Recent J/ψ measurements at the PHENIX experiment

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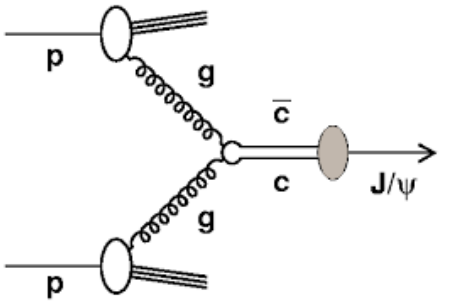
Outline

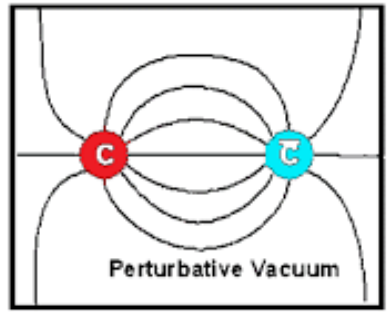
- Motivation
- Multiplicity dependent forward J/ψ and $\psi(2s)$ production in 200 GeV p+p collisions.
- Forward J/ψ elliptic flow in 200 GeV Au+Au collisions.
- Summary

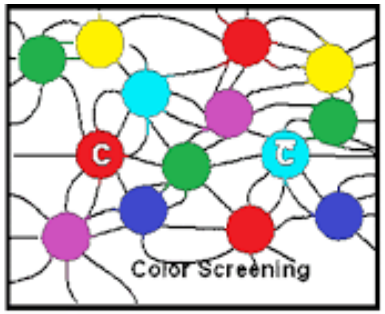
Why to measure Charmonium states

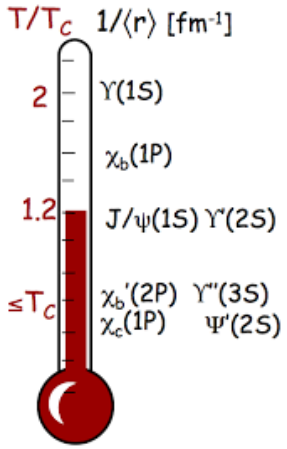
- Charmonium hadron such as J/ψ is an ideal probe to test the QCD prediction.
  - Disentangle perturbative and non-perturbative parts in the charm production.
  - Separate the initial and final state effects.
- Explore the cold and hot nuclear medium effects such as modification of nuclear parton distribution function (nPDF).
- Charmonium production in A+A collisions as a good thermometer to study the properties of Quark Gluon Plasma (QGP). Expect the recombination or color screening effect is smaller at RHIC energy than LHC measurements.

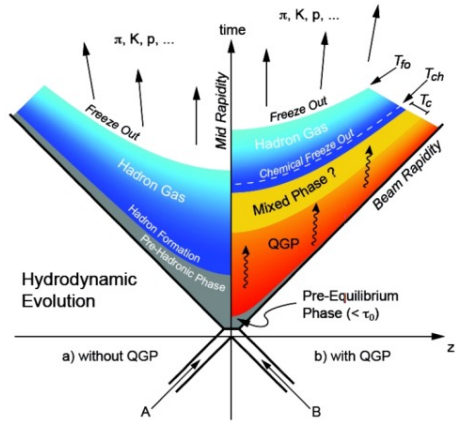
Color singlet or color octet?



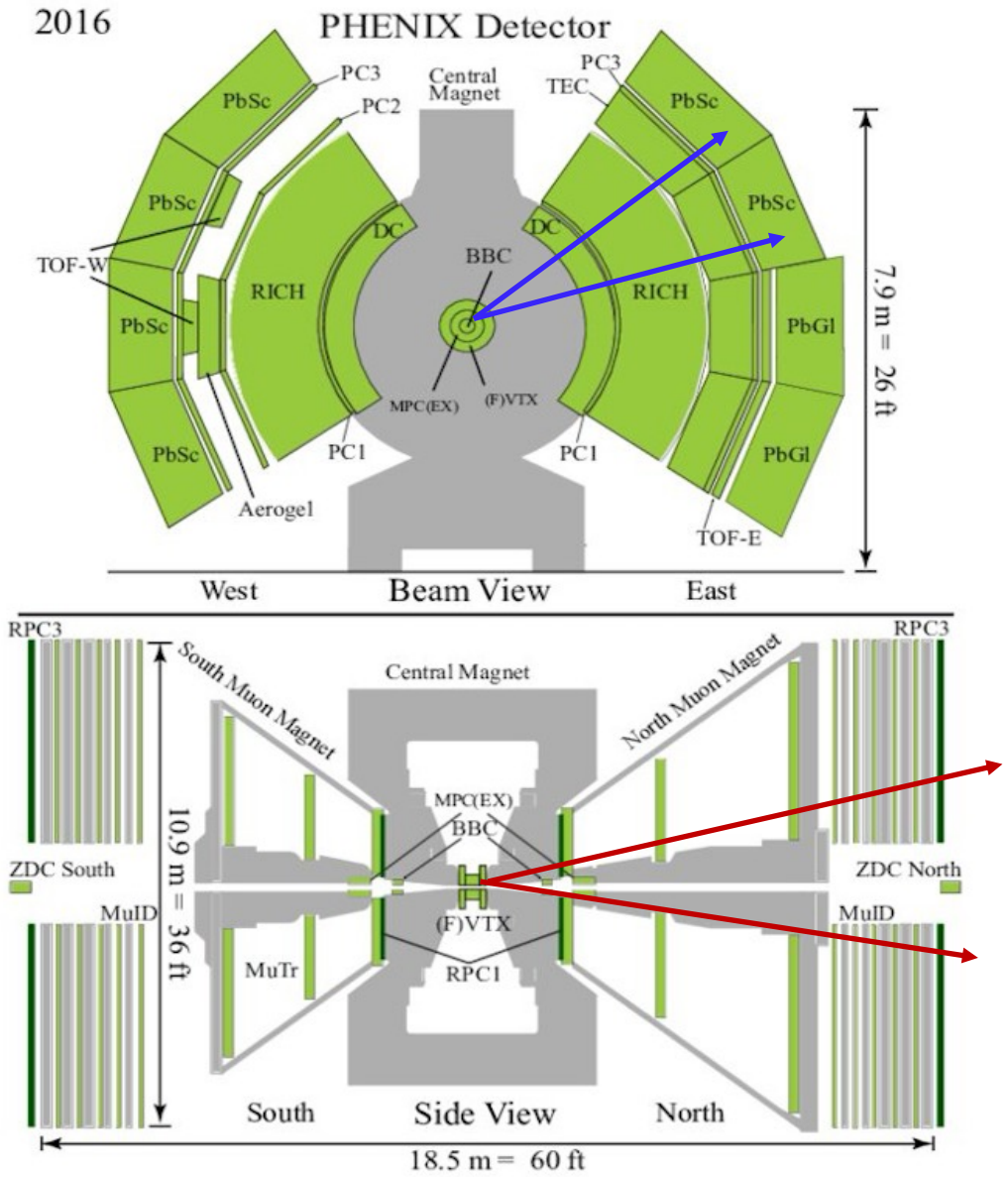








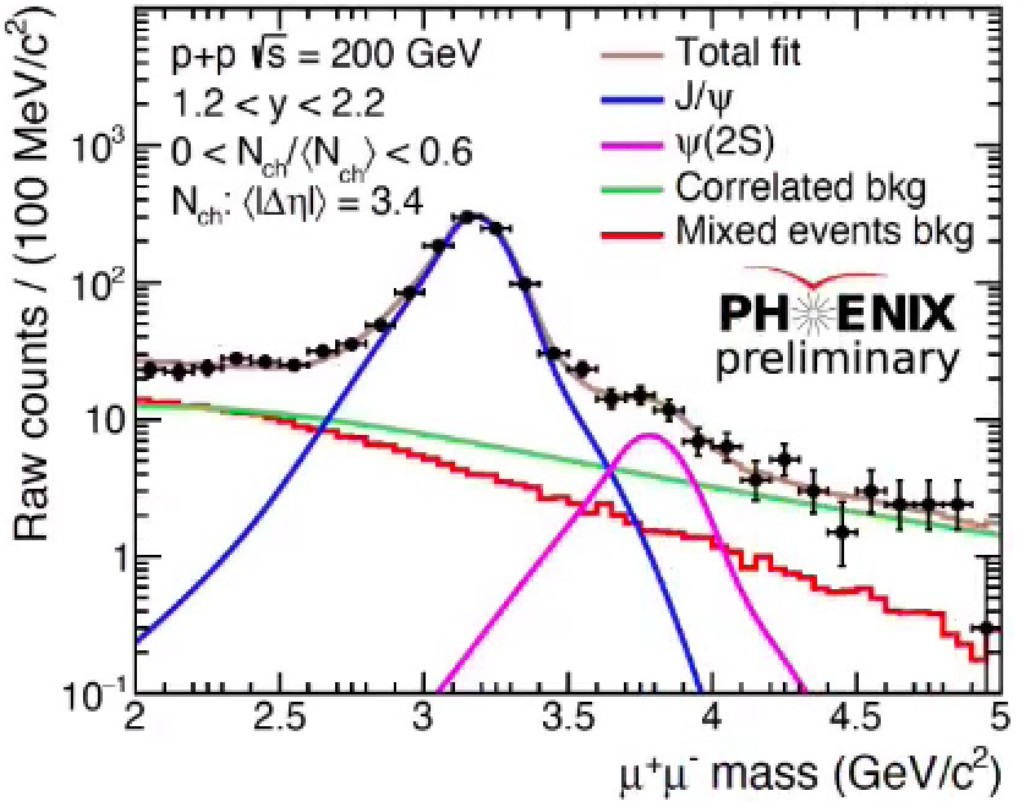
The PHENIX Detector for J/ψ measurements

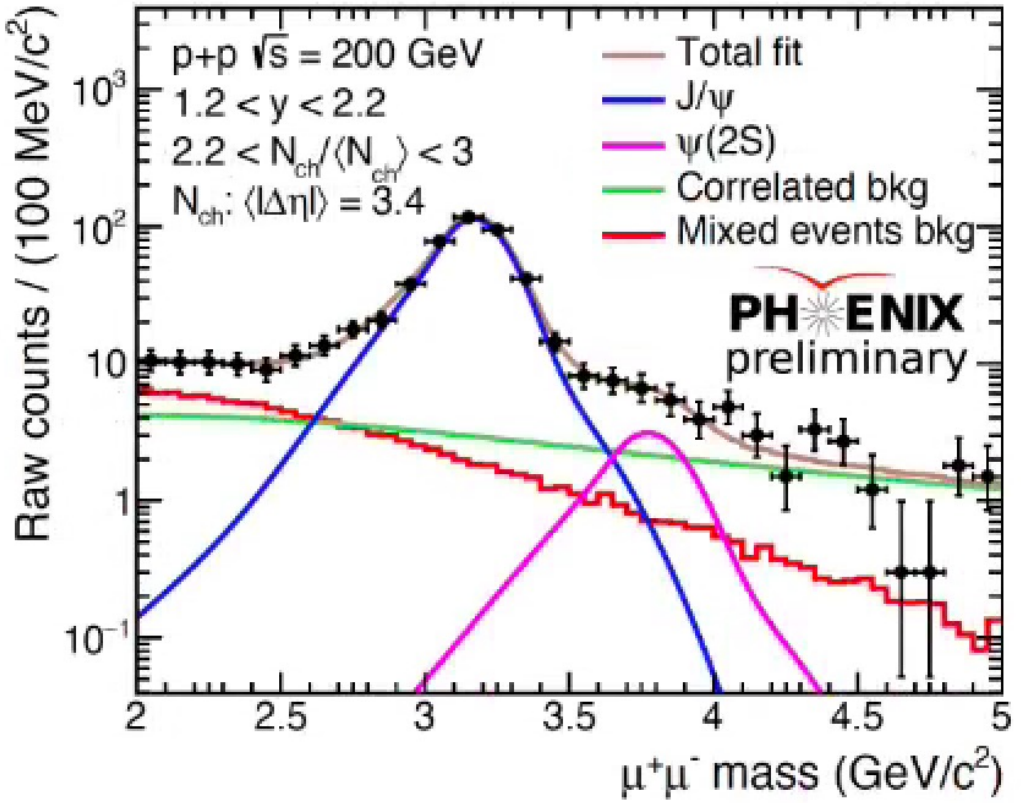


- **A series of J/ψ and ψ(2s) measurements have been achieved in p+p, p+A and A+A collisions at PHENIX.**
- **Central detector (**$|\eta| < 0.35$**) to reconstruct J/$\psi \rightarrow e^+ + e^-$**
  - Tracking: DC, PC, VTX
  - PID: RICH
  - EMCal
- **Forward detector (**$1.2 < |\eta| < 2.4$**) to reconstruct J/$\psi \rightarrow \mu^+ + \mu^-$**
  - ~10 interaction length absorbers
  - Tracking: RPC (cathode strip chamber), MuTr, FVTX
  - MuID: muon identification detector

PHENIX forward J/ψ reconstruction in 200 GeV p+p collisions

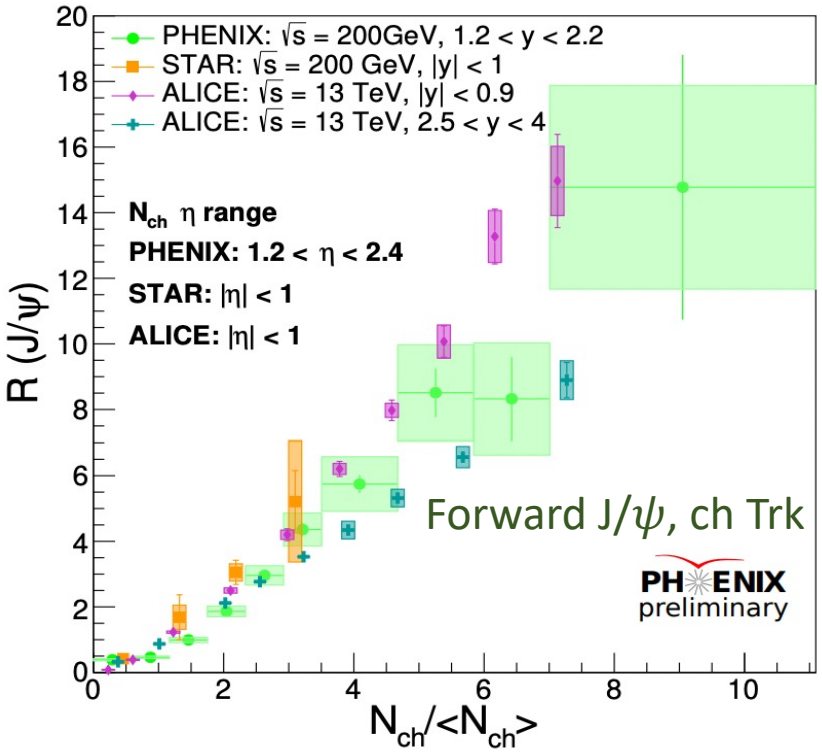
- Good J/ψ and $\psi(2s)$ signals found in di-muon invariant mass spectrums within the 1.2<|η|<2.2 region in 200 GeV p+p collisions.
- With the normalized track multiplicity $N_{ch}/\langle N_{ch}\rangle$: 0-0.6 (left) and $N_{ch}/\langle N_{ch}\rangle$: 2.2-3.0 in the opposite pseudorapidity region (right).

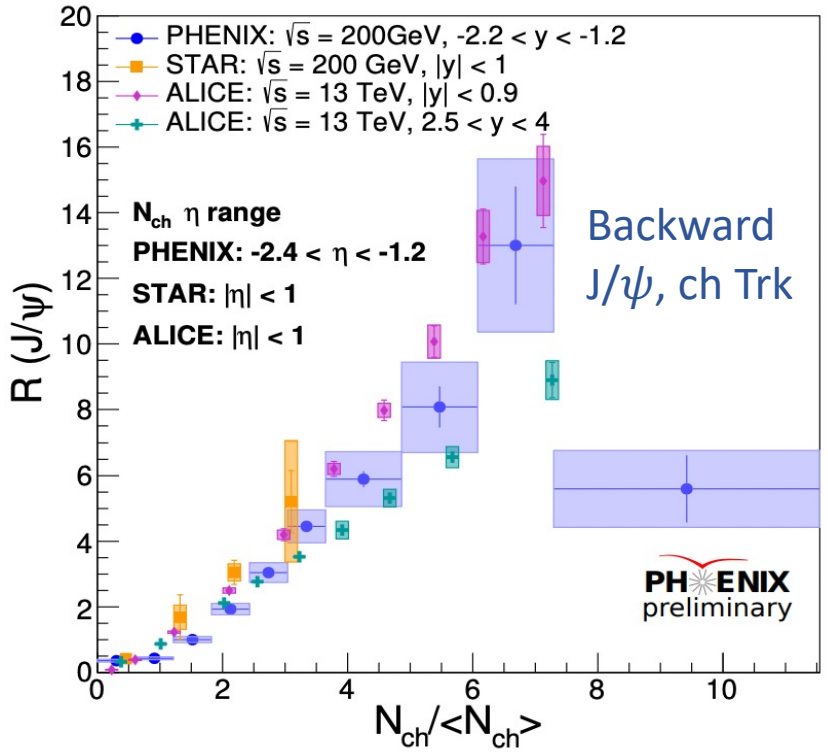


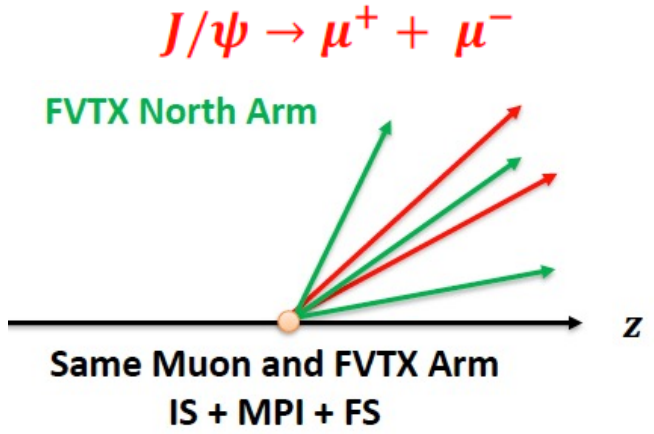


Multiplicity dependent forward J/ψ in 200 GeV p+p collisions

- The normalized J/ψ yields (R(J/ψ)=$N_{J/\psi}/< N_{J/\psi} >$) versus the normalized charged particle multiplicity ($N_{ch}/< N_{ch} >$) in the 1.2<η<2.4 (left) and -2.4<η<-1.2 (right).



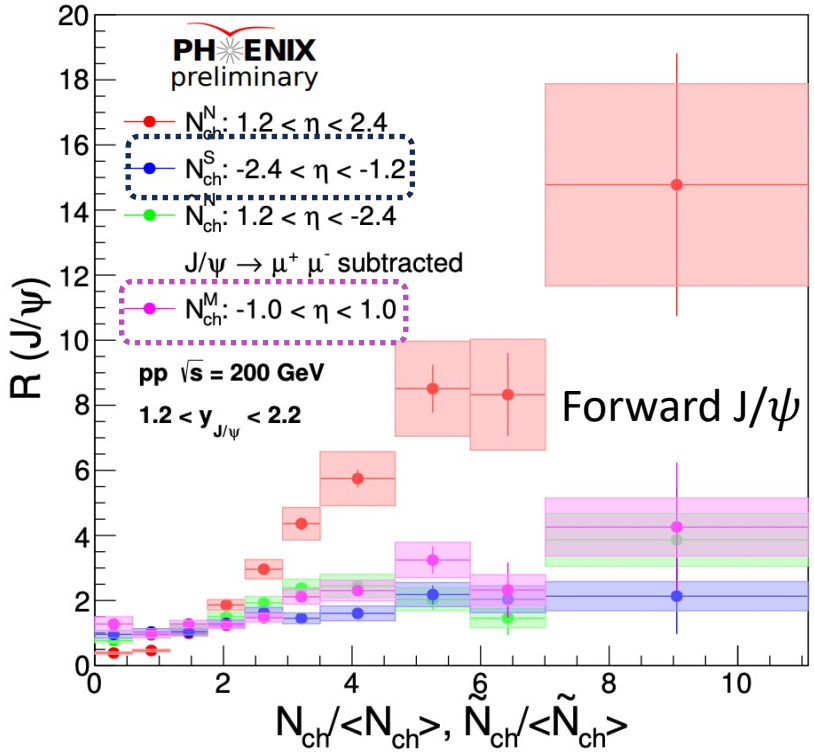


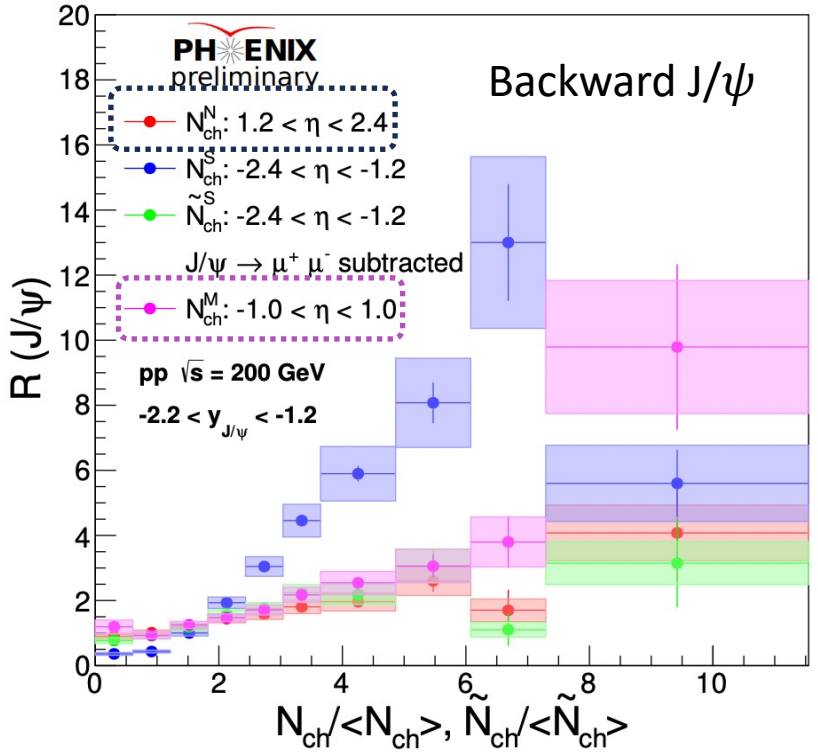


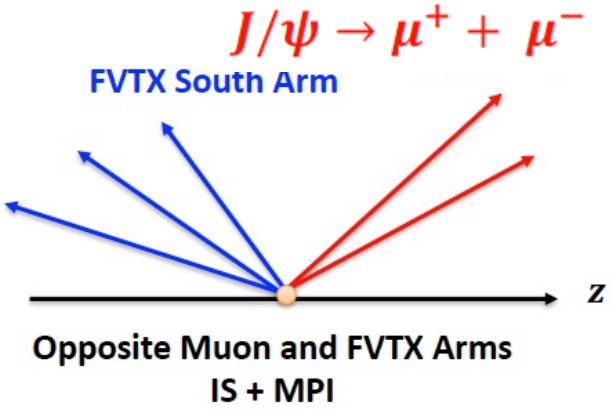
- Multi-Parton Interaction (MPI) and final state contributions along with auto correlation effects up to $N_{ch}/< N_{ch} >$ ~ 10.

Multiplicity dependent forward J/ψ in 200 GeV p+p collisions

- The normalized J/ψ yields (R(J/ψ)= $N_{J/\psi}/< N_{J/\psi} >$) in the 1.2<$\eta$<2.4 (left) and -2.4<$\eta$<-1.2 (right) versus the normalized charged particle multiplicity ($N_{ch}/< N_{ch} >$) in the opposite pseudorapidity region.



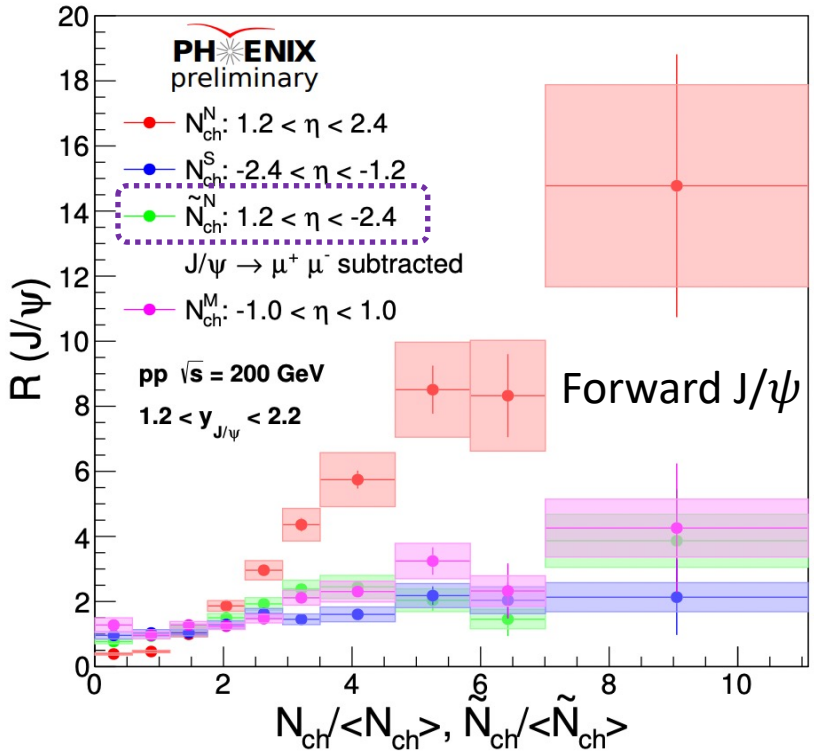


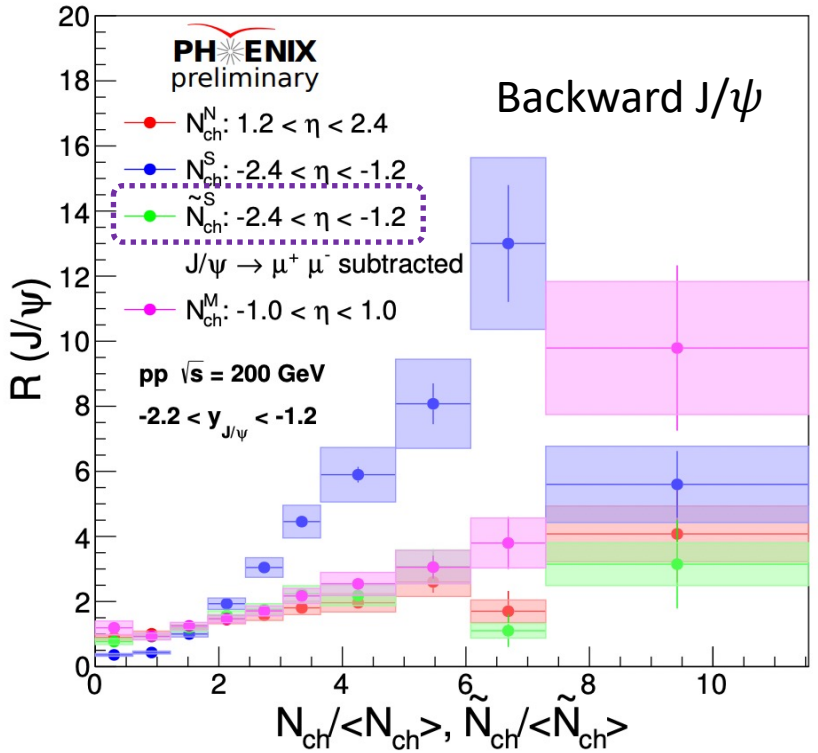


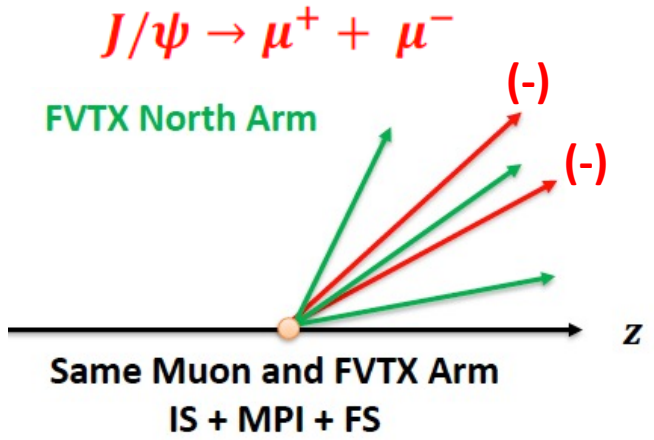
- Reduced dependence on the normalized charged particle multiplicity due to reduced final state correlations.

Multiplicity dependent forward J/ψ in 200 GeV p+p collisions

- The normalized J/ψ yields (R(J/ψ)=$N_{J/\psi}/< N_{J/\psi} >$) versus the normalized charged particle multiplicity ($\widetilde{N_{ch}}/< \widetilde{N_{ch}} >$) after subtracting the J/ψ decay muons in the 1.2<η<2.4 (left) and -2.4<η<-1.2 (right).



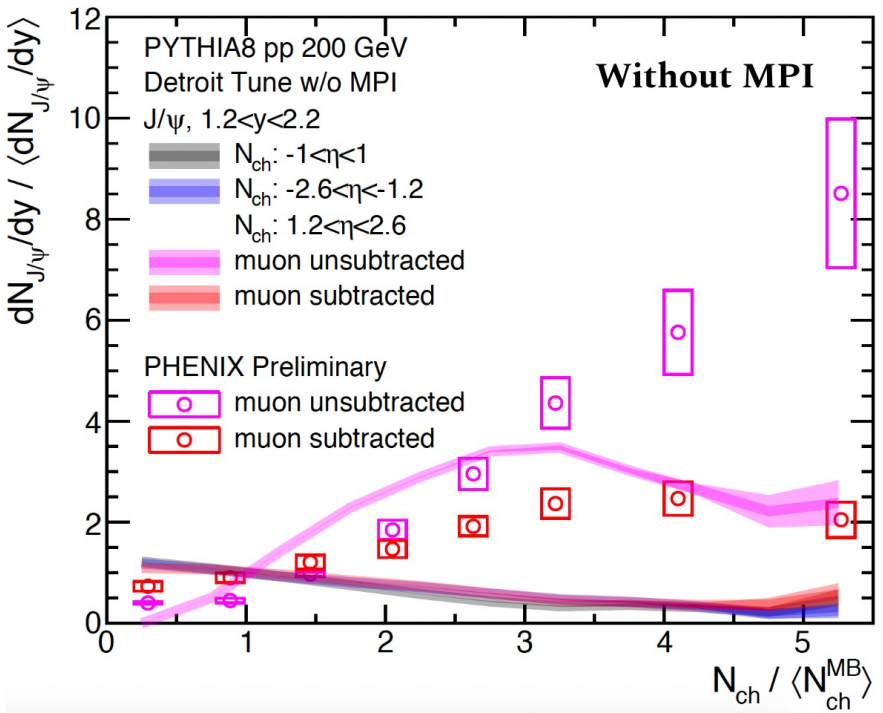


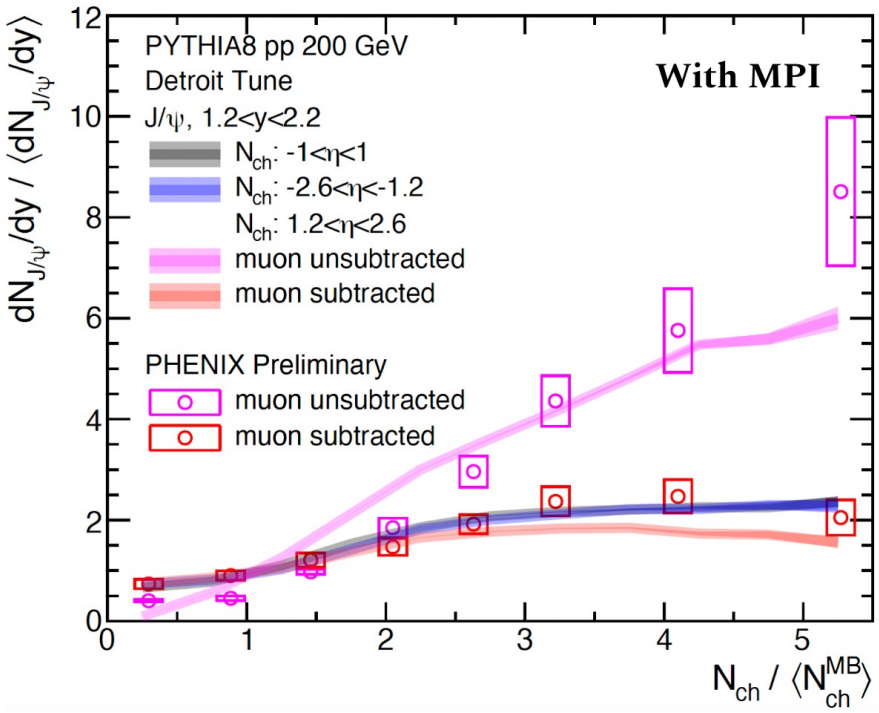


- Subtracting the di-muons to the charge particle multiplicity calculation significantly reduces the track multiplicity dependent R(J/ψ).

Multiplicity dependent forward J/ψ in 200 GeV p+p collisions

- The normalized J/ψ yields (R(J/ψ)=$N_{J/\psi}/< N_{J/\psi} >$) versus the normalized charged particle multiplicity ($\widetilde{N_{ch}}/< \widetilde{N_{ch}} >$) after subtracting the J/ψ decay muons in the 1.2<η<2.4 (left) and -2.4<η<-1.2 (right).





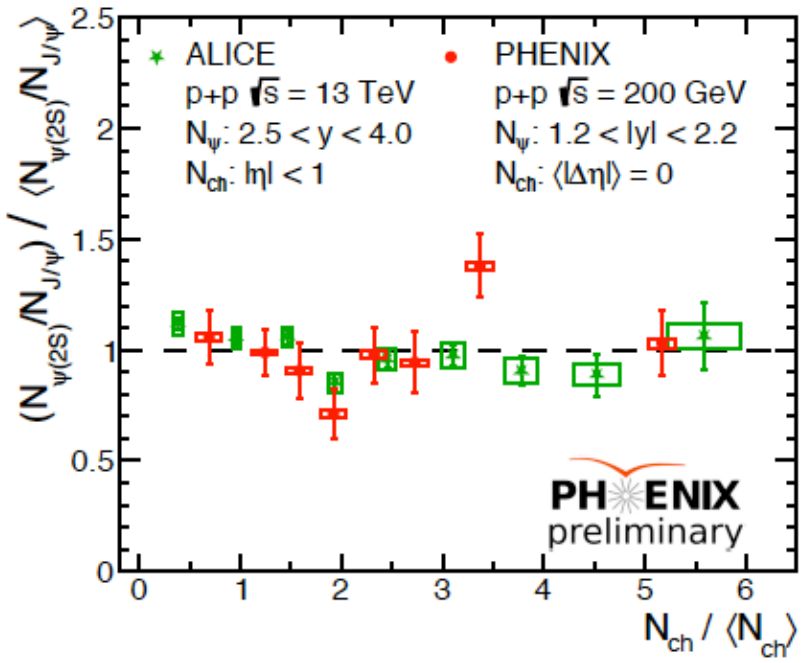
PYTHIA8 Detroit tune in "J. Korean Phys. Soc. 82, 651–657 (2023).

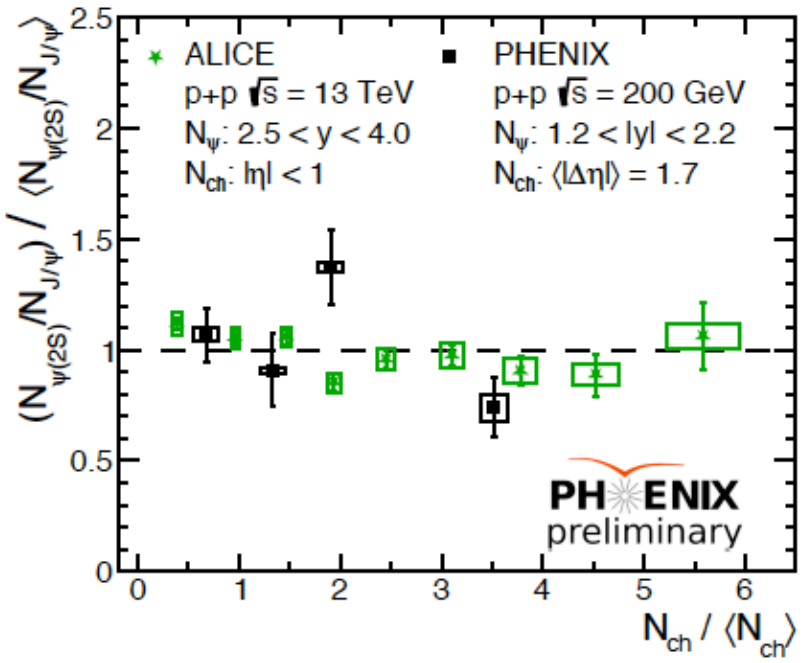
Final paper under preparation!

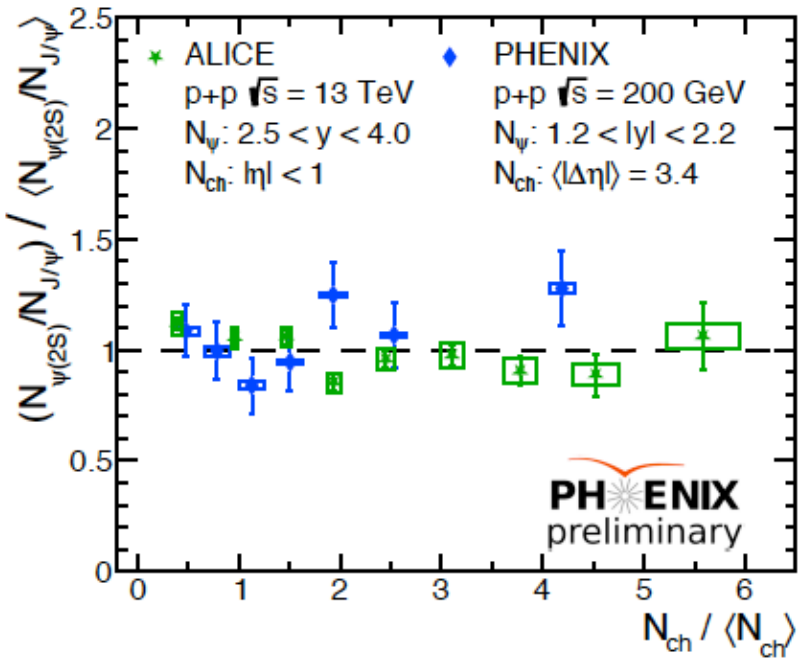
- PYTHIA8 Detroit tune with MPI effects can well reproduce the charged particle multiplicity dependent R(J/ψ) measured at PHENIX after subtracting the J/ψ decay di-muons.

Multiplicity dependent ψ(2s) to J/ψ in 200 GeV p+p collisions

- Normalized forward ψ(2s) to J/ψ versus normalized charged particle multiplicity with different rapidity gaps in 200 GeV p+p collisions.
- Comparison with latest ALICE results measured in 13 TeV p+p collisions.





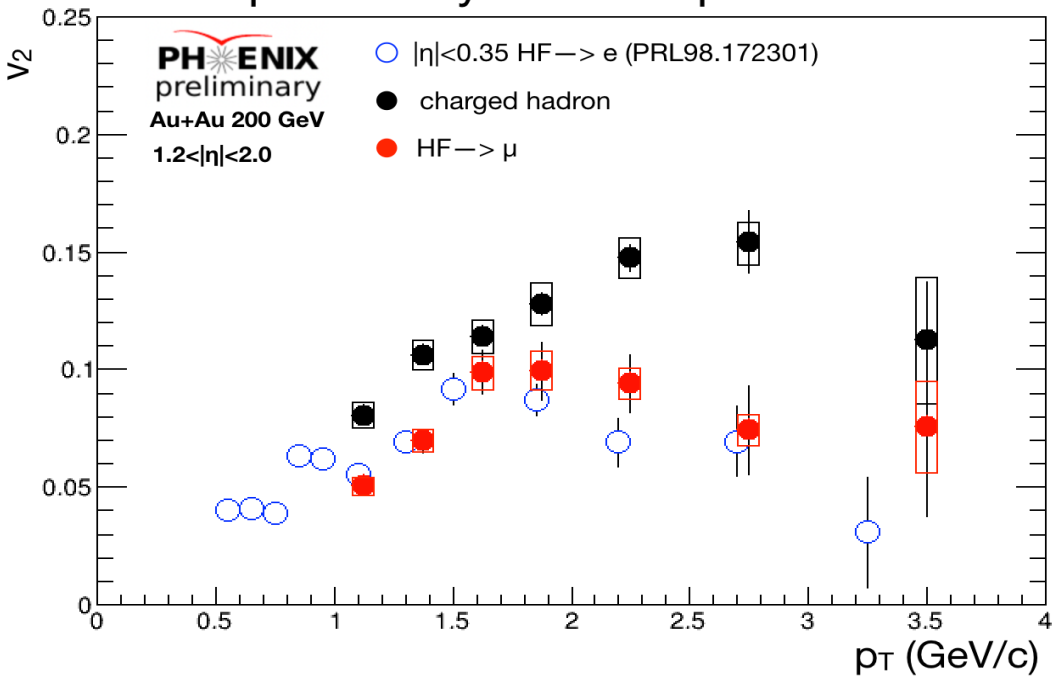


- The result is consistent with unity within 1 σ uncertainty.
- No significant rapidity gap dependence is observed, which indicates no significant final state effects on charmonium production in p+p collisions.

Forward J/ψ elliptic flow in 200 GeV Au+Au collisions

- Significant modification of forward J/ψ R_{AA} has been measured in 200 GeV Au+Au collisions.
- Latest PHENIX forward heavy flavor decay muon elliptic flow is consistent with mid-rapidity heavy flavor decay electron elliptic flow.
- How about forward J/ψ elliptic flow (v_2)?

Open heavy flavor elliptic flow



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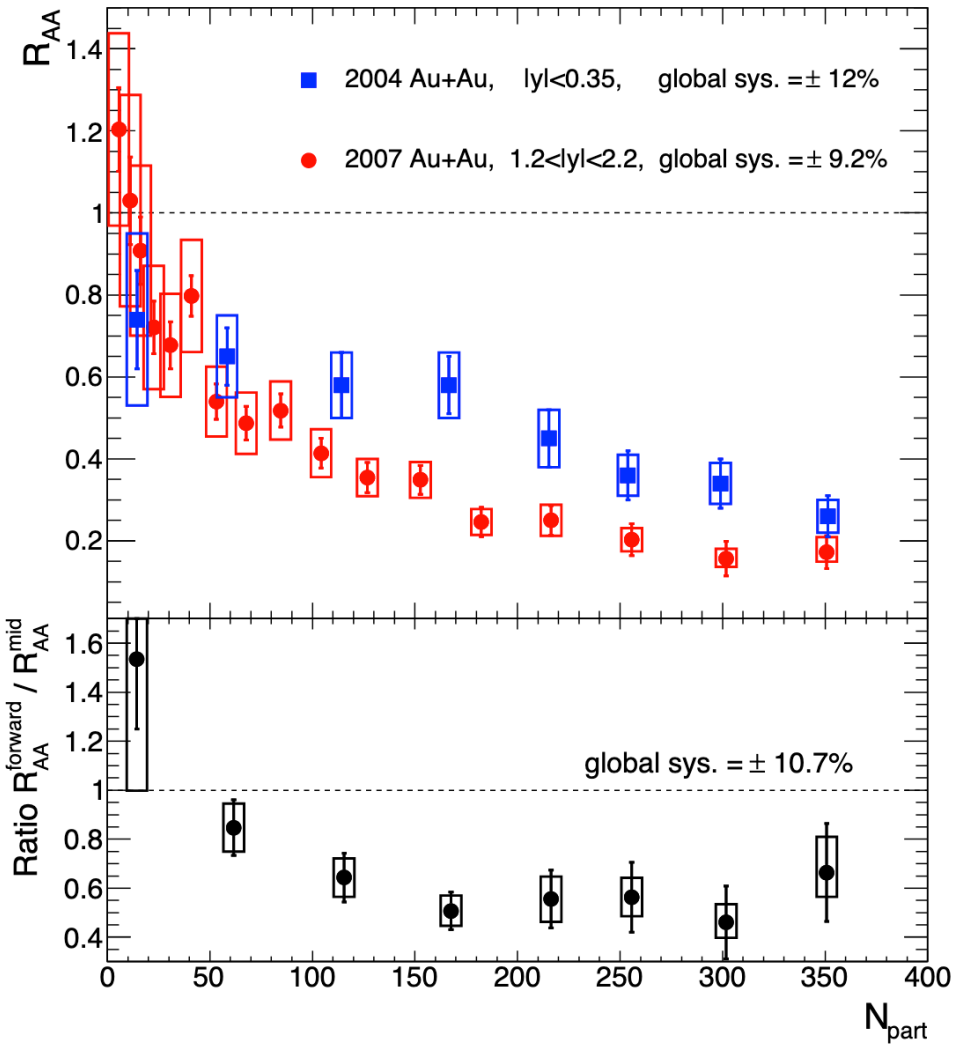
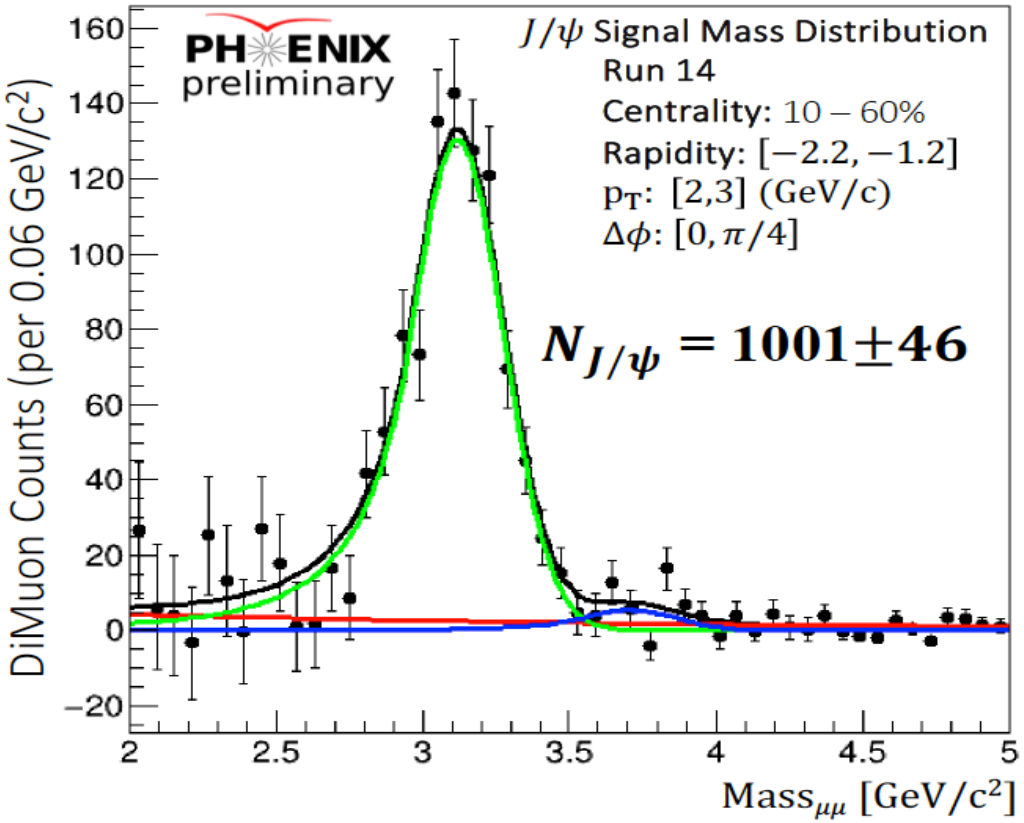
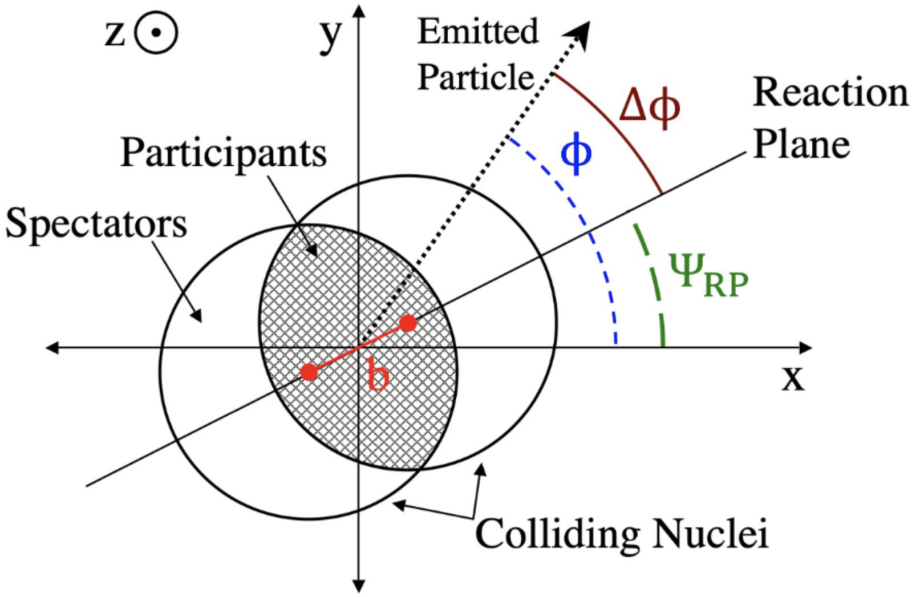


PHENIX forward J/ψ reconstruction in 200 GeV Au+Au collisions

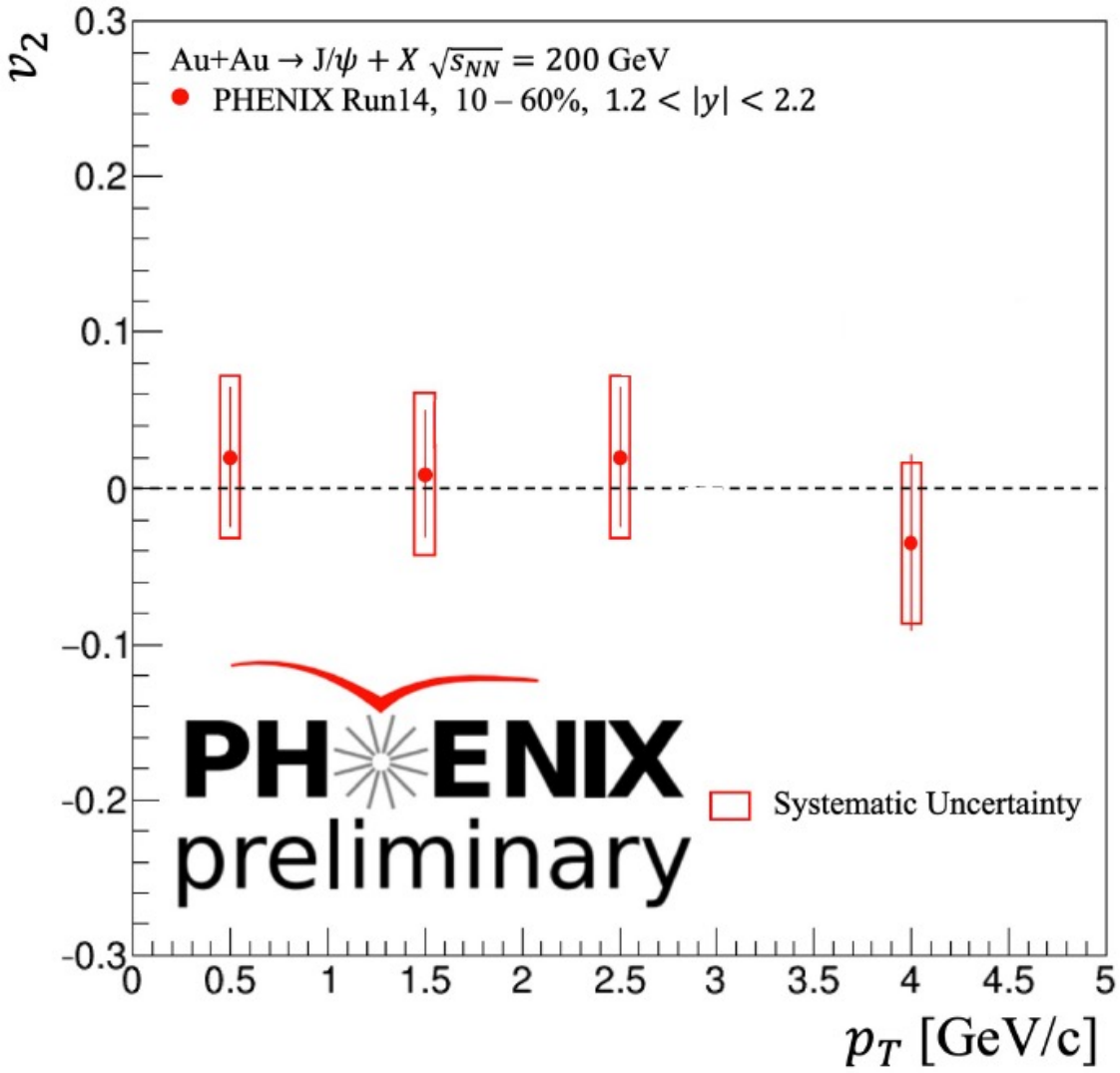
- Clear J/ψ signals are observed in forward and backward di-muon invariant mass distributions within 1.2<|η|<2.2 region in 200 GeV Au+Au collisions.
- 10-60% centrality is selected to reduce combinatorial background contribution and maximize potential v_2 signal.



- Reconstructed J/ψ v_2 is determined relative with the event plane.

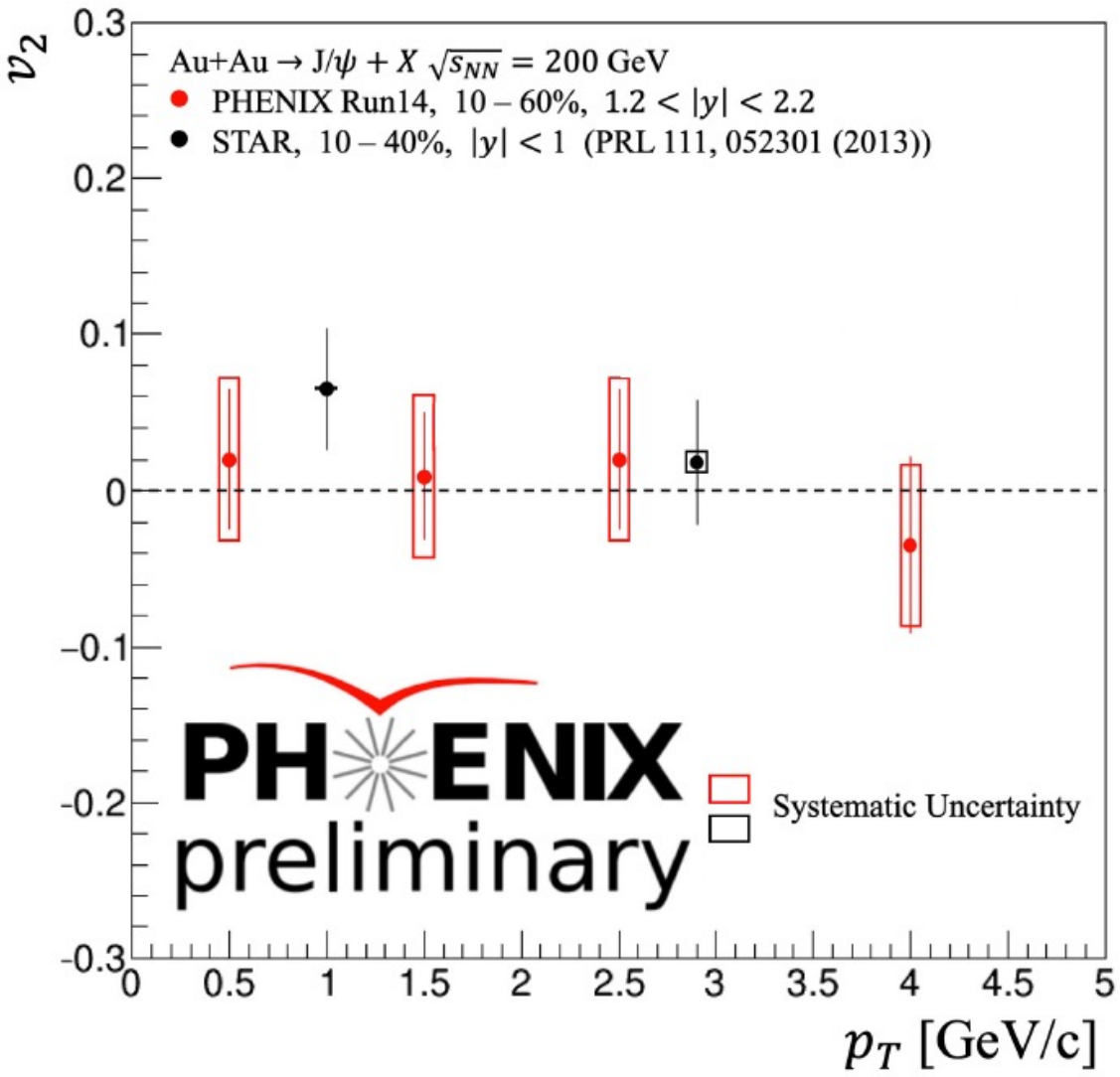


PHENIX forward J/ψ v_2 in 200 GeV Au+Au collisions



- PHENIX forward J/ψ v_2 in 10-60% 200 GeV Au+Au collisions is consistent with zero.

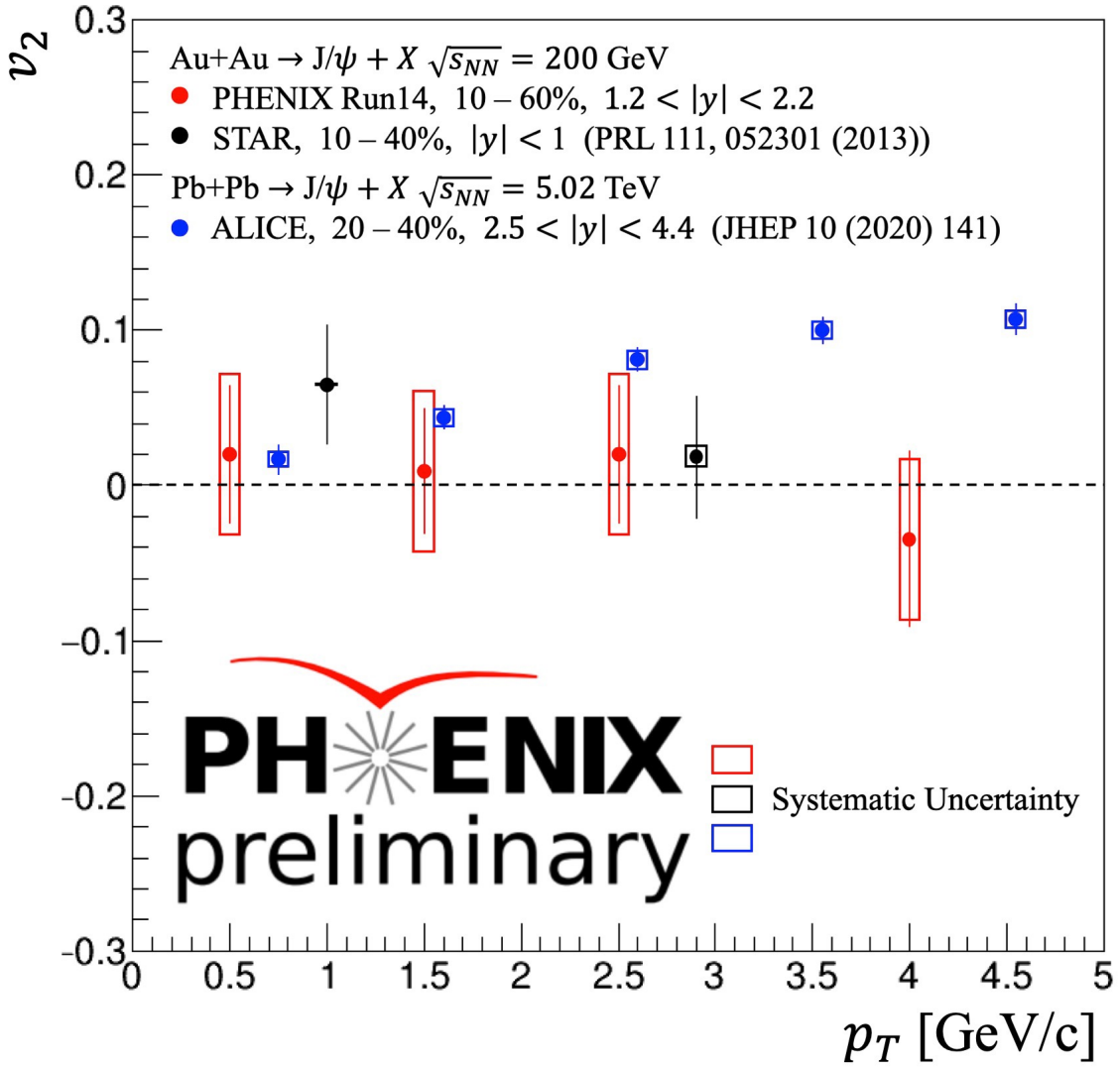
PHENIX forward J/ψ v_2 in 200 GeV Au+Au collisions



- The PHENIX forward J/ψ v_2 in 10-60% 200 GeV Au+Au collisions is consistent with zero.
- This result is consistent with the STAR mid-rapidity J/ψ v_2 in 10-40% 200 GeV Au+Au collisions.

PHENIX forward J/ψ v_2 in 200 GeV Au+Au collisions

Final paper under preparation!



- The PHENIX forward J/ψ v_2 in 10-60% 200 GeV Au+Au collisions is consistent with zero.
- This result is consistent with the STAR mid-rapidity J/ψ v_2 in 10-40% 200 GeV Au+Au collisions.
- Significant forward J/ψ v_2 has been measured at ALICE in 20-40% 5.02 TeV Pb+Pb collisions.
- Difference between the RHIC and LHC results is probably related with different recombination contributions to the J/ψ production.

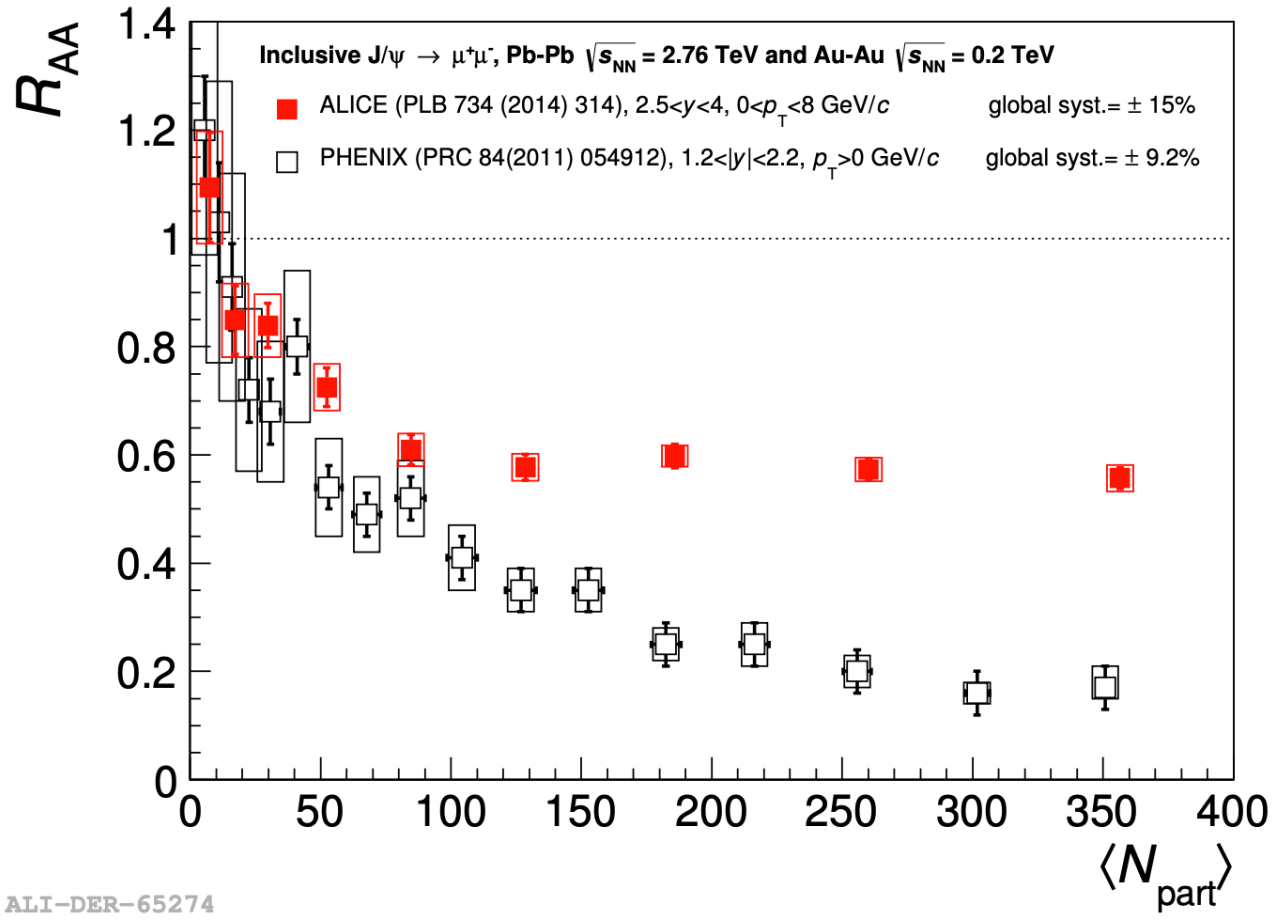
Summary

- Strong correlation between forward J/ψ yields and charged particle multiplicity has been overserved at PHENIX in 200 GeV p+p collisions. Such correlation gets reduced by either applying a rapidity gap between measured J/ψ and charged particles or excluding J/ψ decay daughters in the charged particle multiplicity calculation. PYTHIA8 Detroit tune with MPI effects can well describe latest PHENIX p+p measurements.
- Forward J/ψ elliptic flow is consistent with zero, which indicates less recombination contribution to J/ψ production in Au+Au collisions at RHIC energy.
- Papers are under preparation and expected to be released soon.

Backup

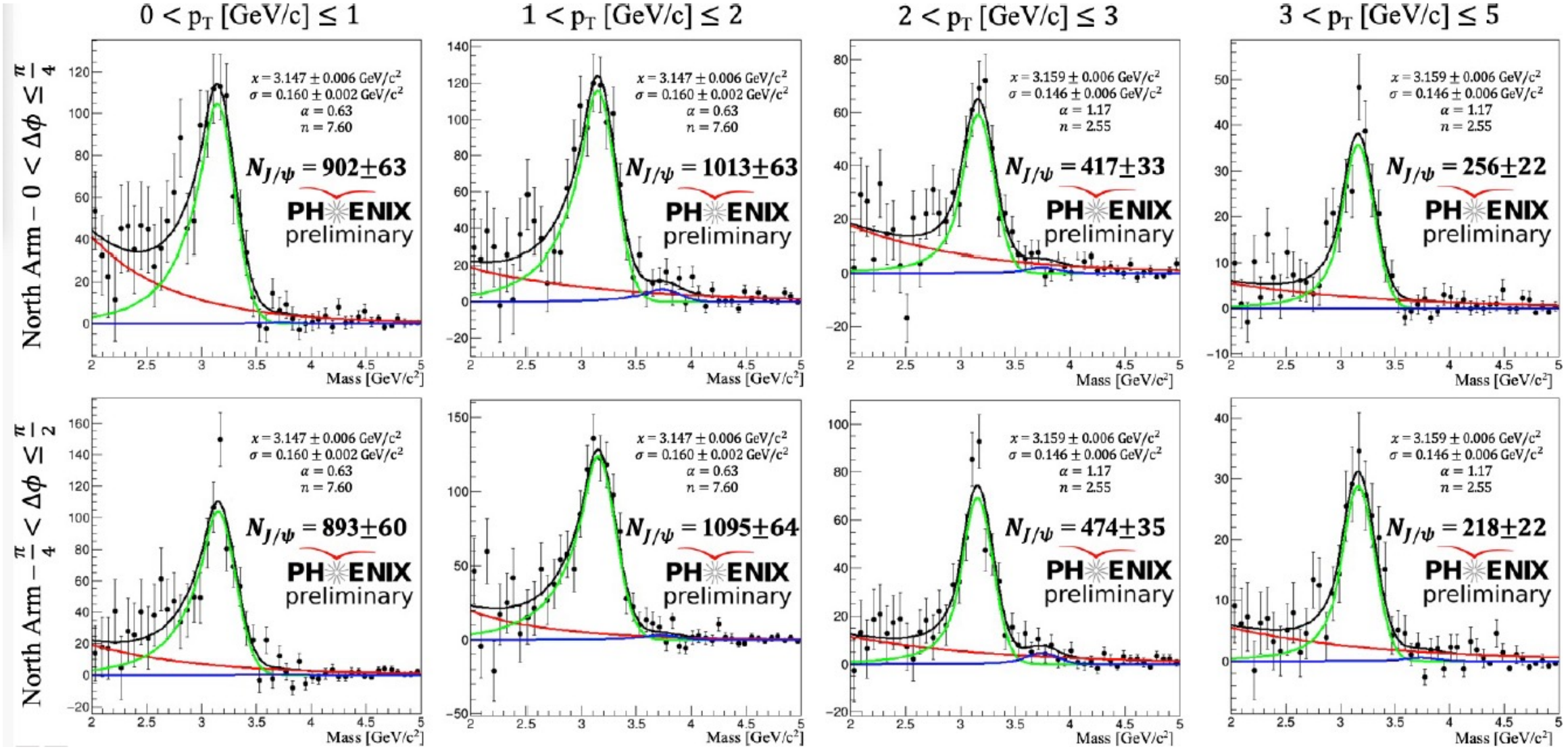
J/ψ R_{AA} comparison between RHIC and LHC

- More color recombination effects at LHC than RHIC leads to less modification of J/ψ RAA at LHC especially at high <N_{part}> region.



J/ψ yields in 200 GeV Au+Au collisions (forward)

- In plane (top) and out of plane (bottom)



J/ψ yields in 200 GeV Au+Au collisions (backward)

- In plane (top) and out of plane (bottom)