Charm and beauty searches using electron-D0 azimuthal correlations and microvertexing techniques in STAR experiment at RHIC

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Abstract. 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 the non-photonic electrons through their semi-leptonic decays. It is essential to determine experimentally the relative contribution of charm and beauty quarks to understand the suppression of heavy flavors 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 the contribution of charm and beauty and to reduce the background below the D^0 invariant mass as well. We discuss the STAR measurement of non-photonic electron and $D^0 \to K\pi$ azimuthal correlations in p+p collisions at 200 GeV. Furthermore, we show results from the application of microvertexing techniques for charm and beauty searches in Cu+Cu and Au+Au collisions at 200 GeV using the information of the Silicon tracker of STAR.

1. Introduction

Jet quenching, namely anomalous energy loss of partons in the dense medium formed in early stage of heavy-ion collisions, is one of the most important discoveries at RHIC and allows for an estimate of the initial gluon density. Due to the dead cone effect [1] one expects a hierarchy in the suppression of partons depending on their mass. In particular the suppression is expected to be decreasing for increasing mass, for radiative energy loss models. It is therefore of particular importance to measure the flavor dependence of jet quenching to test theoretical predictions and allow for an estimate of the gluon density, which is in agreement with the jet quenching observed for different flavors.

Charm and beauty at RHIC at high transverse momenta (p_T) are measured through non-photonic electrons (NPE) originating from their semileptonic decays. The suppression of hadrons is quantified through the nuclear modification factor R_{AA}, which is defined as the yield of charm and beauty in heavy-ion collisions, divided by the yield in p+p collisions at same energy scaled by the average number of binary collisions.

Studies on non-photonic electron yields from heavy flavor semi-leptonic decays at RHIC have shown that R_{AA} exhibits suppression for the high values of p_T, which is similar to the one observed for light quark hadrons [2]. These results contradict with the previously mentioned theoretical expectations that predicted heavy flavor spectra to be less suppressed due to the dead cone effect [1] and constitute an important puzzle which needs to be resolved. To understand this phenomenon the contributions of charm and beauty to NPE spectra have to be studied separately. This can be done through the analysis of electron-D^0 and electron-hadron azimuthal angular correlations.

2. STAR Experiment

STAR (Solenoidal Tracker at RHIC) is a versatile detector which consists of many sub-systems dedicated to measurement of different aspects of heavy-ion collisions. Subdetectors used for the purpose of this analysis were: Time Projection Chamber, Electromagnetic Calorimeter with Shower Maximum Detector, Silicon Vertex Tracker and Silicon Strip Detector. The details about the STAR experiment can be found in [3].

2.1. Time Projecting Chamber

TPC is a main 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.

2.2. Silicon Detectors

In order to improve the pointing resolution, STAR was equipped with two silicon based detectors located at the very center of the detector, between the beam pipe and the inner border of TPC. The inner one, Silicon Vertex Tracker (SVT), is a 3-layered drift detector. Each layer is a cylinder-shaped structure with the radius of 6.85, 10.8 and 14.7 cm. To simplify matching of the tracks reconstructed in TPC with points from SVT, the 4th layer of silicon, Silicon Strip Detector (SSD), with the radius of 23 cm was introduced. Together SSD and SVT can improve the resolution in Au+Au collisions by a factor of 10 for a particle with $p = 1\ GeV/c$ [4], from ~ 0.27 cm for a TPC only track to ~ 0.03 if the track has at least 2 silicon hits (Fig. 3).

2.3. Electromagnetic Calorimeter

The Electromagnetic Calorimeter (EMC), located around TPC barrel, has a form of towers built of lead scintillator with thickness of 21 X_0. This enables a measurement of the energy of electrons within $\mid \eta \mid < 1.0$. The Shower Maximum Detector (SMD) located at 5 X_0 inside the towers is a two-dimensional (ϕ, η) wire proportional detector which enables the analysis of the shower shape with the accuracy of 0.007 in both planes [5].

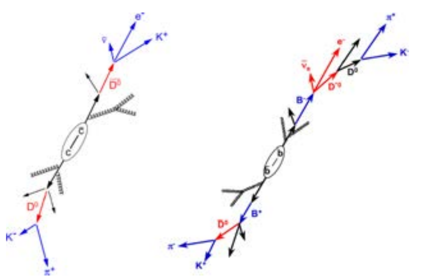

Figure 1: Schematic view of the fragmentation of a $c\bar{c}$ pair (left) and a $b\bar{b}$ pair (right) [6].

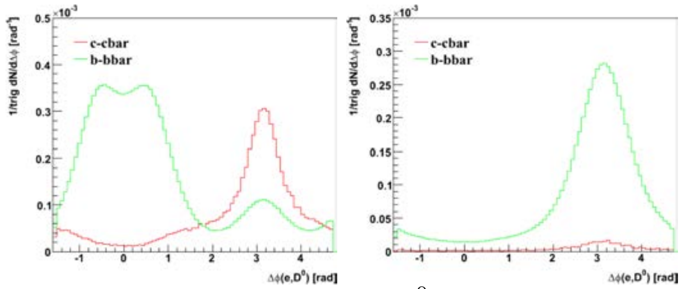

Figure 2: Azimuthal electron-D^0 correlation distribution from PYTHIA for like-sign e-K charge correlation (left plot) and unlike-sign correlation (right plot) [7, 8].

3. Correlation Technique

The D^0 meson can originate either directly from the hadronisation of the $c\bar{c}$ pair or from the B meson decay (as shown on Fig. 1). Thus it can be considered as a good probe for studying charm, but through the B meson, also the beauty. These contributions can be separated by combining the azimuthal correlations $(\Delta\phi)$ between an electron which comes either from the D or B semileptonic decay and the direction of D^0 particle itself with a charge correlation between that electron and kaon which comes from the D^0 hadronic decay. This gives three different possibilities shown on Fig. 2 as the result of a PYTHIA (leading order) simulation. Two of them exist for the e-K like-sign correlation, the beauty only case for $\Delta\phi \sim 0$ and charm dominant case with a small beauty contribution for $\Delta\phi \sim \pi$. In the unlike-sign e-K case only the $\Delta\phi \sim \pi$ correlation is applicable and represents the beauty domination with a small charm contribution. Analogous analysis performed with Next to Leading Order (NLO) simulations gives similar structure [6].

4. Data Analysis and Results

The described technique has been applied to the dataset collected during the 2006 p+p run with the energy of $\sqrt{s} = 200\ GeV$. In the analysis only the events where the primary vertex z coordinate was reconstructed less than 30 cm away from the center of the experiment and for which at least one high energy ($E_t > 5.4\ GeV$) non-photonic electron was registered were taken into consideration.

The electron candidates were selected by taking all particles for which $dE/dx \in (3.5, 5.0)\ keV/cm$ and $p > 1.5\ GeV/c$. Later, in order to exclude hadron contamination, the cut on $p/E \in (0, 2)$ was performed, for which momentum (p) was taken from the track reconstructed in the TPC and the energy (E) was given by the calorimeter. Electrons were expected to give a value close to unity as they are supposed to deposit all their energy inside the calorimeter. Finally a cut on a shower shape was performed with the use of the information gathered by the Shower Maximum Detector. It is known that hadrons give much narrower shower than electrons. Thus only the ones which were covering more than one strip in each plane were considered as electron-originated.

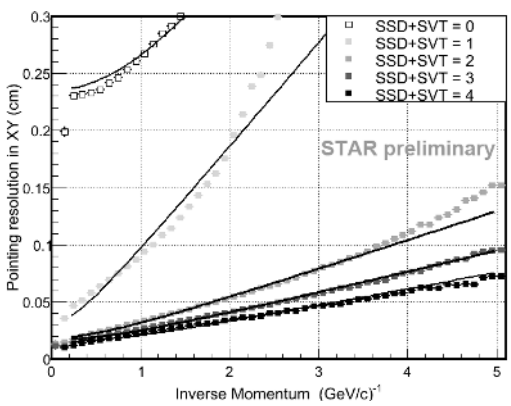

Figure 3: Transverse DCA resolution vs 1/p in Au+Au $\sqrt{s_{NN}} = 200\ GeV$. Tracks with at least two silicon hits have 10 times better pointing resolution than tracks for which only the TPC information is available.

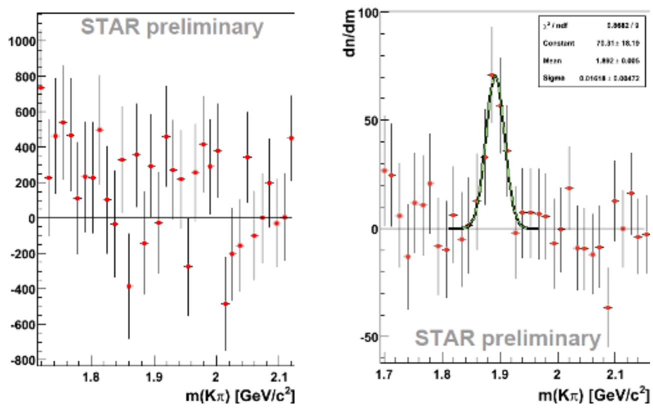

Figure 4: Invariant mass of $K\pi$ pairs in p+p at $\sqrt{s} = 200\ GeV$ for all events (left) and selected by non-photonic electron trigger (right) [9]. Selecting only electron triggered events allows to reduce background by a factor of 100.

The sample of particles selected in the presented way was highly contaminated by photonic electrons which came from neutral meson decays or photon conversions inside the detector. In order to get rid of them for each electron pair the Invariant Mass was calculated and particles for which the obtained value was below 150 MeV/c^2 were rejected. In this way up to 70% of the photonic electrons have been removed.

For events tagged by electrons, selected with the technique described above, the invariant mass method was applied to all $K\pi$ pairs [7, 8]. As a result a D^0 yield was obtained (Fig. 4) and studied in the different azimuthal angle and charge correlation variants. The results shows that charm and beauty contributions are similar as it is presented on Fig. 5 together with PYTHIA and NLO Monte Carlo simulation which have been fitted to the data. The observed effect is also in agreement with the similar analysis done for the electron-hadron correlation and FONLL (Fig. 6).

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 selection (microvertexing) had to be applied in order to reduce the combinatorial background. That method has been 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. More details on the D^0 reconstruction in Au+Au collisions with silicon detectors can be found in [10].

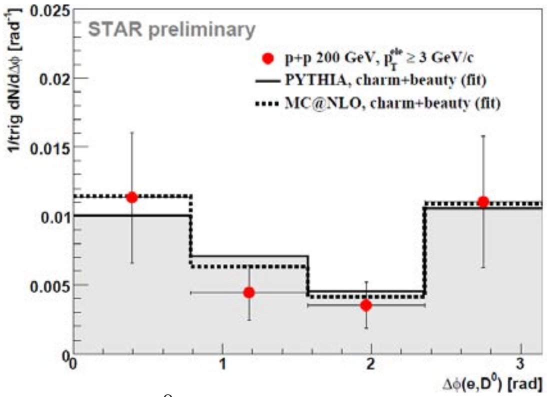

Figure 5: e-D^0 azimuthal angular correlations in p+p collisions at 200 GeV in comparison with PYTHIA and NLO simulations [7, 8].

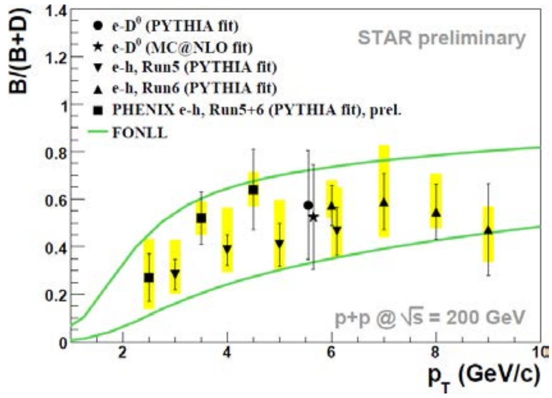

Figure 6: Relative beauty contribution $B/(B + D)$ as a function of trigger electron p_T with a FONLL simulation [7, 8].

Summary

Studies on non-photonic electron yields from heavy flavor semi-leptonic decays at RHIC have shown that R_{AA} exhibits suppression for the high values of p_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. Due to the use of these methods it has been found that in p+p collisions the beauty contribution increases with p_T and becomes comparable to charm contribution around $p_T = 5.5\ GeV/c$. This effect was found to be compatible with the FONLL simulations within the uncertainties. In order to perform a similar analysis in Au+Au collisions 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.

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