



# Exploring the spin structure of the Pomeron through quantum entanglement

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BNL

February 8th, 2023

# Basic information

Proposal title:

**Exploring the spin structure of the Pomeron through quantum entanglement**

Primary Investigator: **Kong Tu (BNL)**

Other Investigators: **Daniel Brandenburg (OSU), Raju Venugopalan (BNL) and Zhangbu Xu (BNL)**

Indicate if this is a cross-directorate proposal. Yes ___ **No** X ___

If yes, identify other directorates/organizations:

Proposal Term: From: **Oct 2023** To: **Sep 2025**

Brookhaven National Laboratory

# LDRD Type B Pre-Proposal

**Exploring the spin structure of the Pomeron through quantum entanglement**
Our LDRD will bring a novel tool to investigate the spin structure of the Pomeron by utilizing the **entanglement enabled quantum interference** discovered by the STAR Collaboration in photon-Pomeron interactions. This effect leads to quantum interference between non-identical particles (recently also discussed in quantum optics) providing a unique window into the **spin structure of the Pomeron**. Our work will investigate this quantum interference effect more deeply by exploring if it turns off at short impact parameters comparable to the wavefunction of the rho meson produced in photon-Pomeron interactions.

Program: **NP**

Return on Investment:

I. **Early Career Award (PI Tu & co-PI Brandenburg (OSU) are eligible)**
II. **Interdisciplinary QIS & NP (DOE FOA on QIS & NP; PIs had attempted FY21)**
III. **Training next-generation scientists with DEI**

Broader impact on the activities at the laboratory:
**Physics that intersects with Heavy Ion, Cold QCD, EIC, and QIS**

Total planned funding per year in FY24 and FY25: **$200k/yr**

# Motivation

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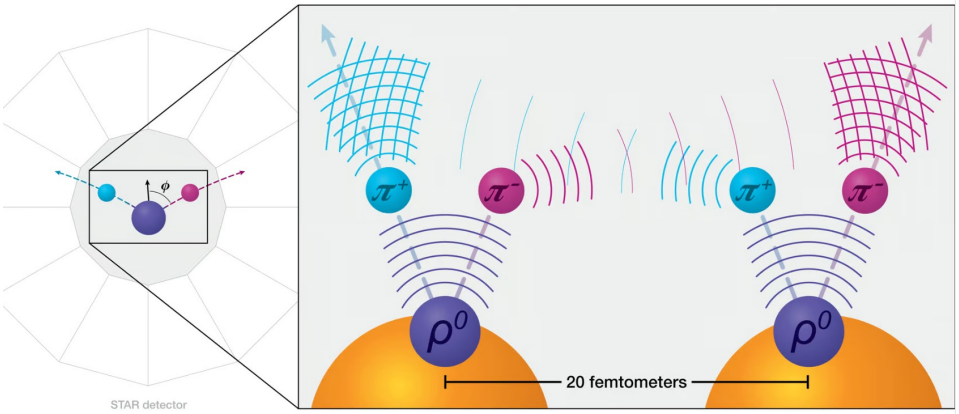
Contact: Karen McNulty Walsh, (631) 344-8350, or Peter Genzer, (631) 344-3174 share:

## New Type of Entanglement Lets Scientists 'See' Inside Nuclei

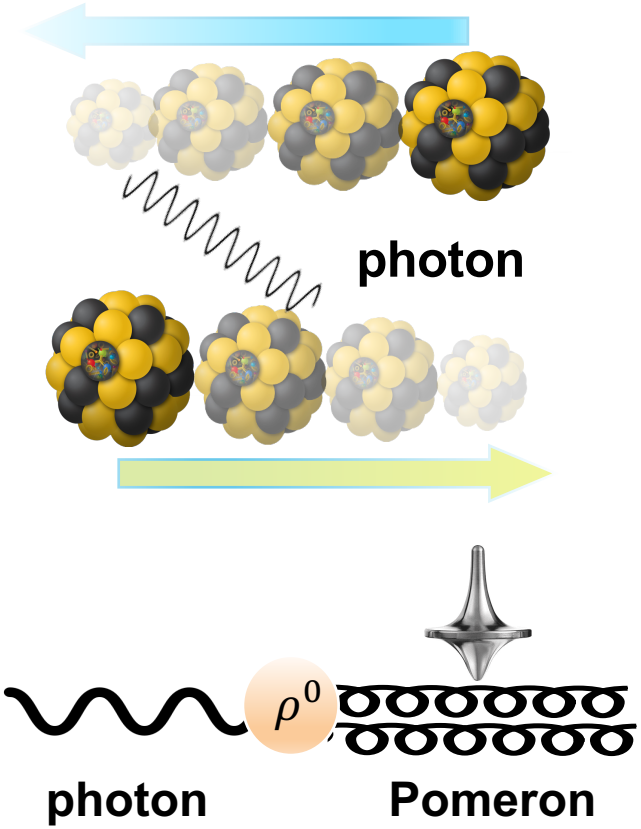
**First-ever observation of quantum interference between dissimilar particles offers new approach for mapping distribution of gluons in atomic nuclei—and potentially more**

January 4, 2023




*A diagram illustrating how the newly discovered type of quantum entanglement was detected. The yellow circles are gold ions, and the blue and pink circles are positive and negative pions respectively. The waves from each reinforce the waves of the same pion from the other ion, so that they hit the detector in two strong signals, seen as the concentrations of blue and pink waves at the top of the image. This can only work if the positive and negative pions from each ion are quantum entangled, in a form that hasn't been seen before* Brookhaven National Laboratory

## Ultraperipheral collisions (UPCs)

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# Research plans

We suggest that STAR UPC data in **polarized p+p** can be exploited to significantly advance these studies in two directions:

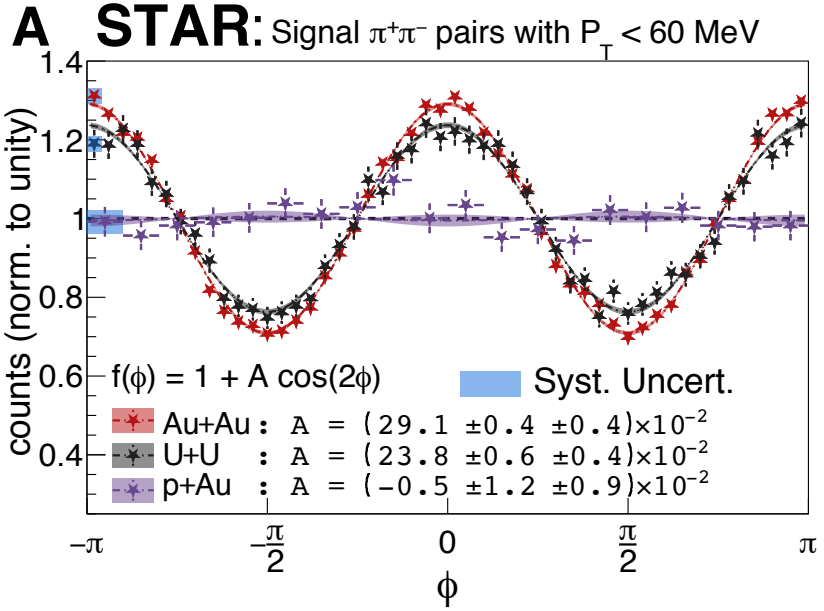
a) Test a “null hypothesis” by turn-off of the quantum entanglement effect in small systems

b) Use the photon-”Pomeron” interactions in UPCs to uncover the spin structure of the Pomeron

# Direction (a)

## Null hypothesis for quantum entanglement (QE):

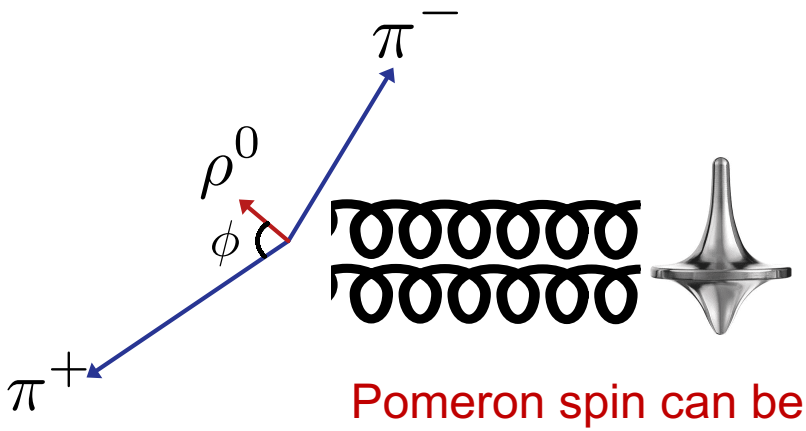
- The novel QE effect for unlike particles observed by STAR results from the superposition of exclusive $\rho^0 \to \pi^+\pi^-$ decay amplitudes from regions separated in impact parameter
- If this result is robust, one should see the turn-off of the effect in p+p collisions at small impact parameters
- This LDRD will develop the fundamental theory and physics analysis of polarized p+p UPC data on exclusive $\rho^0 \to \pi^+\pi^-$ decays to see how such an effect turns off
- We will also discuss a novel "ghost" $\pi^+\pi^-$ annihilation contribution to entanglement and its empirical signatures.



# Direction (b)

## What is the spin structure of the Pomeron:

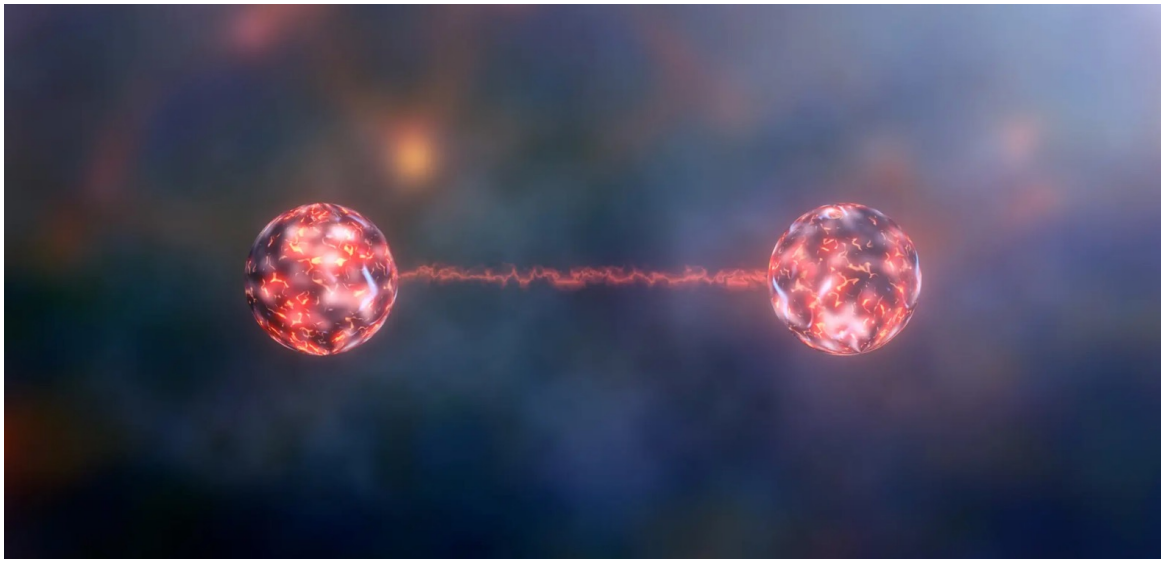
- The pomeron is a colorless compound state of (primarily) glue with vacuum quantum numbers whose exchange dominates high energy cross-sections.
- Despite its fundamental importance, there are debates about its spin structure. The Pomeron was previously thought to **interact like a vector photon.**
- However, there are also strong arguments that its spin structure may be that of a **tensor particle**
- The QE measurements of photo-production in polarized p+p and p+A can provide **conclusive evidence on this matter**. We will develop both theory and physics analysis in this direction




Pomeron spin can be measured by the decay kinematics of rho meson

# Summary

Our **theory-experiment collaborative work** will analyze the polarized proton-proton collision data recorded in 2022 thereby taking full advantage of DOE investment to advance an underappreciated aspect of the data. Further our work will advance the **emerging synergy between high energy nuclear physics and quantum information science (QIS)** allowing us to ask questions about quantum phenomena accessible previously only to tabletop experiments at much lower energies. The role of QIS in EIC physics is only beginning to be explored and the study (real and virtual) of photon-Pomeron exchanges has the potential to put it on a firm basis.



**Entanglement-Enabled Quantum Interference**