Heavy quark quenching from RHIC to LHC and the consequences of gluon damping

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Abstract

In this contribution to the Quark Matter 2012 conference, we study whether energy loss models established for RHIC energies to describe the quenching of heavy quarks can be applied at LHC with the same success. We also benefit from the larger $p_T$-range accessible at this accelerator to test the impact of gluon damping on observables such as the nuclear modification factor.

1. Introduction

Recently, we have proposed a microscopic approach for the quenching of heavy quarks (HQ) in ultra-relativistic heavy ions collisions (URHIC) \cite{1,2}, assuming interactions with light partons through both elastic and radiative processes evaluated by resorting to some parameterization of the running coupling constant, while those partons are spatially distributed along hydrodynamical evolution \cite{3} of the quark-gluon plasma (QGP) created in these collisions. This approach was able to explain successfully several observables measured at RHIC, such as the nuclear modification factor ($R_{AA}$) and the elliptic flow ($v_2$) of non-photonic single electrons (NPSE). The diffusion coefficient $D$ for HQ in QGP – a fundamental property of this state of matter – could thus be extracted \cite{4}. Here, we would like to assess the robustness of our models by confronting their predictions for $D$ and $B$ mesons production in URHIC at LHC to some experimental results obtained so far by ALICE and CMS collaborations.

2. Heavy quark quenching at RHIC

Let us recall that our overall strategy is to establish energy loss models based on the interaction rates of HQ with the QGP constituents and then allow for some global rescaling by a factor $K$ that mimics the left over ingredients and the uncertainties affecting the models. In \cite{1}, a good agreement was found between our collisional model E and the NPSE observables ($R_{AA}$ for all centralities and $v_2$) measured by PHENIX and STAR for $K \approx 2$ (including the mixed phase in the evolution). In \cite{2}, an equally good agreement for the NPSE was obtained with a cocktail of collisional energy loss and radiative energy loss evaluated from a generalization of the Gunion-Bertsch spectrum \cite{5} for heavy quarks. More recently \cite{6}, we have considered coherence effects for the radiation, with however little consequence on the $[0 \ GeV/c; 10 \ GeV/c]$ $p_T$-range presently achievable at RHIC for HQ. Not surprisingly, we still find a good agreement for the $R_{AA}$ of NPSE with this improved model\cite{6}, for $K \approx 0.7$, as illustrated in fig. 1 (right).

\footnote{Hereafter referred to as "radiative (LPM)."}
In this contribution, we take the opportunity of the $R_{AA}$ of $D^0$ mesons presented by the STAR collaboration [7] for $p_T \in [0 \text{ GeV}/c; 6 \text{ GeV}/c]$ at this conference to better constrain our optimal value of $K$. In fig. 2 we display a typical “best set” of curves for both models, while in tables 1 we summarize the best $K$-values for the 3 observables considered at RHIC. The consistence obtained for both $D^0$ and NPSE at RHIC is a rather clear indication that the quenching from $b$
quark at intermediate $p_T$ is correctly described by our models. In fig. 1, we show the $R_{AA}$ of leptons stemming independently from $D$ and $B$ mesons. As both types of energy loss obey mass hierarchy $\frac{dE}{dx}(b) < \frac{dE}{dx}(c)$, we naturally find $R_{AA}(e \rightarrow D) < R_{AA}(e \rightarrow B)$ for $p_T \gtrsim 1.5$ GeV/c. This is however in contradiction with the results from the PHENIX collaboration [8] extracted from the fit of distributions of the distance of closest approach and presented at this conference. In our view, this puzzle should be clarified at some point by the direct measurement of $B$ mesons.

3. The LHC case

We consider the same models for HQ energy loss at LHC, just modifying the initial $p_T$ distribution according to the FONLL scheme [9] as well as the initial entropy density $s_0$ of the QGP phase at the hottest point in order to reproduce the final density $dN_{ch}/dy = 1600$ at mid-rapidity. In comparison with the ALICE results [10] for $D$ mesons, the optimal $K$ values extracted from RHIC lead to a slight excess of quenching [4, 11] at intermediate $p_T$ for both models, while $v_2(D)$ in good agreement [12] with the data. As illustrated in tables 1 and in fig. 3 a 10% decrease of the coupling leads to a reasonable agreement for $p_T \lesssim 10$ GeV/c. In our mind, this is an acceptable rescaling in view of the moderate sophistication of the models, and we would thus argue to have developed a consistent modeling of heavy quark quenching “from RHIC to LHC”.

![Figure 3](image-url)
\[ \frac{d^2 N}{d \omega d t} \] spectrum described in [6] and then quench this radiation with an acceptance probability of \( \min(1, \frac{1}{\Gamma}) \) where \( t_d \) is the damping time and \( l_f \) is the formation length discussed in [15]. Within pQCD, one obtains \( \Gamma \propto T \). For the purpose of the illustration, we have chosen \( \Gamma / T = 0.75 \) and show the consequence of this finite damping in figure 3 (right, dark gray band). The arrow indicates the shift in the \( R_{AA} \) due to gluon damping which softens the radiation spectra and thus reduces the average energy loss, an effect that manifest itself especially at larger energies as discussed in [15]. Although NLO effects such as gluon damping deserve more detailed investigations to be performed in the future, let us mention that they can lead to drastic consequences, as for instance the coincidence of both \( R_{AA} \) of \( D \) and \( B \) mesons at rather moderate \( p_T \), as illustrated by fig. 4. On this fig. it is also important to notice that \( R_{AA}(B) \) for \( p_T \in [6 \text{ GeV}/c; 30 \text{ GeV}/c] \) is compatible with the value extracted by the CMS collaboration for non-prompt \( J/\psi \) [17].

4. Summary

In this contribution, we have argued that the effective models of energy loss that we have developed over the past years to encompass open heavy flavor observables at RHIC are in pretty good agreement – within 10% accuracy – with similar observables at LHC for intermediate \( p_T \). At larger \( p_T \), new effects neglected up to now might be revealed, as for instance the damping of high energy gluon radiated in coherent processes.

References

[1] P.B. Gossiaux, J. Aichelin, Phys. Rev. C78, 014904 (2008), [hep-ph/0802.2525].
[2] P.B. Gossiaux, V. Guiho, J. Aichelin, J. Phys. G: Nucl. Part. Phys. 37 (2010) 094019.
[3] P.F. Kolb, J. Sollfrank, and U. Heinz, Phys. Rev. C 62 (2000) 054909, P.F. Kolb and U. Heinz, in “Quark-Gluon Plasma 3” (World Scientific, Singapore, 2004) [arXiv:nucl-th/0305084].
[4] P.B. Gossiaux, J. Aichelin and T. Gousset, Prog. Th. Phys. 193 (2012) 110 [arXiv:1201.4038].
[5] J. F. Gunion and G. Bertsch, Phys. Rev. D 25 (1982) 746.
[6] P.B. Gossiaux, proceedings from the “Hard probes 2012” conference [arXiv:1209.0844].
[7] Contribution of W. Xie in this volume.
[8] R. Nouicer, QM 2012, http://www.phenix.bnl.gov/phenix/WWW/talk/archive/2012/QM12/1988.ppt.
[9] M. Cacciari et al., [arXiv:1205.6344].
[10] ALICE collaboration, [arxiv 1203.2160v4].
[11] P.B. Gossiaux et al., proceedings from Sixth International Conference on Quarks and Nuclear Physics [arxiv 1207.5445].
[12] J. Aichelin, P.B. Gossiaux and T. Gousset, Acta Physica Polonica B 43 (2012) 655 [arXiv:1201.4192v1].
[13] M. Bluhm, P.B. Gossiaux and J. Aichelin, [arXiv:1106.2956]. PRl 107 (2011) 265004.
[14] L.D. Landau and L Ya. Pomeranchuk, Dokl. Akad. Nauk SSSR 92 (1953) 535; ibid. 92 (1953) 735.
[15] M. Bluhm, P.B. Gossiaux, T. Gousset, J. Aichelin, [arXiv:1204.2469v1].
[16] T.S. Biro et al., Phys. Rev. C 48 (1993) 1275.
[17] CMS collaboration, [arXiv:1201.5069].