Bottomonia results in pp, pPb and PbPb collisions at CMS

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for

CMS Collaboration
Outline

● Motivation

● CMS and Collision Systems

● Upsilon pPb result
  ○ JHEP 04 2014:103

● Upsilon PbPb results
  ○ CMS-PAS-HIN-15-001

● Current/Future Work
  ○ Run 2 @ 5.02 TeV
Motivation

- Matsui and Satz proposed suppression of J/ψ in 1986
  - Suppression attributed to color screening in heavy ion collisions
  - This can be extended to other Heavy Quark systems like the Upsilon

What are we probing?
- Hot Nuclear Matter (HNM)
  - Quark Gluon Plasma (QGP) formation
  - Quarkonia melting
    - Probe for temperature.
    - Recombination at LHC thought less than J/ψ. “clean”
- Cold Nuclear Matter (CNM)
  - nPDF modification
  - Initial state energy loss
  - Absorption …

Phys. Rev. Lett. 114, 082001
Collision Systems

Goal: Understand Quark-Gluon Plasma in PbPb collisions

- PbPb collisions
  - Probe HNM and CNM
- pp collisions
  - Baseline reference
- pPb
  - Probe CNM effects
CMS - Bottomonia

- **Acceptance:**
  - Single Muon $|\eta|<2.4$ $p_T > 4.0$ GeV/c
  - Upsilon down to $p_T = 0$ GeV/c

- **Good momentum resolution**
  - Clear separation of states

- All yields are obtained with unbinned fits to dimuon invariant mass spectrum

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**CMS pp $\sqrt{s} = 2.76$ TeV**

- $m_{\mu\mu}^h \leq 1.93$
- $p_T^\mu > 4$ GeV/c
- $L = 5.4$ pb$^{-1}$

![Graph showing dimuon invariant mass spectrum](image)

- Data
- Total fit
- Background

![PT vs. Y plot](image)

**CMS Simulation**

- PYTHIA + EvtGen + PHOTOS
- pp $\sqrt{s} = 2.76$ TeV
- $Y(1S)$
Upsilon in pPb @ $\sqrt{s_{NN}} = 5.02$ TeV

\[ m_{\mu^+\mu^-} \text{ (GeV/c}^2) \]

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CMS pp $\sqrt{s} = 2.76$ TeV

L = 5.4 pb$^{-1}$

$|\eta_{CM}| < 1.93$

$p_T^{\mu} > 4$ GeV/c

CMS pPb $\sqrt{s_{NN}} = 5.02$ TeV

L = 31 nb$^{-1}$

$|\eta_{CM}| < 1.93$

$p_T^{\mu} > 4$ GeV/c

data

total fit

background
Double Ratio:

- Relative modification of the excited state compared to nuclear modification of the ground state
- Double ratio should cancel initial state effects like shadowing

- PbPb (Black Points)
  - pp normalization from 2011 run with less statistics

- pPb still has some suppression.
  - pp normalization from 2013 run pp @ 2.76 TeV. Single ratio not dep. On √s
Single Ratios in pp and pPb

- pp and pPb dependent on multiplicity
  - Downward trend
  - Event activity in region of upsilon affects production?
  - Final state interactions in pp?

- N_{\text{tracks}} in same region as Upsilon measurement

- JHEP 04 2014:103

- CMS pp $\sqrt{s} = 2.76$ TeV
  - $\Upsilon(2S)/\Upsilon(1S)$
  - $\Upsilon(3S)/\Upsilon(1S)$

- CMS pPb $|\sqrt{s_{NN}}| = 5.02$ TeV
  - $|y_{CM}| < 1.93$
Single Ratios in pp and pPb

- Less dependence on $E_T$
  - Flatter dependence
  - $E_T$ and $N_{\text{tracks}}$ have different trends for single ratio

$E_T$ (HF) in different region as Upsilon measurement
Upsilon @ $\sqrt{s_{\text{NN}}} = 2.76$ TeV

CMS-PAS-HIN-15-001
Nuclear Modification - Centrality

\[ R_{AA} = \frac{L_{pp}}{T_{AA}} \frac{N_{PbPb}}{N_{pp}} \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}} \]

- Nuclear modification as a function of centrality
  - Suppression is largest most central

Integrated Result (0-100%):
\[ R_{AA}(Y(1S)) = 0.425 \pm 0.029 \pm 0.070 \]
\[ R_{AA}(Y(2S)) = 0.116 \pm 0.028 \pm 0.022 \]
\[ R_{AA}(Y(3S)) < 0.14 \text{ at } 95\% \text{ CL} \]

- Currently being updated and to be published soon
  - Data-driven efficiency and systematics

CMS-PAS-HIN-15-001
Nuclear Modification - $p_T$ and $|y|$ 

- Flat dependence as function of Upsilon kinematics.
- Currently being updated, to be published soon
  - Data-driven efficiency and systematics

CMS-PAS-HIN-15-001
Comparison with Predictions

Nuclear Modification as a function of Centrality

- Overlaid with thermal model from the Strickland and Bazow Model
  - Lattice based potentials
  - Sequential melting and feed down $\sim 50\%$
  - Variation in $T_0$ and $\eta/S$
  - Data indicate $539 < T_0 < 550$ MeV

- In good agreement
Comparison with Predictions

Nuclear Modification as a function of Centrality

- Overlaid with Kinetic Theory Model from Emerick, Zhao, Rapp
  - Dissociation + Regeneration
  - Fireball with $T$ evolution
    - $T_0 \sim 600$ MeV
Comparison with Predictions

Nuclear Modification as a function of $|y|$ and $p_T$
- Overlaid with thermal model from the Strickland and Bazow Model
  - In good agreement for $p_T$
  - As a function of $|y|$ data seems to falls at forward instead of rise
Upsilon Candidate - Run2
In CMS-PAS-HIN-15-001:
2013 pp data: $L_{\text{int}} = 5.4 \text{ pb}^{-1}$
2011 PbPb data: $L_{\text{int}} = 166 \mu\text{b}^{-1}$

Current work:
2015 pp: $L_{\text{int}} = 26 \text{ pb}^{-1}$
2015 PbPb data: $L_{\text{int}} = 346 \mu\text{b}^{-1}$

Have more beautiful data at higher energy!
● $R_{AA}$ measurement and Double Ratio have the same PbPb data but with differing pp samples

● Can we improve on these measurements with Run 2 data to better understand:
  ○ Double Ratio and $R_{AA}$ over centrality and more differentially?

Phys. Rev. Lett. 109, 222301
Conclusion

- CMS has extensively measured Upsilon production and nuclear modification.
  - **PbPb**
    - Suppression is dependent on event activity
    - Suppression is independent of Upsilon kinematics in $p_T$ and $|y|$
      - Rapidity dependence does not show forward rise as theory
    - Temperatures from model predictions tells us early onset temperatures
  - **pPb**
    - Final state effects present in Double Ratio.
    - Single Ratio for pp and pPb show decline vs. $N_{\text{tracks}}$

- CMS has collected a substantial amount of data in Run2.
  - Full results shall be coming soon!!!
THANK YOU!
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
- 12,500 tonnes

SILICON TRACKERS
- Pixel (100x150 μm): ~16m² ~66M channels
- Microstrips (80x180 μm): ~200m² ~9.6M channels

SUPERCONDUCTING SOLENOID
- Niobium titanium coil carrying ~18,000A

MUON CHAMBERS
- Barrel: 250 Drift Tube, 480 Resistive Plate Chambers
- Endcaps: 468 Cathode Strip, 432 Resistive Plate Chambers

PRESHOWER
- Silicon strips ~16m² ~137,000 channels

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

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

HADRON CALORIMETER (HCAL)
- Brass + Plastic scintillator ~7,000 channels
$E_T$ and $N_{\text{track}}$

doi:10.1016/j.nuclphysa.2014.06.012
Table 1: The $\sqrt{s}$ dependence of the excited-to-ground-state cross section ratios, $\frac{Y_{(nS)}}{Y_{(1S)}}$, in pp and p\bar{p} collisions. The total quoted uncertainties represent the quadratic sum of the statistical, systematic, and global uncertainties. Listed also are the $Y$ rapidity and transverse momentum ranges for which each measurement is reported.

<table>
<thead>
<tr>
<th>Data</th>
<th>$p_T$ [GeV/c]</th>
<th>Rapidity</th>
<th>$\frac{Y_{(2S)}}{Y_{(1S)}}$ total</th>
<th>$\frac{Y_{(3S)}}{Y_{(1S)}}$ total</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMS pp $\sqrt{s} = 2.76$ TeV</td>
<td>0–40</td>
<td>$</td>
<td>y</td>
<td>&lt; 1.93$</td>
</tr>
<tr>
<td>CMS pp $\sqrt{s} = 7$ TeV [33]</td>
<td>0–38</td>
<td>$</td>
<td>y</td>
<td>&lt; 2.4$</td>
</tr>
<tr>
<td>CDF p\bar{p} $\sqrt{s} = 1.9$ TeV [34]</td>
<td>1–10</td>
<td>$</td>
<td>y</td>
<td>&lt; 0.4$</td>
</tr>
</tbody>
</table>

- Consistent in 3 energies from CDF to CMS
Single Ratios

\[ \frac{\gamma(2S)}{\gamma(1S)} \]

CMS

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