CMS Heavy Ion Results of Charmonia

Yongsun Kim
on behalf of CMS collaboration

QM2015, Kobe
## Recent heavy quark results of CMS

<table>
<thead>
<tr>
<th></th>
<th>Charmonia</th>
<th>Bottomonia [Jo, 11:30 today]</th>
<th>Open heavy flavor [Sun, Monday]</th>
</tr>
</thead>
</table>
| **PbPb**         | Prompt $J/\psi$ $R_{AA}$<br>CMS-HIN-12-014<br>Prompt $J/\psi$ $v_2$
|                  | Prompt $\psi(2S)$ $R_{AA}$<br>PRL 113 (2014)262341<br>$J/\psi$ in UPC CMS-HIN-12-009 | $\Upsilon(nS)$ modification<br>CMS-HIN-15-001<br>PRL 109(2012) 222301<br>Inclusive $J/\psi$ in UPC CMS-HIN-12-009 | Prompt $D^0$ $R_{AA}$<br>CMS-HIN-15-005<br>Jet $R_{AA}$<br>PRL 113 (2014) 132301 |

| **pPb**          | $J/\psi$ production<br>CMS-HIN-14-009<br>$\Upsilon(nS)$ modification<br>JHEP 04 (2014) 103 | $\Upsilon(nS)$ modification<br>JHEP 04 (2014) 103<br>CMS-HIN-14-009 | $c$ jet $R_{pA}$<br>CMS-HIN-15-012<br>$b$ jet $R_{pA}$<br>CMS-HIN-14-007<br>B meson $R_{pA}$<br>CMS-HIN-14-004 |

| **pp**           | $\Upsilon(nS)$ polarization<br>CMS-HIN-15-003                              |                                                                                             |                                                     |
### Outline of this talk

<table>
<thead>
<tr>
<th></th>
<th>Charmonia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PbPb</strong></td>
<td></td>
</tr>
<tr>
<td>2.76 TeV</td>
<td>Prompt $J/\psi$ $R_{AA}$</td>
</tr>
<tr>
<td>160$\mu$b$^{-1}$</td>
<td>Prompt $J/\psi$ $v_2$</td>
</tr>
<tr>
<td></td>
<td>Prompt $\psi(2S)$</td>
</tr>
<tr>
<td></td>
<td>$J/\psi$ in UPC*</td>
</tr>
<tr>
<td><strong>pPb</strong></td>
<td></td>
</tr>
<tr>
<td>5.02 TeV</td>
<td>$J/\psi$ production</td>
</tr>
</tbody>
</table>

**Part I**
Review of results in **PbPb collisions**

**Part II**
Study of cold nuclear matter effects

*UPC = Ultra Peripheral Collision

** Only prompt charmonia discussed in this presentation.
Large coverage of trackers and calorimeters

Muons are tracked by muon system (RPC, CSC, DT) and inner silicon pixels and strips

CMS detector

CMS DETECTOR
- Total weight: 14,000 tonnes
- Overall diameter: 15.0 m
- Overall length: 28.7 m
- Magnetic field: 3.8 T

STEEL RETURN YOKE
- Weight: 12,500 tonnes

SILICON TRACKERS
- Pixel (100x150 μm): ~16m² ~66M channels
- Microstrips (80x110 μm): ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
- Nb3Sn titanium coil carrying ~18.0kMA

MUON CHAMBERS
- Barrel: 230 Drift Tube, 176 Resitive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resitive Plate Chambers

PRE-SHOWER
- Silicon strips ~16m² ~237,000 channels

FORWARD CALORIMETER
- Steel + Quartz fibers ~2,000 Channels

CRYSTAL ELECTROMAGNETIC CALORIMETER (ECL)
- ~76,000 scintillating PbWO₄ crystals

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels
Prompt charmonia reconstructed via $\mu^+\mu^-$

CMS Preliminary

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

$N_{\mu\mu} = 667 \pm 37$
$\sigma = 46 \pm 1$ MeV/c$^2$

$L_{int} = 150 \mu b^{-1}$

$1.6 < |y| < 2.4$

$6.5 < p_T < 30$ GeV/c

Cent. 0-10%

CMS Preliminary

PbPb $\rightarrow$ PbPb+$\psi$ (X$_{2S}$) $\sqrt{s_{NN}} = 2.76$ TeV

$N_{\psi}$: 923 $\pm$ 33
$\sigma = 22 \pm 2$ MeV/c$^2$

Events / (0.024 GeV/c$^2$)

Counts / 20 MeV/c$^2$

CMS Preliminary

PbPb $\rightarrow$ PbPb+$J/\psi$ ($X_0\psi$) $\sqrt{s_{NN}} = 2.76$ TeV

$N_{J/\psi} = 159 \mu b^{-1}$

$1.8 < |y(\psi)| < 2.3$

Complimentary coverages of $J/\psi$ in pPb by 4 experiments

CMS ($\mu\mu$)

ALICE ($\mu\mu$)

ATLAS ($\mu\mu$)

LHCb ($\mu\mu$)

ALICE (ee)

LHCb ($\mu\mu$)

Data

Total fit

bkgd + non-prompt

background

$0.9 < y_{CM} < 0$

$14 < p_T < 30$ GeV/c

Counts / (0.20 GeV/c$^2$)

$34.6 \text{ nb}^{-1}$ (pPb 5.02 TeV)
Charmonia in PbPb: Ground state (1S)

- Strong evidence of medium induced modification of quarkonia
- Path length dependence of yield up to high $p_T$
Charmonia in PbPb: Ground state $\psi(2S)$

• Compared suppression patterns of $J/\psi$ and $\psi(2S)$

$\frac{\psi(2S) R_{AA}}{J/\psi R_{AA}}$

In naïve sequential suppression picture, excited states are more suppressed than the ground states as observed in $\Upsilon(nS)$ study

• However, $\psi(2S)$ is less suppressed than $J/\psi$ in forward
• Cold Nuclear Matter effects
  - Modification of PDF
  - Nuclear absorption
  - Energy loss inside nucleus
  - And more

• Charmonia can probe CNM effects via $J/\psi$ production in...
  (a) $pPb$ collisions
  (b) Ultra Peripheral Collisions
Double differential cross-section for a wide kinematic range

- $p_T : [2, 30] \text{ GeV/c}$, $y_{CM} : [-2.87, 1.93]$
Lessons from $J/\psi$ cross-section in $p+Pb$

**CMS Preliminary** 34.6 nb$^{-1}$ (pPb 5.02 TeV)

- Cross section as a function of rapidity at
  - Low $p_T$ [6.5, 10] GeV/c
Lessons from $J/\psi$ cross-section in $p+Pb$

- Cross section as a function of rapidity at
  - Low $p_T$ $[6.5, 10]$ GeV/c
Lessons from J/ψ cross-section in p+Pb

CMS Preliminary

34.6 nb⁻¹ (pPb 5.02 TeV)

Prompt J/ψ

• Fold plot around \( y_{CM} = 0 \) \( \rightarrow \) A clear asymmetry at low \( p_T \)
• \( R_{FB}(|y|) = \frac{\text{Yield in } +y}{\text{Yield in } -y} \) for systematic approach
• Asymmetry is bigger for lower $p_T$ and higher rapidity range
• Asymmetry is bigger for lower $p_T$ and higher rapidity range
• The effect is enhanced for larger activity events
  - Event activity measured by forward calorimeter $4<|\eta|<5.2$
Lessons from $J/\psi$ cross-section in $p+Pb$

**CMS Preliminary** 34.6 nb$^{-1}$ (pPb 5.02 TeV)

- **Prompt $J/\psi$**
  - 6.5 < $p_T$ < 10 GeV/c
  - 10 < $p_T$ < 30 GeV/c
  - Global uncertainty: 3.5%

**Illustration** of nPDF fit
JHEP 0904 (2009) 065

- One may interpret this by nuclear shadowing effect
- But, cold nuclear matter effects are mixture of various initial and final effect. Can we concentrate on initial state effect only?
• \( J/\psi \) in UPC can do!

Cross section proportional to \((\text{gluon density})^2\)

\(\Rightarrow\) Carries information of nPDF at very low \(x\) and low \(Q^2\)

• UPC trigger
  - Muon hits
  - No activity in Ecal, Hcal
  - Neutron detection in ZDC (zero degree calorimeter)
J/ψ in UPC

- J/ψ in UPC can do!

- UPC trigger
  - Muon hits
  - No activity in Ecal, Hcal
  - Neutron detection in ZDC (zero degree calorimeter)
**J/ψ in UPC**

- **Coherent J/ψ**
  - Dominant for $p_T < 150 \text{MeV/c}$
  - Measured $p_T$ up to 1 GeV/c and fit using MC template (STARLIGHT)
Cross section compared to nPDF models

- Accompanied by ALICE data, the CMS results favors moderate nuclear shadowing models (AB-EPS09, GSZ-LTA) at low $Q^2$
Summary

- During the Run I period of LHC, CMS collaboration produced a variety of charmonium results in pp, pPb and PbPb
- **Observed suppression of J/ψ and ψ(2S) in PbPb**
  - Suppression pattern depends on $p_T$, rapidity
- **Cold Nuclear matter effect probed in pPb**
  - Significant forward-to-backward asymmetry at low $p_T$
  - Phenomena enhanced for bigger event activity
- **Measurement of coherent J/ψ in PbPb UPC**
  - Provides a constraint to nPDF models
- Please stay tuned and excited for quarkonia results from CMS Run II!
ψ(2S) to J/ψ ratio in CMS and 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)