J/ψ suppression and enhancement at LHC

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Introduction

Collisions of Pb ions at Large Hadron Collider (LHC) at energies $\sqrt{s}_{NN} = 5.5$ TeV would create strongly interacting matter at very high temperatures where a phase transition to quark gluon plasma (QGP) is expected. The J/ψ particles are the richest and most interesting probes of QGP. The SPS data [1] convincingly show that J/ψ is suppressed, while PHENIX data are explained by accounting for both partial suppression and partial enhancement scenarios. At LHC, a large number of $c\bar{c}$ pairs are produced initially which could lead to an important source of final charmonium. This coalescence mechanism could lead to enhancement instead of suppression of J/ψ at LHC.

Charm production rates

The analysis begins with the J/ψ cross sections for pp collisions which are taken from CERN yellow report [2] and from Ref. [3] and extrapolated to PbPb collisions. The J/ψ production cross section per nucleon pair is 11.7 μb for PbPb minimum bias collision at 5.5 TeV. This is calculated using parton distribution function (pdf) MRST HO with c quark mass as 1.2 GeV. EKS98 parameterizations are used to take into account the effect of nuclear shadowing in both the cases.

Number of hard processes per triggered event with impact parameter $b < b_c$ can be obtained from the corresponding pp cross section as follows:

$$N_{\rm AB}^{\rm hard}(b_c) = R(b_c)\ \sigma_{\rm pp}^{\rm hard} \qquad (1)$$

where, $R(b_c = 3.5) = 26.6$ mb^{-1} for 5 % centrality and $R(b_c = 5.0) = 23.7$ mb^{-1} for 10 % centrality [3].

Nuclear absorption

The produced quarkonia can interact with the hadronic matter of the colliding nuclei and give open charm mesons.

The quarkonia absorption cross section at LHC can be obtained from the extrapolation from SPS and RHIC data. This is given by $\sigma_{\rm abs} = 11.3$ mb. The survival probability [4] for this cross section from nuclear absorption is obtained as 25 % for central collisions.

Quarkonia dissociation in QGP

In QGP due to colour screening no bound state can exist at temperature $T > T_D$ when the screening radius $1/\mu_b(T) < r_{J/\psi}$. The quarkonium survival probability can be obtained by integrating the dissociation rate over the space time of QGP as,

$$S(\tau) = \exp\left[-\int_{\tau_0}^{\tau} d\tau\, \Gamma(T)\right] \qquad (2)$$

where $\Gamma(T)$ is the quarkonia dissociation rate obtained by quarkonium break up cross section from gluon impact [5]. At LHC, assuming longitudinal expansion with initial conditions $T_0 = 0.72$ GeV and $\tau_0 = 0.5$ fm, the survival probability beyond $\tau = 2$ fm is less than 1 %.

Quarkonia enhancement

The heavy quark production at LHC is substantial which may lead to incoherent recombination of uncorrelated pairs of heavy quarks and anti quarks which result from multiple pair production. Two different approaches have been considered; statistical hadronization and kinetic formation.

In statistical approach [6] the number of J/ψ produced is given by

$$N_{J/\psi} = 4\ \frac{n_{ch} n_{J/\psi}}{n_{\rm open}^2}\ \frac{N_{c\bar{c}}^2}{N_{ch}}. \qquad (3)$$

where n_i's are the thermal densities and $N_{c\bar{c}}$ is the number of charm pairs produced and N_{ch} is the number of total charged particle

TABLE I: J/ψ rates for PbPb collisions at 5.5 TeV. All the numbers are for 5 % centrality.

J/ψ cross section	506 mb
No. of J/ψ per event (5 % centrality)	0.31
No. of $c\bar{c}$ per event (5 % centrality)	115
Survival probability from nuclear absorption	25 %
Survival probability from QGP	< 1 %
No. of J/ψ produced per event (from statistical model)	2.7
No. of J/ψ produced per event (from kinetic model)	1.73

produced. The freeze out parameters are $T =$ 170 MeV and $\mu_B = 0$. For $dN_{ch}/dy = 2000$ and $dN_{c\bar{c}}/dy = 18.75$, we obtain $dN_{J/\psi}/dy =$ 0.37.

In Kinetic approach [7] the proper time evolution of the J/ψ population is given by the rate equation

$$\frac{dN_{J/\psi}}{d_\tau} = \lambda_F \frac{N_c N_{\bar{c}}}{V(\tau)} - \lambda_D N_{J/\psi} \rho_g. \qquad (4)$$

where ρ_g is the gluon number density and $V(\tau)$ is the time dependent volume of the deconfined region. The first term on the right hand side gives the formation process and the second term gives the dissociation process by gluon impact. The λ_F abd λ_D respectively are the formation and decay rates of J/ψ. For $N_{c\bar{c}} = 150$ we obtain $N_{J/\psi} = 2.26$.

Summary

The Table (I) summarizes all the above numbers. In conclusion at LHC all most all of the quarkonium prduced in the collisions will be suppressed. Since the number of initially produced charm pairs is very large it will give a large number of J/ψ at hadronization. The results from different models differ substantially. The transverse momentum distributions of these secondary J/ψ difffer from those initially produced. This aspect is being studied in detail.

References

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