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

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Study of quarkonium production

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**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

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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

**V0**
Minimum Bias and High Multiplicity trigger (Forward rapidity)
Background rejection

**J/ψ → e⁺e⁻**
(prompt/non-prompt separation)

Mid-rapidity
\(|y_{ee}| < 0.9\)

**TPC**
Central barrel tracking

**ITs**
Central barrel tracking

**SPD**
Multiplicity measurement in \(|\eta|<1\)
and vertex reconstruction

**MTR**
Muon trigger

**MCH**
Muon tracking

**J/ψ, ψ(2S), Ψ(nS) → μ⁺μ⁻**
(inclusive measurement)

Forward rapidity
\(2.5 < y_{μμ} < 4\)
J/ψ cross section in pp collisions at 5.02 TeV

- 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

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

$\sigma_{\psi(2S)} (p_T < 12 \text{ GeV}/c) = 0.876 \pm 0.056 \text{ (stat.)} \pm 0.101 \text{ (syst.) \mu b}$
γ(nS) cross section in pp collisions at 5.02 TeV

- First ALICE measurement of γ(1S), γ(2S) and γ(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

* Results presented by F. Damas (HF and Quarkonia 06/01)
J/ψ production vs. multiplicity in pp collisions at 13 TeV (mid-rapidity)

- 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

NEW arxiv:2005.11123
J/ψ production vs. multiplicity in pp collisions at 13 TeV (mid-rapidity)

- 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

NEW arxiv:2005.11123
Charmonium production vs. multiplicity in pp collisions (forward rapidity)

- 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 $\psi(2S)/J/\psi$ production vs. multiplicity in pp at 13 TeV

- New self-normalized $\psi(2S)/J/\psi$ results (on full Run 2 data sample): maximum deviation from unity $\sim 2.2\sigma$ (first bin) → hint of a multiplicity dependence of $\psi(2S)$ suppression w.r.t $J/\psi$?

- Multiplicity dependence of $\psi(2S)$ suppression w.r.t. $J/\psi$ predicted by comovers approach. Amplitude of the suppression stronger in the model than in the measurement
**Γ(nS) production vs. multiplicity in pp at 13 TeV (forward rapidity)**

- **Γ(1S) vs. Multiplicity**
  - ALICE Preliminary
  - Γ(1S) → μ⁺μ⁻, 2.5 < y < 4
  - Mult. classes: |η|<1
  - pp, √s = 13 TeV

- **Γ(2S)/Γ(1S) and ψ(2S)/J/ψ vs. Multiplicity**
  - ALICE Preliminary, pp, √s = 13 TeV
  - J/ψ, ψ(2S), Γ(1S), Y(2S) → μ⁺μ⁻, 2.5 < y < 4

- Γ relative yields (2016 data sample) show a linear dependence on multiplicity → compatible with charmonium yields at forward rapidity

- Charmonium ratio compatible with Γ(2S)/Γ(1S) within large statistical and systematic uncertainties,
  - Full Run 2 Γ(nS) (including 3S) results coming soon
J/ψ production vs. multiplicity in p-Pb collisions at 5.02 and 8.16 TeV

- 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 $\psi(2S)$ suppression w.r.t $J/\psi$ investigated:
  - Predictions based on comovers model tend to overestimate the $\psi(2S)$ suppression at high multiplicity.
  - Incoming more significant $\Upsilon$ results will improve the charm/beauty comparison.

**p-Pb collisions:**

- New results on $J/\psi$ production vs. multiplicity:
  - Rapidity dependence (backward $\ne$ forward).
  - No energy dependence observed.
Thank you!
ψ(2S) cross section in pp collisions at 5.02 TeV

ALICE inclusive J/ψ, ψ(2S), 2.5 < y < 4
- pp \( \sqrt{s} = 5.02 \) TeV, \( L_{\text{int}} = 1.23 \) pb\(^{-1}\) (preliminary)
- pp \( \sqrt{s} = 7 \) TeV, \( L_{\text{int}} = 1.4 \) pb\(^{-1}\) (EPJ C 74 (2014) 2974)
- pp \( \sqrt{s} = 8 \) TeV, \( L_{\text{int}} = 1.2 \) pb\(^{-1}\) (EPJ C 76 (2016) 184)
- pp \( \sqrt{s} = 13 \) TeV, \( L_{\text{int}} = 3.2 \) pb\(^{-1}\) (EPJ C 77 (2017) 392)

BR uncert.: 11%
J/ψ production vs. multiplicity in pp collisions at 13 TeV (in $p_T$ bins)
Quarkonium production vs. multiplicity in pp collisions at 13 TeV

ALICE, pp, $\sqrt{s} = 13$ TeV

- Inclusive $J/\psi$, $|y| < 0.9$, arXiv: 2005.11123 [nucl-ex]
- Inclusive $J/\psi$, $2.5 < y < 4$, Preliminary
- $\Upsilon(1S)$, $2.5 < y < 4$, Preliminary
- $\Upsilon(2S)$, $2.5 < y < 4$, Preliminary
- $y = x$

ALICE-PREL-350445
EPOS predictions on J/ψ production vs. multiplicity in p-Pb collisions at 8.16 TeV
J/ψ production vs. multiplicity in different collisions systems

NEW arxiv:2004.12673