Fractional energy loss of heavy mesons at the LHC energies

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Introduction

One of the main goal of relativistic heavy-ion collider experiments is to study the bulk properties of the strongly-interacting matter, usually referred as the Quark-Gluon Plasma (QGP). Heavy quarks, i.e. charm and beauty quarks, are excellent probes of the QGP as they are produced in the early stage of the collisions and witness the entire space-time evolution of the system. Heavy quarks lose their energy in the hot and dense QCD medium through collision and radiation and ultimately fragments to heavy (D or B) mesons. Medium effects are quantified through the measurement of nuclear modification factor ($R_{\rm AA}$) of particles is defined as the ratio of invariant transverse momentum yield of particles in heavy-ion collisions with respect to the corresponding cross section in pp collisions scaled by the nuclear overlap function. In recent PHENIX collaboration has discussed an alternative way to measure the in-medium energy loss which is effective shift ($\Delta p_{\rm T}$) in $p_{\rm T}$ spectra of light hadrons recorded in nucleus-nucleus and proton-proton collisions [1]. It has been shown that the fractional energy loss of partons, ΔE/E, is indeed significantly different at RHIC and LHC kinematic conditions even though the $R_{\rm AA}$ is similar [2]

The facts motivate us to carry out an emperical study of fractional energy loss of heavy-quarks at RHIC and LHC energies. For this purpose, we have parameterized the invariant momentum yield of heavy mesons by Hagedorn function [3]. The fitt parameters are then utilised to find a relation between fractional energy loss parameter Δm_T and $R_{\rm AA}$ of heavy mesons measured at the LHC experiment.

Formalism

The nuclear modification factor ($R_{\rm AA}$) of produced particles is described as the ratio of the cross section of produced particles in heavy-ion collisions and the same in pp collisions, scaled to per nucleon-nucleon collisions:

$$R_{\rm AA}(p_T, b) = \frac{d\sigma^{\rm AA}/d^2p_Tdy(b)}{d\sigma^{\rm pp}/d^2p_Tdy(b)}. \quad (1)$$

Inspired of Hagedron function, we parameterise the production cross-section of heavy mesons produced in pp collisions as:

$$d\sigma/d^2p_Tdy = A\left(1+\frac{m_T}{p_0}\right)^{-n}, \quad (2)$$

where A, n, p_0 are constants and $m_T = \sqrt{p_T^2+m^2}$. A has dimension GeV^{-2}, p_0 is in GeV and n is dimensionless, can be related to the nature of parton scatterings involved in the collisions. We have chosen m_T instead of p_T as it is the relevant hard momentum scale for heavy quark production [4].

In the same spirit, we write the invariant transverse momentum distribution of hadrons in AA collisions as:

$$d\sigma^{\rm AA}/d^2p_Tdy = A\left(1+\frac{m_T+\Delta m_T}{p_0}\right)^{-n}, \quad (3)$$

The resoning behind writing Eq. 3 lies in the assumption that particle yield at a given p_T in AA collisions would be similar to the yield of particles in pp collisions at $p_T + \Delta p_T$. The shift Δp_T (or Δm_T) includes the medium effect, chiefly energy loss of parent quark inside the plasma. Using Eq. 1, 2 and 3, we shall obtain the expression for energy shift $\Delta m_{\rm T}$:

$$\Delta m_T = \left((R_{AA}(p_T))^{-1/n} - 1\right)(p_0 + m_T). \quad (4)$$

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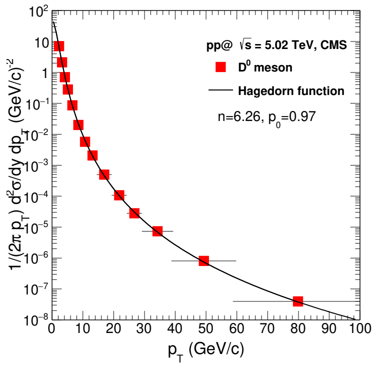

FIG. 1: The invariant yield of D^0 mesons in p + p collisions at $\sqrt{s} = 5.02$ TeV mesured by CMS Collaboration.

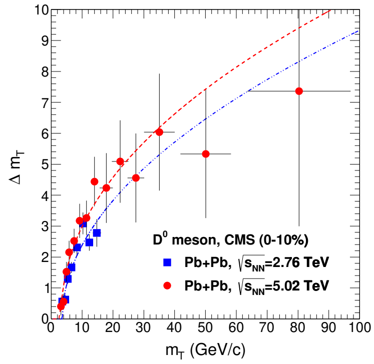

FIG. 2: The fractional energy loss Δm_T vs m_T of D^0 mesons in Pb + Pb collisions at $\sqrt{s_{NN}} = 2.76$, 5.02 TeV. The data of R_{AA} of D^0 mesons are adopted from CMS [5]

Results and Discussions

In order to study the fractional energy loss suffered by heavy quarks in QGP, we have parameterized the invariant yield of D^0 mesons for p+p collisions at the LHC energies with Eq. 2 and obtained the parameters n and p_0. Figure displays the fitted invariant yield of D^0 mesons in pp collisions at $\sqrt{s} = 5.02$ TeV measured by CMS Collaboration [5]. Similar exercise have been performed for different center of mass energies. Next we have calculated the Δm_T using the extracted parameters n and p_0, and the data of R_{AA} for a given centrality. The variation of Δm_T vs m_T is depicted in Figure 2 for Pb+Pb collisions at $\sqrt{s_{NN}} = 2.76$ and 5.02 TeV. Now we are looking for an emperical relation between Δm_T and m_T, thus we have fitted the graph as:

$$\Delta m_T = a(m_T + c)^{\alpha} \tag{5}$$

where a is normalization constant,α is the exponent. c is the offset transverse mass, is so adjusted that Δm_T is positive always. We have found the value of exponent α is about 0.5 at both collision energies. The observation may imply that heavy quark energy loss mechanism does not significantly change while the centre of mass energy increases almost by double. The parent heavy quark lose energy via multiple collisions and radiation while traversing the QGP, results in deficit of yield at a given p_T bin. The effect has been also imprinted on the momenta of D^0 meson, fragmenting from the heavy quark. In addtion, our finding suggests that parent heavy quark may lose energy energy through coherent gluon emission. In this LPM regime, the energy loss per collision (ΔE) is proportional to the square root of energy (E) of the parton [6]. A comparison of ΔE vs E of heavy quarks at the LHC kinematic conditions for different energy loss models is underway.

Acknowledgments

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