Brookhaven National Laboratory

U.S. DEPARTMENT OF ENERGY

FY2024 NPP LDRD Type B Pre-Proposal

Novel direction in QCD exclusive processes

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Program: NP

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Abstract:

With the Electron-Ion Collider (EIC) at Brookhaven National Laboratory on the horizon, the study of the generalized parton distributions (GPDs) is increasingly becoming more important for its unique role in imaging the three-dimensional structure of the nucleons and nuclei. Fundamental to the physics of GPDs is the factorization theorem for the Compton scattering amplitude proven in the late '90s. It allows one to extract, via global analyses, various types of GPDs from the experimental data of exclusive processes. However, together with collaborators the PI very recently has published a paper which challenges the validity of the factorization theorem in Compton scattering (S. Bhattacharya, Y. Hatta, W. Vogelsang, Physical Review D107 (2023) 014026). It has been shown that a consistent calculation of the quark box diagram leads to potentially divergent terms which break QCD factorization but which were missed in all the previous calculations in the GPD literature. These terms originate from the chiral and trace anomalies of QCD, suggesting a novel connection between exclusive processes and the deep problems of QCD such as chiral symmetry breaking and hadron mass generation. In this LDRD, we propose to explore the full consequences of QCD anomalies in high energy scattering. We will revisit the previous calculations of various exclusive processes to next-to-leading order in light of our new observation and seek the possibility of establishing a modified factorization formula. We will also investigate the impact of anomalies on the lattice QCD approach to GPDs to see how they affect the proof of factorization on the lattice as well as the calculation of matching coefficients. Although the study of GPDs is one of the scientific pillars of the EIC, theory activities at BNL in this direction have been quite limited so far. Building on the latest breakthrough development, our LDRD will boost the presence of BNL in the international GPD community.

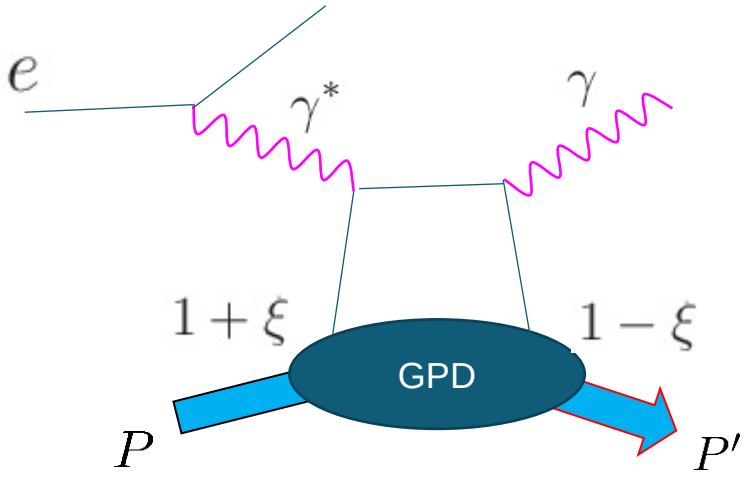
Generalized parton distribution

Multidimensional tomography is one of the main scientific goals of the EIC.

3D partonic imaging encoded in generalized parton distributions (GPDs)

GPD can be extracted from various exclusive processes via global analyses. QCD factorization theorem is the backbone of all theoretical and experimental efforts.

Collins, Freund (1998); Ji, Osborne (1998)



$$T^{\mu\nu}(x_B,\xi) \sim \int_{-1}^{1} dx C(x_B,\xi,x) H(x,\xi,t) + \mathcal{O}(1/Q^2)$$

hard coefficients GPD higher twist

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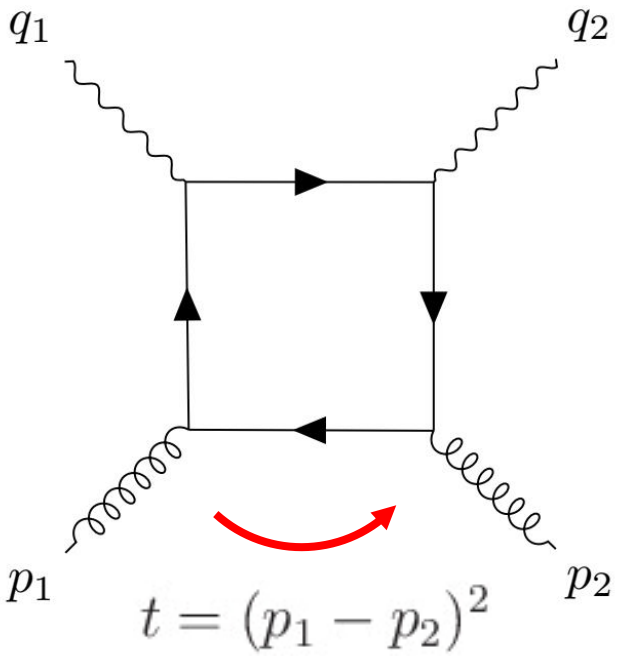
Breakdown of GPD factorization?

Bhattacharya, Hatta, Vogelsang (2022)
see also, Tarasov, Venugopalan (2019)

A careful analysis of the quark box diagram reveals novel poles in momentum transfer



Infrared power divergence in momentum transfer

$$\frac{\langle F^{\mu\nu} F_{\mu\nu} \rangle}{t} \qquad \frac{\langle F^{\mu\nu} \tilde{F}_{\mu\nu} \rangle}{t}$$

Possible breakdown of collinear factorization in Compton scattering

Deeply rooted to chiral anomaly and trace anomaly of QCD

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Theory challenges

- Revisit NLO calculations in various exclusive processes
- Can the poles be canceled? How?
- Can factorization theorem still be established?
- Novel way to probe the origin of nucleon mass and spin through the FF, $F\tilde{F}$ operators.
- How does this affect lattice QCD approach to GPDs?

First formal theory breakthrough on GPD from BNL. Let's build on it.

0.4 FTE for myself, 0.1 FTE for Swagato Mukherjee