



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

Stuart Fegan

Nuclear Physics Group

University of Glasgow

NPPD Conference

Glasgow, April 4th, 2011

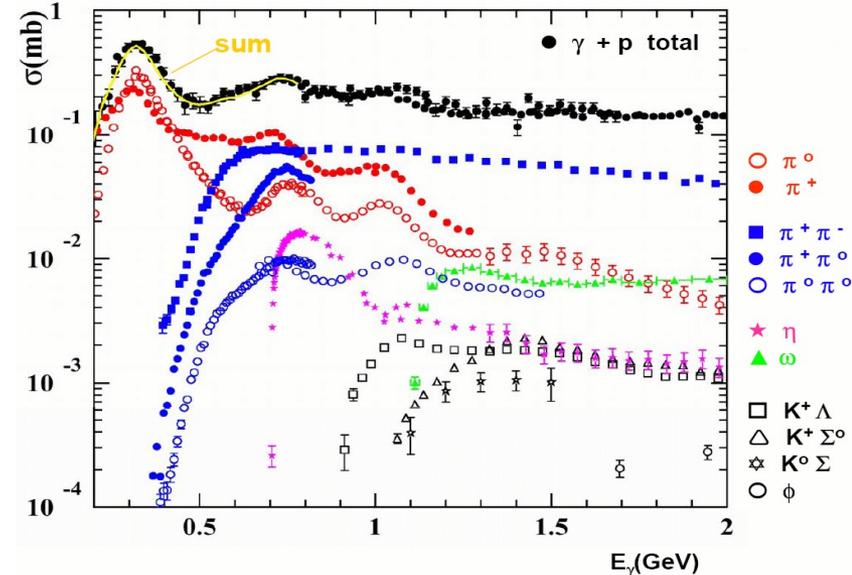


Outline

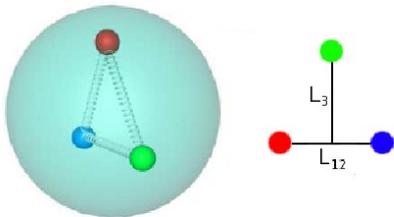
- Motivation
 - “Missing Resonances”
 - Polarisation Observables
- Experimental Set-Up
 - Jefferson Lab
 - Hall B and the FROST experiment
- Analysis
 - Particle Identification
 - Channel Identification
 - Preliminary analysis of the Beam Polarisation Observable (Σ)
 - Moving towards a measurement of G
- Summary

Motivation

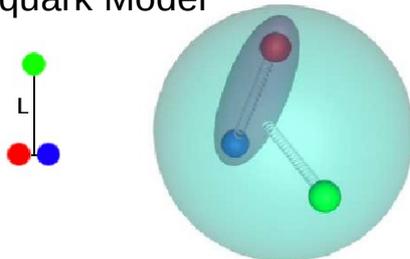
- Proton resonance spectrum for meson photoproduction
- Resolving some states can be difficult due to the wide signatures of some states, which overlap with others
- Some states couple more strongly to certain channels, such as $\gamma p \rightarrow K^+ \Lambda$



Symmetric Quark Model



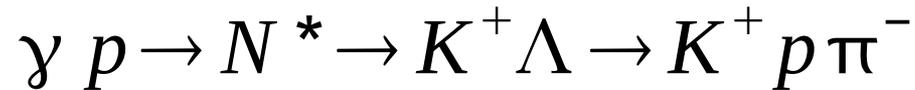
Diquark Model



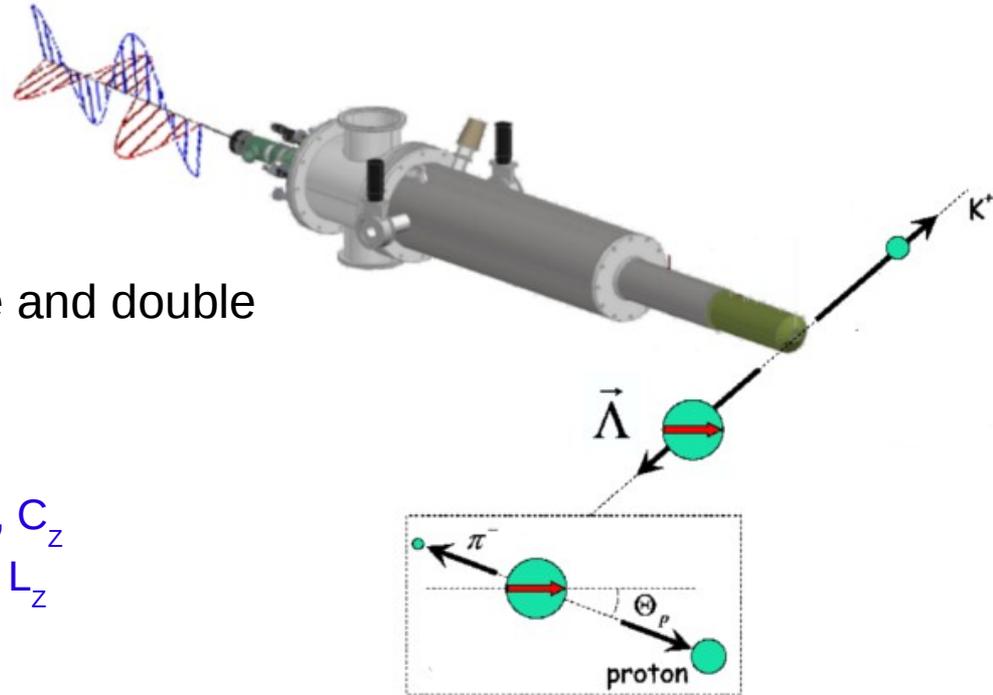
- Two competing phenomenological quark models; symmetric quark model and diquark model
- Key difference is the presence of a bound quark pair in the di-quark model
- Both predict a range of resonances, but the symmetric quark model predicts more resonances than have currently been observed

Polarisation Observables

- Measuring the G polarisation observable for $K\Lambda$ photoproduction:



- 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

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:

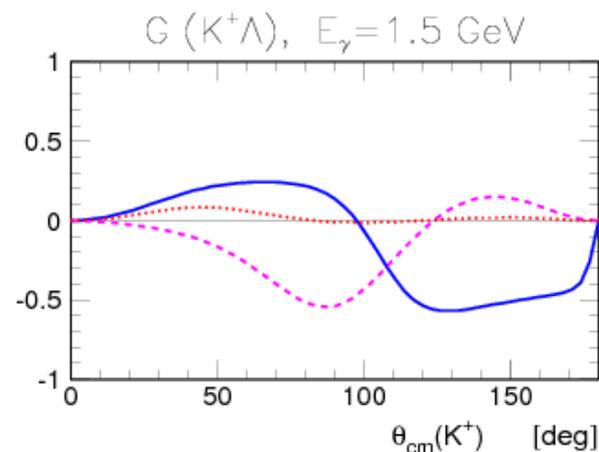
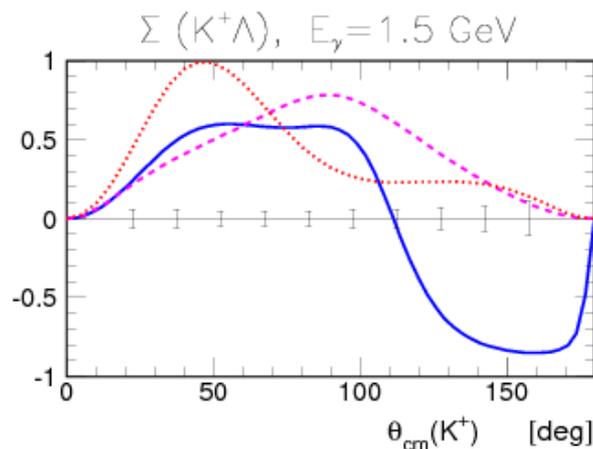
$$\frac{d\sigma}{d\Omega} = \sigma_0 \{ 1 - P_{lin} \Sigma \cos 2\phi + P_z (P_{lin} G \sin 2\phi) \}$$

Polarisation Observables

- Polarisation observables can also be expressed as the difference over the sum of cross-sections for two polarisation states
- For example, G can be expressed in terms of cross-sections for the two states of longitudinal target polarisation (+ z and - z)

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

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



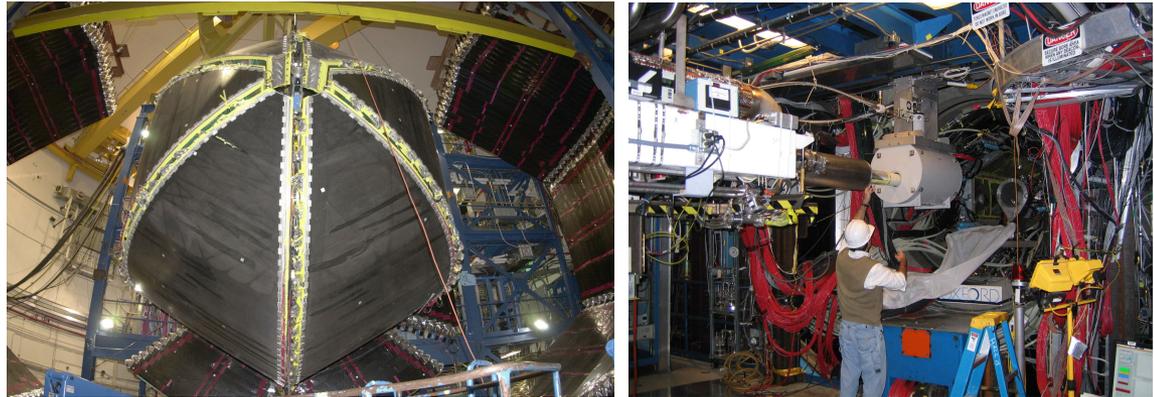
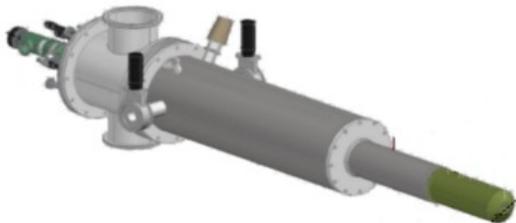
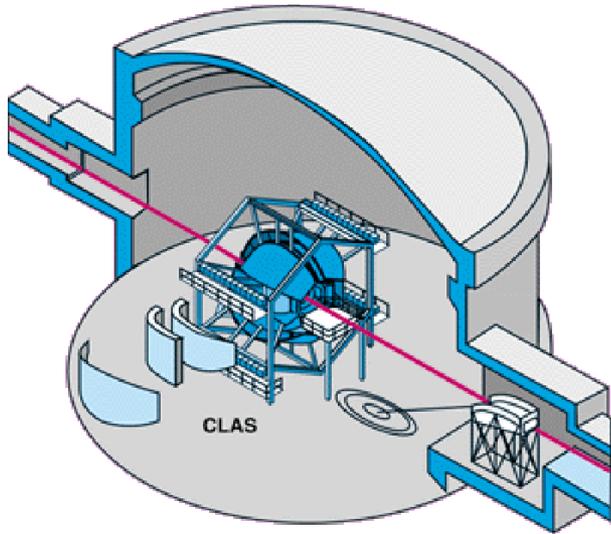
Jefferson Lab



- 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

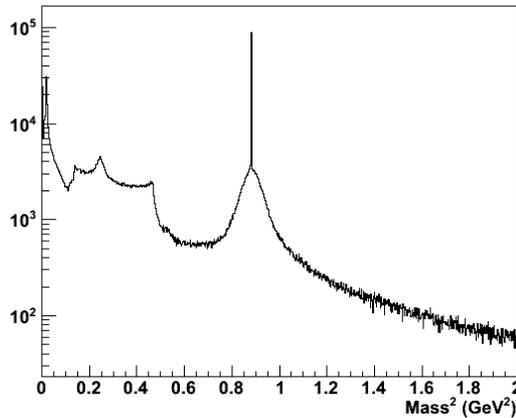
- g9a was the first run period using the CLAS Frozen Spin Target (FROST)
- Linearly and circularly polarised photon beams, produced via coherent bremsstrahlung, interact with a longitudinally polarised target



- 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 beam energies (0.73 – 2.3 GeV)
- Around 10 billion triggers recorded

Particle ID

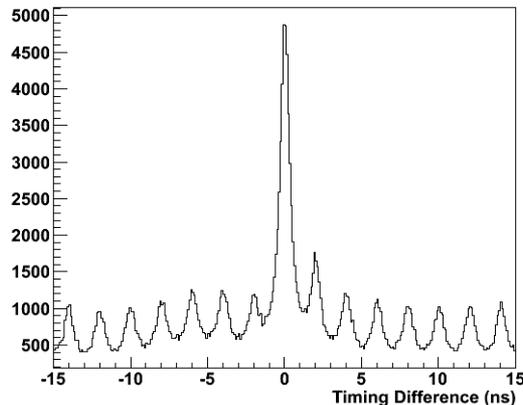
mass_all



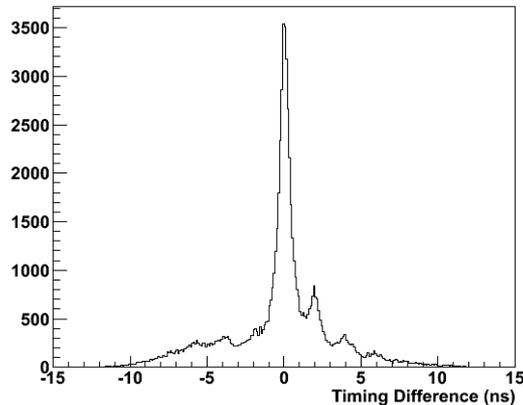
- Initial particle identification realised via a combination of charge and time-of-flight calculated mass
- Select potential events for the channel of interest from possible combinations of detected particles (allowing 1 Proton and 1 Kaon, with the option of 0 or 1 π^- , and 0 or 1 neutrals)

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

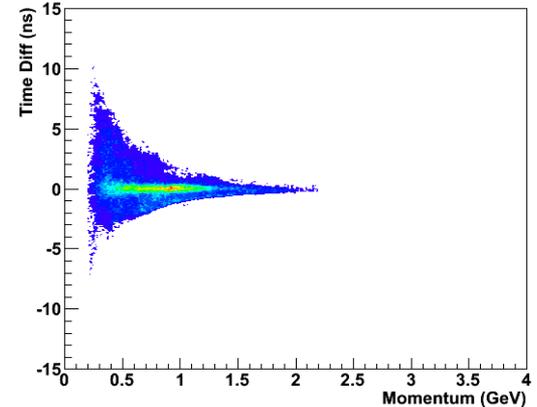
Timing Difference (Proton)



Proton Vertex Time

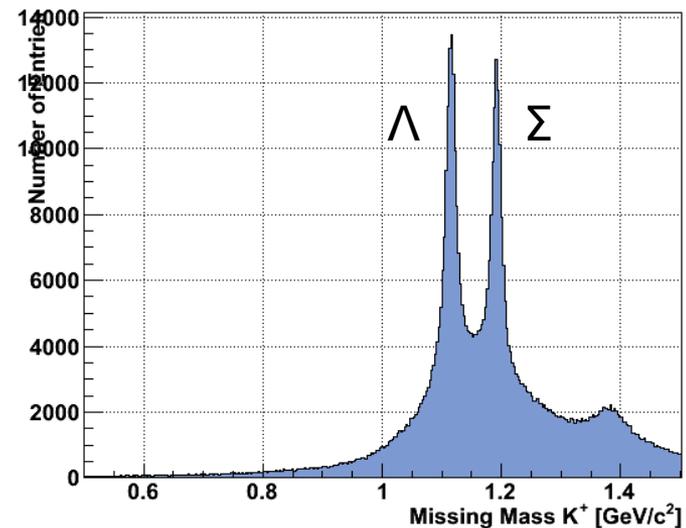
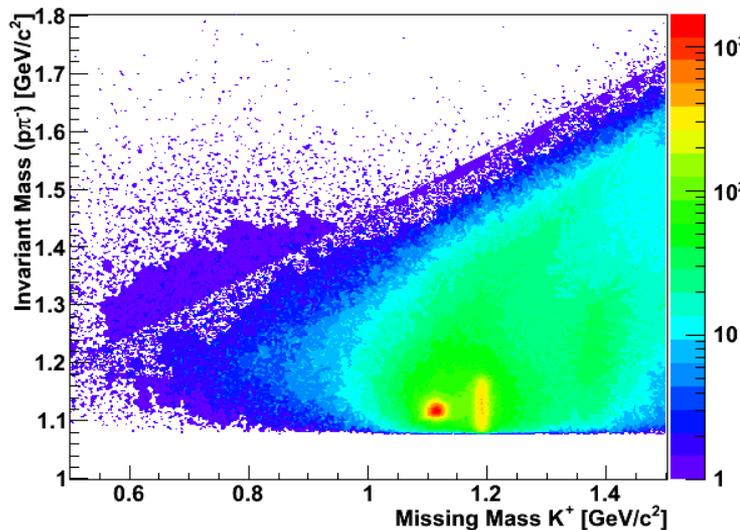
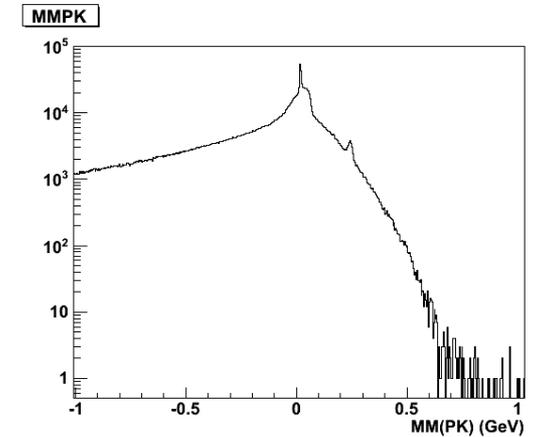


Time vs Momentum (Kaon, after Proton timing cuts)



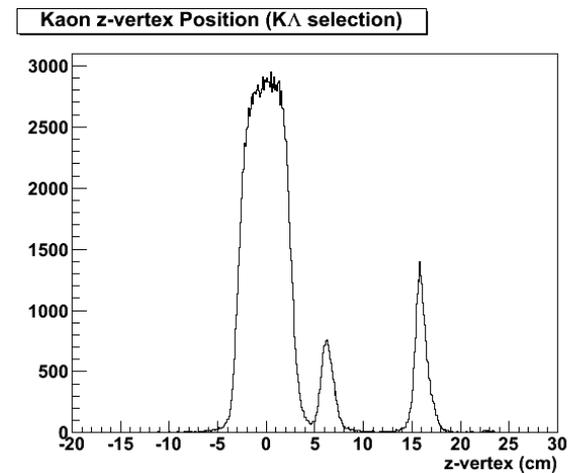
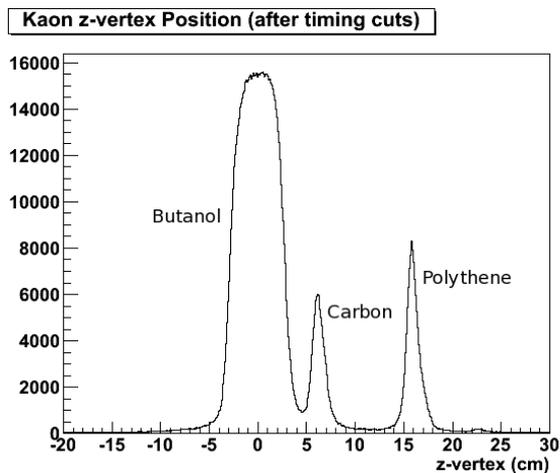
Channel Identification

- Reaction of interest: $\gamma p \rightarrow K^+ \Lambda \rightarrow K^+ p \pi^-$
- Two options, exclusive identification (fewer events), or reconstruct the pion from Lambda decay from missing mass (susceptible to particle misidentification)
- Identify Lambda and Sigma hyperons from a plot of the missing mass of the K^+ vs the invariant mass of $p\pi^-$, where the π^- is assumed to be missing mass of $p K^+$
- $K\Lambda$ events can be selected by a cut on both these axes



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

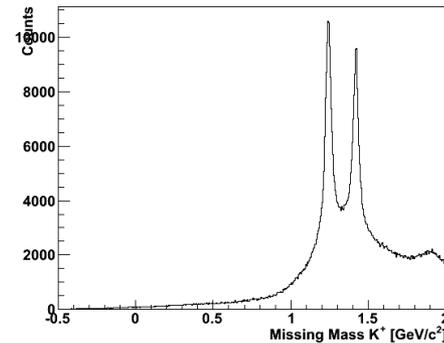


- Only Butanol is polarised, other targets used to account for asymmetry dilution effects due to the unpolarised nuclei in Butanol, as well as cross-checking previous measurements of polarisation observables

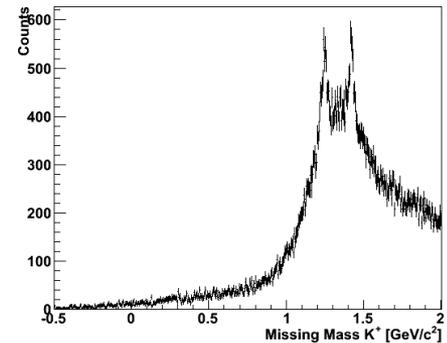
Carbon Scaling Factors

- 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 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
- This method is also used to determine a scaling factor for polythene

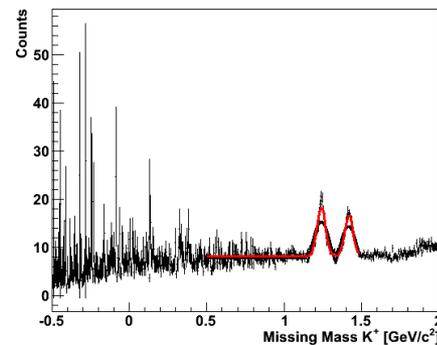
Kaon Missing Mass (Butanol Target, K^{Δ} selection)



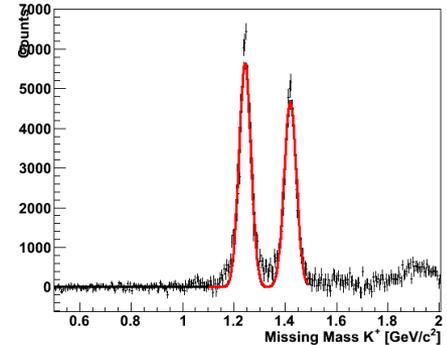
Kaon Missing Mass (Carbon Target, K^{Δ} selection)



Kaon Missing Mass for Butanol divided by Carbon (K^{Δ} selection)



Butanol Minus Scaled Carbon



Extracting Observables

- Recall that polarisation observables contribute to the differential cross section, and that they can also be expressed as the difference over the sum of cross-sections for two polarisation states;

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

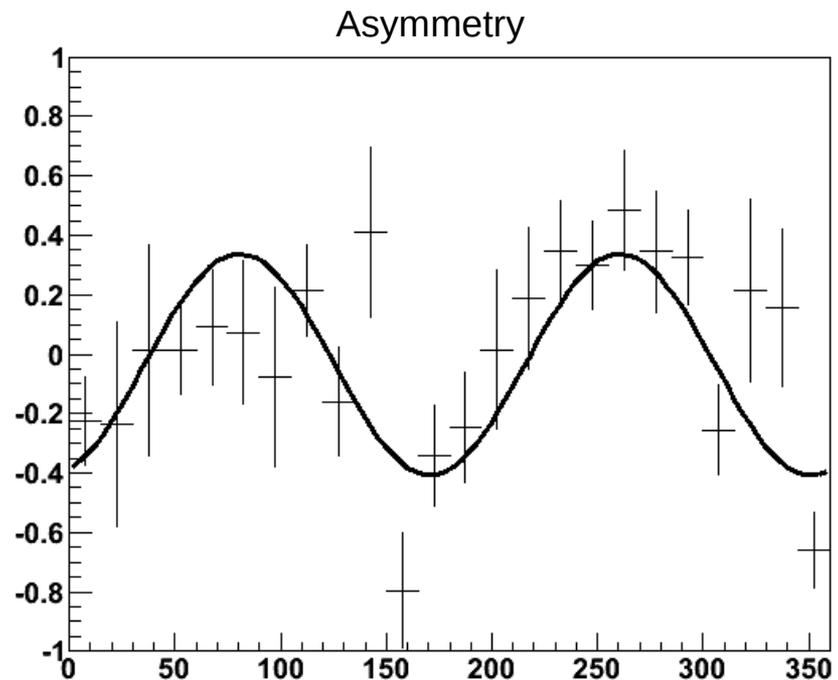
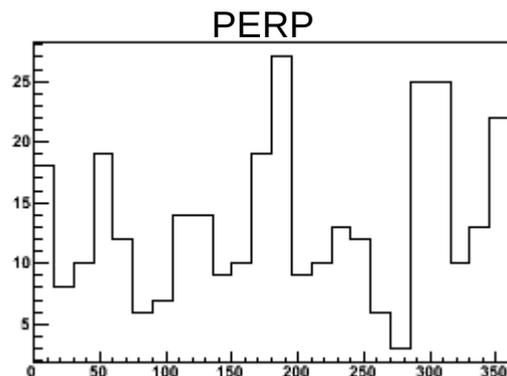
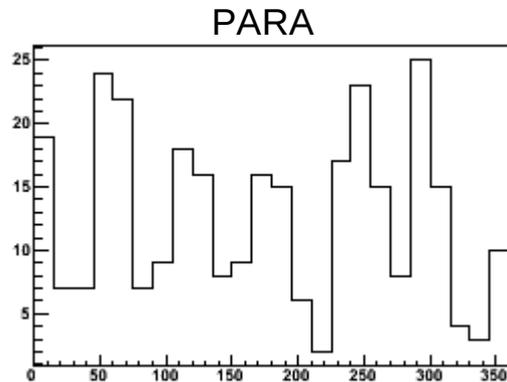
$$\Sigma = \frac{(\sigma(\perp, 0, 0) - \sigma(\parallel, 0, 0))}{(\sigma(\perp, 0, 0) + \sigma(\parallel, 0, 0))}$$

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

- 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 observable, a $\cos(2\phi)$ function is fitted to the asymmetry of the Polythene data (which is unpolarised, and has no G contribution) for the two beam polarisation modes, parallel (PARA), and perpendicular (PERP)

Σ Analysis

- Take an asymmetry of the Kaon azimuthal angle from the unpolarised Polythene target for PARA and PERP beam polarisations and fit a $\cos(2\phi)$ function to the distribution for a series of angular bins
- The amplitude of this is a measure of P_{Σ} for Polythene



Σ Analysis

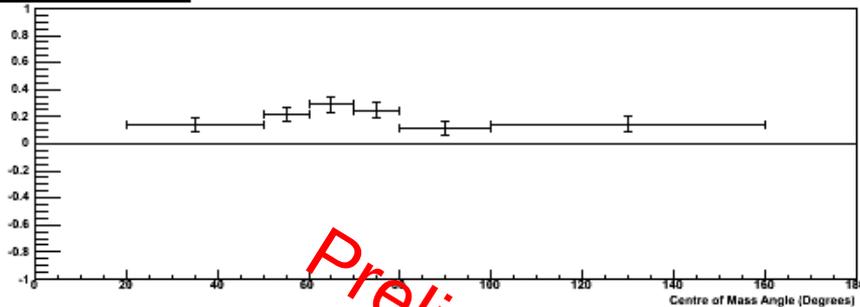
- This measurement of $P_{\gamma\Sigma}$ is actually a measure of two things, $P_{\gamma\Sigma}$ (proton), and $P_{\gamma\Sigma}$ (carbon), with each term diluted by the respective relative amounts of Carbon and Hydrogen (protons) in the target
- $P_{\gamma\Sigma}$ for the free proton can be approximated by the expression:

$$P_{\gamma\Sigma_{\text{PROTON}}} = (1/N_{\text{PROTON}}) * (N_{\text{CH}_2} P_{\gamma\Sigma_{\text{CH}_2}} - N_{\text{CARBON}} P_{\gamma\Sigma_{\text{CARBON}}})$$

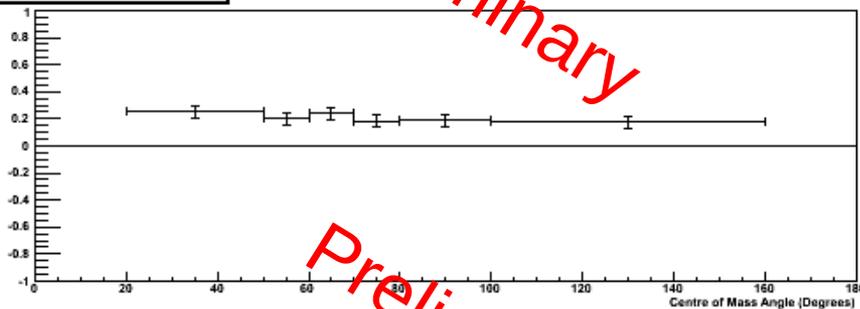
- Limited Polythene data is available for the K Λ channel
- Because of this, verifying previous measurements of Σ on this channel with the polythene target is difficult

Σ Analysis

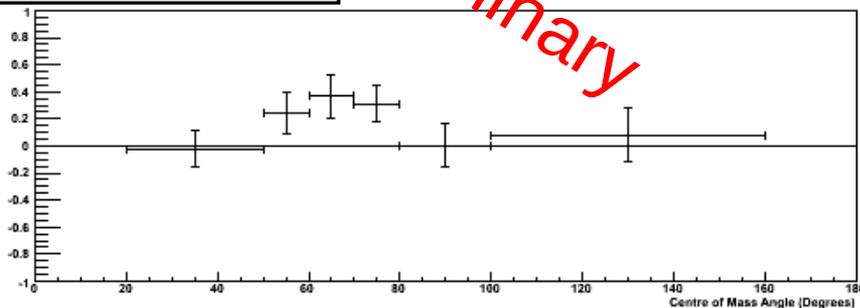
$P_{\text{gamma}\Sigma}$ for $K\Lambda$ from CH2 data



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



$P_{\text{gamma}\Sigma}$ estimated for proton for $K\Lambda$ on polythene



Preliminary

Preliminary

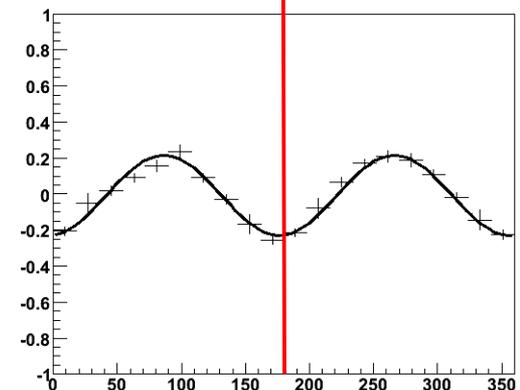
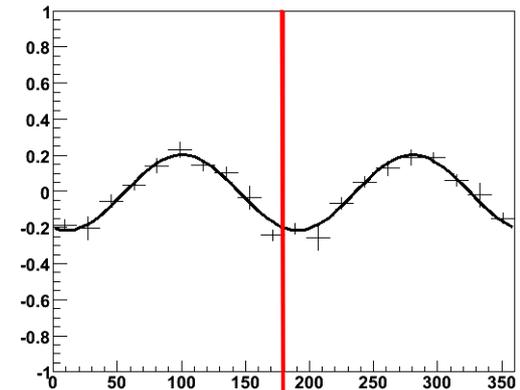
- Attempted Σ measurement for 1.5 GeV photon energy
- Lack of data limits achievable binning
- There is more Proton data available, on the Butanol target
- Dilution can be handled in the same way as for Polythene
- However, the Protons in the Butanol have been polarised, which makes it more difficult to make a pure measurement of Σ

The Σ and G Observables

- If we take similar asymmetries of Kaon azimuthal angle distributions for the Butanol data, the amplitude of a $\cos(2\phi)$ fit is not a pure measurement of the Σ observable – it also contains a contribution from the G observable

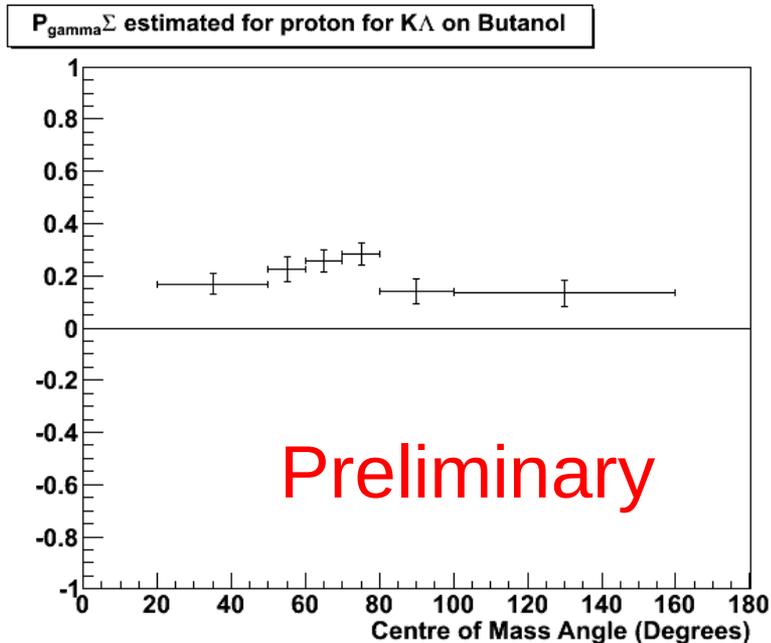
$$\frac{d\sigma}{d\Omega} = \sigma_0 \{ 1 - P_{lin} \Sigma \cos 2\phi + P_z (P_{lin} G \sin 2\phi) \}$$

- The effect of G can be seen by examining the asymmetry distribution for positive and negative longitudinal target polarisations
- The distributions for the positive (top) and negative (bottom) target polarisations show a phase shift due to change in target polarisation
- By adding distributions for the two target polarisations, the G contribution can be eliminated and a measurement of Σ can be attempted on Butanol



Σ Analysis on Butanol

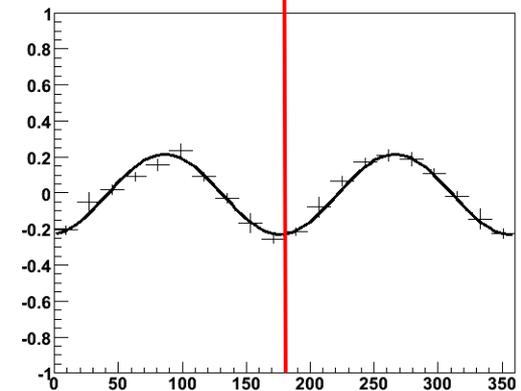
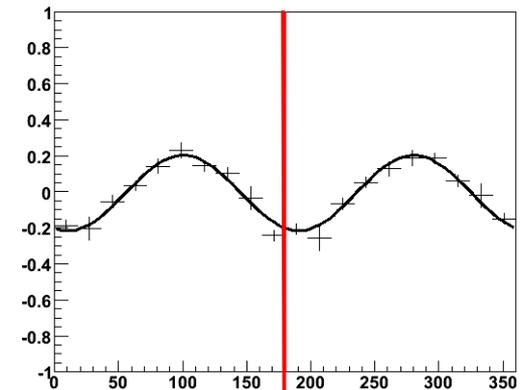
- Add Kaon azimuthal angle distributions for positive and negative target polarisations for PARA and PERP beam polarisations in order to cancel the effect of the G observable
- Fit a $\cos(2\phi)$ function to the PARA/PERP asymmetry as before to measure $P_{\gamma\Sigma}$ for Butanol
- Account for dilution in order to estimate $P_{\gamma\Sigma}$ 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
- Several experiments have measured Σ in the past, by cross-checking these results with FROST data the methods used to account for dilution can be verified and employed for measurements of G

G Analysis

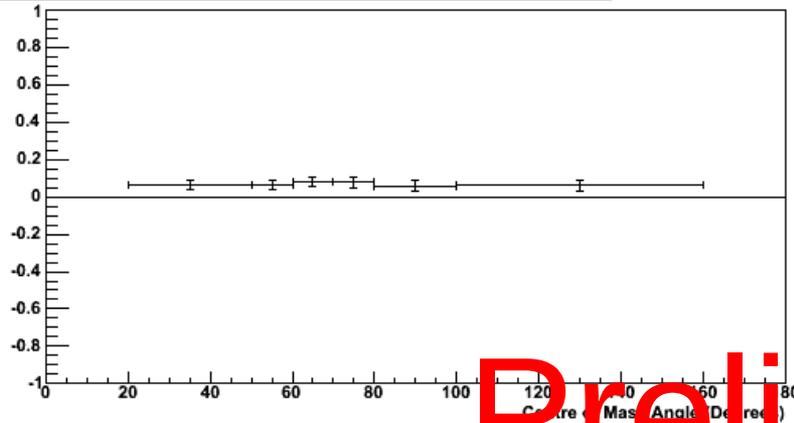
- Extract G by fitting a $\cos(2\phi) + \sin(2\phi)$ function to the PARA/PERP asymmetry for each target state
- $P_{\gamma\Sigma}$ is the amplitude of the $\cos(2\phi)$ term as before, and the amplitude of the $\sin(2\phi)$ term is a measure of $P_{\gamma} P_{\text{TARGET}} G$
- Account for dilution in order to estimate $P_{\gamma} P_{\text{TARGET}} G$ for the Proton
- Also need to account for both beam and target polarisations in order to extract G



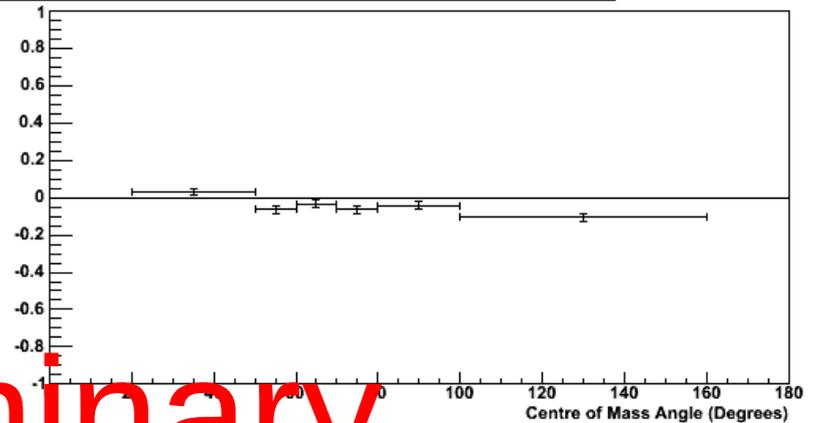
G Analysis

$P_Y P_{TARGET} G$ at 1.5 GeV for positive (left) and negative (right) target polarisations:

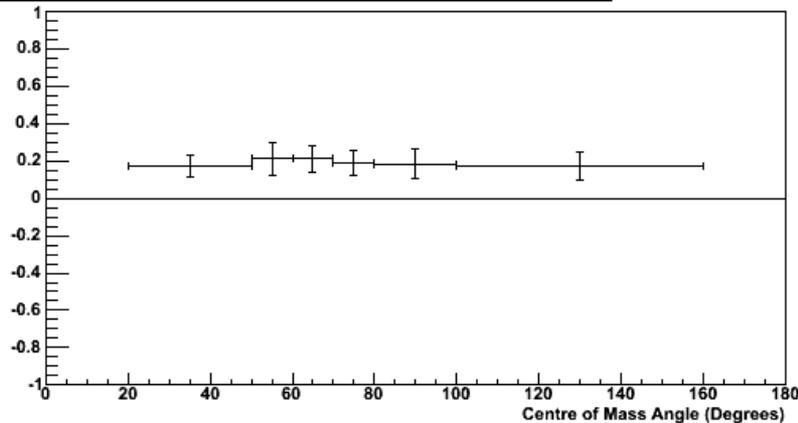
$P_{\gamma} P_{target} G$ for $K\Lambda$ from Butanol data (positive polarisation)



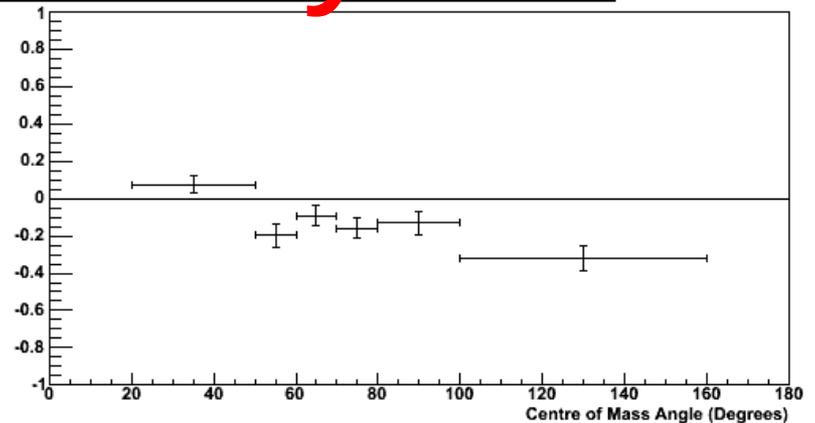
$P_{\gamma} P_{target} G$ for $K\Lambda$ from Butanol data (negative polarisation)



Estimate of $P_{\gamma} P_{target} G$ for $K\Lambda$ on proton (positive polarisation)



Estimate of $P_{\gamma} P_{target} G$ for $K\Lambda$ on proton (negative polarisation)



Preliminary

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
- Preliminary analysis of the beam polarisation observable, Σ , for the $K\Lambda$ channel on unpolarised Polythene data highlights problems due to the lack of available data on this channel
- Attempts have been made to get round this using the polarised target data, where data for the two target states is appropriately added to cancel the signature of the G observable
- Extraction of the G observable is also underway, with work on this hopefully finishing soon