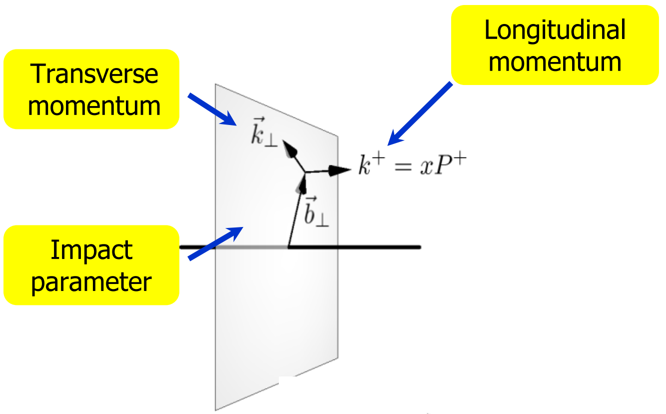
DVCS with polarized targets and CLAS12

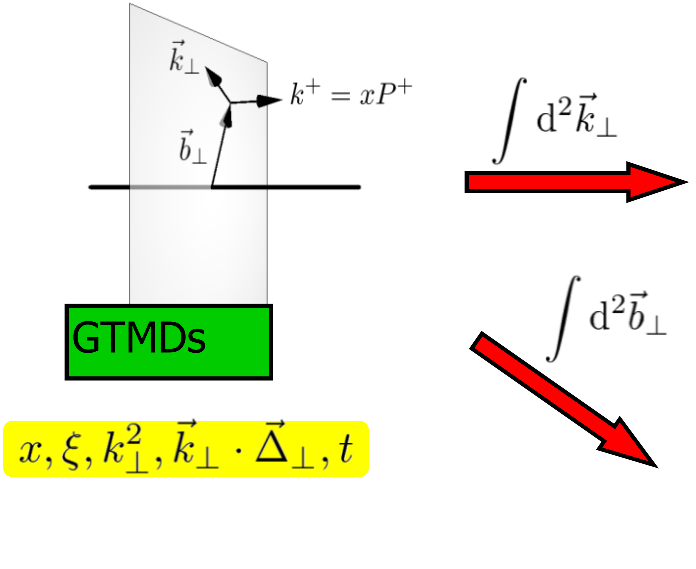
Silvia Niccolai, IJClab (France), CLAS Collaboration

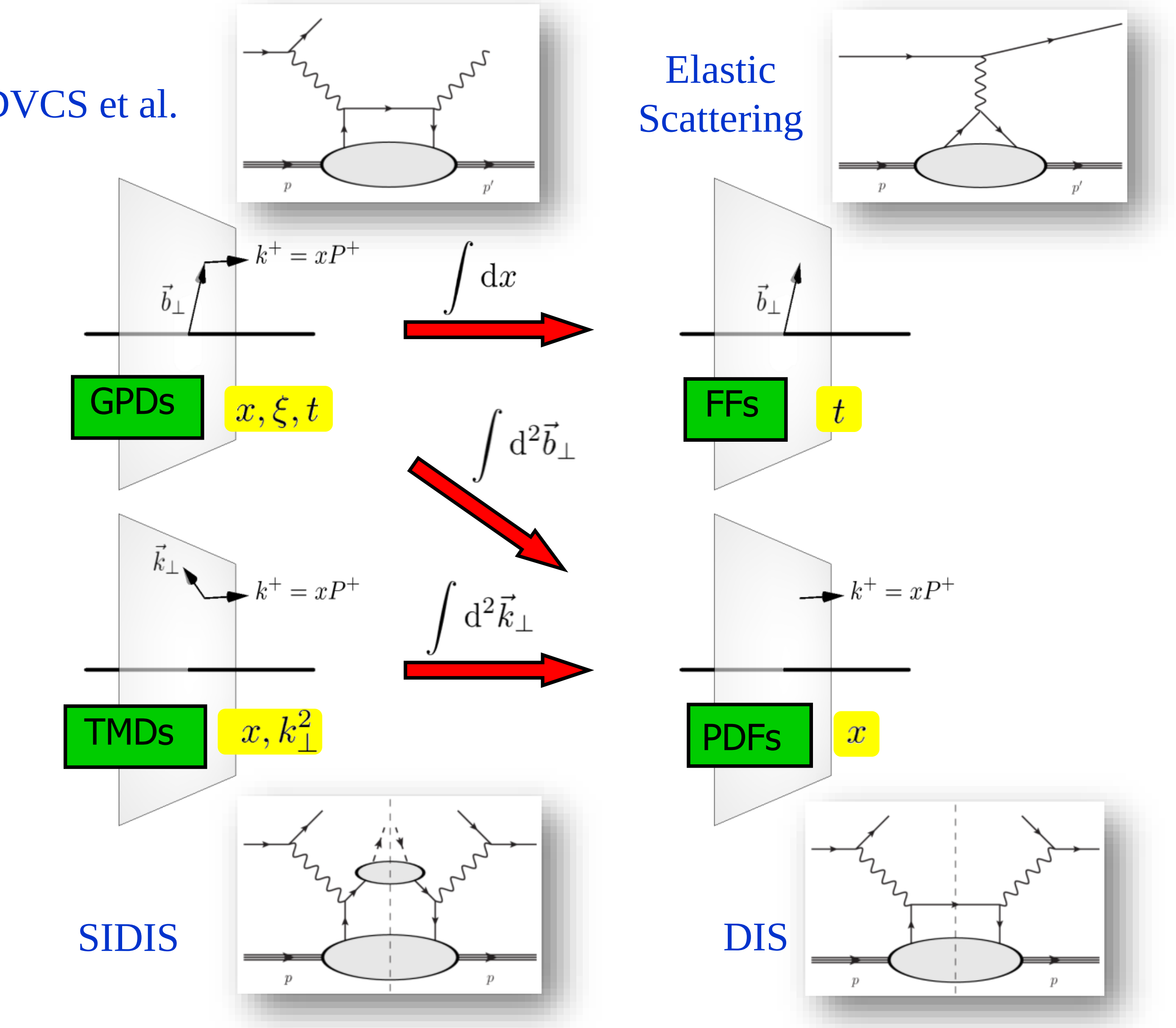
EINN2025

Paphos (Cyprus), 29/10/2025

Multi-dimensional mapping of the nucleon

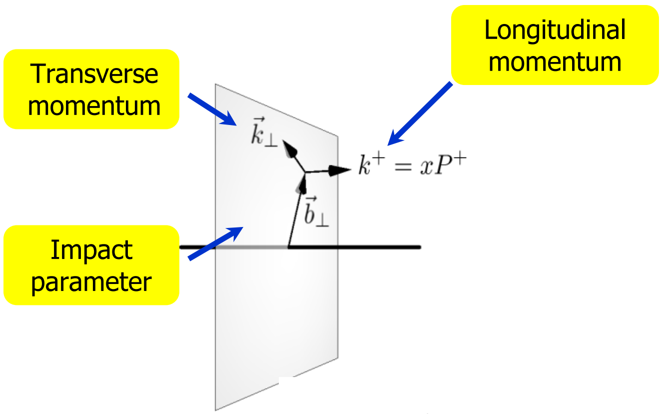




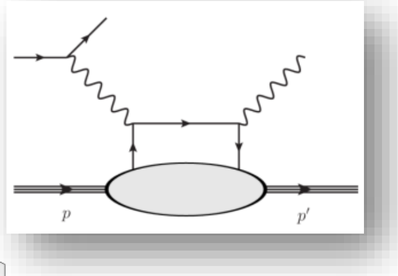


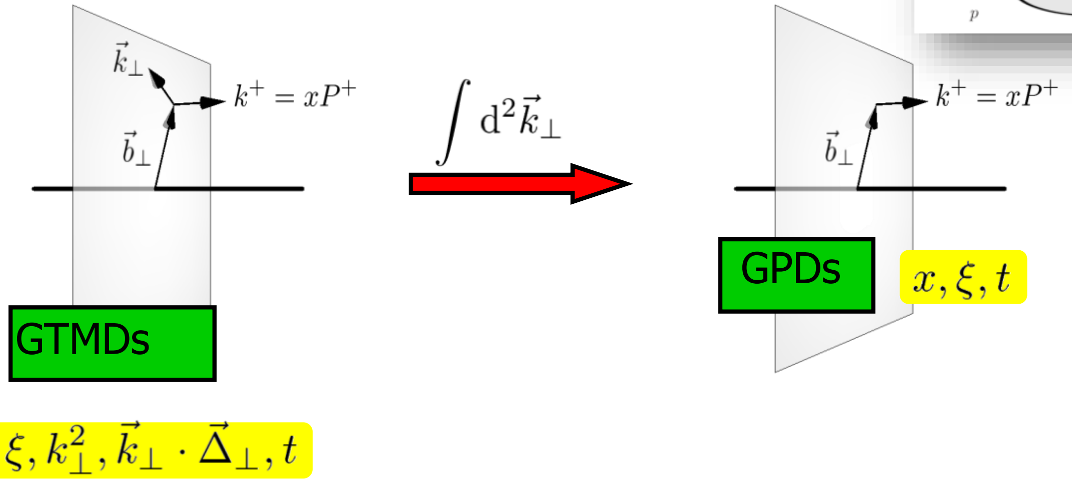
A complete picture of nucleon structure requires the measurement of all these distributions

Multi-dimensional mapping of the nucleon



DVCS et al.





Nucleon tomography

$$q(x, b_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} H(x, 0, -\Delta_\perp^2)$$

$$\Delta q(x, b_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp b_\perp} \tilde{H}(x, 0, -\Delta_\perp^2)$$

Generalized Parton Distributions:

✓fully correlated parton distributions in both **coordinate** and **longitudinal momentum** space

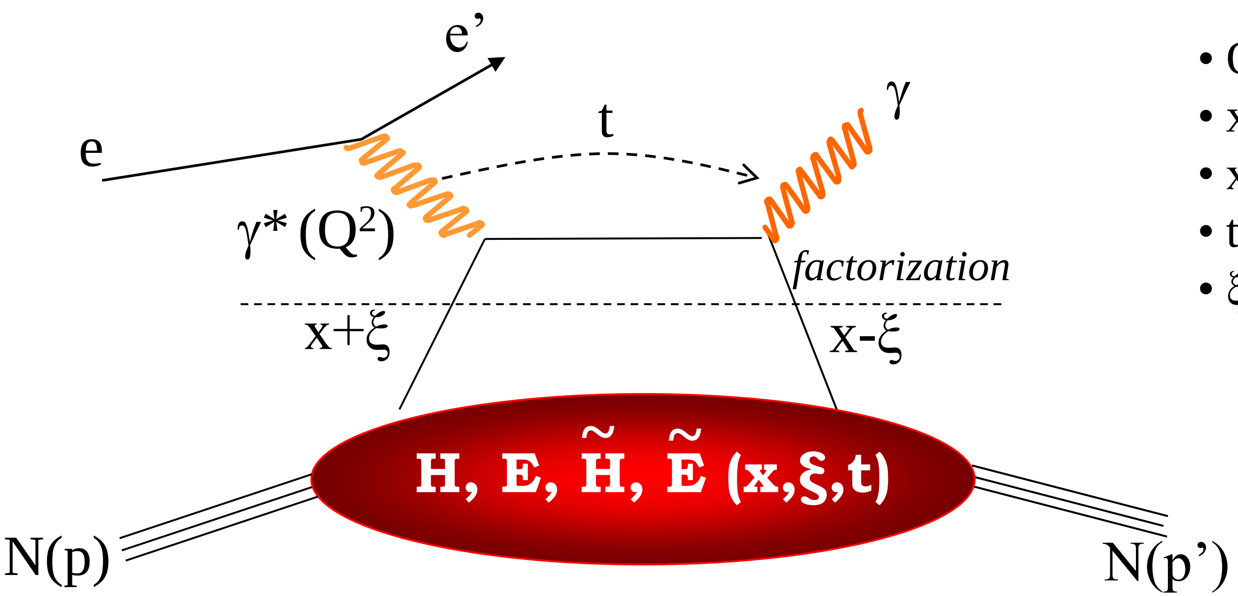
✓ linked to **FFs** and **PDFs**

✓**Accessible in exclusive reactions**

Quark angular momentum (Ji's sum rule)

$$\frac{1}{2}\int_{-1}^{1} x dx (H(x, \xi, t=0) + E(x, \xi, t=0)) = J = \frac{1}{2}\Delta\Sigma + \Delta L$$

Deeply Virtual Compton Scattering and GPDs

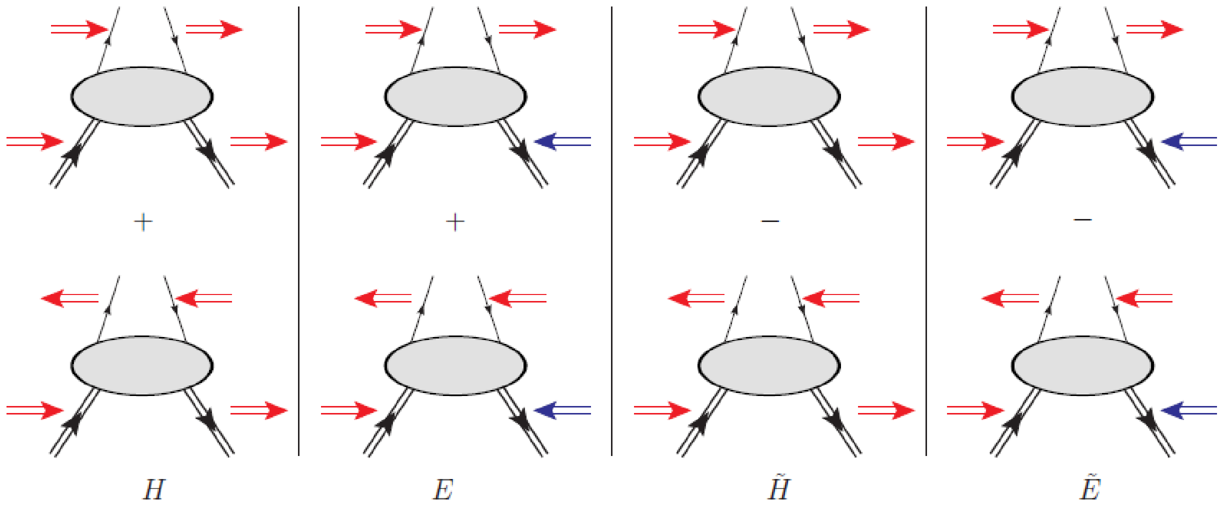


- $Q^2 = -(e-e')^2$
- $x_B = Q^2/2M\nu \quad \nu = E_e - E_{e'}$
- $x+\xi$, $x-\xi$ longitudinal momentum fractions
- $t = \Delta^2 = (p-p')^2$
- $\xi \cong x_B/(2-x_B)$

« Handbag » factorization, valid in the **Bjorken regime** (**high Q^2** and **ν**, fixed x_B**), $t \ll Q^2$**

*GPDs: Fourier transforms of **non-local**, **non-diagonal** QCD operators*

4 GPDs for each quark flavor
(leading-order, leading twist, quark-helicity conservation)

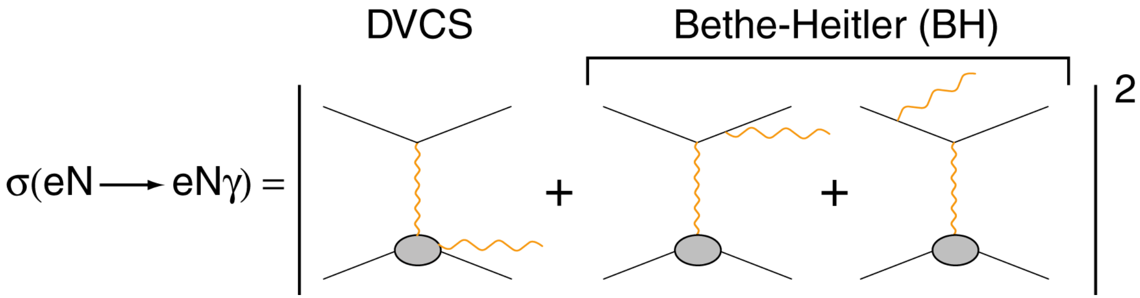


Vector **Tensor** **Axial-vector** **Ps.scalar**

conserve nucleon spin **flip nucleon spin**

Accessing GPDs through DVCS

$$T^{DVCS} \sim P\int_{-1}^{+1} \frac{GPDs(x,\xi,t)}{x\pm\xi}\,dx \pm i\pi GPDs(\pm\xi,\xi,t) + \ldots$$



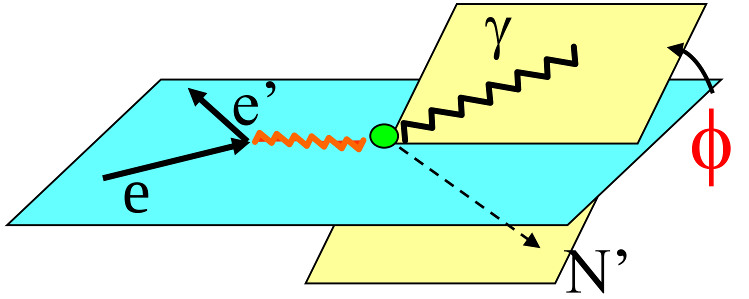
$$\boxed{Re\mathcal{H}_q = e_q^2 P\int_0^{+1}\left(H^q(x,\xi,t) - H^q(-x,\xi,t)\right)\left[\frac{1}{\xi - x} + \frac{1}{\xi + x}\right]dx}$$

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

$$\sigma \sim \left|T^{DVCS} + T^{BH}\right|^2$$

$$\Delta\sigma = \sigma^+ - \sigma^- \propto I\left(DVCS \cdot BH\right)$$

		Proton Neutron
Polarized beam, unpolarized target: $\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - kF_2\mathcal{E} + \ldots\}$	⟹	$Im\{\mathcal{H}_p, \widetilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \widetilde{\mathcal{H}}_n, \boldsymbol{\mathcal{E}_n}\}$
Unpolarized beam, longitudinal target: $\Delta\sigma_{UL} \sim \sin\phi\,\mathrm{Im}\{F_1\widetilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\,\mathcal{E}) - \xi kF_2\widetilde{\mathcal{E}}\}$	⟹	$Im\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\widetilde{\mathcal{H}}_p}\}$ $Im\{\boldsymbol{\mathcal{H}_n}, \mathcal{E}_n\}$
Polarized beam, longitudinal target: $\Delta\sigma_{LL} \sim (A+B\cos\phi)\mathrm{Re}\{F_1\widetilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\,\mathcal{E}) + \ldots\}$	⟹	$Re\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\widetilde{\mathcal{H}}_p}\}$ $Re\{\boldsymbol{\mathcal{H}_n}, \mathcal{E}_n\}$
Unpolarized beam, transverse target: $\Delta\sigma_{UT} \sim \cos\phi\sin(\phi_s - \phi)\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}$	⟹	$Im\{\boldsymbol{\mathcal{H}_p}, \boldsymbol{\mathcal{E}_p}\}$ $Im\{\boldsymbol{\mathcal{H}_n}\}$



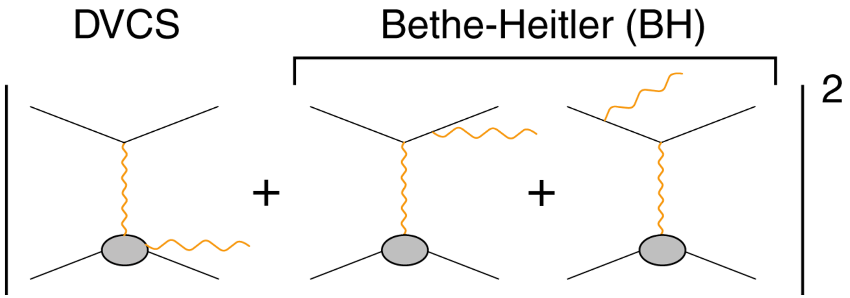
Accessing GPDs through DVCS

$$T^{DVCS} \sim P\int_{-1}^{+1} \frac{GPDs(x,\xi,t)}{x\pm\xi}dx \pm i\pi GPDs(\pm\xi,\xi,t) + \ldots$$

$$\boxed{Re\mathcal{H}_q = e_q^2 P\int_0^{+1}\left(H^q(x,\xi,t) - H^q(-x,\xi,t)\right)\left[\frac{1}{\xi - x} + \frac{1}{\xi + x}\right]dx}$$

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

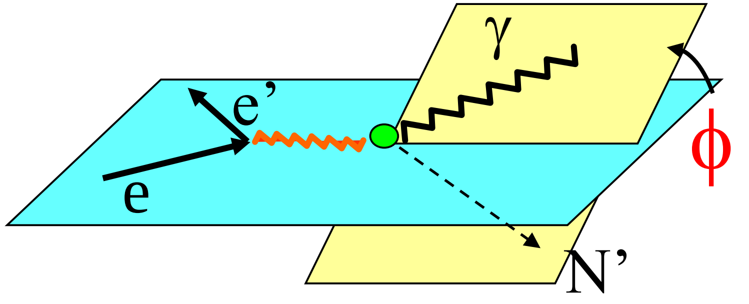
$\sigma(eN \longrightarrow eN\gamma) =$



	Proton Neutron
Polarized beam, unpolarized target: $\Delta\sigma_{LU} \sim \sin\phi\ \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E} + \ldots\}$	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n, \tilde{\mathcal{H}}_n, \mathcal{E}_n\}$
Unpolarized beam, longitudinal target: $\Delta\sigma_{UL} \sim \sin\phi\mathrm{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\tilde{\mathcal{E}}\}$	$Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Im\{\mathcal{H}_n, \mathcal{E}_n\}$
Polarized beam, longitudinal target: $\Delta\sigma_{LL} \sim (A + B\cos\phi)\mathrm{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) + \ldots\}$	$Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$ $Re\{\mathcal{H}_n, \mathcal{E}_n\}$
Unpolarized beam, transverse target: $\Delta\sigma_{UT} \sim \cos\phi\sin(\phi_s - \phi)\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}$	$Im\{\mathcal{H}_p, \mathcal{E}_p\}$ $Im\{\mathcal{H}_n\}$

$$\sigma \sim \left|T^{DVCS} + T^{BH}\right|^2$$

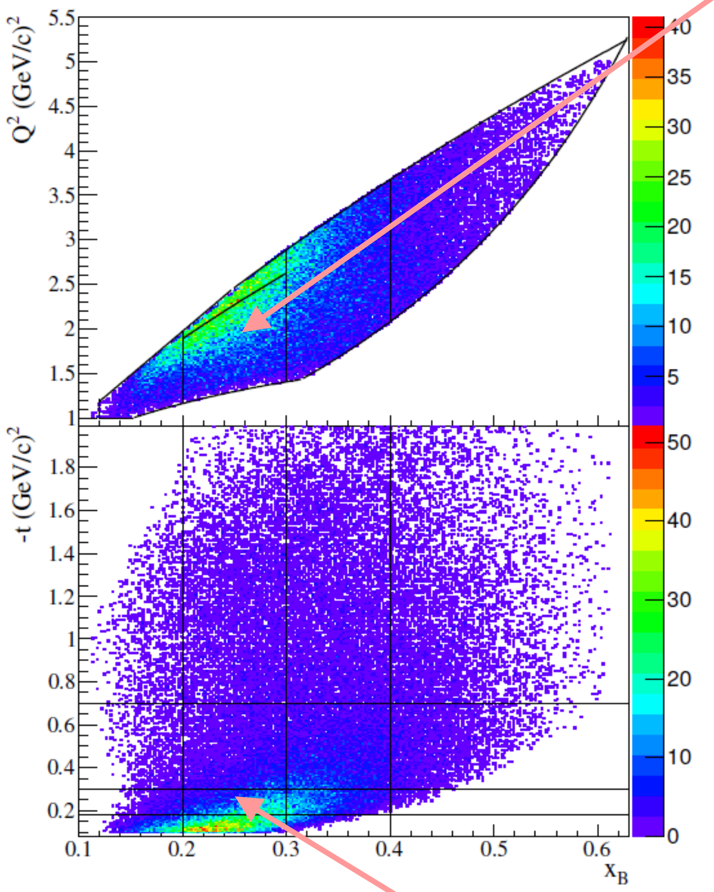
$$\Delta\sigma = \sigma^+ - \sigma^- \propto I\left(DVCS \cdot BH\right)$$

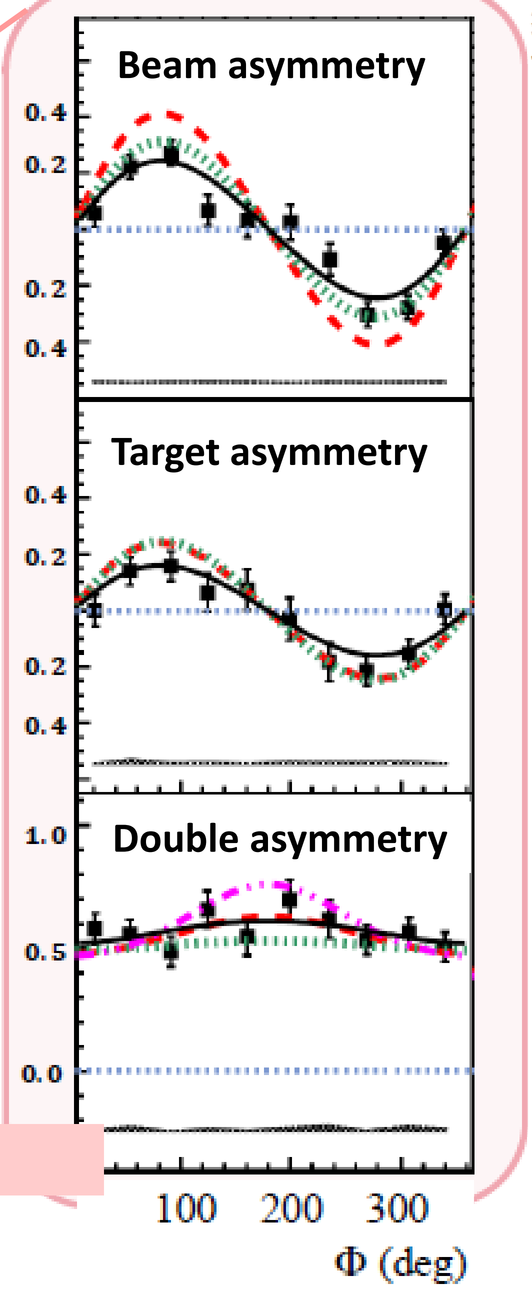


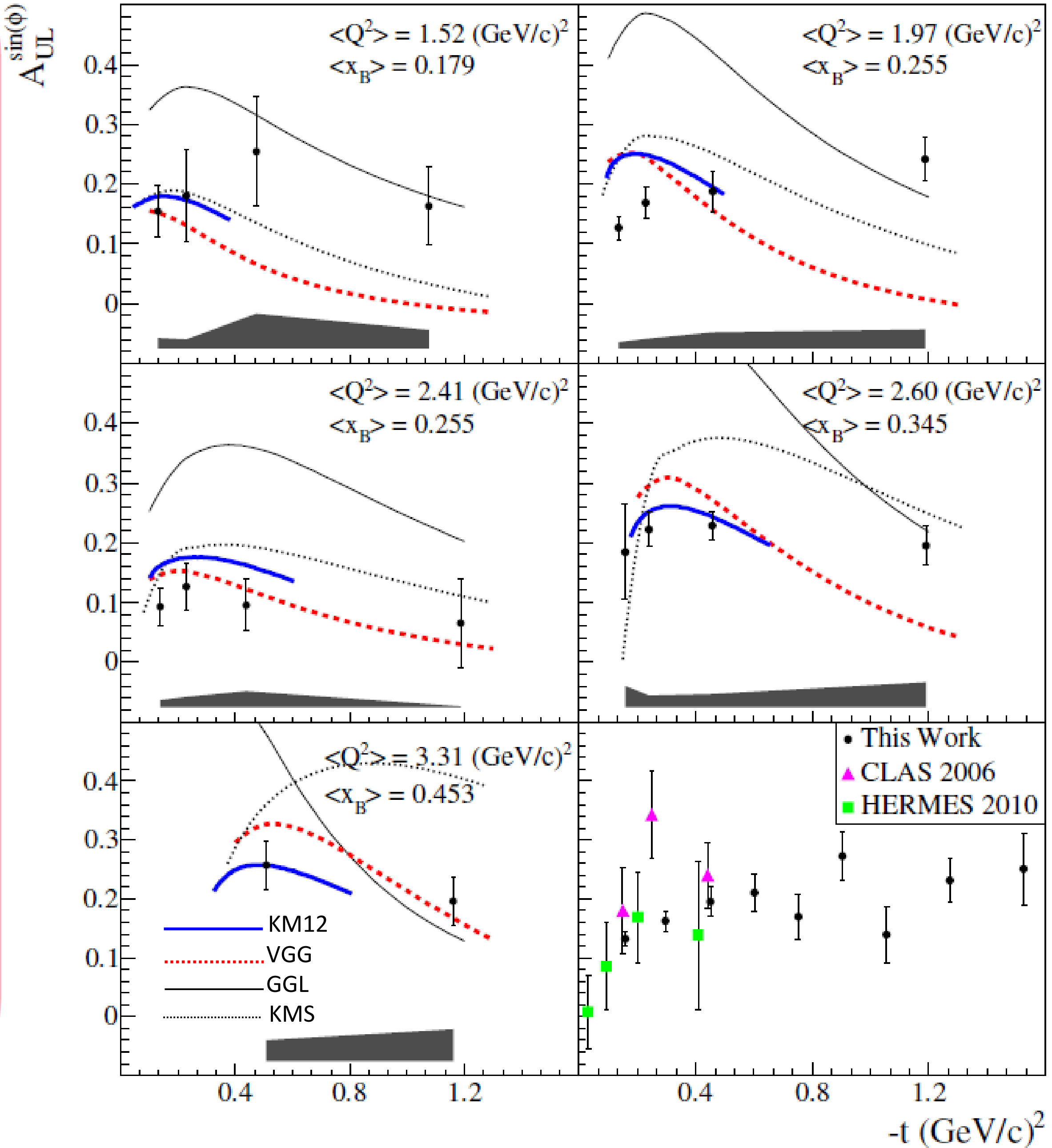
CLAS: pDVCS on longitudinally polarized target

$\vec{e}\vec{p}\to ep\gamma$

$\Delta\sigma_{UL} \sim Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$







5 Q^2-x_B bins, 4 t bins, 10 f bins

S. Pisano et al., PRD 91, 052014 (2015)

E. Seder et al., PRL 114 (2015) 032001

Extraction of CFFs from CLAS
TSA, BSA, DSA

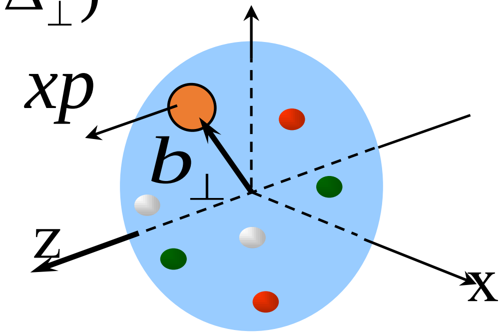
CFFs fitting code by M. Guidal (7 CFFs)

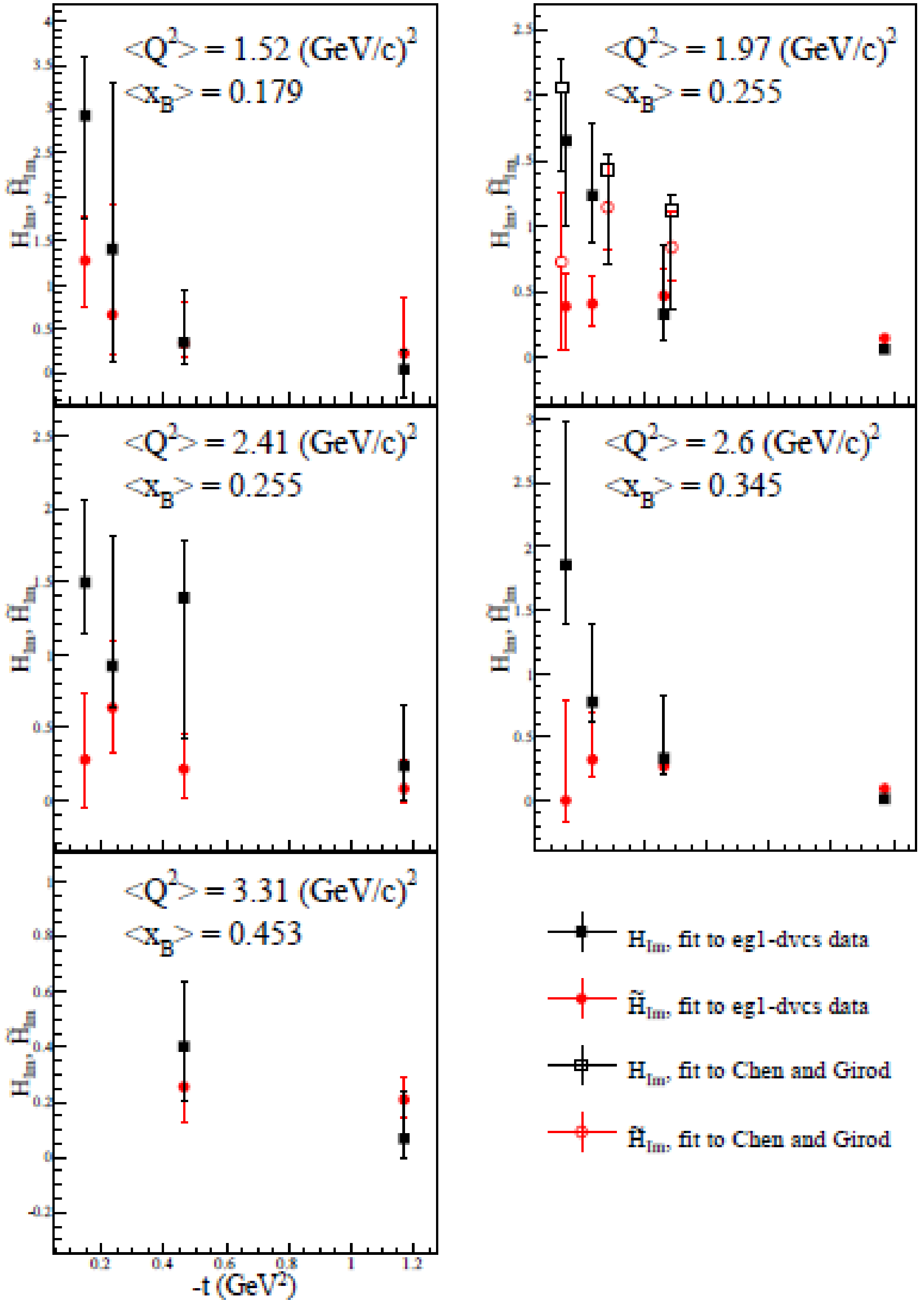
***Im$\mathcal{H}$* has steeper t-slope than *Im$\widetilde{\mathcal{H}}$*: the axial charge is more "concentrated" than the electric charge**
→ PROTON TOMOGRAPHY

$$\Delta q(x,\mathrm{b}_\perp) = \int_0^\infty \frac{d^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp \mathrm{b}_\perp} \widetilde{H}(x,0,-\Delta_\perp^2)$$

$$\int H(x,\xi,t)dx = F_1(t)$$

$$\int \widetilde{H}(x,\xi,t)dx = G_A(t)$$

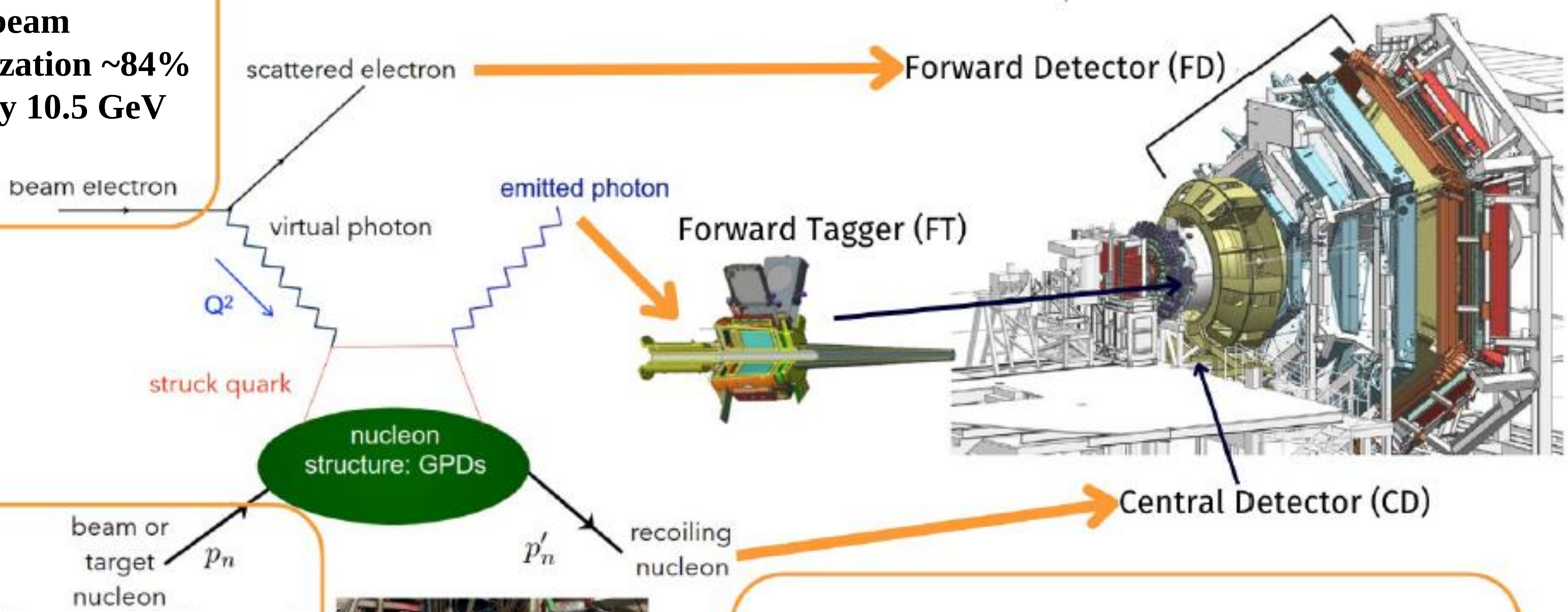




S. Pisano et al., PRD 91, 052014 (2015)

DVCS with longitudinally polarized NH3 and ND3 targets at CLAS12

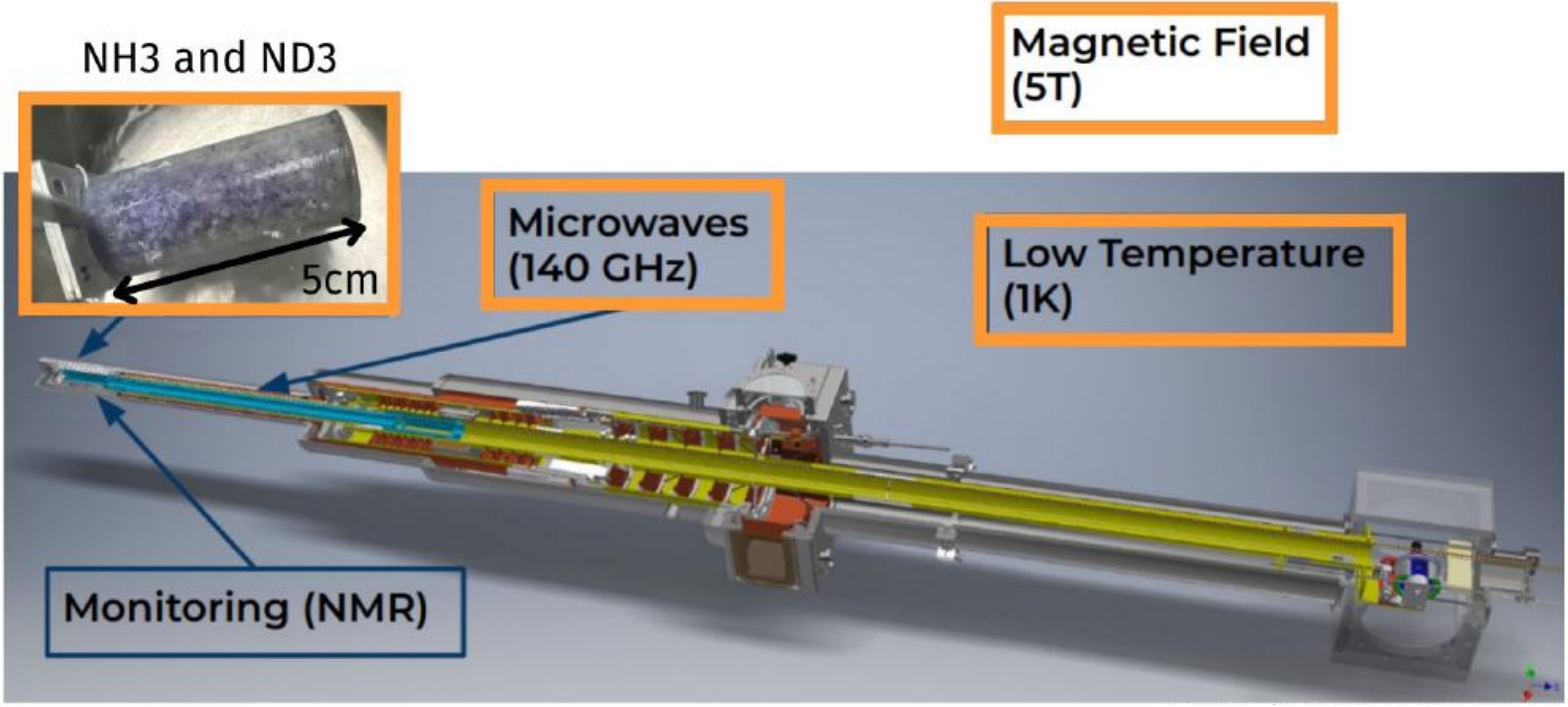
CEBAF polarized electron beam
- **Polarization ~84%**
- **Energy 10.5 GeV**



Run Group C experiment at CLAS12
- **Longitudinally polarized target**
- **Ran between June 2022 and March 2023**
- **Approved to run again (~2027) ~ to get 40% more data**

Exclusive final-state detection with CLAS12
- **Scattered electrons in the FD**
- **Nucleons in the CD**
- **Photons in the FD and in the FT**

The RGC longitudinally polarized target

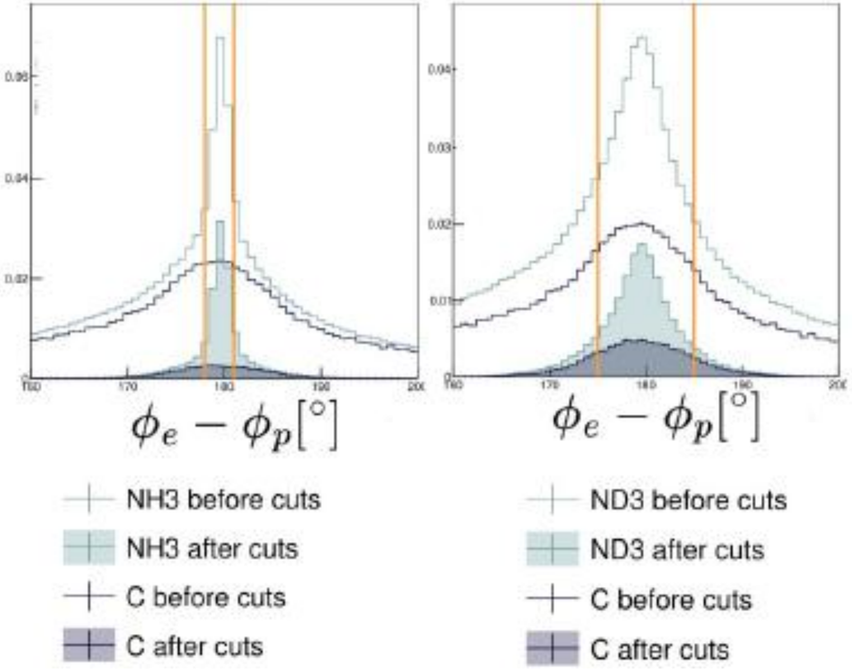


Target polarization measurement with elastic scattering

- Elastic (ep → e’p’) double spin asymmetry: $A_{th} = \frac{2\tau G[\frac{M_p}{E_b} + G(\tau\frac{M_p}{E_b} + (1+\tau)\tan(\frac{\theta}{2})^2)]}{1+G^2\frac{\tau}{\epsilon}}$ $\quad G = \frac{G_M}{G_E} \quad \tau = Q^2/(4M^2)$
- Product of the beam and target polarizations: $P_b P_t = \frac{A_{meas}}{A_{th}}$
- It is measured for each orientation of the target polarization, integrating over the whole experiment to have enough statistics

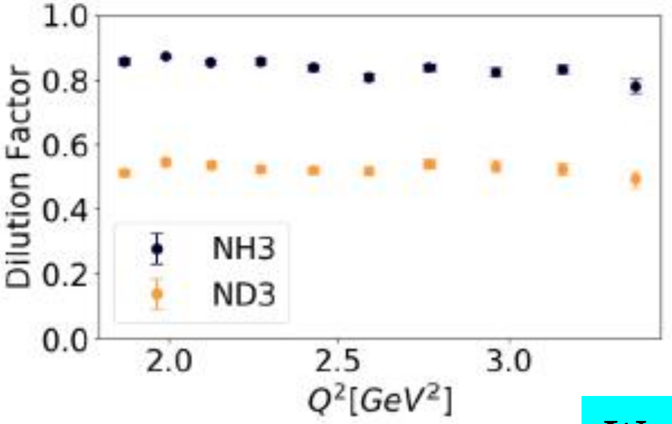
dilution factor yields with positive/negative beam helicity

$$P_b P_t = \frac{\sum_{i=0}^{N_{bins}} \boxed{f_i} A_{th,i}(\boxed{N_i^+} - \boxed{N_i^-})}{\sum_{i=0}^{N_{bins}} f_i^2 A_{th,i}^2 (N_i^+ + N_i^-)}$$



$$D_f = 1 - \frac{cN_C}{N_{ND_3}}$$

$$c = \frac{7}{6}\frac{l_{ND_3}\rho_{ND_3}Q_{ND_3}}{l_C\rho_C Q_C}$$



Preliminary

Target	$P_b P_t$
NH3+	0.71±0.03
NH3-	-0.66±0.03
ND3+	0.20±0.03
ND3-	-0.14±0.04

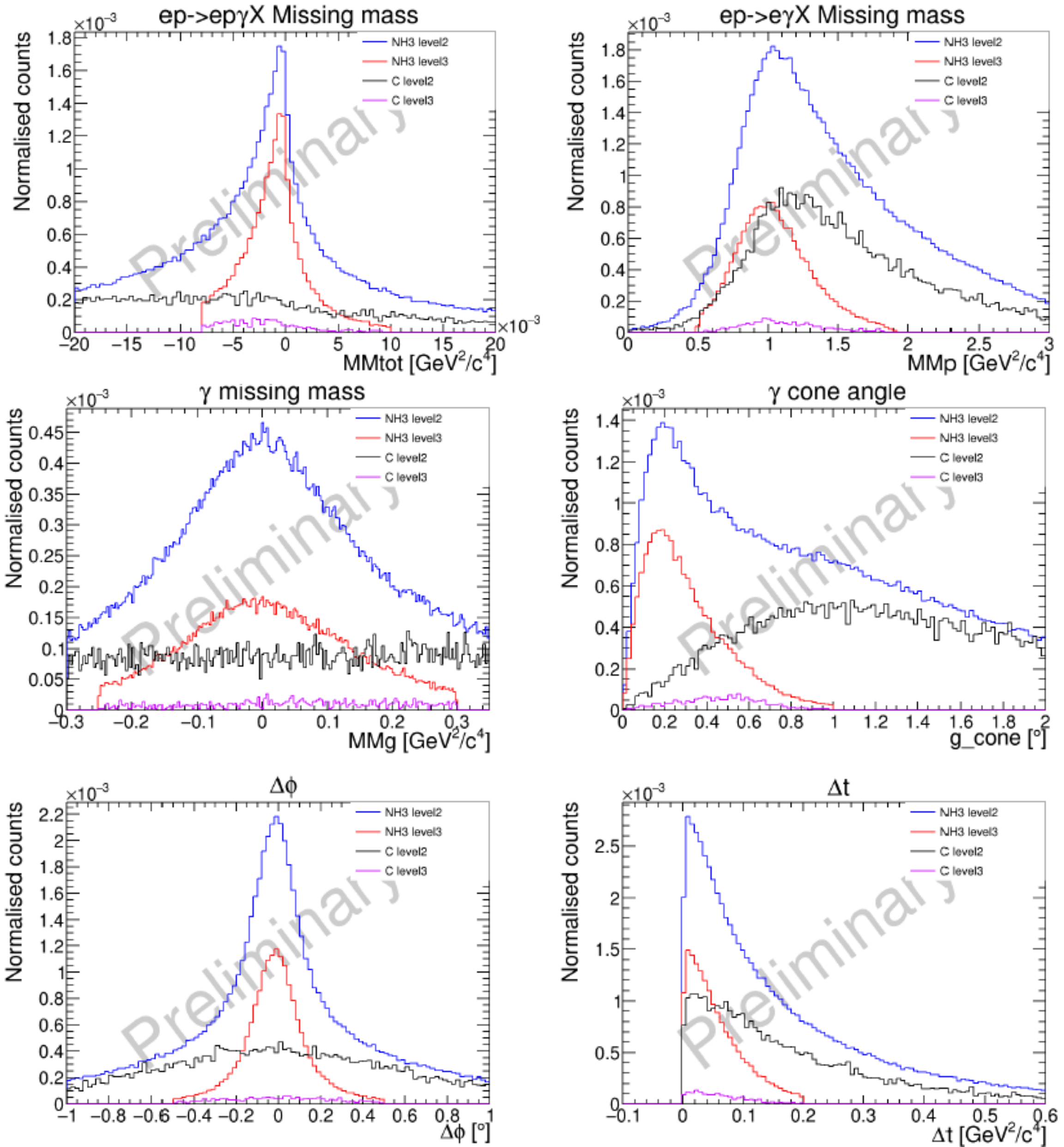
$P_b = 82.6 \pm 2.0\%$

Work by N. Pilleux

pDVCS on longitudinally polarized NH3 target: analysis

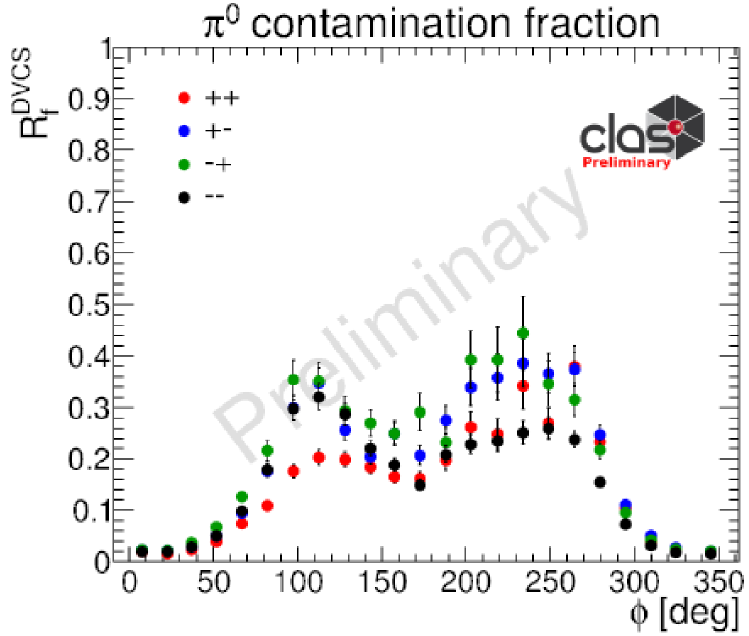
$\vec{e}\vec{p} \to ep\gamma$

Exclusivity cuts to select the epγ final state

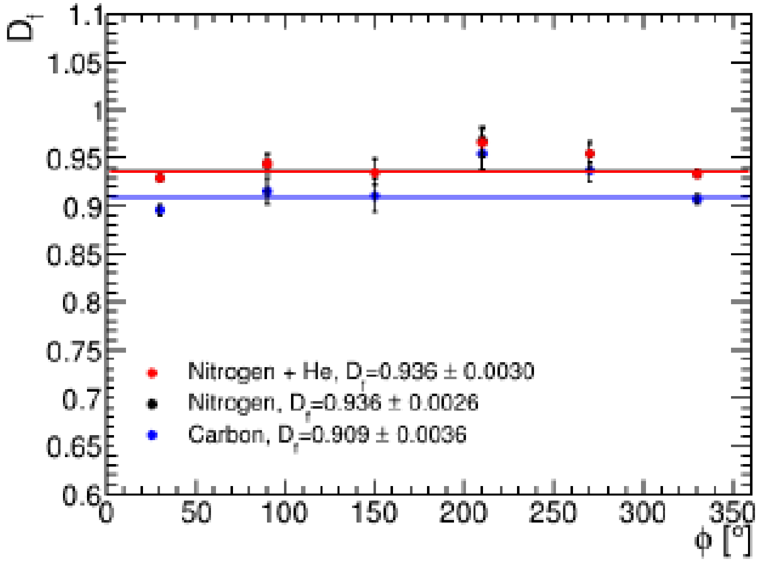


Work by S. Polcher

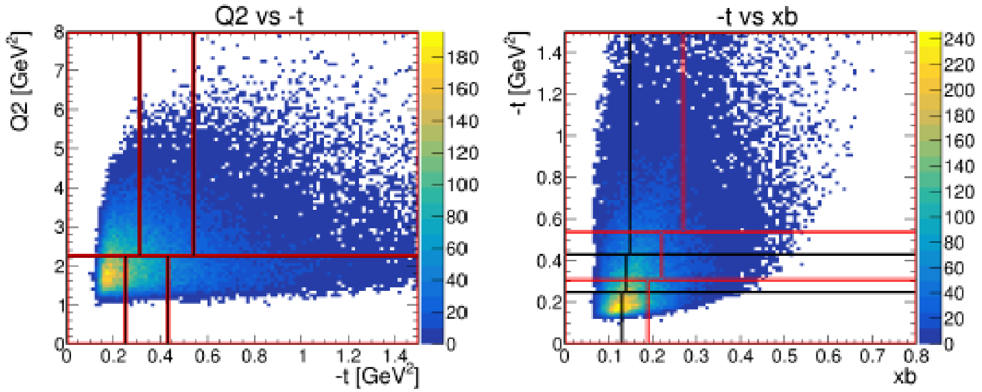
In spite of the several exclusivity cuts, leftover **contaminations** from exclusive π^0 **events** and from events coming from **unpolarized nitrogen** remain.



Correction factors for these contaminations are evaluated and included in the asymmetries



pDVCS on longitudinally polarized NH3 target: results (TSA)

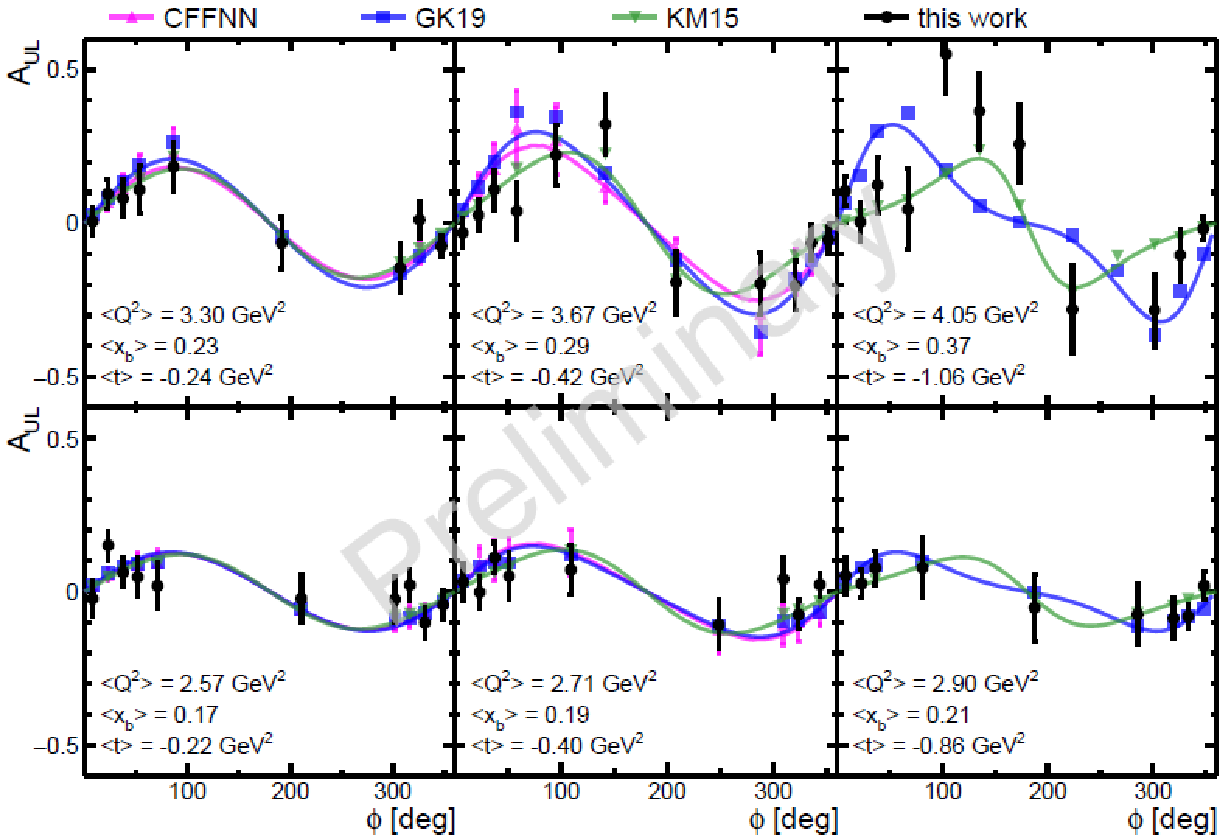


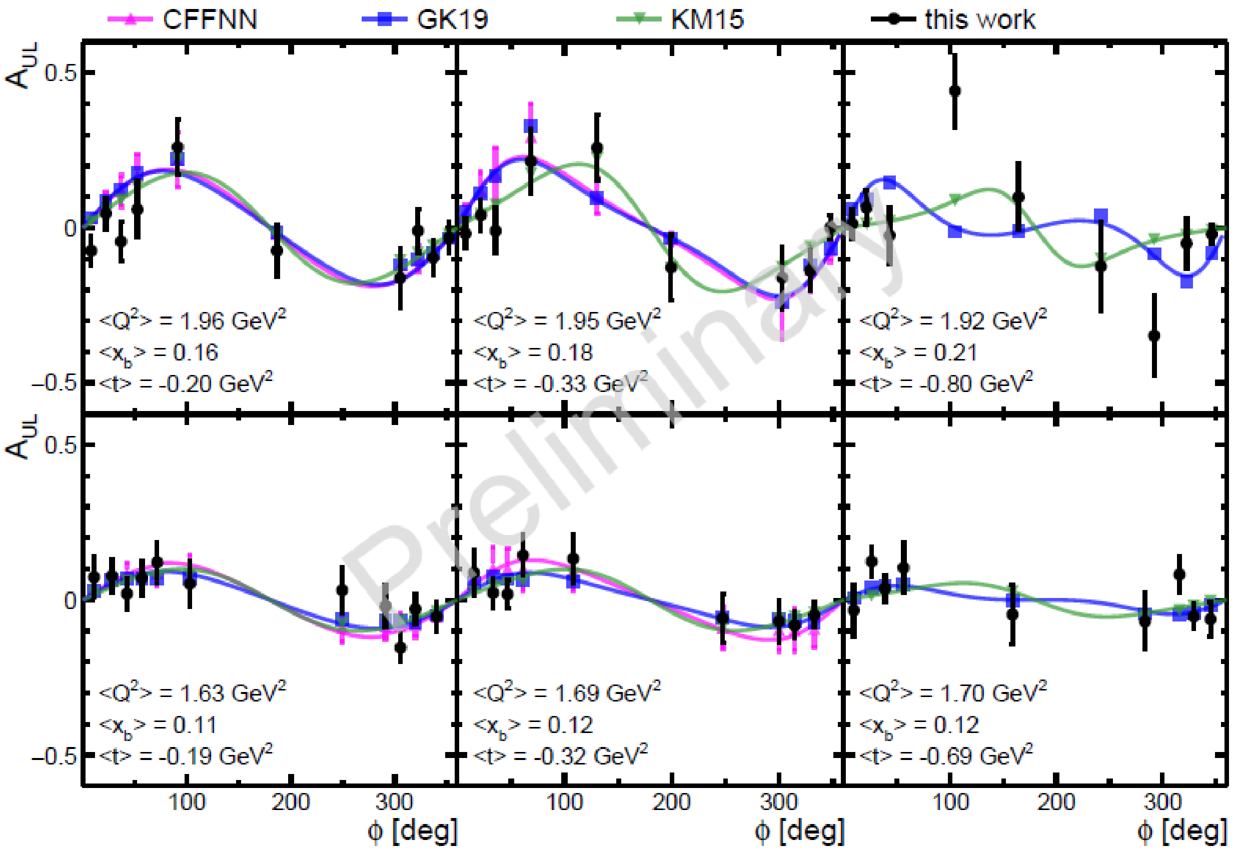
Work by S. Polcher

$\vec{e}\vec{p} \rightarrow ep\gamma$

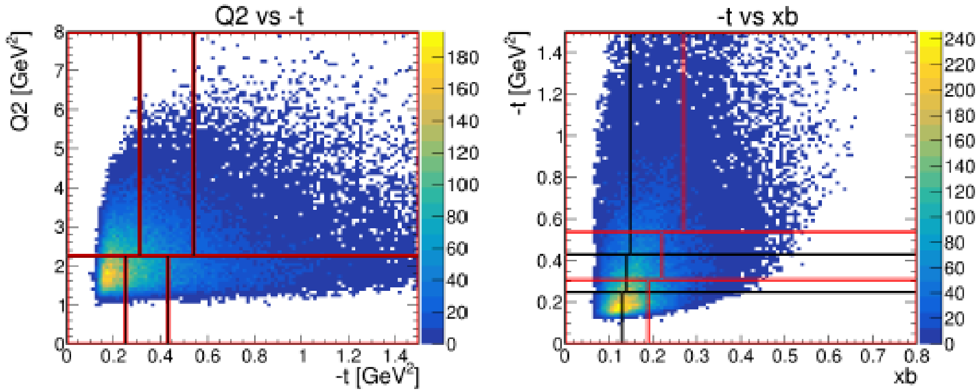
~30% of the collected data

$$\Delta\sigma_{UL} \sim \sin\phi \; \mathrm{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\,\mathcal{E}) - \xi k F_2\,\tilde{\mathcal{E}} + \ldots\}$$





pDVCS on longitudinally polarized NH3 target: results (DSA)

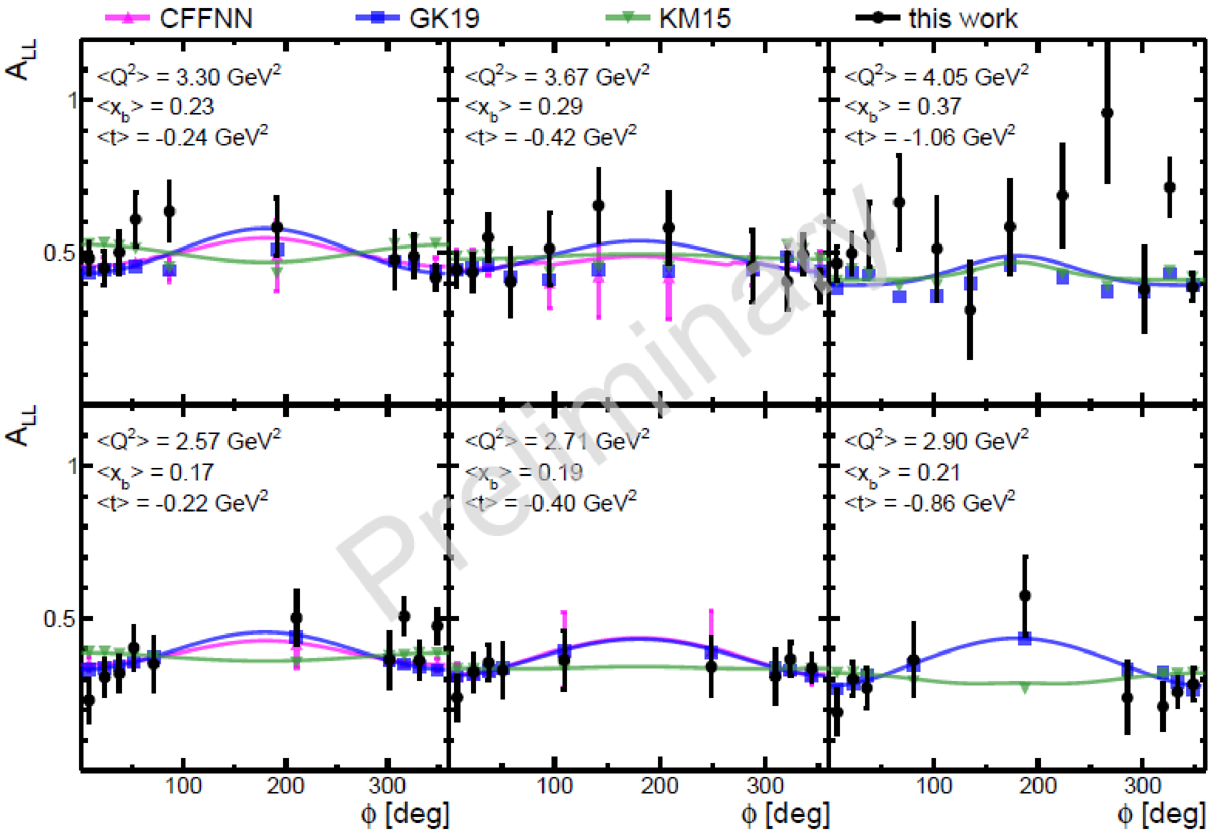


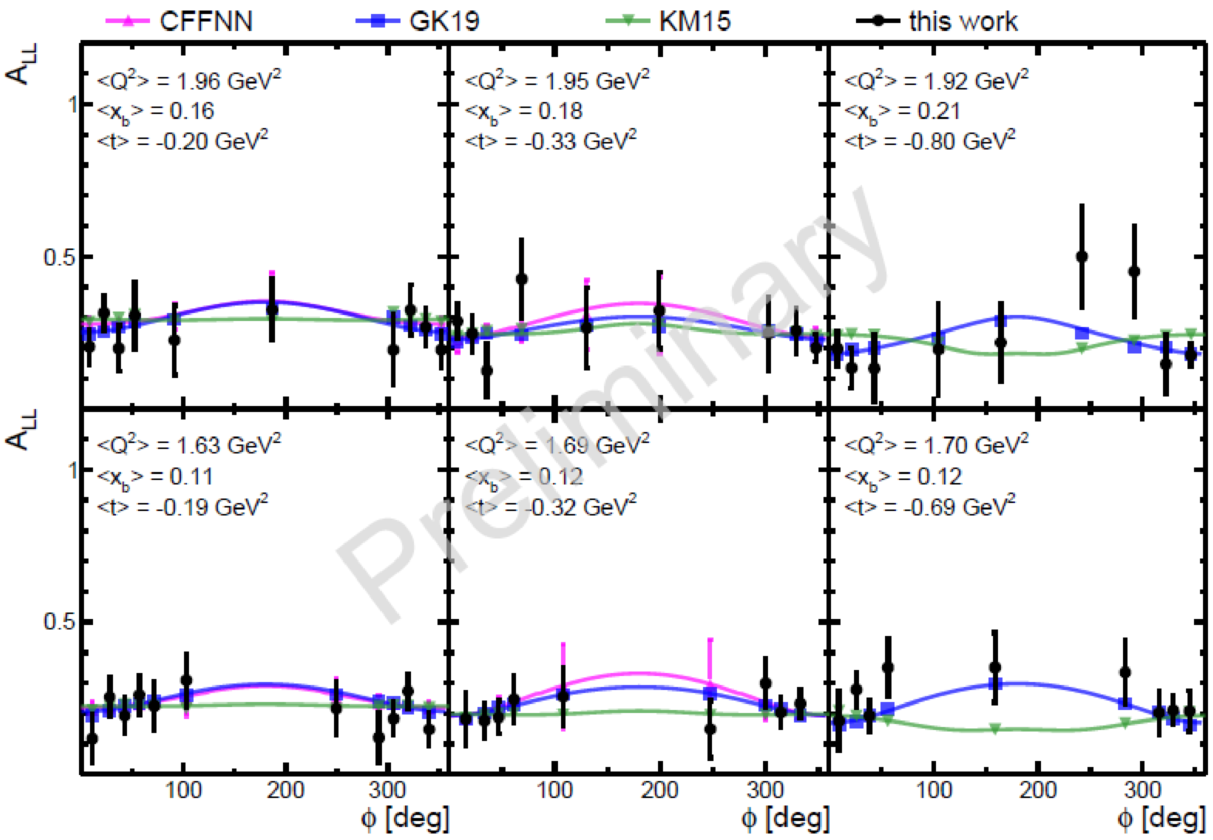
Work by S. Polcher

$\vec{e}\vec{p} \to ep\gamma$

~30% of the collected data

$\Delta\sigma_{LL} \sim (A+B\cos\phi)\ \mathrm{Re}\{F_1\tilde{\mathcal{H}}+\xi(F_1+F_2)(\mathcal{H}+x_B/2\mathcal{E})-\xi k F_2\tilde{\mathcal{E}}+\ldots\}$

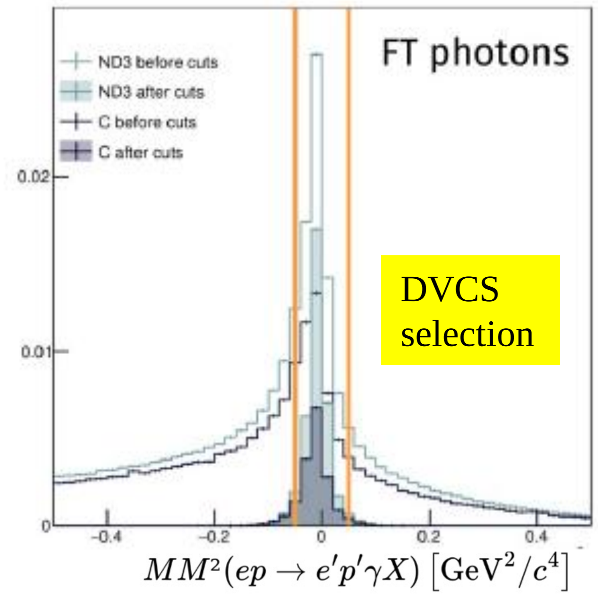


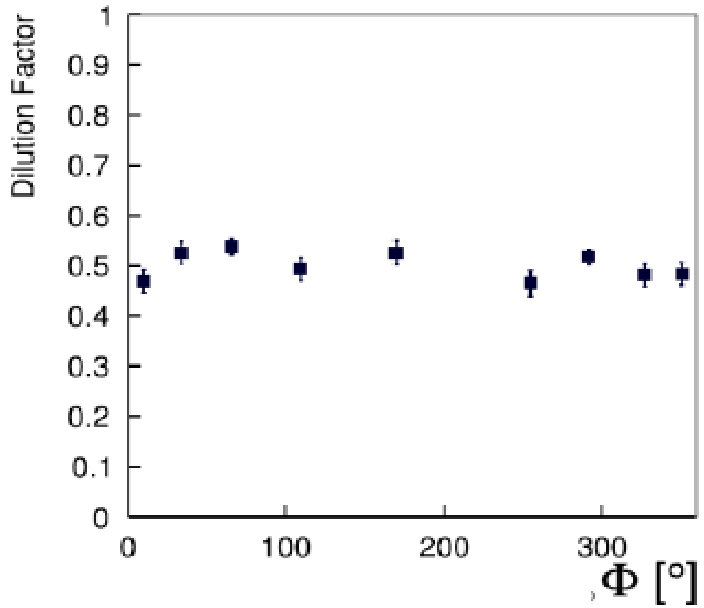


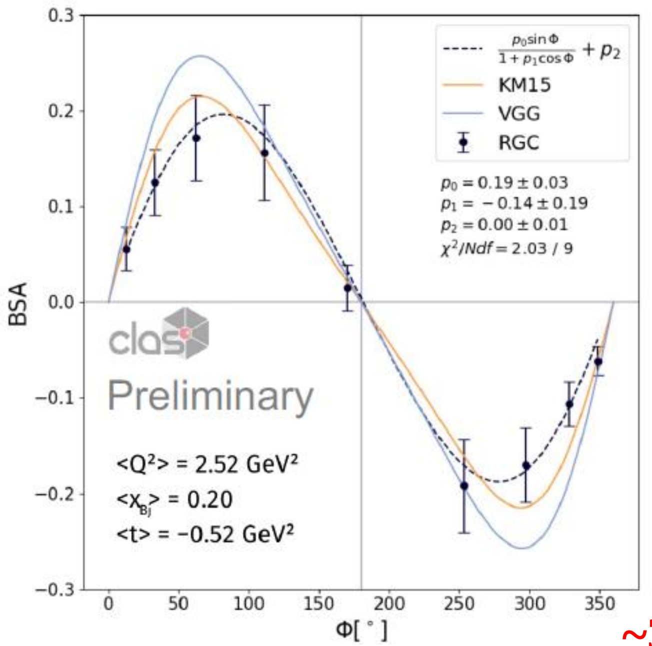
Work by N. Pilleux

pDVCS on longitudinally polarized ND3 target

$\vec{e}\vec{d} \rightarrow ep\gamma(n)$



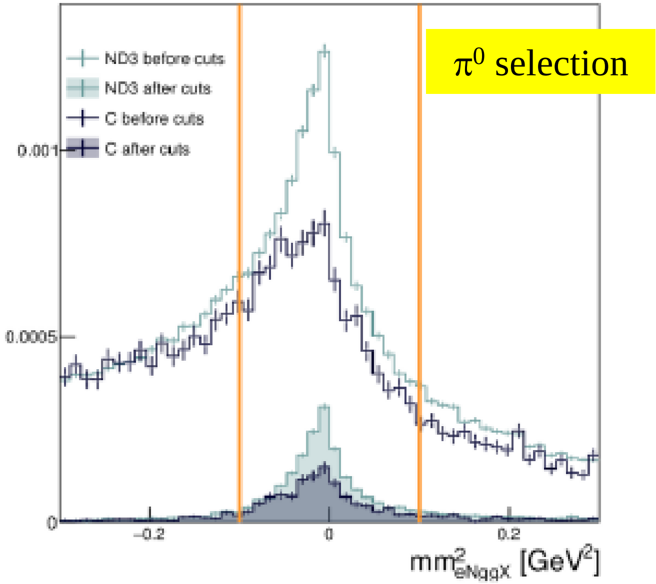


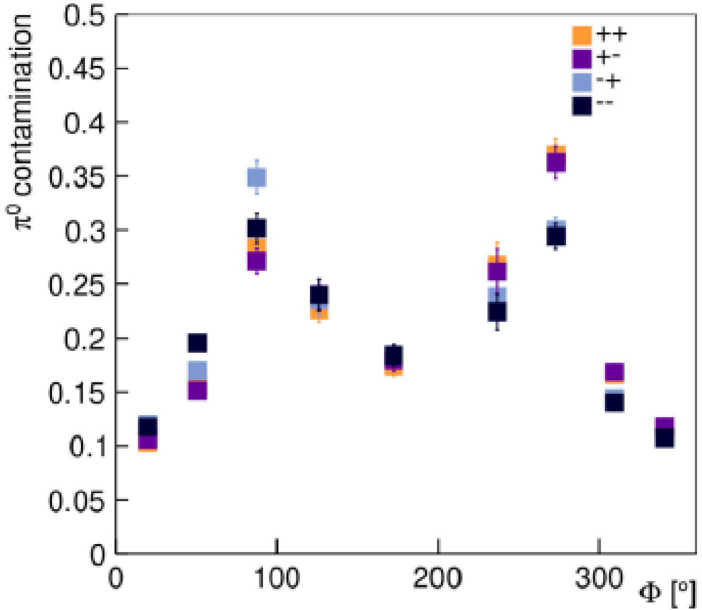


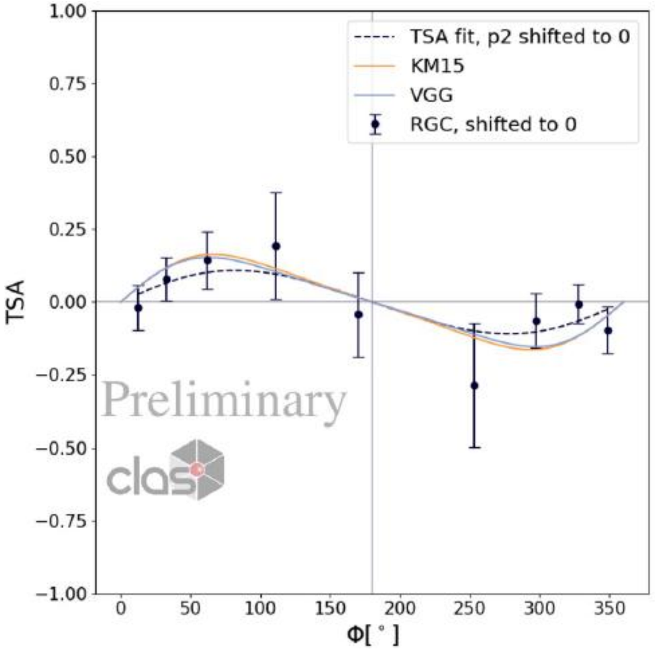
BSA does not account for the N background

- Dilution factor is 50%: contribution from bound protons in N must be considered

~30% of the collected data







Very preliminary **TSA**

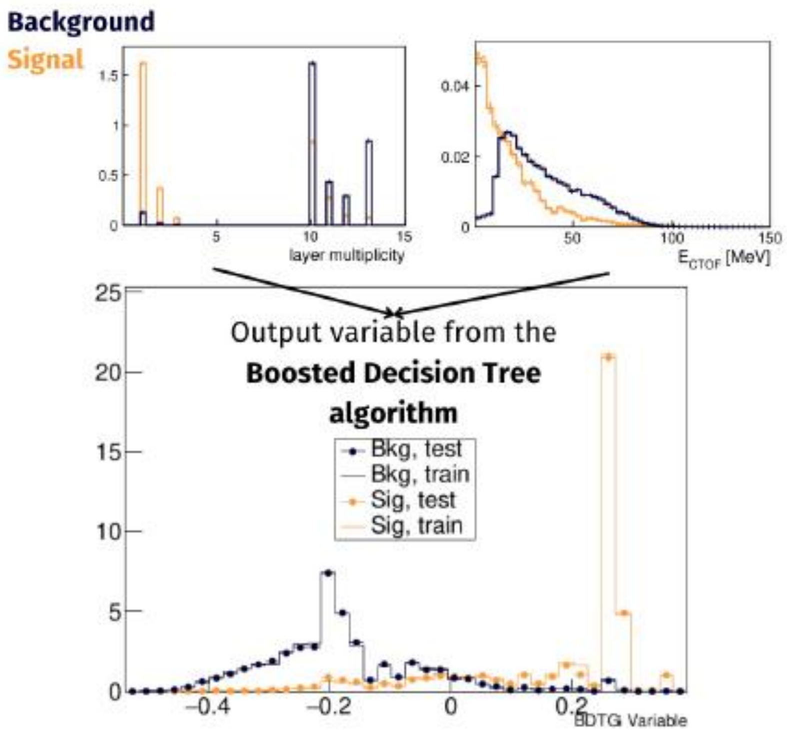
- Shift under study
- Fairly good agreement with models for free proton

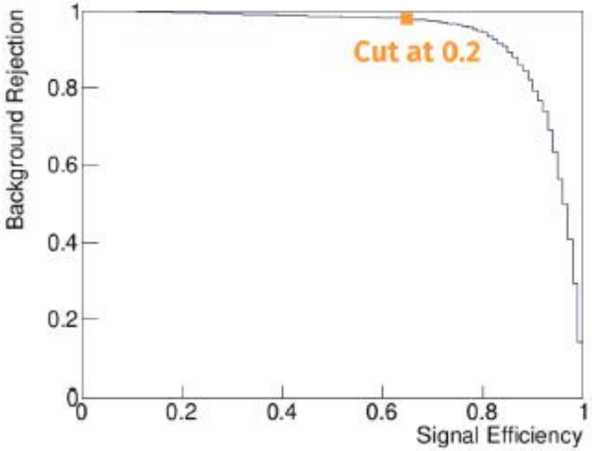
Work by N. Pilleux

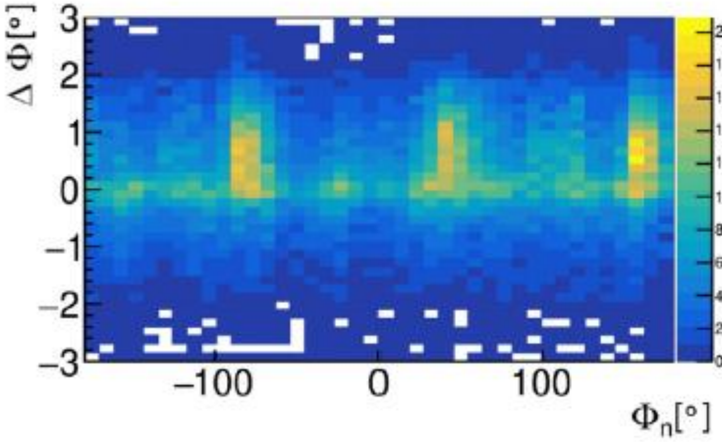
nDVCS on longitudinally polarized ND3 target

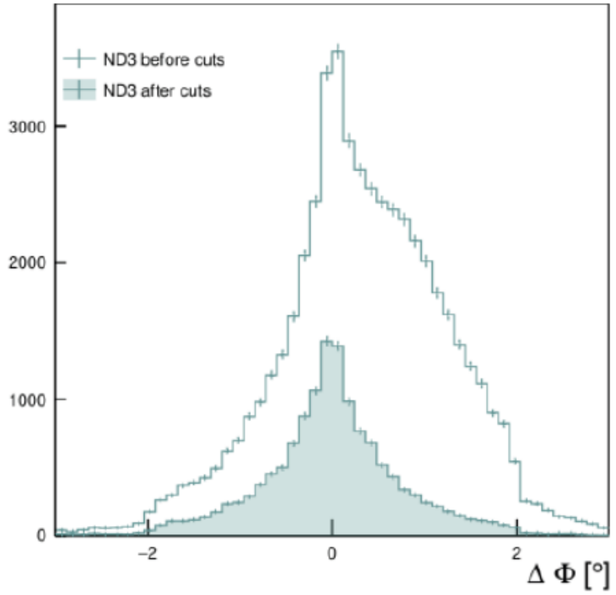
$\vec{e}\vec{d} \to e n \gamma (p)$

Contamination from **protons misidentified as neutrons** – suppressed using **ML**

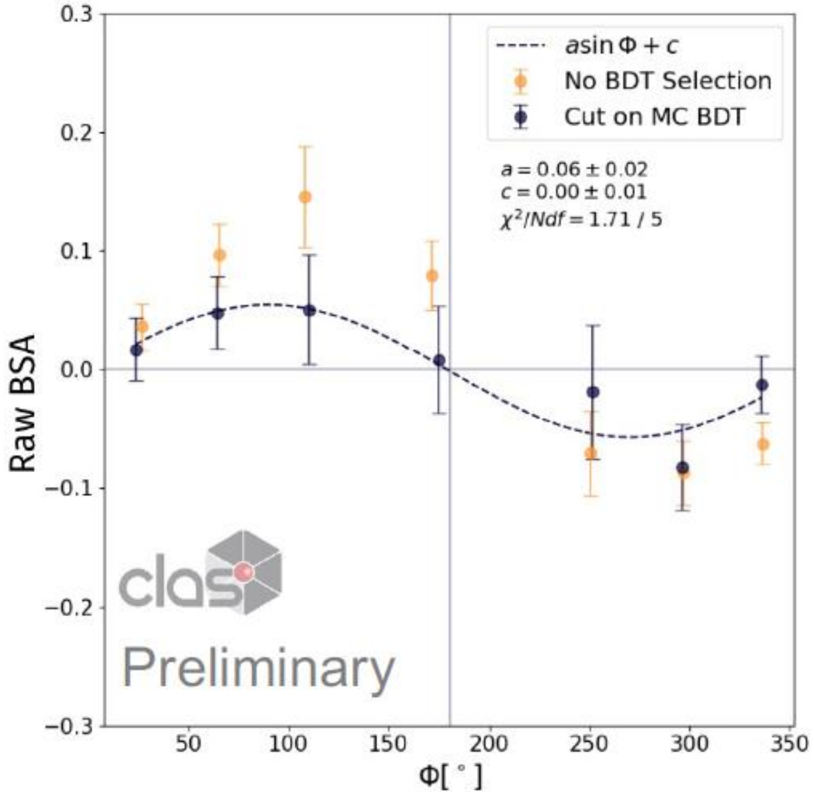








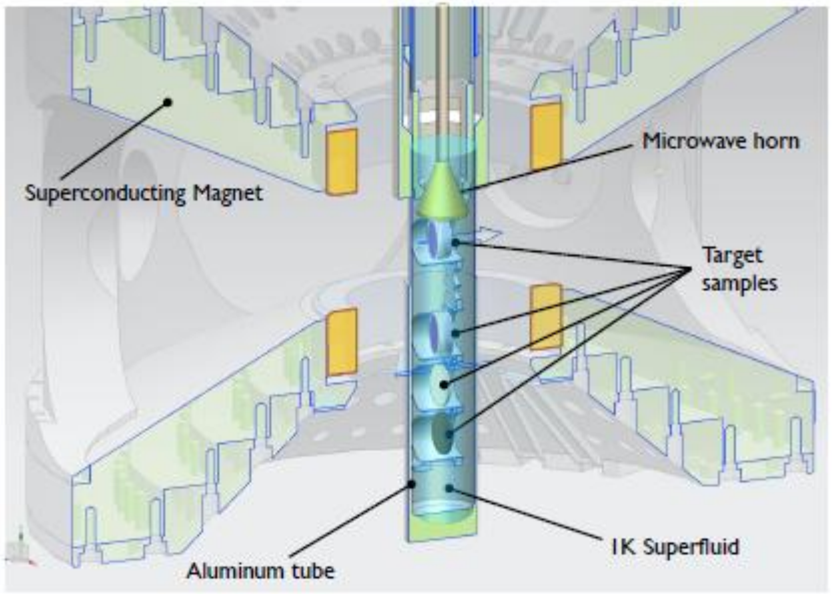
~30% of the collected data

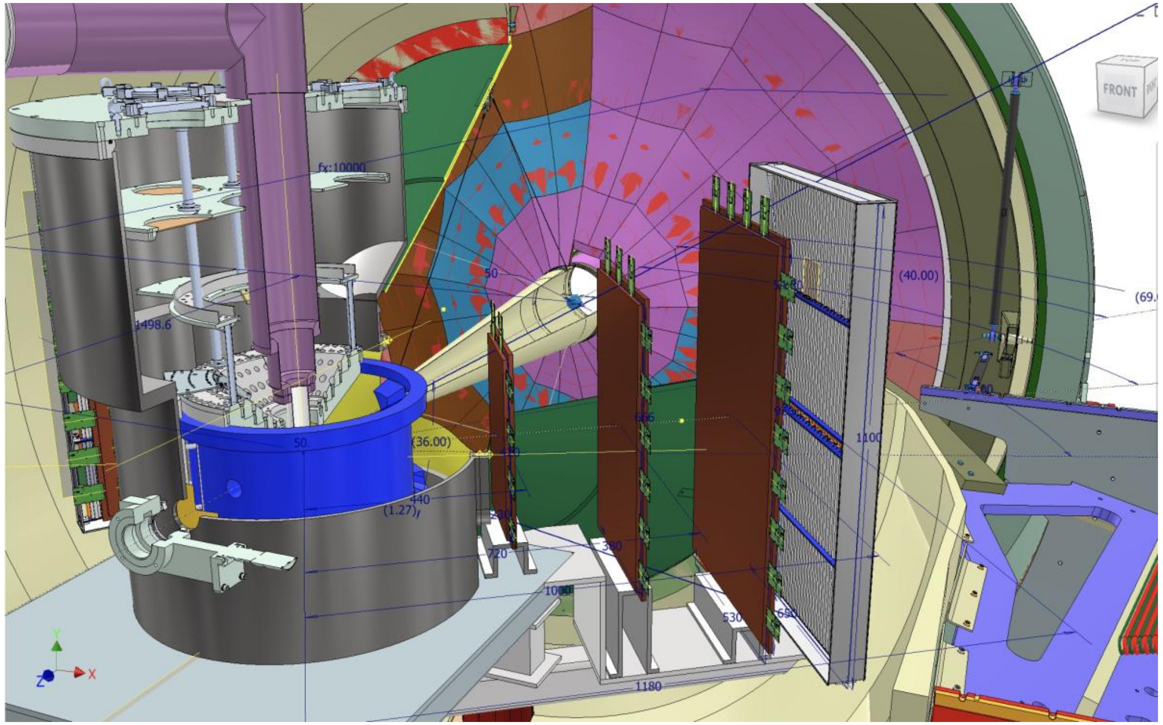


- **Expected shape** for the **raw BSA** (π^0 background not subtracted)
- **Agreement with nDVCS BSA** on unpolarized deuterium, Hobart et al. (CLAS), PRL 133 (2024) (see Adam‘s talk today in Workshop 1)
- Insufficient statistics for TSA and DSA for now
- The remainder of the dataset needs to be analyzed

In preparation: pDVCS on transversely polarized target with CLAS12

Transversely polarized target for CLAS12 under development





- The original idea to use a frozen-spin polarized HD target will not work (beam-induced depolarization)
- An alternative approach, **dynamically polarized NH3** at 5T/1K is expected to work well
- A **new magnet** design is being studied, to maximize the acceptance and to properly fit in CLAS12
- A **chicane of magnets** will be necessary to compensate the bending of the beam electrons by the holding magnet
- A **recoil detector** to compensate the lack of Central Detector is being designed (3 layers of µRwell + 1 scintillator panel)
- Proposal (DVCS+SIDIS) **recently approved** by PAC53 (July 2025) with A rating, will run in ~3-4 years

In preparation: pDVCS on transversely polarized target with CLAS12

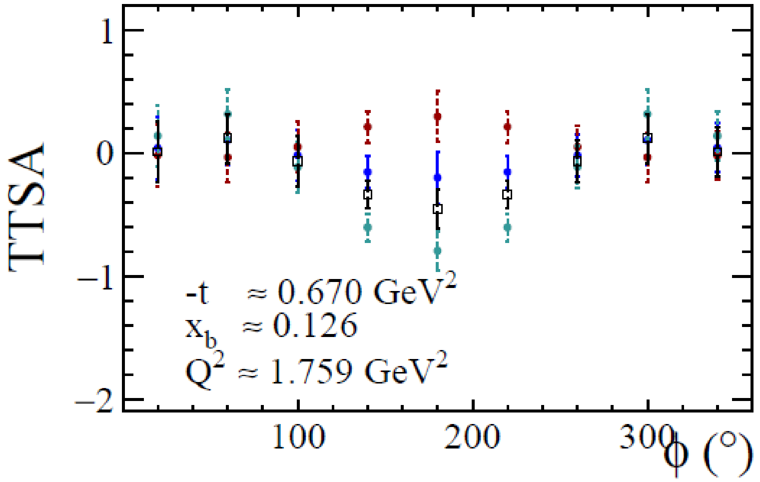
$\vec{e}\vec{p}^{\uparrow} \rightarrow ep\gamma$

$\Delta\sigma_{UT} \sim \cos\phi\sin(\phi_s - \phi)\mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \dots\}$

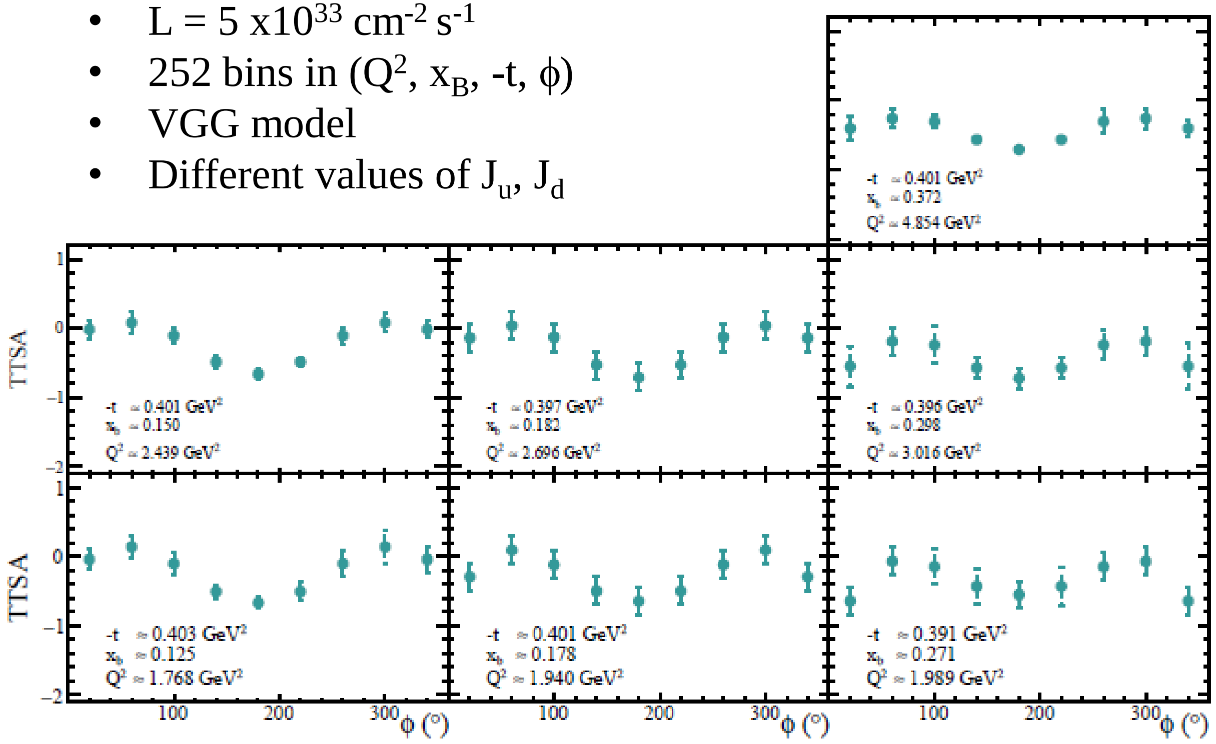
pDVCS on a transverse target is complementary to nDVCS for its sensitivity to the GPD E

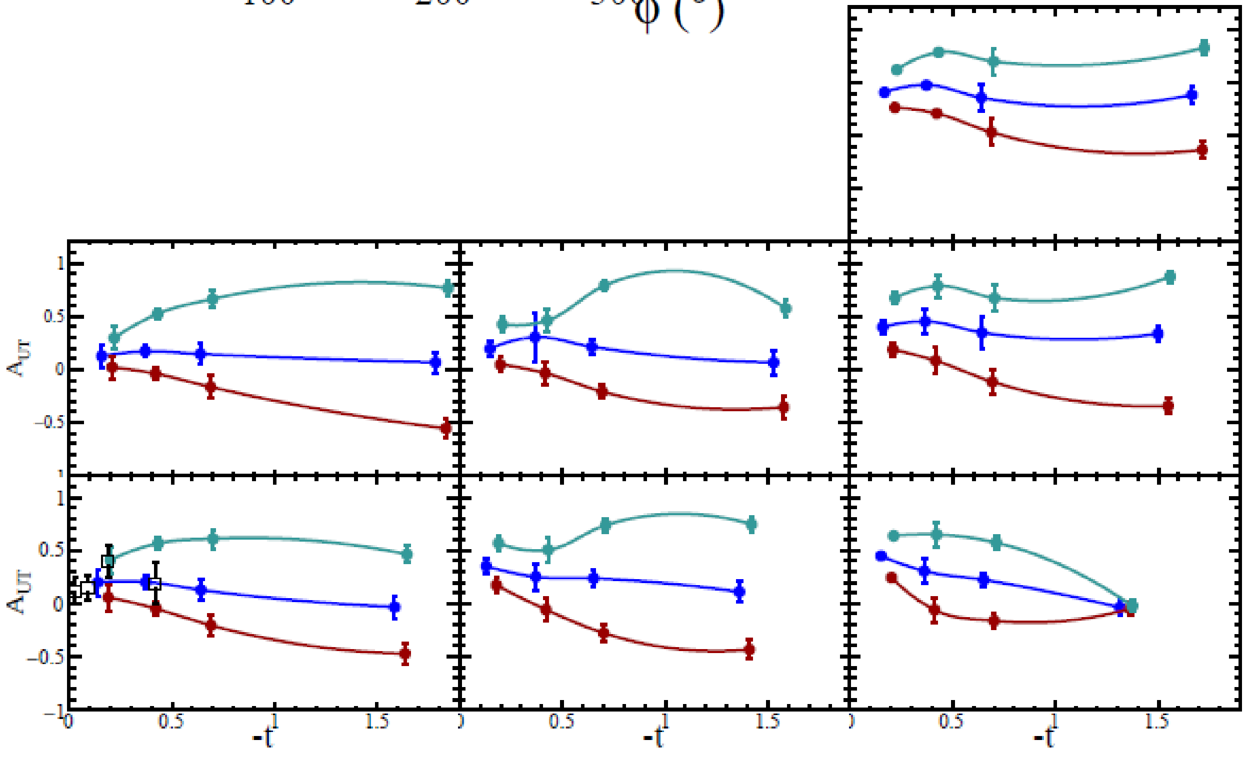
Projections for pDVCS

- 100 days of beam time
- L = 5 x10^{33} cm^{-2} s^{-1}
- 252 bins in (Q^2, x_B, -t, ϕ)
- VGG model
- Different values of J_u, J_d



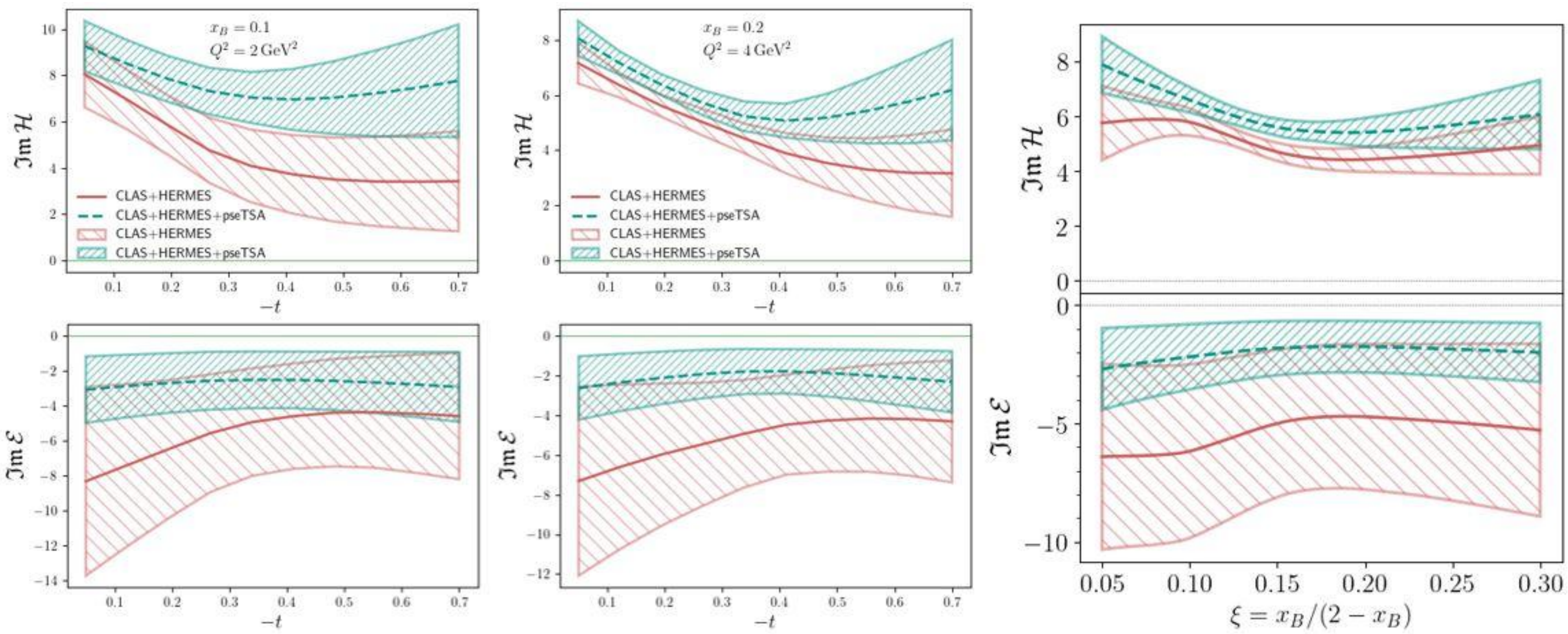
- $J_u = 0.5$, $J_d = 0.1$
- $J_u = -0.5$, $J_d = -0.1$
- $J_u = 0.2$, $J_d = 0$





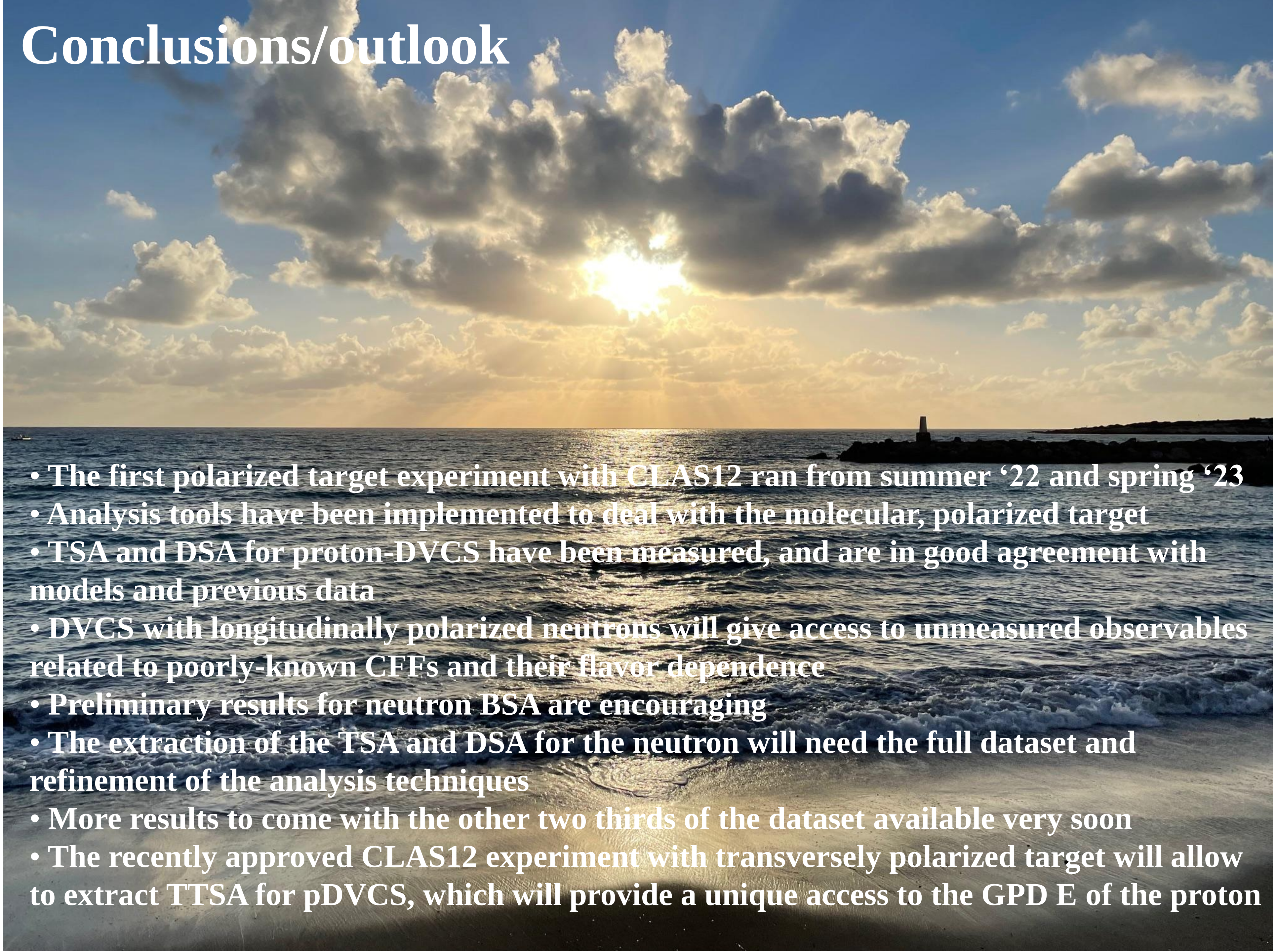
Black points: HERMES data

Impact of projected pDVCS TTSA from CLAS12 on CFF extraction



Uncertainty on $Im\mathcal{E}$ will be reduced by a factor of ~3

Conclusions/outlook



- The first polarized target experiment with CLAS12 ran from summer '22 and spring '23
- Analysis tools have been implemented to deal with the molecular, polarized target
- TSA and DSA for proton-DVCS have been measured, and are in good agreement with models and previous data
- DVCS with longitudinally polarized neutrons will give access to unmeasured observables related to poorly-known CFFs and their flavor dependence
- Preliminary results for neutron BSA are encouraging
- The extraction of the TSA and DSA for the neutron will need the full dataset and refinement of the analysis techniques
- More results to come with the other two thirds of the dataset available very soon
- The recently approved CLAS12 experiment with transversely polarized target will allow to extract TTSA for pDVCS, which will provide a unique access to the GPD E of the proton