Global analysis of GPDs with GUMP program

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In collaboration with Xiangdong Ji, Gabriel Santiago , Kyle Shiells, and Jinghong Yang

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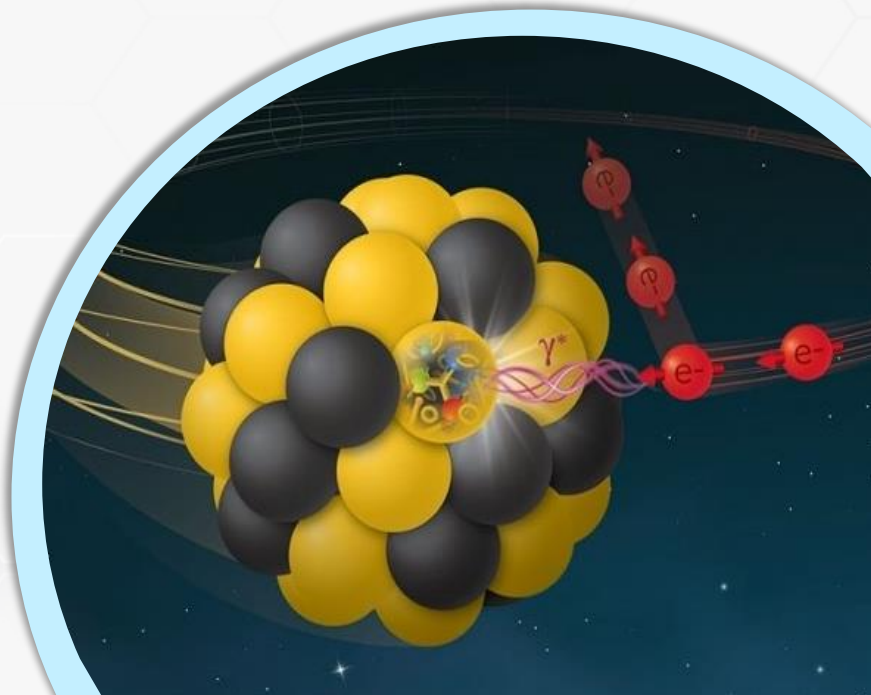
BERKELEY LAB

Outline

- Intro — nucleon spin and GPDs
- Overview global analysis of GPD
- GUMP program and the limitation
- Summary and outlook



Nucleon spin, 3D structure and GPDs

Lorce's Talk
Meziani's Talk
Bhattacharya's Talk

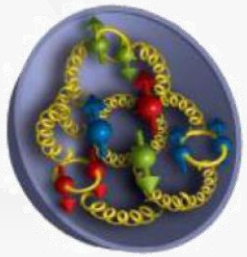
Naïve quark model

Gluonic contribution

Transverse motions

$$\frac{\hbar}{2} =$$

quark spin



gluon spin

quark orbital AM

gluon orbital AM

R. Jaffe and A. Manohar Nucl. Phys. B 337, 509 (1990)

Jaffe-Manohar sum rule

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Jaffe-Manohar sum rule

Nucleon spin can be written with parton distributions localized in coordinate space.

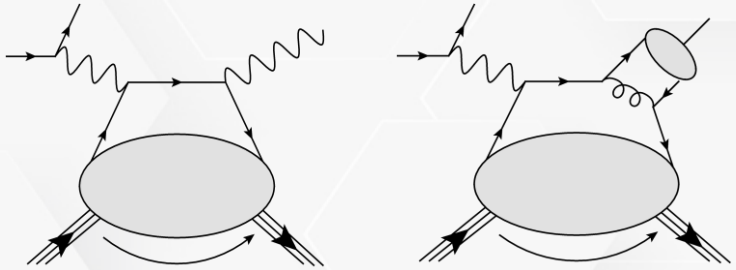
$$J_{q,g} = \frac{1}{2}\int \mathrm{d}x\; x\left(H_{q,g}(x,0,0) + E_{q,g}(x,0,0)\right)$$

X. Ji, Phys. Rev. Lett. 78 610-613 (1997)

Ji sum rule

Composite tasks for GPD study

The high-dimensional nature of GPD requires composite inputs.



X. Ji, Phys. Rev. D 55, 7114 (1997)
A.V. Radyushkin, Phys. Lett. B 385 333 (1996)
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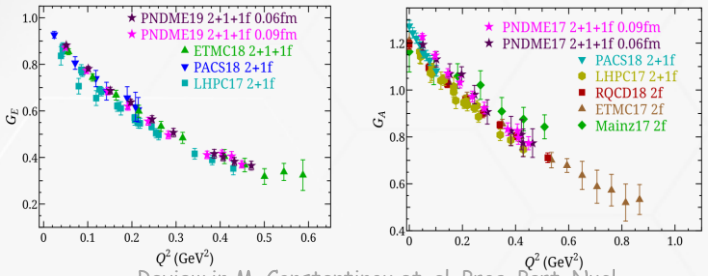
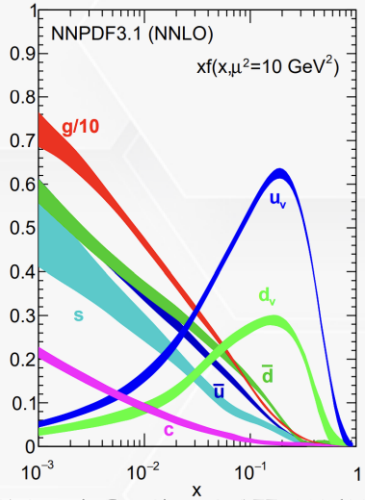
Deeply virtual exclusive processes



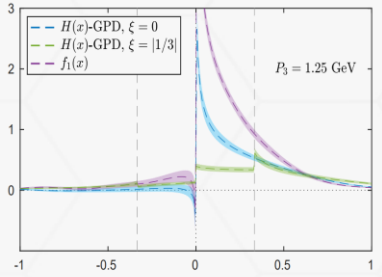
Review in M. Constantinou et. al. Prog. Part. Nucl. Phys. 121 103908 (2021). And references therein

Nucleon form factors from lattice

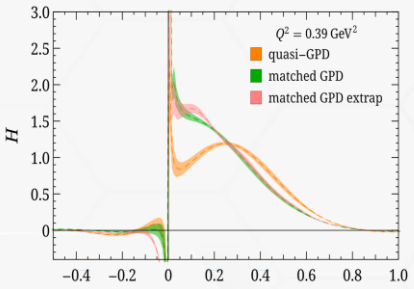


NNPDF et al., Eur. Phys. J. C 77, 663 (2017)

Parton Distribution Function



C. Alexandrou et. al. (ETMC)
Phys. Rev. Lett. 125, 262001 (2020)



Huey-Wen Lin
Phys. Rev. Lett. 127, 182001 (2021)

x-dependence from lattice

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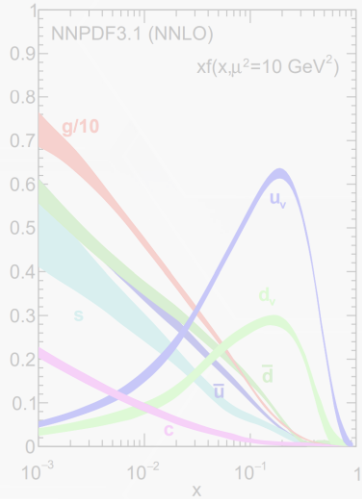

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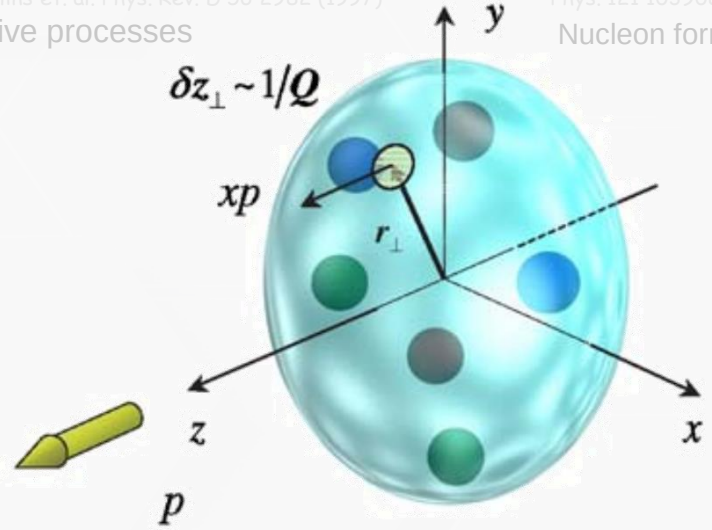


3D Quark-Gluon Tomography

C. Alexandrou et. al. (ETMC)
Phys. Rev. Lett. 125, 262001 (2020)

Huey-Wen Lin
Phys. Rev. Lett. 127, 182001 (2021)

x-dependence from lattice

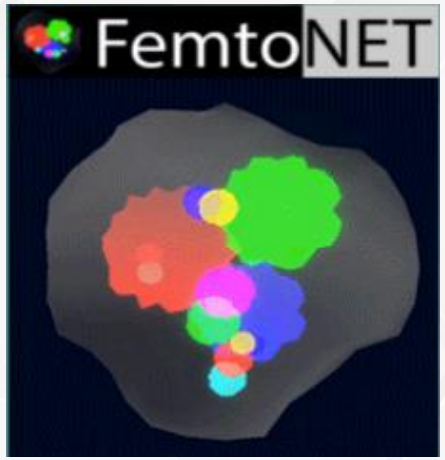
Global GPD Global analysis efforts

Gepard

Tool for studying the 3D quark and gluon distributions in the nucleon

K. Kumericki et al.
Nucl. Phys. B 794 244 (2008)

FemtoNET



M. Almaeen et al.
arxiv: 2207.10766

Liuti's talk

PHENOMENOLOGY LATTICE QCD THEORY
QUARK-GLUON TOMOGRAPHY COLLABORATION

Machine Learning Approach

Eric Moffat et al.
Phys. Rev. D 108 3, 036027 (2023)

Moffat's talk

GPDs through Universal Moment Parameterization (GUMP)

Y. Guo et. al. JHEP 09 215 (2022)
Y. Guo et. al. JHEP 05 150 (2023)

PARTONS

STRONG 2020

B. Berthou et al.
Eur. Phys. J. C 78 6, 478 (2018)

The Gaps

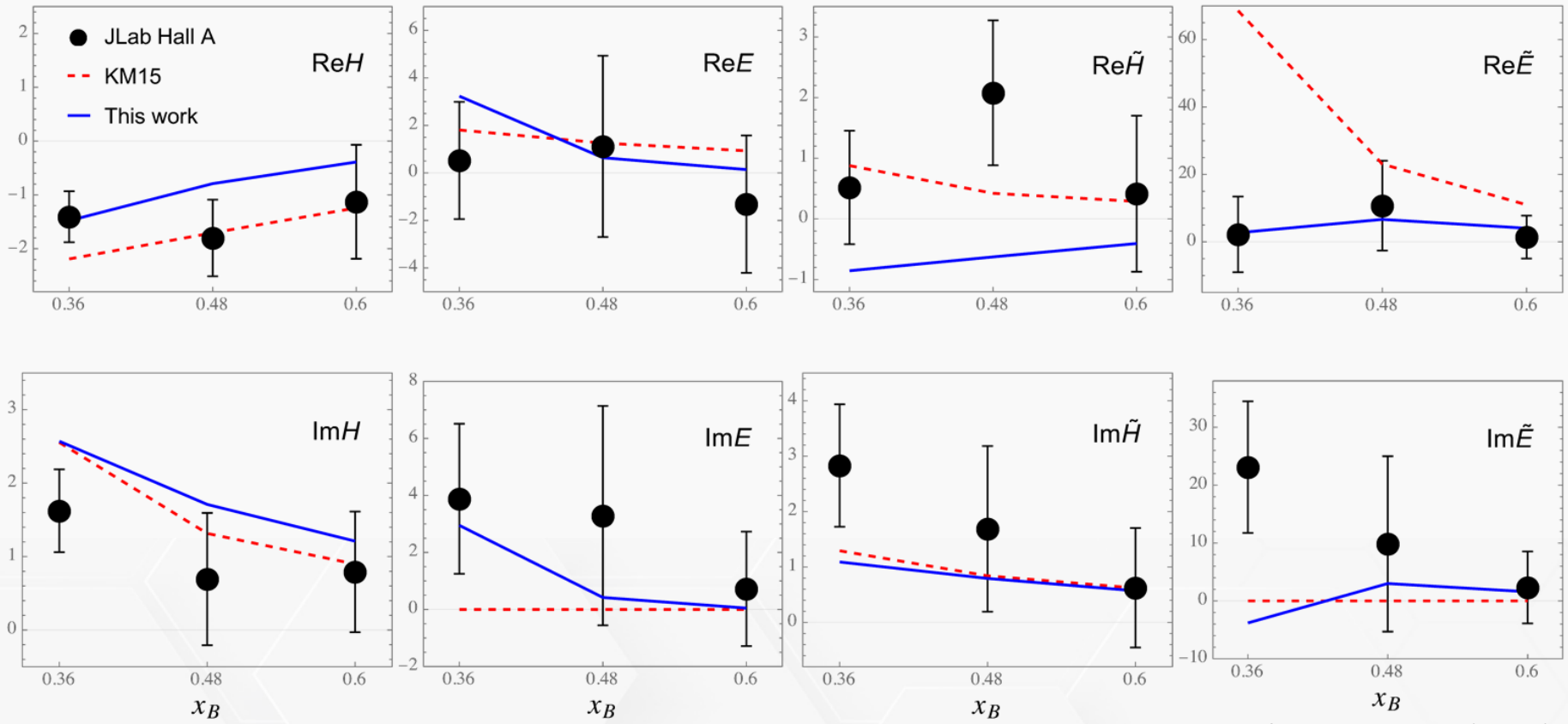
We would want:

- **Benchmark;**
- **Uncertainty quantification;**
- **Higher-order corrections;**
- **…**

However, the reality is:

- **Degeneracy in flavor space;**
- **Degeneracy in species space;**
- **Uncertainties in x-dependence**
- **…**

Degeneracy in Compton form factors



Y. Guo et. al. JHEP 05 150 (2023)

Polarized measurements are crucial to separate the CFFs of different species

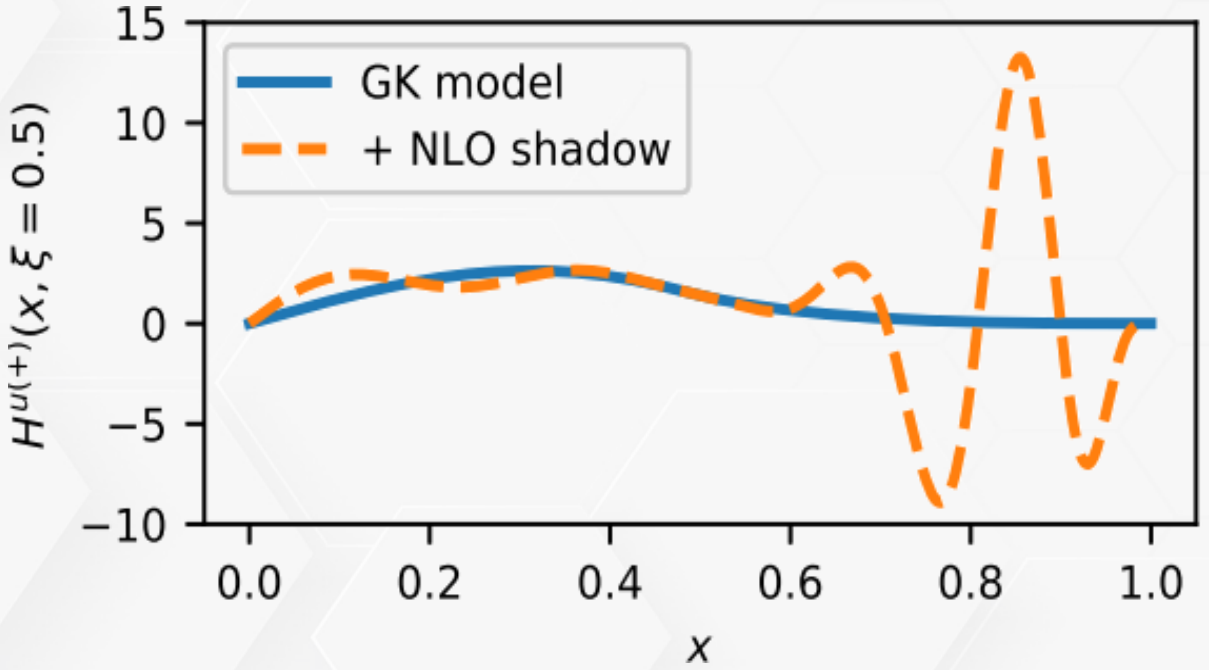
K. Shiells et. al. JHEP 08 048 (2022)

Inverse problem and shadow GPDs

The problem gets more severe at GPD level — the inverse problem.

$$\mathcal{H}_{CFF}(\xi,t) = -\sum_q Q_q^2 \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{x-\xi+i0} + \frac{1}{x+\xi-i0} \right) H_q(x,\xi,t) \ ,$$

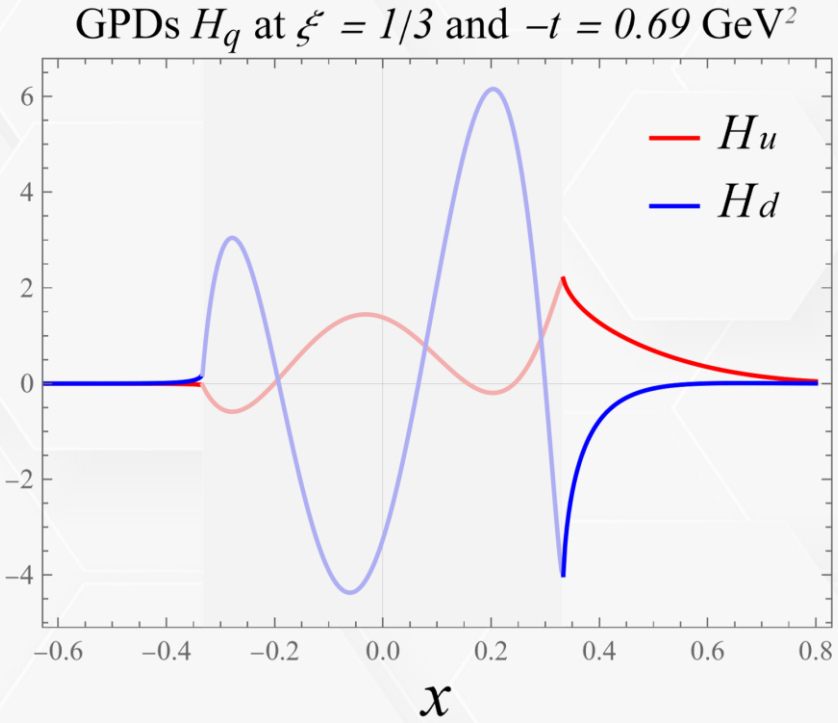
One cannot obtain a unique solution of the GPD from the CFF measurements alone.

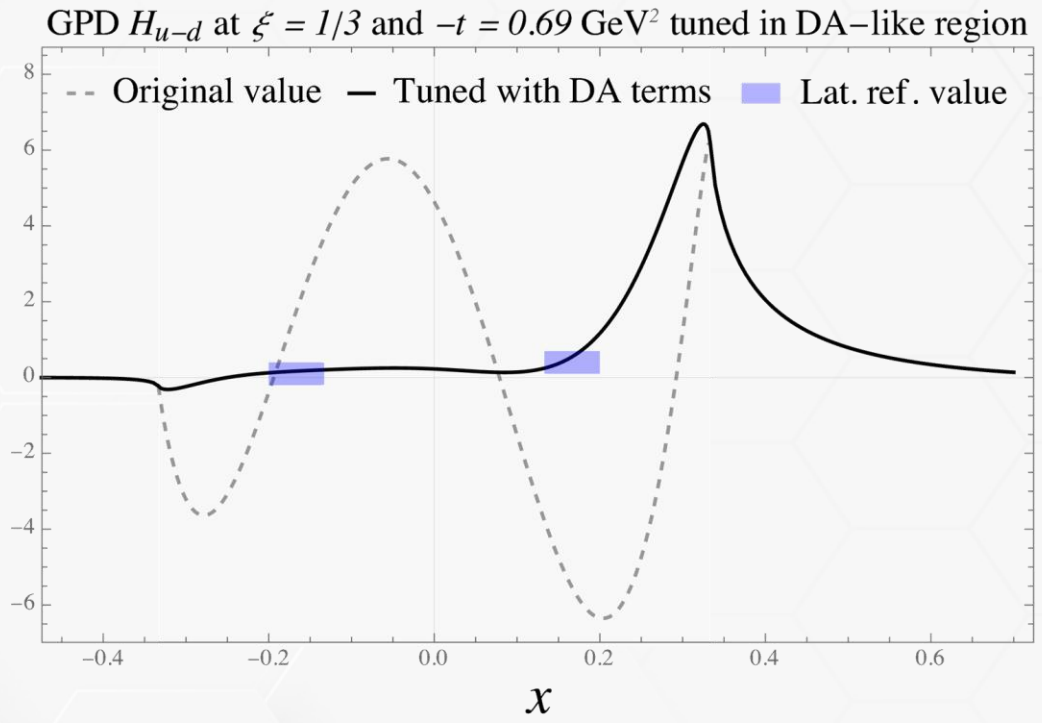


V. Bertone et. al. SciPost Phys.Proc. 8 (2022) 107

GPD tuned in the DA-like region

On the other hand, lattice input can be used to recover the missing x-dependence.





Y. Guo et. al. JHEP 05 150 (2023)

Another day has been saved?

Are we good to go?

The parameter table of the GUMP programs:

$$\lim_{\substack{\xi\to 0\\ t\to 0}} F(x,\xi,t) = N x^{-\alpha}(1-x)^{\beta}$$

1-2 parameters for the *t*-dependence and 1-2 parameters for the skewness.

> 5 parameters for each GPD with 4 species $(H, E, \widetilde{H}, \widetilde{E})$ and 5 flavor $(u, \bar{u}, d, \bar{d}, g)$.

Are we good to go?

The parameter ta

Sub-fits	χ^2	N_{data}	$\chi^2_\nu \equiv \chi^2/\nu$
Semi-forward			
tPDF H	281.7	217	1.41
tPDF E	59.7	50	1.36
tPDF $\widetilde{H}$	159.3	206	0.84
tPDF $\widetilde{E}$	63.8	58	1.23
Off-forward			
JLab DVCS	1413.7	926	~ 1.53
H1 DVCS	19.7	24	~ 0.82
Off-forward total	1433	950	**1.53**
Total	2042	1481	**1.40**

1-2 parameters f e skewness.

> 5 parameters f flavor $(u, \bar{u}, d, \bar{d}, g)$.

In the LO and LT approximation with 56 parameters totally (18 off-forward) .

I look forward to see the failing of the naïve GUMP parameterization.

Inputs for the global analysis

Experiment

- PDFs from global analysis

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

  - Polarized and unpolarized PDFs from JAM

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

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

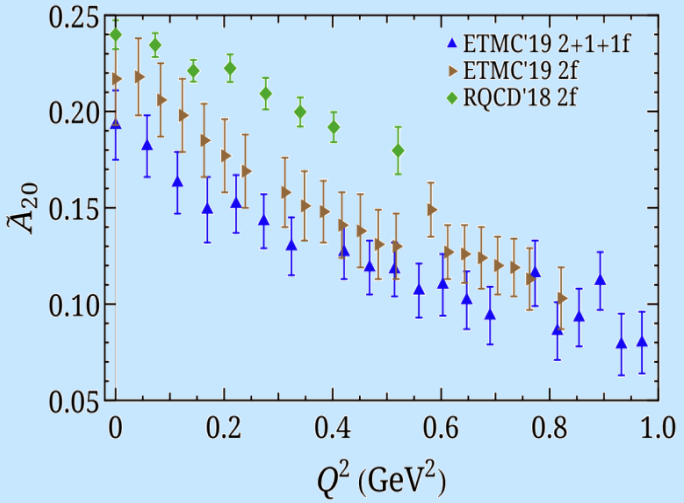
CLAS, Phys. Rev. Lett. 123 3, 032502 (2019)
JLab Hall A, PoS Hadron2017 170 (2018)

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

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

Lattice

- Lattice calculated form factors



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

- Lattice calculated t-dependent PDF at zero skewness

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

Summary and outlook

Summary

- 1st global analysis with DVCS and lattice input.
- The oversimplified ansatz manages to describe the data well.
- More (polarized) experimental/lattice inputs are crucial.

Outlook

- Include gluon distribution (J/psi & others)
- Implementing NLO evolutions.
- Simultaneous quark and gluon extraction.

Thank you!