Sequential regeneration of charmonia in heavy-ion collisions

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The production systematics of heavy quarkonia, i.e., bound states of a heavy charm or bottom quark and its antiquark, in heavy-ion collisions have long been recognized as a valuable probe of the QCD matter produced in these reactions. Originally, quarkonium suppression was suggested as an indicator of the formation of a deconfined quark-gluon plasma (QGP), but regeneration processes through quark recombination complicate the interpretation of observables considerably, especially for charmonia at collider energies (RHIC and LHC) where charm quarks and antiquarks are produced abundantly. Over the last decade, a kinetic rate equation approach has been developed [1] which allows for a fair description [2], with predictive power [3], of charmonium and bottomonium observables from SPS via RHIC to LHC energies. Rather little attention has been paid to the production of the $\psi(2S)$ state to date, primarily due to the difficulty in measuring it. However, recent experiments have shown rather intriguing results, such as a strong suppression in the small d-Au collision system at RHIC [4] versus an enhancement in central Pb-Pb collisions at the LHC [5].

In the present work [6] we have scrutinized $\psi(2S)$ production in the rate equation approach. We have first developed a more complete treatment of hadronic dissociation rates by including inelastic reactions with 52 meson species. Assuming the formation of a thermal fireball in d-Au collisions at RHIC, with a significant hadronic phase, the increased absorption in the rate equation can account for the strong suppression of the $\psi(2S)$ state observed by PHENIX [4], cf. Fig. 1.
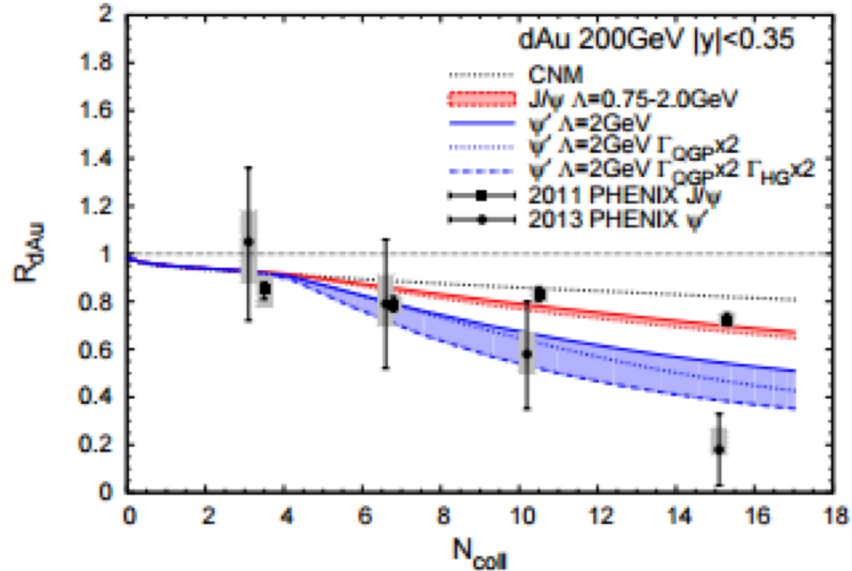

FIG. 1. Nuclear modification factor R_{AA} for charmonia with improved treatment of hadronic suppression d-Au(0.2TeV) collisions at RHIC [6], compared to PHENIX data [4].

We have then implemented the updated treatment of the hadronic phase into calculations for Pb-Pb collisions at the LHC. Here, the inelastic hadronic reaction rates induce an appreciable *regeneration* of the $\psi(2S)$ state, due to the large abundance of charm and anti-charm quarks. The small binding energy of the $\psi(2S)$ compared to the J/ψ state implies that the former is regenerated at lower temperatures, i.e., at later times in the fireball evolution. The stronger radial flow of the $\psi(2S)$ at the time of regeneration leads to a p_T-dependent R_{AA} which peaks a at higher momenta than for the J/ψ state, cf. Fig. 2 left. This - *sequential regeneration* scenario provides a natural mechanism to explain the puzzling CMS data [5] where the R_{AA} double ratio of $\psi(2S)$ over J/ψ exceeds unity for a $p_T > 3$ GeV cut in central Pb-Pb collisions, while showing a suppression for a $p_T > 6.5$ GeV cut, albeit with appreciable uncertainties both theoretically and experimentally, cf. Fig. 2 right.
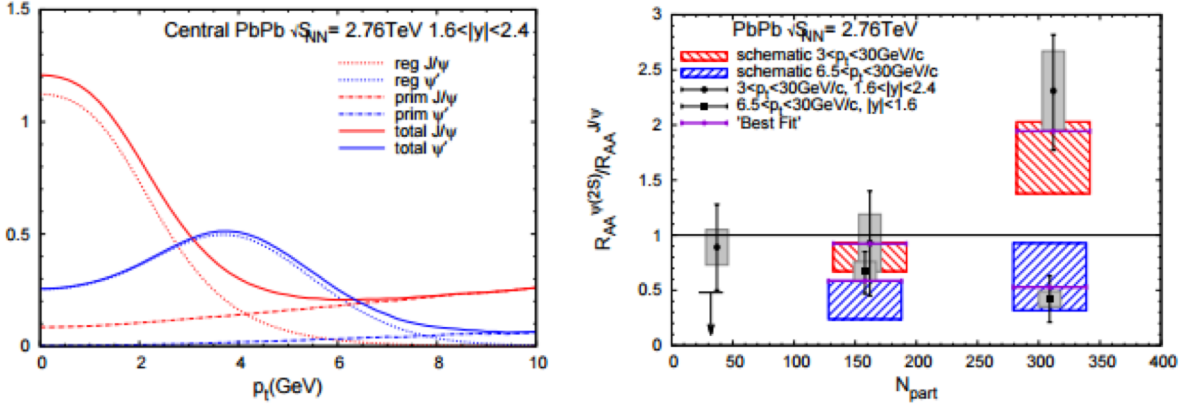

FIG. 2. Sequential regeneration mechanism for charmonia in Pb-Pb(2.76TeV) collisions at the LHC [6]. Left panel: Effect of larger flow from later regenerated $\psi(2S)$ relative to J/ψ on their p_T-dependent R_{AA} in central Pb-Pb(2.76TeV). Right panel: double ratio of $\psi(2S)$ over J/ψ R_{AA} vs. collision centrality with theoretical uncertainties, compared to CMS data [5].

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