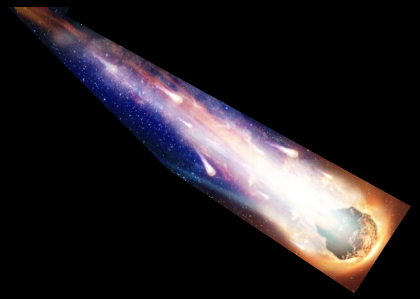


Polarized tomography of the nucleon

Maxime Defurne
Hall A/B/C collaborator

Proton DVCS : What do we know in the valence ?

- **There are 4 CFFs for quarks in the proton :**
  → **CFF H** : Constrained by measurements on **unpolarized protons** (Hall A/C – CLAS – CLAS12)
  Imaginary part +++ Real part ++

  → **CFF $\tilde{H}$** : Constrained by data collected on **longitudinally polarized protons** (CLAS – CLAS12).
  Imaginary part ++ Real part +

  → **CFF E** : Need data on **transversely polarized protons.**
  Imaginary part + Real part 0

  → CFF $\tilde{E}$: DVCS is **poorly sensitive** to this GPD.
  Imaginary part 0 Real part 0

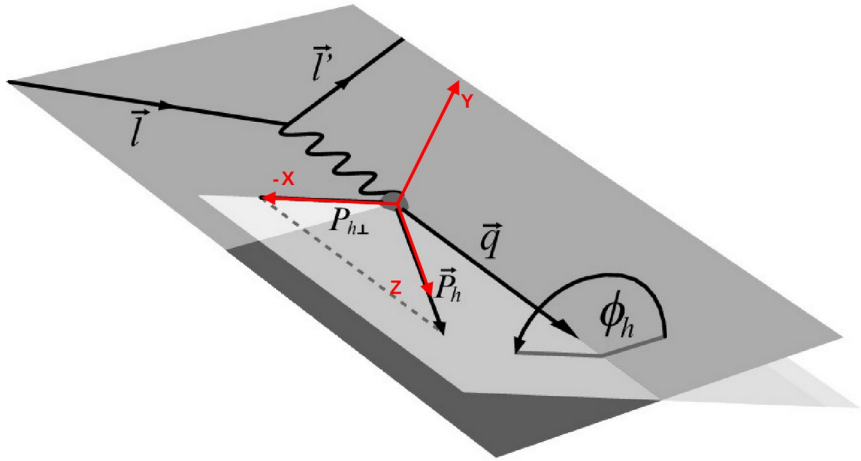
- Proposal with CLAS12 to take data with transversely polarized target scheduled for 2029-ish:
  → **Dedicated magnet is being designed**.
  → Will require **specific detector for proton detection**.

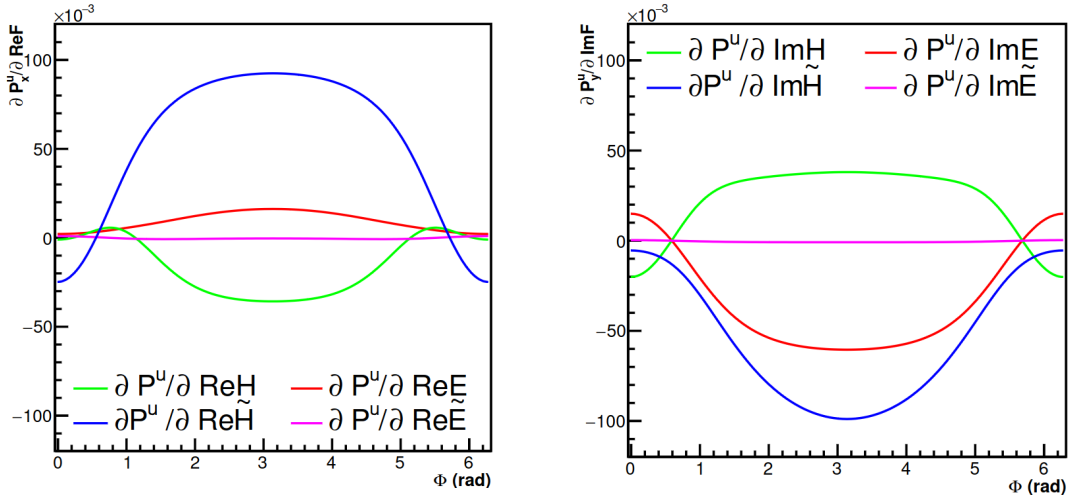
- **Since 2016**, been wondering about sensitivity of **recoil proton polarization (RPP) in DVCS** :
  - **No theoretical calculation** giving the links between CFFs and RPP.
  - **DVCS has a low cross section** : It will be a challenging experiments on many aspects.

PoPEx : A new experimental observable for DVCS

With O. Bessidskaia-Bylund, Postdoc at LSN, funded with Bottom-Up CEA program

- **P. Guichon**, former theoretician at LSN, computed the recoil proton polarization as function of CFFs.
- Sensitivity studies initially performed with GK model.
- Aiming at constraining E, a local measurement is needed.
  - **simultaneous access to ImE and Re$\tilde{H}$**.
  - ImH and Im$\tilde{H}$ constrained by collected JLab data.





$$P^m_{x/z} = h_e\left(P^u_{x/z} + h_e P^h_{x/z}\right) ,$$

$$P^m_y = P^u_y + h_e P^h_y .$$

1) Need a longitudinally polarized beam!

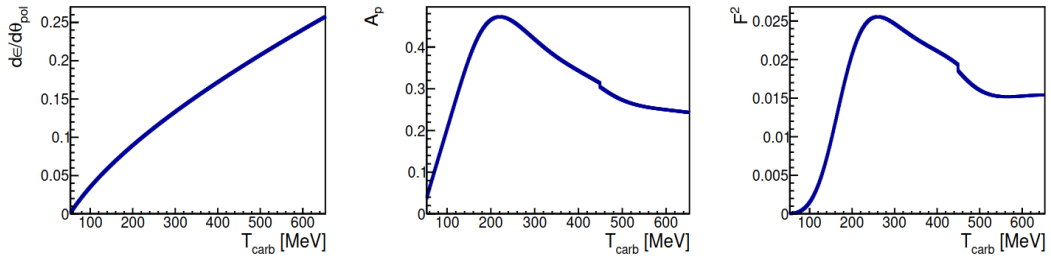
2) Need to avoid spin precession.

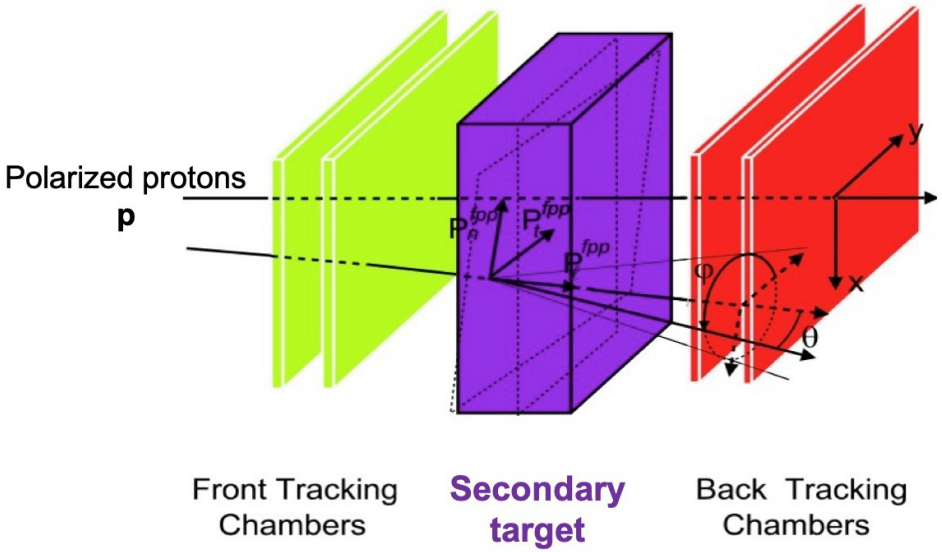
PoPEx : Basics of proton polarimetry

- **Proton polarization** obtained from harmonic analysis of **rescattering off a Carbon or Hydrogen nucleus**.

$$\frac{dN}{d\theta_{pol}} = N_0 \cdot \frac{\mathrm{d}\epsilon}{\mathrm{d}\theta_{pol}} \cdot (1 + A_p(P_y \cos\phi_{pol} - P_x \sin\phi_{pol}))$$

- Regular polarimeter consists of a **secondary target surrounded by trackers** :
  -A_p = **sensibility of the scattering process** to polarization.
  -ε = **Cross section** of p-Nucleus scattering





- **Non-trivial dependences of A_p and ε** with both proton momentum and rescattering angle.

$$F_p^2 = \int_{\theta_{min}}^{\theta_{max}} A_p(\theta_{pol})^2 \epsilon(\theta_{pol}) \mathrm{d}\theta_{pol}$$

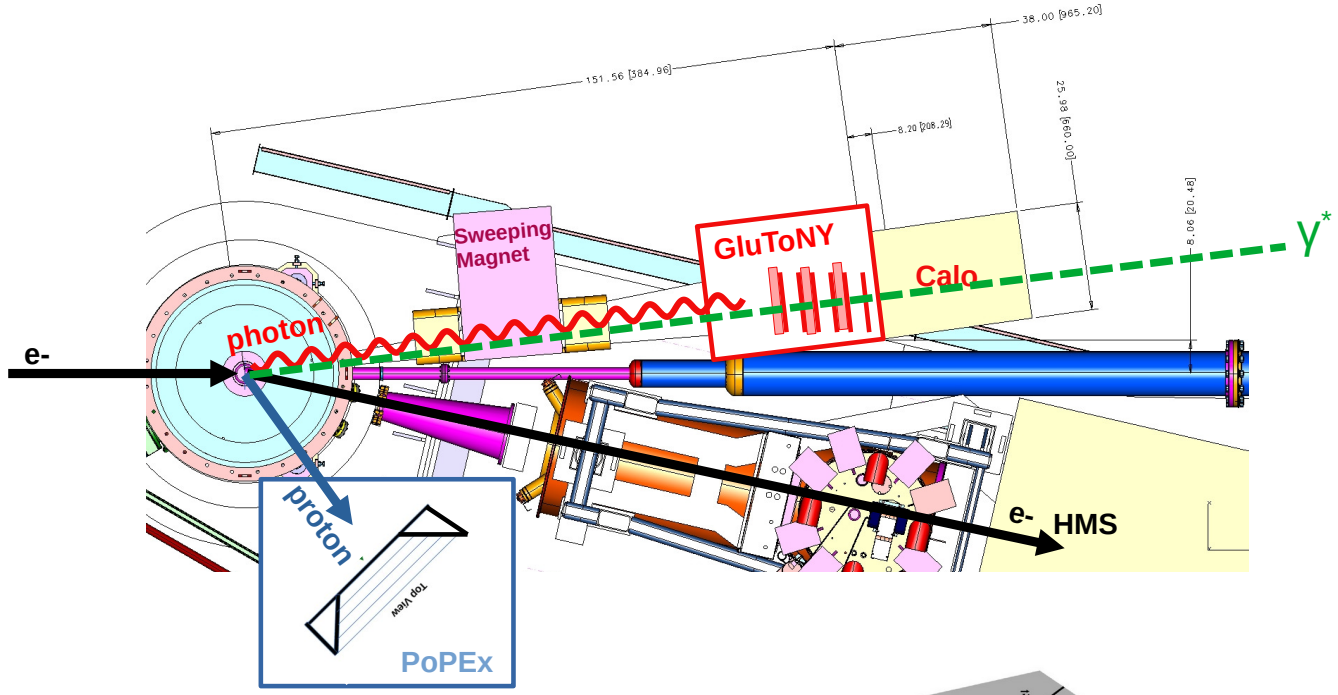
- For the best measurement, **the Figure-of-Merit must be optimized**.

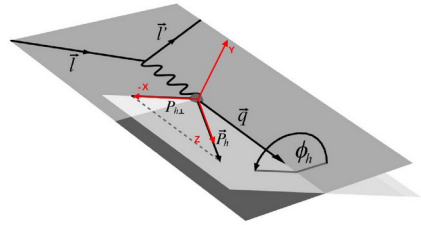
PoPEx : Experimental Hall C at JLab

- For PoPEx, we need :
  - a **local measurement**,
  - with a **high luminosity** (low XS + Polarimetry)

  => **Hall C DVCS setup is a solid solution**.

- A PbWO4 calorimeter has been built and took data in Fall 23 and Spring 24.





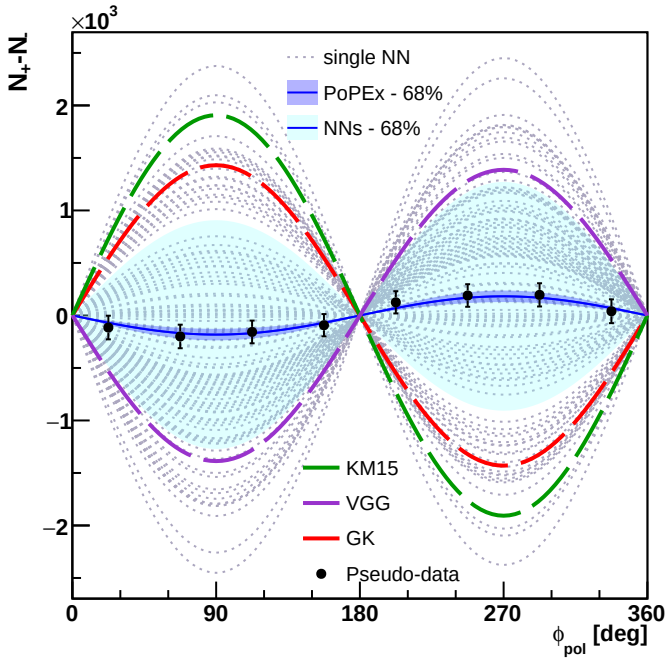
However we need to build a dedicated polarimeter:
- Need to find the space,
- Must sustain the high radiation environment,
- Must be able to find the DVCS proton (Good position and time resolution)

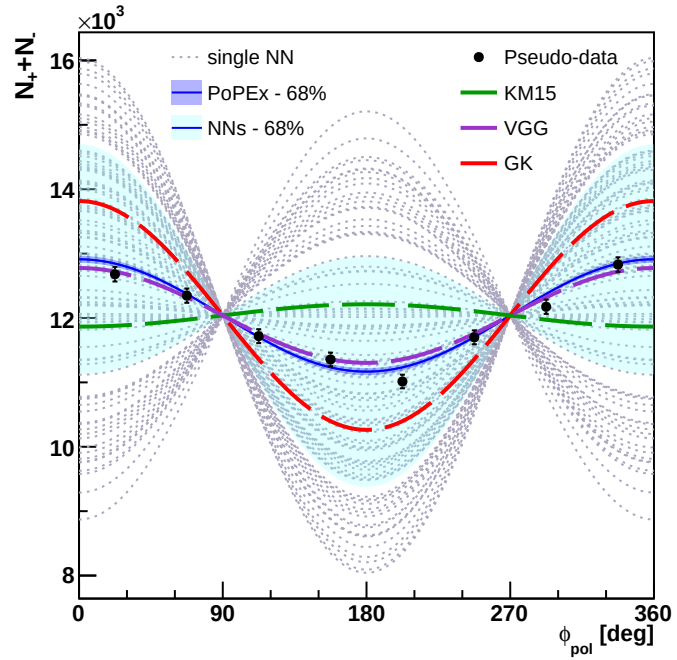
For next slide, the polarimeter is assumed ideal and is $1m^2$ located at 1m from the target.

PoPEx : Scientific impact of a measurement

- First we need to find a kinematics to do a measurement :
  - Relatively high cross section,
  - High Figure-of-Merit for polarimeter,
  - High sensitivity to CFF E.

- Proposed kinematics :
  E_b = 10,6 GeV
  Q^2 = 1,8 GeV²
  x_b = 0,17
  t = -0,45 GeV²
  φ_{Trento} = 180 degrees





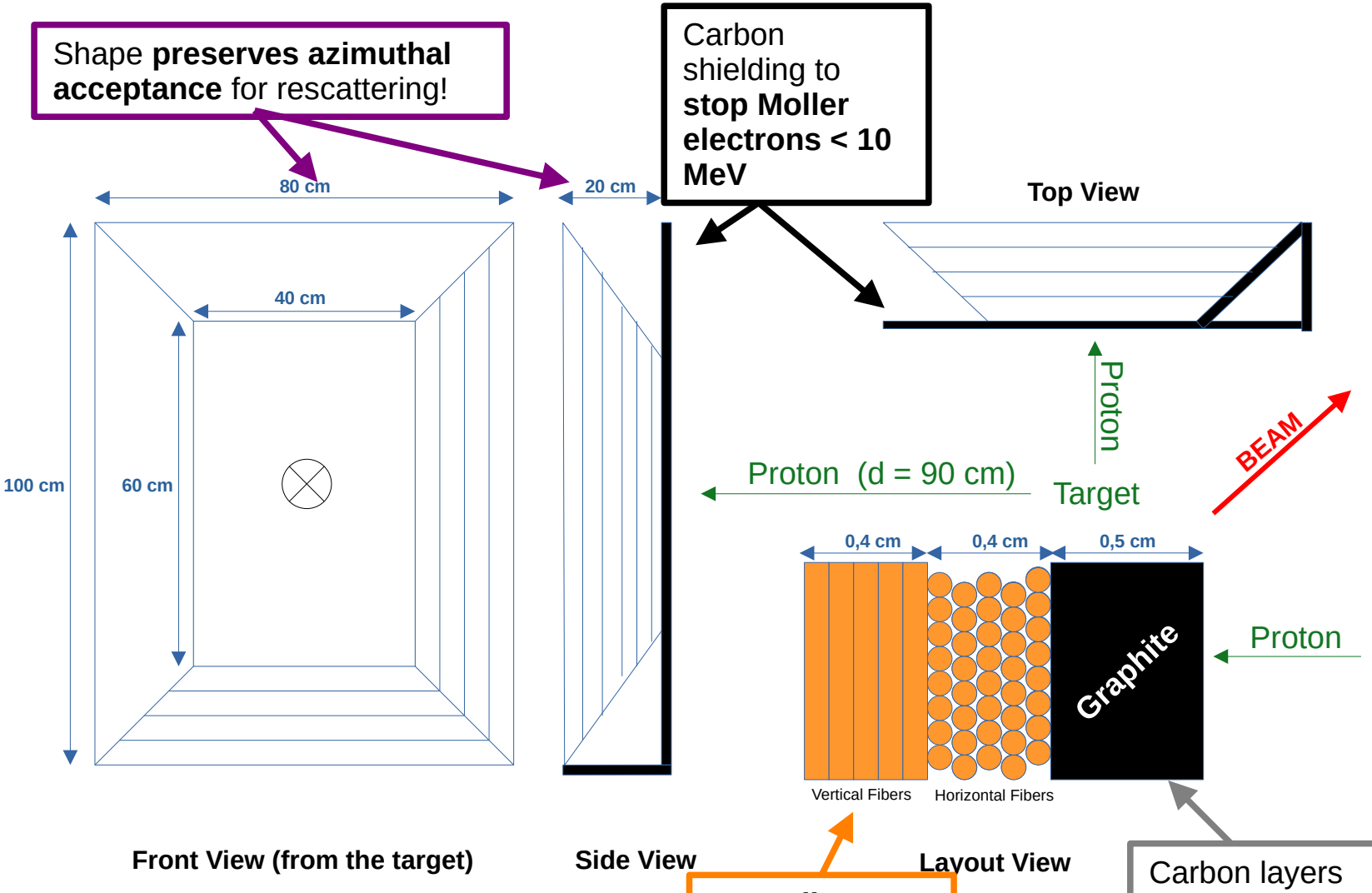
Published in Phys. Rev D107, 014020

- Using the Hall C DVCS Geant4 simulation and **assuming 3 weeks of beam time at 10 µA with ideal Polarimeter**:
  → Measurements of both Px and Py put **stringent constrains on models**.
  → Measurements would **still be relevant with only a tenth of a statistics**.

PoPEx : A first design

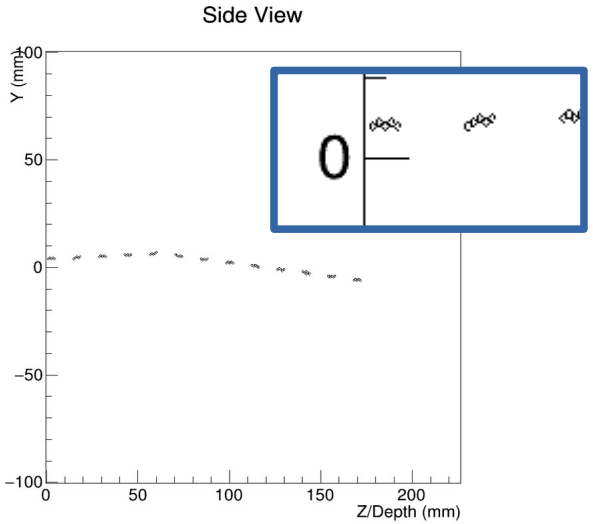
Shape **preserves azimuthal acceptance** for rescattering!

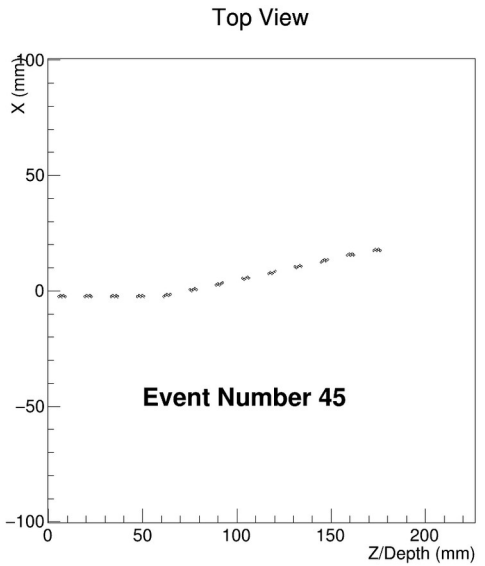
Carbon shielding to **stop Moller electrons < 10 MeV**



1mm-diameter fibers as active secondary target

Carbon layers to **increase efficiency**





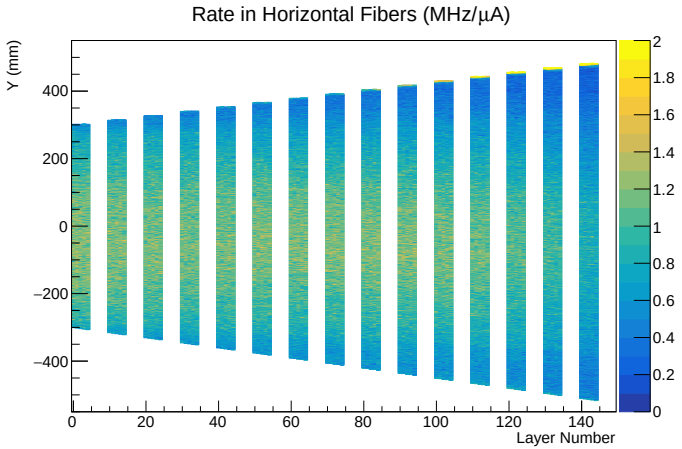
PoPEx : Performance and rates

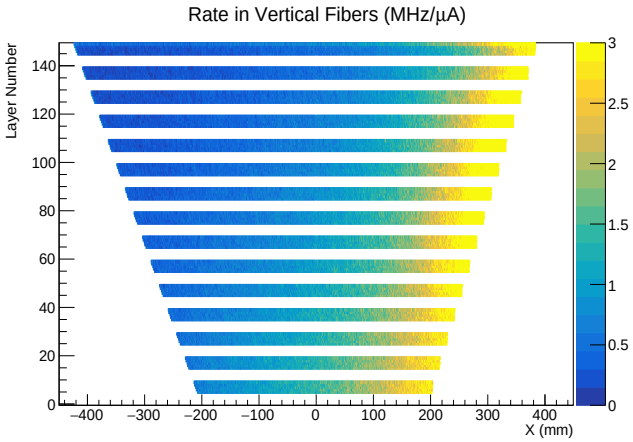
- Design has been implemented in the Hall C DVCS Geant4 simulation.
  → Rates were estimated at **3MHz/µA** for vertical fibers closest to the beam.

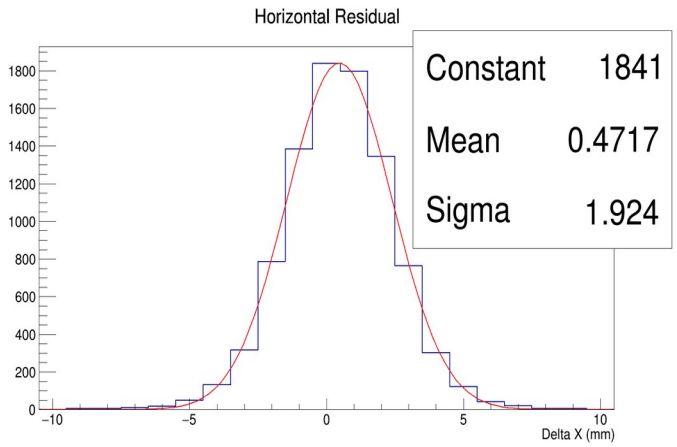
- Assuming a **1ns**-time resolution, hottest fibers will be fired **13 %** of the time within the proton window at **7 µA**.
  → Proton direction will help sorting hits and finding the proton.

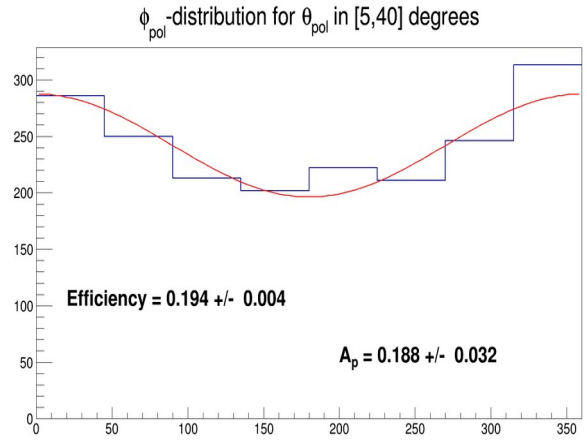
- Glasgow University provided a **specific class for polarized pN-scattering**.

- With a preliminary tracking, Figure-of-merit is found compatible with initial prediction.









PoPEx : Towards a proposal (part I)

- A first experimental setup has been **fully caracterized with Monte-Carlo simulation.**

- As the measurement and its scientific impact are validated, a **Letter-of-Intent was submitted to JLab Program Advisory Committee last year**.

Issues: The TAC theory report points out two issues:
- It is recommended to revisit the theory of QED radiative corrections in DVCS, which may need to be adjusted for the recoil polarization measurement.
- Other physics processes need to be considered for calibration of the recoil polarimeter, such as *ep* elastic scattering or exclusive pion production in kinematics with large known recoil polarization.

Need to be done if an experiment is scheduled

Need to finalize polarimeter design

Summary: The proposed method of using recoil nucleon polarization for DVCS and the π^0 electroproduction is well motivated. Next steps are laid out, including the finalization of the polarimeter design and the development of a Machine Learning tracking algorithm.
The PAC recommends the proponents to proceed to a proposal taking into account the issues raised above.

- Why only a LoI ?
  → Could not determine the maximal beam current (Tracking efficiency),
  → Need to **validate SciFi rates and radiation hardness of setup**,
  → The proposed design not optimized.

PoPEx : Towards a proposal (part II)

- **Item 1 : Optimize the design**
  - → Move away the polarimeter by a factor 2 and use 3mm-diameter fibers (**105 000 → 12 000 kSciFi**)
    Maximal rate expected per fiber ~ **1,5 MHz/µA (6,3 %)**
  - → Multiplexing of SciFi on one electronic channel (**12 000 → 6 000 channels**)

- **Item 2 : Check simulation rates and test SiPM/SciFi hardness**
  - → Beam test is being prepared in collaboration with Hall C and NPS collaborators,
  - → **48 kEuros** = 15 kEuros from CEA-DPhN + 33 kEuros from Paris-Saclay university,
  - → Multi-anode PMTs and ARS provided by JLab,
  - → Do beam test and its analysis for 2025.

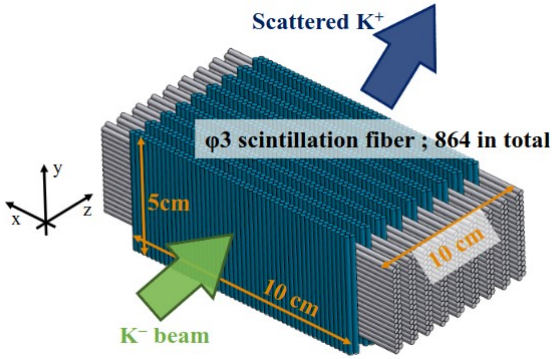
- **Item 3 : Write Tracking/Analysis code**
  - → Adapt simulation code
  - → Maximal beam current will be determined by SciFi occupancies.
  - → Use Electron/Photon information + Machine-Learning

- Aiming at submitting **a full proposal in 2025 !**
  - → **Any collaborator is more than welcome.**
  - → **Excellent opportunities for students and postdocs !**

PoPEx : Some similar detectors... so it is possible

- First **DVCS Hall A experiment built a proton detector** in 2006 :
  - Did not work this well but PoPEx has smaller segmentation.

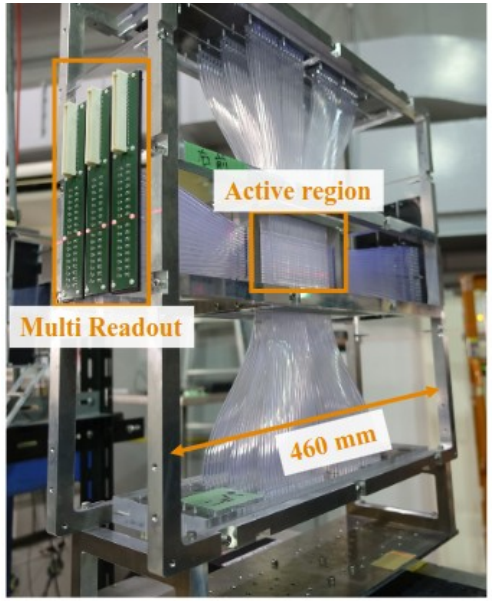
- J-PARC has meson beams including Kaon. It gives an opportunity to study hypernucleus.
  -The Kaon beam is sent through **an Active Fiber Target.**
  - A **prototype has been built** and tested by Japanese teams.
  -However the purpose of the detector is not the same :
  => They need to correct for energy loss in target.

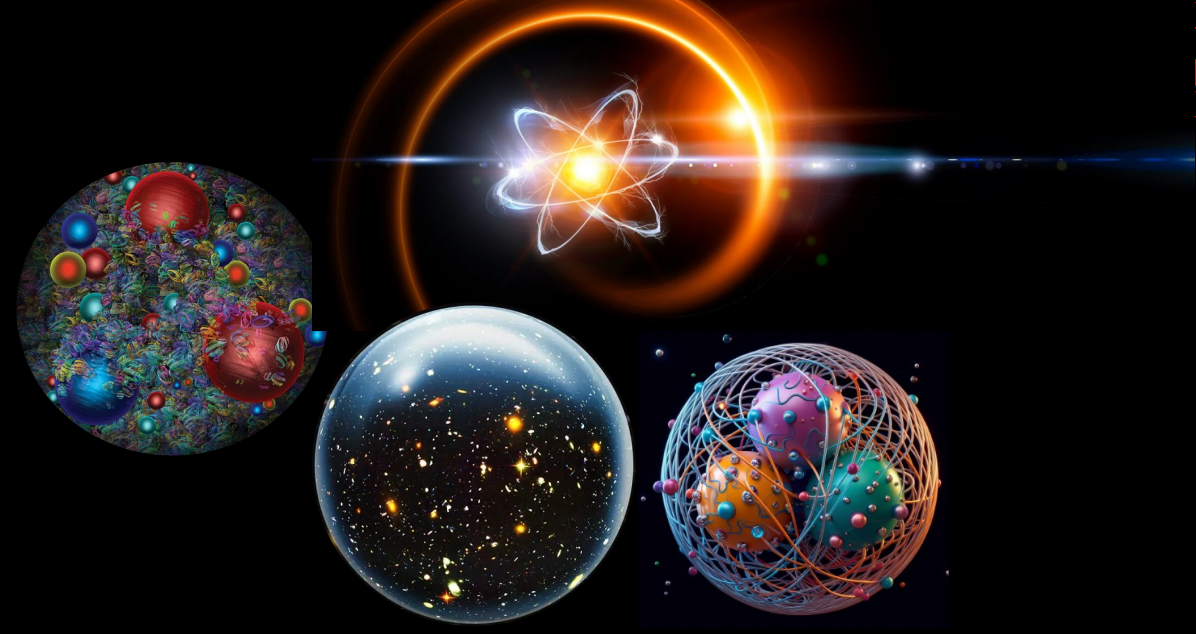


- PoPEx will be larger by one order of magnitude :
  → Need a relatively good time/position resolution.

- **Other measurements possible with PoPEx :**
  → π^0 electroproduction, π^- electroproduction off neutron,
  → epMX SIDIS measurements,
  → Neutron polarimetry ?
  (DVCS on deuterium and changing Carbon by CH2)

Not only seeking experimentalists but theorists as well !!





And slowly but surely we know more and more about the proton.

Introducing Taco,

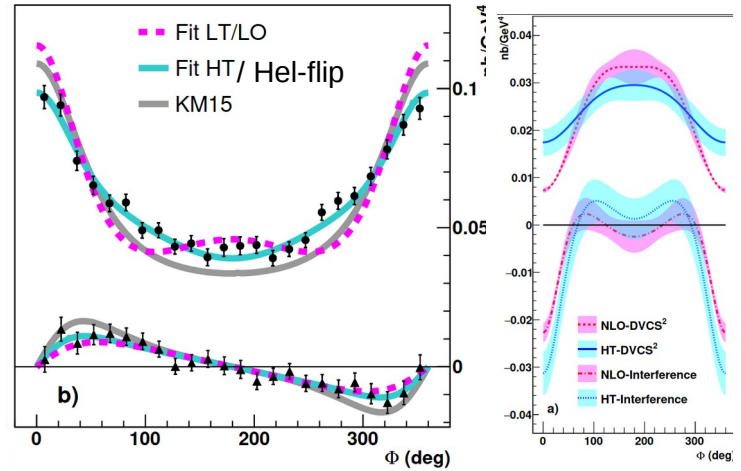
Contributing significantly to my work!

GluToNγ : Gluon Tomography by γ-polarimetry

- **2015** : Fit of DVCS data indicates that there might be **contributions from higher-twist or NLO contributions.**

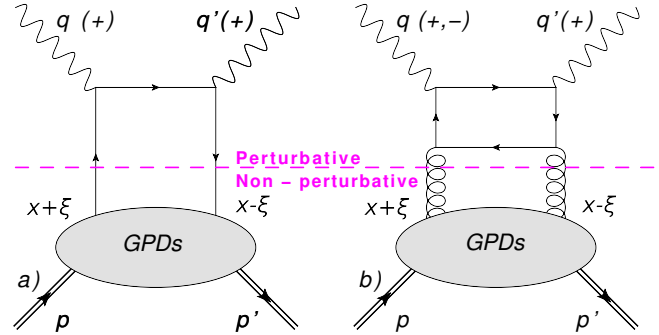
- Their contribution is tightly linked to the γ-helicity amplitudes.

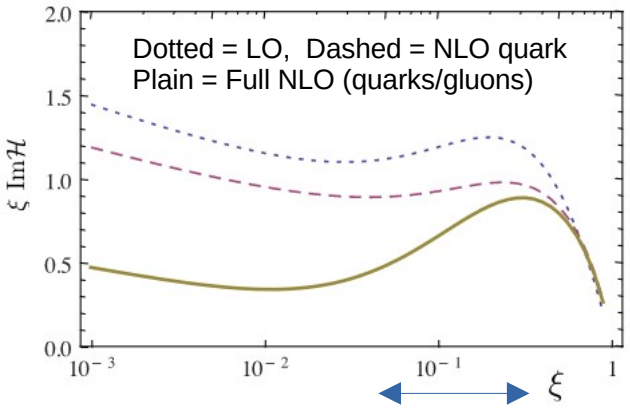
- Therefore let's take a look at the photon polarization at Leading-twist.
  => Higher-twist could be isolated with Rosenbluth separation.



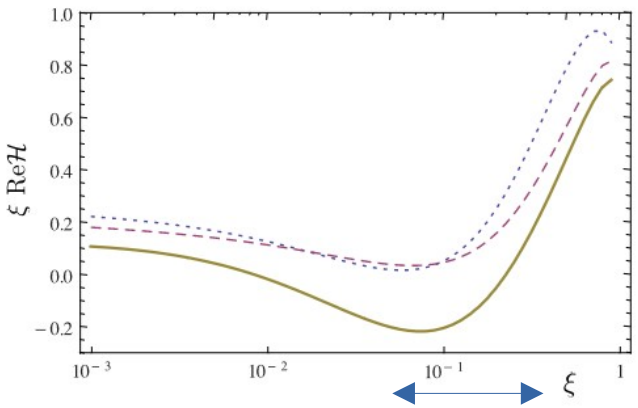
- Two kinds of Gluon GPDs :
  → **Chiral-even GPDs** : Do not flip the photon helicity to be added to quarks.
  → **Chiral-odd GPDs** : Solely flipping the photon helicity (independent term).

Intrinsic Glue binding the proton !





JLab



JLab

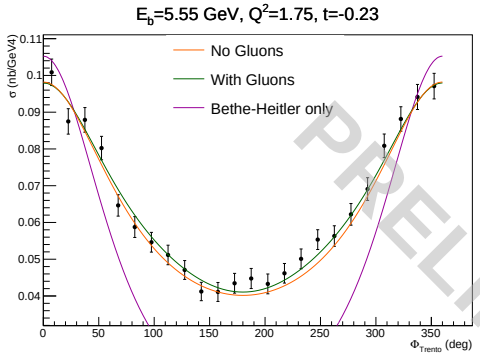
=> Study of DVCS at NLO with gluon chiral-even GPDs: Significant effect!
(Moutarde et al., PRD, 87, 054029)

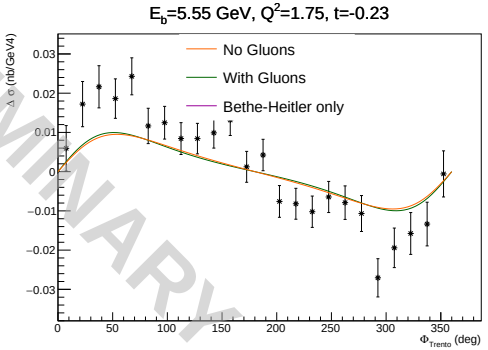
GluToNγ : A first look at theoretical predictions

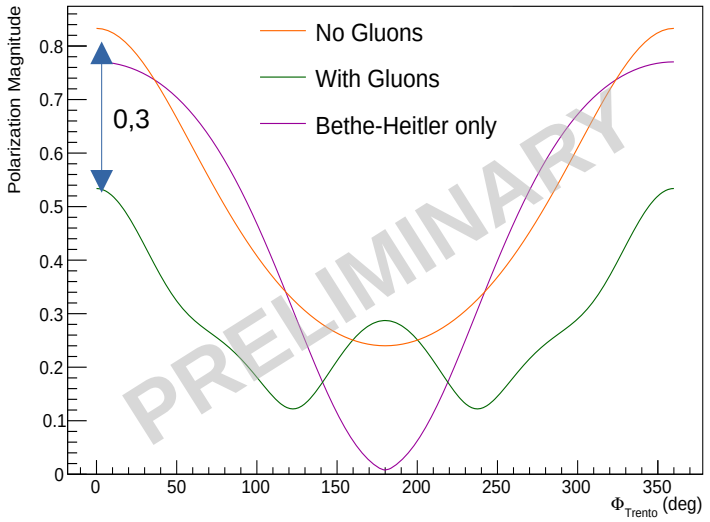
- **P. Guichon**, former theoretician at LSN, computed the fraction of linear polarization and its direction, with H_T^g and E_T^g

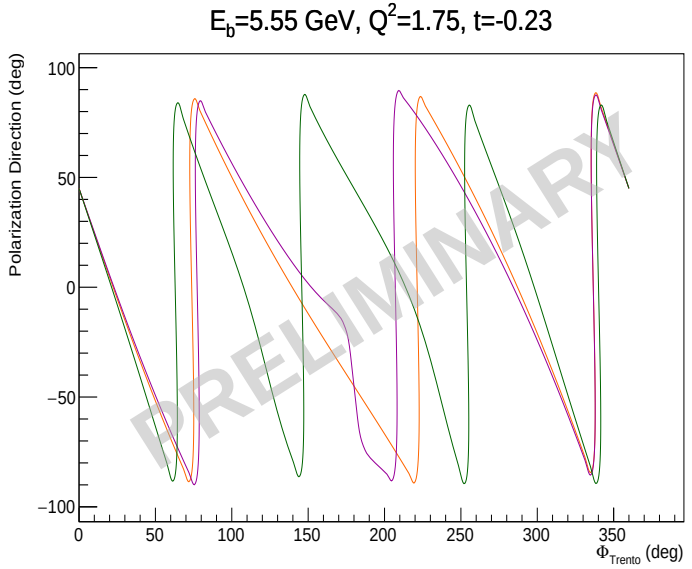
- No model for gluon linearity GPDs => **UNKNOWN !!**

- First try to **fit Hall A data** with various combination of CFFs and **then compute associated polarization**.









- Same XS but :
  → **Different Magnitude**
  → **Different direction**

- φ_{Trento} = 0 degree seems the best angle for measurement.
  (High XS)

GluToNY : Designing a pair polarimeter for DVCS

- **Photon polarization** obtained from harmonic analysis of **pair conversion**.

$$N_{ee}(\phi_{ee}) = N_\gamma \epsilon \left(1 + P_\gamma A_{ee} A_{MS} \cos(2(\phi_{ee} - \phi_\gamma))\right)$$

With following parameters:
-A_{ee} = Sensibility of pair conversion (0,14).
-ε = Conversion rate.
-A_{MS} = Multiple scattering (MS) blurring effect.

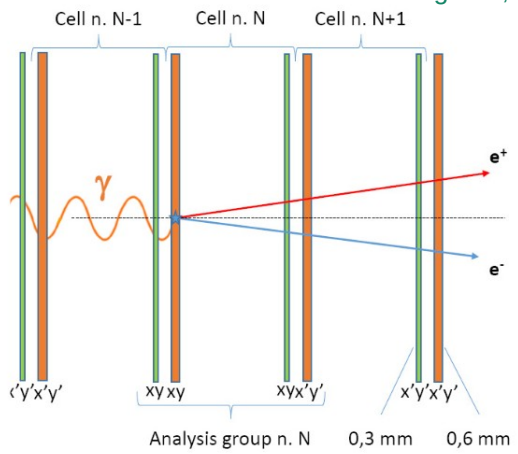
- Need to **optimise the Figure-of-Merit**

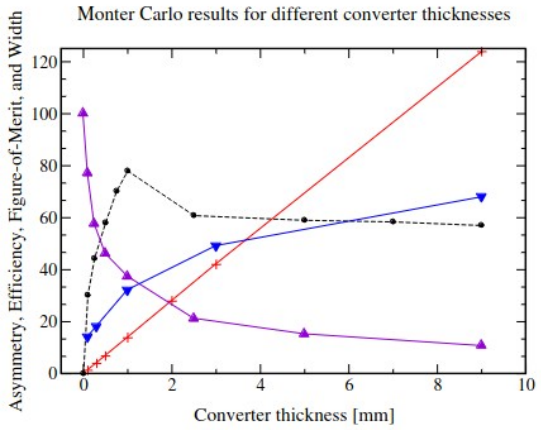
$$FoM = \epsilon \times A_{MS}^2$$

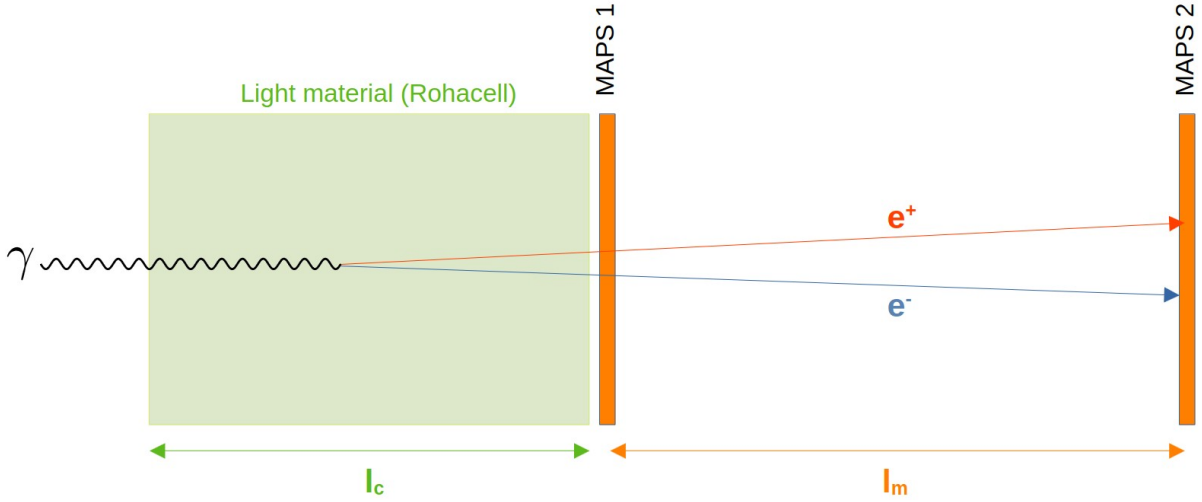
- Revisited with **Pixel Silicon technology**

- **Vary converter parameters to dilute MS :**
  - Density (Uniform, Linear, Quadratic profile)
  - Length

Einghorn, Wojtsekhowski et al, JATIS, Vol 4, Issue 1, 011006



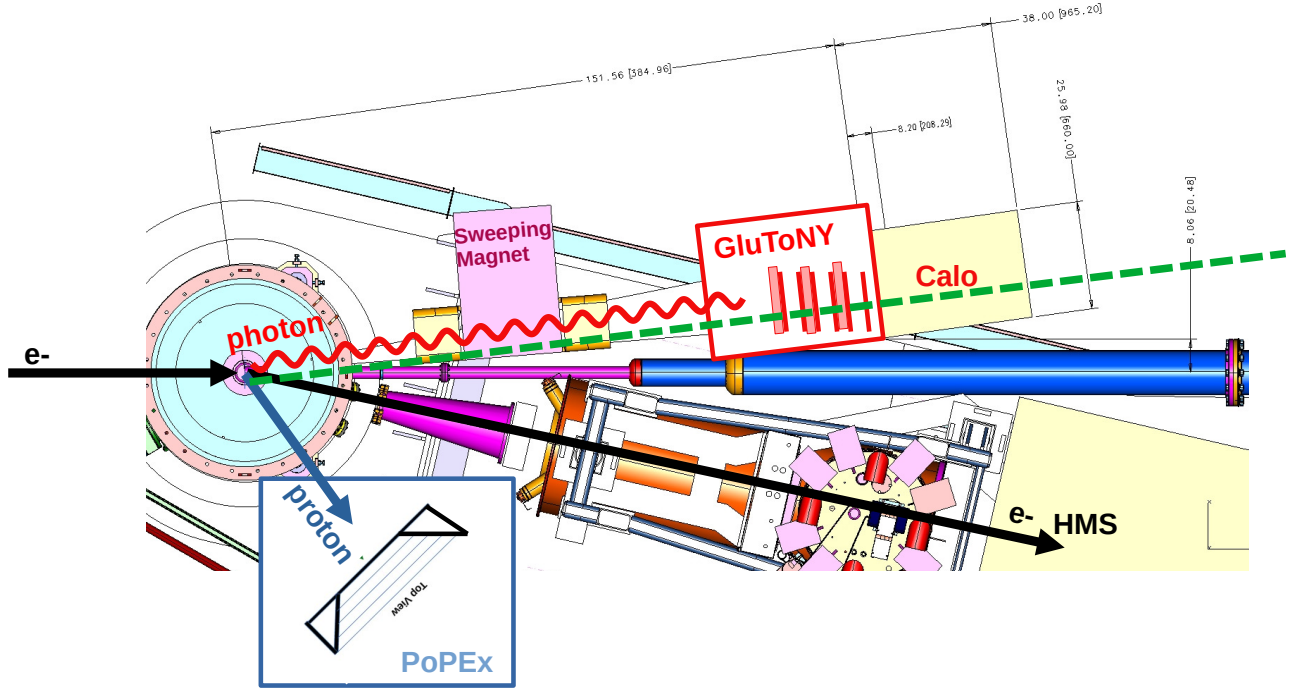




GluToNY : Where to install it ?

- The polarimeter would sit just in front of the calorimeter.

- Given MAPS, GluToNY may be easier to implement than PoPEx :
  - Only two-part experiments,
  - Detector size smaller,
  - Magnet to sweep the background,
  - Move away the calo to reduce background



- Where to find MAPS ?
  → A **few Alpide sensors are available at CEA** and could be used to validate the simulation results.

  → Now we are considering 20 MAPS-planes being 10 cm by 10 cm (or 15 cm by 15 cm) = max 0.5 m² :
  - Not much compare to Upstream tracker of LHCb currently being designed
  => May order at the same time of LHCb to benefit from a reduced cost.

- Now, DVCS photon is very energetic. But we may find processes with lower photon energy and/or higher cross section such as **u-channel DVCS, VCS,… and useful for astrophysics or non-linear QED.**

Conclusion

- Two ambitious projects **fully exploiting the luminosity at Jefferson Lab**
  => Impossible to do anywhere else.

- PoPEx :
  - would be **the first experiment giving access to 3 GPDs** out of 4 (Reduced systematics).
  - No real R&D required !
  - **Detector/SiPM behaviour in the Hall C environment to be tested** with the beam test in 2025.

- GluToNY :
  - **Chasing the gluons** with the golden channel.
  - Easier to **perform feasibility studies**.
  - But will have to wait for a MAPS-design (MVTX ? Upstream Tracker of LHCb ?).

- **Theory/Phenomenology effort important** for the success of this program
  → Kinematic power corrections?
  → Fit to NLO ?
  Theorists/Phenomenologists definitely required !

- Do not hesitate to **contact me if interested** or **advertise these experiments** and soon twitter/instagram accounts will be started :
  #PoPEx #GluToNY #JLab2040