

Study of Forward J/ψ Production vs Event Multiplicity in p+p/A Collisions at PHENIX

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(for the PHENIX Collaboration)

CIPANP 2022

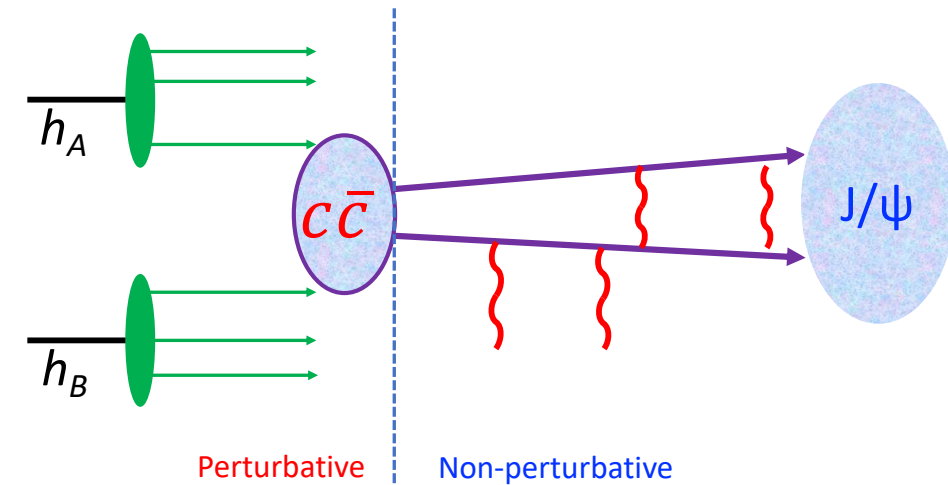
J/ ψ Production in High Energy p+p/A Collisions

How J/ ψ are produced?

Perturbative + **Non-perturbative**

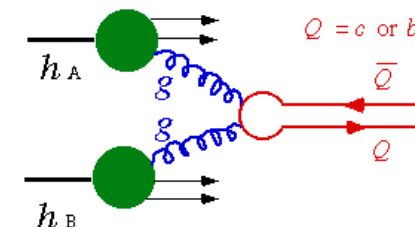
- J/ ψ ($c\bar{c}$), a simplest QCD system

- “ $c\bar{c}$ ” pair from hard scattering
 - pQCD:
 - Single hard scattering
 - Multiple semi-hard parton interactions (MPI)
 - NRQCD models:
 - **Color Singlet (CS)**
 - **Color Octet (CO)**
 - Jet fragmentation
- “ $c\bar{c}$ ” hadronization to J/ ψ
 - Color neutralization
 - Interactions with QCD medium

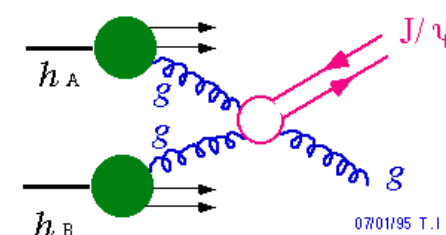


Gluon Fusion

CS:



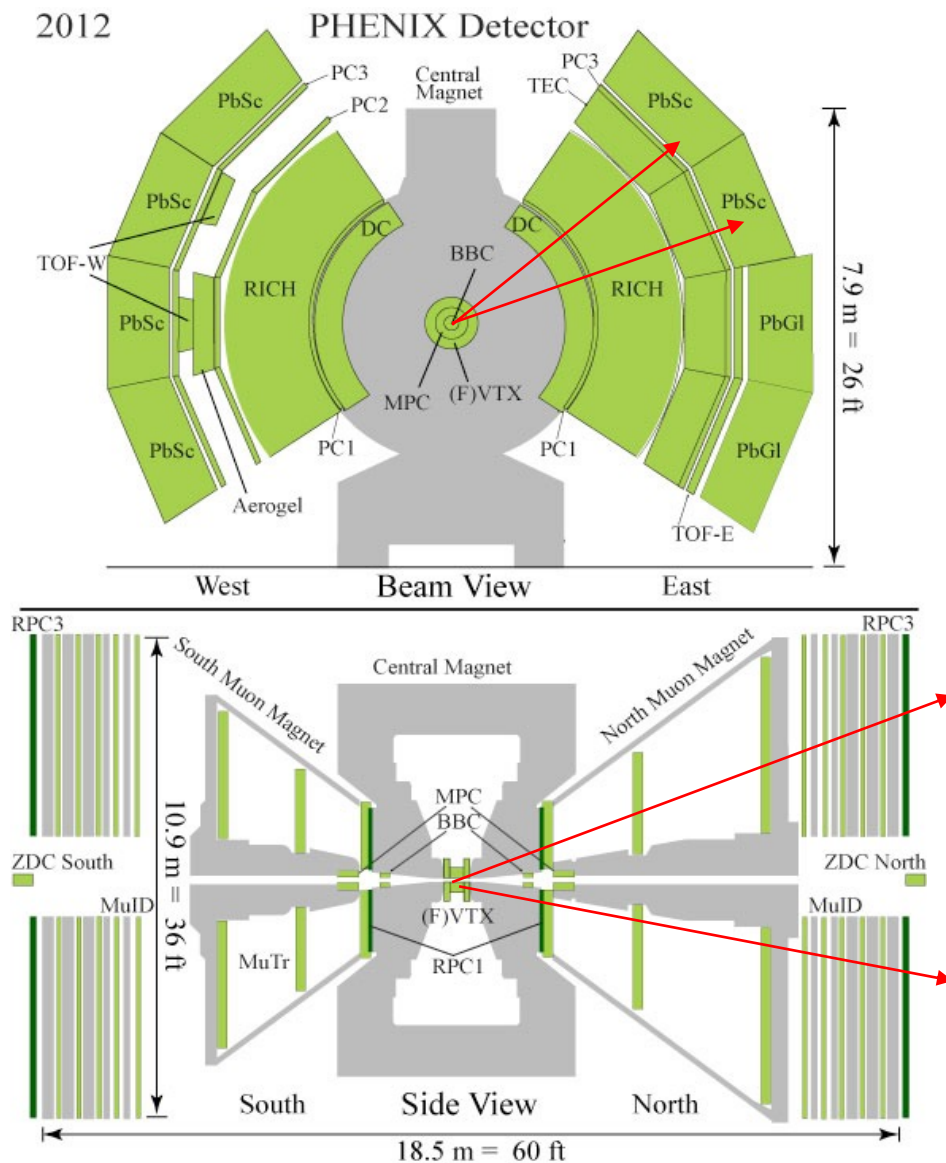
CO:



Gluon fusion dominates at RHIC energy

PHENIX Detector at RHIC

2012



Central Arms $|\eta| < 0.35$

- Identified charged hadrons
- Neutral Pions
- Direct Photon
- J/ψ
- Heavy Flavor

Muon Arms $1.2 < |\eta| < 2.4$

- J/ψ
- Unidentified charged hadrons
- Heavy Flavor

BBC/MPC $3.1 < |\eta| < 3.9$

- Neutral Pion's
- Eta's

ZDC $|\eta| \sim 5.9$

- Neutrons

Event Multiplicity Measurements:

SVX: Silicon Vertex Det.
 $|\eta| < 1$

FVTX: Forward Silicon Vertex Det.
 $1.2 < |\eta| < 2.4$

$J/\psi \rightarrow \mu^+ + \mu^-$

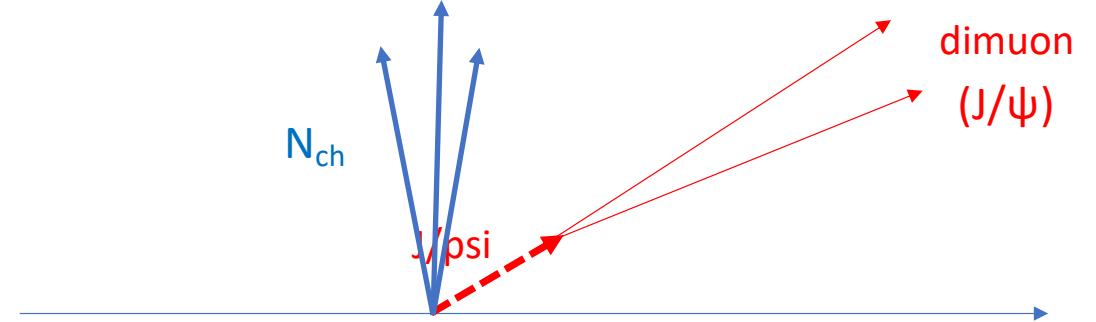
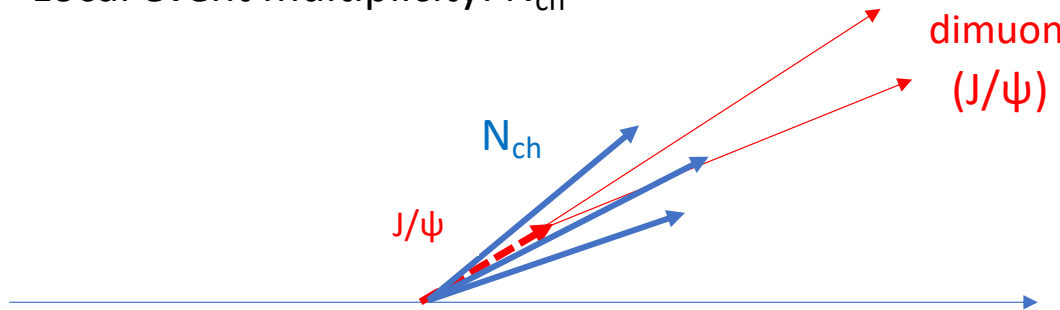
BBC: MB Trigger
 $3.1 < |\eta| < 3.9$

J/ψ Yields vs Event Multiplicity - Topology

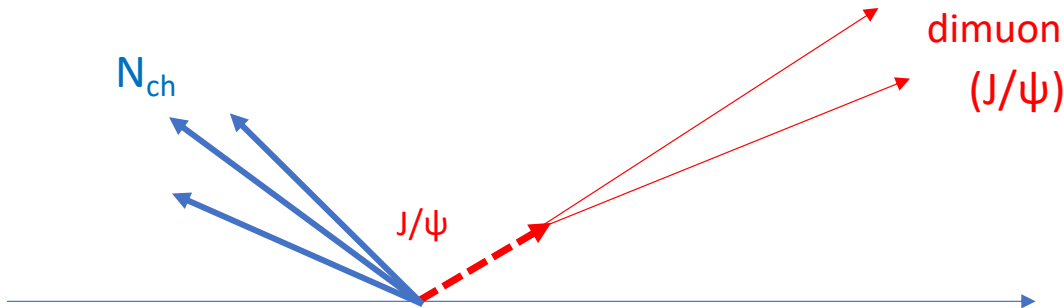
- Multi-Parton Interactions (MPI)
- Final State Interactions (FSI)
- Local event multiplicity: N_{ch}

$$J/\psi \rightarrow \mu^+ + \mu^-$$

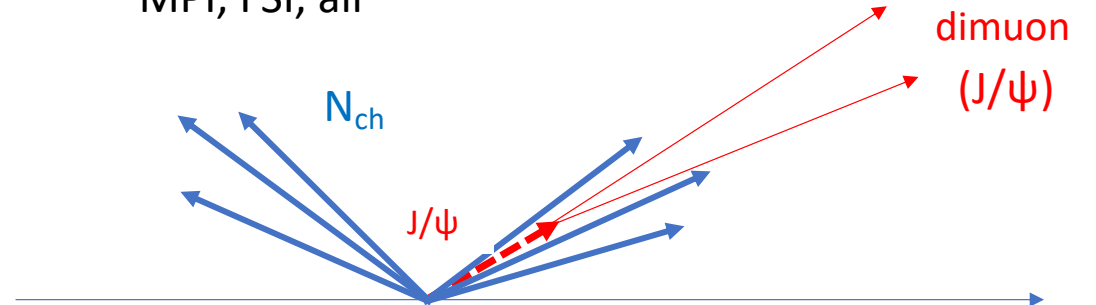
MPI, local energy density?



MPI, local energy density?

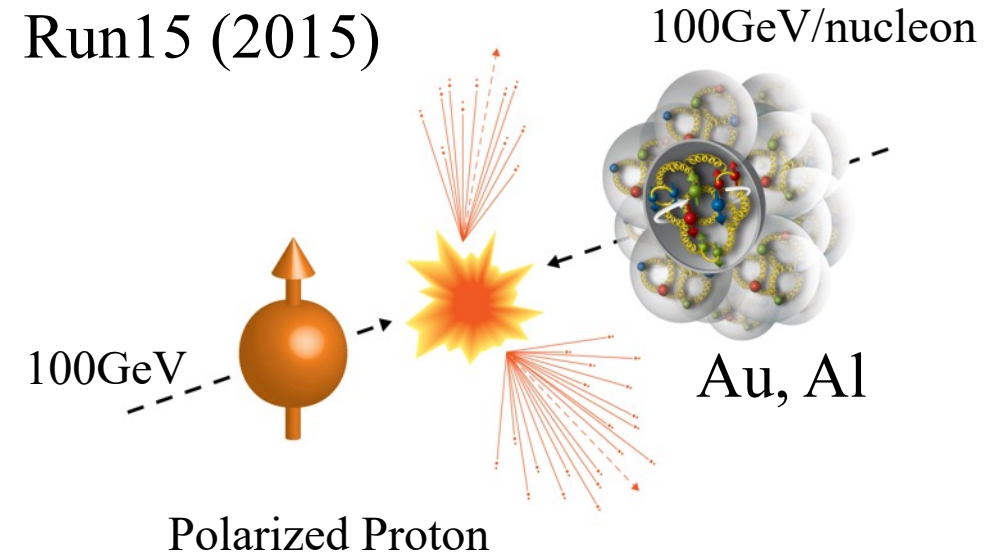
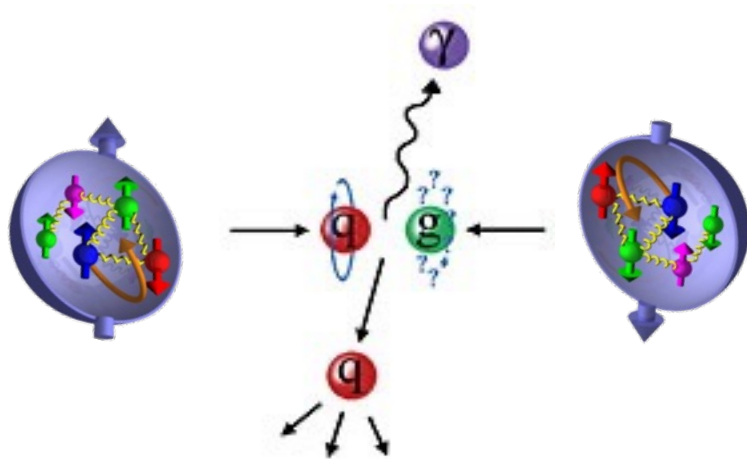


MPI, FSI, all

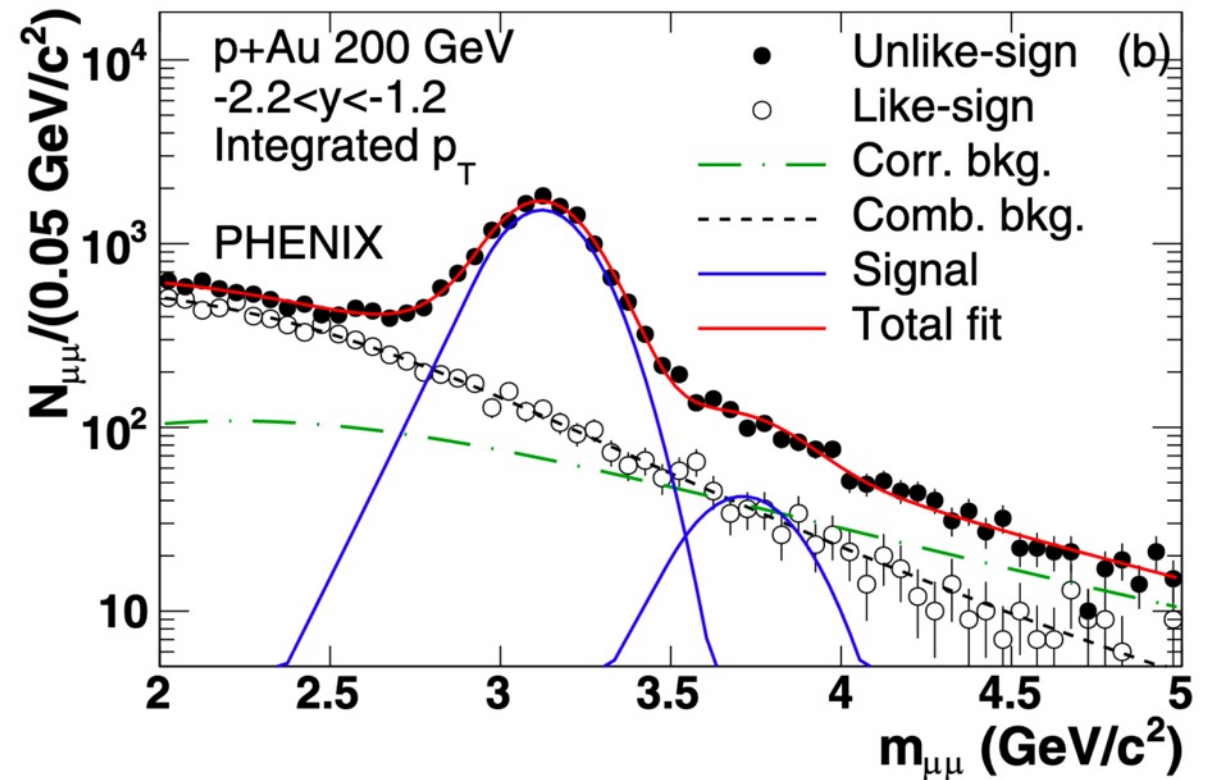
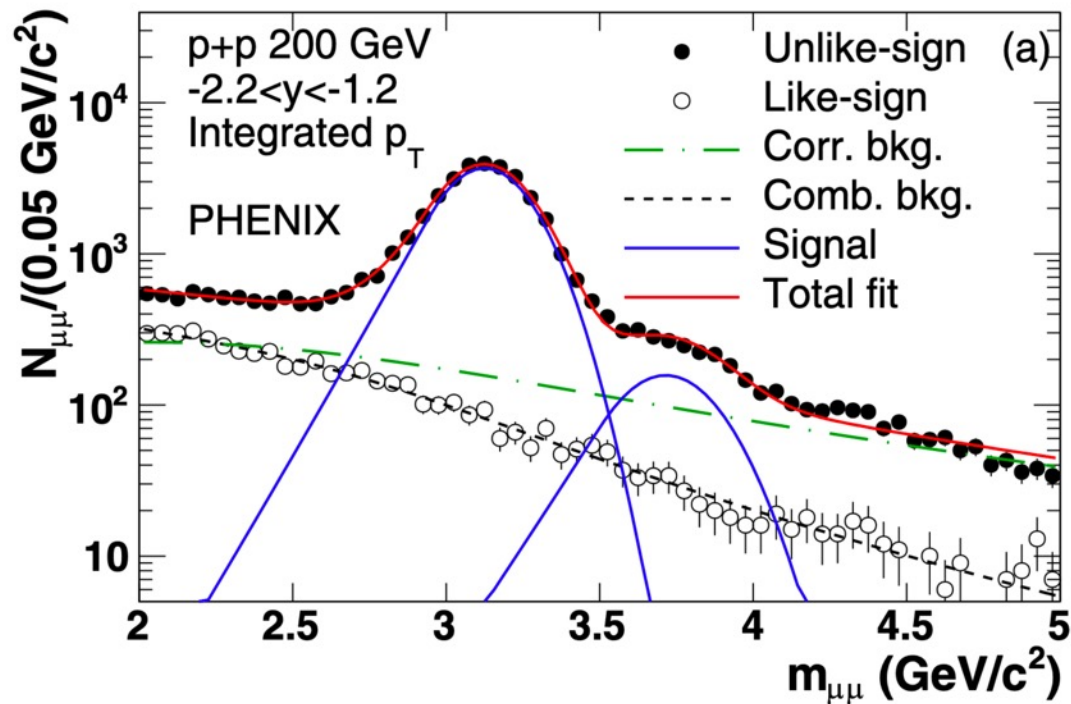
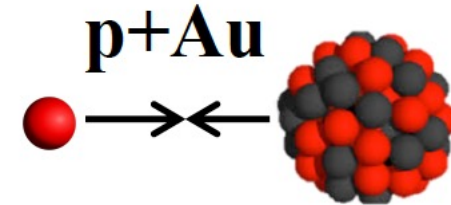
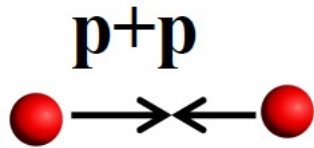


PHENIX Experiment in 2015 Run, 200GeV pp and pA

- Transversely polarized p+p, p+Au and p+Al collisions at RHIC
 - p+p: $L_{NN} \sim 200 \text{ pb}^{-1}$
 - p+Au: $L_{NN} \sim 130 \text{ pb}^{-1}$



J/ψ Production in pp and pAu Collisions at PHENIX

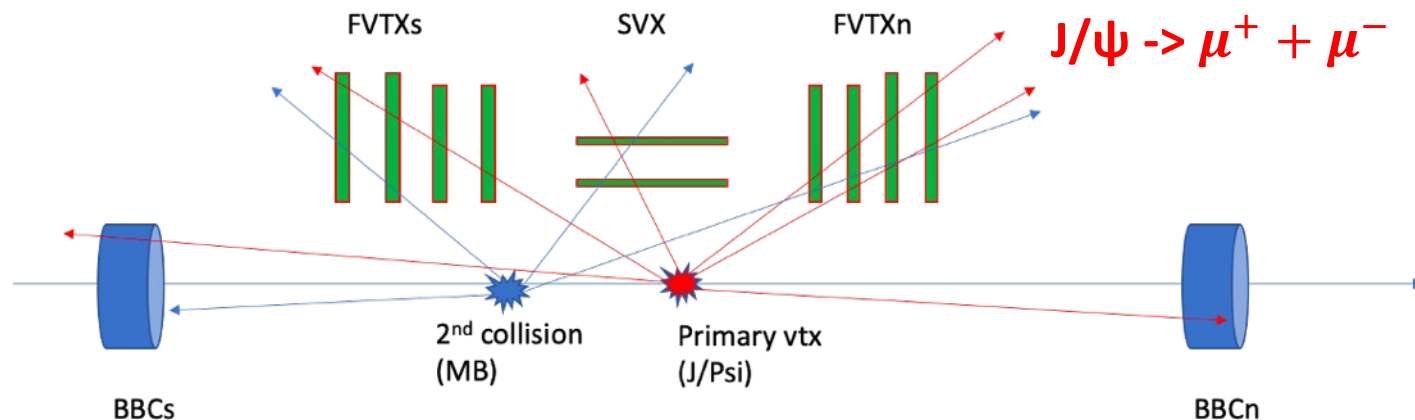


Our Measurements at PHENIX

J/ψ Relative Yields vs Normalized Event Multiplicity from FVTX and SVX

$$R(N_{ch}) = \frac{dN^{J/\psi}/dy}{\langle dN^{J/\psi}/dy \rangle}$$

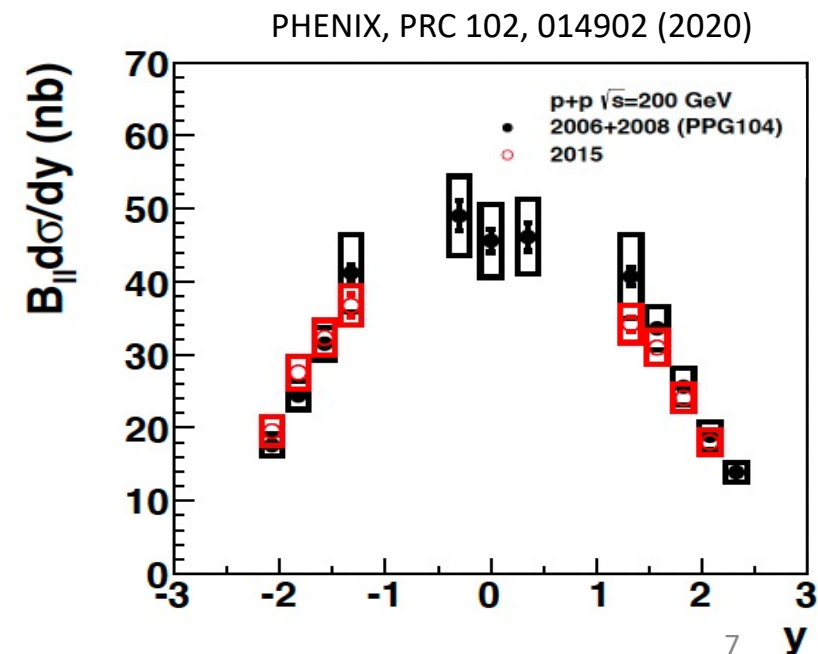
$$R(N_{ch}/\langle N_{ch} \rangle) = \frac{dN^{J/\psi}/dy}{\langle dN^{J/\psi}/dy \rangle} = \left[\frac{N_S^{J/\psi}}{N_{Recorded}^{MB}} \frac{\epsilon_{trig}^{MB}}{\epsilon_{trig}^{J/\psi}} \right] / \left[\frac{N_S^{J/\psi}(total)}{N_{Recorded}^{MB}(total)} \frac{\langle \epsilon_{trig}^{MB} \rangle}{\langle \epsilon_{trig}^{J/\psi} \rangle} \right] f_{coll}$$



Event Multiplicity Measurements: FVTXs, SVX, FVTXn

9/2/22

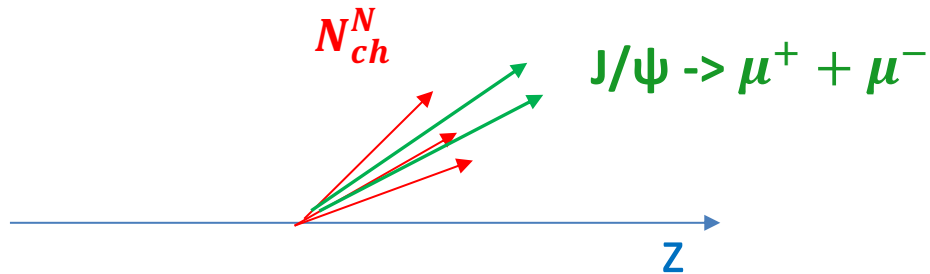
Ming Liu @ CIPANP2022



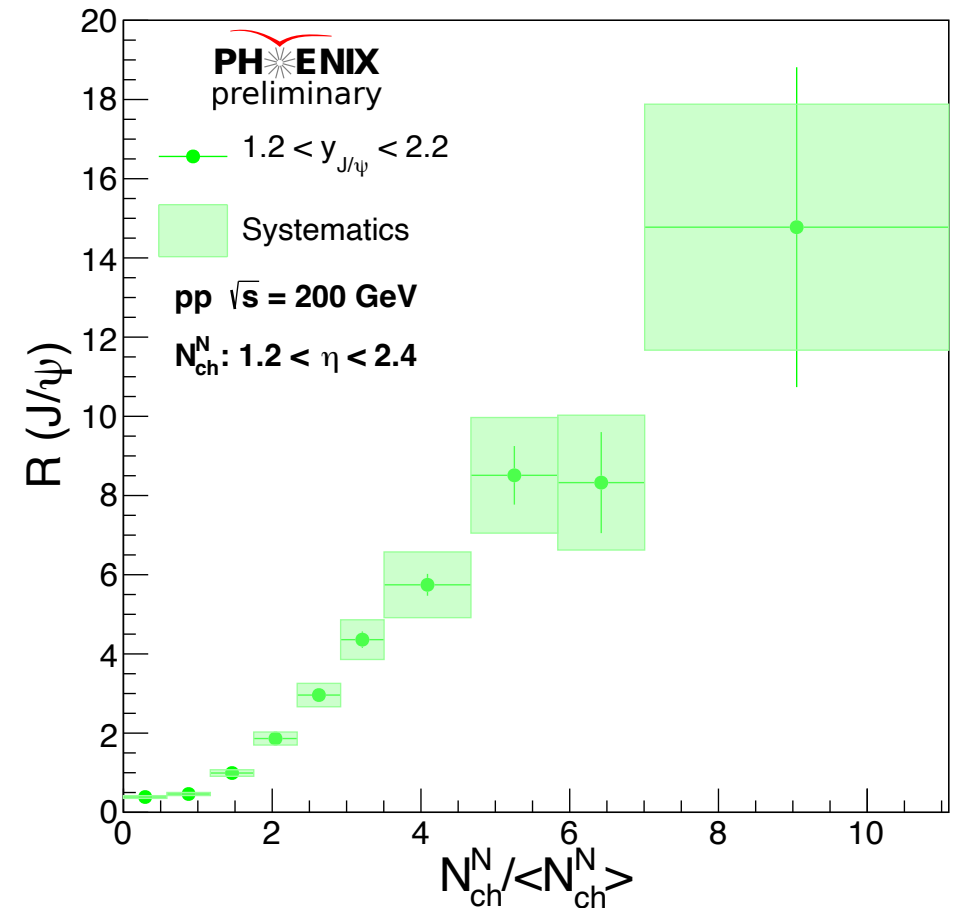
J/ψ Production: same kinematic region

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

Green = J/ψ ($1.2 < y < 2.2$)



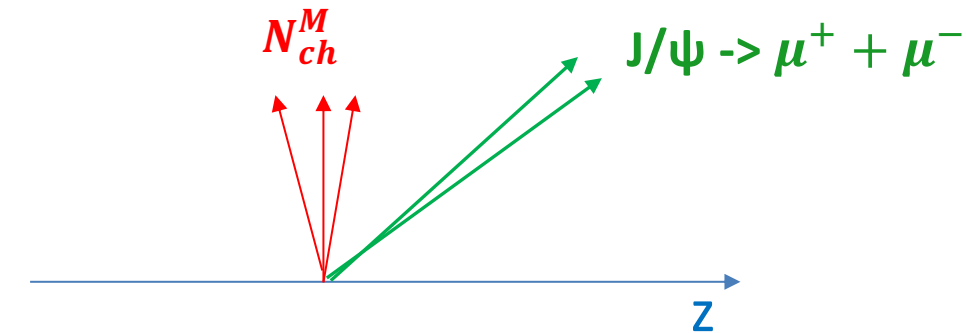
Multiplicity: MPI, FSI contributions to the forward **J/ψ** production?



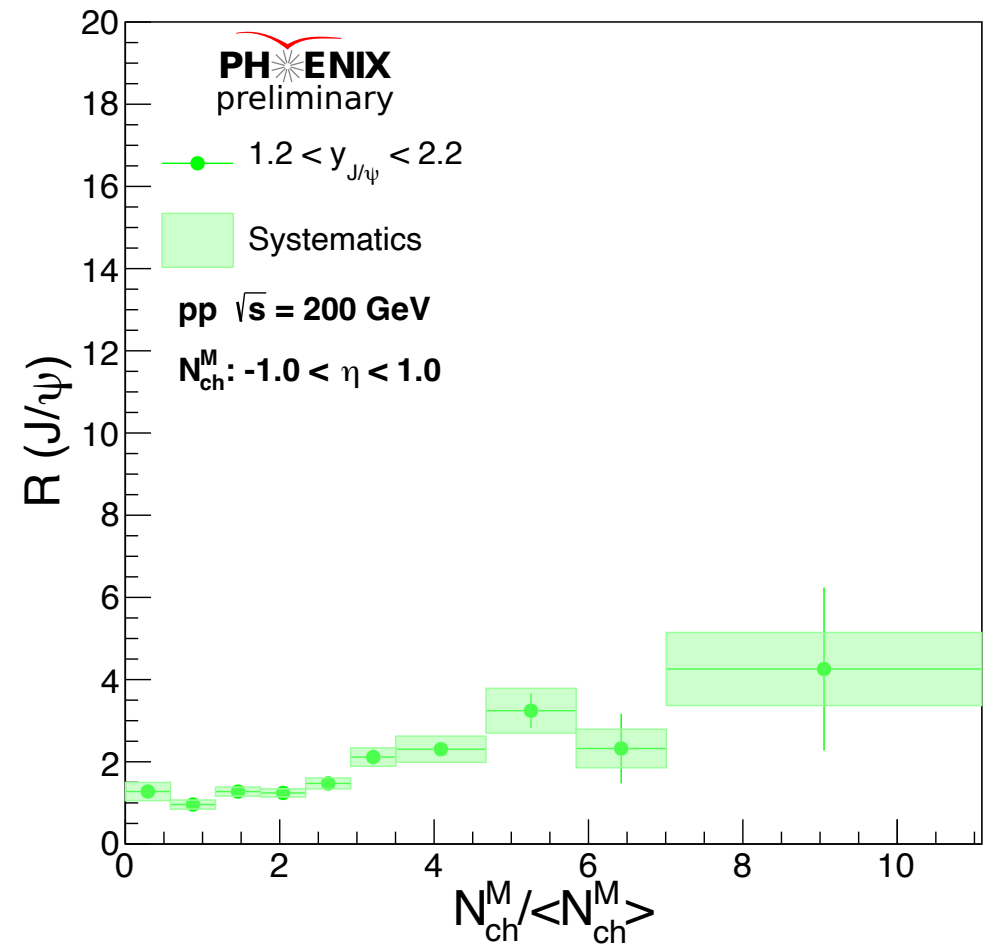
J/ ψ Production vs Multiplicity at Midrapidity

RED = Tracklets N_{ch}^M ($|\eta| < 1$)

Green = J/ ψ ($1.2 < y < 2.2$)



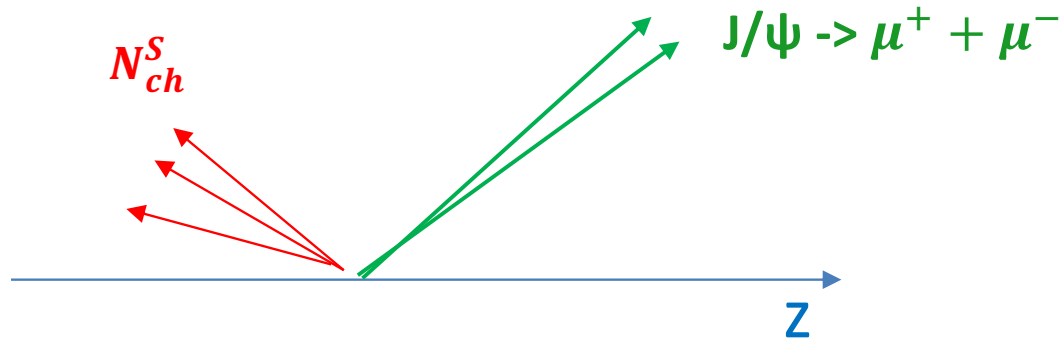
expect less co-mover type FSI at high multiplicity



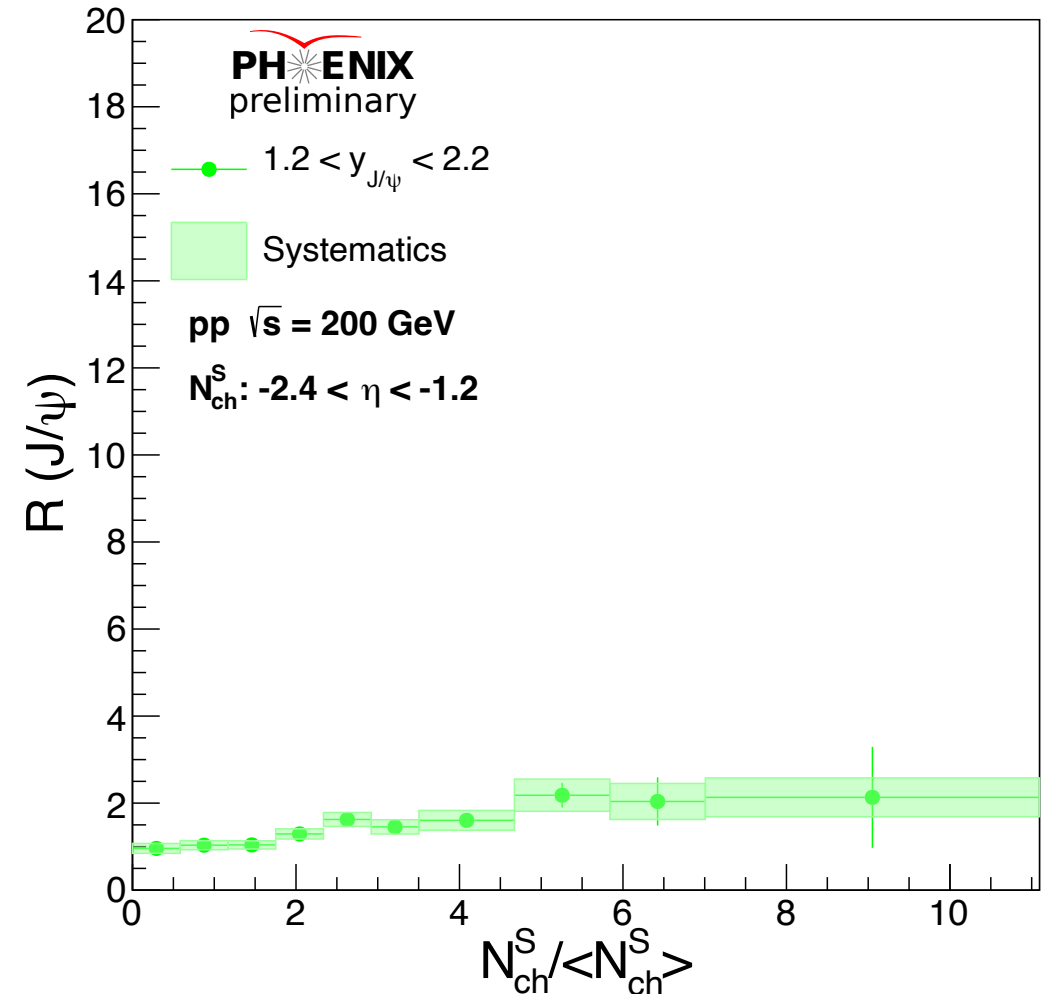
J/ψ Production: far-off kinematic region

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

Green = J/ψ ($1.2 < y < 2.2$)



Expect much less co-mover type FSI at high multiplicity

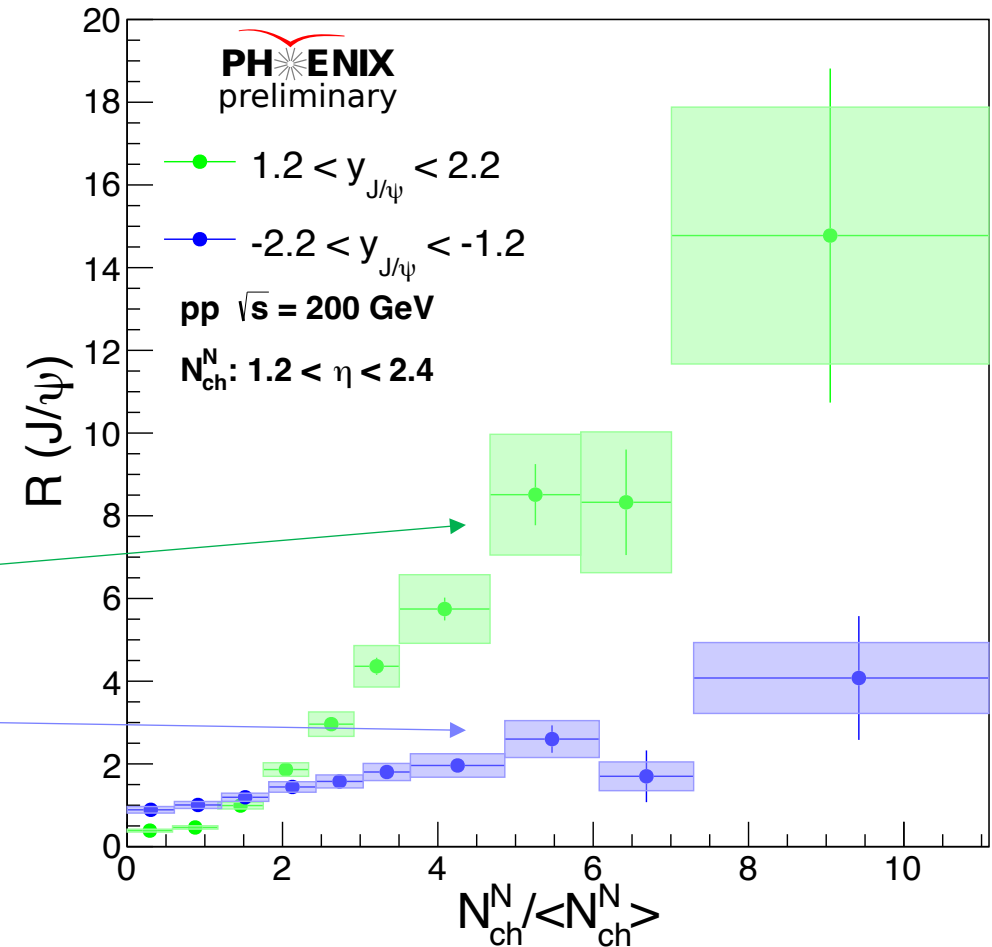
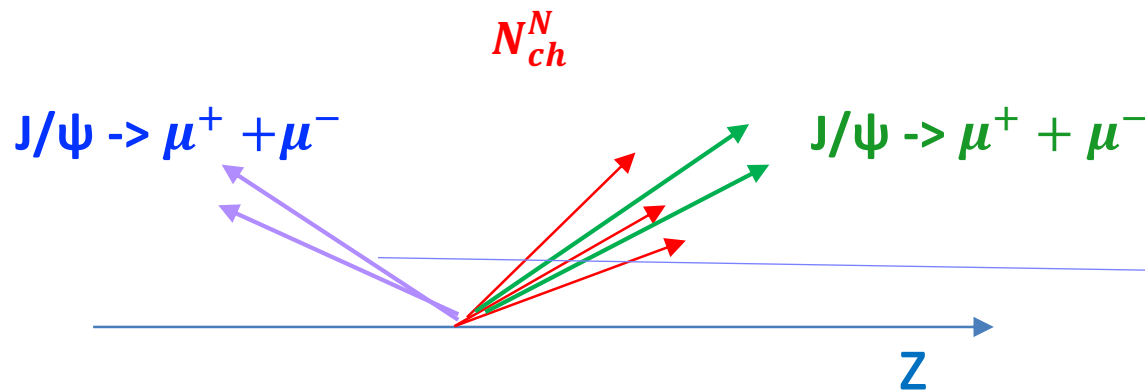


J/ψ Yields vs Event Multiplicity

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

Green = J/ψ ($1.2 < y < 2.2$)

Blue = J/ψ ($-2.2 < y < -1.2$)

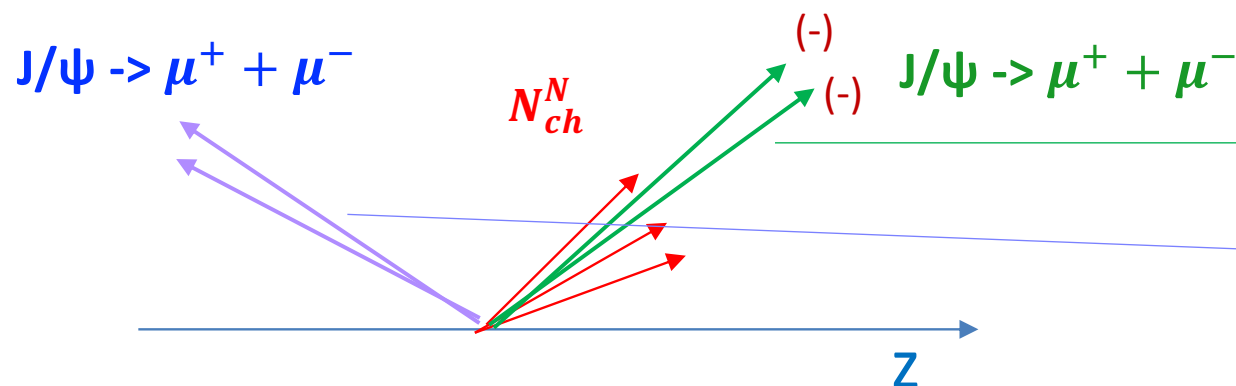


J/ψ Yields vs Event Multiplicity: All Together

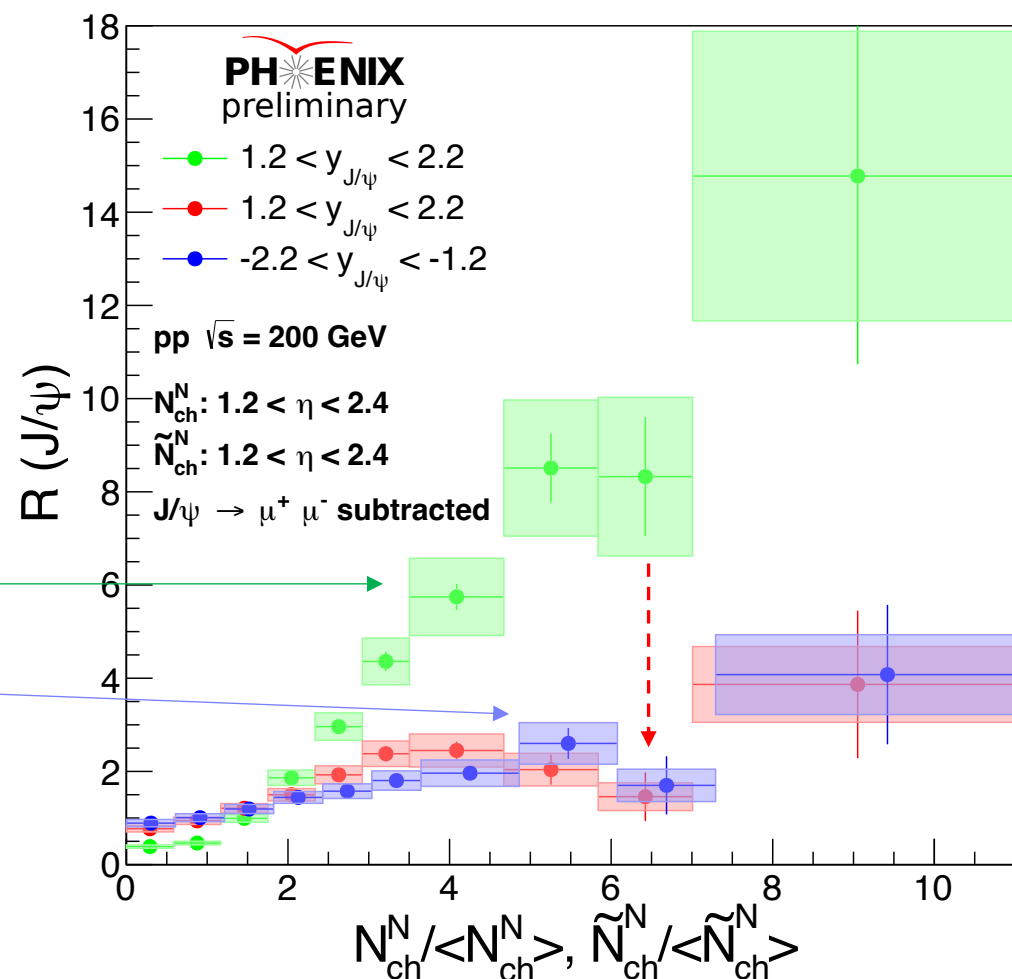
RED = Tracklets $N_{ch}^N (1.2 < \eta < 2.4)$
[inclusive, dimuon subtracted]

Green = J/ψ ($1.2 < y < 2.2$)

Blue = J/ψ ($-2.2 < y < -1.2$)



- Less MPI contribution to the forward J/ψ production?

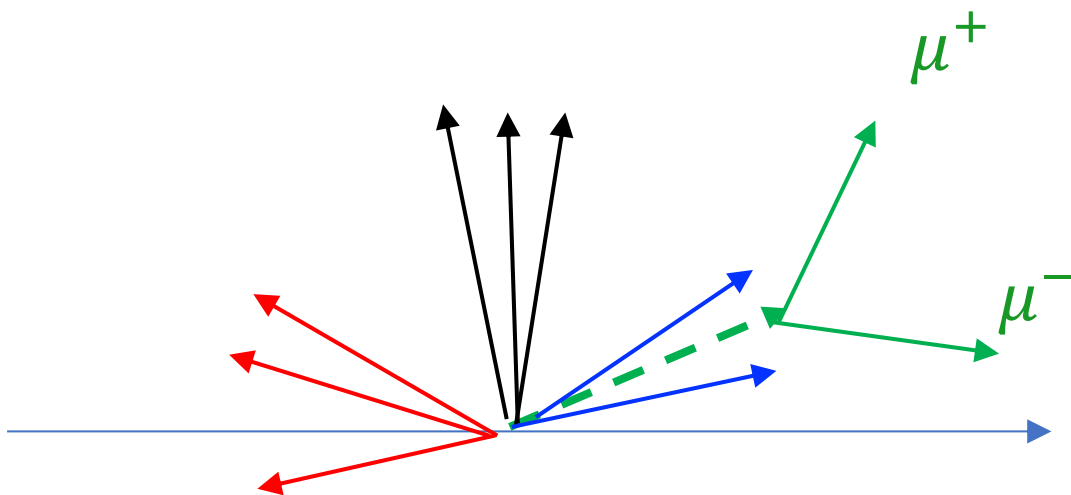


PYTHIA 8 p+p Simulations

- Detroit Tune (RHIC) pp 200GeV

- MPI ON/OFF
- PHENIX acceptance

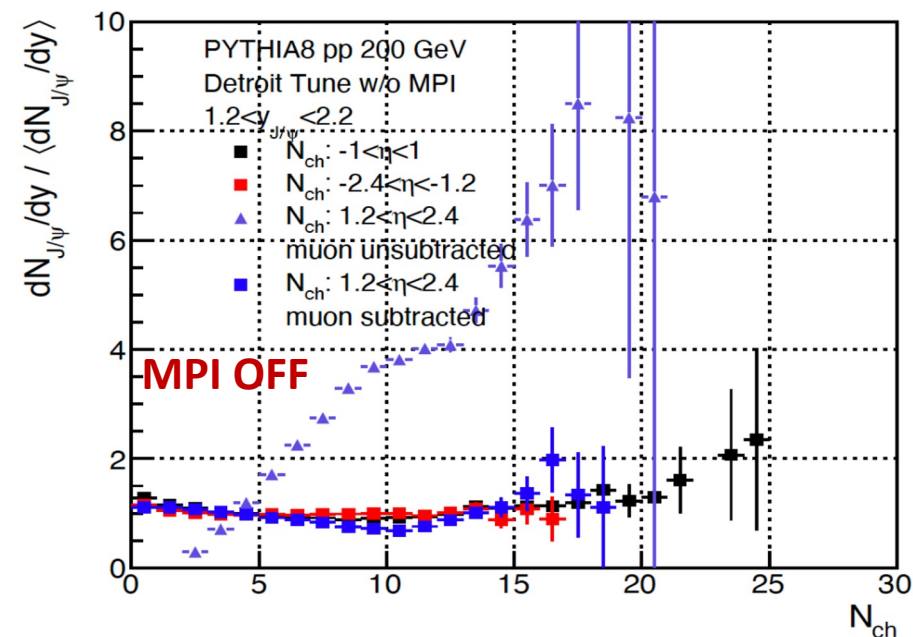
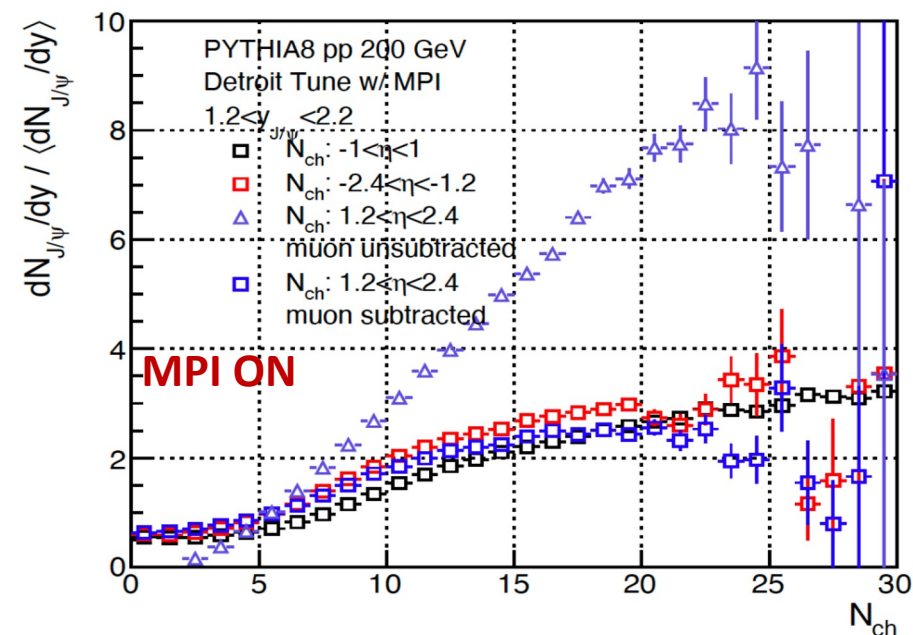
$$J/\psi \rightarrow \mu^+ + \mu^-$$



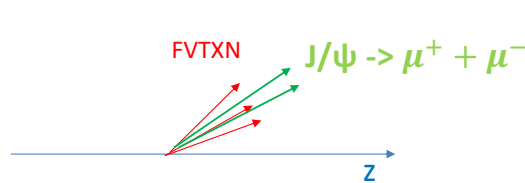
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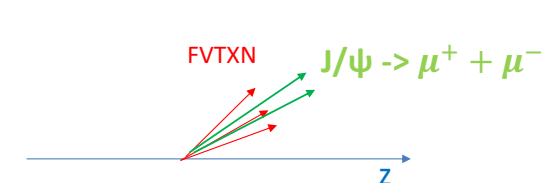
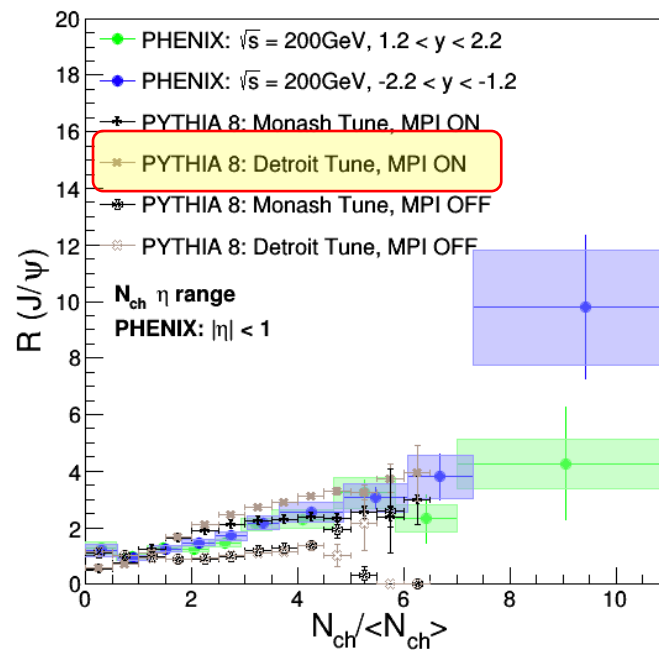
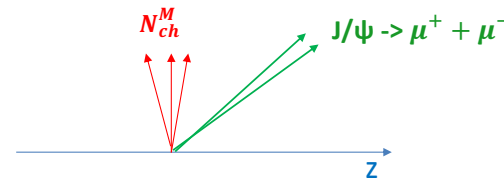
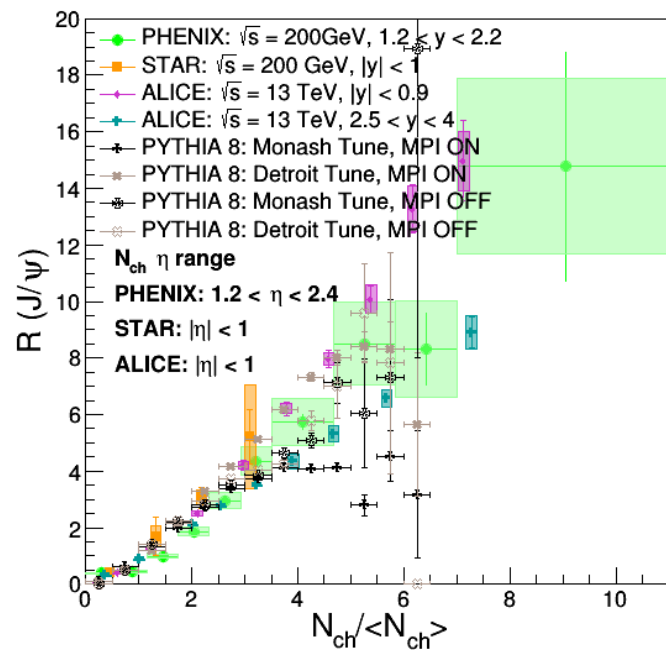
NIX



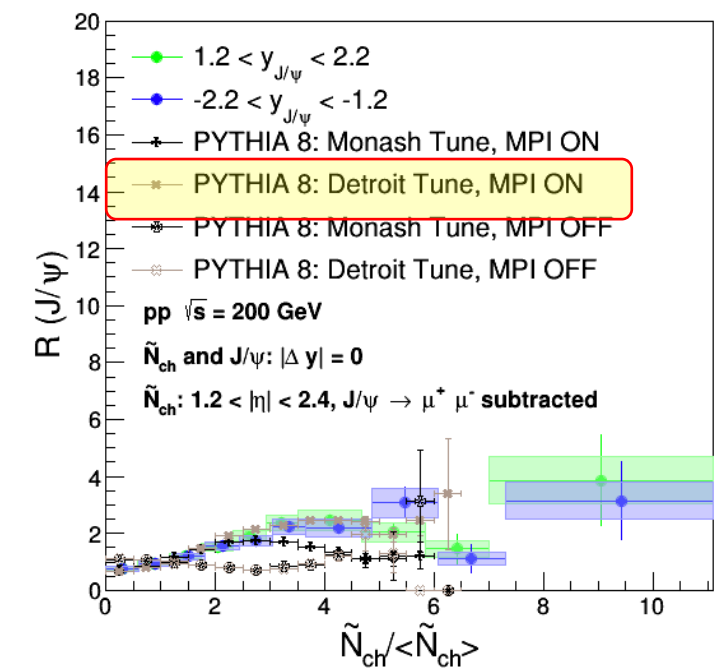
PYTHIA vs Data (RHIC and LHC)



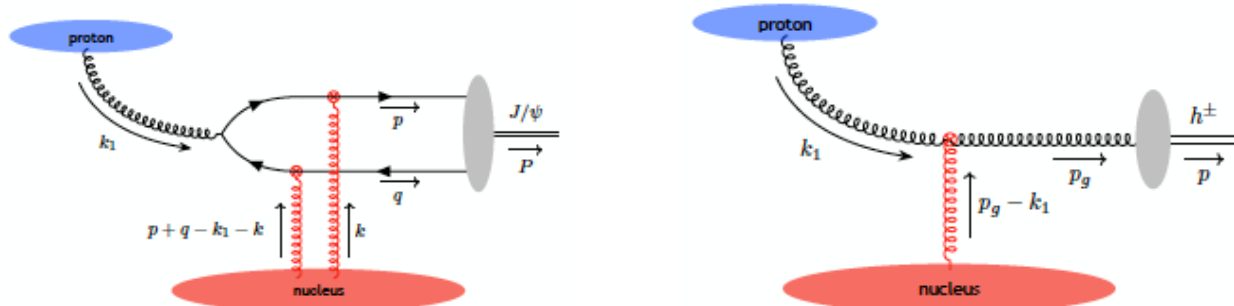
(same arm, inclusive)



(dimuon subtracted)

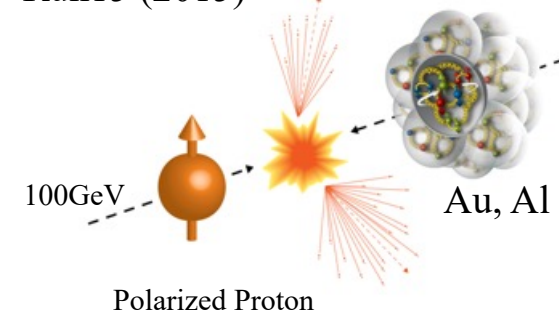


Probe CGC in pAu?

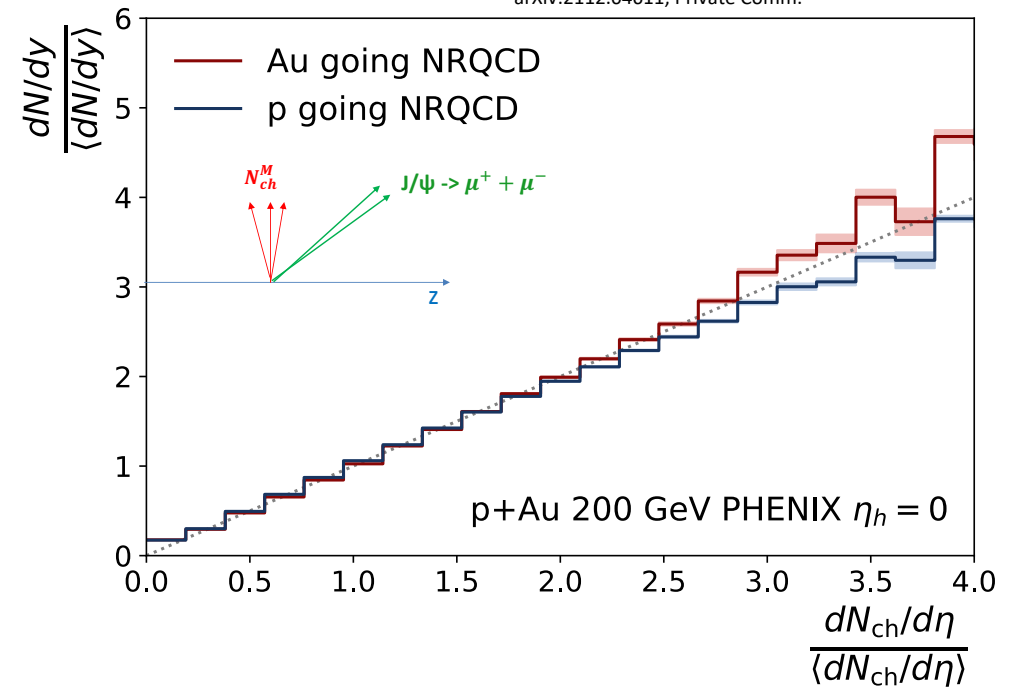
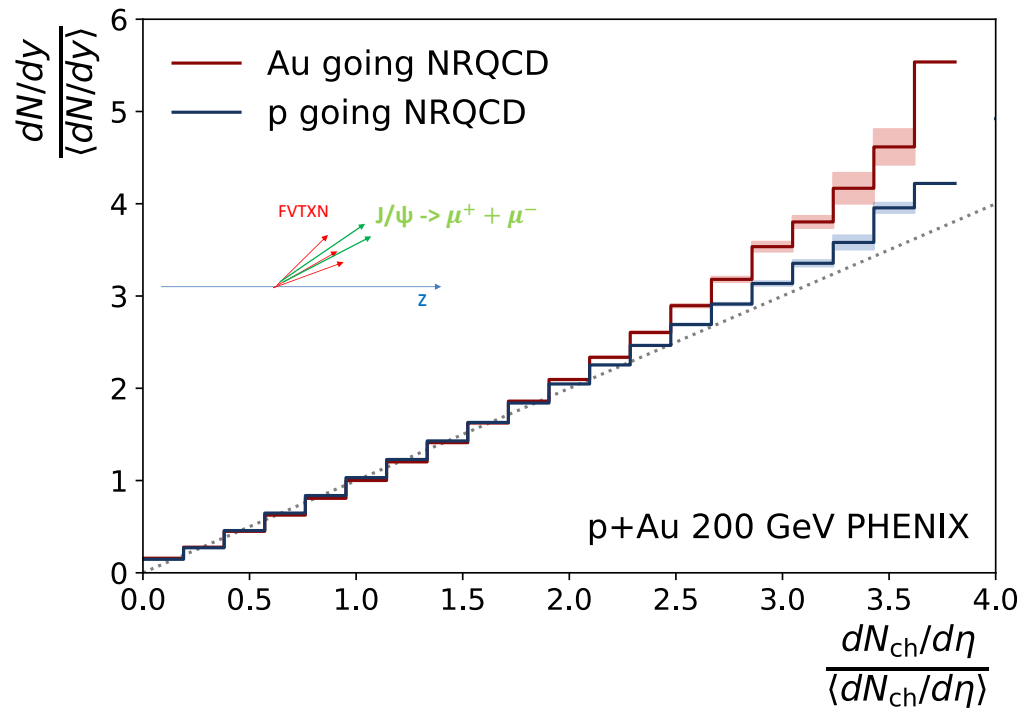


Run15 (2015)

100GeV/nucleon

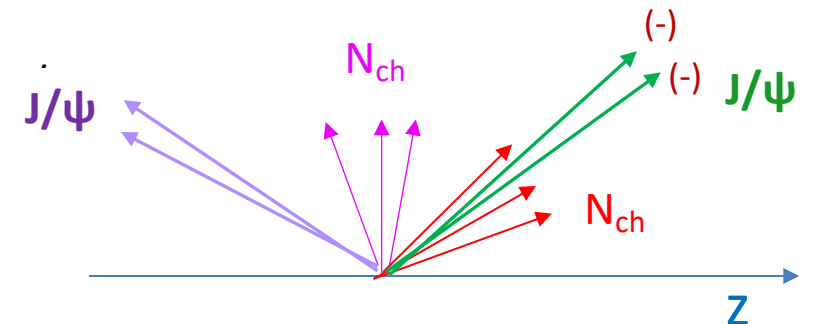
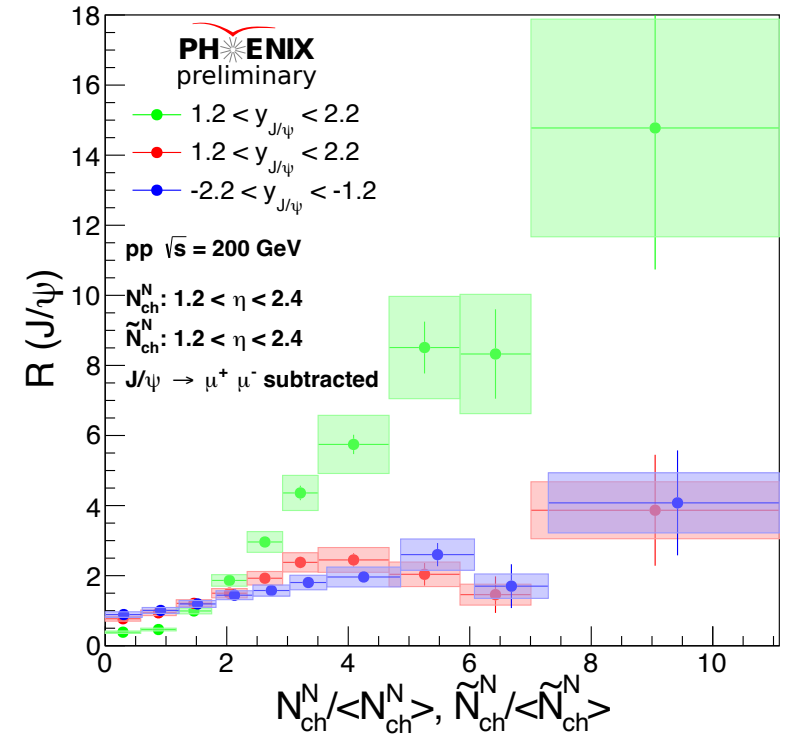


Farid Salazar, Bjorn Schenke and Alba Soto-Ontoso
arXiv:2112.04611; Private Comm.



Summary and Outlook

- **First measurements of the relative J/ψ yields R in the forward rapidity vs normalized event charged particle multiplicity $N_{ch}/\langle N_{ch} \rangle$ in pp at 200GeV**
 - Strong N_{ch} dependence observed when signal and N_{ch} in the same kinematics
 - N_{ch} dependence reduced significantly if dimuon contribution removed
 - Dimuon subtracted N_{ch} dependence similar to the ones from N_{ch} determined in a far kinematic region from the signal
- **Physics discussions**
 - “c-cbar” favors CS state, at low pT ?
 - R depends on not only MPI but also other effects/production mechanisms
 - Comparison with PYTHIA, favors MPI
 - More theoretical inputs welcome
- **p+Au analysis in progress, stay tuned!**
 - Very interesting CGC motivated model predictions



Join us at

INTERSECTIONS

Lake Buena Vista, Fla

THANK
You! 😊

August
September 4

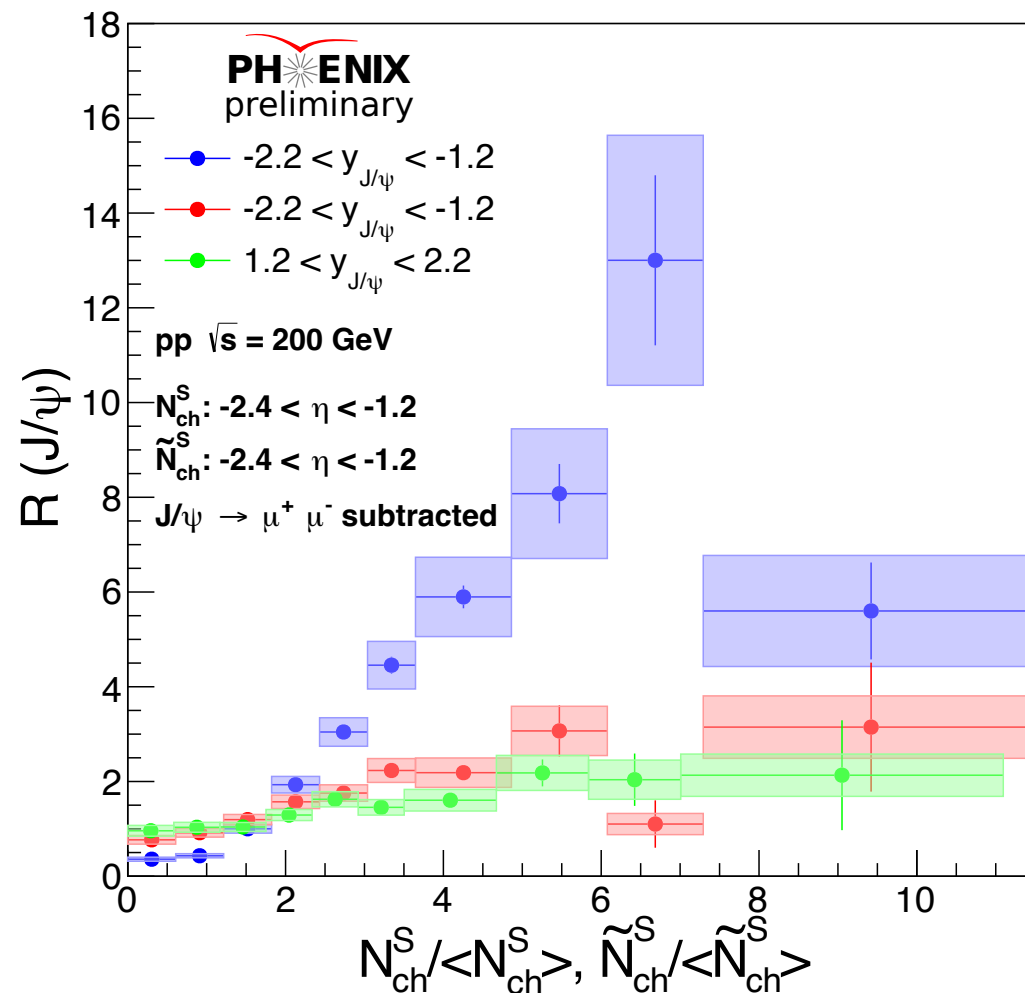
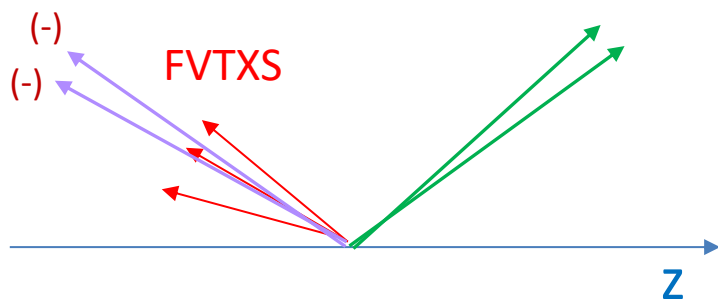
Backup slides

J/ ψ Yields vs Event Multiplicity: All Together

RED = Tracklets ($1.2 < \eta < 2.4$)
[dimuon subtracted]

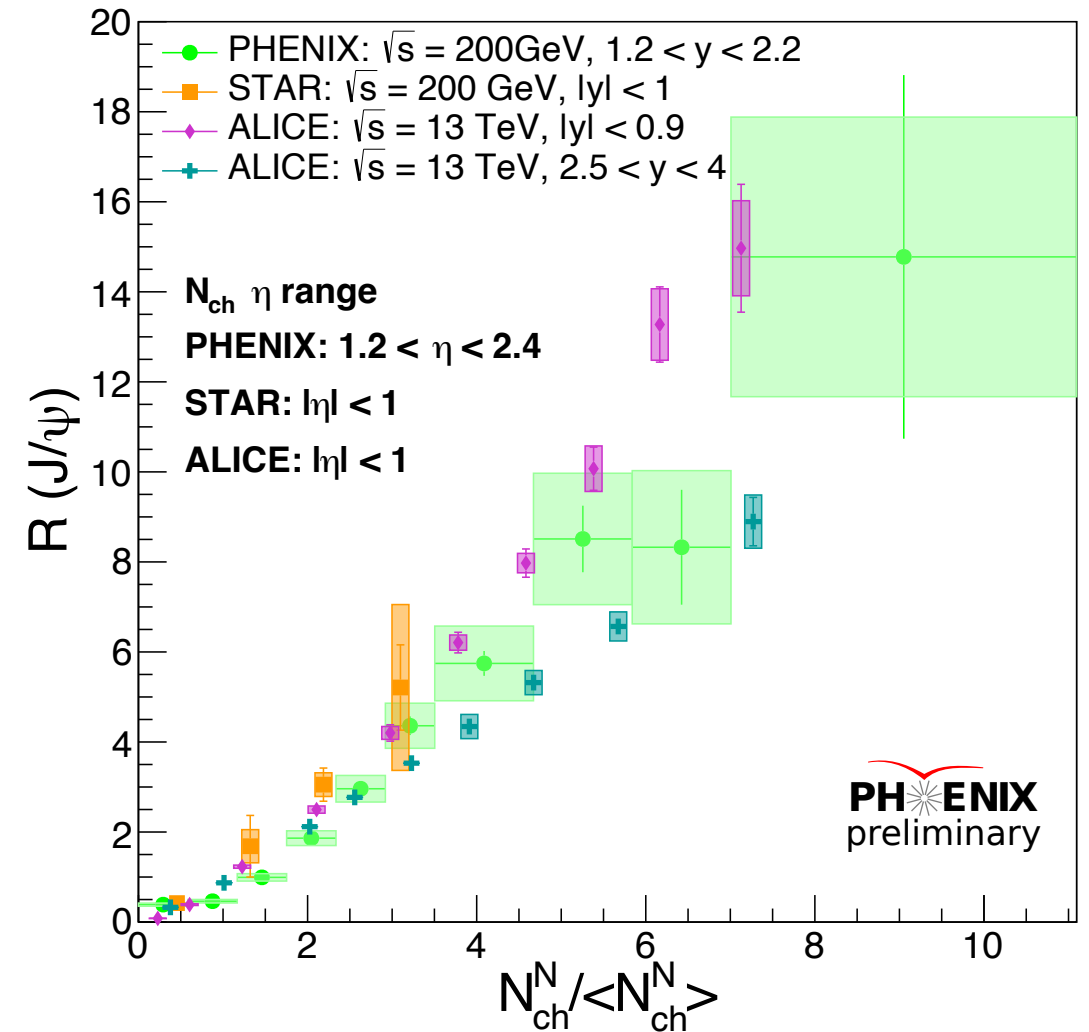
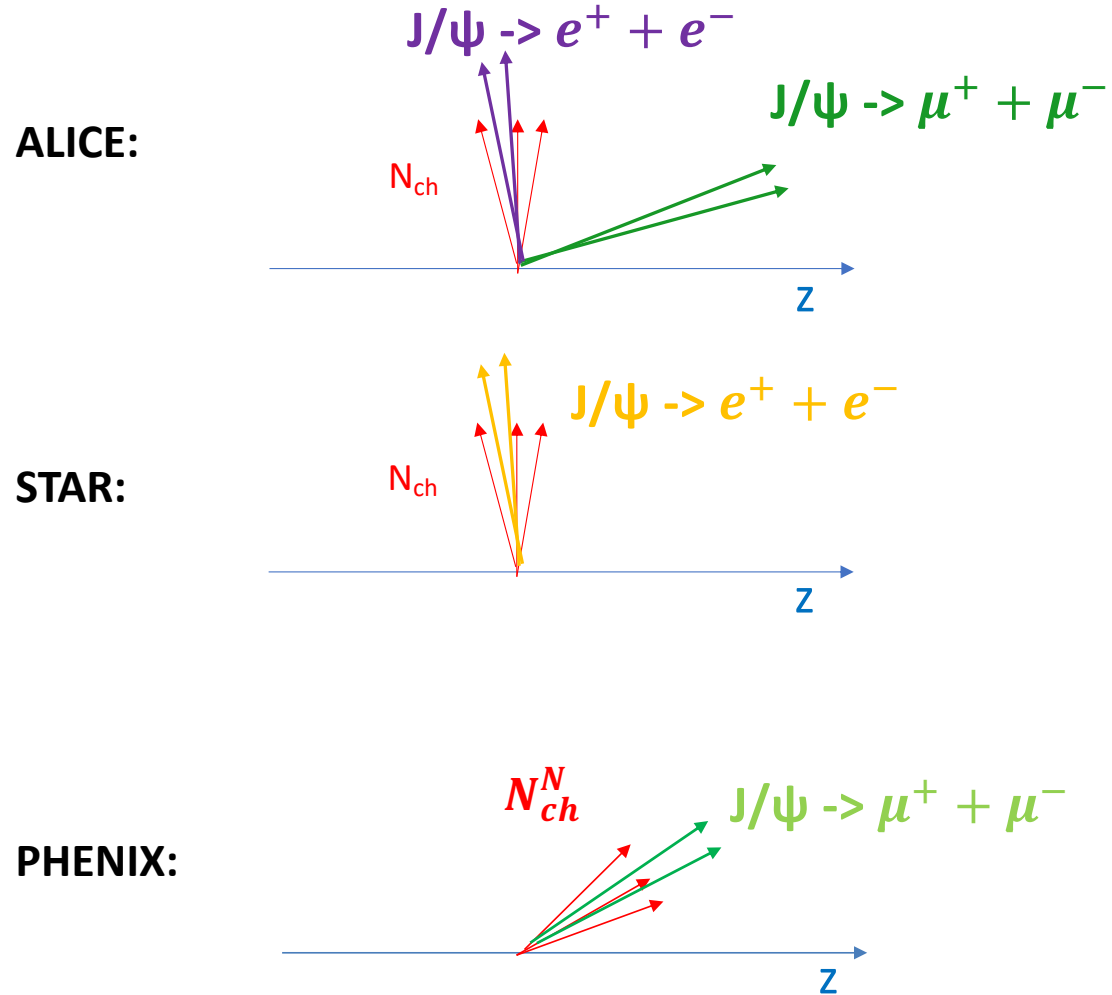
Green = J/ ψ ($1.2 < y < 2.2$)
[inclusive tracklets]

Blue = J/ ψ ($-2.2 < y < -1.2$)

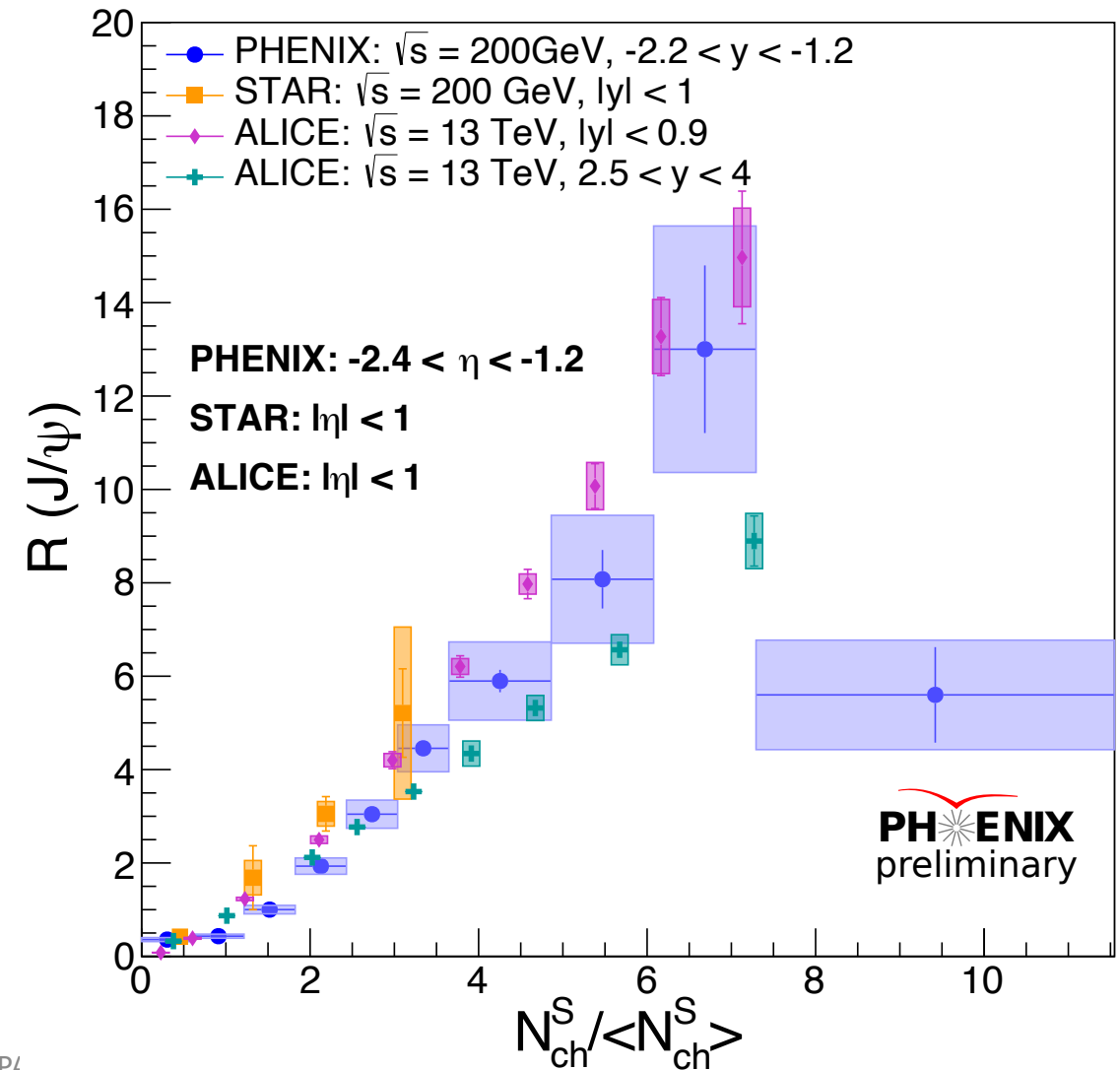
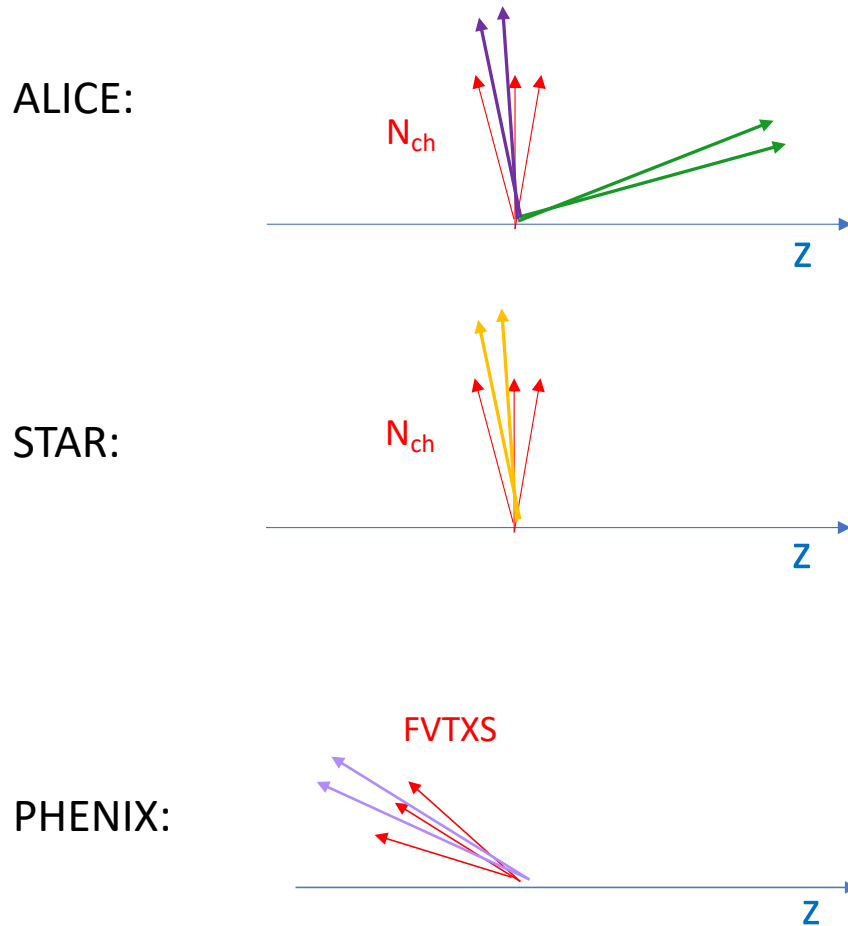


- Less MPI contribution to the forward J/Psi production?

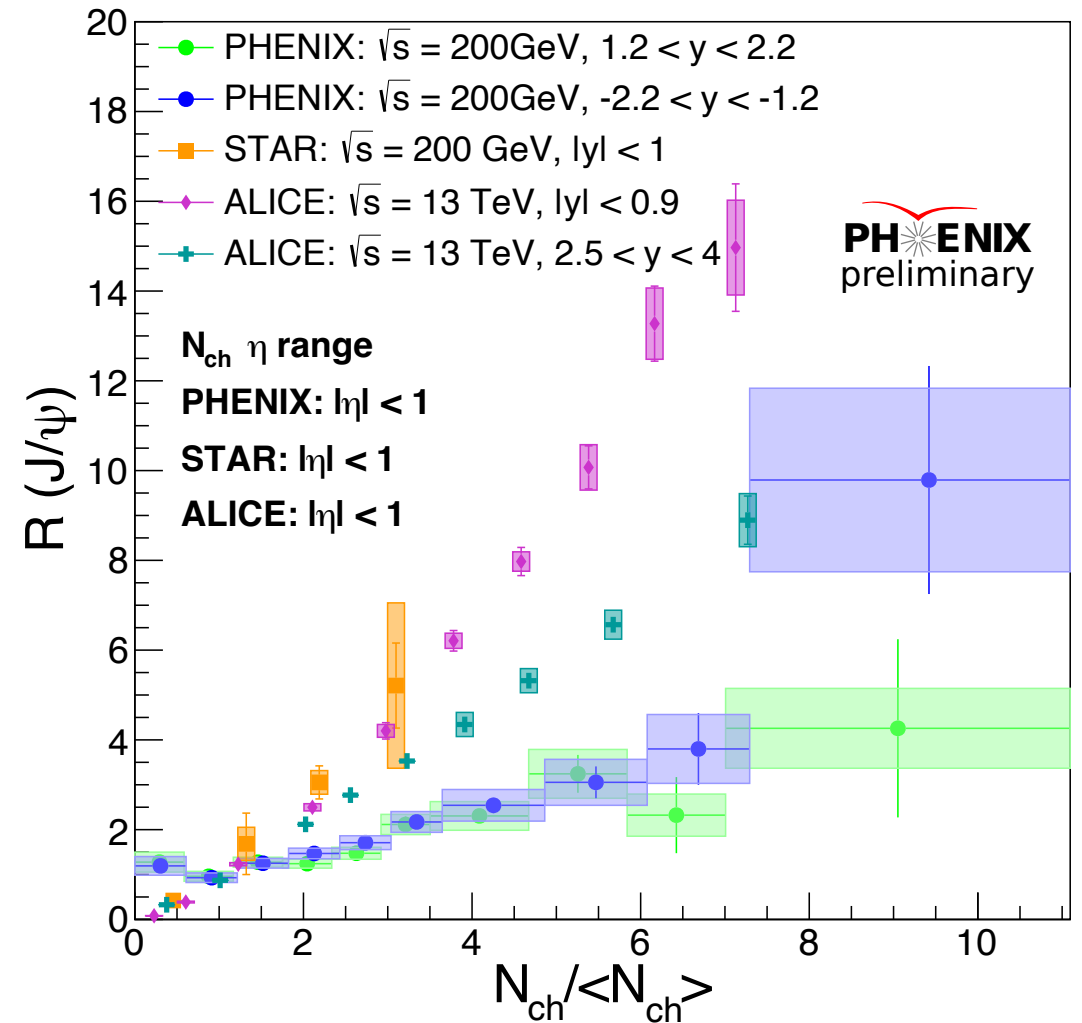
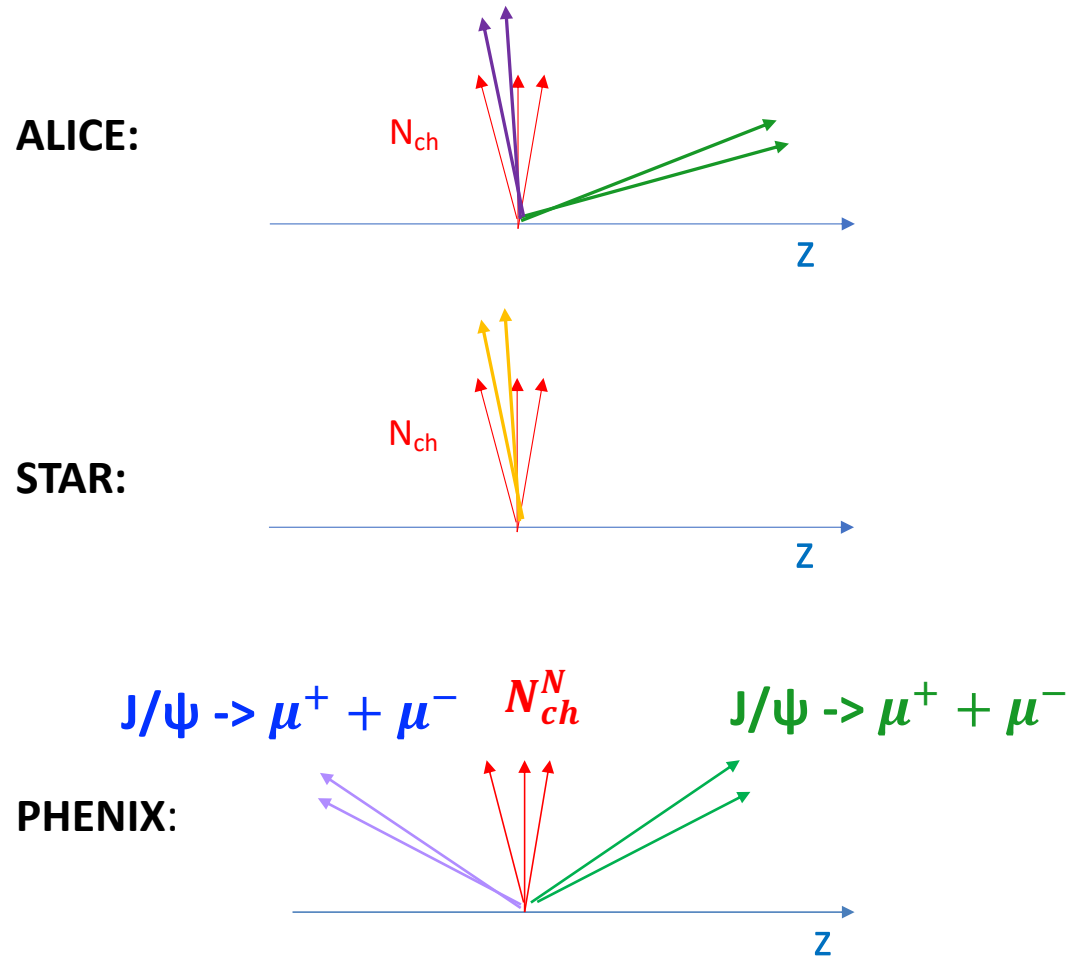
Comparison with other Results (I)



Comparison with other Results (II)



Comparison with other Results (III)

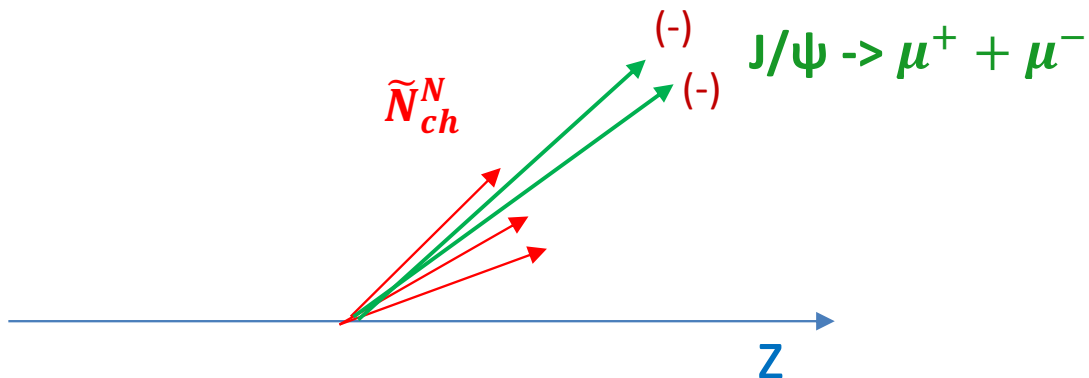


J/ψ Yields vs Event Multiplicity

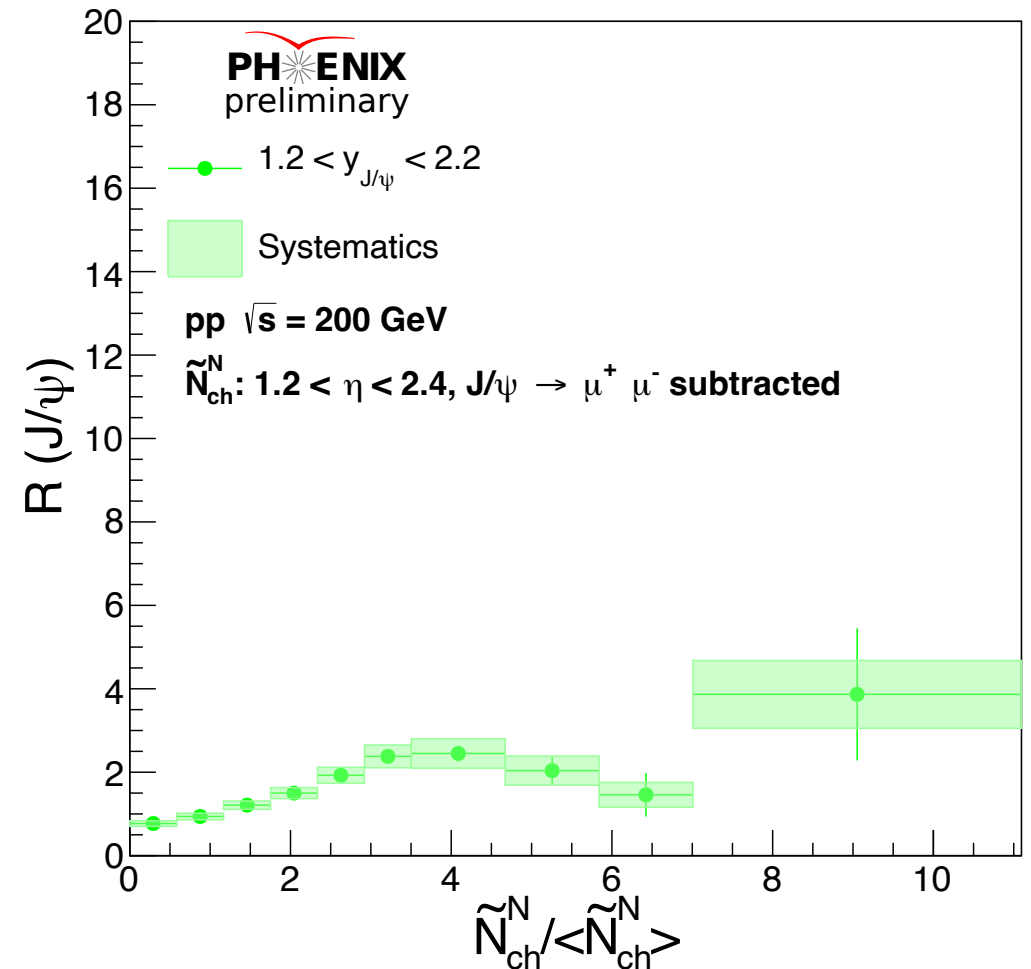
- subtract J/ψ dimuon contributions

RED = Tracklets $\tilde{N}_{ch}^N$ ($1.2 < \eta < 2.4$)
[dimuon subtracted]

Green = J/ψ ($1.2 < y < 2.2$)



“better estimation” of UE activity ?

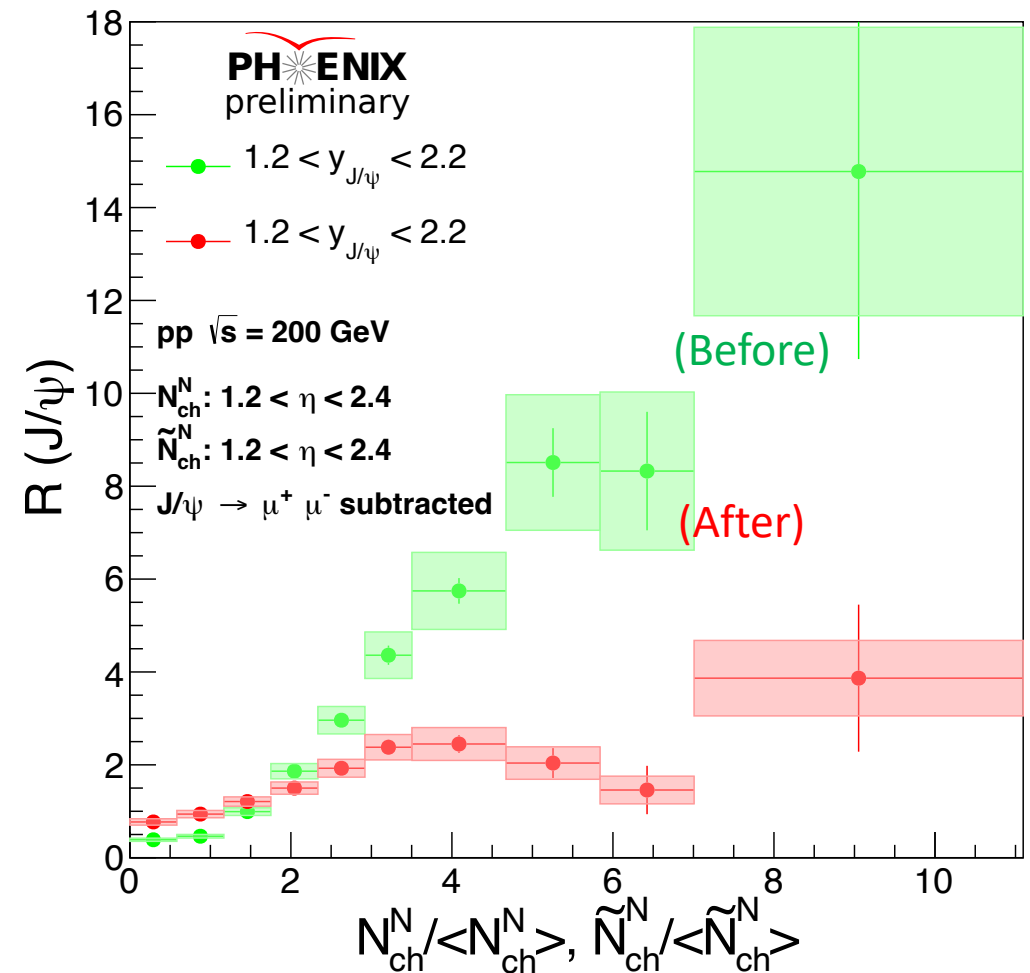
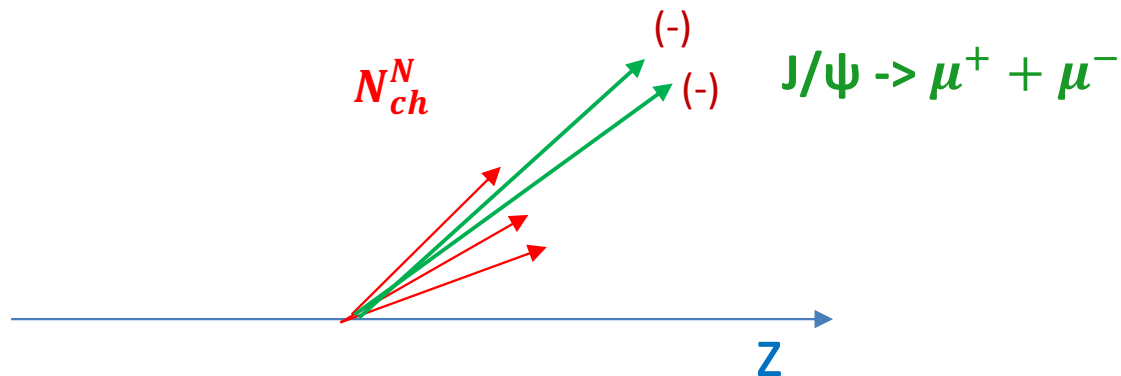


J/ψ Yields vs Event Multiplicity

- subtract J/ψ dimuon contributions

RED' = Tracklets N_{ch} ($1.2 < \eta < 2.4$),
[dimuon subtracted]

Green = J/ψ ($1.2 < y < 2.2$)
[inclusive tracklets]

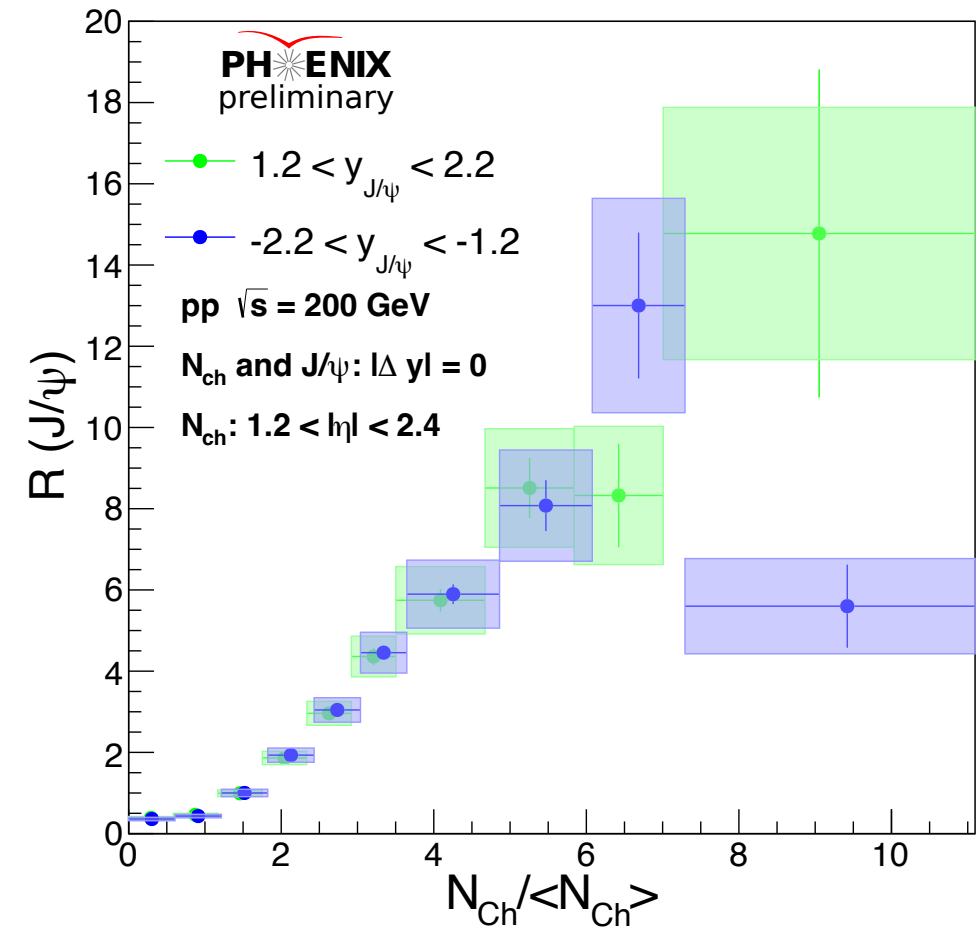


Consistency Check: North vs South Arms (I)

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

Green = J/ψ ($1.2 < y < 2.2$)

Blue = J/ψ ($-2.2 < y < -1.2$)

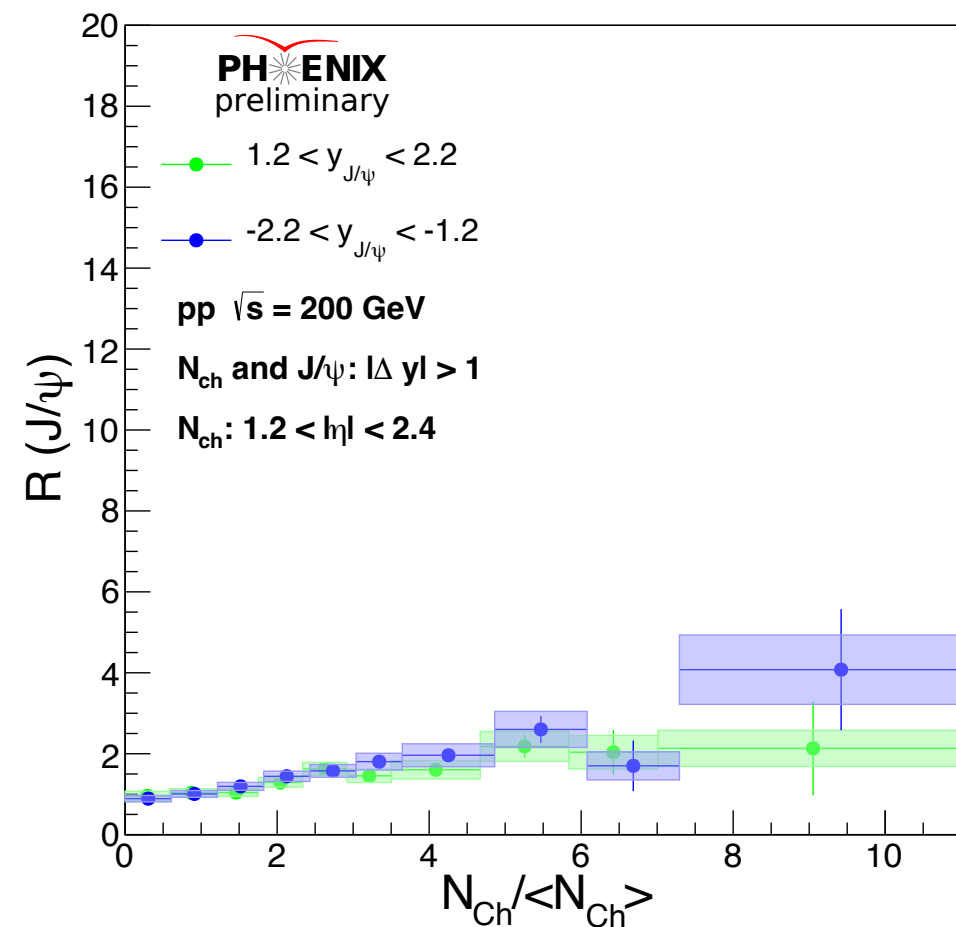
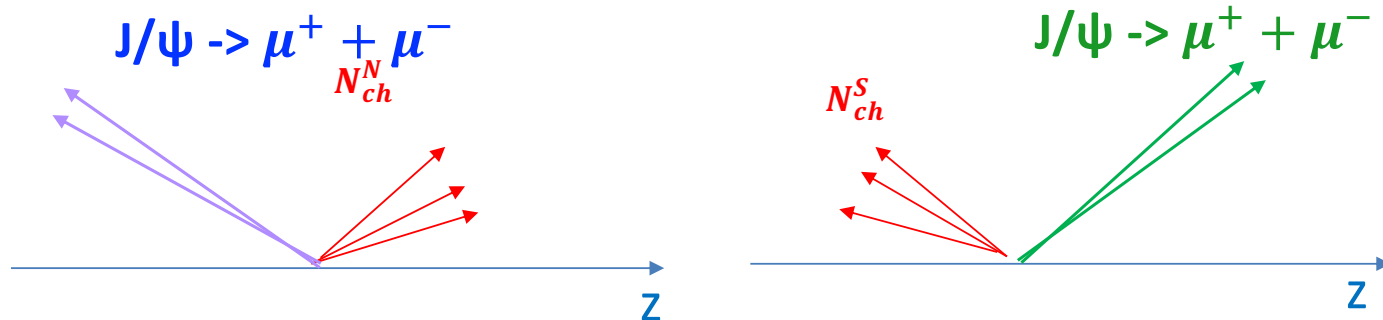


Consistency Check: North vs South Arms (II)

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

Green = J/ψ : $1.2 < y < 2.2$

Blue = J/ψ ($-2.2 < y < -1.2$)

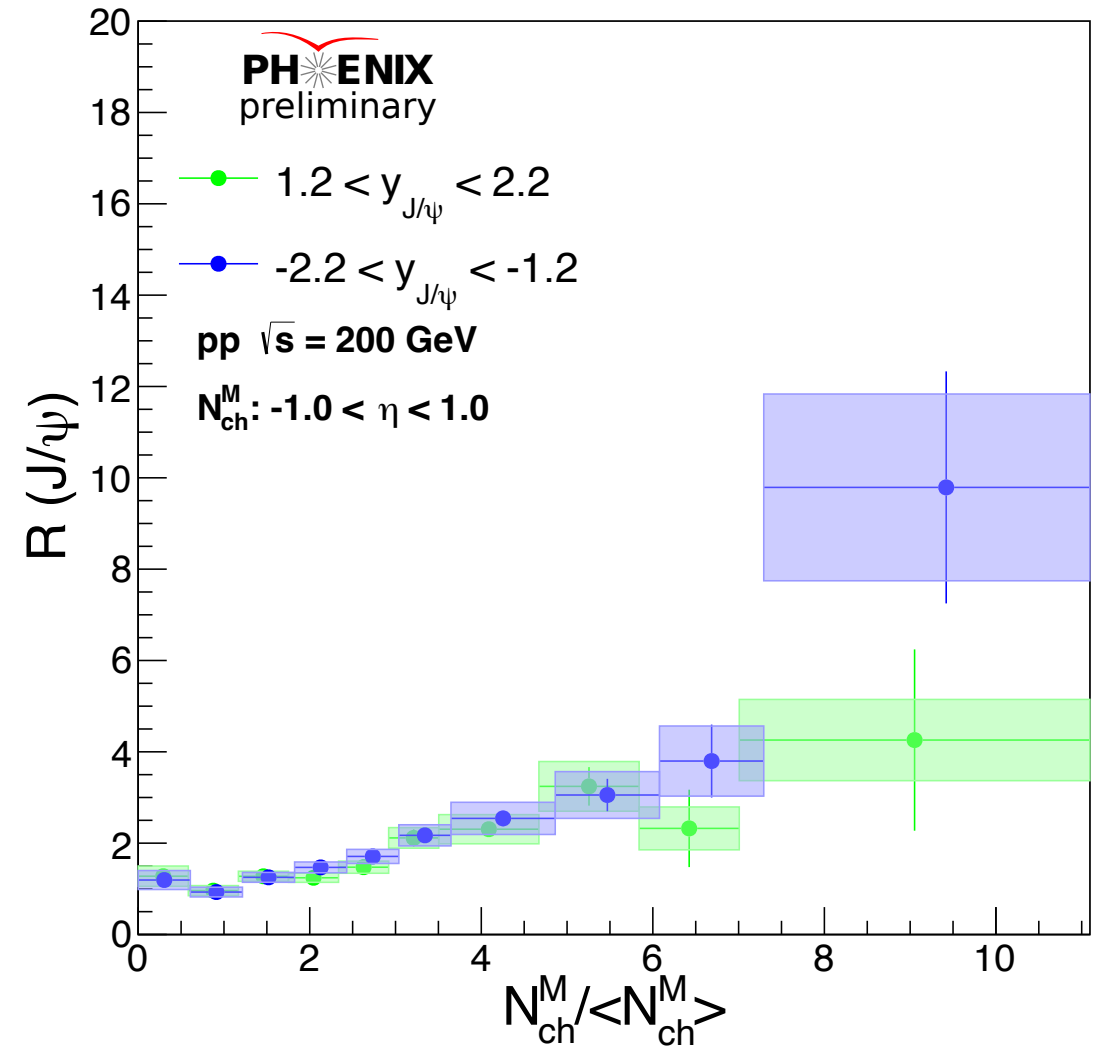
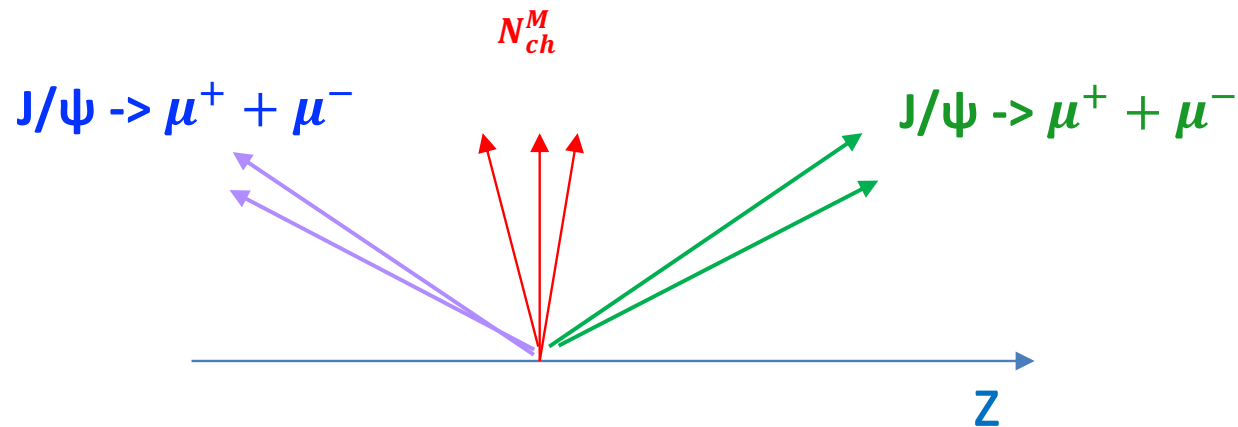


Consistency Check: North vs South Arms

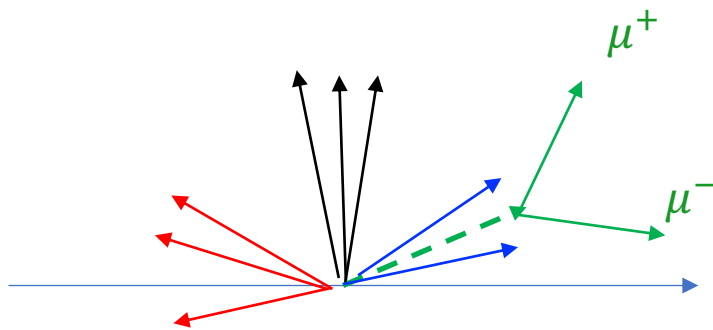
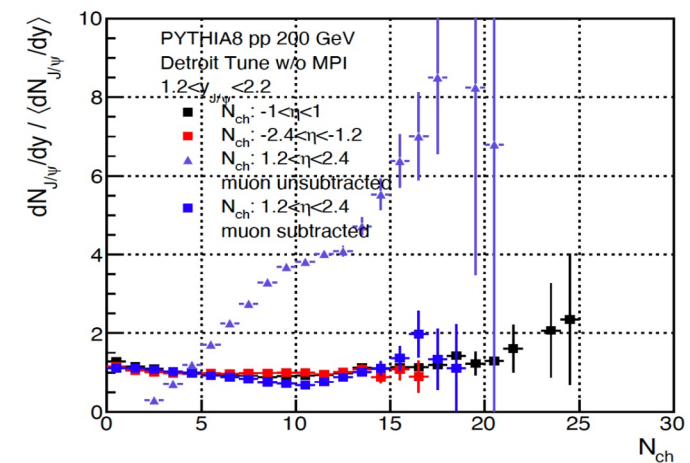
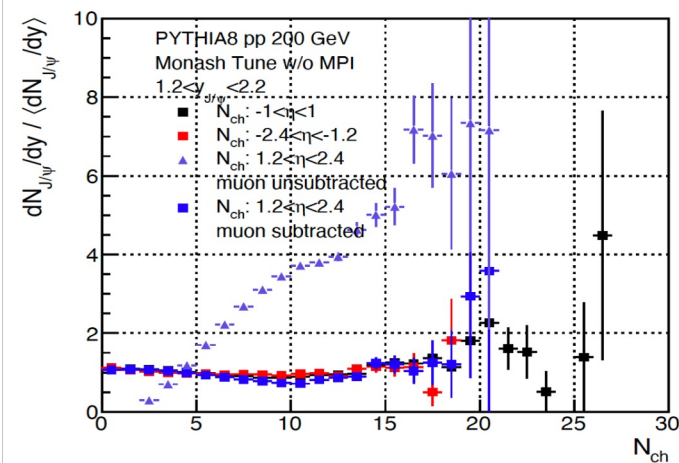
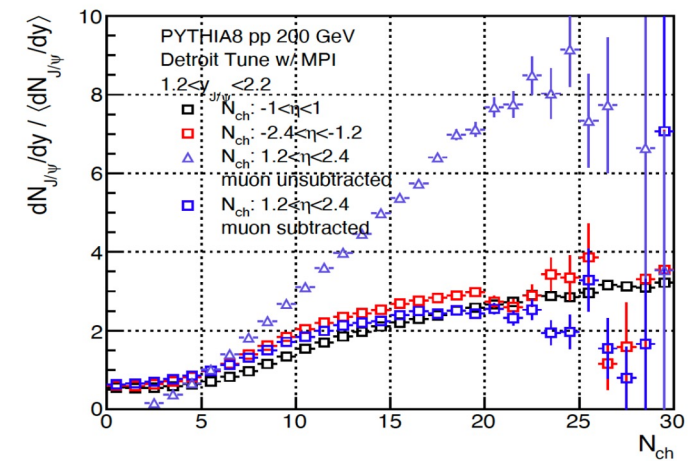
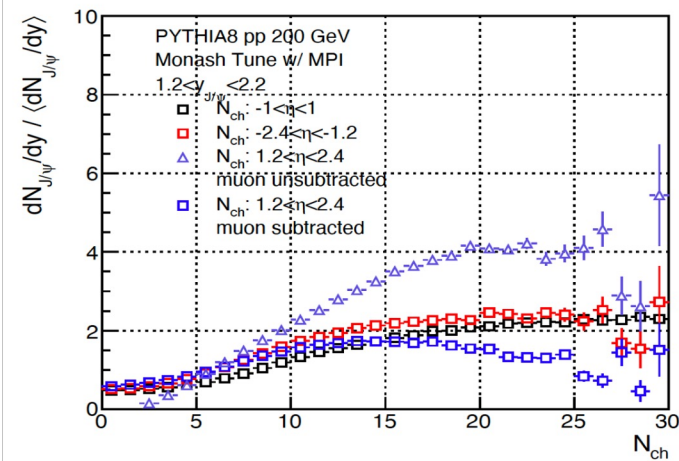
RED = Tracklets $N_{ch}^M (|\eta| < 1.0)$

Green = J/ψ ($1.2 < y < 2.2$)

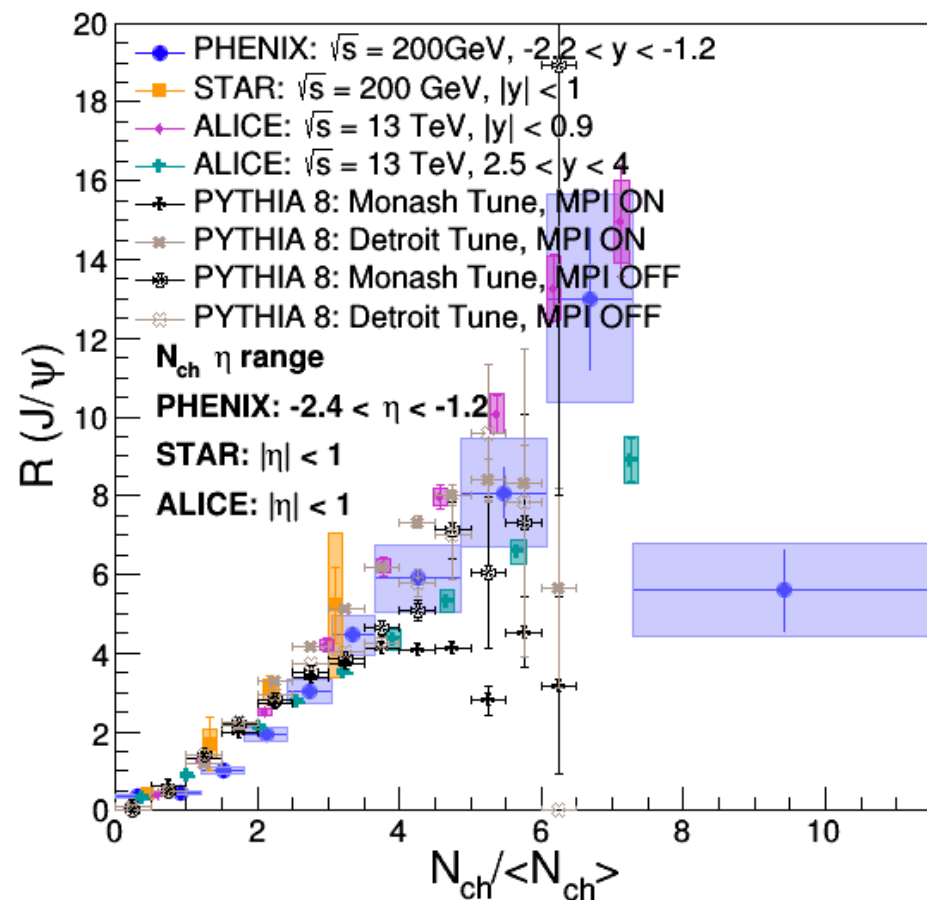
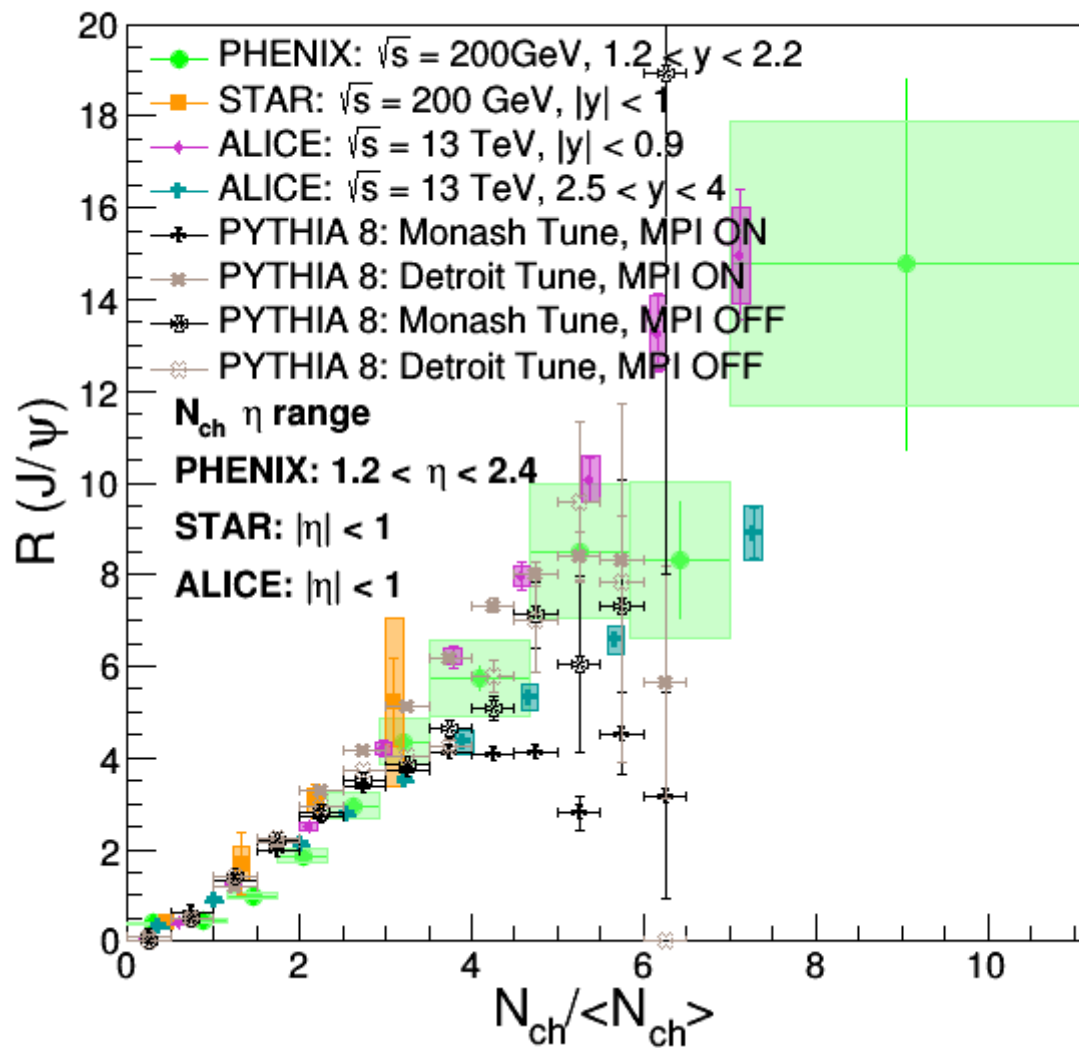
Blue = J/ψ ($-2.2 < y < -1.2$)



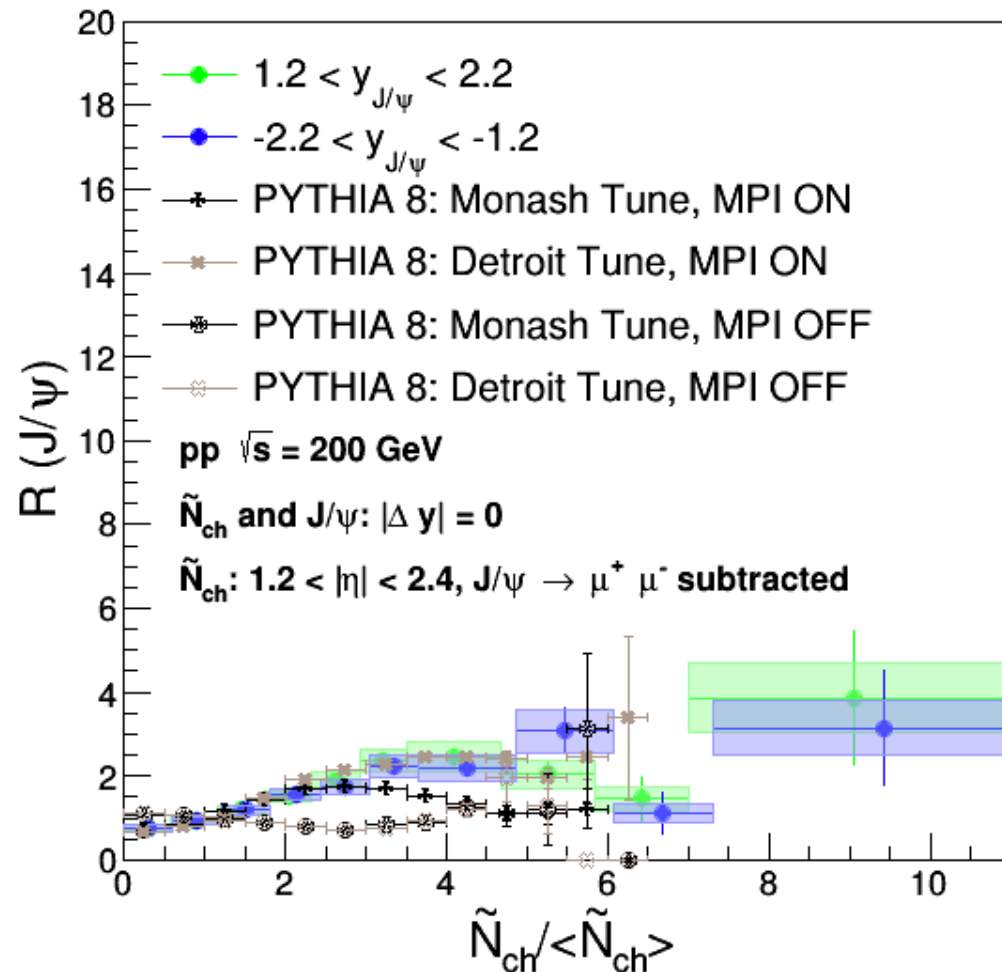
PYTHIA Simulations



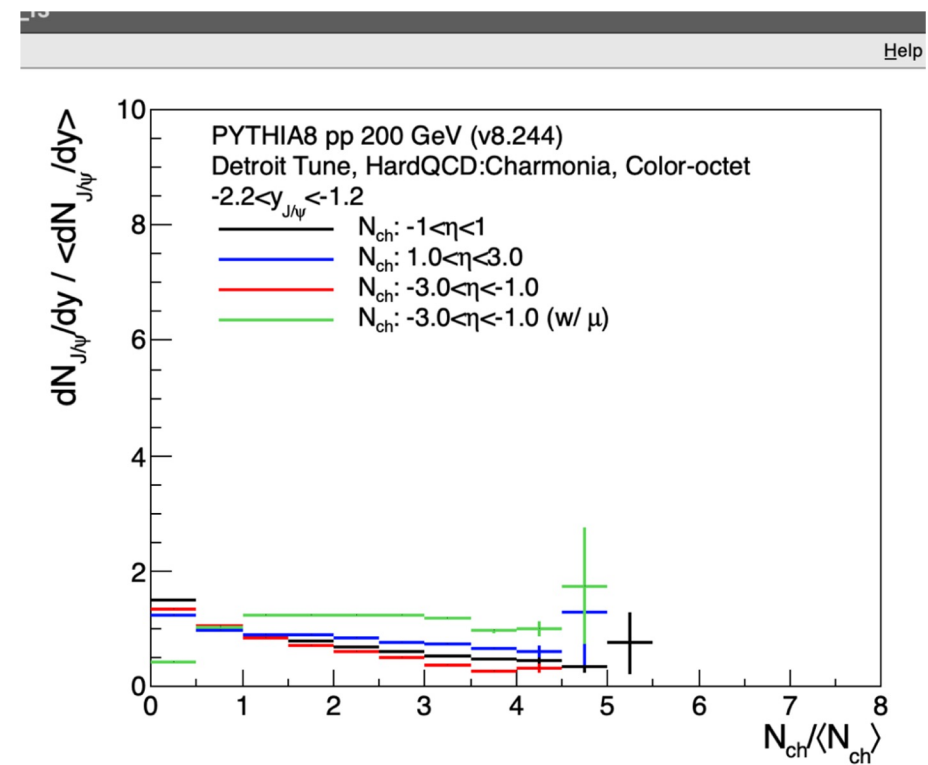
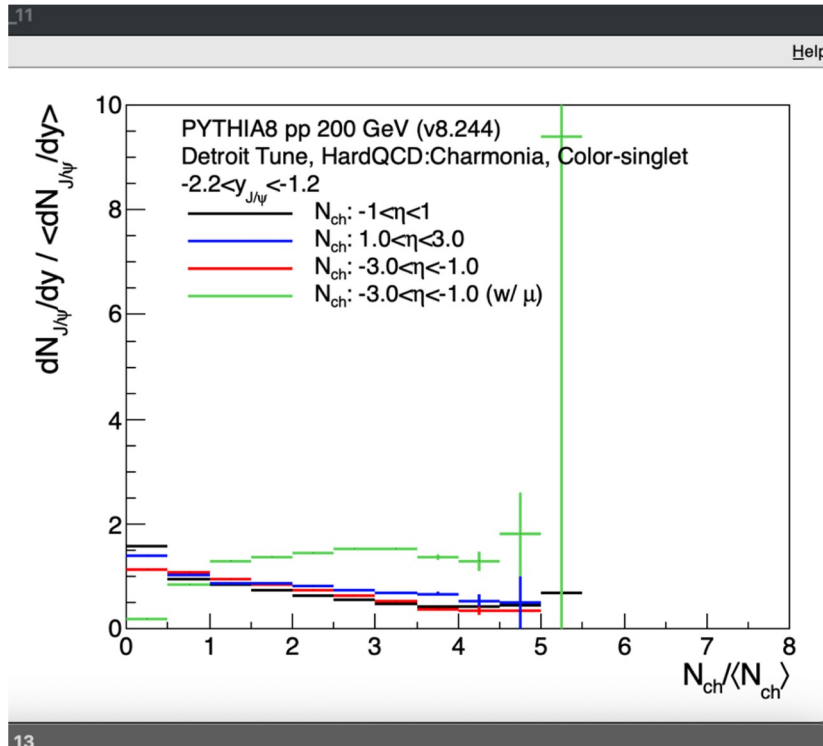
PYTHIA and Data – Same Arms



PYTHIA and Data – Dimuon subtracted

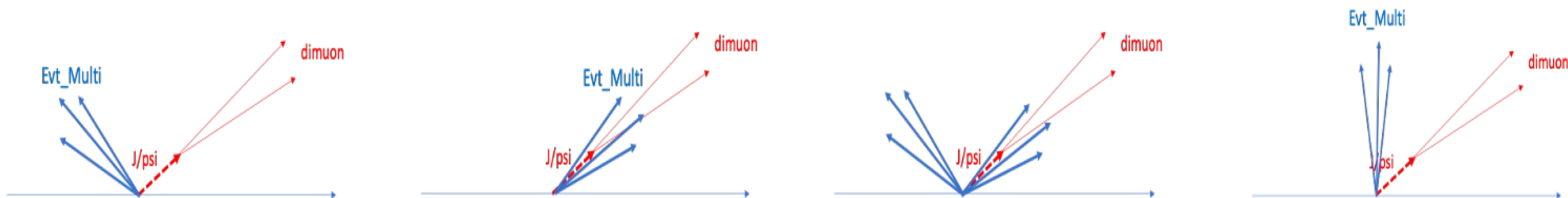


PYTHIA sim with CS and CO, MPI ON

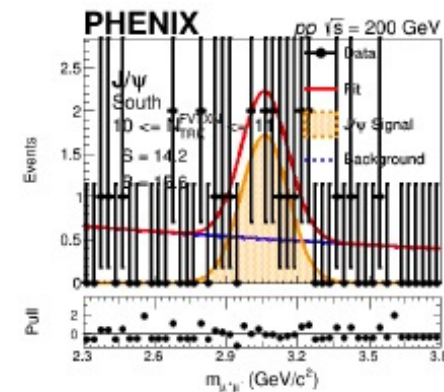
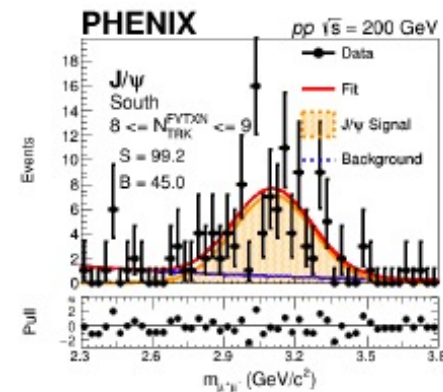
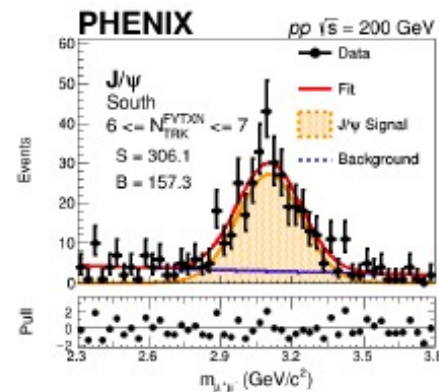
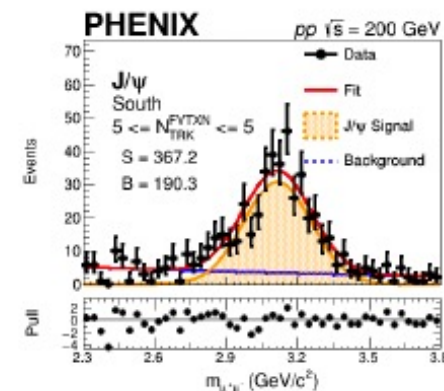
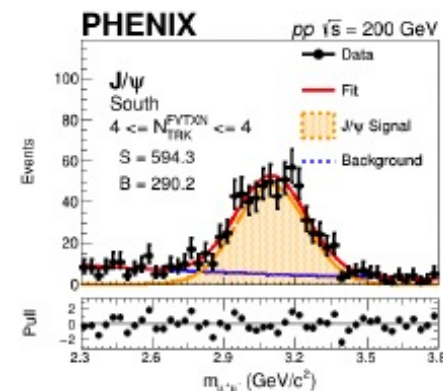
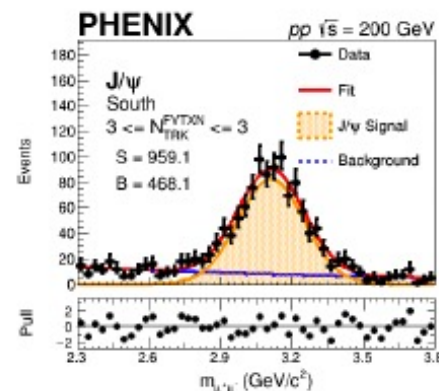
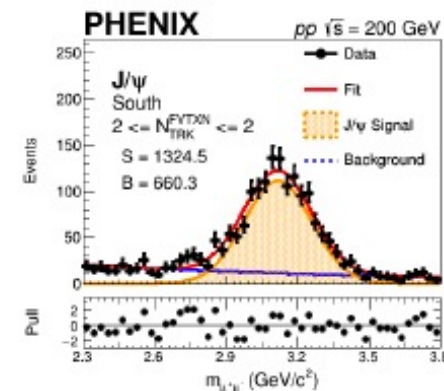
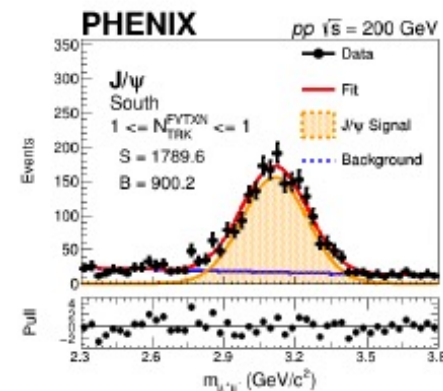
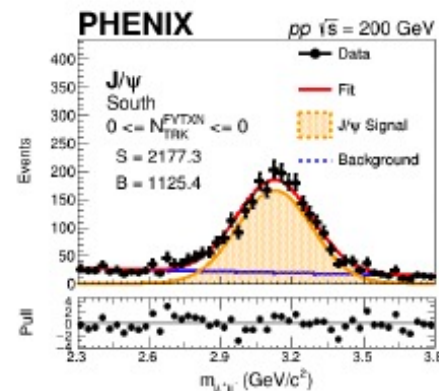


J/Psi Production and QCD Underlying Events

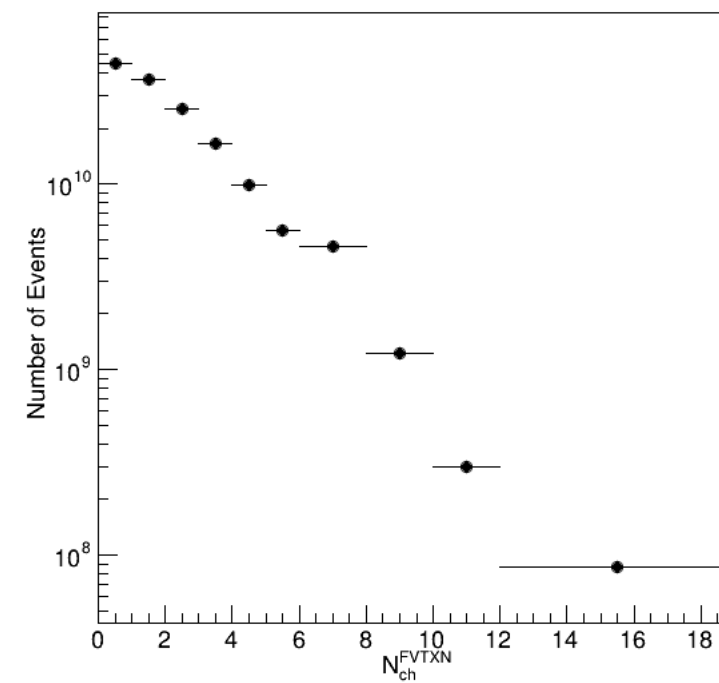
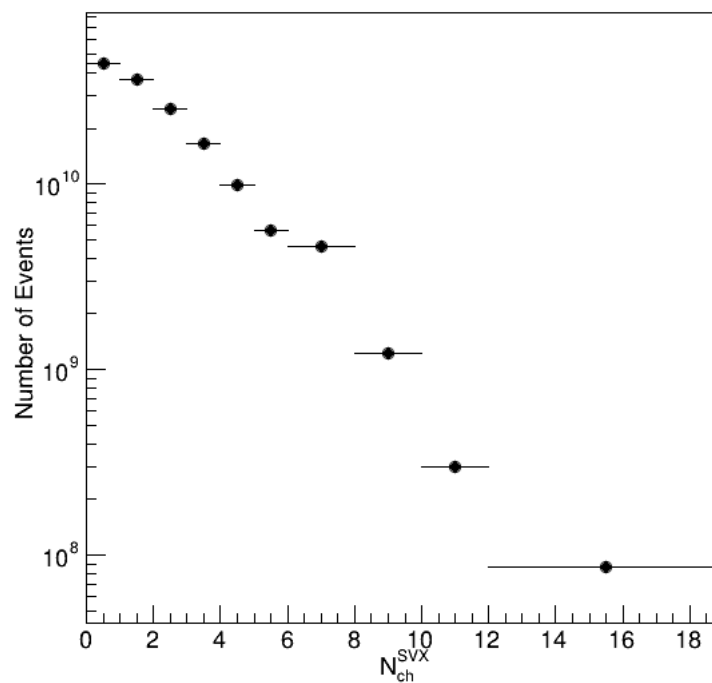
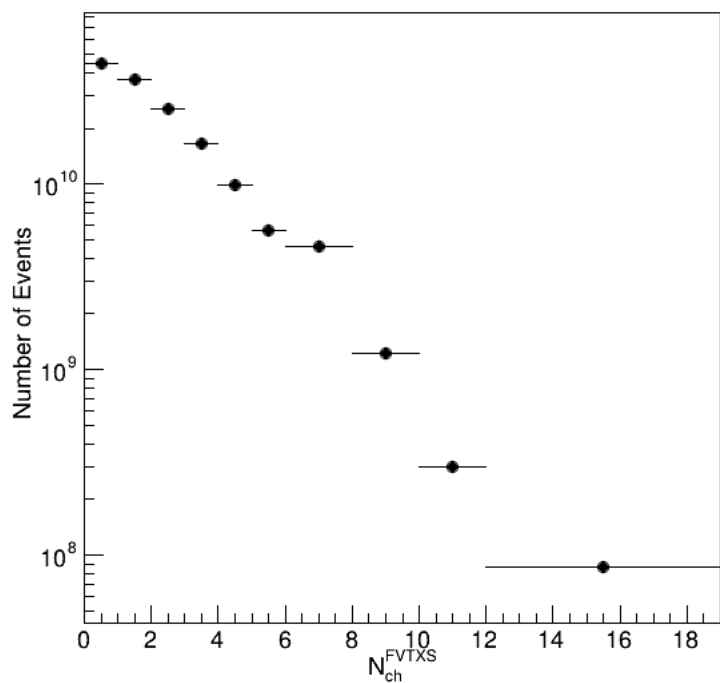
$$R(N_{ch}) = \frac{dN^{J/\psi} / dy}{\langle dN^{J/\psi} / dy \rangle}$$



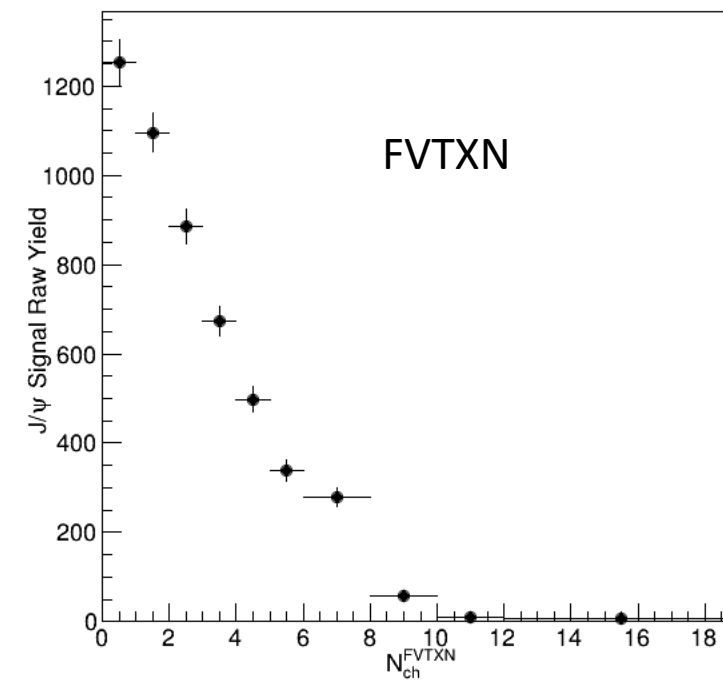
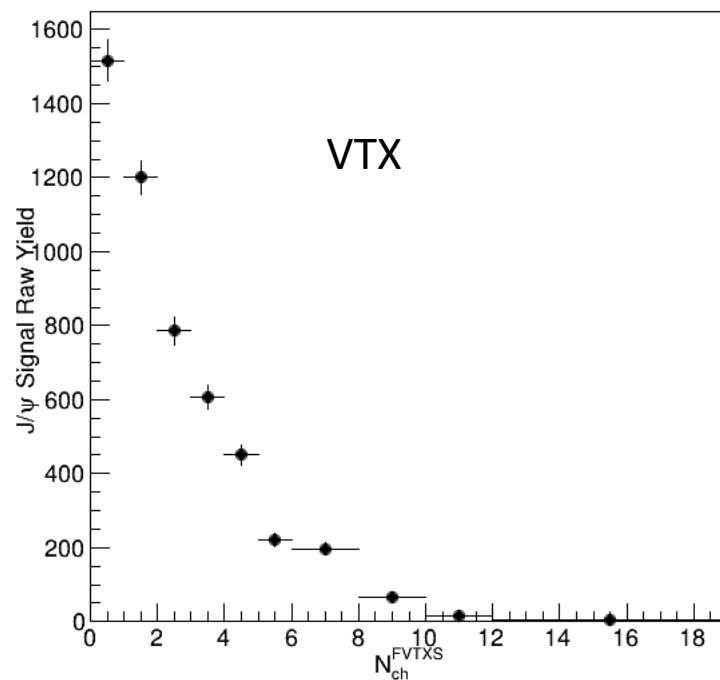
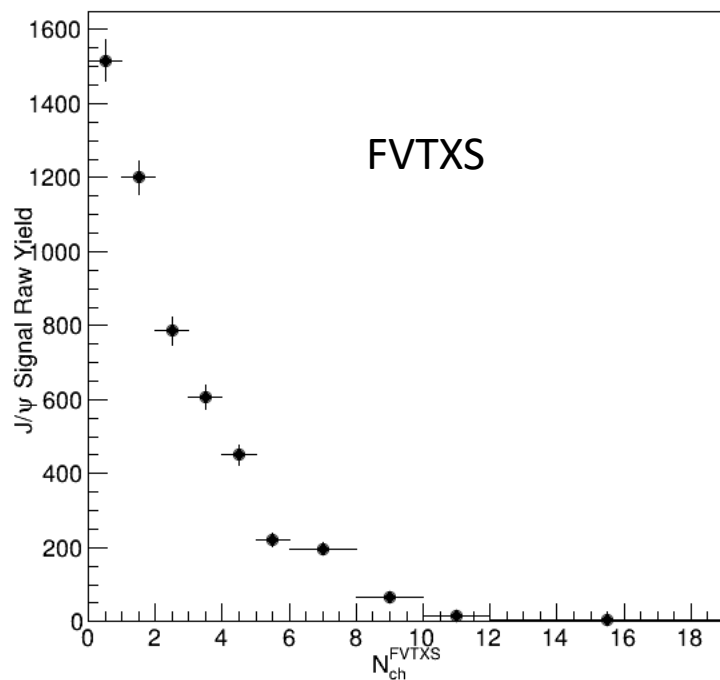
J/ψ Dimuon Mass Fits



MB Events' FVTX and SVX Tracklet Raw Distributions



Raw J/ψ Counts vs FVTX and SVX

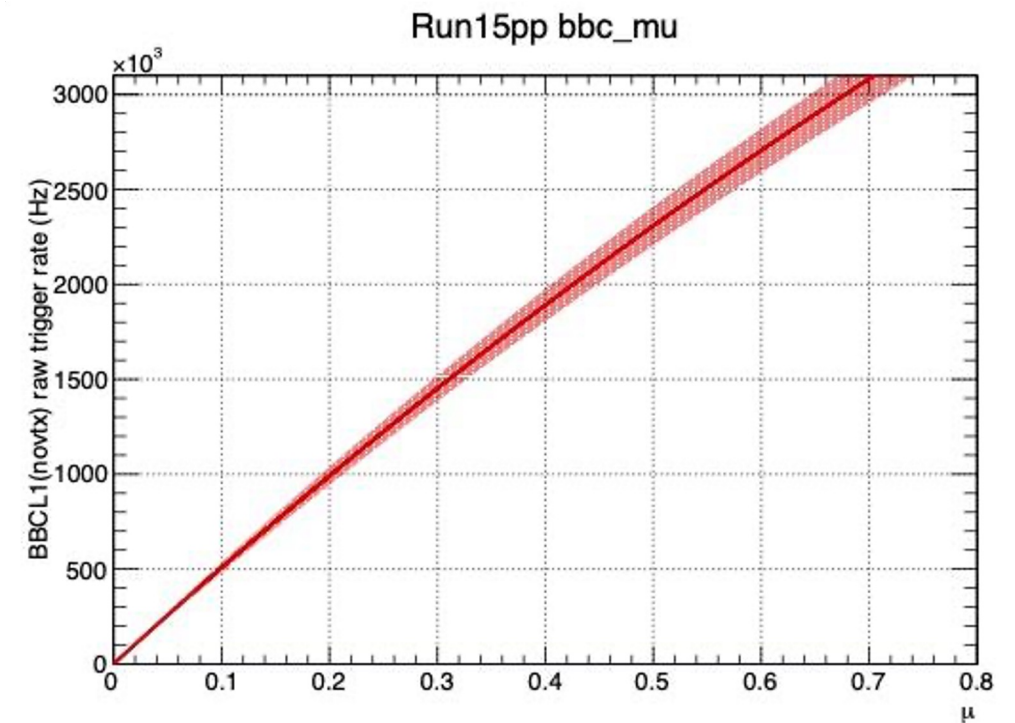


Multiple Collision Probability Table

BBCL1_Eff = 55 +/- 5 % for run15 pp MB; 79 +/- 2 % for hard scattering

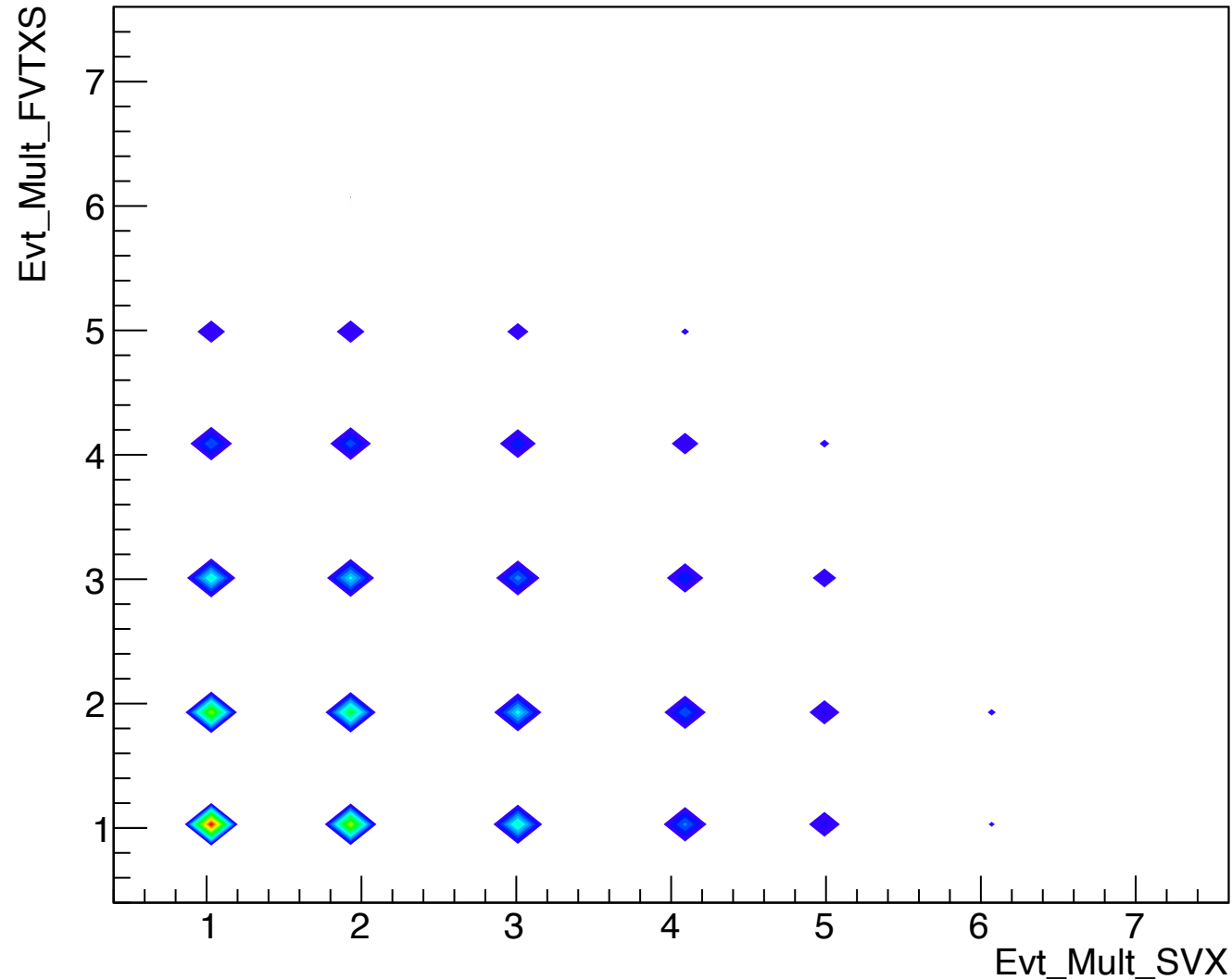
BBC Rate kHz	Mean_Mu	Prob. to have 2+ collisions
250	0.05	0.12%
500	0.1	0.47% <pAu>
1,000	0.2	1.8% <pp>
1,500	0.31	3.9%
2,000	0.43	6.9%
2,500	0.55	10%

```
root [6] 1- ROOT::Math::poisson_cdf(1,0.2)
(double) 0.017523096
```

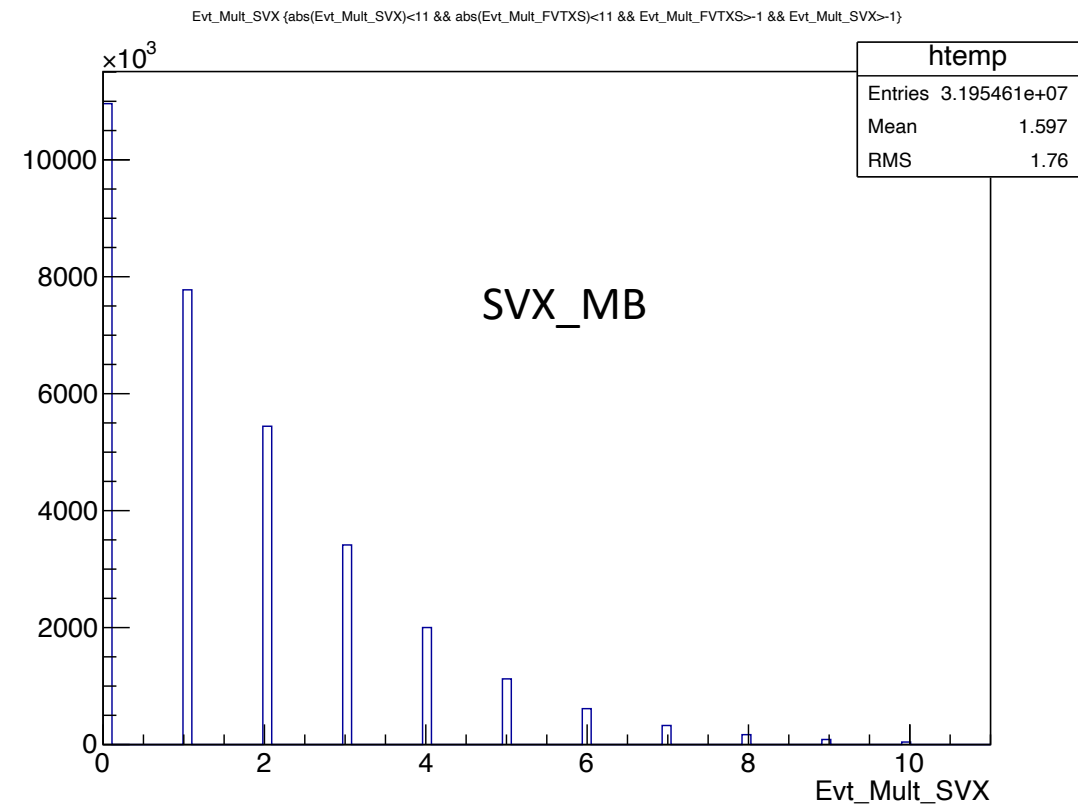
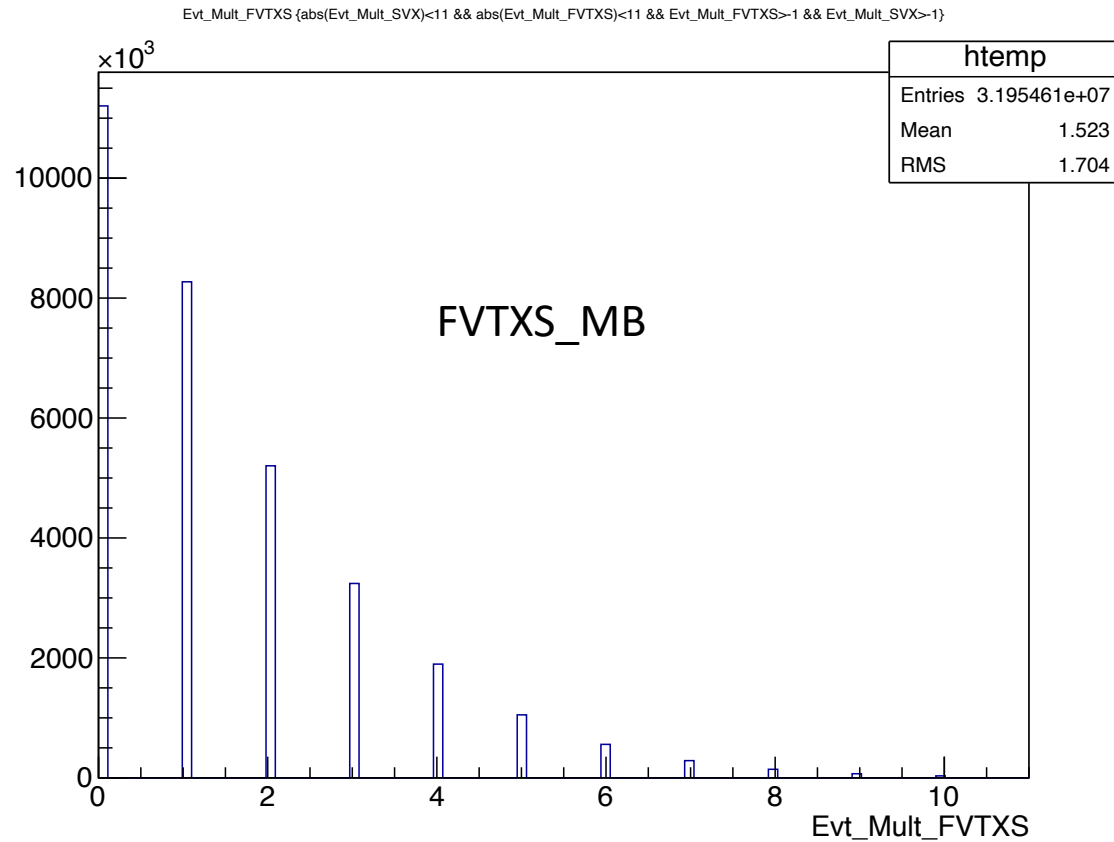


FVTX Track Multiplicity Correlations

Evt_Mult_FVTXS:Evt_Mult_SVX {abs(Evt_Mult_SVX)<8 && abs(Evt_Mult_FVTXS)<8 && Evt_Mult_FVTXS>0 && Evt_Mult_SVX>0}

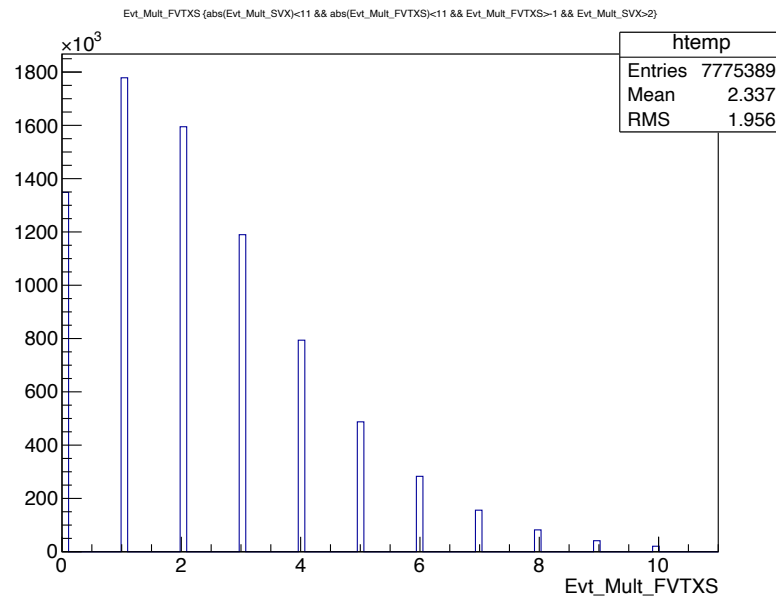


FVTX Track Multiplicity Correlations: MB

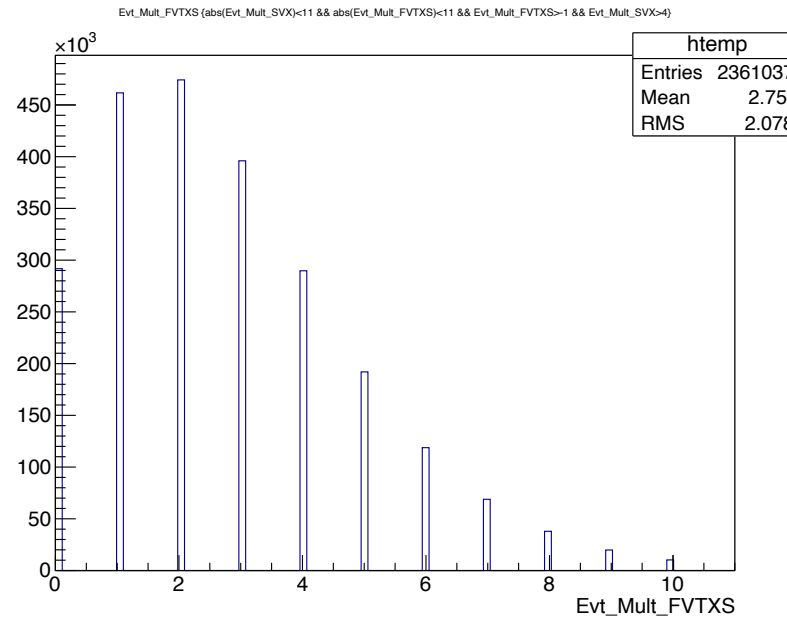


FVTX Track Multiplicity Correlations: MB

FVTXS_MB, SVX>2



FVTXS_MB, SVX>4



FVTXS_MB, SVX>6

