Quarkonium production as a function of multiplicity in pp collisions with ALICE

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Graduiertenkolleg 2149
Research Training Group

ALICE

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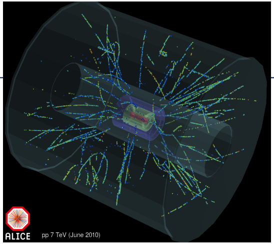
Motivations

Quarkonium → bound state of c (or b) and $\bar{c}$ (or $\bar{b}$) quarks

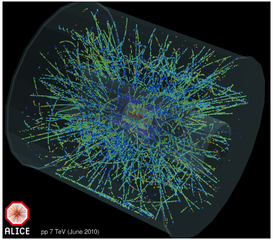
- Heavy quarks produced in hard scattering
  → **Quarkonium = hard scale** (+ hadronization)
- Most of the charged particles produced in soft scattering
  → **Charged-particle multiplicity = soft scale**

Different scales: affected differently by several effects
→ correlation quarkonium vs. multiplicity allows to study **differences** and **interplay** between hard and soft scales and **probing Multi-Parton Interactions (MPI)**

What is happening in **high charged-particle multiplicity density** environment?

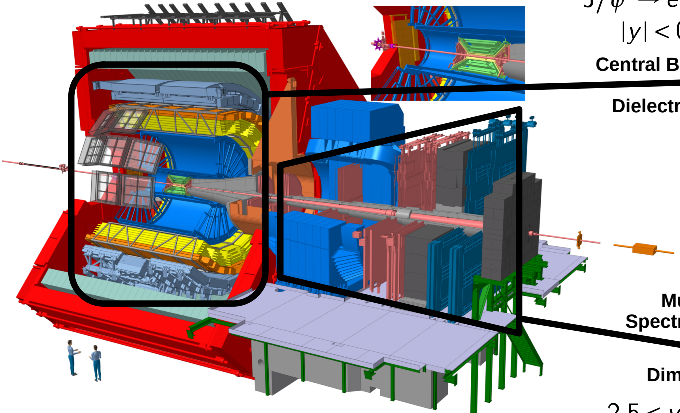


ALICE, pp 7 TeV, low multiplicity



ALICE, pp 7 TeV, high multiplicity

ALICE in Run 2 (Int. J. Mod. Phys. A 29 (2014) 1430044)



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

$$|y| < 0.9$$

Central Barrel

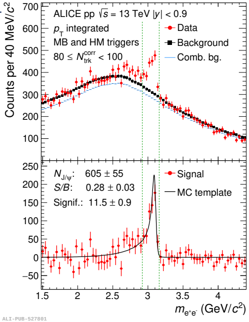
Dielectron

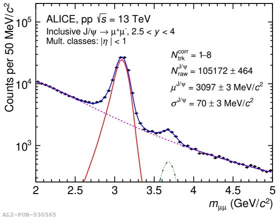
Muon Spectrometer

Dimuon

$$2.5 < y < 4$$

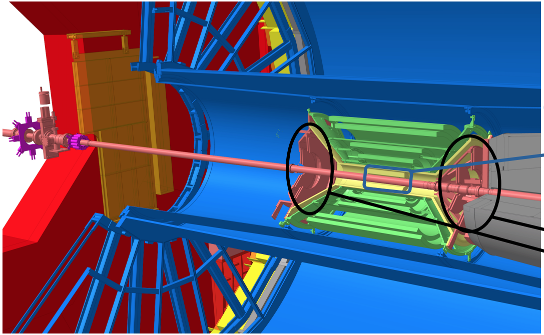
$$J/\psi,\ \psi(2S),\ \Upsilon(nS) \rightarrow \mu^+ + \mu^-$$





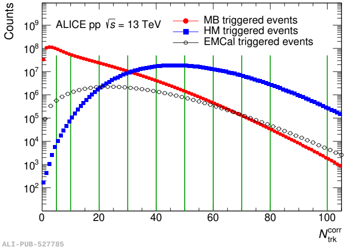
ALICE in Run 2 (Int. J. Mod. Phys. A 29 (2014) 1430044)

SPD: $|\eta| < 1$



Silicon Pixel Detector (SPD) of the Inner Tracking System

Vertexing and multiplicity

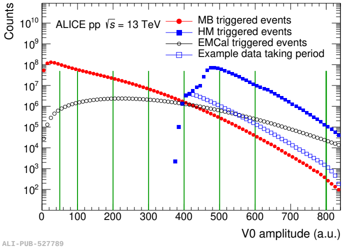


V0

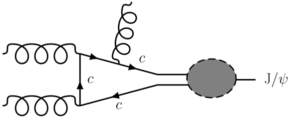
Trigger, multiplicity, background rejection

V0A: $2.8 < \eta < 5.1$

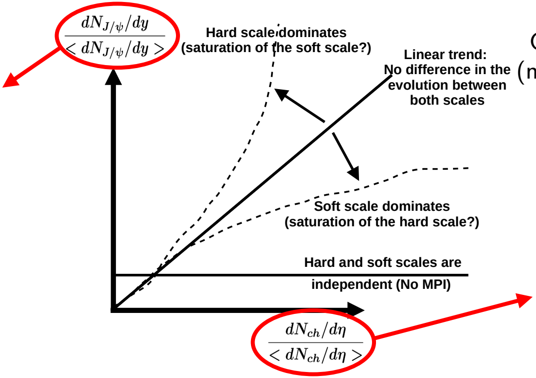
V0C: $-3.7 < \eta < -1.7$



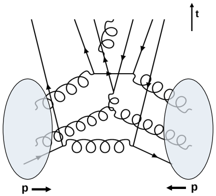
What could we expect?



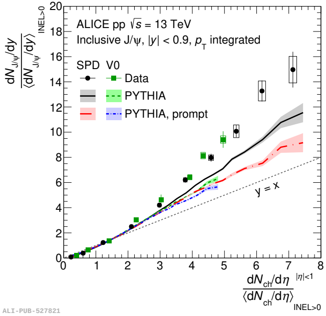
J/ψ yield (normalised to its mean value) increases with $N_{MPI_{hard}}$

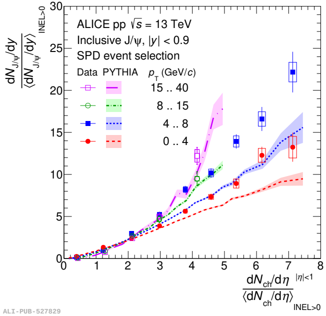


Charged-particle multiplicity (normalized to its mean value) increases with N_{MPI}



J/ψ production at midrapidity (PLB 810 (2020) 135758)

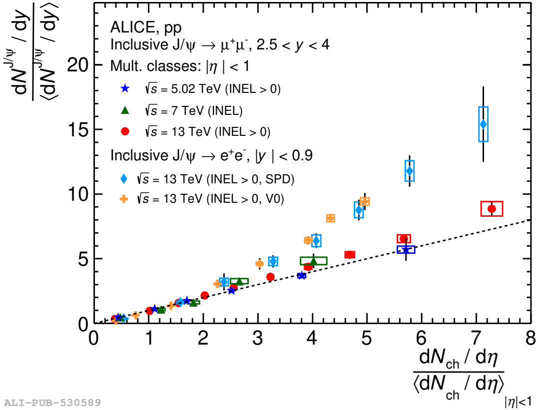




- **Stronger than linear** increase, even stronger at higher p_T
- **PYTHIA8**[1] **underestimates data** at high-multiplicity, but predicts the increase of the slope with p_T
- Influence of **non-prompt** J/ψ?
- Influence of associated particles (**autocorrelations**) should be disfavoured from comparing V0 and SPD selection

[1]: Models references collected at the end of the slides

J/ψ production at forward rapidity (JHEP 06 (2022) 015)



Multiplicity measured at midrapidity, J/ψ at mid or forward rapidity

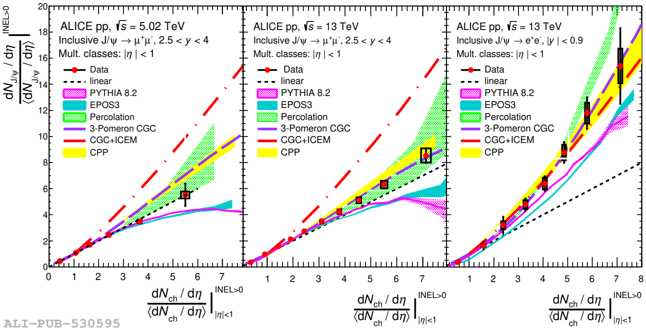
Forward rapidity:

- **Almost linear trend**, small departure from linearity
- Weak dependence on energy

Stronger increase for mid compared to forward rapidity:

- Different level of saturation probed?
- Autocorrelations at midrapidity (but should be ruled out by V0 selection)?

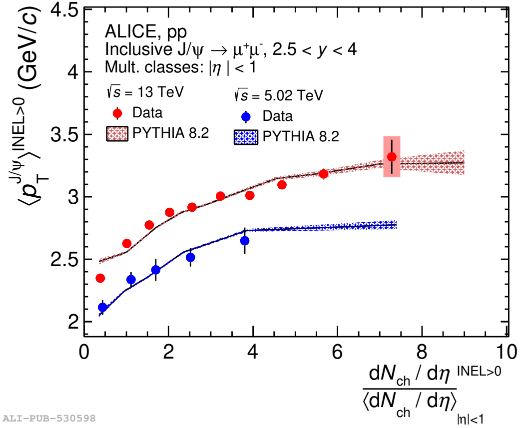
J/ψ production - Comparison to models



- **Initial-state** (MPI, gluon saturation in Color Glass Condensate) vs **final-state** effects (high string density during hadronization)

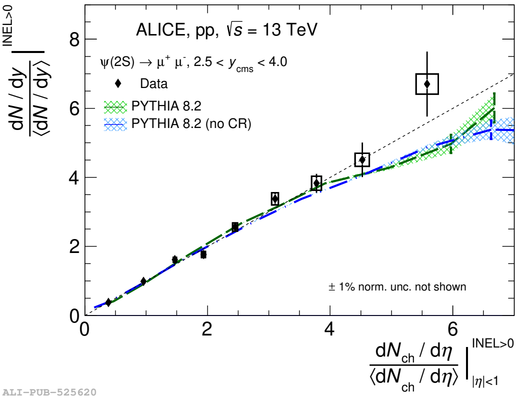
- **3-pomeron CGC[2], CGC+ICEM[3]** have only initial-state effects, **PYTHIA8[1], EPOS3[4], Percolation[5], CPP[6]** have both initial-state and final-state effects
- Most of the models describe data qualitatively, catching difference between mid and forward rapidity, but **PYTHIA8[1]** and **EPOS3[4]** always underestimate the data, while **CGC+ICEM[3]** overestimates forward rapidity data

J/ψ at forward rapidity - mean p_T



- **Increase of $< p_T >$**, then **saturation** at high-multiplicity, good agreement with PYTHIA8[1]
- Insight into **production/hadronization** mechanisms

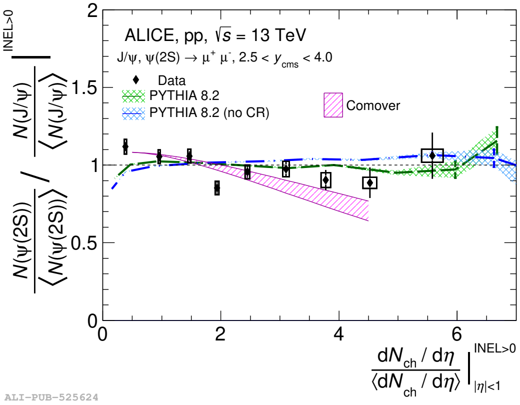
$\psi(2S)$ production at forward rapidity (arXiv:2204.10253)



Radial excitation of J/ψ → **less binding energy**

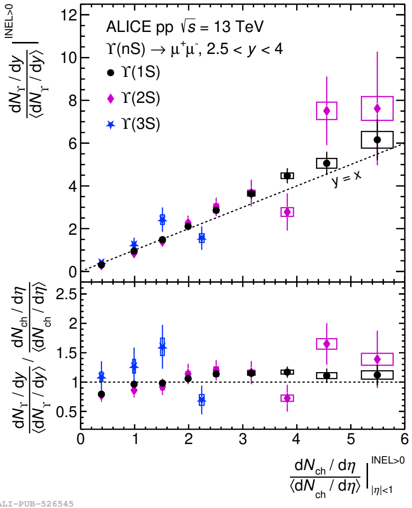
- Same trend as J/ψ, but smaller multiplicity reach due to limited statistics
- PYTHIA8[1] underestimates data at high multiplicity, with and without CR

$\psi(2S)$ to J/ψ ratio



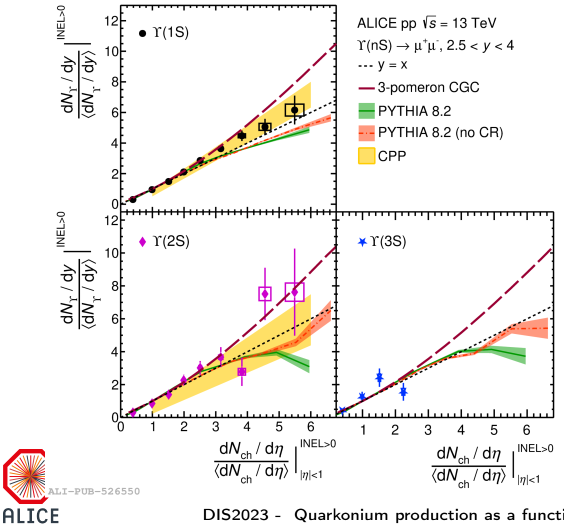
- **No evidence for $\psi(2S)$ suppression** relative to J/ψ within current uncertainties
- **Comover[7]**: quarkonium breaking by co-moving particles in the medium → higher dissociation probability for $\psi(2S)$
- Comover model not excluded as well given current uncertainties

$\Upsilon(nS)$ production at forward rapidity (arXiv:2209.04241)



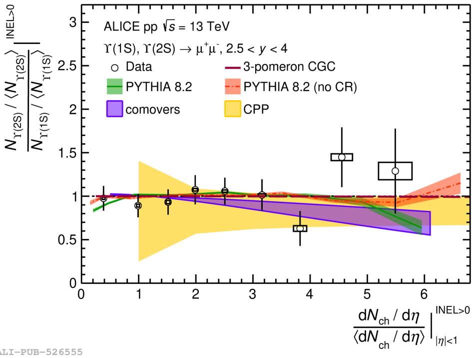
- Bottomonium production: no evidence of departure from linearity
- Statistically limited measurement, especially for $\Upsilon(3S)$

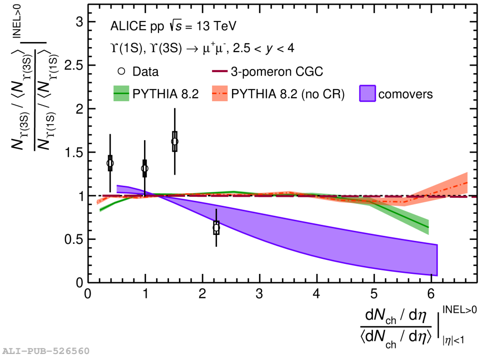
Υ(*nS*) production - Comparison to models



- **Good agreement** between models and data, at least until ≈ 4 times the average multiplicity

$\Upsilon(nS)$ production - Comparison to models

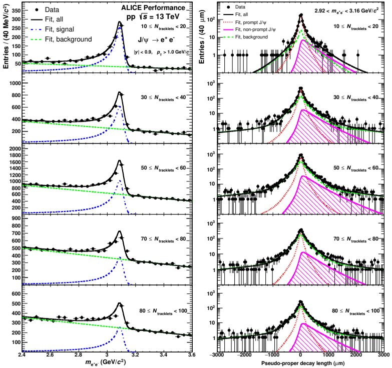




- **Statistics not enough** to notice any increased dissociation as a function of multiplicity for the less bound states → **compatible with all models** within uncertainties

Ongoing studies

- **Non-prompt J/ψ component** vs multiplicity at midrapidity with Run 2 data, from 2D likelihood fit (mass & pseudoproper decay length)



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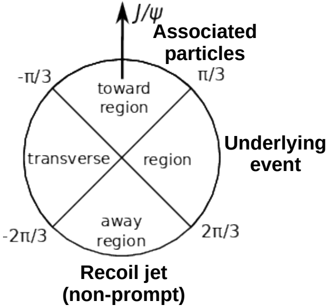
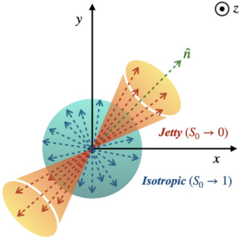
- Multiplicity separated in **azimuthal regions** → disentangle **auto-correlation effects** (idea from **Eur. Phys. J. C 79, 36 (2019)**)



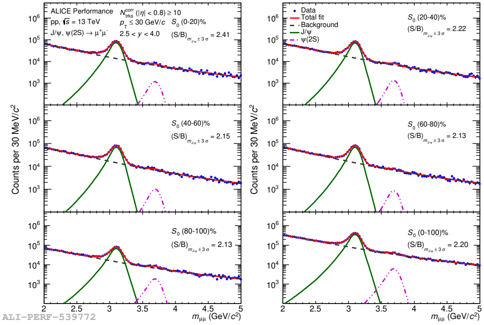
Ongoing studies

- J/ψ as function of transverse-spherocity → event-shape observable to distinguish hard-QCD (jetty) and soft-QCD (isotropic) events

$$S_0 = \frac{\pi^2}{4} \times \min_{\hat{n}=(n_x,n_y,0)} \left(\frac{\Sigma_i |\vec{p}_{T_i} \times \hat{n}|}{\Sigma_i \vec{p}_{T_i}} \right)^2$$



S. Prasad, N. Mallick, D. Behera, R. Sahoo, and S. Tripathy, Sci.Rep. 12, 3917 (2022)



Conclusion

- **Quarkonium vs multiplicity** $\rightarrow$ **production mechanism** + interplay between **soft** and **hard** scales
- **Stronger than linear** increase at midrapidity (for J/ψ), almost **linear** at forward rapidity (for J/ψ, $\Psi(2S)$, and $\Upsilon(nS)$)
- **Models** reproduce some features of the data, implementing **initial-state** and/or **final-state effects** $\rightarrow$ not yet able to distinguish between them with the current uncertainties
- **Run 3 and 4**: better secondary vertex resolution at midrapidity (x3 with new ITS) for prompt/non-prompt separation, secondary vertexing at forward rapidity (MFT), better multiplicity estimation at forward rapidity (MFT), higher minimum bias statistics

Thank you for your attention!

Model references (1/2)

[1] **PYTHIA 8.2**: T. Sjöstrand, S. Ask, J. R. Christiansen, R. Corke, N. Desai, P. Ilten, S. Mrenna, S. Prestel, C. O. Rasmussen, and P. Z. Skands, "An introduction to PYTHIA 8.2", Comput. Phys. Commun. 191 (2015) 159–177, arXiv:1410.3012

[2] **3-pomeron CGC**: E. Levin, I. Schmidt, and M. Siddikov, "Multiplicity dependence of quarkonia production in the CGC approach," Eur. Phys. J. C 80 no. 6, (2020) 560, arXiv:1910.13579

[3] **CGC+ICEM**: Y.-Q. Ma, P. Tribedy, R. Venugopalan, and K. Watanabe, "Event engineering studies for heavy flavor production and hadronization in high multiplicity hadron-hadron and hadron-nucleus collisions," Phys. Rev. D98 no. 7, (2018) 074025, arXiv:1803.11093

[4] **EPOS3**: K. Werner, B. Guiot, I. Karpenko, and T. Pierog, "Analysing radial flow features in p-Pb and p-p collisions at several TeV by studying identified particle production in EPOS3," Phys. Rev. C89 no. 6, (2014) 064903, arXiv:1312.1233

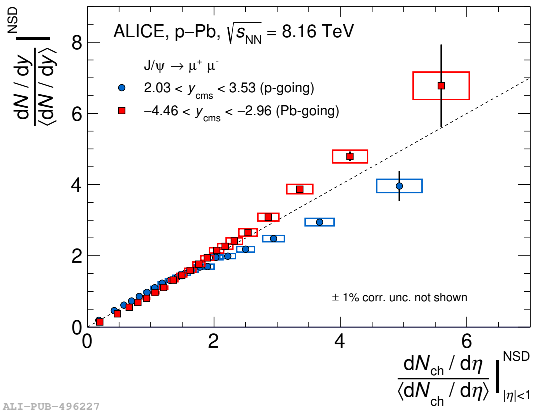
Model references (2/2)

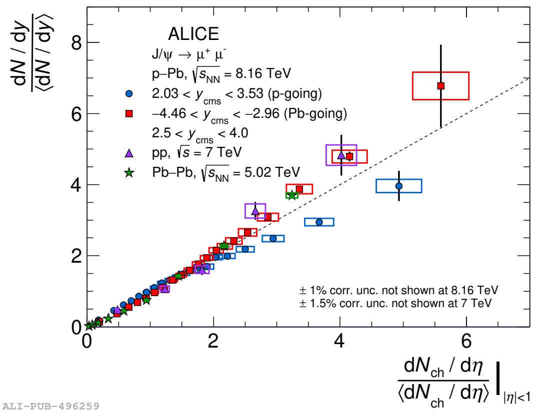
[5] **Percolation**: E. G. Ferreiro and C. Pajares, "High multiplicity pp events and J/ψ production at LHC," Phys. Rev. C86 (2012) 034903, arXiv:1203.5936

[6] **CPP**: B. Z. Kopeliovich, H. J. Pirner, I. K. Potashnikova, K. Reygers, and I. Schmidt, "J/ψ in high-multiplicity pp collisions: Lessons from pA collisions," Phys. Rev. D88 no. 11, (2013) 116002, arXiv:1308.3638

[7] **Comovers**: E. G. Ferreiro, "Excited charmonium suppression in proton–nucleus collisions as a consequence of comovers", Phys. Lett. B 749 (2015) 98–103, arXiv:1411.0549

J/ψ in p-Pb collisions at forward rapidity (Phys. Lett. B 776 (2018) 91)





$\psi(2S)$ in p-Pb collisions at forward rapidity

(arXiv:2204.10253)