Multiplicity dependence of quarkonium production in small systems with ALICE

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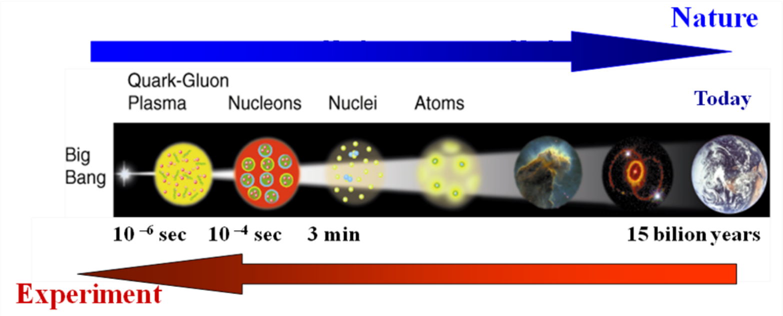
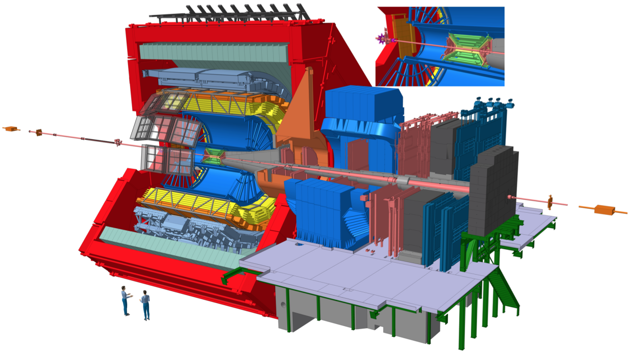
General motivation





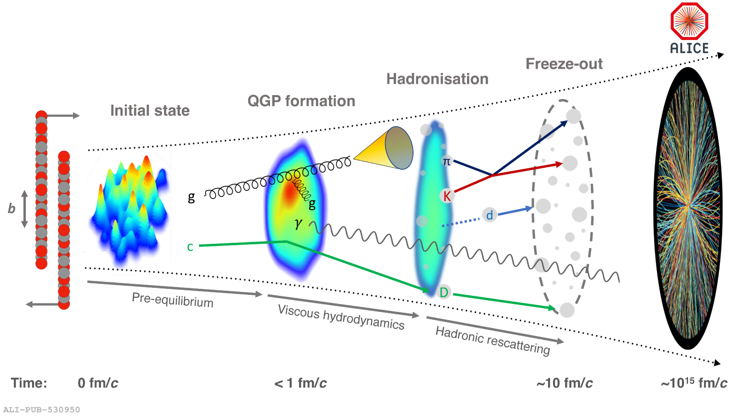
Studying QGP through high energy-heavy ions collisions (Pb–Pb, Xe–Xe)

ALICE experiment at the LHC is dedicated to study the physics of high-energy heavy ions collisions

collision systems:

- Pb–Pb at 2.76, 5.02 TeV
- p–Pb at 5.02, 8.16 TeV
- pp up to 13.6 TeV

Quarkonium



ALICE Collaboration, arXiv:2211.04384 [nucl-ex]

Quarkonia are bound states of a heavy quark and its antiquark

Quarkonium production involves:

- **hard scale processes:** heavy quarks are produced at the early stages of a collision via partonic scattering processes with high momentum transfer
- **soft scale processes**: subsequent binding of the pair into a colorless final state

Production rates sensitive to Parton Distribution Functions (PDF) of the incoming protons or nuclei

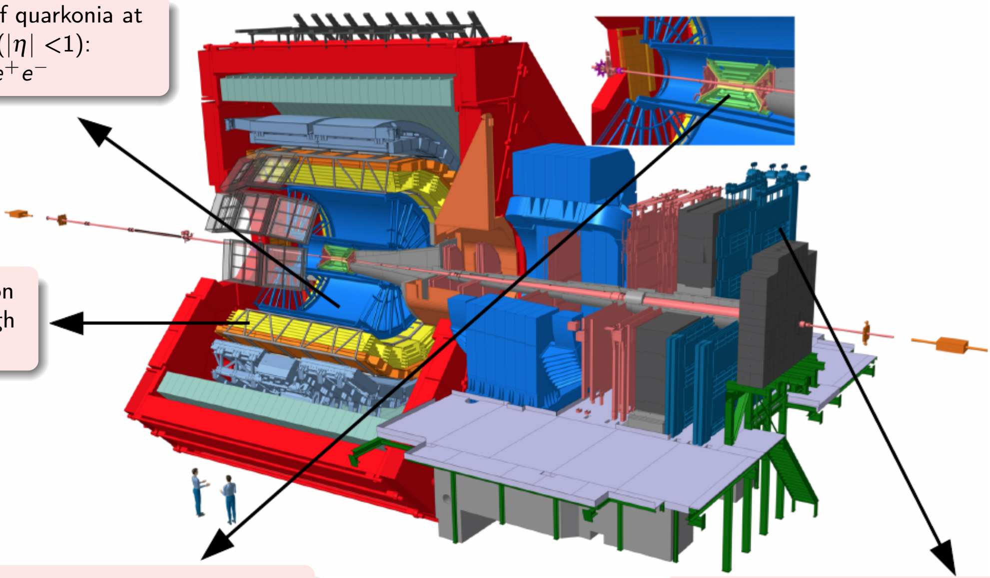
ALICE Detector (Run 2)

TPC: detection of quarkonia at midrapidity ($|\eta| < 1$): $J/\psi \rightarrow e^+e^-$

TRD: Good electron identification at high p_T

ITS: vertex reconstruction and tracking $\Rightarrow$ SPD tracklets as N_{ch} estimator

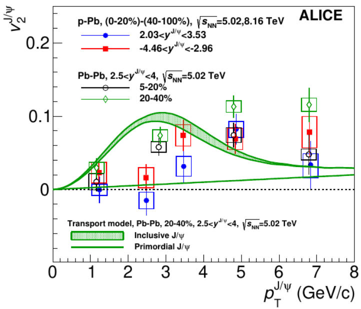
Muon Spectrometer: detection of quarkonia at forward rapidity ($-4 < |\eta| < -2.5$): $J/\psi, \psi(2S), \Upsilon(nS) \rightarrow \mu^+\mu^-$



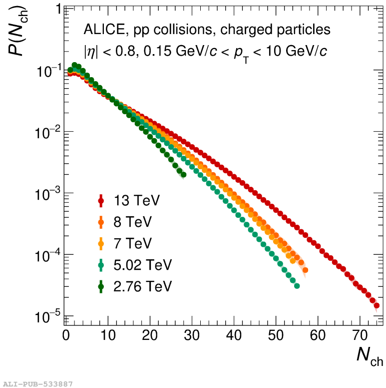
Small collision systems (pp and pPb)

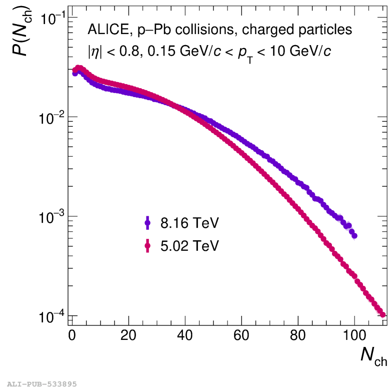
- **pp** ⇒ reference measurements to Pb–Pb collisions
- **p–Pb** ⇒ to evaluate nuclear matter effects in the absence of QGP formation

High charged-particle multiplicity events have recently shown QGP-like features



ALICE Collaboration, Phys. Lett. B 780 (2018) 7-20





ALICE Collaboration, arXiv:2211.15326 [nucl-ex]

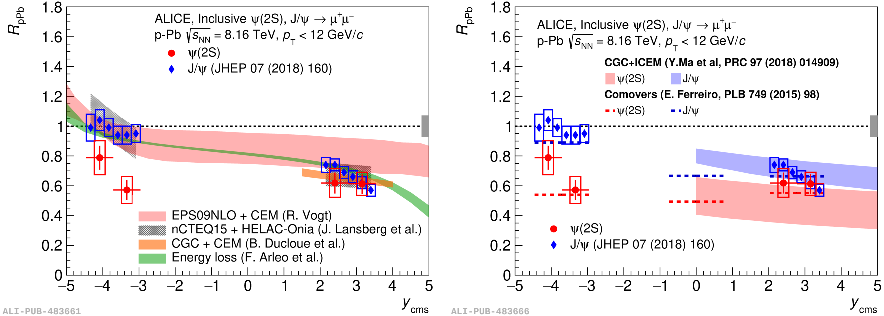
Need for characterization of the initial state and the mechanisms that could contribute to **High Multiplicity** events

Quarkonium in p–Pb

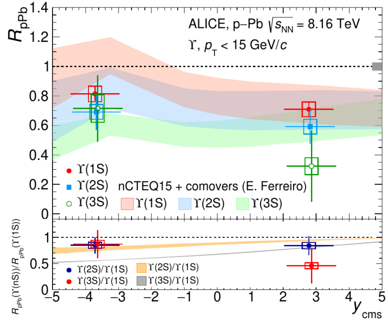
Excited quarkonia states ($\psi(2S)$, $\Upsilon(nS)$):

- More suppressed than their tighter ground states (J/ψ and $\Upsilon(1S)$) $\Rightarrow$ behavior not explained with only initial state effects
- Less bound and therefore more sensitive to final-state interactions

$$R^{Q}_{\mathrm{pPb}}(p_{\mathrm{T}}, y_{cms}) = \frac{\mathrm{d}^2\sigma^{Q}_{\mathrm{pPb}}/dp_{\mathrm{T}}, y_{cms}}{\mathrm{A_{Pb}}\cdot \mathrm{d}^2\sigma^{Q}_{\mathrm{pp}}/dp_{\mathrm{T}}, y_{cms}}$$



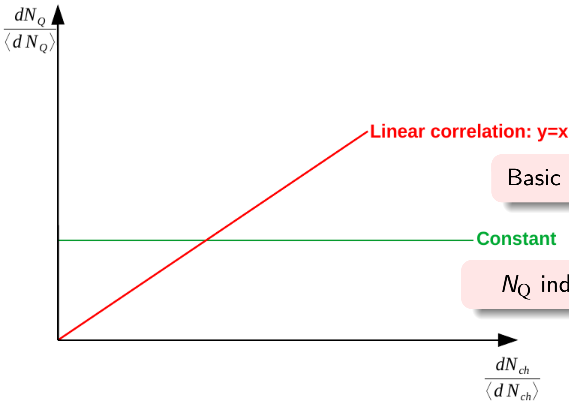
ALICE Collaboration, JHEP07 (2020) 237



ALICE Collaboration, Phys. Lett. B 806 (2020) 135486

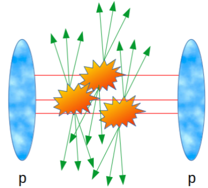
Quarkonium vs. multiplicity

Correlation between the production of hard components (N_{Q}) and the underlying events (N_{ch}) in a collision



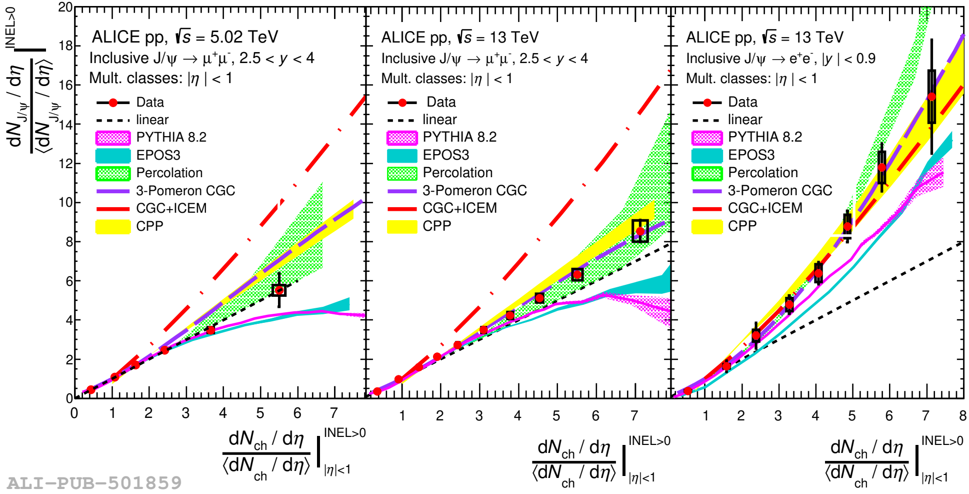
Basic MPI scenario: $N_{\mathrm{Q}} \propto N_{\mathrm{MPIs}} \propto N_{\mathrm{ch}}$

N_{Q} independent from N_{ch}



Key observable to disentangle initial and final state effects affecting particle production

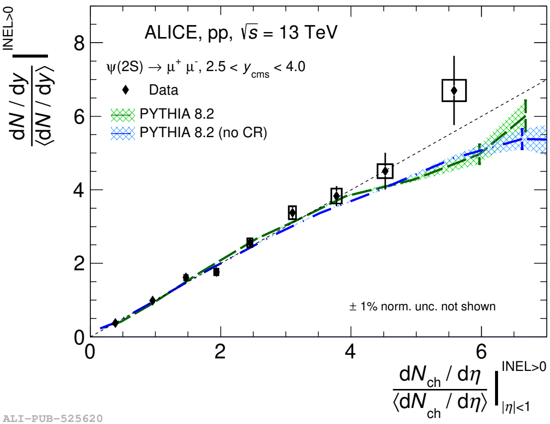
Results on J/ψ vs. multiplicity in pp

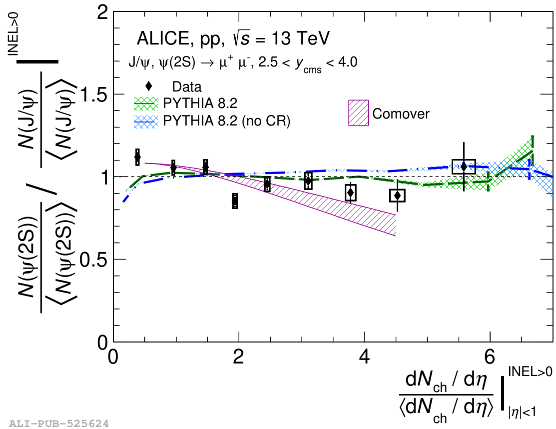


ALICE Collaboration, JHEP 06 (2022) 015

- Good agreement at 13 TeV provided by the Coherent Particle Production (CPP), and the 3-Pomeron Color Glass Condensate models in both rapidity intervals.
- Almost linear growing at midrapidity J/ψ.
- Stronger than linear growing at midrapidity is well reproduced by all the models although the exact origin is not completely understood yet. Previous observations exclude autocorrelations effects.

Results on $\psi(2S)$ vs. multiplicity in pp

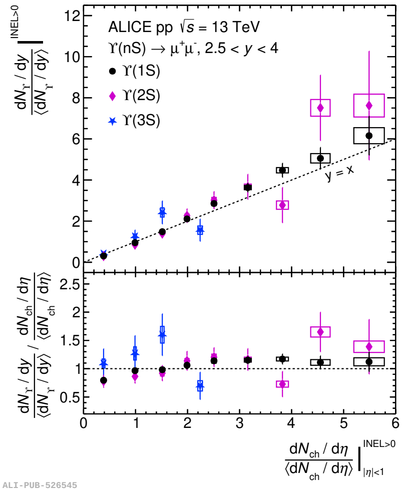




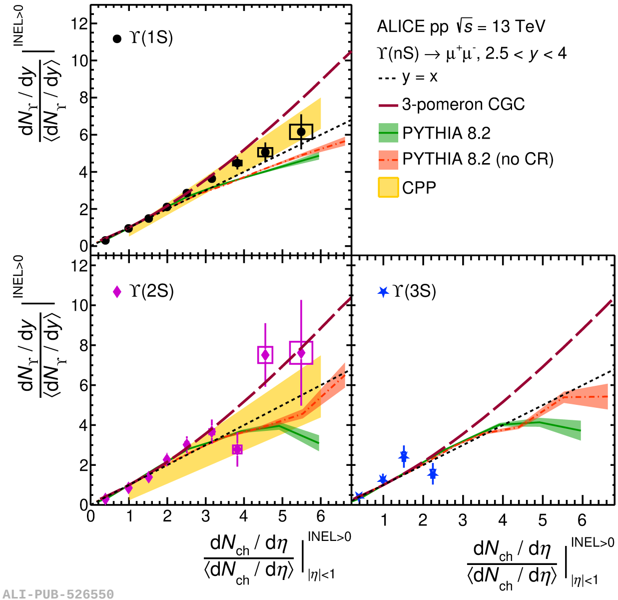
ALICE Collaboration, arXiv:2204.10253 [nucl-ex]

- Linear correlation between the self-normalized $\psi(2S)$ yield and the charged particle multiplicity.
- Within uncertainties the excited-to-ground state ratio is consistent with unity.
- Qualitatively good description provided by PYTHIA 8.2 with and without color-reconnection.

Results on $\Upsilon(nS)$ vs. multiplicity in pp

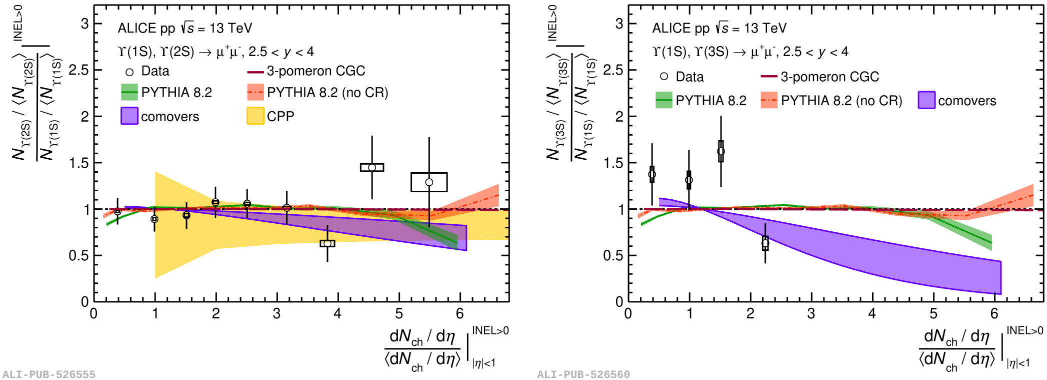


ALICE Collaboration, arXiv:2209.04241 [nucl-ex]



- Linear trend for the $\Upsilon(nS)$ state vs. multiplicity at forward rapidity.
- Theoretical predictions describe the experimental observations, although for the excited states, current statistical uncertainties do not allow firm conclusions.

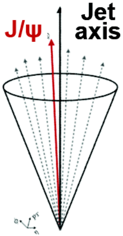
Results on $\Upsilon(nS)$ vs. multiplicity in pp



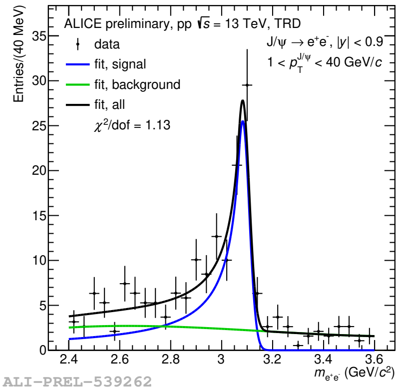
ALICE Collaboration, arXiv:2204.10253 [nucl-ex]

- Within uncertainties the excited-to-ground state ratios in the in the bottomonium sector are consistent with unity.
- Either none or weak dependence of the measured correlation with the binding energy of the state.
- Current measurements uncertainties do not allow to disentangle any final state effects.

J/ψ fragmentation function in pp collisions at 13 TeV using the TRD



- Fragmentation Function: $z^{\text{ch}} = \frac{p_{\text{T}}^{J/\psi}}{p_{\text{T}}^{\text{jet,ch}}}$
- Interplay of J/ψ with the underlying event



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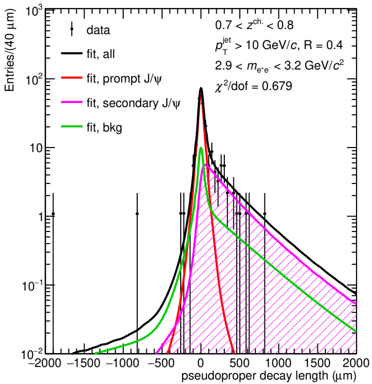

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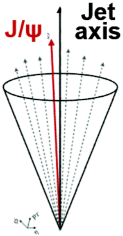

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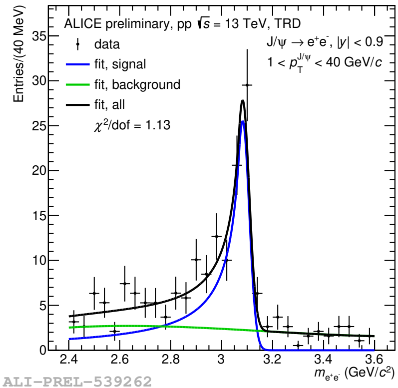
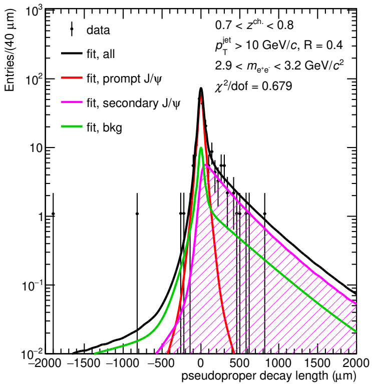
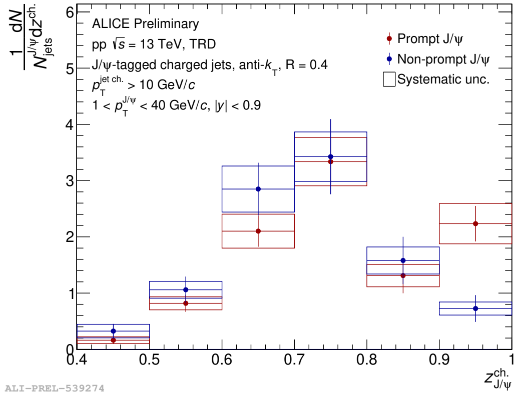
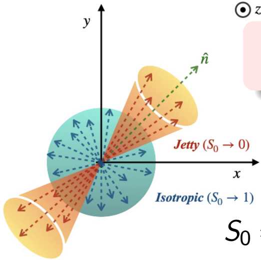






- Prompt and non-prompt J/ψ fragmentation functions are found to be similar within uncertainties.
- Comparison with models are needed ⇒ Ongoing pythia8 studies.

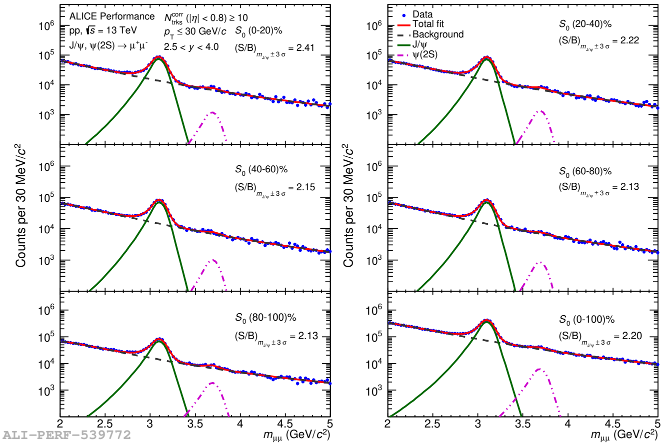
Ongoing studies in pp collisions at 13 TeV



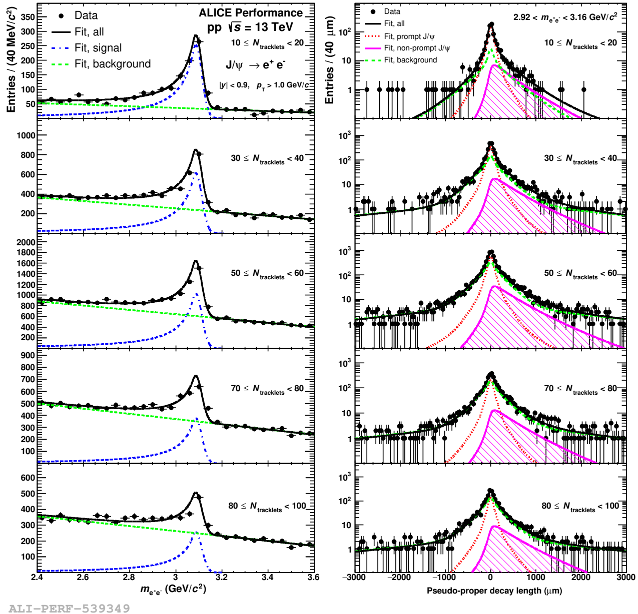
J/ψ production as a function of event activity (spherocity)

- Event shape observable that separates events based on their geometical shape:

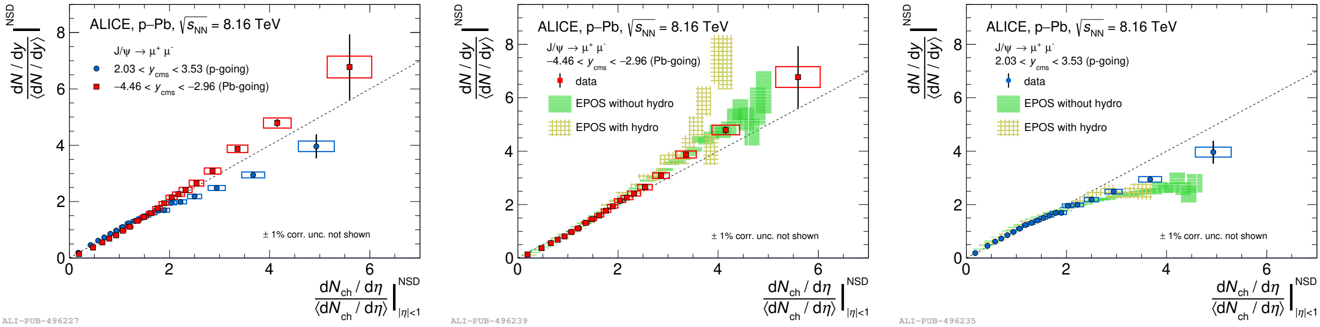
$$S_0 = \frac{\pi^2}{4} \min_{\vec{n}=(n_x,n_y,0)} \left(\frac{\sum_i |\vec{p_{T}}_i \times \hat{n}|}{\sum_i p_{T_i}} \right)^2$$



Midrapidity prompt and non prompt J/ψ yields as a function of the charged particle multiplicity at midrapidity



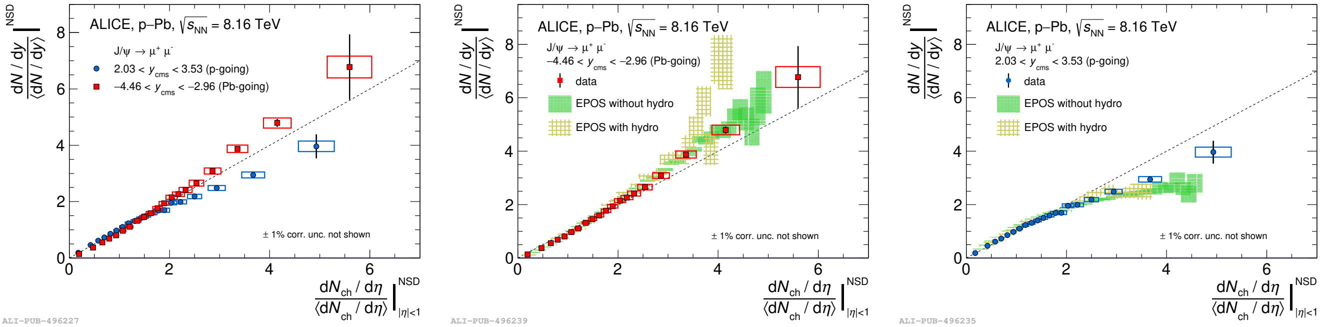
Results on J/ψ vs. multiplicity in pPb



ALICE Collaboration, JHEP 2009 (2020) 162

- Normalized J/ψ yield increases with multiplicity in both rapidity intervals.
- At backward rapidity (Pb-going) the correlation is stronger than linear at higher multiplicities.

Results on J/ψ vs. multiplicity in pPb



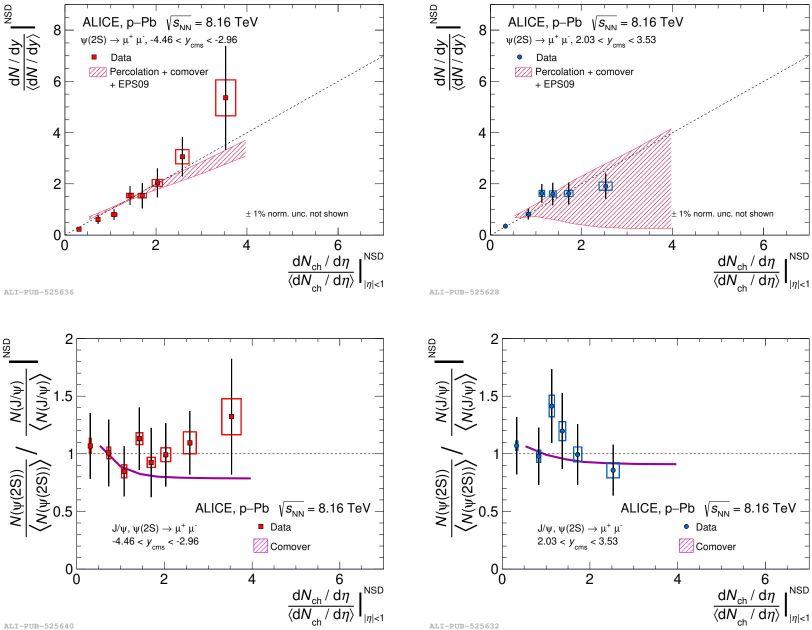
ALICE Collaboration, JHEP 2009 (2020) 162

- Normalized J/ψ yield increases with multiplicity in both rapidity intervals.
- At backward rapidity (Pb-going) the correlation is stronger than linear at higher multiplicities.
- According to a 2-body calculation for $p_{\mathrm{T}} = 0$, the forward (p-going) and the backward rapidity regions probes:
  - **at forward rapidity** $\Rightarrow$ the Pb nucleus low Bjorken-x regime ($x_{Pb} \sim 10^{-5}$)
  - **at backwards rapidity** $\Rightarrow$ higher sensitivity to intermediate-to-large values ($x_{Pb} \sim 10^{-2}$)

  which could explain the differences observed at high multiplicity.
- EPOS 3 event generator without hydrodynamic expansion is in good agreement with the data suggesting J/ψ production from an incoherent superposition of parton-parton collisions.

Results on $\psi(2S)$ vs. multiplicity in pPb

- Nearly linear increase of the $\psi(2S)$ self-normalized yield with multiplicity.
- Calculations by EPS09 coupled with the Percolation and Comovers models are describing within uncertainties the observed results.
- Similar trend of the measurements for J/ψ and $\psi(2S)$.

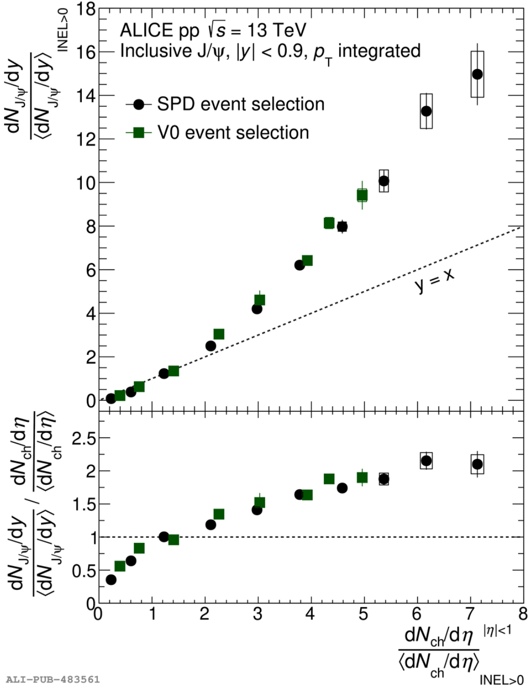


ALICE Collaboration, arXiv:2204.10253 [nucl-ex]

Conclusions

- Small collisions systems are a playground to study the baseline of quarkonium production mechanism.
- Measurements of the correlation between quarkonium production and the charged particle multiplicity are key observables to disentangle the role of initial and final states in particle production.
- Several models are trying to provide a theoretical scenario to describe quarkonium and particle production:
  - Event generators like PYTHIA and EPOS $\Rightarrow$ combination of initial and final state effects
  - CGC and CPP $\Rightarrow$ initial state effects
  - Percolation or Comovers $\Rightarrow$ final state effects
- From the comparison with the models:
  - Need for multiparton interactions (MPI) to describe the measurements.
  - Quarkonium production vs. multiplicity seems to be better known and reproduced by models in p–Pb than in pp.

Backup



ALICE collaboration, Phys.Lett.B 810 (2020) 135758