Study of multiplicity-dependent charmonia production in p+p collisions with PHENIX

JongHo Oh

Pusan National University

XII International Conference on New Frontiers in Physics

PUSAN NATIONAL UNIV.
NPL
NUCLEAR PHYSICS LAB

PUSAN NATIONAL UNIVERSITY

PHENIX

ICNFP

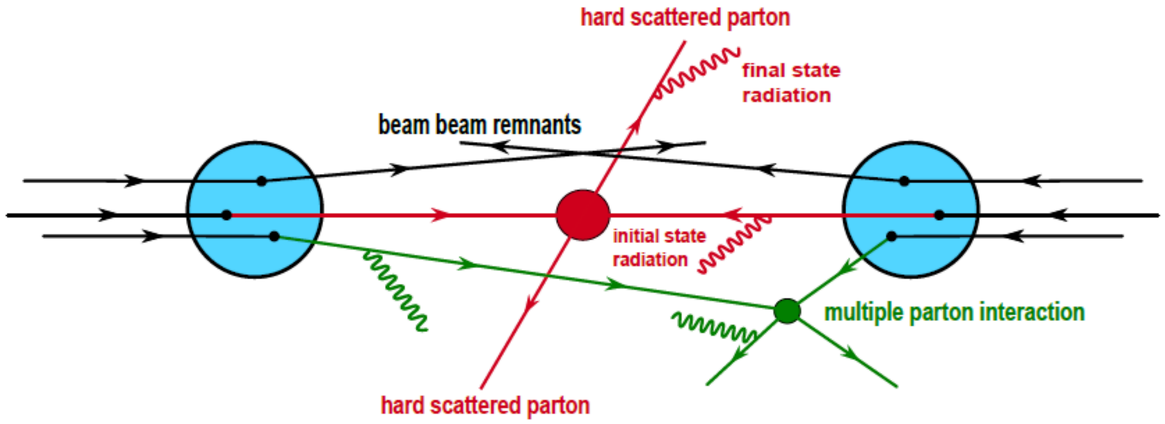
1. Introduction (Quarkonia in small collision)

- MPI effect occurs as the number of multi-parton interactions increase as particle multiplicity increases, leading a high probability of J/ψ and $\psi(2S)$ production in events of higher multiplicity.

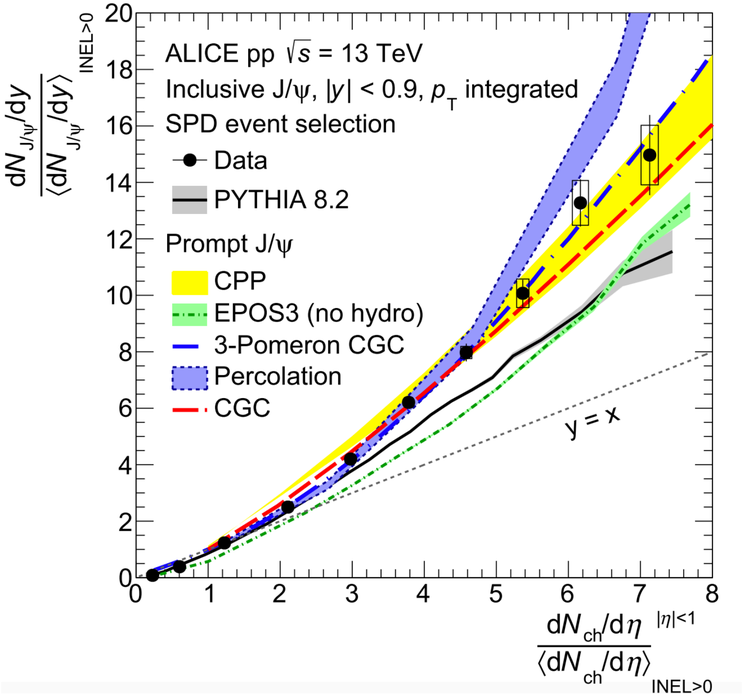
- In the ALICE result, J/ψ yield steeply increases as charged particle multiplicity increases in p+p collisions at 13 TeV.

- In STAR results at 200 GeV, a similar multiplicity dependency as ALICE data.

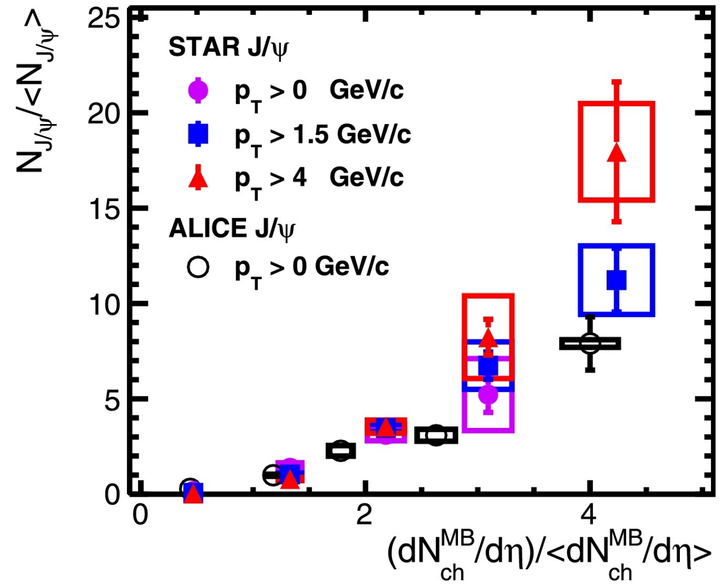
  → In 200 GeV, seems the MPI effect is important.



Schematic representation of MPI Effect



Phys. Lett. B 810 (2020) 135758



Phys. Lett. B 786 (2018) 87-93

1. Introduction (Final state effect)

- To analyze the final-state effect effects, compare the yields of particles of particles with **same quark content but different binding energy.**
  → J/ψ (~640 MeV), ψ(2S) (~50 MeV)

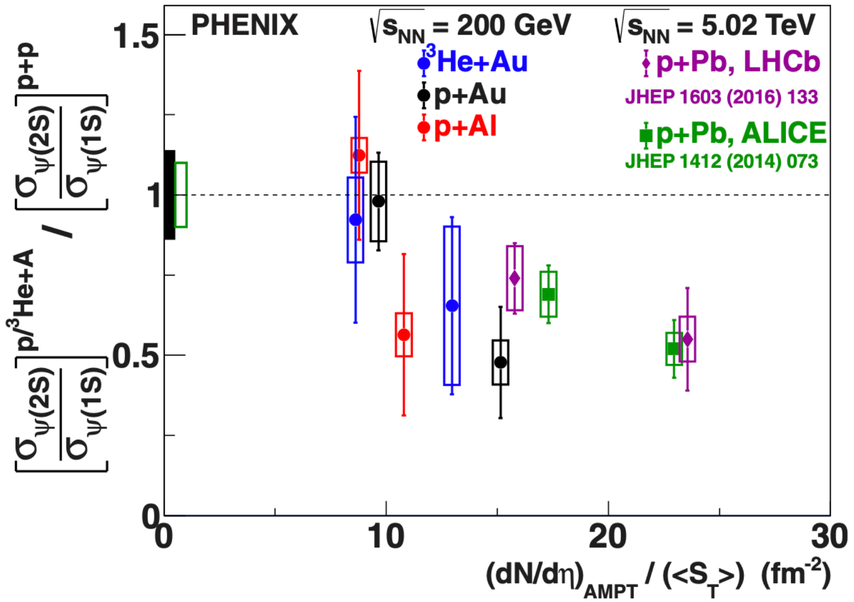
- **Co-mover effect** leads to their breakup where J/ψ or ψ(2S) particles interact with the surrounding hadrons.
  → ψ(2S) will be more broken than J/ψ.

- J/ψ and ψ(2S) ratio decreases
  as charged particle multiplicity increases in p/^{3}He+A collisions.

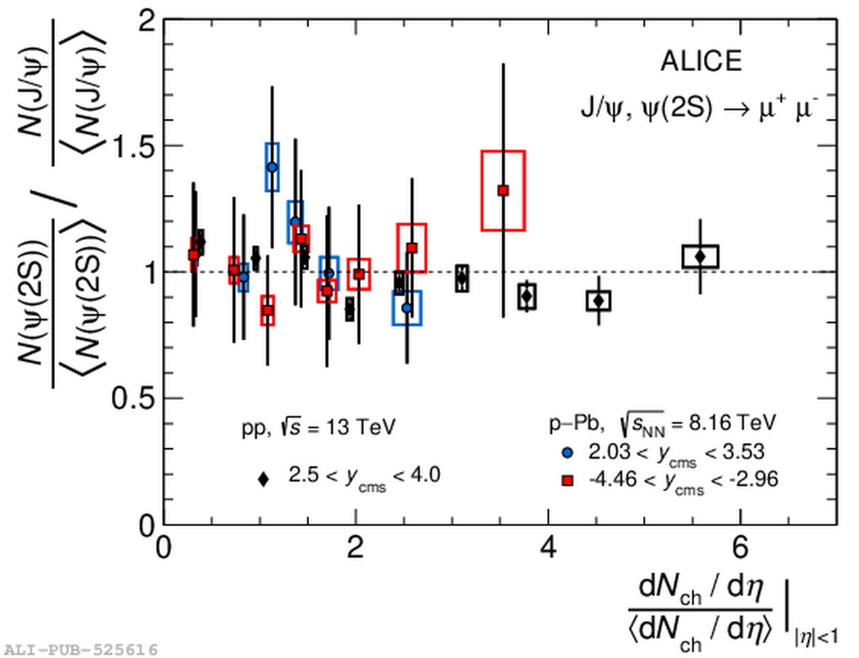
  → Final-state effects such as the co-mover effect
  are also important for quarkonia yields.

- In the recent ALICE results in p+p and p+Pb collisions,
  measure J/ψ and ψ(2S) measure at forward rapidity and multiplicity
  measure at mid-rapidity, no significant multiplicity dependence is observed.

How about pp 200 GeV?



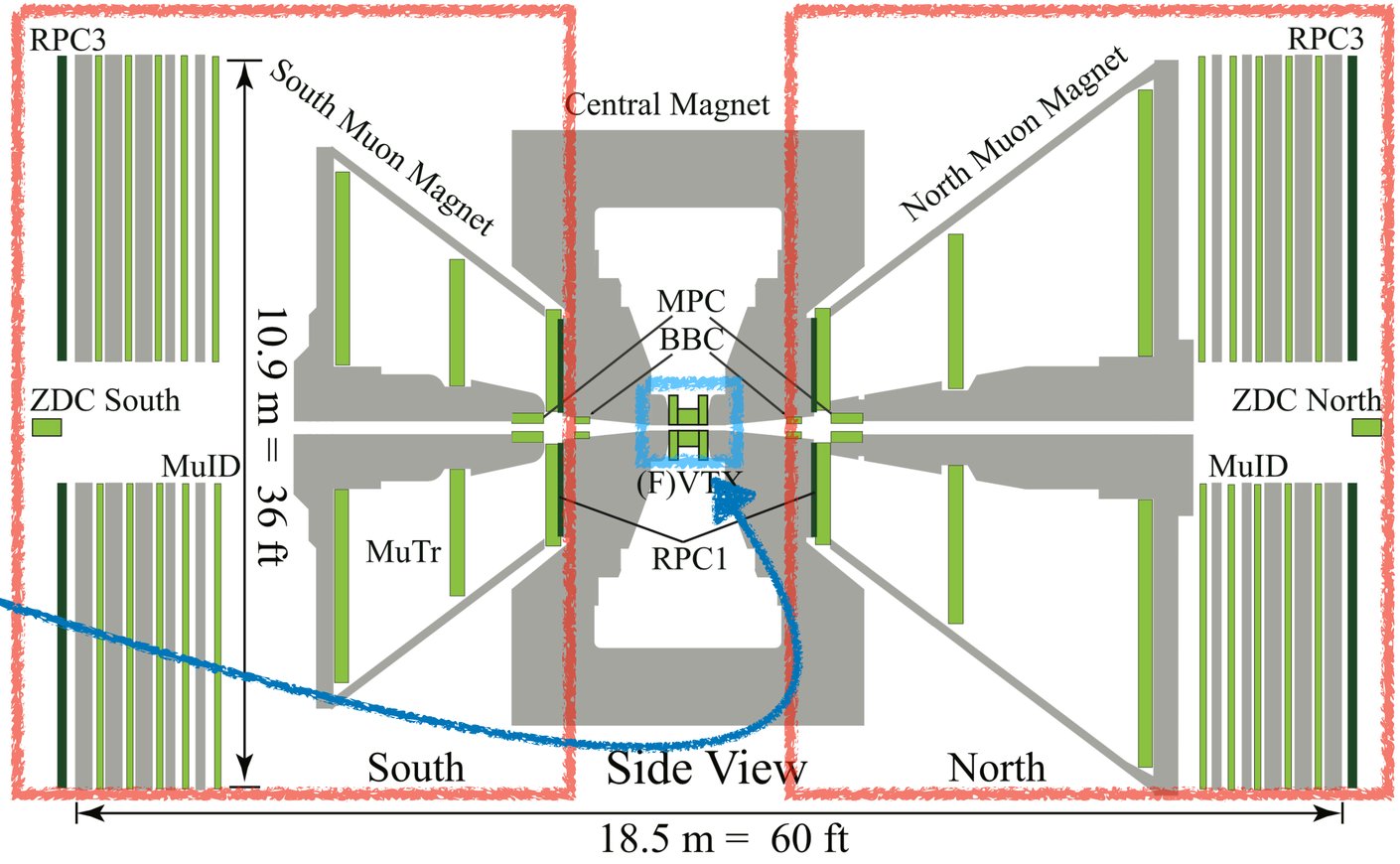
Phys. Rev. C 95, 034904



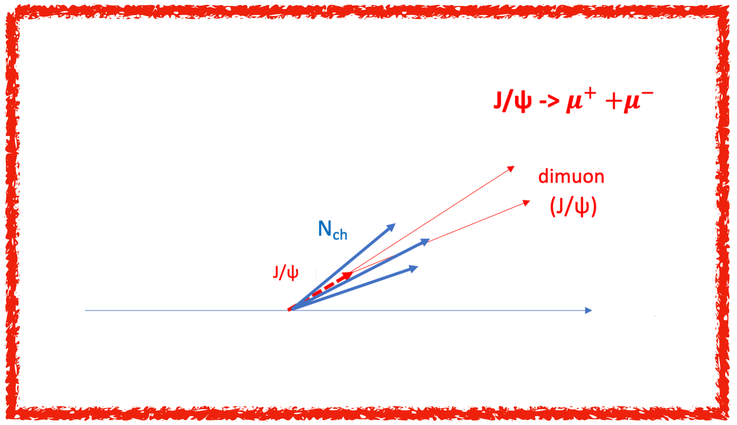
JHEP 06 (2023) 147

2. Analysis in PHENIX

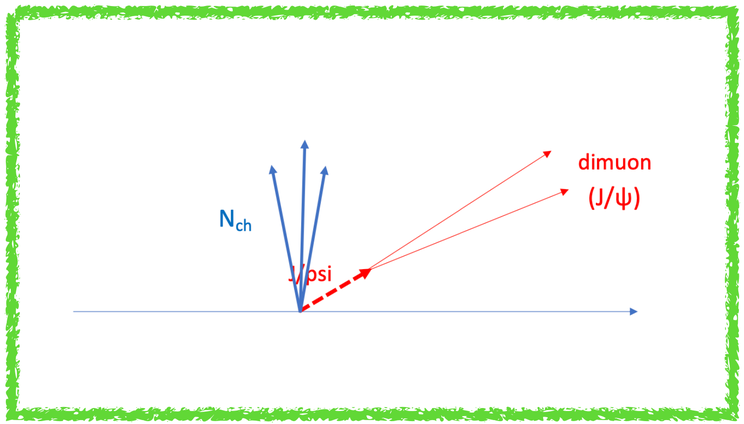
- Acceptance for J/ψ measurement:
  (1)-2.2<y<-1.2, (2)1.2<y<2.2
- MuTr only:
  For high statistics of J/ψ
- MuTr+FVTX:
  For J/ψ and ψ(2S) ratio
- Acceptance for multiplicity measurement:
  (1)$|\eta|$<1, (2)-3<η<-1, (3)1<η<3
- Multiplicity can be measured with various detectors at different pseudo-rapidity
  → We can have a detailed look at the correlation between J/ψ production and multiplicity



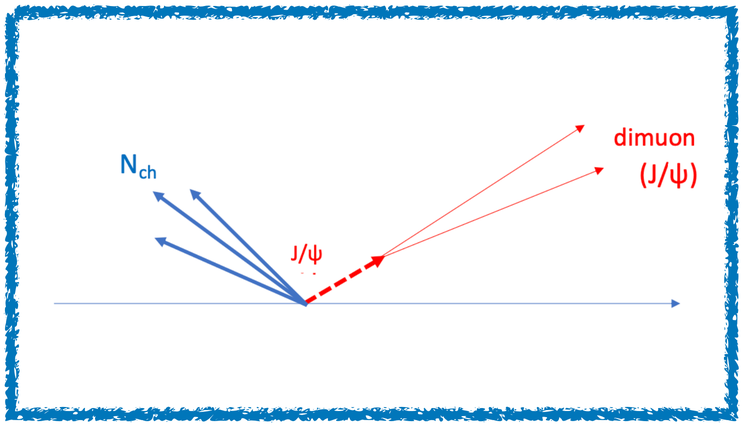
2. Analysis in PHENIX



Case 1
(North Muon Arm and FVTX North)



Case 2
(North Muon Arm and VTX)



Case 3
(North Muon Arm and FVTX South)

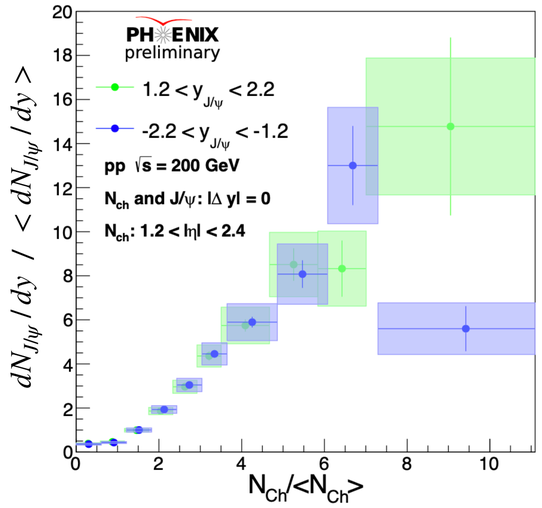
- Case 1) Measure J/ψ and multiplicity at the same direction,
  Can observe MPI effect and final-state effect
  → But the multiplicity is affected by the dimuons from J/ψ

- Case 2,3) Measure J/ψ and multiplicity at the different direction,
  Can check how the correlation changes with the rapidity

3. PHENIX Results

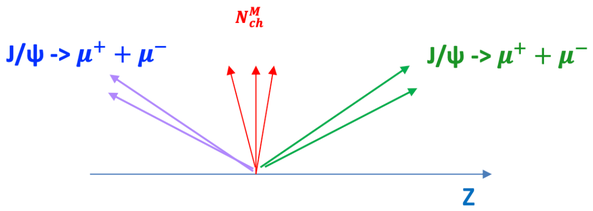
J/ψ and N_{ch} at the same direction

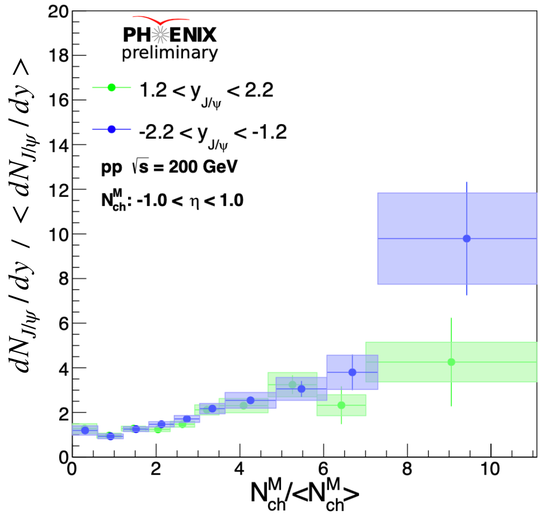
RED = Tracklets N_{ch} (1.2 < |η| < 2.4)
Green = J/ψ (1.2 < y < 2.2)
Blue = J/ψ (-2.2 < y < -1.2)



J/ψ at forward and N_{ch} at mid-rapidity

RED = Tracklets N_{ch}^M(|η| < 1.0)
Green = J/ψ (1.2 < y < 2.2)
Blue = J/ψ (-2.2 < y < -1.2)



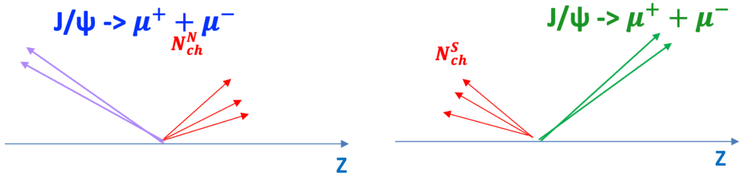


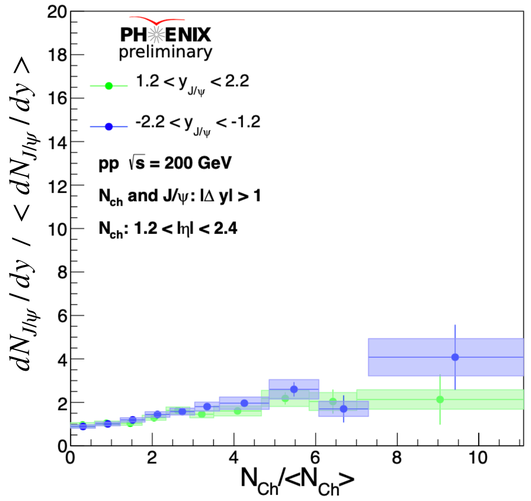
- In the <u>same direction</u>, the MPI effect and final-state effects can be observed,
  <u>When the multiplicity increases, J/ψ yields increase steeply,</u> and the multiplicity dependency is stronger for the <u>same direction case.</u>
  → Different effects between mid- and forward rapidity?
  → Effect from the dimuon contribution to the multiplicity calculation?

3. PHENIX Results

J/ψ and N_{ch} at the opposite direction

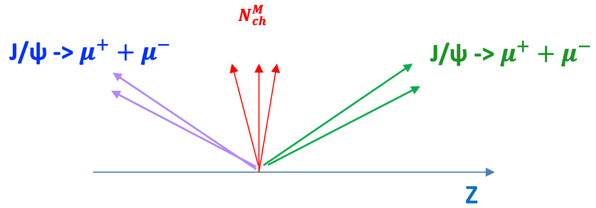
RED = Tracklets N_{ch} (1.2 < |η| < 2.4)
Green = J/ψ : 1.2 < y < 2.2)
Blue = J/ψ (-2.2 < y < -1.2)

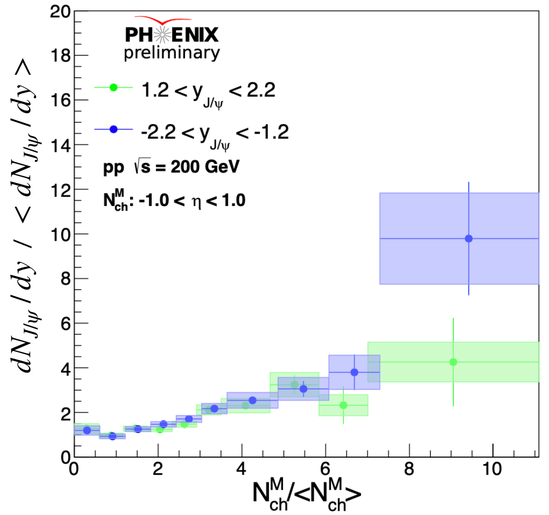




J/ψ at forward and N_{ch} at mid-rapidity

RED = Tracklets N_{ch}^M(|η| < 1.0)
Green = J/ψ (1.2 < y < 2.2)
Blue = J/ψ (-2.2 < y < -1.2)





- In the <u>same direction</u>, the MPI effect and final-state effects can be observed,
  <u>When the multiplicity increases, J/ψ yields increase steeply,</u> and the multiplicity dependency is stronger for the <u>same direction case.</u>
  → Different effects between mid- and forward rapidity?
  → Effect from the dimuon contribution to the multiplicity calculation?

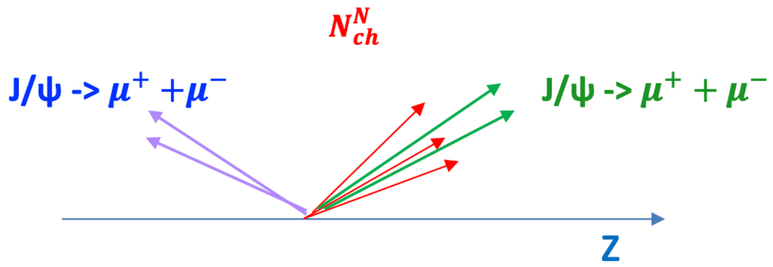
- When J/ψ going to south or north and measuring <u>multiplicity at mid-rapidity or the opposite side.</u>
  → Similar dependency has been observed between opposite direction and N_{ch} at mid-rapidity.

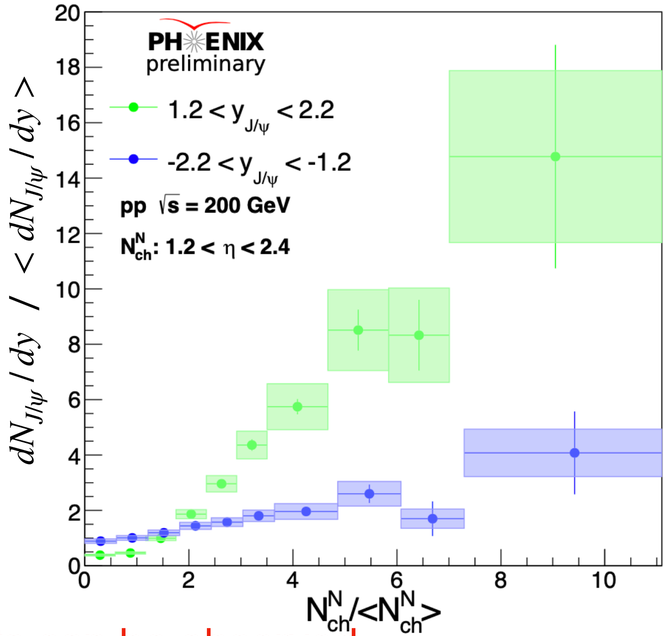
3. PHENIX Results

RED = Tracklets N_{ch}^{N} (1.2 < η < 2.4)

Green = J/ψ (1.2 < y < 2.2)

Blue = J/ψ (-2.2 < y < -1.2)

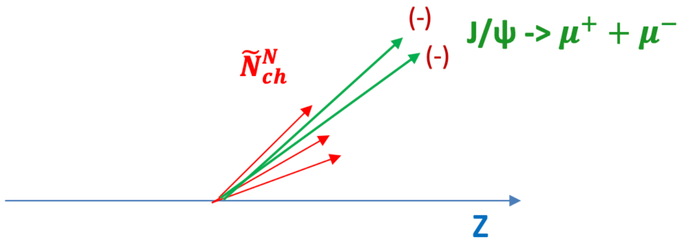


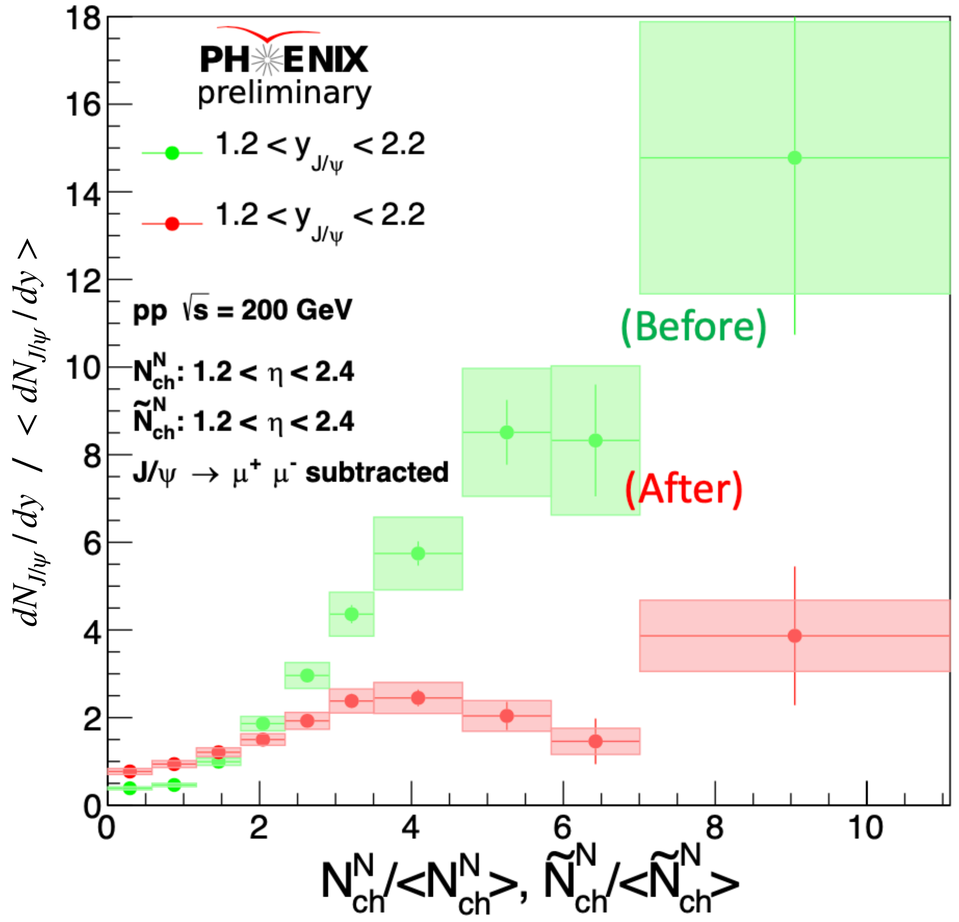


- In the <u>same direction</u>, the MPI effect and final-state effects can be observed,
  <u>When the multiplicity increases, J/ψ yields increase steeply,</u> and the multiplicity dependency is stronger for the <u>same direction case.</u>
  → Different effects between mid- and forward rapidity?
  → Effect from the dimuon contribution to the multiplicity calculation?
- When J/ψ going to south or north and measuring <u>multiplicity at mid-rapidity or the opposite side.</u>
  → Similar dependency has been observed between opposite direction and N_{ch} at mid-rapidity.
- Very different multiplicity dependence between the <u>same direction case and opposite direction case.</u>
  → Note that multiplicity at the same direction includes the dimuon contribution

3. PHENIX Results

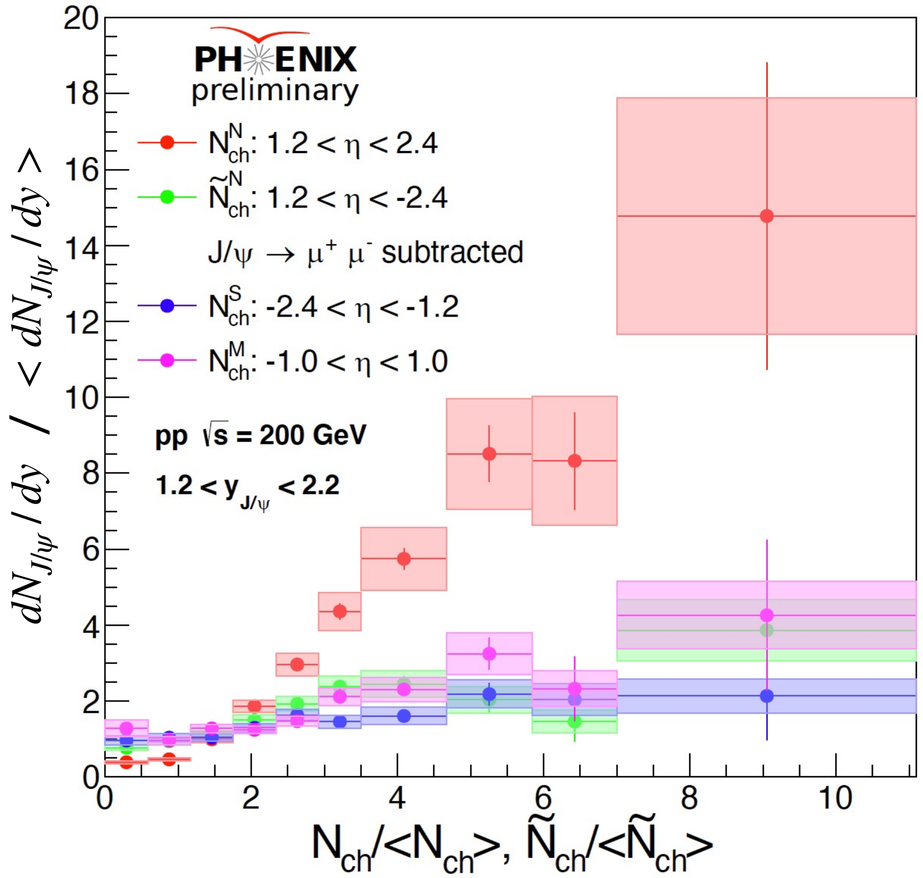
RED = Tracklets $\widetilde{N}_{ch}^{N}$ (1.2 < η < 2.4)
[dimuon subtracted]
Green = J/ψ (1.2 < y < 2.2)





- After <u>subtraction of the dimuon contribution in N_{ch}</u>, multiplicity dependency becomes weaker
(Subtracting dimuon contribution when FVTX-MuTr matched)

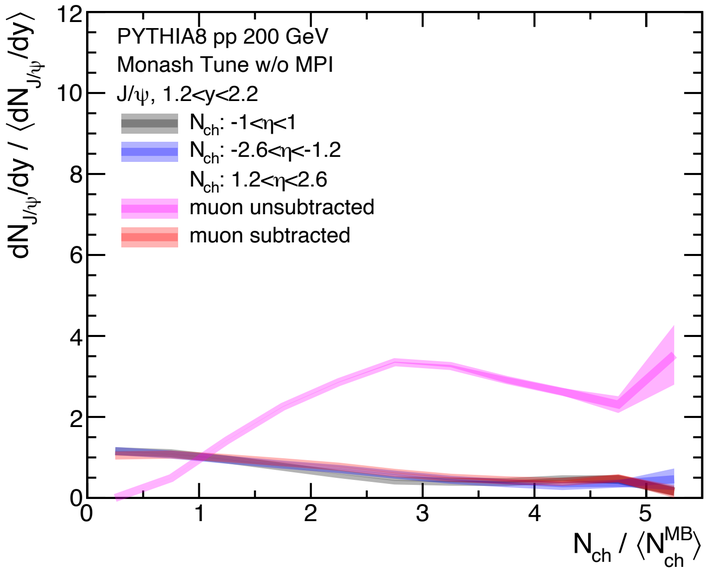
3. PHENIX Results

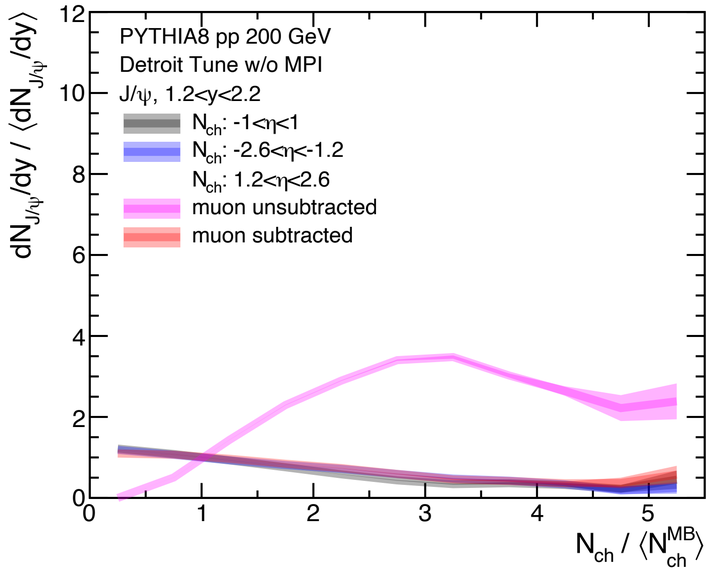


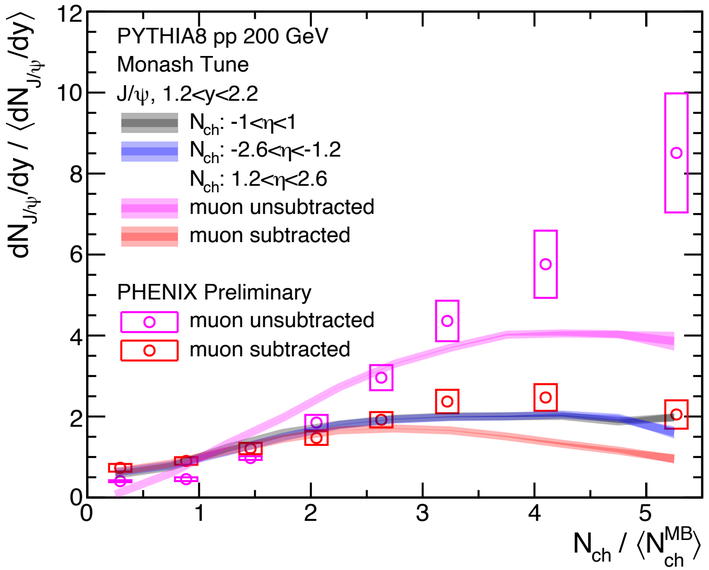
- After subtraction of the dimuon contribution in N_{ch}, multiplicity dependency becomes weaker (Subtracting dimuon contribution when FVTX-MuTr matched)

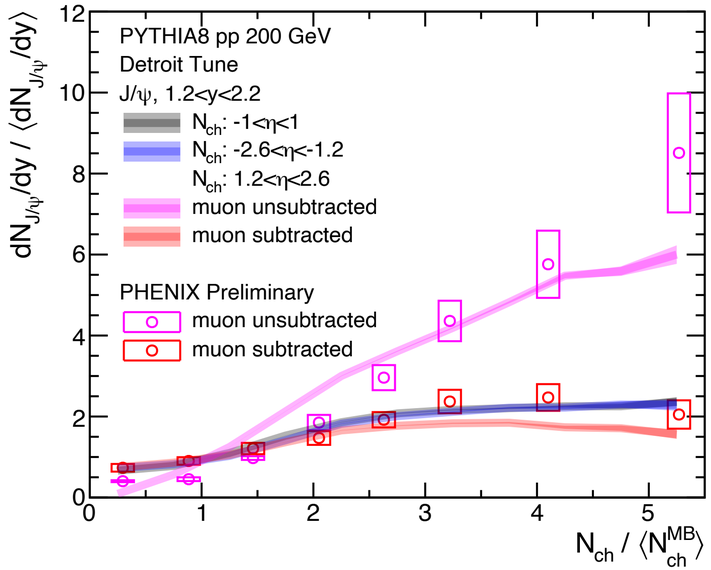
- Compare results with subtraction to the mid-rapidity and opposite direction cases, similar dependence observed

3. PHENIX Results - Comparison with PYTHIA8









Turn off the MPI effect

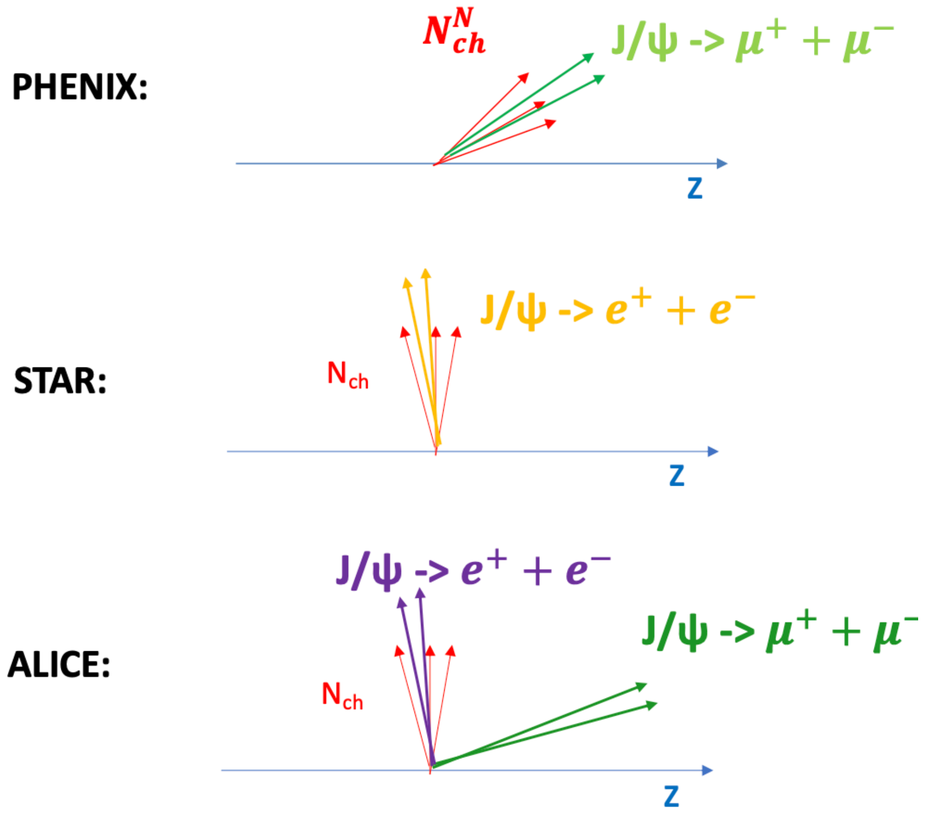
- Multiplicity at different acceptances and the same acceptance with subtraction (red): show a decreasing trend
- PYTHIA with MPI can better describe the data

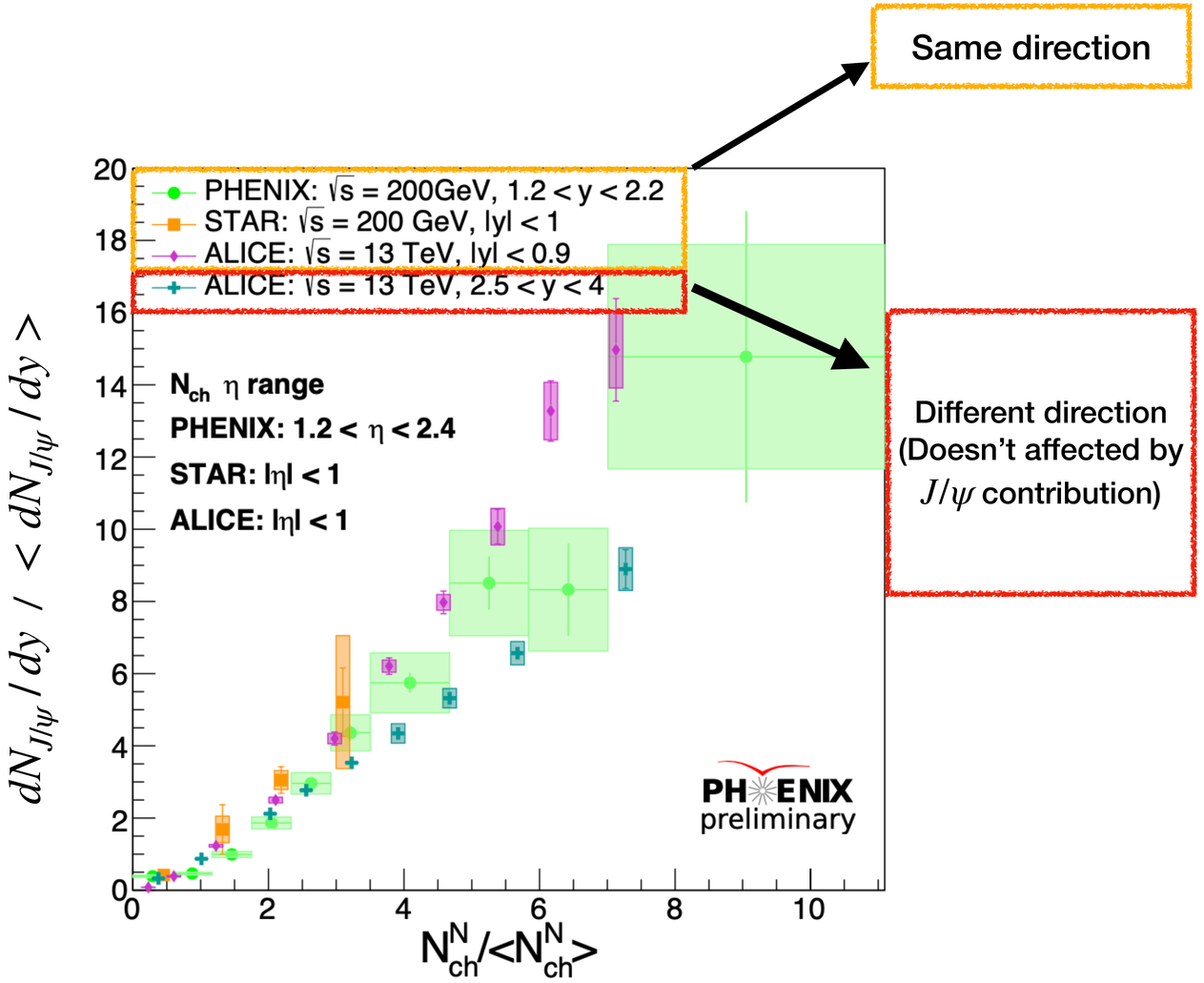
MPI effect is important at 200 GeV

- Monash Tune for the LHC energies
  Detroit Tune for the RHIC energies
  (*Phys.Rev.D 105 (2022) 1, 016011)
- J/ψ at forward rapidity ($1.2<y<2.2$)
  Multiplicity at different (other) acceptance: similar multiplicity dependence between two tunes

  Multiplicity at same acceptance: slightly stronger dependence in Detroit Tune at high multiplicity
- Detroit Tune shows a better agreement with the PHENIX results

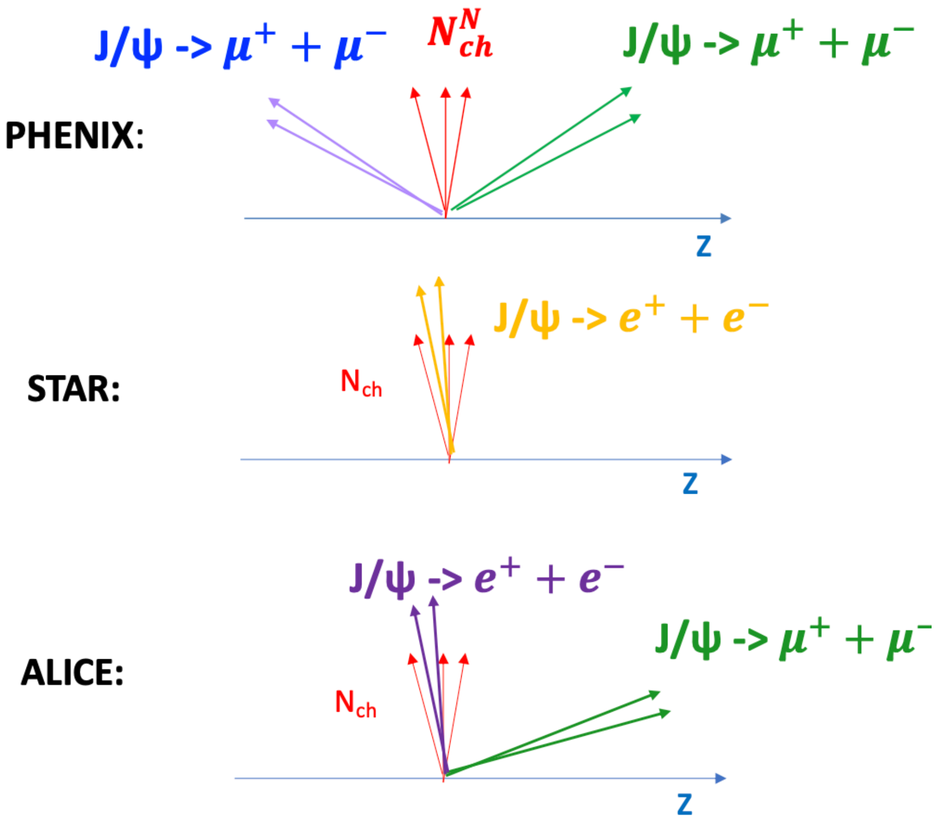
3. PHENIX Results



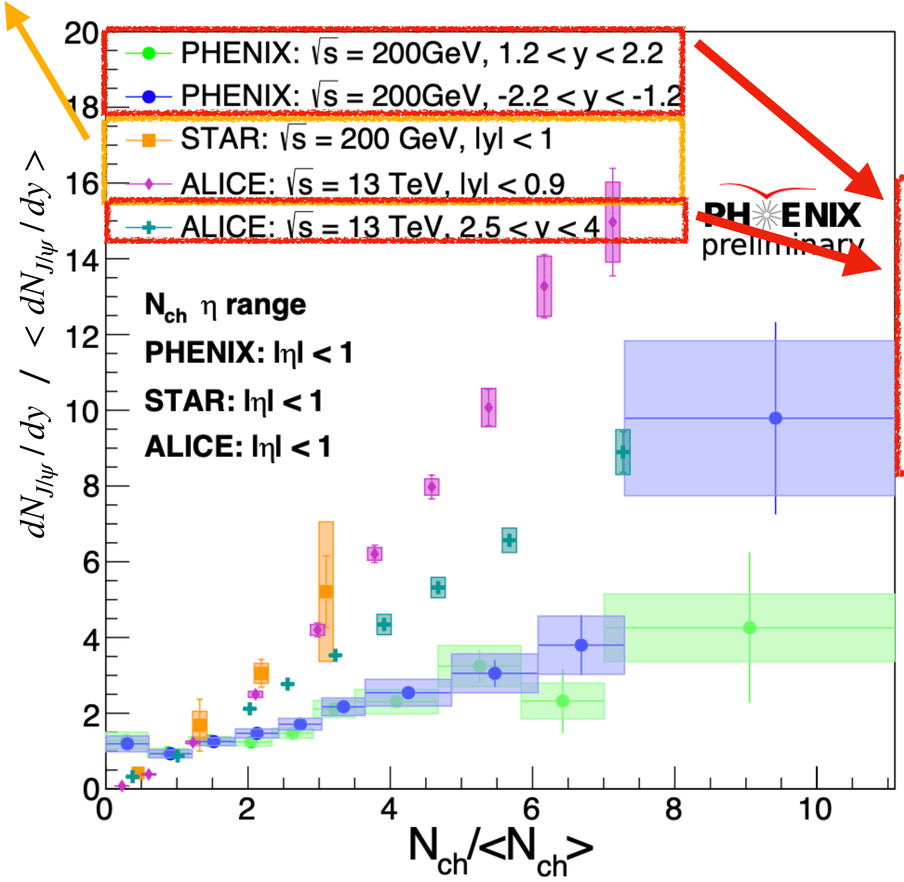


- PHENIX, STAR, ALICE (Measuring multiplicity at the same acceptance with J/ψ)
  → Similar multiplicity dependence despite different center-of-mass energy

3. PHENIX Results



Same direction



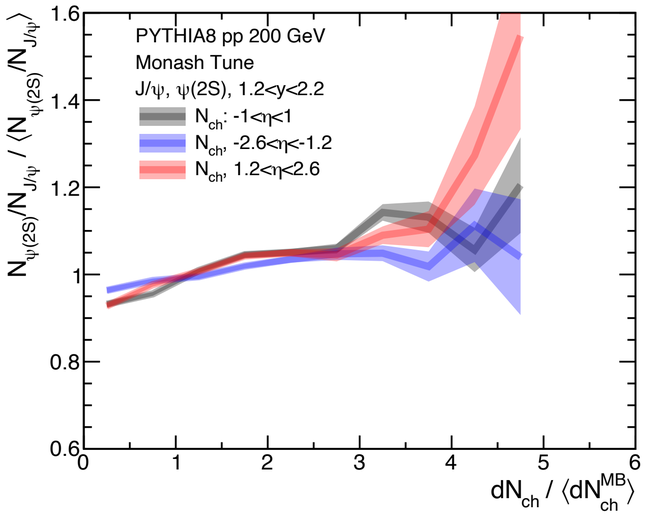
Different direction (Doesn't affected by J/ψ contribution)

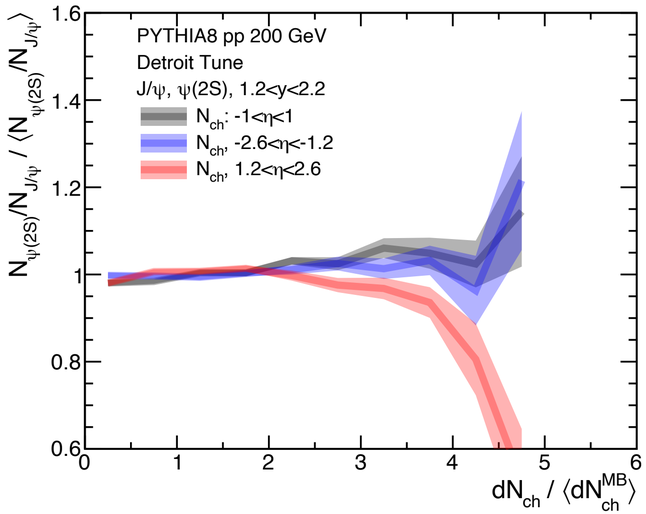
- Compare the **PHENIX result with multiplicity measure at mid-** to STAR* and ALICE*, a weaker dependency is observed

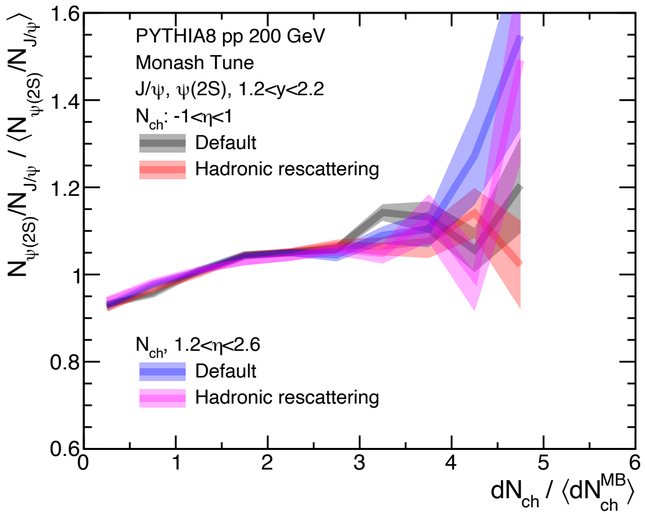
  (***Tracks from J/ψ are included in multiplicity calculation**)

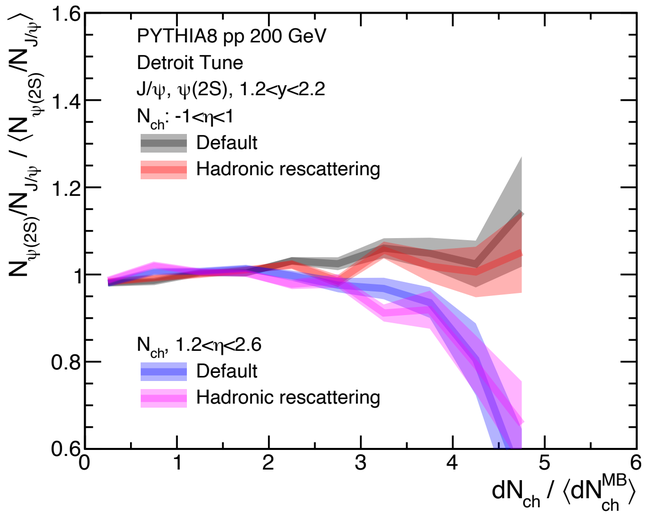
  → Dimuon subtraction is important for particularly at RHIC energies

4. Discussion - Final-state effect









J/ψ and ψ(2S) ratio at forward rapidity (1.2<y<2.2)

- Monash Tune:
  Slightly increasing J/ψ and ψ(2S) ratio
  as multiplicity increases

- Detroit Tune:
  Weak multiplicity at mid-rapidity and opposite direction,
  but a decreasing trend at the high multiplicity
  for the same direction case

Hadronic rescattering

- Both tunes show no difference with and without the hadronic rescattering option.

5. Summary

1. The study of multiplicity-dependent J/ψ and ψ(2S) production in p+p collisions can provide information on the contribution of MPI processes and final-state effects on quarkonia production

2. J/ψ yield as a function of multiplicity at various acceptances in p+p at 200 GeV has been measured at PHENIX
   → Similar multiplicity dependence with STAR and ALICE when including dimuon contribution to the multiplicity
   → When subtracting the dimuon contribution, the multiplicity dependence decrease and become similar to results with multiplicity calculated at other acceptances Detroit Tune shows a better agreement with the PHENIX data

3. In the comparison with PYTHIA8, the Detroit tune shows a better agreement with the PHENIX results than the Monash tune
   → Hadronic rescatterings in PYTHIA shows no effect at 200 GeV
   → MPI effect is important at 200GeV

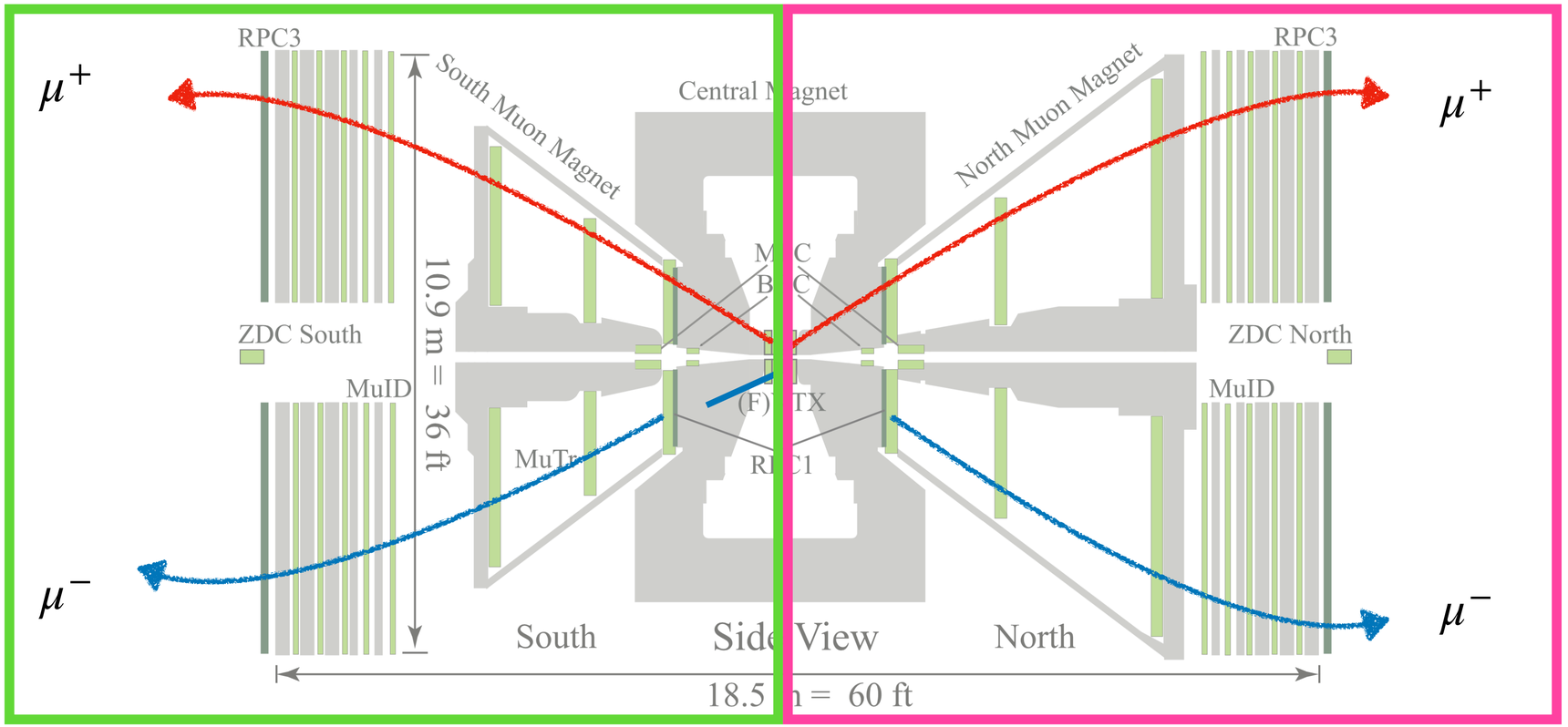
4. Further study can be done with ψ(2S)/J/ψ ratio as a function of multiplicity

Thanks for listening

Back up

Backup - Analysis in PHENIX - ψ(2S) analysis

Case 1



Case 2

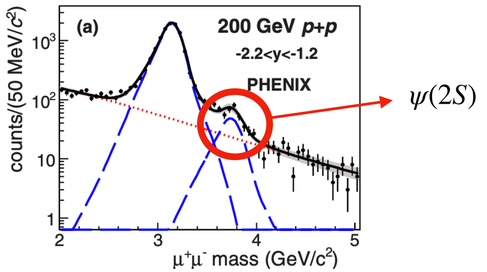
- Dimuons that the single muons associated with FVTX tracks show a good mass resolution for $\psi(2S)$ measurement

→ But, statistics become low

- Recent PHENIX analysis (Phys. Rev. C 95, 034904) showed dimuons of single FVTX matching can be used for ψ(2S) analysis

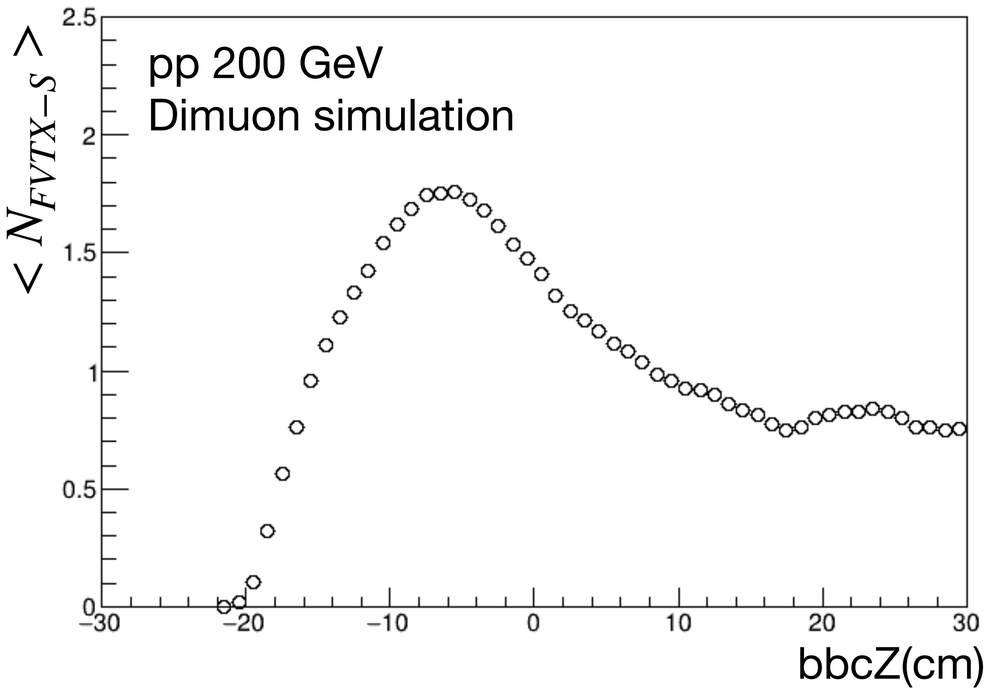
→ Need to be careful to calculate the multiplicity when subtracting the dimuon contribution

MuTr+FVTX



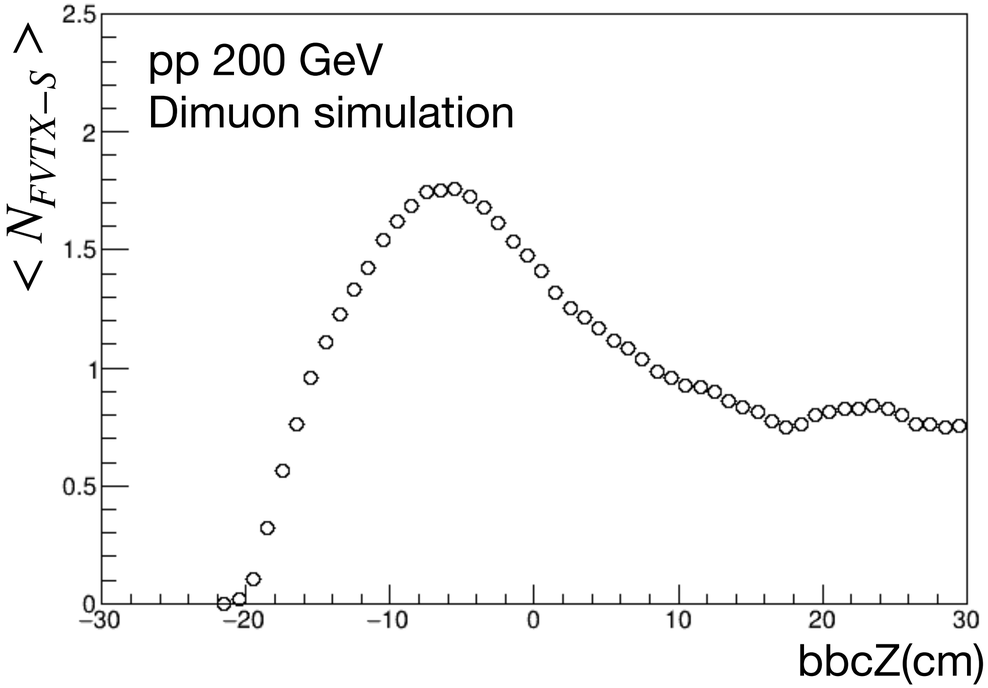
Phys. Rev. C 95, 034904

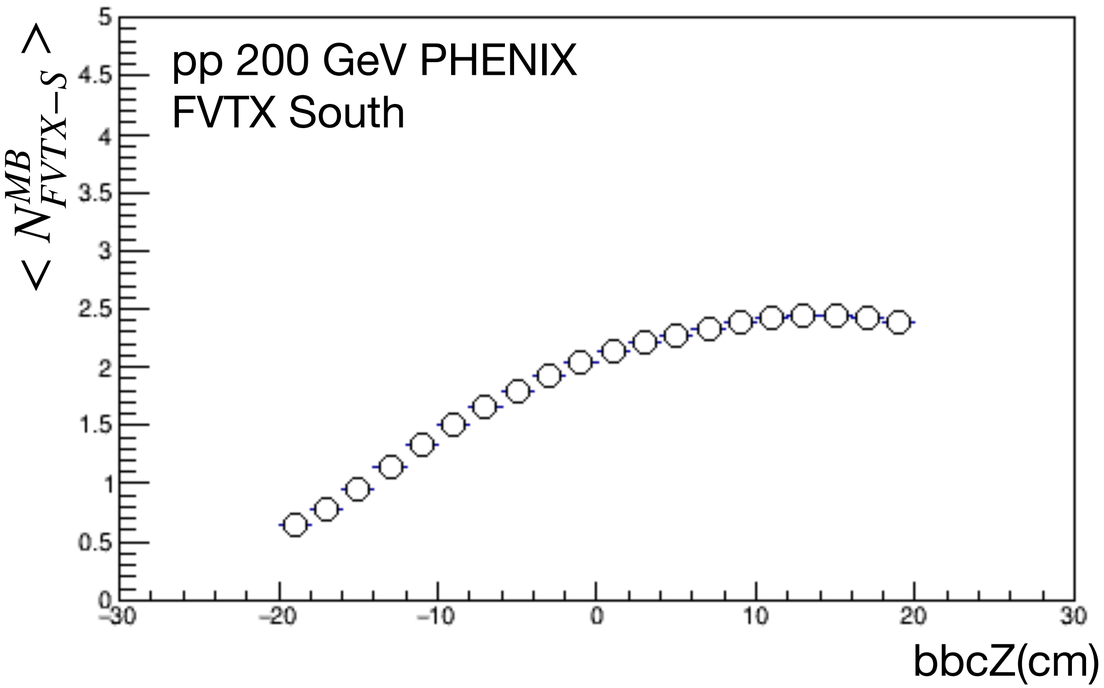
Backup - Analysis in PHENIX - Multiplicity calculation



- To subtract the J/ψ (ψ(2S)) contribution from multiplicity in the same direction, use simulation results from the full GEANT4+reconstruction simulation to consider the z-dependent FVTX acceptance and reconstruction efficiency.

Backup - Analysis in PHENIX - Multiplicity calculation





- To subtract the J/ψ (ψ(2S)) contribution from multiplicity in the same direction, use simulation results from the full GEANT4+reconstruction simulation to consider the z-dependent FVTX acceptance and reconstruction efficiency.

- $<N_{MB}>$ in each detector shows a z-vertex dependence

- bbcZ closer to the FVTX's first station (z=-20 cm for South and z=+20 cm for North), the acceptance and reconstruction efficiency decreases

The z-dependent $<N_{MB}>$ will be used to calculate event-by-event N_{MB} / $<N_{MB}>$