PARTONS project and fits to high precision DVCS data

Paweł Sznajder (on behalf of PARTONS Collaboration)

National Centre for Nuclear Research, Warsaw

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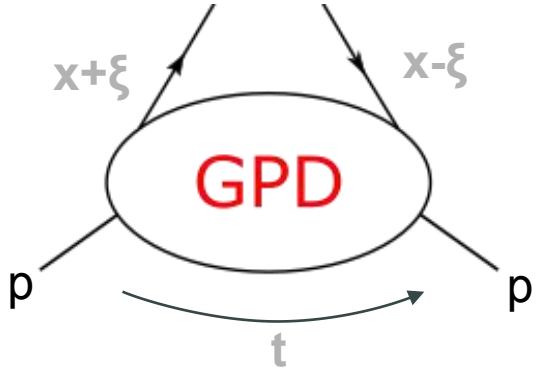
OUTLINE

- Motivation
- PARTONS project
- Fits to JLab DVCS data
- 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 hard scatteing part

handbag diagram:



chiral-even GPDs:

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

GPDs (Generalized Parton Distributions)

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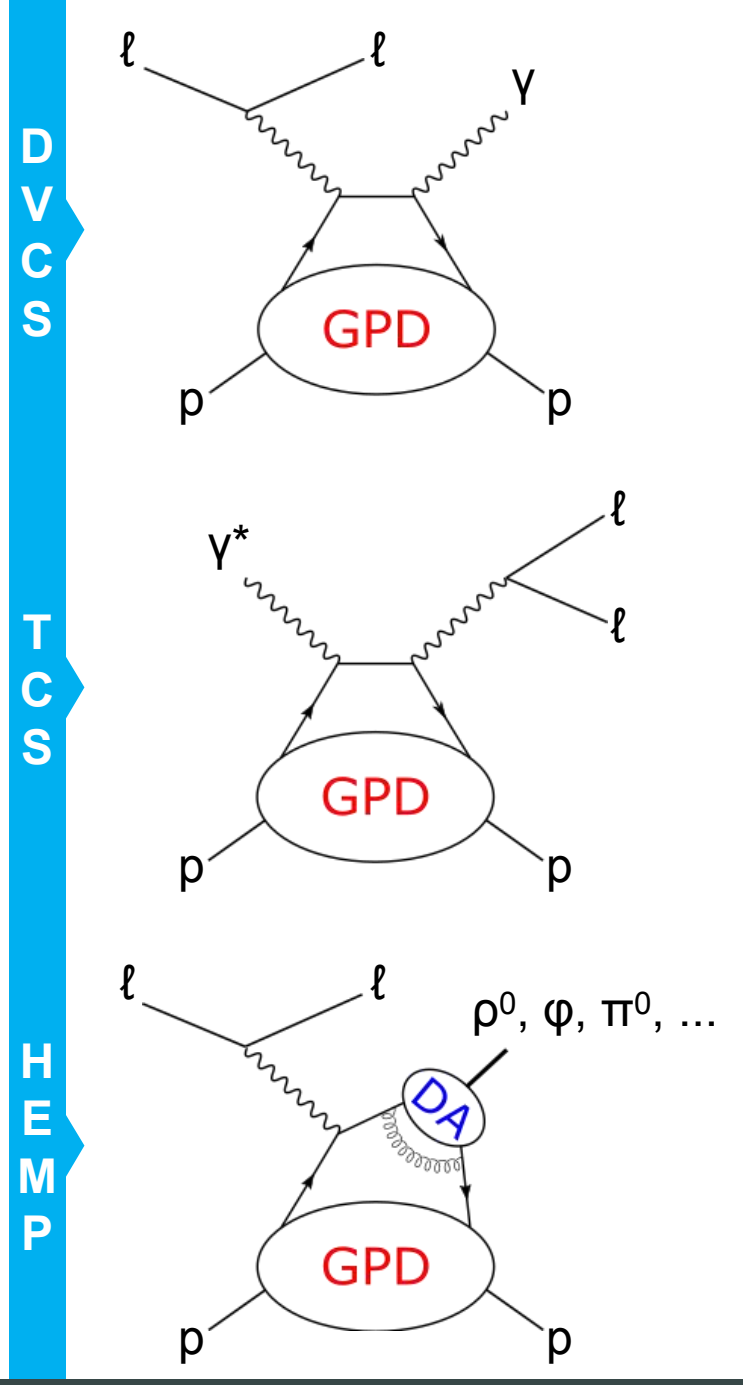
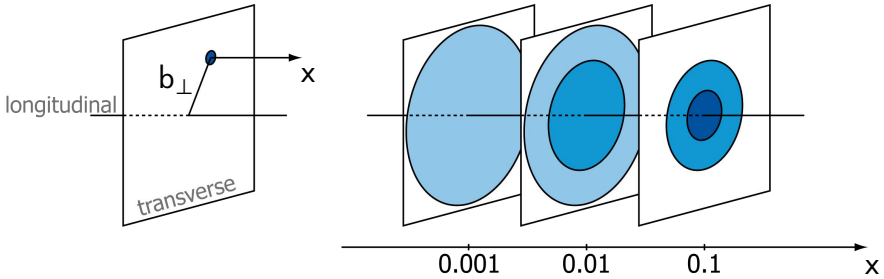


GPDs (Generalized Parton Distributions)

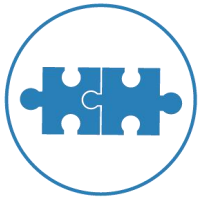
- Nucleon tomography

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

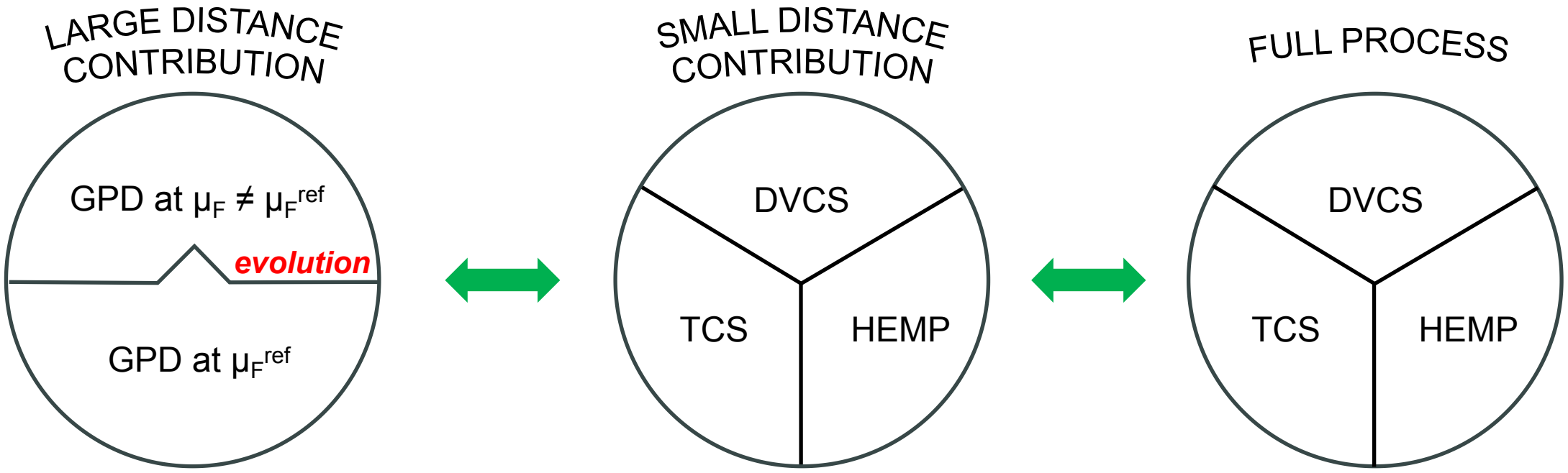


- Total angular momentum

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



S_p = 1/2



First principles and fundamental properties

Computation of amplitudes

Experimental data and phenomenology

Tasks and challenges:

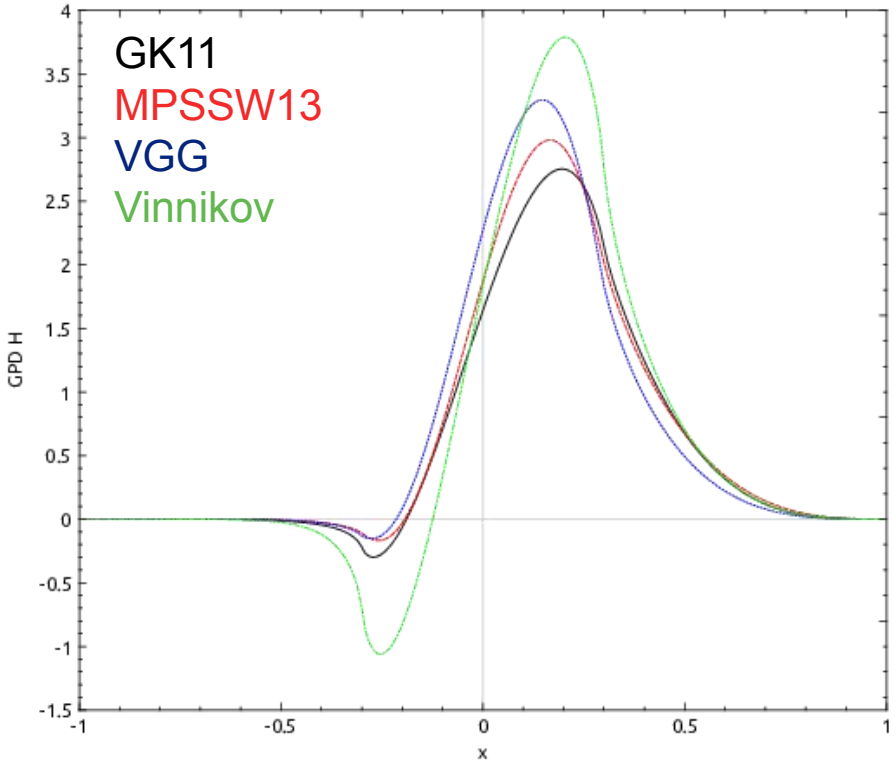
- Physical models
- Perturbative approximations
- Many observables
- Numerical methods
- Accuracy and speed
- Fits

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: hep-ph/1512.06174

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



DISPERSION RELATION

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

- for GPD H

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

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

- 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:

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

- subtraction constant

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

GPDs E and Ẽ:

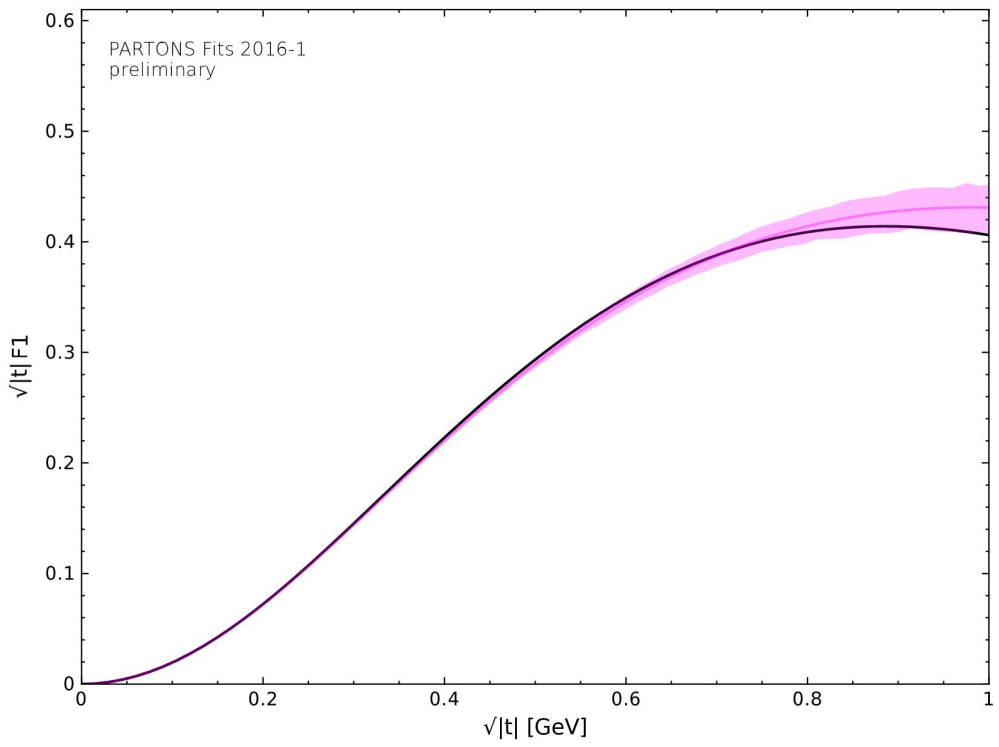
$$\mathcal{E}(\xi,t,Q^2) = N_E \times \mathcal{E}_{\rm GK}(\xi,t,Q^2)$$
$$\widetilde{\mathcal{E}}(\xi,t,Q^2) = N_{\widetilde{E}} \times \widetilde{\mathcal{E}}_{\rm GK}(\xi,t,Q^2)$$

- GK CFFs

FIT ANSATZ FOR H AND H̃

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

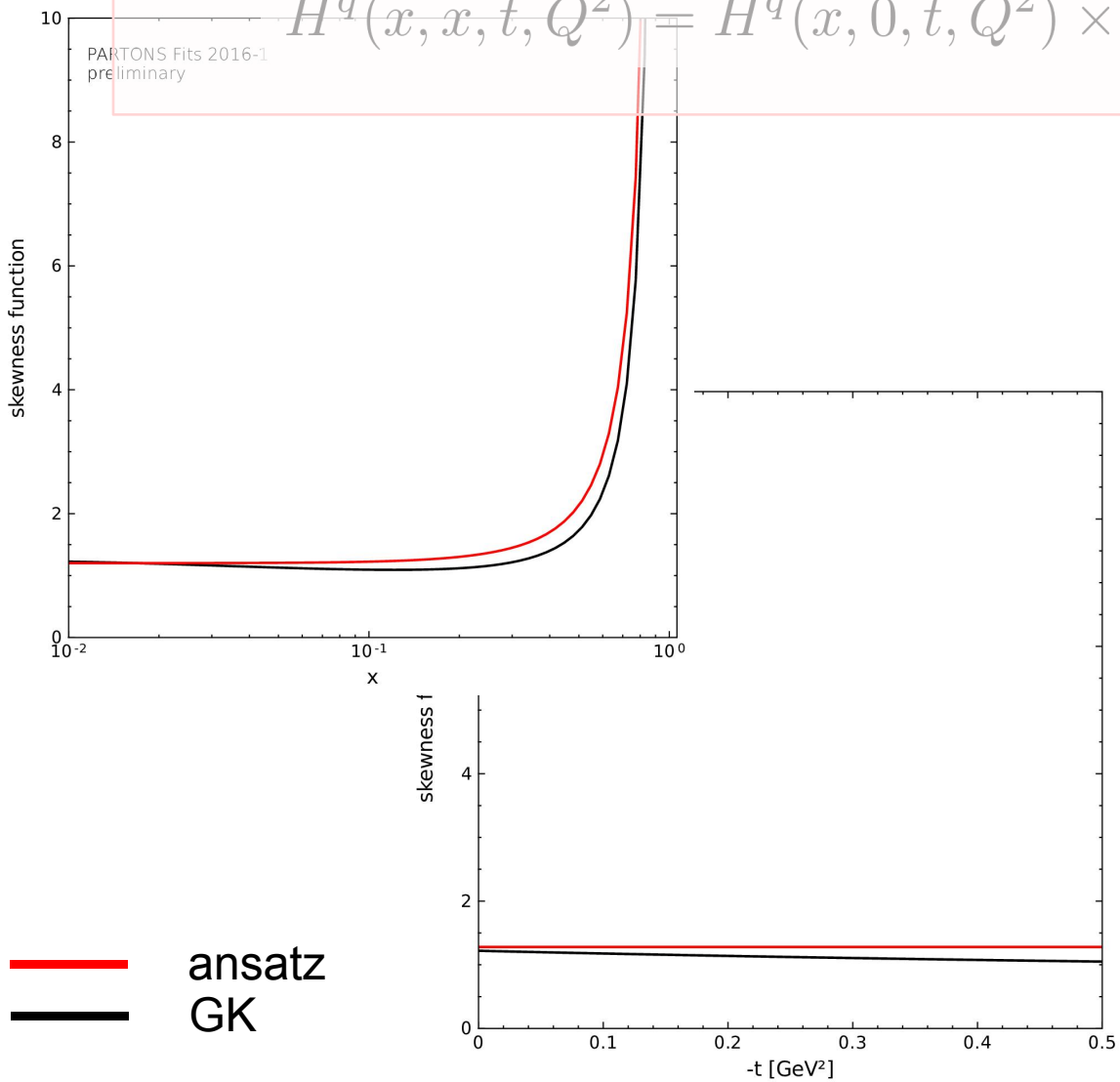
[1] Phys. Rev. C79 (2009) 065204

FIT ANSATZ FOR H AND H̃

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 $Q^2 > 1.5\ \mathrm{GeV}^2$ (*where we can rely on LO approximation*)
  $-t / Q^2 < 0.25$ (*where we can rely on GPD factorization*)
- χ^2 / ndf $3272.6 / (3433 - 7) \approx 0.96$
- Free parameters a_{Hsea}, $a_{\tilde{H}val}$, $a_{\tilde{H}sea}$, 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

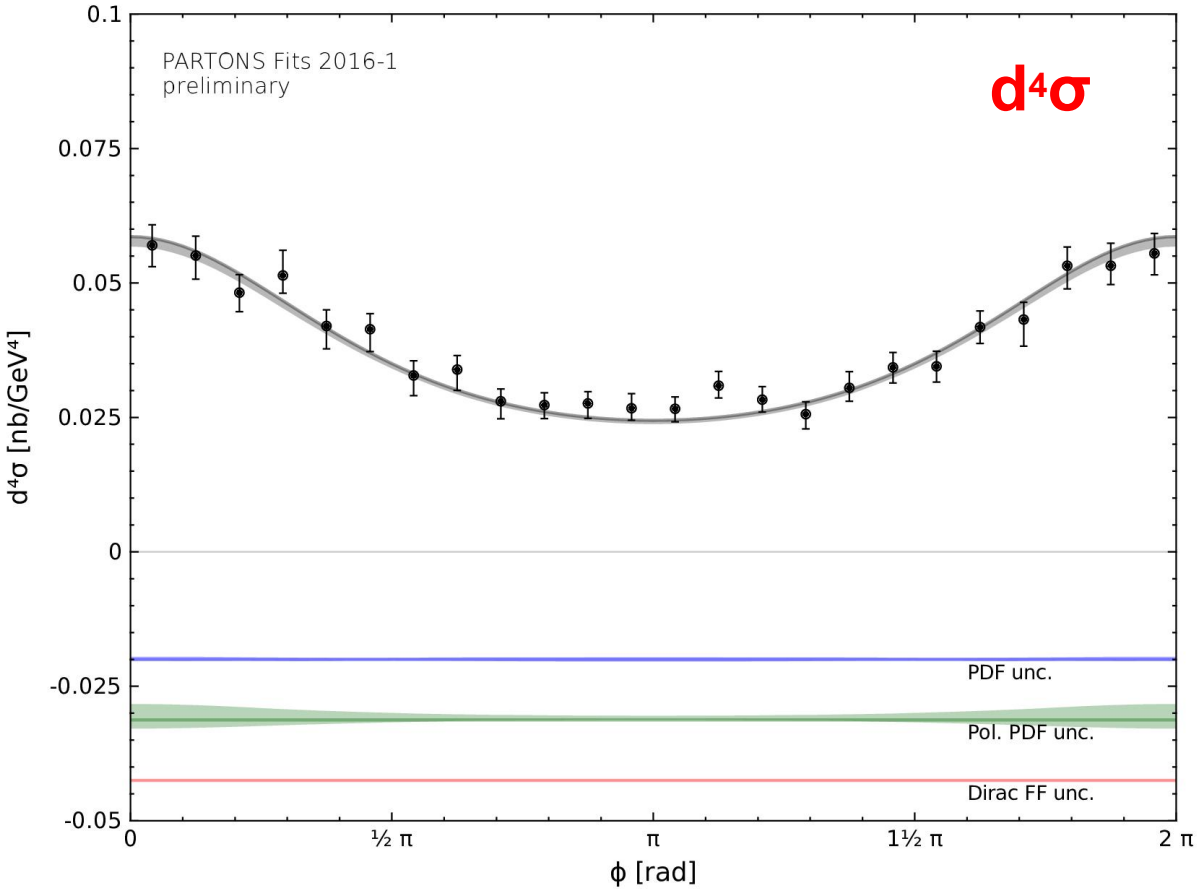
RESULTS

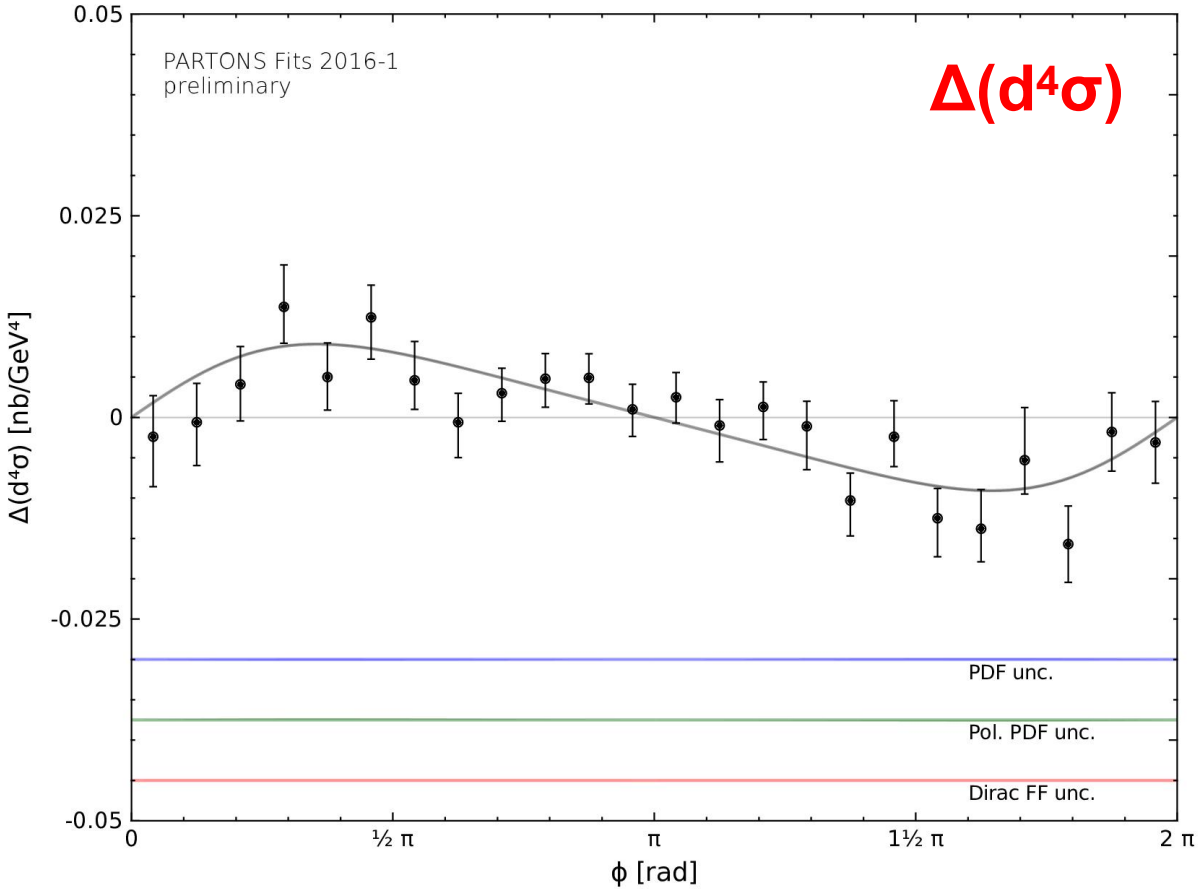
- Values of parameters and correlation matrix

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

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.

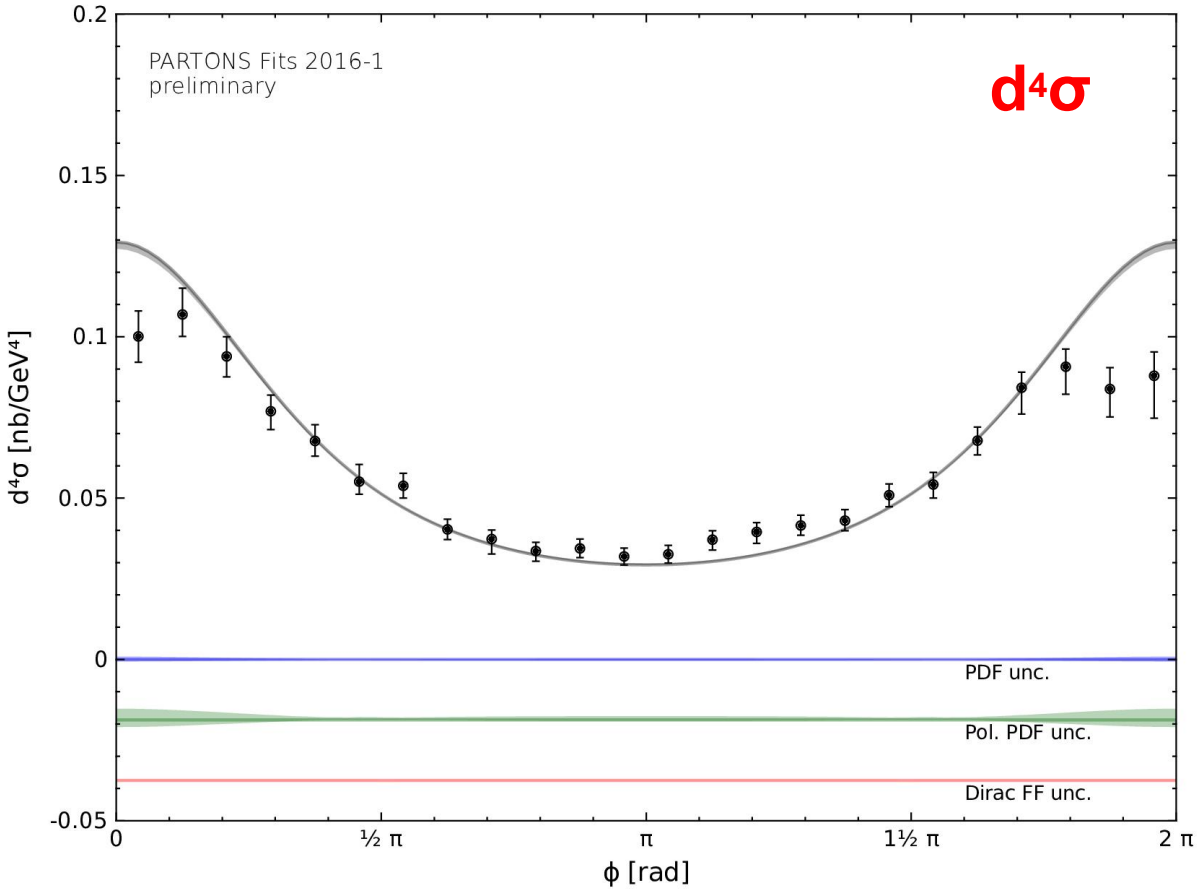


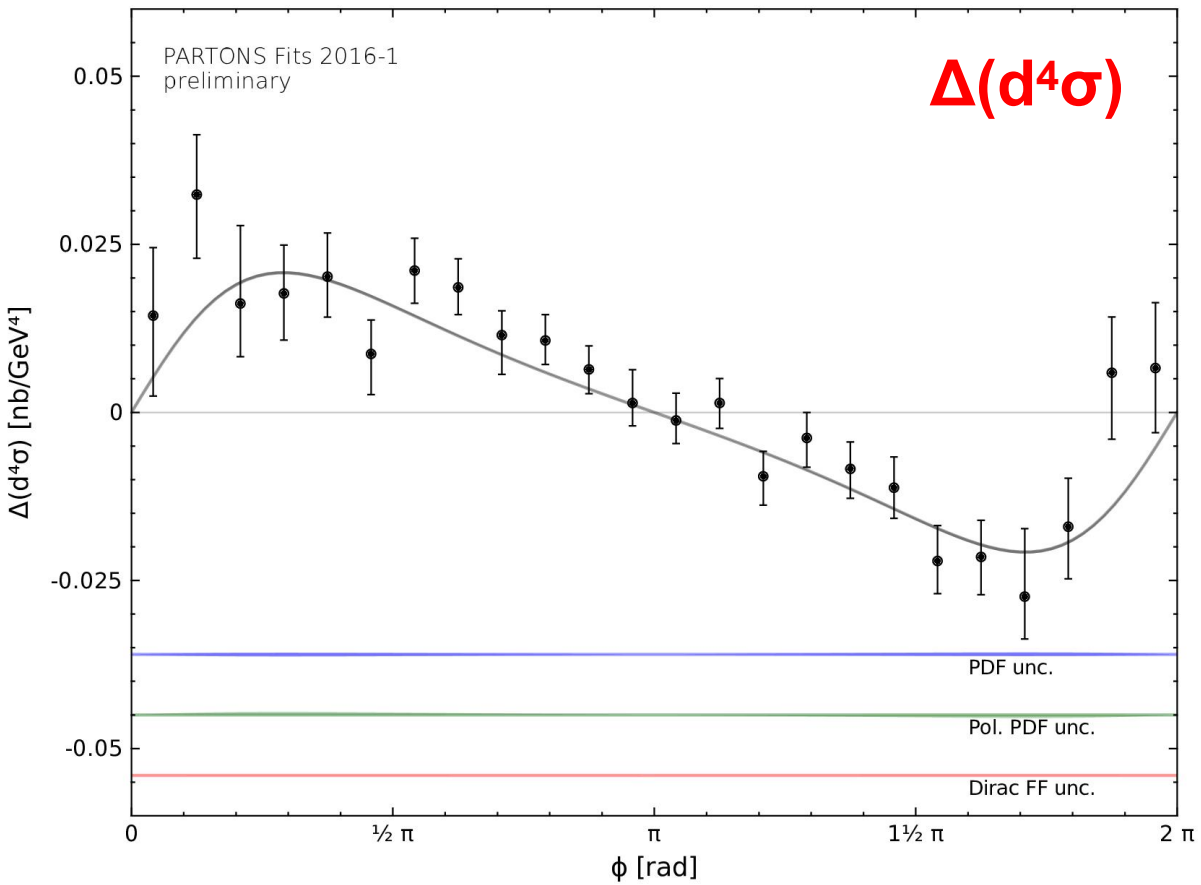


Good description of experimental data

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.

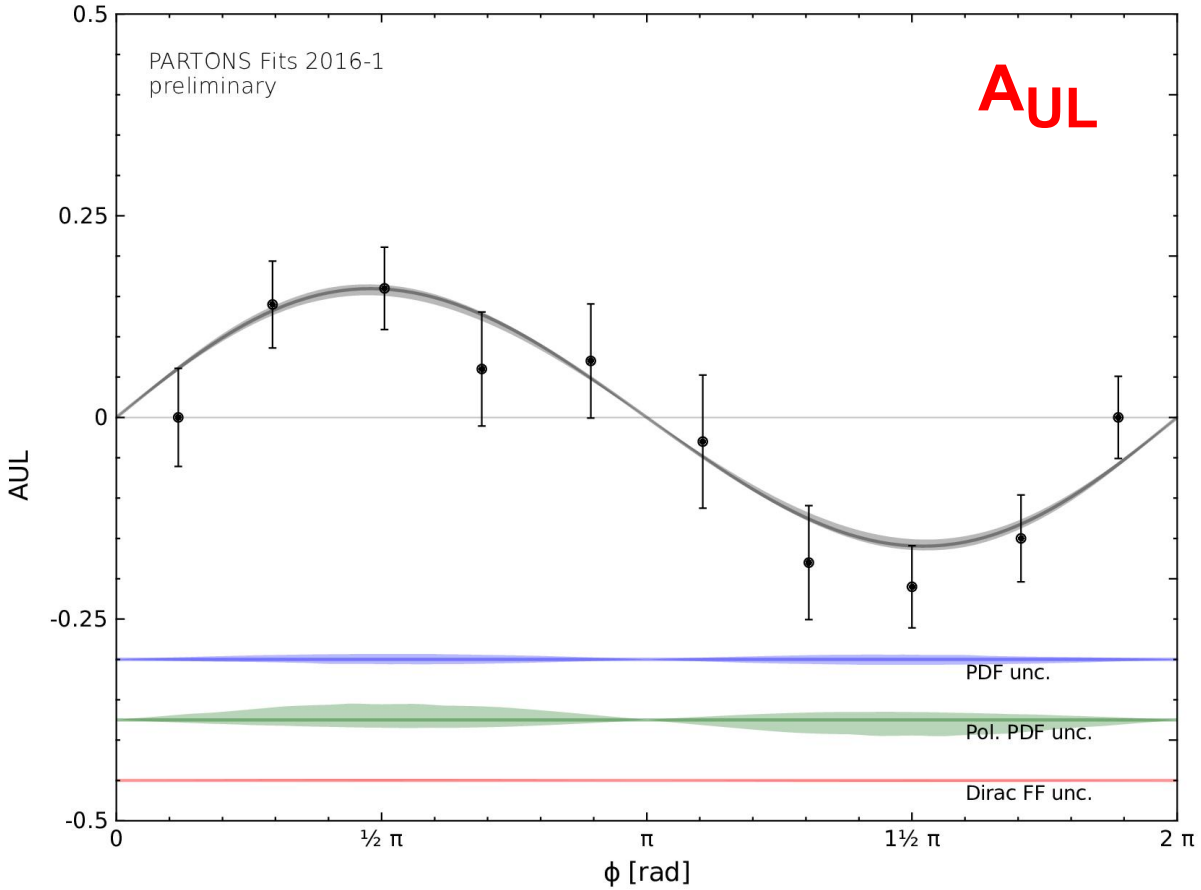


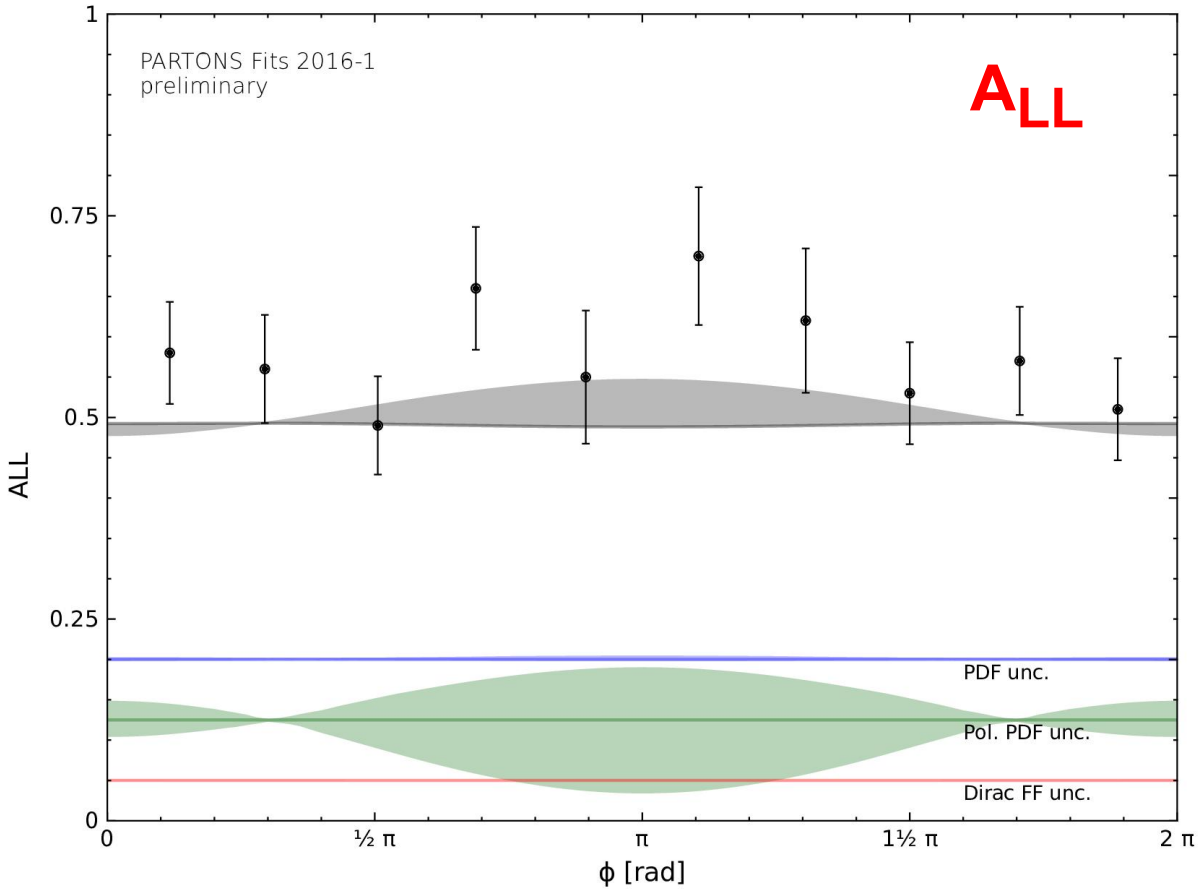


Unable to reproduce $d^4\sigma$ at this kinematics: wrong description of $\tilde{E}$, higher-twist effects, target mass corrections, ...?

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.

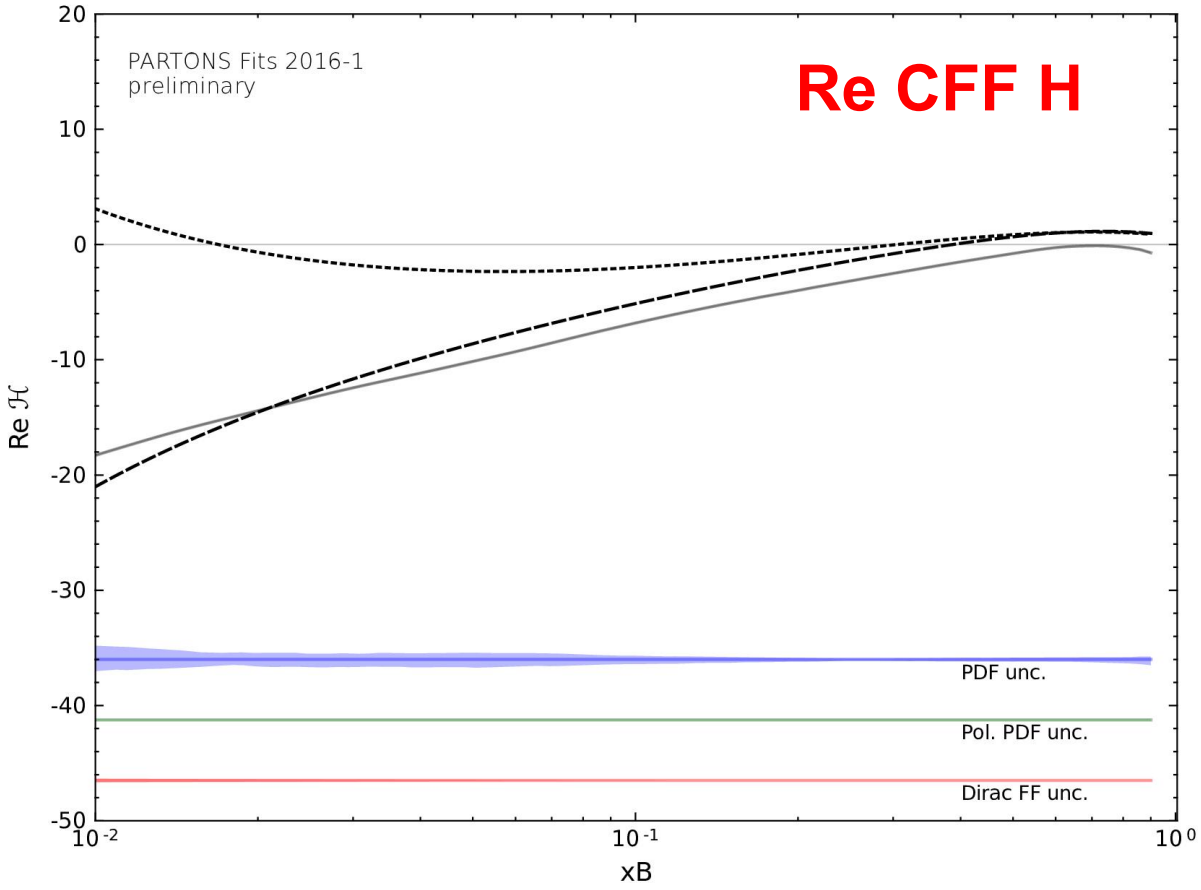


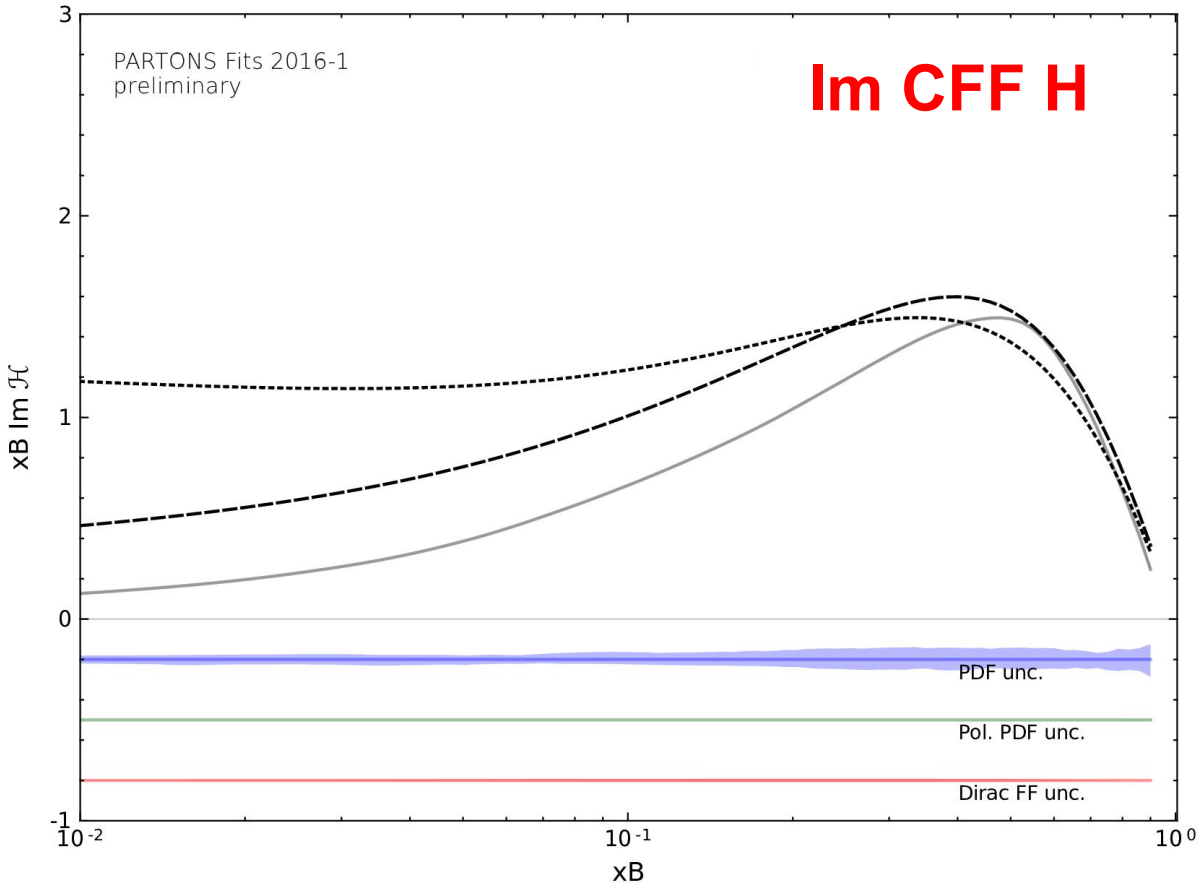


Good description of experimental data, large systematics coming from Δq

Compton form factors for GPD H
@ t = -0.3 GeV², $Q^2 = \mu_F^2 = \mu_R^2 = 2$ GeV²

VGG
GK
0.68 c.l.

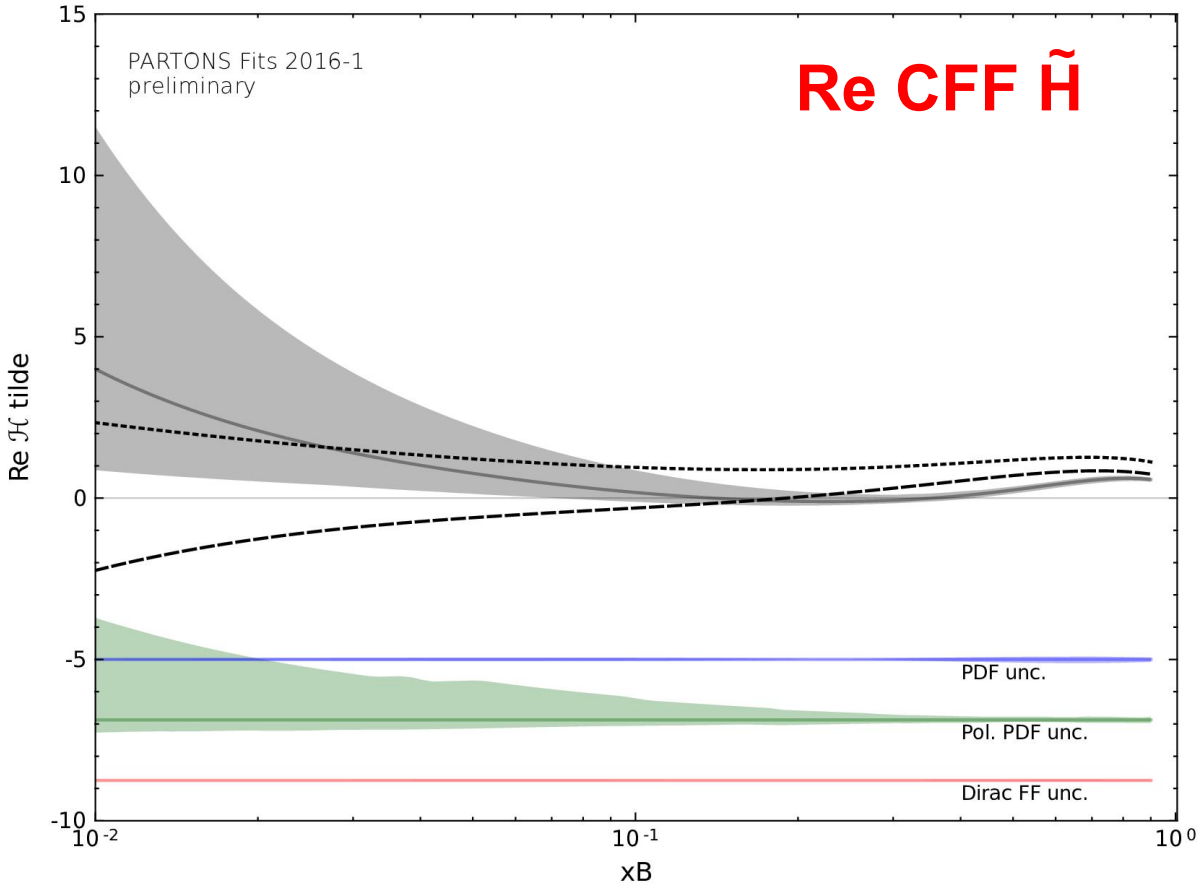


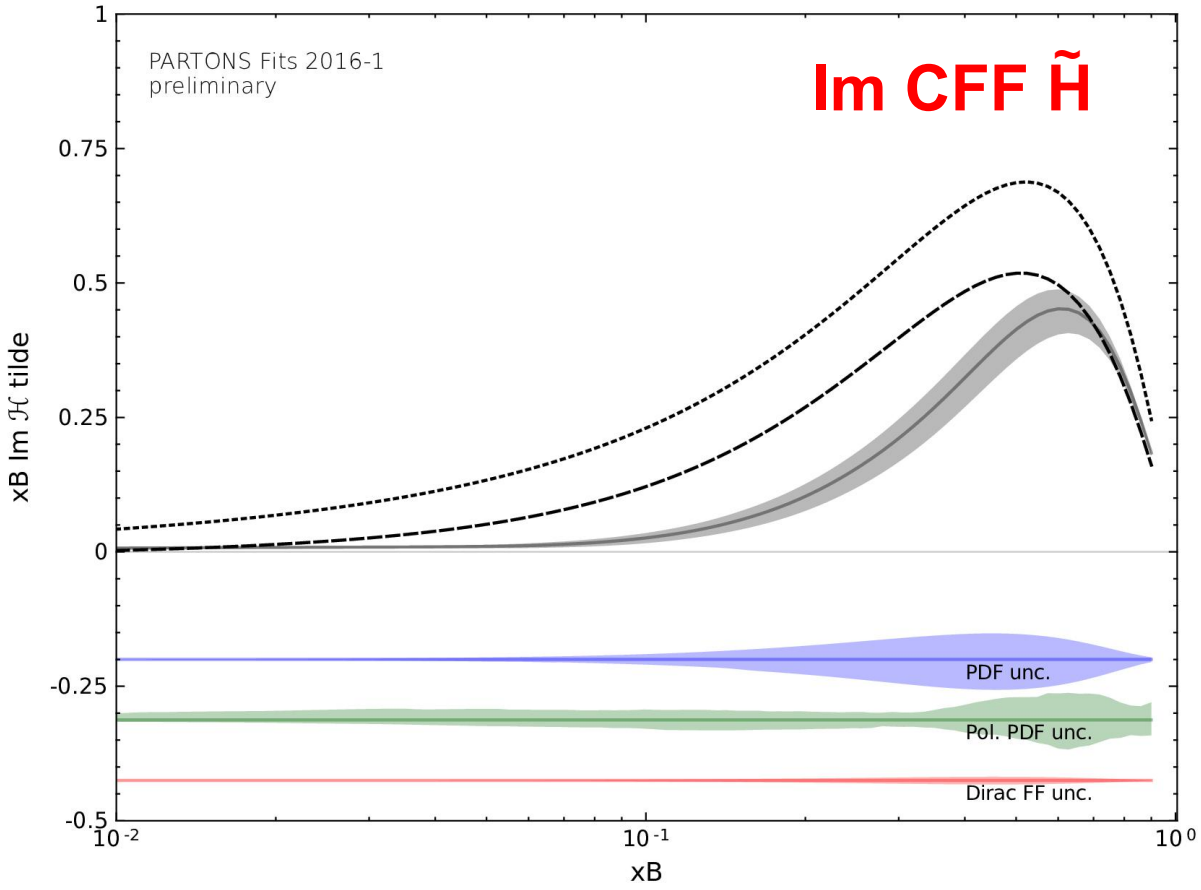


Strong suppression of sea contribution: is exp(-a ln(x) t) appropriate to describe x - t dependence? → nucleon tomography

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

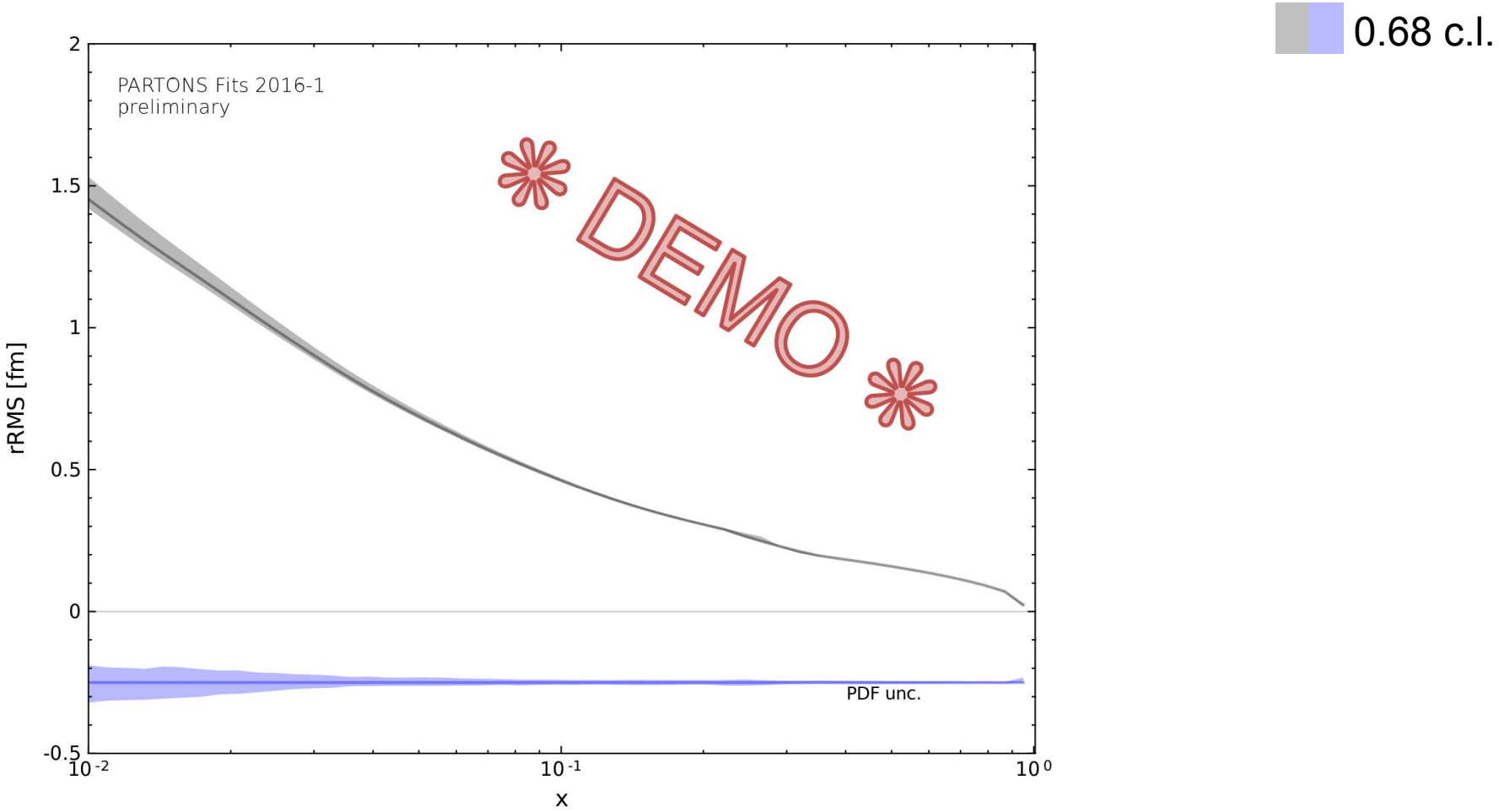
VGG
GK
0.68 c.l.





Smaller contribution w.r.t. VGG and GK

NUCLEON TOMOGRAPHY



Still too model dependent... but we are on the right track to measure it!

PARTONS (PARtonic Tomography Of Nucleon Software)

- Modern platform devoted to study GPDs
- Design to support the effort of GPD community
- Can be used by both theoreticians and experimentalists
- More info in: arXiv: hep-ph/1512.06174

Fits to DVCS data

- 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

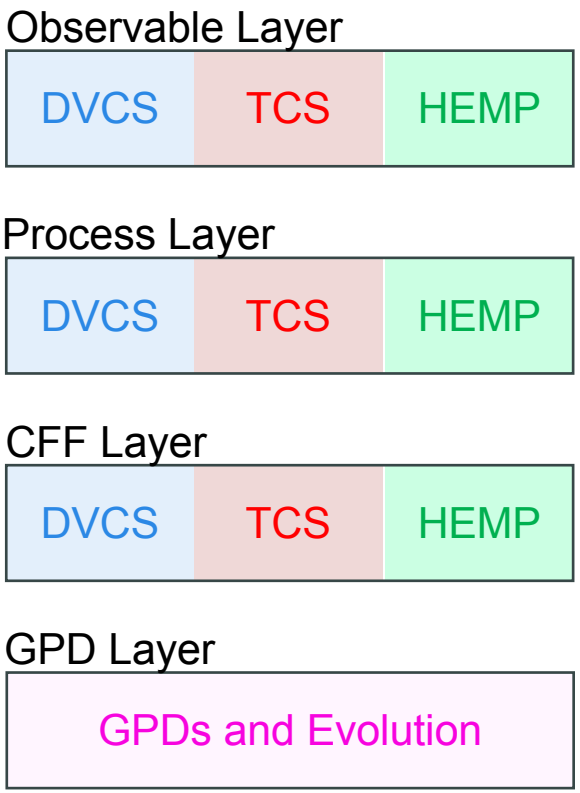
Layered structure:

- 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

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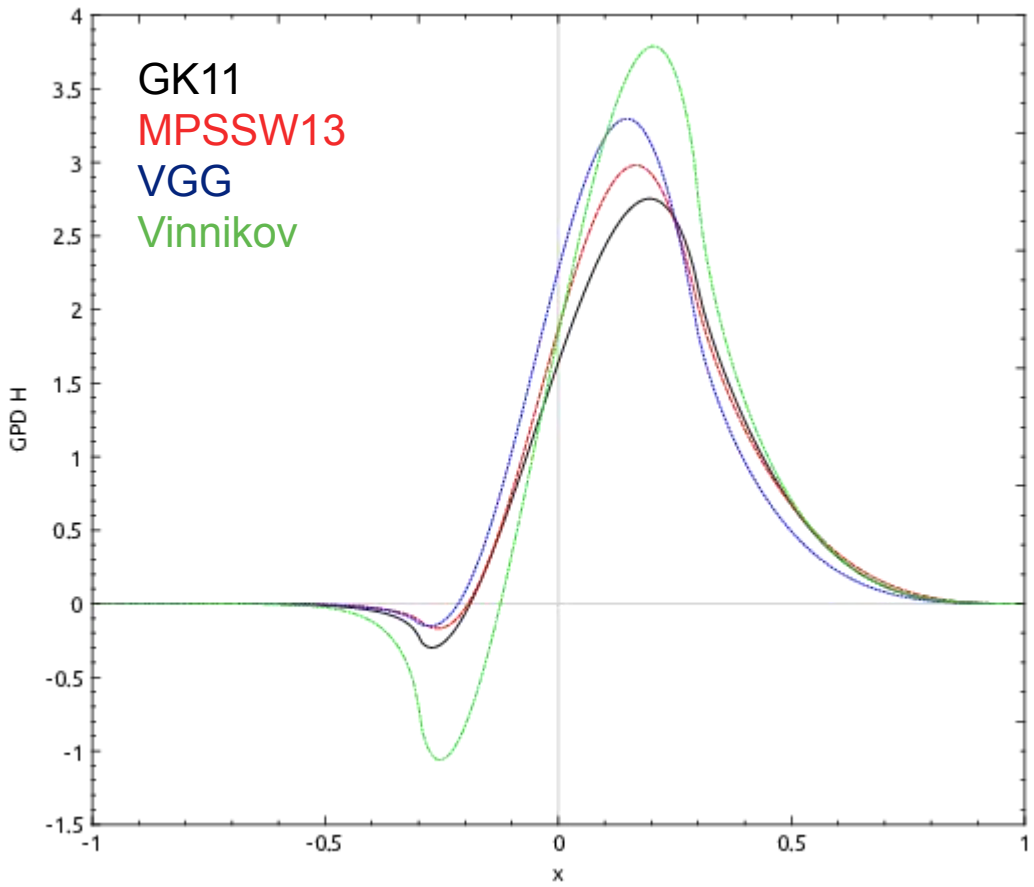
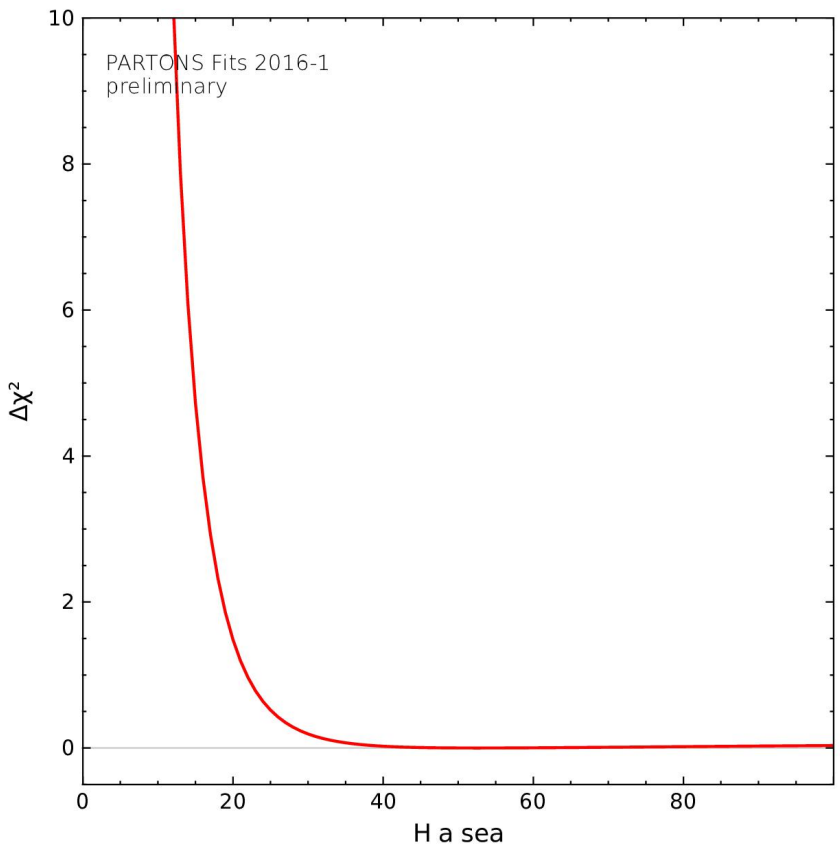


- $\Delta\chi^2$ shape for 'H a sea'



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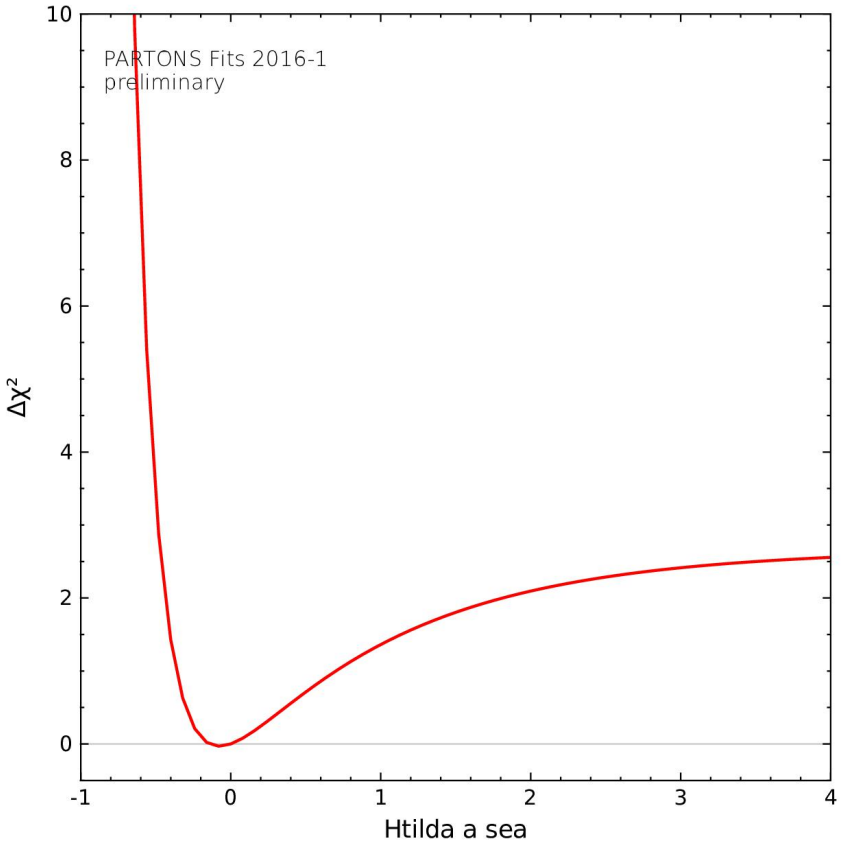
E	N	-8.08	0.57
Etilde	N	-0.45	0.07

Can x - t dependence be described by exp(-ln(x) a · t)?

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

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



Unsymmetric stat. uncertainty

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