Bottomonia thermalization in heavy-ion collisions at the Large Hadron Collider

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Introduction

Bottomonium suppression is considered as a promising diagnostic probe of the properties of the hot and dense medium created in high-energy heavy-ion collisions [1]. If quark-gluon plasma (QGP) is formed in the collision zone, the confining potential of heavy quark-antiquark pairs is expected to be screened because of interactions with quarks and gluons in the medium. The resulting dissociation of the bottomonium states in a hot deconfined plasma depends on the binding energy, with weakly bound states having lower dissociation temperature (T_d). This leads to the characteristic sequential suppression pattern of different bottomonium states in heavy ion collisions compared to their production in p-p collisions. In Pb-Pb collisions at the Large Hadron Collider (LHC), bottomonium states ($\Upsilon(nS)$) are measured with reasonably good statistics at $\sqrt{s_{NN}} = 2.76$ TeV and $\sqrt{s_{NN}} = 5.02$ TeV. A comparable suppression pattern is observed for the $\Upsilon(1S)$ state [2]. Within the large uncertainties, this result seems to indicate a little modification induced by the hot plasma on the strongly bound $\Upsilon(1S)$ state. The excited states ($\Upsilon(2S)$, $\Upsilon(3S)$) show stronger suppression at both collision energies, in line with the sequential suppression scenario. In Ref. [3] the authors have addressed, for the first time, the issue of quarkonium thermalization at LHC by analyzing the relative yields of different bottomonium states in $\sqrt{s_{NN}} = 2.76$ TeV Pb-Pb collisions, using then available data. The observed sequential suppression of the Υ family of mesons as measured by the CMS collaboration, was interpreted as the bottomonium states attaining thermal equilibrium in the fireball and then freezeing out at a temperature $T_f = 220 \pm 29$ MeV, much earlier than the bulk of the medium made of light hadrons. The near constancy of T_F across various collision centralities was cosnidered as an evidence for thermalization, in a sense that initial state information is forgotten. The results however suffered from the large uncertainty associated with the then available data, forbiding one to make any mature claim. Compared to then the situation is much improved now in terms of availability of high precision data. Both CMS and ALICE collaborations have collected high statistics data for bottomonium production in p-p, p-Pb and Pb-Pb collisions. This motivates us to perform a reinvestigation of bottomonium chemical freeze out analysis at LHC, by investigating their relative production yield in Pb-Pb collisions. An ideal Hadron Resonance Gas (HRG) model is employed to calculate the equilibrium density of different bottomonium states.

Brief description of the HRG model

The Hadron Resonance Gas model, a thermal statistical model, is very successful in describing the particle abundances and thereby extracting the chemical freeze-out parameters [4]. The ideal HRG (ID-HRG) model partition function is constructed considering a grand canonical ensemble of non-interacting multi-component hadronic systems. In the ID-HRG model, the primordial yield (N^p) of the i^{th} hadron at zero chemical potential ($\mu = 0$),

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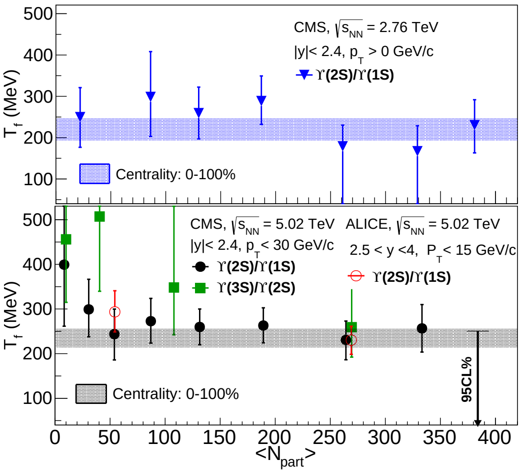

FIG. 1: The centrality dependence freeze-out temperatures in the PbPb system were extracted using different relative yields of the bottomonium states measured by different LHC experiments at $\sqrt{s_{NN}}$ = 2.76 (upper panel) and 5.02 TeV (lower panel). The band represents T_F for centrality integrated events.

can be obtained as

$$N_i^p = \frac{g_i V}{2\pi^2} \int_0^\infty dp \, \frac{p^2}{\exp\left(\sqrt{m_i^2 + p^2}/T\right) \pm 1} \tag{1}$$

where, the sign, '±', corresponds to the fermion and boson respectively and other symbols have their usual meaning. The measured yield of i^{th} hadron also contains the contribution of decay feed-down from heavier resonances. So, the total multiplicity of the i^{th} hadron is given by sum of the primordial (N^p) yield as well as the feed-down contribution from heavier resonances states.

Results & Discussions

The results of our thermal analysis of the relative yields ($\Upsilon(2S)/\Upsilon(1S)$) of the $2S$ and $1S$ bottomonium states measured by both CMS and ALICE collaborations in Pb-Pb collisions at LHC are displayed in Fig. 1. At $\sqrt{s_{NN}}$ = 2.76 TeV (upper panel), our estimated value of T_F, extracted from the centrality integrated data comes out to be, 221^{+21}_{-22} MeV, in agreement with the previous result. No strong centrality dependence of T_F is observed, with a small drop towards more central collisions. The uncertainty in the estimated T_F significantly reduces for $\sqrt{s_{NN}}$ = 5.02 TeV (lower panel) due to improved data quality. There is a small increase in T_F for almost all the centrality intervals at higher $\sqrt{s_{NN}}$, though the trend of the T_F, i.e., centrality independence and modest decrease of freeze-put temperature for the most central collisions, remains the same. Note tha the ALICE measurements are at the forward rapidity [5], but the corresponding T_F values lie within the uncertainty range to that of CMS mid-rapidity data, inferring the rapidity independence of freeze-out temperature. We have also extracted the T_F from the single ratio, $\Upsilon(3S)/\Upsilon(2S)$, recently presented by CMS collaboration. For more central collisions, the extracted T_F matches within uncertainty with that obtained from excited-to-ground state ratio. All these results together possibly indicate the thermalization of the massive hard produced bottomonium states with the hot and dense medium in the nuclear collisions at LHC.

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