Some recent advances in GPD extraction from exclusive processes

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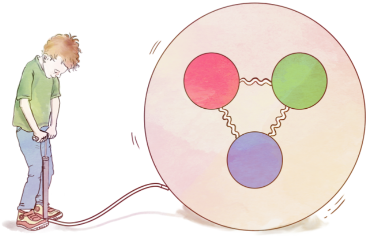
EUROPSKI STRUKTURNI I INVESTICIJSKI FONDOVI

STRONG 2020



Outline

Executive summary

- Experiments — **steady progress**
  - Deeply Virtual Compton Scattering (DVCS): many observables measured in a wide kinematics range
  - Deeply Virtual Meson Production (DVMP)
  - timelike DVCS, double DVCS (soon?)
- Theory — **healthy and fine**
  - factorization theorems; subleading twists; hard scattering coefficients, evolution kernels etc. known up to NNLO (recent developments: [Braun, Manashov, Moch, Strohmeier])
- Phenomenology and fits — **limping behind!**
  - latest global fits don't even use proper full LO evolution
  - [PARTONS], [CNF], [D. Müller, K.K., M. Čuić]

The Method

Two models

1. "Physical" GPD (and CFF) model
2. Neural network parametrization of CFFs

Modelling sea quark and gluon GPDs

- Instead of considering momentum fraction dependence $H(x, \ldots)$
- ...it is convenient to make a transform into complementary space of conformal moments j:

$$H_j^q(\xi, t) \equiv \frac{\Gamma(3/2)\Gamma(j+1)}{2^{j+1}\Gamma(j+3/2)} \int_{-1}^{1} \mathrm{d}x\, \xi^j\, C_j^{3/2}(x/\xi)\, H^q(x, \xi, t)$$

- $C_j^{3/2}(x)$ — Gegenbauer polynomials
- H_j is expanded in SO(3) partial waves and parametrized
- full QCD Q^2 evolution to NLO

Modelling valence quark GPDs

- **Hybrid models** at LO
- Sea quarks and gluons modelled like just described (conformal moments + SO(3) partial wave expansion + Q^2 evolution).
- Valence quarks model (ignoring Q^2 evolution):

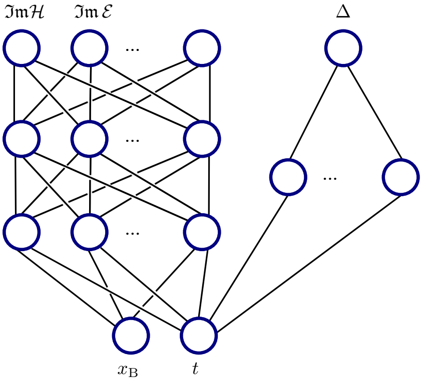
$$\mathfrak{Im}\,\mathcal{H}(\xi,t) = \pi\left[\frac{4}{9}H^{u_{\rm val}}(\xi,\xi,t) + \frac{1}{9}H^{d_{\rm val}}(\xi,\xi,t) + \frac{2}{9}H^{\rm sea}(\xi,\xi,t)\right]$$

$$H(x,x,t) = n\,r\,2^{\alpha}\left(\frac{2x}{1+x}\right)^{-\alpha(t)}\left(\frac{1-x}{1+x}\right)^{b}\frac{1}{\left(1-\frac{1-x}{1+x}\frac{t}{M^2}\right)^{p}}\,.$$

- Fixed: n (from PDFs), $\alpha(t)$ (eff. Regge), p (counting rules)

$$\alpha^{\rm val}(t) = 0.43 + 0.85\,t/{\rm GeV}^2 \quad (\rho,\,\omega)$$

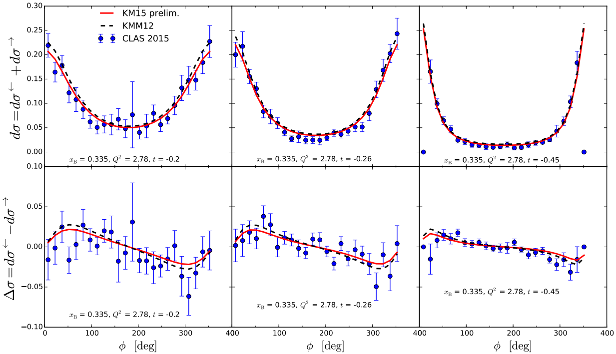
Networks constrained by dispersion relations



- Only imaginary part of CFFs and one subtraction constant $\Delta(t)$ are parametrized by neural nets
- Real parts are then fixed by dispersion relations

DVCS results

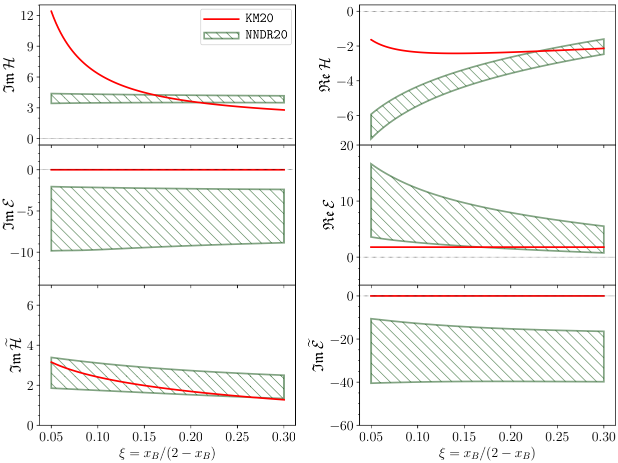
Example: CLAS cross-sections



-
- $\chi^2/\mathrm{npts} = 1032.0/1014$ for $d\sigma$ and $936.1/1012$ for $\Delta\sigma$

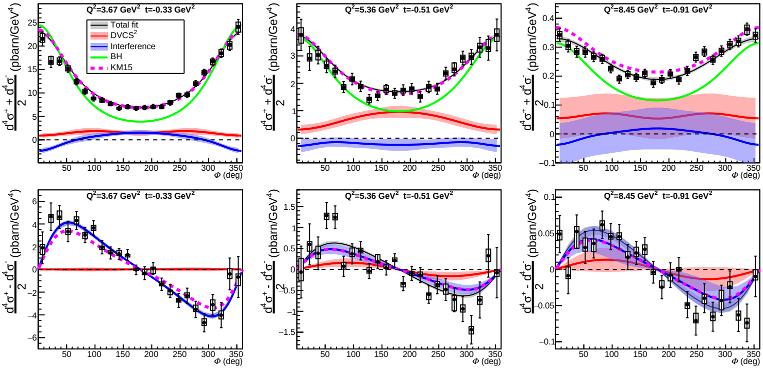
Extraction of 6 (out of 8) CFFs

[M. Čuić, K.K., A. Schäfer, '20], from JLab data



Prediction of large-x JLab DVCS data

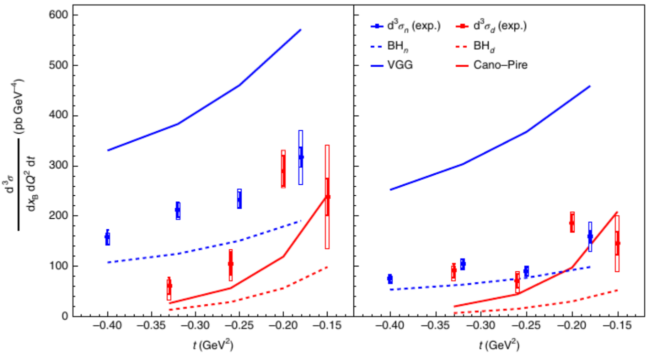
- [Hall A '22]



Neutron DVCS

Hall A neutron DVCS measurement

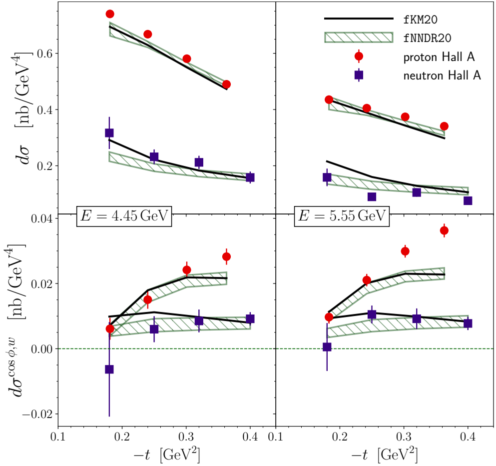
- [Benali et al. '20], DVCS off a deuterium target:



- Idea: combine proton and neutron DVCS data using isospin symmetry and get separate results for up and down quark contributions to CFFs

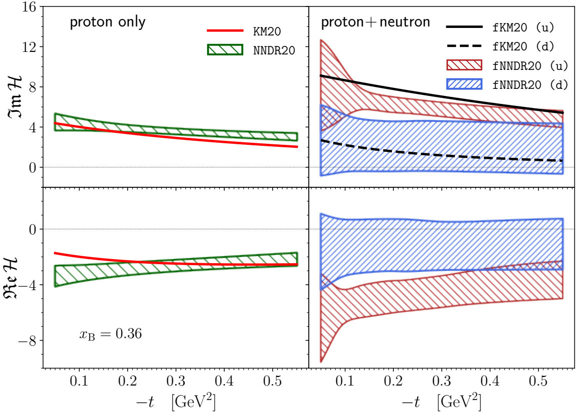
Including the neutron DVCS data

- Separate model for each flavor: $\mathcal{H} \to \mathcal{H}_u, \mathcal{H}_d$, etc.
- Flavored models: fKM ("physical"), fNNDR (neural nets + dispersion relations)



Separating flavored CFFs

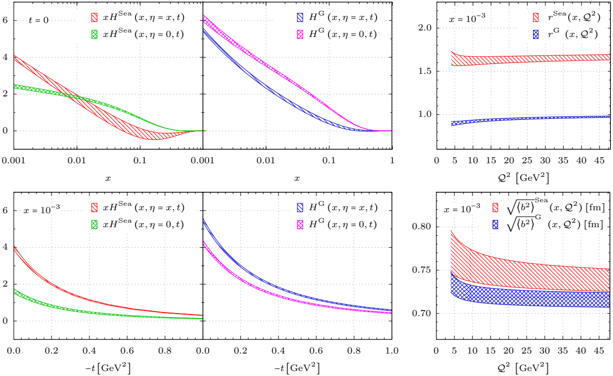
- Contributions of u and d quarks to CFF $\mathcal{H}$ are cleanly separated [M. Čuić, K.K., and A. Schäfer, PRL '20]



DVMP results

First NLO DIS+DVCS+DVMP small-x global fit

First global fits to DIS+DVCS+DVMP HERA collider data
[Lautenschlager, Müller, Schäfer '13, unpublished!]:

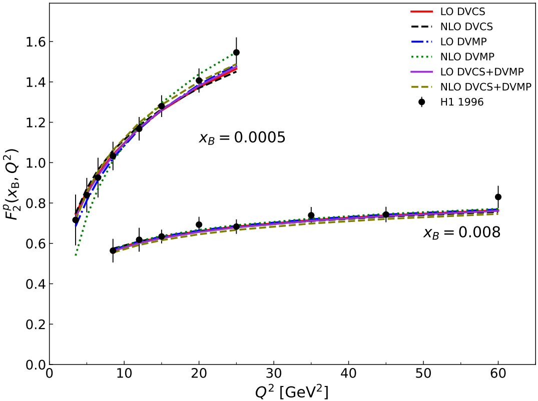


(Normalizations of experimental DVMP datasets treated as fitting parameters.)

New NLO DIS+DVCS+DVMP small-x global fit

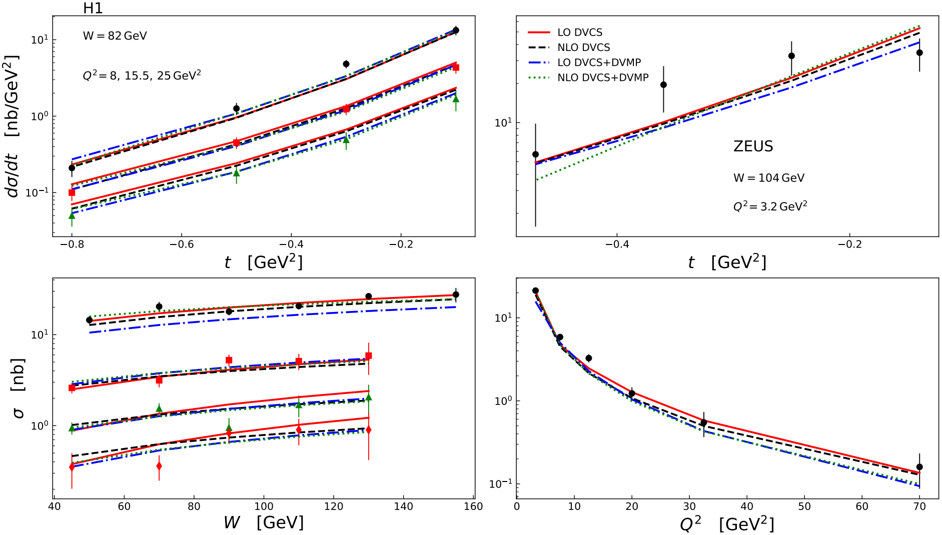
- hard scattering amplitude corrected in the meantime [Duplančić, Müller, Passek-K. '17]
- [M. Čuić, K.K. '22], revisiting DIS+DVCS+DVMP fit, preliminary results
- NLO DIS+DVCS+DVMP fit to HERA collider data (excluding t-dependent DVMP data) $\chi^2/n_{\rm d.o.f} = 254.3/231$
- For comparison, in the following, we also show
  - LO fits
  - fits without DVMP data
  - fits without DVCS data

DIS F2 data description

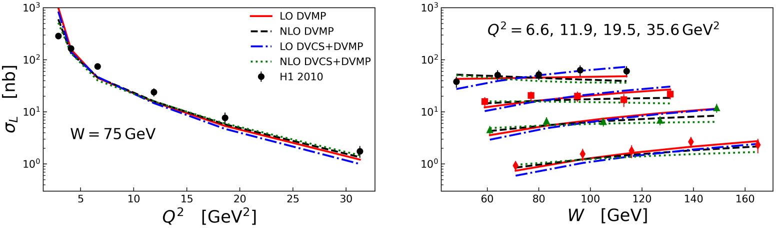


- May seem trivial, but not all popular GPD models describe DIS

DVCS data description

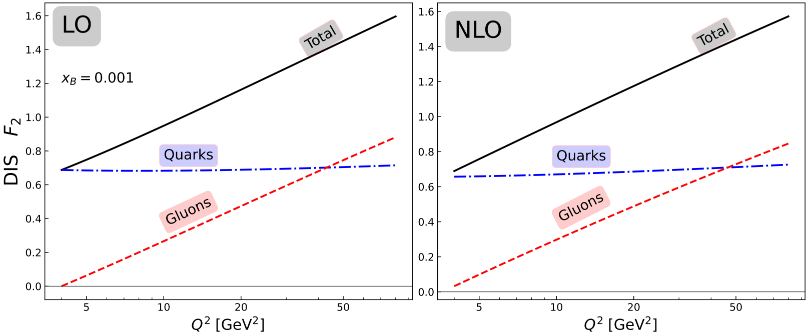


DVMP data description

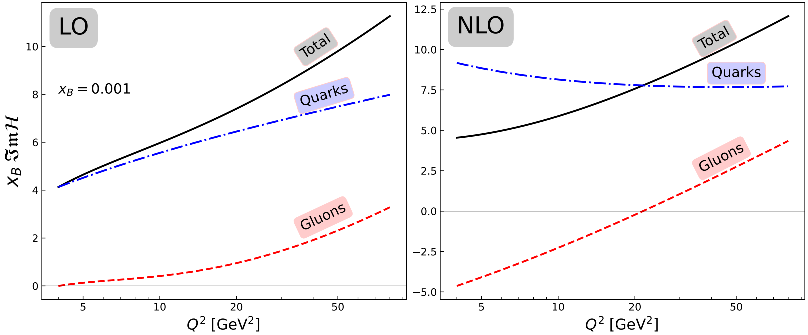


- Things we can learn from fits:
  - Effects of NLO corrections
  - Universality of GPD shape — separately from DVCS and DVMP

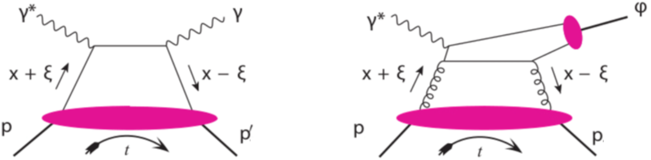
Quarks vs Gluons: DIS



Quarks vs Gluons: DVCS



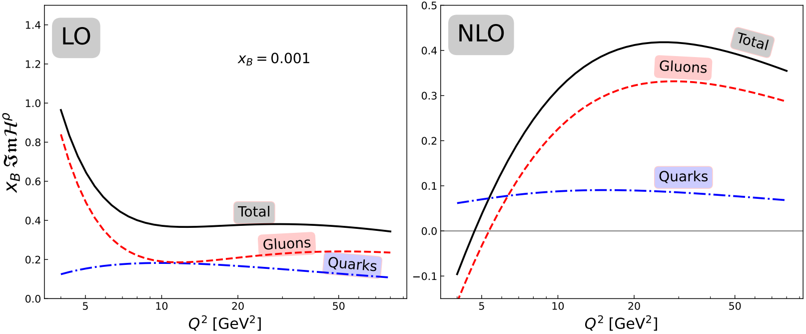
DVCS vs. DVMP



from 1708.00888

- Gluon GPD contributes to DVMP already at LO (at input scale)

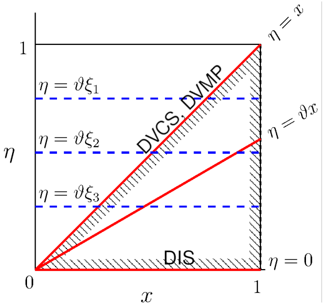
Quarks vs Gluons: DVMP



GPD skewness

- GPD "skewness": ratio of GPD to the corresponding PDF

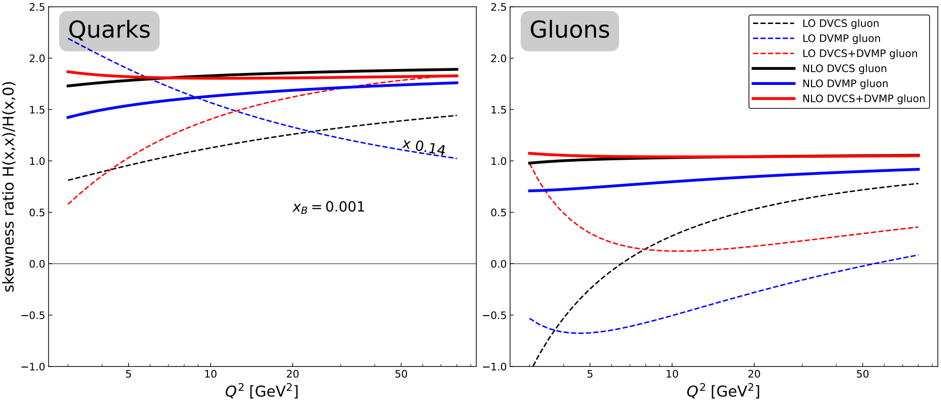
$$r = \frac{H(x, \eta = x)}{q(x)}$$



- Conformal (Shuvaev) values, with GPDs completely specified by PDFs:

$$r^{\text{Quark}} \approx 1.65 \,, \qquad r^{\text{Gluon}} \approx 1.0 \,.$$

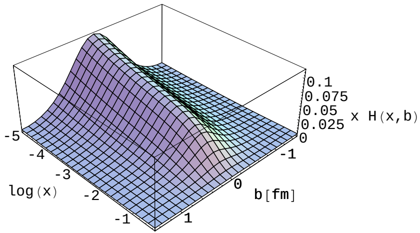
GPD skewness at LO and NLO

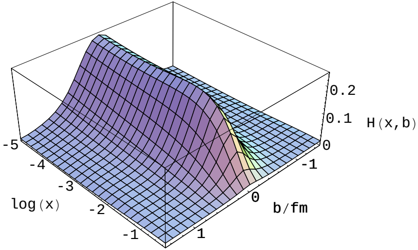


- Universal GPD structure emerges at NLO!

Tomography

- Resulting sea quark and gluon distributions $H(x, \vec{b}_\perp)$:





- (large-x part is still very model dependent)

Gepard - public code for GPD analysis

gepard

Search docs

CONTENTS:

- Software documentation
- Data sets
- Publications
- Credits

https://gepard.phy.hr/datasets.html

» Tool for studying the 3D quark and gluon distributions in the nucleon   View page source

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

Gepard is software for analysis of three-dimensional distribution of quarks and gluons in hadrons, encoded in terms of the so-called Generalized Parton Distributions (GPDs).

This web site has manifold purpose:

- Documentation of the software
- Examples of the use of software
- Interface to various representations of results: numerical and graphical
- Interface to datasets used in analyses: numerical and graphical

Contents:

Gepard - publications

- Aiming for full reproducibility of results.

gepard

Search docs

CONTENTS:

Software documentation

Data sets

Publications

Accompanying code runs with the latest version of Gepard package

Accompanying code runs only with old versions Gepard package

Credits

Accompanying code runs with the latest version of Gepard package

These papers have accompanying Jupyter notebooks, published on the github, which are easily runnable after installing the latest version of Gepard:

- K. Kumerički, D. Mueller, K. Passek-Kumerički and A. Schaefer, *Deeply virtual Compton scattering beyond next-to-leading order: the flavor singlet case*, Phys. Lett. B **648** (2007), 186-194, arXiv:hep-ph/0605237 [Code at github]
- K. Kumerički, D. Mueller, and K. Pasek-Kumerički, *Towards a fitting procedure for deeply virtual Compton scattering at next-to-leading order and beyond*, Nucl. Phys. B **794** (2008) 244-323, arXiv:hep-ph/0703179 [Code at github]
- K. Kumerički and D. Mueller, *Deeply virtual Compton scattering at small xB and the access to the GPD H*, Nucl. Phys. B **841** (2010) 1-58, arXiv:0904.0458 [Code at github]

Accompanying code runs only with old versions Gepard package

These papers have accompanying Jupyter notebooks, published on the github, but need old version of Gepard (available as *pyfortran* branch on the Gepard's github page), which can be tricky to compile and run

- M. Čuić, K. Kumerički, and A. Schäfer, *Separation of Quark Flavors using DVCS Data*, Phys. Rev. Lett. **125** (2020) 23, 232005, arXiv:2007.00029 [Code at github]
- K. Kumerički, *Measurability of pressure inside the proton*, Nature, 570 (2019) no. 7759, E1-E2,

The End