Charmonium production and suppression in PbPb collisions at $\sqrt{s}_{NN}$ = 2.76 TeV with CMS

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The primary aim of the heavy ion experimental program is to produce Quark Gluon Plasma (QGP) and measure its properties. In this new phase of matter partons (quarks and gluons) are deconfined. Heavy quarkonia are important probes of the QGP 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 depending on their binding energy. The ground states, J/ψ and Υ(1S) are expected to dissolve at significantly higher temperatures of the medium than the more loosely bound excited state. Since the ψ(2S) meson is less bound than the J/ψ, it should melt at lower temperatures. The sequential screening provides an effective thermometer for determining the temperature of the QGP by observing which quarkonium states survive and which were unable to form in the QGP.

In this thesis we presented a study on charmonium production in PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV with Compact Muon Solenoid (CMS) at LHC. The CMS detector is best suited for quarkonia analysis. The excellent momentum resolution of CMS results in well-resolved J/ψ and ψ(2S) peaks in the dimuon mass spectrum. We describe the production and suppression of prompt and non-prompt J/ψ and ψ(2S) with the data recorded during the PbPb runs, at the end of 2010 ($L_{\rm int}$ $\sim 7.3\ \mu{\rm b}^{-1}$) and 2011 ($L_{\rm int} \sim 150\ \mu{\rm b}^{-1}$), and during the pp runs, in March 2011 ($L_{\rm int} \sim$ 231 nb^{-1}) and at the beginning of 2013 ($L_{\rm int}$ ~ 5.4 pb^{-1}), all at $\sqrt{s_{\rm NN}}$ = 2.76 TeV, and the study on the relative suppression of J/ψ and ψ(2S) using ratio of their yields in PbPb and pp data. Also we did a theoretical study on quarkonium suppression due to color screening in an expanding QGP based on a dynamical model which takes into account lifetime and size of QGP.

We measure the inclusive J/ψ production produced in PbPb collisions at $\sqrt{s_{\rm NN}}$ = 2.76 TeV. *Non-prompt* J/ψ from b-hadron decays have been separated from *prompt* J/ψ (directly produced or decayed from higher excited states) utilising the reconstructed decay vertex of the $\mu^+\mu^-$ pair. An explicit study was carried out to tune and optimise the cut variables (number of valid tracker hits, $\chi^2/ndof$ of both the inner track and the global fit, etc) which are applied in physics analysis to obtain good quality muons [1]. Experimentally, the suppression is quantified by the ratio of the yield measured in heavy-ion collisions over the yield measured in pp collisions where no QGP is formed. Such a ratio is called nuclear modification factor, $R_{\rm AA}$.

$$R_{\rm AA} = \frac{\mathcal{L}_{\rm pp}}{T_{AA}\dot{N}_{MB}}\frac{N_{PbPb}}{N_{pp}} \cdot \frac{\varepsilon_{pp}}{\varepsilon_{PbPb}}, \quad (1)$$

where $N_{\rm MB}$ is the number of minimum bias events in PbPb, $\rm T_{AA}$ is the nuclear overlap function, $\mathcal{L}_{\rm pp}$ is the integrated luminosity of the pp data and $\varepsilon_{\rm pp}$ and $\varepsilon_{\rm PbPb}$ are the combined trigger and reconstruction efficiency in pp and PbPb respectively. In the absence of medium effects, one would expect $R_{\rm AA} = 1$ for hard processes.

The prompt J/ψ, integrated over the rapidity range $|y| < 2.4$ and high-p$_T$, 6.5 $<$p$_T$ $<$ 30 GeV/c, has been measured in 12 centrality bins, starting with the 0-5% bin (most central), up to 60–100% bin (most peripheral). The $R_{\rm AA}$ shows a steady and smooth decrease of suppression with the $R_{\rm AA}$ remaining < 1 in the most peripheral bin [2]. Integrated over rapidity and centrality, there is no evidence of suppression dependence with p$_T$, while the rapidity dependence is very weak, consistent with being at the same level of suppression.

The centrality-integrated $R_{\rm AA}$ value measured for 6.5 < p_T < 30 GeV/c and |y| < 2.4 is 0.34 ± 0.02 (stat.) ± 0.04 (syst.).

For non-prompt J/ψ, the centrality dependence shows a slow decrease of the $R_{\rm AA}$ with decreasing centrality. For high-p_T (6.5 < p_T < 30 GeV/c) non-prompt J/ψ there is an indication of less suppression in the mid-rapidity region compared to forward region, while the p_T dependence results show hints of less suppression at low p_T (3.0 < p_T < 6.5 GeV/c). However, in both cases, within the present uncertainties, all measured values are compatible with being the same. These measurements represent the first unambiguous and detailed look at the b-quark energy loss dependence on centrality, p_T and rapidity [2].

In charmonia double ratio, the first observation of the ψ(2S) meson in heavy-ion collisions at the LHC has been presented [3]. The double ratio of measured yields, $(N_{\psi(2S)}/N_{J/\psi})_{\rm PbPb}/(N_{\psi(2S)}/N_{J/\psi})_{\rm pp}$ is computed in three PbPb event centrality ranges and two kinematical bins: one at midrapidity, $|y| < 1.6$, covering the transverse momentum range $6.5 < p_{\rm T} < 30\,{\rm GeV}/c$, and the other at forward rapidity, $1.6 < |y| < 2.4$, extending to lower $p_{\rm T}$, 3-30 GeV/c. Most of the non-prompt J/ψ and ψ(2S) mesons, coming from b-hadron decays, are subtracted through a cut on the pseudo-proper decay length, ℓ_ψ. The ℓ_ψ cut value is tuned from MC simulation studies, separately for the pp and PbPb collision systems, such that 90% of the prompt J/ψ and ψ(2S) are kept, typically rejecting 80% of the non-prompt ones. A substantial study is performed to obtain the best shapes of signal and background. The background is described by Chebychev polynomials, of order $0 \leq N \leq 3$ independently determined for each analysis bin, with LLR tests.

The CMS measurements show interesting observations: 1) The derived $R_{AA}(\psi(2S))$ for midrapidity bin is 0.13 ± 0.04 (stat.) ± 0.02 (syst.) ± 0.01 (pp) and for forward rapidity bin it 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. 2) 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 [3].

In theoretical study, we calculated the survival probabilities of quarkonium (Υ and ψ) states and obtain the nuclear modification factors due to colour screening in an expanding quark gluon plasma of finite lifetime and size produced during PbPb collisions $\sqrt{s_{NN}}$ = 2.76 TeV. The formation time and dissociation temperatures of quarkonium states obtained from potential models are used as input parameters in the model. We used slightly lower values of the dissociation temperatures to get a good description of the measured nuclear modification factors of $\Upsilon(1S)$ and $\Upsilon(2S)$. The model reproduces the centrality dependence of measured nuclear modification factors of $\Upsilon(1S)$ and $\Upsilon(2S)$ and the double ratio very well at $\sqrt{s_{\rm NN}}$ = 2.76 TeV [4]. The model calculation performed for charmonia shows that the double ratio is close to one in all centrality region. It means that sole effect of color screening cannot explain the data in the analysed kinematic bins. This phenomenon requires models with new insights which incorporate different nuclear mechanism of charmonium suppression and regeneration in QGP.

References

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