Nuclear Tomography through Entanglement Enabled Spin Interference

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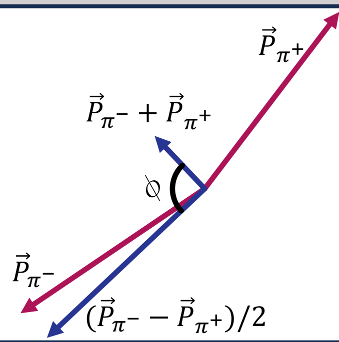
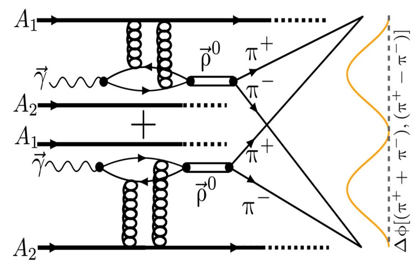
Abstract

Photonuclear interactions have been known for decades as a direct probe of the gluon distribution within nuclei and nucleons. However, a long-standing puzzle, that the extracted radii of nuclei appeared much too large, prevented the extraction of precise nuclear geometry information from photonuclear interactions in ultra-peripheral heavy-ion collisions for nearly two decades. Recent measurements have demonstrated that the quasi-real photons manifest in ultra-peripheral collisions are linearly polarized. Utilizing the photon polarization resolves the two-decade old puzzle - revealing that the true nuclear geometry distribution is hidden by a novel interference effect mediated by entanglement. In this poster, we will present the discovery of quantum interference between distinguishable particles and illustrate how taking it into account allows precise tomographic reconstruction of the gluon distribution within large nuclei. This new technique further provides a potential method of probing initial state entanglement within nucleons and nuclei.

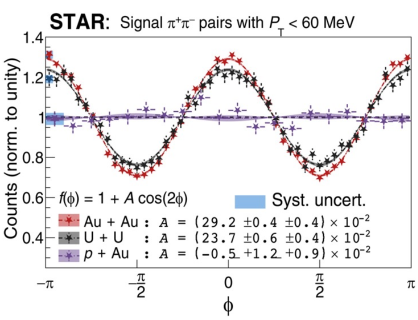
Introduction & Motivation

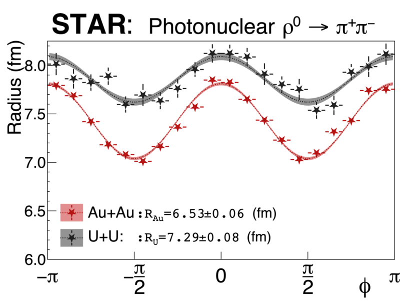
- Observation of Breit-Wheeler process in ultraperipheral collisions demonstrates that photons are linearly polarized.
- Experimentally we can access polarization related effects through the ϕ angle
- Modulations in ϕ are expected due to the initial photon spin being converted into orbital angular momentum of the final state π^+ and π^-

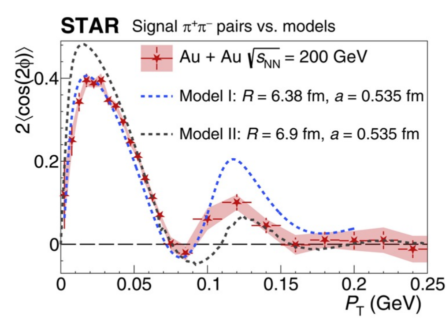




Observation of Interference & Effect on Measured Nuclear Radius





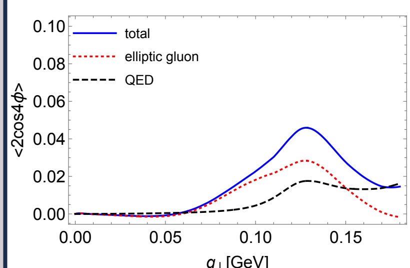


- Observation of strong $\cos 2\phi$ modulation in A+A collisions but not in p+A collisions [1]
- Interference effect modifies the apparent radius of the nucleus – correction needed for precise measurement
- Comparison with models shows qualitative agreement, sensitivity to nuclear geometry [2,3]

Results & Discussion

- Since ρ^0 lifetime is so short, the vector meson must decay before the two wavefunctions overlap
- Interference occurs between daughter, dissimilar particles
- Resolves long-standing puzzle, allows precise neutron skin extraction at high energy for the first time

Future Applications – elliptic gluon distribution



- Theoretical predictions indicate sensitivity to the elliptic gluon[4] distribution within large nuclei
- Experimental signature is a $\cos 4\phi$ modulation
- A similar modulation is expected from a purely QED background process, Sudakov radiation

References: [1] STAR Collaboration, Sci. Adv. 9, eabq3903 (2023) [2] W. Zha, J. D. Brandenburg, L. Ruan, Z. Tang, Phys. Rev. D 103, 033007 (2021). [3] H. Xing, C. Zhang, J. Zhou, Y.-J. Zhou, JHEP 10, 064 (2020). [4] Y. Hagiwara, C. Zhang, J. Zhou, and Y-J Zhou Phys. Rev. D 104, no.9, 094021 (2021)

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The STAR Collaboration

https://drupal.star.bnl.gov/STAR/presentations