Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

FY2024 NPP LDRD Type B Pre-Proposal

Spin-based Projective Imaging of Nuclei at the Electron-Ion Collider

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@BrookhavenLab

FY2024 NPP LDRD Type B Pre-Proposal

Proposal title: Spin-based Projective Imaging of Nuclei at the Electron-Ion Collider

Primary Investigator: Rongrong Ma

Other Investigators: Zhoudunming Tu, Thomas Ullrich, Zhangbu Xu

Indicate if this is a cross-directorate proposal. Yes ___ No_X__

If yes, identify other directorates/organizations:

Proposal Term: 24 months From: 10/01/2023 To: 09/30/2025

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FY2024 NPP LDRD Type B Pre-Proposal

Proposal title and brief abstract:

Spin-based Projective Imaging of Nuclei at the Electron-Ion Collider

A mission-critical measurement at the EIC is exclusive diffractive vector meson production in the scattering of electrons off heavy nuclei. The distribution of the momentum transfer (t) in coherent events reflects the spatial distribution of gluons inside the nucleus. Measurements of the t distribution encounter two critical challenges, *i.e.*, limited precision in measuring t and incoherent background, which severely jeopardize the prospects of utilizing this process. In this work, we propose to utilize the electron beam polarization in e+A collisions at the EIC and measure the projected t distribution by applying a strategy which had been successfully employed in the quantum interference enabled nuclear tomography at RHIC, to overcome those challenges.

Program: NP

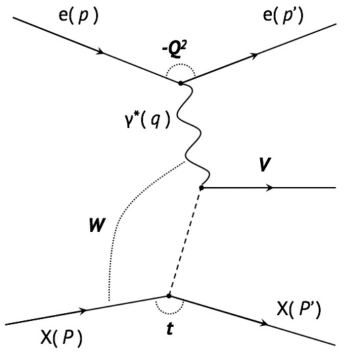
Return on Investment:

- Provides a possible solution for a mission-critical EIC measurement that is rather challenging for the EIC baseline detector
- Ma and Tu are eligible for ECA during or after LDRD

Broader impact on the activities at the laboratory: proposed techniques could be applied to exclusive analyses at RHIC, LHC, JLab, and EIC

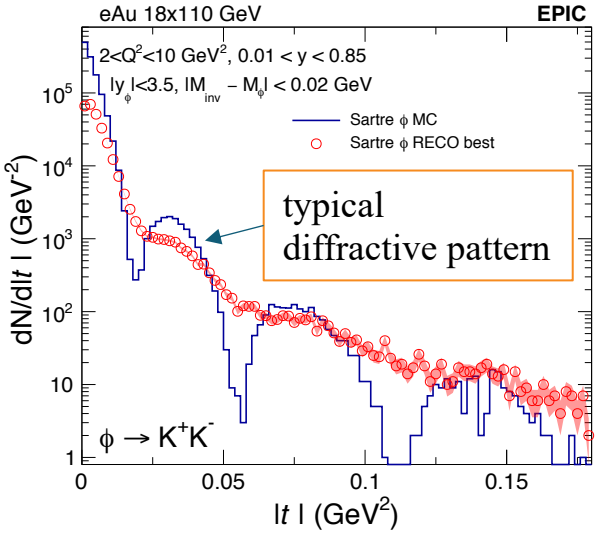
Total planned funding per year in FY24 and FY25: $200,000/yr

Motivation



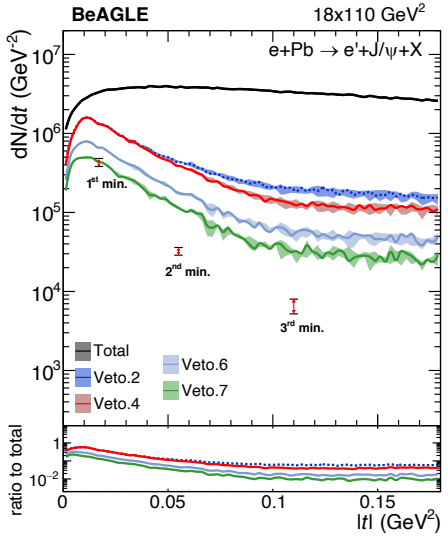
- ✓ Coherent exclusive vector meson (VM) production
  - Gluon distributions in nuclei through measuring $|t|$ distribution
  - Sensitive to saturation effects

➢ Challenge 1



- $t \sim b_T$
- Limited precision in determining $t = (P_{VM} - q)^2 = (P_{VM} - p' + p)^2$

➢ Challenge 2

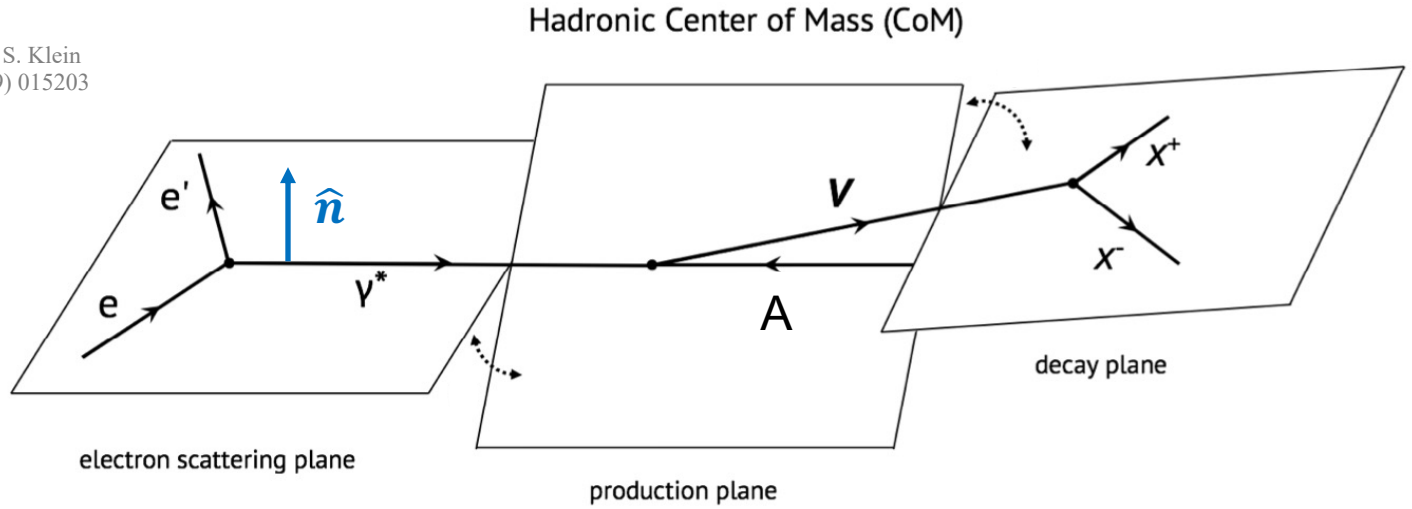


W. Chang, et. al., PRD 104 (2021) 114030

- Large incoherent background that is difficult to suppress
  - Hard to veto soft photons

Avoid momentum resolution

M. Lomnitsz, S. Klein
PRC 99 (2019) 015203



- Project *t* to the normal direction of the electron scattering plane
  - $t \cdot \hat{n} = (P_{VM} \cdot \hat{n} - p' \cdot \hat{n} + p \cdot \hat{n})^2 = (P_{VM} \cdot \hat{n})^2$

- Just need to measure the electron directions, not their momenta
- 1D projection of $|t|$. *Do we lose information on gluon structure?*

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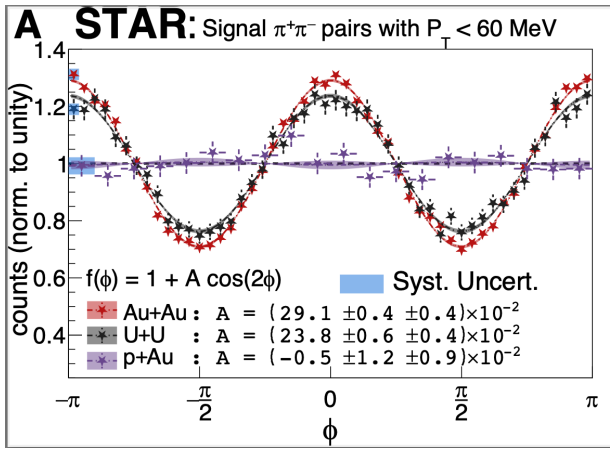
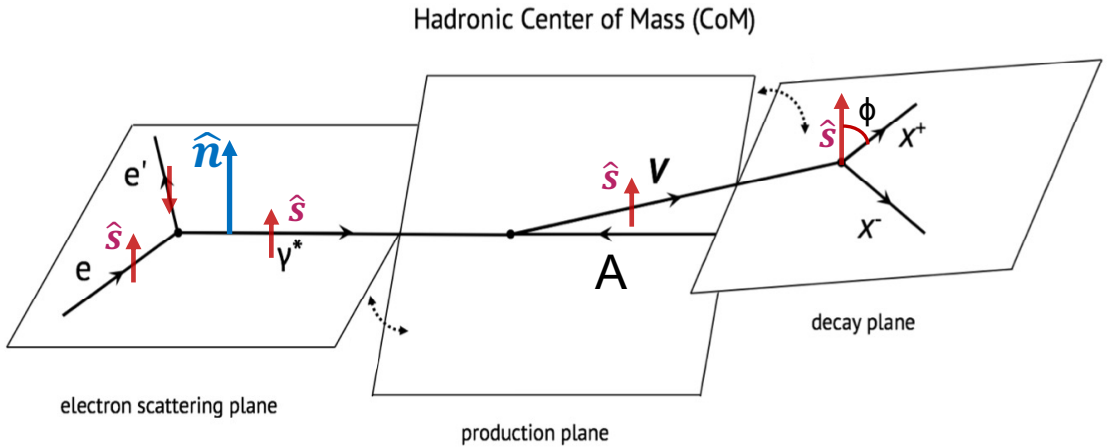
Separate coherent vs. incoherent

VM production in UPC



STAR , Sci. Adv. **9** (2023) 3903

✓ *For cases where the transverse electron spin flips*



- Utilize transversely polarized electron beam ($\hat{s} \perp \vec{p}$).
- If the electron spin flips sign after scattering, virtual photon and vector meson spins will align with incoming electron spin → $\hat{s} \parallel \hat{n}$
  - Pomeron has 0 spin
- Measure pattern of VM decays with respect to $\hat{n}$
  - Coherent with electron spin flip (VM spin aligns with $\hat{n}$): $\cos(2\phi)$ modulation
  - Coherent w/o electron spin flip (VM spin uncorrelated with $\hat{n}$): no preferred direction
  - Incoherent (VM spin uncorrelated with $\hat{n}$): no preferred direction
- Coherent production fraction $\propto \langle \cos(2\varphi) \rangle$

Summary

✓Proposed a novel approach to measure projected $|t|$ distribution for imaging gluon distributions in nuclei, which is a critical scientific goal of the EIC.

➢Not supported by the current EIC funding which focuses on detector construction.

✓Deliverables

- Validate feasibility of the proposed strategy
  - Study spin density matrix of vector mesons relative to different planes
  - Quantitatively simulate vector meson spin alignment cross sections and incoherent background
- Assess the sensitivity to gluon distribution and saturation from the projected $|t|$ distribution vs. isotropic $|t|$ used in EIC science case
  - Collaboration with theorists
- Derive a standard analysis tool for future measurements (RHIC, LHC, JLab, EIC) and theoretical comparisons
- Study impact of realistic EIC detector resolution
  - Incoming and outgoing electron directions; VM momentum

✓Personnel involved: PIs and one postdoc