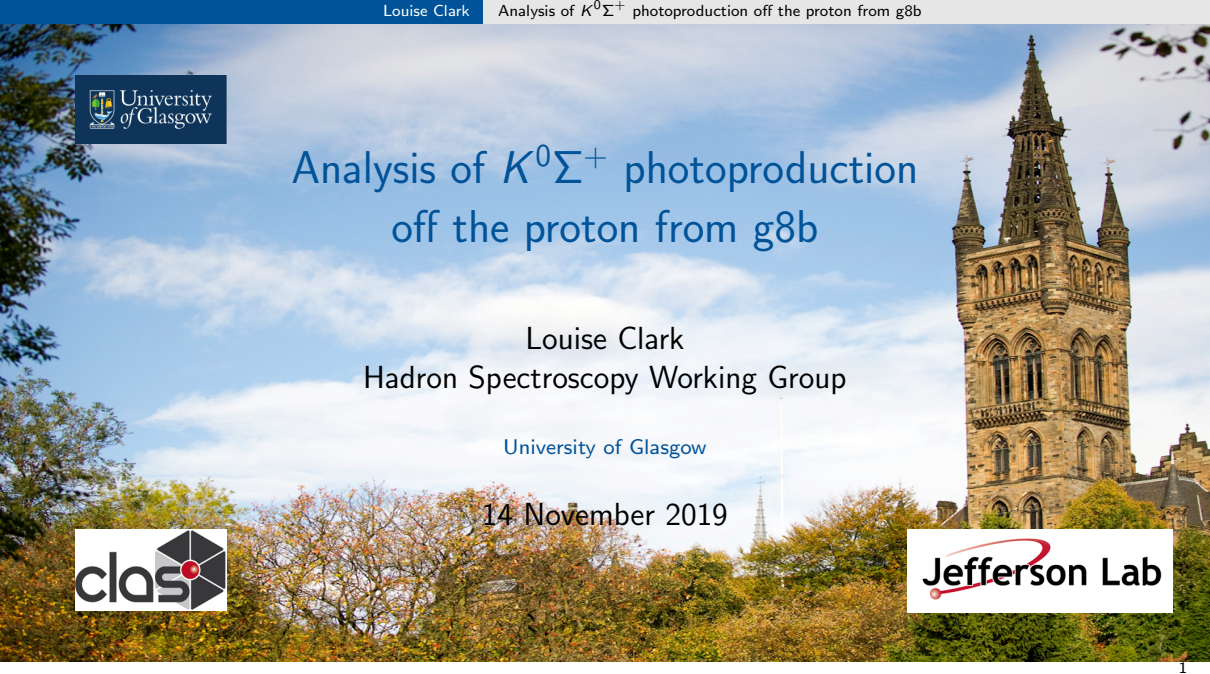


Analysis of $K^0\Sigma^+$ photoproduction off the proton from g8b

Louise Clark
Hadron Spectroscopy Working Group

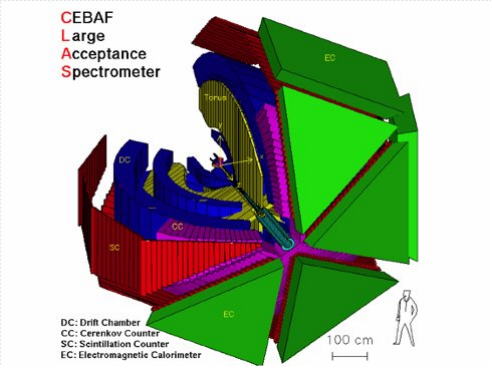
University of Glasgow

14 November 2019

Objectives and status of analysis

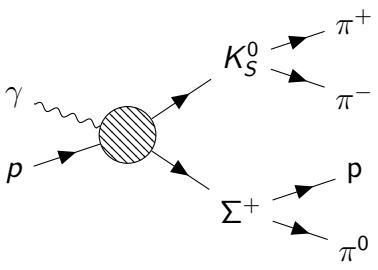
- Objective: Extraction of linear polarisation observables Σ, P, T, O_x, and O_z for the reaction $\gamma p \to K^0\Sigma^+$ using g8b data
- Status of analysis:
  - Preliminary results have been extracted using simultaneous fit of all 5 observables
  - Beginning validation and systematic studies
- Comparisons to previous work
  - CBELSA/TAPS: R. Ewald et al. Measurement of polarisation observables in $K^0_S\Sigma^+$ photoproduction off the proton.
    Physics Letters B, 738:268 – 273, 2014
  - CLAS: C.S. Nepali et al. Transverse polarization of $\Sigma^+(1189)$ in photoproduction on a hydrogen target in clas.
    Phys. Rev. C, 87:045206, Apr 2013
- Current FSU g12 analysis, F. Gonzalez, V. Crede (previous talk)

CLAS g8b



- g8b
- 4.5 GeV electron beam
- Linearly polarised photon beam produced from diamond radiator
  - Photon energy 1.1 - 2.1 GeV
  - Centre-of-mass energy 1.7 - 2.2 GeV
- Liquid hydrogen target

Reaction channel



Final state $p\ \pi^+\ \pi^-\ (\pi^0)$

$\Sigma^+ \rightarrow p\pi^0$
Branching fraction=51.6%
$\alpha = -0.980$

Analysis method

- Identify final state $p\ \pi^+\ \pi^-\ (\pi^0)$
- Identify reaction channel using sPlots to obtain signal and background weights
  - M. Pivk and F. R. Le Diberder. splot: a statistical tool to unfold data distributions.arXiv preprint physics/0402083
- Simulation of phase space $\gamma p \to K^0\Sigma^+$ used for acceptance corrections in likelihood calculations
  - Event generation with https://github.com/lorenzozana/EdGenedgen-event-generator
  - g8b simulation and reconstruction

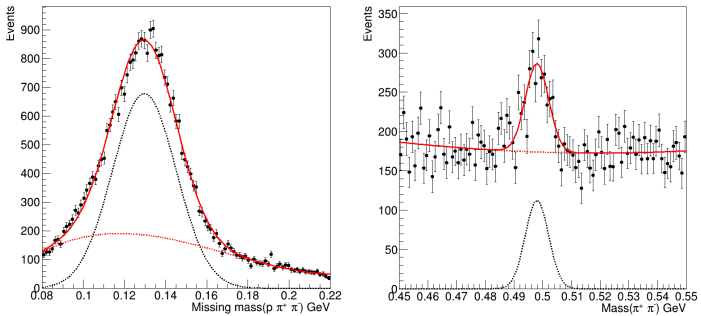
Analysis method

- Likelihood sampling with MCMC using pdf as follows

$$\frac{d\sigma}{d\Omega} \equiv \sigma(\phi, \cos\theta_x, \cos\theta_y, \cos\theta_z) = \sigma_0 \{1 - P^\gamma \Sigma \cos 2\phi - \alpha \cos\theta_x P^\gamma O_x \sin 2\phi + \alpha \cos\theta_y P - \alpha \cos\theta_y P^\gamma T \cos 2\phi - \alpha \cos\theta_z P^\gamma O_z \sin 2\phi\},$$

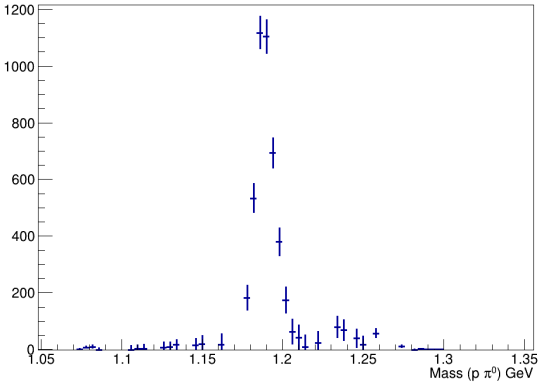
- Preliminary results quoted here are the mean $\pm$ σ of the resulting posterior distribution for each observable
- sPlots fits and MCMC studies performed using the HaSpect framework: Derek Glazier talk this afternoon 17:00

Reaction Channel Identification



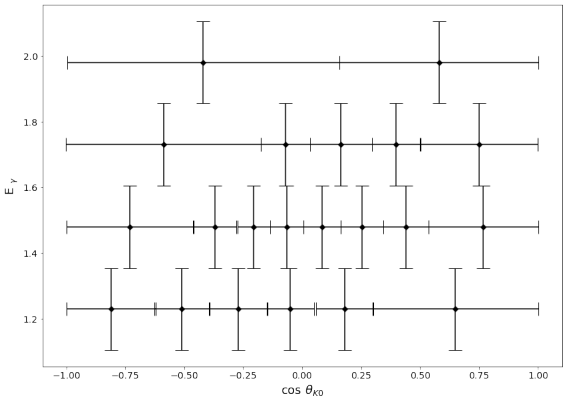
- Use of sPlots technique to separate signal and background
- Model π^0 and K^0 mass as Gaussian peak on polynomial background

Weighted Σ^+ invariant mass



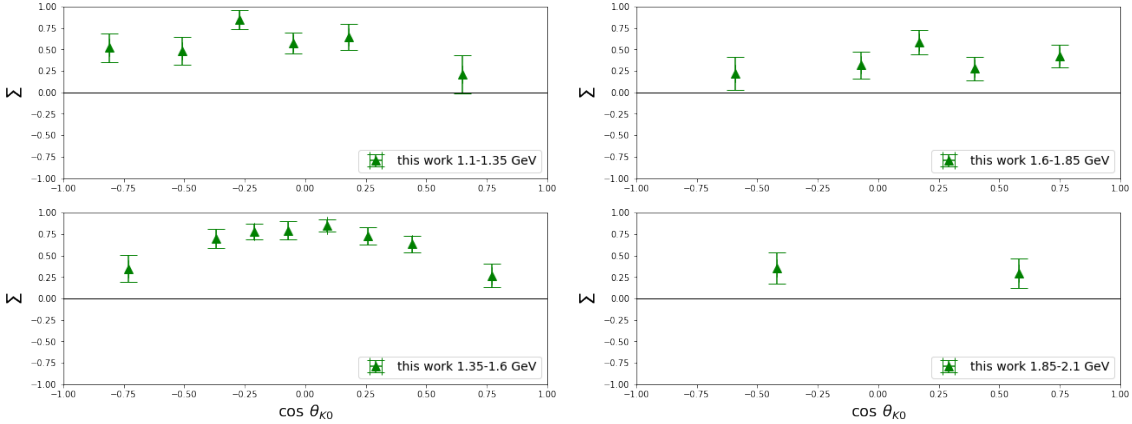
- Mass of reconstructed Σ^+ with signal weights applied
- PDG mass of $\Sigma^+ = 1189$ MeV
- Total integrated signal events 24,000

Preliminary results

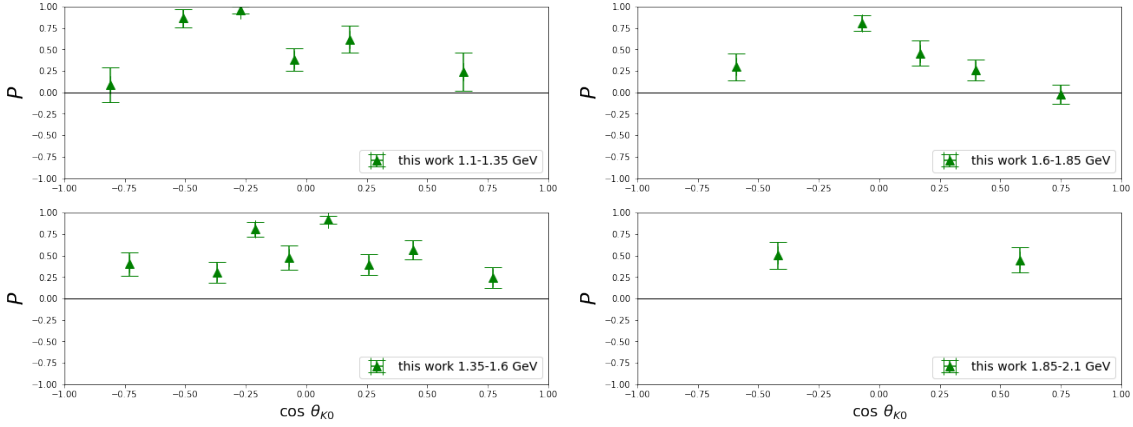


- Preliminary results have been extracted for Σ, P, T, O_x, and O_z
- Current binning
  - 4 energy bins 1.1 GeV - 2.1 GeV
  - Variable width bins in $cos\ \theta_{K_0}$ to produce integrated signal weight of approximately 1000 per bin
  - 21 bins in total

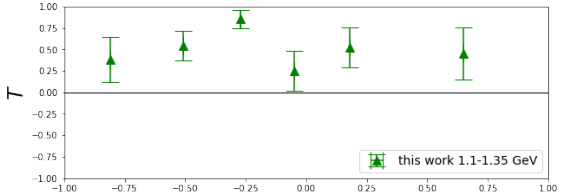
Preliminary results - Σ

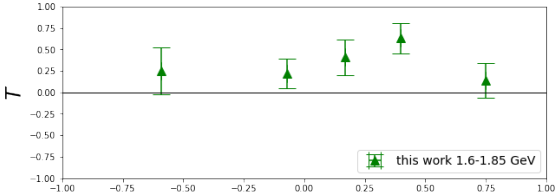


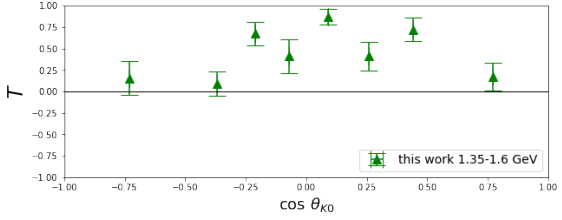
Preliminary results - P

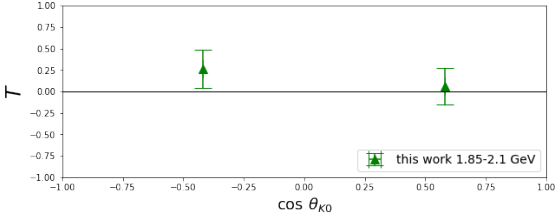


Preliminary results - T

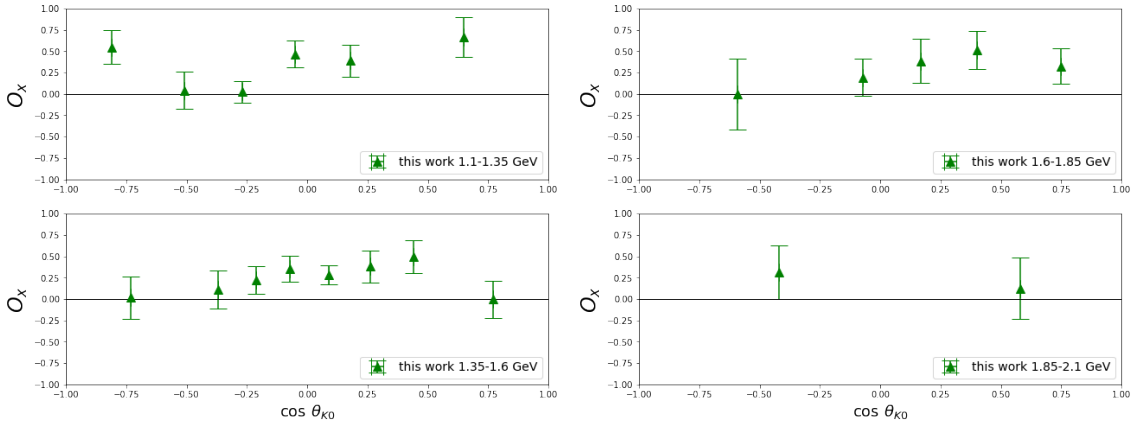




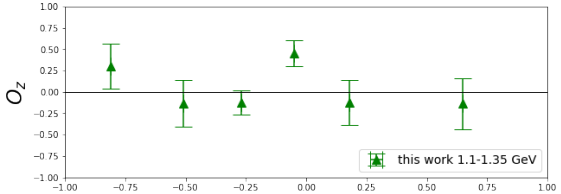


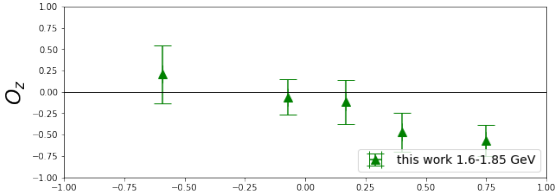


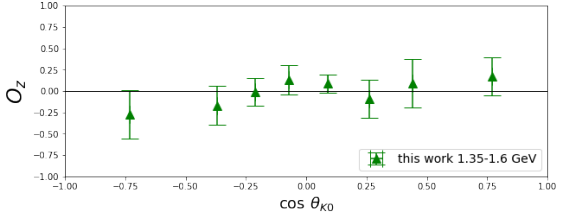
Preliminary results - O_x

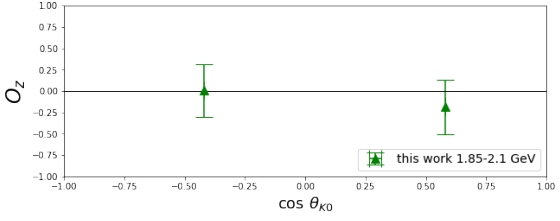


Preliminary results - O_z









Comparison to previous work and current analysis

Experiment	Measurements	$E\gamma$	Notes
CLAS g11	P	1.0–3.5 GeV	Difference in frame means different sign is extracted Some agreement with this work
CBELSA/TAPS	Σ P	1.15-1.65 GeV 1.05-2.25 GeV	Σ extracted using cross sections P results agree, but Σ do not
FSU analysis	P C_x, C_z	1.15-3.05 GeV	Results agree (subject to checking sign)
CLAS g8b	Σ, P, T, O_x, O_z	1.1-2.1 GeV	This work

Recoil polarisation - comparison with Nepali

Definition of frames
In the Σ^+ rest frame

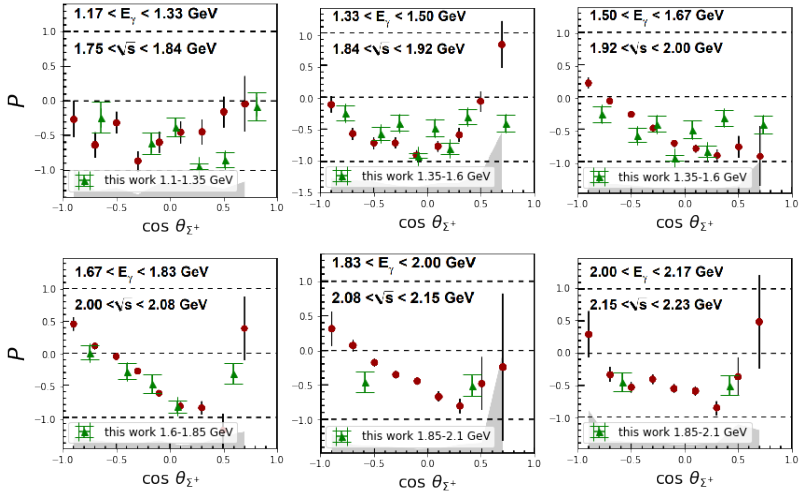
This work: for photon momentum $\vec{k}$ and kaon momentum $\vec{q}$

$$\hat{z}_{\text{evt}} = \frac{\vec{k}}{|\vec{k}|}, \quad \hat{y}_{\text{evt}} = \frac{\vec{k} \times \vec{q}}{|\vec{k} \times \vec{q}\,|}, \quad \hat{x}_{\text{evt}} = \hat{y}_{\text{evt}} \times \hat{z}_{\text{evt}}.$$

Nepali work:

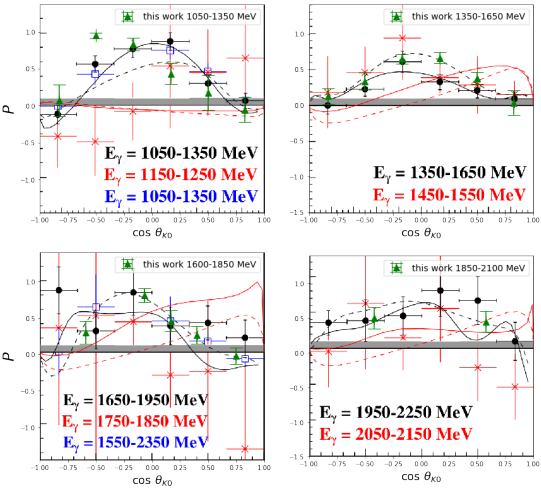
$$\hat{n}_z = \frac{\hat{p}_\gamma \times \hat{p}_{\Sigma^+}}{|\hat{p}_\gamma \times \hat{p}_{\Sigma^+}|},$$
$$\hat{n}_y = \hat{p}_{\Sigma^+},$$
$$\hat{n}_x = \hat{n}_y \times \hat{n}_z.$$

Recoil polarisation - comparison with Nepali

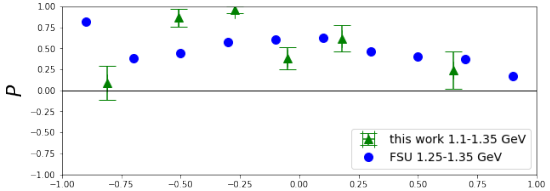


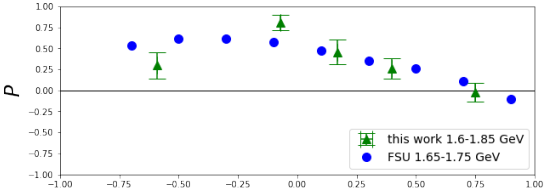
Recoil polarisation - comparison with Ewald

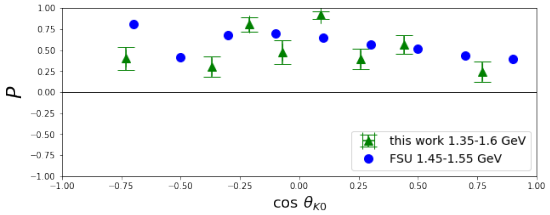
- Latest CBELSA/TAPS (black dots) are compared to the previous CBELSA/TAPS (red crosses) and SAPHIR (blue squares) data
- Curves represent the results of the Bonn–Gatchina-PWA solutions, BG2011-02m (black dashed) and BG2011-02 (black solid), and the K-MAID parametrisations, standard (red solid) and modified to study the origin of the cross section anomaly at the K^* threshold (red dashed)

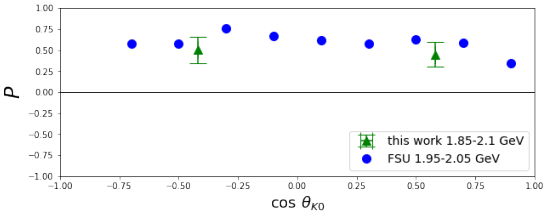


Recoil polarisation - comparison with FSU





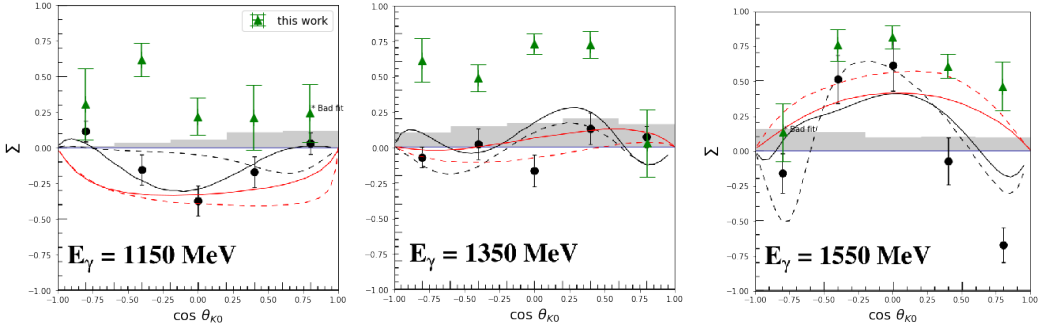




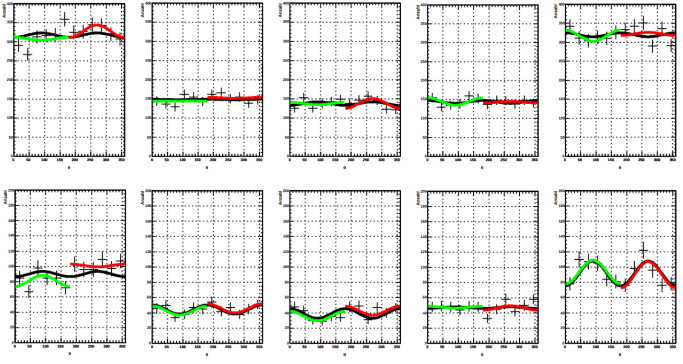
Recoil polarisation - summary

- Preliminary results have reasonable agreement with CBELSA/TAPS, CLAS g11 and g12

Beam asymmetry - comparison with Ewald



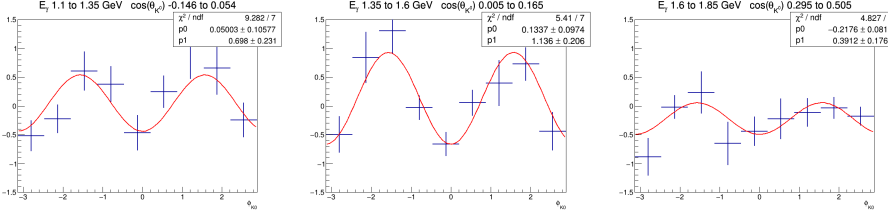
Beam asymmetry - Ewald asymmetries



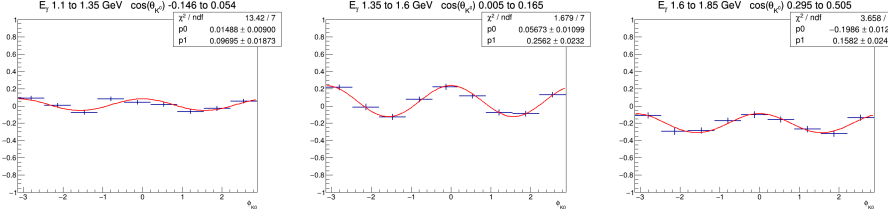
- Fits are made to the modulation of the cross section
- $0 - 180^\circ$ and $180 - 360^\circ$ fitted separately and average taken
- Thesis (in German): http://hss.ulb.uni-bonn.de/2010/2044/2044.pdf

Beam asymmetry - extracted with ϕ asymmetry

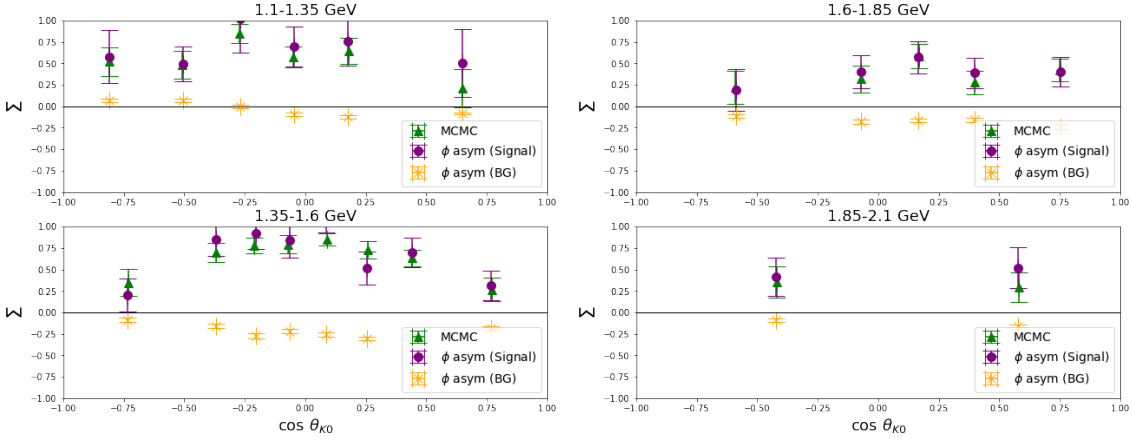
Signal (example bins)



Background (example bins)



Beam asymmetry - comparison of methods



Beam asymmetry - Summary

- Discrepancy in values obtained when comparing to previous CBELSA/TAPS measurements
- Values derived by this work by two different methods are self-consistent
- Beam asymmetry is present in the background events, and is smaller and of opposite sign to signal

Summary and next steps

- Preliminary results have been obtained from g8b data for Σ, P, T, O_x, and O_z for $\gamma p \to K^0\Sigma^+$
- These are first measurements of T, O_x, and O_z
- Comparison to previous measurements of P from CLAS and CBELSA/TAPS show agreement
- Comparison to previous measurement of Σ from CBELSA/TAPS show discrepancy
- Next steps
  - Systematic studies
  - Toy MC studies
  - Improvements to simulation

Thanks for your attention

Feedback welcome at:
l.clark.1@research.gla.ac.uk

Materials website (work in progress) :
http://nuclear.gla.ac.uk/~louise/html/

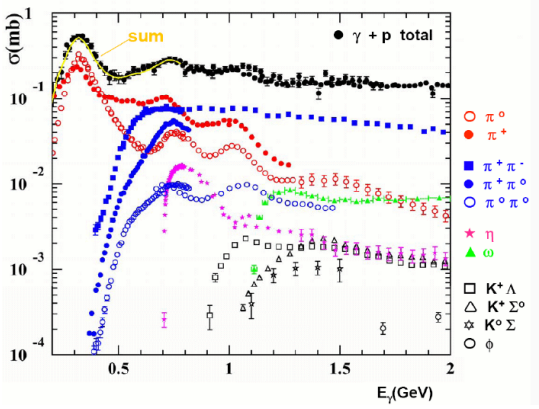
Louise Clark
University of Glasgow

Supplementary material

R. Ewald et al.
Measurement of polarisation observables in $K^0_S\Sigma^+$ photoproduction off the proton.
Physics Letters B, 738:268 – 273, 2014.

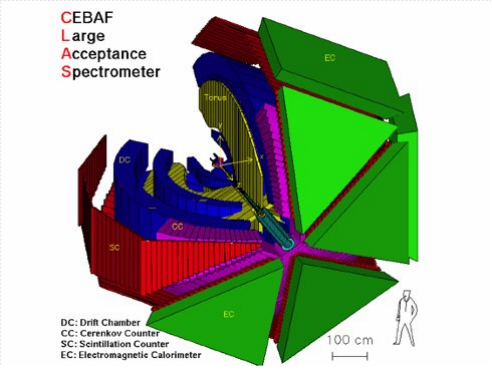
C.S. Nepali et al.
Transverse polarization of $\Sigma^+(1189)$ in photoproduction on a hydrogen target in clas.
Phys. Rev. C, 87:045206, Apr 2013.

Why study this reaction?



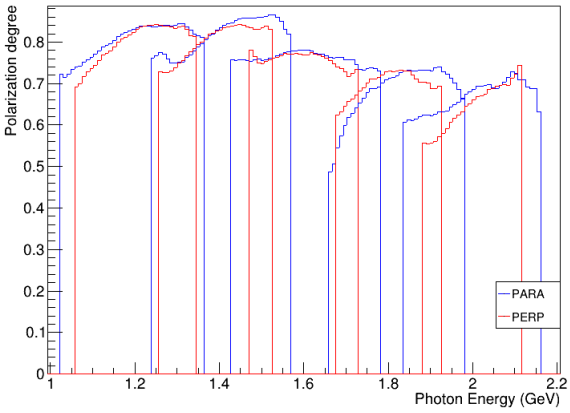
- Goal: understanding the baryon excitation spectrum
- Resonances are predicted but many are not yet measured
- Models / Partial Wave Analyses require further constraints beyond cross-section measurements
- Data for the $K^0\Sigma^+$ channel is limited - this study will be a first measurement of 3 observables

The experiment



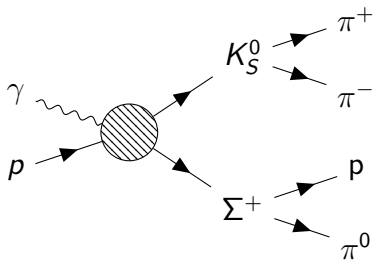
- g8b
- 4.5 GeV electron beam
- Linearly polarised photon beam produced from diamond radiator
  - Photon energy 1.1 - 2.1 GeV
  - Centre-of-mass energy 1.7 - 2.2 GeV
- Liquid hydrogen target

Polarised photon beam



- Mean polarization degree approx 0.7
- Systematic error 2-6%

Particle Identification



Final state $p\ \pi^+\ \pi^-\ (\pi^0)$

Particle ID cuts
3 charged particles, 0, 1 or 2 neutral particles in event
Mass and charge of particles compatible with $p\ \pi^+\ \pi^-$
Reaction vertex contained within the target
Tagged photon identified with absolute time difference < 1 ns
$E_{setting} - 200MeV < E_\gamma < E_{setting}$

Angular distribution dependance on polarisation observables

$$\frac{d\sigma}{d\Omega} \equiv \sigma\left(\phi, \cos\theta_x, \cos\theta_y, \cos\theta_z\right) = \sigma_0 \{1 - P^\gamma \Sigma \cos 2\phi - \alpha \cos\theta_x P^\gamma O_x \sin 2\phi + \alpha \cos\theta_y P - \alpha \cos\theta_y P^\gamma T \cos 2\phi - \alpha \cos\theta_z P^\gamma O_z \sin 2\phi\},$$

- ϕ = angle of reaction plane wrt polarisation plane
- $\cos\theta_x$, $\cos\theta_y$,$\cos\theta_z$ = direction cosines of proton in the rest frame of the hyperon
  - y-axis normal to reaction plan
  - z-axis parallel to beam in rest frame of hyperon

Angular distribution dependance on polarisation observables

$$\frac{d\sigma}{d\Omega} \equiv \sigma\left(\phi, \cos\theta_x, \cos\theta_y, \cos\theta_z\right) = \sigma_0 \{1 - P^\gamma \Sigma \cos 2\phi - \alpha \cos\theta_x P^\gamma O_x \sin 2\phi + \alpha \cos\theta_y P - \alpha \cos\theta_y P^\gamma T \cos 2\phi - \alpha \cos\theta_z P^\gamma O_z \sin 2\phi\},$$

- Polarisation observables: Σ, P, T, O_x, O_z
- Polarisation degree, P^γ
- Weak decay parameter, α