STRONG-2020

Annual Meeting 2024

WP23-JRA5 (GPD-ACT)

Krešimir Kumerički (University of Zagreb, Croatia)
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Plan of presentation

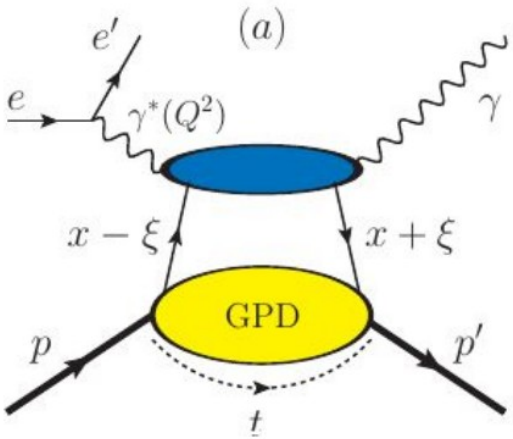
01 Introduction

02 Important highlights of the performed work (last year + full project duration)

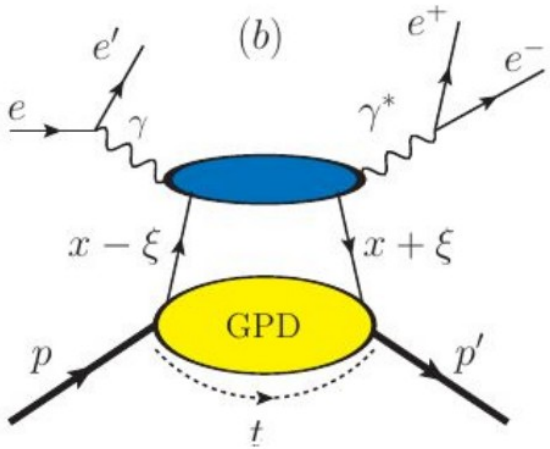
03 Tasks and achievements beyond the initial Work Program and/or tasks which could not be carried out

Objective of this WP : Generalized Parton Distributions (GPDs)

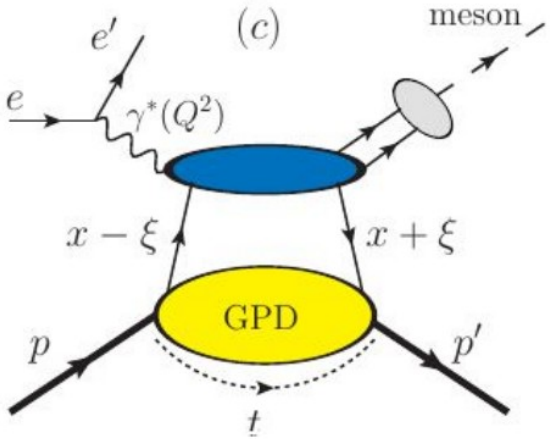
Measurable in many exclusive processes :



DVCS



double DVCS



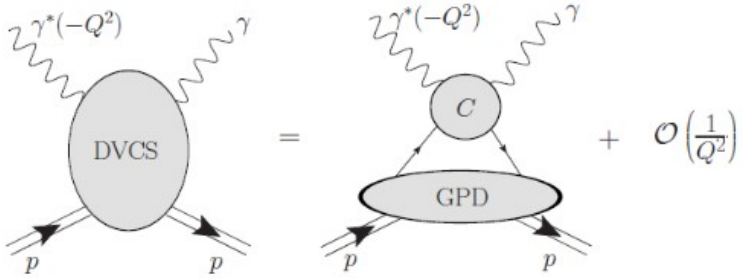
DVMP

GPDs are “hidden” inside Compton Form Factors

Compton form factors (CFFs)

$$\mathcal{H}(\xi, t, Q^2), \quad \mathcal{E}(\xi, t, Q^2), \quad \widetilde{\mathcal{H}}(\xi, t, Q^2), \quad \widetilde{\mathcal{E}}(\xi, t, Q^2)$$

- [Collins et al. '98]



- CFFs are convolution:

$$^a\mathcal{H}(\xi, t, Q^2) = \int \mathrm{d}x \; C^a(x, \xi, \frac{Q^2}{Q_0^2}) \; H^a(x, \xi, t, Q_0^2) \qquad a=q,G$$

- $H^a(x, \eta, t, Q_0^2)$ — Generalized parton distribution (GPD)

  [Müller '92, et al. '94, Ji, Radyushkin '96]

"Classical" objectives of GPD studies :

1. Ji's "sum rule"

$$J^a_z = \frac{1}{2}\int_{-1}^{1} dx\, x \Big[H^a(x,\xi,t) + E^a(x,\xi,t)\Big]_{t\to 0} \qquad \text{[Ji '96]}$$

   - Mellin moments of GPD are generally difficult to access
   - E is particularly poorly constrained by present data

2. 3D tomography

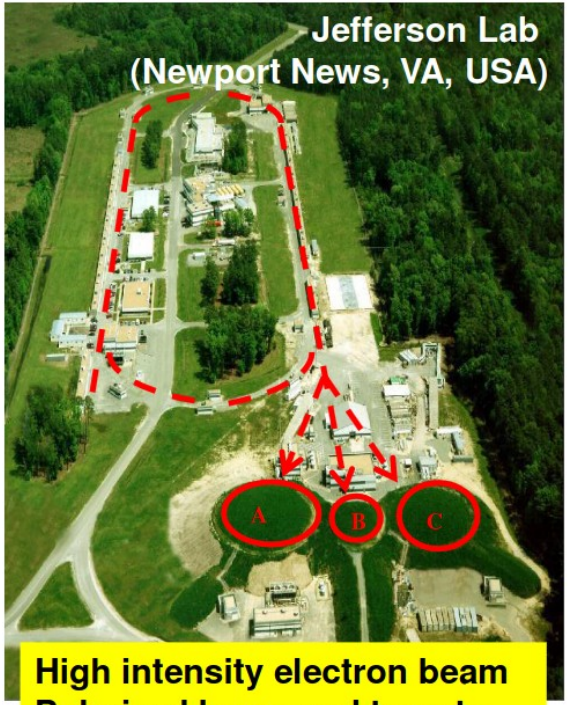
$$\rho(x, \vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} e^{-i\vec{b}_\perp\cdot\vec{\Delta}_\perp} H(x,0,-\vec{\Delta}^2_\perp) \qquad \text{[Burkardt '00]}$$

   - experiments are mostly sensitive to $H(x,x,t)$
   - "deskewing" to $H(x,0,t)$ — model dependent

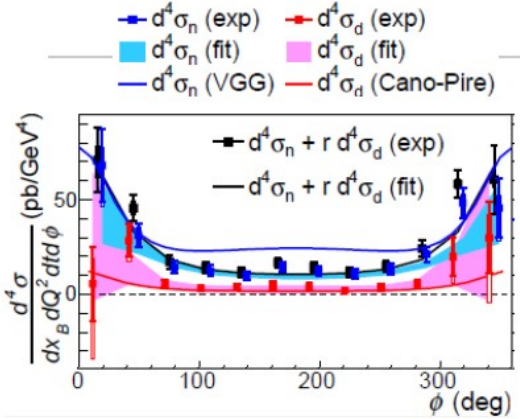
3. Gravitational form factors

Some objectives :

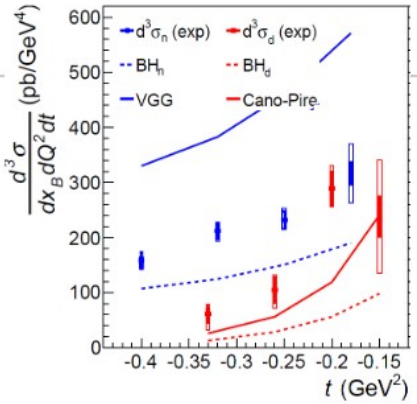
- Analysis of GPD experiments at **JLab@6 GeV** and of DVCS and DVMP with a recoil detector **at COMPASS**
- Preparation, data taking, and analysis of new experiments for **JLab@12GeV** (nDVCS, nuclear DVCS, TCS, DDVCS)
- Producing projections for GPD experiments to propose for the Electron Ion Collider (EIC)
- Building models of GPDs (standard twist-2, but also twist-3 and transversity GPDs), using also the constraints obtained by lattice QCD calculations
- Improved theoretical studies, including higher order and higher twist corrections
- Both experimental and theoretical efforts will be combined in **extraction of GPD information by fits to the data**.



DVCS off the neutron in Hall A @ 6 GeV



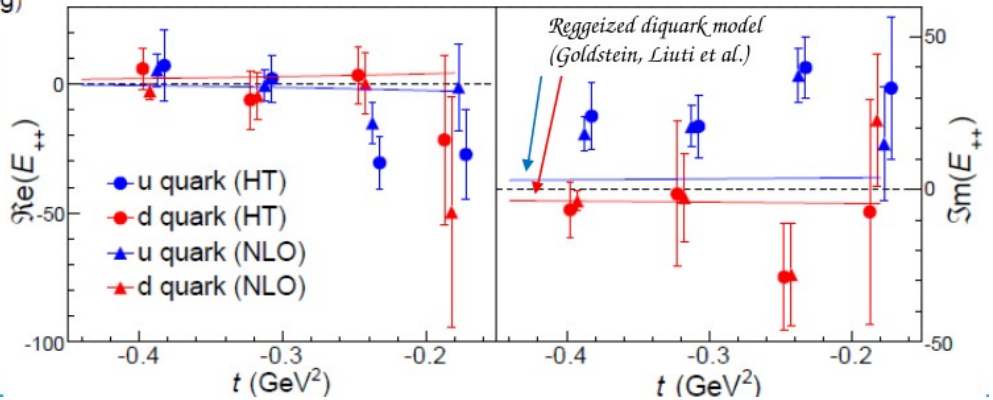
- Coherent deuteron & quasi-free neutron DVCS cross sections off LD_2
- 1st observation of DVCS signal off neutron
- Unique sensitivity to GPD *E*



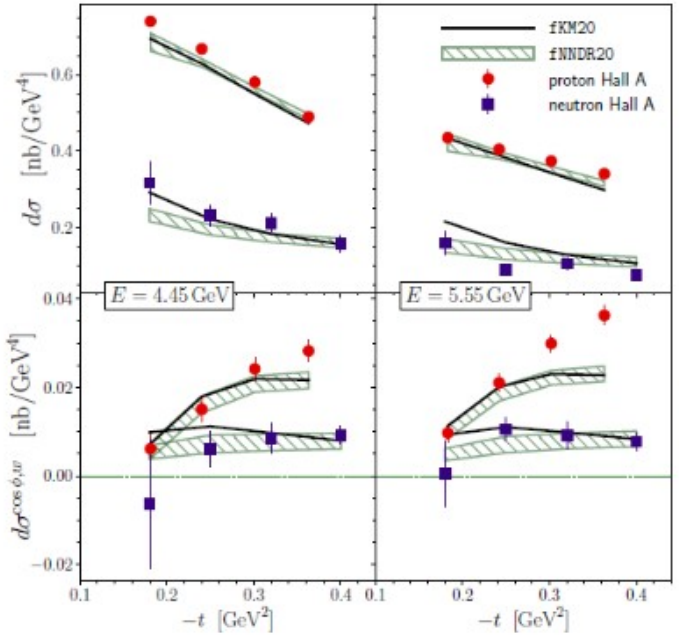
Flavor separation of CFFs when combined with p-DVCS

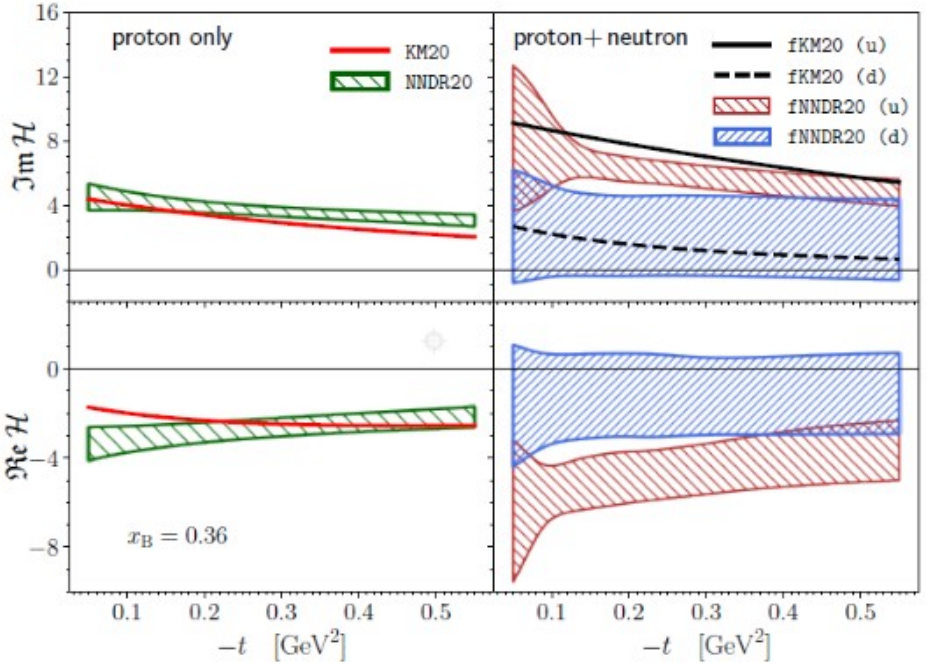
NLO and HT analyses performed:

M. Benali et al., Nature Physics (2020)



Adding neural nets to the mix ...

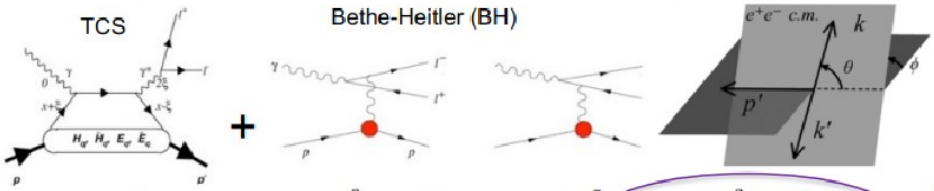




Clean separation of up and down valence quark distributions combining Proton and neutron DVCS data [M. Čuić, K.K., A. Schaefer, Phys.Rev.Lett. (2020)]

CLAS12 : First measurement of timelike Compton scattering

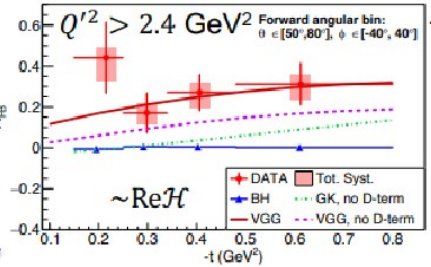
TCS – time-reversal symmetric process to DVCS:
incoming photon is real, and the outgoing photon has large time-like virtuality.

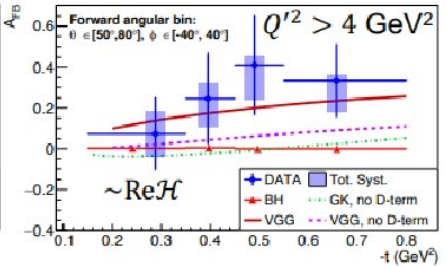


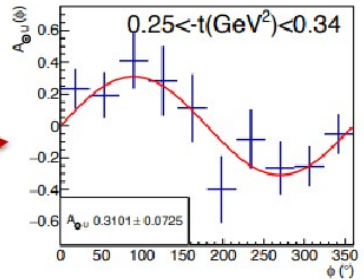
$$\frac{d\sigma_{INT}}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = -\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\Big[\cos\varphi\,\frac{1+\cos^2\theta}{\sin\theta}\,\mathrm{Re}\tilde{M}^{--} - \cos 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Re}\tilde{M}^{0-} + \cos 3\varphi\,\sin\theta\,\mathrm{Re}\tilde{M}^{+-} + O\Big(\frac{1}{Q'}\Big)\Big]$$

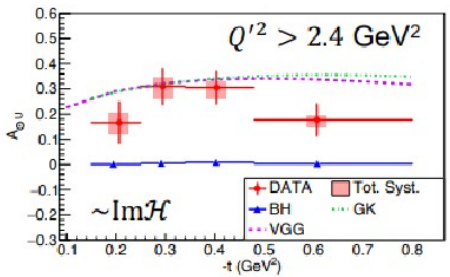
Incoming photon polarization

$$-\lambda\,\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{M}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\Big[\sin\varphi\,\frac{1+\cos^2\theta}{\sin\theta}\,\mathrm{Im}\tilde{M}^{--} - \sin 2\varphi\,\sqrt{2}\cos\theta\,\mathrm{Im}\tilde{M}^{0-} + \sin 3\varphi\,\sin\theta\,\mathrm{Im}\tilde{M}^{+-} + O\Big(\frac{1}{Q'}\Big)\Big].$$







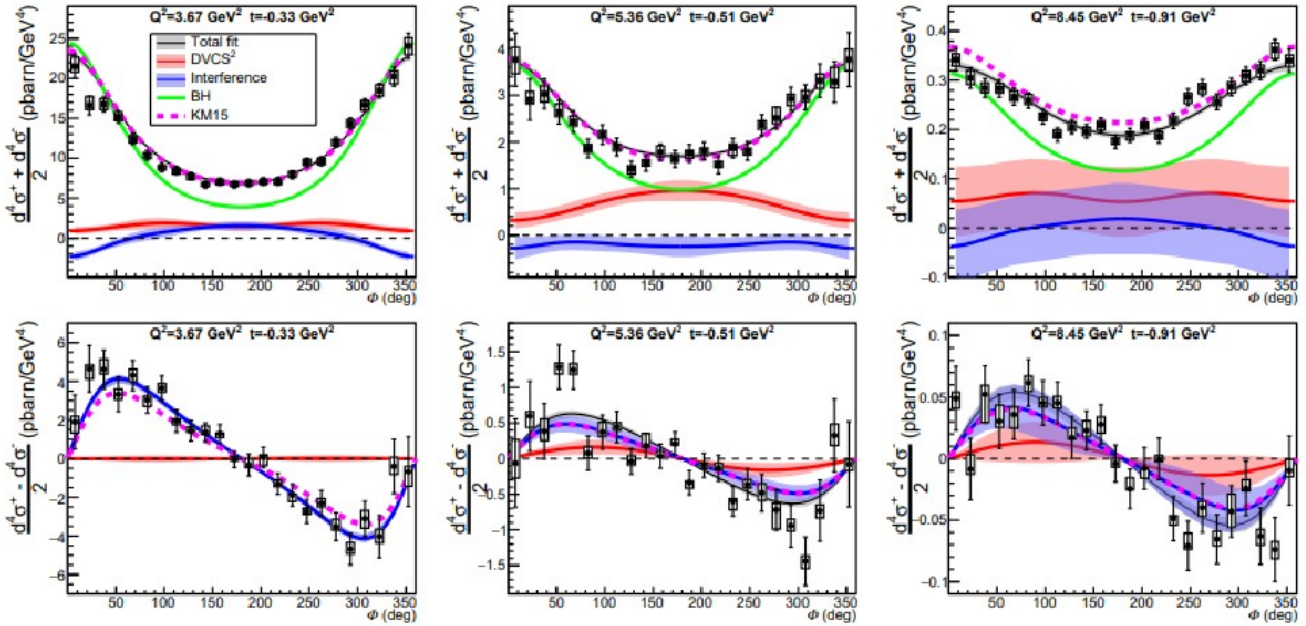


γp→γ*p→e⁺e⁻p

Phys. Rev. Lett. 127, 262501 (2021)

- The beam helicity asymmetry of TCS accesses the imaginary part of the CFF in the same way as in DVCS and **probes the universality of GPDs**
- The forward-backward asymmetry is sensitive to the real part of the CFF → direct access to the Energy-Momentum Form Factor $D_q(t)$ that relates to the **mechanical properties of the nucleon** (quark pressure distribution)
- This measurement proves the importance of TCS for GPD physics.

Hall A : High-precision cross-sections for DVCS on the proton

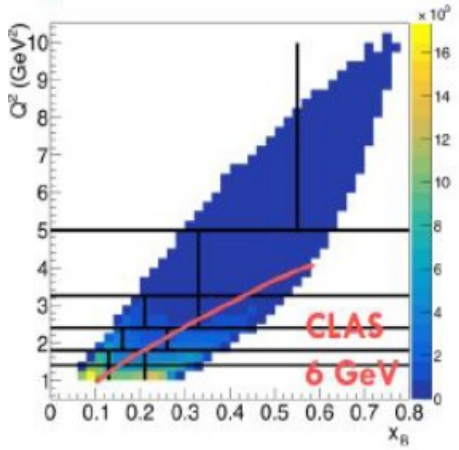


- High precision DVCS cross sections up to large x_B, for 3 beam energies
- Separation of BH, DVCS², Interference terms
- Sensitivity to all 4 Compton Form Factors

Phys. Rev. Lett. 128, 252002 (2022)

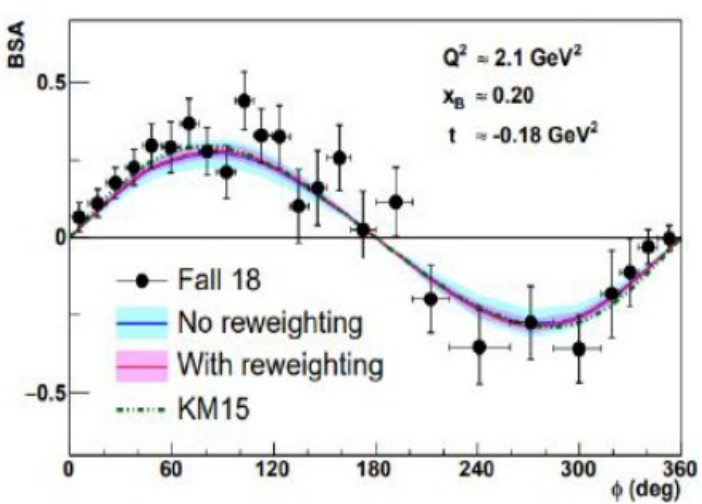
CLAS12 : DVCS beam spin asymmetry

Phys. Rev. Lett. **130**, 211902 (2023)



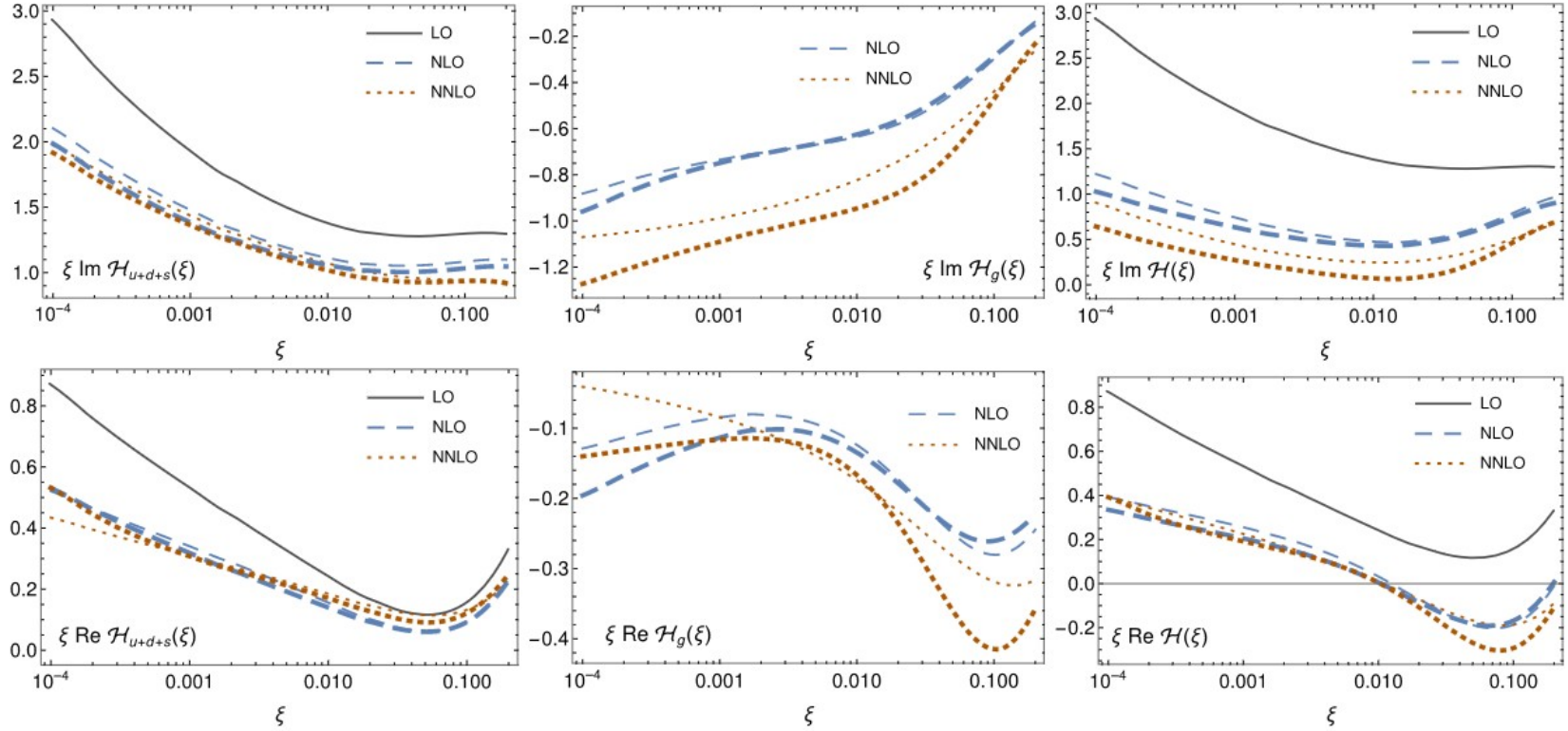
$\vec{e}p \rightarrow epγ$

- Polarized beam (86%) E=10.6 GeV; unpolarized LH2 target
- 64 kinematical bins (Q^2, x_B, -t)
- Many kinematics never covered before
- In previously measured kinematics, the new data are shown to be in good agreement with existing data and improve the precision of GPD fits



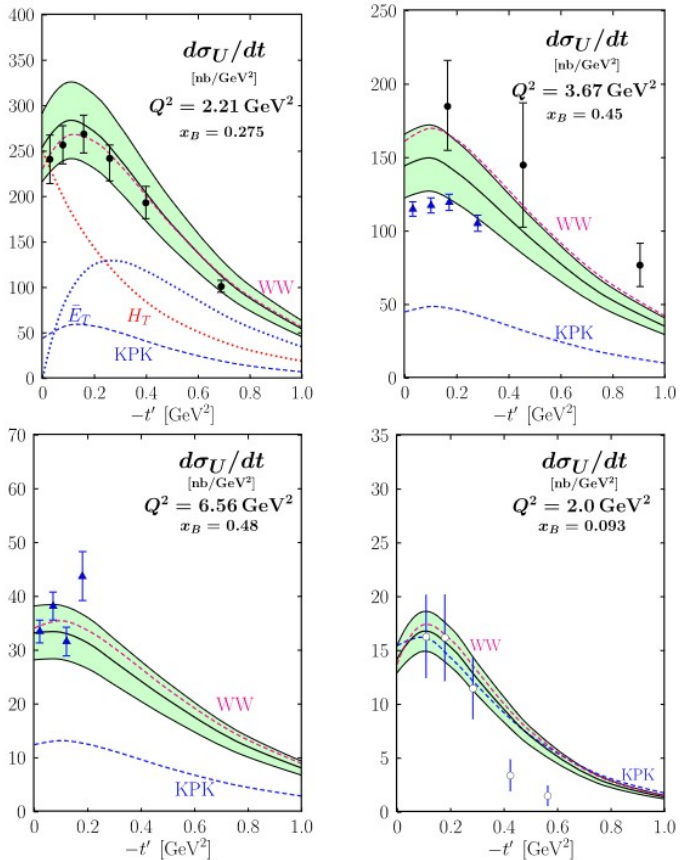
Progress towards NNLO DVCS [V. Braun et al. '22]

PHYSICAL REVIEW LETTERS **129,** 172001 (2022)



Twist-3 contributions to DVMP of pions

$$\frac{d\sigma_U}{dt} = \frac{d\sigma_T}{dt} + \epsilon \frac{d\sigma_L}{dt},$$

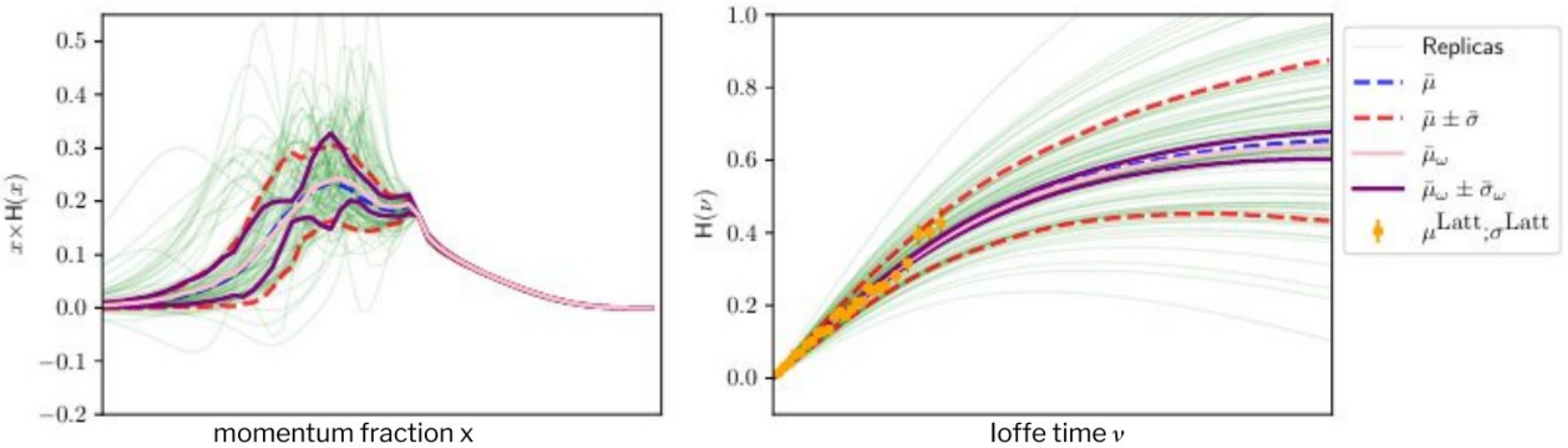


Favorable comparison to Jlab and COMPASS measurements

Constraining GPDs by lattice data

[M.J. Riberdy et al., EPJC (2024)]

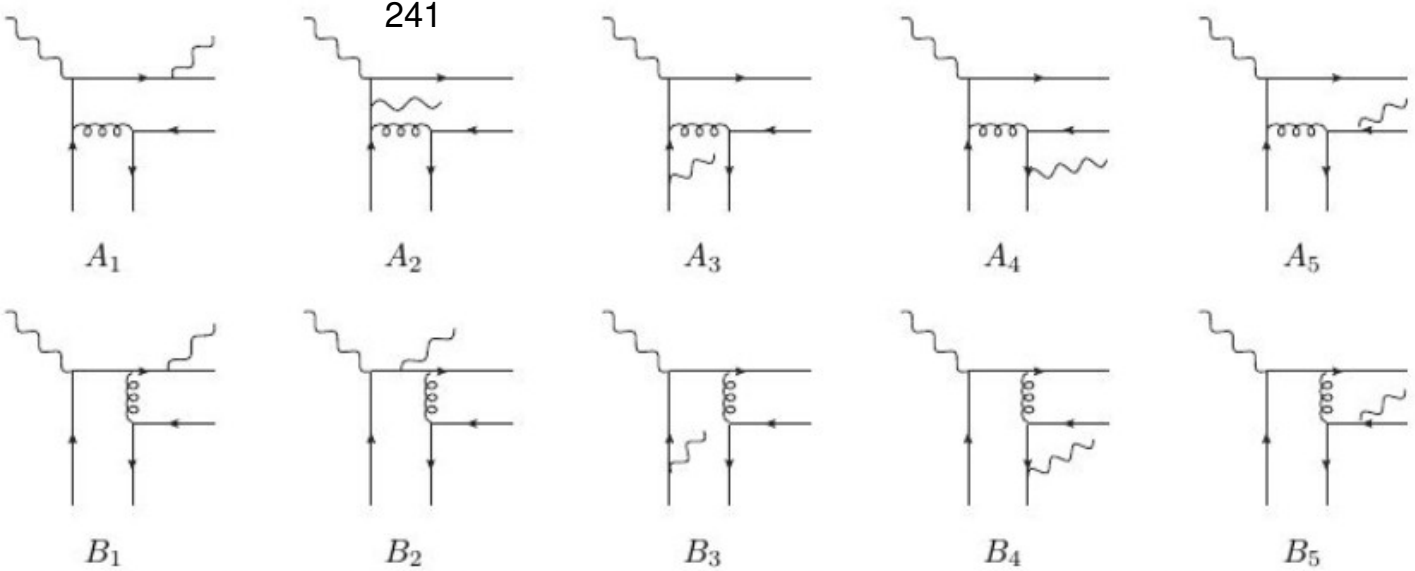
Combining lattice QCD and phenomenological inputs on GPDs at moderate skewness, 2306.01647



Also: *The case for an EIC Theory Alliance*, 2305.14572; *Exclusive meets inclusive particle production at small Bjorken x_B*, 2302.07861; *Matching GTMDs onto GPDs at one loop*, 2207.0952; *Revisiting evolution equations for GPDs*, 2206.01412.

GPDs from other processes

Accessing chiral-even quark GPDs in the exclusive photoproduction of a γπ± pair …, 2212.00655, JHEP (2023) 241

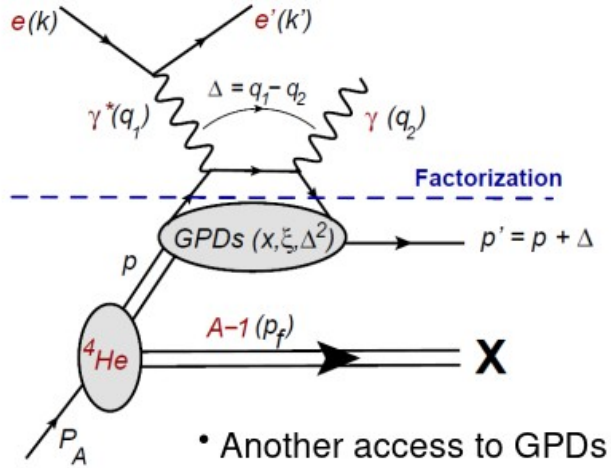


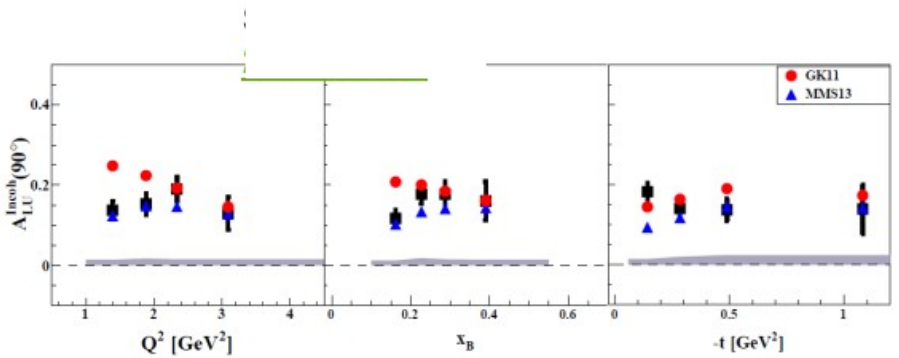
Also: *Transition GPDs and exclusive electroproduction of π-Δ(1232)*, 2211.09474; *Probing chiral-even and chiral-odd leading twist quark GPDs through the exclusive photoproduction of a γp pair*, 2302.12026, PRD 107 (2023) 094023; Breakdown of collinear factorization in the exclusive photoproduction of a $\pi^0\gamma$ *pair with large invariant mass, 2311.09146*

[S. Nabeebaccus et al.]

Incoherent DVCS off 4He

[S. Fucini et al, PRC (2020)]

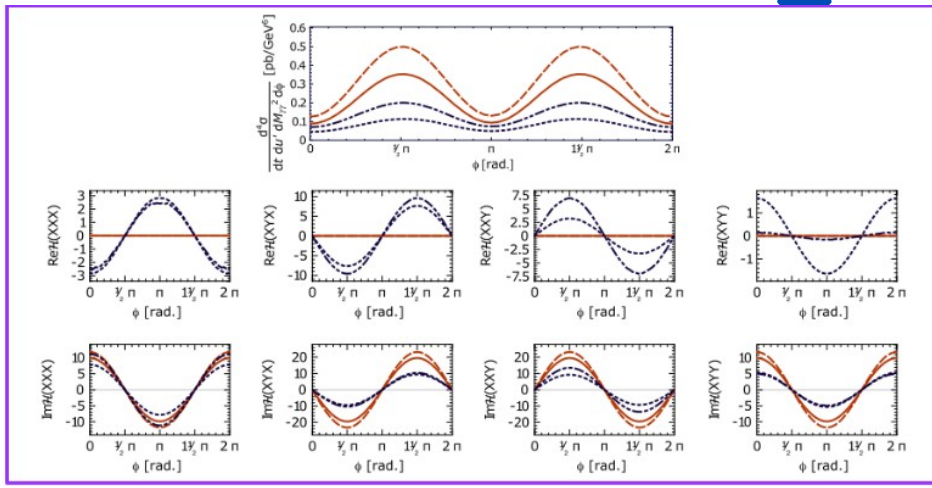




- Another access to GPDs --- of the **bound** proton
- Theory developed and confronted with recent data from JLab
- Perspectives for EIC
- The cross sections for coherent DVCS off ^{4}He calculated by the INFN-Perugia are being used to develop an event generator for JLab12 and EIC

More theory/phenomenology results:

- *Progress and opportunities in backward angle (u-channel) physics*, Eur. Phys. J. A 57 (2021) 12, 342
- *Collinear factorization of diphoton photoproduction at next to leading order*, Phys. Rev. D 104 (2021) 11, 114006
- *Phenomenology of diphoton photoproduction at next-to-leading order*, Phys. Rev. D 105 (2022) 9, 094025
- *Artificial neural network modelling of generalised parton distributions*, Eur.Phys.J.C 82 (2022) 3, 252
- *Accessing the Pion 3D Structure at US and China Electron-Ion Colliders*, Phys.Rev.Lett. 128 (2022) 20, 202501
- *Pion generalized parton distributions: A path toward phenomenology*, Phys.Rev.D 105 (2022) 9, 094012
- *Revisiting evolution equations for generalised parton distributions*, Eur.Phys.J.C 82 (2022) 10, 888
- *EpIC: novel Monte Carlo generator for exclusive processes*, Eur.Phys.J.C 82 (2022) 9, 819
- "Wide-angle photo- and electroproduction of pions to twist-3 accuracy", Phys. Rev. D 104 (2021) 5, 054040
- "Wide-angle photoproduction of the η′-meson and its gluon content", Phys. Rev. D 105 (2022) 3, 034005
- The pion in the graviton soft-wall model: phenomenological applications, Eur. Phys. J. C 82 (2022) 7, 626



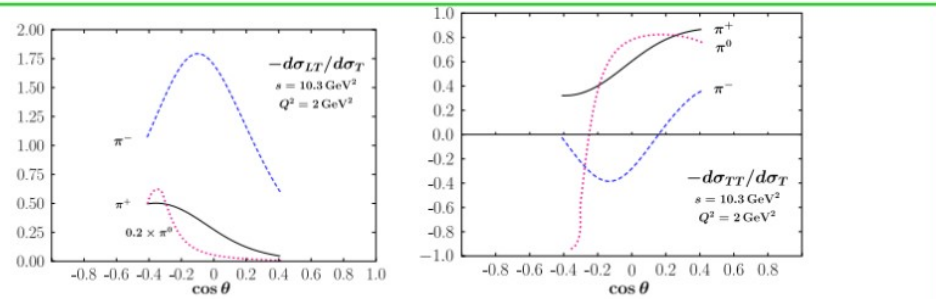
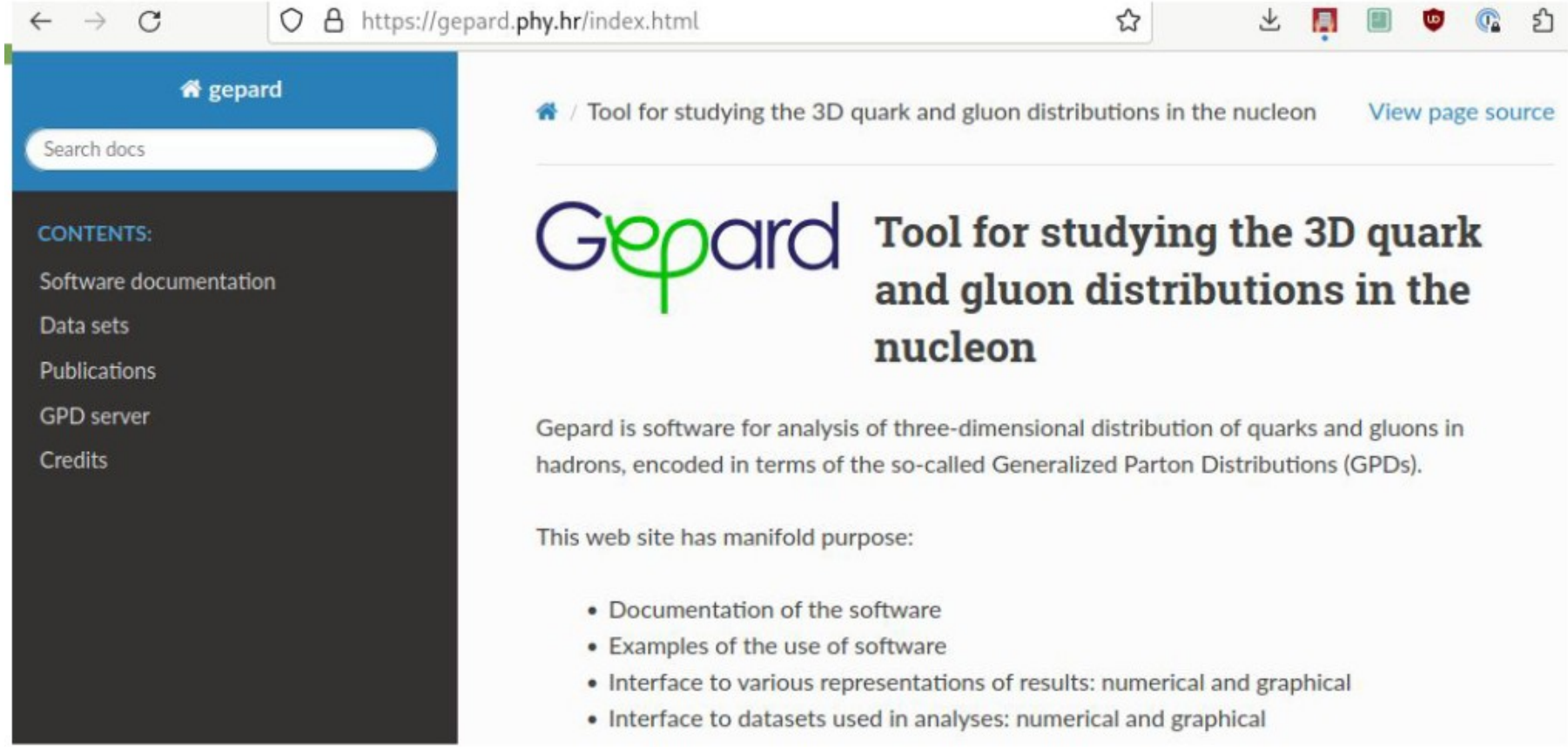


FIG. 9. Predictions for the longitudinal-transverse (left) and transverse-transverse (right) interference cross sections of pion electroproduction vs $\cos\theta$ at at $s = 10.3$ GeV^2 and $Q^2 = 2.0$ GeV^2. The interference cross sections are divided by the corresponding

Public analysis code (together with VA2-3DPartons)



GPD server

Select a model:

KM15

Select CFF:

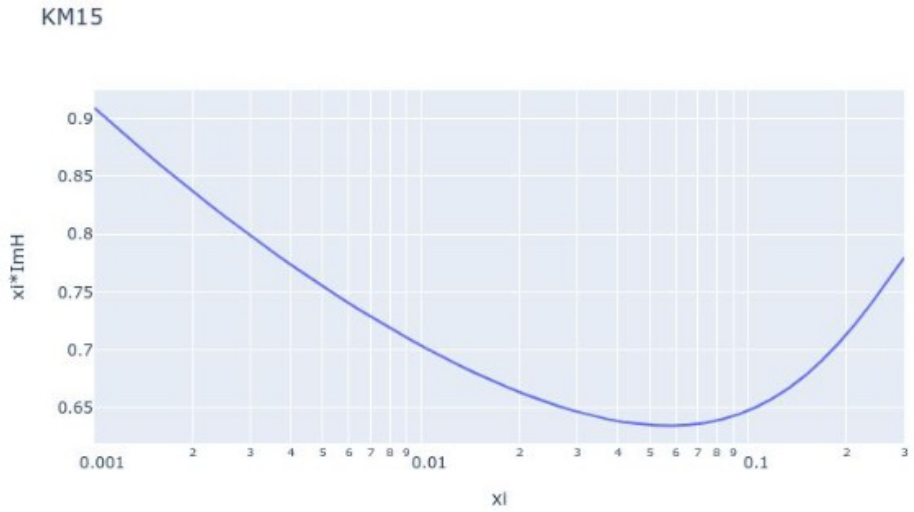
ImH

Mandelstam t -0.2

xi min 0.001 xi max 0.3

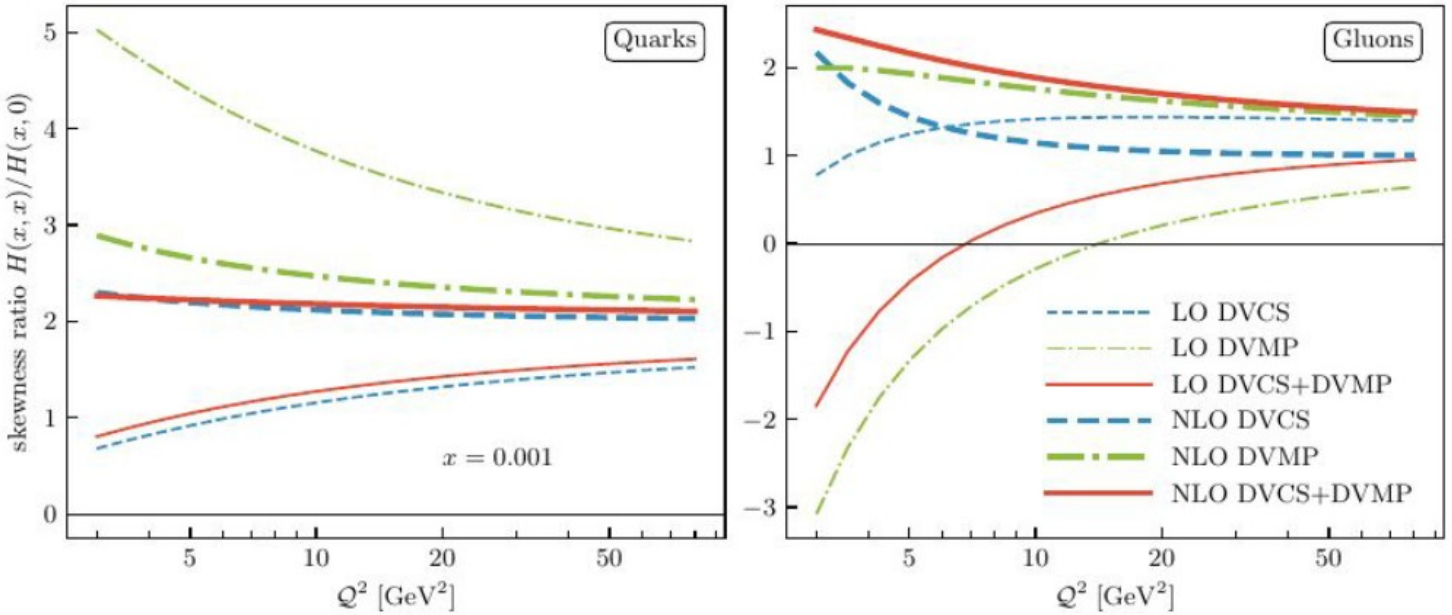
linear

logarithmic



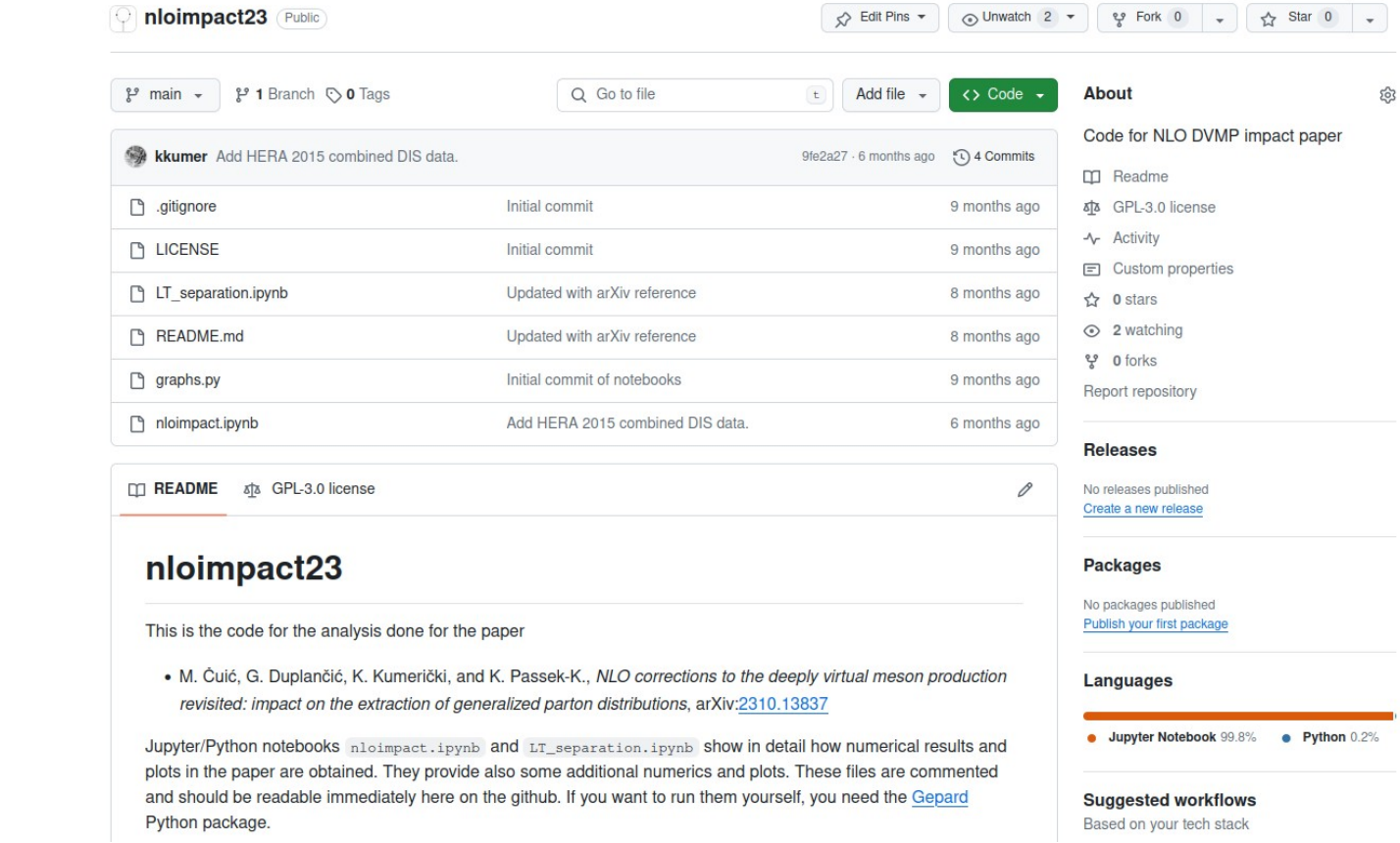
xi	xi*ImH
0.001	0.9089364494367499
0.0011234493440205147	0.8962380895532458

NLO DVMP and multichannel fits (HERA collider data)



[M. Čuić, G. Duplančić, K.K., K. Passek-K. JHEP 12 (2023)]

FULL reproducibility:



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kkumer Add HERA 2015 combined DIS data. 9fe2a27 · 6 months ago | 4 Commits

.gitignore	Initial commit	9 months ago
LICENSE	Initial commit	9 months ago
LT_separation.ipynb	Updated with arXiv reference	8 months ago
README.md	Updated with arXiv reference	8 months ago
graphs.py	Initial commit of notebooks	9 months ago
nloimpact.ipynb	Add HERA 2015 combined DIS data.	6 months ago

README | GPL-3.0 license

nloimpact23

This is the code for the analysis done for the paper

- M. Čuić, G. Duplančić, K. Kumerički, and K. Passek-K., *NLO corrections to the deeply virtual meson production revisited: impact on the extraction of generalized parton distributions*, arXiv:2310.13837

Jupyter/Python notebooks `nloimpact.ipynb` and `LT_separation.ipynb` show in detail how numerical results and plots in the paper are obtained. They provide also some additional numerics and plots. These files are commented and should be readable immediately here on the github. If you want to run them yourself, you need the Gepard Python package.

About

Code for NLO DVMP impact paper

Readme
GPL-3.0 license
Activity
Custom properties
0 stars
2 watching
0 forks
Report repository

Releases

No releases published
Create a new release

Packages

No packages published
Publish your first package

Languages

Jupyter Notebook 99.8% Python 0.2%

Suggested workflows

Based on your tech stack

Status of deliverables

Number	Title	Lead beneficiary	Type	Due Date	Status
D23.1	Publication of TJNAF@12 GeV Resuts of GPD experiments	1 - CNRS	Report	36	DELIVERED
D23.2	Publication of COMPASS results	2 - CEA	Report	48	IN THE WORKS
D23.3	Public software serving GPD fit results	26 - UNIZG	Open Research Data Pilot	46	DELIVERED

COMPASS deliverable

- Exclusive pi0 production results presented on
- several conferences – publication due soon
- Determination of SDME on exclusive phi production – publication
- in the process of writing
- DVCS – hampered by the inconsistency of two measurements

Deliverable unlikely to be delivered.

Contributing institutions

Università degli Studi di Perugia

cea

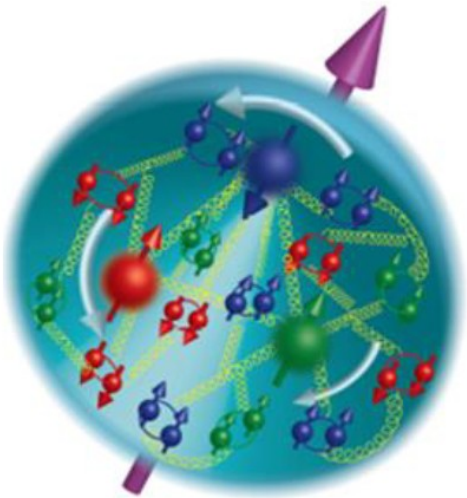
Institut Ruđer Bošković

Universität Regensburg

UNI FREIBURG

Universidad de Huelva

VNIVERSITAT DE VALÈNCIA



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