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Toward a simultaneous description of R_{AA} and v_2 for heavy quarks

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Abstract. The two key observables related to heavy quarks that have been measured in RHIC and LHC energies are the nuclear suppression factor R_{AA} and the elliptic flow v_2. The Simultaneous description of these two observables is a top challenge for all the existing models. We highlight how a consistent combination of four ingredients i.e., the temperature dependence of the energy loss, the full solution of the Boltzmann collision integral for the momentum evolution of heavy quark, the hadronization by coalescence, and the hadronic rescattering, are responsible to address a large part of such a puzzle. We consider four different models to evaluate the temperature dependence of drag coefficients of the heavy quark in the QGP. All these four different models are set to reproduce the same R_{AA} as of the experiments. We show that for the same R_{AA}, the v_2 could be quite different depending on the interaction dynamics as well as other ingredients.

1. Introduction

Theoretical calculations predict that hadronic matter at high temperatures and densities dissolves into a deconfined state of quarks and gluons - called Quark Gluon Plasma (QGP).The experimental efforts at Relativistic Heavy Ion Collider (RHIC) and Large Hadron Collider (LHC) energies is aimed at to create and characterized the properties of QGP. The heavy hadrons (hadrons which contain at least one heavy quark, mainly c and b) constitute a unique probe of the QGP properties, because they are produced in the early stage of the collisions and they are the witness to the entire space-time evolution of the system.

The two key observables related to heavy quarks that have been measured in RHIC and LHC are the nuclear suppression factor R_{AA} [1, 2, 3], which is the ratio between the the p_T spectra of heavy flavored hadrons (D and B) produced in Au+Au collisions with respect to those produced in p+p collisions, and the elliptic flow v_2 [2, 4], which is a measure of the anisotropy in the angular distribution. Several theoretical efforts have been made to study the R_{AA} and the v_2 measured in experiments within the Fokker Planck (FP) approach [5, 6, 7, 8, 9, 10] and the relativistic Boltzmann approach [11, 12, 13, 14, 17, 16]. However all the approaches shown some difficulties to describe both the R_{AA} and v_2 simultaneously.

2. Results

To address the simultaneous description of R_{AA} and v_2, we start with the time evolution of R_{AA} and v_2 to know how they develop during the expansion of the QGP. To study the time


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evolution of R_{AA} and v_2, we have solved the Fokker Planck (FP) equation stochastically in terms of the Langevin equation, for detail we refer to our earlier work [10]. The elastic collisions of heavy quarks with the bulk has been considered within the framework of pQCD. The divergence associated with the t-channel diagrams due to massless intermediate particle exchange has been regularized introducing the Debye screening mass $m_D = 4\pi\alpha_s T$ with the running coupling α_s. For the bulk evolution we are using a transport bulk which can reproduce some of the gross features of the bulk [19, 18]. At RHIC energy, $Au + Au$ at $\sqrt{s} = 200$, we simulate the fireball with initial temperature in the center is $T_i = 340$ MeV and the initial time is $\tau_i = 0.6$ fm/c. for the detail of the initialization, we refer to our early work. Initially the charm quark are distributed according to the charm production in pp collisions [20].

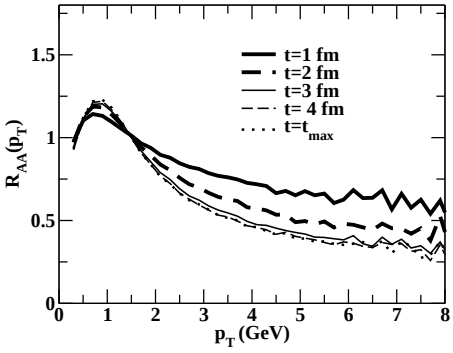

Figure 1. Time evolution of R_{AA}.

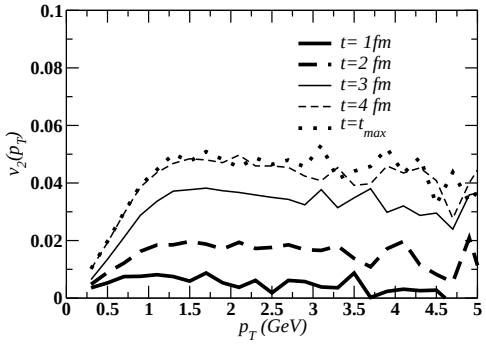

Figure 2. Time evolution of v_2.

As shown in Fig 1, the R_{AA} is develop at the very early stage of the evolution and get saturated within 3-4 fm where as the v_2 (in Fig2) is develop at the latter stage of the evolution. Initially the bulk have zero v_2. First the bulk will develop its own v_2 and then it will transfer it to the heave flavor. Hence the R_{AA} is sensitive to the magnitude of the drag coefficient at the early stage of the evolution i.e at T_i where as the v_2 is very sensitive to the magnitude of the drag coefficient at the latter stage of the evolution i.e at T_c . This highlights the T-dependence of the drag coefficient and may play a significance role for a simultaneous description of R_{AA} and v_2 as they are sensitive to different range of T. To study the impact of T-dependence of drag coefficients on heavy quark observable, we have consider four different model to calculate the drag and diffusion coefficients of heavy quark in QGP.

Model-I (pQCD): The elastic collisions of heavy quarks with the bulk has been considered within the framework of pQCD.
Model-II (AdS/CFT): In this case we have considered the drag force from the gauge/string duality i.e. AdS/CFT [21] which reads $\Gamma_{conf} = C\frac{T^2_{QCD}}{M_{HQ}}$, where $C = 2.1 \pm 0.5$.(also see [22])
Model-III: In the third case, we have employed a quasi particle model (QPM) [23, 24, 25] with T-dependent quasi-particle masses, $m_q = 1/3g^2T^2$, $m_g = 3/4g^2T^2$, plus a T-dependent background field known as bag constant, tuned to the thermodynamics of the lattice QCD. Such a fit lead to the coupling, $g^2(T) = \frac{48\pi^2}{[(11N_c-2N_f)ln[\lambda(\frac{T}{T_c}-\frac{T_s}{T_c})]^2}$, where λ=2.6 and T/T_s=0.57.
Model-IV ($\alpha_{QPM}(T), m_q = m_g = 0$): In this case, we are considering a model where the light quarks and gluons are massless but the coupling is taken from the QPM model discussed in Model III.

This fourth case has been considered to have a drag which is decreasing with T as obtained in the T-matrix approach [6, 26].The T-dependence of the drag coefficients have been shown in Fig 3 obtained within the four model discussed above at $p_T = 100$ MeV. These are the rescaled

drag coefficients which can reproduced the same R_{AA} as of the experiment at RHIC energy.

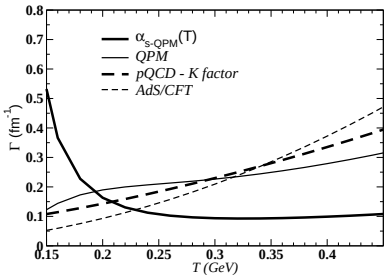

Figure 3. Drag coefficients as a function of temperature.

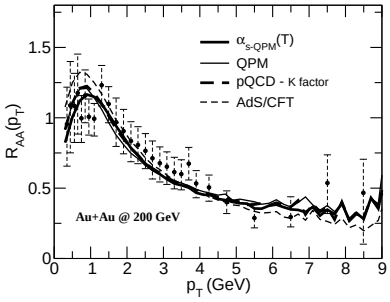

Figure 4. R_{AA} as a function of p_T.

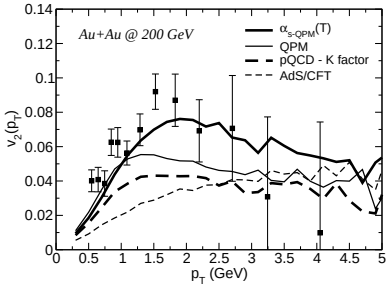

Figure 5. v_2 as a function of p_T.

In Fig 4 we have shown the R_{AA} as a function of p_T for the four different models obtained within the Langevin dynamics at RHIC energy. The v_2 for the same R_{AA} has been plotted in Fig 5 for all models as a function of p_T. We found that for the same R_{AA}, the v_2 build-up can be quite different depending on the T-dependence of the interaction. Larger the interaction at T_c larger is the v_2 [10]. Similar effect has also been found in the light quark sector [27, 28]. This suggests, the correct temperature dependence of drag coefficient has a significant role for a simultaneous reproduction of R_{AA} and v_2.

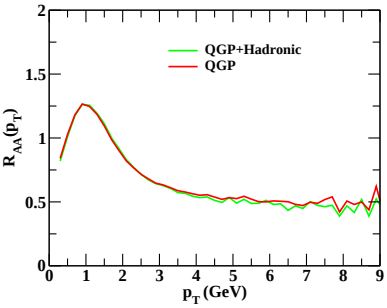

Figure 6. R_{AA} as a function of p_T at RHIC energy for QGP and QGP+hadronic phase.

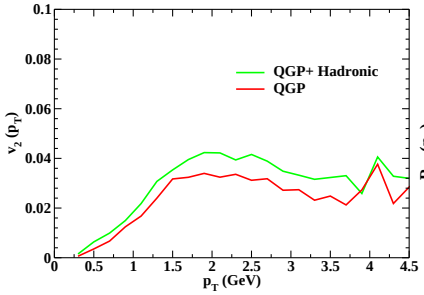

Figure 7. v_2 as a function of p_T at RHIC energy for QGP and QGP+hadronic phase.

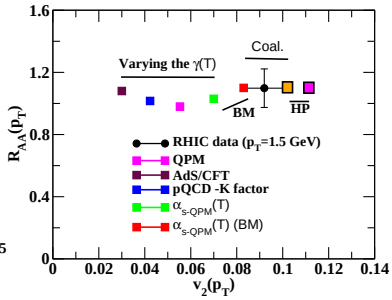

Figure 8. R_{AA} vs v_2 at p_T = 1.5 GeV.

Recently it has been shown [13] that the full solution of the Boltzmann (BM) integral i.e. without the assumption of small collisional exchanged momenta, leads in general to a larger v_2 than that of the Fokker Plank case which is a approximation of the Boltzmann equation under the assumption of small exchanged momenta. Also heavy quark hadronization by coalescence further enhances the v_2 [6, 29].

To study the role of the hadronic phase (HP) on the heavy quark observables, we study the propagation of D mesons in the hadronic medium consist of pions, kaons and eta. The elastic interaction between the D meson with the hadronic matter has been treated within the framework of chiral perturbation theory [30]. In Fig 6 we have shown the impact of the hadronic medium on R_{AA} which is almost unnoticeable. This is because the R_{AA} develops at the early stage of the evolution and get saturated due to radial flow within 3-4 fm. The impact of the hadronic medium on v_2 has been shown in Fig 7. The hadronic medium further enhance the v_2 around 20%. In Fig 8 we have shown how the v_2 build-up depends on the T-dependence of the drag coefficients for the same R_{AA}. Then the v_2 gets a boost from the Boltzmann equation

(BM) in terms of evolution over the Fokker Planck equation. The v_2 is further enhanced due to hadronization by coalescence. Finally the v_2 gets the hadronic phase boost where the R_{AA} remain the same.

3. Summary and outlook

In summary, we have shown how the v_2 build-up for the same R_{AA} depends on the T-dependence of the drag coefficients which is the key for a simultaneous description of R_{AA} and v_2. We have also highlighted how the v_2 gets a boost from the Boltzmann dynamics to study the momentum evolution of heavy quark and from hadronization by coalescence. Then we have shown the effect of the hadronic medium on R_{AA} and v_2. The impact of radiative processes on heavy quark observables will also be investigated in an upcoming study along with all these four ingredients within a single framework . It will also be interesting to study the role of the pre-equilibrium phase [31] on R_{AA} and v_2 relation.

Acknowledgements

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References

[1] Abelev B I *et al.* (STAR Collaboration) 2007 *Phys. Rev.* Lett. **98**, 192301.
[2] Adare A *et al.* (PHENIX Collaboration) 2007 *Phys. Rev.* Lett. **98**, 172301.
[3] Abelev B *et al.* (ALICE Collaboration) 2012 *J. High Ener. Phys.* **09**, 112.
[4] B. Abelev *et al.* (ALICE Collaboration) 2013 *Phys. Rev.* Lett. **111** 102301.
[5] Hees H van, Greco V and Rapp R 2006 *Phys. Rev.* C **73**, 034913
[6] Hees H van, Mannearelli M, Greco V and Rapp R 2008 *Phys. Rev. Lett.* **100** 192301
[7] Das S K, Alam J, Mohanty 2010 *Phys. Rev.* C **82** 014908 ; Majumdar S, Bhattacharyya T, Alam J, Das S K 2011 *Phys. Rev.* C **84** 044901
[8] Alberico W M *et al.* 2011 *Eur. Phys. J.* C **71** 1666
[9] Cao S., Qin G.-Y., Bass S A 2013 *Phys. Rev.* C **88**,4, 044907: 2015 *Phys.Rev.* C **92** 2, 024907
[10] Das S K, Scardina F, Plumari S and Greco V (2015) *Phys. Lett.* B **747**, 260
[11] Gossiaux P B, Aichelin J 2008 *Phys. Rev.* C **78** 014904
[12] Uphoff J, Fochler O, Xu Z and Greiner C 2011 *Phys. Rev.* C **84** 024908; Phys. Lett. B **717** (2012) 430
[13] Das S K, Scadina F, Plumari S, Greco V 2014 *Phys. Rev.* C **90** 044901.
[14] Song T *et al.* 2015 *Phys Rev.* C **92** 014910
[15] Scadina S, Das S K, Plumari P, Greco V 2015 J.Phys.Conf.Ser. *636* 1, 012017; 2014 J.Phys.Conf.Ser. *535* 012019
[16] Younus M, Coleman-Smith C E, Bass S A and Srivastava D K, arXiv:1309.1276 [nucl-th].
[17] Scadina S, Das S K, Plumari P, Greco V 2015 J.Phys.Conf.Ser. *636* 1, 012017; 2014 J.Phys.Conf.Ser. *535* 012019
[18] Ruggieri M, Scardina F, Plumari S, Greco V 2013 *Phys. Lett.* B **727** 177
[19] Scardina F, Colonna M, Plumari S and Greco V 2013 *Phys. Lett. B* **724** 296
[20] Cacciari M,Nason P, Vogt R 2005 *Phys. Rev. Lett.* **95**, 122001
[21] Maldacena J M 1998 Adv. Theor. Math. Phys. **2**, 231
[22] Das S K, Davody A 2014 *Phys. Rev.* C **89**, 054912.
[23] Plumari S, Alberico W M, Greco V, Ratti C 2011 *Phys. Rev.* D **84**, 094004
[24] Das S K, Chandra V, Alam J 2014 *J. Phys.* G **41** 015102.
[25] H. Berrehrah *et al.* (2014) *Phys.Rev.* C **89**, 054901
[26] Riek F, Rapp R 2010 *Phys. Rev.* C **82**, 035201
[27] Liao J, Shuryak E 2009 *Phys. Rev. Lett.* **102** 202302
[28] Scardina F, Toro M Di, Greco V 2010 *Phys. Rev.* C **82** 054901.
[29] Greco V, Ko C M, Rapp R 2004 *Phys. Lett.* B **595** 202
[30] Das S K, Ghosh S, Sarkar S, Alam J 2012 *Phys Rev* D **85** 074017; 2014 *Phys Rev* D **88**, 017501
[31] Das S K, Ruggieri M, Mazumder S, Greco V, Alam J 2015 *J. Phys.* G **42** 9, 095108