

# Jet suppression at LHC: theory vs. experiment

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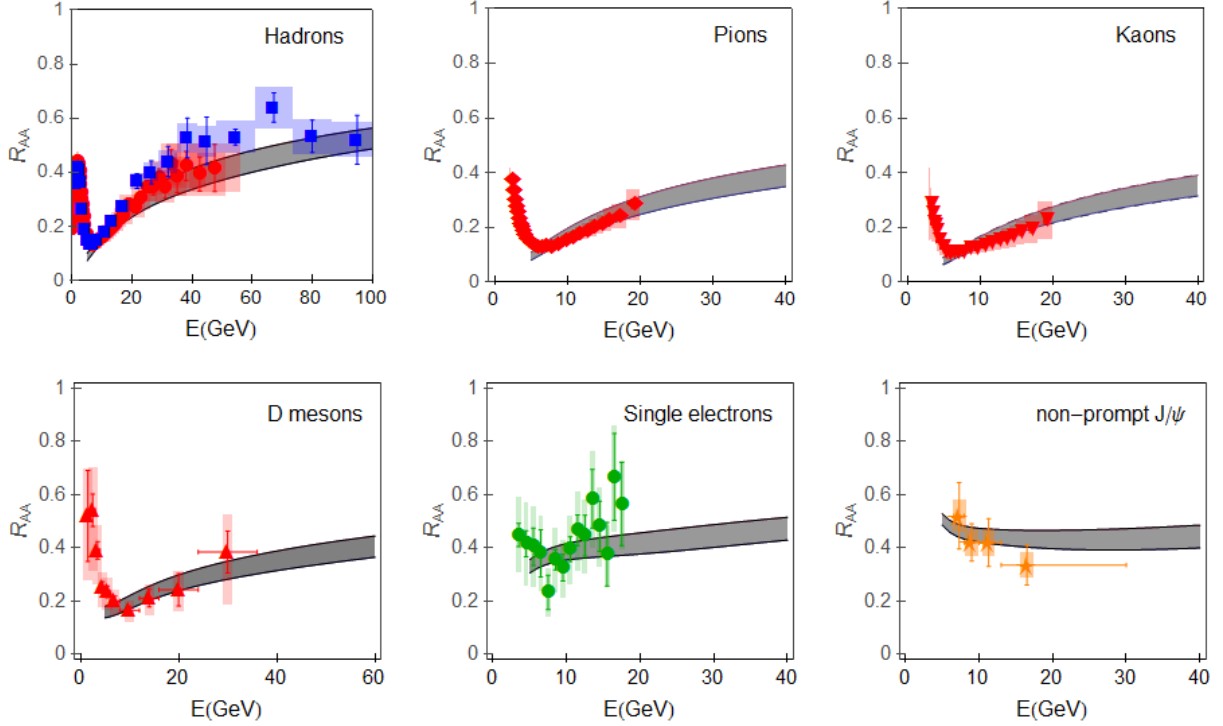
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**Abstract.** Suppression of light and heavy flavor observables is one of the most important probes in studying the properties of QCD matter created at RHIC and LHC experiments. We will here summarize the most up-to-date light and heavy flavor suppression predictions for 2.76 TeV central Pb+Pb collisions at LHC. The predictions are based on our recent improvements in the energy loss calculations that take into account: i) theoretical formalism which includes finite size dynamical QCD medium with finite magnetic mass effects and running coupling, and ii) numerical procedure which includes path-length and multi-gluon fluctuations. Our theoretical predictions, obtained with no free parameters used in model testing, show a very good agreement with the experimental results for all available particle species. Our results show that the developed theoretical formalism is able to robustly explain suppression data at LHC, which strongly suggests that pQCD in Quark-Gluon Plasma can provide a reasonable description of the underlying jet physics in ultra relativistic heavy ion collisions.

Light and heavy flavor suppressions are considered to be excellent probes of QCD matter. Since suppression for a number of observables has been measured at LHC, their comparison with theoretical predictions allows testing our understanding of QCD matter. In this proceedings, we will summarize our theoretical predictions of jet suppression and compare them with recently available LHC measurements. Within this, we will then concentrate on some apparently puzzling results. We will also concentrate on measurements where a fine hierarchy between different probes can be observed.

To obtain suppression predictions, it is necessary to have reliable calculations of production, jet energy loss, fragmentation and decay. Regarding the energy loss, over the last several years we developed the energy loss formalism [1, 2, 3] in a finite size dynamical QCD medium of thermally distributed light quarks and gluons; we used the approach involving two hard thermal loops, which allows removing assumption of static scattering centers. We recently extended this formalism to the case of finite magnetic mass [4] and most recently we included running coupling [5]. To generate suppression predictions, we incorporated this formalism into a numerical procedure, which also includes i) light and heavy flavor productions [6, 7], ii) path-length [8, 9] and multi-gluon fluctuations [10], iii) up-to-date fragmentation functions for light [11] and heavy flavor [12, 13] and iv) in the case of heavy mesons, their decay to single electrons and  $J/\psi$  [6]. The temperature used in our predictions is 304 MeV, as extracted by ALICE, while the rest of the parameters are specified in [5].

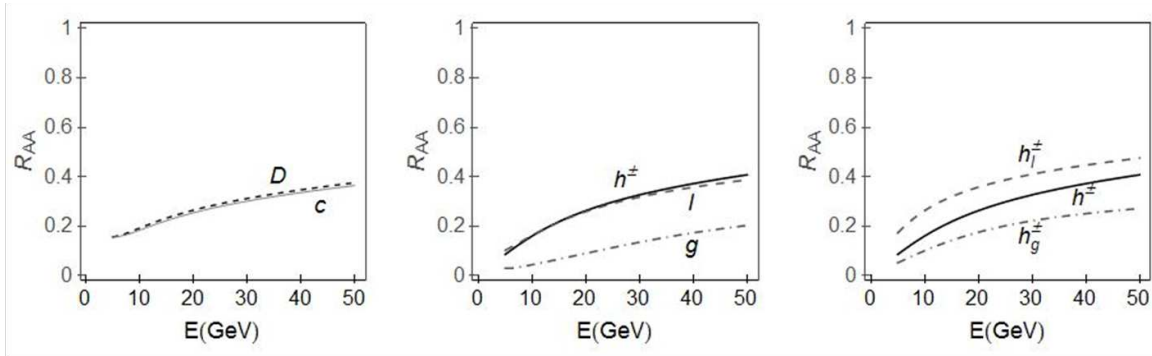
We will now concentrate on the most recent LHC data for central Pb+Pb collisions, and our goal is to use the numerical procedure outlined above, in order to generate joint predictions for all available light and heavy flavor measurements. The predictions shown in Fig. 1 are generated by the same formalism, within the same numerical procedure, and with no free parameters used in model testing. As can be seen in Fig. 1, we compare our predictions with the experimental



**Figure 1.** Our suppression predictions (shown as gray bands) are compared with the available experimental  $R_{AA}$  data for charged hadrons, pions, kaons, D mesons, non-photonic single electrons and  $J/\psi$ . The figure is adapted from [5]. The bands comes from the uncertainty in the magnetic mass value, see Ref. [5].

data for charged hadrons [15, 17], pions [16], kaons [16], D mesons [18], non-photonic single electrons [19] and non-prompt  $J/\psi$  [20]. Note that the light flavor probes are shown in the upper panel of Figure 1, while the heavy flavor probes are shown in the lower panel. We see that we obtain excellent agreement for the light flavor and D mesons. We see that the single electron data are quite noisy, but we still obtain a good agreement with the predictions. There is also a good agreement for non-prompt  $J/\psi$ , except for the last data point, which comes with large error bars.

If we now specifically concentrate on D mesons and charged hadron suppression data, we see that they reveal a puzzle which we call "heavy flavor puzzle at LHC", in a clear analogy to the well known "heavy flavor puzzle at RHIC" [21]. The following facts are relevant for this puzzle: i) while D meson suppression is a clear charm probe, charged hadrons are composed of both light quarks and gluons [22], ii) gluons have significant contribution to the charged hadron production [22], iii) charm and light quarks have about the same suppression, while the suppression of gluons is much higher [21]. Based on these facts, one can clearly infer that the suppression of charged hadrons should be smaller than the suppression of D mesons. However, contrary to this expectation, we see that experimental results actually show the same  $R_{AA}$  for charged hadrons and D mesons [18]. Having in mind the above, a naive conclusion would be that quarks and gluons lose the same amount of energy, which is however not in accordance with pQCD expectations. Even more surprisingly, Fig. 1 shows that that our pQCD based theoretical predictions are actually in an excellent agreement with the data. We therefore ask why both the experimental data and the theoretical predictions are not in an agreement with



**Figure 2.** The right panel shows a comparison of the charm quark suppression predictions (full curve) with the D meson suppression predictions (dashed curve), as a function of momentum. The central panel shows the comparison of charged hadron suppression predictions (full curve) with light quark (dashed curve) and gluon (dot-dashed curve) suppression predictions. On the right panel, the dashed curve shows what would be the charged hadron suppression if only light quarks would contribute to charged hadrons. The dot-dashed curve shows what would be the charged hadron suppression if only gluons would contribute to charged hadrons, while the full curve shows the actual hadron suppression predictions. Figure adapted from [22].

the qualitative expectations outlined above.

To answer this question, in Fig. 2 we investigate how fragmentation functions modify the charged hadron and D meson suppressions, since these functions define the transfer from the parton to the hadron level. For D mesons (the left panel of Fig. 2), we see that the fragmentation does not modify bare charm quark suppression. Consequently, D meson suppression is indeed a genuine probe of the charm quark suppression in QCD medium. However, situation is much more complicated for the charged hadrons. In the central panel of Fig. 2, we compare the charged hadron suppression with the bare light quark and gluon suppression patterns. Surprisingly, we get that the charged hadron suppression is almost the same as the bare light quark suppression. This may suggest that gluon jets do not contribute to the charged hadron suppression, which is however inconsistent with the significant (even dominant) gluon contribution in charged hadrons. To investigate this, in the right panel of Fig. 2, we show what would be the charged hadron suppression if the hadrons were only composed of light quark jets, or only of gluon jets. We see that the charged hadron suppression is clearly in between these two suppression alternatives, so that both light quarks and gluons indeed significantly contribute to the charged hadron suppression. However, by comparing these two figures, we see that charged hadron fragmentation functions modify the bare light quark and gluon suppressions so that, coincidentally, their “resultant” charged hadron suppression almost identically reproduces the bare light quark suppression.

Therefore, the main result that we obtained is that the charged hadron suppression is almost identical to the light quark suppression, despite dominant gluon contribution in the charged hadron production. Since we also have that the D meson suppression is the same as the charm suppression, and that the light quarks have the same suppression as charm, we obtain the solution of the puzzle, i.e. that the charged hadron and D meson  $R_{AA}$ s should indeed be similar.

We next concentrate on whether, and under which conditions, the theory can explain fine hierarchy between the suppression measurements. For this, we come back to the Fig. 1, where we now concentrate on pion and kaon suppression data. That is, the experimental data for kaons and pions reveal an interesting fine resolution hierarchy, i.e. kaons are measured to consistently have somewhat higher suppression compared to pions [16]. From Fig. 1, we see that our

predictions can very well reproduce this hierarchy; note that in obtaining these predictions, we used most up-to-date DSS fragmentation functions. On the other hand, the most widely used KKP fragmentation functions [23] would lead to a reversal of the observed hierarchy, and the reasons for this discrepancy are briefly discussed below.

As can be seen in [24], DSS fragmentation functions predict larger contribution of gluons in kaons compared to pions, while KKP predict the opposite. Since gluons have a larger suppression compared to light quarks, this evidently leads to the fact that DSS fragmentation functions will lead to a larger suppression for kaons compared to pions, which is in agreement with the experimental data. On the other hand, KKP fragmentation functions will lead to a larger suppression of pions compared to kaons, which is a reversed hierarchy and obviously in a disagreement with the experimental data. So, in distinction to the heavy flavor puzzle at LHC that we previously discussed, fine hierarchy between the pion and kaon suppressions represents an example where large gluon energy loss has a clear impact on the experimental observations.

In summary, in this proceedings, we showed that the same theoretical framework, with the same numerical procedure, and with no free parameters used in model testing, can simultaneously explain experimental data for a diverse set of probes at LHC. This also includes explanation of seemingly puzzling data such as the heavy flavor puzzle at LHC, and fine resolution hierarchy for the suppression of different probes. We also obtained an unintuitive, but important qualitative result that suppression of charged hadrons is a genuine probe of light quark suppression, which can considerably simplify interpretation of the relevant data.

#### *Acknowledgments*

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