Low-p_T $\mu^+\mu^-$ pair production in Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV at STAR

Jian Zhou[1,2,*](for the STAR collaboration)

[1]Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China
[2]State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei 230026, China

Abstract. We report the measurements of $\mu^+\mu^-$ pair production for $p_T < 0.10$ GeV/c in 40-80% Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV at STAR. A significant enhancement with respect to the hadronic cocktail is observed. The p_T^2 and $\Delta\phi$ distributions of the excess yields are also reported and compared with model calculations. The EPA-QED calculations can describe the data very well within uncertainties.

1 Introduction

Dileptons are produced in the whole evolution of the heavy-ion collisions and escape with minimum interaction with the strongly interacting medium. Thus, dilepton measurements play an important role in the study of hot and dense nuclear matter produced in Relativistic Heavy Ion Collider (RHIC) [1, 2]. Recently, significant enhancements of e^+e^- pair at very low transverse momentum (p_T) were observed by the STAR collaboration in peripheral Au+Au collisions [3]. The excess can be explained by photon-photon interactions induced by the extremely strong electromagnetic field produced by the fast moving heavy ions. While such photon-photon interactions were traditionally studied in ultra-peripheral collisions without any nuclear overlaps [4–6], they could provide a novel probe to the Quark Gluon Plasma (QGP) created in peripheral collisions since the very-low-p_T dileptons are produced in the early stage of the collisions [7]. Recently, linearly polarized photon-photon collisions were realized that it will lead to cos($2\Delta\phi$) and cos($4\Delta\phi$) angular distribution which is related to vacuum birefringence [8–11]. The $\Delta\phi$ is defined as $\Delta\phi = \phi_{l^+ + l^-}$ - $\phi_{l^+ - l^-}$, where $\phi_{l^+ + l^-}$ and $\phi_{l^+ - l^-}$ are the azimuthal angle of the l^+l^- pair and azimuthal angle difference between l^+ and l^-, respectively. A fourth-order angular modulation has been observed from the measurements of e^+e^- pair production by STAR collaboration [12]. From model calculation in Ref. [9, 10], the cos($2\Delta\phi$) modulation would vanish from dielectron channel, while the cos($2\Delta\phi$) modulation will still be observed through the measurements of dimuon pair production. Measurements of $\mu^+\mu^-$ pair provide a complementary channel to investigate these phenomena and constrain the photon interaction in heavy-ion collisions.

In this proceeding, we will present invariant mass distributions of $\mu^+\mu^-$ pair production at $p_T < 0.10$ GeV/c, as well as p_T distributions. The p_T^2 and $\Delta\phi$ distributions of the excess yields will also be shown. Theoretical calculations [13–15] will be compared with data.

*e-mail: zj1994@mail.ustc.edu.cn

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2 Experiment and analysis

Data are collected by the STAR in the year 2014 and about 800 million Au+Au minimum-bias (MB) good events have been used. In this analysis, the main sub-detectors used are the Time Projection Chamber (TPC) [16] and the Time of Flight (TOF) [17] detectors. The TPC is the main detector for tracking , and it can also measure the ionization energy loss (dE/dx) to provide particle identification. The TOF is used to identify particles by measuring the velocity. By combining the TPC and TOF, the muon can be identified at low momentum. The like-sign technique is used to estimate the combinatorial background, while the mixed-event technique is used to correct for the acceptance difference effect. After subtracting background from unlike-sign distribution, the raw signal can be obtained. Then the raw signal will be corrected for the detector inefficiency. Finally, a Monte-Carlo simulation is applied to evaluate the hadronic cocktail contribution [3].

3 Results and discussion

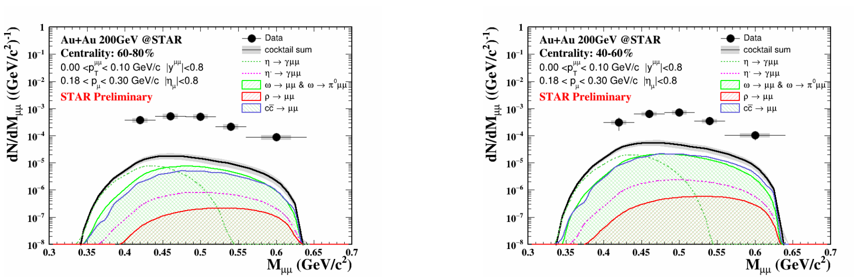
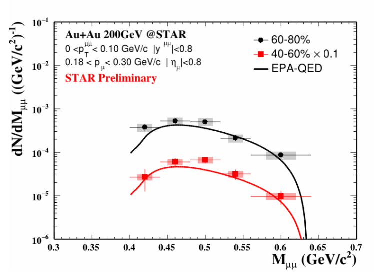


Figure 1: (color online) The $\mu^+\mu^-$ invariant mass spectra in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV for pair p_T < 0.10 GeV/c in different centrality bins compared to the hadronic cocktail. The vertical bars on data points depict the statistical uncertainties and the systematic uncertainties are shown as gray boxes. Left: 60-80% centrality bins. Right: 40-60% centrality bins.

Figure 1 shows the $\mu^+\mu^-$ invariant mass spectra with the fiducial acceptance (0.18<p_μ<0.30 GeV/c, $|\eta_\mu|$<0.8, $|y^{\mu\mu}|$<0.8) in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV for pair p_T < 0.10 GeV/c for 60-80% (left panel) and 40-60% (right panel) centrality bins, respectively. The invariant mass concentrates between 0.4 and 0.64 GeV/c^2 and a significant enhancement is observed with respect to the hadronic cocktail. The enhancement factor for centrality 60-80% is larger than that in semi-peripheral (40-60%) collisions. As shown in Fig. 2, the $\mu^+\mu^-$ excess mass spectra (data - cocktail) can be obtained after removing the hadronic cocktail contribution from the inclusive pair production at very low p_T (p_T < 0.10 GeV/c). Several theoretical calculations of lepton pair (l^+l^-) production from coherent photon-photon interactions in hadronic Au+Au collisions have been proposed in Ref. [15]. The excess yields are found to be consistent with EPA-QED calculations [15] within uncertainties in different centrality bins.

Figure 3 shows the p_T distributions of $\mu^+\mu^-$ pair in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV for mass region between 0.4 and 0.64 GeV/c^2 in different centrality bins. The significant enhancement is found to concentrate below $p_T \approx$ 0.10 GeV/c. When p_T > 0.10 GeV/c, the hadronic cocktail can describe the data reasonably. The enhancement at low p_T is the evidence of photon production in hadronic heavy-ion collisions from the measurements of

Figure 2: (color online) The $\mu^+\mu^-$ excess mass spectra (data - cocktail) in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV for pair p_T < 0.10 GeV/c in different centrality bins compared to the model calculations.



the dimuon channel. Two types of theoretical models in Ref. [15] are also compared to the results. In order to ensure the yields of data and model calculations are consistent in the same acceptance, these models are multiplied by a scale factor. The EPA-QED calculation is compatible with the data at very low p_T (p_T < 0.10 GeV/c), while the EPA calculation [15] can not describe the data very well.

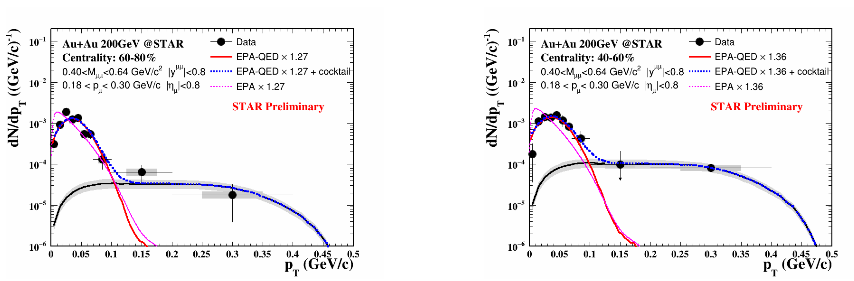


Figure 3: (color online) The p_T distributions of $\mu^+\mu^-$ pair in Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV for mass region between 0.4 and 0.64 GeV/c^2 in different centrality bins compared to the model calculations. The gray bands depict the systematic uncertainties of the cocktails. Left: 60-80% centrality bins. Right: 40-60% centrality bins.

Figure 4 shows the p_T^2 distribution of excess yield in the mass region of 0.40-0.64 GeV/c^2 in Au+Au collisions for 60-80% centrality bin. The EPA and EPA-QED calculations are also shown in Fig. 4 as dotted and solid lines respectively. The EPA-QED curve can describe the data very well, while the EPA calculation overshoots the data at low p_T^2. The $\sqrt{< p_T^2 >}$, which characterizes the p_T broadening, is also calculated for both data and theoretical calculations. The p_T broadening is consistent with EPA-QED calculation within uncertainties.

Figure 5 shows the acceptance-corrected $\Delta\phi$ distribution of excess yield in the mass region of 0.40-0.64 GeV/c^2 for pair p_T < 0.10 GeV/c in 60-80% collisions. EPA-QED calculation is also drawn in this plot. $\Delta\phi$ distributions are fit to a function which is shown as formula in Fig. 5, where C is a constant, $A_{2\Delta\phi}$ represents the magnitude of cos(2$\Delta\phi$) modulation and $A_{4\Delta\phi}$ represents the magnitude of cos(4$\Delta\phi$) modulation. The cos(4$\Delta\phi$) modulation is observed with 3.3σ significance which is consistent the measurements of dielectron channel in Ref. [12]. The cos(2$\Delta\phi$) modulation is observed with 2.3σ significance.

4 Summary

In summary, we present the first measurements of photo-produced $\mu^+\mu^-$ pair production at very low p_T in non-central Au+Au collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV. The observed excess is

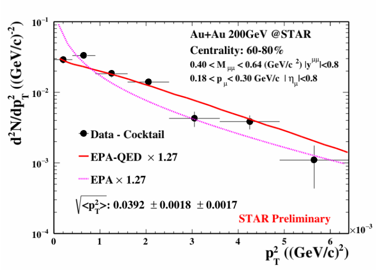


Figure 4: (color online) The p_T^2 distribution of excess yield in the mass region of 0.40-0.64 GeV/c^2 compared to the model calculations in 60-80% collisions.

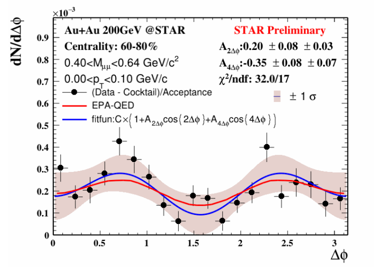


Figure 5: (color online) The $\Delta\phi$ distribution of excess yield in the mass region of 0.40-0.64 GeV/c^2 in 60-80% collisions very-low-p_T ($p_T < 0.10$ GeV/c).

found to concentrate below about $p_T \approx 0.10$ GeV/c which is consistent with EPA-QED calculations. The p_T^2 distribution in mass region of 0.4-0.64 GeV/c^2 is also presented and compared with model calculations. The broadening of p_T distribution shows agreement with EPA-QED calculation within uncertainties. The observation of a 3.3σ 4th-order azimuthal angular modulation is consistent with the measurements of dielectron channel. The 2nd-order azimuthal angular modulation with 2.3σ is indicated to exist in heavy-ion collisions.

Acknowledgments

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