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Nuclear suppression and elliptic flow of heavy flavour decay muons at 2.76 ATeV

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We calculate the nuclear modification factor, R_{AA} and elliptic flow, v_2 of muons from heavy flavours decay at forward rapidities in Pb+Pb collision at LHC and FCC energies. The p_T distribution of heavy quarks produced from the initial fusion of partons is obtained using FONLL approach. We consider both the radiative and collision energy loss along with a boost-invariant expansion of the plasma for the prediction of R_{AA} as well as v_2. We compare our result of muon R_{AA} and v_2 in Pb+Pb collision at 2.76 ATeV with the ALICE data.

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Introduction

Heavy quarks are produced from the initial fusion of gluons or light quarks mainly during the early stage of collision. Their large mass ensures that their production can be treated using pQCD and also nearly negligible production at later times. While traversing the QGP they would not deviate much from the initial direction of production. So, they stands out in the sea of light quarks and gluons, which makes them an excellent probe for QGP. While passing through the QGP, they loose energy by colliding with quarks and gluons and also by radiating gluons before appearing as charm or bottom mesons or baryons. These mesons further decay through leptonic channel and thus the final spectra for these leptons would carry information about the energy loss suffered by the heavy quarks.

In this work we calculate the p_T distribution of heavy quarks from initial fusion and then calculate the final p_T distribution taking into account the energy loss suffered by them as they pass through the QGP. Finally we perform a Monte Carlo calculation to obtain the average change in the transverse momentum spectra of heavy quarks for nucleus-nucleus collisions and get R_{AA} and v_2 as a function of p_T for different rapidities at different centrality bins.

Initial conditions and energy loss formalisms

The p_T distribution of heavy quarks produced from the initial fusion of partons in nucleus-nucleus collisions at different centre of mass energies are obtained by Fixed Order Next to Leading Logarithm (FONLL) calculation [1]. The p_T distribution of initial production of charm and bottom quarks at 2.76, 5.5 and 39 ATeV obtained using FONLL calculation in Pb+Pb collision at rapidity 2.5 are presented in Fig. 1. Here we use CTEQ 6.6 structure function set for nucleons. The Peterson fragmentation function [2] with parameter $\varepsilon_c = 0.06$ and $\varepsilon_b = 0.006$ are used for fragmentation of c quarks into D-mesons and b quarks into B-mesons, respectively. The central particle rapidity densities for Pb+Pb collisions at 2.76, 5.5 and 39 ATeV are taken as 2850, 3600 and 6480 respectively [3, 4].

The energy loss suffered by the heavy quarks will depend upon the path-length of the heavy quarks in the plasma, the temperature evolution of the plasma, and the energy and mass of the heavy quarks. In our simple approach we make several simplifying assumptions. The heavy quarks are expected to loose most of their energy when the temperature is still large, i.e. during the earliest times after the formation of QGP, so, we can neglect the transverse expansion of the plasma. We consider Bjorken cooling works locally at different rapidities and assume a boost-invariant expansion along with a local fluid approximation.

As the heavy quarks loose most of their energy in interaction with gluon we consider only the distribution of gluons and assume a Gaussian rapidity density distribution of gluons given by [5, 6]:

$$\frac{dN_g}{dy} = \left(\frac{dN_g}{dy}\right)_0 \exp\,\left(-y^2/2\sigma^2\right). \tag{1}$$

Their density at the time τ can be written as [7]:

$$\rho\,(\tau) = \frac{1}{\pi\,\mathrm{R}^2\,\tau}\,\frac{dN_g}{dy}. \tag{2}$$

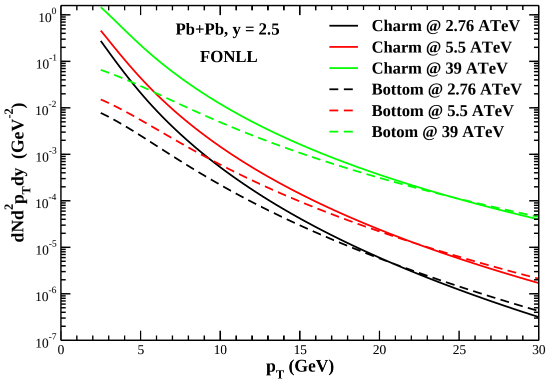

Figure 1: Initial distribution of production of charm and bottom quarks in Pb+Pb collision at 2.76, 5.5 and 39 ATeV at the forward rapidity 2.5.

The corresponding temperature, assuming a chemically equilibrated plasma is

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

In non-central collisions the heavy quarks produced from the initial fusion would cover different path lengths, depending upon the azimuthal angle and the impact parameter, inside the plasma. In a non- central collision, therefore, they would lose different amounts of energy, which will lead to an azimuthal anisotropy of momentum distribution of leptons.

A heavy quark after production at the point (x,y), moves at an angle ϕ with respect to the reaction plane with impact parameter b. It traverses the distance l(x,y,ϕ,b) inside the plasma. Using a simple approach, based on Glauber model, we calculate the dependence of the average path-length on the azimuthal angle and impact parameter with respect to the reaction plane. Assuming uniform densities for the colliding nuclei, the average path-length for an impact parameter b and azimuthal angle ϕ can be written as [8]:

$$\langle L(\phi;b) \rangle = \frac{\iint l(x,y,\phi,b)\, T_{AB}(x,y;b)\, \mathrm{d}x\, \mathrm{d}y}{\iint T_{AB}(x,y;b)\, \mathrm{d}x\, \mathrm{d}y}. \tag{4}$$

Where $T_{AB}(x,y;b) = T_A(x+b/2,y)\, T_A(x-b/2,y)$ is the nuclear overlap function and t_A and t_B are the transverse density profiles of the two nuclei. An average of $L(\phi;b)$ over ϕ (varying from zero to 2π) gives the average path length L(ϕ) (Fig. 2).

The initial time of formation of QGP, τ_0 is taken as 0.2 fm/c. We approximate the expanding and cooling plasma with one at a temperature of T(τ) at $\tau = \langle \mathrm{L} \rangle_{\mathrm{eff}}/2$, where $\langle \mathrm{L} \rangle_{\mathrm{eff}} = \min [\langle \mathrm{L} \rangle, v_T \times \tau_c]$, where v_T is the transverse velocity of the heavy quark and τ_c is the critical temperature [9].

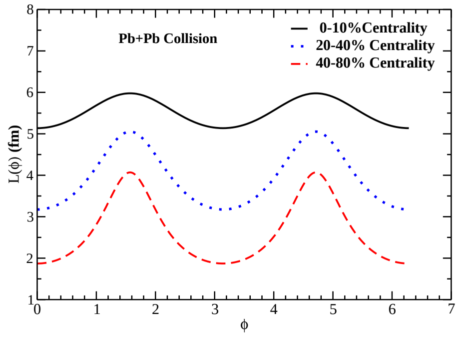

Figure 2: Variation of average path length L(ϕ) with azimuthal angle ϕ

The collisional energy loss suffered by heavy quarks is calculated using Peigne and Peshier (PP) [10] formalism and the radiative energy loss is calculated using AJMS [11] and DGLV formalisms [7]. We plot the transverse radiative energy loss of charm and bottom quarks, ΔE_T as a

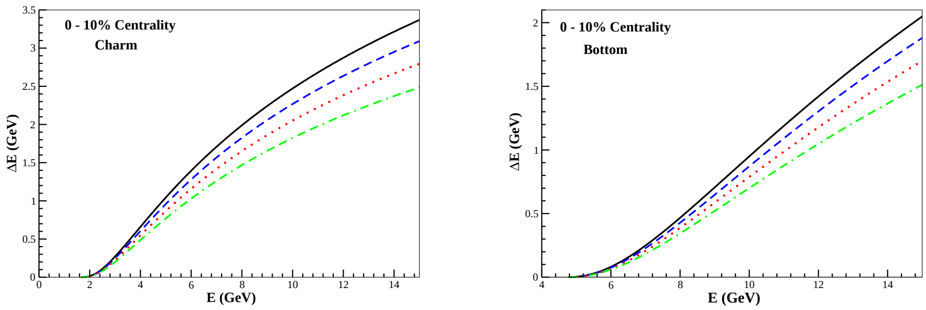

Figure 3: Radiative energy loss suffered by charm and bottom quarks while passing through the QGP at forward rapidities at 0 - 10% centrality.

function of transverse energy E_T $(\sqrt{p_T^2 + M^2})$ at 0 - 10% centrality using AJMS formalism at 2.76 ATeV at LHC. Each of the plots of Fig. 3 is presented for rapidities 2.5 to 4.

R_{AA} of muons

We plot the result of nuclear modification factor of muons at 0 - 10% centrality with both collisional and radiative energy loss at 2.76 ATeV at LHC in Fig. 4. Our result at 0 - 10% centrality with only AJMS formalism found to agree well with the recent data [12] from ALICE collaboration. However, the inclusion of the collisional energy loss further suppresses the nuclear modification factor significantly and predicts more suppression compared to the experimental result. For a better understanding of the predicted trend by AJMS formalism, we also compare our results of R_{AA} at 2.76, 5.5 and 39 ATeV. We see that the nuclear suppression is more with the increase of centre of mass energy. A detailed study comparing the predictions of R_{AA} by DGLV and AJMS formalisms can be found in reference [11].

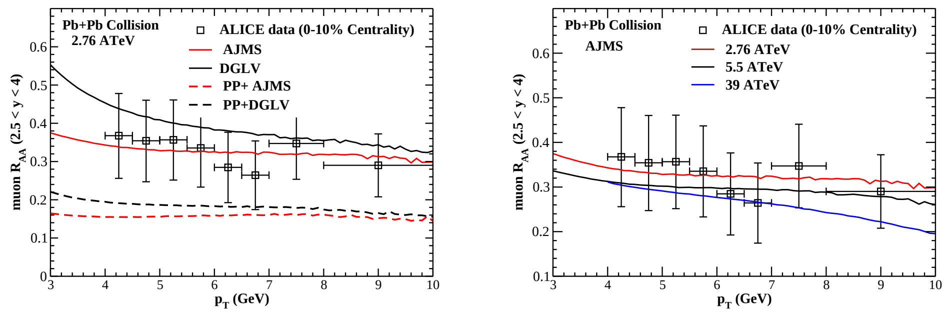

Figure 4: R_{AA} of muons at forward rapidity at 0 - 10% centrality.

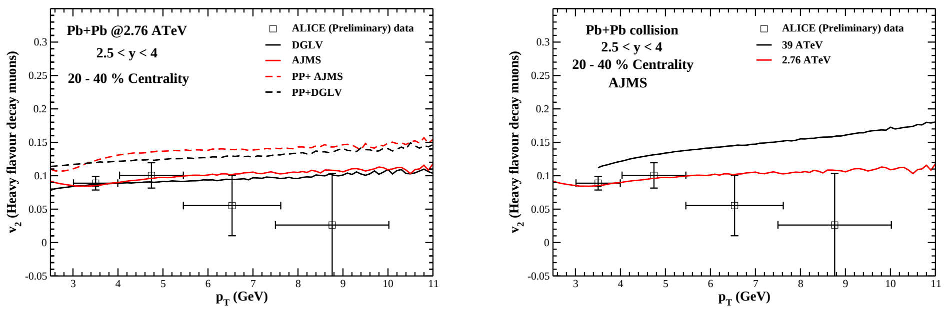

Figure 5: v_2 of muons at 2.76 ATeV for 20-40% centrality.

Azimuthal anisotropy

We calculate the differential azimuthal anisotropy in terms of the parameter $v_2(p_T)$, which is given by:

$$v_2(p_T) = \frac{\int_0^{2\pi} \mathrm{d}\phi \, cos(2\phi) \, dN/d^2p_T \, dy}{\int_0^{2\pi} \mathrm{d}\phi \, dN/d^2p_T \, dy}. \tag{5}$$

In Fig. 5 we plot the result of azimuthal anisotropy of muons in Pb+Pb collision at 2.76 ATeV for 20-40% centrality in the rapidity window 2.5 to 4. We compare the predicted result with the preliminary ALICE data of azimuthal anisotropy of heavy flavour decay muons [13]. We also compare our prediction of $v_2(p_T)$ at 2.76 and 39 ATeV in the same rapidity window with AJMS formalism. From these comparisons, we feel that we need more experimental data for $v_2(p_T)$ at high p_T to understand our predicted trend.

Summary

Our prediction of R_{AA} considering only radiative energy loss agrees well with the ALICE data, but when we consider both the radiative and collisional energy losses, it shows more suppression than the experimental data. In our model we are predicting maximum possible energy loss by assuming one dimensional expansion of the plasma and also by considering constant density distribution of the colliding nuclei while calculating the average path length traversed by the quark. In turns we are predicting maximum possible nuclear suppression and azimuthal anisotropy. We expect that the scenario can be improved by incorporating transverse expansion of the plasma along with Wood-saxon density distribution for the colliding nuclei.

References

[1] M. Cacciari et al., *J. High Energy Phys.* **9805** (1998) 007; *J. High Energy Phys.* **0103** (2001) 006.

[2] C. Peterson et al., *Phys. Rev. D* **27** (1983) 105.

[3] K. Aamdot, et al., [ALICE Coll], *Phys. Rev. Lett.* **105** (2010) 252301.

[4] N. Armesto et al., *Nucl. Phys. A* **00** (2014) 1.

[5] R. Vogt, B. V. Jacak, P. L. McGaughey, and P. V. Ruuskanen, *Phys. Rev. D* **49**, 3345 (1994).

[6] S. Gavin, P. L. McGaughey, P. V. Ruuskanen, and R. Vogt, *Phys. Rev. C* **54**, 2606 (1996).

[7] M. Djordjevic and M. Gyulassy *Nucl. Phys. A* **733**, 265 (2004); S. Wicks et al., *Nucl. Phys. A* **784**, 426 (2007).

[8] S. De, D. K. Srivastava *J. Phys. G* **39** (2012) 015001.

[9] U. Jamil and D. K. Srivastava, *J. Phys. G* **37**, 085106 (2010).

[10] S. Peigne and A. Peshier, *Phys. Rev. D* **77**, 114017 (2008).

[11] R. Abir et al., *Phys. Lett. B* **715**, 183 (2012); arXiv:1203.5221 (2012).

[12] ALICE Collaboration, Phys. Rev. Lett. 109, 112301 (2012).

[13] Grazia Luparello for the ALICE Collaboration, arXiv:1411.2442v1 (2014).