Towards extraction of GPDs from DVCS data

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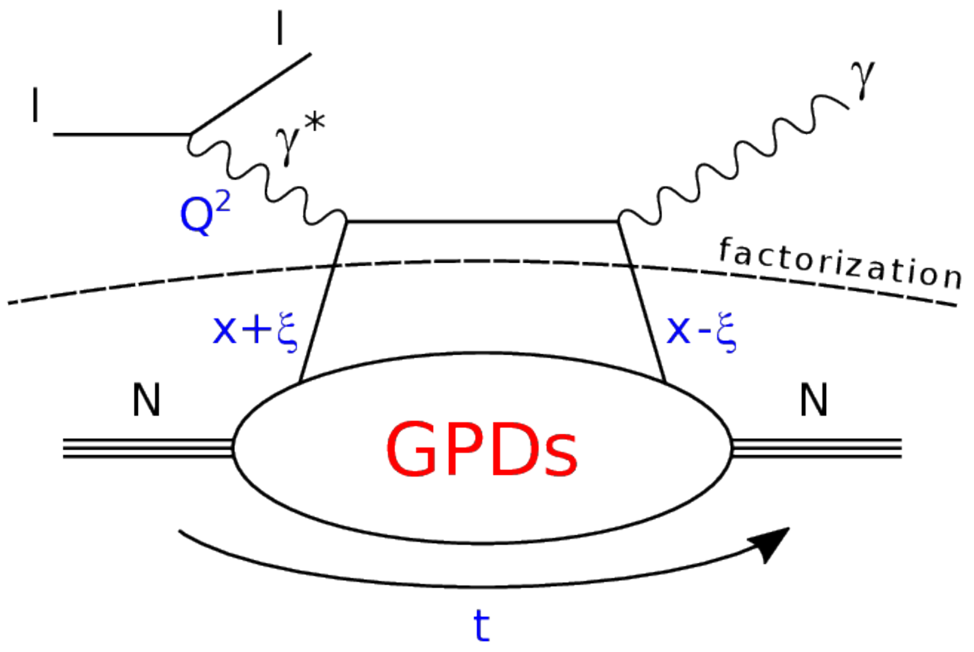
Outline

- Introduction
- Global analysis of DVCS data - “classic” approach
- Global analysis of DVCS data - ANN approach
- Summary

Deeply Virtual Compton Scattering (DVCS)

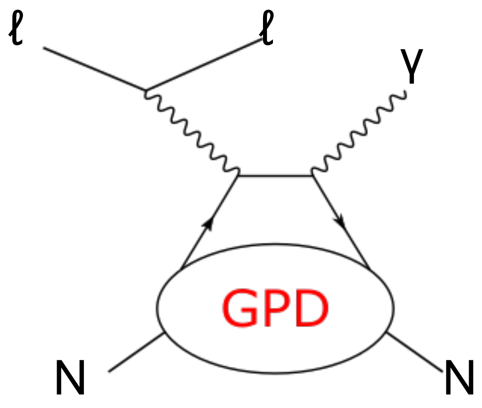


factorization for $|t|/Q^2 \ll 1$

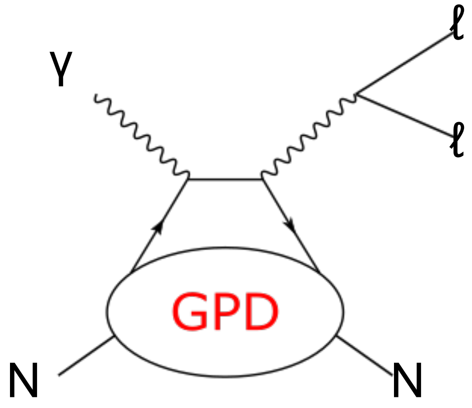
Chiral-even GPDs:
(helicity of parton conserved)

$H^{q,g}(x,\xi,t)$	$E^{q,g}(x,\xi,t)$	*for sum over parton helicities*
$\widetilde{H}^{q,g}(x,\xi,t)$	$\widetilde{E}^{q,g}(x,\xi,t)$	*for difference over parton helicities*
nucleon helicity conserved	*nucleon helicity changed*	

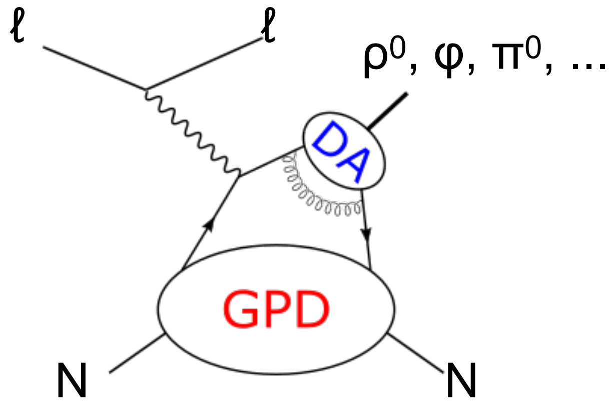
GPDs accessible in various production channels and observables
→ experimental filters



DVCS
Deeply Virtual Compton Scattering



TCS
Timelike Compton Scattering



HEMP
Hard Exclusive Meson Production

more production channels sensitive to GPDs exist!

GPDs studied in various laboratories
→ need to cover a broad kinematic range

experiments

closed **active** **planned**

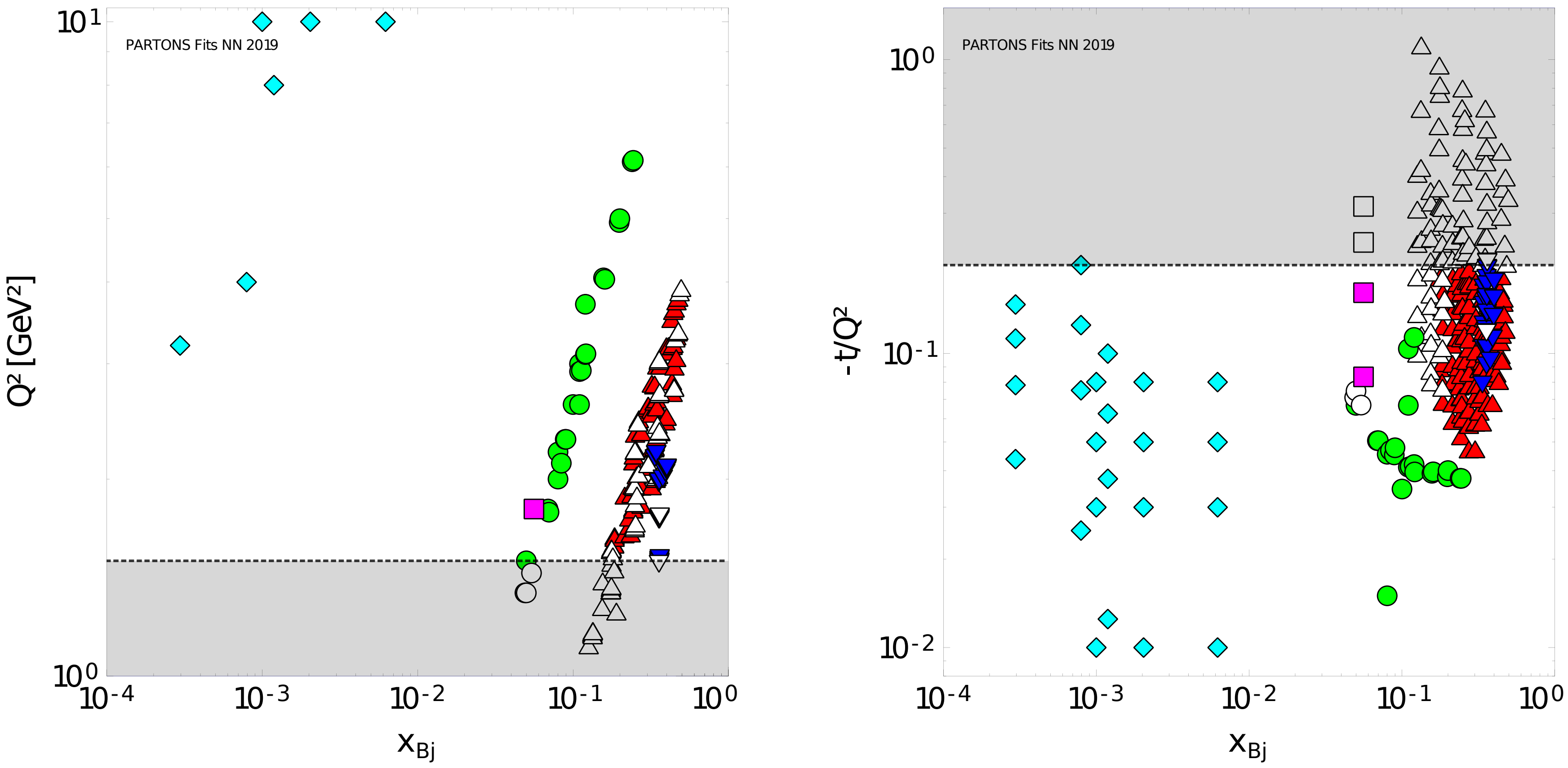
DVCS data

Kinematic cuts
used in presented analyses:

$$Q^2 > 1.5\ \mathrm{GeV}^2$$

$$-t/Q^2 < 0.2$$

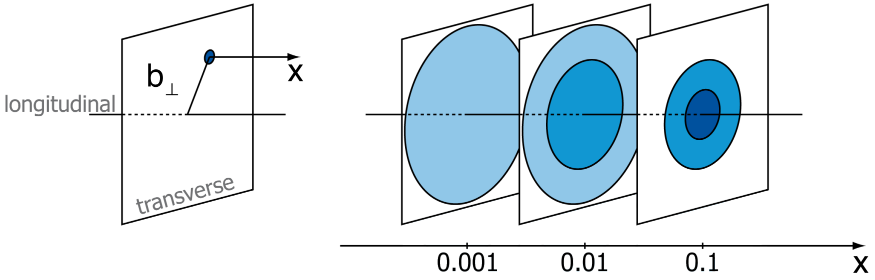
HALL A
CLAS
HERMES
COMPASS
H1 and ZEUS



Nucleon tomography

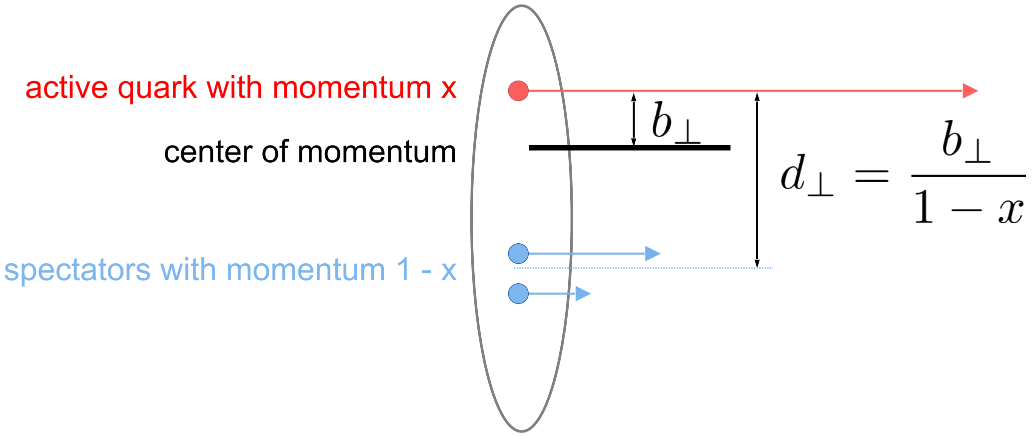
- Nucleon tomography

$$q(x, \mathbf{b}_\perp) = \int \frac{\mathrm{d}^2\boldsymbol{\Delta}}{4\pi^2} e^{-i\mathbf{b}_\perp\cdot\boldsymbol{\Delta}} H^q(x, 0, t = -\boldsymbol{\Delta}^2)$$



- Study of long. polarization with GPD $\widetilde{H}$
- Study of distortion in transv. polarized nucleon with GPD E

- Impact parameter $\mathbf{b}_\perp$ defined w.r.t. center of momentum, such as $\sum x\,\mathbf{b}_\perp = 0$



Energy momentu tensor

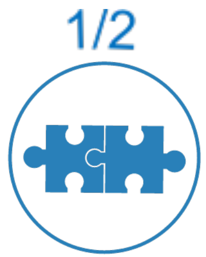
Energy momentum tensor in terms of form factors:

$$\langle p', s' | \widehat{T}^{\mu\nu} | p, s \rangle = \bar{u}(p', s') \left[\frac{P^\mu P^\nu}{M} A(t) + \frac{\Delta^\mu \Delta^\nu - \eta^{\mu\nu} \Delta^2}{M} C(t) + M \eta^{\mu\nu} \bar{C}(t) + \right.$$

$$\left. \frac{P^\mu i \sigma^{\nu\lambda} \Delta_\lambda}{4M} \left[A(t) + B(t) + D(t) \right] + \frac{P^\nu i \sigma^{\mu\lambda} \Delta_\lambda}{4M} \left[A(t) + B(t) - D(t) \right] \right] u(p, s)$$

Access to total angular momentum and “mechanical” forces acting on quarks

$$A^q(0) + B^q(0) = \int_{-1}^{1} x \left[H^q(x, \xi, 0) + E^q(x, \xi, 0) \right] = 2J^q$$



Ji's sum rule

PARTONS project

- PARTONS - platform to study GPDs
- Come with number of available physics developments implemented
- Addition of new developments as easy as possible
- To support effort of GPD community
- Can be used by both theorists and experimentalists

- More info in: Eur. Phys. J. C78 (2018) 6, 478

  http://partons.cea.fr

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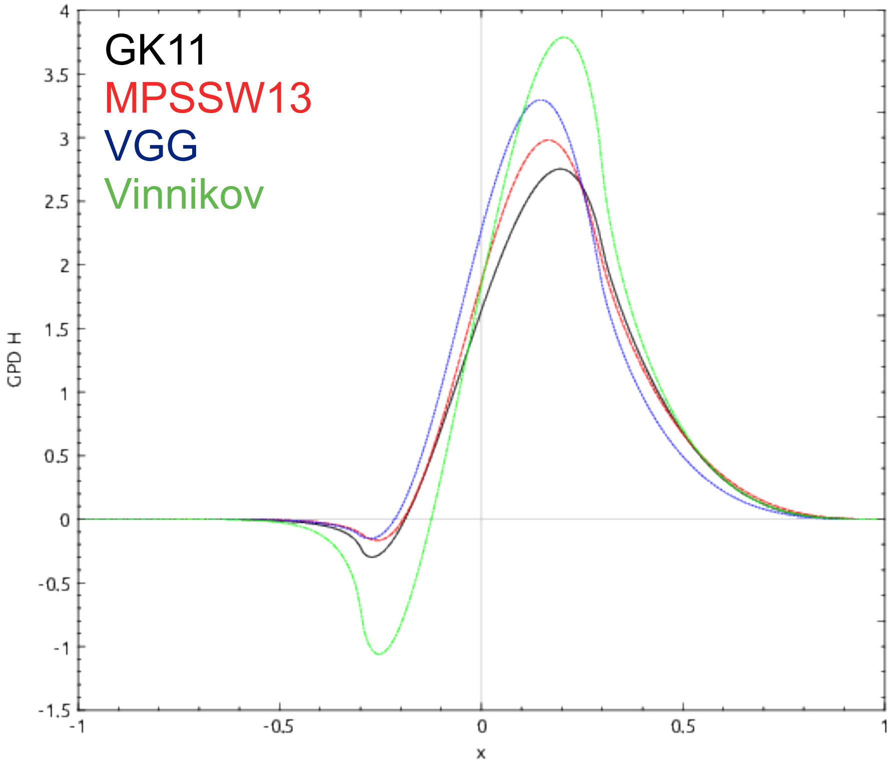
H^u @ xi = 0.2, t = -0.1 GeV^2, μ_F^2 = 2 GeV^2



Analysis

H. Moutarde, P. S., J. Wagner "*Border and skewness functions from a leading order fit to DVCS data*" Eur. Phys. J. C78 (2018) 11, 890

Goal: global extraction of Compton Form Factors (CFFs) from DVCS data using LO/LT formalism

Analysis done within PARTONS framework

Compton Form Factors

- imaginary part

$$Im\mathcal{G}(\xi,t) \quad = \pi G^{(+)}(\xi,\xi,t) = \pi \sum_q e_q^2 G^{q(+)}(\xi,\xi,t)$$

$$G^{q(+)}(x,\xi,t) = G^q(x,\xi,t) \mp G^q(-x,\xi,t)$$
$$G^{q(+)}(\xi,\xi,t) = G^{q_{\mathrm{val}}}(\xi,\xi,t) + 2G^{q_{\mathrm{sea}}}(\xi,\xi,t)$$

"−" for $G \in \{H, E\}$
"+" for $G \in \{\widetilde{H}, \widetilde{E}\}$

- real part

$$Re\mathcal{G}(\xi,t) = \mathrm{P.V.}\int_0^1 G^{(+)}(x,\xi,t)\left(\frac{1}{\xi-x} \mp \frac{1}{\xi+x}\right)\mathrm{d}x$$

$$Re\mathcal{G}(\xi,t) = \mathrm{P.V.}\int_0^1 G^{(+)}(x,x,t)\left(\frac{1}{\xi-x} \mp \frac{1}{\xi+x}\right)\mathrm{d}x + C_G(t)$$

$$C_H(t) = -C_E(t) \qquad C_{\widetilde{H}}(t) = C_{\widetilde{E}}(t) = 0$$

connected to EMT FF

Ansatz

$$C_G^q(t) = 2\int_{(0)}^{1}\left(G^{q(+)}(x,x,t) - G^{q(+)}(x,0,t)\right)\frac{1}{x}dx$$

- subtraction constant as analytic continuation of Mellin moments to *j* = -1

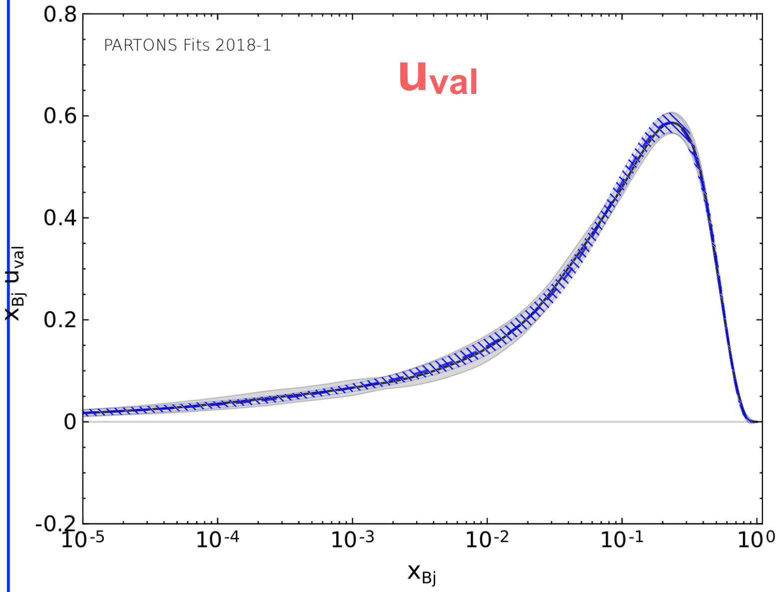
$$G^q(x,0,t) = \mathrm{pdf}_G^q(x)\ \exp(f_G^q(x)t) \qquad f_G^q(x) = A_G^q\log(1/x) + B_G^q(1-x)^2 + C_G^q(1-x)x$$

- reduction to PDFs and correspondence to EFFs
- modify "classical" log(1/x) term by $B_G{}^q(1\text{-}x)^2$ in low-x and by $C_G{}^q(1\text{-}x)x$ in high-x regions
- polynomials found in analysis of EFF data → good description of data
- allow to use the analytic regularisation prescription
- finite proton size at x → 1

$$G^q(x,x,t) = G^q(x,0,t)\ g_G^q(x,x,t) \qquad g_G^q(x,x,t) = \frac{a_G^q}{(1-x^2)^2}\left(1 + t(1-x)(b_G^q + c_G^q\log(1+x))\right)$$

- at x → 0 constant skewness effect
- at x → 1 reproduce power behaviour predicted for GPDs in Phys. Rev. D69, 051501 (2004)
- t-dependence similar to DD-models with (1-x) to avoid any t-dep. at x = 1

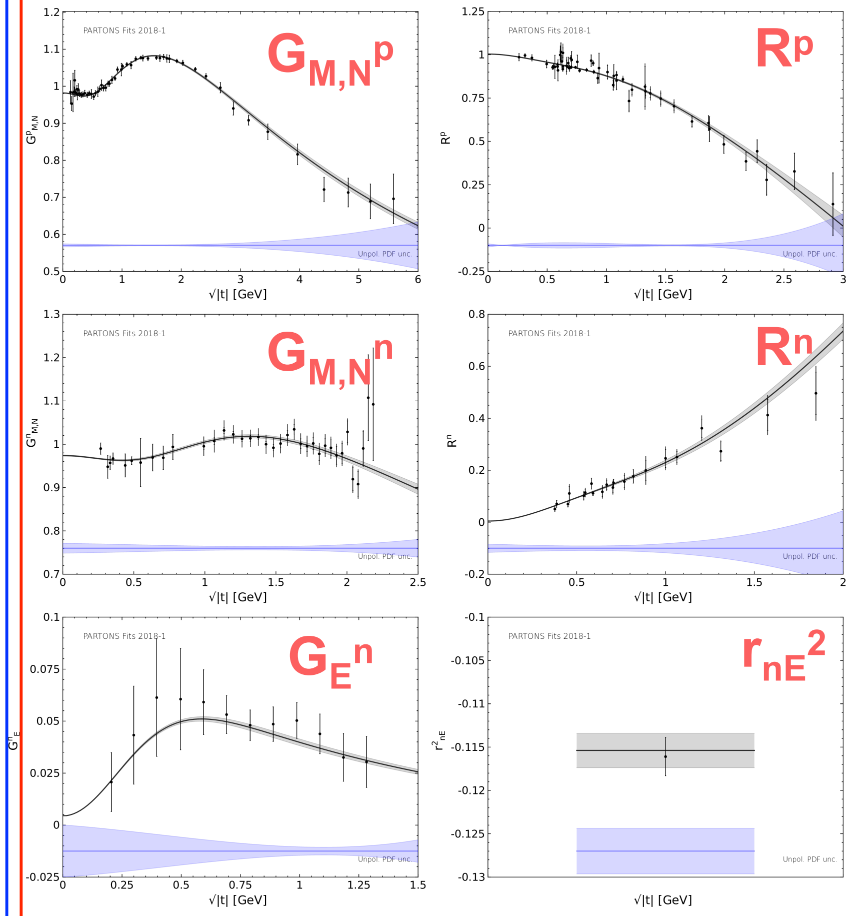
1. Analysis of PDF parameterisations



$$\mathrm{pdf}(x, Q^2) = x^{-g(\delta_p, \delta_q, Q^2)}(1-x)^\alpha \times \sum_{i=0}^{4} g(p_i, q_i, Q^2) x^i$$

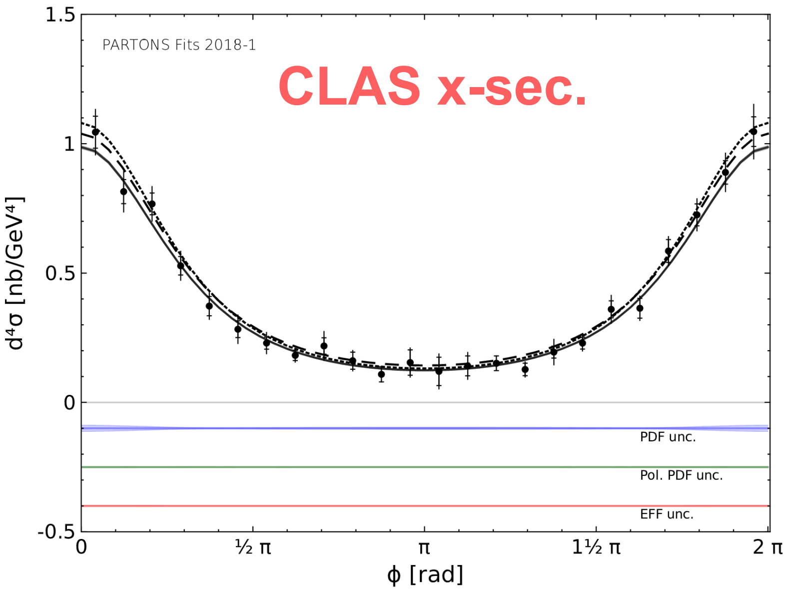
$$g(p, q, Q^2) = p + q \log \frac{Q^2}{Q_0^2}$$

2. Analysis of Elastic Form Factor data



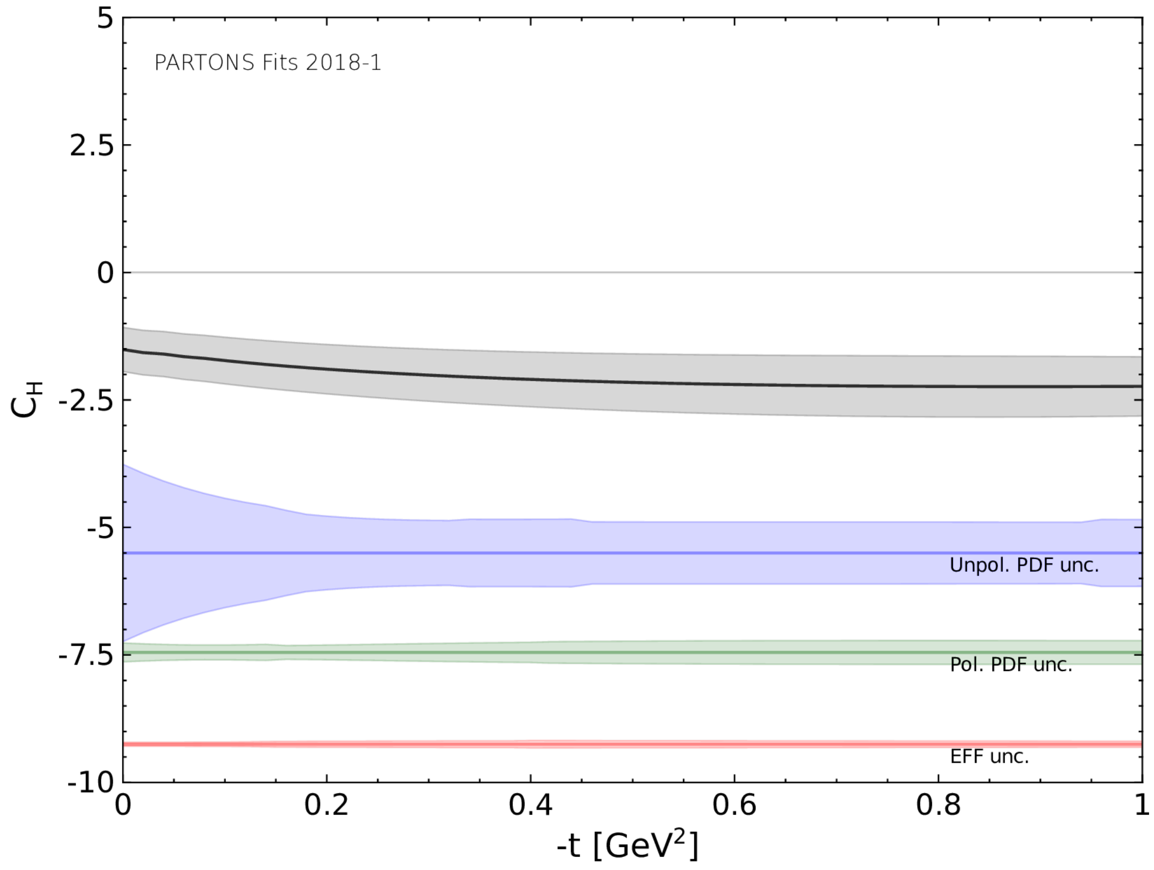
$$\chi^2/\mathrm{ndf} = 129.6/(178-9) \approx 0.77$$

3. Analysis of DVCS data

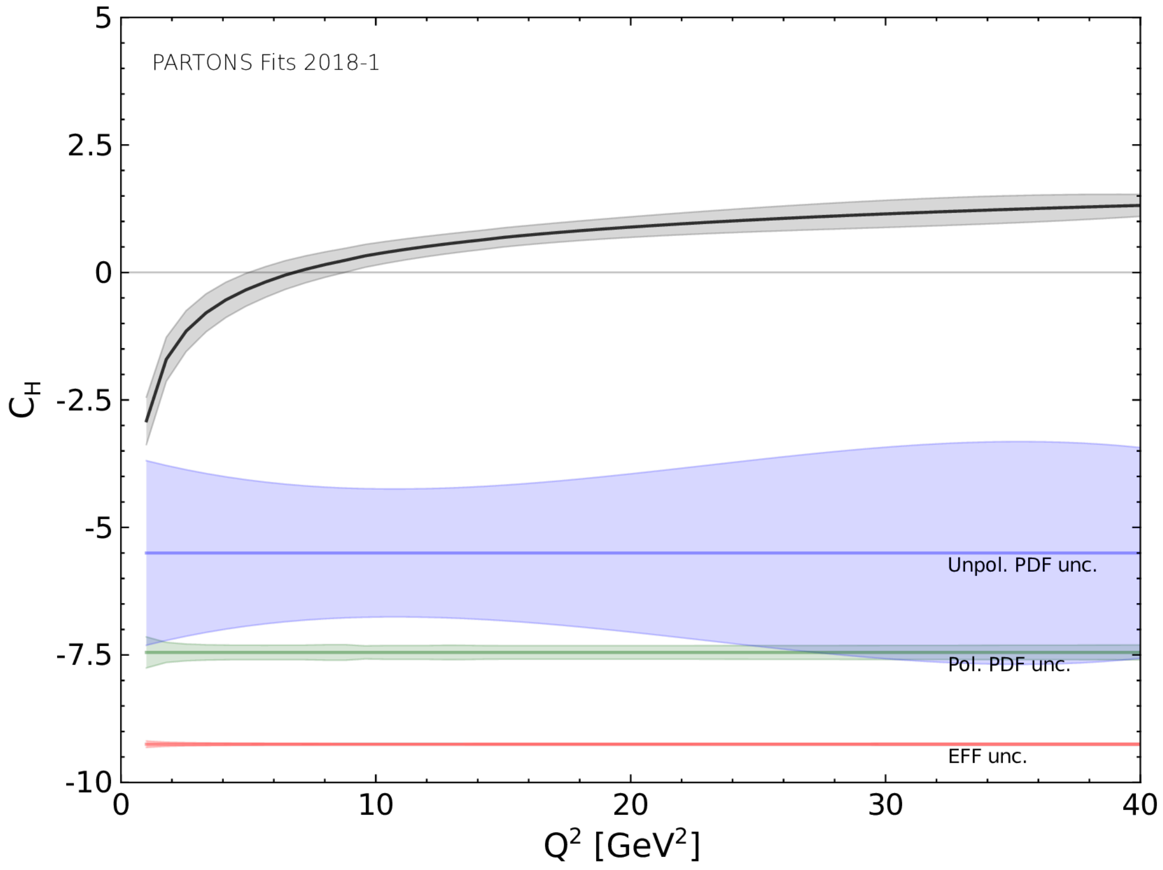


$$\chi^2/\mathrm{ndf} = 2346.3/(2600-13) \approx 0.91$$

Subtraction constant:



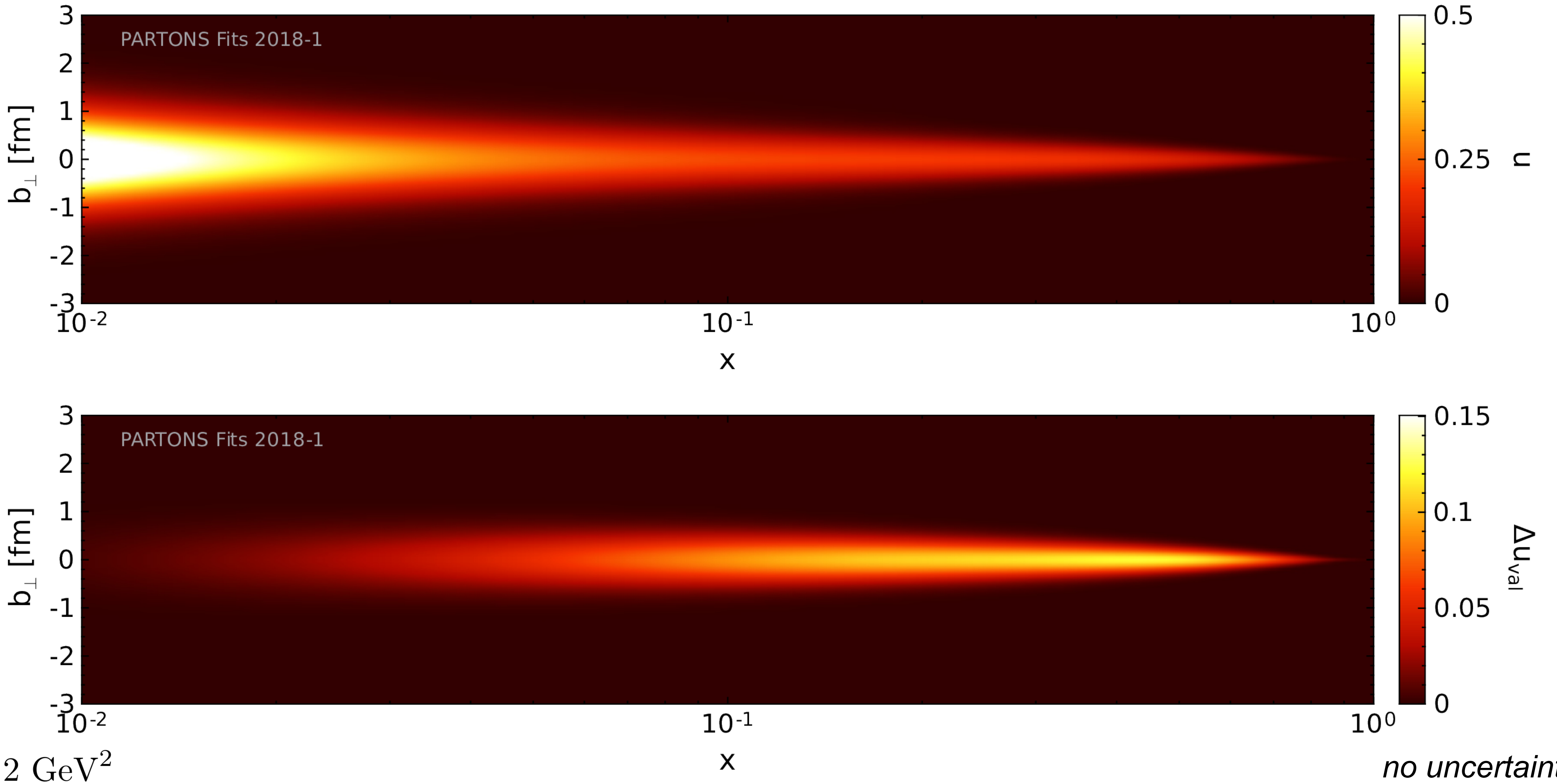
$Q^2 = 2\ \mathrm{GeV}^2$



$t = 0$

Results

Nucleon tomography:



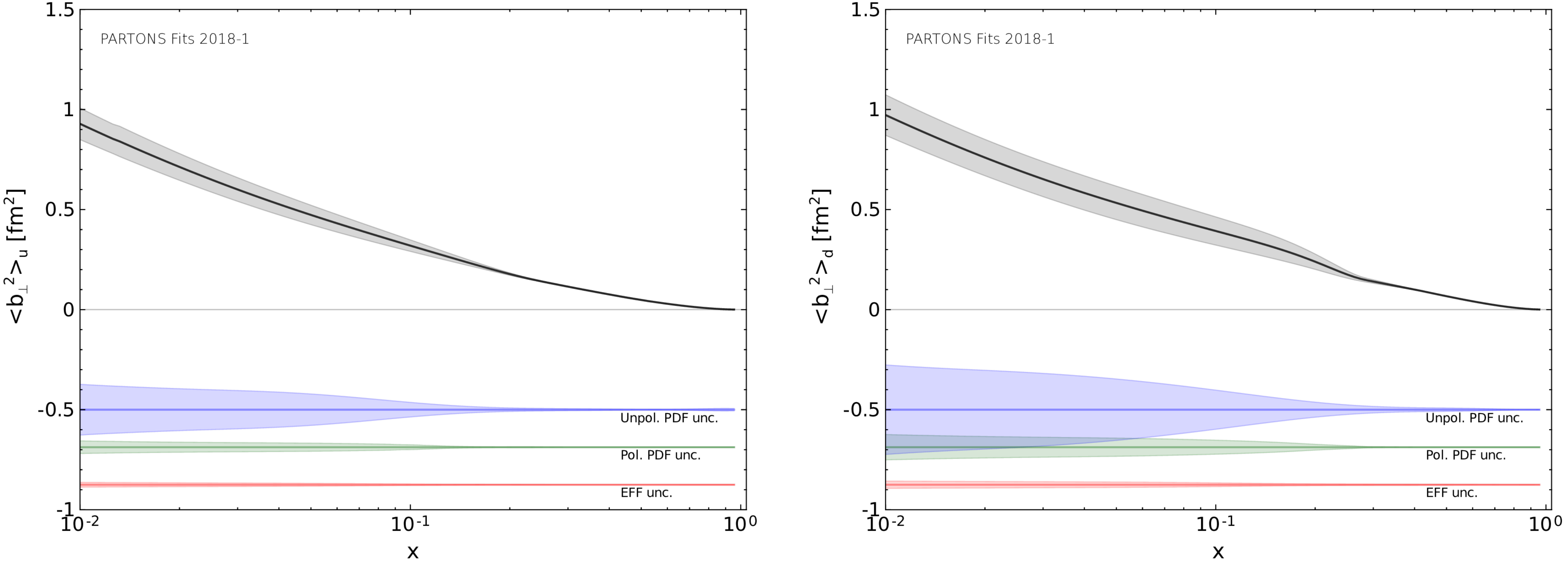
$Q^2 = 2\ \mathrm{GeV}^2$

no uncertainties!

Results

Nucleon tomography:

$$\langle b_\perp^2 \rangle_q(x) = \frac{\int d^2\mathbf{b}_\perp\ \mathbf{b}_\perp^2 q(x, \mathbf{b}_\perp)}{\int d^2\mathbf{b}_\perp\ q(x, \mathbf{b}_\perp)}$$



$Q^2 = 2\ \mathrm{GeV}^2$

Analysis

H. Moutarde, P. S., J. Wagner "*Unbiased determination of Compton Form Factors*"
preliminary results

Goal: global extraction of Compton Form Factors (CFFs) from DVCS data using ANN technique

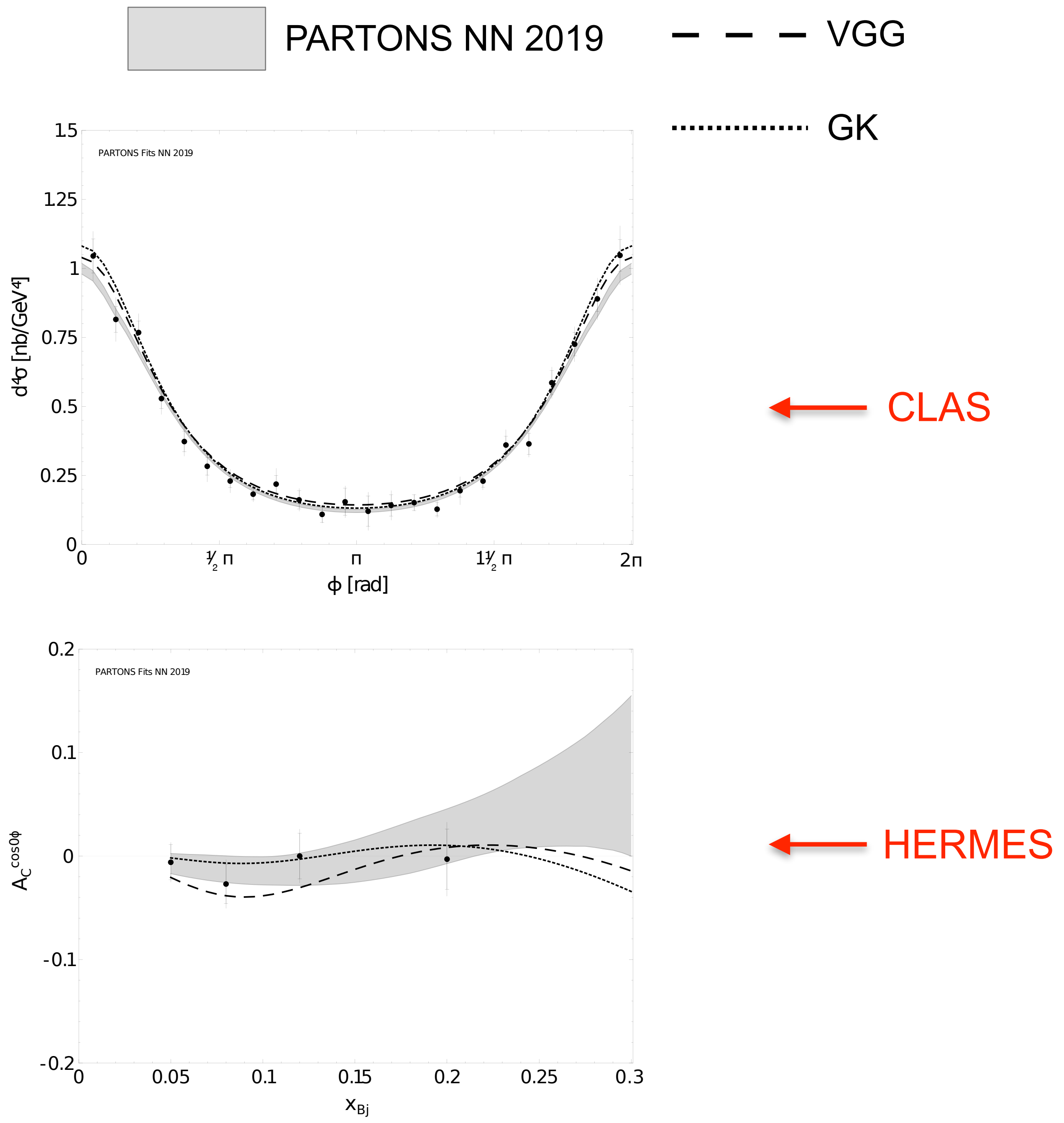
Analysis done within PARTONS framework

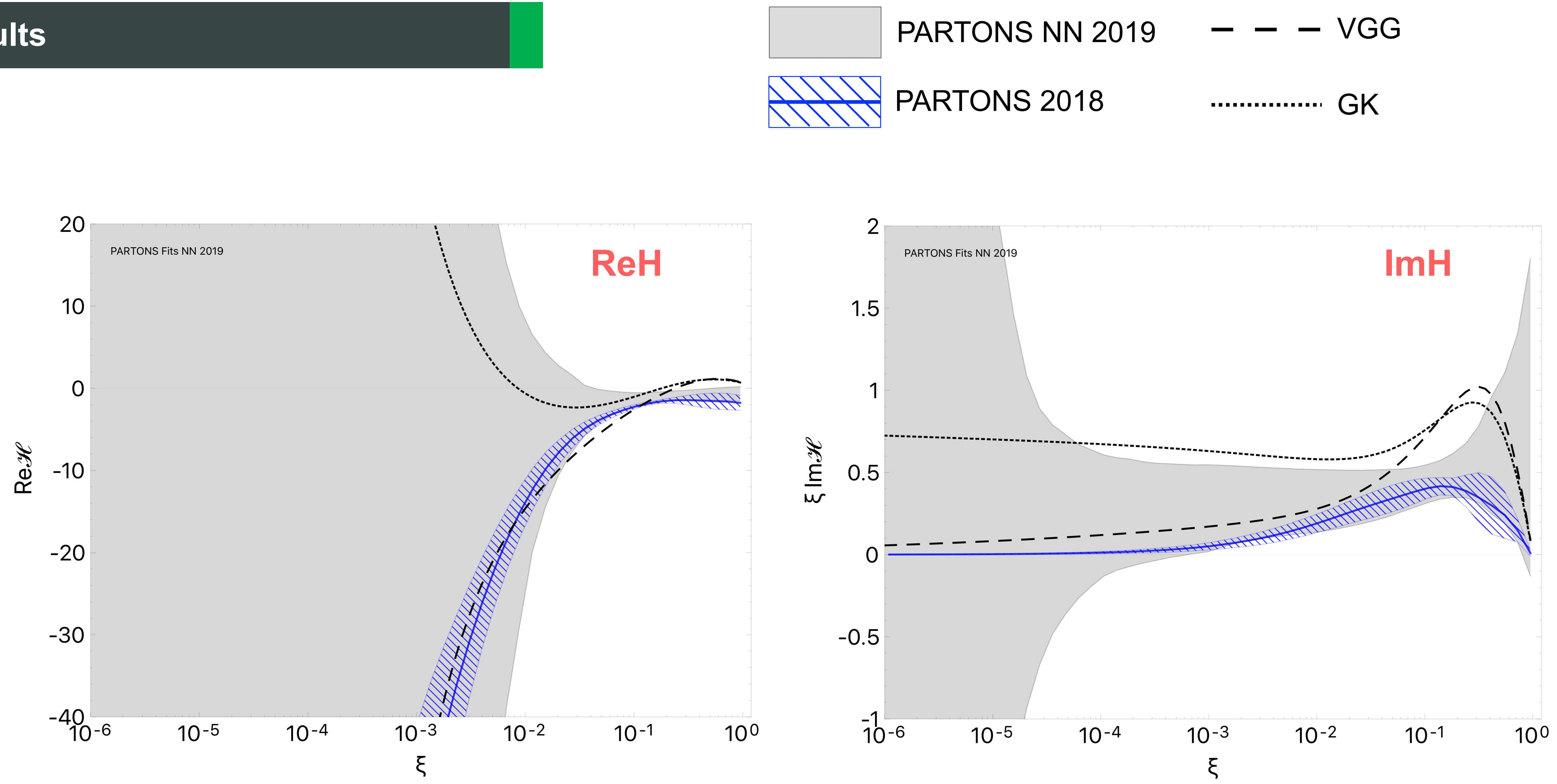
Performance

Quality of fit:

$$\chi^2/\mathrm{nPoints} = 2243.5/2624 \approx 0.85$$

No.	Collab.	Year	χ^2	n	χ^2/n
1	HERMES	2001	10.7	10	1.07
2		2006	5.5	4	1.38
3		2008	18.5	18	1.03
4		2009	34.7	35	0.99
5		2010	40.7	18	2.26
6		2011	16.7	24	0.70
7		2012	22.4	35	0.64
8	CLAS	2001	—	0	—
9		2006	1.0	2	0.52
10		2008	376.4	283	1.33
11		2009	28.3	22	1.29
12		2015	306.6	311	0.99
13		2015	884.7	1333	0.66
14	Hall A	2015	231.8	228	1.02
15		2017	211.4	276	0.77
16	COMPASS	2018	3.0	2	1.50
17	ZEUS	2009	5.49	4	1.38
18	H1	2005	22.2	7	3.17
19		2009	23.4	12	1.95

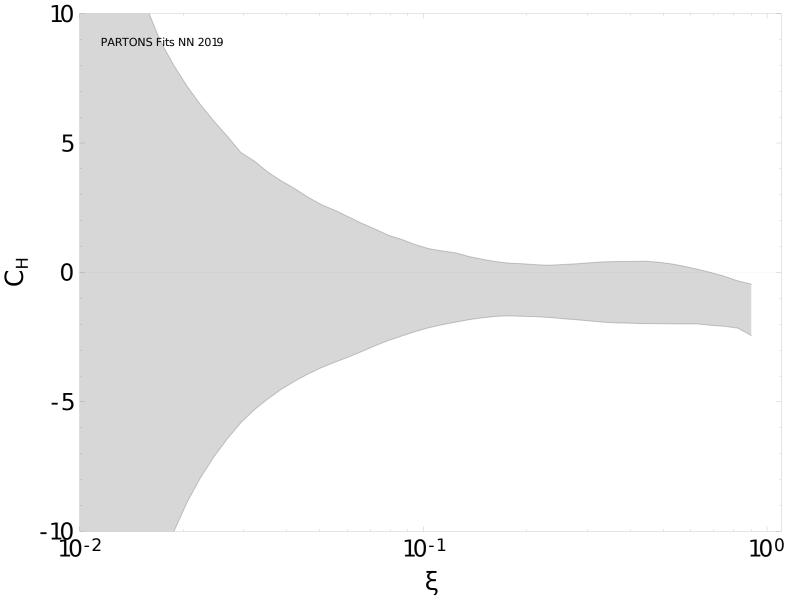




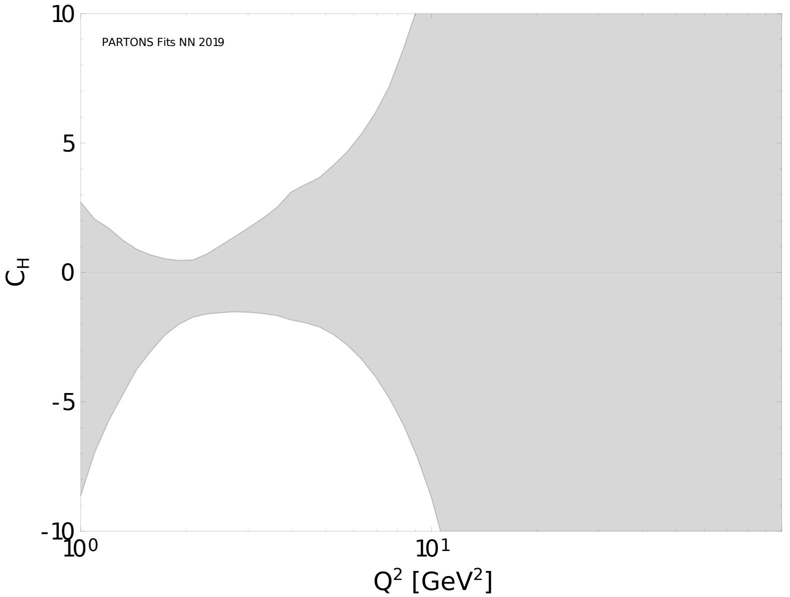
@ $t = -0.3$ GeV^2, $Q^2 = 2$ GeV^2

Subtraction constant

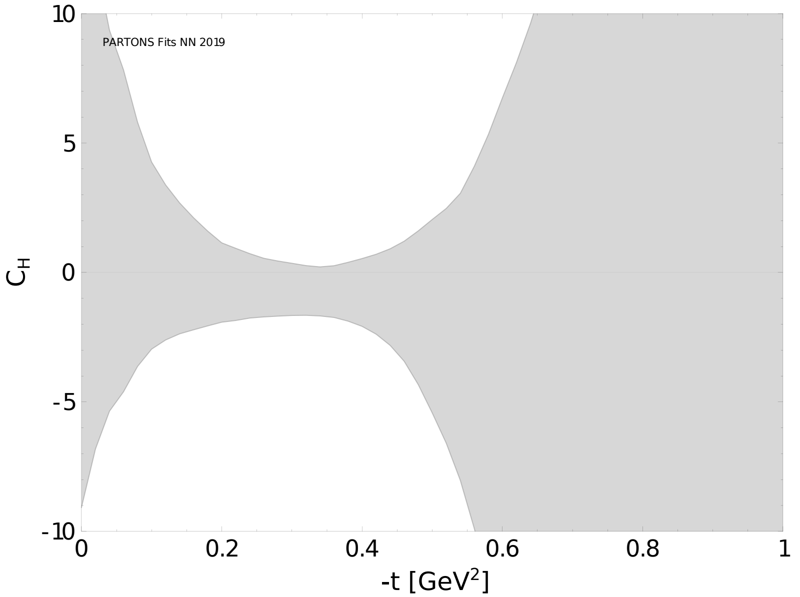
as function of ξ
@ |t| = 0.3 GeV², Q² = 2 GeV²



as function of Q²
@ ξ = 0.2, |t| = 0.3 GeV²



as function of |t|
@ ξ = 0.2, Q² = 2 GeV²



- Direct extraction of subtraction constant → encouraging precision
- As expected, no ξ behaviour observed → consistency check
- Strong, model independent constraints on extraction of pressure information

SUMMARY

- Parameterizations of border and skewness functions

  → basic properties of GPD as building blocks

  → small number of parameters

  → encoded access to nucleon tomography and subtraction constant

- Neural network parameterization of CFFs

  → model independent extraction (also true for subtraction constant)

  → powerful tool to study GPDs / reduction of model uncertainties

  → perfect to study impact of future experiments