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Azimuthal correlation of charm quark pair produced in heavy ion collision

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Abstract. It is known that heavy quarks are produced in pairs. There always exists a correlation in azimuthal angle in transverse momentum plane between the members in a pair. The quark and anti-quark in a pair may lose different amount of energy while traveling through QGP and it is expected that the correlation of $Q\bar{Q}$ will alter considerably. Also in a complete different picture, collective flow of the medium can change the correlation of heavy quark pair. Here we present the effect of charm quark energy loss based on Wang-Huang-Sarcevic model on its correlation. The flow feature is shown using a naive model based on Cautle-Páic model.

1. Introduction

Charm quarks are always produced in pairs in agreement with the conservation of heavy flavour quantum no. in relativistic heavy ion collision. The produced charm pairs($c\bar{c}$), show correlation in azimuthal angle($C(\Delta\phi)$), in transverse momentum plane. It is known that at leading order. c and $\bar{c}$ will be exactly back-to-back($\Delta\phi$=π), with $\mathbf{p_{Tc}}$=-$\mathbf{p_{T\bar{c}}}$. While at next-to-leading order, as one of the produced final state charm may emit a gluon or one of the final state gluons from hard scattering process may split into $c\bar{c}$ pair, this back-to-back correlation is now modified with distribution now extended throughout, $\Delta\phi$=0–π. Again if charm pair undergoes medium modification due to energy loss or due to the collective flow of the medium, then the azimuthal correlation will alter considerably. Thus azimuthal correlation of heavy quark pair is fast emerging as one of the possible signature for the QGP properties.

2. Charm pair production

The correlation of heavy quarks produced in pp collisions is defined as

$$E_1\, E_2\, \frac{d\sigma}{d^3p_1\, d^3p_2} = \frac{d\sigma}{dy_1\, dy_2\, d^2p_{T1}\, d^2p_{T2}} = C\,, \tag{1}$$

where y_1 and y_2 are the rapidities of heavy quark and anti-quark and $\mathbf{p_{Ti}}$ are the respective momenta. One can now calculate [1]

$$\frac{d\sigma_{pp}}{dy_1 dy_2 d^2p_{T1} d^2p_{T2}} = 2x_a x_b \sum_{ij} \left[f_i^{(a)}(x_a, Q^2) f_j^{(b)}(x_b, Q^2) \frac{d\hat{\sigma}_{ij}(\hat{s},\hat{t},\hat{u})}{d\hat{t}} + f_j^{(a)}(x_a, Q^2) f_i^{(b)}(x_b, Q^2) \frac{d\hat{\sigma}_{ij}(\hat{s},\hat{u},\hat{t})}{d\hat{t}} \right] /(1+\delta_{ij})\ , \tag{2}$$

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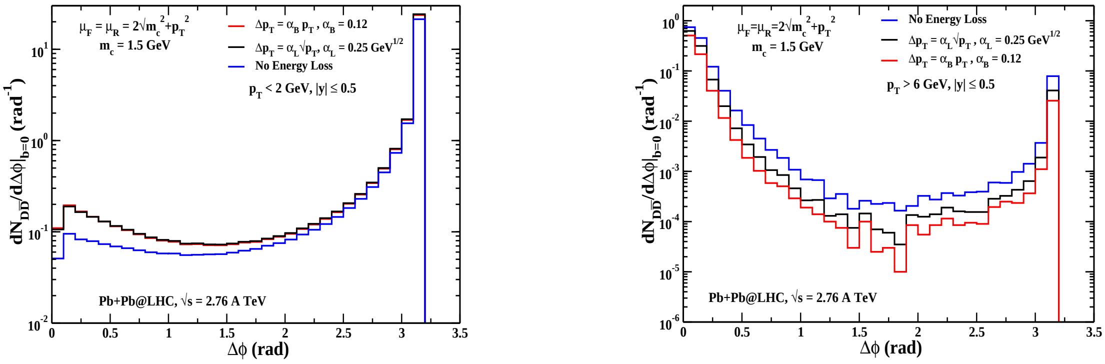

Figure 1. Effect of energy loss on azimuthal correlation of $D\overline{D}$ pair for two different charm momentum region

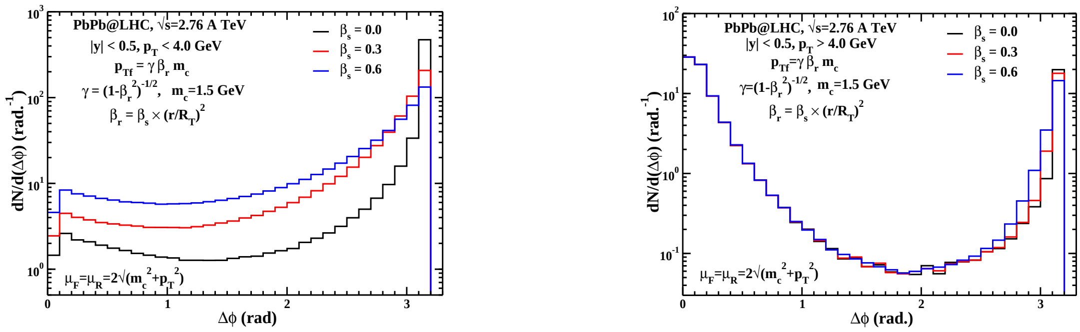

Figure 2. Effect of flow on azimuthal correlation of $c\bar{c}$ for $p_T < 4.0$ GeV(left) and $p_T > 4.0$ GeV

where $p_{T1,2}$ and $y_{1,2}$ are the momenta and rapidities of produced charm and anti-charm and x_a and x_b are the fractions of the momenta carried by the partons from their interacting parent hadrons. We have included all leading and next-to-leading order diagrams for charm quark pair production and obtained the cross-section using NLO-pQCD calculations [2].

The Eq. 1 is used to calculate the correlation of heavy quarks from initial fusion in proton-proton collision. The azimuthal correlation of heavy quark for Pb+Pb collision at given impact parameter is given by

$$E_c\, E_{\bar{c}}\, \frac{dN_{AA}}{d^3p_c\, d^3p_{\bar{c}}} = T_{AA} E_c\, E_{\bar{c}}\, \frac{d\sigma_{pp}}{d^3p_c\, d^3p_{\bar{c}}} \tag{3}$$

For lead on lead collisions at LHC, we have used $T_{AA} = 292$ fm^{-2} for b = 0 fm We have used CTEQ5M structure function. The factorization, renormalization, and fragmentation scales are chosen as $2\sqrt{m_c^2 + p_T^2}$ and the charm quark mass, m_c has been taken as 1.5 GeV.

3. Effect of energy loss and medium flow on charm quark azimuthal correlation and discussions of results:

The medium effect on charm p_T spectrum has been obtained using two different models. The first model shows the effect of momentum loss of charm quark per collision through multiple scattering with medium partons. Partly inspired by Wang-Huang-Sarcevic model, [3], the momentum loss per collision for 'i^{th}' charm with momentum, $|\mathbf{p_T}|=p_i$, is calculated by

$$\Delta p_i = \alpha(p_i)^\beta \,, \alpha = \alpha_L(\beta = 0.5) \,, \text{and}\, \alpha_B(\beta = 1.0) \tag{4}$$

The no. of collisions for given charm momentum is calculated using Poisson distribution(with mean free path,λ $\sim$1 fm) and the net momentum loss is then calculated and included in the Eq. 3 to obtain the correlation for D mesons, Fig. 1, after adding fragmentation calculations to the final charm spectra.

The second model shows the effect of collective flow of the medium on the angular correlation, if the heavy quarks are assumed to be thermalized. In order to estimate the effect of the flow on the correlation of the heavy quarks, we use a toy model used earlier by [4, 5] and proceed as follows. We first give a random orientation and position to the charm quark-pairs at co-ordinates, (x, y), randomly chosen according to the probability:

$$P = \frac{\int\int\, dx\, dy\, T_A(x, y, b = 0)T_B(x, y, b = 0)}{T_{\rm AB}(b = 0)} \,, \tag{5}$$

where T_i is the transverse density profile of the nucleus with uniform density, and $T_{\rm AB}(b = 0)$ is the nuclear thickness for impact parameter, $b = 0$. Then we add vectorially, the flow momentum $\mathbf{p_{Tf}}= p_{Tf}$ $(\mathbf{r}/r)$ to the momentum of the heavy quark $\mathbf{p_T}$.

We use the blast-model [6] to write p_{Tf} as

$$p_{Tf} = \gamma\beta_r m_Q \,, \tag{6}$$

where

$$\beta_r = \beta_s \times \left(\frac{r}{R_T}\right)^2 \,. \tag{7}$$

and $r = \sqrt{x^2 + y^2}$. We show our results in Fig. 2 for two ranges of p_T of the charm quarks, $p_T < 4$ GeV and $p_T > 4$ GeV.

4. Conclusions

We studied heavy quark azimuthal correlation and showed that it affected by both energy loss and flow of the medium and thus it may serve as one of the observables of quark gluon plasma properties. However much improvement in terms of calculations and statistics must be done and will be addressed in future.

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