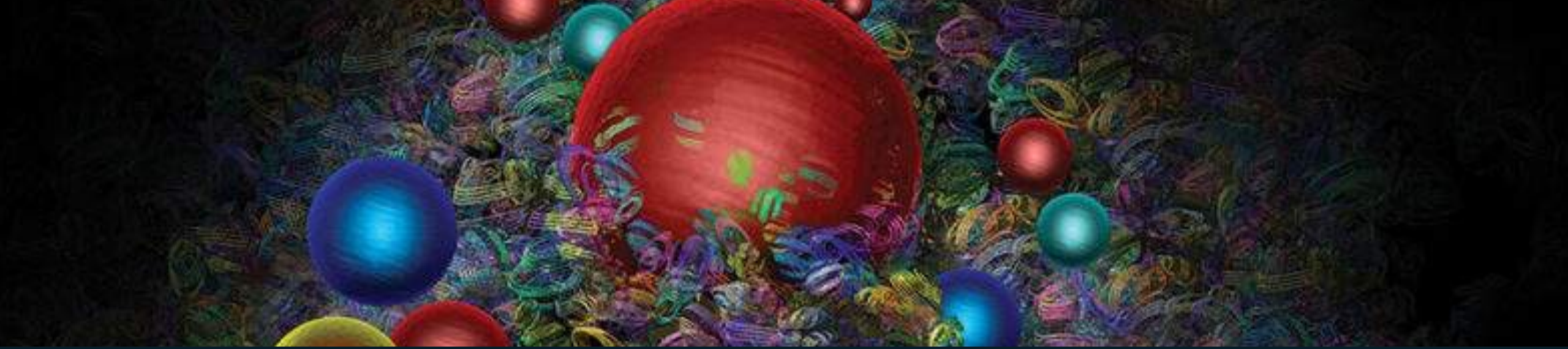




Opportunities of (gluonic) GPDs at High Luminosity Facilities

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Physics Program with High Luminosity Facilities

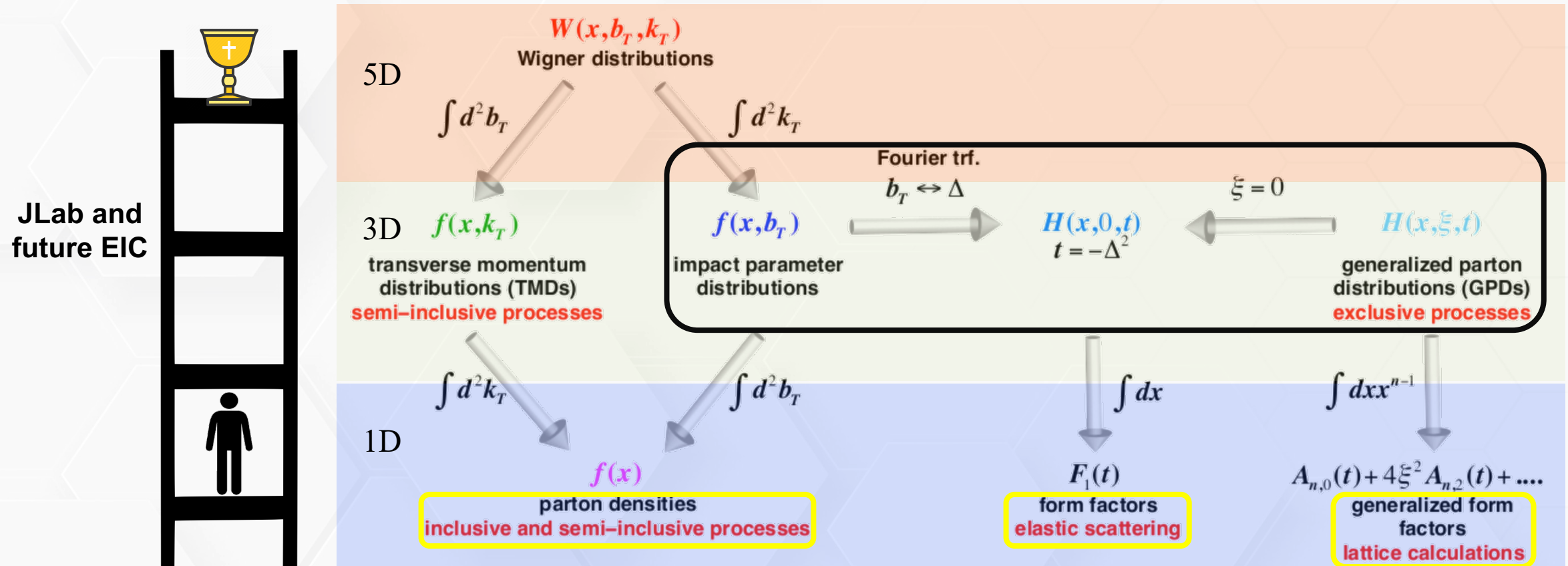
Jefferson Lab, Newport News, VA

Oct. 5-9th, 2026



Road map of multidimensional nucleon structure

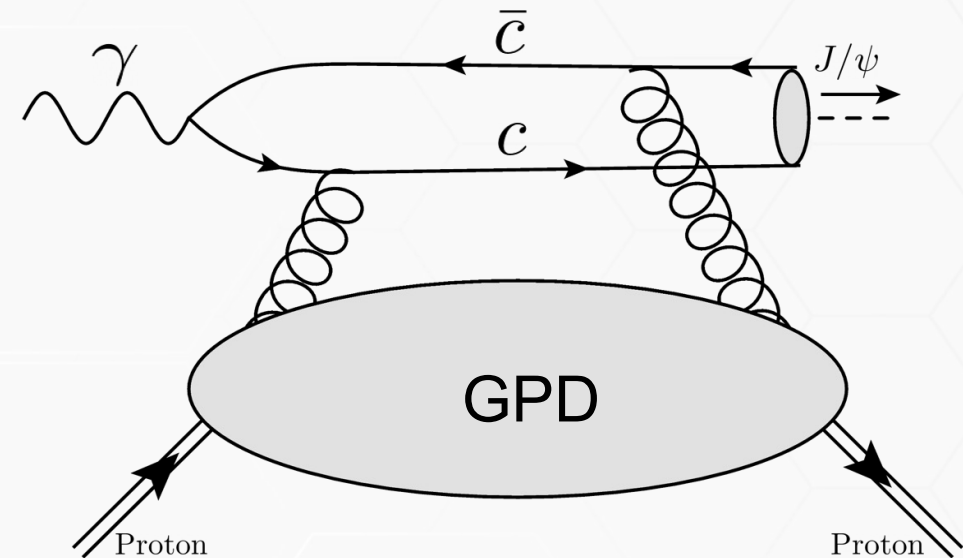
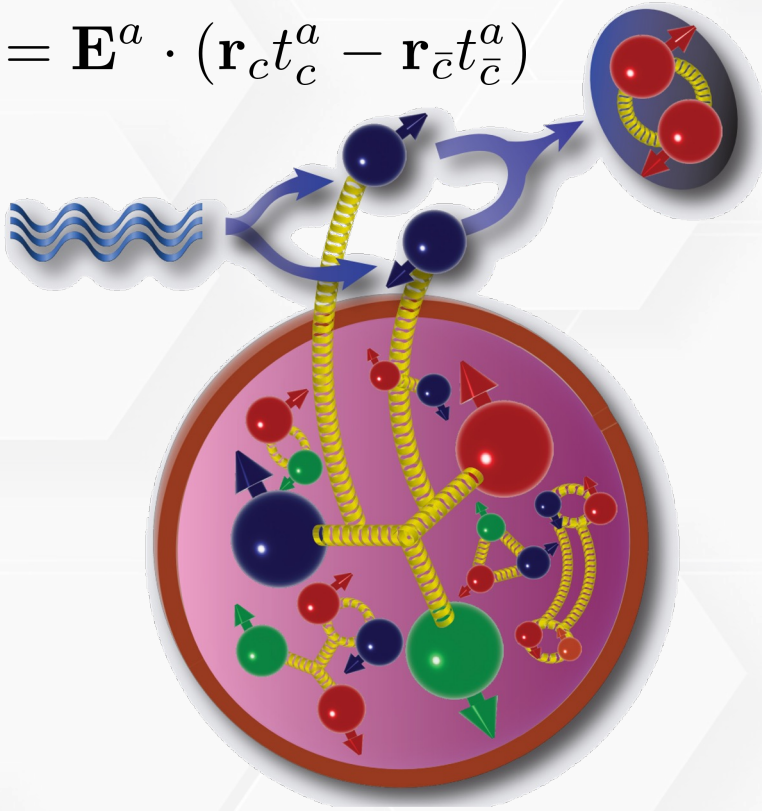
Deciphering the multidimensional structures of the nucleons naturally requires an extensive set of distributions and corresponding inputs.



Heavy quarkonia production in QCD

One thing that draws rising attention in recent years concerns the near-threshold exclusive productions of heavy quarkonia/lepto-production of lighter meson

$$\mathcal{H}_{\text{Int}} = \mathbf{E}^a \cdot (\mathbf{r}_c t_c^a - \mathbf{r}_{\bar{c}} t_{\bar{c}}^a)$$



D. Y. Ivanov et. al. Eur. Phys. J. C 34, 297 (2004)
Z.-Q. Chen et. al. Phys. Lett. B 797,134816 (2019)
Y. Guo et. al. Phys. Rev. D 103 9, 096010 (2021)

One ideal channel to look at the gluonic EMT form factors and GPDs.

Three main challenges: Inverse problem

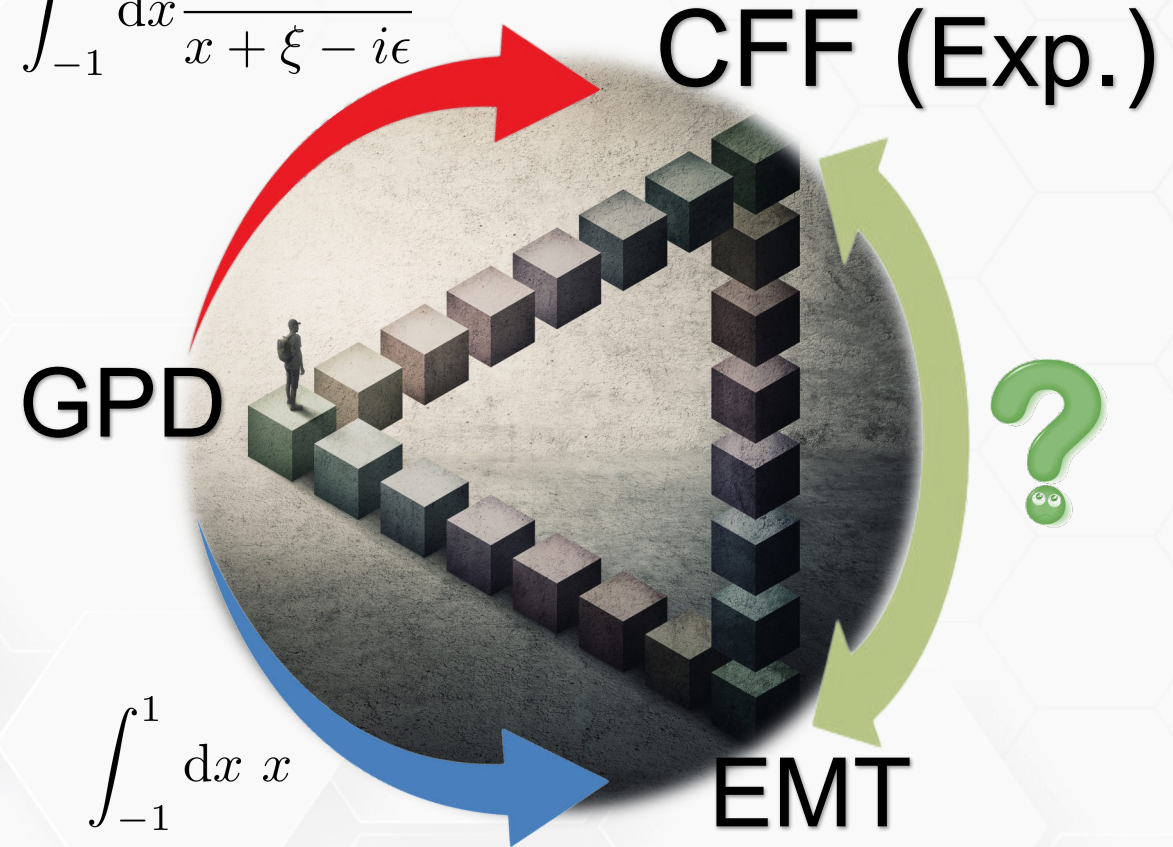
While hard exclusive production processes are typically described by GPDs, their relation between experimental observables (CFFs) to GPDs or EMT FFs are indirect.

Some proposed solutions/walk-around $\int_{-1}^1 dx \frac{1}{x + \xi - i\epsilon}$ CFF (Exp.)

Global analysis

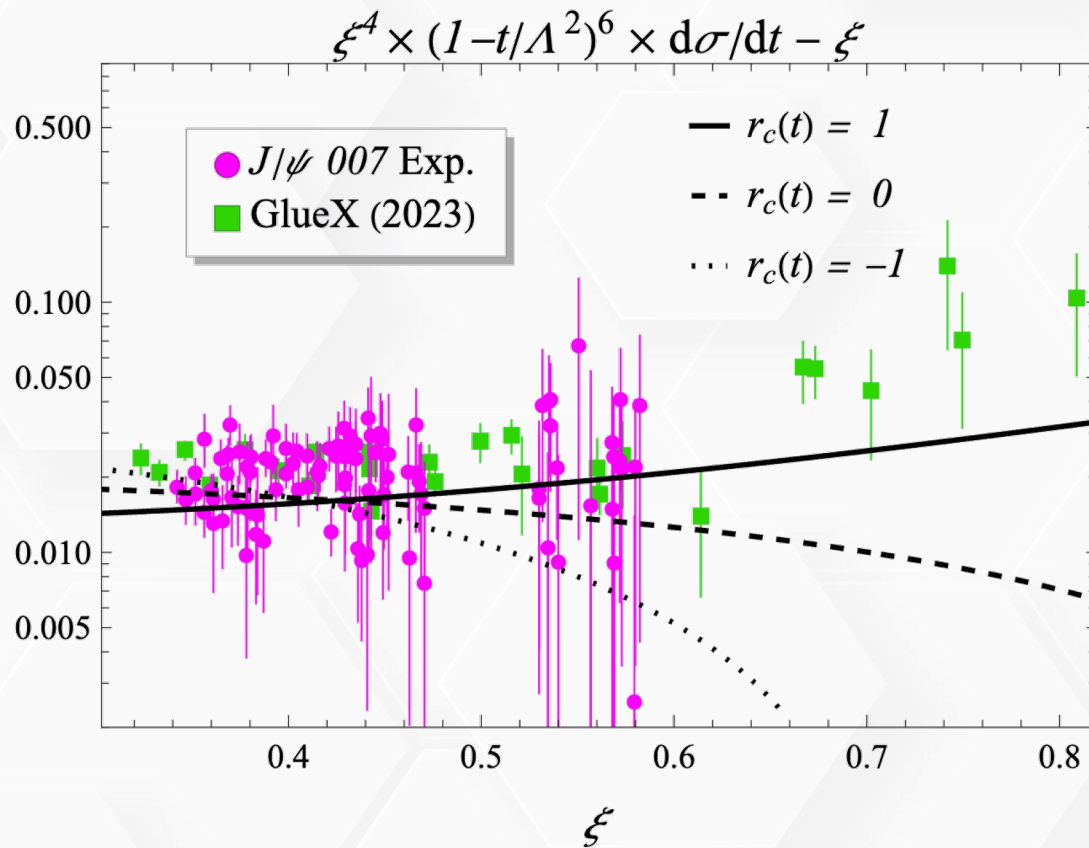
Dispersion relations

Asymptotic expansion

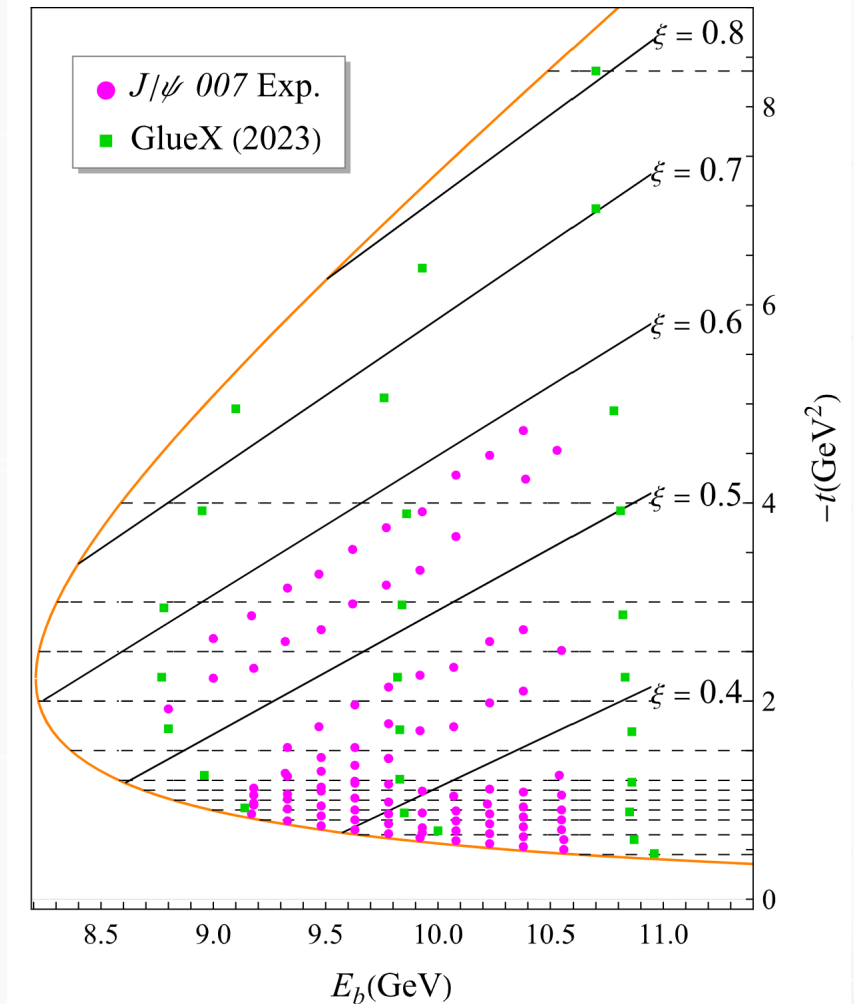


Three main challenges: Kinematic coverage

Also, in the GPD framework the skewness dependence provides the leverage to constrain different EMT form factors



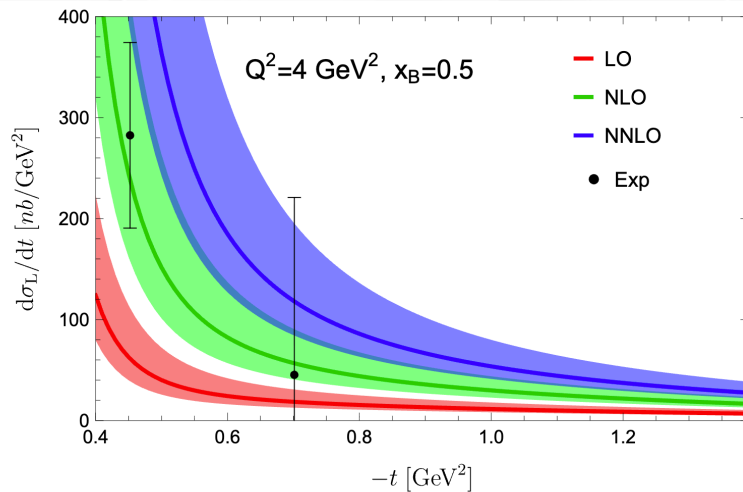
Guo, Ji and Yuan PRD (2024)



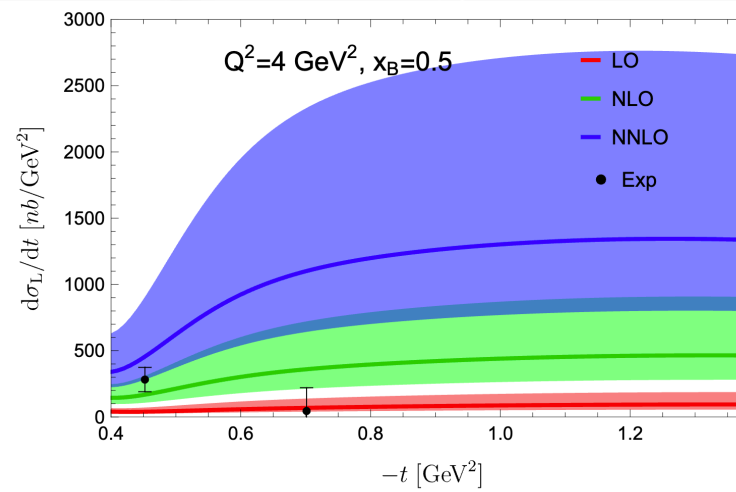
Three main challenges: Pert. convergence

Meanwhile, meson productions are not theoretically well understood due to perturbative convergence and power-suppressed effects (L/T separation, mass corrections)

Large perturbative corrections found for pion-production.



(a) JLab, GK+RQCD

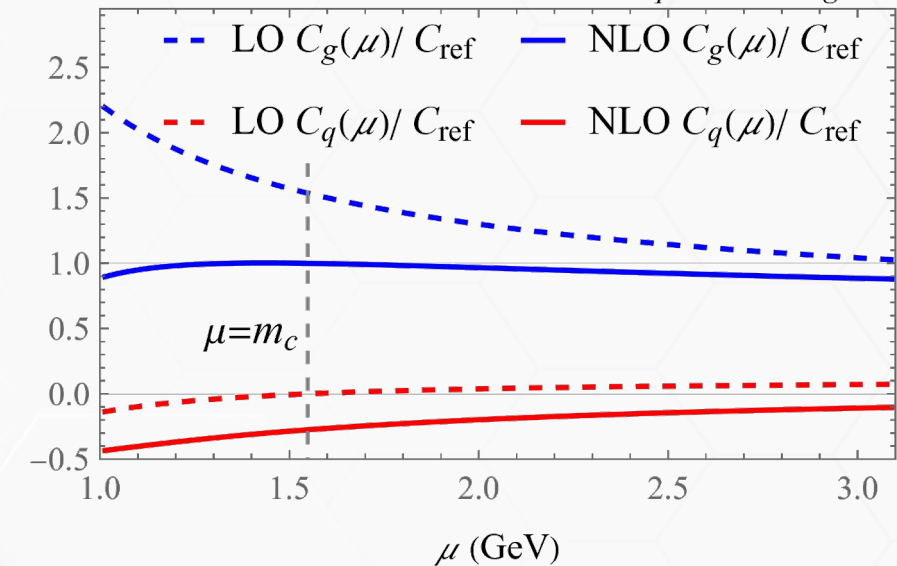


(b) JLab, GUMP+RQCD

Y. Jia et al. arXiv: 2604.28164

$$\bar{C}^{\text{evo}} \equiv \alpha_S(\mu_F) \bar{C}^{(1)}(\mu_F, m_c) \mathcal{E}^{(1)}(\mu_F, m_c)$$

Normalized Wilson coefficients $C_q(\mu)$ and $C_g(\mu)$



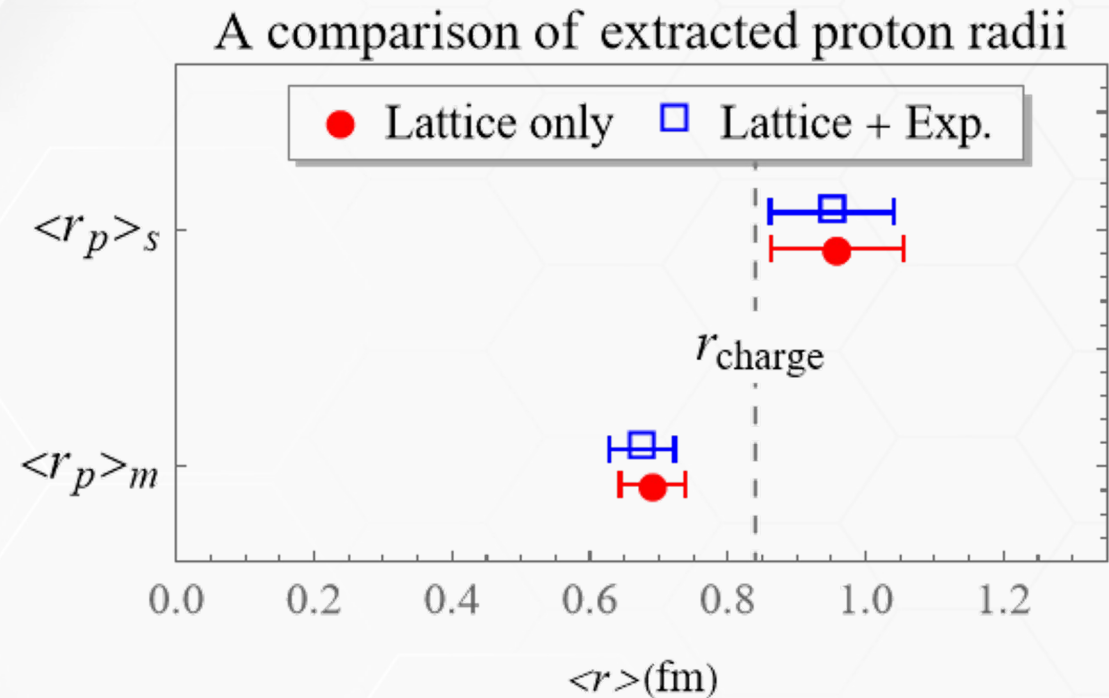
Y. Guo, F. Yuan and W Zhao, PRL (2025)

High precision data and matching theoretical accuracy are crucial for GPD pheno.

Proton radii from near-threshold prod.

The proton radii given by the derivative of the EMT form factors:

$$\langle r^2 \rangle_m = 6 \left. \frac{dA(t)}{dt} \right|_{t=0} - 6 \frac{C(0)}{M_N^2}$$
$$\langle r^2 \rangle_s = 6 \left. \frac{dA(t)}{dt} \right|_{t=0} - 18 \frac{C(0)}{M_N^2}$$

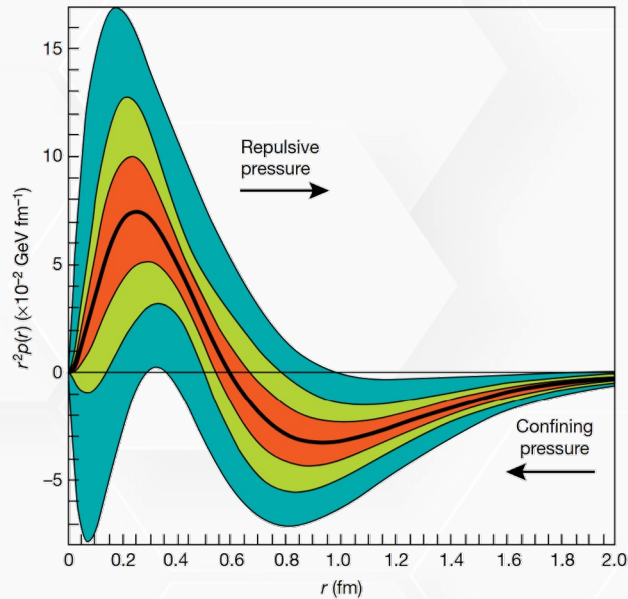


The threshold expansion of GPDs require large-skewness kinematics and therefore will be limited to the precision of large-skewness data.

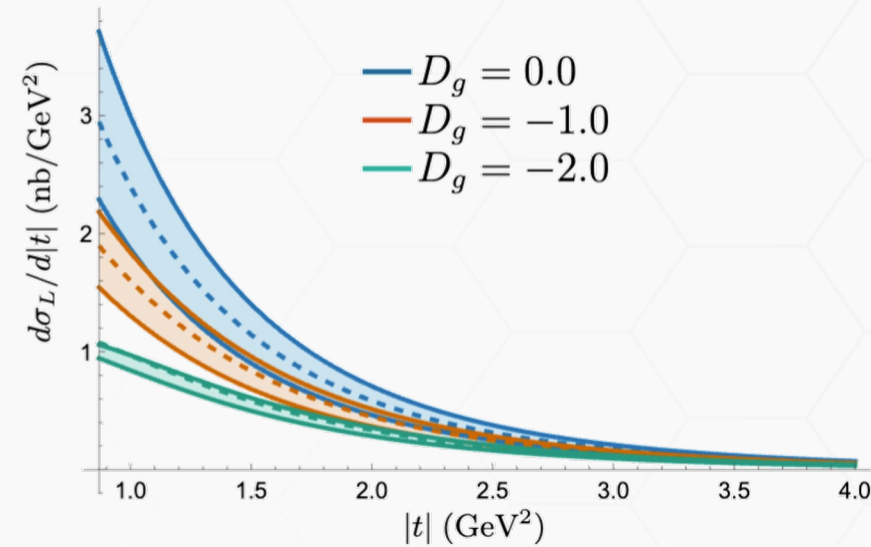
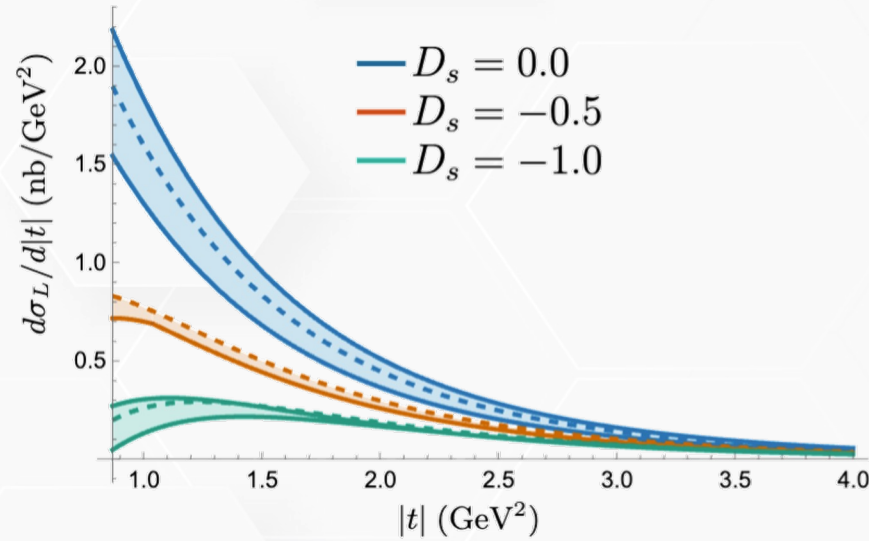
Nevertheless, lower-skewness data can be used in the full GPD framework.

Universality under the guideline of QCD

Various hard exclusive production processes can be studied under the same framework, the production mechanism of which must follow QCD factorization.



V. D. Burkert et. al. Nature 557 (2018)



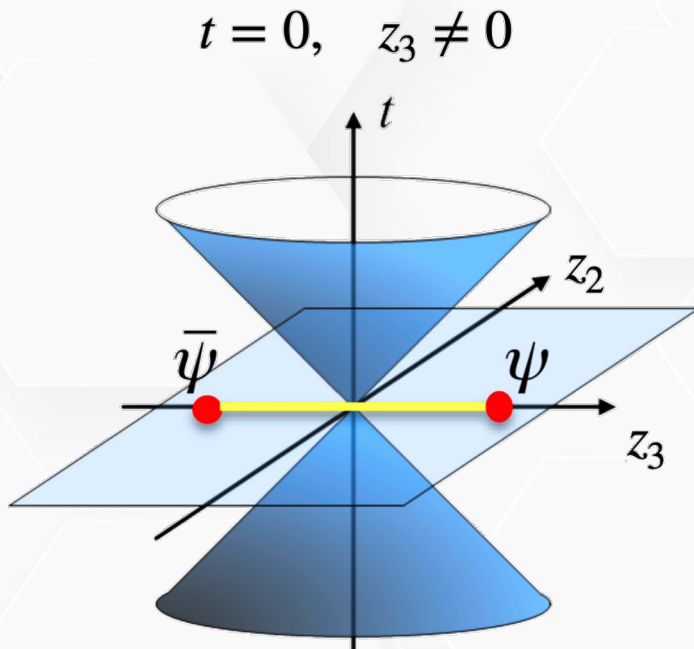
Y. Hatta et. al. PTEP (2025)

- Exclusive photo- and electro-productions of light meson at large skewness
- Time-like Compton scattering (TCS) at large skewness
- Deeply virtual Compton scattering (DVCS) at large skewness

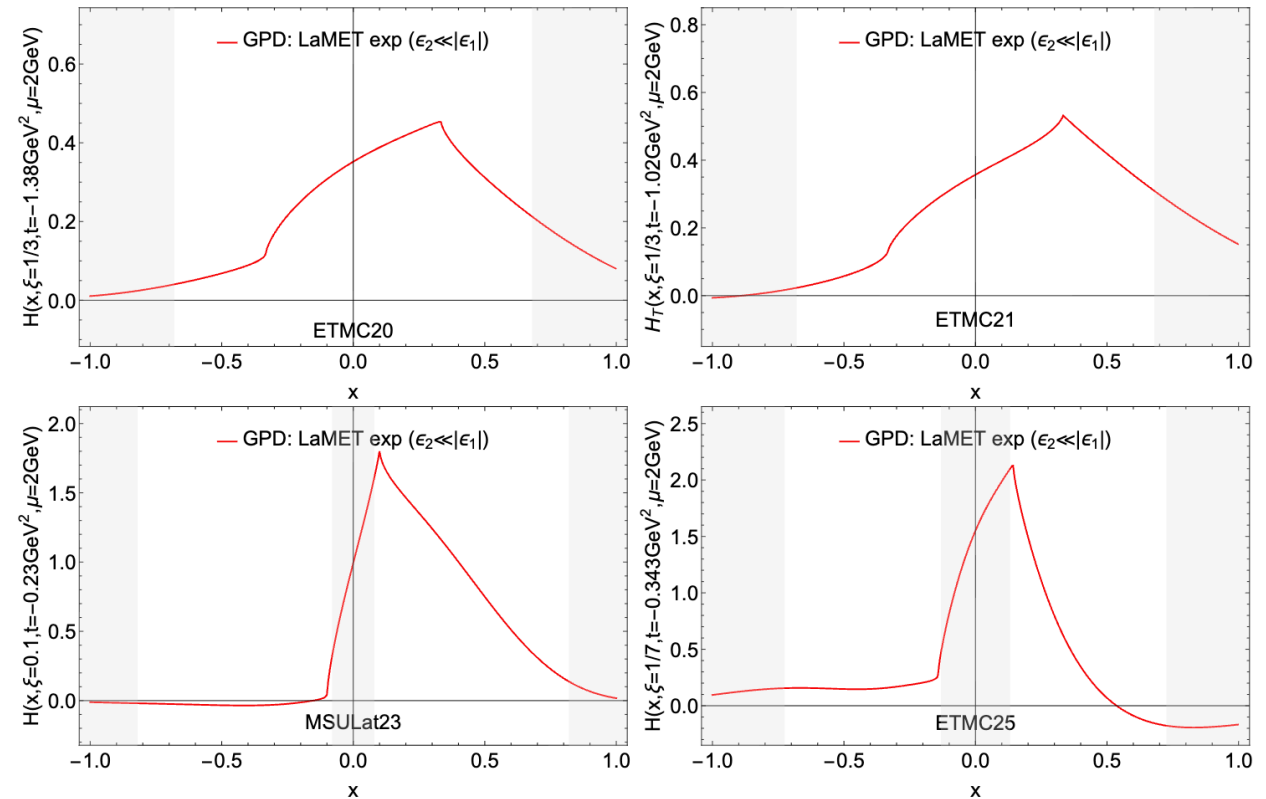
Global extraction of GPDs

Nucleon and parton structure on lattice

Recent developments of Large Momentum Effective Theory (LaMET) allow us to simulate (light-like) parton structure with space-like lattice correlations!



X. Ji et. al., Rev. Mod. Phys. 93 (2021)



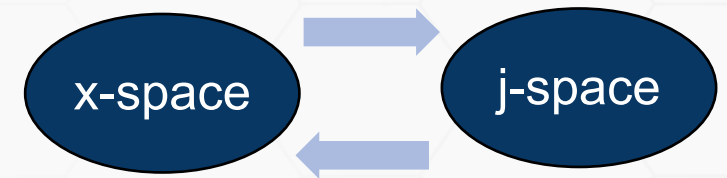
Y. Su et al. arXiv:2609.20545

Moment-space representation of GPDs

GPDs can be formally expanded in the conformal moment space:

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

D. Mueller and A. Schafer 2005



$p_j(x, \xi)$: Orthogonal basis in terms of Gegenbauer polynomials

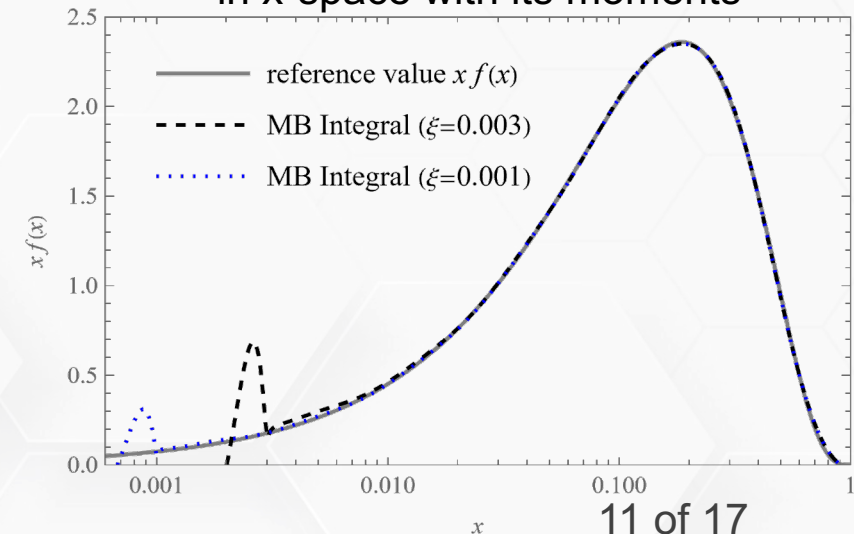
$\mathcal{F}_j(\xi, t)$: Moments of GPDs to be parameterized

Whereas GPDs in x-space can be reconstructed by resumming all the moments through a complex integral in the moment space:

$$F(x, \xi, t) = \frac{1}{2i} \int_{c-i\infty}^{c+i\infty} dj \frac{p_j(x, \xi)}{\sin(\pi[j+1])} \mathcal{F}_j(\xi, t) ,$$

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Example of reconstructed GPD in x-space with its moments



Full next-to-leading (NLO) accuracy

In the past years, we include more processes with improved accuracy:

Full GPD evolutions to the next-to-leading order (NLO)

—Include both evolving-moment and evolving-Wilson-coefficient method

NLO deeply virtual J/ψ production (DV J/ψ P) with mass corrections

—In a hybrid framework to also include the mass corrections

Y. Guo et. al. Phys. Rev. D 112 (2025)

NLO deeply virtual Compton scattering (DVCS) and meson productions (DVMP)

—Covering most of the existing JLab and HERA measurements of DVCS and ρ productions

Extend to other observables such as asymmetries measurements.

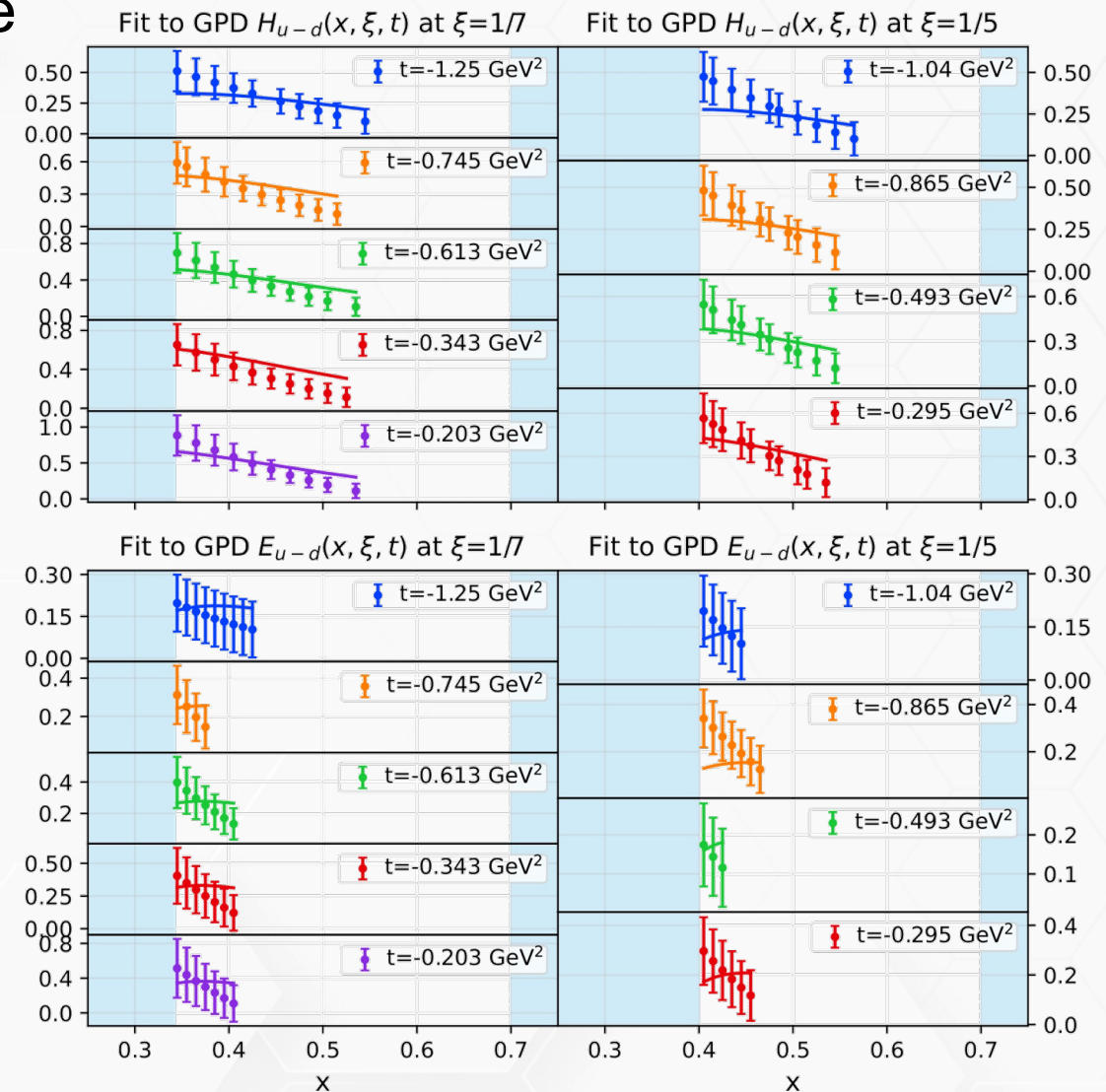
GPDs at non-zero skewness from lattice

Importantly, we also include the recent lattice simulations of GPDs at non-zero skewness.

Significant effects in constraining
GPDs at non-zero skewness!

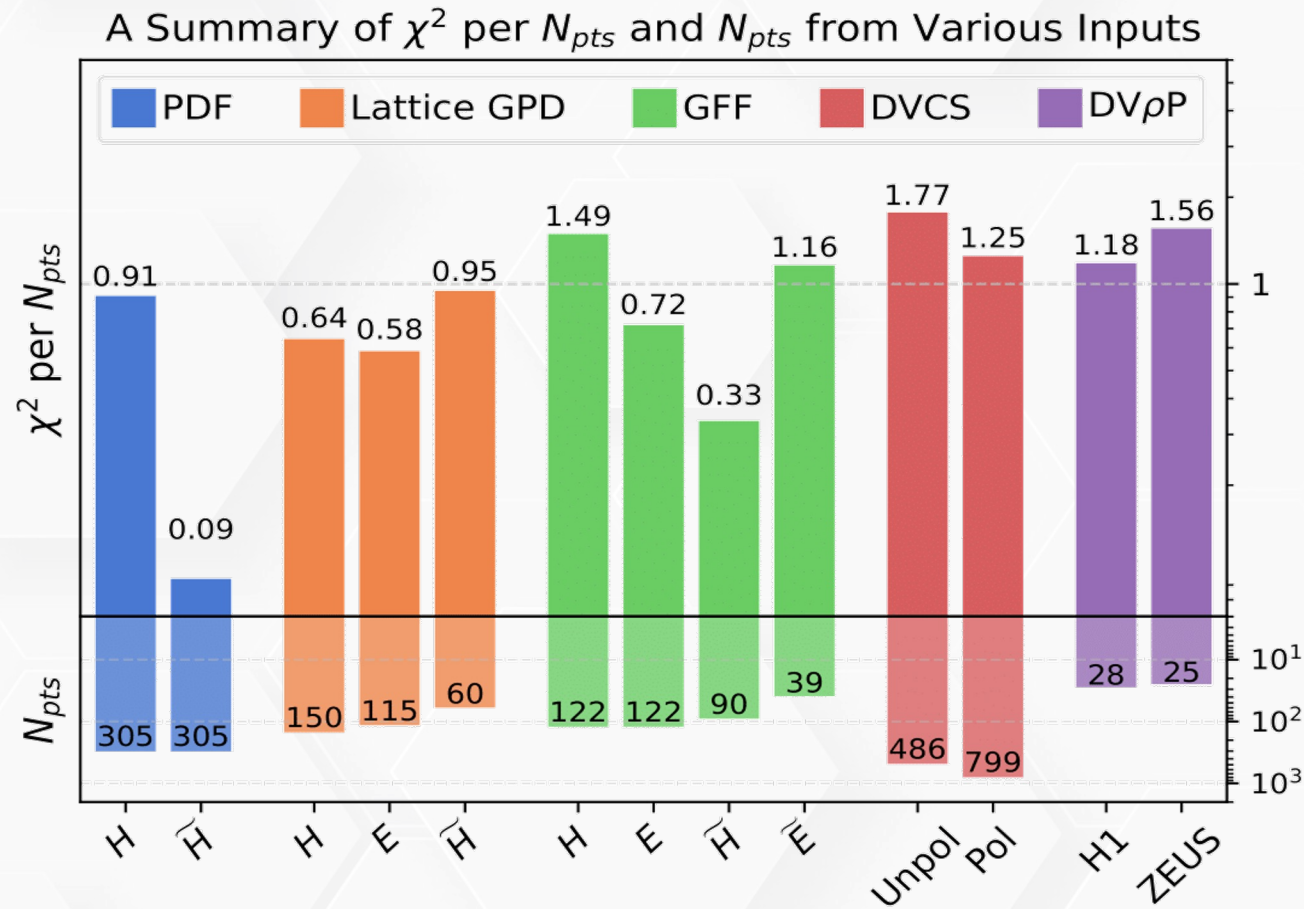
Note: besides the 30% relative uncertainty added to all the lattice data, we have a very conservative selection:

- 1) Only used the data between $0.3 < x < 0.7$ and $|x - x_i| > 0.2$.
- 2) Exclude region where GPDs get negative or very small (lattice artifacts or intrinsic GPD behaviors?)



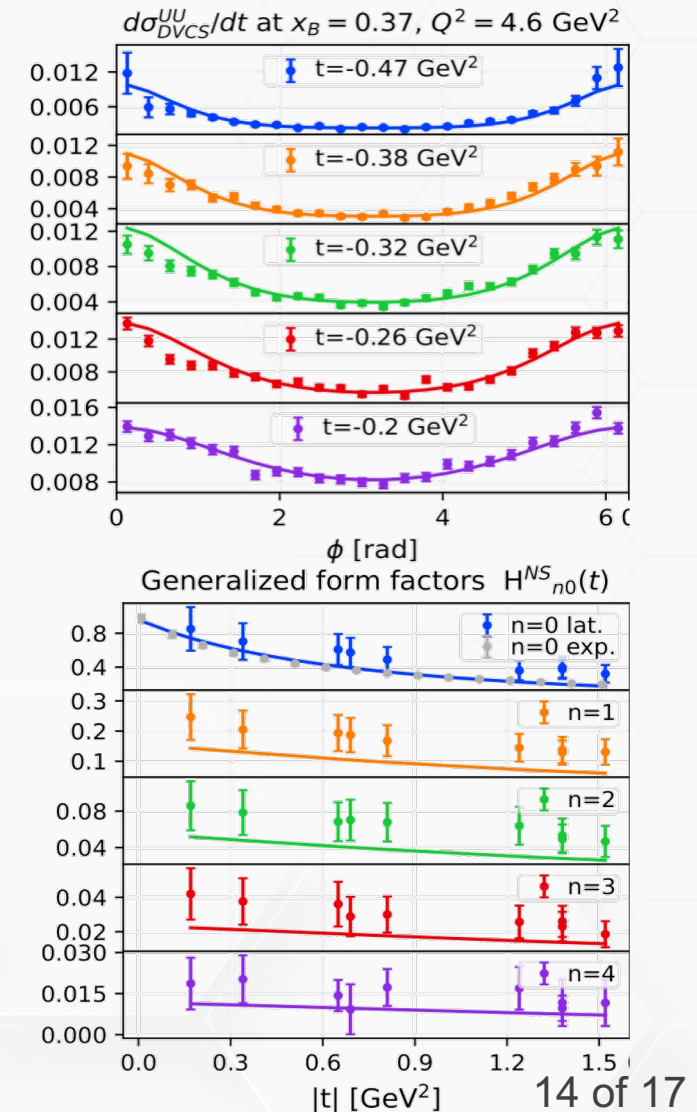
Excellent descriptions of exp. and lattices

Generally, we observe excellent agreement across various inputs:



Reduced chi squared of 1.09 for 2,646 data points

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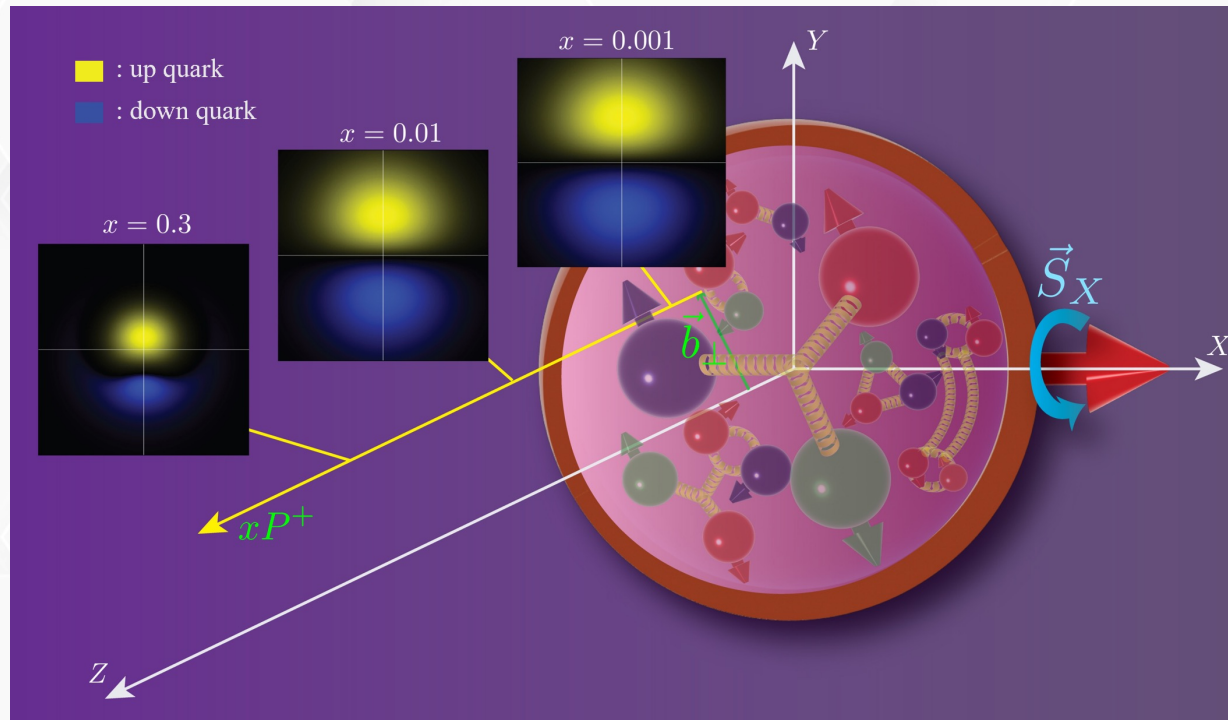


Nucleon tomography with GUMP1.0 GPDs

The tomography of the quark in the nucleons can be obtained via GPDs. In particular, for transversely polarized proton, the intrinsic quark distributions are

$$\rho_{q,\text{In}}^X(x, \mathbf{b}) = \int \frac{d^2 \Delta}{(2\pi)^2} e^{-i\Delta \cdot \mathbf{b}} \left[H_q(x, -\Delta^2) + \frac{i\Delta_y}{2M} (H_q + E_q)(x, -\Delta^2) \right]$$

Y. Guo, X. Ji and K. Shells. Nucl. Phys. B 969 (2021)



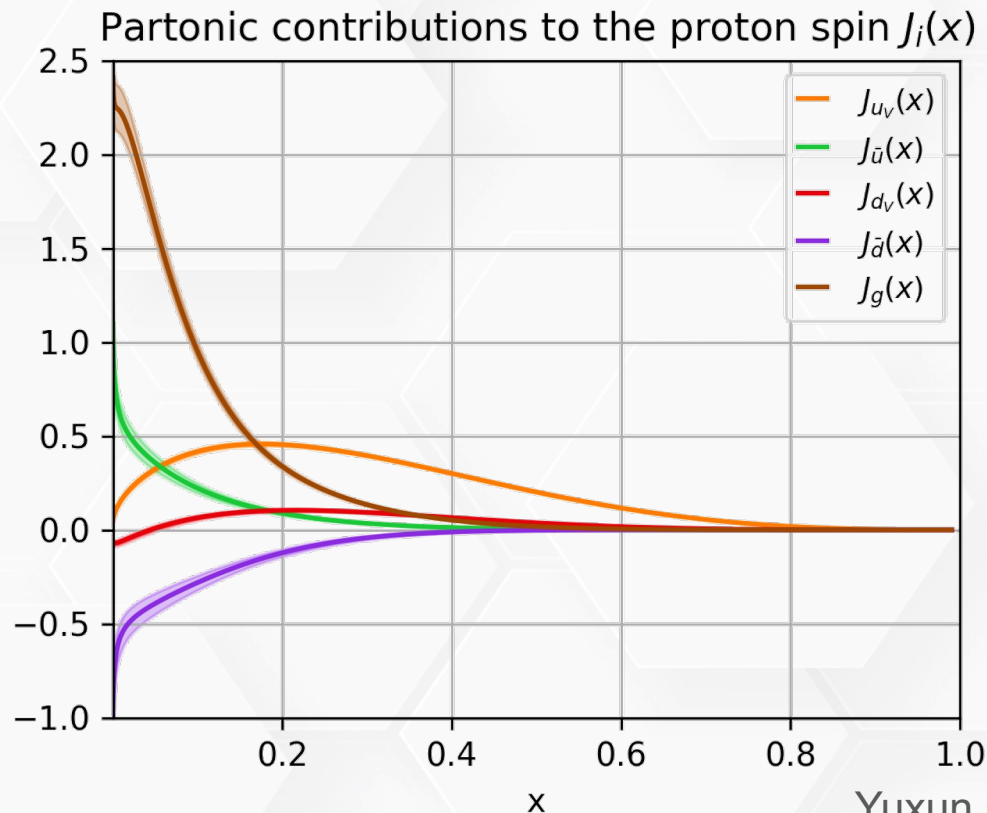
Distributions of quark in the transverse space of a polarized proton with respect to the center of the proton.

The proton is transversely polarized to the +X directions. Thus, quarks are shifted in Y directions that generate orbital angular momenta!

Partonic contributions to the proton spin

The partonic contributions to the proton spin can also be obtained from the extracted GUMP1.0 GPDs. Specifically, they are given by

$$J_{q/g}(x) = \frac{1}{2} (H_{q/g} + E_{q/g}) (x, \xi = 0, t = 0)$$



- Parametric biases/errors not considered

- Consistent with most existing constraints

- Some tension with the lattice GFFs

- Proton spin sum rule satisfied!

Summary

Near-threshold exclusive productions

- Kinematic coverage and high precision data are core of reliable GPD/EMT extractions;
- GPD universality across different channels will significantly strengthen the results;
- Improved theoretical accuracies are also relevant at JLab and EIC kinematics;

GPD Global analysis

- Lattice data provides important complementary info and should be included;
- Quantitative determination of GPDs remains under investigations;
- Polarization, meson productions, TCS, DDVCS ... are crucial components of GPD program;

Thank you!