Peter Hurck

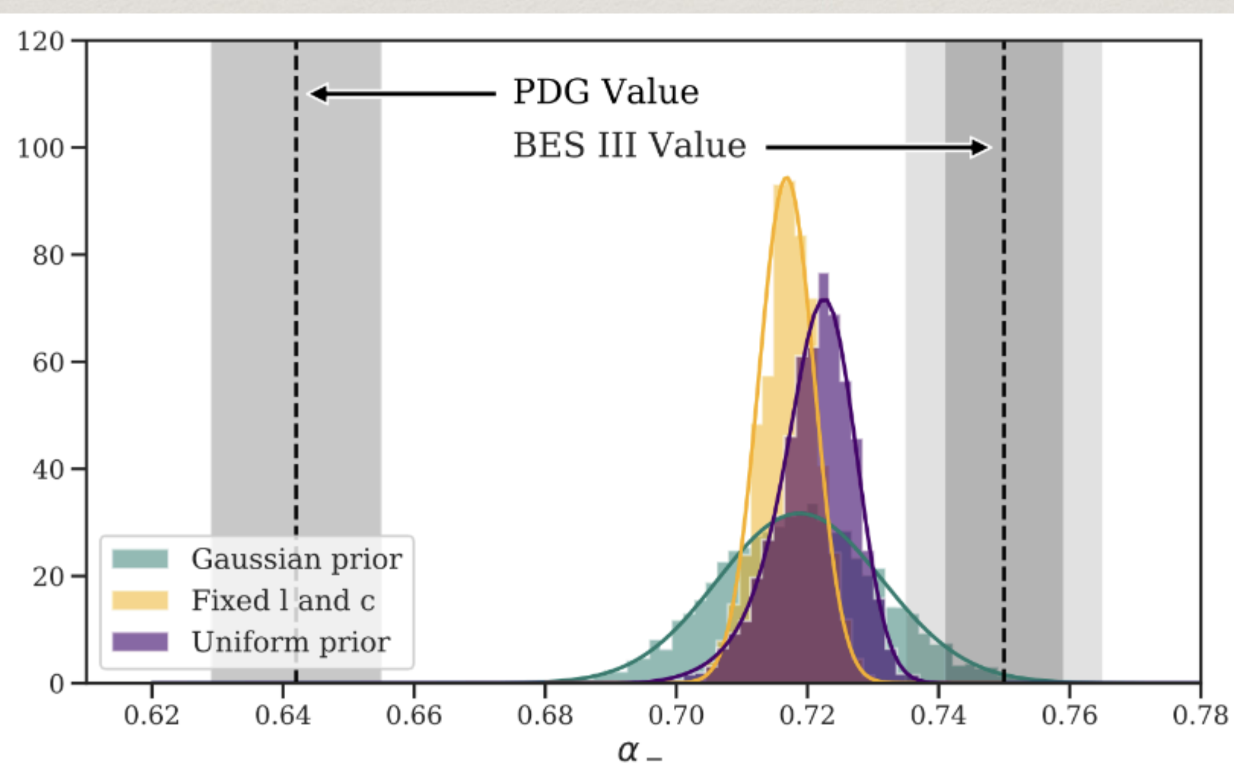
Overview of studies with circular polarisation at GlueX

For the α_{-}^{Λ} group
P. Hurck, D.I. Glazier, D.G. Ireland, K. Livingston
F. Afzal, A. Thiel, Y. Wunderlich
V. Crede
M. M. Dalton

Motivation - the Λ weak decay parameter

- Weak decay parameter α_{-} for $\Lambda \to p\pi^{-}$ is important constant
  - Polarisation observables (self-analysing Λ decay)
  - CP violation measurements
- Affects many reactions decaying through Λ (e.g. Σ, Ξ, Ω)
- PDG until 2019: $\alpha = 0.642 \pm 0.013$
- 2019 BES3: $\alpha = 0.750 \pm 0.009 \pm 0.004$ 420k $J/\psi \to \Lambda\bar{\Lambda}$ events
- 2019 Ireland et al $\alpha = 0.721 \pm 0.006 \pm 0.005$ previously published CLAS $\gamma p \to K^{+}\Lambda$ data (see next slide)

0.584 ±0.046	ASTBURY	1975
0.649 ±0.023	CLELAND	1972
0.67 ±0.06	DAUBER	1969
0.645 ±0.017	OVERSETH	1967
0.62 ±0.07	CRONIN	1963



Our proposal

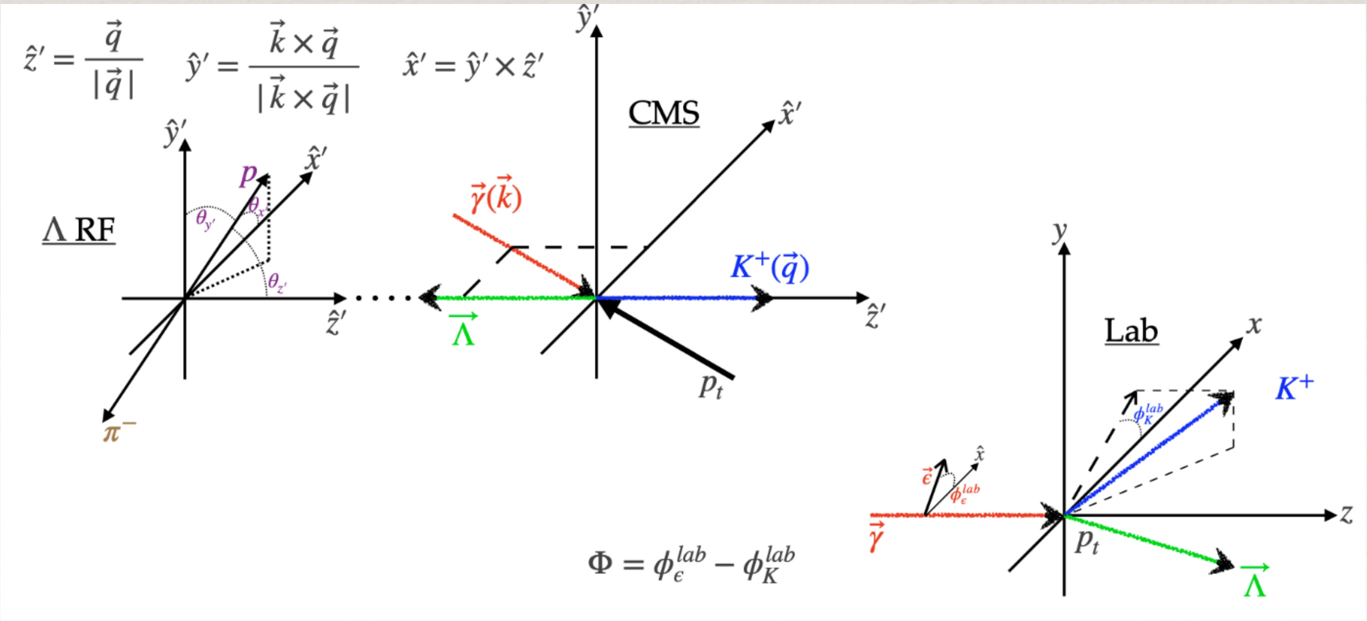
- Provide an independent measurement of α_{-}^{Λ} to resolve remaining discrepancy
- Improve upon the methodology by Ireland et al
- Make a simultaneous measurement of polarisation observables accessible through linearly and circularly polarised photons

$$\begin{aligned} I(\Phi, \theta_{x',y',z'}) = 1 + \alpha_{-} \cos\theta_{y'} P - P_{\gamma}\cos(2\Phi)(\Sigma + \alpha_{-}\cos\theta_{y'} T) \\ - P_{\gamma}\sin(2\Phi)(\alpha_{-}\cos\theta_{x'} O_{x'} + \alpha_{-}\cos\theta_{z'} O_{z'}) \\ - P_{\odot}(\alpha_{-}\cos\theta_{x'} C_{x'} + \alpha_{-}\cos\theta_{z'} C_{z'}) \end{aligned}$$

$$\begin{aligned} \Sigma^2 - T^2 + P^2 + C_{x'}^2 + C_{z'}^2 + O_{x'}^2 + O_{z'}^2 = 1 \\ \Sigma P - T - C_{x'} O_{z'} + C_{z'} O_{x'} = 0 \end{aligned}$$

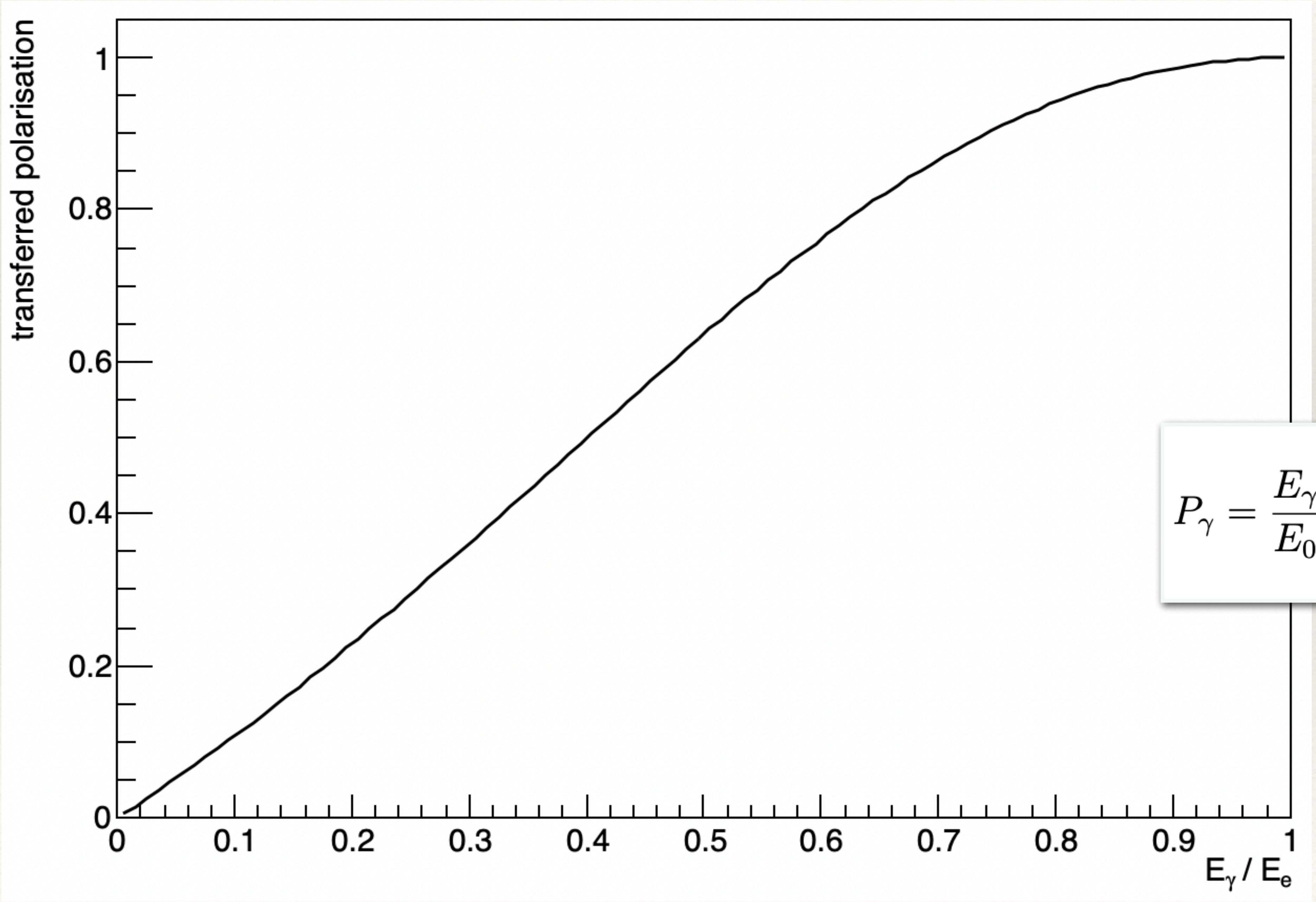
Measured intensity depends on seven polarisation observables which are related through Fierz identities

Overconstrained fit allows α_{-} to be free parameter



Circularly polarised photons

- CEBAF provides longitudinally polarised electrons
- Helicity is transferred to the photon in bremsstrahlung process and results in circularly polarised photons

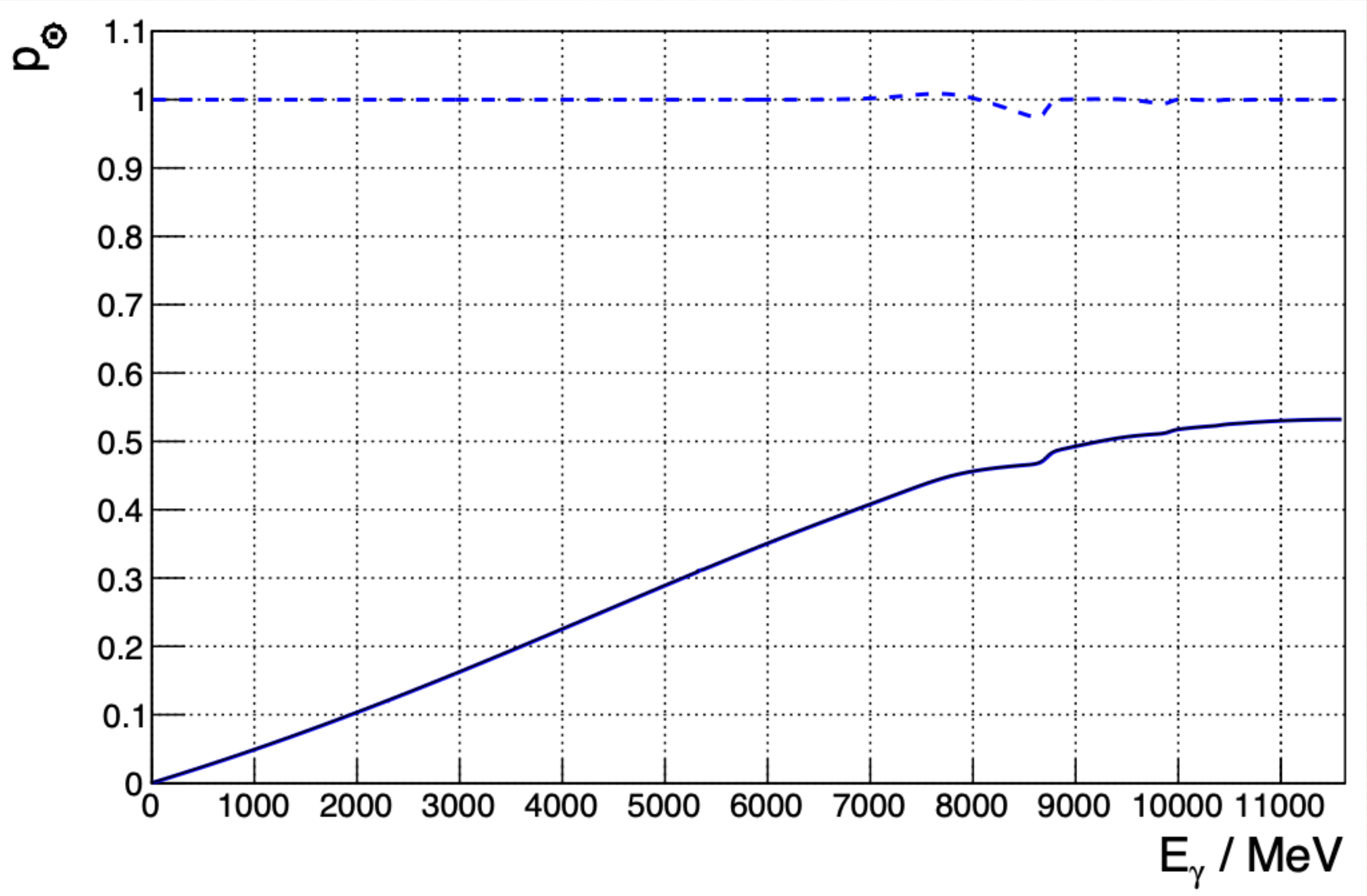


$$P_\gamma = \frac{E_\gamma}{E_0} \frac{1 + \frac{1}{3}\left(1 - \frac{E_\gamma}{E_0}\right)}{1 - \frac{2}{3}\left(1 - \frac{E_\gamma}{E_0}\right) + \left(1 - \frac{E_\gamma}{E_0}\right)^2} P_{e^-}$$

for amorphous radiator

Circular polarisation on a diamond

- In GlueX we use a diamond radiator to produce linearly polarised photons via coherent bremsstrahlung
- This slightly modifies the circular polarisation
- Effect small for standard GlueX running



Afzal et al, First measurement using elliptically polarized photons of the double-polarization observable E for $\gamma p \rightarrow p\pi^0$ and $\gamma p \rightarrow n\pi^+$, accepted by PRL

The situation in Hall D

- GlueX has always had some degree of polarised electron beam incident on the radiator
- Never measured or optimised for circularly polarised photons
- Since 2023-01 (delayed) helicity signal in the data stream
    - See Ken's talk later

Measurement of circular polarisation

- Measure polarisation in other halls and do combined fit
- Project precession into Hall D
- Accuracy depends on detail of available data and how longitudinal the polarisation is in Hall D
- Uncertainty of <2% on longitudinal polarisation should be possible (c.f. REGGE and REGGEON proposal)

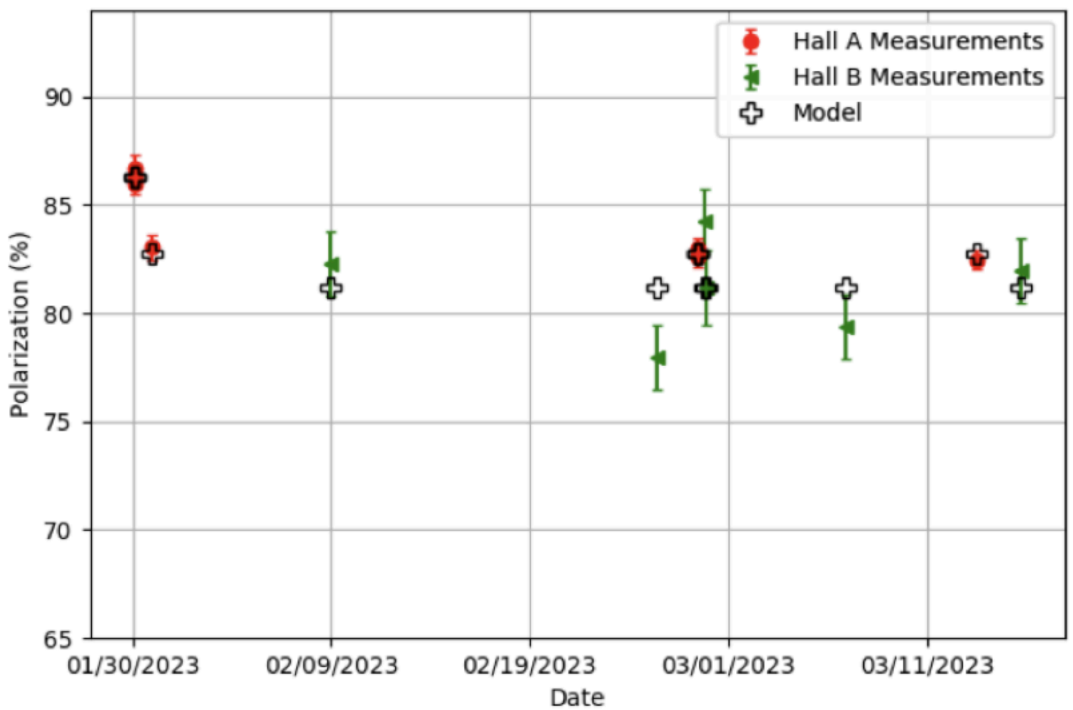


Figure 2: A fit of the Møller measurements made in early 2023 in Hall A and Hall B at 2 Wien angles to a global model of the beam energy and polarization magnitude and launch angle.

In Hall D:

runs	Wien angle	longitudinal polarization
120286 to 120445	-64.6	$53.2 \pm 4.0\%$
120446 to 121207	-47.2	$71.0 \pm 4.0\%$

Møller polarimetry in Hall D

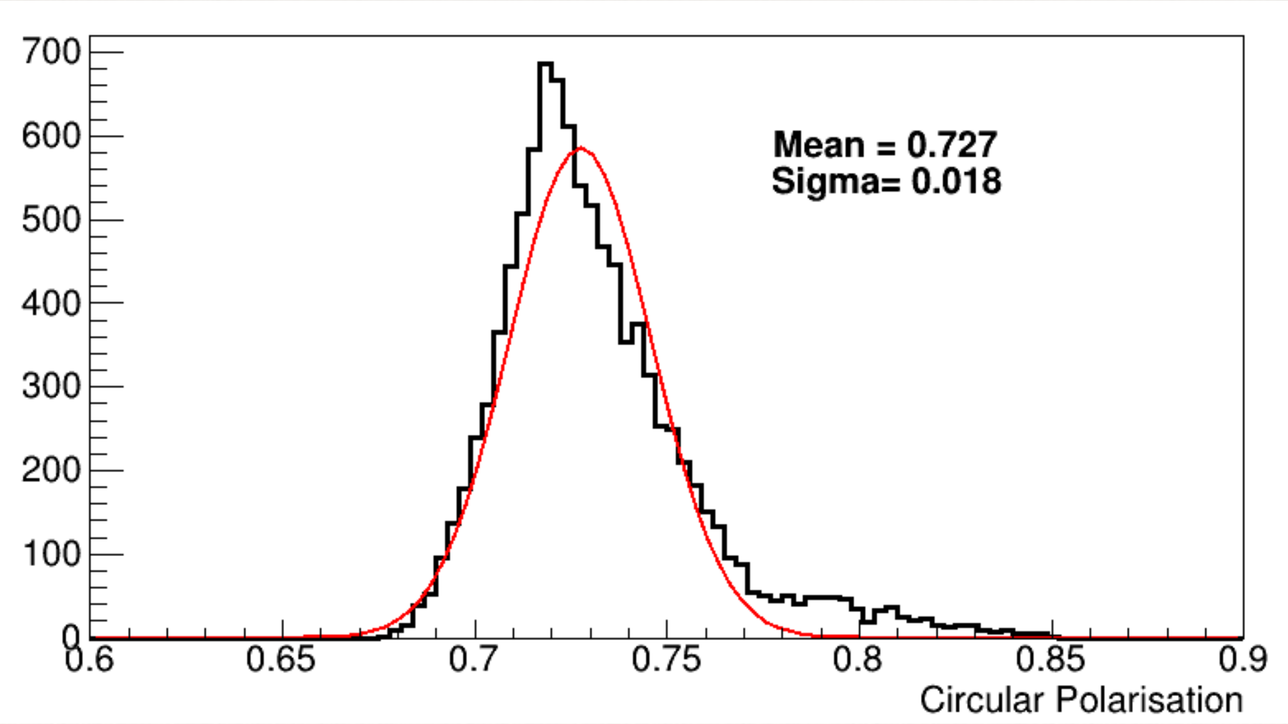
- Is there an "easy" way to measure the electron polarisation directly in Hall D?
- Option A: Build a Møller polarimeter like other halls, probably not feasible on short time scale
- Option B (The Mainz approach, see Ken's talk):
  Use the tagger as polarimeter
  - Møller electrons are produced on a magnetised foil in the goniometer which also functions as amorphous target
  - Carefully selected tagger channel are used to measure the produced Møller electrons and determine the polarisation
- Option B is currently under study, the foil might have to go somewhere else for the tagger to have good analysing power

Using physics reactions in Hall D

- Use a physics reaction to measure absolute polarisation
- $\gamma p \rightarrow \rho p \rightarrow \pi^{+}\pi^{-}p$
  - Similar idea to $\alpha\_$ measurement: use an overconstrained fit and leave polarisations as free parameters

$$\mathcal{I}(\Omega,\Phi) = \mathcal{I}^0(\Omega) - P_{\gamma L}\mathcal{I}^1(\Omega)\cos(2\Phi) - P_{\gamma L}\mathcal{I}^2(\Omega)\sin(2\Phi) - P_{\gamma C}\mathcal{I}^3(\Omega)$$

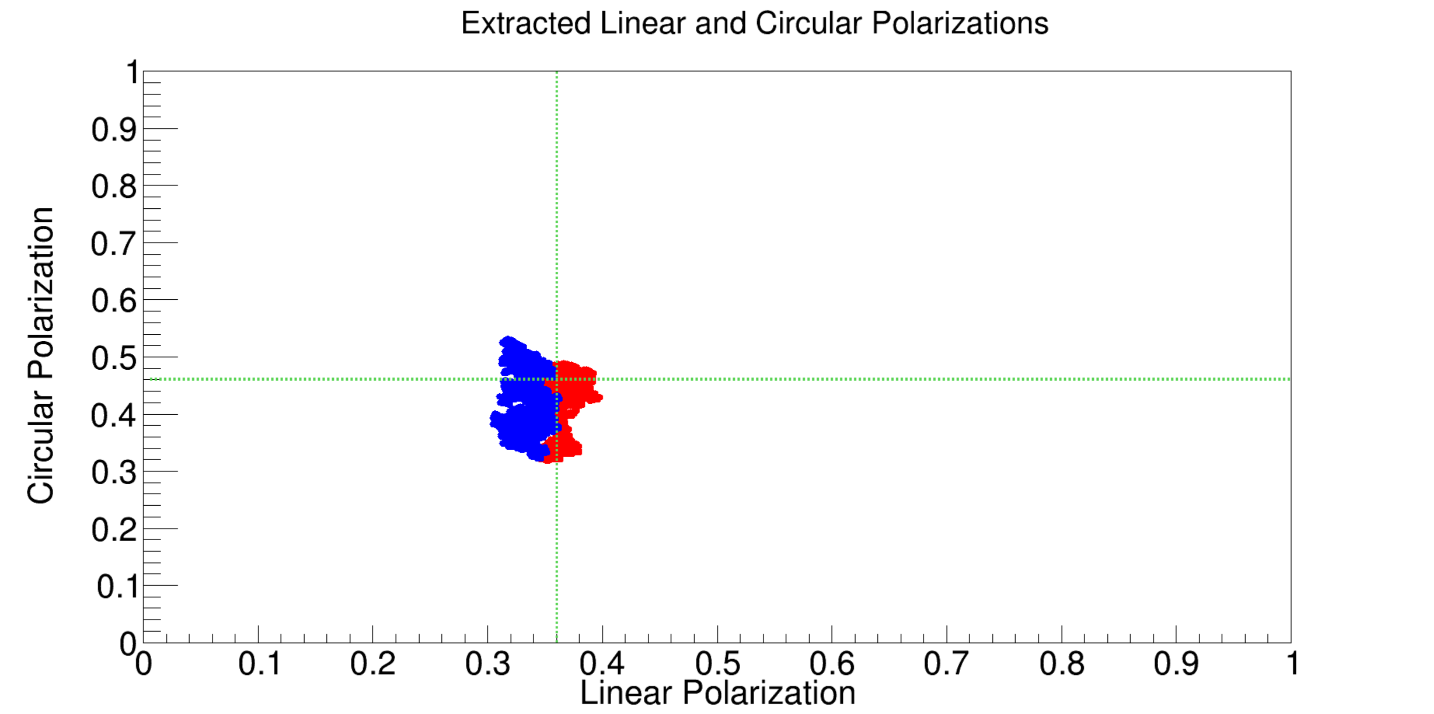
  - Expand intensity in terms of Spherical Harmonics which are related to partial waves which are dominated by P-waves
- Toy study:
  - Fit published SDMEs and extract partial waves
  - Generate I^3 component with $P_{\odot} = 0.73$
  - Fit resulting data and extract $P_{\odot}$

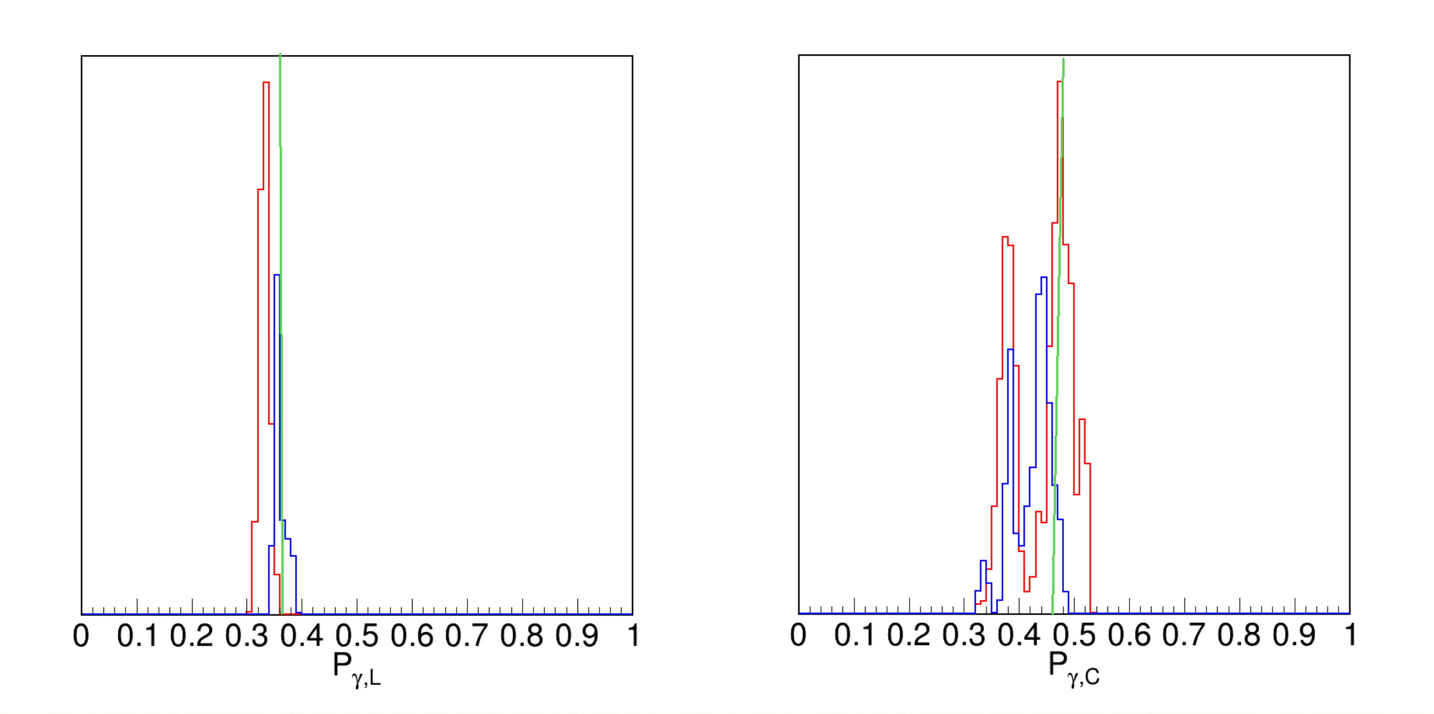


Using physics reactions in Hall D

- Red: $8.0 < E_\gamma < 8.3$ GeV
- Blue: $8.3 < E_\gamma < 8.6$ GeV
- For 1-D projections:
  - Require "good fits" (dominated by pos. refl. P-wave)
- Many fits to different t-bins:
  - Spread indication of current systematics due to acceptance correction

Real Data: 2023-01



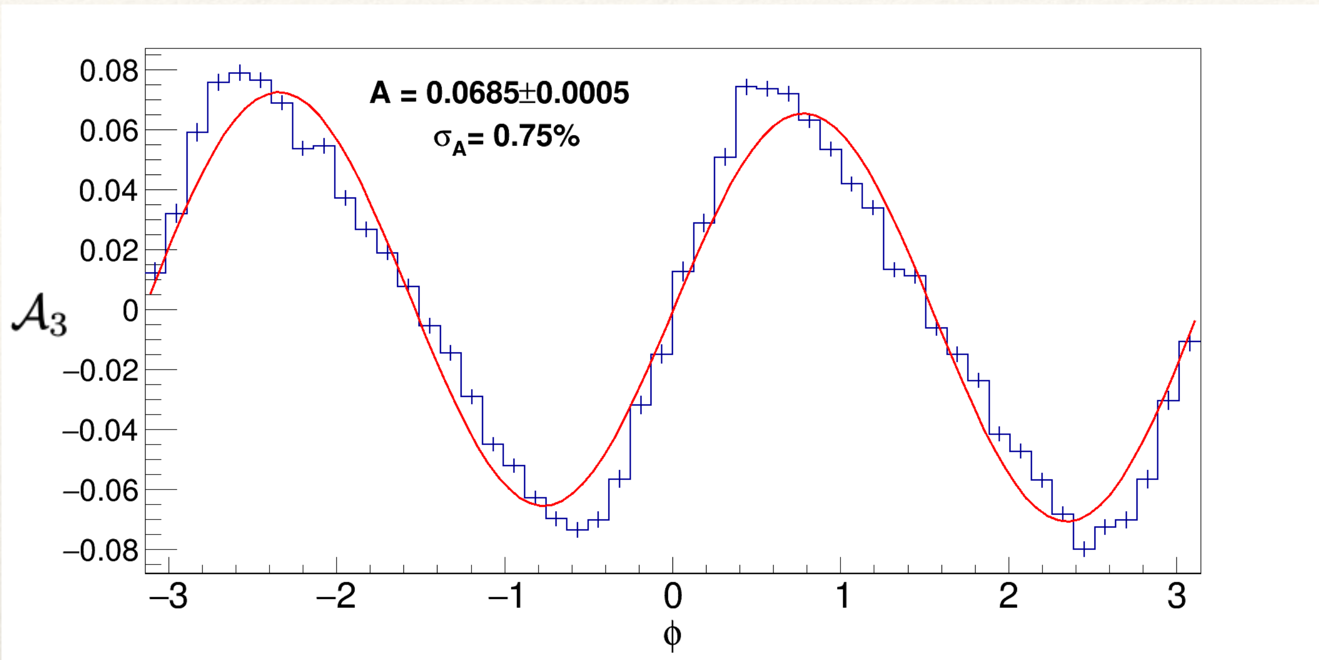


Using physics reactions in Hall D

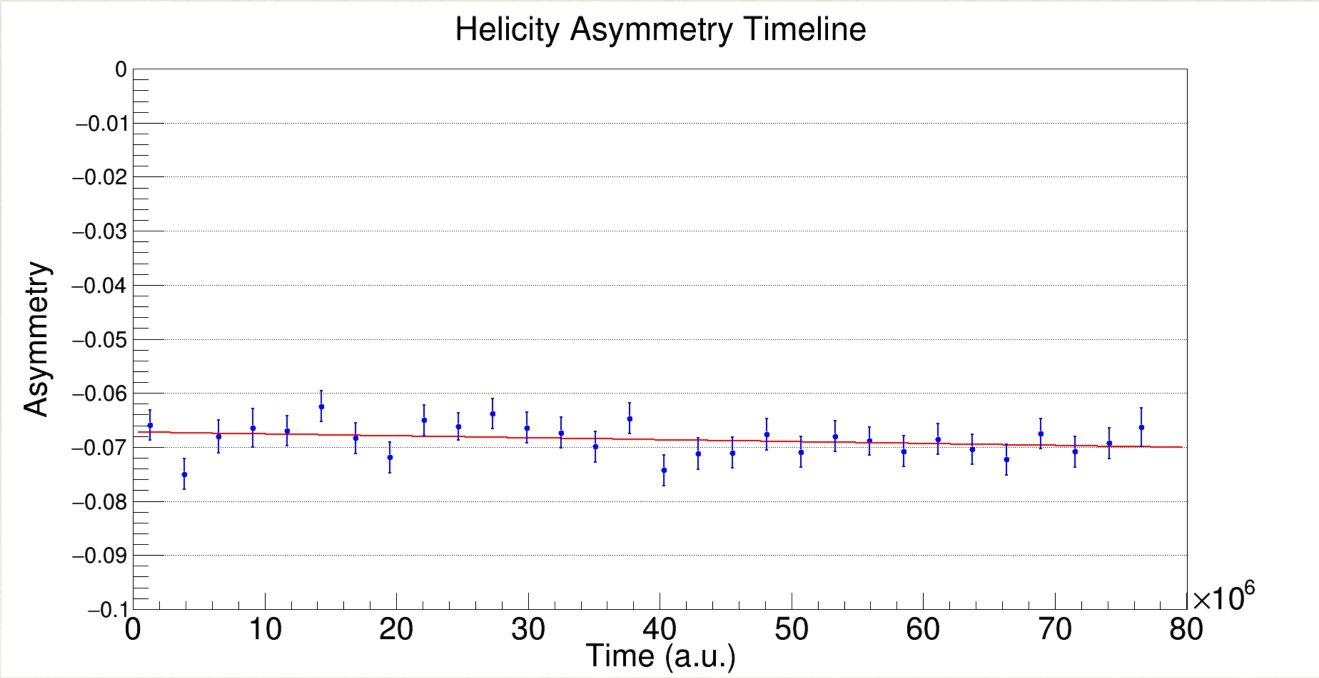
- In order for live monitoring one could use a helicity asymmetry similar to what is done for linear polarisation

$$\mathcal{A}_3 = \frac{\mathcal{I}(\Omega, h=+1) - \mathcal{I}(\Omega, h=-1)}{\mathcal{I}_3(\Omega, h=+1) + \mathcal{I}_3(\Omega, h=-1}) = \frac{\mathcal{I}_3(\Omega)}{\mathcal{I}_0(\Omega)}$$

$$\approx \frac{3}{4\pi}(\sqrt{2}\,\mathrm{Im}\,\rho^3_{10}\sin 2\theta \sin\phi + \mathrm{Im}\,\rho^3_{1-1}\sin^2\theta \sin 2\phi)/\mathcal{I}_0(\Omega)$$



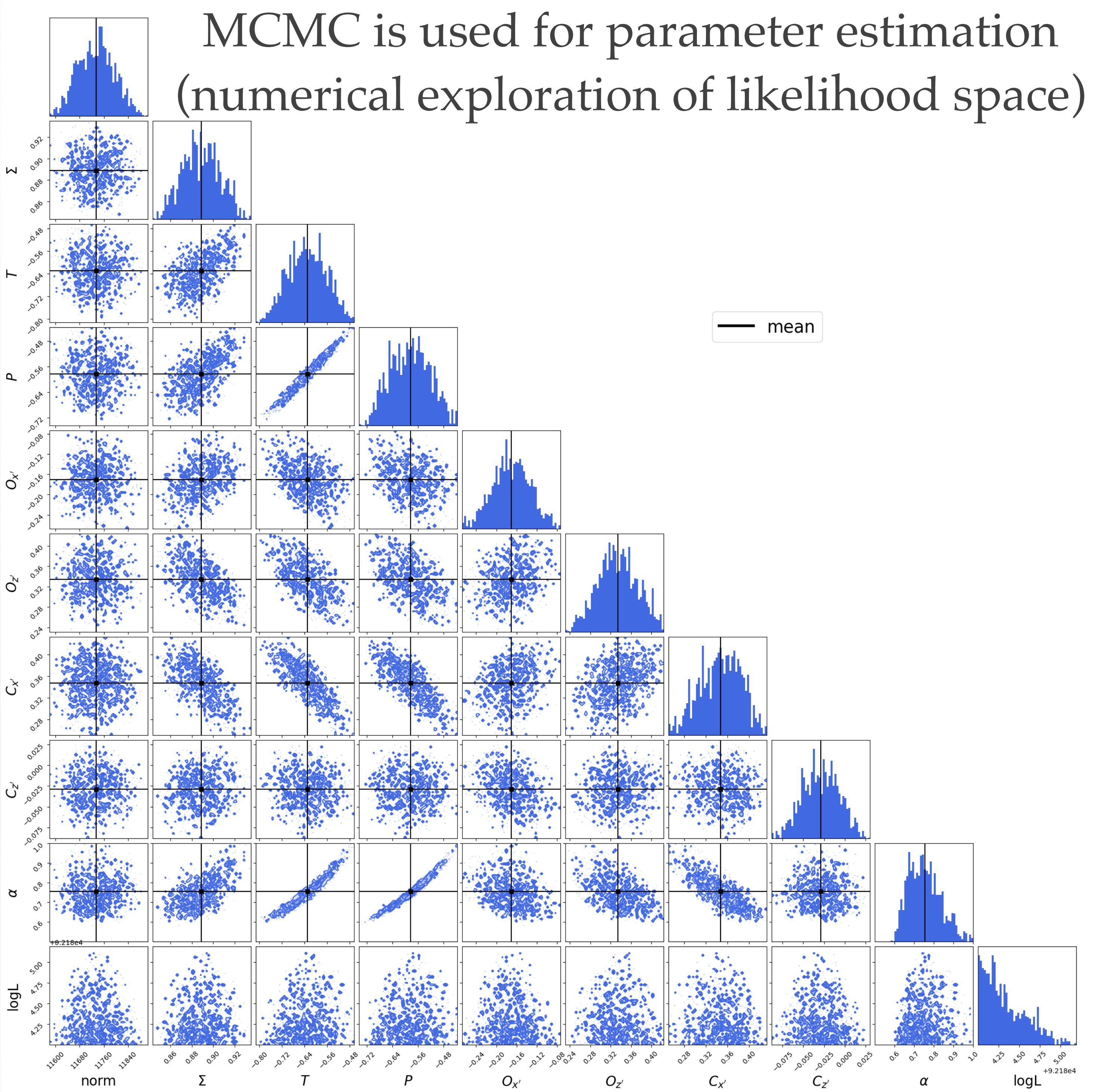
- integrate this over cos(θ) for +ve and -ve values separately, projecting onto ϕ, flipping ϕ in the -ve case

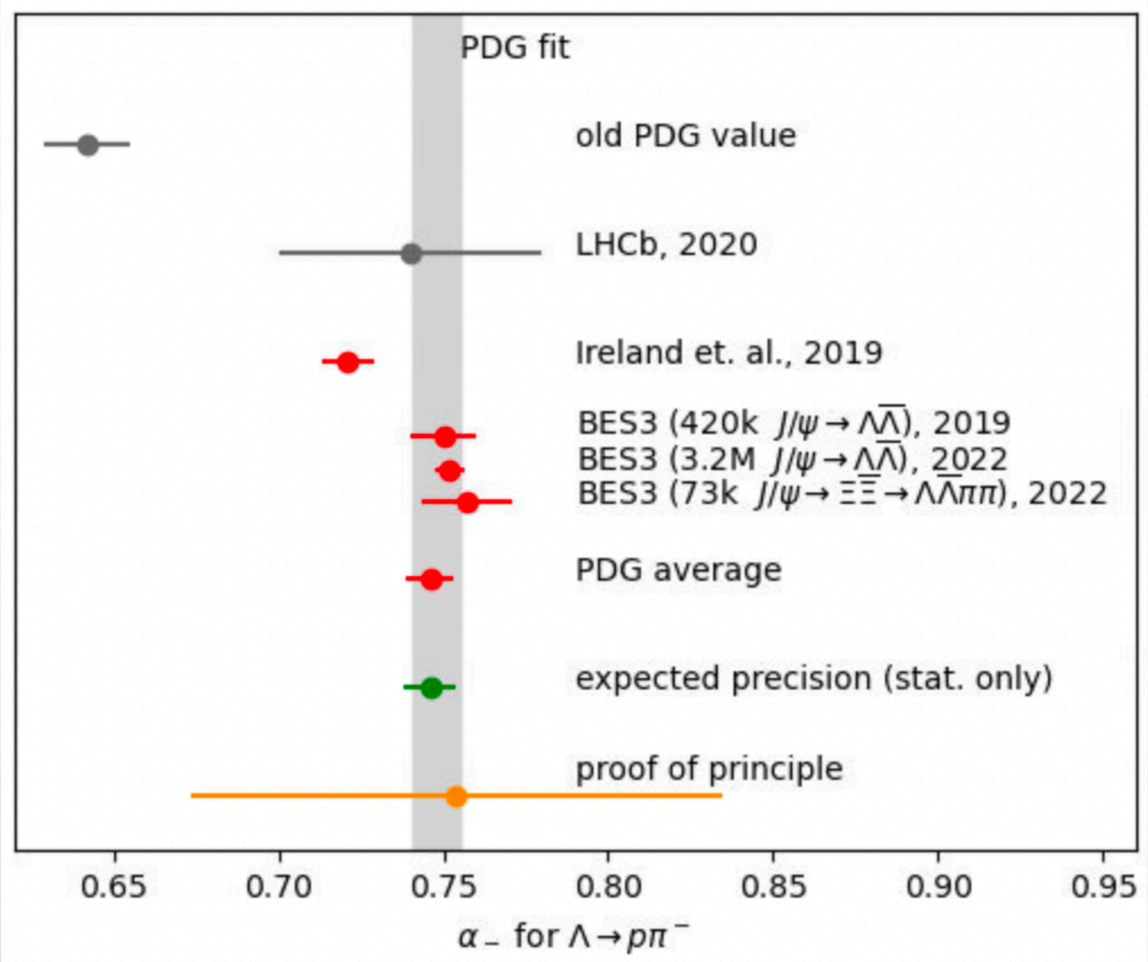


- Approx. 4% precision per run at 53% polarisation
  - Translates to 2.7% @ 75% P_e

Proof-of-concept for the proposal

MCMC is used for parameter estimation (numerical exploration of likelihood space)





$\alpha\_ = 0.754 \pm 0.080$

- We get a very nice result for $\alpha\_$ with large uncertainties
- Running alongside for the remainder of GlueX-II we expect to have a competitive result

More physics with circular polarisation

- Polarised spin-density matrix elements
  - Get access to the ρ^3 components
- Partial Wave Analysis
  - Additional constraints, can remove ambiguities
- Timelike Compton Scattering
  - Access to helicity asymmetry

Summary

- We plan to measure α_{-} for $\Lambda \to p\pi^{-}$
- Needs circularly polarised photons in HallD
  - we already have them, but without optimisation
- Additional plans:
  - Measure effect of linear polarisation on circular polarisation
  - Important if used in high precision measurements
- Wish list:
  - Get helicity signal directly for Hall D (planned)
  - Polarimetry in Hall D (not needed for α_{-} proposal)