Recent quarkonium measurements in small systems with the ALICE detector at LHC

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Study of quarkonium production

ALICE

pp collisions

- Understand the production mechanisms
- Probe the PDFs down to low x
- Reference for p-Pb and Pb-Pb measurements

p-Pb collisions*

- Cold nuclear matter (CNM) effects:
  - Energy loss
  - nPDFs modification
- Reference for Pb-Pb measurements

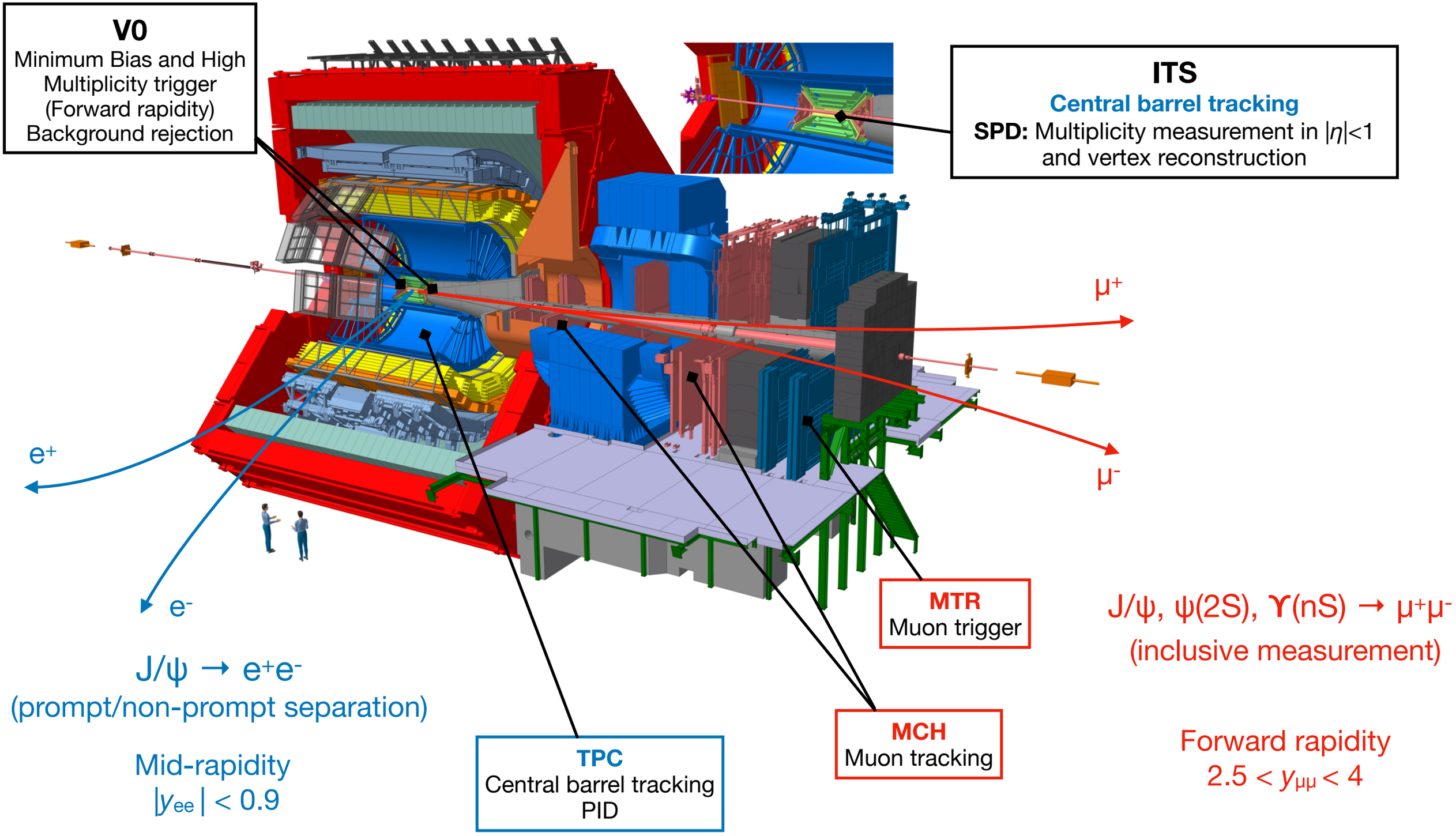
Pb-Pb collisions*

- Hadronic matter properties at high energy density:
  - Color screening
  - Energy loss
  - Regeneration

Small systems: provide tests for calculations based on perturbative QCD

* Latest p-Pb and Pb-Pb quarkonium results presented in:
- HF and Quarkonia 06/01(F. Damas)
- HF and Quarkonia 06/04 (L. Micheletti)

Quarkonium measurement with ALICE



$J/\psi \rightarrow e^+e^-$
(prompt/non-prompt separation)

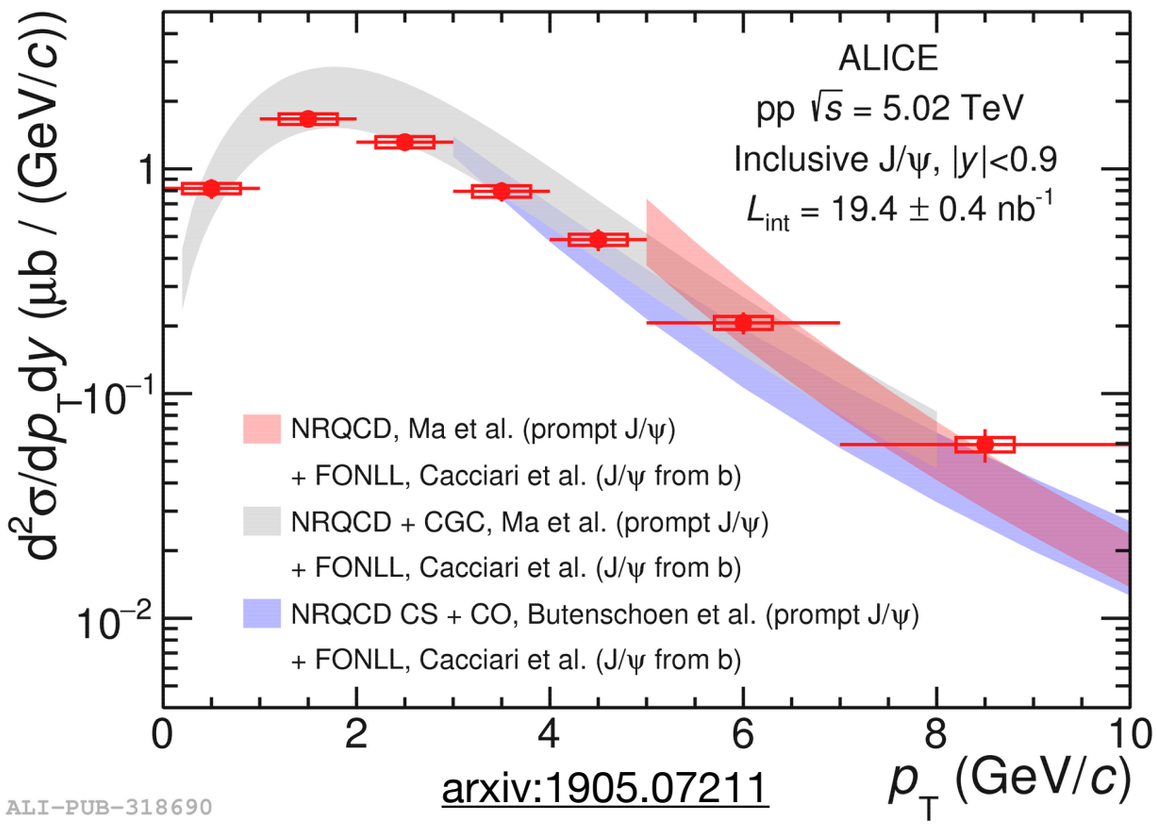
Mid-rapidity
$|y_{ee}| < 0.9$

J/ψ, $\psi(2S)$, $\Upsilon(nS) \rightarrow \mu^+\mu^-$
(inclusive measurement)

Forward rapidity
$2.5 < y_{\mu\mu} < 4$

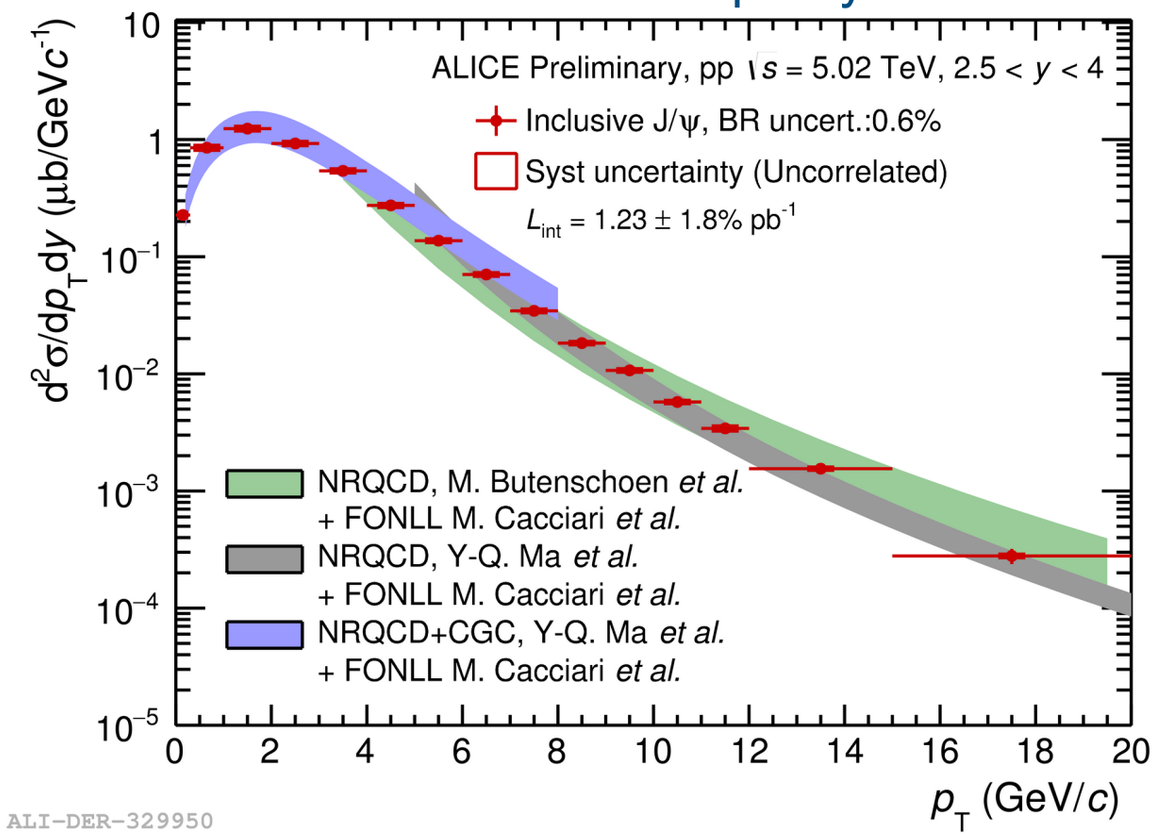
J/ψ cross section in pp collisions at 5.02 TeV

Mid-rapidity



arxiv:1905.07211

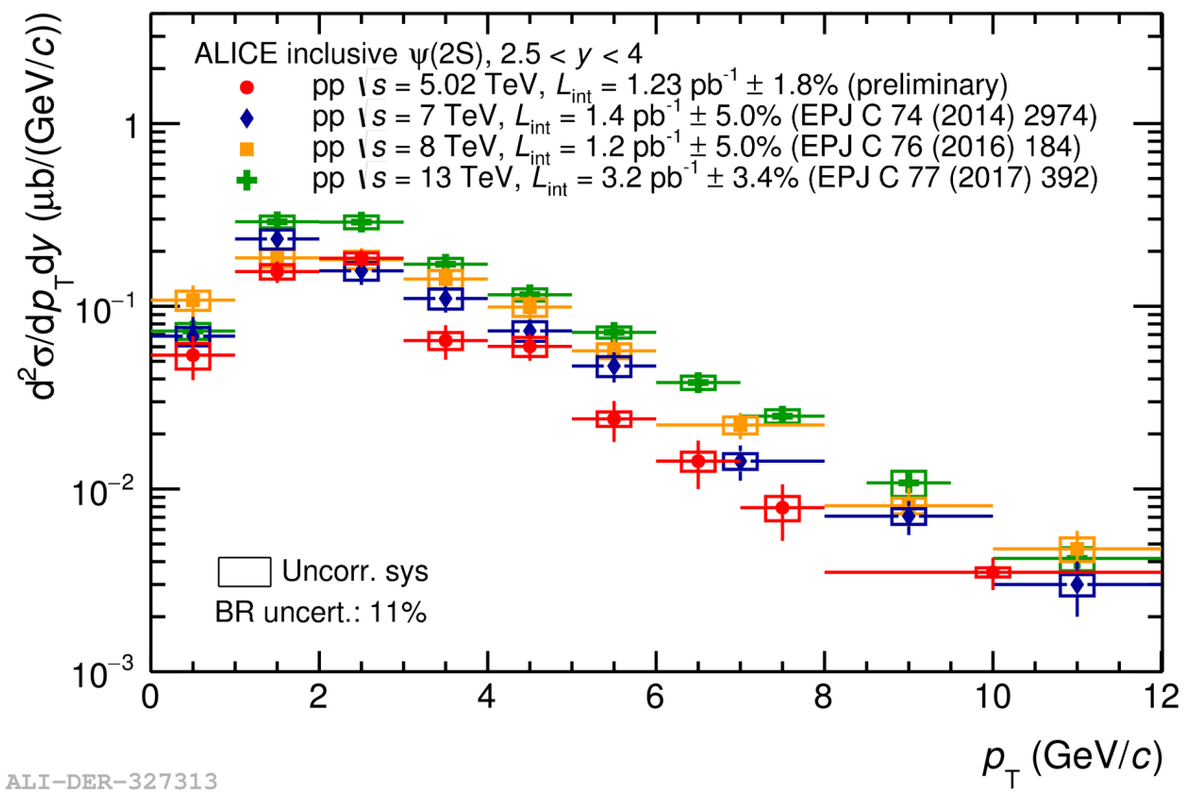
Forward rapidity



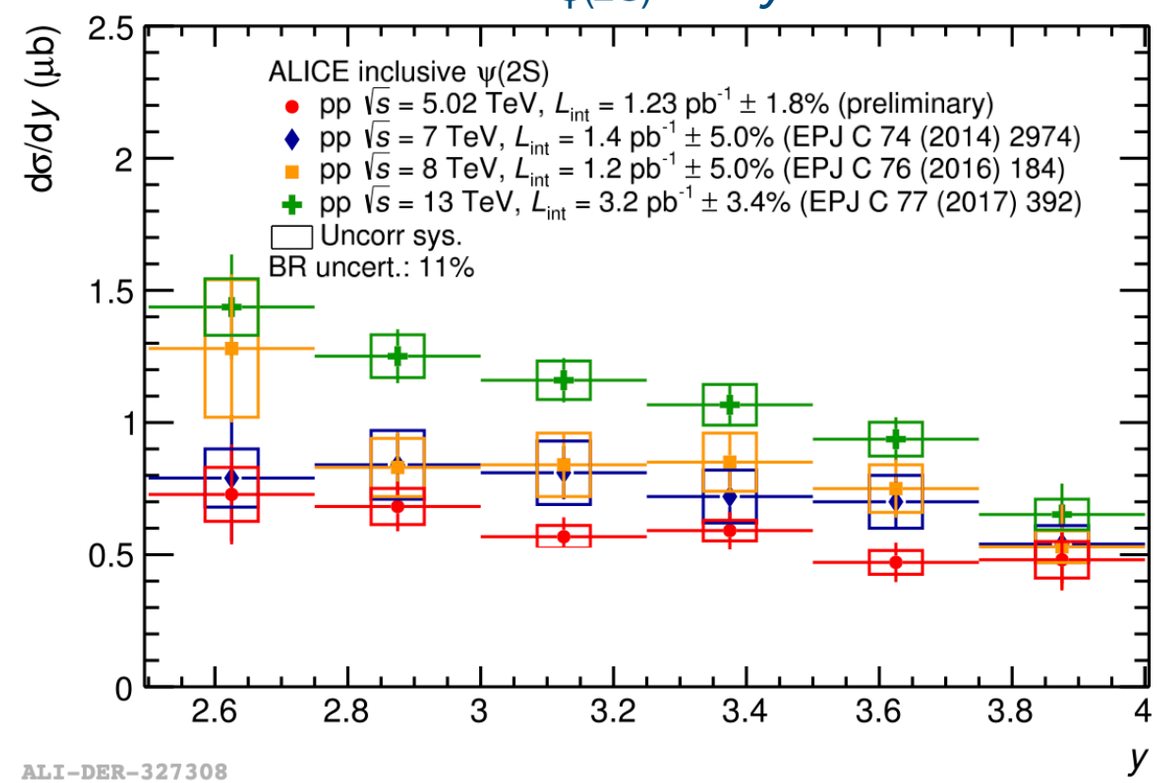
- New cross section measurement up to p_T = 20 GeV/c at forward rapidity providing a reference for R_{AA} measurement
- NRQCD calculations coupled with FONLL for non-prompt J/ψ production and CGC (at low p_T) provide a good description of the data at both rapidities

ψ(2S) cross section in pp collisions at 5.02 TeV

$\sigma_{\psi(2S)}$ vs. p_T



$\sigma_{\psi(2S)}$ vs. y

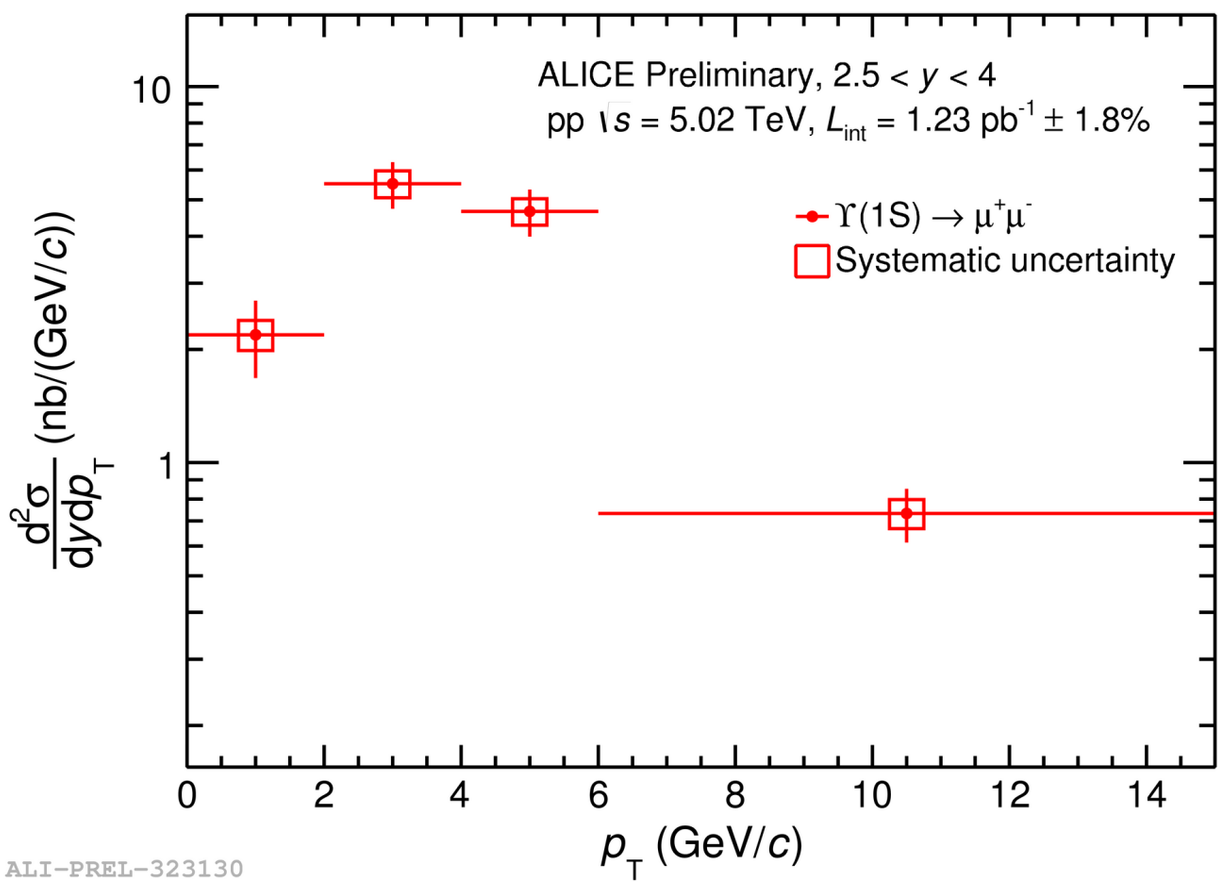


$\sigma_{\psi(2S)}$ (p_T < 12 GeV/c) = 0.876 ± 0.056 (stat.) ± 0.101 (syst.) μb

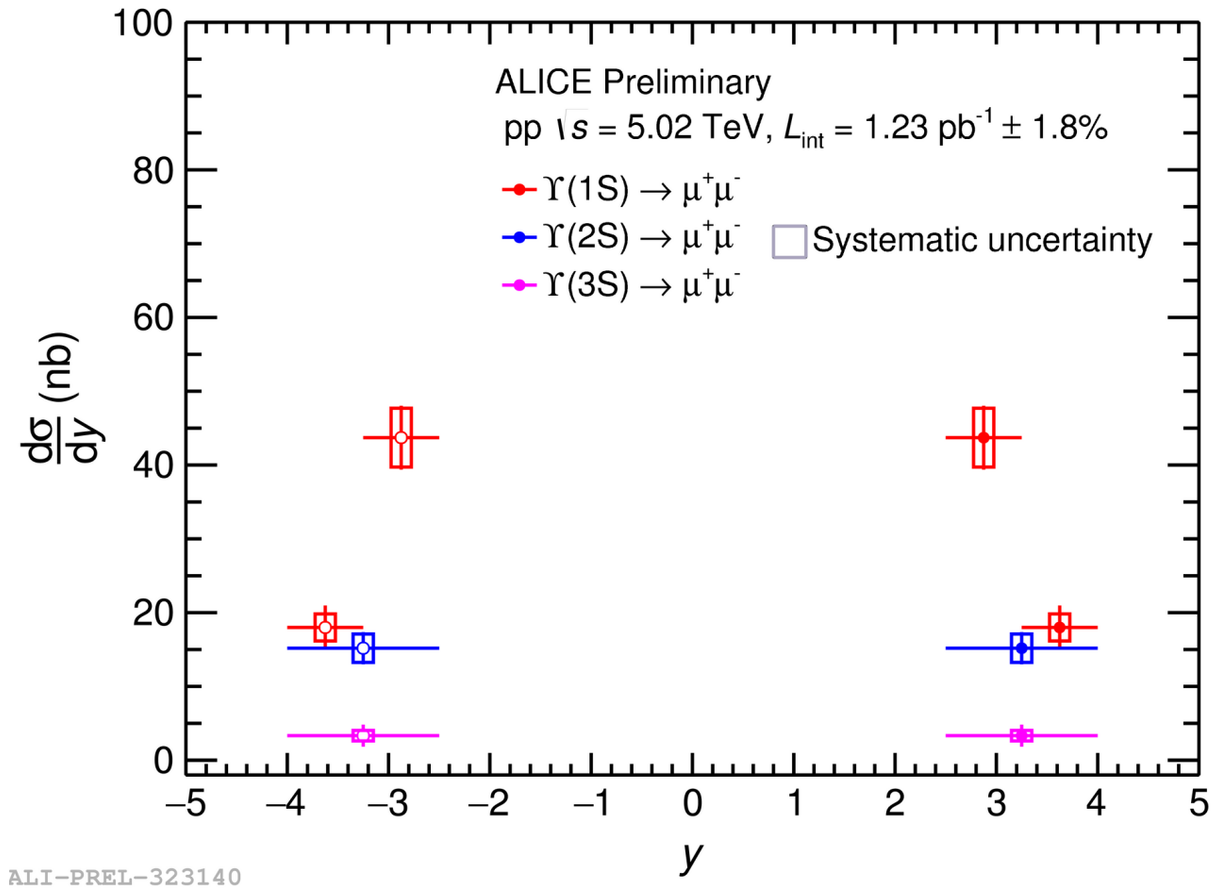
- First p_T and y differential measurement of the ψ(2S) cross section at 5.02 TeV
- Crucial ingredient for the ψ(2S) R_{AA} in Pb-Pb at 5.02 TeV
- Measurement made possible thanks to the increase of statistics ($L_{int,\ 2017}$ ~ 10 x $L_{int,\ 2015}$)

ϒ(nS) cross section in pp collisions at 5.02 TeV

$\sigma_{\Upsilon(1S)}$ vs. p_T



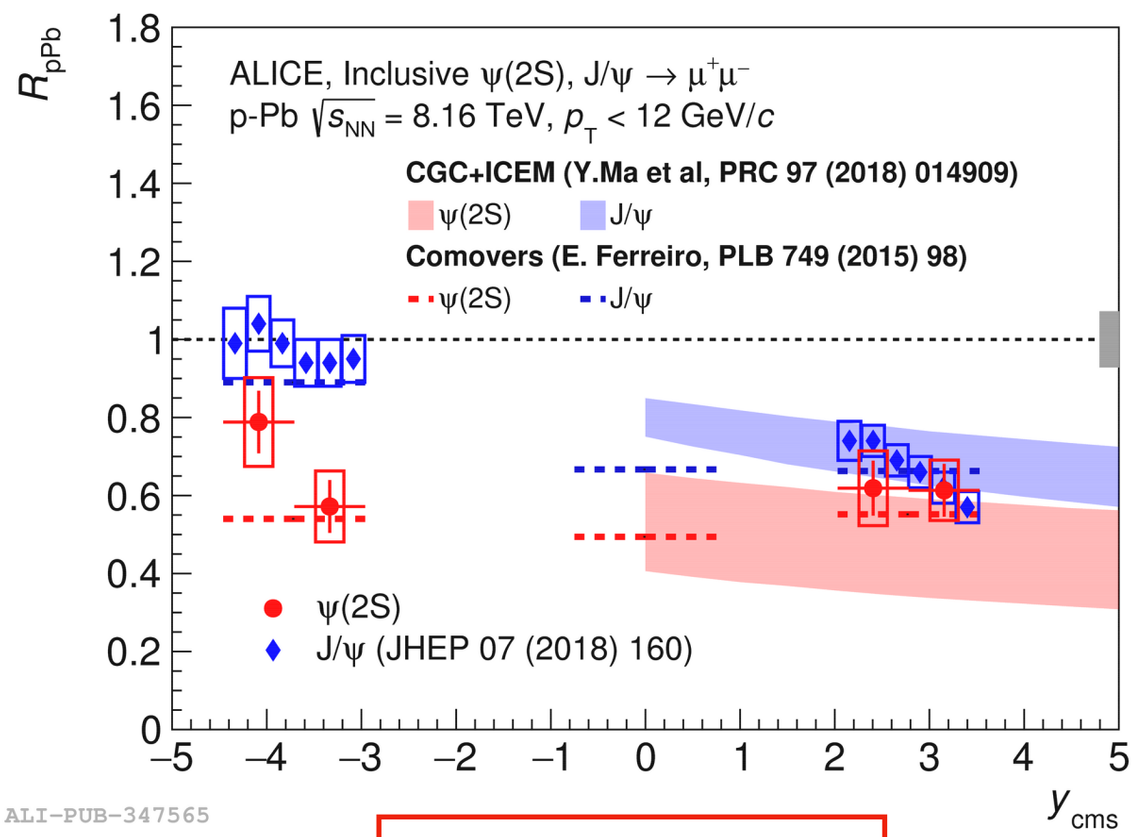
$\sigma_{\Upsilon(nS)}$ vs. y



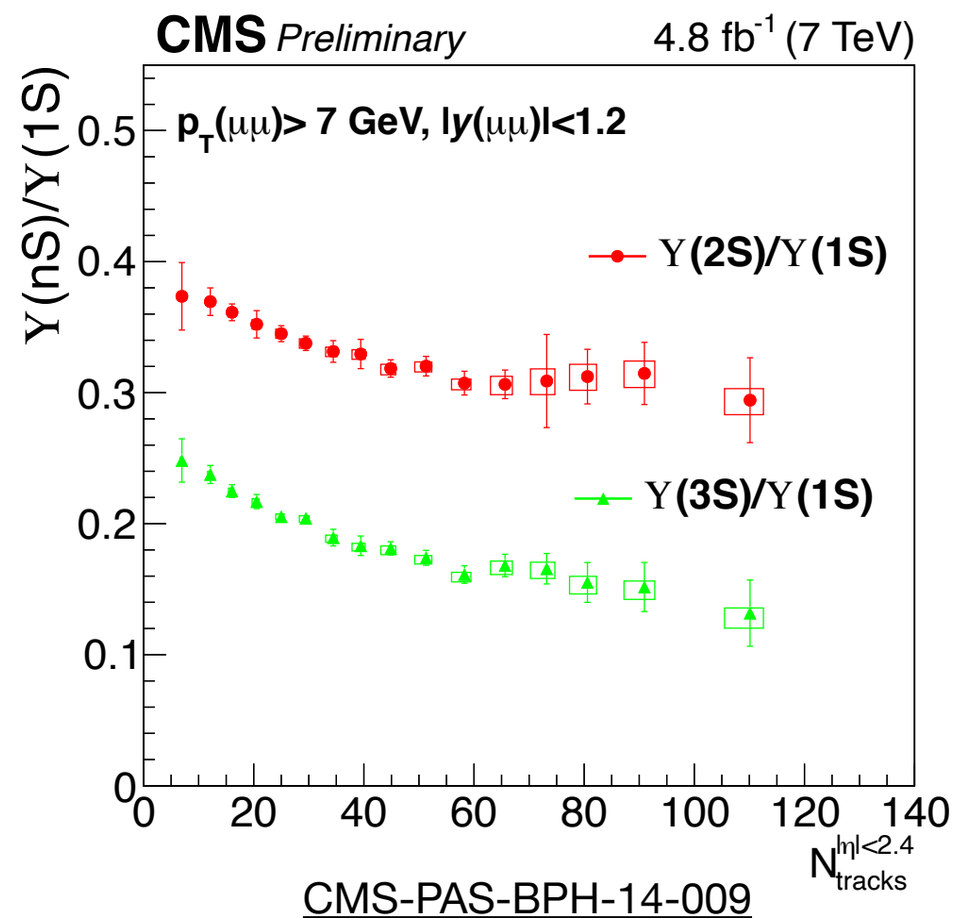
- First ALICE measurement of ϒ(1S), ϒ(2S) and ϒ(3S) cross section at 5.02 TeV
- Reference for R_{AA} measurement (Pb-Pb collisions)

Multiplicity dependence of quarkonium production

- Search for potential correlations between hard (quarkonium production) and soft (charged particle multiplicity) processes
- Study of medium-induced effects observed in small systems: potential suppression of excited states w.r.t ground state in high multiplicity pp collisions?



*NEW arxiv:2003.06053



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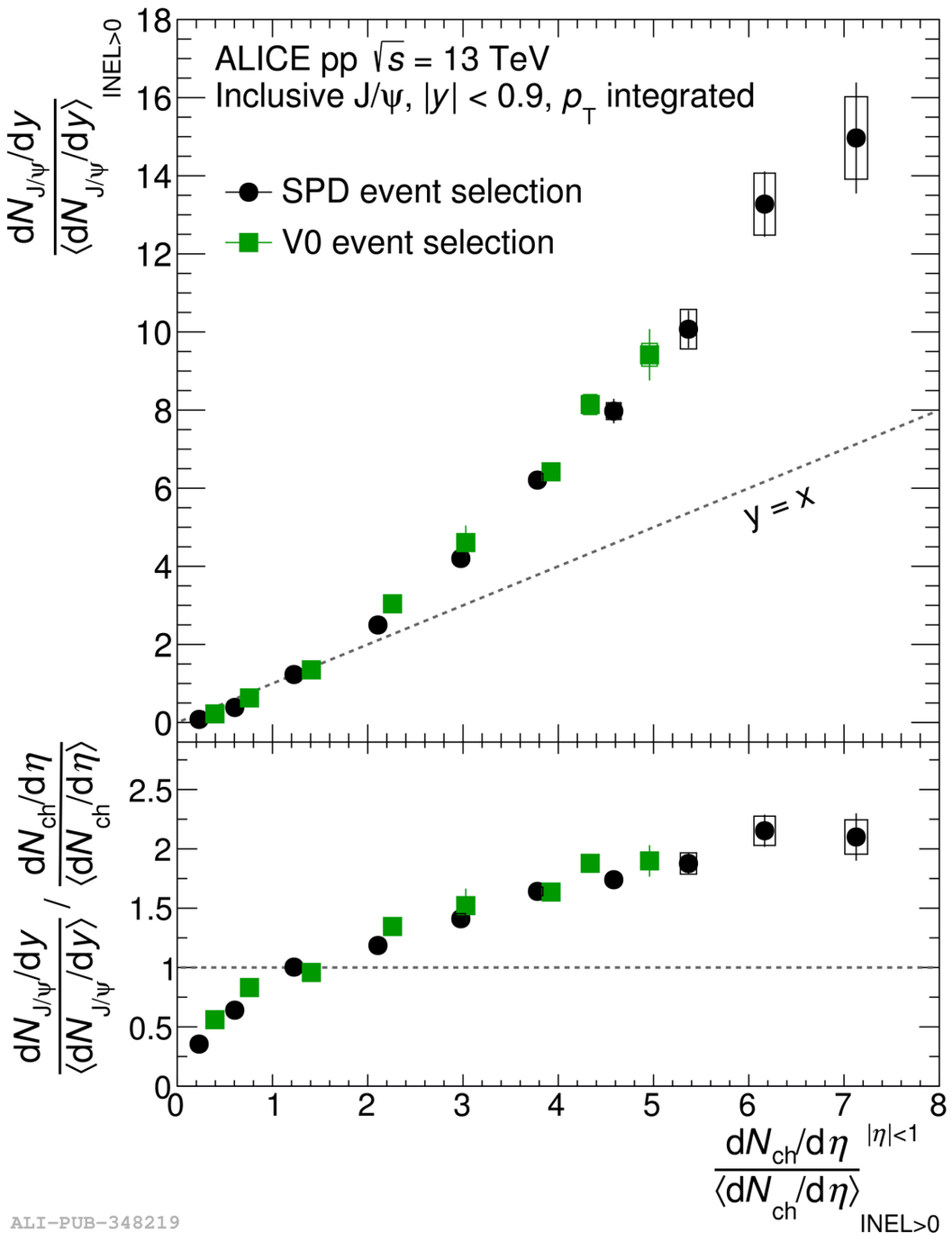
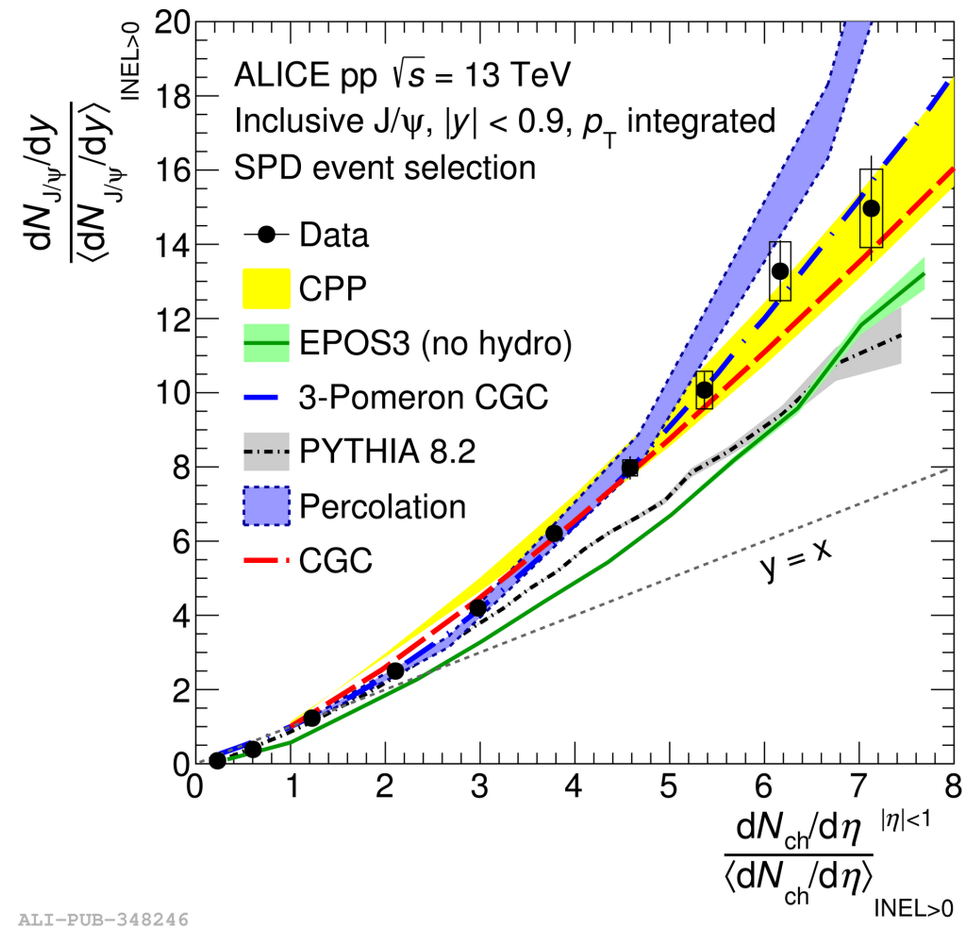
* Results presented by F. Damas (HF and Quarkonia 06/01)

J/ψ production vs. multiplicity in pp collisions at 13 TeV (mid-rapidity)

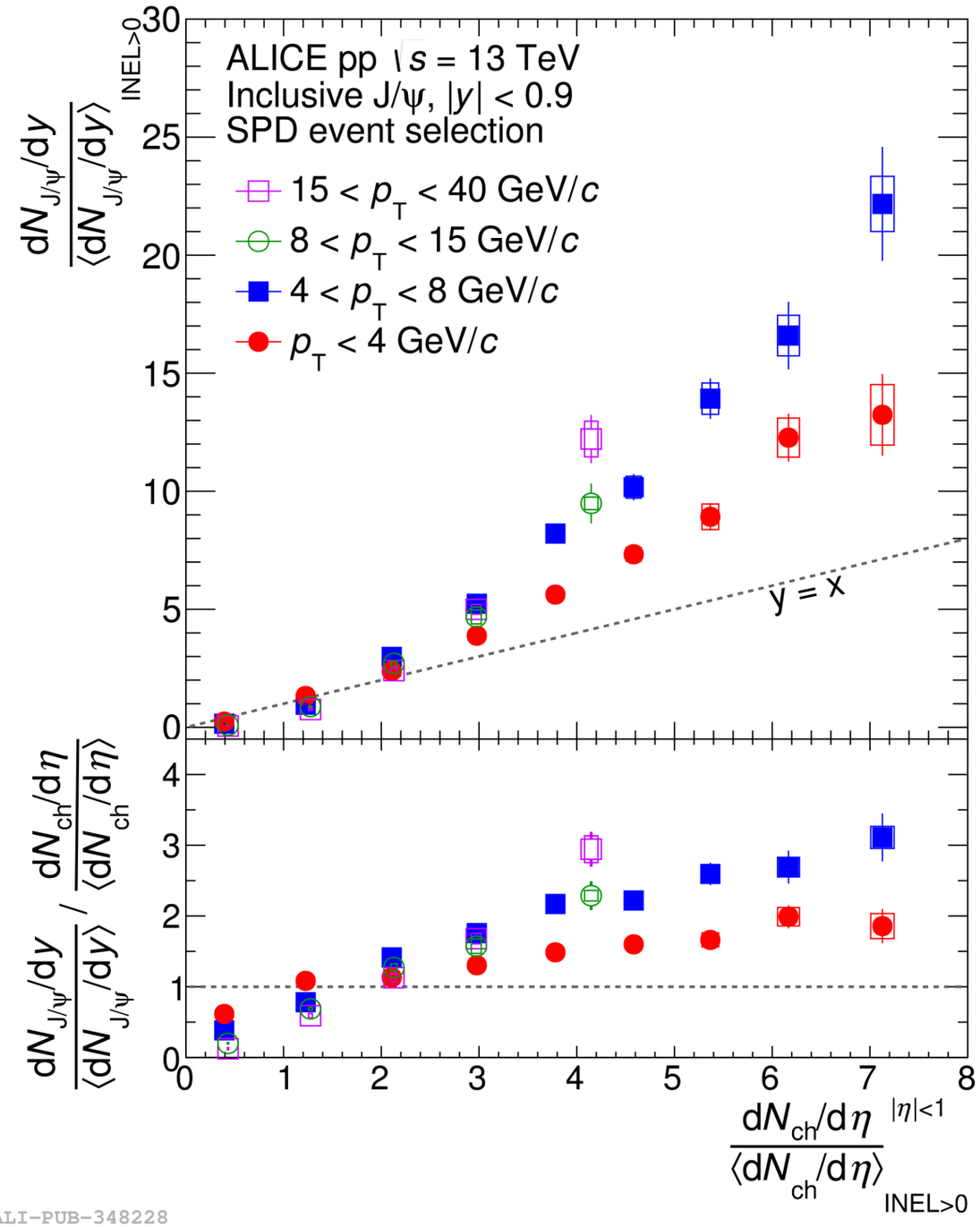


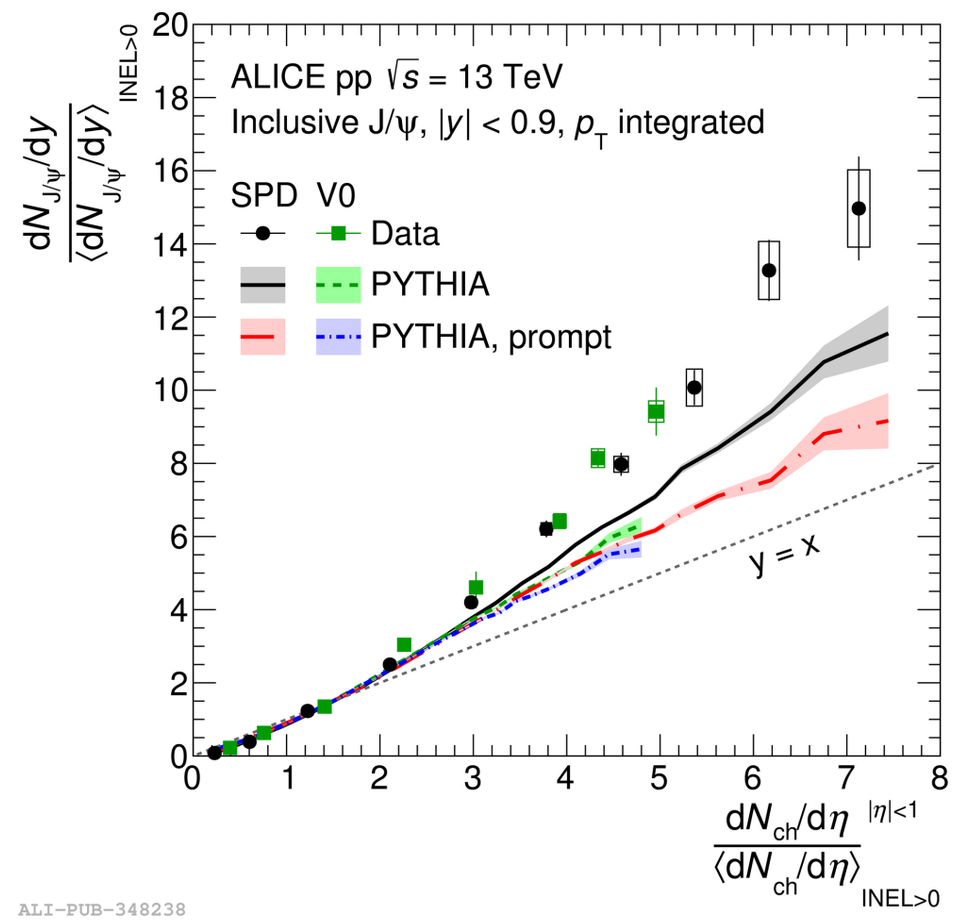


NEW arxiv:2005.11123

- Higher multiplicity coverage w.r.t 7 TeV results (JHEP 09 (2015) 148)
- Stronger-than-linear increase of the J/ψ self-normalized yield with both multiplicity estimators (SPD at mid-*y* and V0 at forward *y*)
- Various mechanisms (e.g. CSR, percolation, gluon saturation) responsible for multiplicity-dependent reduction of $dN_{ch}/d\eta$ in all models
- Good agreement with CGC, CPP and 3-Pomeron models

J/ψ production vs. multiplicity in pp collisions at 13 TeV (mid-rapidity)



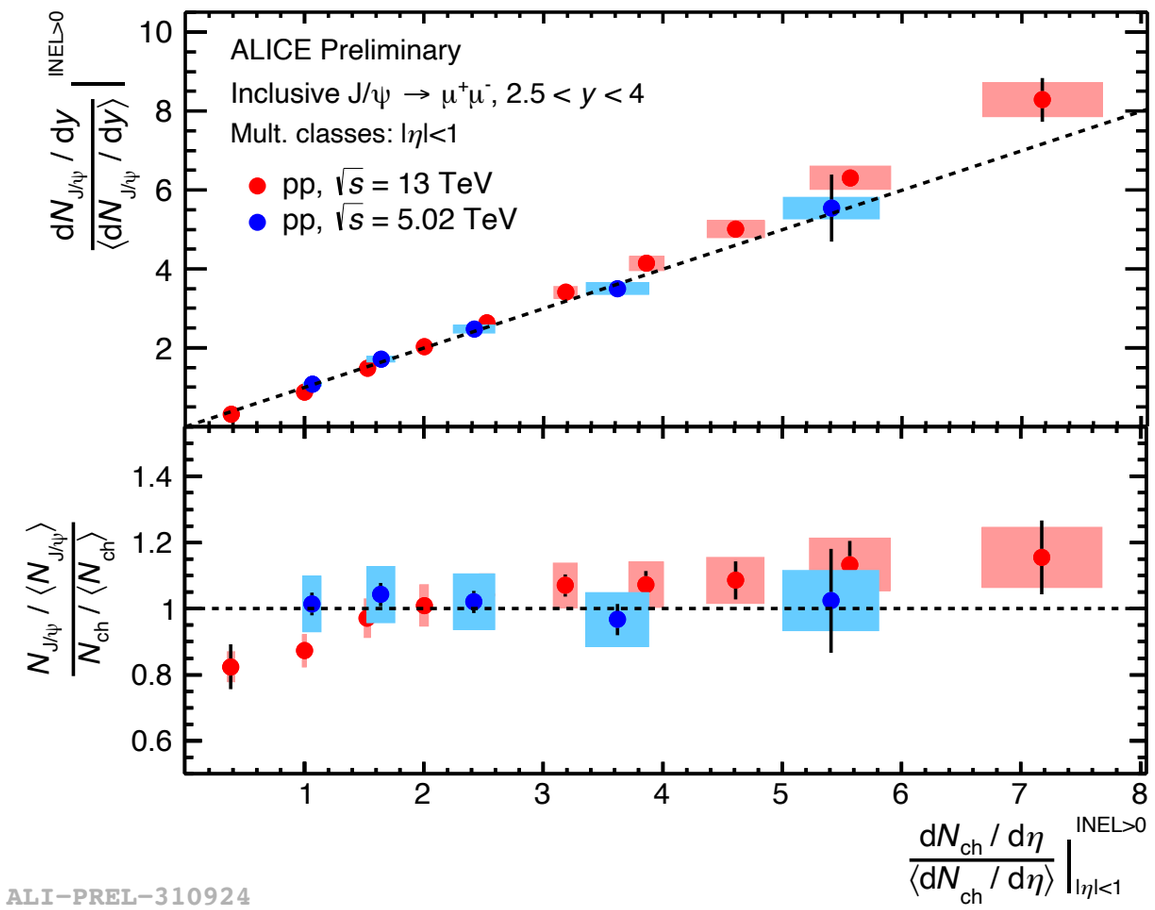


NEW arxiv:2005.11123

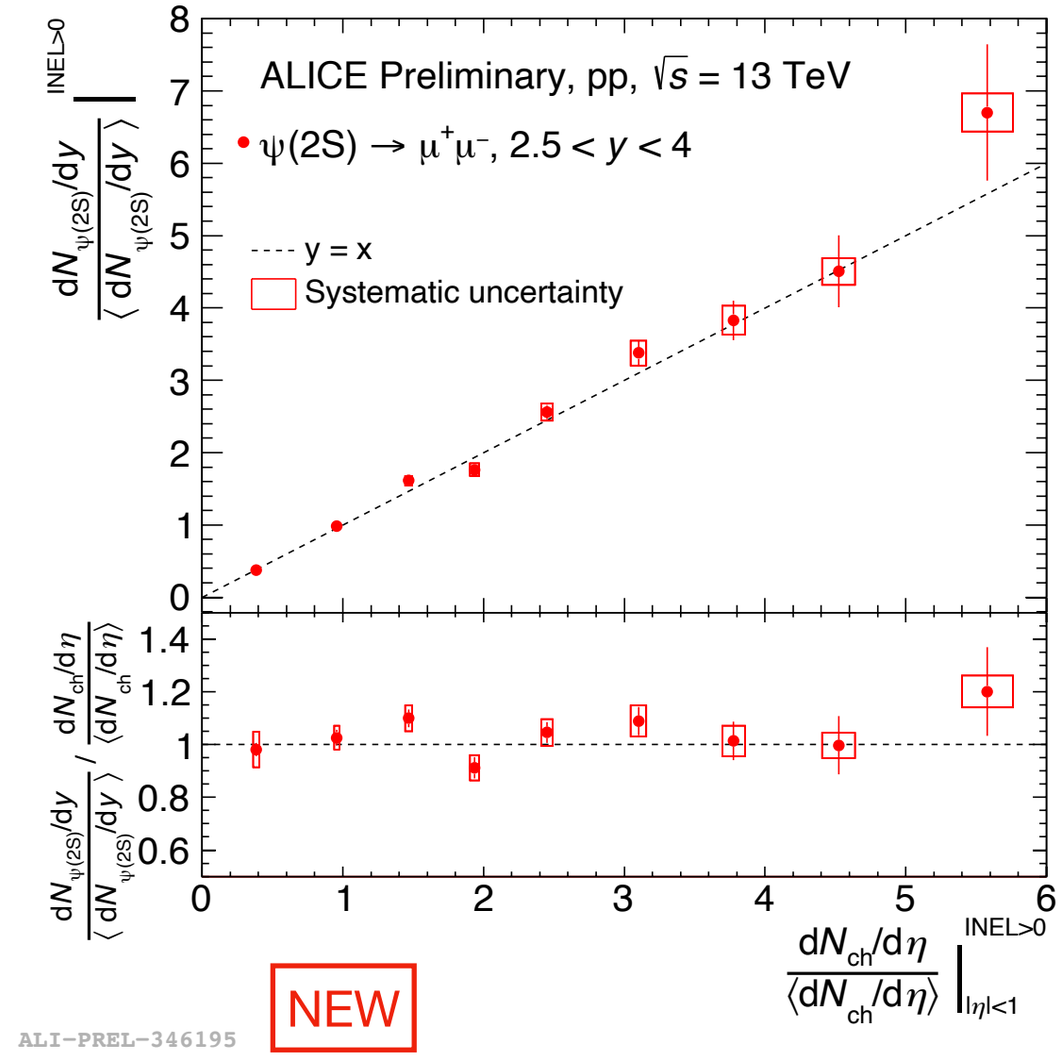
- Significant increase of the self-normalized J/ψ yield with relative multiplicity between the J/ψ p_T intervals 0-4 and 4-8 GeV/*c*
  - ➡Auto-correlation mechanisms e.g. jet or beauty-quark fragmentation?
- Significant reduction of the correlation observed when only including the prompt component in PYTHIA

Charmonium production vs. multiplicity in pp collisions (forward rapidity)

J/ψ vs. Multiplicity



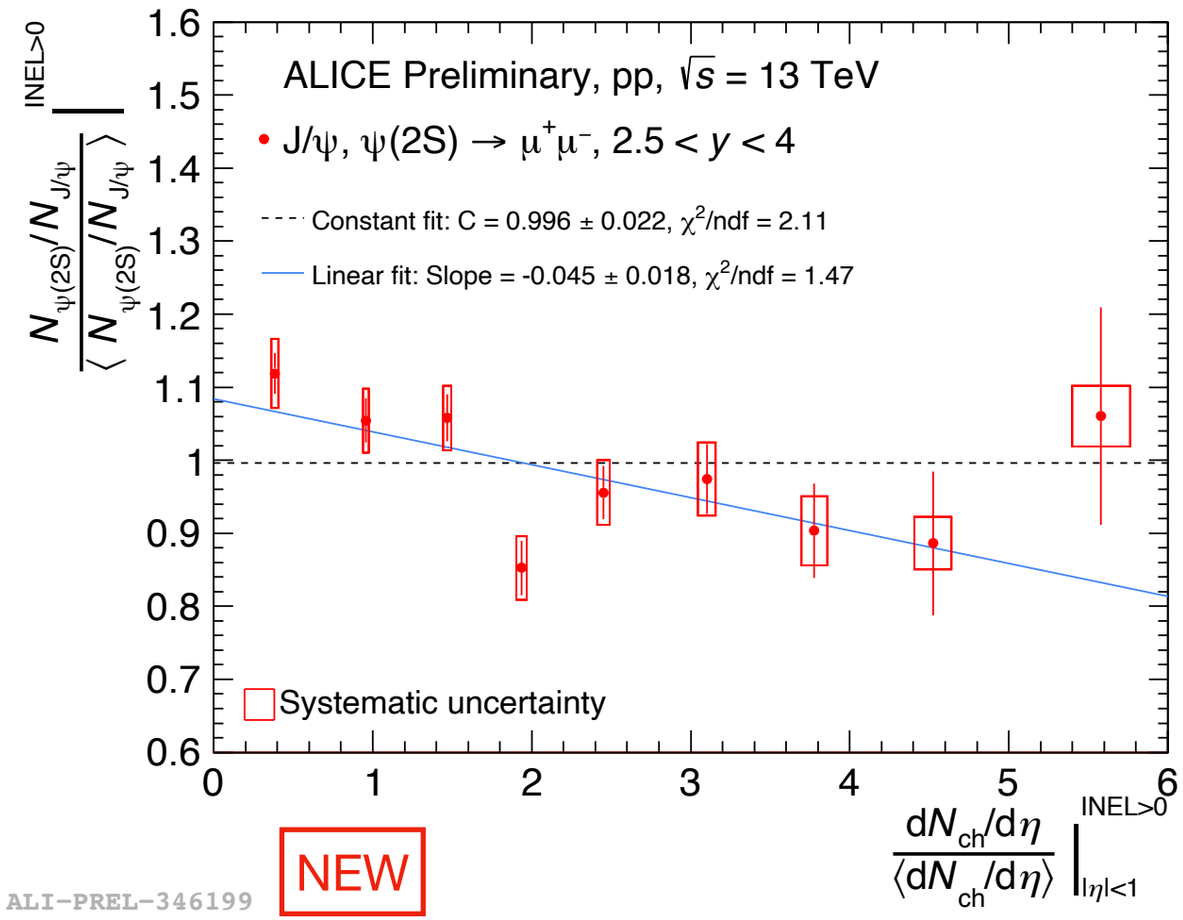
ψ(2S) vs. Multiplicity



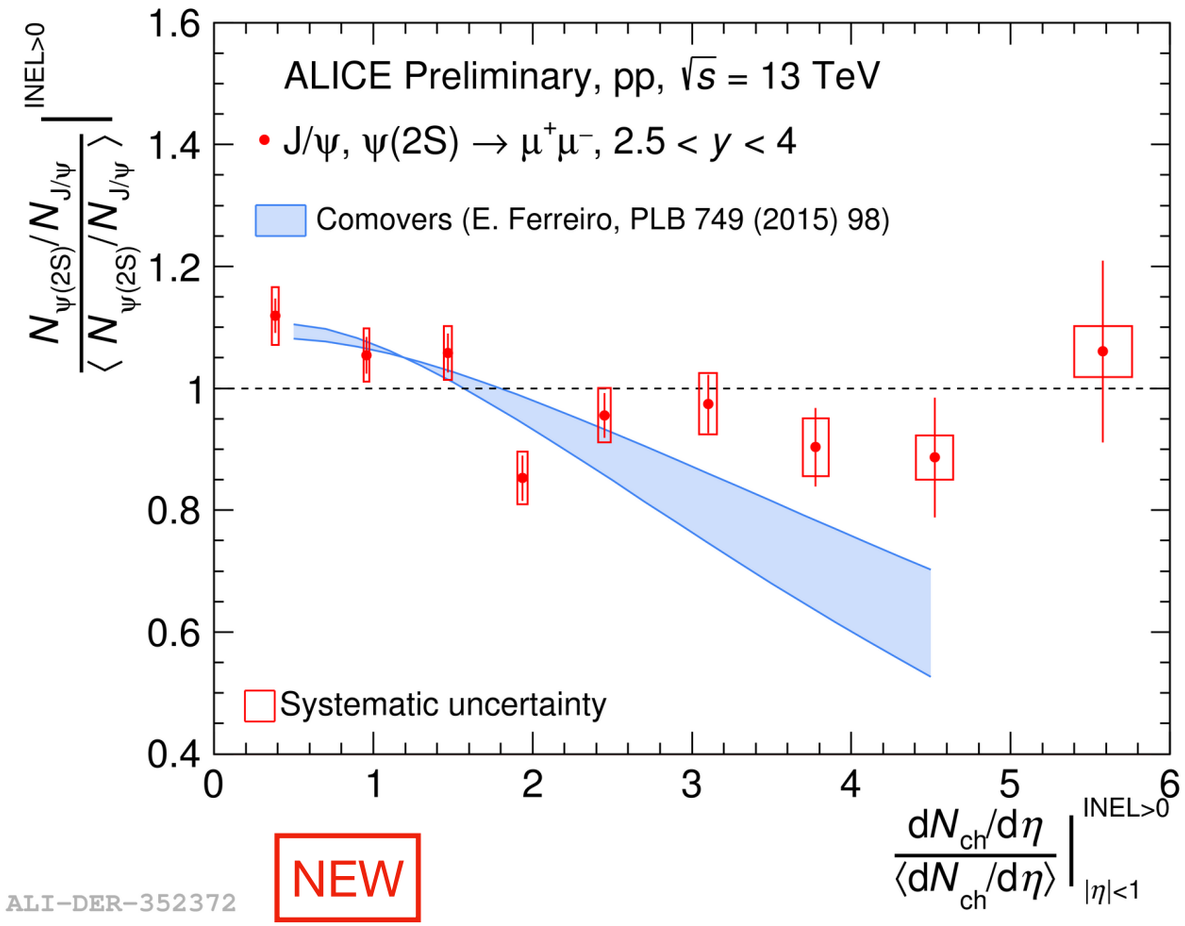
- J/ψ relative yields compatible with linear dependence on multiplicity (unlike mid-*y* results)
- No energy dependence observed for the J/ψ results
- New ψ(2S) results on the full Run 2 data sample also compatible with linear dependence on multiplicity

Relative ψ(2S)/J/ψ production vs. multiplicity in pp at 13 TeV

ψ(2S)/J/ψ vs. Multiplicity



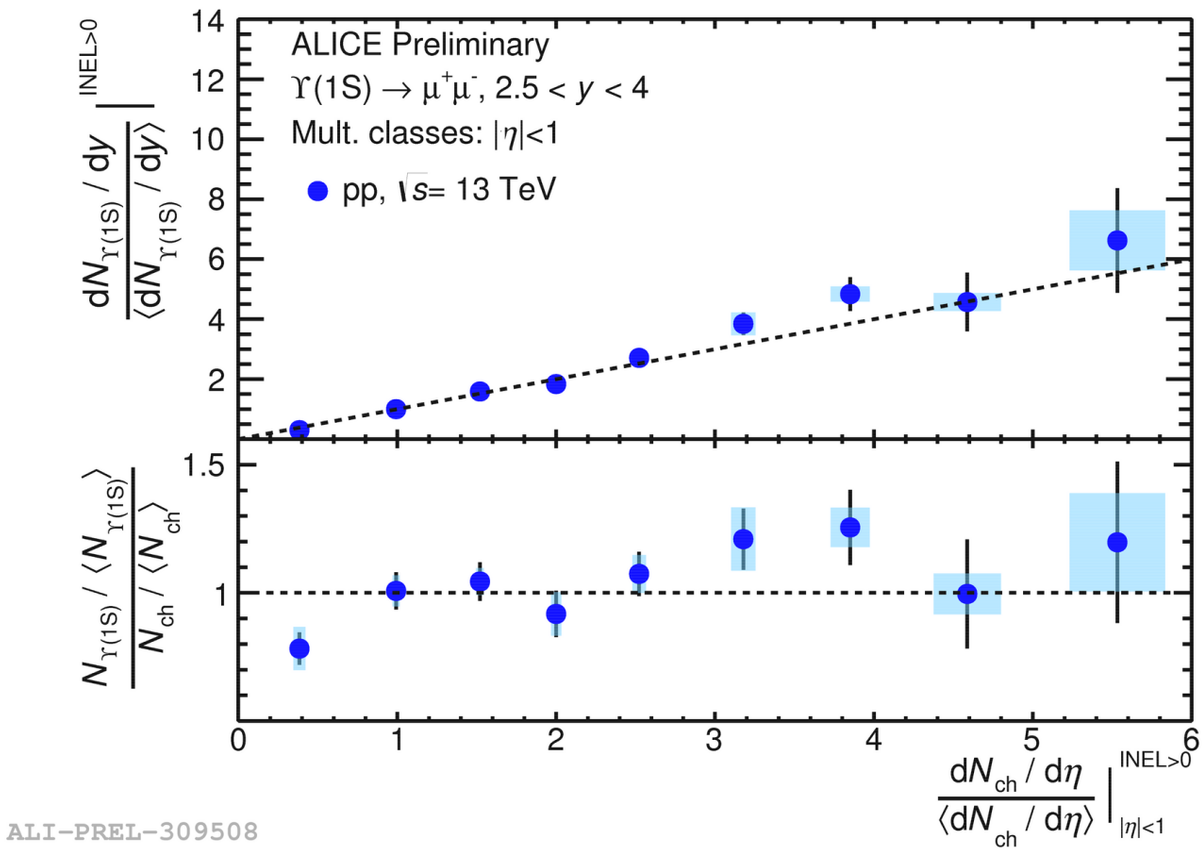
ψ(2S)/J/ψ vs. Multiplicity + comovers



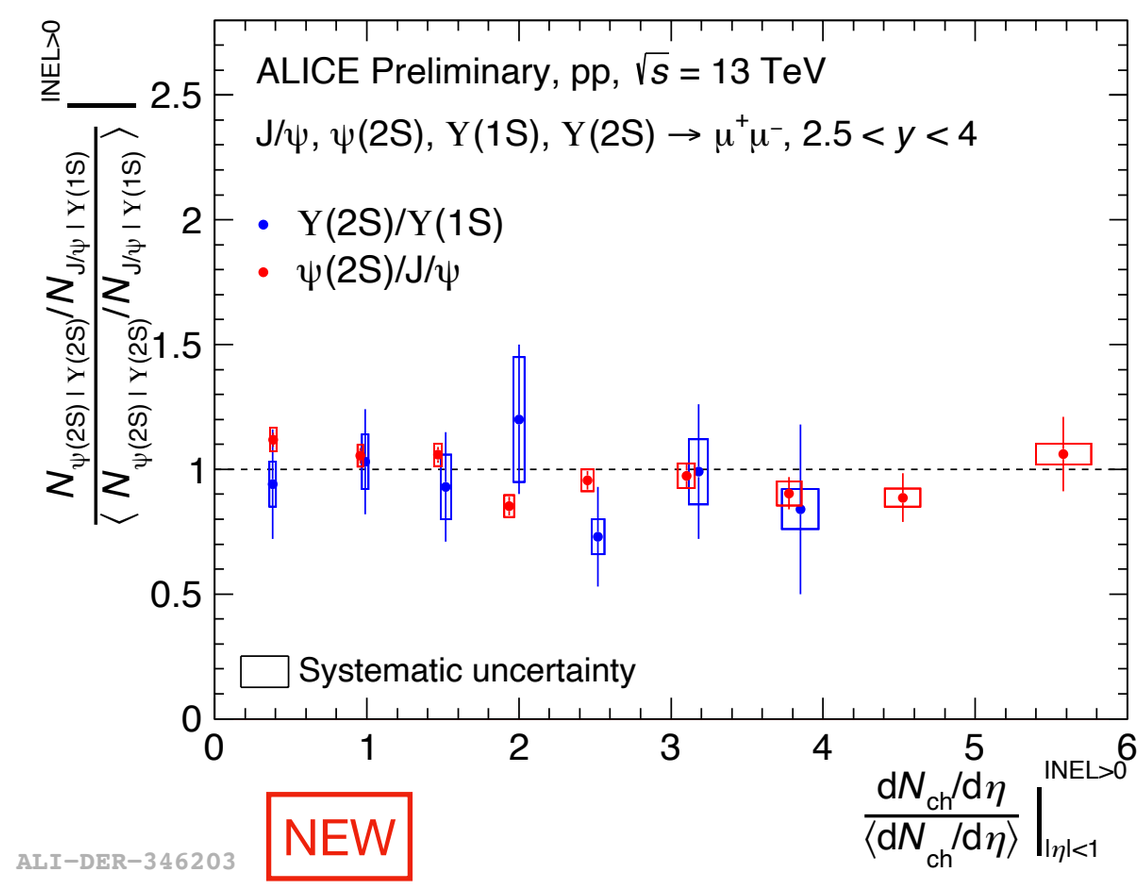
- New self-normalized ψ(2S)/J/ψ results (on full Run 2 data sample): maximum deviation from unity ~2.2σ (first bin) → hint of a multiplicity dependence of ψ(2S) suppression w.r.t J/ψ?
- Multiplicity dependence of ψ(2S) suppression w.r.t. J/ψ predicted by comovers approach. Amplitude of the suppression stronger in the model than in the measurement

ϒ(nS) production vs. multiplicity in pp at 13 TeV (forward rapidity)

ϒ(1S) vs. Multiplicity



ϒ(2S)/ϒ(1S) and ψ(2S)/J/ψ vs. Multiplicity

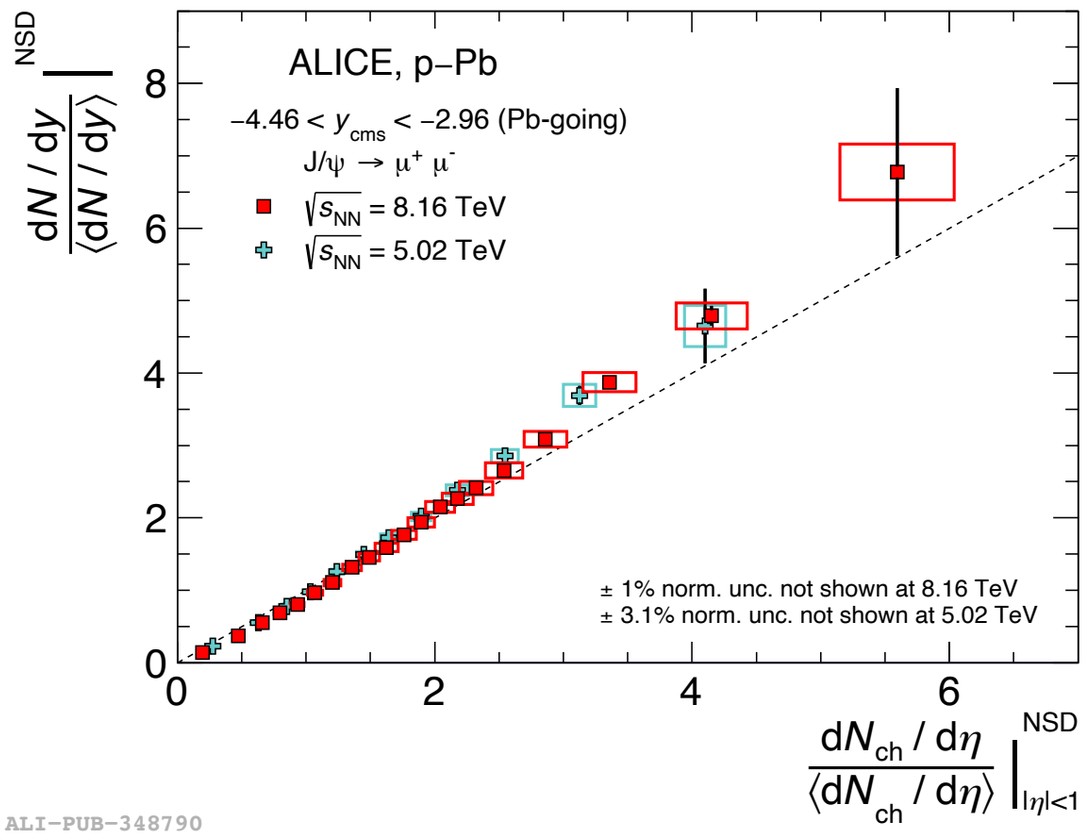


- ϒ relative yields (2016 data sample) show a linear dependence on multiplicity → compatible with charmonium yields at forward rapidity
- Charmonium ratio compatible with ϒ(2S)/ϒ(1S) within large statistical and systematic uncertainties,
  ➡Full Run 2 ϒ(nS) (including 3S) results coming soon

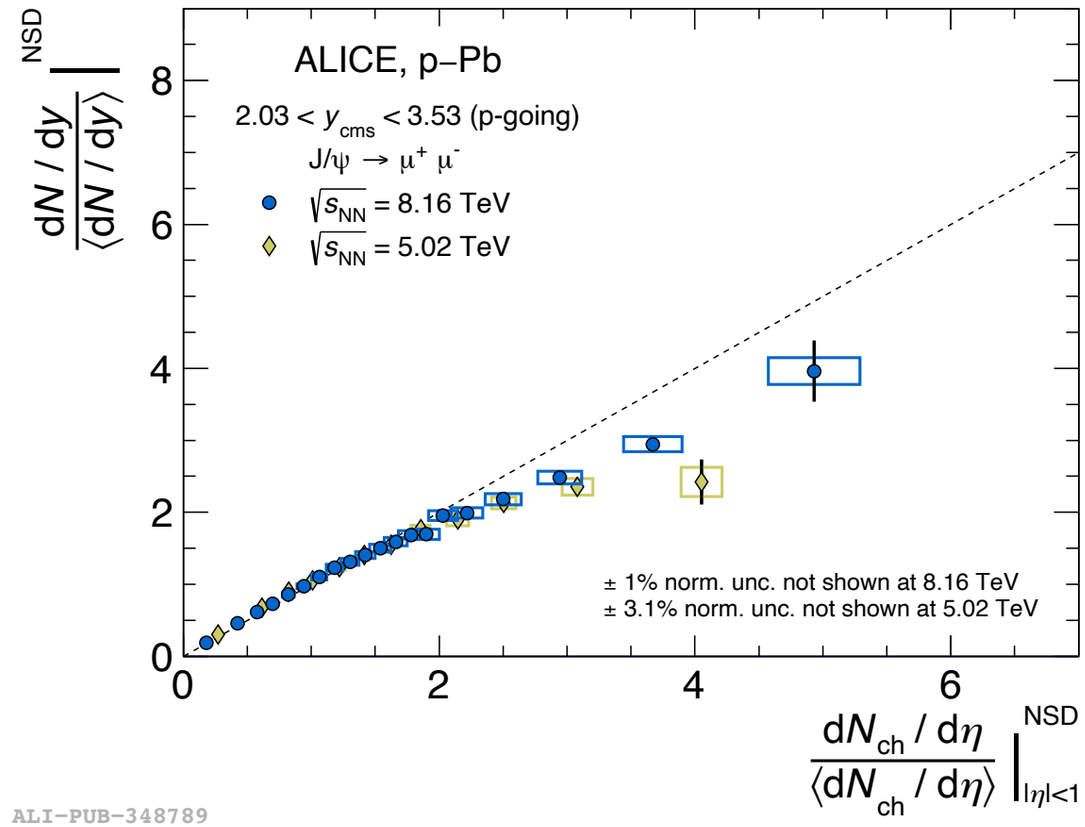
J/ψ production vs. multiplicity in p-Pb collisions at 5.02 and 8.16 TeV

NEW arxiv:2004.12673

Backward rapidity (Pb-going)



Forward rapidity (p-going)



- Slightly faster-than-linear increase of J/ψ relative yield at backward rapidity (Pb-going) ≠ slower-than-linear increase at forward rapidity (p-going)
- New 8.16 TeV results compatible with previous 5.02 TeV ones → no significant energy dependence observed
- Nucleus in the initial state influences the J/ψ yield in p-Pb ≠ linear in pp results
- ψ(2S) measurement in p-Pb will provide the possibility to directly compare 2S/1S results to the pp ones

Conclusions

pp collisions:

- New cross section measurements in pp collisions provide good references for p-Pb and Pb-Pb measurements

- New results on multiplicity dependent production of various quarkonium states:
    - Observation of a rapidity dependence (auto-correlation mechanisms?)
    - Compatible behavior between charmonium and bottomonium at forward rapidity

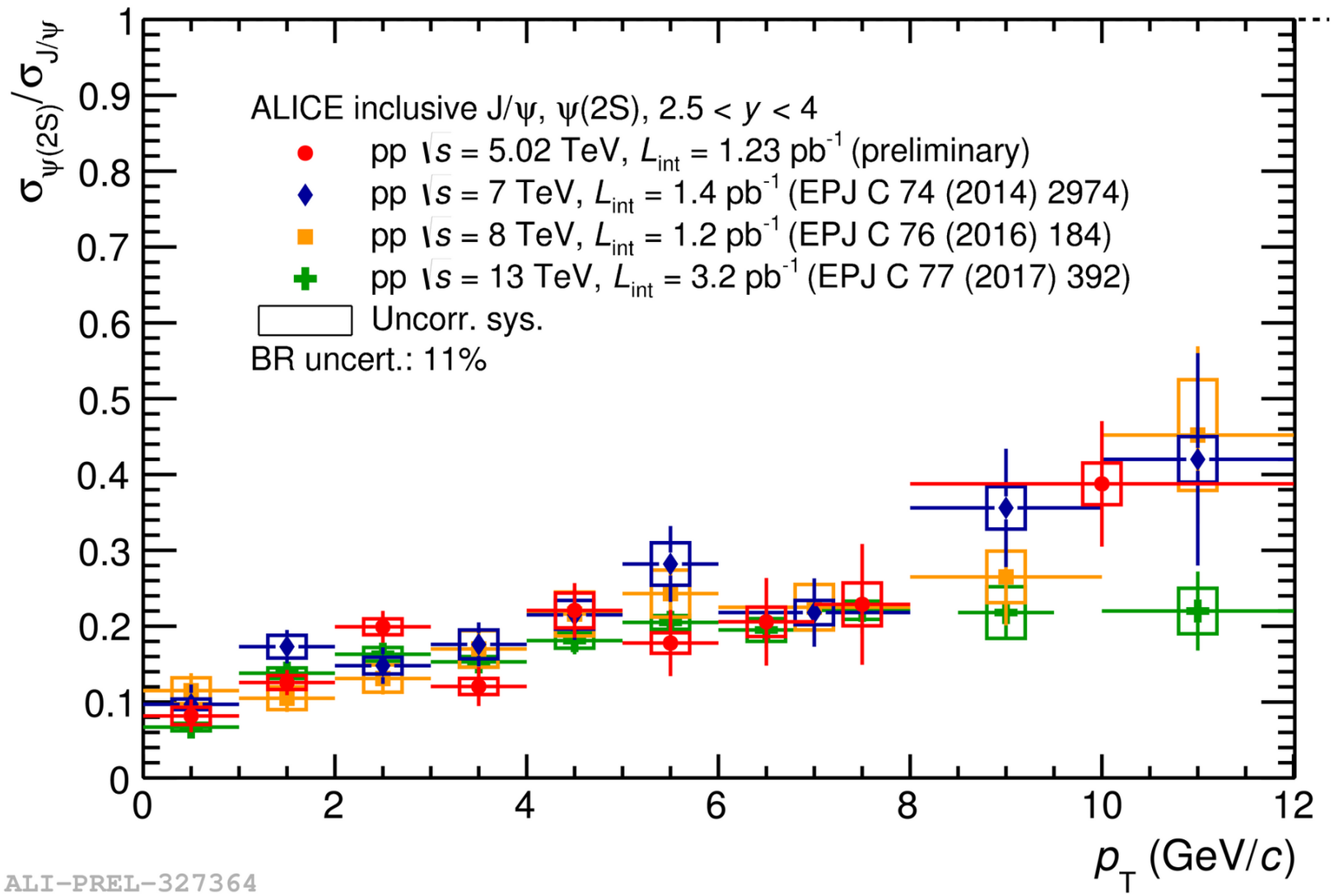
- Multiplicity dependence of ψ(2S) suppression w.r.t J/ψ investigated:
    - Predictions based on comovers model tend to overestimate the ψ(2S) suppression at high multiplicity
    - Incoming more significant ϒ results will improve the charm/beauty comparison

p-Pb collisions:

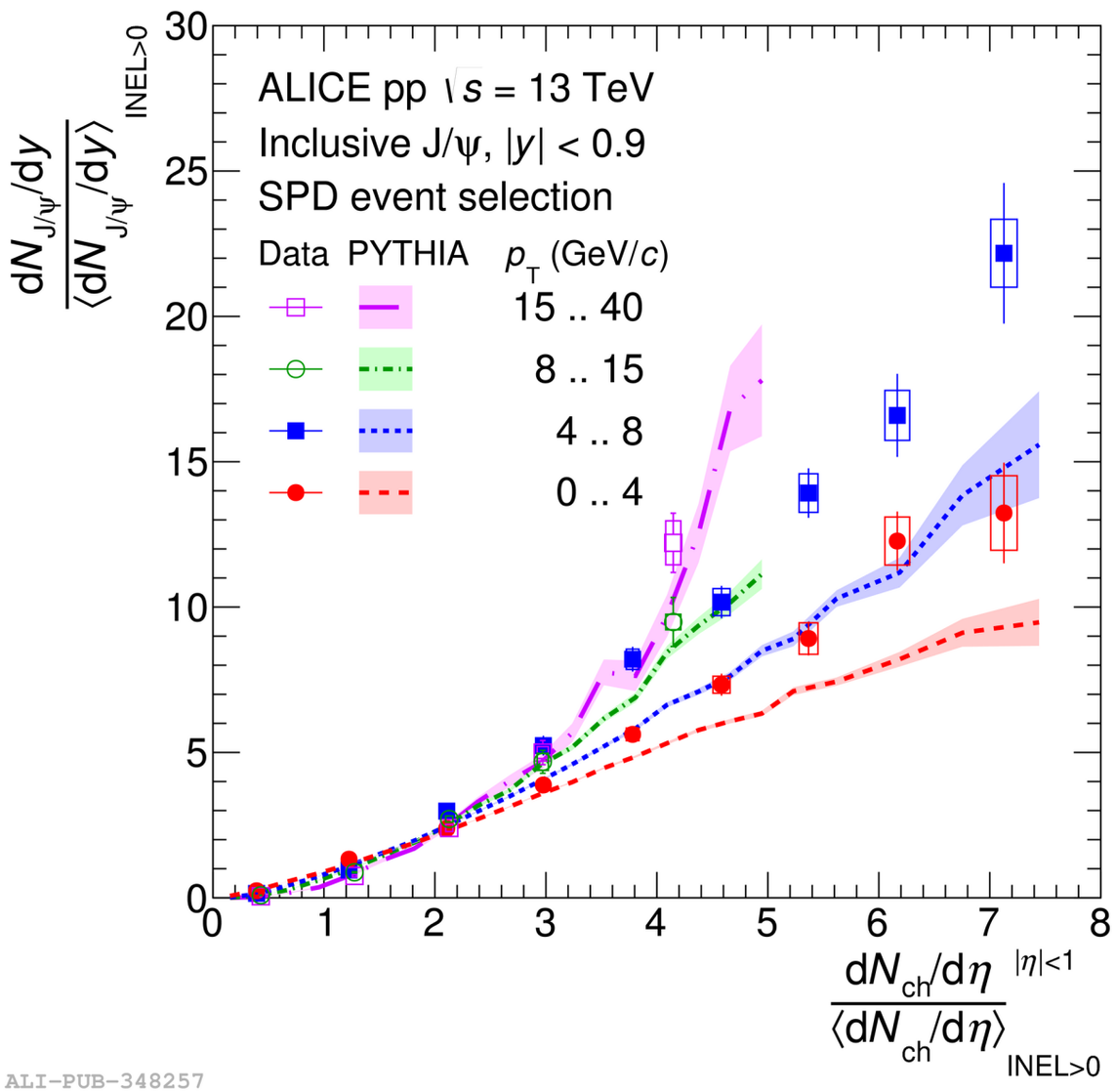
- New results on J/ψ production vs. multiplicity:
    - Rapidity dependence (backward ≠ forward)
    - No energy dependence observed

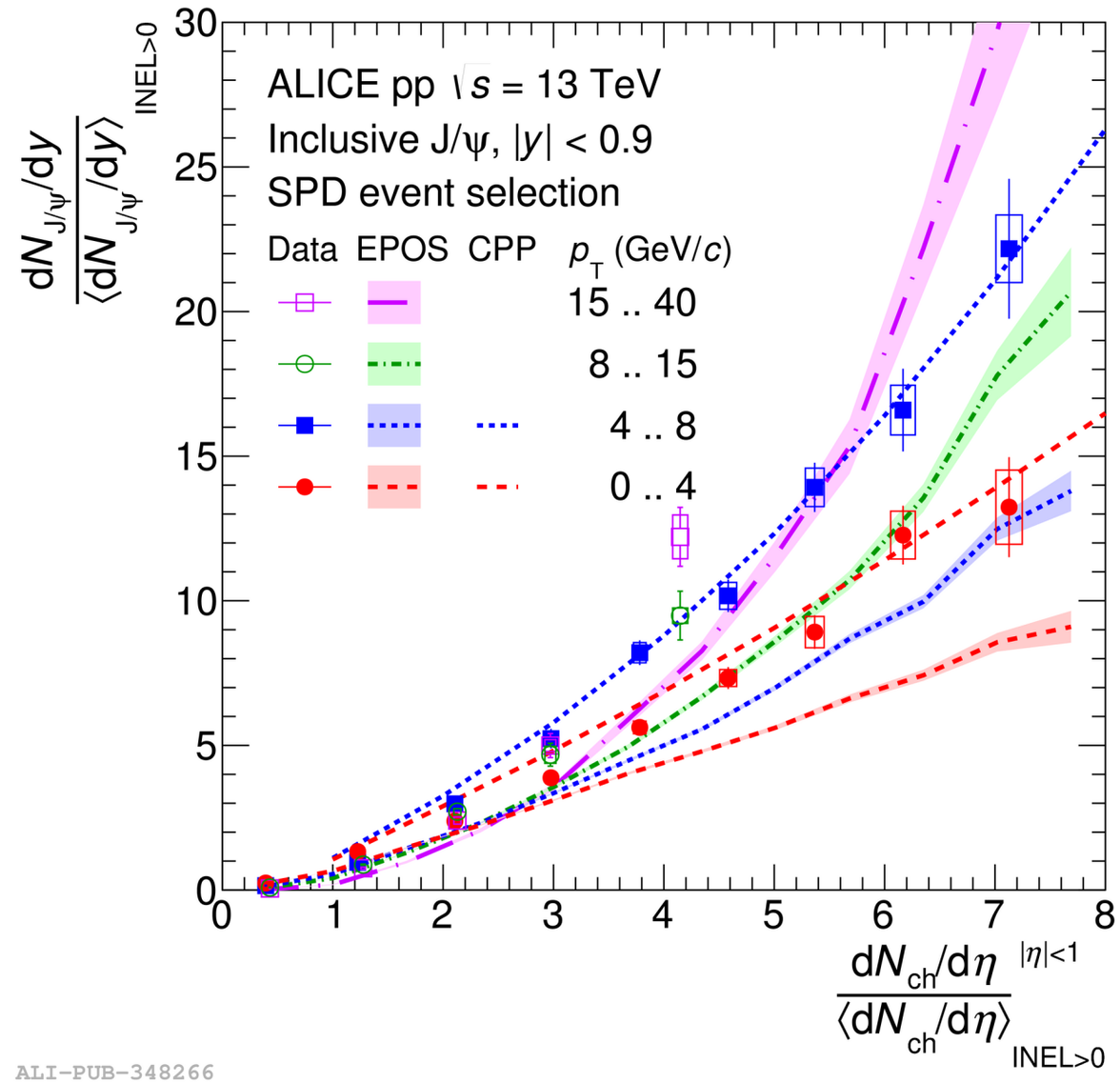
Thank you!

ψ(2S) cross section in pp collisions at 5.02 TeV



J/ψ production vs. multiplicity in pp collisions at 13 TeV (in p_T bins)





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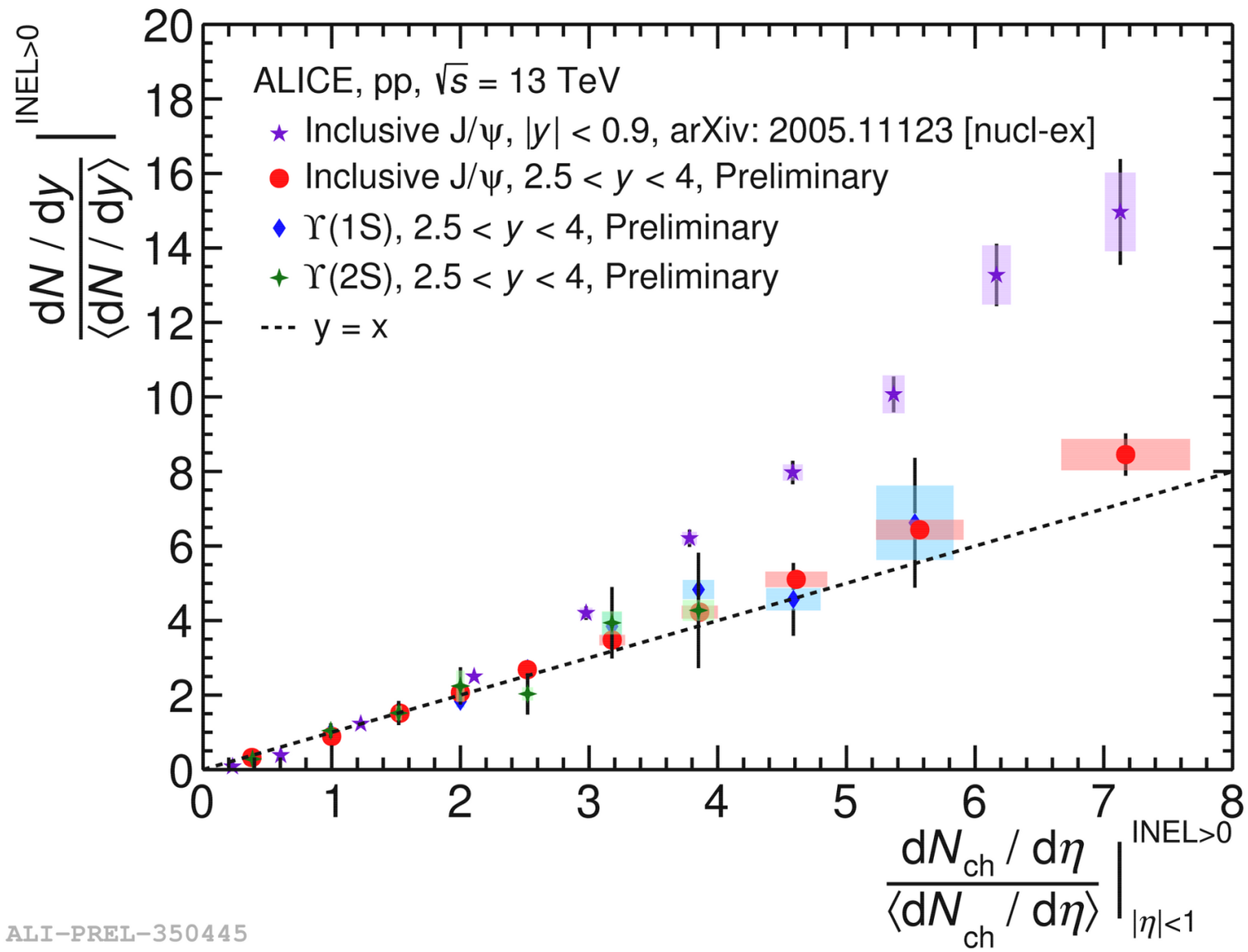
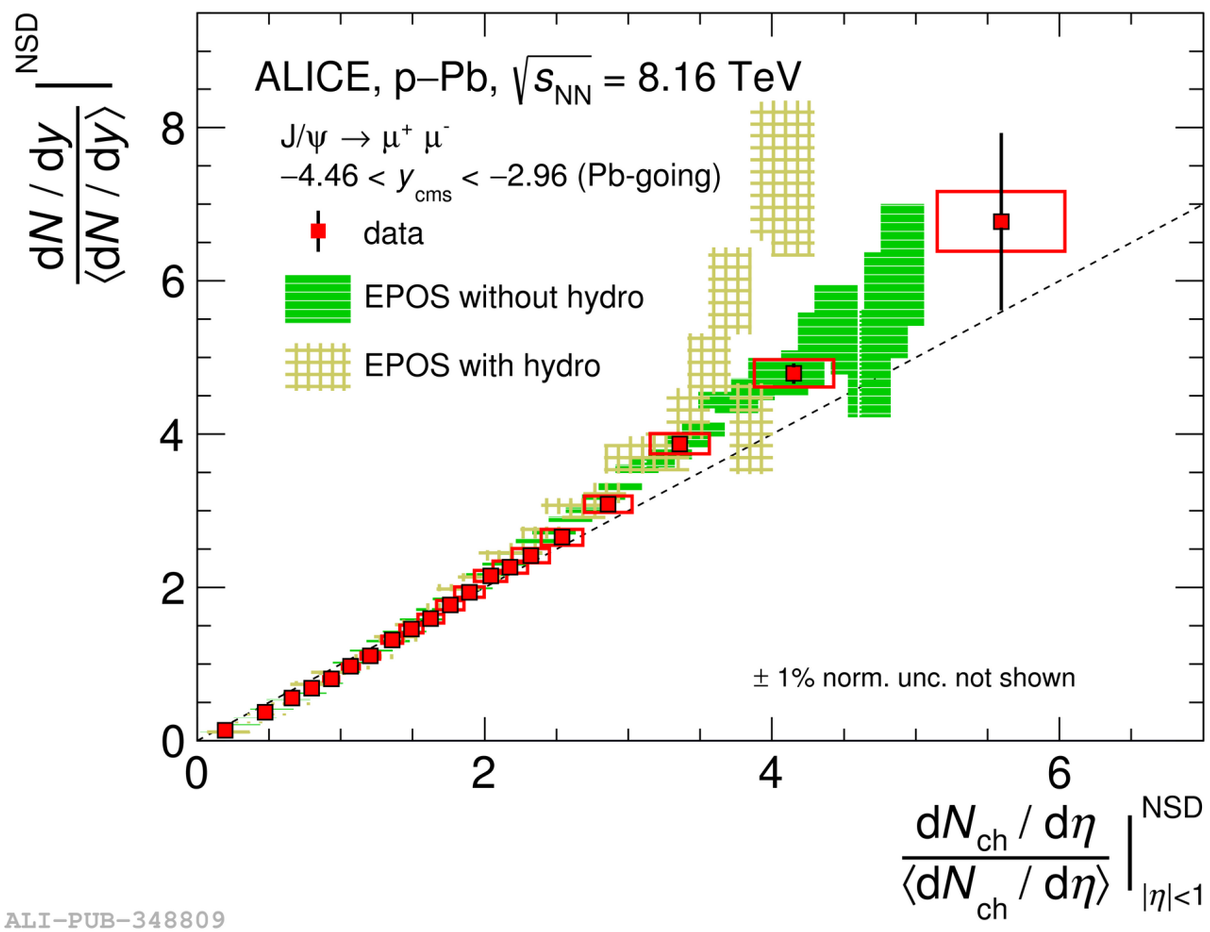
Quarkonium production vs. multiplicity in pp collisions at 13 TeV

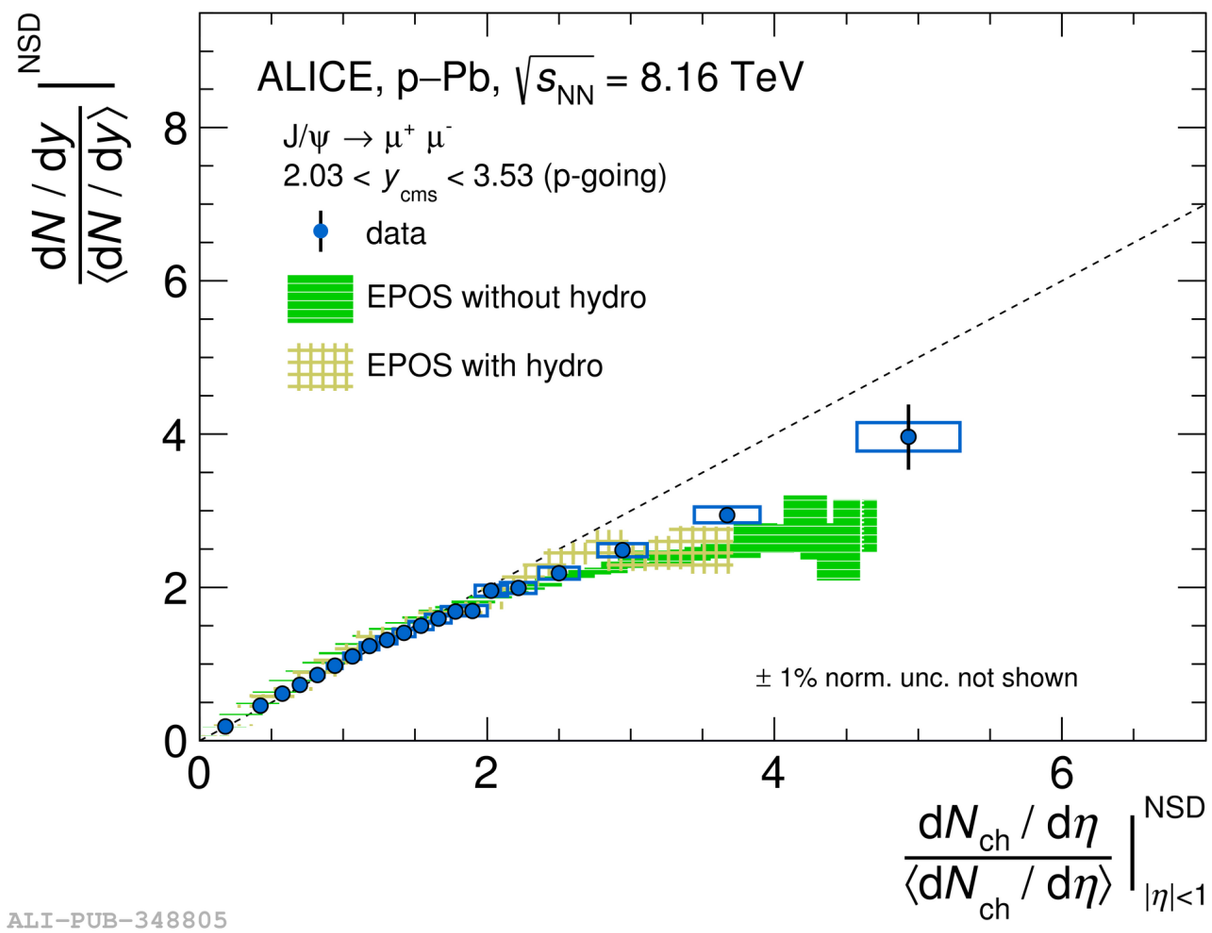


EPOS predictions on J/ψ production vs. multiplicity in p-Pb collisions at 8.16 TeV

Backward rapidity (Pb-going)



Forward rapidity (p-going)



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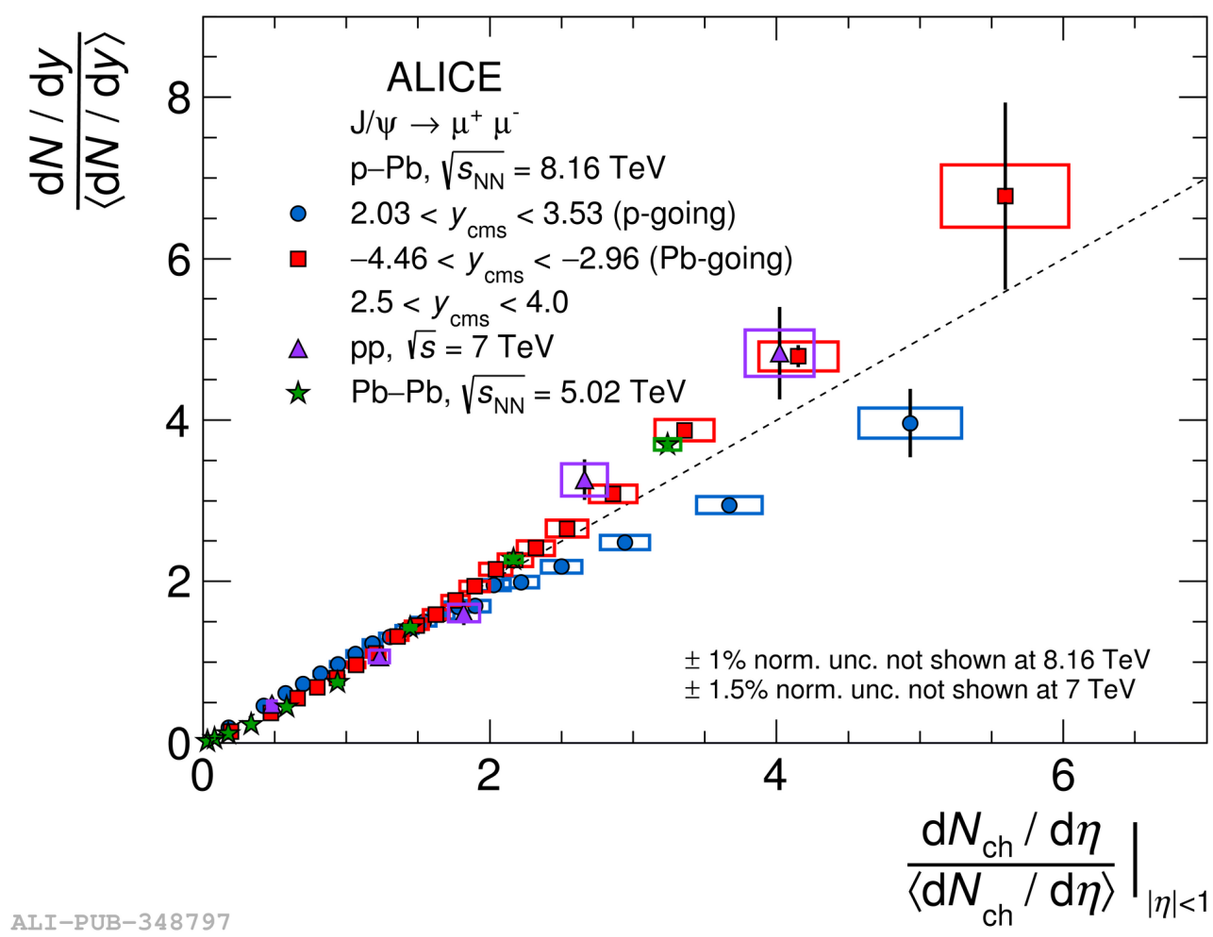
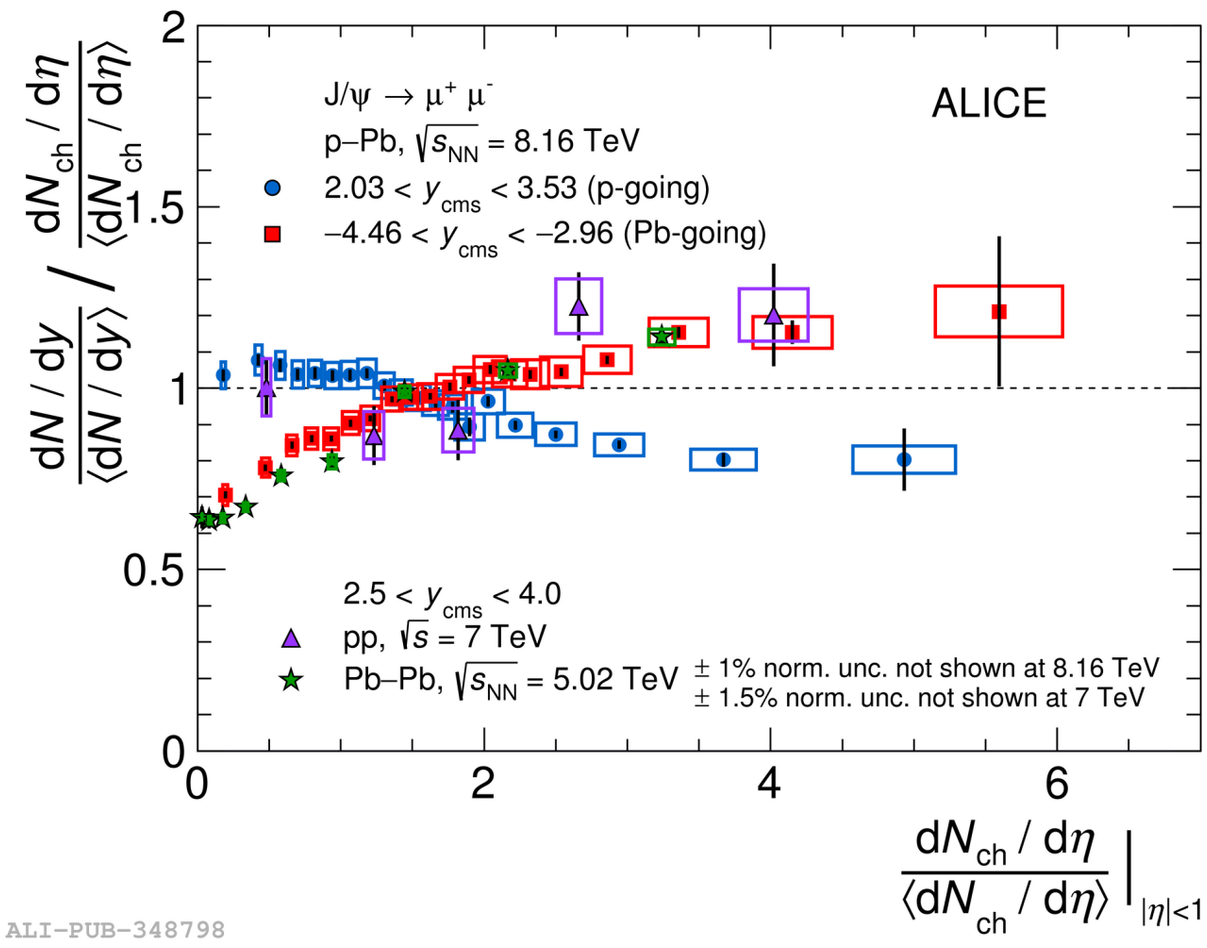
J/ψ production vs. multiplicity in different collisions systems





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