
The J/ψ photoproduction in hadronic heavy-ion collisions

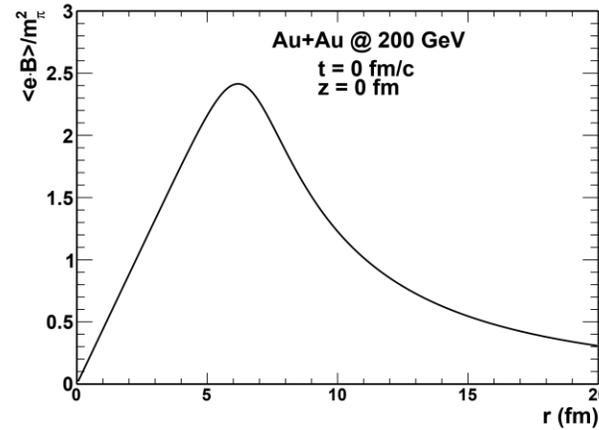
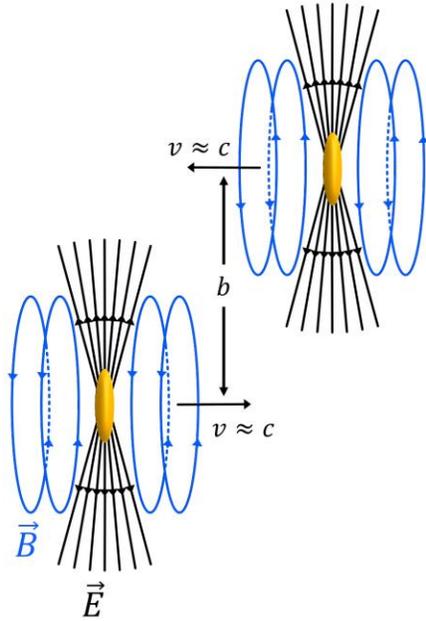
Wangmei Zha

University of Science and Technology of China

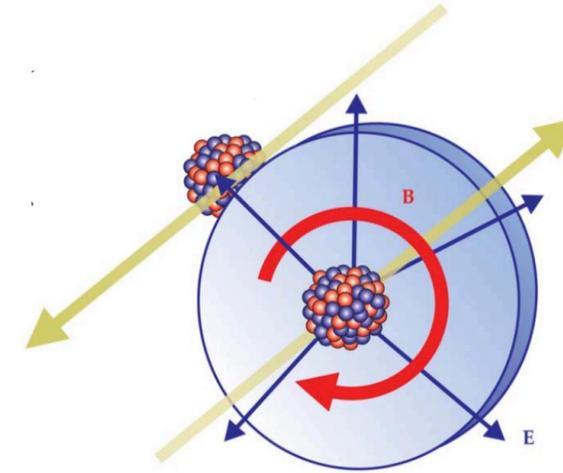
首届喷注与重夸克物理研讨会,
华中师范大学, 武汉, 23-26/01/2026

The giant electromagnetic field in heavy-ion collisions

Physics Today **70**, 10, 40 (2017)



$$m_\pi^2: 3.3 \times 10^{14} \text{ T}$$



Ultra-Peripheral Collisions
(UPC)

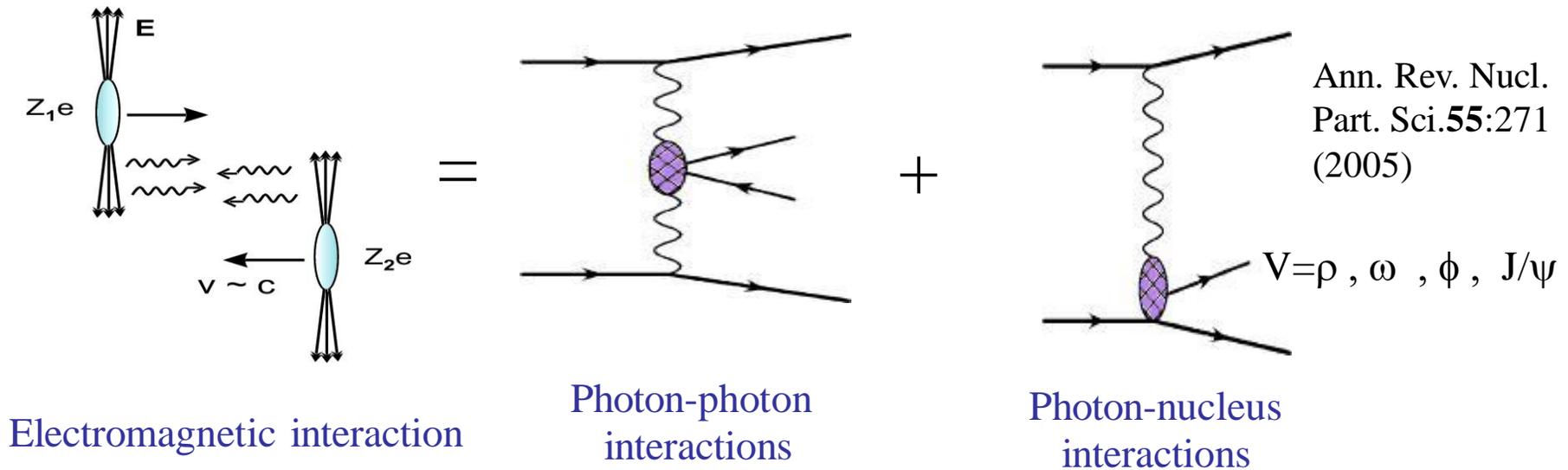
Clouds of quasi-real photons being present with heavy nuclei

$$n(\omega, r_\perp) = \frac{4Z^2\alpha}{\omega} \left| \int \frac{\vec{q}_\perp}{(2\pi)^2} \vec{q}_\perp \frac{f(\vec{q})}{q^2} e^{i\vec{q}_\perp \cdot \vec{r}_\perp} \right|^2$$

$$\vec{q} = \left(\vec{q}_\perp, \frac{\omega}{\gamma} \right)$$

Equivalent Photon
Approximation

The collisions of the electromagnetic field



The abundant photon induced reactions

UPC related physics

||

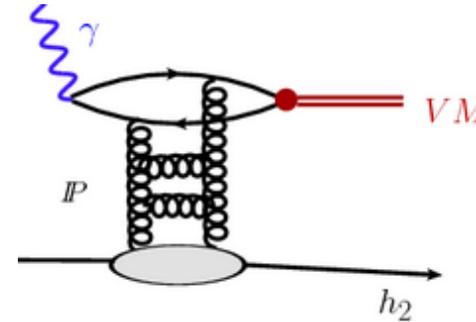
The physics of photoproduction

PRC 89 (2014) 014906

collider species	$\sqrt{s_{NN}}$ GeV	RHIC Au+Au	RHIC U+U	LHC Pb+Pb
BFPP	b	117	329	272
single EMD	b	94.15	150.1	215
<i>mutual EMD</i>	b	3.79	7.59	6.2
nuclear	b	7.31	8.2	7.9
total	b	218.46	487.3	494.9

Vector meson photon-production

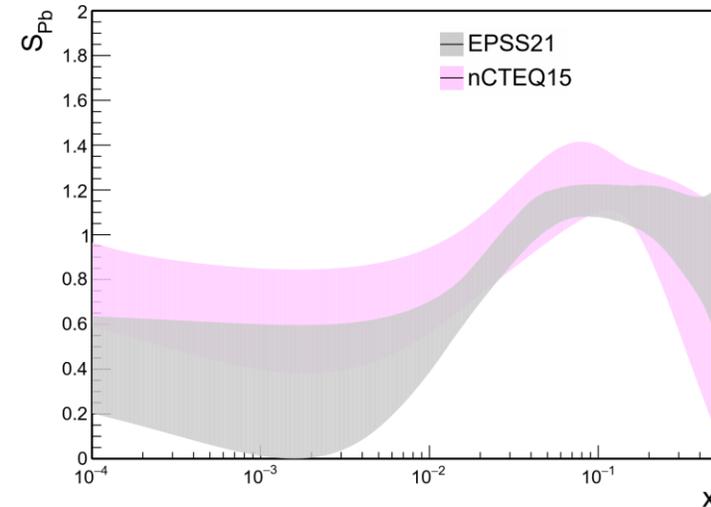
- Vector meson production:
 - ✓ Chargeless ‘Pomeron exchange’
 - ✓ Light meson production is usually treated via vector meson dominance model:
 - ρ , direct $\pi^+\pi^-$, ω
 - ✓ Heavy quarkonia production could be treated with pQCD:
 - J/ψ , ψ' , $Y(1S)$, $Y(2S)$, $Y(3S)$...



- Sensitive to the gluon distribution:

$$\left. \frac{d\sigma(\gamma A \rightarrow V A)}{dt} \right|_{t=0} = \frac{\alpha_s^2 \Gamma_{ee}}{3\alpha M_V^5} 16\pi^3 [xG_A(x, Q^2)]^2$$

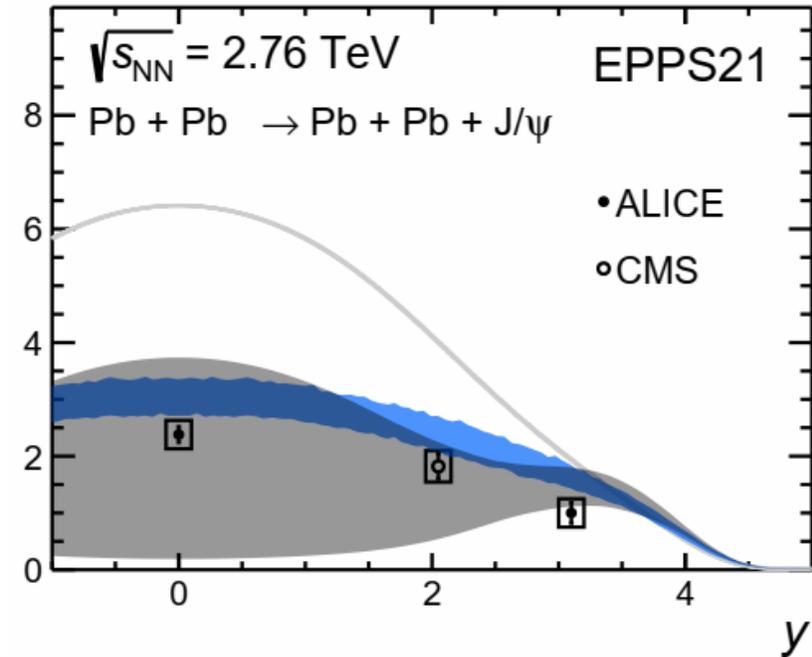
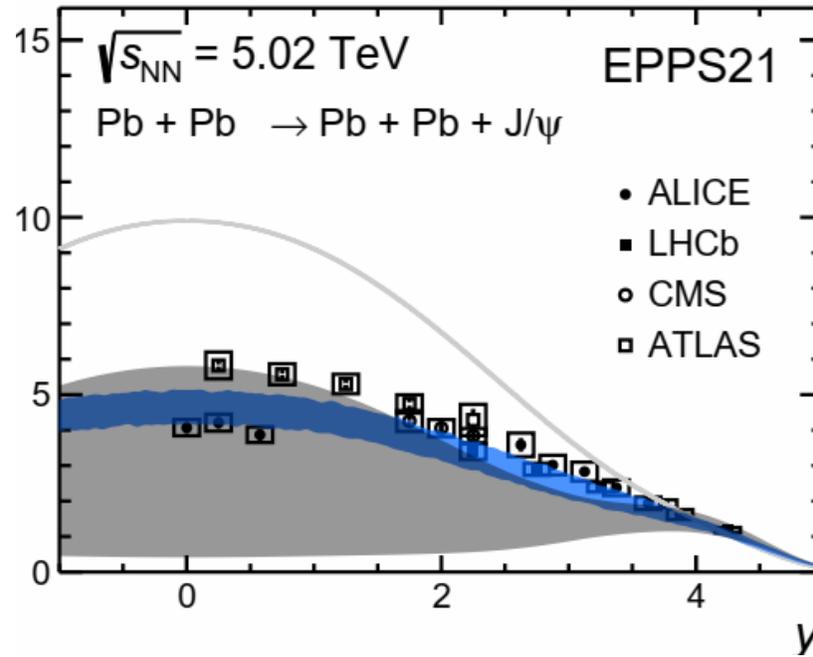
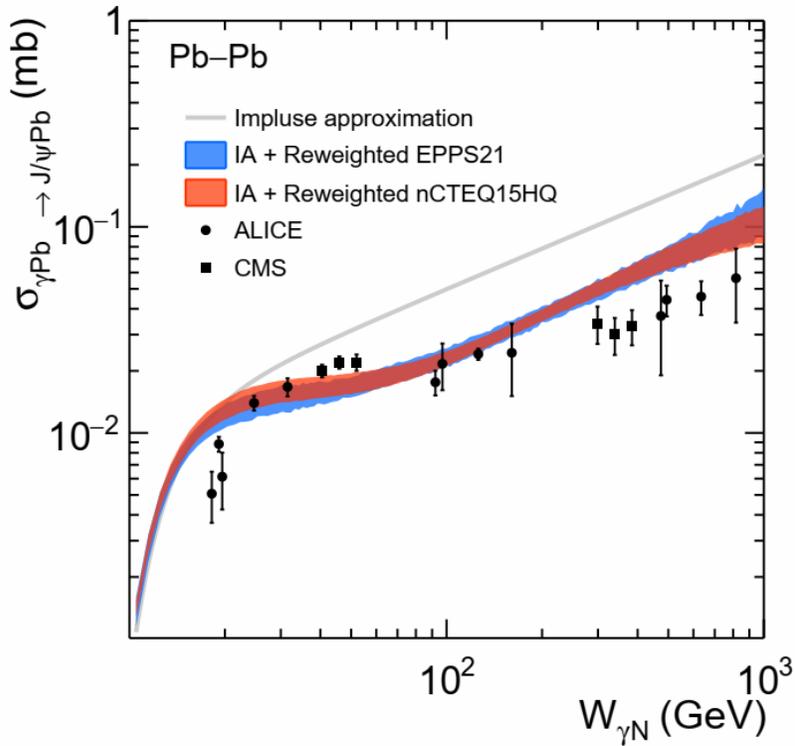
$$x = \frac{M_V e^{\pm y}}{\sqrt{s}} \quad Q^2 = M_V^2/4$$



EPSS21: EPJC 77 (2017) 163

nCTEQ15:PRD 93 (2016) 085037

The nPDF constrain from UPC measurements

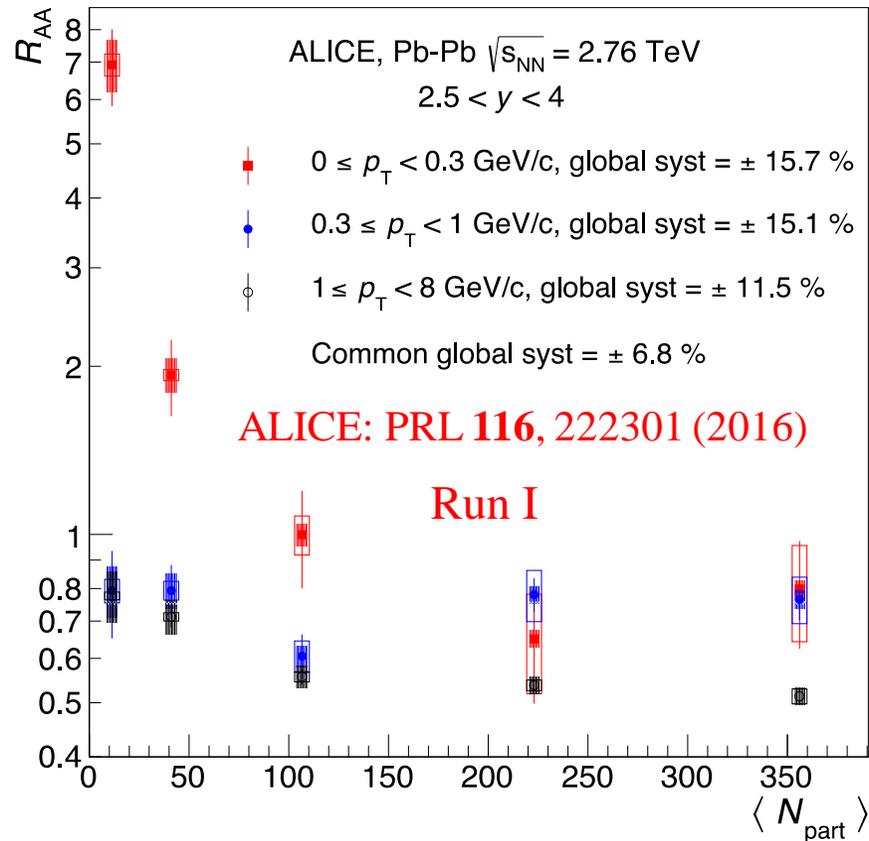


Multiple conflicting in these measurements

- ✓ Neutron Tagging vs. Conventional Measurement
- ✓ Different Collaborations
- ✓ Different energy

Anomalous excess of J/ψ production observed at ALICE

This is where the story begins!

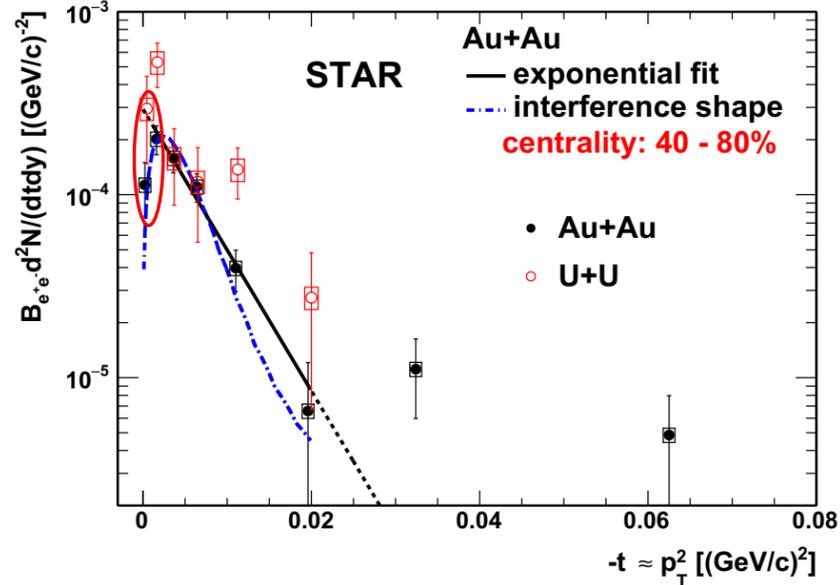
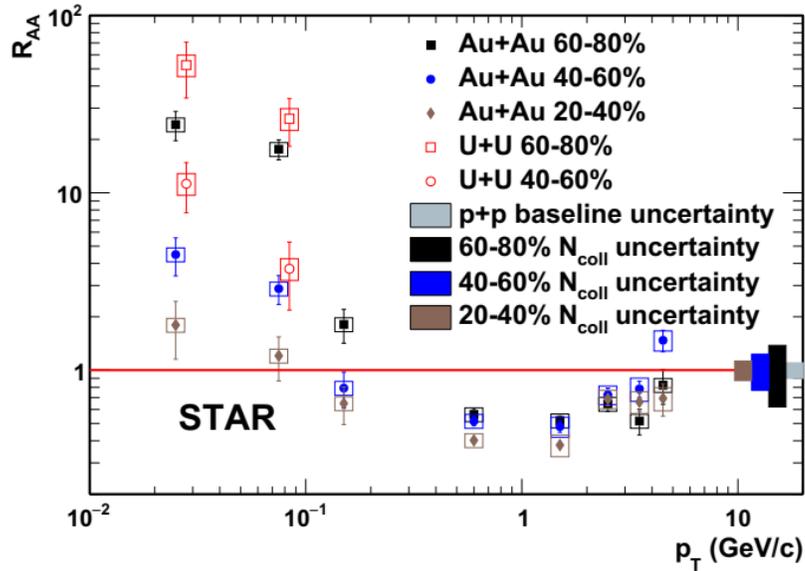


- Significant enhancement of J/ψ yield observed in p_T interval 0 – 0.3 GeV/c for peripheral collisions (50 – 90%).
- Can not be described by hadronic production modified by the hot medium or cold nuclear matter effects!

- Origin from **coherent photon-nucleus interactions?**

The observations at STAR

STAR: PRL 123 (2019) 132302

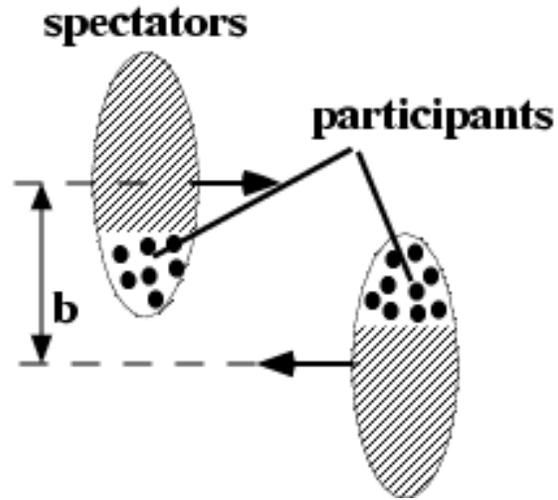


- Significant enhancement of J/ψ yield observed at p_T interval 0 – 0.2 GeV/c for peripheral collisions.
- No significant difference between Au+Au and U+U collisions.

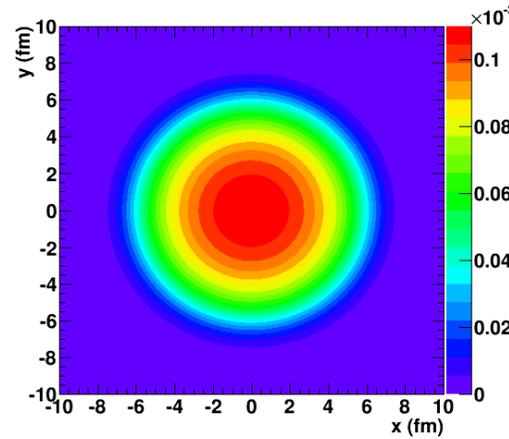
- Similar structure to that in UPC case!
- Indication of interference!
 - ✓ Interference shape from calculation PRC 97 (2018) 044910
- Similar slope parameter!
 - ✓ Slope from STARLIGHT prediction in UPC case – $196 (GeV/c)^{-2}$
 - ✓ Slope w/o the first point: $177 \pm 23 (GeV/c)^{-2} \chi^2/NDF = 1.7/2$

Modeling coherent J/ψ production in A+A collisions

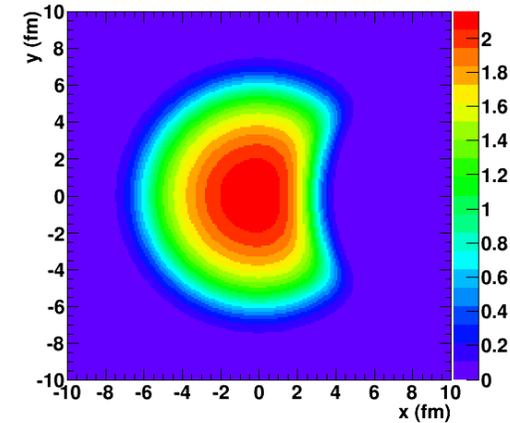
- How does the coherent process stay coherent in violent hadronic collisions?



Photon emitter and target



OR



nucleus

spectator

- The density profile of spectators is from the optical Glauber model!
- The interference has been considered

Photon emitter

Target

Nucleus

Nucleus (1)

Nucleus

Spectator (2)

Spectator

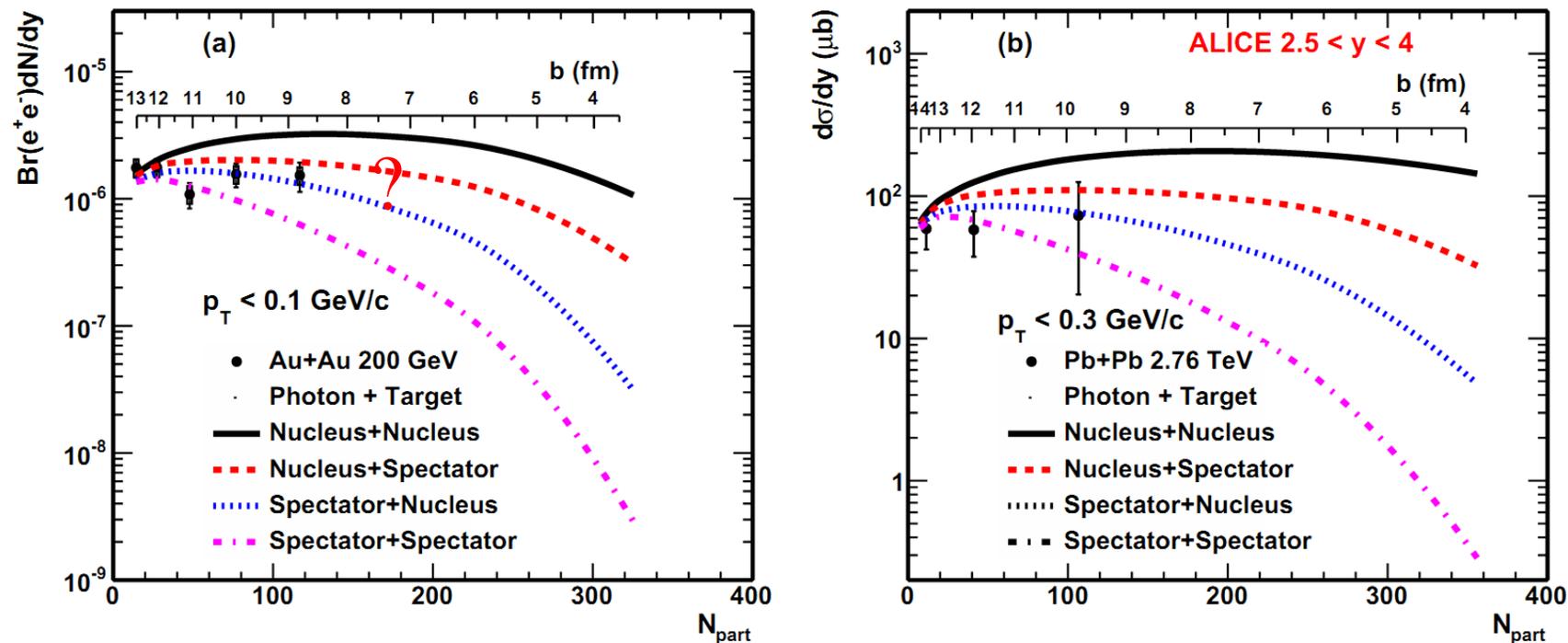
Nucleus (3)

Spectator

Spectator (4)

Calculations with different scenarios

W. Zha et al., PRC 97 (2018) 044910

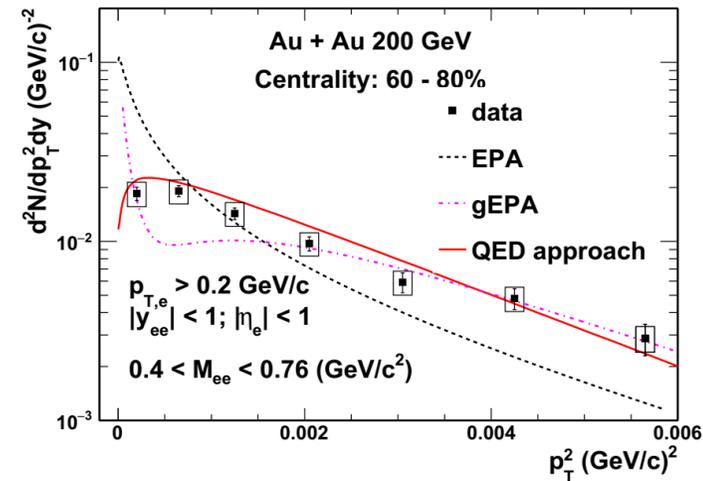
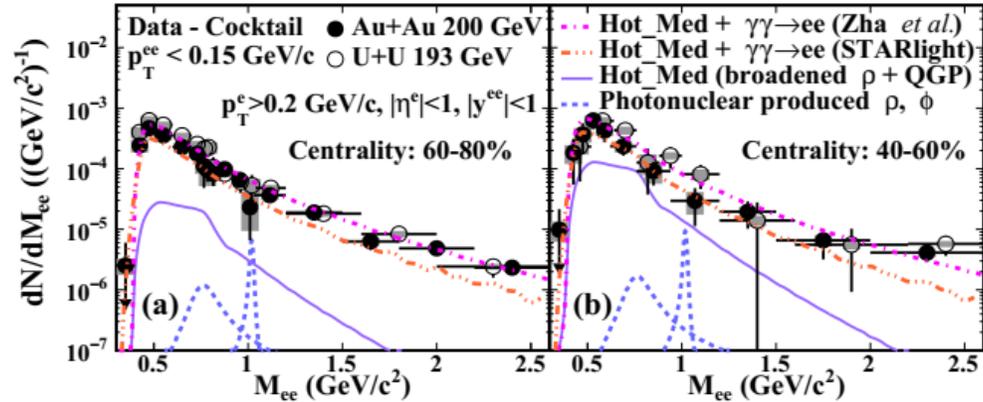
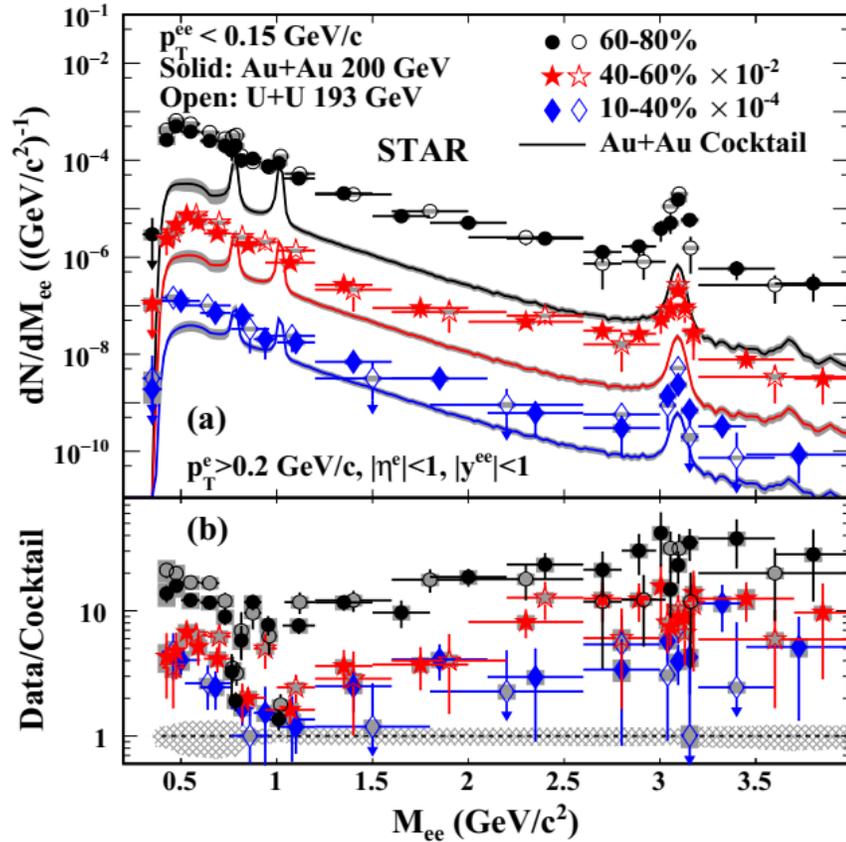


- Different scenarios have different trends toward central collisions!
- Nucleus+Nucleus: over estimate the data in semi-central collisions.
- Spectator+Spectator: under-predicts the data in semi-central collisions.
- To distinguish the different scenarios, measurements at central collisions are needed!
- The hot medium effects are not included in the calculation.

The photon flux should stay intact

STAR, PRL **121** (2018) 132301
 ATLAS, PRL **121** (2018) 212301

W. Zha et al., PLB **781** (2018) 182 PLB 800 (2020) 135089

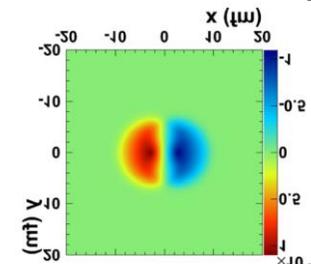
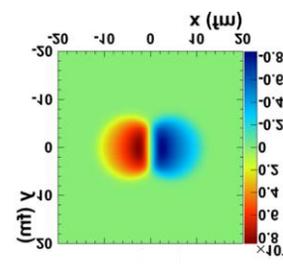
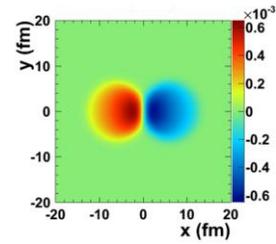
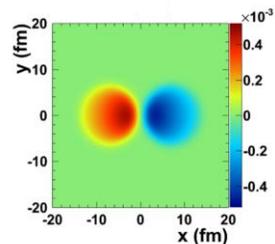
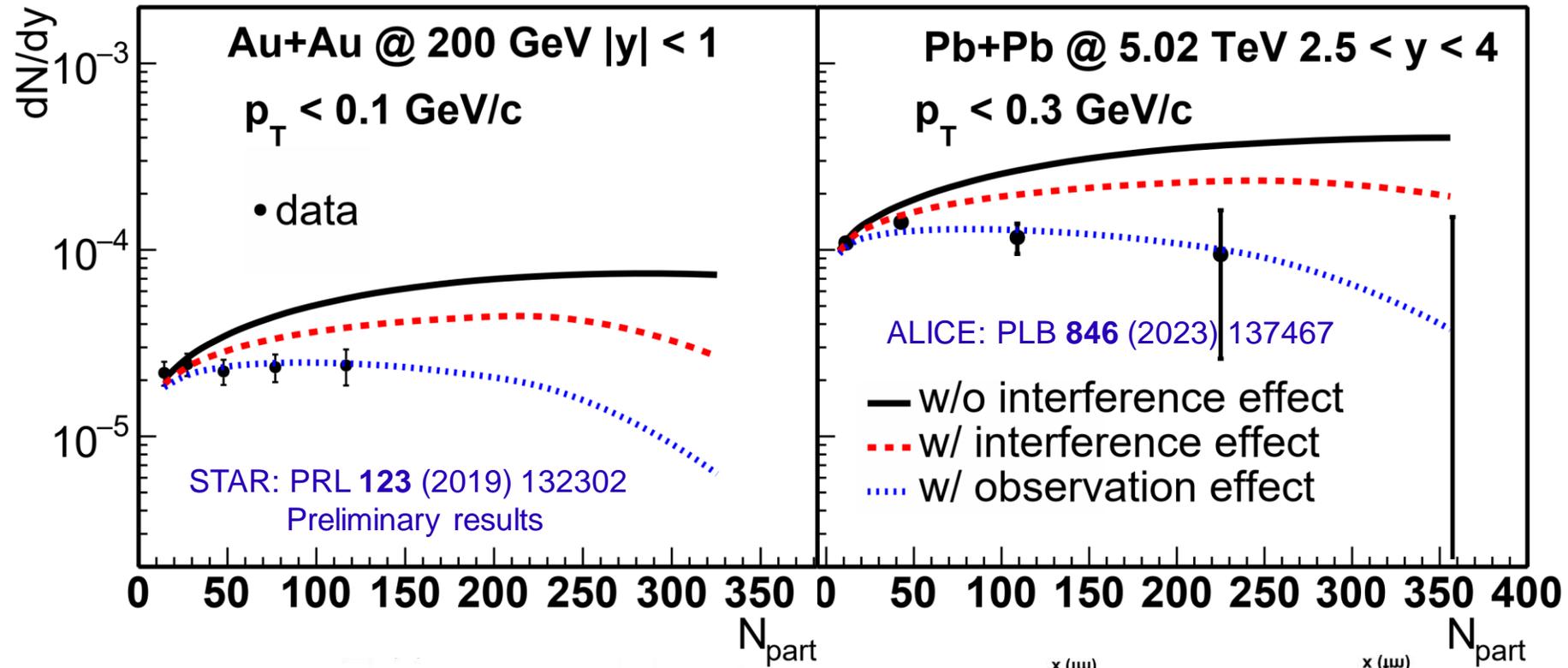


Retarded field:
 Can not feel
 the collision!

Existence of photoproduction in
 hadronic heavy-ion collisions!

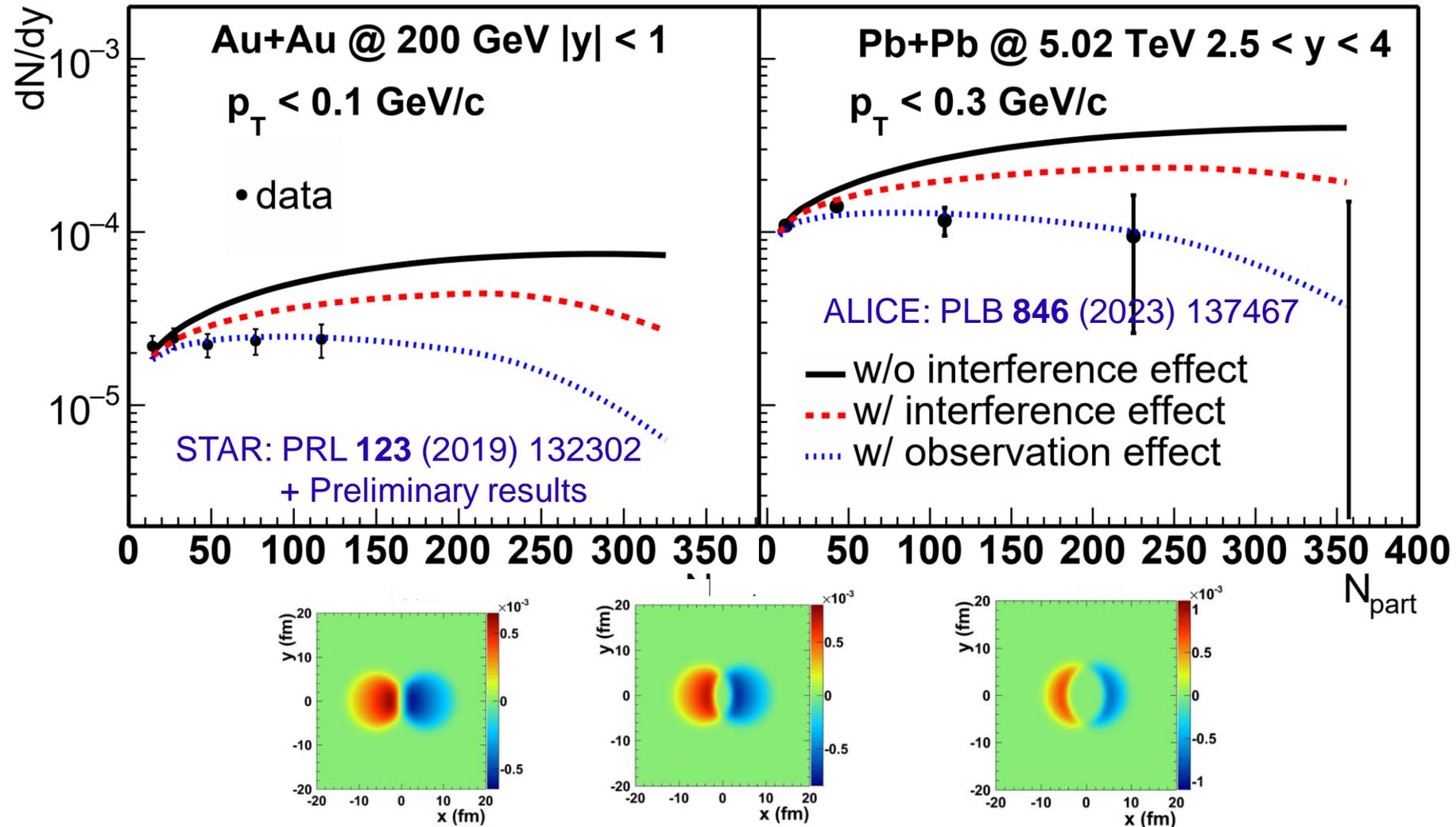
The photon emission seems not affected!

The interference should be considered

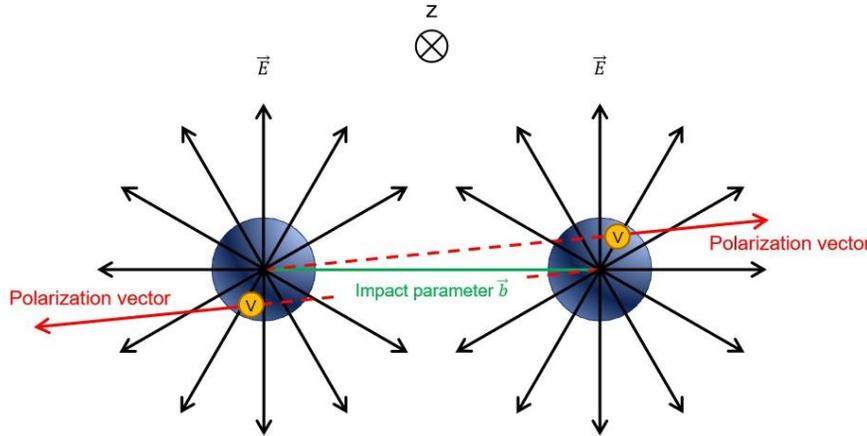


The decoherence in nuclear overlap region

J. D. Brandenburg et al., Prog. Part. Nucl. Phys. **143** (2025) 104174



The linear polarization for vector meson



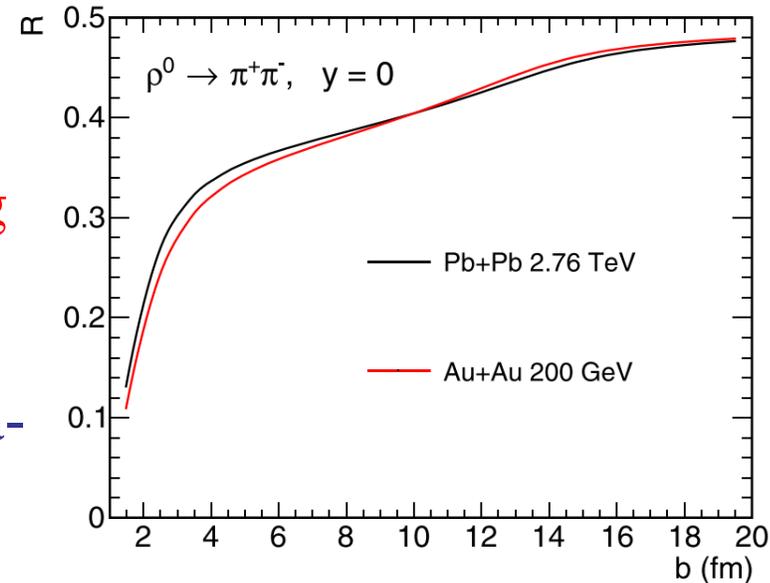
Polarization direction aligned with the impact parameter

Decay products along the polarization direction

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

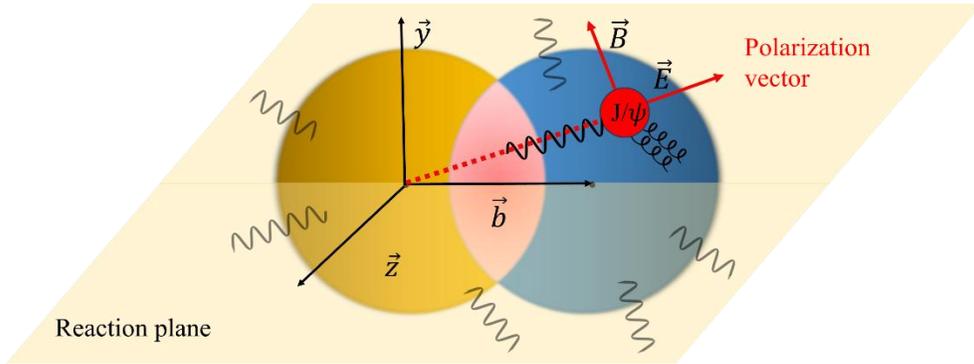
A new method for determining the reaction plane!

Resolution close to 0.5 in ultra-peripheral collisions

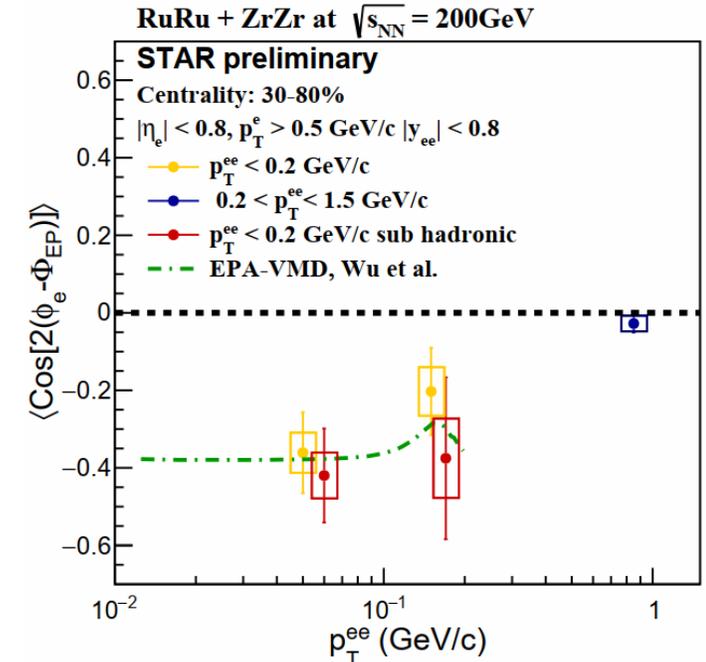
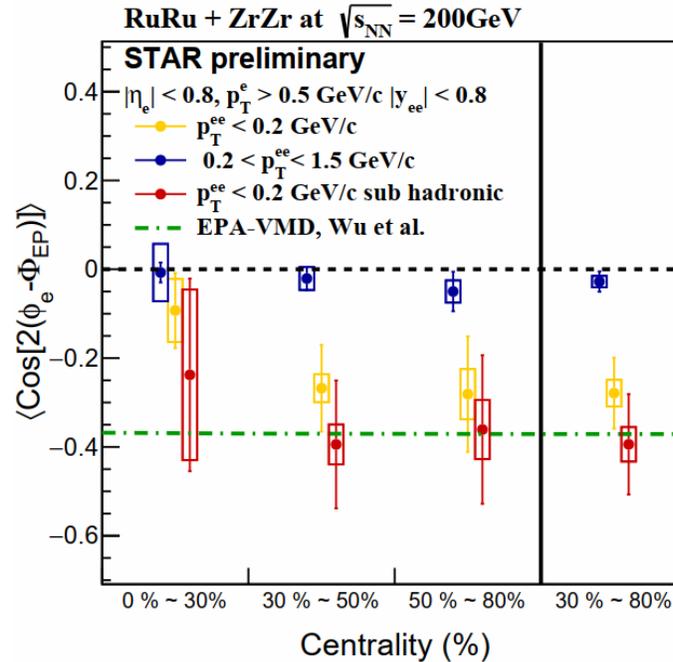


X. Wu et al., PRR 4 (2022) L042048

The linear polarization of J/ψ in hadronic heavy-ion collisions



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



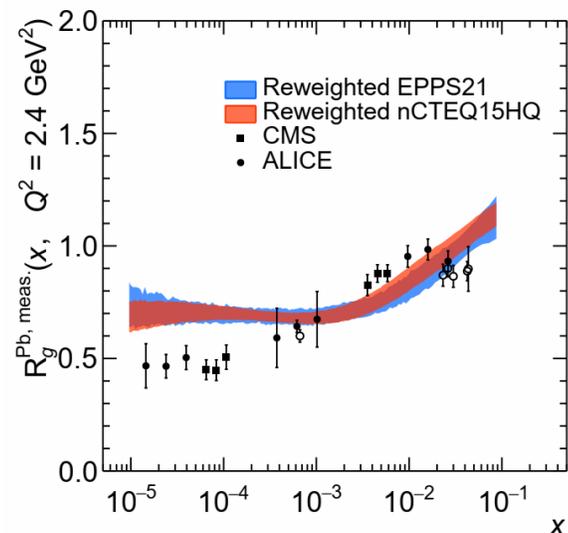
Kaiyang Wang, HP2024 QM2025

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

Summary

● Key takeaways from photon induced reactions in hadronic heavy-ion collisions

- The charge distribution should be considered
- Photon emission: not affected by the strong interactions
- Interference is important
- Pomeron exchange is affected
- The photoproduction products are linearly polarized



● Novel probe for QGP?

- More precise measurement toward central collision
- More solid theoretical baseline

