Quarkonia production in PbPb collisions at $\sqrt{s}_{NN} = 2.76$ TeV

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1. Introduction

One of the most important signal of Quark Gluon Plasma (QGP) is the suppression of quarkonium states [1], both of the charmonium (J/ψ, $\psi(2S)$, χ_c, etc) and the bottomonium ($\Upsilon(1S)$, $\Upsilon(2S)$, χ_b, etc) families. This is thought to be a direct effect of deconfinement, when the binding potential between the constituents of a quarkonium state, a heavy quark and its antiquark, is screened by the colour charges of the surrounding light quarks and gluons. In this paper, we calculate the Quarkonia suppression due to thermal gluon dissociation in an expanding Quark Gluon Plasma. The quarkonia yields in heavy ion collisions are also modified due to non-QGP effects such as shadowing, an effect due to change of the parton distribution functions inside the nucleus, and dissociation due to nuclear or comover interaction [2]. We allow for cold nuclear-matter (CNM) suppression, collectively defined as being due to modifications of quarkonia prior to thermalization.

2. Modification of Quarkonia in presence of QGP

The number of quarkonia at hadronization time τ_f is given by

$$N(\tau_f, p_T) = S(p_T)\, N(\tau_0, p_T), \qquad (1)$$

The survival probability $S(p_T)$ is written as

$$S(p_T) = \exp[-\int_{\tau_0}^{\tau_f} \Theta(\tau - \tau_{\rm F})\lambda_{\rm D}(T)\, \rho_g(T)\, d\tau] \qquad (2)$$

where $\tau_{\rm F}$ is p_T dependent formation time for resonance given by $\tau_F = \tau_{\rm Form}\, p_T/M$. Number density of gluons is given by ρ_g and λ_D is dissociation rate of quarkonia by thermal gluons, given by

$$\lambda_{\rm D}(T)\, \rho_g(T) = \langle \sigma_D v_{\rm rel} \rangle \qquad (3)$$

The Nuclear modification factor (R_{AA}) can be written as

$$R_{AA}(N_{\rm part}) = \frac{\int_{p_{T min}}^{p_{T max}} N(\tau_0, p_T) S(p_T) dp_T}{\int_{p_{T min}}^{p_{T max}} N(\tau_0, p_T) dp_T} \qquad (4)$$

The temperature evolution for different centralities of collision is obtained by assuming an isentropically expanding medium with volume $V(\tau) = \tau\, \pi\, r_0^2 \Delta y$. The initial transverse radius, r_0 as a function of centrality is obtained in terms of the radius of the Pb nucleus (R_0) as

$$r_0(N_{\rm part}) = R_0 \sqrt{\frac{N_{\rm part}}{N_{\rm part0}}}. \qquad (5)$$

where $N_{\rm part0} = 2A$ is the total number of participants in head on collisions. The temperature variation with time is obtained by

$$s(\tau)\, V(\tau) = s(\tau_0)\, V(\tau_0) = S. \qquad (6)$$

Using $s(\tau) = 4a_q T^3$

$$T(\tau)^3 = \frac{S}{4a_q V(\tau)}. \qquad (7)$$

where a_q is the degrees of freedom in quark gluon phase. We relate initial temperature with measured charged particle multiplicity as

$$S = 4a_q V(\tau_0)|_{0-5\%} T_0^3 = 3.6 \left(\frac{dN}{d\eta}\right)_{0-5\%}. \qquad (8)$$

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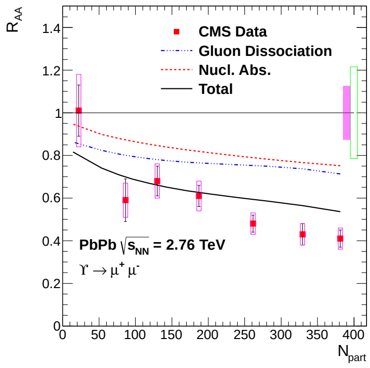

FIG. 1: Nuclear modification factor (R_{AA}) compared with CMS data for Υ suppression.

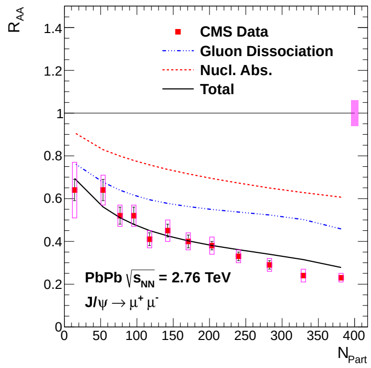

FIG. 2: Nuclear modification factor (R_{AA}) compared with CMS data for J/ψ suppression.

Using $(dN/d\eta)_{0-5\%}$=1.5×1600 obtained from the charge particle multiplicity measured in Pb+Pb collisions at 2.76 TeV [3] and $N_f = 2$, we calculate initial temperature 0.610 GeV at time $\tau_0 = 0.1$ fm/c. Transverse size of the system for 0-5% centrality is $R_{0-5\%} = 0.92R_0$, obtained from Eq. (5). The initial temperature for different centralities is calculated by

$$T_0^3(N_{\rm part}) = T_0^3 \left(\frac{dN/d\eta}{N_{\rm part}/2}\right) / \left(\frac{dN/d\eta}{N_{\rm part}/2}\right)_{0-5\%} \quad (9)$$

The gluon-J/$\psi(\Upsilon)$ dissociation cross section in dipole approximation is given by [?]

$$\sigma_D(q^0) = C \times \frac{1}{m_Q(\epsilon_0 m_Q)^{1/2}} \frac{(q^0/\epsilon_0 - 1)^{3/2}}{(q^0/\epsilon_0)^5} . \quad (10)$$

here m_Q is $c(b)$ quark mass, and q^0 the gluon energy in the J/$\psi(\Upsilon)$ rest frame, its value must be larger than the quarkonia binding energy ϵ_0. We use vacuum binding energies of J/ψ and Υ.

3. Cold Nuclear Matter Effects

For simplicity we approximate the combination of all CNM effects by a suppression factor,

$$S_{Nucl} = \exp[-\rho_N \sigma_{abs} L(b)] \quad (11)$$

with an effective nuclear absorption cross section, σ_{abs}. We take absorption cross section, σ_{abs} = 3 mb (2 mb) for J/$\psi(\Upsilon)$. The other parameters in Eq. 11 are the nuclear density, ρ_N=0.14 fm^{-3}, and the impact-parameter dependent path length, $L(b)$, evaluated with a Glauber model for the nuclear overlap.

4. Results and discussion

Fig. 1 and Fig. 2 show comparison of Nuclear Modification Factor measured by CMS experiment [4, 5] with our calculations respectivily for Υ and J/ψ. Our model with both, gluon dissociation and nuclear absorption describes the data very well although, slight difference in most central collisions may be due to reduction of binding energy of quarkonia with temperature and lowering of vacuum quark mass.

References

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