Unfinished Business in Polarisation Observables from Strangeness Photoproduction at Jefferson Lab

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CEBAF Large Acceptance Spectrometer

Outline

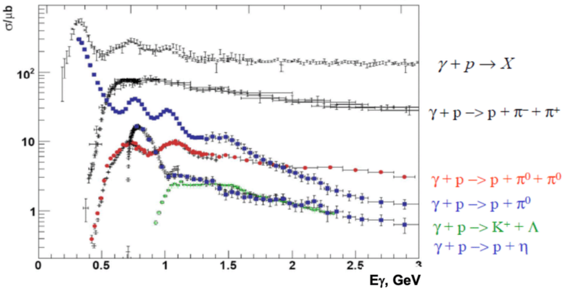
1 Introduction
- A World of Polarisation (Observables)
- JLab, CLAS and FROST

2 Analysis
- Event Selection
- Observable Extraction
- Results

3 Outlook
- Unfinished Business

Motivation

- Baryon Spectroscopy is the study of excited nucleon states
- Finding some states can be difficult in a simple "bump hunt"; many are wide and overlap
- Use alternative means; coupling strength to a reaction channel, manifestation in experimental observables, etc. to aid searches



R. Beck and U. Thoma, EPJ Web Conf 134, 04003 (2017)

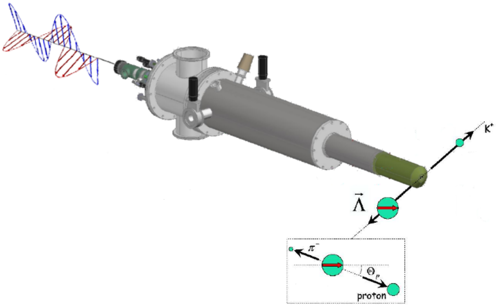
A World of Polarisation (Observables)

- Looking for polarisation observables on strangeness photoproduction
- Many possible channels, but this talk will focus on $K^+\Lambda$

$$\gamma p \to K^+\Lambda \to K^+ p\pi^-$$

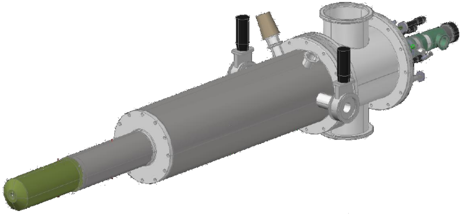
- 16 observables for single meson photoproduction, arising from the scattering amplitudes of the interaction and the particles which carry polarisation

- "Single": σ, Σ, P, T
- 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



PARA/PERP, Target too

- With a polarised beam and target, can access the single and beam-target double observables
  - Single: σ, Σ, P, T
  - Beam-Target: E, F, G, H
- And more with recoil (i.e. with a self-analysing hyperon)

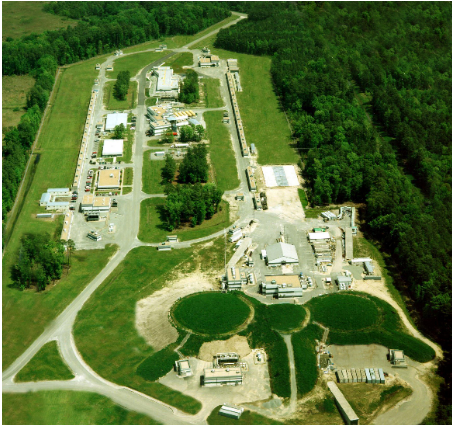


This work has two goals:

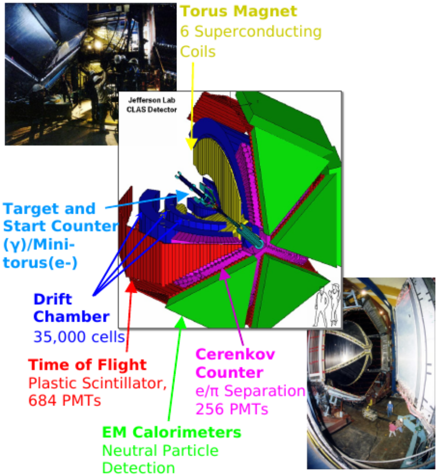
- Verify the beam asymmetry, Σ
- Perform first measurements in this channel of the beam-target observable, G

Jefferson Lab

- US DoE facility, Newport News, VA
- Superconducting RF accelerator electron beams up to 6 GeV, 12 GeV since a 2017 upgrade
- Three Experimental Halls, a Fourth added in the upgrade
- Tagged real photon beam facility available in the 6 GeV era in Hall B, using a secondary bremsstrahlung photon beam

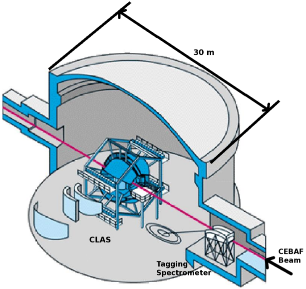


Hall B and CLAS



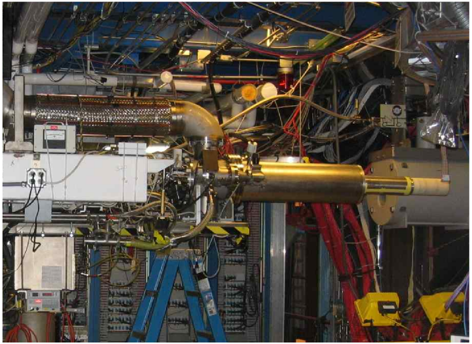
NIM A, 503(3), 2003

- CEBAF Large Acceptance Spectrometer (1995-2012)
- Multi layered and segmented
- Toroidal magnetic field



g9a/FROST

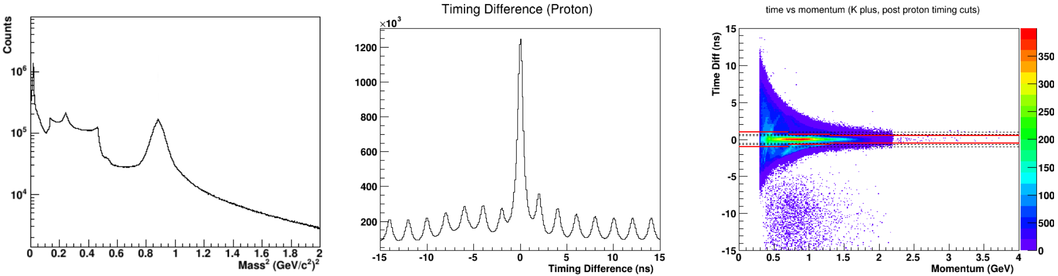
- Data from g9a run period: November 2007 to February 2008
- Linearly and circularly polarised photon beams on a longitudinally polarised target
- Polarisation direction regularly flipped during run
- Nine coherent peak settings in linear polarisation, spanning energy range 0.7 to 2.3 GeV
  - In this case, the reduced cross section can be expressed as:



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

Analysis - Particle ID

- Initial particle ID via combination of charge and time-of-flight mass
- Select candidate Protons and Kaons
- Apply photon-to-particle timing difference cuts eliminate misidentification

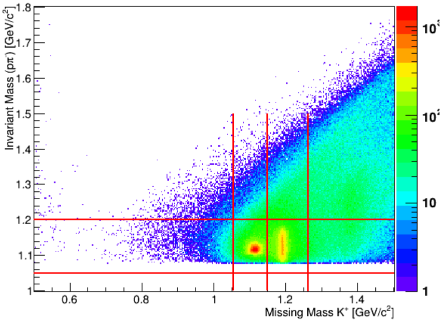


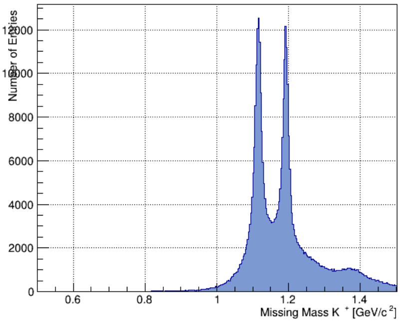
Channel Identification

- Select channel of interest:

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

- Non exclusive selection - reconstruct pion from detected proton and kaon
- Hyperons identified via kaon missing mass and proton pion invariant mass



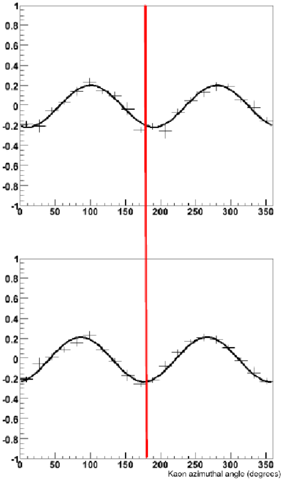


Extracting Observables

- Binned fitting on asymmetries of two states of beam polarisation (PARA and PERP)
- Technique has been extensively employed in the JLab N* program and similar experiments worldwide
- Recall that on a linpol beam and a longitudinally polarised target:

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

- A cos(2ϕ) + sin(2ϕ) fit to a PARA/PERP asymmetry can be used to extract Σ and G for each state of target polarisation



Extracting Observables II

- Binned asymmetry fitting relies on a number of assumptions
- In lower statistics channels, or datasets where PARA and PERP have large variations between them in flux, polarisation, etc., reliable observable extraction is more challenging
- Using a maximum likelihood approach, we can extract observables event-by-event, and better account for variation between polarisation states
- We can define the likelihood function for each event as:

$$L_i = c_i[1 - P_{lin,i}\Sigma cos(2\phi_i) + P_{z,i}(P_{lin,i}Gsin(2\phi_i))]A$$

- And extract observables by maximising the log-likelihood function:

$$\log L = b + \sum_i \log[1 - P_{lin,i}\Sigma cos(2\phi_i) + P_{z,i}(P_{lin,i}Gsin(2\phi_i))]$$

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Dilution of Observables

- Parameters extracted from $\cos(2\phi) + \sin(2\phi)$ fits are the free proton value, diluted with a carbon contribution (and beam and target polarisations)
- i.e. for the Σ observable, we actually measure $\Sigma_{Butanol}$, from which we can infer the free proton value

$$\Sigma_{Proton} = \frac{1}{N_{Proton}}(N_{Butanol}\Sigma_{Butanol} - N_{Carbon}\Sigma_{Carbon})$$

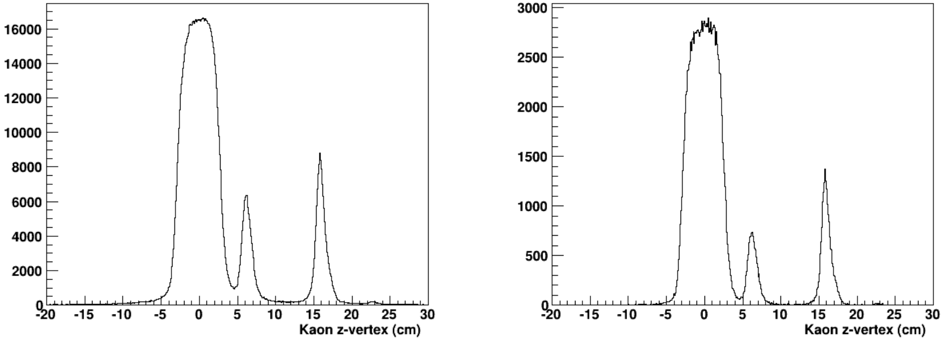
- For G, carbon in the target is unpolarised and we measure $G_{Butanol}$, estimating the free proton value via;

$$G_{Proton} = \frac{N_{Butanol}}{N_{Proton}}(N_{Butanol}G_{Butanol})$$

- The ‘N’ terms represent event yields per bin corresponding to the relevant material
- These must be estimated for Carbon and Proton...

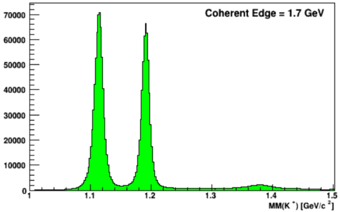
Target Selection

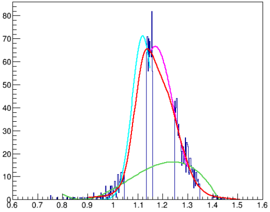
- FROST target contains Butanol (left), Carbon (centre) and Polythene (right)
- Resolvable from Kaon z-vertex after particle and channel identification

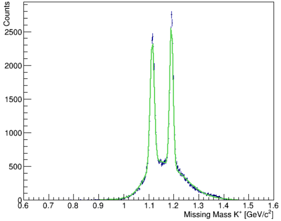


- Only Butanol is polarised, other targets used to account for nuclear backround and dilution effects of unpolarised nuclei in butanol

Estimating Carbon





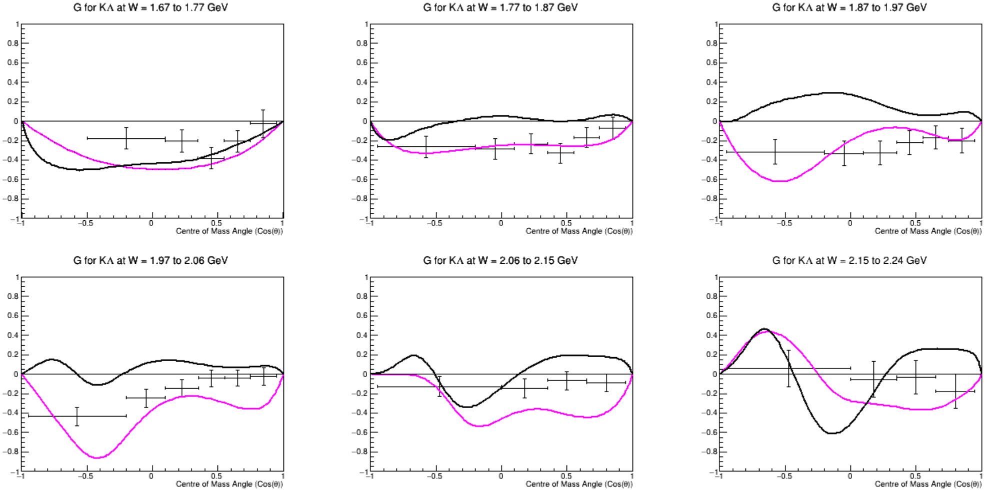


- Controlling systematic uncertainties, particularly on a measurement of G, requires a robust method of accounting for Carbon
- We know from data on proton targets (left) that shape under the hyperon peaks on butanol (right) is almost entirely from bound nucleon effects
- Parameterise, use to estimate amount of Carbon events in each bin on Butanol

Results

- CLAS-approved results from the maximum likelihood technique for the G observable on $K^+\Lambda$
- Comparison to Bonn-Gatchina (pink line) and Jülich Bonn (black line) model predictions (fron 2017)
- Actively seeking new fits

Results for G

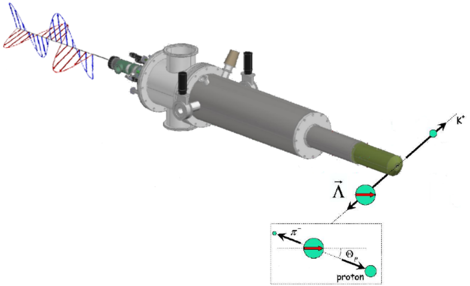


The Future: Target-Recoil Observables

The FROST polarised target also enables access to target-recoil double observables:

$$\frac{d\sigma}{d\Omega} = \sigma_0\{1 + P_{y'}P + P_x(P_{x'}T_{x'} + P_{z'}T_{z'}) + P_y(T + P_{y'}\Sigma) - P_z(P_{x'}L_{x'} + P_{z'}L_{z'})$$

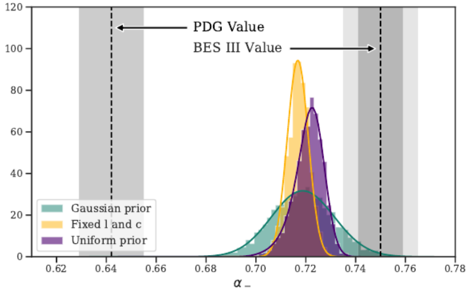
- Polarisation of recoiling hyperon can be inferred from decay angle distribution
- Can exploit this to measure beam-target observables T_X, T_Z, L_X, L_Z
- Requires evaluation of detector acceptance



Identities and Interpretations

Observable	W (MeV)	θ (deg)	Data	Lab
$d\sigma/d\Omega$	1610-2390	18-162	701	ELSA
	1612-1896	66-143	1306	MAMI
	1617-2290	32-148	920	CEBAF
	1617-2108	26-154	90	ELSA
	1625-2395	27-154	1674	CEBAF
	1628-2533	26-143	1377	CEBAF
	1934-2310	13-41	78	Spring-8
Σ	1649-1906	31-144	66	GRAAL
	1721-2180	37-134	314	CEBAF
	1946-2300	13-49	45	Spring-8
	1946-2280	13-49	30	Spring-8
	2041-2238	18-32	4	Spring-8
P	1617-2290	26-154	233	CEBAF
	1625-2545	26-143	1497	CEBAF
	1649-1906	31-144	66	GRAAL
	1660-2017	41-139	12	ELSA
	1660-2280	34-146	30	ELSA
	1721-2180	37-134	314	CEBAF
T	1649-1906	31-144	66	GRAAL
	1721-2180	37-134	314	CEBAF
$C_{x'}$	1678-2454	32-139	144	CEBAF
$C_{z'}$	1678-2454	32-139	146	CEBAF
O_x	1649-1906	31-144	66	GRAAL
	1721-2180	37-134	314	CEBAF
O_z	1649-1906	31-144	66	GRAAL
	1721-2180	37-134	314	CEBAF

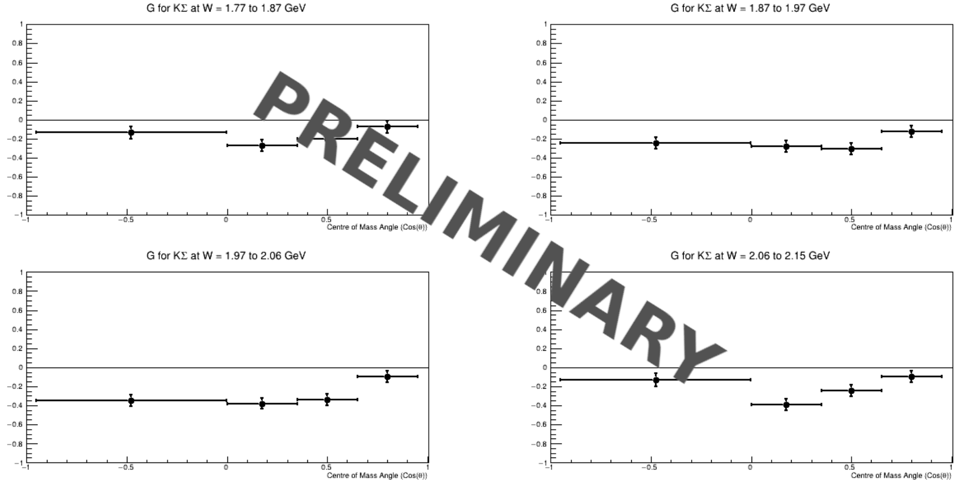
- Polarisation observable data is relatively sparse in $K^+\Lambda$
- Possible to verify the weak decay parameter, α_-, using observables and Fierz identities



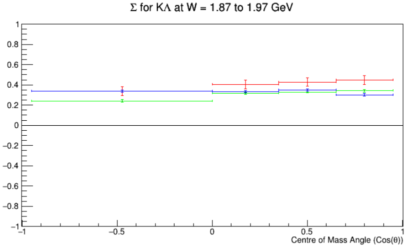
D.G. Ireland et. al., Phys. Rev. Lett. 123, 182301 (2019)

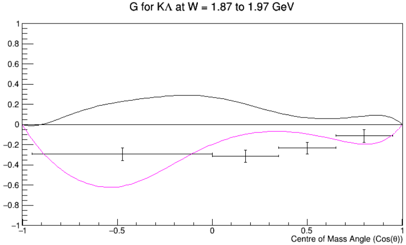
Other Channels

Preliminary Measurements of G on $K^+\Sigma$



Outlook and Plans





- First measurement of the G observable for $K^+\Lambda$ photoproduction using maximum likelihood technique on this data
- Results approved by CLAS, seeking new model fits
- Data allows $K^+\Lambda$ and $K^+\Sigma$ channels to be studied
- Measuring target-recoil observables may be feasible using this method