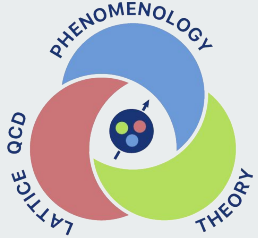
3D quark-gluon structure of hadrons: mass, spin, and tomography



QUARK-GLUON TOMOGRAPHY COLLABORATION

Chris Monahan
William & Mary

Jefferson Lab Users Organization Workshop and Annual Meeting

DOE Topical Collaboration
Award Number: DE-SC0023646

Quark-Gluon Tomography (QGT) Collaboration

The QGT Collaboration's main goal:
To spearhead understanding and discovery in the quark and gluon tomography of hadrons, and the origin of their mass and spin.

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We directly address the three "open QCD questions" highlighted by David Dean, JLUO Meeting 2023

Focus areas

Theory

- Theoretical studies of high-momentum transfer processes using perturbative QCD
- Study generalized parton distributions (GPDs) using non-perturbative methods

Lattice QCD

- Non-perturbative calculations of Euclidean correlation functions relevant to GPDs

Phenomenology

- Global analysis of GPDs based on experimental data, theoretical constraints, and lattice QCD input, using modern data analysis techniques for inference and uncertainty quantification

Focus areas

Theory

- Theoretical studies of high-momentum transfer processes using perturbative QCD
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Lattice QCD

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Phenomenology

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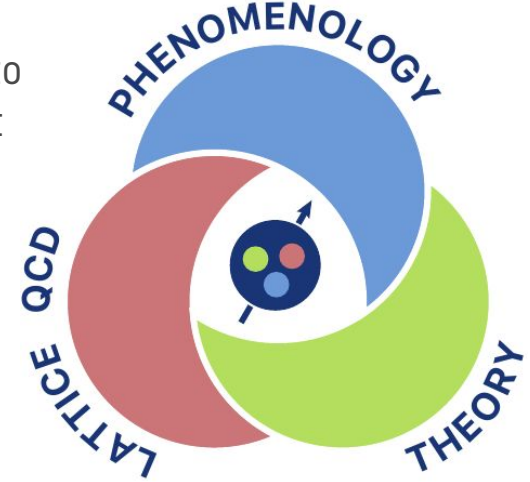
Support and training

- Support 12 postdocs and 6 graduate students
- Provide summer schools and workshops
- Create three bridge positions in nuclear theory

Focus area synergies

Topical collaborations uniquely placed to create new synergies between different focus areas

Focus area efforts are interdependent and connected on multiple levels



For example:

1. impose constraints in **global analysis** guided by **theory**
2. impose constraints by incorporating **lattice data** in **global analysis**
3. address challenges such as the inverse problem by combining **lattice data** and **experimental data**, as guided by **theory**

Objectives

- Perform perturbative QCD calculations at next-to-leading order accuracy.
- Develop the theoretical & computational methods needed for first principles lattice QCD calculations relevant to GPDs.
- Develop a toolkit for the global analysis of experimental data from JLab 12 GeV and other experiments.
- Complement the advances in theory, lattice QCD, and data analysis by integrating results into a common framework, employing modern data science methods.
- Extract tomographic images of the spatial parton distributions of hadrons.
- Create a strong U.S.-based network to develop a next-generation framework for the physics analysis of JLab 12 GeV data and future EIC data for the 3D tomography of hadrons.

Quark-Gluon Tomography Collaboration

12 Universities

3 National Labs

29 Principal Investigators

3 Affiliate members

26 Early career scientists

Administrative structure

...

Martha Constantinou

Principal Investigator - Spokesperson
Temple University

...

Ian Cloët

Spokesperson
Argonne National Lab

...

David Richards

Spokesperson
Jefferson Lab

...

Feng Yuan

Spokesperson
Lawrence Berkeley National Lab

...

Chris Monahan

Executive Committee
William & Mary

...

Nobuo Sato

Executive Committee
Jefferson Lab

Co-Investigators

Yong Zhao (Argonne National Lab)
Thomas Mehen (Duke University)
Alberto Accardi, Jose Goity (Hampton University)
Wally Melnitchouk, Christian Weiss (Jefferson Lab)
William Detmold, John Negele, Phiala Shanahan, Iain Stewart (MIT)
Leonard Gamberg, Alexei Prokudin (Penn State Berks)
Sergey Syritsyn, Edward Shuryak, Ismail Zahed (Stony Brook University)
Andreas Metz (Temple University)
Sean Fleming (University of Arizona)
Peter Schweitzer (University of Connecticut)
Keh-Fei Liu (University of Kentucky)
Xiangdong Ji, Kyle Shiells (University of Maryland)
Gerald Miller (University of Washington, Seattle)
Kostas Orginos (William & Mary/Jefferson Lab)

Affiliated Senior Investigators

Luchang Jin (University of Connecticut)
Jianwei Qiu (Jefferson Lab)
Anatoly Radyushkin (Old Dominion University/Jefferson Lab)

Graduate students

Ignacio Castelli, Chris Cocuzza, Joey Delmar, Josh Miller, Joey Torsiello (Temple University)
Sarah Blask (University of Arizona)
Brean Maynard (University of Connecticut)
Yuxun Guo, Jinchen He, Yushan Hu, Jinghong Yang (University of Maryland)
Chris Chamness, Daniel Kovner (William & Mary)

Postdoctoral Fellows & Research Associates

Xiang Gao, Shaoyang Jia, Bailing Ma, Eric Moffat (Argonne National Lab)
Shohini Bhattacharya, Raza Sufian (Brookhaven National Lab)
Joe Karpie (Jefferson Lab)
Kyle Lee (MIT)
Fatma Aslan (University of Connecticut)
Bigeng Wang (University of Kentucky)
Rui Zhang (University of Maryland)
Adam Freese (University of Washington, Seattle)
Hervé Dutrieux (William & Mary)

Focus areas: Theory

Expertise in:

- designing and using effective field theories
- chiral perturbation theory
- perturbative QCD
- QCD models

Studying:

- quark and gluon GPDs and TMDs
- gravitational form factors
- Wigner functions
- hadron structure on the light front
- spin physics
- small-x physics
- strangeness in exchange currents
- large-Nc limit

Focus areas: Lattice QCD

Expertise in:

- numerical methods in lattice gauge theories
- simulations of QCD
- non-perturbative renormalization
- numerical calculations for hadron structure

Studying:

- quark and gluon PDFs and GPDs
- gravitational form factors
- nucleon spin, momentum & angular momentum
- quark charge & renormalization
- electric dipole moments
- x-dependence of PDFs & GPDs
- neutrino-nucleus scattering cross-sections
- structure of light nuclei

Focus areas: Phenomenology

Expertise in:

- developing frameworks for global analysis
- data science techniques
- analytical studies of aspects of QCD
- interface of lattice QCD and phenomenology

Studying:

- quark and gluon PDFs, GPDs, & TMDs
- tensor charge & single-spin asymmetries
- mass & spin distributions in the nucleon
- hadron radii & gravitational form factors
- perturbative corrections to meson processes
- Bayesian approaches to inverse problems

Support and training

Support for lattice QCD

- Institutional and national HPC resources
- Computational resources through INCITE, ALCC, LRAC, XSEDE, USQCD, etc.

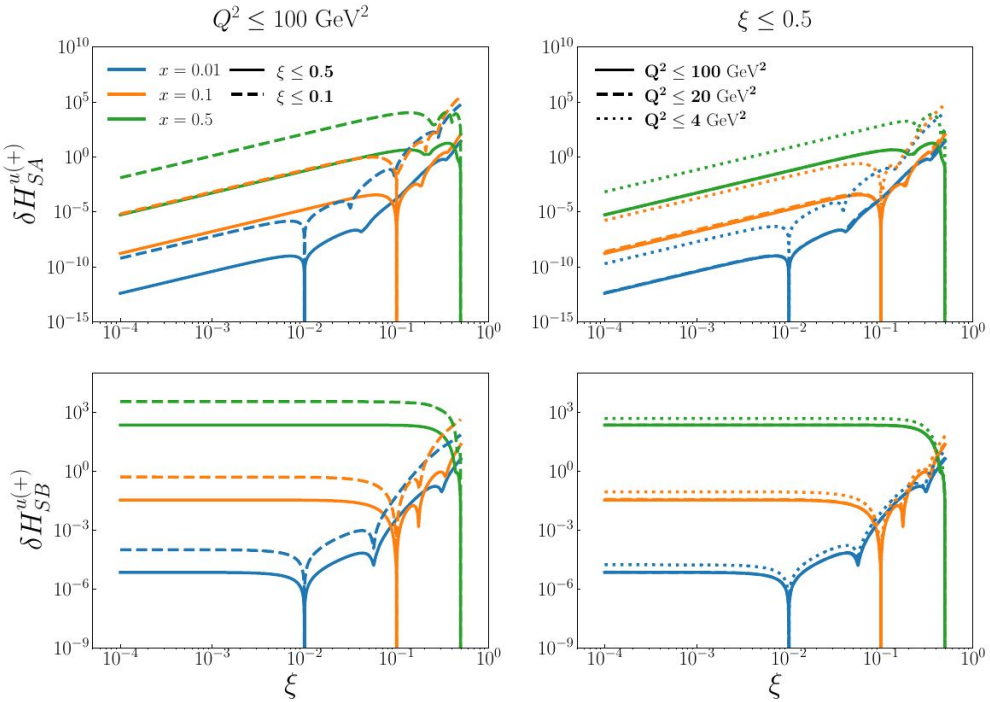
Professional mentoring and training

- Involve undergraduate and graduate students and postdoctoral research in collaboration activities
- Establish a mentoring program for early career researchers with mentors from other institutions
- Provide training and networking opportunities in summer schools, workshops and meetings
- Utilize:
    - Science Graduate Student Research (SGSR) program
    - Science Undergraduate Laboratory Internship (SULI) program

Recent highlights

Moffat et al., 2303.12006

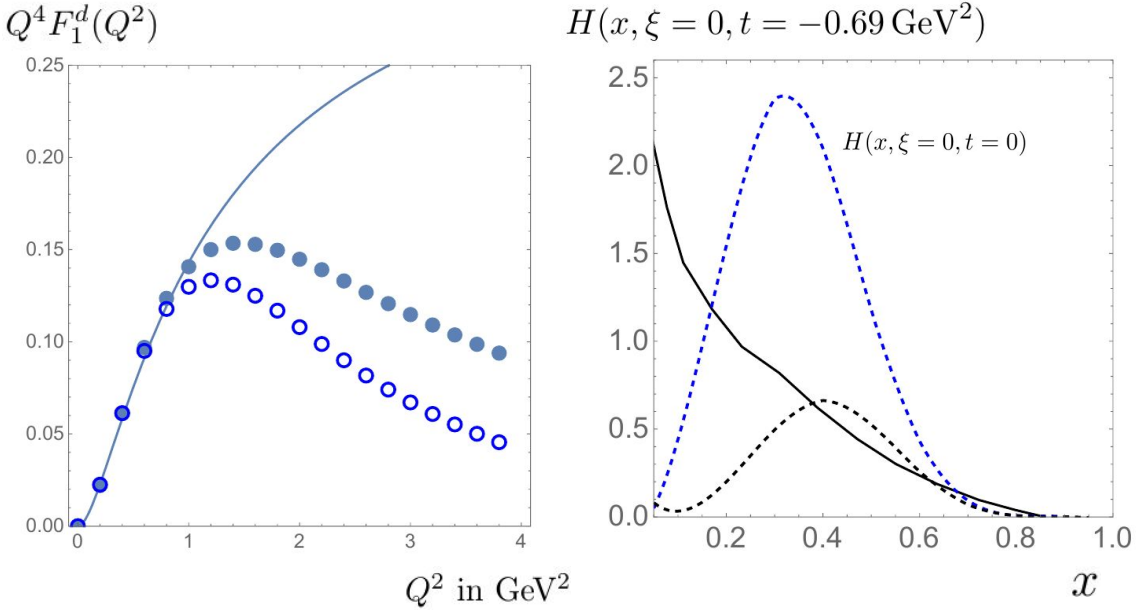
study of QCD evolution as a tool to constrain shadow GPDs, which arise as unphysical solutions to the inverse problem of extracting GPDs from Deeply Virtual Compton Scattering



Recent highlights

Shuryak & Zahed, PRD 17 (2023) 094005

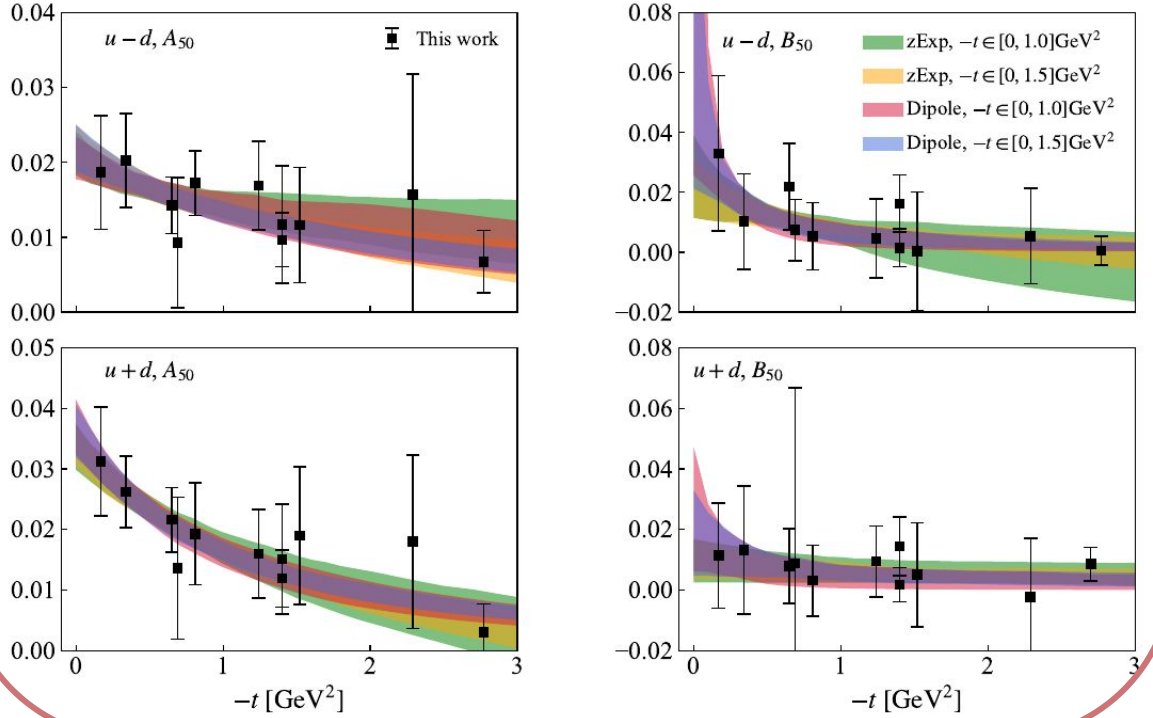
analysis of unpolarized GPDs, and charge and gravitational form factors for mesons, light nucleon and delta using the lowest Fock states; results compared to lattice QCD



Recent highlights

Bhattacharya et al., arXiv:2305.11117

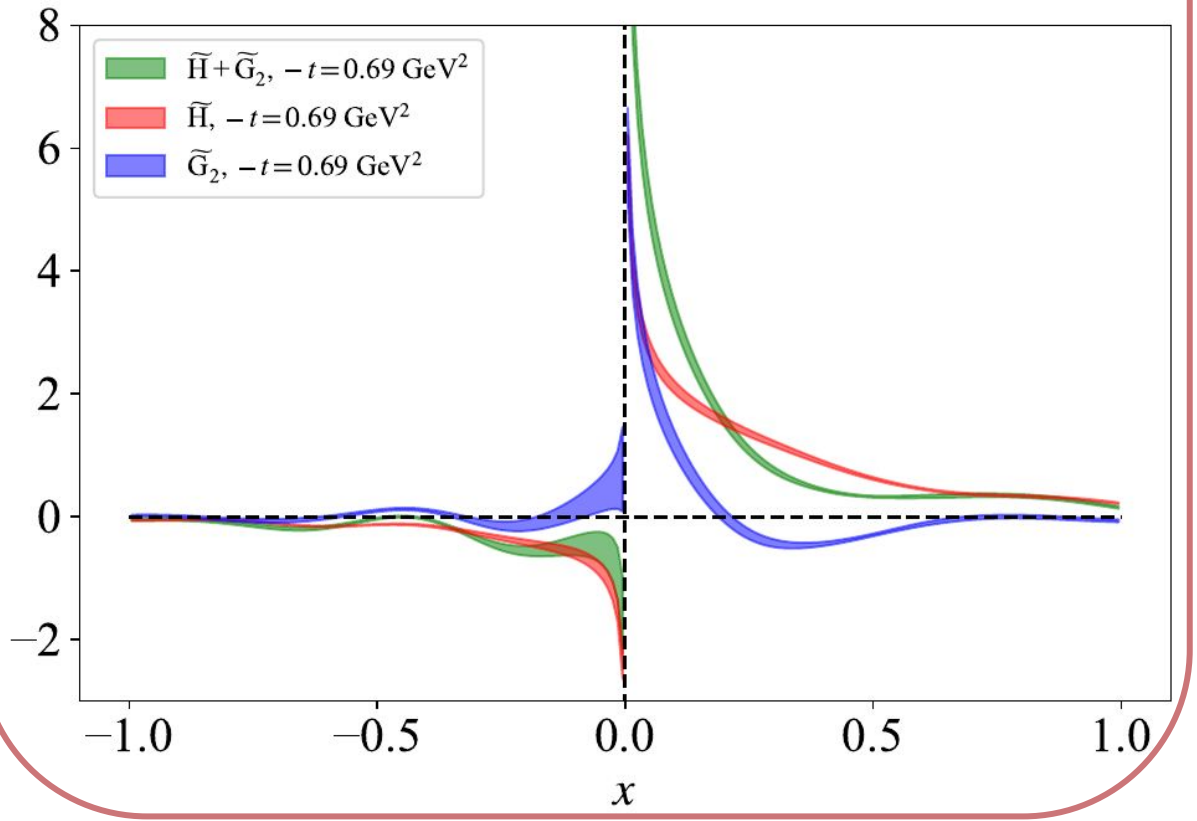
first lattice QCD calculation of the Mellin moments (up to fifth order) of unpolarized quark GPDs from large-momentum effective theory and from local operators



Recent publications

Bhattacharya et al., arXiv:2306.05533

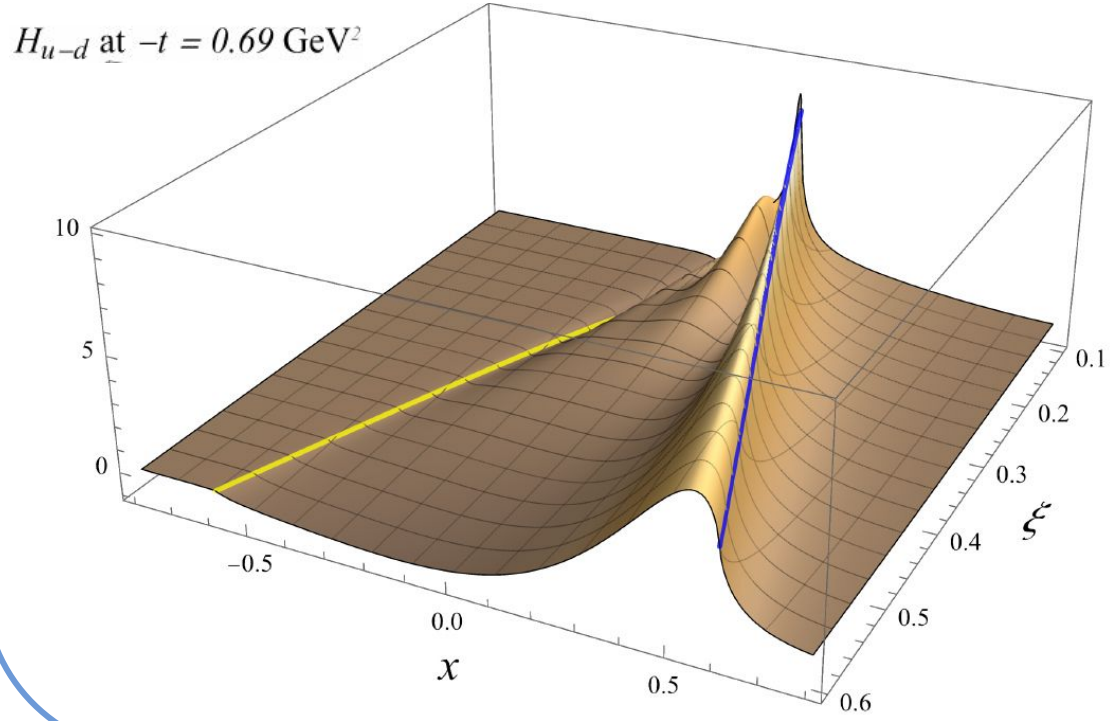
first lattice QCD calculation of the twist-3 axial quark GPDs for the proton using large-momentum effective theory



Recent highlights

Guo et al., JHEP 05 (2023) 150

first global analysis of isovector GPDs, at nonzero skewness, that combines lattice QCD and experimental data, including PDFs, form factors and deeply virtual Compton scattering measurements



Recent publications

- Bhattacharya et al., arXiv:2306.05533, “Chiral-even axial twist-3 GPDs of the proton from lattice QCD”
- Bhattacharya et al., arXiv:2305.11117, “Moments of proton GPDs from the OPE of nonlocal quark bilinears up to NNLO”
- Burkert et al., arXiv:2303.08347, “Colloquium: Gravitational form factors of the proton”
- Moffat et al., arXiv:2303.12006, “Shedding light on shadow generalized parton distributions”
- Guo et al., JHEP 05 (2023) 150, “Generalized parton distributions through universal moment parameterization: non-zero skewness case”
- Shuryak & Zahed, PRD 107 (2023) 094005, “Hadronic structure on the light-front. VI. Generalized parton distributions of unpolarized hadrons”

Summary

Goal: to spearhead understanding and discovery in the quark and gluon tomography of hadrons, and the origin of their mass and spin

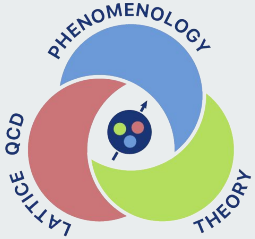
three interdependent focus areas collaborating to form new synergies

QUARK-GLUON TOMOGRAPHY COLLABORATION

12 universities and 3 national labs
29 principal investigators and 3 affiliate members
26 early career researchers

Thank you

cjmonahan@wm.edu



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