CHARMONIUM SUPPRESSION IN THE UrQMD TRANSPORT MODEL*

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We study charmonium physics in heavy-ion collisions within the framework of the non-equilibrium transport model UrQMD. Using this model we compute the nuclear modification factor R_{AA} at SPS, RHIC and LHC energies. For this purpose we test a scenario for charmonium dissociation and charmonium recombination containing charmonium melting, a prehadronic phase and a final hadronic phase. Our UrQMD approach includes explicitly the interactions of the charmed particles with the surrounding medium. We show that we are able to describe the charmonium suppression at different collision energies within this approach.

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1. Introduction

Charmonia are produced in the very early phase of a heavy ion collision and are, therefore, an ideal probe for the whole collision process. One of the most important observables for the charmonium interactions with the hot medium is the nuclear modification factor R_{AA}. This modification factor tells us if charmonia are suppressed in heavy ion collisions compared to *pp* collisions at the same energy. A suppression has been found with various experiments at different collision energies. Three effects to explain this suppression have been put forward [1]:

- Nuclear absorption or baryonic suppression [2]. They depend on the thickness function of the two nuclei and, therefore, depend on centrality. This 'normal' suppression with centrality is not able to describe the

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measured J/Ψ-yield in very central AA collisions at SPS and RHIC-energies [3, 4, 5]. Two possible interpretations of this 'additional' suppression have been suggested and will be discussed next.

- Co-mover absorption [6, 7]. Here the charmonia are additionally absorbed by inelastic scatterings with co-moving mesons. It is assumed that the corresponding J/Ψ hadron cross sections are of the order of several mb [8]. Nevertheless, theoretical approximations for the absorption cross section differ by more than an order of magnitude [9].

- Debye screening [10]. An alternative explanation of the additional suppression is explained by the formation of a QGP. In a QGP the formation of J/Ψ-mesons is suppressed due to Debye screening in the matter. The charm quarks will leave the reaction zone as hadrons with open charm. Therefore, J/Ψ suppression in heavy ion collisions has been proposed as a possible signature for QGP formation [10].

For massive nuclear collisions at highest energies, it was also speculated that J/Ψ-mesons might be reformed via $J/\Psi \leftrightarrow D\overline{D}$ reactions, if the open charm densities become substantial [11, 12, 13]. This is not the case at SPS energies, but gets important at RHIC energies, especially in central heavy ion collisions. One of the major goals of charmonium physics in heavy ion collisions is to disentangle these effects, because it may allow to draw conclusions about the QGP. This disentangling can be done by comparing observables in different systems and at different collision energies.

2. The model

To model the charmonium dynamics in UrQMD [14], we assume three different regimes: A high temperature regime with melting of the J/Ψ ($\varepsilon > 12\,\mathrm{GeV/fm^3}$), a prehadronic stage ($0.6\,\mathrm{GeV/fm^3} < \varepsilon < 12\,\mathrm{GeV/fm^3}$) and final hadronic stage ($\varepsilon < 0.6\,\mathrm{GeV/fm^3}$). The corresponding transition temperatures are taken from [15, 16, 17]. Our assumptions regarding the melting regime are based on [15]. Here the charmonium states still persist in the QGP, but their wave function broadens with increasing energy density. This broadening leads to a breakup of J/Ψs in our model, if the J/Ψ traverses a medium above $\varepsilon > 12\,\mathrm{GeV/fm^3}$ for a proper time of more than $1\,\mathrm{fm}/c$.

In this stage the mechanisms of the prehadronic regime are taken into account additionally. This mimics QGP effects, since UrQMD as a hadronic model is not able to simulate partonic interactions in the QGP directly. Here, all mesons+charmonium have the same inelastic cross section of 0.78 mb, while the baryon+charmonium cross sections are obtained by using quark number scaling. The elastic J/Ψ cross sections in the prehadronic phase are chosen to be the same as the inelastic cross sections. Formation times for particles interacting with charmonia are neglected in this phase.

In the hadronic phase, we use a 2-body transition model [18, 19] for the inelastic cross sections of charmed particles with mesons. Here charmonium dissociation and charmonium recombination are connected via the principle of detailed balance. Regarding the inelastic baryon–charmonium interactions in the hadronic stage, we use a constant dissociation cross section of 4.18 mb for the J/Ψ and χ_c obtained from [4, 20].

For all elastic cross sections with charmonia in the hadronic phase we use a constant cross section of 5 mb.

3. Results

Let us now compare our model calculations to data obtained at SPS, see Fig. 1.

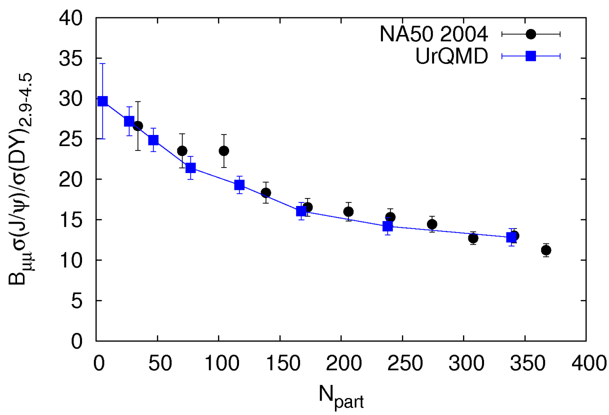

Fig. 1. J/Ψ suppression dependent on the number of participants N_{part}. UrQMD data are compared to data of the NA50 experiment [3].

One can see that the model provides good agreement of our calculation to the SPS data. As mentioned before, the effective matrix element $|M_i|^2 = 0.65$ of the 2-body transition model and the prehadronic cross sections have been fitted to these data. The reason we use SPS data to fit these two free parameters is that recombination of D-mesons is negligible in SPS collisions.

Now, we want to have a look at the corresponding calculation at RHIC energies employing the same parameter set. The goal is to get a consistent description of charmonium dynamics in different systems and at various collision energies. An important difference for charmonium dynamics at RHIC energies compared to SPS energies apart from the higher energy densities that are reached at RHIC is the number of D-mesons that are produced. In central collisions of Au+Au at $\sqrt{s_{NN}} = 200\,\text{GeV}$, the average yield is 16 D-meson pairs. Therefore, recombination gets very important at RHIC energies, especially when looking at central collisions. On the other hand, due to the higher multiplicity of all mesons, the co-mover dissociation causes a stronger suppression. In Fig. 2 we show a comparison of our R_{AA} calculations to PHENIX measurements, both for mid rapidity ($|y| < 0.35$) and forward rapidity ($1.2 < |y| < 2.2$). The value and shape of our calculation matches the PHENIX data reasonably well. An interesting fact here is that the suppression at mid rapidity is a little bit weaker than at forward rapidity as found in the measurements. In our calculation, it is due to the higher phase-space density of D-mesons at mid rapidity, which results in a substantial amount of recombined J/Ψs. At forward rapidity in contrast the biggest fraction of finally observed J/Ψs stems from initially produced J/Ψs.

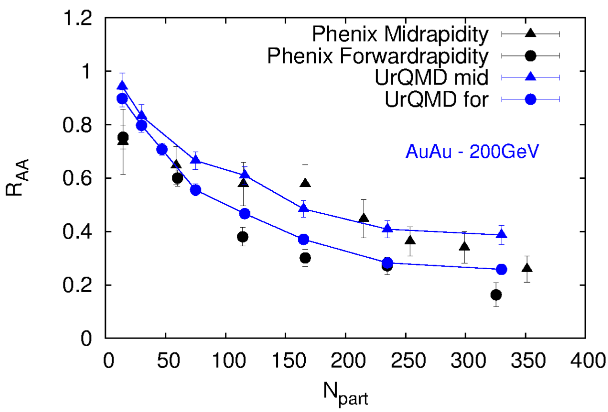

Fig. 2. J/Ψ suppression dependent on the number of participants N_{part}. UrQMD data are compared to data of the PHENIX experiment at RHIC [3]. We applied the corresponding acceptance cuts for the PHENIX mid rapidity and forward rapidity measurement in our calculation.

Next, we turn to the J/Ψ suppression in pp collisions at $\sqrt{s_{NN}} = 7\,\text{TeV}$, *i.e.* at LHC energies. A similar study has recently been performed by [21]. At these energies the particle multiplicities at central rapidities rise to the same order of magnitude as in heavy ion collisions at lower energies, and the energy densities may even exceed the values of central Au–Au/Pb–Pb reactions at SPS and RHIC. A possible suppression in pp is important because pp is used as a reference line for the medium modification in heavy ion collisions. The best way to have a look at this suppression is to compare it in different charged particle multiplicities bins. At low particle multiplicities the probability of J/Ψ dissociation should be smaller as at high particle multiplicities. To get an estimate of the J/Ψ suppression in *pp* we used our model as described before placing one J/Ψ in every collision. The modification factor R_{pp} shows how many J/Ψs survive traversing the medium induced by the *pp* collisions. It is defined as

$$R_{pp} = \frac{dN^{\rm final}_{J/\Psi}/dy|_{|y|\leq 1}}{dN^{\rm initial}_{J/\Psi}/dy|_{|y|\leq 1}}\,.$$

In Fig. 3 our results are shown.

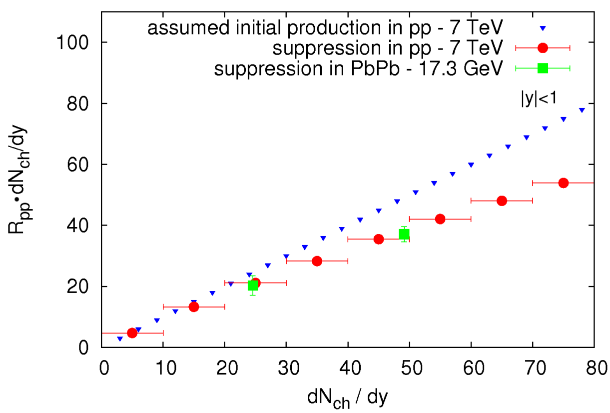

Fig. 3. Number of J/Ψ particles dependent on the charged particle multiplicity. The *pp* and Pb–Pb collisions show a very similar dependence on the charged particle multiplicity.

The initial production is assumed to be proportional to $dN_{\rm ch}/dy$, because at RHIC energies it was shown that the number of produced J/Ψs increases nearly linearly with particle multiplicity. The triangles (blue) in the plot represent the number of initially produced J/Ψs while the circles (red) represent the number of J/Ψs which survive the medium transition. One can see that at low particle multiplicities there is almost no suppression of J/Ψ particles, while at high particle multiplicities of about 70–80 the suppression reaches up to 30%. The squares (green) show a comparison to our scaled calculation for nucleus–nucleus reactions at SPS energies at the same particle multiplicities. The SPS result shows approximately the same suppression as in *pp* at LHC. This means that the J/Ψ suppression seems to depend mainly on the particle multiplicities but not on the collision energies. Therefore, medium effects in *pp* have to be taken into account when J/Ψ dynamics in Pb–Pb collisions are studied at LHC.

4. Summary

We presented an UrQMD approach for charmonium suppression containing different phases. Within this approach we could reproduce charmonium suppression in heavy ion collisions at SPS and RHIC energies. Especially, we could provide an explanation for the rapidity dependence of the PHENIX data. Moreover, we calculated the J/Ψ suppression in pp collisions at $\sqrt{s_{NN}} = 7$ TeV within our model and found a suppression of charmonia, relative to the initial production, at highest multiplicities.

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