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Dynamics of heavy flavor quarks in high energy nuclear collisions

Andrea Beraudo

Istituto Nazionale di Fisica Nucleare – Sezione di Torino, Via Pietro Giuria 1, 10125 Torino, Italy

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Abstract

A general overview on the role of heavy quarks as probes of the medium formed in high energy nuclear collisions is presented. Experimental data compared to model calculations at low and moderate p_T are exploited to extract information on the transport coefficients of the medium, on possible modifications of heavy flavor hadronization in a hot environment and to provide quantitative answers to the issue of kinetic (and chemical, at conceivable future experimental facilities) thermalization of charm. Finally, the role of heavy flavor at high p_T as a tool to study the mass and color-charge dependence the jet quenching is also analyzed.

Keywords: Quark–gluon plasma; Heavy quarks; Transport calculations

1. Introduction

Heavy flavor quarks play a peculiar role as probes of the medium formed in high energy nuclear collisions. If soft observables are nicely reproduced by hydrodynamics, assuming to deal with a system at local thermal equilibrium (no matter why), and jet quenching is interpreted in terms of the energy degradation of high-p_T partons playing the role of external probes, the description of heavy flavor observables requires to develop a setup allowing one to deal with the more general situation of particles which would asymptotically approach kinetic equilibrium with the background medium: such a tool is represented by transport calculations, which I'm going to discuss in my contribution. In the last part of the paper I will also address the quenching of heavy flavor jets, allowing one to study the mass and color charge dependence of the parton energy loss.

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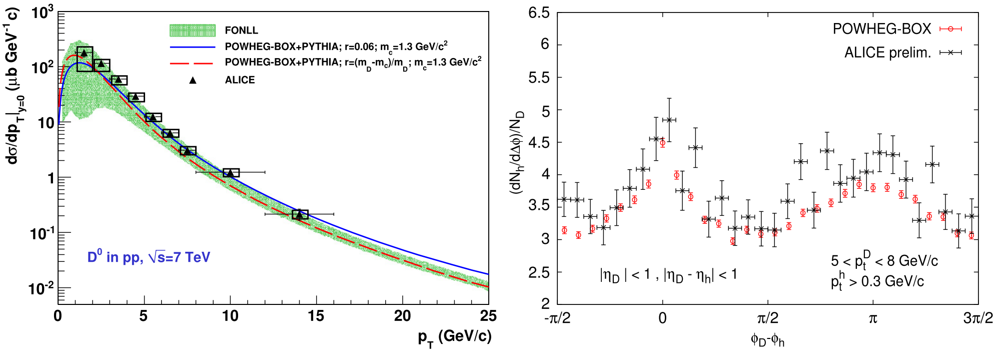

Fig. 1. Left panel: differential cross section for D^0 production in p–p collisions at $\sqrt{s} = 7$ TeV; predictions of the FONLL calculation and of the POWHEG-BOX event generator (with different charm fragmentation functions) are compared to ALICE data. Right panel: POWHEG-BOX predictions for D-hadron correlations in p–p collisions at $\sqrt{s} = 7$ TeV [2] compared to preliminary ALICE results [3].

Before moving to phenomenology one should first of all answer the question why charm and beauty are considered heavy: the reasons are at least three. First of all their mass M is much larger then $\Lambda_{\rm QCD}$, so that their initial production is a hard process described by pQCD. Secondly $M \gg T$, making thermal production during the limited lifetime of the plasma negligible: charm and beauty multiplicity is set by the initial hard processes. Finally $M \gg gT$, gT being the typical momentum exchange with the plasma particles, entailing that many soft scatterings are necessary to change significantly the momentum/trajectory of the heavy quarks; notice that for realistic temperatures $g \sim 2$, so that one might wonder whether charm has to be considered really "heavy", at least at the beginning of the fireball evolution.

The state of the art in the description of the initial $Q\overline{Q}$ production is represented by NLO pQCD calculations (POWHEG, MC@NLO) for the hard process interfaced to some event generators (PYTHIA, HERWIG) to simulate the Initial and Final State Radiation and other non-perturbative processes (intrinsic k_T, Underlying Event and hadronization). One can employ an automated tool like the POWHEG-BOX package to perform such calculations getting a fully exclusive information of the final state. As it can be seen in Fig. 1 this allows one to satisfactory describe heavy flavor production in p–p collisions, reproducing not only their inclusive spectra, but also (letting PYTHIA take care of the hadronization of the whole event) more differential observables like D–h azimuthal correlations, currently at the center of important experimental efforts. A systematic comparison of the outcomes of the various pQCD event generator and of other automated tool like the FONLL calculation can be found in [1].

2. Transport, flow and thermalization in the QGP

In this section I will present a critical overview of the transport calculations used to describe the dynamics of heavy quarks in the medium formed in heavy-ion collisions: the comparison with the experimental data should ideally allow one to put tight constraints on the transport coefficients of the QGP. A more ambitious approach consists in deriving the latter directly from the QCD Lagrangian, either by weak-coupling calculations or through non-perturbative approaches like lattice-QCD (l-QCD) simulations, whose recent results will be discussed. There are important issues to address concerning the fate of heavy flavor in heavy-ion collisions: how close are heavy quarks to thermalization? Are the final hadronic observables able to answer this question? What