Fits to high precision DVCS data by PARTONS collaboration

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Nucleon and Resonance Structure with Hard Exclusive Production
Orsay, 29-31 May 2017

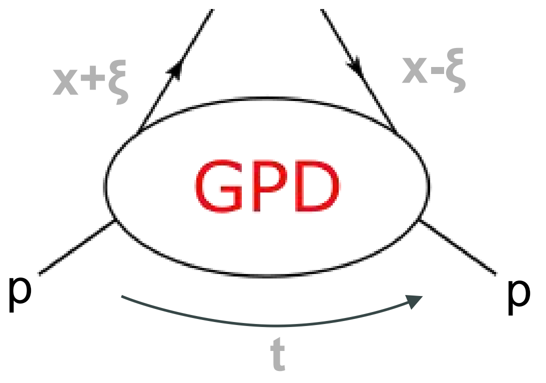
OUTLINE

- Motivation
- PARTONS project → see H. Moutarde's talk
- Fits to JLab DVCS data (classic approach)
- Neural network approach
- Summary

GPDs (Generalized Parton Distributions)

- 3D functions describing partonic structure of nucleon
- Each one defined for specific parton and specific helicity configuration
- Studied in various experimental channels
- In observables always convoluted with the hard scattering part

handbag diagram:



chiral-even GPDs:

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

GPDs (Generalized Parton Distributions)

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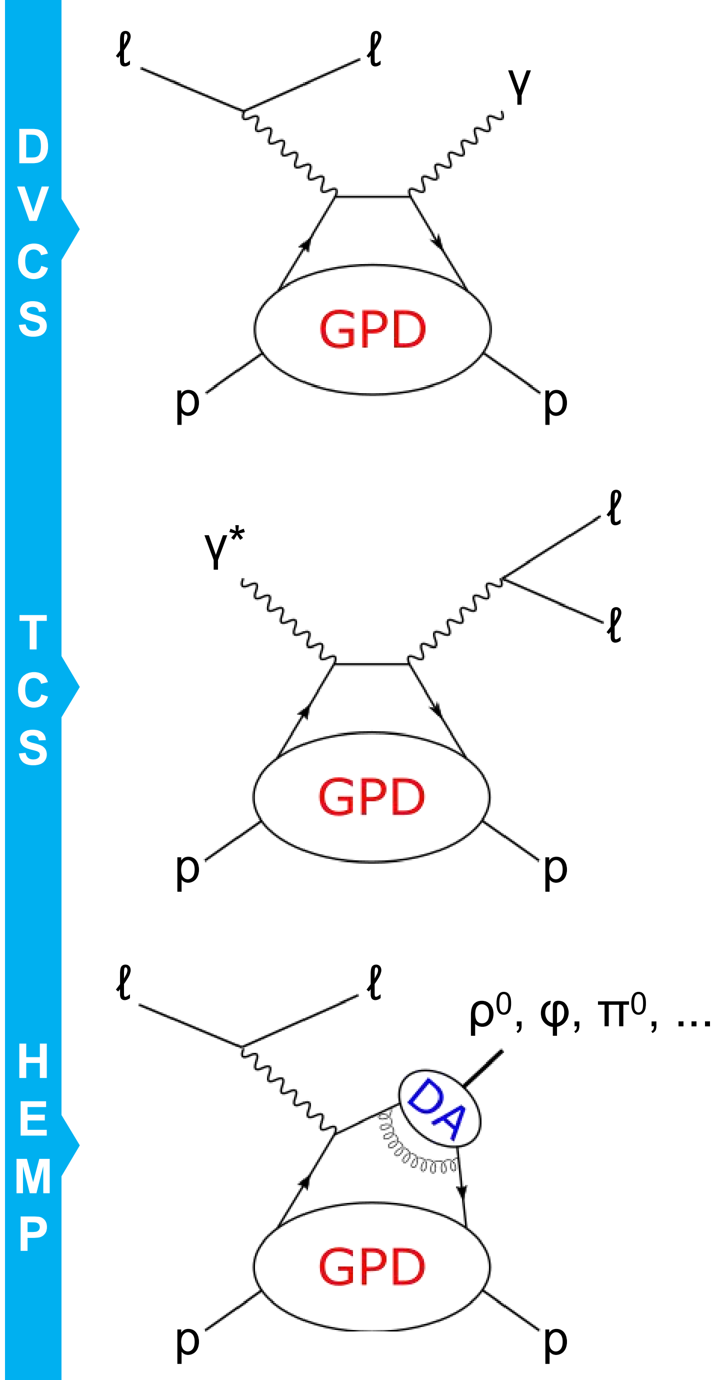
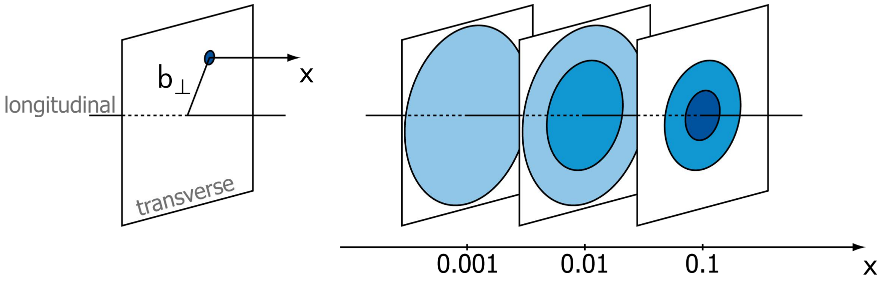
- Studied in various experimental channels
- In observables always convoluted with the hard scattering part



GPDs (Generalized Parton Distributions)

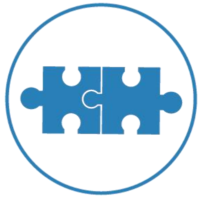
- Nucleon tomography

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



- Total angular momentum

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



$S_p = 1/2$

Compton form factors fitted at LO and leading-twist approximation using dispersion relation technique:

- for GPD H

$$\Im m\mathcal{H}(\xi, t, Q^2) = \pi \sum_q e_q^2 \left[H^q(\xi, \xi, t, Q^2) - H^q(-\xi, \xi, t, Q^2)\right]$$

$$\Re e\mathcal{H}(\xi, t, Q^2) = \frac{1}{\pi}\text{P.V.} \int_0^1 d\xi' \left(\frac{1}{\xi - \xi'} - \frac{1}{\xi + \xi'}\right) \Im m\mathcal{H}(\xi', t, Q^2) + \mathcal{C}_{\mathcal{H}}(t, Q^2)$$

- for other GPDs

$$\mathcal{C}_{\mathcal{H}}(t, Q^2) = -\mathcal{C}_{\mathcal{E}}(t, Q^2)$$

$$\mathcal{C}_{\widetilde{\mathcal{H}}}(t, Q^2) = \mathcal{C}_{\widetilde{\mathcal{E}}}(t, Q^2) = 0$$

FIT ANSATZ

fitted parameter

GPDs H and H̃:

$$H^q(x,x,t,Q^2) = H^q(x,0,t,Q^2) \times r^q(x)$$

- border function

- composed of GPD at (x, 0, t)
- and skewness function

GPDs H:

$$\mathcal{C}_{\mathcal{H}}(t,Q^2) = C_{\text{sub}} \times \exp\left(a_{\text{sub}} t\right)$$

- subtraction constant

- so far proposed ad-hoc
- weak sensitivity of data on this term

GPDs E and Ẽ:

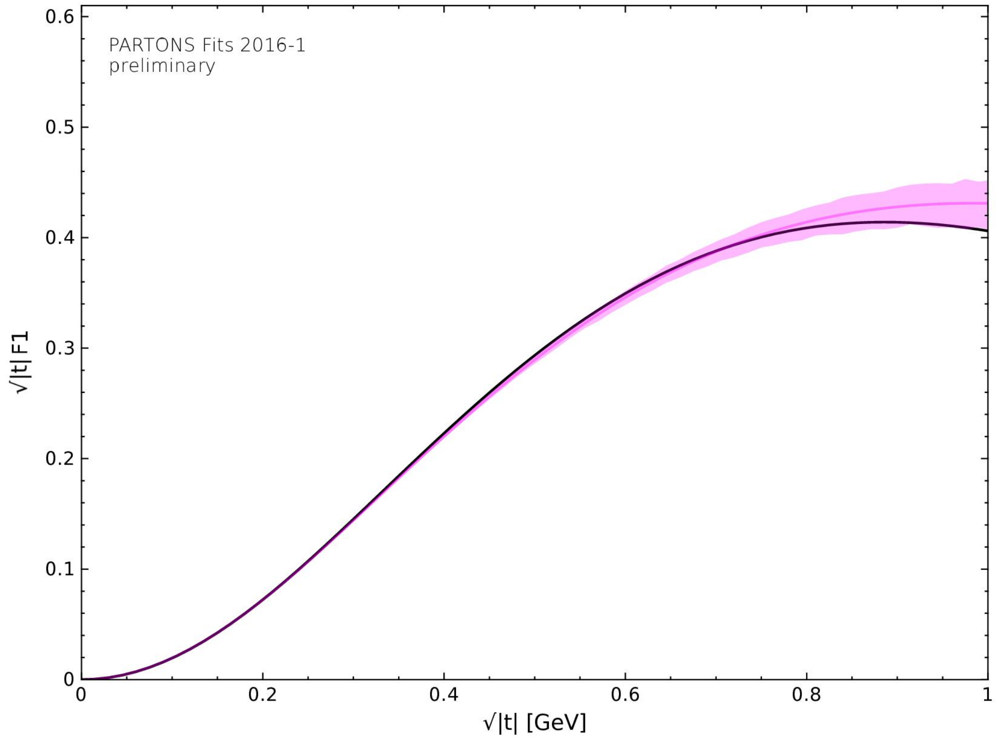
$$\mathcal{E}(\xi,t,Q^2) = N_E \times \mathcal{E}_{\text{GK}}(\xi,t,Q^2)$$
$$\widetilde{\mathcal{E}}(\xi,t,Q^2) = N_{\widetilde{E}} \times \widetilde{\mathcal{E}}_{\text{GK}}(\xi,t,Q^2)$$

- GK CFFs

FIT ANSATZ FOR H AND $\tilde{H}$

fitted parameter

$$H^q(x, x, t, Q^2) = H^q(x, 0, t, Q^2) \times r^q(x) \qquad H^q(x, 0, t, Q^2) = q(x) \times x^{-a_q t}$$



F_1 parameterization

fit

- GPD at (x, 0, t) line

- q(x) and Δq(x) from NNPDF
- a_q for valence quarks fixed from $F_1(t)$ parameterization [1]

$$F_1^q(t) = \int_{-1}^{1} dx H^q(x, \xi, t, Q^2)$$

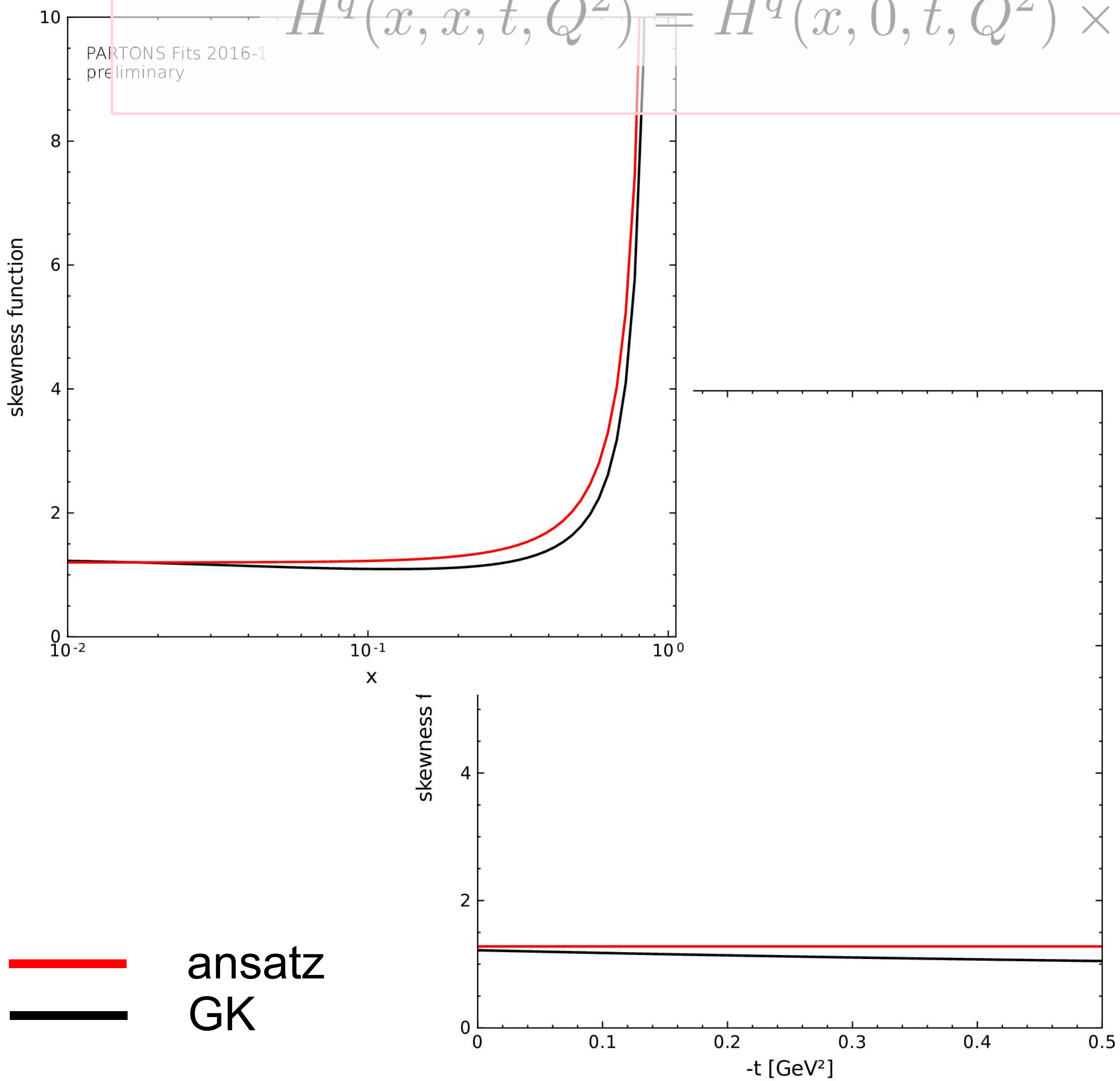
- a_q for sea quarks fitted to data
- note relation between this term and nucleon tomography

[1] Phys. Rev. C79 (2009) 065204

fitted parameter

$$H^q(x, x, t, Q^2) = H^q(x, 0, t, Q^2) \times r^q(x)$$

$$r^q(x) = \frac{C_q}{(1 - x^2)^2}$$



- skewness function

- for $x \to 0$: $r(x) \simeq C_q$
  - C_q fixed using DD modeling, where it depends only on $x^{-\alpha}$ PDF expansion term
- for $x \to 1$: $r(x) \sim 1/(1 - x^2)^2$
  - found with pQCD approach in [1]
  - no t-dependence predicted

[1] Phys. Rev. D69 (2004) 051501

RESULTS

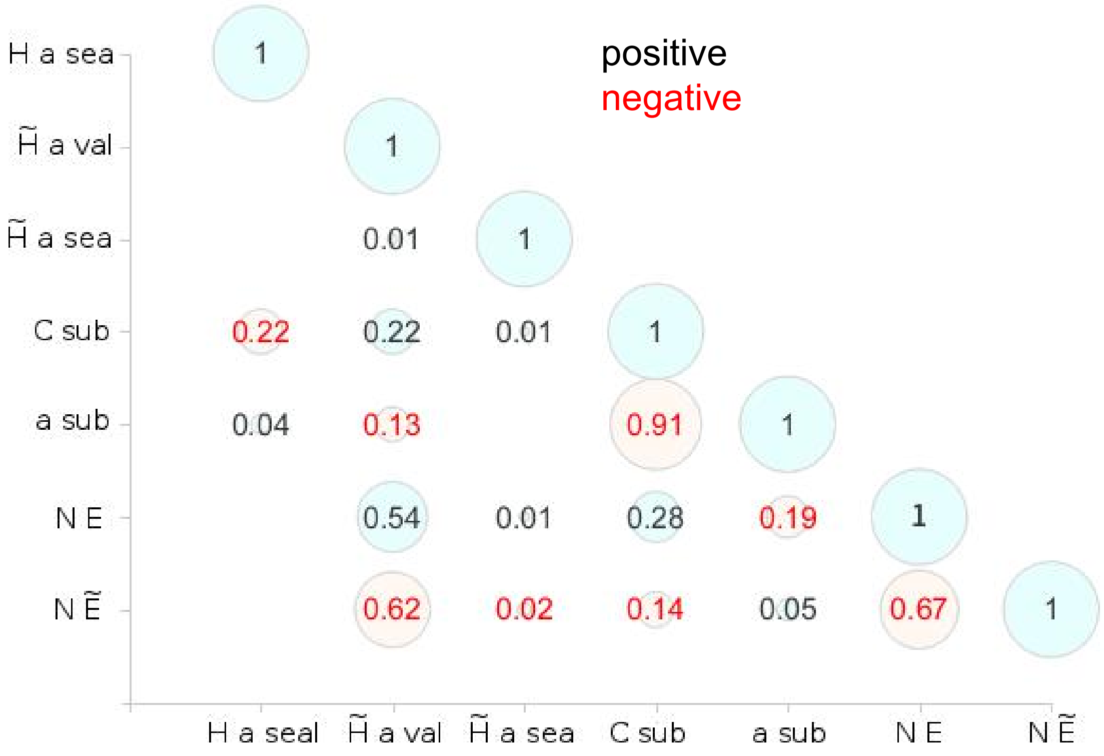
- Kinematic cuts $Q^2 > 1.5$ GeV^2 (*where we can rely on LO approximation*)
  $-t / Q^2 < 0.25$ (*where we can rely on GPD factorization*)
- χ^2 / ndf 3272.6 / (3433 - 7) ≈ 0.96
- Free parameters $a_{H\mathrm{sea}}$, $a_{\tilde{H}\mathrm{val}}$, $a_{\tilde{H}\mathrm{sea}}$, C_{sub}, a_{sub}, N_E, $N_{\tilde{E}}$
- χ^2 / ndf per data set

[1] Phys. Rev. C 92, 055202 (2015)
[2] Phys. Rev. Lett. 115, 212003 (2015)
[3] Phys. Rev. D 91, 052014 (2015)

Experiment	Reference	Observables	N points all	N points selected	chi2	chi2 / ndf
Hall A	[1] KINX2	σUU	120	120	135.0	1.19
Hall A	[1] KINX2	ΔσLU	120	120	98.9	0.88
Hall A	[1] KINX3	σUU	108	108	274.8	2.72
Hall A	[1] KINX3	ΔσLU	108	108	107.3	1.06
CLAS	[2]	σUU	1933	1333	1089.2	0.82
CLAS	[2]	ΔσLU	1933	1333	1171.9	0.88
CLAS	[3]	AUL, ALU, ALL	498	305	338.1	1.13

RESULTS

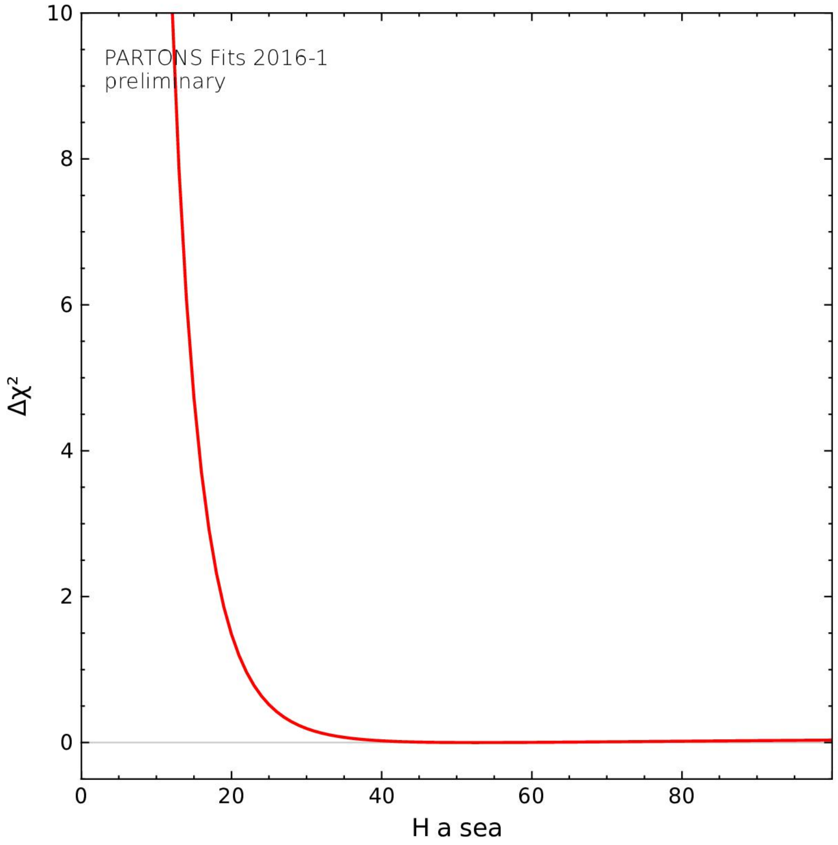
- Values of parameters and correlation matrix



GPD	Parameter	Value	Error
H	Cu val	1.21	-
H	Cu sea	1.27	-
H	Cd val	1.2	-
H	Cd sea	1.27	-
Htilde	Cu val	1.07	-
Htilde	Cu sea	1.06	-
Htilde	Cd val	1.11	-
Htilde	Cd sea	1.07	-
H	a val	0.74	-
H	a sea	52.7	62.2
Htilde	a val	2.51	0.35
Htilde	a sea	0	1.35
H	C sub	-0.81	0.16
H	a sub	-0.39	0.6
E	N	-8.08	0.57
Etilde	N	-0.45	0.07

RESULTS

- $\Delta\chi^2$ shape for 'H a sea'



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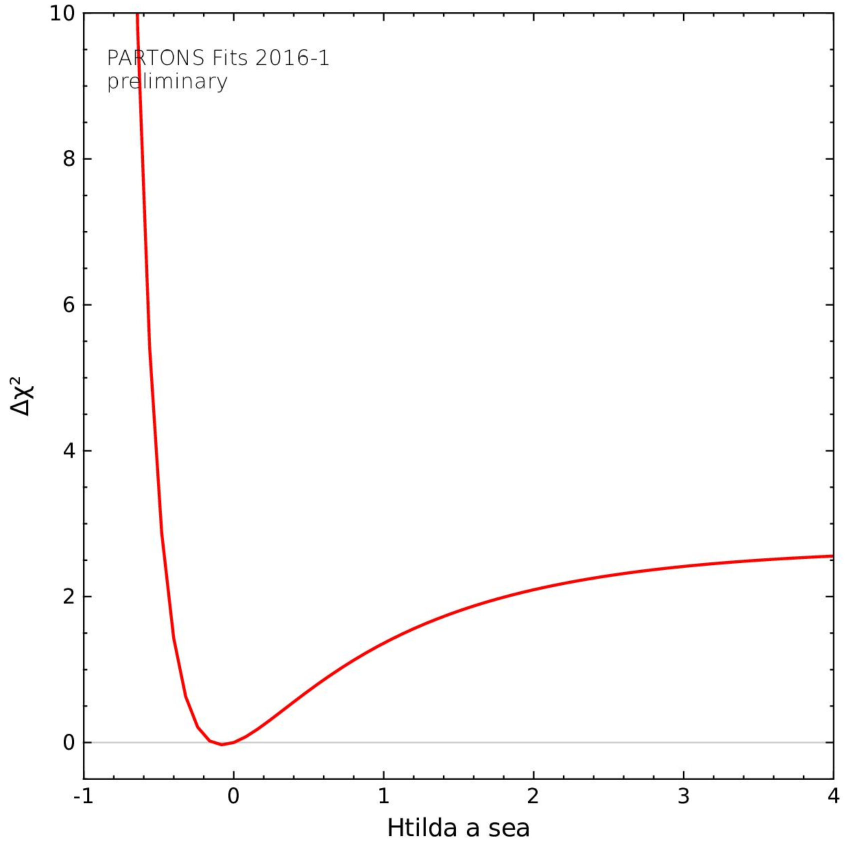
Can x - t dependence be described by $\exp(-\ln(x)\, a \cdot t)$?

Maybe $\exp(-\ln(x)\, a\, (1 - x)\, t)$, $\exp(-\ln(x)\, a\, (1 - x)^2\, t)$, ... more appropriate? → impact on nucleon tomography

RESULTS

- $\Delta\chi^2$ shape for 'Htilde a sea'



Unsymmetrical stat. uncertainty

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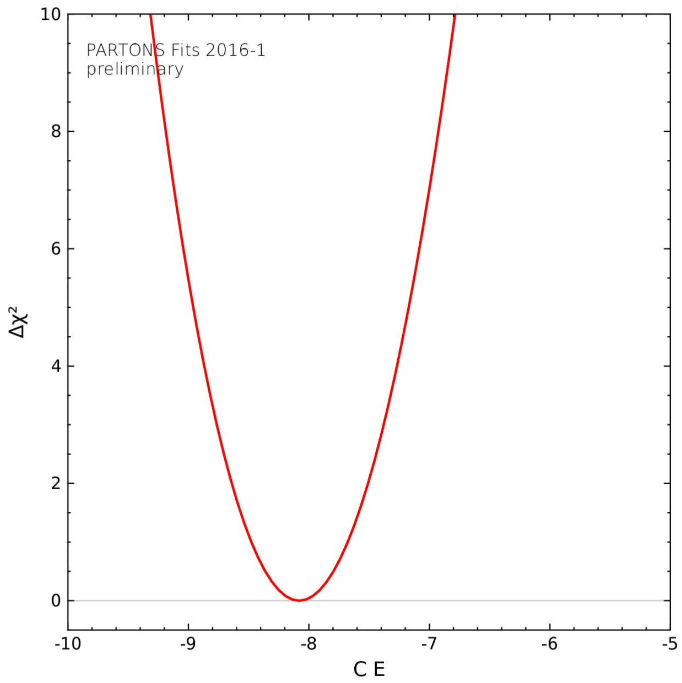
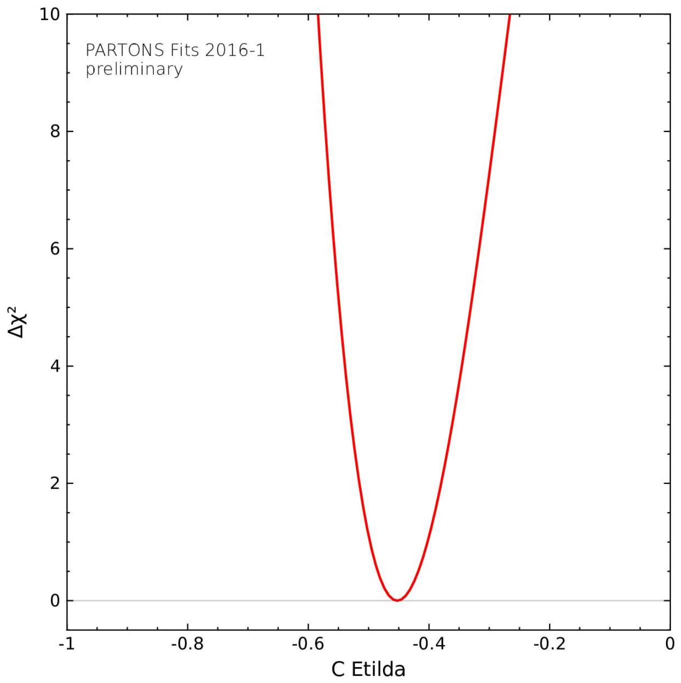
RESULTS

- $\Delta\chi^2$ shape for 'N$_E$' and 'N$_{Etilde}$'





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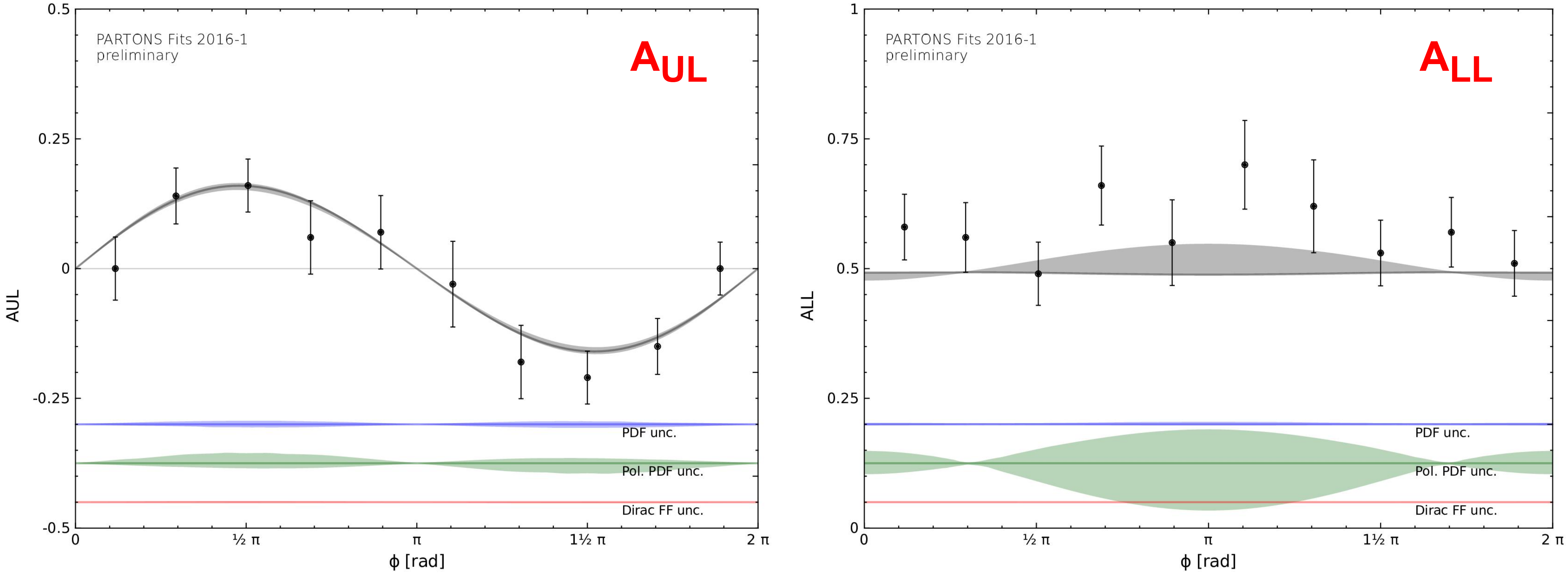
Unexpected sensitivity to GPD E

CLAS: A_{UL} and A_{LL}
@ x_B = 0.26, t = -0.23 GeV^2, Q^2 = 2.0 GeV^2, E = 5.9 GeV

0.68 c.l.

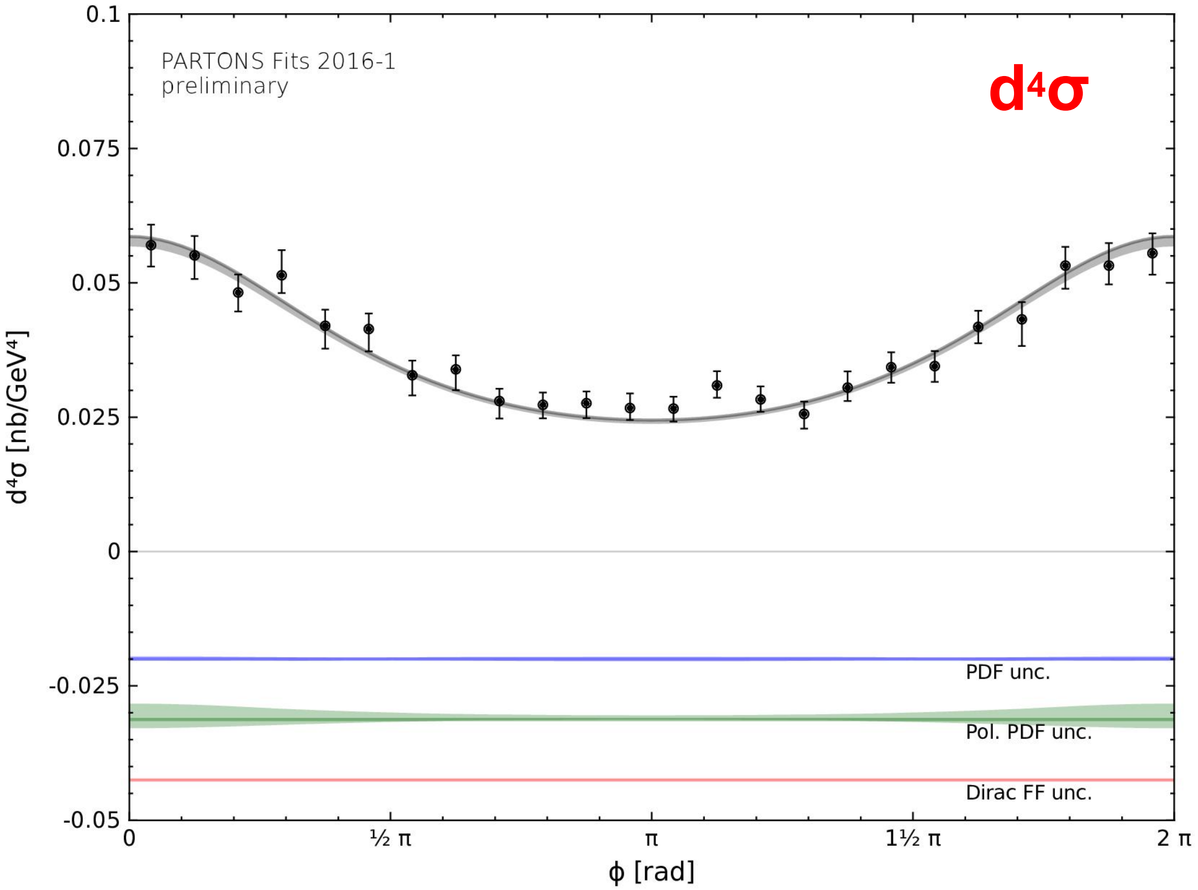


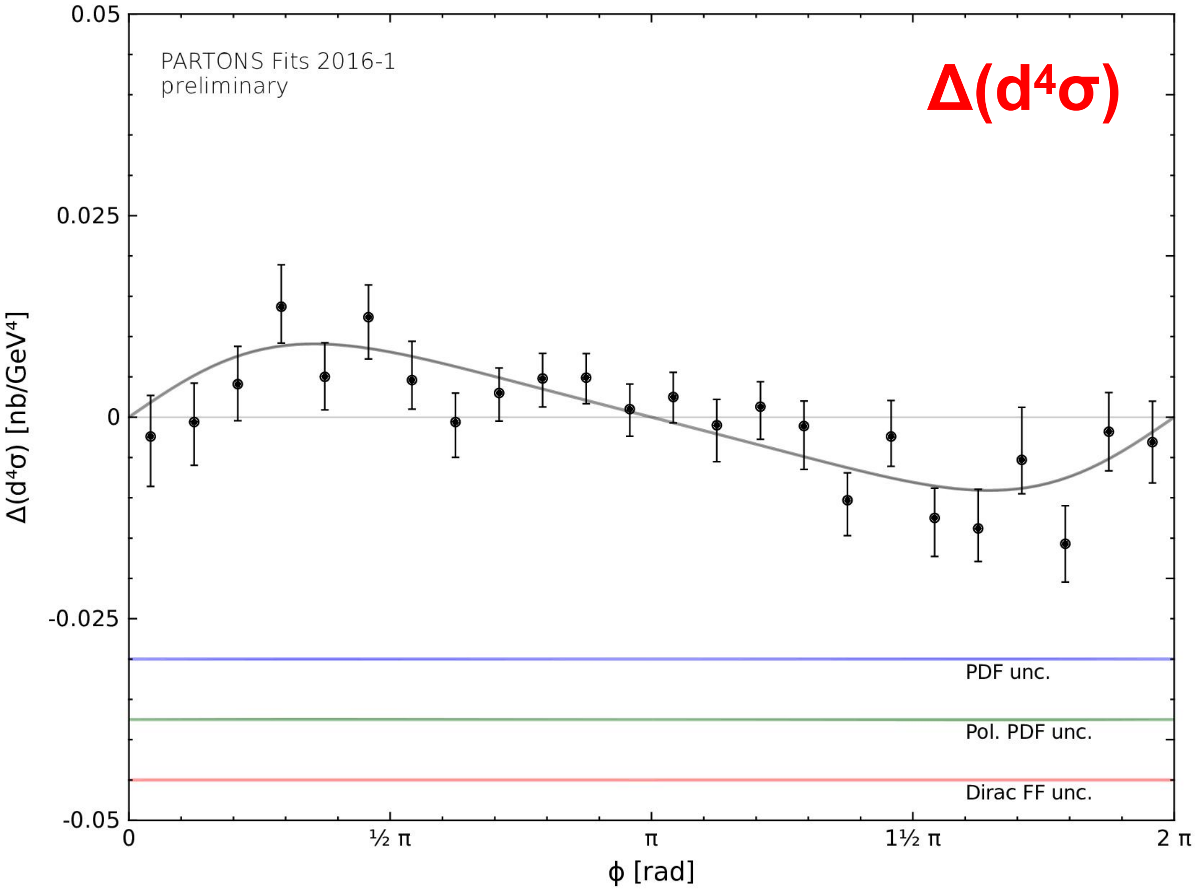
Good description of experimental data, large systematics coming from Δq

RESULTS

Hall A: X2 kinematics: $d^4\sigma$ and $\Delta(d^4\sigma)$
@ x_B = 0.39, t = -0.23 GeV^2, Q^2 = 2.1 GeV^2, E = 5.8 GeV

0.68 c.l.

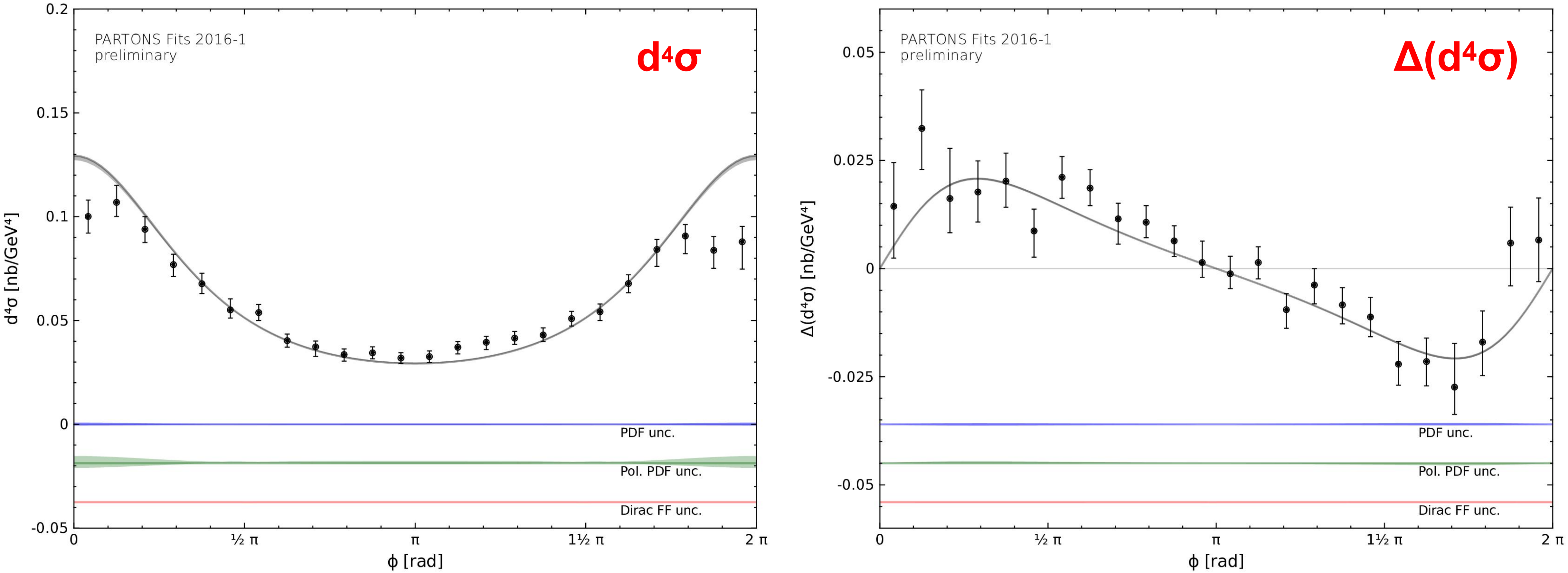




Good description of experimental data

Hall A: X3 kinematics: $d^4\sigma$ and $\Delta(d^4\sigma)$
@ x_B = 0.34, t = -0.23 GeV^2, Q^2 = 2.2 GeV^2, E = 5.8 GeV

0.68 c.l.

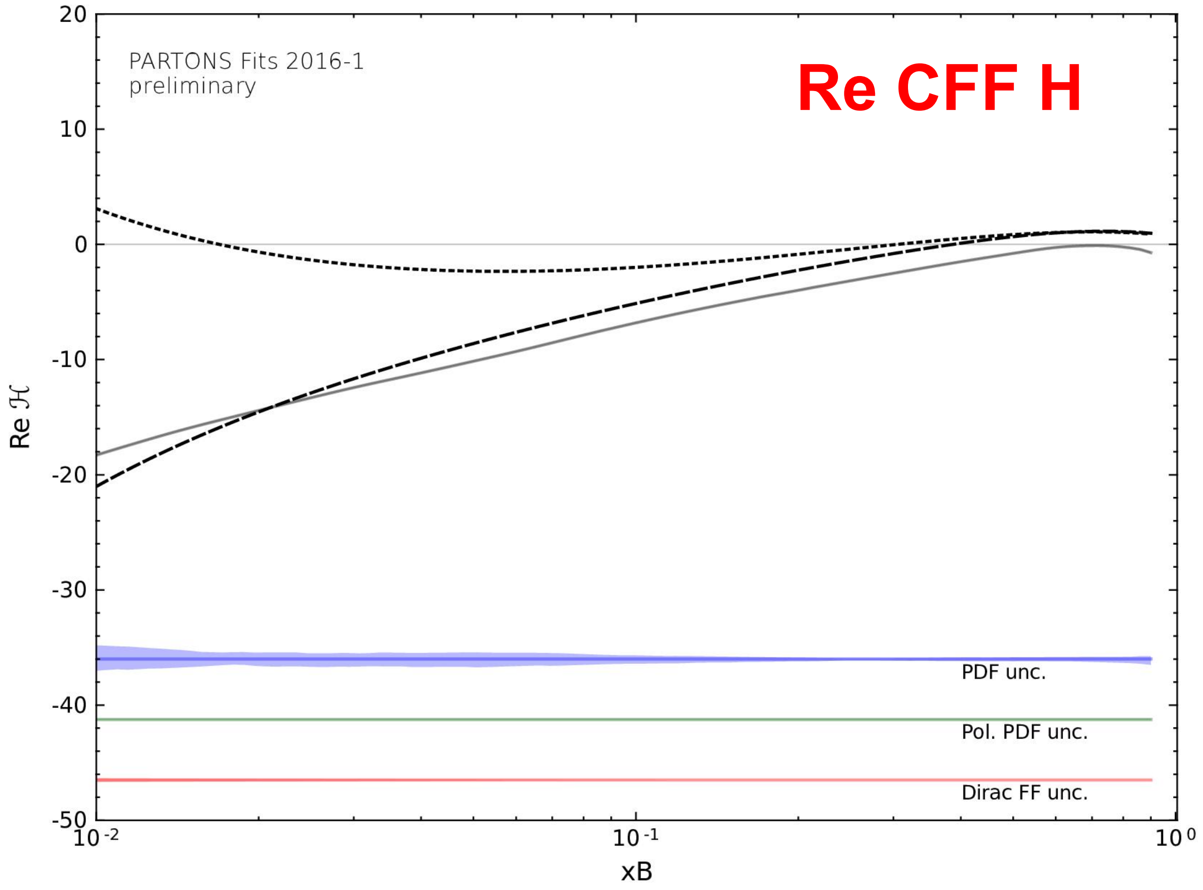


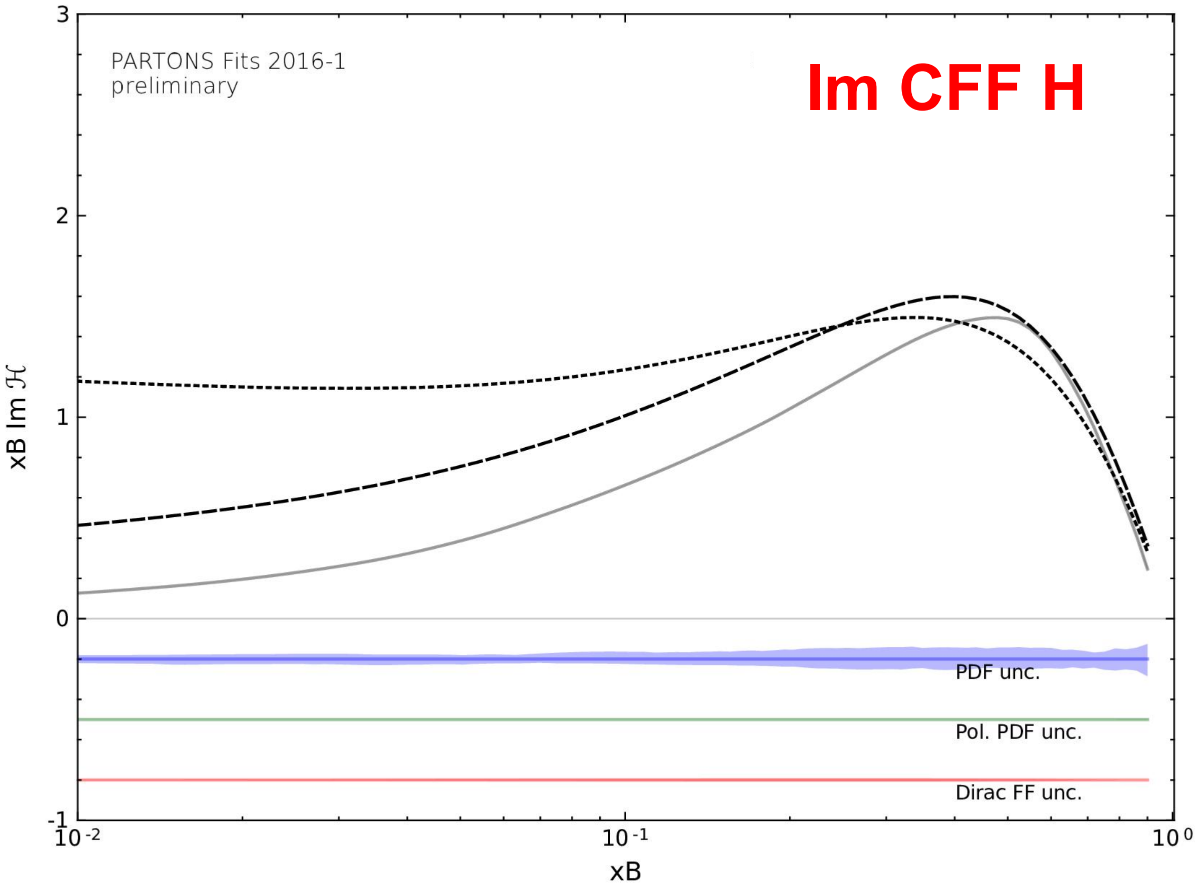
Unable to reproduce $d^4\sigma$ at this kinematics: wrong description of $\tilde{E}$, higher-twist effects, target mass corrections, ...?

CFFs

Compton form factors for GPD H
@ $t = -0.3\ \mathrm{GeV}^2$, $Q^2 = \mu_F^2 = \mu_R^2 = 2\ \mathrm{GeV}^2$

VGG (dashed)
GK (dotted)
0.68 c.l.



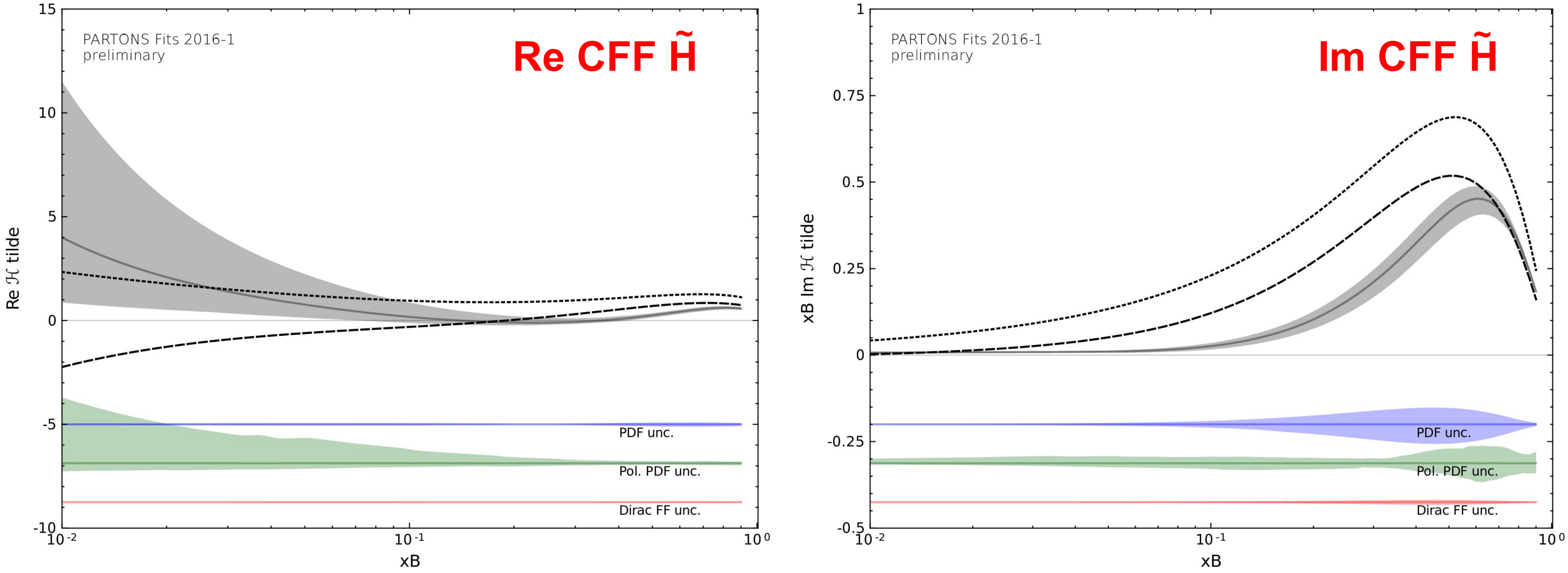


Strong suppression of sea contribution: is exp(-a ln(x) t) appropriate to describe x - t dependence? → nucleon tomography

CFFs

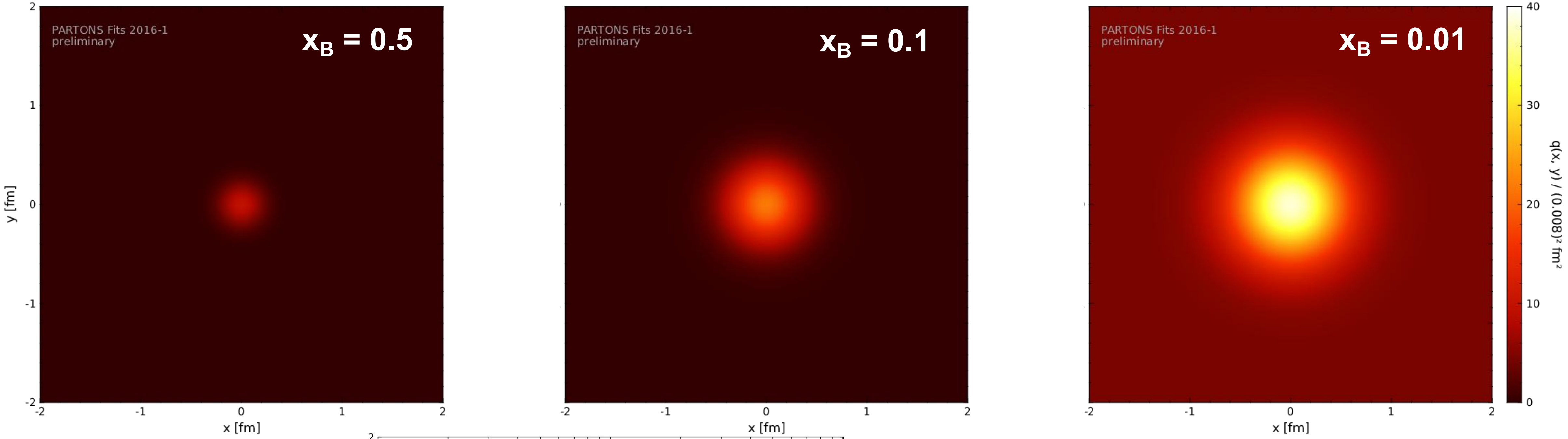
Compton form factors for GPD $\tilde{H}$
@ $t = -0.3\ GeV^2$, $Q^2 = \mu_F^2 = \mu_R^2 = 2\ GeV^2$

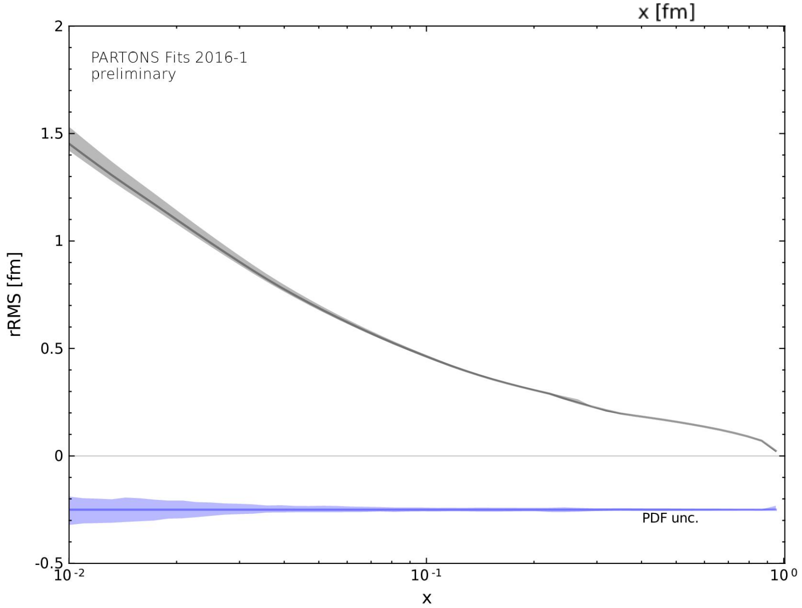
VGG
GK
0.68 c.l.



Smaller contribution w.r.t. VGG and GK

NUCLEON TOMOGRAPHY

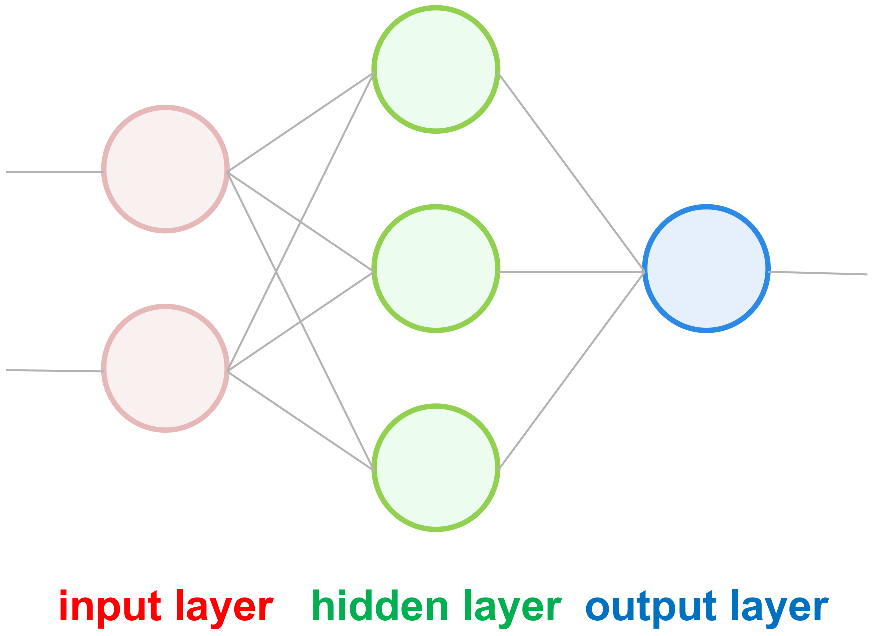




* DEMO *

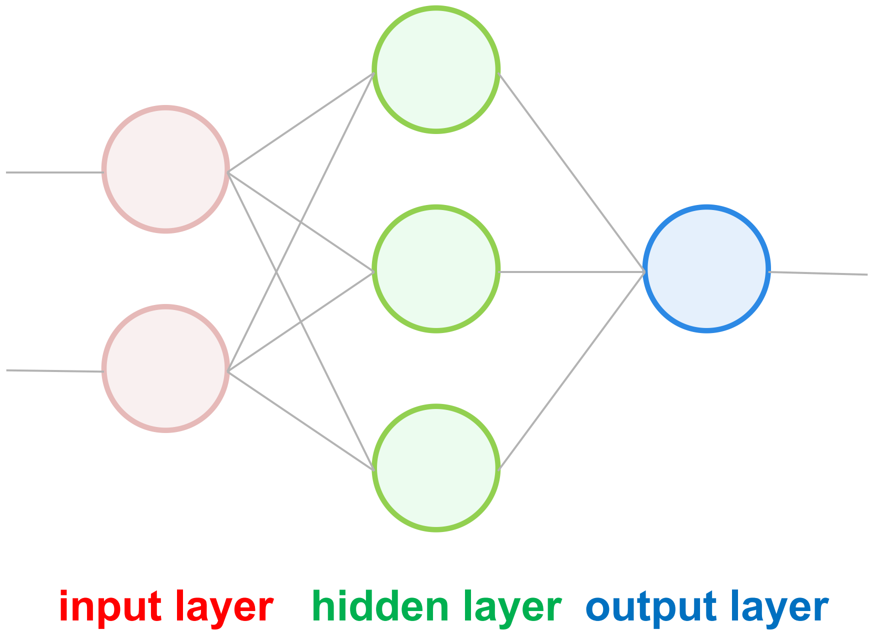
0.68 c.l.

NEURAL NETWORK

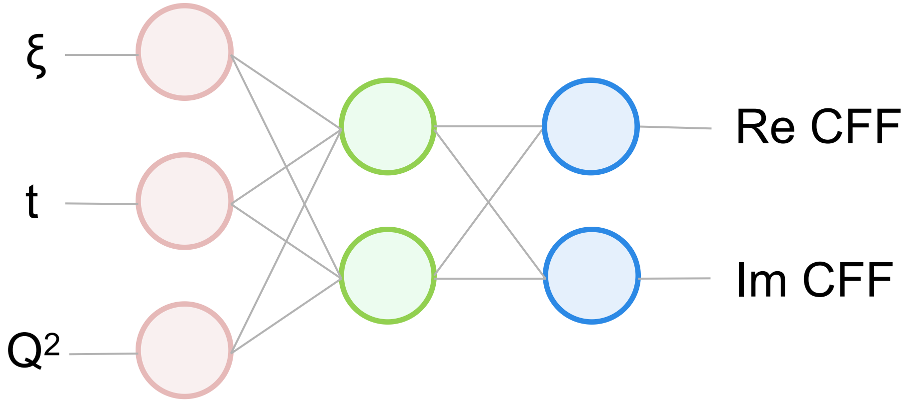


- Machine learning technique
- Made of simple interconnected elements (neurons)
- Process data by dynamic state of neurons
- Need to be trained rather than to be predefined

NEURAL NETWORK



- As model independent as possible (almost no assumptions)
- Flexible to accommodate for new data
- Provides accurate estimation of uncertainties
- Perfect tool for:
  - summarizing of extraction status
  - designing of new experiments



- Our very first attempt to use NN technique → proof of feasibility
- Genetic algorithm (GA) to learn NN
- NN and GA libraries by PARTONS group
- Very simple design of NN
- CLAS asymmetry data only
- χ^2 / ndf = 273.9 / (305 - 68) ≈ 1.16

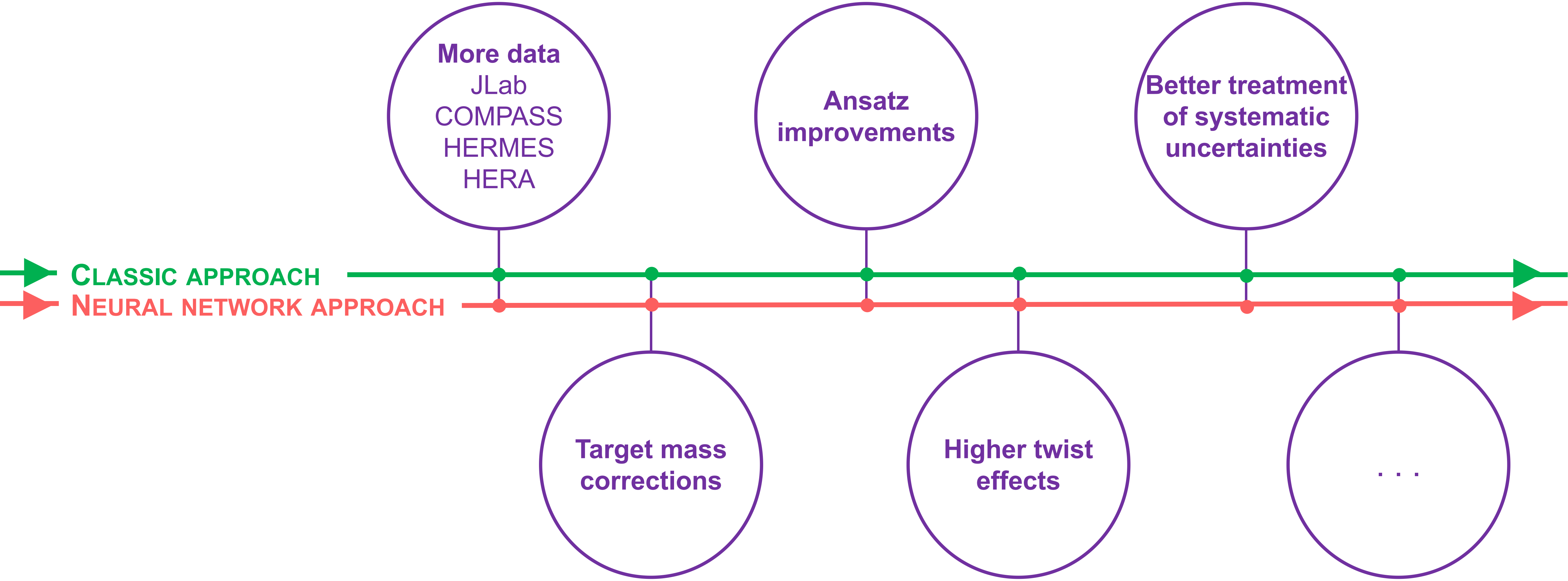
Fits to DVCS data: classic approach

- New way of fitting CFFs proposed
  - → encoded access to nucleon tomography
  - → small number of parameters
  - → should work in wide kinematic domain
- Successful first attempt to fit high-precision JLAB data

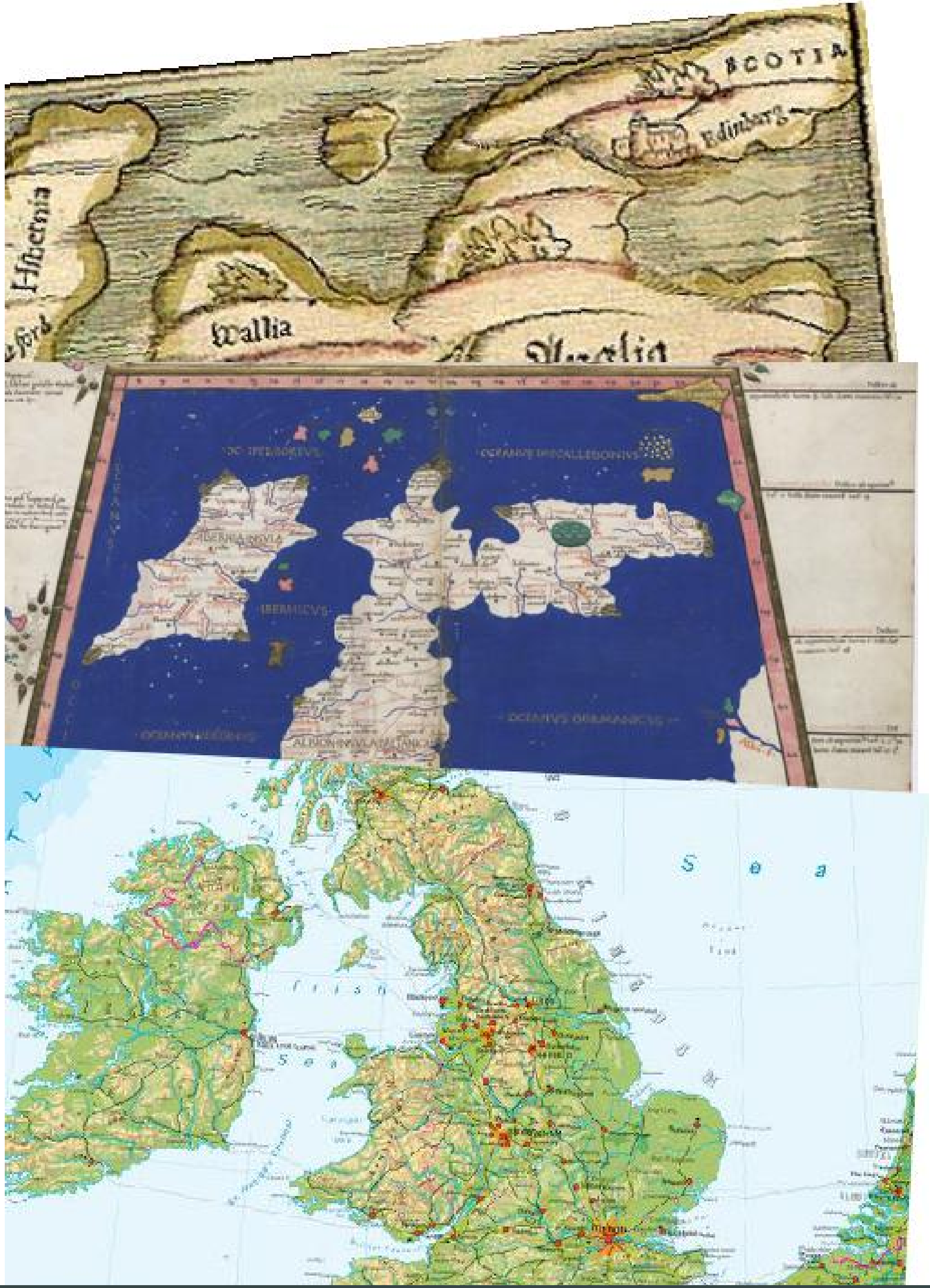
Fits to DVCS data: neural network approach

- Successful feasibility tests

SUMMARY



More data
JLab
COMPASS
HERMES
HERA
Ansatz improvements
Better treatment of systematic uncertainties
Classic approach
Neural network approach
Target mass corrections
Higher twist effects
. . .



Exploration phase

- proof of concept
- feasibility tests
- first measurements

Consolidation phase

- precise measurements by several experiments
- global fits
- extraction of properties

Precision phase

- more precise data
- coveraging "white spots"
- precision tests

based on A. Bacchetta's DIS'17 slides

Exploration phase

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Consolidation phase

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TMD

Precision phase

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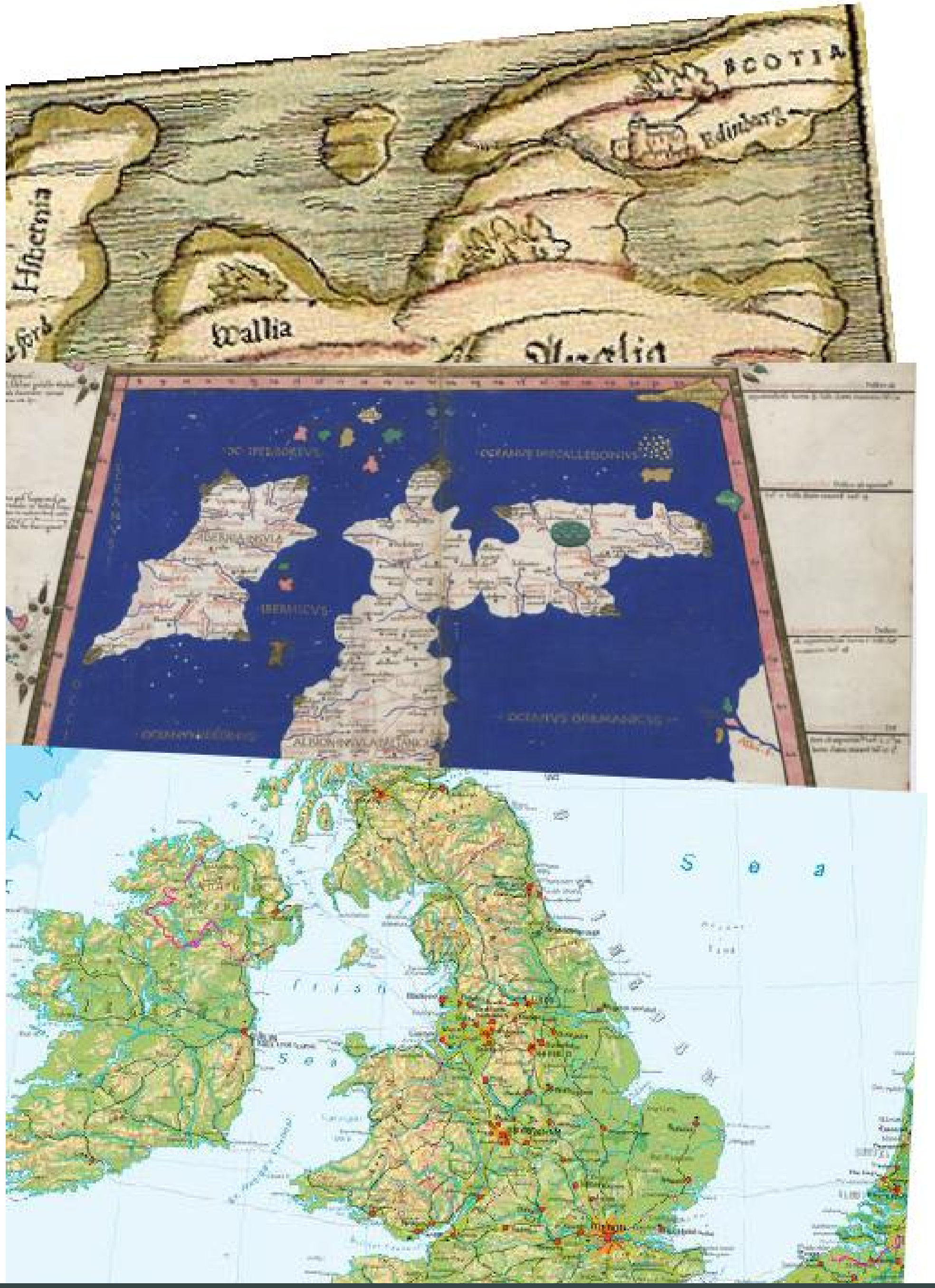
based on A. Bacchetta's DIS'17 slides



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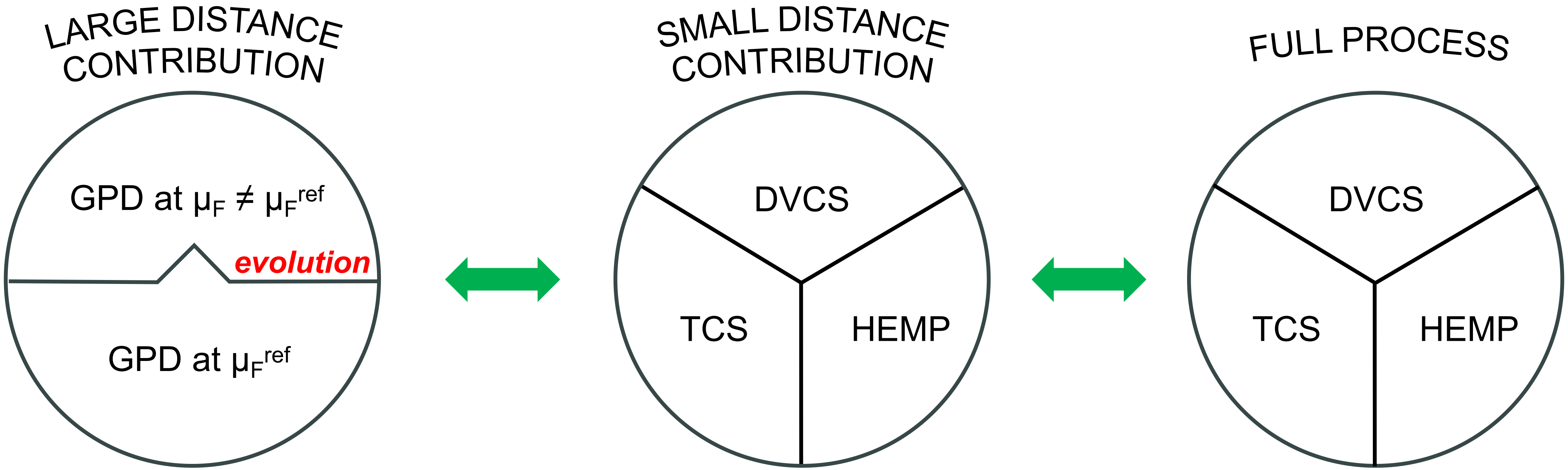
based on A. Bacchetta's DIS'17 slides



First principles and fundamental properties

Computation of amplitudes

Experimental data and phenomenology

Tasks and challenges:

- Physical models
- Perturbative approximations
- Many observables
- Numerical methods
- Accuracy and speed
- Fits

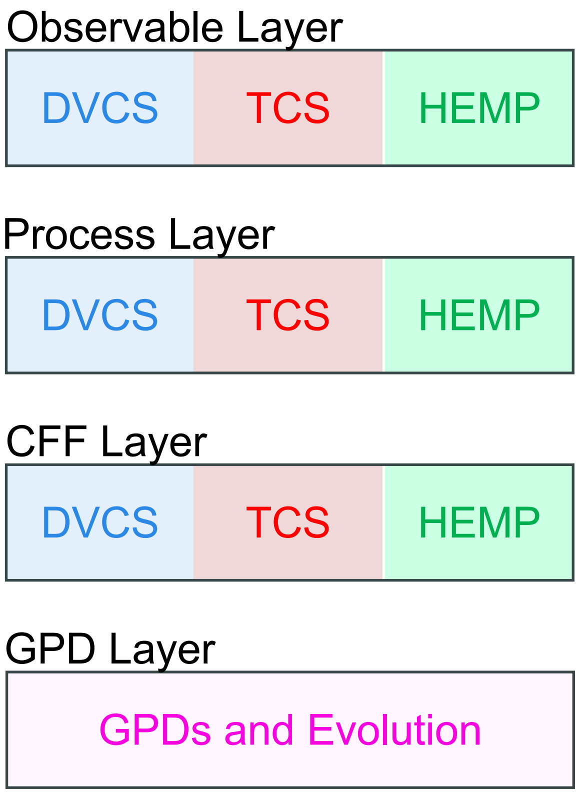
Layered structure:

- one layer = collection of objects designed for common purpose
- one module = one physical development
- operations on modules provided by Services, e.g. for GPD Layer

```
GPDResult computeGPDModel
        (const GPDKinematic& gpdKinematic, GPDModule* pGPDModule) const;
GPDResult computeGPDModelRestrictedByGPDType
        (const GPDKinematic& gpdKinematic, GPDModule* pGPDModule,
        GPDType::Type gpdType) const;
GPDResult computeGPDModelWithEvolution
        (const GPDKinematic& gpdKinematic, GPDModule* pGPDModule,
        GPDEvolutionModule* pEvolQCDModule) const;
...
```

- what can be automated is automated
- features improving calculation speed

  e.g. CFF Layer Service stores the last calculated values



Existing modules:

- GPD: GK11, VGG, Vinnikov, MPSSW13, MMS13
- Evolution: Vinnikov code
- CFF (DVCS only): LO, NLO (gluons and light or light + heavy quarks)
- Cross Section (DVCS only): VGG, BMJ, GV
- Running coupling: 4-loop PDG expression, constant value

H^u @ $x = 0.2$, $t = -0.1$ GeV^2, $\mu_F^2 = \mu_R^2 = 2$ GeV^2