Bottomonium in the QGP: production at RHIC and LHC

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Introduction

The quark-gluon plasma (QGP), the deconfined state of quarks and gluons, is the subject of vast experimental and theoretical investigation. Heavy quarkonia bound states have been found to exist well past the critical temperature (T_C ≅180 MeV): up to 3-4T_C for the $b\bar{b}$ resonance, Υ. These resonances are used as important signatures of the phenomenology of the QGP. Theoretical understanding of these bound states is necessary to properly interpret what is seen in experiments. Motivated by Euclidean correlator ratio calculations, a reexamination of two dissociation models for heavy quarkonia in the QGP is made in order to identify the dominant process in bottomonia dissociation. Using a kinematic rate-equation approach [2], the production, suppression, and regeneration of Υ in AuAu (PbPb) collisions at $\sqrt{s_{NN}}$ = 200 GeV (2.76 TeV) at the Reletavistic Heavy Ion Collider (RHIC) (Large Hadron Collider, LHC) is calculated and compared to preliminary experimental data. In addition, the effects of nuclear absorption on Υ production are treated in order to identify its significance.

Dissociation Models

Heavy quarkonia dissociate in-medium through two processes, arising from the strong and weak binding scenarios *(see Figure 1)*:

- **<u>Gluo dissociation</u>**: massless partons interact with heavy quarkonia, assuming vacuum bound state masses and b-quark mass, m_b=5.280 GeV.
- **<u>Quasi-free dissociation:</u>** massive partons interact with one heavy quark in the bound state with in-medium binding energies satisfying: $\varepsilon_B = 2m_b - m_\Upsilon$.

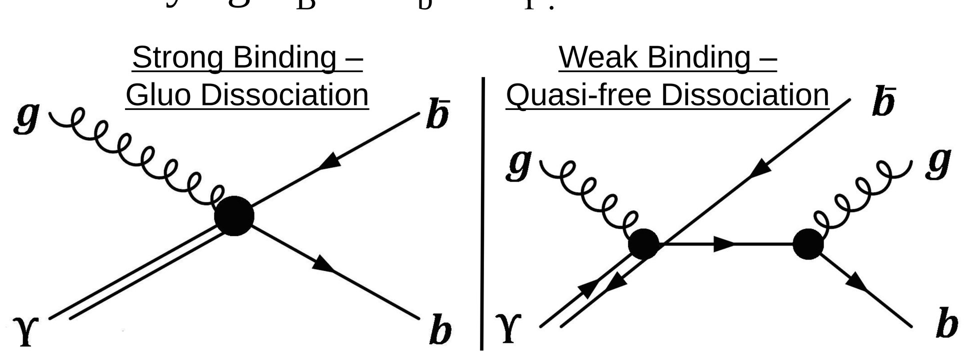

Fig. 1 Feynman diagrams for the two dissociation processes considered in this work: gluo dissociation (left) and quasi-free dissociation (right). The heavy quark as a whole interacts with the gluon in the gluo dissociation model. While, in the quasi-free model, only one b-quark interacts; the other is a spectator.

Correlator Ratios

Lattice QCD calculations suggest the Euclidean correlator ratio

$$R_\alpha(\tau,T)=\frac{G_\alpha(\tau,T)}{G_\alpha^{rec}(\tau,T)}=\frac{\int_0^\infty \sigma(\omega,T)\kappa(\omega,\tau,T)d\omega}{G_\alpha^{rec}(\tau,T)} \qquad (1)$$

remains close to unity. The numerator in *Eq. (1)* is normalized to the denominator of the same form, but evaluated with a vacuum (low T) spectral function. The input spectral functions for Υ were constructed from an ansatz consisting of a bound state combined with a perturbative continuum portion [5]. A comparison of the correlator ratios for the two dissociation models is made for the Υ bound state as a function of imaginary Euclidean time, τ, at various temperatures (*Figure 2*).

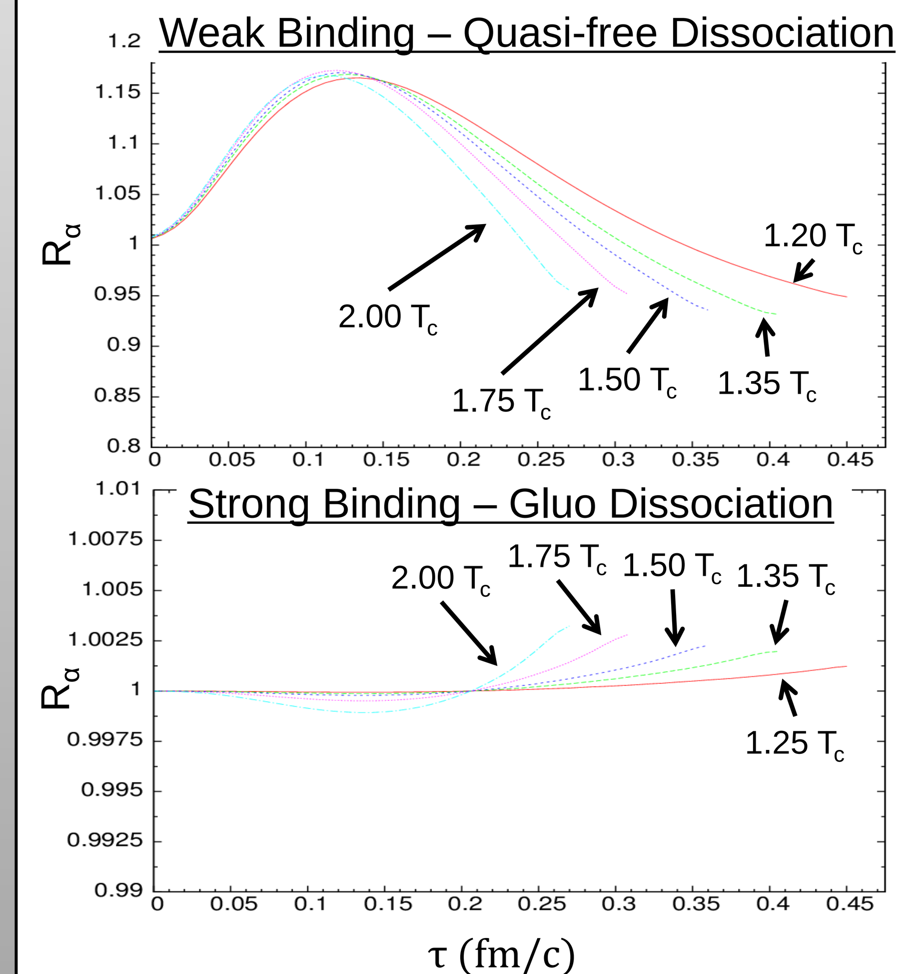

*Fig. 2 Correlator ratios versus Euclidean time, τ, for the quasi-free (top) and gluo (bottom) dissociation models **[Note the change of vertical axis scale]**. These results show that the strong binding model varies <1% with unity, while the weak binding model varies by <17%: a significant difference.*

These results motivate the reconsideration of the strong binding scenario as the dominant effect for bottomonia dissociation in the QGP.

Collision Model

A kinematic rate-equation method was used to calculate the production of Υ at RHIC and LHC. The fireball model treats:

- Suppression
- Regeneration

  } In evolving QGP medium
- Feed-down of Υ',χ_b(1p), and χ_b(2p) to Υ.
- Nuclear absorption cross-section

See reference [2] for a more detailed description of this method. For simplicity, no differentiation is made between the χ_b(1p) and χ_b(2p) states, and feed-down from Υ'' is neglected (~1% of total Υ yield).

Results: Nuclear Modification Factor (R_{AA})

R_{AA} is used to characterize particle production. It is the total production normalized to pp collisions, scaled by the number of NN collisions in the AA reaction. The individualΥ(nS) states cannot yet be resolved at RHIC. Thus, the combined Υ, Υ', and Υ'' R_{AA} is shown below in *Figure 3* compared with recent STAR data [3]. Since regeneration is negligible, the primordial R_{AA} is not shown.

Υ(1s+2s+3s) at RHIC - $\sqrt{s_{NN}}$ = 0.2 TeV

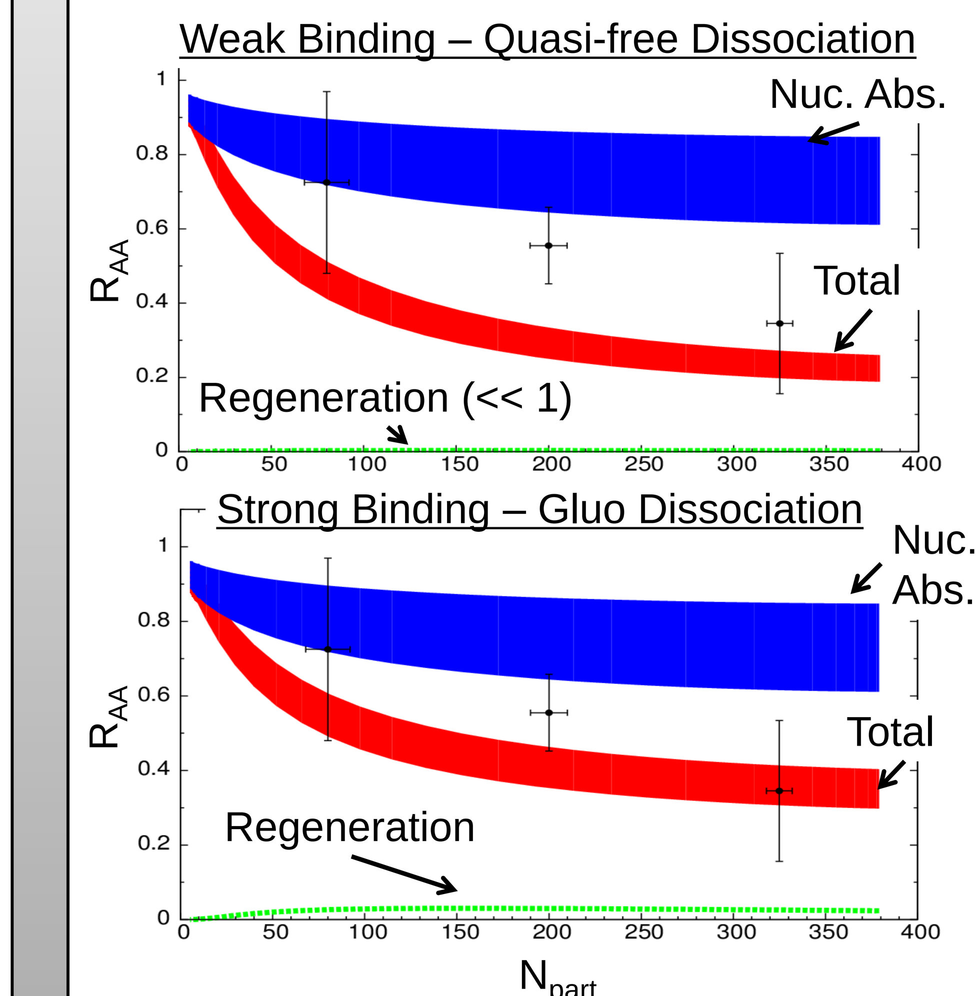

*Fig. 3 Nuclear modification factor as a function of centrality for $\Upsilon+\Upsilon'$ at RHIC. **Blue:** Nuclear Absorption **Red:** Total **Green:** Regeneration (<5%) **Black points:** Recent STAR data [3]. **Note:** Direct component is not shown, as regeneration is not significant. Result shown for $\sigma_{Nuc.\,abs.}$= **[1.0,3.1]mb***

Υ(nS) states ***can*** be resolved at LHC. Plotted is R_{AA} for Υ only, compared with CMS data [1]:

Υ(1s) at LHC - $\sqrt{s_{NN}}$ = 2.76TeV

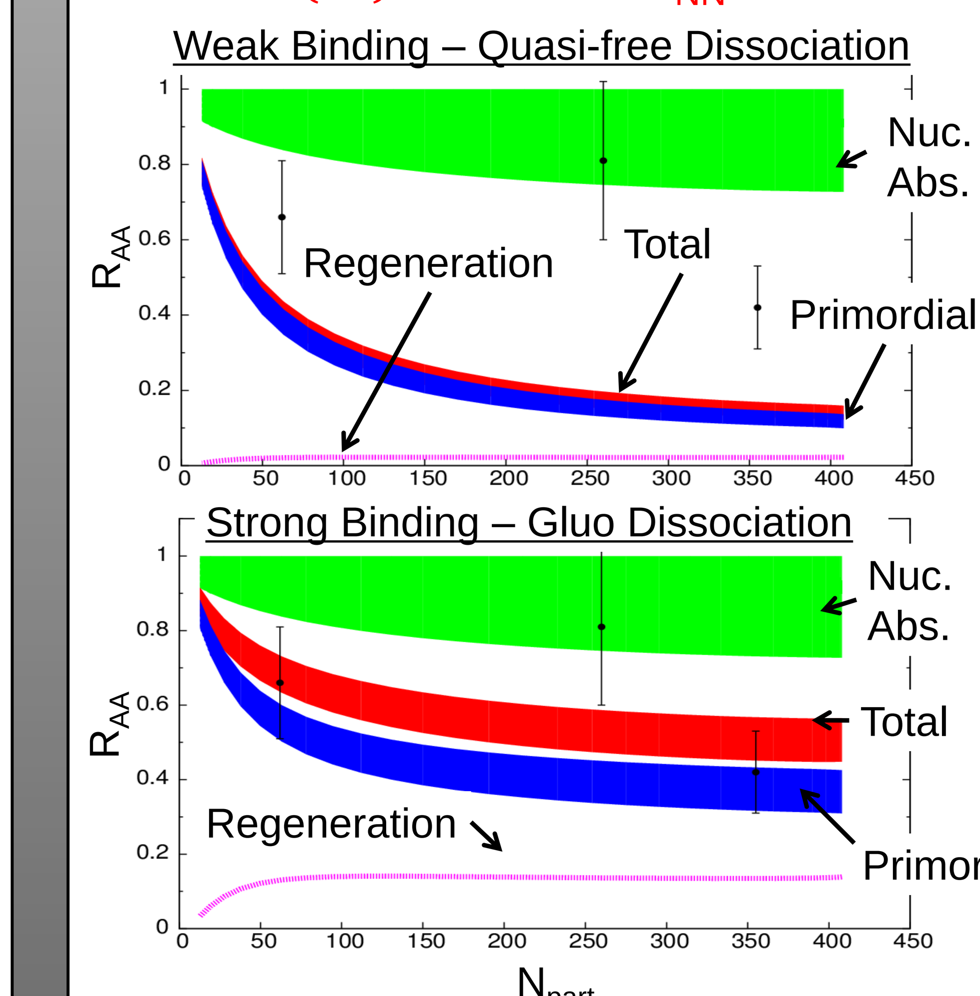

*Fig. 4 Nuclear modification factor as a function of centrality for Υ at the LHC. **Green:** nuclear absorption **Red:** Total **Blue:** Direct **Pink:** Regeneration **Black points:** Preliminary CMS data [1]. Result shown for $\sigma_{Nuc.\,abs.}$= **[0.0,2.0]mb***

Conclusions

Updating previous research, a reconsideration of the dissociation models for Υ production at RHIC and LHC was made.

<u>Important Results at RHIC (*Figure 3*):</u>
The strong binding scenario, implemented with the gluo dissociation model, results in better agreement with the STAR data than the weak binding scenario. The combined R_{AA} shows inclusive Υ yields largely suppressed for fully central collisions. The regeneration component is minimal, and virtually negligible for the weak binding model. The strong binding scenario also indicates the decreased significance of nuclear absorption on Υ production, since agreement with data improves for smaller $\sigma_{nuc.\,abs.}$.

<u>Important Results at LHC (*Figure 4*):</u>
The ability of the strong binding scenario to better reproduce experimental data is significantly more clear than in the RHIC results. The weak binding scenario is > 1σ away for all data points. At LHC energies, the importance of regeneration becomes significantly larger than at RHIC, and is calculated to be more significant than previously expected. Based upon R_{AA} for the Υ' and χ_b states (not shown), suppression of primordial Υ is a direct result of the suppression of the higher states. Interpretation of nuclear absorption is inconclusive, requiring more data points and less uncertainty to make a decisive statement.

<u>Further Improvements</u> can be made, pending explicit determination of direct and inclusive $b\bar{b}$ and Υ production cross sections at $\sqrt{s_{NN}}$ = 2.76 TeV.

References:

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Further information

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