Azimuthal asymmetry of coherent J/ψ in peripheral Pb-Pb collisions at 5.36 TeV

CMS-PAS-HIN-25-006

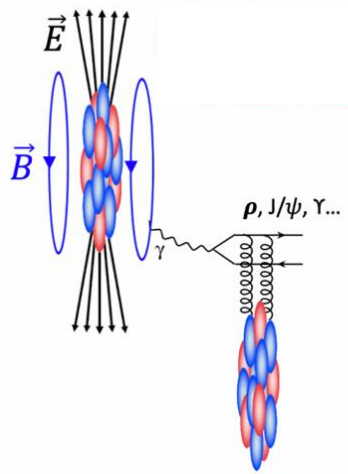
Xueli Hua (化雪丽), for the CMS collaboration
South China Normal University (华南师范大学)

Strangeness in Quark Matter, Los Angeles

22-27 March 2026

Vector meson photoproduction in UPC

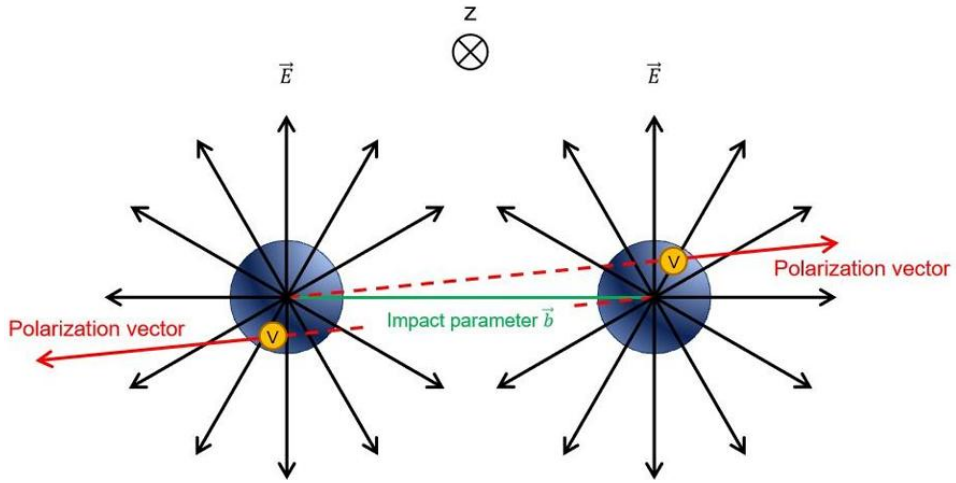
EM fields of nucleus → A flux of quasi-real photons



Photon-nucleus interactions:

- Photon interacts with intact nucleus
- Coherent vector meson production (VM)
- VM $<p_T>$ ~ 60 MeV/c

The quasi-real photons are linearly polarized Zhou et al., Phys.Lett.B 795 (2019) 576-580

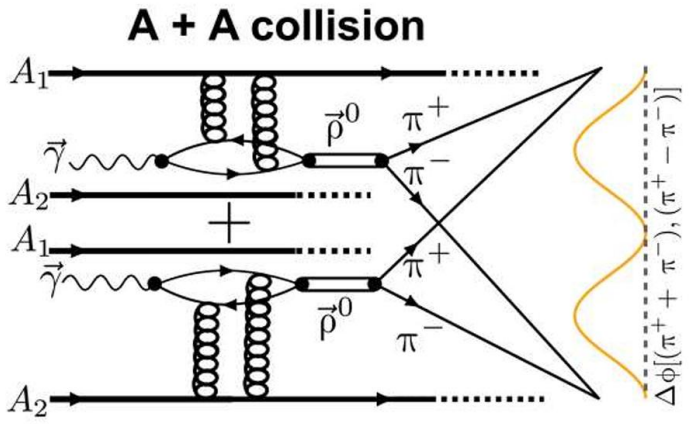


⇨ VM inherits the polarization state

⇨ An azimuthal cos2Δϕ modulation in daughter momentum distribution w.r.t. the polarization direction.

Xing et al., JHEP 10 (2020) 064
Zha et al., Phys.Rev.D 103 (2021) 3, 033007

Cos2Δϕ modulation of coherent $\rho^0 \to \pi^+\pi^-$ in UPC



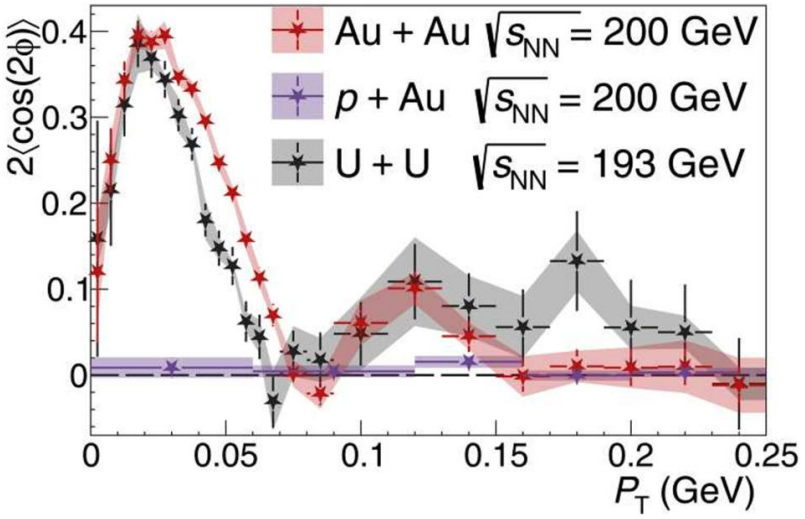
The photon emitters and targets are indistinguishable

⇨ quantum interference of ρ^0 amplitudes

⇨ strong correlation between p_{T,ρ^0} and polarization direction

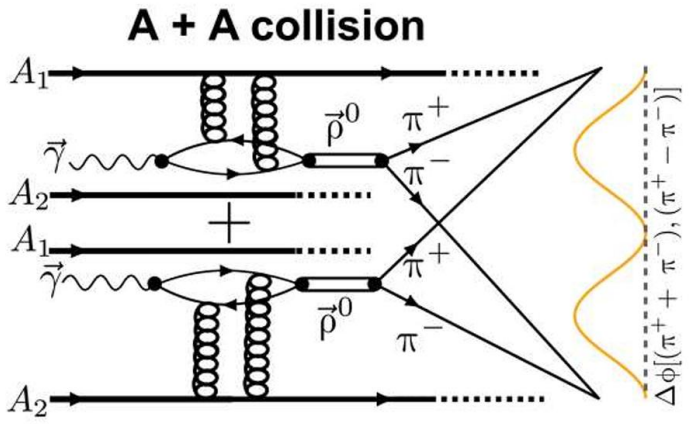
$$\frac{d^2N}{d\cos\theta d\phi} = \frac{3}{8\pi}\sin^2\theta[1+\cos 2(\phi-\Phi)] \longrightarrow \Delta\phi = \phi_\pi - \phi_{\pi\pi}$$

- STAR: signal $\pi^+\pi^-$ pairs



STAR, Sci. Adv. 9 (2023) eabq3903

Cos2Δϕ modulation of coherent $\rho^0 \to \pi^+\pi^-$ in UPC



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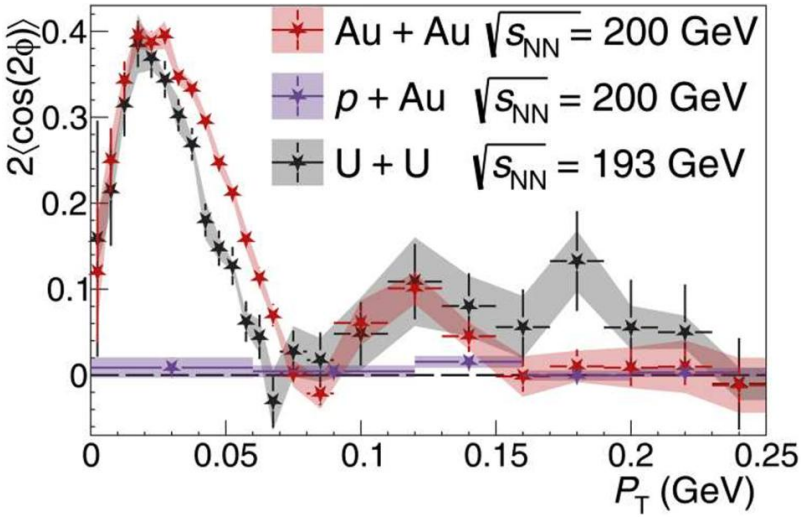
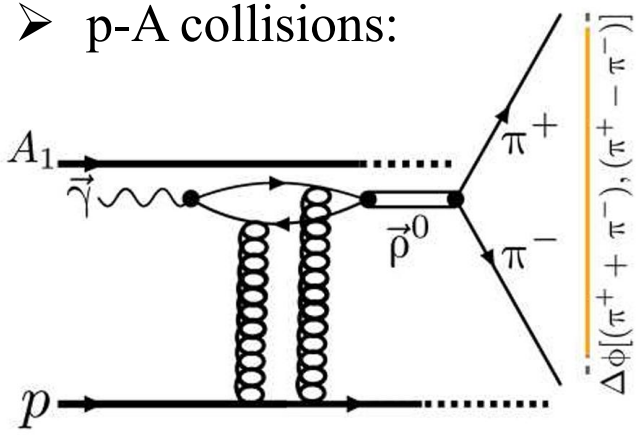


➢ p-A collisions:

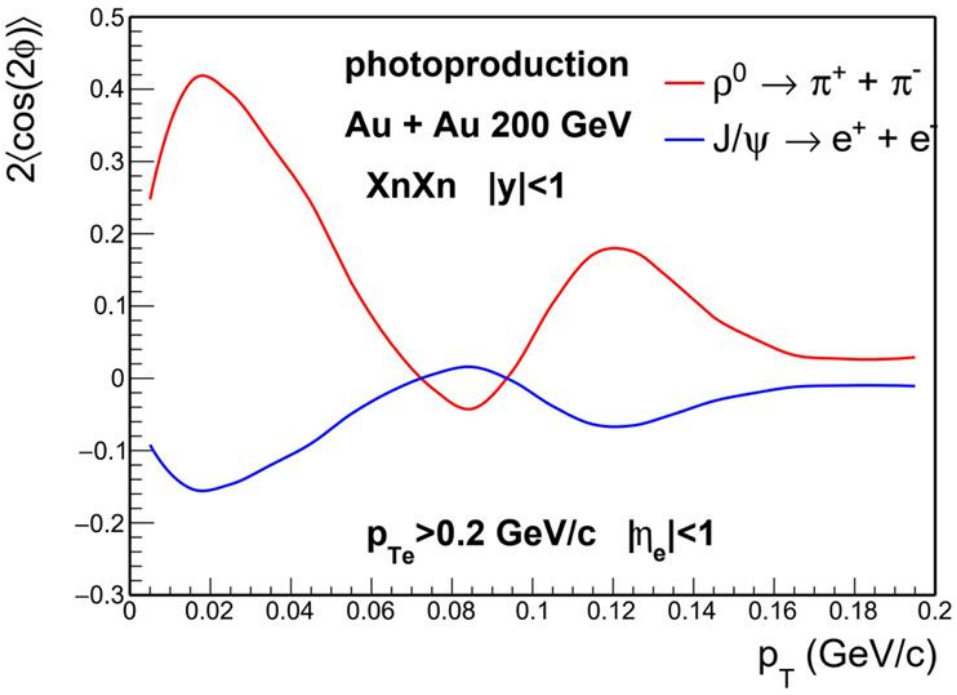


Interference effect reduced in case of

- Asymmetric nuclear collision system
- Forward rapidity

STAR, Sci. Adv. 9 (2023) eabq3903

Spin state dependence of cos2Δϕ modulation

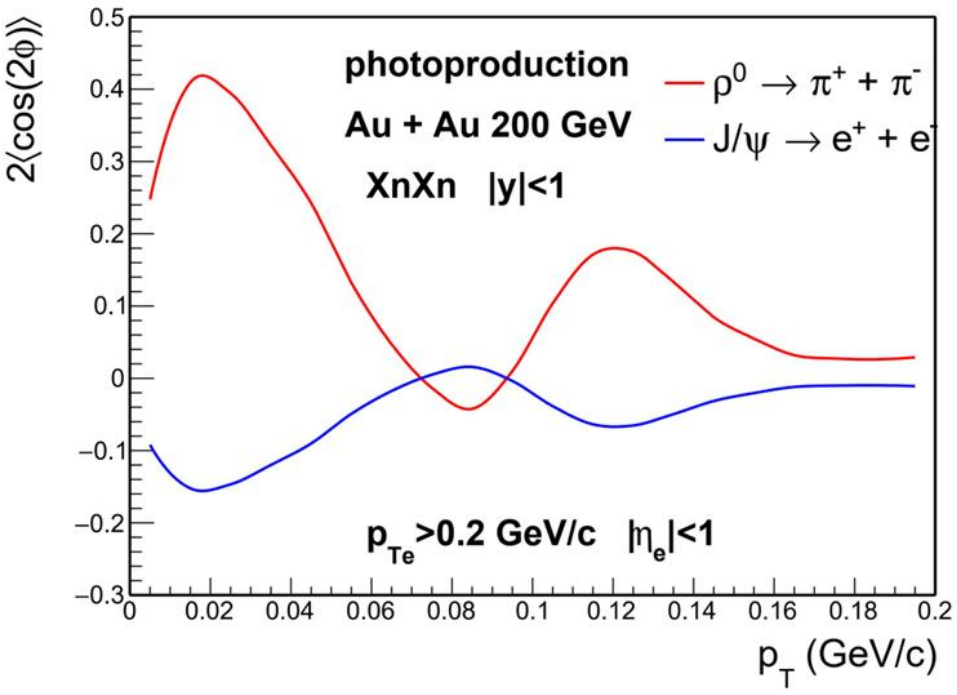


Wu et al., Phys.Rev.Res. 4 (2022) 4, L042048

- spin-0 final states ($\rho^0 \rightarrow \pi^+\pi^-$)
- spin-1/2 final states ($J/\psi \rightarrow \mu^+\mu^-$)

Can we observe spin state dependence?

Spin state dependence of cos2Δϕ modulation



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- $p_{T,J/\psi}$ resolution:

$p_T^{\mu\mu} \approx 60$ MeV

$p_T^{\mu} \approx 1.5$ GeV

STAR, arXiv:2512.02865

coherent J/ψ

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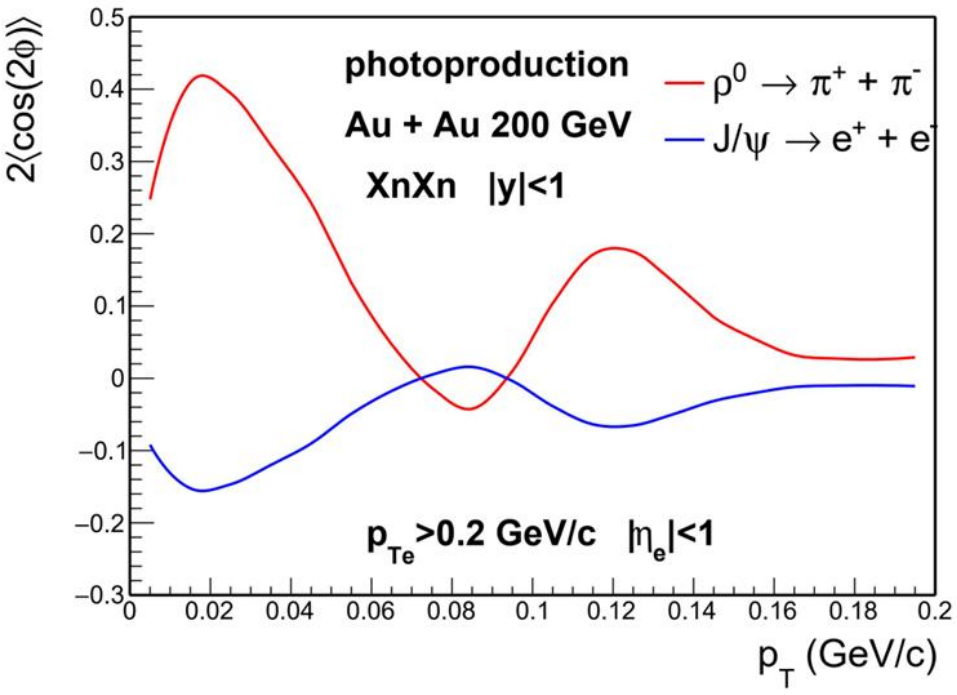

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STAR, arXiv:2512.02865 coherent J/ψ

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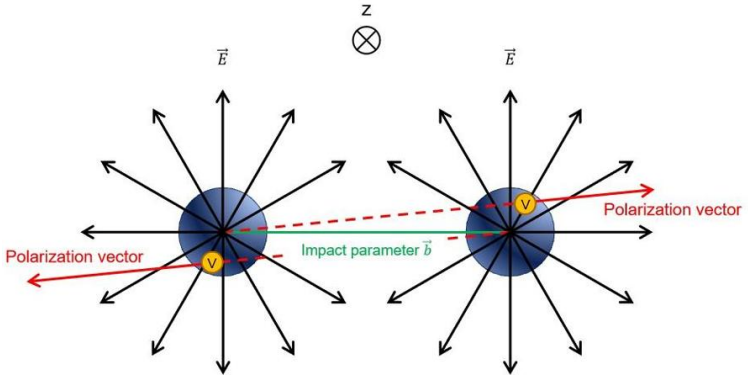
  A more robust estimator of polarization direction



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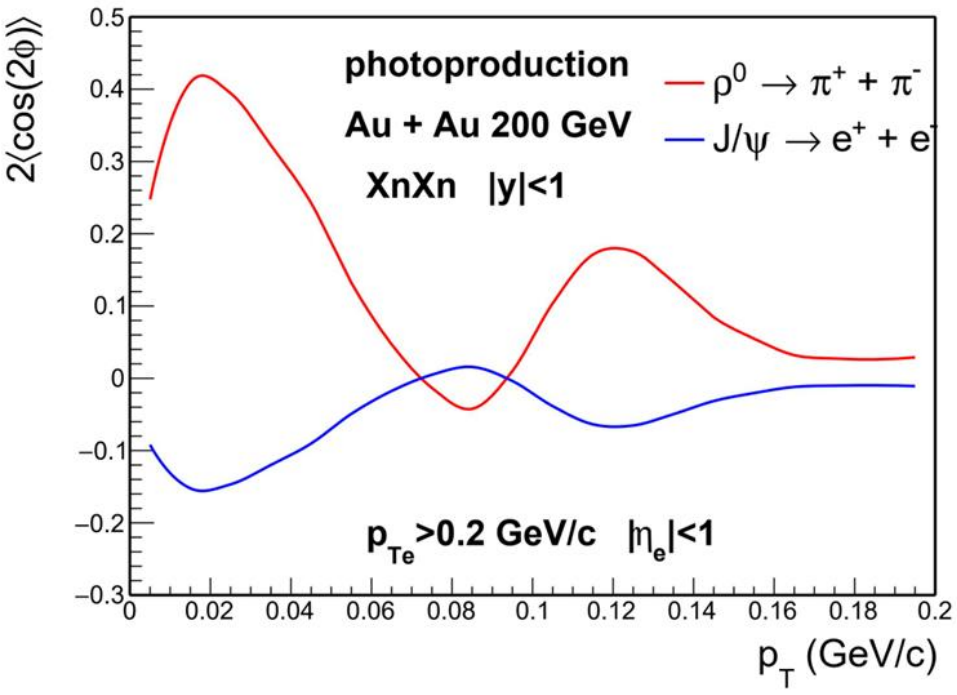

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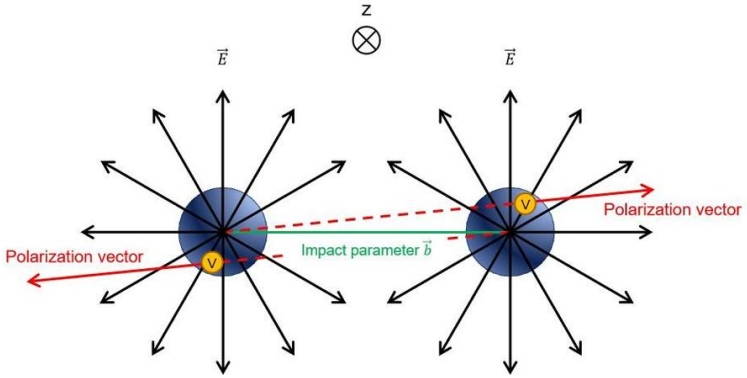
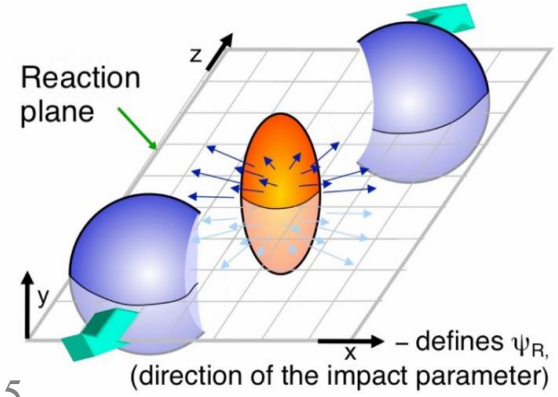


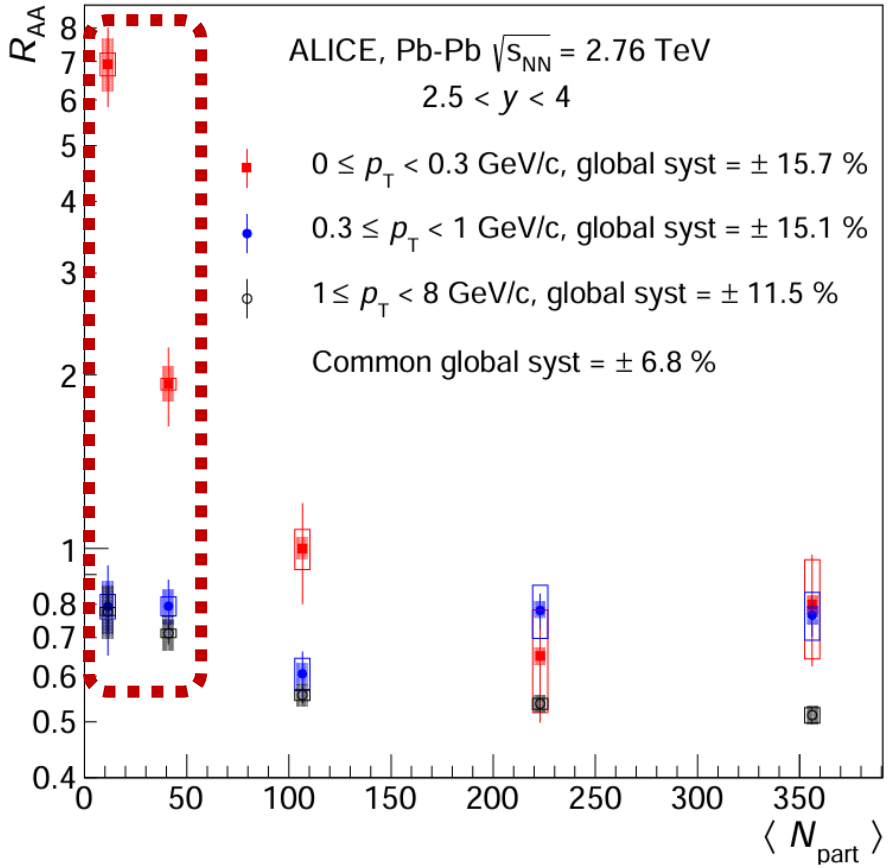
- Hadronic collisions:
  b is estimated by the second order event plane reconstruction



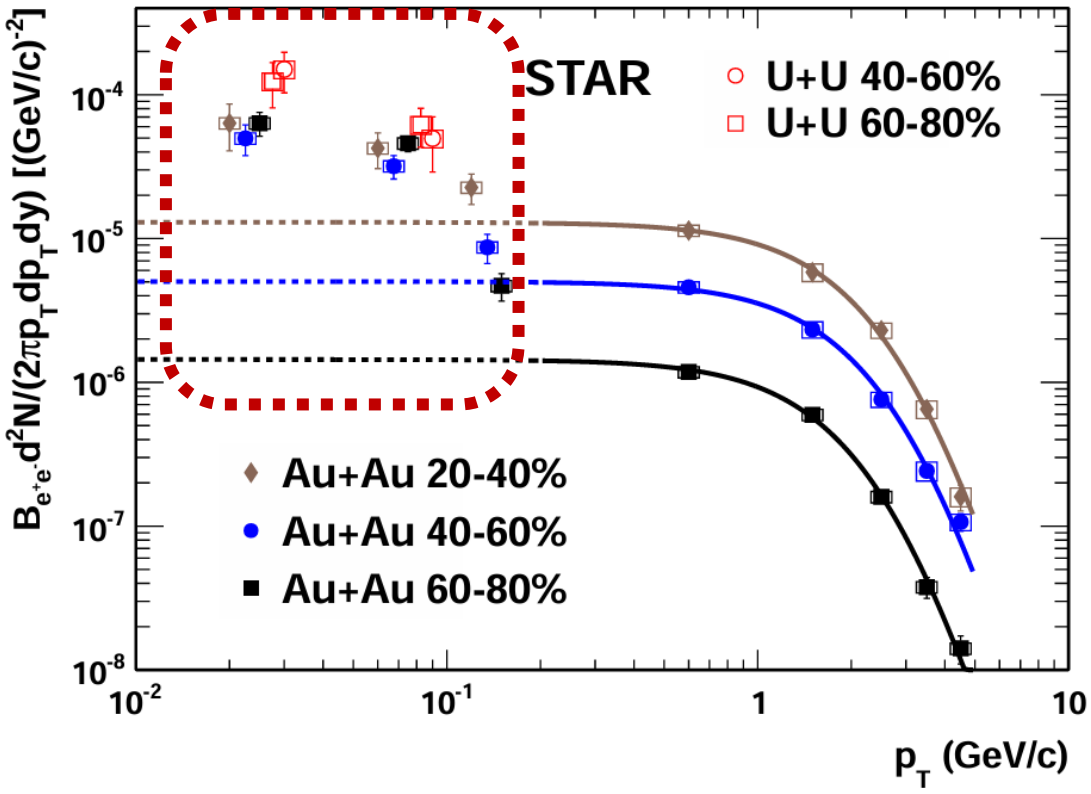
STAR, QM2025

Coherent J/ψ in hadronic collisions

- Coherent J/ψ was observed by the ALICE and STAR collaborations



ALICE, Phys.Rev.Lett. 116 (2016) 22, 222301



STAR, Phys.Rev.Lett. 123 (2019) 13, 132302

Data sample and Selections

- Data sample:
  - 2023 Pb-Pb collisions at $\sqrt{s_{NN}} = 5.36$ TeV
  - Luminosity used in this analysis: 1.26 nb^{-1}
- Decay channel:
  - J/$\psi \rightarrow \mu^+\mu^-$
- J/ψ selections:
  - Centrality: 50-80%
  - $p_T < 0.2$ GeV/c
  - $1.6 < |y| < 2.4$

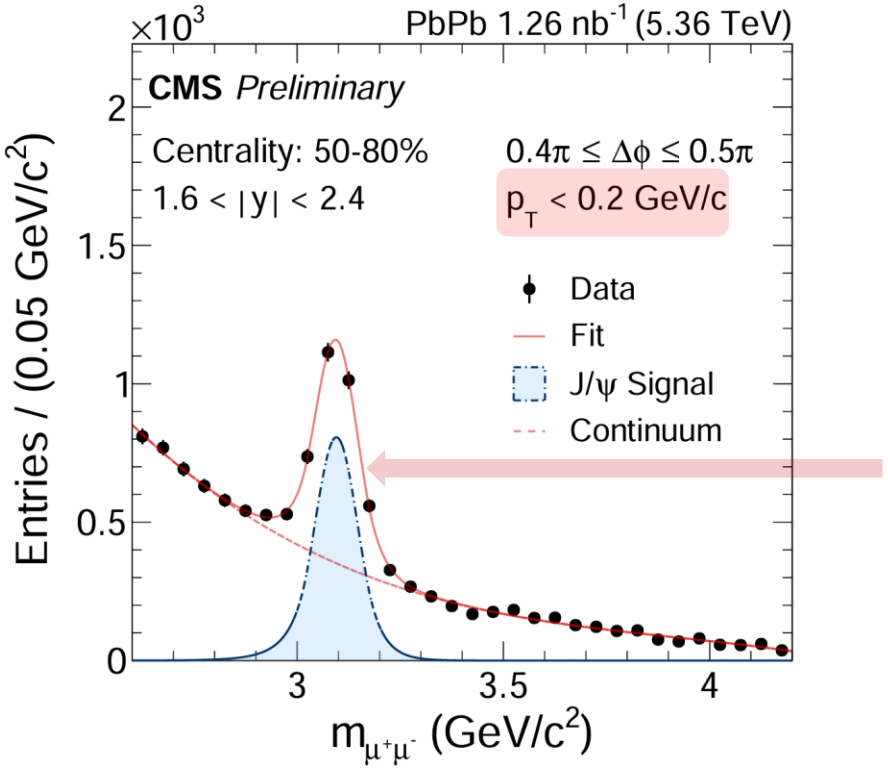
- The second order event plane reconstructed by tracks with $0.3 < p_T < 3$ GeV/c, $|\eta| < 2.4$
  - $\Psi_2 = \frac{1}{2}\mathrm{atan2}(Q_{2,y}, Q_{2,x})$.
  - $Q_{2,x} = Q_2\cos(2\Psi_2) = \frac{\sum_i \omega_i \cos(2\phi_i)}{\sum_i \omega_i}$,
  - $Q_{2,y} = Q_2\cos(2\Psi_2) = \frac{\sum_i \omega_i \sin(2\phi_i)}{\sum_i \omega_i}$.
- EP resolution is calculated by 3-sub event method:

$$\sqrt{\frac{\left\langle \cos\left(2\Psi_2^{trk} - 2\Psi_2^{\mathrm{HFp}}\right)\right\rangle \left\langle \cos\left(2\Psi_2^{\mathrm{tr}k} - 2\Psi_2^{\mathrm{HFm}}\right)\right\rangle}{\left\langle \cos\left(2\Psi_2^{\mathrm{HFp}} - 2\Psi_2^{\mathrm{HFm}}\right)\right\rangle}}$$

Extraction of coherent J/ψ in hadronic Pb-Pb collisions

CMS-PAS-HIN-25-006

1. J/ψ signal extraction:



Double-sided Crystal Ball + Chebyshev3

- J/ψ signal:
  - Coherent J/$\psi \rightarrow \mu^+\mu^-$
  - Hadronic J/$\psi \rightarrow \mu^+\mu^-$
  - Incoherent J/$\psi \rightarrow \mu^+\mu^-$
- Continuum background:
  - QED $\gamma\gamma \rightarrow \mu^+\mu^-$
  - Drell-Yan $q\bar{q} \rightarrow \gamma^* Z \rightarrow \mu^+\mu^-$
  - Heavy flavor $q(\bar{q}) \rightarrow \mu + X$
  - Combinatorial $\mu\mu$

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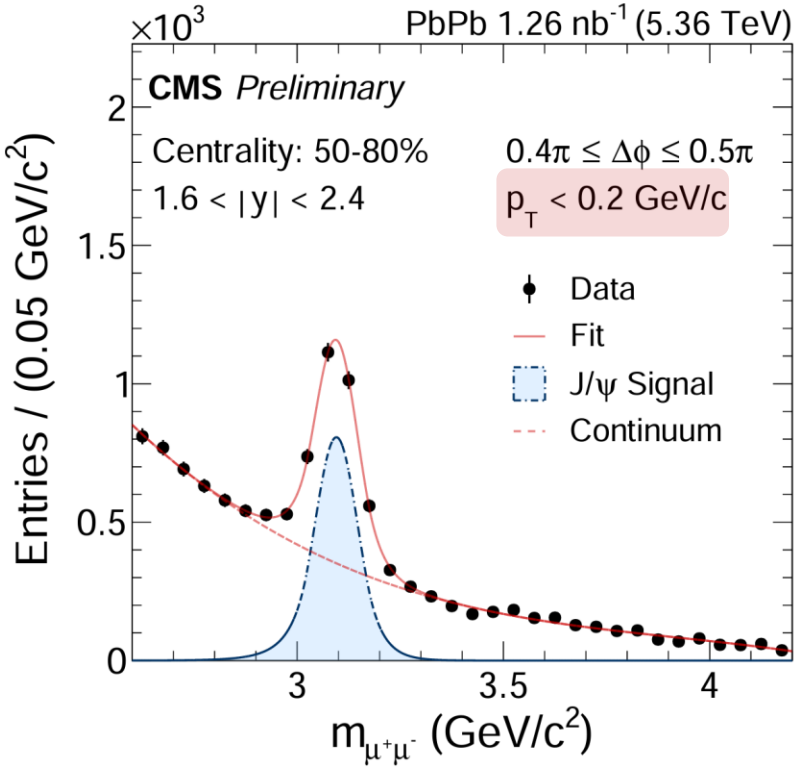
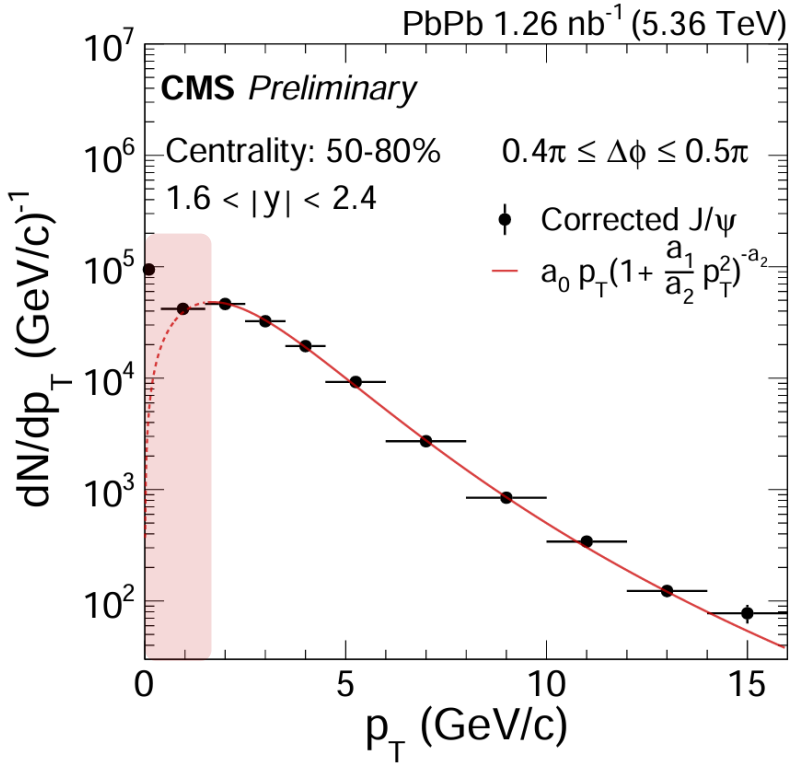


Double-sided Crystal Ball + Chebyshev3

2. Hadronic J/ψ subtraction:

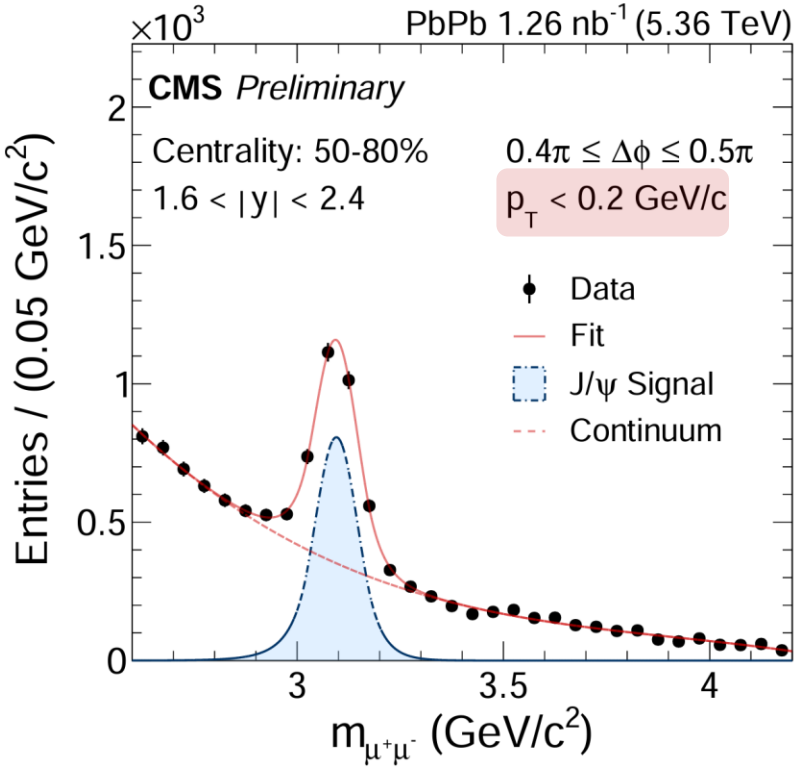


Corrected for efficiency

Extraction of cos2Δϕ amplitude (A_2)

CMS-PAS-HIN-25-006

1. J/ψ signal extraction: → 2. Hadronic J/ψ subtraction: → 3. cos2Δϕ amplitude A_2^{obs} extraction:



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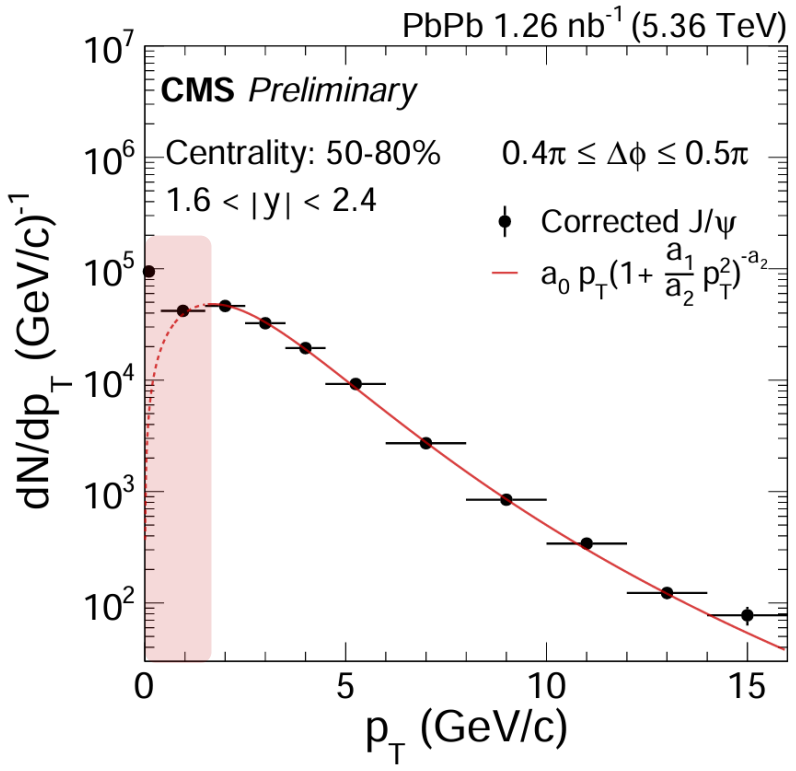

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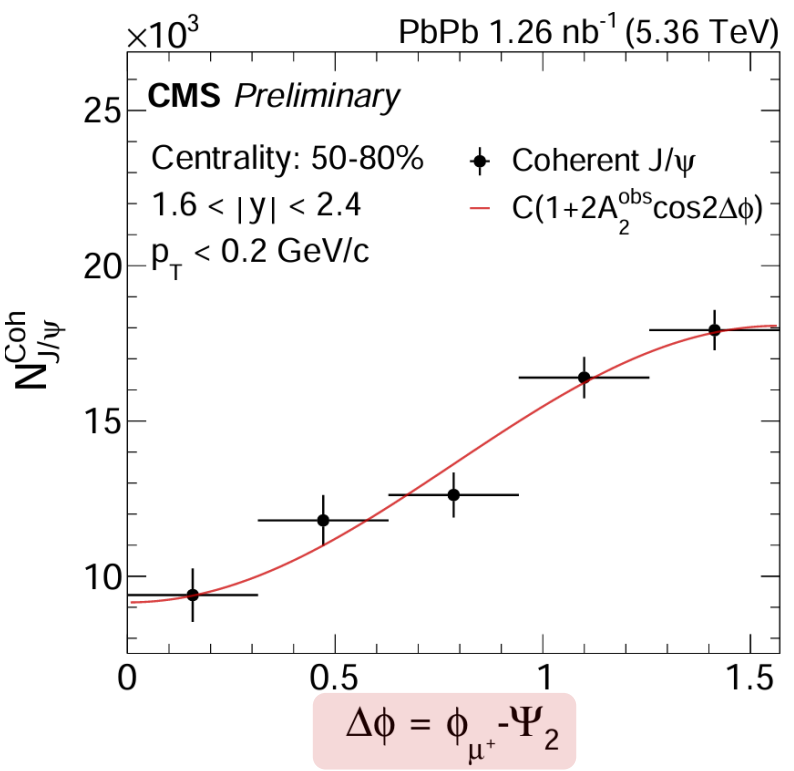
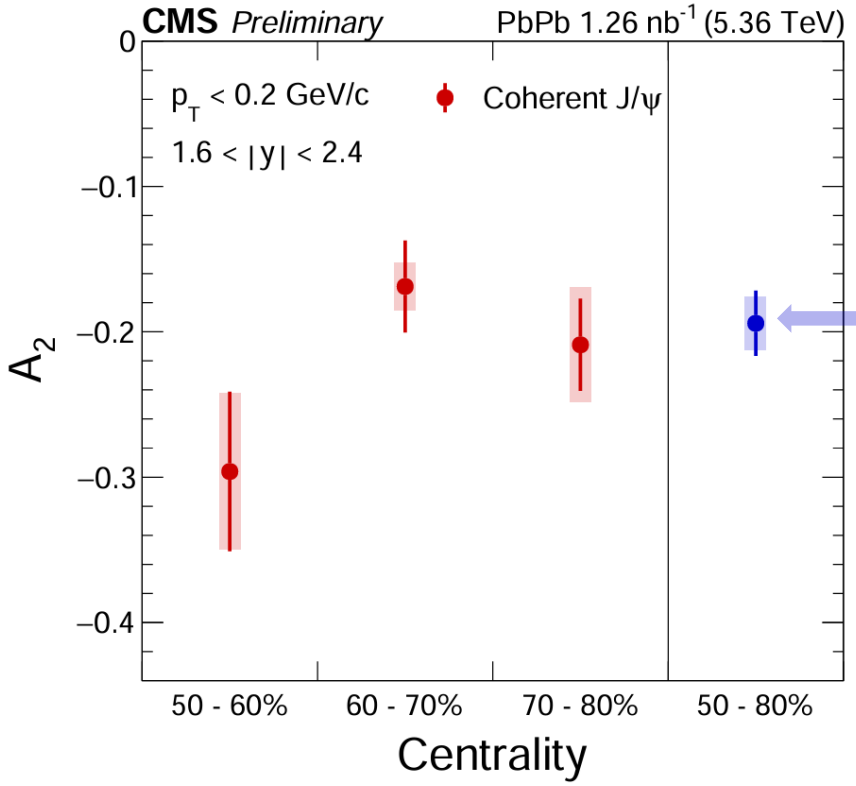


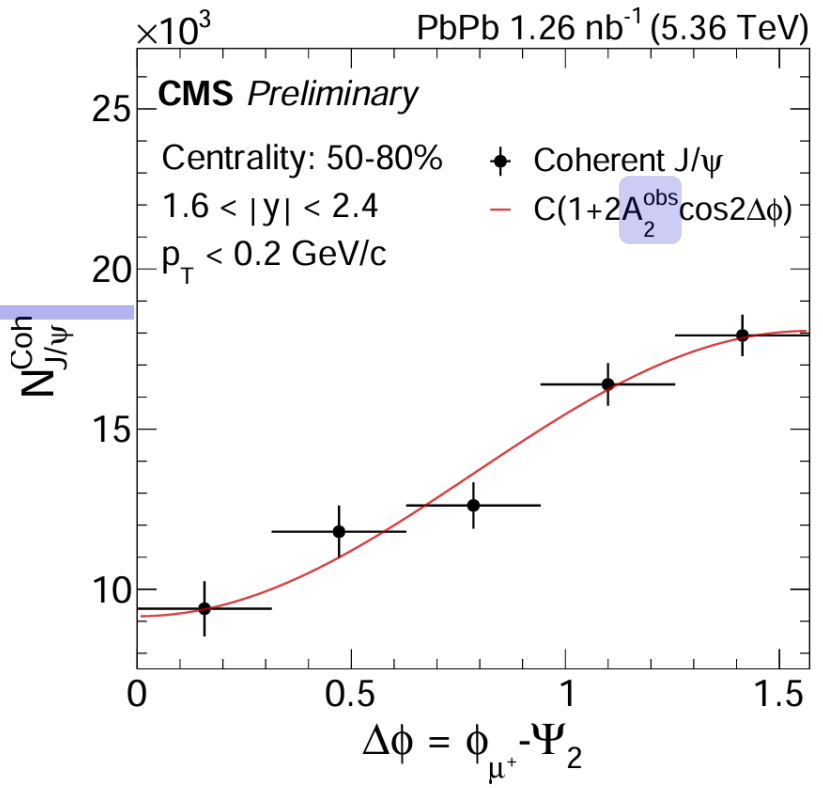
A_2^{obs}: A_2 before EP resolution correction

Cos2Δϕ modulation (A_2) in coherent J/$\psi \rightarrow \mu^+\mu^-$

CMS-PAS-HIN-25-006



$$A_2 = \frac{A_2^{obs}}{\text{EP Res}}$$



- A negative modulation is observed in coherent J/$\psi \rightarrow \mu^+\mu^-$ (spin-1/2 fermions) for the first time.
  - $A_2 = -0.194 \pm 0.022\ (\text{stat}) \pm 0.018\ (\text{syst})$, with a significance of $> 5\sigma$.
  - No significant centrality dependence in 50-80% centrality region.

Cos2Δϕ modulation (A_2) in coherent J/$\psi \to \mu^+\mu^-$

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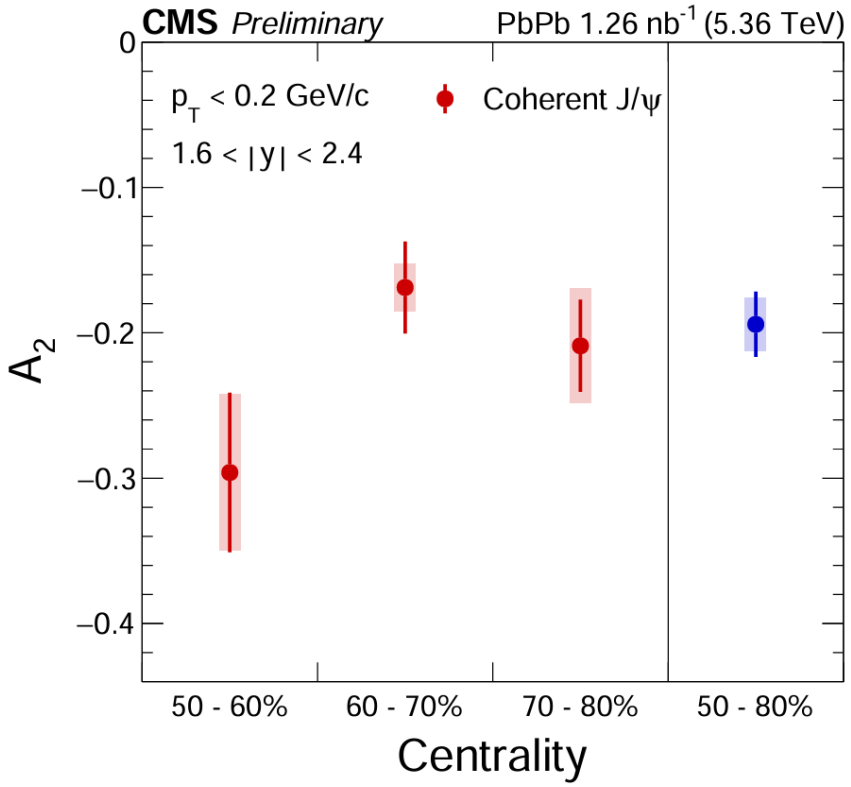
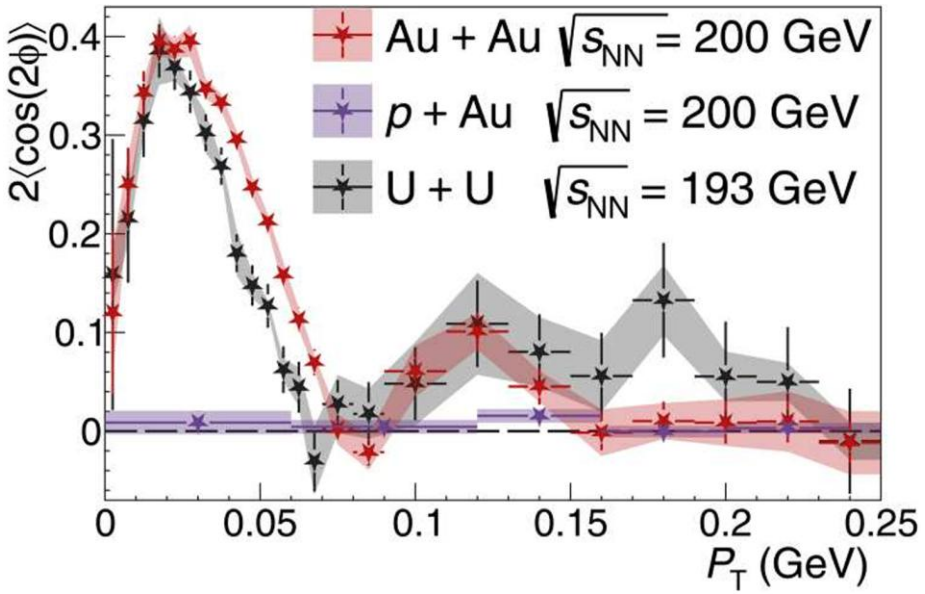


STAR, Sci. Adv. 9 (2023) eabq3903

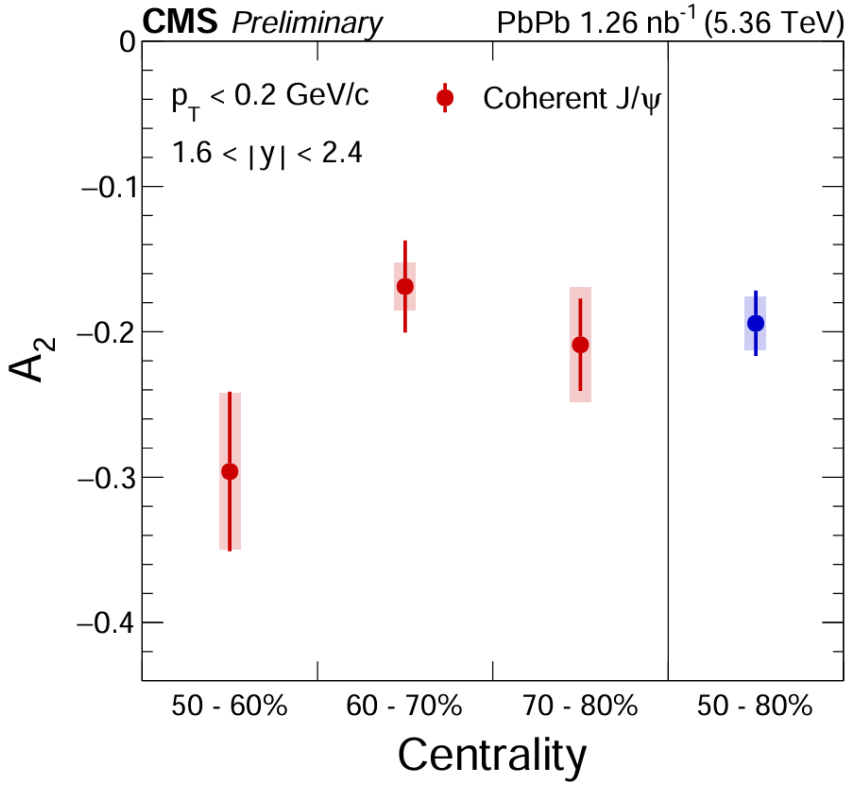


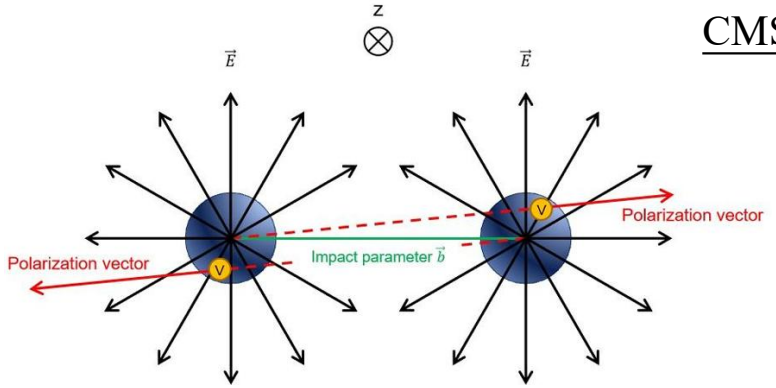
Positive modulation of Coh. $\rho^0 \to \pi^+\pi^-$ (spin-0 bosons) by STAR

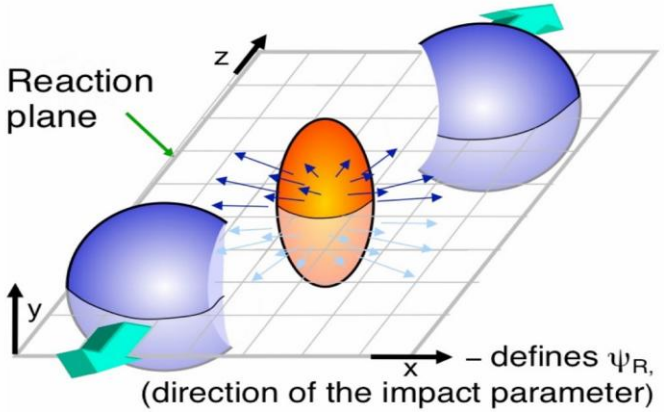
- A negative modulation is observed in coherent J/$\psi \to \mu^+\mu^-$ (spin-1/2 fermions) for the first time.
- Together with coherent $\rho^0 \to \pi^+\pi^-$, this provide the first direct observation of the spin-state dependence in coherent VM azimuthal asymmetry.

Cos2Δϕ modulation (A_2) in coherent J/$\psi \rightarrow \mu^+\mu^-$

CMS-PAS-HIN-25-006







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- These results demonstrate the feasibility of a complementary reaction plane probe.

Cos2Δϕ modulation (A_2) in coherent $J/\psi \to \mu^+\mu^-$

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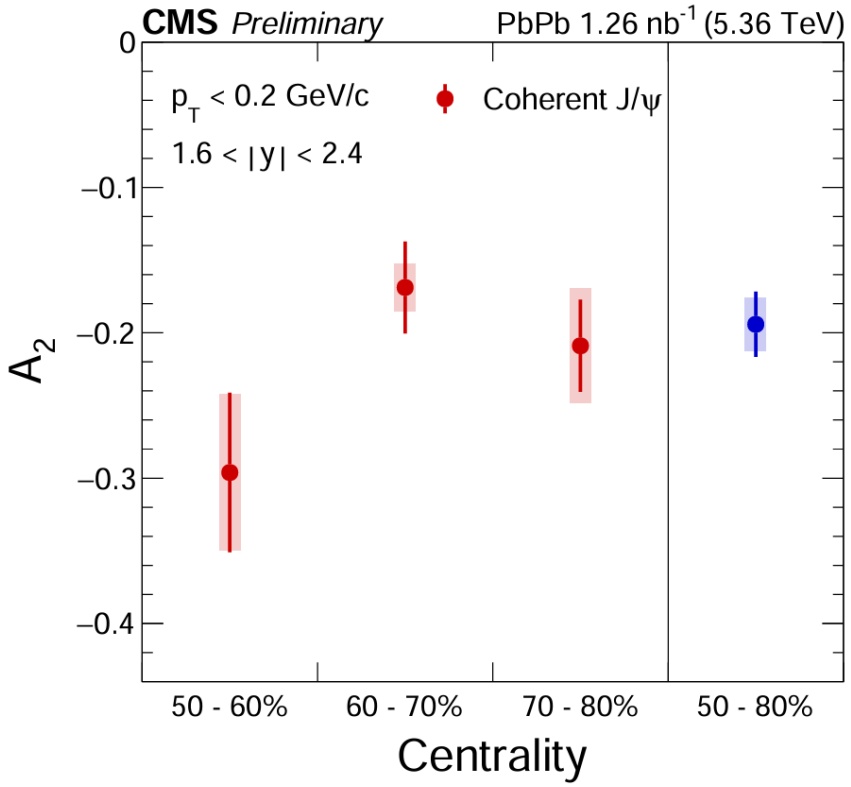

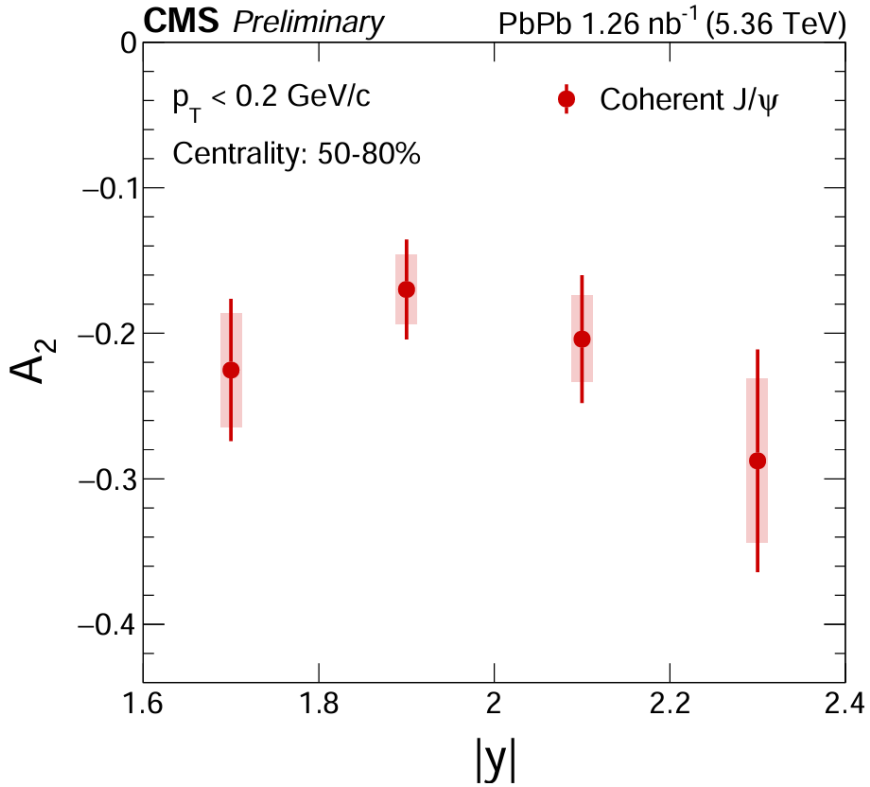

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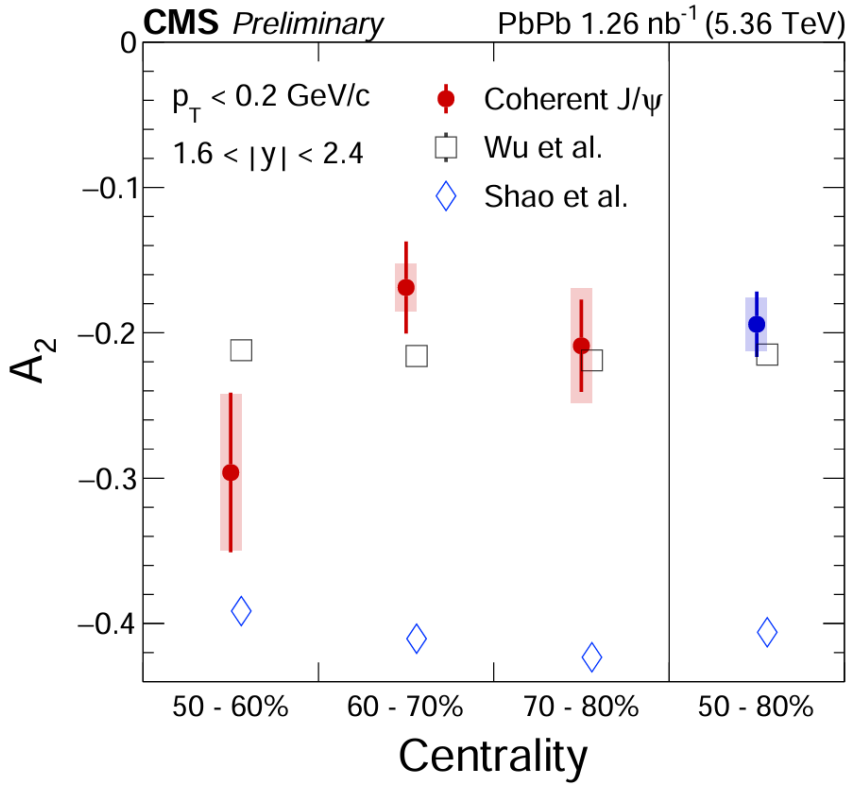
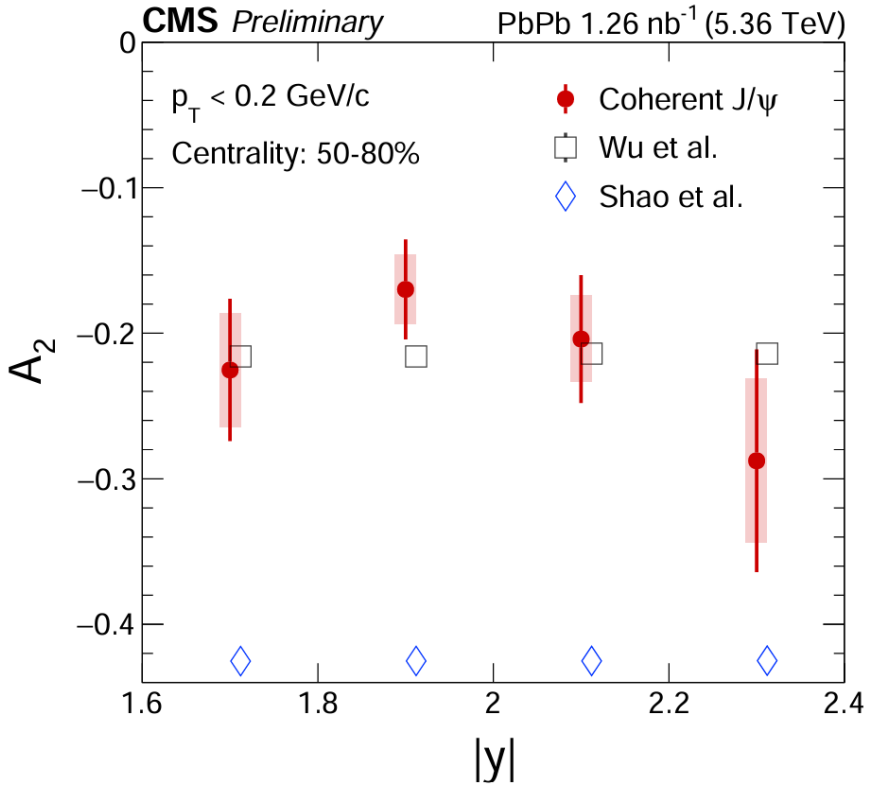
- No significant rapidity dependence in 1.6 < |y| < 2.4.

Comparisons with model calculations

CMS-PAS-HIN-25-006





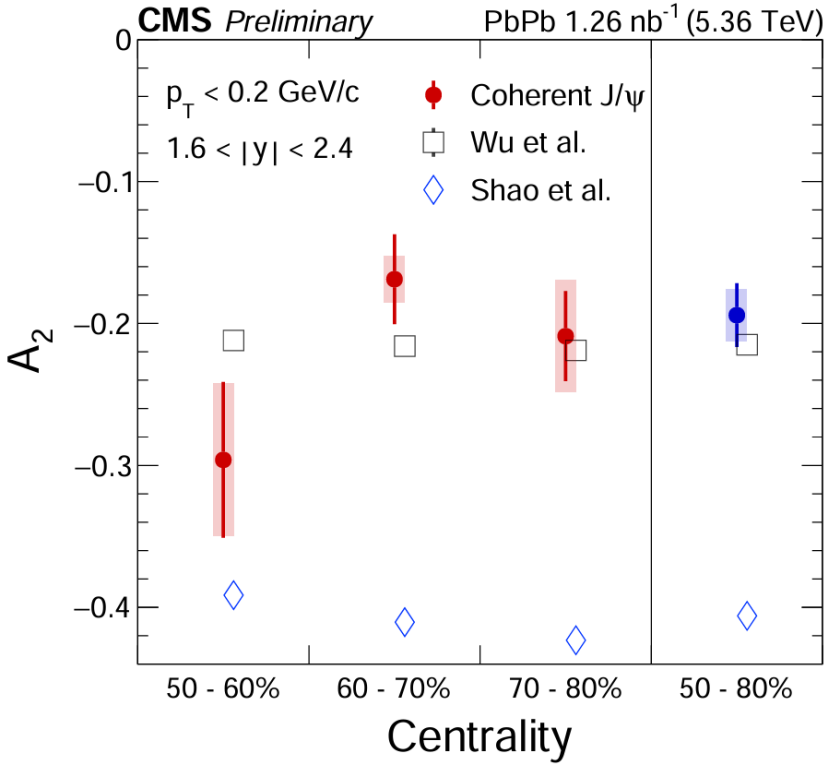
- Both models consider the correlations between VM polarization direction and ***b*** direction.
- The model by Wu et al.
  - Vector-meson dominance framework.
  - Accounts for effects from participating nucleons.
- The model by Shao et al.
  - Dipole framework.
  - Ignoring the effects from participating nucleons.

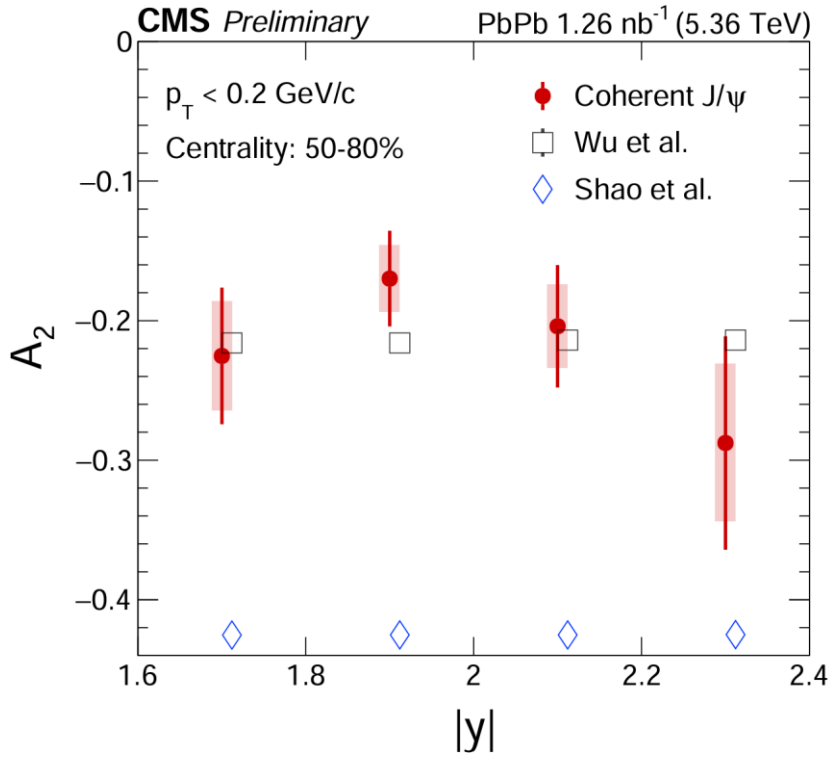
Wu et al., Phys.Rev.Res. 4 (2022) 4, L042048

Shao et al., arXiv:2511.17670

Summary

- A negative A_2 of coherent J/$\psi \rightarrow \mu^+\mu^-$ is observed in hadronic collisions for the first time.
- Provide the first direct observation of the spin-state dependence of A_2.
- These results demonstrate the feasibility of a complementary reaction plane probe.





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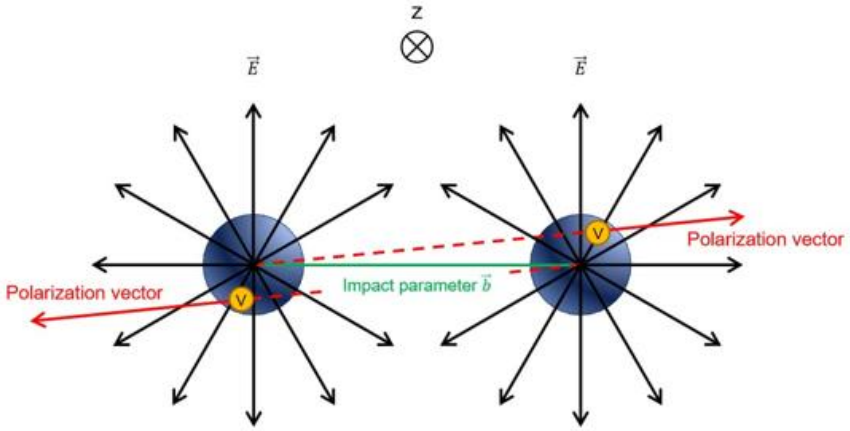
Thank you !

Backup

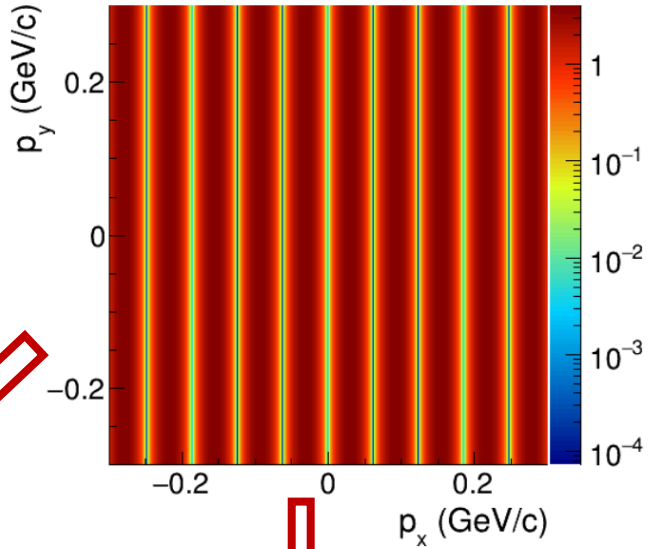
Linearly polarization from vector meson in photo-induced process



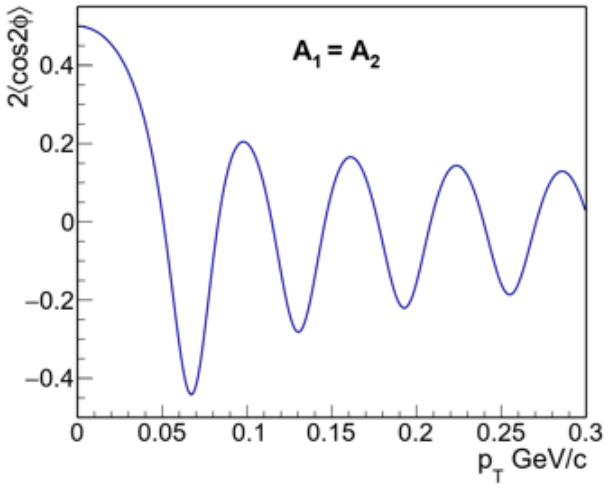
Decay along the polarization direction

$$\frac{d^2N}{d\cos\theta d\phi} = \frac{3}{8\pi}\sin^2\theta[1+\cos 2(\phi-\Phi)]$$

- Photon polarization vector is in the direction of electric field ($\vec{b}$)
- Interference takes place in x-axis ($\vec{b}$ direction) and disappears in p_y direction.



Oscilaton for ⟨cos2ϕ⟩



Zha et al. Phys.Rev.D 103 (2021) 3, 033007