Photon-induced J/ψ production and polarization effects in isobar collisions at STAR

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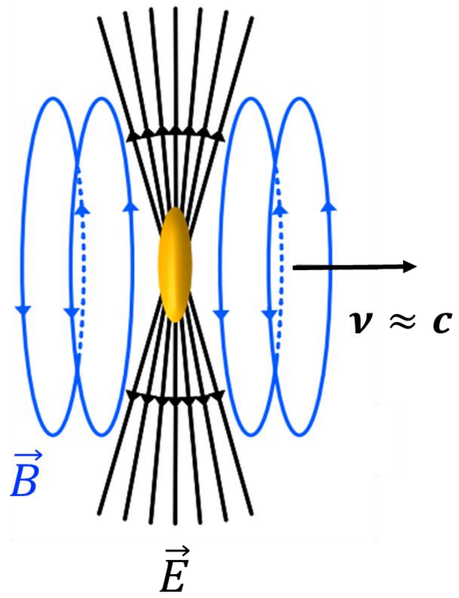
STAR Collaboration

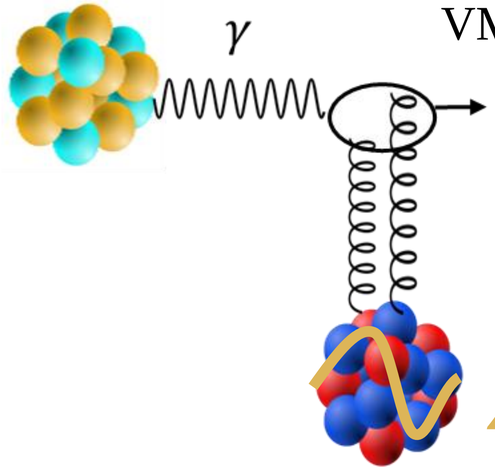
Coherent J/ψ Photoproduction



- Equivalent Photon Approximation
- EM fields → a flux of quasi-real photons

$$n \propto \vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \approx |\vec{E}|^2 \approx |\vec{B}|^2$$

- Flux $\propto Z^2$

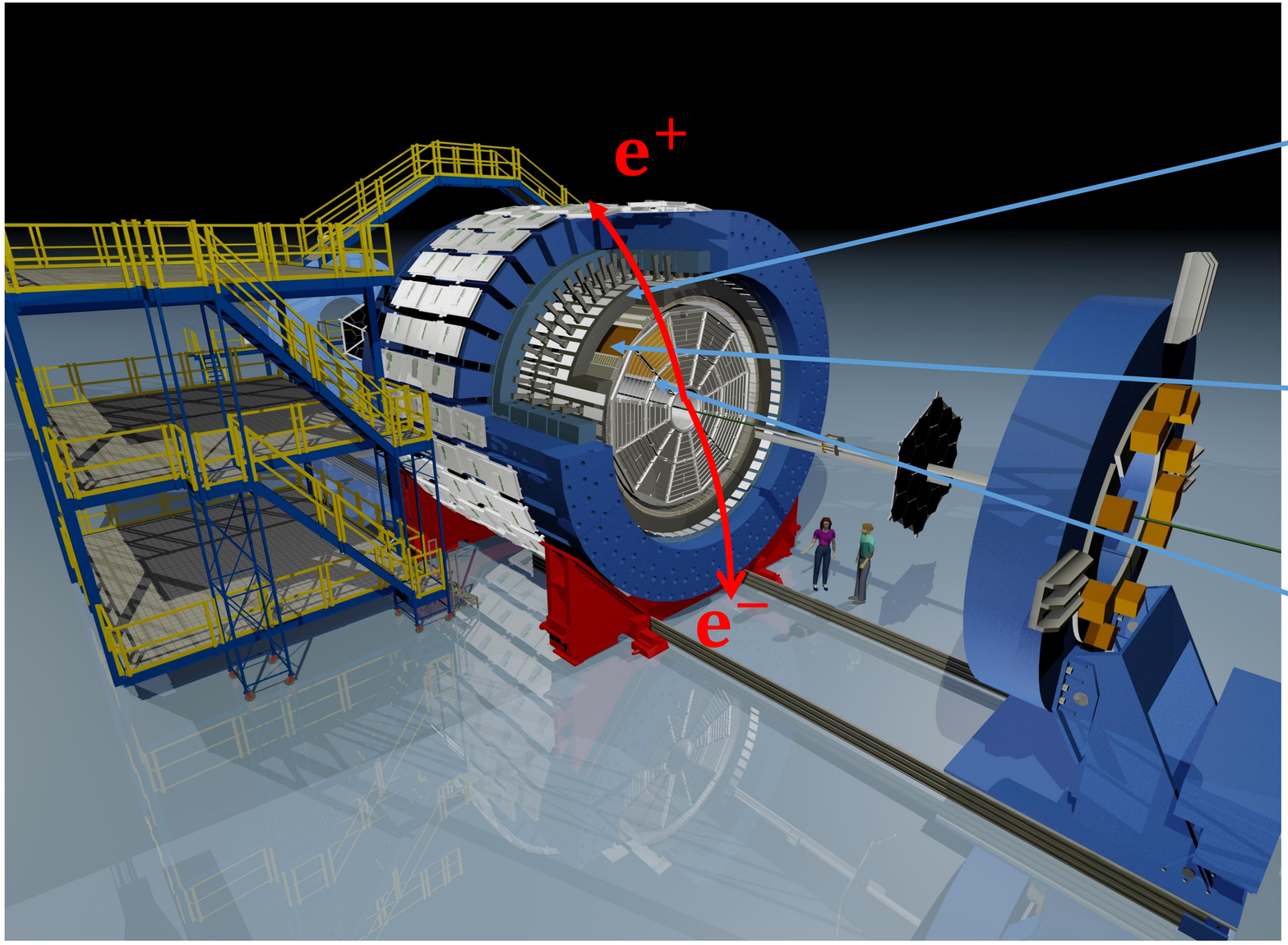


VM (J/ψ, ρ^0 ...)

Vector meson (VM) from " Photon-Ion collider"

- $\gamma + A \rightarrow J/\psi + A$
- Distinctly peaked at very low p_T
- Insightful probe of initial state of collision

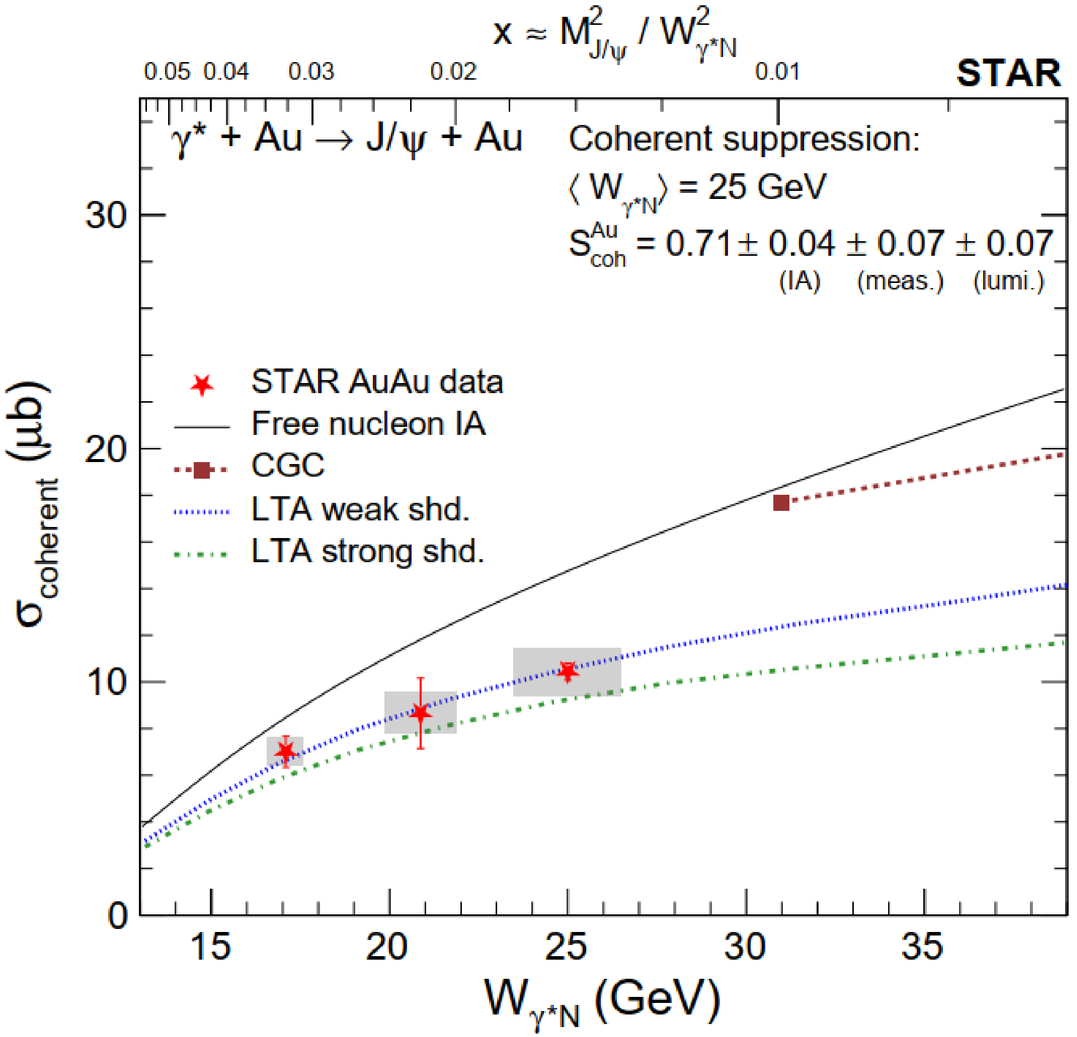
STAR experiment

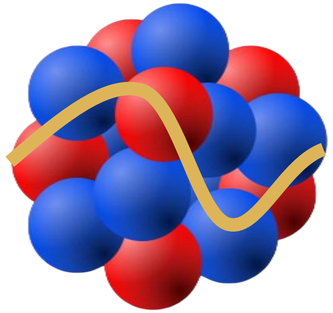


- ✓ BEMC: Electron identification, trigger
- ✓ TOF: Particle identification
- ✓ TPC: Tracking, momentum and dE/dx

Coherent J/ψ: probe of gluon densities

STAR, Phys. Rev. Lett. 133 (2024) 5, 052301&Phys.Rev.C 110 (2024) 1, 014911

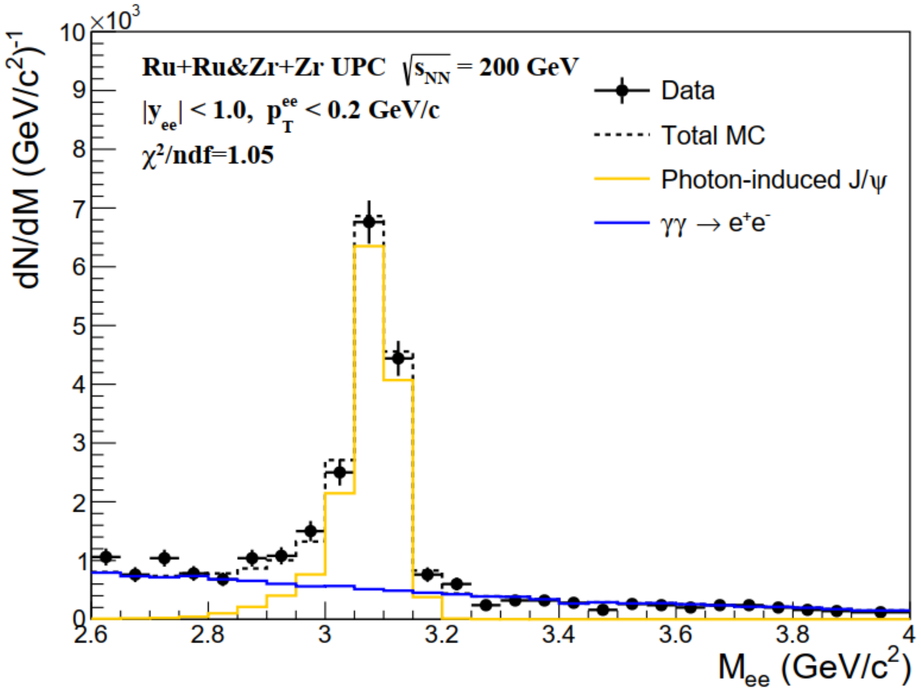


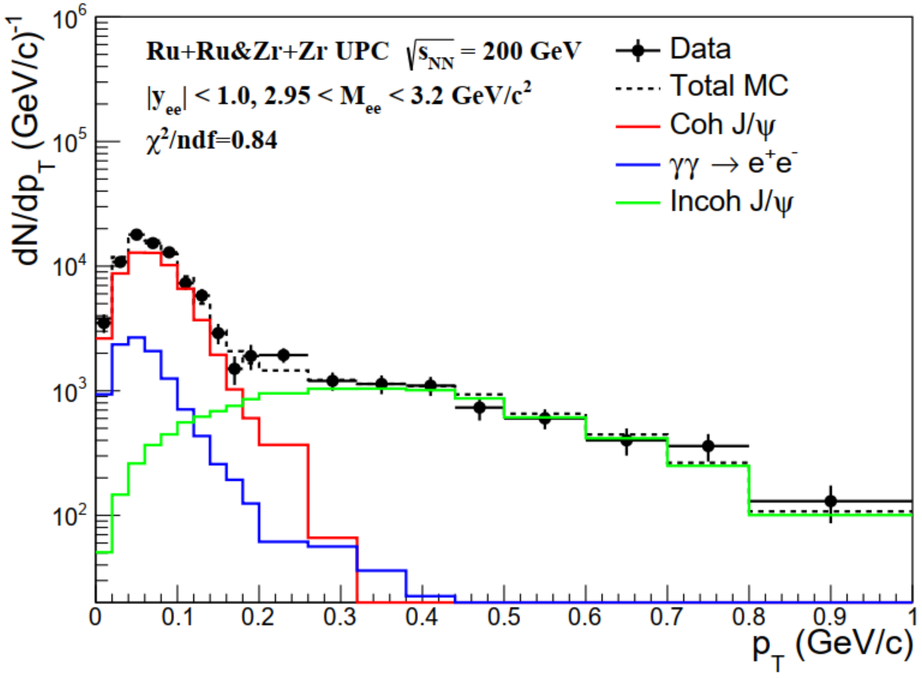


$\lambda_{coherent}$

- Shadowing in $\gamma + {}^{197}Au$ collisions
- Probe dependence of gluon structure on colliding system with ${}^{96}Ru$ and ${}^{96}Zr$

J/ψ measurements in isobar UPCs



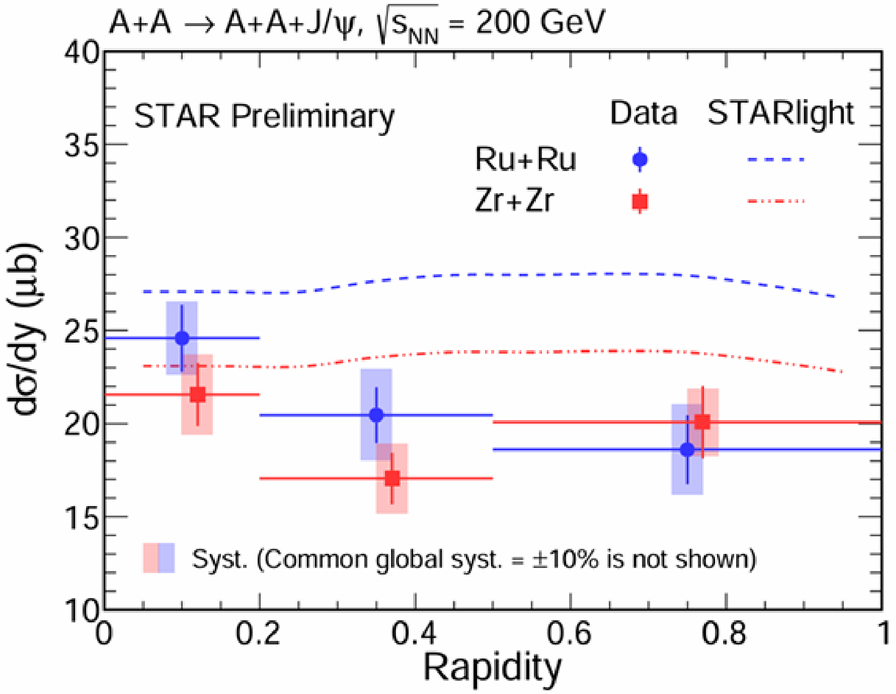


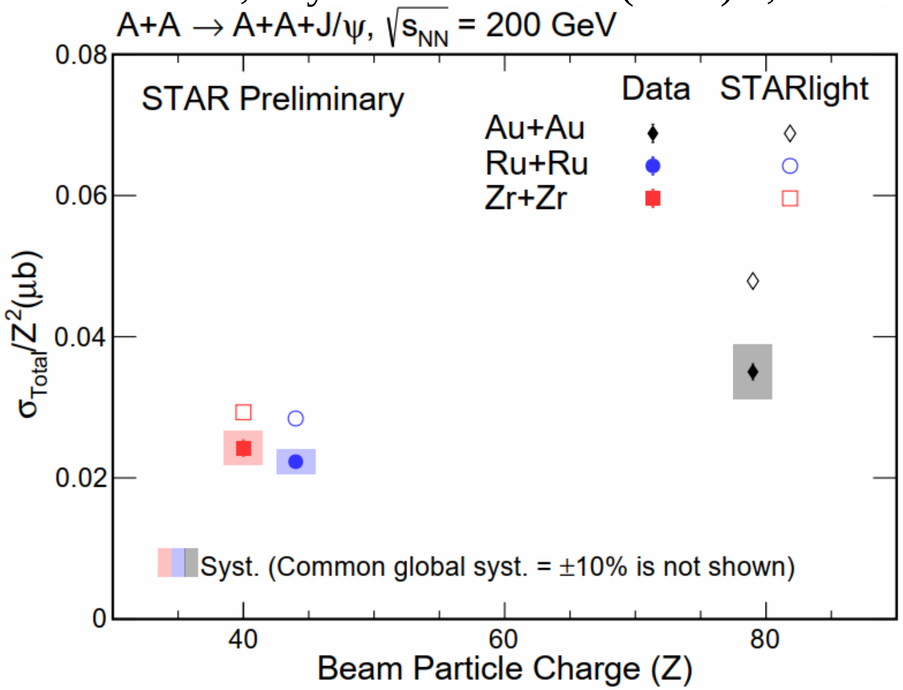
Simulation input
P. Wang et al
Chin.Phys.C 46 (2022) 7, 074103
W. Zha et al
Phys.Lett.B 800 (2020) 135089

- MC simulation templates: coherent and incoherent $J/\psi \rightarrow (\gamma)e^+e^-$, $\gamma\gamma \rightarrow (\gamma)e^+e^-$
- MC templates are fitted to data to extract the coherent J/ψ yields

Coherent J/ψ cross section in isobar UPCs

STAR, Phys. Rev. Lett. 133 (2024) 5, 052301



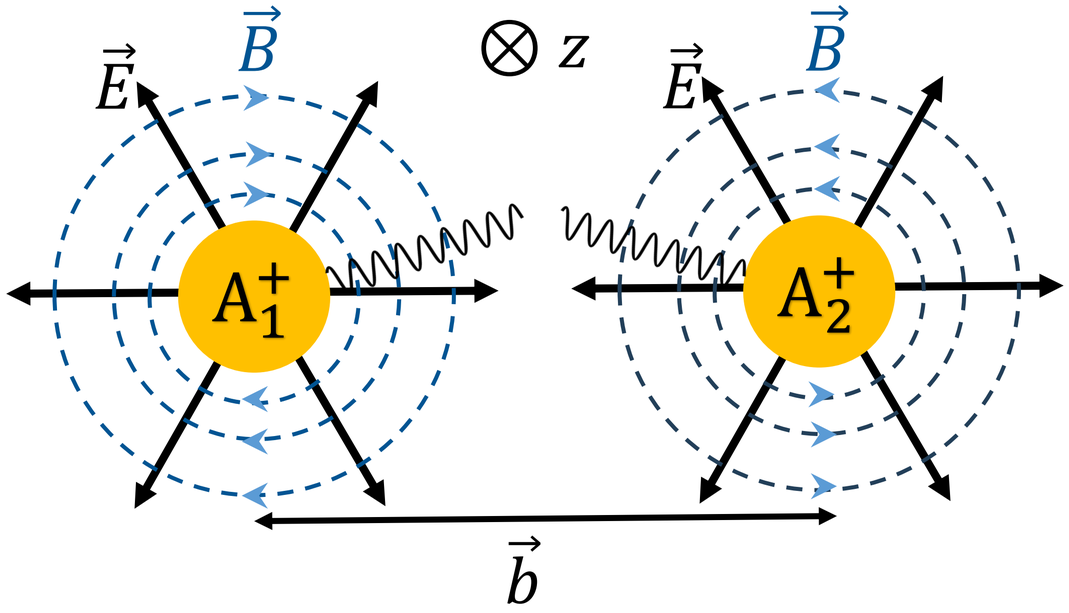


Poster ID 923
Zengzhi Li

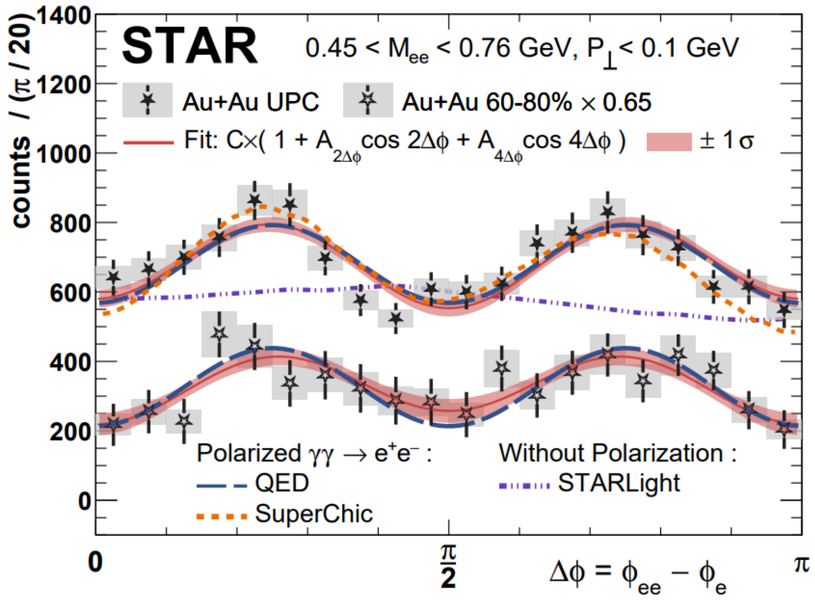
- Measured cross section is lower than STARlight (with nucleon shadowing)
- Roughly cancel out photon flux dependence by dividing Z^2
- Indicating suppression effect in Ru, Zr and Au with respect to STARlight

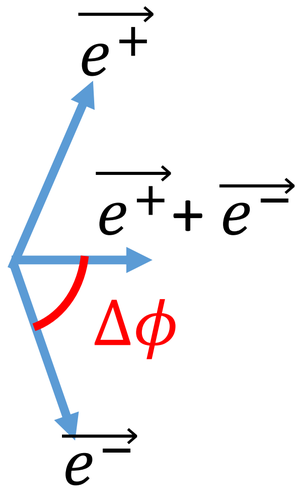
Outlook: $\sigma_{J/\psi}$ vs. $W_{\gamma N}$ by solving photon energy ambiguity with neutron tagging

Linearly polarized photons



STAR, Phys. Rev. Lett. 127, 052302 (2021)

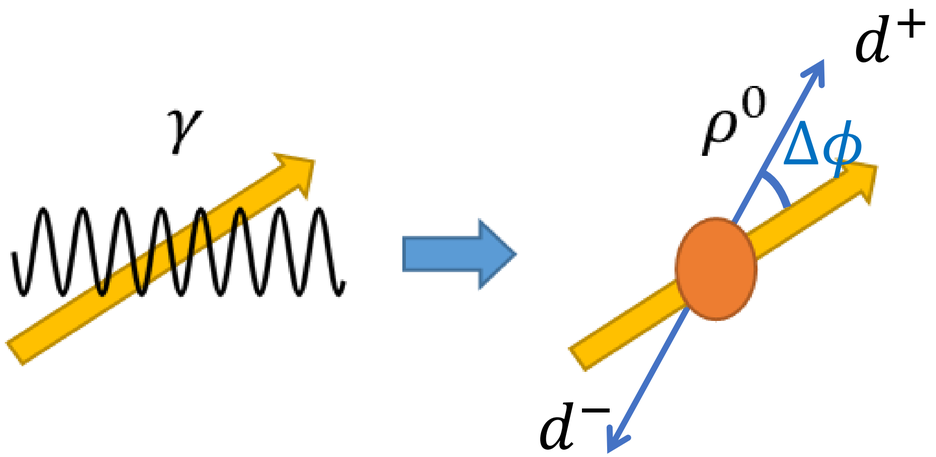


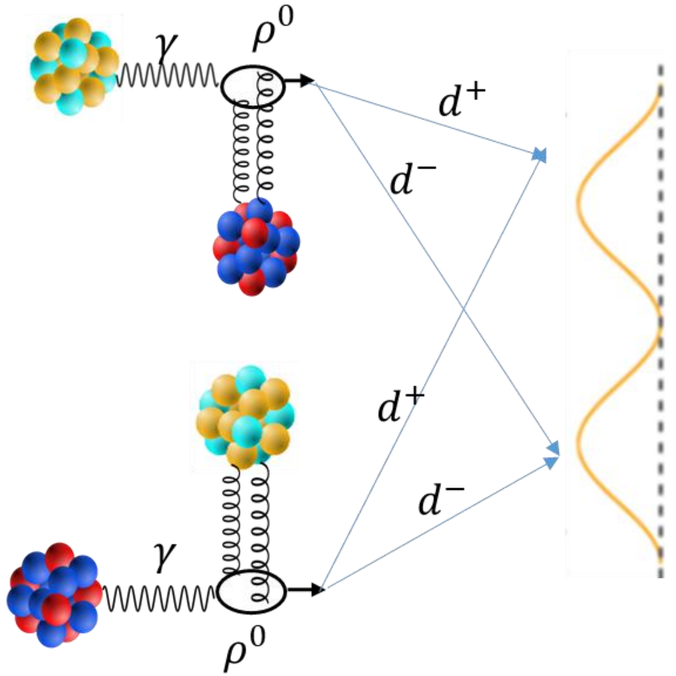


- Linearly polarized photons
- Polarization vector is aligned with impact parameter

- cos4Δϕ modulation via $\gamma\gamma \rightarrow e^+e^-$
- Confirmed the linear polarization of photons
- How about Vector Meson production?

Spin interference effect



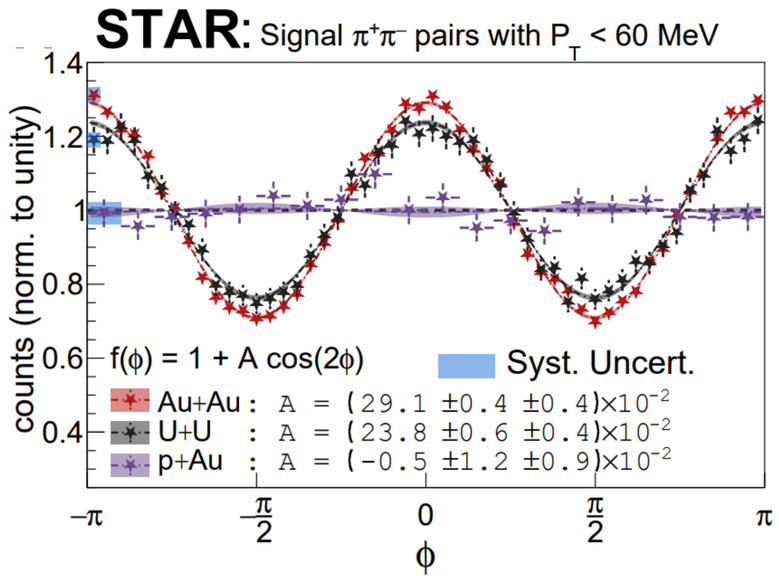


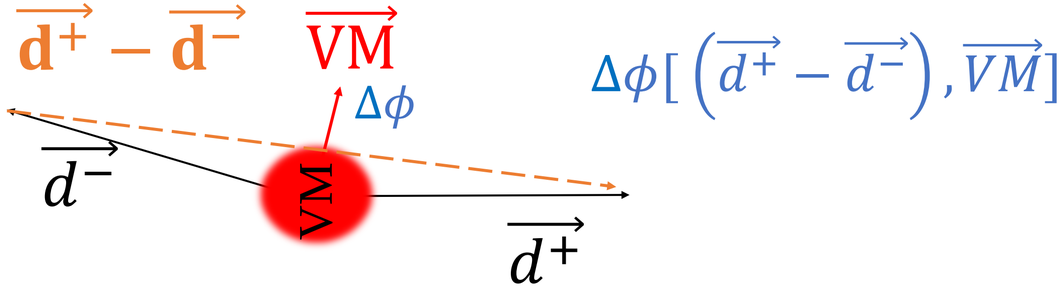
- Polarization of photon
  - ➡ inherited by VM
  - ➡ $\cos(2\Delta\phi)$ modulation w.r.t polarization direction (along $\vec{b}$)

- Interference enabled correlation for the VM momentum and $\vec{b}$
- Polarization from spin interference (Correlation between VM and daughter)

Spin interference effect

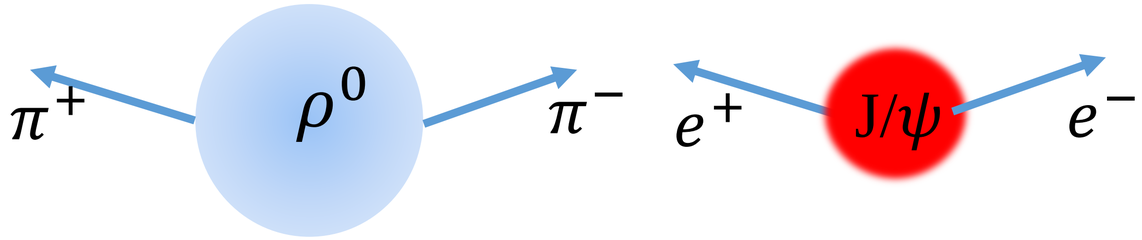
STAR, Sci. Adv. 9, eabq 3903 (2023)





- Spin interference effect has been observed with ρ^0

How about J/ψ ?



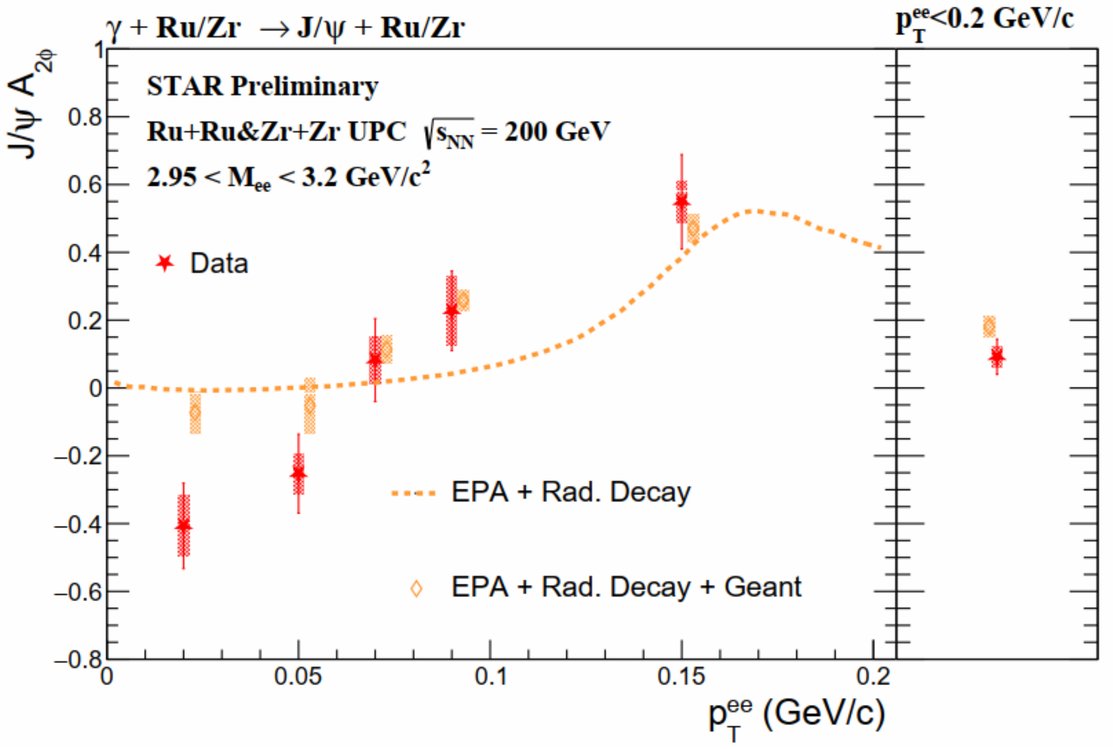
$\tau_{\rho^0} \sim 1.3$ fm/c

$\tau_{J/\psi} \sim 2160$ fm/c

- Decay daughters are fermions
- Longer lifetime than impact parameter (b~20 fm)
- Radiative decay background

Spin interference of J/ψ in isobaric UPCs

Simulation input: P. Wang et al Chin.Phys.C 46 (2022) 7, 074103



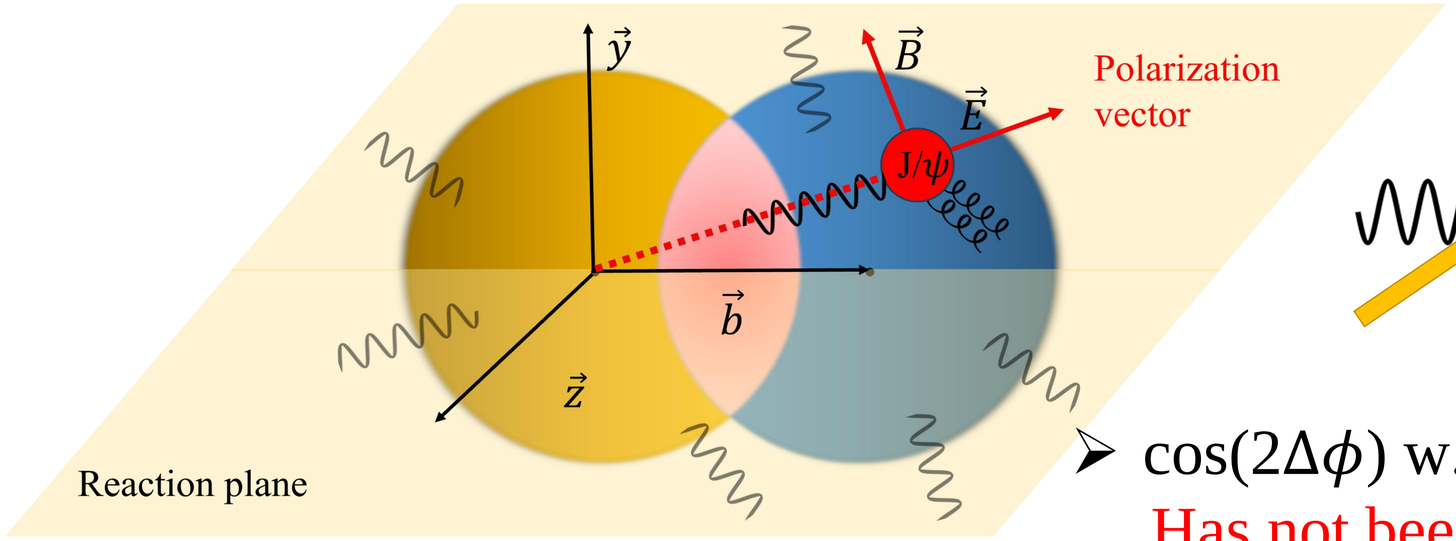
- J/ψ $A_{2\phi} = \langle \mathrm{Cos}\left[2\left(\phi_{J/\psi} - \phi_e\right)\right] \rangle$
- Data: measured J/ψ $A_{2\phi}$, is influenced by radiative decay, detector resolution, and bremsstrahlung
- EPA + Rad.Decay+Geant:
  - EPA: J/ψ photo-production model w/o spin interference effects
  - Rad.Decay: J/ψ → $\gamma e^+ e^-$
  - Geant: Detector simulation accounting for resolution and bremsstrahlung.

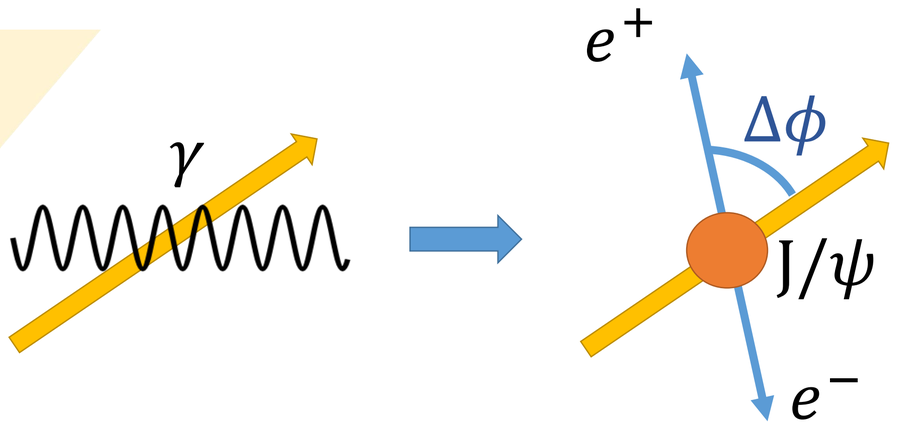
✓ J/ψ $A_{2\phi}$ shows an increasing trend with p_T from negative to positive values

➢ EPA + Rad.Decay+Geant well describes increase trend @ p_T > 0.06 GeV/c

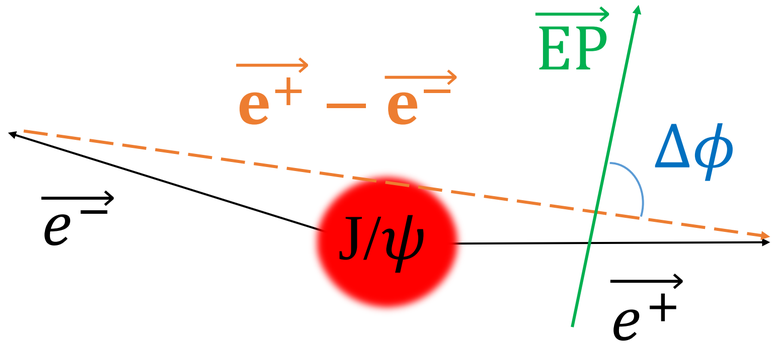
➢ 2.4 σ lower than EPA + Rad.Decay+Geant @ p_T < 0.06 GeV/c

J/ψ polarization w.r.t reaction plane



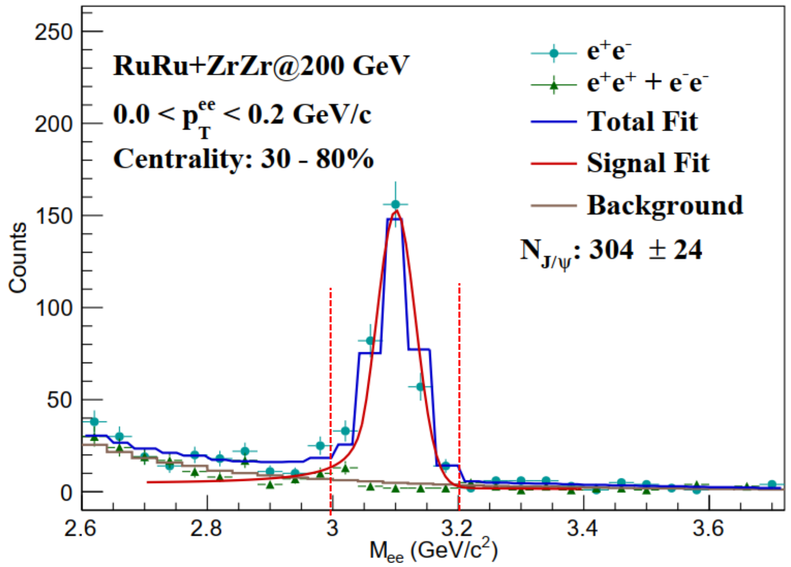


- $\cos(2\Delta\phi)$ w.r.t polarization direction (along $\vec{b}$)
  Has not been confirmed directly yet!

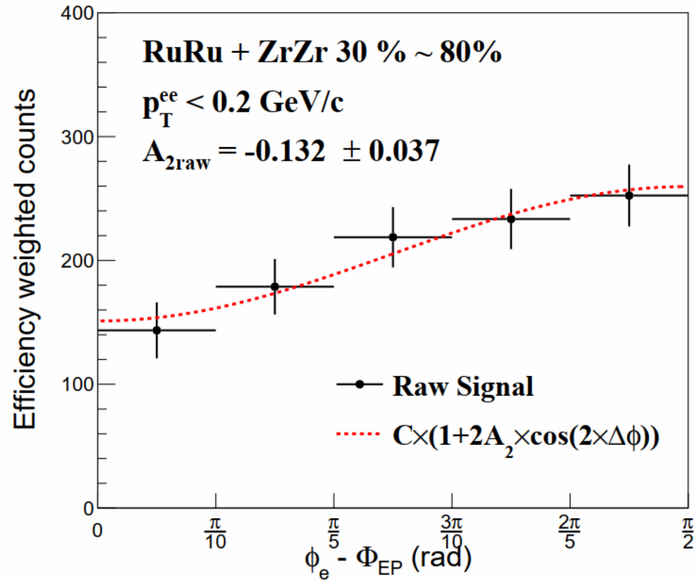


- Observable: $\Delta\phi[\ (\vec{e}^+ - \vec{e}^-), \Psi_{EP}]$
  $\phi\ (\vec{e}^+ - \vec{e}^-)$ measured in J/ψ rest frame,
  Ψ_{EP}^{2nd}: second order TPC event plane
- J/ψ polarization from photon polarization aligned with $\vec{b}$
- Correlation between daughter and RP

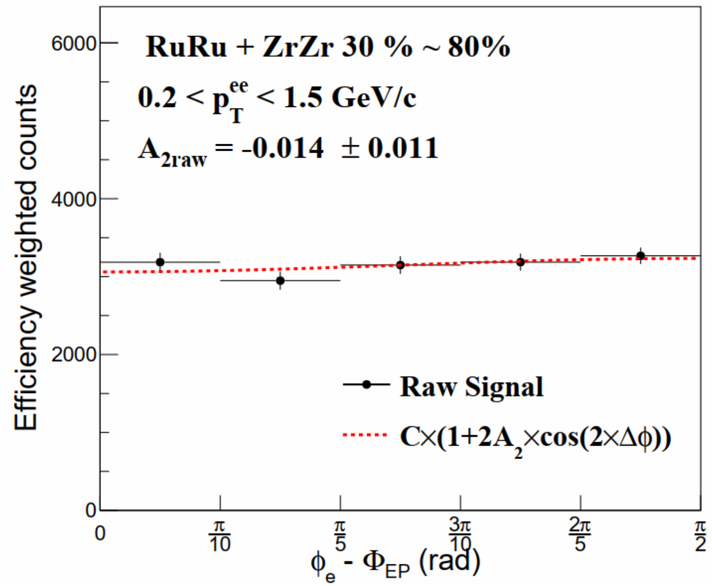
Raw signal



$p_T^{ee} < 0.2$ GeV/c

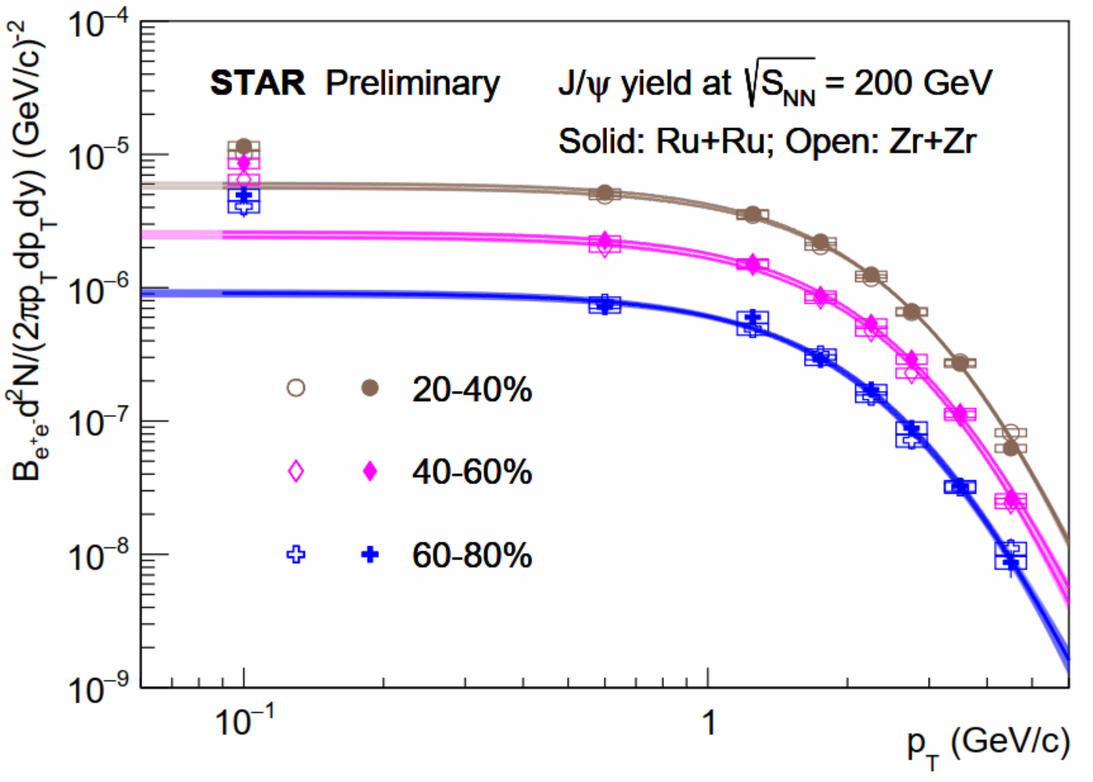


$p_T^{ee} > 0.2$ GeV/c



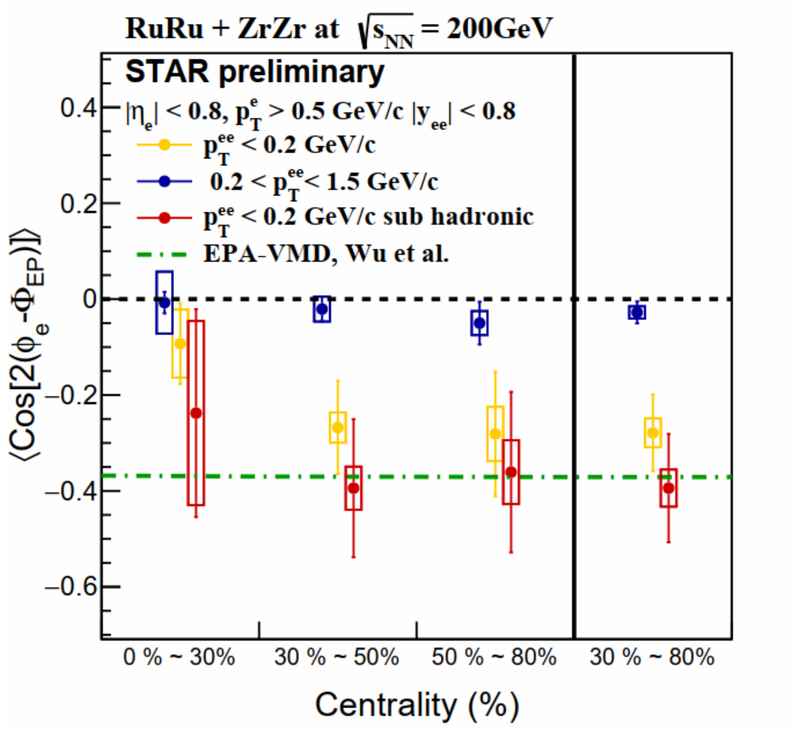
- Clear J/ψ peak from invariant mass spectrum
- Negative A_2 ($\langle \mathrm{Cos}[2(\Delta\phi)] \rangle$) @ $p_T^{ee} < 0.2$ GeV/c (photon induced production dominant)
- A_2 consistent with 0 @ $p_T^{ee} > 0.2$ GeV/c (hadronic process dominant)

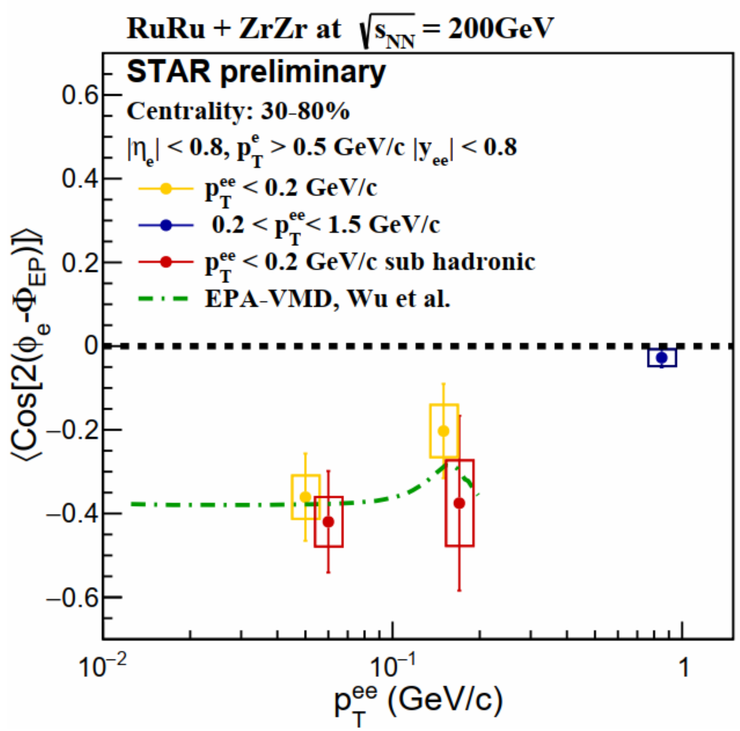
p_T spectrum



- Hadronic yield
  - $p_T^{ee} > 0.2$ GeV/c fitted with Tsallis function
  - Extrapolated to $p_T^{ee} < 0.2$ GeV/c
- Photon-induced yield
  - $p_T^{ee} < 0.2$ GeV/c excess yield w.r.t hadronic yield extrapolation
- Assuming A_2 from hadronic process is 0
  - $A_2^{\mathrm{photon}} = A_2^{meas} \times \frac{\mathrm{Yield_{photon}}}{\mathrm{Yield_{total}}}$

Decay anisotropy of photon induced J/ψ





- For 30%~80%, $p_T^{ee} < 0.2$ GeV/c

Photon-induced A_2

$-0.39 \pm 0.11 \pm 0.04$

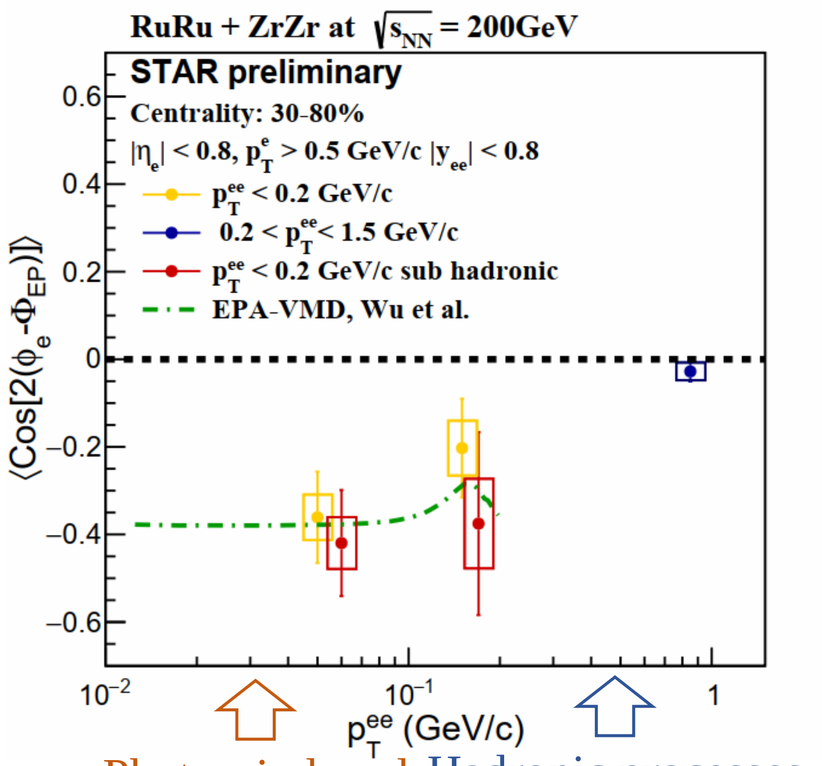
3.3σ below 0

X. Wu et al. Phys. Rev. Res. 4, L042048 (2022)

- Evidence of decay anisotropy from photon polarization aligned with $\vec{b}$
- Accessing impact parameter direction with photon-induced process

Summary

- Coherent J/ψ measurement in isobar UPC
  - ✓ Indicating suppression effect across Ru, Zr, Au w.r.t STARlight
- Spin interference measurement in isobar UPC
  - ✓ p_T dependence & 2.4 σ negative modulation @ p_T < 0.06 GeV/c
- Experimental evidence of J/ψ polarization w.r.t reaction plane in isobar 30%-80% centrality
  - ✓ Accessing impact parameter direction with photon-induced process



Photon-induced dominant

Hadronic processes dominant

Summary

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  - ✓ Indicating suppression effect across Ru, Zr, Au w.r.t STARlight
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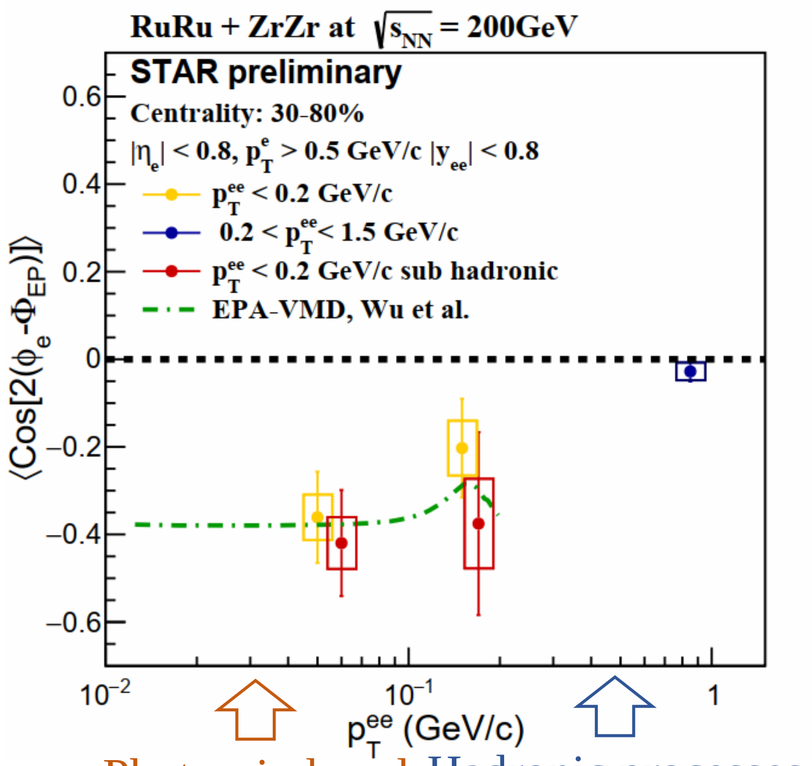
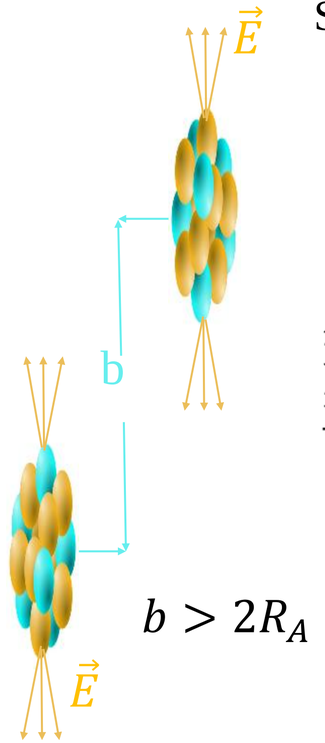


Thank you!

Back up

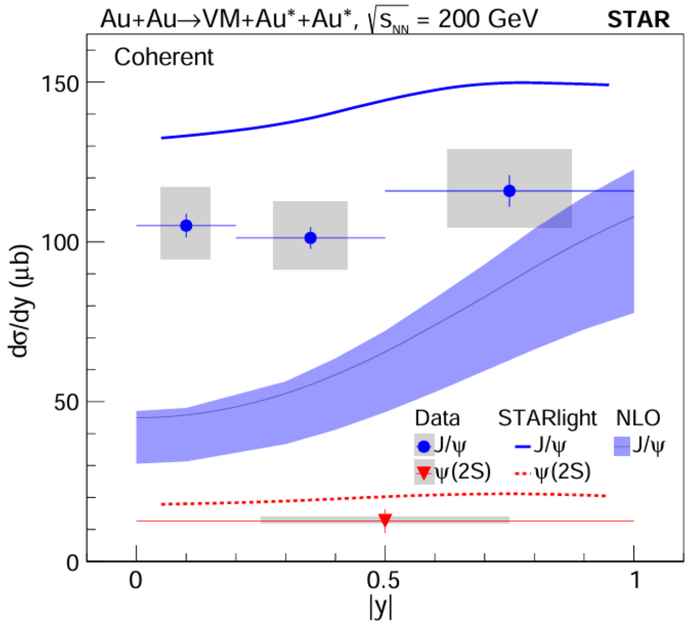
Coherent photon-induced J/ψ production

Ultra-Peripheral Collisions

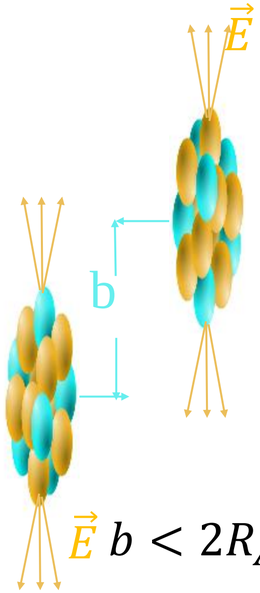


$b > 2R_A$

STAR, Phys. Rev. Lett. 133 (2024) 5, 052301

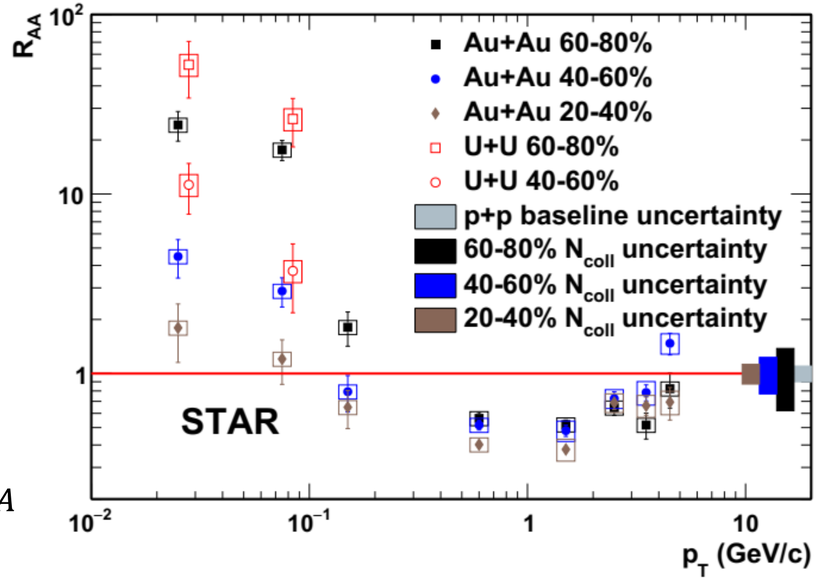


Peripheral Collisions



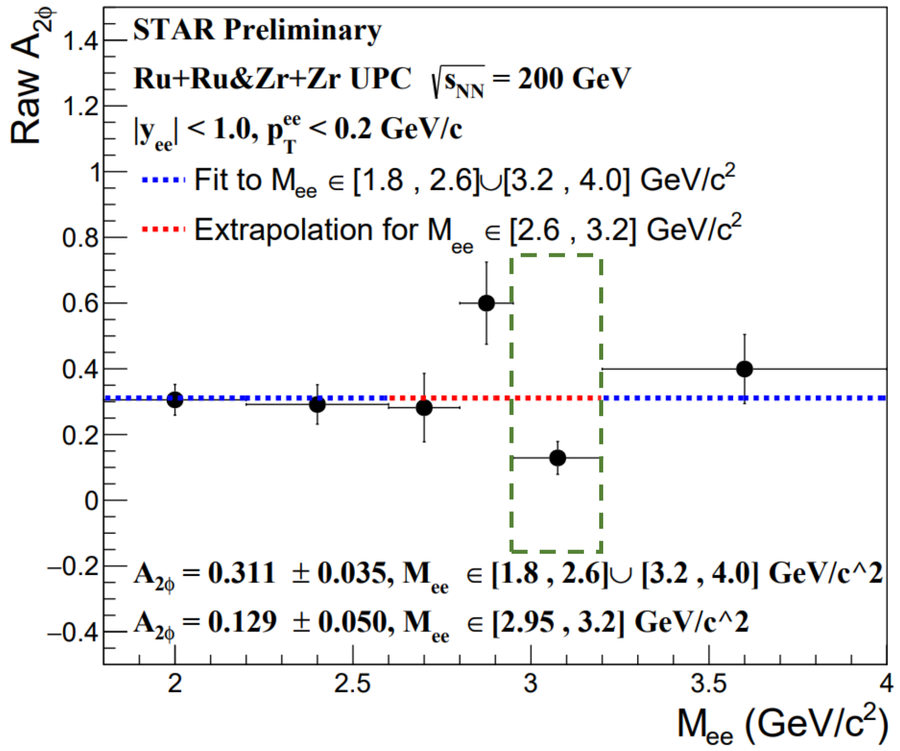
$b < 2R_A$

STAR, Phys. Rev. Lett. 123 (2019) 132302



✓ Insightful probe of the collision initial state both in PCs and UPCs

J/ψ spin interference signal extraction



$$A_2^{raw} = \frac{N_{J/\psi} \times A_2^{J/\psi} + N_{\gamma\gamma} \times A_2^{\gamma\gamma}}{N_{J/\psi} + N_{\gamma\gamma}}$$

$$A_2^{J/\psi} = \left(1 + \frac{N_{\gamma\gamma}}{N_{J/\psi}}\right) \times A_2^{raw} - \left(\frac{N_{\gamma\gamma}}{N_{J/\psi}}\right) \times A_2^{\gamma\gamma}$$

$N_{\gamma\gamma}$&$N_{J/\psi}$: From fitting of M_{ee} spectrum

$A_2^{\gamma\gamma}$: Extrapolated from $M_{ee} \in [1.8, 2.6] \cup [3.2, 4.0]$ GeV/c^2

- ✓ Sizeable contributions from $\gamma\gamma \rightarrow e^+e^-$ process
- ✓ Possible variations for $A_{2\phi}$ in the mass continuum has been considered as systematics
- ✓ Enhancement on left side of J/ψ peak → Bremsstrahlung & soft photon radiation

J/ψ spin interference signal extraction