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Measurements of bottomonium production in pp and PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV

Geonhee Oh, on behalf of the CMS Collaboration∗
Department of Physics, Chonnam National University, Gwangju, South Korea
E-mail: geonhee.oh@cern.ch

Bottomonia are important probes of the Quark-Gluon Plasma (QGP) since they are produced at early times and propagate through the medium. The production cross sections of the three Υ states (1S, 2S, 3S) were measured by CMS in pp and PbPb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV . The nuclear modification factors, R_{AA}, derived from the PbPb to pp ratio of yields for each state, are studied as functions of meson rapidity between 0 to 2.4 and transverse momentum p_{T} spanning from 0 to 30 GeV$/c$, as well as PbPb collision centrality 0 to 100%. A strong suppression of R_{AA} is observed in PbPb collisions but the Υ(3S) was not observed clearly in PbPb collisions. The upper limit on the R_{AA} of Υ(3S) integrated over p_{T}, rapidity and centrality is 0.096 at 95% confidence level, which is the strongest suppression observed for a quarkonium state in heavy-ion collisions to date. The suppression of Υ(1S) is larger than that seen at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV, although the two are still compatible within uncertainties.

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∗Speaker.

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1. Introduction

The measurement of quarkonia in heavy-ion collisions is one of the most promising ways of studying the properties of the Quark-Gluon Plasma (QGP). The bottomonium states are expected to be produced early after the collision, and their production rates can be modified by the surrounding medium [1, 2]. Lattice QCD calculations predict that at the temperatures achieved at the LHC, the bottomonium spectral functions will suffer modifications due to the presence of strong color fields that act over the full volume of the collision, in contrast to our low-energy world where these fields are confined inside the volume of a single hadron. Therefore, bottomonium suppression are expected to be sensitive to deconfinement itself, as well as to the temperatures reached in the collision. Furthermore, the relatively small $b\bar{b}$ production cross section implies an expected very small bottomonium production from the statistical recombination process. This latter effect is invoked to address the observation that suppression of charmonium is larger at RHIC energies compared to LHC. The studies of bottomonium are therefore expected to present a fruitful test of the hypothesis of color deconfinement with additional obfuscating effects. The modification of Υ production is quantified by the ratio of yields in PbPb and pp at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV [3] scaled by the number of binary nucleon-nucleon collisions. The dependence of R_{AA} on the transverse momentum (p_{T}), rapidity and collision centrality is also studied for each Υ state.

2. Data selection and signal extraction

In both pp and PbPb collisions, the dimuon events are selected by a fast hardware-based trigger system, which requires two muon candidates in a given bunch crossing with no explicit requirement on the muon momentum beyond the intrinsic selection due to the acceptance coverage of the CMS muon detectors [4]. In pp collisions, this trigger registered an integral luminosity of 28.0 pb^{-1}. The PbPb data were taken with two triggers based on the same algorithm used for pp data. The first mode, designed to enhance the event count for muon pairs from peripheral events, added an additional selection that the collision centrality is in the 30–100% range. This trigger sampled the full integrated luminosity of 464 $\mu\mathrm{b}^{-1}$. The second mode, using just the pp trigger alone, was prescaled during part of the data taking and therefore sampled a smaller effective integrated luminosity of 368 $\mu\mathrm{b}^{-1}$. Data taken with this latter trigger were used to analyze the yields in the 0–30% and 0–100% centrality bins. For this analysis, Υ mesons are reconstructed in the dimuon decay channels with p_{T} range from 0 to 30 GeV$/c$ and full rapidity range in the CMS.

The invariant mass distribution of Υ mesons are shown Figure. 1. In pp collisions (left), the three Υ mesons are separated clearly, while in PbPb collisions (right), a large suppression is found for all Υ states, the Υ(3S) being the most suppressed.

3. Results

The nuclear modification factor is derived from the pp cross sections and PbPb normalized yields as

$$R_{\mathrm{AA}}(p_{\mathrm{T}},y) = \frac{\mathrm{N}^{AA}(p_{\mathrm{T}},y)}{\langle T_{AA}\rangle \sigma^{pp}(p_{\mathrm{T}},y)} \tag{3.1}$$

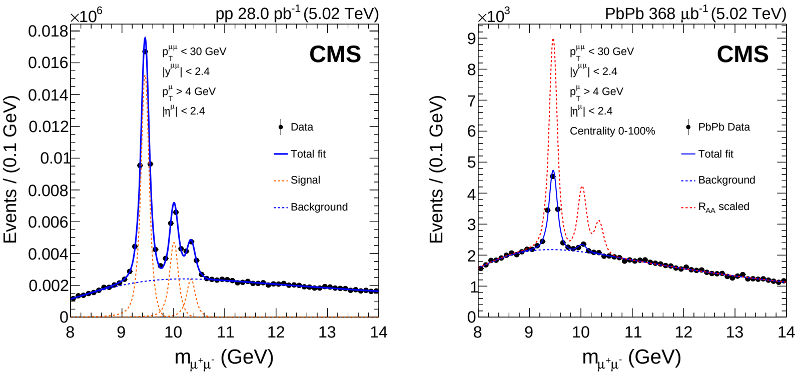

Figure 1: Invariant mass distribution of muon pairs in pp (left) and PbPb (right) collisions, for the kinematic range $p_{\mathrm{T}} < 30$ GeV$/c$ and |y| < 2.4 [3]. In both figures, the results of the fits to the data are shown as solid blue lines. The separate yields for each ϒ state in pp are shown as dashed red lines in the left panel. The dashed red lines in the right panel are derived from the fits to PbPb (blue solid line). In order to show the suppression of all three ϒ states, the amplitudes of the corresponding peaks are increased above those found in the fit by the inverse of the measured R_{AA} for the corresponding ϒ meson.

where $\langle T_{AA} \rangle$ is the average nuclear overlap function (T_{AA}), which is calculated with a Glauber model MC simulation [5, 6] in each centrality bin. The quantities N^{AA} and σ^{pp} refer to the normalized yield of ϒ mesons in PbPb collisions corrected by acceptance and efficiency, and the pp cross section for a given kinematic range, respectively. The nuclear modification factors are shown for the ϒ(1S), ϒ(2S) and ϒ(3S) mesons as a function of centrality, rapidity and transverse momentum in Figures. 2- 4.

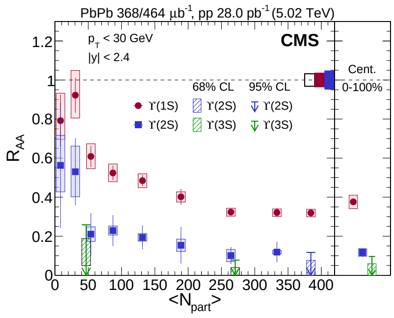

Figure 2: Nuclear modification factors for the ϒ(1S), ϒ(2S) and ϒ(3S) mesons as a function of <N$_{\mathrm{part}}$> [3]. The boxes at the dashed line at unity represent global uncertainties of the integrated luminosity in pp and N_{MB} in PbPb collisions for $p_{\mathrm{T}} < 30$ GeV$/c$ the open box for the integrated luminosity in pp collisions and the closed box for the N_{MB} in PbPb collisions, while the full boxes show the uncertainties of pp yields for ϒ(1S) and ϒ(3S) states (with the larger box corresponding to the excited state). For the ϒ(3S) meson, the upper limits at 68% (green box) and 95% (green arrow) CL are shown.

Figure. 2 shows the dependence of R_{AA} on PbPb collision centrality, as quantifies using the average <N$_{\mathrm{part}}$>. The strong suppression of the ϒ(3S) meson is observed in both centrality bins studied, 0-30% and 30-100%. R_{AA} decreases with increasing centrality in the case of the ϒ(1S) and ϒ(2S) mesons.

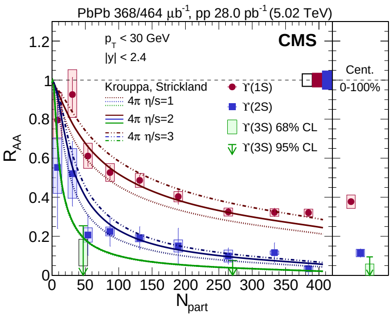

Figure 3: Nuclear modification factors for the ϒ mesons as a function of <N_{part}> [3] with Krouppa and Strickland [7] (left), and Du, He, and Rapp [8] (right).

Figure. 3 shows comparisons between the measured R_{AA} for ϒ mesons and two models of bottomonium suppression from Krouppa and Strickland [7] (left), and from Du, He and Rapp [8] (right). Those models are calculated with different melting temperatures, initial temperatures of the medium and different phenomena included. No regeneration in QGP or cold nuclear matter effects are considered by the first model [7], but included in the second [8]. However, the models describe the data similarly well.

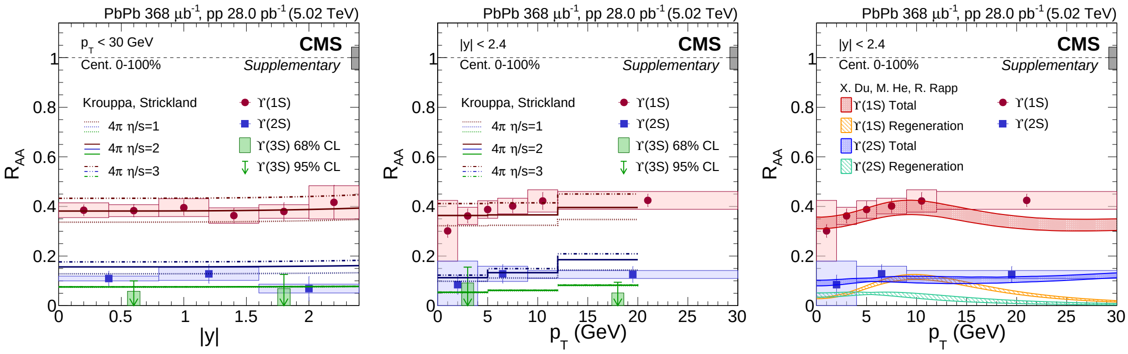

Figure 4: Nuclear modification factors for the ϒ mesons as a function of y (left) [3] with Krouppa and Strickland [7] and as a function of transverse momentum p_{T} [3] with Krouppa and Strickland [7] (center), and Du, He, and Rapp [8] (right).

Figure. 4 shows nuclear modification factor as functions of rapidity and transverse momentum. Within the systematic uncertainties, the R_{AA} values show no clear dependence on y or p_{T}. The excited ϒ states are found to have larger suppression than the ground state, with $R_{\text{AA}} < 0.2$ over the full kinematic range explored here. The kinematic dependence of R_{AA} is useful to constrain models of ϒ meson suppression in a deconfined medium. The model shown in Figure. 4 (center) expects a slight increase of the Raa at high p_{T}, while the one shown on the right includes regeneration and predicts a stronger p_{T} dependence for ϒ(1S) than for ϒ(2S).

Figure. 5 compares centrality-integrated R_{AA} values at $\sqrt{s_{\text{NN}}} = 2.76$ TeV to those at 5.02 TeV. The centrality-integrated R_{AA} for ϒ(1S) is measured to be 0.376 ± 0.013(stat) ± 0.035(syst), to be compared with the result at 2.76 TeV, 0.453 ± 0.014(stat) ± 0.046(syst) [9]. The suppression at 5.02 TeV is larger by a factor of ∼ 1.20 ± 0.15 (in which only the T_{AA} uncertainty was considered correlated and therefore removed), although the two R_{AA} values are compatible within the uncertainties. The centrality-integrated results for the ϒ(2S) and ϒ(3S) states at 5.02 TeV are $R_{\mathrm{AA}}(\Upsilon(2S)) = 0.117 \pm 0.022$ (stat) $\pm$ 0.019 (syst) and $R_{\mathrm{AA}}(\Upsilon(3S)) = 0.022 \pm 0.038$ (stat) $\pm$ 0.016 (syst) (<0.096 at 95% CL) [9].

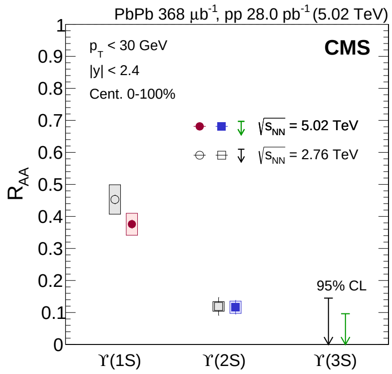

Figure 5: Comparison of R_{AA} values for the ϒ(1S), ϒ(2S) and ϒ(3S) mesons at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV [3] and $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV [9] for integrated centrality in the full kinematic range. The error bars represent the statistical uncertainties and the boxes the systematic uncertainties, including global uncertainties.

4. Summary

The data collected by the CMS detector in pp and PbPb collisions at $\sqrt{s_{\mathrm{NN}}}$ = 5.02 TeV are used to investigate the nuclear modification factors of ϒ mesons as functions of transverse momentum and rapidity, as well as PbPb collision centrality. A gradual decrease in R_{AA} with $\langle N_{\mathrm{part}} \rangle$ for the ϒ(1S) and ϒ(2S) states is observed, while no significant dependence on p_{T} or y is found in the measured region. The suppression of ϒ(1S) is larger than that seen at $\sqrt{s_{\mathrm{NN}}}$ = 2.76 TeV, although the two are still compatible within uncertainties. The R_{AA} of the ϒ(3S) state is measured to be below 0.096 at 95% confidence level, making this the strongest suppression observed for a quarkonium state in heavy-ion collisions to date.

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