Quarkonium production as a function of charged particle multiplicity in pp and p-Pb collisions measured by ALICE at the LHC

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Heavy flavor Vs. multiplicity

- Good observable related to the underlying event accompanying heavy-flavor production in pp collisions.
  - Connection to Multiple Partonic Interaction (MPI)
  - Connection to final-state effect (color reconnection etc.)

- Helps to understand the strong hadronic activity associated with heavy-flavor production.
  e.g. $g \rightarrow c\bar{c}$, $qq\bar{q} \rightarrow c\bar{c}$ etc.

- In particular, these measurements help in understanding the interplay between the soft and hard mechanisms.
**J/ψ(D) meson Vs. multiplicity in pp collisions**

- **ALICE** has measured D mesons and J/ψ as a function of multiplicity.
  - Mid rapidity J/ψ(D) yield (|η|<0.9) Vs. mid rapidity charged particles (|η|<1.0)
    - **Observation:**
      - A stronger than linear increase towards higher multiplicity
  - Forward rapidity (2.5 < y < 4.0) J/ψ yield Vs. mid rapidity charged particles (|η|<1.0)
    - **Observation:**
      - Nearly linear increase

- **The increase of J/ψ and D yield with multiplicity reveals that MPIs are relevant for J/ψ and D production.**

- **Different trend of the behavior w.r.t. rapidity gap hinting for different phenomena.**

- **The higher multiplicity reach for pp collisions at √s = 13 TeV may be able to provide further insight.**

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When going from pp to p-Pb…….

- Stronger increase of relative $J/\psi$ yields at forward and backward rapidity with relative multiplicity.

  - p going direction: Trend shows saturation at high multiplicity
  - Pb going direction: Similar trend as that of pp collisions
These studies have been extended to pp@ 5.02 and 13 TeV, and p-Pb@8.16 TeV.

New exciting results!!
The ALICE Detector

EMCAL
High momentum electron
Triggering
PID

ITS
Tracking
Vertexing
Multiplicity ($|\eta| < 1.0$)

V0
Triggering

ALICE Central barrel
$|\eta| < 0.9$

- $0.9 < \eta < 0.9$
- Di-$e$: $p_T > 0$ GeV/c
- Single-$e$: $p_T > 0.2$ GeV/c

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

$\mu^+$
$\mu^-$

J/$\psi (\Upsilon) \rightarrow \mu^+ \mu^-$

- $-4.0 < \eta < -2.5$
- Di-$\mu$: $p_T > 0$ GeV/c
- Single-$\mu$: $p_T > 0.5$ GeV/c

Charged-particle multiplicity is measured using the number of SPD tracklets in $|\eta|<1$. 

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**Signal Extration**

**Dimuon pp @ 13 TeV**

- **ALICE Performance**
  - **pp, 1 s = 13 TeV**
  - **High Multiplicity**
  - **Integrated $p_T$ 2.5 < $y$ < 4.0**

- **Fitting procedure based on**
  - **Signal:** Extended Crystal Ball function
  - **Background:**
    - variable-width Gaussian function

- **Counts**
  - 10^3
  - 10^2
  - 10
  - 1

- **$M_{\mu\mu}$ (GeV/c^2)**
  - 2
  - 2.5
  - 3
  - 3.5
  - 4.5
  - 5

- **Counts per 50 MeV/c^2**
  - 250
  - 200
  - 150
  - 100
  - 50

- **Counts per 40 MeV/c^2**
  - 100
  - 80
  - 60
  - 40
  - 20

**Dielectron pp @ 13 TeV**

- **ALICE Performance**
  - **pp, 1 s = 13 TeV**
  - **$|y| < 0.9**
  - **$6.5 < \frac{dN_{e^+e^-}}{dy} < 8.9$**

- **Signal:**
  - bin by bin counting in 2.92 - 3.16 GeV/c^2

- **Background:**
  - Subtracted using normalized like-sign pair distribution

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Mid-rapidity $J/\psi$ yield vs. multiplicity in pp@13 TeV

- Stronger than linear increase of $J/\psi$ yield is observed towards higher multiplicity

**Theoretical models**
- String percolation
- Hydro dynamical evolution (EPOS3)
- Multiple parton interaction (PYTHIA8)
- Contributions of higher Fock states

- The higher $p_T$ analysis is based on EMCAL triggered data
- The increase of $J/\psi$ production as a function of multiplicity is steeper at higher transverse momenta
- The $p_T$ dependence behavior is explained at least qualitatively by PYTHIA8, which includes MPI processes.
Forward-rapidity $J/\psi$ yield vs. multiplicity in pp@5.02 TeV

- $J/\psi$ at forward rapidity ($2.5 < y < 4.0$) versus charged-particle at mid-rapidity ($|\eta| < 1.0$) has been measured by ALICE.
  - Linear increase w.r.t charged-particle multiplicity.

![Graph showing the relationship between charged-particle multiplicity and $J/\psi$ yield](image)

ALICE Preliminary
Inclusive $J/\psi \rightarrow \mu^+\mu^-$, $2.5 < y < 4$
Mult. classes: $|\eta| < 1$

- pp, $\sqrt{s} = 5.02$ TeV

New!!
The multiplicity reach is extended w.r.t pp@5.02 TeV

Also, showing linear increase
Forward-rapidity $J/\psi$ yield vs. multiplicity in pp@5 and 13 TeV

Trend is independent of colliding energy.
Forward-y and mid-y $J/\psi$ yield vs. multiplicity in pp@13 TeV

- $J/\psi$ Vs. multiplicity at forward-rapidity is compared with mid-rapidity ($|\eta|<1.0$) measurement
  - Different $J/\psi$ vs. multiplicity trend has been observed at mid and forward rapidity.
  - Increase is faster than linear at mid-y, while it is almost linear at forward-y
  - Hinting possible bias of auto-correlations and jets in mid rapidity $J/\psi$ Vs. multiplicity result

ALICE Preliminary
pp, \( \sqrt{s} = 13 \) TeV

Mult. classes: $|\eta|<1$
- inclusive $J/\psi \rightarrow \mu^+\mu^-$, $2.5 < y < 4$
- inclusive $J/\psi \rightarrow e^+e^-$, $|y| < 0.9$

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For the first time, $\Upsilon(1S)$ and $\Upsilon(2S)$ at forward rapidity ($2.5 < y < 4.0$) versus charged-particle at mid-rapidity ($|\eta|<1.0$) have been measured by ALICE.

- A linear increase of relative $\Upsilon(1S)$ and $\Upsilon(2S)$ yield as a function of relative charged-particle multiplicity is observed.
The double ratio $\Upsilon(1S)/J/\psi$ and $\Upsilon(2S)/\Upsilon(1S)$ has been studied for pp@ 13 TeV

- The ratio is found to be unity irrespective of charged-particle multiplicity.
- The multiplicity dependence production is same for $J/\psi$, $\Upsilon(1S)$ and $\Upsilon(2S)$.
- $\Upsilon(nS)/\Upsilon(1S)$, are found to decrease with increasing charged-particle multiplicity, when $\Upsilon$ and charged particles are measured in mid-rapidity. (CMS Collaboration, JHEP04(2014)103)
Recently, ALICE has also measured forward rapidity $J/\psi$ versus charged-particle multiplicity at mid-rapidity for p-Pb@8.16 TeV.

- At low multiplicity, both p-Pb and Pb-p show a linear increase with charged-particle multiplicity.

- Beyond $dN_{\text{ch}}/d\eta/<dN_{\text{ch}}/d\eta> \approx 2$, $J/\psi$ yield in p-Pb collisions show slower than linear increase, whereas $J/\psi$ yield in Pb-p continue to increase linearly.
Forward-rapidity $J/\psi$ yield vs. multiplicity in p-Pb@8.16 TeV

- When we compare with similar measurement at p-Pb@5.02 TeV ….
  - Colliding energy independent but a rapidity dependence behavior is seen.
Recently, $<p_T>$ of $J/\psi$ as a function of charged-particle multiplicity has been studied by ALICE

- Both rapidity regions show a similar trend for $<p_T>$ of $J/\psi$ which saturates around relative multiplicity $\approx 1.5$.
- The relative $<p_T>$ is independent of rapidity.
Recently, $<p_T>$ of $J/\psi$ as a function of charged-particle multiplicity has been studied by ALICE.

- Both rapidity regions show a similar trend for $<p_T>$ of $J/\psi$ which saturates around relative multiplicity $\approx 1.5$.
- The relative $<p_T>$ is independent of rapidity.
- When comparing with results of p-Pb@5.02 TeV: Relative $<p_T>$ is independent of center-of-mass energy.
Summary

ALICE has extended the study of quarkonium production versus charged-particle multiplicity in pp collisions at 5.02 and 13 TeV, and p-Pb collisions at 8.16 TeV at forward and backward rapidities.

- Forward rapidity quarkonia vs. mid rapidity charged-particle multiplicity is showing almost a linear increase, irrespective of collision energy.

- $J/\psi$ production at forward rapidity is approximately linear as a function of mid-rapidity multiplicity, while a faster than linear trend is observed for $J/\psi$ without rapidity gap.

- Double differential ratios of $\Upsilon(1S)$ to $J/\psi$ and $\Upsilon(2S)$ to $\Upsilon(1S)$ are found to be close to unity and independent on multiplicity.

- New results hinting for auto-correlation and jet-bias for mid rapidity $J/\psi$ vs. mid rapidity charged-particle multiplicity study.

- The $J/\psi$ vs. multiplicity study extended to p-Pb collisions to understand $J/\psi$ production from pp to Pb-Pb collisions. The $J/\psi$ vs. multiplicity results for p-Pb collisions is also center-of-mass independent as like pp collisions.

Thank you!!

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Multiplicty determination

- Charged-particle multiplicity is measured using the number of SPD tracklets in |\eta|<1. The variation of the SPD efficiency with the z position of the primary vertex (z_{\text{vertex}}) is corrected using a data-driven method.

\[
\Delta N = \frac{<N_{\text{trk}}>(z_v^0) - <N_{\text{trk}}>(z_v)}{<N_{\text{trk}}>(z_v)}
\]

\[N_{\text{trk}}^{\text{corr}}(z_v) = N_{\text{trk}}(z_v) + \Delta N_{\text{rand}}\]

- Here, \(\Delta N_{\text{rand}}\) follows a Poissonian distribution centered around \(\Delta N\).

- \(z_v^0\) corresponds to \(z_{\text{vertex}}\) position where \(<N_{\text{trk}}>\) is maximum.

- The efficiency loss at \(z_0\) and other track-to-particle-corrections need to be taken into account to evaluate the actual charged-particle value.

\[
\frac{<dN_{\text{ch}}/d\eta>}{<dN_{\text{ch}}/d\eta>} = f(\frac{<N_{\text{trk}}^{\text{corr}}>_i}{<N_{\text{trk}}>_i}) \text{ INEL} > 0
\]

- The conversion function “\(f\)” is estimated using Monte Carlo simulations.
The excited-to-ground-states ratios, $\Upsilon(nS)/\Upsilon(1S)$, are found to decrease with increasing charged-particle multiplicity.

The tightest bound state, $\Upsilon(1S)$, was observed to be less suppressed than the more loosely bound excited states, $\Upsilon(2S)$ and $\Upsilon(3S)$.

Global behavior of double ratio has been observed irrespective of the collisions system; pp, p-Pb, and Pb-Pb.
Analysis strategy

- Silicon Pixel Detector (SPD) is used for charged particle and vertex determination

\[ \frac{J}{\psi} \rightarrow e^+ e^- \]

- Dimuon trigger: MB and two opposite sign muon tracks
  - -4.0 < \eta < -2.5
  - 17.6 cm < R_{\text{abs}} < 89.5 cm
  (R_{\text{abs}} = \text{Radial position of the track at the end of the absorber})

- MB trigger
- -0.9 < \eta < 0.9
- Track quality cuts
- Rejection of tracks from photon conversion
- TPC electron identification

\[ \frac{J}{\psi} \rightarrow \mu^+ \mu^- \]
Low multiplicity region is below linear: Would be more interesting to investigate