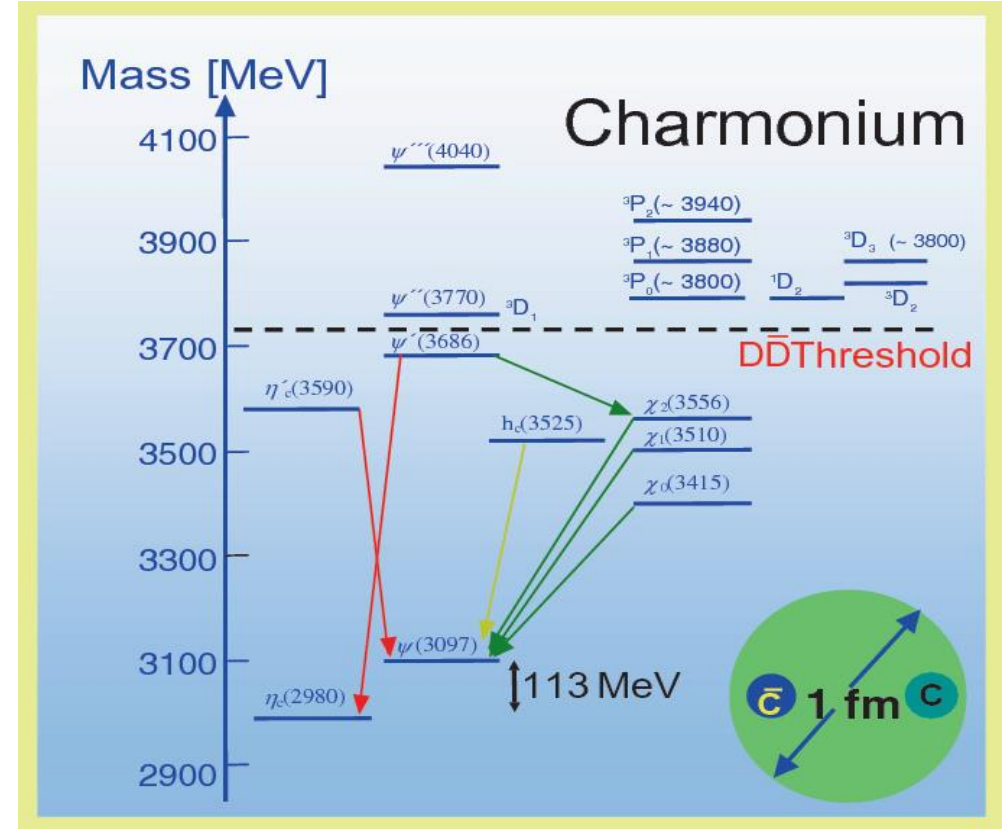
Quarkonium in Heavy Ion

- Color screening?

Matsui & Satz, Phys. Lett. B178 (1986)
- first quantitative predictions



https://link.springer.com/chapter/10.1007/978-3-030-79489-7_2/figures/1



Binding energy $\sim O(10^2)$ MeV \sim QGP Temperatures

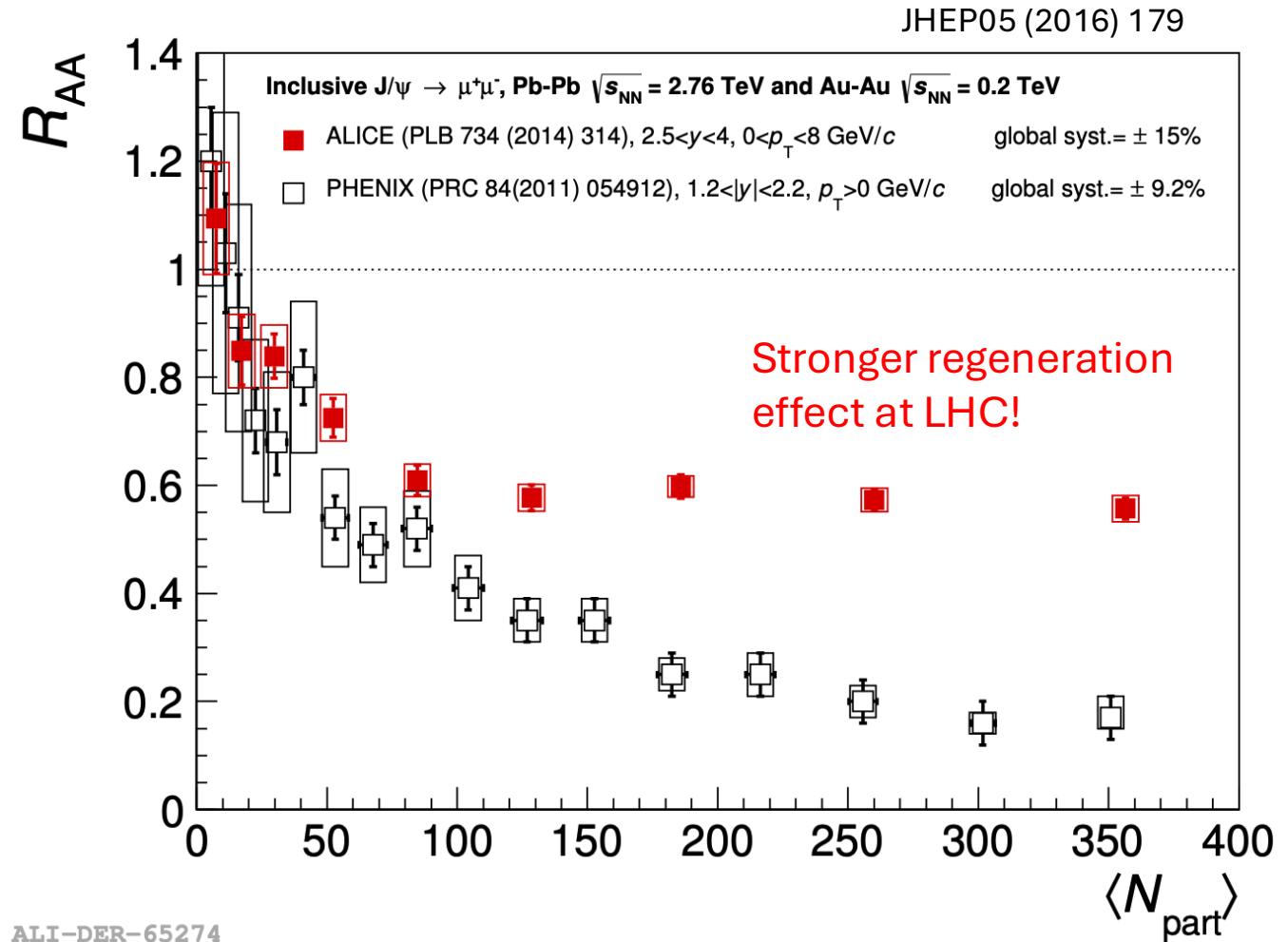
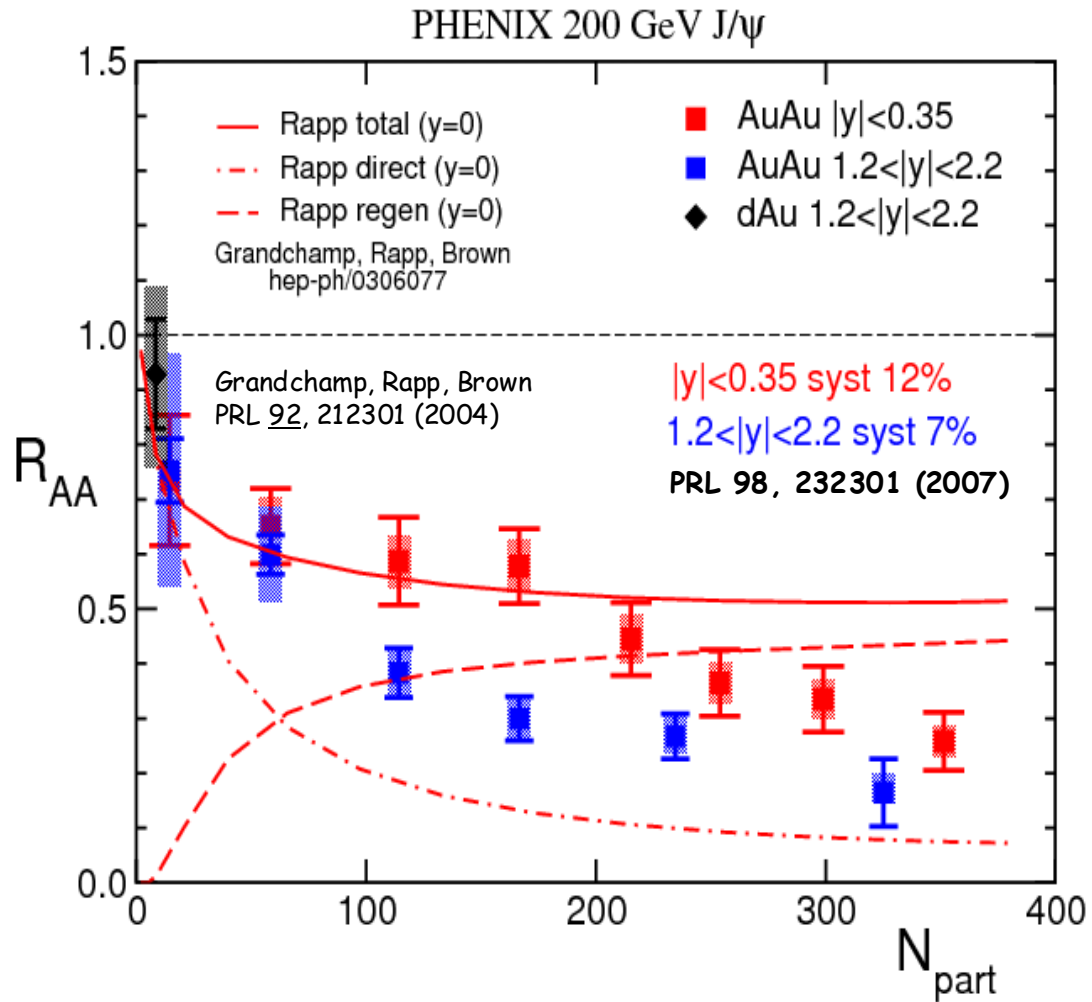
Quarkonium dissociation by string breaking

S. Digal et al. / Physics Letters B 514 (2001) 57–62

State	J/ψ	χ_c	ψ'	Υ	χ_b	Υ'	χ'_b	Υ''
E_s^i (GeV)	0.64	0.20	0.05	1.10	0.67	0.54	0.31	0.20
T_d/T_c	–	0.74	0.1–0.2	–	–	$\gtrsim 0.93$	0.83	0.74

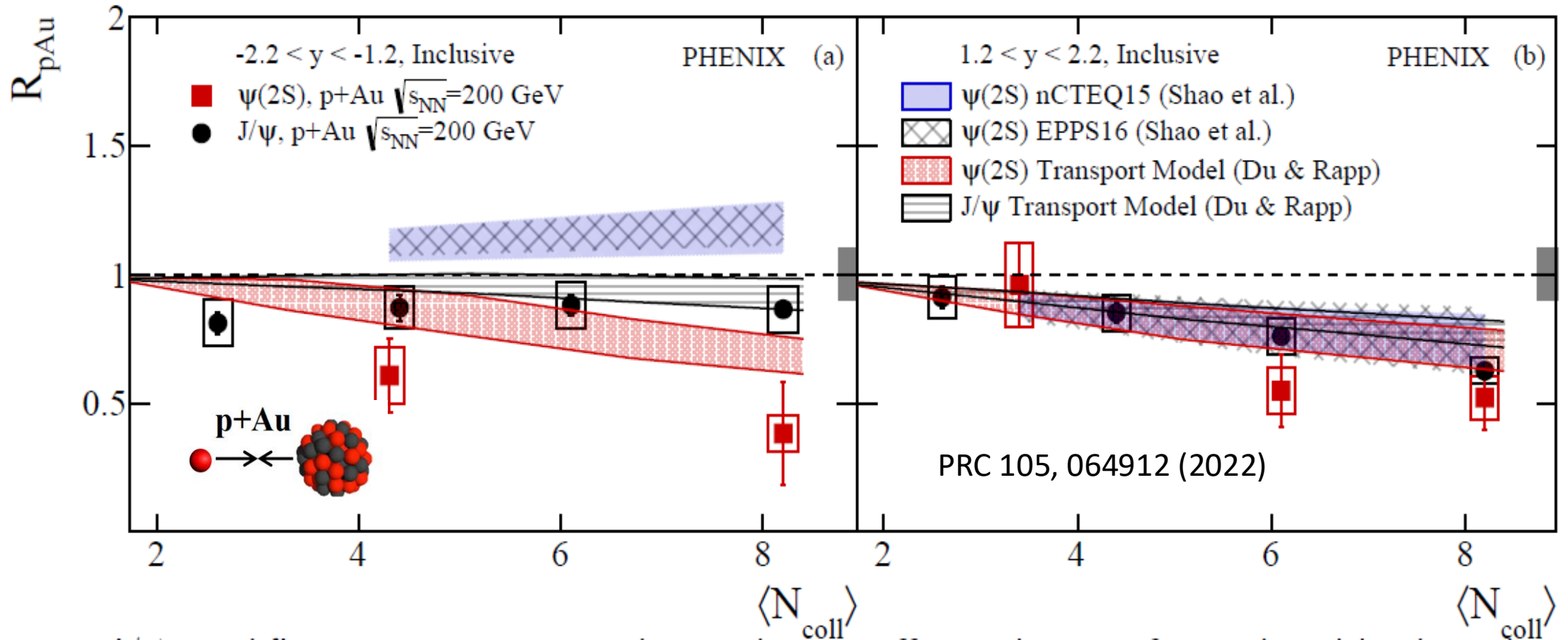
J/ψ Nuclear Modification: RHIC vs LHC

Coalescence of charm and anticharm quarks leads to more J/ψ regeneration at LHC than RHIC



ALI-DER-65274

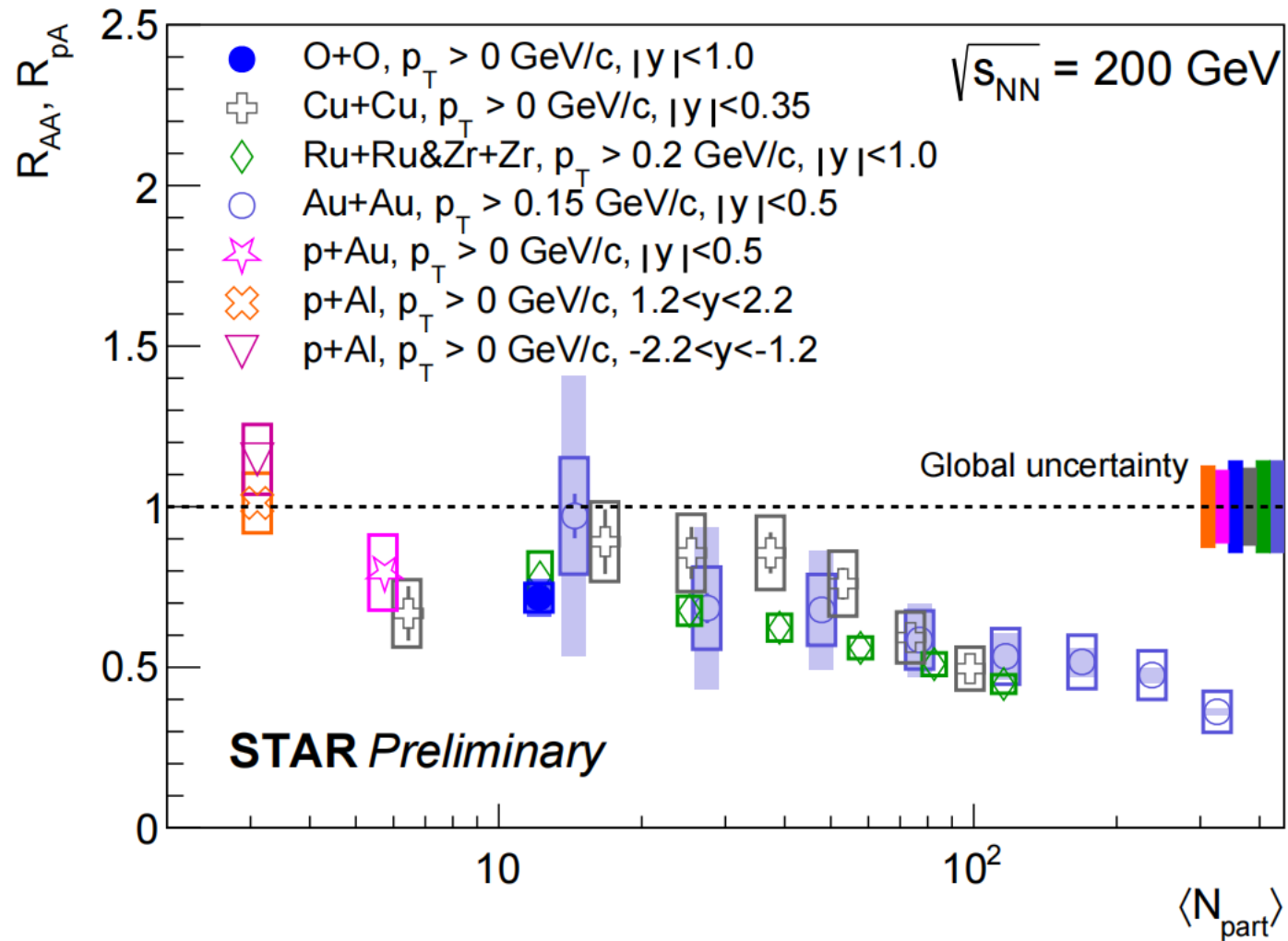
J/ψ and ψ(2S) in Small Systems: p+Au



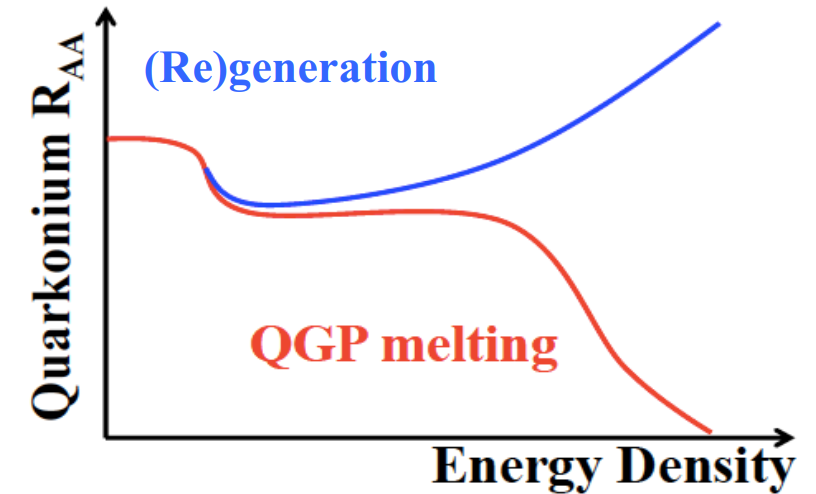
1. J/ψ modification consistent with INITIAL state effects at FW and BW rapidity
 2. ψ(2S) modification indicates presence of FINAL state effects at BW rapidity
- How about at the extreme case of very high event multiplicity through MPI?
 - Any sign of QGP formation?

“0-20%”
centrality

Inclusive J/Psi R_{AA} vs N_{part} at RHIC



PHENIX, *Phys. Rev. Lett.* 101, 122301 (2008)
 STAR, *Phys. Lett. B* 797, 134917 (2019)
 STAR, *Phys. Lett. B* 825, 136865 (2022)
 PHENIX, *Phys. Rev. C* 102, 014902 (2020)



Normalized J/Psi yield vs Normalized N_{ch}

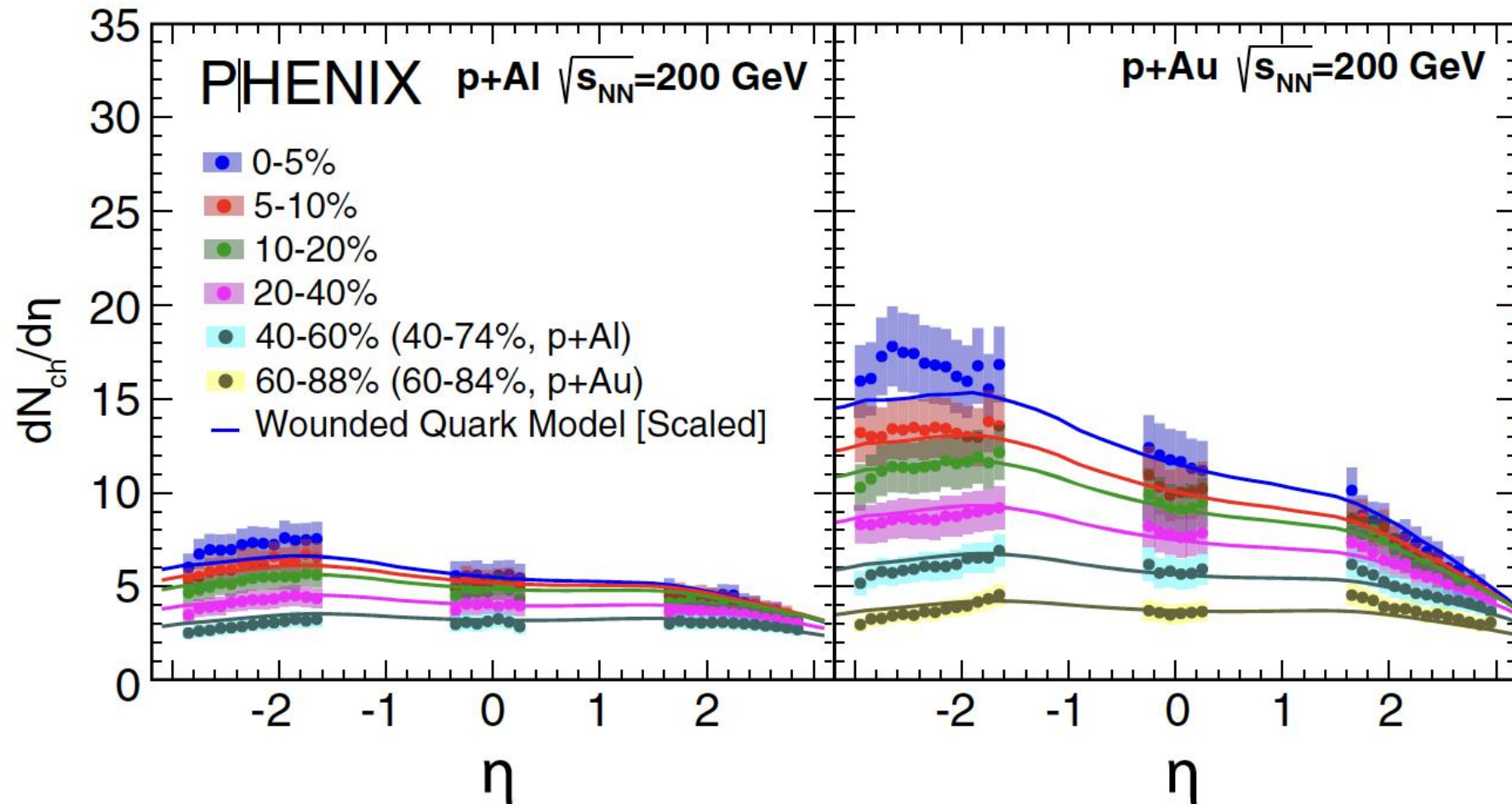
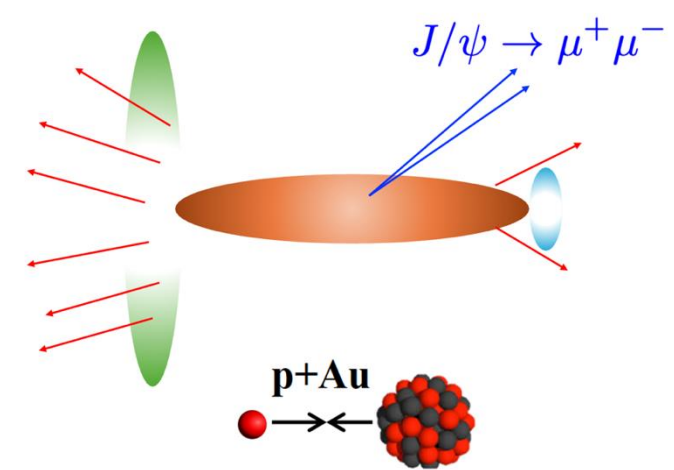
At a given N_{ch} event category, calculate the normalized J/Psi yield:

$$N_{J/\psi} / \langle N_{J/\psi} \rangle = \frac{N_{J/\psi}^{\text{raw}}}{N_{\text{evt}}} \frac{N_{\text{evt}}^{\text{total}}}{N_{J/\psi}^{\text{raw, total}}} \frac{\epsilon_{\text{trig}}^{\text{MB}}}{\epsilon_{\text{trig}}^{J/\psi}} \frac{\langle \epsilon_{\text{trig}}^{J/\psi} \rangle}{\langle \epsilon_{\text{trig}}^{\text{MB}} \rangle} f_{\text{coll}}$$

- Most of acceptance & efficiency corrections are canceled

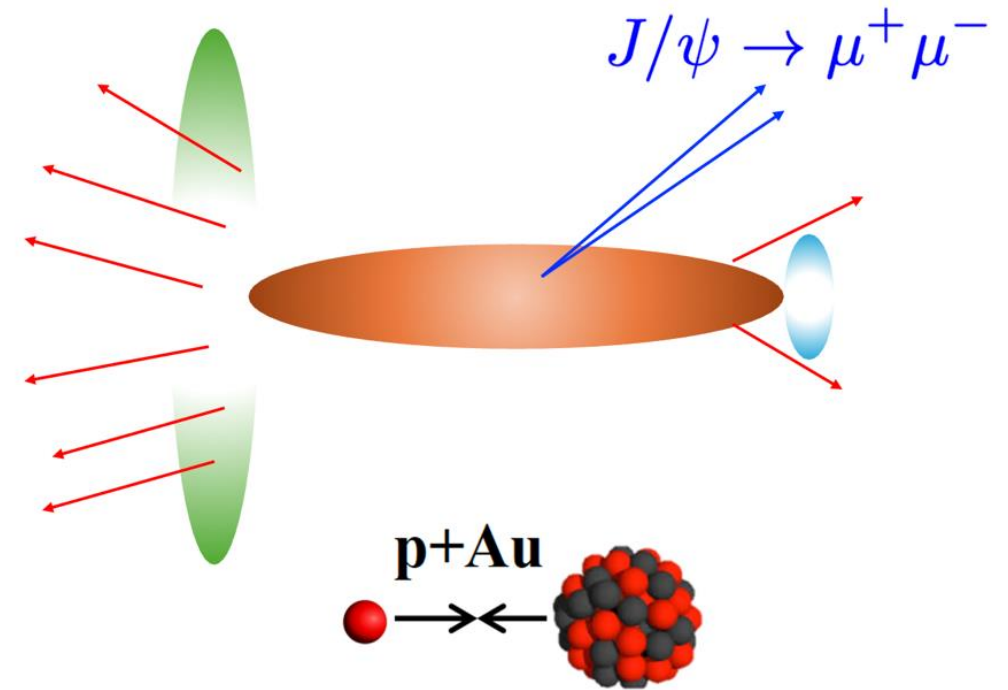
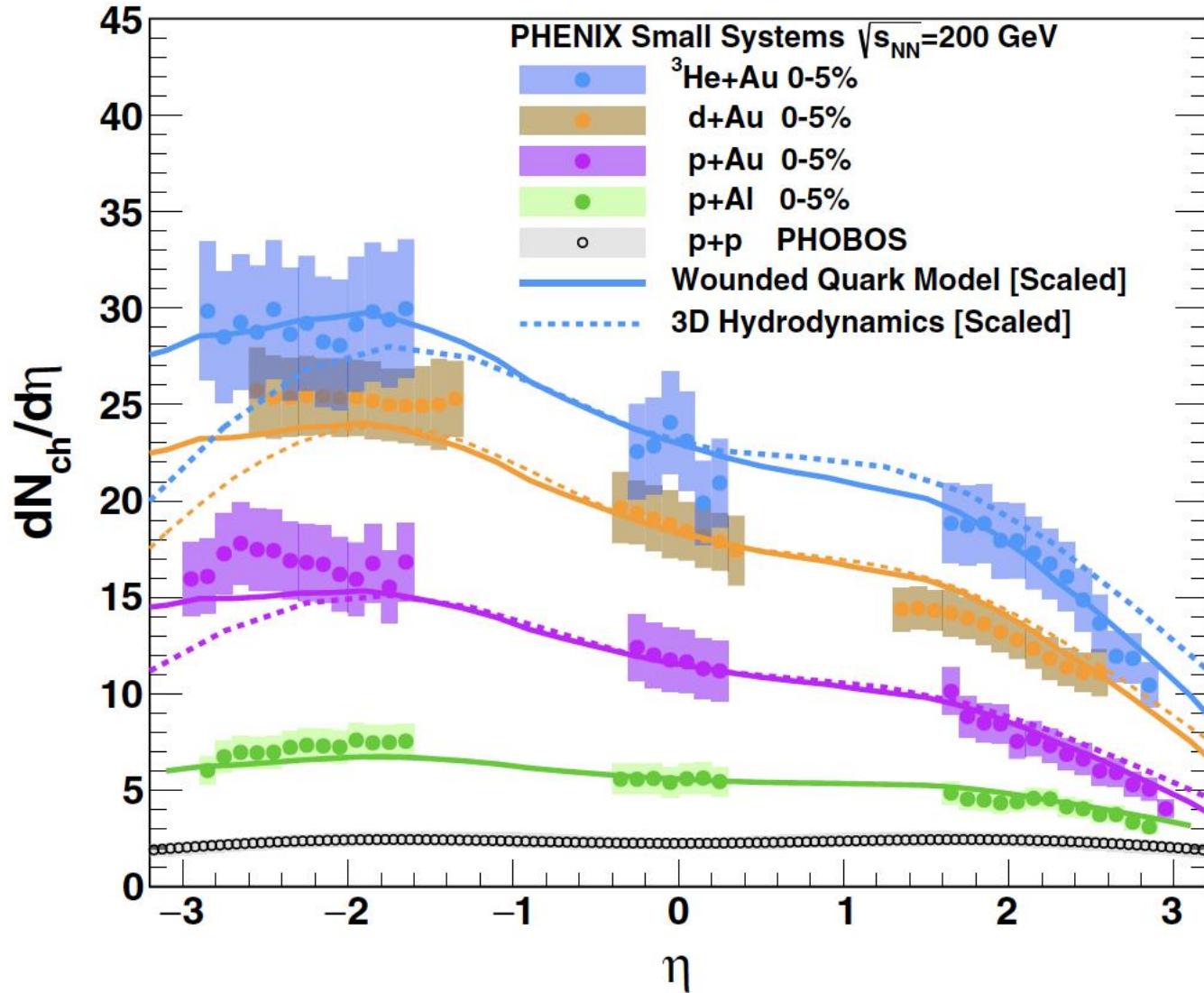
p+A Collisions: - Centrality Dependence

Centrality determined by $dN/d\eta$ in “A-going” @large rapidity
PHENIX: 3.1 – 3.9 (BBC)



“Central” p+Au Collisions

PHYSICAL REVIEW LETTERS 121, 222301 (2018)



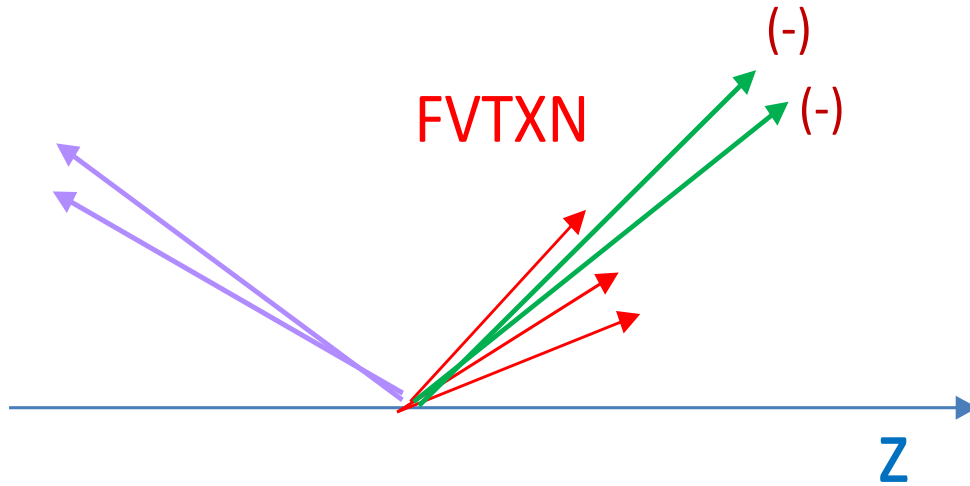
J/ψ Yield vs N_{ch} in p+Au Collisions

Unique collision event topology:

- Study correlations over wide rapidity gaps
- Small-x vs large-x in Au
- Core-corona, QGP, CNM, MPI ...

-2.2 < y < -1.2
J/ψ → μ⁺ + μ⁻

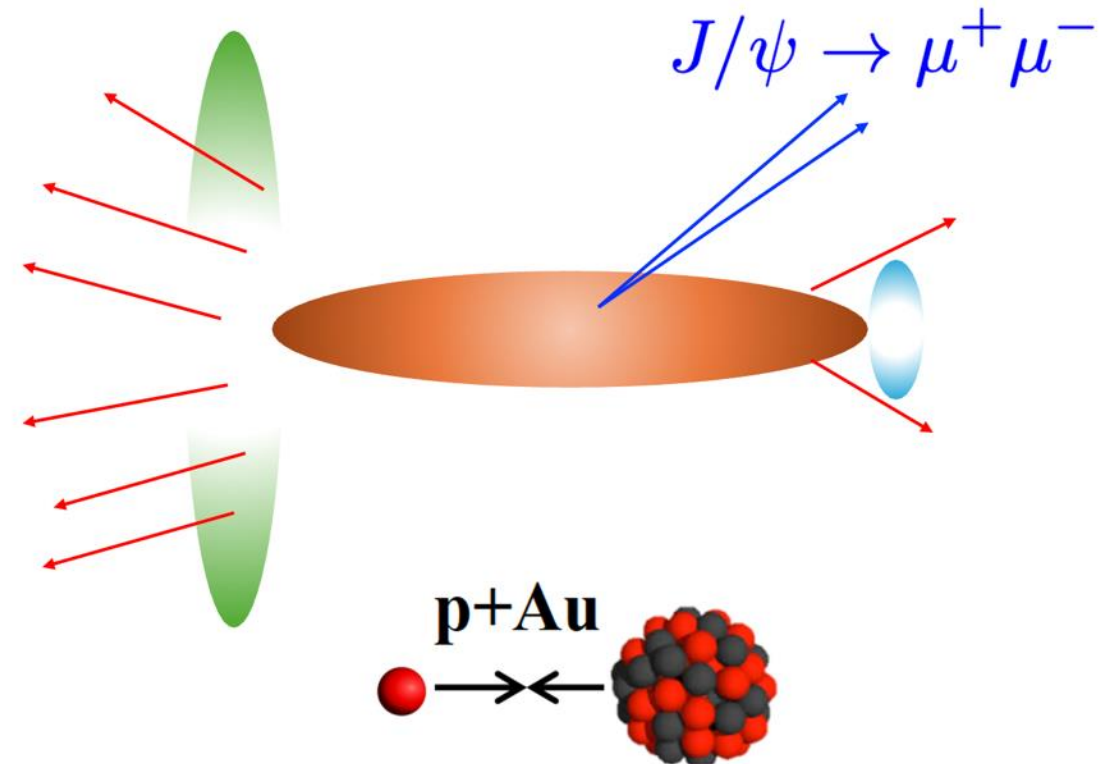
1.2 < y < 2.2
J/ψ → μ⁺ + μ⁻



y_{beam} = 5.36 @100GeV (LHC pp @13TeV: 9.54)

large-x of Au

small-x of Au



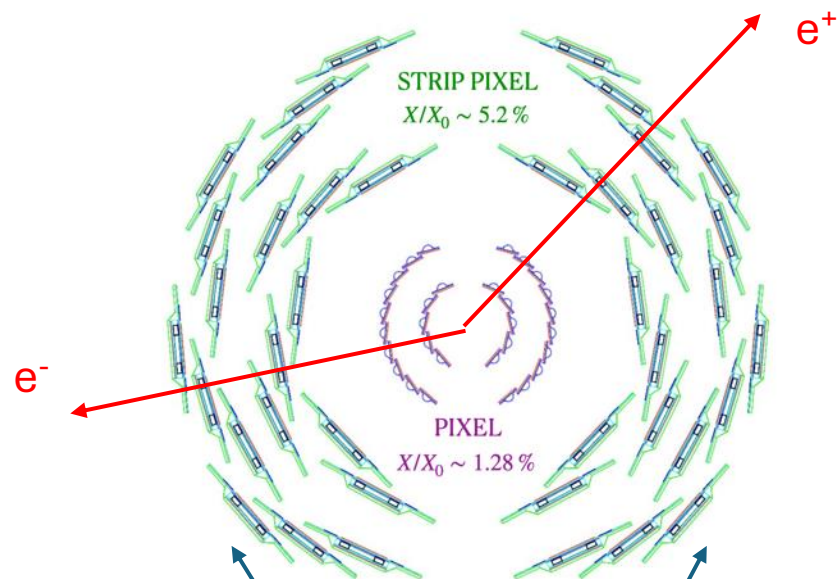


Outline

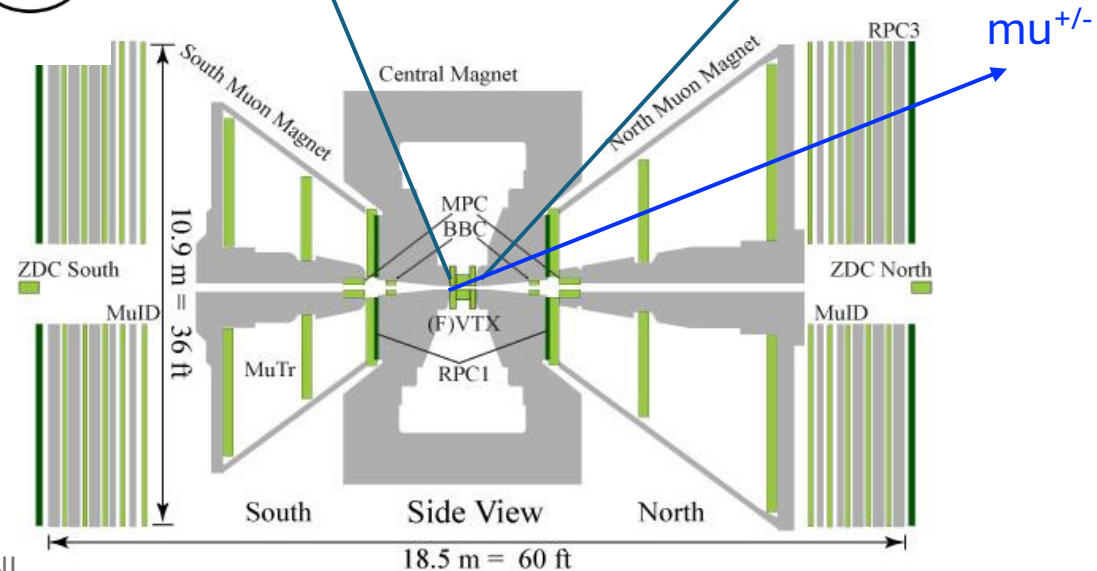
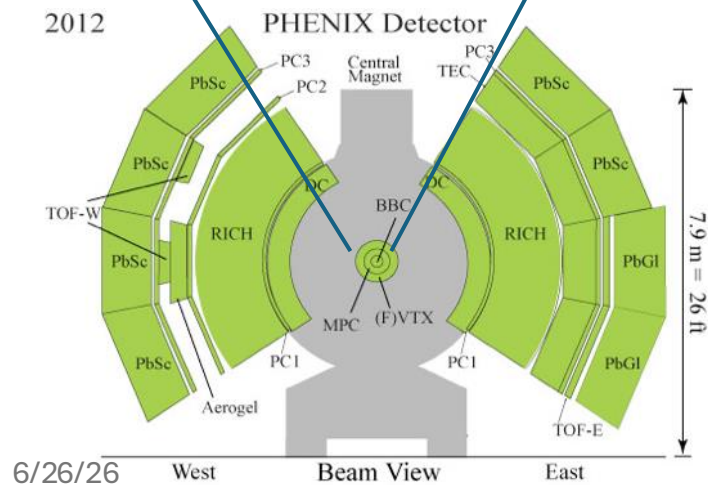
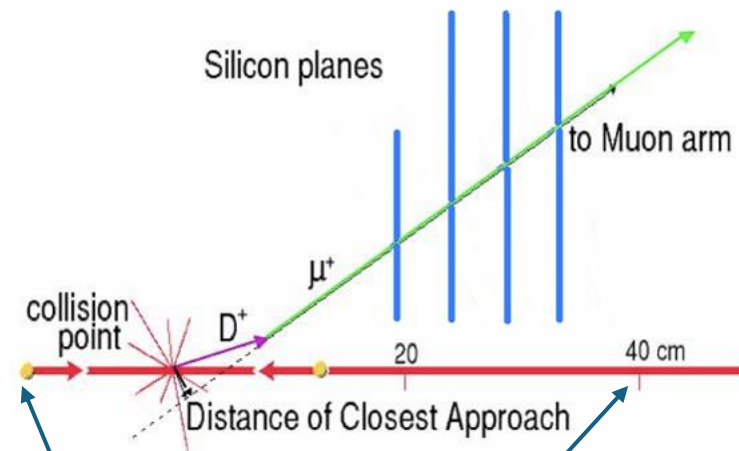
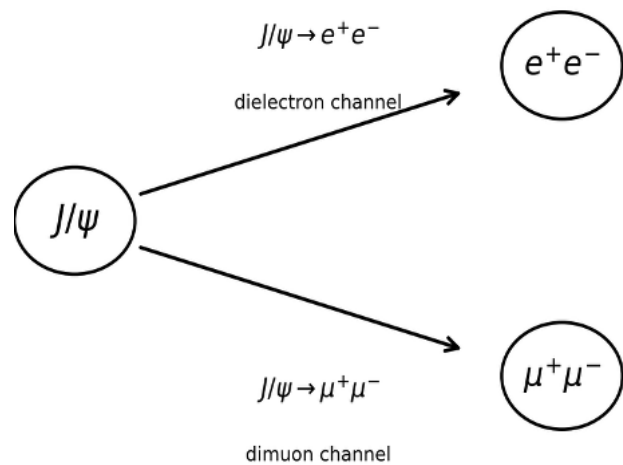
- J/Psi measurements
- J/Psi vs event multiplicity in p+p and p+Au (NEW!)

PHENIX Experiment at RHIC: 2001-2016

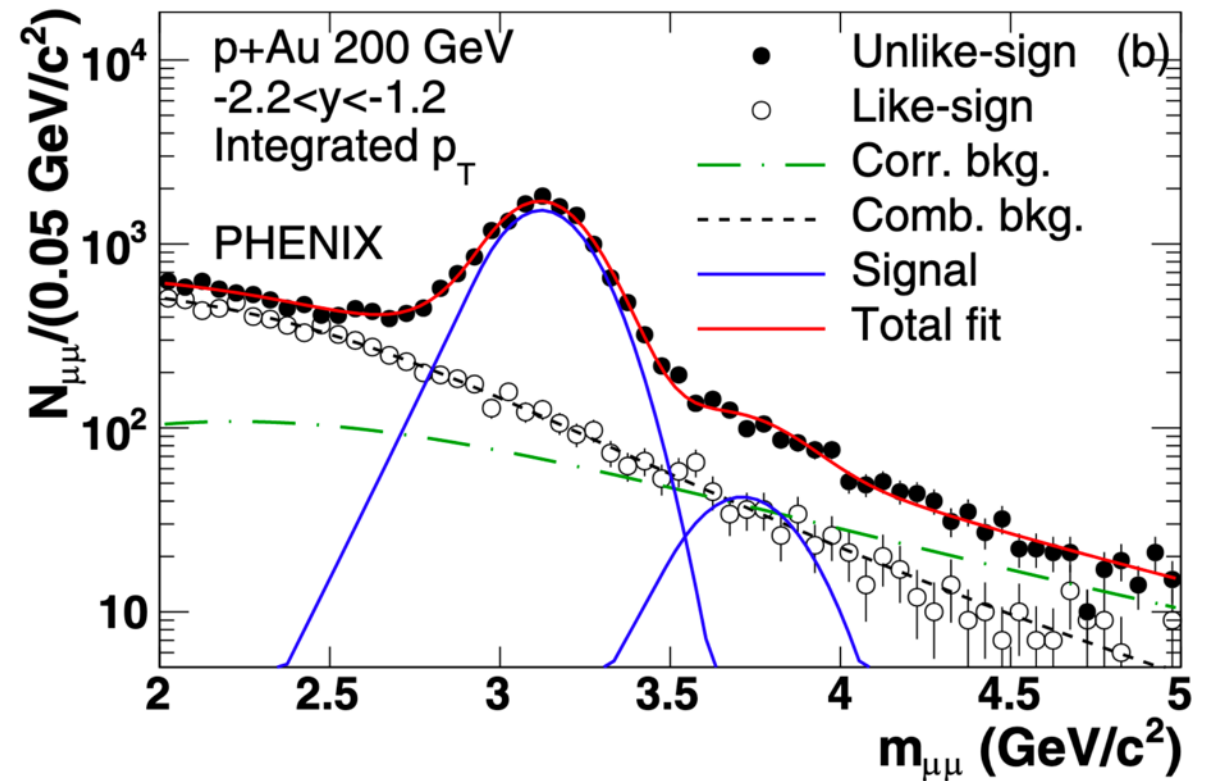
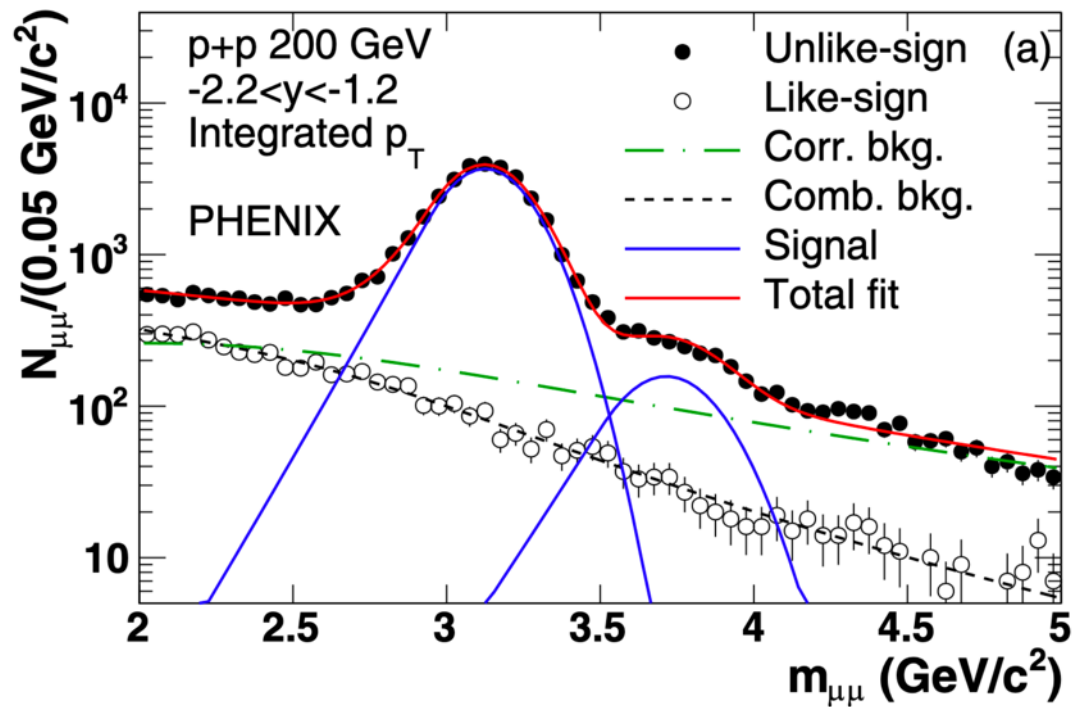
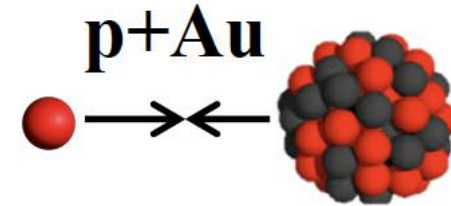
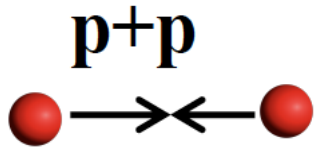
J/ψ Measurements in Central and Muon Arms



- e^+e^- , $|\eta| < 0.35$
- $\mu^+\mu^-$, $1.2 < |\eta| < 2.2$



J/ ψ , Psi(2S) Measurements in Dimuon Channel

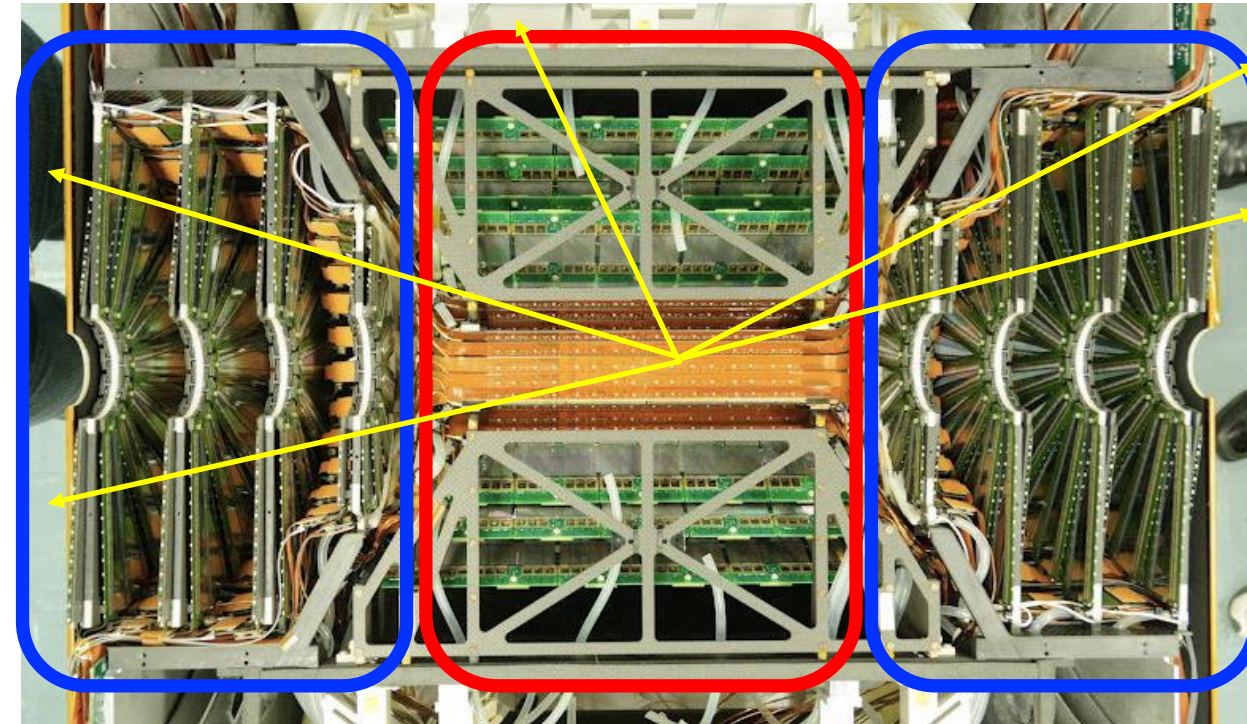
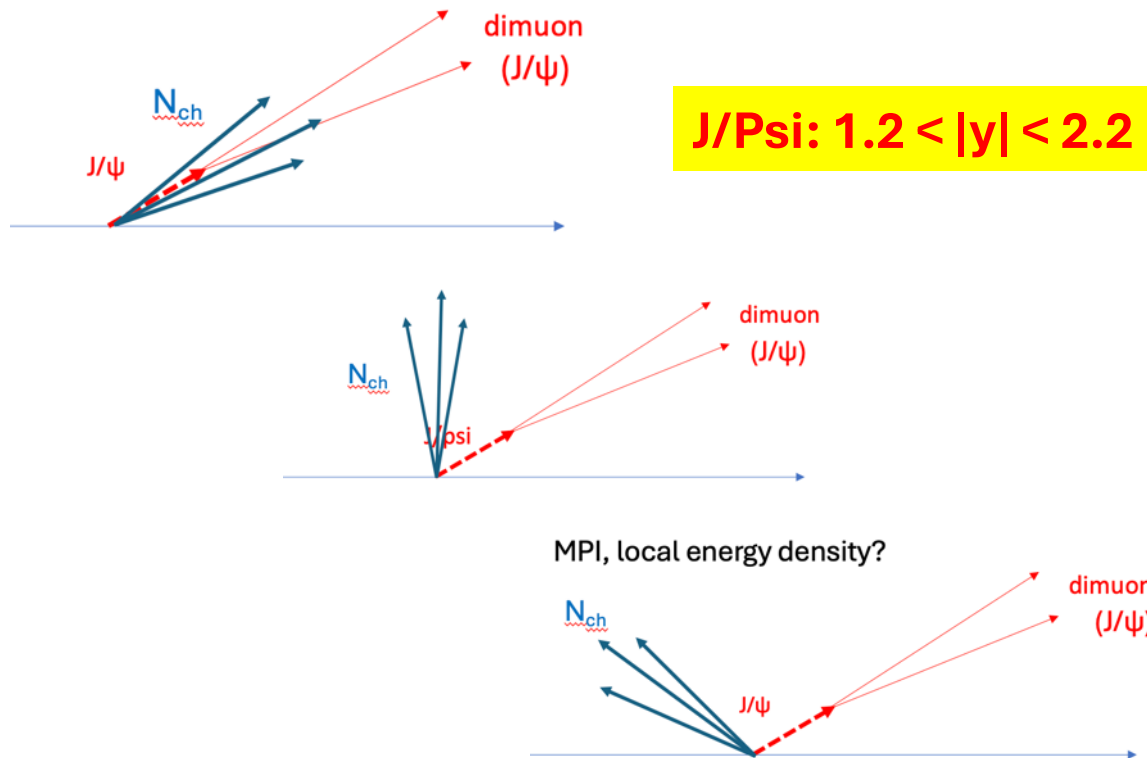


J/ψ Production vs N_{ch} in p+p and p+Au at 200GeV

- Final State Interactions (FSI), CNM, QGP
- Local event multiplicity: N_{ch}
- Multi-Parton Interactions (MPI)
- Long-range particle correlations

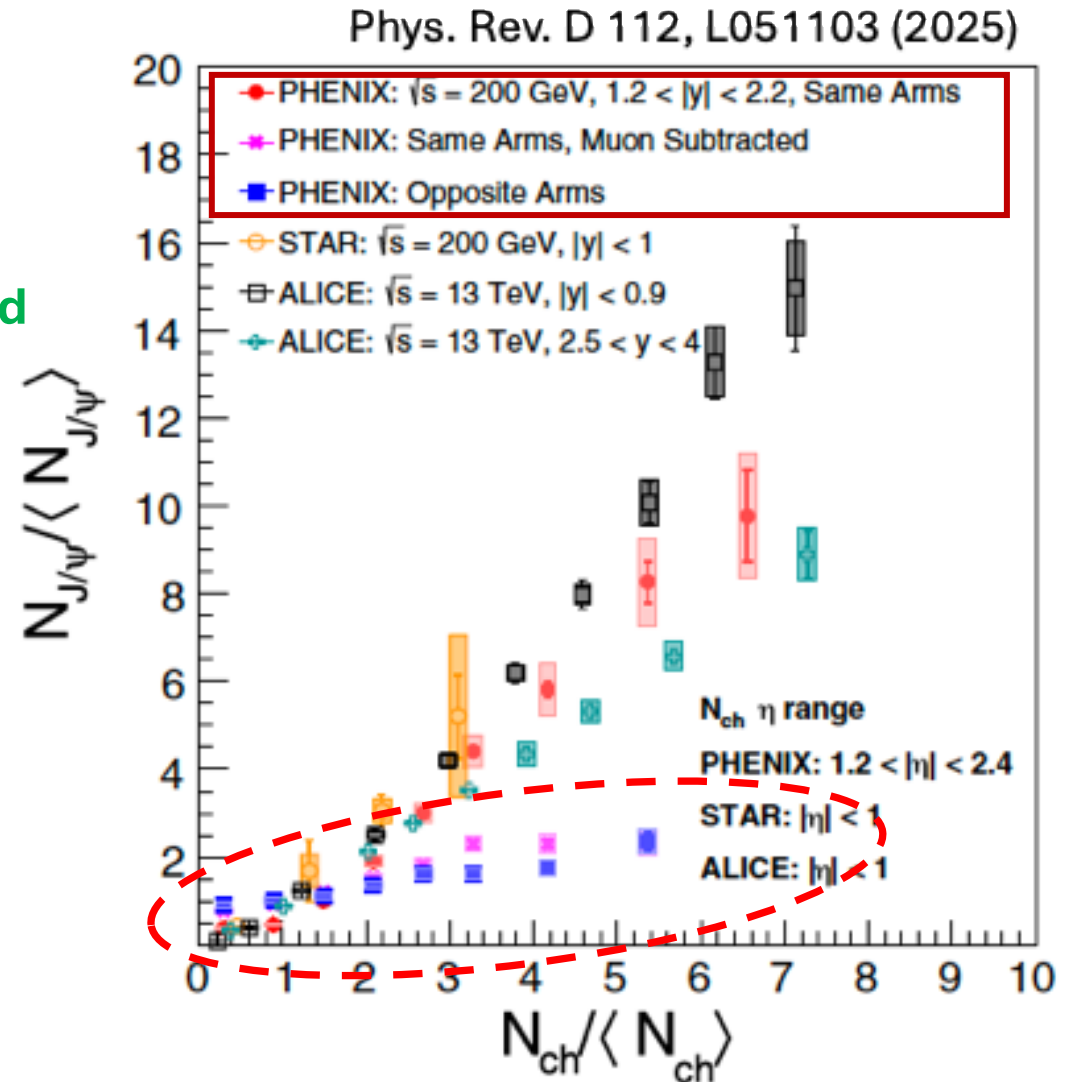
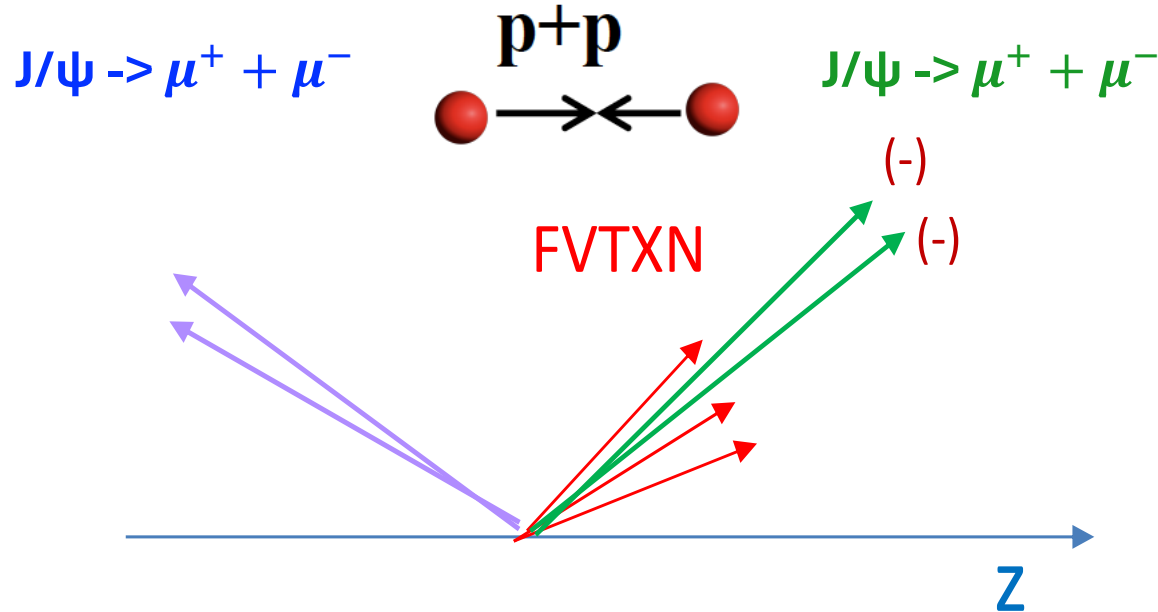
Event track multiplicity: N_{ch}

- SVX, $|\eta| < 1$
- FVTX, $1 < |\eta| < 3$



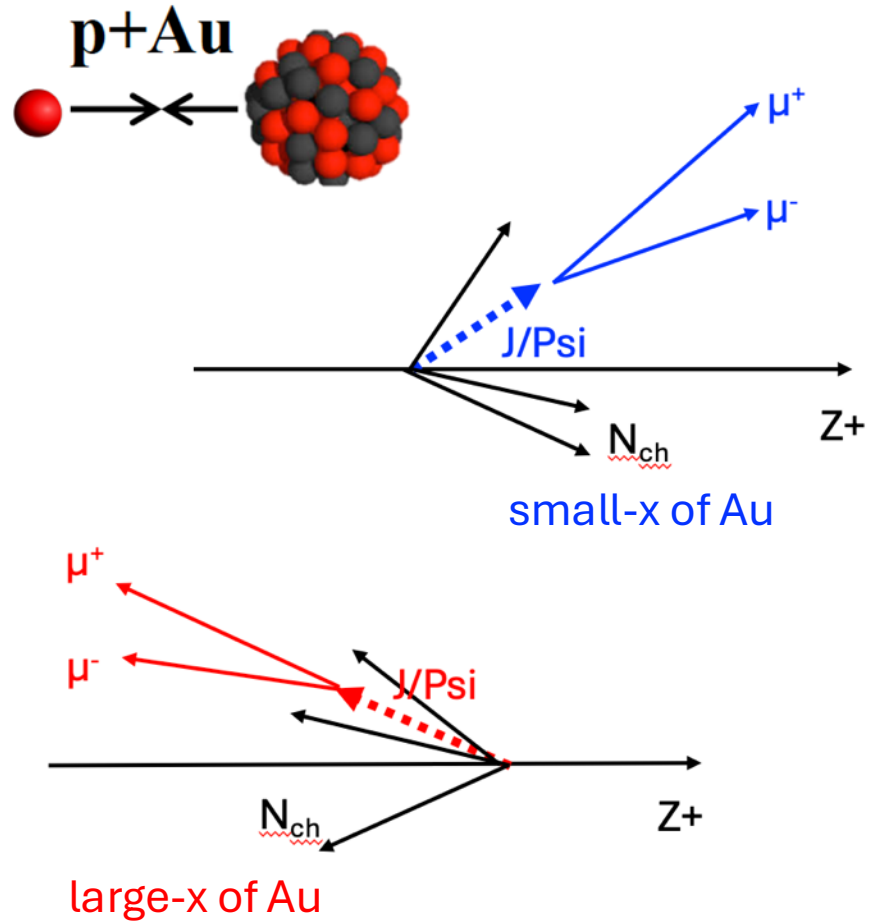
J/ψ Yield vs N_{ch} in p+p Collisions

1. J/Psi yields increase vs N_{ch}
2. Similar trend as others, same-arm “inclusive” N_{ch}
3. **Apparent clear difference** in long-range <J/Psi – N_{ch}> correlations, **same arm** vs **opposite arm**
4. **Consistent** once same-arm **auto-correlation** removed
 ➤ **Long range correlation in p+p**

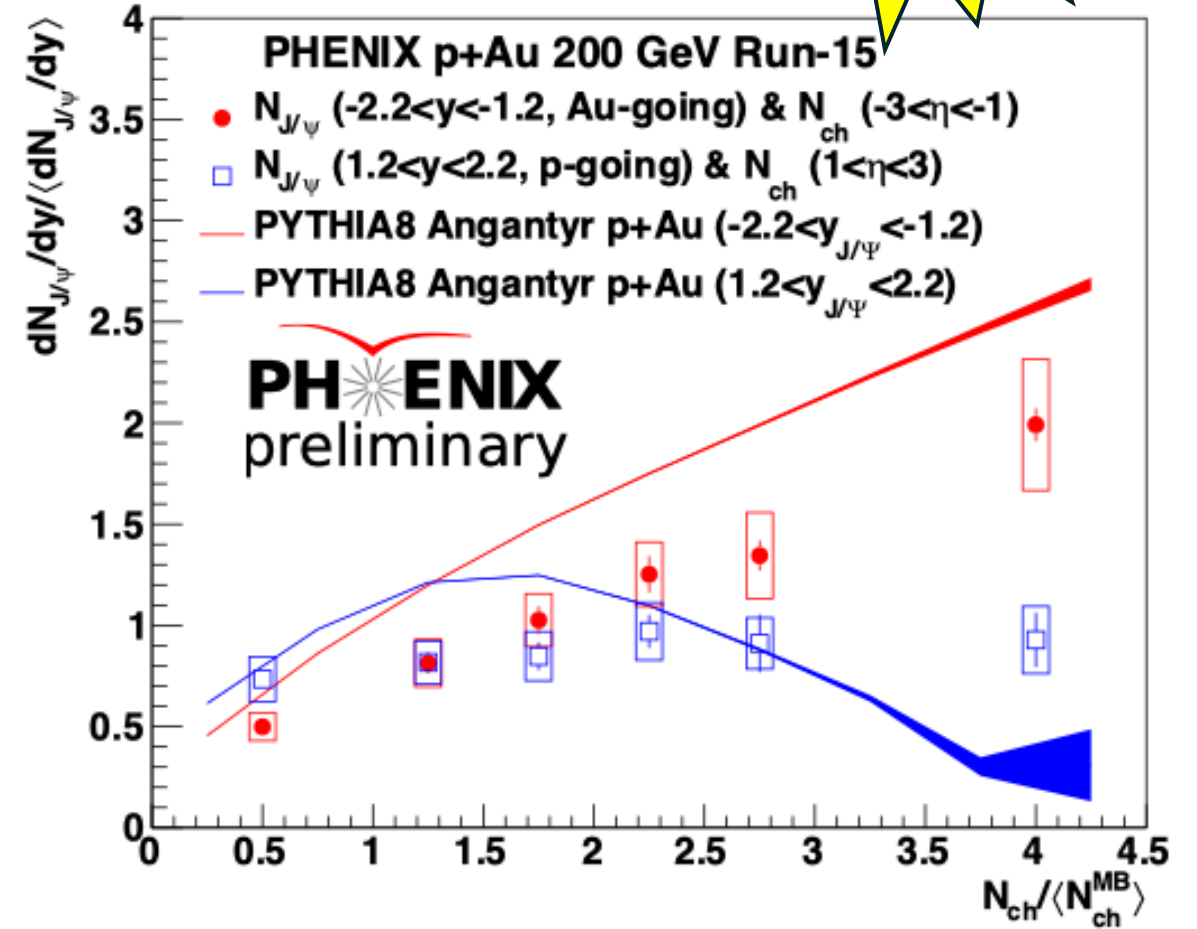


J/ψ and N_{ch} Correlation: Same Arm

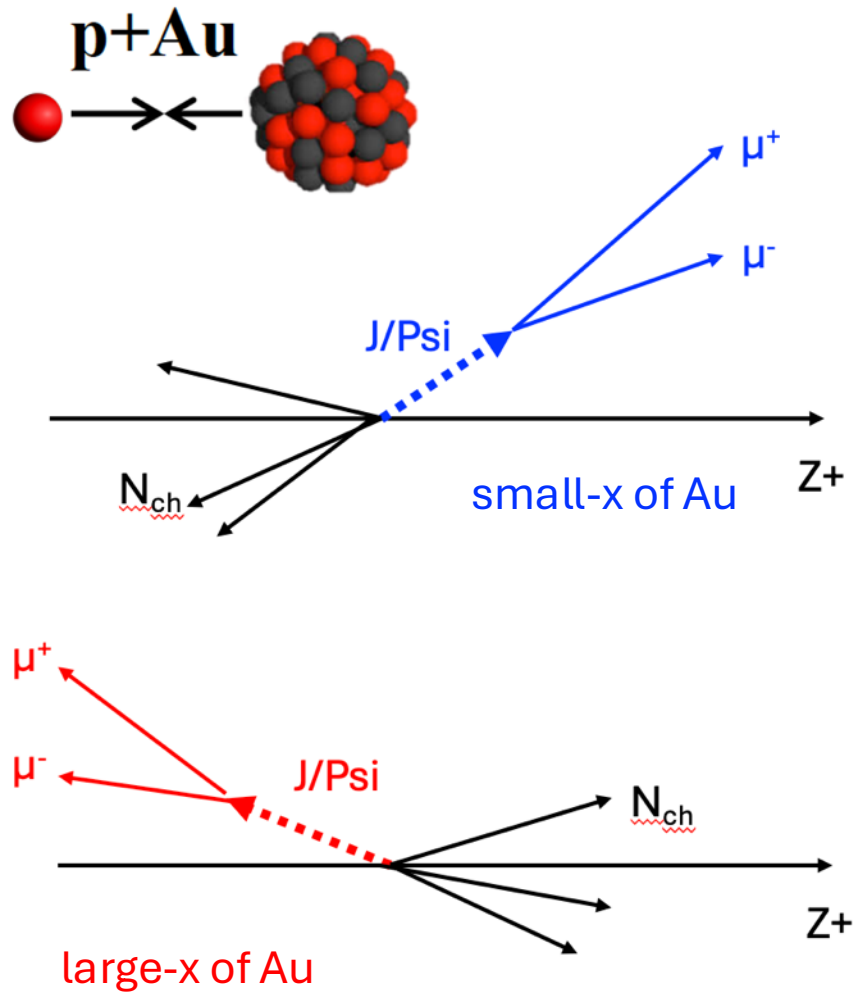
NEW



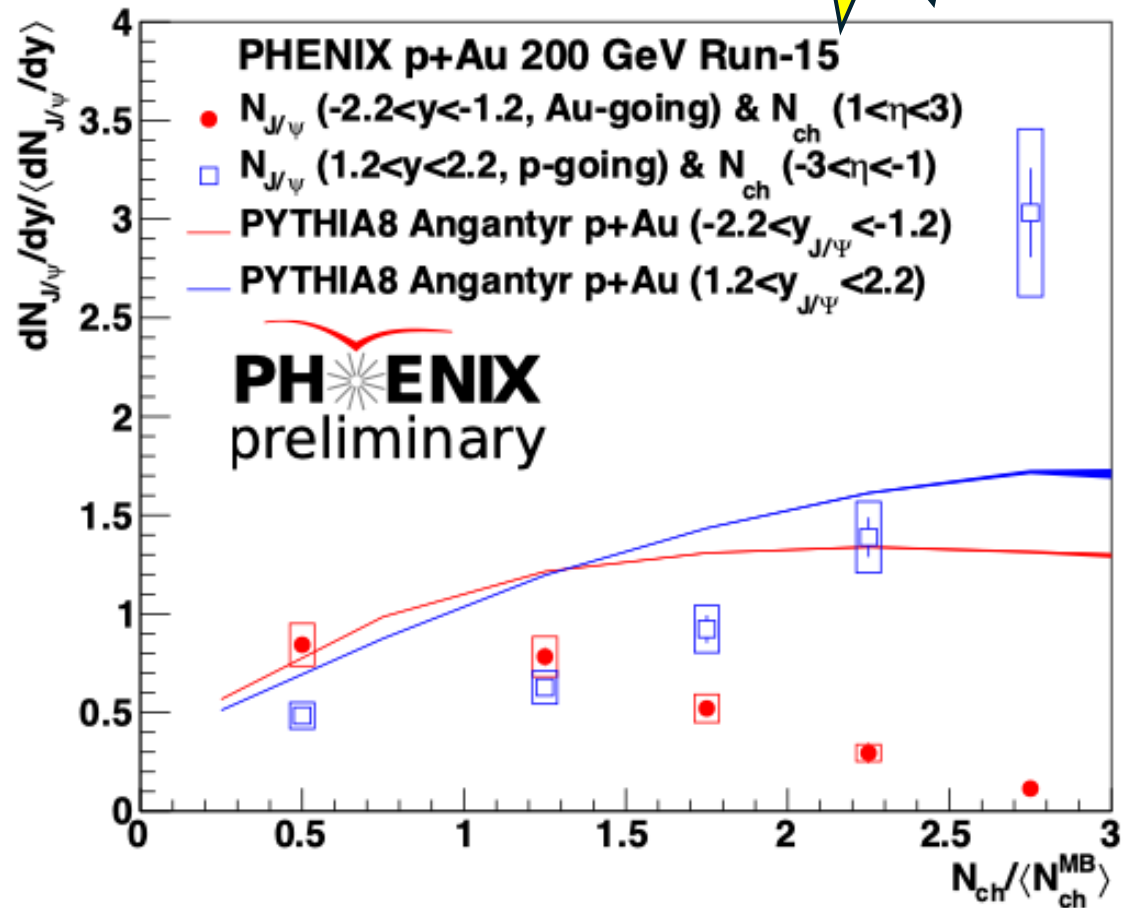
muon subtracted



J/ψ and N_{ch} Correlation: Opposite Arm



muon subtracted



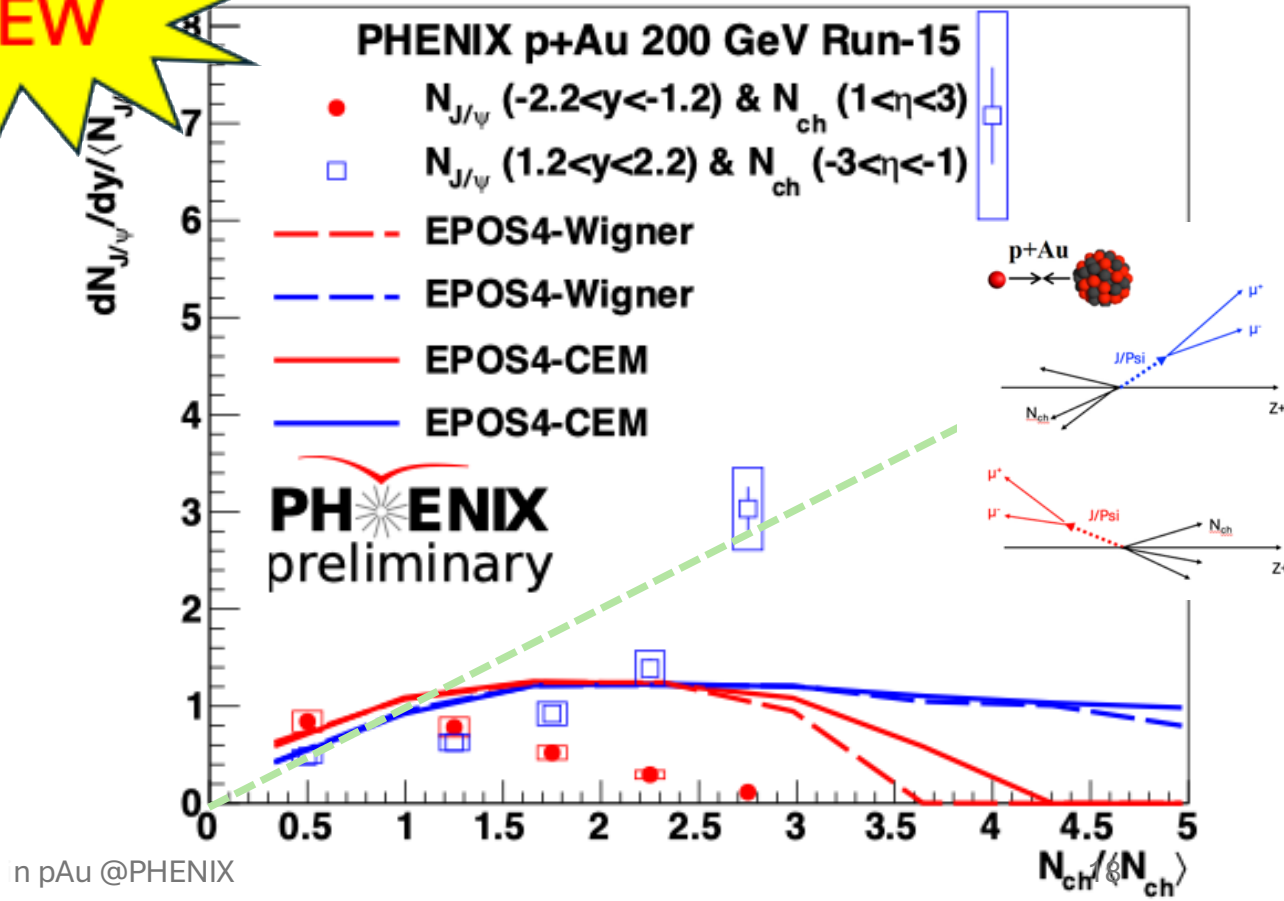
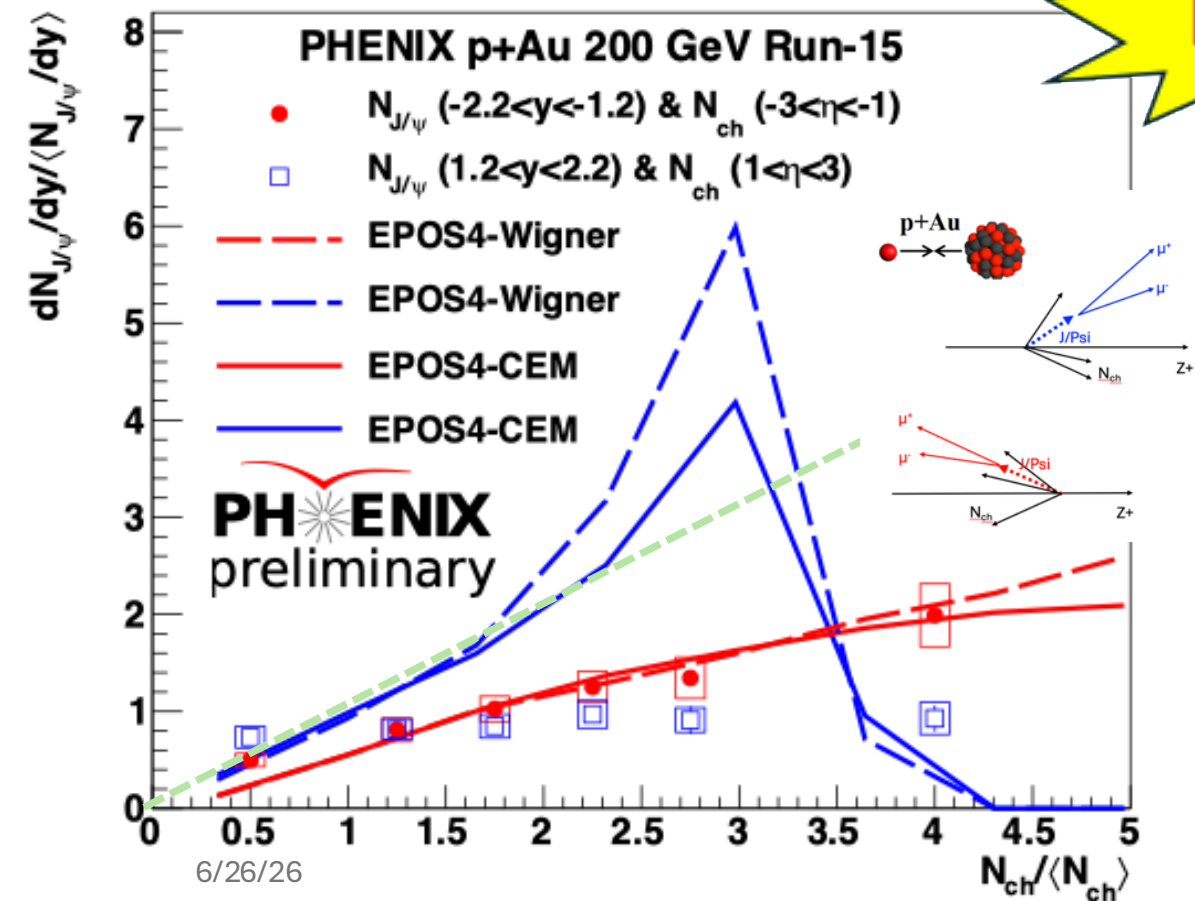
EPOS-4 and PHENIX Data

- Good agreement with “same-arm” data in **Au-going direction**
- Failed **p-going direction**

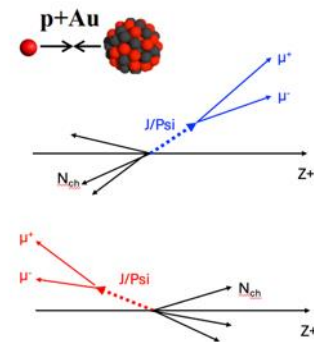
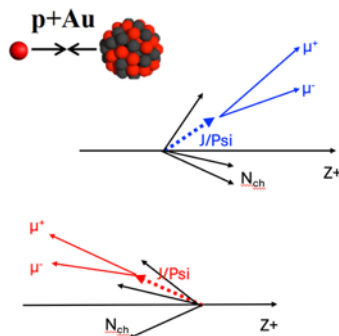
- Challenging for “opposite -arm” data in both **Au-going direction** and **p-going direction**

muon subtracted

muon subtracted

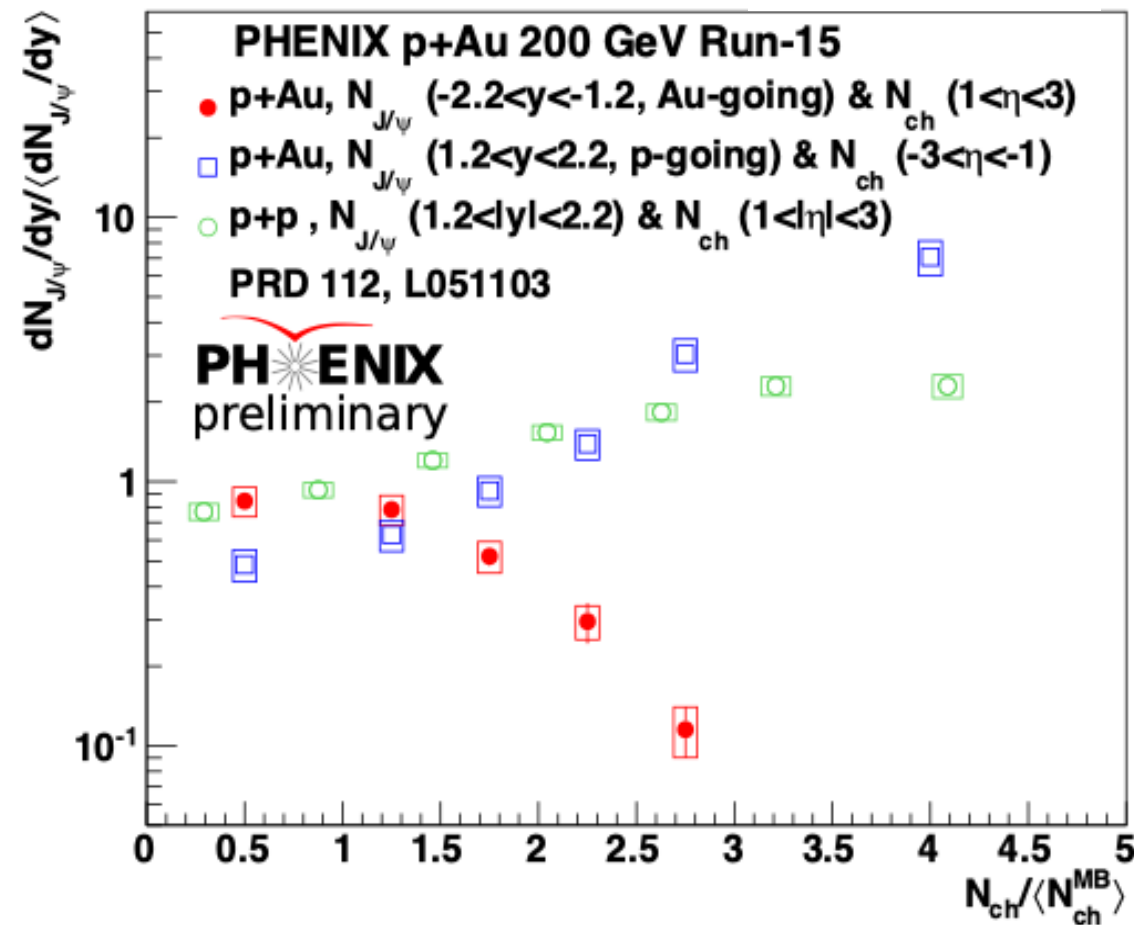
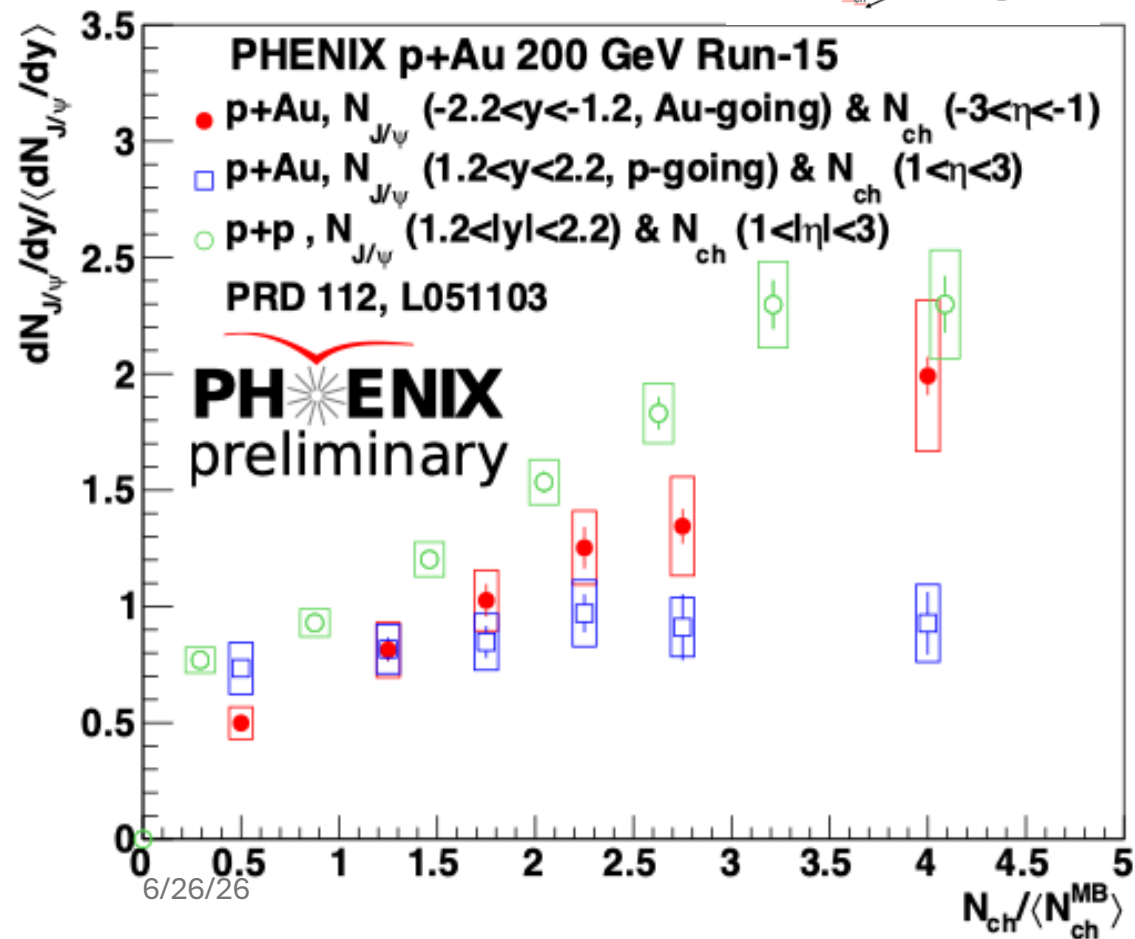


Physics Discussions: p+p and p+Au

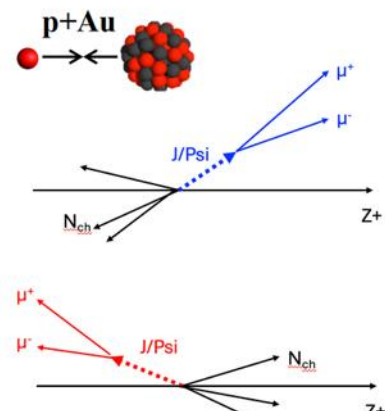
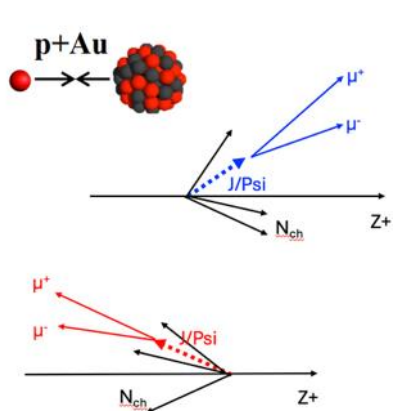


muon subtracted

muon subtracted

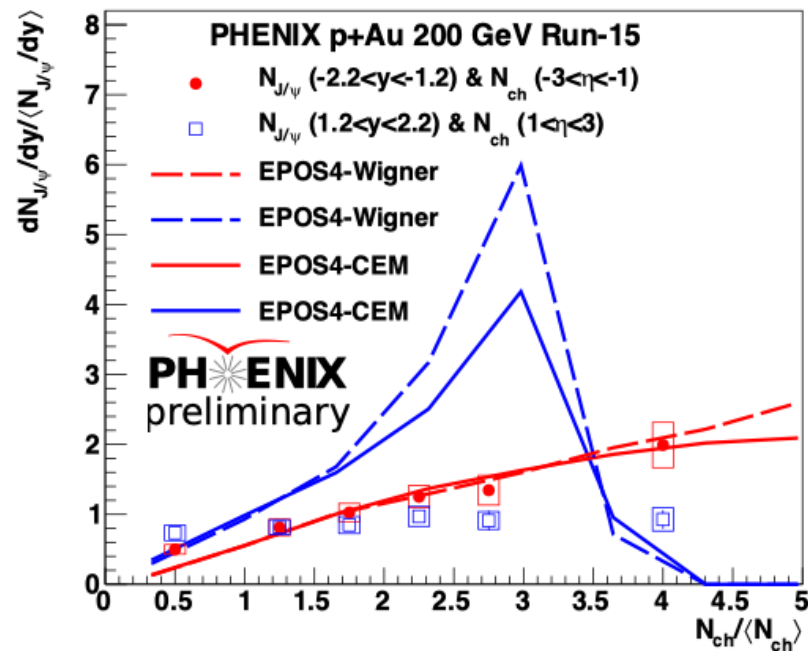


Physics Discussions

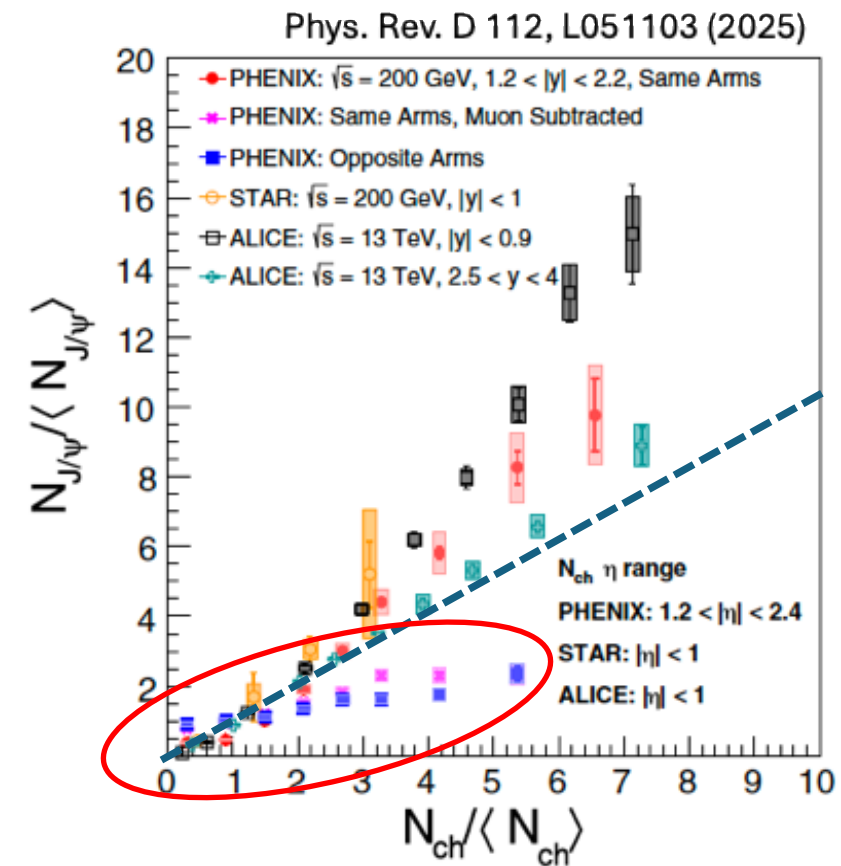
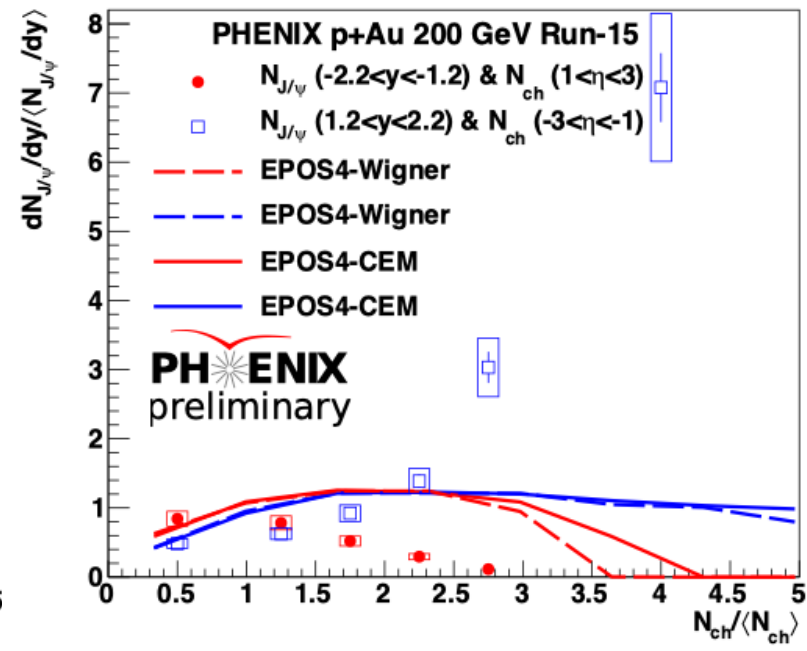


p+p

muon subtracted



muon subtracted



Probe CGC in p+Au?

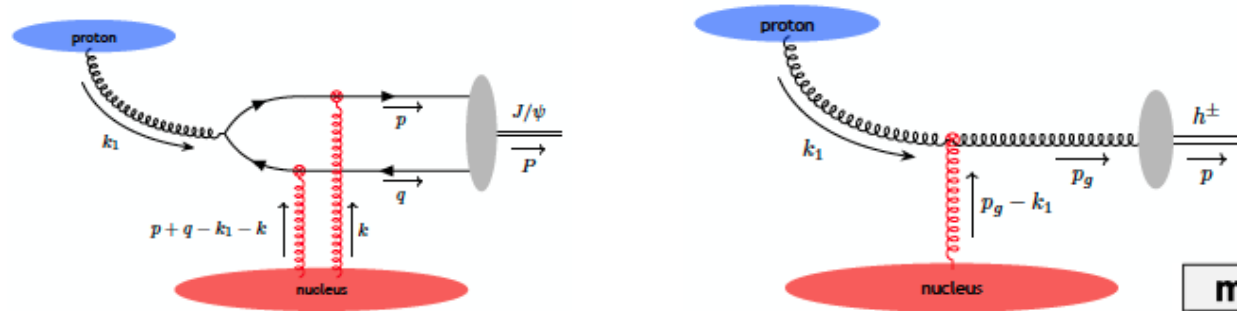
Run15 (2015)

100GeV/nucleon  ENIX

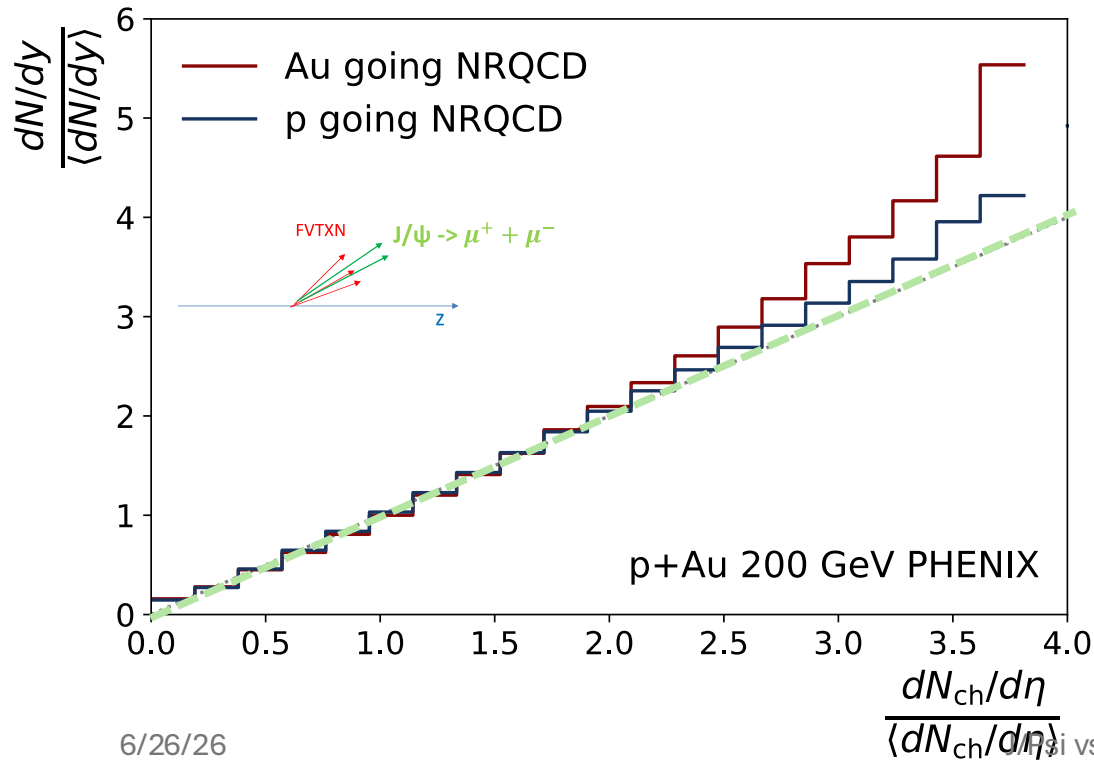
100GeV

Polarized Proton

Au, Al



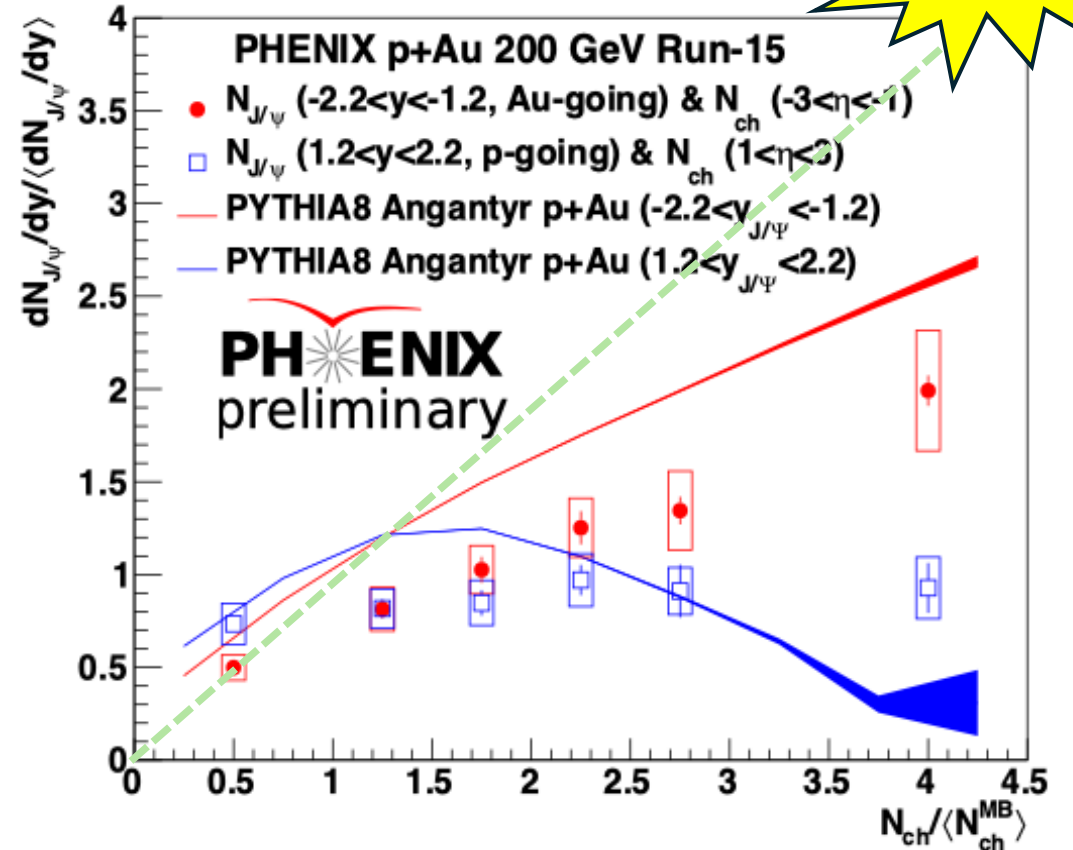
Farid Salazar, Bjorn Schenke and Alba Soto-Ontoso
arXiv:2112.04611; Private Comm.



6/26/26

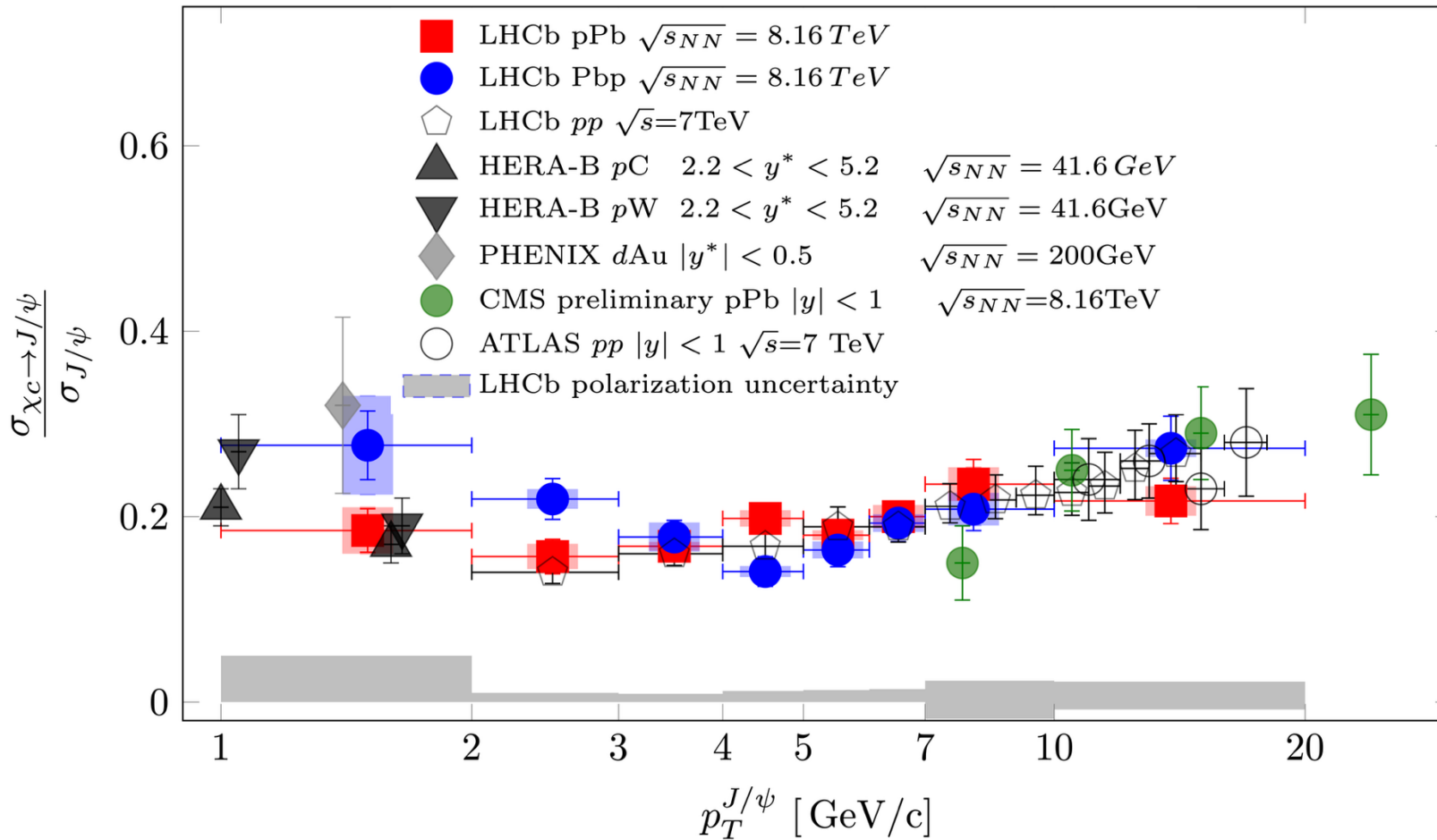
$\langle \frac{dN_{J/\psi}}{dy} \rangle$ vs N_{ch} in pAu @P

muon subtracted



NEW

J/Psi Production: Feed down contributions



- Feed-down contribution

- J/ ψ : ~20% from χ_c , >10% from b at LHC
 ~5% from b at RHIC

- $\psi(2S)$: >10% from b at LHC

LHCb: PRL 132 (2024) 102302

HERA-B: PRD79, 012001 (2009)

PHENIX: PRL111, 202301 (2013)

ATLAS: JHEP07(2014)154

CMS: CMS-PAS-HIN-22-003

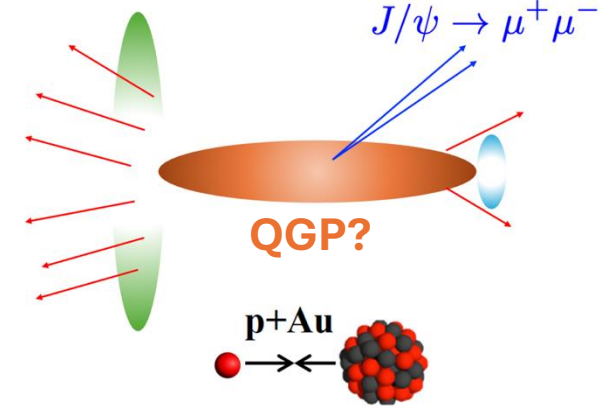
Summary and Outlook

- **Inclusive J/Psi yields vs event multiplicity in p+p and p+Au**

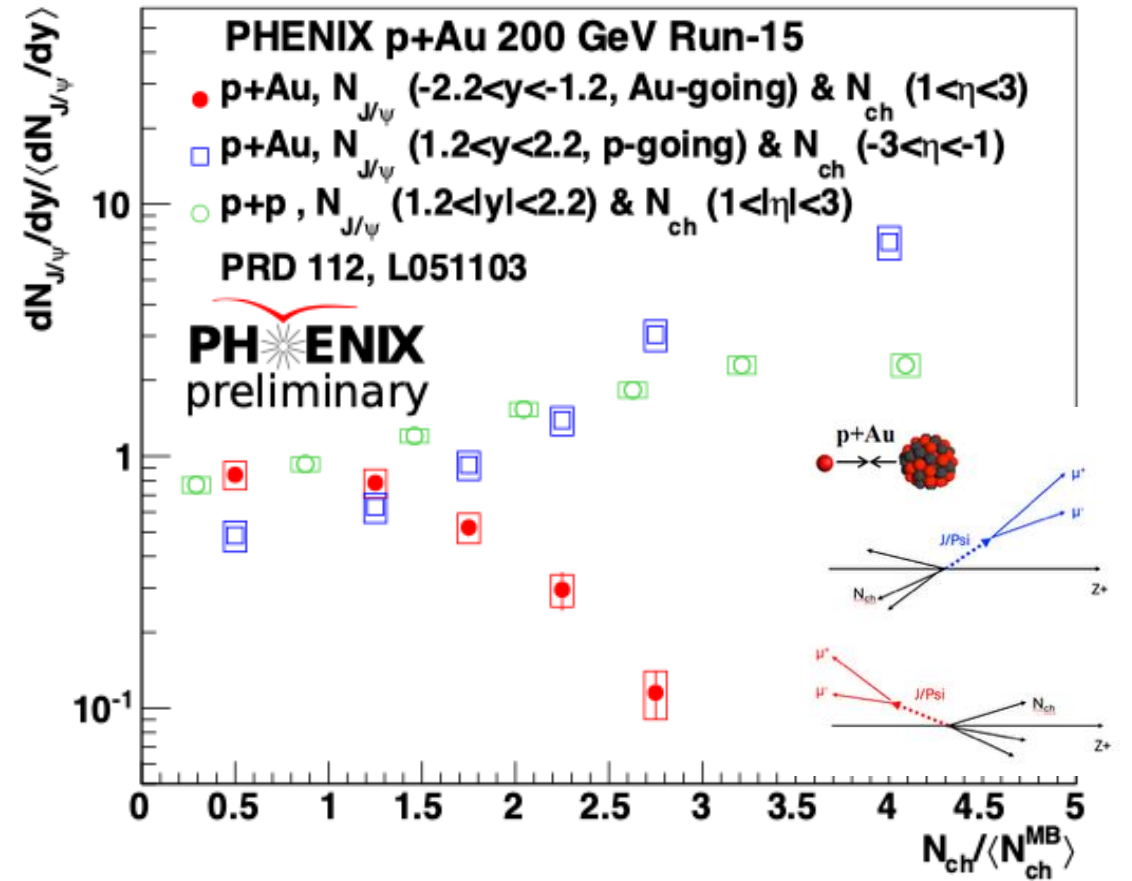
- pp results consistent with other data at RHIC and LHC
- **Novel effects observed in p+Au in large rapidity gap correlation**
- **QGP droplet?**

- **Work in progress on other signals**

- Event geometry, short/long range correlation
- QGP, CNM, CGC model calculations
- Revisit centrality determination of pAu etc...



muon subtracted



Thank You!



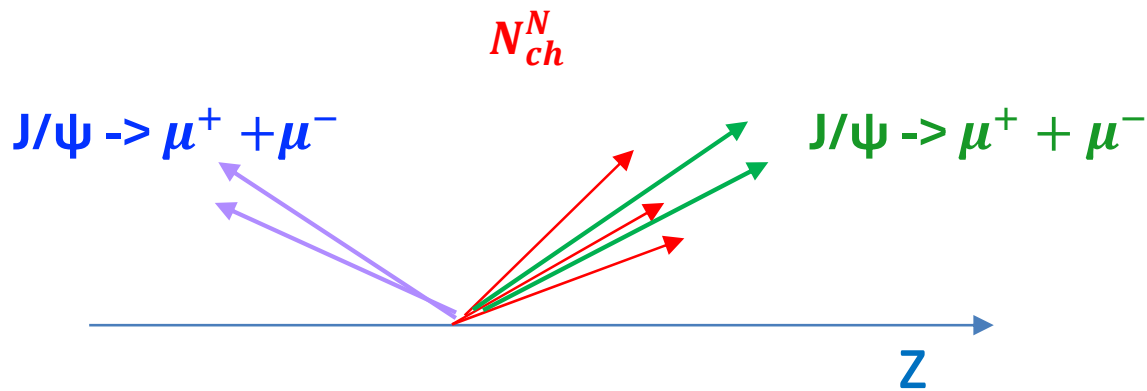
J/ψ Yields vs Event Multiplicity in pp

- sensitive to underlying event activities, MPI

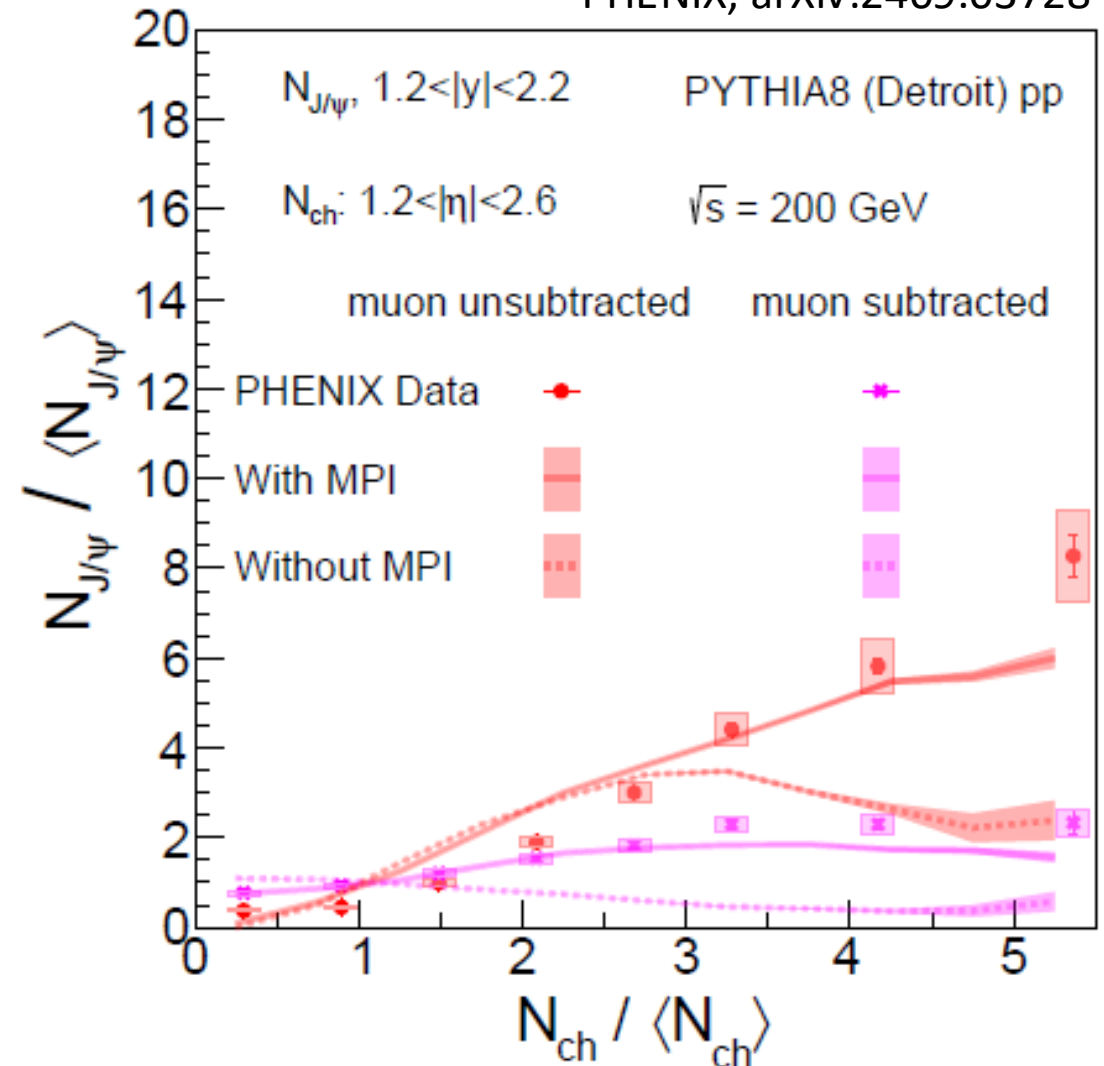
RED = Tracklets N_{ch}^N ($1.2 < \eta < 2.4$)

Green = J/ψ ($1.2 < y < 2.2$)

Blue = J/ψ ($-2.2 < y < -1.2$)

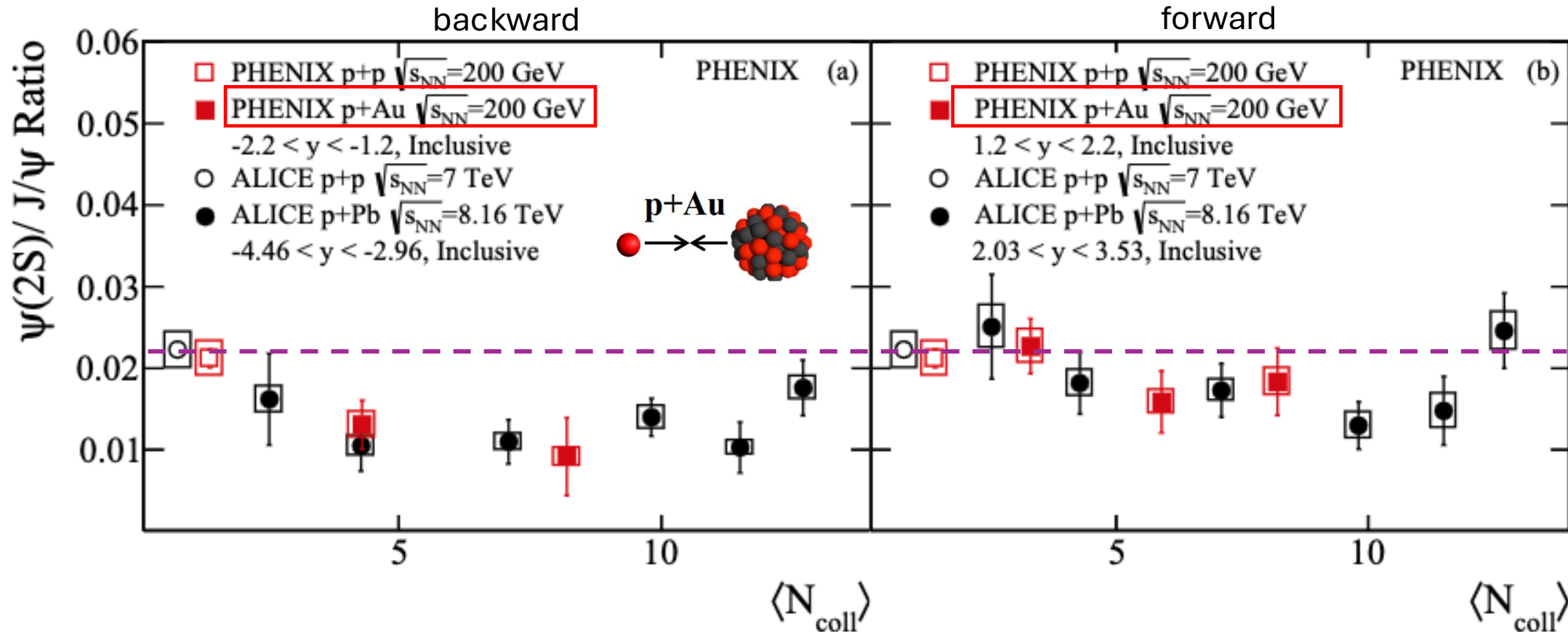


PHENIX, arXiv:2409.03728



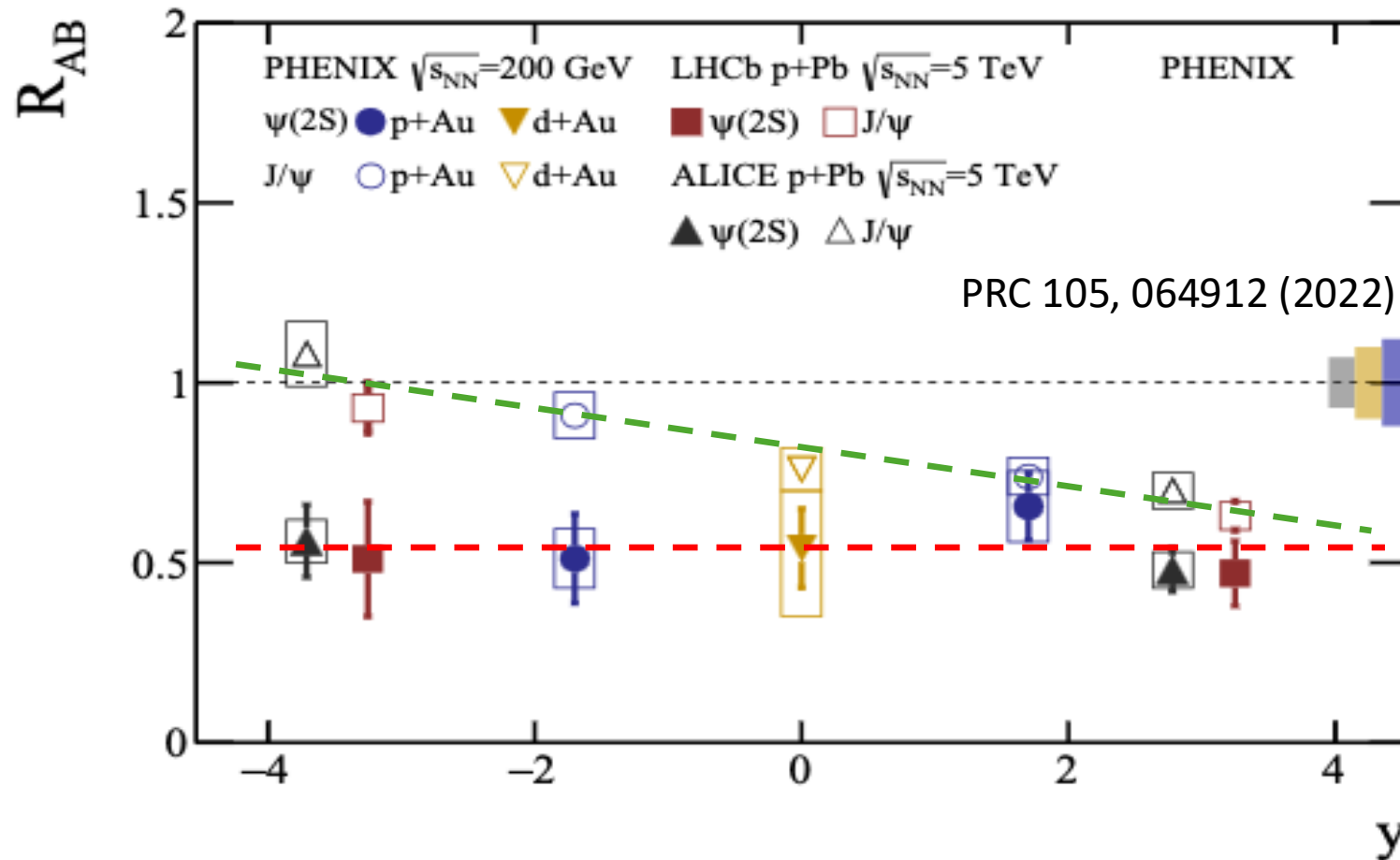
$\psi(2S)$ to J/ψ Ratios in p+A at RHIC and LHC

- sensitive to FSI



- Similar suppression pattern, weak energy dependence
- **Final state effect is significant**, and larger in the backward rapidity where multiplicity is higher

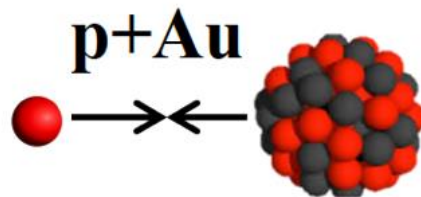
RHIC vs LHC R_{AB} : Put them all together



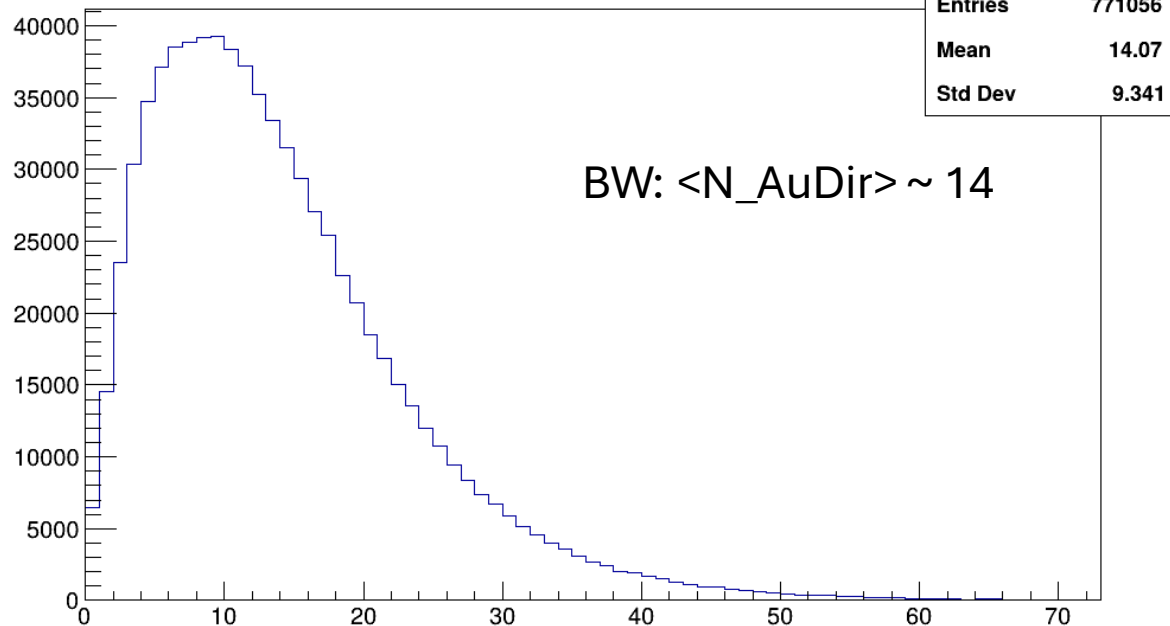
- J/Psi R_{AB} ~ strong rapidity dependence, FSI?
- Psi(2S) R_{AB} remain ~flat vs rapidity, also independent of collision energy, suppression already saturated?

PYTHIA8 p+Au MB Simulations

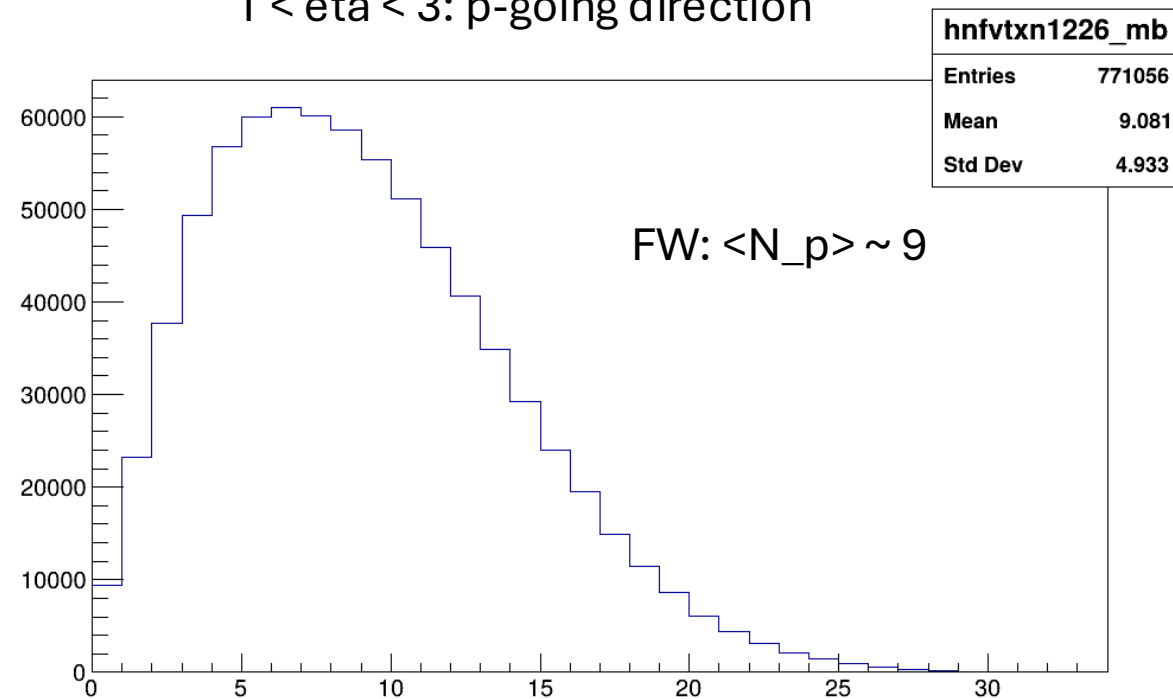
- inclusive N_{ch} in Forward(p)/Backward(Au)



-3 < eta < -1: Au-going direction



1 < eta < 3: p-going direction



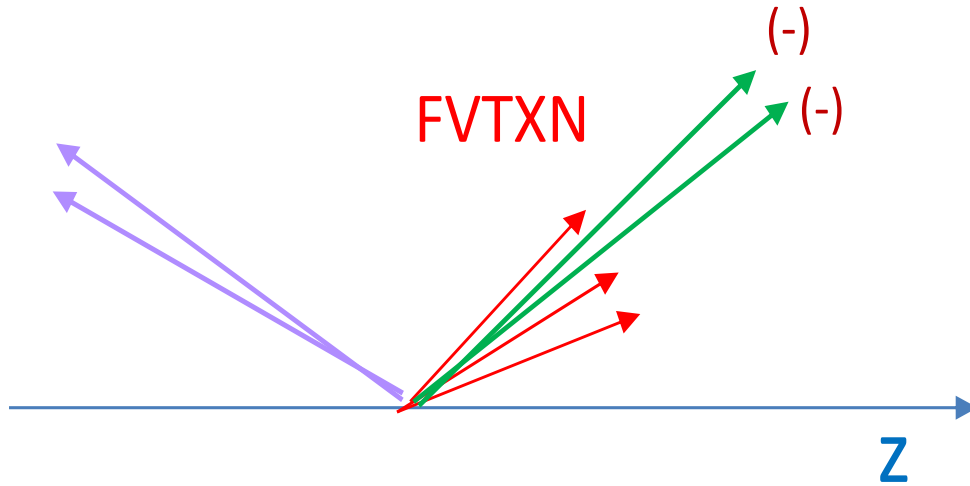
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Unique collision event topology:

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$-2.2 < y < -1.2$
 $J/\psi \rightarrow \mu^+ + \mu^-$

$1.2 < y < 2.2$
 $J/\psi \rightarrow \mu^+ + \mu^-$



$y_{beam} = 5.36$ @100GeV (LHC pp @13TeV: 9.54)

large-x of Au

small-x of Au

