Measurement of prompt $\psi(2S)$ to J/ψ meson yield ratios in PbPb and pp collisions at at $\sqrt{s}_{NN} = 2.76$ TeV

Abdulla Abdulsalam, Vineet Kumar, and Prashant Shukla
Nuclear Physics Division, Bhabha Atomic Research Centre, Mumbai - 400085, INDIA and
(For CMS Collaboration)

Introduction

Heavy quarkonia are important probes of the quark gluon plasma since they are produced early in relativistic heavy-ion collision and their survival is affected by the surrounding medium. Quarkonia should dissociate in the QGP when the debye screening radius of the medium, which decreases with increasing QGP temperature, becomes smaller than the binding radius of the quarkonium state. Since the $\psi(2S)$ meson is less bound than the J/ψ, it should melt at lower temperatures. In this analysis, we present a study of the prompt $\psi(2S)$ and J/ψ yields measured in PbPb and pp collisions at $\sqrt{s}_{NN} = 2.76$ TeV with integrated luminosities of 150 μb^{-1} and 5.4 pb^{-1} respectively. The main result is presented in the form of a raw yield double ratio $(N_{\psi(2S)}/N_{J/\psi})_{\mathrm{PbPb}}/(N_{\psi(2S)}/N_{J/\psi})_{\mathrm{pp}}$. The double ratio can also be written as the ratio of $\psi(2S)$ and J/ψ nuclear modification factors: $= \mathrm{R(PbPb)/R(pp)} = \mathrm{R}_{AA}(\psi(2S))/\mathrm{R}_{AA}(\mathrm{J/}\psi)$.

Analysis procedure

The details of data selection and signal extraction is given in Ref [1]. Non-prompt charmonia are removed with a cut on pseudo-proper decay length, $\ell_{J/\psi}$. The $\ell_{J/\psi}$ selection condition is tuned from Monte Carlo (MC) simulation studies, separately for the pp and PbPb collision systems, such that 90% of the prompt J/ψ and $\psi(2S)$ are kept, typically rejecting 80% of the non-prompt ones. The remaining non-prompt contamination is accounted for as a systematic uncertainty. The analysis is performed in two [p_T,$|y|$] kinematical ranges: 1) Lower-p_T J/ψ and $\psi(2S)$, down to 3 GeV/c for $1.6 < |y| < 2.4$ (forward rapidity). 2) At mid-rapidity, $|y| < 1.6$, only J/ψ and $\psi(2S)$ of $p_T > 6.5$ GeV/c are reconstructed, as imposed by the single-muon ac-
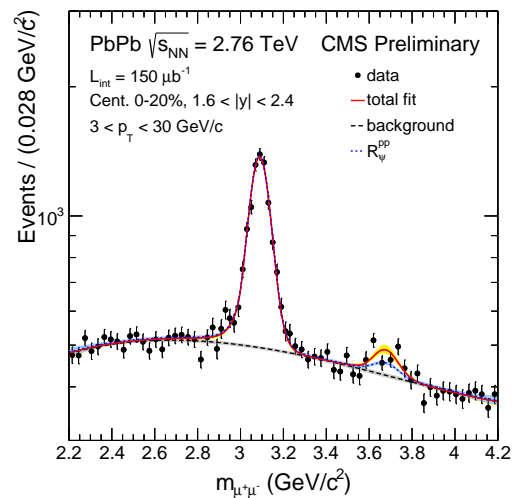

FIG. 1: Dimuon invariant-mass distributions measured in 20% most central PbPb collisions, for $1.6 < |y| < 2.4$ and $3.0 < p_T < 30$ GeV/c. The results of unbinned maximum likelihood fits are shown as solid lines (signal plus background) and dashed lines (background only) [2].

ceptance. The centrality classes used in this analysis are 40-100% 20-40% and 0-20%, ordered from the lowest to the highest HF energy deposit.

Figure 1 shows the dimuon invariant-mass ($\mu^+\mu^-$) distributions measured in central (0-20%) PbPb collisions, for the forward rapidity bin. The invariant-mass distribution for each of the two charmonium resonances is described by the sum of a Gaussian function and a Crystal Ball (CB) function, with common mean m_0 and independent widths σ_G and σ_{CB}. The background is described by Chebychev polynomials, whose orders are in the range $0 \leq N \leq 3$ and are independently

determined for each analysis bin, with log-likelihood ratio (LLR) tests. Once the background function is selected, the pp and three PbPb centrality samples are fitted simultaneously.

The systematic uncertainties from the fitting method are studied by varying the signal and background shapes as well as the fitted invariant-mass range. As alternative signal shape, the sum of two CB functions with common mean and tail parameters is used. The uncertainty on the background is evaluated by varying (i) an exponential function with a Chebychev polynomial as the argument is used, (ii) the fitted mass region is extended to $1.8 \leq \mu^+\mu^- < 5$ GeV/c^2; and (iii) the J/ψ and ψ(2S) regions are fitted with independent background functions. Of these three, the maximum deviation from the nominal fit is added in quadrature with the signal shape uncertainty to obtain the total systematic uncertainty in the fit. Residual effects from imperfect double-ratio cancellations of the muon reconstruction and trigger efficiency corrections have been evaluated with MC simulation studies. A total systematic uncertainty of 13-30% is obtained adding in quadrature the uncertainties mentioned above.
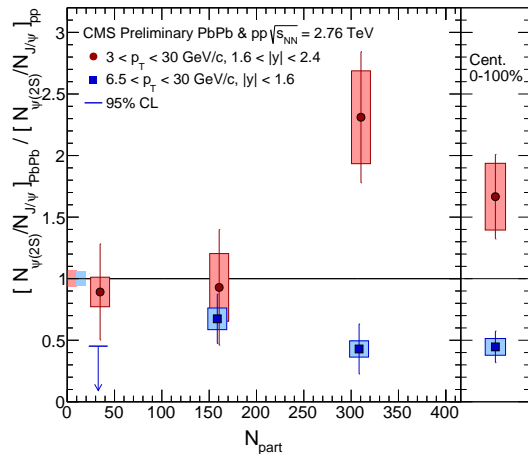

FIG. 2: Double ratio of measured yields as a function of centrality. Statistical (systematic) uncertainties are shown as bars (boxes). The boxes at unity indicate the (global) pp uncertainties [2].

Results

The double ratio of measured yields is shown in Figure 2 as a function of centrality, for both kinematic bins. The quadratic sum of the pp statistical and systematic uncertainties, $\approx 6\%$, is common to all centralities. The centrality-integrated results are also displayed, at the rightmost edge of the figure. In the most peripheral (40-100%) PbPb collisions, no significant ψ(2S) signal has been observed in the midrapidity bin and an upper limit of 0.46 at 95% confidence level (CL) is set on the double ratio.

In the midrapidity bin, where all measured charmonia must have $p_T > 6.5$ GeV/c, the double ratio is less than unity in all three centrality bins, with a centrality-integrated value of 0.45 ± 0.13 (stat.) ± 0.07 (syst.), including the global pp uncertainties. In the forward rapidity bin, the double ratio increases with centrality, reaching the value 2.31 ± 0.53 (stat.) ± 0.38 (syst.) ± 0.15 (pp) in the most central collisions; indicating that the ψ(2S) to J/ψ meson ratio is enhanced in central PbPb collisions with respect to pp collisions. At forward rapidity, the centrality-integrated double ratio is 1.67 ± 0.34 (stat.) ± 0.27 (syst.), becoming consistent with unity in peripheral events.

In summary, the derived $R_{AA}(\psi(2S))$ for midrapidity bin it is 0.13 ± 0.04 (stat.) ± 0.02 (syst.) ± 0.01 (pp) and for forward rapidity bin is 0.67 ± 0.16 (stat.) ± 0.11 (syst.) ± 0.07 (pp). ψ(2S) production is suppressed in PbPb collisions with respect to pp collisions, in both kinematic regions investigated. In comparison to J/ψ production and in the most central PbPb collisions, ψ(2S) production is suppressed in the midrapidity bin, as expected in the sequential melting scenario, while it is enhanced in the forward rapidity bin extending to lower p_T.

References

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

[2] CMS twiki on Heavy-Ion Public Results, https://twiki.cern.ch/twiki/bin/view/CMSPublic/ PhysicsResultsHIN12007.