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# Kaon Tagging at 0° Scattering Angle for High-Resolution Decay-Pion Spectroscopy

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A1 hypernuclear collaboration

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**Abstract.** At the Mainz Microtron hypernuclei can be studied by (e,e'K) reactions. By detecting the kaon which is emitted in forward direction, with the KAOS spectrometer placed at 0° scattering angle, reactions involving open strangeness production are tagged. High-resolution magnetic spectrometers are then used to coincidentally detect the mono-energetic decay-pions from mesonic two-body weak decays of light hypernuclei at rest.

As a pioneering experiment has confirmed, the KAOS spectrometer is exposed to a large flux of background particles, mostly positrons from bremsstrahlung pair production. In order to increase the efficiency of kaon identification the KAOS spectrometer was modified to suppress background particles at the cost of a high momentum resolution, which is less important for this experiment. This was achieved by placing up to 14 cm of lead absorbers in front of the detectors, in which positrons are blocked by forming electromagnetic showers while the effect on kaons is limited. An additional time-of-flight wall and a new threshold Čerenkov detector help to increase the detection efficiency of kaons.

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## 1 Introduction

Light nuclei containing one or more strange baryons are a good testing ground for models of nucleon interactions. By measuring the ground-state mass differences of strange mirror nuclei like ${}^{4}_{\Lambda}$H and ${}^{4}_{\Lambda}$He with a high precision, one gains access to the charge symmetry breaking of the strong force in the hyperon-nucleon interaction [1]. Most spectroscopic methods applicable to hypernuclei are however restricted to only one of the isobars so the resulting mass differences are subject to the systematical errors of the different spectroscopic techniques.

The spectroscopy of pions originating in the decay of light hypernuclei at rest offers a unique way of accessing the ground-state masses of several light hypernuclei in a single experiment thus minimising the effect of systematic errors. Detecting the kaon produced in the initial (e,e′K) reaction assures that a strange baryon has been produced in the target. If a hypernucleus is formed, it is likely to fragment into a lighter nucleus still containing strangeness. After being stopped inside the target a large fraction of these decay in a two-body mesonic weak reaction resulting in mono-energetic pions. These decay-pions then carry the information needed for calculating the ground-state mass of the light hyperfragment [2].

At the Mainz Microtron MAMI two experiments addressing the decay-pion spectroscopy were conducted, a pioneering experiment, in which the KAOS spectrometer was for the first time used to detect kaons at 0° scattering angle, and a second experiment for which it has been upgraded to better serve the requirements. The set-up of both experiments is discussed in [3].

## 2 Set-up Improvements

In contrast to the pioneering experiment in which KAOS was used as a high-resolution multi-purpose spectrometer, in the subsequent experiment it was modified to serve as a dedicated kaon tagger. Therefor a substantial modification of the detector set-up was performed with the aim to suppress the background of positrons originating in the pair-production of bremsstrahlung photons by a passive absorber.

For the placement of the absorber one has to make a compromise between placing it close to the entrance of the spectrometer thus blocking the particles before they enter any detector but increasing the severity of small angle scattering, and placing it in the backmost part of the detector assembly where the scattering has little effect on the momentum reconstruction but positrons can still contribute to the background by causing spurious tracks and random coincidences. With the help of a Monte Carlo simulation, it was decided to place the absorber in front of all detectors.

To increase the possible count-rate and due to space constraints, the multi-wire proportional chambers (MWPCs) were entirely removed from the spectrometer. For tracking purposes, the time-of-flight walls were used. With their segmentation of 70 mm for the rear wall and 74 mm for the other walls and an incident angle of the particles of approx. 60° a position resolution of $\delta x \leq 40$ mm and an angular resolution in dispersive direction of $\delta\Theta \leq 1.7°$ can be reached, when the number or paddles struck by a particle is taken into account.

To improve the detector set-up and the lead absorber placement, a Geant4 simulation has been developed for the KAOS spectrometer. It comprised the main components i.e. the magnetic field map, the different detectors, the parts of the spectrometer which define the angular acceptance and the lead absorber. The simulation helped to find an appropriate geometry and placement of the detectors and the absorber wall, as well as it helped to analyse the resulting data.

When travelling through the lead wall the kaons are mostly effected by multiple Coulomb scattering. Thereby they are on one hand slowed down which leads to a higher decay probability inside the spectrometer, and on the other hand change their flight direction which can cause them not to hit all

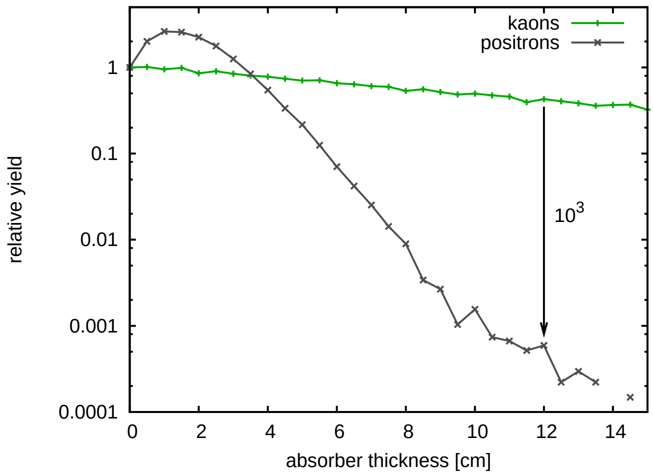


**Figure 1.** Simulation result for the relative number of detected tracks for kaons and positrons in the KAOS spectrometer for a 1 GeV/c incident momentum depending on the thickness of a lead wall installed in front of the detectors. The radiation length of lead is 0.56 cm whereas the nuclear interaction length is 17.1 cm. In the range of 10 - 14 cm a reduction of positrons by a factor of $10^3$ is possible while more than 35% of the kaons are detected correctly. For absorber thicknesses below 4 cm the electromagnetic shower leakage increases the number of detectable tracks.

detectors necessary for tracking. This constrains the thickness of the absorber wall, which has to be thin enough to allow a large fraction of kaons to be detected and thick enough so that the leakage of charged particles from electromagnetic showers is minimised.

The number of detected tracks for kaons and positrons as a function of the lead wall thickness is shown in fig. 1. It can be seen that for a thickness of more than 100 mm the rate of detected tracks per incident positron is reduced by approx. three orders of magnitude while the loss of kaons is less than 65%. This result was used for the design of a wall of three segments for different momentum ranges with thicknesses of 100 mm, 120 mm and 140 mm, which corresponds to 35.7, 42.9 and 50 radiation lengths when taking the mean incident angle of 60° into account.

This incident angle increases the probability for particles to be scattered to the lower momentum side due to the lower material budget on this side; resulting in a decreased chance of re-scattering. In the simulation this effect can be well observed for protons and is also present for kaons. To compensate for it, individual transfer matrices were created for each particle type using the correct particle type in the simulation instead of charged non-interacting particles usually used for the transfer matrix generation. These matrices not only give the first-order transformation of focal-plane coordinates to target coordinates and momentum, but also include significant elements up to fifth order.

The impact of the set-up change can already be observed when comparing the trigger-rates of the experiment with the ones of the pioneering run, both obtained with a $^9$Be target with an effective thickness of 213 $\mu$m. In the previous beamtime the trigger rate per beam current was $R/I \approx 1000$ kHz/$\mu$A allowing for a maximum beam current of $I = 2$ $\mu$A. With the hardware background suppression and an improved triggering using three scintillator walls in the second experiment it was possible to increase the beam current to 20 $\mu$A while the relative trigger rate of the KAOS spectrometer was limited to $R/I \approx 2.5$ kHz/$\mu$A.

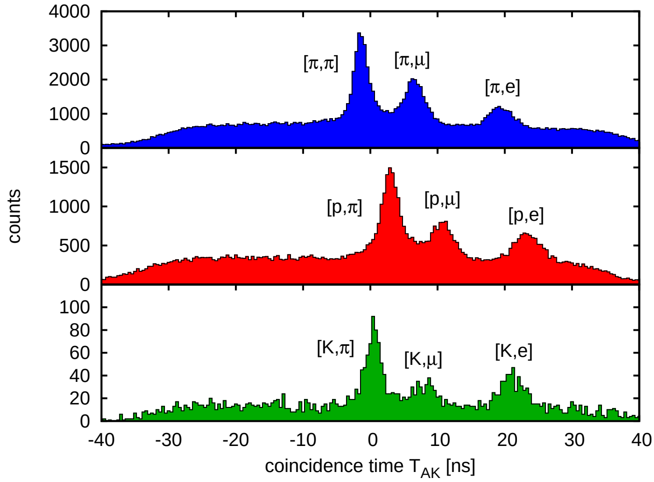


**Figure 2.** Coincidence time spectra between the kaon tagger and the high-resolution spectrometer for different identified reactions. The first particle in each label corresponds to the one in the kaon tagger, the second to the one in the high-resolution spectrometer. To correct the flight time all reactions were treated as kaon-pion coincidences, which shifts the peaks of other reactions away from the origin and broadens them. By a Čerenkov cut the reactions including an electron in the high-resolution spectrometer can be excluded from the spectra. A distinct peak for coincidences of kaons and decay-pions is visible in the lower spectrum.

According to the simulation the removal of the MWPCs limits the momentum resolution for kaons to $\delta p/p \approx 0.015$, with the addition of the lead wall a further limitation to $\delta p/p \approx 0.1$ occurs.

## 3 Data analysis

The focus of the data analysis lies on the clean identification of kaons in the KAOS spectrometer, the reaction can then be identified by the coincidence timing between kaon tagger and high resolution spectrometer. The main criteria for the particle identification are the flight time between the different scintillator walls, the specific energy loss in these detectors and the signals from the threshold Čerenkov detectors. To combine all parameters for the particle identification a value $\chi^2$ is defined as the sum of the squared deviation of each parameter from the expectation for a particular particle type. The value of $\chi^2$ is then used for selecting the events for each particle type. To optimise the particle identification, the coincidence time spectra as shown in fig. 2 were used, in which distinct peaks for several different reactions can be observed.

For the kaon selection, the aim was to maximise the signal to background ratio at the same time as the total number of events. Therefore the corresponding spectrum was fitted with a set of three Gaussian distribution on a flat background to extract numbers for the coincident as well as for the non-coincident events. A parameter $F = S \cdot S/B$ was then defined and maximised, which combines the number of coincident events $S$ and the signal to background ratio $S/B$ where $B$ is the number of non-coincident events in the selected time interval. The lower time spectrum shown in fig. 2 was obtained after this optimisation.

## 4 Outlook

With the help of simulations and the data collected in a pioneering experiment, the KAOS spectrometer was modified to serve as a dedicated kaon tagger in which the electromagnetic background is reduced on a hardware level. It has been shown, that with this set-up and a $^{9}$Be target a clean identification of kaons associated with electroproduced $\Lambda$-hyperons at $0°$ scattering angle in coincidence with pions originating in weak decays of strange systems is possible. The analysis now concentrates on the discrimination between quasifree decays of $\Lambda$-hyperons and decays of hyperfragments, to allow for the identification of mono-energetic peaks in the decay-pion momentum spectrum and therefore the hypernucleus ground-state mass determination.

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