Event activity dependent quarkonium production in pp collisions with ALICE at the LHC

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- Physics motivation
- The ALICE Detector
- Results and discussion
- Conclusion

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Physics motivation

Multiplicity dependence of quarkonium production in small systems

- Production mechanism
- Study the role of multiple parton interaction
- Interplay between soft and hard processes

**J/ψ** yield vs. multiplicity in pp at 13 TeV

Linear increase:
- Multiple parton interaction

Faster than linear increase:
- Gluon saturation
- Color reconnection

Hint of hot-medium at high multiplicity?
The ALICE Detector

Charged-particle multiplicity is measured using the number of SPD (the first two layers of the ITS) tracklets in $|\eta| < 1$

Central barrel, $|\eta| < 0.9$
- ITS:
  - Tracking, vertexing, multiplicity
- TPC:
  - Tracking, PID
- EMCal:
  - High-$p_T$ electrons
  - Triggering
  - PID

Quarkonia are studied at:
Mid-rapidity: $|y| < 0.9$
Forward rapidity: $2.5 < y < 4$

Smaller detectors
- V0, T0, ZDC...
- Event activity characterization

$J/\psi \rightarrow e^+e^- (|y| < 0.9)$

$J/\psi(Y) \rightarrow \mu^+\mu^- (2.5 < y < 4)$

Muon Spectrometer, $-4 < \eta < -2.5$
- Muon Tracker
- Muon Identifier (triggering)
- Open heavy flavours and quarkonia
- $W/Z$ bosons
- Low mass resonances
Multiplicity estimation

Correction for detector inefficiency

- Data-driven method
  - Equalize acceptance $\times$ efficiency along the $z$-vertex direction
**Multiplicity estimation**

**Tracklet-to-charged-particle conversion**

\[ \langle N^i_{ch} \rangle = \alpha_i \times \langle N^\text{cor,}i_{trk} \rangle \]

- Based on simulations which reproduce the realistic detector transport

**Correction for detector inefficiency**

- Data-driven method
  - Equalize acceptance × efficiency along the z-vertex direction

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Signal extraction

- Clear signal peak at both mid-rapidity and forward rapidity
- A combined fit is applied to disentangle signal and background
J/ψ production vs. event multiplicity

Mid-rapidity vs. forward rapidity

ALICE Preliminary
pp, \( \sqrt{s} = 13 \) TeV
Mult. classes: \(|\eta|<1\)
- inclusive J/ψ \( \rightarrow e^+e^-\), \(|y| < 0.9\)
- J/ψ \( \rightarrow \mu^+\mu^-\), \(2.5 < y < 4\)

NEW forward rapidity

- Faster than linear scaling with multiplicity at mid-rapidity
- w/o rapidity gap between signal and multiplicity estimator
- Linear increase at forward rapidity
- rapidity gap
- Hint of auto-correlation bias
**J/ψ production vs. event multiplicity**

5.02 TeV vs. 13 TeV

- No colliding energy dependence
• First measurement of $\Upsilon$ production vs. charged-particle multiplicity with ALICE

• Similar trend between $\Upsilon(1S)$ and $\Upsilon(2S)$: linear increase with the charged-particle multiplicity
γ(1S)/J/ψ and γ(2S)/γ(1S) vs. event multiplicity

- The double ratios of γ(1S)/J/ψ and γ(2S)/γ(1S):
  - The double ratio is found to be unity irrespective of charged-particle multiplicity
  - The multiplicity dependence production is the same within uncertainties for J/ψ, γ(1S) and γ(2S)
D mesons and muons from HF vs. event multiplicity

- Similar multiplicity dependence as J/ψ and Υ at low multiplicity
- Stronger than linear increase at high multiplicity
- The increase appears slightly faster at mid-rapidity than at forward, which is similar to what is observed in J/ψ
- Need to study the role of jet fragmentation in J/ψ production
Conclusion

ALICE has measured the correlation of quarkonia and open heavy-flavours production with charged particles in pp collisions

Quarkonia:
• $J/\psi$:
  → Faster than linear increase at high multiplicity and mid-rapidity
  → Linear increase observed at forward rapidity
  → Indication of auto-correlation bias
  → No colliding energy dependence
• $\Upsilon$: Linear increase observed at forward rapidity
• $\Upsilon(1S)/J/\psi$ and $\Upsilon(2S)/\Upsilon(1S)$ ratios:
  → Consistent with unity, for all multiplicities
  → No dependence on quarkonium state

Open heavy flavours:
• Enhancement at high multiplicity for both $D$-meson and muons from HF

Thank you
Back up
Analysis strategy

Mid-rapidity multiplicity estimation

2) Tracklet-to-charged particle conversion
   - Based on MC information
   - Reproduce data well

\[
\langle N_{ch}^i \rangle = \frac{\sum N_j \times f \rightarrow Eval(N_{trk}^{cor, j})}{\sum N_j}
\]

\[
\frac{dN_{ch}}{d\eta} / \Delta \eta = \frac{\langle N_{ch}^i \rangle}{\Delta \eta}
\]

1) Data-driven method:
   → Flatten \( <N_{trk}(v_z)> \) distribution

\[
N_{trk}^{cor}(v_z) = N_{trk}(v_z) + Poisson(\Delta N)
\]

\[
\Delta N = N_{trk}(v_z) \langle N_{trk}(v_z^0) \rangle - \langle N_{trk}(v_z) \rangle
\]

\( <N_{trk}(v_z^0)> \): reference value
Analysis strategy

- Data sample
  - Minimum bias triggered events: baseline
  - High multiplicity triggered events: $J/\psi \rightarrow e^+e^-$
  - Di-muon triggered events: $J/\psi \rightarrow \mu^+\mu^-$, $\Upsilon \rightarrow \mu^+\mu^-$

- Multiplicity estimators
  - Mid-rapidity: $1.4 < |\eta| < 2.0$
  - Forward-rapidity: $2.8 < \eta < 5.1$, $-3.7 < \eta < -1.7$

- Observables:
  - Relative charged-particle pseudo rapidity density:
    $$\frac{<dN_{ch}/d\eta>_i}{<dN_{ch}/d\eta>_{\text{inel}}} = \frac{<N_{ch}^i>/\Delta \eta}{<N_{ch}^i>/\Delta \eta} = \frac{f(N_{\text{trk},i})/\Delta \eta}{f(N_{\text{trk},i})/\Delta \eta}_{\text{inel}}$$
  - Relative $J/\psi$ or $\Upsilon$ yield:
    $$\frac{<dN_S/dy>_i}{<dN_S/dy>_i} = \frac{<Y_S>_i}{<Y_S>_i} = \frac{N_S^i}{N^i_{\text{MB}}} \times \frac{N_{MB}^t}{\varepsilon_{MB}} \times \frac{\varepsilon^i_S}{\varepsilon^i_{S: J/\psi or \Upsilon}}$$
J/ψ yield vs. event multiplicity

- Similar trend at low multiplicity (< 2)
- Pb-going: faster linear increase at high multiplicity
- p-going: slower than linear increase when multiplicity density > 2
Comparison: $J/\psi$ yield in multiplicity bins at forward rapidity in p-Pb collisions at 5.02 vs. 8.16 TeV

- Independent of colliding energy
New!!