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Measurement of photon-induced J/ψ azimuthal anisotropy in isobar collisions at STAR

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STAR

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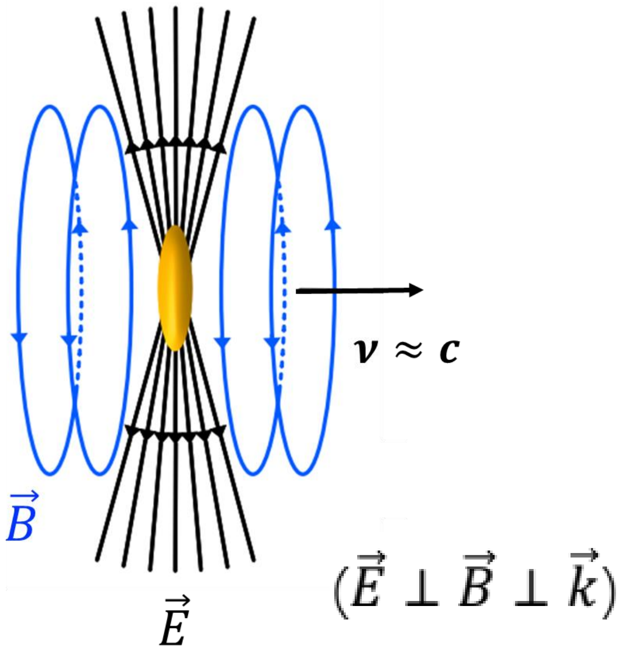
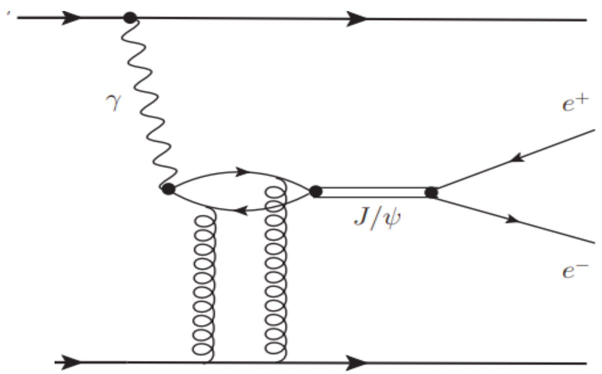
Outline

- Introduction: “polarized $\gamma + A$ collider”
- Photon polarization and alignment with impact parameter
- Spin interference effect
- Summary

Photon-induced process





- 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 $\propto Z^2$

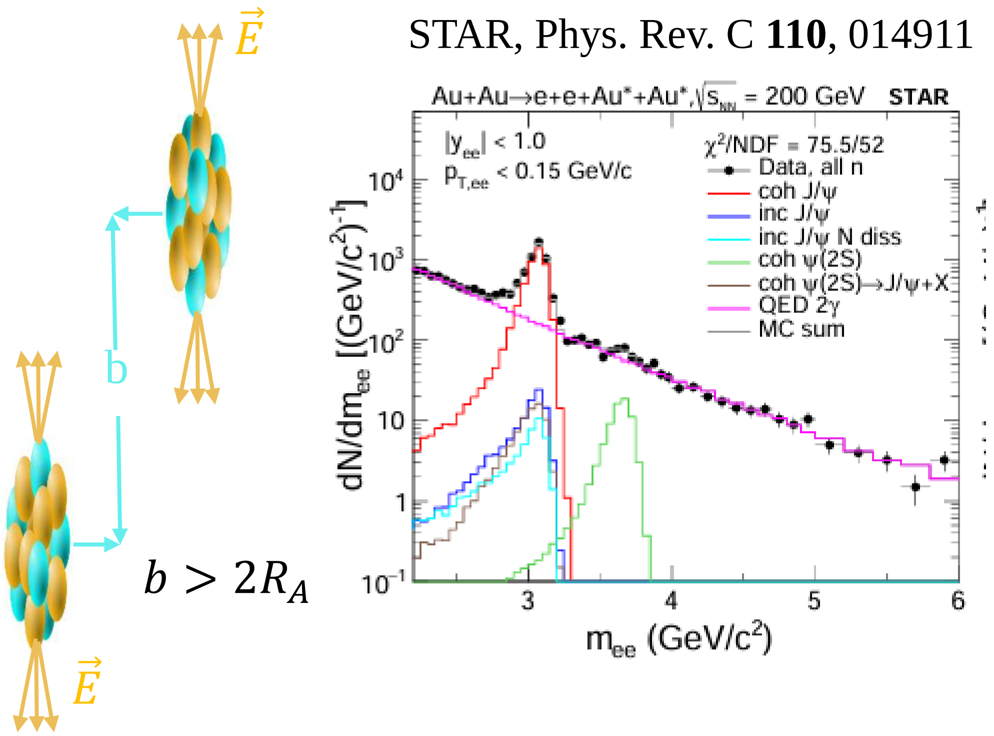
" Photon-Nucleus collider"

- $\gamma + A \rightarrow J/\psi + A$
- Distinctly peaked at very low p_T

Photon-induced J/ψ production

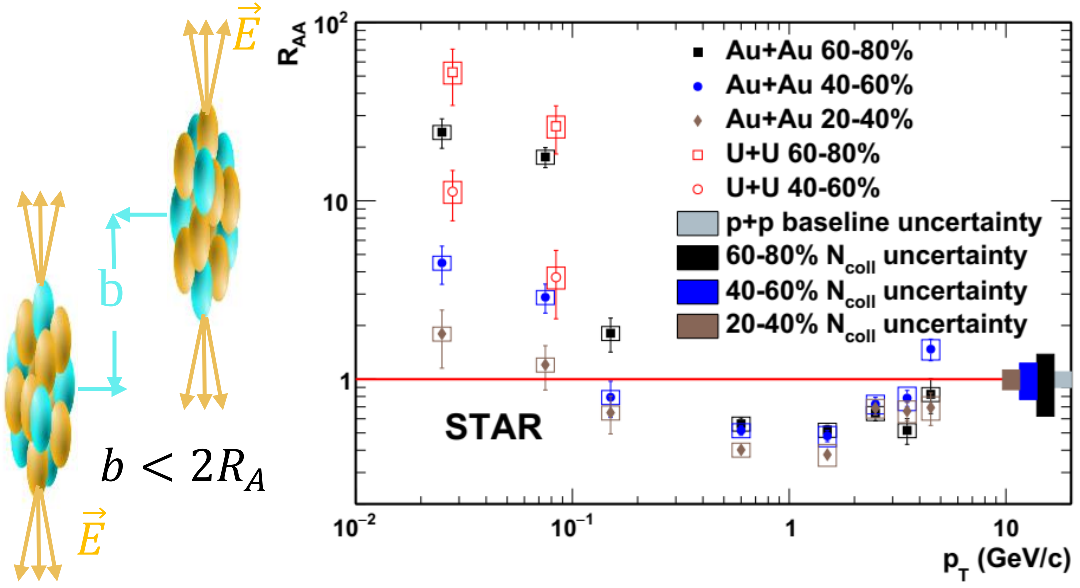
Ultra-Peripheral Collisions

STAR, Phys. Rev. C **110**, 014911



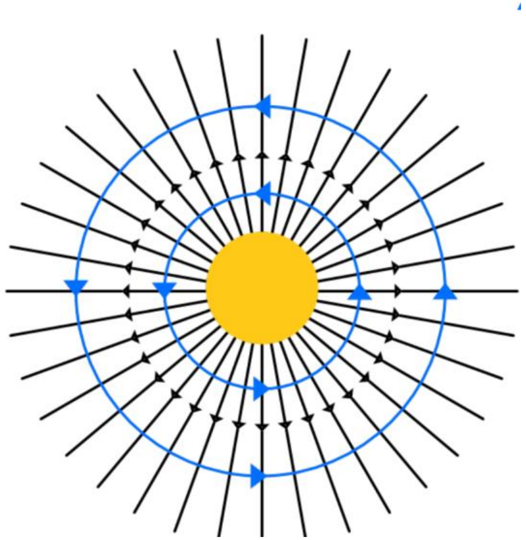
Peripheral Collisions

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

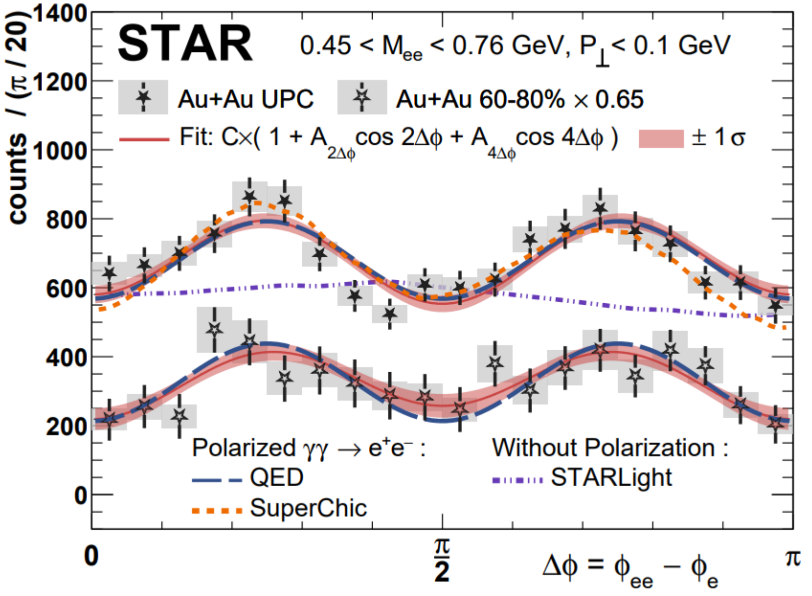


✓ Coherent photon-induced interactions could explain the low p_T J/ψ yields

Linearly polarized photons



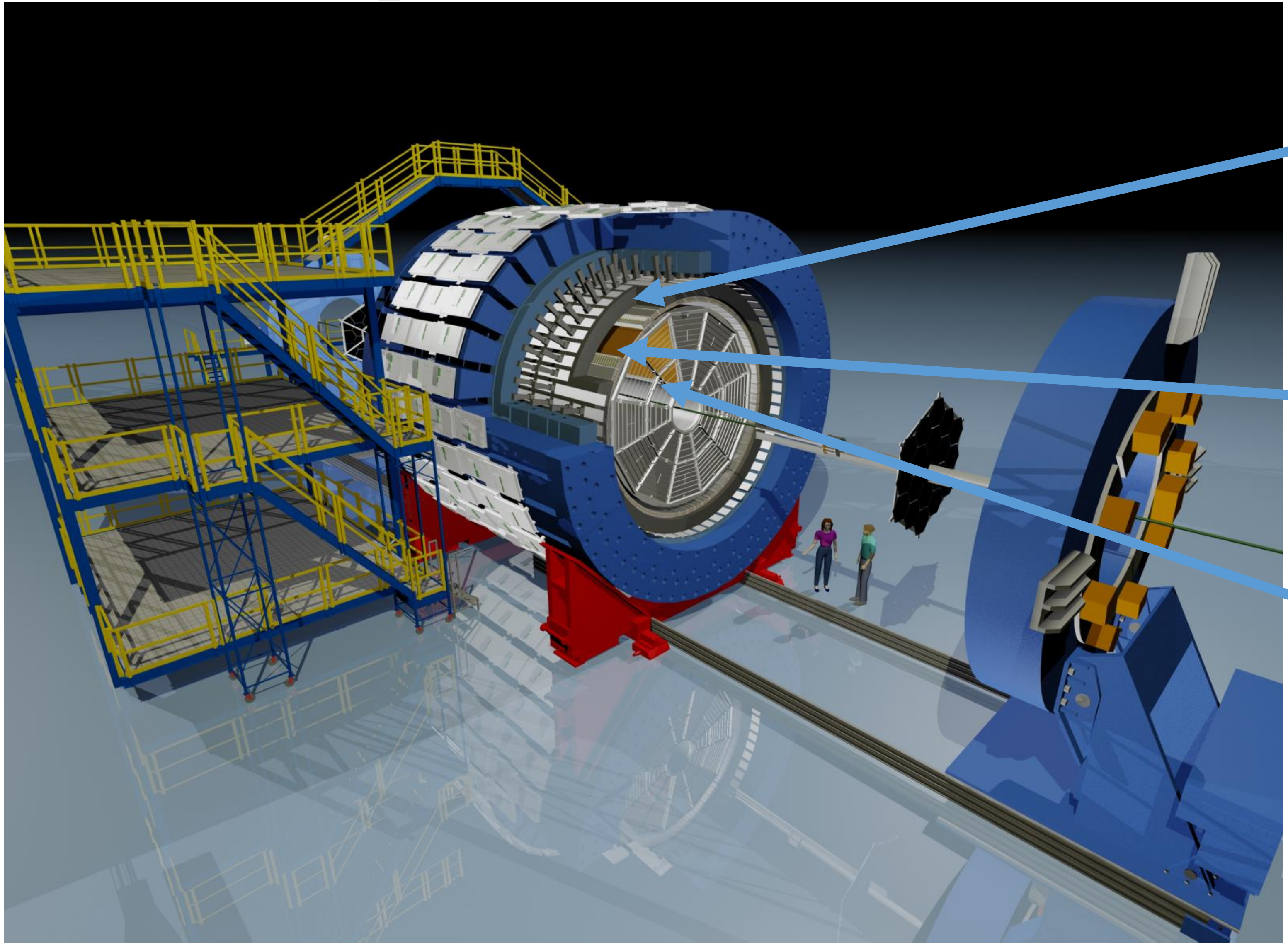
STAR, Phys. Rev. Lett. 127, 052302 (2021)



- Linearly polarized photons
- Polarization vector is radially outward along the emitting source

- cos4Δϕ modulation via $\gamma\gamma \rightarrow e^+e^-$
- Confirmed the linearly polarization of photons
- **How about Vector Meson production?**
  $\boldsymbol{\gamma + A \rightarrow J/\psi + A}$

STAR experiment

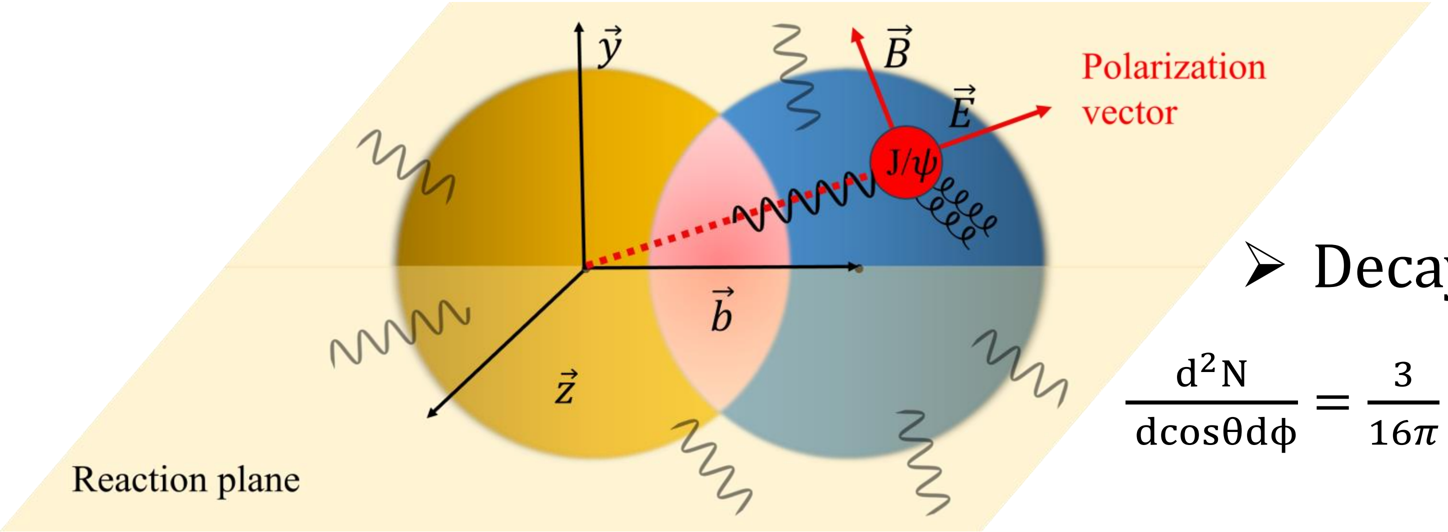


✓ BEMC: Particle identification, trigger

✓ TOF: Time of flight, particle identification

✓ TPC: Tracking, momentum and dE/dx

Polarized Photon-Nucleus collider

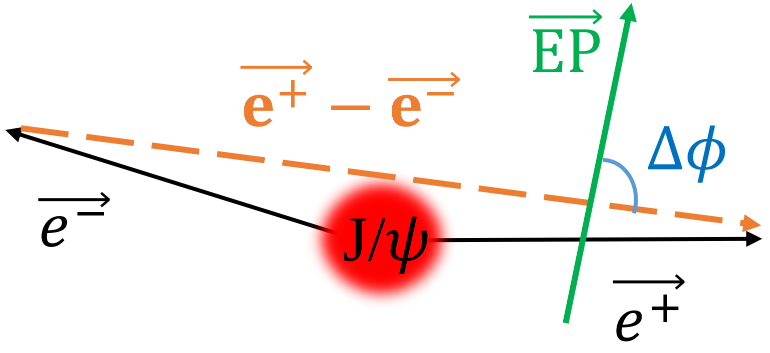


$\gamma + A \rightarrow J/\psi + A$

$\vec{\mathbf{E}}$ is aligned with $\vec{\mathbf{b}}$

- Decay angular distribution:

$$\frac{d^2N}{d\cos\theta d\phi} = \frac{3}{16\pi}(1+\cos^2\theta)\left[1 - \frac{\sin^2\theta}{1+\cos^2\theta}\cos 2(\phi)\right]$$



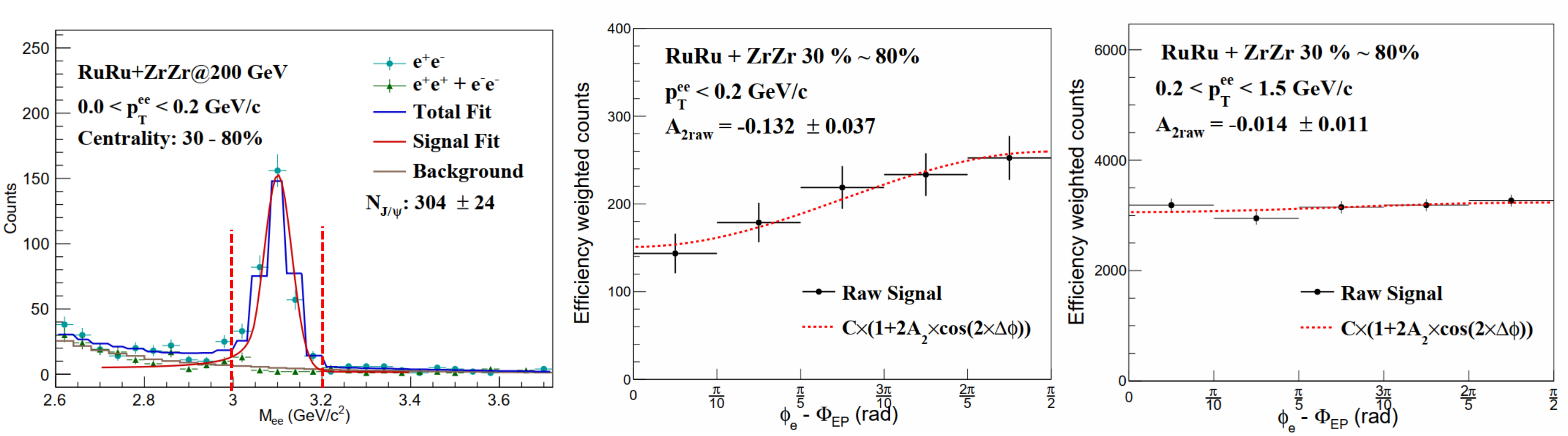
- $\Delta\phi[(\vec{e}^+ - \vec{e}^-), \Psi_{EP}^{2nd}]$

$\phi\ (\vec{e}^+ - \vec{e}^-)$ is in J/ψ rest frame,

Ψ_{EP}^{2nd}: second order TPC event plane

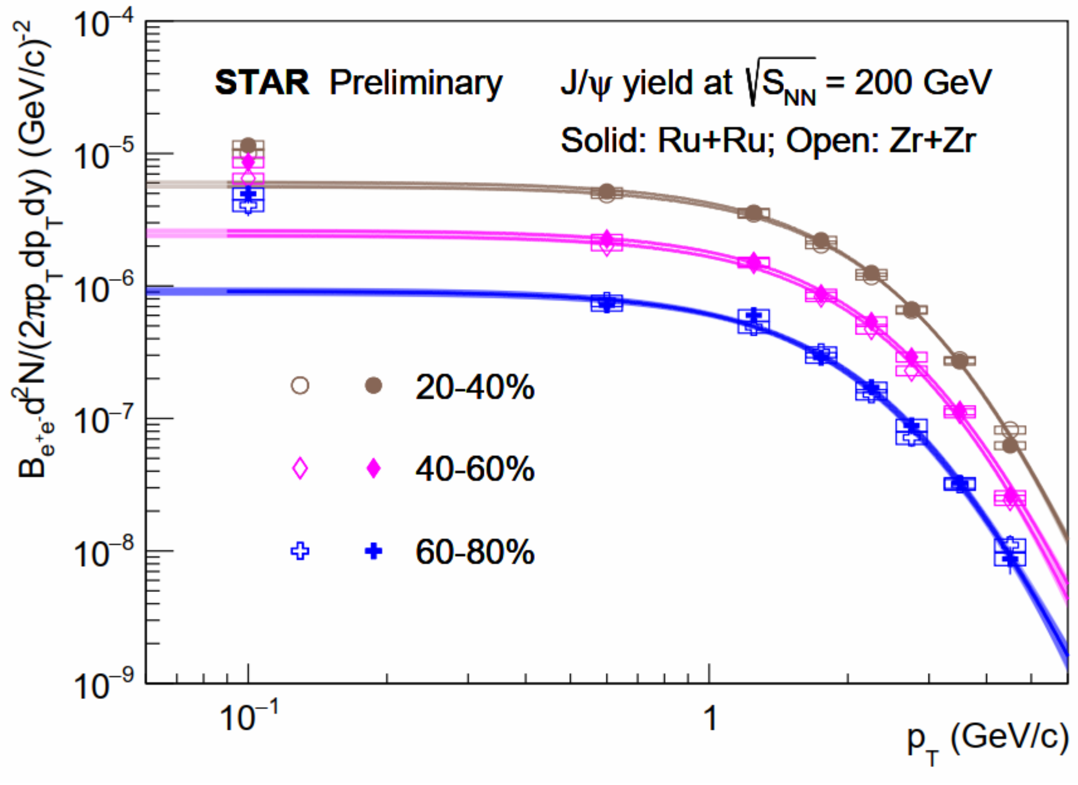
- J/ψ polarization could originate from linear polarization and geometry

Raw signal



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

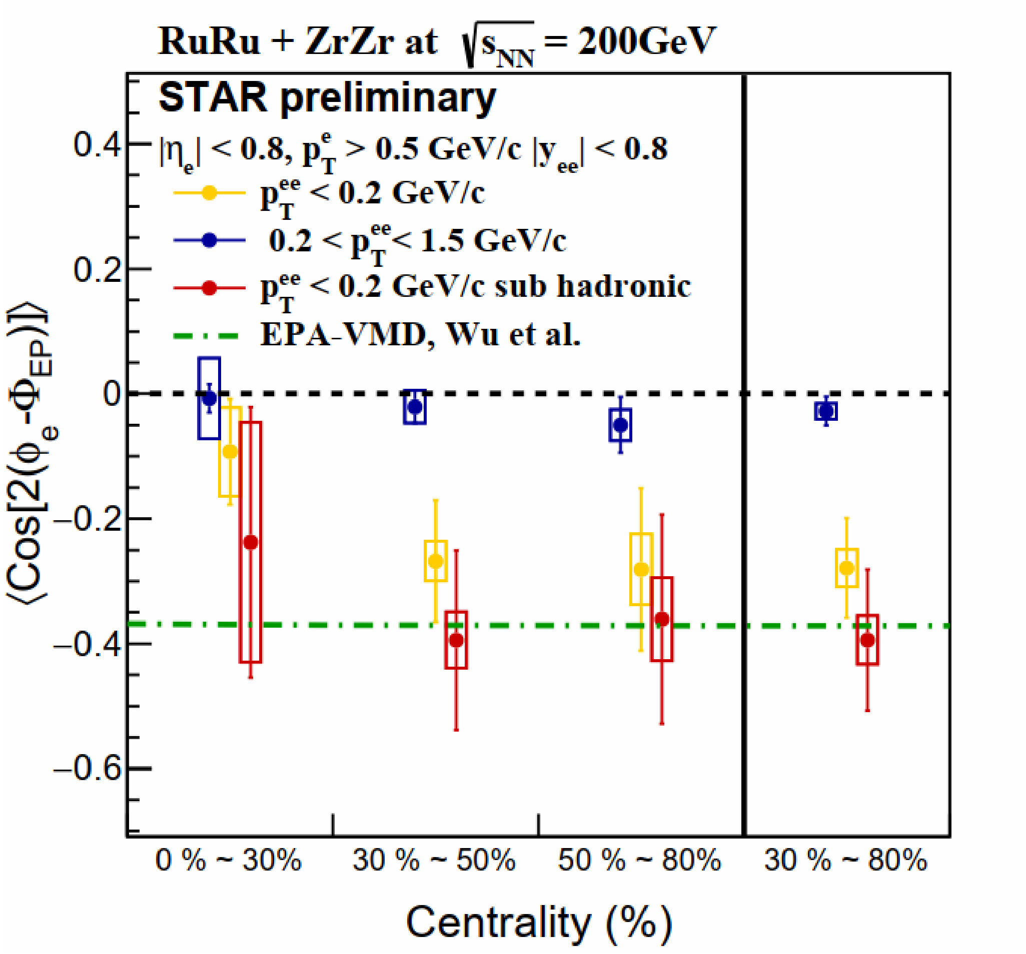
p_T spectrum



- 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

✓ $A_2^{photon} = A_2^{meas} \times \frac{\text{Yield}_{\text{photon}}}{\text{Yield}_{\text{total}}}$

A_2 vs. centrality



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

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

Measured A_2

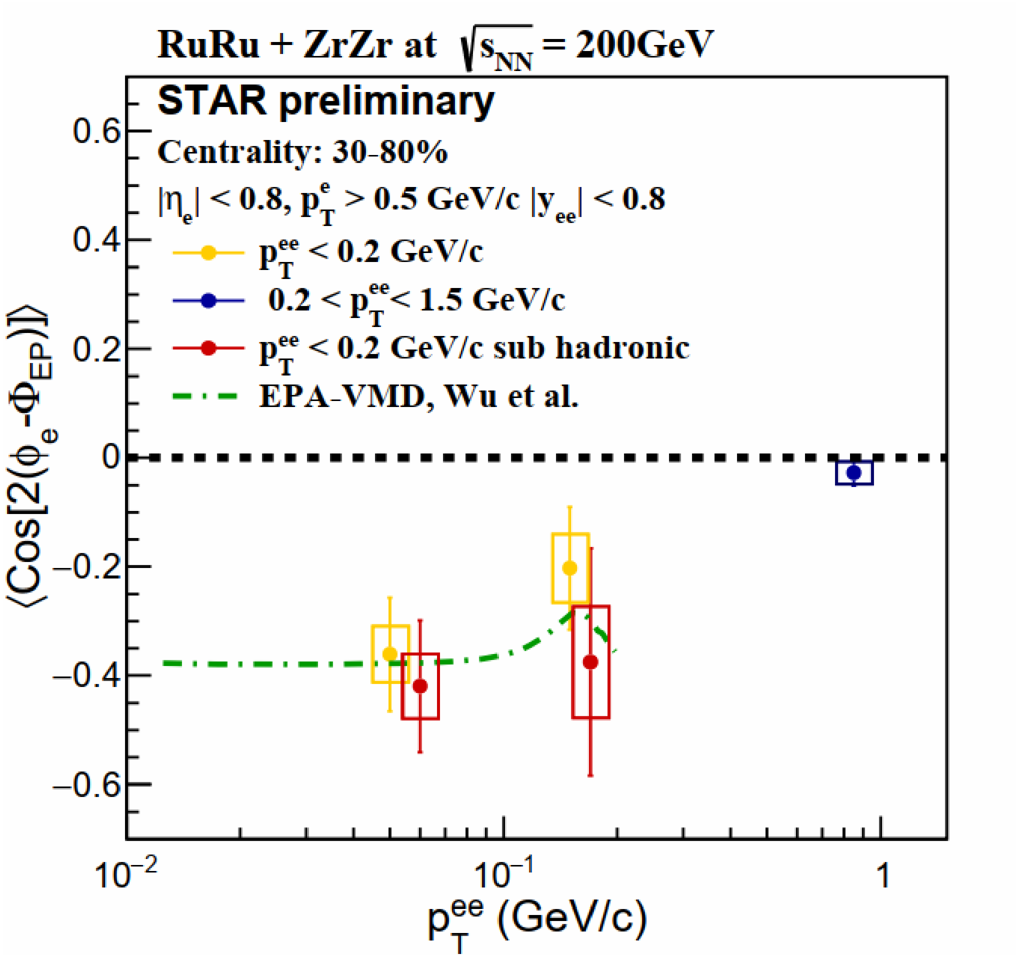
$-0.28 \pm 0.08\ (\mathrm{stat.}) \pm 0.03 (\mathrm{sys.})$ ~3.3σ

Photon-induced A_2 after subtracting the hadronic contribution

$-0.39 \pm 0.11\ (\mathrm{stat.}) \pm 0.04 (\mathrm{sys.})$

- Photon-induced A_2 agrees with EPA-VMD model prediction
- No obvious centrality dependence

A_2 vs. p_T

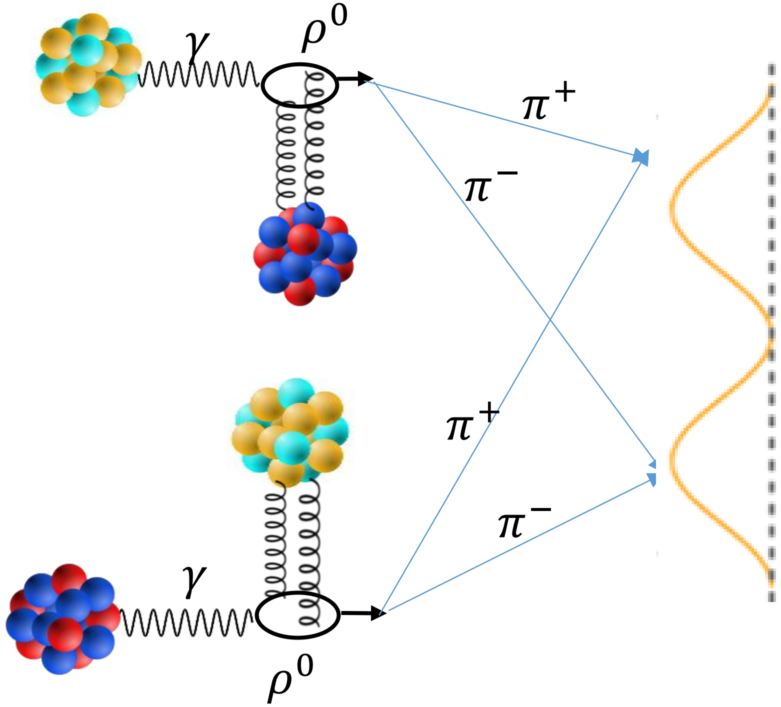


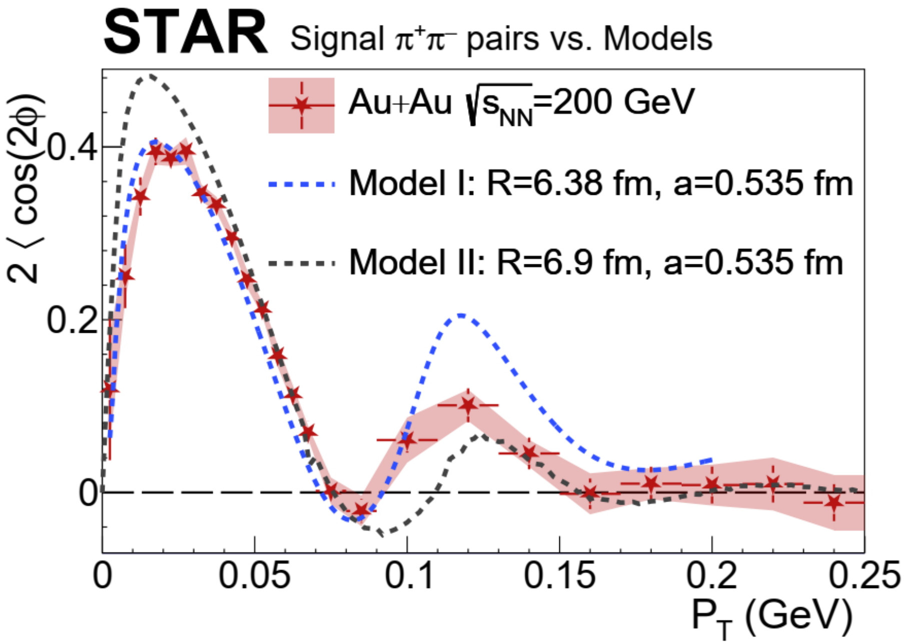
- ➢ No obvious p_T dependence for photon induced A_2

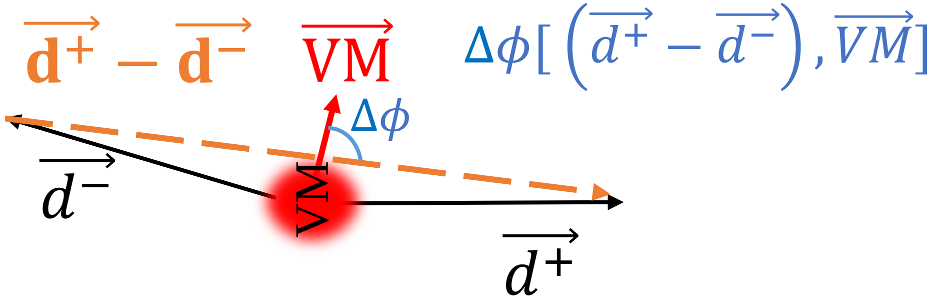
- ✓ Evidence of decay anisotropy from photon polarization and initial geometry
- ✓ Direct measurement of photon polarization

Spin interference effect

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

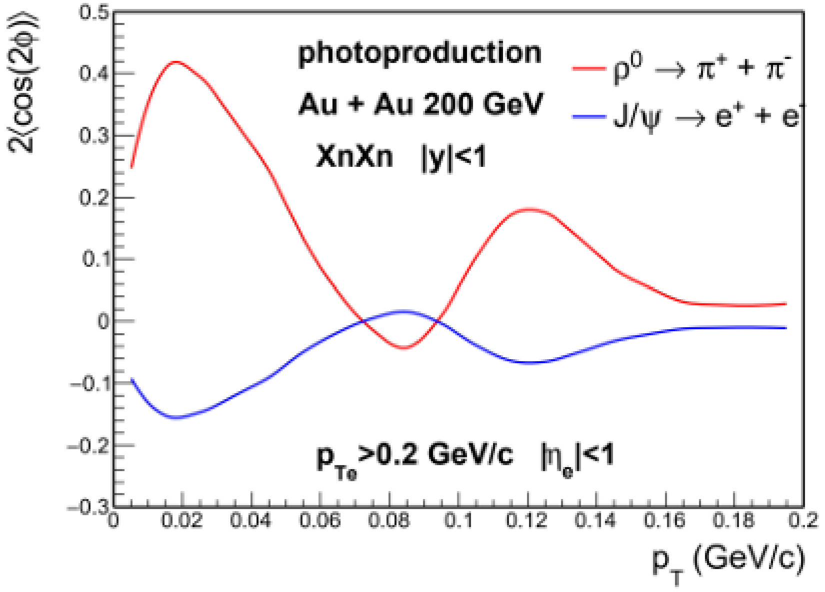




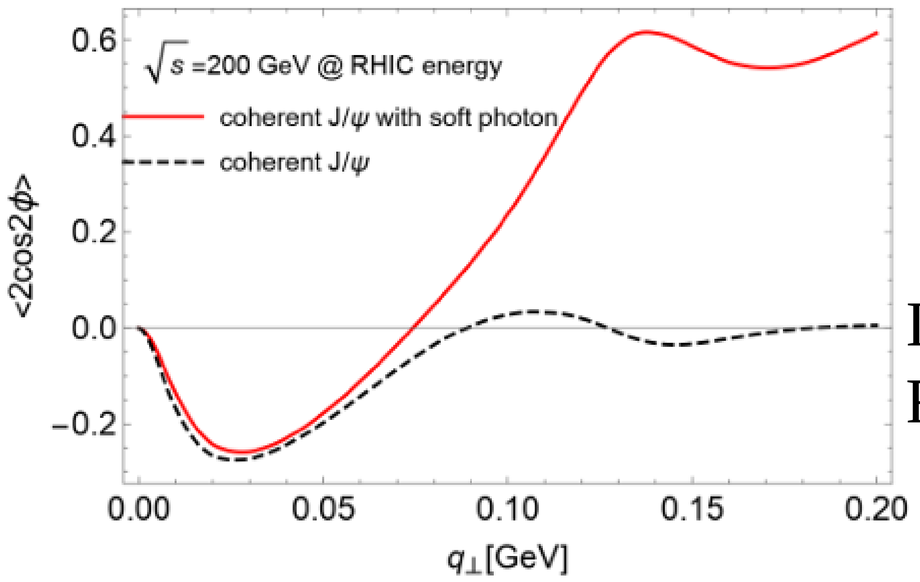


- Two sources for ρ^0 photo-production lead to final state interference effect
- Sensitive to nuclear structure

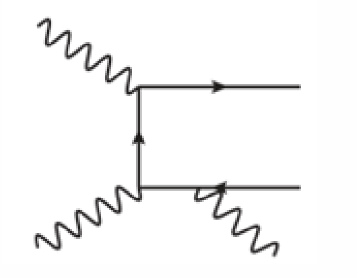
Spin interference effect for J/ψ



W. Zha et.al Physical Review D 103, 033007 (2021)



J. D. Brandenburg etal.,Phys. Rev. D 106, 074008 (2022)



Internal Photon Radiation Effect

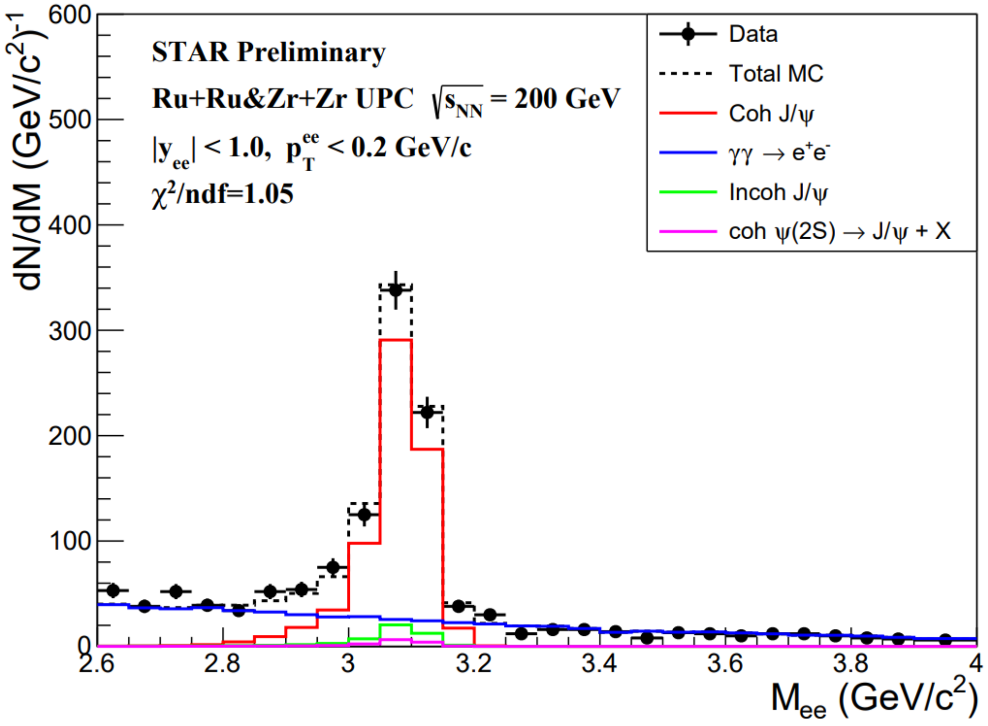
How about J/ψ ?

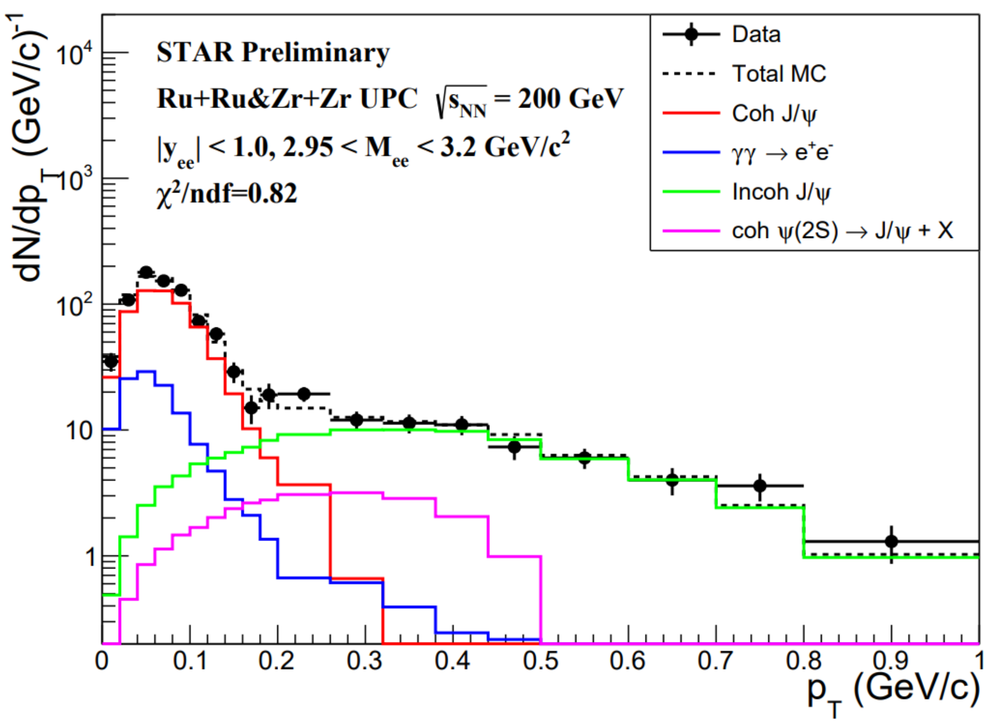
- Decay daughters, e^+e^- are fermions
- Longer lifetime than impact parameter

ρ^0 ~ 1.3 fm/c   J/ψ ~ 2160 fm/c   b ~ 20 fm

- Internal photon radiation

J/ψ measurements in isobaric UPCs

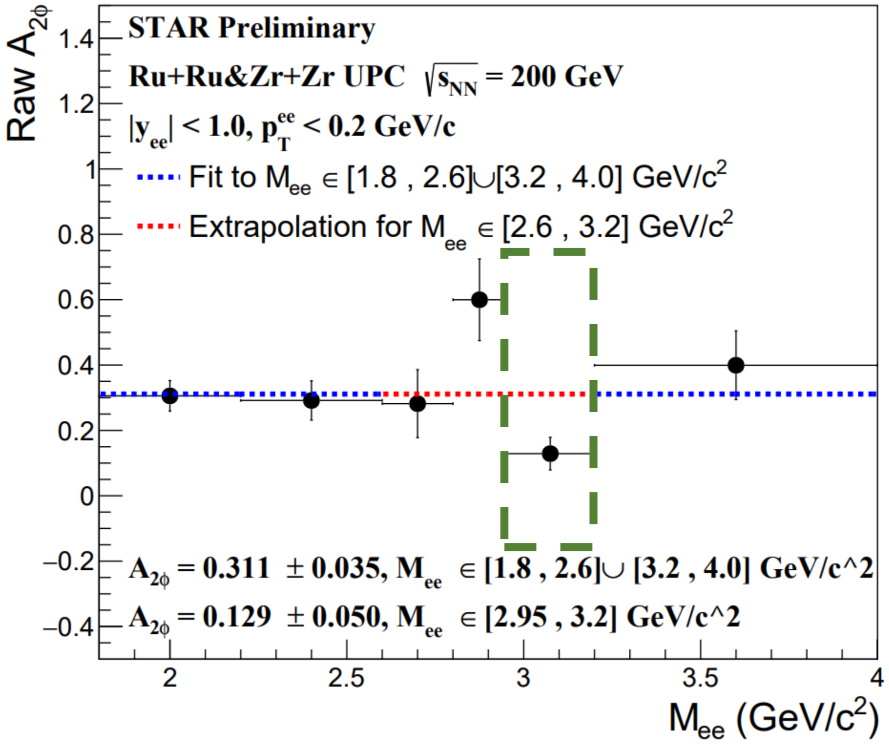




Simulation input
P. Wang et al 2022 Chinese Phys. C 46 074103
W. Zha et al Phys. Lett. B 800,135089 (2020)

- Measured $\gamma A \to J/\psi \to e^+e^-$ & $\gamma\gamma \to e^+e^-$ (in the mass continuum) within $|y| < 1$
- Signal extractions are performed via fitting to the M_{ee} & p_T distributions

J/ψ spin interference signal extraction



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

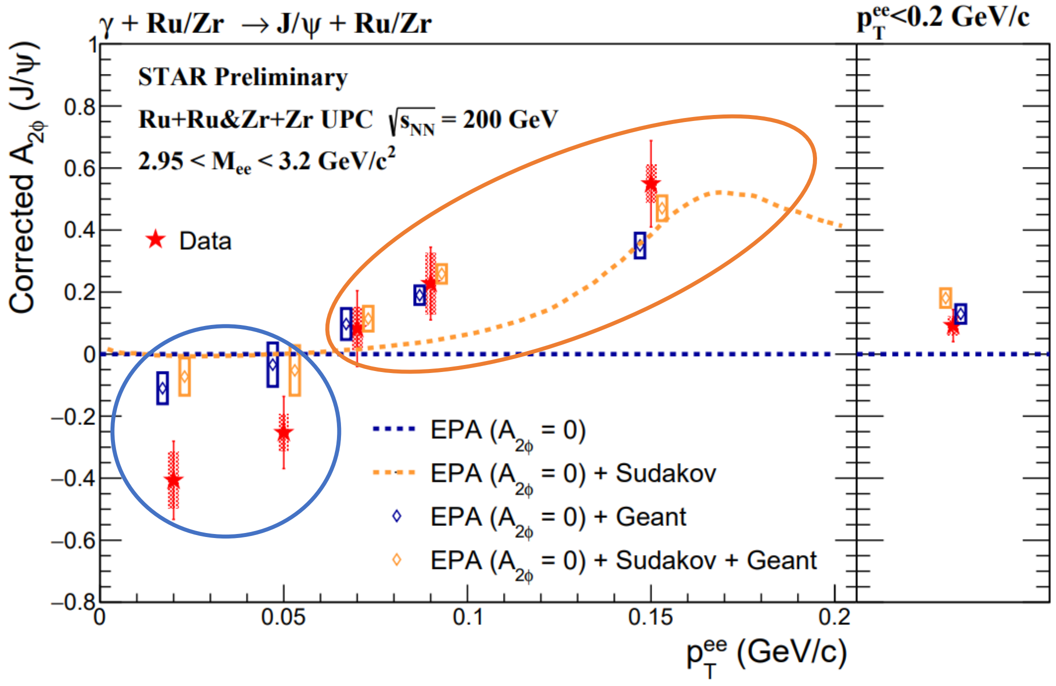
$$A_2^{J/\psi} = \left(1 + \frac{N_{\gamma\gamma}}{N_{J/\psi}}\right) \times A_2^{raw} - \left(\frac{N_{\gamma\gamma}}{N_{J/\psi}}\right) \times A_2^{\gamma\gamma}$$

$N_{\gamma\gamma}$&$N_{J/\psi}$: 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/c²

- ✓ 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

p_T-dependent spin interference of J/ψ



- ❑ Data: J/ψ modulation extracted from raw signals
- ❑ EPA + Geant: zero amplitude of modulations input
  - Bremsstrahlung & detector effect
- ❑ EPA + Sudakov + Geant: internal photon radiation modulation input
  - Soft photon radiation
  - Bremsstrahlung & detector effect

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

✓ J/ψ signal shows an increasing trend with p_T from negative to positive values

➢ MC with soft photon radiation well describes increase trend @ $p_T > 0.1\ GeV/c$

➢ 2.4 σ lower than MC with zero modulation input @ $p_T < 0.06\ GeV/c$

Summary

- Global polarization for photon-induced J/ψ
  - ✓ Evidence of significant decay anisotropy from photon polarization and initial geometry
  - ✓ Direct measurement of photon polarization
  - ☐ Electron direction: a novel tool for determination of reaction plane in peripheral and ultra-peripheral collisions
- Spin interference measurement in isobaric UPC
  - ✓ Strong p_T dependence
  - ✓ 2.4 σ negative modulation @ $p_T < 0.06$ GeV/c

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THANK YOU!