Electron-D^0 correlations in p+p and Au+Au collisions at 200 GeV with the STAR experiment at RHIC

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ELECTRON-D^0 CORRELATIONS IN $p+p$ AND Au+Au COLLISIONS AT 200 GeV WITH THE STAR EXPERIMENT AT RHIC*

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The energy loss of heavy quarks in the hot and dense matter created at RHIC can be used to probe the properties of the medium. Both charm and beauty quarks contribute to non-photonic electrons through their semi-leptonic decays. Thus it is essential to determine experimentally the relative contribution of those flavors for understanding the suppression of beauty at high p_{T} in central Au + Au collisions. The azimuthal angular correlations of non-photonic electrons with the reconstructed D^0 allow to disentangle that contribution. Furthermore, presence of a non-photonic electron significantly reduces the background in the D^0 invariant mass region. In this paper the STAR measurement of a non-photonic electron and $D^0 \to K\pi$ azimuthal correlations in $p+p$ collisions at 200 GeV will be presented along with perspectives on such measurement for the Au + Au system.

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1. Introduction

Heavy quarks, charm and beauty, are produced at RHIC predominantly through the parton interactions in the early stage of the collision. Thus they are considered as a good probe to study the hot and dense medium which is believed to exist in the heavy-ion reactions. While traversing that system, particles can lose their energy through the gluon radiation. However, according to the so-called "dead cone" effect, heavy quarks are expected to radiate less than light ones as the probability of this process decreases for the small angles with the increasing particle mass [1].

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Both charm and beauty are being studied at STAR through the spectra of non-photonic electrons (NPE) which come from semi-leptonic decays of heavy flavor mesons. The possible suppression can be then quantified by the nuclear modification factor (R_{AA}) defined as the yield of particles in heavy-ion collisions, divided by the yield in $p+p$ collisions at the same energy and scaled by the average number of binary collisions.

Recent measurements of R_{AA} for NPE suggest that heavy quarks are suppressed in the same way as the light quark hadrons [2]. This contradicts previously mentioned theoretical predictions and constitutes an important puzzle in the model of heavy flavor interactions. In order to understand the nature of this phenomenon, charm and beauty have to be studied separately. This can be done through the analysis of electron-D^0 and electron–hadron azimuthal angular correlations.

2. Correlation technique

Charm quark mesons, for example D^0, can originate either directly from the hadronisation of the charm quarks or from the decay of B particles, which contain beauty quarks. In the first case, a $c\bar{c}$ pair is created in the interaction (left-hand side of Fig. 1). Both of the quarks are traveling in opposite directions and both of them can form a D^0 ($\bar{D}^0$) meson. One of them can then decay in the semi-leptonic channel ($D^0 \to e^+ + X$, $\bar{D}^0 \to e^- + X$) while the other through the hadronic channel ($D^0 \to K^-\pi^+$, $\bar{D}^0 \to K^+\pi^-$), that then can be registered and reconstructed by STAR. Thus, in this situation the angle between the electron from the semi-leptonic decay and the direction of the reconstructed D^0 ($\bar{D}^0$) particle is close to $\Delta\phi = \pi$ and the charge of the mentioned electron is the same as the charge of the kaon from the hadronic decay of the D^0 ($\bar{D}^0$).

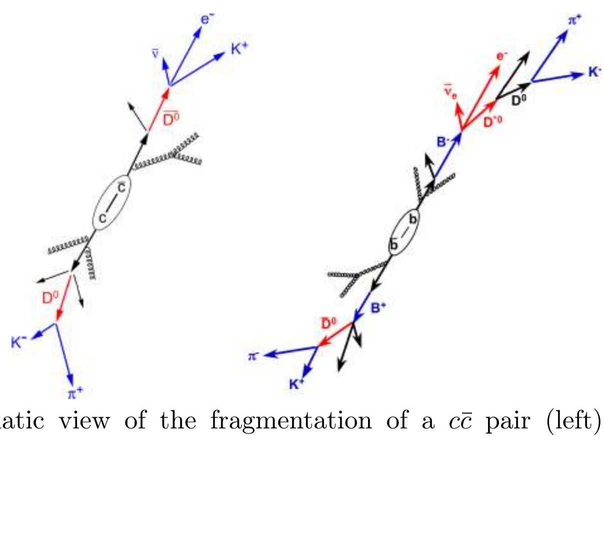

Fig. 1. Schematic view of the fragmentation of a $c\bar{c}$ pair (left) and a $b\bar{b}$ pair (right) [3].

In the second case, $b\bar{b}$ quarks are created in the collision (right-hand side of Fig. 1) and later form a pair of B mesons. Again, one of them can decay in the semi-leptonic channel ($B \to e^{\pm} + X$) and form an electron and a D^0 ($\bar{D}^0$) through its excited state. Thus the angle between these two is close to $\Delta\phi = 0$ and the electron has the same sign as the kaon from the D^0 ($\bar{D}^0$) hadronic decay.

Therefore, the measurement of D^0 ($\bar{D}^0$) yields for different angles between reconstructed meson and NPE, together with a demand of the same-sign charge correlation between electron and the kaon from the D^0 ($\bar{D}^0$) hadronic decay, delivers a beauty yield for the near-side ($\Delta\phi = 0$) and charm with some beauty contribution from other decay modes of B meson for the away-side ($\Delta\phi = \pi$). This has been observed in PYTHIA (leading order) (Fig. 2) and Next to Leading Order (NLO) simulations performed for the $p + p$ system [3].

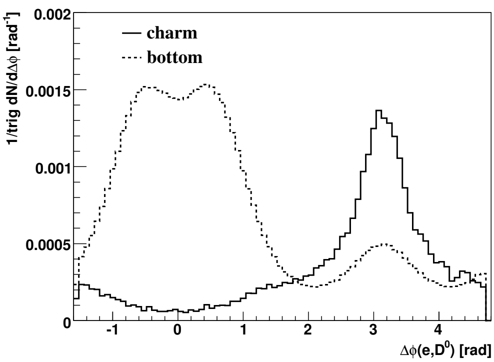

Fig. 2. Azimuthal electron-D^0 correlation distribution from PYTHIA for like-sign e–K pairs [4].

3. STAR experiment

STAR (Solenoidal Tracker at RHIC) is a versatile detector which consists of many sub-systems dedicated to measurement of different aspects of particle interactions. The detail description of them can be found in [5]. Subdetectors used for the purpose of this analysis were: Time Projection Chamber (TPC), Electromagnetic Calorimeter (EMC) with Shower Maximum Detector (SMD), Silicon Vertex Tracker (SVT) and Silicon Strip Detector (SSD).

A large volume TPC with full azimuthal acceptance is the primary tracking and particle identification device of STAR. It is located around the interaction point inside the magnet, which is capable of generating a magnetic field up to 0.5 T. This tandem allows to reconstruct particles with momentum in the range of 0.1 to 30 GeV/c and provides a dE/dx resolution sufficient to separate of pion and proton spectra up to $p = 1$ GeV/c [6].

The EMC, located around the TPC barrel, has a form of towers built of a lead and plastic scintillator with thickness of 21 X_0. The SMD, a two-dimensional (ϕ, η) wire proportional detector, is situated inside the towers, at 5 X_0, where the electron originated shower is expected to be maximally developed. It enables the analysis of the shower shape with the accuracy of $\Delta\eta = \Delta\phi = 0.007$ in both planes. Together they allow separation of electron spectra from the hadronic background for the particles with the momentum $p > 1.5$ GeV/c within $\mid \eta \mid < 1.0$ [7].

In order to improve the pointing resolution, STAR was also equipped with two silicon based, cylinder-shaped detectors located at the very center of the experiment, between the beam pipe and the inner border of the TPC. The inner one — SVT, was a 3-layered drift detector. Combined with the outer, single-layered SSD, it could improve the resolution in Au + Au collisions by a factor of 10 for a particle with $p = 1$ GeV/c [8].

4. Data analysis and results

The technique described previously has been applied to the dataset collected during the 2006 $p+p$ run with the energy of $\sqrt{s} = 200$ GeV. The analysis has been performed on the preselected events where the reconstructed primary vertex z coordinate was not more than 30 cm away from the center of the detector and for which at least one high energy ($E_{\rm t} > 5.4$ GeV) non-photonic electron was registered.

Electron candidates were selected by taking every particle for which $dE/dx \in (3.5, 5.0)$ keV/cm and $p > 1.5$ GeV/c. Then, in order to exclude the hadron contamination, a $p/E \in (0, 2)$ cut was performed, where p was a momentum of the track obtained through the reconstruction process and E was an energy deposited by the particle in the EMC. Electrons are expected to give a value close to unity as they are supposed to lose all their energy in the calorimeter. Finally, the information from the SMD was used for further suppression of the hadron contamination. It is known that hadrons give much narrower shower than electrons. Thus only those which were covering more than one strip in each plane were considered as electron-originated. Together those cuts delivered a set of electrons with a purity over 90%.

A large sample of electrons registered by STAR during the collision come from the gamma conversions in the detector and Dalitz decays of light quark mesons. In order to get rid of such contamination for each pair of electrons, the invariant mass was calculated and the particles for which the obtained value was below 150 MeV/c^2 were rejected. This way, up to 70% of the photonic electrons were removed.

For the events tagged by electrons, selected with the technique described above, the invariant mass method was applied to every $K\pi$ pair [9]. As an outcome a D^0 yield was obtained and studied in the different azimuthal angle ranges with respect to the trigger electron. Then the spectrum of the D^0 production in a function of the azimuthal angle was used to fit the simulations from PYTHIA and NLO Monte Carlo in order to disentangle charm and beauty, as it is presented in Fig. 3. The result shows that the electrons from charm are produced in the approximately equal amount as the electrons from beauty, which is in agreement with the similar analysis done for the electron–hadron correlation and FONLL (Fig. 4). The combined outcome from those two methods proves that the beauty contribution (r_B) to the NPE spectrum rises with the transverse momentum of a trigger electron to reach about 50% for $p_{\rm T} \sim 5$ GeV/c.

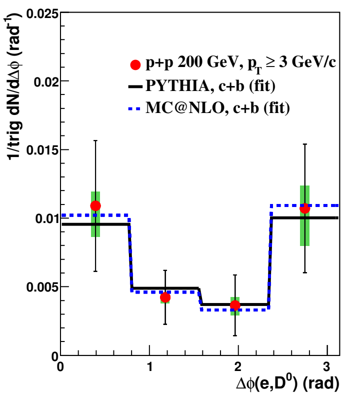

Fig. 3. Distribution of the azimuthal angle between trigger NPEs and D^0 [9].

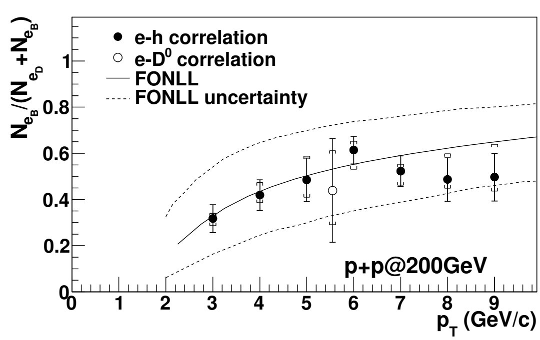

Fig. 4. Relative beauty contribution $B/(B+D)$ as a function of trigger electron $p_{\rm T}$ with a FONLL predictions [9].

The obtained result was then confronted with the R_{AA} of NPEs measured by the PHENIX Experiment. For both variables the mean value above $p_{\rm T} = 5$ GeV/c was calculated and put into the equation

$$R_{AA}^{\rm NPE} = (1-r_B)R_{AA}^{e_D} + r_B R_{AA}^{e_B}\,,$$

where $R_{AA}^{e_D}$ and $R_{AA}^{e_B}$ are nuclear modification factors of NPEs from charm and beauty meson decays respectively. The plot of the relation between the last two factors (Fig. 5) shows that even without any further modifications of the beauty to charm production ratio the R_{AA} of both is expected to be significantly suppressed in heavy ion collisions within the confidence level of 90%. However, a separate measurement of charm and beauty production in that system is necessary to find the exact value between those two [9].

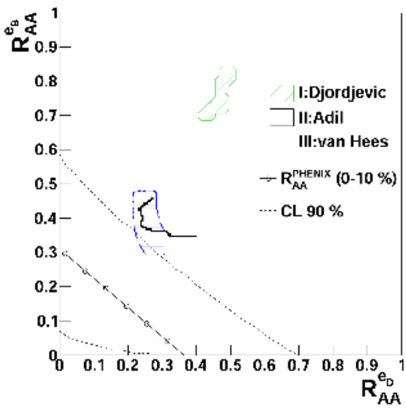

Fig. 5. Correlation between nuclear modification factor of NPEs from D ($R_{AA}^{e_D}$) and B ($R_{AA}^{e_B}$) mesons. Detailed description of this picture can be found in [9].

The studies on electron-D^0 correlations in $p+p$ have provided a baseline for analysis in Au + Au collisions. However, due to much greater multiplicity and particle density of such events another technique of secondary vertex

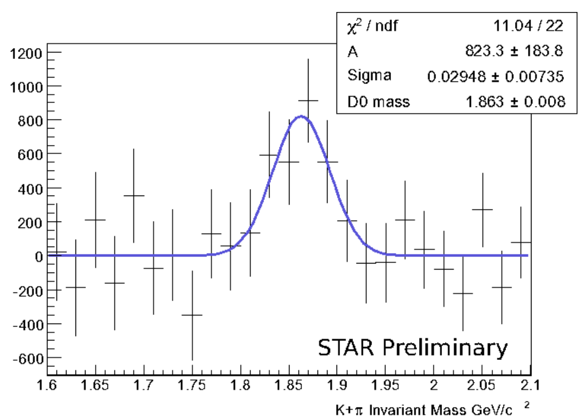

Fig. 6. Invariant Mass distribution of $K\pi$ pairs in Minimum Bias Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV after background subtraction with a Gaussian fitted to the data in the peak region [10].

selection (microvertexing) had to be applied in order to reduce the combinatorial background. That method was tested on minimum bias Au + Au $\sqrt{s_{NN}} = 200$ GeV data collected in the run 2007 and provided a preliminary D^0 peak. To improve the pointing precision, silicon detectors were used in that run. The peak in Fig. 6 was obtained by demanding every track to have at least two hits in any of the silicon detectors [10].

5. Summary

Studies on NPE yields from heavy flavor semi-leptonic decays at RHIC have shown that R_{AA} exhibits suppression for the high values of $p_{\rm T}$, which is similar to the one observed for light quark hadrons. To understand this phenomenon, the contribution of charm and beauty to NPE spectra has been studied through the electron-D^0 and electron–hadron azimuthal angular correlations. The outcome of these methods in $p + p$ collisions has shown that beauty contribution increases with $p_{\rm T}$ and becomes comparable to charm contribution around $p_{\rm T} = 5$ GeV/c. This effect has been found to be compatible with the FONLL calculations within the uncertainties. Based on this result a derivation has been made for the Au + Au system which has shown that both flavors are expected to be significantly suppressed. In order to measure this directly, the microvertexing method has been applied to the data collected by STAR with inner silicon subdetectors. The technique has been successfully tested and the analyses on correlations are underway.

REFERENCES

[1] Y.L. Dokshitzer, D.E. Kharzeev, *Phys. Lett.* **B519**, 199 (2001).
[2] A. Adare *et al.*, `arXiv:1005.1627 [nucl-ex]`.
[3] A. Mischke, *Phys. Lett.* **B671**, 361 (2009) [`arXiv:0807.1309 [hep-ph]`].
[4] A. Mischke, *J. Phys. G* **35**, 104117 (2008) [`arXiv:0804.4601 [nucl-ex]`].
[5] K.H. Ackermann *et al.*, *Nucl. Instrum. Methods* **A499**, 624 (2003).
[6] M. Anderson *et al.*, *Nucl. Instrum. Methods* **A499**, 659 (2003).
[7] M. Beddo *et al.*, *Nucl. Instrum. Methods* **A499**, 725 (2003).
[8] Y.V. Fisyak *et al.*, *J. Phys. Conf. Ser.* **119**, 032017 (2008).
[9] M.M. Aggarwal *et al.*, *Phys. Rev. Lett.* **105**, 202301 (2010).
[10] S. LaPointe, *Nucl. Phys.* **A830**, 627c (2009).