# Initial electromagnetic field dependence of photon-induced production in isobaric collisions at STAR

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**Abstract.** In these proceedings, we present the measurements of $e^+e^-$ pair production at very low transverse momentum in $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV by the STAR experiment. The electromagnetic field dependence of photon-induced production is studied for the first time, via comparisons between the measurements in isobaric collisions to the published results in Au+Au and U+U collisions. Taken the initial electromagnetic field dependence into account, the excess yield of $e^+e^-$ pair production shows an impact parameter dependence. The results are also compared to model calculations based on EPA-QED, which describe the observed excess yields for different collision species.

## 1 Introduction

Quark gluon plasma (QGP), a deconfined state of partonic matter, can be produced in ultra-relativistic heavy-ion collisions. Traditionally, di-leptons, one of probes used to study the properities of the QGP, refer to those produced via the violent hadronic interactions in the nuclear overlap region. However, di-letpons can also be generated by interactions of strong electromagnetic fields induced by the colliding nuclei with velocities close to the speed of light. Due to the strong Lorentz contraction and the large number of charge ($Z$) carried by heavy nuclei, the induced strong electromagnetic fields can be viewed as large flux of quasi-real photons, which leads to production of di-leptons from photon-photon process ($\gamma\gamma \to l^+l^-$). The cross section of such photon-photon process is proportional to $Z^4$. Recently, significant enhancements of $e^+e^-$ pair at very low transverse momentum ($p_T$) have been observed in peripheral hadronic heavy-ion collisions [1], which can be reasonably explained by these photon-induced production [2–4]. In order to further prove that photon-induced interactions are the cause of the very low-$p_T$ $e^+e^-$ excess yield observed in heavy-ion collisions, it is essential to measure its production yield in various collision systems with varying $Z$.

In 2018, the STAR experiment has collected a large sample of $^{96}_{44}$Ru+$^{96}_{44}$Ru and $^{96}_{40}$Zr+$^{96}_{40}$Zr collisions at $\sqrt{s_{\rm NN}}$ = 200 GeV to search for the Chiral Magnetic Effect signals [5] since the electromagnetic fields in Ru+Ru and Zr+Zr are expected to be different while the hadronic backgrounds should be similar. Since photon-induced processes are sensitive to the electromagnetic field, they can be used to experimentally study the difference of the initial electromagnetic fields between Ru+Ru and Zr+Zr collisions. The isobaric collisions also provide a

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unique opportunity to test the electromagnetic field dependence of photon-induced production.

## 2 Experiment and Analysis

The STAR experiment has recorded around 4 billion minimum-bias Ru+Ru and Zr+Zr collision events in 2018. Electrons with $p_T^e > 0.2$ GeV/c and $|\eta^e| < 1$ are selected by combining the ionization energy loss measured by the Time Projection Chamber (TPC) [6] and the flight time measured by the Time-of-Flight (TOF) detector [7]. The raw signal of $e^+e^-$ pairs at very low $p_T$ is obtained by subtracting background from the unlike-sign pair distribution. A Monte Carlo (MC) simulation is used to estimate the contributions from known hadronic sources, usually referred to the hadronic cocktail, which need to be subtracted in order to obtain the excess yields.

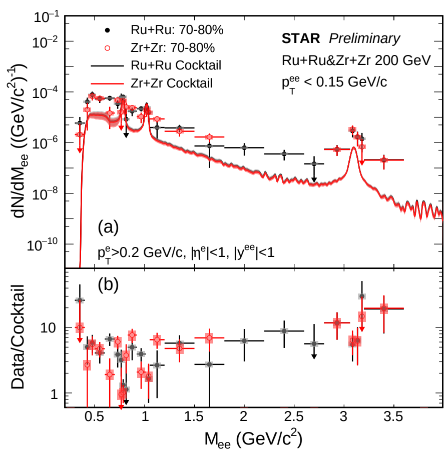


Figure 1: (a) The $e^+e^-$ invariant mass spectra within the STAR acceptance from Ru+Ru and Zr+Zr collisions for pair $p_T^{ee} < 0.15$ GeV/c in 70-80% centrality. The hadronic cocktails are shown as solid lines of different colors. (b) The corresponding ratios of data over cocktail.

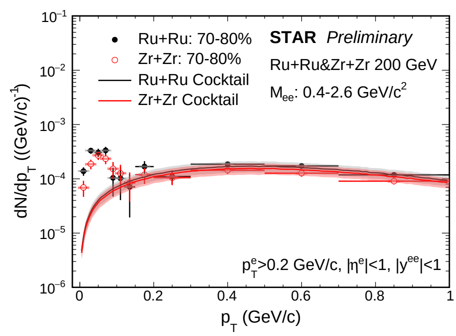


Figure 2: The $e^+e^-$ pair $p_T$ distribution within the STAR acceptance in 0.4-2.6 GeV/$c^2$ mass region in 70-80% centrality, compared to cocktails.

## 3 Results

In Fig. 1(a), the $e^+e^-$ invariant mass distributions corrected for detector inefficiency in Ru+Ru and Zr+Zr collisions are shown as solid and open circles respectively in 70-80% centrality for pair $p_T < 0.15$ GeV/c within STAR acceptance ($p_T^e > 0.2$ GeV/c, $|\eta^e| < 1$, and $|y^{ee}| < 1$). The corresponding enhancement factors are defined as ratios of data over hadronic cocktail in the same mass regions, which are displayed in Fig. 1(b). The enhancement factors reach local minima around $M_\phi$ before rising towards larger mass, similar to the trends seen in Au+Au and U+U collisions [1].

The $p_T$ distributions of $e^+e^-$ pairs in the mass region from 0.4-2.6 GeV/$c^2$ are shown in Fig. 2 for 70-80% isobaric collisions. While for $p_T^{ee} > 0.15$ GeV/c, data are consistent with hadronic cocktails, significant excesses above hadronic cocktails are seen at $p_T^{ee} < 0.15$ GeV/c.

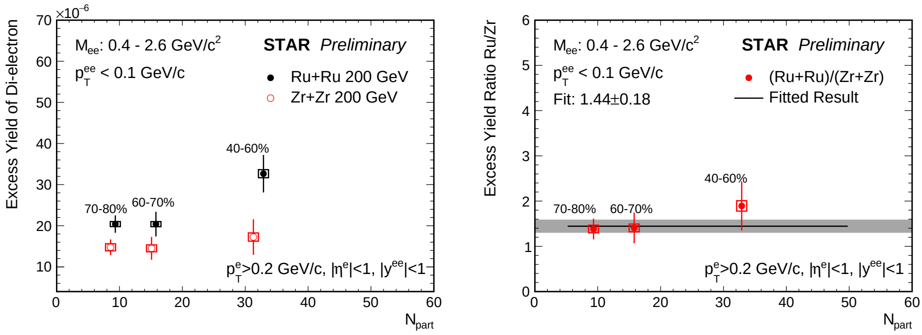


Figure 3: *Left panel*: The centrality dependence of integrated excess yields at $p_T^{ee} < 0.1$ GeV/c in the mass region of 0.4-2.6 GeV/$c^2$ in Ru+Ru and Zr+Zr collisions within the STAR acceptance. *Right panel*: The centrality dependence of the ratios of integrated low-$p_T$ excesses between Ru+Ru and Zr+Zr collisions. The solid line is the fitted result to data points by a constant function.

After subtracting the hadronic cocktail, the integrated low-$p_T$ excess yields of $e^+e^-$ pairs as a function of average number of participating nucleons $\langle N_{\text{part}} \rangle$ are shown in the left panel of Fig. 3. The integrated excesses yields in Ru+Ru collisions are systematically higher than those in Zr+Zr collisions. The right panel of Fig. 3 is the centrality dependence of excess yield ratios between Ru+Ru and Zr+Zr collisions, and a constant function is utilized to fit the ratios. The fitted result is about $2.4\sigma$ higher than unity, which hints at the initial electromagnetic field dependence between the two collision systems.

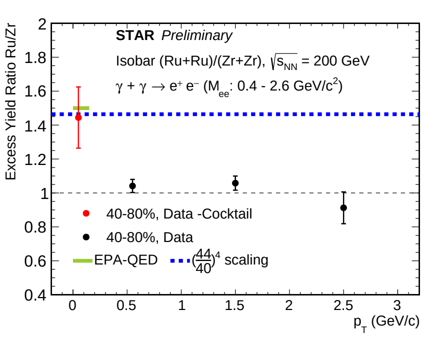


Figure 4: The $p_T$ dependence of $e^+e^-$ yield ratios between Ru+Ru and Zr+Zr collisions in 40-80% centrality. The statistical and systematical uncertainties are combined and shown as the vertical bars. The green solid line is the prediction at low-$p_T$ based on EPA-QED [8] and the blue dash line is the $(\frac{44}{40})^4$ scaling.

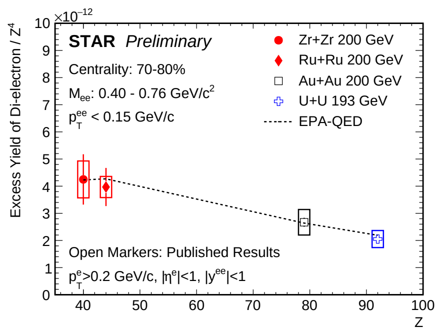


Figure 5: The collision system dependence of the integrated $e^+e^-$ excess yield within the STAR acceptance, scaled with $Z^4$, in 70-80% centrality. The dash line is the EPA-QED prediction [9].

Figure 4 shows the $p_T$ dependence of the $e^+e^-$ yield ratios. For $p_T > 0.1$ GeV/c, the hadronic cocktail is not subtracted, and the yield ratio is consistent with unity, indicating the hadronic contribution dominates in this $p_T$ range. The two collision systems' distinct nuclear structures could be the cause of the small deviation from unity. At $p_T < 0.1$ GeV/c, the hadronic cocktail is subtracted in order to study the collision system dependence of the photon-induced production. The excess yield ratio at low-$p_T$ can be described by the EPA-QED calculation [8] shown as the green line and also follows the $(\frac{44}{40})^4$ scaling.

Figure 5 shows the integrated excess yields in the mass region of 0.4-0.76 GeV/$c^2$ at $p_T$ < 0.15 GeV/c in 70-80% centrality scaled by $Z^4$ as function of $Z$ for different collisions. The $Z^4$ scaled yield shows a clear collision system dependence, likely originating from the impact parameter dependence of photon-induced interactions. The decreasing trend can be described by the EPA-QED calculations [9] taking such impact parameter dependence into account.

## 4 Summary

In this contribution, the electromagnetic field and collision species dependence of $e^+e^-$ pair production by photon-photon process from STAR are presented. We observe a hint of initial electromagnetic field dependence in peripheral Ru+Ru and Zr+Zr collisions. Taken the initial electromagnetic field dependence into account, the excess yield of $e^+e^-$ shows a clear impact parameter dependence. The results can be well described by calculations of photon-photon interactions based on EPA-QED, pointing to the existence of photon-phonton interactions in hadronic heavy-ion collisions.

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