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Mainz Microtron MAMI

Collaboration A2: "Real Photons"
Spokesperson: A. Thomas

Letter of Intent for an Experiment

"$K^0\Sigma^+$ Photoproduction with MAMI-C"

Collaborators :

CrystalBall@MAMI collaboration

Spokespersons for the Experiment : D. I. Glazier, K. Livingston, G. Rosner, University of Glasgow

Abstract of Physics :

We propose to measure the strangeness photoproduction reaction $\gamma p \to K^0\Sigma^+$, using data from the upcoming MAMI-C experiments with the Glasgow photon tagger and Crystal Ball/TAPS detectors. We will require access to data with maximum beam energy and the liquid hydrogen target. The strange particles will be reconstructed from their decays to neutral pions which subsequently decay to 2 photons. We will measure the differential cross section, the induced recoil hyperon polarisation P and the transfered polarisation from circularly polarised photons $C_{x'}$.

Abstract of Equipment :

We plan to take advantage of MAMI-C electron beam energies in conjunction with the upgraded Glasgow Tagger. We will use data from the standard Crystal Ball/TAPS setup in the A2 hall. These detectors are ideal for detecting the 6 photon, 1 proton final state proposed.

MAMI–Specifications :

beam energy	1500 MeV
beam current	< 100nA
time structure	cw
polarization	circularly polarized photons

Experiment–Specifications :

experimental hall/beam	A2
detector	Crystal Ball, TAPS, MWPC, PID
target material	liquid hydrogen

Beam Time Request :

This letter of intent does not request any specific beamtime.

1 Motivation

With its upgrade to 1.5 GeV photon energies MAMI experiments will enter the strangeness production region. As the Crystal Ball collaboration are due to operate in the A2 hall for the next few years it is important to determine the suitability of this setup for detecting and reconstructing strange particles. Currently investigations are underway to determine its response to charged mesons and in particular Kaons. In the meantime the possibility of measuring $K^0\Sigma^+$ photoproduction, resulting in a final state of 6 photons and one proton, is presented here.

1.1 Strangeness Production

High duty factor electron beam facilities with energies of the order of 1 GeV, make it feasible to measure strangeness production reactions with electromagnetic probes. These reactions have relatively low cross sections of the order of a μb compared to π, K beams which have cross sections of the order of a mb. However the weakly interacting electromagnetic probe will result in less distortion for the ingoing channel and hence the extraction of quantitative information will be less model dependent [1].
Another benefit of such reactions, in comparison to pion and eta photoproduction, is that the produced hyperons are self-analysing, i.e their recoil polarisation can be determined from the angular distributions of their decay products, which is particularly useful with 4π solid angle detectors. Photoproduction of pseudoscalar mesons is described by 4 complex amplitudes. This gives 16 observables that can be measured in photoproduction reactions [1]: the differential cross section; 3 single spin asymmetries Σ, T and P with a polarised beam, target and recoiling baryon respectively; and 12 double polarisation observables requiring combinations of beam, target and baryon spin. Without access to the recoiling baryon polarisation only 4 of these double polarisation observables are measurable with linear and circularly polarised beam and a longitudinally and transversely polarised target. Unambiguously measuring the 4 amplitudes requires the measurement of 8 carefully chosen observables, in particular double polarisation observables from more than one class are required [2] e.g. Beam-Target and Beam-Recoil.
The last 10 years has seen a great increase in the amount of strangeness photoproduction data. In particular the $\gamma p \rightarrow K^+ (\Lambda, \Sigma^0)$ channels have produced good quality data from JLAB [3], SAPHIR [4, 5], GRAAL [6] and SPring8/LEPS [7].
However, the $\gamma p \rightarrow K^0\Sigma^+$ channel has proven more elusive due to its small cross section and branching ratio for detected particles.

1.2 Previous Measurements

There have been two recent publications of K^0 photoproduction, both from the SAPHIR collaboration, Goers *et al.* [8] and Lawall *et al.* [9]. In addition there has been a JLAB Hall B thesis [10] by B. Carnahan, giving measurements of the differential cross section from 1.15 to 2.35 GeV. The results for the total cross section from these experiments are shown in Fig. 1.
The more recent SAPHIR results of ref. [9] are a factor of 2 lower than those of ref. [8]. Lawall *et al.* attribute this to an underestimation of the background contribution to the original measurements. The data from Carnahan, although they can only be considered as preliminary results for the experiment, show reasonable agreement with the recent SAPHIR results, however they are systematically lower, particularly at the lower photon energies.
The SAPHIR publications also include measurements of the recoil Σ^+ polarisation, these are shown in fig. 2. The quality of the polarisation data are not so good. The data of Lawall *et al.* are split into 5 angular and 2 E_γ bins. The lower bin, $1.05 < E_\gamma < 1.55$, has the best statistical accuracy of around $\sigma_P \simeq 0.12$ and suggests the Σ^+ may have large recoil polarisation at central angles.

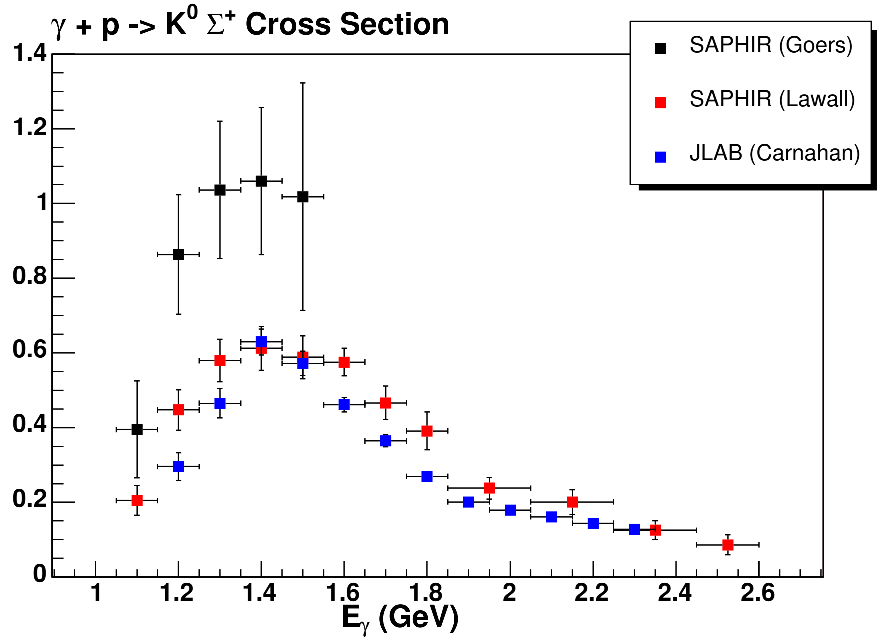

Figure 1: Previous measurements of the $K^0\Sigma^+$ cross section.

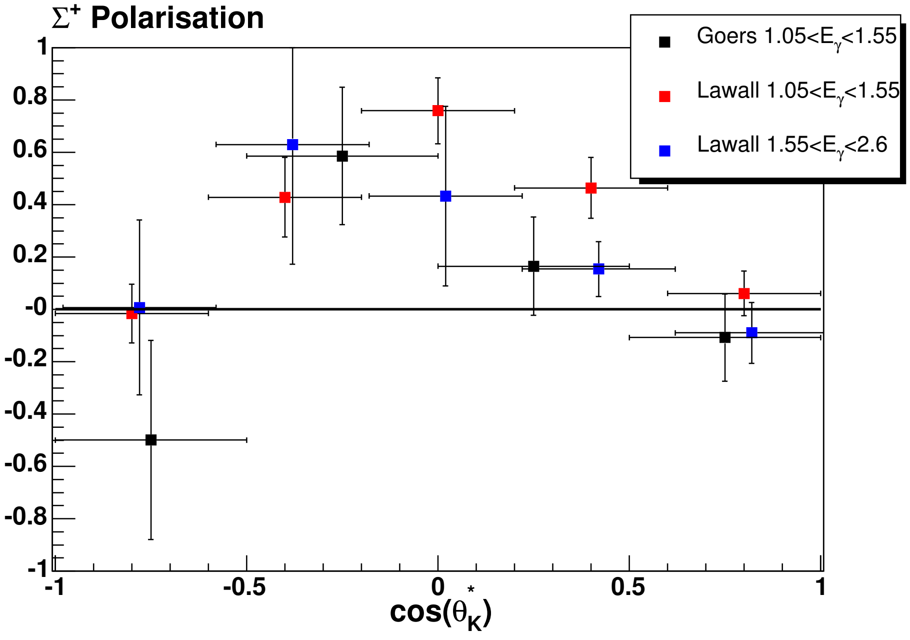

Figure 2: Previous measurements of the Σ^+ recoil polarisation, P.

Measurements with the MAMI-Crystal Ball setup would constitute a significant check of the systematics of the other experiments and greatly increase the statistics in the region close to threshold. This region should provide a particularly good test of the underlying mechanisms as few partial waves contribute [11].

The previous measurements have all measured the decay of the K^0 into $\pi^+\pi^-$, whereas this measurement proposes to measure the decay into two π^0 using the neutral meson detection capabilities of the Crystal Ball. This will provide a systematically different measurement in conjunction with the excellent MAMI-Glasgow Tagger photon beam.

1.3 Theoretical Considerations

Theoretical methods traditionally used to investigate strangeness photoproduction include dispersion relations, multipole analysis and isobaric models. More recently Chiral Pertubation Theory [12] and Regge-type analyses [13] have been undertaken to connect with more fundamental concepts in QCD. However despite all the theoretical work a comprehensive and consistent understanding of the underlying reaction mechanism is far from available [13]. It is clear that a multi-channel approach is essential for progress. Therefore good quality $K^0\Sigma^+$ data is necessary to complement the other channels.

In the analysis of their data Lawall et al. indicated that more missing resonances may be required to explain the Kaon photoproduction process.

In their paper [14] Mart, Bennhold Hyde-Wright show that the $K^0\Sigma^+$ channel could provide a particularly strong constraint to models of Kaon photoproduction on the proton. And in his paper " Role of the P_{13} (1720) in $K\Sigma$ Photoproduction", Mart states, "To further elucidate the role of this state, more accurate $K^0\Sigma^+$ data are advocated, especially in the polarization observable."

A recent paper by Usov and Scholten [15], using a coupled-channel analysis, shows the difference in Σ^0 and Σ^+ cross section may to some extent be explained by an additional P_{13} resonance with a mass of 1830 MeV contributing constructively to the Σ^0 and destructively to the Σ^+ channel.

In their paper Adelseck and Saghai [1] (investigating $K^+(\Lambda, \Sigma^0)$) suggested that, "*Absolute* measurements of the differential cross section over a wide range of the phase space with total error bars of ±10% will put a strong enough constraint on the extracted coupling constants." Additionally single polarisation measurements, particularly at backward angles, with errors of ±0.2, "would be of great help". And double polarisation measurements with an accuracy of ±0.3, "offer additional means to deepen our understanding of the underlying mechanisms."

2 $K^0\Sigma^+$ Detection with the Crystal Ball

2.1 Experimental Setup

This Letter of Intent proposes to use data parasitically from other Crystal Ball experiments. It requires the maximum MAMI-C beam energy, preferably polarised, to access the strangeness production regions. The photon beam will be incident on the A2 liquid Hydrogen target. It is anticipated that a number of experiments will require such conditions.

We would measure an exclusive final state of 6 photons and 1 proton :

$$\gamma + p \to K^0\left(\to \pi^0\pi^0\right)\Sigma^+\left(\to \pi^0 p\right) \text{ and } \pi^0 \to \gamma\gamma.$$

The complete kinematics and high multiplicity gives little background from final states other than $3\pi^0 p$. The background from direct $3\pi^0$ and η production can be dealt with in the data analysis. As the following Monte Carlo simulations show this measurement can be performed with the most basic Crystal Ball-TAPS setup.

The Crystal Ball detector consists of a sphere of 672 NaI crystals. The crystals are each 15.7 radiation lengths thick giving a very high detection efficiency for photons. The electromagnetic showers produced by the photons in the crystals allow an energy resolution of $\sigma_E/E \simeq$ 2%. The segmentation of the detector allows a resolution of $2-3^\circ$ for the polar and $2/\sin\theta$ for the azimuthal angles.

In addition to the Crystal Ball the TAPS detector is used at forward angles to plug the hole for the beamline. It consists of 384 BaF_2 crystals. This detector is particularly important for MAMI-C energies and strangeness production close to threshold as the final state protons will normally be boosted forward through the Crystal Ball beamline hole.

Although these two detectors are sufficient for this analysis, extra help will be gained by using the scintillator barrel PID detector, Multi-Wire Proportional Counters and TAPS veto detectors, which will all be a permanent part of the Crystal Ball setup.

2.2 Monte Carlo Simulation

To measure $K^0\Sigma^+$ photoproduction we have to detect the 7 particle final state, i.e 6 photons and 1 proton. To test the response of the Crystal Ball-TAPS setup to this final state we used the Crystal Ball GEANT3 simulation interfaced to the standard A2-Crystal Ball analysis software AcquRoot.

First phase space $K^0_S\Sigma^+$events were generated, then passed to the simulation which tracked the initial particles and their decay products through the detectors. The output of the simulation in the form of energy deposits in crystals was subsequently passed to AcquRoot for physics reconstruction and analysis.

As well as $K^0_S\Sigma^+ \rightarrow 3\pi^0 p$ there will be substantial background from direct $3\pi^0$ production on the proton as well as η production with a subsequent decay to $3\pi^0$. Both these reactions have a cross section of around $1\mu b$ at 1 GeV, much larger than the cross section with branching ratio of $0.015\mu b$ for the final state of interest. So additionally events of these types were passed through the simulation so we could investigate the contamination.

The basic analysis is described in the following :

- Clusters of crystals were combined to give the energy of the particle and interaction position.
- Lorentz vectors were formed assuming each cluster was due to a photon.
- 7 cluster events were selected.
- The 7 clusters were looped over to see which combination gave the best masses for $3\pi^0$s. The extra cluster was taken to be the proton and its energy was calculated from the beam and $3\pi^0$s.
- Cuts were made on the missing energy and momentum.
- The π^0s were looped over to see which combination gave the best K^0 mass. The other was combined with the proton to give the Σ^+. Fig. 3 shows the reconstructed masses.
- Fits and 2σ cuts were made to the pion missing mass ($\simeq M_{prot}$), reconstructed K^0 mass, reconstructed Σ^+ mass and the angle between the measured proton and pion missing momentum.

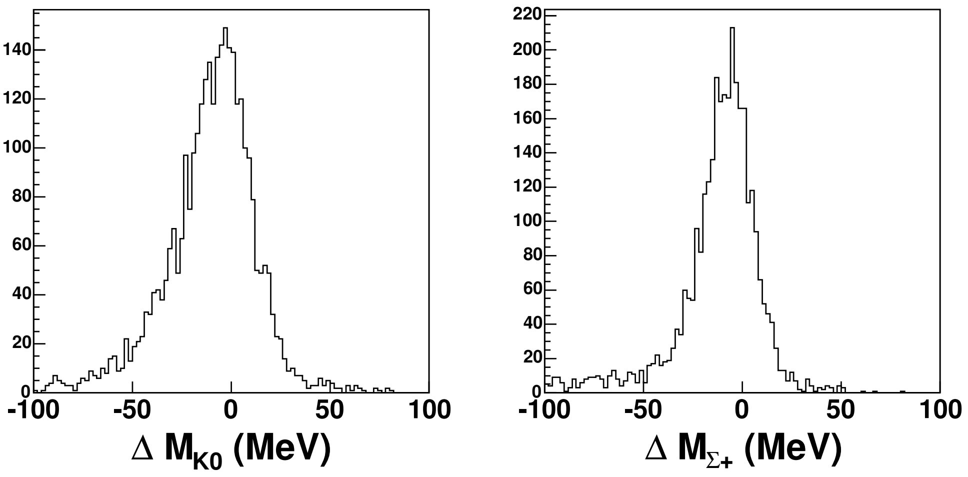

Figure 3: Reconstructed masses of the K^0 and Σ^+ minus their PDG values.

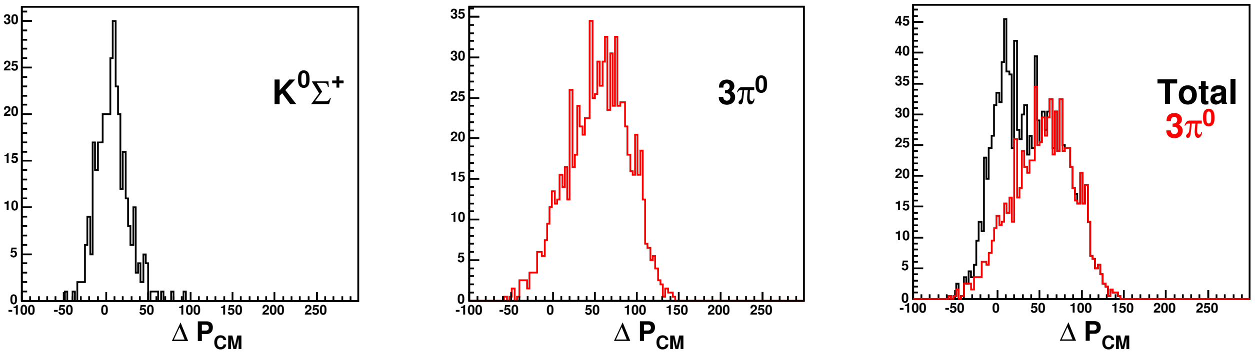

Figure 4: Measured K^0 centre of mass momentum minus that calculated from the beam energy. Shown are the contribution from real and phase space events after the cuts described in the text.

The final plots of ΔP_{CM} (the centre of mass momentum of the K^0 minus that for real $K^0_S\Sigma^+$events) showing the $K^0_S\Sigma^+$ and $3\pi^0$ phase space data, normalised to their cross sections, are shown in fig. 4. The background from η production was entirely suppressed by the cuts. Even with this simple analysis the ratio of real to phase space is just 1. With a more elaborate analysis this could be improved by the use of constrained fitting which should greatly reduce the width of the mass cuts and thus the background contribution. In addition, analysis of direct $3\pi^0$ data below and above $K^0_S\Sigma^+$ threshold should allow a good understanding of this background.
With the tight cuts used in this analysis the overall detection efficiency was found to be around 5%. Again with a more elaborate analysis taking into account cluster split offs and constrained fitting it may be possible to at least double this efficiency.

3 Count Rate Estimates

- For a count rate estimate we will use the SAPHIR measurement of Lawall et al, which found $\sigma\left(K^0\Sigma^+, 1.050 < E_\gamma < 1.105\text{GeV}\right) \simeq 0.2\mu b$.

- With the upgraded Glasgow tagger we can optimistically expect a tagger rate of 1MHz/channel, or approximately $\dot{N}^{tag}_\gamma = 30\frac{\text{MHz}}{100\text{MeV}}$.

- We estimate a tagging efficiency of 50% giving a photon rate at the target of $\dot{N}^{target}_\gamma =$

$15\frac{\text{MHz}}{100\text{MeV}}$.

- The number of protons in hydrogen target is $N_p = 2.1 \times 10^{23}\text{cm}^{-2}$.
- The livetime is estimated to be $L_{time} \simeq 70\%$.
- The detection efficiency was found to be $\varepsilon_{det} = 5\%$ from the simulation.
- Therefore the number of $K^0\Sigma^+$events with $1.050 < E_\gamma < 1.105\text{GeV}$:

$$N\left(K^0\Sigma^+\right) = \sigma.\dot{N}_\gamma^{target}.N_p.\varepsilon_{det}.L_{time} \simeq 80/\text{hour}$$

- The branching ratio for $K^0\Sigma^+ \to 3\pi^0 p$ is approximately 7.5%.

$$N\left(K^0\Sigma^+ \to 3\pi^0 p,\ 1.050 < E_\gamma < 1.105\text{GeV}\right) \simeq 6/\text{hour}.$$

If we consider measuring 10 angular bins in 100 hours then we get a statistical error of 12% per bin for cross section measurements.

3.1 Polarisation Measurements

The induced (P) and transferred ($C_{x\prime}$) polarisation will be measured from $\cos\phi$ angular distributions. The error in such a measurement is given approximately by :

$$\sigma_P = \frac{\sqrt{2}}{A\sqrt{N}}$$

The weak decay of the $\Sigma^+ \to \pi^0 p$ benefits from a high analysing power: $A = 0.98$. Hence for P, assuming 10 angular bins, the error per bin is $\sigma_P \simeq 0.17$.
For $C_{x\prime}$ the asymmetry is also dependent on the degree of circular polarisation which will be around 70% : $A \simeq 0.7$. The error for $C_{x\prime}$ is therefore, $\sigma_{C_x} \simeq 0.23$.
A real to background ratio of 1 would increase these errors by a factor of $\sqrt{2}$.
This analysis will rely on data from other experiments on a hydrogen target with maximum MAMI-C energy and therefore should be able to access data from more than 100 hours beamtime.
With 500 hours we should detect 3000 events in the first 100MeV bin above threshold. By comparison the Lawall et al results contained 3310 events between threshold and 1600MeV, of which 2114 were of use for polarisation measurements. The errors on differential cross section, P and $C_{x\prime}$ for this measurement should be of the order 8%, 0.11 and 0.17 respectively. We will be able to use data from threshold (1.046 GeV) to the maximum tagger limit of around 1.4 GeV photon energy. The cross section increases with energy over this photon energy range.

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