J/ψ production as a function of charged particle multiplicity in ALICE at the LHC

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Outline

- J/ψ production in hadronic collisions
- Event multiplicity dependence of J/ψ production
- Detector used for the analysis
- Analysis methodology
- Results from pp collisions at $\sqrt{s}$ = 7 and 13 TeV
- Results from p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV
- Summary

J/ψ production in hadronic collisions

- ❖ Charmonium production in hadronic collisions is a complex process and still debated in the scientific community

  - ➢ There are mainly three theoretical frameworks used to describe the charmonium production in hadronic collisions
    - ✓ Color Evaporation Model (CEM) (Halzen F 1977 Phys. Lett. B69 105 – 108 ISSN 0370-2693)
    - ✓ Color Singlet Model (CSM) (Einhorn M B and Ellis S D 1975 Phys. Rev. D12(7) 2007–2014)
    - ✓ Non-Relativistic Quantum Chromo-Dynamics Model (NRQCD) (Ma et al., PRL 106 (2011) 042002)

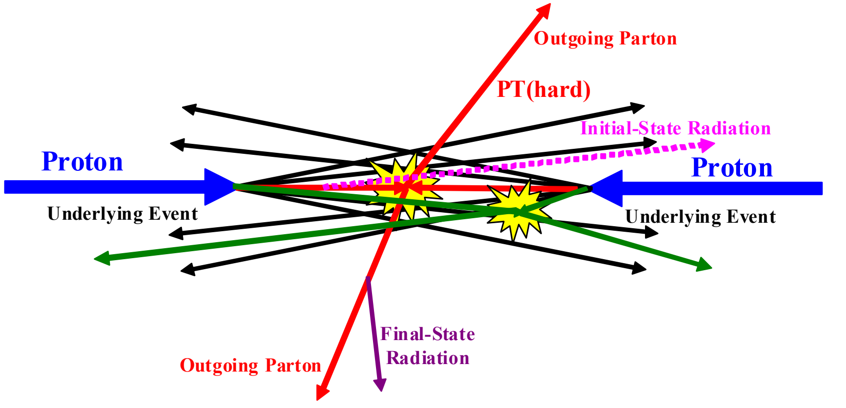
  - ➢ These models make prediction on transverse momentum and energy dependence of J/ψ production as well as polarization in hadronic collisions

  - ➢ At the LHC, J/ψ production versus event multiplicity is of great interest
    - ✓ Provides insight into contribution from multiple-parton interactions and interplay between soft and hard processes
    - ✓ Useful to address onset of collective effects in high multiplicity events

- ❖ J/ψ production versus event multiplicity in p-Pb collision helps in understanding CNM effects and serves as a bridge between pp and AA systems

Event multiplicity dependence of J/ψ production

- Several interactions- soft and hard, occur in parallel, known as Multiparton Interactions (MPI)



- High charged-particle multiplicity may be used as an indicator of MPI

- Understanding of elementary interaction in pp collisions is crucial:
  - ✓ Interplay of soft-hard
  - ✓ MPI structure
  - ✓ Underlying event (UE)

- If MPI relevant for J/ψ production: J/ψ yield should increase with multiplicity

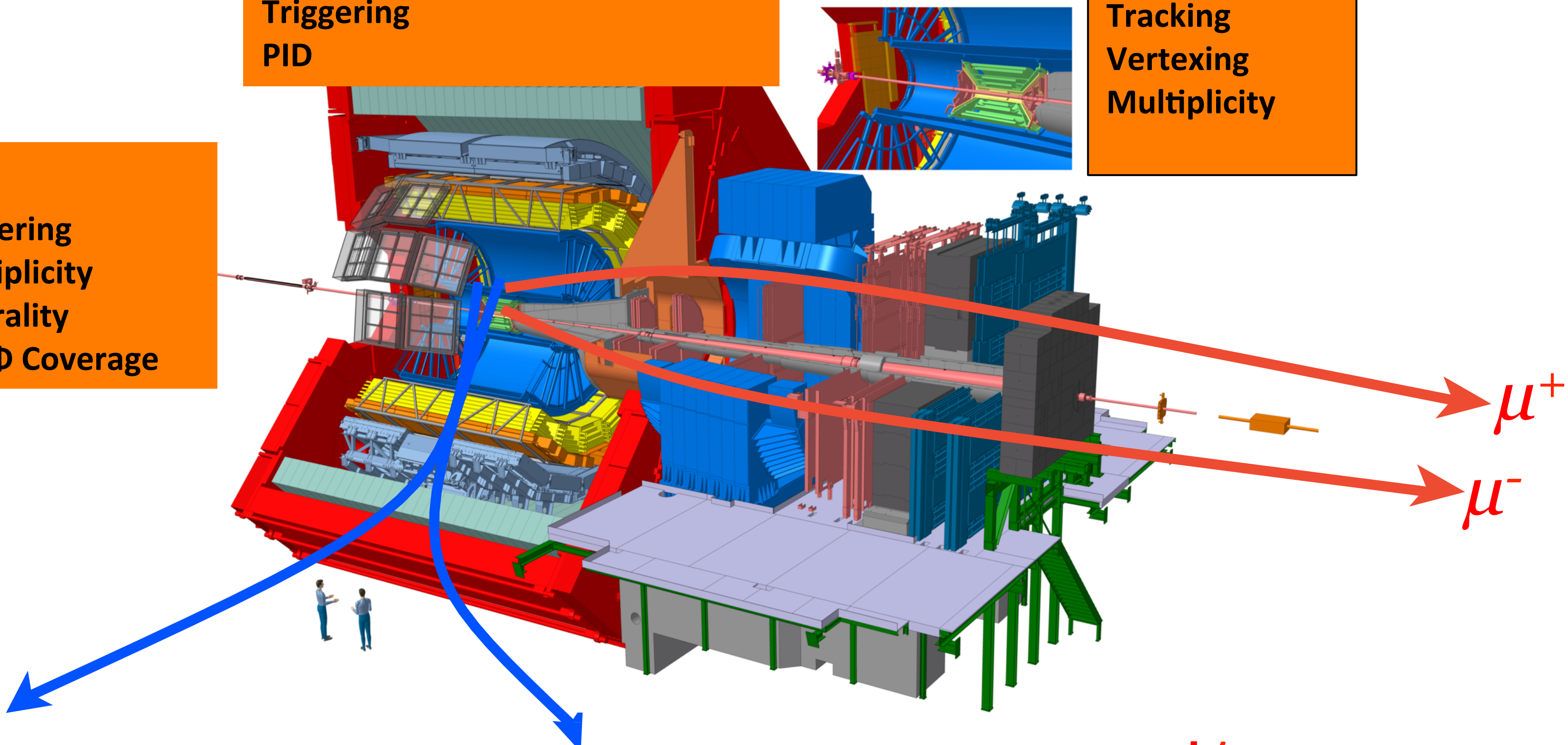
- Charged particle multiplicity dependence of J/ψ yield provides an insight into the processes of interplay between the soft and hard mechanism

The ALICE Detector

EMCAL
High momentum electron
Triggering
PID

ITS
Tracking
Vertexing
Multiplicity

V0
Triggering
Multiplicity
Centrality
Full Φ Coverage



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

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

TPC
-0.9 < η < 0.9
Di-e: **p_T > 0 GeV/*c***
Single-e: p_T > 0.2 GeV/*c*

ALICE Central barrel
|η| < 0.9
Full azimuthal coverage

MUON
-4.0 < η < -2.5
Di-μ: **p_T > 0 GeV/*c***
Single-μ: p_T > 0.5 GeV/*c*

Analysis strategy

Event Selection

- Pile Up rejection
- Silicon Pixel Detector for charged particle and vertex determination
- $|Z_{vertex}|$ > 10.0 cm (for di-electron analysis and charged particle determination)

$J/\psi \rightarrow e^{+}e^{-}$

- MB trigger
- $-0.9 < \eta < 0.9$
- Track quality cuts
- Rejection of tracks from photon conversion
- TPC electron identification

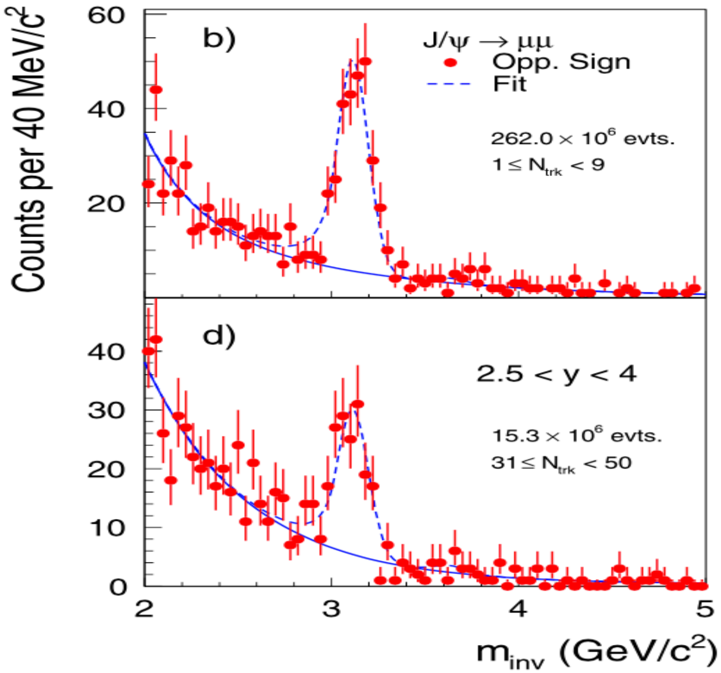
$J/\psi \rightarrow \mu^{+}\mu^{-}$

- Dimuon trigger: MB and two opposite sign muon tracks
- $-4.0 < \eta < -2.5$
- 17.6 cm < R_{abs} < 89.5 cm

(R_{abs} = Radial position of the track at the end of the absorber)

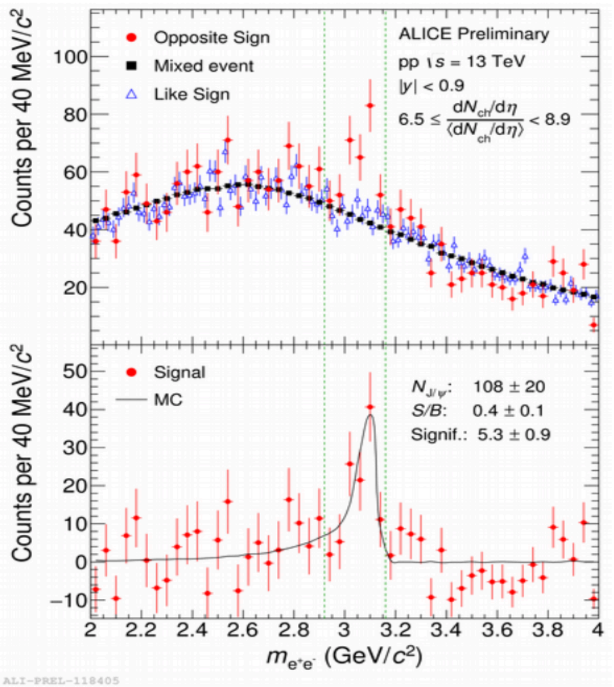
Signal Extraction

Dimuon pp@7 TeV



Physics Letters B 712 (2012)

Dielectron pp@13 TeV



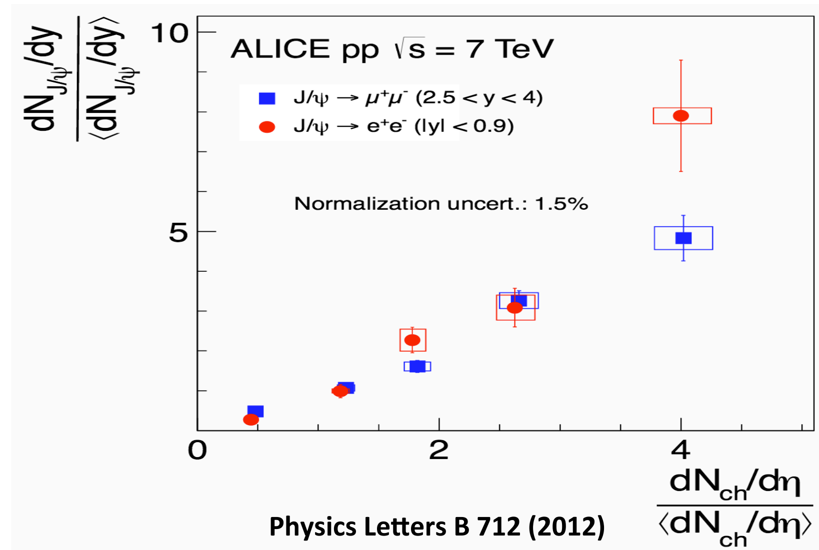
- **Signal:**
  Extended Crystal Ball
- **Background:**
  variable-width Gaussian, sum of two exponential

- **Signal:**
  bin by bin counting in 2.92 - 3.16 GeV/c^2
- **Background:**
  Subtracted using normalized like-sign pair distribution

Relative J/ψ yield vs. multiplicity in pp@7 TeV

❖ **The relative J/ψ is increasing faster than charged particle multiplicity**

➢ **For events having 4 times the average N_{ch}, the relative J/ψ increase is a factor 5 at forward rapidity and a factor 8 at mid rapidity**



Physics Letters B 712 (2012)

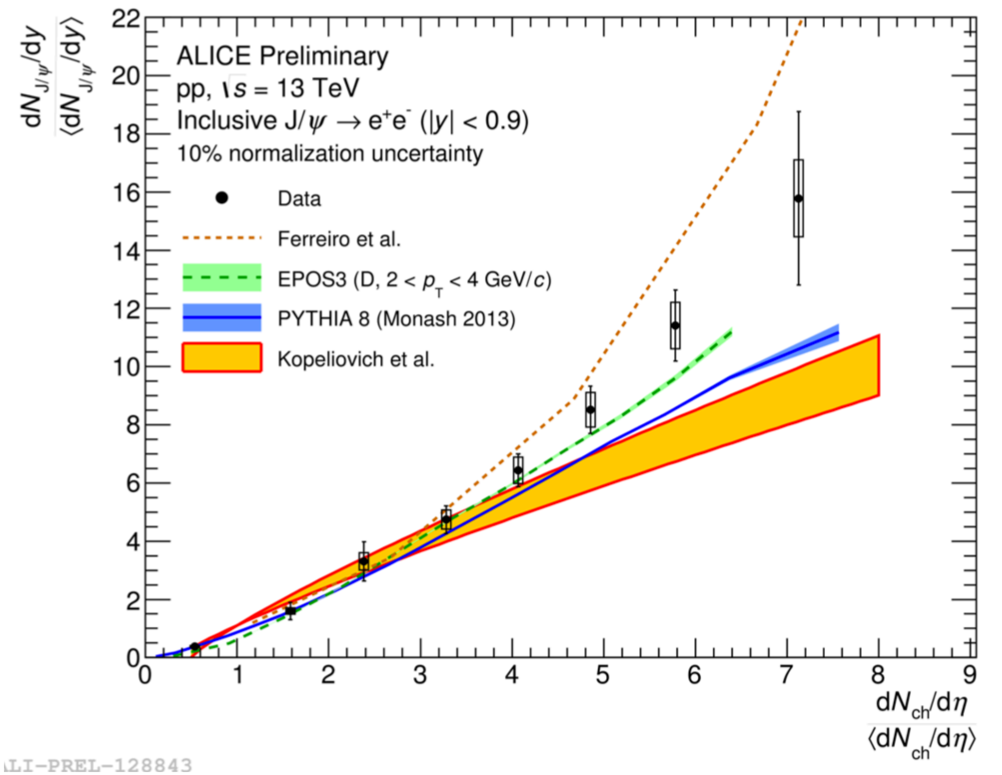
❖ **The increase of J/ψ production with event multiplicity might be due to MPI**

Relative J/ψ yield vs. multiplicity in pp@13 TeV

❖ Stronger than linear increase of J/ψ yield is observed towards higher multiplicity

❖ Possible explanations

- Multiple parton interaction (PYTHIA8)
- Hydrodynamical evolution (EPOS3)
- Contributions of higher Fock states
- String percolation



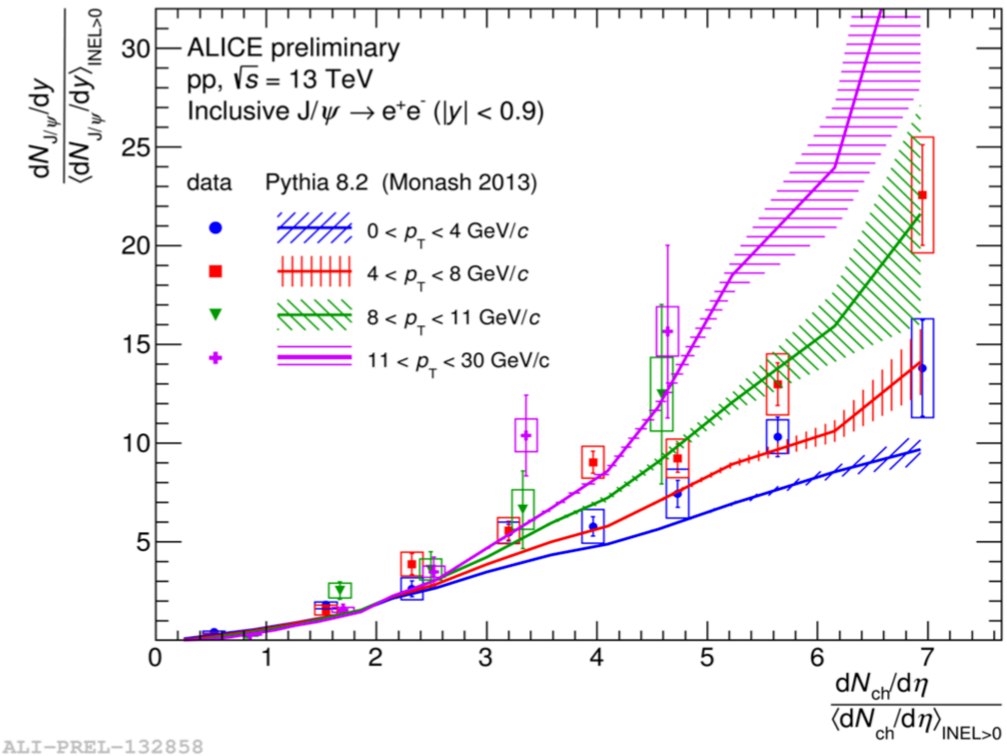
Ferreiro PRC86 (2012) 034903
EPOS3 Phys. Rept.350 (2001) 93
PYTHIA8 Comput. Phys.Commun. 178(2008)852
Kopeliovich PRD88 (2013) 116002

Transverse momentum dependence

- Multiplicity dependence study done in four p_T intervals

- The higher p_T analysis is done using EMCAL triggered data

- The behavior of J/ψ production as a function of multiplicity is steeper at higher transverse momenta

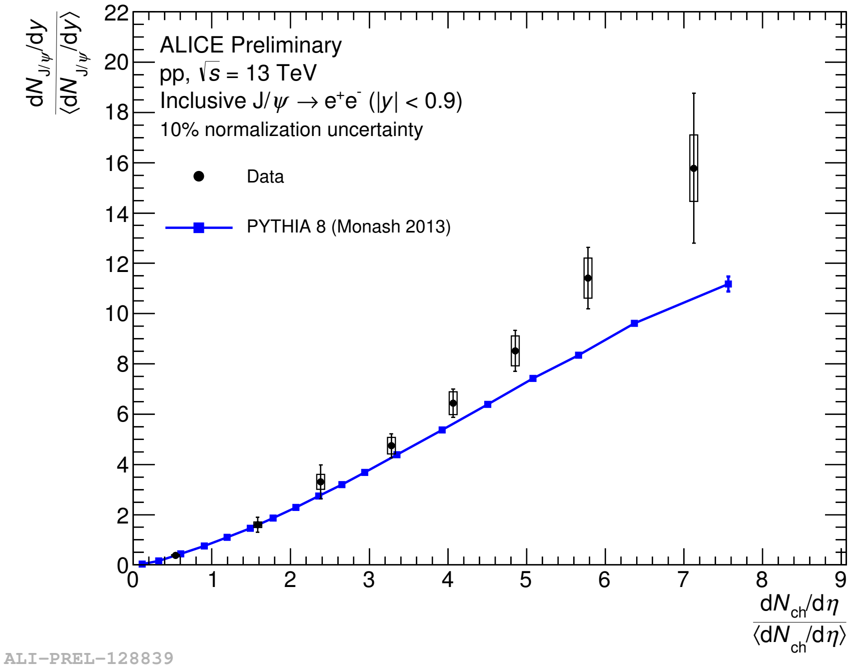


- The p_T dependence behavior is well explained by PYTHIA8 which includes MPI processes. Thus it indicates the importance of MPI in hadronic collisions

What PYTHIA8 tells us ?

❖ **J/ψ production has contributions from dedicated processes in PYTHIA8:**

- ➢ **Initial *c* or *b* quarks originate via first hardest 2->2 partonic interactions**
- ➢ **Has finite production probability from the subsequent hard processes in MPI**
- ➢ **Heavy quarks from gluon splitting**
- ➢ **Gluons from initial/final state radiations**
- ➢ **Color reconnection (at hadronization state)**

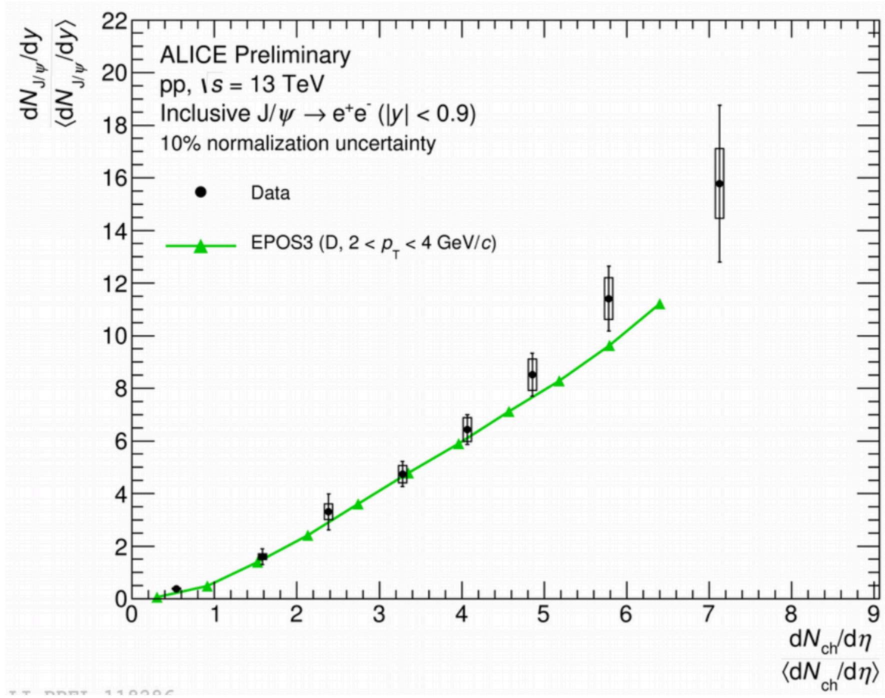


❖ **The events with small number of MPI contribute to the low multiplicity interval, while high multiplicity events are dominated by a large number of MPI**

❖ **Monash 2013 tuned PYTHIA8 describes well the data in the low multiplicity region**

What EPOS3 tells us ?

- ❖ EPOS3 imposes the same theoretical scheme in pp, pA and AA systems
- ❖ Initial conditions followed by a hydrodynamical evolution
- ❖ Initial conditions based on "Gribov-Regge" formalism. Multiple interaction occurs in parallel



- ❖ The good description of the data with EPOS3 model shows that the energy density reached in pp collisions at the LHC is high enough to apply hydrodynamical evolution

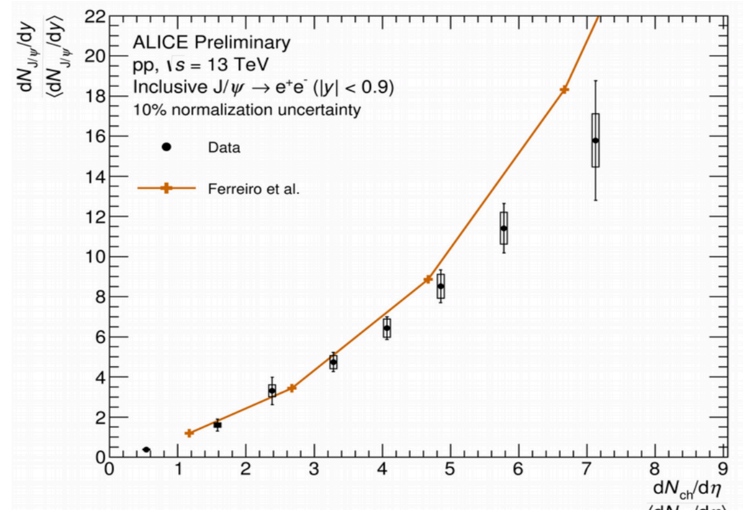
What Percolation tells us ?

- High-energy hadronic collisions are driven by the exchange of color sources (strings) between the projectile and the target

- The number of parton-parton collisions is reflected as the number of produced strings (N_s)
  - J/ψ multiplicity α N_s
  - Charged particle multiplicity α $\sqrt{N_s}$

$$\frac{\frac{dN}{d\eta}}{\left\langle\frac{dN}{d\eta}\right\rangle} = \left(\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle}\right)^{1/2}\left[\frac{1-e^{-\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle}\langle\rho\rangle}}{1-e^{-\langle\rho\rangle}}\right]^{1/2}$$

$$\langle\rho\rangle = \langle N_s\rangle\frac{\sigma_0}{\sigma}.$$



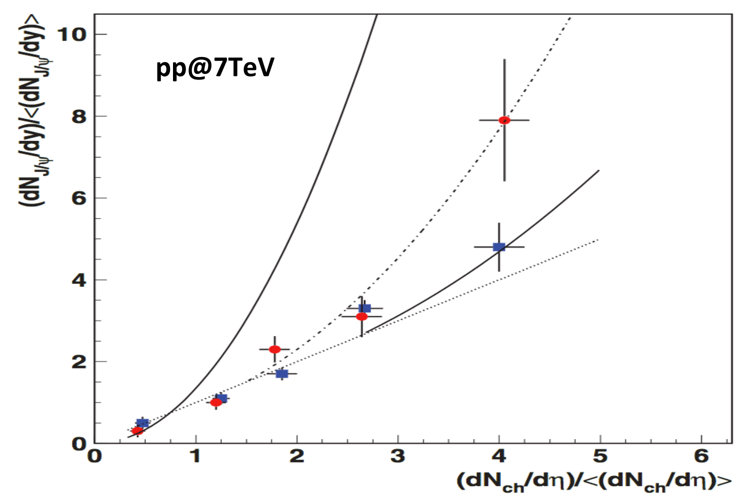
Model: Phys.Rev. C86 (2012) 034903

At Low multiplicity

$$\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle} = \frac{\frac{dN}{d\eta}}{\left\langle\frac{dN}{d\eta}\right\rangle}$$

At High multiplicity

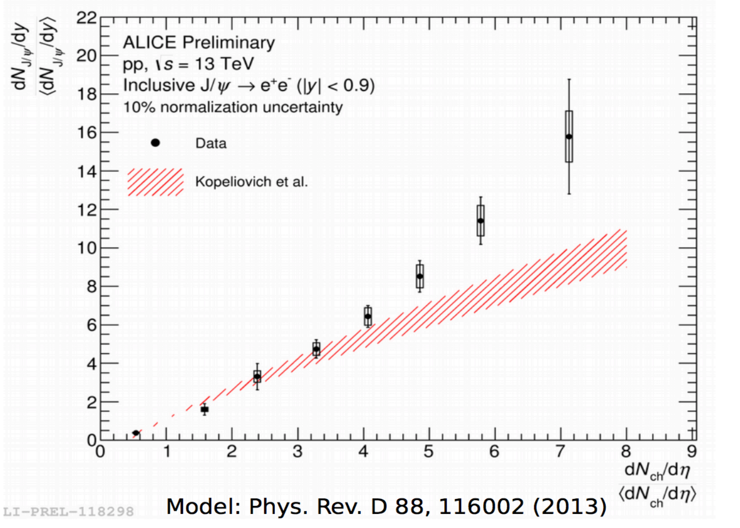
$$\frac{n_{J/\psi}}{\langle n_{J/\psi}\rangle} = \langle\rho\rangle\left(\frac{\frac{dN}{d\eta}}{\left\langle\frac{dN}{d\eta}\right\rangle}\right)^2$$



PRC86 (2012) 034903

What higher Fock states tell us ?

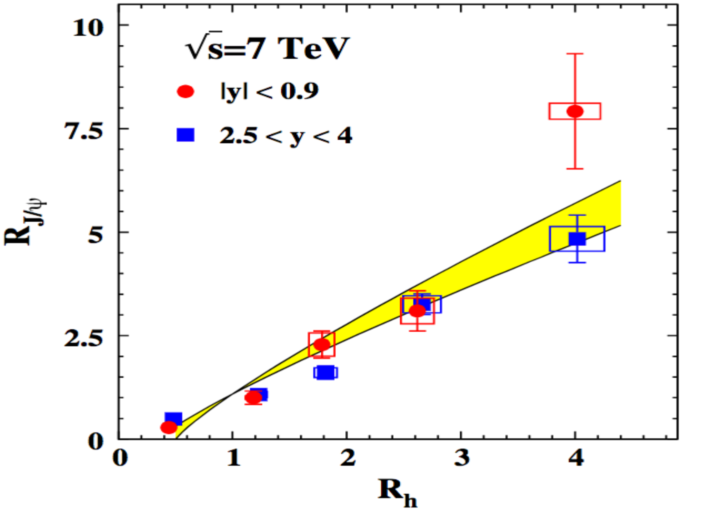
- **Higher Fock component:** **In high energy nuclei, gluons at small-x overlap longitudinally, act as a single source of gluons**
- **The inelastic collisions of the Fock components lead to high hadron multiplicity**
- **The relative production of J/ψ is enhanced in such gluon-rich collisions**



Model: Phys. Rev. D 88, 116002 (2013)

$$R_h^{pp} \equiv \frac{dN_h^{pp}/dy}{\langle dN_h^{pp}/dy \rangle},$$

$$R_{J/\Psi}^{pp} \equiv \frac{dN_{J/\Psi}^{pp}/dy}{\langle dN_{J/\Psi}^{pp}/dy \rangle},$$

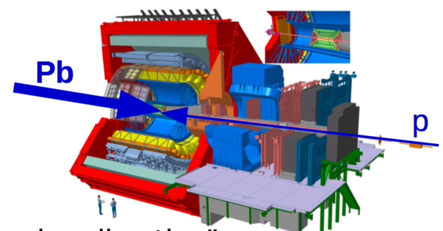


- **More gluons participating in collisions with $R_h^{pp} > 1$, explains why $R_{pp}^{J/\Psi}$ rises with increasing R_h**

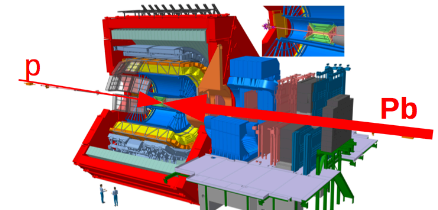
PRD88 (2013) 116002

Relative J/ψ yield vs. multiplicity in p-Pb@5.02 TeV

When going from pp to p-Pb



"Pb-going direction"

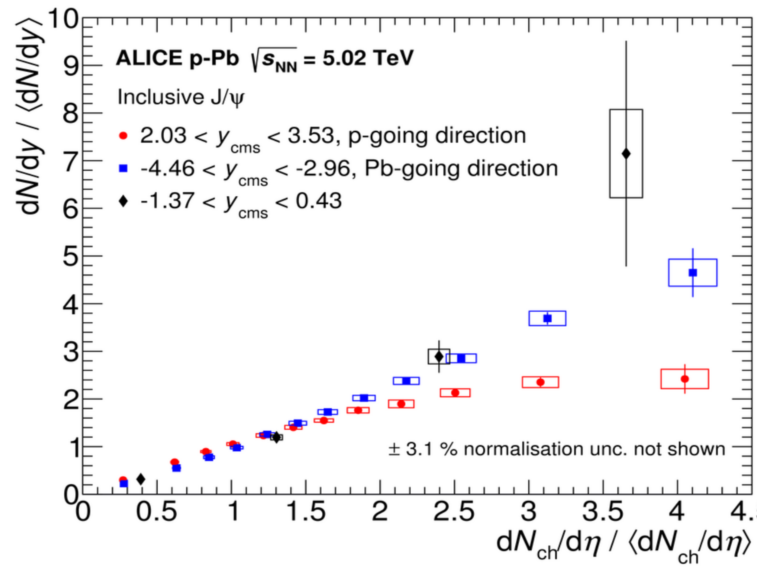


"p-going direction"

- **Stronger increase of relative J/ψ yields at forward and backward rapidity with relative multiplicity**

- **p going direction: A trend towards saturation at high multiplicity**

- **Pb going direction: Similar trend as that of pp**



arXiv:1704.00274 (Accepted by PLB)

- **The present data impose strong constraints on theoretical models of J/ψ production in p-Pb collisions**

- **Helps in understanding the connection between pp and Pb-Pb collisions.**

Summary

ALICE has measured J/ψ production in pp collisions at 7 and 13 TeV, and p-Pb collisions at 5.02 TeV at forward and backward rapidities.

- **Event generators including MPI reproduce well the data, thus revealing the importance of MPI in hadronic collisions**

- **The p-Pb results will help to understand J/ψ production from pp to Pb-Pb collisions**

Thank you !!