Bottomonium production in pp, pPb, and PbPb collisions with CMS

Vineet Kumar,* Abdulla Abdulsalam, and P. Shukla
Nuclear Physics Division,
Bhabha Atomic Research Centre, Mumbai
For CMS Collaboration

1. Introduction

The suppression of the Υ(1S), Υ(2S) and Υ(3S) yields produced in heavy-ion relative to proton proton (pp) collisions was first measured by the CMS experiment in PbPb collisions at a centre of mass energy per nucleon pair of $\sqrt{s_{\rm NN}} = 2.76$ TeV [1, 2]. The tightest bound state, Υ(1S), was observed to be less suppressed than the more loosely bound excited states, Υ(2S) and Υ(3S). Such ordering is theoretically predicted [3] to occur in the presence of a deconfined medium in which the coloured fields modify the spectral properties of the bb quark pair and prevent formation of a bound state. However, other phenomena can affect the bottomonium yields at stages that precede or follow the formation of the $b\bar{b}$ pair and of the bound state, independently of the presence of a deconfined partonic medium. Some of these phenomena could lead to a suppression sequence that depends on binding energy, as is observed. In this context, measurements in reference collisions are essential: proton-lead (pPb) collisions can probe nuclear effects in the absence of a deconfined medium, while pp collisions are essential for understanding the elementary bottomonium production mechanisms.

2. Data Selection

The results presented in this paper use 5.4 pb^{-1} of pp data collected at a centre-of-mass energy $\sqrt{s} = 2.76$ TeV and 31 nb^{-1} of pPb collisions where the beam energies are 4 TeV for protons, and 1.58 TeV per nucleon for lead nuclei, resulting in a centre-of-mass energy per nucleon pair $\sqrt{s_{\rm NN}} = 5.02$ TeV. As a result of the energy difference of the colliding beams, the nucleon-nucleon centre-of-mass in the pPb collisions is not at rest with respect to the laboratory frame. Massless particles emitted at $|\eta_{CM}| = 0$ in the nucleon-nucleon centre-of-mass frame are detected at $|\eta| = 0.465$ in the laboratory frame. Hadronic PbPb collisions were selected using information from the two Beam Scintillator Counters and Forward Hadronic calorimeters (HF), in coincidence with a bunch crossing identified by the Beam Pick-up Timing Experiment detectors. Simulated events were used to tune the muon selection criteria, to check the agreement with data, and to compute the acceptance and efficiency corrections.

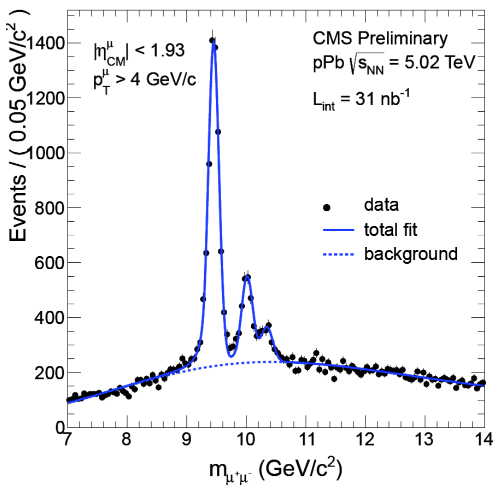

FIG. 1: Invariant mass spectrum of $\mu^+\mu^-$ pairs measured in p+Pb collisions at $\sqrt{s_{NN}} = 5.0$ TeV.

*Electronic address: vineet.salar@gmail.com

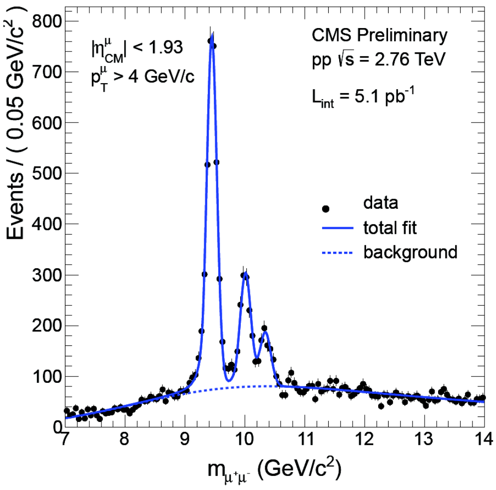

FIG. 2: Invariant mass spectrum of $\mu^+\mu^-$ pairs measured in p+p collisions at $\sqrt{s_{NN}} = 2.76$ TeV.

3. Analysis and results

The Υ states are identified through their dimuon decay. The events were selected online with a hardware-based trigger requiring two muon candidates in the muon detectors with no explicit momentum or rapidity thresholds. Offline, only reconstructed muons with pseudorapidity $|\eta^{\mu}_{CM}| < 1.93$ and transverse momentum $p^{\mu}_{T} > 4$ GeV/c, passing several quality cuts, as described in Ref. [2], were selected. The p_T range of the selected dimuon candidates extends down to zero. The dimuon rapidity is limited to $|\eta^{\mu}_{CM}| < 1.93$. The resulting opposite-charge dimuon invariant-mass distributions are shown in Fig.1 for the pPb and in Fig.2 for pp data sets. The Υ(nS)/Υ(1S) ratios are extracted from an unbinned maximum likelihood fit to the invariant dimuon mass spectra, following the method described in Ref. [2]. The reconstructed mass lineshape of each Υ(nS) state is parameterized by a “Crystal Ball” (CB) function, i.e. a Gaussian function with the low-side tail replaced by a power law describing final-state radiation. The resolution, given by the width of the Gaussian component of the CB, is constrained to scale with the ratios of the resonance masses. The CB tail parameters are fixed to values obtained from MC simulation. The Υ(nS) mass ratios are fixed to their world-average values[4], with the Υ(1S) mass left free and found consistent to its world-average value. The background shape is modeled by an exponential function multiplied by an error function and all its parameters are left free in the fit, as in Ref. [2]. Using the yield ratios found from fitting the pPb and pp data, the double ratios are computed:

$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\rm pPb}}{\Upsilon(2S)/\Upsilon(1S)|_{\rm pp}} = 0.83 \pm 0.05 \pm 0.05,$$
$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{\rm pPb}}{\Upsilon(3S)/\Upsilon(1S)|_{\rm pp}} = 0.71 \pm 0.08 \pm 0.09,$$
$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\rm PbPb}}{\Upsilon(2S)/\Upsilon(1S)|_{\rm pp}} = 0.21 \pm 0.07 \pm 0.02,$$
$$\frac{\Upsilon(3S)/\Upsilon(1S)|_{\rm PbPb}}{\Upsilon(3S)/\Upsilon(1S)|_{\rm pp}} < 0.17(95\%CL). \qquad (1)$$

The double ratios for PbPb as shown in equation 1 are taken from Ref [2]. In equation 1 first uncertainty is statistical and second is systematic. In summary, the production of the three Υ states is investigated in the pPb and pp collisions collected in 2013 by the CMS experiment, in the $|y_{\rm CM}| < 1.93$ centre-of-mass rapidity range. The above pPb double ratios, in which to first approximation the initial-state effects cancel, suggest the presence of final-state effects in the pPb collisions compared to pp collisions, that are different for the Υ(2S) and Υ(3S) compared to Υ(1S). These effects suppress the yield of the excited states compared to the yield of the ground state. Event activity dependence of results will be persented in the symposium.

References

[1] CMS Collaboration Phys. Rev. Lett. **107** (2011) 052302.

[2] CMS Collaboration Phys. Rev. Lett. **109** (2012) 222301.

[3] S. Digal, P. Petreczky, and H. Satz, Phys. Rev. C **64** (2001) 094015.

[4] Particle Data Group Collaboration, J. Phys. G **37** (2010) 383 075021.