Heavy-Quark Kinetics at RHIC and LHC

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Abstract

In ultrarelativistic nuclear collisions heavy quarks are produced out of thermal equilibrium in the very early stage of the reaction and their thermalization time was expected to be considerably larger than that of light quarks. On the other hand, a strongly-interacting QGP can be envisaged in the heavy quark sector due to the presence of heavy-light hadron-like resonances in the QGP for temperatures up to $\sim 2T_C$. We investigate the consequences of such states employing a relativistic Langevin simulation. Hadronization is modeled by a coalescence-fragmentation scheme. We present the predictions for the nuclear modification factor and elliptic flow of D and B mesons at LHC energies and compare the results with the successful predictions of this model for RHIC conditions. We find similar heavy-quark thermalization effects at LHC and RHIC.

1. Introduction

For heavy quarks, their mass $m_Q \gg T_c \simeq 180$ MeV (critical temperature). Hence their kinetic equilibration time is expected to be larger than that for light partons, thus showing better sensitivity to the in-medium interactions. Due to a slower thermalization a smaller elliptic flow of D mesons, v_2^D, was expected; however, it was suggested that a sizable v_2^D could result from that of the light quarks [1] through a coalescence hadronization mechanism [1,9]. Surprisingly, data from the Relativistic Heavy-Ion Collider (RHIC) for single electrons ($e^\pm$) associated with semileptonic B and D decays in semi-central Au-Au collisions exhibited a v_2 of up to 10% [2,5], indicating substantial collective behavior of charm (c) quarks consistent with the assumption of a c-quark v_2 similar to the one for
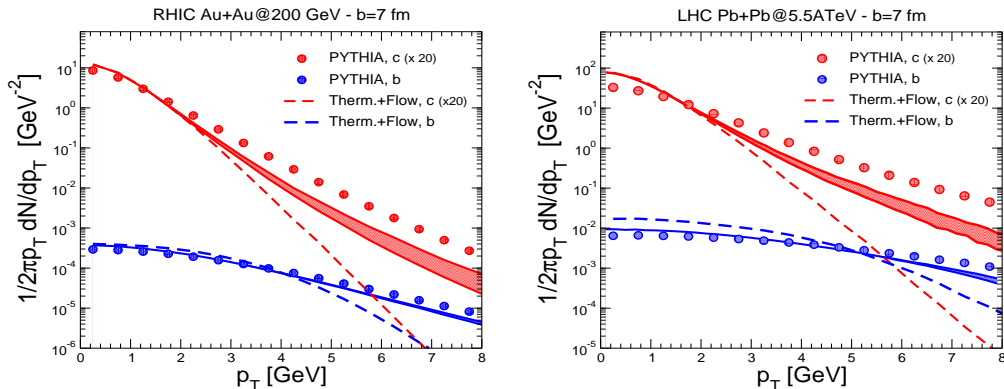

Fig. 1. (Color online) HQ p_T distributions at RHIC (left) and LHC (right). Circles are the initial distribution, the bands show the ones after interactions in the QGP. Dashed lines are the thermal distributions shown for comparison.

light quarks, apart from a p_T shift due to radial-flow effects [1]. In addition, the nuclear suppression factor was found to be comparable to the pion one, $R_{AA} \simeq 0.3$ [3,4]. Perturbative QCD (pQCD) calculations of radiative energy loss cannot explain these findings, even after inclusion of elastic scattering. Based on lattice QCD (lQCD) results which suggest resonance structures in the meson-correlation function at moderate temperatures, an effective model for heavy-light quark scattering via D and B resonances was suggested [6]. When implementing such a picture into a Langevin simulation the results for semileptonic $e^{\pm}$ spectra [7] are in reasonable agreement with RHIC data [3–5].

2. Heavy-Quark Transport in a sQGP Fireball

We employ a Fokker-Planck approach to evaluate drag and diffusion coefficients for c and b quarks in the QGP based on elastic scattering with light quarks via D- and B-meson resonances with a width Γ=400-750 MeV (supplemented by perturbative interactions) [6]. Heavy-quark (HQ) kinetics in the QGP is treated as a relativistic Langevin process [7], and the medium is modeled by a spatially homogeneous elliptic thermal fireball which expands isentropically.

For RHIC the details of the fireball and the parameters used can be found in [7]; for LHC we extrapolate to $dN_{ch}/dy \simeq 1400$ for central $\sqrt{s_{NN}}$=5.5 TeV Pb-Pb collisions. The expansion parameters are adjusted to hydrodynamic simulations, resulting in a total lifetime of $\tau_{fb} \simeq 6$ fm/c at the end of a hadron-gas QGP mixed phase and an inclusive light-quark elliptic flow of $\langle v_2 \rangle$=7.5%. The main change with respect to RHIC is the expectation of a new "phase" in which hadron-like resonances melt at higher temperature. In order to implement this "melting" of D- and B-mesons above $T_{diss}=2\,T_c \simeq 360$ MeV, a "transition factor" $(1 + \exp[(T - T_{diss})/\Delta])^{-1}$ (Δ=50 MeV) has been introduced into the transport coefficients.

Initial HQ spectra are computed using PYTHIA with parameters as used by the ALICE Collaboration [10], and c and b quarks are hadronized into D and B mesons at T_c by coalescence with light quarks [1]; "left-over" heavy quarks are treated by δ-function fragmentation.
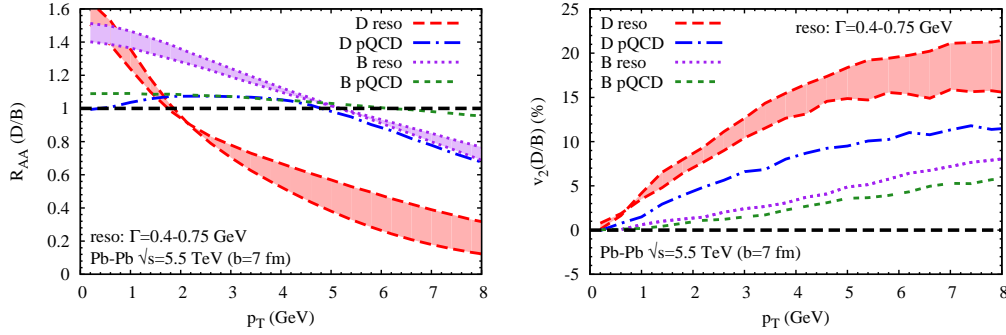
Fig. 2. (Color online) Predictions of relativistic Langevin simulations for heavy qurks in an sQGP for b=7 fm, $\sqrt{s_{NN}}$=5.5 TeV Pb-Pb collisions: R_{AA} (left) and v_2 (right) for D and B mesons.

3. Results and Predictions for RHIC and LHC

In Fig. 1 the invariant p_T distributions for c (red) and b (blue) quarks at RHIC (left) and LHC (right) are shown. It is evident that the charm-quark distributions after rescattering in the sQGP (band corresponding to the uncertainty in the resonance width) are close to the thermal distribution for $p_T \lesssim 2m_c$ where most of the yield resides. On the contrary, b quarks are predicted to be off-equilibrium (even at LHC energies).

Fig. 2 summarizes our results for HQ diffusion in a QGP in terms of the meson $R_{AA}(p_T)$ and $v_2(p_T)$ for b=7 fm Pb-Pb collisions at the LHC. Our most important findings are: (a) resonance interactions substantially increase (decrease) v_2 (R_{AA}) compared to perturbative interactions; (b) b quarks are much less affected than c quarks, reducing the effects in the $e^{\pm}$ spectra; (c) there is a strong correlation between a large v_2 and a small R_{AA} at the quark level, which, however, is partially reversed by coalescence contributions which increase *both* v_2 and R_{AA} at the meson (and $e^{\pm}$) level. This feature turned out to be important in the prediction of $e^{\pm}$ spectra at RHIC; (d) the predictions for LHC are quantitatively rather similar to our RHIC results [7], due to a combination of harder initial HQ-p_T spectra (see circles in Fig. 1) and a decrease in interaction strength in the early phases where non-perturbative resonance scattering is inoperative. Therefore we conclude that if at RHIC the dominant contribution to HQ interactions are hadron-like resonances, at LHC we should observe an R_{AA} and v_2 pattern similar to RHIC.

References

[1] V. Greco, C. M. Ko and R. Rapp, Phys. Lett. B **595**, 202 (2004).
[2] S. Kelly [PHENIX Collaboration], J. Phys. **G30**, S1189 (2004).
[3] S. S. Adler *et al.* [PHENIX Collaboration], Phys. Rev. Lett. **96**, 032301 (2006).
[4] B. I. Abelev et al. [STAR Collaboration], Phys. Rev. Lett. **98**, 192301 (2007).
[5] A. Adare et al. [PHENIX Collaboration], Phys. Rev. Lett. **98**, 172301 (2007).
[6] H. van Hees and R. Rapp, Phys. Rev. C **71**, 034907 (2005).
[7] H. van Hees, V. Greco and R. Rapp, Phys. Rev. C **73**, 034913 (2006).
[8] H. van Hees, V. Greco and R. Rapp, LHC last call for prediction 2007, arXiv:0706.4456 [hep-ph].
[9] V. Greco, C. M. Ko and P. Levai, Phys. Rev. C **68**,034904 (2003).
[10] ALICE Collaboration, J. Physics **G32**, 1295 (2006).