New Measurement of Heavy-Flavor Electron v_2 and Separation of Bottom and Charm Using VTX in PHENIX

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Abstract.
Heavy quarks are important probes to understand the properties of the Quark Gluon Plasma (QGP) created in the relativistic heavy-ion collision. The PHENIX measurement of electrons from heavy-flavor decays shows large flow and strong suppression in Au+Au collisions at 200 GeV [1][2], which is not well understood. In these proceedings, we will present both the new PHENIX heavy-flavor electron v_2 results in Au+Au collisions at 62.4 GeV collisions using the Hadron Blind Detector (HBD) and the latest PHENIX measurement of charm and bottom separately in p+p collisions at 200 GeV with the recently installed Silicon Vertex Track (VTX).

1. Introduction

Heavy quarks are hard probes to study the properties of the hot dense matter created in relativistic heavy ion collisions at RHIC because they are produced in parton-parton collisions at the early stage of the reaction, then propagate through and interact with the Quark Gluon Plasma (QGP). Because of their heavy mass, small angle gluon radiation is suppressed when heavy quarks interact with the medium: this is the dead cone effect [3, 4] . Therefore, heavy quarks are predicted to lose less energy by gluon radiation compared to light quarks. However, unexpected large flow and strong suppression of electrons from heavy-flavor meson semi-leptonic decays are observed at PHENIX in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}} = 200$ GeV [1] [2]. These results indicate that heavy quarks are suppressed in a similar way in the QGP compared to light quarks. The energy loss mechanism of heavy quarks is still a puzzle for us to solve.

In 2010, PHENIX took high quality data in Au+Au collision at $\sqrt{s_{\mathrm{NN}}} = 62.4$ GeV. In order to understand the density dependence and the geometrical dependence of the partonic energy loss, we measured heavy-flavor electron azimuthal anisotropy (v_2) at this lower beam energy of 62.4 GeV, where the medium formed in collisions is expected to have a lower energy-density than at 200 GeV.

Additionally, all the previous PHENIX measurements are a mixture of electrons from charm and bottom quarks. Because bottom quarks have much larger mass than charm quarks, they may interact with the medium differently. To separate charm and bottom, an accurate measurement of secondary decay vertex or the distance of closest approach (DCA) is required. The Silicon Vertex Track (VTX) installed in PHENIX in December 2010 makes the separation of charm and bottom possible in the PHENIX experiment.
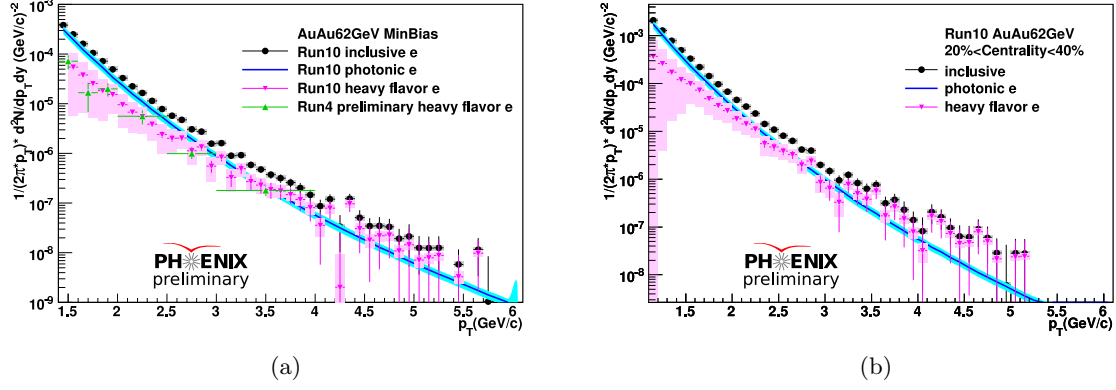
Figure 1. Inclusive, photonic and heavy-flavor electron spectra for (a) MinBias and (b) $20\% < centrality < 40\%$ in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV.

2. Heavy-Flavor Electrons v_2 Measurement in Au+Au Collisions at 62.4 GeV

The PHENIX Central Arm detectors, which cover $|\eta| < 0.35$ and $|\Delta\phi| = \pi$, provide track reconstruction and electron identification for this analysis. In Run-10, the Hadron Blind Detector (HBD) was also installed in PHENIX. The HBD is a windowless Cherenkov detector which is blind for hadrons up to around 4.5 GeV/c. Typically, the photoelectron associated with a single electron is around 20. By carefully tuning the cut on the HBD charge, we can achieve around 90% efficiency for single electrons, while rejecting more than 90% of the background from random matching and conversions that happened at or after the HBD backplane.

After applying all the cuts, the inclusive electrons contain heavy-flavor electrons and photonic electron background. The photonic electron sources include light meson Dalitz decays, photon conversions in the material (e.g. beam pipe, HBD entrance, HBD gas), vector meson decays, Ke3 decays, direct photon decays. The dominant backgrounds come from the π^0 and η Dalitz decay and photon conversions. The ingredients for all relevant background sources are measured and used to produce a cocktail estimate of the photonic background.
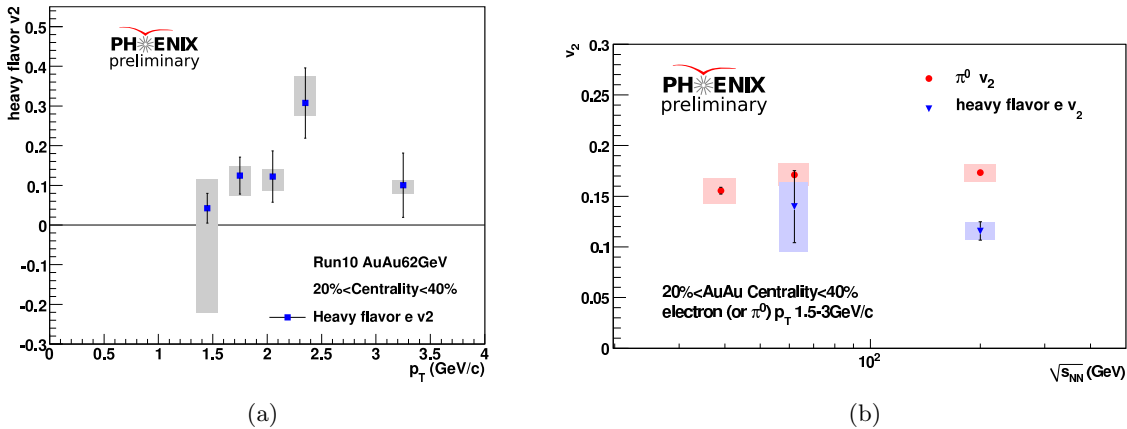

Figure 2. Left panel is the heavy-flavor electron v_2 as a function of p_T for 20%<centrality<40% data set in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. Right panel shows the v_2 for heavy-flavor electrons and π^0 as a function of beam energy at $1.5 < p_T < 3$ GeV/c, $20\% < centrality < 40\%$.

Heavy-flavor electron spectra for MinBias (Figure 1(a)) and centrality $20\% - 40\%$ (Figure 1(b)) data sets are obtained by subtracting the photonic cocktail from the inclusive electron spectra. Figure 1(a) shows a good agreement with PHENIX run4 preliminary results which gives us the confidence that the HBD detector is well understood in the analysis. The heavy-flavor electron v_2 is calculated from the inclusive electron v_2 by subtracting photonic electron v_2 at centrality $20\% - 40\%$ (Figure 2(a)). For $p_T >$1.5GeV/c, the heavy-flavor electron has a nonzero v_2 at 62.4 GeV given the statistical and systematic errors. Comparing the heavy-flavor electron v_2 and π^0 v_2 at 1.5< p_T <3GeV/c, $20\% < centrality < 40\%$ as a function of beam energy at RHIC (Figure 2(b)), we observe the heavy-flavor v_2 at 62.4 GeV is consistent with 200 GeV, and π^0 flow is saturated from 39GeV to 200 GeV. The error bars for heavy-flavor can be further reduced in the future analysis by tuning the HBD cuts to reject pairs of photonic e^+ and e^- that produce a double signal in the HBD.

3. Charm and Bottom Separation Using VTX Detector

The VTX detector was ready to take data in Run2011. The VTX detector has large coverage: $|\eta| <$1.2, $\sim 2\pi$ in azimuth [5]. Due to the fine spatial resolution ($\sim 80\mu$m in Au+Au MB events), the most important capability VTX provides is to measure distance of closest approach (DCA) to separate charm and bottom components of heavy-flavor spectra. DCA is the shortest distance from the track to the primary vertex. Since B mesons have longer life time than D mesons, they have a wider width compared to the DCA distribution of D mesons. The bottom to charm ratio can be obtained by fitting the electron DCA.
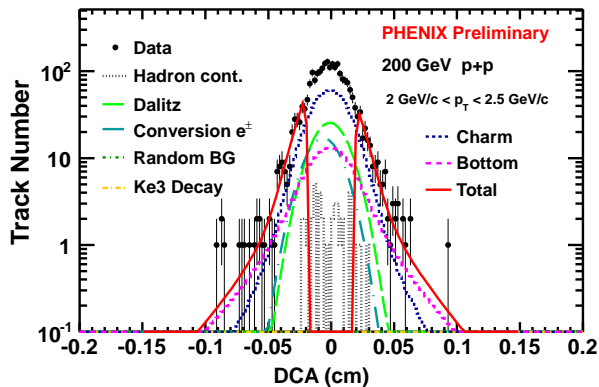

Figure 3. DCA decomposition at electron p_T range 2 to 2.5GeV/c in p+p collisions at $\sqrt{s_{NN}}$ = 200 GeV. The black dots are raw DCA distribution from data. The color curves represent the decomposed contribution from different sources. The total curve in red agrees with the raw DCA shape in the fitting range $0.2 < |DCA| < 1.5$ mm.

Similar to the previous analysis, firstly, the Central Arm electron identification cuts are applied to data to select the inclusive electron candidates. We also require electron candidates to associate with VTX clusters, especially a cluster in the most inner pixel layer to maximally reduce the photon conversions that happen in the VTX. To further reduce the photonic contribution, isolation cuts, i.e. conversion tagging cuts, are applied to each VTX layer to suppress the photonic electrons from Dalitz decay and photon conversions that happen at the beam pipe and the most inner VTX layer. The efficiency of Central Arm cuts and VTX cuts are studied through GEANT simulation.

After surviving all these cuts, the raw DCA is decomposed to different sources to obtain the bottom to charm ratio. Backgrounds in the raw DCA distribution are from hadron contamination, random matching with a VTX cluster, remaining photonic electrons. They can be estimated and subtracted from the raw DCA distribution. In p+p collisions at 200 GeV, the DCA shape of c→e and b→e are studied by GEANT simulation assuming the PYTHIA parent (e.g. D, B) p_T distribution and decay kinematics. Then the DCA distributions are fitted by the background components and the signal components to obtain b→e to c→e ratio at each p_T bin
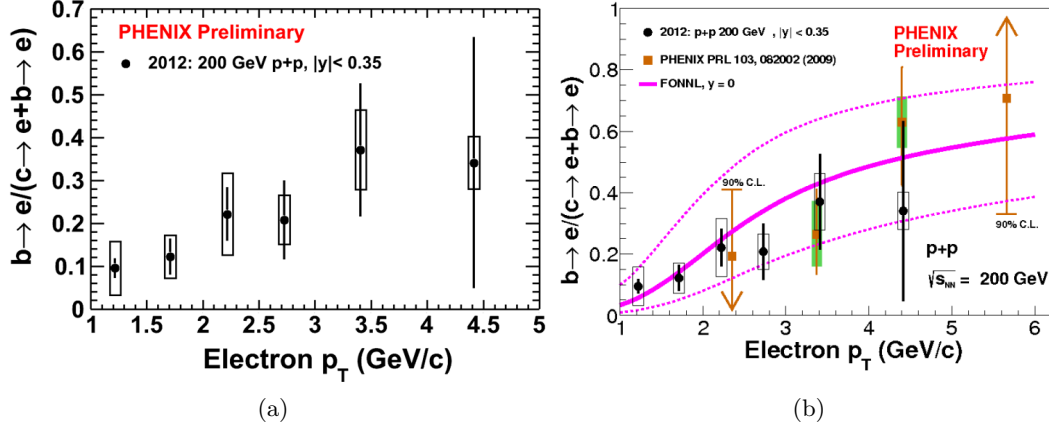
Figure 4. $b \rightarrow e/(b \rightarrow e + c \rightarrow e)$ ratio as a function of electron p_T in p+p collisions at $\sqrt{s_{NN}} = 200$ GeV. The fraction is extracted from the DCA decomposition at each p_T bin assuming PYTHIA D and B parents p_T spectra. The right panel shows a comparison between the $b \rightarrow e/(b \rightarrow e + c \rightarrow e)$ ratio in p+p at $\sqrt{s_{NN}} = 200$ GeV and the FONLL calculation [7].

[5]. Figure 3 shows the raw DCA distribution of electrons and all the signal and background contributions in the raw DCA in the range $2 < p_T^e < 2.5 \text{GeV/c}$ in p+p collisions at 200 GeV.

Figure 4(a) shows the resulting $b \rightarrow e/(b \rightarrow e + c \rightarrow e)$ ratio as a function of p_T^e in p+p $\sqrt{s_{NN}} = 200$ GeV collisions. Figure 4(b) shows that the latest results are consistent with the previous PHENIX measurement [6]. The fixed order plus next to leading log (FONLL) perturbative QCD calculation [7] also agrees with the PHENIX measurements. The first direct measurement of charm and bottom separately by DCA decomposition using VTX detector in p+p collision at RHIC has been achieved.

4. Summary

Heavy-flavor electron flow at $20\% < centrality < 40\%$ is measured in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV in PHENIX. The HBD detector is working well on rejecting background including photon conversions happened at HBD backplane. The 62.4 GeV heavy-flavor electrons have non-zero flow at $p_T > 1.5 \text{GeV/c}$ and v_2 is consistent with the 200 GeV result at $1.5 < p_T < 3 \text{GeV/c}$, given the stated statistical and systematic uncertainties.

Using the VTX detector, the first direct measurement of charm and bottom separately in p+p collision at RHIC has been achieved by an accurate DCA measurement assuming PYTHIA parent meson (D and B) p_T distribution. The FONLL perturbative QCD calculation of $b \rightarrow e/(b \rightarrow e + c \rightarrow e)$ agrees with the p+p data. For the charm and bottom separation in Au+Au collisions, the PHENIX Collaboration has identified different DCA unfolding procedures to properly account for the modification of parent p_T spectra and is actively working towards robust, self-consistent results.

References

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