Recent CMS results on Quarkonium in pPb and PbPb

Andre Ståhl
on behalf of the CMS Collaboration

T.W. Bonner Laboratory, William Marsh Rice University

13th International Workshop on Heavy Quarkonium
Quarkonia are produced in the early stages of the collision.

The Quark-Gluon Plasma is expected to modify the quarkonium production.

Quarkonia are good probes of the medium evolution.
Quarkonia in pPb Collisions

- Study of quarkonia in pPb allows to probe Cold Nuclear Matter effects:
  - Initial state energy loss
  - Nuclear PDF modifications
  - Nuclear absorption

Excited States in Heavy-Ion Collisions

- The study of ψ(2S), Y(2S) and Y(3S) brings additional information:
  - Excited states are less tightly bounded than the 1S states
    - More suppressed in the QGP compared to J/ψ or Y(1S)
  - Models including nPDF and energy loss effects predict similar suppression for ψ(2S) as for J/ψ
Prompt and Nonprompt Charmonia

**Prompt J/ψ**
- Direct J/ψ
- Feed-down from \(\Psi(2S)\) and \(\chi_c\)

**Nonprompt J/ψ**
- From B hadron decays

- **Prompt Charmonia:**
  Directly affected by the QGP

- **Non-Prompt Charmonia:**
  Reflects energy loss of b quarks in the QGP

Separation based on **pseudo-proper decay length** \(l_{J/\psi}\)

\[
l_{J/\psi} = \frac{m_{J/\psi}}{p_{\mu\mu}} L
\]
Outline

- **Y(nS) in PbPb at 5.02 TeV**

- **J/ψ in PbPb at 5.02 TeV**

- **Prompt ψ(2S) in pPb at 5.02 TeV**

- **Prompt J/ψ in high-multiplicity pPb at 8.16 TeV**
Y(nS) in PbPb at 5 TeV
• Clear suppression of bottomonium states in PbPb collisions compared to pp
Y(nS) modification in PbPb

- Y(nS) suppression increases with collision centrality
- Weakly bound states more suppressed -> $R_{AA}(Y(3S)) < R_{AA}(Y(2S)) < R_{AA}(Y(1S))$
- Still no observation of Y(3S) mesons in PbPb collisions
Y(nS) modification in PbPb

Hydrodynamic model
Universe 2 (2016) 16
PbPb 368/464 μb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

Transport model
PRC 96 (2017) 054901
PbPb 368/464 μb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

- Comparisons with an hydrodynamic model (Krouppa et al) and a transport model (Du et al), show good agreement with the measurements
Y(nS) modification in PbPb

- Hint of less suppression of Y(1S) at high $p_T$
- No significant dependence of Y(nS) $R_{AA}$ on rapidity
J/ψ in PbPb at 5 TeV
Prompt J/ψ modification in PbPb

- Similar $p_T$ trend between different rapidities bins
- Less suppression at low $p_T$ in central events (cent < 30%)
- Regeneration of J/ψ at $p_T > 3$ GeV/c?
Prompt J/ψ modification in PbPb

- Hints of increasing J/ψ $R_{AA}$ towards high $p_T$
- Similar level of suppression between prompt J/ψ and $D^0$ mesons
  - Contribution from energy loss on J/ψ?
Nonprompt $J/\psi$ modification in PbPb

PbPb 368 $\mu$b$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

- Less suppression of nonprompt $J/\psi$ at high $p_T$ and more central collisions
- No significant dependence on rapidity
Nonprompt $J/\psi$ modification in PbPb

- Less suppression of nonprompt $J/\psi$ at lower $p_T$
- Similar suppression at high $p_T$ between open beauty, open charm and light hadrons -> Universal flavour dependence of $E_{\text{loss}}$ at high $p_T$?
Prompt $\psi(2S)$ in pPb at 5 TeV
Ratio: $R_{pPb}(\psi(2S)) < R_{pPb}(J/\psi)$ especially at backward (Pb-going direction)

• Different suppression between $J/\psi$ and $\psi(2S)$ could be consistent with FS inelastic interactions of $\psi(2S)$ with comoving particles in the medium
Prompt $J/\psi$ in high-multiplicity $pPb$ at 8 TeV
Charm quark dynamics in pPb

Heavy quark collectivity in PbPb reflects the presence of QGP medium and its response to the initial collision geometry.

Observation of charm flow at high-multiplicity pPb

$0 < v_2(D^0) < v_2(K_s)$

Collectivity in small systems from charm or light quarks?

Measurements of J/$\psi$ flow needed to complete the picture of charm dynamics
Prompt J/ψ $v_2$ in high-multiplicity pPb

- Measure J/ψ elliptic flow by fitting the dimuon invariant mass and $v_2$ spectra
- Prompt J/ψ extracted by selecting candidates with low decay lengths ($l_{J/ψ}$)

CMS pPb 8.16 TeV


alignment issues corrected
Observation of prompt $J/\psi$ flow in high-multiplicity pPb -> charm collectivity

Smaller $v_2$ of charm quarks compared to light quarks
Non-zero J/ψ v₂ in model calculations (Du, Rapp) arise from FS interactions in the elliptic fireball, but significantly underpredicts the CMS results.

Initial-state (or pre-equilibrium) effects beyond QGP?
SUMMARY

Hot Nuclear Matter Effects:

Sequential suppression of bottomonia

Energy loss and regeneration of J/ψ

Cold Nuclear Matter Effects:

ψ(2S) interactions with comovers?

Collectivity in small systems:

Physics beyond QGP?
Thank you for your attention!
Acknowledgement

U.S. DEPARTMENT OF ENERGY
Office of Science

Alfred P. Sloan Foundation
The Welch Foundation
CMS Detector

Muon acceptance: $|\eta| < 2.4$

Key:
- Blue: Muon
- Red: Electron
- Green: Charged Hadron (e.g. Pion)
- Dashed Green: Neutral Hadron (e.g. Neutron)
- Dotted Blue: Photon

Transverse slice through CMS

Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid

Iron return yoke interspersed with Muon chambers

0m 1m 2m 3m 4m 5m 6m 7m
Prompt and Non-Prompt Charmonia

Two techniques to separate components:

1. **2D fits of dimuon mass and pseudo-proper decay length**

![2D fits of dimuon mass and pseudo-proper decay length](image)

2. **Rejecting non-prompt applying a cut on pseudo-proper decay length**

Data-based corrections applied to remove non-prompt contamination

- Using reverted $I_{J/\psi}$ cut
- MC efficiency of $I_{J/\psi}$ cut
Y(nS) modification in PbPb

2.76 vs. 5.02 TeV

Y(1S)

Y(2S)

PbPb 368/464 μb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

\[ p_T < 30 \text{ GeV} \]
\[ |y| < 2.4 \]

Krouppa, Strickland (5.02 TeV)

-1

\[ \sqrt{s_{NN}} = 5.02 \text{ TeV} \]
\[ \sqrt{s_{NN}} = 2.76 \text{ TeV} \]

\[ \eta/s = 1 \]
\[ \eta/s = 2 \]
\[ \eta/s = 3 \]

CMS Supplementary

Cent. 0-100%


CMS

QWG 2019

13/05/19
Y(nS) modification in PbPb

PbPb 368 μb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

Cent. 0-100%

|Y(1S) Total|
|Y(1S) Regeneration|
|Y(2S) Total|
|Y(2S) Regeneration|

X. Du, M. He, R. Rapp

CMS Supplementary

$\psi(2S)$ modification in pPb

$\psi(2S)$ modification in pPb

CMS

![Graph showing $R_{ppb}$ vs. $y_{CM}$ for different $p_T$ intervals.](image)

- **Prompt $\psi(2S)$**
  - $4 < p_T < 6.5$ GeV/c
  - $5 < p_T < 6.5$ GeV/c
  - $6.5 < p_T < 10$ GeV/c
  - $10 < p_T < 30$ GeV/c

Prompt $J/\psi$ [EPJC 77, 269 (2017)]

- **Prompt $J/\psi$**
  - $4 < p_T < 6.5$ GeV/c
  - $5 < p_T < 6.5$ GeV/c
  - $6.5 < p_T < 10$ GeV/c
  - $10 < p_T < 30$ GeV/c

**J/ψ modification in PbPb**

*2.76 vs. 5.02 TeV*

**Prompt J/ψ**

- **Cent. 0-100%**
  - \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
  - \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \)

**Collisions**

- PbPb 368 \( \mu b^{-1} \)
- pp 28.0 \( pb^{-1} \) (5.02 TeV)


- **2.76 vs. 5.02 TeV**
- **R_{AA}**
  - \( |y| < 2.4 \)
  - \( p_T < 50 \text{ GeV/c} \)
  - \( \sqrt{s_{NN}} = 2.76 \text{ TeV} \)
  - \( \sqrt{s_{NN}} = 5.02 \text{ TeV} \)

**CMS**

- PbPb (93%) / 464 (>30%) \( \mu b^{-1} \)
- pp 28.0 \( pb^{-1} \) (5.02 TeV)

**Plot Details**

- **R_{AA}** vs. \( |y| \)
- **R_{AA}** vs. \( N_{\text{part}} \)
- **R_{AA}** vs. \( p_T \) (GeV/c)
$\psi(2S)$ is more suppressed than $J/\psi$ at 5.02 TeV

- No strong $N_{\text{part}}$ dependence at 5.02 TeV
- Double ratio at 5.02 TeV consistently lower than at 2.76 TeV in $1.6 < y < 2.4$, $3 < p_T < 30$ GeV/c, especially for most central collisions (~3 s.d. in 0-100%)
A sequential regeneration model of charmonia states in the fireball evolution might explain the smaller suppression of $\psi(2S)$ compared to $J/\psi$ observed by CMS in PbPb at 2.76 TeV.

Due to the increase in transverse flow from 2.76 TeV to 5.02 TeV, the model predicts that more regenerated $J/\psi$ are produced at $p_T > 3$ GeV/c, thus suppressing the double ratio at $3 < p_T < 30$ GeV/c, in agreement with the CMS measurements.