Transverse momentum dependence of Υ'/Υ ratio in heavy ion collisions at LHC

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Introduction

The heavy ion collisions at high energy are performed to produce and study strongly interacting matter at high temperatures where a formation of quark gluon plasma (QGP) is expected. The most popular signal of this phase is the suppression of quarkonia due to screening by color charges. The suppression is predicted to occur above a critical temperature T_c, sequentially, in order of the binding energy. The dissociation temperatures are < 1 T_c, 1.2 T_c, and above 2 T_c for the Υ'', Υ' and Υ respectively. The ratios of the two quarkonia states are better probes of QGP as the nuclear matter effects cancel out. Ratio of upsilon states has been measured in Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV[1]. It was shown many years back [2, 3] that the p_T dependence of such ratio would show large variation and would be a direct probe of the QGP. In this work, we calculate the the ratio Υ'/Υ using essentially same model with the parameters relevant for LHC.

Quarkonia suppression model

For a screening mass μ(T) above a certain critical value, the resonance no longer forms in the plasma. The temperature T_D at which this happens is break up temperature for each bound state [4]. The time at which the temperature drops to T_D is

$$t_D = t_0 \left(\frac{T_0}{T_D}\right)^3, \tag{1}$$

where t_0 is formation time and T_0 is initial temperature of the QGP.

The p_T suppression pattern of a resonance is the consequence of the competition between the resonance formation time, τ_F and temperature, lifetime and spatial extent of the QGP. As long as $t_D/\tau_F > 1$, quarkonium formation will be suppressed. The maximum p_T below which suppression occurs is

$$P(T, max) = M\sqrt{\frac{t_D}{\tau_F} - 1}. \tag{2}$$

The T_D is obtained from SU(N) lattice simulations referred as SU(N) QGP, for which T_c = 260 MeV. The mass, radius, formation time and screening temperature of the resonances are given in Table I . The minijet initial conditions are $t_0 = 0.1$ fm, $T_0 = 0.9$ GeV.

TABLE I: Resonance masses, radii, formation time, screening temperature and time.

	Mass GeV	Radius fm	τ_F fm	T_D GeV	t_D fm/c
Υ	9.445	0.226	0.76	0.391	1.22
Υ'	10.004	0.509	1.9	0.260	4.15

At any time t, during the evolution of the QGP, the spatial boundary of the screening region is located at the transverse radius r_S given by $t_D(r_S) = t$,

$$r_S = R(1 - (\gamma\tau_F/t_D(0))^{1/\beta})^{1/2}, \tag{3}$$

where $t_D(0)$ is the value of t_D calculated by eq. (1) for resonances produced in the center of the system and $\gamma = \sqrt(1 + (p_T/M)^2)$. The $Q\overline{Q}$ can escape the QGP before the τ_F for a range of angles between r and p_T provided $(r + \tau_F p_T/M) > r_S$. The probability $S(p_T)$ that the $Q\overline{Q}$ pair survives and is able to

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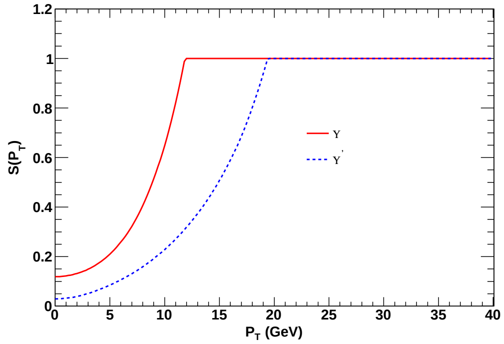

FIG. 1: Survival probability versus p_T.

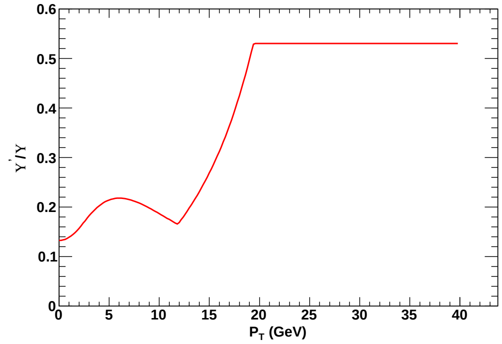

FIG. 2: The ratio Υ'/Υ versus p_T.

form an onium state is the ratio of the number of bound states produced by those pairs that escape the plasma to the maximum possible number of onium bound states that would be formed at the given p_T in the absence of the QGP:

$$S(p_T) = \frac{\int_0^R drr\rho(r)\theta(r,p_T)}{\pi\int_0^R drr\rho(r)}, \tag{4}$$

where $\rho(r)$ and $\theta(r,p_T)$ are

$$\rho(r) = (1-(r/R)^2)^\alpha \tag{5}$$

and

$$\begin{aligned} \theta(r,p_T) &= \pi \qquad z \le -1 \\ &= cos^{-1}z \qquad |z| < 1 \\ &= 0 \qquad z \ge 1, \end{aligned}$$

where z

$$z = \frac{r_S^2 - r^2 - (\tau_F p_T/M)^2}{2r\tau_F p_T/M}. \tag{6}$$

The parameters $\beta = 1/3$ and $\alpha = 1/2$.

Results and Discussion

Figure 1 shows the survival probability versus p_T for Υ and Υ' for an SU(N) QGP with initial conditions $T_0 = 0.9$ GeV and $t_0 = 0.1$ fm/c and $R = 7.1$ fm. One can observe that both Υ and Υ' are suppressed in the medium. At small p_T, $S(p_T) \sim 0$ corresponding to total suppression. The maximum transverse momentum $p_{T,\max}$ below which the upsilon is suppressed is different for the two states. If the QGP is of smaller spatial extent, the survival probability can become unity even for a smaller p_T.

Figure 2 shows the Υ'/Υ ratio versus p_T. Only directly produced Υ' and Υ are included in the ratio. Due to different suppression patterns of the two states, the ratio is small at low p_T with some fluctuating behavior and will become constant at high p_T.

To summarize, both the upsilon states will be suppressed at low p_T. The p_T above a certain value $p_{T,\max}$ the upsilons will escape. This $p_{T,\max}$ is different for both the states and thus their ratio will show large variation in low p_T range in the presence of QGP.

References

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