Charmonium production at forward rapidity at RHIC

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One of the key issues in understanding charmonium production in ultra-relativistic heavy-ion collisions is the discrimination of suppression (due to Debye screening and/or dissociation reactions) vs. regeneration mechanisms (due to recombination of charm and anti-charm quarks). Both mechanisms are believed to be primarily active in the putatively formed Quark-Gluon Plasma (QGP). Since suppression and regeneration effects in general depend differently on collision energy and centrality, or on transverse momentum and rapidity of the charmonium, a systematic analysis of the corresponding observables is believed to yield decisive insights. Here we apply a previously constructed thermal rate-equation approach [1,2] to evaluate the rapidity dependence of J/Ψ production at RHIC [3]. Experimental data [4] indicate that the inclusive J/ψ yield in $s^{1/2}$ =200AGeV Au-Au collisions is more strongly suppressed at forward rapidity compared to mid-rapidity. This trend is opposite to the naïve expectation that the larger multiplicity of produced hadrons at mid-rapidity leads to the formation of a hotter medium and thus stronger charmonium suppression.

Our approach is based on a rate equation for the time evolution of charmonium state Ψ,

$$\frac{dN_\Psi}{d\tau} = -\Gamma_{diss}\,(N_\Psi - N_\Psi^{eq}) \qquad (\Psi = J/\psi, \chi_c, \psi')$$

Using in-medium reduced charmonium binding energies, the inelastic reaction rate, Γ_{diss}, is calculated using ‘’quasi-free” dissociation, Ψ+p → cbar+c+p, induced by light partons p=q,qbar,g in the QGP. The equilibrium limit, N_ψ^{eq}, is evaluated in the statistical model with an additional reduction factor to schematically account for incomplete thermalization of c-quarks. The rate equation has to be convoluted over a realistic temperature profile of Au-Au collisions at RHIC. To this end, we employ an isentropically expanding fireball where the total entropy at a given centrality is estimated from the number of produced hadrons in the final state. The equation of state of QGP and hadronic phase is based on quark quasiparticles and a hadron resonances gas, respectively. This model leads to a fair description of charmonium observables at SPS and RHIC at mid-rapidity (cf. left panel of Fig. 1), including transverse-momentum spectra [2].

At forward rapidity, |y|=1.2-2.2, as covered by PHENIX dimuon measurements, total hadron production is reduced compared to mid-rapidity by 5-10% [5], leading to a slightly modified temperature profile of the underlying thermal fireball, cf. right panel of Fig. 1. At the same time, the input cross sections for initial J/ψ and open-charm production are both reduced by about 30% relative to mid-rapidity (the former is obtained from PHENIX data [4] and for the latter we take guidance from perturbative QCD calculations [5]). The reduced QGP lifetime entails slightly less suppression, while the regeneration component decreases due to a reduction in the charmonium equilibrium limit. More precisely, the latter behaves as $N_\Psi^{eq} \sim (N_{ccbar})^\alpha$ where α lies between 1 (canonical limit) and 2 (grand canonical limit). The resulting centrality dependence of the inclusive J/Ψ yield overestimates the PHENIX data for mid-/central collisions [4].

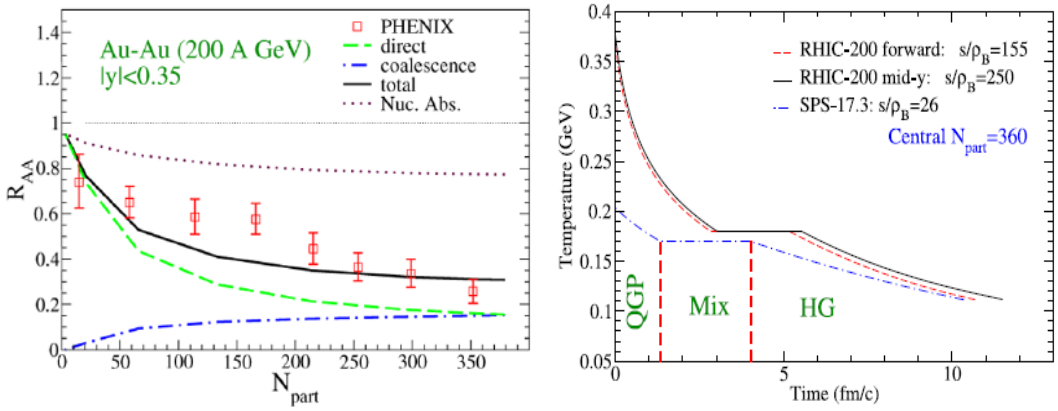

FIG. 1. Left panel: Results of the thermal rate-equation approach [1,2] for the centrality dependence of the J/ψ nuclear modification factor, $R_{AA} = N_\psi^{AA}/(N_{coll}\, N_\psi^{pp})$, in Au-Au collisions at RHIC at mid-rapidity, |y|<0.35. Right panel: temperature profile of a thermal fireball model in central Au-Au and Pb-Pb collisions at RHIC (√s=200AGeV) and SPS (√s=17.3AGeV), respectively.

The origin of this discrepancy could be related to nuclear shadowing effects in the parton distribution functions of the incoming nuclei. PHENIX data [7] indeed suggest that J/Ψ production in d-Au collisions is suppressed at forward relative to mid-rapidity. Implementing such an effect into our calculations (along the lines of Ref. [8]) reduces the discrepancy with the mid-/central Au-Au data (cf. middle panel of Fig. 2), but does not fully resolve it (cf. right panel of Fig. 2), similar to Ref. [8]. Further investigations are in progress.

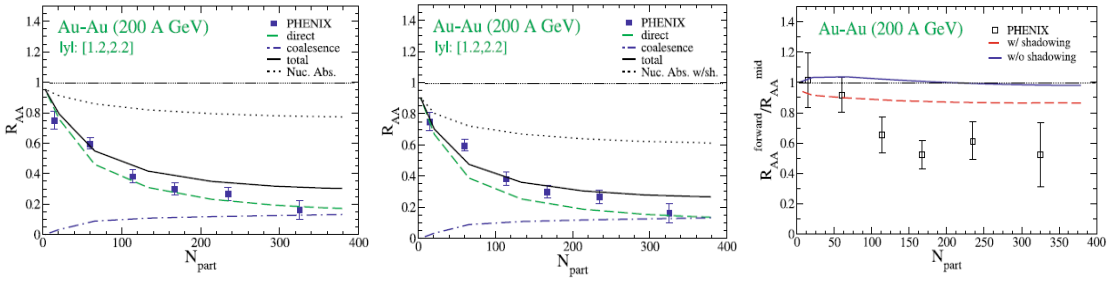

FIG. 2. Centrality dependence of the J/ψ nuclear modification factor at forward rapidity compared to PHENIX data [4] without (left panel) and with (middle panel) nuclear shadowing effects. The right panel shows the ratio of the data at forward rapidity to the ones at mid-rapidity shown in the right panel of Fig. 1.

[1] L. Grandchamp, G.E. Brown, and R. Rapp, Phys. Rev. Lett. **92**, 212301 (2004).

[2] X. Zhao, R. Rapp, Phys. Lett. B **644**, 253 (2008).

[3] X. Zhao and R.Rapp, Eur. Phys. J. C (in press), and arXiv:0810.4566 [nucl-th].

[4] A. Adare *et al.* (PHENIX Collaboration), Phys. Rev. Lett. **98** 232301 (2007), *ibid.* 232002.

[5] I. Arsene *et al.* (BRAHMS Collaboration), Nucl. Phys. **A757**, 1 (2005).

[6] M. Cacciari *et al.*, Phys. Rev. Lett. **95**, 122001 (2005).

[7] A. Adare *et al.*, Phys. Rev. C **77**, 024912 (2008).

[8] A. Capella *et al.*, Eur. Phys. J. C **58,** 437 (2008).