Di-electron elliptic flow in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions at STAR

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Abstract. In minimum-bias (0-80%) Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, the elliptic flow ($v_2$) measurements of di-electrons for the low mass region ($M_{ee} < 1.1$ GeV/$c^2$) are presented. The differential $v_2$ as a function of transverse momentum in different mass regions are also reported. The simulated and measured $v_2$ of di-electrons are compared in the low mass region.

1. Introduction

Ultra-relativistic heavy ion collisions provide a unique environment to study the properties of strongly interacting matter at high temperature and high energy density [1]. Di-leptons constitute one of the crucial probes of this strongly interacting matter because they are not affected by the strong interaction once produced. In the low mass region of produced lepton pairs ($M_{ll} < 1.1$ GeV/$c^2$), we can study the vector meson in-medium properties through their di-lepton decays, where any modifications observed may be related to the possibility of chiral symmetry restoration. In the intermediate mass region ($1.1 < M_{ll} < 3.0$ GeV/$c^2$), the di-lepton spectra are directly related to the thermal radiation of Quark-Gluon Plasma (QGP) [2, 3]. However, other sources significantly contribute in this mass region, such as $c\bar{c} \rightarrow l^+l^-X$ or $b\bar{b} \rightarrow l^+l^-X$ [4].

Elliptic flow ($v_2$) is generated in the early stage of heavy-ion collisions, via the transformation of the initial spatial eccentricity of the nuclear overlap region into momentum anisotropy through the action of azimuthally anisotropic pressure gradients [5]. Di-leptons, which escape from the expanding fireball with minimum interaction, will be able to probe specifically this early stage where the $v_2$ first develops. It has been proposed that transverse momentum ($p_T$) and $M_{ll}$ dependence of $v_2$ of di-leptons could provide very rich information on specific stages of the fireball expansion, distinguishing partonic and hadronic radiation sources [5].

At STAR, the newly installed Time-of-Flight detector (TOF) which covers $|\eta| < 0.9$ and with complete azimuthal coverage ($\Delta \phi = 2\pi$), offers large acceptance and high efficiency for particle identification [6]. The TOF, combined with the measurements of the ionization energy loss ($dE/dx$) from the Time Projection Chamber (TPC) [7, 8, 9], enables the electron identification with high purity from low to intermediate $p_T$ [9, 10, 11, 12]. In this article, we present the $M_{ee}$, $p_T$, and centrality dependence of di-electron elliptic flow in $\sqrt{s_{NN}} = 200$ GeV Au+Au collisions at STAR.
2. Data analysis and results
The TPC is the primary tracking device at STAR which provides the $dE/dx$, momentum, and path-length measurements of particles produced in the collision. The $dE/dx$ is used for particle identification [8, 9]. The TOF measures the particles’ time of flight from their decay vertex to a matched hit in the TOF detector. Combined with a path-length measurement, the particle velocity ($\beta$) extends the identification of $\pi$ and $K$ up to 1.6 GeV/c and the proton to 3 GeV/c in momentum [10, 11]. We utilize 720 million minimum-bias (0-80% top centrality) Au+Au collisions taken in years 2010 and 2011 with full TOF system coverage. In these events, primary z-vertex position is required to be within $\pm 30$ cm, which is the distance from the center of the detector. With the $\beta$ and $p_T$ dependent $dE/dx$ cuts for $p_T > 0.2$ GeV/c and $|\eta|<1$, electrons can be clearly identified from low to intermediate $p_T$. The purity of electron candidates is about 97% in minimum-bias Au+Au collisions.

The $e^+$ and $e^-$ candidates from the same events are combined to reconstruct the invariant mass distributions ($M_{ee}$) marked as unlike-sign distributions, which contain both signal and background. The background contains random combinatorial, and other correlated pairs. We use two methods to estimate the background: same-event like-sign and mixed-event unlike-sign techniques. In the same-event like-sign technique, electron candidates from the same event with same charge sign are combined. In the mixed-event technique, unlike-sign electron candidates from different events are combined. In the mixed-event technique, the event used to mix must be in the same centrality bin, vertex $z$-coordinate bin and event plane angle bin. We divide the centrality into 9 bins, vertex-$z$ into 10 bins, and event plane angle into 100 bins so that the events used to mix have a similar structure. In the mass region $M_{ee} < 0.7$ GeV/$c^2$, we subtract the like-sign background. In the mass region $M_{ee} > 0.7$ GeV/$c^2$, we subtract the unlike-sign mixed-event background: since the like-sign and mixed-event background distributions are consistent for the higher mass region ($M_{ee} > 0.7$ GeV/$c^2$), we use mixed-event background for better statistics.

![Figure 1](image_url)

**Figure 1.** (left panel) The di-electron $v_2$ as a function of $M_{ee}$ for Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions. The circles represent the $v_2$ of unlike-sign pairs ($v_2^U$). The triangles represent the $v_2$ of background pairs ($v_2^B$). (right panel) Ratio = $N_S/N_{S+B}$ as a function of $M_{ee}$ for Au+Au $\sqrt{s_{NN}} = 200$ GeV collisions.

We use the event-plane method to calculate the $v_2$ of the di-electron signal. The event-plane is reconstructed using tracks from the TPC. The details of the method are in Refs. [13, 14]. The di-electron signal $v_2$ can be obtained by using the following two formulas:

$$v_2^S \times \frac{N_S}{N_{S+B}} = v_2^T - v_2^B \times (1 - \frac{N_S}{N_{S+B}}), \tag{1}$$
\[ v_2 = \langle \cos(2(\phi_i - \psi_2))/r_j \rangle, \]  

where \( v_2^T \) is the \( v_2 \) of the signal+background, \( v_2^S \) is the di-electron signal \( v_2 \), \( v_2^B \) is the background \( v_2 \), and we use the formula (2) to calculate \( v_2^T \) and \( v_2^S \) which are shown in the left panel of Fig.1. \( N_S/N_{S+B} \) is the ratio of signal over signal+background shown in the right panel of Fig. 1. We use the sub-event method to calculate \( r_j \) which is the resolution of event-plane in centrality \( j \), and \( \phi_i \) is the di-electron pair angle, and \( \psi_2 \) is the event-plane angle. Angle brackets denote averages over all di-electron pairs in all events. In each mass bin, with the \( v_2^T \), \( v_2^B \), and \( N_B/N_{S+B} \), we calculate the \( v_2^S \) by the Eqn. (1).

**Figure 2.** (left panel (a)) The di-electron \( v_2 \) as a function of \( M_{ee} \). The star symbol is the measured di-electron \( v_2 \). The line shape is the simulated di-electron \( v_2 \). (right panels (b-e)) The \( v_2 \) of di-electron as a function of \( p_T \) for different mass regions. The star symbol is for the measured results. The dashed curve is for the simulated results. The charged pion \( v_2 \) [15] and neutral pion \( v_2 \) [16] are also shown in panel (b) for comparison. The error bars and the band represent statistical and systematic uncertainties, respectively.

Figure 2 shows the di-electron \( v_2 \) as a function of \( M_{ee} \) (left panel) and \( v_2 \) as a function of \( p_T \) in different mass regions (right panels) in minimum-bias Au+Au collisions at \( \sqrt{s_{NN}} = 200 \) GeV. The star symbol is the measured di-electrons \( v_2 \). The line shapes are the simulated cocktail \( v_2 \). The components of the cocktail are \( \pi^0 \), \( \eta \), \( \omega \) and \( \phi \). We assume that the \( \eta \) has the same \( v_2 \) as \( K_S^0 \) [14] because the value of their mass are nearly the same, and also assume the \( \omega \) \( v_2 \) same as the \( \phi \) \( v_2 \). For each component, we parameterize its \( v_2 \), simulate its two body or Dalitz decays, and obtain di-electron \( v_2 \) from its decay. The cocktail \( v_2 \) is obtained by combining the di-electron \( v_2 \) from each component, which are weighted by their yields. The cocktail \( v_2 \) is consistent with the measured \( v_2 \) as a function of \( M_{ee} \) as well as \( p_T \). The consistency between the simulation and measurements demonstrates the credibility of our method to obtain the di-electron \( v_2 \).

The left panel of Fig. 3 shows the \( p_T \) dependent \( v_2 \) of di-electrons in the mass region of \( 0.98 < M_{ee} < 1.06 \) GeV/c\(^2\), which is consistent with the measured \( v_2 \) of \( \phi \) meson through the \( K^+K^- \) decays [17]. The simulated cocktail \( v_2 \) is also consistent with the measured \( v_2 \). The right panels of Fig. 3 shows the centrality dependence of di-electron \( v_2 \) for the mass region \( M_{ee} < 0.14 \) GeV/c\(^2\). In this mass region, the \( \pi^0 \) Dalitz decay contribution dominates. We parameterize \( \pi^0 \) \( v_2 \) from low to high \( p_T \) [16, 18], do the \( \pi^0 \) Dalitz decay, and obtain the simulated di-electron \( v_2 \) from \( \pi^0 \) Dalitz decay shown by the dashed curve. In each centrality interval, the measured di-electron \( v_2 \) is consistent with the simulated di-electron \( v_2 \).

### 3. Summary

Measurements of the di-electron \( v_2 \) are presented as a function of \( M_{ee} \) and \( p_T \) for the low mass regions in minimum-bias Au+Au \( \sqrt{s_{NN}} = 200 \) GeV collisions. The \( v_2 \) of di-electrons in different
mass regions is in agreement with the expectations from previous measurements. For $M_{ee} < 0.14$ GeV/$c^2$, there is a good agreement between the measured and the simulated di-electron $v_2$ for each centrality interval.

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