Strangeness Photoproduction At Threshold Energies

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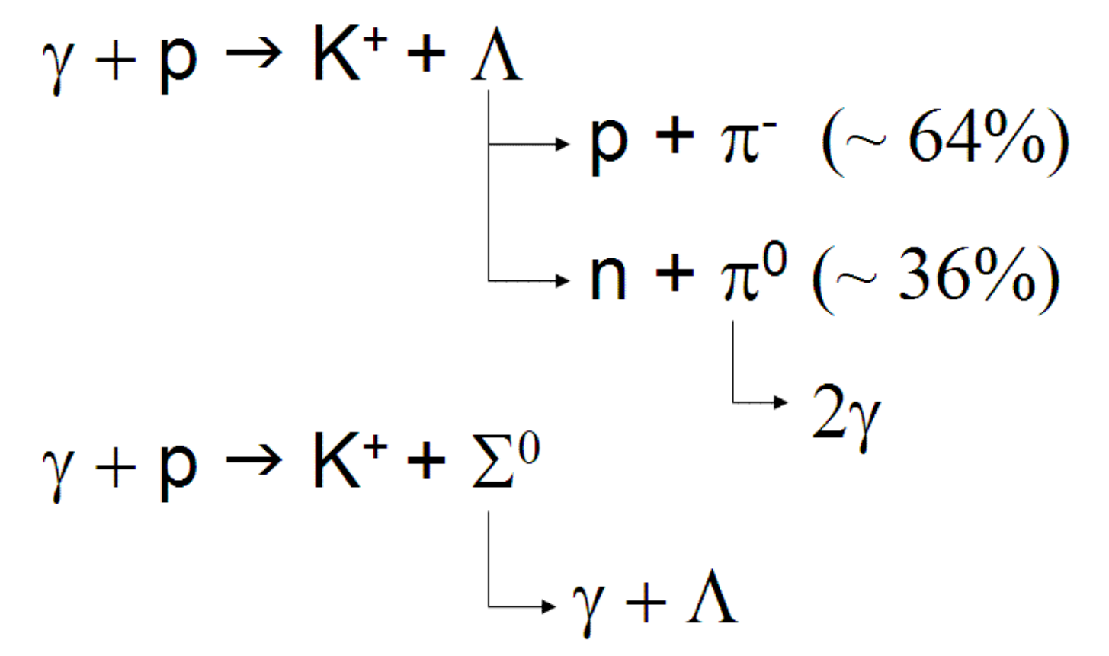
Strangeness photoproduction is an important challenge to recent QCD based chiral perturbation theories in the strange quark sector and is an important constraint on the nucleon excitation spectrum. Data is presented from a new measurement using the Crystal Ball detector at the Mainz Microtron facility. The measurement pioneers a new technique for tagging strangeness which has application at present and future hadron physics facilities.

1. Introduction

A large challenge of non-perturbative QCD is understanding the excited states of nucleons, which are predicted by phenomenological quark models or in recent years from lattice QCD calculations. Near the threshold regions of reactions, additional effective field theories based on the approximate chiral symmetry of the QCD lagrangain are applicable. These have shown success in describing pion production, but predictions for strange meson production are largely unchallenged by experiment.

Many properties of the nucleon resonance spectrum are not well defined and there are still many missing resonances which have been predicted yet not observed. This could be due to inadequacies in quark models of the nucleon, or that experiments have been insensitive to these resonances. It has been suggested that these missing resonances may couple to strange decay channels and could be observed more easily via the photoproduction of strange mesons and hyperons [1].

We present cross sections of the photoproduction of K^+ mesons from the proton near threshold energies (Fig.1). These have been measured at an unprecedented photon beam energy resolution. This gives new constraints on the excitation spectrum of the nucleus and gives the data sufficient quality to challenge the existence of narrow nucleon structure.



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

$\quad \hookrightarrow p + \pi^- \ (\sim 64\%)$

$\quad \hookrightarrow n + \pi^0 \ (\sim 36\%)$

$\qquad \hookrightarrow 2\gamma$

$\gamma + p \rightarrow K^+ + \Sigma^0$

$\quad \hookrightarrow \gamma + \Lambda$

Fig.1. Strangeness photoproduction

2. Previous Strangeness Measurements

Previous measurements of the cross section for $\gamma p \rightarrow K^+\Lambda$ have significant discrepancies (Fig.2 [2,3]). Fits from partial wave analysis and multipole models yield different resonant parameters depending on the data set used [4]. The world data set is also at an insufficeint energy resolution to discern any narrow structure in the photoproduction process.

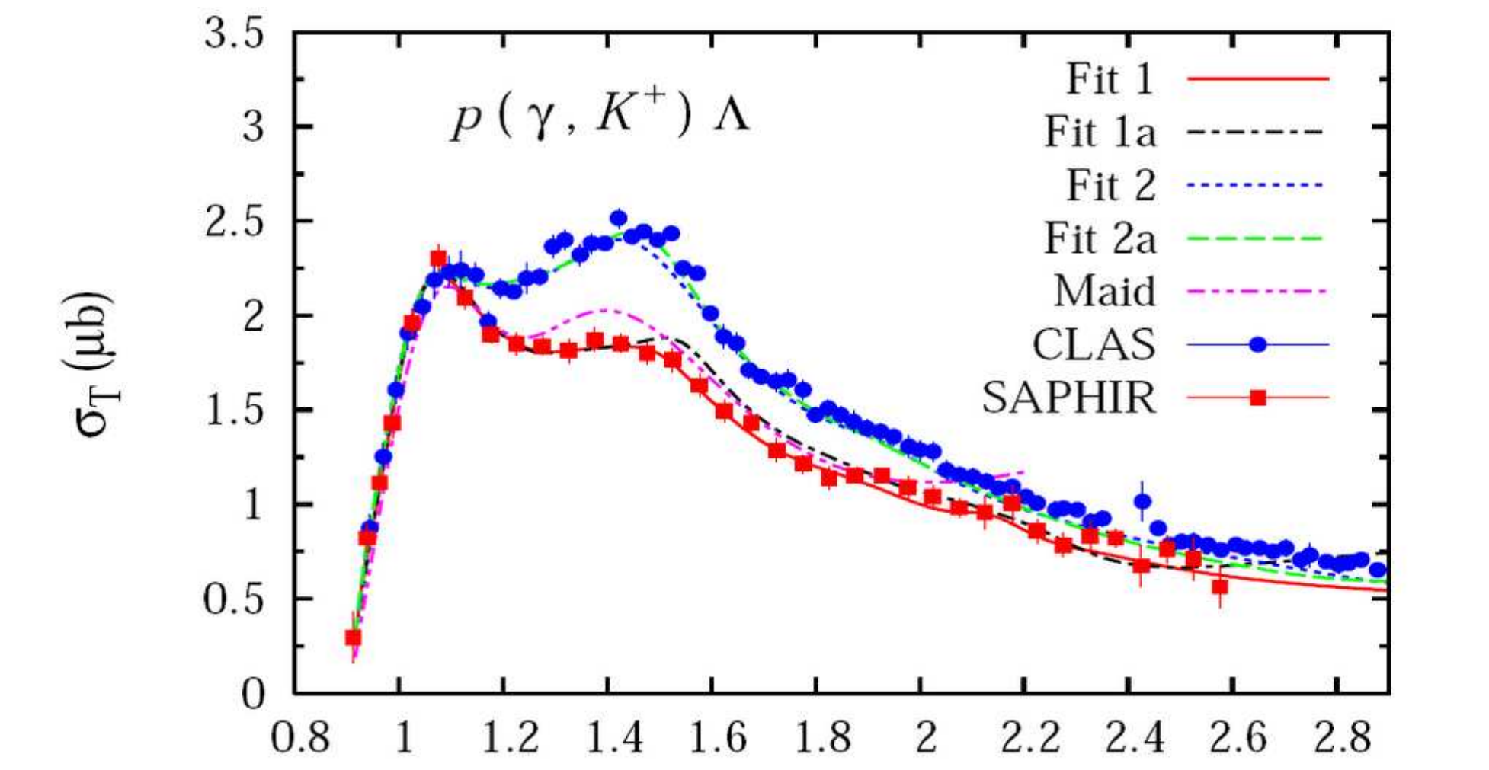


Fig.2. Total cross section measurements from JLab [2] (blue points) and ELSA [3] (red points). The applied fits are from multipole analysis

Measurements of polarisation transfer have recently been obtained above the threshold region for $K^+ \Lambda$ photoproduction [5]. Over a large kinematic range, the polarisation observables C_X and C_Z were consistent with zero and one respectively. This surprising result suggests the strange quark retains its full polarisation magnitude, with complete spin polarisation transferred to the Λ and none to the angular momentum of the $K^+\Lambda$ final state [6].

Measurement of strangeness photoproduction at MAMI-C will clear discrepancies in cross sections of the world data set and measure at an unprecedented energy resolution ($\tilde{4}$ MeV) in a search for any narrow structure. With a circular polarised beam, Polarisation observables C_X and C_Z can be extracted down to threshold energies, verifying recent measurements [5].

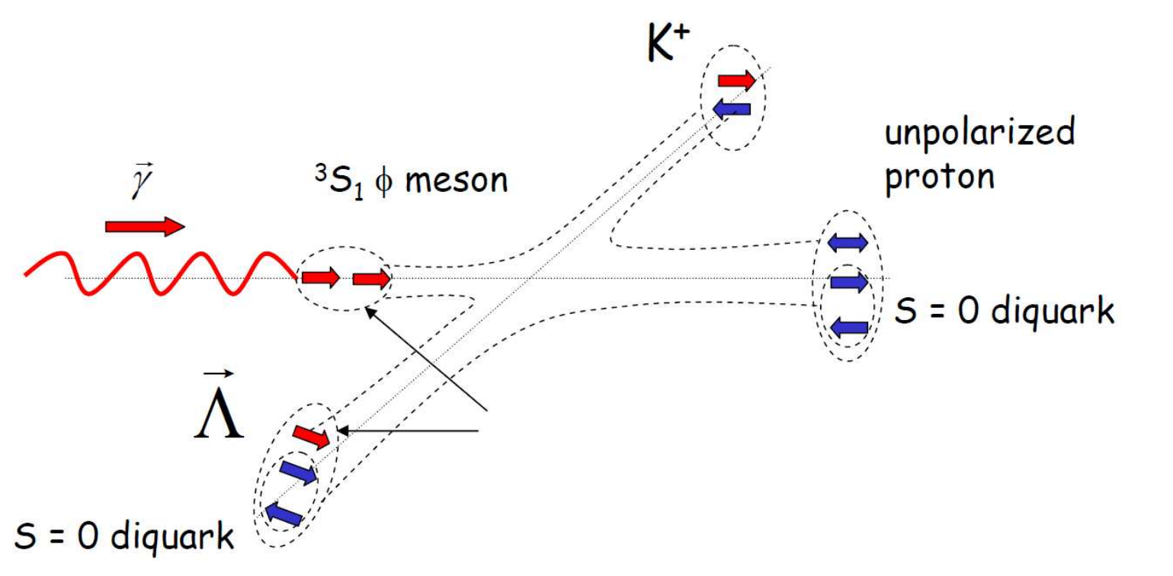
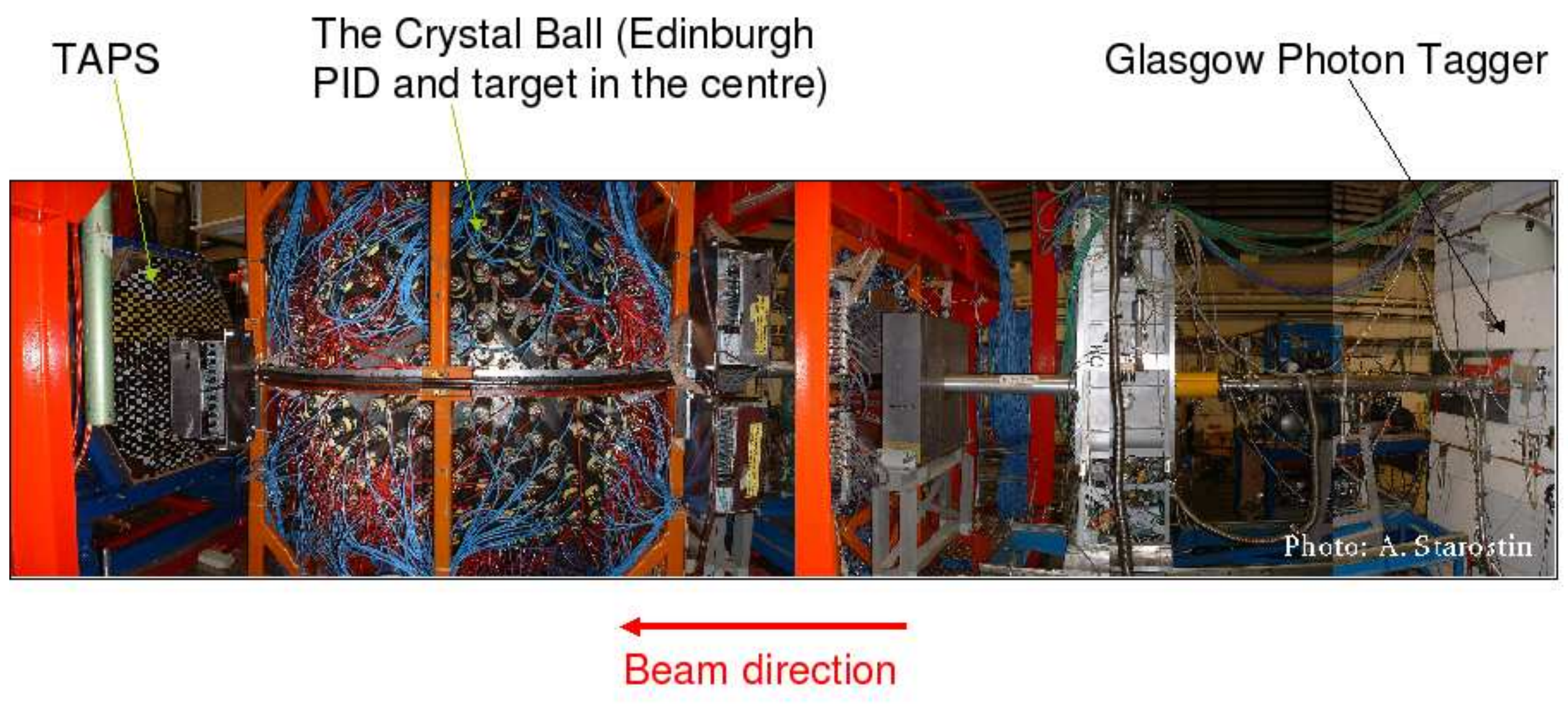


Fig.3. Quark level explanation of Λ polarisation. The strange quark is produced polarised and retains the magnitude of its polarisation throughout the hadronisation process. Diagram from [6]

3. Experimental Apparatus

- **Mainz Microtron (MAMI-C)**: An electron accelerator facility capable of accelerating electrons up to 1.5 GeV.
- **Glasgow Photon Tagger**: Accelerated electrons are incident upon a thin metal radiator. Bremsstrahlung radiation up to 1.4 GeV is collimated towards the target. The electrons are focussed in a magnetic spectrometer to determine their energy and "tag" the energy of the photon.
- **The Crystal Ball**: A highly segmented calorimeter capable of measuring 93% of 4π steradians. The Crystal Ball is built from 672 optically isolated NaI crystals. The liquid hydrogen target is at the centre of the Crystal Ball
- **The Edinburgh Particle Identification Detector (PID)**: 24 plastic scintillators parallel to beam with PMTs at the up stream end. Particle identification is achieved by comparing energy deposited in the PID as particles pass through and energy deposited in the Crystal Ball as particles are completely stopped (Fig.4).
- **TAPS**: Segmented BaF_2 detector used as a forward wall for the Crystal Ball.



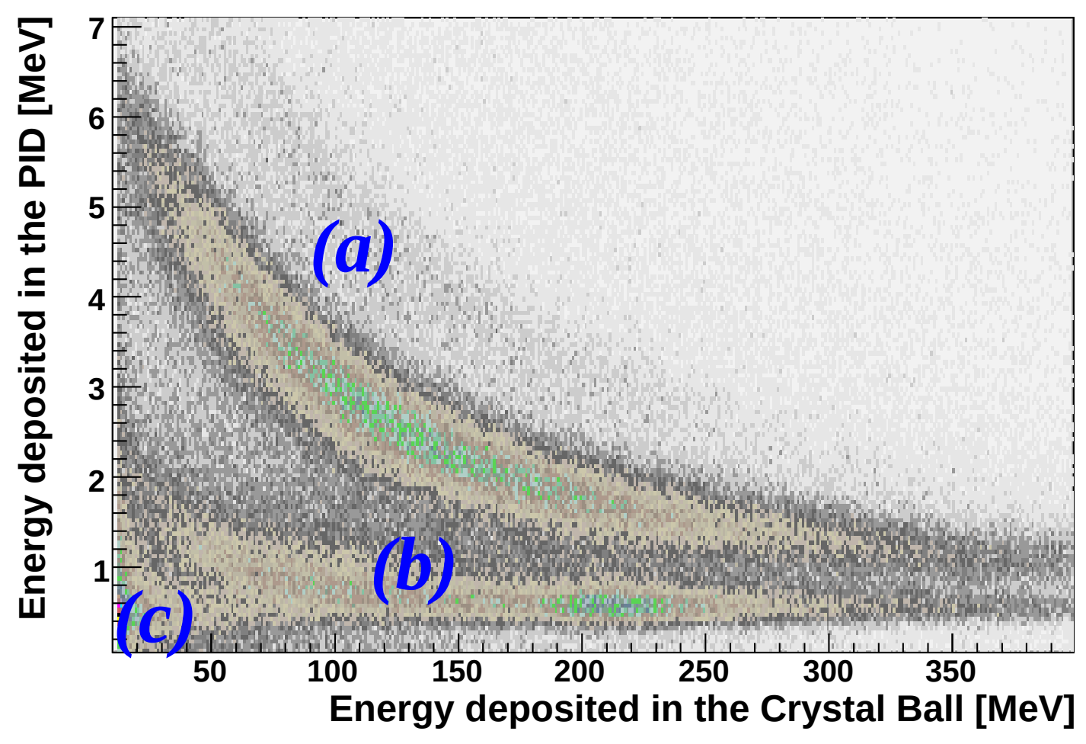


Fig.4. $\Delta E - E$ plot from the energy deposited in the PID and the Crystal Ball. Characteristic loci of charged particles (a) protons, (b) pions , (c) electrons

4. Kaon Identification

Previous measurements with charged kaon detection used large magnetic spectrometers or time of flight techniques for identification. The Crystal Ball's design does not allow this so a new technique was required.

K^+ mesons are identified by the decay of the stopped K^+ inside the detector crystals themselves. Excellent timing resolution allow distinction between the K^+ detection and the subsequent decay with a mean lifetime of 12 ns. The measured energy of the K^+ decay is consistent with the energy released for $K^+ \rightarrow \mu^+\nu_{\mu^+}$ (150 MeV) and $K^+ \rightarrow \pi^+\pi^0$ (350 MeV). A further 2D energy cut using the Edinburgh PID eliminates random coincidences from other charged particles.

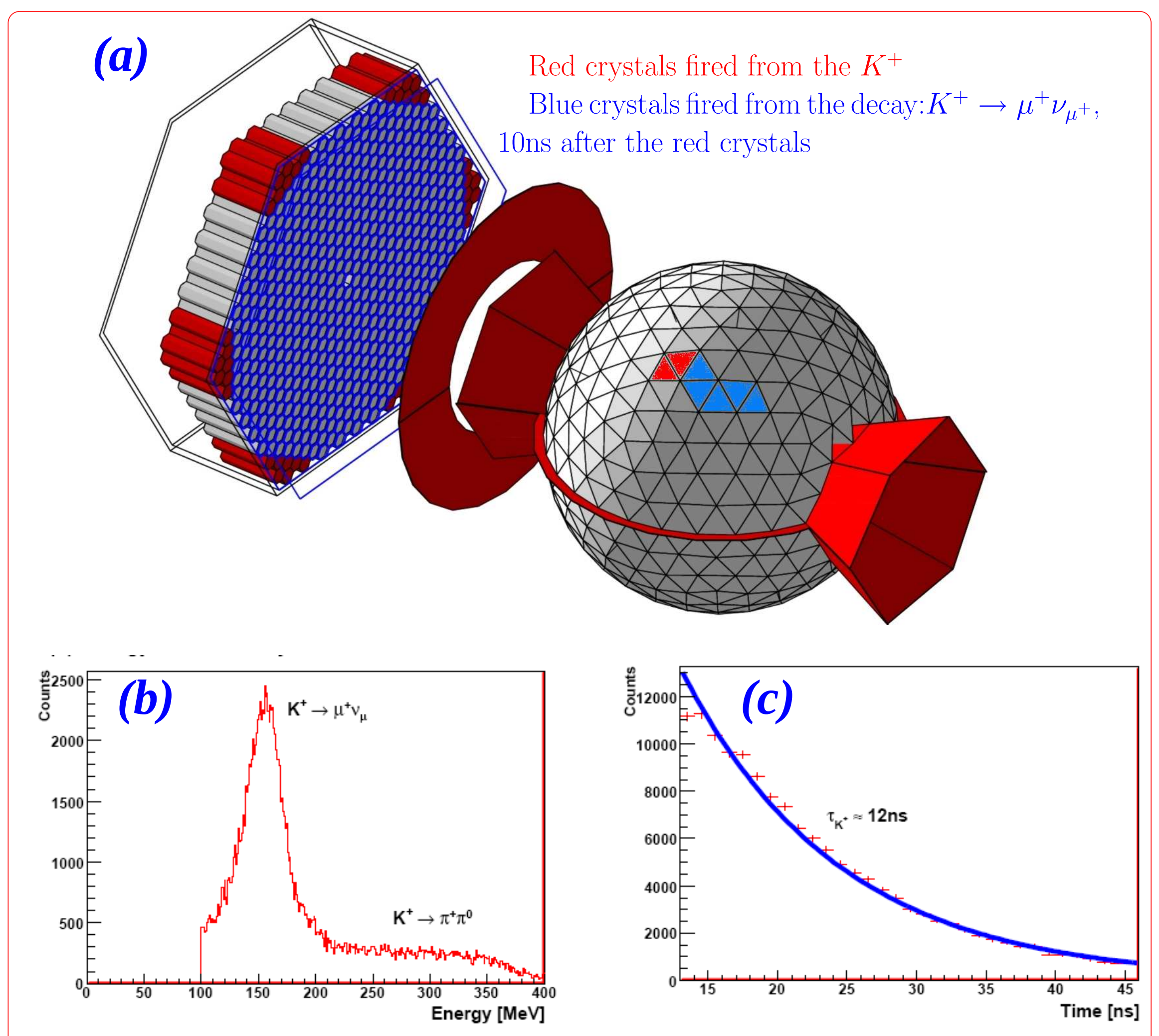


Fig.5. (a) Schematic diagram of the detection method which uses the K^+ decay as identification. (b)Energy and (c) time of the decay cluster which are constent with kinematics and K^+ mean lifetime.

5. Cross Section Measurements

The Photon from the decay $\Sigma^0 \rightarrow \gamma\Lambda$ is identified by selecting neutral particles over expected kinematic regions. In the Σ^0 rest frame, the energy of the decay photon is the mass difference between Σ^0 and Λ hyperons (77 MeV). Plots of the missing mass from K^+ detection have peaks over the Λ and Σ^0 masses (Fig. 7). Fitting to these plots gives the yield of $K^+\Lambda$ photoproduction over different energy and angular intervals.

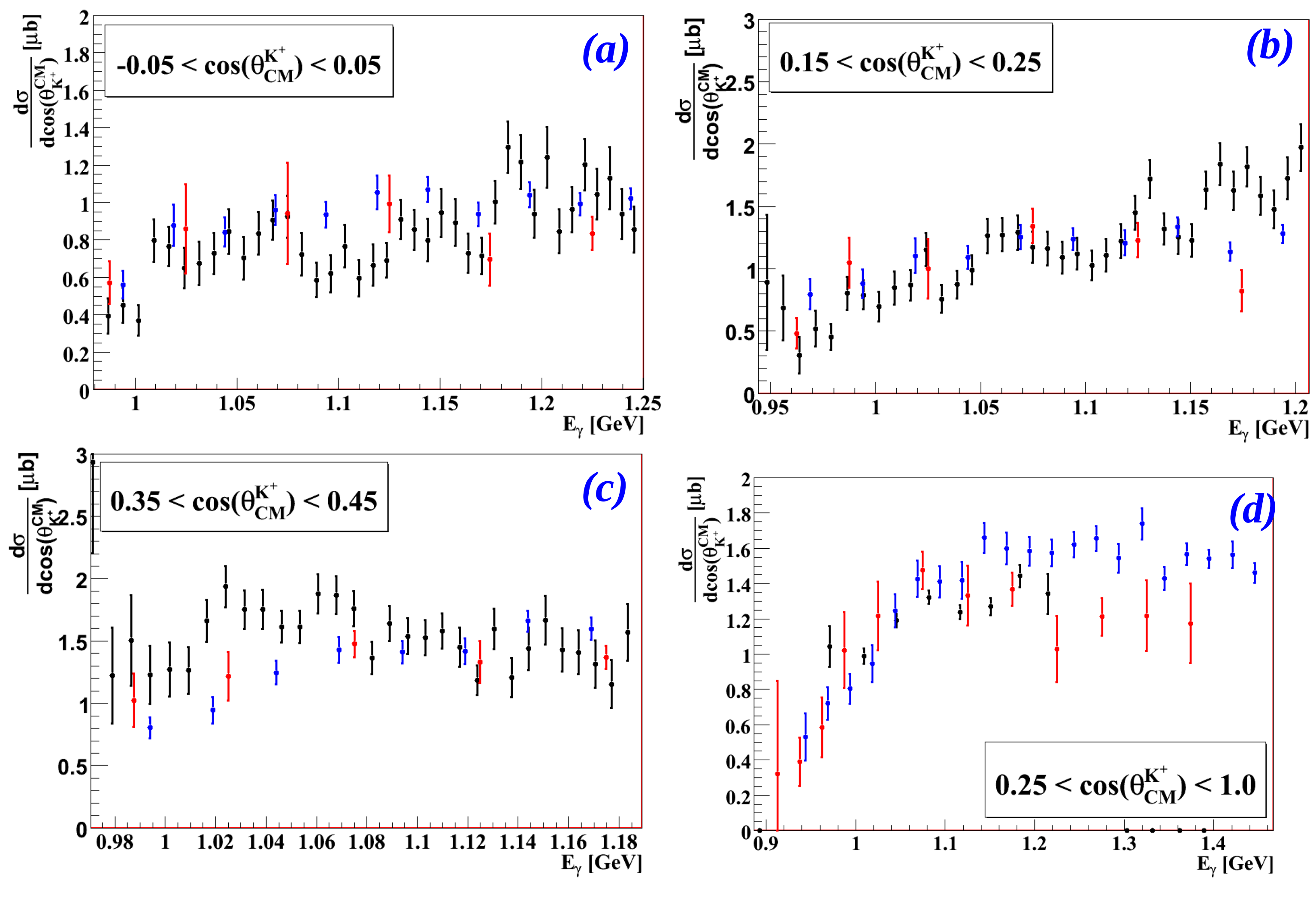


Fig.6. Cross Section measurements for different centre of mass K^+ polar angles plotted against photon beam energy (black points). Blue and red points are previous JLab [2] and ELSA [3] data respectively

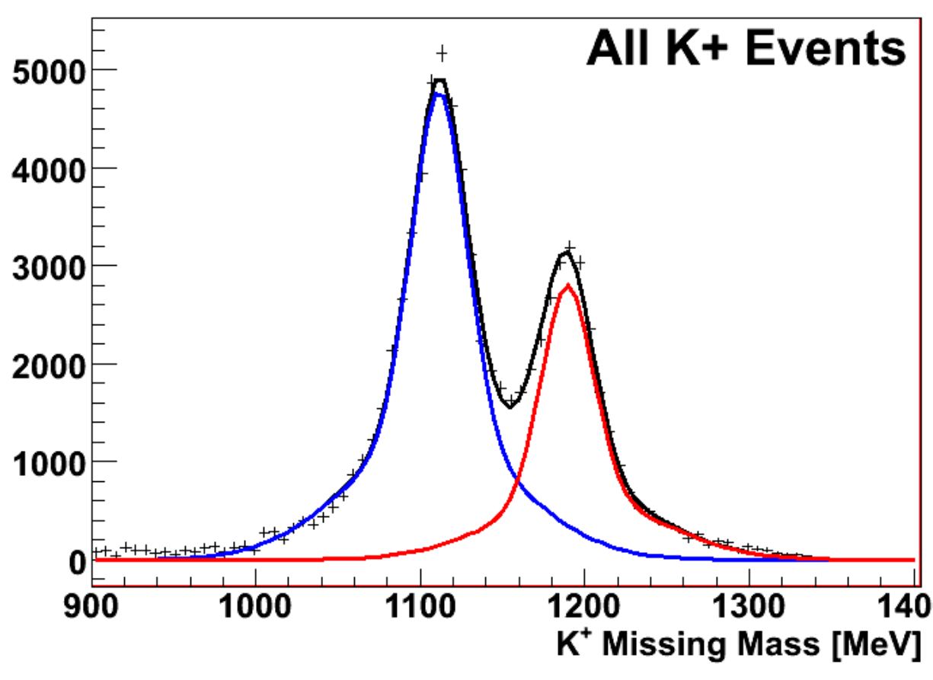


Fig.7. Missing mass from K^+ detection with peaks on Λ and Σ^0 masses. The fits two the data is used to measure $K^+\Lambda$ photoproduction yield over different energy and polar angles.

Preliminary cross section measurements are consistent with the previous data in Fig. 6. The 4 MeV resolution is able to resolve smaller structure than was possible before. Fig. 6(d) is the data at more forward angles. Due to electronic triggers in the detector system there is a paucity of data in the forward region, however with future beam times, data from the Crystal Ball will be able to resolve the discrepancy in the world data set which is most obvious at forward angles.

6. Future Plans

Detection efficiency from simulation will be improved and better understood to remove any systematic errors. Fig. 8 is a preliminary asymmetry measurement with a circularly polarised beam for the Λ weak decay from which C_Z can be extracted. A frozen spin target which is scheduled to be installed in the Crystal Ball will allow access to beam-target polarisation observables. "Missing" nucleon resonances which are sensitive to these observables (such as $D_{13}(1900)$) can be accessed by the strangeness reaction channels [7].

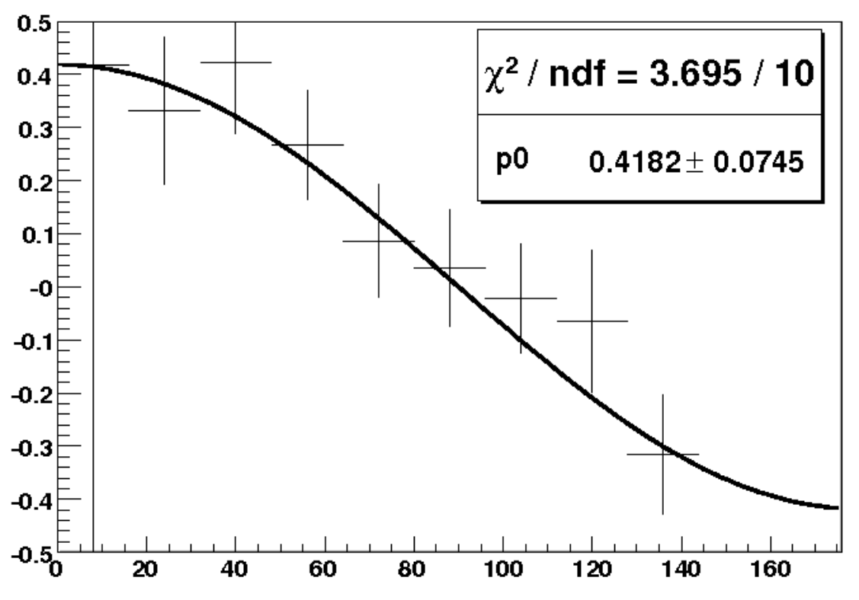


Fig.8. Asymmetry of the decay $\Lambda \rightarrow n\pi^0$ with a cicularly polarised beam for beam energies 1.0 - 1.2 GeV.

References

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