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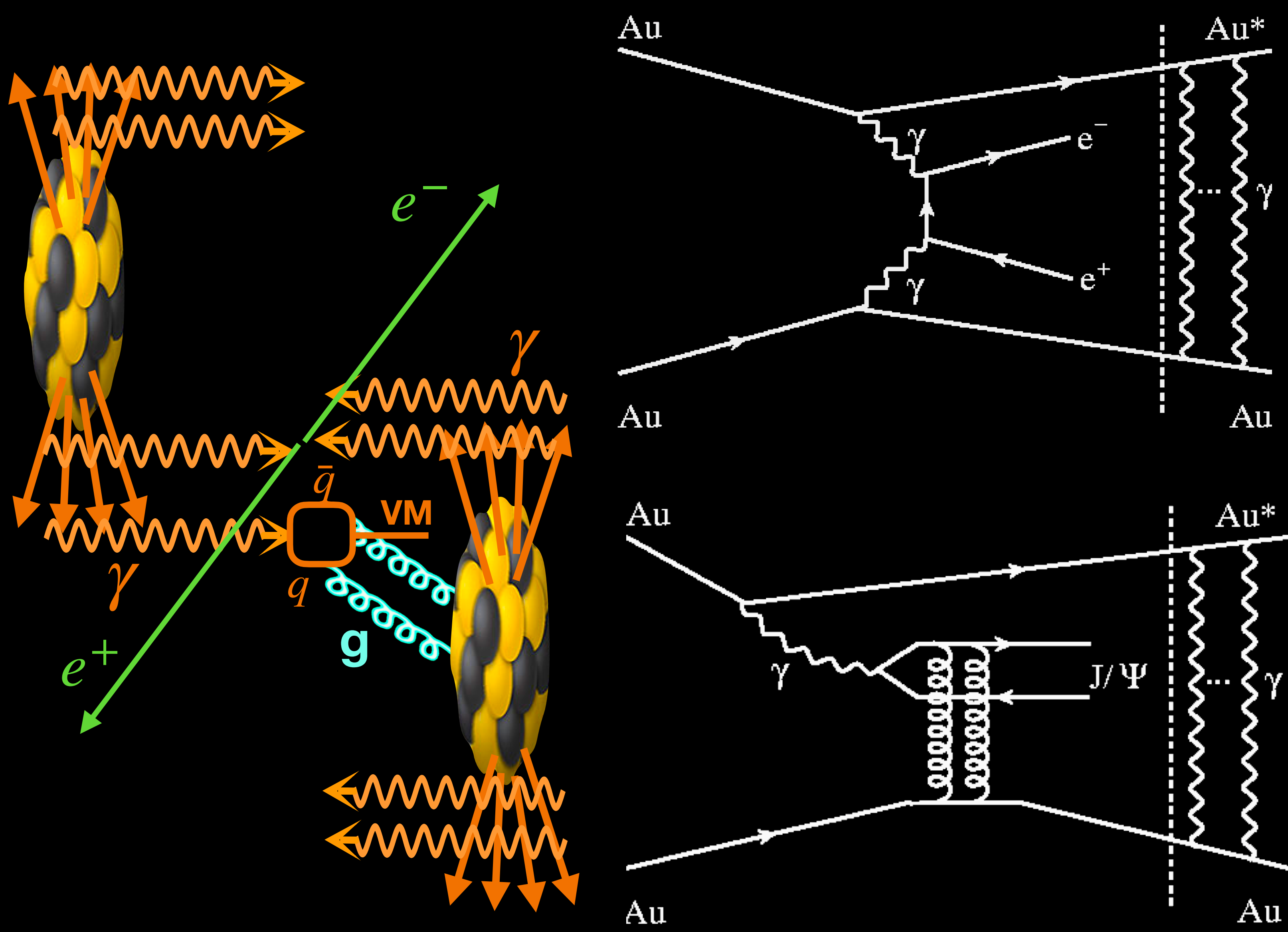
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Imaging a nucleus with vector meson photo-production in ultra-peripheral collisions at STAR

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Kent State University

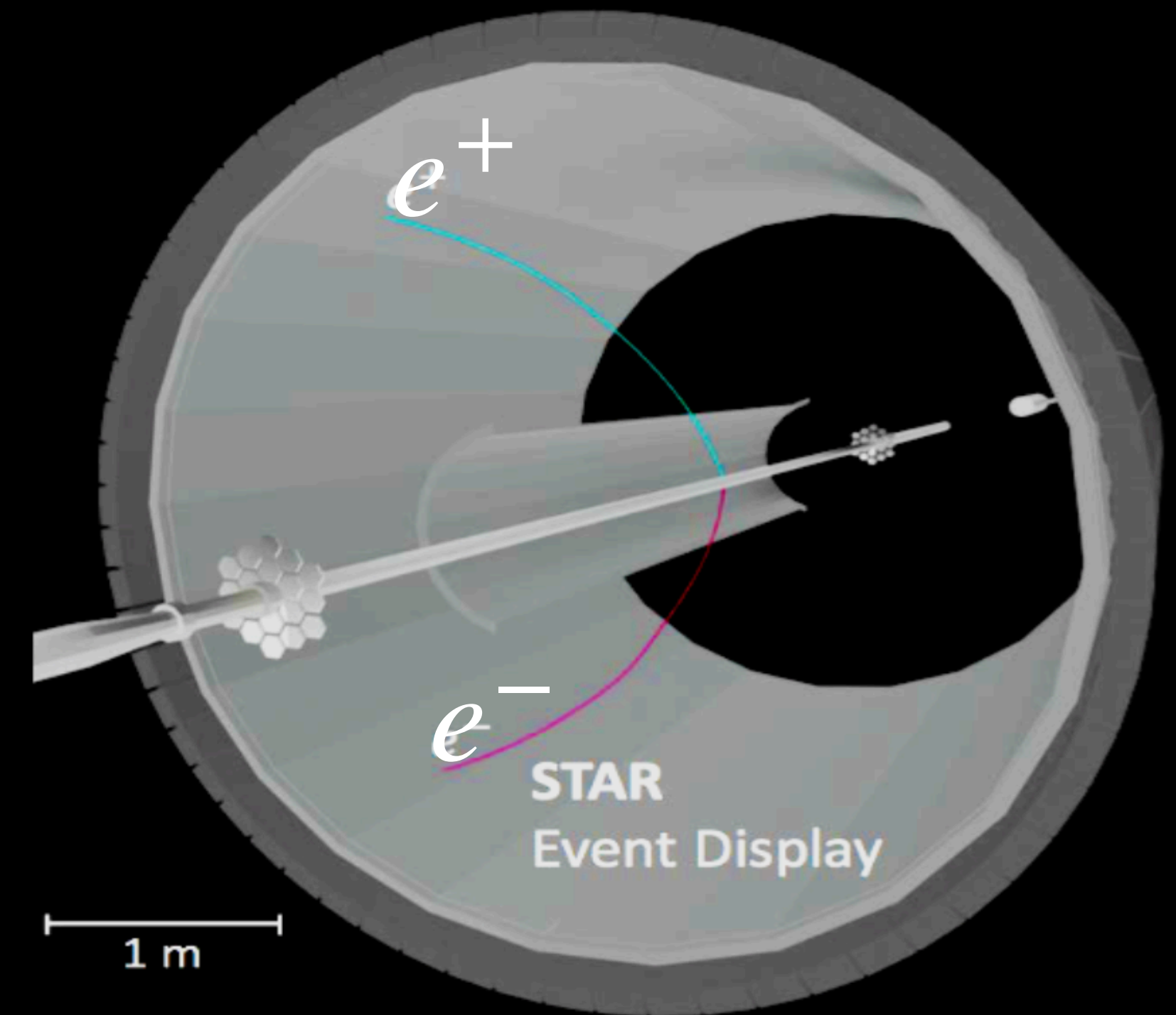
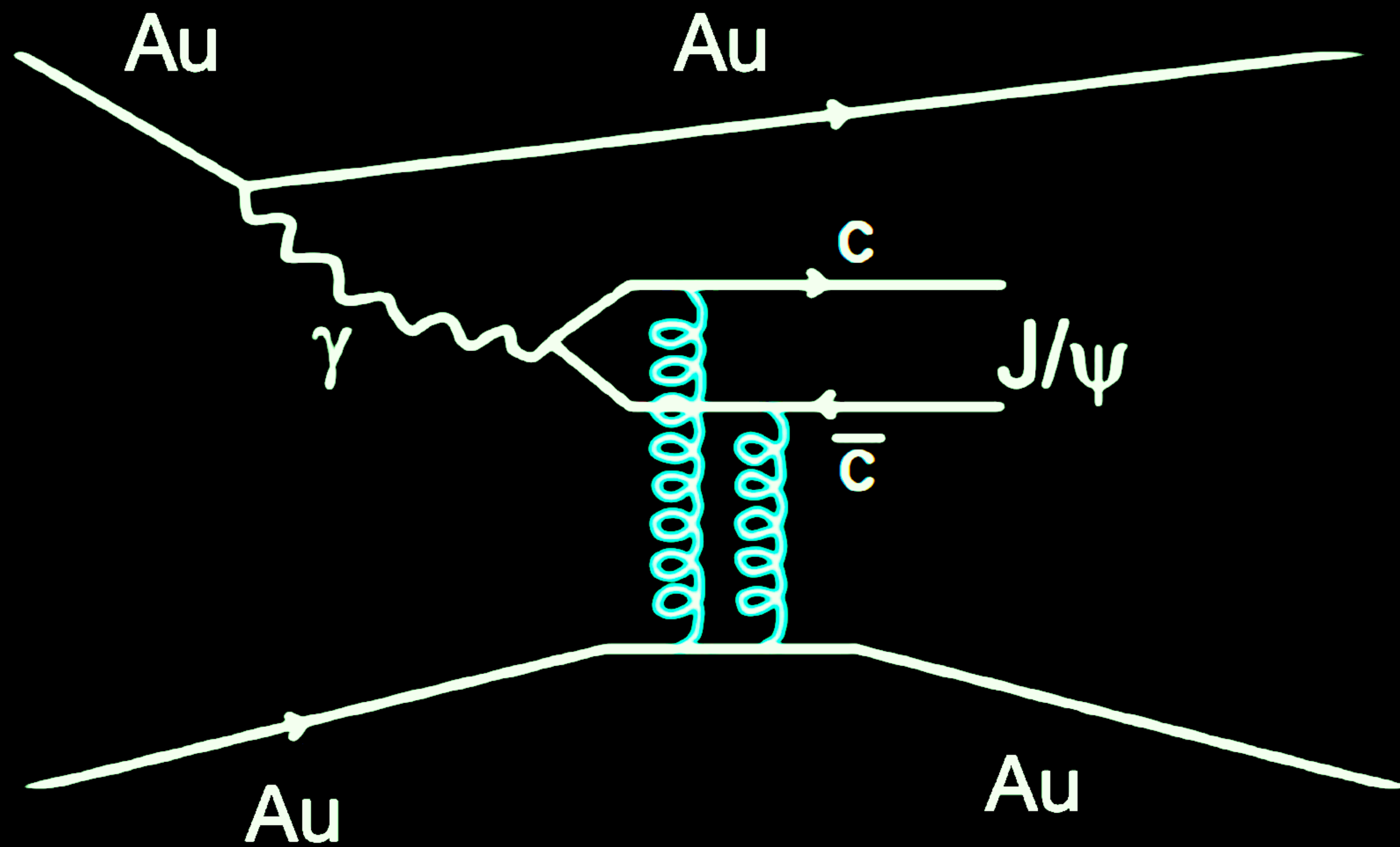
8th International Conference on Physics and Astrophysics of Quark Gluon Plasma (ICPAQGP-2023)
07 - 10 Feb, 2023, Blue Lily Beach Resort, Puri, Odisha, India

Quasi-real photons in UPCs



- In UPCs, $b > 2R \Rightarrow$ no hadronic interactions occur
- Photon flux induces $\gamma\gamma$ and γA interactions
- QED processes occur in $\gamma\gamma$ interactions (e.g., $\gamma\gamma \rightarrow e^+e^-$)
- Vector Meson (VM) production occurs in γp or γA interactions ($\gamma A \rightarrow VM + A$)

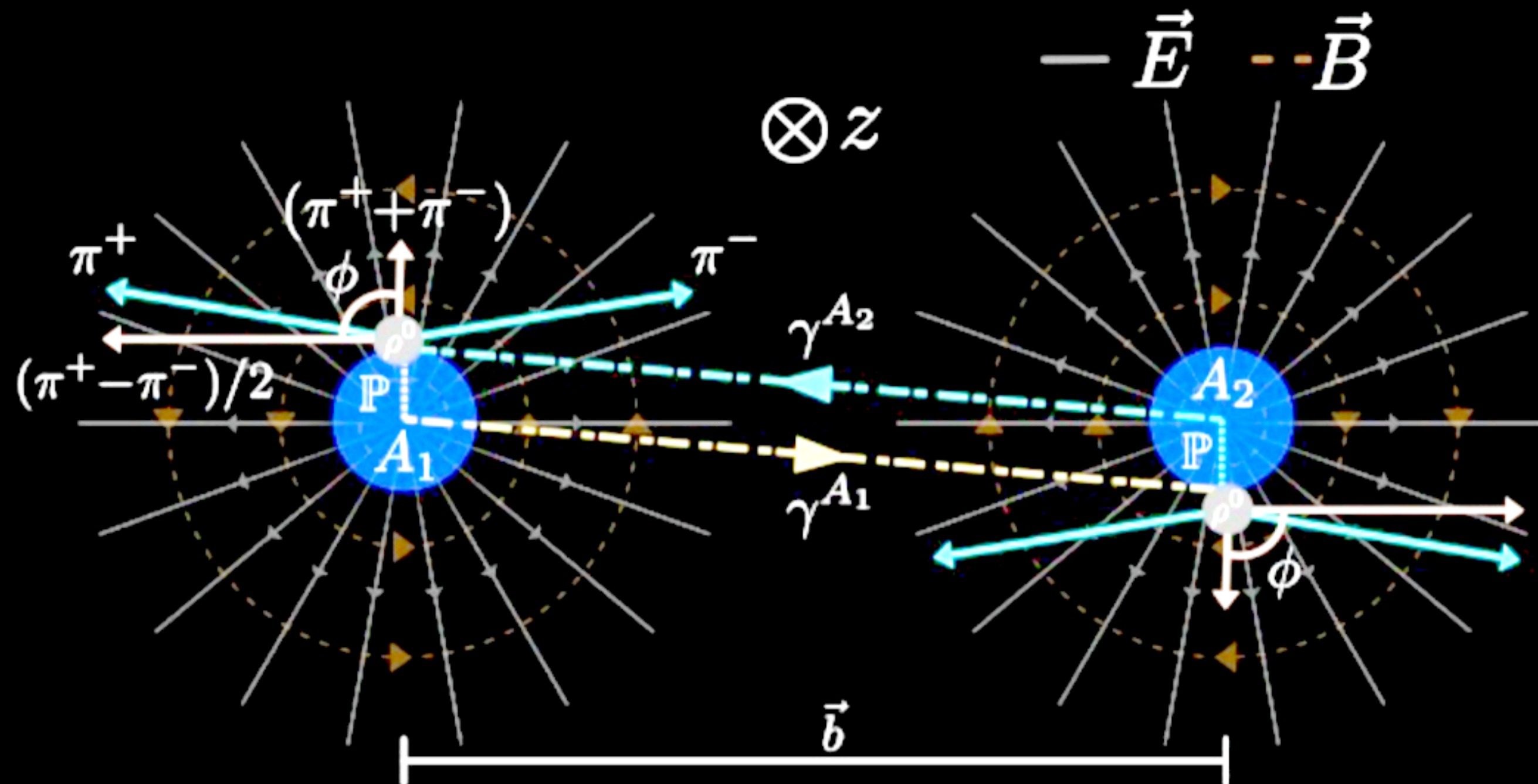
VM photoproduction in UPCs



- Photon from one nucleus fluctuates into quark-antiquark pair and interact with gluons of other nucleus \Rightarrow Produce a VM (e.g., J/ψ , ρ^0 , ϕ)
- Kinematics of produced VM is sensitive to the gluon distribution of the nucleus

Spin interference effect with VM ($J/\psi, \rho^0$)

Interference patterns in ultra-peripheral collisions

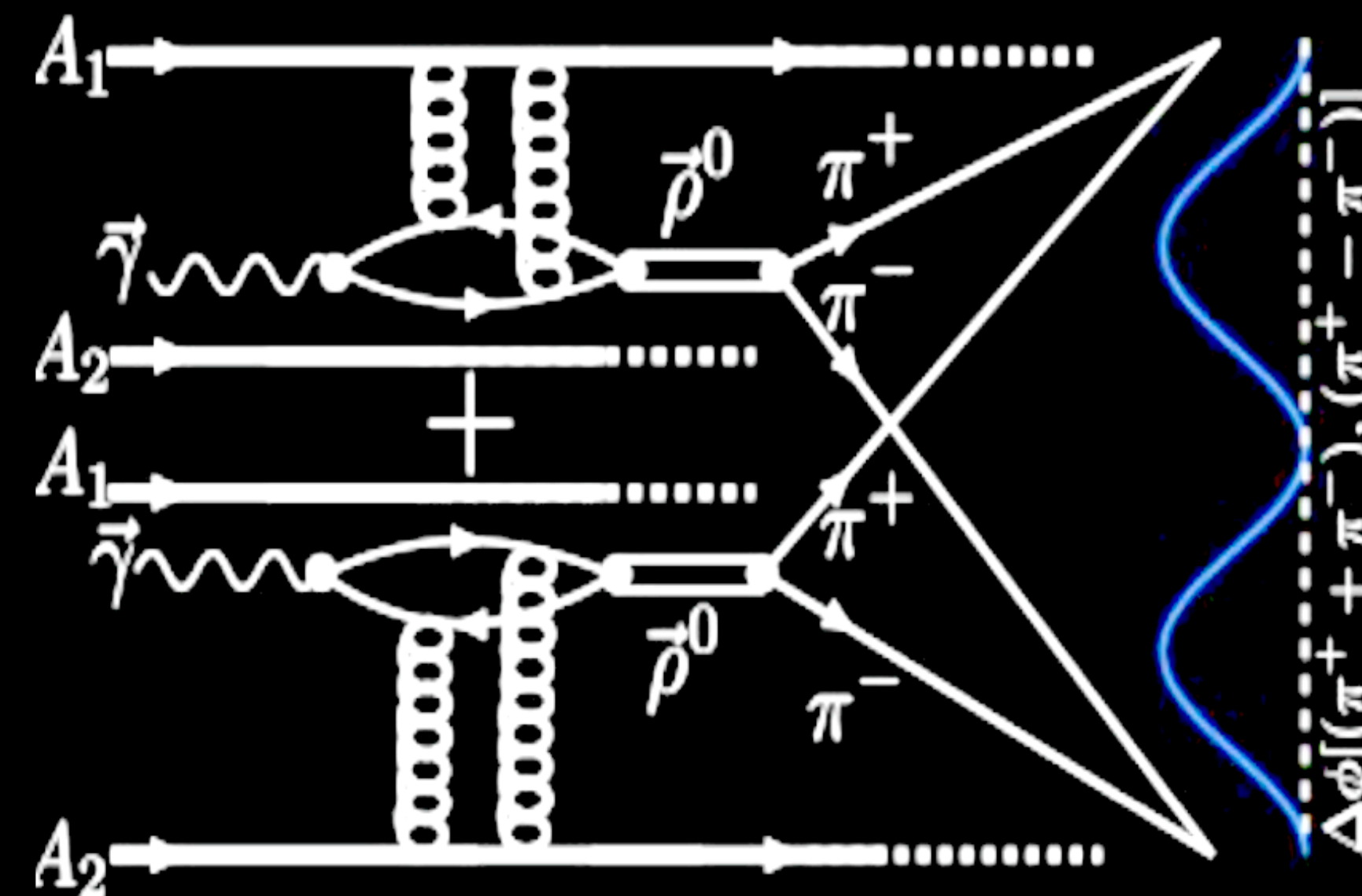


Double slit experiment

Light Source

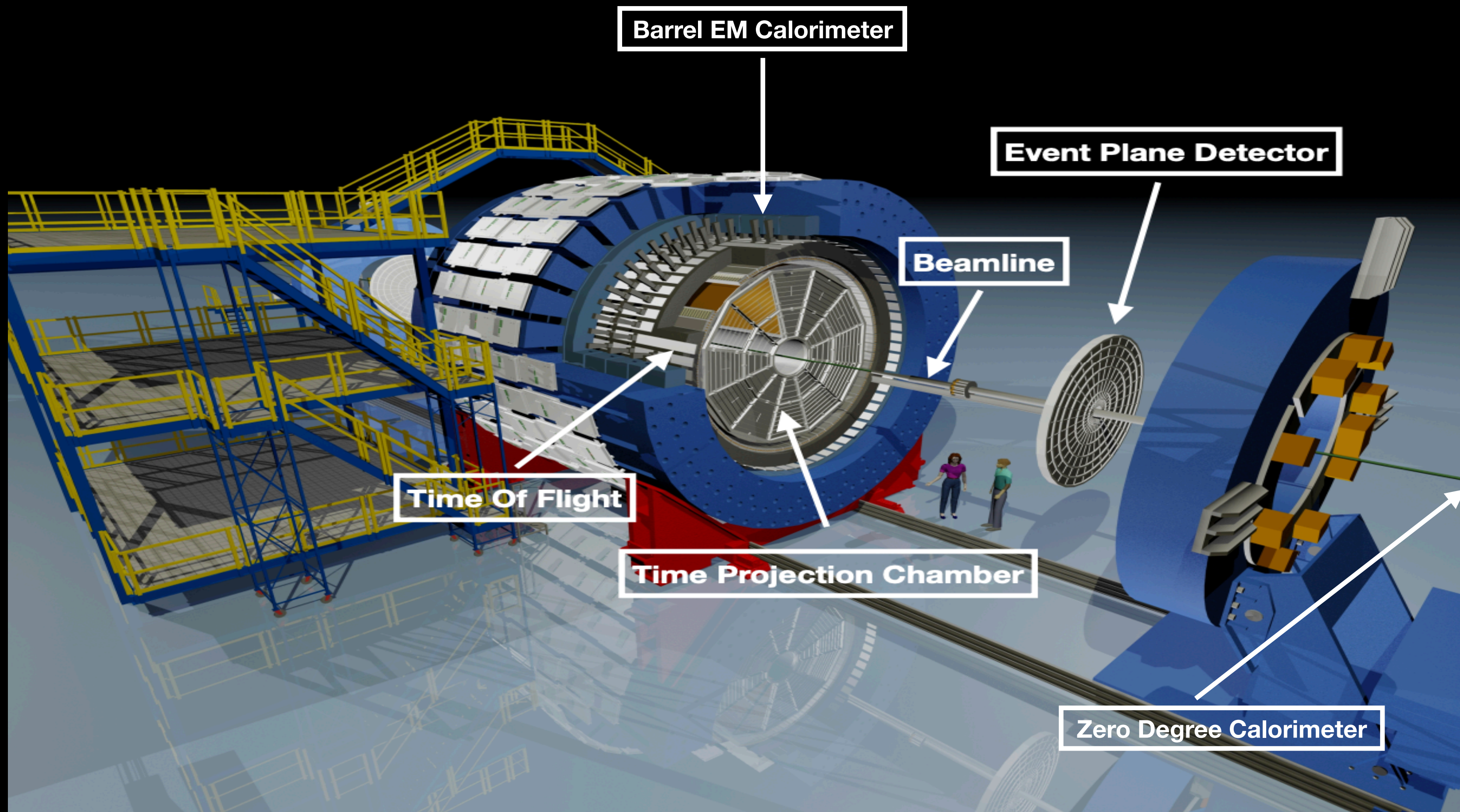
Metal Sheet

Screen



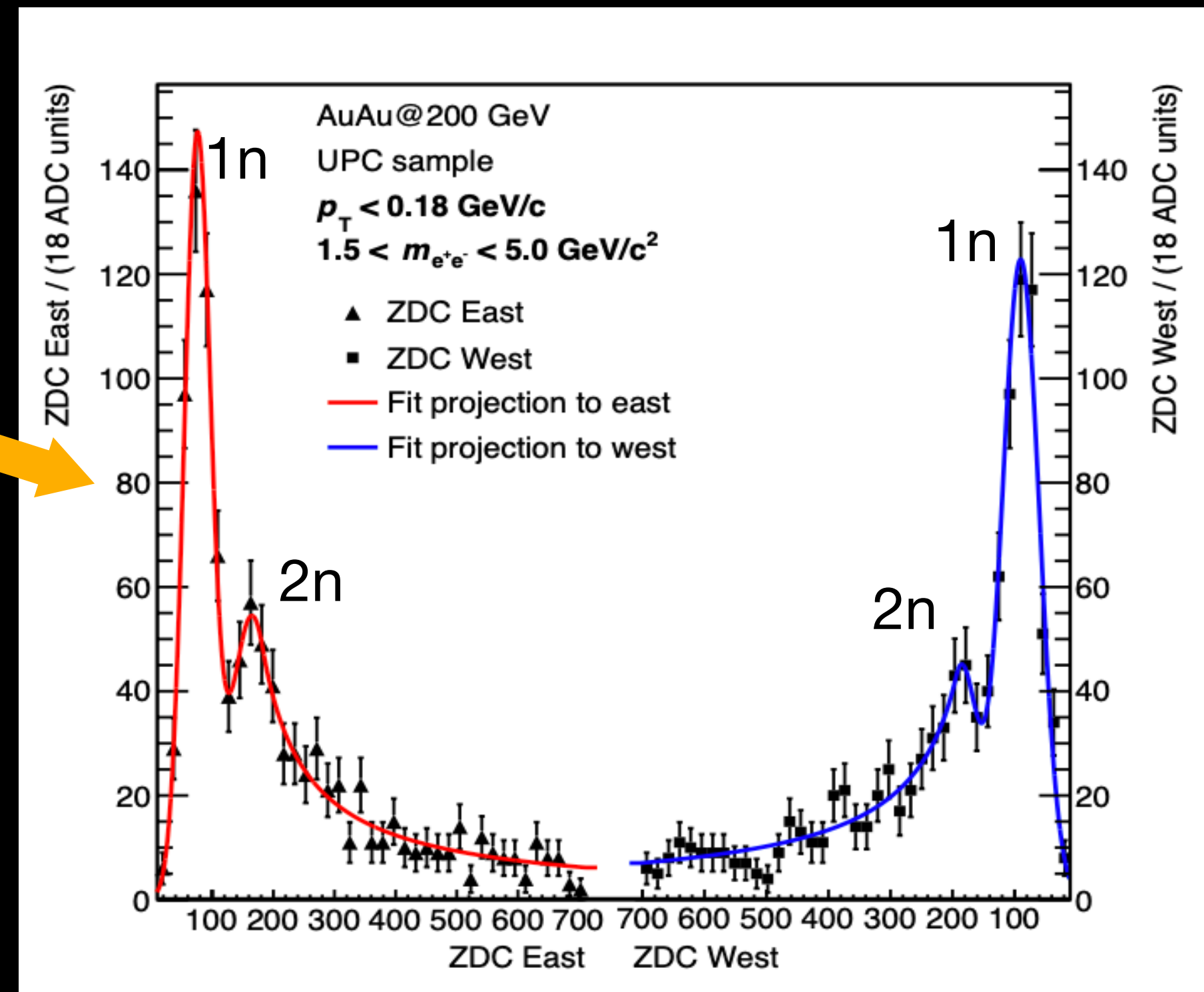
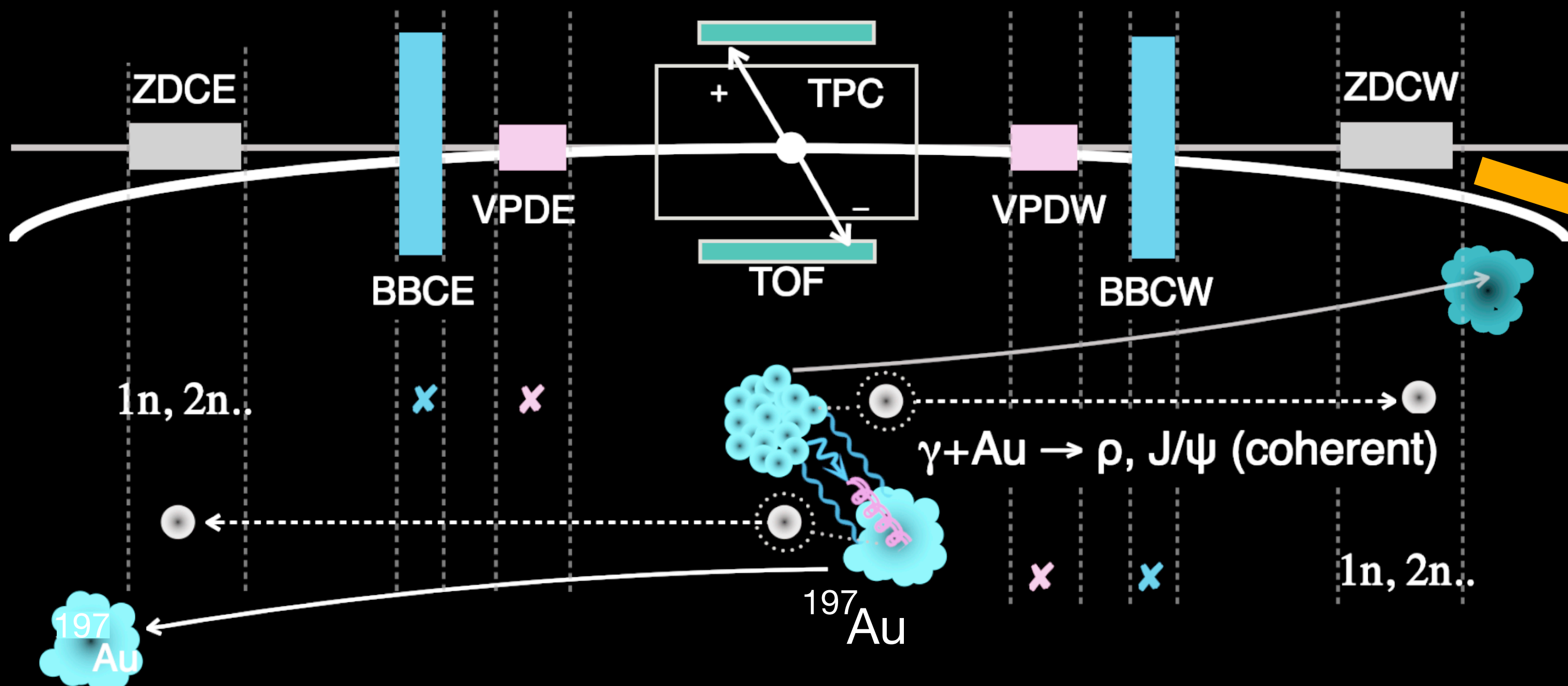
- Correlation of VM spin & daughter angle (ϕ) \rightarrow ($\cos(2\phi)$) pattern ($J=L+s$ conservation)
- Photoproduction occurs from both the nuclei \Rightarrow interference of the two diagrams makes the ($\cos(2\phi)$) pattern observable
- Decay of the VM helps to observe this effect

Towards UPC measurements: STAR detector



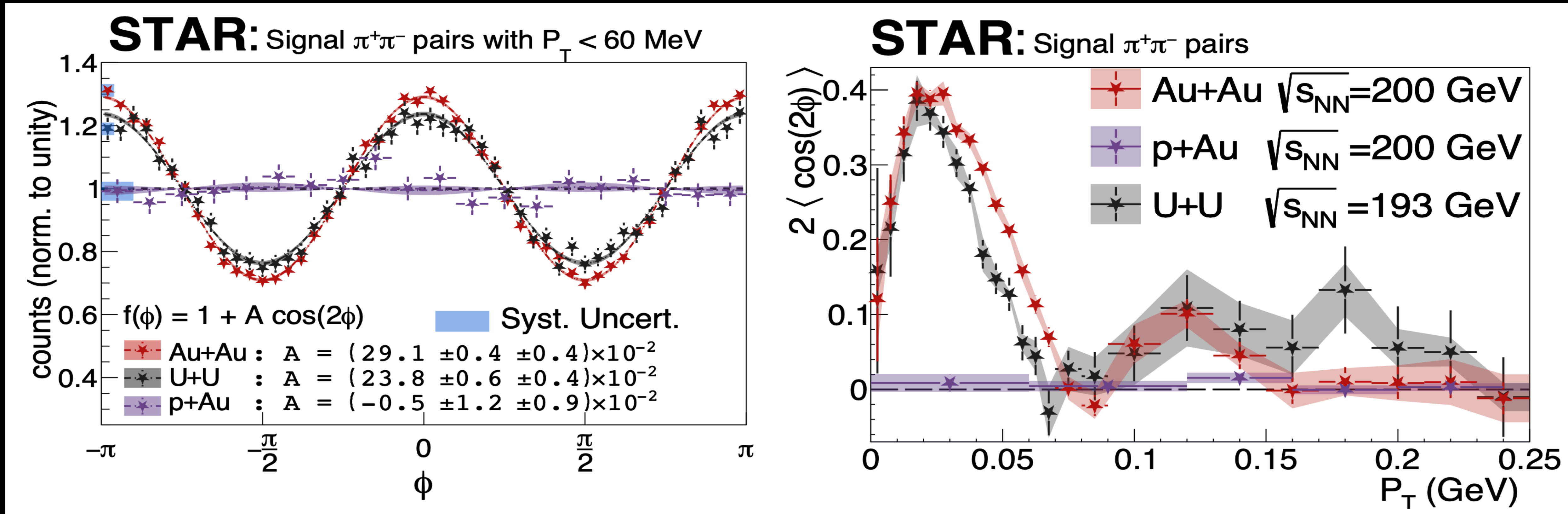
- Main central barrel detectors : TPC, TOF, BEMC
- Forward detectors: BBC or EPD, ZDC

UPC events with STAR detector



- Both nuclei get excited and emit neutrons in beam direction
 - Neutron(s) detected in ZDCs
 - ZDC signals show peak structure for neutrons
- Way to trigger UPC events

- Two tracks of opposite charges in TPC
- No activity in both BBCs \rightarrow Diffractive events (η -gap)



○ $\cos(2\phi)$ oscillation pattern is measured for ρ^0 decay, ϕ : angle between ρ^0 and one of its decay daughters

○ Measured in p+Au, Au+Au and U+U — Different patterns in different collision systems

○ Oscillation is absent in p+Au system => Needs two photon sources to observe this effect

Nuclear imaging with spin interference effect

STAR, arXiv:2204.01625
(Sci. Adv. 9, eabq 3903 (2023))

SCIENCE ADVANCES | RESEARCH ARTICLE

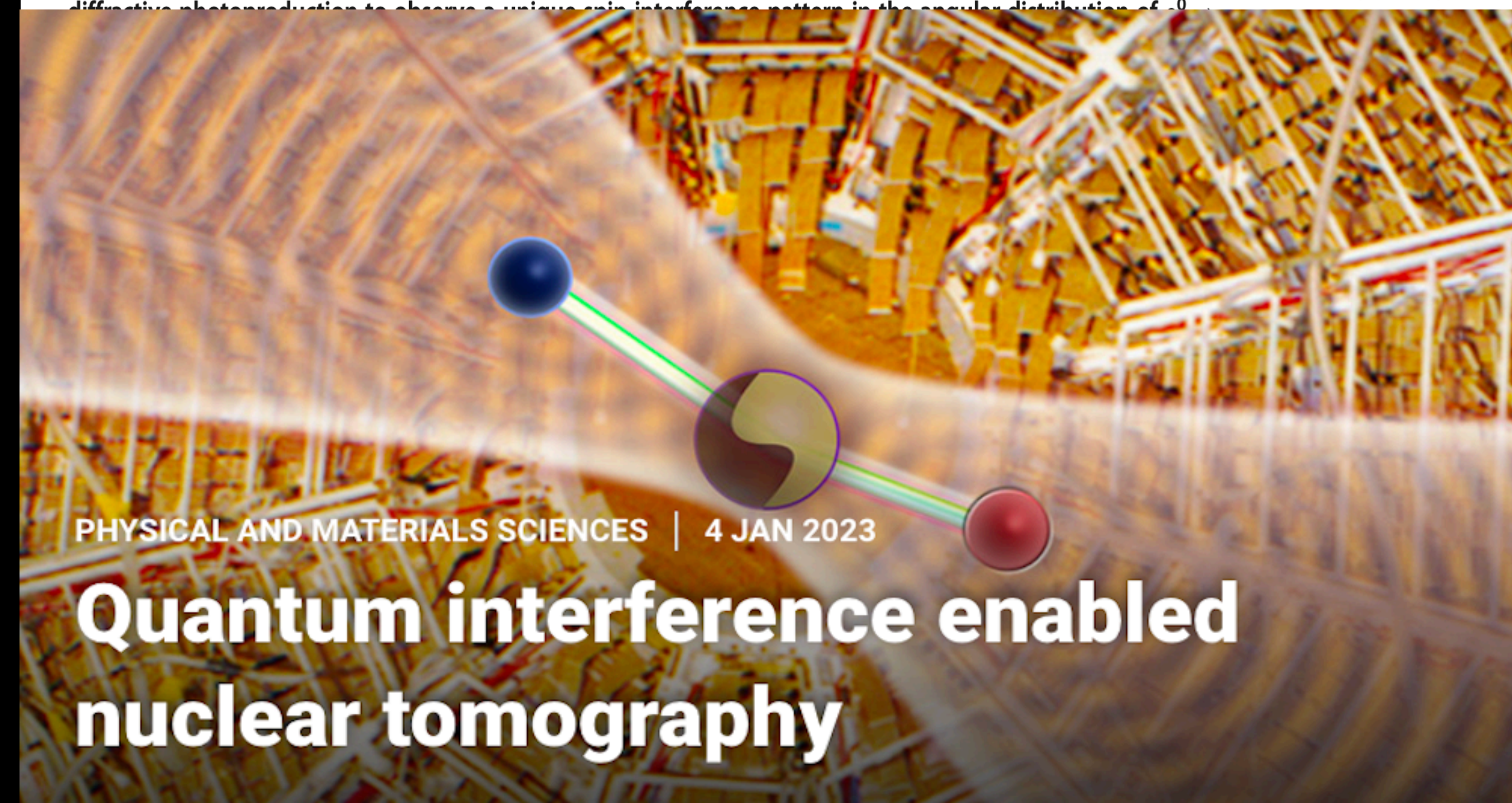
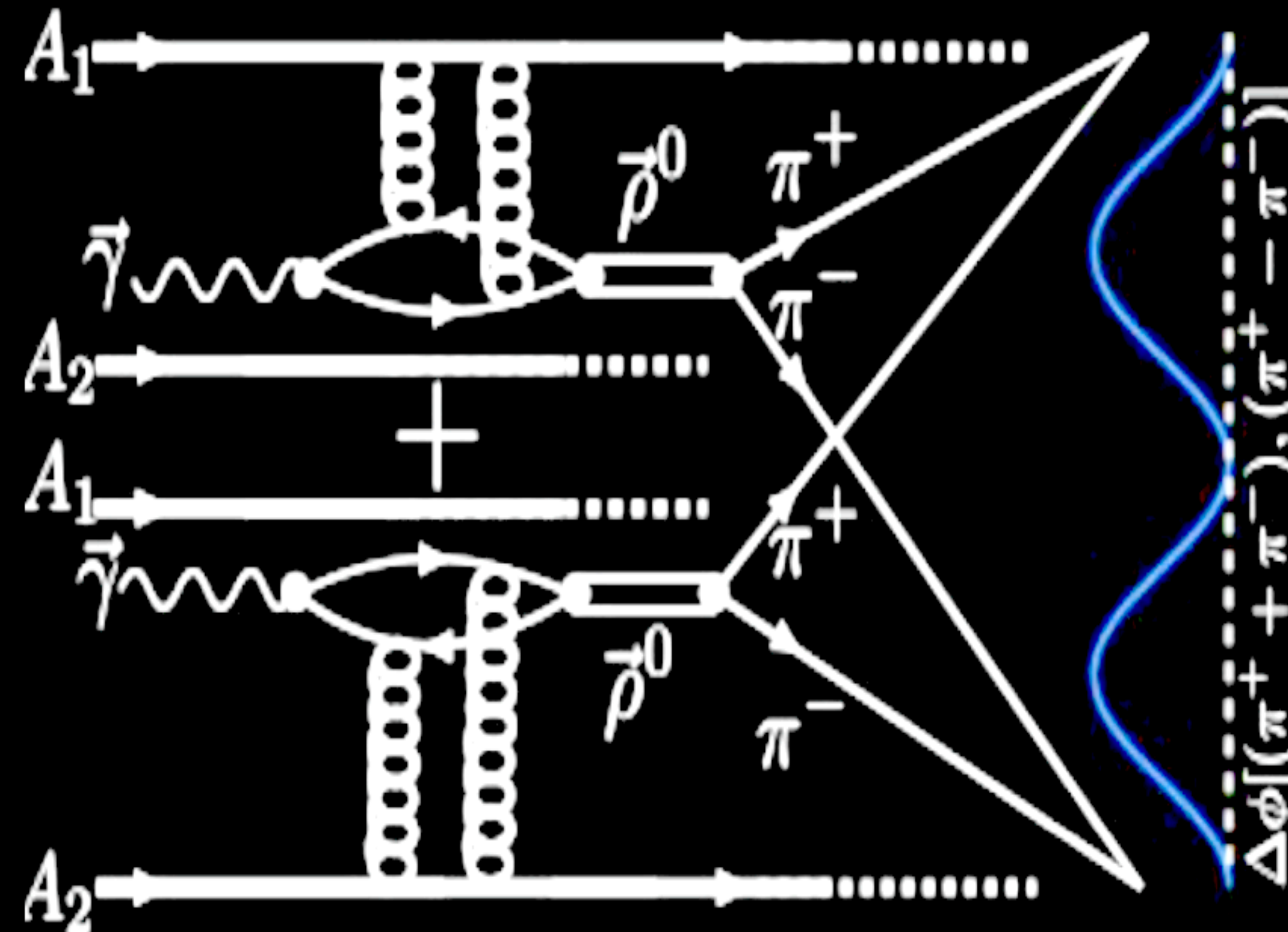
PHYSICS

Tomography of ultrarelativistic nuclei with polarized photon-gluon collisions

STAR Collaboration

A linearly polarized photon can be quantized from the Lorentz-boosted electromagnetic field of a nucleus traveling at ultrarelativistic speed. When two relativistic heavy nuclei pass one another at a distance of a few nuclear radii, the photon from one nucleus may interact through a virtual quark-antiquark pair with gluons from the other nucleus, forming a short-lived vector meson (e.g., ρ^0). In this experiment, the polarization was used in diffractive photoproduction to observe a unique spin interference pattern in the angular distribution of ρ^0 .

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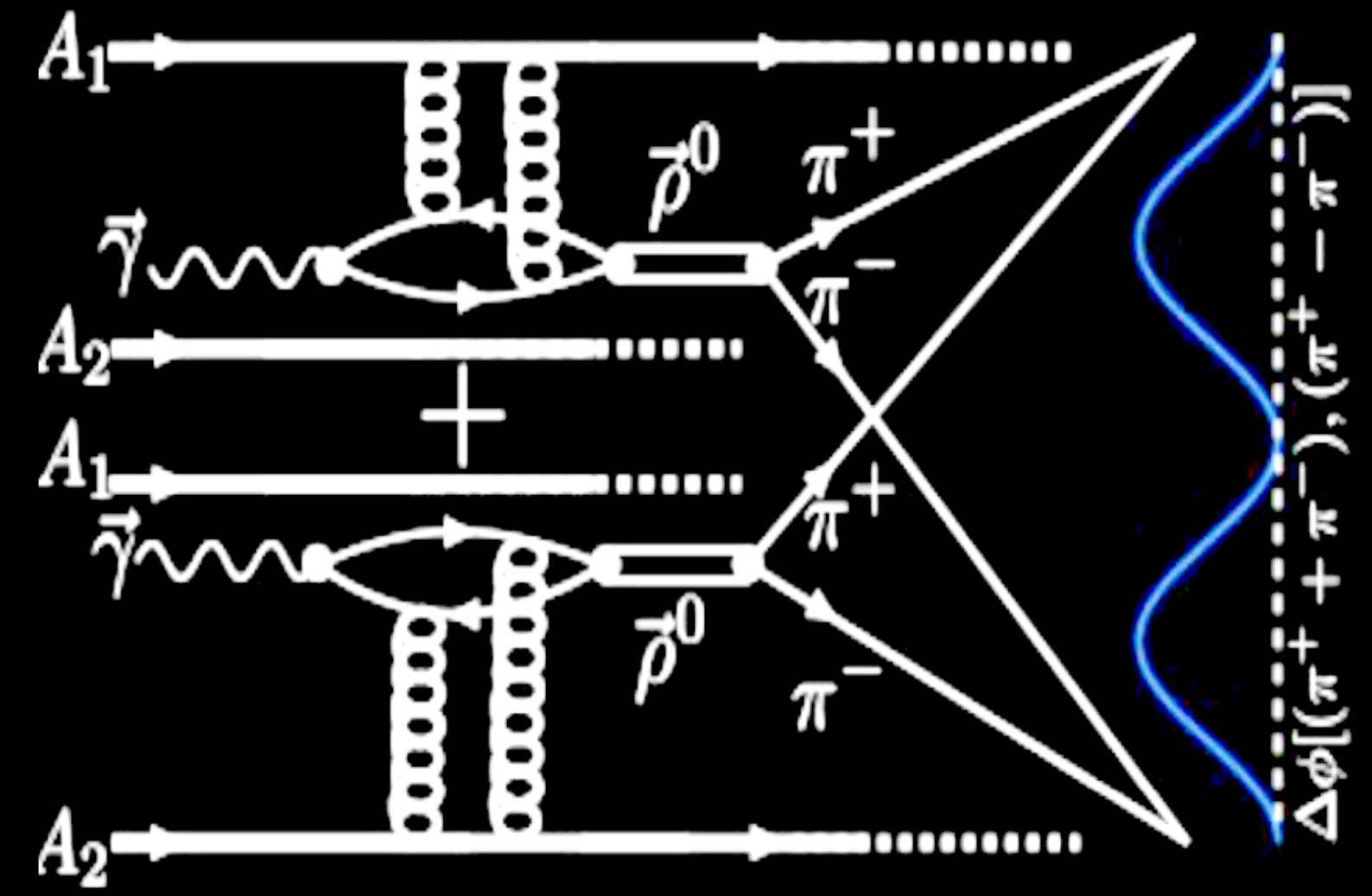


PHYSICAL AND MATERIALS SCIENCES | 4 JAN 2023

Quantum interference enabled nuclear tomography

$\gamma + Au \rightarrow \rho^0 \rightarrow \pi^+ \pi^-$

$\rho \rightarrow$ short lifetime (1 fm), localized wave function $\ll b$

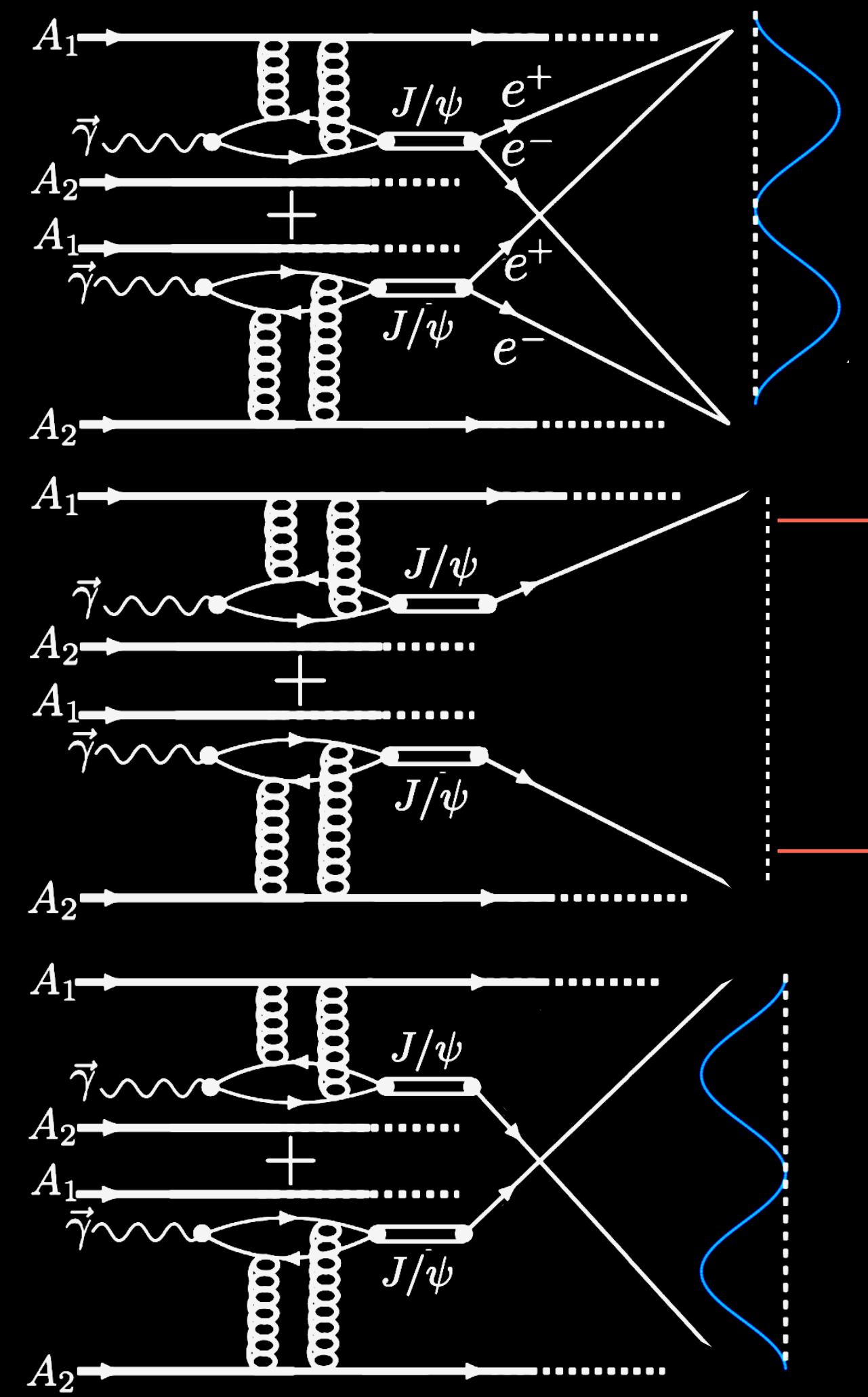


Amplitude >0 : daughter π^\pm (boson) interfere

$J/\psi \rightarrow$ longer lifetime, extended wave function

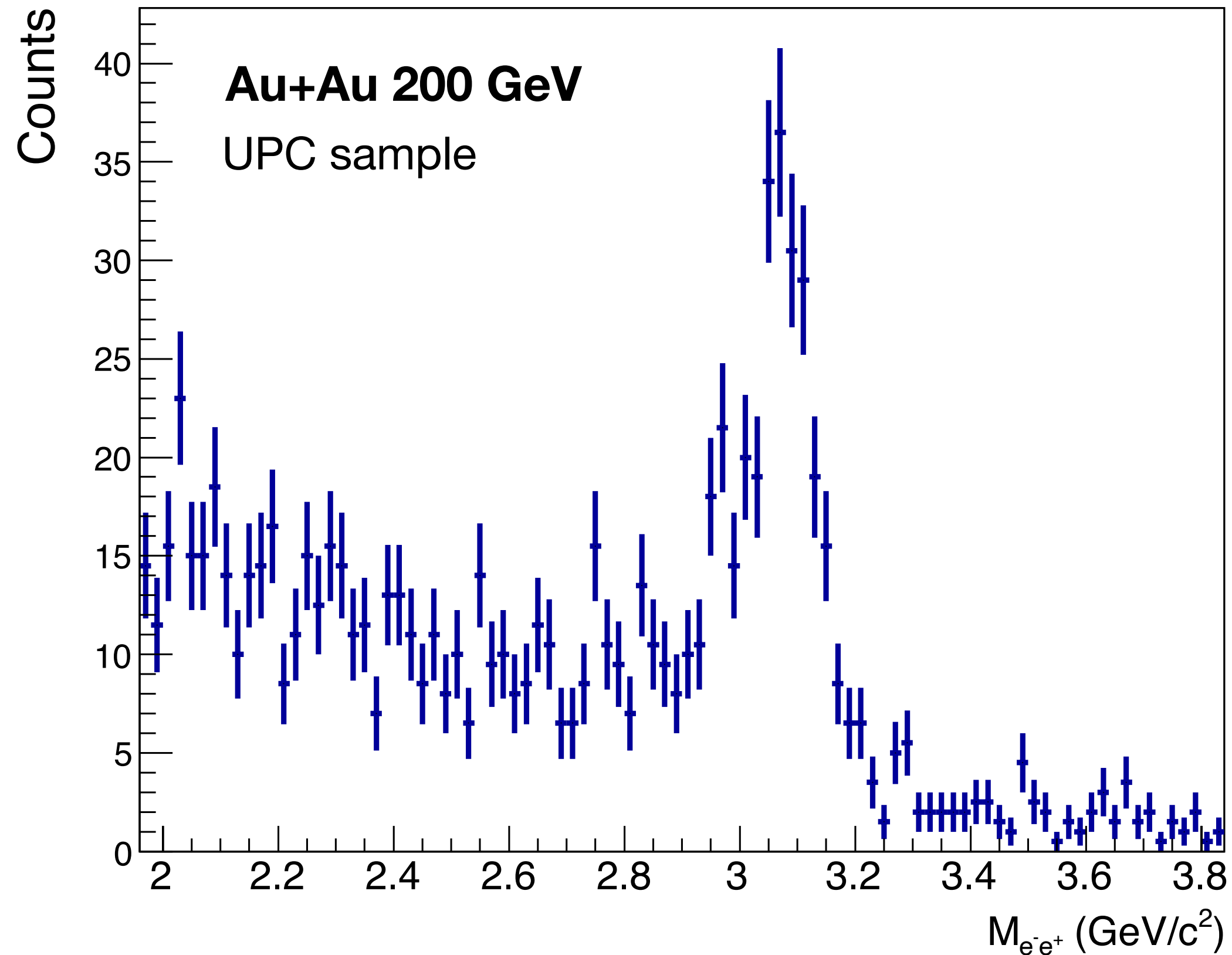
$\gamma + Au \rightarrow J/\psi \rightarrow e^+ e^-$

1. Amplitude <0 : daughter e^\pm (fermions) interfere
2. Amplitude = 0: J/ψ interfere (bosons) random phase cancel
3. Amplitude >0 : New physics of photon-pomeron phase correlation



Unique opportunity to study new physics with J/ψ

Selection of J/ψ candidates

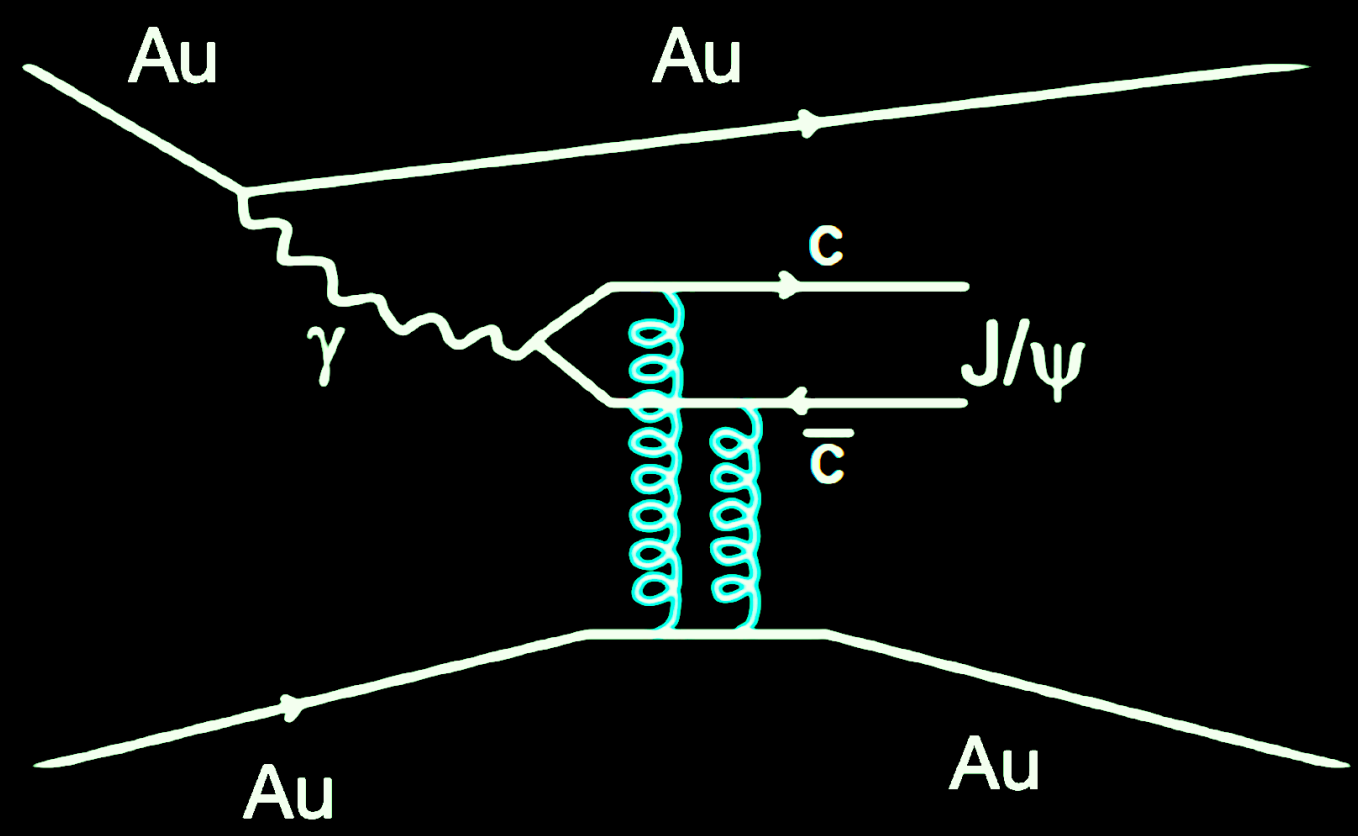


- Invariant mass distribution of $J/\psi \rightarrow e^+e^-$ in Au+Au UPCs at 200 GeV
- Using Au+Au (2014+2016) at 200 GeV, obtained approx 350 J/ψ candidates
- Approximated error in J/ψ measurements, $1/\sqrt{350} \sim 0.053$
- Unique opportunity to test the spin interference effect

We are working on it, and stay tuned!

Summary and take home

- STAR observed spin interference effect in ρ^0 photoproduction in Au+Au and U+U
 - The effect is absent in p+Au
- Measurements of spin interference with J/ ψ will bring new insights
- RHIC, LHC and future EIC experiments can provide further experimental insights into these phenomena



Thank You 🙏

