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

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For the CLAS Collaboration

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Outline

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  - “Missing Resonances”
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- Experimental Set-Up
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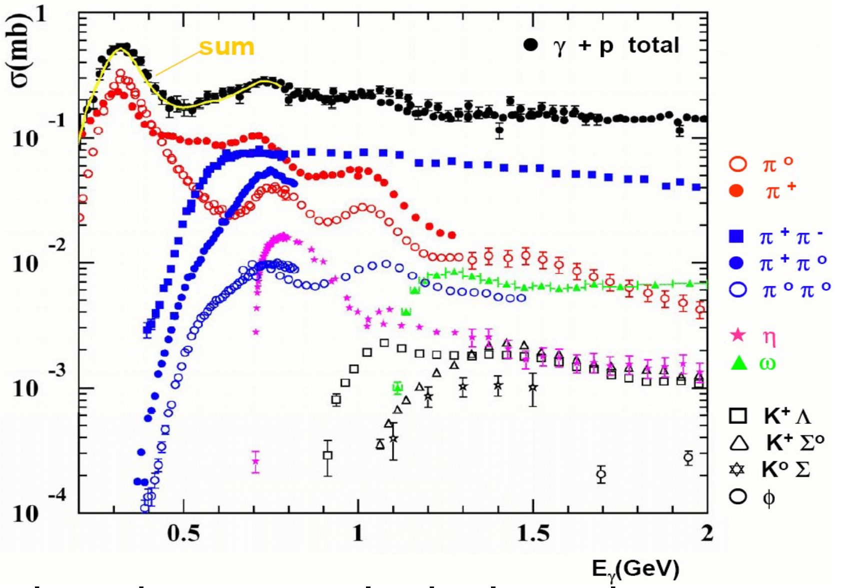
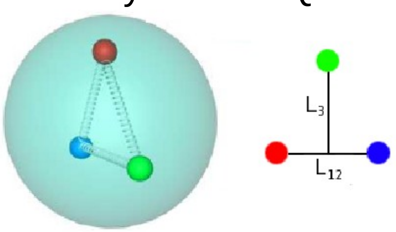
  - Hall B and the FROST experiment
- Analysis
  - Particle Identification
  - Channel Identification
  - Extracting Observables
  - Preliminary Results for the Beam Polarisation Observable (Σ)
  - Preliminary Results for the G Observable
- Summary

Motivation

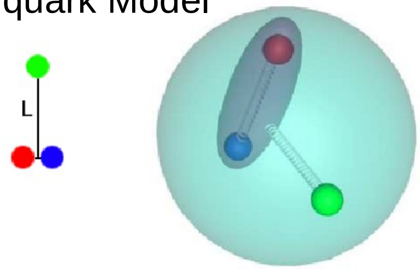
- Proton resonance spectrum for meson photoproduction
- Resolving some states can be difficult due to the wide signatures of some states, which overlap with others
- Some states couple more strongly to certain channels, such as $\gamma p \rightarrow K^{+}\Lambda$



Symmetric Quark Model



Diquark Model



- Two competing phenomenological quark models; symmetric quark model and diquark model
- Key difference is the presence of a bound quark pair in the di-quark model
- Both predict a range of resonances, but the symmetric quark model predicts more resonances than have currently been observed

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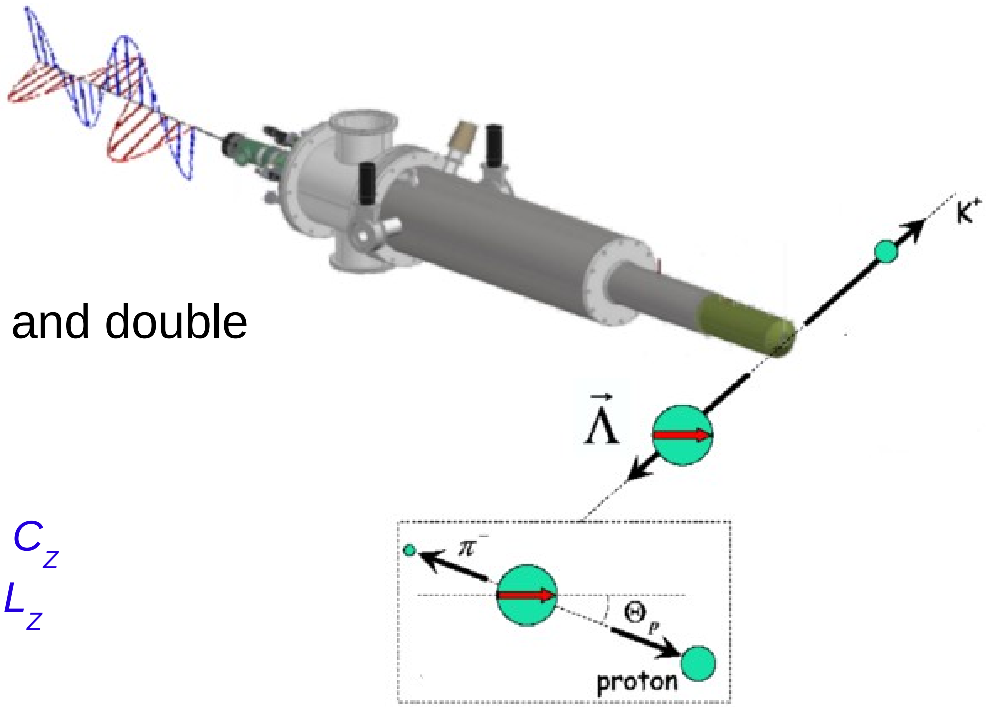
Polarisation Observables

- Measuring the G polarisation observable for the KΛ and KΣ strangeness photoproduction reactions:

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

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

- Property associated with polarised particles in a reaction, arising from the study of transversity amplitudes



- 16 polarisation observables, of 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

- With a polarised beam and target, can measure the observables shown in green (and more with recoil information...)

Polarisation Observables

- Each polarisation observable contributes to the overall differential cross-section:

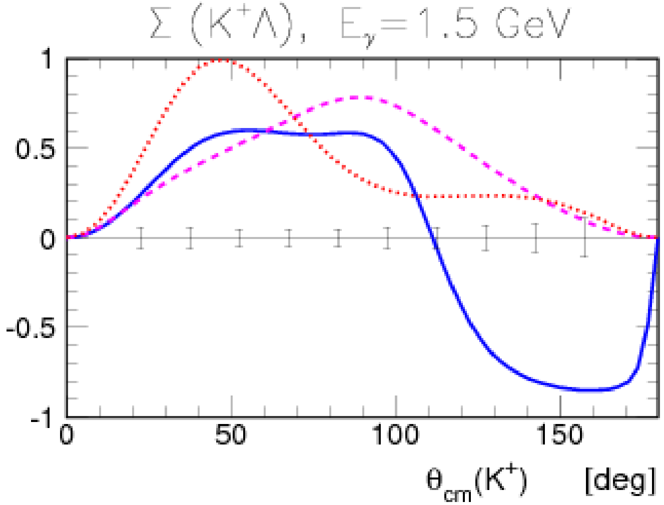
$$\frac{d\sigma}{d\Omega}=\sigma_0\{1-P_{lin}\Sigma\cos 2\phi+P_x(P_{\text{circ}}F+P_{lin}H\sin 2\phi)$$
$$+P_y(T-P_{lin}P\cos 2\phi)+P_z(P_{\text{circ}}E+P_{lin}G\sin 2\phi)$$
$$+\sigma'_x[P_{\text{circ}}C_x+P_{lin}O_x\sin 2\phi+P_x(T_x-P_{lin}L_z\cos 2\phi)$$
$$+P_y(P_{lin}C_z\sin 2\phi-P_{\text{circ}}O_z)+P_z(L_x+P_{lin}T_z\cos 2\phi)]$$
$$+\sigma'_y[P+P_{lin}T\cos 2\phi+P_x(P_{\text{circ}}G-P_{lin}E\sin 2\phi)$$
$$+P_y(\Sigma-P_{lin}\cos 2\phi)+P_z(P_{lin}F\sin 2\phi+P_{\text{circ}}H)]$$
$$+\sigma'_z[P_{\text{circ}}C_z+P_{lin}O_z\sin 2\phi+P_x(T_z+P_{lin}L_x\cos 2\phi)$$
$$+P_y(-P_{lin}C_x\sin 2\phi-P_{\text{circ}}O_z)+P_z(L_z+P_{lin}T_x\cos 2\phi)]\}$$

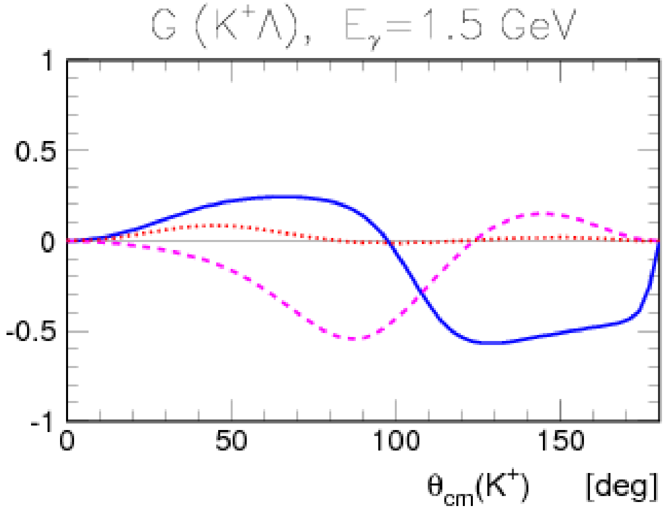
- 'G' is one of the beam-target double polarisation observables, arising from a linearly polarised beam with a longitudinally polarised target
- In this case, terms not involving linear polarisation of the beam and longitudinal polarisation of the target are zero and the above expression becomes a lot simpler:

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

Polarisation Observables

- Measuring polarisation observables is important because theoretical predictions of the observables vary depending 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

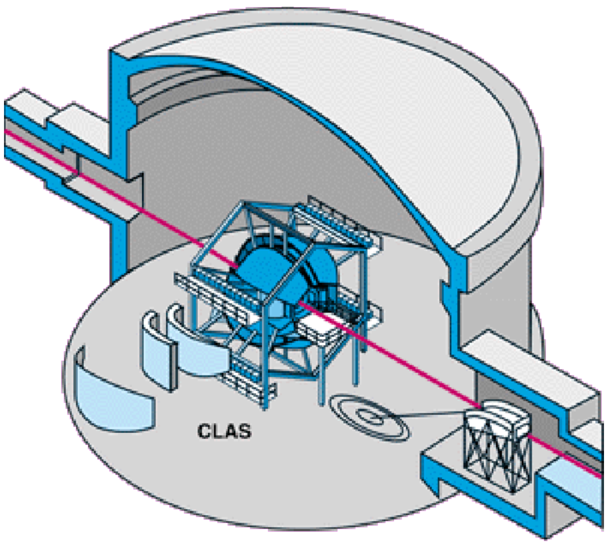
[1] Invited talk, *International Symposium on Hadrons and Nuclei*, Seoul (2001)
[2] Phys. Rev. **C61**, 012201 (2000)

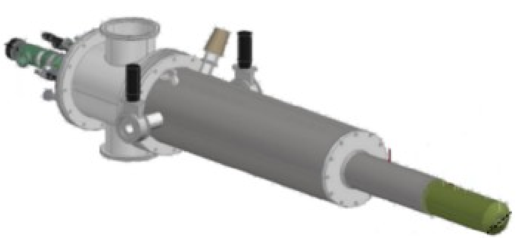
Jefferson Lab

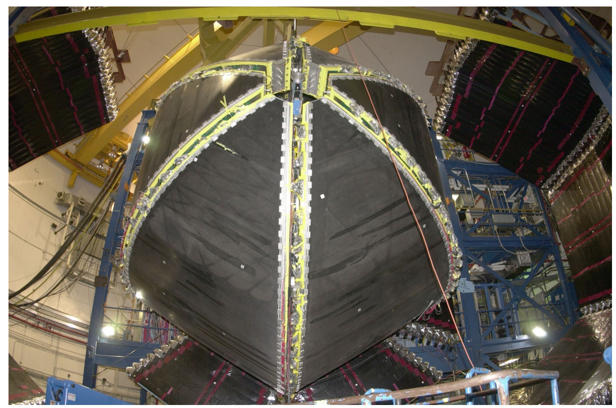
- Jefferson Lab is a US Department of Energy National Facility, located in Newport News, Virginia
- The lab's 6 GeV continuous wave electron accelerator, CEBAF, provides beam simultaneously to three experimental halls
- Work has started on an energy upgrade to 12 GeV and construction of a fourth hall
- Photonuclear experiments take place in Hall B, using CLAS – the CEBAF Large Acceptance Spectrometer

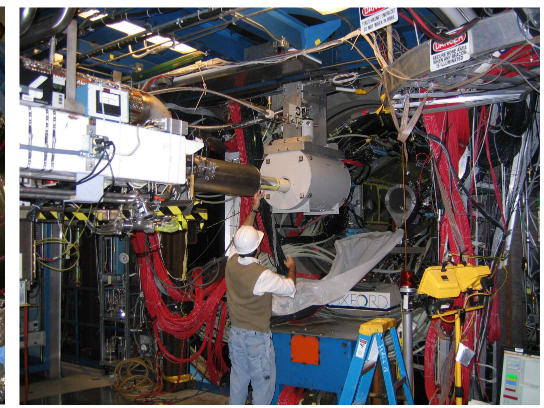
The g9a Experiment in Hall B

- 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



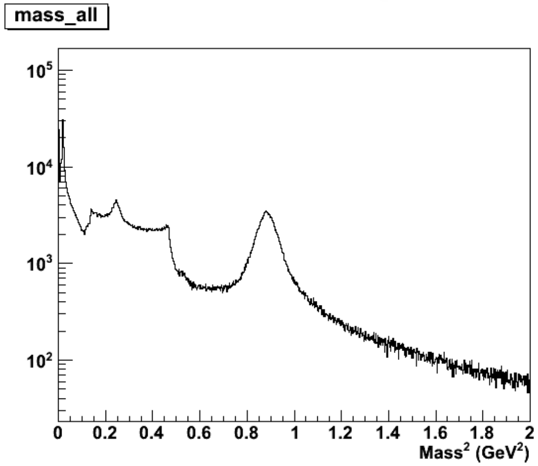




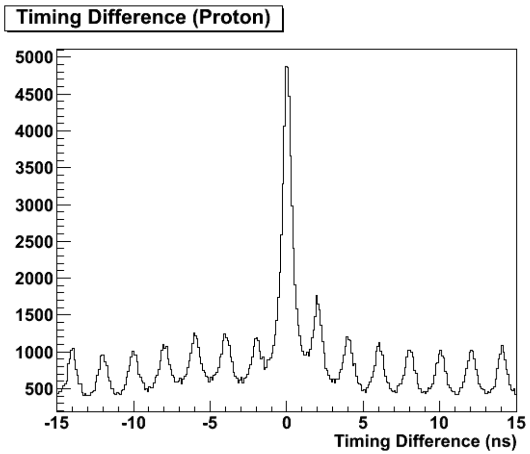


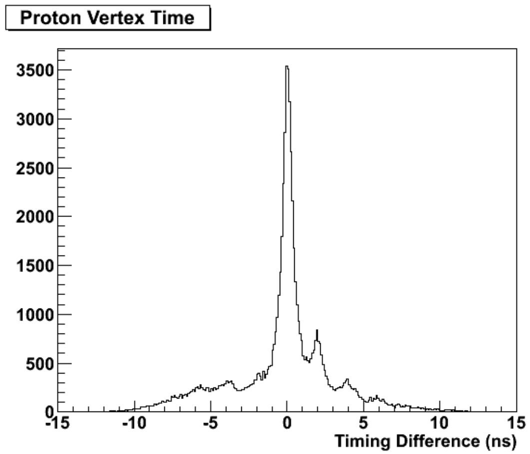
- Innovative design of the target allows the large acceptance of CLAS to be fully exploited
- Data was collected between November 2007 and February 2008 for a range of photon beam energies (0.73 – 2.3 GeV)
- Around 10 billion triggers recorded

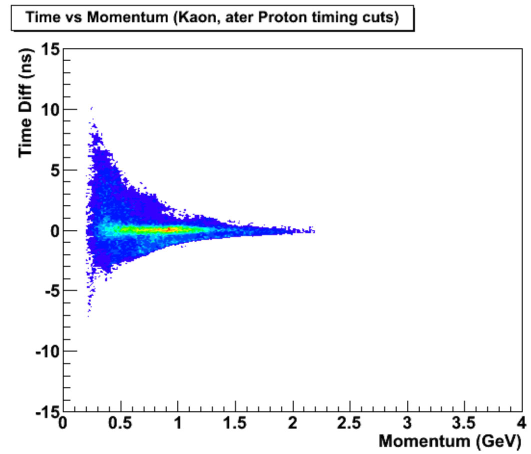
Particle ID



- 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







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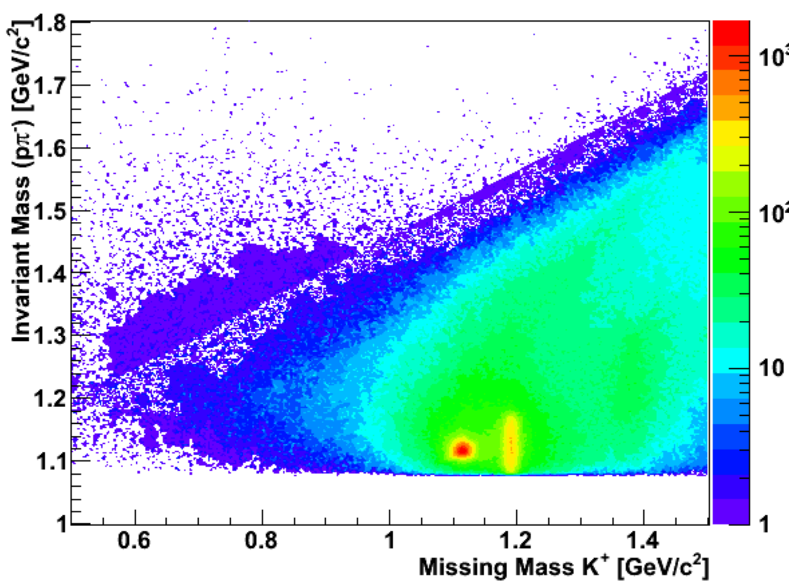
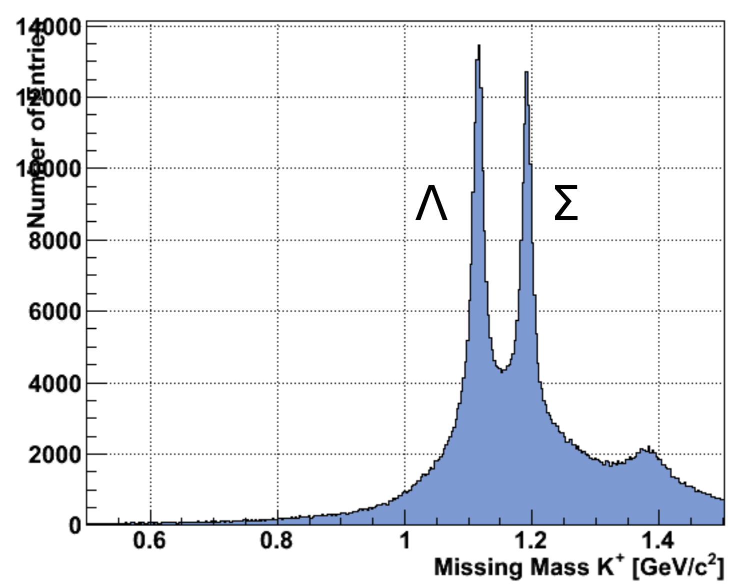
Channel Identification

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

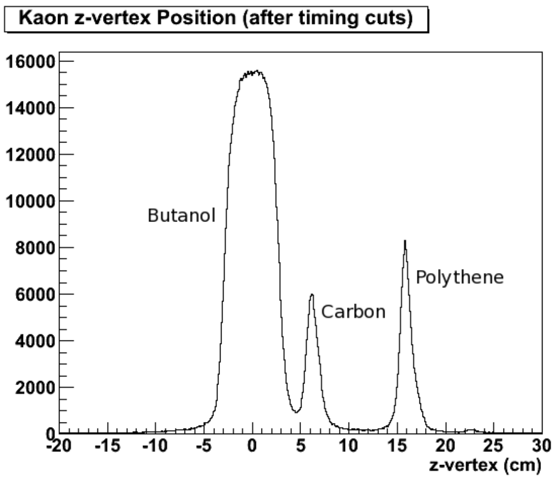
  and: $\gamma\, p \rightarrow K^+ \Sigma \rightarrow K^+ \Lambda \gamma \rightarrow K^+ p \pi^- \gamma$
- Two options; exclusive ID (fewer events), or non exclusive, reconstructing undetected particles via missing mass (susceptible to particle misidentification)
- Identify Lambda and Sigma hyperons from 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^+

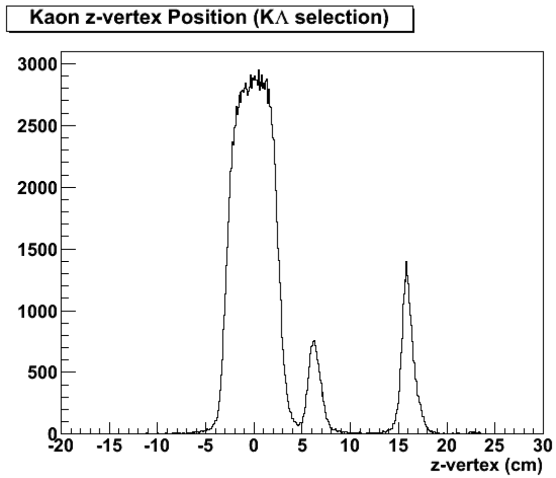




Target Selection

- 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

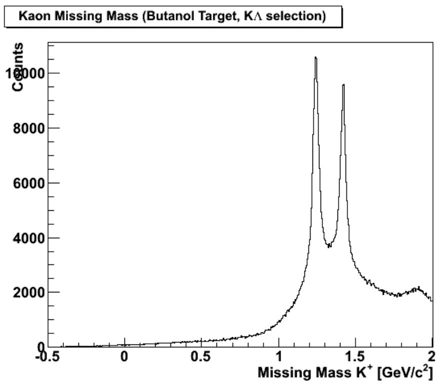


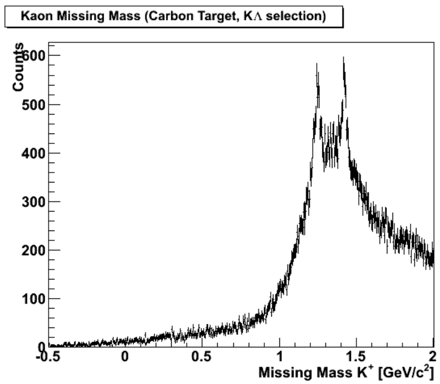


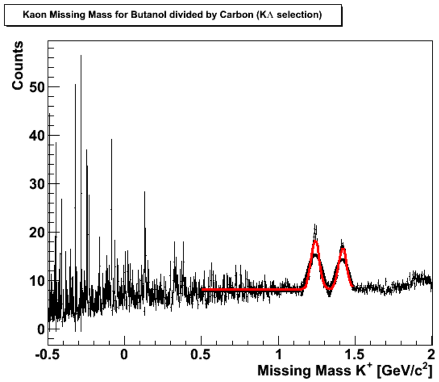
- Only Butanol is polarised, other targets used to account for nuclear background in channel identification plots and asymmetry dilution effects due to the unpolarised nuclei in Butanol
- Can also use polythene to cross-check previous measurements of polarisation observables, but low statistics prevents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

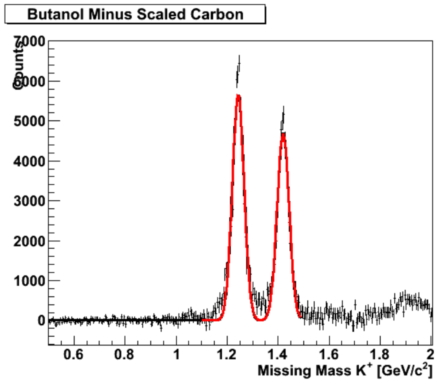
Carbon Scaling Factors

- 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;

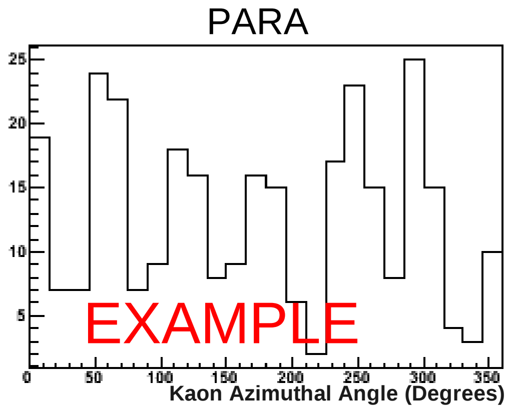
$$\Sigma=\frac{(\sigma(\perp,0,0)-\sigma(\|,0,0))}{(\sigma(\perp,0,0)+\sigma(\|,0,0))} \qquad G=\frac{(\sigma(\pi/4,+z,0)-\sigma(\pi/4,-z,0))}{(\sigma(\pi/4,+z,0)+\sigma(\pi/4,-z,0))}$$

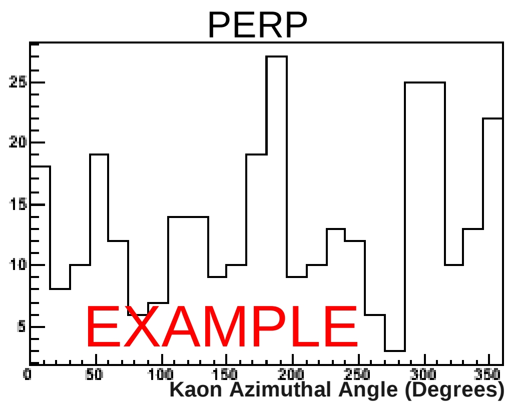
- If we produce an asymmetry of the Kaon azimuthal angle for two polarisation states, polarisarion observables can be extracted from the resulting distribution
- To measure the Σ and G observables, sinusoidal functions are fitted to an asymmetry distribution made from the two beam polarisation modes,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

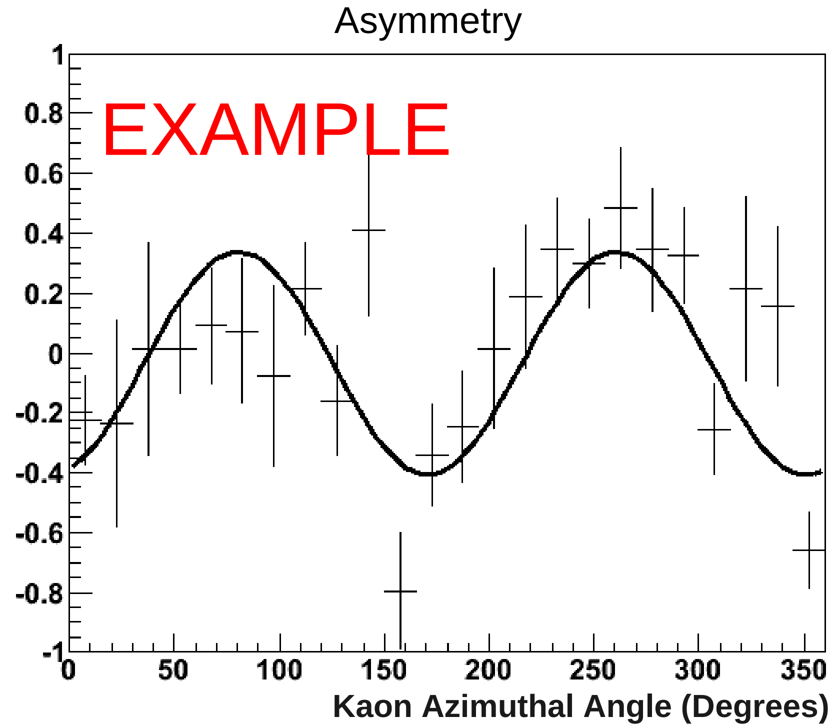
Extracting Observables

- For example, $P_\gamma \Sigma$ can be extracted from the magnitude of a $\cos(2\phi)$ function fitted to the PARA/PERP asymmetry of the Kaon azimuthal angle for an unpolarised target

- Sample $K\Lambda$ data from the polythene target at 1.5 GeV photon energy:





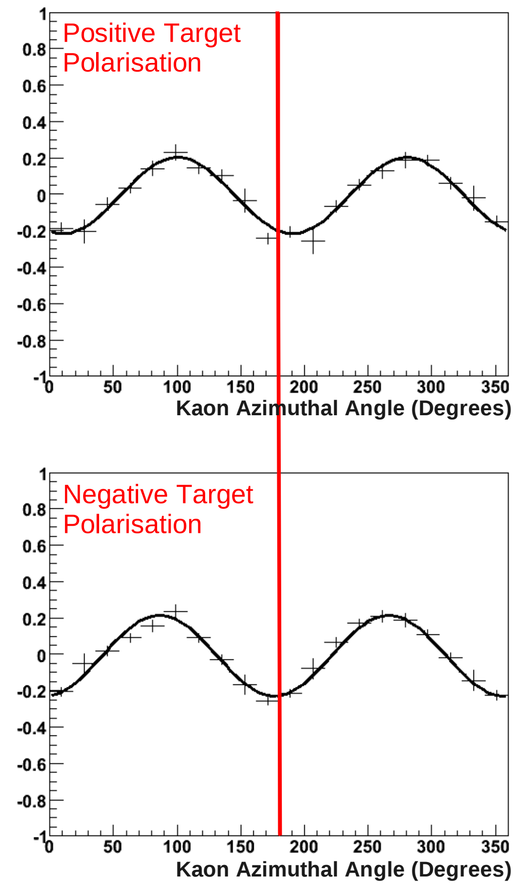


Measuring Σ and G

- 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

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

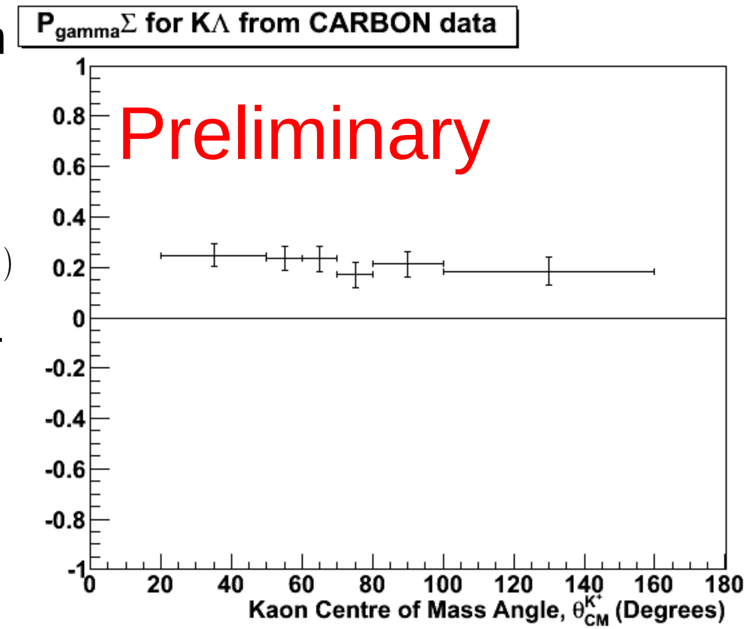
- The effect of G can be seen by examining these distributions for positive and negative longitudinal target polarisations
- The positive (top) and negative (bottom) target polarisation distributions show a phase shift due to change in target polarisation
- Extract Σ and G by fitting a cos(2φ) + sin(2φ) 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;



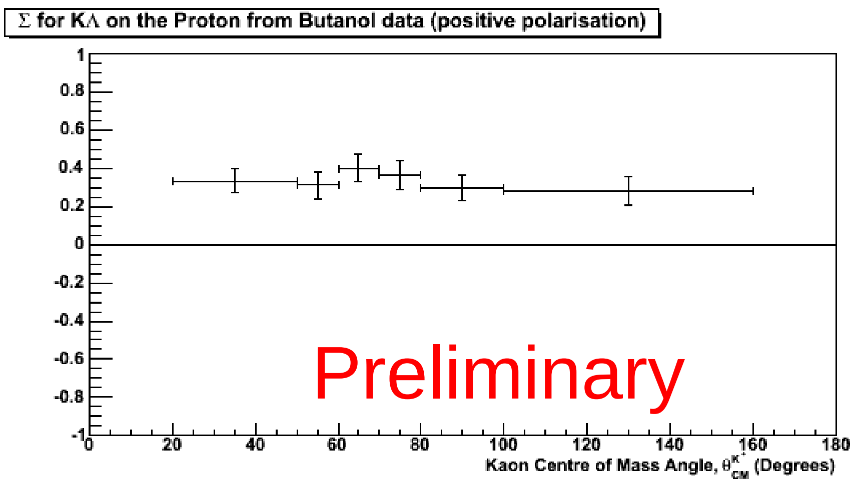
$$P_\gamma \Sigma_{PROTON} = \left(\frac{1}{N_{PROTON}}\right) * \left(N_{BUTANOL} P_\gamma \Sigma_{BUTANOL} - N_{CARBON} P_\gamma \Sigma_{CARBON}\right)$$

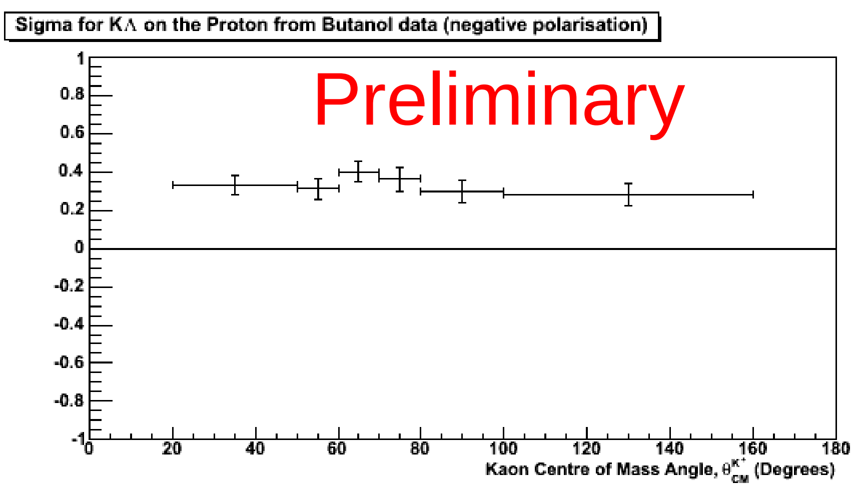
- Carbon is unpolarisable so dilution is simpler for G measurements and $P_\gamma P_{TARGET} G$ for the Proton is given by;

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

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

Σ Analysis

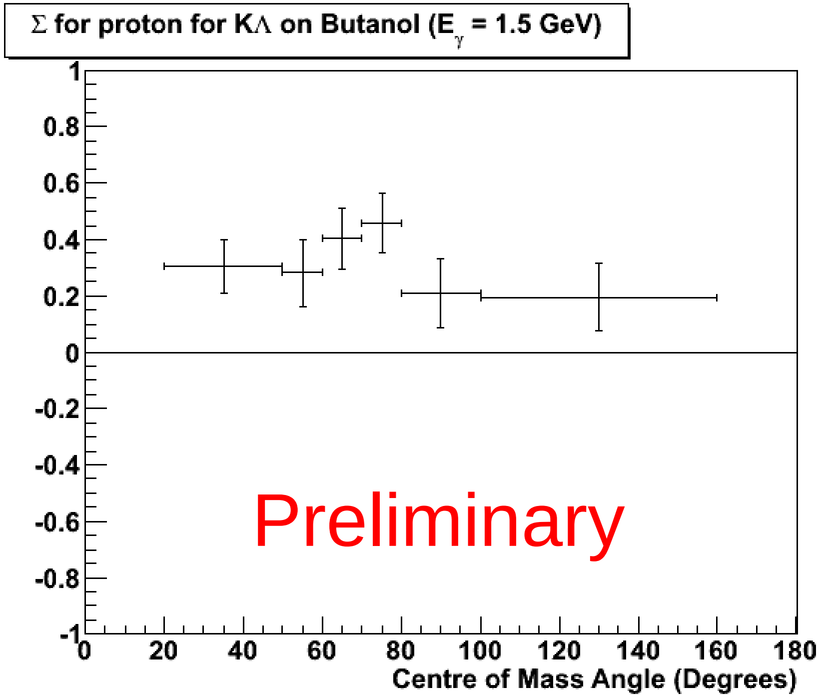




- Attempted measurement of Σ for 1.5 GeV photon energy on the KΛ channel for the positive (top) and negative (bottom) target polarisation settings
- Small amount of carbon data leads to significant errors when accounting for dilution
- Not a huge problem as the main purpose of Σ measurements on FROST is to verify previous results, and dilution of the G observable has no contribution from the unpolarised carbon
- Can also attempt Σ measurement by adding the positive and negative target data in such a way as to cancel the contribution from the G observable

Σ Analysis

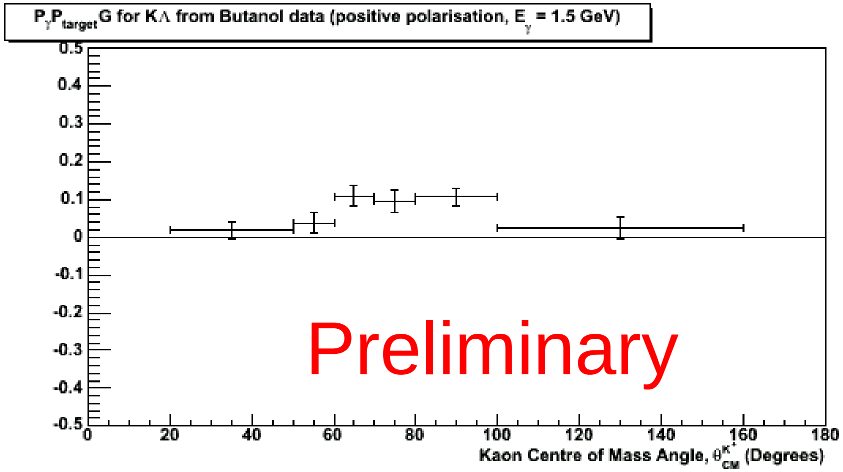
- Add Kaon azimuthal angle distributions for positive and negative target polarisations for each beam polarisation mode (PARA/PERP) in order to cancel the effect of the G observable
- Fit a cos(2ϕ) function to the PARA/PERP asymmetry to measure $P_\gamma\Sigma$ for Butanol

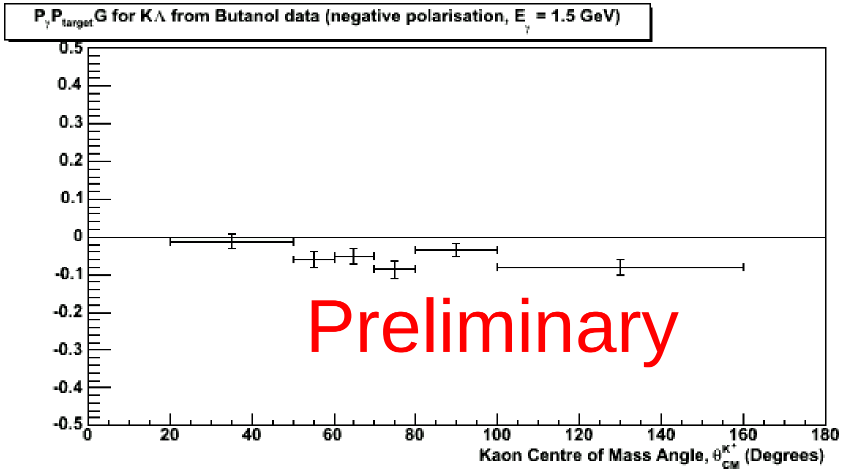


- Account for dilution and beam polarisation in order to estimate Σ for the Proton
- Target polarisation not identical in each direction
- Further work needed to ensure adding data for each polarisation direction properly accounts for this, otherwise the contribution from the G observable is not fully cancelled

G Analysis

- $P_\gamma P_{TARGET} G$ for 1.5 GeV photon energy on the $K\Lambda$ channel on Butanol
- Can see the sign change between positive (top) and negative (bottom) target polarisations
- Account for beam and target polarisations, as well as dilution, to extract G





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
- Non-exclusive event selection on the strangeness channels enables more events to be analysed from the limited data
- Preliminary analysis of the beam polarisation observable, Σ, has been carried out, with the intention of comparing these results to previous CLAS analyses
- Work on extracting the G observable is also underway, providing new information where there is no previous data

Backup Slide(s)

Σ Analysis on KΣ

- Attempted measurement of $P_\gamma\Sigma$ for 1.5 GeV photon energy on the KΣ channel