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Theoretical predictions of jet suppression: A systematic comparison with RHIC and LHC data

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Abstract

Accurate theoretical predictions of jet suppression are necessary for studying the properties of QCD matter created in ultra-relativistic heavy ion collisions. However, testing the prediction accuracy – and extracting useful qualitative knowledge – is often limited by constraining the predictions to only few experimental probes at a time, and by using free parameters. To address this issue, we here summarize comprehensive suppression predictions, which run across all available probes and different centrality regions at RHIC and LHC. These predictions are generated by the finite size dynamical QCD formalism that we previously developed, together with its recent extensions to finite magnetic mass and running coupling; this formalism is integrated into a numerical procedure that uses no free parameters in model testing, and we here briefly review the entire computational procedure. We demonstrate that a very good agreement with the experimental results is obtained across all particle species, for different centrality regions, and for both RHIC and LHC. We will also discuss improved qualitative understanding of the relevant experimental data, which follows from this comprehensive comparison.

Keywords: Jet suppression; Heavy quark energy loss; Dynamical QCD medium; Hard probes

1. Introduction

Jet suppression [1] is considered to be excellent probe of QCD matter. Furthermore, suppression for a number of observables under different experimental conditions has been measured at both RHIC and LHC. Consequently, their systematic comparison with theoretical predictions allows both testing our understanding of QCD matter, and the underlying assumptions used in

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theoretical predictions. However, to generate reliable suppression predictions, one must have reliable calculations of jet energy loss, since the suppression is a consequence of the energy loss of energetic partons that move through the plasma [2–4]. Having this in mind, over the past several years we developed a dynamical energy loss formalism, which removes the widely used assumption of static scattering centers, and calculates parton radiative [5,6] and collisional [7] energy loss within the same theoretical framework. We further integrated this energy loss into numerical procedure for jet suppression calculations, which enables generating a wide set of suppression predictions for different experiments, observables and collision centralities. In this proceedings, we first provide a brief overview of the dynamical energy loss and numerical procedure used in our suppression calculations, and then summarize a comprehensive comparison of generated predictions with the available experimental data from both RHIC and LHC, in order to test how well our model describes the underlying medium created in these collisions. Note that only the main results are presented in this proceedings, while for more details please refer to [8–10].

2. Jet suppression predictions

The dynamical energy loss formalism that we developed, calculates the jet radiative and collisional energy loss in a finite size QCD medium of thermally distributed light quarks and gluons (for more details see [5–7]). To calculate the energy loss we used the hard thermal loop approach (see e.g. [11]), which allowed removing the assumption of static scattering centers [12]. We recently extended the formalism to the case of finite magnetic mass [13], and most recently we included running coupling [8]. To generate suppression predictions, we incorporated this formalism into a numerical procedure (for more details see [8,10]), which also includes light [14] and heavy flavor [15] production, path-length [16,17] and multi-gluon [18] fluctuations, fragmentation for light [19] and heavy flavor [20,21] and, in the case of heavy mesons, their decays to single electrons and J/ψ [15]. As a starting point in our calculations, for LHC we used effective temperature of 304 MeV [22] as extracted by ALICE, and for RHIC we used 221 MeV [23] as extracted by PHENIX. All other parameters correspond to standard literature values, and are provided in [8,10].

We next concentrate on RHIC and LHC data, and our goal is to generate a comprehensive set of joint predictions for all available light and heavy flavor suppression measurements. Within this, our goal is to test how our model works for different probes, experiments and centrality regions. Note that all predictions are generated by the same (above outlined) formalism, with the same numerical procedure, and with no free parameters used in model testing. Also, note that on each figure gray regions correspond to finite magnetic mass case [29,30] (i.e. $0.4 < \mu_M/\mu_E < 0.6$), where the lower boundary corresponds to $\mu_M/\mu_E = 0.4$ and the upper boundary corresponds to $\mu_M/\mu_E = 0.6$.

In Fig. 1,we show the predictions for central collisions at LHC, which are, as pointed above, generated for a diverse probes, for which LHC measurements are available. Specifically, we generate predictions and compare them with experimental data for charged hadrons, D mesons, non-photonic single electrons and non-prompt J/ψ. We see that we obtain an excellent agreement for charged hadrons and D mesons. We see that the single electron data are quite noisy, but we still obtain a very good agreement with the predictions. There is also a good agreement for non-prompt J/ψ, except for the last datapoint, which comes with large error bars.

In Fig. 2, we test how our model works for RHIC central-collision data, since it is known that the suppression data at RHIC lead to a well-known heavy flavor puzzle at RHIC; that is, the previous static energy loss models were not able to explain these data. However, from this figure,

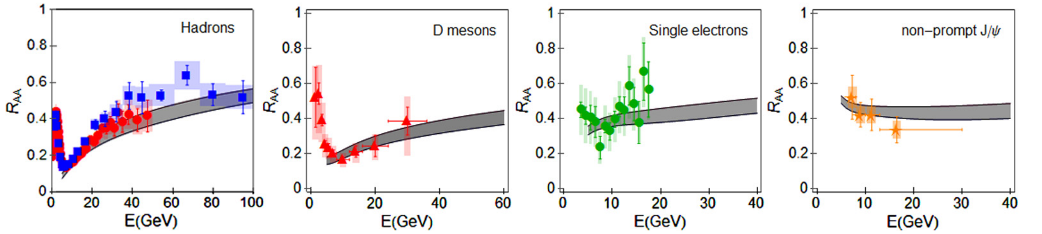

Fig. 1. Theory vs. experimental data for momentum dependence of hard probes suppression at LHC. First panel shows the comparison of charged hadron suppression predictions with experimentally measured R_{AA} for charged hadrons. The red circles and the blue squares, respectively, correspond to ALICE [24] and CMS [25] experimental data. Second panel shows the comparison of D meson suppression predictions with D meson R_{AA} ALICE preliminary data [26] (the red triangles) in 0–7.5% central 2.76 TeV Pb + Pb collisions. Third panel shows the comparison of non-photonic single electron suppression with the corresponding ALICE preliminary data [27] (the green circles) in 0–10% central 2.76 TeV Pb + Pb collisions. Fourth panel shows the comparison of J/ψ suppression predictions with the preliminary non-prompt J/ψ R_{AA} CMS data [28] (the orange stars) in 0–100% 2.76 TeV Pb + Pb collisions. Figure adapted from [8]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

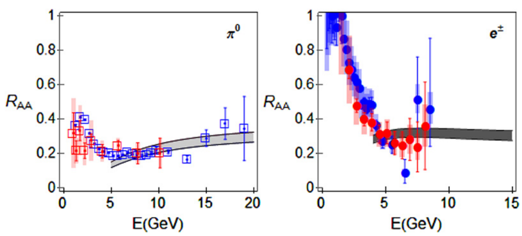

Fig. 2. Momentum dependence of neutral pion and non-photonic single electron R_{AA} at RHIC. Left panel shows the comparison of pion suppression predictions with π^0 PHENIX [31] (blue squares) and STAR [32] (red squares) experimental data from central 200 GeV Au + Au collisions at RHIC. Right panel shows the comparison of single electron suppression predictions with non-photonic single electron data from PHENIX [33] (blue circles) and STAR [34] (red circles) at central 200 GeV Au + Au collisions. Figure adapted from [35]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

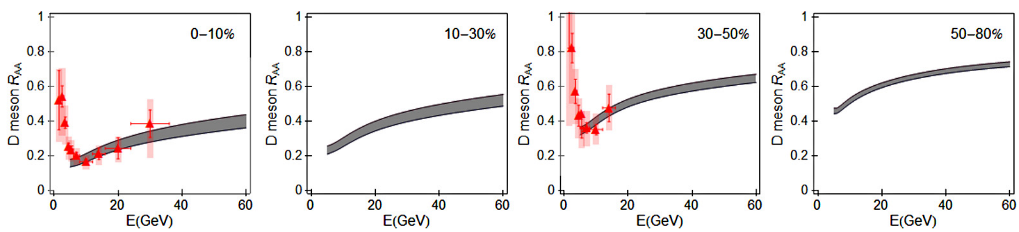

Fig. 3. Theory *vs.* experimental data for momentum dependence of D meson R_{AA} for different centrality bins at LHC. The left panel shows the comparison of D meson suppression predictions with D meson R_{AA} at 0–7.5% central 2.76 Pb + Pb collisions at LHC [26] (the red triangles). The other three panels show the theoretical predictions for D meson R_{AA} for, respectively, centrality bins 10–30%, 30–50% and 50–80%. In the third panel, the predictions are compared with recently available ALICE preliminary data [36]. Figure adapted from [10]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

we see that the dynamical energy loss formalism outlined above can well explain the data. Note that no free parameters are used in the model testing, for either RHIC or LHC.

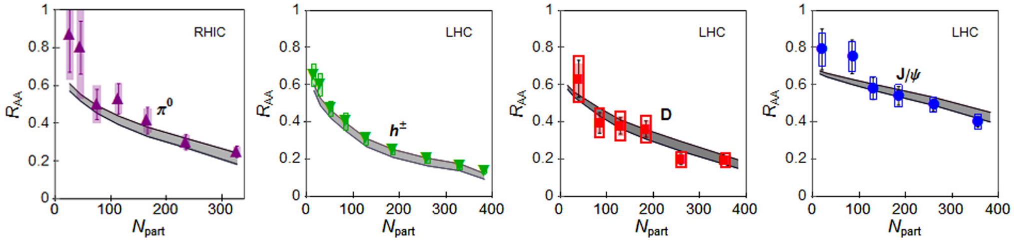

Fig. 4. Theory vs. experimental data for participant dependence of light and heavy flavor R_{AA} at RHIC and LHC. The first panel compares theoretical predictions with experimental data for participant dependence of π^0 R_{AA} [37] at 200 GeV Au + Au collisions at RHIC. The second, third and fourth panel compares theoretical predictions with experimental data for participant dependence of, respectively, $h^\pm$ [38], D meson [39] and non-prompt J/ψ [40] R_{AA} at 2.76 TeV Pb + Pb collisions at LHC. The jet momentum range for the first panel is larger than 7 GeV, for the second panel is 6–12 GeV, for the third panel is 8–16 GeV and for the fourth panel is 6.5–30 GeV. Figure adapted from [10].

We also generated predictions for non-central collisions and compared them with available LHC and RHIC data. We first generated suppression predictions at different fixed centrality ranges for charged hadrons and D mesons at LHC, and neutral pions at RHIC. Comparison of our predictions shows a very good agreement with the available experimental data for both RHIC and LHC. Due to space limit, in Fig. 3, we only present predictions for D mesons, while for other probes, please see [10]. Note that in Fig. 3, predictions for 30-50% centrality range had been generated *before* the data became available. Finally, we also generated predictions for the case when the suppression is measured for fixed momentum range and the changing centrality, for different probes at RHIC and LHC, which are shown in Fig. 4. RHIC data are shown for neutral pions, while LHC data are shown for charged hadrons, D mesons, and non-photonic J/ψ. We here also observe a very good agreement with the experimental data. Therefore, we conclude that our model is able to provide an accurate descriptions of the non-central measurements as well.

3. Conclusion

We obtained a robust agreement with experimental data, for different probes, experiments and centrality regions. These predictions are generated within the same model, parameter set and with no free parameters. We also note that we use a sophisticated energy loss model, but do not explicitly include the medium evolution (i.e. we take average/effective medium parameters).

The systematic comparison of our theoretical predictions with experimental data, and the obtained robust agreement across diverse set of probes and experiments strongly suggest that pQCD can accurately describe the extreme state of nuclear matter that is created at ultra-relativistic heavy ion collisions and that the medium evolution may not be of a major effect for hard probe suppression. This observation may lead to a hypothesis that high energy jets sense only the average (effective) medium conditions, which in turn may significantly simplify both generating predictions and analyzing phenomena behind experimental data.

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