Multiple Partonic Interactions and Production of Charmonia in proton+proton Collisions at the LHC energies

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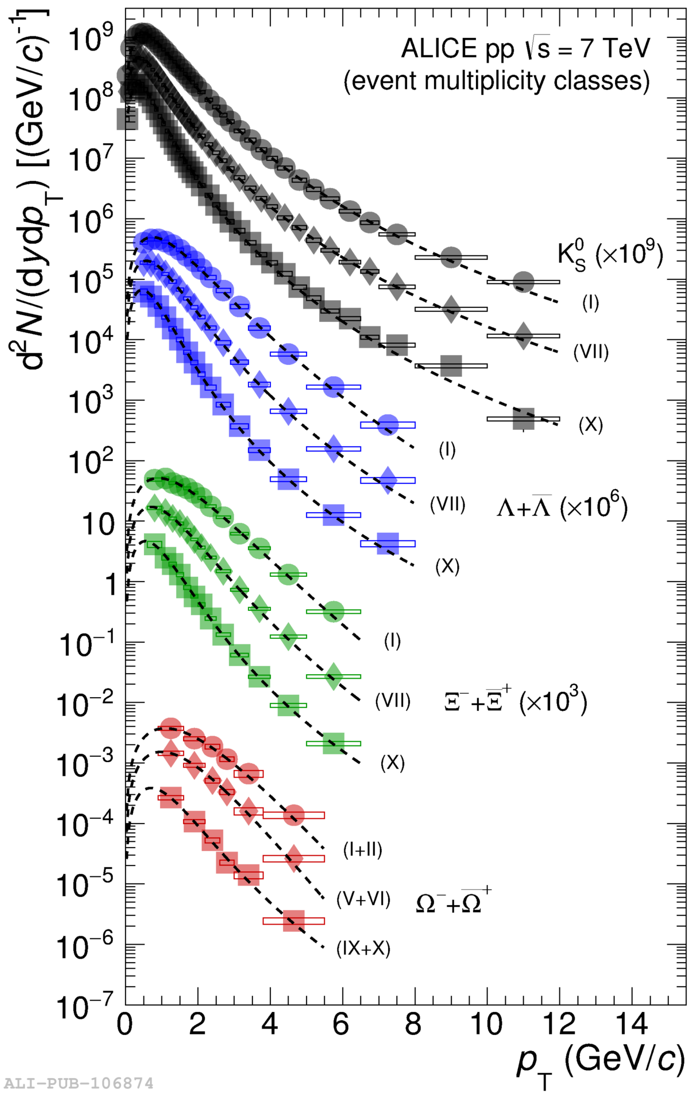
(arXiv: 1709.06358)

❑ Outline
- ❖ Introduction and motivation
- ❖ The Multiple Partonic Interactions
- ❖ Analysis details
- ❖ Results and Summary

Motivation: High Multiplicity pp Events



- ✓ Spectra becomes harder as multiplicity increases
- ✓ Hardening more pronounced for higher mass particles
- ✓ Similar observations like p-Pb and Pb+Pb showing collective behavior

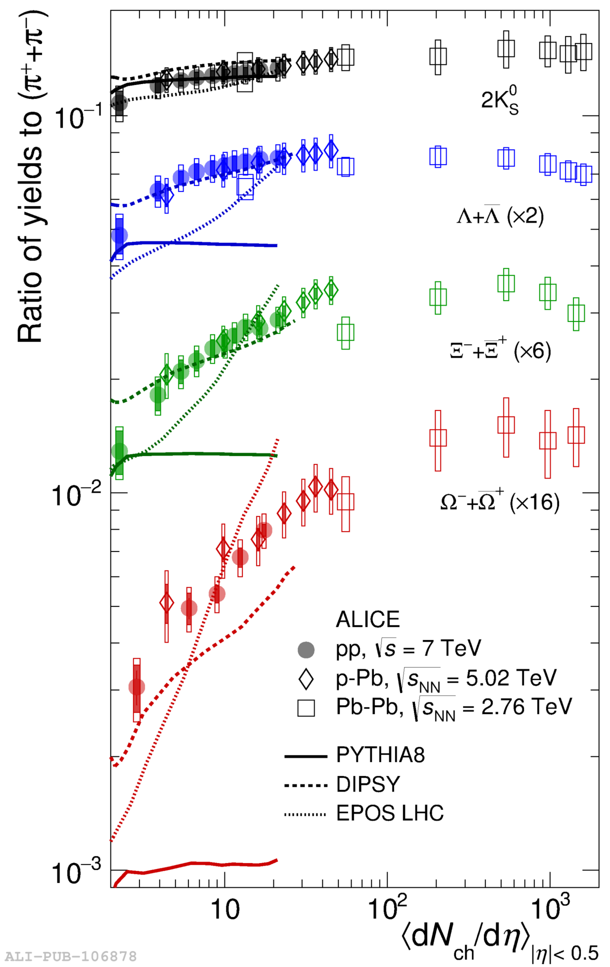
(In A+A collisions, this is described by relativistic hydrodynamics): p_T-distribution determined by particle emission from a collective expanding thermal source)

- ✓ Simultaneous fit: T_{fo} = 163 ± 10 MeV, $\langle \beta_T \rangle$ = 0.49 ± 0.02

→ Similar to same class of events in pPb with comparable $dN_{ch}/d\eta$

ALICE: Nature Phys. 13 (2017) 535

Motivation: High Multiplicity pp Events



✓ Significant enhancement of strange-to- non-strange ratio with particle multiplicity

Obs: σ_{inel} independent of energy at the LHC.

✓ Origin of strangeness production in hadronic collisions is driven by the characteristics of the final state rather than by the collision system and energy

✓ At high-multiplicity, the yield ratios reach values similar to that observed in Pb+Pb collisions

✓ Non-trivial Observation: Particle ratios in *pp* and pPb are identical at the same $dN_{ch}/d\eta$: final state particle density might be a good scaling variable between systems

ALICE: Nature Phys. 13 (2017) 535

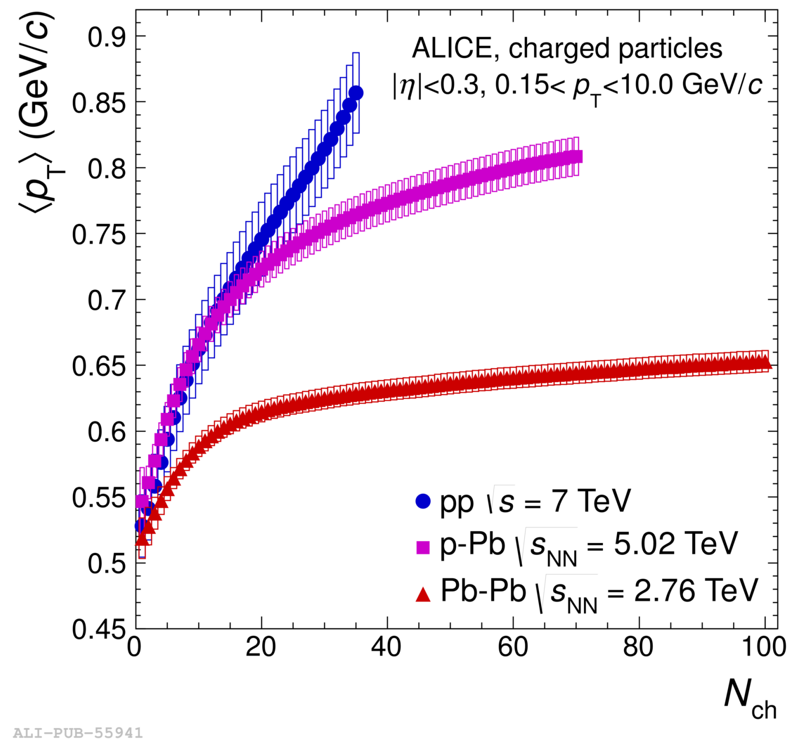
Motivation: High Multiplicity pp Events

There are several observables at the LHC, which need MPI and CR to have an understanding of the underlying mechanisms.

Flow-like phenomena in pp events with MPI and CR (G. Paic: PRL).

so on and so forth........

What about J/Ψ production in pp@LHC?



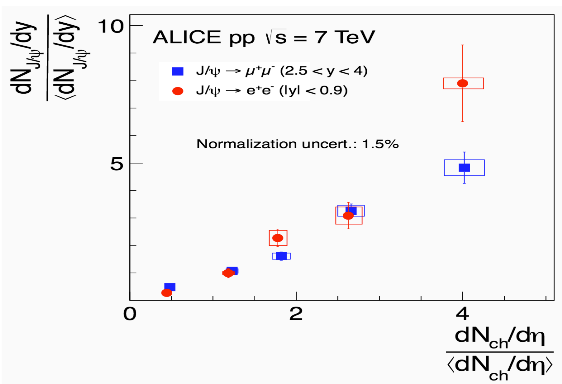
ALICE: Physics Letters B, 727, 371 (2013)

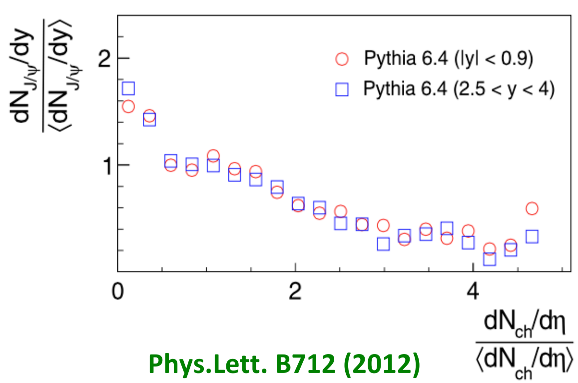
Motivation: Yield vs Multiplicity

❖ **The understanding of quarkonia production in hadronic collisions stays very interesting as always. Recently, event multiplicity dependence yield is of great interest**

❖ **It gives insight into the processes occurring in partonic level and provides interplay between the soft and hard mechanism**

❖ ***Results pp@7 TeV by ALICE***



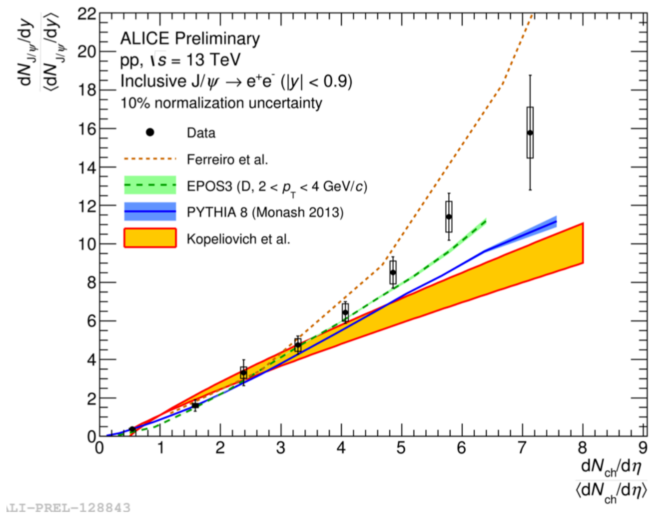


Phys.Lett. B712 (2012)

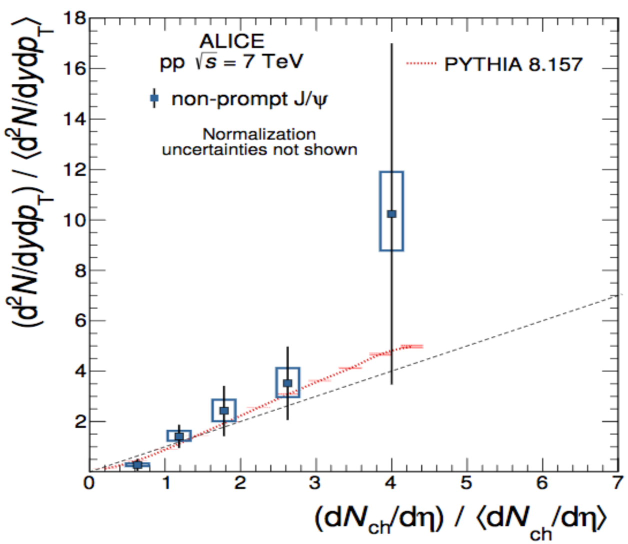
❖ **Possible explanations**

- **Several interactions at the partonic level in parallel (MPI), and hard-MPI leads to J/psi production**
- **Role of collision geometry**
- **Final-state effects like color reconnection, string percolation etc.**

Motivation: Recent ALICE Results



(Nuclear Physics A (2017) (QM17))



JHEP09(2015)148

- **Among all the models, EPOS3 is close to data**
- **PYTHIA8 well explains the behaviour up to $N_{ch} \approx 4.5$**

➢ **The results leave some curiosity**

- ✓ **Is the behavior 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?**

- ***To answer these questions up to certain extent, we try to study energy dependence of charmonia production using PYTHIA8, which includes MPI and CR***

PYTHIA8 Settings

- Advantages of PYTHIA8 over PYTHIA6 is inclusion of MPI in harder scale
  - Which can produce "c " and "b" quarks via first 2 -> 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

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 $p_T \rightarrow 0$

Analysis Procedure

- **J/Ψ is reconstructed via di-muon channel in 2.5 < y < 4.0 to compare with ALICE measurements**
- **The charged particles are measured at mid-rapidity: -1.0 < y < 1.0**
- **10^{10} events are generated for all the LHC energies**

Calculation

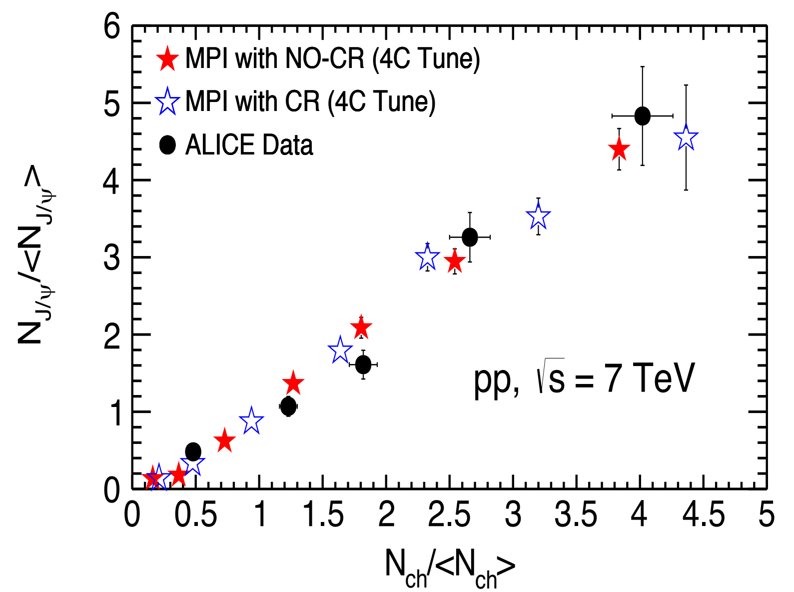
- **Relative charged particle = N_{ch}/<N_{ch}>**

  N_{ch} = mean of the charged particle multiplicity in multiplicity bins

  < Nch> = mean of the charged particle multiplicity in minimum bias events

- **Relative J/Ψ yield:** $$\frac{Y_{J/\psi}}{<Y_{J/\psi}>} = \frac{N^{i}_{J/\psi}}{N^{total}_{J/\psi}} \frac{N_{evt}}{N^{i}_{evt}}$$

  Here, *i* stands for *i*th multiplicity bin



- **MPI with CR and No-CR explain the ALICE data up to N_{ch} ≈ 4.5 for pp@7 TeV**
- **Keeping the same settings, we extend the study for all other LHC energies**

Study at all LHC energies

- The J/Ψ relative yield increases linearly with charged particle multiplicity

- Fitted with the percolation inspired function

$$\frac{Y_{J/\psi}}{< Y_{J/\psi} >} = A[Bx + Cx^2 + Dx^n],$$

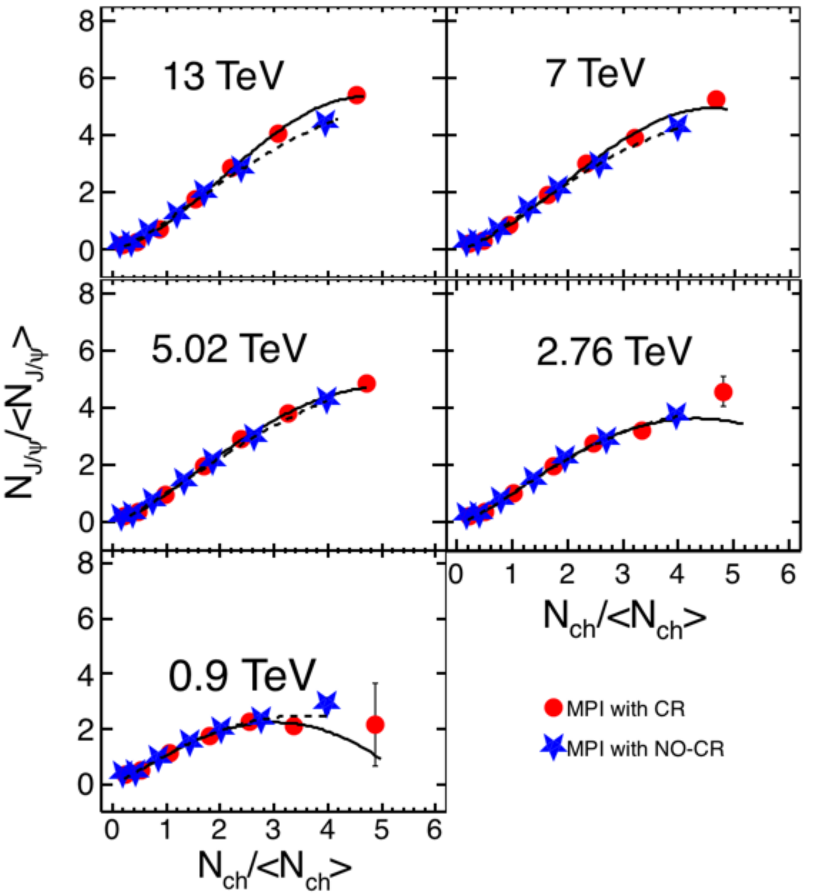
(Detail will be discussed in the next slide)

According to percolation theory

$$\frac{n_{J/\psi}}{< n_{J/\psi} >} = (1- < \rho >)\left(\frac{\frac{dN}{d\eta}}{< \frac{dN}{d\eta} >}\right) + < \rho > \left(\frac{\frac{dN}{d\eta}}{< \frac{dN}{d\eta} >}\right)^2$$

- The saturation of relative J/Ψ yield towards higher multiplicity bins needs to be understood

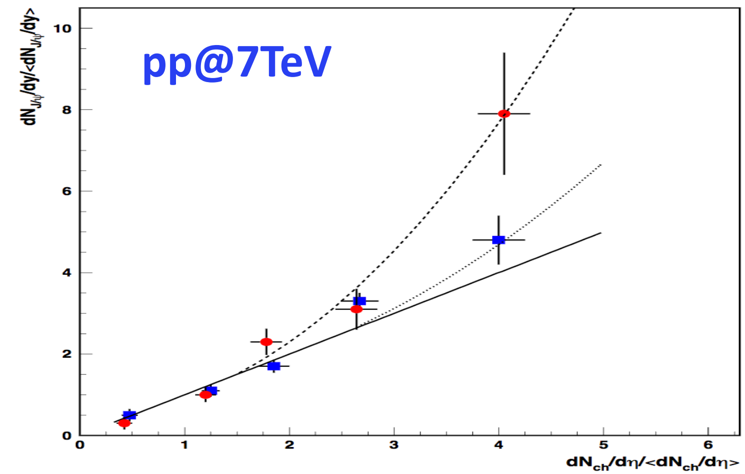
- The CR effect on J/Ψ production is more prominent at higher multiplicity and higher CM energies



The percolation inspired function

- String percolation theory has been successful in describing J/Ψ relative yield as a function of charged particle multiplicity (ALICE)

$$\frac{n_{J/\psi}}{<n_{J/\psi}>} = (1-<\rho>)\left(\frac{\frac{dN}{d\eta}}{<\frac{dN}{d\eta}>}\right) + <\rho>\left(\frac{\frac{dN}{d\eta}}{<\frac{dN}{d\eta}>}\right)^2$$

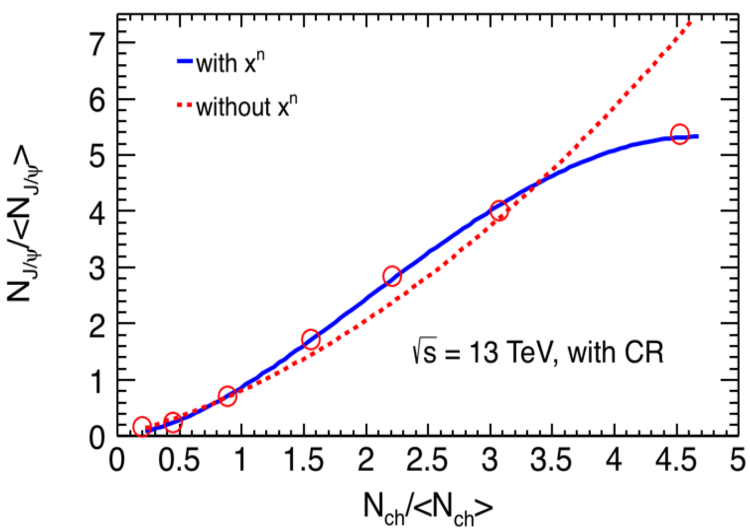


(PhysRevC.86.034903)

- PYTHIA8 results show saturation towards higher multiplicities. An extra term x^n takes care of the effect

$$\frac{Y_{J/\psi}}{<Y_{J/\psi}>} = A[Bx + Cx^2 + Dx^n],$$

- Experimental data of other energies need to be understood to validate the percolation/tuning PYTHIA8 in describing J/psi production



Quantifying CR effect on J/Ψ production

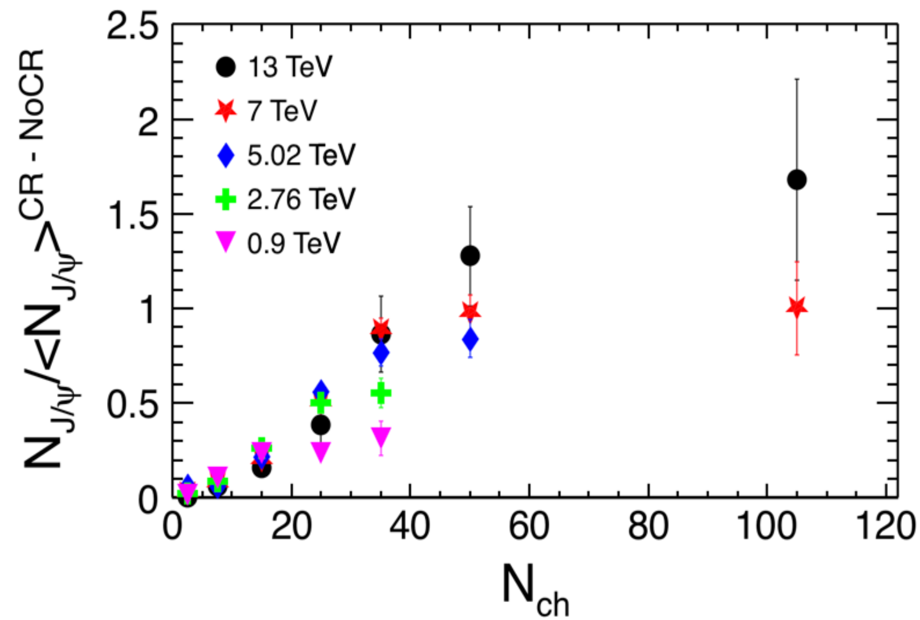
- The Color reconnection has more contribution to J/Ψ production at higher multiplicities as well as higher center of mass energies

➢ Expected reasons

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

➢ In hadronic collisions

- ✓ At the partonic level, hard-MPIs have significant contribution to J/Ψ production
- ✓ At the final state, CR has less contribution to J/Ψ production



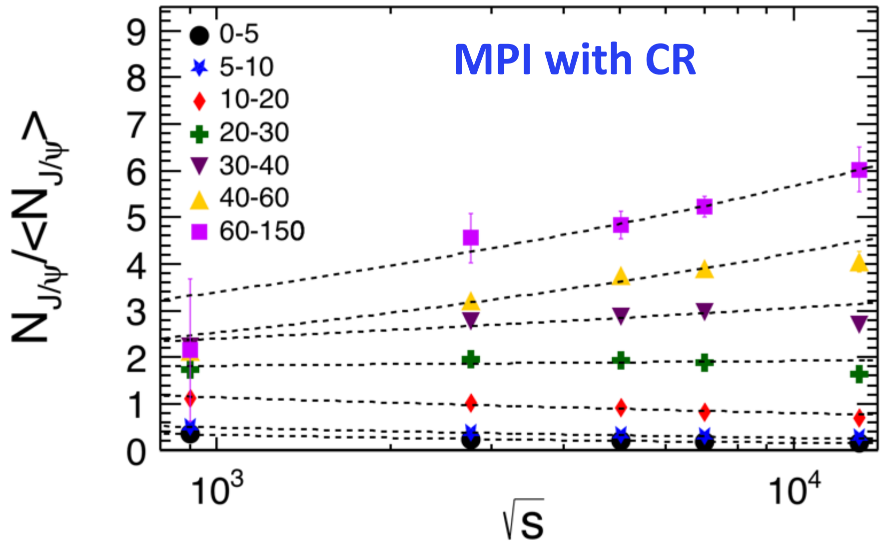
Energy dependence of J/Ψ production

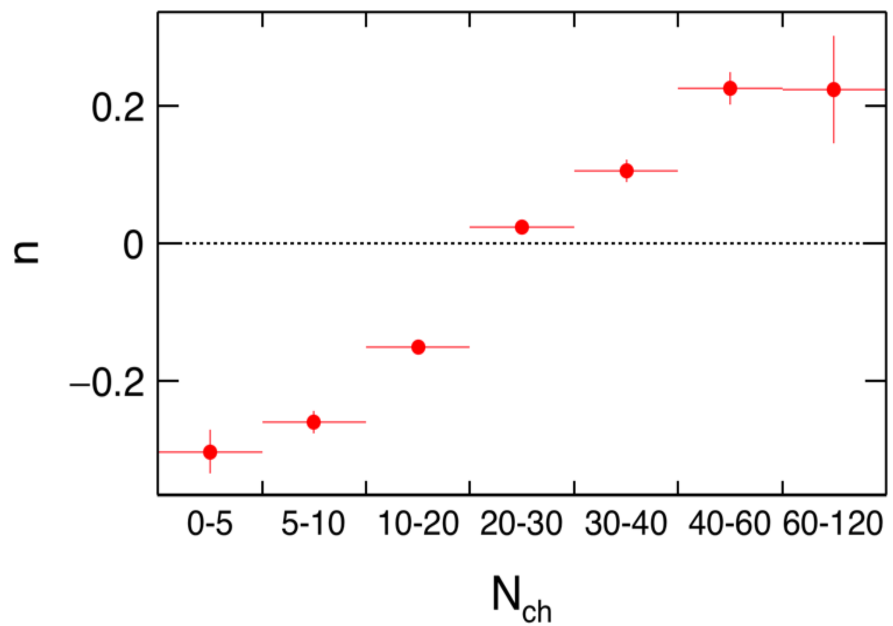
- The hard-MPIs increase with center of mass energy

- To get a qualitative idea: fitting with $f(x) = A x^n$
  → indicates the rate of increase of relative J/Ψ with √s

- n is negative for $N_{ch} < 20$
  positive for $N_{ch} > 20$

- $N_{ch} \approx 20$ is the threshold number of charged particle multiplicity in the final state for substantial MPI effects on the charmonia production





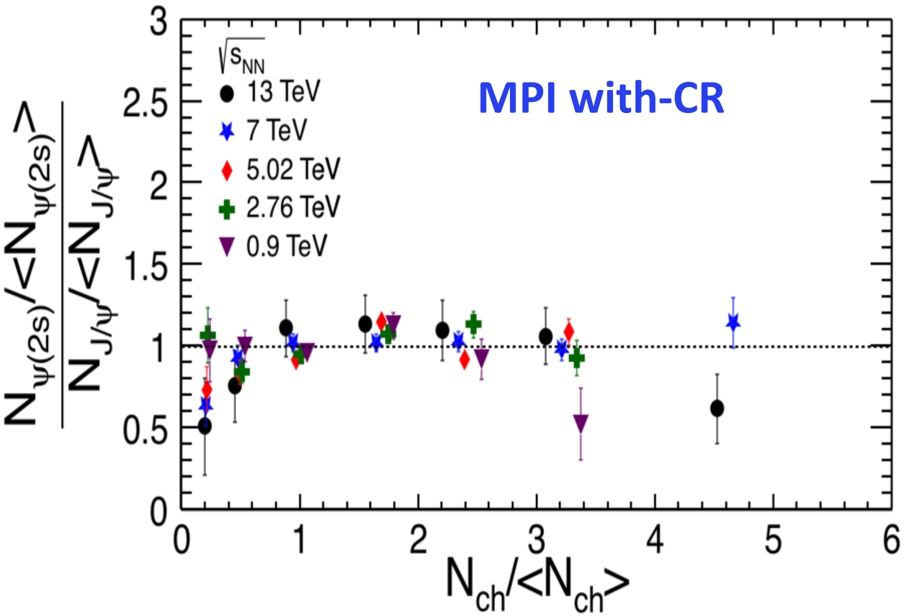
Ratio of Ψ(2S) to Ψ(1S) as a function of multiplicity

- Ψ(2S) as a function multiplicity behaves similarly like J/Ψ as a function of multiplicity

- The ratio of Ψ(2S) to J/Ψ is calculated as

$$\frac{Y_{\psi(2S)}/<Y_{\psi(2S)}>}{Y_{J/\psi}/<Y_{J/\psi}>} = \frac{N_{\psi}^{total}}{N_{J/\psi}^{total}}\frac{N_{J/\psi}^{i}}{N_{\psi}^{i}}$$

$N_{\psi}^{total}/N_{J/\psi}^{total}$ is fixed for a particular center of mass energy



- The Ψ(2S) and J/Ψ are produced almost in equal proportion in each multiplicity bins

Summary

- pp@LHC: MPI drives the the quarkonia production with little effect of CR: final state
- CR has effect at higher multiplicity classes and higher collision energies
- $N_{ch} \approx 20$ is the threshold number of charged particle multiplicity in the final state for substantial MPI effects on the charmonia production
- The Ψ(2S) and J/Ψ are produced almost in equal proportion in each multiplicity bins

Thank you very much.