

Measurement of the ratio $\psi(2S)/J/\psi$ in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV

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Abstract

This document describes a first measurement of the ratio $\psi(2S)/J/\psi$ in p-Pb collisions at center of mass energy per nucleon pairs of $\sqrt{s_{NN}} = 5.02$ TeV with an integrated luminosity of $L_{int} = 34.6 \text{ nb}^{-1}$ collected by the CMS experiment at LHC in 2013.

The ratio has been measured within the center of mass rapidity $-1.93 < y_{CM} < 1.93$ and the transverse momentum $5 < p_T < 30 \text{ GeV}/c$ in rapidity, p_T and event activity bins.

Since the analysis is still in progress and the results are not yet approved for public presentation by the CMS Collaboration, the report describes the analysis procedure but doesn't include any result.

1 Introduction

The Quark Gluon Plasma (QGP) is an extended volume of free quarks and gluons predicted by lattice QCD calculations at high energy densities above a critical value ϵ_c and at very high temperature ($T_c \simeq 170$ MeV).

Heavy quark bound states in nucleus-nucleus (AA) collisions are sensitive probes of the thermodynamical properties of the QGP because the produced hot medium generates the screening of the colour charge of the quarks by the surrounding free quarks and gluons, with a colour screening radius of the medium that decreases with increasing temperature. Charmonium and bottomonium states dissociate at temperature for which the colour screening radius of the medium falls below their corresponding binding radius and this results in the sequential suppression of the quarkonium states that have different binding radii and melt at different temperatures.

In relativistic heavy ions experiments a suppression of the J/ψ and $\psi(2S)$ yields has been observed over a wide rapidity (y) and transverse momentum (p_T) range for increasingly central AA collisions [1, 2, 3]. Those results are consistent with expectations for the formation of the Quark Gluon Plasma (QGP) phase at temperatures where the $c\bar{c}$ bound state dissociates due to the screening of the colour charge by the surrounding quarks and gluons [4, 5, 6].

Several other processes, independent from the produced hot medium, can affect the quarkonia production reducing their yields compared to expectations based on incoherent superposition of pp collisions. The nuclear parton distribution functions (nPDFs) are modified when the nucleon is embedded in a nucleus compared to those in a free nucleon. E.g., the gluon nPDFs are expected to be depleted at small fractional momentum and in this "shadowing regime" the quarkonium yield can be reduced compared to pp collisions at the same energy. Also a group of theoretical models attribute the quarkonium suppression in p-A collisions to the gluon radiation induced by multiple scattering with the surrounding cold medium [7]. In this context the study of charmonia in p-A collisions can allow us to understand the "cold nuclear matter" effects that can modify the quarkonia production independently of the produced hot medium in AA collisions.

This document reports a first measurement of the ratio $\psi(2S)/J/\psi$ in p-Pb collisions at center of mass energy per nucleon pairs of $\sqrt{s_{NN}} = 5.02$ TeV, which contributes to the characterization of the cold nuclear matter effects. J/ψ and $\psi(2S)$ mesons are reconstructed via their decays in $\mu^+\mu^-$ pairs over a wide kinematic range of $-1.93 < y_{CM} < 1.93$ and $5 < p_T < 30$ GeV/c. Their ratio is measured in p_T and rapidity bins and as a function of the event activity expressed in terms of the transverse energy deposited in the forward hadronic calorimeters.

2 Data samples and event selection

The p-Pb data set used corresponds to an integrated luminosity of $L_{int} = 34.6$ nb $^{-1}$ collected with the CMS detector in 2013. The beam energies were 4 TeV for protons and 1.58 TeV per nucleon for the lead nuclei, resulting in a center of mass energy per nucleon pair $\sqrt{s_{NN}} = 5.02$ TeV.

The direction of the proton beam was initially set up to be clockwise (Pb-p) and it was reversed (p-Pb) after 20.7 nb $^{-1}$ data were taken, so there are two independent and comparable data samples Pb-p and p-Pb.

As a result of the beam energy difference, the nucleon-nucleon center of mass in p-Pb collisions is not at rest with respect to the laboratory frame. Massless particles emitted at $|\eta_{CM}| = 0$ in the nucleon-nucleon center of mass frame are detected at $\eta_{LAB} = -0.465$ for the first run period (Pb-p, clockwise proton beam) and at $\eta_{LAB} = +0.465$ for the second run period (p-Pb, counter-clockwise proton beam) in the laboratory frame. The forward region in the center of mass frame (positive η_{CM}) is defined in the proton direction for both run periods.

All the events in the dataset are selected requiring two muon candidates in the muon chambers with no explicit momentum or rapidity thresholds and then skimmed selecting events with two tracker muons with invariant mass higher than 2 GeV/c 2 . All charge combinations are considered and all possible combinations within an event are kept. Starting from this dataset TTrees are filled applying single muon p_T cuts, chosen depending on the η detector region, to select the single muons within the acceptance.

3 Signal extraction

In order to extract the number of J/ψ and $\psi(2S)$ and compute their ratio, a simultaneous unbinned extended maximum likelihood fit is performed on the invariant mass distribution of the selected $\mu^+\mu^-$ pairs in the mass range $2.2 - 4.2 \text{ GeV}/c^2$.

The fitting function is the sum of the signal function and the background function, where the signal function is the sum of a gaussian and a crystal ball for both J/ψ and $\psi(2S)$ and the background function is a Chebychev polynomial of order from 1st to 4th depending on the χ^2 (the one with the best χ^2 probability is chosen).

The crystal ball function combines a gaussian core with a power-law tail described by the two parameters: α to define the threshold between the gaussian and the power law function, and n to account for the energy loss due to final state QED radiation of the muons.

In the fitting procedure, the crystal ball parameters α and n are free parameters and they are common between J/ψ and $\psi(2S)$, while the two width parameters of the gaussian and the crystal ball are free independent parameters for the J/ψ and they are scaled by the mass ratio ($m_{\psi(2S)}/m_{J/\psi} = 1.1902$) for the $\psi(2S)$. Figure 1 shows an example of the dimuons invariant mass fit (p_T and rapidity ranges are not mentioned on purpose and the numbers on the y axis are not shown to avoid giving any confidential information) .

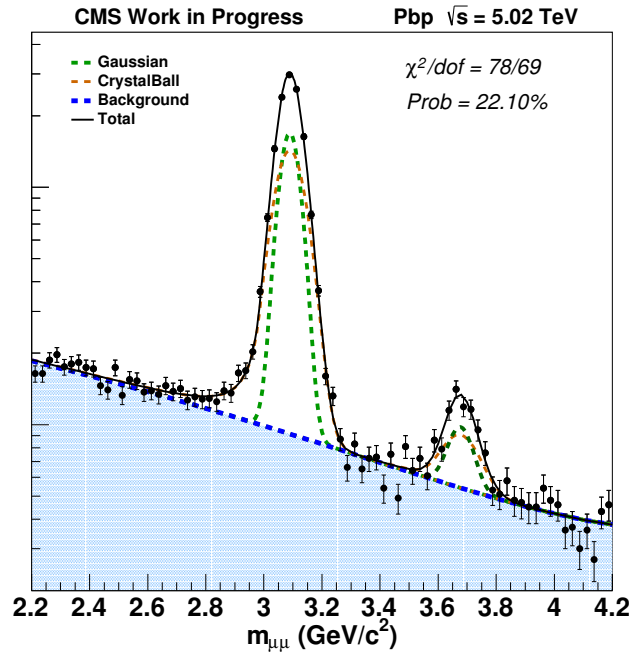


Figure 1: Example of the dimuon invariant mass fit. The black line is the total fit, the blue line shows the background function and the green and the brown lines are respectively the gaussian and the crystal ball functions.

The fit has been done in different rapidity (y) and p_T bins reported respectively in Table 1 and Table 2.

	Backward				Forward		
y_{CM}	-1.93, -1.5	-1.5, -0.90	-0.90, 0	0, 0.90	0.90, 1.5	1.5, 1.93	
y_{LAB} Pb-p	1.03, 1.46	0.43, 1.03	-0.47, 0.43	-1.37, -0.47	-1.97, -1.37	-2.40, -1.97	
y_{LAB} p-Pb	-1.46, -1.03	-1.03, -0.43	-0.43, 0.47	0.47, 1.37	1.37, 1.97	1.97, 2.40	

Table 1: rapidity bins used for the evaluation of the charmonia yields

$ y_{CM} $	p_T [GeV/c]
0, 1.93	6.5, 30
0, 1.93	6.5, 10
0, 1.93	10, 30
1.5, 1.93	5, 6.5

Table 2: p_T bins used for the evaluation of the charmonia yields

Moreover, in order to study the event activity dependence of the ratio, the fit has been performed in three different bins, reported in Table 3, of the variable $E_T^{HF} |\eta| > 4$, that is the transverse energy deposited in the forward hadronic calorimeters for $4 < |\eta| < 5.2$. For this study the fit has been done for $6.5 < p_T < 30$ GeV/c in two rapidity regions, the forward region of $0 < y_{CM} < 1.93$ and the backward region of $-1.93 < y_{CM} < 0$.

$E_T^{HF} \eta > 4$ [GeV]
0, 20
20, 30
30, 120

Table 3: $E_T^{HF} |\eta| > 4$ bins used for the evaluation of the charmonia yields

4 Acceptance and efficiency corrections

In order to compute acceptance and efficiency we need to use Monte-Carlo simulations and we used Pythia generated $J/\psi \rightarrow \mu^+\mu^-$ and $\psi(2S) \rightarrow \mu^+\mu^-$ events in boosted collisions.

The acceptance reflects the finite geometrical coverage of the CMS detector and the limited kinematical reach, constrained by the thickness of the material in front of the muon detectors and by the track curvature in the magnetic field.

Since the acceptance is not affected by detector performances we computed it using a MC sample equivalent to the 1st run period Pb-p and then flipped the rapidity sign for the 2nd run period p-Pb. The kinematical criteria for detecting the dimuons coming from the J/ψ and the $\psi(2S)$ are that both muons should be within the geometrical acceptance of the muon detectors and have enough momentum to reach the muon stations. The detectable dimuons are then dimuons that pass the single muon acceptance cuts which are p_T cuts chosen depending on the η region.

The dimuon signal acceptance A is defined as the fraction of dimuon signal, within a restricted mass range M_1 , that is considered detectable with the CMS detector:

$$A(p_T, y) = \frac{N_{detectable, M_1}^{dimuon}(p_T, y)}{N_{generated}^{dimuon}(p_T, y)}. \quad (1)$$

We used MC samples for prompt J/ψ and $\psi(2S)$ to compute their acceptance with the binning for the analysis. Figure 2 shows the ratio of prompt J/ψ and $\psi(2S)$ acceptances in p_T and rapidity bins.

The efficiency corrections take into account the correction factors introduced by the trigger, tracking and muon ID cuts. The efficiency can be computed dividing the number of reconstructed dimuon pairs in the mass range M_2 with muon ID cuts and trigger selection by the detectable ones in the mass range M_1 in the MC samples:

$$\epsilon_{MC}(p_T, y) = \frac{N_{reconstructed, M_2}^{dimuon, \mu ID, trigger selection}(p_T, y)}{N_{detectable, M_1}^{dimuon}(p_T, y)}. \quad (2)$$

The efficiencies have been computed using MC samples for prompt and non-prompt J/Ψ and $\Psi(2S)$ for both beam directions. The ratio of prompt J/ψ and $\psi(2S)$ efficiencies in p_T and rapidity bins is shown in Figure 3 for Pb-p and in Figure 4 for p-Pb.

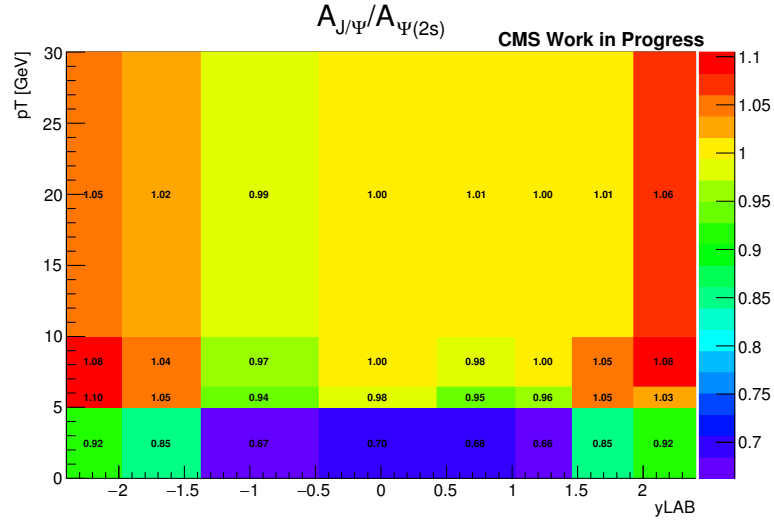


Figure 2: Ratio of the acceptances of prompt J/ψ and $\psi(2S)$

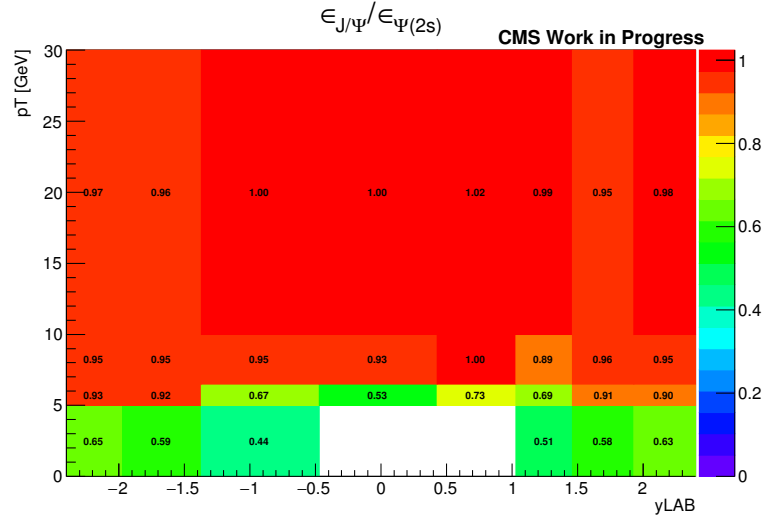


Figure 3: Ratio of the efficiencies of prompt J/ψ and $\psi(2S)$ for Pb-p

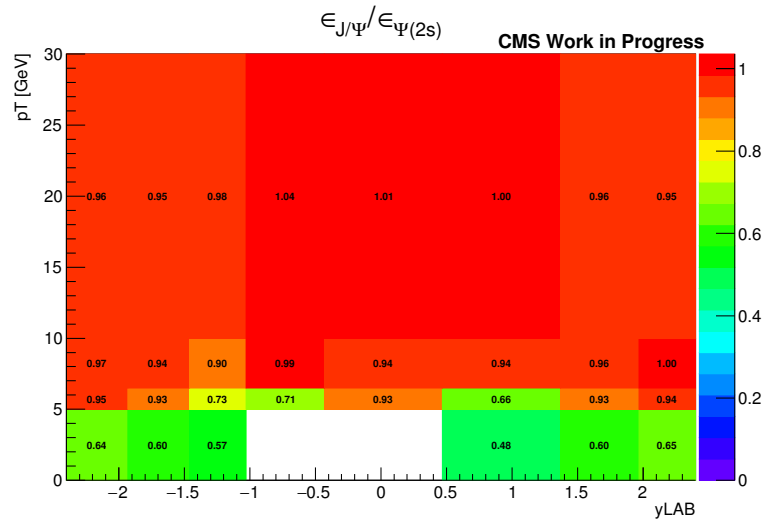


Figure 4: Ratio of the efficiencies of prompt J/ψ and $\psi(2S)$ for p-Pb

Once the J/ψ and $\psi(2S)$ yields are extracted by fitting the dimuons invariant mass distribution and the acceptance and efficiency correction factors for J/ψ and $\psi(2S)$ are computed in each bin, we can compute the corrected $\psi(2S)/J/\psi$ ratio by multiplying the uncorrected one by the ratios of the J/ψ and $\psi(2S)$ acceptances (R_A) and efficiencies (R_ϵ):

$$R_{\psi(2S)/J/\psi} = \frac{\sigma_{\psi(2S)}}{\sigma_{J/\psi}} = \frac{N_{\psi(2S)}}{A_{\psi(2S)}\epsilon_{\psi(2S)}} \frac{A_{J/\psi}\epsilon_{J/\psi}}{N_{J/\psi}} = \frac{N_{\psi(2S)}}{N_{J/\psi}} R_A R_\epsilon. \quad (3)$$

Since the corrections for prompt and non-prompt J/ψ and $\psi(2S)$ are very similar, we made a first order correction using the correction factors for the prompt component on the inclusive prompt and non-prompt data.

5 Results

The ratio of the $\psi(2S)$ and J/ψ yields has been measured in p_T and rapidity bins and as a function of the event activity as described in Section 3 and Section 4.

The results are not included in this report but they will be reported in a CMS internal analysis note.

6 Conclusions

A first measurement of the ratio $\psi(2S)/J/\psi$ in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV has been evaluated. To do this we defined the dimuons invariant mass fitting procedure and tested it with the p_T and rapidity binning that we chose for the measurement of the ratio and we computed acceptance and efficiency correction factors for prompt and non-prompt J/ψ and $\psi(2S)$.

The corrected ratio of the $\psi(2S)$ and J/ψ yields has been evaluated using a first order MC correction factor. The corrections based on the difference between data and MC still need to be taken into account and it is also required to apply the corrections for prompt and non-prompt mesons according to their fraction from the B decay.

The systematic uncertainties due to the fitting procedure and induced by the efficiency corrections have still to be estimated.

The results of the first measurement of the ratio $\psi(2S)/J/\psi$ are not shown in this report because they need to be approved for public presentation by the CMS Collaboration.

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