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Flavor aspects of parton energy loss

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Abstract

Understanding flavor dependence of the parton energy loss is one of key tasks of the jet quenching physics. In these proceedings we provide a summary of recent works on a quantification of the flavor dependence of parton energy loss along with a summary and discussion of a subset of contributions presented at the Hard Probes 2016 conference which are related to the flavor aspects of parton energy loss.

Keywords: heavy ion collisions, parton energy loss, jet quenching, color factor, flavor

1. Introduction

Understanding flavor dependence of the parton energy loss is one of key tasks of the jet quenching physics. The original results presented in these proceedings are largely based on Refs. [1, 2] that put forward a model or method which allows to quantify some of the basic properties of the parton energy loss. Besides that, we included here also a summary and discussion of a subset of contributions presented at the conference which are related to the flavor aspects of the parton energy loss and we include also an outcome of some of discussions which took place at the conference.

This paper is organized as follows: in the first section we discuss basic features seen in the data on inclusive charged particles and jets in Pb+Pb collisions at the LHC and relate them with the flavor dependence of the parton energy loss. In the second section we put forward a quantification of the flavor dependence of the parton energy loss and provide further discussion on the impact of the flavor dependence on dijet measurements, jet substructure measurements, and measurements employing charged particles. In the last section we discuss the latest results on charmonia in the kinematic domain of large-p_T and we point to a similarity between the jet quenching and charmonia suppression which indicates that radiative energy loss may be a dominant source of the energy loss of charmonia at high-p_T.

2. Suppression of inclusive charged particles and jets at the LHC

Many precise measurements of the suppression of inclusive charged particles quantified using the nuclear modification factor, R_{AA}, have been published by LHC experiments [3, 4, 5, 6]. Direct quantification of the magnitude of parton energy loss using the charged particle R_{AA} is not straightforward since the correspondence between the kinematics of the initial parton and observed final state hadron is smeared by the fragmentation process. Consequently, more direct quantification of the parton energy loss may be done from the measurements of jet R_{AA}. At this conference a new result on the R_{AA} of fully reconstructed jets with different jet sizes has been presented [7]. This new measurement follows the previously measured jet R_{AA} [8]. Complementary to these measurements is the measurement of fragmentation functions which was presented at this conference by several speakers and which was published in Refs. [9, 10, 11].

The above cited results bring questions about some interesting features seen in the data:

- *Why do have the jet R_{AA} and charge particle R_{AA} almost no rapidity dependence given different input parton spectra and flavor composition at different rapidities?*

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- *What is responsible for the enhancement at high momentum fractions (z) seen in the fragmentation? Can we find a connection among charged particle R_{AA}, jet R_{AA} and jet fragmentation measurement?*
- *Having the jet R_{AA} at hand can we directly quantify the size of the parton energy loss?*

To answer these questions we introduced a model [1] which is based on parameterizations of initial parton spectra and the parton energy loss. The only assumption on the physics of the jet quenching in this model is the functional form for the parton energy loss which is assumed to be of the power-law form – the total transverse momentum lost by the parton is

$$\Delta p_T = c_F \cdot s \cdot \left(\frac{p_{T,\mathrm{ini}}}{p_{T,0}}\right)^{\alpha} \quad (1)$$

Here s, α, and c_{F} are free parameters of the model, $p_{T,\mathrm{ini}}$ is the transverse momentum of a parton initiating a jet and $p_{T,0}$ is an arbitrary scale (set to 40 GeV). Parameter c_{F} represents a color factor which quantifies the difference between the in-medium radiation of quark-initiated jets and gluon-initiated jets. For the first studies, the c_{F} was fixed to be 1 and $C_A/C_F = 9/4$ for light-quark-initiated jets and gluon-initiated jets, respectively.

For a better orientation we label this our approach Effective Quenching (EQ) model but it could very well be called *the model independent method* which allows to extract basic properties of the average parton energy loss.

The EQ model is capable of describing the full p_T^{jet}, rapidity, and centrality dependence of the measured jet R_{AA} using three effective parameters which are obtained by minimizing with respect to the R_{AA} data published in Ref. [8]. The successful description of the jet R_{AA} in the full kinematic space implies that the absence of a clear rapidity dependence seen in the data comes from a cancellation between two competing effects which evolve with increasing rapidity: steepening of initial parton spectra and enhancing the fraction of quark initiated jets. While the former alone generally leads to a smaller R_{AA} the later alone generally leads to a larger R_{AA}.

The quantification of the average parton energy loss provided by minimizing the difference between the model and the data revealed three interesting properties of the energy loss: 1) the magnitude of the energy loss, s, depends linearly on the N_{part}; 2) the power α is approximately 0.5 and it is constant as a function of N_{part}; 3) the linear dependence of s on N_{part} does not extrapolate to zero for N_{part} approaching zero. For more details on this quantification see Refs. [1, 2].

The model can be further used to evaluate the impact of the change in the jet spectra on the measured fragmentation functions in a simple way. The main principle of the procedure is following: subtract the energy from the initial parton and then let it fragment as in the vacuum. The modifications of fragmenation functions were quantified in the data e.g. by a ratio, $R_{D(z)}$, of fragmentation functions measured in central collisions to those measured in peripheral or proton-proton collisions. The modifications seen from $R_{D(z)}$, excluding the enhancement at low-z, are described by the model. Thus, it may be concluded that these modifications result primarily from the different quenching of the quark and gluon jets. The assumption on the fragmentation of the quenched parton used here reflects a physics scenario in which the parton shower looses the energy coherently. Indeed, it was recognized in several theoretical papers that such color coherence effects play an important role in the jet quenching process [12, 13, 14, 15]. The successful description of the jet fragmenation when employing this assumption within EQ model may be considered an independent argument speaking in favor of the physics scenario based on the color coherence.

The charged particle R_{AA} and jet R_{AA} can in principle be connected using fragmentation functions since each charged particle with sufficiently high-p_T which does not come from the underlying event has to be found in a jet. The fact that the model can reasonably well reproduce the R_{AA} of inclusive charged particles at $p_T \gtrsim 20$ GeV is a cross-check. Besides that, it answers a question which was posed several times at this conference: *How to reconcile the fact that the charged particle R_{AA} reaches values greater than the values of R_{AA} of inclusive jets?* The answer to that question is that such a direct interpretation of the charged particle R_{AA} is not possible since charged particle R_{AA} is a non-trivial convolution of flavor dependent jet suppression and fragmentation functions. The fact that the EQ model can reproduce all three kinds of jet related measurements implies that the data do not contradict each other.

It should be mentioned that the advantage of the above described modelling is that it allows to obtain exact analytic formulae for the R_{AA} and $R_{D(z)}$ which can then be used in a straightforward way to extract information about the modification of jet yields and jet structure. Another advantage is that the model employs *minimal* assumptions on the physics of the jet quenching. While this may be judged as an advantage it may also be judged as a disadvantage since we explore here just the *average* jet quenching ignoring e.g. the path-length dependence of the quenching or the role of fluctuations in the jet quenching. On the other hand, if the model fails