GPD studies with hard exclusive processes

Marija Čuić

University of Zagreb, Croatia

QCD Evolution Workshop 2023

May 22 – 26, 2023, IJCLab, Orsay

HRZZ Croatian Science Foundation

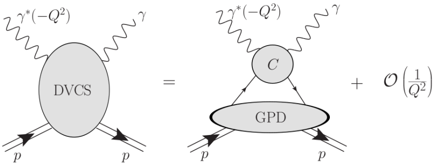
STRUKTURNI I INVESTICIJSKI FONDOVI

Outline

1. Introduction
2. Modelling
3. Results
   - CFF extraction
   - Flavor separation
   - DIS+DVCS+DVMP

Accessing GPDs

- exclusive processes such as DVCS and DVMP
- at leading order and twist-2 four complex Compton form factors $\mathcal{H}\left(\xi, t, Q^2\right), \mathcal{E}\left(\xi, t, Q^2\right), \widetilde{\mathcal{H}}\left(\xi, t, Q^2\right), \widetilde{\mathcal{E}}\left(\xi, t, Q^2\right)$
- factorization theorem [Collins et al. '98]



- CFFs are a convolution [Müller '92, et al. '94, Ji, Radyushkin '96]

$$^{a}\mathcal{H}\left(\xi, t, Q^2\right) = \int \mathrm{d}x \, C^a\left(x, \xi, \frac{Q^2}{Q_0^2}\right) \underbrace{H^a\left(x, \eta = \xi, t, Q_0^2\right)}_{\text{GPD}}, \ a = q, G$$

Types of models

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

Modelling GPDs

GPD evolution

- evolution in x space complicated, we use conformal moments

$$F_n(\eta, t) = \int_{-1}^{1} dx c_n(x,\eta) F(x,\eta,t)$$
$$c_n(x,\eta) = \eta^n \frac{\Gamma\left(\frac{3}{2}\right)\Gamma(1+n)}{2^n \Gamma\left(\frac{3}{2}+n\right)} C_n^{\frac{3}{2}}\left(\frac{x}{\eta}\right)$$

- $C_n^{3/2}$ Gegenbauer polynomials
- analytic continuation $n \to j \in \mathbb{C}$
- evolution diagonal in j space at LO

$$\mu \frac{d}{d\mu} F_j^q\left(\eta, t, \mu^2\right) = -\frac{\alpha_s(\mu)}{2\pi} \gamma_j^{(0)} F_j^q\left(\eta, t^2, \mu^2\right)$$

Hybrid model

- valence quarks modelled in x space ($q = u, d$) at crossover line $x = \xi$ (no Q^2 evolution)

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

- sea quarks and gluons modelled in j space
- $SO(3)$ partial waves expansion
- leading contribution

$$H_j^a(\eta = 0, t) = N^a \frac{\mathrm{B}\left(1 - \alpha^a + j, \beta^a + 1\right)}{\mathrm{B}\left(2 - \alpha^a, \beta^a + 1\right)} \frac{\beta(t)}{1 - \frac{t}{\left(m_j^a\right)^2}},$$

$$\left(m_j^a\right)^2 = \frac{1 + j - \alpha^a}{\alpha'^a}, \quad \beta(t) = \left(1 - \frac{t}{M^2}\right)^{-p}, \quad a = \{sea, g\}$$

- full NLO QCD Q^2 evolution

Dispersion relations

- CFFs constrained by dispersion relations

$$\mathfrak{Re}\,\mathcal{H}(\xi,t) \stackrel{LO}{=} \Delta(t) + \frac{1}{\pi}\mathrm{P.V.}\int_0^1 \mathrm{d}x \left(\frac{1}{\xi - x} - \frac{1}{\xi + x}\right)\mathfrak{Im}\,\mathcal{H}(x,t)$$

- only imaginary part of CFFs and one subtraction constant $\Delta(t)$ are modelled

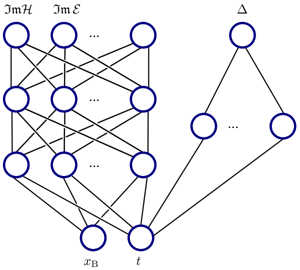


Figure: Neural nets architecture

Results

Models

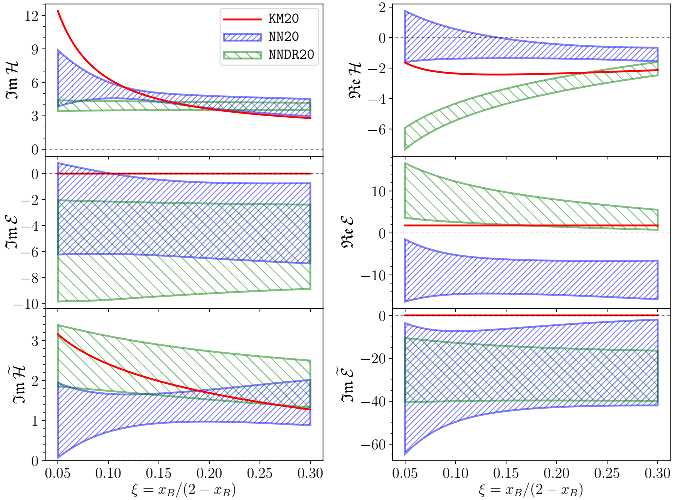
- physical models: KM, neural nets models: NN, dispersion relation constrained neural nets models: NNDR
- separate model for each flavor CFF: $\mathcal{H}_u$, $\mathcal{H}_d$, $\mathcal{E}_u$, $\mathcal{E}_d$
- using isospin symmetry and a simple model $\mathcal{H} = \frac{4}{9}\mathcal{H}_u + \frac{1}{9}\mathcal{H}_d$ $\rightarrow$ flavoured models fKM, fNN, fNNDR

	2020	2023
fNN	1.5	1.25
fNNDR	1.5	>3

Table: χ^2/N_{pts}

Extraction of 6 CFFs 2020

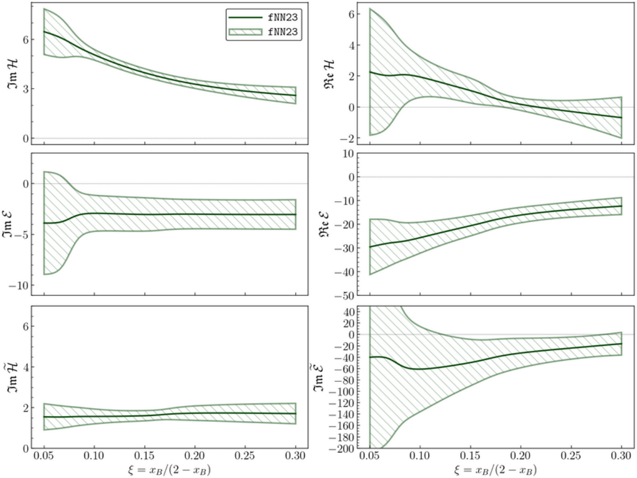
[M. Č., K. Kumerički, A. Schäfer, '20], JLab Hall A and CLAS data



$\mathcal{Q}^2 = 4$ GeV^2
$t = -0.2$ GeV^2

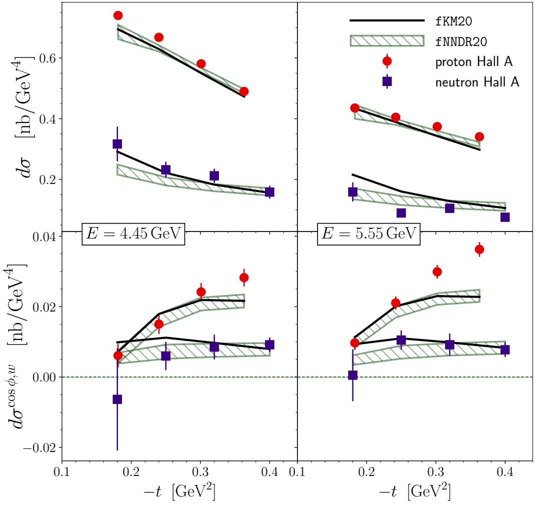
Extraction of 6 CFFs 2023

Preliminary CLAS proton and neutron DVCS BSA, S. Niccolai, A. Hobart, $E = 10.4$ GeV



$\mathcal{Q}^2 = 4$ GeV^2
$t = -0.2$ GeV^2

Hall A 2020 measurements



$x_B = 0.36$
$\mathcal{Q}^2 = 1.75$ GeV^2

Flavor separation of $\mathcal{H}$

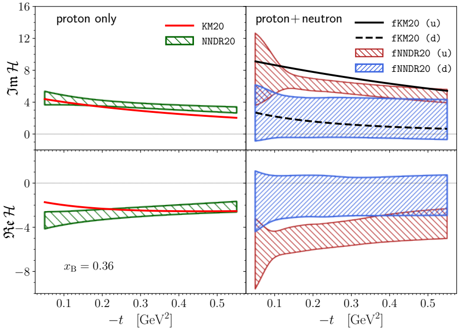


Figure: 2020 fits

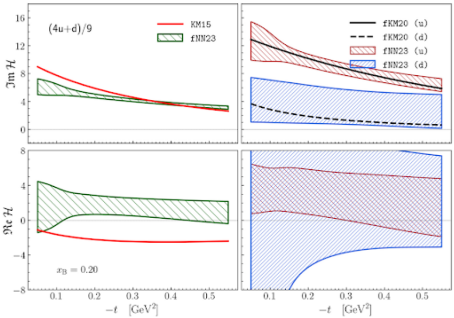


Figure: 2023 fits

Flavor separation of $\mathcal{E}$

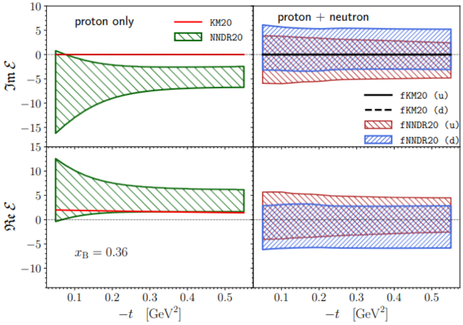


Figure: 2020 fits

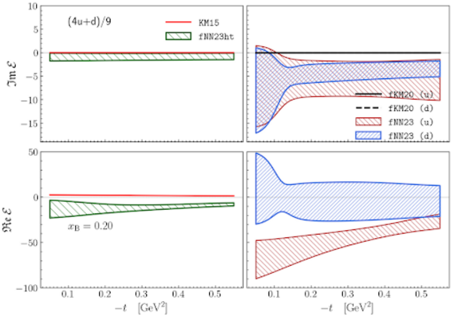


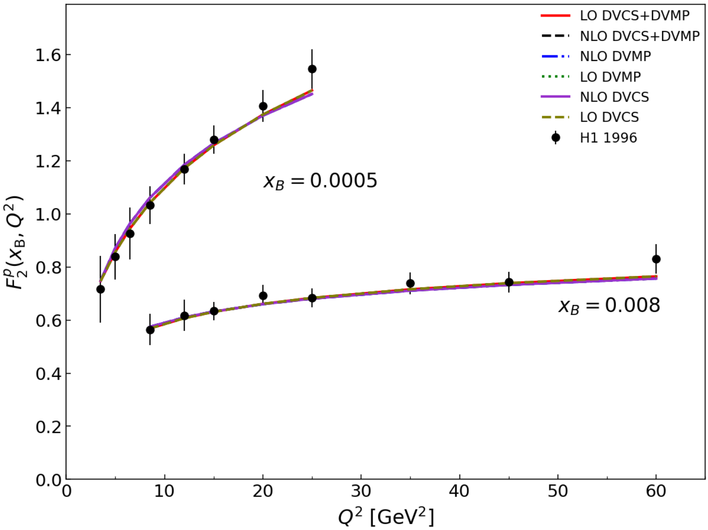
Figure: 2023 fits

NLO DIS+DVCS+DVMP small-x global fit

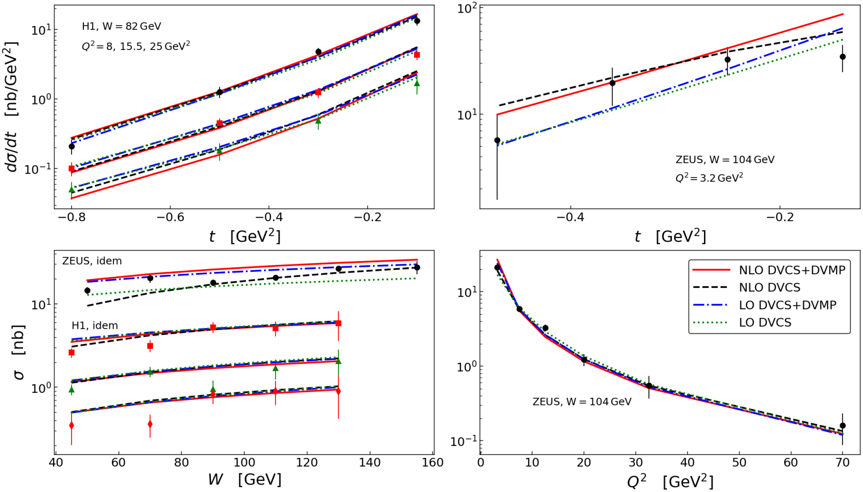
- First global fits to DIS+DVCS+DVMP HERA collider data [Lautenschlager, Müller, Schäfer, '13, unpublished!]
- hard scattering amplitude corrected in the meantime [Duplančić, Müller, Passek-Kumerički '17]

- [M. Č. et al., '23] preliminary results for NLO DIS+DVCS+DVMP small-x global fit
- only considered sea quarks and gluons, full NLO Q^2 evolution
- H1 and ZEUS measurements of ρ^0 DVMP
- fit to HERA collider data (excluding t-dependent DVMP data): $\chi^2/n_{\text{d.o.f.}} = 172.45/146 \approx 1.2$
- we also studied LO fits, fits to DIS+DVCS and fits to DIS+DVMP
- what are the effects of NLO corrections?
- can we get universal GPDs regardless of DVCS and DVMP data?

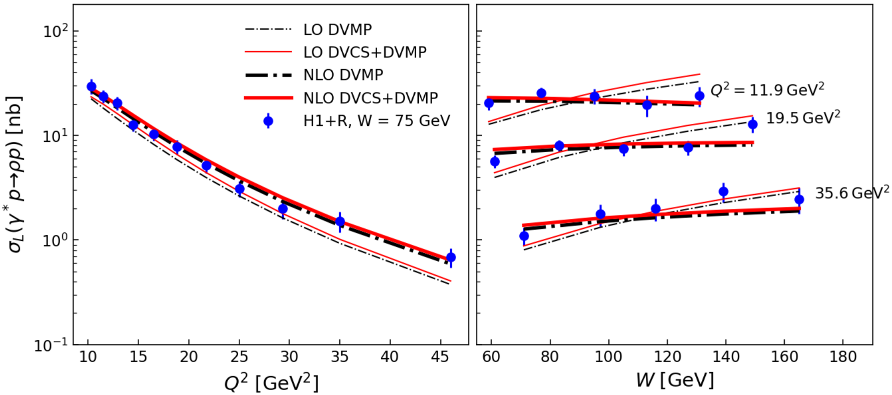
DIS F_2 data description



DVCS data description



DVMP data description



Skewness

- skewness: ratio of GPD to corresponding PDF

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

- conformal (Shuvaev) values, PDFs completely specify GPDs:

$$r^q \approx 1.65, \quad r^G \approx 1$$