UPC 2023 First international workshop on the physics of Ultra Peripheral Collisions

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)

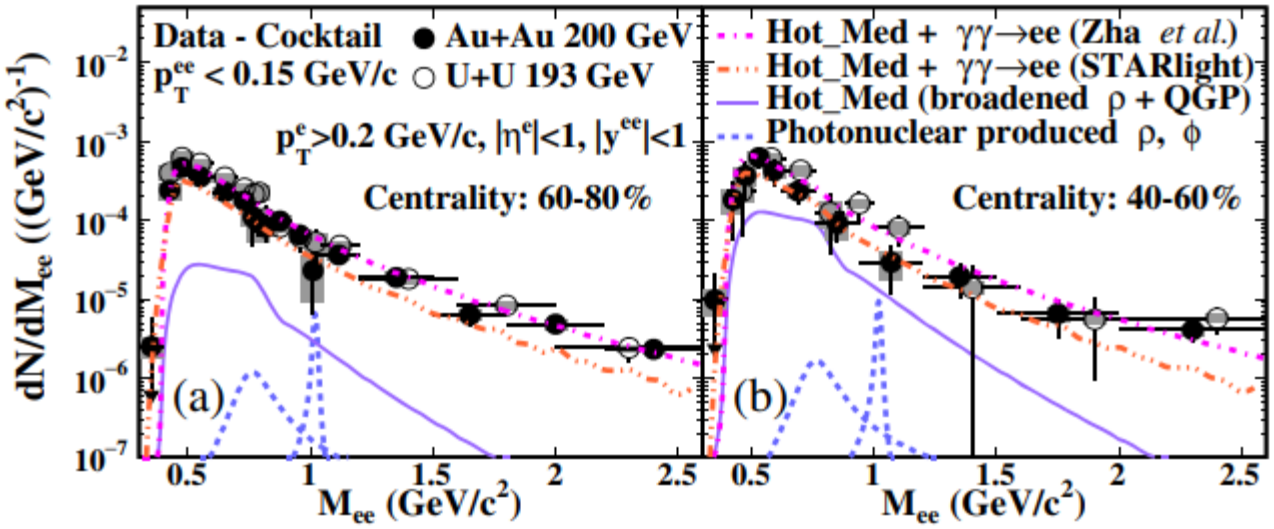
Supported in part by
U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- Motivation and the STAR experiment
- e^+e^- photoproduction in Ru+Ru and Zr+Zr collisions
- J/ψ photoproduction in Ru+Ru and Zr+Zr collisions
- Summary

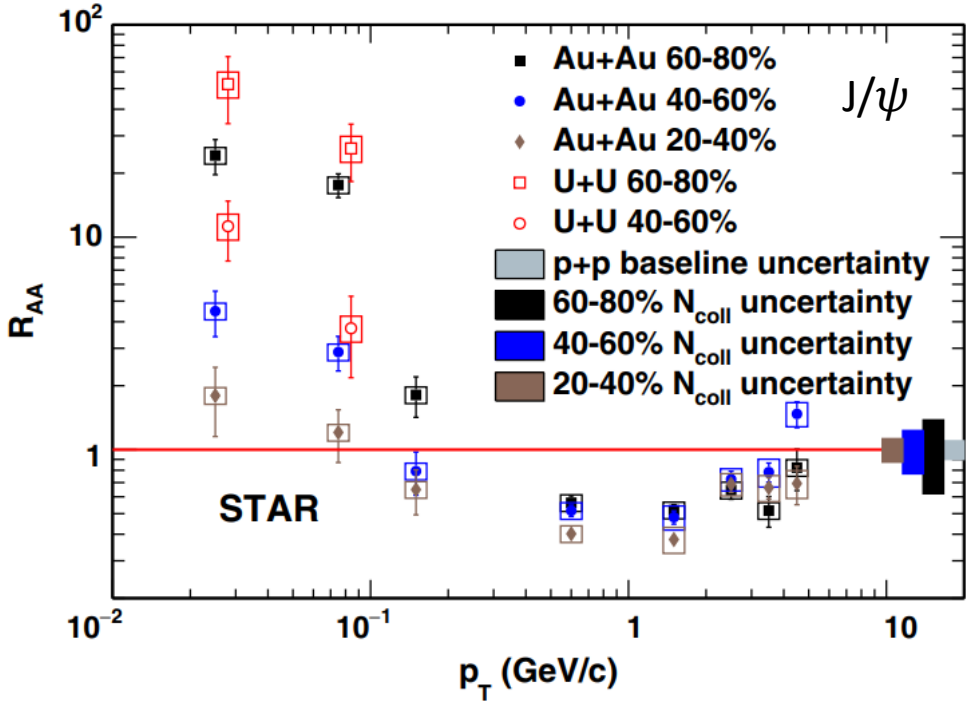
Photon-induced Production in Peripheral Collisions

- Photon-induced processes are traditionally studied in ultra-peripheral collisions (b>2R_A,UPCs)



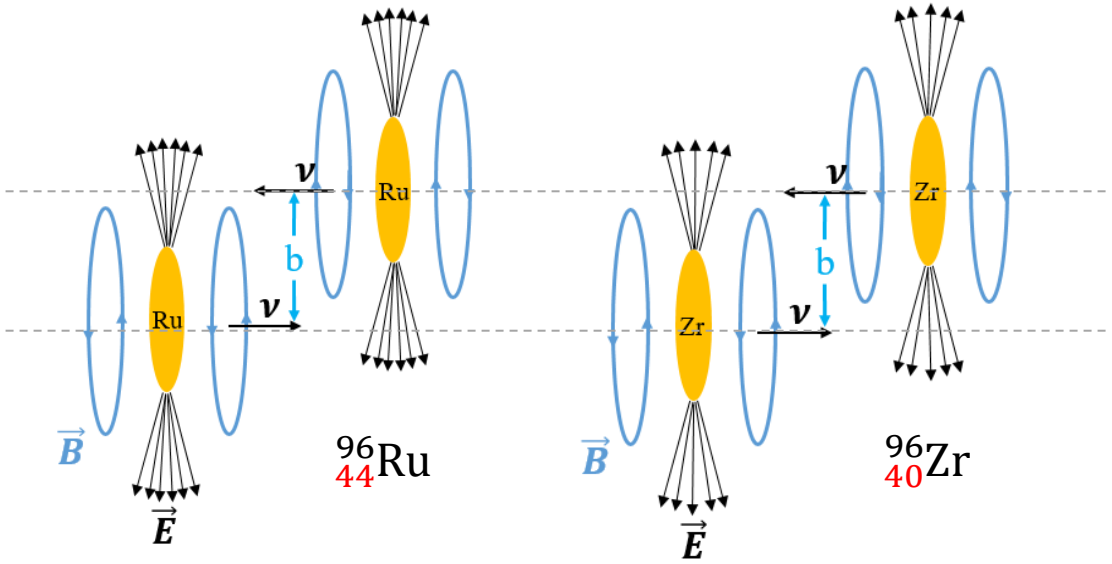
J.Adam et al. (STAR) Phys. Rev. Lett. 121 (2018) 132301

J.Adam et al. (STAR) Phys. Rev. Lett. 123 (2019) 132302.



- In the last few years, the enhancements of e^+e^- and J/ψ production at very low p_T have been observed in peripheral heavy-ion collisions
  - ➢ Well described by theoretical calculations considering photon-induced interactions

Photon-induced Production in Peripheral Collisions

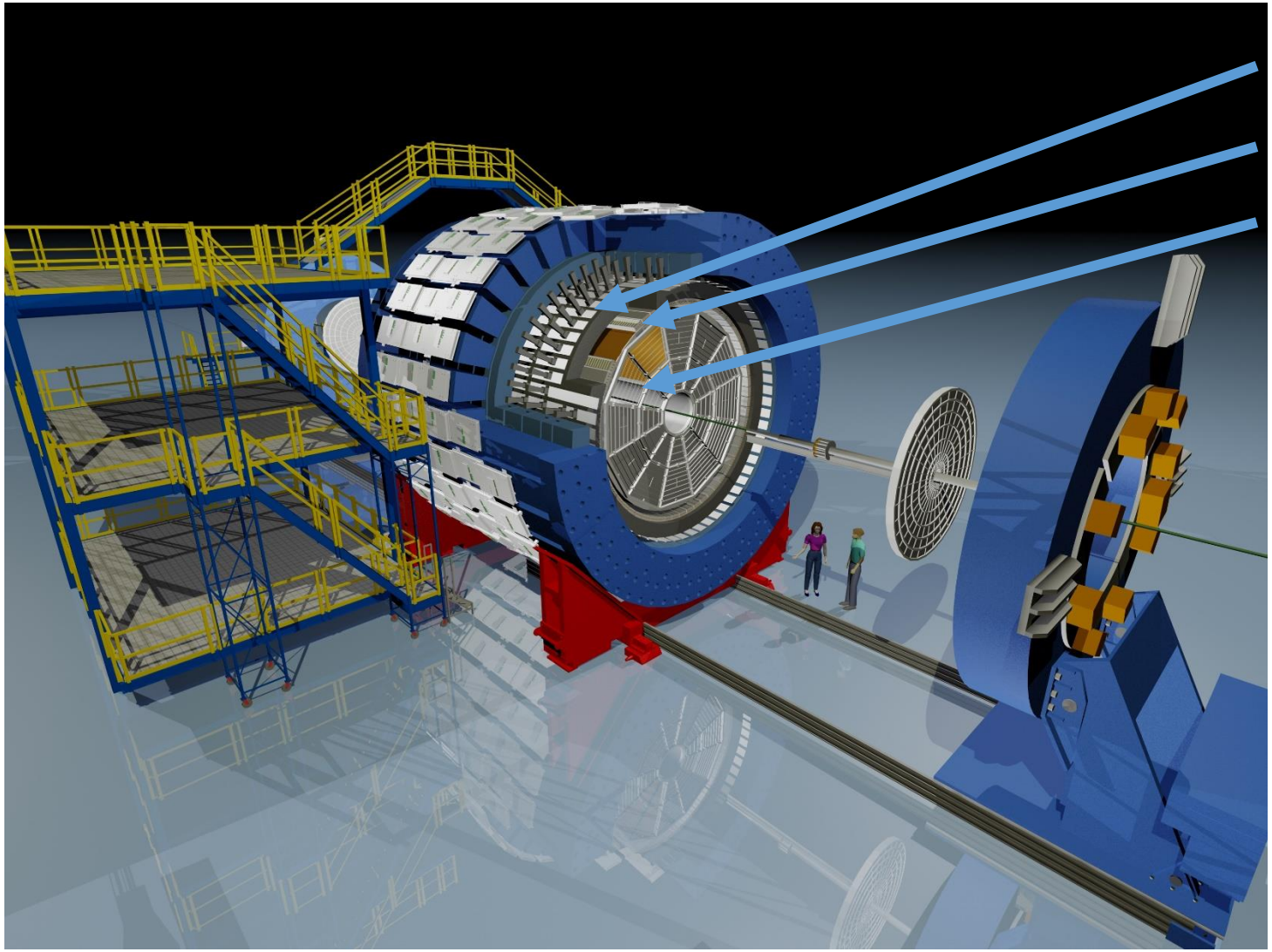


$\vec{E} \perp \vec{B} \perp \vec{k}, |\vec{E}| \approx |\vec{B}|$

- Transverse EM fields are equivalent to a flux of quasi-real photons ($\propto Z^2$, and $q^2 \to 0$)
  - $\sigma_{\gamma\gamma \to ee} \propto Z^4$ & $\sigma_{\gamma A \to VA} \propto Z^2$
- High-energy heavy ion collisions can test QED under extreme conditions ($|\vec{B}| \approx 10^{14}$-$10^{16}$T)

- The isobaric collisions provide a unique opportunity to study the EM field dependence
  Zr (Z = 40) vs. Ru (Z = 44) vs. Au (Z = 79) vs. U (Z = 92)
- The coherent photon-nucleus interaction is sensitive to the gluonic structure of nuclear matter
  Pomeron (a color-neutral two-gluon state) exchange

The Solenoid Tracker At RHIC



- ✓ BEMC: E_0/p, high p_T electron identification
- ✓ TOF: Time of flight, particle identification
- ✓ TPC: Tracking, momentum and energy loss

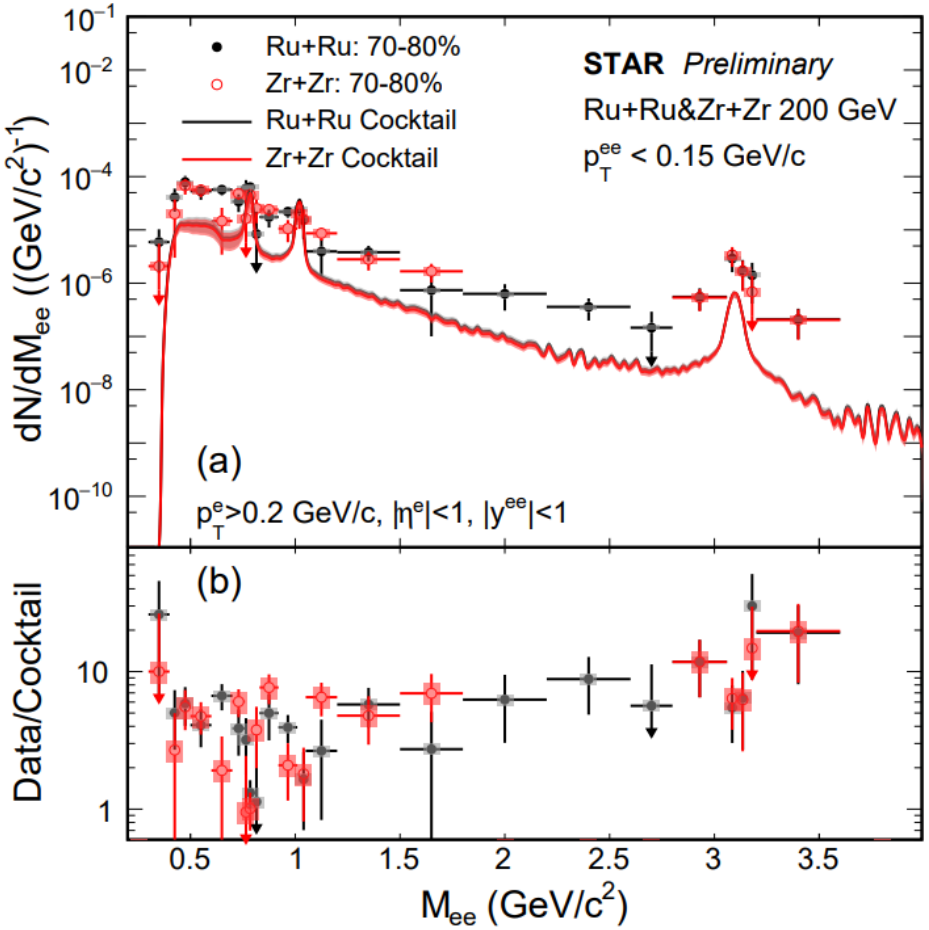
Collision species (taken in 2018)

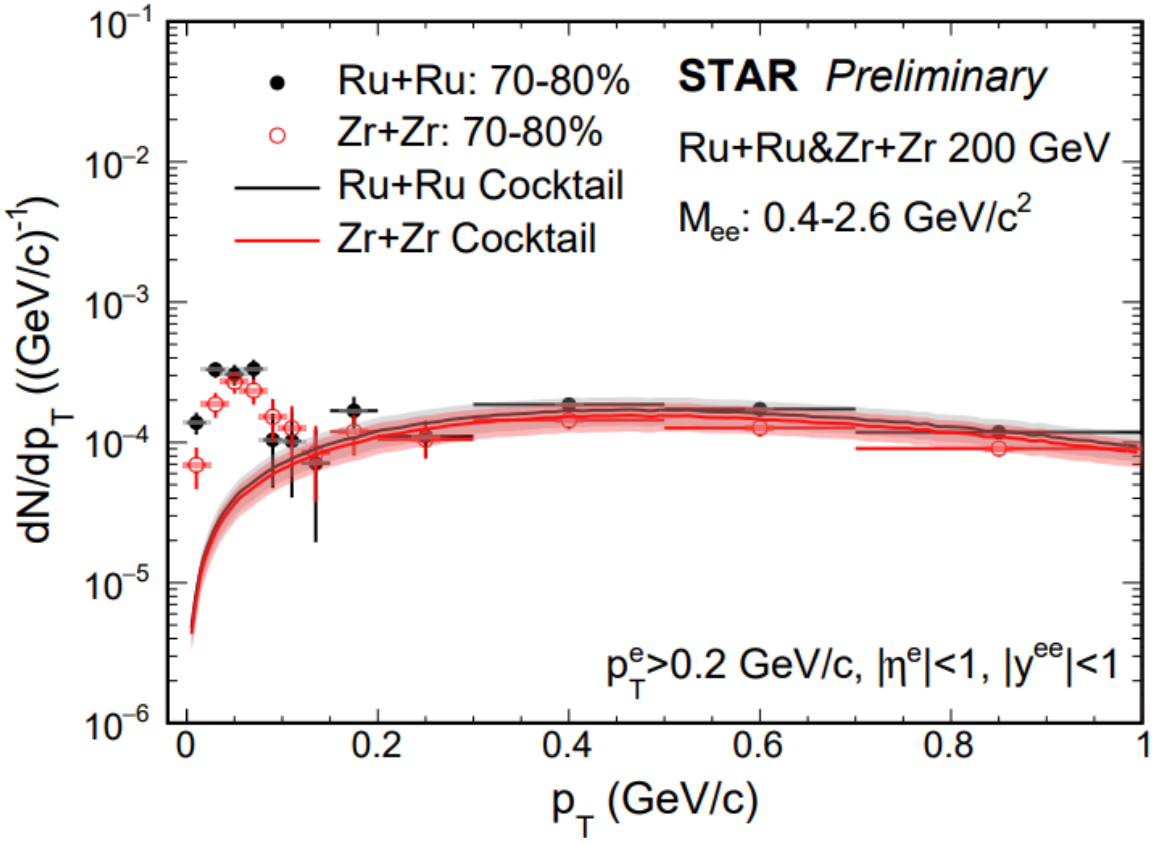
- $^{96}_{44}Ru+^{96}_{44}Ru$ (~2B events)
- $^{96}_{40}Zr+^{96}_{40}Zr$ (~2B events)

Kinematic acceptance:

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

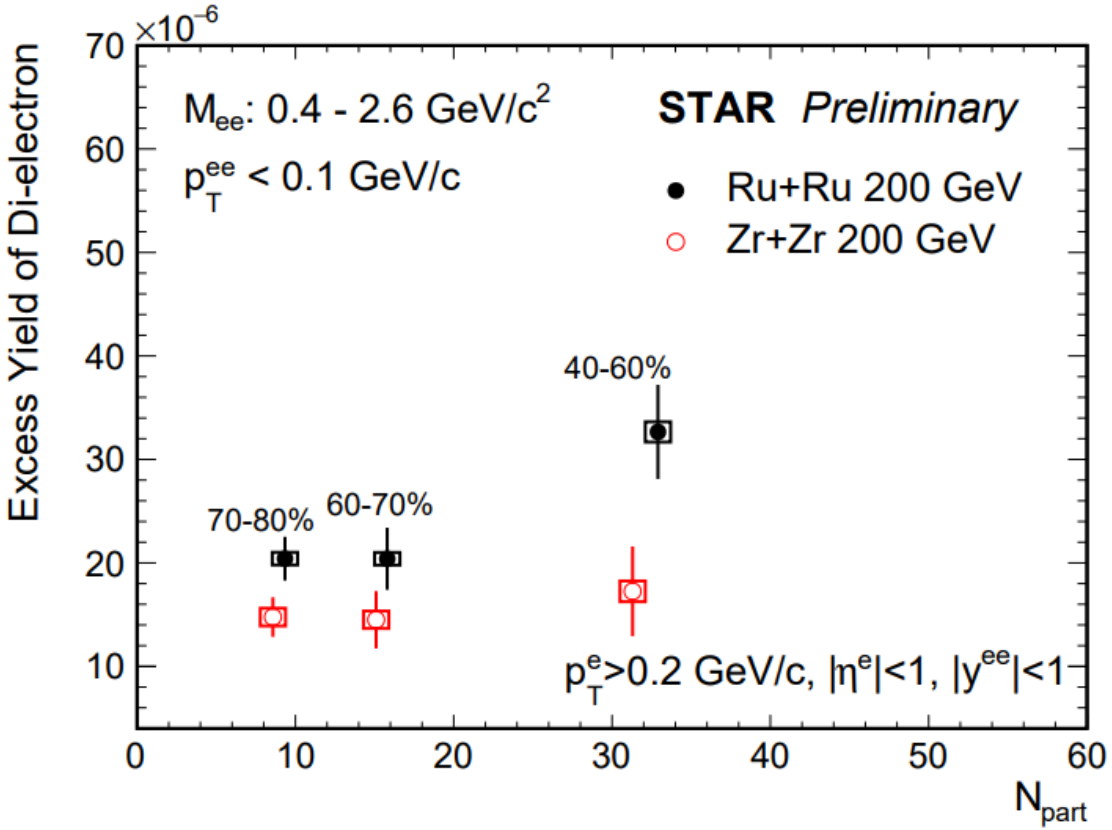
Invariant Mass and Transverse Momentum Distributions of e^+e^-

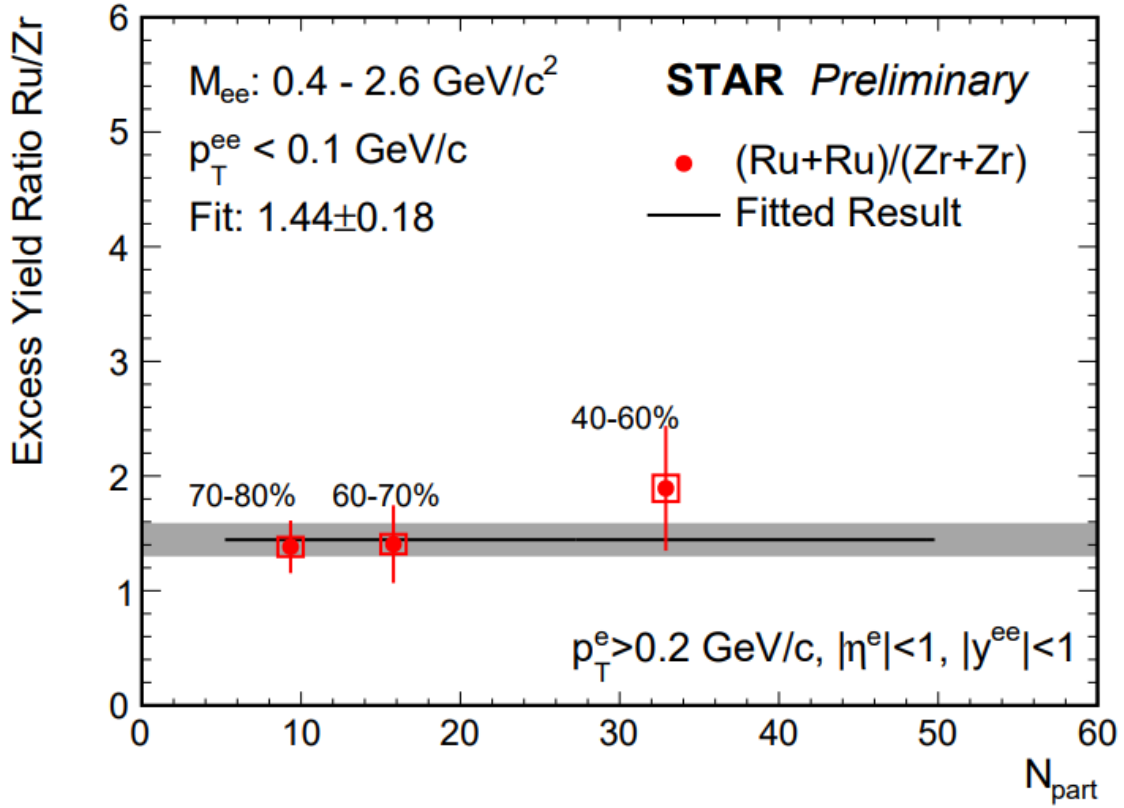




- Excesses above known hadronic production are observed at low-p_T in both Ru+Ru and Zr+Zr peripheral collisions

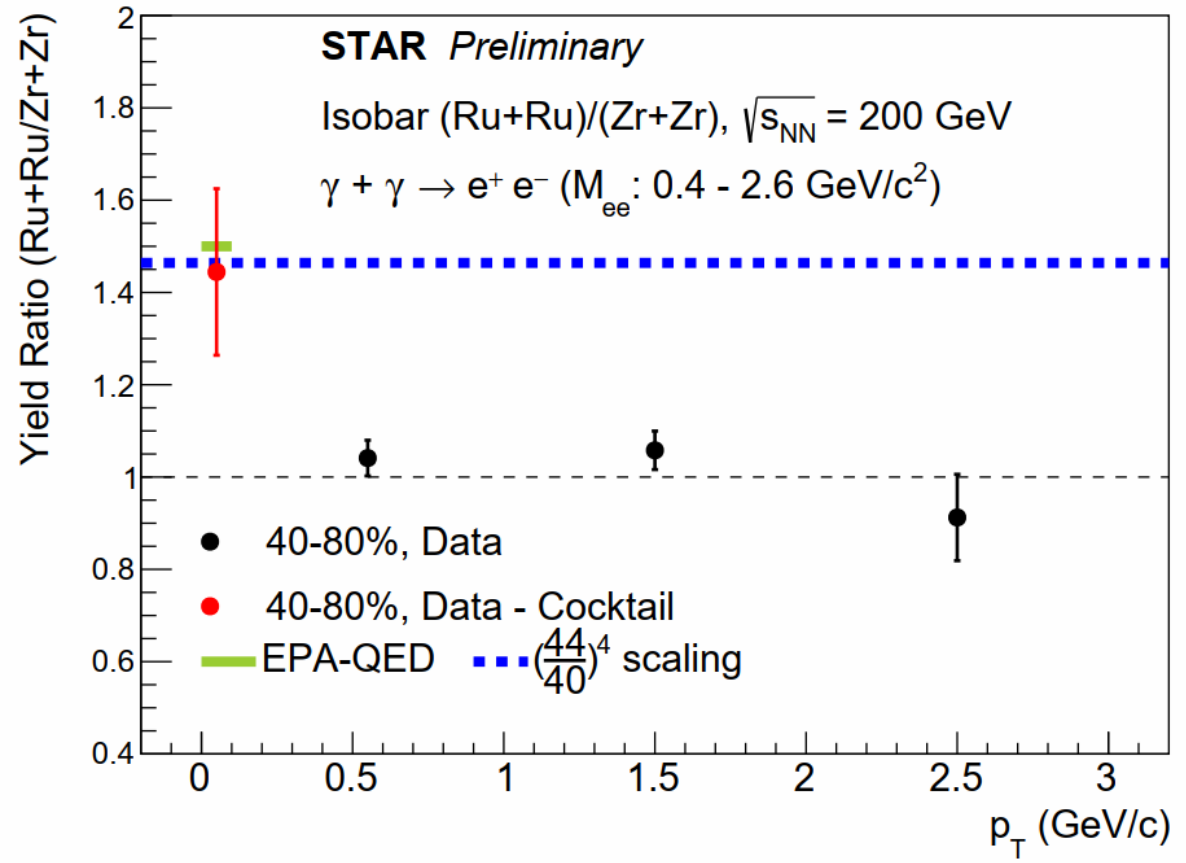
Centrality Dependence of Excess Yield





- The low-p_T (p_T < 0.1 GeV/c) e^+e^- excess and the ratio of excess are shown as a function of $\mathrm{N_{part}}$
- The excess yields in Ru+Ru collisions are systematically higher than those in Zr+Zr collisions
- A constant function is used to fit the ratio, which is close to $\left(\frac{44}{40}\right)^4$

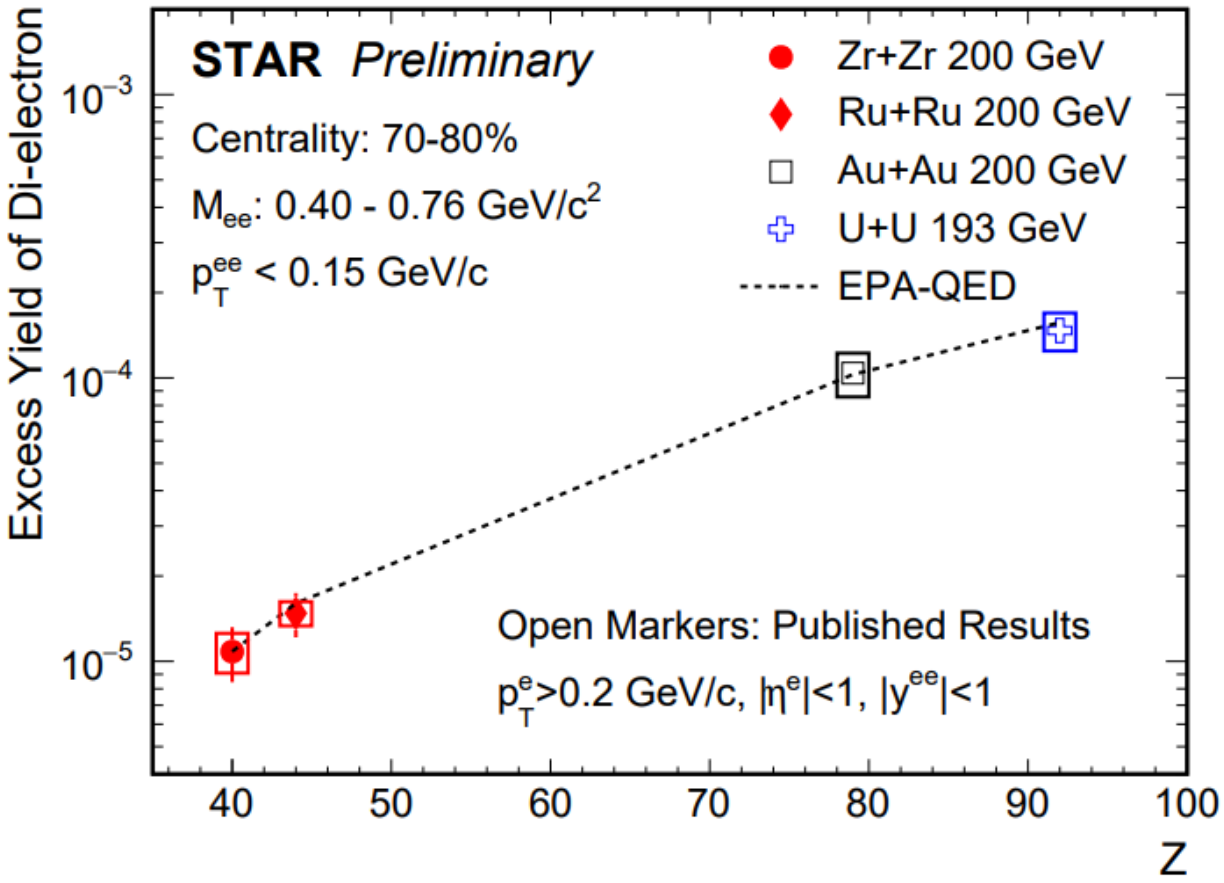
p_T Dependence of Excess Yield Ratio

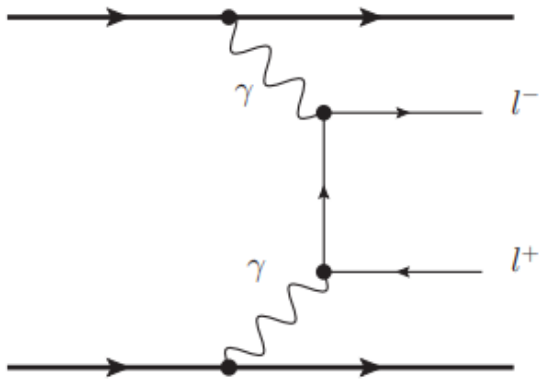


W. Zha et al, Phys. Lett. B 789 (2019) 238-242

- e^+e^- yield ratio of (Ru+Ru)/(Zr+Zr):
  - Excess (Data-Cocktail) at p_T < 0.1 GeV/c, dominated by photon-induced contributions, is consistent with the EPA-QED calculation and Z^4 scaling ➔ EM field difference between Ru+Ru and Zr+Zr QED interactions
  - Data at p_T > 0.1 GeV/c, dominated by hadronic contributions, consistent with unity ➔ no difference between Ru+Ru and Zr+Zr hadronic interactions

Charge Dependence of Excess Yield

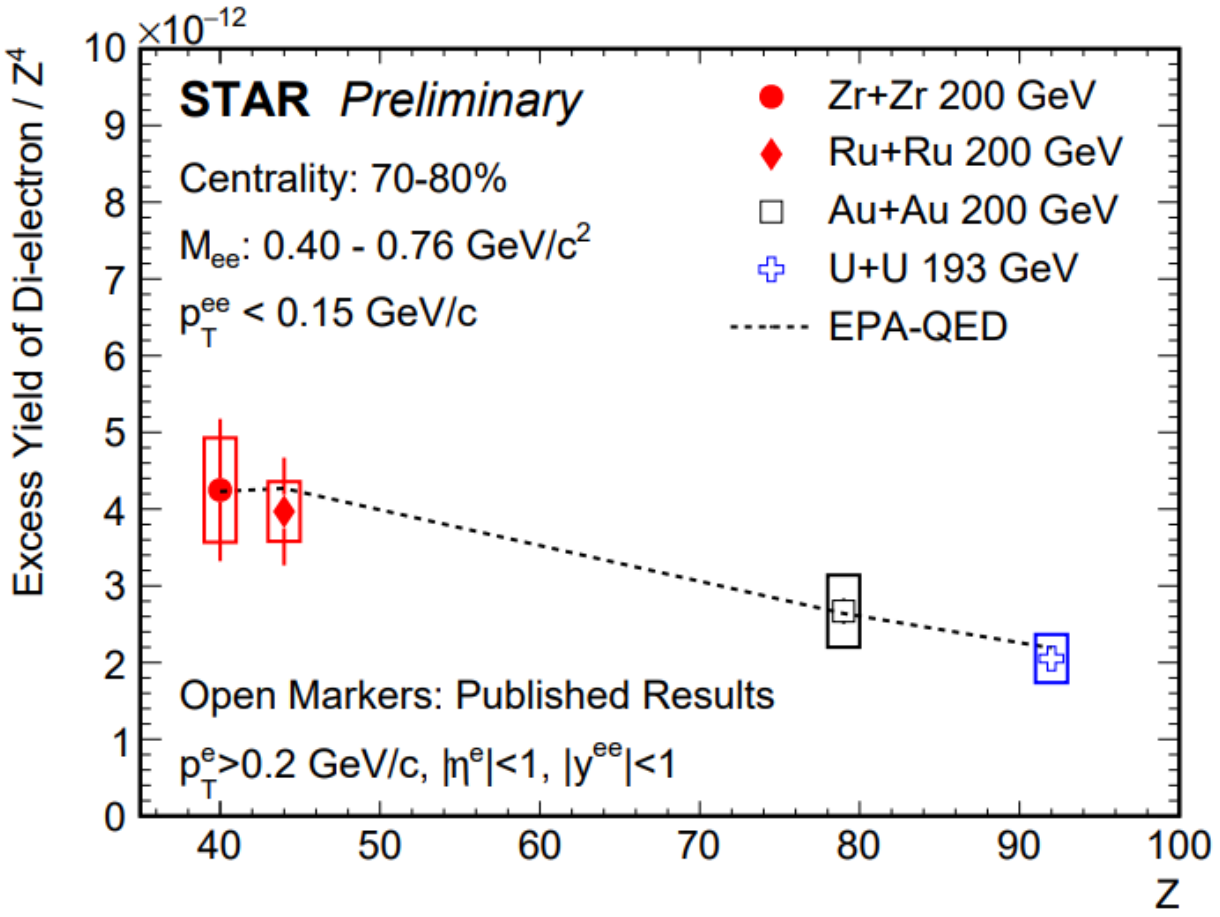


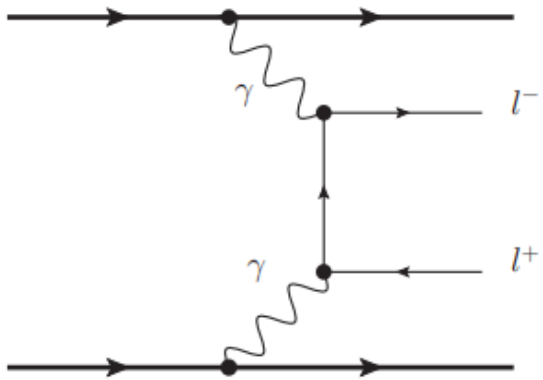


- The excess yields in isobaric collisions are significantly smaller compared to those in Au+Au and U+U collisions
- The charge difference is the dominant effect and understood both in theory and experiment ($\propto Z^4$)

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

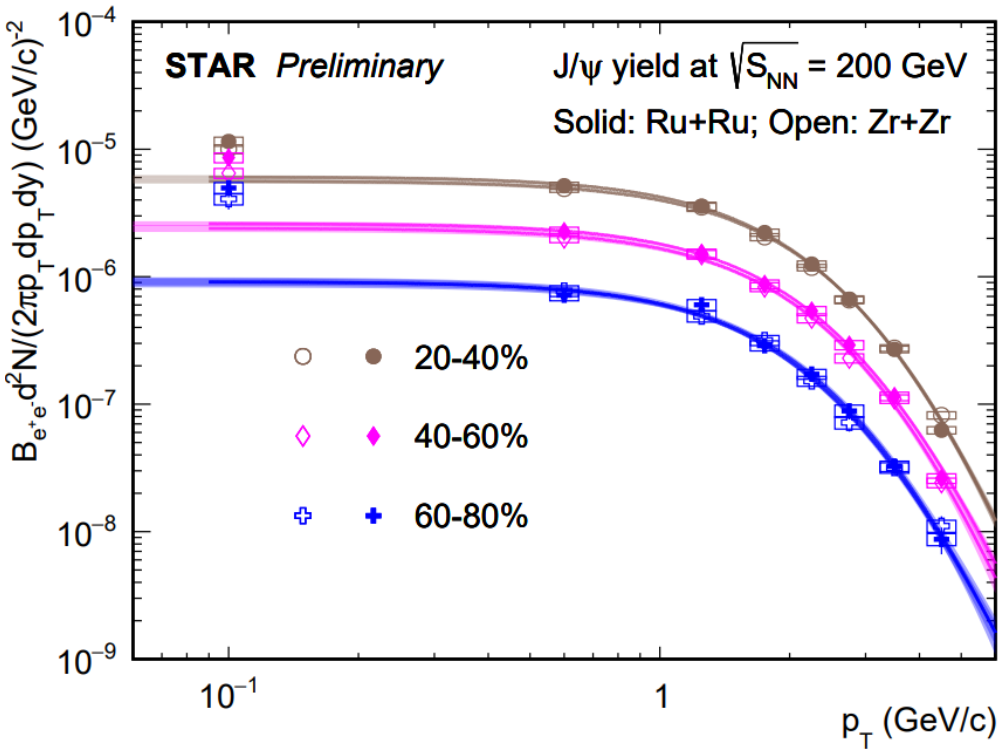


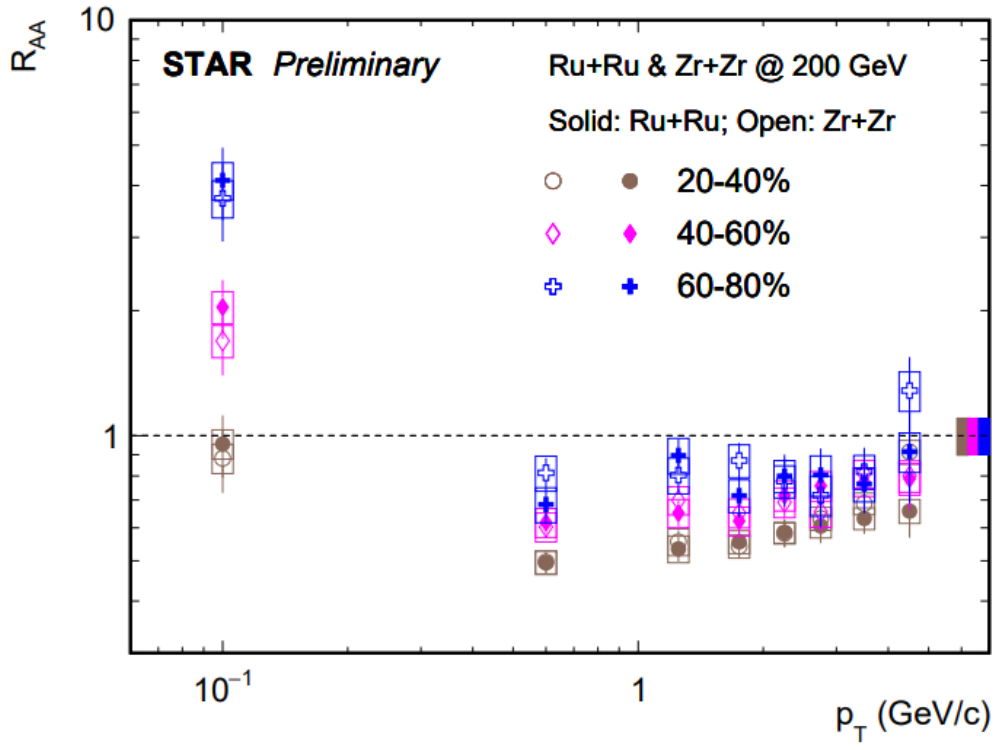


- Z^4 scaled yield shows clear collision system dependence, likely originating from impact parameter dependence
- Decreasing trend is described by the EPA-QED calculation

J.Adam et al. (STAR) Phys. Rev. Lett. 121 (2018) 132301
W. Zha et al, Phys. Lett. B 800 (2020) 135089

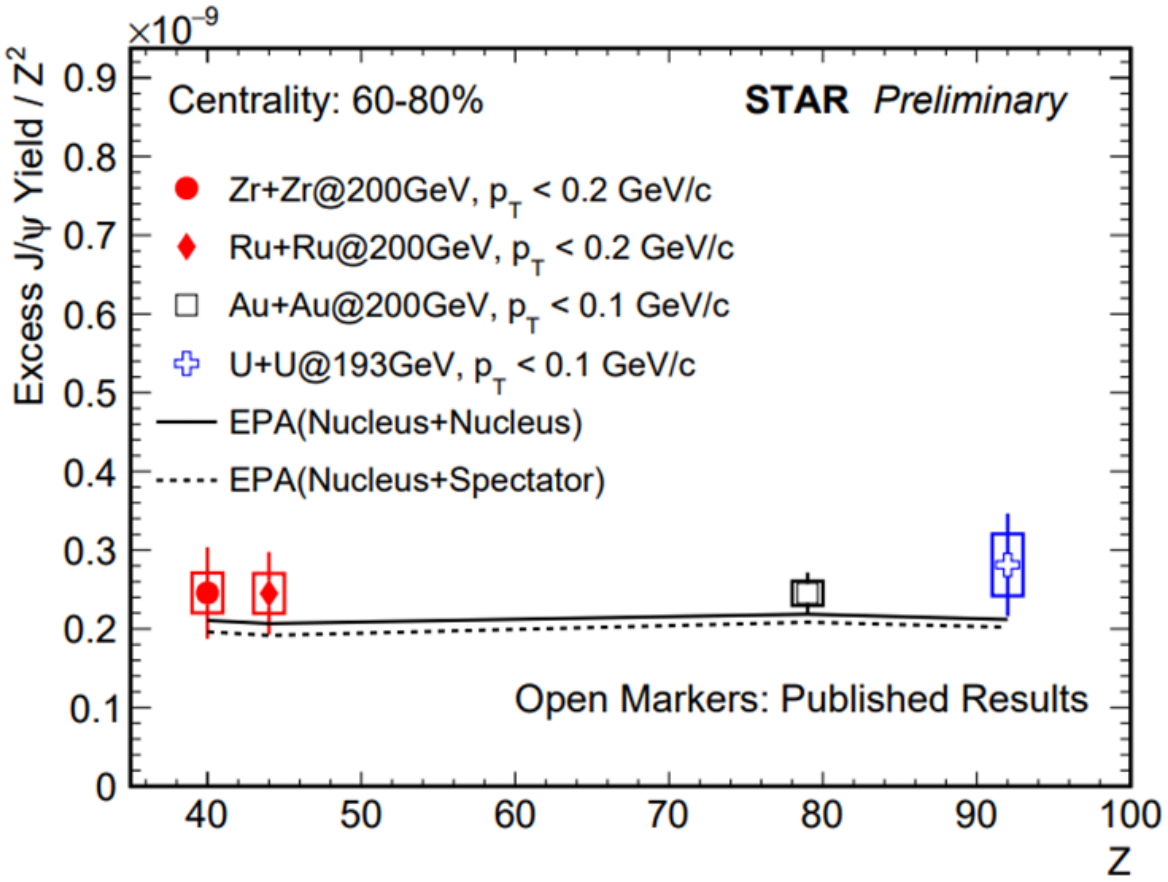
Invariant Yield and Nuclear Modification Factor of J/ψ



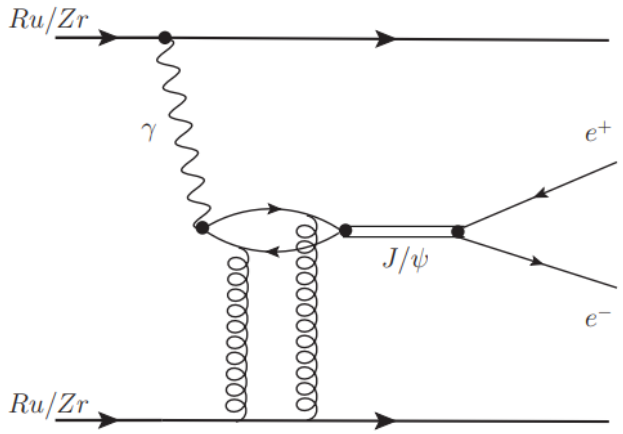


- The yield spectra are fitted by the Tsallis function at p_T larger than 0.2 GeV/c, and extrapolated to low-p_T range
- The data are well described by the fitted curves above 0.2 GeV/c, but show significant enhancements at low-p_T range
- The R_{AA} is significantly higher than unity at the very low-p_T range in 40-60% and 60-80% centrality classes

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)



- Photoproduction J/ψ yield / Z^2 are found to be flat vs. Z
- Effects of form factor and impact parameter seem to balance each other?

Summary

- Enhancements of e^+e^- and J/ψ production at very low $\mathrm{p_T}$ have been observed in peripheral Ru+Ru and Zr+Zr collisions at $\sqrt{s_{\mathrm{NN}}}$ = 200 GeV
- Indication of initial EM field difference between peripheral Ru+Ru and Zr+Zr collisions
- Photoproduced e^+e^- yields are observed to be approximately proportional to Z^4
  - With a possible additional effect from impact parameter
- Photoproduced J/ψ yields are observed to be directly proportional to Z^2
  - Effects of form factor and impact parameter seem to be balanced

Thank you!