The strong suppression of the $J/\psi$ is studied in the framework of hadronic and quark gluon plasma models. Predictions for RHIC energies are presented.

1 Introduction

The NA50 collaboration data on PbPb central collisions at SPS energies has shown a strong suppression of ratio $R(E_T)$ of $J/\psi$ over Drell-Yan (DY) that increases with increasing $E_T$. This suppression has been proposed as an evidence of the obtention of the quark gluon plasma (QGP). We present our results in the framework of an hadronic model (without QGP) and those of a string model which includes percolation of strings as a way of QGP.

2 Hadronic model

We use the model of ref. Here, as in most non-QGP models, the $J/\psi$ suppression is due to two mechanisms: absorption of the pre-resonant $c\bar{c}$ pair with nucleons (the nuclear absorption) and the interaction of the $J/\psi$ with comovers. The corresponding $J/\psi$ survival probabilities are given by

$$S_{abs}(b,s) = \frac{1 - \exp[-A T_A(s) \sigma_{abs}]}{\sigma_{abs}^2 AB T_A(s) T_B(b-s)} \{ 1 - \exp[-B T_B(b-s) \sigma_{abs}] \} ,$$

$$S_{co}(b,s) = \exp \left\{ -\sigma_{co} N_{co}^y(b,s) \ln \left( \frac{N_{co}^y(b,s)}{N_f} \right) \right\} .$$

The survival probability $S_{co}$ depends on the density of comovers $N_{co}^y(b,s)$, that we have computed using the dual parton model (DPM), and $N_f = 1.15$ fm$^{-2}$ is the corresponding density in $pp$ collisions.

At fixed impact parameter $b$, the $J/\psi$ cross-section is given by

$$\sigma_{AB}^\psi(b) = \frac{\sigma_{pp}^\psi}{\sigma_{pp}} \int d^2s m(b,s) S_{abs}(b,s) S_{co}(b,s) ,$$

where $m(b,s) = AB \sigma_{pp} T_A(s) T_B(b-s)$. The corresponding one for DY pair production is obtained from putting $\sigma_{abs} = \sigma_{co} = 0$ (i.e. $S_{abs} = S_{co} = 1$).
Figure 1. The ratio $R(E_T)$ of $J/\psi$ over DY cross-sections, obtained with $\sigma_{abs} = 4.5$ mb and $\sigma_{co} = 1$ mb, compared to the NA50 data. The non-saturation of the ratio at $E_T > 100$ GeV is obtained when including $E_T$ fluctuations.

and is proportional to $AB$. In this way we can compute the ratio of $J/\psi$ over DY as a function of the impact parameter. Experimentally, however, the ratio $R(E_T)$ is given as a function of the transverse energy $E_T$. In order to compute $R(E_T)$ we have to know the correlation $P(E_T, b)$ between $E_T$ and impact parameter, which is given by

$$P(E_T, b) = \frac{1}{\sqrt{2\pi q a E_{NF}^T(b)}} \exp \left[ \frac{-[E_T - E_{NF}^T(b)]^2}{2q a E_{NF}^T(b)} \right],$$

(4)

where $E_{NF}^T(b) = q N_{co}^b (b)$. The quantity $E_{NF}^T(b)$ in eq. (4) does not contain fluctuations. In effect, if we calculate the quantity $F(E_T) = E_T/E_{NF}^T(E_T)$, we see that $E_{NF}^T$ coincides with $E_T$ only up to the knee of the $E_T$ distribution. Beyond it, $E_{NF}^T$ is smaller than the true value of $E_T$.

So in order to compute the ratio $R(E_T)$ beyond the knee of the $E_T$ distribution it is necessary to introduce in $N_{co}^b$ the $E_T$ (or multiplicity) fluctuations responsible for the tail of the distribution. This leads to the replacement $N_{co}^b(b, s) \rightarrow N_{co}^b(b, s) F(E_T)$ in the above equations. In this way the results for the ratio $R(E_T)$ are unchanged below the knee of the distribution. Beyond it, the $J/\psi$ suppression is increased as a result of the fluctuation.
3 Percolation of strings

In most of the hadronic models of multiparticle production, color strings are exchanged between projectile and target. These strings may be viewed as small areas $\pi r_0^2$, $r_0 \simeq 0.2$ fm, in the transverse space. Particles are produced via emission of $q\bar{q}$ pairs in this color field. The number of exchanged strings grows with the energy and the atomic number of the colliding particles. When the density of strings is high, they can overlap, forming clusters. At a certain critical density a large cluster appears, which signs the percolation phase transition.

A cluster formed by many strings has a very high color and therefore a very large string tension which can enhance the $c\bar{c}$ pair production. This effect works in the opposite direction to the Debye screening which makes that above the percolation threshold the probability of binding the $c\bar{c}$ pair to form a $J/\psi$ is strongly reduced.

Here we are going to compute in a single and direct way the two opposite effects at SPS, RHIC and LHC energies.

3.1 Enhancement of $c\bar{c}$ production

We consider the extension of the Schwinger formula for the production of $q\bar{q}$ pairs of mass $m_j$ in a uniform color field with charge $g_j$, per unit space-time volume

\[
\frac{dN_{q\bar{q}}}{dy} = \frac{1}{8\pi^2} \int_0^\infty d\tau T \int d^2x |g_j E|^2 \sum_{n=1}^\infty \frac{1}{n^2} \exp\left(-\frac{\pi nm_j^2}{|g_j E|}\right). \tag{5}
\]

The strings form clusters, each of them with a constant color field $E_i = Q_i/S_i$, where $Q_i$ and $S_i$ correspond to the cluster color charge and the cluster area. The charge and the field of each cluster before the decay, $Q_{i0}$ and $E_{i0}$, depend on the number $n_i$ of strings and the area $S_i$ of each individual string that comes into the cluster, as well as on the total area of the cluster $S_i$, $Q_{i0} = \sqrt{\frac{n_i S_i}{S_1}} Q_1$, $E_{i0} = \frac{Q_{i0}}{S_1} = \sqrt{\frac{n_i S_i}{S_1}} E_1$.

We also take into account the evolution of the field and the charge with the decay of the cluster, $E_i = E_{i0} \left(1 + \frac{1}{(1 + \sqrt{m_j E_{i0}})^2}\right)$, $Q_i = Q_{i0} \left(1 + \frac{1}{(1 + \sqrt{m_j E_{i0}})^2}\right)$ where $\tau \sim 1/\sqrt{E_{i0}}$.

3.2 Probability of QGP formation

It is assumed that the $J/\psi$ is formed only in events in which there is not percolation. The probability of percolation is taken to be

\[
P_{\text{perc}} = 1/(1 + \exp(-(\eta - \eta_c)/a)) \tag{6}
\]
where \( \eta = \frac{\pi r_0^2 N_s}{A(\nu)} \) corresponds to the density of strings, \( \eta_c = 1.15 \) is the critical density for percolation and \( a = 0.04 \). The probability for DY and \( J/\psi \) production when there are \( \nu \) elementary collisions are

\[
P(DY|\nu) = \alpha_{DY} \nu ,
\]

\[
P(J/\psi|\nu) = \alpha_{J/\psi} \nu e^{-\sigma\eta/\pi r_0^2} \frac{1}{\exp((\eta - \eta_c)/a) + 1} ,
\]

and the ratio \( R \) of \( J/\psi \) to DY events is

\[
R = k \exp(-\sigma\eta/\pi r_0^2)/[\exp((\eta - \eta_c)/a) + 1] .
\]

However, as we said before, the probability of \( c\bar{c} \) production increases with \( \eta \). In order to include this fact, we multiply the expression (9) by

\[
P_{c\bar{c}}(\eta)/P_{c\bar{c}}(\eta_{SPS})
\]

assuming that the leading \( c\bar{c} \) pair production energies is given by the Schwinger mechanism [3]. Our results are plotted in Fig. 2.

References

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