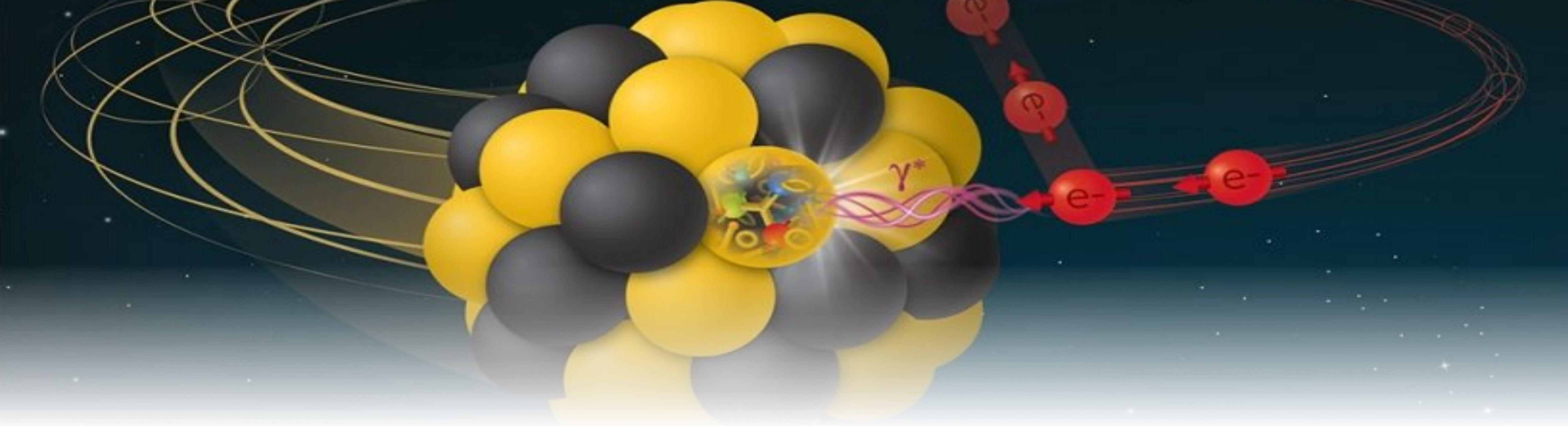

GPD through Universal Moment Parameterization (GUMP)

— Global DVCS analysis with quark GPDs

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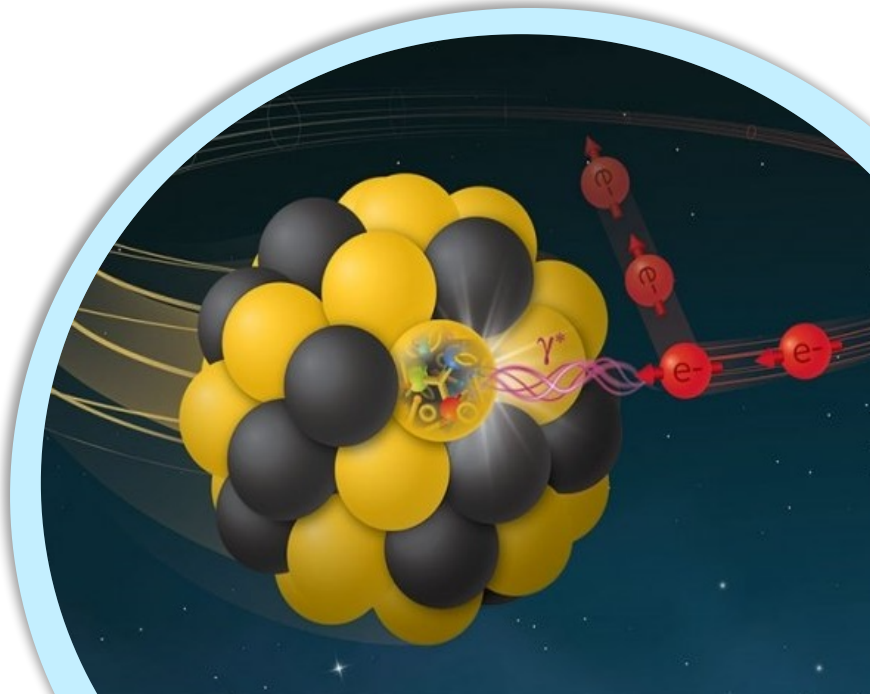
10th workshop of APS GHP

Apr. 12th, 2023

Outline

- Intro: GPD global analysis and GUMP
- Experimental and lattice inputs
- Extracted quantities: CFFs and GPDs
- Summary and outlook



General strategy of GPD global analysis

Parameterization of GPDs

Compute GPD observables

Inputs (constraints) on GPDs

Compare and iterate

Unique for GPDs with off-forward kinematics:

- GPDs are 3D whereas PDFs are 1D
- More GPDs species

$$\langle \bar{\psi} \not{n} \psi \rangle \sim \bar{u}(P', S') \left[\not{n} H(x,\xi,t) + \frac{i\sigma^{\mu\nu} n_\mu \Delta_\nu}{2M} E(x,\xi,t) \right] u(P,S)$$

$$\langle \bar{\psi} \not{n} \gamma^5 \psi \rangle \sim \bar{u}(P', S') \left[\not{n} \gamma^5 \tilde{H}(x,\xi,t) + \frac{n^\mu \Delta_\mu \gamma^5}{2M} \tilde{E}(x,\xi,t) \right] u(P,S)$$

- Mixed in the amplitude

$$F_{UU} \propto 4 \left[(1-\xi^2) \left(\mathcal{H}^* \mathcal{H} + \widetilde{\mathcal{H}}^* \widetilde{\mathcal{H}} \right) - \frac{t}{4M^2} \left(\mathcal{E}^* \mathcal{E} + \xi^2 \widetilde{\mathcal{E}}^* \widetilde{\mathcal{E}} \right) - \xi^2 \left(\mathcal{E}^* \mathcal{E} + (\mathcal{E}^* \mathcal{H} + \mathcal{H}^* \mathcal{E}) + (\widetilde{\mathcal{E}}^* \widetilde{\mathcal{H}} + \widetilde{\mathcal{H}}^* \widetilde{\mathcal{E}}) \right) \right],$$

Parameterization of GPD

The conformal moment parameterization of GPD is helpful

$$F(x,\xi,t)=\sum_{j=0}^{\infty}(-1)^j p_j(x,\xi)\mathcal{F}_j(\xi,t)$$

D. Mueller and A. Schafer
Nucl.Phys.B 739 1-59 (2006)

Advantages:

- Polynomiality condition: $\int_{-1}^{1}\mathrm{d}x x^{n-1}F(x,\xi,t)=\sum_{k=0,\mathrm{even}}^{n}\xi^k F_{n,k}(t)$
  - In moment space, you get this almost for free.

X. Ji, J.Phys.G 24 1181-1205 (1998)

- Conformal moments are (LO) multiplicatively renormalizable
  - Solve evolution equation in *x* space is much slower.

I. Balitsky and V. Braun
Nucl.Phys.B 311 541-584 (1989)

GPDs through Universal Moment Parameterization (GUMP)

Collaborators: Xiangdong Ji, Kyle Shiells, Gabriel Santiago, Jinghong Yang

Inputs for the global analysis

Experiments

- PDFs from global analysis
  - Polarized and unpolarized PDFs from JAM

JAM, Phys. Rev. D 106 3, L031502 (2022)

- Charge form factors from global analysis

Z. Ye et. Al., Phys. Lett. B 777 8-15 (2018)

  - YAHL global analysis of EM form factors
  - Flavor separation combing proton and neutron data

CLAS, Phys. Rev. Lett. 123 3, 032502 (2019)

- DVCS cross-section measurements

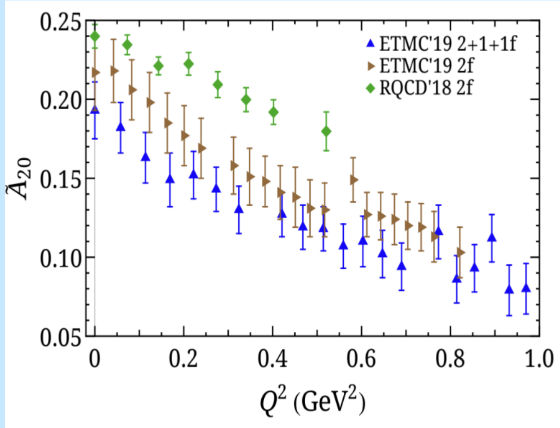
JLab Hall A, PoS Hadron2017 170 (2018)

  - Combined data from CLAS and Hall A (UU and LU)
  - H1 experiments at HERA

H1, Phys. Lett. B 681 391-399 (2009)

Lattice

- Lattice results themselves have tensions



M. Constantinou et. al. Prog. Part. Nucl. Phys. 121 103908 (2021)

- Lattice form factors and GPDs from a single group.

C. Alexandrou et. al. Phys. Rev. Lett. 125 26, 262001 (2020)
C. Alexandrou et. al. PoS LATTICE2021 250 (2022)

Caveat: ansatz and empirical constraints

Even so, the GPDs are still far from being fully determined!

Ansatz for GPDs: $$\mathcal{F}_{j,k}(t) = N_k B(j+1-\alpha_{i,k}, 1+\beta_k)\frac{j+1-k-\alpha_k}{j+1-k-\alpha_k(t)}\beta(t)$$

/s. B 841 1-58 (2010)

Empirical constraints:

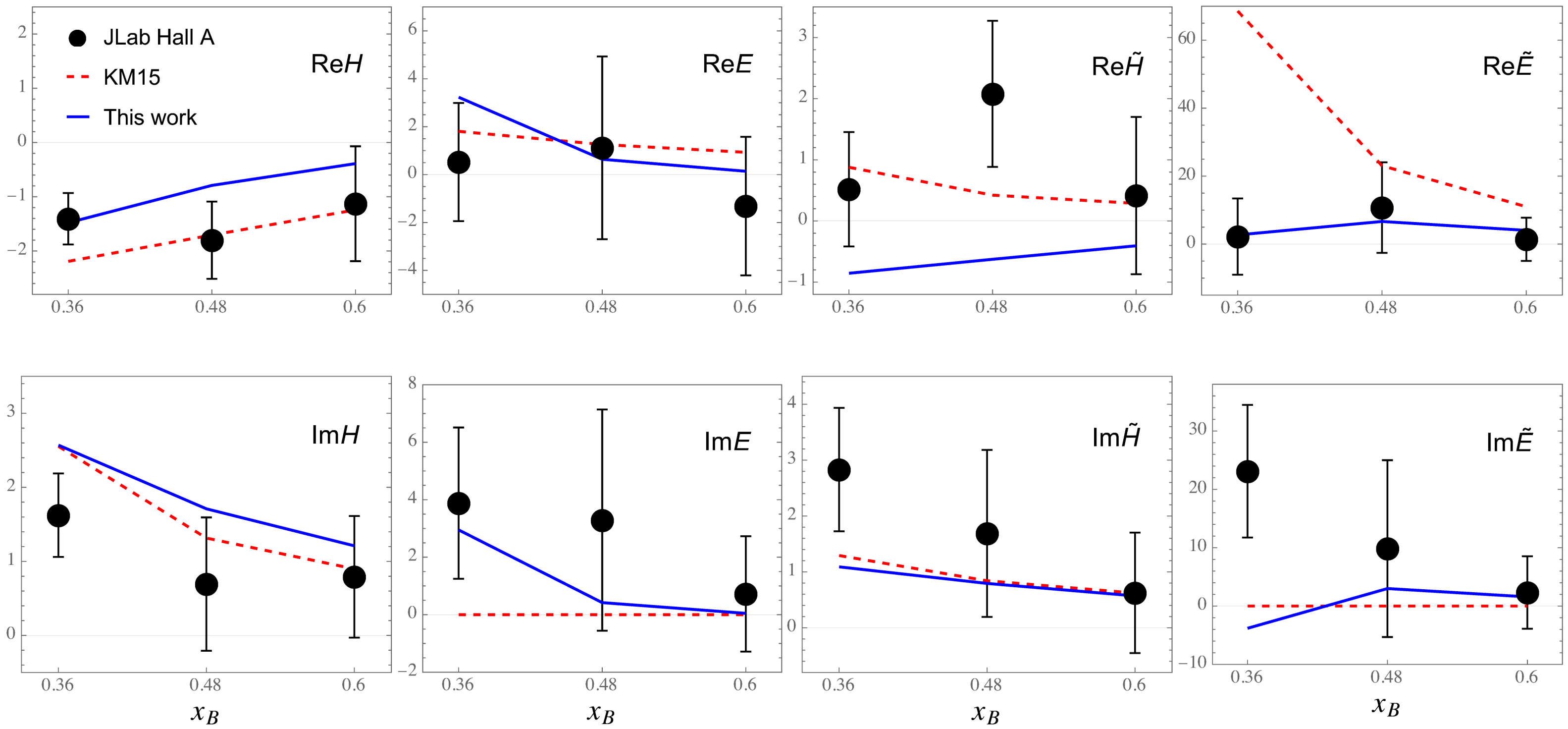
GPDs species and flavors	Fully parameterized	GPDs linked to	Proportional constants
H_{u_V} and $\widetilde{H}_{u_V}$	✔	-	-
E_{u_V} and $\widetilde{E}_{u_V}$	✔	-	-
H_{d_V} and $\widetilde{H}_{d_V}$	✔	-	-
E_{d_V} and $\widetilde{E}_{d_V}$	✘	E_{u_V} and $\widetilde{E}_{u_V}$	$R_{d_V}^{E/\widetilde{E}}$
$H_{\bar{u}}$ and $\widetilde{H}_{\bar{u}}$	✔	-	-
$E_{\bar{u}}$ and $\widetilde{E}_{\bar{u}}$	✘	$H_{\bar{u}}$ and $\widetilde{H}_{\bar{u}}$	$R_{\rm sea}^{E/\widetilde{E}}$
$H_{\bar{d}}$ and $\widetilde{H}_{\bar{d}}$	✔	-	-
$E_{\bar{d}}$ and $\widetilde{E}_{\bar{d}}$	✘	$H_{\bar{d}}$ and $\widetilde{H}_{\bar{d}}$	$R_{\rm sea}^{E/\widetilde{E}}$
H_g and $\widetilde{H}_g$	✔	-	-
E_g and $\widetilde{E}_g$	✘	H_g and $\widetilde{H}_g$	$R_{\rm sea}^{E/\widetilde{E}}$

Table 1: A summary of how each GPDs with different species and flavors are parameterized respectively. Fully parameterized GPDs are expressed in terms of eq. (2.6), whereas the other GPDs are linked to the fully parameterized GPDs with proportional constants.

Extracted CFFs and GPDs

The extracted CFFs are generally close to the local extracted values

Y. Guo et. al. [2302.07279]

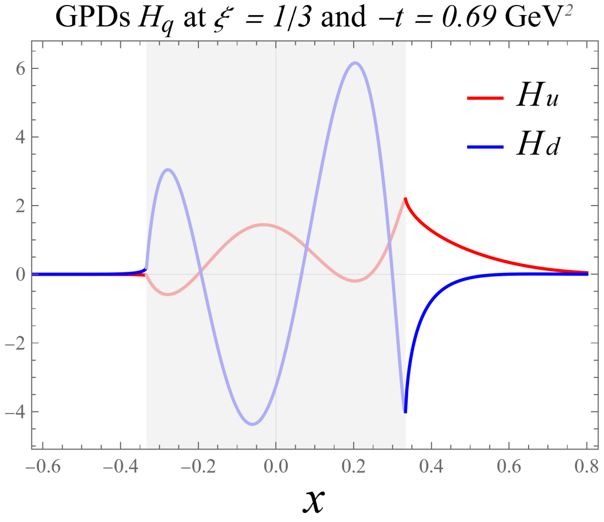


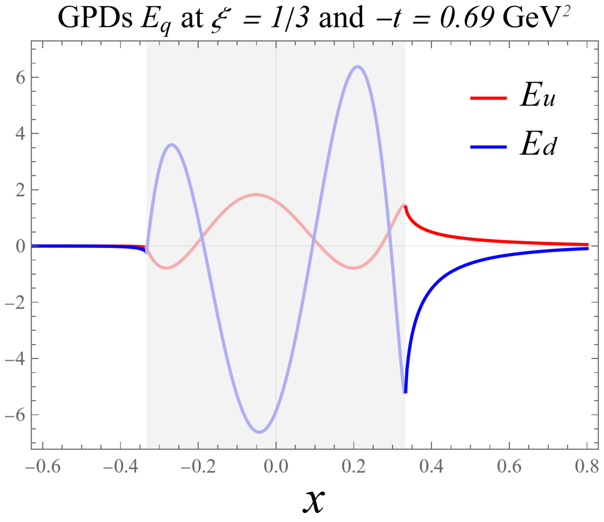
There are degeneracy in CFFs themselves

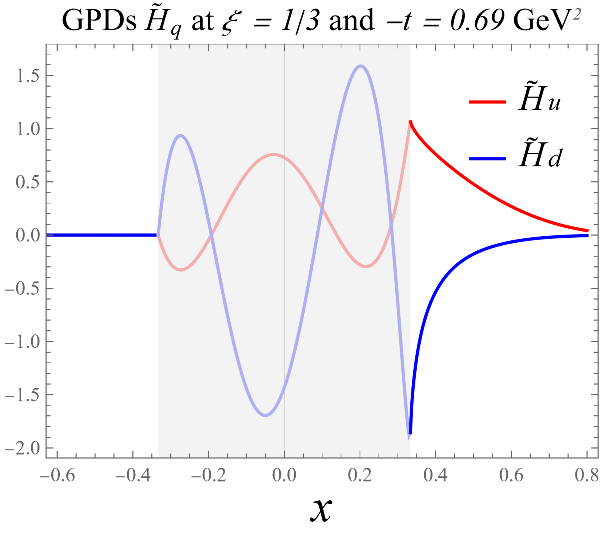
– quadratic equations have multiple solutions

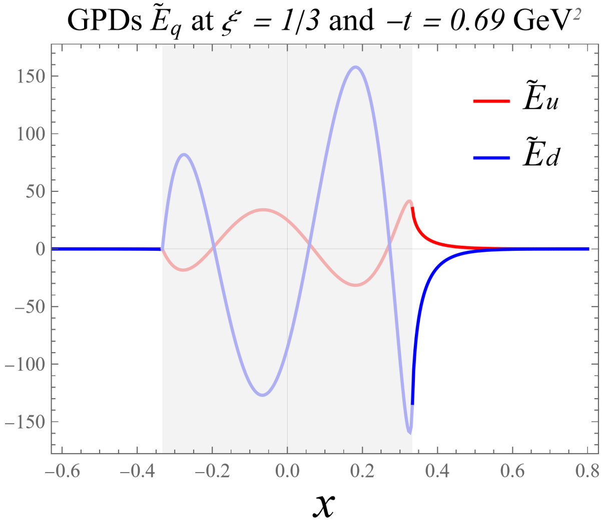
K. Shiells et. al. JHEP 08 048(2022)

Extracted CFFs and GPDs

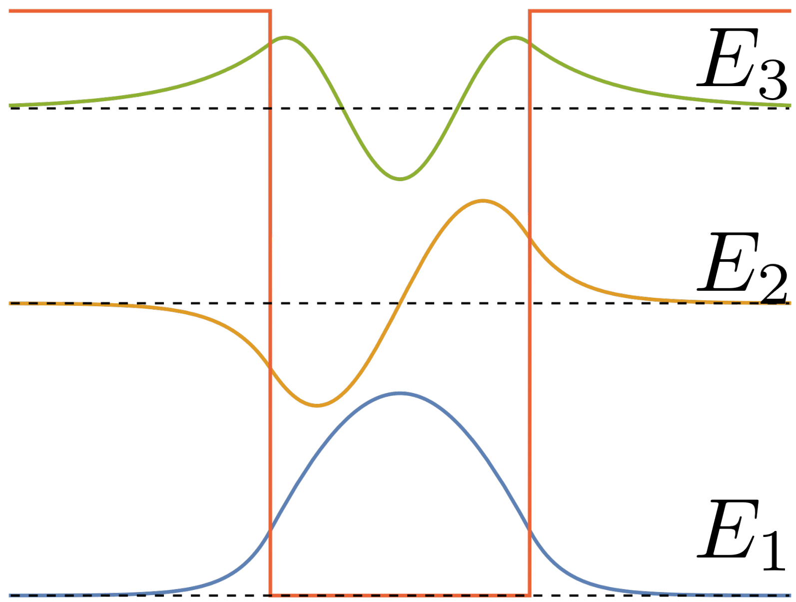






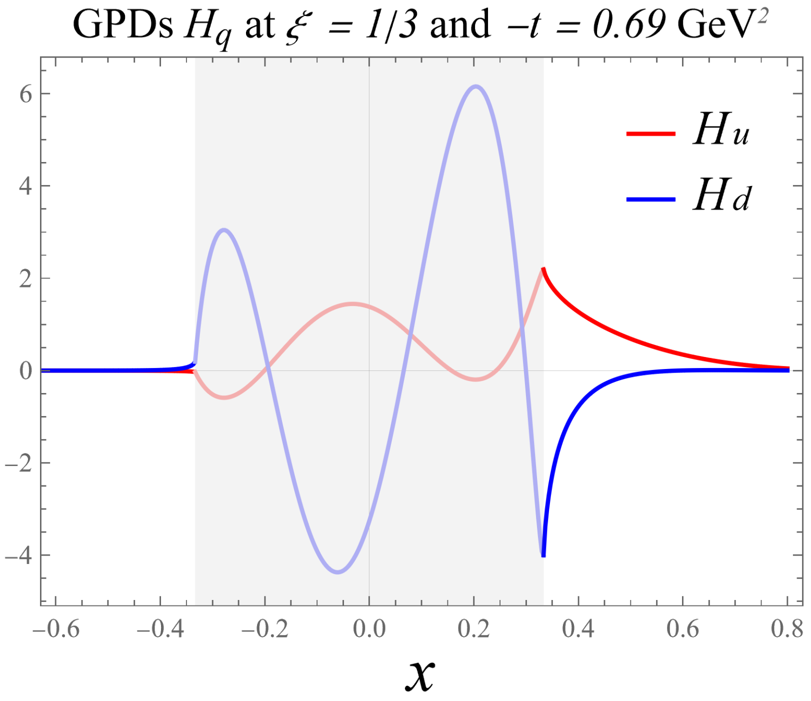


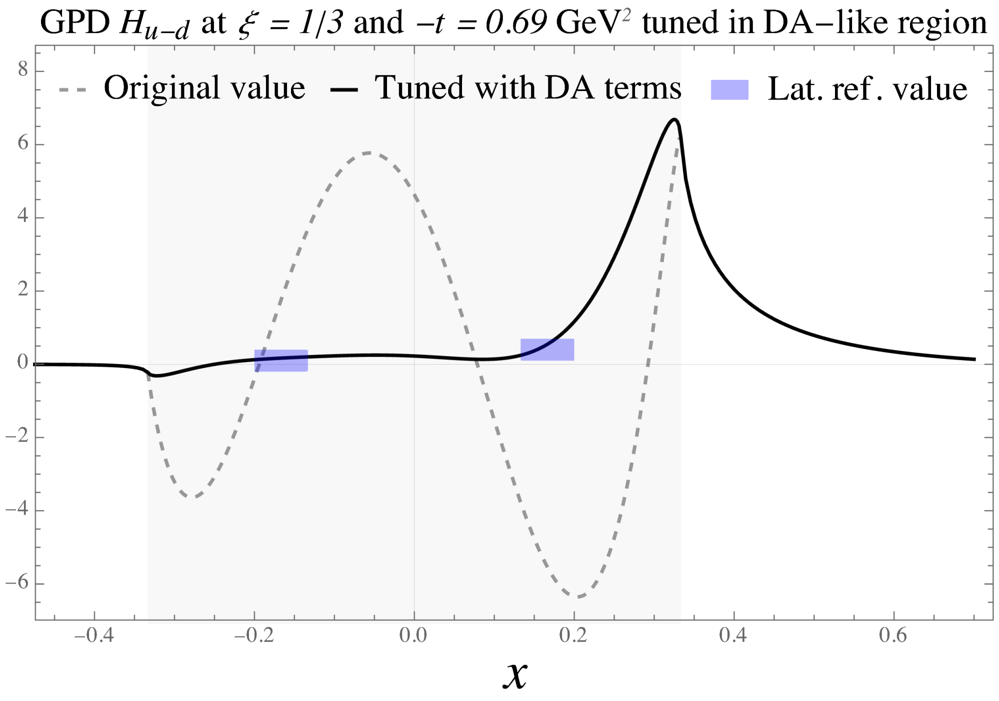
The wiggling behavior is an artifact of the partial wave construction



GPDs in the DA-like regions

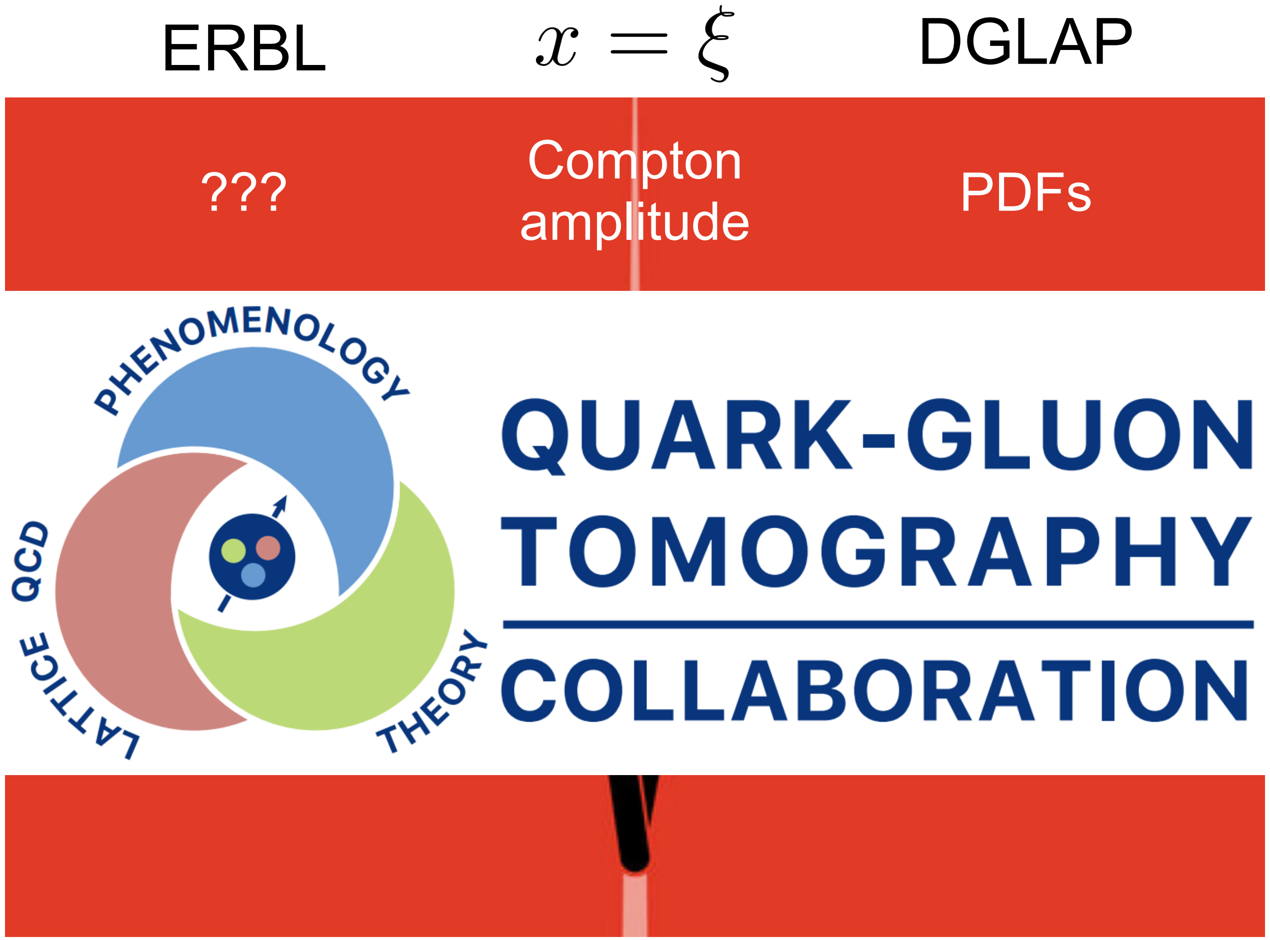
There ARE extra terms you can play with to modify the shape of GPDs.





Extra inputs crucial to determine the shape of GPDs in the middle regions.

Challenge of GPD extraction



Summary and outlook

Summary

- GPDs reveals the nucleon 3D structures including mass and spin.
- Inputs from both experiment and lattice are necessary for determination of GPDs
- Global analysis program by parameterization moments of GPDs.

Outlook

- Global fitting with more data inputs (Hopefully all existing data)
- Extend to other processes that can probe GPDs
- Higher order corrections and more quark flavor

Thank you!