Access to decoupled information of Generalized Parton Distributions via Double Deeply Virtual Compton Scattering

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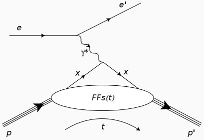
Generalized Parton Distributions (GPDs)

elastic scattering $ep \rightarrow ep$

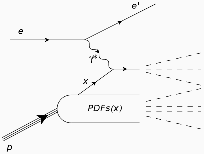


R. Hofstadter, Nobel Prize 1961

Form Factors (FFs)

$\rightarrow$ transverse position space.

DIS $ep \rightarrow eX$

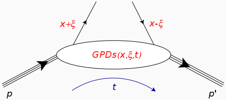


Friedman, Kendall, Taylor, Nobel Prize 1990

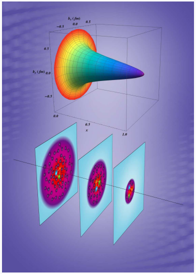
Parton Distribution Functions (PDFs)

$\rightarrow$ longitudinal momentum.

exclusive inelastic scattering

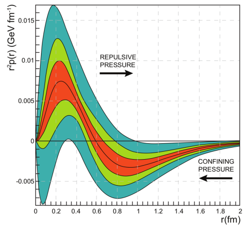


GPDs: $H^q, E^q, \widetilde{H}^q, \widetilde{E}^q(x, \xi, t)$
describe the non-perturbative quark (gluon) structure of the nucleon.



Dupré, Guidal, Niccolai, Vanderhaeghen 2017

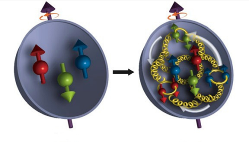
$\rightarrow$ nucleon tomography from the correlation between transverse position and longitudinal momentum



Burkert, Elouadrhiri, Girod 2018

$\rightarrow$ internal pressure distribution

$$\int xH(x, \xi, t)dx = M_2(t) + \frac{4}{5}\xi^2 d_1(t)$$



Ji 1997

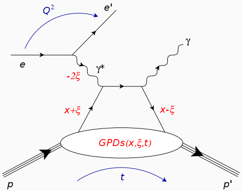
$\rightarrow$ quark angular momentum

$$\int x\left[H^q(x, \xi, 0) + E^q(x, \xi, 0)\right] dx$$

GPDs measurements

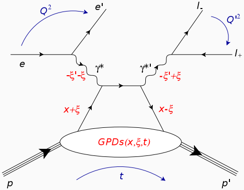
DVCS and DDVCS [1-4] are two golden processes for direct measurements of GPDs

$ep \to ep\gamma$



Deeply Virtual Compton Scattering (DVCS)

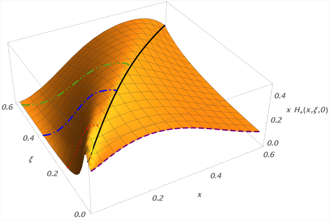
$ep \to epl^- l^+$



Double DVCS (DDVCS)

$$\mathcal{H}(\xi,\xi,t) = \sum_q e_q^2 \Big\{ \mathcal{P}\int_{-1}^{1} dx\, H^q(x,\xi,t)\left[\frac{1}{x-\xi}+\frac{1}{x+\xi}\right] - i\pi\left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]\Big\}$$

$$\mathcal{H}(\xi',\xi,t) = \sum_q e_q^2 \Big\{ \mathcal{P}\int_{-1}^{1} dx\, H^q(x,\xi,t)\left[\frac{1}{x-\xi'}+\frac{1}{x+\xi'}\right] - i\pi\left[H^q(\xi',\xi,t) - H^q(-\xi',\xi,t)\right]\Big\}$$



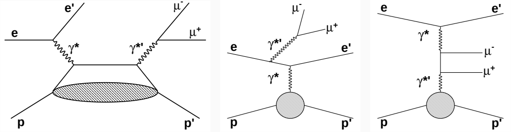
- DVCS can access GPDs only at $x = \pm\xi$;
- DDVCS allows one to measure the GPDs for each x, ξ, t values independently ($|\xi'| < \xi$).

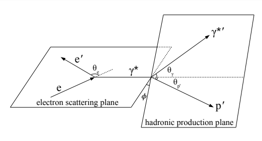
[1] M. Guidal and M. Vanderhaeghen, Phys. Rev. Lett. **90** 012001 (2003).
[2] A. V. Belitsky and D. Müller, Phys. Rev. Lett. **90** 022001 (2003).
[3] I. V. Anikin, *et al.*, Acta Phys. Pol. B **49** 741 (2018).
[4] S. Zhao, PoS (SPIN2018) 068.

DDVCS observables

channel: $ep \to ep\mu^-\mu^+$ (avoid antisymmetrization)

$$\sigma \propto \mathcal{T}^2 = |\mathcal{T}_{\text{ddvcs}}|^2 + |\mathcal{T}_{\text{BH}_1} + \mathcal{T}_{\text{BH}_2}|^2 + \mathcal{I} \text{ (linear in Compton form factors)}$$





polarized electron, unpolarized proton

$$\Delta\sigma_{\text{LU}} \sim \Im\text{m}\left\{F_1\mathcal{H} + \xi'(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right\}\sin\phi$$

electron and positron, unpolarized proton

$$\Delta\sigma_{\text{C}} \sim \Re\text{e}\left\{F_1\mathcal{H} + \xi'(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}\right\}\cos\phi$$

⇒

JLab12

- high luminosity
- existing polarized e^-
- future polarized e^+

(PEPPo collaboration)

unpolarized electron, longitudinally polarized proton

$$\Delta\sigma_{\text{UL}} \sim \Im\text{m}\left\{F_1\widetilde{\mathcal{H}} + \xi'(F_1+F_2)(\mathcal{H} + \frac{\xi}{1+\xi}\mathcal{E}) + \cdots\right\}\sin\phi$$

unpolarized electron, transversely polarized proton

$$\Delta\sigma_{\text{UT}} \sim \Im\text{m}\left\{\xi^2F_1(\mathcal{H}+\mathcal{E}) - \frac{t}{4M^2}(F_2\mathcal{H} - F_1\mathcal{E}) + \cdots\right\}\sin\phi$$

⇒

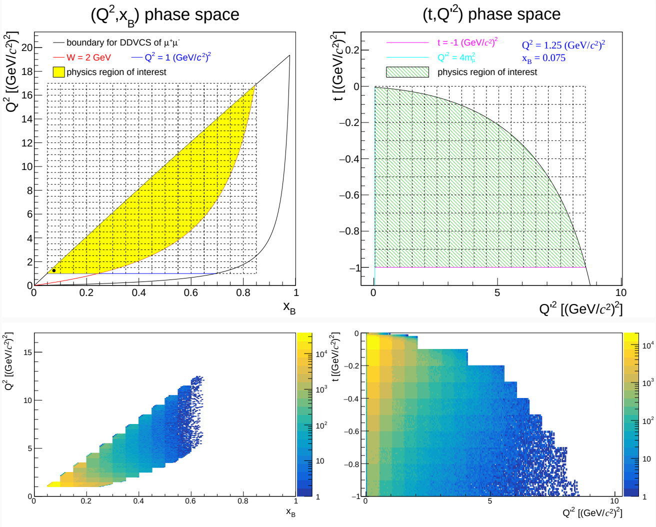
EIC

see more on the website of 2019 EIC User Group meeting (22-26 July 2019 Paris France)

Outline

- Experimental projections
  - Events generation
  - Pseudo-data analysis
  - Experimental observables
- CFFs extraction
  - Fitter algorithm
  - Decoupled singlet GPD H

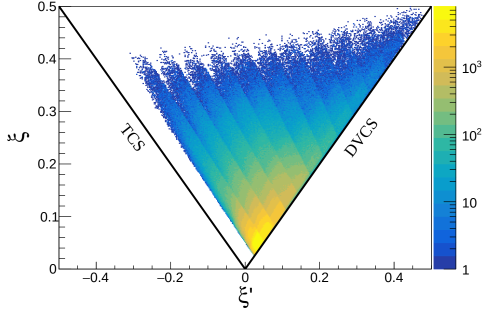
Experimental projections I

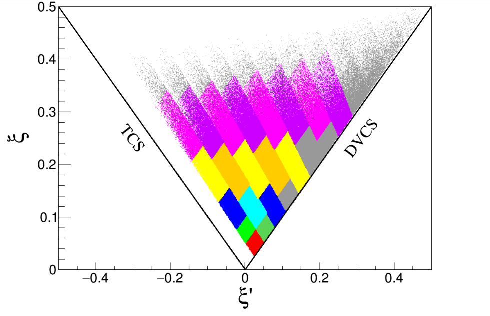


- 1st order approximation
- Monte Carlo for the bin acceptance
- cross section computing using VGG model [5]
- $\sigma \sim \dfrac{d^5\sigma}{dQ^2\,dx_B\,dt\,dQ'^2\,d\phi}$
- count number calculation
- events generation

[5] I. V. M. Vanderhaeghen, P. A. M. Guichon and M. Guidal, Phys. Rev D, **60**, 094017 (1999).

Experimental projections II





Transfer all the events into (ξ', ξ) plane

$$\xi' = \frac{Q^2 - Q'^2 + t/2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

$$\xi = \frac{Q^2 + Q'^2}{2Q^2/x_B - Q^2 - Q'^2 + t}$$

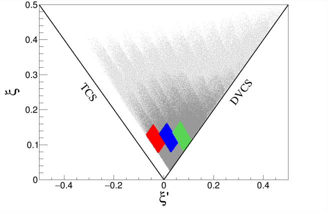
covering decoupled region where $|\xi'| < \xi$

Goal: access to $H(\xi', \xi, t, \mu^2)$

Binning

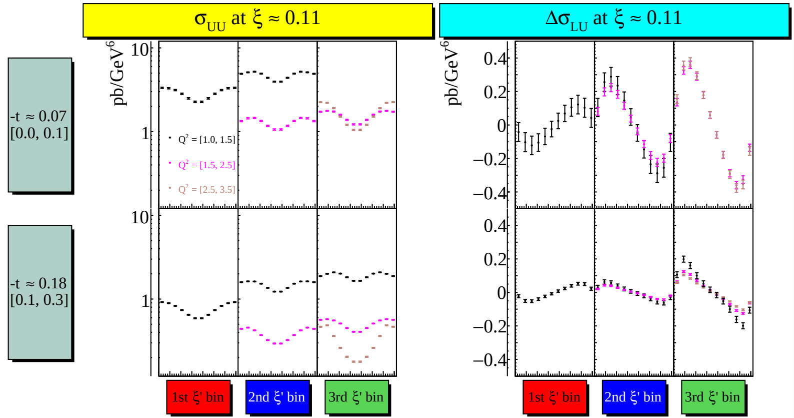
bins in ξ' and ξ - left figure
4 bins in $-t$ - [0.0, 0.1, 0.3, 0.6, 1.0]
5 bins in Q^2 - [1.0, 1.5, 2.5, 3.5, 5.5, Q^2_{max}]
12 bins in ϕ - equally divided in 2π

Experimental projections III



example at $\xi \approx 0.11$

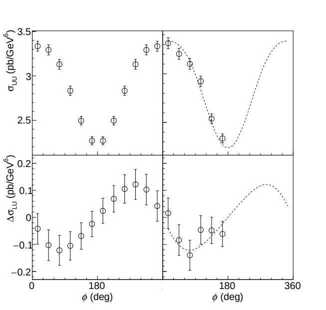
The observables are calculated with ideal detector at luminosity of 10^{36} $cm^{-2} \cdot s^{-1}$ for 50 days. In this case, the experimental projection of both the observables can be obtained with good precision.

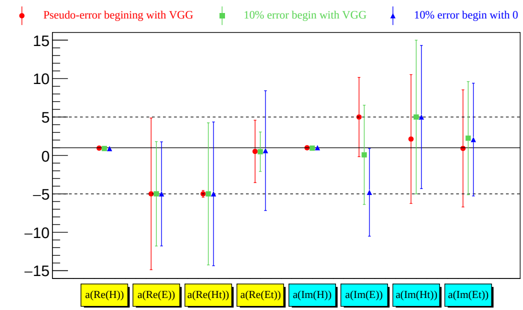


CFFs extraction I

We've developed a fitter algorithm being a quasi-model-independent way to extract CFFs:

- taking the 8 CFFs as free parameters;
- knowing the well-established BH and DDVCS leading-twist amplitudes;
- to fit simultaneously the ϕ-distributions of several experimental observable at a fixed kinematics.

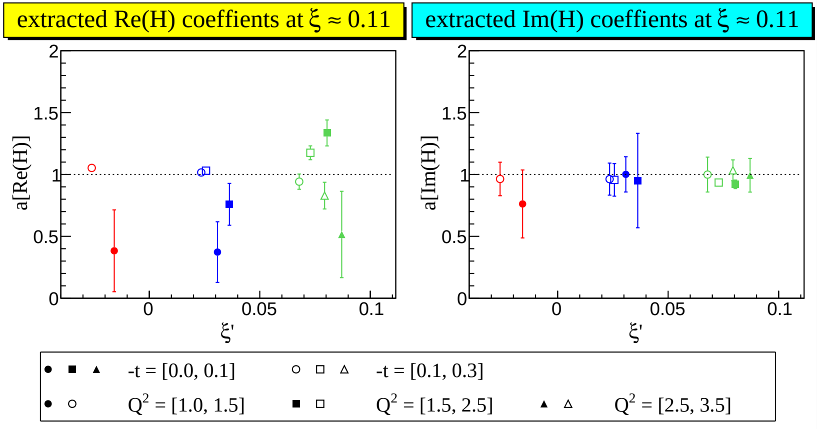




- smearing the central value for 6 ϕ according to a Gaussian probability distribution whose standard deviation is equal to the error bar.
- Fitting only σ_{UU} and $\Delta\sigma_{\mathrm{LU}}$, only CFF $\mathcal{H}$ can be well recovered, with σ_{UU} being particularly sensitive to the real part of $\mathcal{H}$ and $\Delta\sigma_{\mathrm{LU}}$ to the imaginary part.

CFFs extraction II

The simultaneous fit of σ_{UU} and $\Delta\sigma_{LU}$ allows us to access Im($\mathcal{H}$) at a relative high efficiency level and to a somewhat lesser extent Re($\mathcal{H}$).

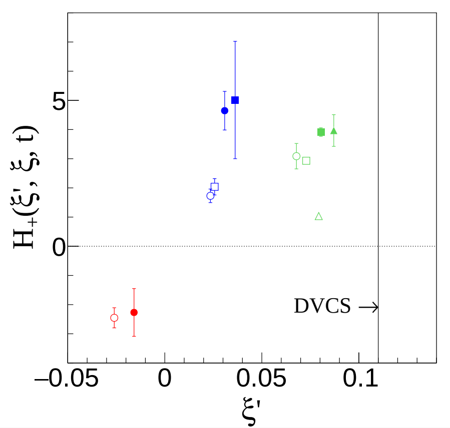


For better extraction of the real part, positron beams are needed since the beam charge difference is sensitive to Re($\mathcal{H}$).

CFFs extraction III

singlet GPD $H_{+} = -\text{Im}(\mathcal{H})/\pi$

$$H_{+}(\xi', \xi, t) = H(\xi', \xi, t) - H(-\xi', \xi, t)$$



$\xi \approx 0.11$

- Finally, decoupled singlet GPD H_{+} of proton can be obtained at fixed ξ.
- The information of GPDs obtained from DDVCS experiment could have a positive impact on the study of

→ internal pressure distribution

$$\int xH(x, \xi, t)dx = M_2(t) + \frac{4}{5}\xi^2 d_1(t);$$

→ quark angular momentum

$$\int x \left[H^q(x, \xi, 0) + E^q(x, \xi, 0)\right] dx.$$

Conclusion and outlook

conclusion

- Based on the model-predicted experimental projection of DDVCS at JLab12, it is possible to obtain experiment observables with good precision.
- If only σ_{UU} and $\Delta\sigma_{\mathrm{LU}}$ are measured, valuable decoupled information of GPD H can still be extracted. For better extraction of the real part of CFF $\mathcal{H}$, positron beams are needed.

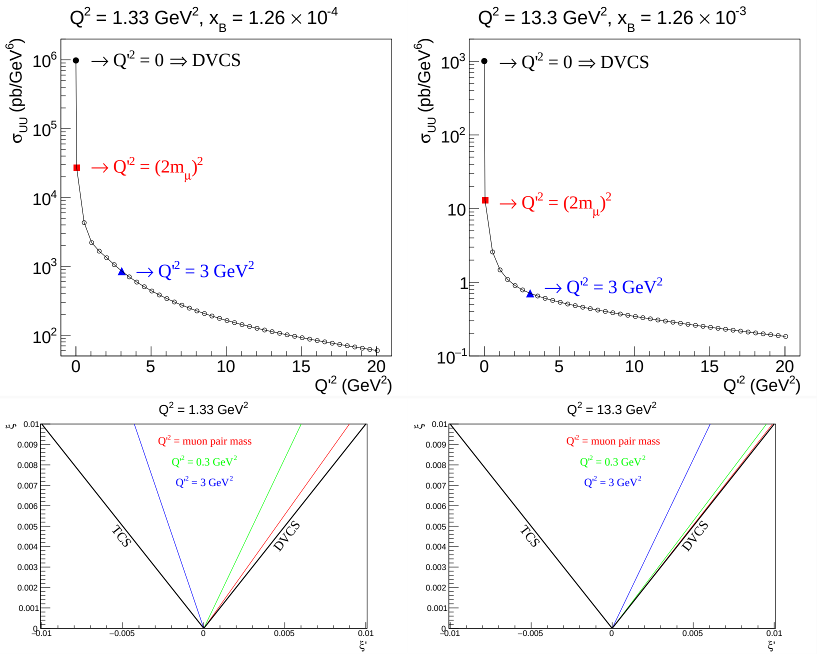
outlook

- Extraction of CFF $\mathcal{H}$ with beam charge cross section difference $\Delta\sigma_{\mathrm{C}}$;
- Improvement of the fitter program with respect to the time consuming.

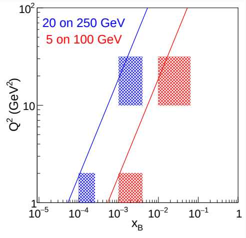
Thank you!

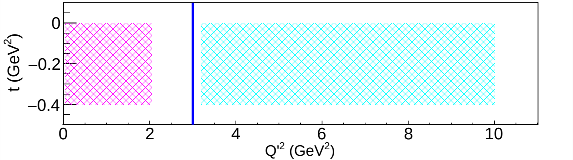
backups

cross section at EIC I

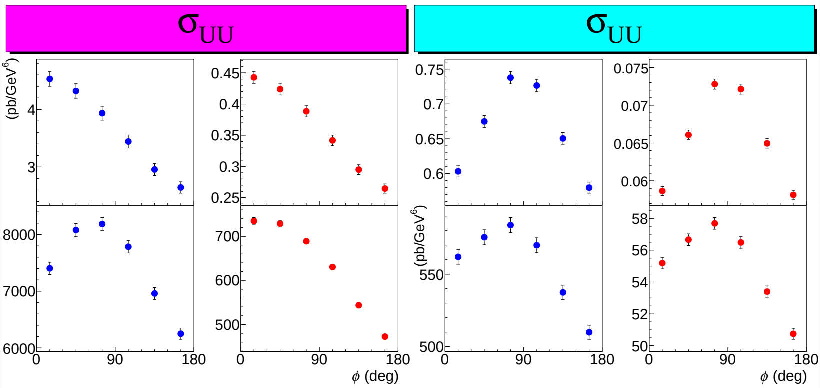


cross section at EIC II

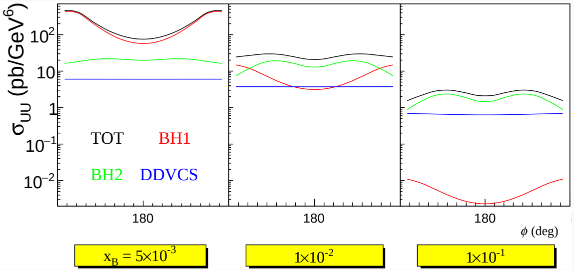




small Q'^2 - $\int \mathcal{L}dt = 10\ \mathrm{fb}^{-1}$, large Q'^2 - $\int \mathcal{L}dt = 100\ \mathrm{fb}^{-1}$

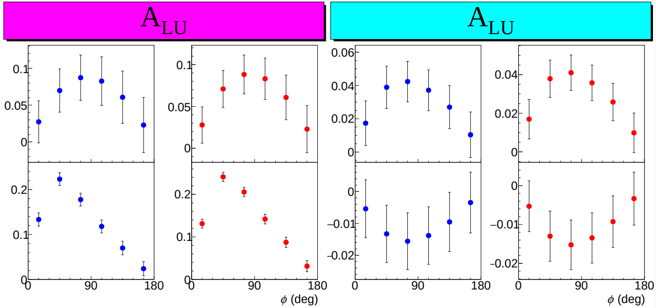


asymetries at EIC I



asymmetry: $A = \dfrac{\Delta\sigma}{\sigma_{UU}}$

additional BH2 increases the denominator

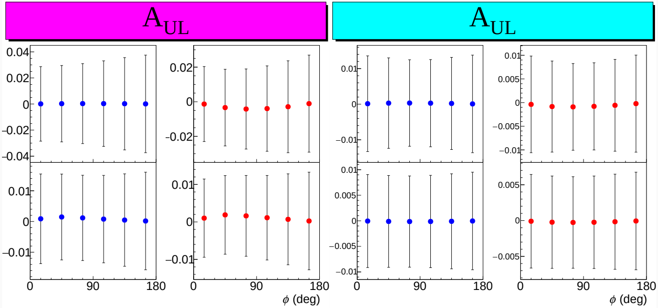


$$A_{LU} = \frac{\Delta\sigma_{LU}}{\sigma_{UU}}$$

$\rightarrow \mathcal{H}$

promising

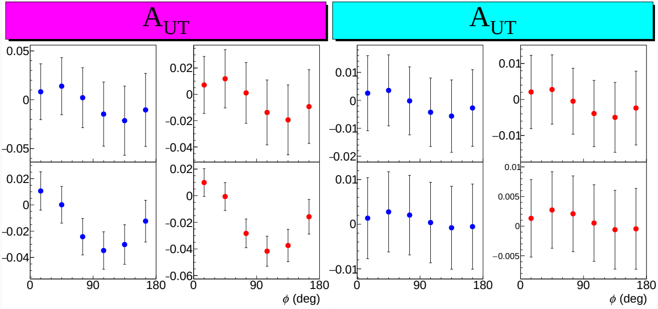
asymetries at EIC II



$$A_{\mathrm{UL}} = \frac{\Delta\sigma_{\mathrm{UL}}}{\sigma_{\mathrm{UU}}}$$

$$\rightarrow \widetilde{\mathcal{H}}$$

difficult



$$A_{\mathrm{UT}} = \frac{\Delta\sigma_{\mathrm{UT}}}{\sigma_{\mathrm{UU}}}$$

$$\rightarrow \mathcal{H}, \mathcal{E}$$

challenging