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Precision measurements of strangeness photoproduction at threshold energies with the Crystal Ball at MAMI-C

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Abstract The photoproduction of K^+ mesons from the nucleon provides important constraints on the nucleon excitation spectrum and at threshold energies challenges effective field theories based on chiral perturbation in the strange quark sector. Preliminary cross-section measurements for $\gamma(p, K^+)\Lambda$ are presented at an unprecedented beam energy resolution. The data was collected at the MAMI-C facility in Mainz using the Crystal Ball Detector. A new method of K^+ detection was used in which the K^+ is tagged from its weak decay products in the detector crystals. This technique has application with other calorimeters at present and future hadron facilities.

Key words Crystal Ball Detector, strange meson photoproduction

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1 Introduction

Hyperon photoproduction is an important reaction for investigations into the nucleon excitation spectrum. Constituent quark models have predicted many resonances that have not been observed or not consistently established in previous extensive measurements. It has been suggested, as most of these measurements come from the pion decay of resonances, that either the models are deficient or that these "missing resonances" couple to other decay channels[1]. As well as for detailed studies of the nucleon excitation spectrum, accurate measurements of hyperon photoproduction at threshold energies are also a crucial test of chiral perturbation theory in the strange quark sector.

There are no detailed measurements of $\gamma(p, K^+)\Lambda$ approaching the threshold energy of 911 MeV. The two most recent cross-section measurements at JLab[2] and ELSA[3] contain large discrepancies over the photon beam energy range 1.0—1.4 GeV. Fits to these data from partial wave analysis reveal large differences in the roles of nucleon resonances when describing the photoproduction process[4].

The MAMI-C facility provides an intense photon beam with an energy resolution of approximately 4 MeV and energies up to 1.4 GeV. Approximately 4π solid angle acceptance is provided by the Crystal Ball Detector and TAPS. We present preliminary cross-section measurements of $\gamma(p, K^+)\Lambda$ with high statistics. The new data has the potential to address discrepancies in previous measurements over this range and provide data with significant improvements in statistics and beam energy resolution.

2 The Crystal Ball detector at the MAMI-C facility

The Mainz Microtron (MAMI-C) is an electron accelerator facility in Mainz, Germany, capable of accelerating electrons up to 1.55 GeV. The electrons produce circularly or linearly polarised photons via bremsstrahlung in a solid radiator. The photon energy is tagged by momentum analysis of the recoiling bremsstrahlung electrons in the Glasgow Photon Tagger[5].

The Crystal Ball[6] is a calorimeter with 672 op-

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tically isolated NaI crystals. The output of the photomultiplier for each crystal is digitised using multi-hit TDC and ADC modules. Surrounding the liquid hydrogen target at the centre of the Crystal Ball is the Edinburgh Particle Identification Detector (PID). The PID comprises 24 plastic scintillator detectors parallel to the beam and read out by photomultipliers at the upstream end. ΔE-E analysis provides a means of proton, charged pion and electron identification. The Crystal Ball is an excellent neutral meson detector via the detection of the decay photons.

TAPS[7] is a 350 element BaF_2 spectrometer which covers the forward angle range. The Crystal Ball and TAPS cover approximately 93% of 4π steradian.

3 K$^+$ identification

Previous measurements of K$^+$ production have used large magnetic mass spectrometers[2] or have isolated the decay vertex of the associated hyperon using tracking chambers[3]. A new method of detection was needed with the Crystal Ball. Identification of K$^+$ using $\Delta E - E$ techniques was not possible as the signals in the PID and Crystal Ball are too similar to protons and are further spoiled by the decay products of the K$^+$. Instead, the wesk decay of the stopped K$^+$ within the crystals of the detector was detected and used as a means of identification.

The technique proceeds as follows: the K$^+$ meson enters the Crystal Ball where it is stopped. The crystals involved in this initial interaction are identified as those having a timing within 8 ns of the reaction time. The meson decays weakly via: $K^+ \to \mu^+\nu_\mu$ or $K^+ \to \pi^+\pi^0$,with branching ratios 64% and 36% respectively and a mean lifetime of 12 ns. The 2 ns resolution of the Crystal Ball allows a seperation of the cluster of crystals from the stopped K$^+$ and the second cluster from the subsequent decay. The crystals in the second cluster are identified with a timing gate of between 10-50 ns later than the K$^+$ entry time. A GEANT4 simulation is used to optimise upper and lower limits on parameters such as the number of crystals in the cluster from the stopped K$^+$ and the K$^+$ decay, the distance to the furthest crystal and the total energy deposition. A subsequent $\Delta E - E$ analysis using the PID provides a final constraint to suppress background from charged particles. Fig. 1 is a schematic diagram of the K$^+$ identification method. From simulation, this method of identification detects approximately 15% of all K$^+$, mis-identifying non-strange reaction channels approximately 10^{-3}% of the time.

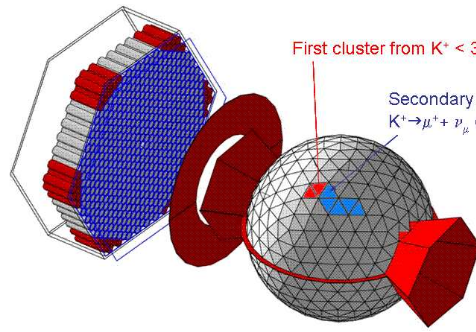

Fig. 1. Schematic diagram of the K$^+$ detection method with the Crystal Ball Detector.

A histogram of the energy of the decay cluster (Fig. 2(a)) yields a peak over 150 MeV and a broader shoulder from 350—400 MeV which is consistent with the energy released from K$^+$ decay to $\mu\nu_\mu$ and $\pi^+\pi^0$ respectively. Counts of the time difference between the first and second cluster of crystals shows the expected exponential shape and the mean K$^+$ lifetime can be extracted with a fit to this (Fig. 2(b)).

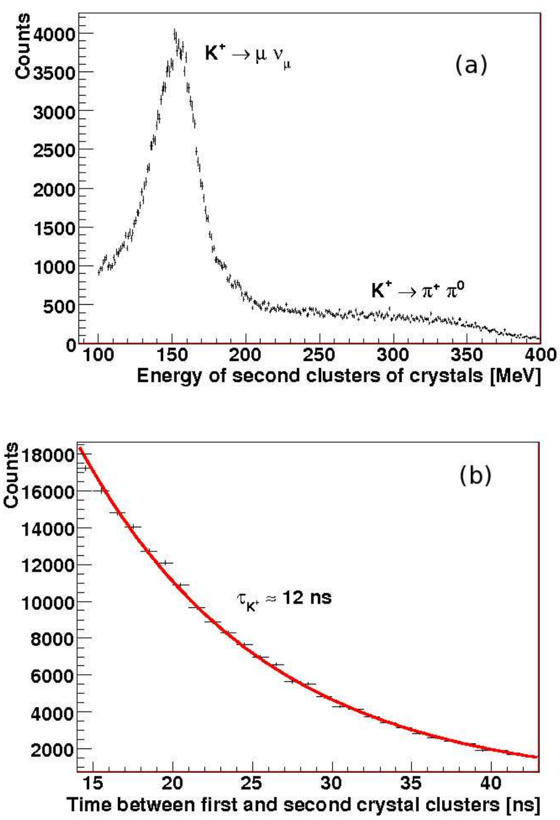

Fig. 2. (a) Energy of the second cluster (the K$^+$ decay) with a peak at 150 MeV, the energy released in the decay muonic decay, and a broader shoulder at 350 MeV corresponding to the pionic decay. (b) The time difference between the first and second cluster. Fitting an exponential to the data yields the K$^+$ mean lifetime of 12 ns.

4 Cross-section measurements

Above the photon beam energy of 1.05 GeV, the $\gamma(\mathrm{p},\mathrm{K}^+)\Sigma^0$ reaction channel contributes to the K^+ yield. The missing mass from the K^+ momentum is used to seperate the yields from the two channels. A typical missing mass spectra is shown in Fig. 3 and clearly shows two peaks originating from Λ and Σ^0 production. The peaks are each fitted with a two Gaussian fit, with parameters constrained by a GEANT4 simulation.

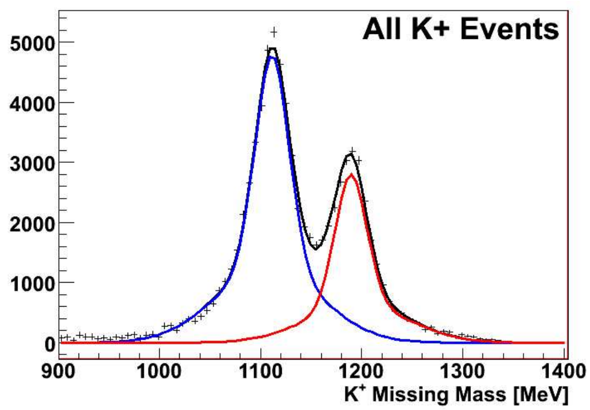

Fig. 3. Missing invariant mass from K^+ momentum reconstruction. $\mathrm{K}^+\Lambda$ and $\mathrm{K}^+\Sigma^0$ yields are measured from the blue and red fits respectively.

In addition to missing mass analysis, the Σ^0 contribution is suppressed by identification of the photon from the decay of the Σ^0. These photons are identified by boosting into the Σ^0 rest frame and looking for photons with an energy of the $\Sigma^0-\Lambda$ mass difference (77 MeV). This reduces systematic error from the missing mass fits. Events are also rejected from the data sample if the K^+ has an energy which punches out of the Crystal Ball (over 340 MeV), or the first cluster of crystals from the K^+ is too large as these events have poor K^+ momentum reconstruction.

A GEANT4 simulation of 20 million $\gamma(\mathrm{p},\mathrm{K}^+)\Lambda$ was used to measure the detection effeciency for different energy and polar angle bins. These efficiencies were used to convert the K^+ yield into cross-section. Fig. 4 shows preliminary cross-sections as a function of photon beam energy, binned in centre of mass K^+ polar detection angles. Good statistical accuracy is obtained even with 4 MeV photon beam energy resolution. The data presented here comprises approximately one half of the available data set and later runs had experimental trigger setups to greatly increase detection efficiencies in the forward K^+ angular bins. It is clear the new measurements will provide accurate constraints of partial wave analysis and chiral perturbation theory predictions.

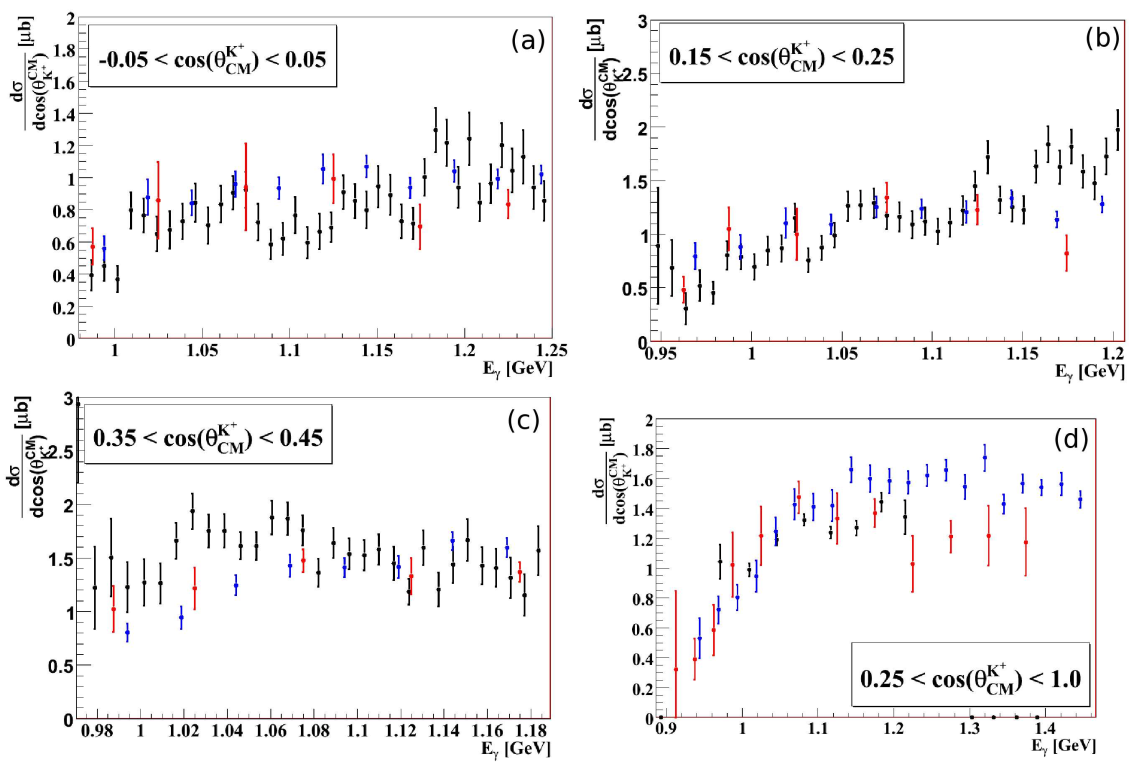

Fig. 4. Preliminary cross-section measurements for $\gamma(\mathrm{p},\mathrm{K}^+)\Lambda$ (black points). Blue and red data are from previous JLab[2] and SAPHIR[3] measurements respectively.

5 Branching ratio of the rare Σ^0 Dalitz decay

The Dalitz decay: $\Sigma^0 \rightarrow e^-e^+\Lambda$ was first measured by Courant et al. to measure the relative parity between Σ^0 and Λ[8]. The branching ratio quoted in the PDG is given as 0.5%. Current volume of data from the Crystal Ball Detector will not be able to improve the accuracy of this measurement, however this is the first published detection of this decay seen without using a bubble chamber and provides a bench mark test of the effectiveness of this new method of K^+ identification.

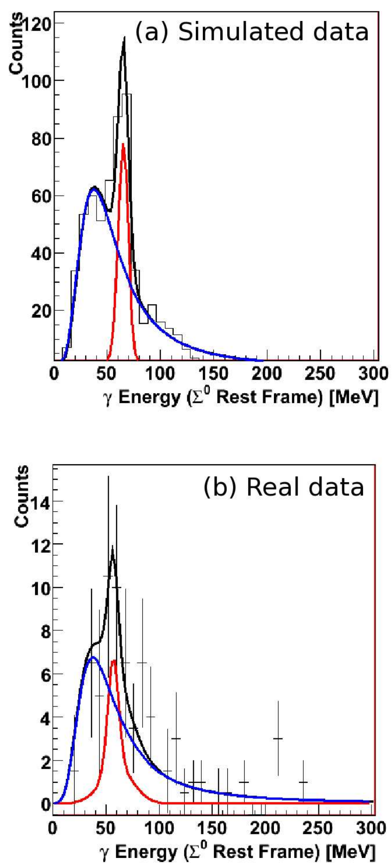

Fig. 5. (a) Simulated and (b) real data of the summed energy of electron positron pairs in the Σ^0 rest frame. a Gaussian fit (red line) describes real events in the simulation, a Landau (blue line) describes background in the simulation. The black line is the sum of the two fits.

The K^+ identification was achieved as described in section 3. Additionally, two dimensional cuts Using $\Delta E - E$ analysis from the PID and the Crystal Ball were used to identify possible electron and positron candidates. These were boosted into the Σ^0 rest frame and their energies were summed and compared with the $\Sigma^0 - \Lambda$ mass difference.

The characteristics of the signal from the Dalitz decay and the background were studied using GEANT4 simulations of $\gamma(p, K^+)\Sigma^0$ events. The simulated Dalitz decay data gave the expected peak over the $\Sigma^0 - \Lambda$ mass difference. This peak was well described by a two Gaussian fit. The suppressed background of non-Dalitz decays of the Σ^0 resulted in a broad shoulder which was well described by a Landau function.

The simulated data and fits are shown in Fig. 5(a) in which the expected branching ratio of 0.5% is employed. The same analysis method was applied to real data (Fig. 5(b)). The parameters to the fit to the real data were constrained by the fit from the simulation with the exception of the height of the peak from the Dalitz decay. This allows the branching ratio of the Σ^0 to be constrained by the experimental data.

Comparison of the ratio of the areas of background to real events in the simulation and the experimental data yields a branching ratio , $\Gamma_{\rm expt} = (0.49 \pm 0.36)\%$. This is in agreement the PDG value. Further studies of systematic effects will be studied with the more complete data set.

6 Future work

New accurate measurements of the double polarisation observables, C_X and C_Z can be extracted with further analysis[9]. A frozen spin target for the Crystal Ball will enable the double polarisation observables E, G, H and F to be extracted which a considered particularly sensitive to missing nucleon resonances for strangeness channels[10].

The reaction: $\gamma(n, p_s, K^+)\Sigma^-$ will be studied using data from a deuteron target. With an increase in tagged beam energy, K^+ photoproduction can also be measured in the $\Lambda(1405)$ region.

References

1 Capstick V, Roberts W. Phys. Rev. D, 1998, **58**: 074011
2 Bradford R et al. Phys. Rev. C, 2006, **73**: 035202
3 Glander K H et al. Eur. Phys. J. A, 2004, **19**: 251
4 Mart T. arXiv:0803.0601v1 [nucl-th], 2008
5 McGeorge J C et al. Eur. Phys. J. A, 2008: 10606
6 Starostin A et al. Phys. Rev. C, 2001, **64**: 055205
7 Novotny R. IEEE Trans. Nucl. Sci., 1991, **38**: 2
8 Courant H et al. Phys. Rev. Lett., 1963, **10**: 409
9 Bradford R et al. Phys. Rev. C, 2007, **75**: 035205
10 Thomas A. Helicity Dependence of Meson Photoproduction on the Proton, 13th Crystal Ball Meeting, Mainz, Germany, March 2009