PROMPT $\psi(2S)$ AND $J/\psi$ MODIFICATION IN pPb AND PbPb COLLISIONS AT 5.02 TeV WITH CMS

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Charmonia are bound states of $c\bar{c}$

$$\tau_{\text{formation}}^{c\bar{c}} \lesssim \tau_{\text{formation}}^{QGP} < \tau_{\text{life}}^{QGP} < \tau_{\text{decay}}^{\text{quarkonium}}$$

→ expected to experience the whole QGP evolution

The presence of QGP should affect charmonia production (yield and kinematics)

Charmonia are excellent probes for the QGP

Need also to address effects due to Cold Nuclear Matter
CHARMONIA IN pPb COLLISIONS

• Study of J/ψ in pPb allows to probe **Cold Nuclear Matter effects:**
  ✦ Initial state: Modification of nuclear PDFs
  ✦ Initial-Final: Coherent energy loss
  ✦ Final state: Nuclear absorption (negligible @ LHC)

• Study of ψ(2S) in pPb brings additional information:
  ✦ Excited states are less tightly bound than the 1S state (J/ψ)
  ✦ Models including **Cold Nuclear Matter effects** predict similar suppression as for J/ψ

• **Other final state effects** can be important in pPb: e.g. interaction with comovers

• Reference from **pp data** (28.0 pb⁻¹)
• **Prompt component:**
  affected by color screening and regeneration in the QGP

• **Nonprompt component:**
  reflects $E_{\text{loss}}$ of $b$ quarks in the medium

Separation of components based on **pseudo-proper decay length** ($\ell_{J/\psi}$):

$$\ell_{J/\psi}^{3D} = L_{xyz} \cdot \frac{m_{J/\psi}}{p_{\mu\mu}}$$

This talk: **prompt charmonia**

Ta-Wei Wang’s talk (8th): **nonprompt charmonia** & full B reconstruction
Two techniques to separate components:

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

   ![Graph showing 2D fits of dimuon mass and pseudo-proper decay length.]

2. **Rejecting nonprompt using a cut on $\ell J/\psi$**
   (can be used with low stats: $\Psi(2S)$ analyses)

   Correction (from data) to account for remaining nonprompt contamination:
   - Using reverted $\ell J/\psi$ cut
   - MC efficiency of $\ell J/\psi$ cut

   ![Diagram illustrating the separation of prompt and nonprompt charmonia.]
• **Prompt $J/\psi$ in pPb at 5 TeV**
  ✦ HIN-14-009, arXiv:1702.01462

• **Prompt $\psi(2S)$ in pPb at 5 TeV**
  ✦ HIN-16-015

• **Relative modification of prompt $J/\psi$ and $\psi(2S)$ from pp to PbPb at 5 TeV**
  ✦ HIN-16-004, arXiv:1611.01438

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**Songkyo Lee’s poster: L03**
• Prompt $J/\psi$ in pPb at 5 TeV

• Prompt $\psi(2S)$ in pPb at 5 TeV

• Relative modification of prompt $J/\psi$ and $\psi(2S)$ from pp to PbPb at 5 TeV
• Prompt $J/\psi$ $R_{pPb}$ above unity at mid and backward (Pb-going direction) rapidity

• Suppression in the most forward bin ($1.5 < y_{CM} < 1.93$) for $p_T \lesssim 7.5$ GeV/c
• Prompt $J/\psi$ $R_{pPb}$ above unity at mid and backward (Pb-going direction) rapidity

• Suppression in the most forward bin ($1.5 < y_{CM} < 1.93$) for $p_T \lesssim 7.5$ GeV/c

• Shadowing calculations slightly lower than data, but describe suppression at forward
• CMS measurement extends ALICE one to higher $p_T$

• Different rapidity ranges, so effects could be different

• Results in the most forward and backward bins ($4 < p_T < 8 \text{ GeV/c}$) consistent with ALICE
• Lower $p_T$: decrease of $R_{pPb}$ with $y_{CM}$

• Higher $p_T$: $R_{pPb}$ above unity for the whole $y_{CM}$ range

• Shadowing calculations slightly lower than data but describe the $y_{CM}$ trend
• Prompt $J/\psi$ $R_{FB}$ below with unity for $p_T \lesssim 7.5$ GeV/c and $|y_{CM}| > 0.9$.

• $y_{CM}$ dependence in $6.5 < p_T < 10$ GeV/c
Event activity characterised by the transverse energy deposited in the Hadron Forward calorimeters in $4 < |\eta| < 5.2$ ($E_{T}^{HF|\eta|<4}$).

- $R_{FB}$ decreases for increasing event activity
- Enhanced nuclear effects for increasing event activity
• Prompt $J/\psi$ in pPb at 5 TeV

• Prompt $\psi(2S)$ in pPb at 5 TeV

• Relative modification of prompt $J/\psi$ and $\psi(2S)$ from pp to PbPb at 5 TeV
PROMPT $\psi(2S)$ IN pPb

- **Ratio:** $R_{pPb}(\psi(2S))/R_{pPb}(J/\psi) < 1$ at backward (Pb-going direction)

- $\psi(2S)$ suppression stronger at most backward rapidity and lowest $p_T$

- Indication of final state effect: suppression by interactions with co-moving matter?
  Note: multiplicity does not change much from backward to forward
• Prompt $J/\psi$ in pPb at 5 TeV

• Prompt $\psi(2S)$ in pPb at 5 TeV

• Relative modification of prompt $J/\psi$ and $\psi(2S)$ from pp to PbPb at 5 TeV
Double ratio of charmonia in PbPb and pp at 5 TeV:

\[
\frac{\psi(2S)}{J/\psi}_{PbPb} \left\{ \frac{\psi(2S)}{J/\psi}_{pp} \right\} = \frac{R_{AA}(\psi(2S))}{R_{AA}(J/\psi)}
\]

- Many corrections and uncertainties cancel (experimental and theoretical)
- Relative modification of $\psi(2S)$ and $J/\psi$ in PbPb
95% CL where no significant $\psi(2S)$ signal in PbPb

- $R_{AA}(\psi(2S))/R_{AA}(J/\psi) < 1$ in all bins $\rightarrow \psi(2S)$ is more suppressed than $J/\psi$
- No $p_T$ dependence within uncertainties
- X. Du and R. Rapp: transport model with temperature dependent reaction rates $\rightarrow \psi(2S)$ regenerated later than $J/\psi$ in the fireball evolution?

\[ (\psi(2S)/J/\psi)_{\text{pp}} / (\psi(2S)/J/\psi)_{\text{PbPb}} \]
\( \psi(2S) / J/\psi \) vs CENTRALITY

2.76 vs. 5.02 TeV

- \( \psi(2S) \) 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 \( 1.6 < \gamma < 2.4, \ 3 < p_T < 30 \text{ GeV}/c \), especially for most central collisions (~3 s.d. in 0-100%)
CMS results vs centrality, $p_T$ and rapidity can help to constrain the model:

- Relative contribution of primordial and regenerated charmonia
- Dissociation and regeneration rates
- Temperatures at which $J/\psi$ and $\psi(2S)$ regenerate
- …
SUMMARY

Probing **Cold Nuclear Matter effects:**

Less strong effects than in PbPb in the kinematical ranges studied by CMS

- **No strong** $p_T$ or $y_{CM}$ dependence
- **Nuclear effects increase** with event activity
- **Effects beyond** CNM (final state) affecting $\psi(2S)$?
Probing **Cold Nuclear Matter effects:**

Less strong effects than in PbPb in the kinematical ranges studied by CMS

No strong \( p_T \) or \( y_{CM} \) dependence

Nuclear effects increase with event activity

Effects beyond **CNM** (final state) affecting \( \psi(2S) \)?

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Probing **QGP effects:**

Strong effects in the kinematical ranges studied by CMS

\( \psi(2S) \) is more suppressed than \( J/\psi \)

\( \psi(2S) \) regenerated later than \( J/\psi \) in the fireball evolution? Results help to constrain model ingredients
THANK YOU FOR YOUR ATTENTION
Muon acceptance: $|\eta| < 2.4$
Nonprompt J/ψ IN pPb

CMS | QM2017 | 07/02/2017 | Javier Martin

pPb 34.6 nb$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

Nonprompt J/ψ

$R_{pPb}$

$0 < y_{CM} < 0.9$

$0.9 < y_{CM} < 1.5$

$1.5 < y_{CM} < 1.93$

$-0.9 < y_{CM} < 0$

$-1.5 < y_{CM} < -0.9$

$-1.93 < y_{CM} < -1.5$

$-2.4 < y_{CM} < -1.93$

$0 < p_T < 30$ GeV/c
Prompt

$pPb$ 34.6 nb$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

CMS

$R_{pPb}$

- $10 < p_T < 30$ GeV/c
- ATLAS: $8 < p_T < 30$ GeV/c

$y_{CM}$

- $|y_{CM}| < 1.5$
- ATLAS: $|y_{CM}| < 1.5$

$p_T$ (GeV/c)
Nonprompt J/ψ IN pPb

Nonprompt J/ψ

CMS

pPb 34.6 nb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

\[ R_{pPb} \]

- \( 10 < p_T < 30 \text{ GeV/c} \)
- ATLAS: \( 8 < p_T < 30 \text{ GeV/c} \)

CMS

Nonprompt J/ψ

pPb 34.6 nb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

\[ R_{pPb} \]

- \( |y_{CM}| < 1.5 \)
- ATLAS: \( |y_{CM}| < 1.5 \)

arXiv:1702.01462
Nonprompt

CMS

Nonprompt $J/\psi$

$pPb$ 34.6 nb$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

$R_{pPb}$ vs $y_{CM}$

$6.5 < p_T < 10$ GeV/c

$pPb$ 34.6 nb$^{-1}$, pp 28.0 pb$^{-1}$ (5.02 TeV)

$R_{pPb}$ vs $y_{CM}$

$10 < p_T < 30$ GeV/c

arXiv:1702.01462
J/ψ IN pPb

CMS

Open beauty

Nonprompt J/ψ: 10 < p_T < 30 GeV/c

B⁺: 10 < p_T < 60 GeV/c

Nonprompt J/ψ: |y_{CM}| < 1.93

B⁺: -2.86 < y_{CM} < 1.93

pPb 34.6 nb⁻¹, pp 28.0 pb⁻¹ (5.02 TeV)

CMS

New result

QM17
$\psi(2S)$ in pPb
**ψ(2S) IN pPb**

CMS PAS HIN-16-015

![Graphs showing the ratio of prompt ψ(2S) yields in pPb collisions compared to pp collisions.](image)
$\psi(2S) / J/\psi$ DOUBLE RATIO: CMS VS ALICE

CMS PbPb & pp $\sqrt{s_{NN}} = 2.76$ TeV
- $3 < p_T < 30$ GeV/c, $1.6 < |y| < 2.4$
- $6.5 < p_T < 30$ GeV/c, $|y| < 1.6$
- 95% CL

ALICE PbPb $\sqrt{s_{NN}} = 2.76$ TeV & pp $\sqrt{s} = 7$ TeV
- $p_T < 3$ GeV/c, $2.5 < |y| < 4$
- 95% CL
- $3 < p_T < 8$ GeV/c, $2.5 < |y| < 4$ (95% CL)

CMS: PRL 113 (2014) 262301
ALICE: JHEP 1605 (2016) 179
**Sequential Regeneration**

Nucl. Phys. A 943 147

**PbPb $\sqrt{s_{NN}} = 2.76$ TeV**

- $0 < \eta < 0.4$
- $2.76$ TeV
- $5$ TeV

**$T_0$ ~ 600 MeV**

- 7% increase of initial temperature
- 10% more shadowing
- 40% increase charm cross section

**PbPb $\sqrt{s_{NN}} = 5.02$ TeV**

- $0 < \eta < 0.4$
- $5.02$ TeV

**$T_0$ ~ 640 MeV**

2.76 TeV $\rightarrow$ 5 TeV

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**Prompt charmonia**
- $J/\psi$ (arXiv:1610.00613)
  - $p_t \in [6.5,30]$ GeV/c, $|y| < 2.4$, Cent. 0-5%
- $\psi(2S)$ (PRL 113, 2014)
  - $p_t \in [6.5,30]$ GeV/c, $|y| < 1.6$

**Bottomonia**
- $p_t \in [0,20]$ GeV/c, $|y| < 2.4$
  - arXiv:1611.01510
  - $\Upsilon(1S)$
  - $\Upsilon(2S)$
  - $\Upsilon(3S)$ 95% C.L.