Nuclear modification of charm quarks in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV at LHC

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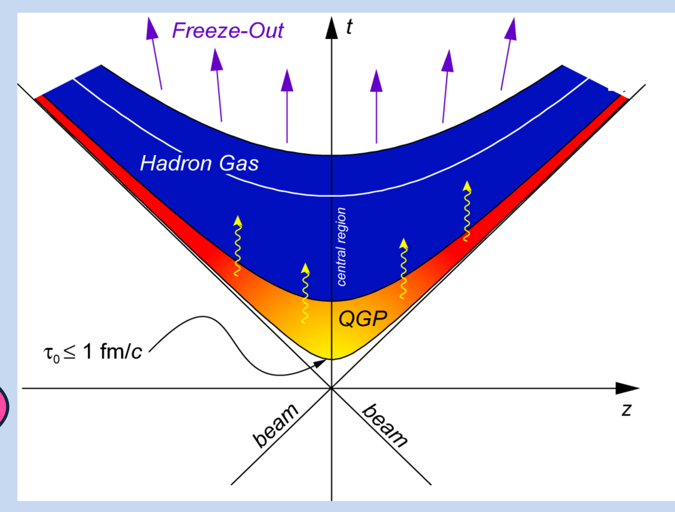
Abstract

We calculate the nuclear suppression R_{AA} of a charm quark produced from the initial fusion of partons in Pb+Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV. We take into account the shadowing as well as the energy loss suffered by them while passing through the quark–gluon plasma. We obtain the results for charm quark at several rapidities using different mechanisms for energy loss, to see if we can distinguish between them.

Charm quark is an excellent probe for QGP:

- Produced mainly during the early stage of collision. Their production is small.
- As they are massive, while propagating through the medium they do not change direction much from scatterings with light quarks and gluons.
- The p_T distribution of D mesons will closely reflect the p_T distribution of charm quarks.

A charm quark (antiquark) produced at the early stage of interaction passes through the QGP phase and it combines with a light quark(antiquark) to produce a D meson whose subsequent semileptonic decay will carry information about the initial hot and dense stage of the collision.



Energy loss of a charm quark = Collisional energy loss + Radiative energy loss

The cross-section for the production of charm quarks from pp collisions at LO:

$$\frac{d\sigma}{dy_1\,dy_2\,dp_T}=2x_1x_2p_T\sum_{ij}\left[f_i^{(1)}(x_1,Q^2)f_j^{(2)}(x_2,Q^2)\hat{\sigma}_{ij}(\hat{s},\hat{t},\hat{u})+f_j^{(1)}(x_1,Q^2)f_i^{(2)}(x_2,Q^2)\hat{\sigma}_{ij}(\hat{s},\hat{t},\hat{u})\right]\Big/(1+\delta_{ij})$$

The fractional momenta of the interacting hadrons carried out by the partons can be expressed as:

$$x_1=\frac{m_T}{\sqrt{s}}\left(e^{y_1}+e^{y_2}\right),\quad x_2=\frac{m_T}{\sqrt{s}}\left(e^{-y_1}+e^{-y_2}\right)$$

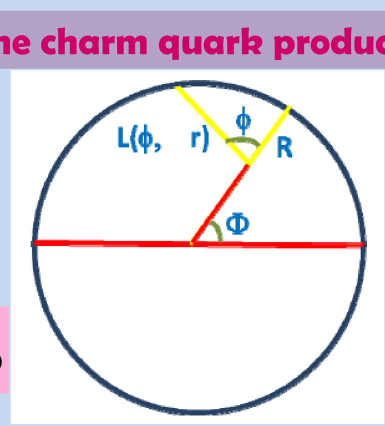
where

$$m_T=\sqrt{M_c^2+p_T^2}$$

The short-range subprocesses for the charm quark production is defined as:

$$\frac{d\sigma}{dt}=\frac{1}{16\pi\hat{s}^2}|\mathcal{M}|^2$$

The distance covered by the charm quark in the plasma, L, is given by:



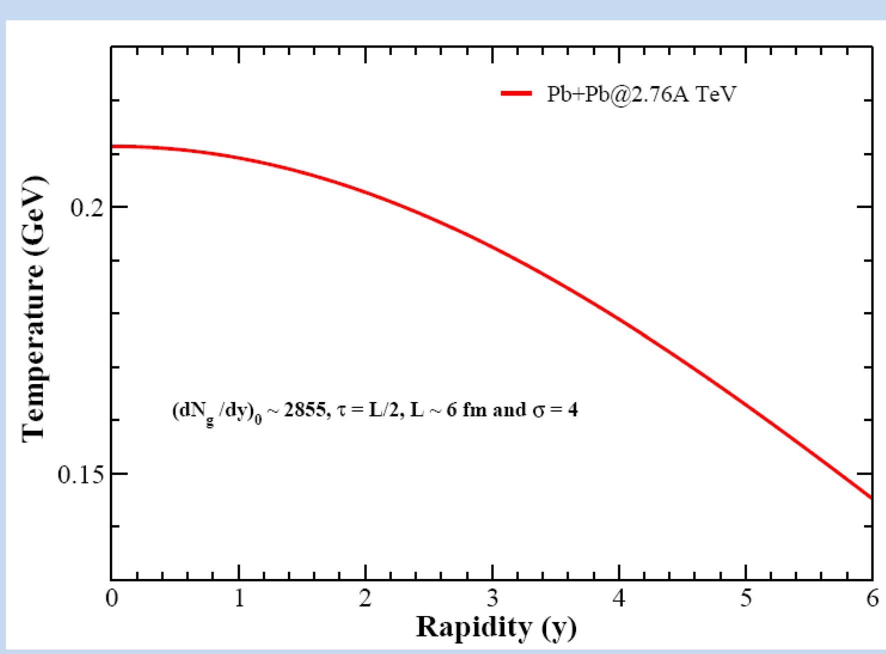
$$L(\phi,r)=\sqrt{R^2-r^2\sin^2\phi}-r\cos\phi$$

The temperature of the plasma varies with rapidity (y) as:

$$T(\tau)=\left(\frac{\pi^2}{1.202}\,\frac{\rho(\tau)}{9n_f+16}\right)^{\frac{1}{3}}$$

with

$$\rho(\tau)=\frac{1}{\pi R^2\tau}\frac{dN}{dy}\qquad \frac{dN}{dy}=\frac{dN}{dy}\bigg|_0\; e^{-\frac{y^2}{2\sigma^2}}$$



- $v_T = p_T/m_T \Rightarrow \tau_L = \langle L\rangle/v_T$, m_T is the transverse mass of the charm quark.
- If $\tau_c \geq \tau_L$, the charm quark would be inside QGP during the entire period 0 to τ_L.
- If $\tau_c < \tau_L$, the charm quark would be inside QGP only while covering the distance $v_T \times \tau_c$.
- $\langle\tau\rangle = \langle L\rangle_{eff}/2$, where $\langle L\rangle_{eff} = \min[\langle L\rangle, v_T \times \tau_c]$.

There are different approaches in the literature to calculate the energy loss of a charm quark while passing through the QGP phase.

In order to perform a systematic test of various models for energy loss, we have estimated the radiative energy loss of a charm quark by

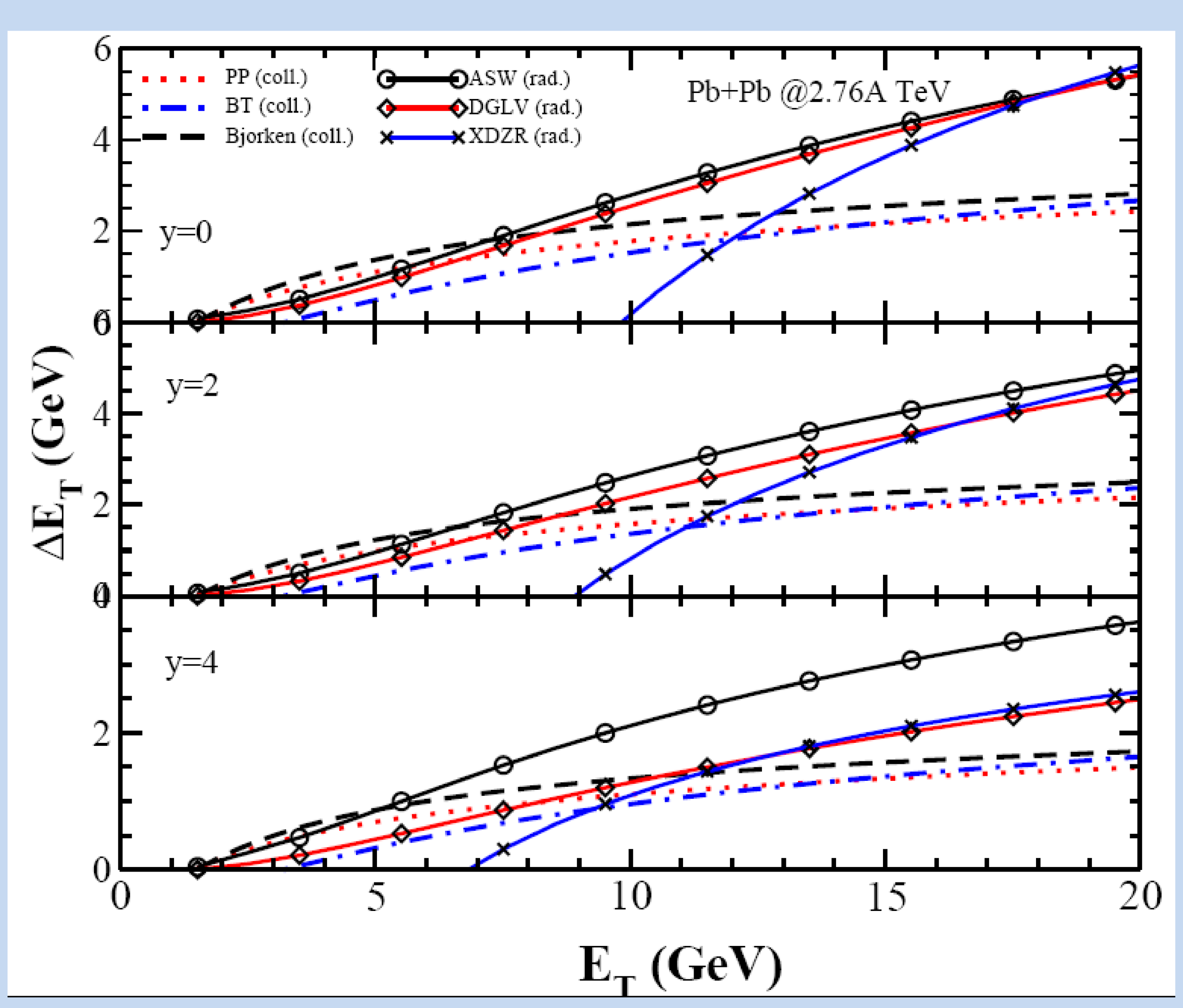
- Djordjevic, Gyulassy, Levai and Vitev (DGLV) formulation,
- Xiang, Ding, Zhou and Rohrich (XDZR) formulation and
- Armesto, Salagado and Wiedemann (ASW) formulation.

And collisional energy loss of a charm quark by

- Peigne and Peshier (PP) formulation,
- Braaten and Thoma (BT) formulation and
- Bjorken formulation.

The initial conditions:

- Number of flavours N_f = 3,
- Color factor C_f = 4/3,
- Mass of the charm quark = 1.5 GeV,
- Running coupling constant α_s = 0.3,
- Average path length <L> = 6.14 fm,
- τ_0 = 0.1 fm/c and τ_c at T_c = 170 GeV, and
- The central particle rapidity density $(dN_g/dy)_0$ ≈ 2855.

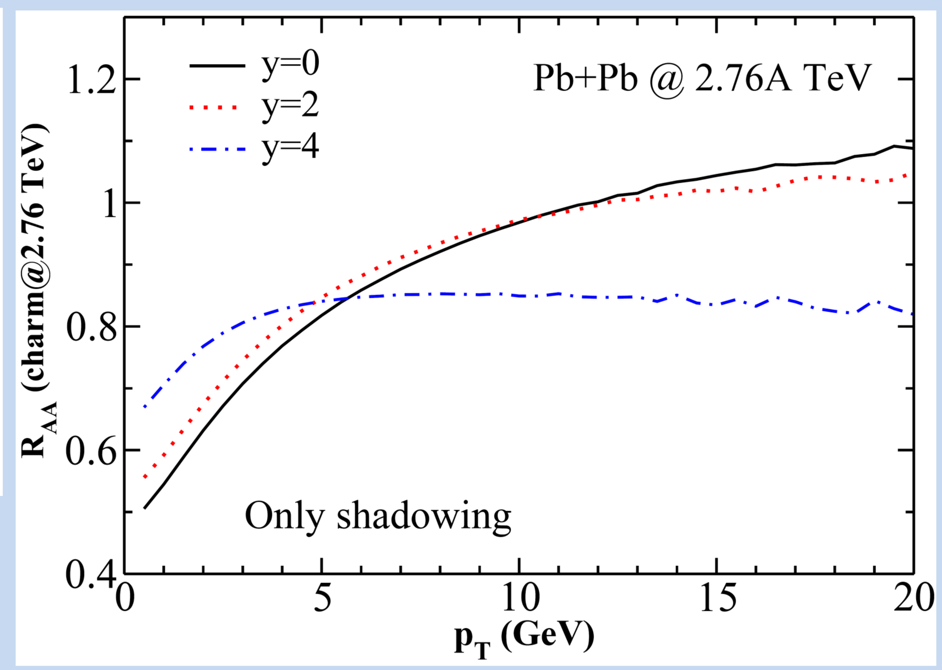


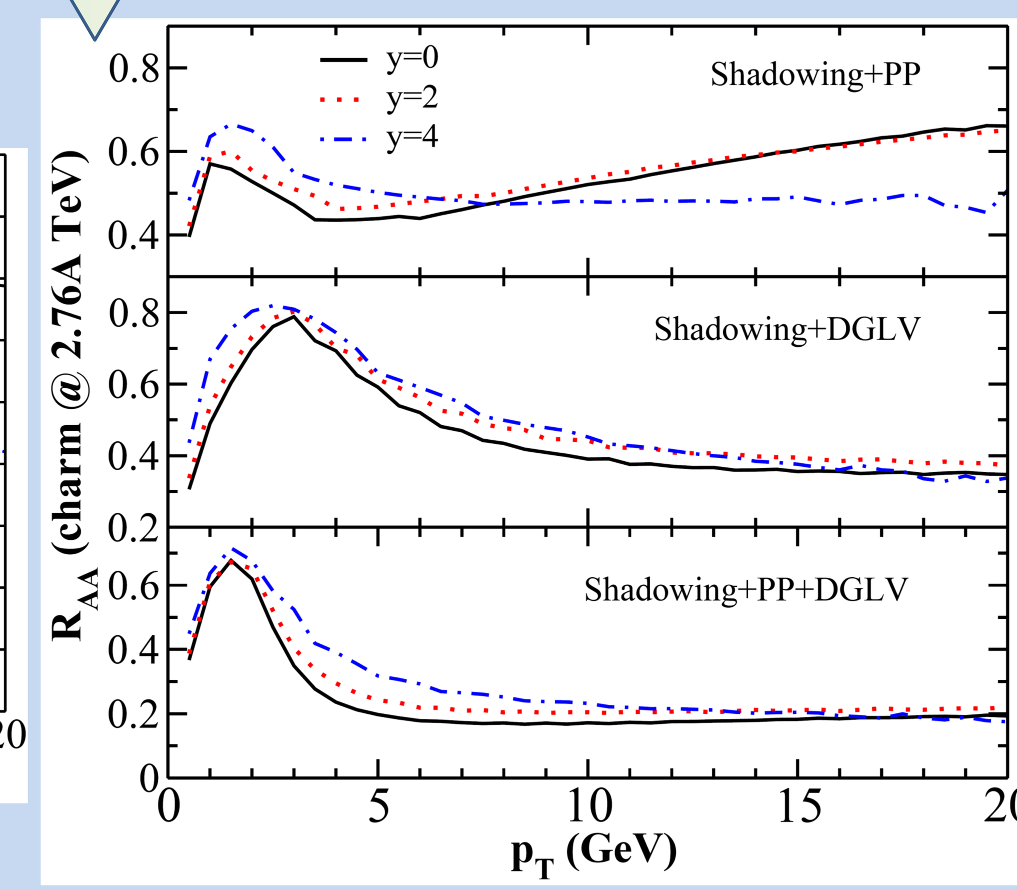
The nuclear modification factor at impact parameter b:

$$R_{AA}(b)=\frac{dN^{AA}/dp_T dy}{T_{AA}(b)\,d\sigma^{NN}/dp_T dy}$$

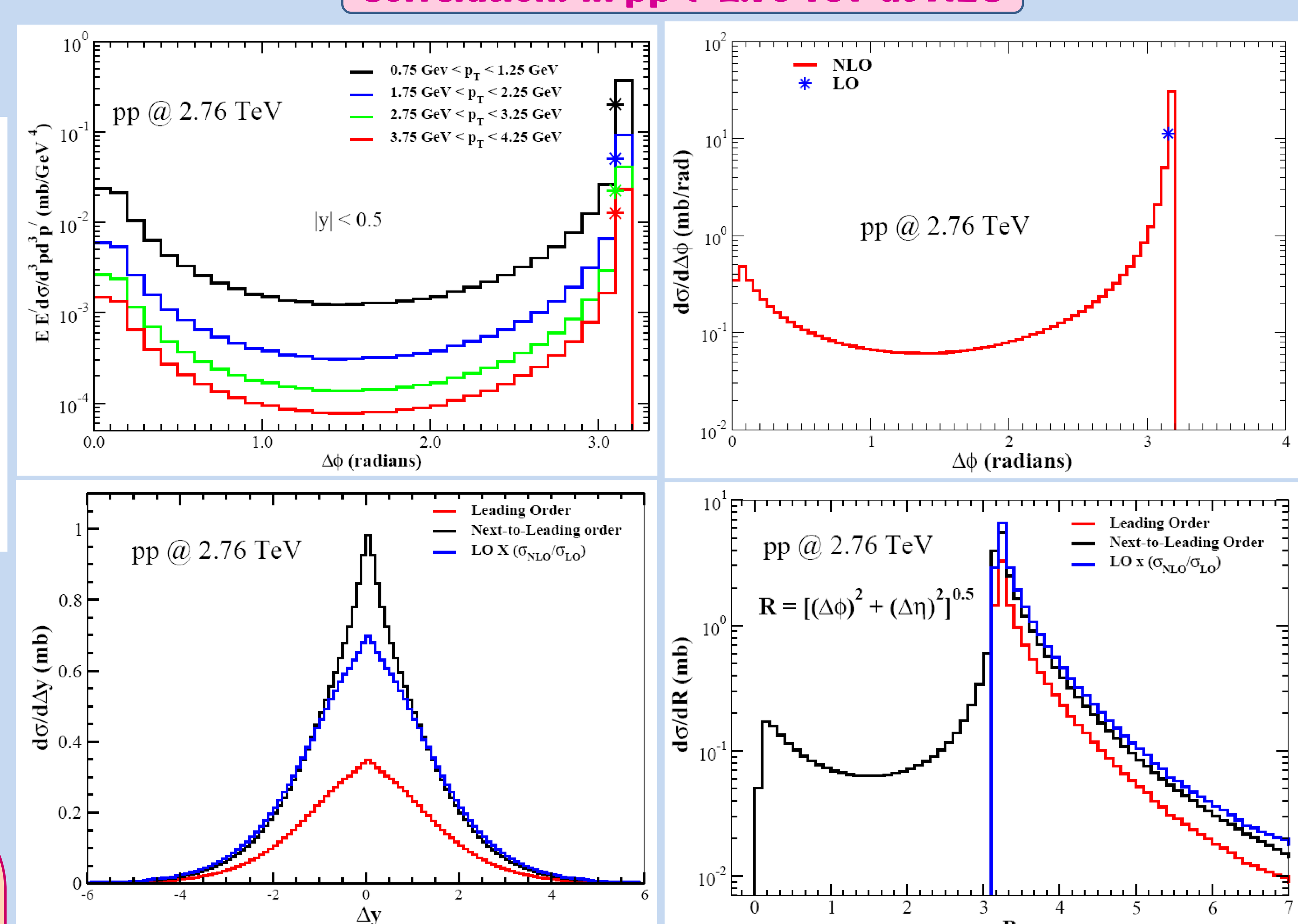
Glauber model formalism → Nuclear thickness function $T_{AA}(b)$ → ≈ 292 fm^{-2} for 2.76A TeV Pb+Pb collisions at LHC at impact parameter b=0.

Introducing the energy loss and also the shadowing effect (EKS 98 parameterization) of the charm quark distributions at 2.76 TeV, we studied the suppression in the nuclear modification factor and the results for the suppression factor are shown with only PP and DGLV formulations.





Correlations in pp @ 2.76 TeV at NLO



Conclusions

- We have made a detailed study of average energy loss of charm quarks at different rapidities due to collisions and radiations of gluons.
- We have seen that the collisional energy loss for charm quarks is only marginally dependent on the rapidity whereas the radiative energy loss, shows a much more complex behaviour and is quite different for the different formalisms under consideration.
- The nuclear suppression factor R_{AA} is calculated by additionally incorporating nuclear shadowing and found a rich picture of the dependence of R_{AA} on rapidity and transverse momentum of the charm quark.
- We see that the outcome of the shadowing and energy loss gives an interesting structure to R_{AA}.
- The description for energy loss for one quark mass at one single rapidity for a particular incident energy may not be sufficient to identify the most reliable energy loss treatment for either collisional or radiative energy loss.
- The correlations are shown only for pp collision whereas they are likely to change in case of nucleus-nucleus collisions because of the medium effects. This is under investigation.

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