NUKLEONIKA 2006;51(Supplement 3):S33–S35

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

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Abstract 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.

Key words electron • charm quark • elliptic flow

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Received: 30 September 2005
Accepted: 8 May 2006

Introduction

The azimuthal anisotropy of particle emissions is a powerful tool to study the early stage of ultrarelativistic nuclear collisions. Previous measurements of v_2 for light hadrons, such as pions and kaons [2], are consistent with the quark coalescence model [6], 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 [1, 3]. 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.

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 (π^0, η, η', ω and ϕ) and photon conversions in the detector material [3]. 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 ($dN^{\text{non-}\gamma}/d\phi$):

$$\frac{dN_e}{d\phi} = \frac{dN_e^{\gamma}}{d\phi} + \frac{dN_e^{\text{non}-\gamma}}{d\phi} \quad (1)$$

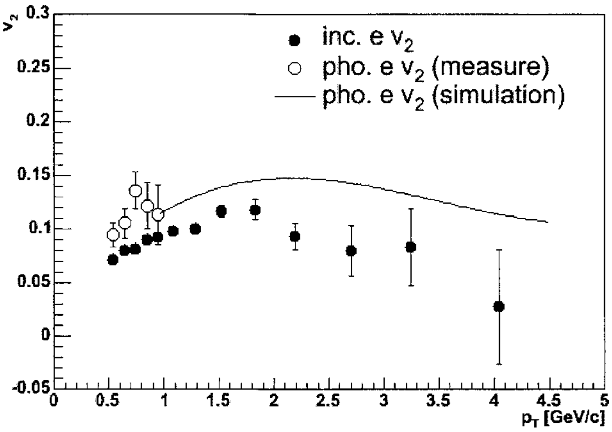

Fig. 1. The transverse momentum dependence of the inclusive electron ν_2 (closed circle) and the photonic electron ν_2 (open circle and solid line).

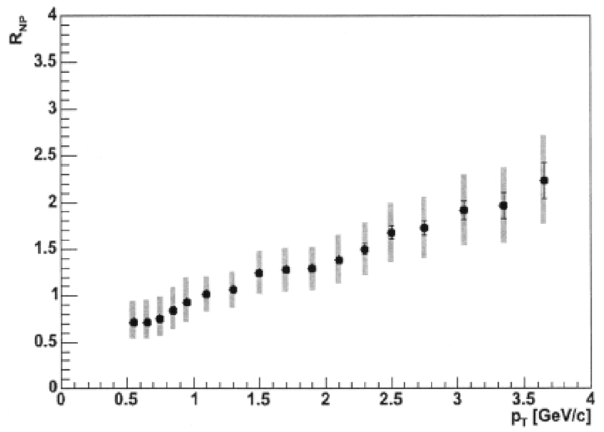

Fig. 2. The transverse momentum dependence of the ratio of the number of non-photonic electrons to photonic electrons ($N_e^{\text{non-}\gamma}/N_e^{\gamma}$).

From Eq. (1), the non-photonic electron ν_2 ($\nu_{2_e}^{\text{non-}\gamma}$) is expressed as

$$\nu_{2_e}^{\text{non}-\gamma} = \frac{\left(1+R_{NP}\right)\nu_{2_e} - \nu_{2_e}^{\gamma}}{R_{NP}} \tag{2}$$

where ν_2 is the inclusive electron ν_2, $\nu_{2_e}^{\gamma}$ is the photonic electron ν_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 the analysis of special runs in which a photon converter was installed. The details of the method are described in [3].

The transverse momentum dependence of the inclusive electron ν_2 measured by the reaction plane method [7] is shown in Fig. 1. The reaction plane is determined by beam-beam counters and the electrons are identified by a ring imaging Cherenkov counter and an electromagnetic calorimeter. The photonic electron ν_2 is obtained by two methods: (1) directly from data with and without the converter and (2) Monte Carlo simulation [4]. In the first method, the yield of electron with ($N_e^{\text{conv-in}}$) and without the converter ($N_e^{\text{conv-out}}$) can be written as,

$$\begin{aligned} N_e^{\text{conv-in}} &= R_\gamma N_e^{\gamma} + N_e^{\text{non-}\gamma} \\ N_e^{\text{conv-out}} &= N_e^{\gamma} + N_e^{\text{non-}\gamma} \end{aligned} \tag{3}$$

where R_γ 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 ν_2 are given as:

$$\begin{aligned} N_e^{\text{conv-in}}\nu_2^{\text{conv-in}} &= R_\gamma N_e^{\gamma}\nu_{2_e}^{\gamma} + N_e^{\text{non-}\gamma}\nu_{2_e}^{\text{non-}\gamma} \\ N_e^{\text{conv-out}}\nu_2^{\text{conv-out}} &= N_e^{\gamma}\nu_{2_e}^{\gamma} + N_e^{\text{non-}\gamma}\nu_2^{\text{non-}\gamma} \end{aligned} \tag{4}$$

where: $\nu_{2_e}^{\text{conv-in}}$ is inclusive electron ν_2 measured with the converter and $\nu_{2_e}^{\text{conv-out}}$ is inclusive electron ν_2 measured without the converter. From Eq. (4), the photonic electron ν_2 is given as:

$$\nu_{2_e}^{\gamma} = \frac{\left(1+R_{NP}\right)\nu_{2_e}^{\text{conv-out}} - \left(R_\gamma + R_{NP}\right)\nu_{2_e}^{\text{conv-in}}}{\left(1-R_\gamma\right)} \tag{5}$$

The photonic electron ν_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 ν_2 is smaller than the photonic electron ν_2, which means that the non-photonic electron ν_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.

Results

The transverse momentum dependence of the non-photonic electron ν_2 is shown in Fig. 3. The statistical errors are shown as vertical lines and the 1σ systematic uncertainties are shown as brackets in the figure. Assuming the quark coalescence model, decay electron ν_2 from D mesons has been predicted [5]. In the model D mesons are formed from charm quark coalescence with thermal light quarks at hadronization. For charm quark momentum spectra, two extreme scenarios are

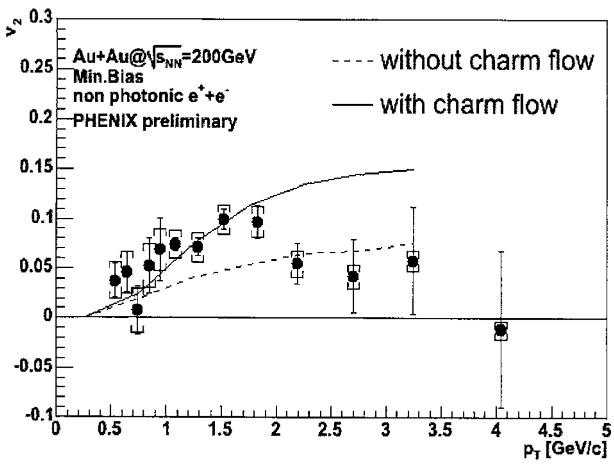

Fig. 3. The transverse momentum dependence of the non-photonic electron ν_2 and the model prediction with and without charm flow [5].

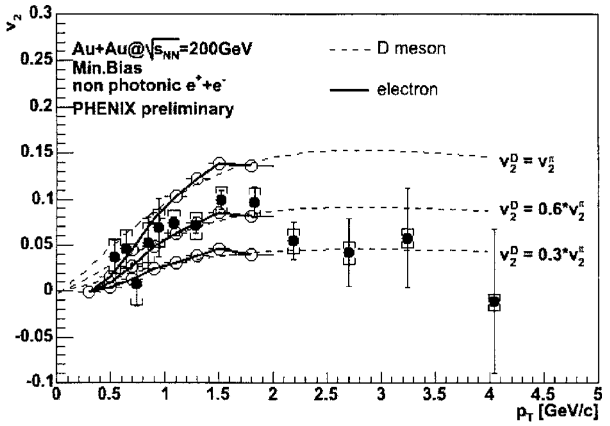

Fig. 4. Electron v_2 from D meson assuming the shape is proportional to pion v_2.

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 [2] as

$$v_2^D(p_T) = a v_2^\pi(p_T) \tag{6}$$

here a is a scale factor of the pion v_2. We calculate the v_2 with several a parameter (30%, 60% and 100%). A comparison of the measured non-photonic electron v_2 and the simulation results are shown in 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.

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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