# Modelling jet quenching with Quenching Weights

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**Abstract.**
We present a phenomenological study of the single- and double-inclusive suppression data of high-$p_T$ particles in central Pb-Pb collisions at LHC. The analysis is based on quenching weights for medium-induced gluon radiation computed in the multiple soft scattering approximation and embedded in a hydrodynamic description of the bulk medium.

## 1. Introduction

*Jet quenching* has been established as an important tool to study the QGP created in heavy-ion collisions. The goal of this talk is to study the suppression of high-$p_T$ particles in central Pb-Pb collisions at the LHC. This work is based on the partonic Quenching Weights (QW) for medium-induced gluon radiation computed in the multiple soft scattering approximation then embedded in a hydrodynamic description of the bulk medium.

This analysis is an extension of a previous similar one [1] for RHIC and our aim is to compare the results obtained for RHIC with the ones obtained for LHC.

## 2. The analysis

In heavy-ion collisions the medium evolves dynamically. We use the results of *Hirano et al.* [2] for 3D ideal hydrodynamics to describe its evolution.

The production of a hadron $h$ at transverse momentum $p_T$ and rapidity $y$ can be described by

$$\frac{d\sigma^{AA\to h+X}}{dp_T dy} = \int \frac{dx_2}{x_2}\frac{dz}{z}\sum_{i,j} x_1 f_{i/A}(x_1,Q^2) x_2 f_{j/A}(x_2,Q^2)\frac{d\hat{\sigma}^{ij\to k}}{d\hat{t}} D_{k\to h}(z,\mu_F^2), \tag{1}$$

where $f_{i/A}(x_1,Q^2)$ are the parton distribution functions (PDFs) for a colliding object. In our case, EKS98 analysis [3] for nPDFs and CTEQ6L (LO) free proton parton densities are used. $x$ is the momentum fraction of the hadron carried by the parton and $D_{k\to h}(z,\mu_F^2)$ are the fragmentation functions for a parton $k$ into a hadron $h$, where $z$ is the momentum fraction of the parton carried by the hadron. We take the factorization and renormalization scales as $Q^2 = (p_T/z)^2$.

We model our medium modified fragmentation functions as:

$$D_{k\to h}^{(med)}(z,\mu_F^2) = \int_0^1 d\epsilon P_E(\epsilon)\frac{1}{1-\epsilon} D_{k\to h}^{(vac)}\left(\frac{z}{1-\epsilon},\mu_F^2\right), \tag{2}$$

where $P_E(\epsilon)$ are the *Quenching Weights* [4], i.e. the probability distribution of a fractional energy loss, $\epsilon = \Delta E/E$, of the fast parton in the medium. The vacuum fragmentation functions, $D^{(vac)}_{k\to h}(z, \mu_F^2)$, are taken from *Florian, Sassot and Stratmann* [5].

Eq.(2) assumes that the only effect of the medium in the fragmentation functions is the energy loss taking place before hadronization. That is, hadronization is not modified by the medium, it takes place in the vacuum. Fragmentation functions are modified by medium-induced gluon radiation through the Quenching Weights (QW) [6].

The QW are Poisson distributions obtained assuming an independent gluon emission. In the multiple soft scatterting approximation and for a static medium, they only depend on two quantities, the transport coefficient, $\hat{q}$, and the length of the medium, $L$, (or $\omega_c$ and $R$), given by: $\omega_c = \frac{1}{2}\hat{q}L^2$ and $R = \omega_c L$.

In a dynamical medium we can make use of two of the following scaling relations:

$$\omega_c^{eff}(x_0, y_0, \tau_{prod}, \phi) = \int d\xi \xi \hat{q}(\xi), \quad [\hat{q}L]^{eff}(x_0, y_0, \tau_{prod}, \phi) = \int d\xi \hat{q}(\xi)$$

$$R^{eff}(x_0, y_0, \tau_{prod}, \phi) = \frac{3}{2}\int d\xi \xi^2 \hat{q}(\xi), \tag{3}$$

corresponding to an equivalent static scenario, to write the effective quantities. In contrast to the RHIC analysis [1], we choose to use $\omega_c^{eff}$ and $R^{eff}$. So, we need to specify the relation between the local value of the transport coefficient, $\hat{q}(\xi)$, at a given point, $\xi$, on the trajectory and the medium properties given by our hydrodynamic model:

$$\hat{q}(\xi) = K\hat{q}_{QGP}(\xi) \simeq K \cdot 2\epsilon^{3/4}(\xi), \tag{4}$$

where $\epsilon$ is the local energy density.

As we have seen, the transport coefficient is defined by Eq.(4). However, there is an ambiguity on its value for times smaller than the thermalization time $\tau_0$. Consequently, we consider here three different extrapolations for the time from the hard production to the thermalization time:

- Case i): $\hat{q}(\xi) = 0$ for $\xi < \tau_0$,
- Case ii): $\hat{q}(\xi) = \hat{q}(\tau_0)$ for $\xi < \tau_0$,
- Case iii): $\hat{q}(\xi) = \hat{q}(\tau_0)/\xi^{3/4}$ for $\xi < \tau_0$.

In the case i) we are assuming that there is no energy loss for small times, which is a really strong assumption as thermalization is not necessary in the QW approach. In the second case, the transport coefficient is frozen before thermalization; there is a continuous interaction since the production time. In the last one, called the free-streaming case, the medium is assumed to have an energy density which decreases with time as $1/\xi$.

## 3. Results

The experimental data used in our analysis are given in terms of the nuclear modification factor for single measurements

$$R_{AA} = \frac{dN_{AA}/d^2p_T dy}{\langle N_{coll}\rangle dN_{pp}/dp_T^2 dy}. \tag{5}$$

Experimental data are all for Pb-Pb collisions at LHC energy $\sqrt{s_{NN}} = 2.76$ TeV. We use ALICE data on $R_{AA}$ for charged particles with $p_T > 5$ GeV in the centrality class 0-5% and for $|\eta| < 0.8$ [7] and CMS data on $R_{AA}$ for charged particles with $p_T > 5$ GeV in the centrality class 0-5% and for $|\eta| < 1$ [8].

For the double-inclusive measurements we have:

$$I_{AA} = \frac{D_{AA}(z_T, p_T^{trig})}{D_{pp}(z_T, p_T^{trig})}, \quad D_{AA}(z_T, p_T^{trig}) \equiv p_T^{trig} \frac{d\sigma_{AA}^{h_1 h_2}/dy^{trig} dp_T^{trig} dy^{assoc} dp_T^{assoc}}{d\sigma_{AA}^{h_1}/dy^{trig} dp_T^{trig}} \tag{6}$$

and $z_T = p_T^{assoc}/p_T^{trig}$ and the factorization scale is taken as the $p_T$ of the hadrons.

We compare the predictions of our model to ALICE data on $I_{AA}$ on the away side for central (0-5%) PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV [9].

We present the results for both, single- and double-inclusive measurements, for the three different extrapolations before thermalization. They are presented for different values of $2K = K'/0.73$, with $K' = 0.5, 1, 2, 3, ..., 20$. In figure 1 of reference [1], it is shown that the value of $K$ obtained for RHIC was 4.1 which, as it is shown in the following figures, is bigger than the one we obtain for LHC.

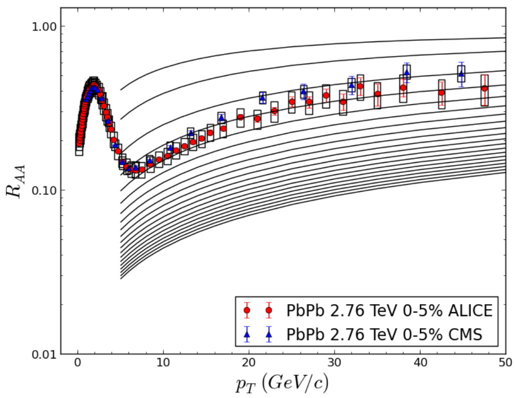


**Figure 1.** $R_{AA}$ for the first extrapolation: Case i) $\hat{q}(\xi)$ =0 for $\xi < \tau_0$. Curves that best fit experimental data are the corresponding to $K = 1.37$ and $K = 2.05$.

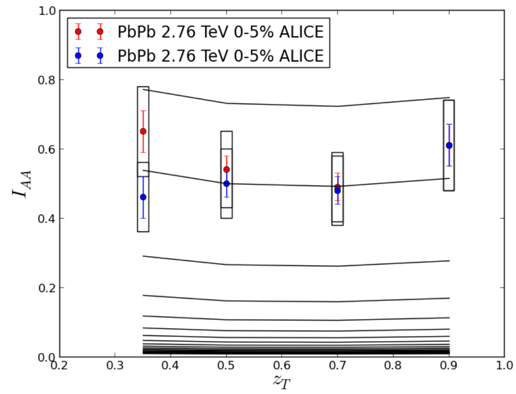


**Figure 2.** $I_{AA}$ for the first extrapolation: Case i) $\hat{q}(\xi)$ =0 for $\xi < \tau_0$. The value of $K$ obtained is $K = 1.37$.

## 4. Discussion and conclusions

There is a good agreement with experimental data and single- and double-inclusive results obtained are compatible. As it happened for the RHIC analysis - see Figure 2 of [1] - our results turn out to be relatively insensitive to the early time treatment except for the case i). In this case the parton travels the first 0.6 fm/c without suffering any effect of the medium and, therefore, the strong dependence of the jet quenching on the in-medium path length forces the value of $K$ to increase.

The value of $K$ obtained in our model is smaller than the one obtained for RHIC [1]. This means that, in our model, the medium created at LHC is more transparent than the medium created at RHIC. That is, that the behaviour of the medium is more similar to an ideal gas for LHC than for RHIC, i.e, the coupling is less strong for LHC.


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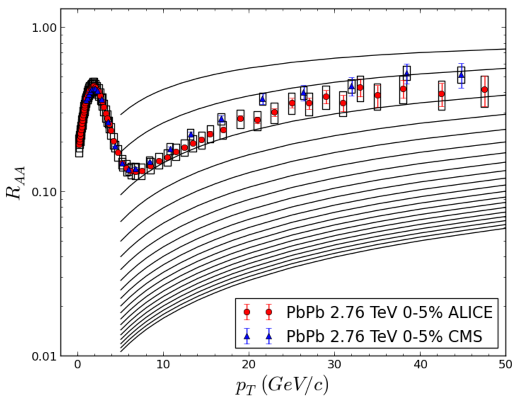


**Figure 3.** $R_{AA}$ for the extrapolation $\hat{q}(\xi) = \hat{q}(\tau_0)$ for $\xi < \tau_0$. Curves that best fit experimental data are the corresponding to $K = 0.68$ and $K = 1.37$.

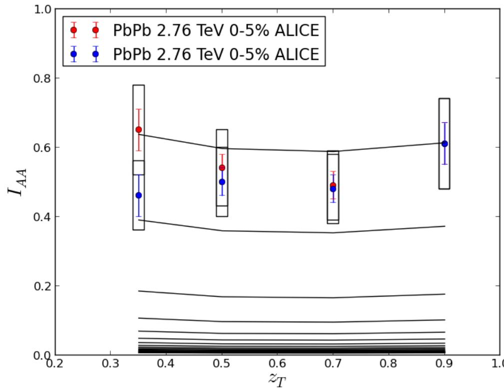


**Figure 4.** $I_{AA}$ for the extrapolation $\hat{q}(\xi) = \hat{q}(\tau_0)$ for $\xi < \tau_0$. The curve that best fit experimental data is the one with $K = 0.68$.

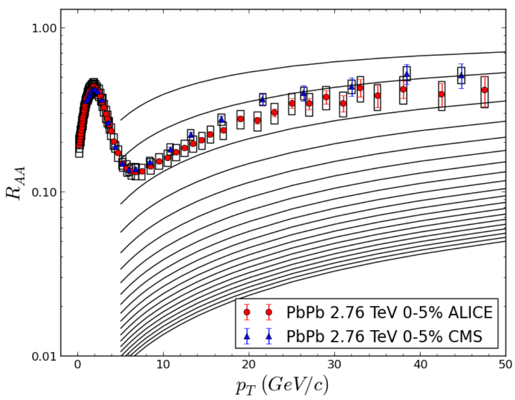


**Figure 5.** $R_{AA}$ for the free streaming case $\hat{q}(\xi) = \hat{q}(\tau_0)/\xi^{3/4}$ for $\xi < \tau_0$. The value of $K$ obtained in this case is $K = 0.68$.

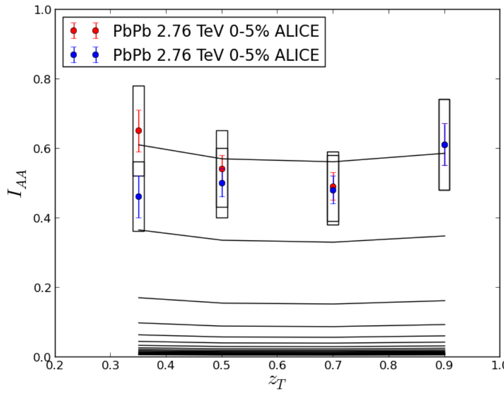


**Figure 6.** $I_{AA}$ for the free streaming case $\hat{q}(\xi) = \hat{q}(\tau_0)/\xi^{3/4}$ for $\xi < \tau_0$. The value of $K$ obtained in this case is $K = 0.68$.

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