Strangeness physics with KAOS at MAMI

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Abstract

At the Institut für Kernphysik in Mainz, Germany, the microtron MAMI has been upgraded to 1.5 GeV electron beam energy. The magnetic spectrometer KAOS is now operated by the A1 collaboration to study strangeness electro-production. Its compact design and its capability to detect negative and positive charged particles simultaneously under forward scattering angles complements the existing spectrometers. In 2008 kaon production off a liquid hydrogen target was measured at \( \langle Q^2 \rangle = 0.050 \text{(GeV/c)}^2 \) and 0.036 \text{(GeV/c)}^2. Associated \( \Lambda \) and \( \Sigma^0 \) hyperons were identified in the missing mass spectra. Major modifications to the beam-line are under construction and a new electron arm focal-surface detector system was built in order to use KAOS as a double-arm spectrometer under zero degree scattering angle.

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1 Introduction

At the Institut für Kernphysik in Mainz, Germany, the microtron MAMI has been upgraded to 1.5 GeV electron beam energy [1]. The microtron delivers an electron beam with excellent spatial and energy definition that can now be used to study strange hadronic systems produced on solid-state or liquid cryogenic targets.

The elementary electro-production of kaons off the proton is used mainly as a test of production mechanisms. Effective field theories expressed in terms of resonant baryon formation and kaon exchange [2] have been successfully applied to describe the data. However, in contrast to the well studied flavour $SU(2)$ sector, more precision data in the threshold energy region are needed. Also for calculating hypernuclear production cross-sections, precise data from very forward angle kaon production are urgently required. In this kinematics the elementary amplitude serves as the basic input, which determines the accuracy of predictions for hypernuclei [3].

For the strangeness programme the KAOS spectrometer was recently dismantled at the SIS facility at GSI and re-installed in the spectrometer hall at MAMI. KAOS is a very compact magnetic spectrometer suitable especially for the detection of kaons [4]. The first-order focusing is achieved in the set-up at MAMI with a bending of the central trajectories on both sides by $\sim 45^\circ$ with a momentum dispersion of 2.2 cm/% for the hadron arm and 4.0 cm/% for the electron arm. From the magnet optics, the beam diameter, and the spatial resolution in the focal-surface a first order momentum resolution of $\Delta p/p \sim 10^{-3}$ is expected.

2 Particle tracking and identification with KAOS

The tracking of particles through KAOS is performed by means of two large MWPC with a total of $2 \times 310$ analogue channels. Five cathode wires are connected together and are brought to one charge sensitive pre-amplifier followed by an ADC card. The transputer-based read-out system is connected to a multi-link card of a front-end computer. To determine the particle track the measured charge distributions are analysed by the centre-of-gravity method.

Particle identification in the KAOS spectrometer is based on the particle’s time-of-flight and its specific energy loss. A segmented scintillator wall with 30 paddles read out at both ends by fast photomultipliers is located near the focal-surface and measures the arrival time. A second wall with 30 paddles is
used to discriminate valid tracks against background events. A top–bottom mean timing for deriving the trigger is performed by summing the analogue signals. The signal amplitudes were corrected for the particle’s path-length through the scintillator bulk material and the light absorption inside the paddle.

The time spectrum is systematically broadened by the propagation time dispersion inside the scintillator, the time differences between different scintillator paddles and their associated electronic channels, and by the variation of the time-of-flight, being proportional to the path-length through the spectrometer. The coincidence time spectrum for the \( p(e, e'\pi) \) reaction before and after corrections is shown in fig. 1 where the flight time, \( t \), was corrected by using the reconstructed momentum, \( p \), and path-length, \( L \), under the assumption that a pion was detected. The Gaussian width of the \((e', \pi)\) peak is \( \Delta t_{FWHM} = 1.07 \) ns, which is a typical inter-spectrometer time resolution.

The necessity of the pion and proton suppression is seen in fig. 2 where the mass distribution of the detected particles, \( M = p/(c \cdot \beta \gamma) = p/(Lt)\sqrt{1 - (Lt/c)^2} \), is shown under the effect of specific energy-loss cuts. Kaons were identified subsequently by a cut on the coincidence time.
Figure 2: Mass distribution of the detected particles based on time-of-flight measurement and the reconstructed momentum. The outer contour includes all events with valid tracks in the MWPC, the underlying curves show event samples that were cut on the specific energy-loss expectation for protons (red, leaning hatch), pions (blue, vertical hatch), and kaons (green, solid fill).

3 Pilot kaon electro-production measurements

A pilot experiment on the electro-production of kaons off a liquid hydrogen target was performed with an electron beam of 1.508 GeV energy in 2008. The reaction can lead to two possible final states with either a Λ or Σ⁰ hyperon, which are easily separable by a missing mass analysis. The data was taken at two different kinematic settings in \((e,e'K)\) reactions with kaons in the momentum range of 400–700 MeV/c and angular range of 21–43°. Positive kaons were detected in KAOS in coincidence with the scattered electron into spectrometer B. The electron was identified by its minimum ionisation in the scintillators of spectrometer B and a signal in the gas Čerenkov detector. The momentum transfer squared was \(\langle Q^2 \rangle = 0.050 \text{(GeV/c)}^2\), resp. 0.036 \text{(GeV/c)}^2, and the total energy in the virtual-photon-nucleon cm system was \(\langle W \rangle = 1.670 \text{ GeV}\), resp. 1.750 GeV. The kinematic conditions for two beam-times with a total integrated luminosity of 284 fb\(^{-1}\) taken on a 48 mm \(\ell\)\(\text{H}_2\) target with 1–4 \(\mu\)A beam current are summarised in table 1.

After electron and kaon identification, the measured momenta allow for a full reconstruction of the missing energy and missing momentum of the recoiling system. The missing mass \(M_X\) is calculated from the four-momenta \(q^\mu\) of the virtual photon and the four-momentum \(p_K^\mu\) of the detected kaon according to \(M_X^2 = (q^\mu + P_{targ}^\mu - p_K^\mu)^2\), where \(P_{targ}^\mu = (M_{targ}, \vec{0})\) is the target.
Table 1: Experimental settings during the kaon electro-production beam-times of 2008. The second setting was selected to acquire data from Λ and Σ⁰ production channels, with the two different associated kaon momenta being simultaneously within the large momentum acceptance of KAOs.

| virt. photon | electron arm | kaon arm |
|--------------|--------------|----------|
| \( \langle Q^2 \rangle \) (GeV/c)² | \( \langle W \rangle \) (trans.) | \( \langle \epsilon \rangle \) GeV |
| 0.050 | 1.670 | 0.540 |
| 0.036 | 1.750 | 0.395 |

| \( \langle \omega \rangle \) GeV | \( \langle \theta_{e'}^\text{lab} \rangle \) deg | \( \langle p_K^\text{lab} \rangle \) GeV/c |
|----------------------|-----------------|-----------------|
| 1.044 | 455 | 15.8 | Λ : 0.466 -31.5 |
| 1.182 | 318 | 15.5 | Λ : 0.642 -31.5 |

| Σ⁰ : 0.466 |
|----------------------|-----------------|-----------------|
| \( \langle q_{e'}^\text{lab} \rangle \) GeV | \( \langle \theta_{K}^\text{lab} \rangle \) deg |
| 0.455 | 15.8 |

| Missing mass (MeV/c)² |
|----------------------|
| 1060 | 1080 | 1100 | 1120 | 1140 | 1160 | 1180 | 1200 | 1220 |
| Counts/bin after PID cuts |
| 0 | 10 | 20 | 30 | 40 |

Figure 3: Preliminary missing mass spectra in the \( p(e, e'K^+)Y \) reaction at the \( Q^2 = 0.036 \) (GeV/c)² kinematical point as defined in the text. The random background distribution is shown as a blue histogram in the left figure. The right figure shows the background subtracted spectrum with a fit to the two peaks. The shape of each peak was assumed to include a Gaussian and an exponential tail.

-four-momentum.

An example of the preliminary missing mass spectra is shown in fig. 3 which demonstrate the power of the spectrometer facility to detect open strangeness channels. The mass resolution is limited by errors in the estimated transfer matrix that was not yet corrected. The overlaid blue histogram shows the random background distribution in two averaged \( (e', K) \) coincidence time side-bands with the appropriate weights.

4 Extension to hypernuclei electro-production

The electro-production of hypernuclei offers the unique possibility to vary the energy and momentum transfer independently and to gain information on hypernuclear wave-functions. Such experiments are planned at MAMI for
single Λ-hypernuclei in light targets [5]. The special kinematics for electro-
production of hypernuclei requires the detection of both, the associated kaon
and the scattered electron, at very forward laboratory angles which will be
achieved by instrumenting the Kaos spectrometer in two arms, to either
side of the main dipole. This implies that the electron beam must be steered
through the spectrometer and a magnetic chicane comprising two compen-
sating sector magnets is under development. A new vacuum chamber has
been installed and the spectrometer platform has been mechanically adapted
to the two-arm operation. A new coordinate detector has been developed
for the electron arm [6]. It consists of two vertical planes of 18,432 fibres
that will be supplemented by one or two horizontal planes. Detectors and
electronics for the 4,608 read-out and level-1 trigger channels are now being
installed.

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