Σ− production in pn interactions at ANKE at COSY

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Abstract. Study of light hyperon production in nucleon-nucleon interactions is a large part of scientific program at the ANKE-spectrometer which is an internal-beam experiment at the Cooler Synchrotron (COSY-Juelich). The Σ− production in pn collisions was studied at two proton beam momenta of 2915 MeV/c and 3015 MeV/c. The deuterium target was exploited as an effective neutron target due to measurement of “spectator” proton momentum to determine the energy of reaction. The Fermi motion allowed to cover a wide range of excess energy Q = 30 – 130 MeV where data was absent. The Σ− production was identified by the missing mass technique. Preliminary result for the energy dependence of the pn → pK+Σ− total cross section is presented.

1. Introduction
Investigation of meson and hyperon production in nucleon-nucleon (NN) interaction at intermediate energies is necessary for solution of the fundamental problem — theoretical description of the strong interaction at low and intermediate energies. Here quark’s degrees of freedom vanish, and one should use effective exchange models. Despite there are a significant database and numerous dedicated theoretical investigations, the mechanism of these processes still is far from being understood. Strangeness production in NN collisions is interesting for various reasons. A creation of an s-quark flavour, which can occur out of the vacuum as well as from the quark-antiquark sea in nucleon, allows one to investigate the internal structure of...
baryons through the dedicated studies of the $NN \rightarrow NKY$ reactions ($Y = \Lambda, \Sigma$). There are also some indications that several excited nucleon states decay into the $\Lambda N$ channel. In addition such reactions give a possibility to study nucleon-hyperon interaction which is still poorly known, but it is essential for questions related to the validity of the SU(3) flavour symmetry. A close-to-threshold regime is very suitable for such investigations because it implies a suppression of high partial waves. It simplifies the theoretical description. Moreover, final state interaction (FSI) effects are much more pronounced at such conditions.

For example, the information about the hyperon-nucleon interaction is very important for theoretical study of neutron stars radii and masses. Gravitation compression in a core of neutron star is generally considered to generate hyperon condensation, but calculations of such processes depend on properties of the $YN$ interaction [1].

The energy dependence of total cross section for the $pp \rightarrow pK^+\Lambda$ reaction near threshold has been investigated in several experiments carried out at the COSY accelerator [2]–[11]. Its behavior can be described in terms of the three-body phase space modified by a strong $\Lambda p$ FSI. However, the analysis of Dalitz plot and angular distributions does not give definite answer on a possible excitation of nucleonic resonances in intermediate state [12].

On other hand, the $pp \rightarrow pK^+\Sigma^0$ reaction does not demonstrate any influence of the $\Sigma^0 - p$ FSI on the energy dependence of total cross section which is found to behave according to the three-body phase space [4,5,9,11]. At the same value of excess energy the $\Sigma^0$ production total cross section is about one order of magnitude less than one for $\Lambda$ production (Fig. 1). This probably reflects difference in the underlying reaction mechanisms as well as between the two FSIs involved.

Investigations of the $pp \rightarrow nK^+\Sigma^+$ reaction show that the energy dependence of total cross sections does not differ much from the three body phase space but there is an indication on some small repulsive $\Sigma^+ - n$ FSI [9,10,13]. It should be also mentioned that the ratio of total cross sections $\sigma(pp \rightarrow nK^+\Sigma^+)/\sigma(pp \rightarrow pK^+\Sigma^0) = 0.7 \pm 0.1$.

In this report we present preliminary results on the relative energy dependence of total cross section for the $pn \rightarrow pK^+\Sigma^-$ reaction near threshold which has not been measured so far.

2. Experimental setup

![Figure 2. Sketch of the relevant parts of the ANKE detector system, showing the positions of the two bending magnets D1 and D3 and the target placed before the analyzing magnet D2. Information obtained from the forward (Fd), positive side (Pd) detectors, and the Silicon Tracking Telescope (STT) was used in this experiment. Typical trajectories, leading to the measurement of protons and $K^+$, are also shown.](image)

The experiment was carried out at the Cooler-Synchrotron COSY-Juelich using unpolarized proton beam of 2915 and 3015 MeV/c momenta interacting with a deuterium cluster-jet target. Reaction products were detected in the ANKE magnetic spectrometer [16] located inside the storage ring of the COSY. The windowless cluster deuterium target was used as an effective neutron target due to the detection of low-energy protons emitted from the target. Thus, events of the $pn \rightarrow pK^+\Sigma^-$ reaction could be reconstructed in framework of the spectator model approximation.

The layout of ANKE detector system used in this measurement is sketched in Fig. 2.
3. Reaction identification

Figure 3. Principle of vertical angle cut. Ejectiles from the target ($K^+$) and scattering background ($P_{BG}$) in general have different vertical angles $\theta$ in the spectrometer.

Figure 4. Vertical angle distribution summed over all the stop counters.

Kaons were identified by the Positive (Pd) detector, high momentum protons – by the Forward (Fd) detector and low energy spectator protons – by the Spectator detector. The Pd detector consists of start and stop counters used for the time-of-flight (TOF) measurement and of two multiwire proportional chambers providing momentum reconstruction and background suppression. The Fd detector system consists of three multiwire proportional chambers and of the hodoscope of scintillation counters. The Spectator detector includes two telescopes (STT). Each of them consists of three layers of position-sensitive silicon detectors with thickness of 60 $\mu$m, 300 $\mu$m and 5.1 mm.

So, the goal of further analysis is to select the $K^+$-meson in the Pd in coincidence with proton in the Fd and low-energy proton in the STT.

Figure 5. The total Sa-So TOF spectra summarized over all start-stop combinations.

Figure 6. Example of Pd-Fd TOF from calculations vs TOF by TDC’s.

Figure 7. Energy loss in the 60 $\mu$m detector versus energy loss in the 300 $\mu$m silicon detector.

To get rid of the particles rescattered in magnet poles, the vertical angle criterion was applied. The principle of the vertical angle cut is illustrated in Fig. 3. Particles coming from the target within the angular acceptance pass through the first MWPC at some vertical coordinate $y$ from...
which one can expect some certain vertical angle to be measured by the second MWPC. In contrast to ejectiles coming directly from the target, particles scattered in the magnet have in general much larger difference between the expected angle and the one measured in the second chamber. The experimental vertical angle distribution is shown in Fig. 4. Here, the central prominent peak is formed by ejectiles from the target while the wide side peaks are related to rescattered particles.

The main criterion for particle identification in the Pd is the time-of-flight between start and stop counters. This technique provides clear separation of pions and protons in each of start-stop combinations. The TOF distribution for the 11-th stop counter summed over the all start counters is presented in Fig. 5. The left and right peaks correspond to pions and protons coming from the target. The position of $K^+$ peak is marked by the arrow but it can be hardly seen because of the large background from tails of of pion and proton distributions. The further suppression of the background near $K^+$ peak was achieved due to coincidence with high momentum protons detected in the Fd and low-energy protons detected in the STT.

Particles detected in the Fd are dominantly protons with a very small admixture of deuterons. So, the kinematic cut which reject protons with momenta higher than it is allowed by conservation lows for the $pd \rightarrow pspK^+\Sigma^-$ reaction ($|\vec{p}_{Fd}| < 1.8$ GeV/c) can be made.

The additional criterion was applied on the correlation between $K^+$ in the Pd and protons in the Fd as shown in Fig. 6. The time-of-flight difference between corresponding particles detected in Fd and Pd counters was calculated and compared with experimantaly calibrated TOF data. Points related to valid events are grouped along the diagonal of the presented histogram.

The momentum of “spectator” proton was reconstructed using the position and energy loss information from STT. The separation of protons from deuterons by the $\Delta E - E$ method is presented in Fig. 7.

4. Energy dependence

![Figure 8](image1.png)

**Figure 8.** Missing mass distriution for $p_{beam} = 2915$ MeV/c. The $\Sigma^-$ peak is highlighted with the arrows.

![Figure 9](image2.png)

**Figure 9.** Energy dependence of the total cross section in arbitrary units. The red points correspond to 2915 MeV/c, the blue points correspond to 3015 MeV/c. The phase space dependency is shown with the solid line.

The final identification of reaction under investigation was done by the missing mass method:

$$M^2 = (P^{cosy} + P^{target} - P^{Pd} - P^{Fd} - P^{STT})^2$$

where $P^{cosy}$ is the 4-momentum of the proton beam, $P^{target}$ is the 4-momentum of the deuterium target and $P^{Pd}$, $P^{Fd}$ and $P^{STT}$ are 4-momenta of corresponding particles selected in the Pd,
Fd and STT detectors as described above. The missing mass distribution obtained at the 2915 MeV/c beam momentum is presented in Fig. 8. It demonstrates a clear peak at 1.2 GeV/c^2 which can be interpreted as a signal from the \( pd \rightarrow p_{sp}pK^+\Sigma^- \) reaction. The total number of \( \Sigma^- \) events under the peak is about 500 events at each of beam momenta.

Similar missing mass distributions were plotted for each excess energy bin, and the number of \( \Sigma^- \) events was extracted. Monte-Carlo simulations of the \( pd \rightarrow p_{sp}pK^+\Sigma^- \) reaction were performed to calculate the acceptance value [14]. The preliminary energy dependence of total cross section presented in Fig. 9 follows the 3-body phase space behaviour quite well without involving any strong FSI effects.

The further analysis of the absolute normalisation and uncertainties is in progress.

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