Charmonia in medium: from euclidean to minkowski time

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Charmonia are valuable probes of hot and dense matter as created in heavy-ion collisions (HICs) because (i) they are bound states of charm quarks which are exclusively produced in primordial hard collisions; (ii) they have large binding energies so that their dissolution is expected only at rather high temperatures. Further studies [1] have shown that primordial production, followed by various phases of dissociation (direct component), should be complemented by the inverse processes in which open-charm states coalesce into charmonia (regeneration component). An important quantity controlling the strengths of these competing mechanisms is the charmonium binding energy, ε_B. E.g., for $J/\Psi+g\leftrightarrow c+\bar{c}$bar, a larger ε_B reduces the initial-state phase space for dissociation while increasing the final-state phase space for the reverse process of coalescence.

In this work [2] we calculate the production of charmonia in HICs with their binding energies extracted from a T-matrix approach [3] which utilizes input potentials from lattice QCD (lQCD). Specifically, we study limiting cases of strong- and weak-binding scenarios representing the use of the internal and free energy as the heavy-quark potential, respectively. The latter also determines the in-medium HQ mass, $m_c(T)=m_c^0+ V(r\to\infty;T)/2$, via its non-zero asymptotic value. With $\varepsilon_B(T)$ and $m_c(T)$

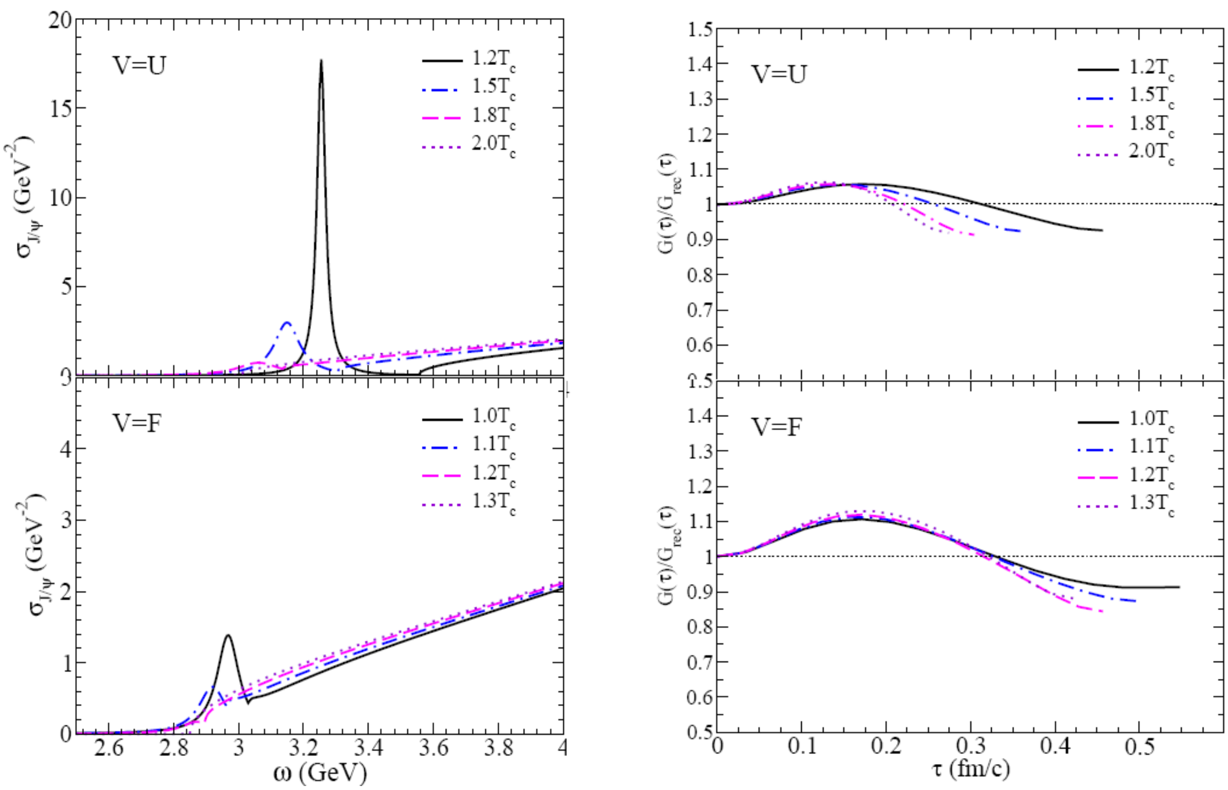

FIG. 1. Left panel: S-wave charmonium spectral functions in the strong (V=U) and weak (V=F) binding scenarios. Right panel: Corresponding correlation functions (normalized to the vacuum one) in euclidean time, τ. Current lattice QCD data suggest the ratio $(G(\tau)/ G_{rec}(\tau))$ to be close to 1 up to ~$3T_c$ [5].

fixed we calculate charmonium dissociation rates in “quasi-free” approximation [4].

Using the binding-energies, widths and charm-quark masses we calculate charmonium spectral functions and euclidean-time correlators (see Fig. 1). In both scenarios, the latter show variations at the 10% level, which is consistent with current lQCD computations.

Next we implement the binding energies, dissociation rates and quark masses into a thermal rate equation [1, 6] to calculate charmonium production in heavy-ion collisions. We also introduce a thermal relaxation time for charm quarks which controls the magnitude of the regeneration yield.

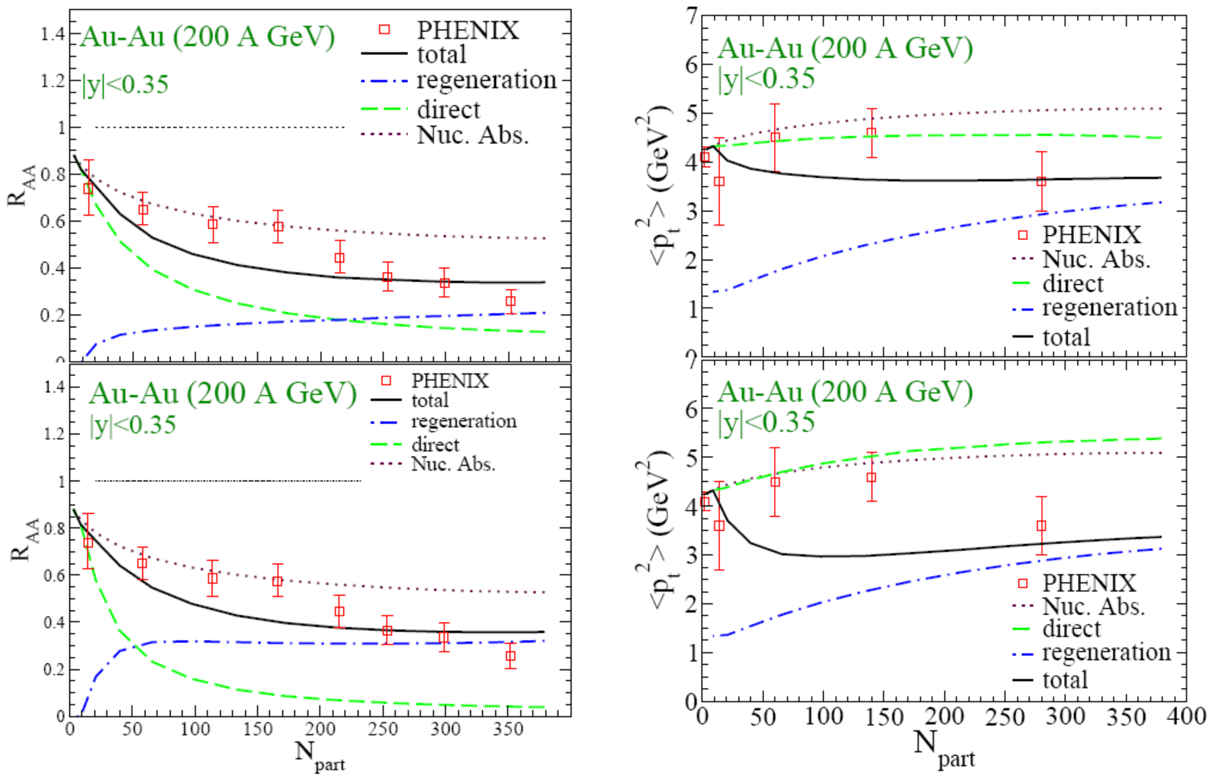

FIG. 2. Left panels: Centrality dependence of the nuclear modification factor (R_{AA}) for J/Ψ at RHIC compared to PHENIX data [7]. Right panels: Centrality dependence of $<p_t^2>$ of J/Ψ compared to PHENIX data [7]. Upper panels: strong binding scenario. Lower panels: weak binding scenario.

The numerical results at RHIC energy are compared to the experimental data in Fig. 2. We find that within the current uncertainty of charm-quark thermalization times, both strong- and weak-binding scenarios can reproduce the measured yields of J/Ψ’s. However, the relative partition of direct and regeneration components is rather different in the two scenarios. For central Au-Au collisions, the strong-binding scenario predicts a sizable contribution of primordially produced charmonia while in the weak-binding scenario they are almost entirely suppressed. To better discriminate the two scenarios we calculate the transverse-momentum (p_t) spectra of J/Ψ, and plot their average $<p_t^2>$ in the right panels of Fig. 2. The regenerated J/Ψ‘s are characterized by softer spectra than the primordial ones. The strong-binding scenario, with a larger direct component, tends to reproduce the data better than the weak-binding scenario. The current uncertainty in the experimental data prevents definitive conclusions but our calculations show that p_t spectra are of crucial importance to disentangle in-medium production mechanisms of charmonia in heavy-ion collisions, and thus to extract properties of the Quark-Gluon Plasma.

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

[2] X. Zhao and R. Rapp, in preparation.

[3] F. Riek and R. Rapp, arXiv:1005.0769.

[4] L. Grandchamp and R. Rapp, Phys. Lett. B **523**, 60 (2001).

[5] S. Datta *et al.*, Phys. Rev. D **69**, 094507 (2004).

[6] X. Zhao and R. Rapp, Phys. Lett. B **664**, 253 (2008).

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