

Measurement of bottomonium states in pp, pPb and PbPb collisions at 2.76 TeV from CMS

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Abstract. The bottomonium states are one of the cleanest probes to study the characteristics of the quark-gluon plasma (QGP) as they are produced through hard scattering at the early stage of the collision. Their relative production cross section in PbPb collisions compared to pp collisions, the nuclear modification factor R_{AA} , has been studied and strong suppression was found in PbPb collisions. The R_{AA} has been obtained in centrality intervals for $\Upsilon(1S)$ & $\Upsilon(2S)$ and also reported as a function of p_T and rapidity. Also the yield ratios of the excited states $\Upsilon(nS)$ compared to the ground state $\Upsilon(1S)$ in both pp and PbPb collisions are combined to form the double ratio, which is equivalent to the ratio of the nuclear modification factor R_{AA} . This quantity has been studied for the two excited states $\Upsilon(2S)$ and $\Upsilon(3S)$ in pPb and PbPb collisions.

1 Introduction

A medium consist of deconfined quarks and gluons at high density and high temperature, the Quark-Gluon Plasma (QGP) is predicted to be formed at the early stage of high energy heavy ion collisions. Measurement of quarkonium states is a promising way to study the characteristics of the QGP. Suppression of those quarkonium states is one of the most important signatures in understanding the property of the medium, which was expected to be in the order of the binding energy due to the debye screening of the neighboring color charges [1]. The suppression of the various states is therefore expected to be denoted in a sequential pattern and can provide information of the dissociation temperature in the medium which is dependent on the binding energy of each quarkonia. Since the binding energy of the bottomonium states is stronger for the ground state than the other excited states, the ground state ($\Upsilon(1S)$) has a larger dissociation temperature compared to the others ($\Upsilon(2S)$ & $\Upsilon(3S)$) and that would lead the three states to follow the expected sequential suppression. The modification of the quarkonium production is not only affected by the hot nuclear matter but also by the effect of the nucleus itself which is so-called the cold nuclear matter (CNM) effect. The CNM effect includes the modification of the parton distribution function, cronin effect and nuclear absorption [2]. The bottomonium production was measured with the data collected at $\sqrt{s_{NN}} = 5.02$ TeV in pPb collisions and $\sqrt{s_{NN}} = 2.76$ TeV in pp and PbPb collisions. In this conference proceeding, the latest results of the Υ measurement will be described for the three different collision system.

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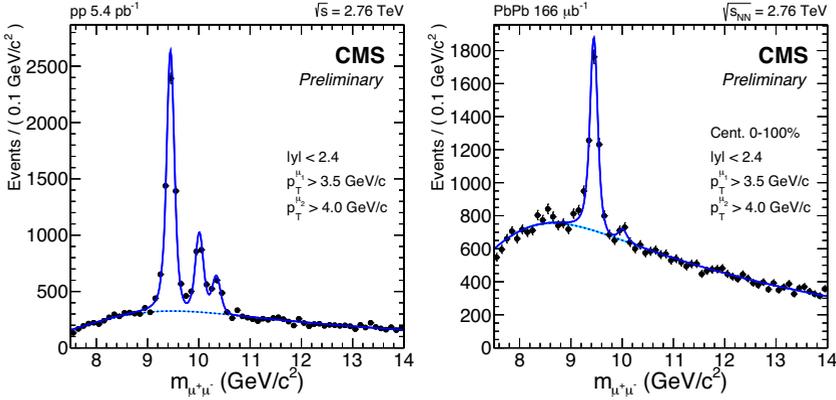


Figure 1. Dimuon mass distribution in pp and PbPb collisions at 2.76 TeV [4].

2 Signal Extraction of Υ states

In this analysis, the Υ states were measured via the di-muon decay channel which is easy to detect from the CMS detector. The detailed description of the CMS detector can be found in Ref. [3]. The single muons were reconstructed within 7.5-14 GeV/c² di-muon mass window applied with the single muon p_T cut ($p_T^{\mu_1} > 3.5$ GeV/c & $p_T^{\mu_2} > 4.0$ GeV/c). The mass spectrum in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV is shown in figure 1. An unbinned maximum likelihood fit was performed to describe the $m_{\mu^+\mu^-}$ mass spectrum by a signal PDF and a background PDF in each collision system. The sum of two Crystal Ball (CB) functions was used for the signal PDF while the parameters were fixed to the obtained values from the Monte Carlo (MC) simulation. Those fixed parameters were then released one by one in order to compute the systematic uncertainty of the signal function variation. The background PDF consists of an error function multiplied by an exponential function in order to fit the low-mass turn on. Additional function to the nominal background PDF such as first and second order Chebychev polynomial was used to estimate the systematics of the background PDF variation. The extracted yields were corrected by the acceptance and efficiency which was obtained from MC simulation and also corrected by a data-driven technique called tag-and-probe [5].

3 Results

3.1 $\Upsilon(nS)$ in double ratios

The double ratio of the excited states to the ground states is calculated by dividing the single ratios in pp & PbPb (pPb) collisions as in Eq 1. It quantifies how much more the excited states are suppressed compared to the ground state and has an advantage in the cancellation of the acceptance and efficiency while it also eliminates the fraction of the systematic uncertainties. The double ratio in PbPb collisions from Ref. [6] and pPb collisions is shown on Fig 2 over the integrated centrality and event activity. Strong suppression was found for both excited states in PbPb collisions and the large amount of suppression shows that the effect of the hot nuclear matter (HNM) is dominant in PbPb collisions. Although the suppression is much larger in PbPb collisions, the double ratio results in pPb collisions shows a significant amount of suppression which can be interpreted as the cold nuclear matter (CNM) effect.

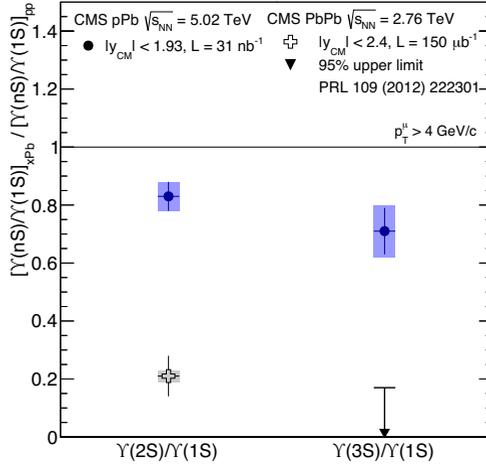


Figure 2. Double ratios of the $\Upsilon(nS)$ to the $\Upsilon(1S)$ in pPb collisions (circles) and the corresponding ratios in PbPb collisions (cross) [7].

$$\frac{\Upsilon(2S)/\Upsilon(1S)|_{\text{PbPb(pPb)}}}{\Upsilon(2S)/\Upsilon(1S)|_{pp}} = \frac{R_{AA(pPb)}(\Upsilon(2S))}{R_{AA(pPb)}(\Upsilon(1S))} \quad (1)$$

3.2 R_{AA} of Υ states

The normalized yield ratio of the bottomonium states in PbPb collisions compared to pp collisions, quantified as the nuclear modification factor R_{AA} , is one of the direct signal of the quarkonium suppression due to the color screening. The R_{AA} can be obtained by dividing the yields of Υ in PbPb by the pp cross sections and nuclear overlap function T_{AA} as in Eq 2. Fig 3 shows the R_{AA} results as a function of centrality, p_T and rapidity. The centrality dependent left plot in Fig 3 shows gradual decrease of $\Upsilon(1S)$ and strong suppressions of $\Upsilon(2S)$ in all centrality bins. Hence no clear peak of $\Upsilon(3S)$ was observed within the given statistics in PbPb collisions, an upper limit of the R_{AA} was calculated as less than 0.14 at 95% C.L. over the whole centrality and kinematic range. $\Upsilon(1S)$ and $\Upsilon(2S)$ in the integrated 0-100 % bin shows suppression by a factor of 2 and 10, respectively in PbPb collisions compared to pp collisions. The sequential suppression of the three bottomonium states indicates the pattern of the sequential binding energy that was expected from the screening effect of the heavy quark potential. The middle and right plot shows the p_T and rapidity dependent R_{AA} in the kinematic range of $|y| < 2.4$ & $p_T < 20 \text{ GeV}/c$ and no significant dependence was observed.

$$R_{AA} = \frac{1}{T_{AA}} \frac{d^2 N^{AA} / dp_T d\eta}{d^2 \sigma^{NN} / dp_T d\eta} \quad (2)$$

4 Summary

The three bottomonium states $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ were measured in pp, pPb and PbPb collisions from the data collected during RUN I of the CMS experiment. The double ratio results in pPb &

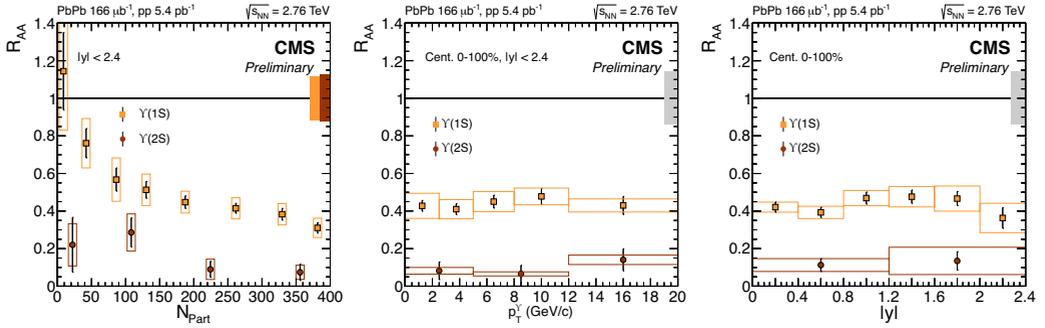


Figure 3. R_{AA} for $\Upsilon(1S)$ and $\Upsilon(2S)$ as a function of centrality (left), p_T (middle) and y (right) in pp and PbPb collisions [4].

PbPb collisions has been reported and the results of the nuclear modification factor R_{AA} has been shown in PbPb collisions. The cold nuclear matter (CNM) effect was probed in the double ratio with a distinct amount of suppression, while much more suppression appeared in PbPb collisions due to the hot dense matter. R_{AA} has been presented as a function of N_{part} , p_T and $|y|$ and strong suppression of $\Upsilon(1S)$ and $\Upsilon(2S)$ with sequential order was observed with no kinematic dependence. Gradual decrease in the centrality dependent R_{AA} was observed for $\Upsilon(1S)$ while $\Upsilon(2S)$ was strongly suppressed in all centrality intervals.

References

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