DVCS on a polarised proton target at CLAS12

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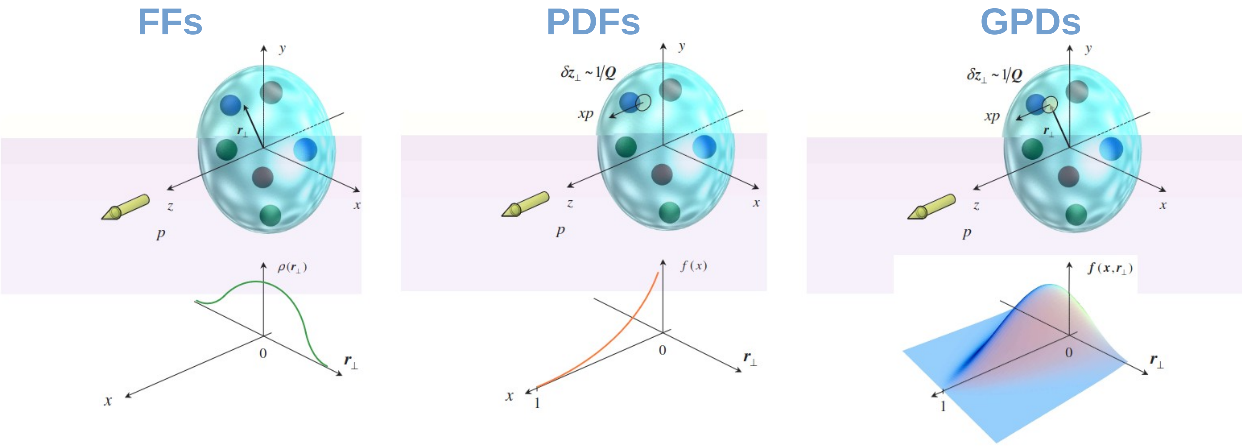
Introduction

- **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



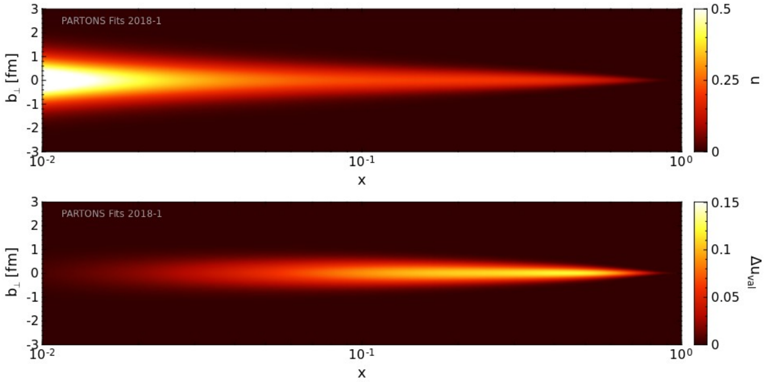
3D structure

→ Access to the spin decomposition of the nucleon

→ Access to its mechanical properties

$$\frac{1}{2} = \sum_q J^q + J^g$$

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



[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

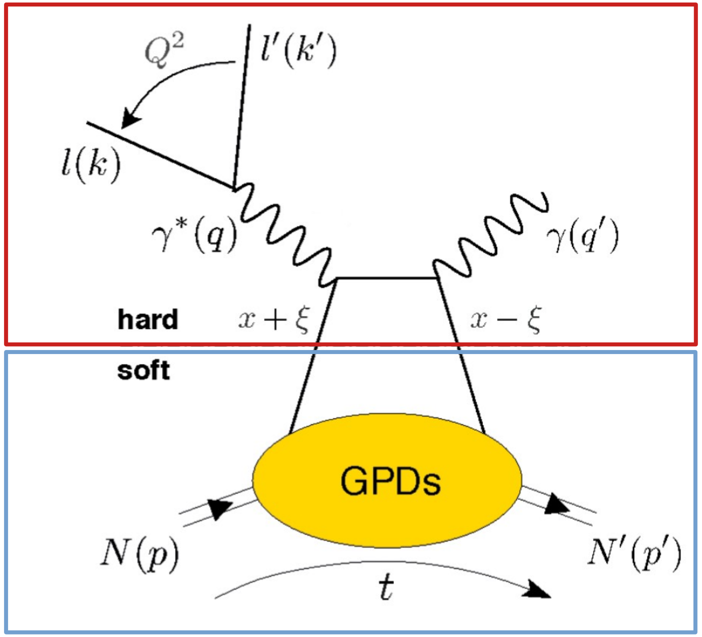
- Two indistinguishable processes, DVCS and Bethe-Heitler

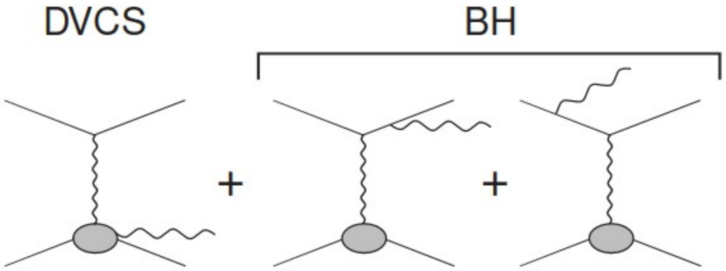
$$|T|^2 = |T_{\mathrm{DVCS}}|^2 + |T_{\mathrm{BH}}|^2 + \underbrace{T_{\mathrm{DVCS}}T^*_{\mathrm{BH}} + T^*_{\mathrm{DVCS}}T_{\mathrm{BH}}}_{\mathrm{I}}$$

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

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

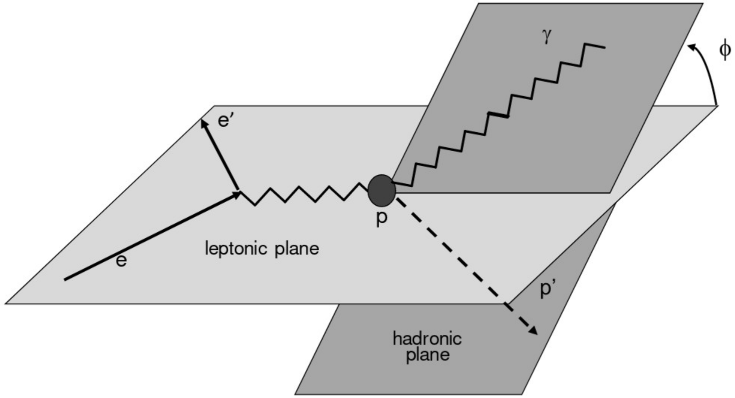
$$s^{\mathcal{I}}_{1,\rm unp} \propto \Im{\rm m}[F_1\mathcal{H} + \xi(F_1+F_2)\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}].$$

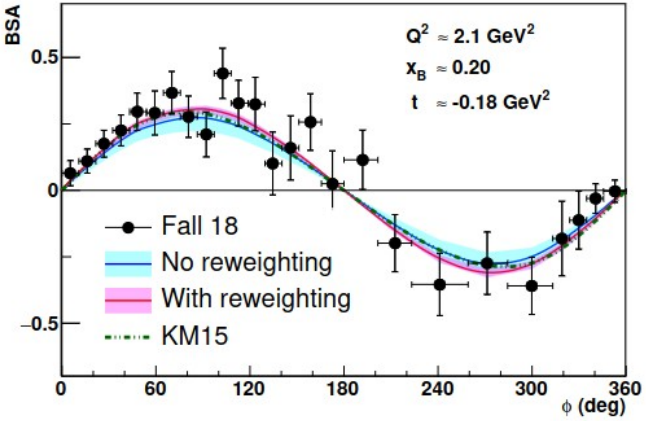
- Target spin asymmetry (TSA), unpolarised electron and polarised proton

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

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

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

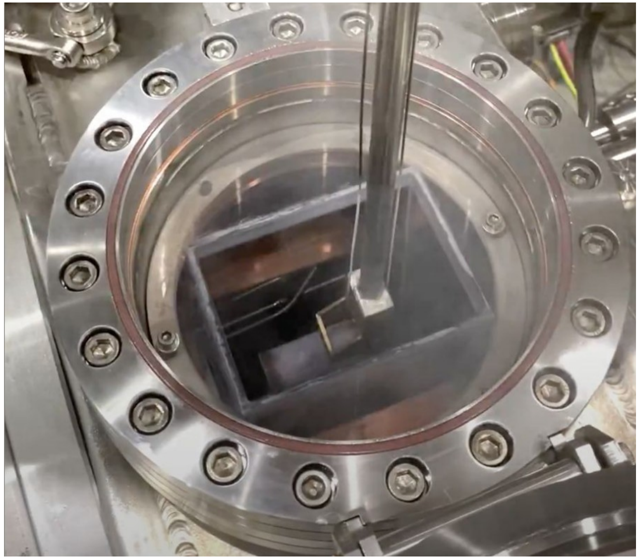


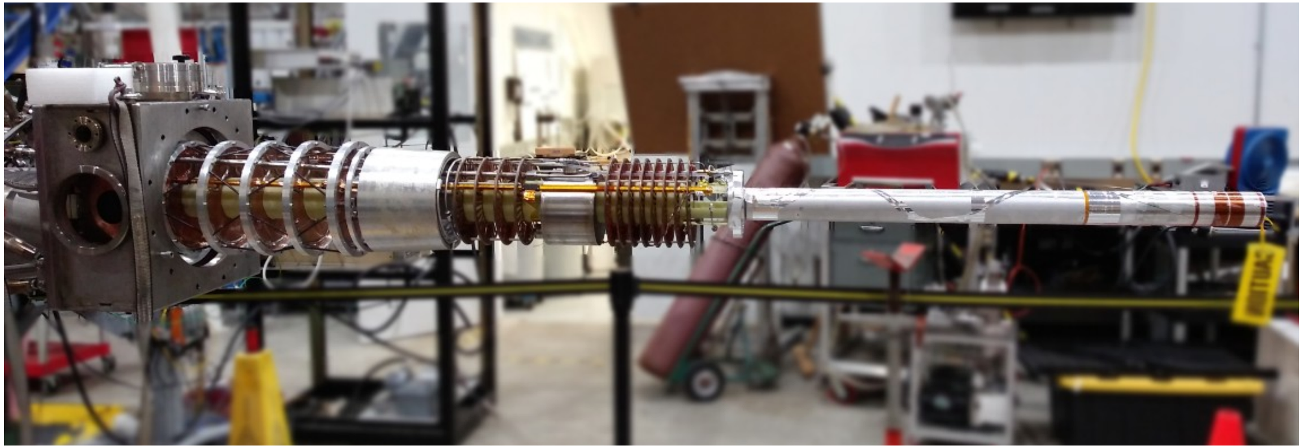


[arXiv:2211.11274]

The RGC experiment

- New polarised target APOLLO, cryogenic solid target
- Dynamic polarisation of hydrogen or deuterium in NH3 or ND3 cells
- Took data from June 2022 to March 2023 in three run periods
  - Summer 22, FTON 28 PAC days (pass 1 completed)
  - Fall 22, FTOUT 30 PAC days (pass 1 ongoing)
  - Winter 23, FTON 22 PAC days
- Only Summer22 is in the current analysis (~50% of the DVCS stat collected)

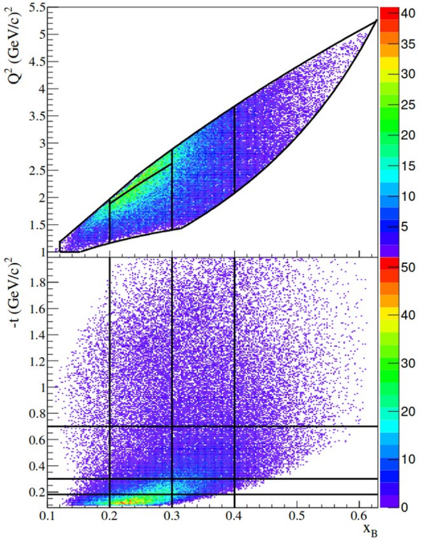


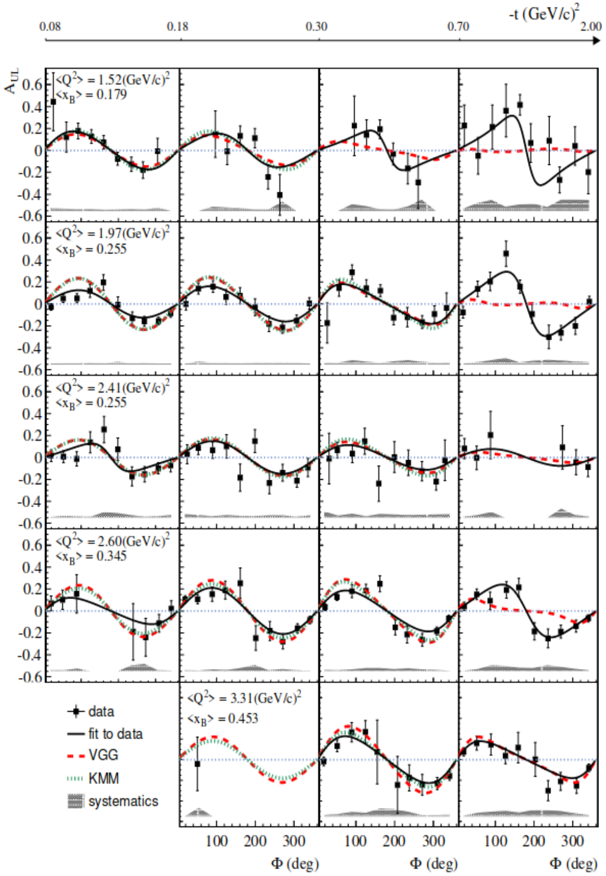


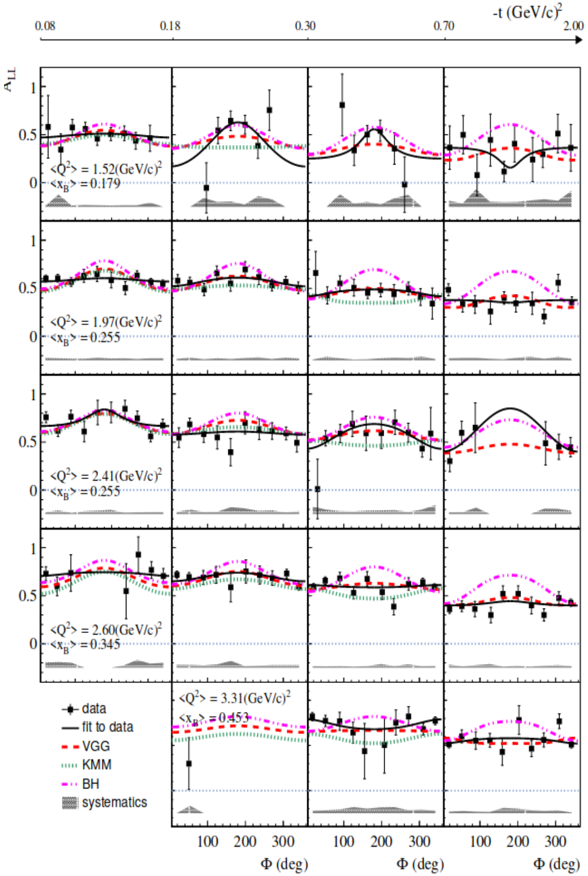
[DOI: 10.25777/36yz-ft35]

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



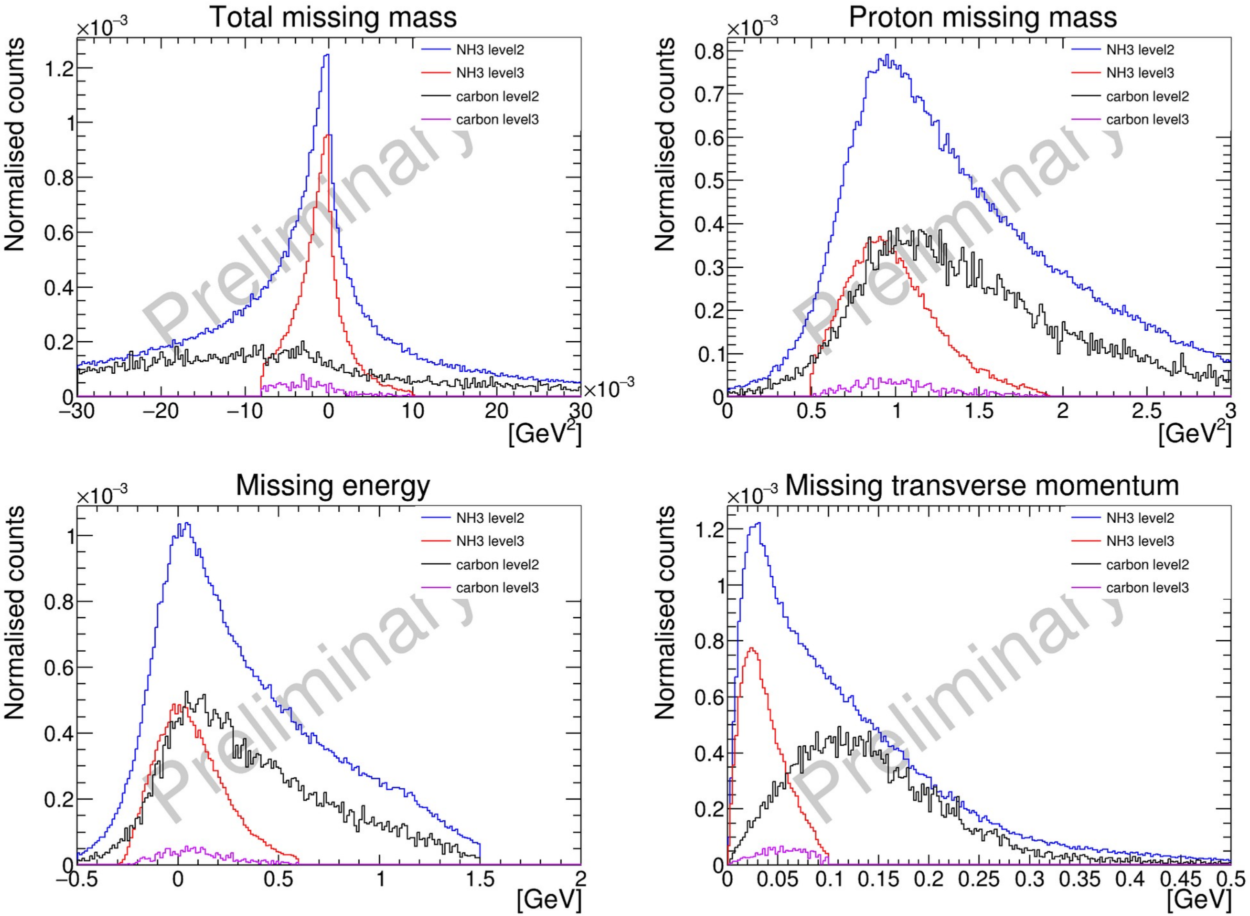




[arXiv:1501.07052]

DVCS Event selection

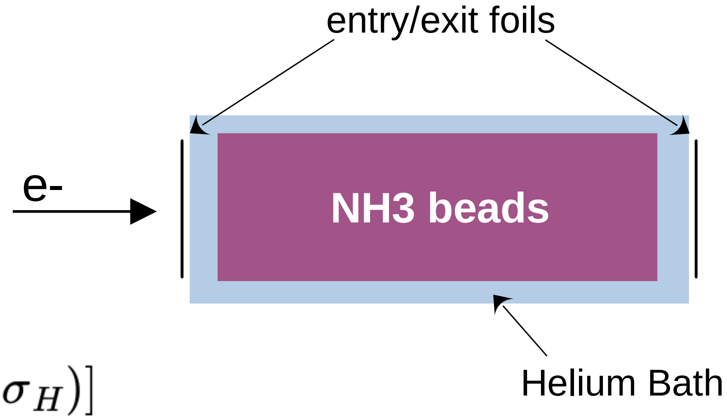
- The event must have at least one electron one proton and one photon
- Apply particle identification and fiducial cuts
- Exclusive process → exclusivity variables
- Nuclear background due to the unpolarised nitrogen in the target
  - Data taken on Carbon target to estimate the background
- Apply exclusivity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



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



$$n_{NH3} = f_c[(L - l_{NH3})\rho_{He}\Delta\sigma_{He} + l_{NH3}\rho_{NH3}(\frac{7}{6}\Delta\sigma_C + 3\Delta\sigma_H)]$$

- RGC took data with multiple targets:
  - Empty target → Foil contribution
  - He bath → He contribution
  - Carbon → Nitrogen contribution
  - CH2 → Hydrogen contribution

Target	Fcup (mC)	#events after cuts
Empty target	0.47	3
He bath	0.35	200
C	0.44	550
CH2	0.19	2.5k
NH3	4.28	60k

[S.E. Kuhn]

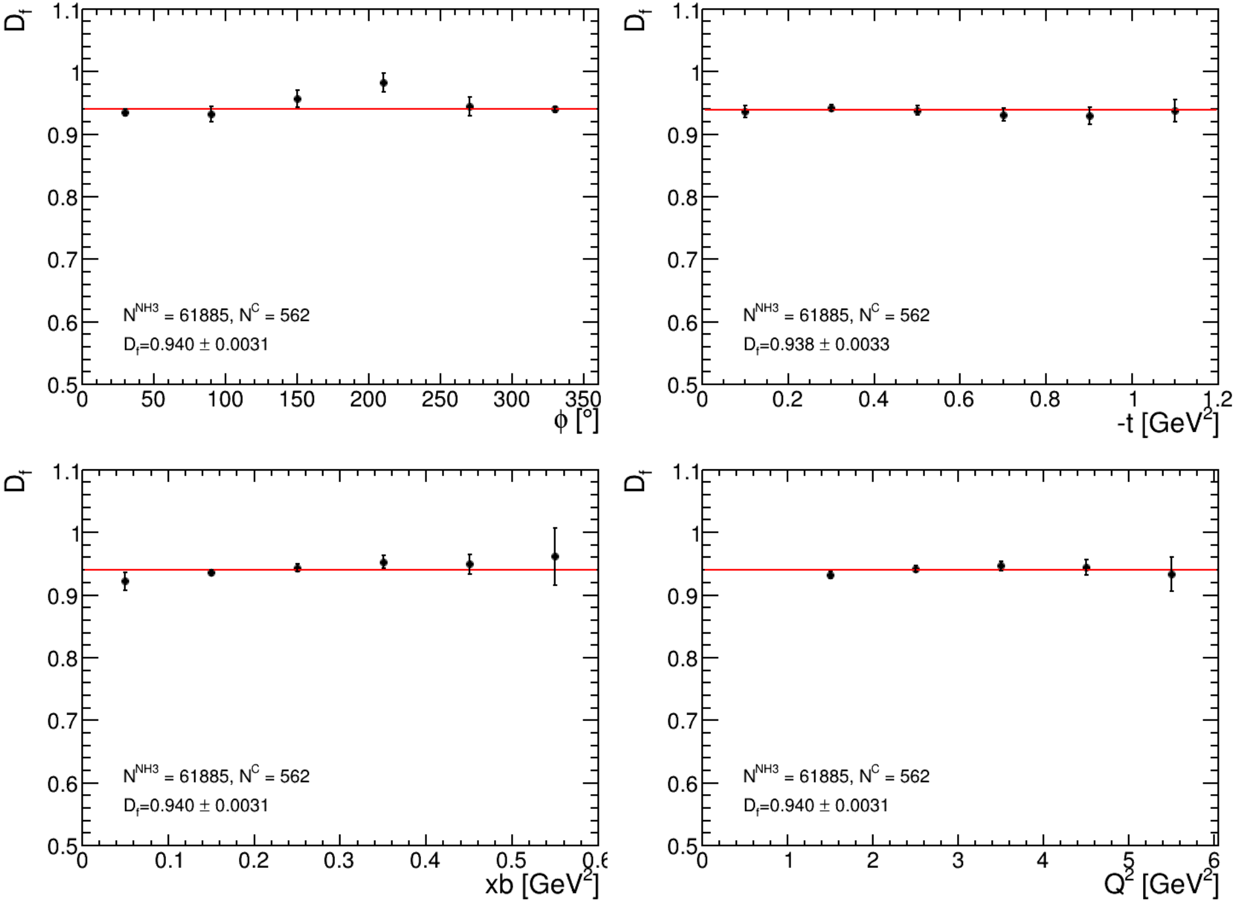
Dilution factor

$$Df = \frac{3l\rho_{NH3}\Delta\sigma_H}{(L-l)\rho_{He}\Delta\sigma_{He} + l\rho_{NH3}(\frac{7}{6}\Delta\sigma_C + 3\Delta\sigma_H)}$$

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

- Target packing fraction : ~57%

D_f = 94 ± 1 %



Target polarisation

N. Pilleux

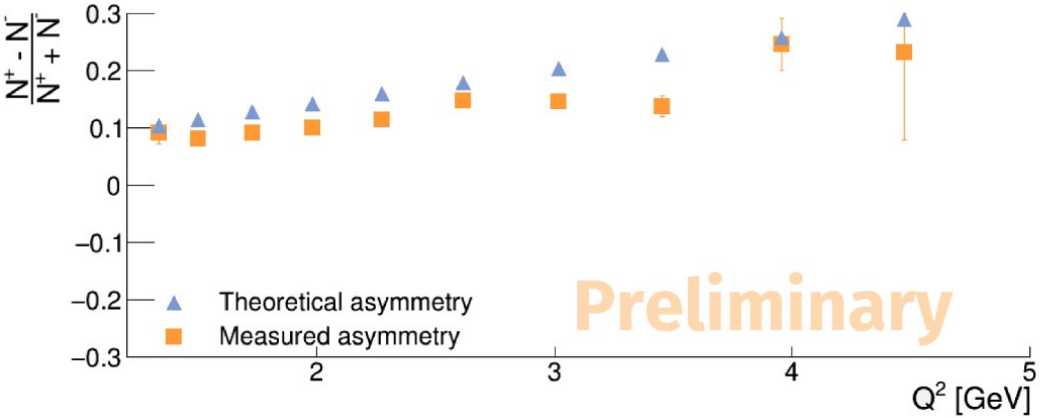
$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^{-}(N^{++} + N^{-+}) + P_t^{+}(N^{+-} + N^{--})}$$

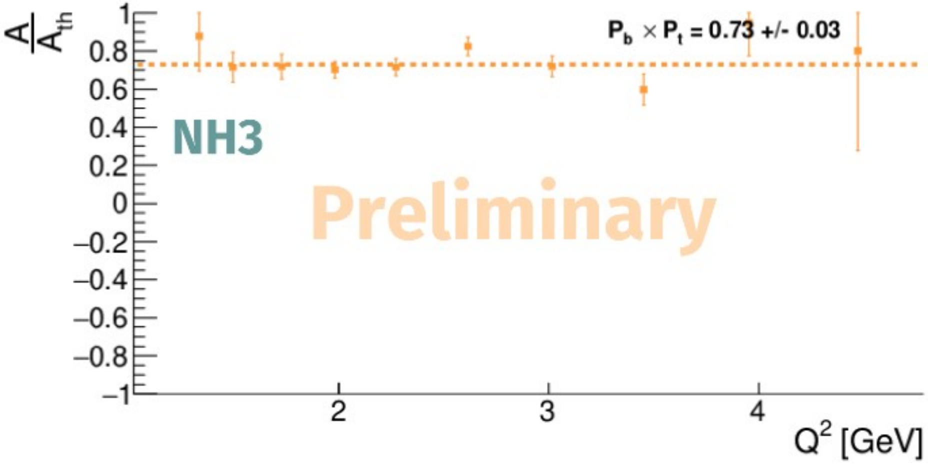
- The ep→e'p' **elastic** double spin asymmetry is well known

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

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

P_t^{+} = 87 ± 3 %
P_t^{-} = 80 ± 3 %





Yields and π^0 background

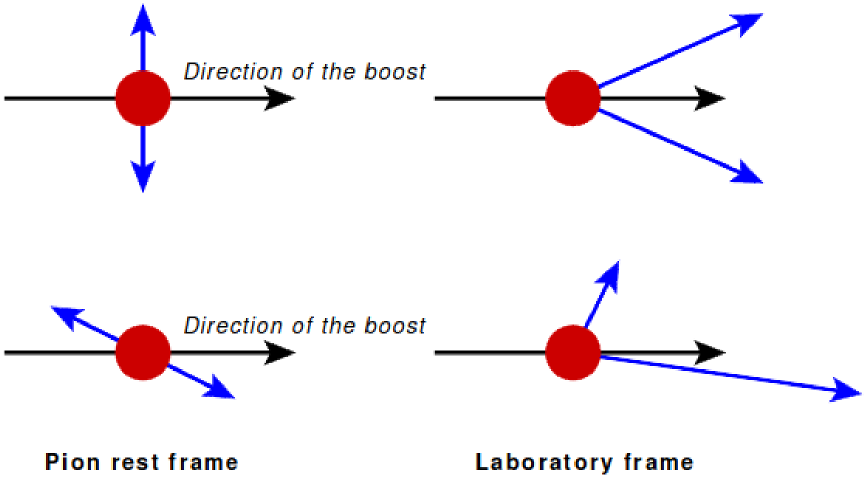
$$A_{UL} = \frac{1}{D_f} \frac{N^{++} + N^{-+} - N^{+-} - N^{--}}{P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--})}$$

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

- 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 $\pi^0 \to \gamma\gamma$ 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

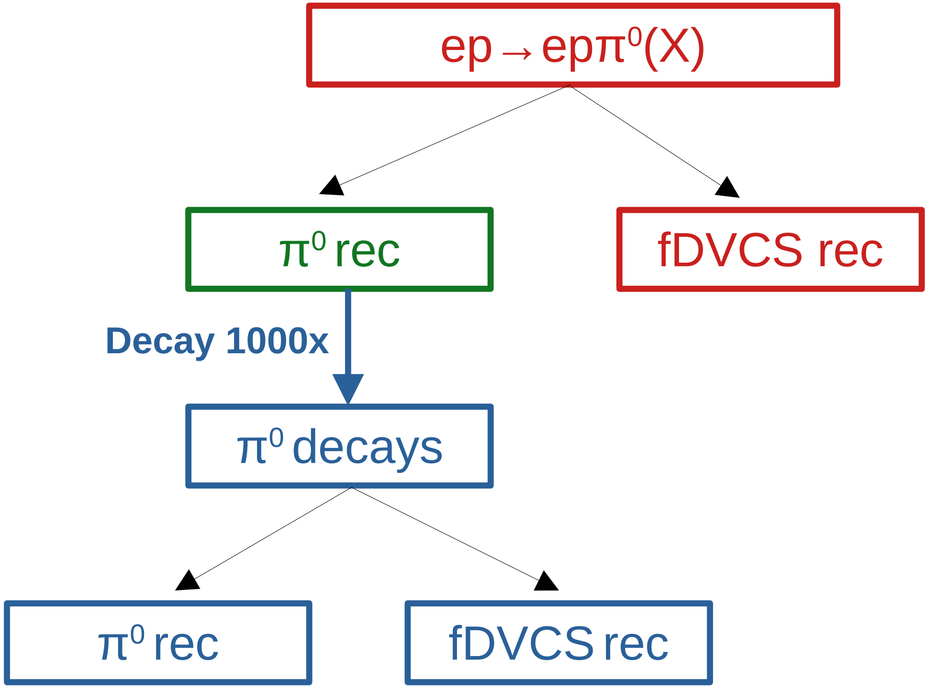
π^0 events that pass the DVCS selection
→ What we need to estimate

π^0 rec

Wide π^0 sample selected from data
with loose exclusivity cuts

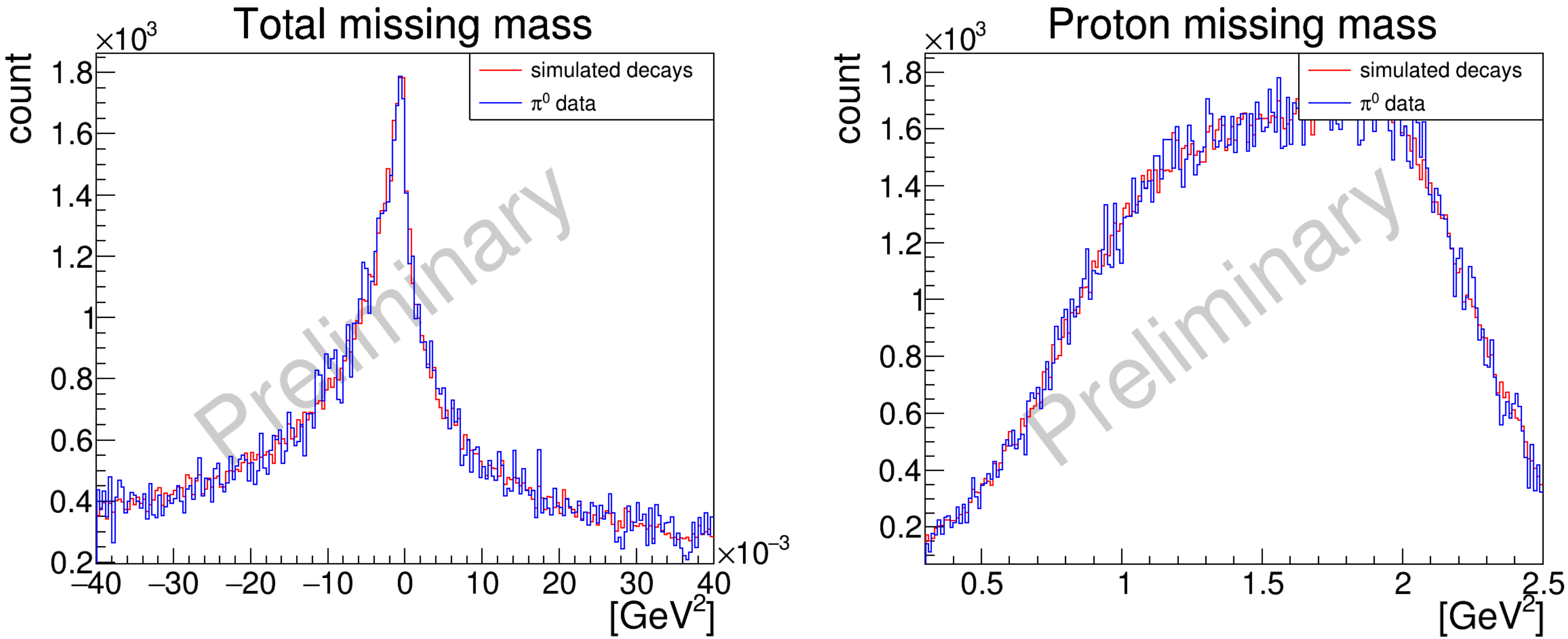
π^0 decays

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



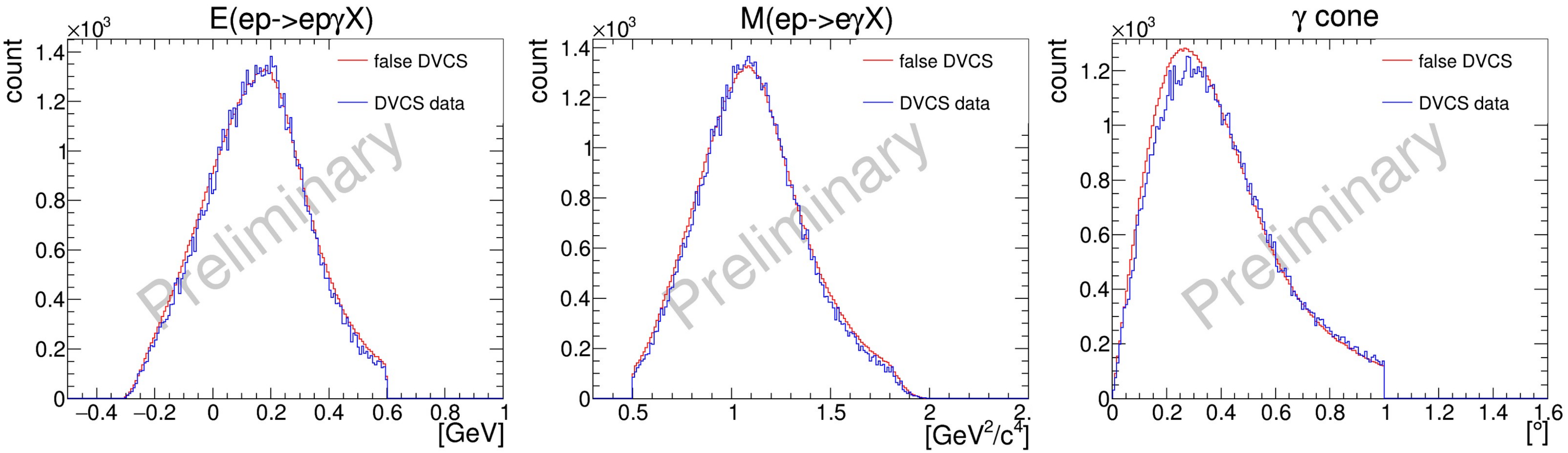
π^0 data and decays

- The π^0 decay distributions matches data



Method validation

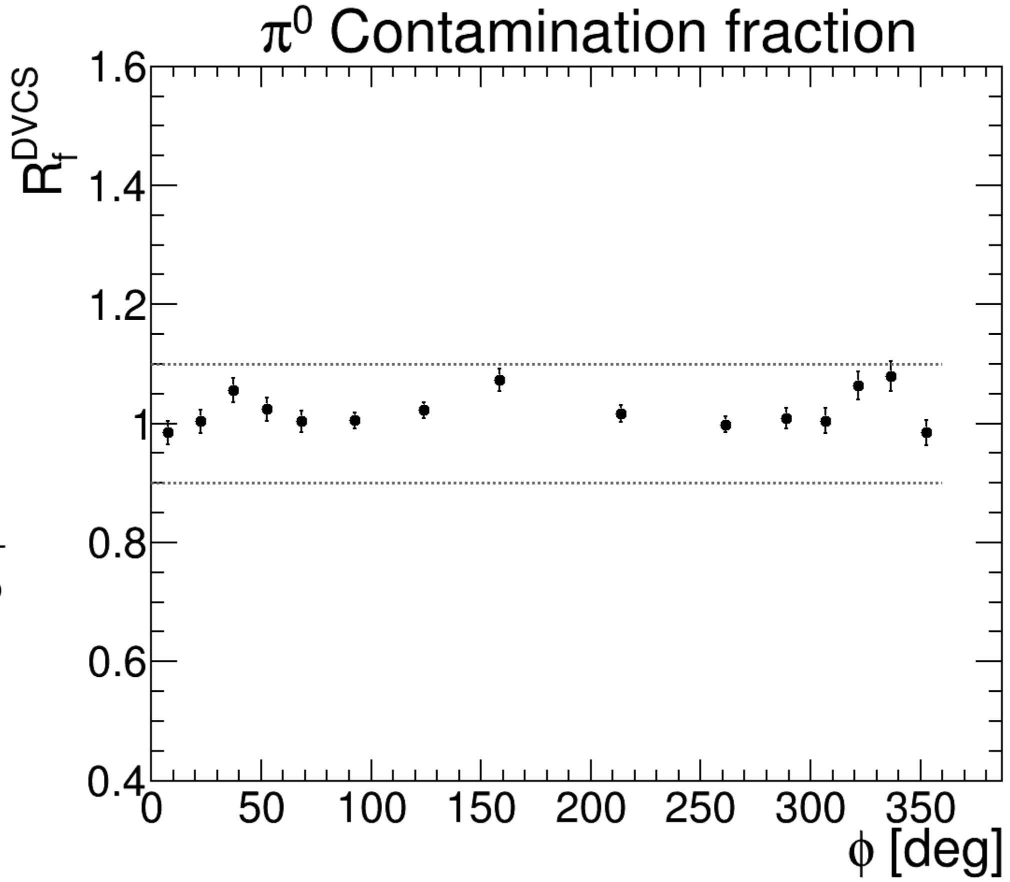
- Apply the method to a π^0 simulation
- All events reconstructed as DVCS are background contamination
  - ➔ The false DVCS distribution estimated match the mock data well



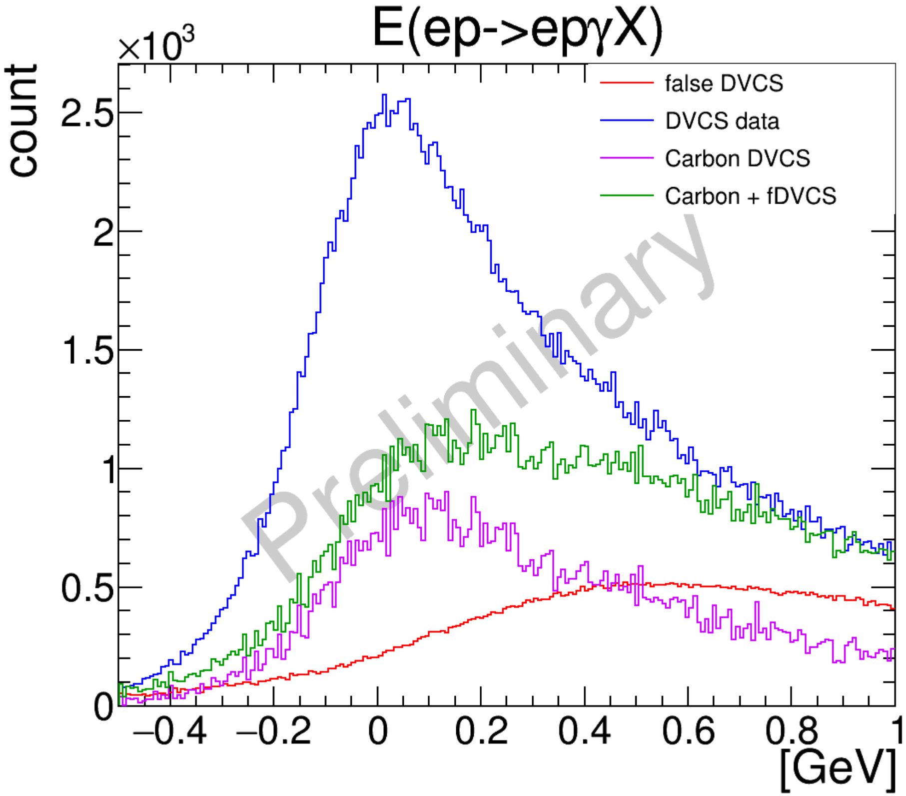
Method validation

- 100% contamination fraction
- Evaluate a 10% systematic on the subtraction method

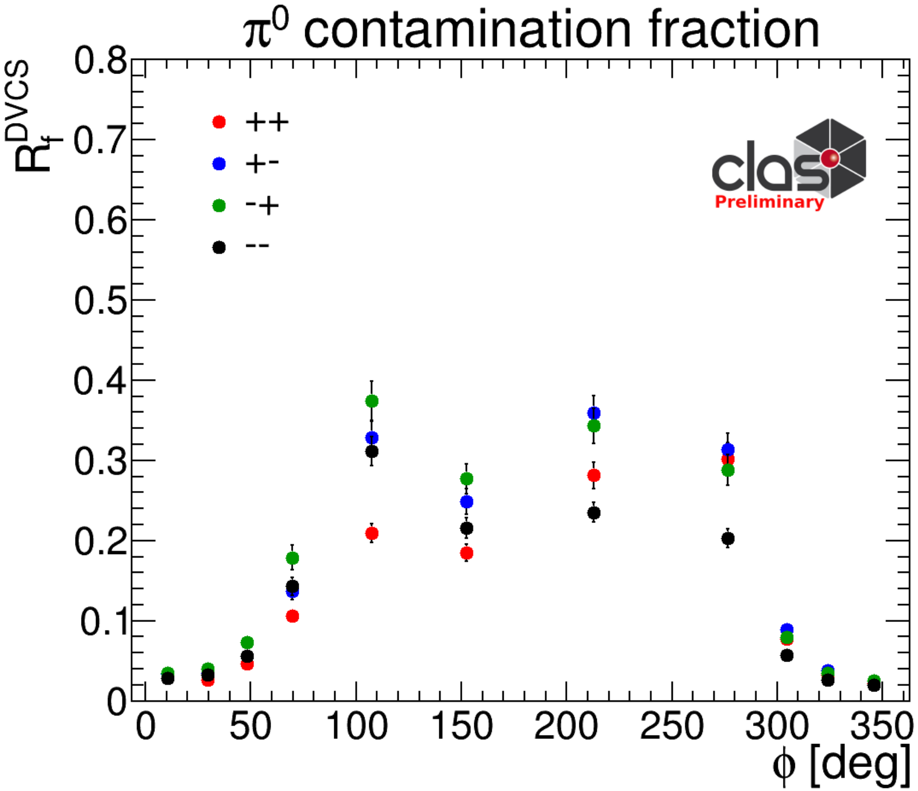
$$R^{bt} = \frac{\text{decay fDVCS}}{\text{decay } \pi^0} \times \frac{\text{data } \pi^0}{\text{data DVCS}}$$



π^0 contamination in data



Wide exclusivity cuts, data event distribution overlaid with π^0 and nuclear background

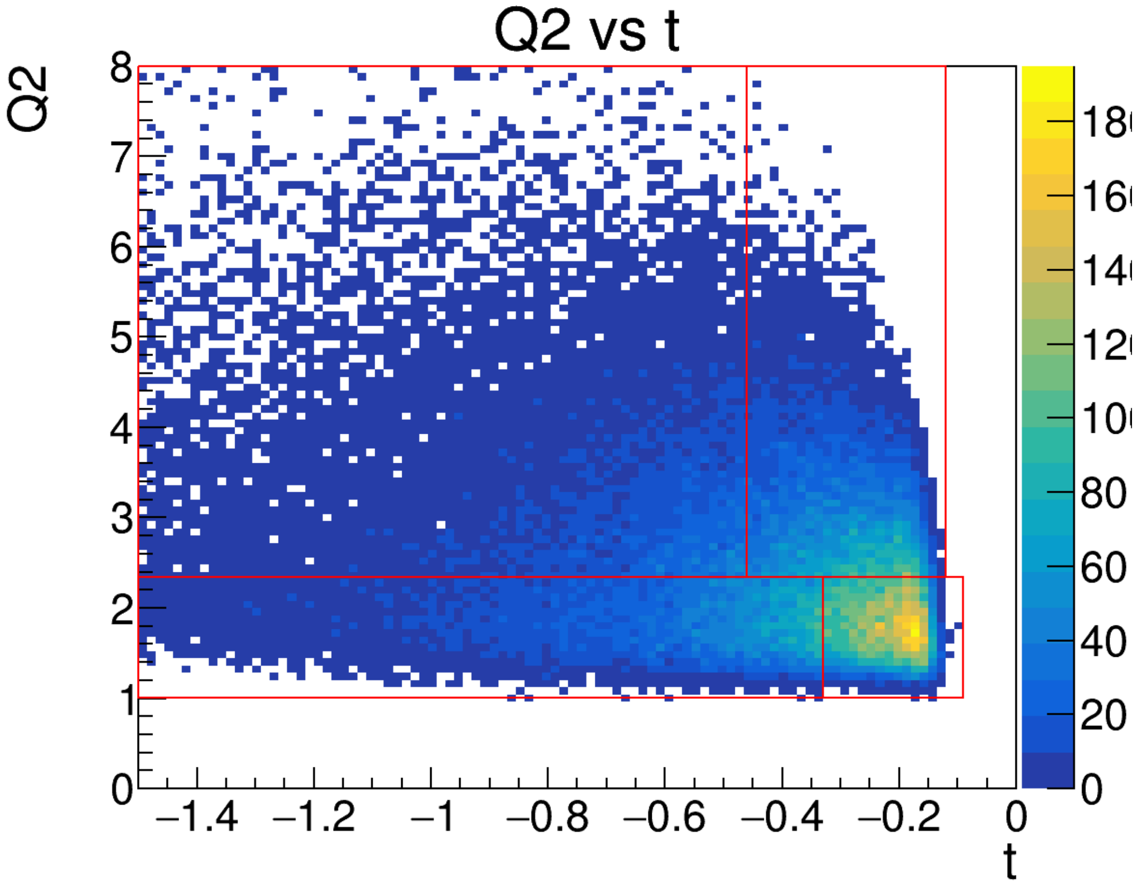


Contamination fraction after the final strict exclusivity cuts

Binning

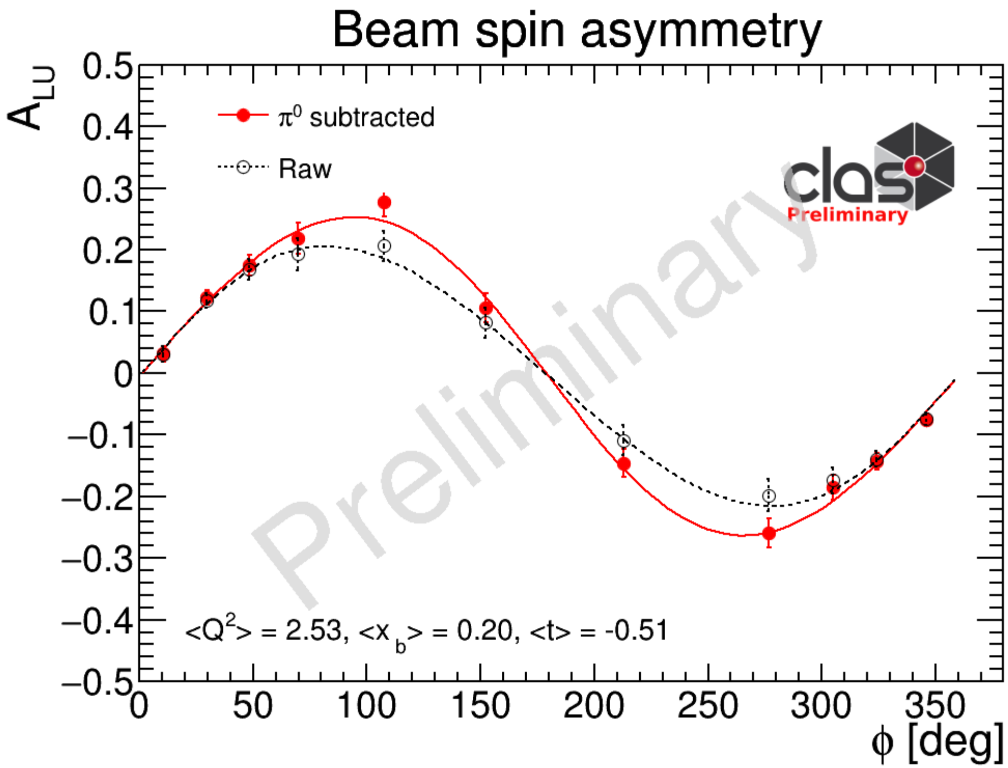
- 2 bins in Q^2, t, x_b so that there is the same number of events per bin

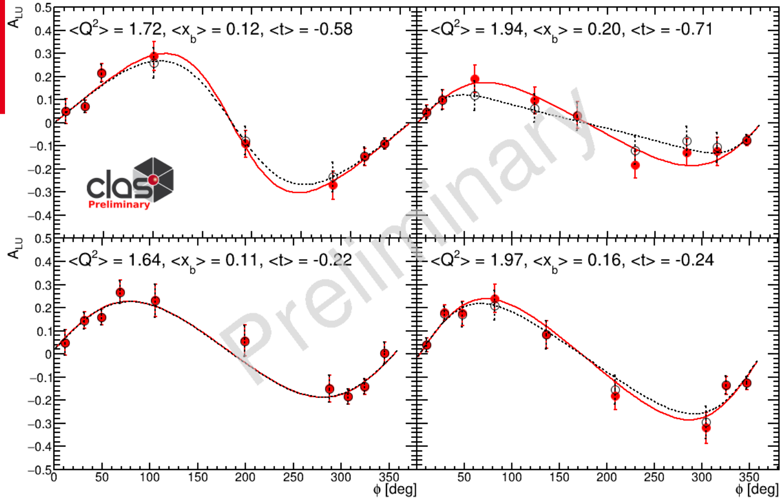
- N bins in phi with at least 500events per bin and at least 15° wide.

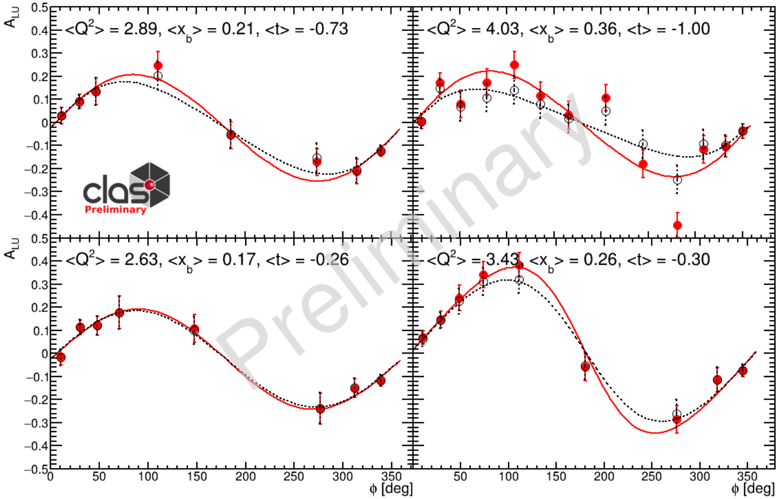


Beam spin asymmetry

- Only statistical errors are included

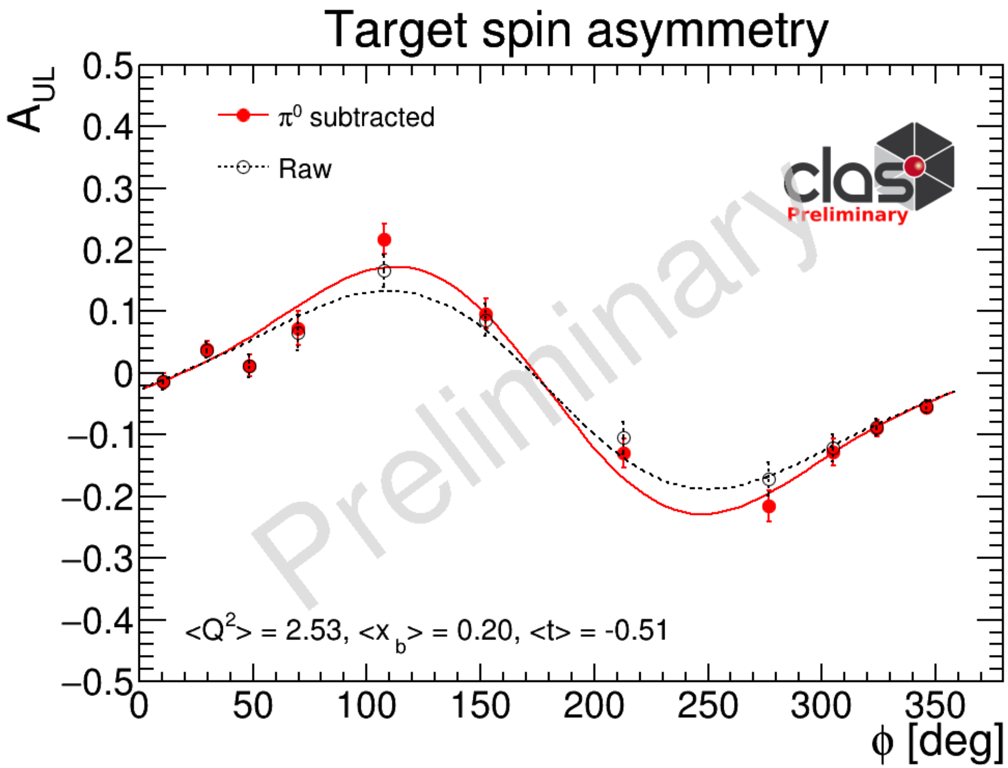


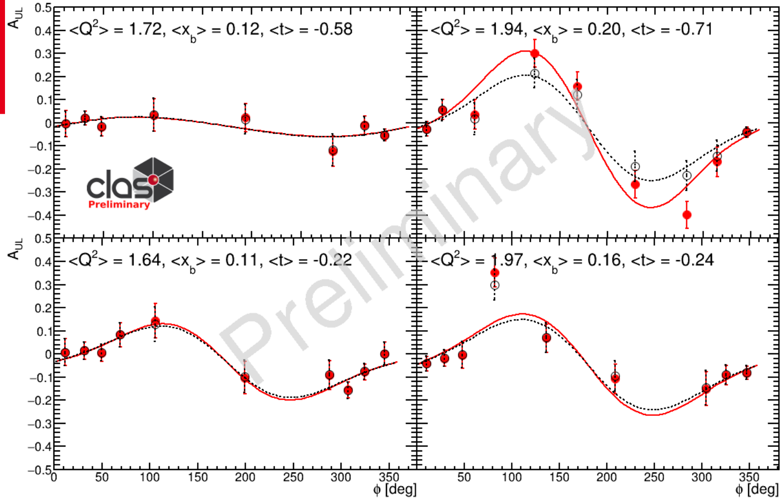


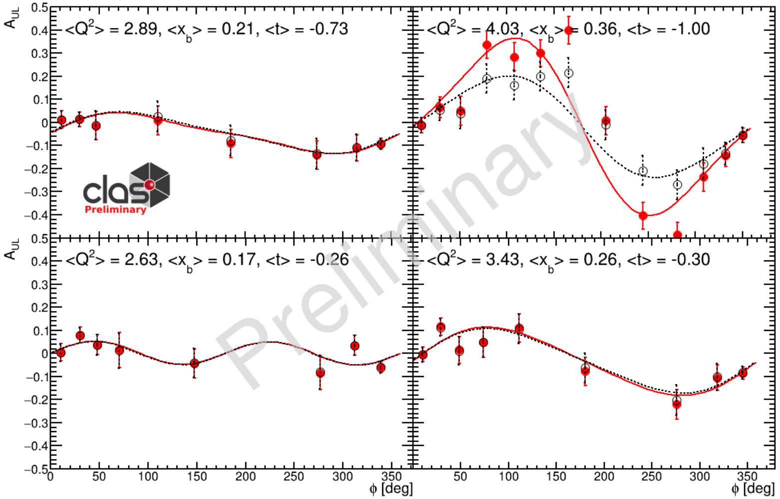


Target spin asymmetry

- Only statistical errors are included







Work in progress: Mahalanobis distance cut

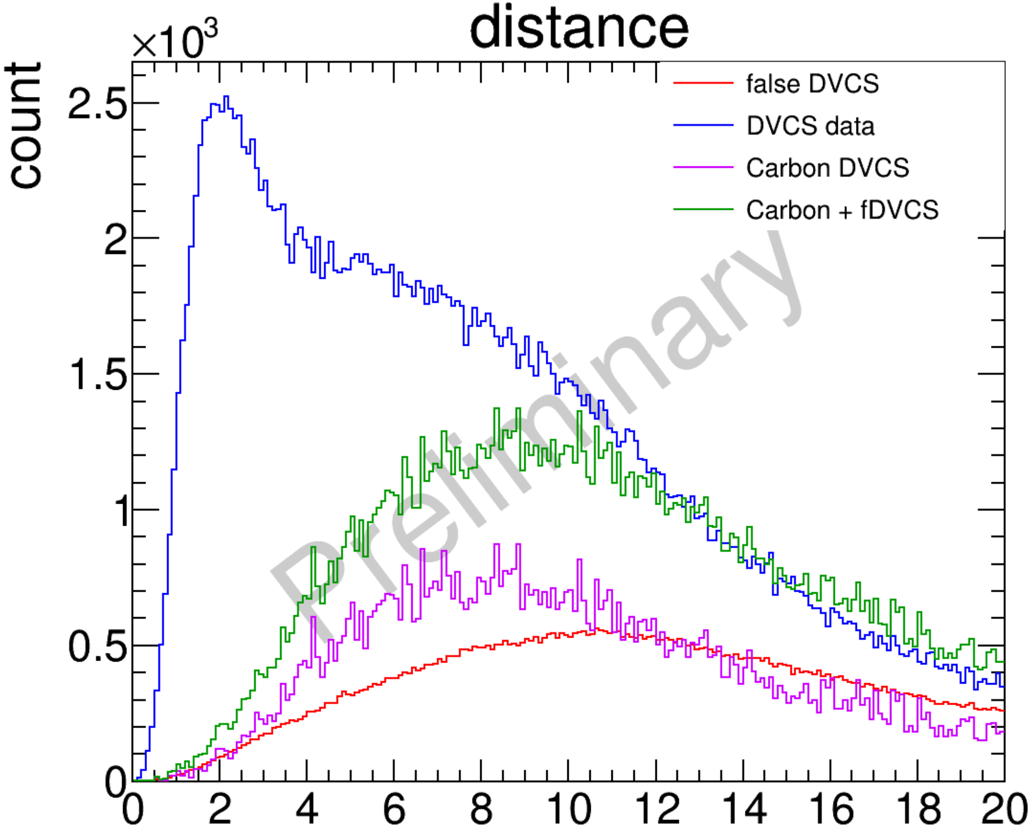
- 1D cuts on 8 different variables are difficult to adjust systematically
- We know the value of each variable for an ideal exclusive event

➔ Define a distance between each event to that ideal reference

➔ Mahalanobis distance: distance weighted by the covariance matrix between all variables

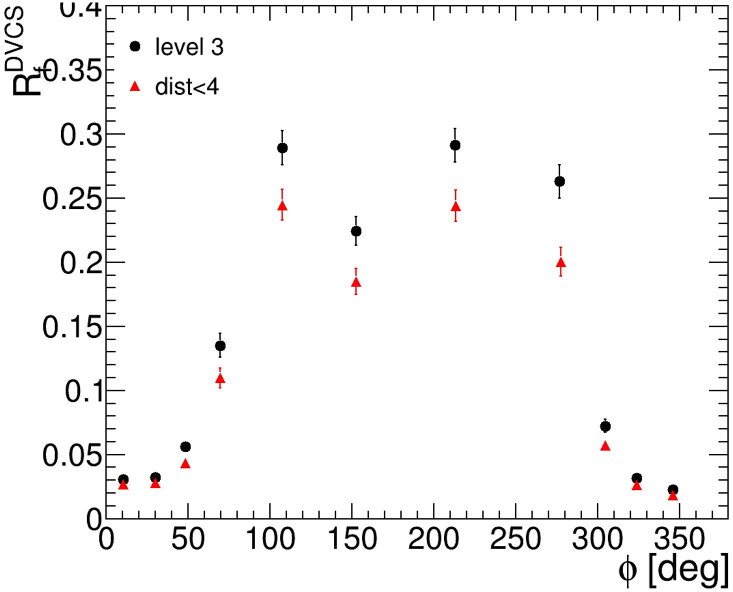
➔ The covariance matrix is taken from a GEMC dvcs simulation

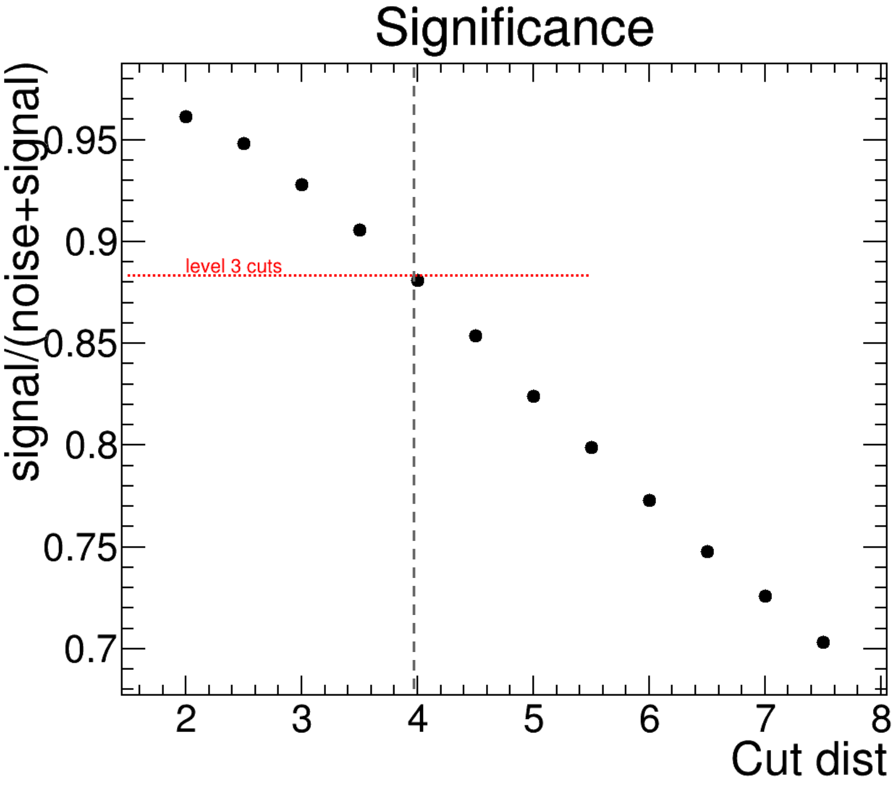
$$d(\vec{x},\vec{y}) = \sqrt{(\vec{x}-\vec{y})^T\Sigma^{-1}(\vec{x}-\vec{y})}$$



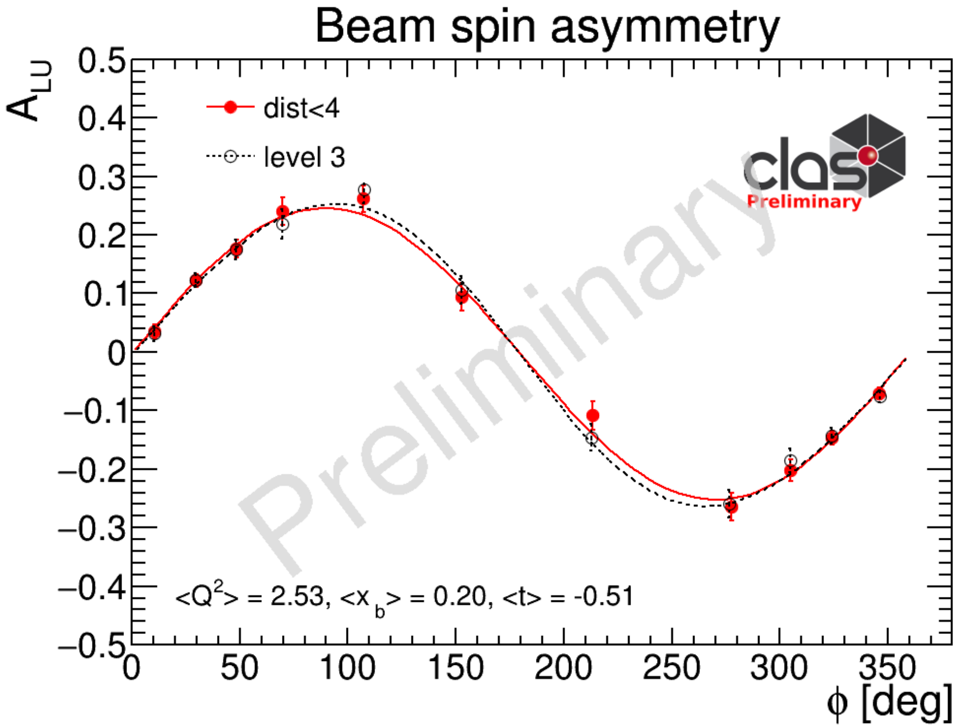
Work in progress: Mahalanobis distance cut

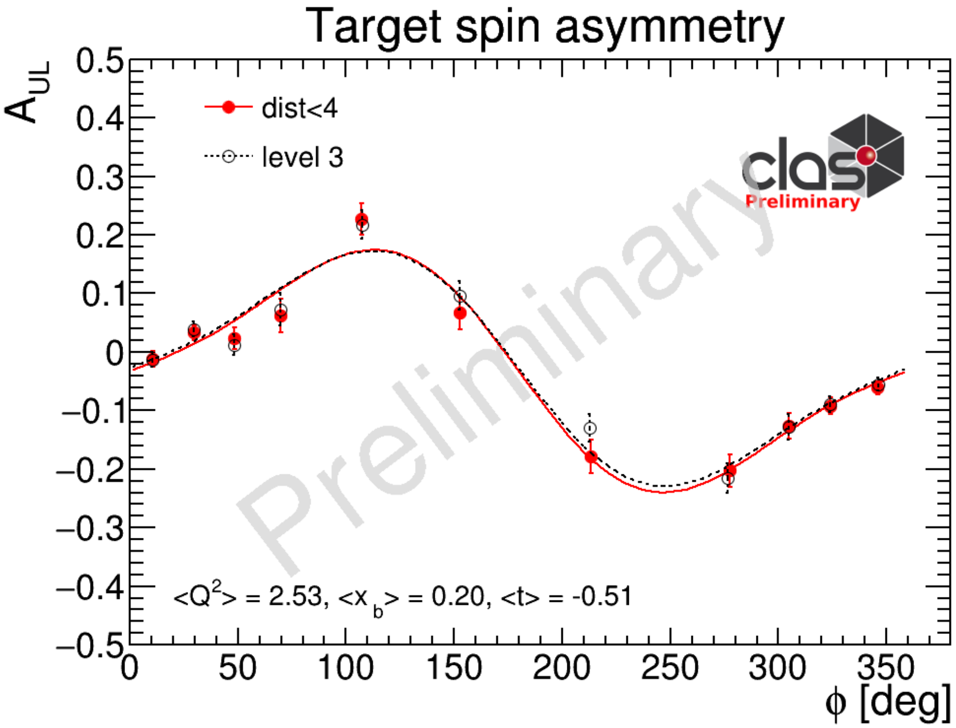
- Cut at distance<4 to have a cut comparable to the 1D cuts
- **10% increase in statistics**, more π^0 background is removed but the dilution factor goes from 94% to 92%



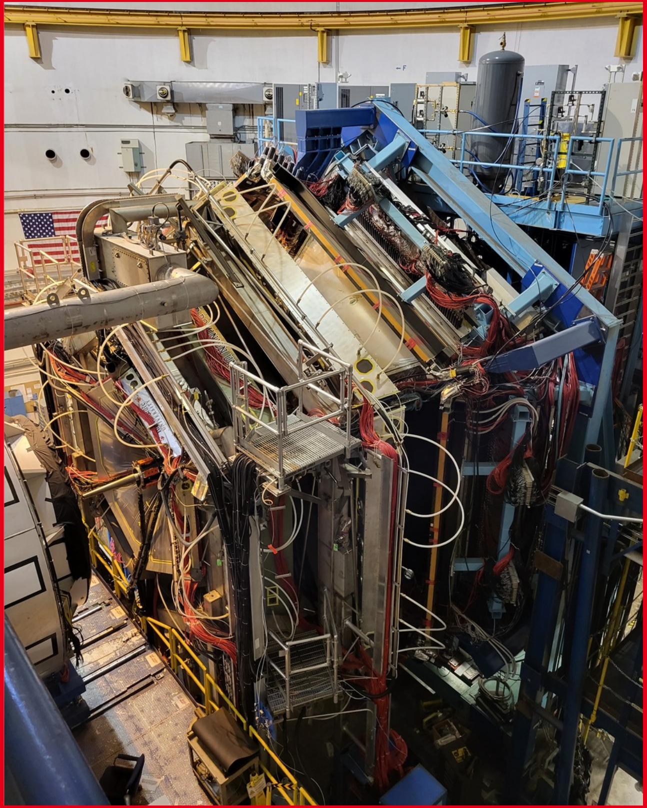


Work in progress: Mahalanobis distance cut





Summary & Outlook

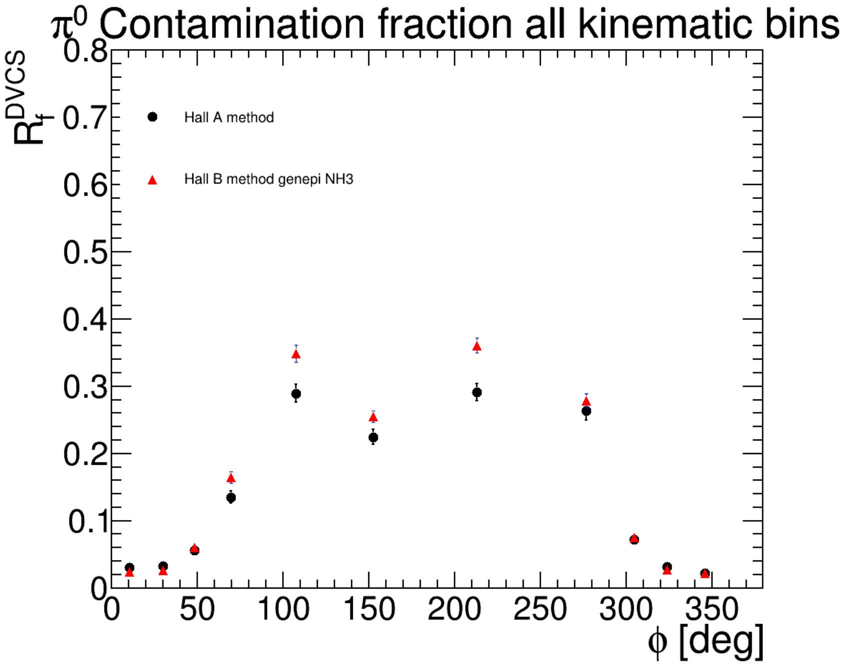


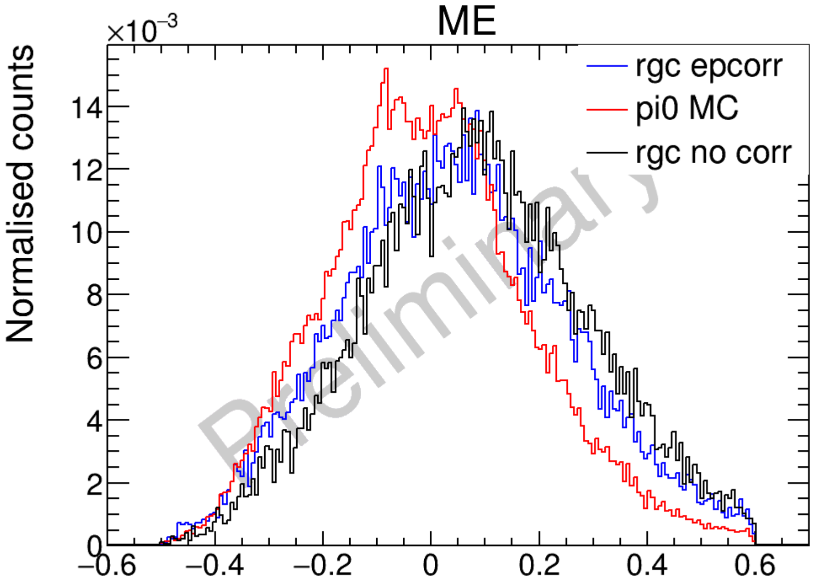
- RGC is the first polarised target experiment with the CLAS12 detector
- The pDVCS analysis is ongoing and shows promising results
- Tools are in place to take into account nuclear and π^0 backgrounds
- The main remaining steps are:
  - Refined momentum correction
  - Systematic error estimates
- The 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.

π^0 method comparison

- Full Monte-Carlo method, the 1ɣ to 2ɣ acceptance ratio is computed from a simulation and scaled to data
- Genepi π^0 simulation on NH3 target

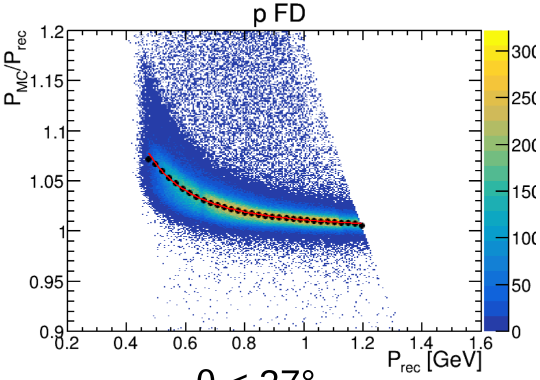
$$R^{fDVCS} = \frac{N^{\gamma}_{MC}}{N^{\gamma\gamma}_{MC}} \times \frac{N^{\pi^0}_{Data}}{N^{DVCS}_{Data}}$$



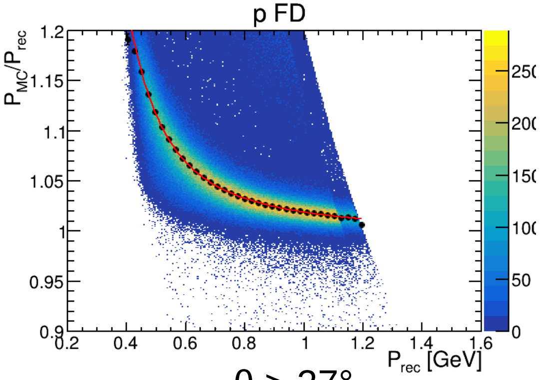


Work in progress: Momentum corrections

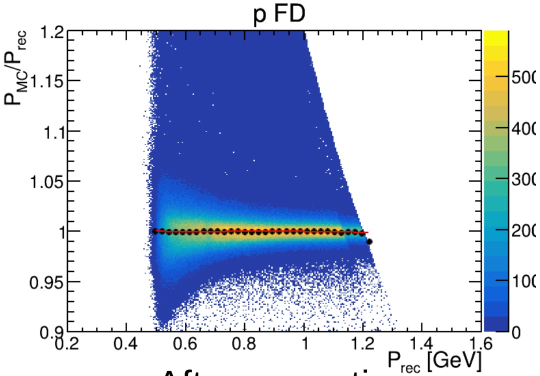
- Electron and proton corrections from Monte-Carlo
- Photon in FT: RGA pass2 correction (Asli Acar)



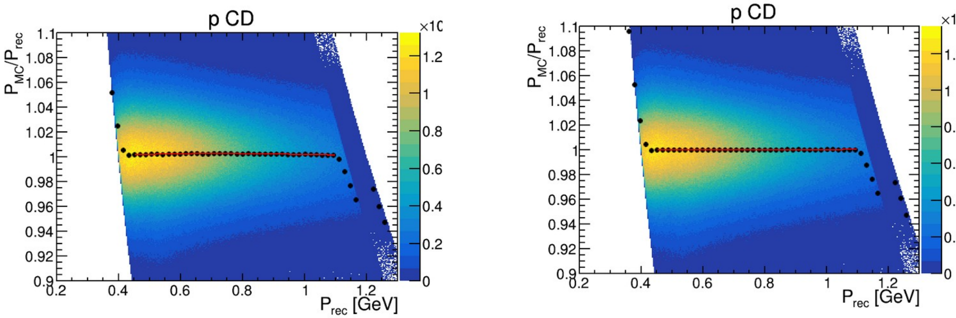
θ < 27°



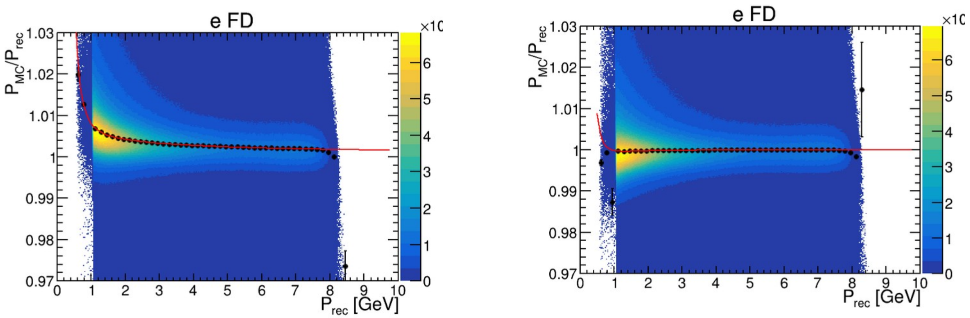
θ > 27°



After corrections



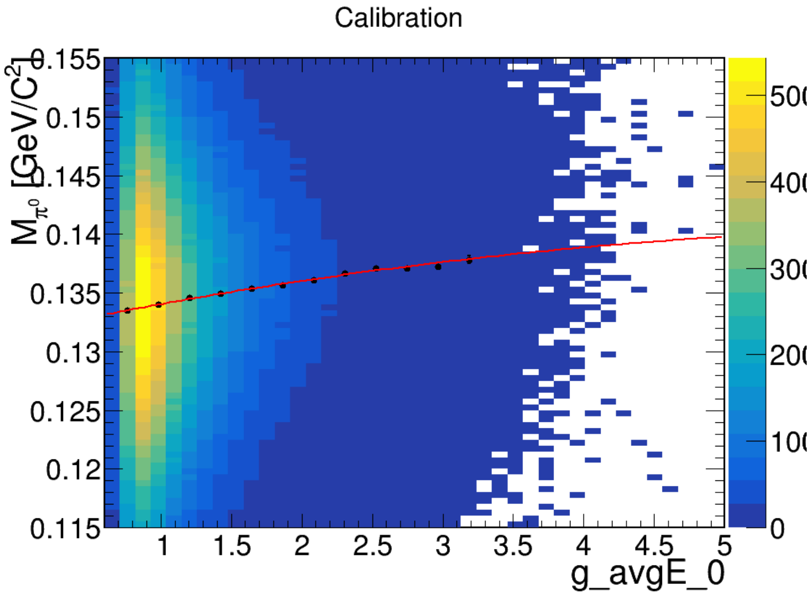
Proton in CD, before/After correction

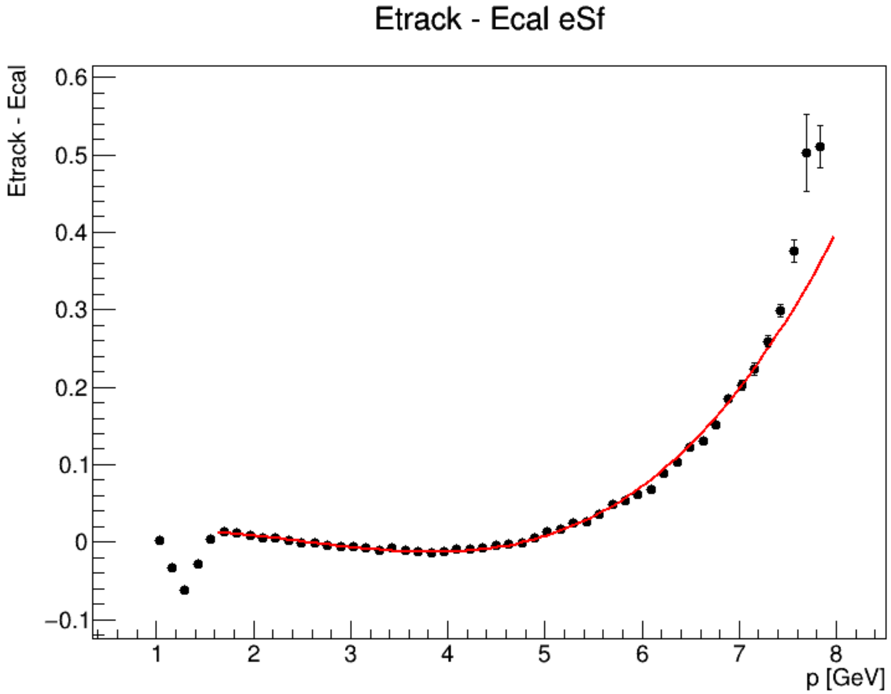


Electron in FD, before/After correction

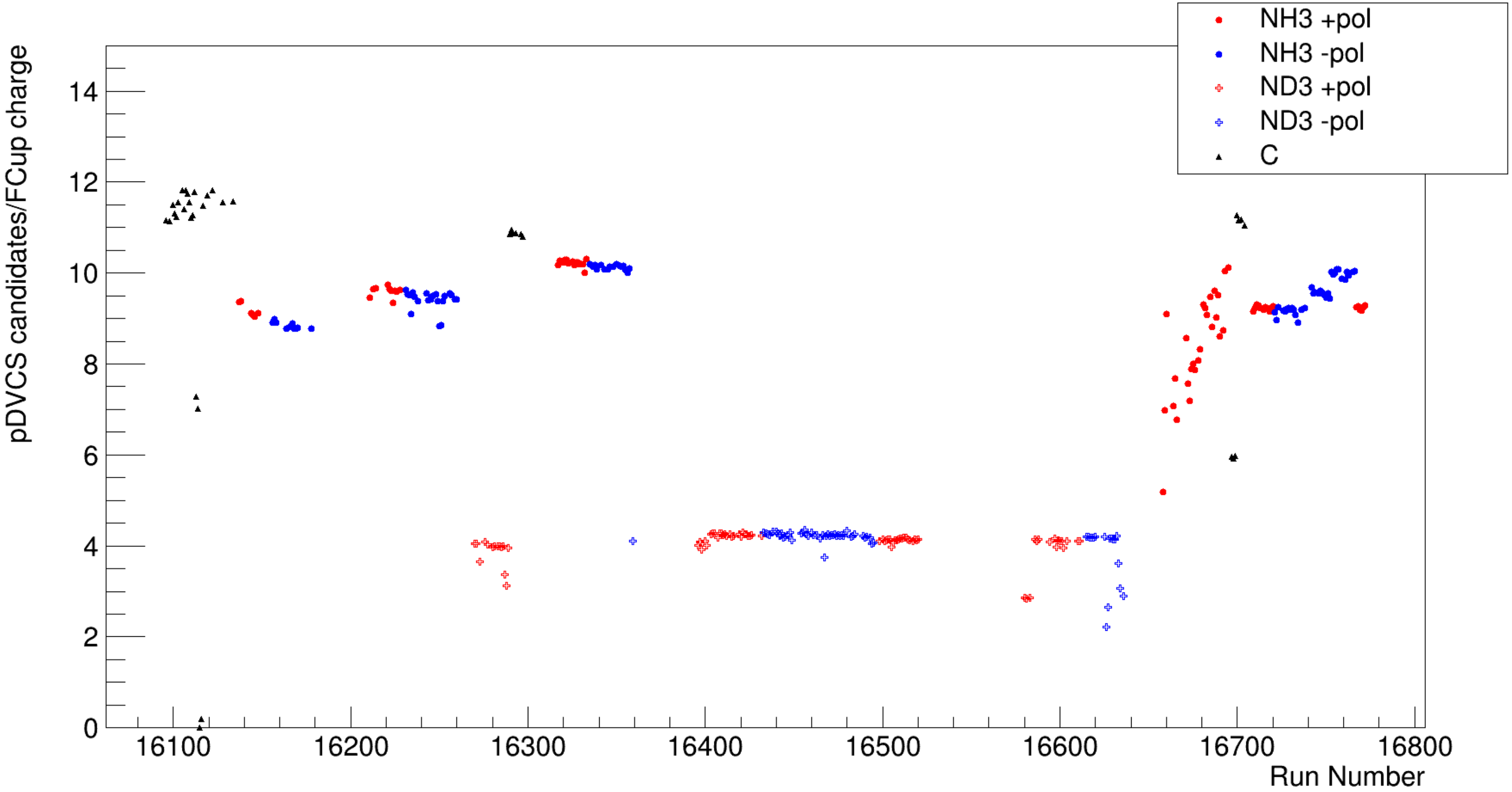
Work in progress: Photon in the FD correction

- Energy correction as a function of momentum from electron (trackin - ECAL energy deposit)
- sector/low E correction with pi0 mass, fit of the pi0 mass for events with |θg1 – θg2|<5°



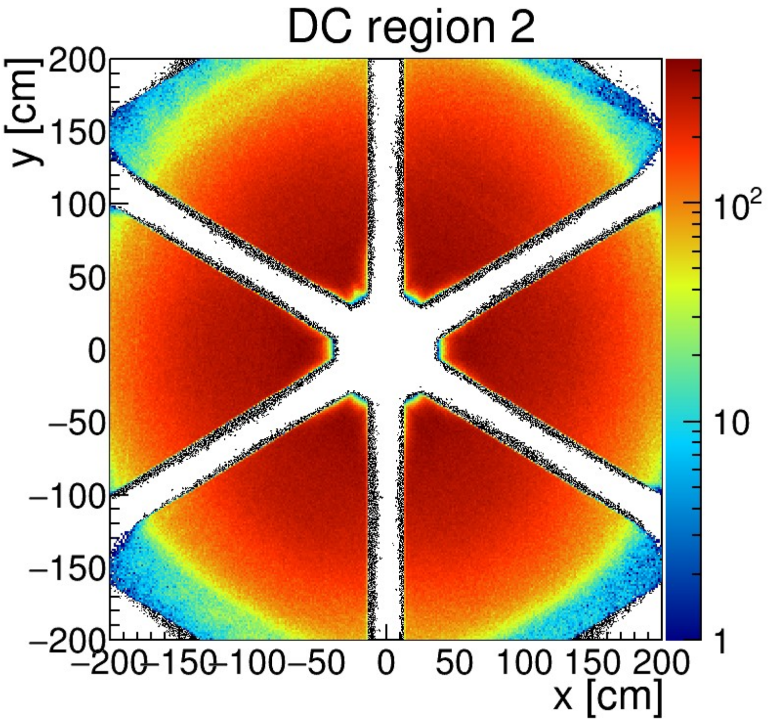


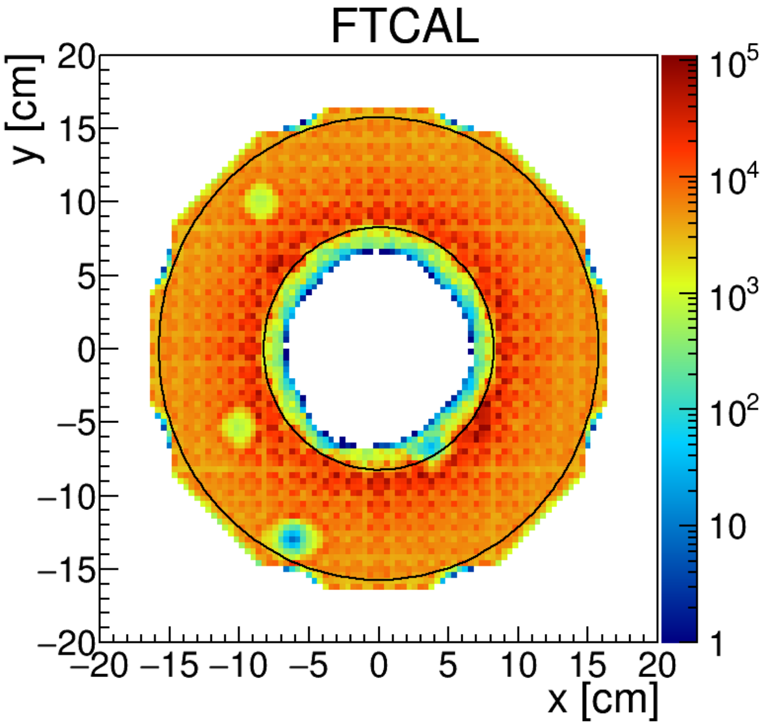
Potential FCup issues



Fiducial cuts, DC and FTCAL

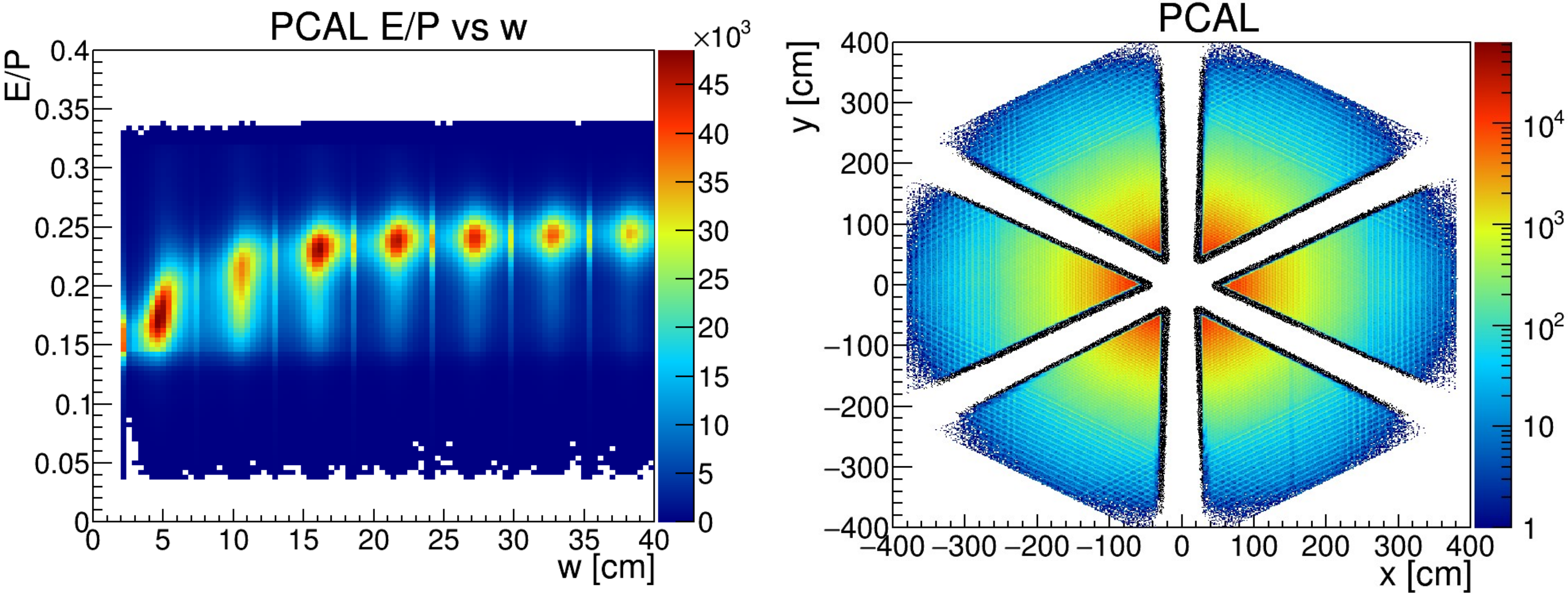
- DC: edge > 4cm on region 2
- FTCAL: 8.25 < r < 15.75 cm





Fiducial cuts PCAL

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



Beam polarisation

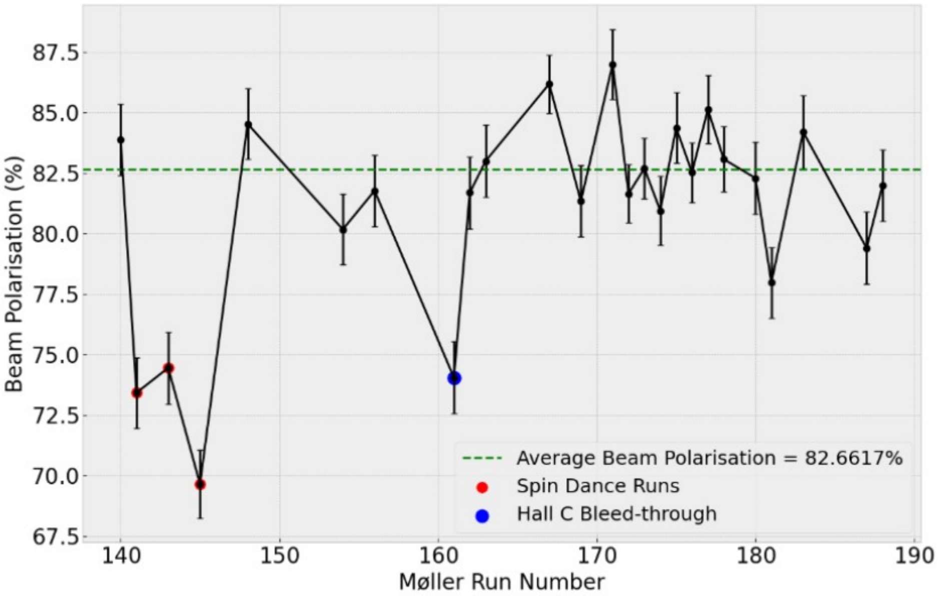
$$A_{\mathrm{LU}} = \frac{P_t^-(N^{++} - N^{-+}) + P_t^+(N^{+-} - N^{--})}{P_b(P_t^-(N^{++} + N^{-+}) + P_t^+(N^{+-} + N^{--}))}$$

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

P_b: Beam polarisation

Measured with a Moller polarimeter regularly all along the experimental run

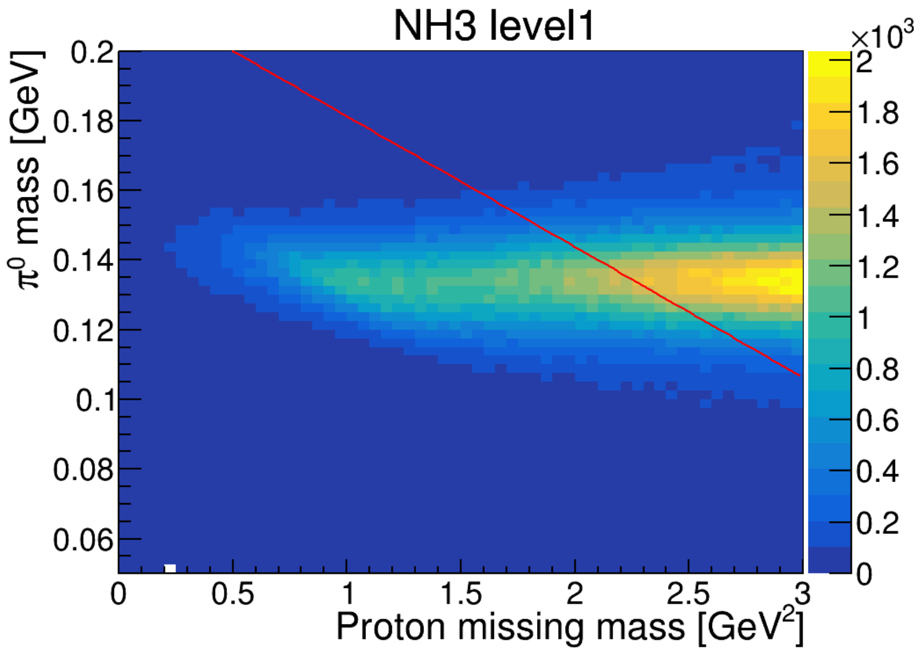
$P_b = 82.6 \pm 0.2$ %

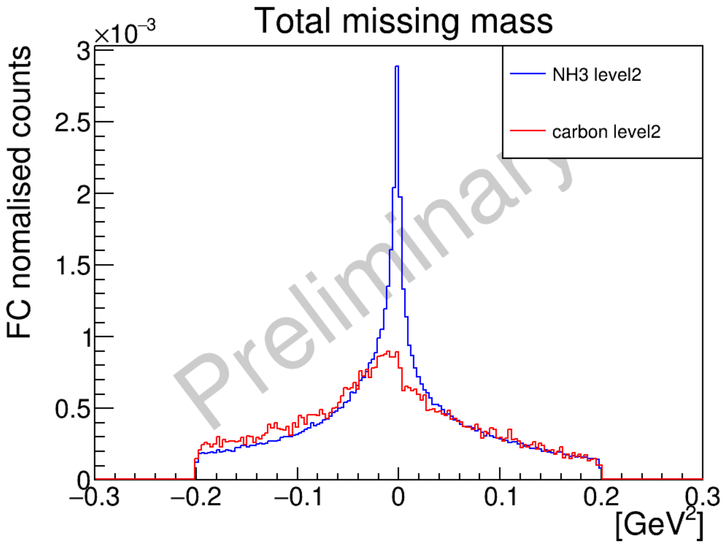


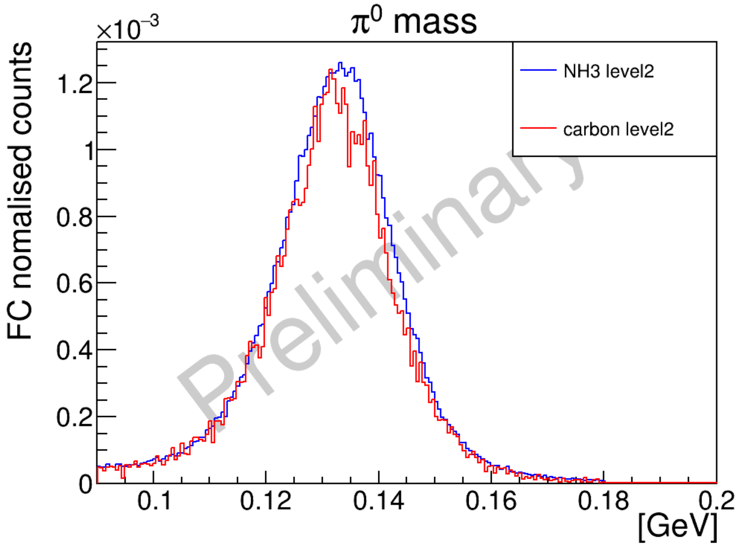
K. Gates

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



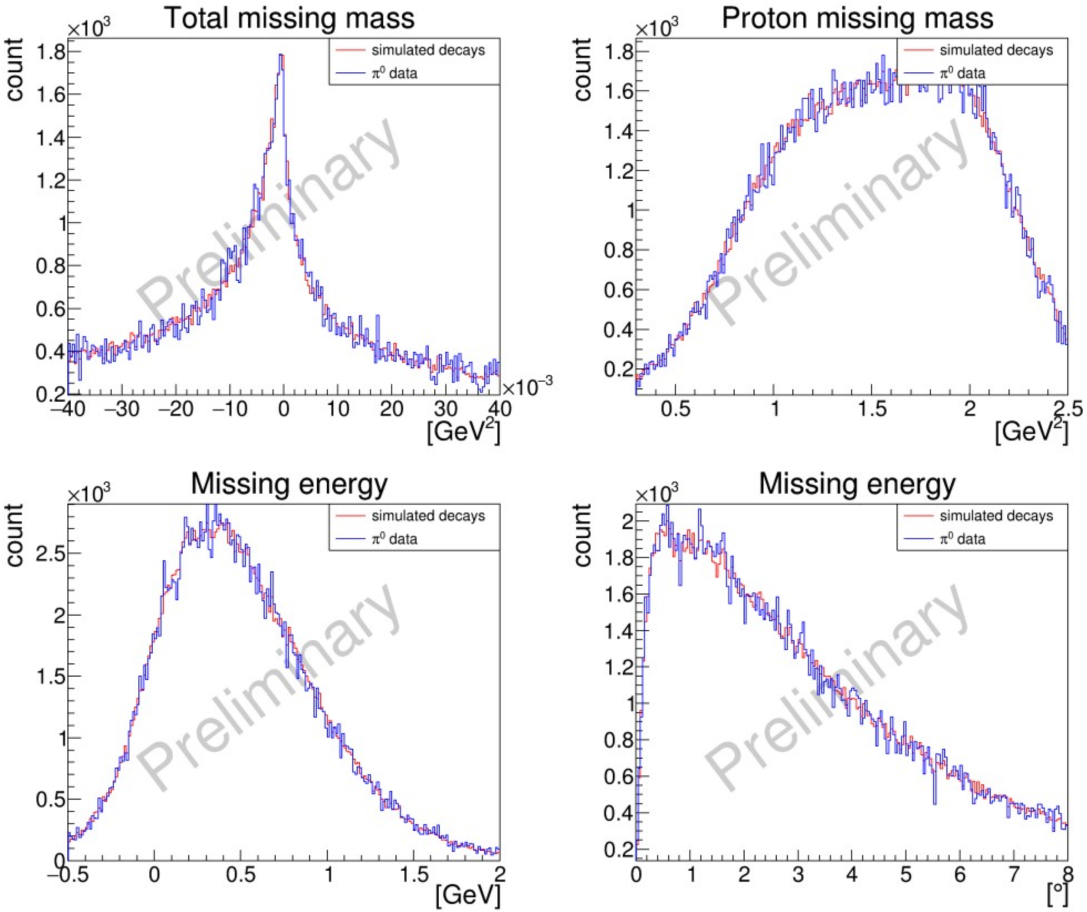




Data and decays agreement

- 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