Proton Deeply Virtual Compton Scattering at 10.6 GeV with CLAS12 at Jefferson Lab

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for the CLAS Collaboration

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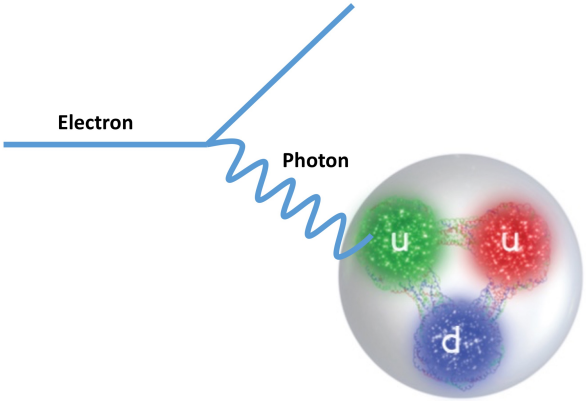
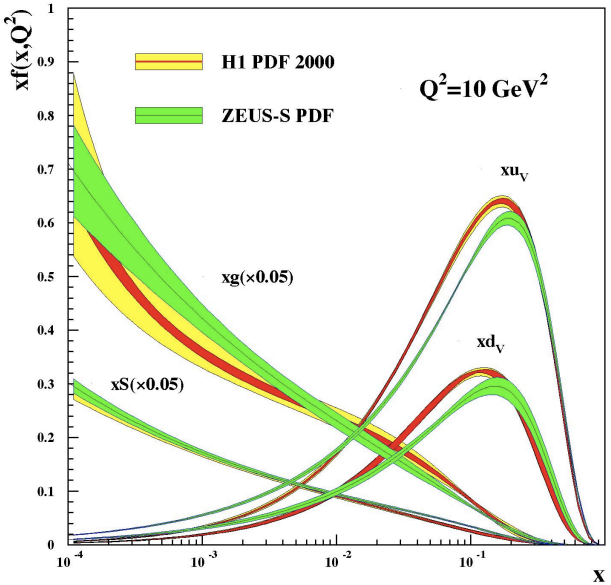
Introduction

- Scattering experiments to access the **proton structure**:
  - 1950's Form Factors: transverse spatial distributions of partons (elastic scattering)
  - 1960's Parton Distribution Functions: longitudinal momentum of partons (deep inelastic scattering)
  - 1990's **Generalized Partons Distributions (GPDs)**: correlations of longitudinal momentum and transverse position (deep exclusive processes)





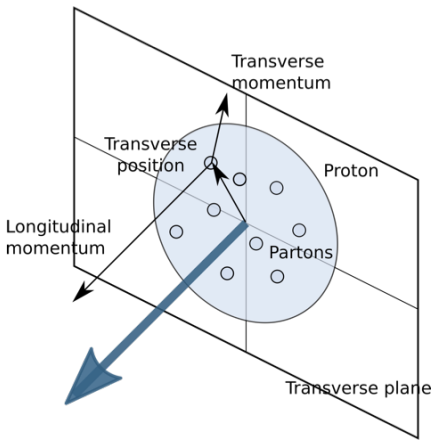
Generalized Parton Distributions

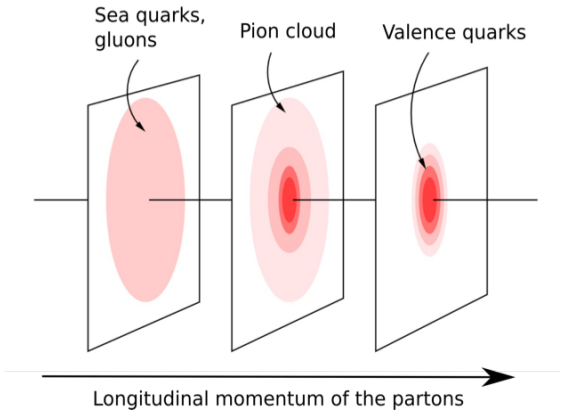
- **Tomography of the nucleon**

$$\rho(x, \vec{r_\perp}) = \int \frac{d^2\Delta_\perp}{(2\pi)^2} e^{-i\vec{\Delta_\perp}\cdot\vec{r_\perp}} H(x, \xi = 0, t = -\Delta_\perp^2)$$

Burkardt, 2003

$\Delta_\perp$ transverse momentum transfer
Distribution of longitudinal momentum x and transverse position $\vec{r_\perp}$





- Contribution of quark orbital angular momentum to the **proton spin**:

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

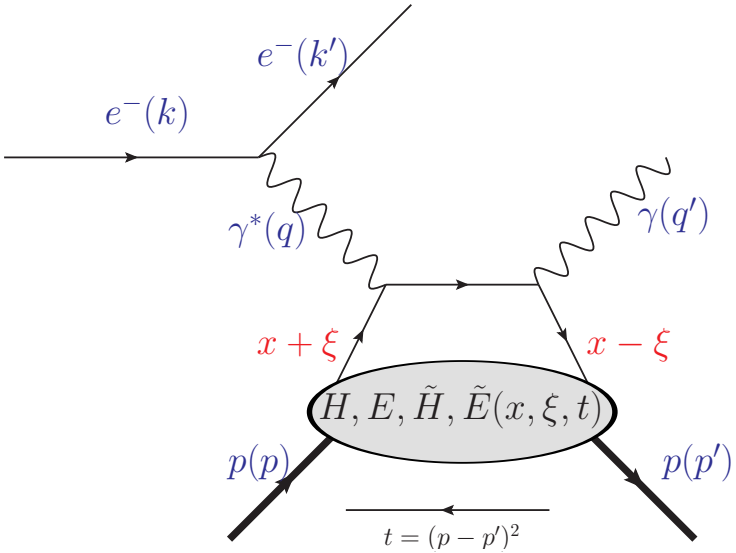
Ji, 1997

Deeply Virtual Compton Scattering

Deeply Virtual Compton Scattering

- GPDs appear in the DVCS amplitude through Compton Form Factors (CFF) such as:

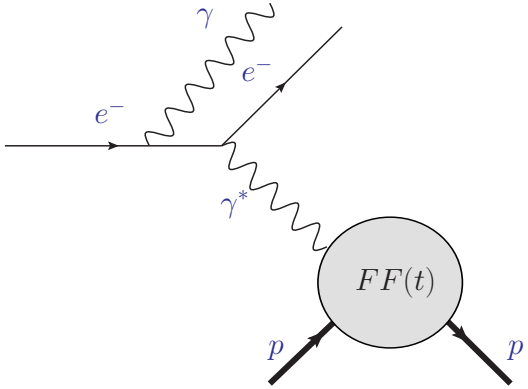
$$\mathcal{H} = \int_{-1}^{1} H(x,\xi,t)\left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right)dx$$



DVCS at leading order

- Experimentally we measure photon leptoproduction: interference of DVCS and Bethe-Heitler (BH)

$$\sigma_{(}ep \to ep\gamma) = |DVCS|^2 + |BH|^2 + Interference$$



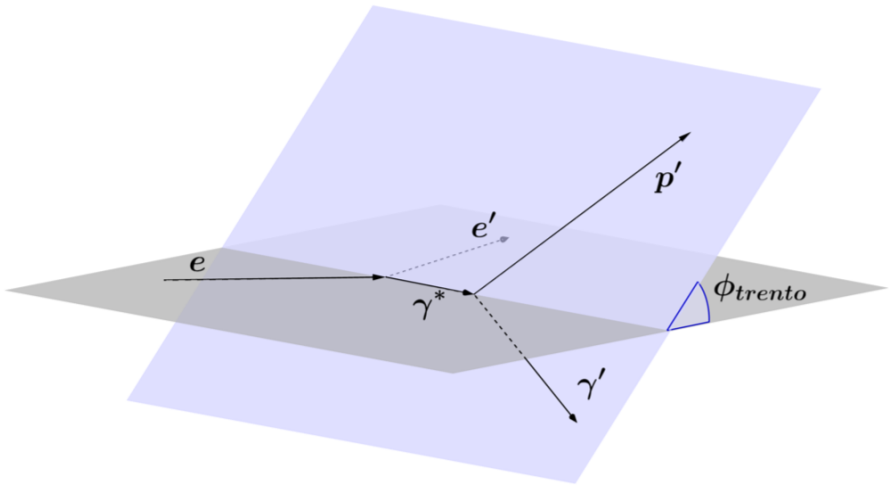
BH at leading order

Beam-spin asymmetry

- Extraction of GPDs from DVCS with polarized lepton beam and unpolarized target

- Photon leptoproduction **beam-spin asymmetry**:

$$A_{LU} = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$$



- At leading order the asymmetry is:

$$A_{LU} \simeq \frac{A \sin(\phi_{trento})}{1 + B \cos(\phi_{trento})} \qquad A = \frac{s_1^{\mathcal{I}}}{\kappa c_0^{BH} + c_0^{\mathcal{I}}} \qquad B = \frac{\kappa c_1^{BH} + c_1^{\mathcal{I}}}{\kappa c_0^{BH} + c_0^{\mathcal{I}}}$$

κ known function of kinematical variables

$c_1^{\mathcal{I}},\ c_0^{\mathcal{I}},\ s_1^{\mathcal{I}}$ combinations of CFF

$$s_1^{\mathcal{I}} \propto Im(F_1\mathcal{H} + \xi(F_1 + F_2)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E})$$

F_1, F_2 form factors

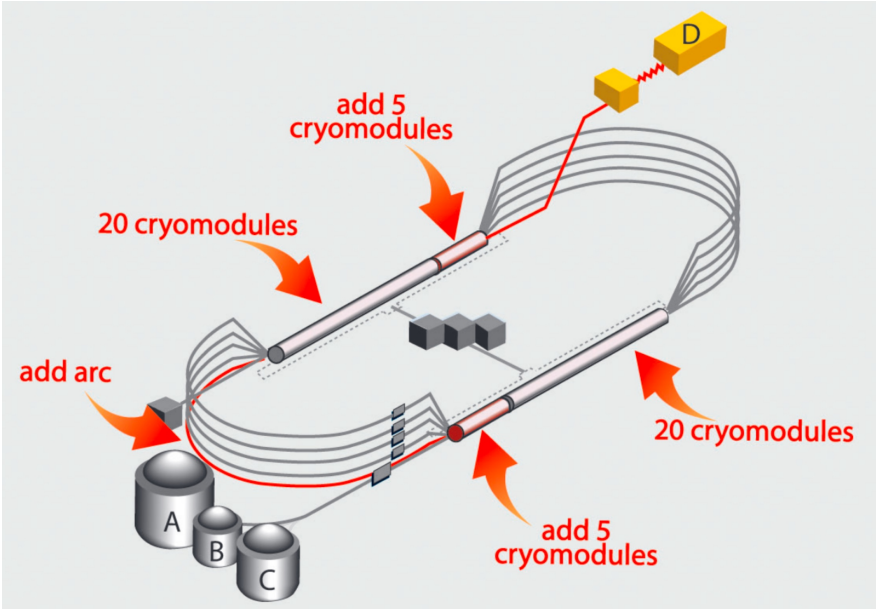
CLAS12 installation complete

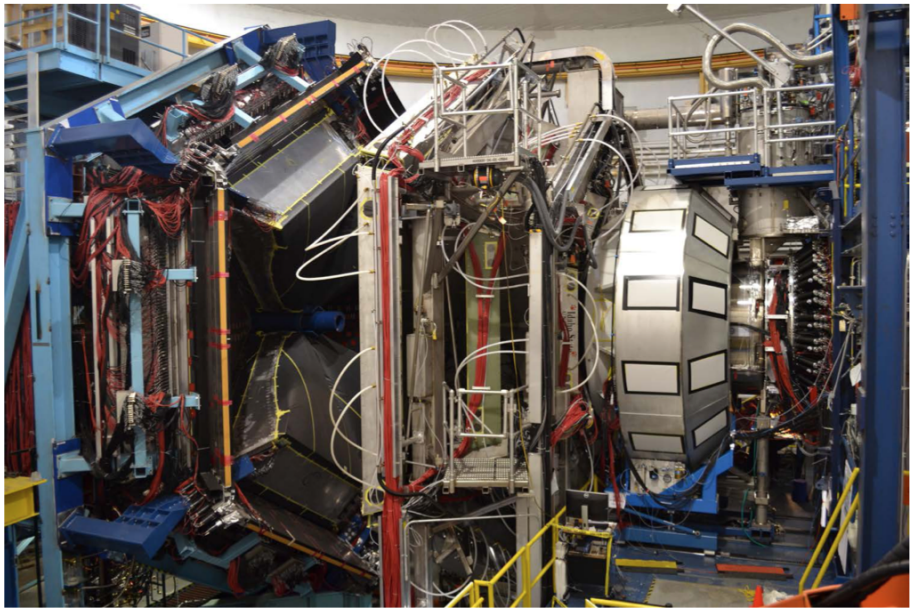
Jefferson Lab

- **CEBAF upgraded** to deliver longitudinally polarized 12GeV electron beam

CLAS12 data taking started in 2018

- **10.6 GeV electron beam**
- **Unpolarized liquid hydrogen** target





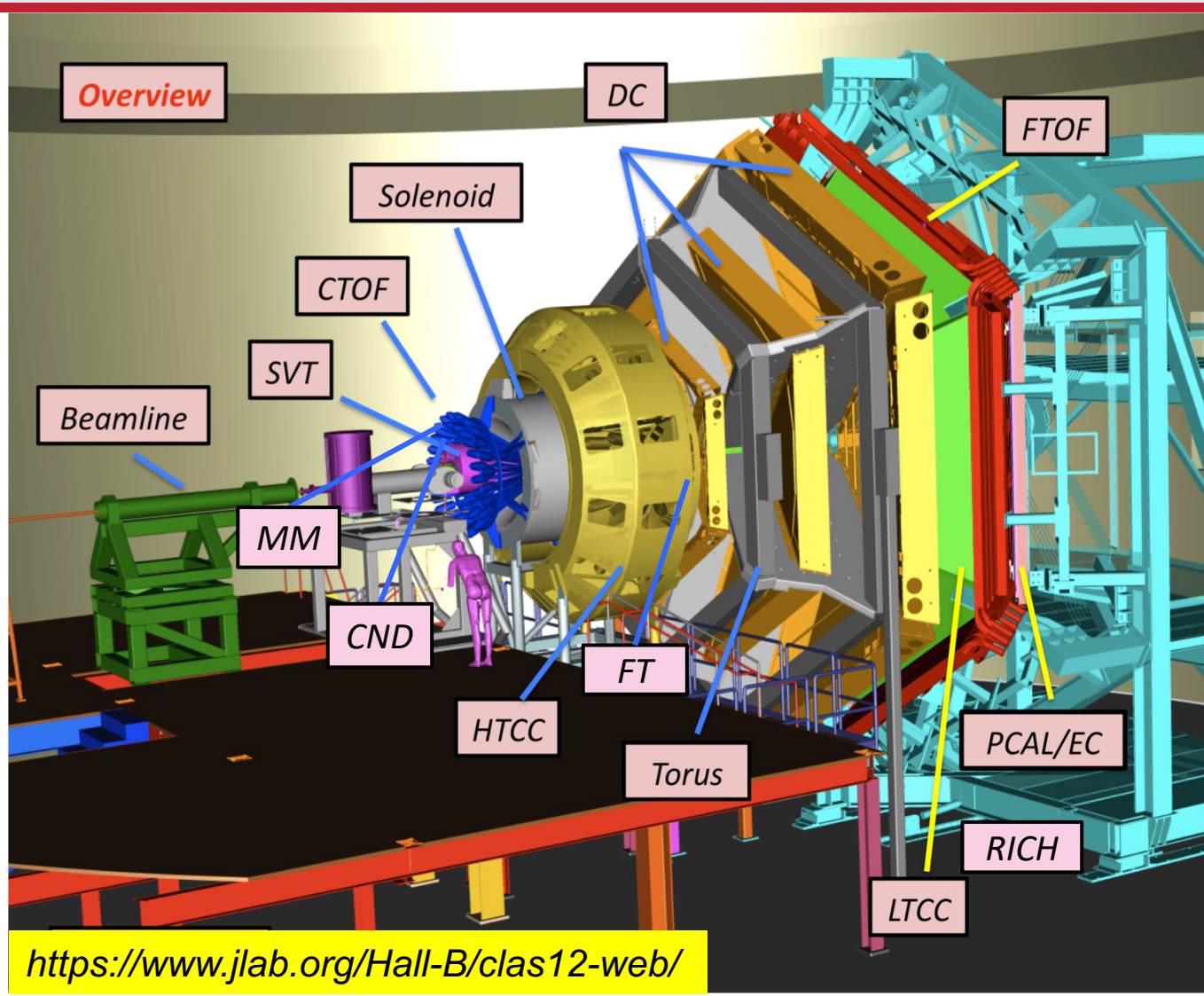
CLAS12

Forward Detector (FD):

- ***TORUS magnet***
- ***Drift chamber system***
- ***HT Cherenkov Counter***
- *LT Cherenkov Counter*
- ***Forward ToF System***
- ***Preshower calorimeter***
- ***E.M. calorimeter***
- *RICH detector*
- ***Forward Tagger***

Central Detector (CD):

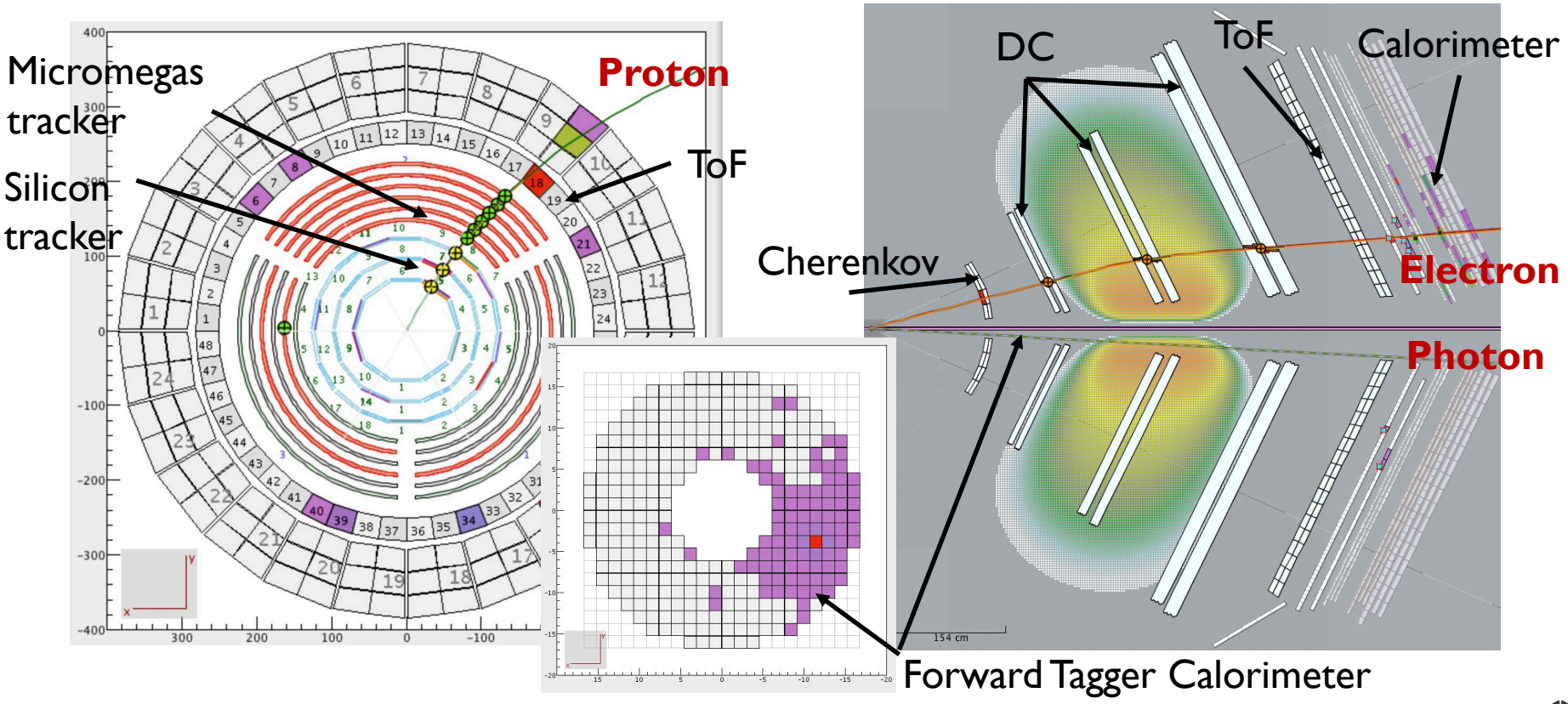
- ***SOLENOID magnet***
- ***Barrel Silicon Tracker***
- ***Micromegas***
- ***Central Time-of-Flight***
- *Central Neutron detector*



DVCS event in CLAS12

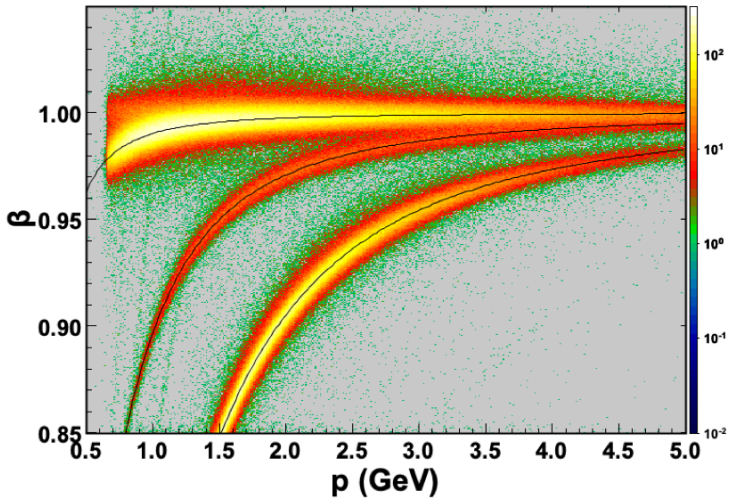
Typical DVCS event:

- Electron in the forward detector (torus, DC, ToF, Cherenkov, Calorimeter)
- Photon in the forward tagger (calorimeter)
- Proton in the central detector (solenoid, Silicon, Micromegas and ToF)



DVCS kinematics and particle selection

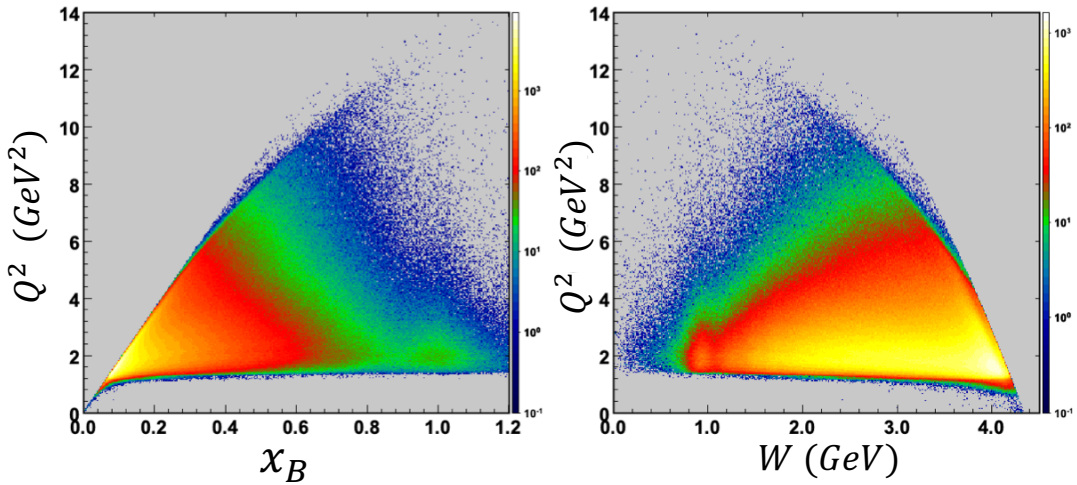
- High energy **electron**
  $E_{electron} > 2\ GeV$
- High energy **photon**
  $E_{photon} > 2\ GeV$
- **Proton**



Positive charges β vs momentum p

Kinematical cuts:

- virtuality
  $Q^2 = -q^2 > 1\ GeV^2$
- $W^2 = (p+q)^2 > 4\ GeV^2$

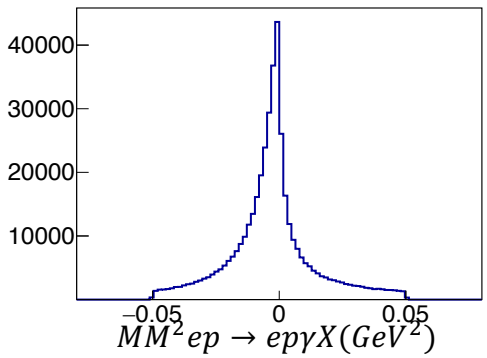


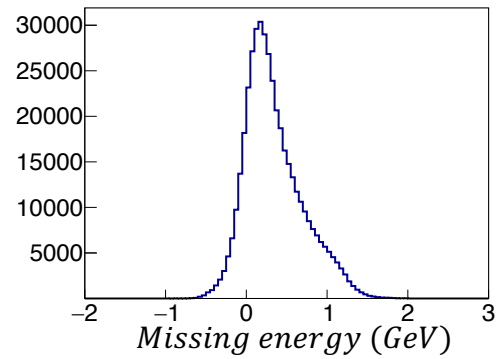
Reaction kinematics

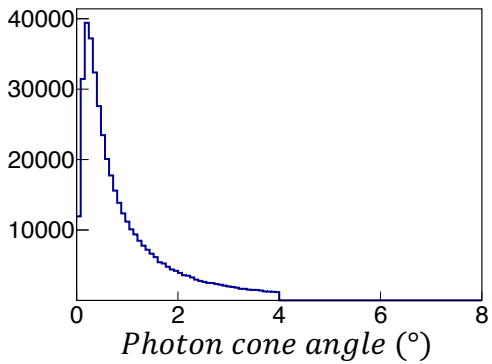
Exclusivity

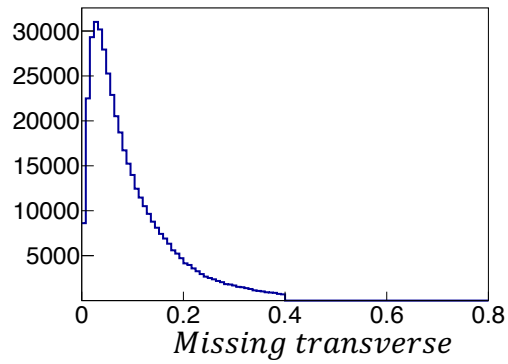
Selection of exclusive DVCS events:

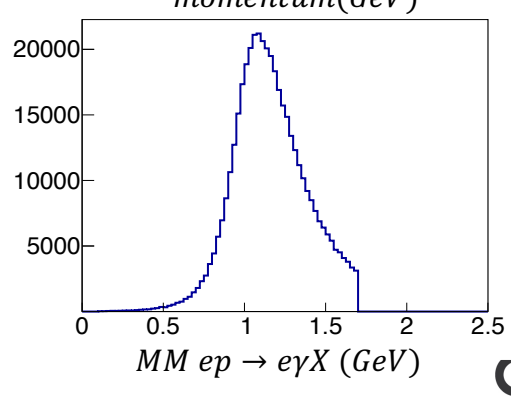
- **Missing mass**
  $ep \rightarrow ep\gamma X$
- **Missing energy**
- **Photon cone angle** (angle between measured photon and exclusive photon)
- **Missing transverse momentum**
- **Missing mass**
  $ep \rightarrow e\gamma X$











Raw beam-spin asymmetry

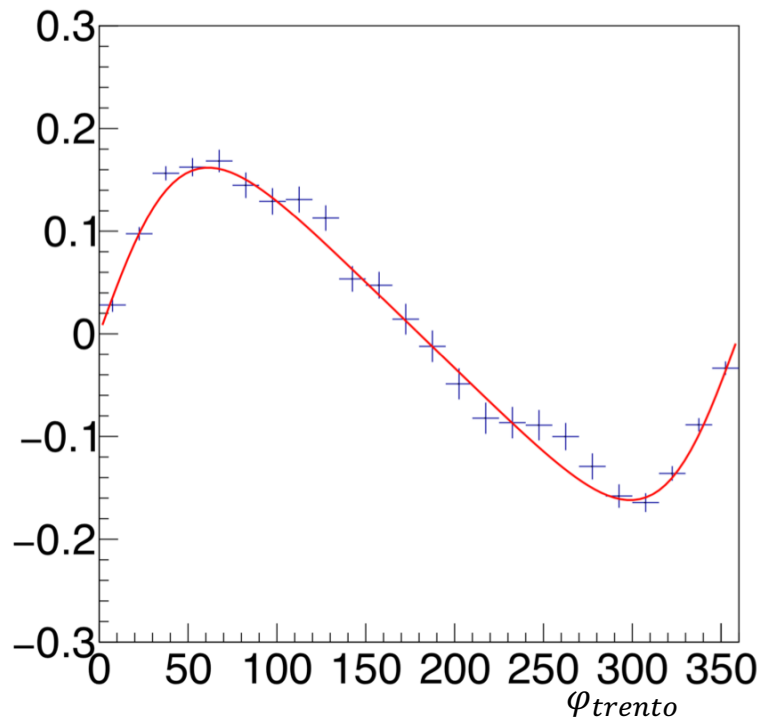
Beam-spin asymmetry:

$$A_{LU} = \frac{1}{P}\frac{N^+(\phi_{trento}) - N^-(\phi_{trento})}{N^+(\phi_{trento}) + N^-(\phi_{trento})}$$

P polarization

N^+ / N^- number of events with helicity + / -

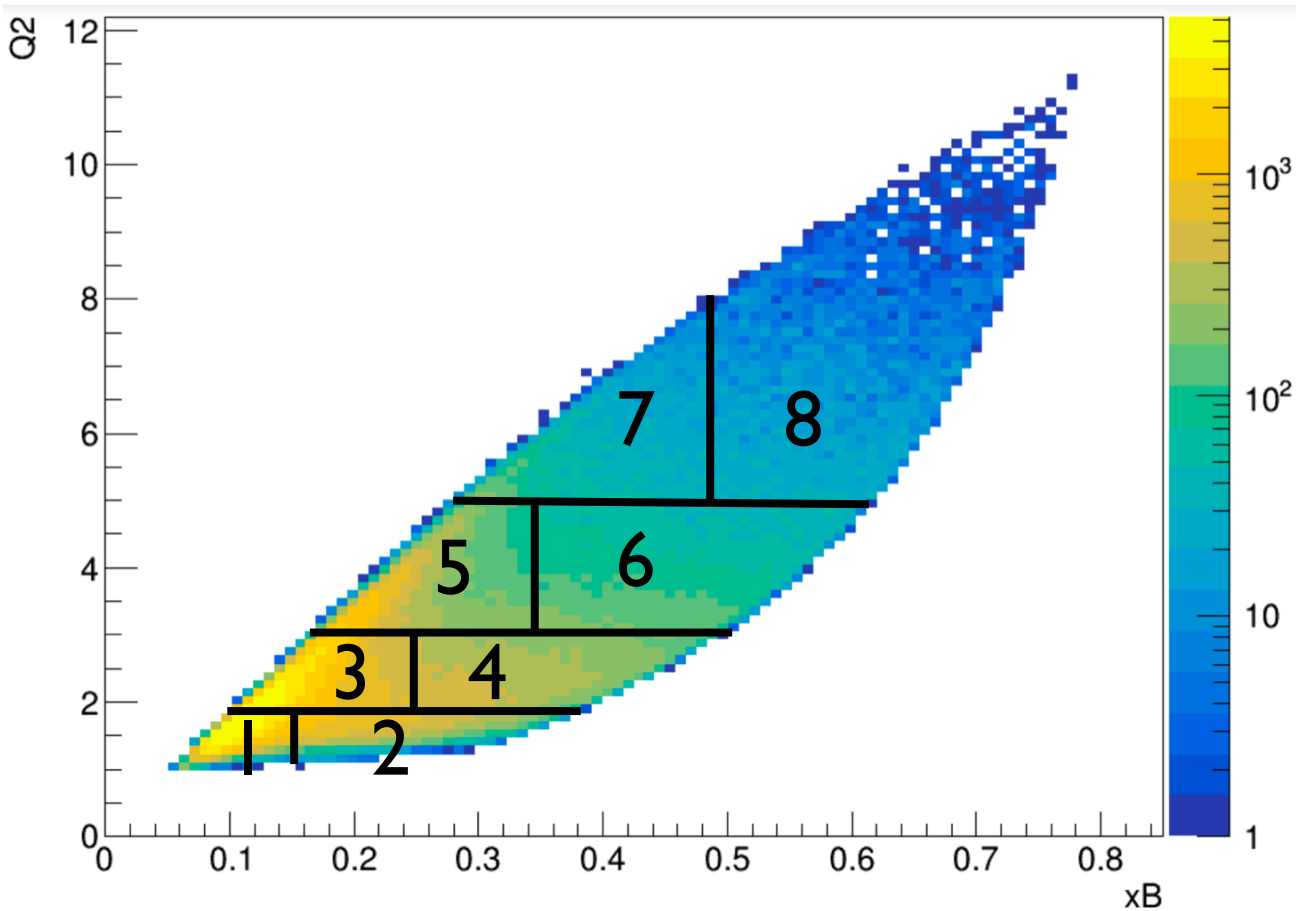
- Background
  not yet subtracted
- Only statistical errors
- Integrated over all kinematic domain



Binning

A total of 16 bins:

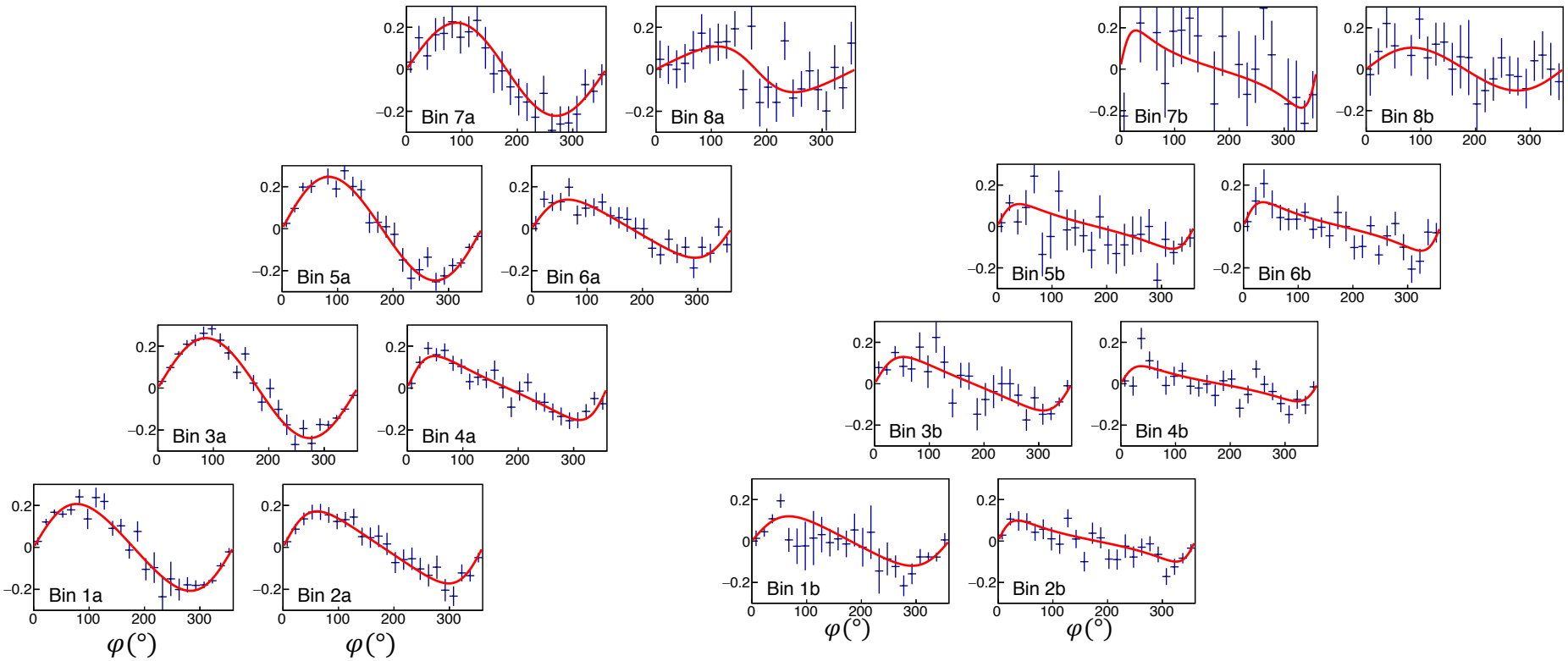
- 8 Q^2 / x_B bins:
  - Bins 1 to 8
- 2 t bins:
  - Bins a
    $-\frac{t}{Q^2} < 0.25$
  - Bins b
    $-\frac{t}{Q^2} > 0.25$



First look at beam-spin asymmetry

Raw asymmetry:

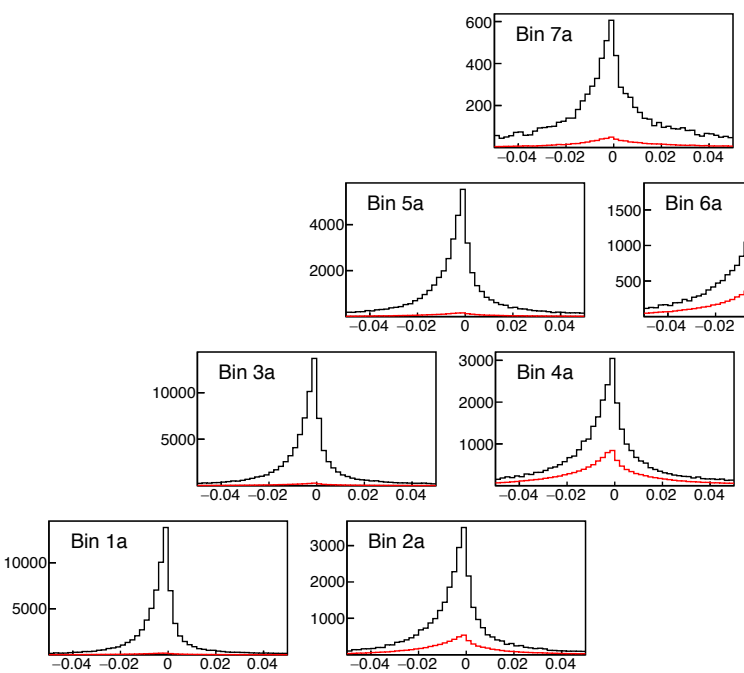
without background subtraction



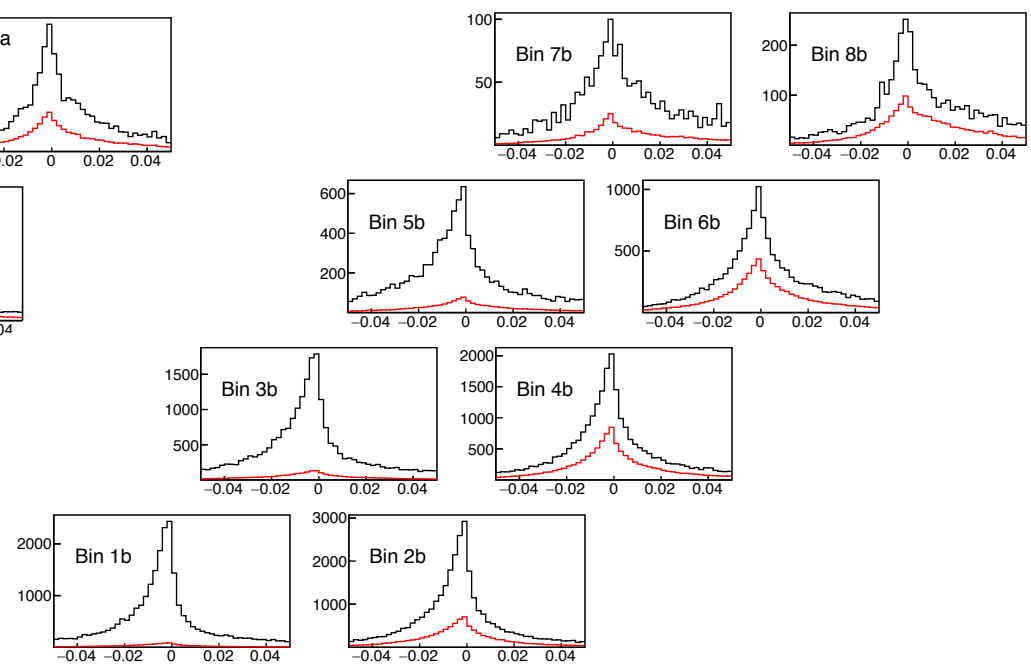
Contamination from pion background

Main source of background come from π^0electroproduction.
Estimated using π^0 from data.

Black: total DVCS candidates (after cuts)
Red: estimated π^0 contamination



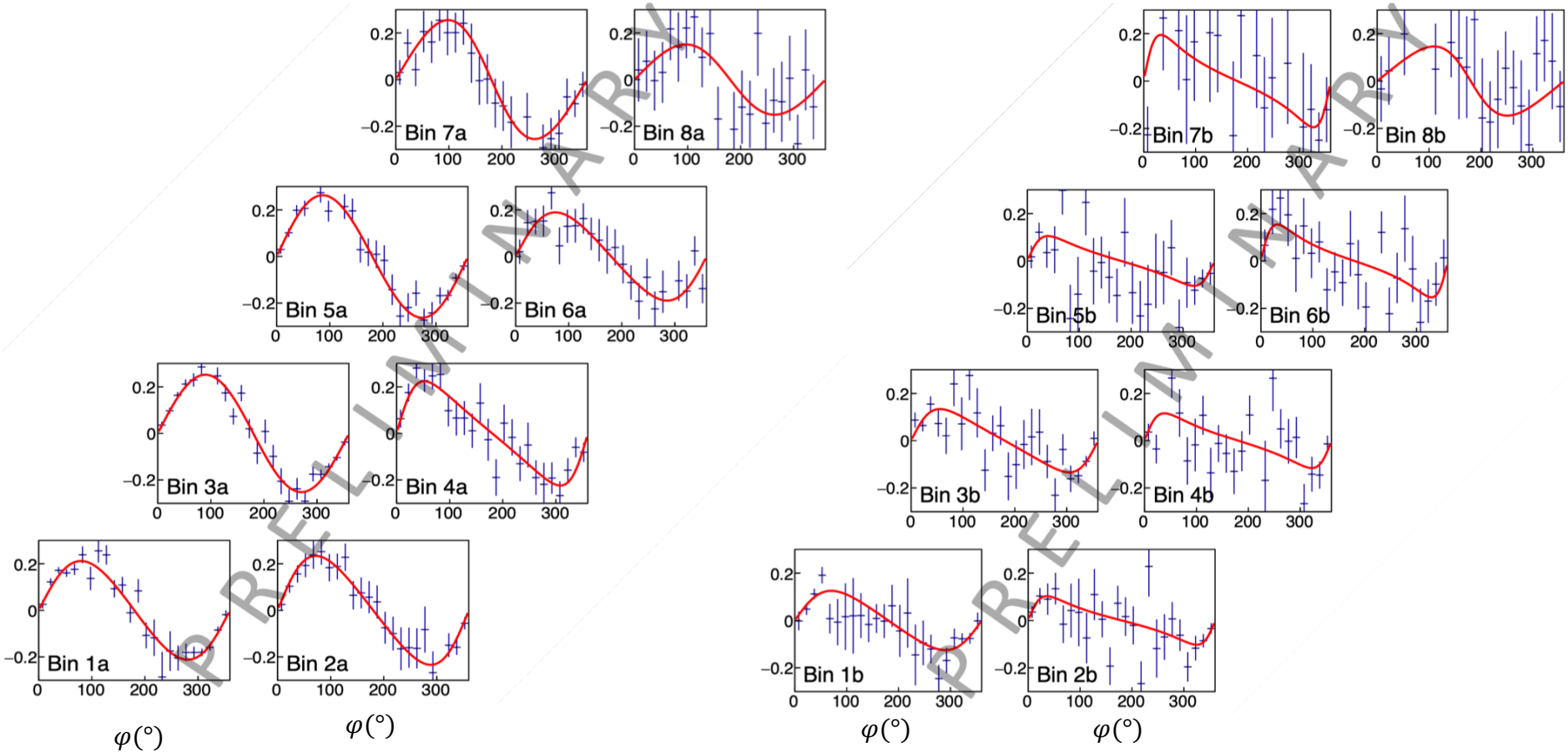
$MM^2 ep \rightarrow ep\gamma X\ (GeV^2)$



$MM^2 ep \rightarrow ep\gamma X\ (GeV^2)$

Subtracted beam-spin asymmetry

Subtracted asymmetry:
after pion subtraction



Summary and outlook

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- Data shown correspond to about 6% of approved beam time
  - more bins
- Preliminary beam-spin asymmetry taking into account pion contamination
- Work still ongoing:
  - Fiducial cuts
  - Exclusivity cuts
  - Systematics