Multiplicity Dependence of Charmonia Suppression in *pp* Collisions at the LHC Energies

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Introduction

The ultra-relativistic heavy-ion collisions at energies available at the RHIC and LHC promise the rich physics of the QCD matter, which is proposed to have existed for a brief period after the few microseconds of the big-bang. However, investigating such an exotic medium in these collisions was challenging, and the reasons were obvious from the physics perspective. The quarkonium suppression proposed by Matsui and Satz [1] and observed at RHIC and LHC energies opened up the possibility for an indirect study of QGP formation in heavy-ion collisions. The suppressed production of quarkonia in heavy-ion collisions is measured by scaling its production with *pp* collisions where QGP-like medium is most unlikely to exist. Nevertheless, in recent observations in *pp* collision, a few QGP-like phenomena have been seen. Getting motivated by these recent observations, we attempted to study the charmonium suppression to investigate the existence of QGP medium in ultra-relativistic *pp* collisions. In this work UMQS model is used to study the multiplicity ($dN_{ch}/d\eta$) and transverse momentum (p_T) dependent suppression of J/ψ and ψ(2S) in *pp* collisions at mid-rapidity [2, 3].

Model Formulation

For the hot QCD matter created in ultra-relativistic collisions, thermalization and isoentropic expansion are considered. The initial thermalization temperature T_0, is obtained as [2];

$$T_0 = \left[\frac{90}{g_k 4\pi^2} C' \frac{1}{A_T \tau_0} \frac{dN_{ch}}{dy}\right]^{1/3}$$

The calculated T_0 is found to be large enough to hold QGP like medium in *pp* collisions at $\sqrt{s}$ = 5.02, 7 & 13 TeV. The cooling rate for T_0 is obtained using second-order viscous hydrodynamical equations under 1+1D evolution,

$$\frac{dT}{d\tau} = -\frac{T}{3\tau} + \frac{T^{-3}\phi}{18a\tau}$$

$$\frac{d\phi}{d\tau} = -\frac{2aT\phi}{3b} - \frac{1}{2}\phi\left[\frac{1}{\tau} - \frac{5}{\tau}\frac{dT}{d\tau}\right] + \frac{8aT^4}{9\tau}$$

These equations are solved numerically to obtain the temperature cooling rate $T(\tau)$. We have observed that medium created in *pp* collisions cool down below $T < Tc$ at $\tau = 3 \sim 4$ fm. In this time scale, the charmonium suppression is expected, as the kinematics of quarkonia gets modified in the presence of the QGP medium. The transport equation that governs the charmonium kinematics in QGP medium is given as;

$$\frac{dN_{J/\psi}}{d\tau} = \Gamma_{F,nl} N_c \; N_{\bar{c}} \; [V(\tau)]^{-1} - \Gamma_{D,nl} N_{J/\psi}$$

here, $\Gamma_{F,nl}$ and $\Gamma_{D,nl}$ represent the formation and dissociation of the $c\bar{c}$ bound states, respectively. The solution of this transport equation gives the net number of charmonia by taking gluonic dissociation, collision damping, and regeneration mechanisms into account. Color screening is another mechanism that does not allow charmonium to form if $T > T_D$, (here T_D is the dissociation temperature of the charmonia). Therefore, suppression due to color screening is not included in the transport equation. However, to obtain the net suppression, color screening, gluonic dissociation, collisional damping, and regeneration mechanisms are put together in the UMQS framework [2, 3]. Finally, charmonia suppression is measured in terms of the survival probability (S_P) of the particle propagating through deconfined QCD matter. The net survival probability (S_P) also includes the feed-down of the higher resonances into J/ψ.

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Results and Discussions

To check the feasibility of our model (UMQS model) with the experimental data, we have compared the normalized p_T -integrated J/ψ production as a function of the normalized charged-particle multiplicity, defined as [3];

$$N_m^{J/\psi} = \frac{dN_{J/\psi}/d\eta}{\langle dN_{J/\psi}/d\eta \rangle}, \qquad N_m^{ch} = \frac{dN_{ch}/d\eta}{\langle dN_{ch}/d\eta \rangle}$$

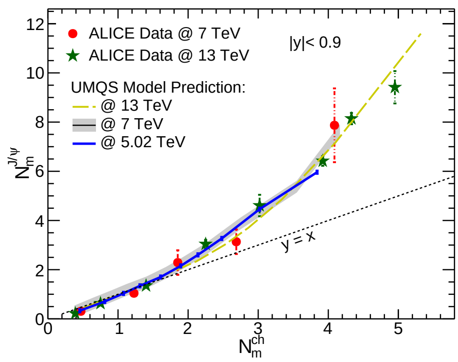

FIG. 1: Normalized yield as a function of normalized multiplicity at mid-rapidity is compared with ALICE data corresponding to V0M selection. A prediction for the same at $\sqrt{s} = 5.02$ TeV is also shown [3].

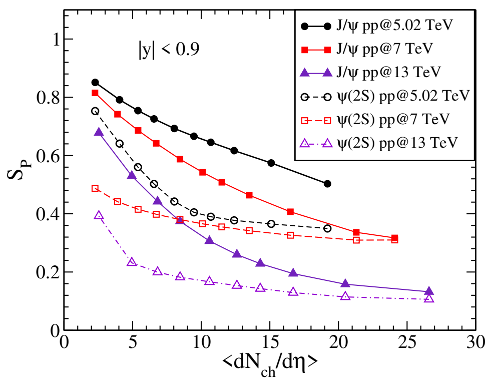

FIG. 2: Model predictions for J/ψ and ψ(2S) suppression as a function of multiplicity corresponding to various *pp* collision energies [3].

Fig. 1 depicts that our model prediction of the normalized p_T-integrated J/ψ production, explains the data within the uncertainties. Fig. 2, shows that suppression of charmonium states increases with the multiplicity, and it further increases with increasing center-of-mass energy from $\sqrt{s} = 5.02$ to 13 TeV. At all the collision energies, ψ(2S) suppression is higher than J/ψ. Similar behavior is also observed in the transverse momentum-dependent suppression study in Fig. 3. Here we observed that suppression for both the charmonium species decreases for $p_T > 6$ GeV, as shown in Fig 3.

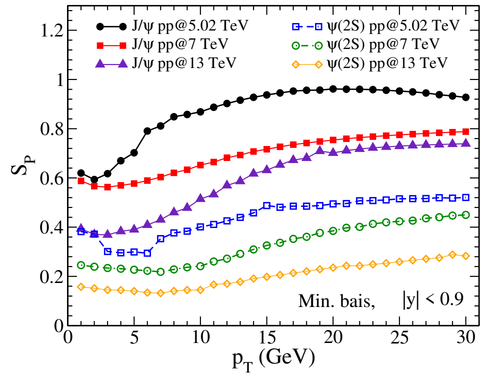

FIG. 3: Model prediction for J/ψ and ψ(2S) suppression as the function of transverse momentum (p_T) corresponding to various *pp* collision energies are shown [3].

Conclusions

Our current study shows a QGP like behaviour at all the multiplicities bin in ultra-relativistic *pp* collisions at $\sqrt{s} = 5.02, 7$ & 13 TeV LHC energies. The formation of QGP-like medium in such a small system requires a new baseline to analyze QGP effects in *AA* collisions at LHC energies.

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