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Quarkonia measurements by the CMS experiment in PbPb collisions

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Quarkonia have been studied in different collision system and energy in order to understand the effects of the hot and dense medium created in heavy-ion collisions. CMS is well suited to measure quarkonia decays to muons given the muon identification and charged particle tracking capability. The J/ψ and Υ production in PbPb at $\sqrt{s_{NN}} = 2.76$ TeV and pp collisions at the same per nucleon energy are compared. Prompt and non-prompt J/ψ contributions are separated for the first time in heavy-ion collisions, as is the ground from the excited states in the Υ family. CMS observed a suppression in PbPb compared to pp at $\sqrt{s_{NN}} = 2.76$ TeV for $B \to J/\psi$, prompt J/ψ, and Υ(1S), as well as the relative suppression of Υ(2S+3S) compared to Υ(1S).

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1. Introduction

Quarkonia are especially relevant for studying the quark gluon plasma (QGP) since they are produced at early times and propagate through the medium mapping its evolution. In particular, J/ψ in heavy-ion collisions was suggested to be a promising probe as the deconfined medium should screen the two quarks leading to a suppression of its production[1]. It has been studied at different energies and with different collision systems without yet giving a fully understood global picture [2, 3, 4, 5]. Measuring the charmonium production at the LHC energies in PbPb collisions will help understand the QGP, constraining predictions which can include large recombination probability for prompt J/ψs caused by the abundance of charm quarks in the medium at LHC energies [6], or nuclear matter effects such as shadowing for example. In addition to charmonium precision studies, the LHC center-of-mass energy allows copious Υ production in PbPb collisions. Detailed measurements of bottomonia will complement the measurements accessible at RHIC energies. The full spectroscopy of quarkonium states has been suggested as a possible thermometer for the QGP [7].

2. Experimental setup

This paper reviews CMS J/ψ and Υ measurements based on the LHC first year PbPb data. Quarkonia are identified through their dimuon decay. The silicon pixel and strip trackers measure charged-particle trajectories for the range $|\eta| < 2.5$. The tracker consists of 66M pixel and 10M strip detector channels, providing a vertex resolution of $\sim 15\ \mu$m in the transverse plane. A detailed description of the CMS detector can be found in [10]. Muons are detected for the $|\eta| < 2.4$ range, with detection planes based on three technologies: drift tubes, cathode strip chambers, and resistive plate chambers. Due to the strong magnetic field and the fine granularity of the silicon tracker, the muon transverse momentum measurement based on information from the silicon tracker alone has a resolution between 1 and 2% for a typical muon in this analysis. CMS is therefore very well suited to measure dimuons. The resolution obtained measuring J/ψ in $|y| < 2.4$ is 34 MeV/c^2 using the dedicated algorithm to deal with PbPb high occupancy.

In March 2011, CMS recorded a little more than $\mathscr{L}_{\rm int} = 220\ {\rm nb}^{-1}$ pp events at $\sqrt{s} = 2.76$ TeV. This data is used as a reference for the PbPb measurement. In November 2010, CMS recorded $\mathscr{L}_{\rm int} = 7.28\ \mu b^{-1}$ of PbPb events, leading to about the same amount of quarkonia statistics as the reference pp run at 2.76 TeV. Both data sets have been analyzed following similar conditions [8, 9]: (1) events are selected by the CMS two-level trigger keeping any dimuon activity in the muon chambers, (2) offline muon reconstruction is seeded with $\simeq 99\%$ efficient tracks in the muon detectors, which are then matched to tracks reconstructed in the silicon tracker by means of an algorithm optimized for the heavy-ion environment [11, 12], (3) the same analysis procedure is followed for the offline selection with very loose criteria. Signal extraction is based on the procedures in CMS 7 TeV publications for the signal extraction [13, 14].

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3. Quarkonia production

3.1 PbPb run

Using both data sets, the production measured in PbPb collisions is compared to expectations from an independent superposition of nucleon-nucleon collisions typically expressed in terms of the nuclear modification factor:

$$R_{AA} = \frac{\mathscr{L}_{pp}}{T_{AA} N_{\rm MB}} \frac{N_{\rm PbPb}(\mathbf{Q\overline{Q}})}{N_{pp}(\mathbf{Q\overline{Q}})} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{\rm PbPb}}. \tag{3.1}$$

Here T_{AA} is the nuclear overlap function[1], $\mathscr{L}_{pp}$ is the pp luminosity, $N_{\rm MB}$ is the measured number of equivalent minimum bias events in PbPb, $\frac{N_{\rm PbPb}(\mathbf{Q\overline{Q}})}{N_{pp}(\mathbf{Q\overline{Q}})}$ is the raw yield ratio, and $\frac{\varepsilon_{pp}}{\varepsilon_{\rm PbPb}}$ the multiplicity dependent fraction of the efficiency ($\frac{\varepsilon_{pp}}{\varepsilon_{\rm PbPb}} \sim 1.17$ for the most central bin).

Trigger, reconstruction and selection efficiencies of muon pairs are estimated using quarkonia PYTHIA signal embedded in heavy-ion PbPb events generated by HYDJET [17]. These events were processed through the trigger emulation and event reconstruction chain. The final efficiency corrections correspond to the fraction of reconstructed signal passing all the analysis selections with respect to the generated signal.

3.1.1 B→ J/ψ

J/ψs can be classified into two types depending on whether they come from the primary vertex (prompt J/ψs) or are produced from decays of B mesons (non-prompt J/ψs). Prompt J/ψs group direct J/ψ production and J/ψs coming from the feed-down of higher states such as ψ' and χ_c. Non-prompt J/ψs are produced at a distance L_{xy} from the primary vertex and can therefore be separated from the prompt contribution if the resolution of the detector is good enough. This is done in CMS by reconstructing the $\mu^+\mu^-$ vertices and making a 2-dimensional simultaneous fit of the invariant mass distribution and the pseudo-proper decay length, $l_{J/\psi} = L_{xy}\frac{m_{J/\psi}}{p_T}$. The CMS detector performs very well in the heavy-ion environment such that the good momentum resolution can be used to separate non-prompt from prompt J/ψ as in pp, making use of the distance between the non-prompt vertex and the primary vertex. For more details see [8].

For the first time, secondary J/ψ R_{AA} is measured in heavy-ion collisions. Fig. 1 (left) illustrates B-meson strong suppression through their J/ψ decays through the R_{AA} as a function of N_{part}: $R_{AA} = 0.37\pm0.07(\text{stat})\pm0.03(\text{syst})$ in the 20% most central collisions. This could be a hint of b-quark energy loss. The level of suppression is of the same order of magnitude as charged hadrons as observed on Fig. 1 (right) where the non-prompt J/ψ R_{AA} is plotted as a function of $p_{\rm T}$ for 0–20% while the bosons and charged hadrons are presented as a function of the transverse mass for 0–10% [18].

3.1.2 Prompt J/ψ

Figure 2 shows the prompt J/ψ R_{AA} (filled squares) as a function of $p_{\rm T}$, y and N_{part}. A factor of three suppression is observed for the two $p_{\rm T}$ bin. CMS points are compared to measurements at

[1] Ratio of the number of binary nucleon-nucleon collisions N_{coll} calculated from a Glauber model of the nuclear collision geometry [15, 16] and the inelastic nucleon-nucleon cross section $\sigma^{NN}_{inel} = (64\pm5)$ mb at $\sqrt{s} = 2.76$ TeV

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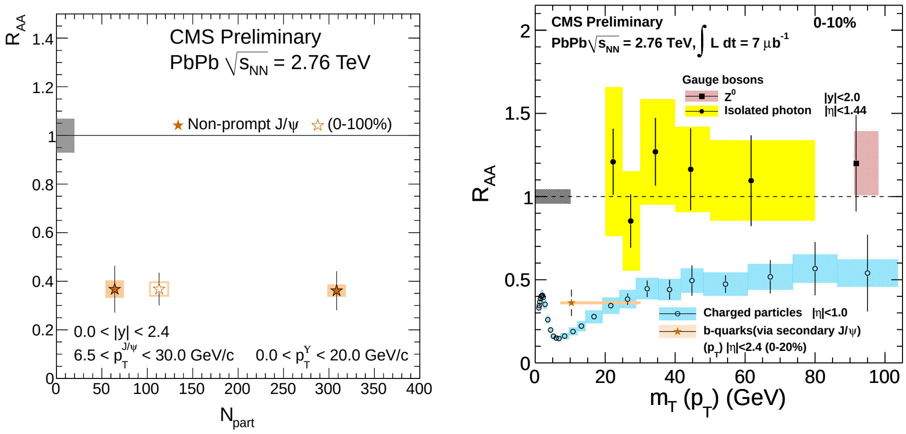

Figure 1: Left: Non-prompt J/ψ R_{AA} in three centrality bin 0–20% and 20–100% in closed symbols and 0–100% in open symbols. Right: R_{AA} vs. m_T for Z (squares), isolated photons (closed circles) and charged hadrons (open circles) compared to the secondary J/ψ measurement as a function of $p_{\rm T}$ (stars).

$\sqrt{s_{NN}} = 200$ GeV from PHENIX [19] at mid- (open squares) and forward (open circles) rapidity for lower $p_{\rm T}$s, and from STAR [20] up to $p_{\rm T} = 8$ GeV/c^2. The tendency of high $p_{\rm T}$ J/ψ's to survive at RHIC is not seen at the LHC. Furthermore, CMS measures less suppression at forward rapidity for high $p_{\rm T}$ J/ψ. One should remember that the x probed with $\langle p_{\rm T}^{J/\psi} \rangle = 10$ GeV/c by CMS over $|y| < 2.4$ are $x_1 \sim 0.02$ and $x_2 \sim 5 \cdot 10^{-4}$. Therefore, anti-shadowing could play a role in the suppression observed and could contribute to seeing an opposite trend than PHENIX as a function of y, or an increase of the R_{AA} when going to low $p_{\rm T}$ and more forward regions as with ALICE measurements [21], which on the other hand should be more sensitive to recombination scenario. For $p_T > 3$ GeV/c and $1.6 < y < 2.4$, CMS measures $R_{AA} = 0.39 \pm 0.06(\text{stat.}) \pm 0.03(\text{syst.})$. Finally, in the 10% most central collisions, CMS observes a factor five suppression, much greater than measured by STAR.

3.2 Υ

CMS is able to disentangle the $\Upsilon(1\text{S})$ contribution from the higher states in PbPb as in pp collisions. Fig. 3 compares the Υ invariant mass distribution at $\sqrt{s} = 2.76$ TeV in pp (left) and PbPb (right) collisions, for $p_{\rm T}^{\mu} > 4$ GeV/c. The higher state contribution relative to the ground state is strikingly smaller in PbPb collisions. In order to quantify this suppression, an extended unbinned maximum likelihood simultaneous fit to the pp and PbPb mass spectra is performed, following the method described in [9], using the parameters detailed in [8]. The ratio of $\Upsilon(2S+3S)/\Upsilon(1S)$ in PbPb and pp benefits from an almost complete cancellation of possible acceptance and/or efficiency differences among the reconstructed resonances. The double ratio obtained is

$$\frac{\Upsilon(2S+3S)/\Upsilon(1S)|_{\text{PbPb}}}{\Upsilon(2S+3S)/\Upsilon(1S)|_{pp}} = 0.31^{+0.19}_{-0.15}\,(\text{stat.}) \pm 0.03\,(\text{syst.}), \tag{3.2}$$

[2]PHENIX and STAR measurements are inclusive measurements but the contamination from secondary J/ψ is expected to be small at RHIC energies.

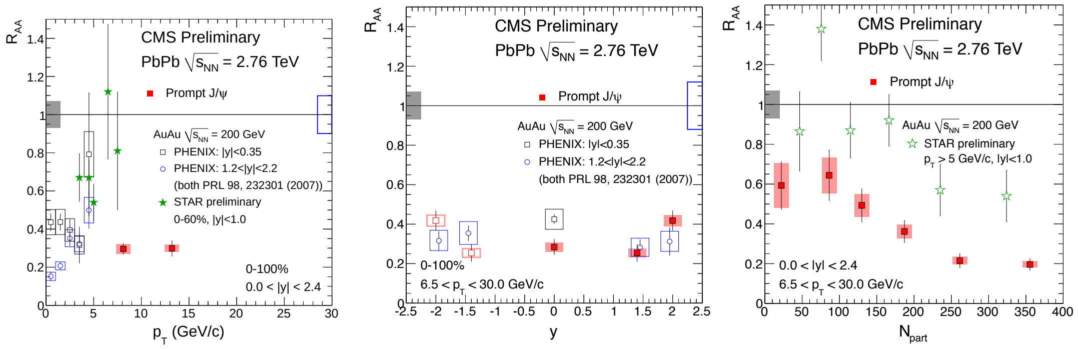

Figure 2: CMS prompt J/ψ R_{AA} measurement (filled squares) compared to PHENIX mid (open squares) and forward (open circles) rapidity measurement and STAR higher p_T measurement (stars) as a function of p_T (left), y (center), and N_{part} (right).

where the systematic uncertainty (9%) arises from varying the lineshape in the simultaneous fit, thus taking into account partial cancellations of systematic effects. Finally, using an ensemble of one million pseudo-experiments generated with the signal lineshape obtained from the pp data, Fig. 3 (left), the background lineshapes from both data sets, and a double ratio (Eq. 3.2) equal to unity within statistical and systematic uncertainties (absence of a suppression), the probability of finding the measured value of 0.31 or a downward fluctuation is estimated to be 0.9%., corresponding to 2.4 sigma in a one-tailed integral of a Gaussian distribution.

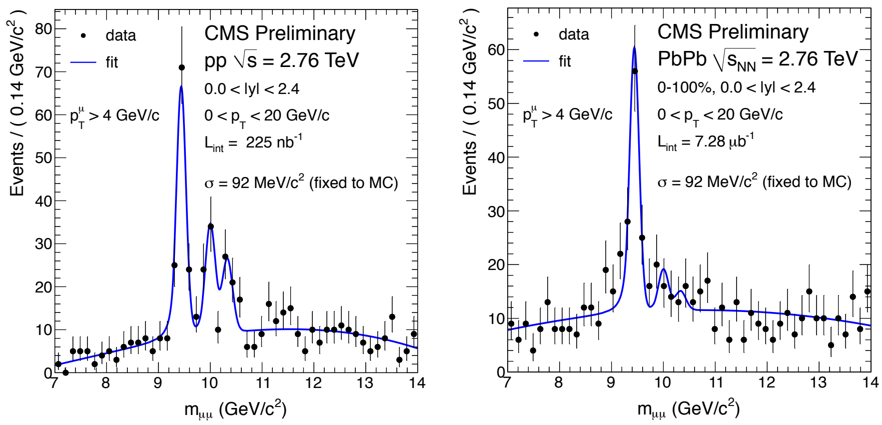

Figure 3: Invariant mass distribution in pp (left) and PbPb (right) collisions at 2.76 TeV for $p_T^{\mu} > 4$ GeV/c.

The Υ(1S) suppression has a been studied as a function of p_T, y and centrality as shown on Fig. 4. A suppression by a factor ~ 2.3 is observed for low p_T. This seems to disappear for $p_T >$ 6.5 GeV/c. The rapidity dependence indicates a slightly smaller suppression at forward rapidity. In both cases however, the statistical uncertainties are too large for any strong conclusions. In addition, Υ(1S) are suppressed by a factor two in 0–10% central collisions. The CMS measurement over the whole centrality range, R_{AA}(0-100) $= 0.62 \pm 0.11$(stat.)± 0.10(syst.), is compared to STAR Υ(1+2+3S) preliminary result in AuAu collisions at $\sqrt{s_{NN}} = 200$ GeV [22] showing a suppression of the same order of magnitude but with large uncertainty.

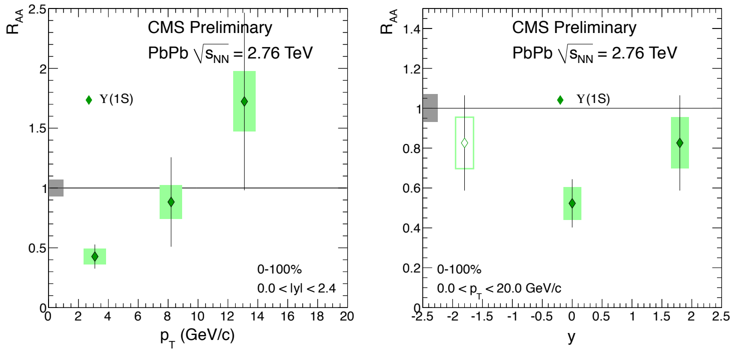

Figure 4: Υ(1S) R_{AA} as a function of p_T (left), y (middle), and N_{part} (right), compared to STAR inclusive preliminary measurement (stars) for the latter.

4. Conclusion

In summary, CMS has quantified the suppression of non-prompt and prompt J/ψ, as well as of the Υ(1S) and Υ(2S+3S) mesons via their decay into $\mu^+\mu^-$ pairs in PbPb relative pp collisions at 2.76 TeV. Prompt J/ψ has been separated from non-prompt J/ψ for the first time in heavy-ion collisions. Non-prompt J/ψ, though strongly suppressed, show no strong centrality dependence within uncertainties. This is the first hint of b-quark energy loss in the hot medium. A strong suppression of prompt J/ψ with $p_T > 6.5$ GeV/c is measured in central collisions, and already in peripheral collisions, showing a clear dependence with centrality. Furthermore, Υ(1S) are suppressed by 40% in the 20% most central collisions. The comparison of the ratios of Υ(nS)-states in pp and PbPb collisions, taken at the same center-of-mass energy, is consistent with the partial disappearance of the higher states with respect to the ground state in the PbPb collisions. Those two observations could indicate that the Υ(1S) suppression is due to the melting of the excited states only in PbPb collisions. Measuring the amount of suppression caused by shadowing through pA collisions together with more precise measurements will be crucial for interpreting quarkonia suppression.

References

[1] T. Matsui and H. Satz, *Phys. Lett.* **B178** (1986) 416, doi:10.1016/0370-2693(86)91404-8.

[2] NA38 Collaboration, *Phys. Lett.* **B345** (1995) 617, doi:10.1016/0370-2693(94)01614-I.

[3] NA50 Collaboration, *Eur. Phys. J.* **C49** (2007) 559, arXiv:nucl-ex/0612013.

[4] NA60 Collaboration, *Phys. Rev. Lett.* **99** (2007) 132302, doi:PhysRevLett.99.132302.

[5] PHENIX Collaboration, arXiv:nucl-ex/1103.6269.

[6] X. Zhao, R. Rapp, arXiv:1102.2194.

[7] C. Miao *et. al.*, *Nucl. Phys.* **A855** (2011) 125, doi:10.1016/j.nuclphysa.2011.02.028.

[8] CMS Collaboration, *CMS Physics Analysis Summary* **CMS-PAS-HIN-10-006** (2011).

[9] CMS Collaboration, arXiv:nucl-ex/1105.4894.

[10] CMS Collaboration, *JINST* **0803** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[11] C. Roland, for the CMS Collaboration, *NIM* **A566** (2006) 123, doi:j.nima.2006.05.023.

[12] CMS Collaboration, *J. Phys.* **G34** (2007) 2307, doi:10.1088/0954-3899/34/11/008.

[13] CMS Collaboration, *Eur. Phys. J.* **C71** (2011) 1575, doi:10.1140/epjc/s10052-011-1575-8.

[14] CMS Collaboration, *Accepted by PRD*, arXiv:hep-ex/1012.5545.

[15] CMS Collaboration. arXiv:nucl-ex/1102.1957.

[16] B. Alver *et. al.*, *Phys. Rev.* **C77** (2008) 014906, doi:10.1103/PhysRevC.77.014906.

[17] I. P. Lokhtin *et. al.*, *Eur. Phys. J.* **C45** (2006) 211–217, doi:10.1140/epjc/s2005-02426-3.

[18] Y-J. Lee, for the CMS Collaboration, *J. Phys.* **G38** (2011) 124015, doi:10.1088/0954-3899/38/12/124015.

[19] PHENIX Collaboration, *Phys. Rev. Lett.* **98** (2007) 232301, doi:10.1103/PRL.98.232301.

[20] Z. Tang, for the STAR Collaboration, *J. Phys.* **G38** (2011) 124107, doi:10.1088/0954-3899/38/12/124107.

[21] P. Pillot , for the ALICE Collaboration, *J. Phys.* **G38** (2011) 124111, doi:10.1088/0954-3899/38/12/124111.

[22] R. Reed, for the STAR Collaboration, *J. Phys.* **G38** (2011) 124185, doi:10.1088/0954-3899/38/12/124185.

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