Polarisation Observables for Strangeness Photoproduction on a Frozen Spin Target with CLAS at Jefferson Lab

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  - Polarisation Observables
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  - Particle Identification
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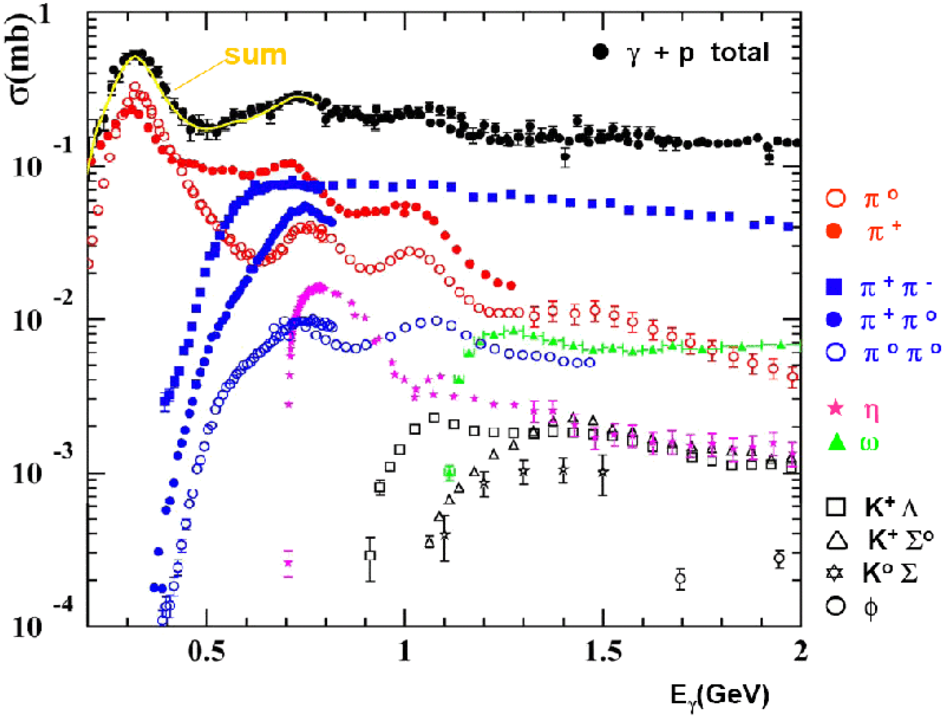
  - Extracting Observables
  - Preliminary Results for the Beam Polarisation Observable (Σ)
  - Preliminary Results for the G Observable
- Summary

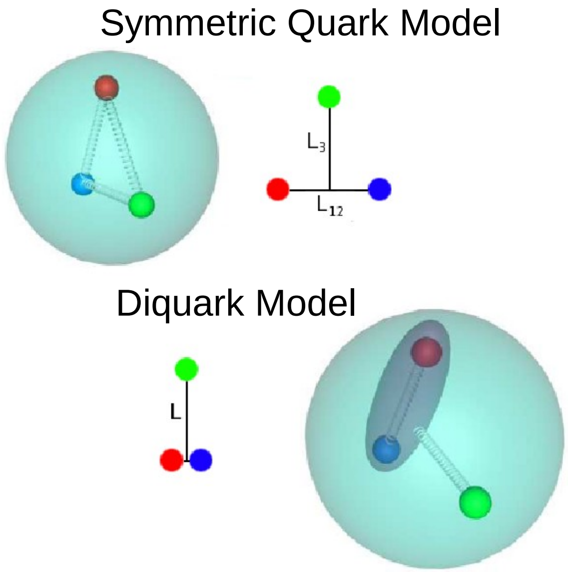
Motivation



S. Schadmand, *Proceedings of the first workshop on quark-hadron duality and the transition to pQCD* (2005)

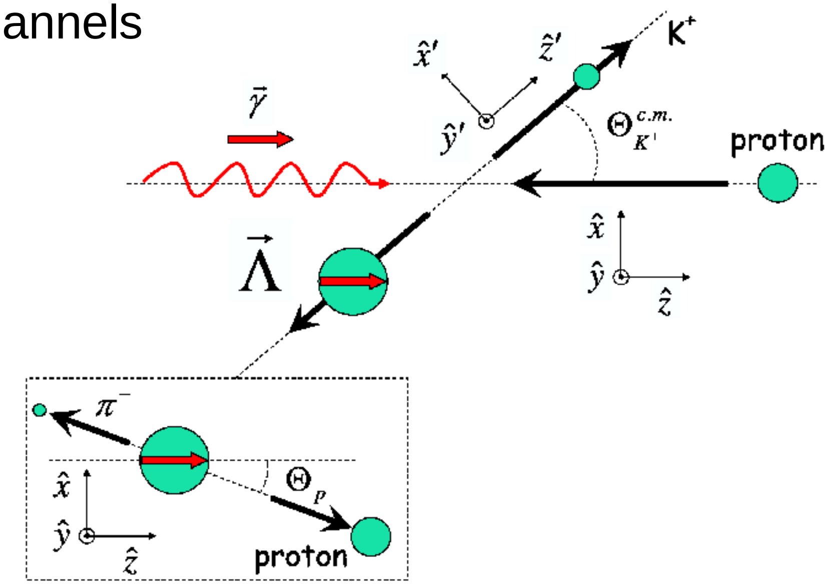
- Studying the hadronic spectrum with electromagnetic probes offers advantages over other methods (such as pi N scattering)
  - Simpler reaction amplitudes
  - Access to polarisation information
- As a result, meson photoproduction has emerged as an important experimental tool
- However, states are wide and overlap, making measurements difficult from cross-sections alone

Models and Observables



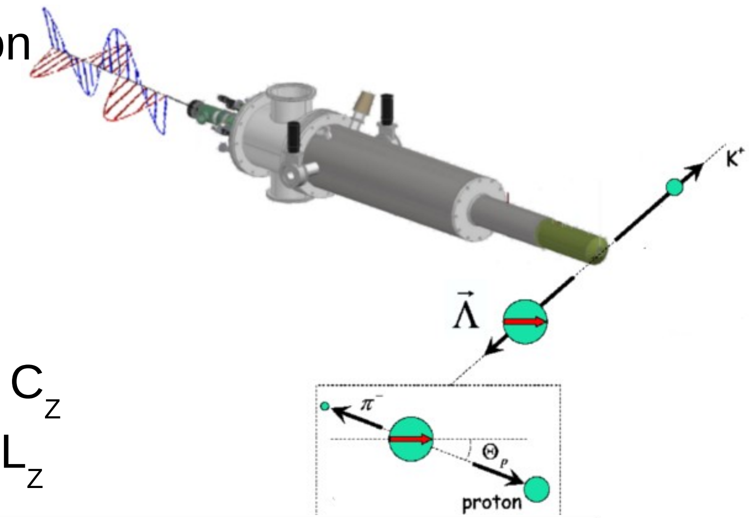
- Resonances can be predicted theoretically by phenomenological models based on non-perturbative QCD, but different models predict different spectra in addition to the observed states – the “Missing Resonance” problem
- Some states couple more strongly to certain reactions, such as the strangeness channels

- Even high quality, high statistics data is insufficient to resolve the full resonance spectrum purely from cross-section measurements
- Polarisation of the reaction particles can be exploited to probe resonances in more detail by measuring **Polarisation Observables**



Polarisation Observables

- Polarisation observables arise from the study of reaction scattering amplitudes
- Meson photoproduction can be described in this way using four transversity amplitudes, a set of four complex amplitudes describing the reaction
- Taking bilinear combinations of these gives rise to sixteen observables
- The observables are accessed via polarisation in the reaction particles and are grouped into single and double types
  - Single: σ, Σ, P, T
  - Double: Beam – Target: E, F, G, H
    Beam – Recoil: O_x, O_z, C_x, C_z
    Target – Recoil: T_x, T_z, L_x, L_z



		Target (P^T)			Recoil (P^R)			Target (P^T) + Recoil (P^R)								
					x'	y'	z'	x'	x'	x'	y'	y'	y'	z'	z'	z'
Beam (P^γ)		x	y	z				x	y	z	x	y	z	x	y	z
Unpolarized	$d\sigma_0$		$\hat{T}$			$\hat{P}$		$\hat{T}_{x'}$		$\hat{L}_{x'}$		$\underline{\hat{\Sigma}}$		$\hat{T}_{z'}$		$\hat{L}_{z'}$
$P_L^\gamma \sin(2\phi_\gamma)$		$\hat{H}$		$\hat{G}$	$\hat{O}_{x'}$		$\hat{O}_{z'}$		$\hat{\mathbf{C}}_{\mathbf{z}'}$		$\hat{\mathbf{E}}$		$\hat{\mathbf{F}}$		$-\hat{\mathbf{C}}_{\mathbf{x}'}$	
$P_L^\gamma \cos(2\phi_\gamma)$	$-\hat{\Sigma}$		$\underline{-\hat{P}}$			$\underline{-\hat{T}}$		$-\hat{\mathbf{L}}_{\mathbf{z}'}$		$\hat{\mathbf{T}}_{\mathbf{z}'}$		$-\mathrm{d}\sigma_0$		$\hat{\mathbf{L}}_{\mathbf{x}'}$		$-\hat{\mathbf{T}}_{\mathbf{x}'}$
Circular P_c^γ		$\hat{F}$		$-\hat{E}$	$\hat{C}_{x'}$		$\hat{C}_{z'}$		$-\hat{\mathbf{O}}_{\mathbf{z}'}$		$\hat{\mathbf{G}}$		$-\hat{\mathbf{H}}$		$\hat{\mathbf{O}}_{\mathbf{x}'}$	

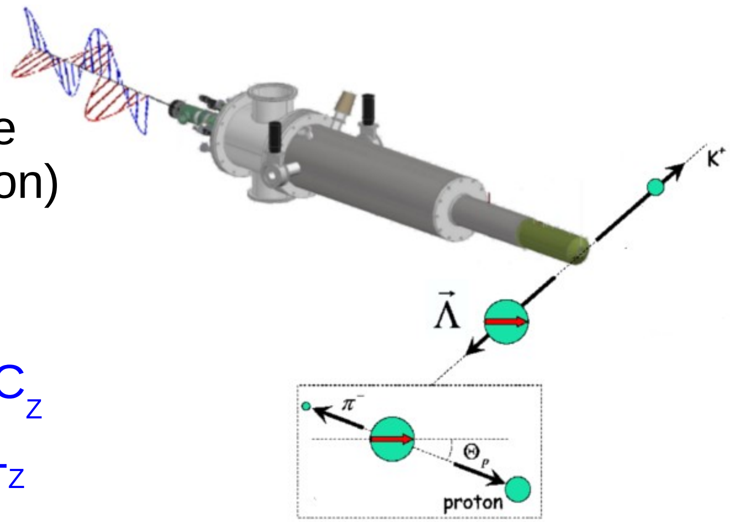
The Plan

- Want to measure the G observable for the KΛ (and KΣ) strangeness photoproduction reactions:

$$\gamma p \rightarrow N^* \rightarrow K^+ \Lambda \rightarrow K^+ p \pi^-$$

$$\gamma p \rightarrow N^* \rightarrow K^+ \Sigma \rightarrow K^+ \Lambda \gamma \rightarrow K^+ p \pi^- \gamma$$

- This requires a polarised beam and a polarised target, allowing access to the observables shown in green (we can get to the others via recoil from the self-analysing hyperon)
  - Single: σ , Σ, P, T
  - Double: Beam – Target: E, F, G, H
    Beam – Recoil: O_x, O_z, C_x, C_z
    Target – Recoil: T_x, T_z, L_x, L_z

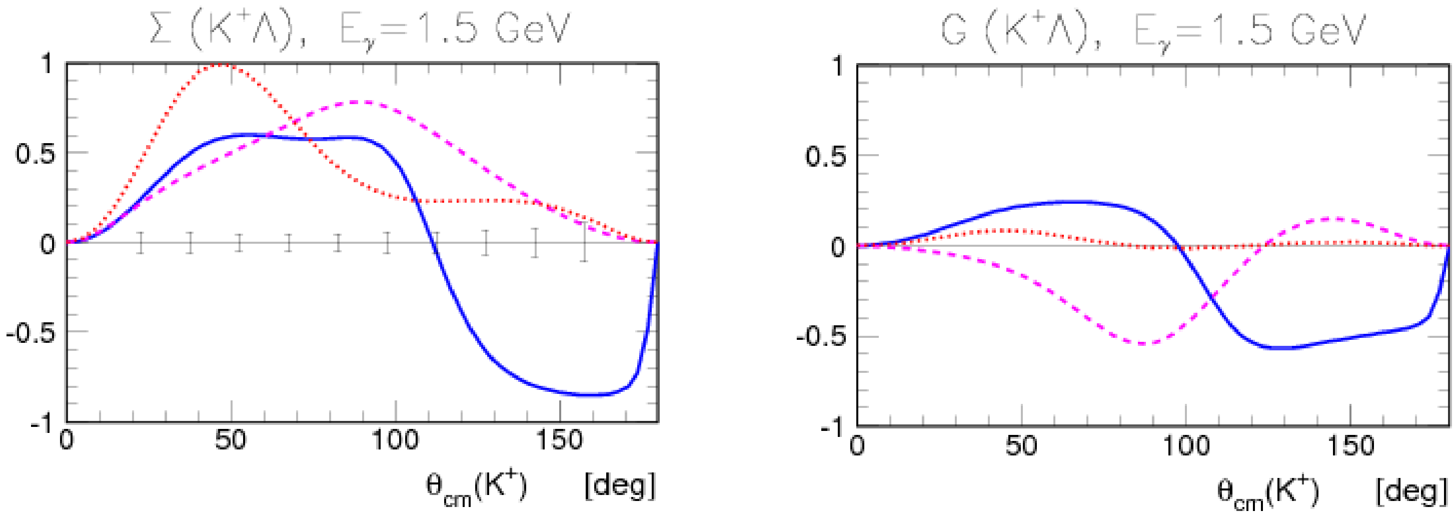


- For G, we need a linearly polarised photon beam and a longitudinally polarised target, and the reduced cross section looks like this;

$$\frac{d\sigma}{d\Omega} = \sigma_0 \{1 - P_{lin} \Sigma \cos 2\phi + P_z (P_{lin} G \sin 2\phi)\}$$

Why Observables?

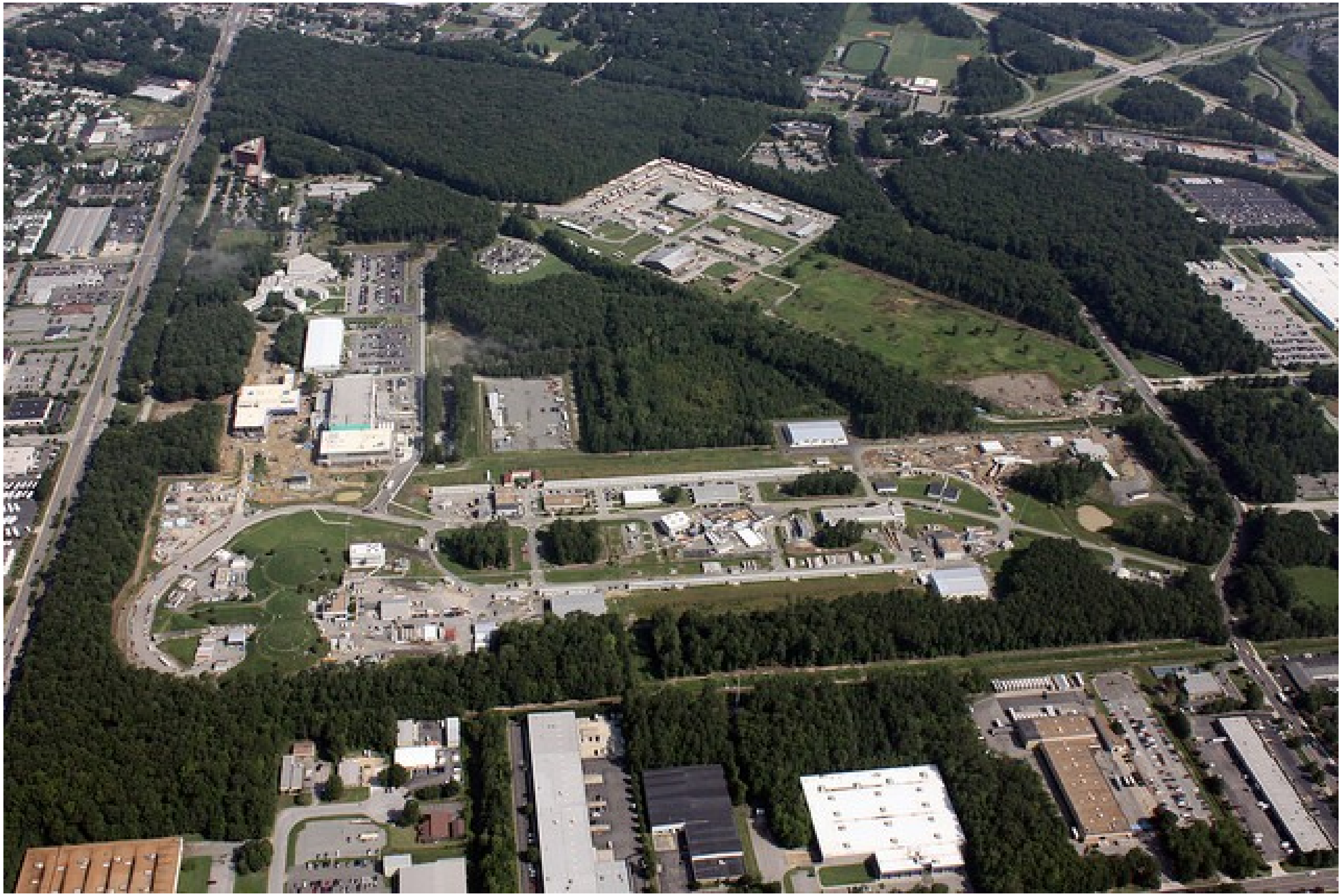
- Measuring polarisation observables is important because theoretical predictions of the observables vary dependant on the resonances included in the prediction



- The blue line shows the SAID partial wave analysis solution, the red dotted curve is Saghai's model [1], and the pink dashed curve represents the Mart-Bennhold model [2], which unlike the others, includes a D_{13}(1960) resonance
- No previous data exists for the G observable on the strangeness channels, so FROST data will provide important constraints for models

[1] Invited talk, *International Symposium on Hadrons and Nuclei*, Seoul (2001)
[2] Phys. Rev. **C61**, 012201 (2000)

Jefferson Lab

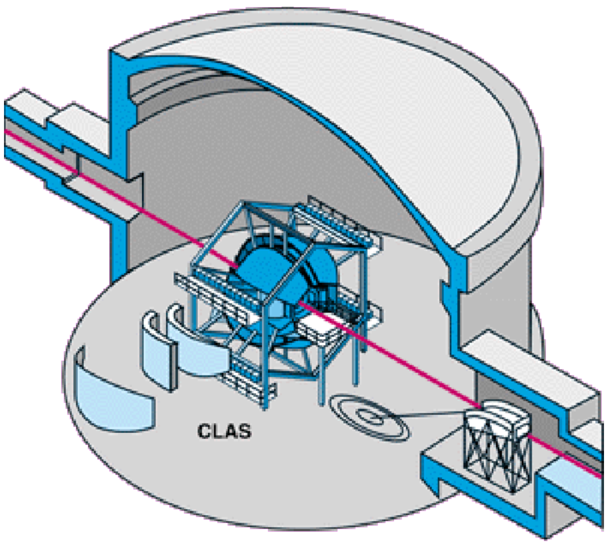


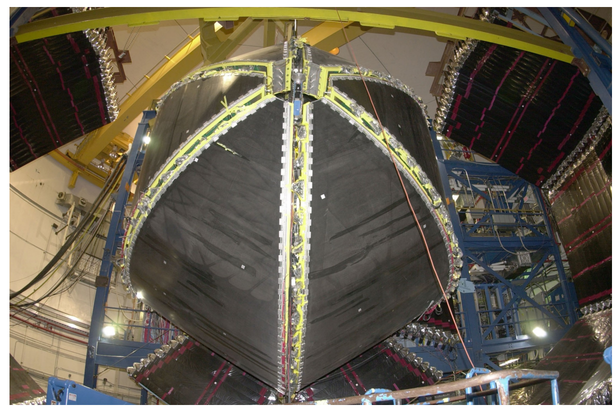
Jefferson Lab

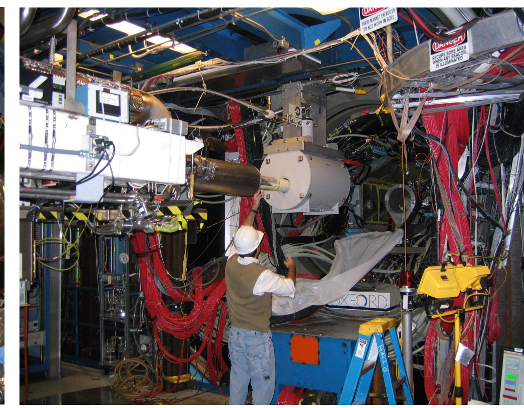
- Jefferson Lab is a US Department of Energy National Facility, located in Newport News, Virginia
- Its centrepiece is CEBAF, a superconducting radio frequency accelerator
- In its initial phase of operation (1995-2012), CEBAF provided beams up to 6 GeV in energy simultaneously to up to three experimental halls
- Today, work is well underway on an energy upgrade to 12 GeV and a fourth hall has been constructed
- In the 6 GeV era, photonuclear experiments took place in Hall B, using CLAS – the CEBAF Large Acceptance Spectrometer

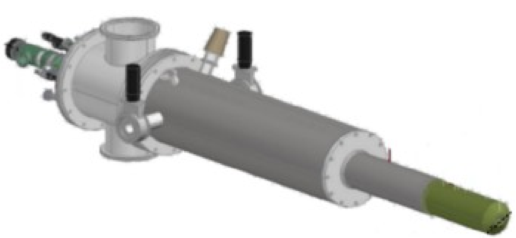
The g9a Experiment in Hall B

- g9a was the first run period using the CLAS Frozen Spin Target (FROST)
- Linearly and circularly polarised photon beams, produced via coherent bremsstrahlung, interact with a longitudinally polarised target



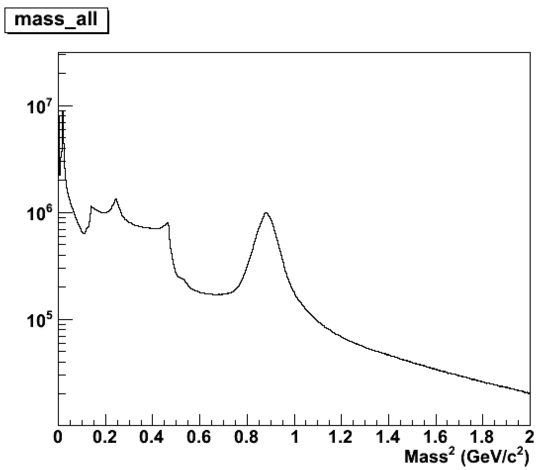




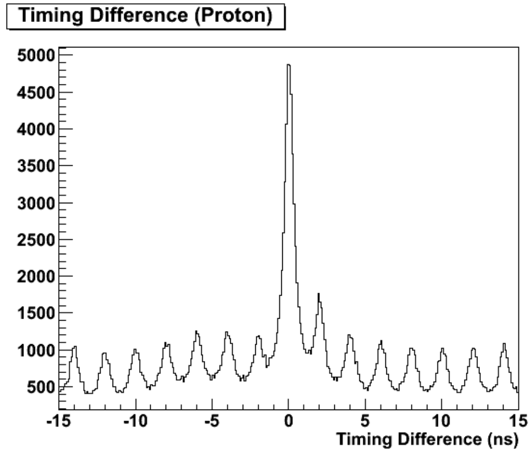


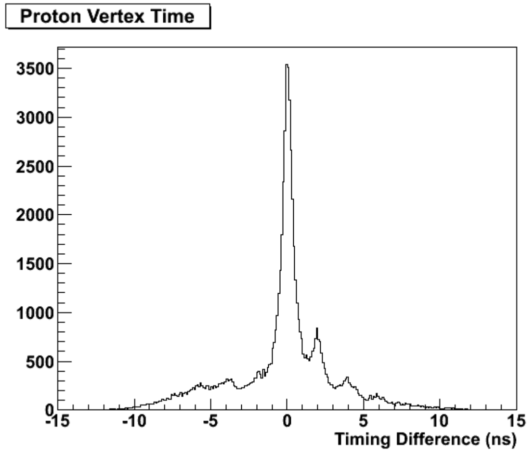
- Innovative design of the target allows the large acceptance of CLAS to be fully exploited
- Data was collected between November 2007 and February 2008 for a range of photon beam energies (0.73 – 2.3 GeV)
- Around 10 billion triggers recorded

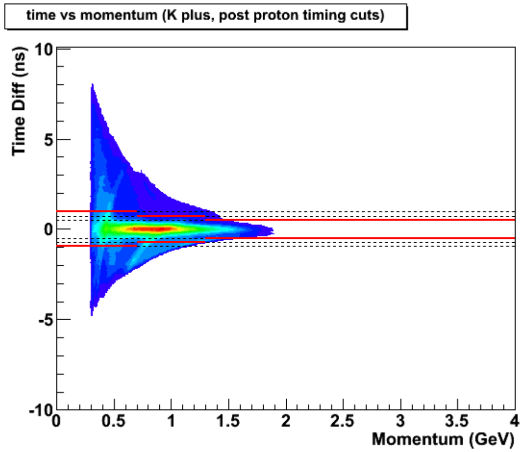
Particle ID



- Initial particle identification realised via a combination of charge and time-of-flight calculated mass
- Select potential events for the channel of interest from possible combinations of detected particles (allowing 1 Proton and 1 Kaon, with the option of 0 or 1 π^-, and 0 or 1 neutrals, i.e. photons)
- Important to identify correct photon to reduce particle misidentification using the photon to particle timing difference







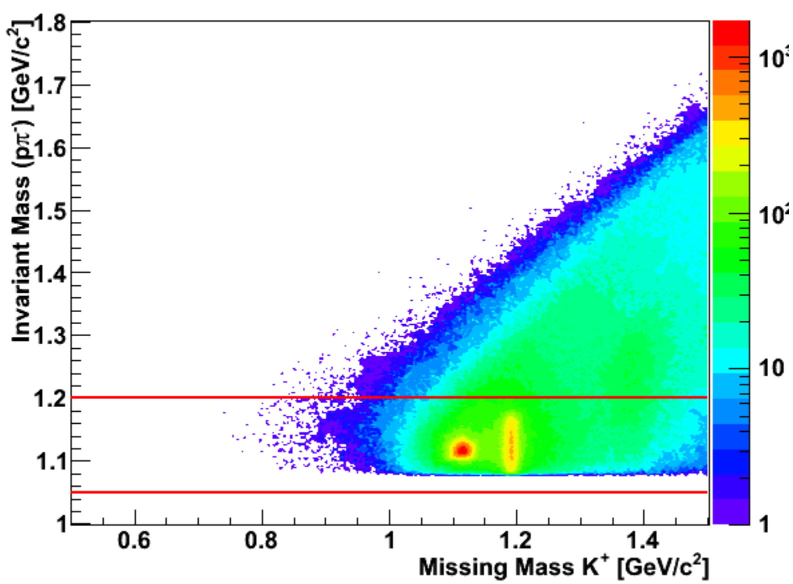
Channel Identification

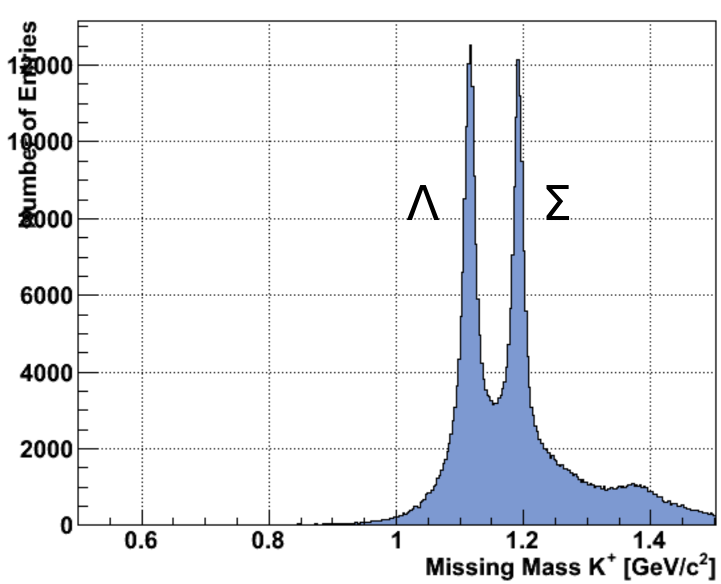
- Reactions of interest: $\gamma\, p \rightarrow K^{+}\Lambda \rightarrow K^{+} p\, \pi^{-}$

  and: $\gamma\, p \rightarrow K^{+}\Sigma \rightarrow K^{+}\Lambda\, \gamma \rightarrow K^{+} p\, \pi^{-}\gamma$

- Two options; exclusive ID (fewer events), or non exclusive, reconstructing undetected particles via missing mass (susceptible to particle misidentification)

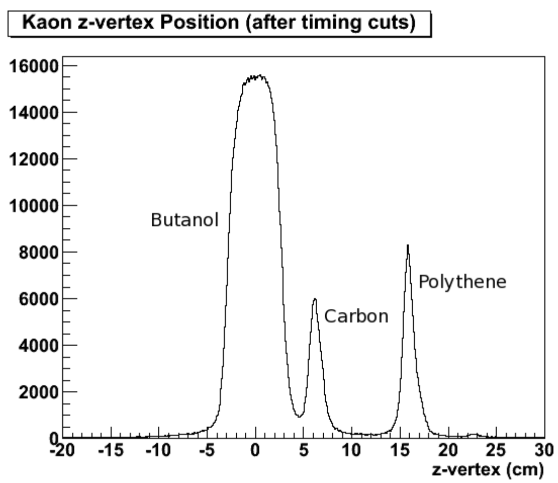
- Identify Lambda and Sigma hyperons from a plot of missing mass of the K^{+} vs the invariant mass of $p\pi^{-}$, where the π^{-} is assumed to be missing mass of p K^{+}

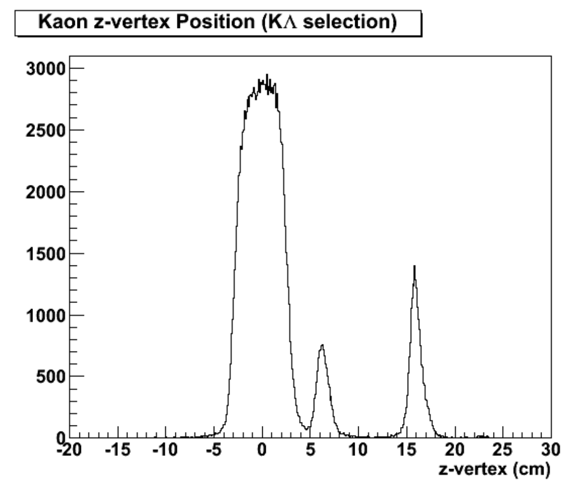




Target Selection

- The FROST target assembly contains three target materials; Butanol (C_4H_9OH), Carbon (^{12}C) and Polythene (CH_2), resolvable after particle and channel identification

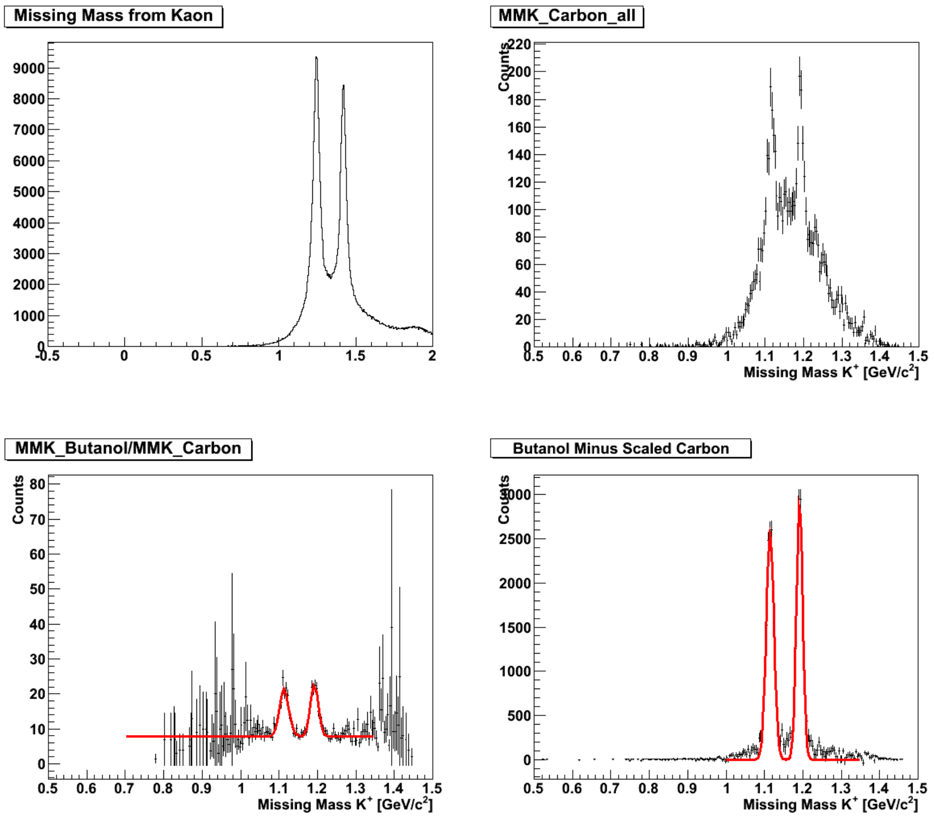




- Only Butanol is polarised, other targets used to account for nuclear background in channel identification plots and asymmetry dilution effects due to the unpolarised nuclei in Butanol
- Can also use polythene to cross-check previous measurements of polarisation observables, but low statistics prevents this for the strangeness channels

Carbon Scaling Factors

- Quantify how much Carbon (unpolarised nuclei) is present in the Butanol, in order to account for its effect on asymmetries and isolate Hydrogen (Protons)
- Determine a Carbon scaling factor by dividing kaon missing mass histogram for Butanol by the same histogram for the Carbon
- Scaling factor can be used to subtract scaled Carbon spectrum from the Butanol, verifying the hyperon selection cuts
- Can also provide an estimate of the number of carbon events in Butanol when diluting asymmetries



Extracting Observables

- Recall that polarisation observables contribute to the differential cross section;

$$\frac{d\sigma}{d\Omega}=\sigma_0\{1-P_{lin}\Sigma\cos 2\phi+P_z(P_{lin}G\sin 2\phi)\}$$

- Observables can also be expressed as the difference over the sum of cross-sections for two polarisation states;

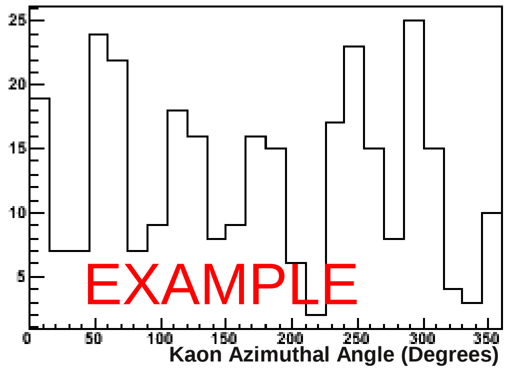
$$\Sigma=\frac{(\sigma(\perp,0,0)-\sigma(\|,0,0))}{(\sigma(\perp,0,0)+\sigma(\|,0,0))} \qquad G=\frac{(\sigma(\pi/4,+z,0)-\sigma(\pi/4,-z,0))}{(\sigma(\pi/4,+z,0)+\sigma(\pi/4,-z,0))}$$

- If we produce an asymmetry of the Kaon azimuthal angle for two polarisation states, polarisarion observables can be extracted from the resulting distribution
- To measure the Σ and G observables, sinusoidal functions are fitted to an asymmetry distribution made from the two beam polarisation modes, parallel (PARA), and perpendicular (PERP)

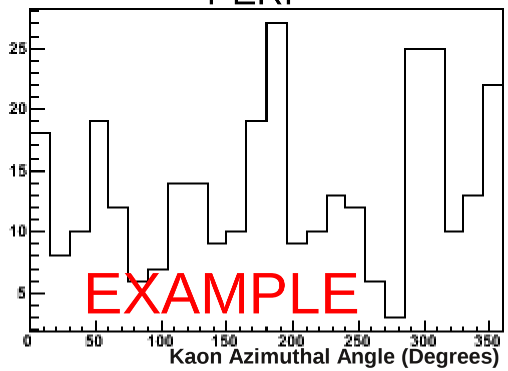
Extracting Observables

- For example, $P_\gamma \Sigma$ can be extracted from the magnitude of a cos(2ϕ) function fitted to the PARA/PERP asymmetry of the Kaon azimuthal angle for an unpolarised target
- Sample KΛ data from the polythene target at 1.5 GeV photon energy:

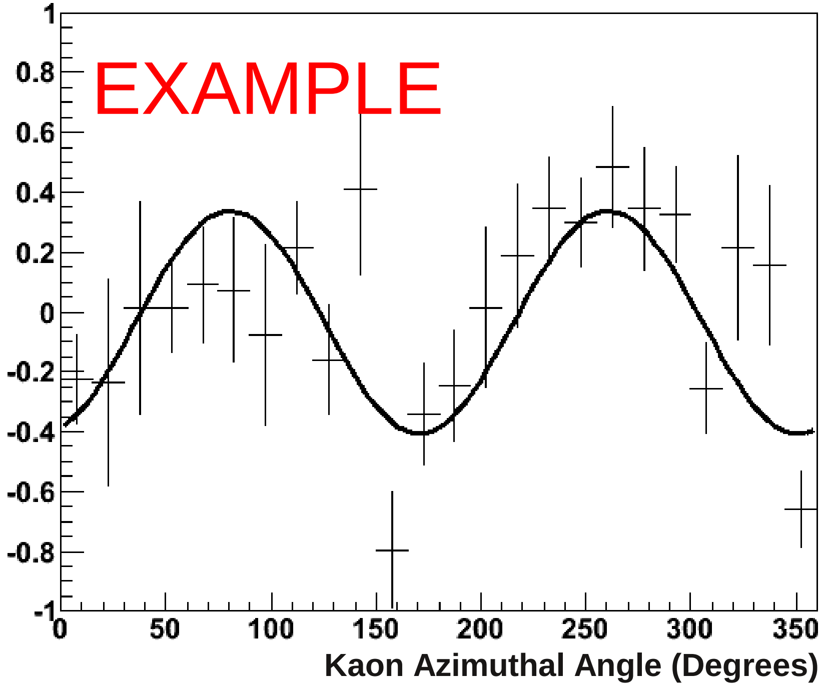
PARA



PERP



Asymmetry

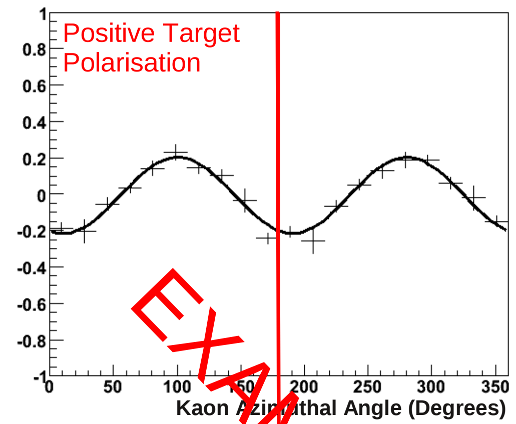


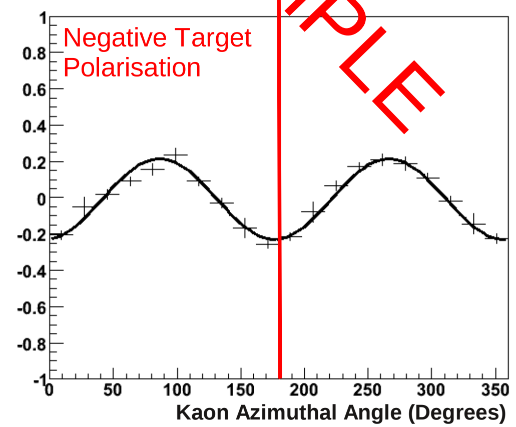
Measuring Σ and G

- If we make asymmetries of Kaon azimuthal angle distributions for the Butanol data, the amplitude of a cos(2ϕ) fit is not just a measurement of the Σ observable – it also contains a contribution from the G observable

$$\frac{d\sigma}{d\Omega}=\sigma_0\{1-P_{lin}\Sigma\cos 2\phi+P_z(P_{lin}G\sin 2\phi)\}$$

- The effect of G can be seen by examining these distributions for positive and negative longitudinal target polarisations
- The positive (top) and negative (bottom) target polarisation distributions show a phase shift due to change in target polarisation
- Extract Σ and G by fitting a cos(2ϕ) + sin(2ϕ) function to the PARA/PERP asymmetry for each target state
- $P_\gamma\Sigma$ is the amplitude of the cos(2ϕ) term, and the amplitude of the sin(2ϕ) term is a measure of $P_\gamma P_{TARGET}G$





Dilution of Observables

- The extracted $P_\gamma\Sigma$ from Butanol is actually a measure of two things, $P_\gamma\Sigma$ (proton), and $P_\gamma\Sigma$ (carbon), with each term diluted by the respective relative amounts of Carbon and Hydrogen (protons) in the target
- $P_\gamma\Sigma$ for the proton can be approximated from measurements of $P_\gamma\Sigma$ on the Butanol and Carbon targets by;

$$P_\gamma \Sigma_{PROTON} = \left(\frac{1}{N_{PROTON}}\right) * \left(N_{BUTANOL} P_\gamma \Sigma_{BUTANOL} - N_{CARBON} P_\gamma \Sigma_{CARBON}\right)$$

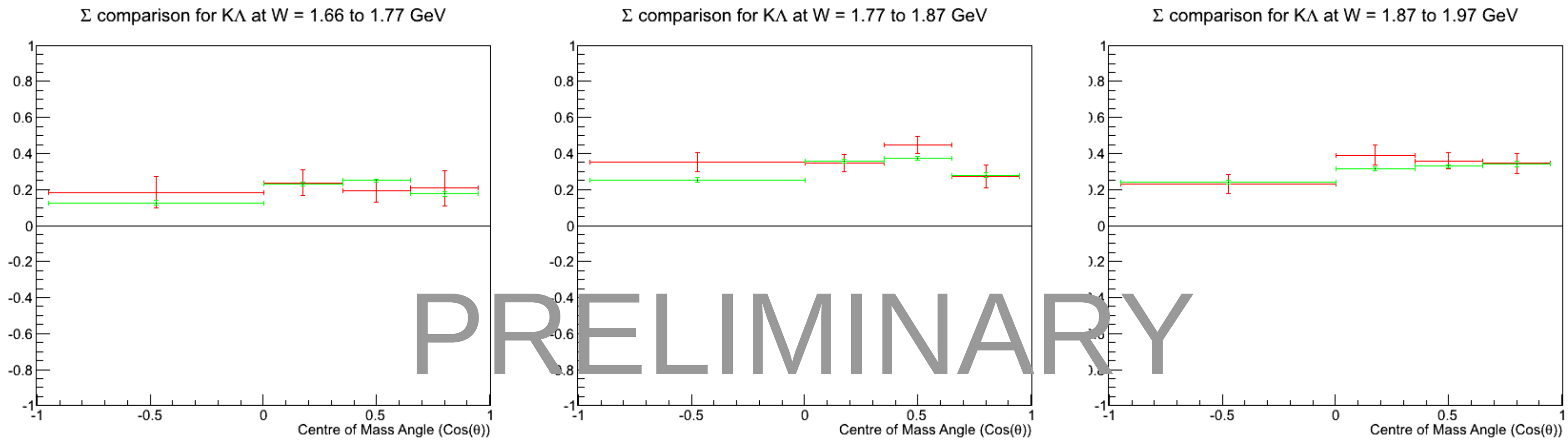
- Carbon is unpolarisable so dilution is simpler for G measurements and $P_\gamma P_{TARGET} G$ for the Proton is given by;

$$P_\gamma P_{TARGET} G_{PROTON} = \left(\frac{N_{BUTANOL}}{N_{PROTON}}\right) * P_\gamma P_{TARGET} G_{BUTANOL}$$

- Also need to account for both beam and target polarisations in order to measure Σ and G

Σ Results for KΛ

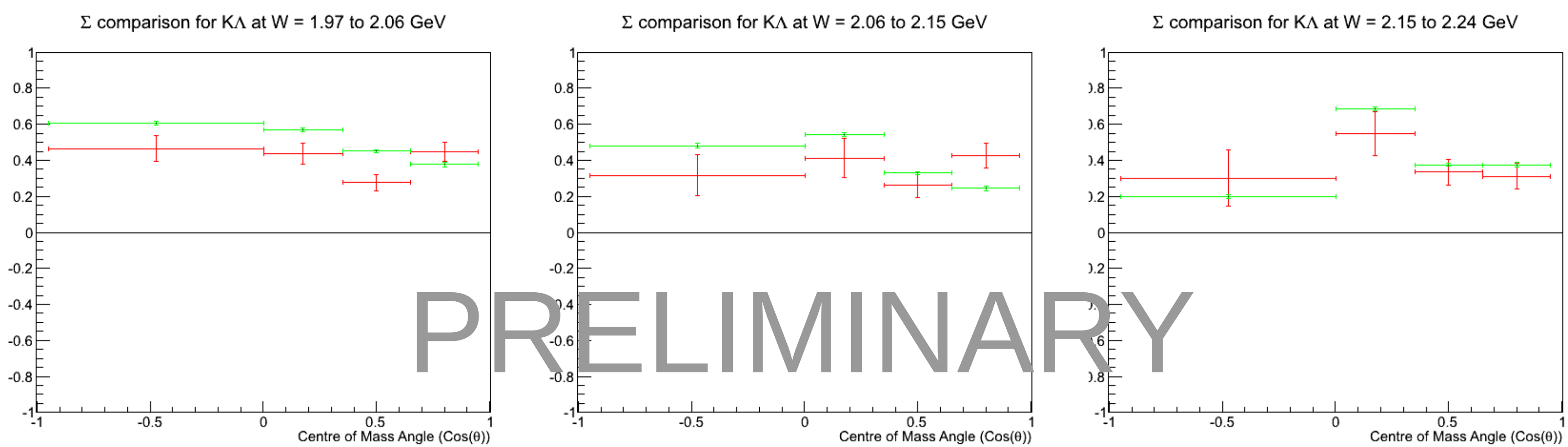
- Beam asymmetry for the KΛ channel, averaged over the two target polarisation settings
- Comparison with a (preliminary) CLAS analysis on an unpolarised proton target (g8b experiment)



- Red points indicate g9a data, green points are g8b data

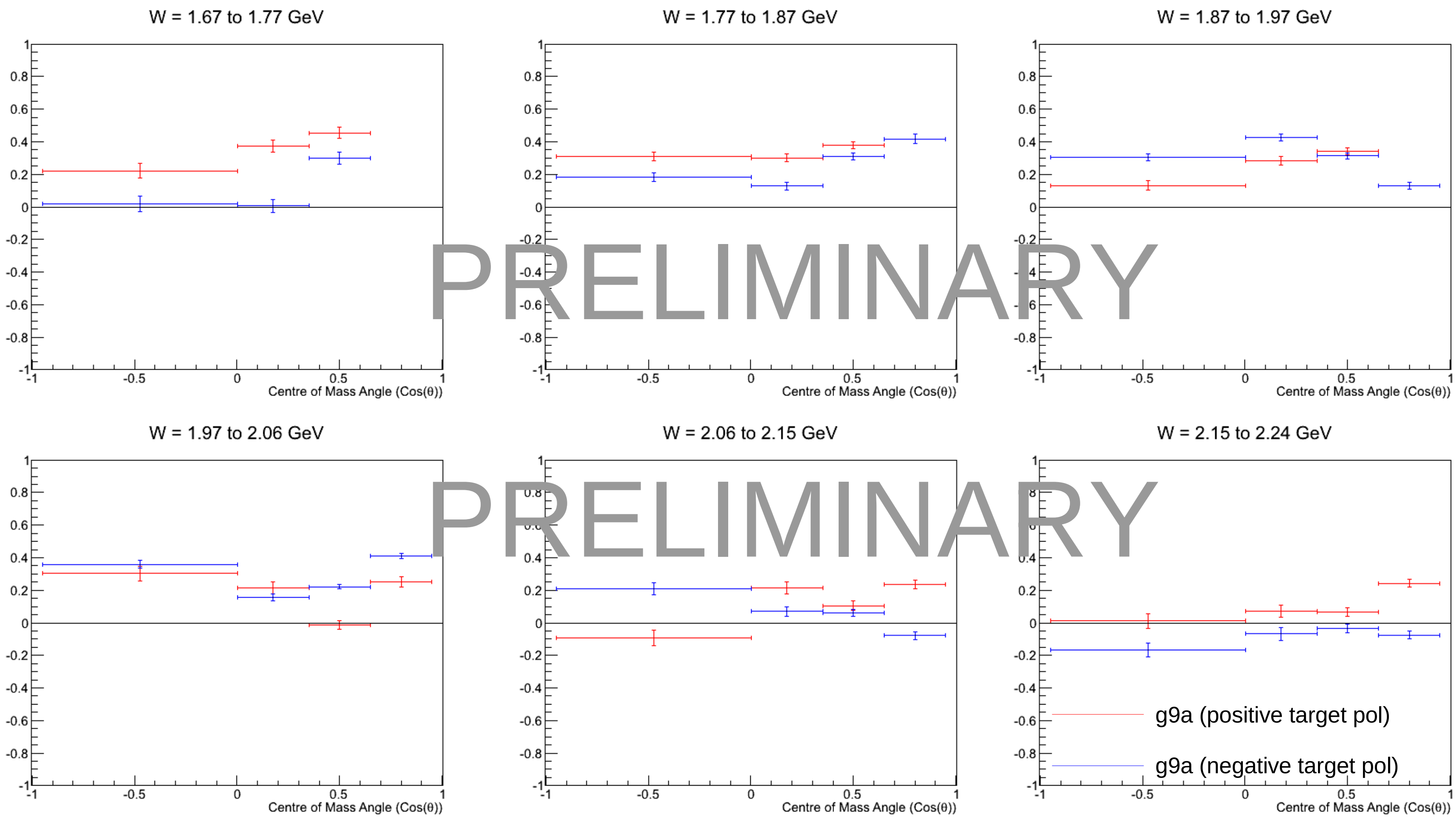
Σ Results for KΛ (continued)

- Fewer events available for determining carbon scaling
- Larger errors as a result



G Results for KΛ

- G observable for $\gamma p \rightarrow K^{+}\Lambda$ from beam asymmetries

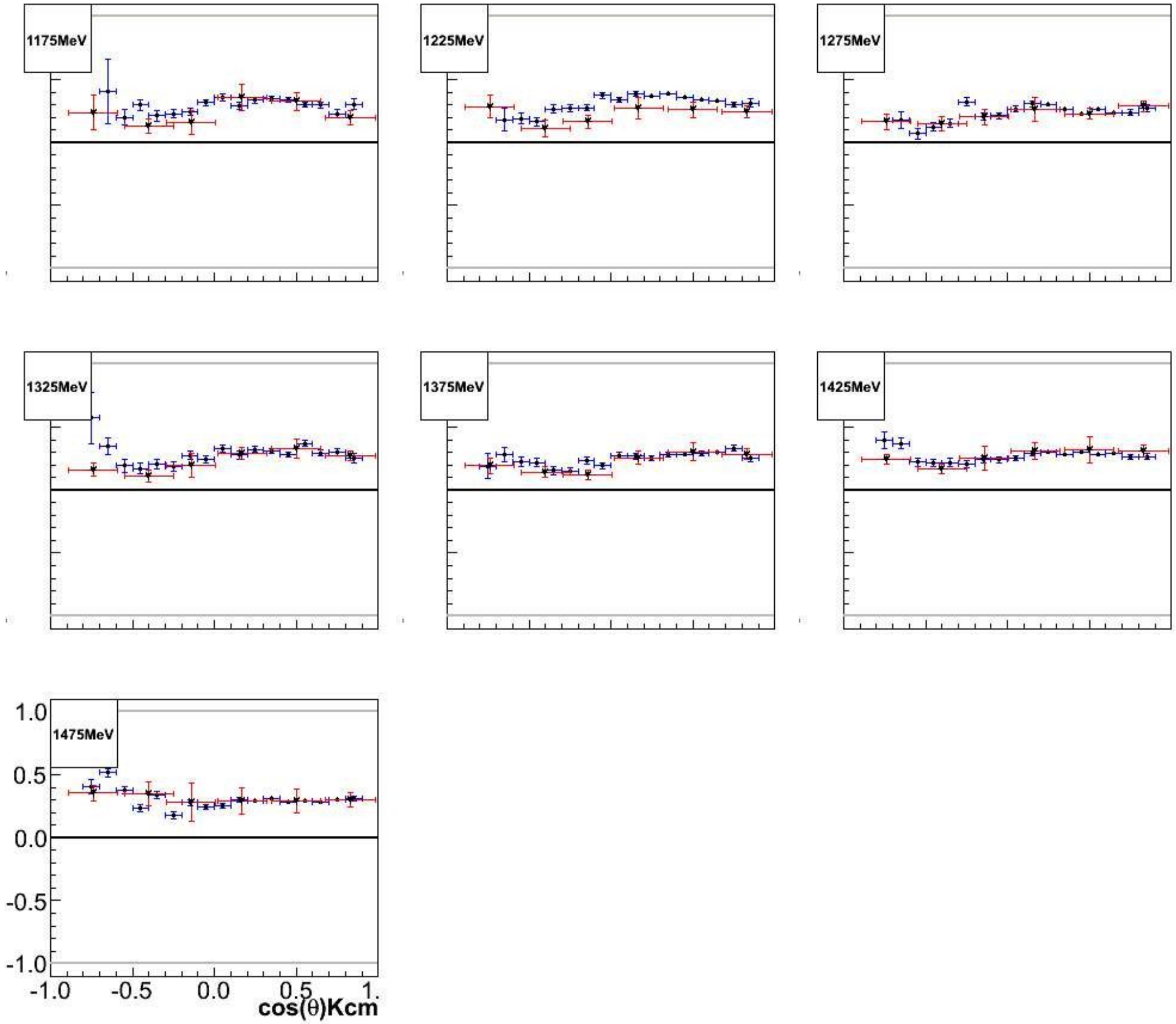


Summary

- In order to provide a more complete set of observables from which to determine contributing states, a polarised target has been used and analysis is ongoing for several channels
- Employed non-exclusive event selection to identify strangeness channels and measure observables
- Preliminary analysis of the beam polarisation observable, Σ, has been carried out
- By comparing these results to previous CLAS analyses, we demonstrate that the added complications of using a butanol target can be quantified and observables measured
- This allows us to proceed with measuring new observables, where there is no previous data, and a preliminary measurement of the G observable has been carried out

Backup Slide(s)

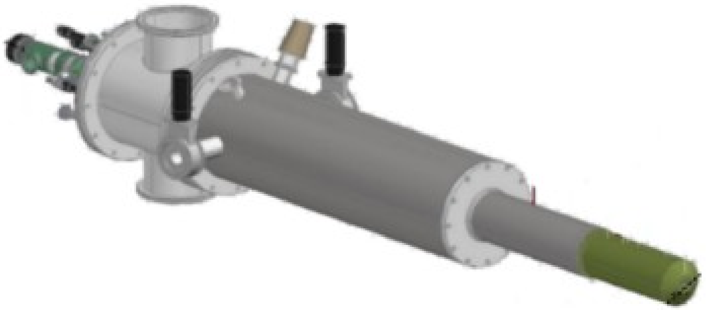
Σ Results from g8b compared to GRAAL



Targets

- Liquid hydrogen (LH2) is typically used as the target in CLAS photonuclear experiments, which maximises the density of atomic protons available for reactions
- To access the G polarisation observable, a polarised target is required

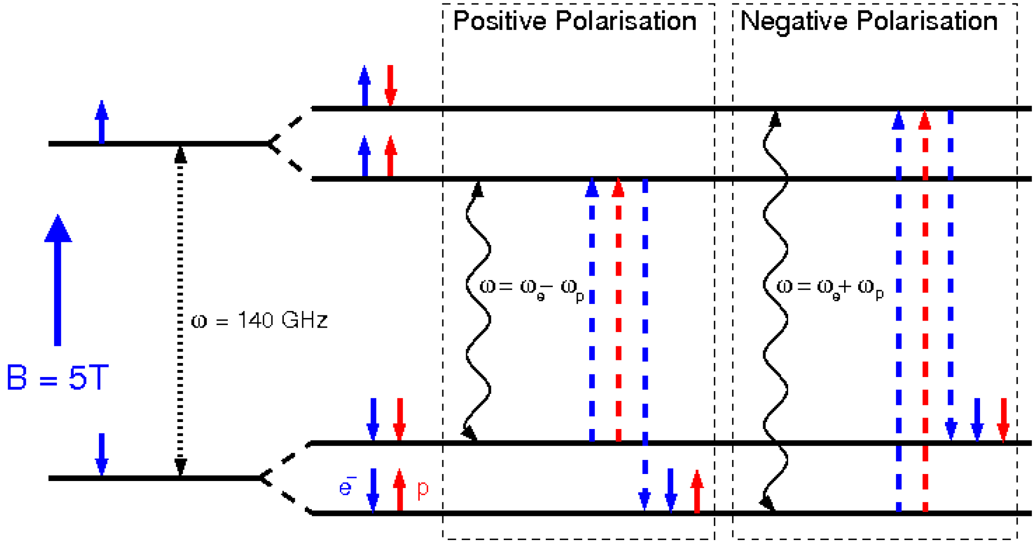
- Materials can be polarised using a high magnetic field, but this has two problems; at the operating temperatures of the CLAS LH2 target, hydrogen is unpolarisable, and polarising magnets would obscure a large part of the angular coverage of the detector



- Resolving these issues has led to the development of the FROST target at Jefferson Lab

The FROST Target

- FROST, which stands for FROzen Spin Target, is the name of the polarised proton target designed and built by the Jefferson Lab Target Group
- Combining Dynamic Nuclear Polarisation (DNP) of a solid (butanol) target with millikelvin cooling enables the target to operate in "frozen spin" mode, eliminating the need for a large continuous polarising field
- DNP enables target nuclei to be polarised by polarising free electrons in the target first, then transferring the polarisation to the nucleon by applying microwaves



The FROST Target

- Once the target has been polarised, the polarising magnet and microwaves are switched off, and it is cooled to around 40 mK
- A smaller holding magnetic field is switched on, and in this “frozen spin” mode, the polarisation can be maintained for periods of several days
- During this time, the target is positioned inside CLAS and data is taken with the polarised photon beam
- After several days, the target is removed from CLAS and repolarised