DVCS on a polarised proton target at CLAS12

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On behalf of the CLAS collaboration

Introduction

- **Outstanding question : How does the nucleon's mass and spin arise from partons ?**

- First step is to map out the nucleon

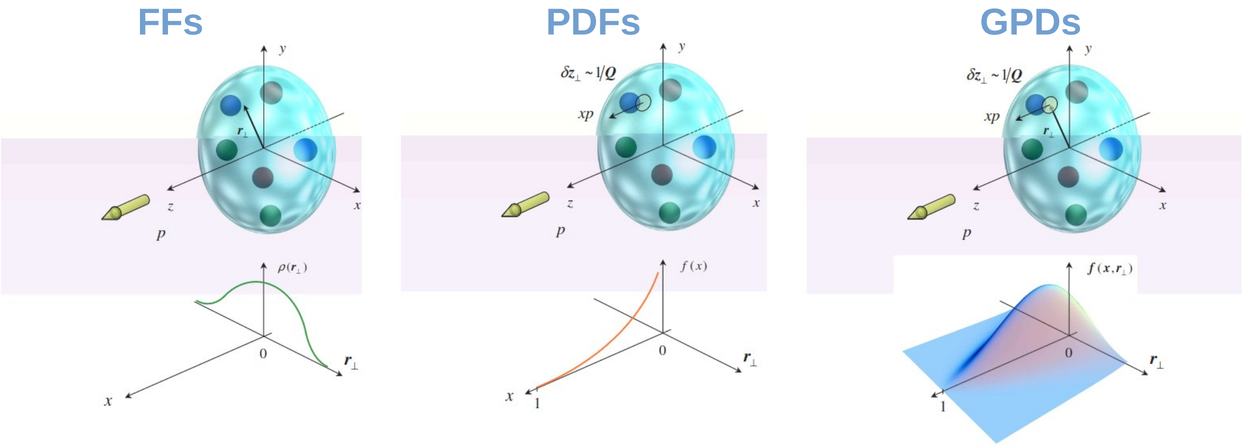
- **GPDs** describe the longitudinal momentum and transverse position of partons in the nucleon

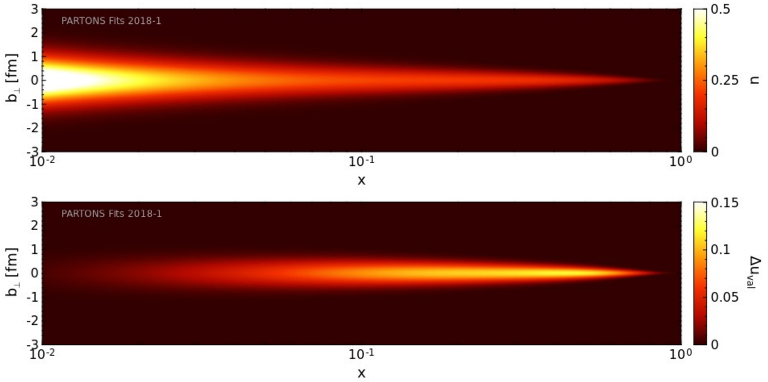
3D structure

$$\frac{1}{2} = \sum_q J^q + J^g$$
$$= \sum_q \frac{1}{2} \int_{-1}^{1} \mathrm{d}x\, x(H^q(x,\xi,0) + E^q(x,\xi,0)) + \frac{1}{2} \int_{-1}^{1} \mathrm{d}x\, H^g(x,\xi,0) + E^g(x,\xi,0)$$

→ Access to the spin decomposition of the nucleon

→ Access to its mechanical properties





[arXiv:hep-ph/0504030] [arXiv:1807.07620]

Deeply Virtual Compton Scattering

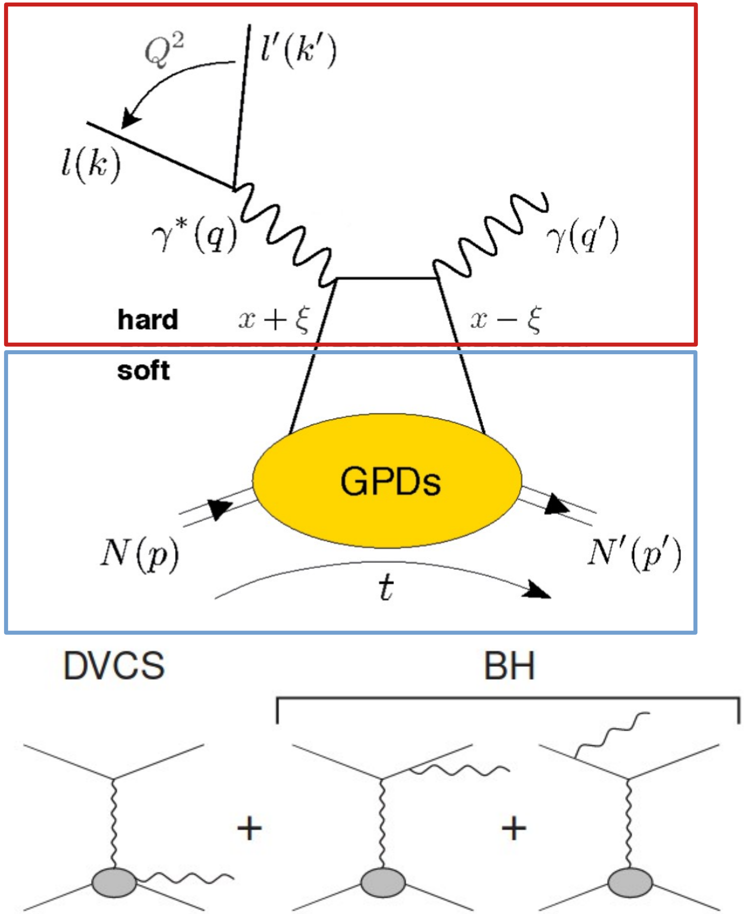
- DVCS offers the most straightforward access to GPDs
- DVCS can be **factorised** into :
  - **Hard part** ɣ*q scattering computed in perturbative QCD
  - **Soft part** described by 4 GPDs H, H̃, E, Ẽ at leading order & twist
- Two indistinguishable processes, DVCS and Bethe-Heitler

$$|T|^2 = |T_{\text{DVCS}}|^2 + |T_{\text{BH}}|^2 + \underbrace{T_{\text{DVCS}}T^*_{\text{BH}} + T^*_{\text{DVCS}}T_{\text{BH}}}_{\text{I}}$$

Amplitude is expressed as a function of FFs and CFFs which are functions of GPDs

$$\mathcal{F} = \int_{-1}^{1} dx F(\mp x, \xi, t) \left[\frac{1}{x - \xi + i\epsilon} \pm \frac{1}{x + \xi - i\epsilon} \right]$$

[d'Hose2016]



Observables

- Asymmetries in the DVCS cross section are sensitive to CFFs
- Beam spin asymmetry (BSA), polarised electron and unpolarised proton

$$A_{\mathrm{LU}}(\phi) \sim \frac{s^{\mathcal{I}}_{1,\mathrm{unp}} \sin\phi}{c^{\mathrm{BH}}_{0,\mathrm{unp}} + (c^{\mathrm{BH}}_{1,\mathrm{unp}} + c^{\mathcal{I}}_{1,\mathrm{unp}} + ...)\cos\phi ...}$$

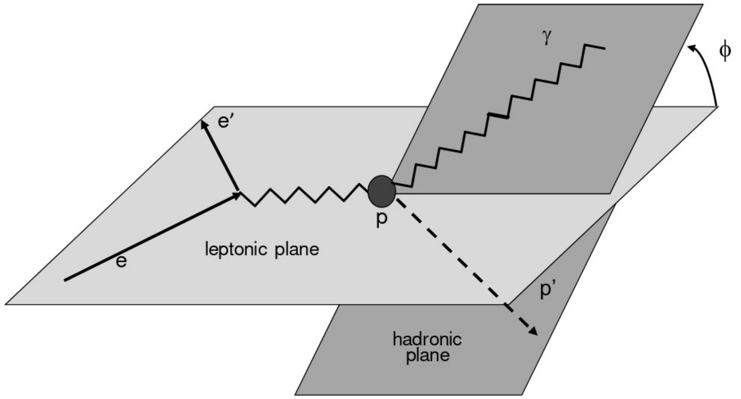
$$s^{\mathcal{I}}_{1,\mathrm{unp}} \propto \Im\mathrm{m}[F_1\mathcal{H} + \xi(F_1 + F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}].$$

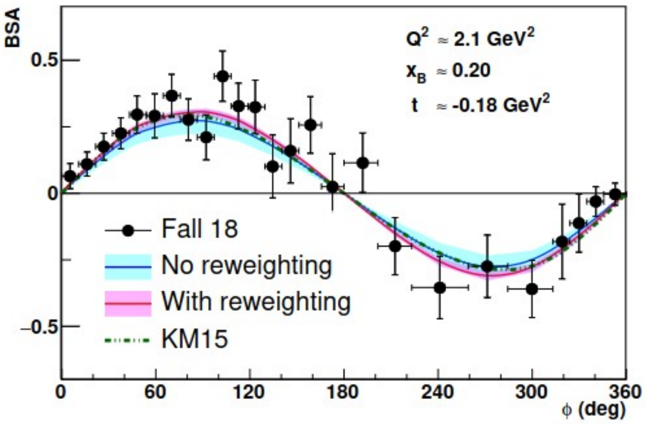
- Target spin asymmetry (TSA), unpolarised electron and polarised proton

$$A_{\mathrm{UL}}(\phi) \sim \frac{s^{\mathcal{I}}_{1,\mathrm{LP}} \sin\phi}{c^{\mathrm{BH}}_{0,\mathrm{unp}} + (c^{\mathrm{BH}}_{1,\mathrm{unp}} + c^{\mathcal{I}}_{1,\mathrm{unp}} + ...)\cos\phi + ...}$$

$$s^{\mathcal{I}}_{1,\mathrm{LP}} \propto \Im\mathrm{m}[F_1\widetilde{\mathcal{H}} + \xi(F_1 + F_2)(\mathcal{H} + \frac{x_b}{2}\mathcal{E}) - \xi(\frac{x_b}{2}F_1 + \frac{t}{4M^2}F_2)\widetilde{\mathcal{E}}]$$

- Both are sensitive to the imaginary part of the H and H̃ CFFs, measuring both is essential to separate the two contributions.

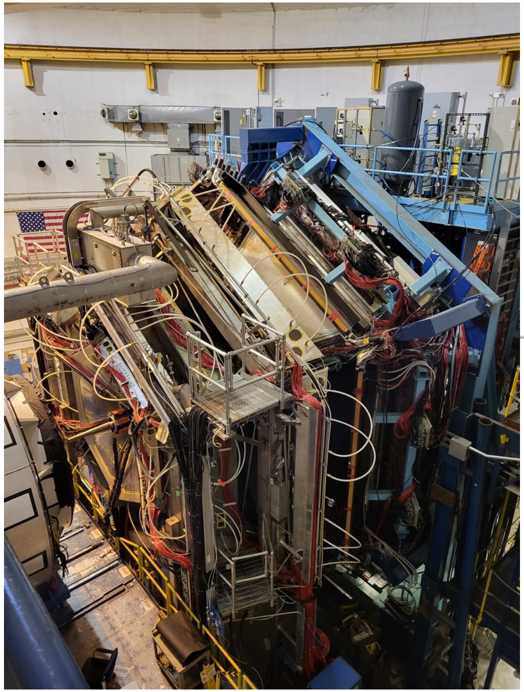


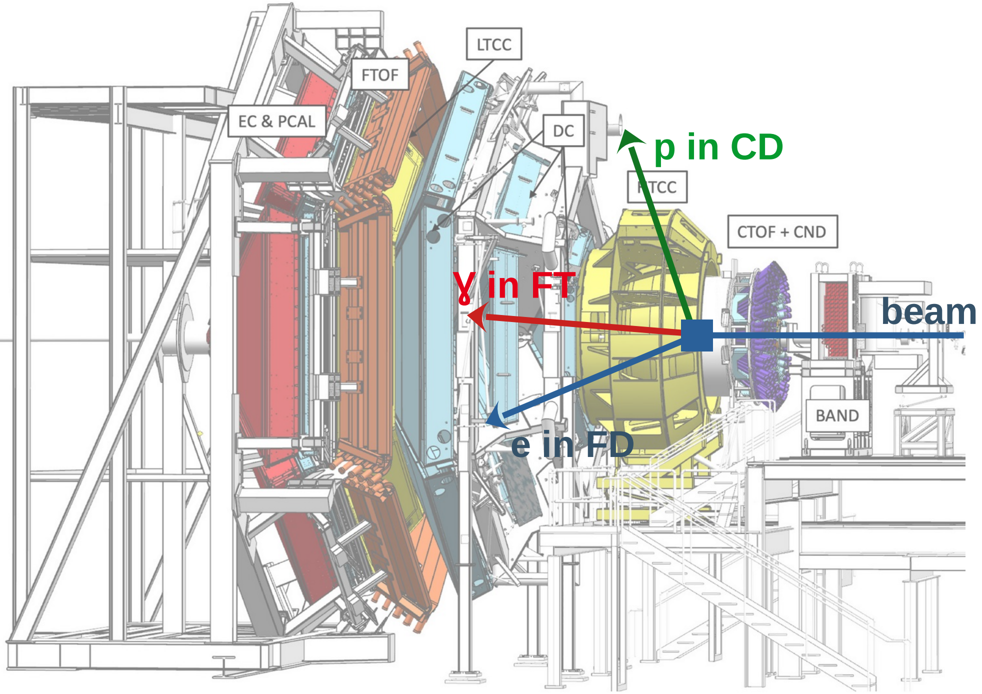


[arXiv:2211.11274]

CLAS12 @ Jefferson Lab

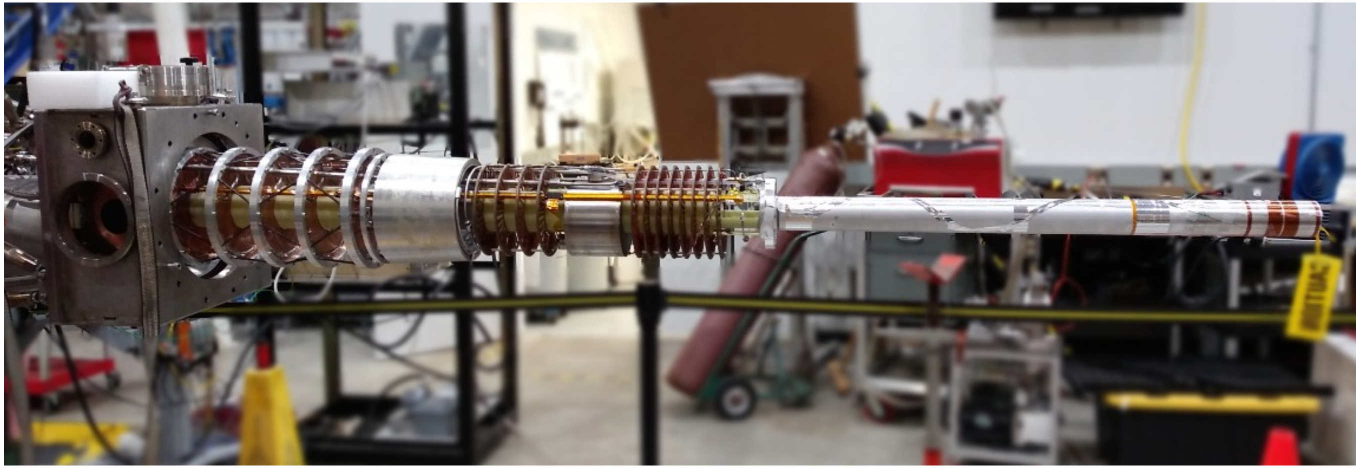
- CEBAF: 12GeV electron beam with very high polarisation ~85%
- CLAS12 is a large acceptance spectrometer → we can measure all the final state particles

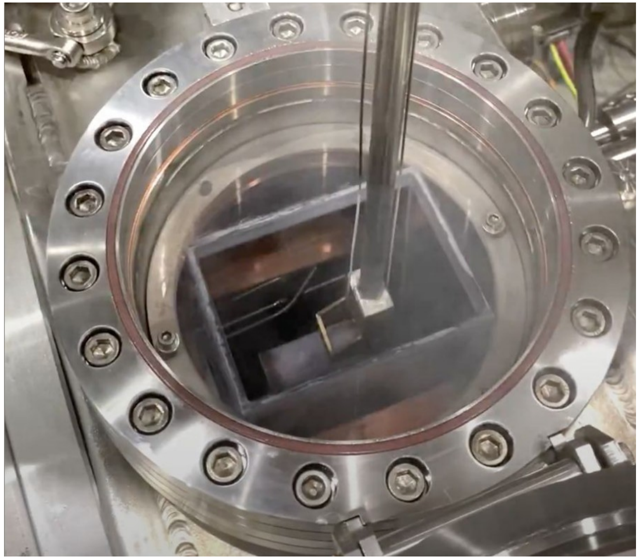




The RGC experiment

- New polarised target APOLLO, cryogenic solid target
- Polarises hydrogen or deuterium in NH_3 or ND_3 cells
- Took data from June 2022 to March 2023 in multiple run periods
- In this analysis ~50% of the DVCS statistic is available
- **Goal of this analysis: Measure BSA, TSA and DSA on polarised proton**

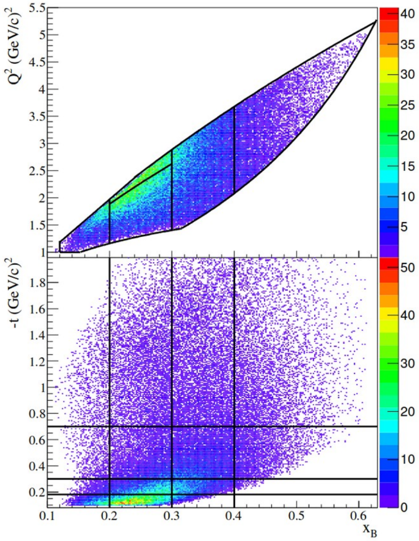


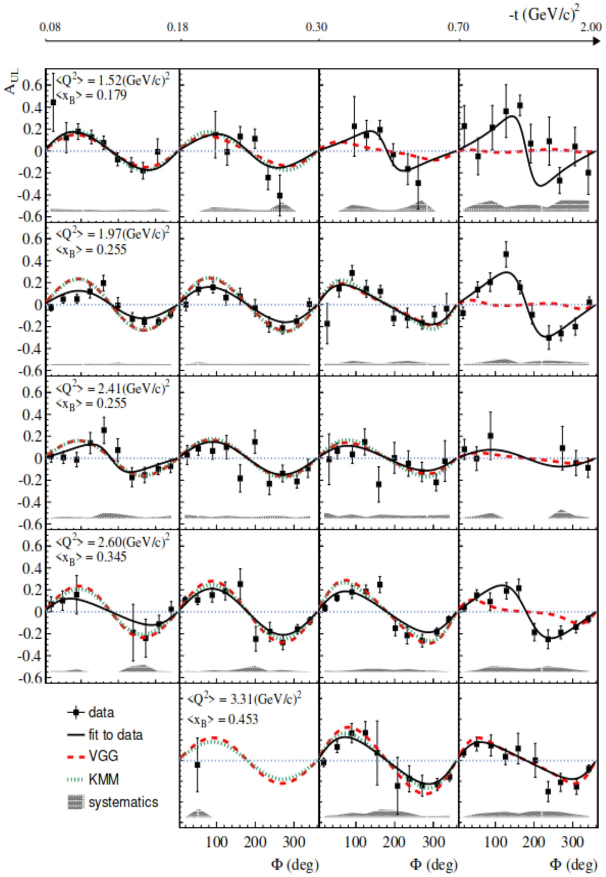


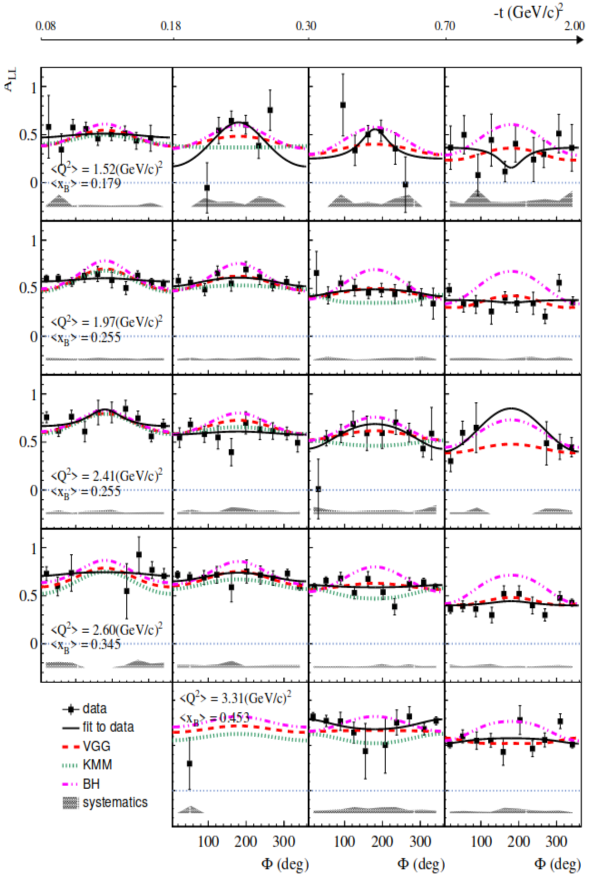
[DOI: 10.25777/36yz-ft35]

Previous CLAS6 measurement

- In 2009 data taken at CLAS on a polarised proton target with JLab 6GeV
- Measurement of the BSA, TSA and DSA in JLab6 kinematics
- RGC can expand the phase space probed with the Jlab 12GeV and CLAS12 upgrades



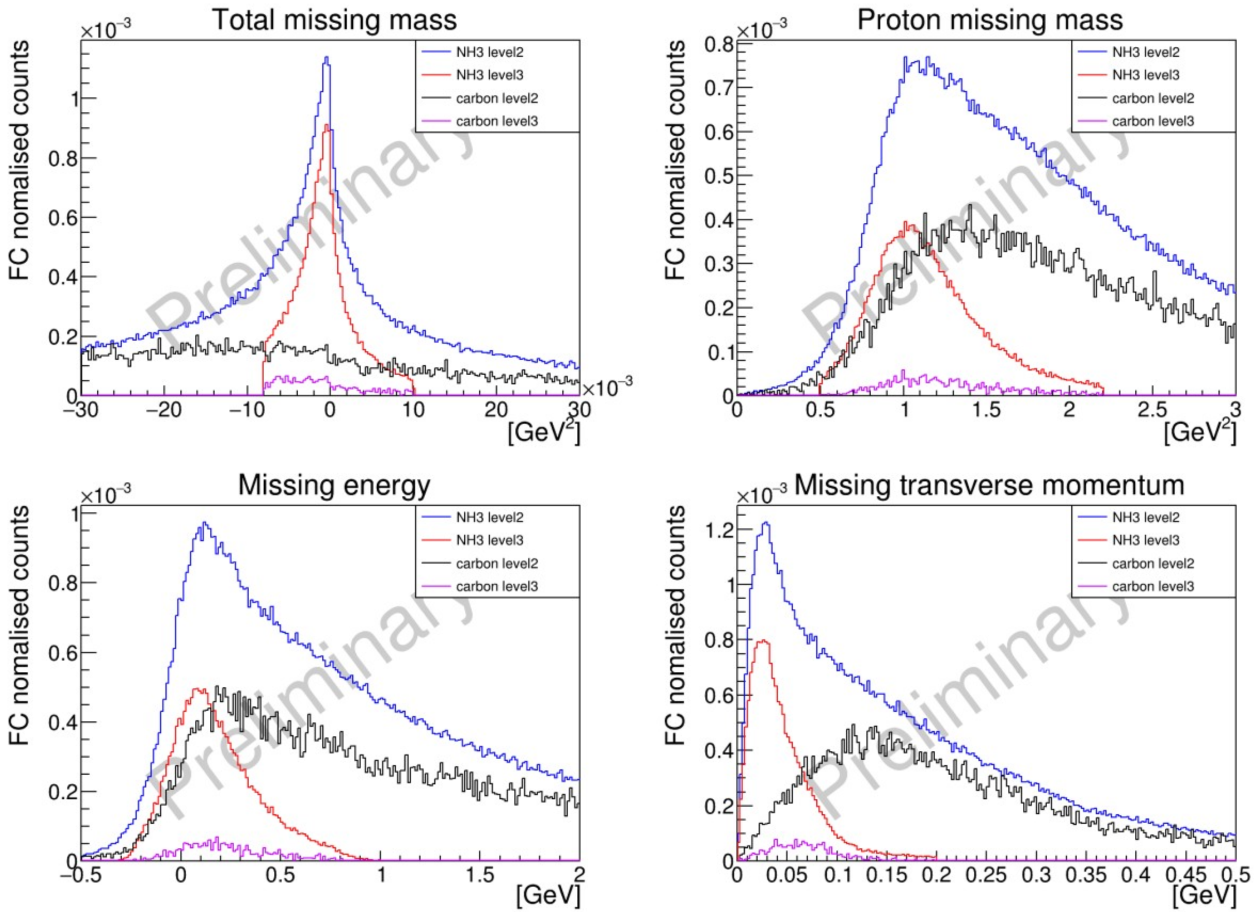




[arXiv:1501.07052]

DVCS Event selection

- The event must have at least one electron one proton and one photon
- Apply particle identification and fiducial cuts
- Nuclear background due to the unpolarised nitrogen in the target
  - Data taken on Carbon target to estimate the background
- Exclusive process → exclusivity variables
- Apply exclusivity cuts to remove as much of the nuclear background as possible



Measuring asymmetries

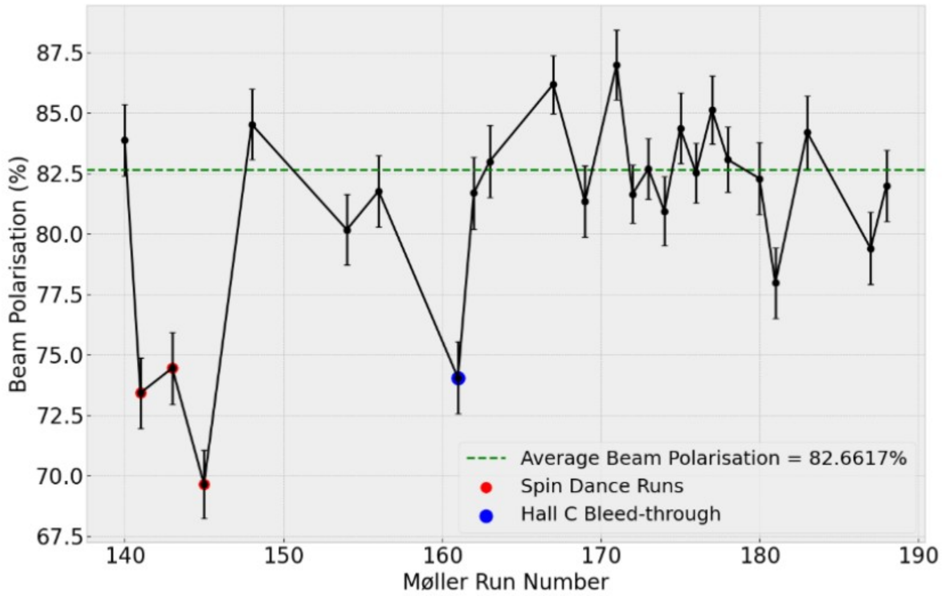
$$A_{\mathrm{LU}} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b(P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--})}$$

P_b: Beam polarisation

Measured with a Moller polarimeter regularly all along the experimental run

$P_b = 82.6 \pm 0.2$ %



K. Gates

Dilution factor

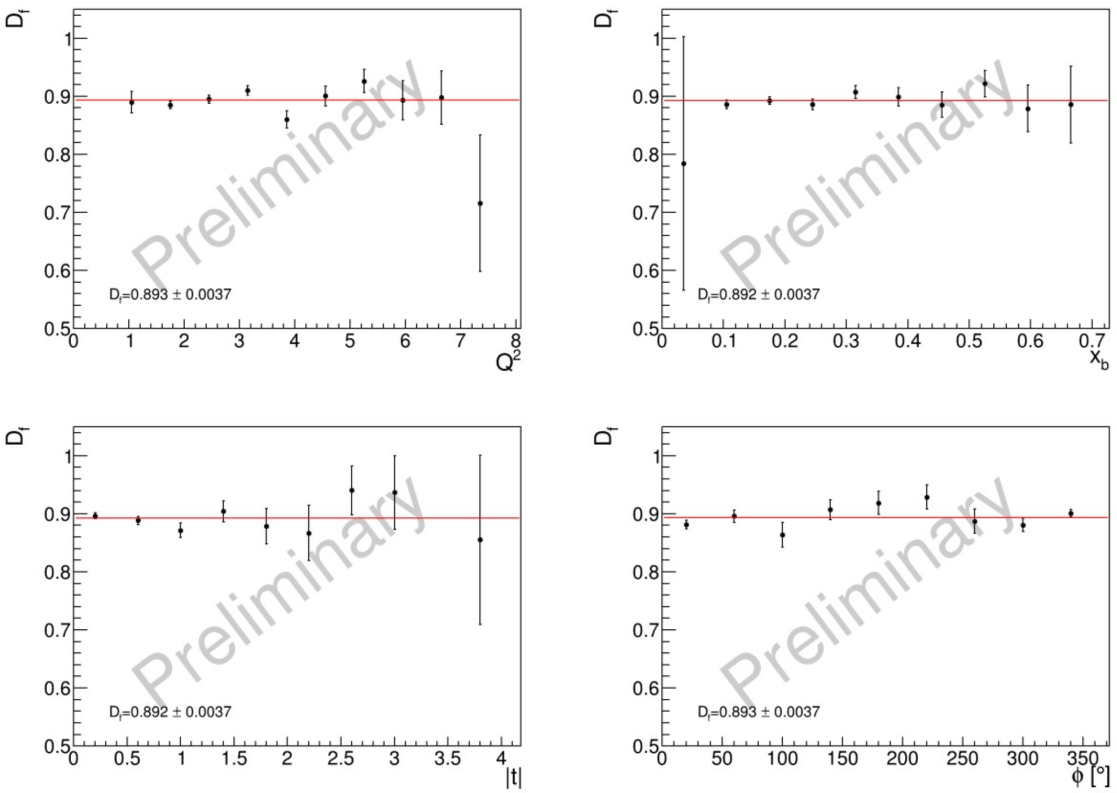
$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--})}$$

- To take into account the remaining nuclear background the TSA and DSA are scaled by the dilution factor

$$D_f = 1 - \frac{N^{\text{Carbon}}}{N^{\text{NH3}}}$$

- The dilution factor is stable as a function of all kinematic variable so we use a single value for all bins

D_f = 89 ± 1 %



Target polarisation

N. Pilleux

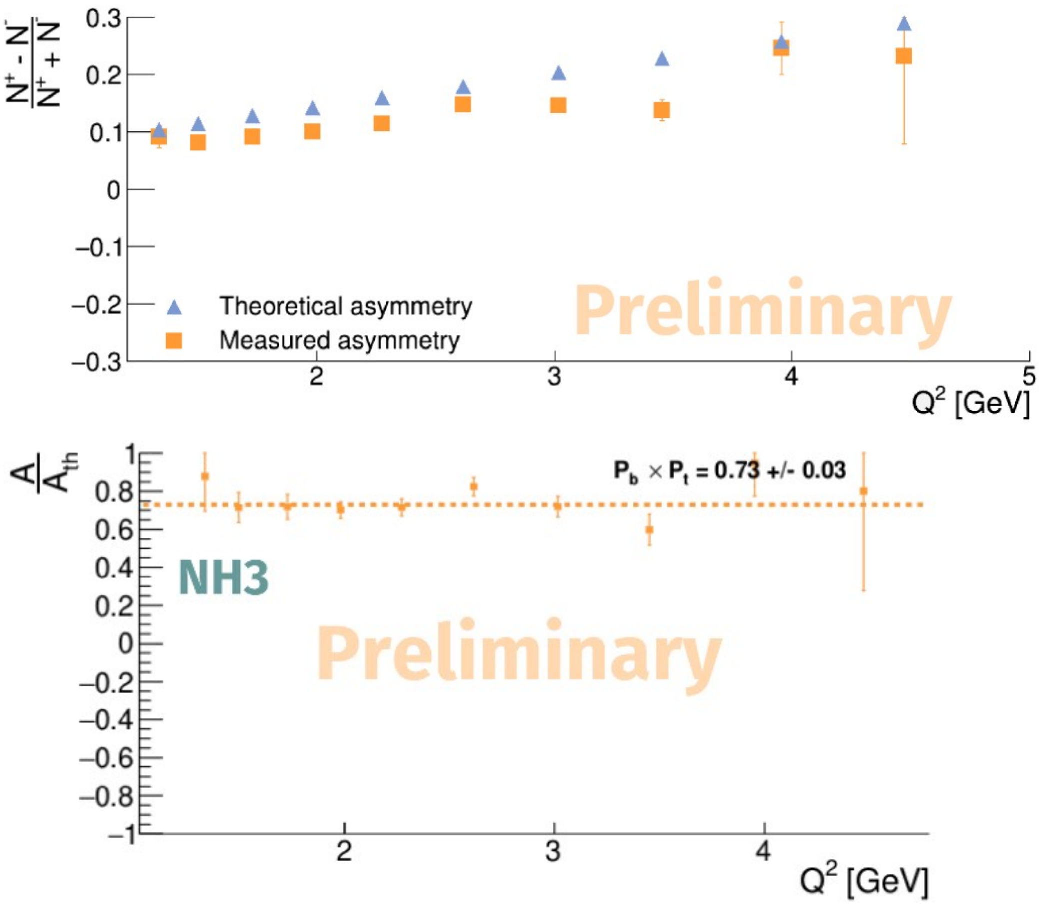
$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--})}$$

- The ep → e'p' **elastic** double spin asymmetry is well known

$$A_{th} = \frac{A_{exp}}{P_b P_t} \qquad A_{exp} = \frac{N^+ - N^-}{D_f(N^+ + N^-)}$$

- We can extract the target polarisation by comparing it to the measured elastic asymmetry

$P_t^+ = 89 \pm 4$ %
$P_t^- = 83 \pm 3$ %



Yields and π^0 background

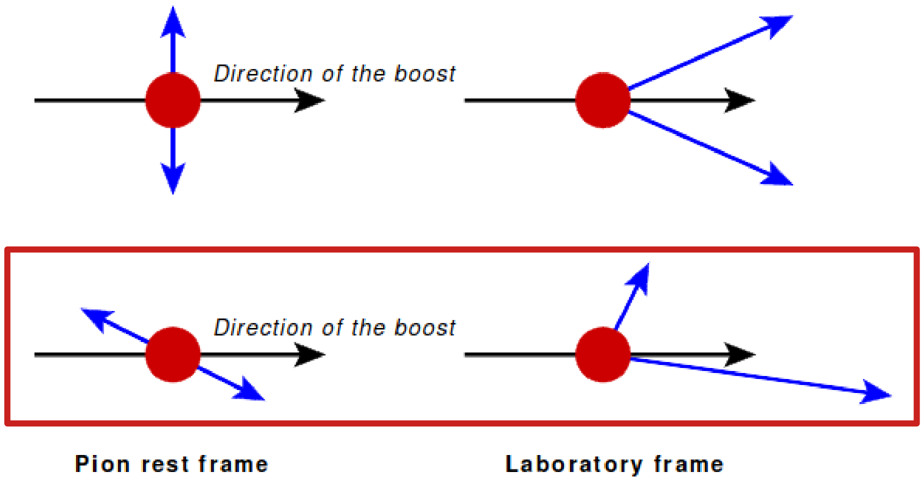
$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--})}$$

$$N^{bt} = \frac{Y^{bt}}{\mathrm{FC}^{bt}}(1 - R^{bt})$$

- Y^{bt} event count in the bin with beam polarisation b and target polarisation t
- FC^{bt} Beam charge in the spin configuration
- R^{bt} π^0 contamination fraction

- A π^0 decay $\pi^0 \rightarrow \gamma\gamma$ can pass as a DVCS is one of the photons carries most of the momentum

➔ Significant background contribution that needs to be subtracted

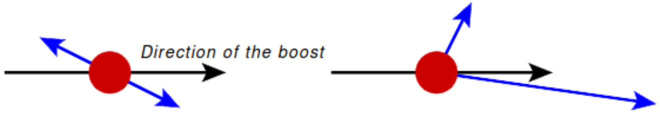


[tel-01281332]

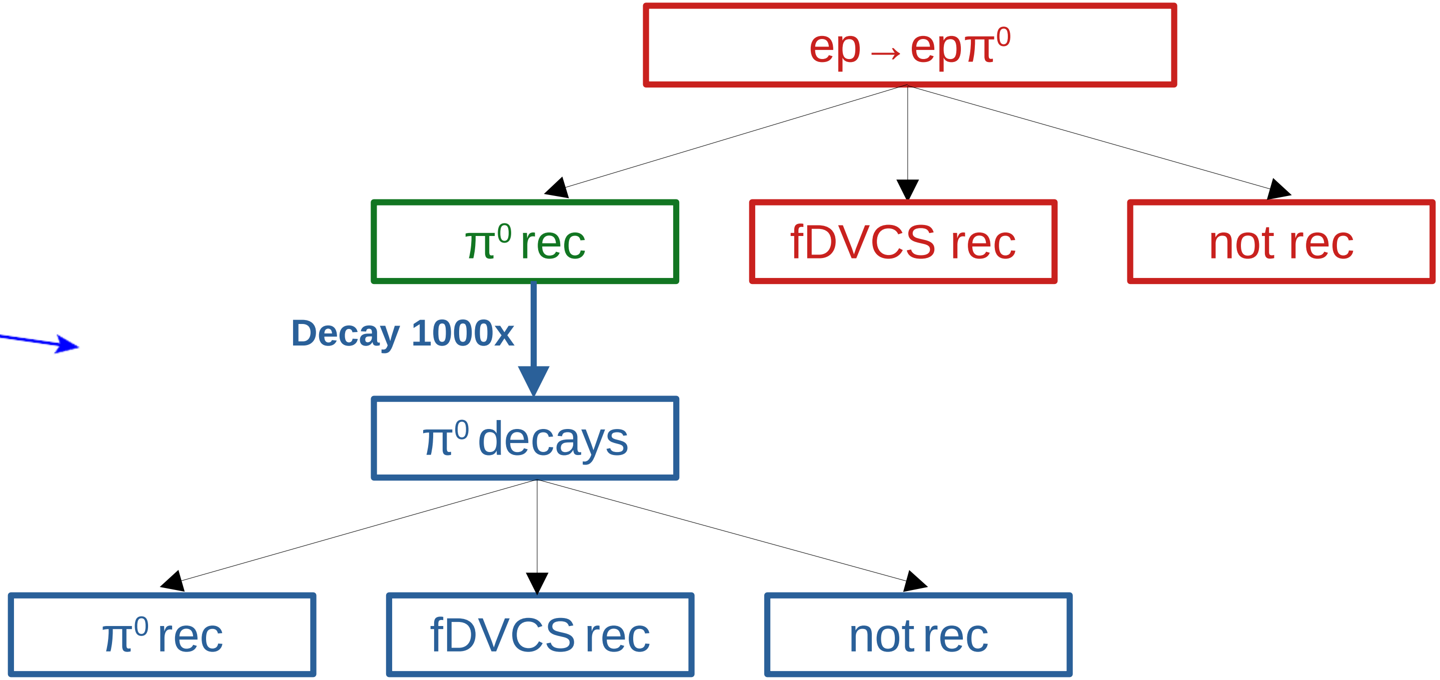
π^0 subtraction method

fDVCS rec

π^0 events that pass the DVCS selection



Pion rest frame **Laboratory frame**

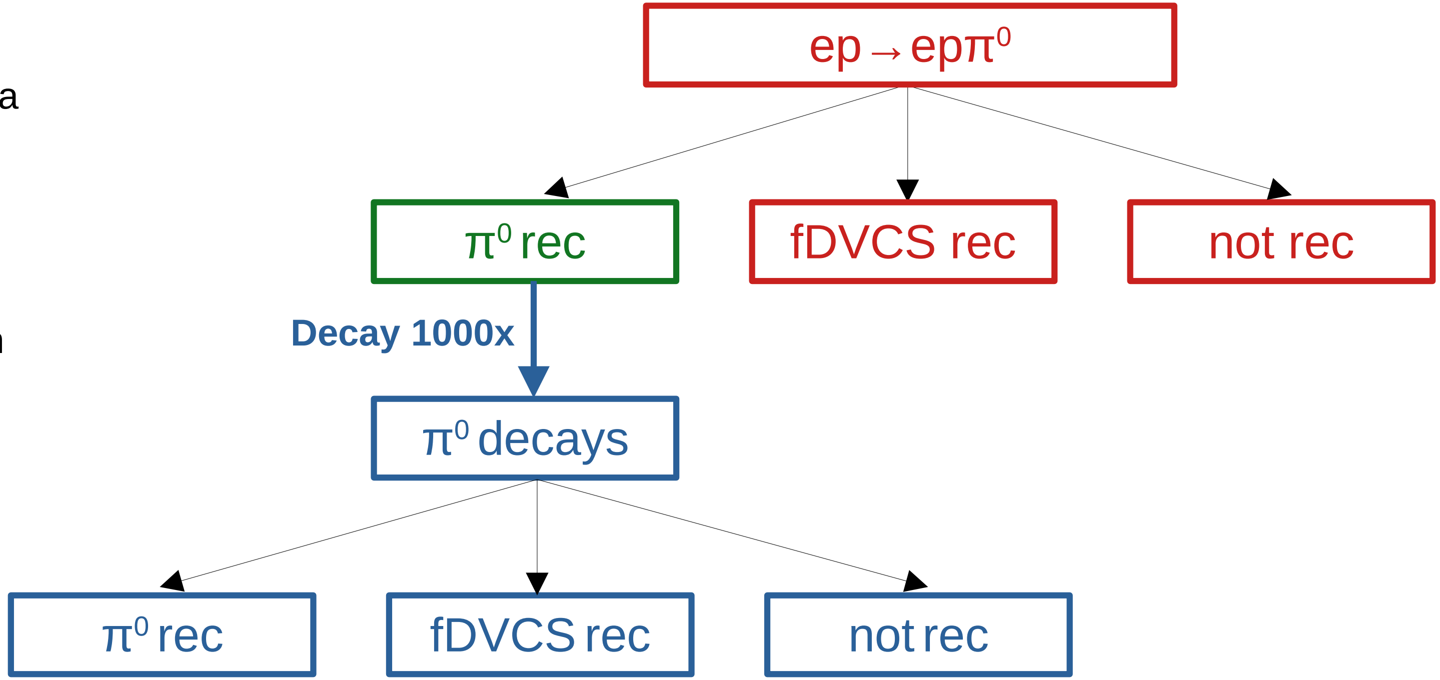


π^0 subtraction method

π^0 rec

Wide π^0 sample selected from data with loose cuts
Includes :

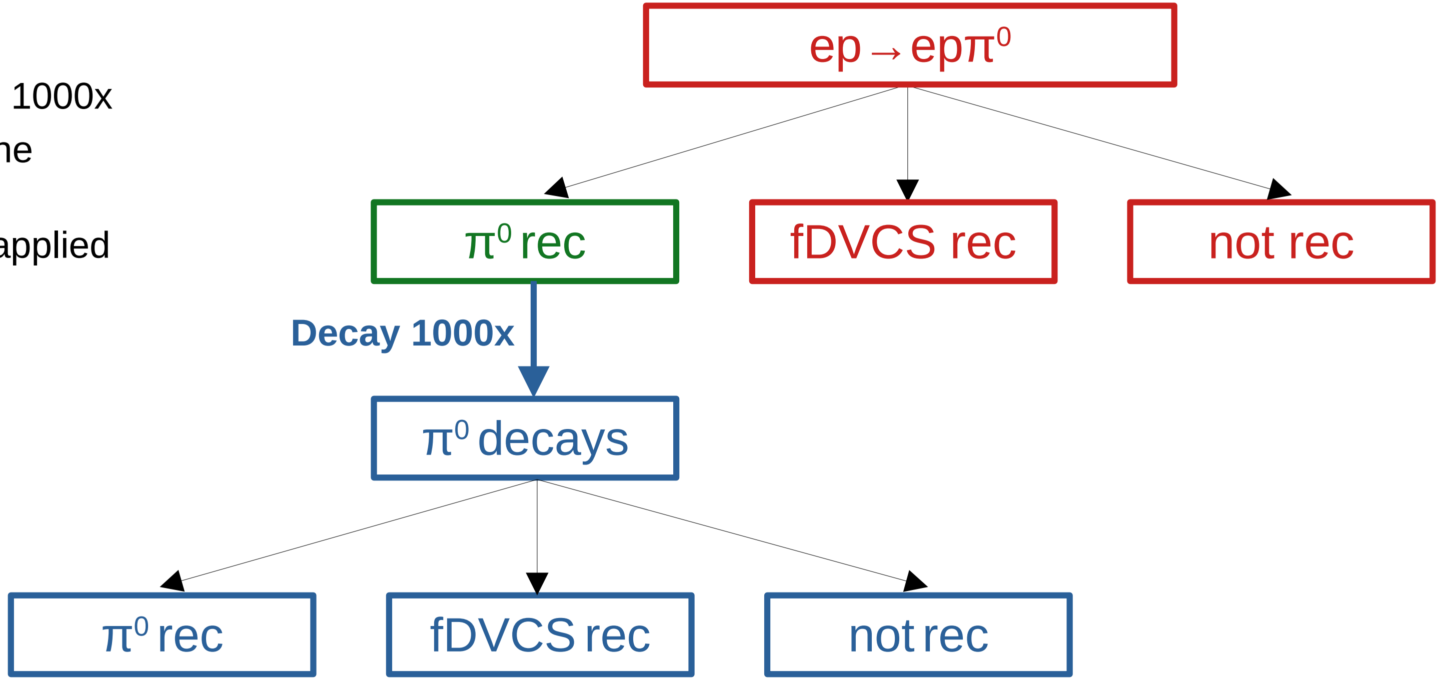
- Exclusive π^0
- SIDIS π^0
- From Hydrogen and Nitrogen background



π^0 subtraction method

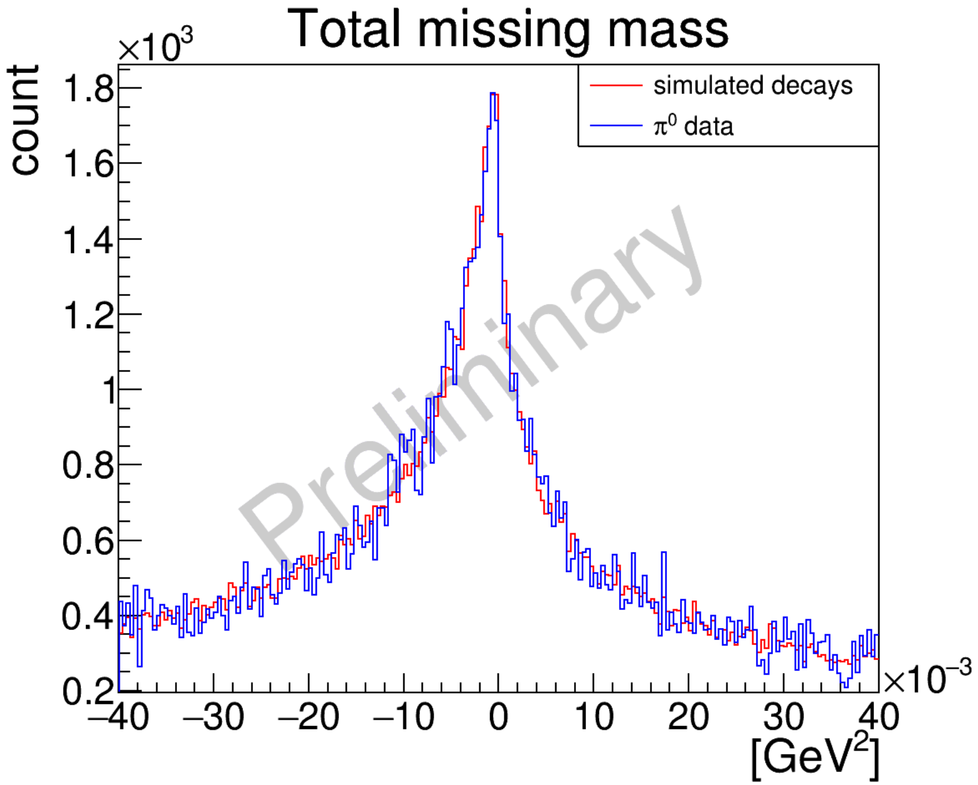
π^0 decays

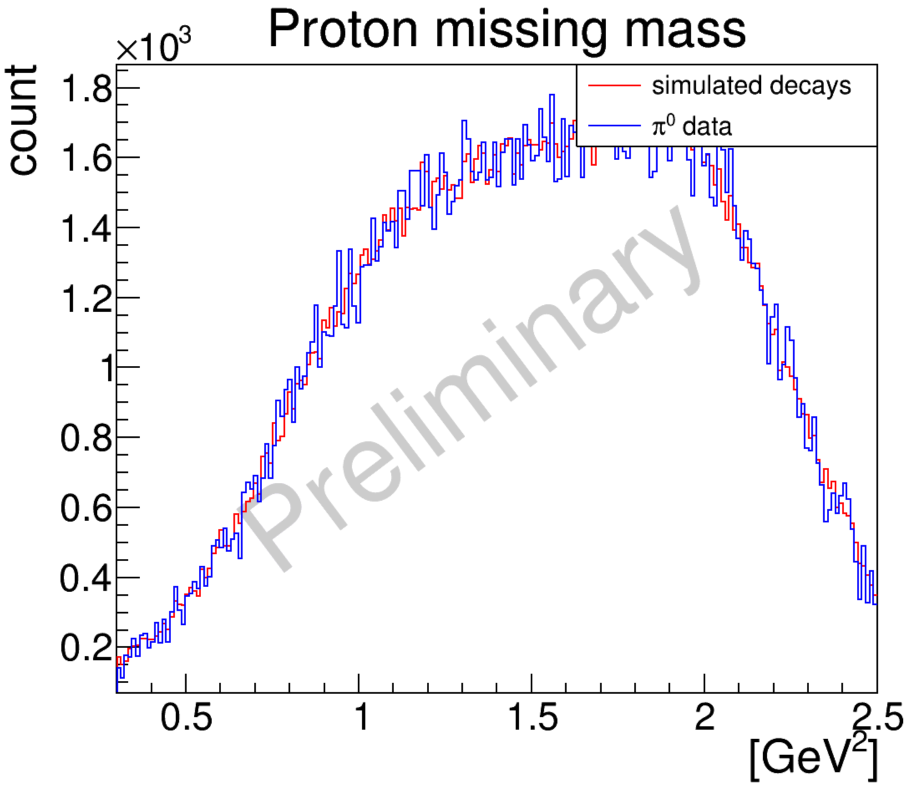
- Each π^0 is randomly decayed 1000x
- Decays are passed through the detector simulation
- π^0 and DVCS selections are applied
- Decays are weighted



π^0 data and decays

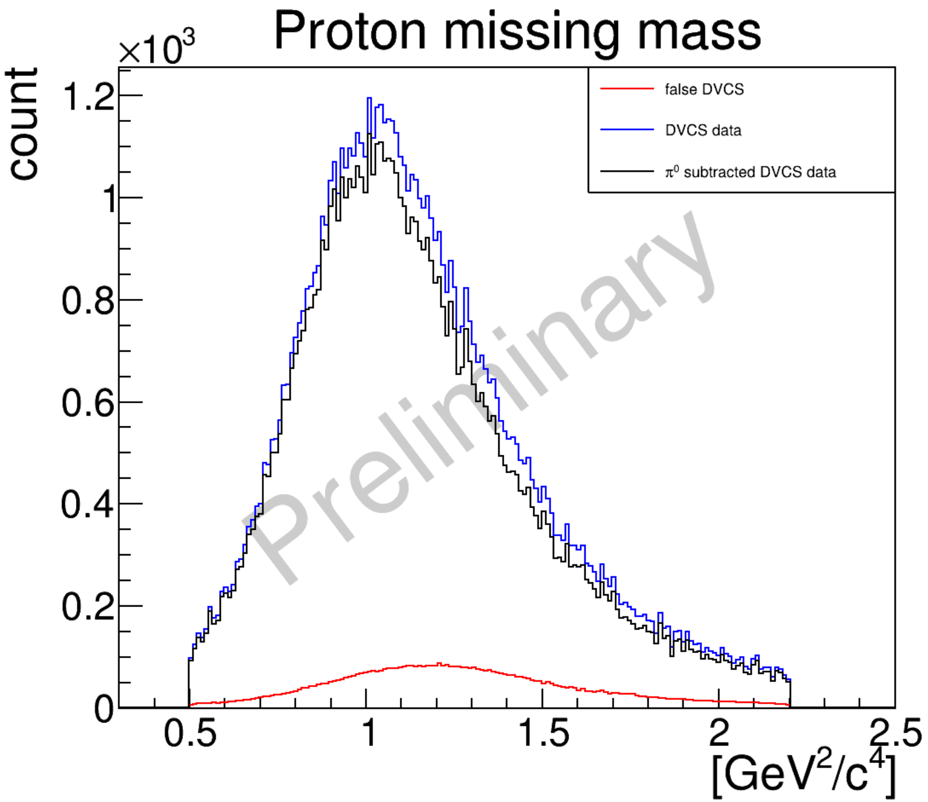
- The π^0 decay distributions match data distributions

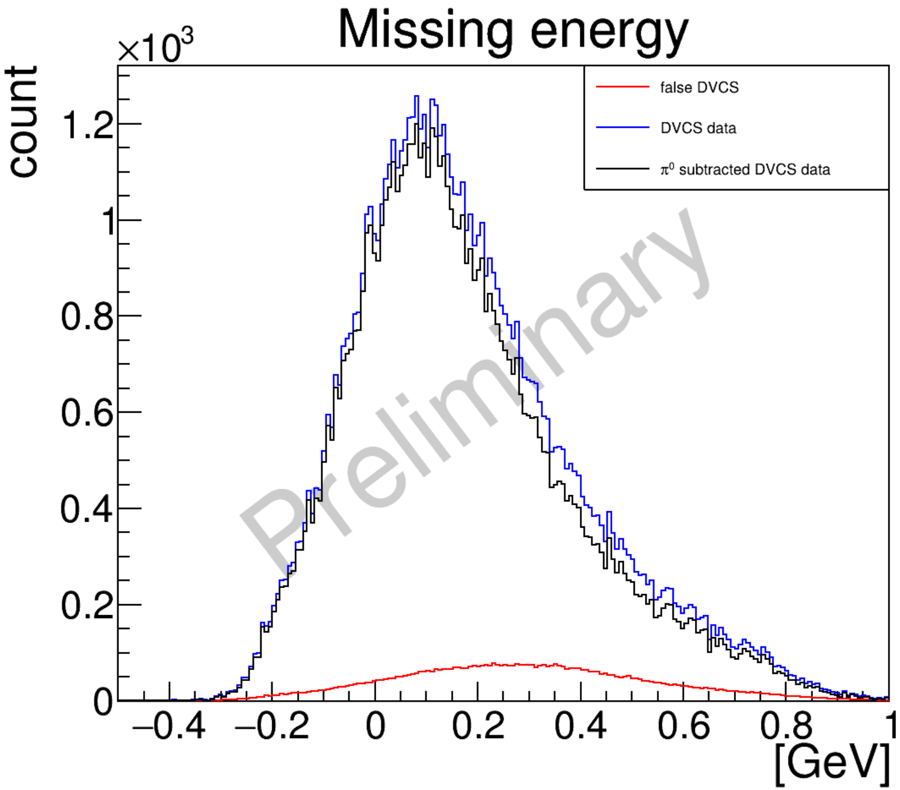




π^0 contamination in the DVCS sample

- What is the distribution of false DVCS events ?



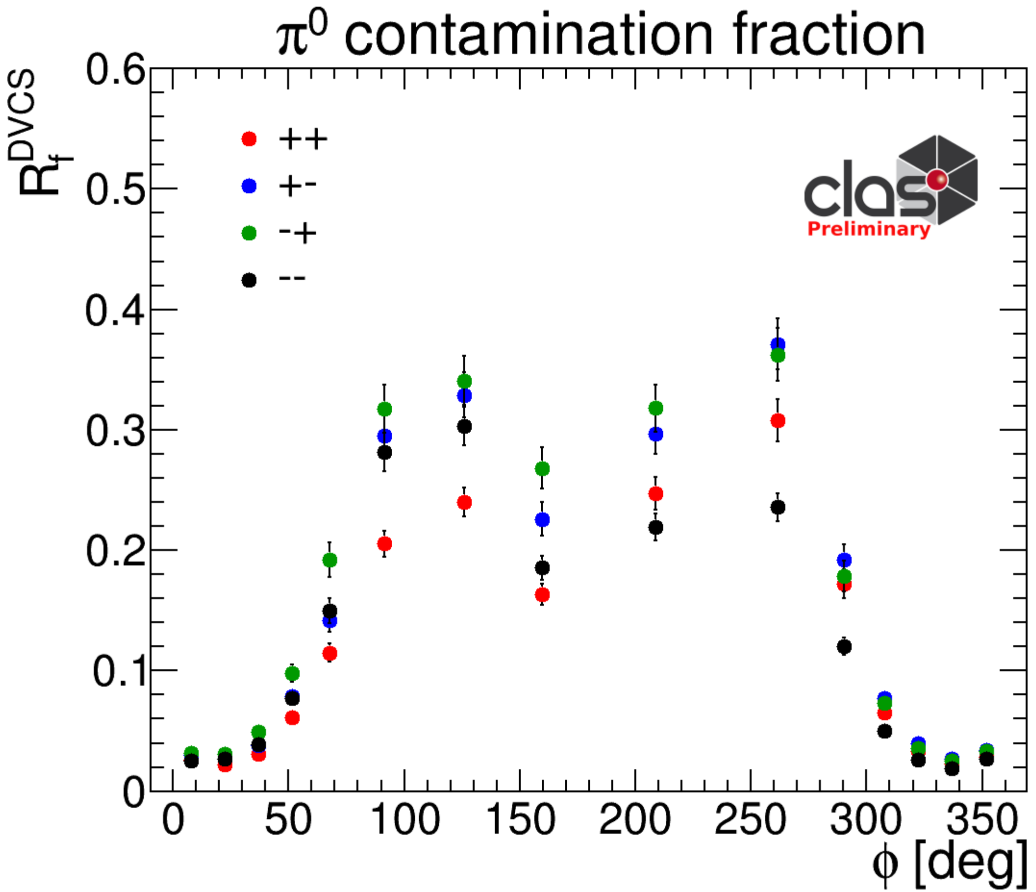


π^0 contamination fraction

- Fraction of fake DVCS events per kinematic bin and spin configuration

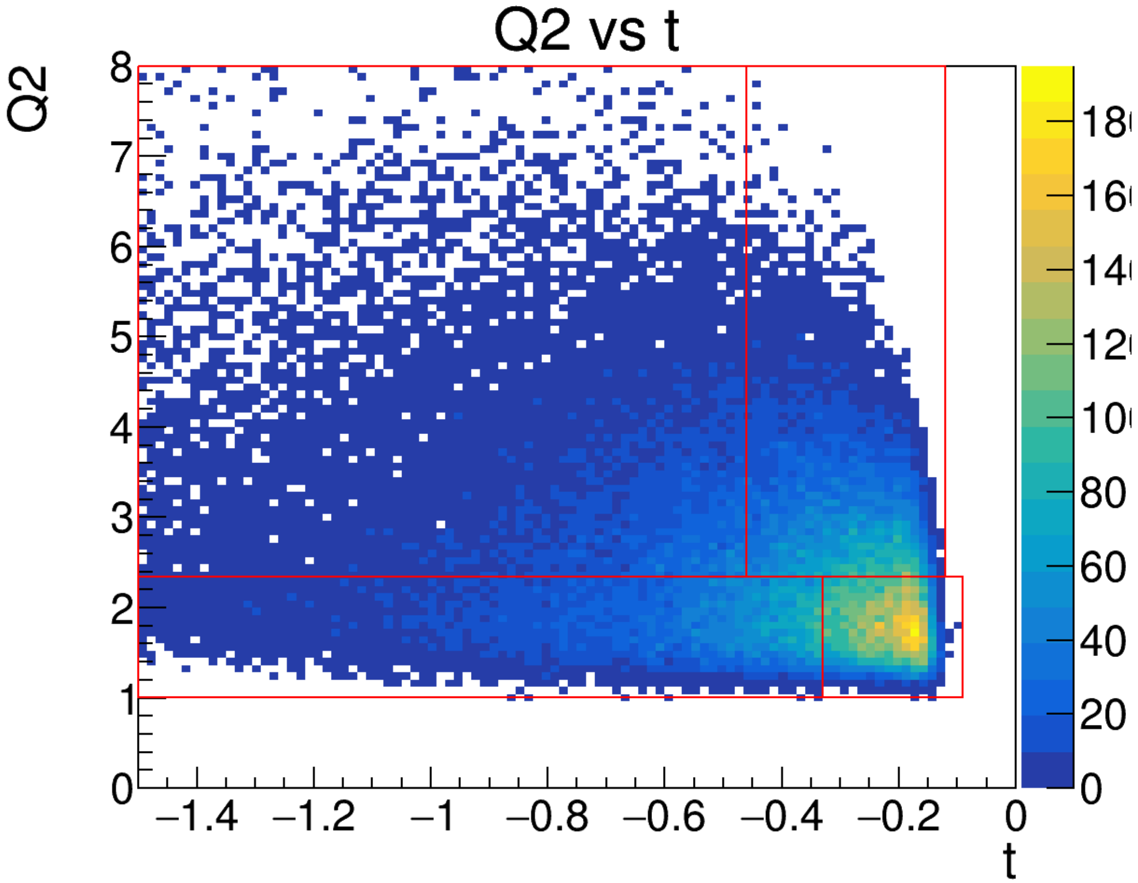
$$R^{bt} = \frac{\text{decay fDVCS}}{\text{decay } \pi^0} \times \frac{\text{data } \pi^0}{\text{data DVCS}}$$

$$N^{bt} = \frac{Y^{bt}}{\text{FC}^{bt}}(1 - R^{bt})$$



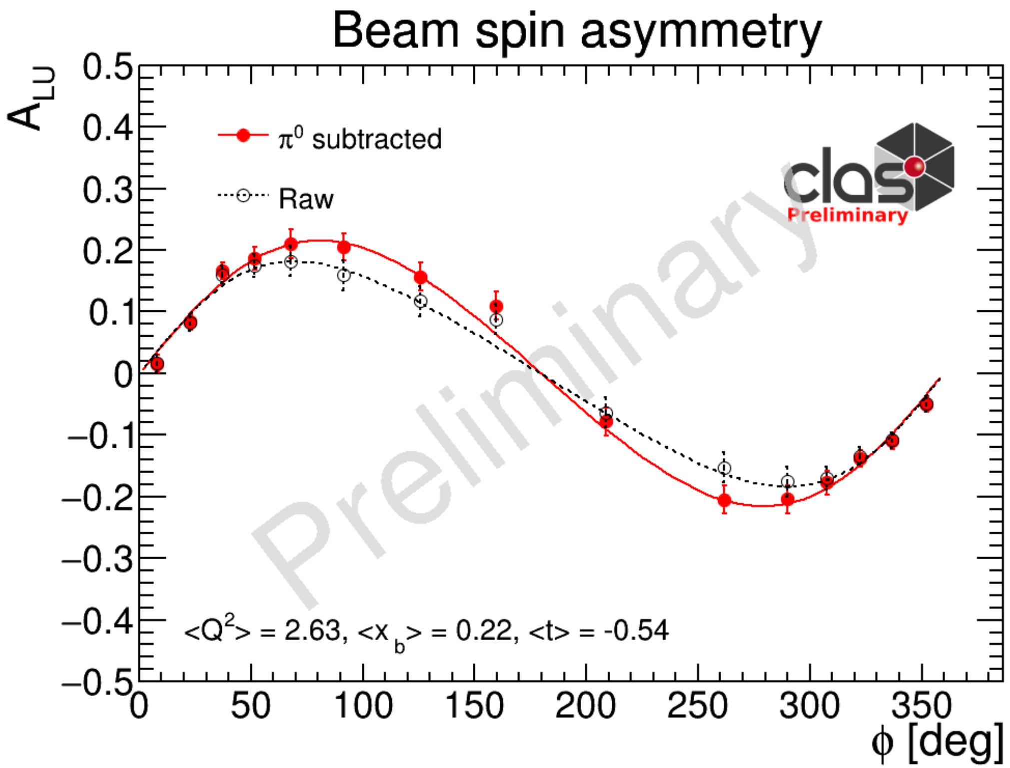
Binning

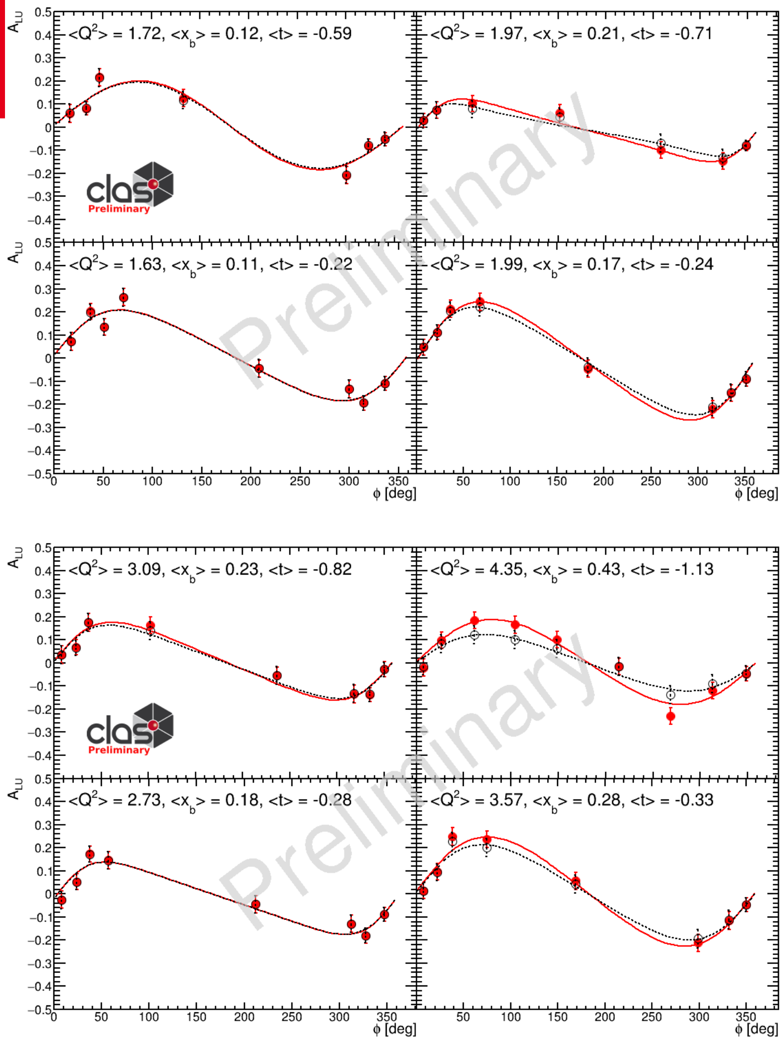
- 2 bins in Q^2, t, x_b so that there is the same number of events per bin
- N bins in phi with at least 1000events per bin and at least 15° wide.



Beam spin asymmetry

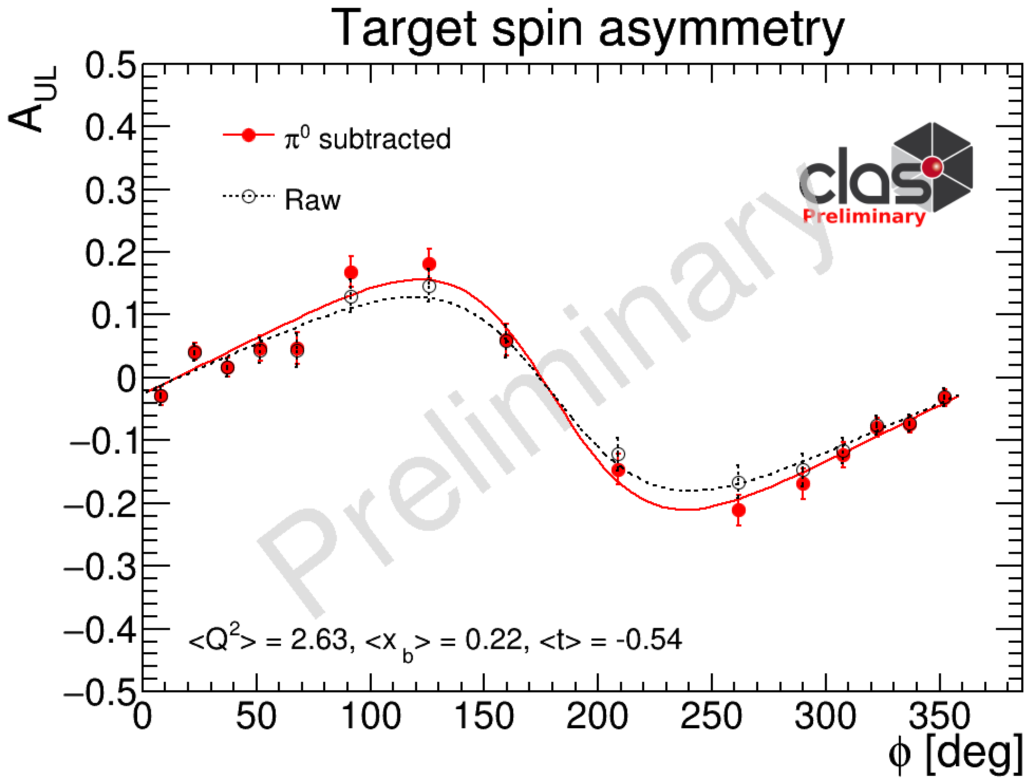
- Only statistical errors are included

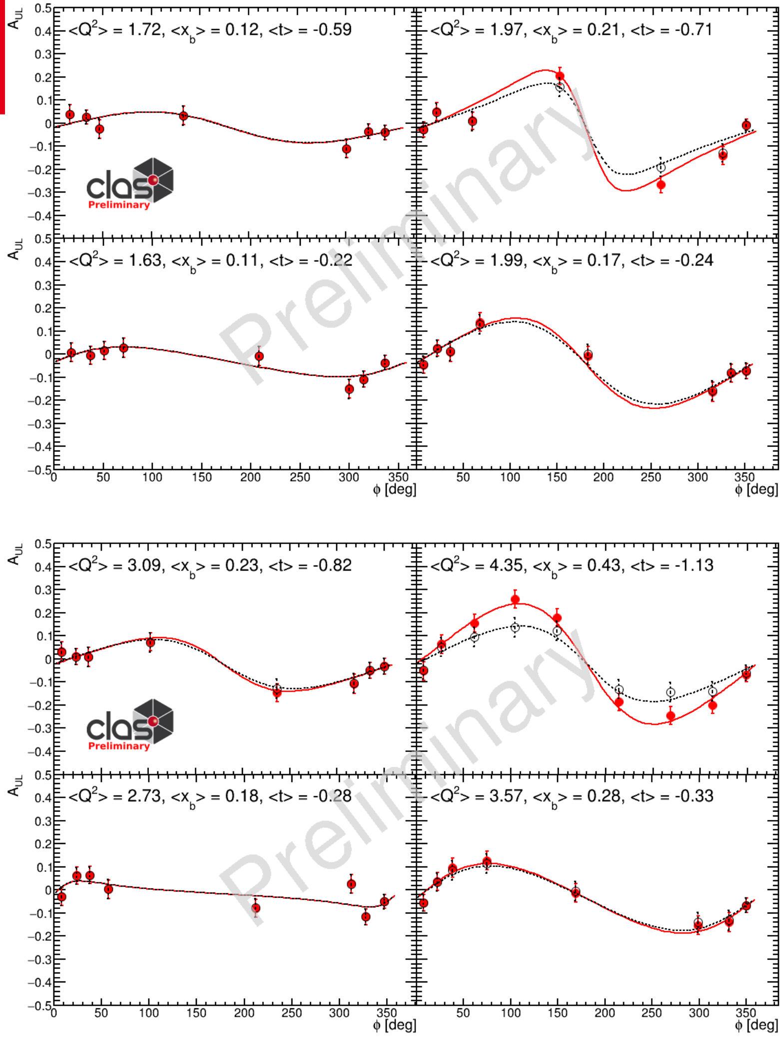




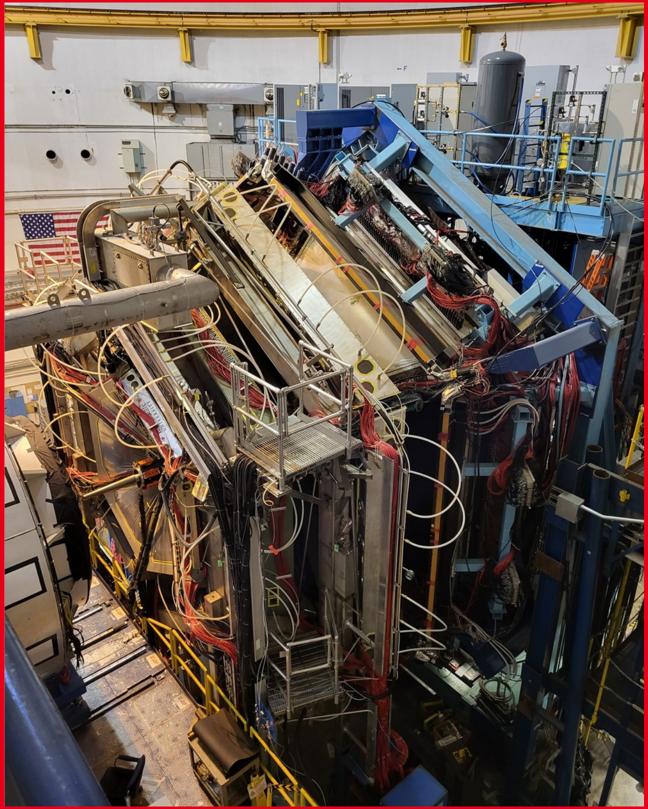
Target spin asymmetry

- Only statistical errors are included



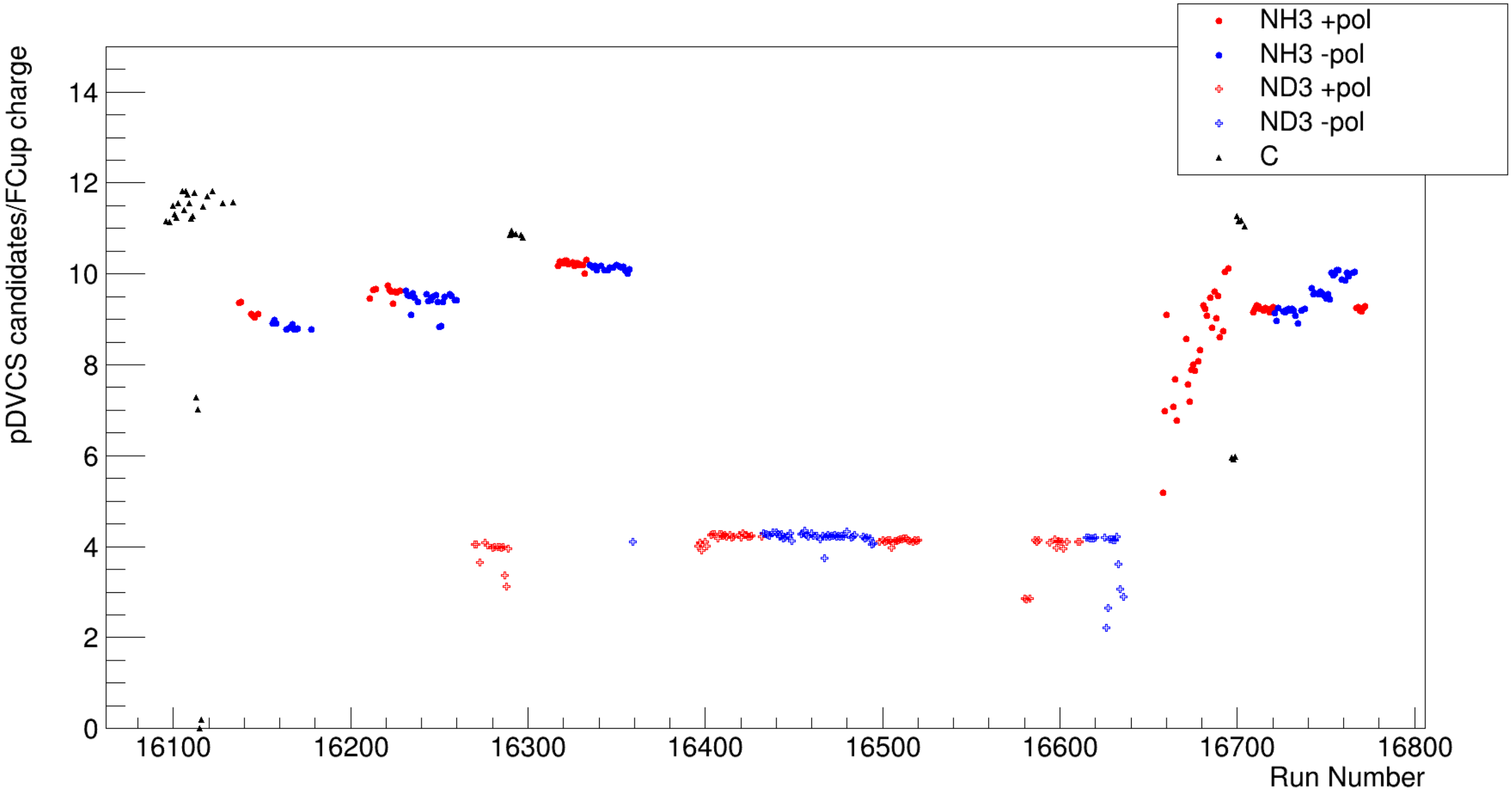


Summary & Outlook



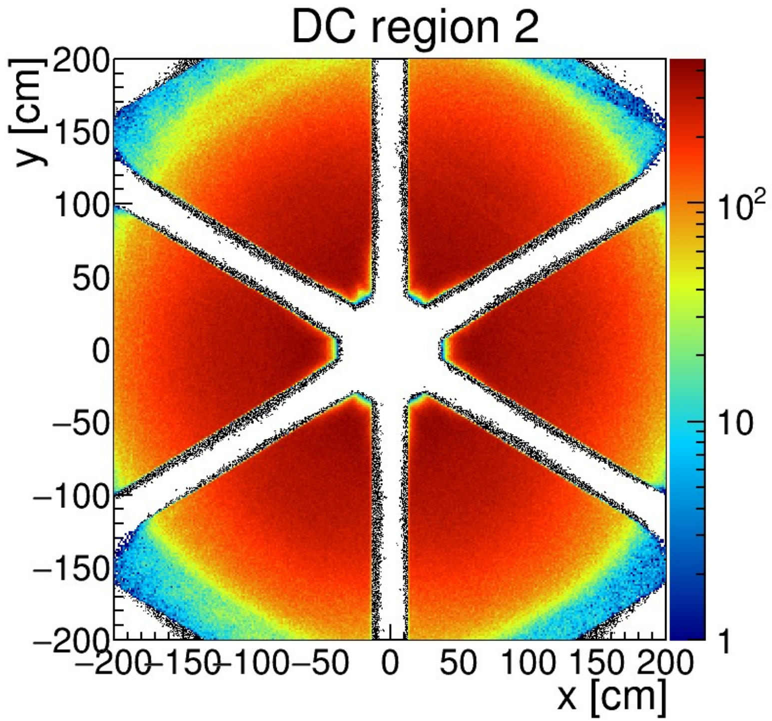
- RGC is the first polarised DVCS experiment with the CLAS12 detector
- The pDVCS analysis is ongoing and shows promising results
- Tools are in place to take into account nuclear and π^0 backgrounds
  - Need for dilution factor refinements
  - Validation and cross check of the π^0 subtraction method
- The main remaining steps are:
  - Momentum correction
  - Systematic error estimates
- The rest of the data collected is being processed and will be available in the coming month. It is is expected to double the proton DVCS statistics for this analysis.

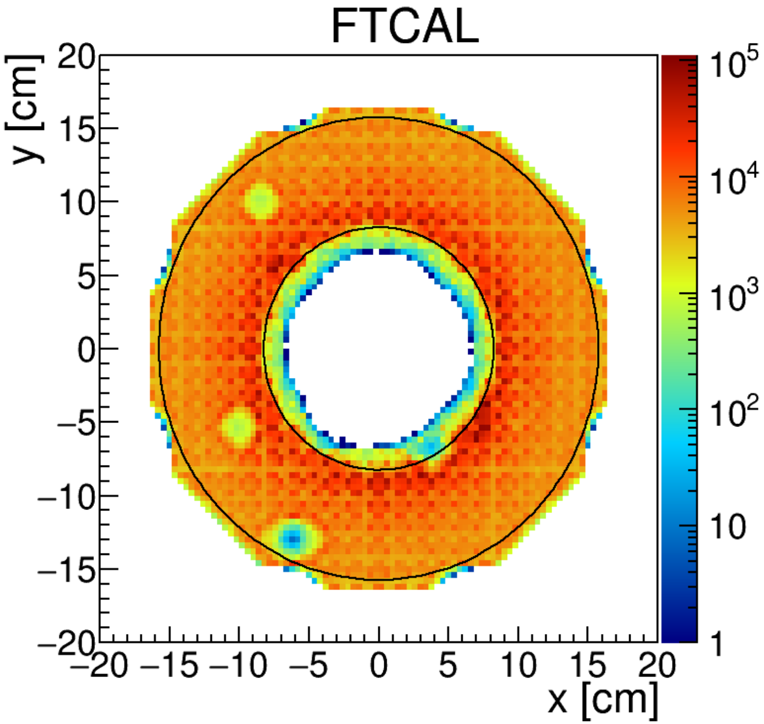
Potential FCup issues



Fiducial cuts, DC and FTCAL

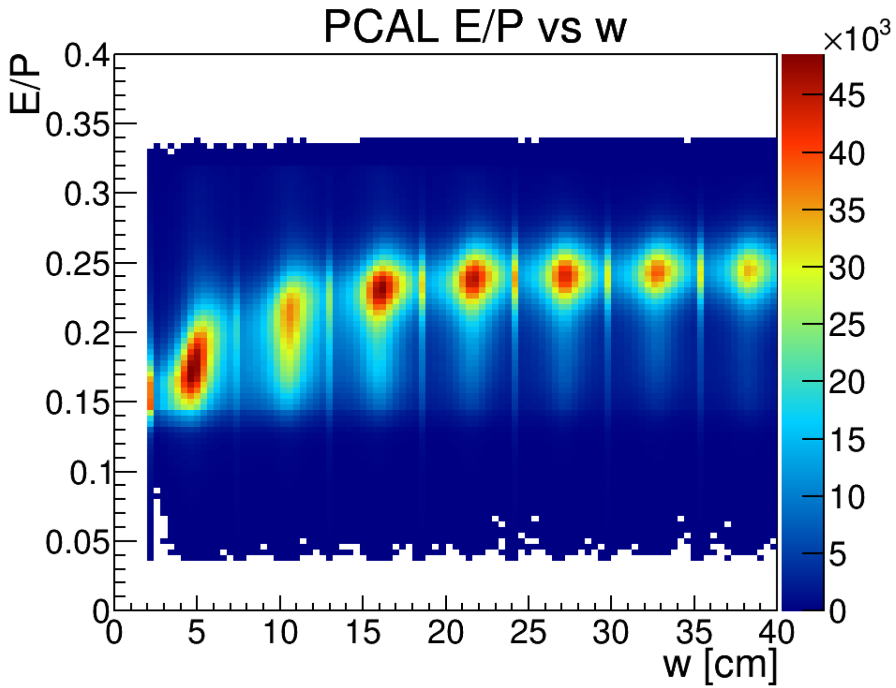
- DC: edge > 4cm on region 2
- FTCAL: 8.25 < r < 15.75 cm

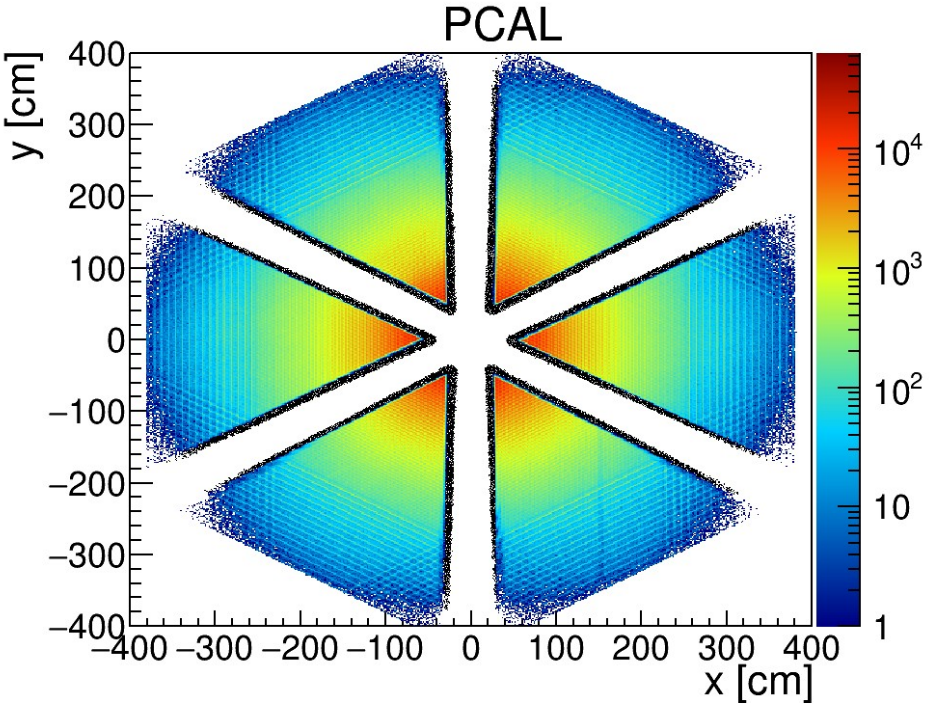




Fiducial cuts PCAL

- RGA common analysis note medium cuts
  u,v,w > 14cm. ~3 scintillator bars



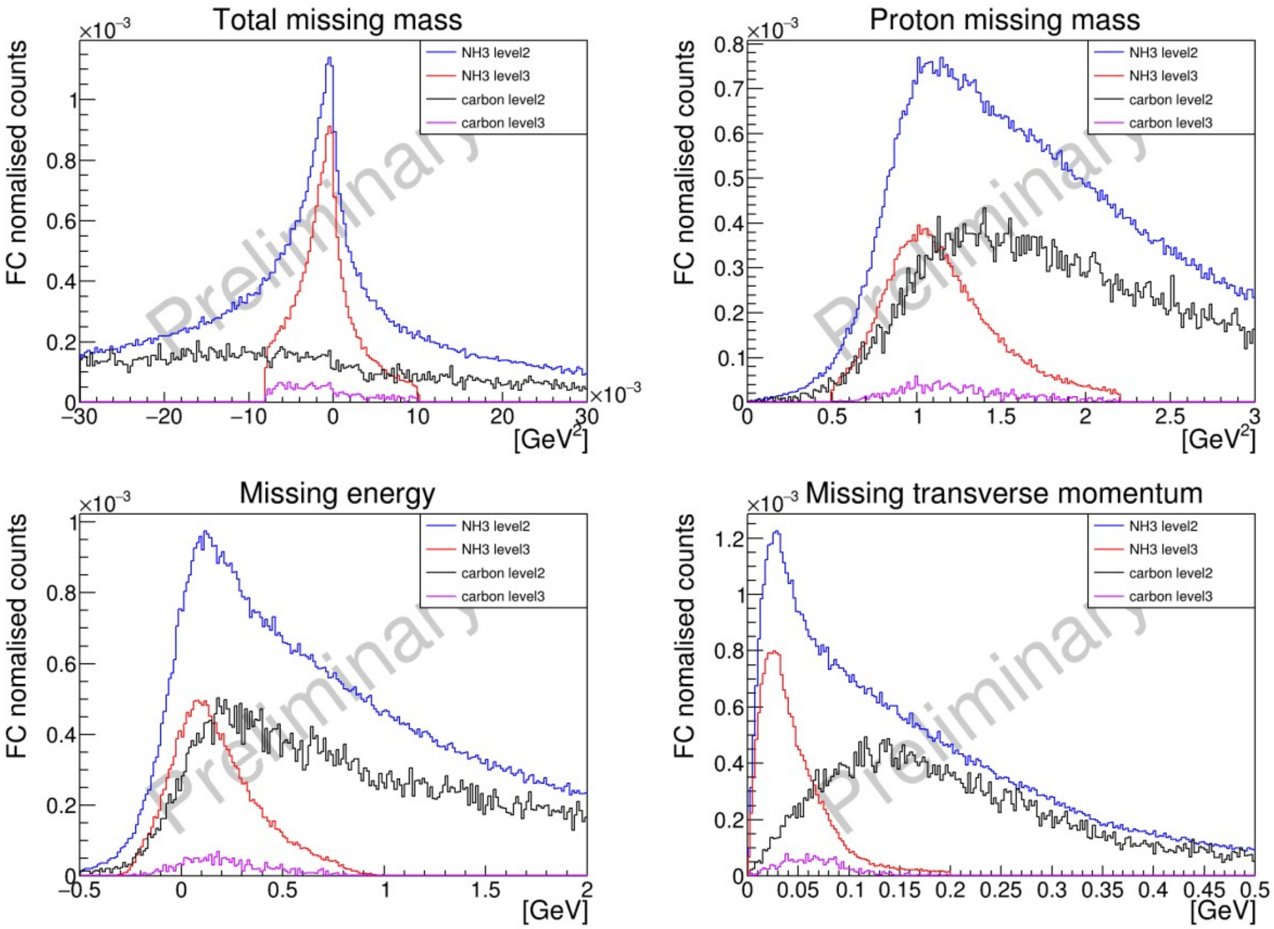


Exclusivity cuts

Cuts on exclusivity variables to isolate DVCS events and reduce nuclear background

Contribution from nuclear background estimated with the Carbon target

Total missing mass	[-0.008, 0.01] GeV²
Proton missing mass	[0.5, 2.2] GeV²
Missing energy	[-0.5, 1] GeV
Missing transverse momentum	< 0.2 GeV
Photon missing mass	[-0.25, 0.3] GeV²
ɣ cone angle	< 1°



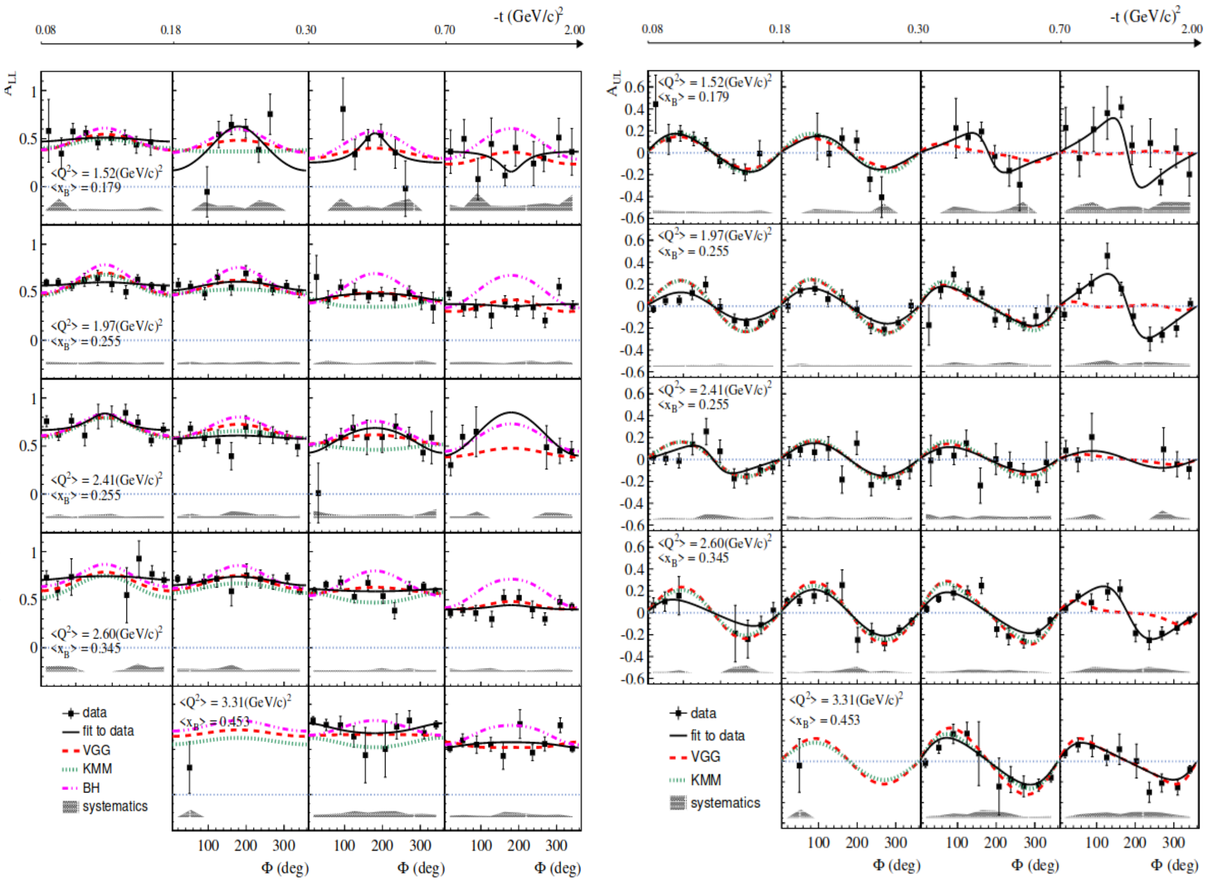
Target-Spin & Double-Spin asymmetry (TSA, DSA)

- The TSA is also sensitive to the imaginary parts of the H and H̃ CFFs, but in different combinations
  - Important to separate the two contributions

$$A_{\mathrm{UL}}^{\mathrm{lab}} = \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{D_f(P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

$$A_{\mathrm{LL}}^{\mathrm{lab}} = \frac{N^{++} + N^{--} - N^{+-} - N^{-+}}{P_b \cdot D_f(P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

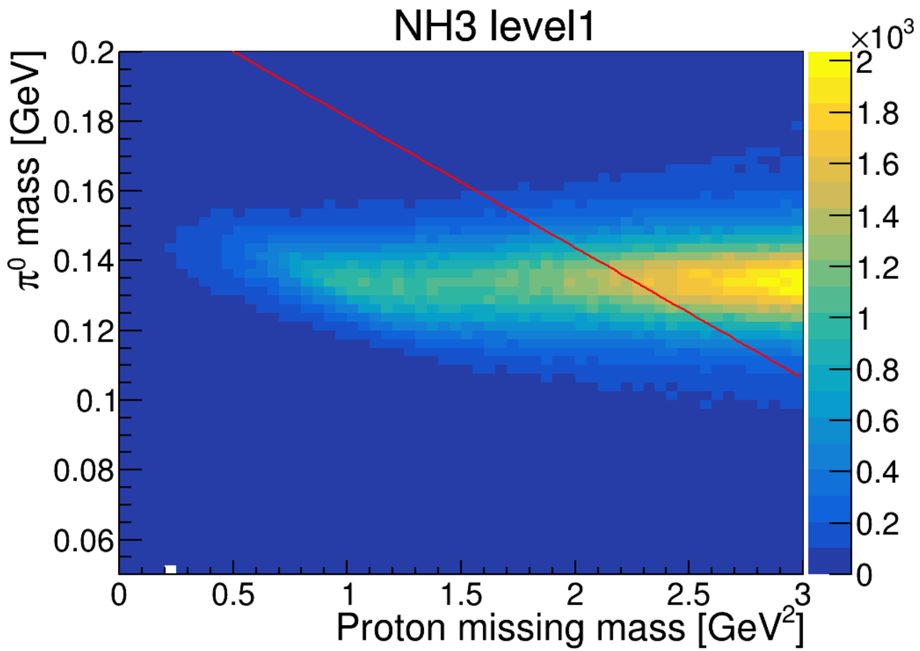
- This analysis follows the experiment done in the CLAS 6GeV era arXiv:1501.07052

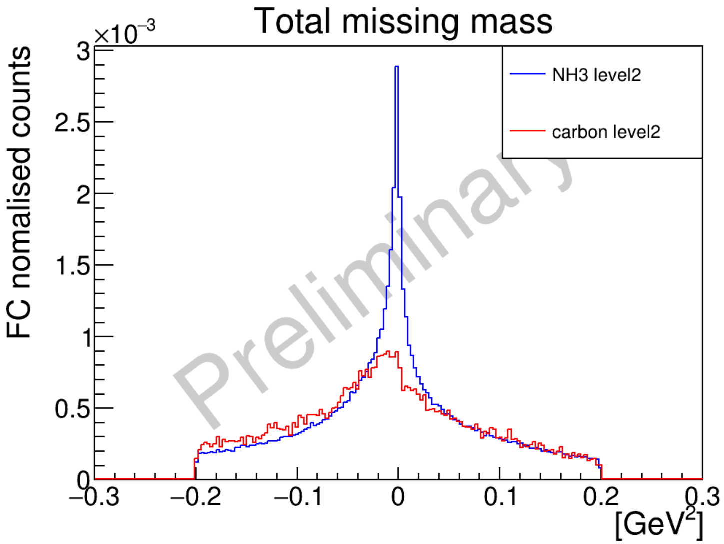


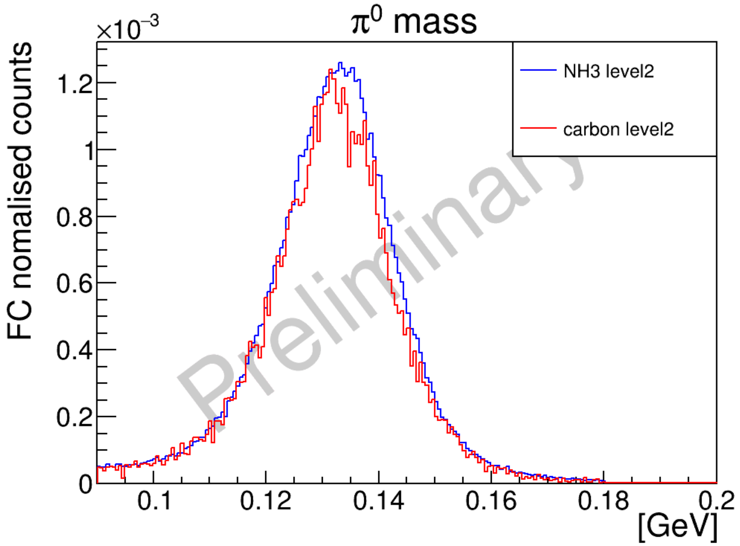
CLAS 6GeV DSA & TSA measurements

π^0 event selection

- Wide selection to include all potential contamination including from some SIDIS π^0
- There is a significant contribution from nuclear background π^0



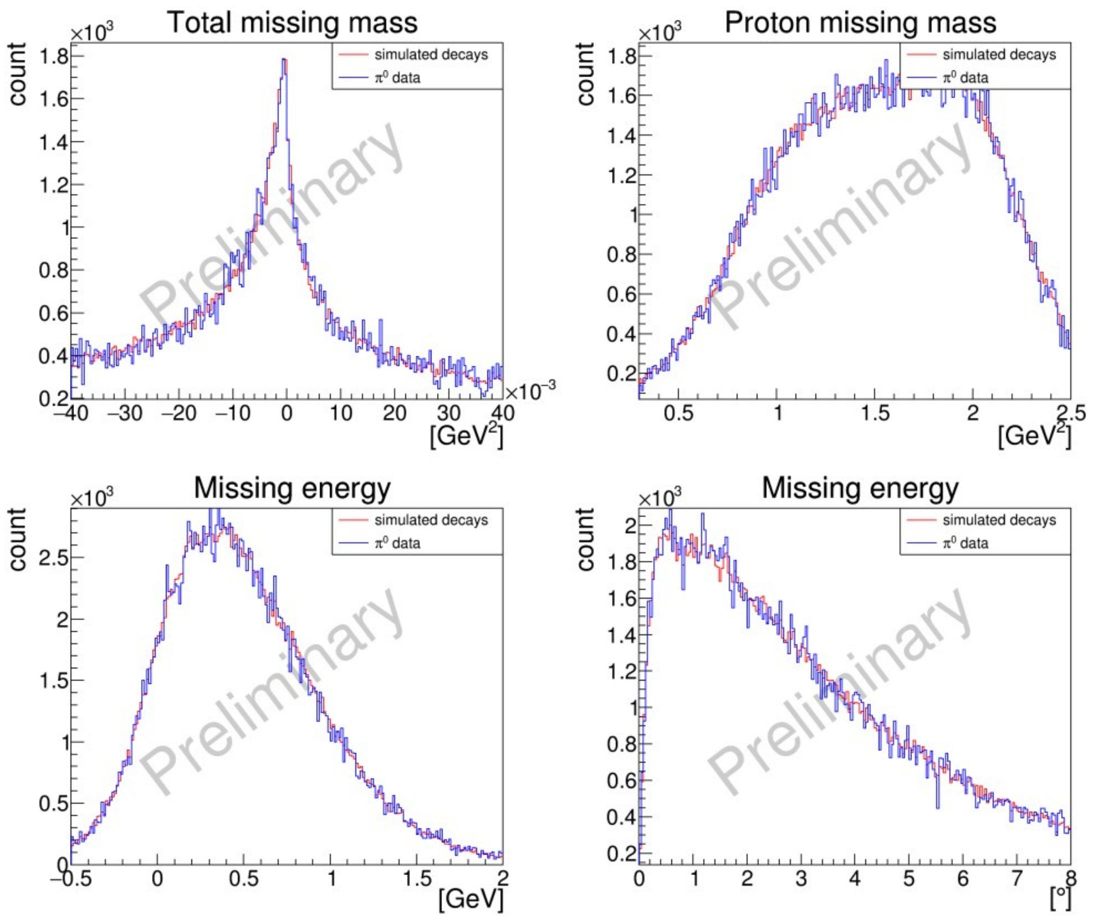




Data and decays agreement

- We apply the π^0 cuts to the simulated decays
- The decays need to be weighted so that one data event has the same weight as all the decays coming from that event

$$W_i = \frac{1}{N_i^{\mathrm{lev2}}}\left(1 - \frac{N_i^{\mathrm{badElec}}}{N^{\mathrm{decay}}}\right)$$



Double spin asymmetry