The measurement of J/ψ production as a function of multiplicity in pp and p-Pb collisions with ALICE

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Outline

- Motivation
- Multiplicity Dependence
- Theoretical Approaches
- Results from Run-1
- Results from Run-2
- Conclusion and Outlook

Motivation

Why J/ψ production studied in ALICE ?

In pp collisions:

- Provide a crucial test for hadronisation models and QCD.
- As a baseline for p-Pb and Pb-Pb measurements.

In p-Pb collisions:

- To study the Cold Nuclear Matter (CNM) effects.
  - such as gluon shadowing, gluon saturation, coherent parton energy loss, nuclear absorption.
- As a reference for Pb-Pb measurements.

In Pb-Pb collisions:

- To probe the formation of QGP.

1. J/ψ suppression [T.Matsui and H.Satz,PLB178 (1986) pp.416-422].
2. (re)generation of charmonium. [R.Thews et al., PRC63 (2001) 054905] & [P. Braun-Munzinger et al., PLB490 (2000) 196-202].

Multiplicity dependence

Why Study multiplicity?

- To study general properties of collisions [ALICE arXiv: 1704.00274].
- To find out the collective behaviour in a small systems like pp & p-Pb collisions.
- To understand the effect of Multiple Parton Interactions (MPI) .
- MPIs contribution to hard processes [Sjöstrand & van Zijl, PRD36 (1987) 2019].

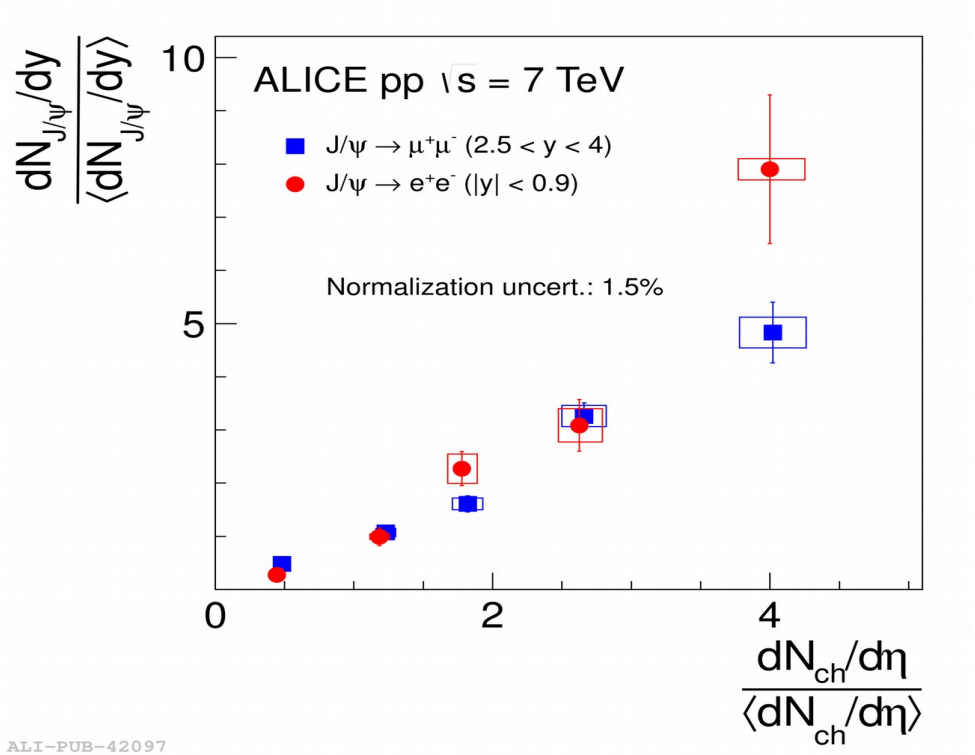
Soft vs hard processes :

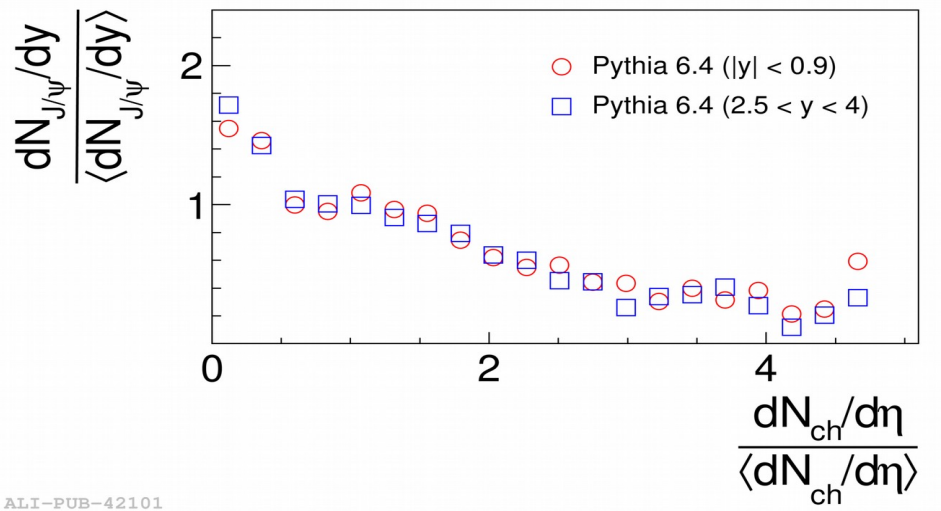
- Correlation between soft and hard processes.
- Role of MPIs in soft & hard particle multiplicity .

Studies performed in ALICE :

- Verified for D meson & J/ψ production [ALICE, JHEP 09 (2015) 148].
- Effects related to MPIs observed in pp might be also relevant in p-Pb collisions.

J/ψ yield vs multiplicity in pp collisions at 7 TeV





ALICE PLB712 (2012) 165

- First observation in pp collisions with ALICE. Motivation for further studies on J/ψ vs multiplicity.
- Linear increase of the relative J/ψ yield as a function of relative multiplicity.
- J/ψ produced only in hard processes via NRQCD do not reproduce the trend in PYTHIA 6.4.25 (Perugia 2011) calculations.

Theoretical Interpretations

PYTHIA8 simulation:

[Comput.Phys.Commun.178 (2008) 852–867]

- First hard process.
- Hard processes in MPI.
- Gluon splitting.
- Initial/final state radiation.

EPOS3:

[Phys.Rept. 350 (2001) 93–289]

- Gribov-Regge formalism (MPI included).
- Hydro evolution of the system.

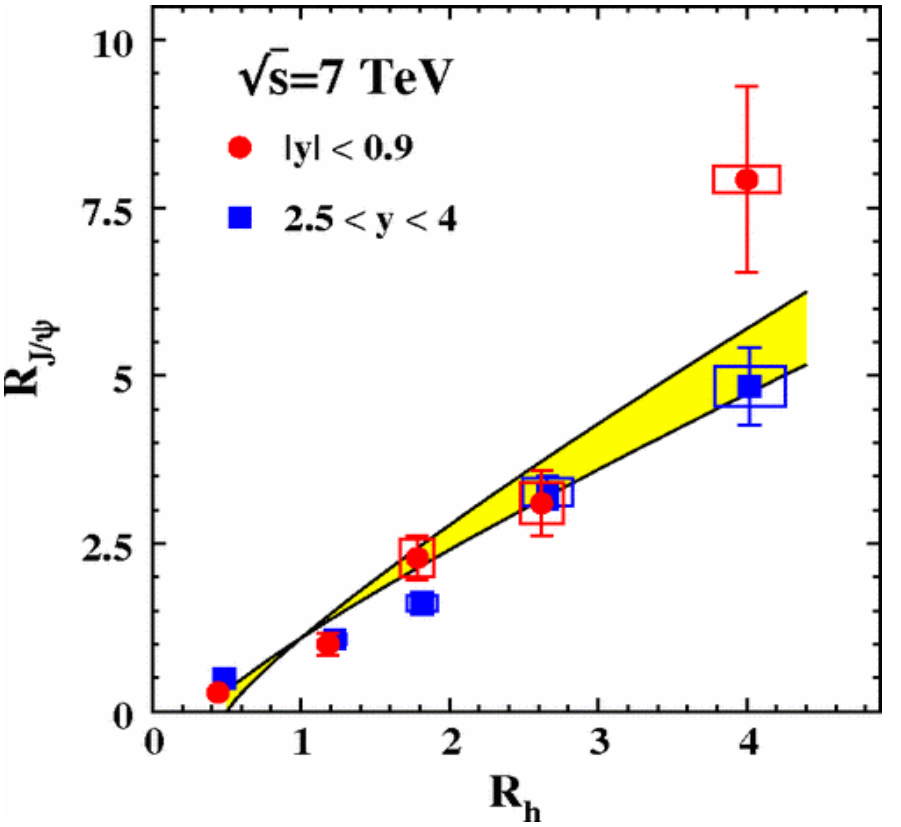
Percolation model:

[PRC86 (2012)034903]

- Linear increase at low density.
- Quadratic increase at higher density.

Kopeliovich et al:

- Contributions of higher Fock states to reach high multiplicity in pp.
- Higher number of gluons → J/ψ rate also enhanced.



ALICE,JHEP 09 (2015) 148

B.Z. Kopeliovich et al.
PRD 88, 116002 (2013)

J/ψ measurement with ALICE

J/ψ → $e^+ + e^-$ (Central Barrel: **|η|< 0.9**)

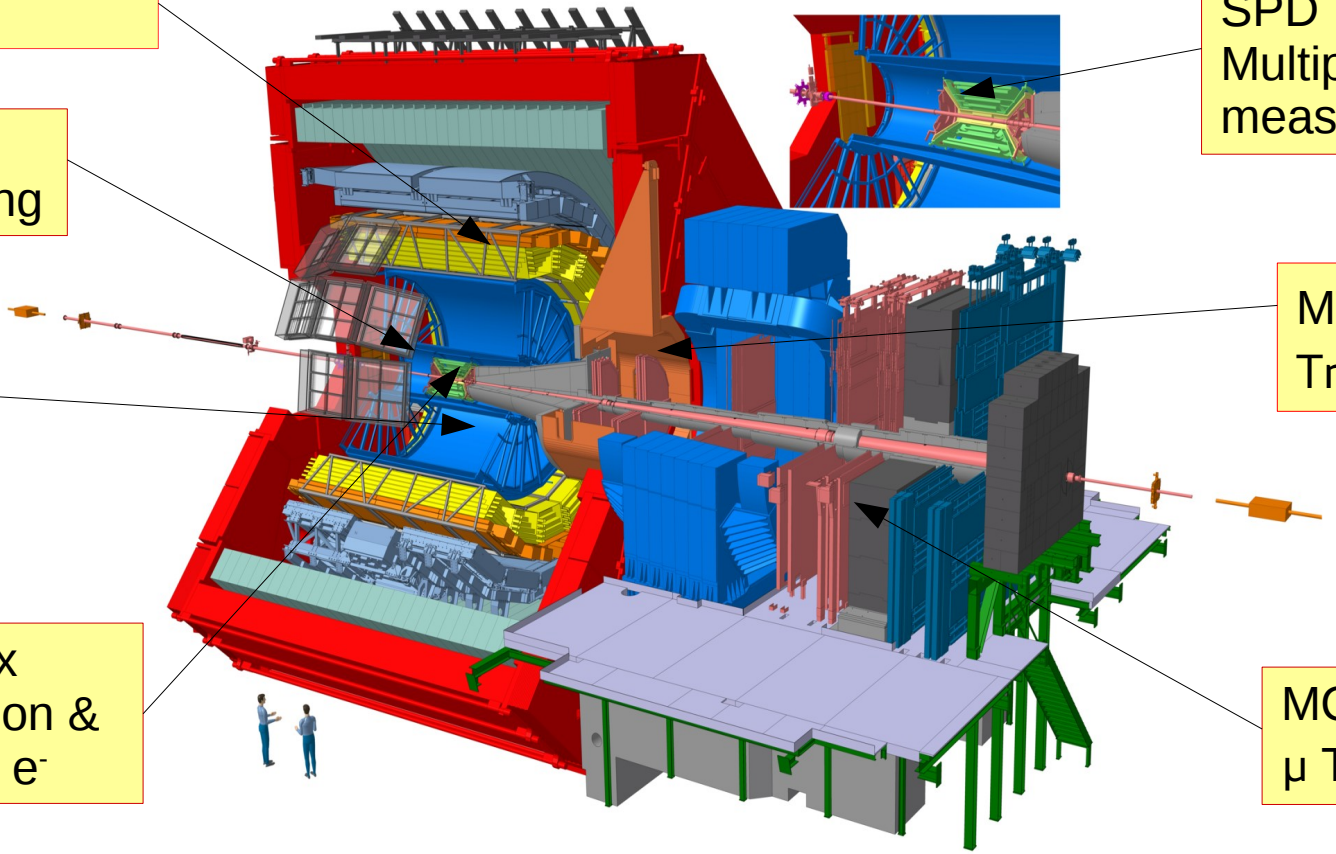
→ $\mu^+ + \mu^-$ (Muon Spectrometer: **-4.0 < η < -2.5**)

EMCAL : trigger, electron ID

T0,V0 : Triggering

TPC : Tracking & PID

ITS : Vertex reconstruction & tracking e^+ , e^-



SPD : Multiplicity measurement

MTR : μ Tracking

MCH : μ Trigger

Experimental Method: Track Selection

Electron Channel

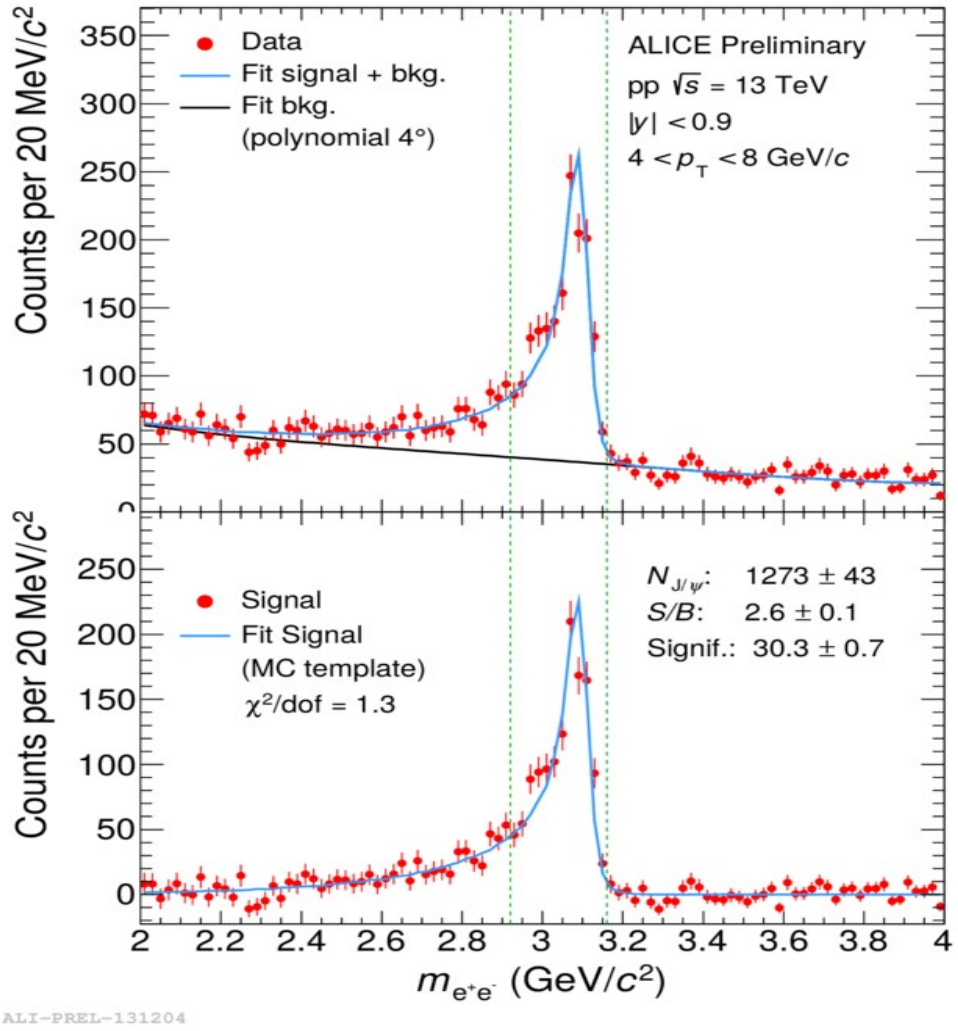
- V0 triggered events for MB & high multiplicity events.
- EMCAL triggered events for high p_T J/ψ analysis.
- Electron identification & hadron rejection via specific energy loss in TPC.
- $|\eta| < 0.9$
- DCA cut and SPD hit requirement.
- Reduce combinatorial background by rejecting electron originating from a photon conversion or from other sources of low mass dielectron.

Muon Channel

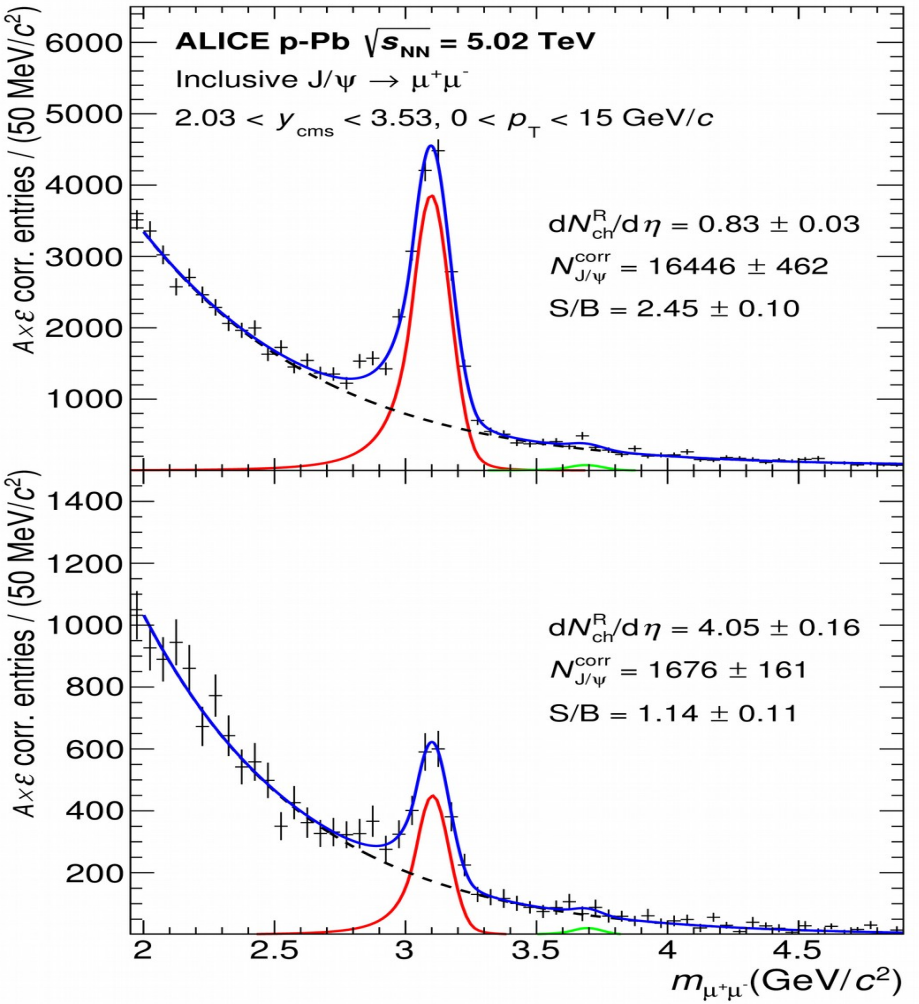
- V0 triggered events for MB.
- Low p_T muon triggered events.
- Unlike sign dimuon pair.
- $2.5 < \eta < 4$ (on both muons) belonging to dimuon , to reject tracks at the edge of the acceptance.
- $17.6 < R_{abs} < 89.5$ (cm) (on both muon), removes tracks crossing the thicker part of the absorber.
- $2.5 < y < 4$ (on dimuon pair), to match with the spectrometer acceptance.
- Both muons μ^+ & μ^- matching the trigger.

Experimental Method: Signal Extraction

From Electron pair



From Muon pair

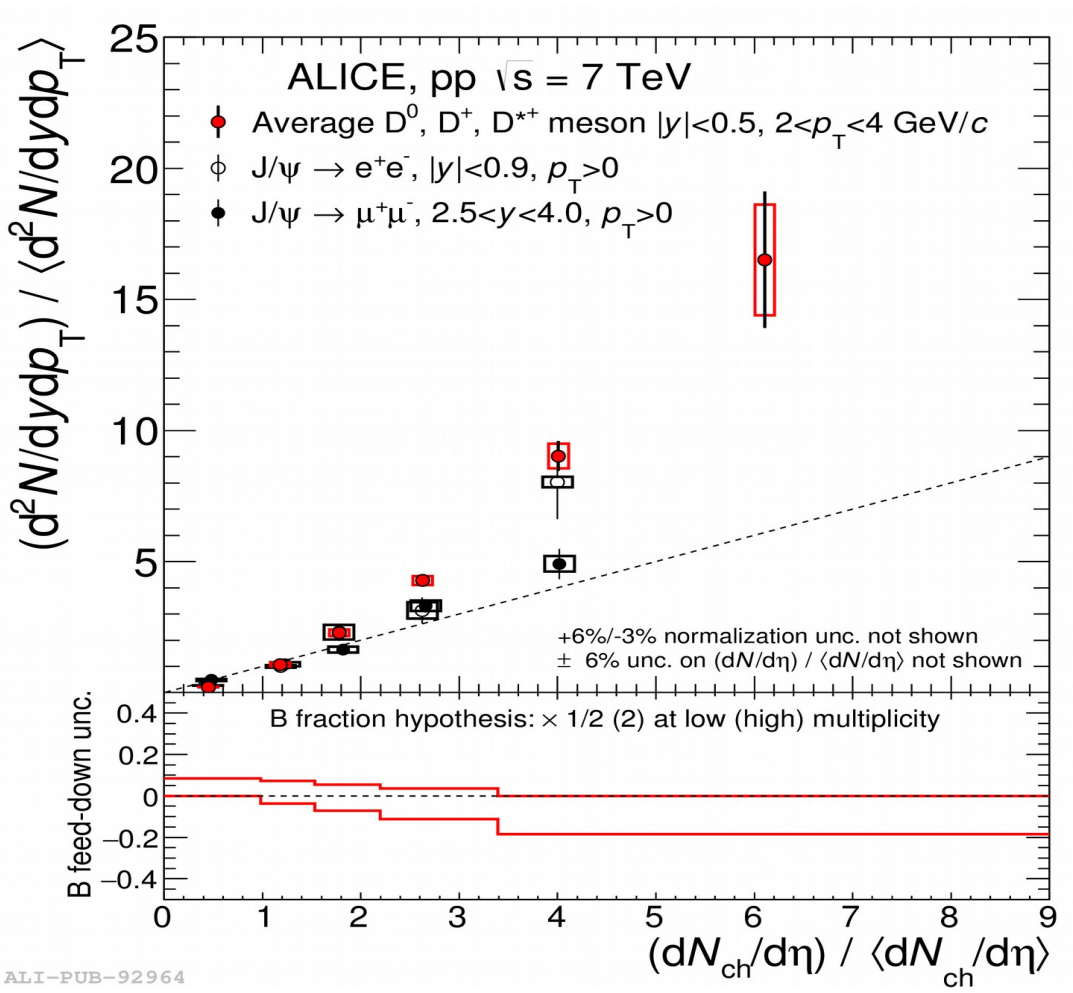


ALICE arXiv: 1704.00274

Results from Run -1

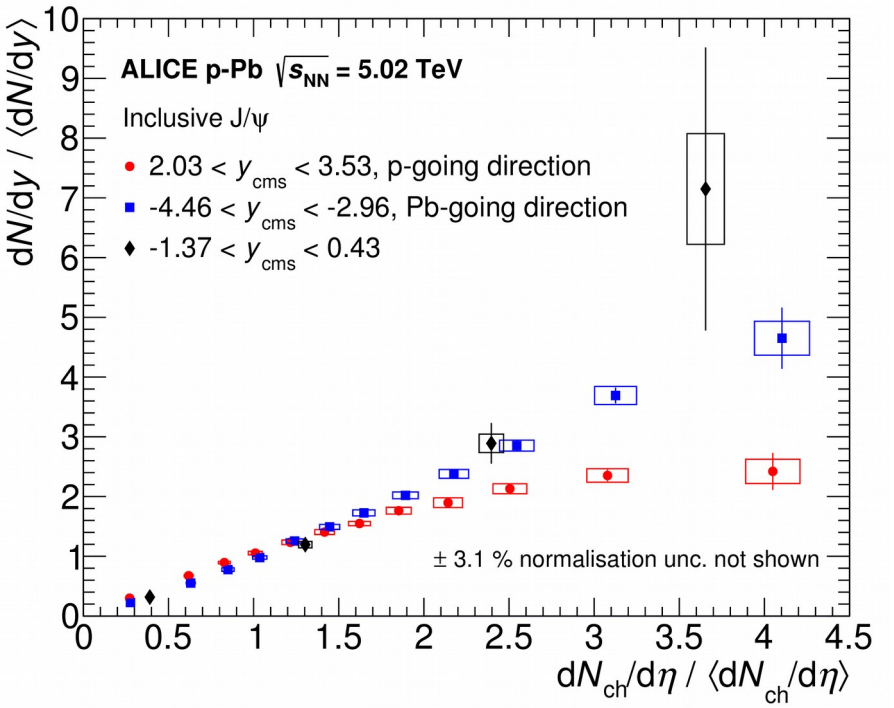
Multiplicity dependence of D mesons in pp collisions at 7 TeV

- Similar trend is observed for average D meson and J/ψ relative yields as a function of the relative charged-particle multiplicity at central rapidity.
- Open charm and J/ψ relative yields present a similar increase with charged-particle multiplicity.
- Independent of hadronisation.

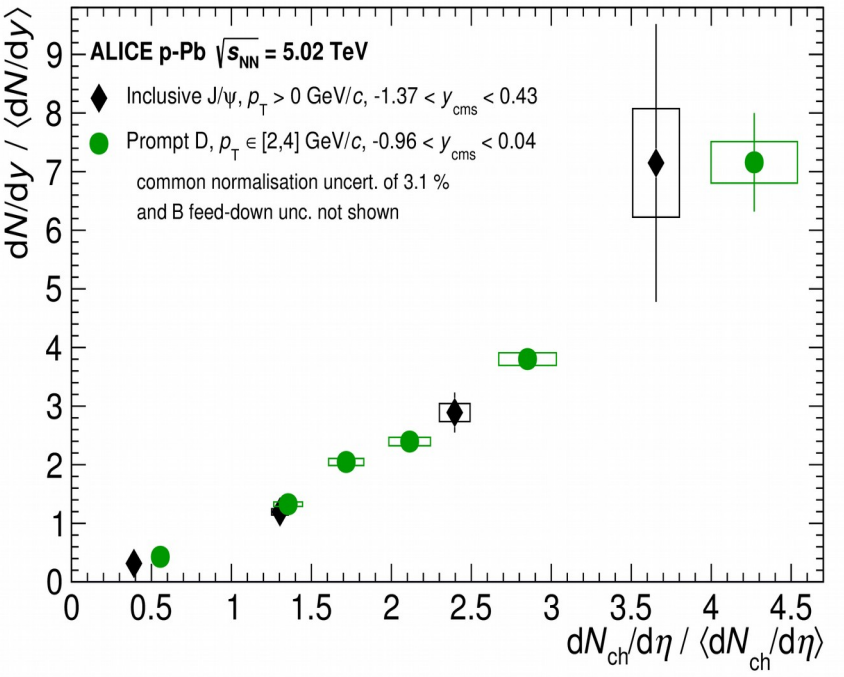


ALICE JHEP09 (2015) 148

J/ψ yield vs multiplicity in p-Pb collisions $\sqrt{s_{NN}}$= 5.02TeV



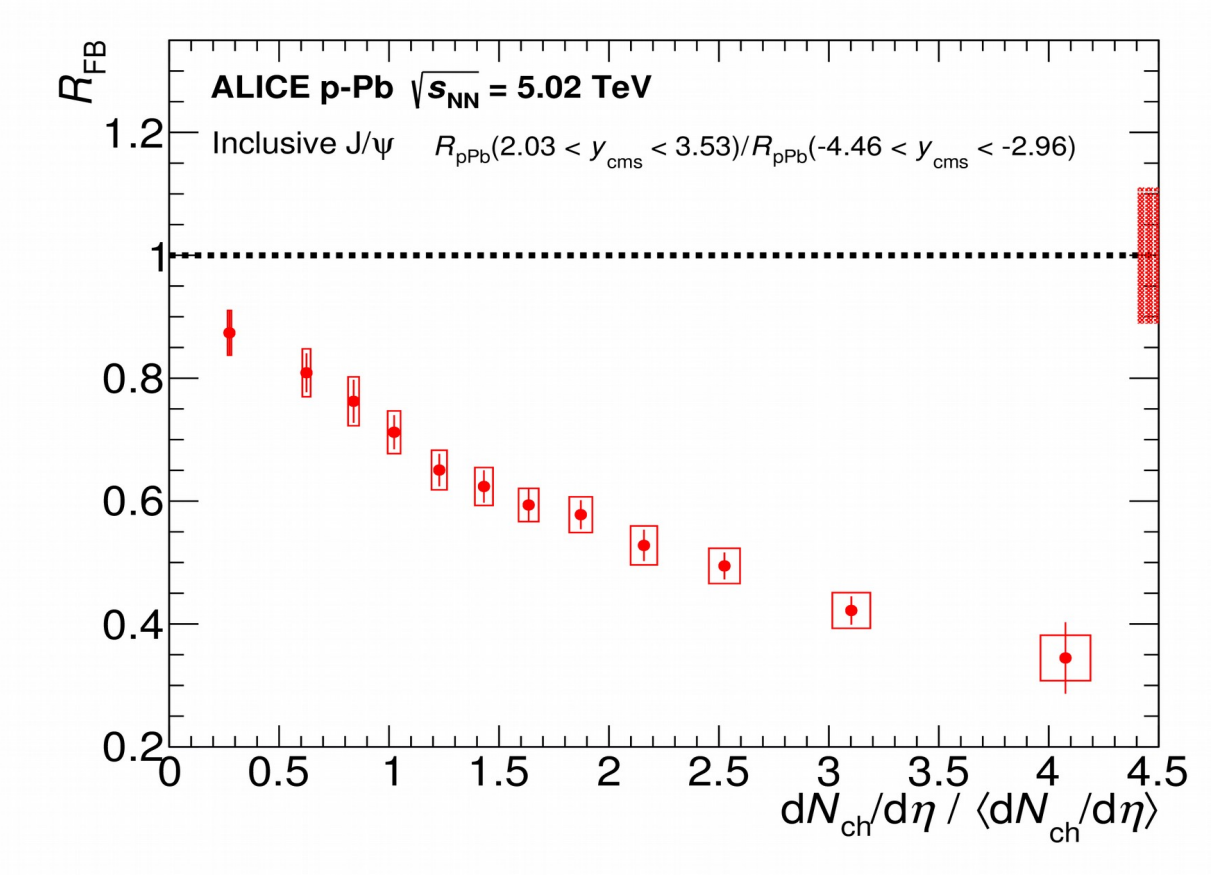
ALICE arXiv: 1704.00274



- Increase of the relative J/ψ yield with the charged particle multiplicity at both mid and forward rapidity.
- At forward rapidity window a saturation of the relative yield sets in for high multiplicities.
- J/ψ and D mesons at mid rapidity follow similar trend.

R_{FB} vs multiplicity in p-Pb collisions $\sqrt{s_{NN}}$= 5.02TeV

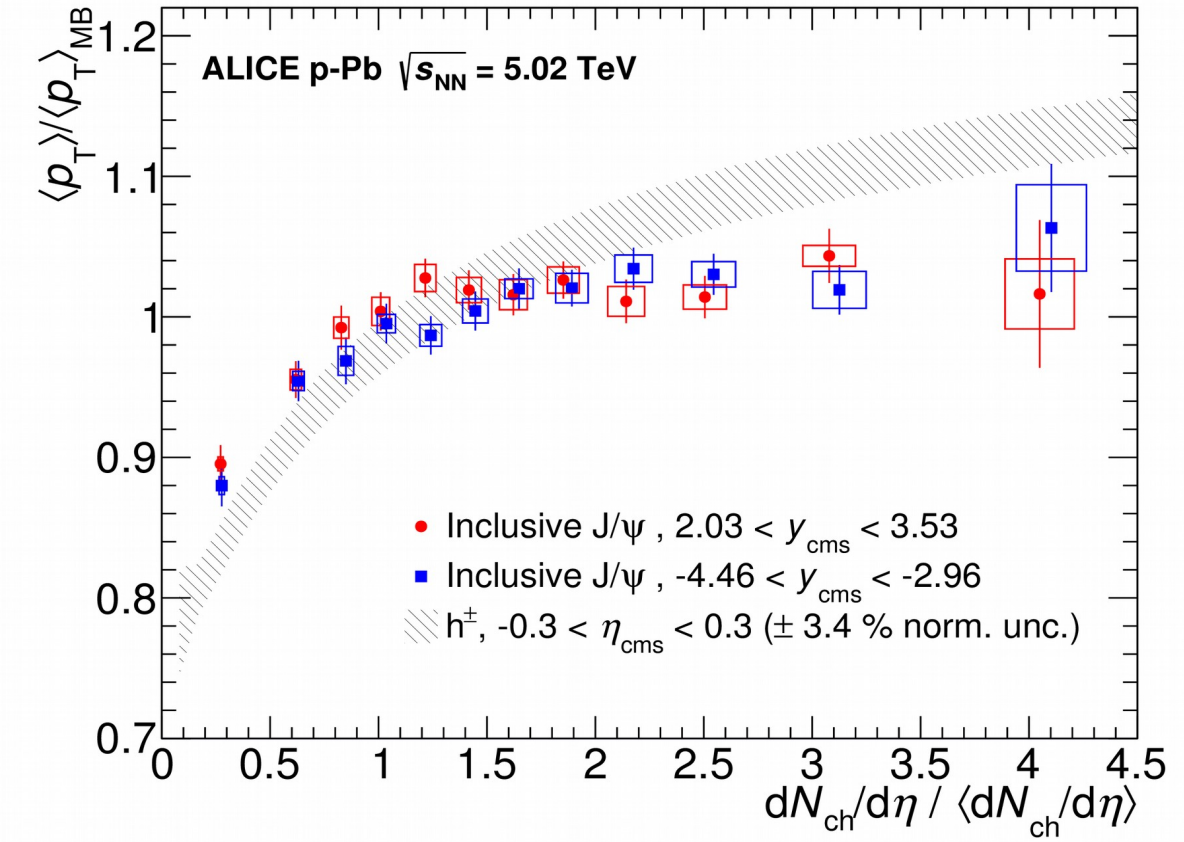
- Forward-to-backward nuclear modification factor (R_{FB}) ratio indicates a strong suppression in the forward direction w.r.t the backward rapidity. (as expected from CNM effects).



ALICE arXiv: 1704.00274

J/ψ mean p_T vs multiplicity in p-Pb collisions $\sqrt{s_{NN}}$= 5.02TeV

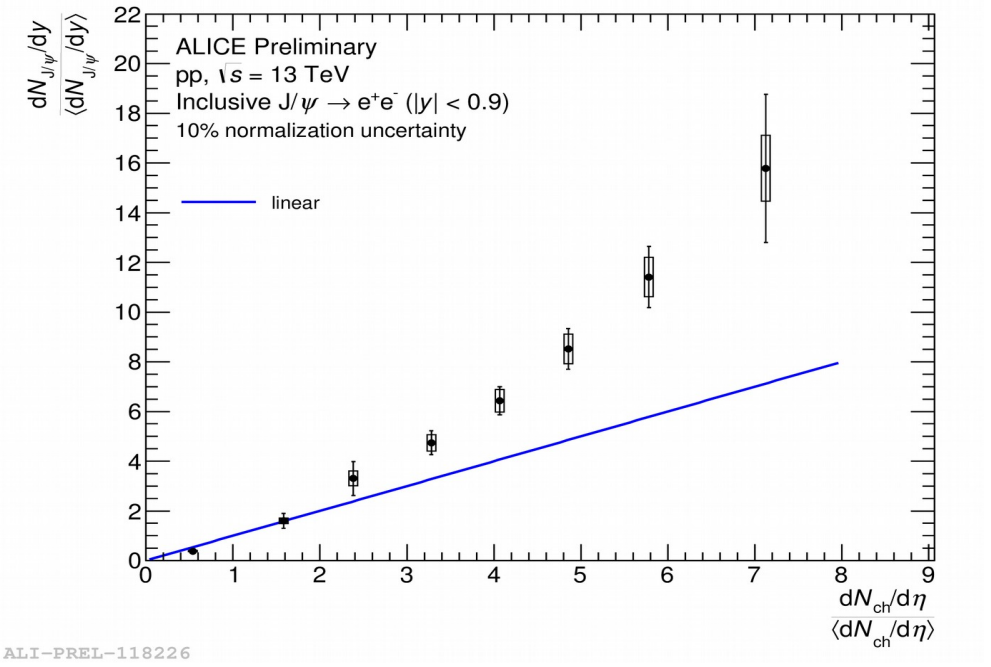
- Relative average p_T of J/ψ at forward & backward rapidity showing same trend.
- Different from mean p_T charged hadrons vs multiplicity at mid rapidity.
- Saturation observed above for higher than average multiplicities.

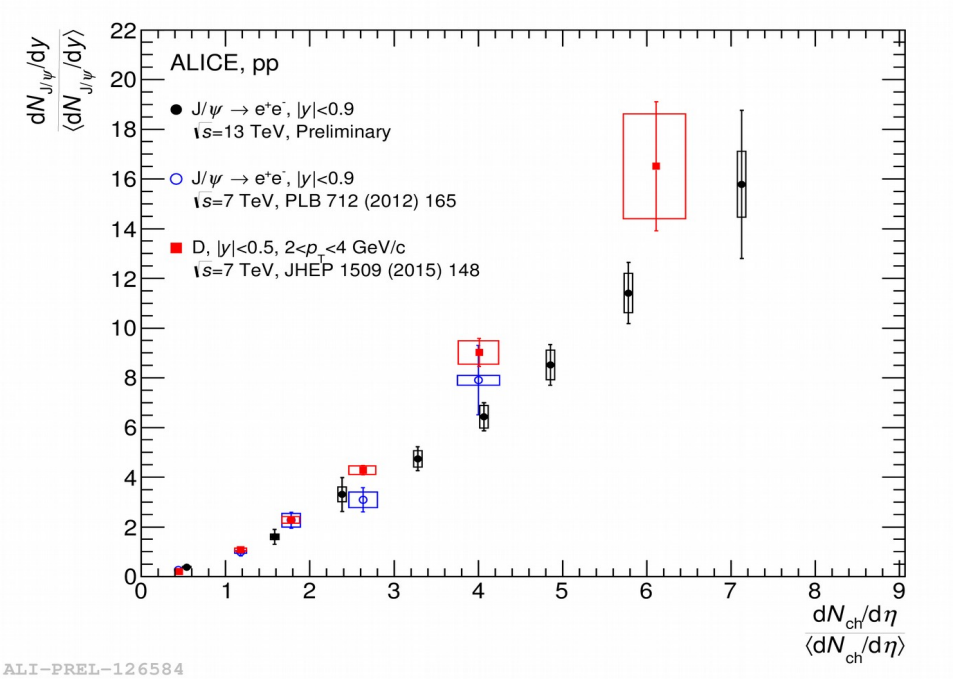


ALICE arXiv: 1704.00274

Results from Run -2

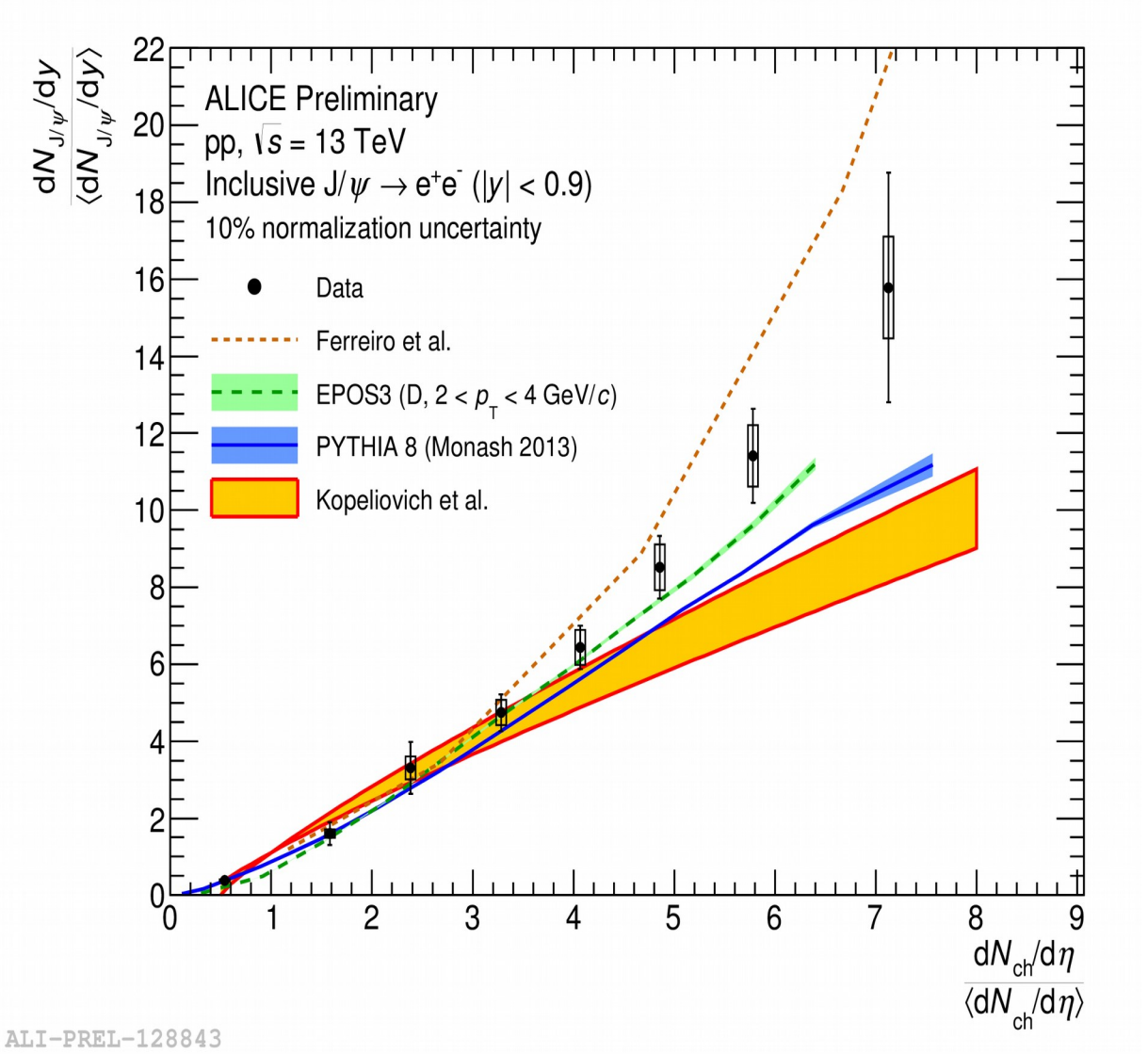
J/ψ yield vs multiplicity in pp collisions √s = 13 TeV





- J/ψ production as a function of multiplicity at mid rapidity.
- Increase of relative J/ψ yields with a slope >1.
- Multiplicity reach extended by a factor of 2 as compared to multiplicity in pp collisions at 7 TeV.

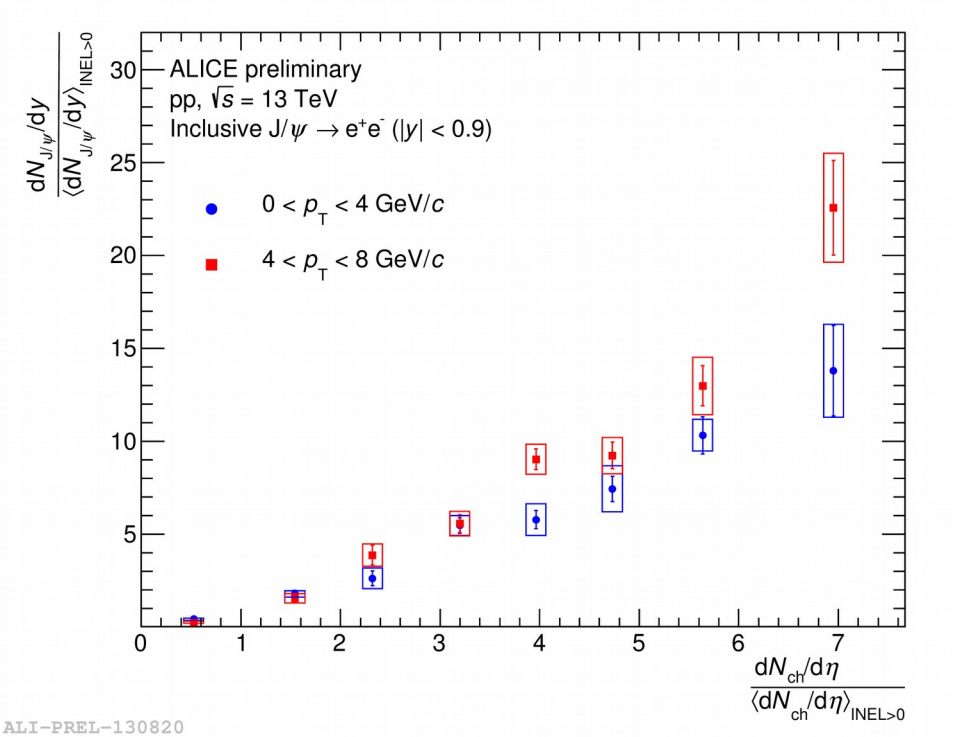
J/ψ yield vs multiplicity in pp collisions $\sqrt{s}$ = 13 TeV

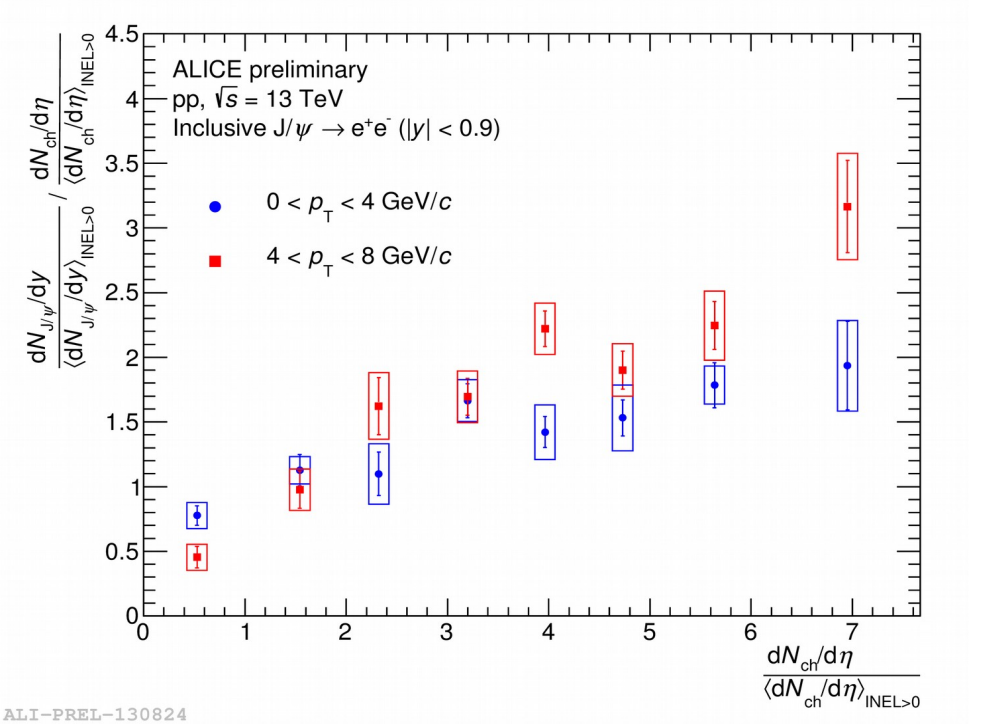


- All models show J/ψ enhancement with multiplicity as data.
- Models have slightly different trend at high multiplicity.
- Percolation model & PYTHIA8 have slightly different trend at higher multiplicity bins.

Ferreiro, Pajares, PRC86 (2012) 034903
EPOS3, Werner et al., Phys.Rept.350 (2001) 93
PYTHIA8, Sjostrand et al., Comput.Phys.Commun.178(2008)852
Kopeliovich et al., PRD88 (2013) 116002

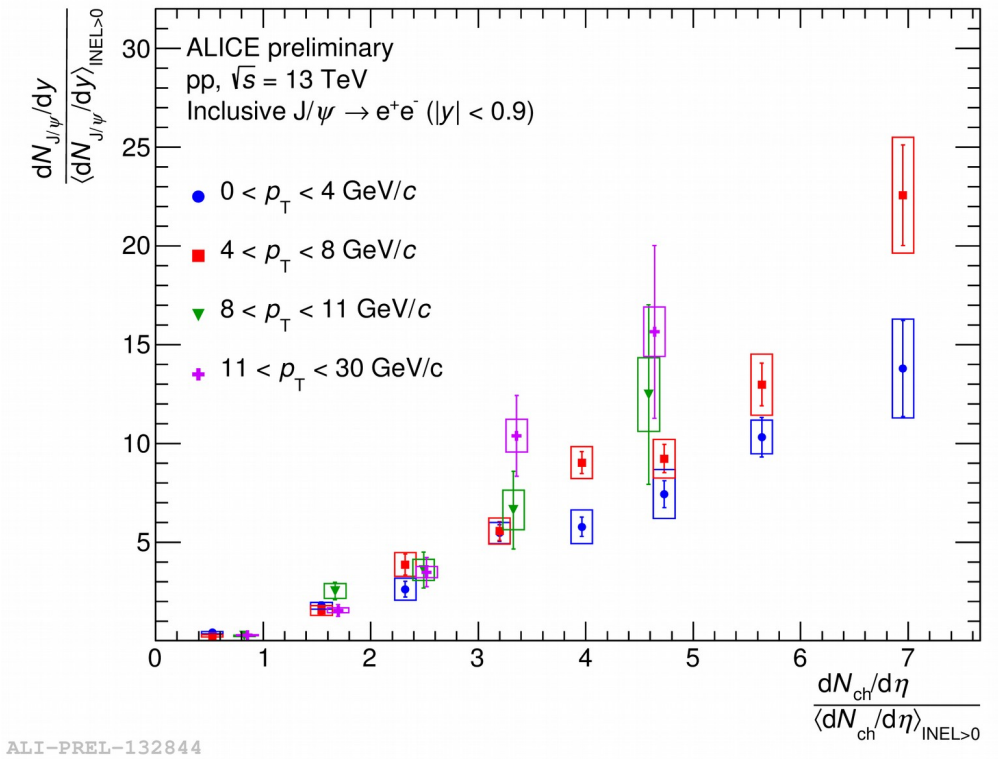
J/ψ vs multiplicity in different p_T bins

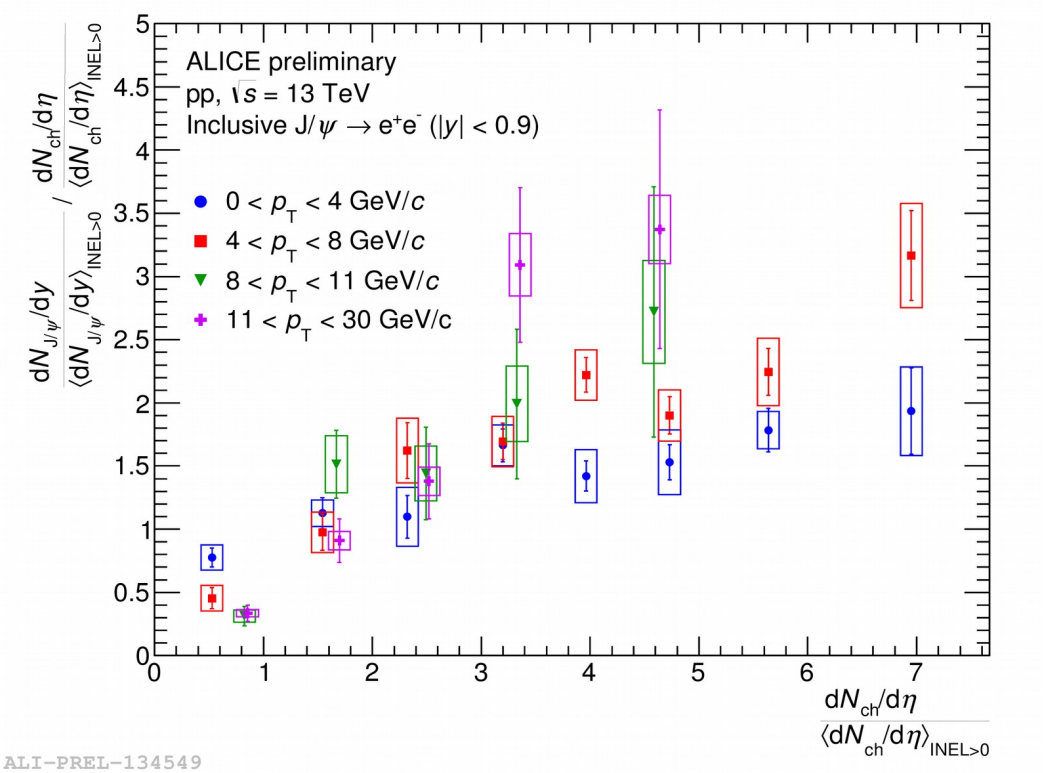




- The slope increases sharply in two p_T intervals .
- The slope increases at higher p_T.

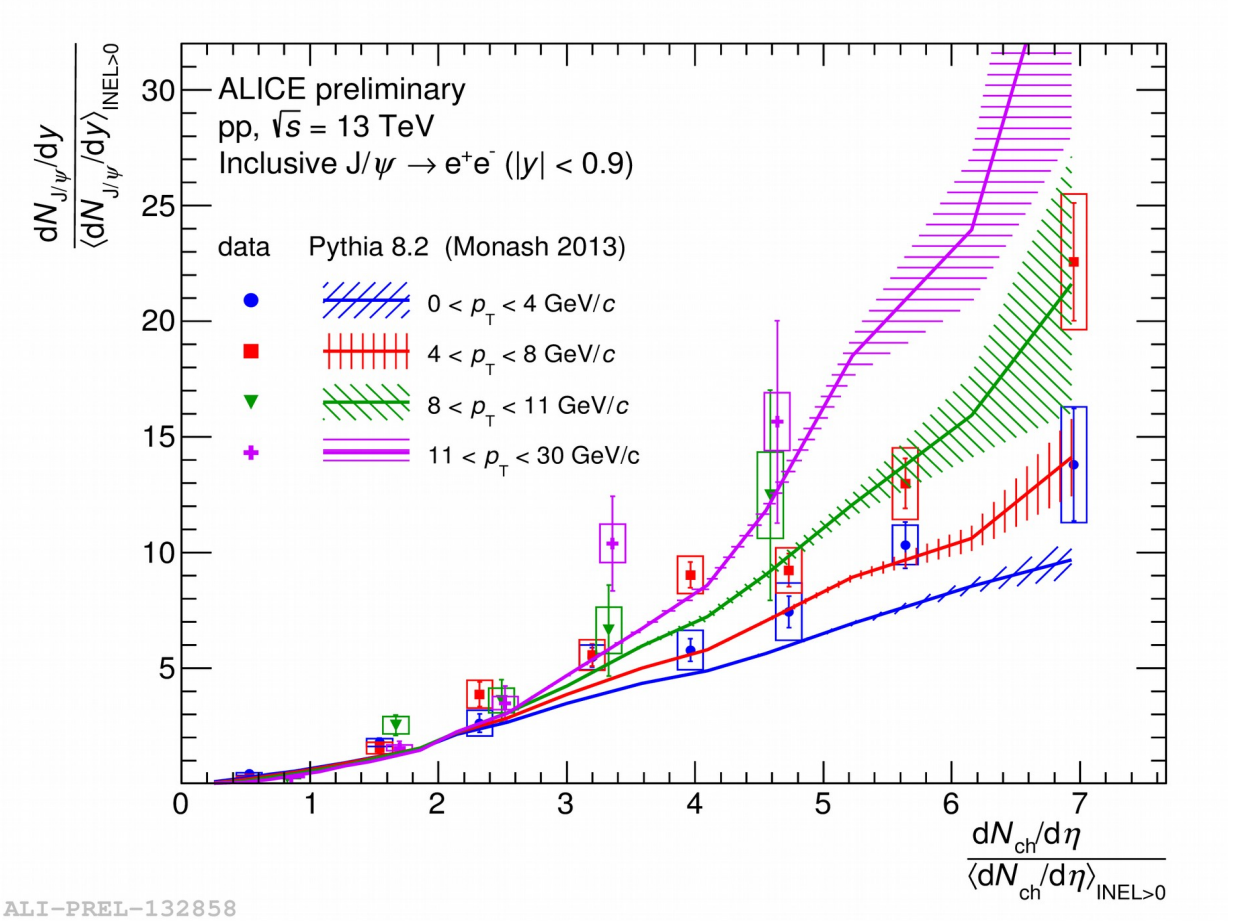
J/ψ vs multiplicity in different p_T bins with EMCAL





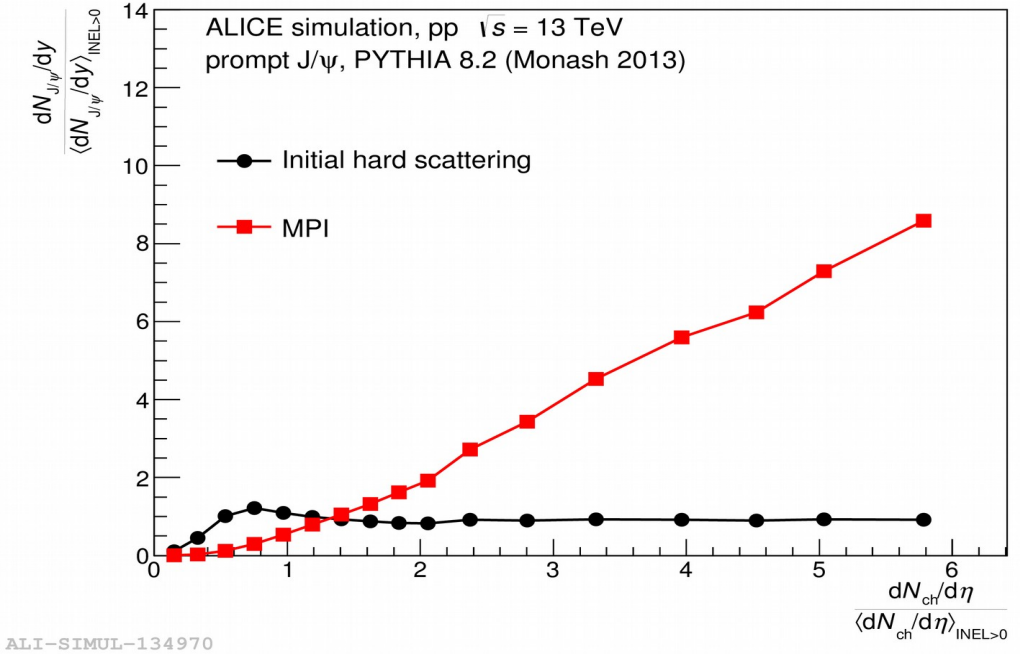
- EMCAL triggered data extend J/ψ p_T reach.
- High p_T J/ψ indicate even stronger increase with multiplicity.

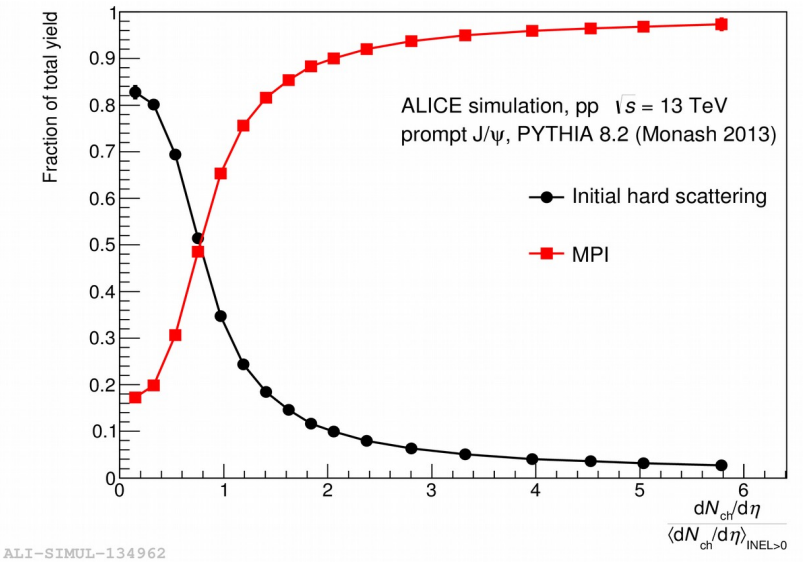
J/ψ vs multiplicity in different p_T bins with PYTHIA8

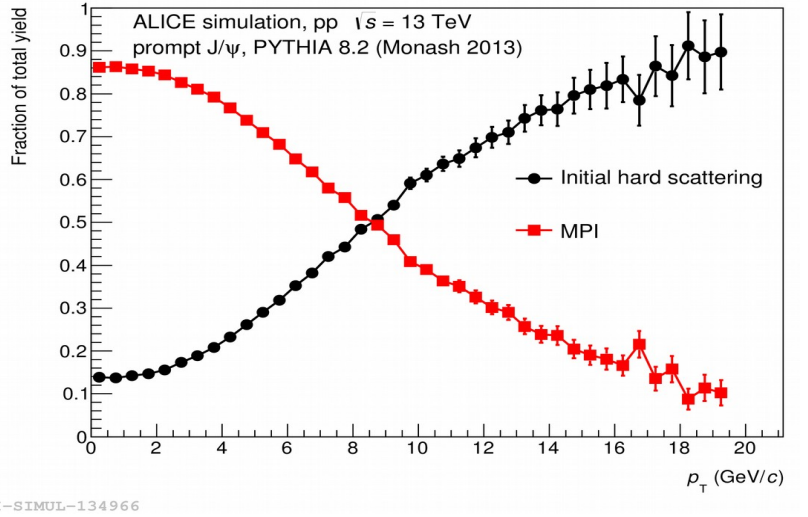


PYTHIA8 simulation results matches the trends seen in data in pp 13 TeV.

J/ψ production mechanism (PYTHIA8)

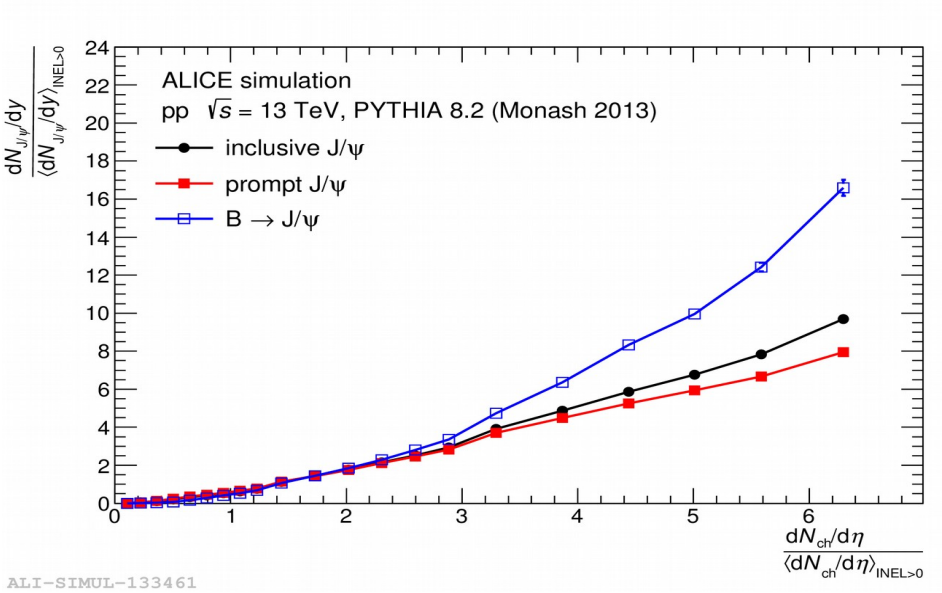


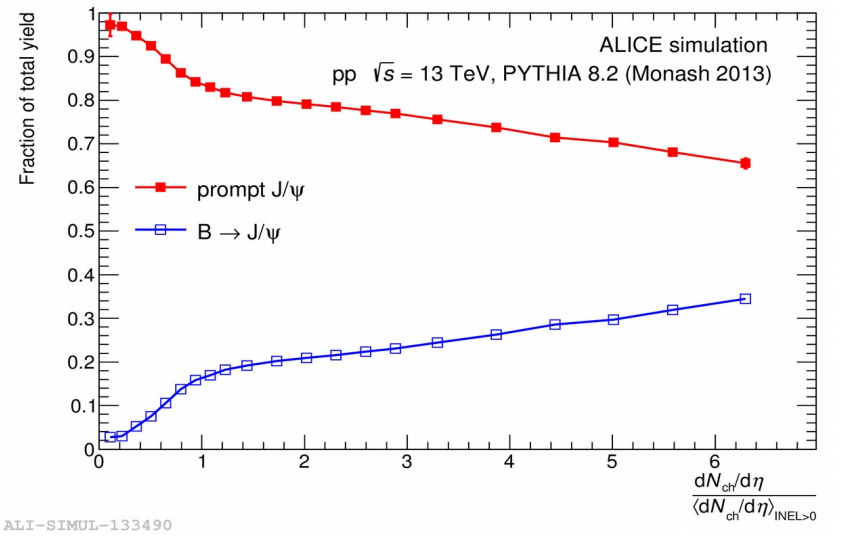




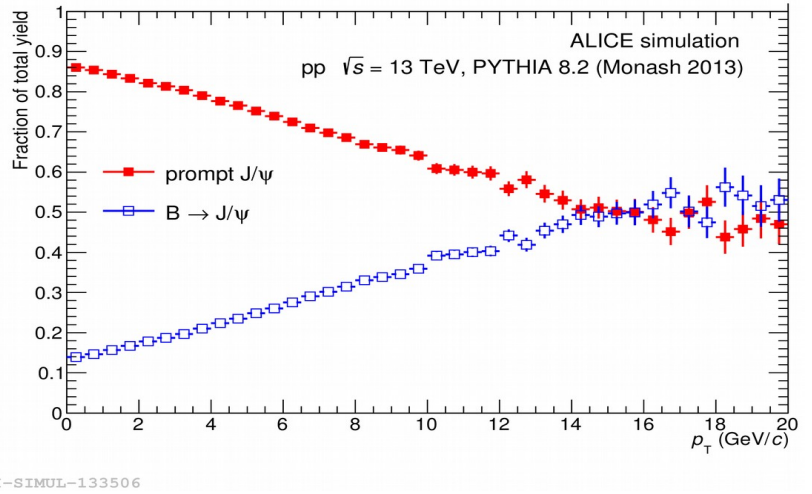
- Initial hard scatterings & MPI show opposite trend for J/ψ production.
- Contributions from initial hard scatterings largest at low multiplicity and high p_T(>8 GeV/c)
- MPI dominate at high event multiplicity and low p_T

J/ψ production mechanism (PYTHIA8)





- Relative J/ψ yields from beauty steeper than prompt J/ψ → auto-correlation.
- Non-prompt fraction grows with both p_T and multiplicity.



Conclusion & outlook

- Multiplicity dependence of J/ψ has been studied in pp and p-Pb collisions at different energies.
- J/ψ yields increase with multiplicity are similar in all cases.
- Relative J/ψ yield increases steeply with multiplicity in pp at 13TeV. Effect is stronger for high p_T
- Data are qualitatively described by theoretical models .
- Run 2 data extended measurements to higher multiplicity and high p_T .
- More investigations are ongoing in pp and p-Pb collisions.

Thank You.

Extras

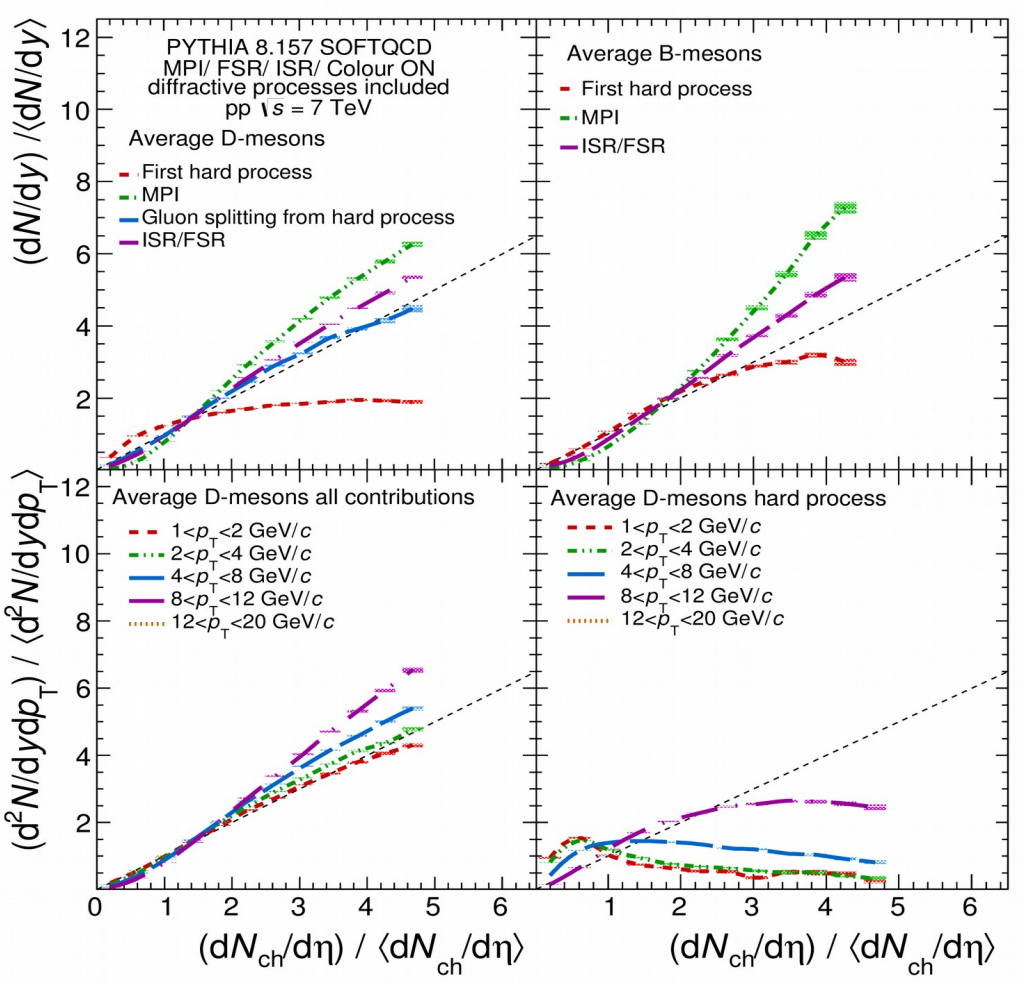
Theoretical Interpretation

PYTHIA8 simulation

[T. Sjostrand, S. Mrenna, P. Z. Skands:Comput.Phys.Commun. 178 (2008) 852–867]

- Heavy flavour production via four mechanism :
  1. First hard process.
  2. Hard processes in MPI.
  3. Gluon splitting.
  4. Initial/final state radiation.

- Small number of MPI contribute to the low multiplicity intervals.
- High multiplicity events are dominated by a large number of MPI.



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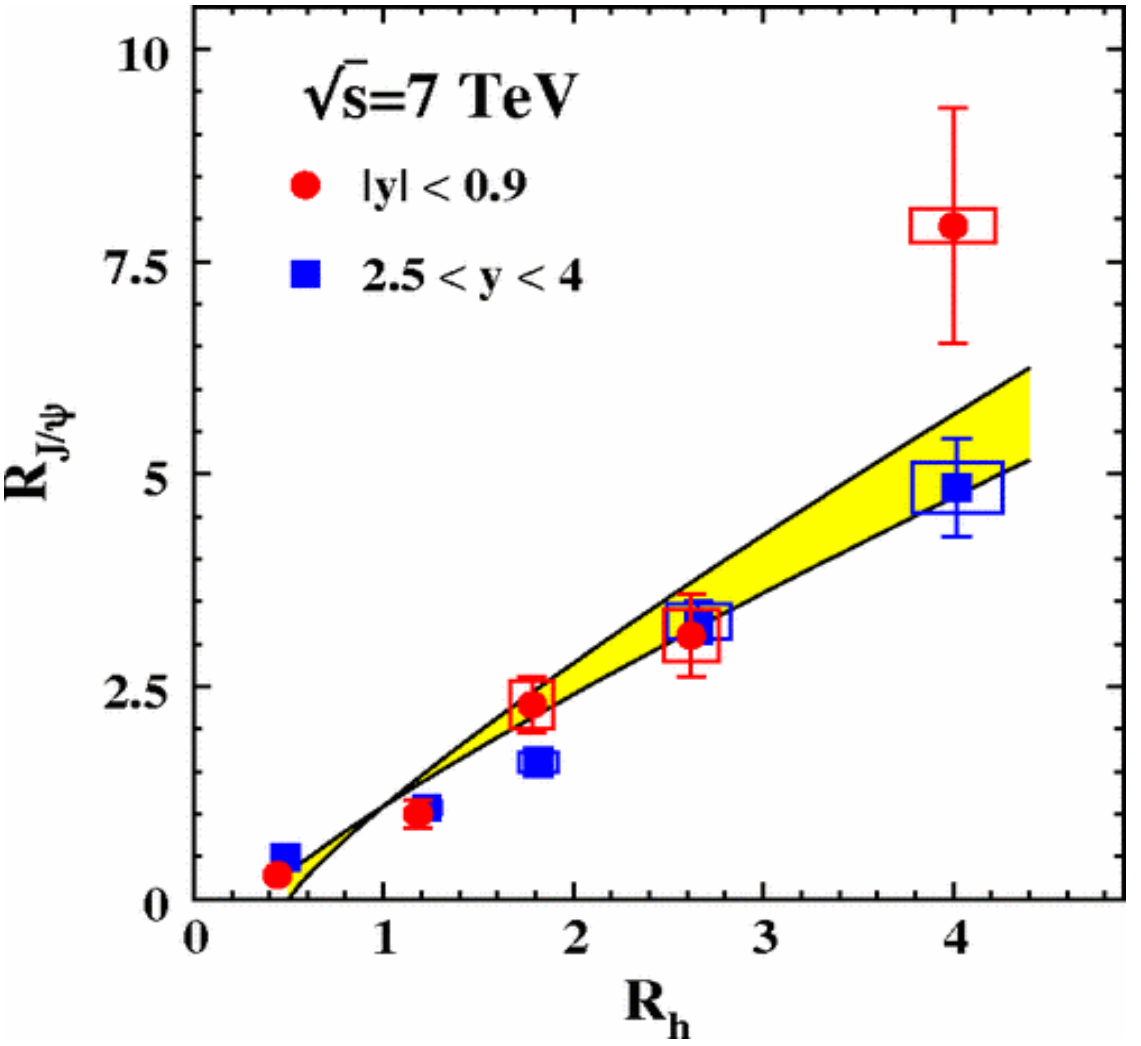
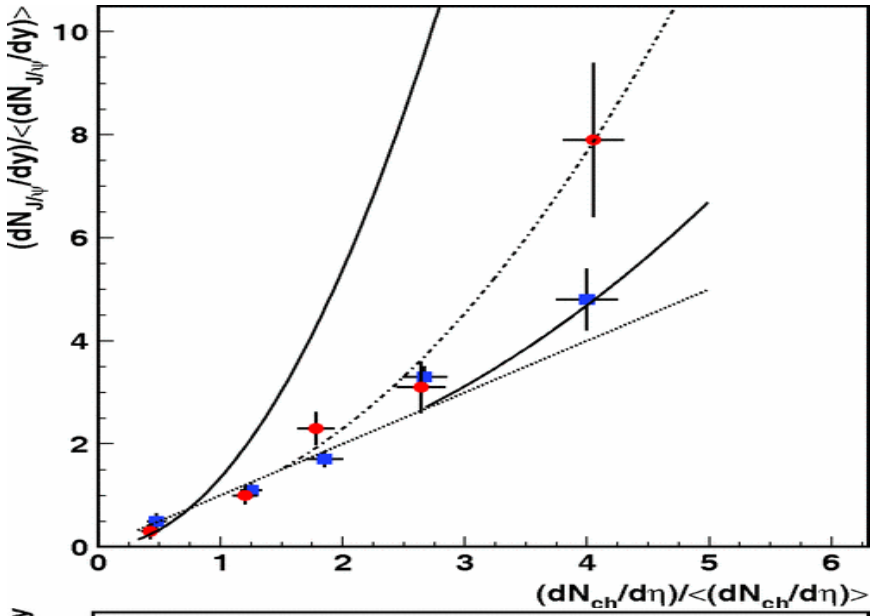
Theoretical Interpretation

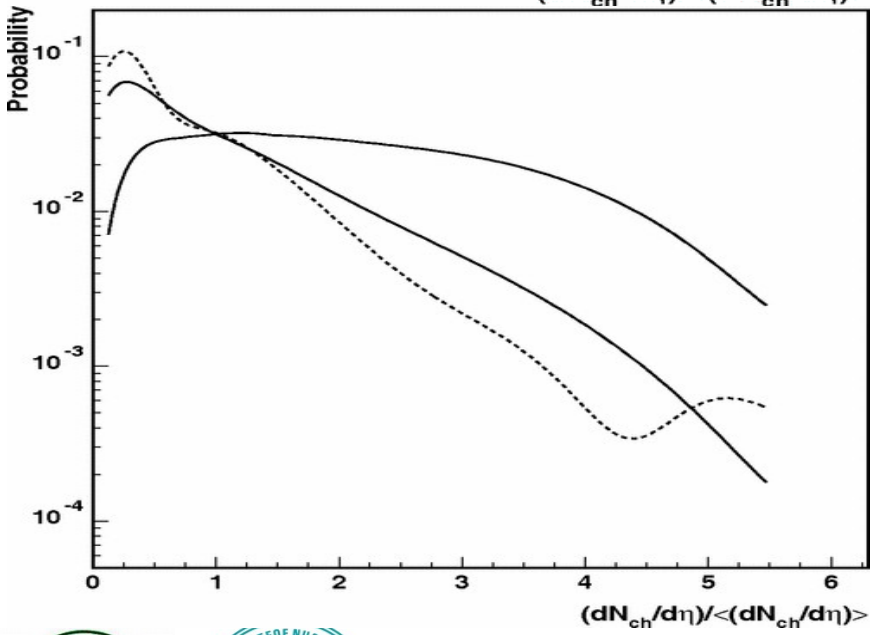
- Larger Hadron multiplicities than the mean value in collisions can be reached due to an increased number of gluons in p-Pb .
- Nucleus act as single source of gluon.
- J/ψ production rate also enhanced.
- Analogy between high-multiplicity pp collisions and p-A collisions



B.Z. Kopeliovich et al.
PRD 88, 116002 (2013)

Theoretical Interpretation





(E. G. Ferreiro, C. Pajares: Phys.Rev. C86 (2012)034903)

Parton saturation & String Interaction Model :

- Central (|y|<0.9 dashed line) & forward (2.5<y<4, dotted line) rapidity ranges from ALICE.
- Linear increase at low density,
- Quadratic increase at higher density.
- The departure from linearity, consequence of the parton saturation or the strong interaction among colour ropes that take place at LHC energies.