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

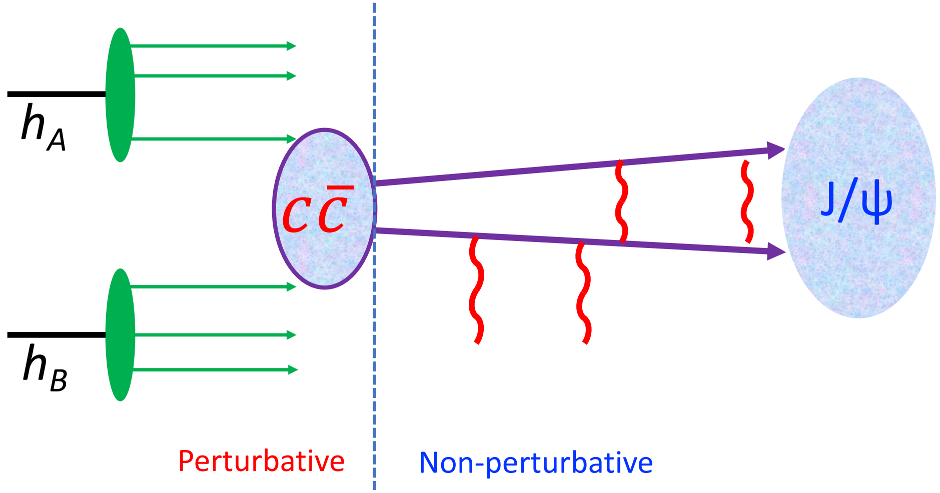
J/ψ Production in High Energy p+p/A Collisions

PHENIX

How J/ψ are produced?

Perturbative + Non-perturbative

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

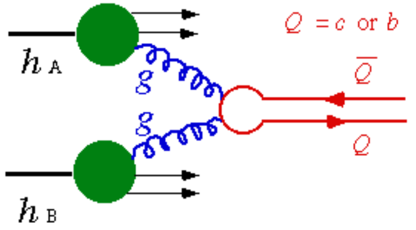


- "$c\bar{c}$" pair from hard scattering
  - pQCD:
    - Single hard scattering
    - Multiple semi-hard parton interactions (MPI)
  - NRQCD models:
    - Color Singlet (CS)
    - Color Octet (CO)
  - Jet fragmentation

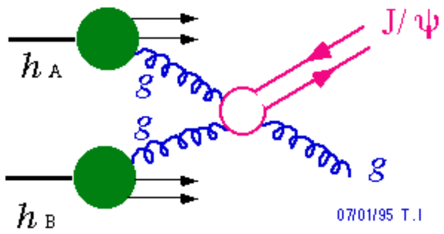
"IS/MPI"

Gluon Fusion

CS:



CO:

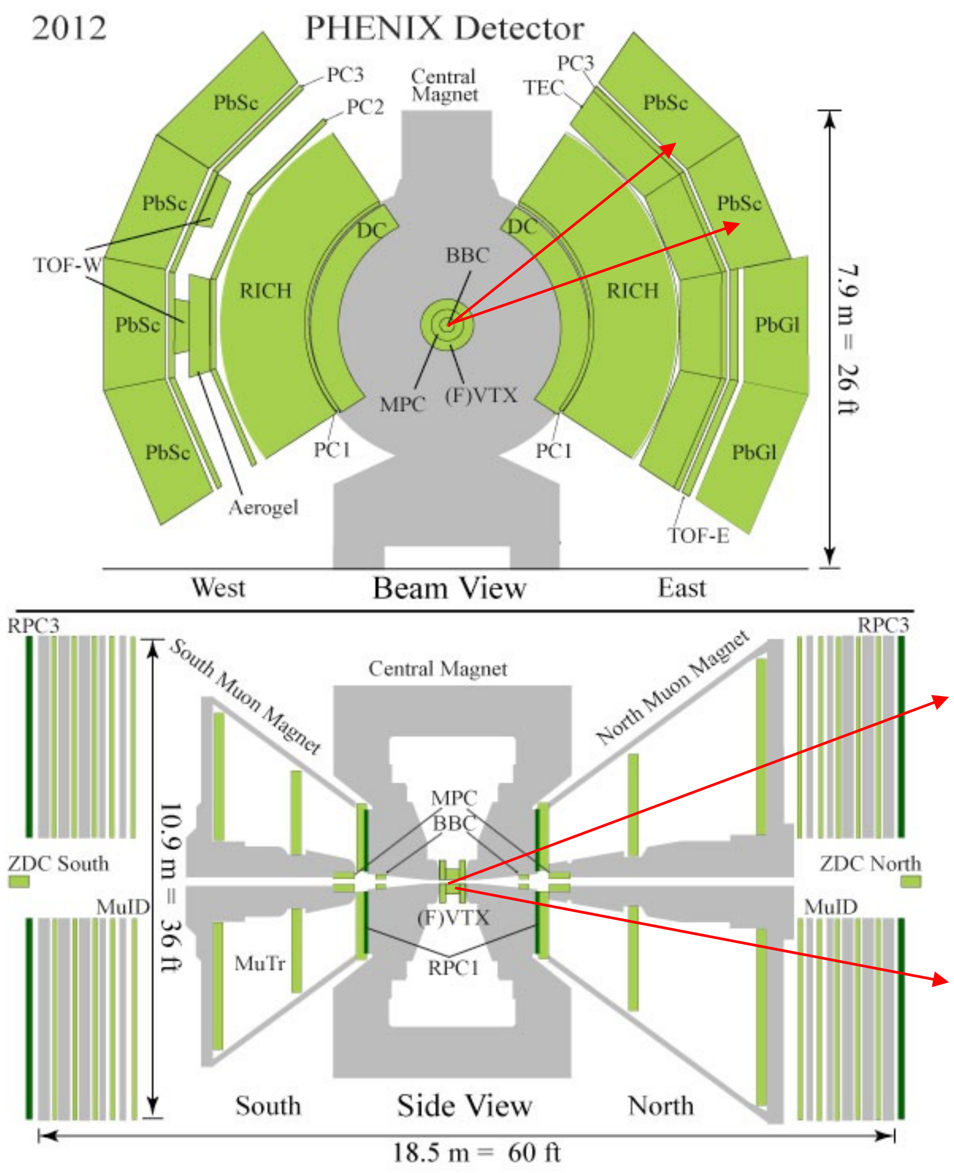


Gluon fusion dominates at RHIC energy

- "$c\bar{c}$" hadronization to J/ψ
  - Color neutralization
  - Interactions with QCD medium

"FSI"

PHENIX Detector at RHIC (Last Run 2016)



Central Arms | η | < 0.35
- Identified charged hadrons
- Neutral Pions
- Direct Photon
- J/ψ
- Heavy Flavor

Muon Arms 1.2 < | η | < 2.4
- J/ψ
- Unidentified charged hadrons
- Heavy Flavor

BBC/MPC 3.1 < | η | < 3.9
- Neutral Pion's
- Eta's

ZDC |η| ~ 5.9
- Neutrons

Event Multiplicity Measurements:

SVX: Silicon Vertex Det.
| η | < 1

FVTX: Forward Silicon Vertex Det.
1.2< | η | < 2.4

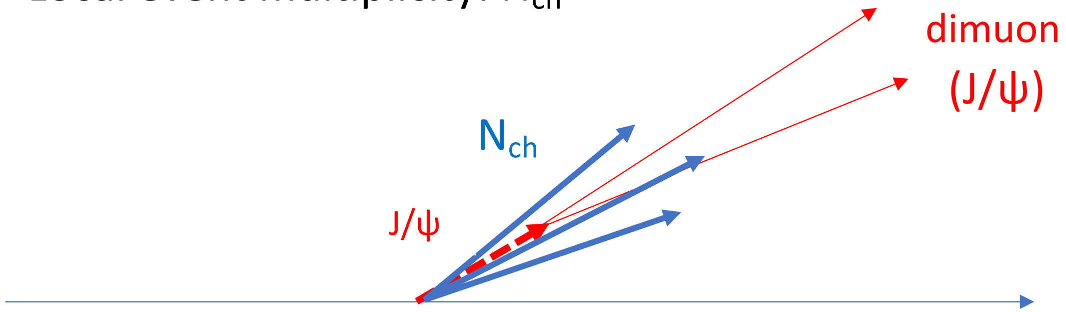
J/ψ -> $\mu^+ + \mu^-$

BBC: MB Trigger
3.1< | η | < 3.9

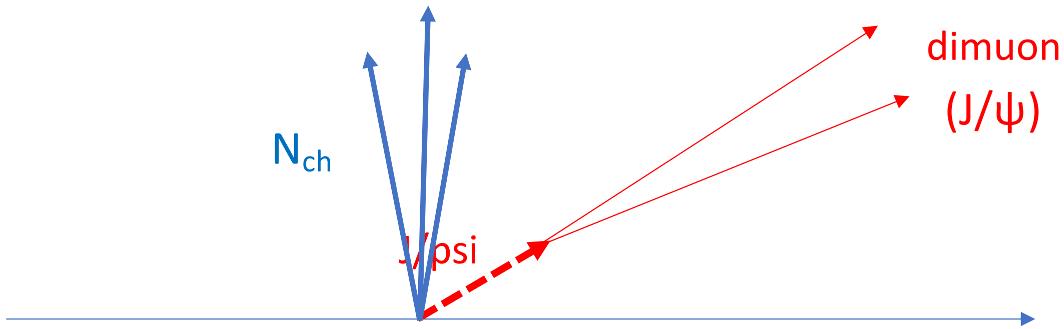
J/ψ Yields vs Event Multiplicity - Topology

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

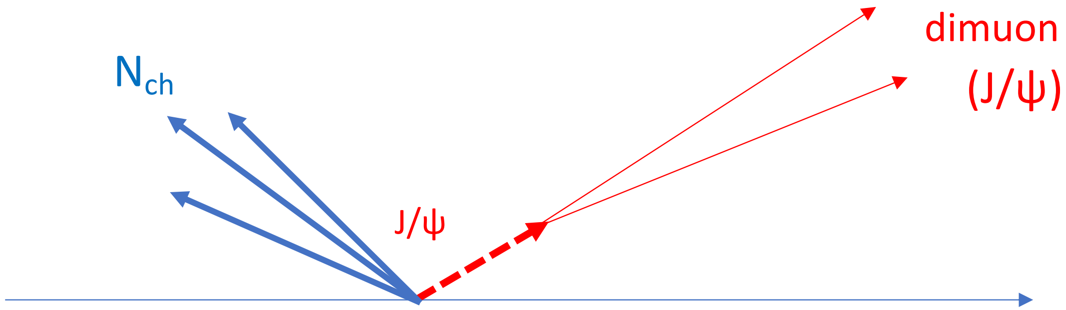
$J/\psi \to \mu^{+} + \mu^{-}$



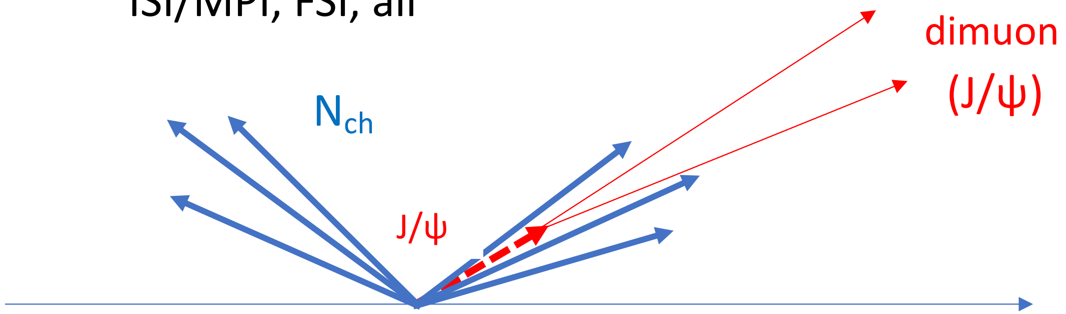
MPI, local energy density?



MPI, local energy density?

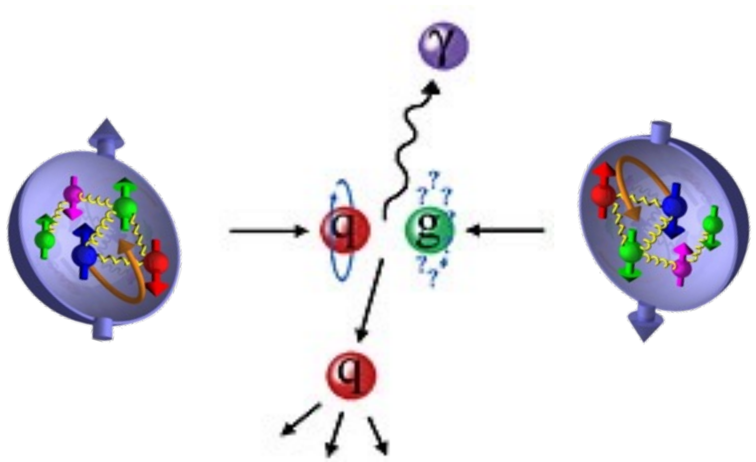


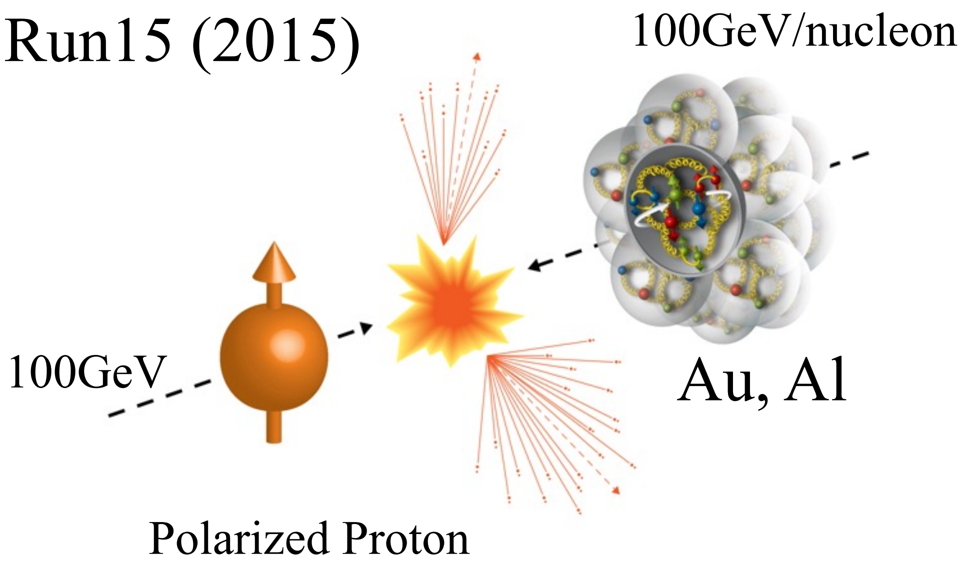
ISI/MPI, FSI, all



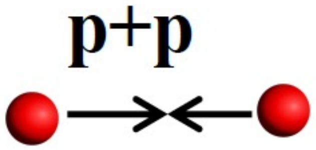
PHENIX Experiment in 2015 Run, 200GeV pp and pA

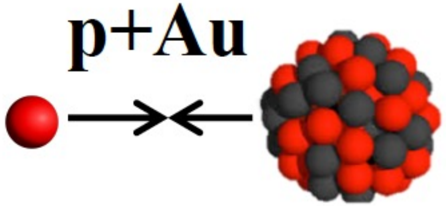
- Transversely polarized p+p, p+Au and p+Al collisions at RHIC
  - p+p: $L_{NN} \sim 200\ pb^{-1}$
  - p+Au: $L_{NN} \sim 130\ pb^{-1}$

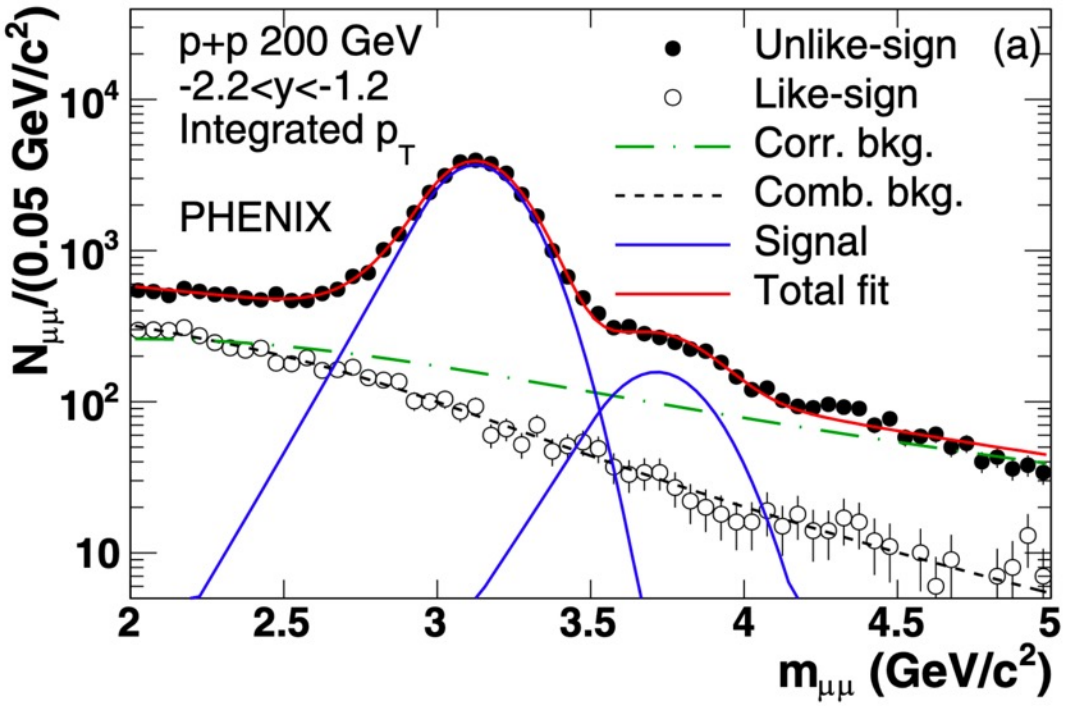


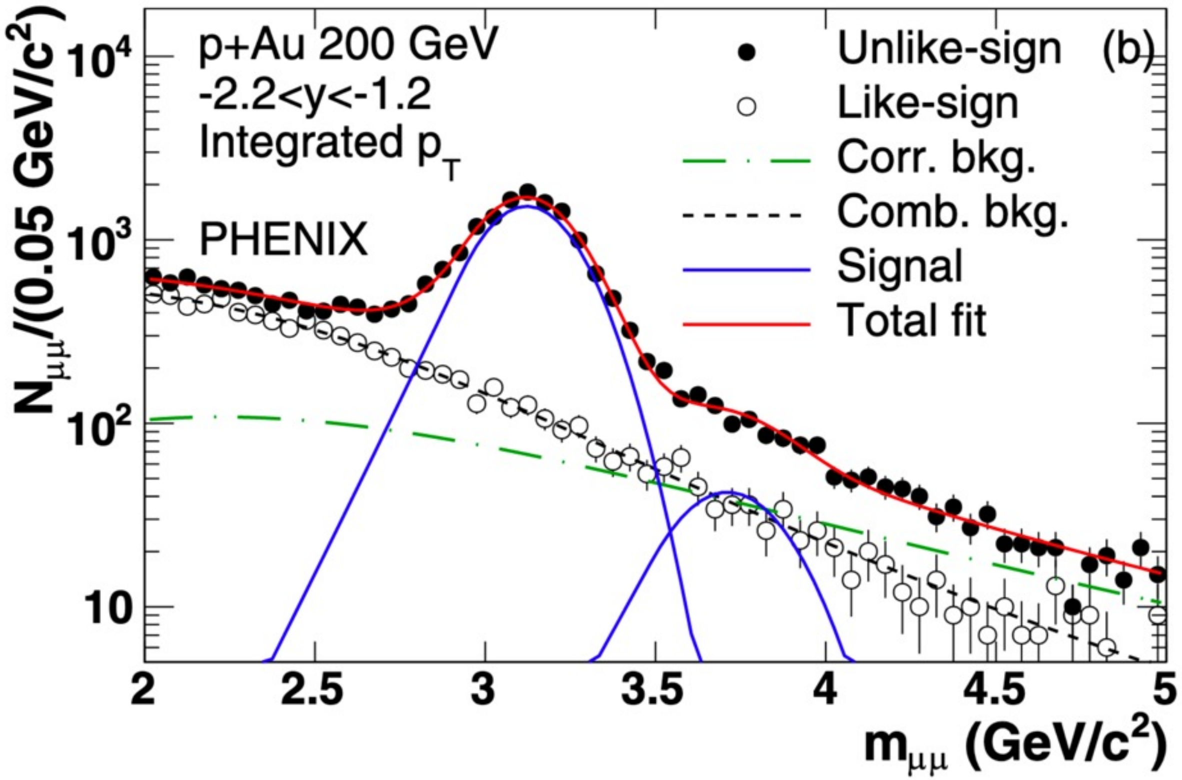


J/ψ Production in pp and pAu Collisions at PHENIX







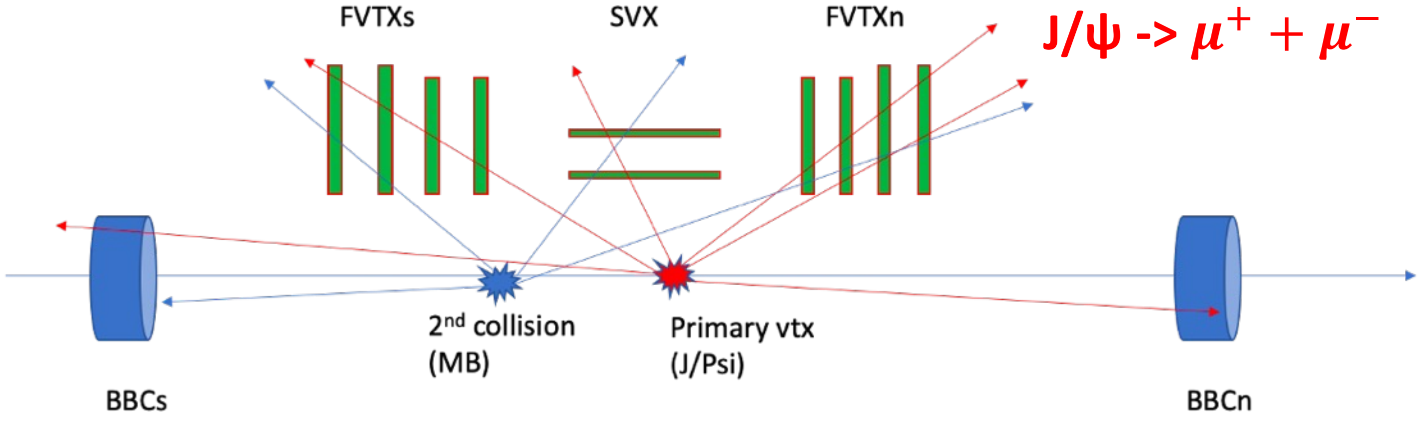


Our Measurements at PHENIX

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

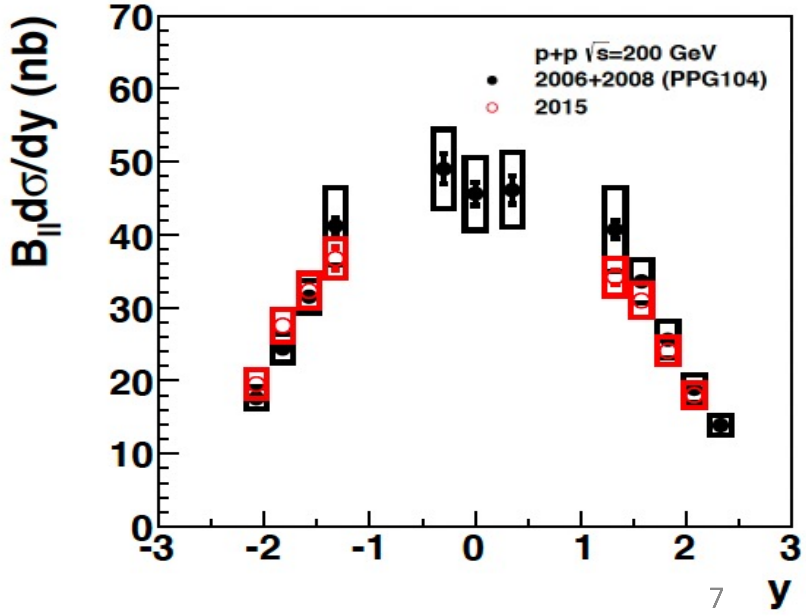
$$R(N_{ch}) = \frac{dN^{J/\psi}/dy}{\langle dN^{J/\psi}/dy \rangle}$$

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



Event Multiplicity Measurements: FVTXs, SVX, FVTXn

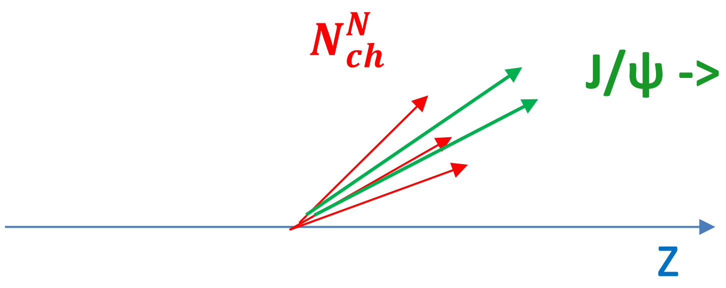
PHENIX, PRC 102, 014902 (2020)

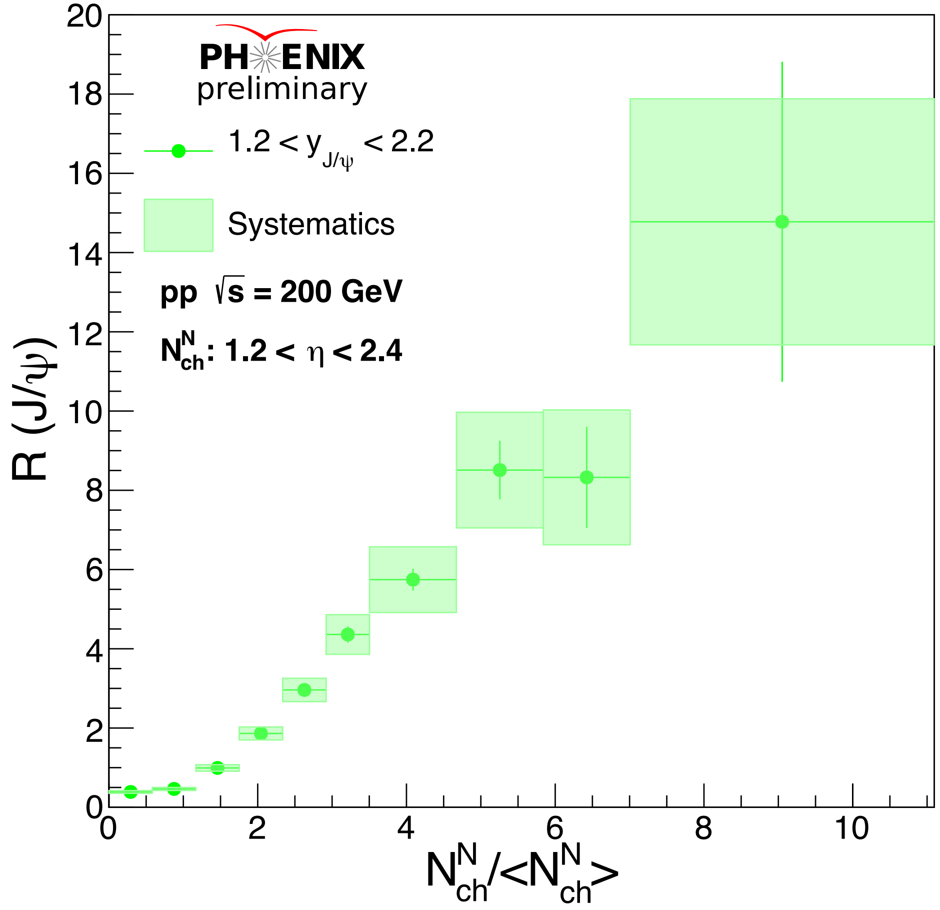


J/ψ Production: same kinematic region

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

Green = J/ψ (1.2 < y < 2.2)



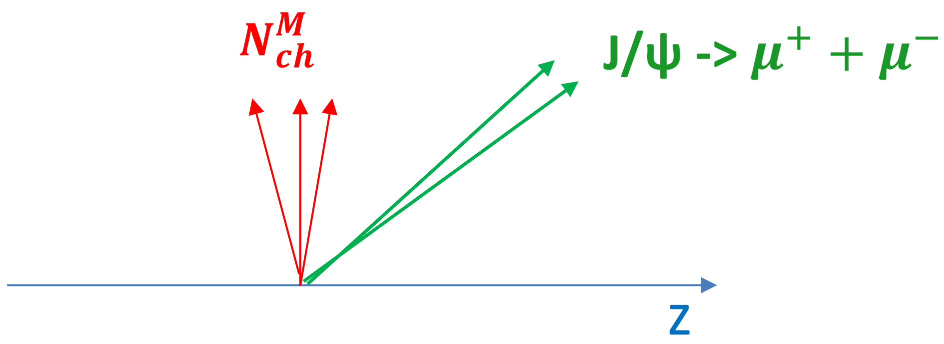


Multiplicity: MPI, FSI contributions to the forward **J/ψ** production?

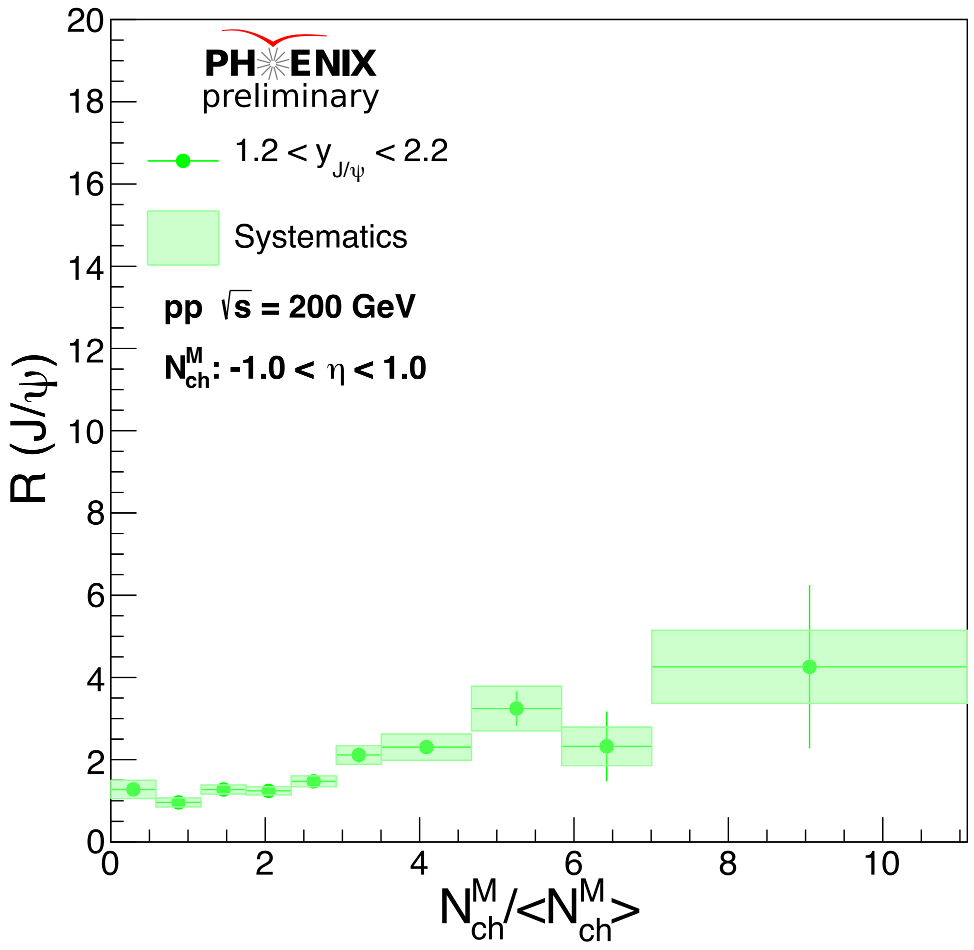
J/ψ Production vs Multiplicity at Midrapidity

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

Green = J/ψ (1.2 < y < 2.2)



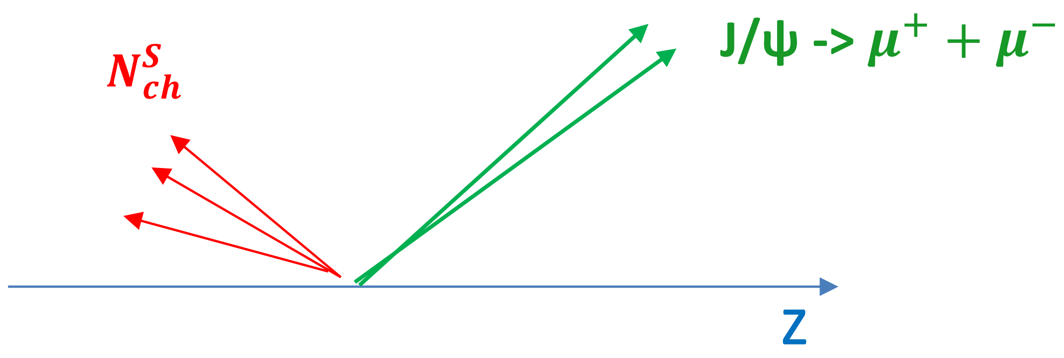
expect less co-mover type FSI at high multiplicity



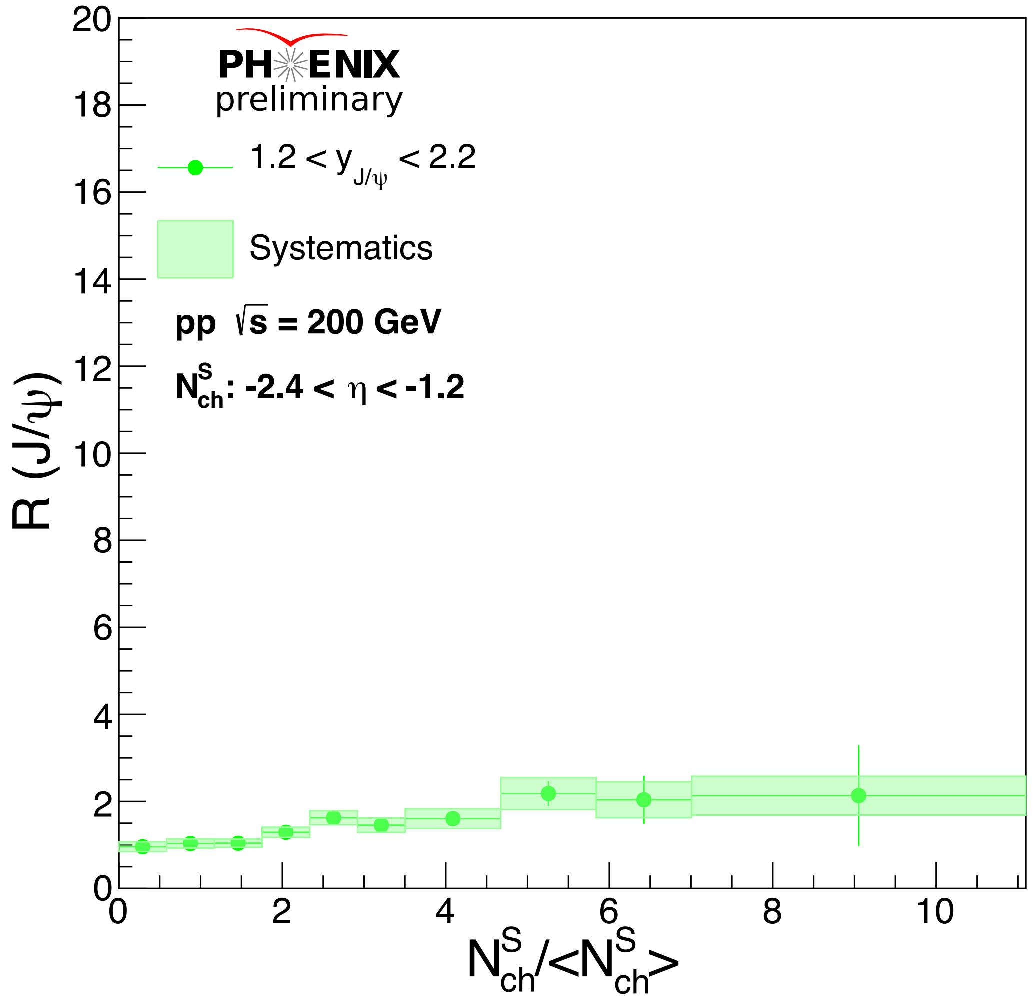
J/ψ Production: far-off kinematic region

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

Green = J/ψ (1.2 < y < 2.2)



Expect much less co-mover type FSI at high multiplicity

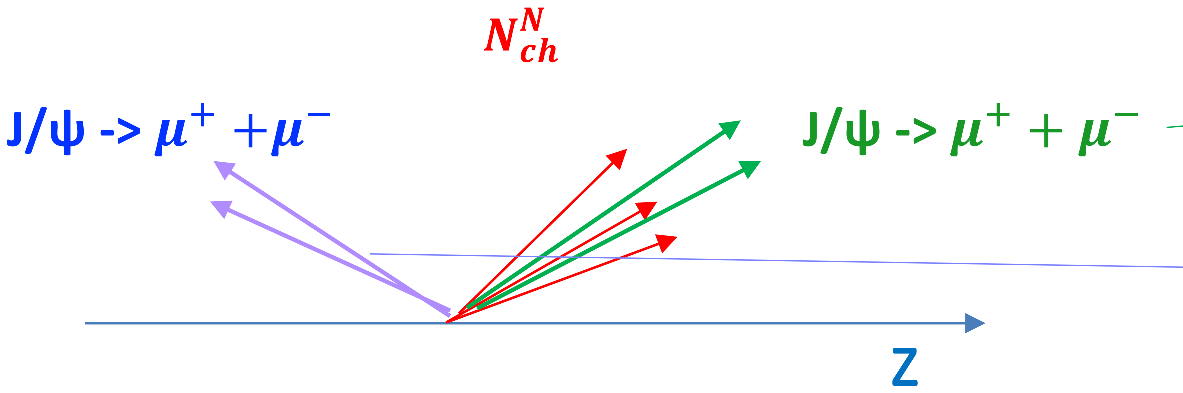


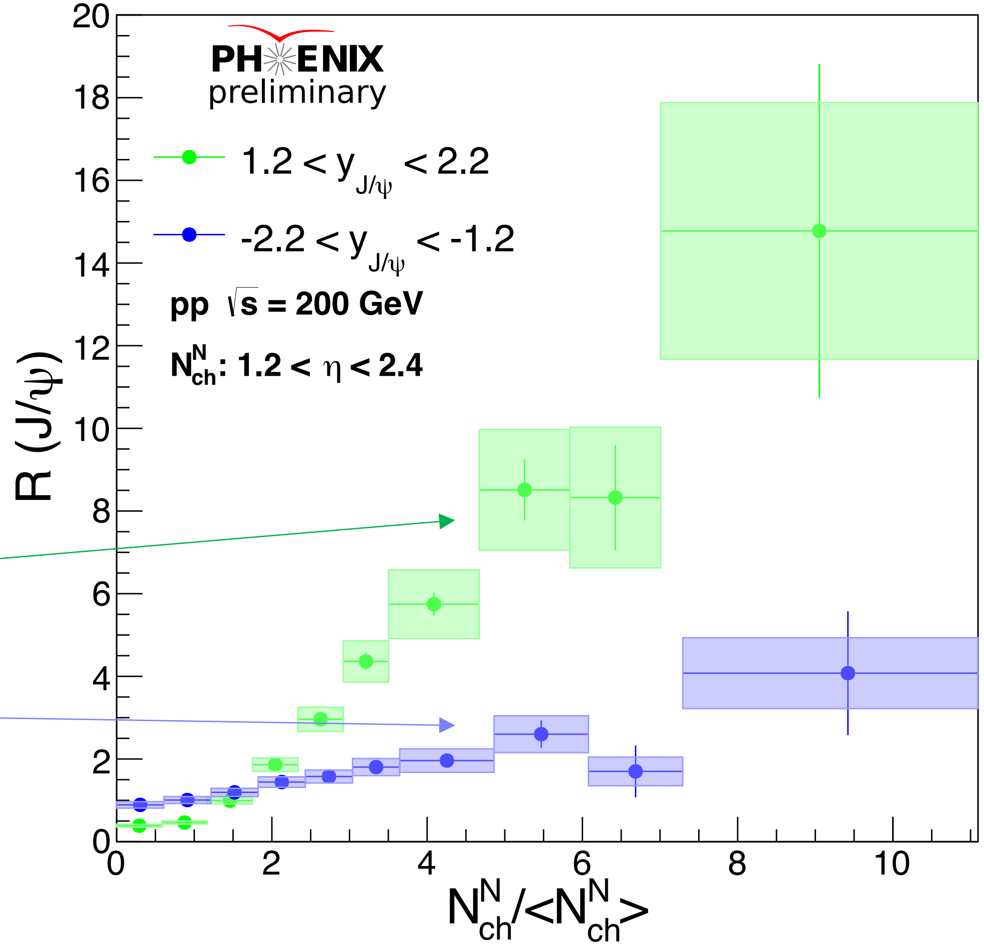
J/ψ Yields vs Event Multiplicity

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

Green = J/ψ ($1.2 < y < 2.2$)

Blue = J/ψ ($-2.2 < y < -1.2$)



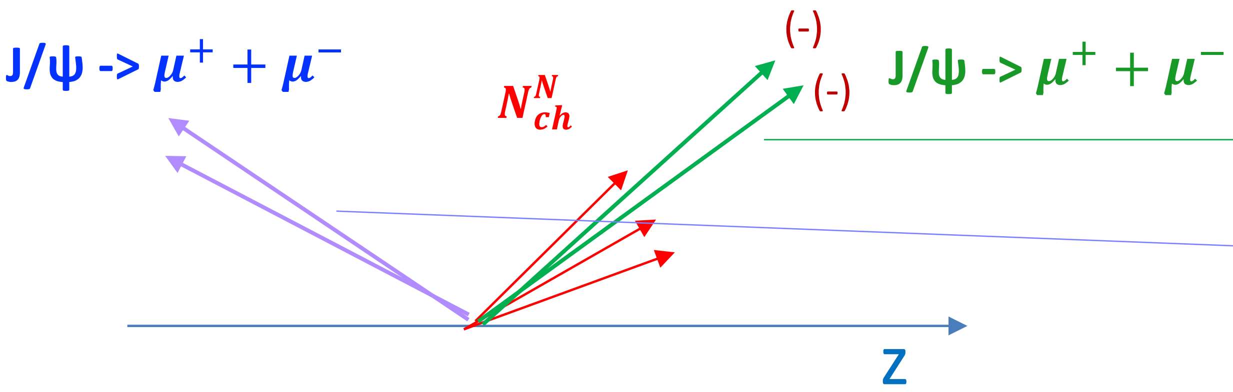


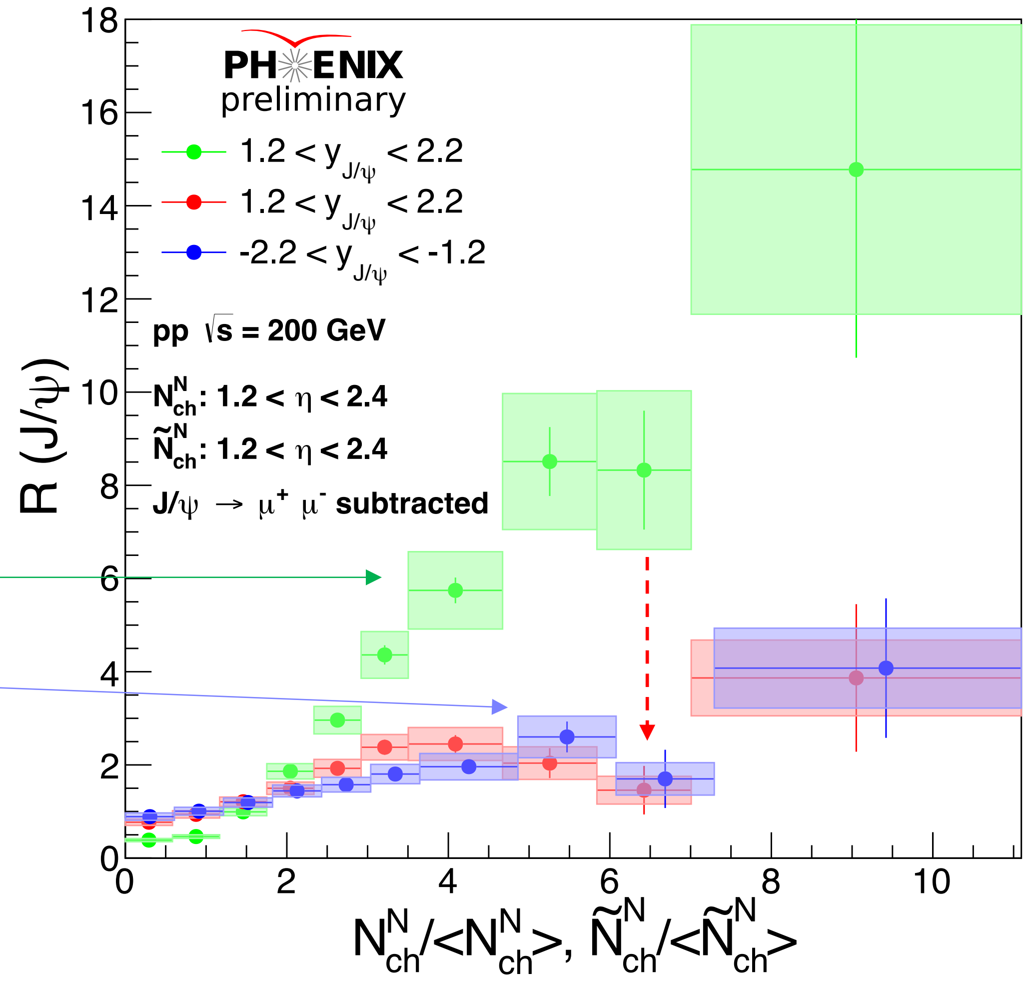
J/ψ Yields vs Event Multiplicity: All Together

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)



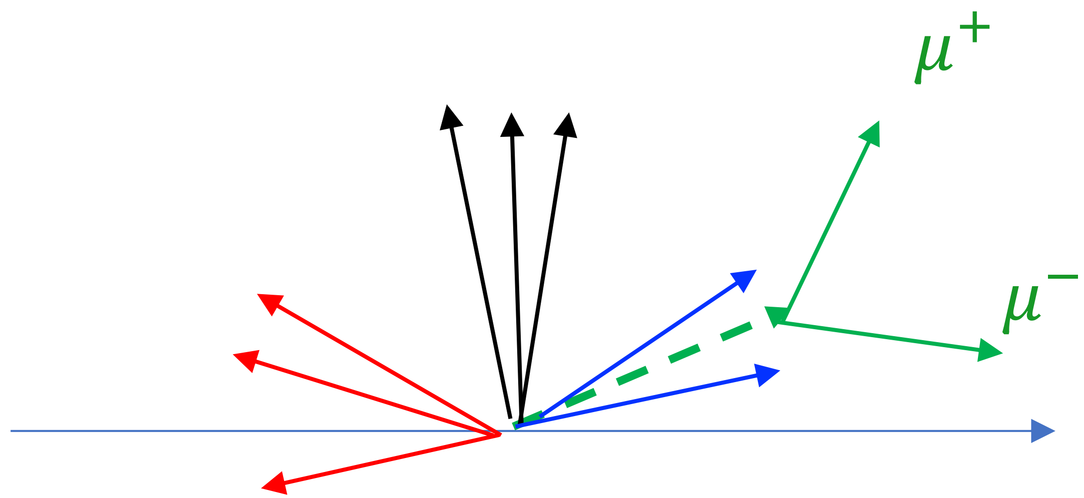


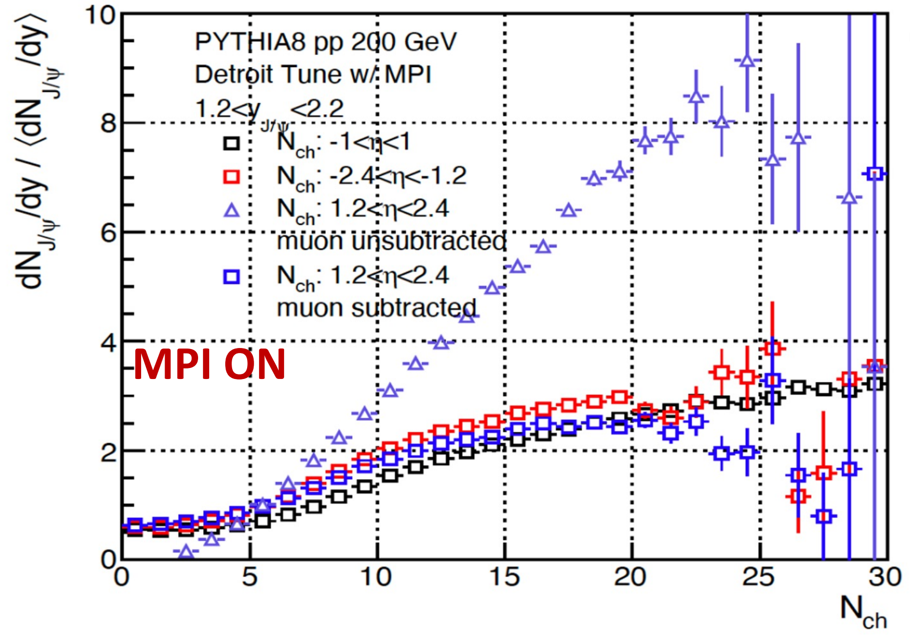
- Less MPI contribution to the forward **J/ψ** production?

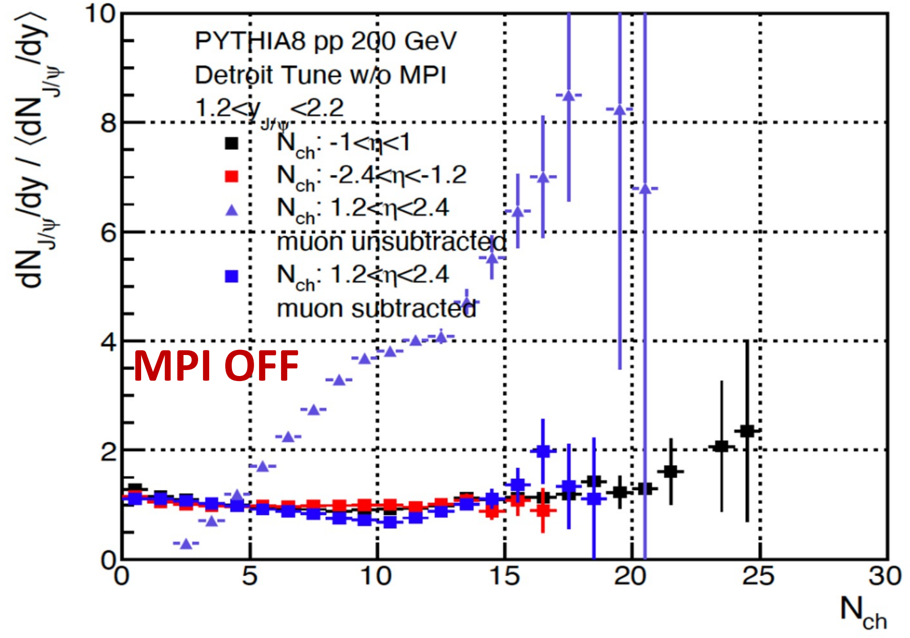
PYTHIA 8 p+p Simulations

- Detroit Tune (RHIC) pp 200GeV
  - MPI ON/OFF
  - PHENIX acceptance

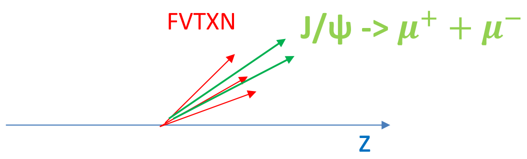
$J/\psi \rightarrow \mu^+ + \mu^-$



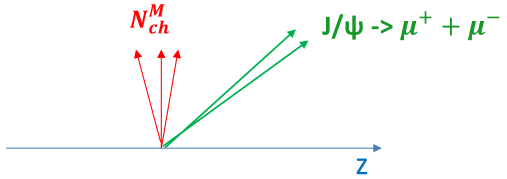


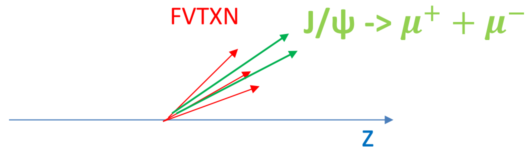


PYTHIA vs Data (RHIC and LHC)

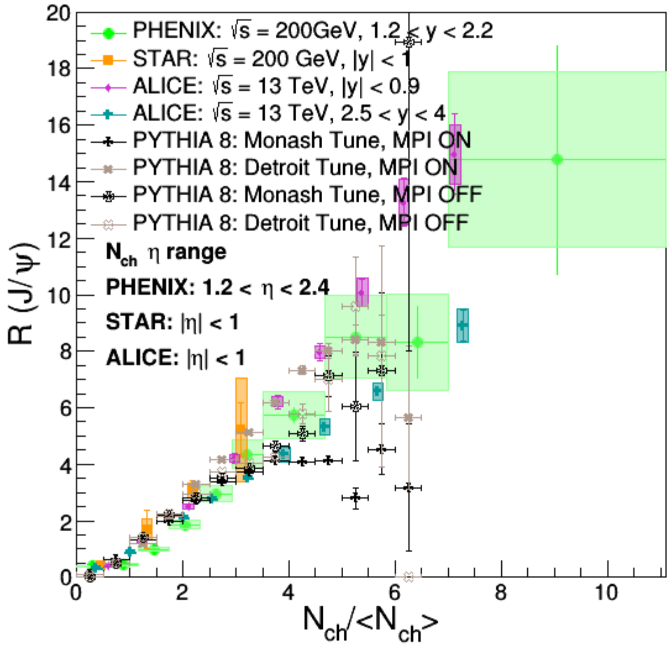


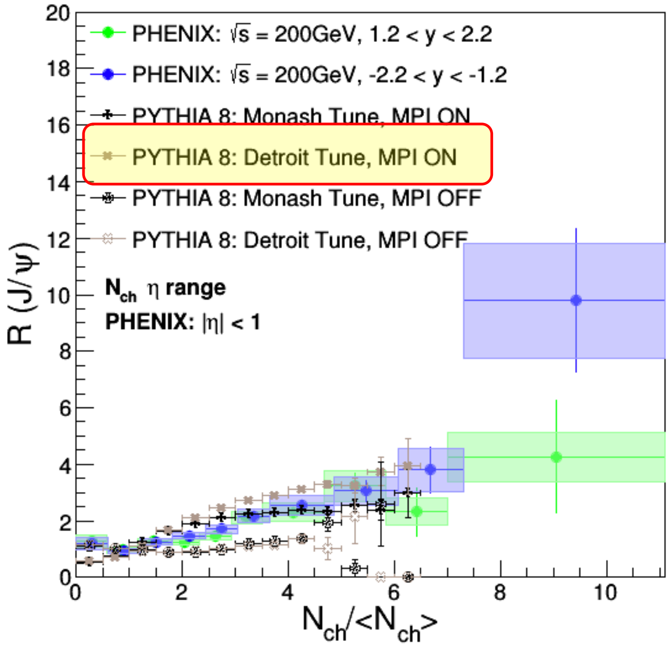
(same arm, inclusive)

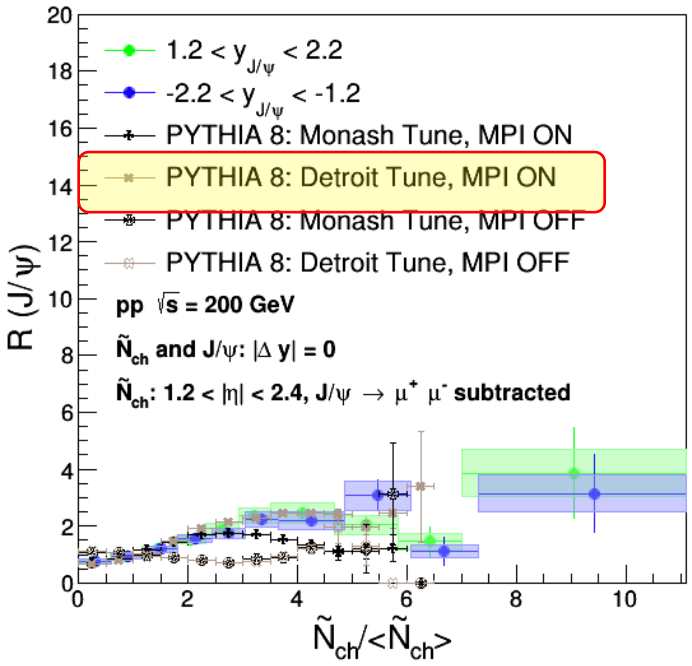




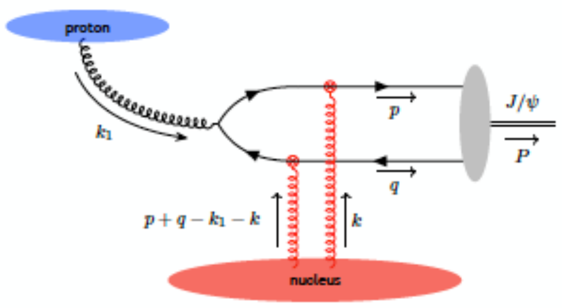
(dimuon subtracted)

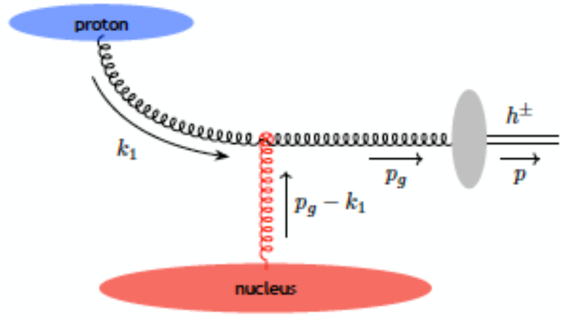


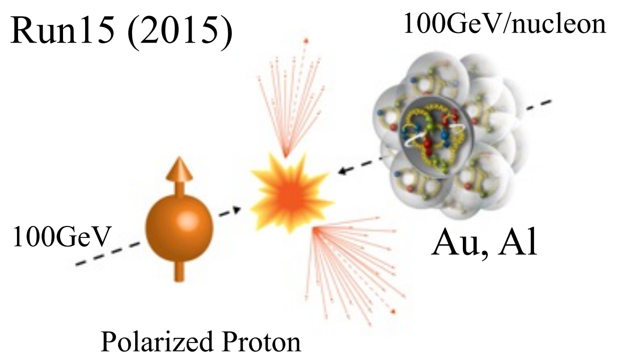




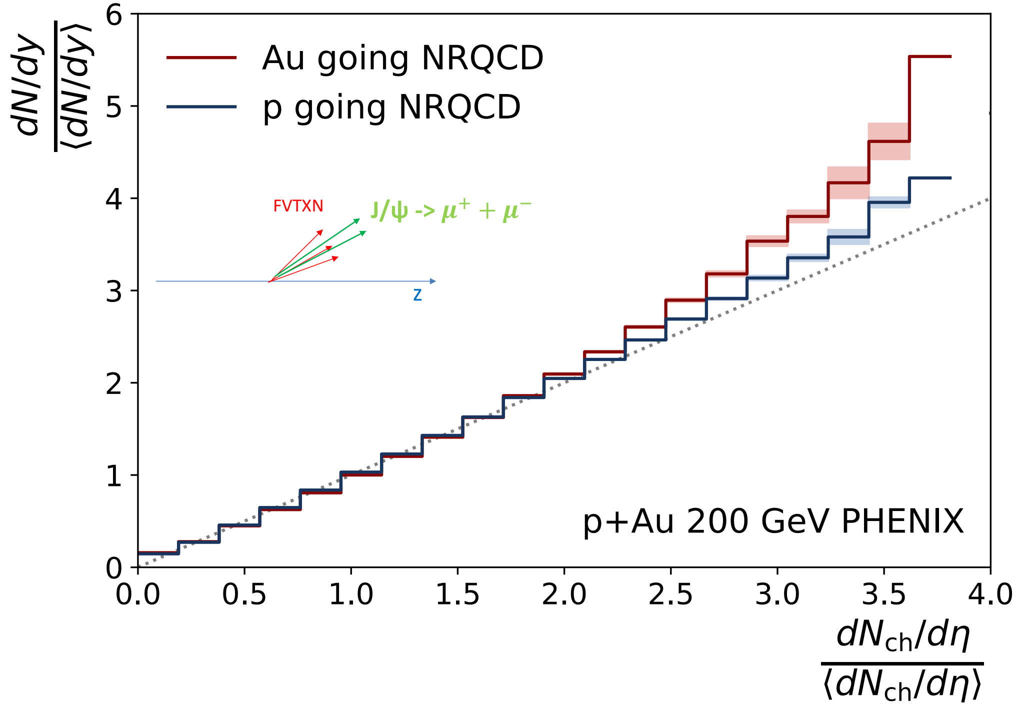
Probe CGC in pAu?

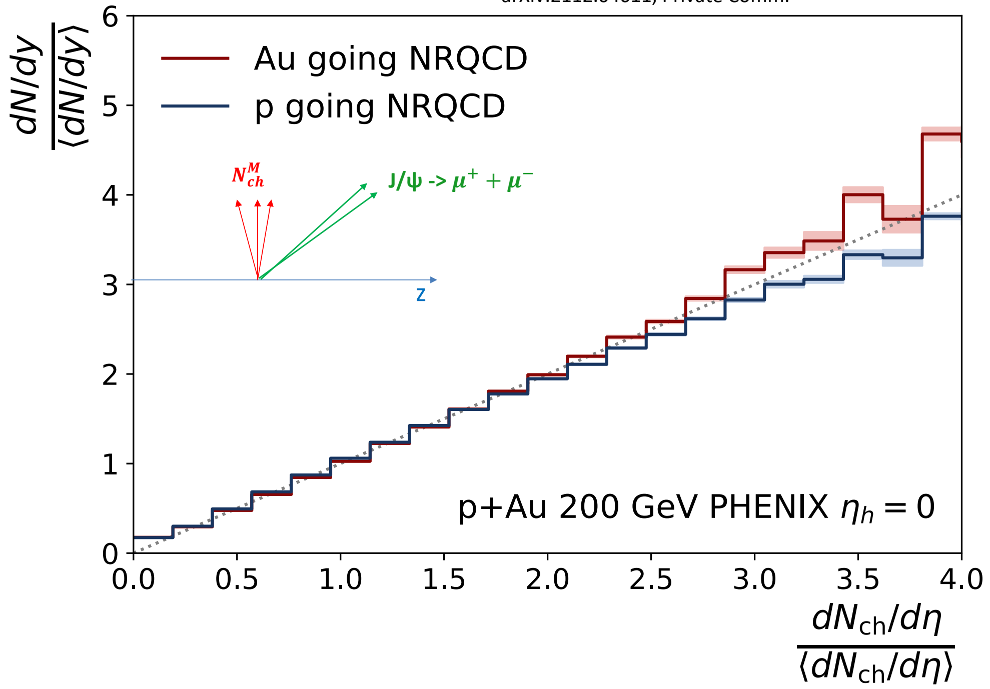






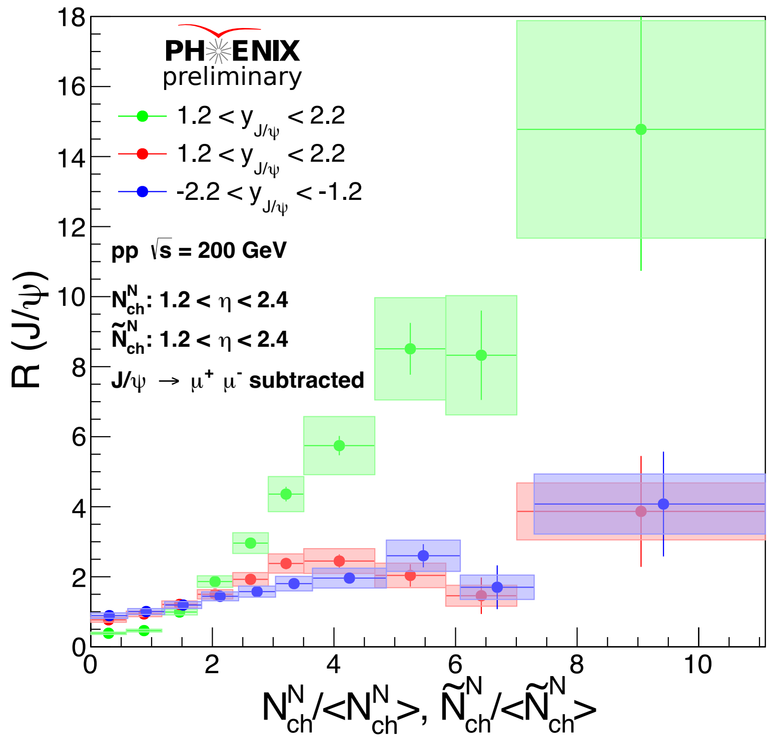
Farid Salazer, Bjorn Schenke and Alba Soto-Ontoso
arXiv:2112.04611; Private Comm.



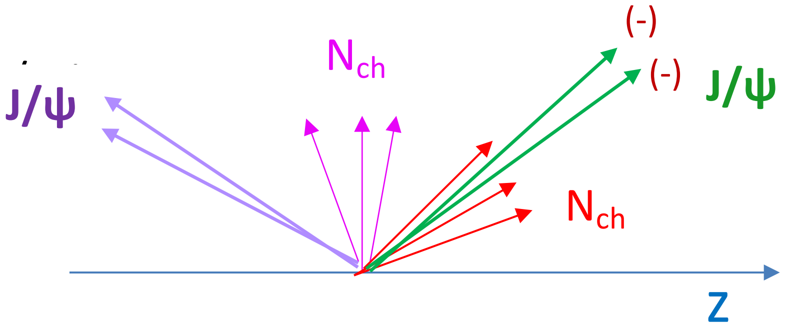


Summary and Outlook

- **First measurements of the relative J/ψ yields R in the forward rapidity vs normalized event charged particle multiplicity N_{ch}/< N_{ch} > 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

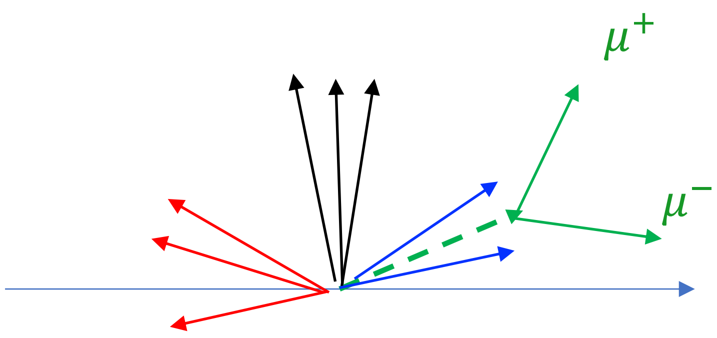


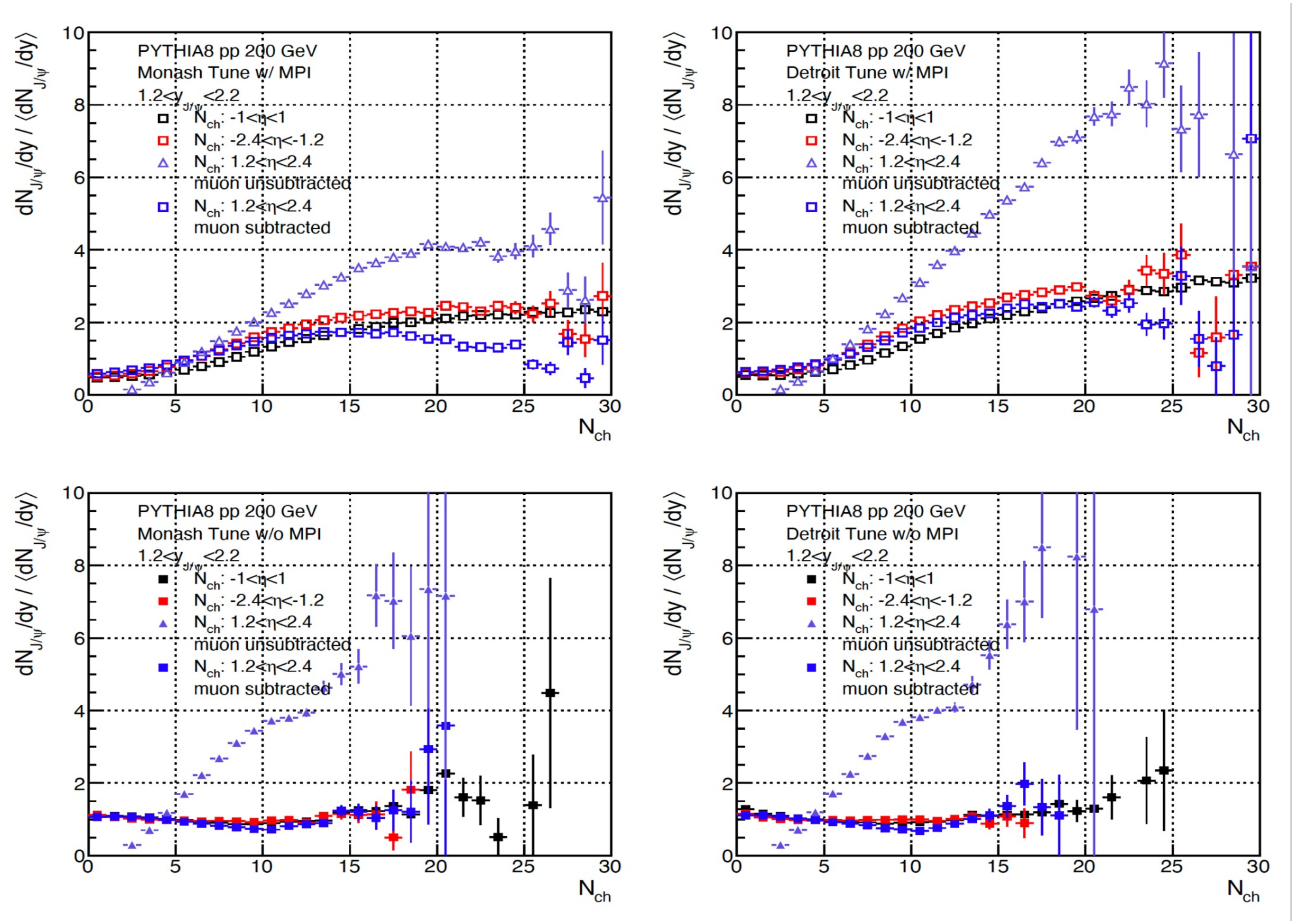
- **p+Au analysis in progress, stay tuned!**
  - Very interesting CGC motivated model predictions


Join us at
INTERSECTIONS
Lake Buena Vista, Fla
Augus
September 4
THANK YOU!

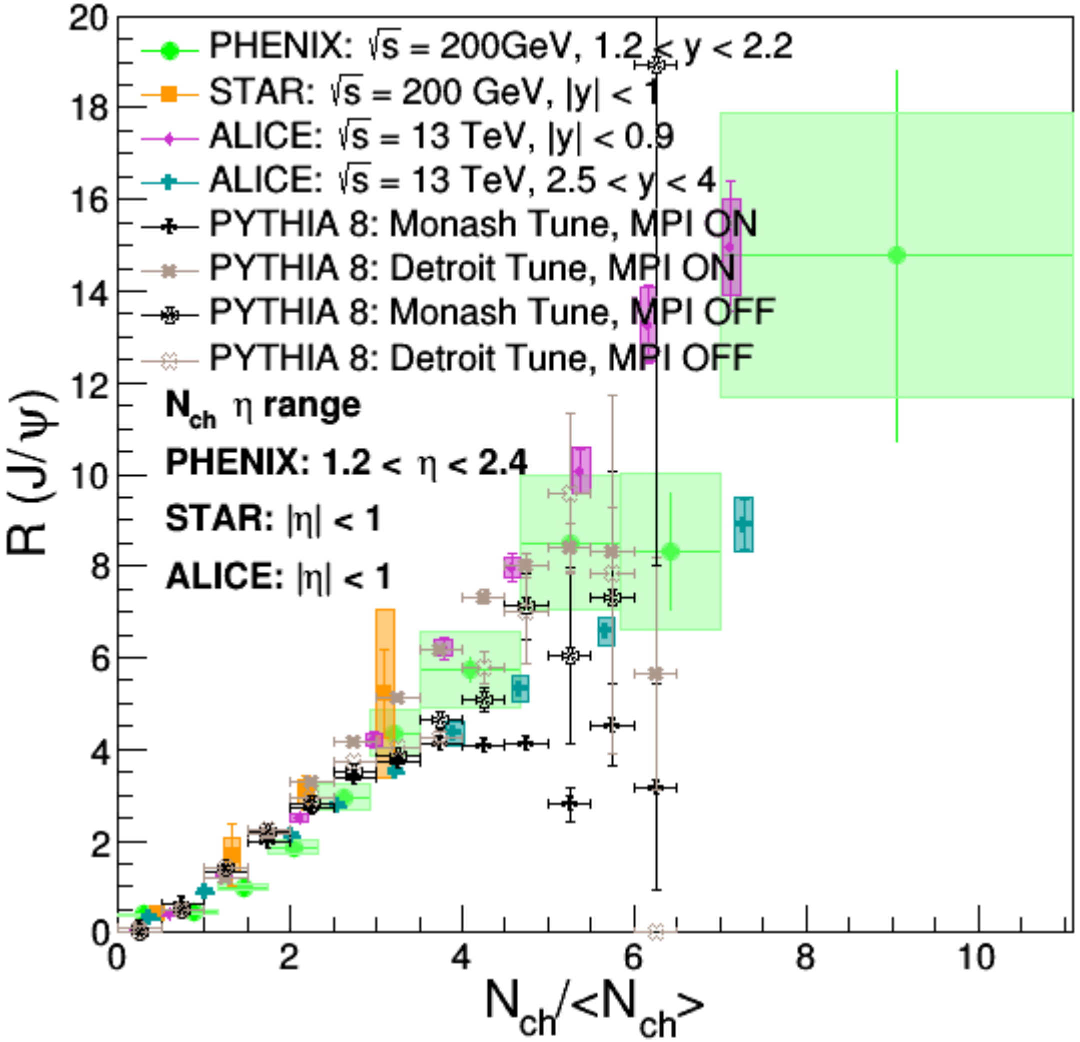
Backup slides

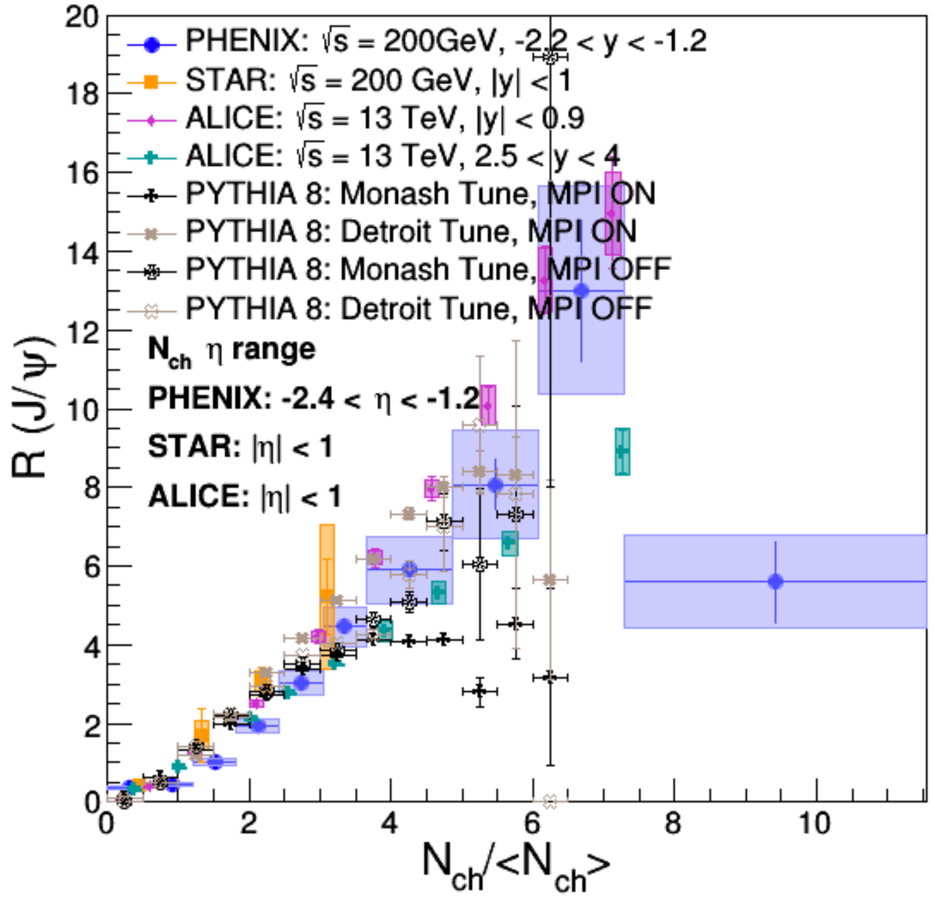
PYTHIA Simulations



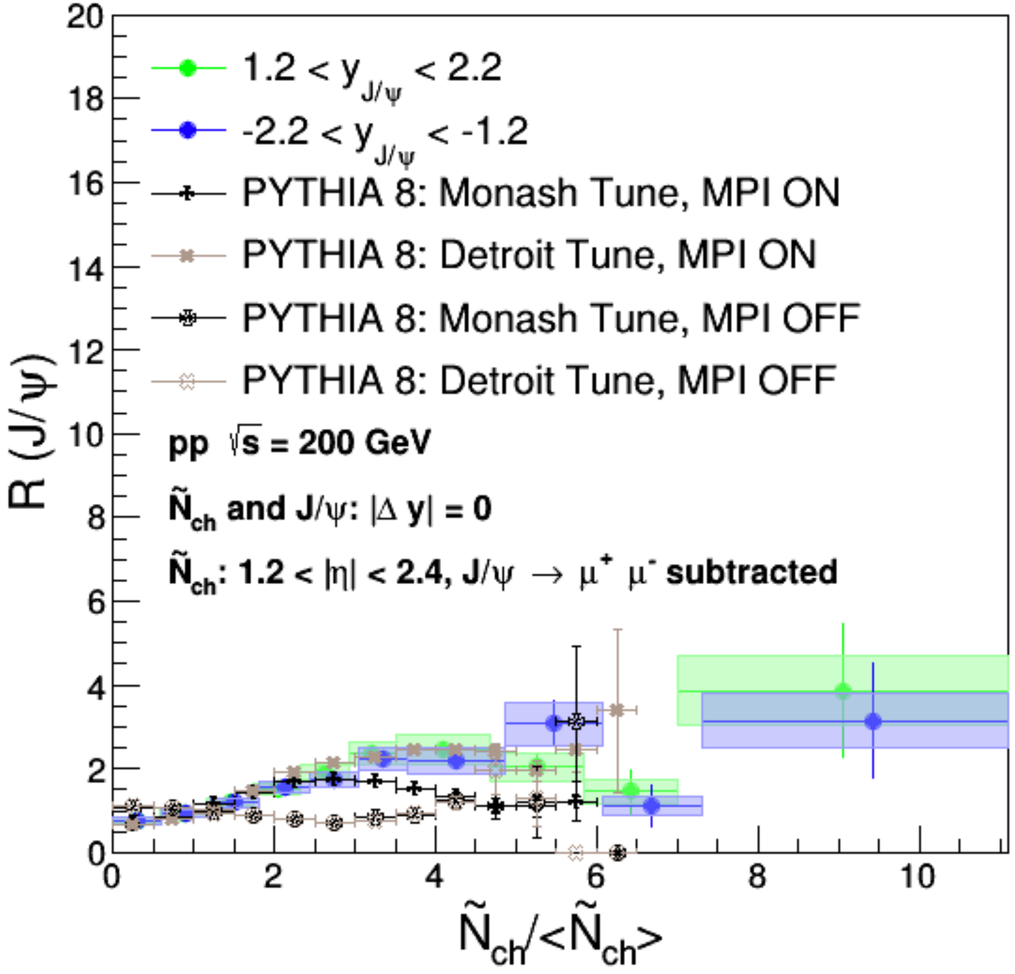


PYTHIA and Data – Same Arms

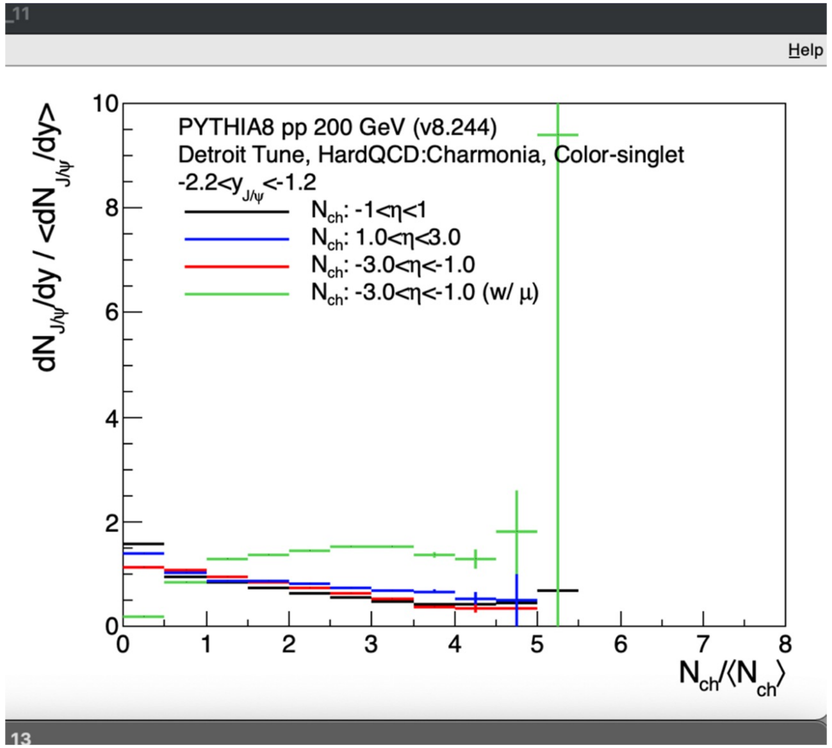


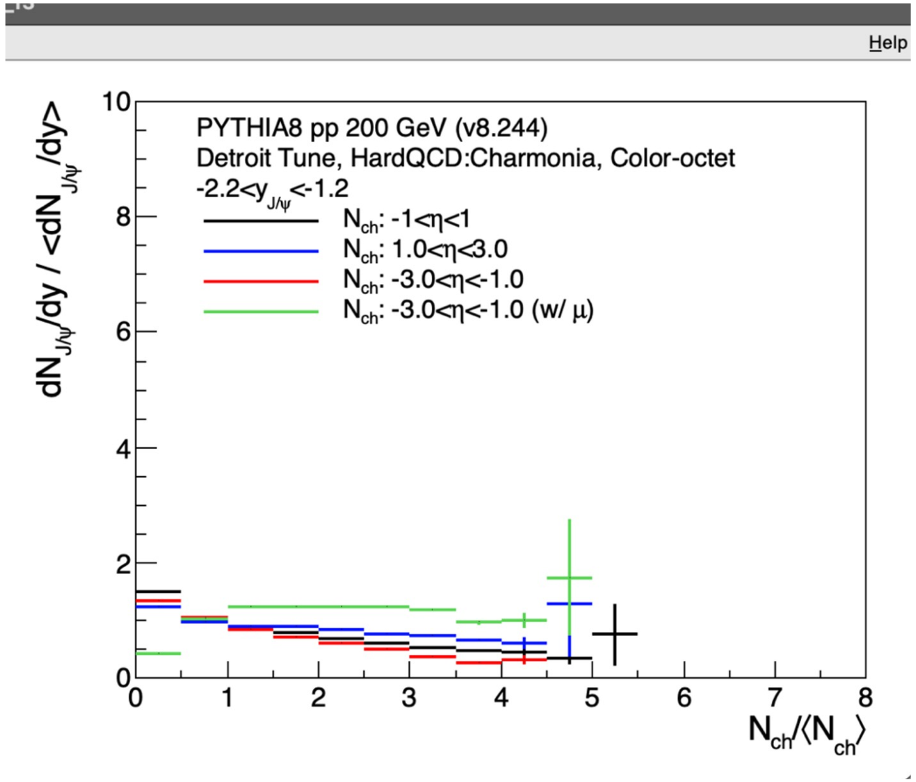


PYTHIA and Data – Dimuon subtracted

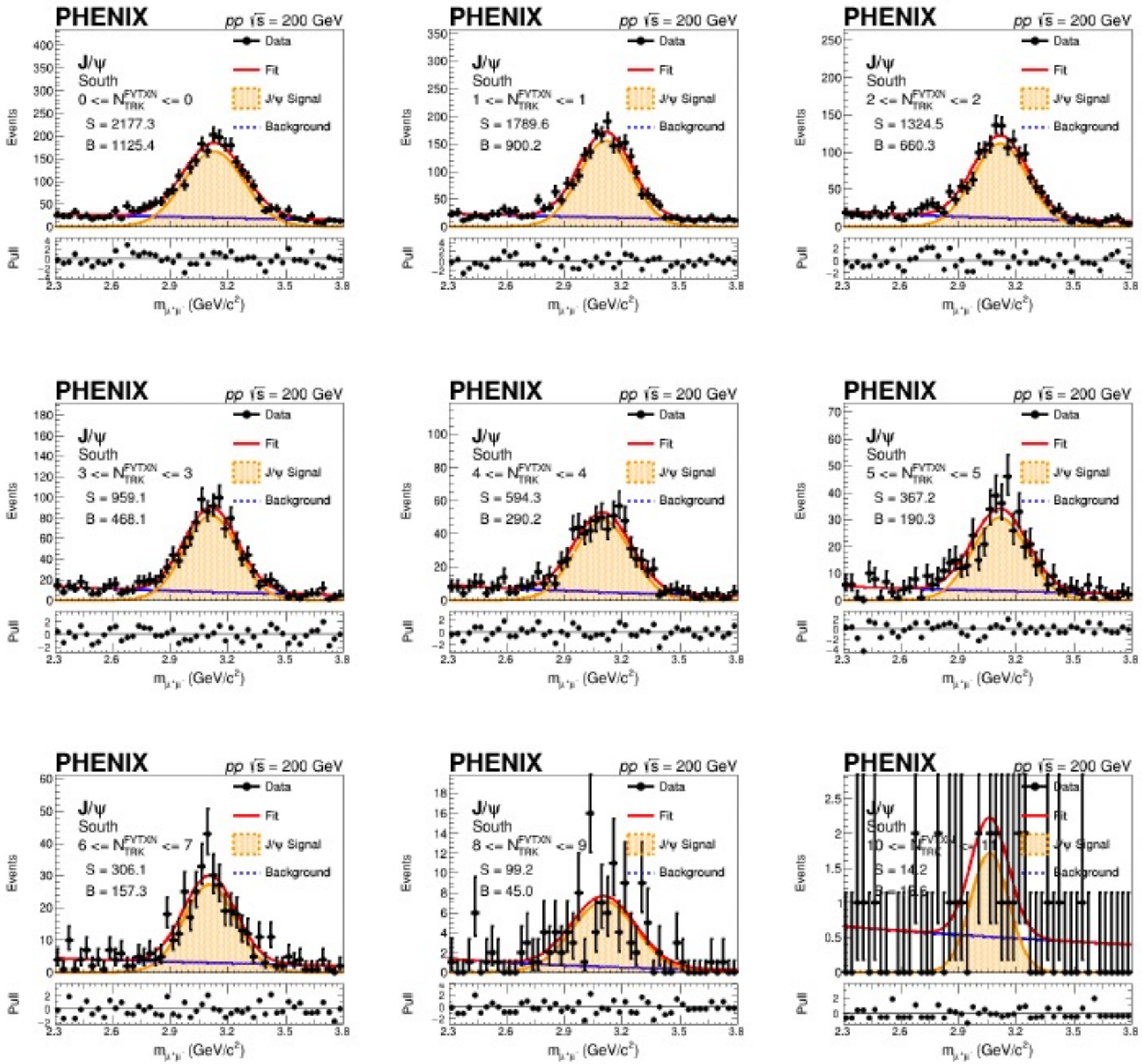


PYTHIA sim with CS and CO, MPI ON

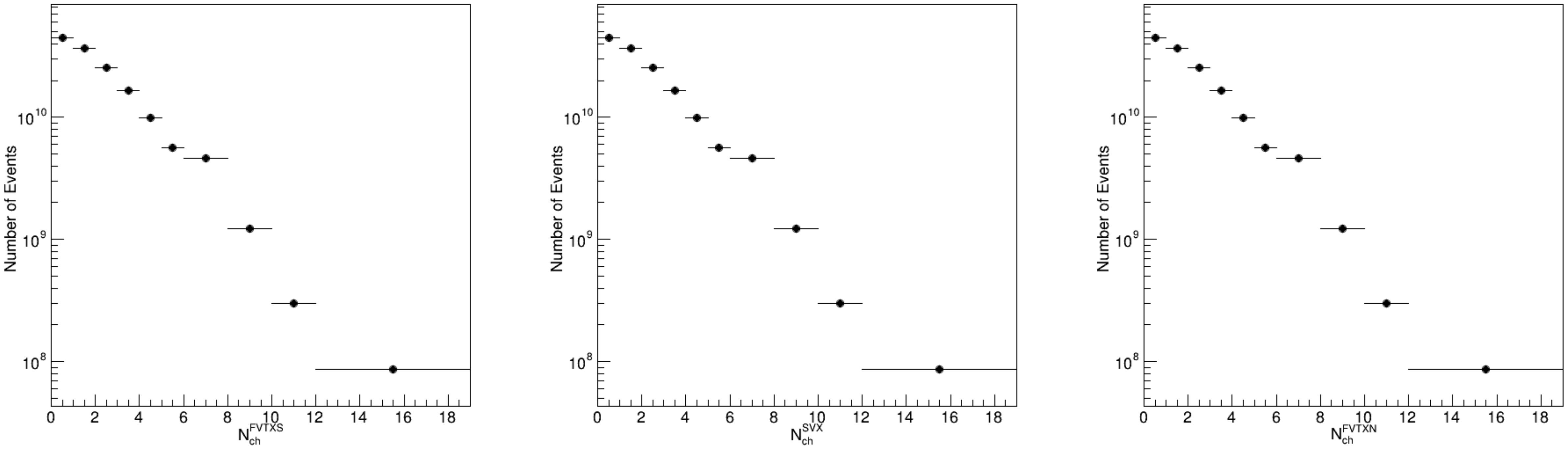




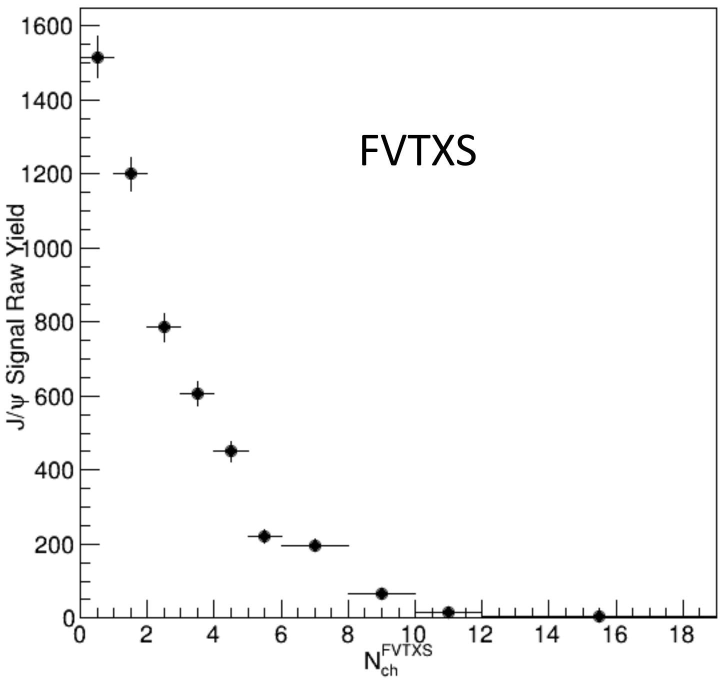
J/ψ Dimuon Mass Fits

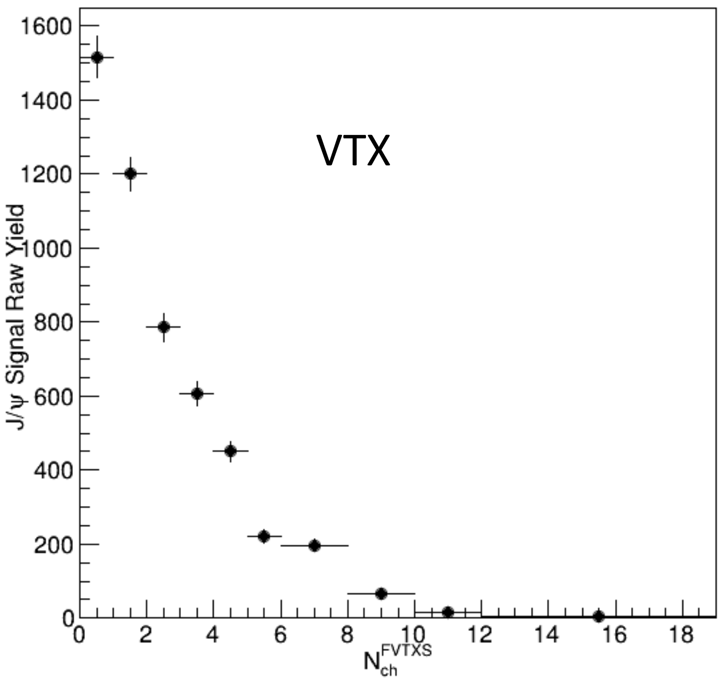


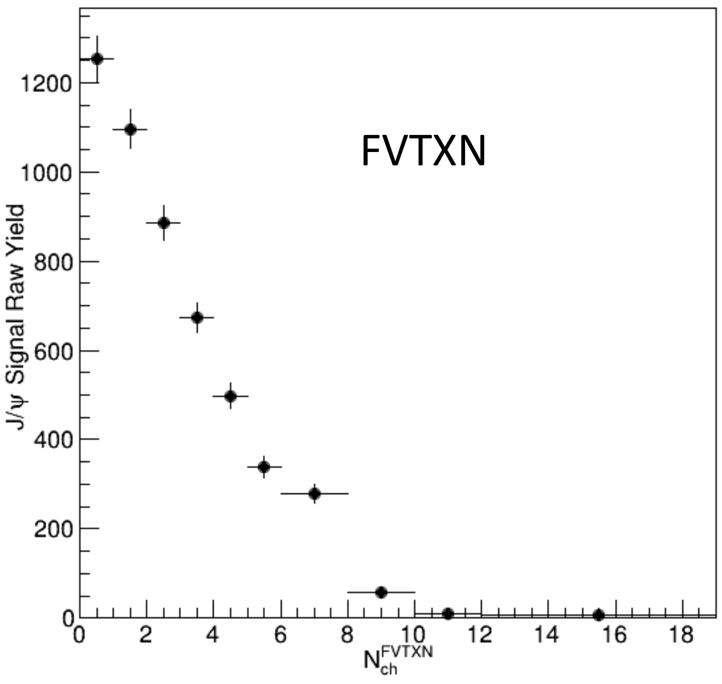
MB Events' FVTX and SVX Tracklet Raw Distributions



Raw J/ψ Counts vs FVTX and SVX







Multiple Collision Probability Table

PHENIX

BBCLL1_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
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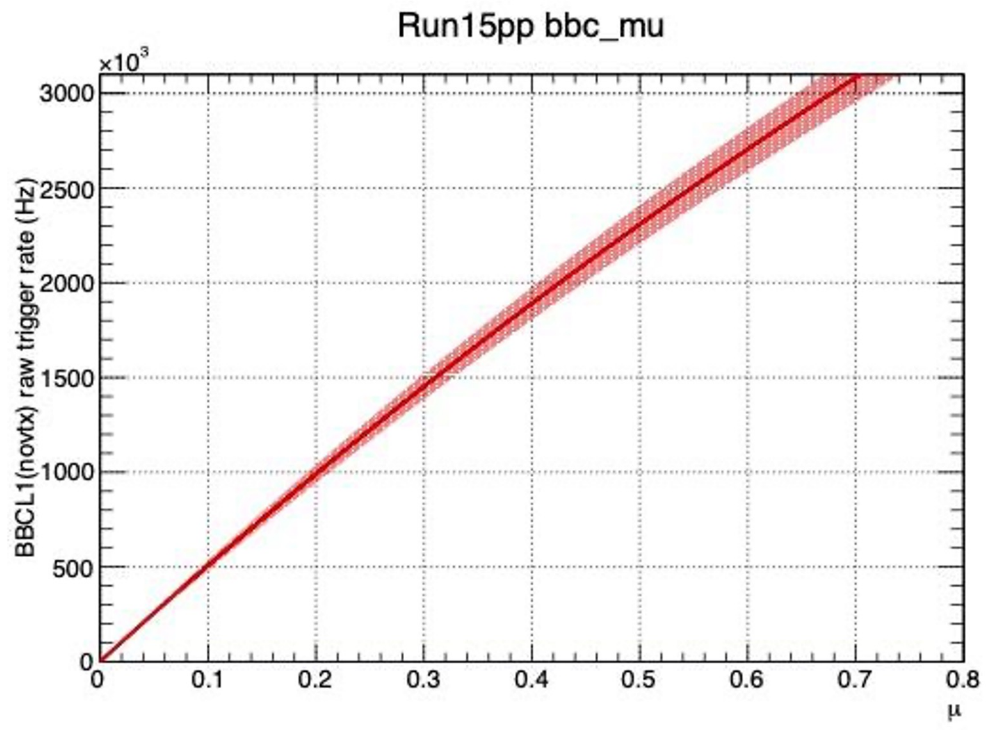
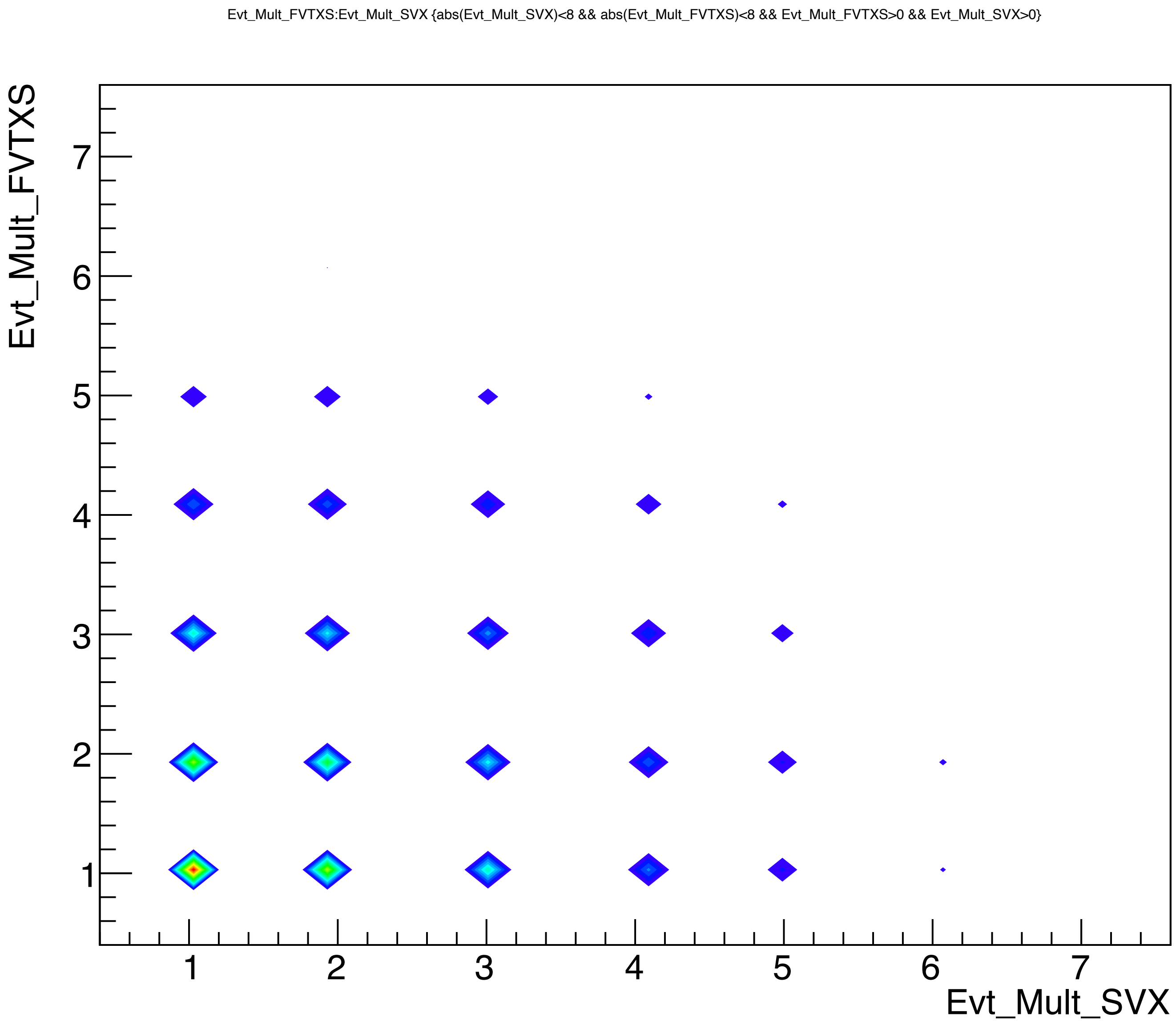


FVTX Track Multiplicity Correlations



PHENIX

LHC: p-Pb @8TeV

Farid Salazer, Bjorn Schenke and Alba Soto-Ontoso
arXiv:2112.04611;

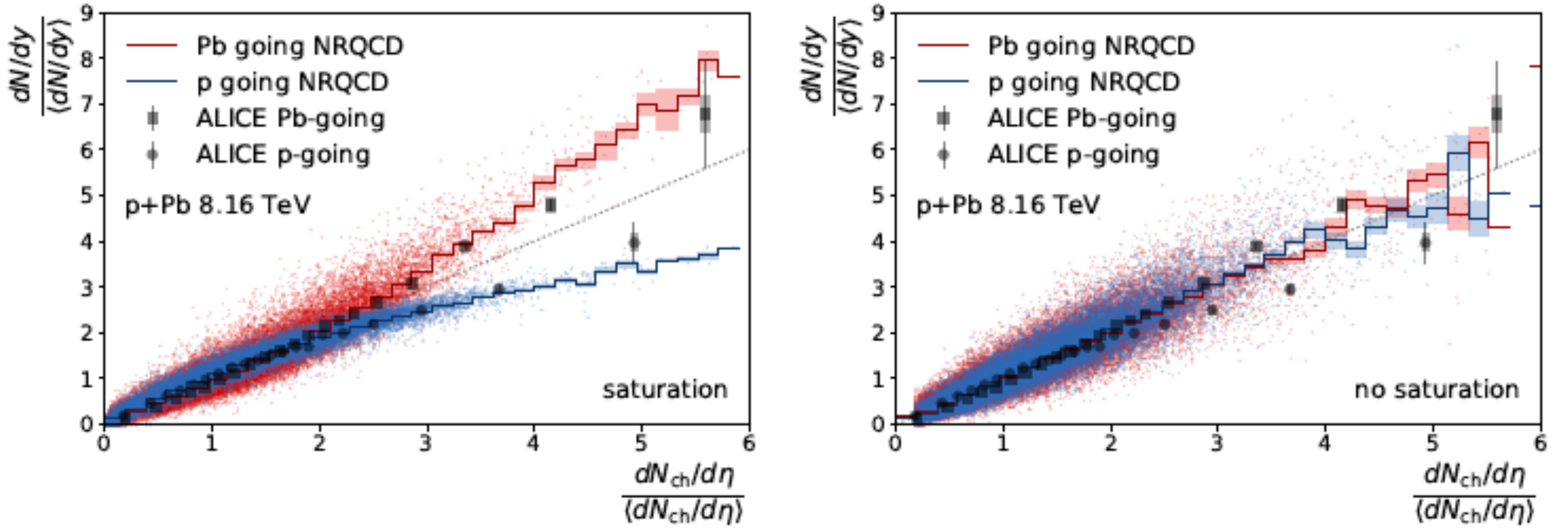


Figure 3. Correlation between normalized J/ψ and charged hadron yields in $p + Pb$ collisions at 8.16 TeV for BK evolved dipoles and using NRQCD to describe the J/ψ hadronization. Shown are results from individual events as scatter plots and the event average with statistical errors. Experimental data from ALICE [13]. Left: Using values of Q_s that lead to multiplicities in line with experimental results. Right: Artificially low Q_s to mimic the situation of no, or much weaker, saturation effects.