Beam energy and collision species dependences of photon-induced lepton pair production at STAR

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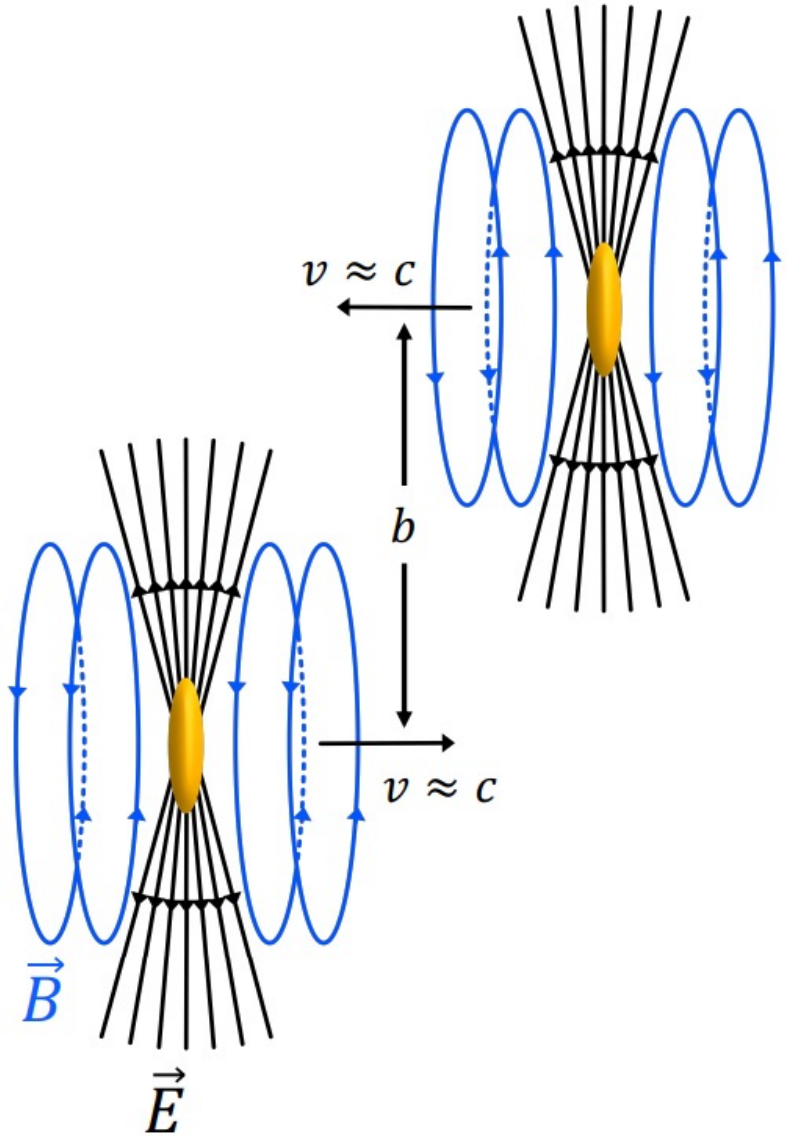
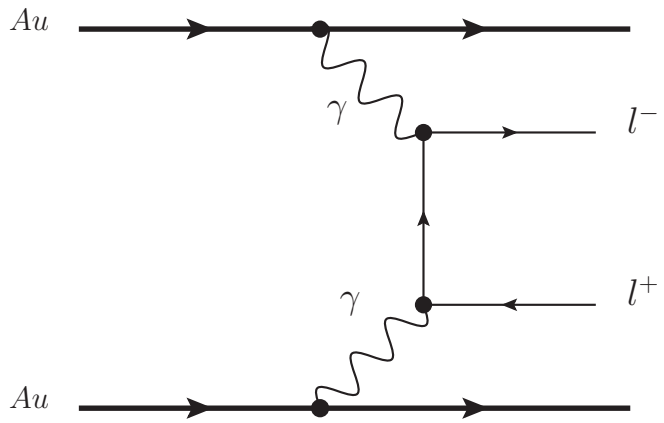
National Natural Science Foundation of China

$\gamma\gamma \rightarrow l^+l^-$ Process





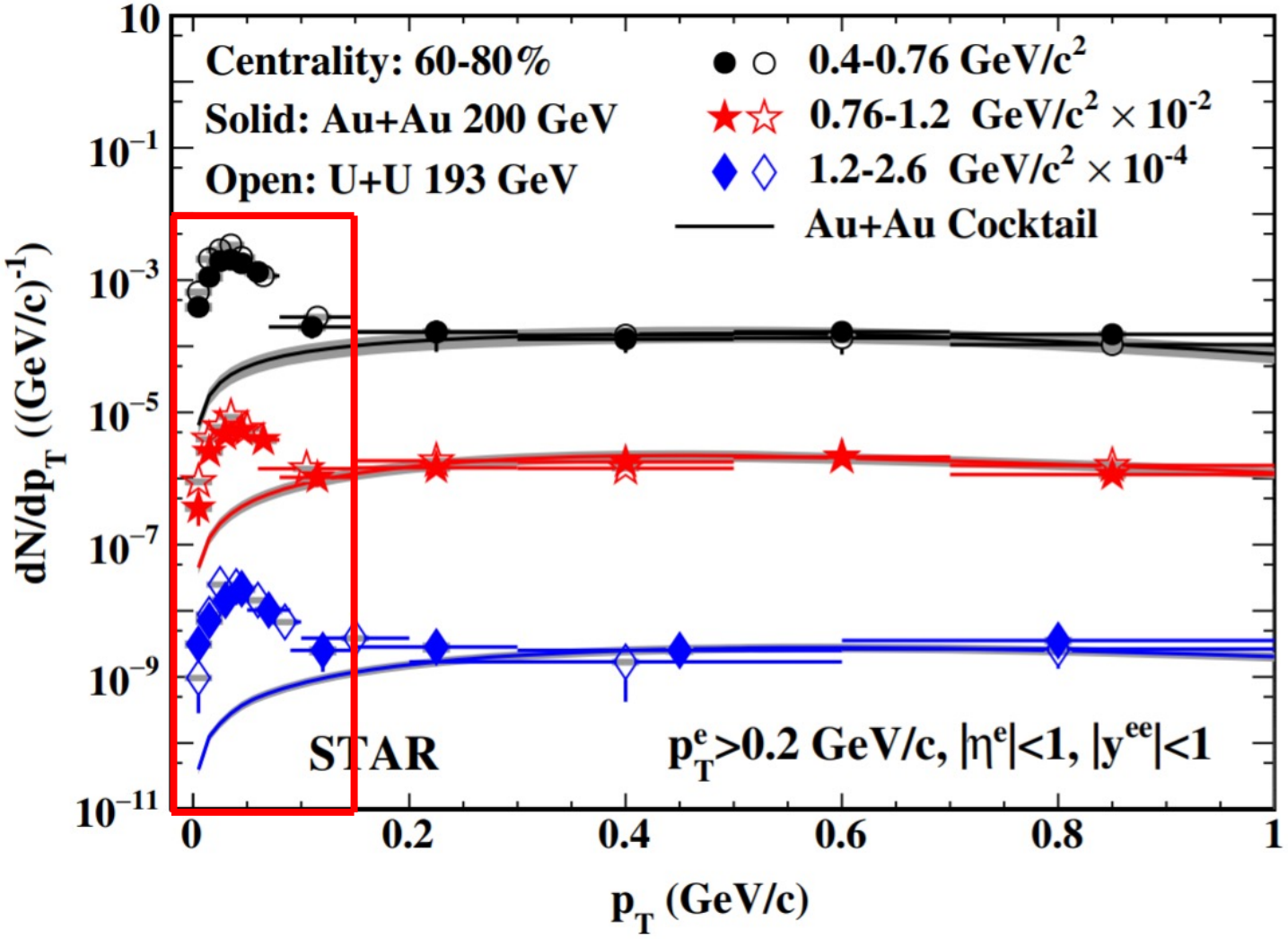
- Highly Lorentz-contracted charged nuclei produce electromagnetic fields (EM)
- Equivalent Photon Approximation (EPA):
  EM fields → a flux of **quasi-real photons**

  Weizsäcker, C. F. v. Zeitschrift für Physik 88 (1934): 612
- 1934 Breit & Wheeler : “Collision of two Light Quanta”

  G. Breit and J. A. Wheeler. *Physical Review* 46 (1934): 1087
- High photon density with highly charged nuclei ($\propto Z^2$)

$\gamma\gamma \rightarrow l^+l^-$ in Peripheral Collisions

STAR: Phys.Rev.Lett. 121, 132301 (2018)



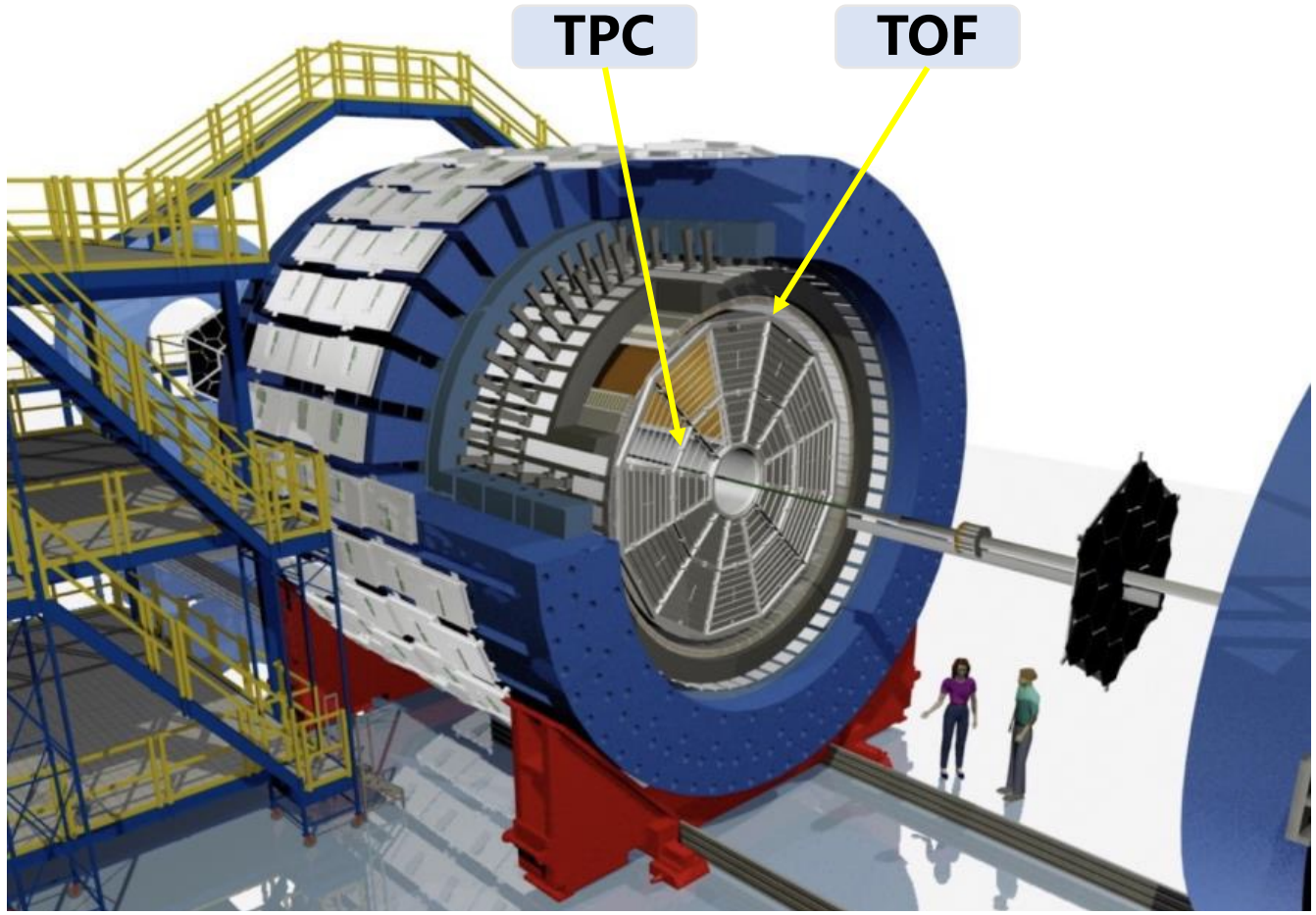
Observation of $\gamma\gamma \rightarrow e^+e^-$ in hadronic heavy ion collisions at STAR

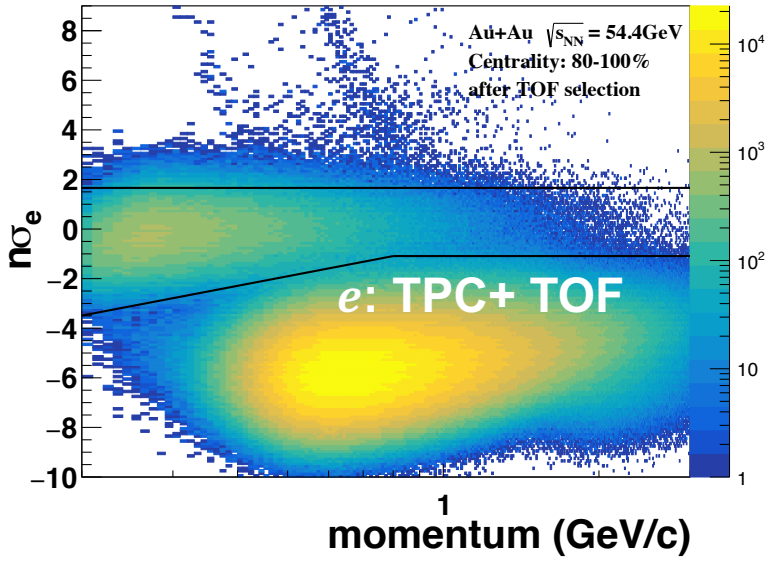
Energy dependence?
Centrality dependence?

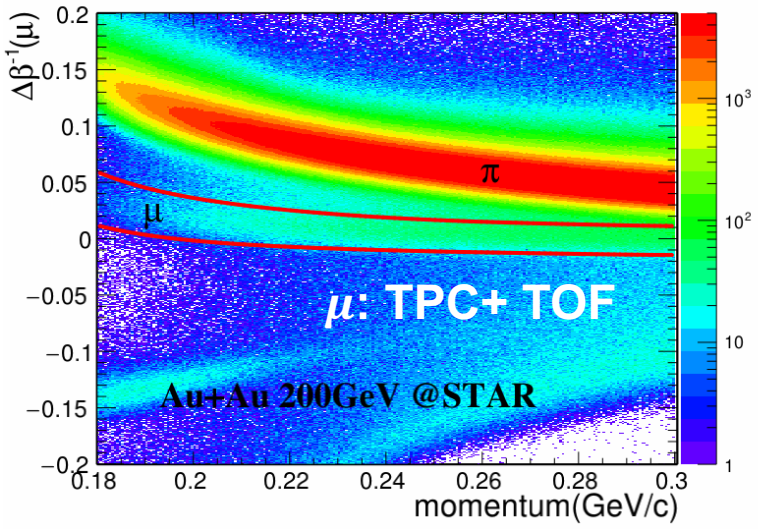
Di-muon?

Collision species dependence?

The Solenoid Tracker At RHIC (STAR) and PID



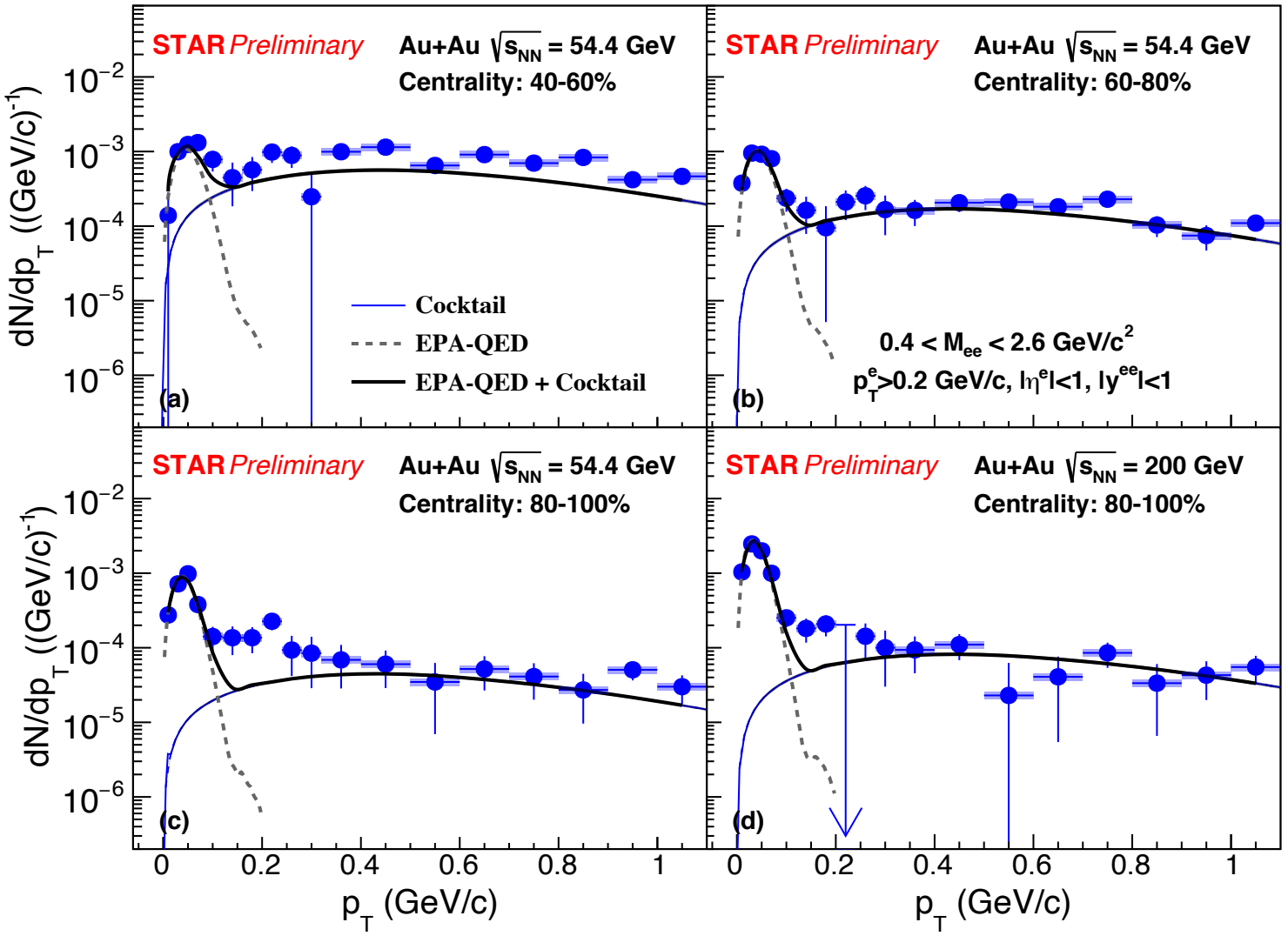




Time **P**rojection **C**hamber (**TPC**): momentum and energy loss

Time **O**f **F**light (**TOF**): velocity

Transverse Momentum Distribution



EPA-QED: W. Zha et al, Phys.Lett.B 800 (2020) 135089

e^+e^- pairs

Excesses above hadronic production are observed at low-p_T

Lowest order EPA-QED predictions are consistent with observed excesses

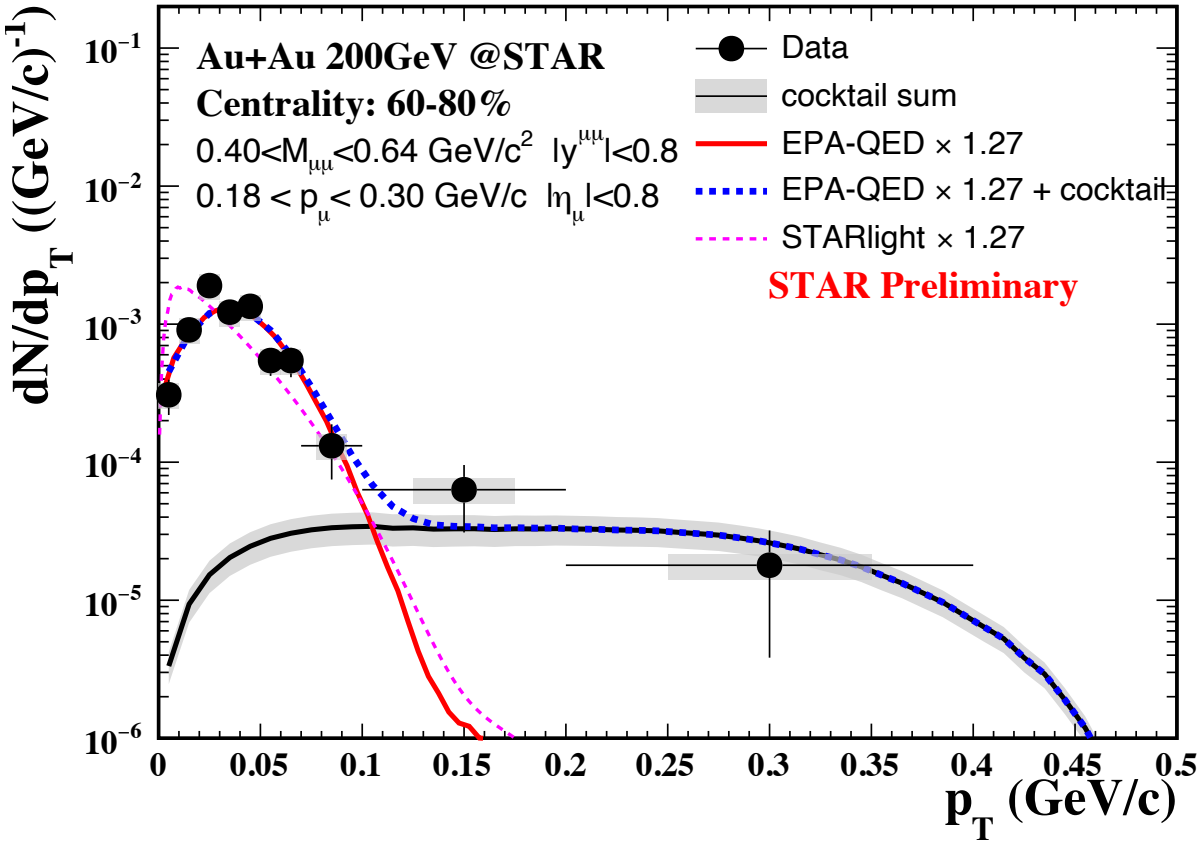
Energy dependence
54.4 GeV, 200 GeV

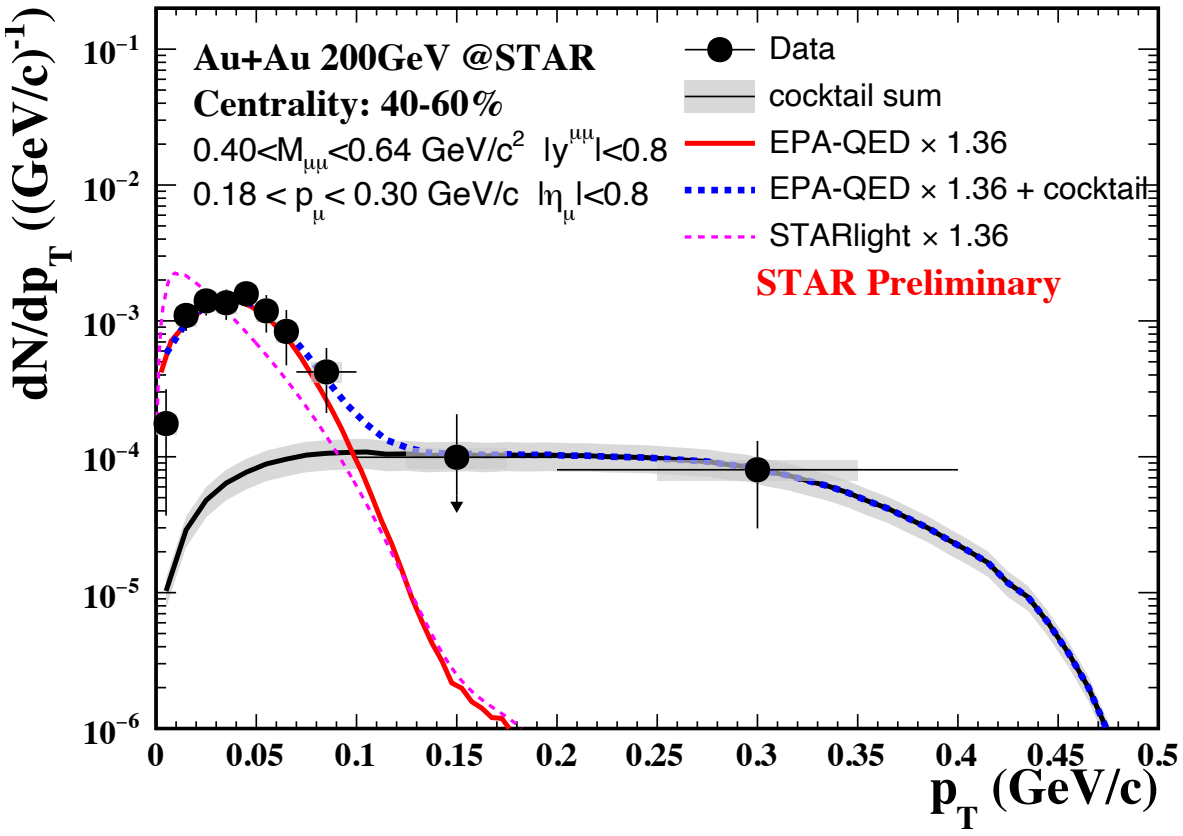
Centrality dependence
40-60%, 60-80%, 80-100%

Transverse Momentum Distribution

$\mu^+\mu^-$ pairs

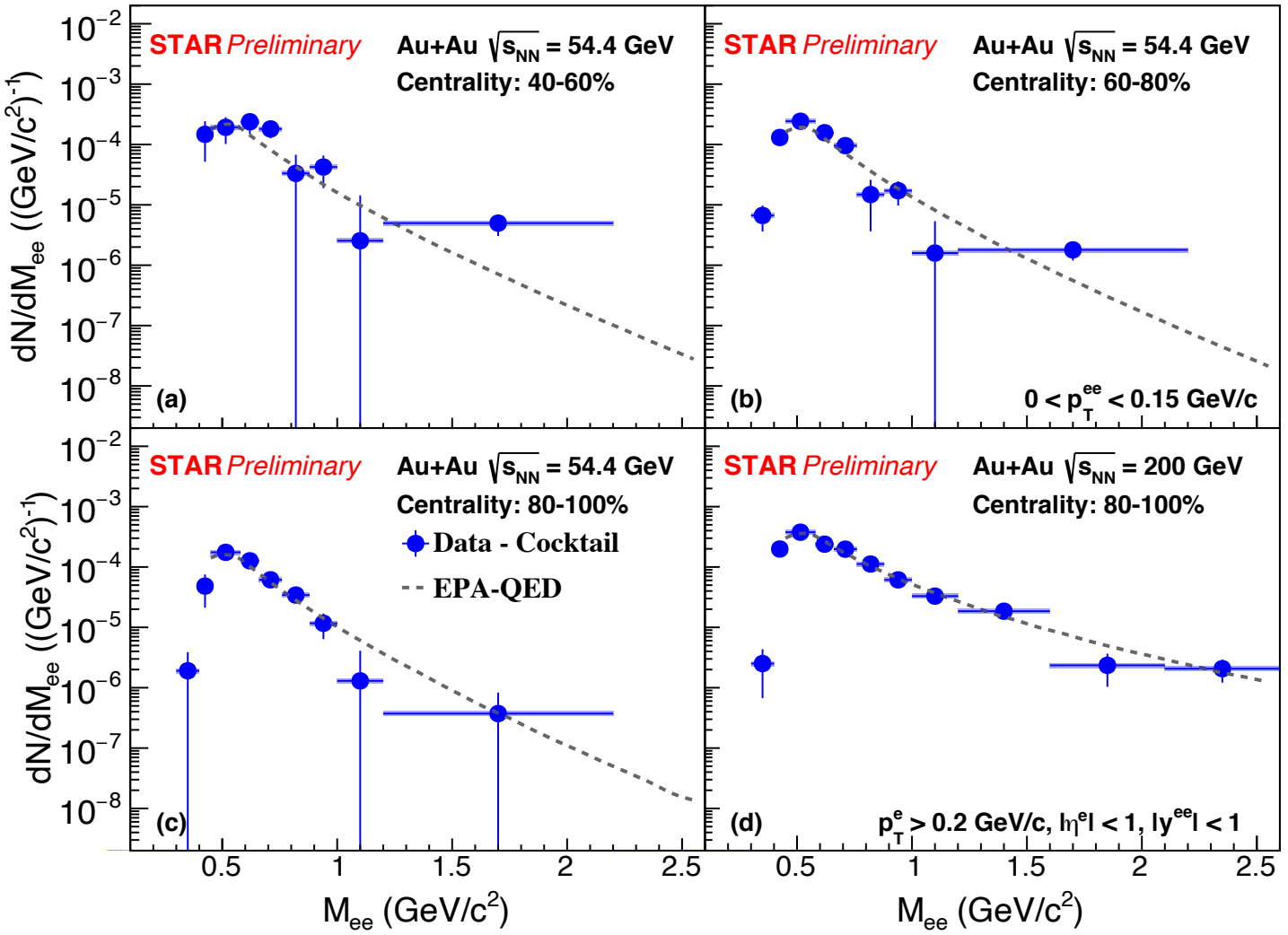
Poster by Jian Zhou (04/06/22 6:30-7:30)





Similar excesses at low-p_T observed in the $\mu^+\mu^-$ channel

Invariant Mass Distribution at Low-p_T



$$\gamma\gamma \rightarrow e^+e^-$$

Excesses (Data - Cocktail) are extracted

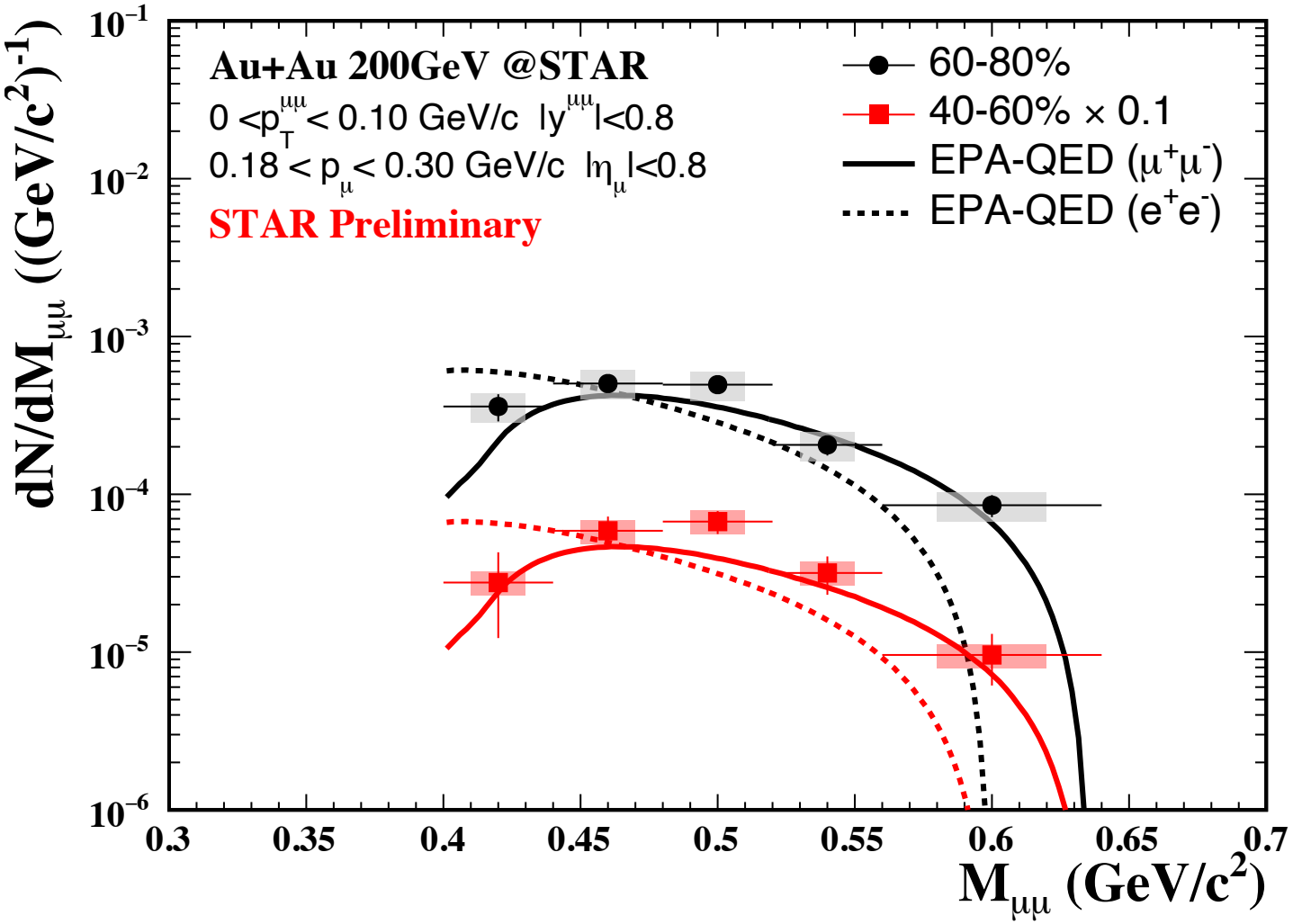
No vector meson observed
($\gamma\gamma \not\rightarrow$ vector meson)

Excesses are well described by lowest order EPA-QED predictions

Invariant Mass Distribution at Low-p_T

$\gamma\gamma \rightarrow \mu^+\mu^-$

Poster by Jian Zhou (04/06/22 6:30-7:30)



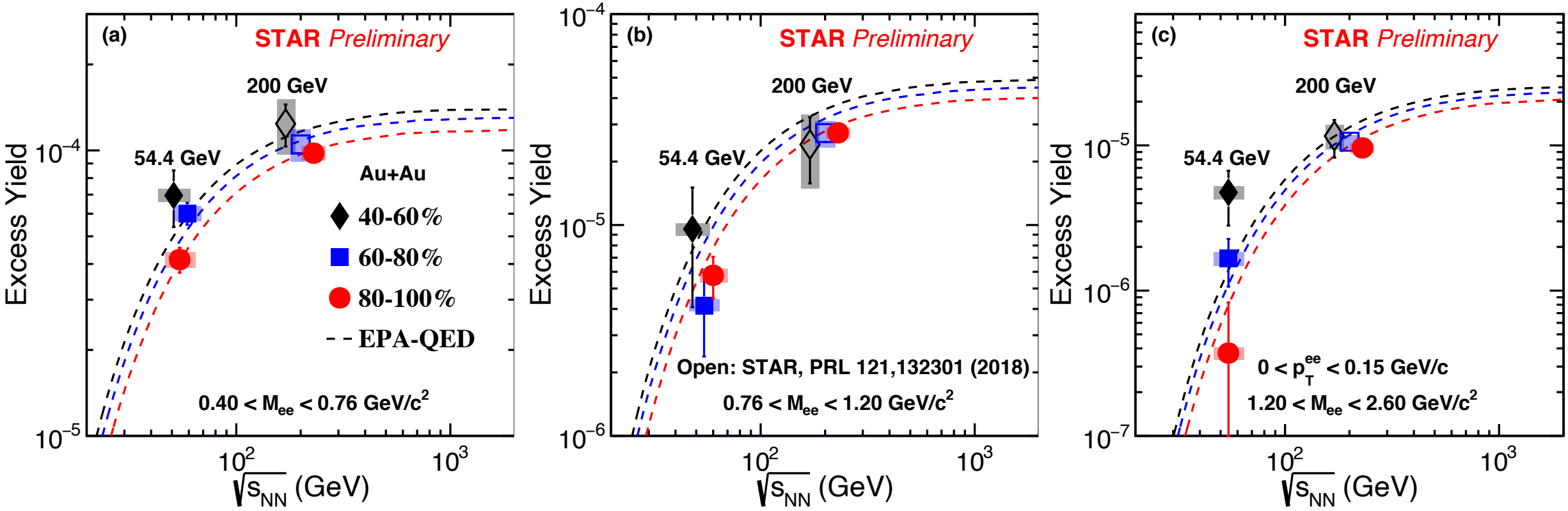
EPA-QED predicts different cross sections due to electron and muon mass difference

Excesses (Data - Cocktail) are extracted

Excesses are well described by lowest order EPA-QED predictions

Energy Dependence of Excess Yield

$$\gamma\gamma \rightarrow e^+e^-$$

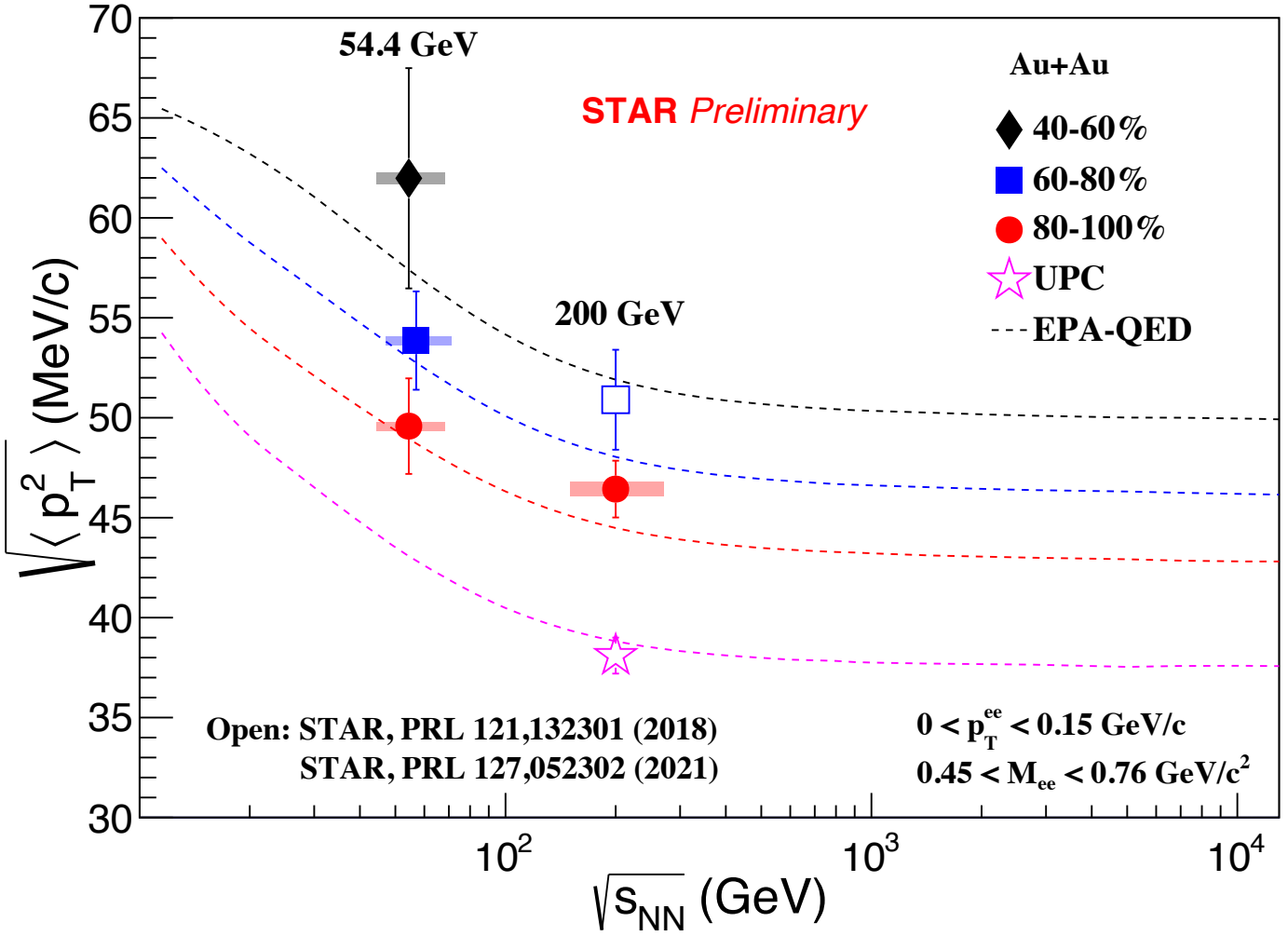


Excess yield increase with beam energy

EPA-QED predicts similar energy dependence

Energy and Centrality Dependence of $\sqrt{\langle p_T^2 \rangle}$

$\gamma\gamma \rightarrow e^+e^-$



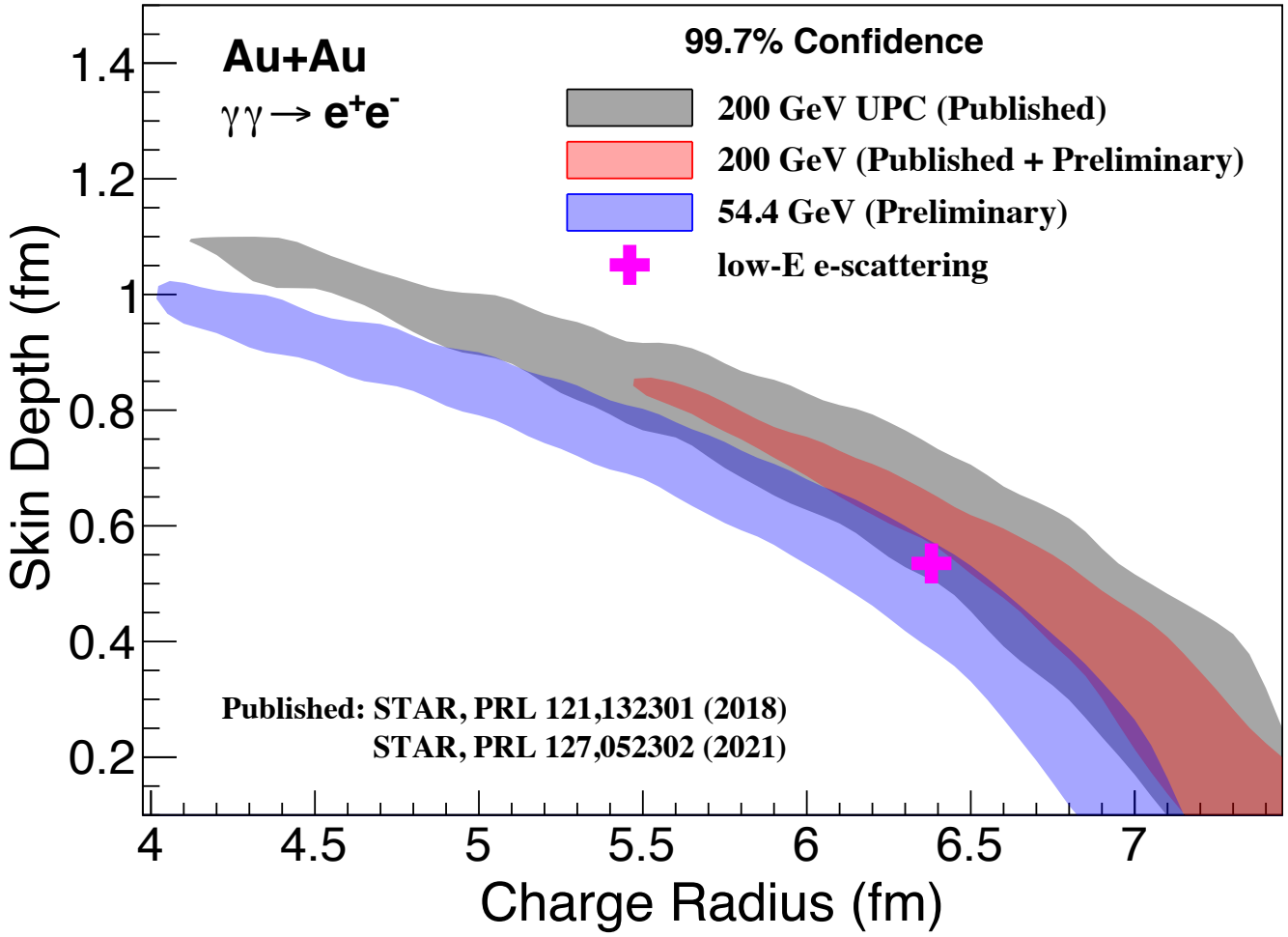
$\sqrt{\langle p_T^2 \rangle}$ is sensitive to p_T broadening

$\sqrt{\langle p_T^2 \rangle}$ decreases from semi-peripheral to peripheral collisions

Initial state effect: Impact parameter dependence

Energy dependence(3.7σ compared to 200 GeV QED) and/or final state effect(1.8σ)

Application: Constrain Charge Distribution



$\gamma\gamma \rightarrow l^+l^-$ can be used to constrain nucleus charge distribution at RHIC energy

STAR data compared to EPA-QED

Low energy scattering: R=6.38 fm, d=0.535 fm

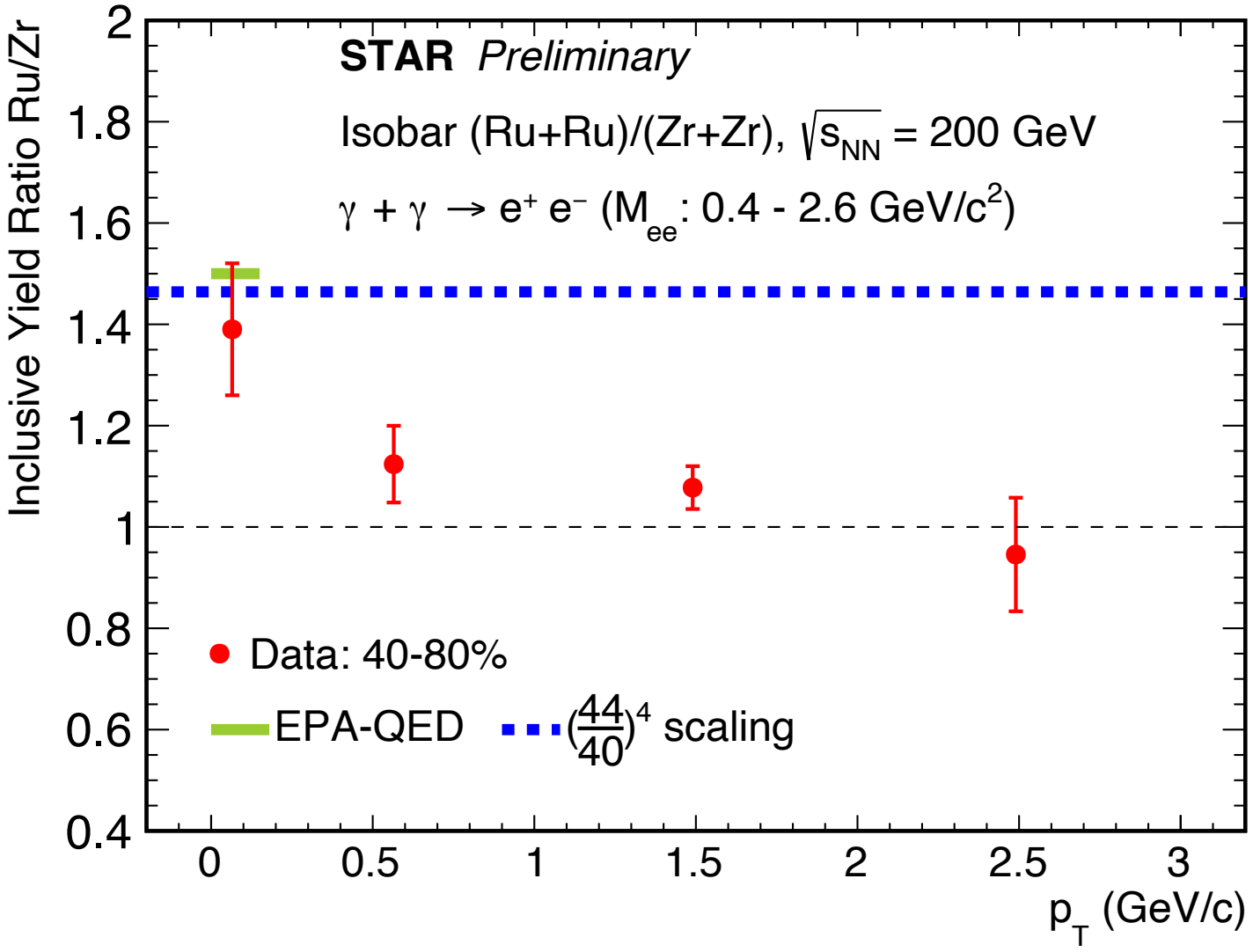
R. C. Barrett and D. F. Jackson, Nuclear Sizes and Structure (Oxford University Press, 1977)

200 GeV vs 54.4 GeV: maybe due to energy dependence of charge distribution

Low-energy vs RHIC (3σ difference): maybe due to energy dependence of charge distribution and/or final state effect

EPA-QED: J. D. Brandenburg et al, Eur. Phys. J. A 57 (2021) 299.

Collision Species Dependence ($^{96}_{44}\mathrm{Ru} + {}^{96}_{44}\mathrm{Ru}$, $^{96}_{40}\mathrm{Zr} + {}^{96}_{40}\mathrm{Zr}$)



$\gamma\gamma \rightarrow e^+e^-$

At very low p_T (< 0.15 GeV/c), e^+e^- pairs dominated by $\gamma\gamma \rightarrow e^+e^-$

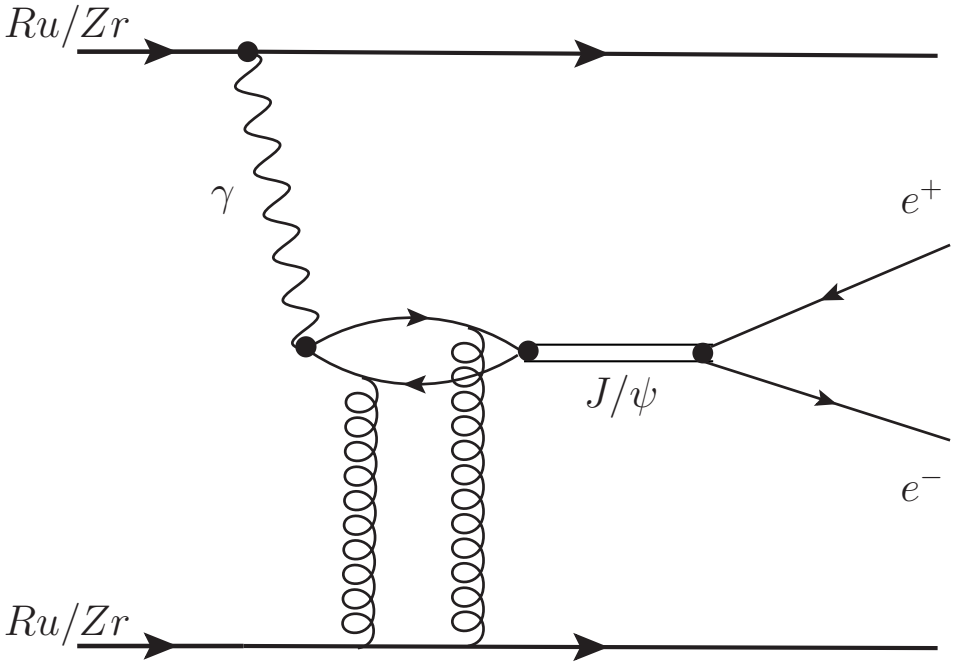
Ratio is consistent with $\left(\frac{44}{40}\right)^4$ at very low p_T

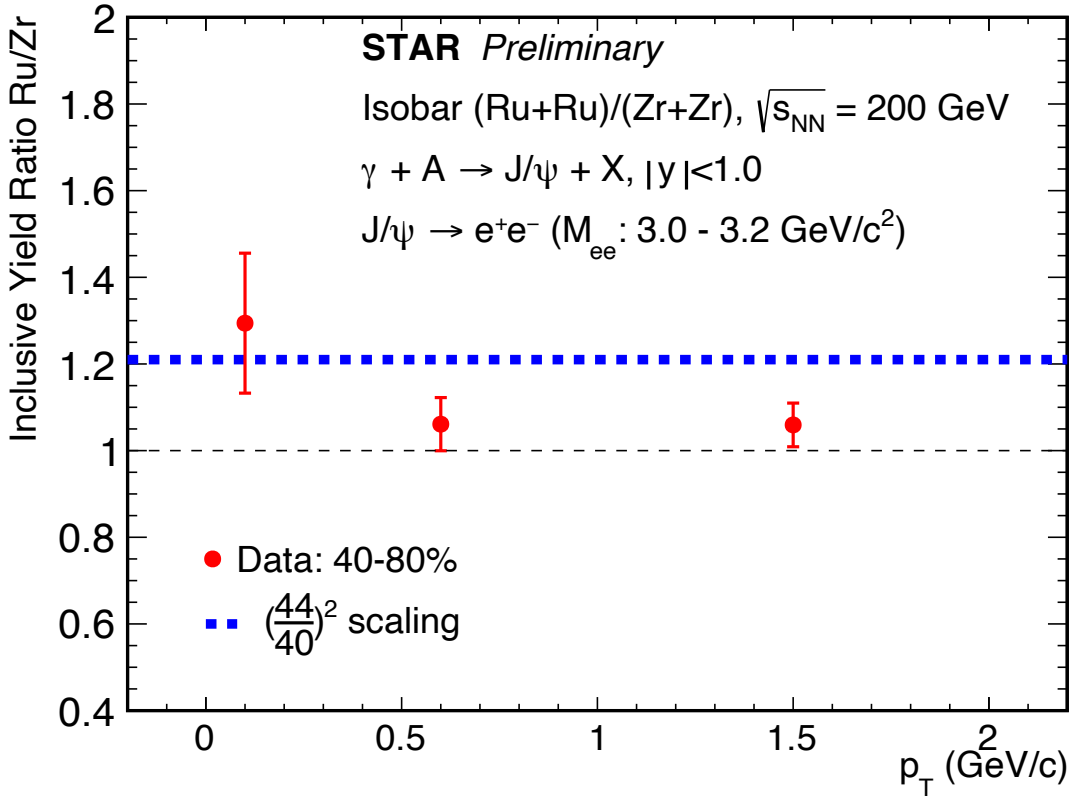
Initial EM field is different in $\mathbf{Ru + Ru}$ and $\mathbf{Zr + Zr}$ (~3σ)

At p_T > 0.15 GeV/c, hadronic production contributions to e^+e^- pairs are similar in $\mathrm{Ru + Ru}$ and $\mathrm{Zr + Zr}$

Poster by Kaifeng Shen (04/06/22 6:30-7:30)

Collision Species Dependence ($^{96}_{44}Ru + {}^{96}_{44}Ru$, $^{96}_{40}Zr + {}^{96}_{40}Zr$)

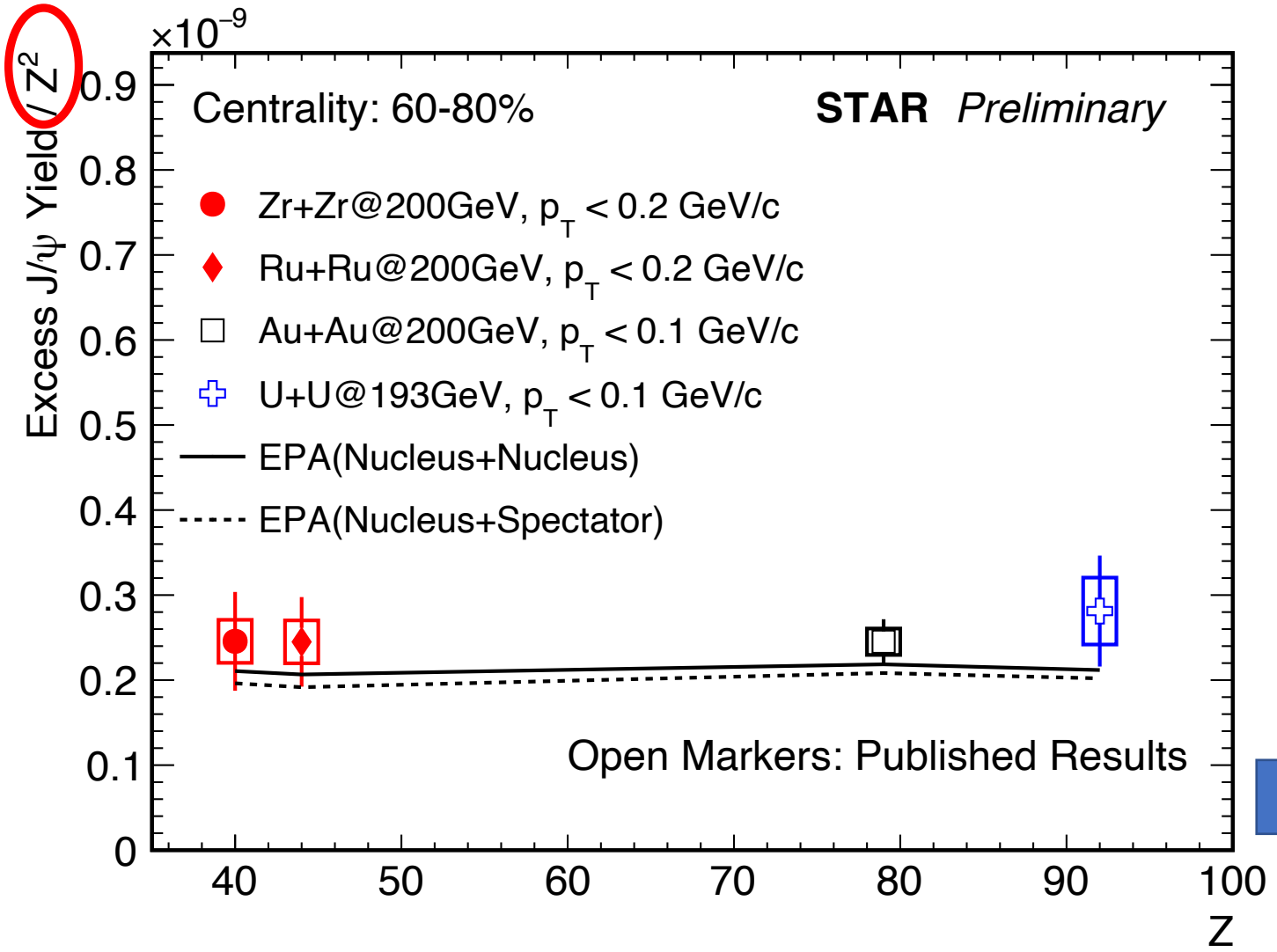




- At very low p_T, J/ψ dominated by $\gamma A \rightarrow J/\psi$
- Ratio is consistent with $\left(\frac{44}{40}\right)^2$ at very low p_T
- Initial EM field is different in $\mathrm{Ru} + \mathrm{Ru}$ and $\mathrm{Zr} + \mathrm{Zr}$ ($\sim 1.7\sigma$)
- At p_T > 0.2 GeV/c, hadronic production contributions to J/ψ are similar in $\mathrm{Ru} + \mathrm{Ru}$ and $\mathrm{Zr} + \mathrm{Zr}$

Poster by Kaifeng Shen (04/06/22 6:30-7:30)

Collision Species Dependence ($^{96}_{44}Ru + ^{96}_{44}Ru$, $^{96}_{40}Zr + ^{96}_{40}Zr$)



$\gamma A \rightarrow J/\psi$

J/ψ excess yield $\propto Z^2$

Photoproduced J/ψ yields seem to be independent of form factor and impact parameter

Poster by Kaifeng Shen (04/06/22 6:30-7:30)

Published Results: J. Adam et al. (STAR Collaboration), Phys.Rev.Lett. 123 (2019) 132302
EPA: W. Zha et al, Phys. Lett. B 789 (2019) 238–242

Summary

- Beam energy and centrality dependences of $\gamma\gamma \to l^+l^-$ have been measured at STAR
  - ✓ Excess yield: **Increases with beam energy**
  - ✓ $\sqrt{\langle p_T^2 \rangle}$: Decreases with increasing impact parameter
  - ✓ $\sqrt{\langle p_T^2 \rangle}$: **Energy dependence** (3.7σ compared to 200 GeV QED)
  - ✓ **Application:** $\gamma\gamma \to l^+l^-$ can be used to **constrain nuclei charge distribution at RHIC energy**

- Collision species dependence of $\gamma\gamma \to l^+l^-$ and $\gamma A \to J/\psi$ have been measured at STAR
  - ✓ **Initial EM field is different** in $\mathrm{Ru} + \mathrm{Ru}$ and $\mathrm{Zr} + \mathrm{Zr}$ (~3σ in $e^+e^- \bigoplus$ ~1.7σ in J/ψ)
  - ✓ Photon-induced J/ψ yield $\propto Z^2$