Modeling jet-medium interactions at RHIC and LHC - which energy loss effect is crucial?

To cite this article: B Blagojevic and M Djordjevic 2016 J. Phys.: Conf. Ser. 668 012044

View the article online for updates and enhancements.
Modeling jet-medium interactions at RHIC and LHC - which energy loss effect is crucial?

B Blagojevic and M Djordjevic
Institute of Physics Belgrade, Pregrevica 118, 11080 Zemun, Serbia
E-mail: bojanab@ipb.ac.rs

Abstract. High momentum hadrons’ suppression is considered to be excellent probe of QCD matter created in ultra-relativistic heavy ion collisions. Here we apply our recently developed dynamical energy loss formalism, which includes the following effects: dynamical scattering centers, QCD medium of a finite size, both radiative and collisional energy losses, running coupling and finite magnetic mass, and which we further incorporate into numerical procedure, to generate angular averaged $R_{AA}$ predictions and to compare them with experimental $R_{AA}$ data, by using no free parameters. A robust agreement of our predictions and experimentally measured $R_{AA}$ for different energies, probes and all available centrality regions, raised the question whether this agreement is consequence of a single effect or of a superposition of all these effects. We obtained that, although the inclusion of dynamical scattering center has the largest relative importance, all the other effects are also important, since they lead to fine improvements of the agreement. Therefore, the robust agreement is a cumulative effect of all these features, with dynamical effect being crucial for accurate $R_{AA}$ predictions.

1. Introduction

High momentum light and heavy flavor suppression [1] is considered to be excellent tool for studying QCD matter created in ultra-relativistic heavy ion collisions at RHIC and LHC. An abundance of suppression data, that has become available at RICH and LHC since recently, and its comparison with theoretical $R_{AA}$ predictions [2–4], allows testing our understanding of QGP matter. In order to generate these predictions, we recently developed dynamical energy loss formalism, which we further integrated into numerical procedure as described in [5]. This formalism includes the following energy loss effects: i) dynamical scattering centers, ii) QCD medium of a finite size [6,7], iii) both radiative [6,7] and collisional [8] energy losses, iv) running coupling [5] and v) finite magnetic mass [9]. Also, note that, accurate energy loss calculation is considered to be the main ingredient responsible for obtaining reliable $R_{AA}$ predictions.

In our previous papers [5,10,11], we demonstrated a robust agreement between our $R_{AA}$ predictions, obtained as explained in previous paragraph, and $R_{AA}$ data for both RHIC and LHC experiments, diverse set of probes and all available centrality ranges.

Here we address the relative importance of different energy loss effects in obtaining accurate angular averaged $R_{AA}$ predictions for D mesons (as the clearest energy loss probe), for which it was previously shown that fragmentation function does not alter bare charm quark $R_{AA}$ [10,12]. High momentum D meson $R_{AA}$ data, obtained recently at LHC [13], serve as a baseline for testing the models. We concentrate on central 200 GeV Au+Au collisions at RHIC and 2.76 TeV Pb+Pb collisions at LHC. Our approach is to systematically include the effects in energy
loss calculations [14], i.e. we first compare the relative importance of radiative and collisional contribution to $R_{AA}$ predictions, next we address the importance of including the dynamical scattering centers, then the running coupling and finally the finite magnetic mass. Note that only the main results are presented here; for the full account on the results, please see [14].

2. Theoretical and computational formalism

In this section, we concisely describe computational formalism, our dynamical energy loss formalism [5] and how each effect, when introduced, changed energy loss expressions.

For obtaining quenched spectra we apply generic pQCD convolution given by Eq.(2) from [14] ([15]). The initial charm quark spectrum is calculated in accordance with [16], while energy loss probability includes both radiative and collisional energy losses in a finite size dynamical QCD medium, multi-gluon [17] and path length fluctuations [15,18].

The expression for radiative energy loss in a finite size dynamical QCD medium is given by Eq.(2.12) from [6], while the transition from static to dynamical scattering centers is explained in [7]. The collisional energy loss is calculated according to Eq.(14) from [8]. The running coupling is introduced in accordance with [5], while for constant coupling we use $\alpha_S = 0.3$ ($\alpha_S = 0.25$) in RHIC (LHC) case. Debye screening mass is $\mu_E = gT$ ($g = 2$). The finite magnetic mass is introduced as in [9], and its range $0.4 < \mu_M / \mu_E < 0.6$ is set according to many non-perturbative approaches [19–23], otherwise $\mu_M = 0$ is used.

We model the medium by assuming an effective temperature of 221 MeV at RHIC [24] and 304 MeV at LHC [25]. No medium evolution is accounted. The validity of this assumption is discussed in [14]. For charm quark mass we use $M_c = 1.2$ GeV, and for the number of effective light quark flavors we use $n_f = 2.5$ ($n_f = 3$) in RHIC (LHC) case.

3. Results and discussion

![Figure 1](image_url)

**Figure 1. Necessity of abolishing static approximation.** D meson $R_{AA}$ predictions, as a function of transverse momentum, are shown for only static radiative (dotted curve) and for only dynamical collisional (dot-dashed curve) contribution in a finite size QCD medium. Left (right) panel corresponds to RHIC (LHC) case. Right panel also displays D meson $R_{AA}$ data in 0 – 7.5% central 2.76 TeV Pb+Pb collisions at LHC (red triangles) [13]. Debye mass is $\mu_E = gT$, coupling constant is $\alpha_S = 0.3$ ($\alpha_S = 0.25$) for RHIC (LHC) and finite magnetic mass is not included ($\mu_M = 0$). Adapted from [14].

In this section we apply historically-driven approach, starting from static approximation [26, 27] and gradually adding energy loss effects. We display only the main results of our study carried out in [14]. Finite size QCD medium is assumed throughout the paper. The constant coupling and constant Debye mass (as mentioned above), and no finite magnetic mass are considered in Fig. 1 and Fig. 2. Static approximation, which assumes that the medium is composed of static
scattering centers, was firstly commonly used. It entails also, that collisional energy loss can be
neglected compared to radiative one. However, Fig. 1 clearly shows that static approximation
has to be abolished in favor of dynamical scattering centers’ approximation, since collisional $R_{AA}$
is comparable with radiative one. Further, we compute these both energy losses within the

Figure 2. Dynamical approximation as the main effect. D meson $R_{AA}$ predictions, as a function of transverse momentum, are shown for radiative (dashed curve), collisional (dot-dashed curve) and radiative + collisional (solid curve) energy losses in a finite size dynamical QCD medium. Left (right) panel corresponds to RHIC (LHC) case. Right panel also displays D meson $R_{AA}$ data in 0–7.5% central 2.76 TeV Pb+Pb collisions at LHC (red triangles) [13]. Debye mass is $\mu_E = gT$, coupling constant is $\alpha_S = 0.3$ ($\alpha_S = 0.25$) for RHIC (LHC) and finite magnetic mass is not included ($\mu_M = 0$). Adapted from [14].

same dynamical framework (Fig. 2) and we draw three conclusions: 1) dynamical radiative $R_{AA}$
alone is not sufficient to explain qualitatively nor quantitatively the LHC experimental data; 2)
radiative and collisional $R_{AA}$ are still both important; 3) the total $R_{AA}$ is in rough agreement
with experimental data. Therefore, the inclusion of dynamical scattering centers is the main
effect responsible for obtaining accurate $R_{AA}$ predictions. Finally, we address the importance of

Figure 3. Our dynamical energy loss formalism. D meson $R_{AA}$ predictions, as a function of transverse momentum, are shown for the constant coupling $\alpha_S = 0.3$ ($\alpha_S = 0.25$) for RHIC (LHC) (light gray band) and for the running coupling (dark gray band). In both cases radiative + collisional contributions in a finite size dynamical QCD medium are accounted. Upper (lower) boundary of each band corresponds to $\mu_M/\mu_E = 0.6$ ($\mu_M/\mu_E = 0.4$). Left (right) panel corresponds to RHIC (LHC) case. Right panel also displays D meson $R_{AA}$ data in 0–7.5% central 2.76 TeV Pb+Pb collisions at LHC (red triangles) [13]. Adapted from [14].

including the running coupling (leads to a significant $R_{AA}$ decrease at lower jet momenta) and
finite magnetic mass (leads to a significant $R_{AA}$ increase) [14]. From Fig. 3 we see that these two effects (although taken alone worsens the agreement [14]) taken together lead to quantitatively and qualitatively better agreement with the LHC $R_{AA}$ data, compared to the case when these effects are omitted. This illustrates possible synergy in including these two effects.

4. Conclusions
A robust agreement of angular averaged $R_{AA}$ predictions, based on our dynamical energy loss formalism, with $R_{AA}$ data, for different energies, probes and centrality ranges, initiated the question: whether this agreement is a consequence of a one dominant energy loss effect or a joint effect of several smaller improvements [14]. With the LHC suppression data serving as a baseline, we here showed that (for the clearest energy loss probe: D meson $R_{AA}$), inclusion of dynamical scattering centers has the largest relative importance in obtaining accurate $R_{AA}$ predictions. Furthermore, we found that all other considered effects are also important and responsible for the finer agreement with the data. So the good agreement is a result of a superposition of all these effects. Therefore, detailed study of partons’ energy loss, as well as, inclusion of all relevant medium effects is necessary to correctly model the jet-medium interactions.

Acknowledgments
This work is supported by Marie Curie International Reintegration Grant within the 7th European Community Framework Programme PIRG08-GA-2010-276913 and by the Ministry of Science and Technological Development of the Republic of Serbia, under project No. ON171004.

References
[1] Bjorken J D 1982 FERMILAB-PUB-82-059-THY pp 287-92
[2] Brambilla N et al 2014 Eur. Phys. J. C 74 2981
[3] Gyulassy M 2002 Lect. Notes Phys. 583 37
[4] d’Enterria D and Betz B 2010 Lect. Notes Phys. 785 285
[5] Djordjevic M and Djordjevic M 2014 Phys. Lett. B 734 286
[6] Djordjevic M 2009 Phys. Rev. C 80 064909
[7] Djordjevic M and Heinz U 2008 Phys. Rev. Lett. 101 022302
[8] Djordjevic M 2006 Phys. Rev. C 74 064907
[9] Djordjevic M and Djordjevic M 2012 Phys. Lett. B 709 229
[10] Djordjevic M and Djordjevic M 2014 Phys. Rev. C 90 034910
[11] Djordjevic M, Djordjevic M and Blagojevic B 2014 Phys. Lett. B 737 298
[12] Djordjevic M 2014 Eur. Phys. J. C 33 495
[13] Grelli A 2013 Nucl. Phys. A 904-905 635c
Abelev B et al 2012 J. High Energy Phys. JHEP1209(2012)112
[14] Blagojevic B and Djordjevic M 2015 J. Phys. G 42 075105
[15] Wicks S, Horowitz W, Djordjevic M and Gyulassy M 2007 Nucl. Phys. A 784 426
[16] Kang Z B, Vitev I and Xing H 2012 Phys. Lett. B 718 482-7
[17] Gyulassy M, Levai P and Vitev I 2002 Phys. Lett. B 538 282
[18] Dainese A 2004 Eur. Phys. J. C 33 495
[19] Maezawa Yu, Aoki S, Ejiri S, Hatsuda T, Ishii N, Kanaya K, Ukita N and Umeda T 2010 Phys. Rev. D 81 091501
[20] Maezawa Yu, Aoki S, Ejiri S, Hatsuda T, Ishii N, Kanaya K, Ukita N and Umeda T 2008 Proc. of Science Lattice 2008 (Williamsburg) p 194 (Preprint hep-lat/0811.0426)
[21] Nakamura A, Saito T and Sakai S 2004 Phys. Rev. D 69 014506
[22] Hart A, Laine M and Philipsen O 2000 Nucl. Phys. B 586 443
[23] Bak D, Karch A and Yaffe L G 2007 J. High Energy Phys. JHEP0708(2007)049
[24] Adare A et al 2010 Phys. Rev. Lett. 104 132301
[25] Wilde M 2013 Nucl. Phys. A 904-905 573c
[26] Djordjevic M and Gyulassy M 2004 Nucl. Phys. A 733 265-98
[27] Gyulassy M and Wang X N 1994 Nucl. Phys. B 420 583
Wang X N, Gyulassy M and Plumer M 1995 Phys. Rev. D 51 3436