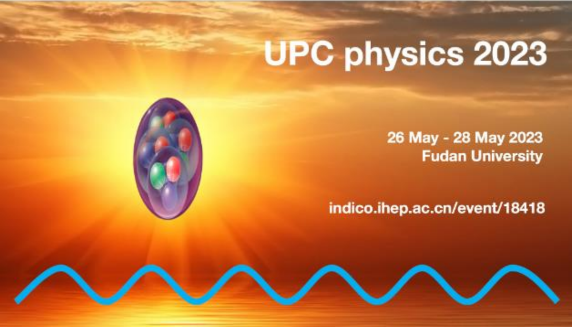

Initial electromagnetic field dependence of photon-induced production in isobaric collisions at STAR

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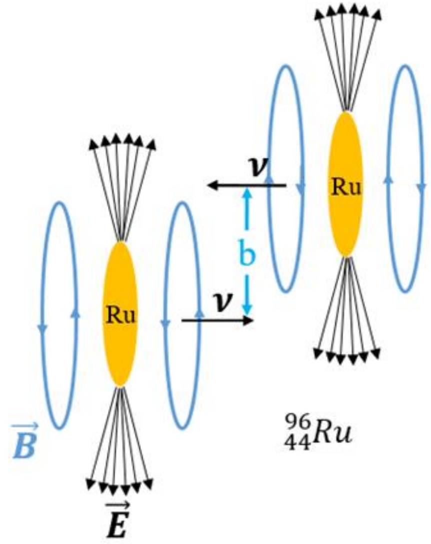
Supported in part by

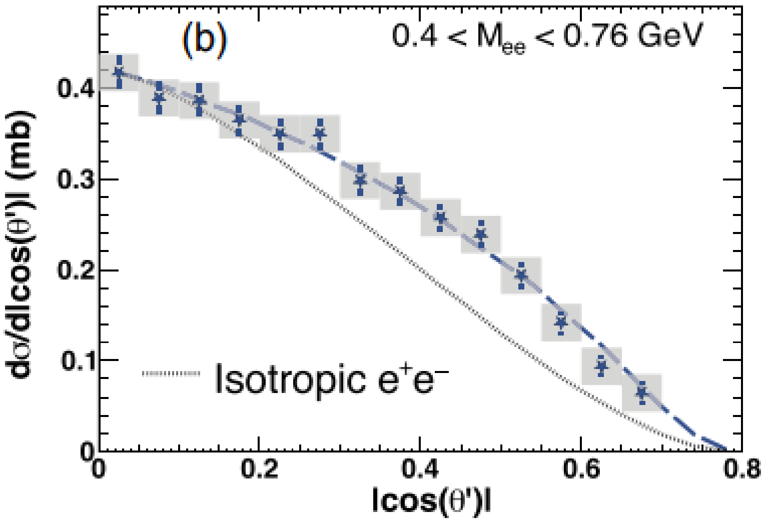
Outline

- 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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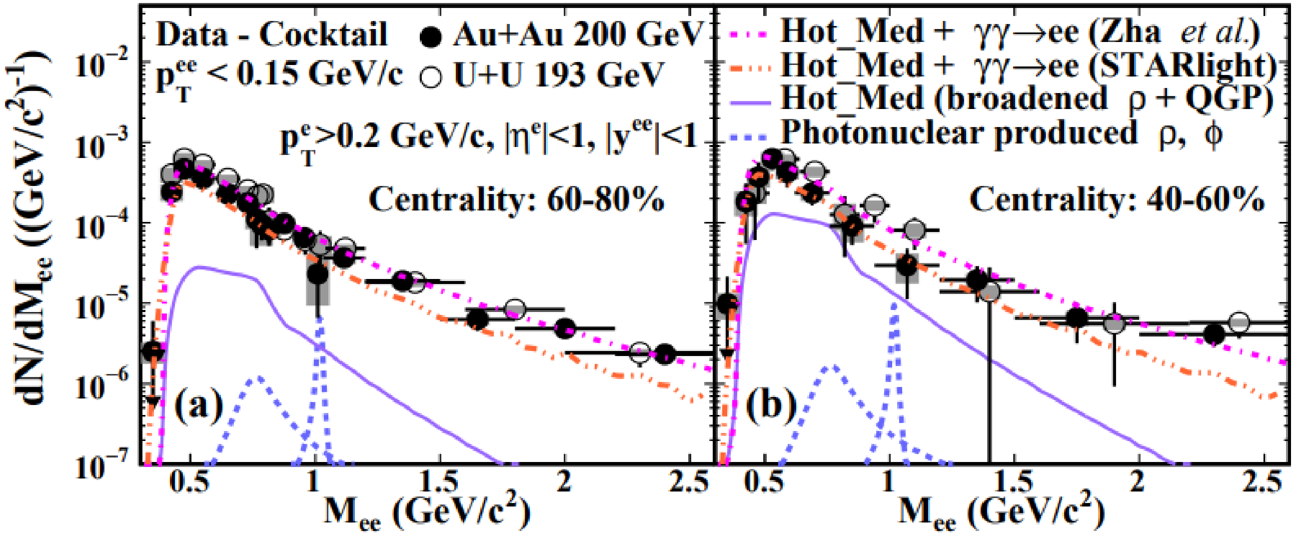
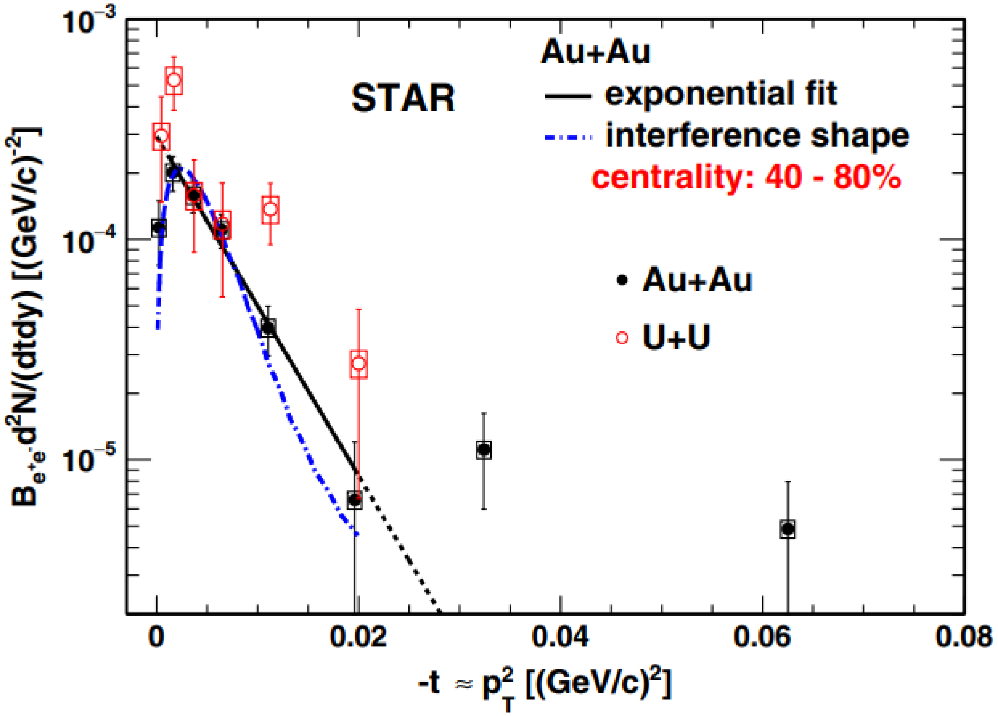
Photon-induced Production in Peripheral Collisions

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





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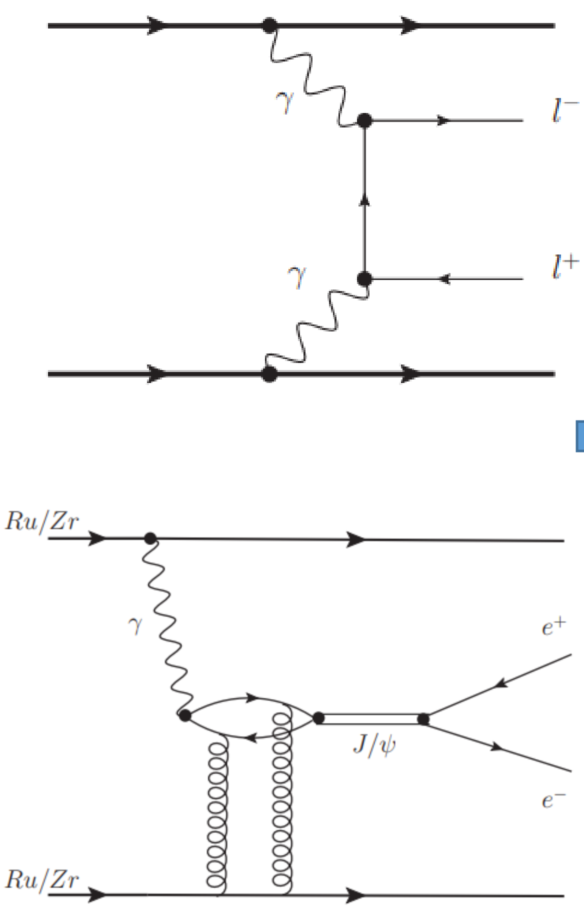
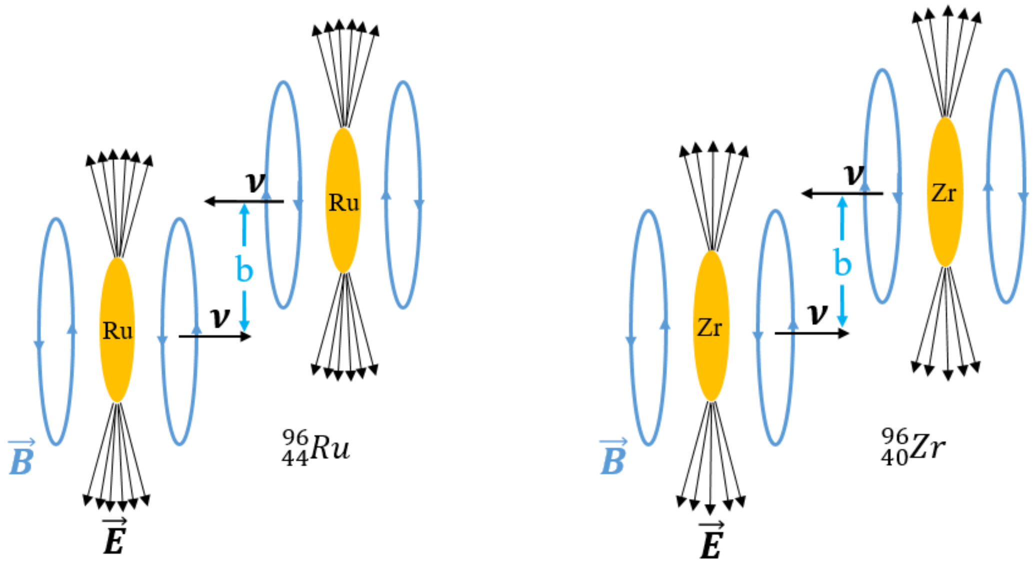
- The enhancements of J/ψ and e^+e^- production at very low $\mathrm{p_T}$ have been observed in peripheral collisions
- Photon-induced interactions can explain the observed enhancements

Photon-induced Production in Peripheral Collisions

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



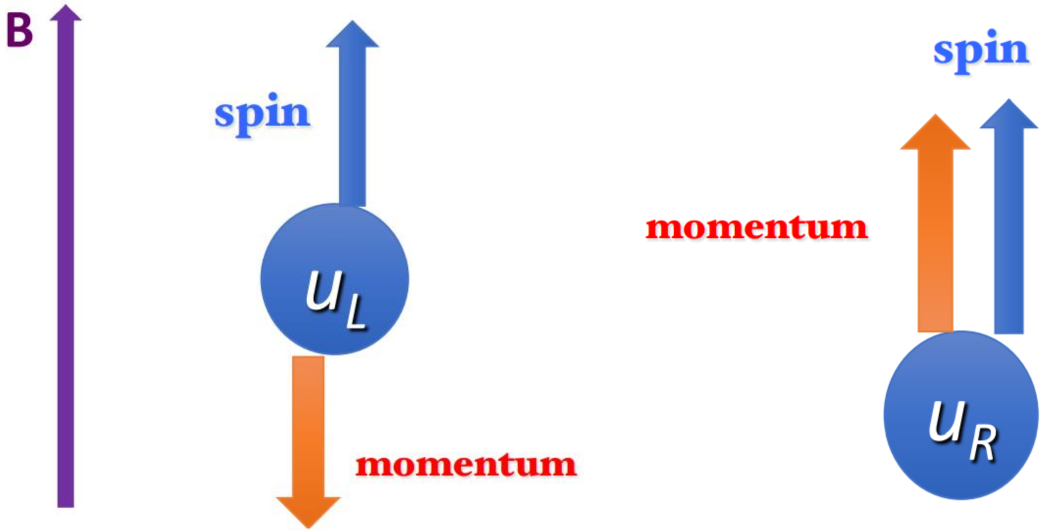
- Charge (Z)
- Impact parameter
- …



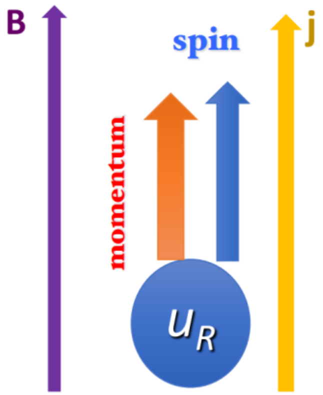
- Photon-induced production is sensitive to initial EM field:
  - Charge (Z) of the colliding nuclei
  - Collision system

Implication on the Search for Chiral Magnetic Effect

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



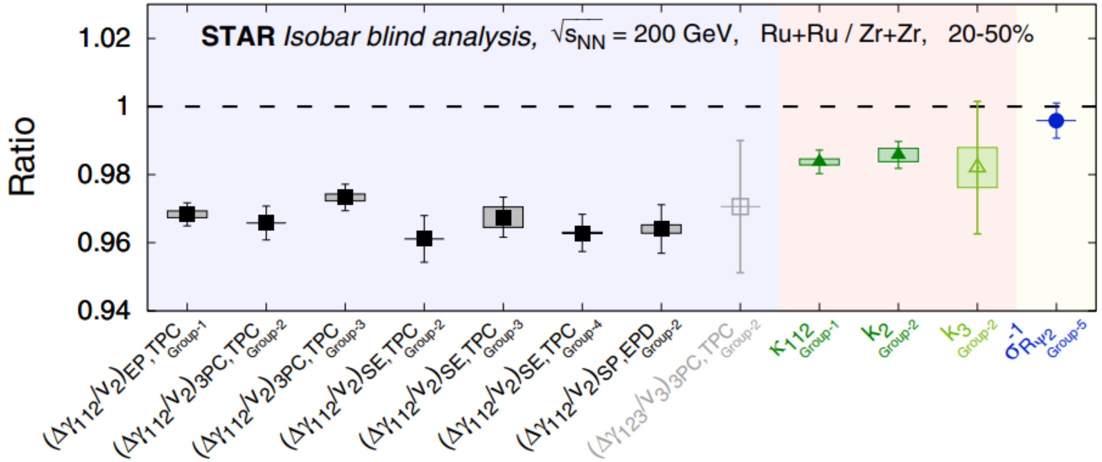
Heavy ion collisions:
- Strong magnetic fields
- Quark-Gluon Plasma
- Imbalance of left-handed & right-handed quarks



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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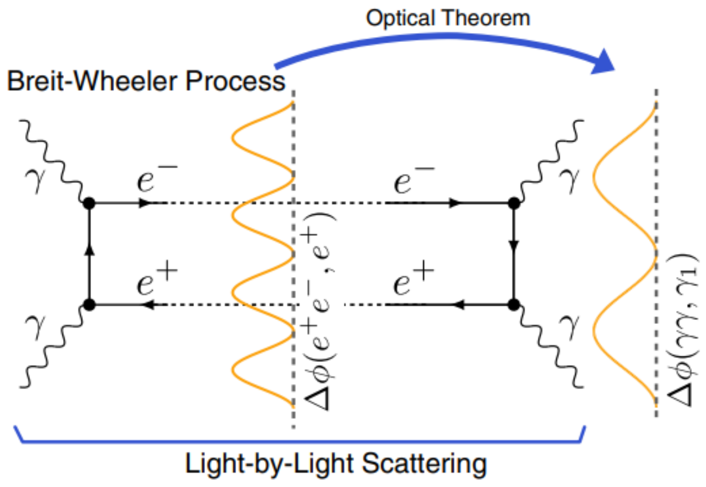
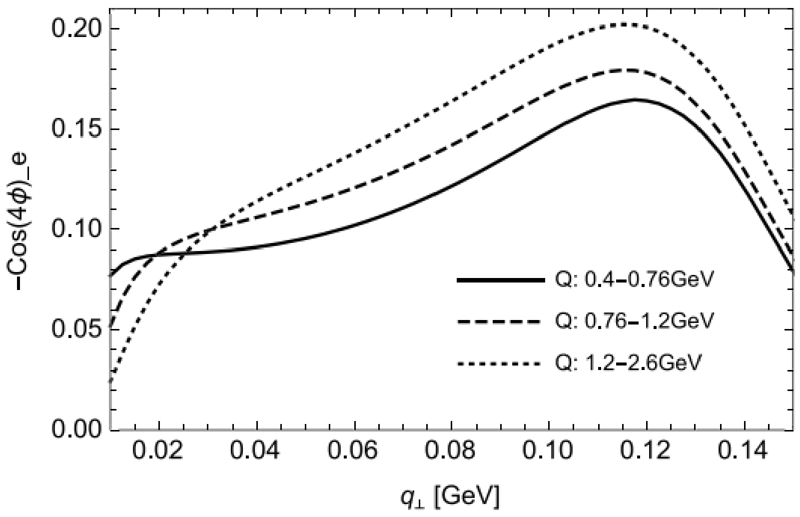
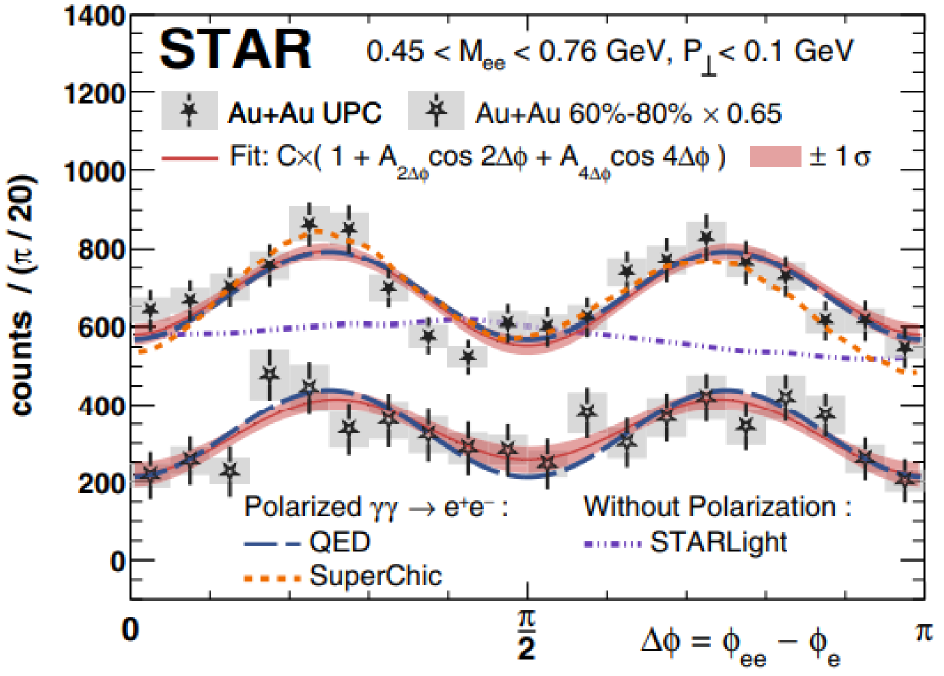
Birefringence of the QED Vacuum



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



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



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

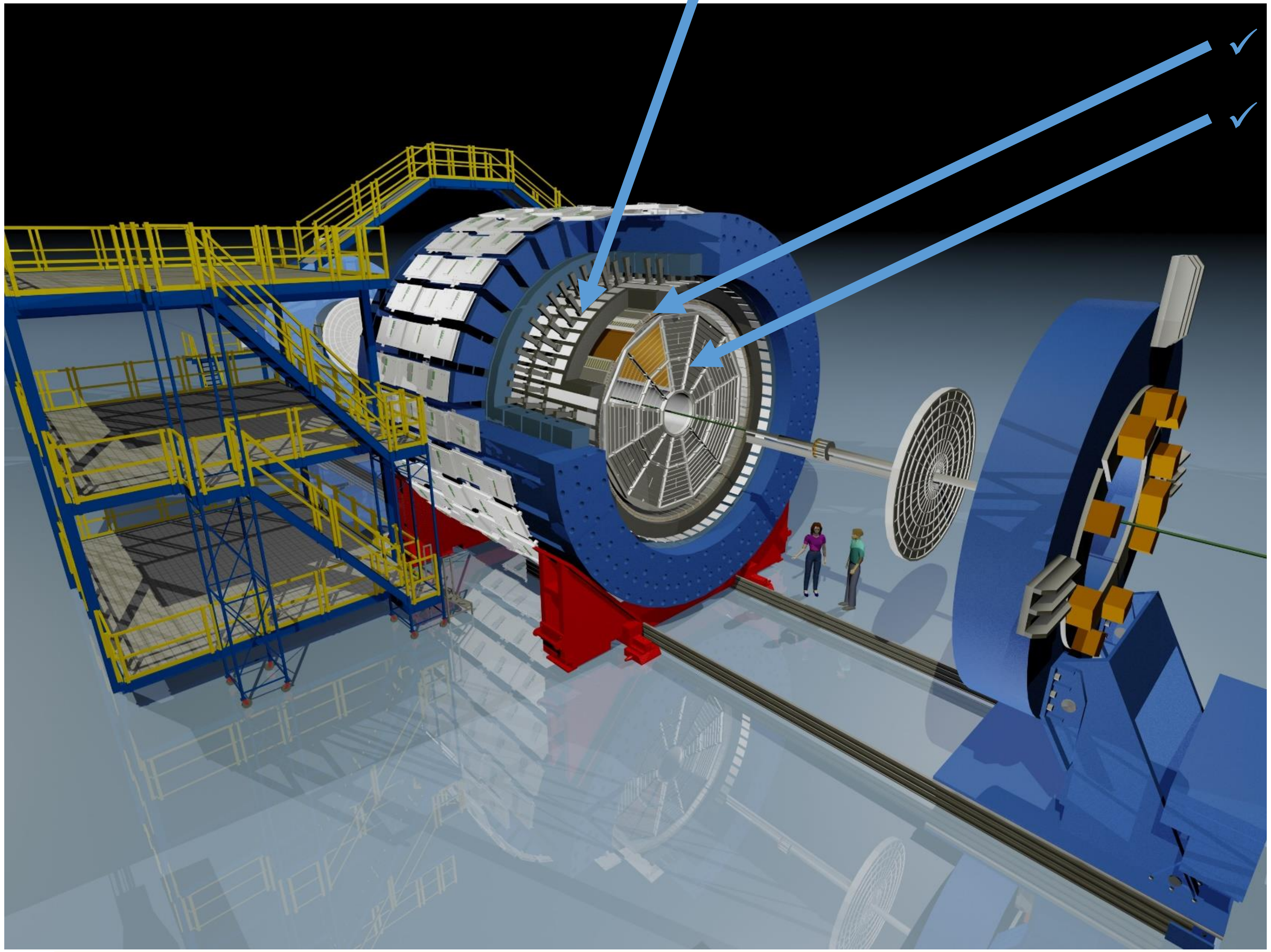
- Investigate collision system dependence of cos($4\Delta\phi$) modulation

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



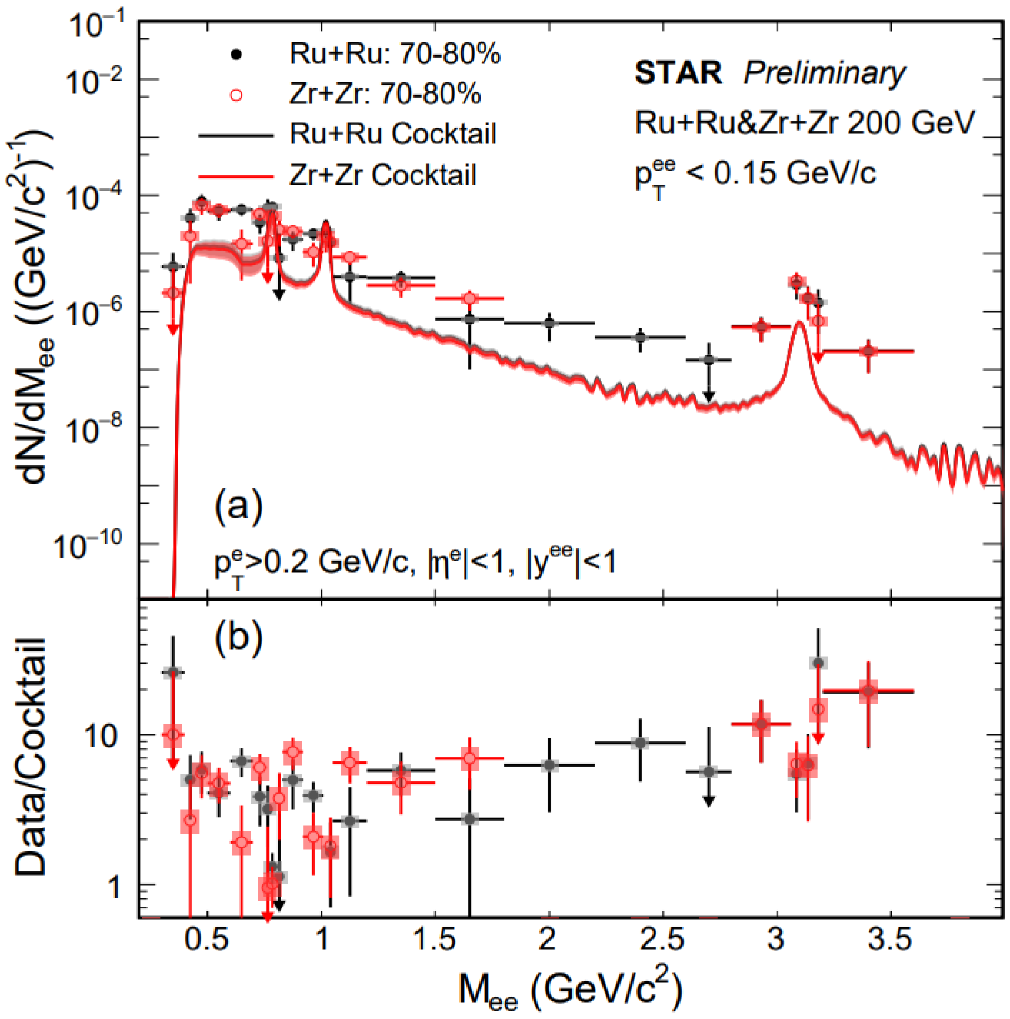
Collision species (taken in 2018)

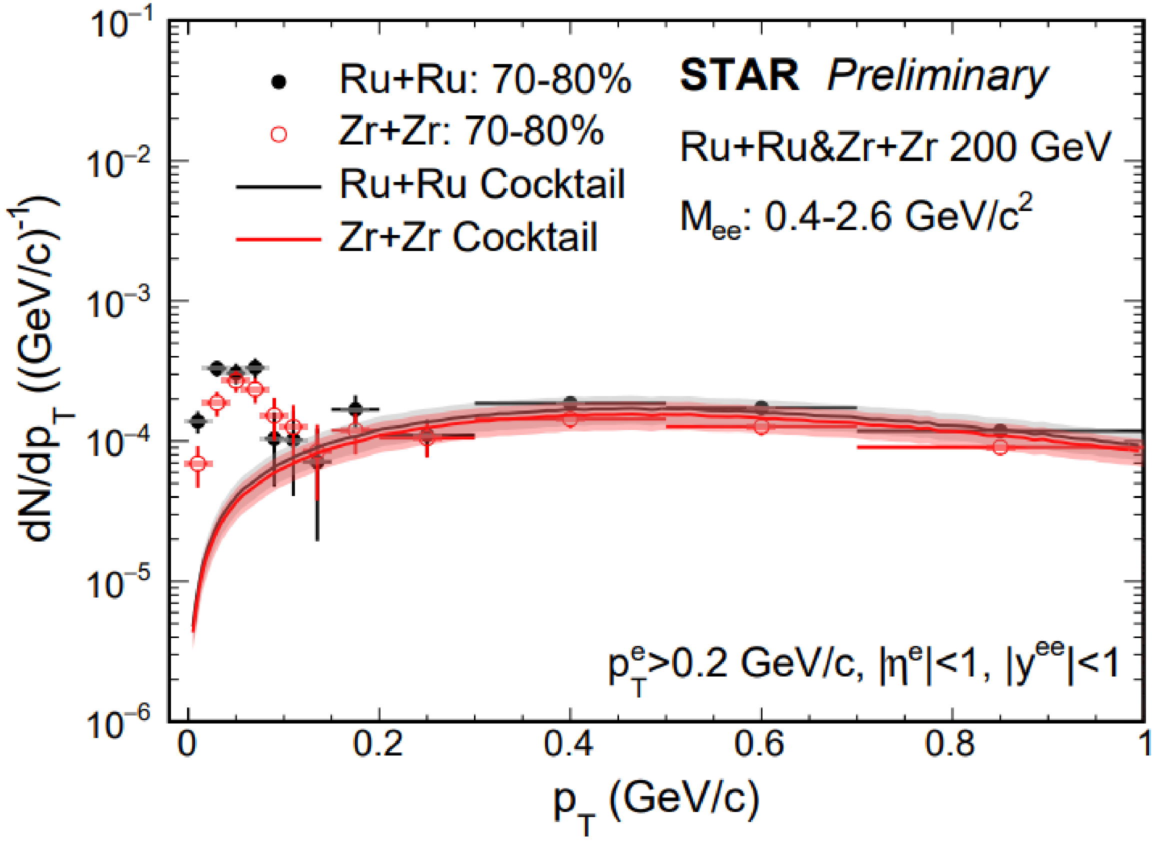
- ${}^{96}_{44}Ru + {}^{96}_{44}Ru$, $\sqrt{s_{\rm NN}}$=200GeV (~2B)
- ${}^{96}_{40}Zr + {}^{96}_{40}Zr$, $\sqrt{s_{\rm NN}}$=200GeV (~2B)

Acceptance cuts:

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

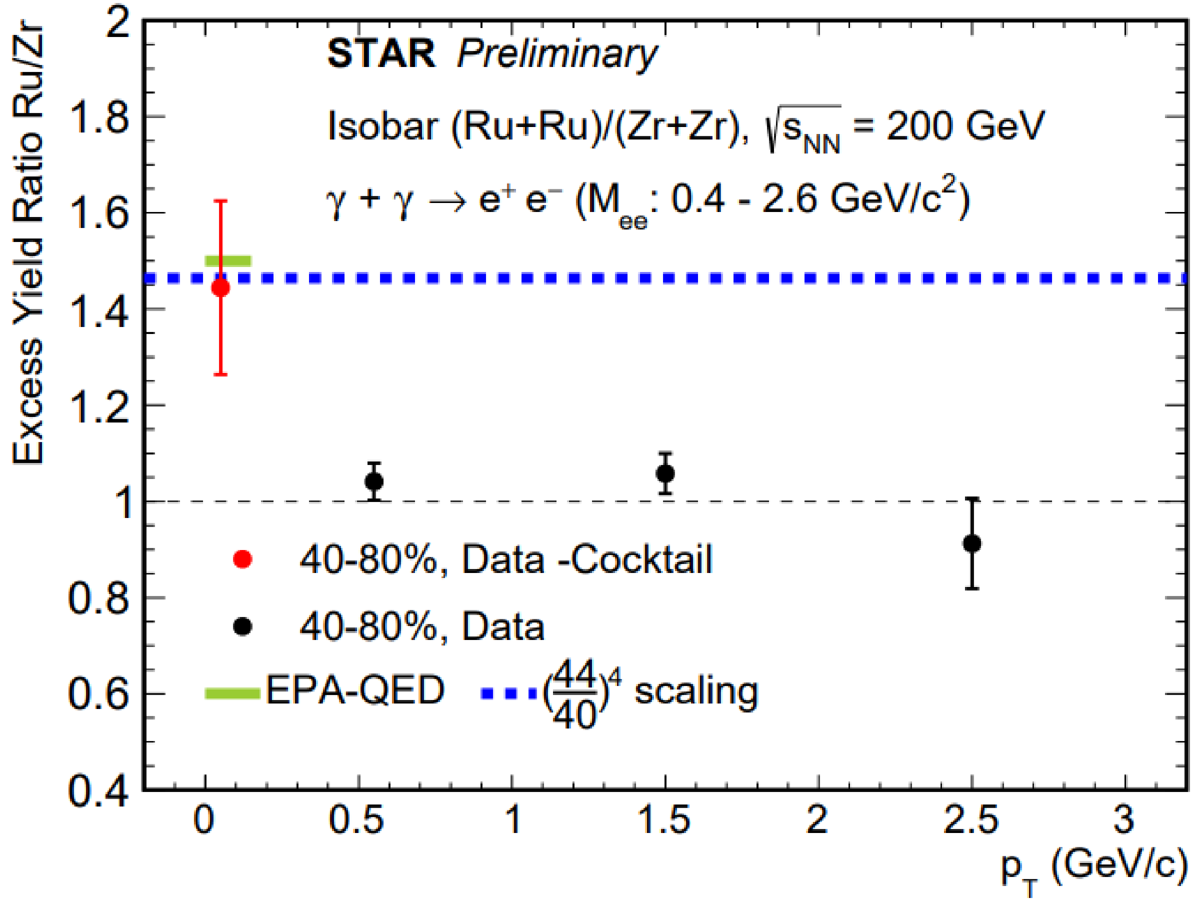
Invariant Mass and Transverse Momentum Distributions of e^+e^-





- Excesses above known hadronic contributions are observed at low p_T

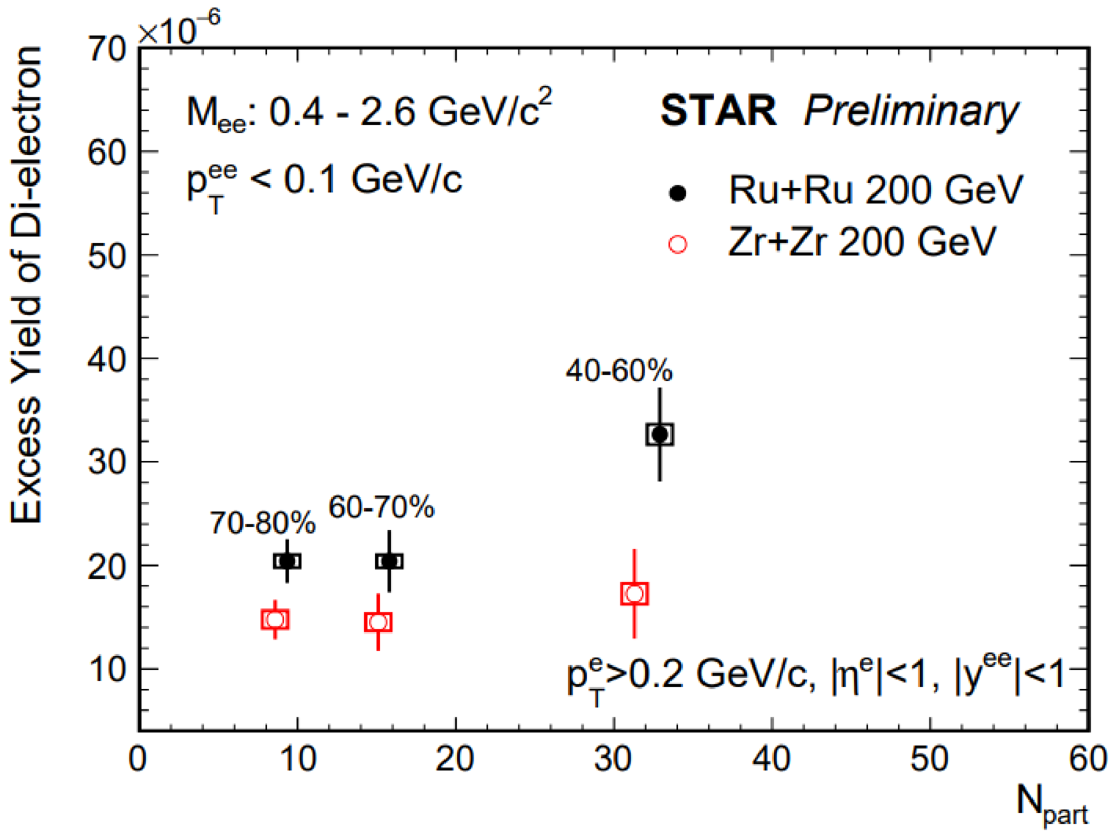
p_T Dependence of Excess Yield Ratio

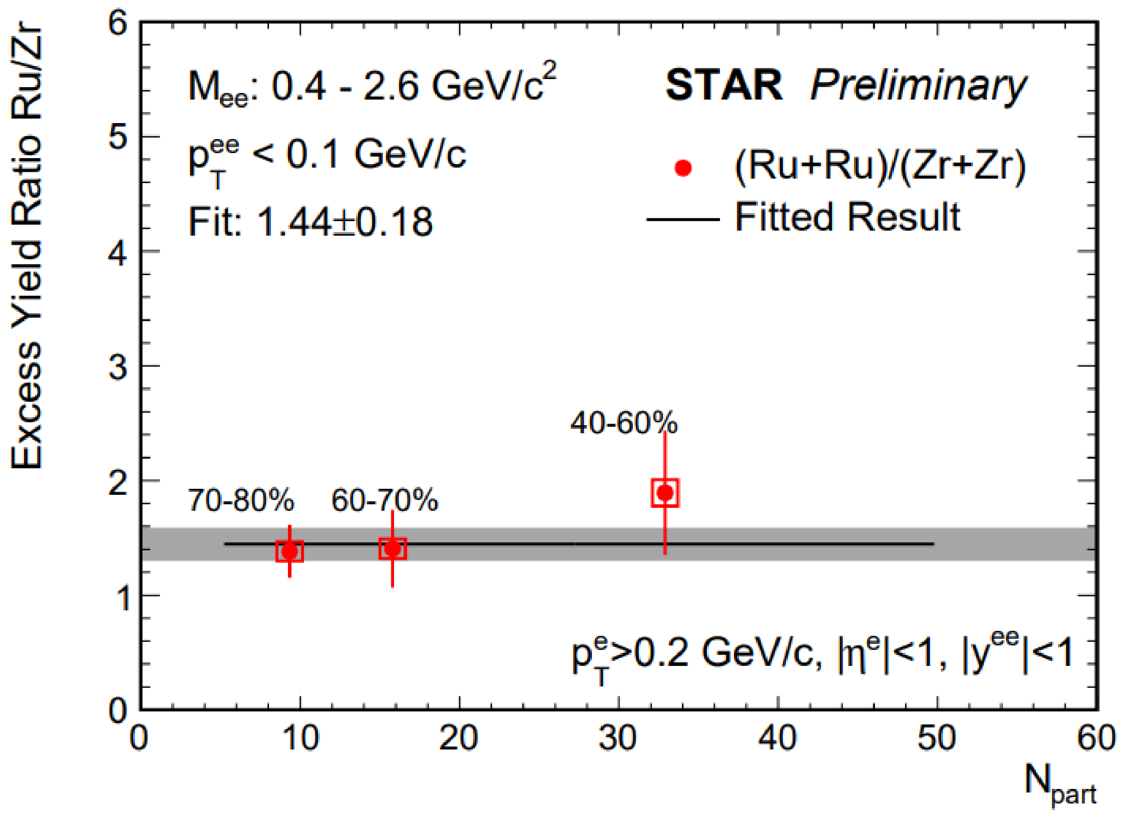


W. Zha et al, Phys. Lett. B 789 (2019) 238-242

- 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

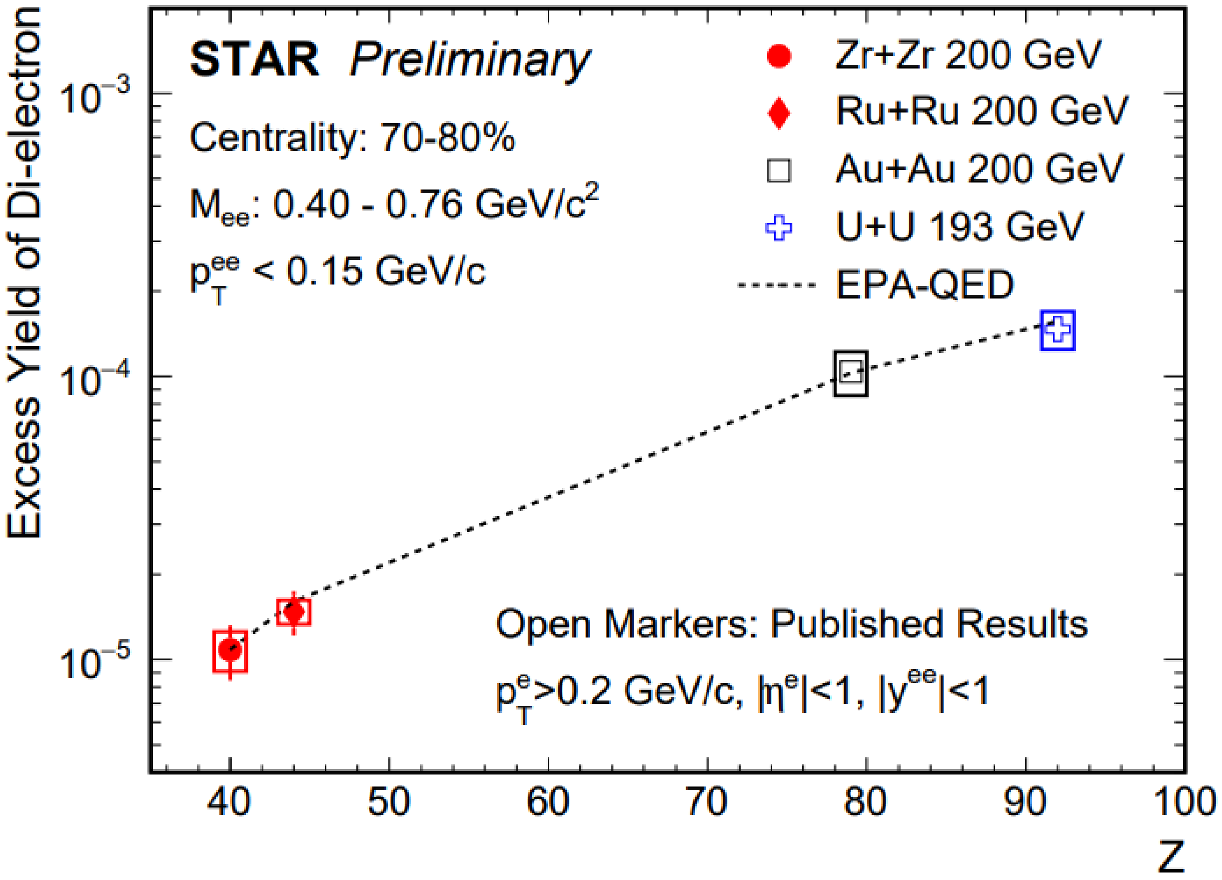
Centrality Dependence of Excess Yield

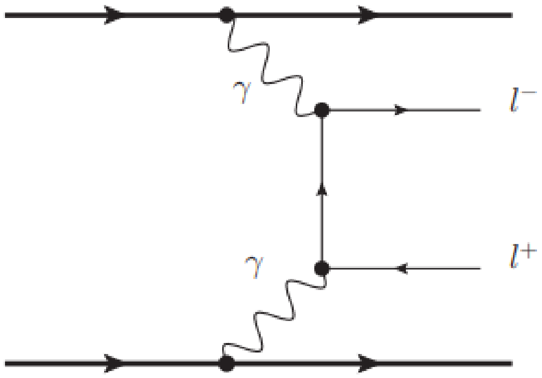




- The low p_T (p_T < 0.1 GeV/c) e^+e^- excess and the ratio of excess are shown as a function of N_{part}
- The excess yields in Ru+Ru collisions are systematically higher compared to those from Zr+Zr collisions
- A constant function is used to fit the ratio and is about 2.4σ higher than unity

Charge Dependence of Excess Yield

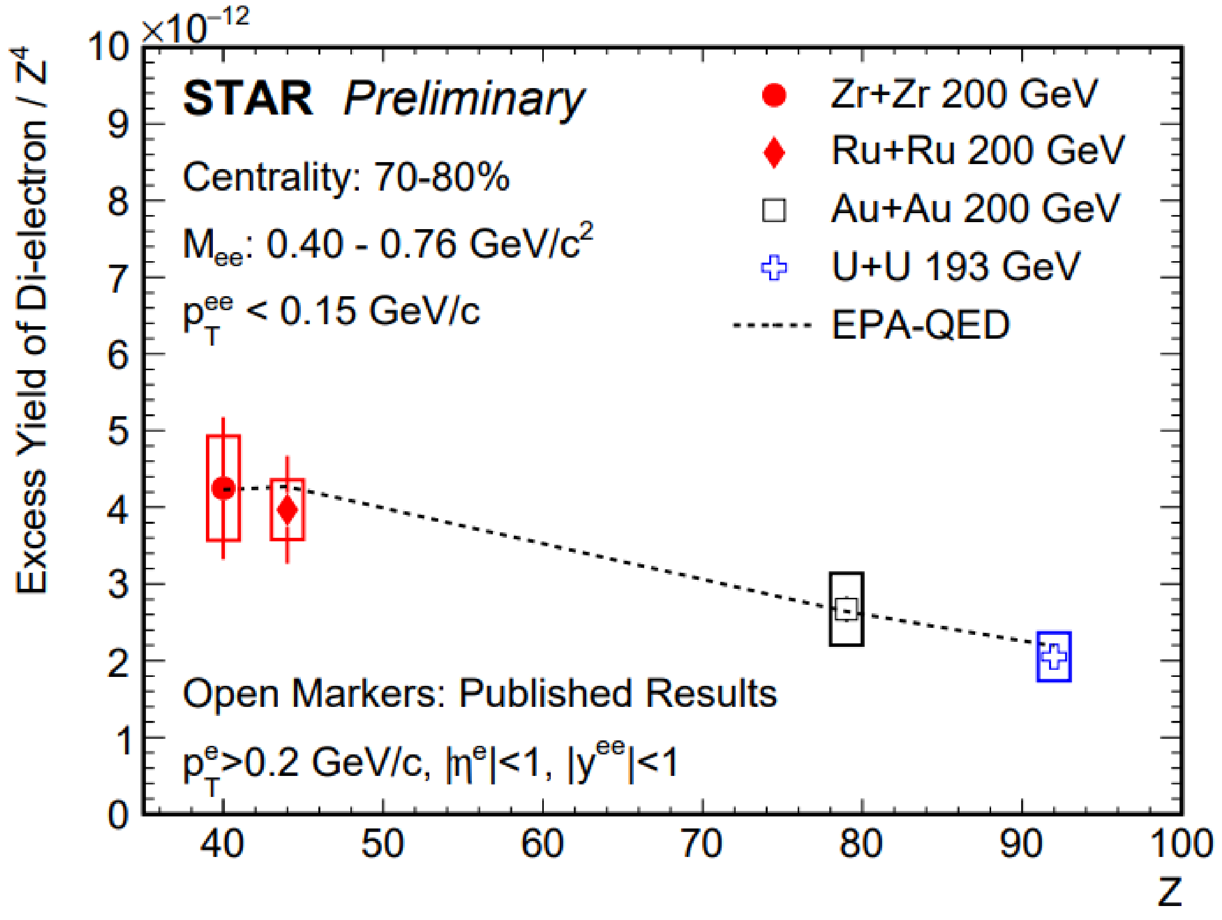


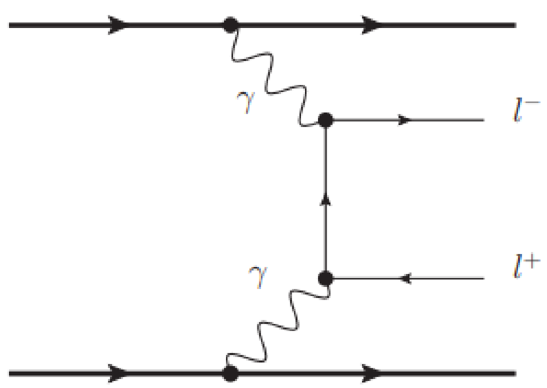


- The excess yields in isobaric collisions are significantly smaller compared to those in Au+Au and U+U collisions
- The charge difference is the dominant driving factor ($\propto Z^4$)

J.Adam et al. (STAR) Phys. Rev. Lett. 121 (2018) 132301
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

J.Adam et al. (STAR) Phys. Rev. Lett. 121 (2018) 132301
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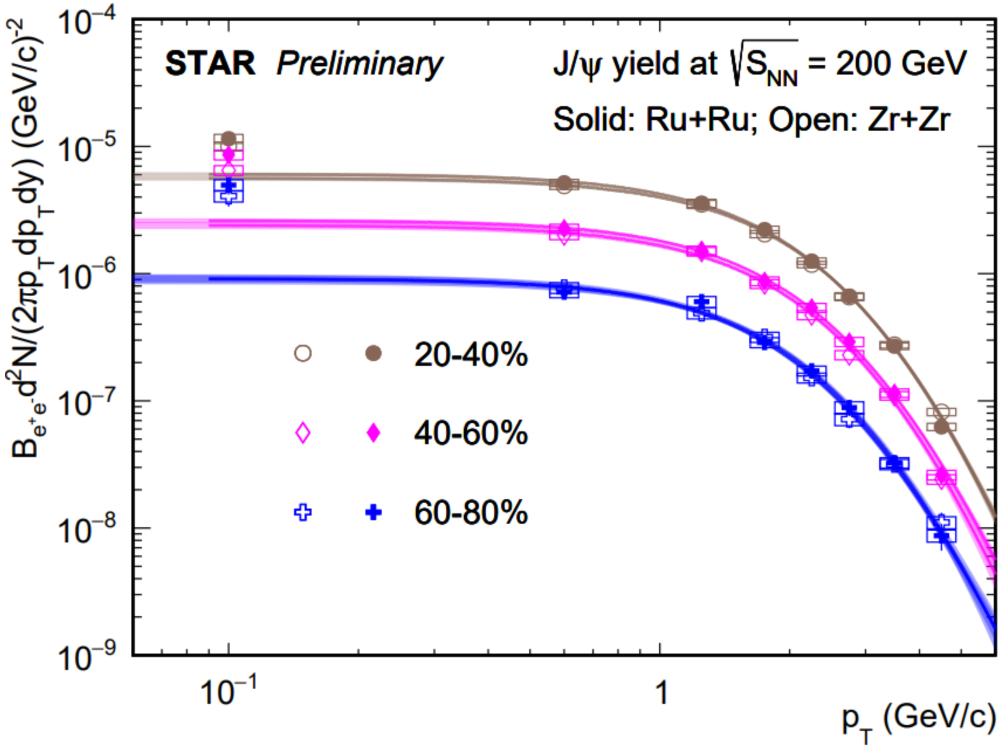
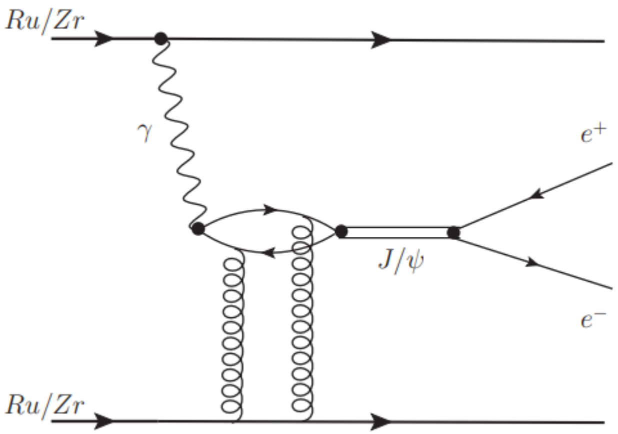
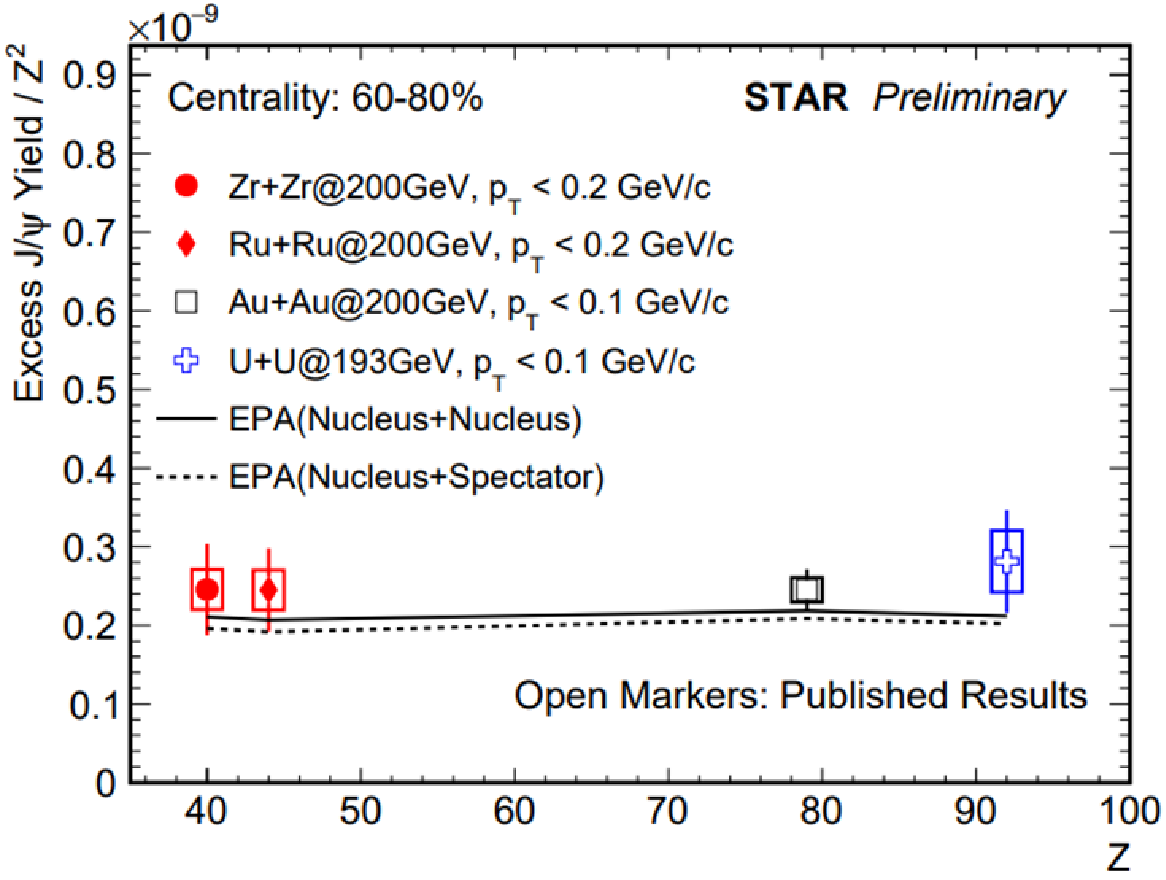
Invariant Yield and Nuclear Modification Factor of J/ψ



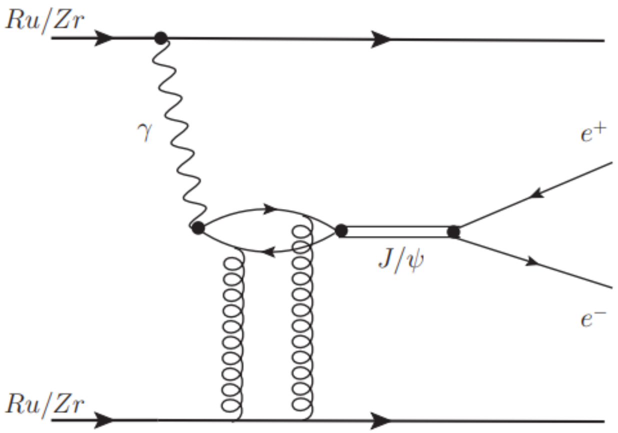


- The yield spectra are fitted by the Tsallis function at p_T larger than 0.2 GeV/c, and extrapolated to low p_T range to illustrate the expected hadronic contribution
- Data are well described by the fitted curves above 0.2 GeV/c, but show significant enhancements at low p_T range

Collision System Dependence of Scaled Excess J/ψ yield

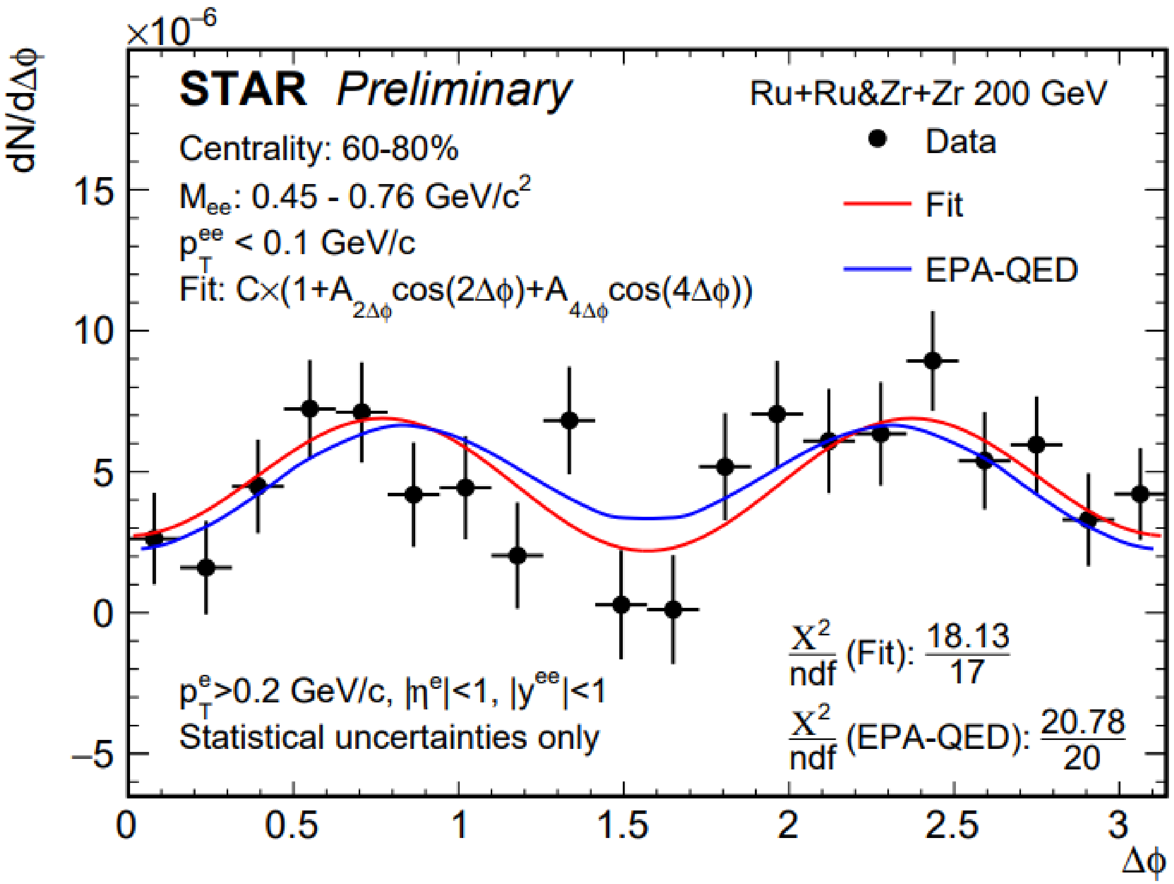


J.Adam et al. (STAR) Phys. Rev. Lett. 123 (2019) 132302.
W. Zha et al. Phys. Rev. C 97, 044910 (2018)



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

Summary

- Enhancements of J/ψ and e^+e^- production at very low $\mathrm{p_T}$ have been observed in peripheral isobaric collisions

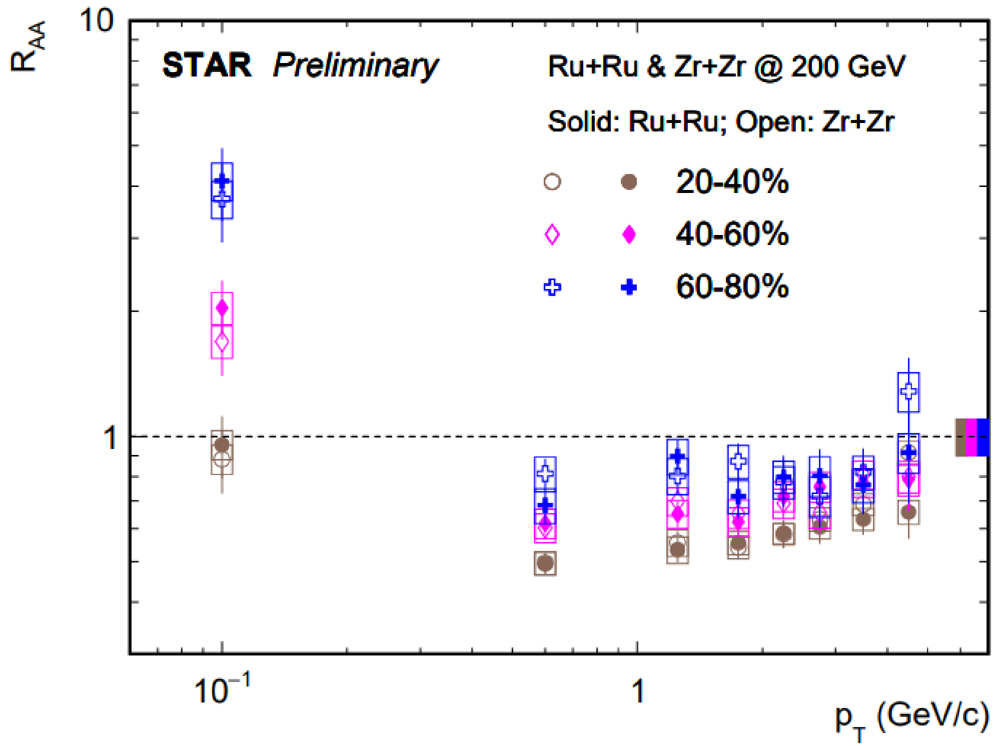
- The collision species dependence of photon-induced production have been measured at STAR
  - The initial EM field seems to be different in peripheral Ru+Ru and Zr+Zr collisions
  - After taking out the charge difference, the excess yield of J/ψ is mostly independent of collision system, while e^+e^- shows an impact parameter dependence

- The cos(4Δϕ) signal is prominent (~3.6σ) in isobaric collisions, and there is a hint that the magnitude of cos(4Δϕ) 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