Very low p_{T} dimuon production in peripheral Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV at STAR

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We present the recent measurements of very low transverse momentum (p_{T}) dilepton and J/ψ production in peripheral Au+Au collisions via the $\mu^+\mu^-$ channel by the STAR experiment. Significant J/ψ and $\mu^+\mu^-$ enhancements are observed at very low p_{T} compared to the expectation of hadronic production. The comparison to model calculations is presented, and its physics implications are discussed.

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1. Introduction

In relativistic heavy-ion collisions, ultra-strong electromagnetic (EM) fields are induced by incoming ions at the very early stages of the collision and can generate various QED and QCD related phenomena. The strong EM field can be represented by a flux of quasi-real photons [1, 2] leading to photon-induced interactions [3, 4]. While such interactions are traditionally studied in ultraperipheral collisions (UPCs) without any nuclear overlap, a significant enhancement of dilepton and J/ψ production at very low transverse momentum ($p_{\mathrm{T}} < 0.2$ GeV/c) above the expected hadronic interaction yields have been observed experimentally in non-UPC events [5–7]. The observed excess yields exhibit a much weaker centrality dependence compared to the hadronic production and are consistent with photon-induced interactions. Measurements of the vector meson and dilepton production at very low p_{T} in peripheral events provide a unique opportunity to study the photoproduction in heavy-ion collisions with well-defined and relatively smaller impact parameters compared to that of UPC. It also provides information of the strength and the spatial distribution of the EM fields produced in these collisions.

The STAR experiment recorded a large sample of Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV in 2014. In total, an integrated luminosity of 14.2 nb^{-1} was sampled by the dimuon trigger, which is used for the J/ψ measurement, while approximately 800 million minimum-bias events are used for $\mu^+\mu^-$ continuum measurement. In these proceedings, we present the new measurements of the dilepton and J/ψ production at very low p_{T} in peripheral collisions via the $\mu^+\mu^-$ channel using the 2014 dataset, which are complementary to the previous dielectron results. Distributions of invariant mass, p_{T}, and p_{T}^2 are shown. Different models are compared to the data and their implications are discussed.

2. Results

2.1 J/ψ measurements

The invariant yield of J/ψ, as a function of p_{T} in different centrality bins, is shown in the left panel of Fig. 1. The data points are fitted with the Tsallis function for $p_{\mathrm{T}} > 0.2$ GeV/c. Significant enhancements at $p_{\mathrm{T}} < 0.2$ GeV/c are observed with respect to the extrapolation of the fit. To quantify the modification of J/ψ production in Au+Au collisions with respect to that in p+p collisions, the nuclear modification factor (R_{AA}) is used. It is defined as,

$$R_{\mathrm{AA}} = \frac{1}{N_{\mathrm{coll}}} \times \frac{\left(dN_{J/\psi}/dp_{\mathrm{T}}\right)_{\mathrm{Au+Au}}}{\left(dN_{J/\psi}/dp_{\mathrm{T}}\right)_{p+p}}, \quad (1)$$

where the N_{coll} is the average number of nucleon-nucleon binary collisions and $\left(dN_{J/\psi}/dp_{\mathrm{T}}\right)_{\mathrm{Au+Au}}$, $\left(dN_{J/\psi}/dp_{\mathrm{T}}\right)_{p+p}$ are the J/ψ invariant yields in Au+Au and p+p collisions, respectively. The reference J/ψ distribution in p+p collisions at $\sqrt{s}$ = 200 GeV is obtained by combining STAR and PHENIX measurements [9, 10]. In the right panel of Fig. 1, R_{AA} as a function of p_{T} in different centrality bins is shown. A large enhancement of the J/ψ yield at low p_{T} in peripheral collisions relative to the p+p collisions is observed. It suggests that the excess J/ψ yield is due to the photon-induced production in peripheral collisions.

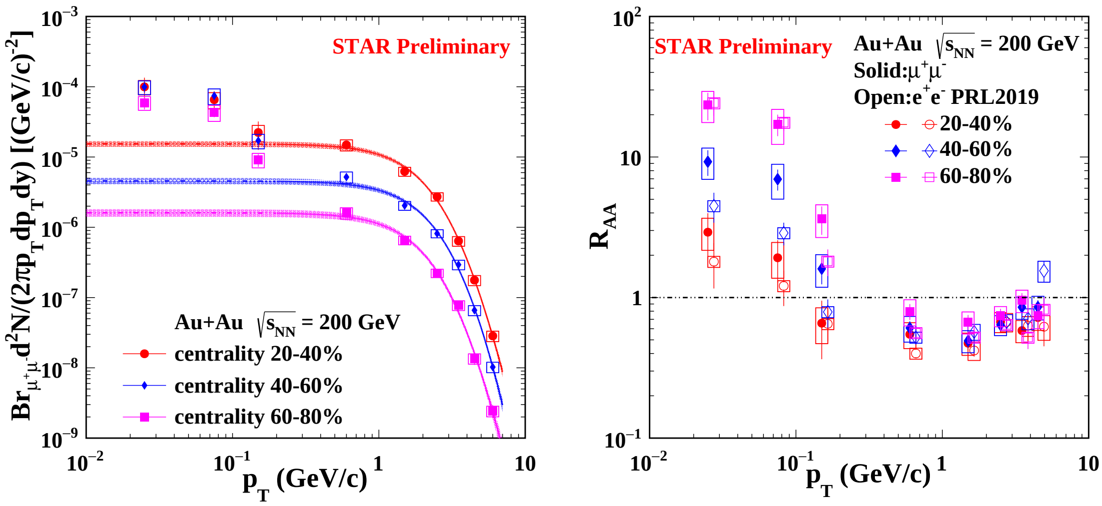

Figure 1: The invariant yield (left) and R_{AA} (right) of J/ψ as a function of p_T in different centrality bins. The R_{AA} distributions are compared with previous dielectron measurements [7]. The error bars represent the statistical uncertainties and the boxes represent the systematic uncertainties.

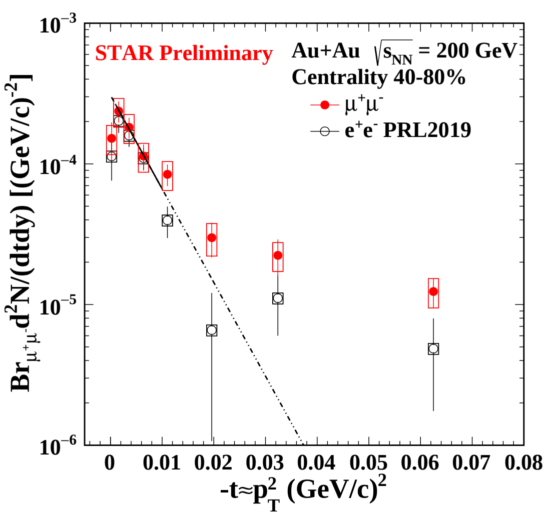

Figure 2: The J/ψ yield as a function of the negative momentum transfer squared –t ($\approx p_T^2$) for the 40%–80% centrality class in Au+Au collisions, in comparison with previous dielectron measurements [7]. The error bars represent the statistical uncertainties, while the boxes represent the systematic uncertainties. The black solid line is an exponential fit to the data points in the range of 0.002–0.015 (GeV/c^2). The dashed black line is an extrapolation of the fit.

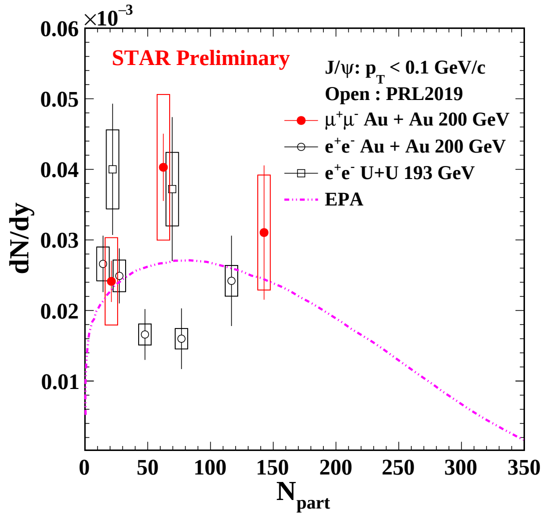

Figure 3: The p_T-integrated J/ψ yield (p_T < 0.1 GeV/c) with the expected hadronic contribution subtracted as a function of N_{part}, in comparison with previous dielectron measurements [7] and model calculation [8]. The error bars represent the statistical uncertainties, while the boxes represent the systematic uncertainties.

Figure 2 shows the J/ψ yield as a function of –t ($\approx p_T^2$) for the 40-80% centrality class. An exponential fit is performed on the distribution. The slope parameter of this fit can be related to the size of the interaction region within the target. The extracted slope parameter is 153 ± 55 (GeV/c)$^{-2}$, consistent with that expected for an Au nucleus [199 (GeV/c)$^{-2}$] within uncertainties. Figure 3 shows the J/ψ yields for $p_T < 0.1$ GeV/c with the expected hadronic contribution subtracted as a function of N_{part}. The excess yield is consistent with the EPA calculation [8], indicating photon induced production.

The J/ψ measurements via the dimuon channel are also compared with previous dielectron results. They are consistent within uncertainties.

2.2 $\mu^+\mu^-$ continuum measurements

Figure 4 shows the p_T distribution of $\mu^+\mu^-$ pairs in low mass region (0.4-0.65 GeV/c^2) in peripheral collisions. The observed excess is found to concentrate below $p_T \approx 0.15$ GeV/c, while the hadronic cocktail, also shown in the figure, can describe the data for $p_T > 0.15$ GeV/c. The EPA-QED calculations are consistent with the data, while the STARlight calculations can not describe the data.

Figure 5 shows the p_T^2 distributions of excess yield within the STAR acceptance in the mass region of 0.44-0.56 GeV/c^2 in 60-80% centrality class. The STARlight [11, 12] and EPA-QED [13] calculations are shown for comparison. The EPA-QED calculations describe the results very well, while the STARlight calculation overshoots the data at low p_T^2 but falls below the data at high p_T^2. The $\sqrt{\langle p_T^2 \rangle}$ is also calculated, which is consistent with the EPA-QED calculation but larger than the STARlight prediction. It confirms that the observed p_T broadening in data compared to the STARlight calculations [6] is not from the interaction of the dilepton with the QGP, but due to the lack of impact parameter dependence in the STARlight model.

Figure 6 shows the $\mu^+\mu^-$ invariant yields as a function of invariant mass with hadronic cocktail subtracted for $p_T^{\mu\mu} < 0.1$ GeV/c in different centralities. Data are consistent with EPA-QED calculations [13].

3. Summary

The measurements of dimuon production in low and high mass regions at very low p_T in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV from STAR are presented. Significant J/ψ and $\mu^+\mu^-$ enhancements are observed at very low p_T in peripheral collisions. The data are comparable with the EPA calculations indicating the enhancements at very low p_T come from the photon-induced interactions. These observables provide the experimental confirmation of the EPA predictions and can be used to map the strength and spatial distribution of the initial EM field.

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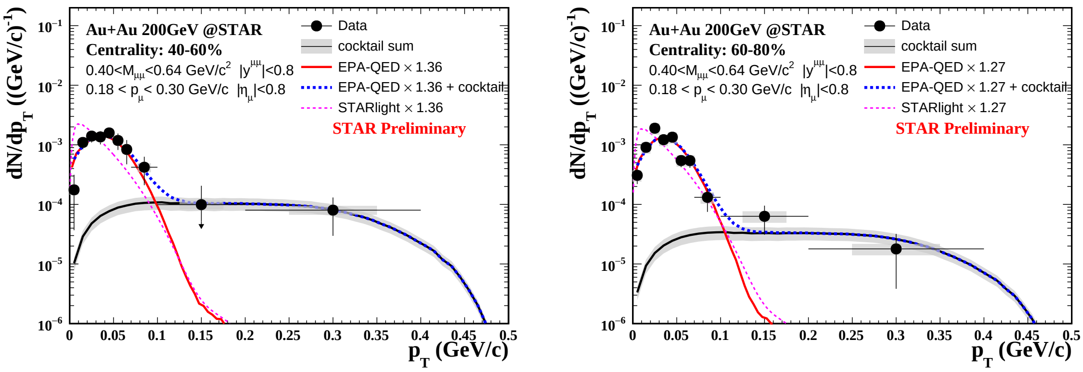

Figure 4: The $\mu^+\mu^-$ pair spectra in the mass range between 0.44 and 0.56 GeV/c^2 within the STAR acceptance are compared with the hadronic cocktail in different centralities (Left: 60-80%. Right: 40-60%). The vertical bars on data points depict the statistical uncertainties, and the systematic uncertainties are shown as gray boxes. Different model calculations are also shown for comparison.

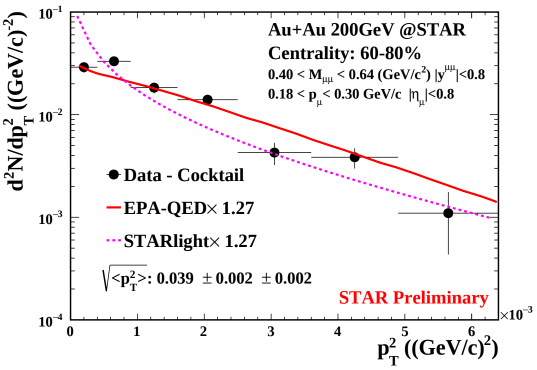

Figure 5: The p_T^2 distributions of excess yield within the STAR acceptance in the mass region of 0.44-0.56 GeV/c^2 in 60-80% centrality compared to different model calculations.

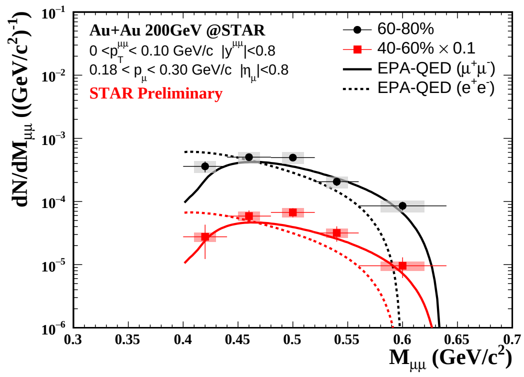

Figure 6: The $\mu^+\mu^-$ excess yields (data - cocktail) as a function of invariant mass for $p_T^{\mu\mu}$ < 0.10 GeV/c in different centrality bins compared to the model calculations [13]. The vertical bars on data points depict the statistical uncertainties and the systematic uncertainties are shown as gray boxes.

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