

Multiplicity dependence study and role of MPIs on J/Ψ production in $p+p$ collisions at $\sqrt{s} = 13$ TeV using PYTHIA8

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Flash Talk, 3rd Heavy Flavour Meet 2019

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Multiplicity dependence study and role of MPIs on J/Ψ production in $p + p$ collisions at $\sqrt{s} = 13$ TeV using PYTHIA8

Suman Deb*, Dhananjaya Thakur*, Sudipan De*, Raghunath Sahoo*, Soumya Dansana*

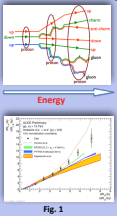
*Indian Institute of Technology Indore, Simrol, India
*Indian Institute of Science Education and Research, Kolkata, India

Introduction and motivation

In inelastic $p+p$ collisions, the interaction objects are partons. In a single $p+p$ collisions, a large number of interaction of partons occurs in parallel which is called as multi-parton interactions (MPIs)[1]. If the interaction involves large p_T transfer, the semi-hard interaction multiple interactions of partons lead to the production of heavy particles like J/Ψ .

Motivation for the multiplicity dependence studies of J/Ψ production:

1. Recently, ALICE has observed that the relative J/Ψ yield increases nearly linearly with charged particle multiplicity in $p + p$ collisions [Fig1].
2. These results leave some curiosity:
 - Is the behaviour solely due to MPI at the partonic level or it has some contribution from CR at the final state?
 - What will be the energy dependence behaviour of MPI and CR?
 - How do the higher states of charmonium behave?
 - What is the contribution of quark/gluons with multiplicity?
 - Is there any J/Ψ kind of suppression between?
3. As PYTHIA8 well explains the trends up to $(dN_{ch}/d\eta)/\sqrt{s} < dN_{ch}/d\eta > \sim 4.5$, we have tried to study the multiplicity dependence and the contribution of $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$ toward J/Ψ production using pQCD inspired model (PYTHIA8).



PYTHIA8 Settings

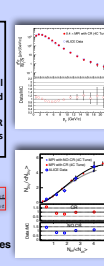
4C-Tuned PYTHIA8 is used for the analysis[3].

- General Settings:
 - ISR and FSR is ON for the whole analysis
 - MPI with CR/MPI is used
- Specific settings:
 - Multiparton-interactions: bProfile=3, to allow all incoming partons to undergo hard and semi-hard interactions
 - ColourReconnection: model(0), MPI-based scheme of CR
 - HardQCD: all-on, inelastic, non-diffractive components of the total cross section for all had QCD processes.

Formula

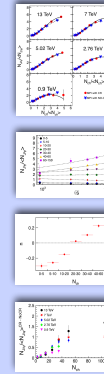
The relative J/Ψ yield is defined as: $\frac{Y_{J/\Psi}}{Y_{p+p}} = \frac{N_{J/\Psi}}{N_{p+p}}$

- where, i stands for its multiplicity bin.
- These setting reproduces ALICE Results
- Analysis is extended for all other LHC energies keeping the same setting



Energy dependence and CR effect on J/Ψ production

- The J/Ψ relative yield increases linearly with charged particle multiplicity
- The hard-MPIs increase with centre of mass energy and is more significant for higher multiplicity
- To get a qualitative idea, it is fitted with a phenomenological function $f(x) = A \cdot x^n$. Here " n " indicates the rate of increase of relative J/Ψ yield with \sqrt{s}
- n -parameter is plotted versus multiplicity. It is found that n is negative for $N_{ch} < 20$ and is positive for $N_{ch} > 20$
- $N_{ch} = 20$ is the threshold number of charged particle multiplicity in the final state for substantial MPI effects on the charmonium production
- Color reconnection has more contribution to J/Ψ production at higher multiplicities as well as higher center of mass energies
- The difference between CR and no-CR is very less: reveals that final state effects have little contribution to J/Ψ production and it may be from the hard MPIs

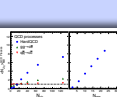


Reference

- (1) D. Thakur, S. De, R. Sahoo and S. Dansana, Phys. Rev. D 97 (2018) no. 9, 094002
- (2) S. Deb, D. Thakur, S. De and R. Sahoo, arXiv:1808.01841 [hep-ph] (Reference Preprint)
- (3) R. Corke and T. Sjostrand, JHEP10(2012)011

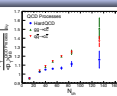
Effect of hard QCD processes on yield and $\langle p_T \rangle$ of J/Ψ production

- Contribution of gluon to J/Ψ production is little higher compared to contribution of quark.
- Inclusive hardQCD processes is dominant over $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$.
- The contribution of MPI to the J/Ψ production (semi-hard J/Ψ) is dominant process and is increasing with multiplicity.



Effect on $\langle p_T \rangle$

- The $\langle p_T \rangle$ of J/Ψ for inclusive hard QCD processes is less compared to $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$.
- Inclusive hardQCD processes contains semi-hard MPI, which lowers down the $\langle p_T \rangle$ of J/Ψ .
- $\langle p_T \rangle$ of J/Ψ increase with increase of multiplicity. Indicates more harder J/Ψ are produced in going from low to high multiplicity.



Nuclear Modification Like Factors (R_{pA}/R_{pp})

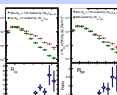
To understand the Possibility of system formation in high-multiplicity events for $pp@13$ TeV, we define

$$R_{pp} = \frac{(dN/N_{ch} d\eta d\eta_{ch})_{\sqrt{s}=13\text{ TeV}}}{(dN/N_{ch} d\eta d\eta_{ch})_{\sqrt{s}=2.76\text{ TeV}}} \quad \text{for } N_{ch} > 20$$

$$R_{cp} = \frac{(dN/N_{ch} d\eta d\eta_{ch})_{\sqrt{s}=13\text{ TeV}}}{(dN/N_{ch} d\eta d\eta_{ch})_{\sqrt{s}=2.76\text{ TeV}}} \quad \text{for } N_{ch} < 20$$

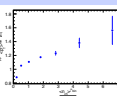
Observations

- For $p_T < 2$ GeV/c, R_{pp} shows 10% suppression
- There is no suppression observed for R_{cp}



It gives us idea about possible system size in high multiplicity

$$r_{pp} = \frac{\langle p_T \rangle_{pp}}{\langle p_T \rangle_{cp}}$$



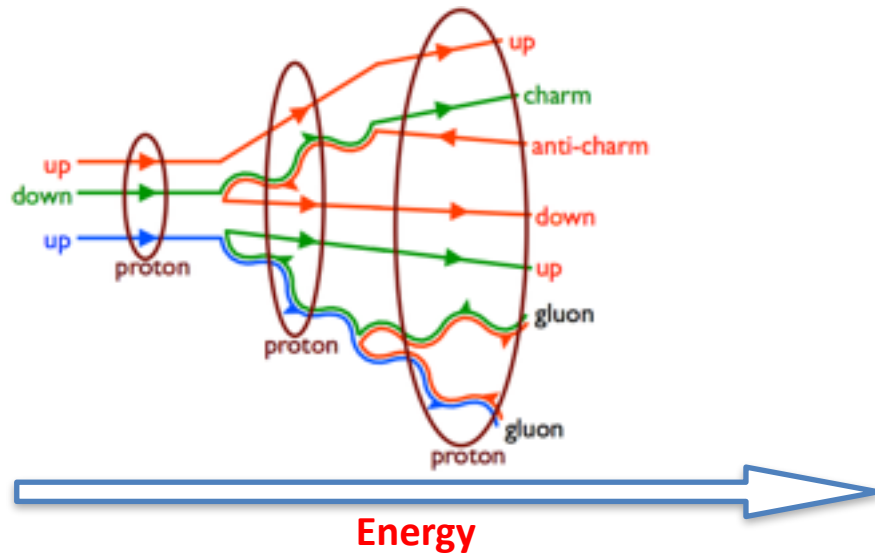
Summary

- MPI drives the J/Ψ production with little effect of CR in $pp@LHC$ energies
- From $\langle p_T \rangle$ study, it is found that $gg \rightarrow c\bar{c}$ dominates over $q\bar{q} \rightarrow c\bar{c}$ towards high multiplicities.
- r_{pp} trends shows that even at high centre-of-mass energy of pp collisions, regeneration is negligible and almost all the measured J/Ψ are produced from initial hard processes.
- R_{pp} shows suppression: the QCD medium formed in high multiplicity pp collisions is different than MBL.

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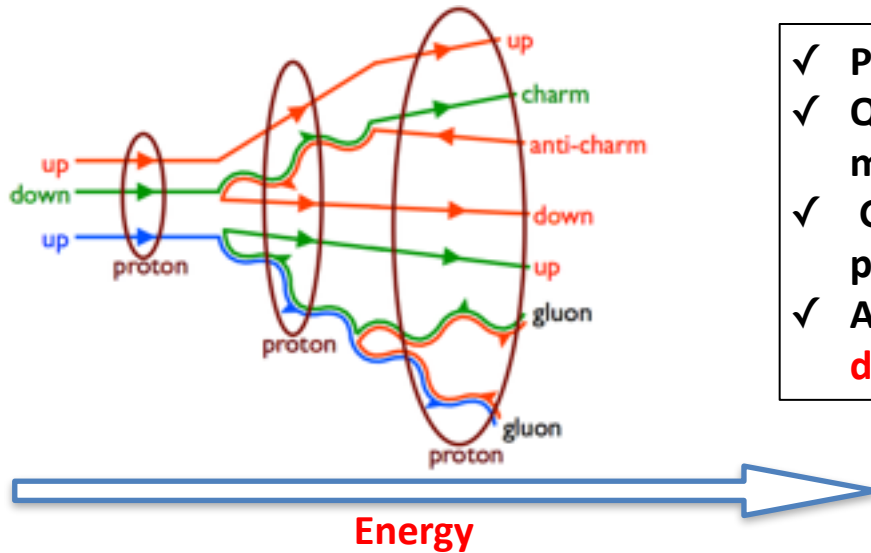
Motivation: The pp Collisions

- ❖ At very high LHC energies, protons are no more a point particle.



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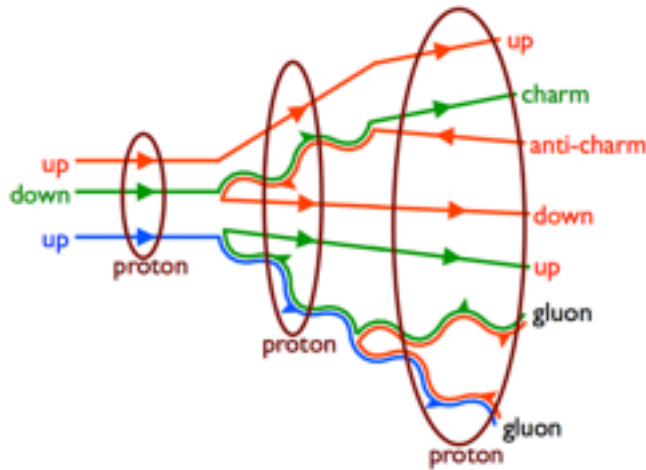


- ✓ Proton contains partons (quark and gluons)
- ✓ Quark radiates gluons and the gluon density is more at very high energy.
- ✓ Gluon splits in to quark and anti-quarks or a pairs or gluons.
- ✓ At very high energy proton is treated as “**Parton distribution**”

T. Sjöstrand, M. van Zijl, Phys. Rev. D36 (1987)

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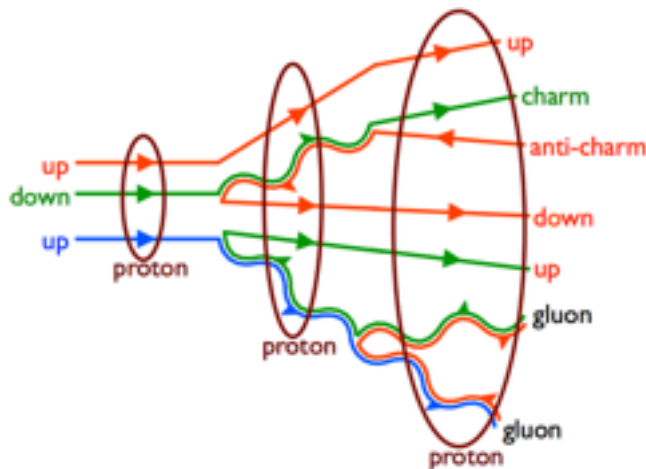
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Associated Event activity

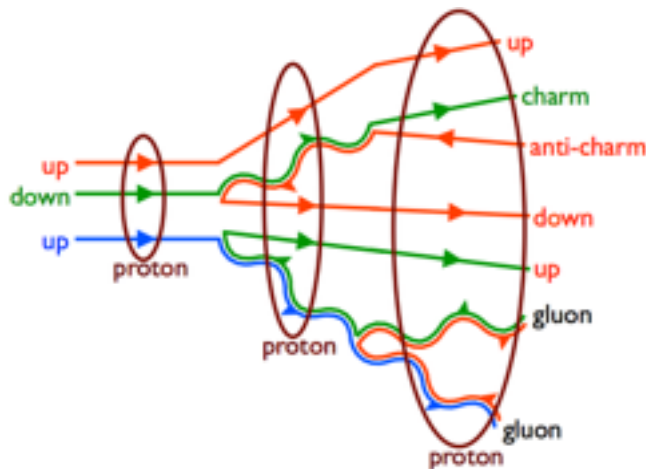
- Multipartonic interaction (MPI)
- Color-reconnection
- hadronic activity like

$$q\bar{q} \rightarrow c\bar{c} \quad gg \rightarrow c\bar{c}$$

PHYSICAL REVIEW D96,114019 (2017)

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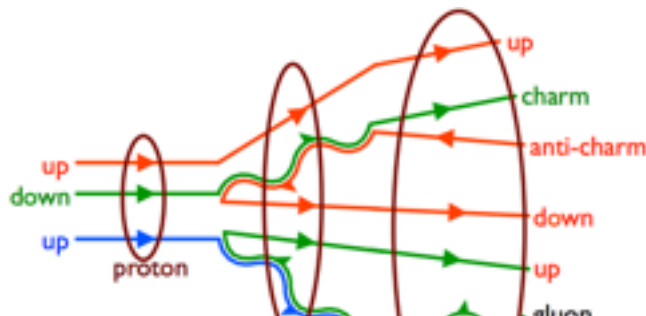
PHYSICAL REVIEW D96,114019 (2017)

QGP signature in high-multiplicity pp events

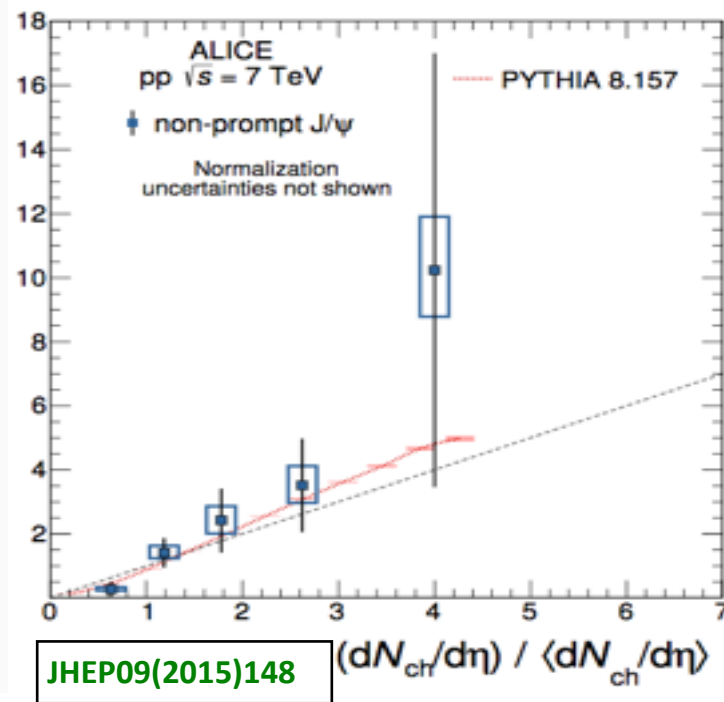
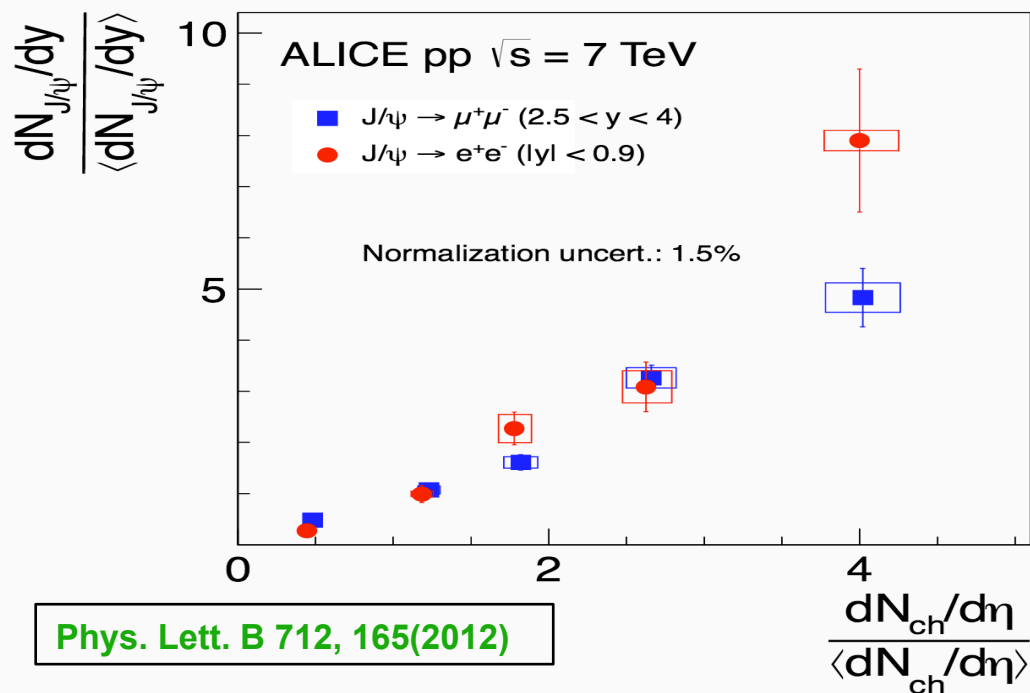
- Strangeness enhancement (Nature Physics 13, 535–539 (2017))
- Indication of collective behavior at $\sqrt{s} = 0.9, 2.76$ and 7 TeV. (W. Li, et al., CMS Collaboration, J. Phys. G 38 (2011) 124027, V. Khachatryan, et al., CMS Collaboration, JHEP 1009 (2010) 091)
- **J/ Ψ Suppression?**

Motivation: The pp Collisions

- ❖ At very high LHC energies, protons are no more a point particle.



- ✓ Proton contains partons (quark and gluons)
- ✓ Quark radiates gluons and the gluon density is more at very high energy.
- ✓ Gluon splits in to quark and anti-quarks or a pairs or gluons.
- ✓ At very high energy proton is treated as “Darton”



- ❖ Some of the question can be answered by pQCD inspired model like PYTHIA8, which describes well the multiplicity dependence behaviour of particle production.

❖ Advantages of PYTHIA8 over PYTHIA6 is inclusion of MPI in harder scale

- Which can produce “c” and “b” quarks via first 2 \rightarrow 2 partonic interaction
- Finite probability of production in subsequent hard interactions

❖ “4C Tune” is used, which well explains the charged particle multiplicity in pp@ 7 TeV

(J. High Energy Phys. 03 (2011)032, Phys. Rev. D 95 , 014016 (2017))

The detailed about the setting is in back up slide

Simulating J/ Ψ using PYTHIA8

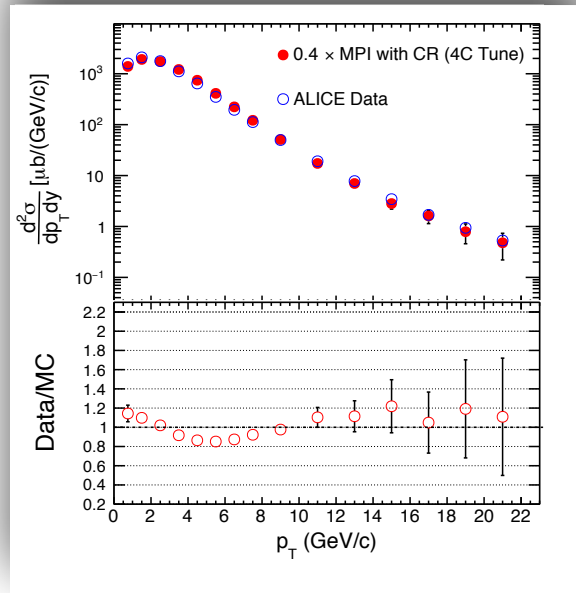
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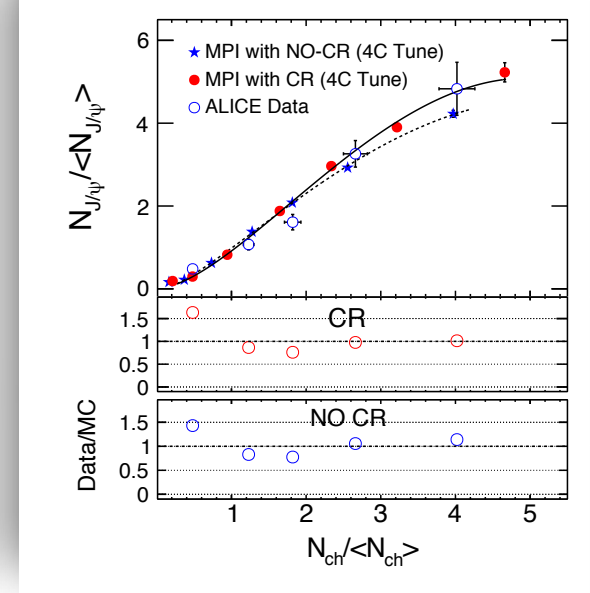
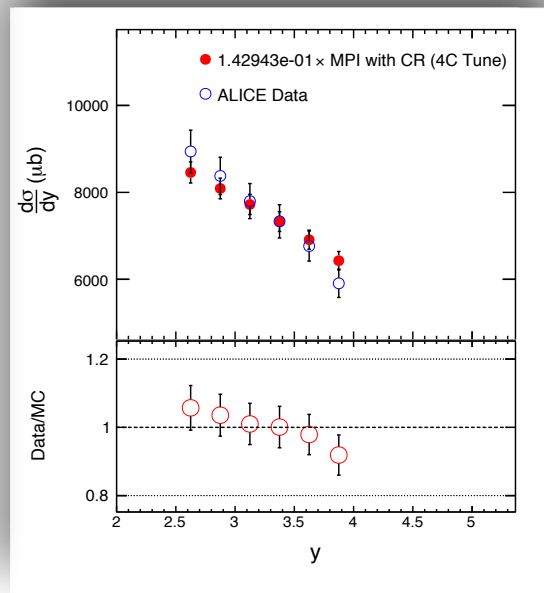
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Eur. Phys. J. C77, 392 (2017)



Phys. Lett. B712, 165 (2012)

❖ PYTHIA8 is well explaining the experimental data!

Energy dependence of J/Ψ production

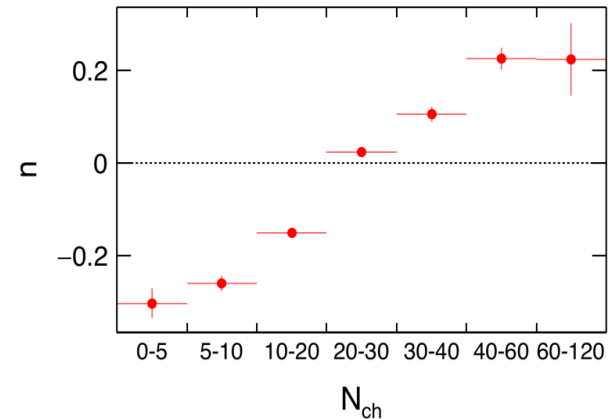
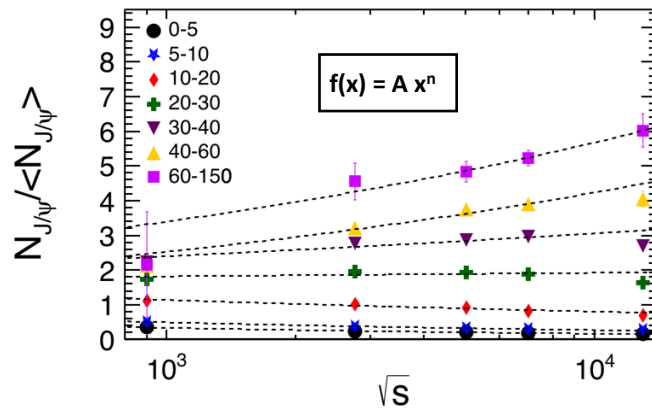
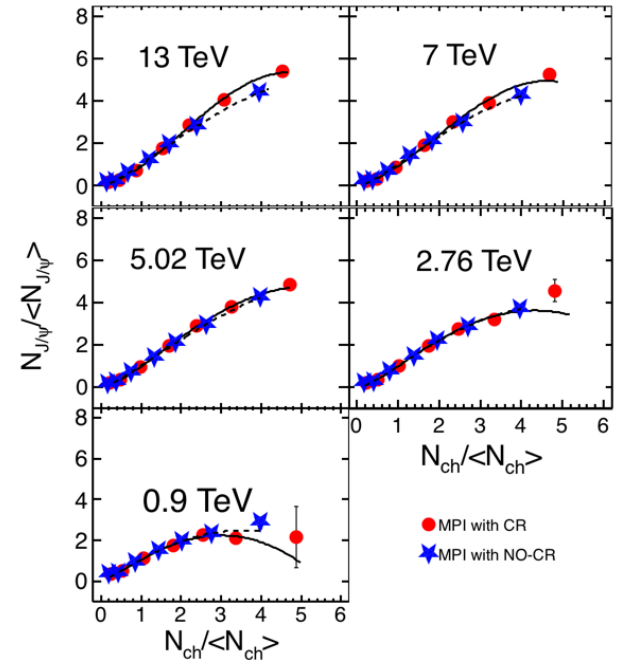
- The J/Ψ relative yield increases linearly with charged particle multiplicity.
- The saturation of relative J/Ψ yield towards higher multiplicity bins needs to be understood.
- The hard-MPIs increase with center-of-mass energy

• n-parameter vs. N_{ch}

✓negative for $N_{ch} < 20$

✓positive for $N_{ch} > 20$

❖ The event activity beyond $N_{ch} \approx 20$ is more prominent to the production of charmonia



(Phys.Rev. D97 (2018), 094002)

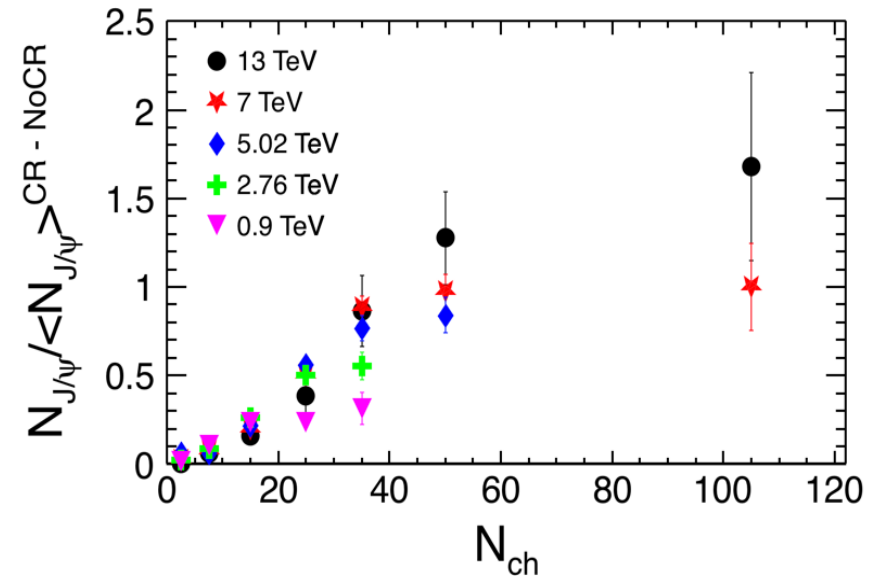
✓ “n” indicates the rate of increase of relative J/Ψ with \sqrt{s}

Effect of color reconnection on J/ Ψ production

- Color reconnection has more contribution to J/ Ψ production at higher multiplicities as well as higher center of mass energies.

Expected reasons

- ✓ High density of color partons
- ✓ Substantial overlap of color strings in position and momentum space leads to higher probability of color reconnection
- ✓ Partons from two MPIs connect, hence probability of combination of charm and anti-charm quark increases



(Phys.Rev. D97 (2018), 094002)

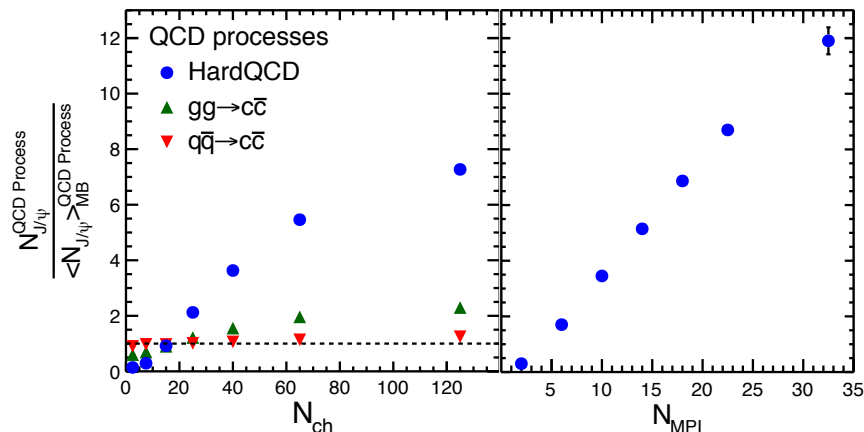
Conclusion of the study

- ✓ At the final state, CR has less contribution to J/ Ψ production. Most of the J/ Ψ s are coming from the initial event activity.

Multiplicity dependence of quark/gluon contribution to J/Ψ production

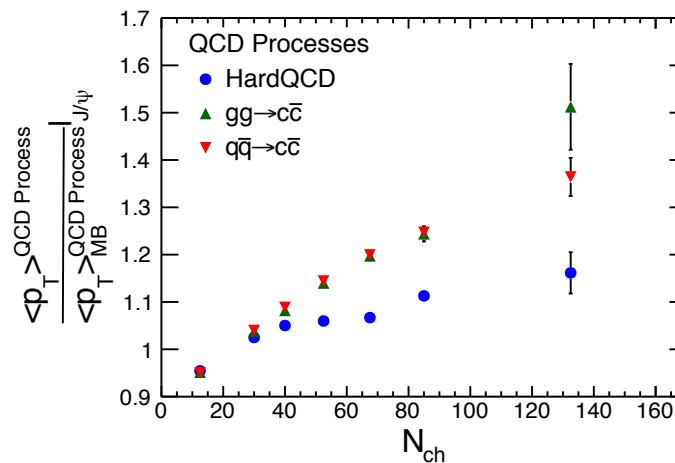
The effect to yield of J/Ψ

- Contribution of gluon to J/Ψ production is little higher compared to contribution of quark.
- Inclusive hardQCD processes is dominant over $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$.
- The contribution of MPI to the J/Ψ production (semi-hard J/Ψ) is dominant process and is increasing with multiplicity.



Effect to $\langle p_T \rangle$ of J/Ψ

- The $\langle p_T \rangle$ of J/Ψ for inclusive hard QCD processes is less compared to $gg \rightarrow c\bar{c}$ and $q\bar{q} \rightarrow c\bar{c}$.
- Inclusive hardQCD processes contains semi-hard MPI is lowering the $\langle p_T \rangle$ of J/Ψ.
- With increase of multiplicity, $\langle p_T \rangle$ of J/Ψ is increasing, indicates more harder J/Ψs are produced as we go from low multiplicity to high multiplicity.



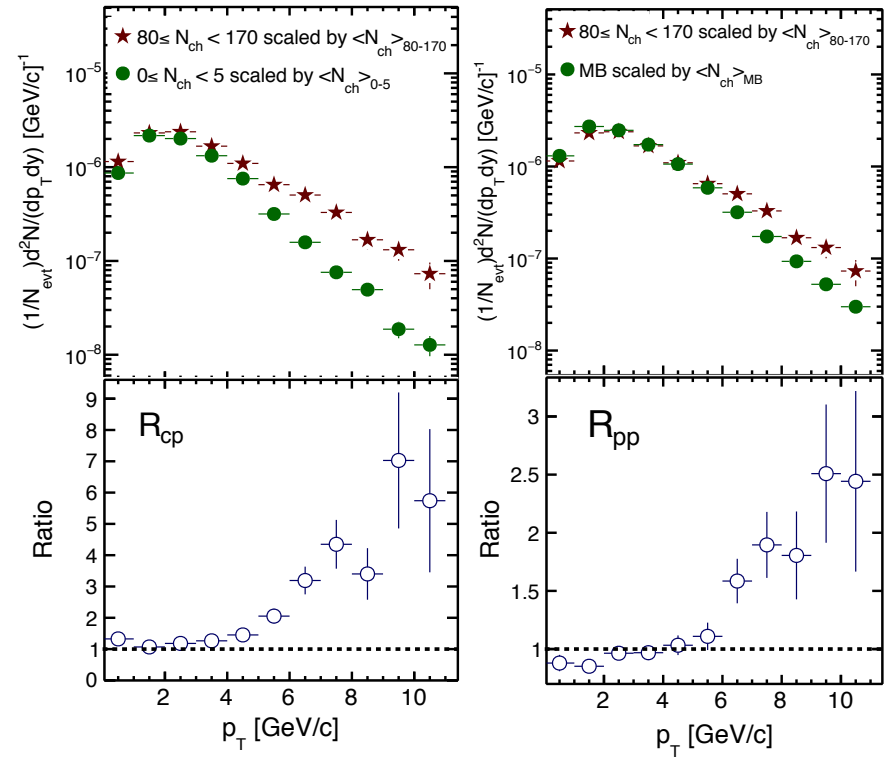
(arXiv:1808.01841)

Medium modification factor (R_{pp}/R_{cp})

- Medium modification (or biasing to the pp reference) is calculated as:

$$R_{pp} = \frac{\langle N_{ch} \rangle_{MB}}{\langle N_{ch} \rangle_{80-170}} \frac{(dN/N_{evt} dp_T)_{80-170}}{(dN/N_{evt} dp_T)_{MB}},$$

$$R_{cp} = \frac{\langle N_{ch} \rangle_{0-5}}{\langle N_{ch} \rangle_{80-170}} \frac{(dN/N_{evt} dp_T)_{80-170}}{(dN/N_{evt} dp_T)_{0-5}},$$



- For $p_T < 2.0$ GeV R_{pp} show around 10 % medium modification (or biasing), where as there is no medium modification observed from low-multiplicity to high-multiplicity (R_{cp}).

- QCD medium formed at high multiplicity p+p collisions is different than MB.

(arXiv:1808.01841)

- ✓ **pp@LHC energies, MPI drives the the quarkonia production with little effect of CR at the final state**
- ✓ **$gg \rightarrow c\bar{c}$ dominates over $q\bar{q} \rightarrow c\bar{c}$ as we go from low multiplicity to high multiplicity**
- ✓ **R_{pp} hinting that the QCD medium formed in high multiplicity p+p collisions is different than that of MB**

Thanks !!

Collaborators

D. Thakur, Dr. R. Sahoo, Dr. S De, S. Dansana

Backup Slide

Summary

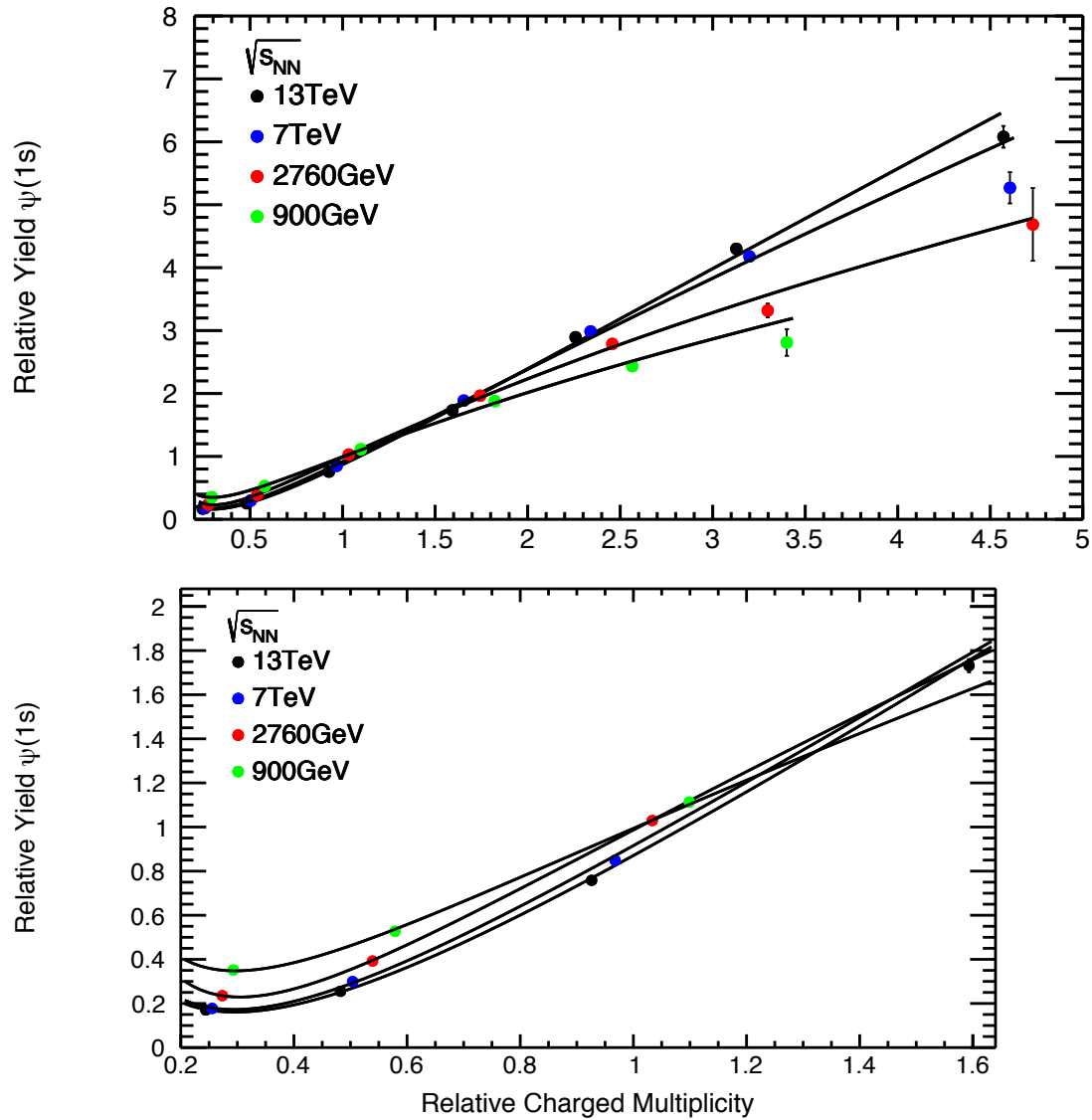
➤ General settings

- ✓ ISR and FSR are ON for whole analysis
- ✓ MPI with CR and MPI with no-CR are used

➤ Specific Settings

- ✓ **Multiparton-Interactions:bProfile=3**, to allow all incoming partons to undergo hard and semi-hard interactions
- ✓ **ColourReconnection:mode(0)**, MPI-based scheme of Colour Reconnection
- ✓ **HardQCD:all=on**, inelastic, non-diffractive component of the total cross section for all hard QCD processes
- ✓ **p_T cut off 0.5 GeV/c is used using PhaseSpace:pTHatMinDiverge**, to avoid divergences of QCD processes in the limit $p_T \rightarrow 0$

Test



Medium modification factor (r_{pp})

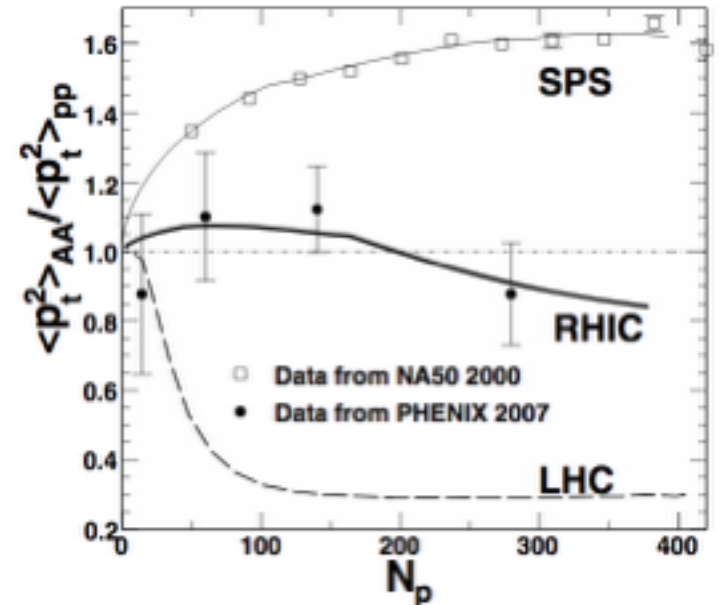
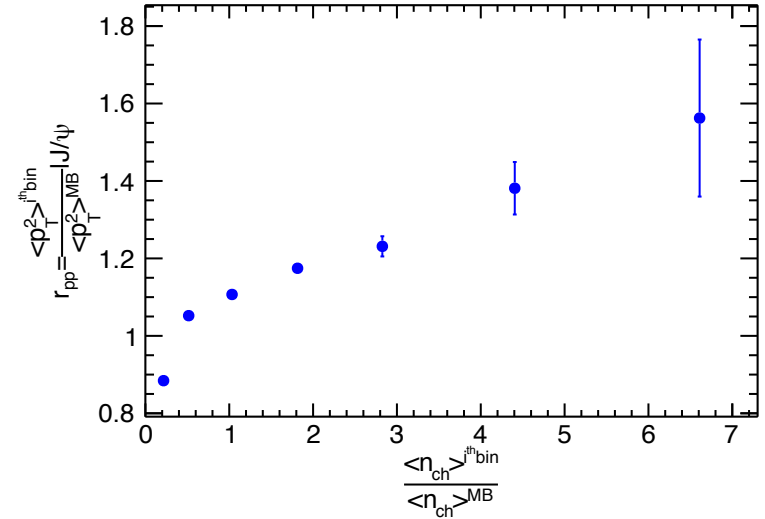
$$r_{pp} = \frac{\langle p_T^2 \rangle_{i^{th} bin}}{\langle p_T^2 \rangle_{MB}}$$

✓ $\langle p_T^2 \rangle_{i^{th} bin}$ = mean p_T of i^{th} multiplicity bin

✓ $\langle p_T^2 \rangle_{MB}$ = mean p_T of MB

- $\langle p_T^2 \rangle$ attributes toward the multi scattering of partons in the initial state. Hence, can be treated as random walk in transverse momentum space.
- $\langle p_T^2 \rangle$ is predicated to increase linearly with the mean path length of the traversed parton.
- At SPS almost all the measured J/ψ are produced via initial hard processes and the increase with centrality/multiplicity.

(arXiv:1808.01841)



(Nucl. Phys. A834(2010)249C)