



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

Stuart Fegan

Nuclear Physics Group

University of Glasgow

For the CLAS Collaboration

NStar 2011 Conference

Jefferson Lab, USA, May 17th, 2011

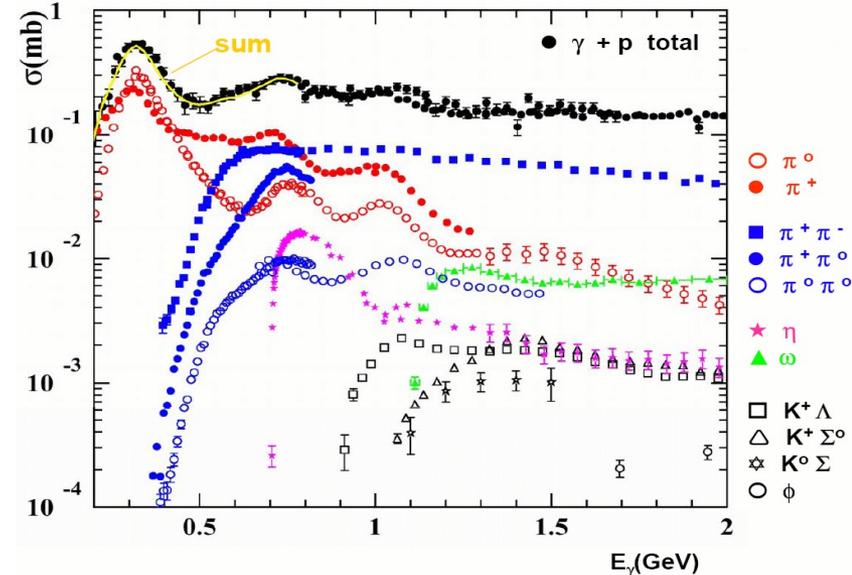


Outline

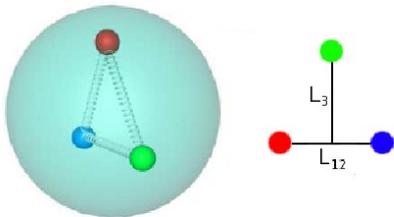
- Motivation
 - “Missing Resonances”
 - Polarisation Observables
- Experimental Set-Up
 - Jefferson Lab
 - Hall B and the FROST experiment
- Analysis
 - Particle Identification
 - Channel Identification
 - Extracting Observables
 - Preliminary Results for the Beam Polarisation Observable (Σ)
 - Preliminary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

Motivation

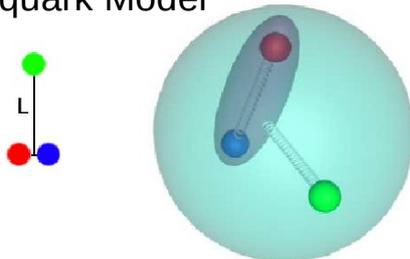
- Proton resonance spectrum for meson photoproduction
- Resolving some states can be difficult due to the wide signatures of some states, which overlap with others
- Some states couple more strongly to certain channels, such as $\gamma p \rightarrow K^+ \Lambda$



Symmetric Quark Model



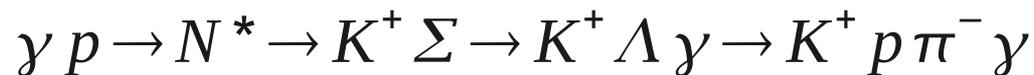
Diquark Model



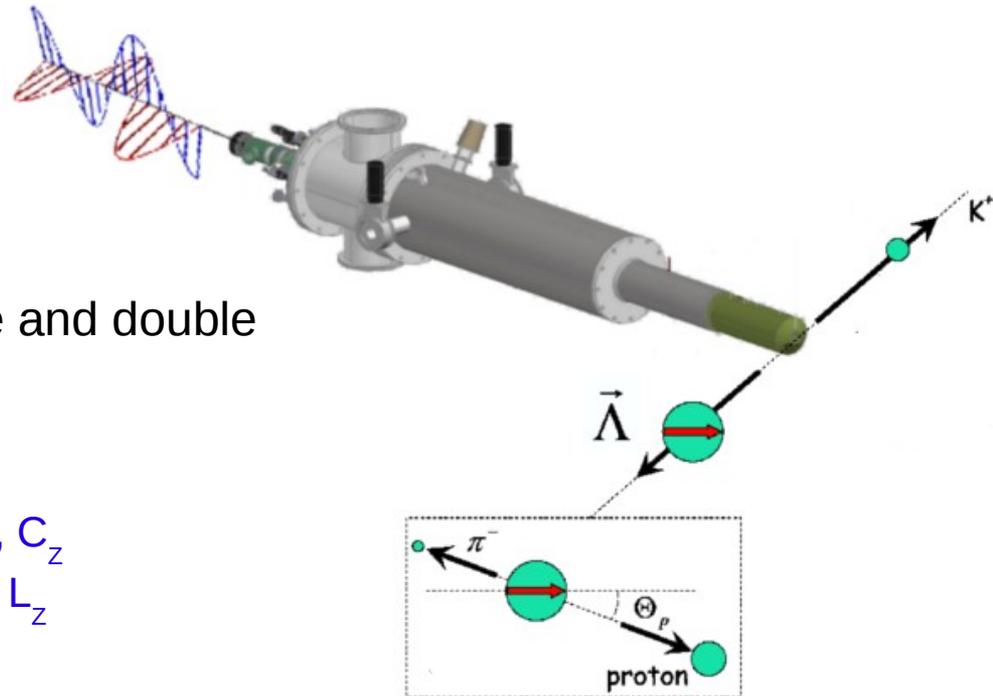
- Two competing phenomenological quark models; symmetric quark model and diquark model
- Key difference is the presence of a bound quark pair in the di-quark model
- Both predict a range of resonances, but the symmetric quark model predicts more resonances than have currently been observed

Polarisation Observables

- Measuring the G polarisation observable for the $K\Lambda$ and $K\Sigma$ strangeness photoproduction reactions:



- 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:

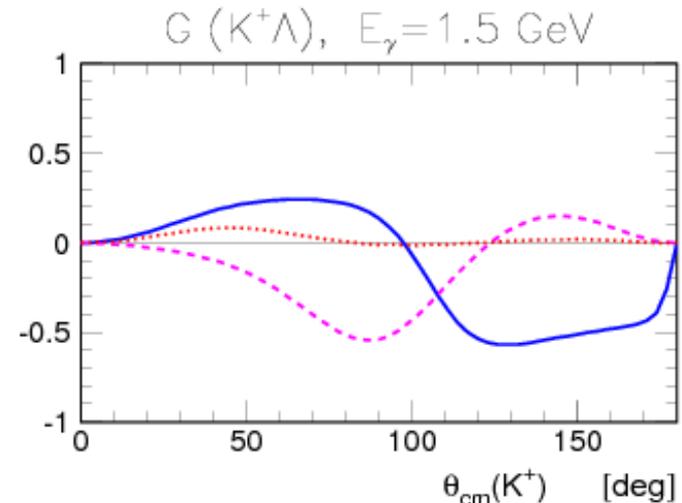
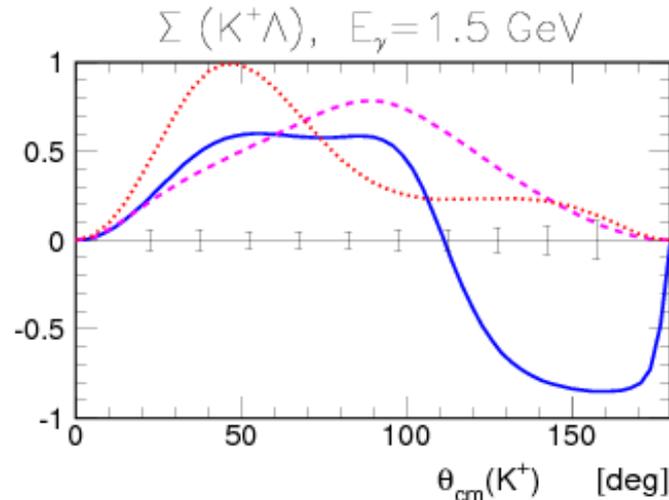
$$\begin{aligned}
 \frac{d\sigma}{d\Omega} = \sigma_0 \{ & 1 - P_{lin} \Sigma \cos 2\phi + P_x (P_{circ} F + P_{lin} H \sin 2\phi) \\
 & + P_y (T - P_{lin} P \cos 2\phi) + P_z (P_{circ} E + P_{lin} G \sin 2\phi) \\
 & + \sigma'_x [P_{circ} C_x + P_{lin} O_x \sin 2\phi + P_x (T_x - P_{lin} L_z \cos 2\phi)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

- '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 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)

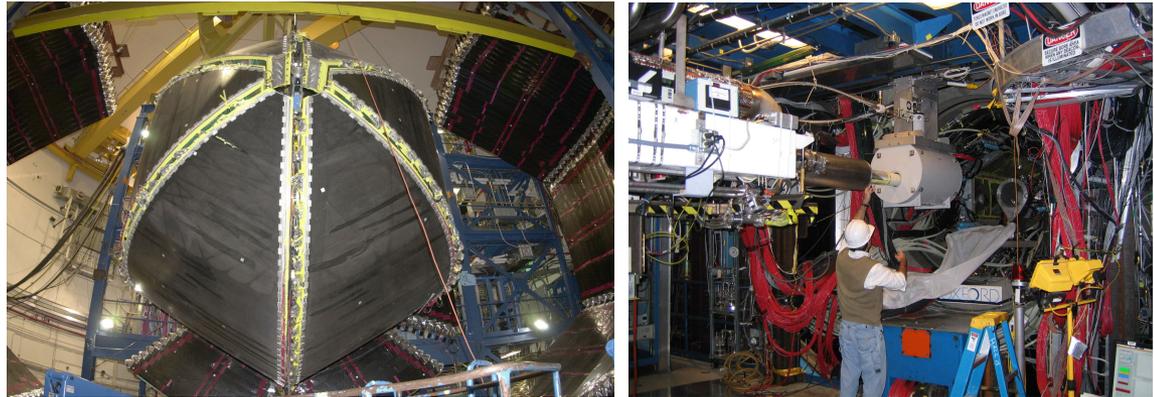
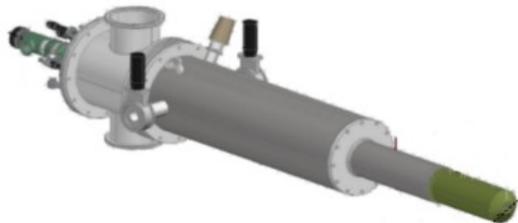
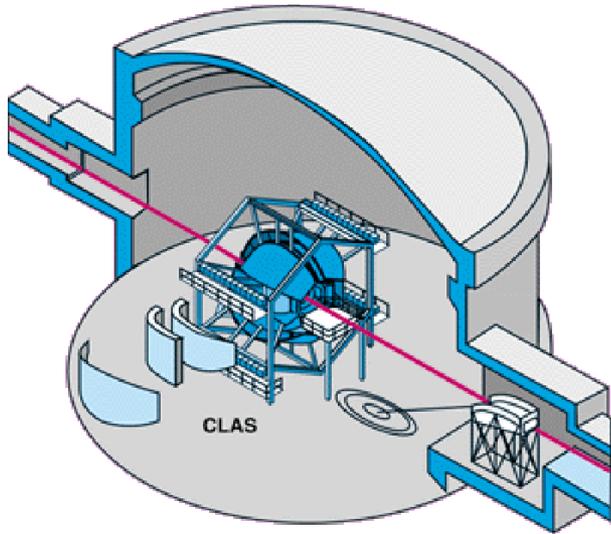
Jefferson Lab



- Jefferson Lab 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

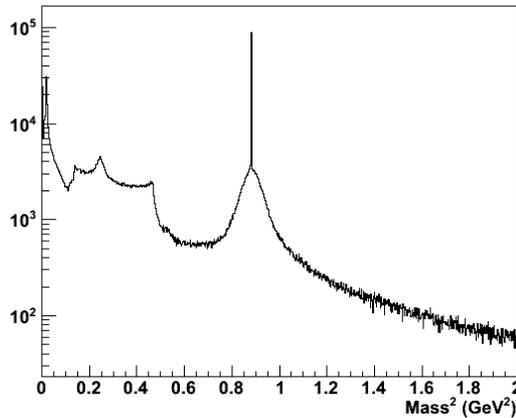
- g9a was the first run period using the CLAS Frozen Spin Target (FROST)
- Linearly and circularly polarised photon beams, produced via coherent bremsstrahlung, interact with a longitudinally polarised target



- Innovative design of the target allows the large acceptance of CLAS ($\sim 4\pi$) 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

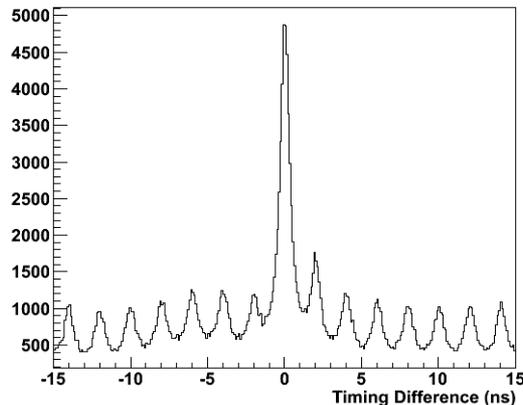
mass_all



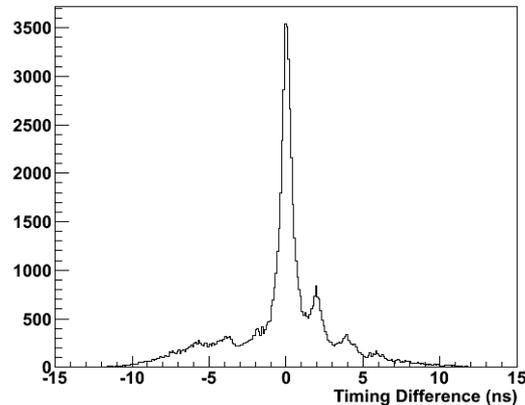
- Initial particle identification realised via a combination of charge and time-of-flight calculated mass
- Select potential events for the channel of interest from possible combinations of detected particles (allowing 1 Proton and 1 Kaon, with the option of 0 or 1 π^- , and 0 or 1 neutrals, i.e. photons)

- Important to identify correct photon to reduce particle misidentification using the photon to particle timing difference

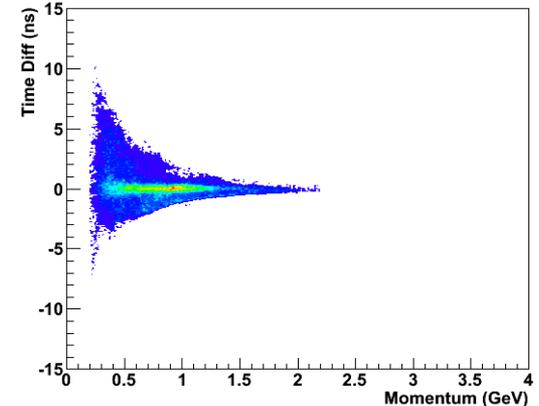
Timing Difference (Proton)



Proton Vertex Time

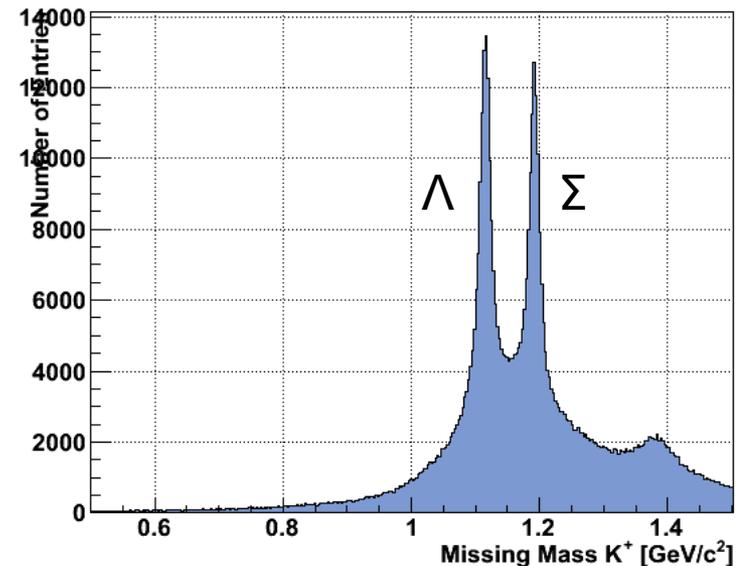
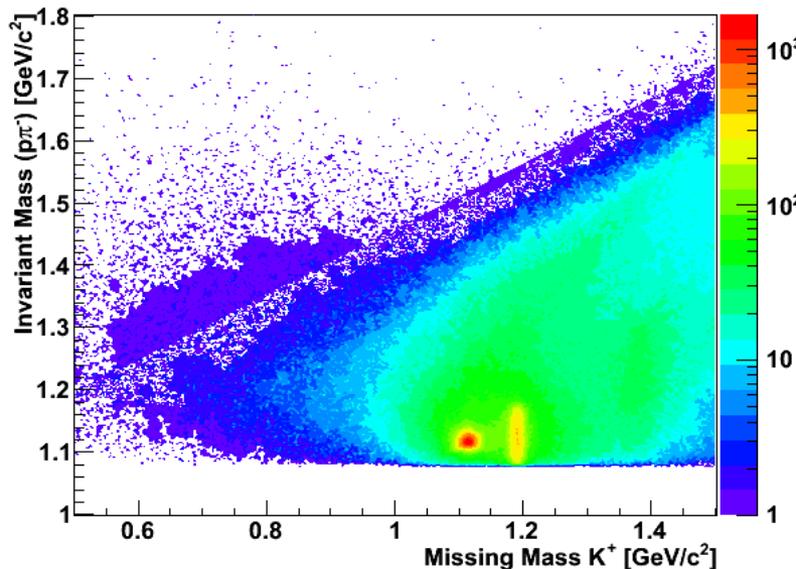


Time vs Momentum (Kaon, after Proton timing cuts)



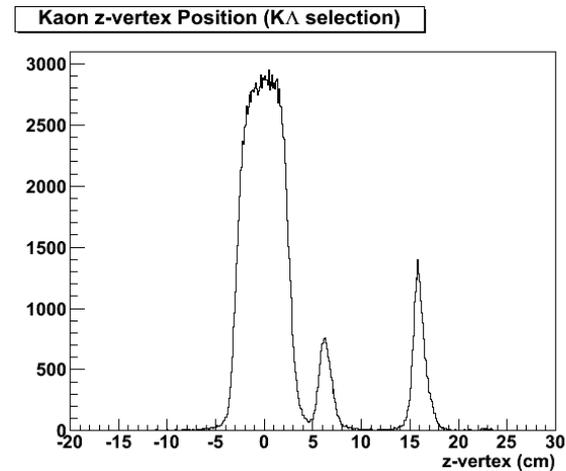
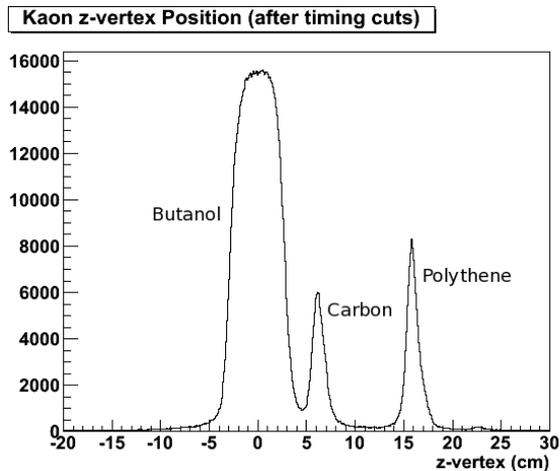
Channel Identification

- 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

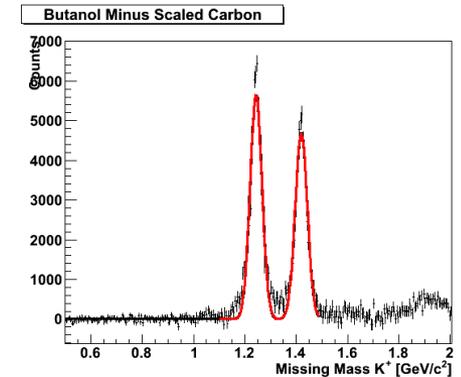
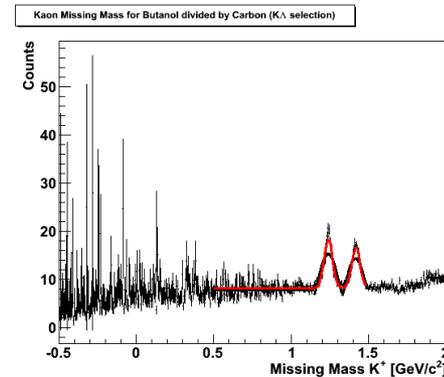
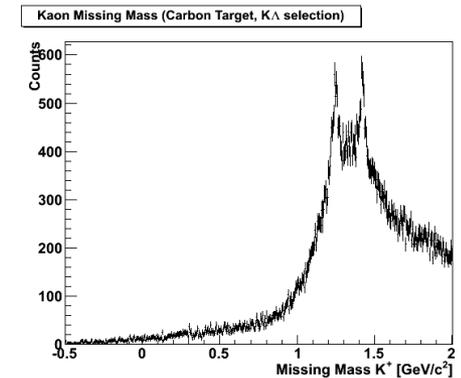
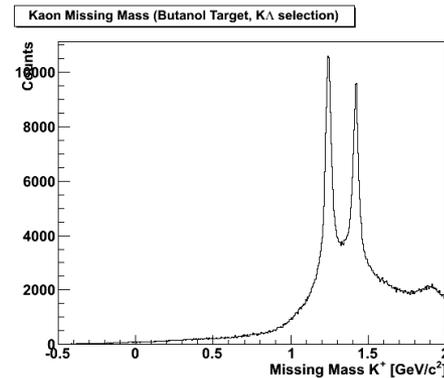
- The FROST target assembly contains three target materials; Butanol (C_4H_9OH), Carbon (^{12}C) and Polythene (CH_2), resolvable after particle and channel identification



- 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;

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

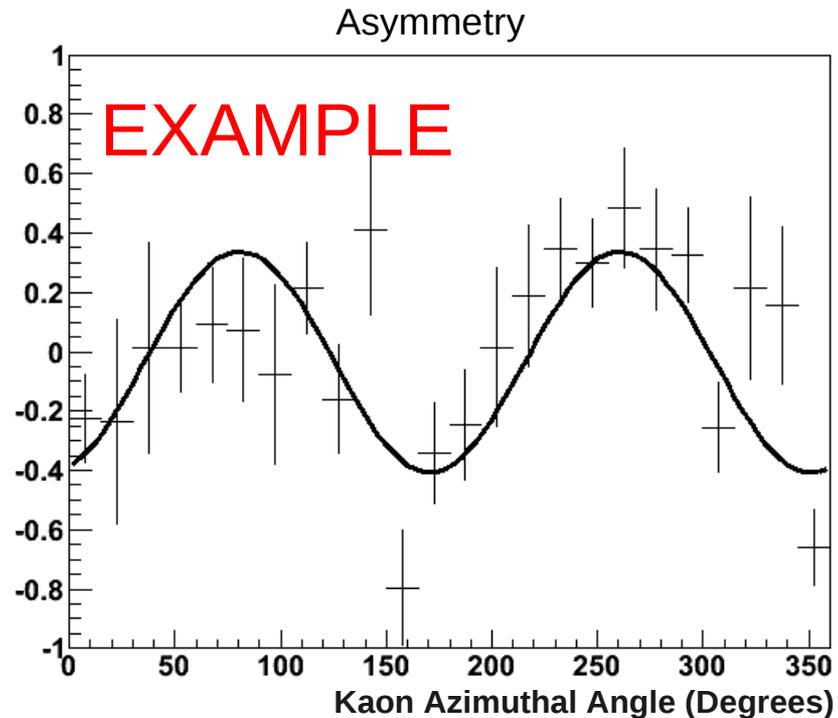
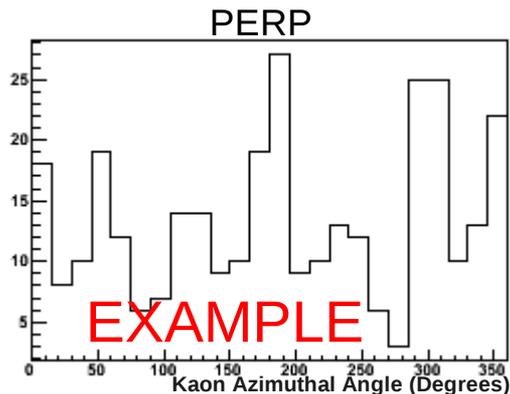
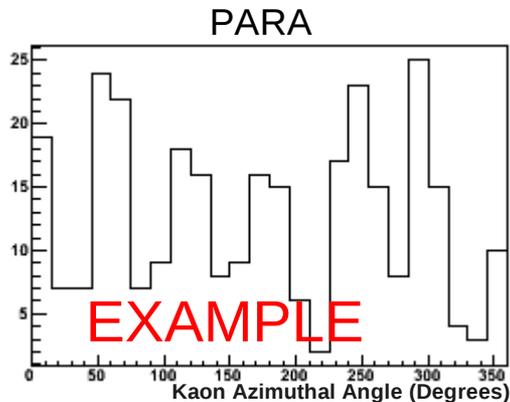
- Observables can also be expressed as the difference over the sum of cross-sections for two polarisation states;

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

- If we produce an asymmetry of the Kaon azimuthal angle for two polarisation states, polarisation 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:

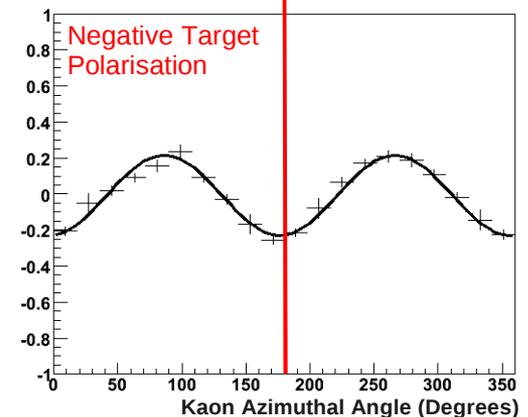
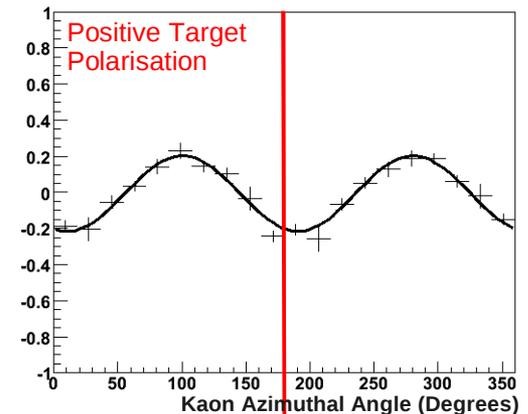


Measuring Σ and G

- If we make asymmetries of Kaon azimuthal angle distributions for the Butanol data, the amplitude of a $\cos(2\phi)$ 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 $\cos(2\phi) + \sin(2\phi)$ function to the PARA/PERP asymmetry for each target state
- $P_Y \Sigma$ is the amplitude of the $\cos(2\phi)$ term, and the amplitude of the $\sin(2\phi)$ term is a measure of $P_Y P_{TARGET} G$



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;

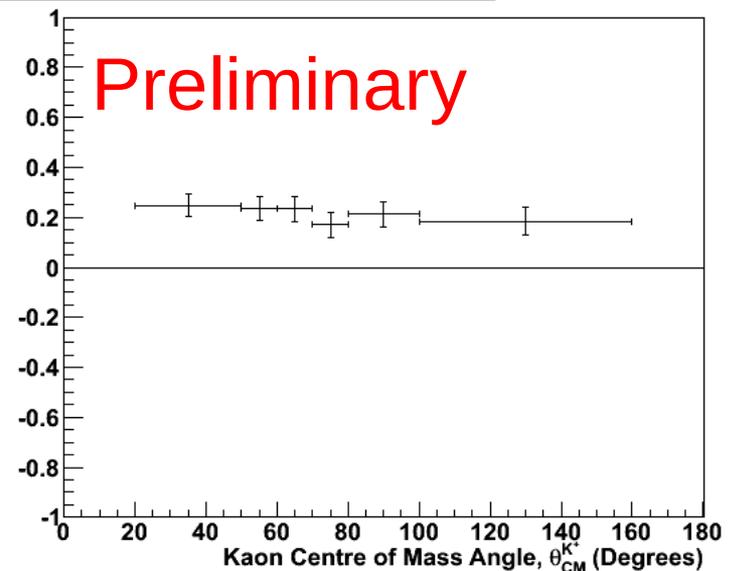
$$P_{\gamma\Sigma_{PROTON}} = \left(\frac{1}{N_{PROTON}} \right) * (N_{BUTANOL} P_{\gamma\Sigma_{BUTANOL}} - N_{CARBON} P_{\gamma\Sigma_{CARBON}})$$

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

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

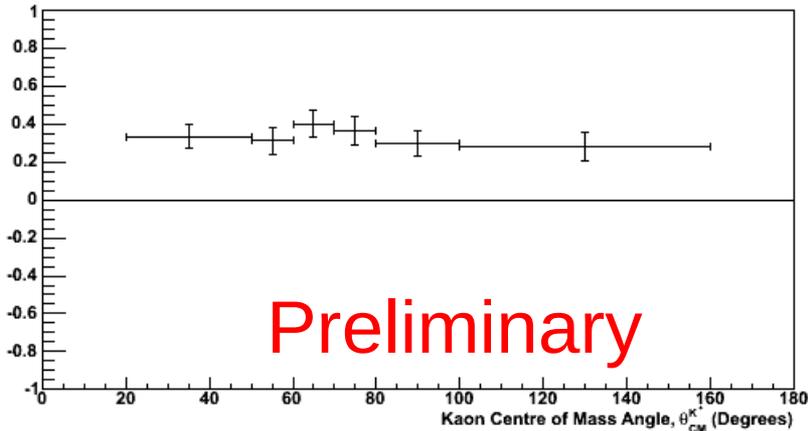
- Also need to account for both beam and target polarisations in order to measure Σ and G

$P_{\gamma\Sigma}$ for $K\Lambda$ from CARBON data

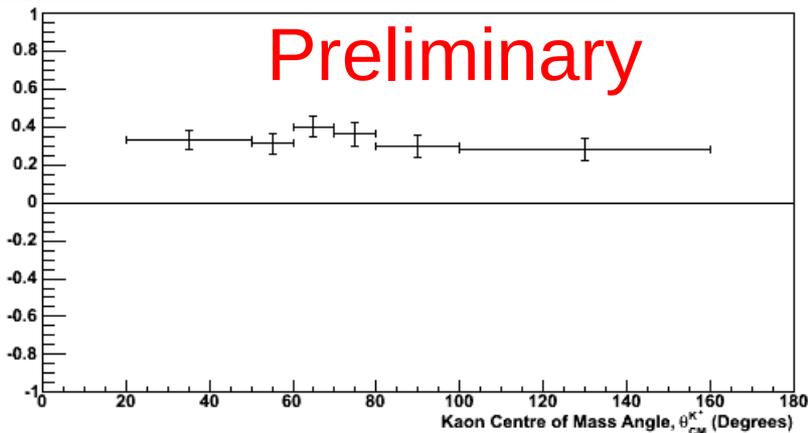


Σ Analysis

Σ for $K\Lambda$ on the Proton from Butanol data (positive polarisation)



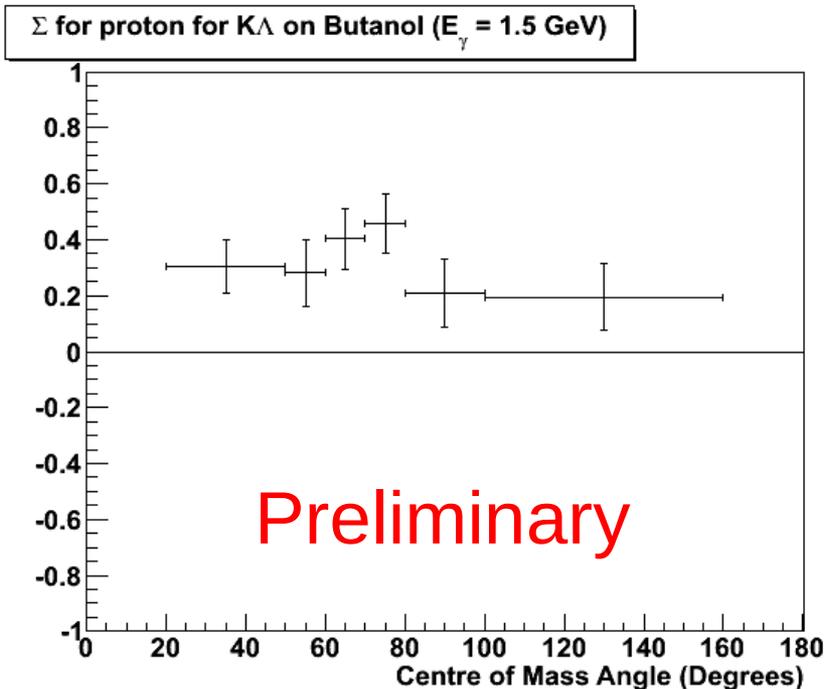
Σ for $K\Lambda$ on the Proton from Butanol data (negative polarisation)



- Attempted measurement of Σ for 1.5 GeV photon energy on the $K\Lambda$ 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

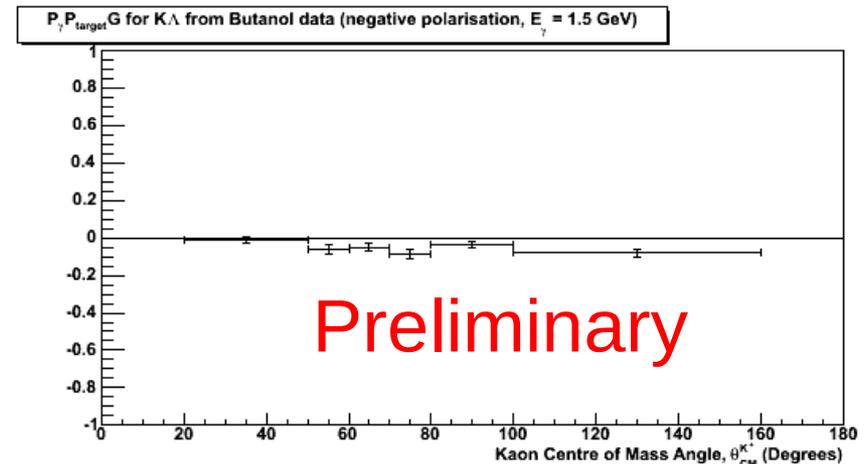
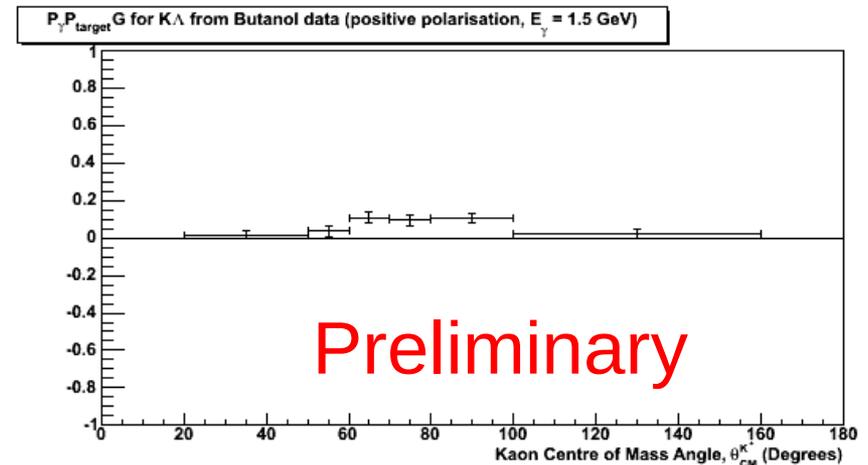
- Add Kaon azimuthal angle distributions for positive and negative target polarisations for each beam polarisation mode (PARA/PERP) in order to cancel the effect of the G observable
- Fit a $\cos(2\phi)$ function to the PARA/PERP asymmetry to measure $P_{\gamma}\Sigma$ for Butanol



- 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

- $P_{\gamma} P_{\text{target}} G$ 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 $K\Sigma$

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

