

# $J/\psi$ production and multiplicity dependence in pp and p-Pb collisions with ALICE

Testing QCD with charmonium cross sections  
 $J/\psi$  production as a function of multiplicity

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# Motivation

Charmonia are bound states of charm quark-antiquark pairs.

- ▶ production of charmonia combines both hard and soft scales of QCD
- ▶  $c\bar{c}$  pair produced in the initial hard scattering in collisions of relativistic hadrons → pQCD
- ▶ hadronization of the  $c\bar{c}$  pair into a colourless bound state → non-perturbative

$(c\bar{c})$ state	mass (MeV/ $c^2$ )
$J/\psi$	$3096.900 \pm 0.006$
$\psi(2S)$	$3686.097 \pm 0.025$

This talk will focus on  $J/\psi$  and  $\psi(2S)$  results with ALICE.

# Motivation

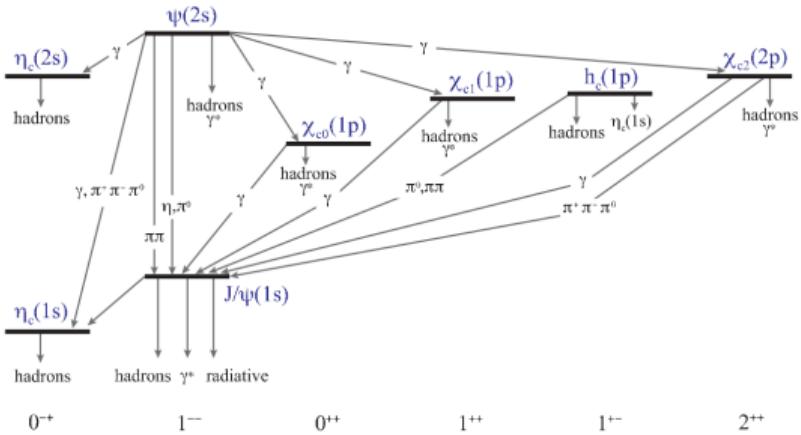
## Contributions to the total inclusive $J/\psi$ yield

- ▶ direct production - from the original  $c\bar{c}$
- $c\bar{c} \rightarrow J/\psi + X$
- ▶ decay from higher mass resonances ( $\psi(2S)$  and  $\chi_c$ )

$c\bar{c} \rightarrow \psi(2S) \rightarrow J/\psi + X$

- ▶ decay from b-hadrons

$b \rightarrow J/\psi + X$



Á. Mócsy *et al.*, Int. J. of Mod. Phys. A, Vol. 28, 1340012 (2013)

# Motivation

Charmonia production measurements serve

in pp collisions:

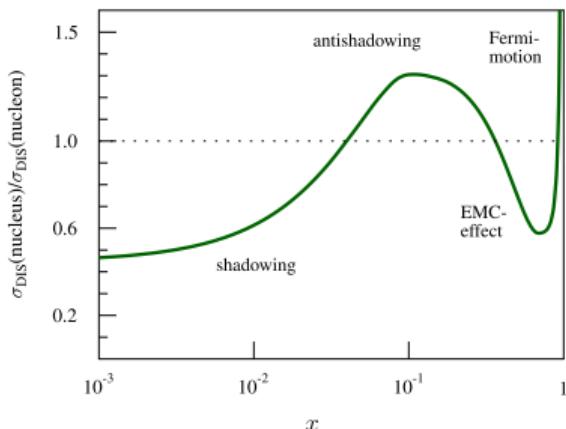
- ▶ to understand production mechanism
- ▶ to probe PDFs down to low  $x$
- ▶ as a reference for p-Pb and Pb-Pb measurements

in p-Pb collisions:

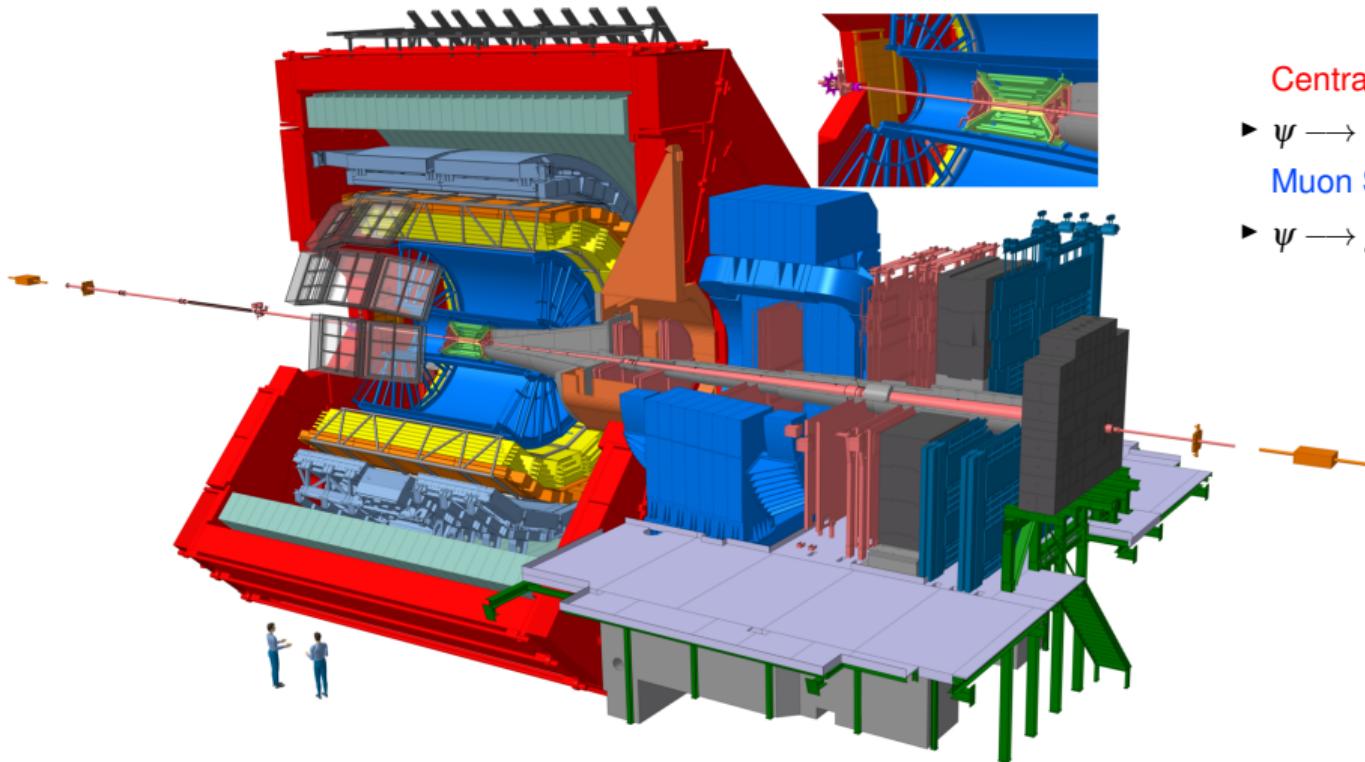
- ▶ to study the effect of nuclear medium on observables
- ▶ those are called *Cold Nuclear Matter effects*
  - ▷ e. g. modification of nPDFs, energy loss, ...
- ▶ as a reference for Pb-Pb measurements

in Pb-Pb collisions:

- ▶ to study properties of the hot and dense QCD matter
  - ▷ e. g. colour screening, recombination

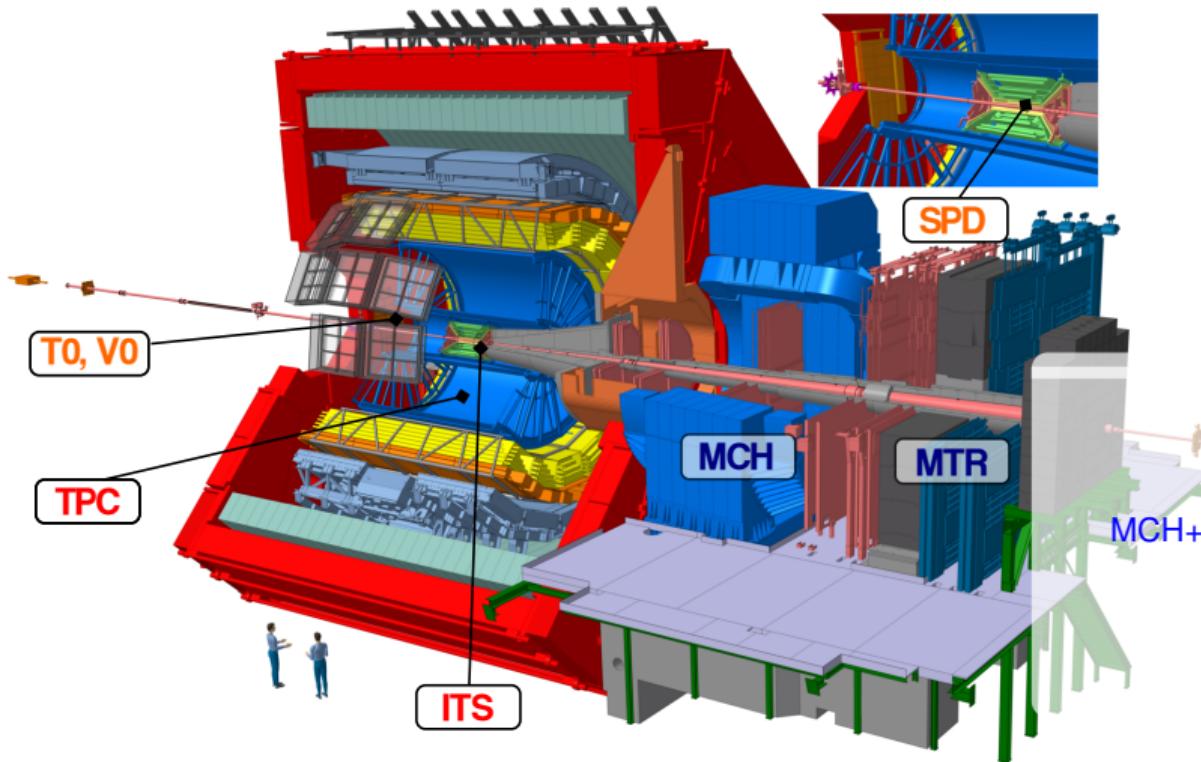


# Measurement of charmonia with ALICE



- ▶ down to  $p_T = 0$
- Central Barrel
- ▶  $\psi \rightarrow e^+ e^-$  at  $|y_{\text{lab}}| < 0.9$
- Muon Spectrometer
- ▶  $\psi \rightarrow \mu^+ \mu^-$  at  $2.5 < y_{\text{lab}} < 4$

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**ITS** vertex reconstruction, tracking  
( $e^+ e^-$ )

**TPC** tracking and PID ( $e^+ e^-$ )

**MCH+MTR**  $\mu$  trigger and tracking

**V0** trigger, luminosity

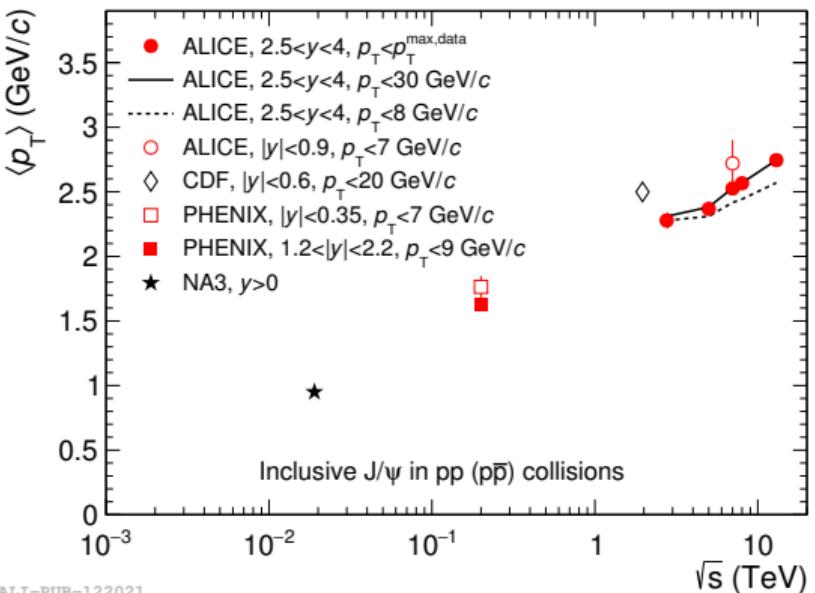
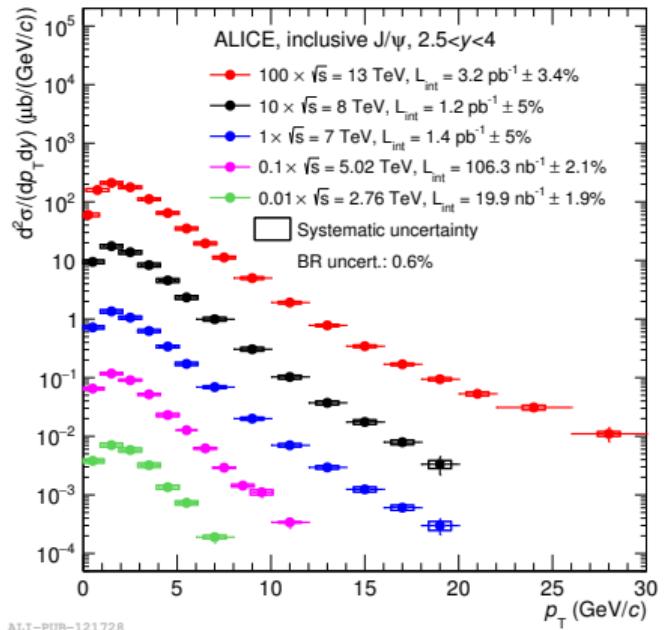
**T0** luminosity

**SPD** multiplicity measurement

Energy dependence of charmonium cross  
section at forward rapidity

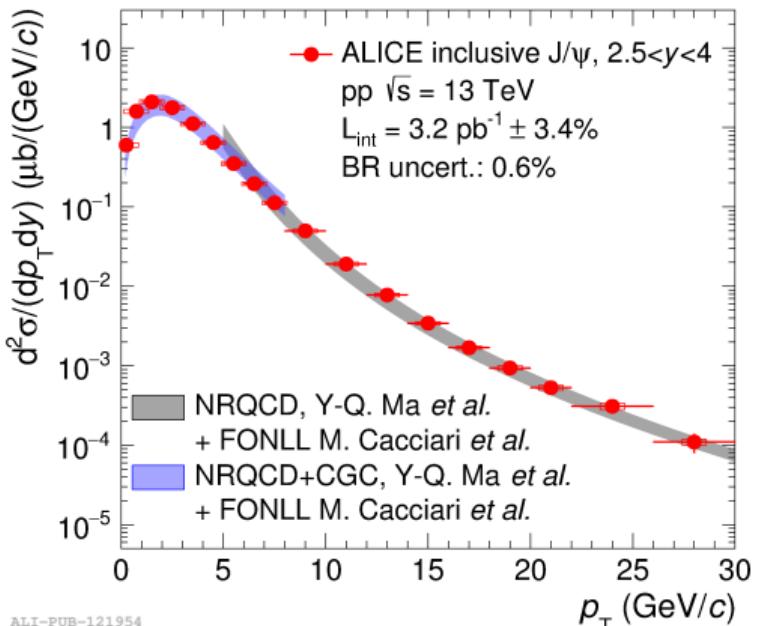
# Energy dependence of charmonium cross section at $2.5 < y < 4$

Eur. Phys. J. C 77 (2017) 392



- measurement of  $J/\psi$  production in pp at all available LHC energies
- observed an increase of the production cross section and  $\langle p_T \rangle$  with  $\sqrt{s}$

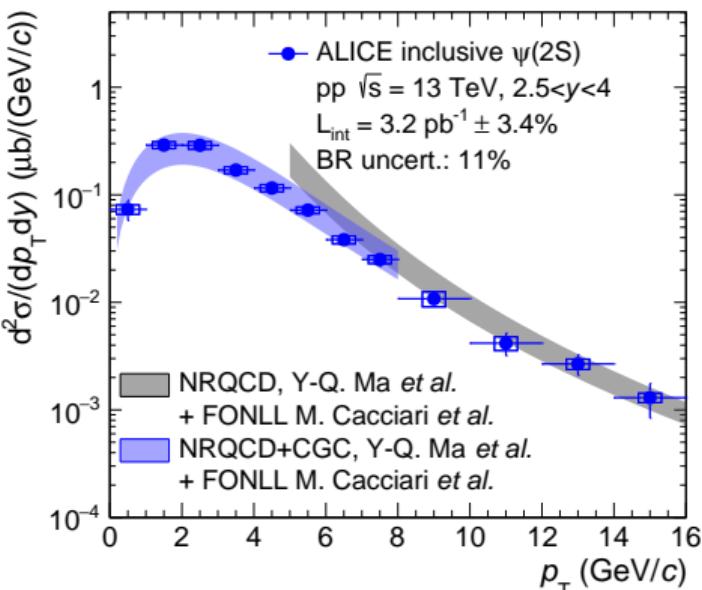
# Comparison with theoretical predictions



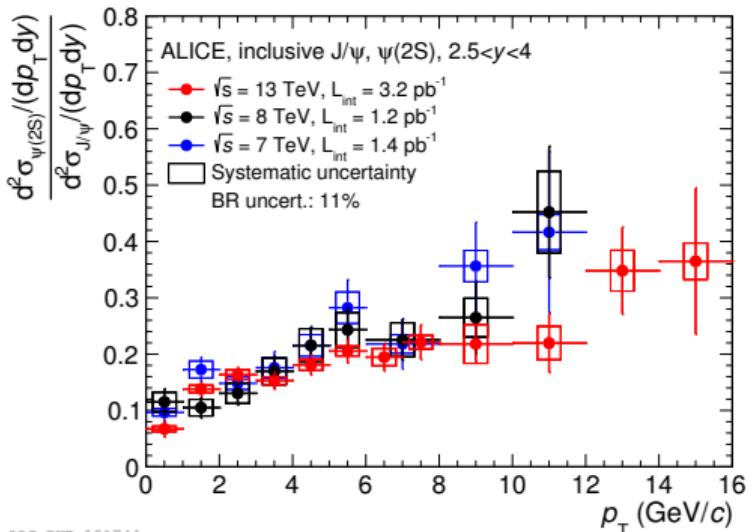
ALI-PUB-121954

- NRQCD to account for prompt production
- FONLL for non-prompt production ( $b$ -decays)

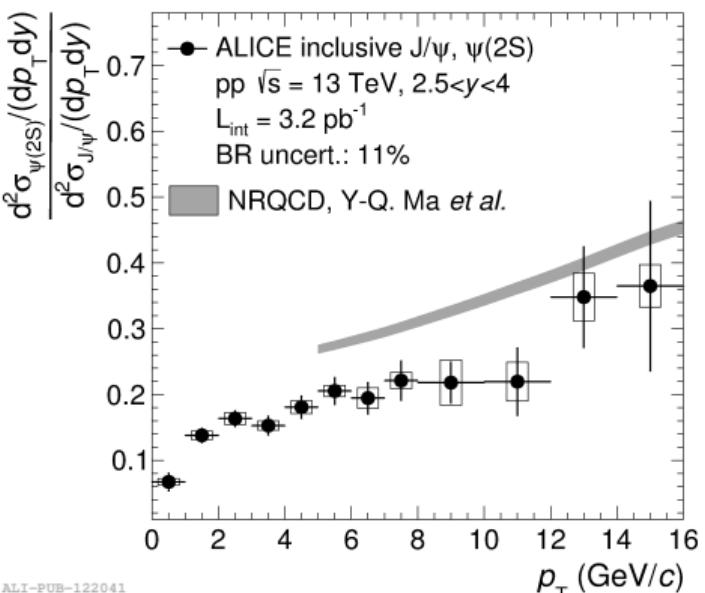
}  $\Rightarrow$  their sum describes the data in the full measured  $p_T$  range



# Ratio of charmonium cross sections



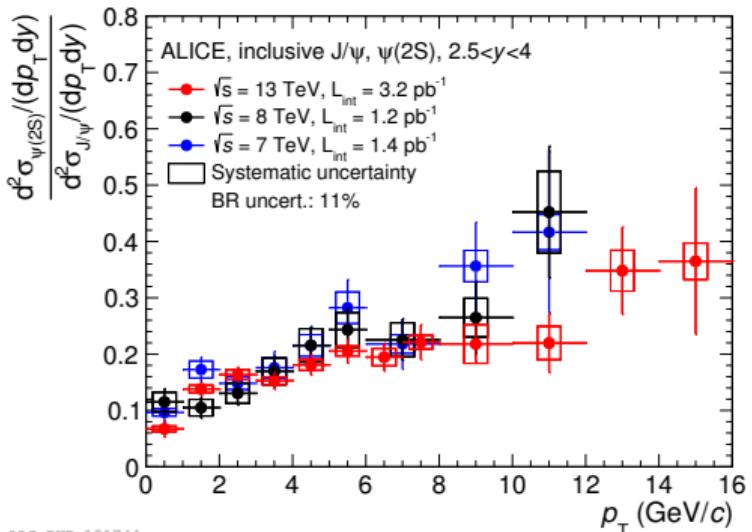
ALI-PUB-121744



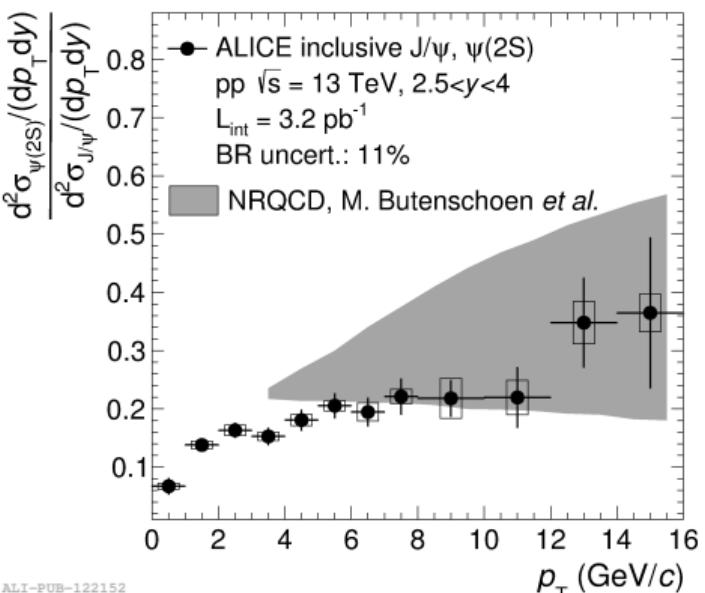
ALI-PUB-122041

- no visible dependence of the  $\psi(2S)/J/\psi$  ratio on energy
- more stringent test on comparison between data and theory

# Ratio of charmonium cross sections



ALI-PUB-121744



ALI-PUB-122152

- no visible dependence of the  $\psi(2S)/J/\psi$  ratio on energy
- more stringent test on comparison between data and theory

# Measurement of $J/\psi$ production as a function of multiplicity in pp and p-Pb collisions

# Motivation

- ▶ charged-particle multiplicity is proportional to the energy density in the collision
- ▶ collective-like behaviour is observed in high multiplicity pp and p-Pb events
- ▶ current studies to show whether similar behaviour observed in events involving hard processes

## Multiple Parton Interaction

- ▶ multiple parton scatterings in one hadron-hadron collision
- ▶ possible correlation between hard processes (e. g.  $J/\psi$  production) with soft processes (multiplicity)

# Multiplicity dependence of charmed mesons in pp collisions at $\sqrt{s} = 7$ TeV

D: JHEP 1509 (2015) 148  
 J/ $\psi$ : PLB 712 (2012) 165-175

## Inclusive J/ $\psi$ :

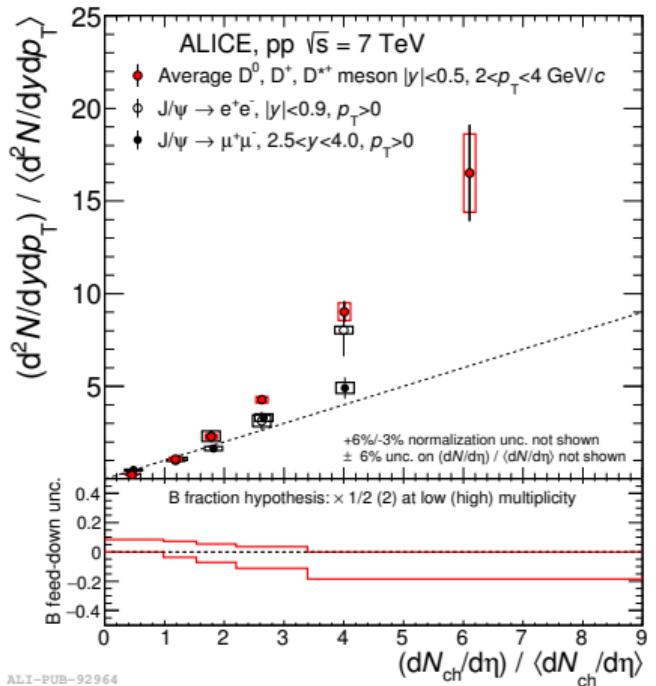
- ▶  $|y| < 0.9$
- ▶  $2.5 < y < 4$

$dN_{ch}/d\eta$  at  $|\eta| < 1$

## Prompt D:

- ▶ at  $|y| < 0.5$
- ▶ bins in  $p_T$
- ▶  $2 < p_T < 4$  compatible with  $\langle p_T \rangle$  of J/ $\psi$

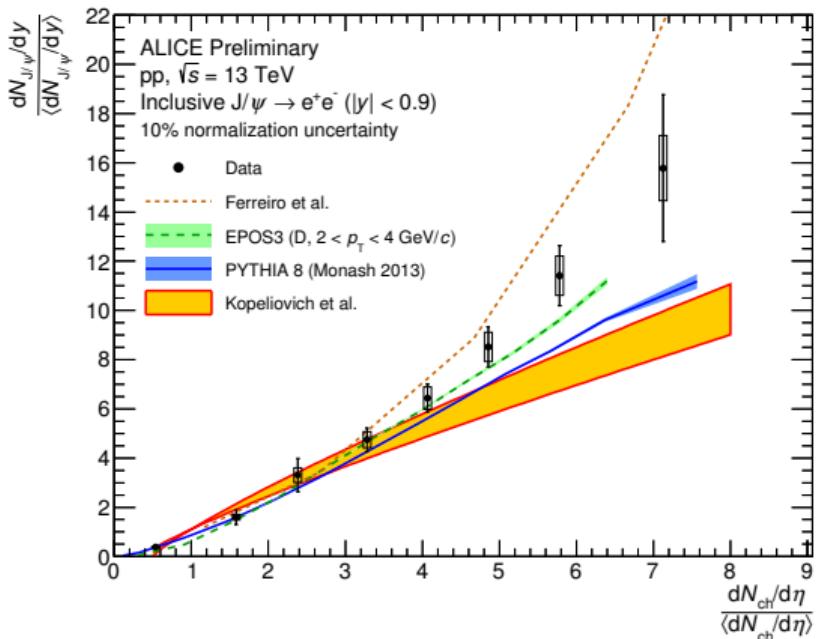
- ▶ yields demonstrate an increase with multiplicity
- ▶ increase similar for J/ $\psi$  and D at midrapidity  $\Rightarrow$  independent of hadronization process



# Multiplicity dependence of J/ $\psi$ in pp collisions at $\sqrt{s} = 13$ TeV

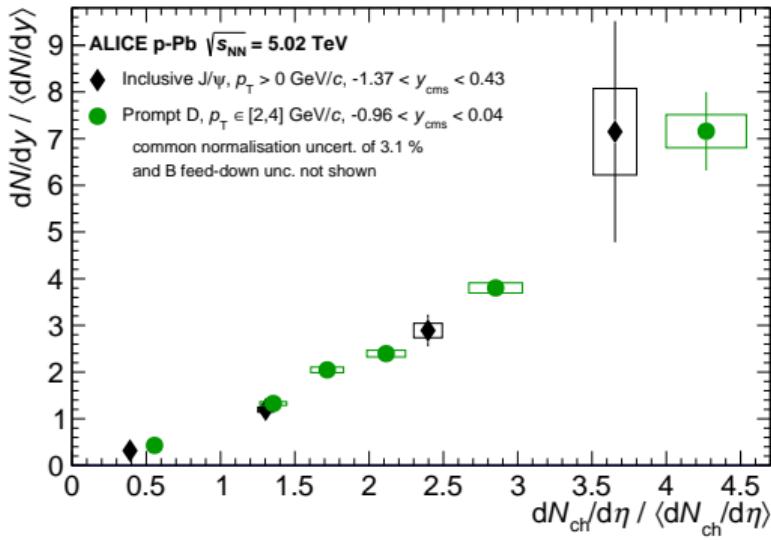
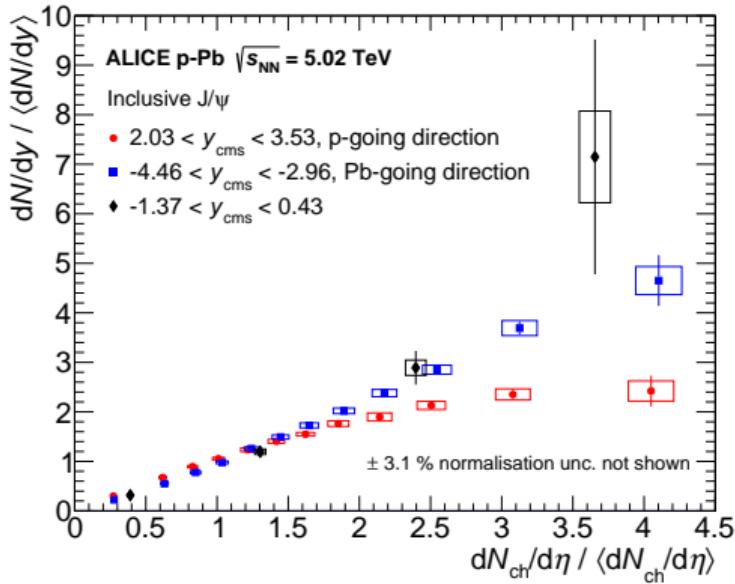
EPOS3: Phys. Rept. 350 (2001) 93–289  
 PYTHIA8: Comput.Phys.Commun. 191 (2015) 159-177  
 Ferreiro: PRC 86 (2012) 034903  
 Kopeliovich: PRD 88 (11) (2013) 116002

- ▶ measurement at midrapidity with high-multiplicity triggered data
  - ▷ extended reach up to  $dN_{ch}/d\eta / \langle dN_{ch}/d\eta \rangle \sim 8$
- ▶ consistent behaviour with 7 TeV
- ▶ stronger-than-linear increase at high multiplicity



# Multiplicity dependence of $J/\psi$ in p-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02 \text{ TeV}$ in Run 1

$J/\psi$ : submitted to PLB, arXiv:1704.00274  
D: JHEP 1509 (2015) 148



- in p-going direction, saturation of the yields at  $dN_{\text{ch}}/d\eta / \langle dN_{\text{ch}}/d\eta \rangle > 1.5$
- midrapidity  $J/\psi$  consistent with D-mesons measurement

<b>p-Pb</b>	<b>Pb-p</b>
$4.7 \cdot 10^{-3} < x_p < 2.1 \cdot 10^{-2}$	$7.1 \cdot 10^{-6} < x_p < 3.2 \cdot 10^{-5}$
$8.1 \cdot 10^{-5} < x_{\text{Pb}} < 1.8 \cdot 10^{-5}$	$5.3 \cdot 10^{-2} < x_{\text{Pb}} < 1.2 \cdot 10^{-2}$

# Conclusion

- ▶ J/ $\psi$  production studied at forward rapidity in all available pp measurements in ALICE
- ▶ charmonium production cross section and  $\langle p_T \rangle$  increase with  $\sqrt{s}$
- ▶ similar measurements also available for bottomonia ( $b\bar{b}$ )
  
- ▶ J/ $\psi$  production investigated as function of multiplicity in pp and p-Pb systems
- ▶ J/ $\psi$  yields demonstrate an increase with multiplicity similar to other hard probes, i. e. D mesons
- ▶ data compared with available models - different MPI implementation
- ▶ Run 2 data extend measurements to higher multiplicity

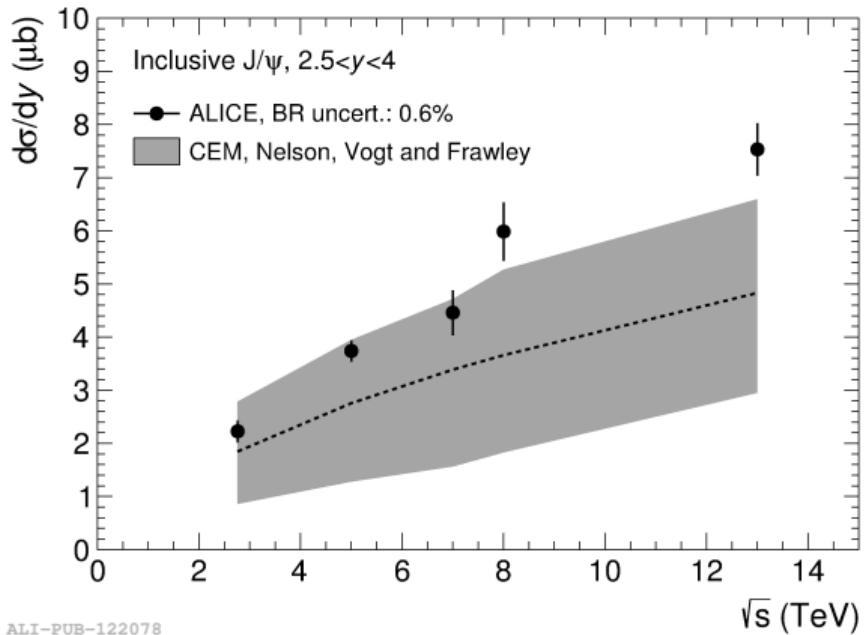
**More Run 2 measurements to come!**

On-going multiplicity analysis in p-Pb at  $\sqrt{s_{NN}} = 8.16$  TeV, several in pp at different  $\sqrt{s}$ .

# Back-up

# J/ $\psi$ cross section as a function of $\sqrt{s}$ at $2.5 < y < 4$

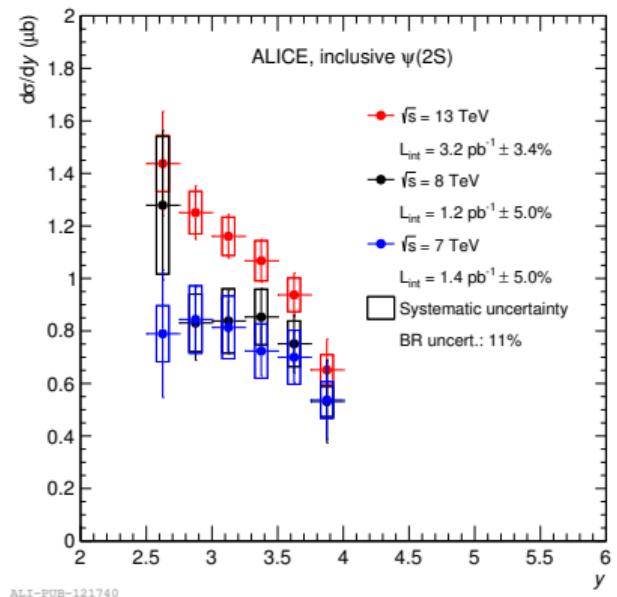
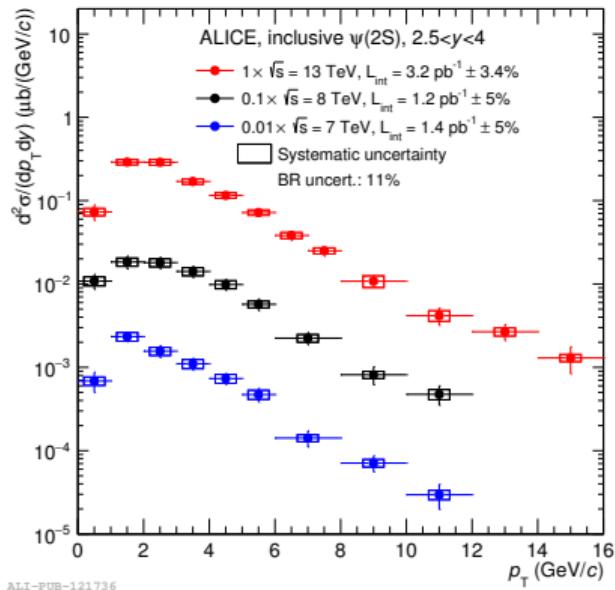
Eur. Phys. J. C 77 (2017) 392  
 Nelson: PRC 87 (2013) 014908



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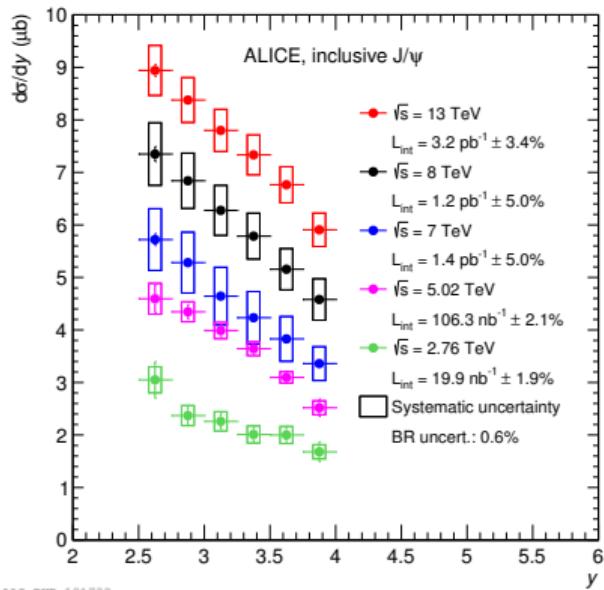
# $\psi(2S)$ cross section as a function of collision energy

Eur. Phys. J. C 77 (2017) 392

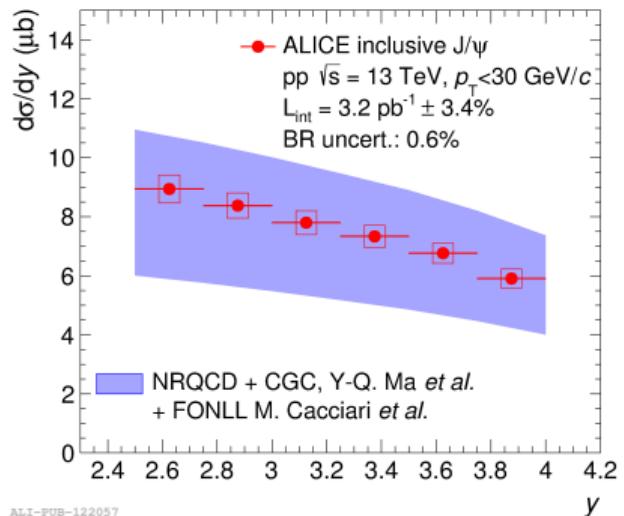


# $y$ -dependence of $J/\psi$ cross section

NRQCD+CGC: PRL 113 (2014) 192301  
 FONLL: JHEP 1210 (2012) 137  
 Eur. Phys. J. C 77 (2017) 392



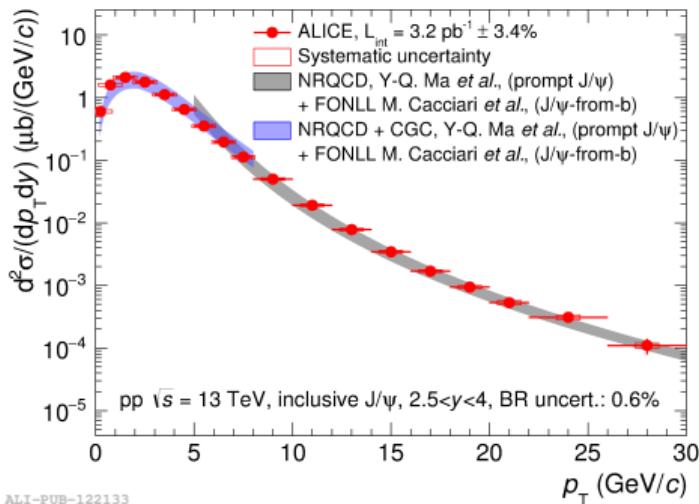
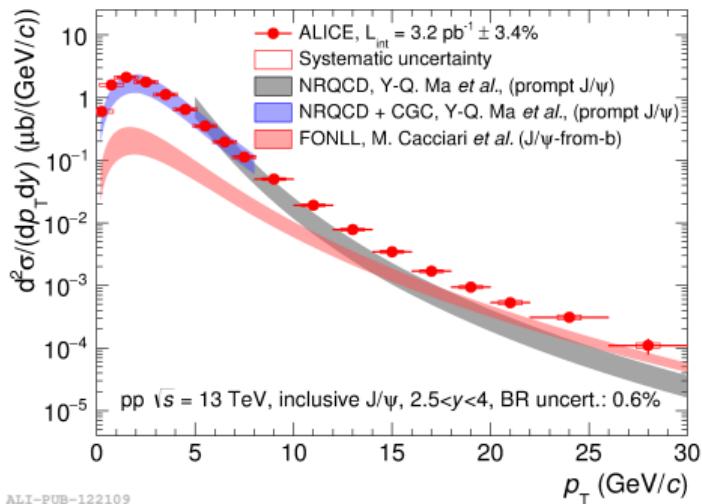
ALI-PUB-121732



ALI-PUB-122057

# J/ $\psi$ cross-section compared to theory

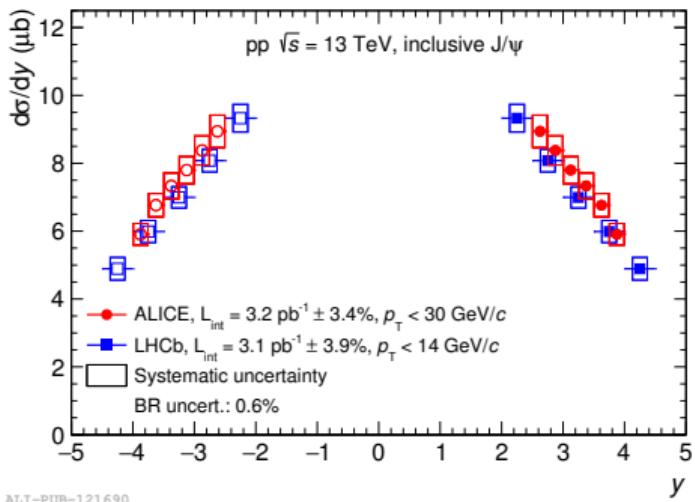
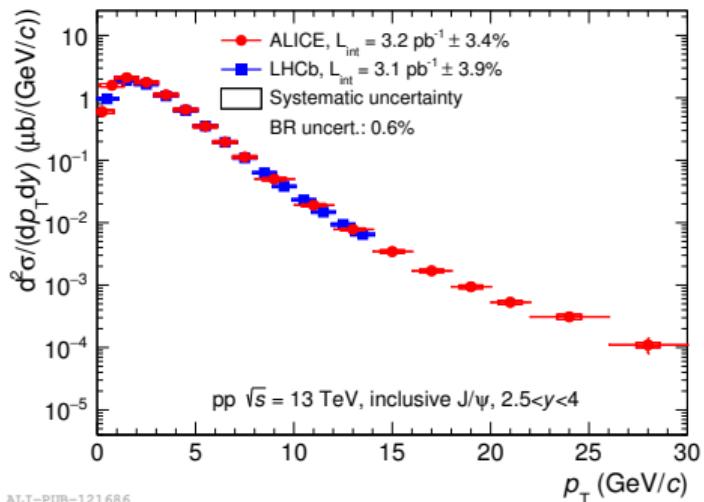
NRQCD: PRL 106 (2011) 042002  
 NRQCD+CGC: PRL 113 (2014) 192301  
 FONLL: JHEP 1210 (2012) 137  
 Eur. Phys. J. C 77 (2017) 392



ALI-PUB-122109

# J/ $\psi$ cross section - comparison between ALICE and LHCb

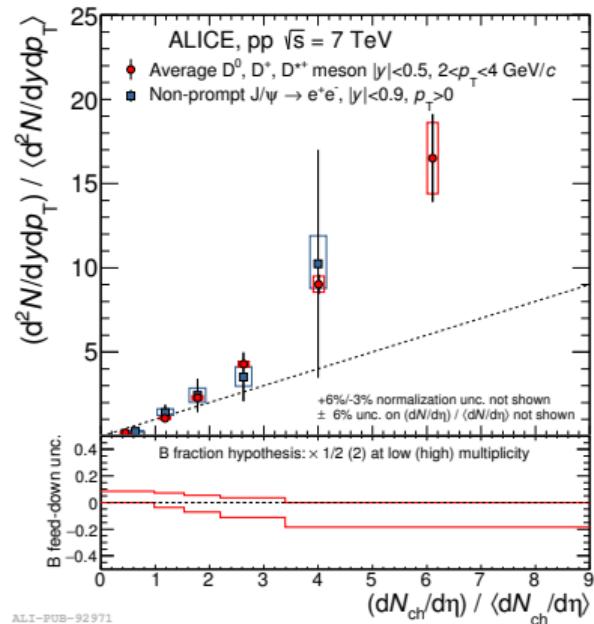
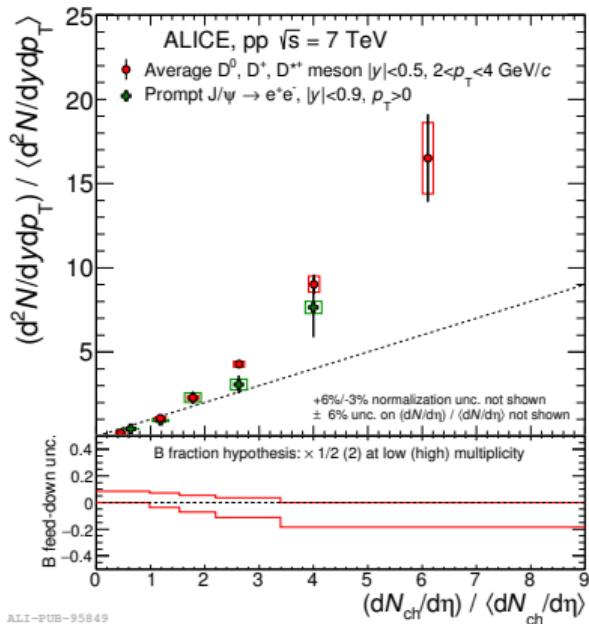
Eur. Phys. J. C 77 (2017) 392  
 LHCb: JHEP 10 (2015) 172 ;  
 Erratum: JHEP 05 (2017) 063



ALI-PUB-121686

# Prompt vs non-prompt J/ $\psi$ versus multiplicity

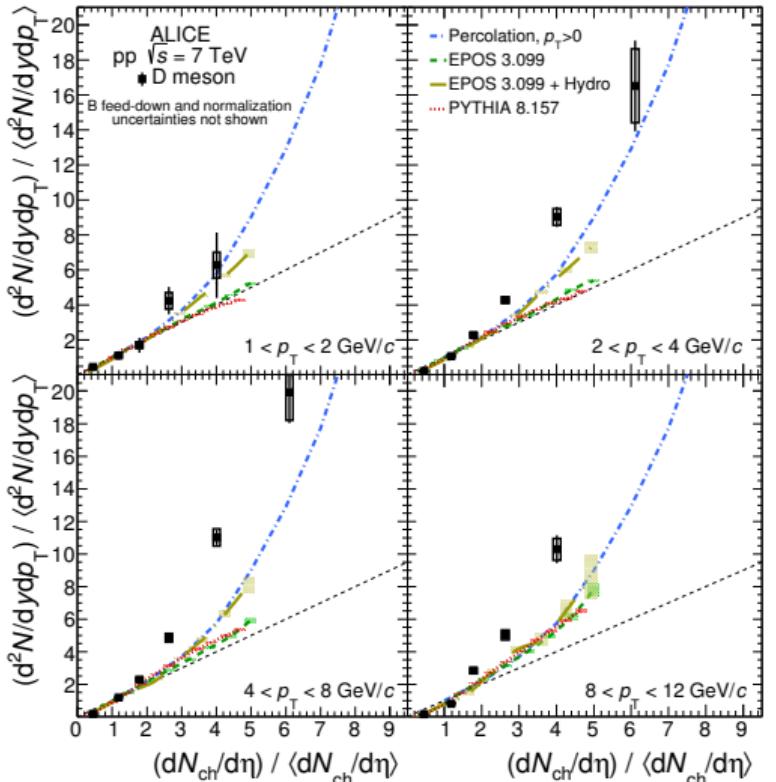
JHEP 1509 (2015) 148



# Comparison with models at 7 TeV

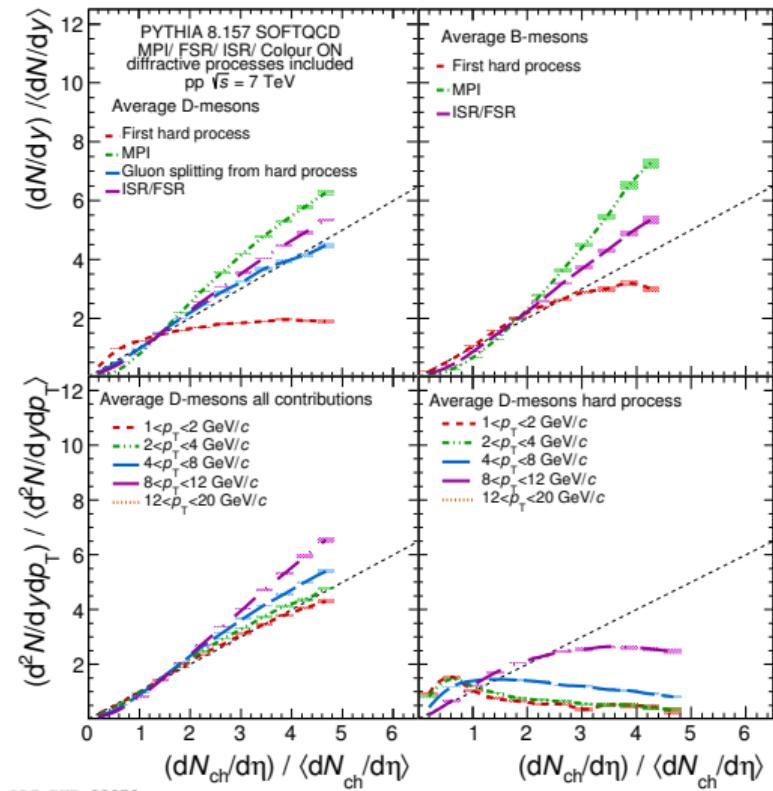
JHEP 1509 (2015) 148  
 EPOS3: Phys.Rept. 350 (2001) 93-289  
 EPOS3+Hydro: PRC 89 (2014) 064903  
 PYTHIA8: Comput. Phys. Commun. 178 (2008) 852-867  
 Percolation: PRC 86 (2012) 034903/arXiv:1501.03381

- ▶ EPOS3 and Pythia predict linear increase
- ▶ adding Hydro component to EPOS3 yields stronger than linear increase
- ▶  $p_T$  integrated Percolation also stronger than linear increase
- ▶ stronger than linear increase reproduced by models at  $1 < p_T < 2$



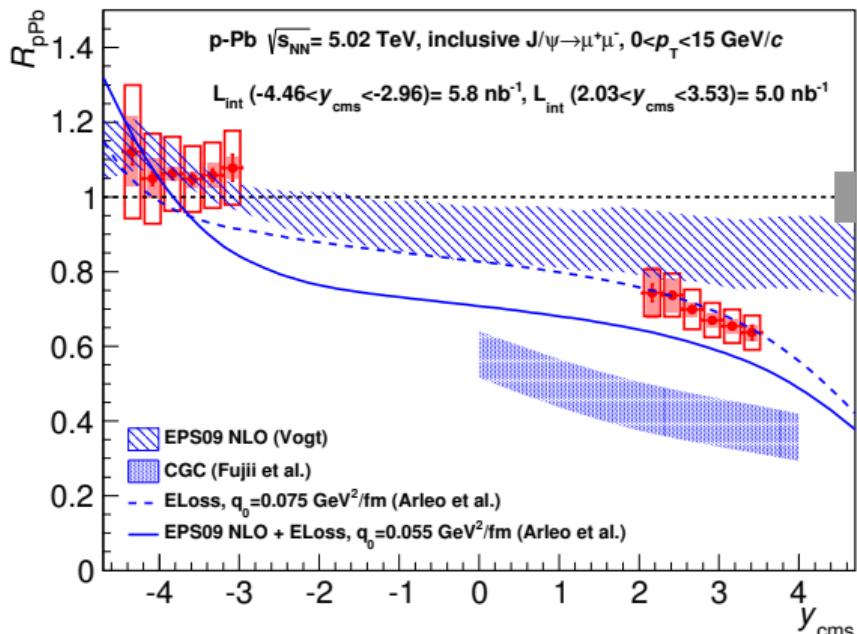
# Charm meson multiplicity dependence at 7 TeV

JHEP 1509 (2015) 148



# Nuclear modification factor $R_{pPb}$

$$R_{pPb} = \frac{1}{\langle T_{pPb} \rangle} \frac{d^2 N_{pPb} / dp_T dy}{d^2 \sigma_{pp} / dp_T dy}$$



ALI-PUB-75287