Quarkonium suppression in PbPb collisions @ CMS

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On behalf of the CMS Collaboration

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the Compact Muon Solenoid detector

- 3.8T Superconducting Solenoid
- Lead tungstate E/M Calorimeter (ECAL)
- Redundant Muon System (RPCs, Drift Tubes, Cathode Strip Chambers)
- All Silicon Tracker (Pixels and Microstrips)
- Hermetic ($|\eta|<5.2$) Hadron Calorimeter (HCAL) [scintillators & brass]
the Compact Muon Solenoid detector

3.8T Superconducting Solenoid

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dimuon spectrum pp@7TeV

(update of plot shown at ICHEP’2010, here w/ full 2010 dataset)
quarkonium production pp@7TeV

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**Charmonia**

- $\Upsilon(1S)$
- $\Upsilon(2S)$
- $\Upsilon(3S)$

**Bottomonia**

- $J/\psi$
- $\psi(2S)$

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**Graphs and Data**

- CMS Preliminary, $\sqrt{s} = 7$ TeV
  - $L = 36$ pb$^{-1}$, $|y|<0.2$
  - $d^2\sigma/dp_T^\Upsilon \times B(\Upsilon \rightarrow \mu^+\mu^-)$ (nb/(GeV/c))

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**Legend**

- Total uncertainty except luminosity (4%)
- Data
- Total fit
- Background

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**Inclusive $J/\psi \rightarrow \mu^+\mu^-$, corrected for acceptance**

**Luminosity and polarization uncertainties not shown**

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**References**

- CMS-BPH-11-001
- CMS-BPH-11-001
- JHEP 02 (2012) 011
- JHEP 02 (2012) 011
dimuon spectrum @2.76TeV

CMS Preliminary
PbPb $\sqrt{s_{NN}} = 2.76$ TeV
$L_{\text{int}} = 150 \mu b^{-1}$

$J/\psi$, $\Upsilon(1,2,3S)$, $\psi(2S)$

$p_{\mu} > 4.0$ GeV/c

$10^2$ $10^3$ $10^4$

Events/(GeV/c$^2$)

$m_{\mu\mu}$ (GeV/c$^2$)

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dimuon spectrum @2.76TeV

Events/(GeV/c^2)

CMS Preliminary
pp & PbPb \( \sqrt{s_{NN}} = 2.76 \) TeV

\( L_{\text{int}} (\text{PbPb}) = 150 \text{ } \mu \text{b}^{-1} \)

\( L_{\text{int}} (\text{pp}) = 231 \text{ } \text{nb}^{-1} \)

\( J/\psi \)

\( \Upsilon(1,2,3S) \)

\( \psi' \)

\( p_T^\mu > 4.0 \text{ GeV/c} \)

\( m_{\mu\mu} (\text{GeV/c}^2) \)

PbPb @2.76TeV

PP @2.76TeV
quarkonia as probe for QGP

- one of the most striking expected characteristics of QGP formation is the suppression of quarkonium states
  - Debye color-screening of the $Q-\bar{Q}$ binding potential
  - suppression pattern $\Rightarrow$ indication of medium temperature

Matsui-Satz: screening the potential

- Screening in a deconfined medium: effective charge of $Q$ and $\bar{Q}$ reduced

<table>
<thead>
<tr>
<th>State</th>
<th>$J/\psi$ (1S)</th>
<th>$\chi_c$ (1P)</th>
<th>$\psi'$ (2S)</th>
<th>$\Upsilon$ (1S)</th>
<th>$\chi_b$ (1P)</th>
<th>$\Upsilon'$ (2S)</th>
<th>$\chi_b'$ (2P)</th>
<th>$\Upsilon''$ (3S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m$ (GeV/c²)</td>
<td>3.10</td>
<td>3.53</td>
<td>3.68</td>
<td>9.46</td>
<td>9.99</td>
<td>10.02</td>
<td>10.26</td>
<td>10.36</td>
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<tr>
<td>$r_0$ (fm)</td>
<td>0.50</td>
<td>0.72</td>
<td>0.90</td>
<td>0.28</td>
<td>0.44</td>
<td>0.56</td>
<td>0.68</td>
<td>0.78</td>
</tr>
</tbody>
</table>

PLB178, 416 (1986)

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suppression of excited $\Upsilon(nS)$ states

\[ \frac{N_{\Upsilon(2S+3S)} / N_{\Upsilon(1S)} |_{PbPb}}{N_{\Upsilon(2S+3S)} / N_{\Upsilon(1S)} |_{pp}} = 0.31^{+0.19}_{-0.15} \pm 0.03 \]

indication of 2S+3S relative suppression (significance: $2.4\sigma$, p-value 0.9%)

PRL 107 (2011) 052302
suppression of excited $\Upsilon(nS)$ states

2011 PbPb data

observation of relative suppression
(significance larger than $5\sigma$)

$\frac{\Gamma(2S)/\Gamma(1S)|_{\text{PbPb}}}{\Gamma(2S)/\Gamma(1S)|_{\text{pp}}} = 0.21 \pm 0.07 \pm 0.02$

$\frac{\Gamma(3S)/\Gamma(1S)|_{\text{PbPb}}}{\Gamma(3S)/\Gamma(1S)|_{\text{pp}}} < 0.17$ (95% C.L.)

HIN-11-011
Y(nS)/Y(1S) double ratio

- double ratio: experimentally (acceptance and efficiencies cancel out) and theoretically robust observable
- all 3 states separated
- suppression of Y(2S) relative to Y(1S) does not vary strongly with PbPb collision centrality
Absolute $\Upsilon(nS)$ suppression

- nuclear modification factor ($R_{AA}$)

$$R_{AA} = \frac{\sigma(\text{PbPb})}{\sigma(\text{pp}) \times N_{\text{coll}}}$$

- $>1$ enhancement
- $=1$ no medium effect
- $<1$ suppression

- measured for the first time for the individual $\Upsilon$ states

$$R_{AA}(\Upsilon(1S)) = 0.56 \pm 0.08 \text{ (stat.)} \pm 0.07 \text{ (syst.)}$$
$$R_{AA}(\Upsilon(2S)) = 0.12 \pm 0.04 \text{ (stat.)} \pm 0.02 \text{ (syst.)}$$
$$R_{AA}(\Upsilon(3S)) = 0.03 \pm 0.04 \text{ (stat.)} \pm 0.01 \text{ (syst.)}$$

- $< 0.10$ (95% C.L.).

- $\Upsilon$ states are suppressed sequentially: $\Upsilon(3S) \rightarrow \Upsilon(2S) \rightarrow \Upsilon(1S)$

- $\Upsilon(1S)$ not incompatible with excited state suppression only
  - considering $\sim 50\%$ excited to ground state feed-down
$R_{AA}$ vs centrality

- suppression observed to increase with the centrality of the collisions

- $\Upsilon(2S)$
  - always more suppressed than ground state
  - still suppressed in 50-100% centrality bin (which is broad)

- consistent with rapid onset of excited states suppression
  - detailed studies of onset will require very high statistics
• prompt $J/\psi$: clear suppression, with strong centrality dependence
  ‣ suppression by factor 5 in 0-10%
J/ψ suppression

• prompt J/ψ: clear suppression, with strong centrality dependence
  ‣ suppression by factor 5 in 0-10%

• comparison w/ theory
  ‣ recombination effects expected to be small at high p$_T$
**J/ψ suppression**

- **prompt J/ψ**: clear suppression, with strong centrality dependence
  - suppression by factor 5 in 0-10%
- **comparison w/ theory**
  - recombination effects expected to be small at high pt
- **comparison w/ other experiments**
- **ALICE**
  - less suppression at forward rapidity, low pt (includes b-hadron feeddown)
- **RHIC**
  - similar (PHENIX) and less (STAR) suppression observed than at LHC
excited charmonia

- carry out the measurement of the excited-to-ground state relative suppression in the charmonia as done for the bottomonia case
For $p_T > 3$ GeV/c and $1.6 < |y| < 2.4$:
Indication of $\psi(2S)$ being less suppressed than $J/\psi$,
but more pp data is needed.

$R_{AA}^{0-100\%}(\psi(2S)) = 1.54 \pm 0.32$ (stat) $\pm 0.22$ (syst) $\pm 0.76$ (pp)

For $p_T > 6.5$ GeV/c and $|y| < 1.6$:
$\psi(2S)$ are more suppressed than $J/\psi$

$R_{AA}^{0-100\%}(\psi(2S)) = 0.11 \pm 0.03$ (stat) $\pm 0.02$ (syst) $\pm 0.02$ (pp)

$R_{AA}(J/\psi) = 0.29 \pm 0.05$
summary

• first measurements of the individual $\Upsilon$ states in the heavy-ion environment

• established the relative excited-to-ground state suppression (>5σ)

• measured the quarkonium sequential melting:
  
  ‣ $\Upsilon(3S) > \Upsilon(2S), \psi(2S)^* > J/\psi^* > \Upsilon(1S)$

(*) for high-pT charmonia

• more data (pp, pPb, PbPb) will allow further studies of bottomonia & charmonia

• characterizing the medium properties, one peak at a time.
thanks!
overview recap

• CMS & Dimuon spectra

• Quarkonium production in pp
  ‣ baseline reference
  ‣ see also talks in Y(nS), χc cross sections & ratios (K. Ulmer, Tk5&7, 5/7), Y(nS) polarizations (V. Knunz, Tr6, 7/7)

• Quarkonium suppression in PbPb
  ‣ Charmonia
  ‣ Bottomonia

• Summary
botomonia comparisons

with RHIC

STAR measured $\Upsilon(1S+2S+3S)$ combined

$$R_{AA}(\Upsilon(1S + 2S + 3S)) = 0.56 \pm 0.21^{+0.08}_{-0.16}$$

compatible with CMS ($\approx 0.32$)

with models (an example)

comparison to: M. Strickland, PRL 107, 132301 (2011)

Data indicate:

$552 < T_0 < 580$ MeV, for $3 > 4\pi\eta/S > 1$
bottomonia suppression vs $N_{\text{part}}$

HIN-11-011

CMS Preliminary, PbPb $\sqrt{s_{NN}} = 2.76$ TeV

$R_{AA}$

$\gamma(1S)$

$\gamma(2S)$

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

$|y| < 2.4$

Potential Model A

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

Potential Model B

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

arXiv:1112.2761v4
charmonia

- raw yield ratio of $\psi(2S) / J/\psi$
- $p_T > 6.5$ GeV, $|y| < 1.6$
- in 0-20% PbPb $\sim 2x$ smaller than in pp
- $p_T > 3$ GeV, $1.6 < |y| < 2.4$
- in 0-20% PbPb $\sim 5x$ larger than in pp