Kaon Electroproduction on Deuterium

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Kaon electroproduction on deuterium and hydrogen targets has been measured at beam energies of 3.245 and 2.445 GeV and momentum transfer Q^2=0.38 and 0.5 GeV^2. Associated Λ production off a proton in the deuteron exhibits a quasifree production mechanism. The production of Σ^- off the neutron could be extracted for the first time with reasonable errors.

1. INTRODUCTION

Studying the interaction of hyperons with nucleons is curently one of the frontier areas of nuclear physics. The investigation of hypernuclear states in complex nuclei allows one to probe the nuclear interior with a baryonic probe not subject to Pauli blocking, and will shed light on the features of hyperon-nucleon interactions in the nuclear medium. While there are many data for (K^-,π^-) and (π^+,K^+) reactions on nuclei, there are no data available for electroproduction of hypernuclei and only one measurement of kaon electroproduction on deuterium [3]. In contrast to meson induced reactions, electro- and photoproduction of kaons offers several advantages. The incoming probe (electron or photon) interacts relatively weakly with the nucleus and thus allows homogeneous illumination of the entire nucleus. In addition the electron carries spin and therefore, may induce spin flip transitions. While there are some data for kaon electroproduction on hydrogen [1–5], very little is known about the elementary production process in the nuclear medium.

The availablility of a high intensity continuous electron beam at the Thomas Jefferson National Accelerator Facility's CEBAF accelerator now makes feasible detailed measurements of kaon electroproduction on nucleons and nuclei. In this experiment, E91-16, (e,e'K^+) reactions on hydrogen and deuterium targets were measured. Data from the deuteron, the simplest nucleus, allow a first test of the concept of quasifree production of strangeness off a proton embedded in a nucleus through comparison with hydrogen target data. Detailed understanding of the in-medium production mechanism is important for the planning of future experiments on heavier nuclei. In addition to the two possible reaction channels on the proton, p(e,e'K^+)Λ and p(e,e'K^+)Σ^0, the deuterium target also allows further the extraction of the elementary process on the neutron, n_{bound}(e,e'K^+)Σ^-. Moreover, studying the resulting final state hyperon-nucleon distribution has the potential of providing information on the elementary hyperon-nucleon interaction and may also give some hints about the controversial issue of strange di-baryonic states postulated to occur in the vicinity of the Σ^0n threshold.

2. EXPERIMENT

The experiment was performed in August and September 1996 at the Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Laboratory (TJNAF). Electron beams with intensities up to 30 μA were directed onto liquid hydrogen and deuterium targets in experimental Hall C. Target cells with lengths of 4 cm were used, resulting in

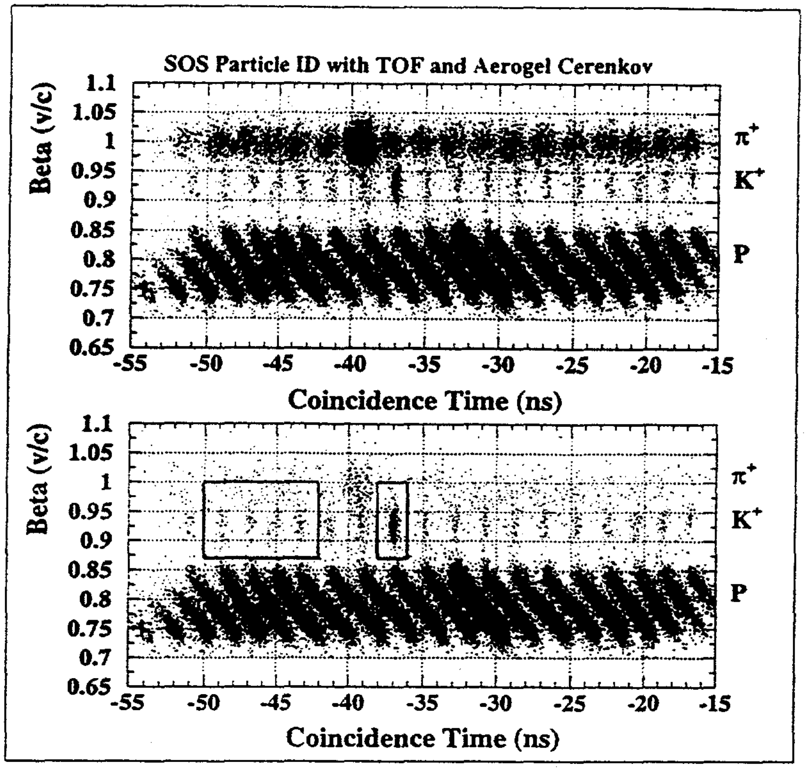

Figure 1. Measured velocity in the SOS versus coincidence time between the spectrometers. Upper figure: raw data. Bottom figure: with additional cut on aerogel Čerenkov to suppress pions.

densities of 317±3 mg/cm^2 and 701±7 mg/cm^2 for the hydrogen and deuterium targets, respectively. The beam was rastered by ±0.5 mm in both the horizontal and vertical directions to avoid local boiling of the target; e.g. density fluctuations were shown to be less than 1% for the beam currents used. The beam position was closely monitored with resonance cavities and the beam intensity was determined with an accuracy $<$2%.

The scattered electrons and electroproduced kaons were detected in coincidence in the High Momentum Spectrometer (HMS) and Short Orbit Spectrometer (SOS), respectively. Both spectrometers were equipped with similar detector systems that consist of a pair of multiwire drift chambers for track reconstruction, four segmented scintillator planes for triggering and time-of-flight measurements, and a gas Čerenkov detector together with a lead-glass shower counter array for electron identification. For the purposes of this experiment, the SOS detector package was upgraded with a threshold aerogel Čerenkov detector to facilitate pion identification. With the use of a conservative threshold level, this detector provided some pion suppression at the hardware trigger level. Another feature of the SOS that was important for this experiment is its short flight path, approximately 7.5 m from the target to the focal plane. For the momentum settings used, this allowed

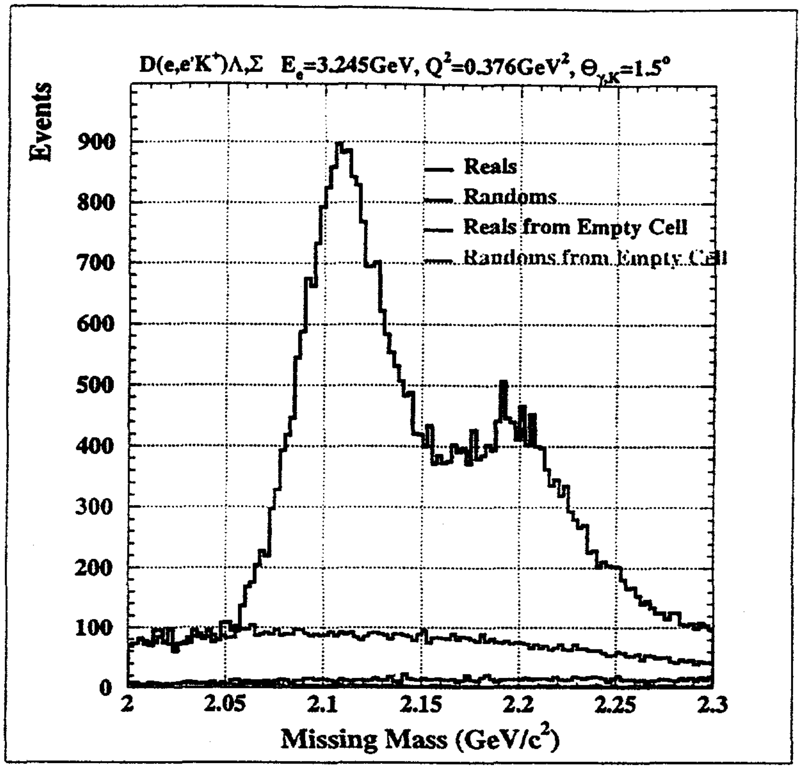

Figure 2. Reconstructed missing mass for d(e,e'K^+)M_x.

detection of ≈30-40% of the kaons before decay; decay corrections are included in the analysis.

Data have been taken at two different beam energies, 3.245 and 2.445 GeV, at momentum transfers (Q^2) of 0.5 and 0.38 GeV^2. Kaons were detected in the general direction of the momentum transfer (direction of the virtual photon), where, at the higher beam energy, kaon angular distributions were obtained in forward angles with respect to the virtual photon. In each setting, data have been obtained on hydrogen, deuterium, and a "dummy" target simulating an empty target cell. In the following, preliminary results for an angular distribution at Q^2 = 0.38 GeV^2 and E_{beam} = 3.245 GeV are presented.

3. RESULTS

Fig. 1 shows the measured velocity of the hadron detected in the SOS versus the coincidence time between the hadron and the electron in the HMS. Clearly visible are three horizontal bands; the velocities correspond to pions, kaons, and protons with momenta within the acceptance of the spectrometer. The structure within each band is a signature of the 500 MHz radio frequency (RF) cycle of the accelerator. Here the strongest distribution within each band originates from in-time coincidences from the same RF cycle (real coincidences) and the fainter neighboring distributions to the left and right from

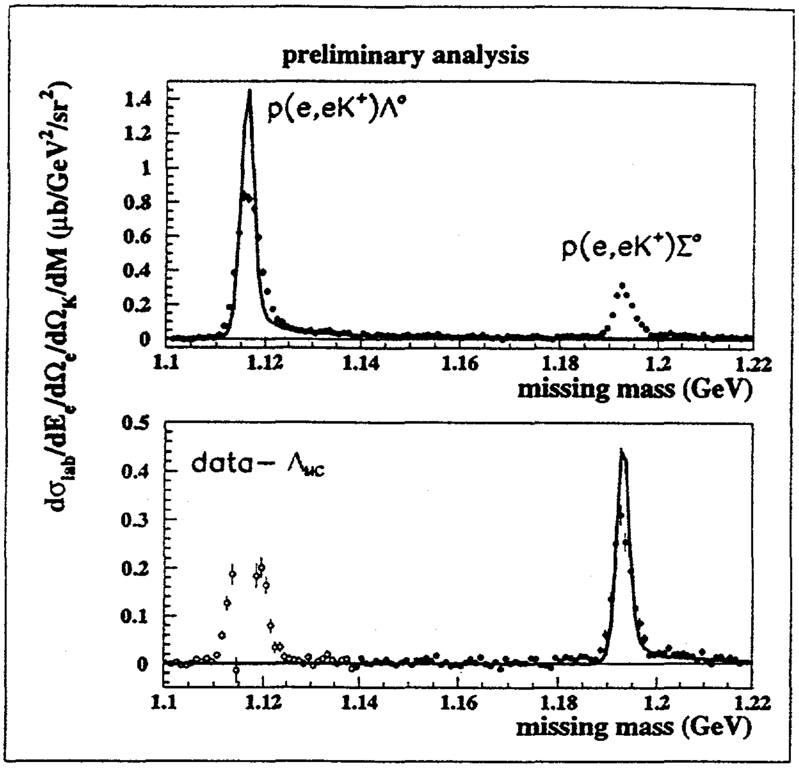

Figure 3. Reconstructed missing mass for p(e,e'K$^+$) at E_{beam}=3.2 GeV, Q^2=0.38 GeV^2, and $\Theta^{lab}_{\gamma K} = 1^o$. Upper histogram: comparison with a normalized Monte Carlo simulation for p(e,e'K$^+$)Λ. Lower histogram: p(e,e'K$^+$)Σ^0 , obtained by subtracting the simulated p(e,e'K$^+$)Λ distribution shown in the upper figure.

the "real" coincidence peak correspond to electrons and hadrons from different RF cycles (accidental coincidences). The lower picture in Fig. 1 is obtained with (the upper picture without) additional conditions on the aerogel Čerenkov signal. Placing a tight window in velocity and coincidence time, as indicated by the small rectangle in Fig. 1, allows selection of a clean kaon sample. Underlying this real coincidence distribution are ≈20% accidental coincidences. These are accounted for by sampling over several neighboring accidental coincidence peaks (large rectangle in lower part of Fig. 1) and subsequently subtracting them with the appropriate weight. Fig. 2 shows an example of a reconstructed missing mass distribution for d(e,e'K$^+$)M_x at E_{beam}=3.245 GeV and Q^2=0.38 GeV^2. No background has been subtracted and the different contributions, determined by sampling over accidental coincidence distributions and measuring an empty target, are shown with different lines.

The two prominent distributions in Fig. 2 correspond to Λ production (left peak) from the proton and the unresolved Σ^0 and Σ^- production (right peak) off the proton and neutron, respectively. The width of these distributions is given by the initial momentum

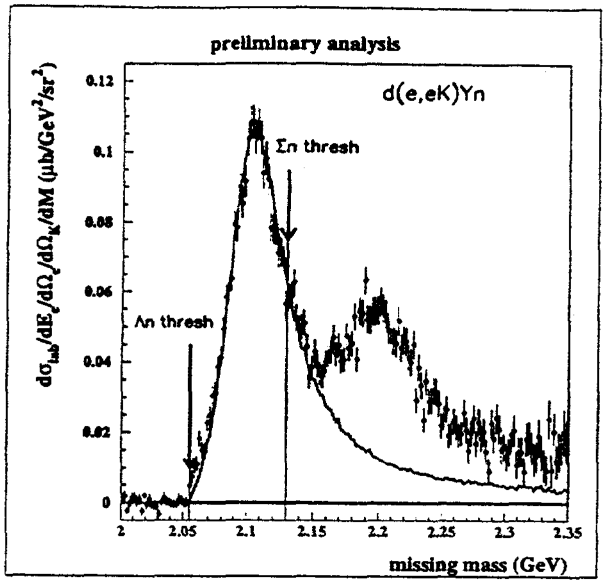

Figure 4. Reconstructed missing mass for d(e,e'K$^+$) at E_{beam}=3.2 GeV, Q^2=0.38 GeV^2, and $\Theta^{lab}_{\gamma K} = 1°$. Only statistical errors are shown. The full line shows a Monte Carlo simulation for d(e,e'K$^+$)Λn.

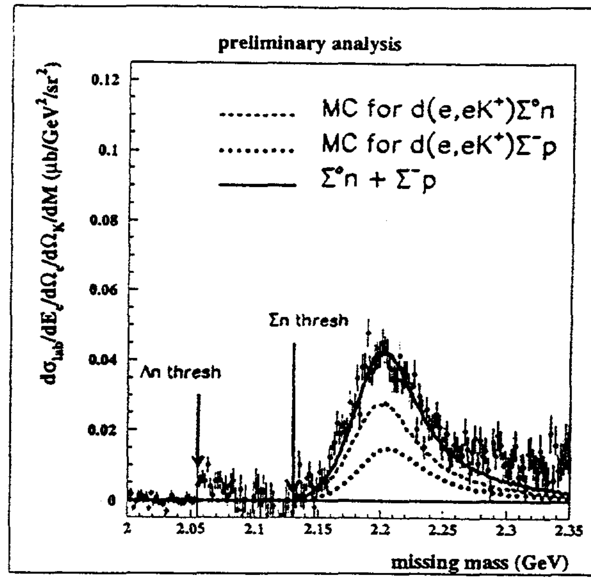

Figure 5. Reconstructed missing mass for d(e,e'K$^+$) at E_{beam}=3.2 GeV, Q^2=0.38 GeV^2, and $\Theta^{lab}_{\gamma K} = 1°$. The normalized simulated distribution for d(e,e'K$^+$)Λn (Fig. 4) has been subtracted to obtain the d(e,e'K$^+$)ΣN distribution. The lines show different Monte Carlo simulations. Only statistical errors are shown.

distribution of the nucleons in the deuteron. Due to the relatively low Fermi momentum, the two contributions from Λ and Σ production are well separated, which is not the case for heavier nuclei (see also [6]). To obtain a quantitative analysis, the data are compared to a Monte Carlo simulation that models the acceptance of both spectrometers and also accounts for radiative effects. For elastic scattering from hydrogen targets, p(e,e'p), this model has been shown to agree to within <2% [7] for data measured with the same spectrometers. For this experiment, the event generator of this model has been extended to include kaon production. The deuterium target is treated as purely quasifree production on a nucleon with an initial momentum distribution determined from wavefunctions calculated with the Bonn [8] potential.

The upper part of Fig. 3 shows a prediction of this model for p(e,e'K$^+$)Λ compared with data from this experiment. Cross sections from a phenomenological model [9] have been used as an input for the calculation. The model somewhat underestimates the width of the Λ distribution, but this can be partly explained by the preliminary state of understanding the details of the reconstruction matrix elements. Integration of both the data and the model for missing masses below the Σ threshold then allows a direct comparison of the input model with our data. Here, radiative and acceptance corrections are applied to the model in the Monte Carlo simulation, rather than de-radiating the data. At all three

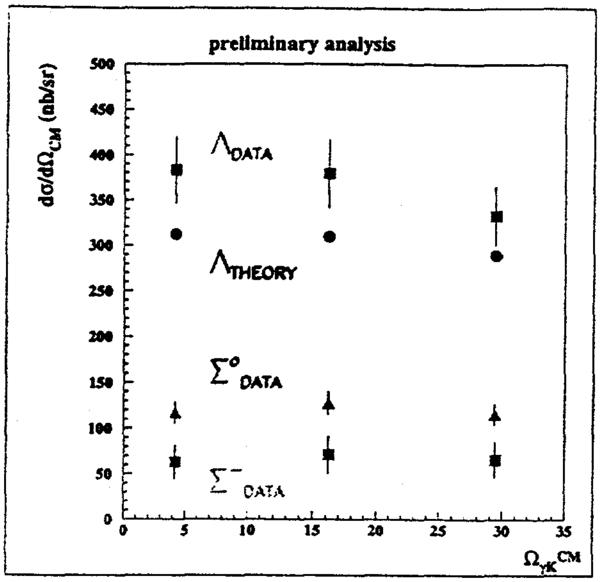

Figure 6. Virtual photon cross sections for p(γ_v,K$^+$)Λ,Σ and n(γ_v,K$^+$)Σ^- as a function of the center-of-mass angle between the photon and the kaon at Q^2=0.38 GeV^2. The theoretical prediction for p(γ_v,K$^+$)Λ was taken from [9].

measured angles ($\Theta_{\gamma K}^{CM}$ = 4, 16, and 29°), the Monte Carlo underpredicts the data by about 20% (see also Fig. 6), where a systematics dominated error of $\pm$10% is assigned to the measurement.

In the lower part of Fig. 3, the properly scaled simulated distribution for p(e,e'K$^+$)Λ is subtracted from the data, showing only the p(e,e'K$^+$)Σ^0 distribution. (The remaining structure close to the Λ mass is due to the previously mentioned resolution problem, but this should have no influence upon the subtraction of the tail of the Λ distribution from beneath the Σ^0 distribution). Again the full line shows the shape of a Monte Carlo simulation. Since no theoretical value for the cross section in the model input was available for this preliminary analysis, an arbitrary cross section for p(e,e'K$^+$)Σ^0 was used in the model. Cross sections for p(e,e'K$^+$)Σ^0 were then extracted by direct comparison of the Monte Carlo and data.

The results obtained for the hydrogen target were then used as input for the deuterium simulations. Fig. 4 shows a comparison of measured data, now background subtracted, with a simulation for d(e,e'K$^+$)Λn. The strength of the Monte Carlo has been fitted to the data below the Σ threshold. For all three angles analyzed, 95-99% of the strength measured for p(e,e'K$^+$)Λ on the hydrogen target is also observed for the d(e,e'K$^+$)Λn reaction channel. Assuming the same quasifree behaviour for Σ^0 production, the d(e,e'K$^+$)Σ^-p reaction channel can be extracted from the data by first subtracting the simulated d(e,e'K$^+$)Λn distribution and then assigning any strength greater than that predicted for the d(e,e'K$^+$)Σ^0n distribution to the d(e,e'K$^+$)Σ^-p reaction channel (see Fig. 5). A ratio for Σ^- to Σ^0 production of $\approx$0.5 is determined at all three angles measued at this Q^2; a preliminary analysis error of $\approx$30% being assigned.

In both figures, Fig. 4 and Fig. 5, the current stage of the Monte Carlo simulation underpredicts the slope of the Λ distribution immediately above threshold. There, final state interactions between the Λ and neutron could lead to such an effect; however, before quantitive conclusions can be drawn from this observation, a thorough investigation of the acceptances and the model used for the simulation must be performed.

4. SUMMARY

Kaon electroproduction on deuterium has been measured for the first time with high statistics and resolution. Associated Λ production at Q^2=0.38 GeV^2 agrees to within a few percent with yields extracted from hydrogen. Thus, assuming a quasifree production mechanism, the cross section for associated Σ^- production on the neutron has been determined with reasonable errors ($\approx \pm$30% for the preliminary analysis); the ratio of Σ^-/Σ^0 production being $\approx$0.5 for all three angles analyzed to date. The final analysis is expected to yield lower systematic errors and will also provide an angular distribution at higher momentum transfer (Q^2=0.5 GeV^2).

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