Momentum spectra of bottomonium in heavy-ion collisions

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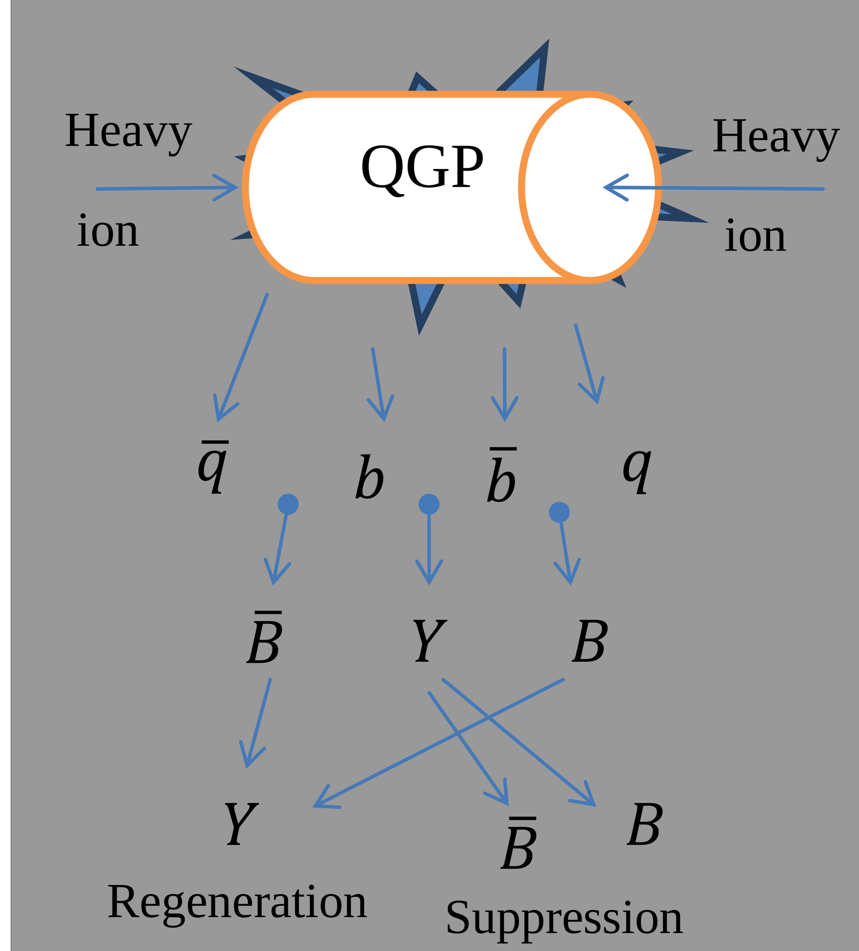
Background & Purpose

The hadrons that make up everything we see today were not created immediately in the Big Bang. Rather, the early universe consisted of a dense nuclear medium that took a short time to expand and cool; this medium is called the quark-gluon plasma (QGP). The QGP is characterized as a nuclear medium with sufficient energy density to overcome the strong coupling responsible for quark confinement. This makes QGP difficult to create and study, but it is suspected that this state is formed in ultra-relativistic heavy ion collisions (URHICs). In a collision there can be quarks created of every flavor (u, d, s, c, b, t), but the heavy quarks (notably b and c) are created early in the collision, making them a good probe of the QGP suspected to exist. The bottom quarks and anti-quarks mainly go into making B mesons, but a rare few create a bottomonium state (Υ). We investigate transverse momentum spectra of bottomonium states in URHICs at RHIC and LHC energies; the goal of this research is to describe the regeneration of bottomonia from the QGP as it depends on transverse momentum (p_T).

Transport Equation



To simulate the evolution of the bottomonium abundance in URHICs we rely on the results of the rate equation approach, which describes the number of bottomonia N_Y as it approaches equilibrium as:

$$\frac{dN}{d\tau} = -\Gamma_{\Upsilon}^{\text{diss}}(T)\left[N_{\Upsilon} - N_{\Upsilon}^{\text{eq}}(T)\right]$$

Here, $\Gamma_{\Upsilon}^{\text{diss}}$ denotes the inelastic reaction rate and N_{Y}^{eq} is the equilibrium limit. The loss term describes bottomonium suppression, where $b\bar{b}$ pairs are dissociated by the in-medium partons, while the gain term accounts for regeneration, where $b\bar{b}$ pairs form new bottomonium states.

These suppression and regeneration rates have been solved for independently, thus allowing the calculation of the nuclear modification factor as a function of the number of nucleon collisions.

Nuclear Modification Factor

The nuclear modification factor R_{AA} describes the scale applied to the number of particles produced in a pp-collision (N_{pp}^{Y}) to anticipate the number in a URHIC and is defined as a function of participant number: $R_{AA}(N_{\text{part}}) = \frac{N_{AA}^{Y}(N_{\text{part}})}{N_{\text{coll}}(\mathrm{N}_{\text{part}})\mathrm{N}_{pp}^{Y}}$. The total R_{AA} must account for suppression and regeneration mechanisms and thus is given as $R_{AA}(p_T) = R_{AA}^{\text{prim}}(p_T) + R_{AA}^{\text{reg}}(p_T)$ where $R_{AA}^{\text{reg}}(p_T) = R_{AA}^{\text{reg}} \frac{f_{\Upsilon}(p_T)}{f_{pp}(p_T)}$ and $f_{pp}(p_T)$ denotes the transverse momentum spectrum for bottomonium in proton-proton collisions. Here we use pp-spectra taken from the CDF collaboration. The regeneration of bottomonium is described by $f_{\Upsilon}(p_T)$ and can be accounted for in several ways, here we use a blastwave model and a quark coalescence model.

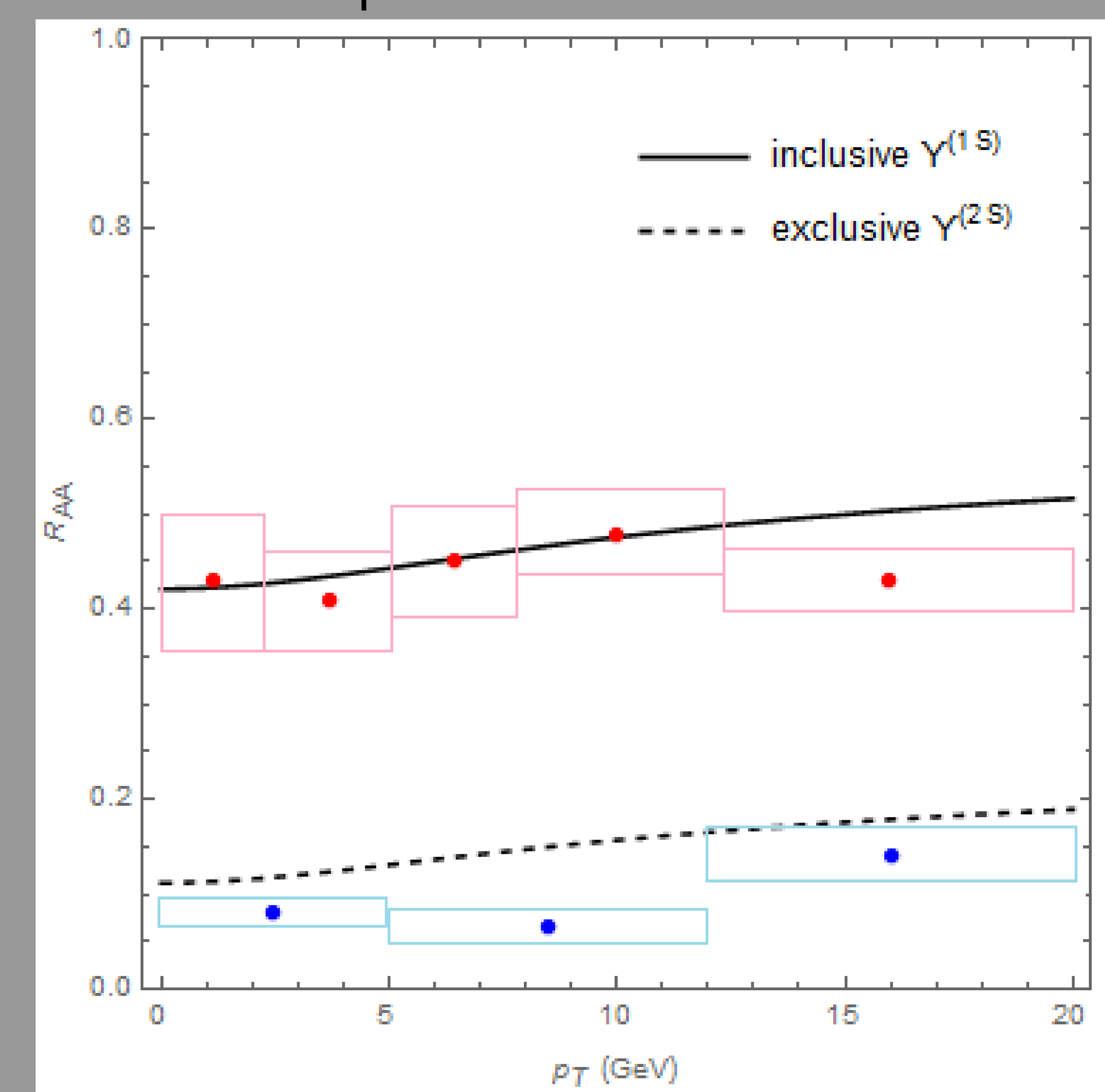
Blastwave & Coalescence Models

The blastwave model [1] provides the transverse momentum spectra of locally thermalized particles boosted by a flow field, where thermal flow is from fireball expansion. Since the medium is highly relativistic, we employ the Cooper-Frye formula to count the particle number in the freeze-out hypersurface. By specifying the temperature and volume evolution of the thermal bulk medium, the total R_{AA} is parameterized in proper time τ. However, since bottomonium is not fully thermalized by the time of freeze-out, the blaswave model is an insufficient description of bottomonium abundance.

Since the blastwave model is an unrealistic description of bottomonium abundance, a quark coalescence model [2] is employed for the calculation of R_{AA}^{Υ}. Parton coalescence describes meson production as a convolution integral of the parton distribution functions with a meson Wigner distribution function. The parton distribution functions give the quark and antiquark transverse momentum spectra, while the meson distribution function describes the allowed parton coordinate and momenta for bottomonium coalescence. In the case of the Υ this model is superior to the blastwave because it does not require a thermal description of the medium.

Conclusions

Bottomonium abundance in URHICs depends on the detailed interplay of suppression and regeneration mechanisms. The blastwave model is not a realistic description of the Υ^{1S} and Υ^{2S} because bottomonium are not fully thermalized by the time of freeze-out. A coalescence model provides a more reasonable picture of Υ abundance. The plot below shows the inclusive $R_{AA}^{\Upsilon(1S)}$ (including feed-down from excited states) and the exclusive $R_{AA}^{\Upsilon(2S)}$ as calculated by the coalescence model and compared to data from lead-lead collisions at CMS. We anticipate that further research into these topics will offer more insight and explanation for these phenomena.



Acknowledgments

- [1] Emerick, Zhao, Rapp. arXiv: 1111.6537v1 28/11/2011
- [2] Greco, Ko, Levai arXiv: nucl-th/0305024v1 10/5/2003

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