Inclusive $J/\psi$ production in pp and A-A collisions with ALICE

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XIIIth Quark confinement and the Hadron Spectrum
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Introduction and previous measurements

Results: $J/\psi$ production

- vs multiplicity in pp collisions at $\sqrt{s} = 13$ TeV

- in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

- in Xe-Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV

Conclusions and outlook
J/ψ production in pp collisions

Hadronic J/ψ production can be factorized in 2 stages:

- $c\bar{c}$-quarks production via hard scattering
- Hadronization part **poorly understood**

**High multiplicity** pp collisions:

- Multi-parton interactions (MPI) included in the models to describe high multiplicities
- Collective behaviour in pp collisions? PYTHIA → color reconnection mechanisms
  EPOS → hydro
**Initial idea:** suppression of J/ψ production as a probe of deconfinement in heavy-ion collisions \(^{[1]}\)

Temperature dependent **sequential suppression** of charmonium states due to the different binding energies \(^{[2]}\)

Large c\(\bar{c}\)-cross section at LHC energies → enhanced charmonium production via **(re-)generation** at hadronization or during the QGP phase \(^{[3],[4]}\)

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\(^{[1]}\) T.Matsui, H.Satz, Phys Lett B.178 (1986) 416


$J/\psi \rightarrow e^+ e^-$
Central barrel: $|y| < 0.9$
Electrons identified via the $dE/dx$ in the Time Projection Chamber

$J/\psi \rightarrow \mu^+ \mu^-$
Forward muon arm: $-4.0 < y < -2.5$
Muons tracked and filtered by the muon spectrometer
pp collisions at $\sqrt{s} = 13$ TeV

Results:

J/ψ vs multiplicity
The observable: relative J/ψ production vs relative charged-particle multiplicity

Advantages: full data driven analysis

Easier to compare at different energies and systems

Approximately linear increase of the relative J/ψ yield as a function of relative multiplicity

Similar increase at mid and forward-rapidity

pp collisions at $\sqrt{s} = 13$ TeV

Signal extraction in 8 different multiplicity intervals. Reaching up to $\frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle} = 7$

Background description with mixed event and like-sign methods
J/ψ vs multiplicity

Extended multiplicity up to 2 times w.r.t $\sqrt{s} = 7$ TeV

Clear stronger than linear increase
Extended multiplicity up to 2 times \( w.r.t \sqrt{s} = 7 \text{ TeV} \)

Clear stronger than linear increase

Models describe the enhancement with multiplicity:

**PYTHIA:** Initial hard processes also in MPIs

**EPOS:** Hydrodynamic evolution of the system

**Kopeliovich:** Contribution of higher Fock states to reach high multiplicities

**Percolation:** Overlapping strings \( \rightarrow \) saturation of soft particle production, hard probes unaffected.
A-A collisions

Results:

Inclusive $J/\psi \ R_{AA}$ in Pb-Pb and Xe-Xe collisions
Previous results in A-A collisions

Nuclear modification factor

\[ R_{AA} = \frac{Y_{Pb-Pb}^{J/\psi}}{\langle T_{AA} \rangle \sigma_{pp}^{J/\psi}} \]

- Smaller suppression for central events in ALICE compared to PHENIX

- Indication of new production mechanism → (re)generation for charmonium at LHC energies

ALICE Pb-Pb at $\sqrt{s_{NN}} = 2.76$ TeV

PHENIX Au-Au at $\sqrt{s_{NN}} = 0.2$ TeV
Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

Signal extraction in different centrality classes

$|y| < 0.9$

![Graph with data points and error bars showing event counts per 40 MeV/c^2 in the range 1.5 to 4.0 GeV/c^2.]

$N_{y/y'}$: 4160 ± 416

S/B: 0.025 ± 0.003

S/\S+B: 10.1 ± 1.0

-4 < y < -2.5

![Graph with data points and error bars showing event counts per 50 MeV/c^2 in the range 2.5 to 4.5 GeV/c^2.]

ALICE Pb-Pb, $|y| < -2.5$

L_{int} ≈ 225 μb⁻¹

Centrality 0-10 %

$\chi^2$/ndf = 1.10, S/B_{3σ} = 0.10

Mixed-event background subtracted

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XIIIth Quark confinement and the Hadron Spectrum
No significant dependence on centrality for $\langle N_{\text{part}} \rangle$ larger than 50

Slightly higher $R_{AA}$ values at $\sqrt{s_{NN}} = 5.02 \text{ TeV}$ compared to $\sqrt{s_{NN}} = 2.76 \text{ TeV}$ measurement, compatible within uncertainties.

\begin{align*}
|y| &< 0.9 \\
-4 < y < -2.5
\end{align*}
Most of the models in agreement with the data within the large uncertainties

Uncertainties do not allow any discrimination between the statistical hadronization and transport models

Precise charm cross section measurement and more differential analyses needed
**J/ψ $R_{AA}$ versus transverse momentum**

Increase of the $R_{AA}$ at low $p_T$ compatible with (re)generation scenario

Stronger **suppression at high $p_T$** in central collisions due to parton energy loss

![Graph showing $R_{AA}$ versus $p_T$ at different $s_{NN}$ values](image-url)
Increase of the $R_{AA}$ at low $p_T$ compatible with (re)generation scenario

Stronger suppression at high $p_T$ in central collisions due to parton energy loss
J/ψ $R_{AA}$ versus centrality at forward rapidity:

- $A_{Xe} = 129$, $L_{int} \approx 0.34 \mu b^{-1}$
- $A_{Pb} = 208$, $L_{int} \approx 225 \mu b^{-1}$

• $R_{AA}$ results of Xe–Xe and Pb–Pb agree within uncertainties
  ⇒ Similar $\sqrt{s_{NN}}$ and $\langle N_{part} \rangle$ lead to similar relative contributions of suppression and regeneration

ALICE Collaboration arXiv:1805.04383
Conclusions

J/ψ vs multiplicity in pp collisions

- Steep increase of relative J/ψ yield with event multiplicity
- Qualitatively well described by different models

J/ψ production in A-A collisions

- Similar $R_{AA}$ values in Pb-Pb at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV
- Compatible J/Ψ $R_{AA}$ in Xe-Xe and Pb-Pb collisions
- Maximum of the $R_{AA}$ towards low $p_T$ (< 4 GeV/c) in compatibility with (re)generation scenarios
Outlook:

- Study possible multiplicity estimator bias
- Improvement on the pp reference with 2017 data
- Higher statistics in Pb-Pb data at the end of the year
- Distinction among the different models will come in LHC-Run 3 → $\psi(2S)$ / $J/\psi$
Relative $J/\psi$ yields vs multiplicity in different $p_T$ intervals.

Extended high $p_T$ (up to 30 GeV/c) using EMCAL

The steepness of the dependence increases strongly with the $J/\psi$ $p_T$

PYTHIA 8 qualitatively describes the trend
Contributions from initial hard scattering approximately multiplicity independent

MPI contributions dominate the high multiplicity
$R_{AA}$ measurements vs centrality are consistent at mid- and forward-rapidity.

Small increase of the $R_{AA}$ in the most central collisions w.r.t forward rapidity
Still compatible with fluctuations

Hint of enhanced $J/\psi$ production towards mid-rapidity
Transport models describe the data with TM1\cite{1} describe the data within uncertainties. TM2\cite{2} at high $p_T$ misses the quantitative description.

$p_T$ spectra comparison would be interesting to compare. ...
The J/ψ production due to (re)generation dominates at low $p_T$.

Striking difference at LHC energies in comparison to RHIC (STAR & PHENIX).

Suppression at high $p_T$ attributed to charm energy loss in QGP.

Inclusive J/ψ → e⁺e⁻, Centrality 0-20%

- ALICE, Pb-Pb $s_{NN} = 5.02$ TeV, $|y| < 0.9$ (Preliminary)
- PHENIX, Au-Au $s_{NN} = 0.2$ TeV, $|y| < 0.35$ PRL 98 (2007) 232301
- STAR, Au-Au $s_{NN} = 0.2$ TeV, $|y| < 1$ PRC 90, 024906
$J/\psi$ $R_{AA}$ versus centrality in Pb-Pb collisions at $s_{NN}$ 5.02 TeV

$\sigma_{pp}^{J/\psi}$: Interpolation of $J/\psi$ measurements at mid-rapidity for different collision energies $\sqrt{s} = 0.2$ [1], 1.96 [2], 2.76 [3] and 7 [4] TeV

Xe-Xe collisions at $\sqrt{s_{NN}} = 5.44$ TeV

$J/\psi$ $R_{AA}$ versus centrality:

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