Strangeness photoproduction on the deuterium target
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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2007

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Chapter 7

Summary and conclusion

7.1 The experiment

The knowledge on the hyperon-nucleon (YN) interaction is limited till today. Experimental information on the YN interaction is available from hyperfragments and hyperon scattering experiments. Another possible mechanism to extract this information is kaon photoproduction on the deuteron in which the photoproduced hyperon interacts with the other nucleon through final-state interaction. Therefore, to understand the YN interaction, the $K^0$ photoproduction experiment off the deuteron in $\gamma d \rightarrow K^0\Sigma^+ n$ channel has been studied in this thesis. The selection of this channel allows us to extract information on the $\Sigma^+ n$ interaction.

For this experiment the continuous electron beam with energies upto 3.2 GeV provided by the ELSA facility in Bonn (Germany) was used. The bremsstrahlung photon beam was obtained by passing the electron beam through a copper radiator. The energy of the photon beam was measured by recording the position of scattered electrons on the tagger system. Observing energy conservation we are able to calculate the energy of the incident photon beam, which was used to study the $\gamma d \rightarrow K^0\Sigma^+ n$ reaction. The final state of this reaction further decays into 6$\gamma$’s, a proton and a neutron. In order to reliably measure such multi-photon final state, a detector set up with high acceptance was needed. The combination of Crystal Barrel (CB) and TAPS covers almost 95% of the solid angle. High granularity was achieved by using about 1800 detector modules. The combination of CB detector and TAPS photon spectrometer is very well suited to measure the reactions which involve multiple photons in the final state. The Crystal Barrel detector was equipped with photodiodes and TAPS with photomultiplier tubes. Because of the fast performance of the photomultiplier tubes, the first-level trigger was provided by TAPS. The low cross section for this reaction ($\approx 0.4 \, \mu b$) and the low branching ratio (7.8%) make this reaction difficult to measure. A suffi-
cient amount of data has been gathered from this experiment during a running period of about 600 hours.

7.2 Reconstruction

A high-energy photon does not deposit its complete energy into one single crystal, but shares some of its energy with the neighboring crystals. Therefore, to read the full energy, a cluster of the relevant detectors was formed and the total energy in the cluster was determined. In order to tag the charged particles, the TAPS detector was equipped with the CPV detector (plastic scintillation material) and CB was equipped with the Inner detector (scintillation fibers).

Before the reconstruction of the channel under investigation, the calibration of each detector had to be performed. The calibration procedure involves the energy and time calibration for TAPS and the tagger system, and the energy calibration for the Crystal Barrel. At the beginning of each data taking period the cosmic runs were recorded only with the TAPS detector. These runs provide the first calibration point for TAPS using the deposited energy of cosmic muons. A more accurate energy calibration was performed during the offline analysis. The two-gamma invariant-mass spectrum has been reconstructed from any two photons in TAPS. For this purpose all the possible combinations of the photons have been considered. If these photons originate from the decay of $\pi^0$, the two-gamma invariant-mass spectrum must show a peak at the $\pi^0$ mass. The two-gamma invariant-mass spectrum has been generated for all 528 detector modules of TAPS. If the $\pi^0$ peak position is not found at the correct mass, then it is corrected by adjusting the gain and offset for the corresponding detector. This procedure was repeated several times, improving the calibration in each subsequent iteration. The $\pi^0$ mass resolution ($\sigma$) of 8 MeV was obtained after the last iteration. The energy dependent calibration was performed by using the position of the $\eta$ mass. Similarly to the $\pi^0$ case, the two-gamma invariant-mass spectrum also shows a peak at the $\eta$ mass for events from the decay $\eta \rightarrow \gamma\gamma$. A second order polynomial was used for this calibration and the coefficients were determined by using the $\pi^0$ and $\eta$ peak positions. For the time calibration of TAPS, the time difference between the two photons in TAPS was measured. The offset of each detector was corrected so that the time difference between the two photons should be zero. The energy calibration for Crystal Barrel was performed offline by inspecting the two-gamma invariant-mass spectrum and the $\pi^0$ mass.
position in a similar manner as for TAPS.

Since the energy of the beam electrons after the bremsstrahlung process in the radiator was measured by the tagger and hence the energy of the corresponding photons was determined, the energy calibration for the tagger was essential. For this calibration a fourth order polynomial function was calculated by using the measured field map of the bending magnet and the known positions of the tagger fibers. The time calibration for the tagger was performed by measuring the time difference between a photon in TAPS and the electron hitting the tagger fibers.

7.3 Analysis

The complete decay of the channel under investigation is:

$$\gamma d \rightarrow K^0 \Sigma^+ n \rightarrow (\pi^0 \pi^0)(\pi^0 p)n \rightarrow 6\gamma pn$$  \hspace{1cm} (7.1)

which results in 6 photons, a proton and a neutron in the final state. The photons and a proton were measured by the detector setup. The energy and momentum of the neutron were calculated by using the kinematic fitting procedure. In order to constrain the fit, seven equations were used: one equation for energy balance, three equations for momentum balance and three equations for $\pi^0$ mass constraints. The energy and momentum balance equations determine the energy and momentum of the neutron and the three $\pi^0$ mass constraint equations improve the resolution of the signals. The measured parameters of the photons and a proton were used as the input values for the fit. The energy deposited by a proton is not accurate whenever the proton punches through the detector. Therefore, the deposited energy was not used for punch-through protons and instead a corrected energy determined from the average of energy and momentum balance was used. After the kinematic fit the $\eta$ mass resolution ($\sigma$) in the $3\pi^0$ invariant-mass spectrum was improved from 21 MeV to 10 MeV. The background in our channel of interest originates from two sources: $\eta$ photoproduction ($\gamma d \rightarrow \eta pn \rightarrow 3\pi^0 pn \rightarrow 6\gamma pn$) and $3\pi^0$ sequential decay ($\gamma d \rightarrow 3\pi^0 pn \rightarrow 6\gamma pn$) which have the same final state as the channel of interest. The background generated from the $\eta$ production was removed by discarding all events which are forming the $\eta$ mass. After removing the $\eta$ signal, the $\pi^0\pi^0$ invariant-mass spectrum was reconstructed which shows a clear peak at the $K^0$ mass. A considerable amount of background stemming from $3\pi^0$ sequential de-
cay remained present below the peak. This background was fitted by a polyno-
mial function. The fitted background was then subtracted from the total $\pi^0\pi^0$ spectrum and the remaining counts were integrated over the $K^0$ mass to find the peak content.

### 7.4 Acceptance

The acceptance for the $\gamma d \rightarrow K^0\Sigma^+ n$ reaction was determined by a Monte Carlo simulation using GEANT 3.21. The phase space event generator GENBOD was used to generate the events. The simulated data were treated in exactly the same manner as the experimental data. The acceptance was calculated by taking the ratio of the total number of reconstructed events to the number of generated events. The overall acceptance amounts to about 8%. For the $K^0$ angular dis-
tribution an acceptance on the same level is observed. This means that the pro-
duced particles, the $K^0$ and the $\Sigma^+$, are still detected even if they are heading towards the region where the detector has no coverage, such as the most forward and backward angles.

### 7.5 Results

In this experiment for the first time the $K^0$ photoproduction cross section on the deuteron target was measured. The experimental excitation function was compared to the excitation function obtained on the free proton target in the $\gamma p \rightarrow K^0\Sigma^+$ channel [15] using the same experimental set up. The comparison shows that the total cross section determined in this thesis is lower than for the free proton by about 40%. This tendency is in agreement with the theoretical calculations. The reason for this discrepancy might be found in additional not measured interactions on the deuteron target.

The single-channel calculations for $K^0$ photoproduction on the deuteron using the Isobar Model were performed by A. Salam [23]. The comparison of those calculations with the data points obtained from this work points out that the predicted cross sections are higher than the measurements. Comparison with the differential cross sections for the $K^0$ angular distribution shows the discrepancy not only on the absolute scale but also in the shape of the distribution. One important point to be noted is that the coupling constants for these calculations were fitted to latest SAPHIR data in the $\gamma p \rightarrow K^0\Sigma^+$ channel. Since no data are
available for the neutron channel, the corresponding coupling constants were treated as free parameters in the fit.

7.6 Evidence for YN FSI

The main purpose of the study of this reaction is to investigate evidence for the $\Sigma^+ n$ final-state interaction. The experimental proposal was based on predictions of strong YN final-state interaction obtained by Kerbikov [21] using the P-matrix approach. The inclusive cross section for $K^+$ photoproduction on the deuteron shows a strong enhancement close to the $\Sigma$ threshold. In the analysis of Yamamura et al. [46] the authors observed a cusp-like structure near the $K^+\Sigma N$ threshold.

According to the calculations performed by A. Salam, the YN rescattering effect is observable towards higher hyperon angles ($\theta^\prime_{Y} > 20^\circ$) (see figure 2.6), but for these angles the cross section is very low. Our experimental data are limited to $\theta^\prime_{\Sigma^+} \leq 20^\circ$ in the laboratory system (see figure 6.19). Therefore, this effect is not visible in our data set for this observable. This also implies, that the contribution to the total cross section is small.

The hyperon angular distribution for $\Sigma^+ n$ relative momentum ($|\vec{k}| \leq 500$ MeV/c) shows an enhancement at larger angles (figure 6.22). This might be interpreted as a signature of YN FSI effects, however, at smaller angles than predicted by A. Salam in [23]. Furthermore, the comparison of phase space simulation and experimental data reveals a difference at lower $|\vec{k}|$ values (figure 6.21). This observation as well might give a hint for contributions due to $\Sigma^+ n$ FSI. To confirm this evidence, detailed calculations are required for these observables.

7.7 Conclusions

The results of the investigations presented in this thesis can be summarized in the following concluding statements:

- This analysis of the reaction $\gamma d \rightarrow K^0\Sigma^+ n$ yielded an excitation function and differential cross sections in the energy region between threshold (1050 MeV) and 2000 MeV in incoming photon energy. The measured cross section values are lower than those obtained for $K^0$ photoproduction on the free proton target.
• The acceptance of the detector system for $K^0\Sigma^+n$ covers all angles in the center-of-mass system. The observed acceptances are found rather stable on the same level for all the incoming photon beam energies.

• The obtained $K^0$ photoproduction cross section for the deuteron target is lower than that for the proton target by about 40%.

• In our analysis the reconstructed neutron momentum for $|P_n| > 200$ MeV/c deviates from the Paris Model. The detailed investigation revealed that for some events in this region the neutron momentum was not reconstructed correctly. Therefore, in this analysis we analysed the events for which $|P_n| \leq 200$ MeV/c.

• The single-channel calculations on the deuteron performed by A. Salam largely disagree with the experimental data set. The coupling constants were fitted to the recent SAPHIR data. For the neutron channel the coupling constants were adjusted. In order to get more precise coupling constants more precise data are needed particularly in the neutron channel.

• The effect of the YN interaction in the total cross section and in the $K^0$ angular distribution is negligible for this channel and could not be observed. This effect is prominent for larger hyperon angles ($\theta'_Y$). Unfortunately, because of the lower cross sections for larger $\theta'_Y$, we are limited to $\theta'_Y \leq 20^\circ$. Therefore, this effect is not visible in our data set for this observable.

• The hyperon angular distribution ($\theta_{\Sigma^+}$) for lower $\Sigma^+n$ relative momentum difference ($|\vec{k}|$) shows an enhancement at larger angles. The $|\vec{k}|$ distribution for the measured data shows deviations from the phase space simulation. The behaviour of data at lower $|\vec{k}|$ values might shed some light on YN final-state interaction effects.

• Until now the kaon production on the deuteron has been studied by single-channel calculations. Future coupled-channel calculations might solve the puzzle of YN interaction.