Strangeness Photoproduction with the Frozen Spin Target at Jefferson Lab

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  - Polarisation Observables
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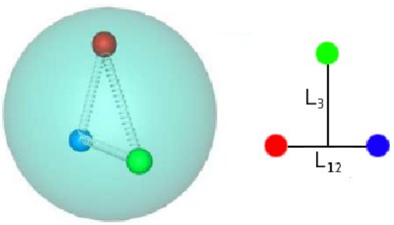
  - Identifying the $K\Lambda$ reaction
  - Analysis of the Beam Polarisation Observable (Σ)
  - Towards a measurement of the G Observable
- Summary

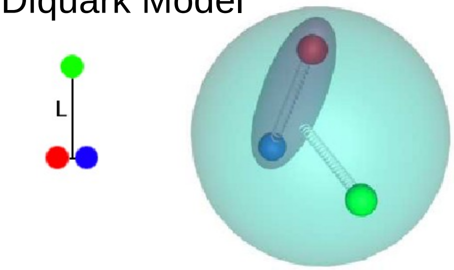
Motivation

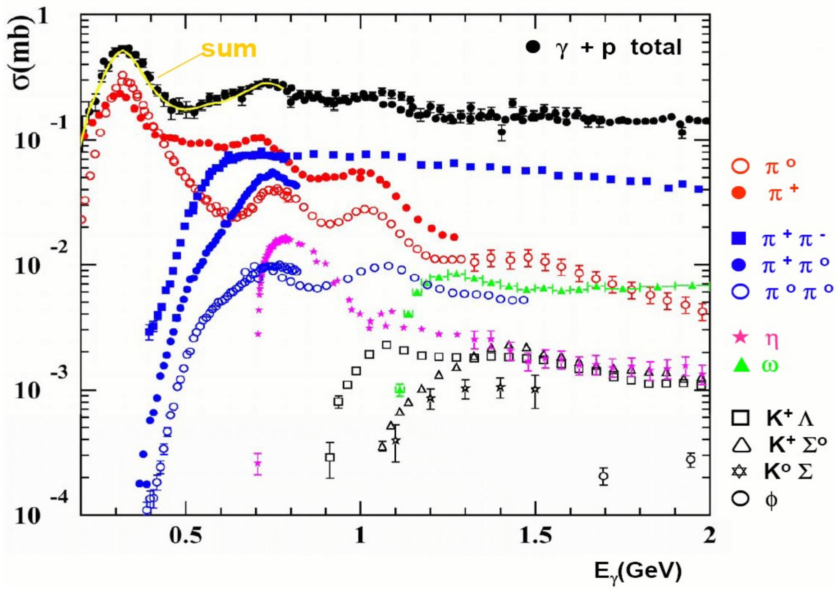
- Baryon Spectroscopy is the study of excited states of the nucleon
- Aids study of the internal structure of the nucleon by providing evidence favouring certain theoretical models over others
- Two competing types of quark model; symmetric quark and di-quark, these models can be used to predict a series of resonances

Symmetric Quark Model



Diquark Model





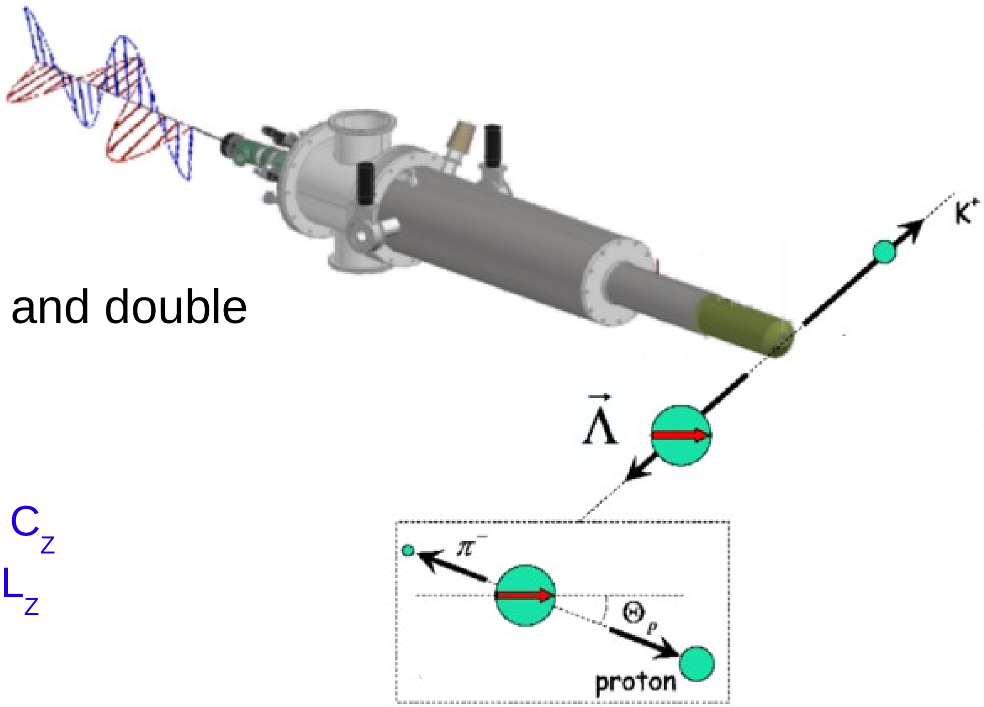
- Key difference is the presence of a bound quark pair in the di-quark model
- Symmetric quark models predict more resonances than have been observed
- Diquark models do not predict these “missing resonances”
- Experiments involving strangeness reactions may find some of these states

Polarisation Observables

- Measuring the G polarisation observable for KΛ photoproduction:

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

- 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:

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

- '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:

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

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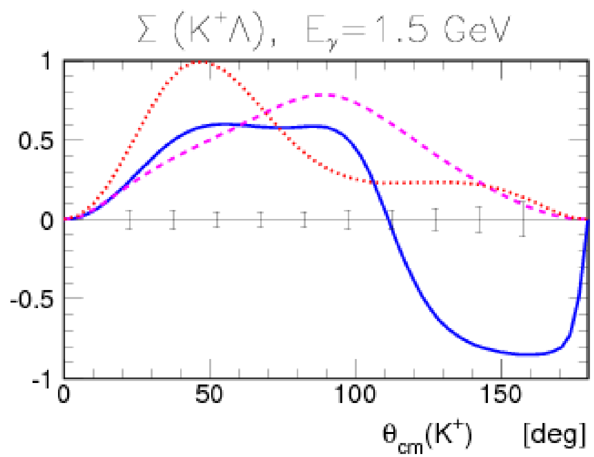
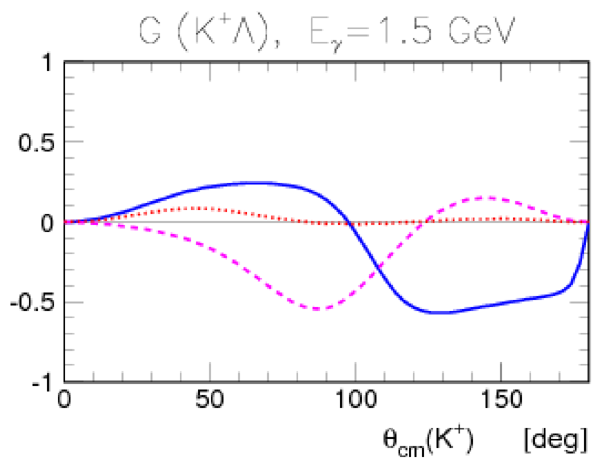
Polarisation Observables

- 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)

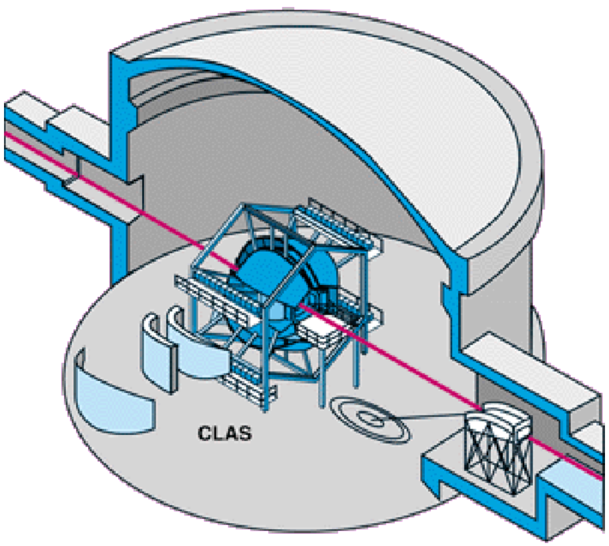
$$G=\frac{(\sigma(\pi/4,+z,0)-\sigma(\pi/4,-z,0))}{(\sigma(\pi/4,+z,0)+\sigma(\pi/4,+z,0))}$$

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



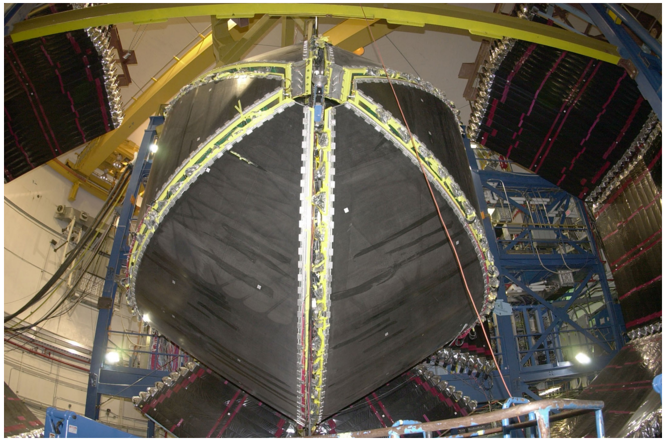


Jefferson Lab Hall B



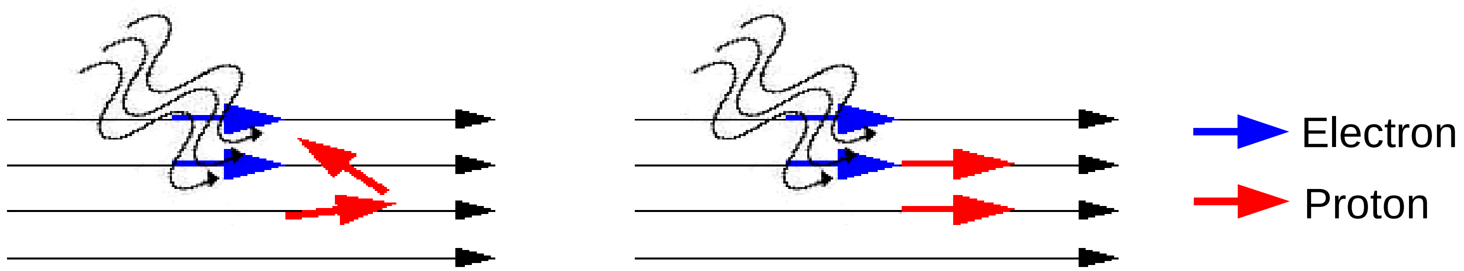
- Hall B at Jefferson Lab is home to the CEBAF Large Acceptance Spectrometer (CLAS)
- CLAS is a multi-layered and segmented arrangement of particle detectors surrounding a target
- Used in either electron or photon beam experiments, the FROST experiment uses photons

- In photonuclear experiments, tagged photon beam interacts with target in centre of the CLAS detector
- Collects data on the products of the interaction between beam and target with close to 4π coverage



The FROST Target

- FROST (FROzen Spin Target) is the name of the polarised proton target designed and built by the Jefferson Lab target group
- Materials can be polarised using a high magnetic field, however a polarising magnet obscures reaction products from the full angular range of CLAS
- Using a technique called Dynamic Nuclear Polarisation (DNP), it is possible to polarise the target without a continuously maintained polarising field



- DNP employs a high magnetic field to polarise free electrons in the target which is then transferred to the nuclei by applying microwaves
- FROST uses solid butanol pellets, chemically doped to provide free electrons, as the polarised target material, alongside unpolarised carbon and polythene targets, held in a cylindrical target holder which is positioned inside CLAS

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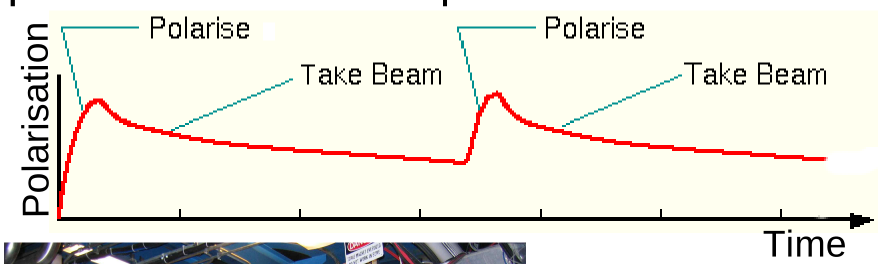
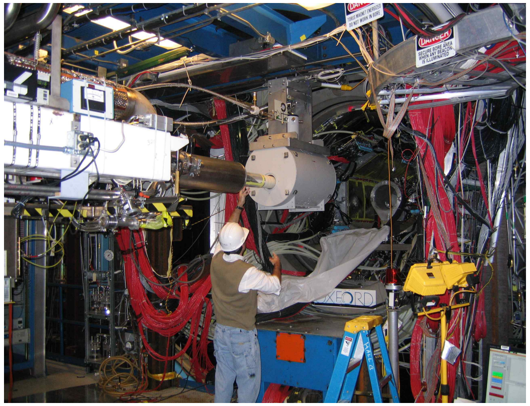
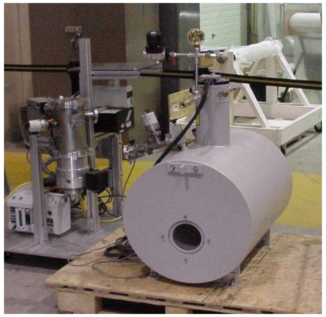
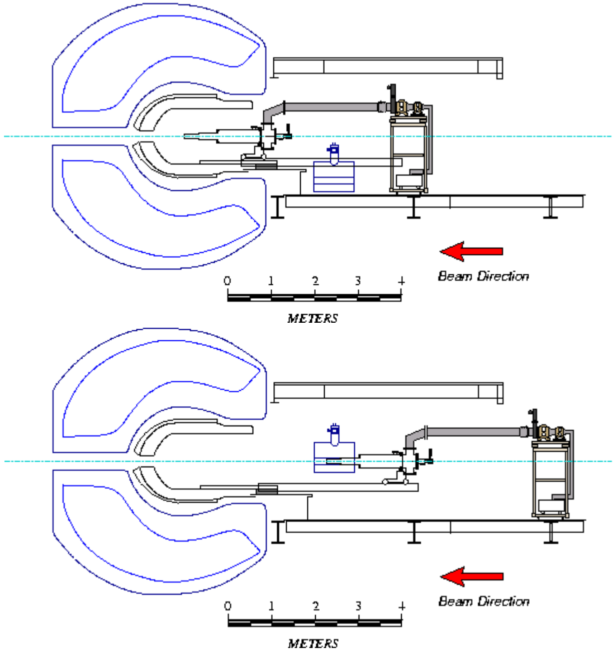
The FROST Target

- By combining millikelvin cooling (~40 mK) with a weaker holding magnetic field, target polarisation is maintained for several days while data is taken using CLAS
- When the polarisation has decayed, FROST is removed from CLAS, repolarised, and the cycle continues
- During the first FROST experimental run (October 2007 – February 2008), the target performed exceptionally well, exceeding design expectations in the level of polarisation and the polarisation relaxation time



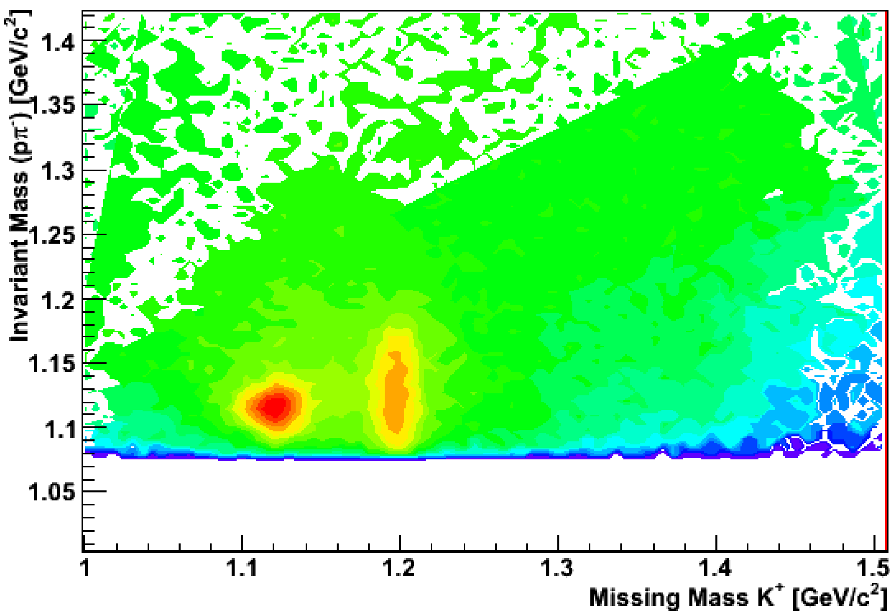


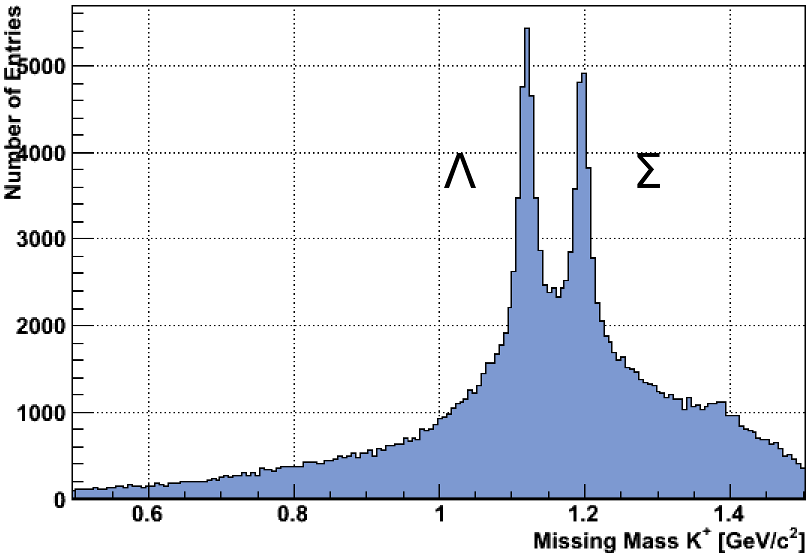




Channel Identification

- Once data has been calibrated, reaction products can be identified and analysed to identify events corresponding to Kaon-Lambda reactions
- $\gamma\, p \rightarrow K^+ \Lambda \rightarrow K^+\, p\pi^-$
- Two channels can be identified from potential KΛ events; KΛ and KΣ
- A plot of the missing mass of the K^+ vs the invariant mass of $p\pi^-$ allows identification of the Lambda and Sigma





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;

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

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

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

- If we produce an asymmetry of the Kaon azimuthal angle for two polarisation states, polarisarion observables can be extracted from the resulting distribution
- To measure the Σ observable, a cos(2ϕ) function is fitted to the asymmetry of the data for the two beam polarisation modes, parallel (PARA), and perpendicular (PERP)

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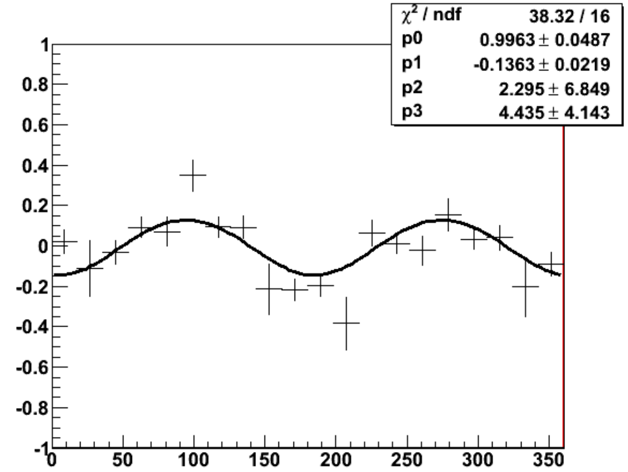
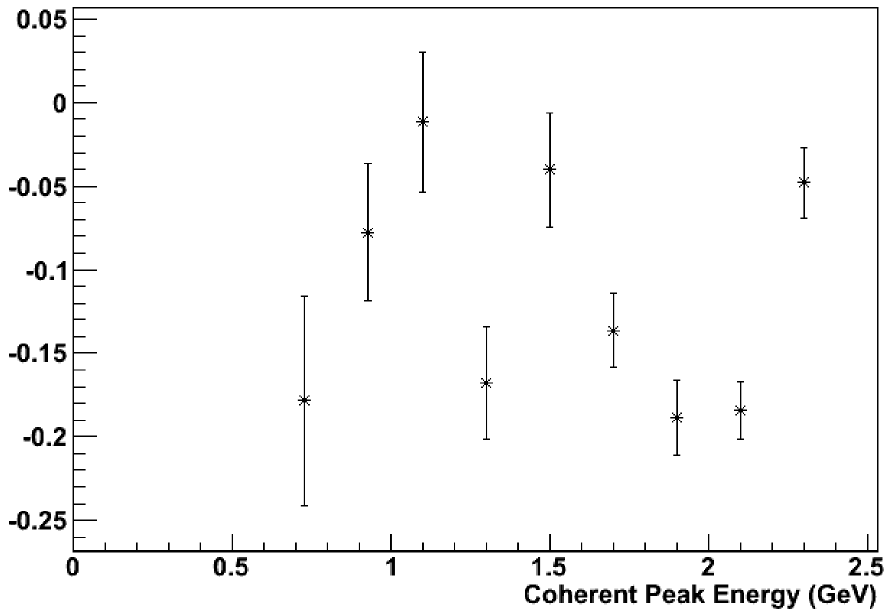
Σ Analysis

- Take an asymmetry of the Kaon azimuthal angle from the unpolarised polythene target for PARA and PERP beam polarisations and fit a cos(2ϕ) function to the distribution
- The amplitude of this is a measure of PΣ
- Can do this for a series of bins in photon energy and θ, the Kaon polar angle





- Plot on the left shows preliminary measurements of PΣ for the polythene target
- One measurement for each photon beam energy setting over the full polar angle range
- Calculating P, the photon beam polarisation, allows us to obtain Σ from the PΣ measurements

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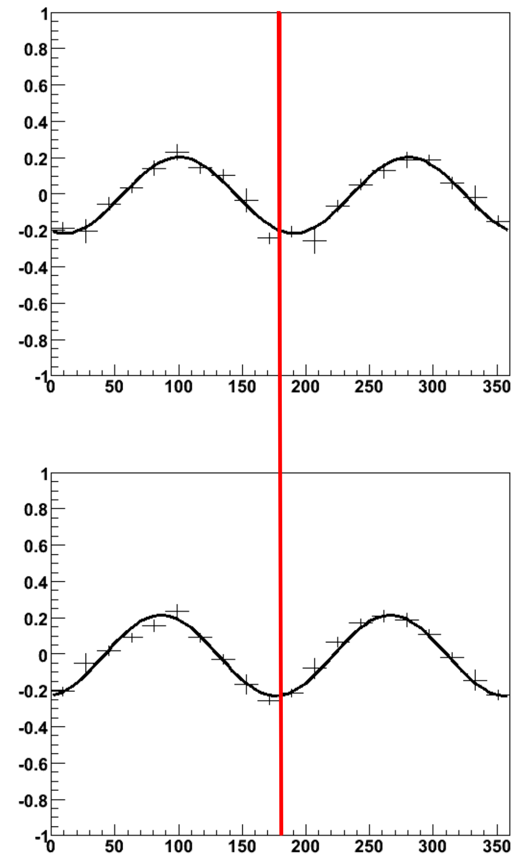
Towards G

- If we take similar asymmetries on polarised target data, the effect of the G observable can be seen by examining the asymmetry for positive and negative longitudinal target polarisations
- Preliminary asymmetry plots of the beam polarisation modes for positive (top) and negative (bottom) target polarisations show a phase shift due to change in target polarisation
- Extracting G from this isn't quite as easy as getting the beam asymmetry from the unpolarised target
- Measurements of Σ are required to constrain the fit to the asymmetry for extracting G, as well as additional work to account for the molecular nature of the target material for measurements of both Σ and G



Summary

- In order to provide a more complete set of observables from which to determine contributing states, a polarised target is required
- Using a polarised photon beam and a polarised target, beam-target double polarisation observables can be measured
- Potential for finding previously unseen resonances, constraining models of quark interaction in the nucleon
- The FROST target at Jefferson Lab was developed to enable the large angular coverage of the CLAS detector to be fully exploited, and continues to perform reliably and beyond design expectations in the current run at the lab in transverse polarisation mode
- Preliminary analysis of the beam polarisation observable, Σ, on unpolarised target data is progressing well, an important step towards measuring G for the polarised target