

1 **Low- p_T e^+e^- pair production in Au+Au collisions at**
2 **$\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} =$**
3 **193 GeV at STAR**

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We present the first measurement of e^+e^- pair production at $p_T < 0.15$ GeV/ c in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV with the STAR experiment. Significant enhancement with respect to known hadronic contributions is observed in the 40-80% centrality of these collisions. The yield excess peaks distinctly at low p_T with a width ($\sqrt{\langle p_T^2 \rangle}$) between 40 and 60 MeV/ c . Model calculations of photon-photon interaction describe the observed excess yields but fail to reproduce the p_T^2 distributions.

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4 1. Introduction

5 Dileptons play an essential role in studying the hot, dense, and strongly interacting matter,
 6 created in Relativistic Heavy Ion Collider (RHIC) [1], because they are produced during the entire
 7 evolution of the collisions and escape with minimum interaction with strongly interacting matter.
 8 Dileptons can also be produced via photon-photon and photonuclear interactions [2], which are
 9 known to peak distinctly at very low transverse momenta (p_T). The photon interaction processes
 10 are traditionally studied in ultra-peripheral collisions (UPC) with impact parameters larger than
 11 twice the nuclear radius [3–9]. Recently, ALICE and STAR collaborations reported a significant
 12 J/ψ excess yield at very low p_T in peripheral heavy-ion collisions [10, 11], which could be qualita-
 13 tively explained by coherent photonuclear production mechanism [10–12]. The explanation implies
 14 the photon-photon interactions would also occur and contribute to e^+e^- pair production. Measure-
 15 ments of mass-differential e^+e^- pair production at very low p_T for different collision systems and
 16 energies thus become necessary to verify and further constrain the photon interactions in hadronic
 17 collisions. In such collisions, the photon-photon interactions could be further used to probe the
 18 electromagnetic properties of QGP, e.g., the possible existence of residual magnetic fields [13].

19 In these proceedings, we report centrality and invariant mass dependence of inclusive e^+e^-
 20 pair production at $p_T < 0.15$ GeV/ c in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions
 21 at $\sqrt{s_{NN}} = 193$ GeV [14]. The observed excess of e^+e^- yields with respect to the known hadronic
 22 sources are presented as a function of centrality and p_T^2 . Model calculations that include an in-
 23 medium modified ρ spectral function, QGP radiation [15], photon-photon processes [16–18], and
 24 coherent photonuclear interactions [12] are compared with the measurements.

25 2. Experiment and analysis

26 STAR [19] has collected 7.2×10^8 Au+Au and 2.7×10^8 U+U minimum-bias (0-80%) events
 27 during the 2010, 2011, and 2012 RHIC runs. The Time Projection Chamber (TPC) [20] and Time-
 28 of-Flight (TOF) [21] detectors are used to identify the electrons and positrons. The TPC is used
 29 for tracking and ionization energy loss (dE/dx) measurements for the particle identification while
 30 the TOF measures velocity of the particles and enables us to reject the hadrons from electrons. By
 31 combining the TPC and TOF, the electron purity of $\sim 95\%$ for $p_T^e > 0.2$ GeV/ c can be achieved in
 32 Au+Au and U+U minimum-bias collisions.

33 The unlike-sign pair distribution (signal and background) is generated by combining electron
 34 and positron candidates in the same event. The like-sign technique, combining the same charge
 35 sign electrons into pairs in the same event, is used to estimate the combinatorial and correlated
 36 backgrounds. Due to dead areas of the detector and the different bending directions of positively
 37 and negatively charged particle tracks in the transverse plane, the unlike-sign and like-sign pair
 38 acceptances are not identical. A mixed-event technique is used to correct for the acceptance differ-
 39 ence as a function of pair invariant mass (M_{ee}) and p_T . The raw signal, obtained by subtracting the
 40 background from the unlike-sign distribution, is corrected for the detector inefficiency.

41 3. Results and discussion

42 Figure 1(a) shows the centrality dependence of efficiency-corrected e^+e^- invariant mass spec-

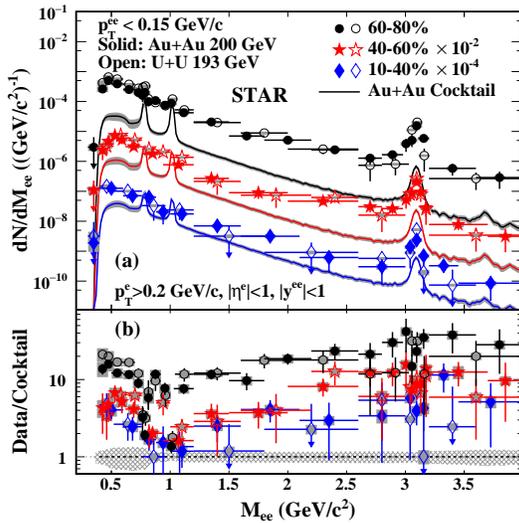


Figure 1: (Color online) (a) The centrality dependence of e^+e^- invariant mass spectra from Au+Au and U+U collisions for pair $p_T < 0.15$ GeV/c. The vertical bars on data points depict the statistical uncertainties while the systematic uncertainties are shown as grey boxes. (b) The corresponding ratios of data over cocktail.

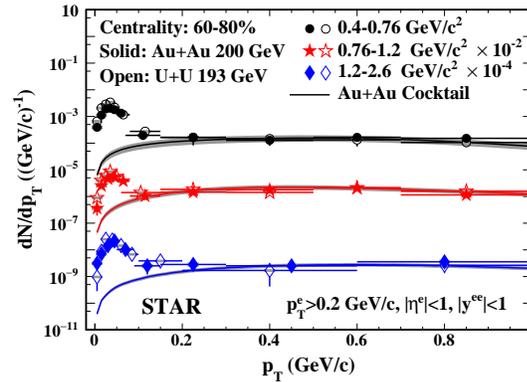


Figure 2: (Color online) The e^+e^- pair p_T distributions for different mass regions in 60-80% Au+Au and U+U collisions compared to cocktails. The systematic uncertainties of the data are shown as gray boxes. The gray bands depict the systematic uncertainties of the cocktails.

tra within the STAR acceptance ($p_T > 0.2$ GeV/c, $|\eta^e| < 1$, and $|y_{ee}| < 1$) in Au+Au and U+U collisions for pair $p_T < 0.15$ GeV/c while the corresponding enhancement factors (data/cocktail) are shown in Fig. 1(b). A significant enhancement with respect to known hadronic sources (cocktail) is observed for the whole measured mass region in the most peripheral (60-80%) collisions. Meanwhile, the enhancement factors get less significant as one goes from peripheral to semi-peripheral (40-60%) and to semi-central (10-40%) collisions.

To gain more insight into the significant low- p_T e^+e^- excess, the e^+e^- pair p_T distributions in 60-80% Au+Au and U+U collisions with the most significant enhancement factors are shown in Fig. 2 for three mass regions (0.4-0.76, 0.76-1.2 and 1.2-2.6 GeV/c²). Interestingly, the observed excess is found to concentrate below $p_T \approx 0.15$ GeV/c, while the hadronic cocktail can describe the data for $p_T > 0.15$ GeV/c in all three mass regions.

The excess in the invariant mass spectra (data - cocktail) for $p_T < 0.15$ GeV/c is shown in Fig. 3(a) and 3(b) for 60-80% and 40-60% centralities, respectively. Theoretical calculations incorporating an in-medium broadened ρ spectral function and QGP radiation [15], which consistently describe SPS [22, 23] and RHIC [24–26] data over a wide p_T region, cannot describe the enhancement observed at very low p_T in 40-80% centrality heavy-ion collisions. The integrated excess yields show much less significant centrality dependence than those from hadronic cocktail, as depicted in Fig. 3(c). These two phenomena suggest that hadronic interactions only are unlikely to be the source of the excess e^+e^- pairs. In order to investigate the origin of the low- p_T e^+e^- enhancement, two types of theoretical models [12, 16–18] based on equivalent photon approximation (EPA) method [27], are used to account for the photon interactions in Au+Au collisions and com-

64 pared to our results. The main difference of these models is that the model by Zha *et al.* [16] takes
 65 into account the e^+e^- production within the geometrical radius of the nucleus. Based on model
 66 calculations, the contributions from photonuclear produced ρ and ϕ vector mesons are found to be
 67 negligible while photon-photon interactions become dominant sources. The photon-photon con-
 68 tributions from Ref. [16] describe the 60-80% centrality data fairly well ($\chi^2/\text{NDF} = 19/15$, where
 69 NDF is the number of degrees of freedom, in 0.4-2.6 GeV/c^2), while the results from STARlight
 70 underestimate that data ($\chi^2/\text{NDF} = 32/15$). In 40-60% centrality, both models can describe the data
 71 within the large statistical uncertainties.

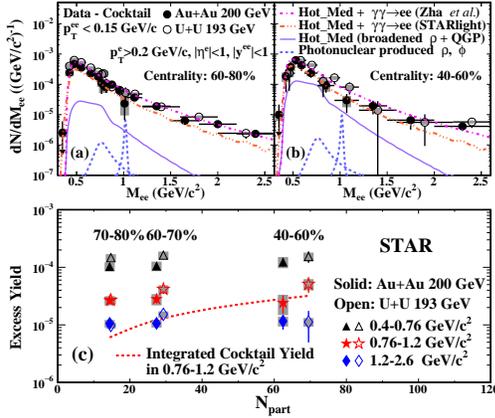


Figure 3: (Color online) The low- p_T e^+e^- excess mass spectra (data – cocktail) in (a) 60-80%, (b) 40-60% for Au+Au and U+U collisions, compared with model calculations for Au+Au collisions in the corresponding centrality bins. (c) The centrality dependence of integrated excess and hadronic cocktail yields in both collisions.

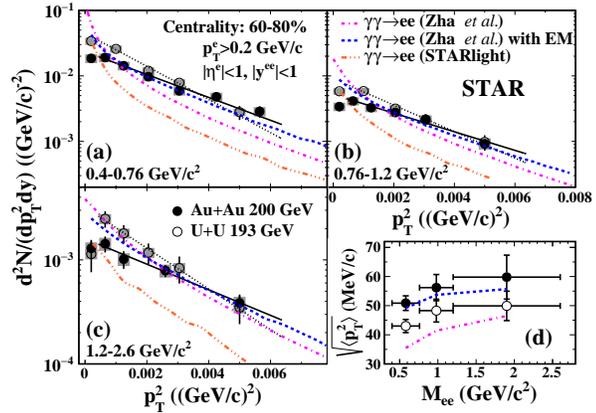


Figure 4: (Color online) The p_T^2 distributions of excess yields within the STAR acceptance in the mass regions of (a) 0.4-0.76, (b) 0.76-1.2, and (c) 1.2-2.6 GeV/c^2 in 60-80% collisions. The solid and dotted lines are exponential fits to the data. (d) The corresponding $\sqrt{\langle p_T^2 \rangle}$ of excess yields. The vertical bars on data points are the combined statistical and systematic uncertainties.

72 The p_T^2 ($\approx -t$, the squared four-momentum transfer) distributions of the excess yields within
 73 the STAR acceptance for 60-80% central Au+Au and U+U are shown in Fig. 4(a)-(c) for three
 74 different mass regions. The calculations from [16], which successfully describe the observed excess
 75 yields, fail to reproduce the p_T^2 spectra. The calculation from STARlight is lower than that from [16]
 76 but has a similar p_T shape. The $\sqrt{\langle p_T^2 \rangle}$ characterizing the p_T broadening, is calculated for both data
 77 and aforementioned photon-photon models. In data, a fit of the exponential function ($Ae^{-p_T^2/B^2}$) is
 78 performed by excluding the first data points and extrapolated to the unmeasured higher p_T^2 region
 79 to account for the missing contribution. The uncorrelated systematic uncertainties arising from
 80 the raw signal extraction are added in quadrature to the statistical errors, and the resulting total
 81 uncertainties are included in the fits. The invariant mass dependence of the extracted $\sqrt{\langle p_T^2 \rangle}$ from
 82 Au+Au collisions are systematically larger than from U+U collisions and both increase slightly
 83 with increasing pair mass, as shown in Fig. 4(d). However, the systematic trends are marginally at
 84 the level of 1.0-2.3 σ . The values of the $\sqrt{\langle p_T^2 \rangle}$ from Au+Au data are about 6.1 σ , 3.3 σ , and 1.8 σ
 85 above models [16, 18] in the 0.4-0.76, 0.76-1.2 and 1.2-2.6 GeV/c^2 mass regions, respectively. The

86 general agreement between the data and model calculations for p_T and invariant mass distributions
 87 of l^+l^- pairs produced by photon-photon interactions in UPC [4, 6, 8] are suggestive of possible
 88 other origins of the p_T broadening in peripheral collisions as shown in Fig. 4(d), e.g. the residual
 89 magnetic field. To illustrate the sensitivity the $\sqrt{\langle p_T^2 \rangle}$ measurement may have to a postulated
 90 magnetic field trapped in a conducting QGP [13], we assume each and every pair member generated
 91 by model [16] traverses 1 fm through a constant magnetic field of 10^{14} T perpendicular to the beam
 92 line ($eBL \approx 30$ MeV/c, where B is 10^{14} T, L is 1 fm) [28, 29]. The corresponding p_T^2 distributions
 93 of e^+e^- pairs are found to describe data much better as compared to the same model without
 94 incorporating the magnetic field effect. Both models [16, 18] used in this proceedings assume there
 95 is no impact-parameter dependence of the e^+e^- pair p_T distribution from initial photon-photon
 96 interaction, however, the latest model calculation [30] shows strong impact-parameter dependence
 97 of the cross section and p_T spectra of e^+e^- pair production from initial photon-photon interaction.
 98 If such a dependence exists, then it will have to be taken into account in the future analyses before
 99 extracting the possible medium effects.

100 4. Summary

101 In summary, we report measurements of e^+e^- pair production with $p_T < 0.15$ GeV/c in non-
 102 central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and U+U collisions at $\sqrt{s_{NN}} = 193$ GeV. The e^+e^-
 103 yields are significantly enhanced over a wide mass range with respect to the hadronic cocktails in
 104 the 40-80% collisions for both collision species. The entire observed excess is found to be below
 105 $p_T \approx 0.15$ GeV/c and the excess yield exhibits a much weaker centrality dependence as compared
 106 to the expectation for hadronic production. The p_T^2 distributions of the excess yields in the three
 107 mass regions in 60-80% Au+Au and U+U collisions are also reported. The $\sqrt{\langle p_T^2 \rangle}$ of these distri-
 108 butions show weak invariant mass and collision species dependence. Based on comparisons with
 109 model calculations, the observed excess for $p_T < 0.15$ GeV/c is very likely linked to photon-photon
 110 production and represents the first observation showing the magnitude of two-photon interactions
 111 in heavy-ion collisions with hadronic overlap. In addition, model calculations of photon-photon in-
 112 teractions describe the observed excess yields but fail to reproduce the p_T^2 distributions. Compared
 113 to the model without the magnetic field effect, the same model calculations incorporating magnetic
 114 field effect are found to describe the p_T^2 distributions much better.

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