Heavy flavor and Quarkonia in heavy-ion collisions with the CMS

To cite this article: Hyunchul Kim and the CMS Collaboration 2013 J. Phys.: Conf. Ser. 422 012015

View the article online for updates and enhancements.
Heavy flavor and Quarkonia in heavy-ion collisions with the CMS

Hyunchul Kim on behalf of the CMS Collaboration

Department of Physics, Korea University, Seoul 136-701, REPUBLIC of KOREA
E-mail: hyunchul.kim@cern.ch

Abstract.
Quarkonia are important probes for diagnosing and characterizing the quark-gluon plasma since they are produced in the early stage and propagate through the medium. The Compact Muon Solenoid (CMS) detector at the LHC is ideally suited to measure muon pairs from quarkonia in the high-multiplicity environment of nucleus-nucleus collisions. During the 2011 heavy-ion run, CMS has recorded an integrated luminosity of about $150 \, \mu b^{-1}$, which is about a factor of twenty higher compared to the 2010 heavy-ion data. With this significantly larger data sample, CMS has analyzed the nuclear modification factors of prompt $J/\psi$, non-prompt $J/\psi$ from B mesons, $\psi(2S)$ and separated three upsilon states (1S, 2S, 3S) in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

1. Introduction
A phase transition to a state of quark-gluon plasma (QGP) is predicted by lattice quantum chromodynamics at large energy densities and high temperatures. In the hot and dense medium, the binding potential of the quarkonia, which consist of heavy quark-antiquark pairs such as $c\bar{c}$ or $b\bar{b}$, is expected to be screened by the presence of deconfined color charges. The quarkonia states are then dissociated or are prevented from forming. Because the screening length depends on the temperature, the different quarkonia states that have different binding energy and radius are expected to be dissociated sequentially in the QGP. This sequential suppression is considered as one of the powerful signatures for existence of deconfined quarks and gluons [1, 2, 3, 4]. Previous SPS and RHIC results show suppression of the $J/\psi$ yield in heavy-ion collisions compared to pp collisions [5, 6, 7, 8], but several observations are yet to be understood. Despite of 10 times higher center-of-mass energy, a similar $J/\psi$ suppression is observed at SPS and RHIC, and the suppression of $J/\psi$ does not increase with local energy density. Heavy-ion collisions at the LHC can help us to resolve those puzzles, as the beam energy and luminosity are more than ten times larger than those at RHIC. Additionally, the CMS detector has excellent capabilities for muon detection and provides measurements of $\psi(2S)$ and the $\Upsilon$ family, which enables the quantitative analysis of quarkonia.

Until now the LHC has provided PbPb collisions twice at $\sqrt{s_{NN}} = 2.76$ TeV in 2010 and 2011. During the first heavy-ion run of LHC in 2010, the LHC delivered 7.28 $\mu b^{-1}$ integrated luminosity. In 2011 thanks to the significant improvement of the accelerator performance, CMS recorded about $150 \, \mu b^{-1}$. In addition, CMS collected 231 $nb^{-1}$ of pp collisions at the same center-of-mass energy and these data serve as a reference for the measurements in PbPb.
collisions.

The CMS detector, as evident by its name, Compact Muon Solenoid, is optimized for the detection of muons. The muon analysis uses the inner tracker and the muon system. The inner tracking system is located near the collision vertex, and is used to reconstruct the tracks of charged particles, including muons. The muon detectors are located outside of the superconducting solenoid magnet. In the barrel and endcap region, drift tubes and cathode strip chambers are employed for tracking respectively. Resistive plate chambers are used for muon triggering in both regions [9].

2. Results

In order to study effects due to the medium, the nuclear modification factor $R_{AA}$ is analyzed. $R_{AA}$ is defined by the ratio of the yield in nucleus-nucleus (AA) collisions to the yield in pp collisions scaled by the number of average binary nucleon-nucleon collisions:

$$R_{AA} = \frac{L_{pp}}{T_{AA} N_{MB}} \frac{N_{PbPb}(J/\psi)}{N_{pp}(J/\psi)} \frac{\epsilon_{pp}}{\epsilon_{PbPb}}$$

Here $L_{pp}$ is the integrated luminosity of the pp data set, $T_{AA}$ is the nuclear overlap function which is calculated from a Glauber model accounting for the nuclear collision geometry, $N_{MB}$ is the number of minimum-bias events sampled by the event selection, and $\epsilon_{pp}/\epsilon_{PbPb}$ is the ratio of the reconstruction efficiency in pp and PbPb collisions [10].

![Figure 1.](image)

**Figure 1.** Centrality dependence of double ratio (left) and $R_{AA}$ (right). $N_{part}$ is the number of participating nucleons determined by the Glauber model. (Left): double ratio defined as $(N_{\Upsilon(2S)}/N_{\Upsilon(1S)})_{PbPb}/(N_{\Upsilon(2S)}/N_{\Upsilon(1S)})_{pp}$ versus $N_{part}$. The global uncertainty was represented by a grey box. (Right): $R_{AA}$ of $\Upsilon(1S)$ (green diamonds) and $\Upsilon(2S)$ (blue circles) as a function of $N_{part}$. The uncertainties of 14% for $\Upsilon(1S)$ and 21% for $\Upsilon(2S)$ from luminosity, pp yields and efficiency are represented by the boxes at unity and are not included in the data points [12].

Using the first heavy-ion data at LHC for bottomonia analysis, the double ratio of bottomonia yields measured in PbPb and in pp collisions $(N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)})_{PbPb}/(N_{\Upsilon(2S+3S)}/N_{\Upsilon(1S)})_{pp}$ was estimated to be 0.31 with significance of 2.4 sigma [11]. With the large data sample of heavy-ion data taken in 2011, the $\Upsilon(2S)$ and $\Upsilon(3S)$ states were separated clearly, which enabled us to estimate the double ratio for these two states individually. The left panel of Fig. 1 shows the centrality dependence of the double ratio for the $\Upsilon(2S)$: the centrality integrated double ratio is 0.21 and no strong centrality dependence is observed. For the $\Upsilon(3S)$ because no clear peak can
be identified in PbPb collisions, only an upper limit of the double ratio could be estimated as 0.1 with 95% confidence level.

In the right panel of Fig. 1, the centrality dependences of $R_{AA}$ for the $\Upsilon(1S)$ and $\Upsilon(2S)$ states are displayed. The centrality-integrated (0 - 100%) $R_{AA}$ values for each $\Upsilon$ states are $R_{AA}[\Upsilon(1S)] = 0.56 \pm 0.08$ (stat.) $\pm 0.07$ (syst.), $R_{AA}[\Upsilon(2S)] = 0.12 \pm 0.04$ (stat.) $\pm 0.02$ (syst.) and $R_{AA}[\Upsilon(3S)] = 0.03 \pm 0.04$ (stat.) $\pm 0.01$ (syst.). The $R_{AA}$ result for the $\Upsilon(3S)$ state is consistent with the upper limit of 0.1 for the double ratio at 95% confidence level. Assuming about 50% of $\Upsilon(1S)$ originate in the decay of excited states such as $\Upsilon(2S)$ and $\chi_b$, the current result implies the dissociation of only the excited states, not $\Upsilon(1S)$.

Figure 2. Centrality dependence of $R_{AA}$ for prompt and non-prompt $J/\psi$. The grey box at $R_{AA} = 1$ represents the global scale uncertainty from the pp data sample. (Left) : Prompt (red squares) and non-prompt (orange stars) $J/\psi$ measured by CMS. (Right) : The detailed centrality dependence of $R_{AA}$ for prompt $J/\psi$ compared with the low energy results at 200 GeV obtained by STAR (green stars) [13, 14].

For charmonia analysis, the prompt $J/\psi$ and non-prompt $J/\psi$ from B-meson decay can be separated by using the two-dimensional simultaneous fit of $\mu^+\mu^-$ mass and pseudo-proper decay length which is proportional to the distance between the primary and secondary vertices of $J/\psi$ [13].

The $R_{AA}$ values of prompt and non-prompt $J/\psi$ in measured in the transverse momentum range $6.5 < p_T < 30$ GeV/$c$ and in the rapidity interval $|y| < 2.4$ are compared in the left panel of Fig. 2. The results hint the quenching of high-$p_T$ b quarks for the first time [13]. The right panel of Fig. 2 shows the centrality dependence of $R_{AA}$ for prompt $J/\psi$ in more detail. In the most central collisions 0 – 10% prompt $J/\psi$ are suppressed by a factor of 5 with respect to the pp reference, and in the most peripheral collisions 50 – 100% they are suppressed by a factor of about 1.6. The right panel of Fig. 2 also shows the $R_{AA}$ of prompt $J/\psi$ measured by STAR for $p_T > 5$ GeV/$c$ in AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV. This comparison clearly demonstrates more suppression at LHC than at RHIC [14].

Thanks to the improved statistics in 2011 heavy-ion data, the analysis of $\psi(2S)$ became possible. The double ratio of the yields of $\psi(2S)$ to those of $J/\psi$ measured in PbPb and in pp collisions ($N_{\psi(2S)}/N_{J/\psi})_{PbPb}/(N_{\psi(2S)}/N_{J/\psi})_{pp}$ are analyzed in both low $p_T$ ($p_T > 3$ GeV/$c$ and $1.6 < |y| < 2.4$) and high $p_T$ ($p_T > 6.5$ GeV/$c$ and $|y| < 1.6$) and shown in Fig. 3. In the low $p_T$ region, $\psi(2S)$ is less suppressed than $J/\psi$ with large uncertainties that are dominated by the limited statistics in the pp collision sample. In the high $p_T$ region, $\psi(2S)$ is more suppressed than $J/\psi$. From the above double ratio the $R_{AA}$ of $\psi(2S)$ were
Figure 3. Centrality dependence of double ratio \((N_{\psi(2S)}/N_{J/\psi})_{\text{PbPb}}/(N_{\psi(2S)}/N_{J/\psi})_{\text{pp}}\). Grey area is global pp uncertainty. (Left) : double ratio in a low \(p_T\) region, \(3 < p_T < 30 \text{ GeV/c}\) and \(1.6 < |y| < 2.4\) (Right) : double ratio in a high \(p_T\) region, \(6.5 < p_T < 30 \text{ GeV/c}\) and \(|y| < 1.6\)

estimated as \(1.54 \pm 0.32\) (stat.) \(\pm 0.22\) (syst.) \(\pm 0.76\) (pp) in the low \(p_T\) region, and \(0.11 \pm 0.03\) (stat.) \(\pm 0.02\) (syst.) \(\pm 0.02\) (pp) in the high \(p_T\) region [15].

3. Summary
With improved statistics of 2011 heavy-ion data, CMS measured the \(\Upsilon(2S)\) suppression for the first time and set the upper limit on \(\Upsilon(3S)\) production using a double ratio of the yield with respect to the \(\Upsilon(1S)\) state measured in PbPb and in pp collisions. The nuclear modification factors \(R_{\text{AA}}\) for \(\Upsilon(1S), \Upsilon(2S)\) and \(\Upsilon(3S)\) show suppression by factors of about 2, 8 and larger than 10. These measurements imply the dissociation of the excited states in the Upsilon family, but not the \(\Upsilon(1S)\) state. The \(\psi(2S)\) are more suppressed than \(J/\psi\) in the high \(p_T\) region, but less suppressed in the low \(p_T\) region. Future precise measurements in pp collisions are required to draw a definite conclusion in the low \(p_T\) region.

4. Acknowledgements
This work was supported in part by the National Research Foundation of Korea under grant No. K20802011718-11B1301-00610.

References
[1] T.Matsui and H.Satz 1986 Phys. Lett. B 178 416
[2] H.Satz 2007 Nucl. Phys A 783 249
[3] H.Satz 2006 J. Phys. G 32 R25
[4] A.Mocsy 2009 Eur. Phys. J. C 61 705
[5] NA50 Collaboration 2005 Eur. Phys. J. C 39 335
[6] NA60 Collaboration 2007 Phys. Rev. Lett. 99 132302
[7] NA38 Collaboration 1999 Phys. Lett. B 449 128
[8] PHENIX Collaboration 2011 Phys. Rev. C 84 054912
[9] CMS Collaboration 2008 JINST 3 S08004
[10] B. Alver et al. 2008 Phys. Rev. C 77 014906
[11] CMS Collaboration 2011 Phys. Rev. Lett. 107 052302
[12] CMS Collaboration 2012 accepted by Phys. Rev. Lett. arXiv : 1208.2826
[13] CMS Collaboration 2012 JHEP 1205 063
[14] STAR Collaboration 2011 J. Phys. G 38 124007
[15] CMS Collaboration 2012 CMS-PAS-HIN-12-007