CHARMONIUM DISSOCIATION AND RECOMBINATION: COLD EFFECTS

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Thirty years ago, Matsui and Satz proposed the J/ψ destruction as a signal of a Quark Gluon Plasma (QGP) formation, due to the Debye screening between the pair c-cbar. At the light of the recent experimental data, I review the different effects on J/ψ production, from SPS to LHC energies, distinguishing between Cold Nuclear Matter (CNM) and QGP effects. Different possibilities and explanations for the available experimental data are discussed. Model predictions for the arriving LHC data are also presented

1 Introduction

The J/ψ production constitutes one of the most puzzling fact of the present and futures experiments. Its suppression was initially proposed as a signal of the formation of a QGP. Data from NA50 collaboration at SPS energies have shown an anomalous suppression, greater than the expected one from the usual nuclear absorption. The data at RHIC energies from PHENIX collaboration show the same amount of suppression as the SPS data, while their energy collision is 10 times higher, and show stronger suppression at forward than at mid rapidity.

Trying to explain all these facts, I propose the following distinction among the effects: I will consider on one side the Cold effects, meaning by cold the fact that in those effects no thermalization is considered, even if the medium is dense. So these are effects without QGP.

On the other side we have the Hot effects, where thermalization is taken into account and QGP formation is included.

I will focus on the first group. Note that this group is constituted by both initial and final effects. In fact, the shadowing of the nuclear structure functions, the nuclear absorption –that is, the suppression of the J/ψ due to the scattering of the pre-resonant c-cbar pair within the nucleus– and the partonic and hadronic dissociation of the c-cbar pair with the dense medium produced in the collision –the comover interaction– belong to this group.

2 Shadowing

Shadowing refers to the mechanism that makes the nuclear structure functions in nuclei different from the superposition of those of their constituents nucleons. The data on $d-Au$ collisions obtained by PHENIX collaboration show that there is an important suppression of the J/ψ production due to this initial state effect. An exhaustive study of the nuclear modification factor versus rapidity, the number of collisions and transverse momentum has been developed in [1]. Note that the shadowing increases with x and decreases with Q^2, so in principal its effect can be considered negligible at SPS energies. A comparison of two different types of shadowing is shown in Fig. 1 where the results from gluon shadowing[2] (CF) and EKS evolution model (EKS) are compared.

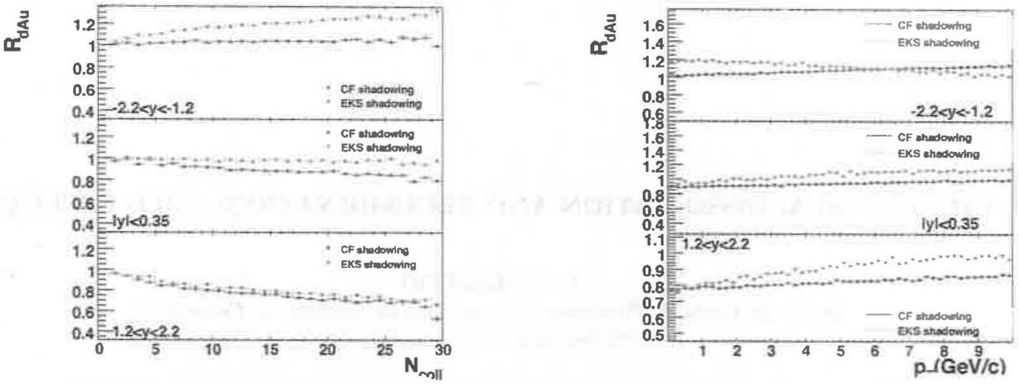

Figure 1: Nuclear modification factor as a function of the number of collisions (left) and as a function of the J/ψ transverse momentum (right) from CF shadowing and EKS models in the absence of nuclear absorption.

3 Nuclear absorption

The primordial spectrum of particles is altered by interactions with the nuclear matter they traverse on the way out to the detector. This effect is known as nuclear absorption. It depends on the coherence length,

$$\Delta = \frac{1}{l_c} = m_p \frac{M_{c\bar{c}}}{s x_1},$$

in such a way that, at low energy, the heavy system undergoes successive interactions with nucleons in its path and has to survive all of them leading to a strong nuclear absorption. This is the case at SPS energies, where the absorptive cross section is estimated to be $\sigma_{abs} = 4.18$ mb. At high energies, on the contrary, the coherence length is large and the projectile interacts with the nucleus as a whole leading to a small nuclear absorption. Then, at RHIC energy, we have taken an absorptive cross section at mid rapidity equal to zero. Note that the coherence length shows a dependence on rapidity. Because of this, at forward rapidity a small nuclear absorption may be included.

4 Comover interaction with recombination

The comover interaction model was developed to explain both the suppression of charmonium yields and the strangeness enhancement in nucleus-nucleus collisions at the SPS. It is based on the interaction of a particle or a parton with the medium, which is described by the gain and loss differential equations which govern the final state interactions.

Assuming only J/ψ dissociation[2], the rate equation governing the density of charmonium in the final state, $N_{J/\psi}$, can be written in a simple form assuming a pure longitudinal expansion of the system and boost invariance. For an AA collision the density of J/ψ at a given transverse coordinate, s, impact parameter b, and rapidity is given by

$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}(b,s,y) = -\sigma_{co} N^{co}(b,s,y) N_{J/\psi}(b,s,y) , \quad (1)$$

where σ_{co} is the cross section of charmonium dissociation due to interactions with the co-moving medium, with density N^{co}. It is found from fits to low-energy experimental data to be $\sigma_{co} = 0.65$ mb.

In the last years, a secondary J/ψ production due to recombination of $c\bar{c}$ pairs in order to explain the PHENIX data has been wildly discussed. To incorporate the effects of recombination, we have to include an additional gain term proportional to the (squared) density of open charm produced in the collision [3]. Then eq. (1) is generalized to

$$\tau \frac{\mathrm{d}N_{J/\psi}}{\mathrm{d}\tau}(b,s,y) = -\sigma_{co}\left[N^{co}(b,s,y)N_{J/\psi}(b,s,y) + N_c(b,s,y)N_{\bar{c}}(b,s,y)\right] , \tag{2}$$

where we have assumed that the effective recombination cross section is equal to the dissociation cross section. This extension of the model therefore does not involve additional parameters.

Equation (2) leads to the survival probability for the J/ψ

$$S^{co}(b,s,y) = \exp\left\{-\sigma_{co}\left[N^{co}(b,s,y) - \frac{N_c(b,s,y)N_{\bar{c}}(b,s,y)}{N_{J/\psi}(b,s,y)}\right]\ln\left[\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right]\right\} , \tag{3}$$

where the first term in the exponent of eq. (3) is exactly the survival probability of a J/ψ interacting with comovers. The density of open and hidden charm in AA collisions, $N_c, N_{\bar{c}}$ and $N_{J/\psi}$ respectively, can be computed from their densities in pp collisions as $N_c^{AA}(b,s) = n(b,s)S_{HQ}^{sh}(b,s)N_c^{pp}$, with similar expression for $N_{\bar{c}}^{AA}$ and $N_{J/\psi}^{AA}$. Here $n(b,s)$ corresponds to the number of collisions S_{HQ}^{sh} is the shadowing factor for heavy quark production. Then eq. (3) becomes

$$S^{co}(b,s,y) = \exp\left\{-\sigma_{co}\left[N^{co}(b,s,y) - C(y)n(b,s)S_{HQ}^{sh}(b,s)\right]\ln\left[\frac{N^{co}(b,s,y)}{N_{pp}(0)}\right]\right\} \tag{4}$$

where

$$C(y) = \frac{\left(\mathrm{d}N_{pp}^{c\bar{c}}/\mathrm{d}y\right)^2}{\mathrm{d}N_{pp}^{J/\psi}/\mathrm{d}y} = \frac{\left(\mathrm{d}\sigma_{pp}^{c\bar{c}}/\mathrm{d}y\right)^2}{\sigma_{pp}\,\mathrm{d}\sigma_{pp}^{J/\psi}/\mathrm{d}y} . \tag{5}$$

We expect the effect of recombination to be stronger at mid-rapidity than at forward ones. At $y \neq 0$ the recombination term is smaller (relative to the first one) since the rapidity distribution of D,D^* is narrower than the one of comovers. This will produce a decrease of $R_{AA}^{J/\psi}$ with increasing y which may over-compensate the increase due to a smaller density of comovers at $y \neq 0$.

In the left picture of Fig. 2 we present the results of our model compared to experimental data at mid-rapidity. The different contributions to J/ψ suppression are shown. Note that at mid-rapidities the initial-state effect is just the shadowing. As discussed above, nuclear absorption is present at forward rapidities but is negligibly small at mid-rapidities. In the r.h.s. of Fig. 2, our results at forward rapidity are presented. Note that, contrary to the results in [2] with no recombination, the J/ψ suppression at forward rapidity is somewhat larger that the one at mid-rapidities, in agreement with experimental data. This is due both to the recombination term and to the initial-state effects. The latter are stronger for forward rapidities.

In Fig. 3 we have calculated the J/ψ suppression at LHC for several values of C, including the case of absence of recombination effects ($C = 0$). We consider that realistic values of C at LHC are of the range 2 to 3. Although the density of charm grows substantially from RHIC to LHC, the combined effect of initial-state shadowing and comovers dissociation appears to overcome the effect of parton recombination. This is in sharp contrast with some of the findings in the framework of QGP and recombination, where a strong enhancement of the J/ψ yield with increasing centrality is predicted.

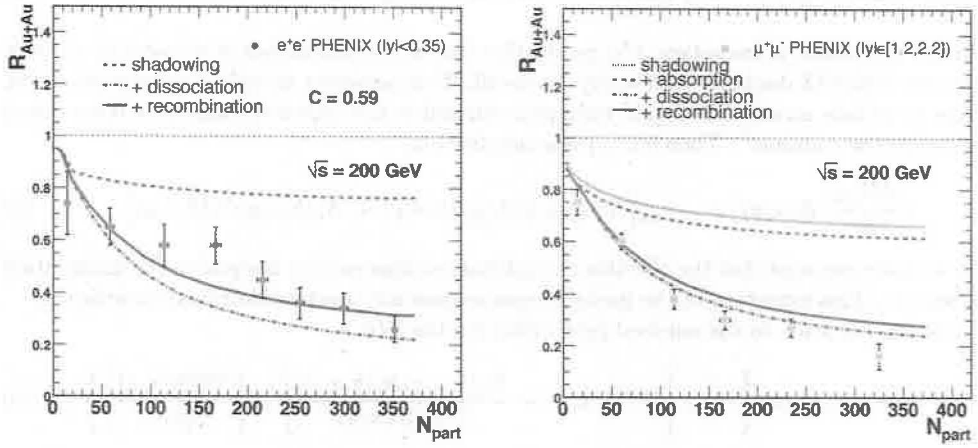

Figure 2: Results for J/ψ suppression in $AuAu$ at RHIC ($\sqrt{s} = 200$ GeV) at mid-rapidity (left), and at forward rapidity (right). Data are from [4]. The solid curves are the final results. The dashed-dotted ones are the results without recombination ($C = 0$). The dashed line is the total initial-state effect. The dotted line in the right figure is the result of shadowing.

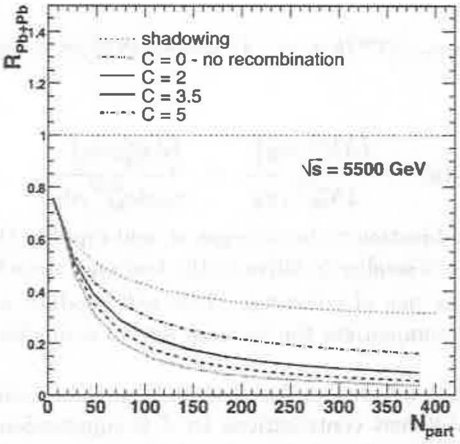

Figure 3: Results for J/ψ suppression in $PbPb$ at LHC ($\sqrt{s} = 5.5$ TeV) at mid-rapidities for different values of the parameter C. The upper line is the suppression due to initial-state effects (shadowing).

References

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