Charmonium production in heavy-ion collisions at the large hadron collider

X. Zhao and R. Rapp

Charmonium has been suggested as a probe of deconfinement in the hot/dense medium created in relativistic heavy-ion (A-A) collisions: once charmonia dissolve as a result of color-Debye screening in the Quark-Gluon Plasma (QGP) their yields in A-A collisions ought to be suppressed compared to the superposition of individual nucleon-nucleon collisions. J/ψ suppression was indeed observed, first in Pb-Pb collisions at SPS at CERN and later in Au-Au collisions at RHIC at BNL. However, the finally observed charmonia may "regenerate" during the collision, by recombination of charm and anti-charm quarks in the later stages of the medium evolution. At RHIC, an increase of c-cbar production leads to a larger regeneration component, but the observed (lack of) suppression renders it difficult to establish unambiguously. A more sensitive test of regeneration becomes possible at the even higher energies at the LHC, where c-cbar pairs are produced abundantly, which could result in significantly less suppression of observed the J/ψ yield compared to RHIC and SPS, contrary to the expectation of stronger suppression.

In our previous work [1] we have employed a thermal rate-equation approach to describe the evolution of charmonium yields in the thermalized medium formed in A-A collisions. The main inputs to the rate-equation are the in-medium charmonium reaction rates and the equilibrium limit which is governed by the charmonium and open-charm masses. The dissociation rate is evaluated using perturbative QCD assuming charmonia to be loosely bound states in the deconfined medium; detailed balance has been applied to obtain the formation rate (regeneration processes). These rates are sensitive to the in-medium charmonium binding energies, which are extracted from in-medium T-matrix calculations [2] with input potentials inferred from lattice-QCD. The current ambiguity in using free (F) or internal energies (U) as potential (V) has been bracketed by two limiting scenarios, assuming V=F or V=U, leading to either weak or strong J/ψ binding in the QGP, respectively. An important aspect in our approach of Ref. [1] is that we have verified the consistency between the resulting charmonium spectral functions with Euclidean current-current correlators computed in thermal lattice QCD. Essentially two tunable parameters remain: the strong coupling constant, α_s (controlling the reaction rate) and the thermal charm-quark relaxation time, τ_c (affecting the regeneration yields). They have been adjusted in an overall fit to the observed inclusive J/ψ yields at SPS and RHIC which can be fairly well reproduced. In the present work [3] we apply this approach at the LHC, to predict inclusive J/ψ yields in Pb-Pb collisions at $\sqrt{s}$=2.76ATeV without adjusting parameters.

The initial condition of the rate equation is estimated from J/ψ yields in p-p collisions scaled by the number of collisions in A-A and augmented with cold-nuclear-matter (CNM) effects. For p-p we use $d\sigma^{J/\psi}/dy$=4μb and $d\sigma^{cc}/dy$=0.75mb. Since the nuclear absorption and Cronin effects are expected to be small at LHC, the only considered CNM effect is nuclear shadowing. The charged-particle multiplicity of the fireball expansion has been adjusted to first LHC data, $dN_{ch}/d\eta$=1600, which yields an initial QGP temperature of ~600MeV.

We first present the results for the centrality dependence of inclusive J/ψ yields without shadowing in Fig.1 (feeddown from χ_c, ψ' and B mesons are included). The total yields are found to be similar for the V=F and V=U scenarios. In both scenarios the regeneration component dominates in central collisions. The total yields remain below one and are much smaller than the predictions from the statistical model.

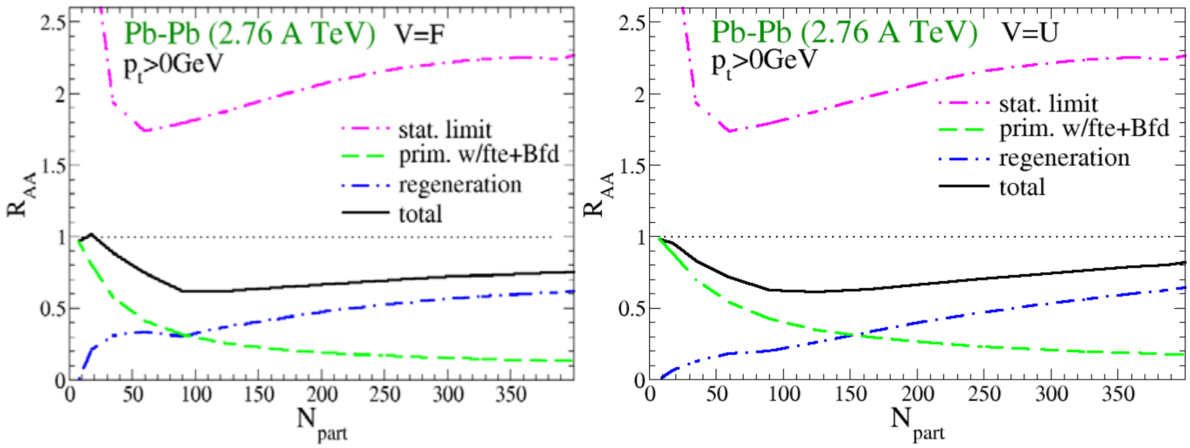

FIG. 1. Centrality dependence of the J/ψ nuclear modification factor at LHC without nuclear shadowing on either J/ψ or c-cbar. Left panel: weak binding scenario (V=F); right panel: strong binding scenario (V=U).

A more realistic prediction for J/ψ production at LHC includes nuclear shadowing effects on both primordial J/ ψ and c-cbar, cf. left panel of Fig. 2. Nuclear shadowing suppresses both primordial and regeneration components so that the total R_{AA} is reduced to ~0.45. It is approximately constant with centrality for N_{part}>100 due to the interplay of primordial and regeneration components. These predictions are in good agreement with recent ALICE data (which, however, are for forward rapidity). At high p_t >6.5GeV, where the regeneration contribution is negligible, our results agree fairly well with ATLAS data [5], cf. right panel of Fig. 2.

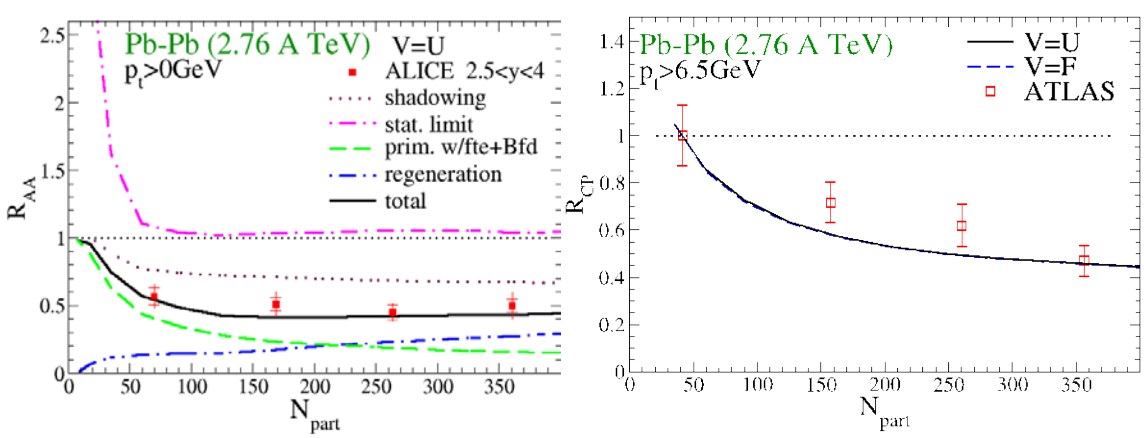

FIG. 2. Left panel: Centrality dependence of the J/ψ nuclear modification factor in the strong binding scenario (V=U) including nuclear shadowing, compared to ALICE data [4]; right panel: centrality of the J/ψ central-to-peripheral ratio (R_{CP}) for p_t>6.5 GeV (no shadowing), compared to ATLAS data [5].

The agreement of our calculations with LHC data support the picture that charmonia produced in heavy-ion collisions are from both primordial production and c-cbar recombination.

[1] X. Zhao and R. Rapp, Phys. Rev. C **82**, 064905 (2010).
[2] F. Riek and R. Rapp, Phys. Rev. C **82**, 035201 (2010).
[3] X. Zhao and R. Rapp, Nucl. Phys. **A859**, 114 (2011).
[4] G. Martinez-Garcia *et al.* (ALICE Collaboration), LANL e-print arXiv:1106.5889 [nucl-ex]
[5] G. Aad *et al.* (ATLAS Collaboration), Phys. Lett. B **697,** 294 (2011).