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

Kaifeng Shen (for the STAR collaboration)

State Key Laboratory of Particle Detection and Electronics,
Department of Modern Physics,
University of Science and Technology of China
(skfwyl@mail.ustc.edu.cn)

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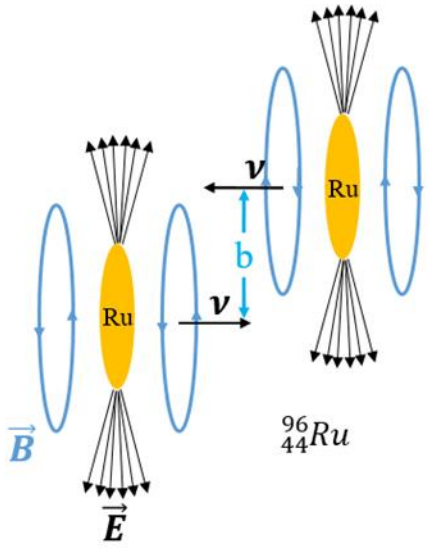
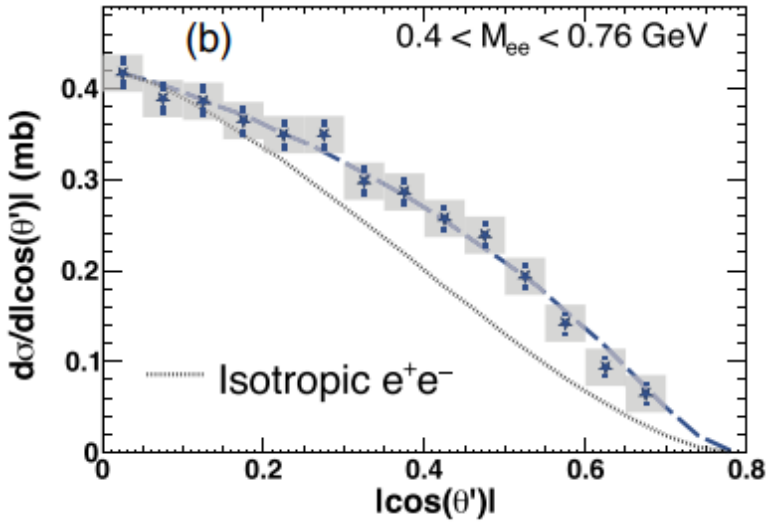
Outline

- Introduction and motivation
- e^+e^- pair production in isobaric collisions
- J/ψ production in isobaric collisions
- Angular distribution of e^+e^- in isobaric collisions
- Summary

Initial Electromagnetic Field in Heavy Ion Collisions

- Transverse EM fields are equivalent to a flux of quasi-real photons ($\propto Z^2$, and $q^2 \to 0$)





- Photons are transverse and linearly polarized
- High photon density only possible in high-energy heavy ion collisions ($|\vec{B}| \approx 10^{14}$-$10^{16}$T) – test the property of EM fields

$\vec{E} \perp \vec{B} \perp \vec{k}, |\vec{E}| \approx |\vec{B}|$

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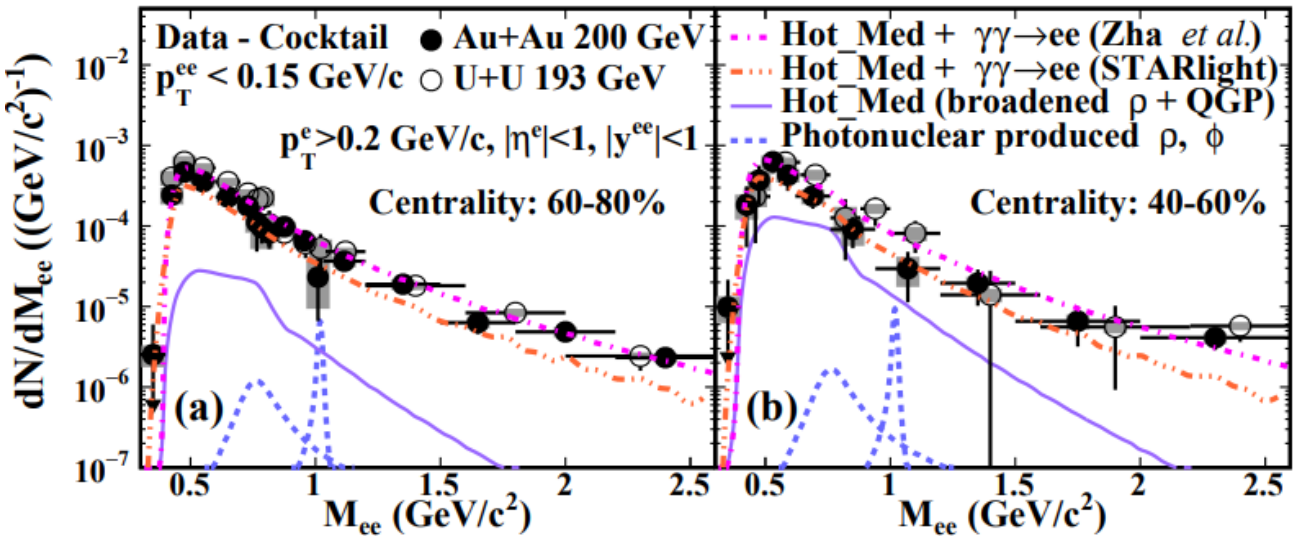
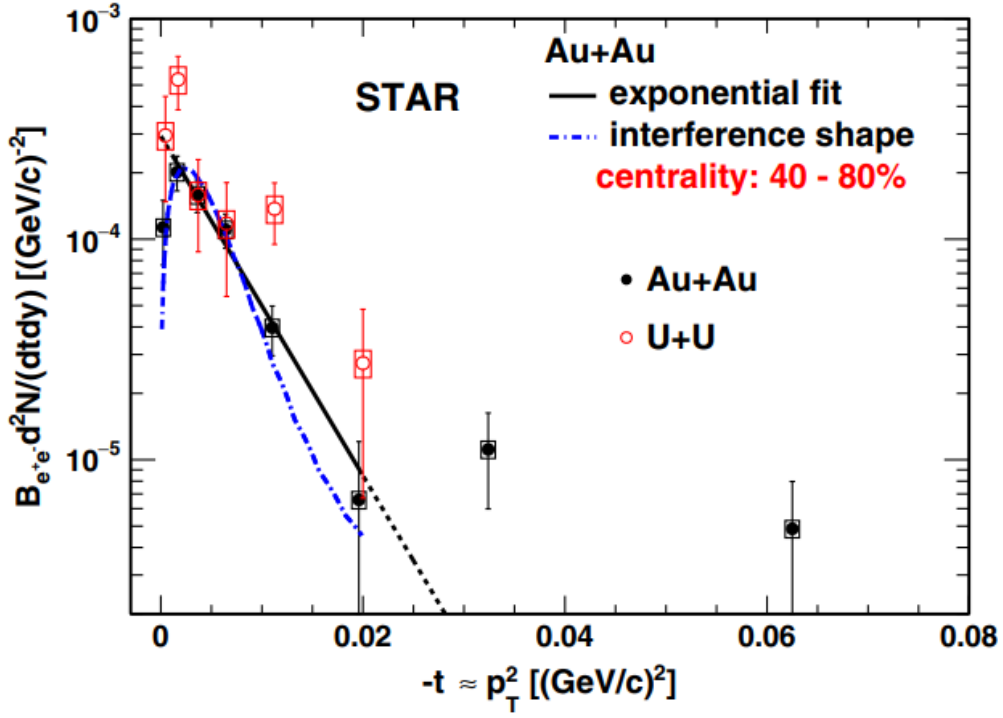
Photon-induced Production in Peripheral Collisions

- Conventionally, photon-induced process is studied in ultra-peripheral collisions (b>$2R_A$,UPCs) to satisfy the coherence condition





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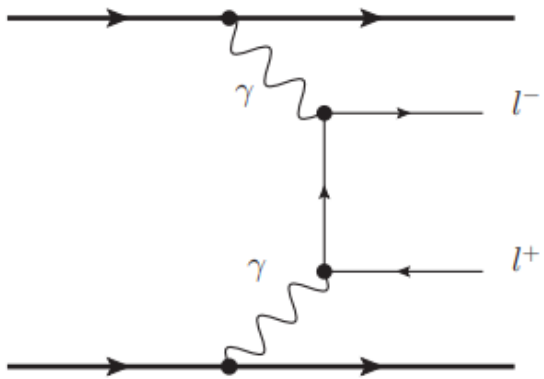
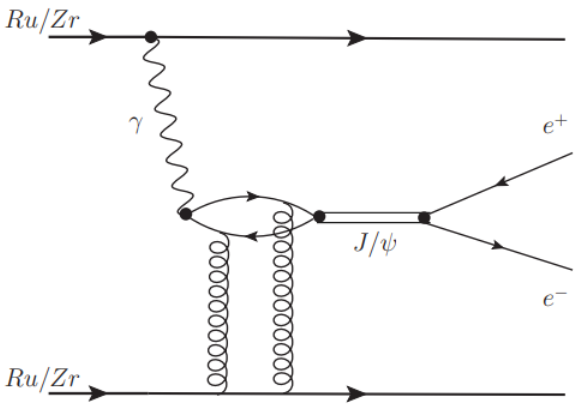
- The enhancements of J/ψ and e^+e^- production at very low p_T have been observed in peripheral collisions
- Photon-induced interactions can explain the observed enhancements

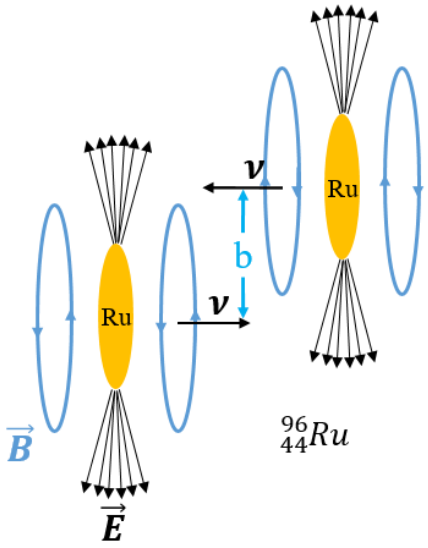
Photon-induced Production in Peripheral Collisions

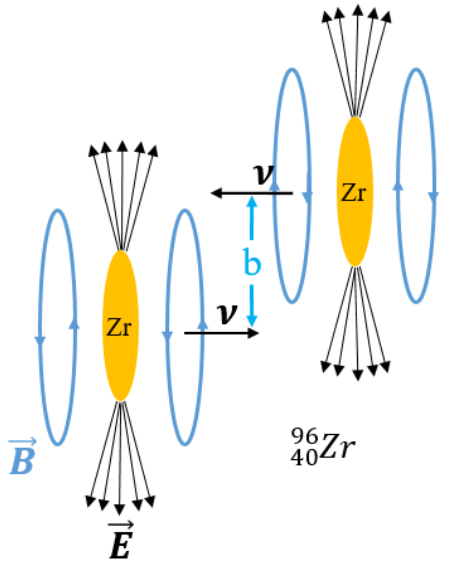
- Isobaric collisions provide a unique opportunity to test the electromagnetic field dependence





- Charge (Z)
- Impact parameter
- …

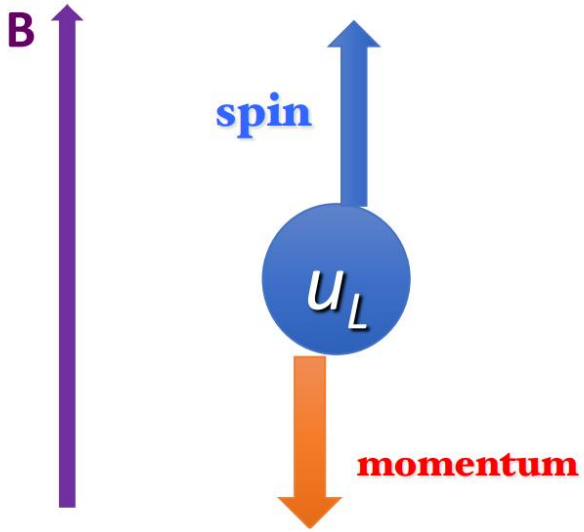


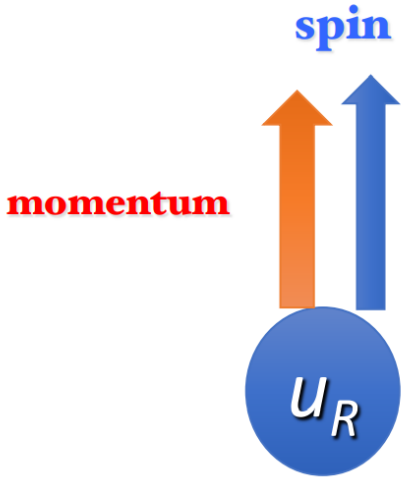


- Photon-induced production is sensitive to initial EM field:
  - ➢Charge (Z) of the colliding nuclei
  - ➢Collision system

Implication on the Search for Chiral Magnetic Effect

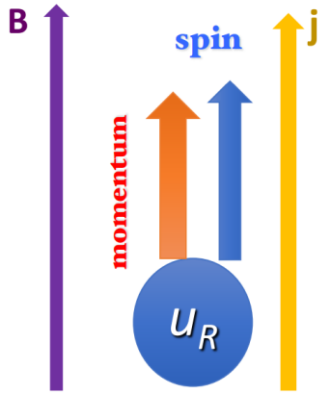
- The photon-induced production is sensitive to initial EM field





Heavy ion collisions:

- Strong magnetic fields
- Quark-Gluon Plasma
- Imbalance of left-handed & right-handed quarks

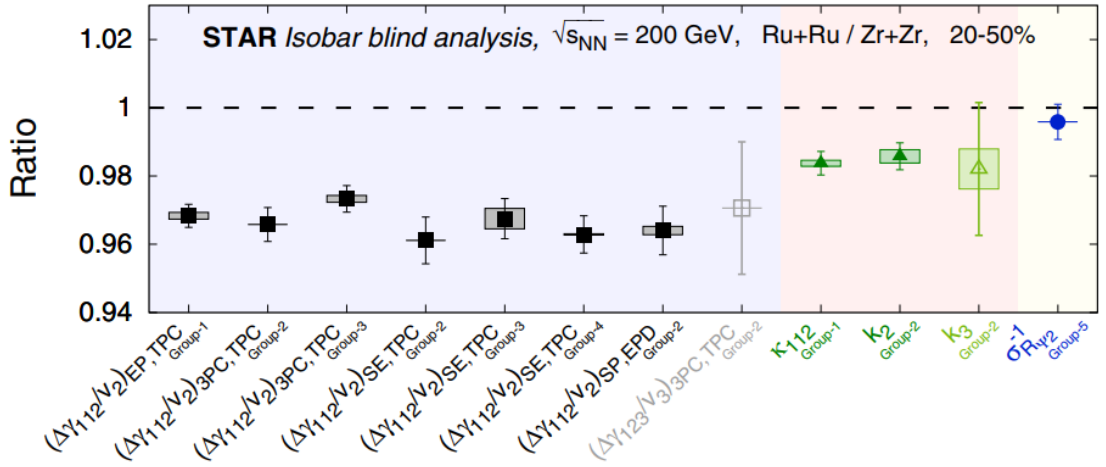


Charge current, called Chiral Magnetic Effect

Results from blind analysis of isobaric collisions:

- No pre-defined CME signatures observed

Need to confirm the EM field difference in isobaric collisions for further CME study



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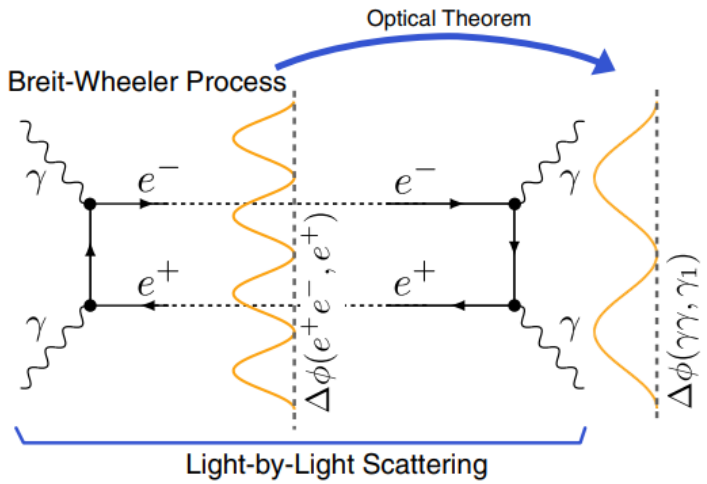
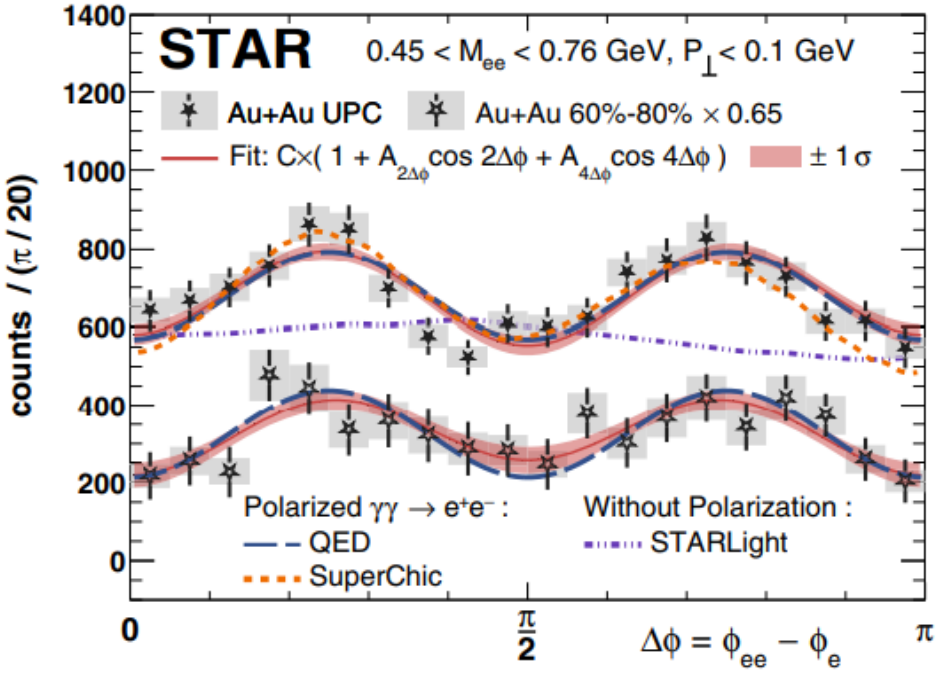
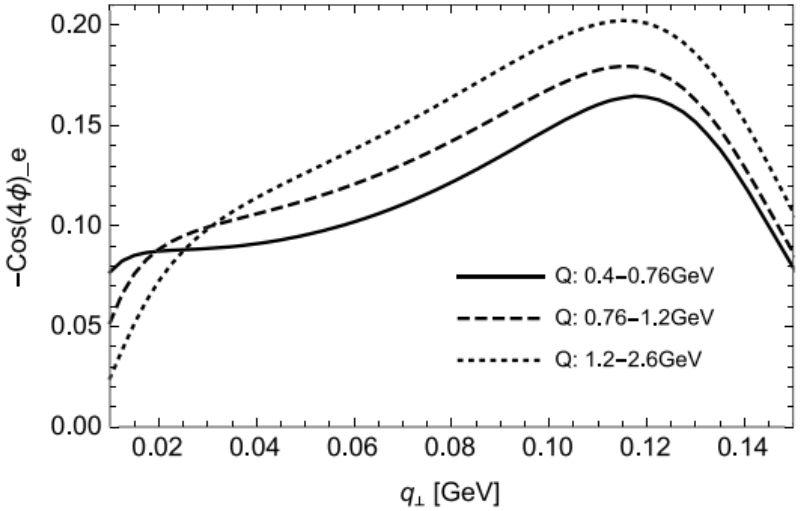
Birefringence of the QED Vacuum



- The Breit-Wheeler process has been investigated in peripheral and ultraperipheral Au+Au collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV



$$\frac{d\sigma}{d^2p_{1\perp}d^2p_{2\perp}dy_1dy_2} = \frac{2\alpha_e^2}{Q^4}[\mathrm{A+B\times cos}(2\varphi)+\mathrm{C\times cos}(4\varphi)]$$



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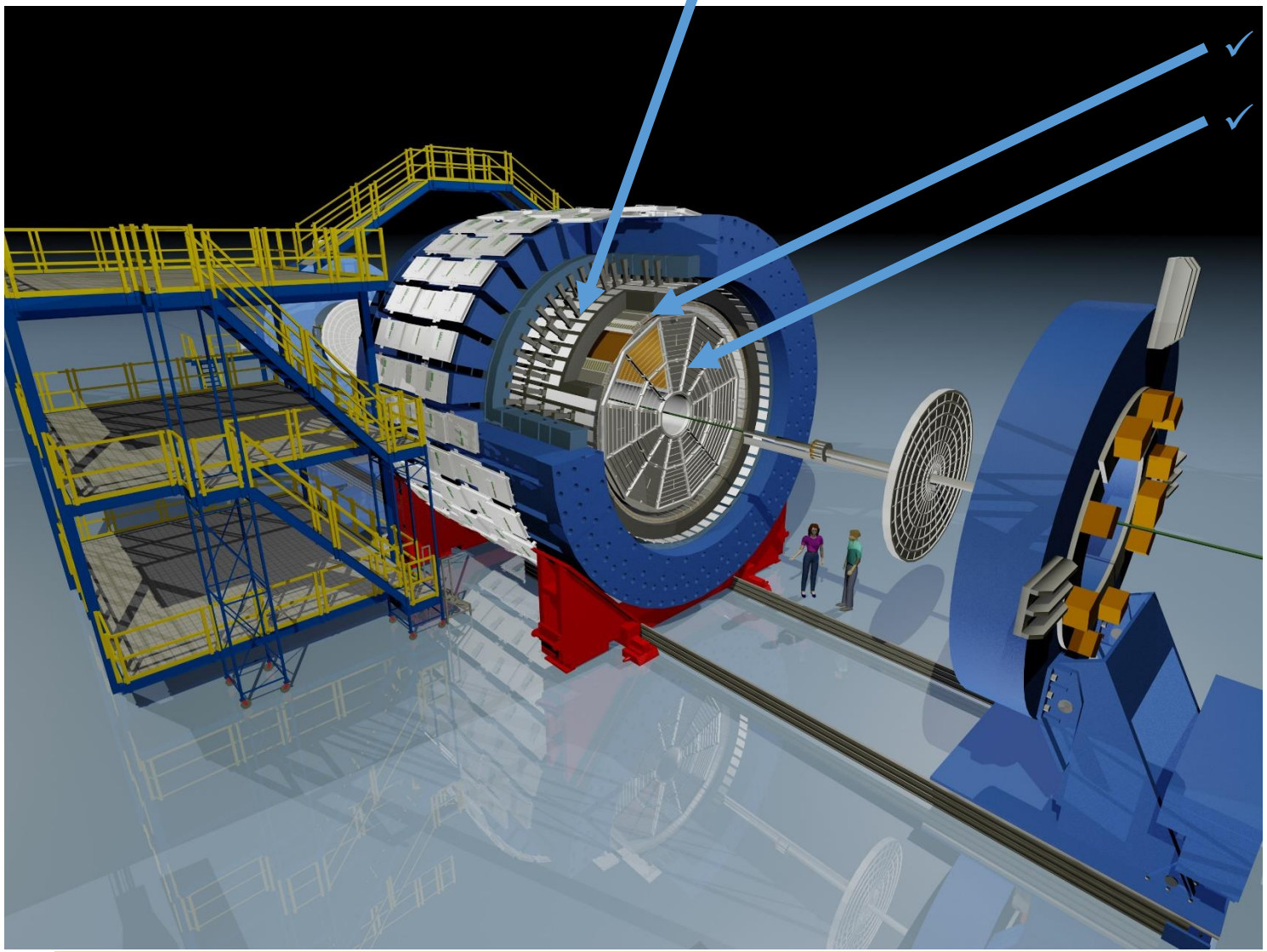
C.Li, J.Zhou, Y.J.Zhou, Phys. Lett. B. 795, 576 (2019)

- Investigate collision system dependence of cos(4Δϕ) modulation

The Solenoid Tracker At RHIC

✓ BEMC: E_0/p, identify high-p_T electron



✓ TOF: Time of flight, particle identification

✓ TPC: Tracking, momentum and dE/dx

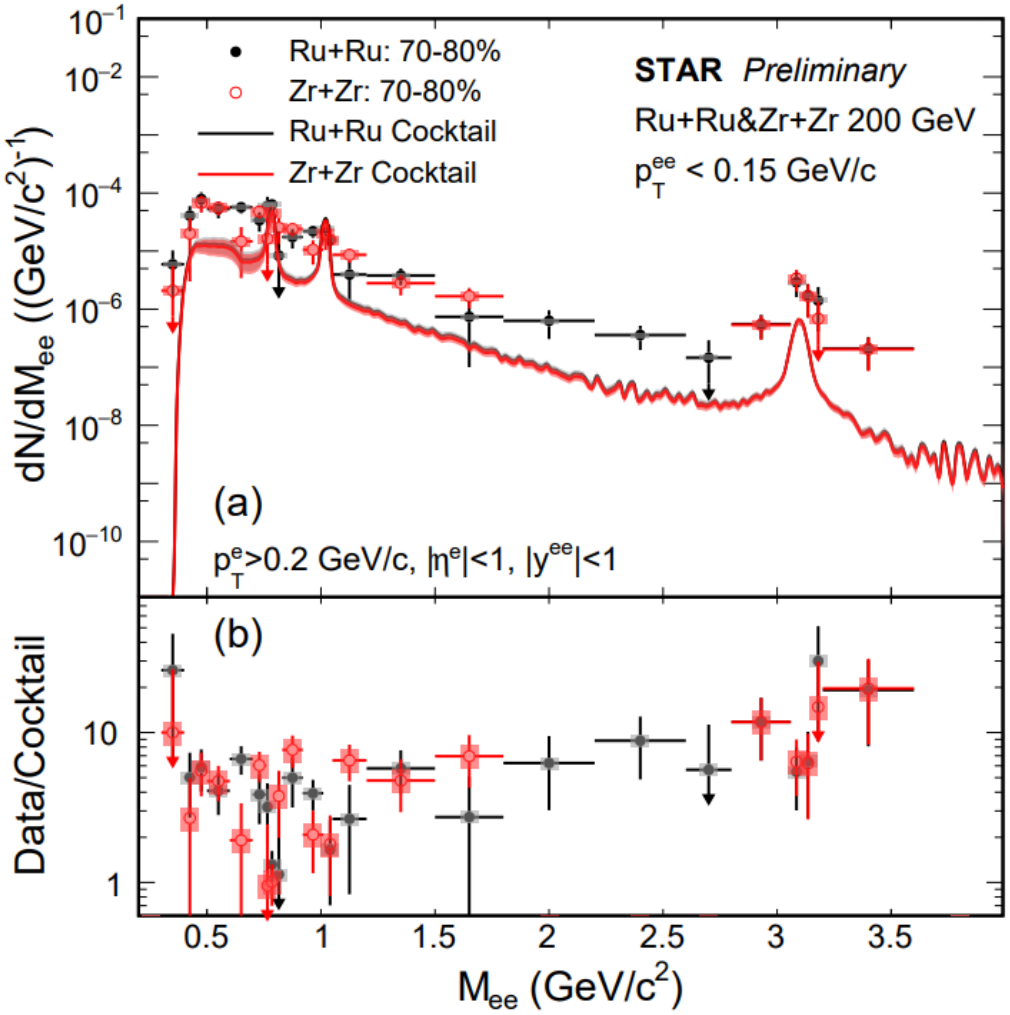
Collision species (taken in 2018)

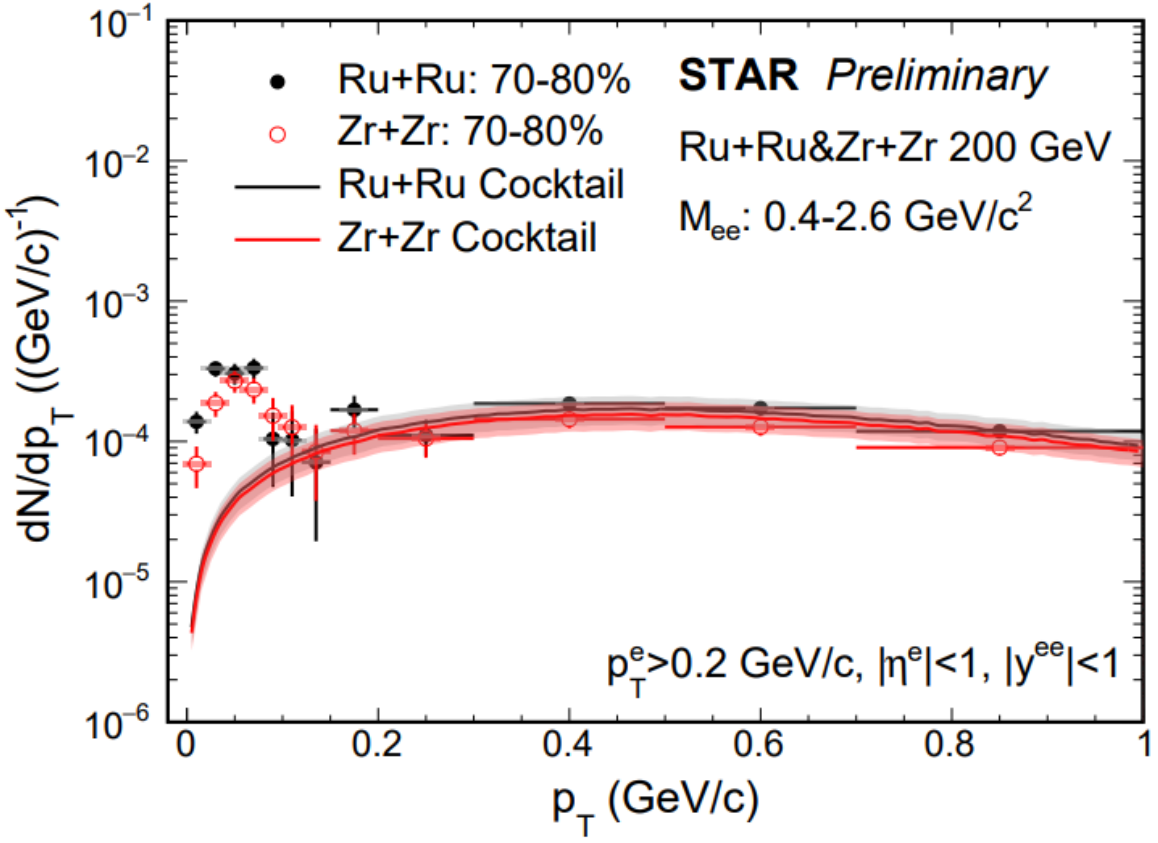
- $^{96}_{44}Ru+^{96}_{44}Ru$, $\sqrt{s_{\mathrm{NN}}}$=200GeV (~2B)
- $^{96}_{40}Zr+^{96}_{40}Zr$, $\sqrt{s_{\mathrm{NN}}}$=200GeV (~2B)

Acceptance cuts:

- p_T^e> 0.2 GeV/c
- $|\eta^e| < 1$
- $|y^{ee}| < 1$

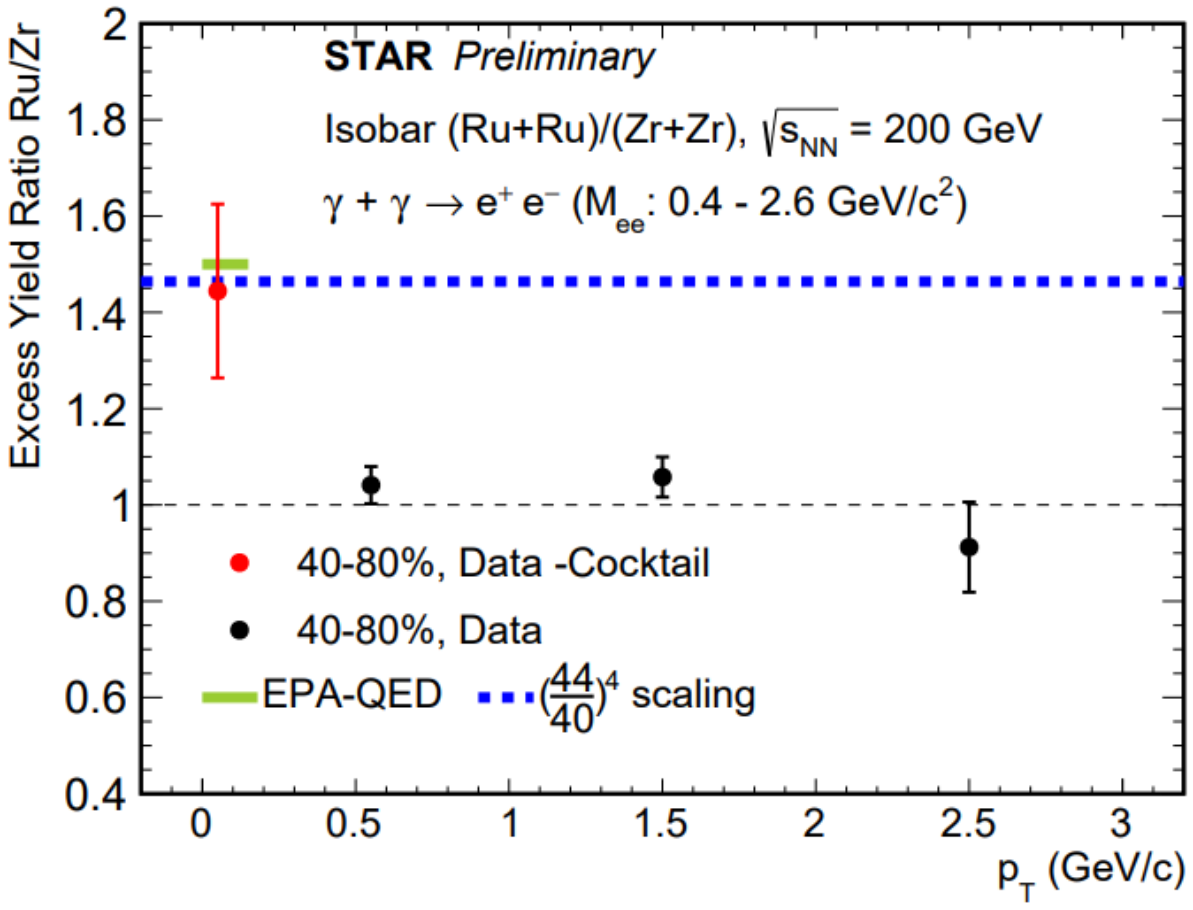
Invariant Mass and Transverse Momentum Distributions of e^+e^-





- Excesses above known hadronic contributions are observed at low p_T

p_T Dependence of Excess Yield Ratio



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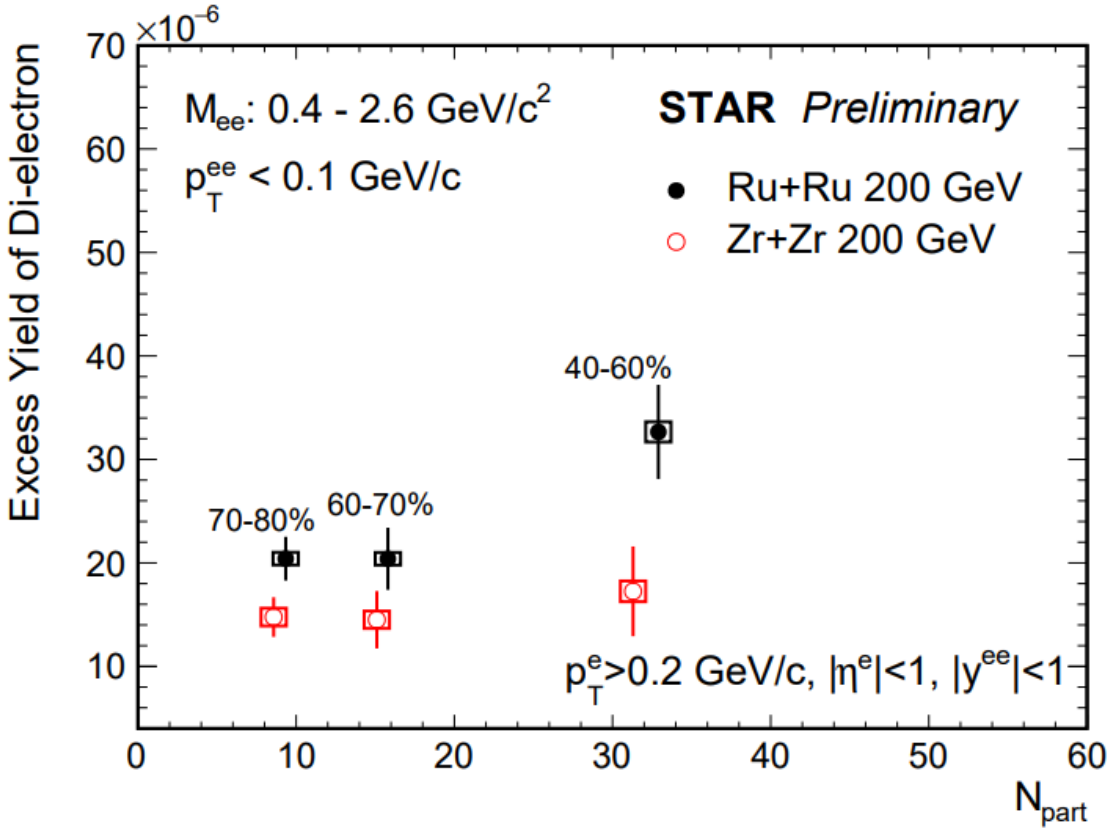
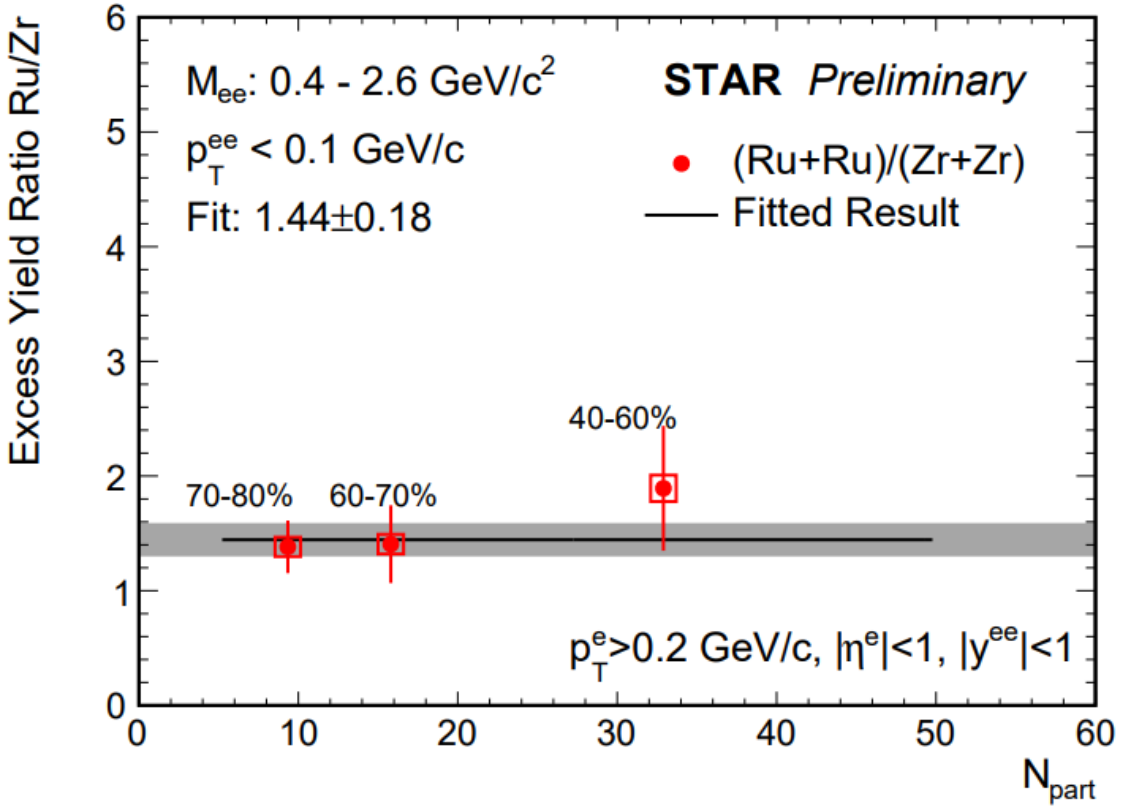
- With cocktail subtracted, the yields at low p_T are mainly from photon-induced interactions while the hadronic contributions dominate in intermediate p_T range
- The ratio of excess e^+e^- yield at low p_T (< 0.1 GeV/c) in the 40-80% centrality is consistent with EPA-QED calculation and Z^4 scaling, and is above unity
- The initial EM fields for Ru+Ru and Zr+Zr seem to be different

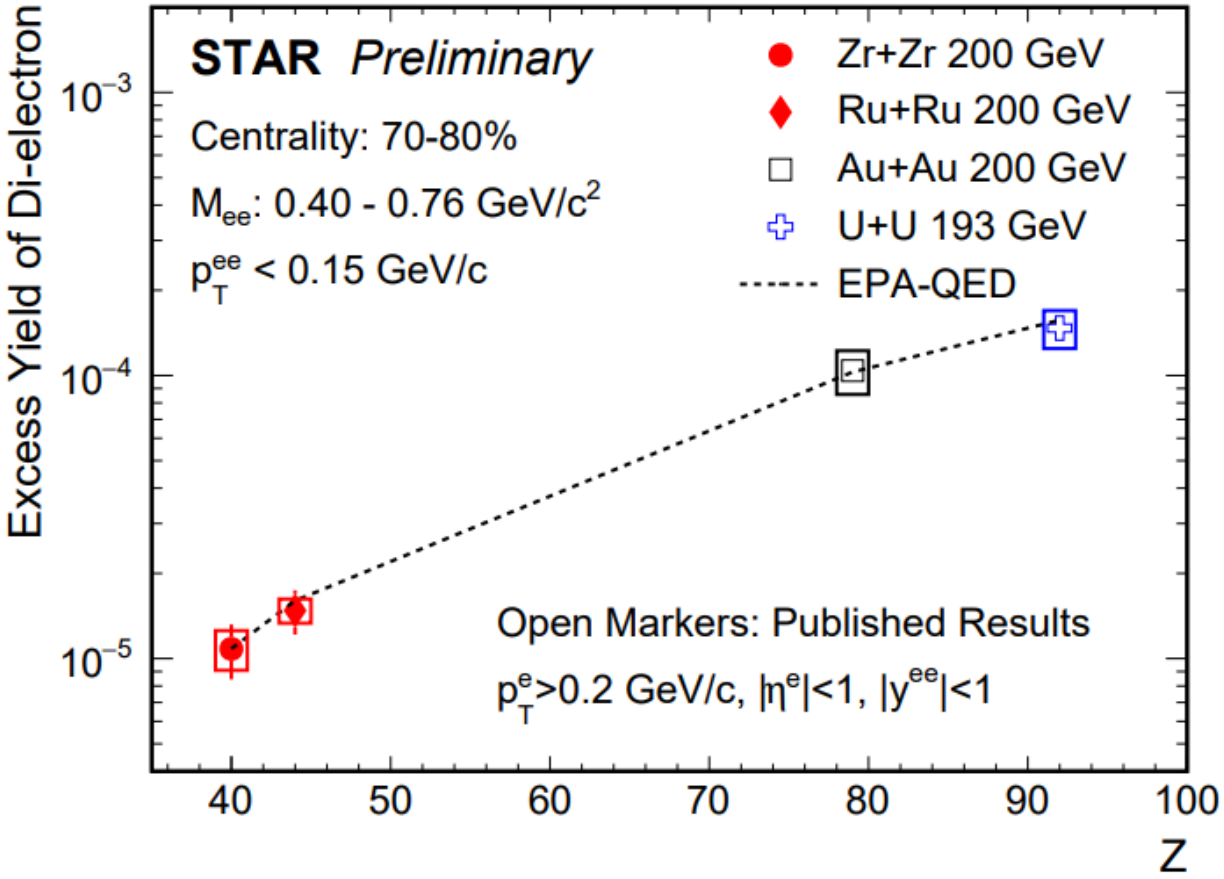
Centrality Dependence of Excess Yield

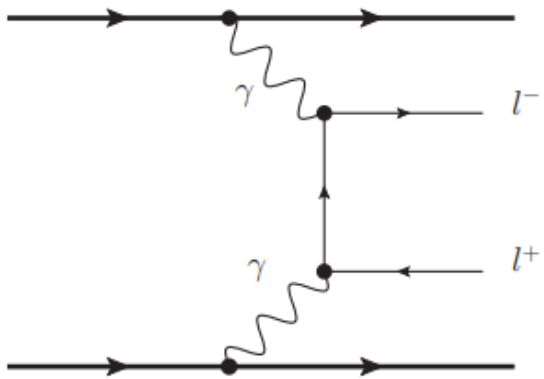




- The low p_T (p_T < 0.1 GeV/c) e^+e^- excess and the ratio of excess are shown as a function of N_{part}
- The excess yields in Ru+Ru collisions are systematically higher compared to those from Zr+Zr collisions
- A constant function is used to fit the ratio and is about 2.4σ higher than unity

Charge Dependence of Excess Yield





- The excess yields in isobaric collisions are significantly smaller compared to those in Au+Au and U+U collisions
- The charge difference is the dominant driving factor ($\propto Z^4$)

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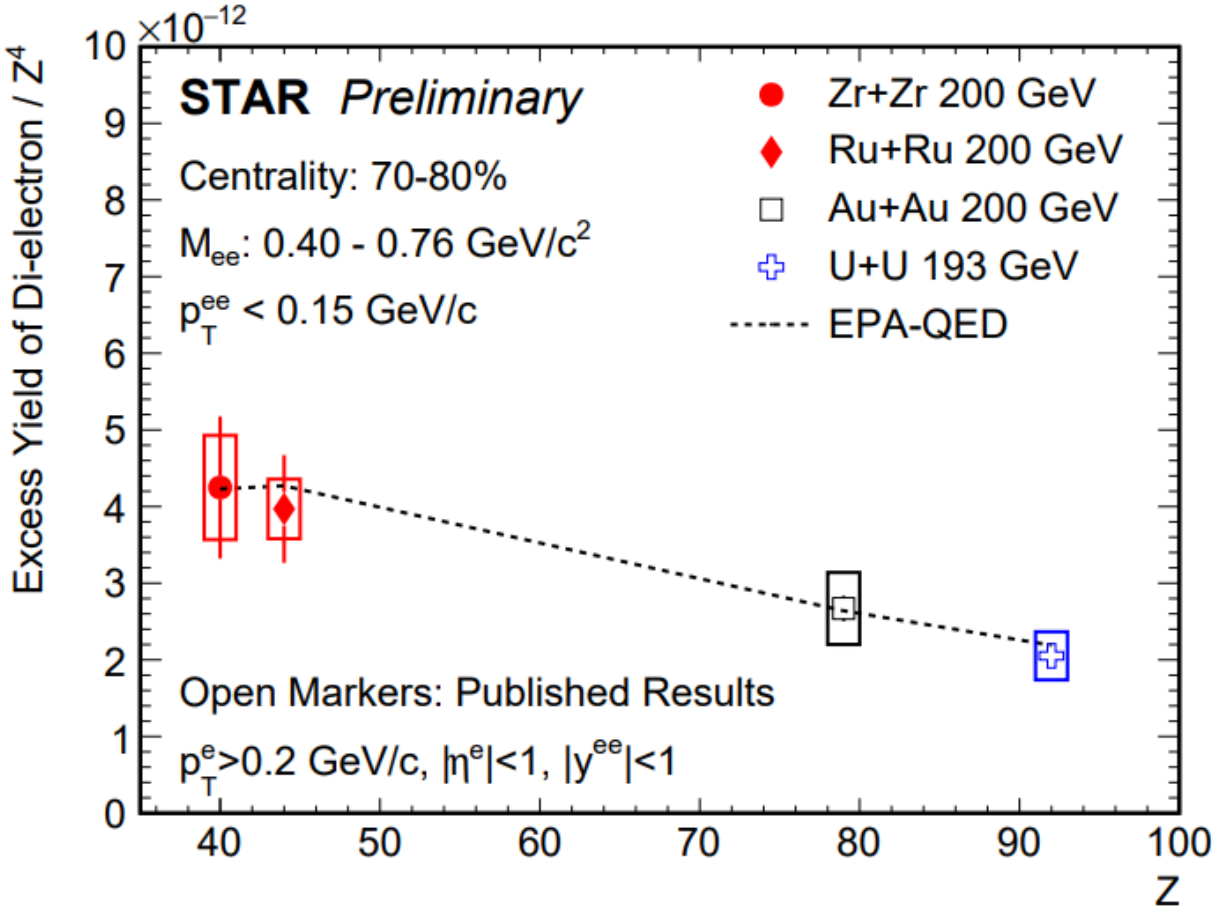
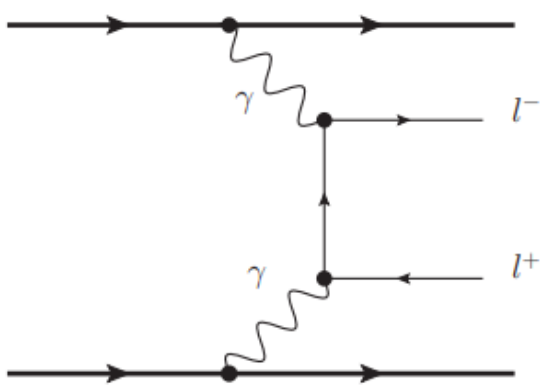
W. Zha et al, Phys. Lett. B 800 (2020) 135089

Collision System Dependence of Scaled Excess Yield





- Z^4 scaled yield shows clear collision system dependence, likely originating from impact parameter dependence
- Decreasing trend described by EPA-QED calculation

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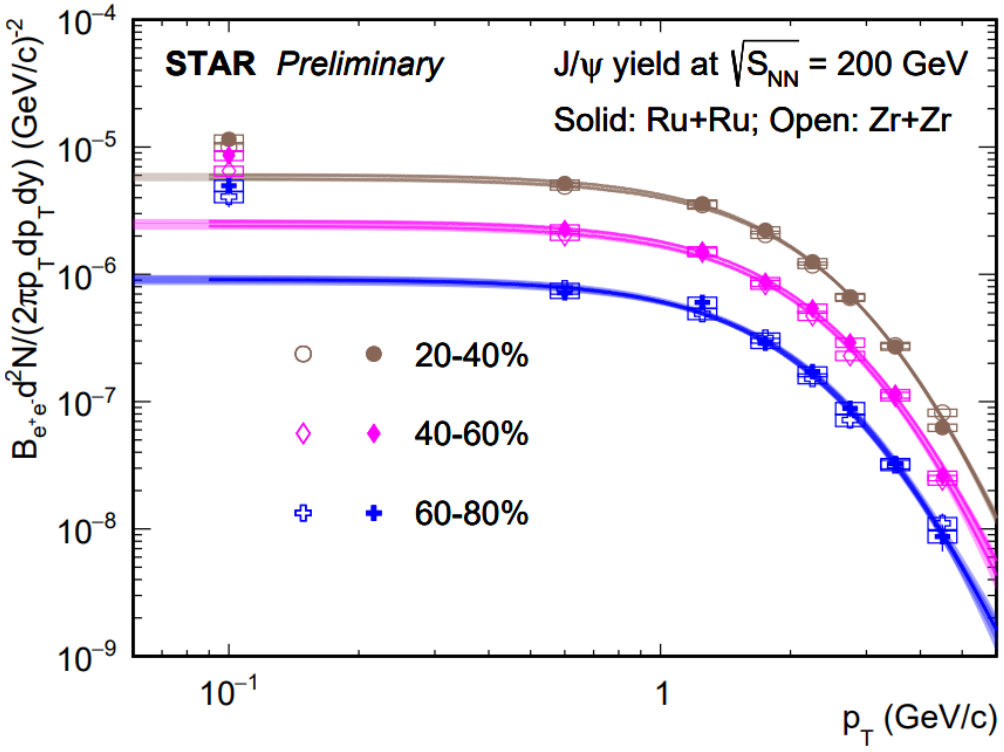
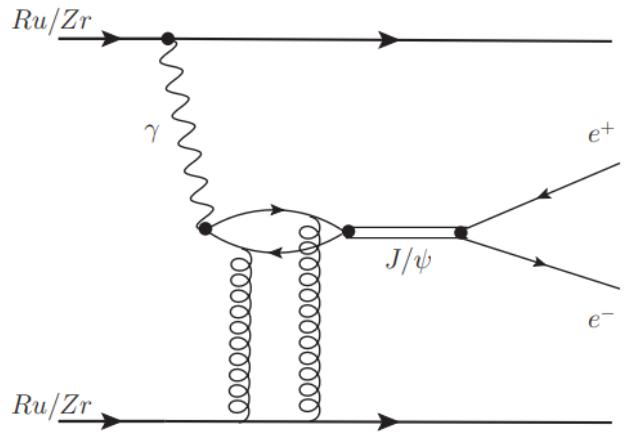
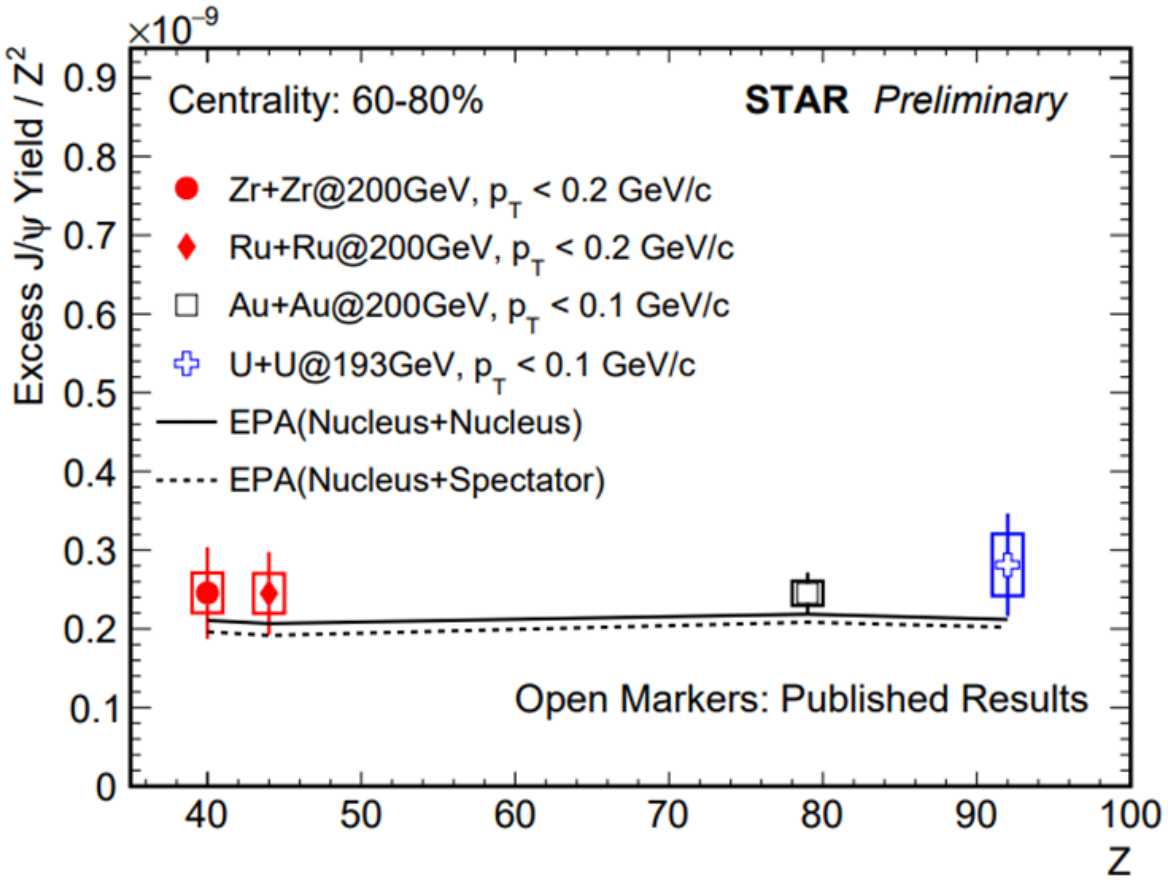
Invariant Yield and Nuclear Modification Factor of J/ψ





- The yield spectra are fitted by the Tsallis function at p_T larger than 0.2 GeV/c, and extrapolated to low p_T range to illustrate the expected hadronic contribution
- Data are well described by the fitted curves above 0.2 GeV/c, but show significant enhancements at low p_T range

Collision System Dependence of Scaled Excess J/ψ yield



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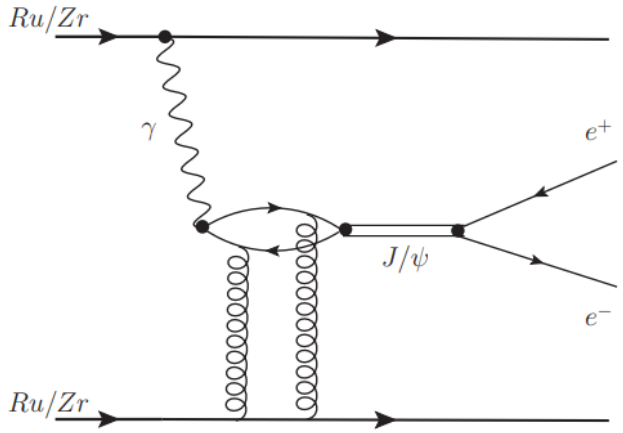
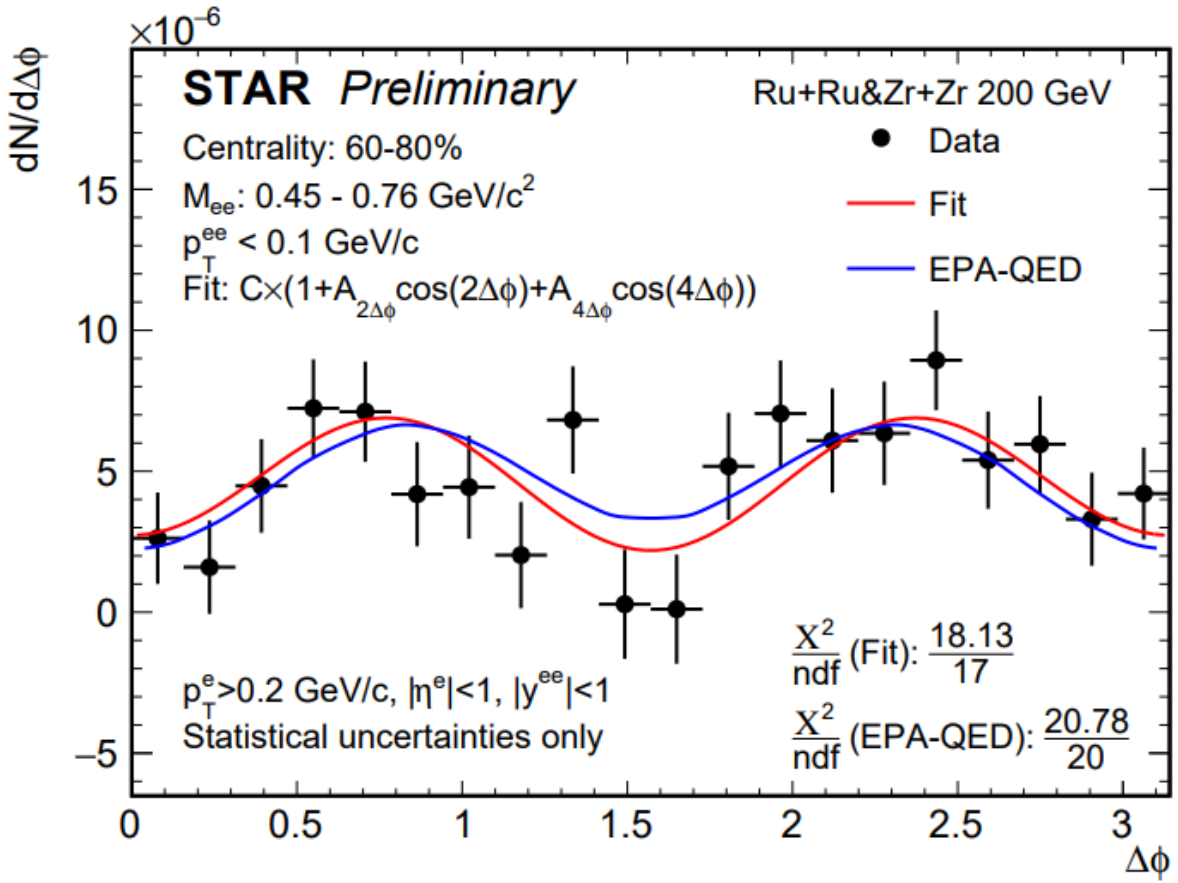
W. Zha et al. Phys. Rev. C 97, 044910 (2018)



- Scale J/ψ excess yields at very low p_T with Z^2
- The Z^2-scaled photonuclear production of J/ψ seems to be independent of collision species at a given centrality
- Effects of form factor and impact parameter seem to balance each other

cos(4Δϕ) Modulation in Isobaric Collisions



	$\lvert A_{4\Delta\phi}\rvert$ (%)	$\lvert A_{2\Delta\phi}\rvert$ (%)
Isobar(60-80%)	47±14	6±13
Au+Au(60-80%)	27±6	6±6
QED-EPA for Isobar	40	0

- Clear cos(4Δϕ) signal (~3.6σ) in isobaric collisions: $\lvert A_{4\Delta\phi}\rvert$ = 0.47±0.13(stat)±0.05(sys)
  - $\lvert A_{4\Delta\phi}\rvert$ predicted by QED-EPA is 0.40

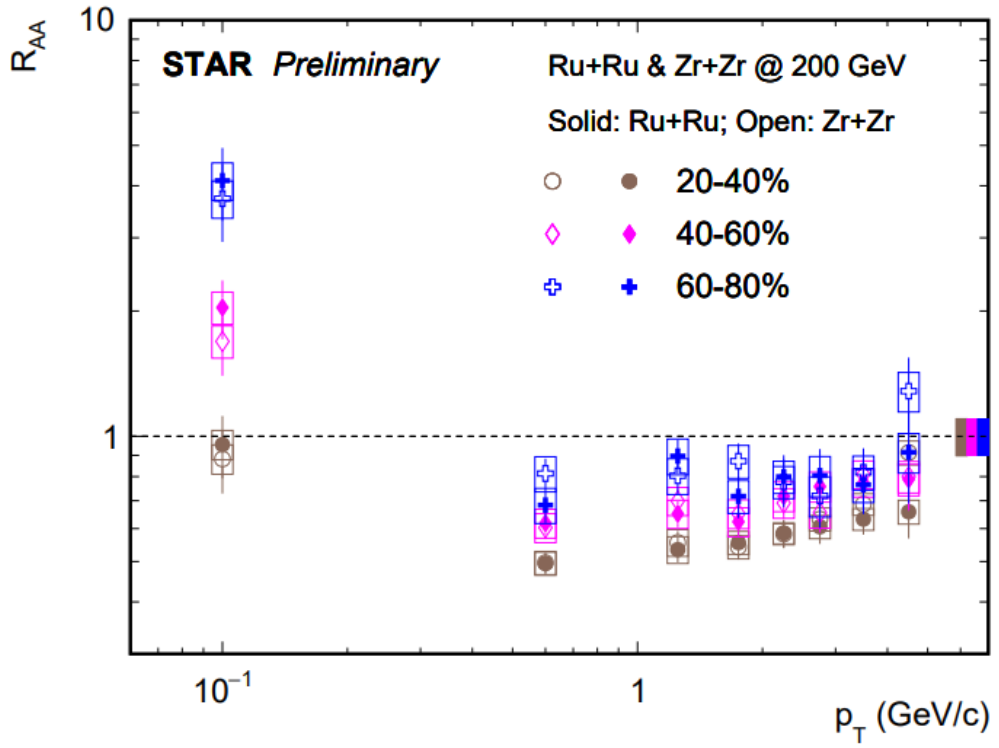
Summary

- Enhancements of J/ψ and e^+e^- production at very low p_T have been observed in peripheral isobaric collisions
- The collision species dependence of photon-induced production have been measured at STAR
  - The initial EM field seems to be different in peripheral Ru+Ru and Zr+Zr collisions
  - After taking out the charge difference, the excess yield of J/ψ is mostly independent of collision system, while e^+e^- shows an impact parameter dependence
- The cos(4$\Delta\phi$) signal is prominent (~3.6σ) in isobaric collisions, and there is a hint that the magnitude of cos(4$\Delta\phi$) modulation in isobaric collisions is possibly higher than that in Au+Au collisions

Thank you!

Back up

Invariant Yield and Nuclear Modification Factor of J/ψ



- The R_{AA} is significantly higher than unity at the very low p_T range