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Upsilon measurements in pp, pPb abd PbPb collisions

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The CMS experiment enables the measurement of the three Upsilon states $\Upsilon(1S)$, $\Upsilon(2S)$, $\Upsilon(3S)$ in pp, pPb and PbPb collisions. The PbPb measurements at 2.76 TeV as a function of event centrality shows that less stable excited states are more suppressed than ground state, a phenomenon termed as sequential suppression. The measurements in pPb collisions, at 5.02 TeV shows that the ratio of the excited to the ground state varies as a function of the global event activity. The three states are also observed to be individually more produced in events with more activity, for the three collision systems. How these CMS measurements compare with other experiments at RHIC and LHC and have improved the understanding of quarkonia physics in heavy ion collisions has been discussed.

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1. Introduction

The PbPb collisions at LHC are performed with the aim to create and characterize quark gluon plasma (QGP), a phase of strongly-interacting matter with colour degrees of freedom. The quarkonia states (Jψ and Υ) have been among the most popular tools since their suppression was proposed as a signal of QGP formation [1]. The understanding of these probes has evolved substantially via measurements through three generations of experiments: the SPS, RHIC and now the LHC and by a great deal of theoretical activities. (For recent reviews see Refs. [2].) The Compact Muon Solenoid (CMS) detector has produced a wealth of results on quarkonia measurements in PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [3, 4]. The quarkonia in heavy ion collisions are modified by colour screening and/or dissociation due to thermal gluons, cold nuclear matter effects such as shadowing and collisions with comovers and can even be regenerated by recombination of heavy quark pairs [5]. The three states $\Upsilon(1S)$ ($M = 9.46$ GeV), $\Upsilon(2S)$ ($M = 10.02$ GeV) $\Upsilon(3S)$ ($M = 10.23$ GeV) are very close in mass but have different radii given respectively by 0.226, 0.509, 0.78 fm and thus are expected to be suppressed sequentially. The relative yield analysis of the 3 states would cancel cold nuclear matter effects and initial parton energy loss. In addition, similar detector acceptance and efficiencies would also cancel in yield ratios. Due to these reasons bottomonia provide a better handle to probe colour screening in QGP. The bottomonia are produced in large numbers at LHC and do not suffer with weak decay feed downs. The CMS has excellent muon detection capability and all three Υ states can be resolved starting from zero transverse momentum p_T.

In this article we present the CMS results on Υ production in the pp, pPb and PbPb collisions in mid mid-rapidity, $|y^{\Upsilon}| \leq 2.4$. The results are compared with the ALICE measurements at forward rapidity, ($2.5 \leq y^{\Upsilon} \leq 4.0$) and also with mid-rapidity STAR measurements at RHIC energy.

2. CMS detector at LHC

The CMS detector is made of a superconducting solenoid which provides a field of 3.8T. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). The forward hadronic calorieme-ters (HF) are used for event triggers. Muons are measured in gas-ionization detectors embedded in the steel return yoke. The muons are measured in the pseudorapidity window $|\eta| \leq 2.4$, with muon station consists of: Drift Tubes, Cathode Strip Chambers, and Resistive Plate Chambers. Matching the tracks from muon stations to the tracks measured in the silicon tracker results in a transverse momentum resolution better than 1.5% for p_T smaller than 100 GeV/c. A detailed description of CMS can be found in Ref. [6].

3. Measurements of Υ states at CMS

The bottomonia are produced in large numbers at LHC and do not suffer with weak decay feed downs. The CMS has excellent muon detection capability and all three Υ states can be resolved.

Figure 1(left panel) shows the nuclear modification factor R_{AA} of Υ(1S) and Υ(2S) as a function of centrality measured by CMS [7, 8]. The comparison with STAR measurement of Υ(1S) R_{AA} [9] shows that Υ's at LHC are more suppressed as compared to that at RHIC. The CMS measurements reveal that the higher Υ states, Υ(2S) and Υ(3S), are more suppressed relative to the ground state Υ(1S), a phenomenon termed as sequential suppression. Figure 1(right panel) shows the R_{AA} of Υ(1S) and Υ(2S) measured by CMS along with the ALICE measurements [10] at forward rapidity, $(2.5 \le y^{\Upsilon} \le 4.0)$. The figure indicates that at forward rapidity, Υ(1S) is slightly more suppressed than the CMS measurements at mid-rapidity, $|y^{\Upsilon}| \le 2.4$.

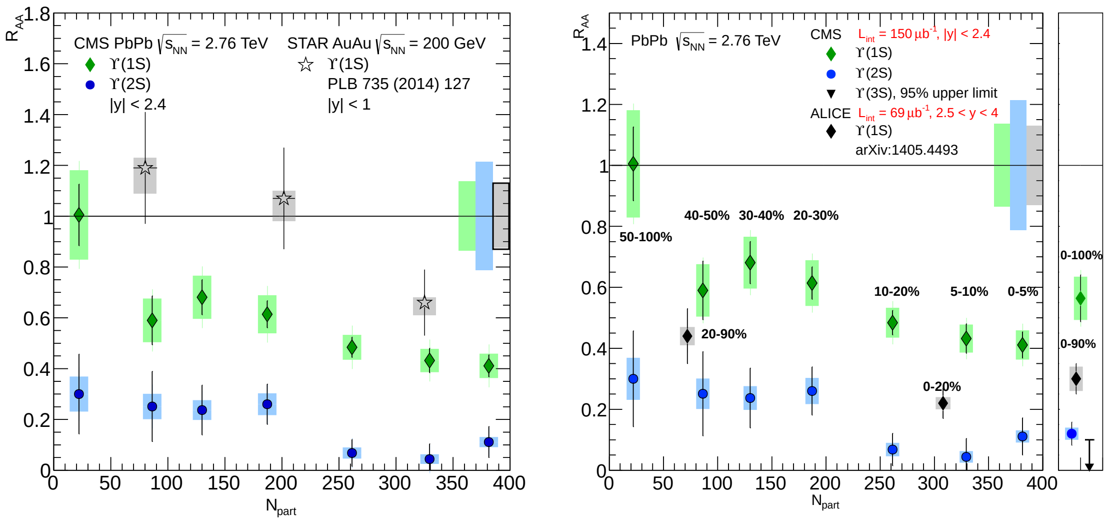

Figure 1: (left panel) The nuclear modification factor R_{AA} of Υ(1S) and Υ(2S) as a function of centrality measured by CMS along with the measurements of Υ(1S) by STAR [9]. (right panel) CMS measurements along with Υ(1S) R_{AA} measured in the forward rapidity range (2.5<y<4) by ALICE[10]

To understand different mechanism of suppression in hot and cold nuclear matter CMS utilizes proton-lead (pPb) collision data provided by LHC in the start of 2013. This dataset provides an essential reference to understand initial state effects and may also provide insight into cold nuclear effects that may be distinct from the suppression effects observed in PbPb collisions. Figure 2 shows the ratios of the excited states, Υ(2S) and Υ(3S), to the ground state, Υ(1S) in pPb collisions at $\sqrt{s_{NN}}$=5.02 TeV with respect to pp collisions at $\sqrt{s}$=2.76 TeV. These ratios are compared to the corresponding ratios for PbPb (cross) collisions at $\sqrt{s_{NN}}$=2.76 TeV [8, 11]. Double ratios in pPb collision are larger than PbPb ratios but are still less than one. This suggest presence of final state effects in pPb and PbPb collisions, which affect more strongly the excited states Υ(2S) and Υ(3S) than Υ(1S).

The pp and pPb data are further analyzed separately as a function of event activity variables. Figure 3 (left panel) shows the excited to ground states cross section ratios, Υ(2S)/Υ(1S) for $|y_{\rm CM}| <$ 1.93 as a function of number of charged particles in the rapidity range $|\eta|$ <2.4 for all three collision systems. Figure 3 (right panel) shows the excited to ground states cross section ratios, Υ(2S)/Υ(1S) for $|y_{\rm CM}| < 1.93$ as a function of of energy deposit in HF measured in $|\eta| > 4.0$. These ratios, are found to decrease with increasing charged-particle multiplicity. This trend can be explained in two opposite ways. If, on the one hand, the Υ(1S) is systematically produced with more particles than the excited states, it would influence the underlying distribution of charged particles and create an artificial effect when selected in small multiplicity bins. On the other hand, if the Υ interact with the

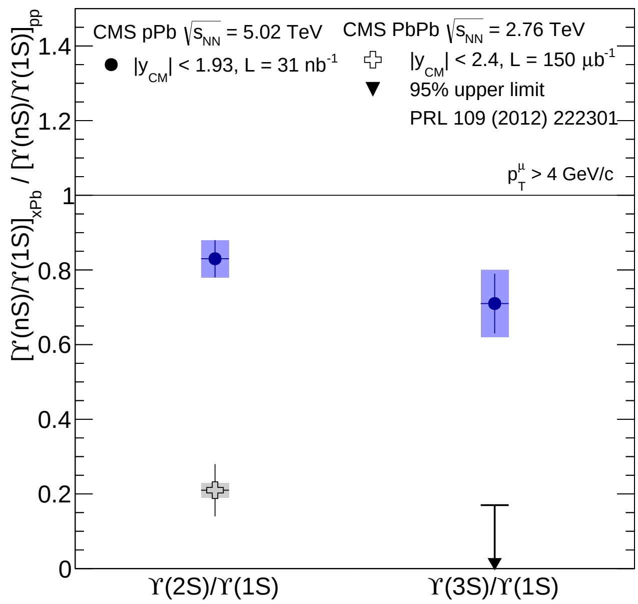

Figure 2: (left) Event activity integrated double ratios of the excited states, ϒ(2S) and ϒ(3S), to the ground state, ϒ(1S) in pPb collisions at $\sqrt{s_{NN}}$=5.02 TeV with respect to pp collisions at $\sqrt{s}$=2.76 TeV (circles), compared to the corresponding ratios for PbPb collisions at $\sqrt{s_{NN}}$= 2.76 TeV.

surrounding environment, the ϒ(1S) as the most tightly bound state is expected to be less affected than ϒ(2S) and ϒ(3S), leading to a decrease of the ϒ(nS)/ϒ(1S) ratios with increasing multiplicity. In either cases, the ratios will continuously decrease from the pp to pPb to PbPb systems, as a function of event multiplicity.

4. Summary

The LHC measurements have advanced the understanding of quarkonia production in heavy ion collisions. One of the the most noticeable results is sequential suppression of ϒ states observed first time in heavy ion collisions. The ϒ suppression at LHC is more than that at RHIC showing that the matter at LHC has stronger colour screening. The forward rapidity, ϒ(1S) measured by ALICE is slightly more suppressed than that from the CMS measurements at mid-rapidity. The measurements of ϒ states in pPb collisions suggest the presence of final effects in pPb collisions affecting ground state and excited states differently. More statistics expected in PbPb collisions at 5 TeV, a better p_T and rapidity dependence of quarkonia will certainly quantify the effects of colour screening and regeneration.

References

[1] T. Matsui and H. Satz, “J/ψ Suppression by Quark-Gluon Plasma Formation”, Phys. Lett. B **178**, 416 (1986).

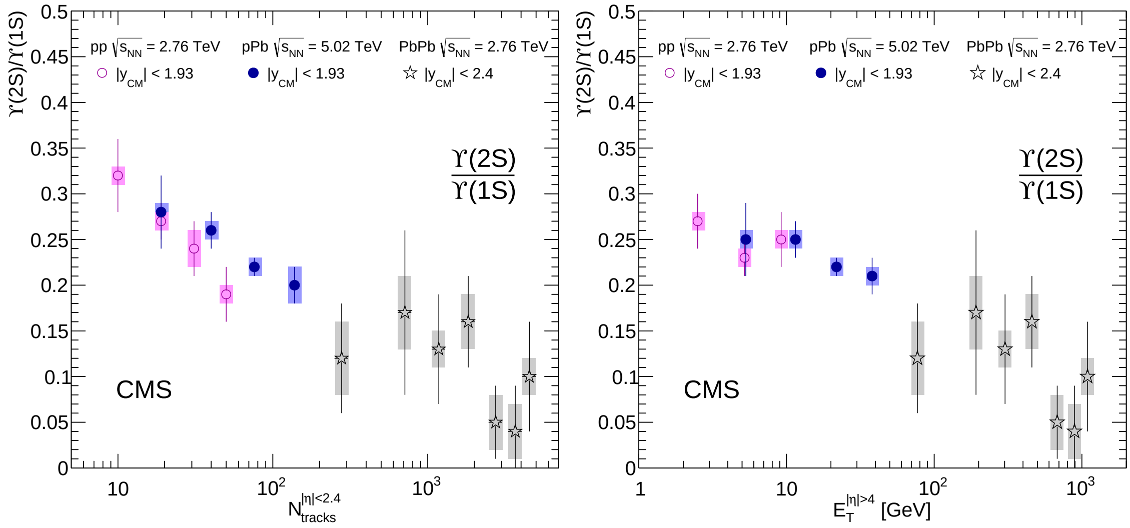

Figure 3: (left panel) Excited to ground state ratios ϒ(2S)/ϒ(1S) for $|y_{\rm CM}| < 1.93$ as a function of charged tracks measured in $|\eta| < 2.4$ for pp collisions at $\sqrt{s} = 2.76$ TeV, pPb collisions at $\sqrt{s_{NN}} = 5.02$ TeV and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV. (right panel) Same as left panel but as a function of energy deposit in HF measured in $|\eta| > 4.0$.

[2] J. Schukraft, "Heavy Ion Physics at the LHC: What's new ? What's next ?", arXiv:1311.1429 [hep-ex].

[3] P. Shukla [CMS Collaboration], "Overview of quarkonia and heavy flavour measurements by CMS," arXiv:1405.3810 [nucl-ex].

[4] V. Kumar [CMS Collaboration], "Quarkonia results in heavy-ion collisions from CMS," This proceedings.

[5] V. Kumar, P. Shukla and R. Vogt, Phys. Rev. C **92**, no. 2, 024908 (2015)

[6] S. Chatrchyan *et al.* [CMS Collaboration], "The CMS experiment at the CERN LHC," JINST **3**, S08004 (2008).

[7] S. Chatrchyan *et al.* [CMS Collaboration], "Indications of suppression of excited ϒ states in PbPb collisions at $\sqrt{S_{NN}}$ = 2.76 TeV," Phys. Rev. Lett. **107**, 052302 (2011).

[8] S. Chatrchyan *et al.* [CMS Collaboration], "Observation of sequential Upsilon suppression in PbPb collisions," Phys. Rev. Lett. **109**, 222301 (2012).

[9] L. Adamczyk *et al.* [STAR Collaboration], "Suppression of ϒ production in d+Au and Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV," Phys. Lett. B **735**, 127 (2014) [Phys. Lett. B **743**, 537 (2015)].

[10] B. B. Abelev *et al.* [ALICE Collaboration], "Suppression of ϒ(1S) at forward rapidity in Pb-Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV," Phys. Lett. B **738**, 361 (2014).

[11] S. Chatrchyan *et al.* [CMS Collaboration], "Event activity dependence of ϒ(nS) production in $\sqrt{s_{NN}}$=5.02 TeV pPb and $\sqrt{s}$=2.76 TeV pp collisions," JHEP **1404**, 103 (2014).