Dielectron differential cross section in Au+Au collisions at different beam energies at STAR

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Abstract

Dielectron invariant mass spectra have been measured at mid-rapidity by the STAR experiment at RHIC in Au+Au collisions at $\sqrt{s_{NN}}$=19.6, 39, 62.4, and 200 GeV. The spectra exhibit excess yields for $M_{ee} < 1.0$ GeV/c^2, when compared to the expected contributions from known hadronic sources. The enhanced production rates can be consistently described by a broadened ρ spectral function. In addition, the elliptic flow, v_2, has been measured for dielectron invariant mass $M_{ee} <$ 1.1 GeV/c^2 in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV.

1. Introduction

A hot and dense medium can be created in heavy-ion collisions at the Relativistic Heavy Ion Collider (RHIC). One of the important physics goals at RHIC is to study the properties of this medium using dileptons. Leptons originate from all stages of the collision and, once produced, do not undergo strong interaction with the medium. Hence, lepton pairs are excellent candidates to probe the entire space-time evolution of the medium. The dominant dilepton sources in the low mass range (LMR) at $M_{ll} < 1.1$ GeV/c^2 are vector mesons, including ρ, ω, ϕ. The in-medium modifications of vector mesons can be directly accessed by means of their dilepton decay channels. The modifications of their spectral functions may provide a possible link to chiral symmetry restoration [1]. As an additional observable, the differential measurements of dilepton elliptic flow provide very rich information on the fireball evolution and the dilepton radiation sources. Elliptic flow is generated in the early stage of heavy-ion collisions and develops in the expanding fireball due to the initial spatial eccentricity of the nuclear overlap region [2]. Thus, the measured elliptic flow could disentangle the components of dilepton sources.

In this paper, we present the measurements of dielectron production in Au+Au collisions at beam energies from 19.6 to 200 GeV at STAR, taking advantage of the newly installed full barrel Time-of-Flight detector (TOF) [3]. The centrality dependence of dielectron production, as well as the mass dependence of dielectron elliptic flow, v_2, in Au+Au collisions at 200 GeV are also presented.

2. Analysis

The data were taken from the RHIC runs of 2010-2011. The analysis is based on two subdetectors of the STAR detector system [4], namely the Time Projection Chamber (TPC) [5] and the Time-Of-Flight detector (TOF) each with 2π azimuthal coverage at mid-rapidity. The TPC

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measures track momentum and ionization energy loss (dE/dx) in the TPC gas for the purpose of particle identification. The dE/dx of electrons overlaps with slow π, K, and protons at momenta $p < 1$ GeV/c. The TOF provides track velocity information, and enables us to separate the slow hadrons from electrons. Combining TPC dE/dx and TOF velocity information, we can select clean electron candidates [6]. An electron purity of > 95% is reached in Au+Au analyses.

The dielectron foreground is reconstructed through the combination of e^+ and e^- candidates within the same events. The background is reconstructed using like-sign and mixed-event techniques. In the like-sign technique, the same-charged electrons are combined into pairs within the same events. The mixed-event technique picks up two electron candidates from different events with similar vertex positions, event plane angles, and charged-particle multiplicities. The like-sign technique can reproduce correlated cross pair background well in LMR, but suffers from limited statistics in the higher mass region. The mixed-event technique, on the other hand, allows for the generation of basically unlimited statistics but can only reproduce the combinatorial background. We subtract the like-sign background in the low mass region, and the mixed-event background at higher invariant masses. The mixed-event background subtraction range is chosen as $M_{ee} > 0.9$ GeV/c^2 for 39 and 62.4 GeV, and $M_{ee} > 0.75$ GeV/c^2 for 200 GeV. At 19.6 GeV, we subtract like-sign background in the full mass range. The acceptances of the like-sign and unlike-sign pairs are slightly different due to acceptance gaps in the detector system. The like-sign background spectra are corrected for this acceptance difference and then subtracted from the foreground spectra. The final dielectron production is measured within the STAR acceptance ($p_T^e > 0.2$ GeV/c, $|\eta_e| < 1$ for 19.6 and 200 GeV, $|\eta_e| < 0.9$ for 39 and 62.4 GeV, $|y_{ee}| < 1$) and corrected for efficiency losses.

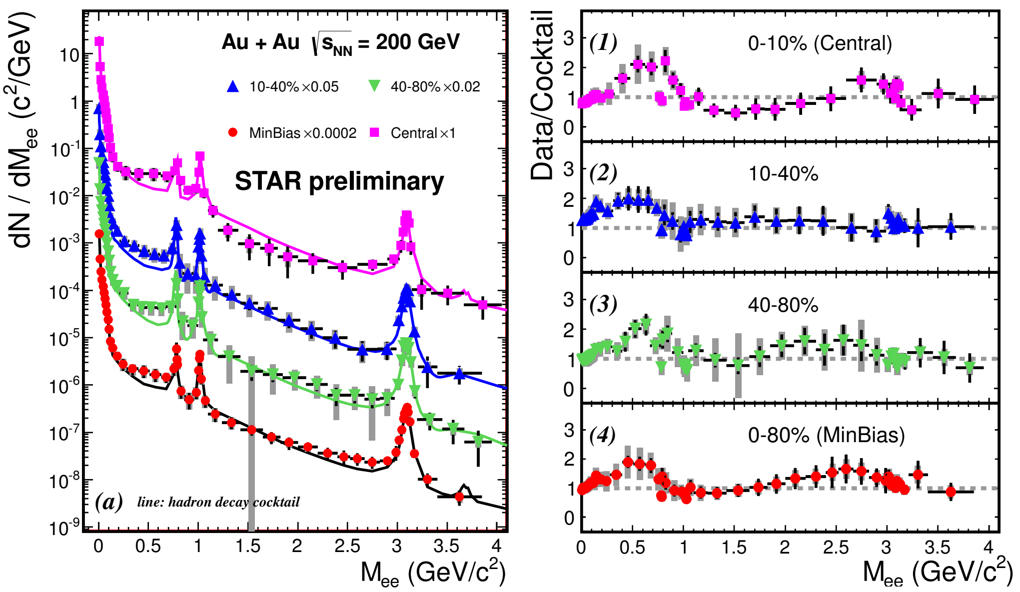

Figure 1: (Color online) Centrality dependence of dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$= 200 GeV. The left panel shows the mass spectra compared to hadronic cocktails, and the right panel depicts the ratios of data to cocktail [7]. Systematic uncertainties are represented by boxes.

3. Results

The invariant mass spectra for various centralities in collisions at $\sqrt{s_{NN}}$=200 GeV are shown in Fig. 1. The spectra for centrality bins 10-40% and 40-80% complement the results already presented in [8]. The hadronic cocktail consists of Dalitz decays: $\pi^0, \eta, \eta' \rightarrow \gamma e^+e^-$, $\omega \rightarrow \pi^0 e^+e^-$, $\phi \rightarrow \eta e^+e^-$, direct dielectron decays: $\omega, \rho^0, \phi, J/\psi \rightarrow e^+e^-$, semi-leptonic decays of heavy flavor hadrons: $c\bar{c}, b\bar{b} \rightarrow e^+e^-X$, and Drell-Yan processes. $b\bar{b} \rightarrow e^+e^-X$ and Drell-Yan processes are not included in the analyses at 19.6, 39, and 62.4 GeV due to their cross sections being negligible at these beam energies. The $c\bar{c} \rightarrow e^+e^-X$ component is not included in the 19.6 GeV cocktail spectra. The analyses at 39 and 62.4 GeV do not evaluate the contribution of η'. The $c\bar{c}$ components are simulation results in p+p collision scaled by number of binary collisions in Au+Au.

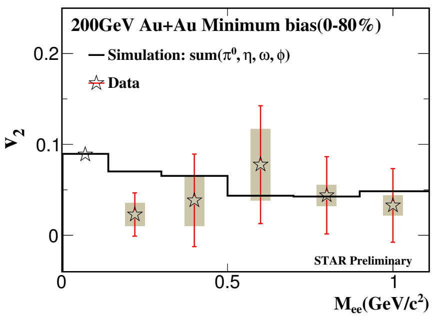

Figure 2: Invariant mass dependence of elliptic flow v_2 of dielectrons in Au+Au collisions at $\sqrt{s_{NN}}$=200 GeV [9]. Vertical error bars denote statistical errors, and boxes are systematic uncertainties.

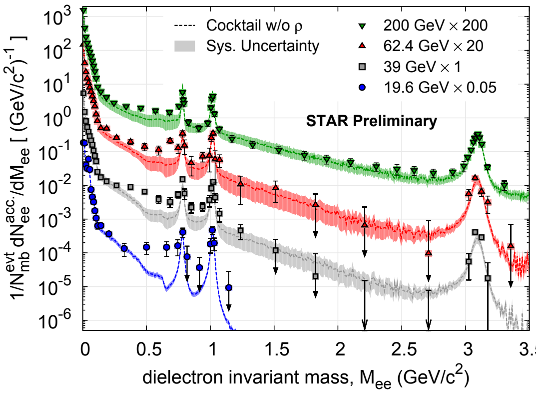

Figure 3: (Color online) Dielectron production in Au+Au minimum bias collisions (0-80%) at $\sqrt{s_{NN}}$=19.6, 39, 62.4, and 200 GeV within STAR acceptance [11, 12]. The colored bands denote systematic uncertainties due to uncertainties in the hadronic yields.

Figure 2 shows the invariant mass dependence of dielectron v_2. Experimental data is based on the integrated yields in the respective invariant mass bins. The simulated v_2 is derived from azimuthal distributions of the dielectron decayed mother particles (π^0, η, ω, and ϕ). The mother particles' v_2 are taken from previous measurements [10]. As a result, the measured dielectron v_2 is consistent with our simulated v_2 within the given uncertainties.

The inclusive dielectron mass spectra in Au+Au collisions from 19.6 to 200 GeV are shown in Fig. 3. All the cocktails do not include contributions due to ρ meson decays. The vacuum ρ contribution clearly fails to describe the excess in LMR [13]. The comparison of data and cocktail suggests that the ρ spectral function undergoes in-medium modifications in Au+Au collisions at 19.6, 39, 62.4, and 200 GeV.

Such an extensive measurement of dielectron production over a wide range of beam energies allows for the systematic comparison to theoretical model calculations. The scenario of a broadened ρ spectral function [1] is currently favored in order to describe the CERES [13] and especially the dimuon results from NA60 [14]. The underlying model incorporates finite temperature effects into ρ self-energy corrections through resonant baryonic and mesonic interactions as well as pion-cloud polarization. The resulting broadened ρ spectral function is integrated over a cylindrical fireball expansion to obtain the pair production rates. Our results in Au+Au collisions

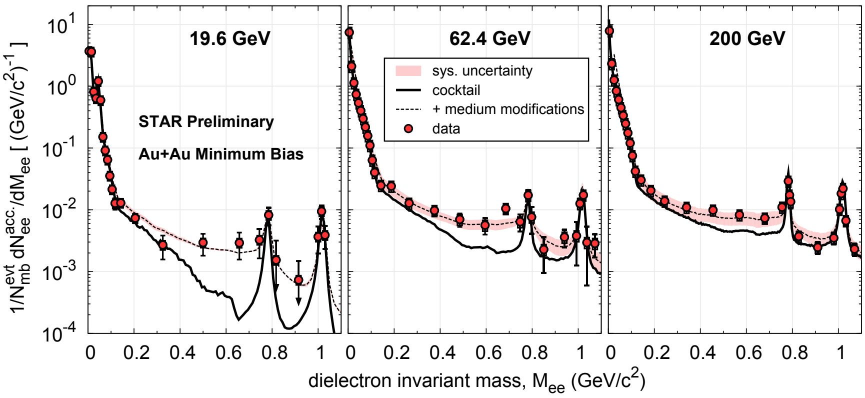

Figure 4: Comparisons of dielectron mass spectra to in-medium ρ spectral functions at $\sqrt{s_{NN}}$=19.6, 62.4, and 200 GeV [11, 12, 15]. The dashed curve shows the sum of theoretical calculation and hadronic cocktail. The bands are systematic uncertainties.

at 19.6, 62.4 and 200 GeV are compared to this model, shown in Fig. 4. The enhanced dielectron rates in the LMR can be consistently described by the broadened ρ spectral function scenario in Au+Au collisions from 19.6 to 200 GeV. This is suggestive of a partial chiral symmetry restoration possibly happening in heavy ion collisions at these energies.

4. Summary

STAR has measured dielectron production in Au+Au collisions at $\sqrt{s_{NN}}$=19.6, 39, 62.4, and 200 GeV. The centrality dependence of the LMR enhancement are measured at 200 GeV. Within systematic and statistical uncertainties dielectron elliptic flow v_2 is consistent with the simulated flow caused by known hadronic sources. The LMR enhancement in Au+Au collisions from SPS up to top RHIC energies can be consistently described via the scenario of a broadened ρ spectral function.

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