Deeply Virtual Compton Scattering at Jefferson Lab

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Outline

- Introduction – physics motivation
- Experimental setup
- High Resolution Spectrometer optics optimization
- Outlook

Physics motivation

- Form factors → partons position
- Parton distribution functions → partons momentum

But no correlations between the two!

→ Generalized Parton Distributions (GPDs) correlate longitudinal momentum and transverse position of partons.

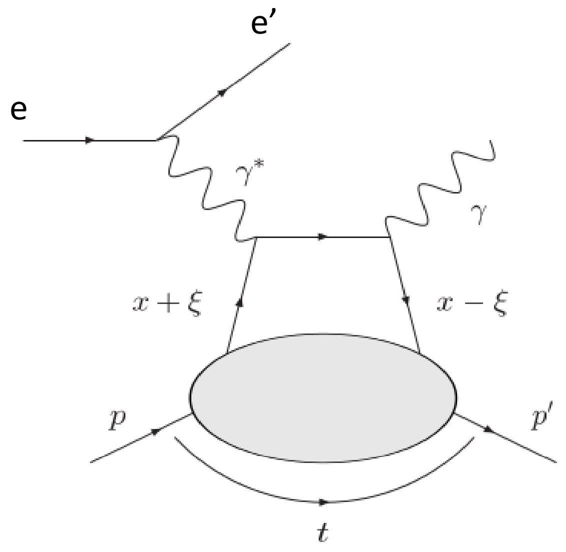
→ GPDs also give insights on nucleon spin structure.

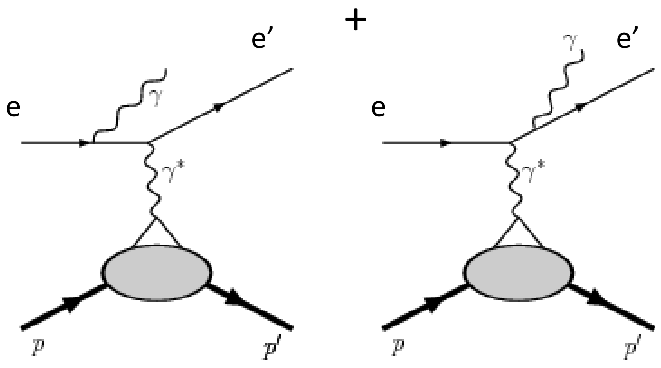
GPDs accessible through Deeply Virtual Compton Scattering (DVCS) & interference with Bethe-Heitler.

My PhD subject: DVCS experiment at Jlab, Hall A!

→ Extract DVCS cross-sections, as a function of Q^2, for fixed values of x_B

The DVCS + Bethe-Heitler interactions ep → e’p’γ





$Q^2 = -(e' - e)^2$: virtuality of γ^*

$\nu = E - E'$, energies of the electron before and after scattering

$x_B = \frac{Q^2}{2M\nu}$ (NB: $x_B \neq x$)

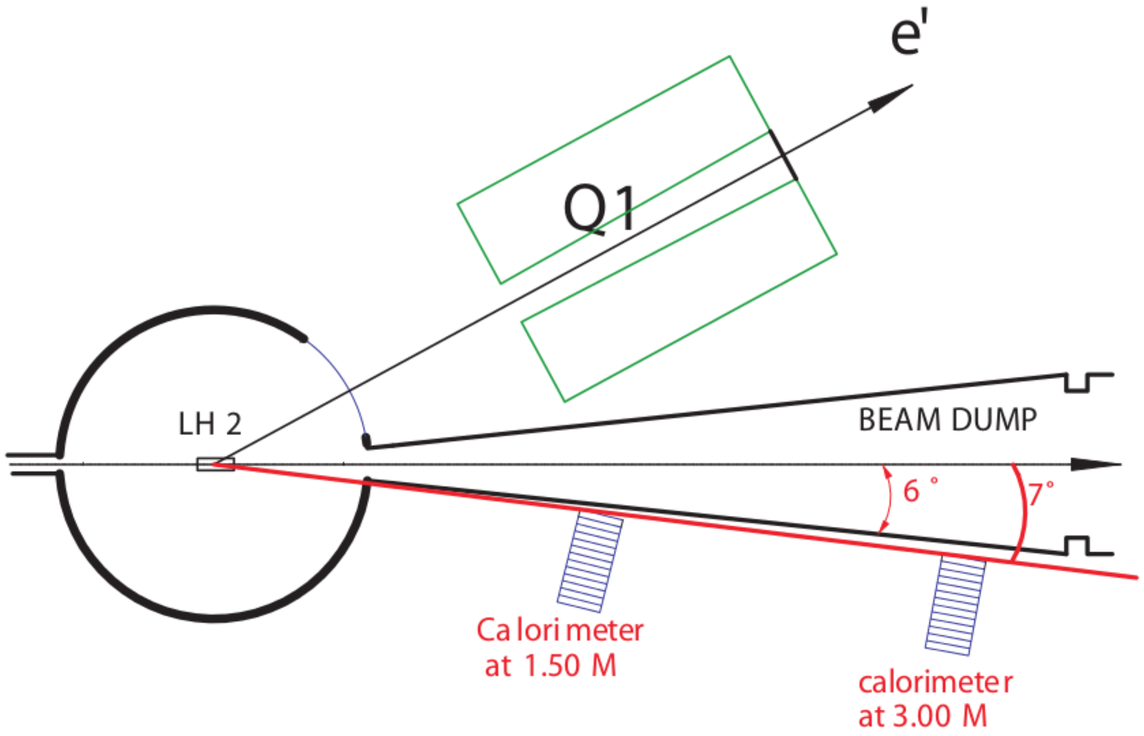
$\xi = \frac{x_B}{2 - xB}$

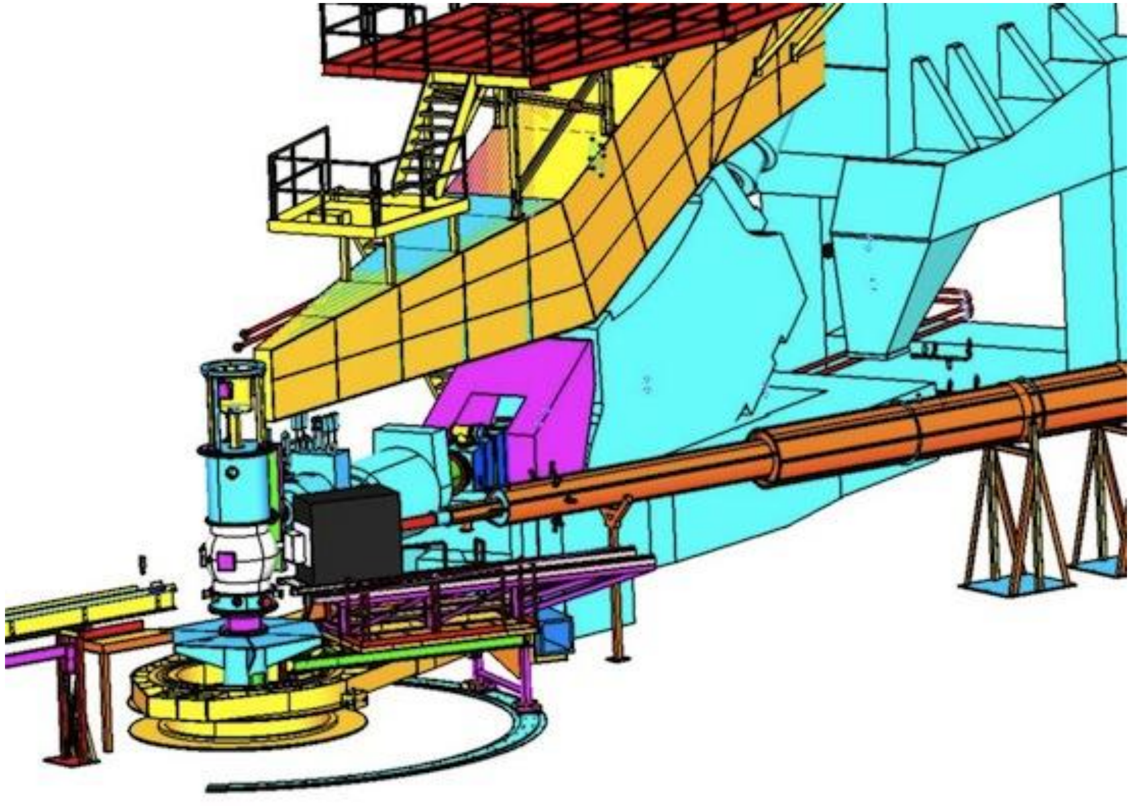
-2ξ : longitudinal momentum transfer to the struck quark.

$t = (p - p')^2$: squared momentum transfer to the proton

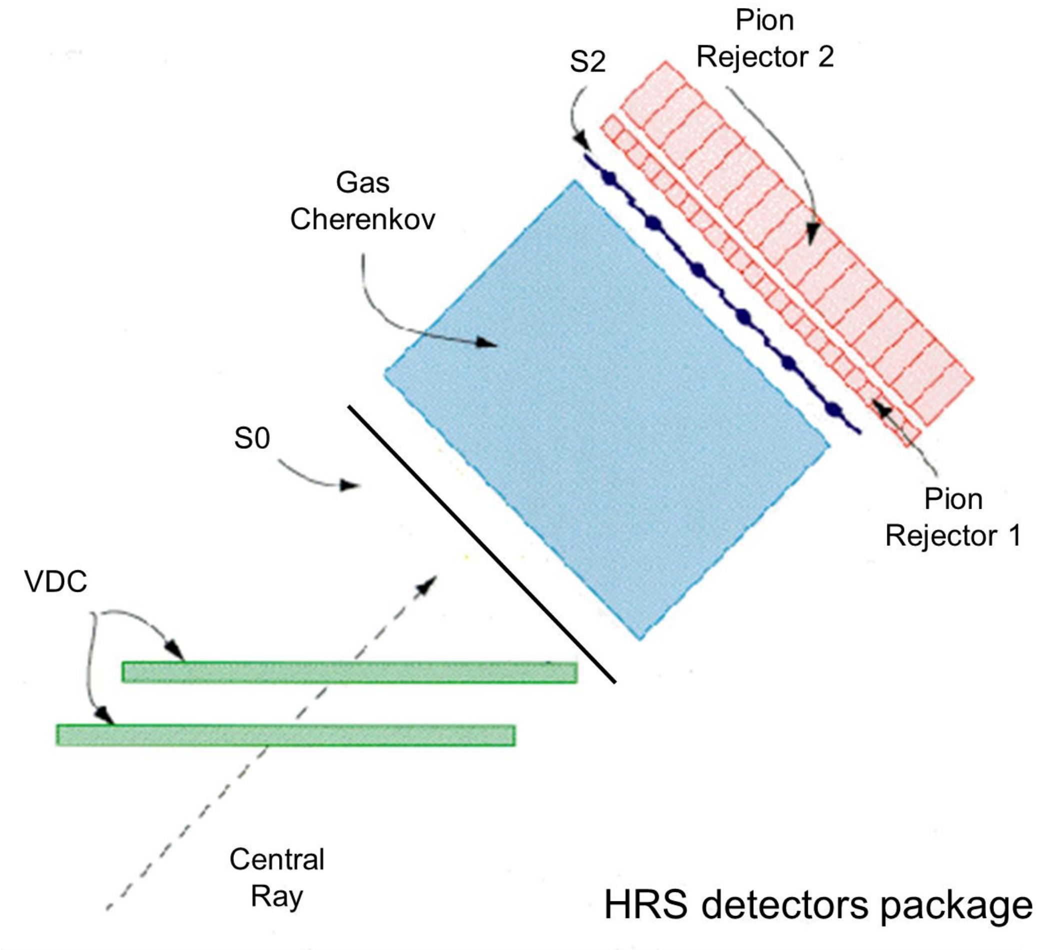
In the limit $Q^2 \to \infty$ and $\nu \to \infty$ but fixed x_B (Bjorken limit), the virtual photon γ^* interacts with a single quark in the proton.

The experimental setup



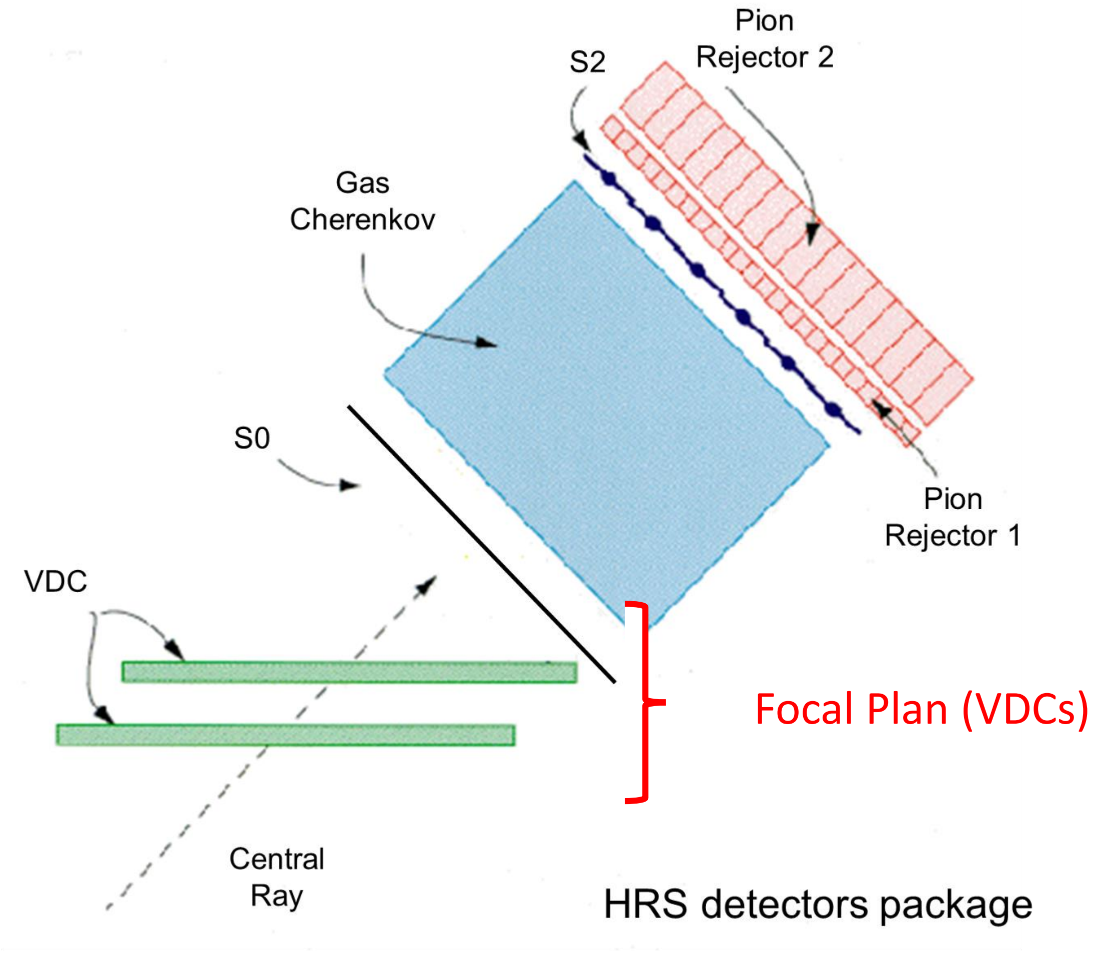


The LHRS detector package



- Vertical Drift Chambers : tracking
- Scintillators + Cherenkov : triggering
- Cherenkov + "Pion Rejector" (electromagnetic calorimeter) : particle identification (electrons VS pions)

The focal plan



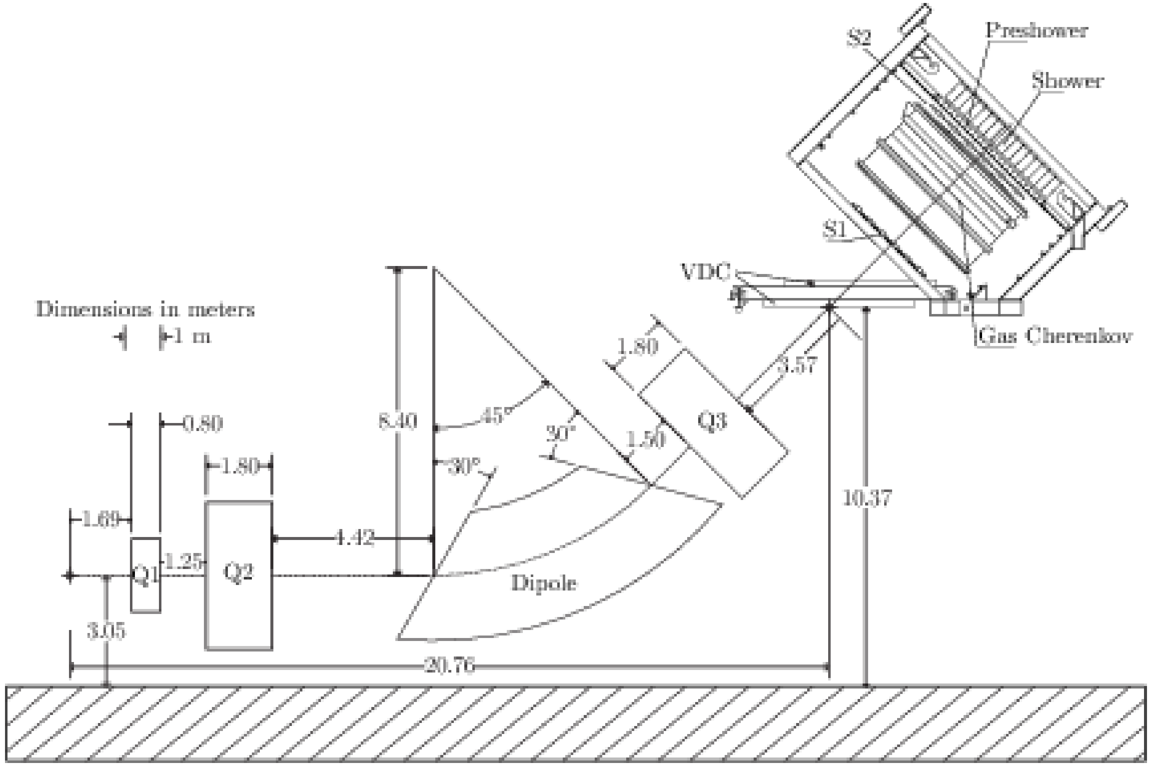
- LHRS focal plan ~ camera focal plan
- Electron detected at focal plan:
  - Position x_{fp}, y_{fp}
  - Angles θ_{fp}, ϕ_{fp} (electron trajectory VS central ray axis)
- From x_{fp}, y_{fp}, θ_{fp}, and ϕ_{fp} : reconstruction at the target of :
  - Event vertex: y_{tg}
  - Angles θ_{tg}, ϕ_{tg} (electron trajectory VS central ray axis)
  - Momentum δ_{tg} ($p_{electron}$ - p_{LHRS})

Reconstructing vertex, trajectory & momentum

- How ?

LHRS : made of 4 superconducting magnets + detector package

Magnets : QQDQ configuration



The optics matrix

- Knowledge of how the electron trajectory is bent in the magnets allows the reconstruction.
- Electric currents/Magnetic fields of each magnet "tuned" for specific bending.

→ Optics Matrix

"On the paper" (1st order approximation):

$$\begin{bmatrix} \delta \\ \theta \\ y \\ \phi \end{bmatrix}_{tg} = \begin{bmatrix} \langle\delta|x\rangle & \langle\delta|\theta\rangle & 0 & 0 \\ \langle\theta|x\rangle & \langle\theta|\theta\rangle & 0 & 0 \\ 0 & 0 & \langle y|y\rangle & \langle y|\phi\rangle \\ 0 & 0 & \langle\phi|y\rangle & \langle\phi|\phi\rangle \end{bmatrix} \begin{bmatrix} x \\ \theta \\ y \\ \phi \end{bmatrix}_{fp}$$

The optics matrix coefficients

In real life:

$$y_{tg} = \sum_{j,k,l} Y_{jkl}\theta^j_{fp} y^k_{fp} \phi^l_{fp},$$

$$\theta_{tg} = \sum_{j,k,l} T_{jkl}\theta^j_{fp} y^k_{fp} \phi^l_{fp},$$

$$\phi_{tg} = \sum_{j,k,l} P_{jkl}\theta^j_{fp} y^k_{fp} \phi^l_{fp},$$

$$\delta = \sum_{j,k,l} D_{jkl}\theta^j_{fp} y^k_{fp} \phi^l_{fp},$$

$$Y_{jkl} = \sum_{i=1}^{m} C_i^{Y_{jkl}} x^i_{fp}$$

$$y_{tg} = \sum_{j,k,l} \sum_{i=1}^{m} C_i^{Y_{jkl}} x^i_{fp} \theta^j_{fp} y^k_{fp} \phi^l_{fp}$$

$C_i^{Y_{jkl}}$ "Optics matrix coefficients"

LHRS optics optimization

- What is the problem ?

Superconducting magnet: maximum current threshold above which loss of superconductivity.

(you do not want that to happen)

But Q1 is old! → threshold lower than in his youth!

→ Threshold lower than experimental requirement

→ Required current cannot be reached, magnetic field too low

→ Different electron trajectory bending in magnet Q1

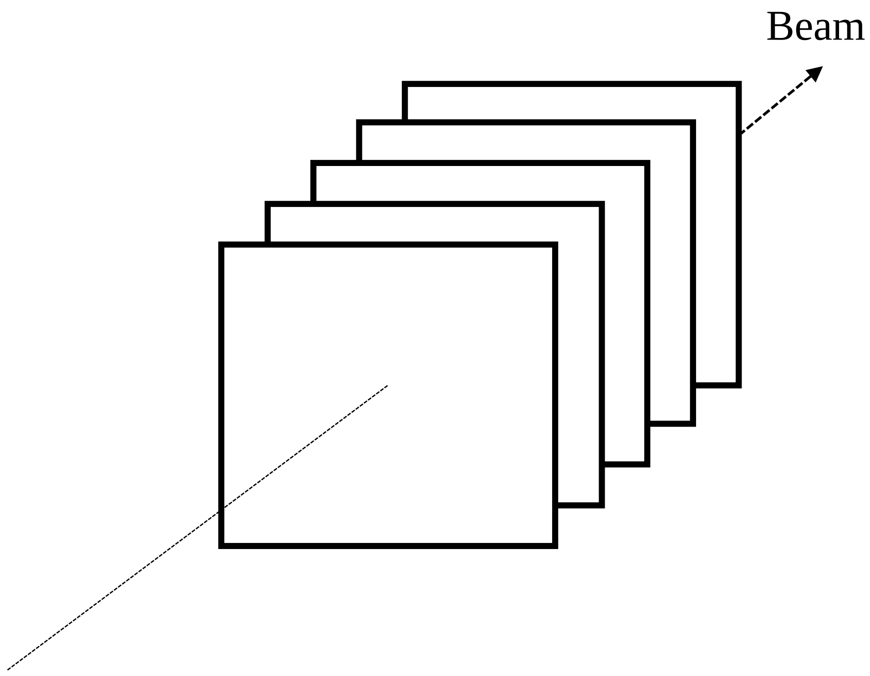
→ Q1 is “detuned”

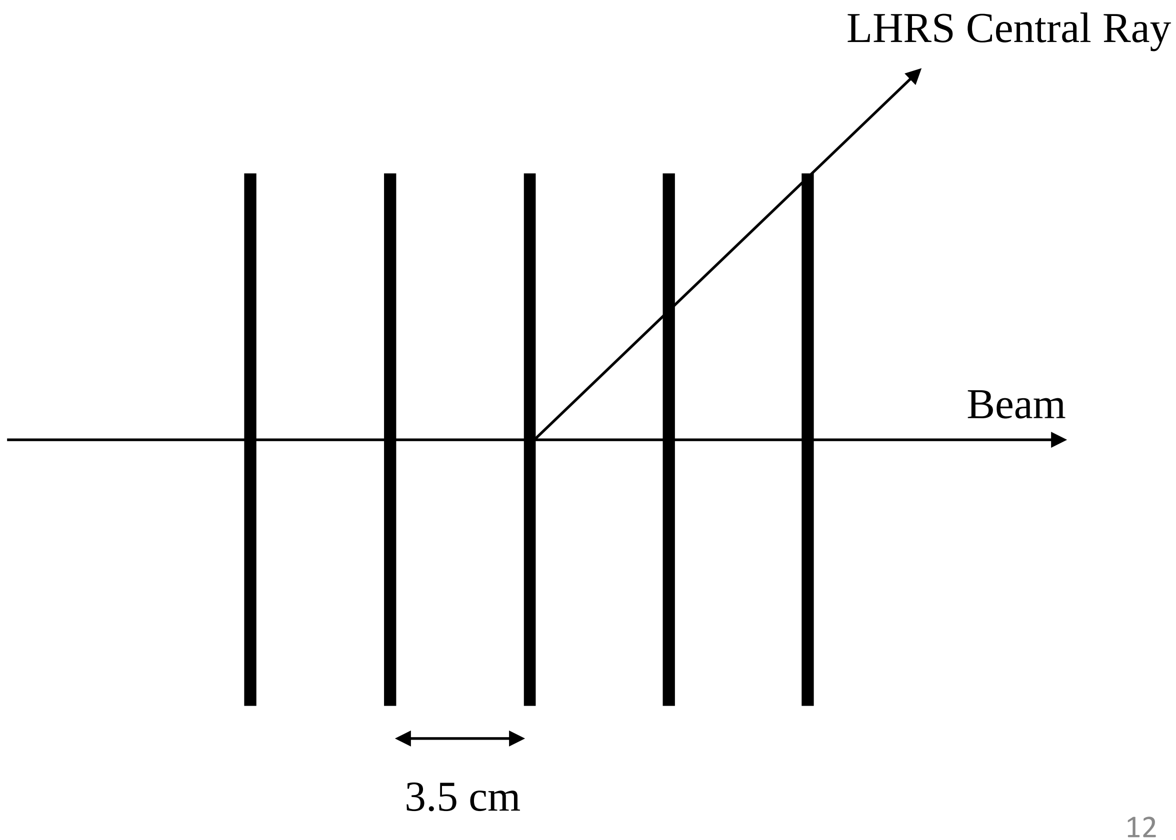
→ Need to compute new optics matrix coefficients $C_i^{Y_{jkl}}$

Step 1 – optimization of the vertex reconstruction

- Data taken on a 5 thin carbon foils target (1mm thick)

→ Expected vertex values y_{tg}^{0}





Step 1 – optimization of the vertex reconstruction

- Data taken on a 5 thin carbon foils target (1mm thick)

→ Expected vertex values y_{tg}^0

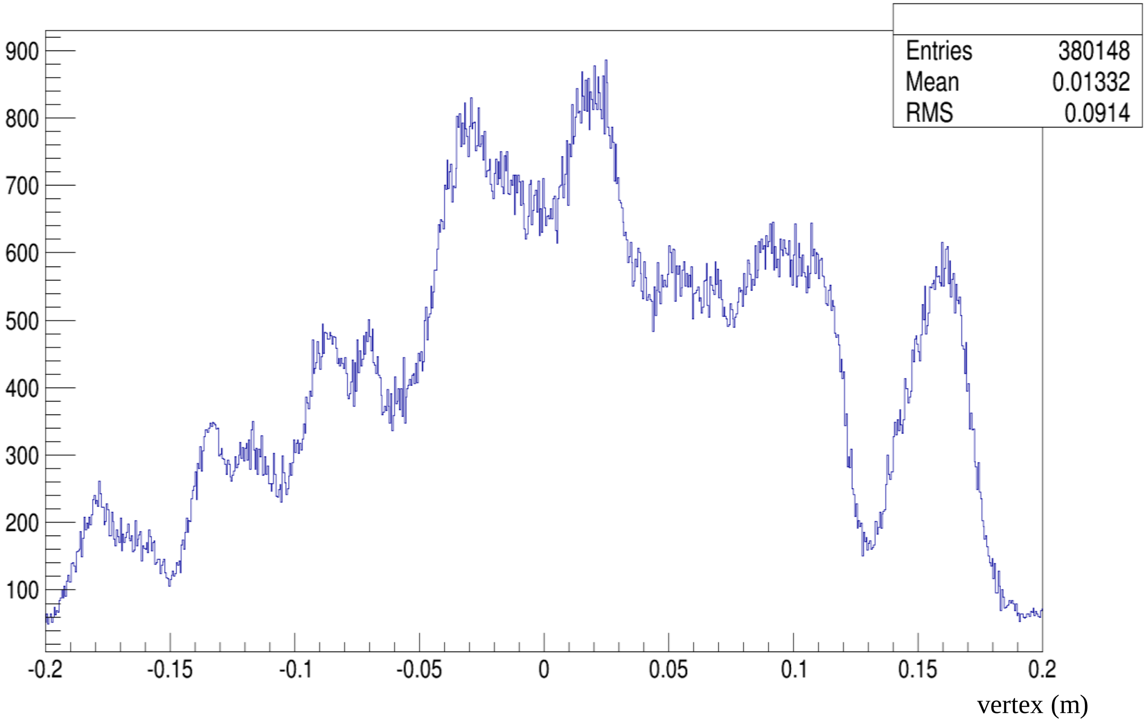
→ Computation of the new optics matrix coefficients $C_i^{Y_{jkl}}$ by minimizing:

$$\Delta(y) = \sum_s [\frac{\sum_{j,k,l} Y_{jkl} \theta_{fp}^j y_{fp}^k \phi_{fp}^l - y_{tg}^0}{\sigma_y^s}]^2$$

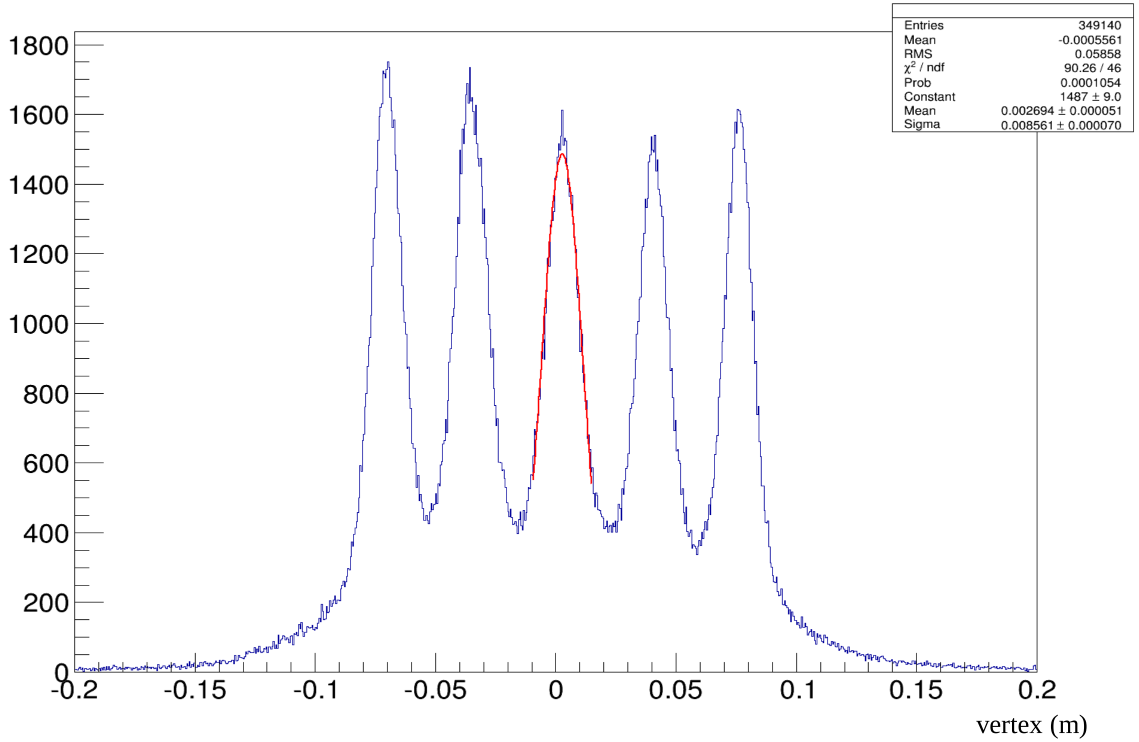
(aberration function)

Step 1 – optimization of the vertex reconstruction

Vertex reconstruction



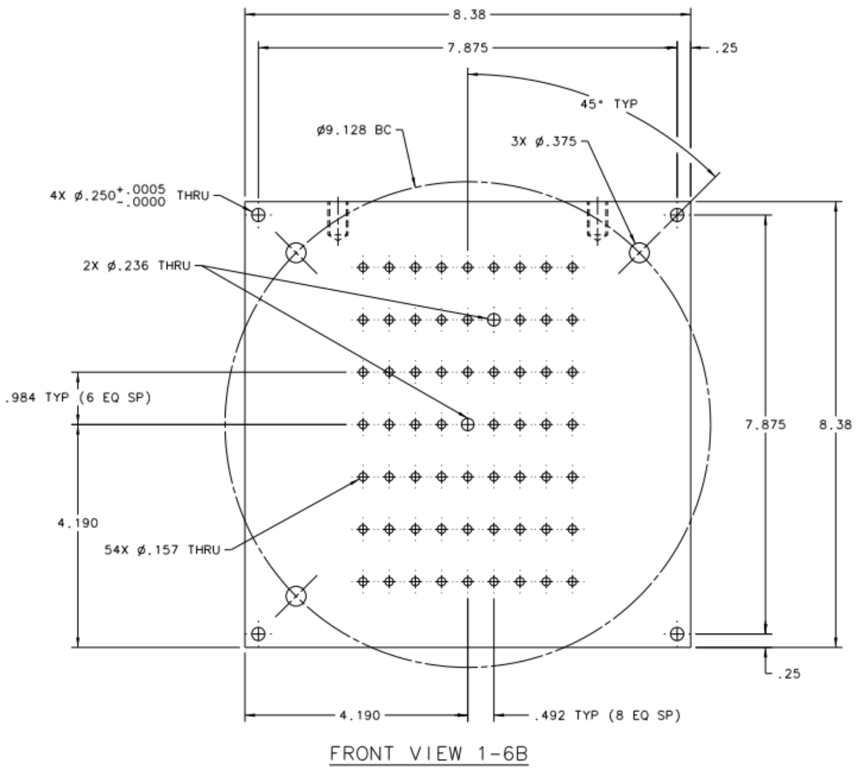
Before optimization

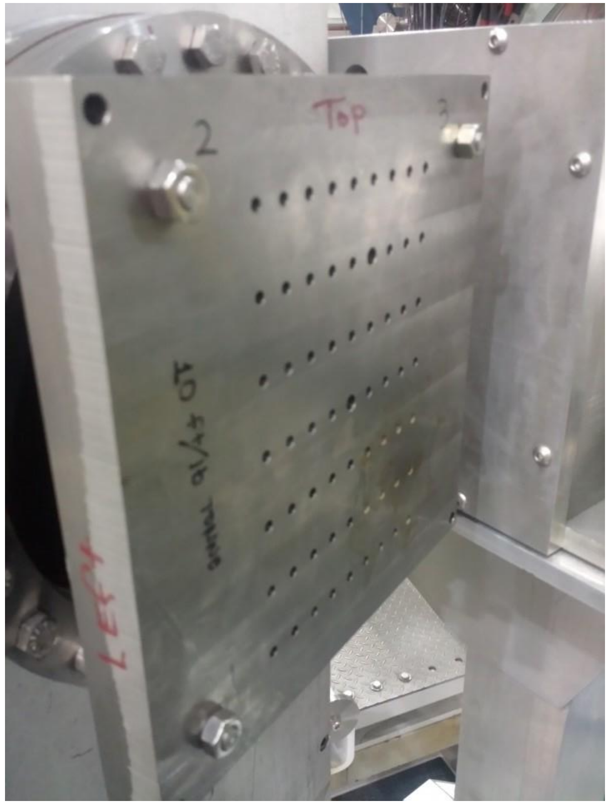


After optimization

Step 2 – optimization of angles reconstruction

- Data taken on a 5 thin carbon foils target (1mm thick)
- Thick metal plate with holes inserted in front of the LHRS entrance (Sieve)





Step 2 – optimization of angles reconstruction

- Data taken on a 5 thin carbon foils target (1mm thick)
- Thick metal plate with holes inserted in front of the LHRS entrance (Sieve)

→ Holes = expected values for angles θ_{tg} and ϕ_{tg}

→ Computation of new optics matrix coefficients by minimization of aberration function.

Step 3 – optimization of the momentum reconstruction

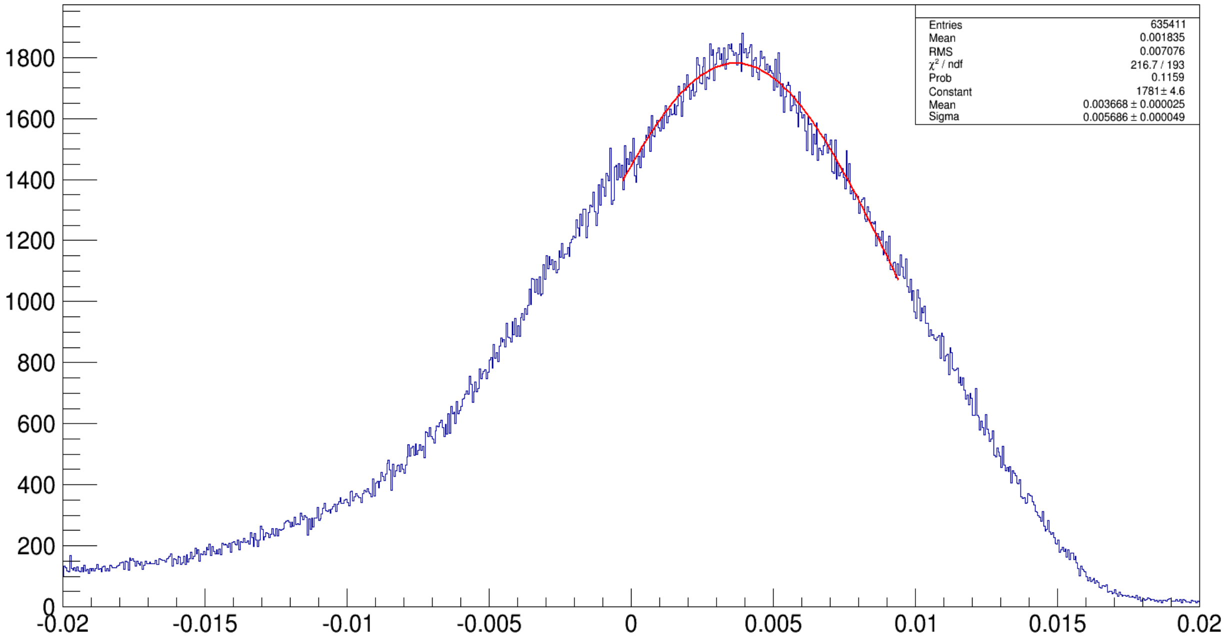
- Data taken on an LH_2 target, elastic scattering ep → ep setting
  - Constrained system: known scattering angle = known scattering momentum
- Sieve out (not useful, would only decrease statistics)
- "Delta Scan"
  - LHRS angle fixed
  - 5 runs varying central momentum setting (central momentum, ± 2%, ± 4%)
    - Central momentum selection made by varying magnetic fields
    - Because of elastic momentum-scattering angle correlation, need to "move" central ray to illuminate whole focal plane

→ Expected values for momentum δ_{tg}

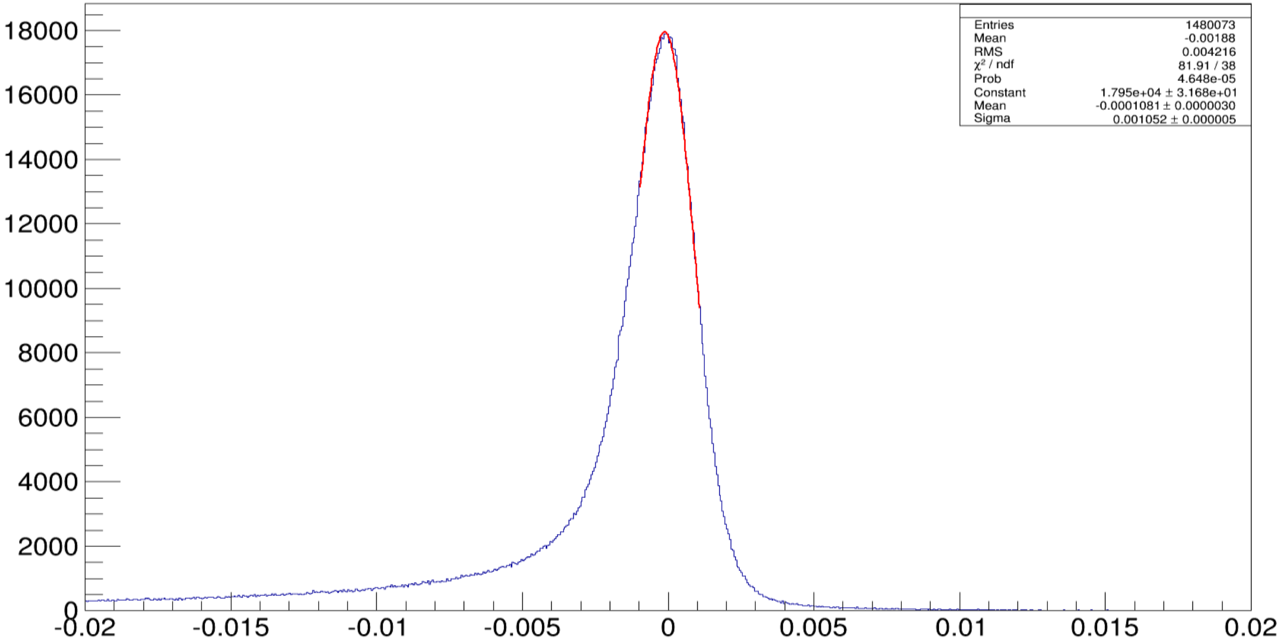
→ Computation of new optics matrix coefficients by minimization of aberration function.

Step 3 – optimization of the momentum reconstruction

Relative momentum dp/p reconstruction



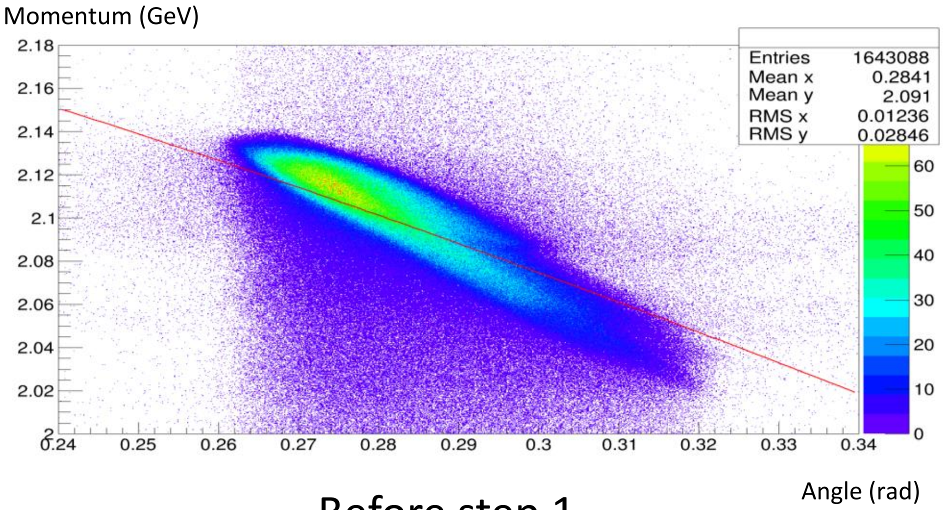
Before optimization



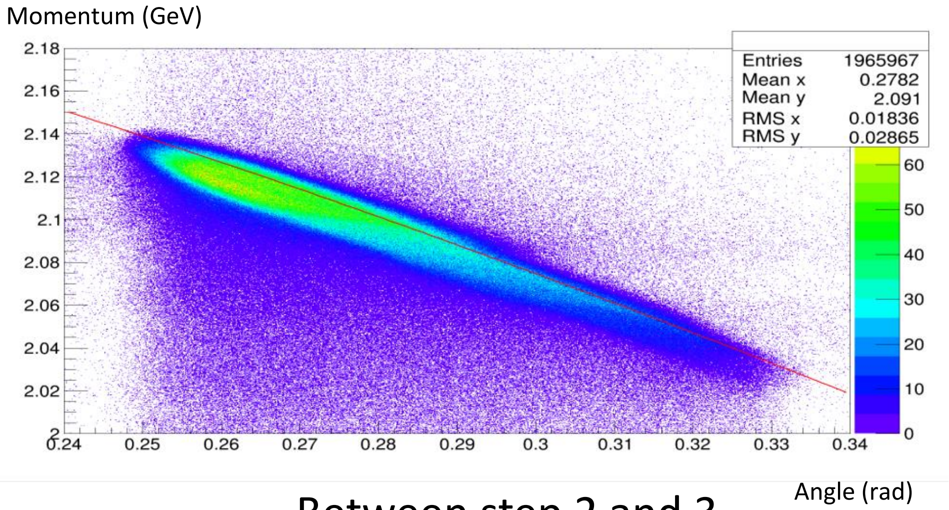
After optimization

Step 1, 2 and 3 – optimization of all 4 variables reconstruction

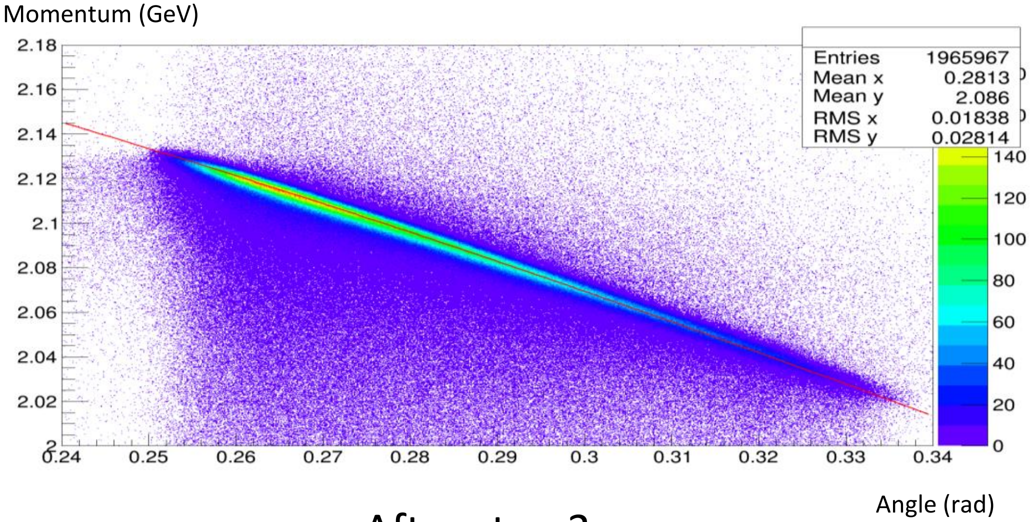
Elastic line: momentum – scattering angle



Before step 1



Between step 2 and 3



After step 3

Conclusion and outlook

- DVCS experiment was running Winter/Spring 2016. Will come back Fall 2016.
- Spectrometer optics calibration almost complete (small corrections).
- However, still needs a thorough acceptance study.
- And a lot more, done by the DVCS collaboration…

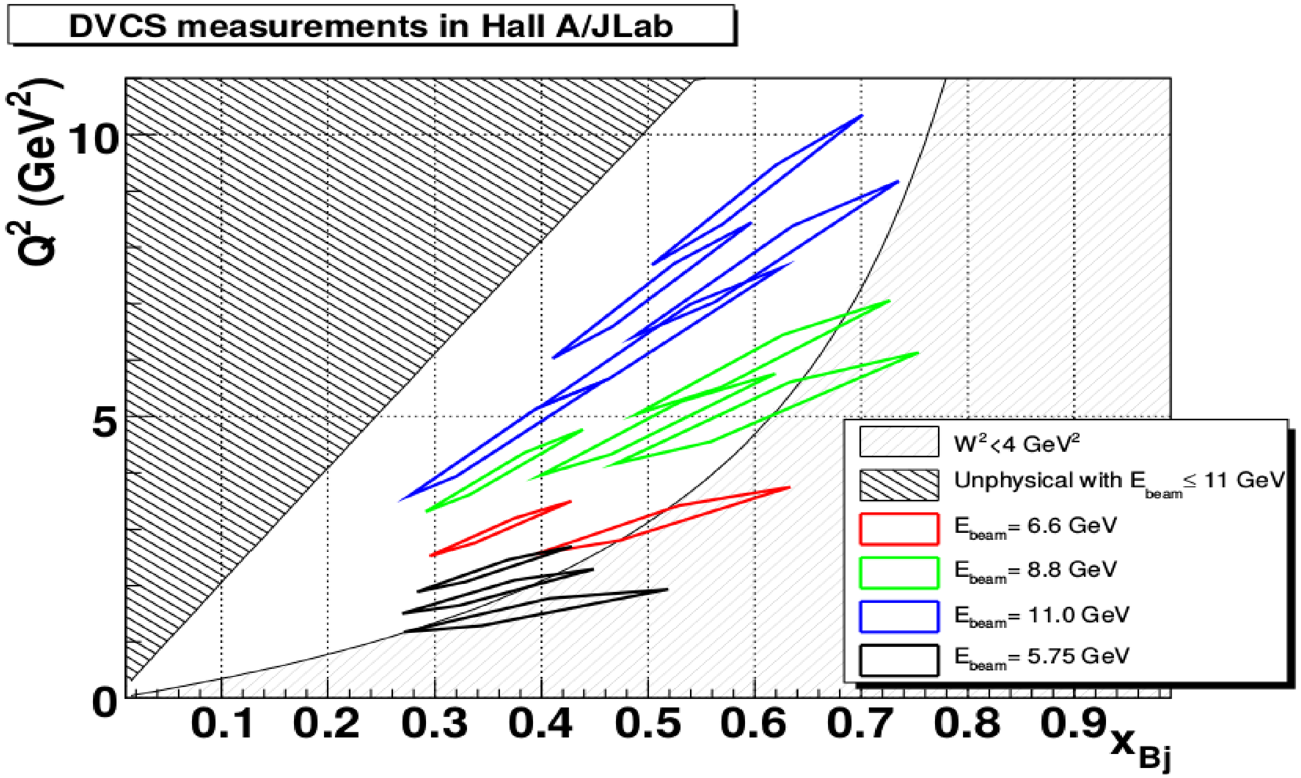
- Long term: DVCS cross-sections extraction

Thank you for your attention!

Questions ?

Annexes

DVCS experiment (Q^2,x_B) phase space



$W^2 = (p + q)^2$ invariant mass of the hadronic final state.

From DVCS cross-section to GPDs

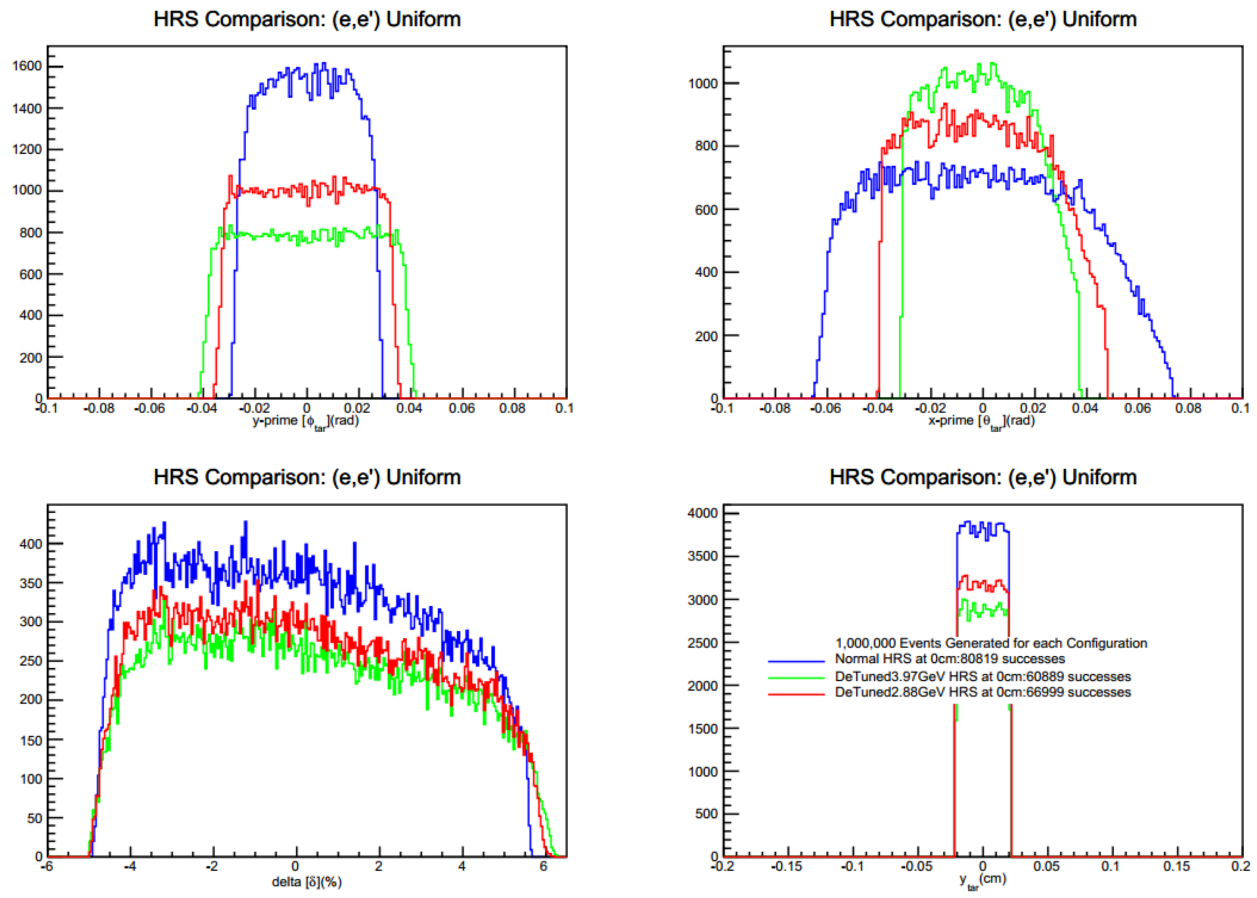
DVCS cross-section is parametrized by GPDs, but integrated other x. We cannot directly extract GPDs from DVCS cross-section.

Extracted cross-section is proportional to $|BH|^2 + |DVCS|^2$ + Interference

- BH term: QED, well known and computed
- DVCS term: parametrized by bilinear combination of Compton Form Factors
  - Compton Form Factors are defined from GPDs combinations, integrated other x. Dependence on ξ and t.
  - Gives access to Compton Form Factors modulus
  - Needs several values of Q^2 and x_B to extract them
- Interference term: parametrized by real and imaginary parts of Compton Form Factors.

- DVCS + Interference terms allow to extract Compton Form Factors, from which GPDs are then extracted.

LHRS optics - acceptance study



Simulation shows that acceptance is affected. Will need further study to fully understand the new acceptance (correlations between parameters).