Measurement of charmonium production and its double ratio in PbPb and pp collisions at 2.76 TeV with CMS

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Introduction

In high-energy heavy-ion collisions, one of the most striking characteristics is the suppression of quarkonium states. The suppression is predicted to occur above a critical temperature of the medium, and sequentially, in the order of the $Q\overline{Q}$ binding energy [1]. CMS has measured the nuclear modification factors of non-prompt J/ψ (from b-hadron decays) and prompt J/ψ in PbPb collisions at $\sqrt{s}_{\rm NN}$ = 2.76 TeV. Prompt J/ψ and Non-prompt J/ψ from b-hadron decays show a strong suppression in the transverse momentum range (6.5 < $p_{\rm T}$ < 30 GeV/c) when compared to the yield in pp collisions scaled by the number of inelastic nucleon-nucleon collisions. The sequential melting should manifest itself in nuclear modification factors ($R_{\rm AA}$) for the ψ(2S) that are smaller, or at most equal, to those measured for the J/ψ. The existing double ratio analysis presented in [2] could not draw a strong conclusion due to large uncertianty from low statistics pp recorded in 2010. In this study, the main result presented in the form of a double ratio $\frac{\rm R(\psi(2S))_{PbPb}}{\rm R(\psi(2S))_{pp}}$ = $({\rm N}\psi(2{\rm S})/{\rm NJ}/\psi)_{PbPb}/({\rm N}\psi(2{\rm S})/{\rm NJ}/\psi)_{pp}$ is updated with RegIt PbPb data and high statistics pp data which provide a twenty times larger reference sample. The double ratio can also be written as the ratio of ψ(2S) and J/ψ nuclear modification factors: $\frac{\rm R(\psi(2S))_{PbPb}}{\rm R(\psi(2S))_{pp}} = \frac{R_{\rm AA}(\psi(2S))}{R_{\rm AA}(J\psi)}$.

Data Selection

The analysis is based on a data sample recorded by the CMS detector in PbPb collisions at $\sqrt{s}_{\rm NN}$ = 2.76 TeV with higher luminosity about a factor of 20 compared to 2010 PbPb run. The PbPb data is reconstructed with procedure referred to as iterative tracking which resulted in improved statistics about a factor of 1.5 higher compared to the normal reconstructed data. The PbPb sample corresponds to an integrated luminosity of $L_{\rm int}$ = 150 $\mu{\rm b}^{-1}$ and the recorded pp luminosity in CMS was 5.4 ${\rm pb}^{-1}$ in 2013.

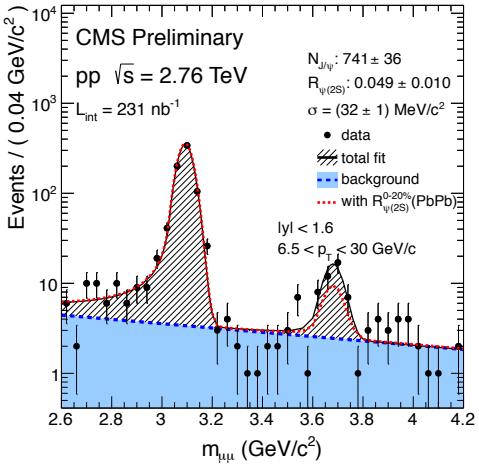

FIG. 1: Invariant mass spectrum of $\mu^+\mu^-$ pairs (black circles) in pp collisions for the kinematic range 6.5< $p_{\rm T}$ <30 GeV/c and |y| <1.6. The fit to the data with a Crystal Ball and exponential is shown as the black line. The dashed blue line shows the fitted background contribution. The dashed red line illustrates the fit to the J/ψ peak assuming the $\psi(2S)$/J/ψ ratio to be the same as in the 20% most central PbPb collisions.

Signal extraction and analysis

The analysis is performed in two [$p_{\rm T}$,|y|] kinematical ranges. 1) Lower-$p_{\rm T}$ J/ψ and ψ(2S), down to 3 GeV/c, can only be reached for 1.6 < |y| < 2.4. 2) At mid-rapidity, |y| < 1.6, only J/ψ and ψ(2S) of $p_{\rm T}$ > 6.5 GeV/c

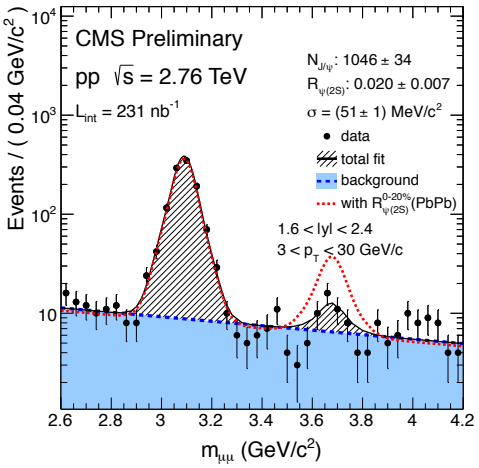

FIG. 2: Invariant mass spectrum of $\mu^+\mu^-$ pairs (black circles) in pp collisions for the kinematic range 3.0< p_T <30 GeV/c and 1.6< $|y|$ <2.4. The fit to the data with a sum of a Crystal Ball and a Gaussian and an exponential is shown as the black line. The dashed blue line shows the fitted background contribution. The dashed red line illustrates the fit to the J/ψ peak assuming the $\psi(2S)$/J/ψ ratio to be the same as in the 20% most central PbPb collisions.

are reconstructed, as imposed by the single-muon acceptance. The centrality classes used are 40-100% 20-40% and 0-20%.

The invariant-mass spectrum of $\mu^+\mu^-$ pairs in pp collisions($L_{\rm int}$ = 225 nb^{-1}) are shown in Figure 1 for mid-rapidity and in Figure 2 for forward-rapidity. The signal is fitted with a Crystal Ball (sum of a Crystal Ball and a Gaussian) in mid-rapidity (forward-rapidity) shown as the black line and the background is fitted with exponential shown as dashed blue line. The dashed red line illustrates the fit to the J/ψ peak assuming the $\psi(2S)$/J/ψ ratio to be the same as in the 20% most central PbPb collisions. In the updated study with pp data ($L_{\rm int}$ = 5.4 pb^{-1}), the signal is fitted with sum of Crystal Ball and Gaussian(CBG) and the background contribution is fitted with Chebyechev 3rd order polynomial (Chebyechev 4th order polynomial) in forward-rapidity (mid-rapidity). The CB function f_{CB} combines a Gaussian core and a power-law tail with an exponent n to account for energy loss due to final-state photon radiation.

The systematic uncertainties on the single ratio due to the fitting method are studied by varying the signal and background shapes. For the background description, different background shapes are tried such as single exponential, double exponential, Gaussian, Chebychev 4th and 5th order polynomials. To evaluate possible imperfect cancellations of acceptance and efficiency effects in the double ratio, efficiencies and acceptances have been calculated from full MC simulations of ψ(2S) and J/ψ in PbPb and pp. The double ratio of efficiencies is found to be compatible with unity in all cases.

Results

In the most central collisions(0-20%) the double ratio measured with pp data ($L_{\rm int}$ = 225 nb^{-1}) is 5.32 ± 1.03(stat.) ± 0.79(syst.) ± 2.58(pp) which means that more ψ(2S) are produced compared to J/ψ than in pp collisions with large uncertainties [2]. At lower p_T and forward rapidity, the result suggests an enhancement of the ψ(2S)/J/ψ ratio and in higher p_T and midrapidity ψ(2S) is more suppressed than J/ψ. The large uncertainties from the pp which prevent to draw a strong conclusion on the results, is considerably reduced by the the high statistics pp data. The improved result of double ratio shows that in the most central collisions the double ratio value is still lareger than unity at forward rapidity giving a clear eveidence of lesser suppression of ψ(2S) or regeneration.

References

[1] CMS Collaboration, "Suppression of non-prompt J/ψ, prompt J/ψ, and in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", JHEP **05** (2012) 063.

[2] CMS Collaboration, "Measurement of the ψ(2S) meson in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV", CMS PAS HIN-12-007.