The azimuthal anisotropy of electrons from heavy flavor decays in $\sqrt{s_{NN}} = 200$ GeV Au-Au collisions by PHENIX

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The transverse momentum dependence of the azimuthal anisotropy parameter $v_2$, the second harmonic of the azimuthal distribution, for electrons at mid-rapidity ($|\eta| < 0.35$) has been measured with the PHENIX detector in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with respect to the reaction plane defined at high rapidities ($|\eta| = 3 - 4$). From the result we have calculated non-photonic electron $v_2$, which is expected to reflect the heavy-flavor azimuthal anisotropy, by subtracting $v_2$ of electrons from other sources such as photon conversions, Dalitz decay etc.

1. Introduction

The azimuthal anisotropy of particle emissions is a powerful tool to study the early stage of ultra-relativistic nuclear collisions. Previous measurements of $v_2$ for light hadrons, such as pions and kaons [1], are consistent with the quark coalescence model [2], which assumes that the $v_2$ of light hadrons comes from their parent quarks. This suggests that the $v_2$ already develops in the partonic phase for hadrons made of light quarks. Heavy flavor $v_2$ measurement will provide important information on the origin of the flow due to the much larger mass.

Heavy quark production is well studied by measuring electrons from their semi-leptonic decays in the PHENIX experiment at RHIC [3] [4]. We have studied the azimuthal anisotropy of heavy flavor by measuring the $v_2$ of electrons from semi-leptonic heavy flavor decays in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

2. Analysis

The inclusive electron sample has two components: (1)“non-photonic” - primarily semi-leptonic decays of mesons containing heavy (charm and bottom) quarks, and (2)“photonic” - Dalitz decays of light neutral mesons ($\pi_0$, $\eta$, $\eta'$, $\omega$ and $\phi$) and photon conversions in the detector material [4]. The azimuthal distribution of electrons ($dN_e/d\phi$) is the sum of the azimuthal distributions of photonic electrons ($dN_{\gamma}/d\phi$) and non-photonic electrons ($dN_{\text{non-}\gamma}/d\phi$):

$$
\frac{dN_e}{d\phi} = \frac{dN_{\gamma}}{d\phi} + \frac{dN_{\text{non-}\gamma}}{d\phi}.
$$

*for the full list of PHENIX authors and acknowledgements, see Appendix ’Collaboration’ of this volume.
From Eq. 1 the non-photonic electron $v_2$ ($v_{2e}^{\text{non-\gamma}}$) is expressed as

$$v_{2e}^{\text{non-\gamma}} = \frac{(1 + R_{NP})v_{2e} - v_{2e}^{\gamma}}{R_{NP}}.$$  \hspace{1cm} (2)

where $v_{2e}$ is the inclusive electron $v_2$, $v_{2e}^{\gamma}$ is the photonic electron $v_2$ and $R_{NP}$ is the ratio of the number of non-photonic electrons to photonic electrons ($N_{e}^{\text{non-\gamma}}/N_{e}^{\gamma}$). We experimentally determined the ratio from analysis of special runs in which a photon converter was installed. The details of the method are described in [4].

The transverse momentum dependence of the inclusive electron $v_2$ measured by the reaction plane method [5] is shown in Fig. 1. The reaction plane is determined by the beam-beam counters and the electrons are identified by the ring imaging Cherenkov counter and the electromagnetic calorimeter. The photonic electron $v_2$ is obtained by two methods: (1) directly from data with and without the converter and (2) Monte Carlo simulation [6]. In the first method, the yield of electron with ($N_{\text{conv-in}} - N_{\text{conv-out}}$) and without the converter can be written as,

$$N_{\text{conv-in}} = R_{\gamma}N_{e}^{\gamma} + N_{e}^{\text{non-\gamma}}$$
$$N_{\text{conv-out}} = N_{e}^{\gamma} + N_{e}^{\text{non-\gamma}}.$$  \hspace{1cm} (3)

where $R_{\gamma}$ is the ratio of the number of photonic electrons with and without the converter. From Eq. 3 the relation between the number of electrons and the values of $v_2$ are given as:

$$N_{e}^{\text{conv-in}}v_{2e}^{\text{conv-in}} = R_{\gamma}N_{e}^{\gamma}v_{2e}^{\gamma} + N_{e}^{\text{non-\gamma}}v_{2e}^{\text{non-\gamma}}$$
$$N_{e}^{\text{conv-out}}v_{2e}^{\text{conv-out}} = N_{e}^{\text{conv-out}}v_{2e}^{\gamma} + N_{e}^{\text{conv-out}}v_{2e}^{\text{conv-out}}.$$  \hspace{1cm} (4)

where $v_{2e}^{\text{conv-in}}$ is inclusive electron $v_2$ measured with the converter and $v_{2e}^{\text{conv-out}}$ is inclusive electron $v_2$ measured without the converter. From the Eq. 4 the photonic electron $v_2$ is given as:

$$v_{2e}^{\gamma} = \frac{(1 + R_{NP})v_{2e}^{\text{conv-out}} - (R_{\gamma} + R_{NP})v_{2e}^{\text{conv-in}}}{1 - R_{\gamma}}.$$  \hspace{1cm} (5)

The photonic electron $v_2$ determined from the first method (open circles) and from the second method (solid line) are shown in Fig. 1. Due to the limited statistics of the runs with the converter, the second method is applied above 1.0 GeV/c in this analysis. From the result the inclusive electron $v_2$ is smaller than the photonic electron $v_2$, which means that the non-photonic electron $v_2$ is smaller than both of them. The transverse momentum dependence of $R_{NP}$ is shown in Fig. 2. Above 1.0 GeV/c more than 50% of electrons come from the non-photonic component.

### 3. Results

The transverse momentum dependence of the non-photonic electron $v_2$ is shown in the Fig. 3. The statistical errors are shown as vertical lines and the 1 $\sigma$ systematic uncertainties are shown as brackets in the figure. Assuming the quark coalescence model, decay electron $v_2$ from $D$ mesons has been predicted [2]. In the model $D$ mesons are
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formed from charm quark coalescence with thermal light quarks at hadronization. For charm quark momentum spectra, two extreme scenarios are considered. The first scenario assumes no reinteractions after the production of charm-anticharm quark pairs in initial state hard processes (calculated from PYTHIA). The second scenario assumes complete thermalization with the transverse flow of the bulk matter. The heavy flavor electron $v_2$ with decay electrons from $D$ mesons in the “no reinteraction” scenario is shown as a solid line, while the “thermalization” scenario is shown as a dashed line in the figure. Below 2.0 GeV/c the non-photonic electron $v_2$ is in good agreement with the electron $v_2$ obtained by assuming charm quark flow.

We also compare the non-photonic electron $v_2$ with the simulation of electron $v_2$ from $D$ meson assuming the shape is proportional to pion $v_2$ as

$$v_2^D(p_T) = av_2^\pi(p_T)$$  \hspace{1cm} (6)\]

here $a$ is a scale factor of the pion $v_2$. We calculate the $v_2$ with several $a$ parameter (30 %, 60 % and 100 %). The comparison of the measured non-photonic electron $v_2$ and the simulation results are shown in the Fig. 4. The solid line is $D$ meson $v_2$ and the open circle plot is decay electron $v_2$. The non-photonic electron $v_2$ seems to prefer the $D$ meson $v_2$ assuming 60 % of the pion $v_2$. It might be suggested that $D$ meson has non-zero $v_2$ and has smaller $v_2$ than the pion.
Figure 3. The transverse momentum dependence of the non-photonic electron $v_2$ and the model prediction with and without charm flow [7].

Figure 4. Electron $v_2$ from $D$ meson assuming the shape is proportional to pion $v_2$.

4. Summary

In this paper we present the methods of measuring non-photonic electron $v_2$ and show the results. We compare our results with two extreme model predictions which assume no charm quark flow or complete thermalization of charm quarks in the medium. Below 2.0 GeV/c the non-photonic electron $v_2$ is in good agreement with the electron $v_2$ obtained by assuming the complete thermalization of charm quarks. In addition, we calculate electron $v_2$ from $D$ meson assuming the shape is proportional to pion $v_2$. The non-photonic electron $v_2$ seems to prefer the $D$ meson $v_2$ assuming 60% of pion $v_2$. It might be suggested that $D$ meson has non-zero $v_2$ but smaller $v_2$ than that of pions.

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