



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

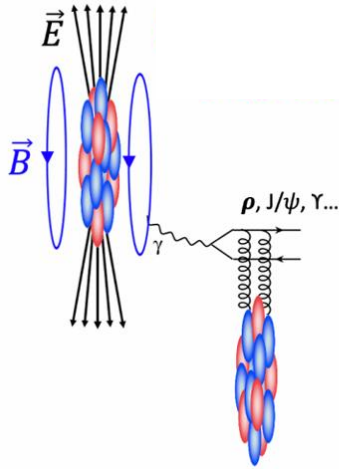
[CMS-PAS-HIN-25-006](#)

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中国物理学会高能物理分会第十二届全国委员代表大会暨学术年会
13-19 July 2026

Vector meson photoproduction in UPC

EM fields of nucleus $\rightarrow$ A flux of quasi-real photons

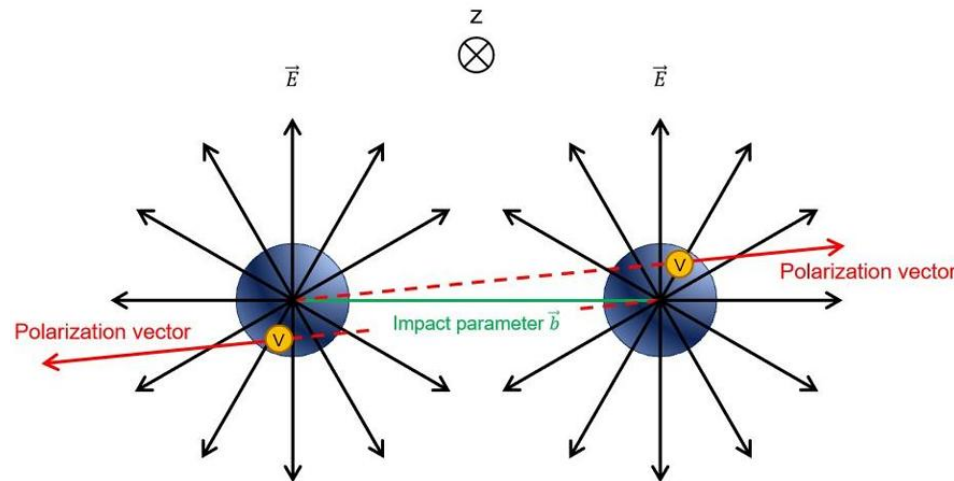


Photon-nucleus interactions:

- Photon interacts with intact nucleus
- Coherent vector meson production (VM)
- VM $\langle p_T \rangle \sim 60 \text{ MeV}/c$

The quasi-real photons are linearly polarized

Zhou et al., Phys.Lett.B 795 (2019) 576-580



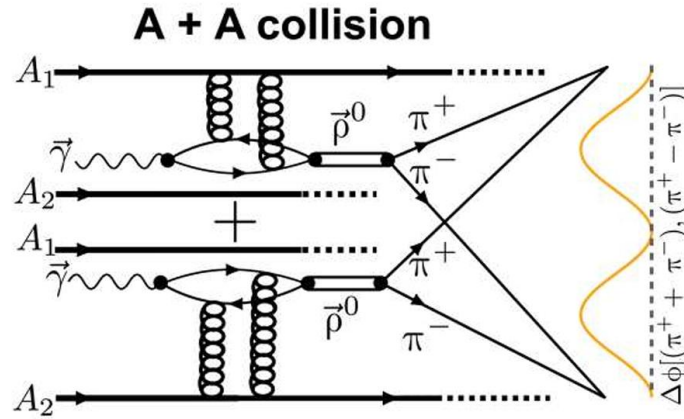
$\Rightarrow$ VM inherits the polarization state

$\Rightarrow$ An azimuthal $\cos 2\Delta\phi$ 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 $\rho^0 \rightarrow \pi^+\pi^-$ in UPC



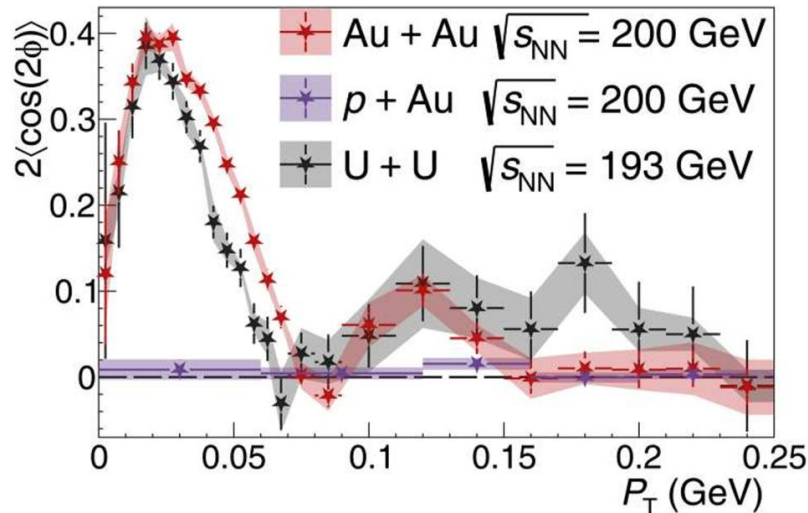
The photon emitters and targets are indistinguishable

⇒ quantum interference of ρ^0 amplitudes

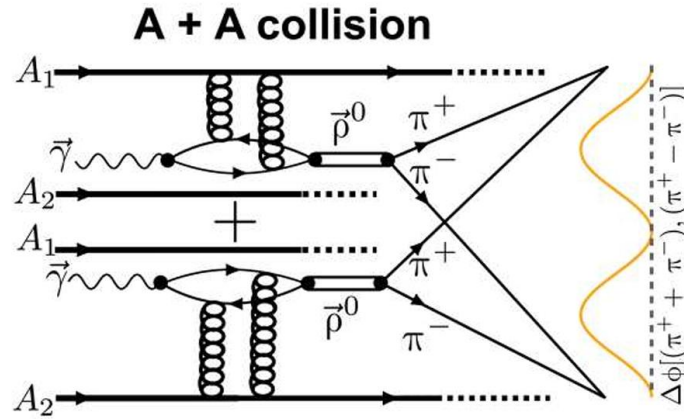
⇒ strong correlation between p_{T,ρ^0} and polarization direction

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

➤ STAR: signal $\pi^+\pi^-$ pairs



Cos2 $\Delta\phi$ modulation of coherent $\rho^0 \rightarrow \pi^+\pi^-$ in UPC



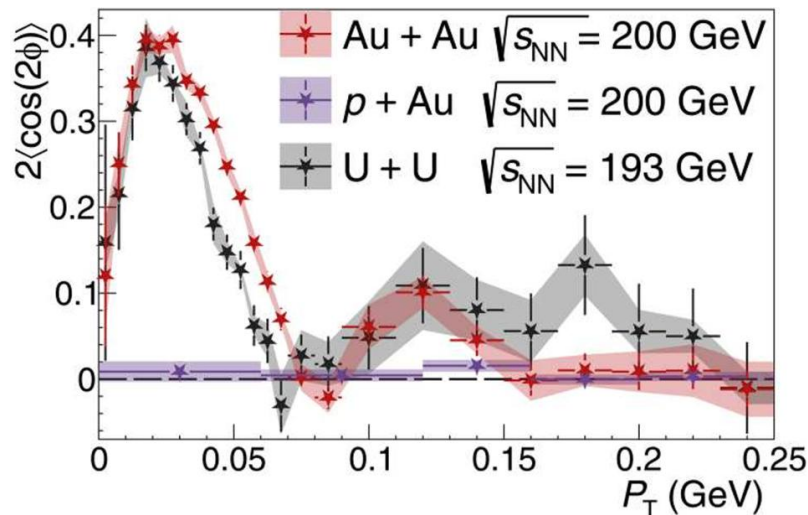
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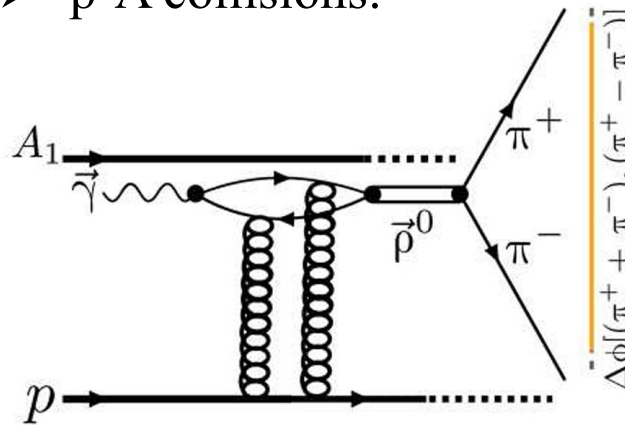
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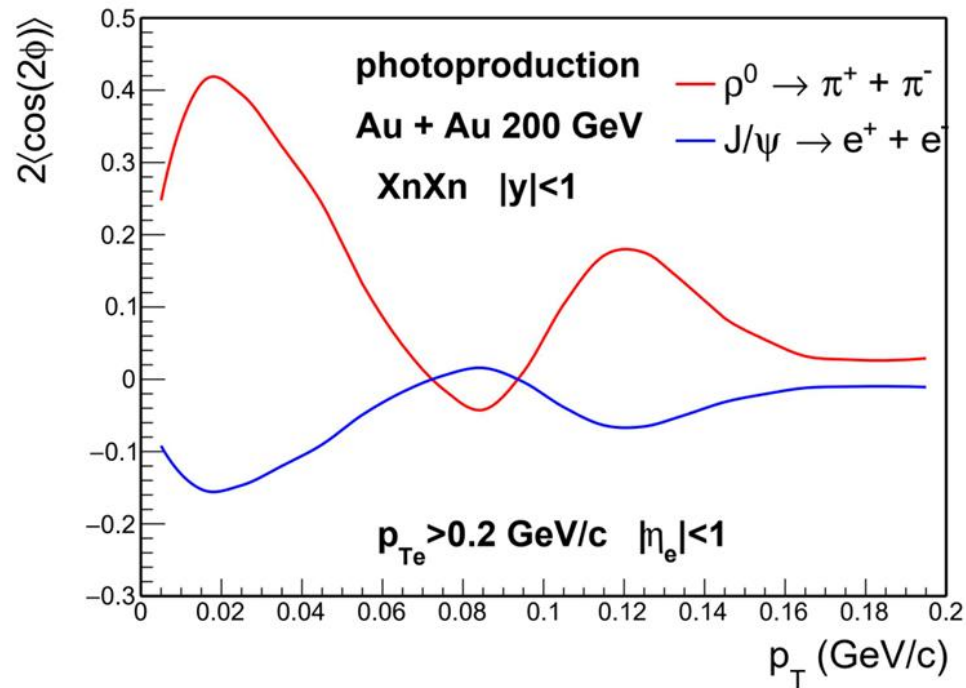
➤ p-A collisions:



Interference effect reduced in case of

- Asymmetric nuclear collision system
- Forward rapidity

Spin state dependence of $\cos 2\Delta\phi$ modulation

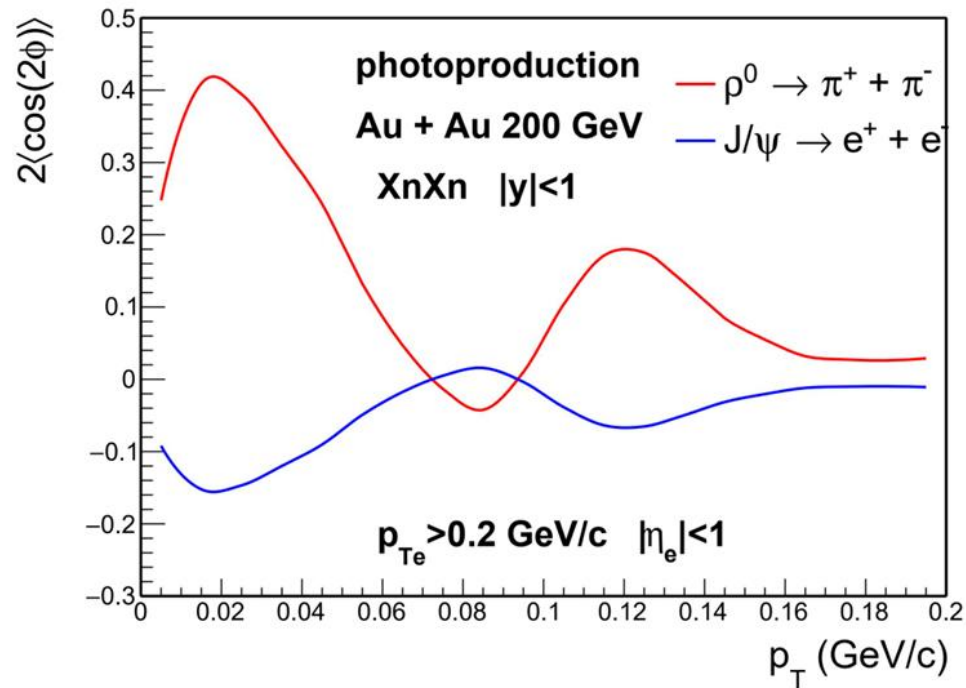


Zha et al., PRD 103 (2021) 033007

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

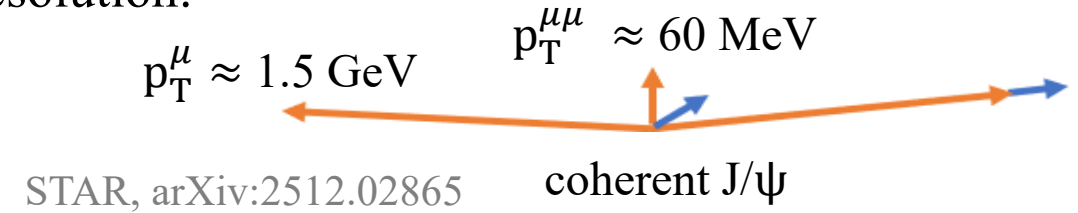
Can we observe spin state dependence?

Spin state dependence of $\cos 2\phi$ modulation



Zha et al., PRD 103 (2021) 033007

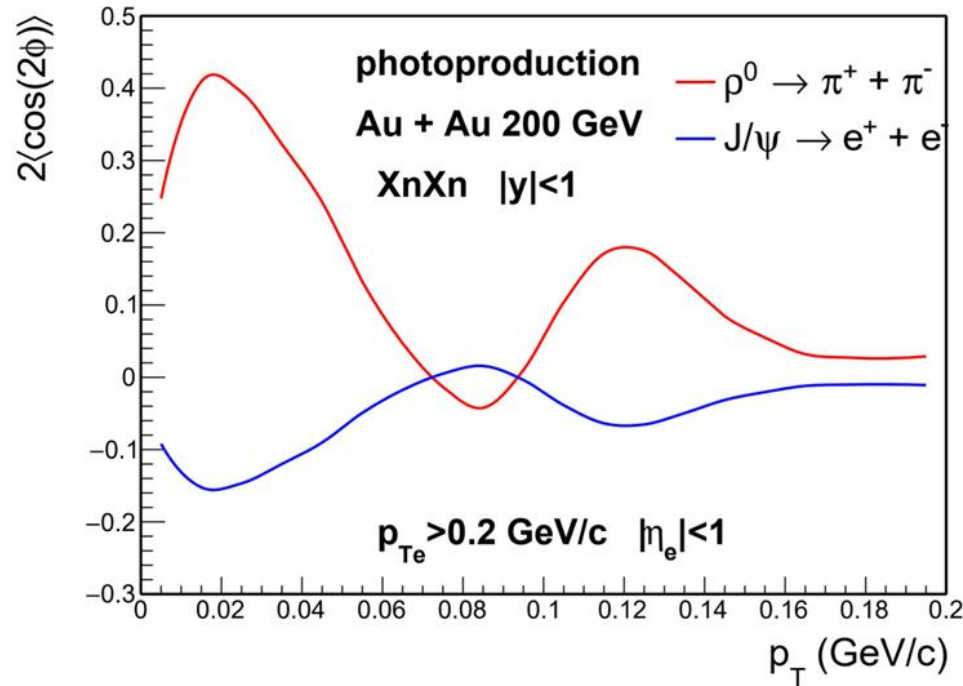
- $p_{T,J/\psi}$ resolution:



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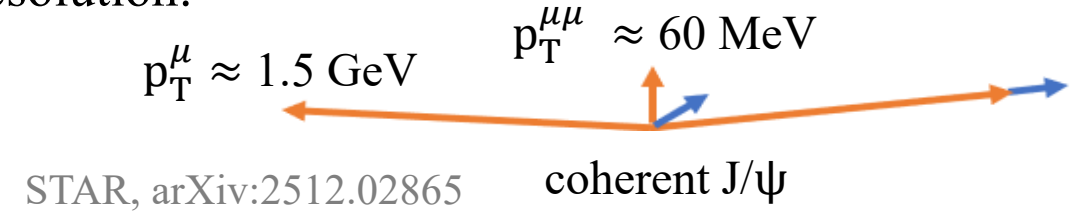
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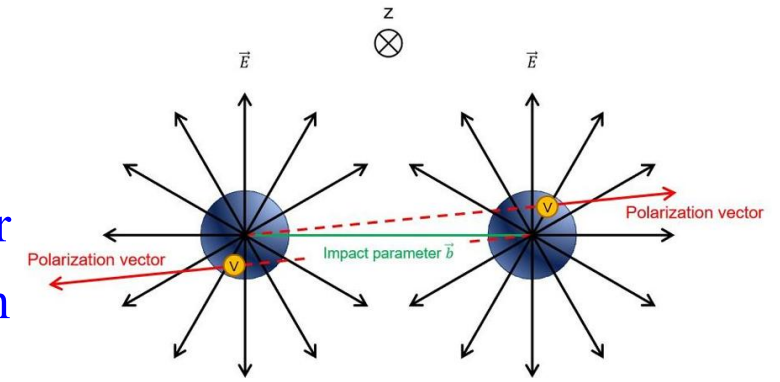


Zha et al., PRD 103 (2021) 033007

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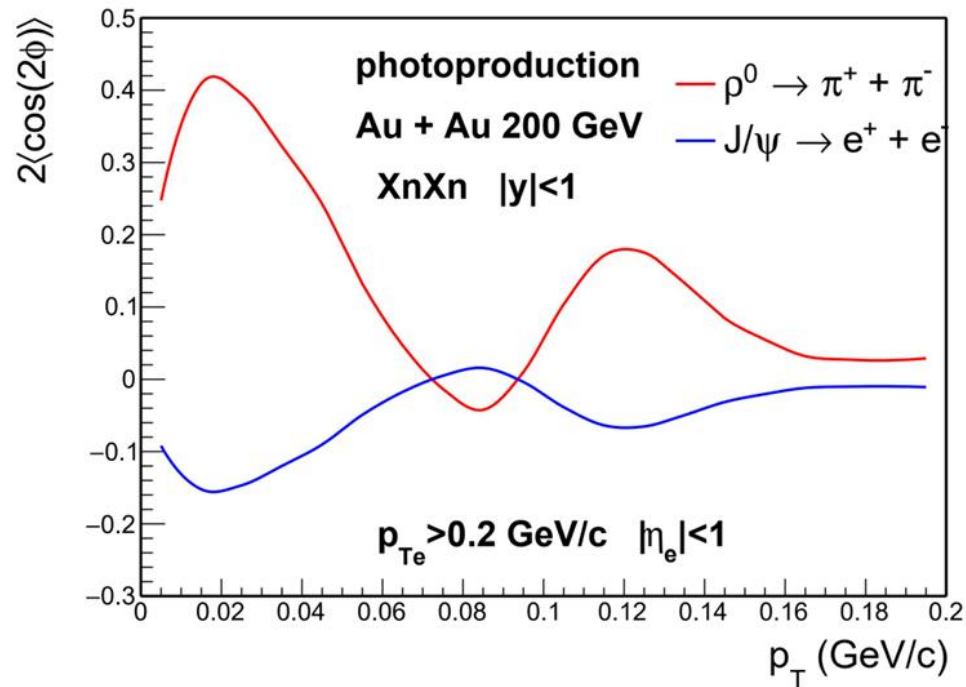
- Impact parameter (b):
A more robust estimator
of polarization direction



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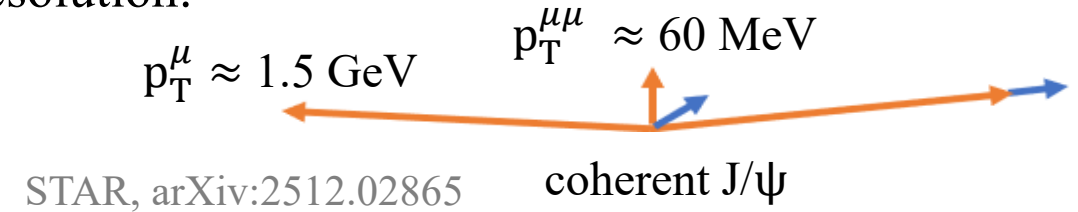
Zha et al., PRD 103 (2021) 033007

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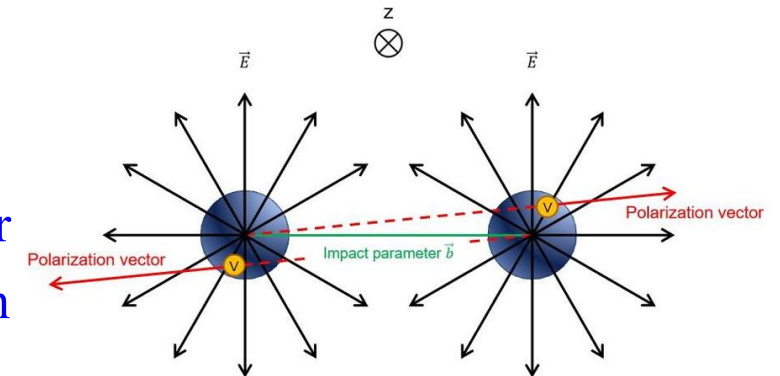
Can we observe spin state dependence?

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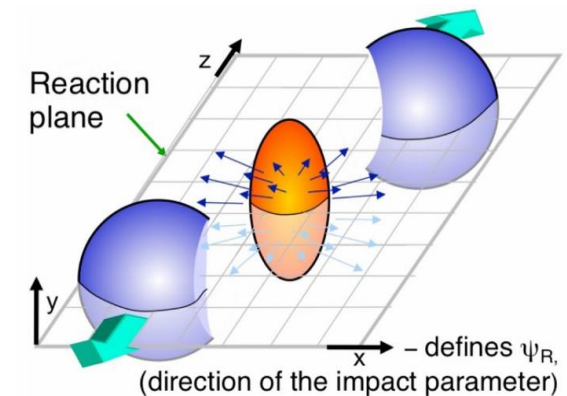
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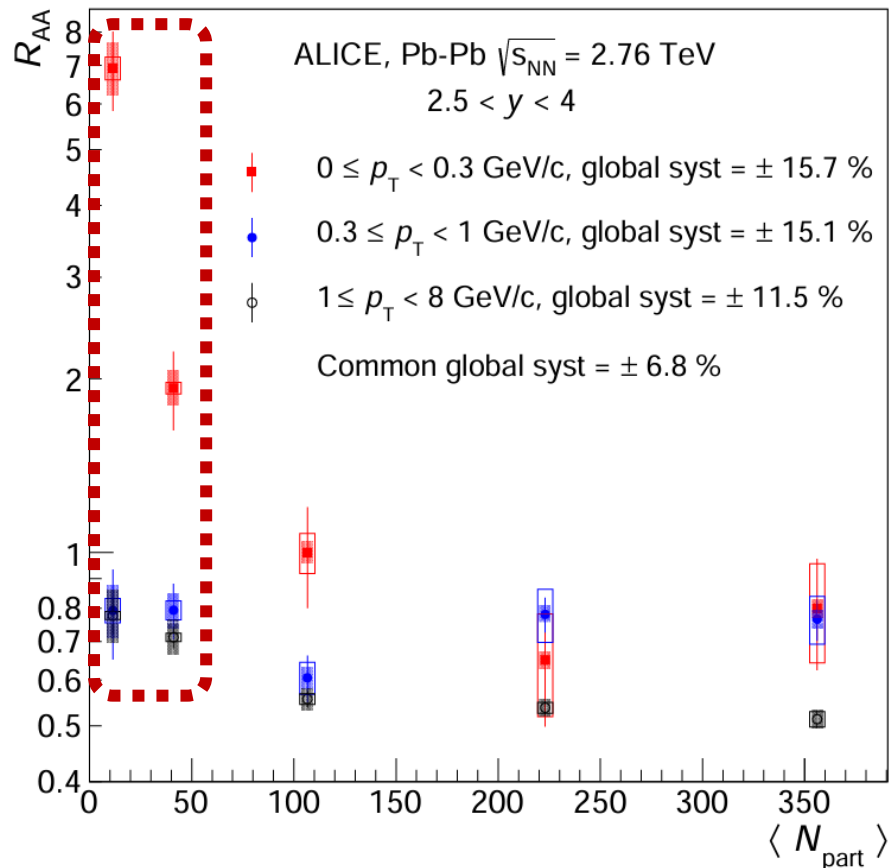
- Hadronic collisions:
 b is estimated by the
second order event
plane reconstruction



STAR, QM2025

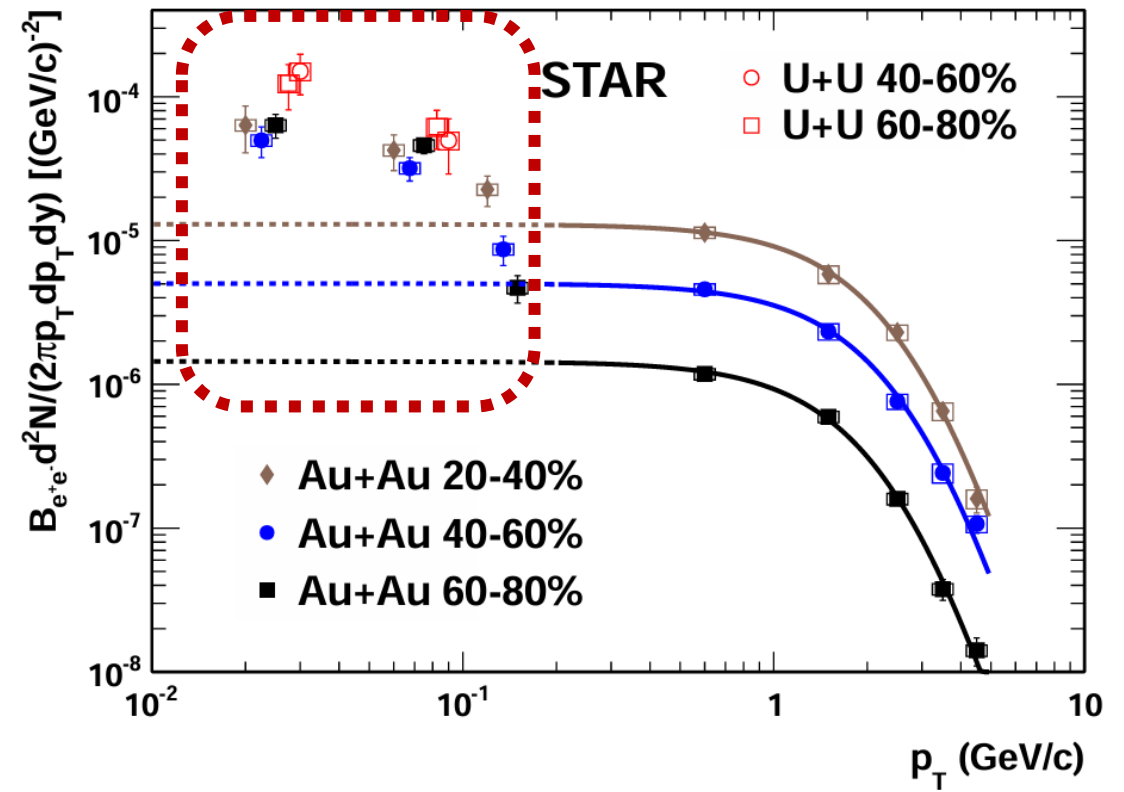
Coherent J/ψ in hadronic collisions

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



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

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

➤ 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%
- $p_T < 0.2 \text{ GeV/c}$
- $1.6 < |y| < 2.4$

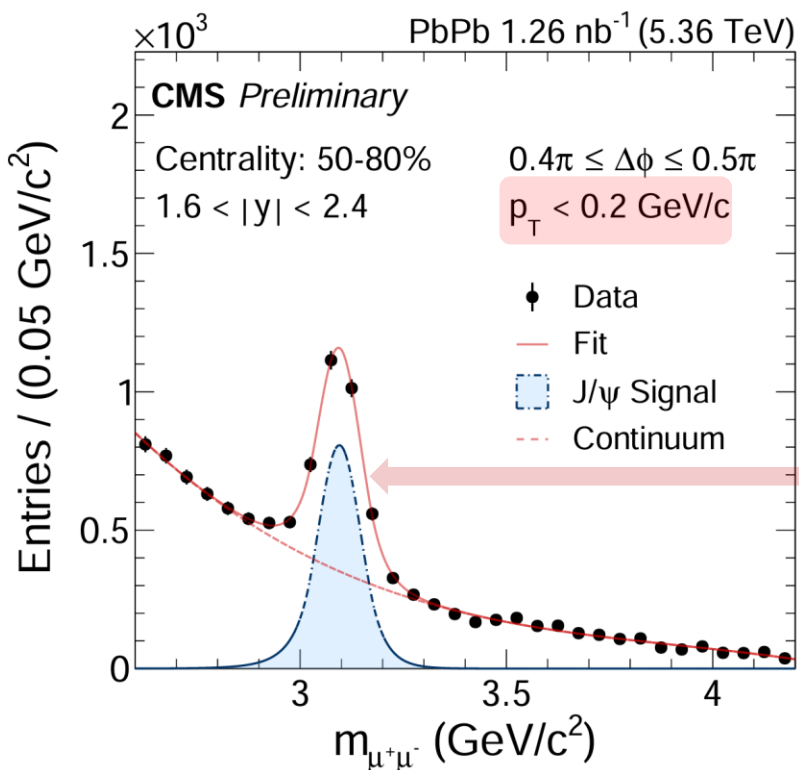
➤ The second order event plane reconstructed by tracks with $0.3 < p_T < 3 \text{ GeV/c}$, $|\eta| < 2.4$

- $\Psi_2 = \frac{1}{2} \text{atan2}(Q_{2,y}, Q_{2,x})$.
- $Q_{2,x} = Q_2 \cos(2\Psi_2) = \frac{\sum_i \omega_i \cos(2\phi_i)}{\sum_i \omega_i}$,
- $Q_{2,y} = Q_2 \sin(2\Psi_2) = \frac{\sum_i \omega_i \sin(2\phi_i)}{\sum_i \omega_i}$.

➤ EP resolution is calculated by 3-sub event method:

$$\sqrt{\frac{\langle \cos(2\Psi_2^{trk} - 2\Psi_2^{HFp}) \rangle \langle \cos(2\Psi_2^{trk} - 2\Psi_2^{HFm}) \rangle}{\langle \cos(2\Psi_2^{HFp} - 2\Psi_2^{HFm}) \rangle}}$$

1. J/ψ signal extraction:



➤ J/ψ signal:

- Coherent $J/\psi \rightarrow \mu^+ \mu^-$
- Hadronic $J/\psi \rightarrow \mu^+ \mu^-$
- Incoherent $J/\psi \rightarrow \mu^+ \mu^-$

➤ Continuum background:

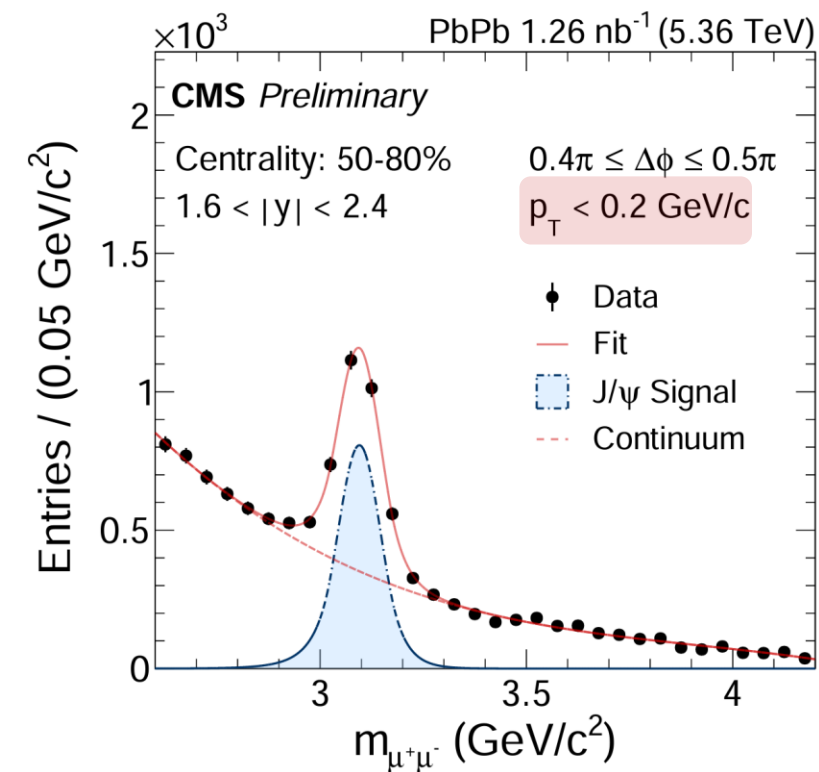
- QED $\gamma\gamma \rightarrow \mu^+ \mu^-$
- Drell-Yan $q\bar{q} \rightarrow \gamma^* Z \rightarrow \mu^+ \mu^-$
- Heavy flavor $q(\bar{q}) \rightarrow \mu + X$
- Combinatorial $\mu\mu$

Double-sided Crystal Ball + Chebyshev3

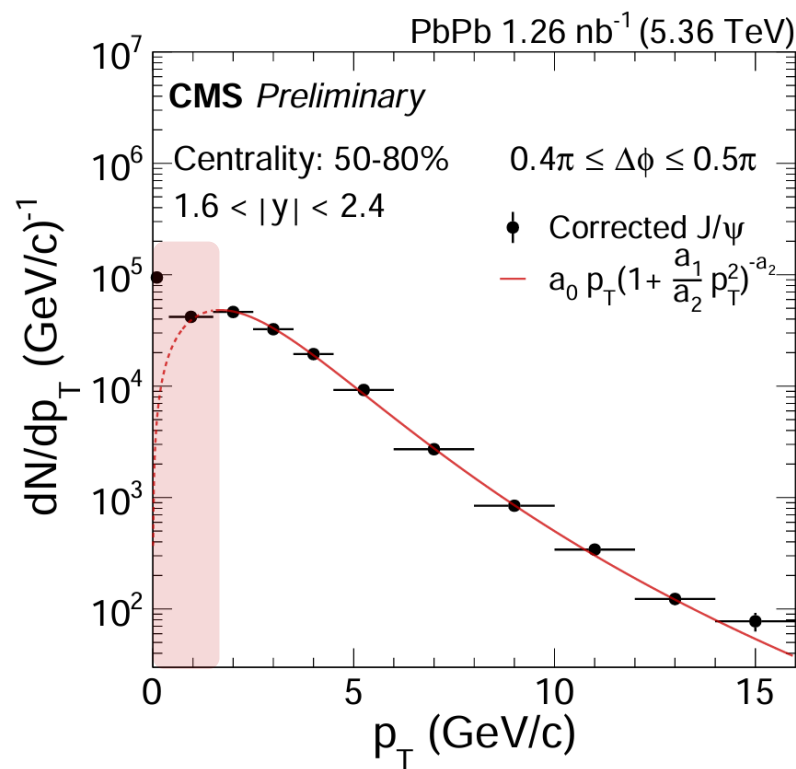
1. J/ψ signal extraction:



2. Hadronic J/ψ subtraction:



Double-sided Crystal Ball + Chebyshev3



Corrected for efficiency

Extraction of $\cos 2\Delta\phi$ amplitude (A_2)

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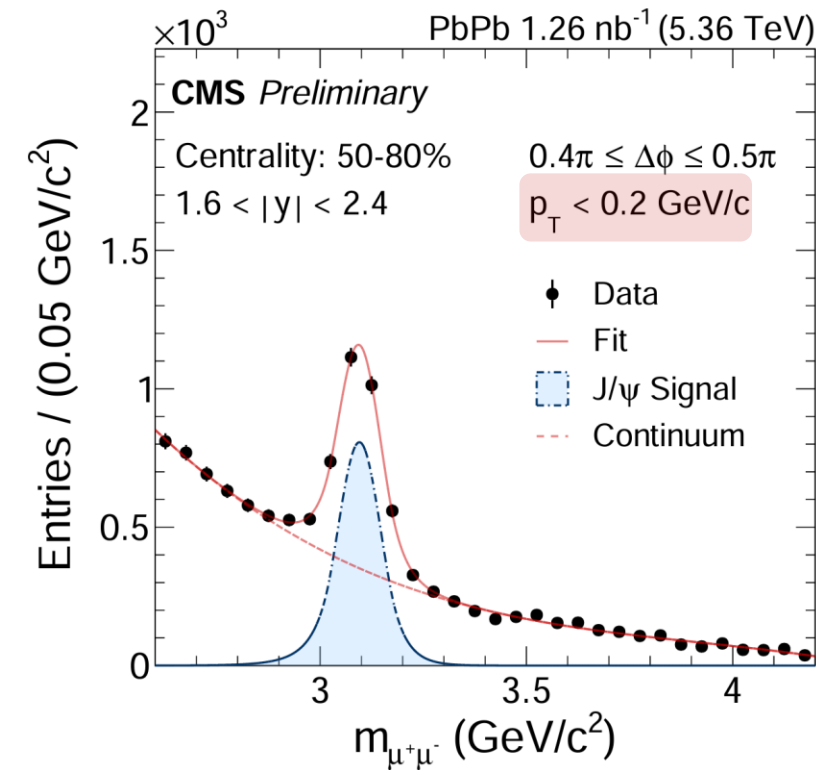
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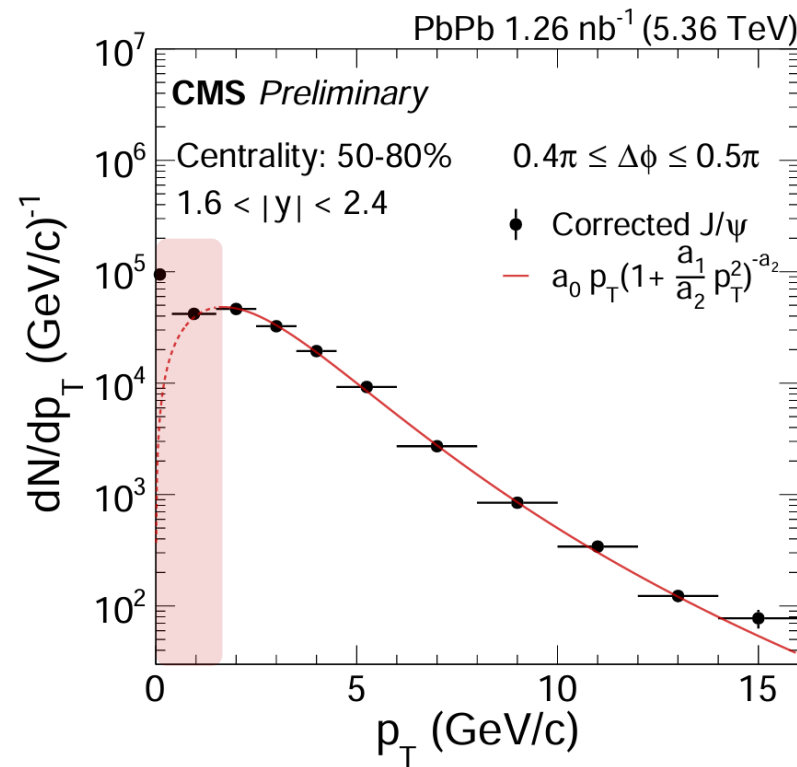
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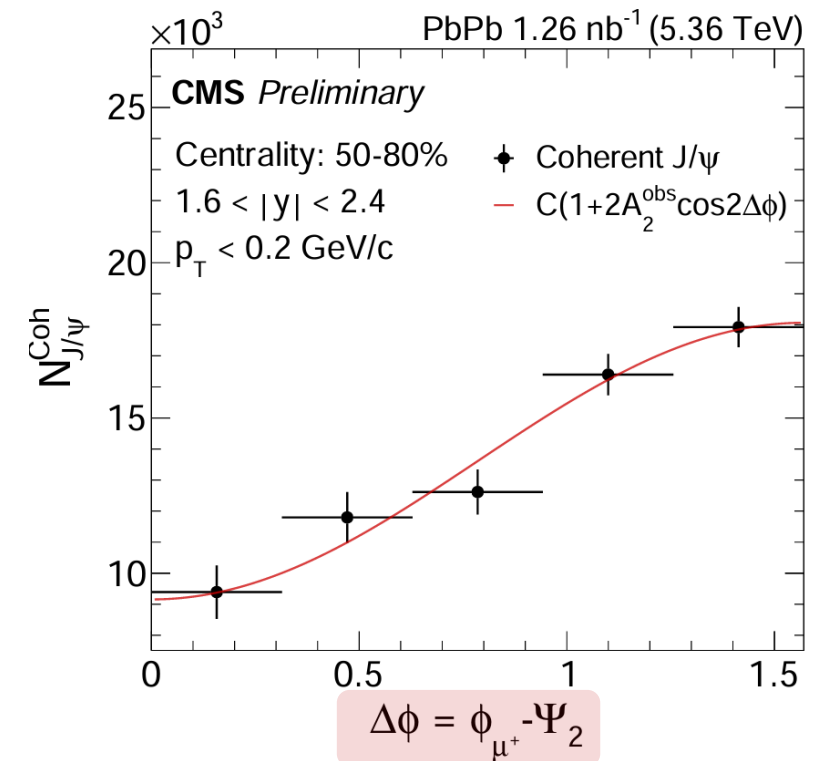
3. $\cos 2\Delta\phi$ amplitude A_2^{obs} extraction:



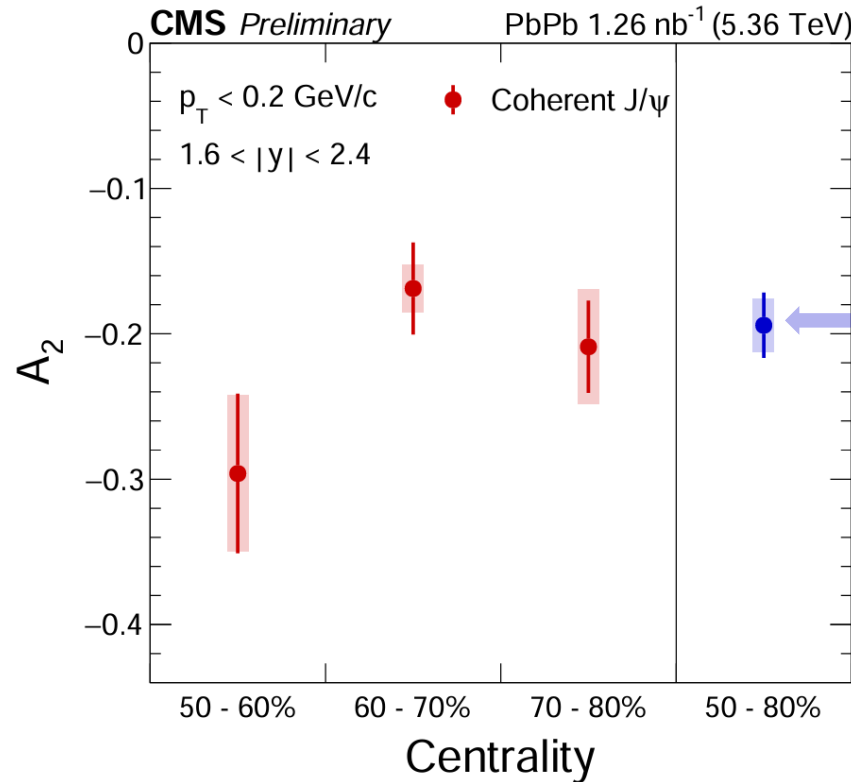
Double-sided Crystal Ball + Chebyshev3



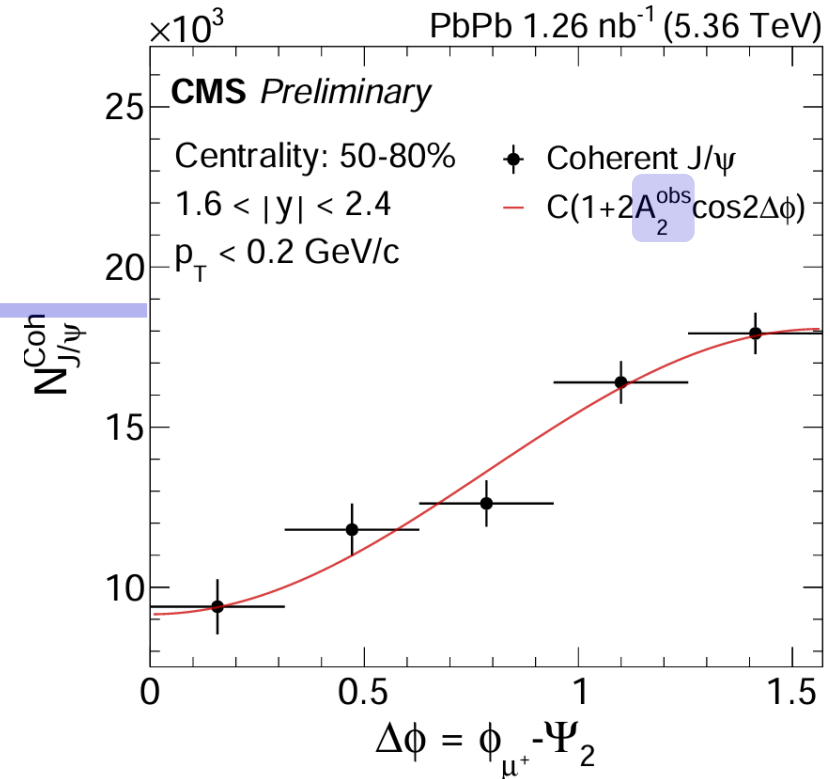
Corrected for efficiency



A_2^{obs} : A_2 before EP resolution correction



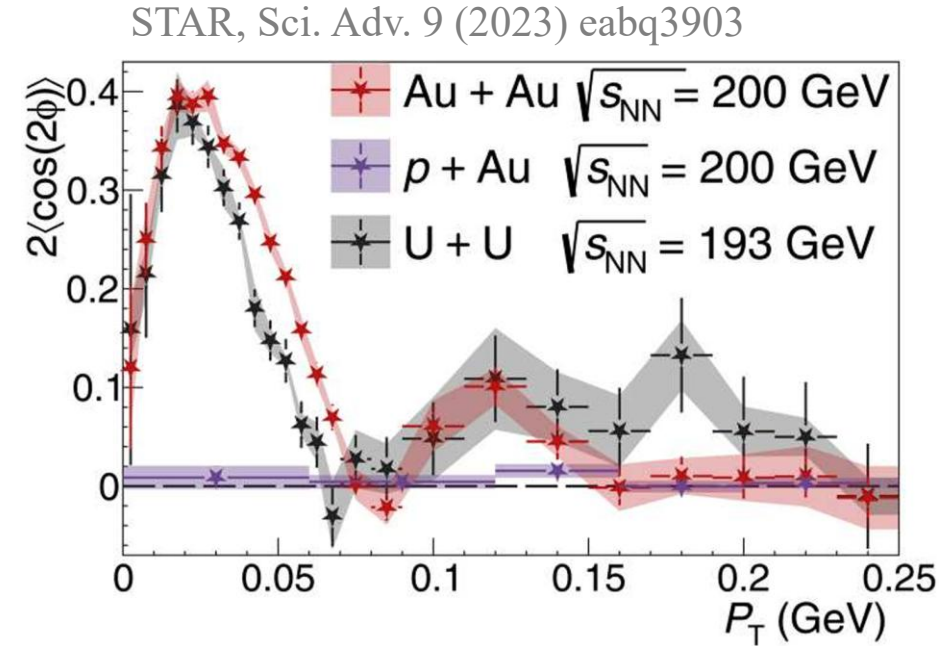
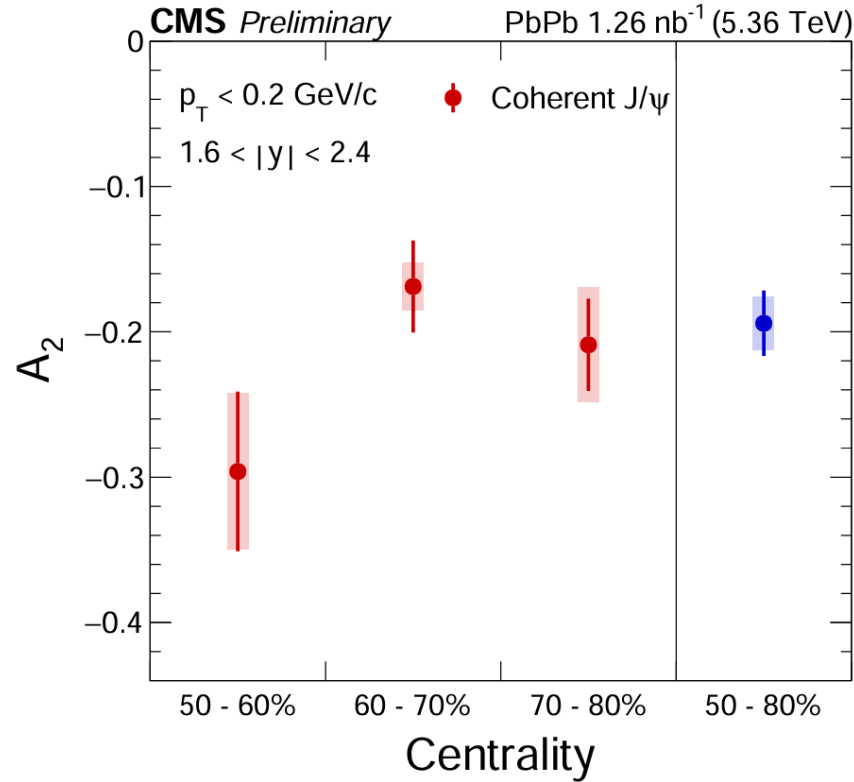
$$A_2 = \frac{A_2^{\text{obs}}}{\text{EP Res}}$$



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

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

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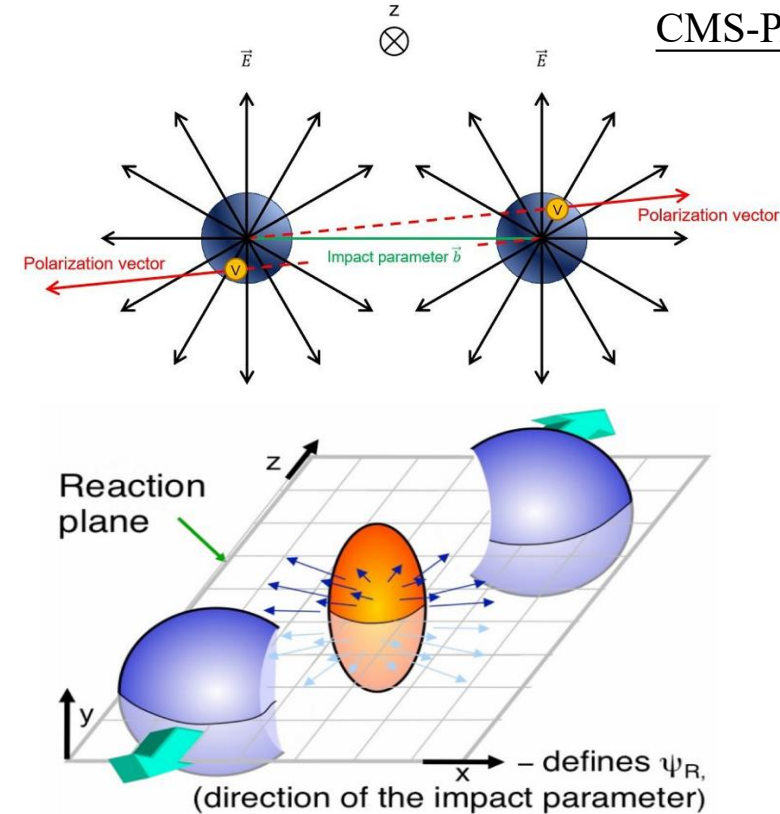
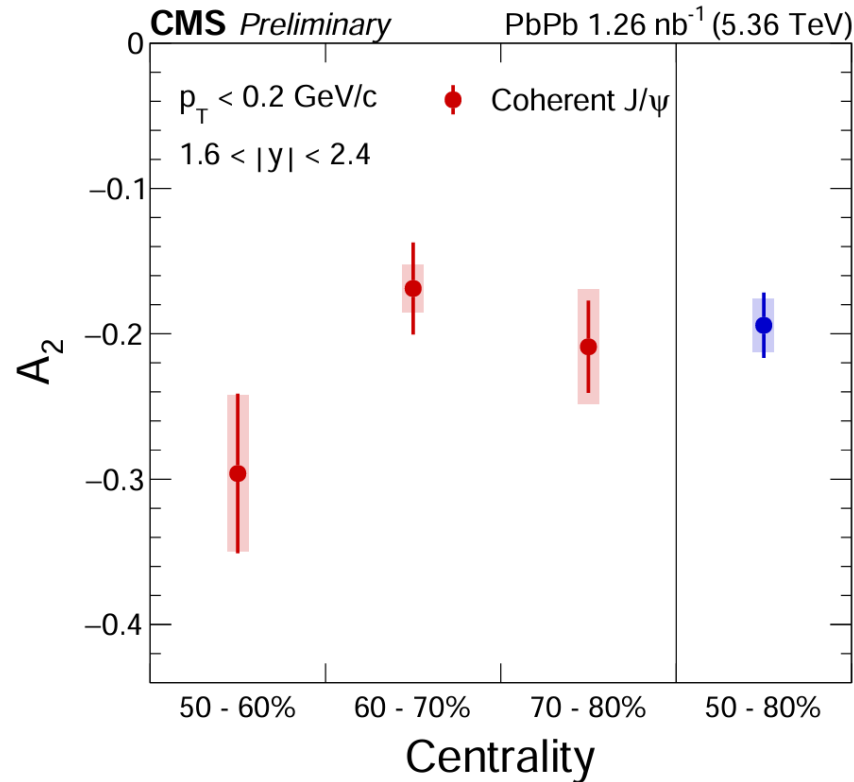


Positive modulation of Coh. $\rho^0 \rightarrow \pi^+\pi^-$
(spin-0 bosons) by STAR

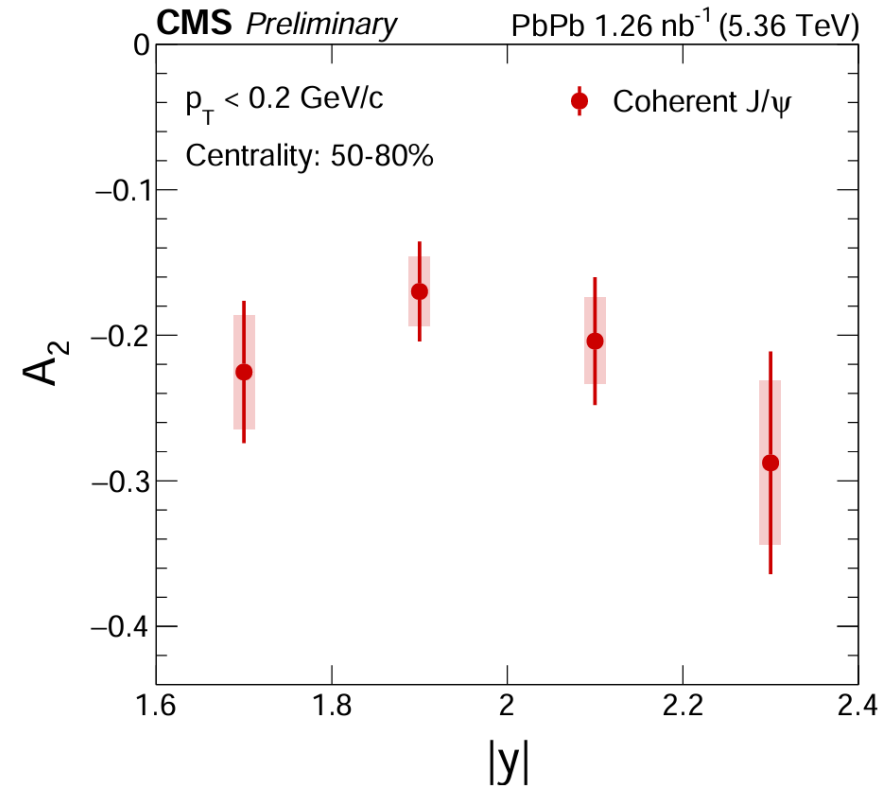
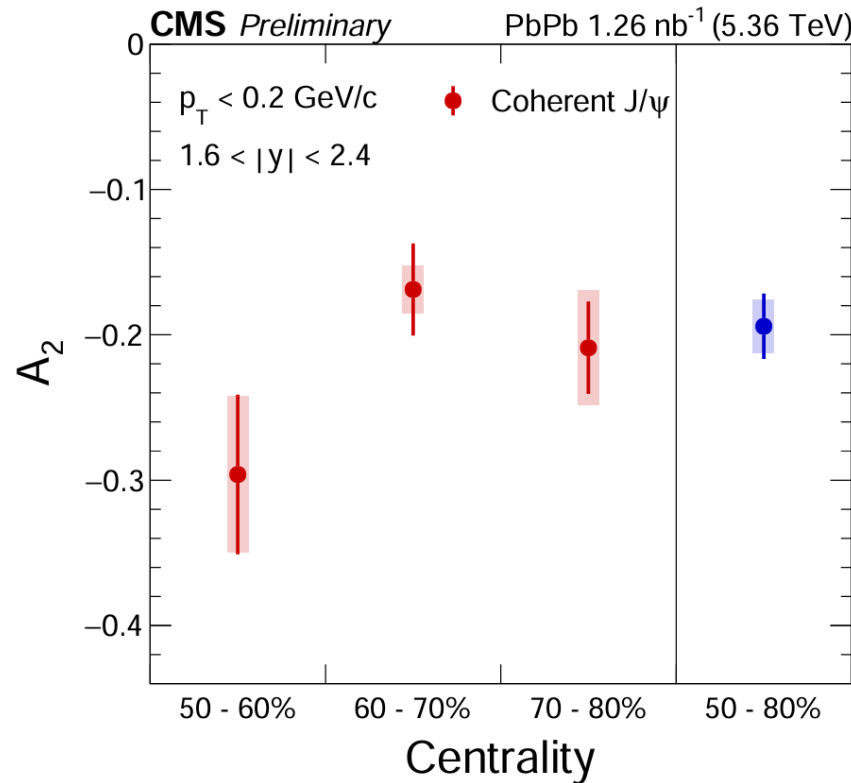
- A negative modulation is observed in coherent $J/\psi \rightarrow \mu^+\mu^-$ (spin-1/2 fermions).
- Together with coherent $\rho^0 \rightarrow \pi^+\pi^-$, this provide the first direct observation of the spin-state dependence in coherent VM azimuthal asymmetry.

Cos2 $\Delta\phi$ modulation (A_2) in coherent $J/\psi \rightarrow \mu^+\mu^-$

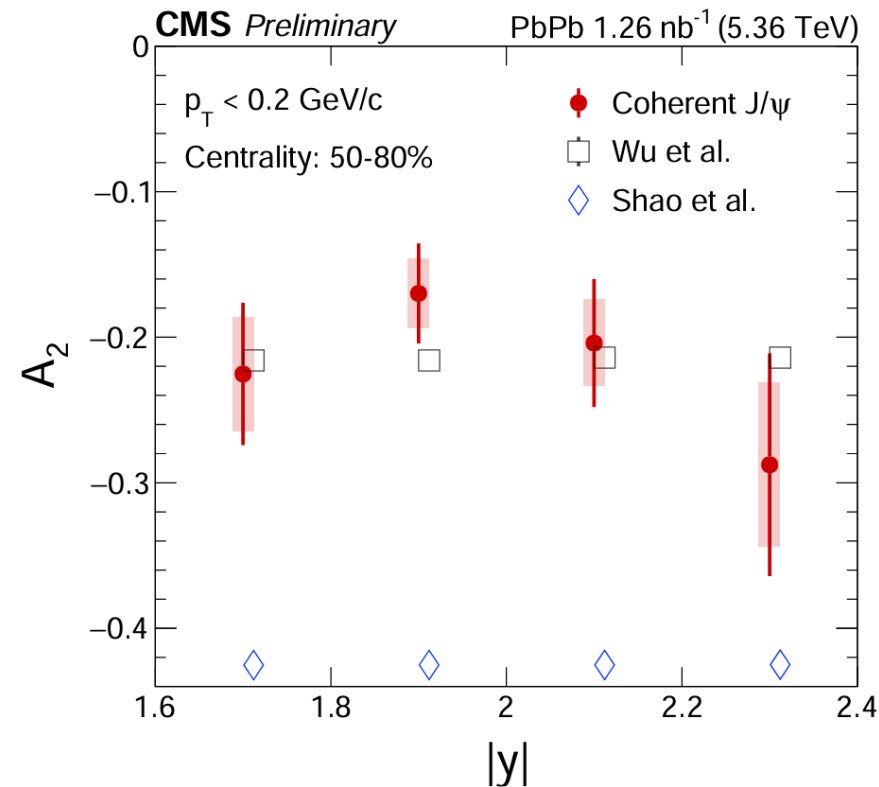
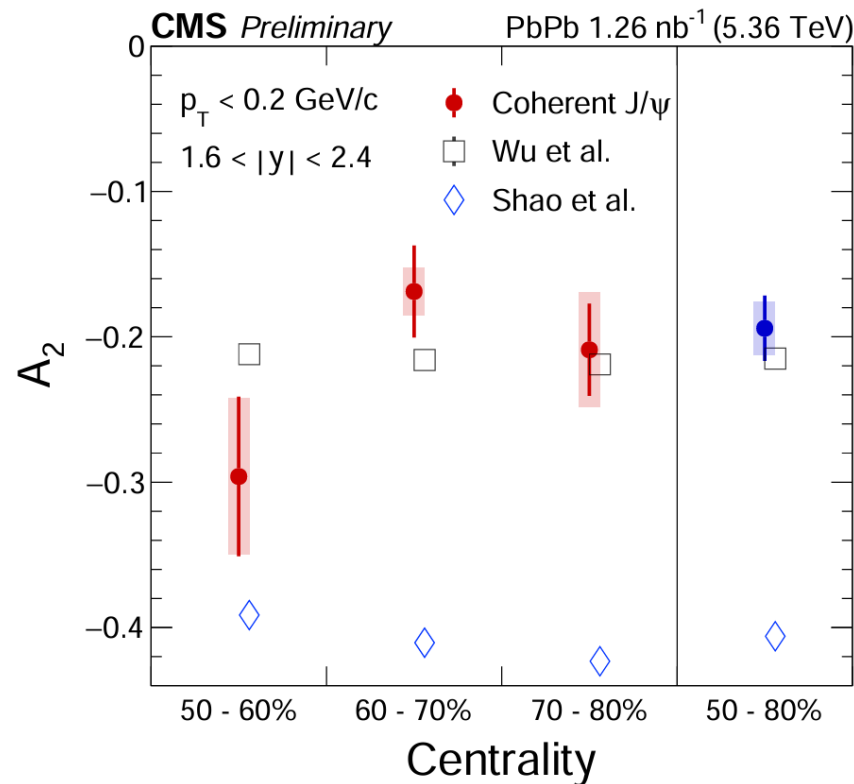
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- A negative modulation is observed in coherent $J/\psi \rightarrow \mu^+\mu^-$ (spin-1/2 fermions).
- Together with coherent $\rho^0 \rightarrow \pi^+\pi^-$, this provides the first direct observation of the spin-state dependence in coherent VM azimuthal asymmetry.
- These results demonstrate the feasibility of a complementary reaction plane probe.



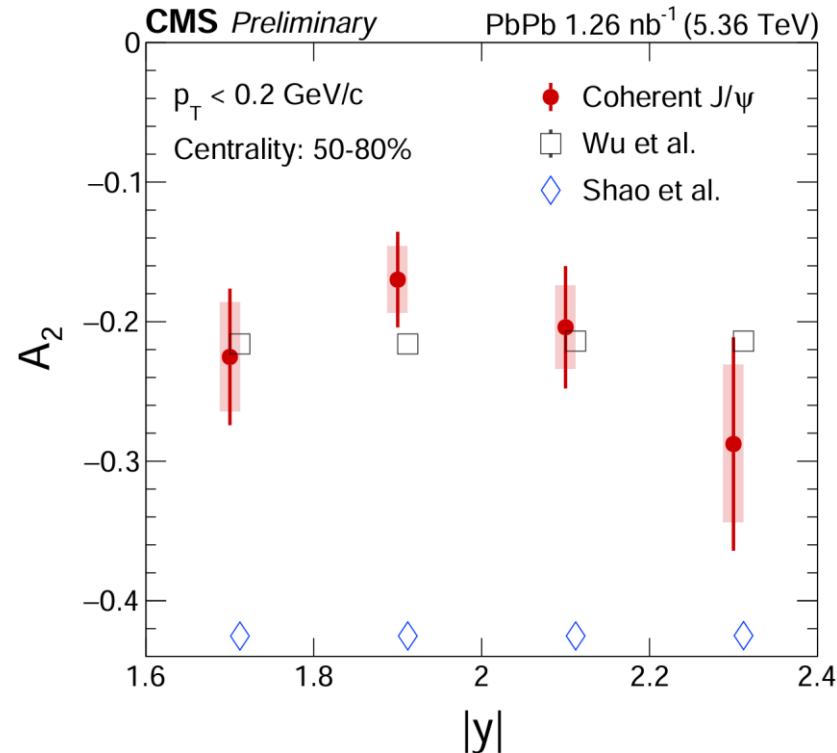
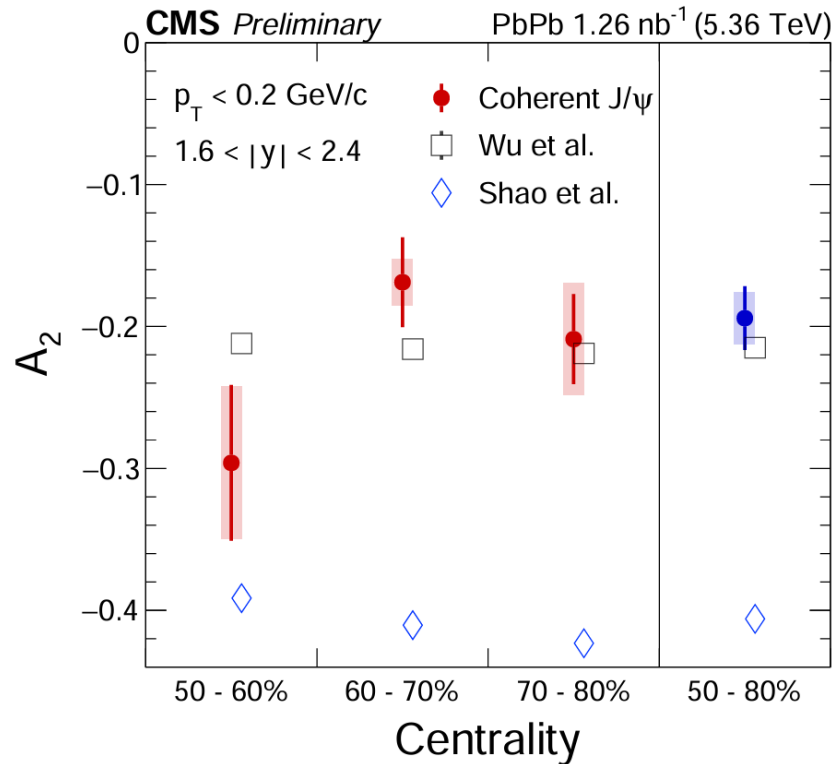
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- Together with coherent $\rho^0 \rightarrow \pi^+\pi^-$, this provide the first direct observation of the spin-state dependence in coherent VM azimuthal asymmetry.
- These results demonstrate the feasibility of a complementary reaction plane probe.
- No significant rapidity dependence in 1.6 < $|y|$ < 2.4.



- Both models consider the correlations between VM polarization direction and $\mathbf{b}$ direction.
- The model by Wu et al.
 - Vector-meson dominance framework.
 - Accounts for the partial loss of coherence due to participating nucleons.
- The model by Shao et al.
 - Dipole framework.
 - Does not include effects from participating nucleons.

Summary

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

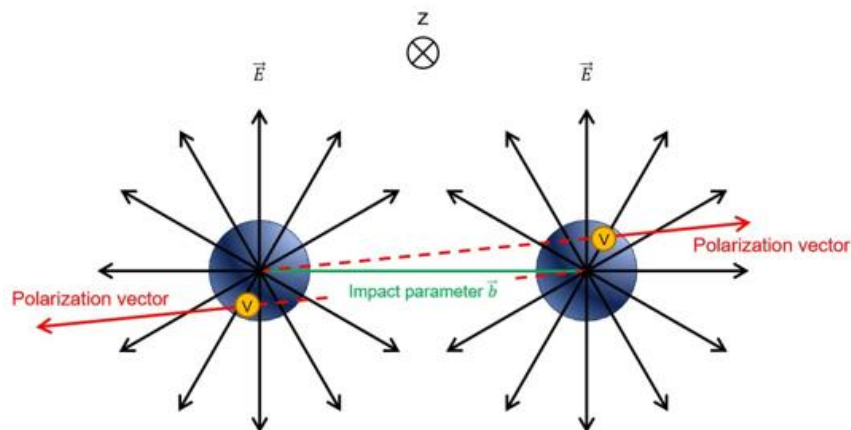


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Thank you !

Backup

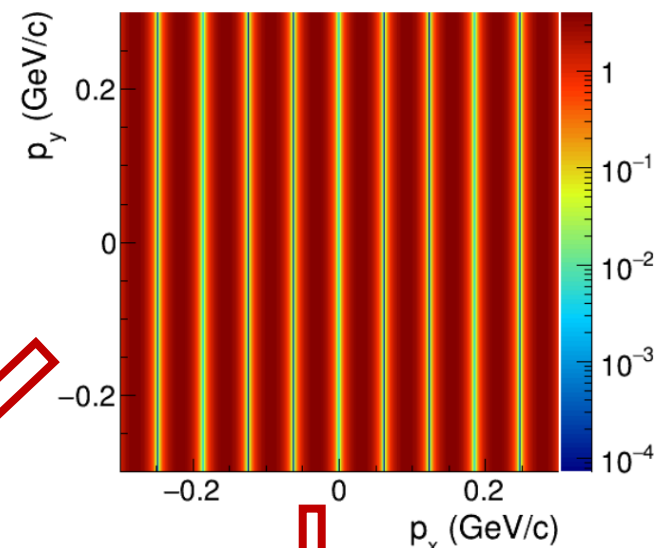
Linearly polarization from vector meson in photo-induced process



Decay along the polarization direction

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

- 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.



Oscillation for $\langle \cos 2\phi \rangle$

