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STRANGENESS PRODUCTION IN THE COSY-TOF EXPERIMENT* **

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The hyperon production in elementary proton induced reactions is studied exclusively at the external COSY beam using the time-of-flight spectrometer TOF. For the associated strangeness production process $pp \to K^+ \Lambda p$ total and differential cross sections as well as Dalitz plots, mass spectra of the subsystems and the Λ-polarization are measured. The data show evidence for the influence of N^* resonances and the $p\Lambda$-final state interaction on the production process. In the actual step the production of Σ^+ and Σ^0 hyperons in the channels $pp \to K^0 \Sigma^+ p$, $K^+ \Sigma^+ n$ and $K^+ \Sigma^0 p$ is included. In the future in addition a polarized beam and a polarized target as well as a deuterium target will be used.

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1. Introduction

The interest in the investigation of the associated strangeness production in elementary reactions like $pp \to KYN$ close to threshold is to get information about the manifestation of the QCD in the nonperturbative regime going a step beyond low energy pion physics. The produced strange and anti-strange quarks act as sensitive probes to find out the relevant degrees of freedom of the dynamics of the mass creation process. Moreover, the investigation of the strangeness production should give insight in the structure of the involved strongly interacting objects. Of special interest in this context is a possible strangeness content of the nucleon, which should influence the observables of the $\bar{s}s$ production in the favourable case [1]. To get conclusive results in this complex situation dedicated model calculation are essential.

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In the meson exchange model the questions especially concern the contribution of the various strange and non strange mesons, including the influence of N^* resonances and the role of the final state interaction which is known to be of special importance close to threshold. Besides these effective descriptions more elementary models are needed. The goal of more QCD inspired calculations which are now in progress is to find the link from the effective degrees of freedom to the underlying fundamental interaction.

To come to more conclusive results the comparison of different reactions is essential. In figure 1 are shown for the four hyperon channels $pp \to K^+ \Lambda\, p$, $K^0 \Sigma^+ p$, $K^+ \Sigma^+ n$ and $K^+ \Sigma^0 p$, which can be investigated at COSY-TOF, the cross section data from older exclusive experiments (open symbols, [2]) together with the recent data from COSY (filled symbols). Apart from an old data point for the Λ-channel (consisting of 11 events) nothing was known in the COSY range. Now there exist measurements of COSY-11 (just at threshold, [3]) and COSY-TOF (2.50 and 2.75 GeV/c, [4]) for the Λ-channel and data of COSY-11 for the Σ^0-channel [5].

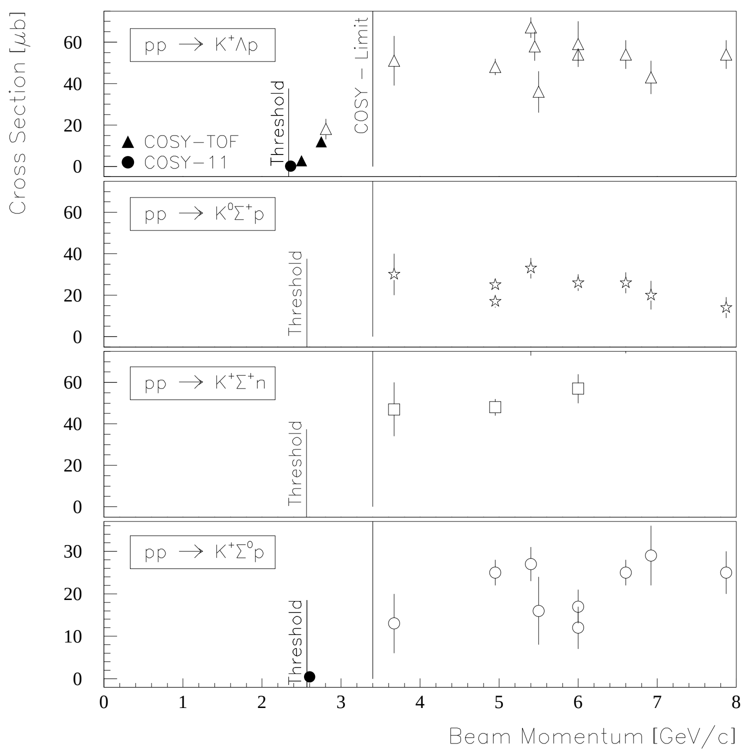

Fig. 1. Existing cross section data for the four hyperon production channels $pp \to K^+ \Lambda\, p$, $K^0 \Sigma^+ p$, $K^+ \Sigma^+ n$ and $K^+ \Sigma^0 p$.

It is obvious that more precise data are needed especially in the threshold region. The measurements should concentrate on exclusive data covering the full phase space. Moreover, spin observables are important, in particular the polarization of the hyperon, which can be extracted via the weak decay.

Apart from the $\bar{s}s$ creation process itself there are more special topics related to the strangeness production close to threshold. An interesting example is the question of the existence of an exotic $qqqq\bar{q}$ resonance which is proposed in the soliton model [6]. It should show up in the reaction $pp \to K\Sigma^+N$ as a narrow peak in the mass spectrum of the KN subsystem.

Moreover, the data of the strangeness production in nucleon–nucleon reactions in the threshold region are important as an input to describe and control $\bar{s}s$ creation in heavy ion collisions at high energies. Here the observation of particles carrying strangeness is considered a promising method to get information about hot, dense matter and the nuclear equation of states. Data on the elementary system are also of special interest concerning the discussion about the unexpected K^-/K^+ ratio recently observed in nucleus–nucleus collisions [7].

2. Experiment

The external experiment COSY-TOF is a wide angle, non magnetic system with various start and stop detector components for time-of-flight measurement. The apparatus combines high efficiency and acceptance with an energy and momentum resolution of a few percent. The whole detector system together with a tiny liquid hydrogen target is installed in a vacuum vessel. This ensures a rather precise definition of the interaction point and a strongly reduced contamination from background reactions in air. The modular structure of the system allows a time of flight path between about one and eight meters and a large variation of the detected angular range covering the full phase space in the case of threshold reactions. Figure 2 shows a standard version with a length of about 3.4 meters.

The outer detector serving as stop for the time-of-flight consists of several plastic scintillator hodoscopes: basically a huge cylindrical segmented barrel and a circular endcap in the forward direction. The endcap is made up by two separate scintillator hodoscopes, a central one ("quirl") with a diameter of one meter and a ring-like having an outer diameter of three meters. Both consist of three segmented layers, one by wedge like parts and two by left and right hand spirally formed elements [8]. Furthermore, a neutron detector consisting of a large area scintillator wall is installed behind the vessel to measure primary and decay neutrons in the Σ^+channel. The data shown in this contribution have been taken using a short version of about 1 m with the quirl as outer detector. In a very recent run, however, the complete system with ring and barrel could be used successfully.

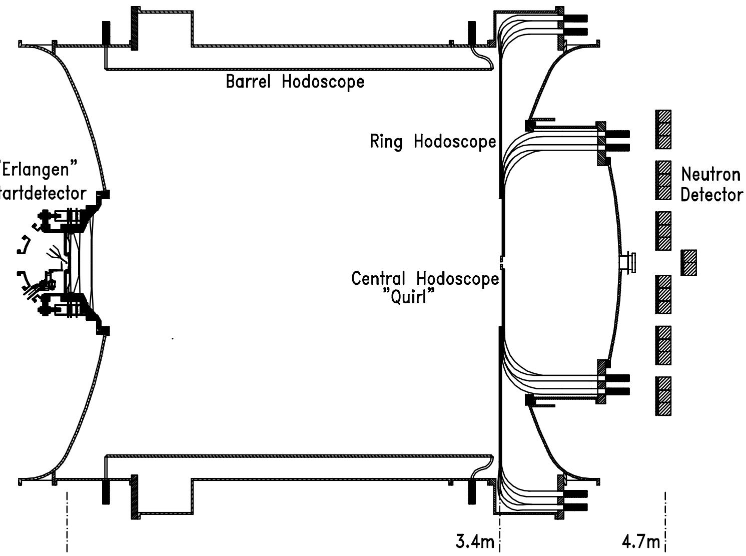

Fig. 2. Scheme of the TOF-detector (standard version of about 3.4 m length).

Together with a real event the inner detector system optimised for strangeness production is schematically shown in figure 3. It consists of the "starttorte", made of two thin segmented layers of plastic scintillators providing

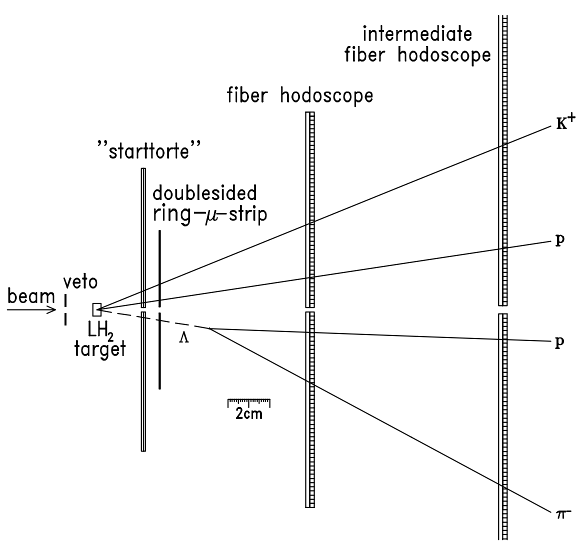

Fig. 3. Schematic view of the startdetector system

the start timing, a double-sided silicon micro-strip detector with ring and sector structure, respectively, and two hodoscopes built by scintillating fibres [9].

This system with small beam holes between 2 and 4 mm diameter covers the full angular range of the reaction products and allows the complete reconstruction of the $pp \to K^+ \Lambda\, p$ events including the delayed decay $\Lambda \to \pi^- p$. From the angular distribution of its decay products the polarization of the Λ is extracted. It should be pointed out that for the nonmagnetic TOF facility the identification and reconstruction of the delayed Λ-decay is the key for the extraction of the $K^+ \Lambda\, p$ events. Existing overconstraints from the time-of-flight and dE/dx measurements improve the precision of the observables.

3. Results

First data were taken for the channel $pp \to K^+ \Lambda\, p$ at the two beam momenta of 2.50 GeV/c and 2.75 GeV/c. Clean nearly background free samples could be extracted, which allowed to evaluate total cross sections, angular distributions, Dalitz plots with mass projections and for the run at 2.75 GeV/c also the Λ-polarization. In part these results are already published [4]. The total cross section together with the results of COSY-11 just at threshold give a consistent picture allowing already to test different model calculations and their parameters. The Dalitz plots show that the data more or less smoothly cover the full phase space. The projections for the $K\Lambda$- and $p\Lambda$-subsystems for the beam momentum of 2.75 GeV/c (see figure 4), however, indicate significant deviations from the phase space.

The enhancement on the left side of the $p\Lambda$-mass corresponds to the $p\Lambda$-final state interaction. It is also interesting to notice that the isolated data point sticking up in the middle of this spectrum is just at the $p\Sigma^0$-mass. Obviously the one data point is insufficient for a conclusive explanation which needs further input from upcoming data. Also the $K\Lambda$-spectrum shows some deviation from the phase space. There is a shift to higher masses. This can be explained in resonance model calculations [10] where the influence of the $N^*(1710)$ and $N^*(1720)$ resonances affects the $K\Lambda$-spectrum in the observed way. On the other hand also the final state interaction should give deviations from the phase space in this spectrum. This observation needs further investigations on the basis of high precision data. The same holds for the observed Λ-polarization, where the data indicate a trend to negative polarization with increasing transverse Λ-momentum.

After an upgrade of the startdetector system measurements were done at beam momenta of 2.59, 2.68 and 2.85 GeV/c where most of the time was spent at the highest momentum. The goals concerning the Λ-channel were

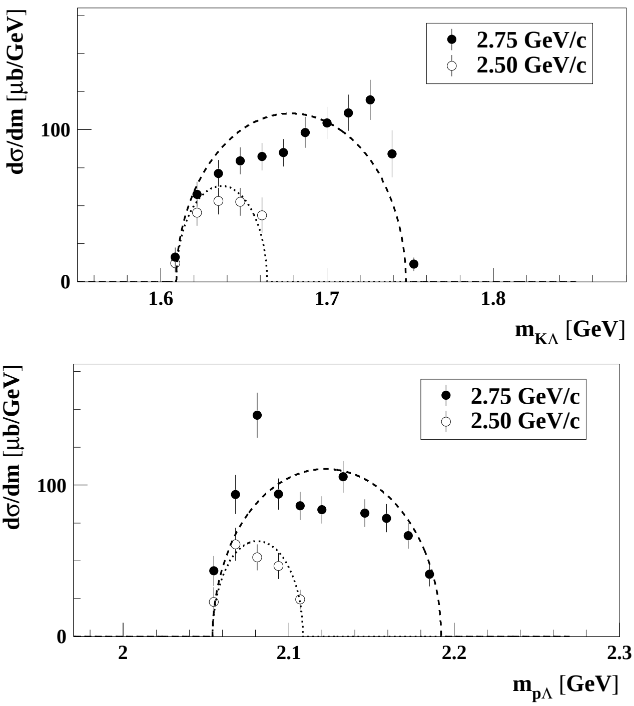

Fig. 4. Dalitz plot projections on 2-particle subsystems at 2.50 and 2.75 GeV/c

to get further data points and a sample with improved statistics for the momentum of 2.85 GeV/c. Moreover, it was a pilot run for the two Σ^+-channels $pp \to K^+\Sigma^+n$ and $K^0\Sigma^+p$. Obviously they are of great importance for a consistent understanding of the strangeness production.

The Σ^+-production is much harder to measure than the Λ-channel. The signature of the Σ^+-decay is only a kink in the track. Due to the short decay length ($c\tau$ = 2.4 cm) a precise measurement of the Σ^+-track very close to the target is essential. This is done by the micro-strip-detector. Additional indications are the delayed decay $K^0 \to \pi^+\pi^-$ and/or a detected neutron, respectively.

The upper part of figure 5 shows for a subsample of the 2.85 GeV/c data the reconstructed Λ-peak on a low background, the lower part a corresponding spectrum of the reaction $pp \to K^0\Sigma^+p$, respectively. It demonstrates, that also for the Σ^+-channel the interesting events can be extracted with a sufficient precision. From these data one gets a preliminary cross section ratio of Σ^+/Λ= 0.11 ± 0.03, which is an interesting quantity to be compared with model calculations.

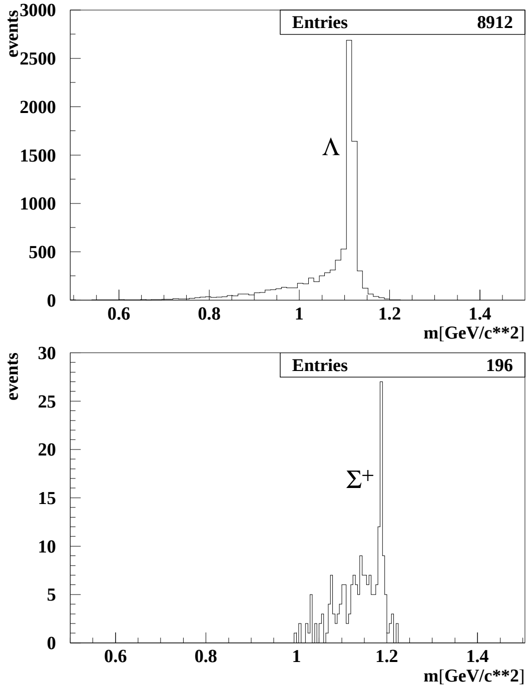

Fig. 5. Missing mass of reconstructed Λ (top) and Σ^+ (bottom) events for subsamples of the 2.85 GeV/c data.

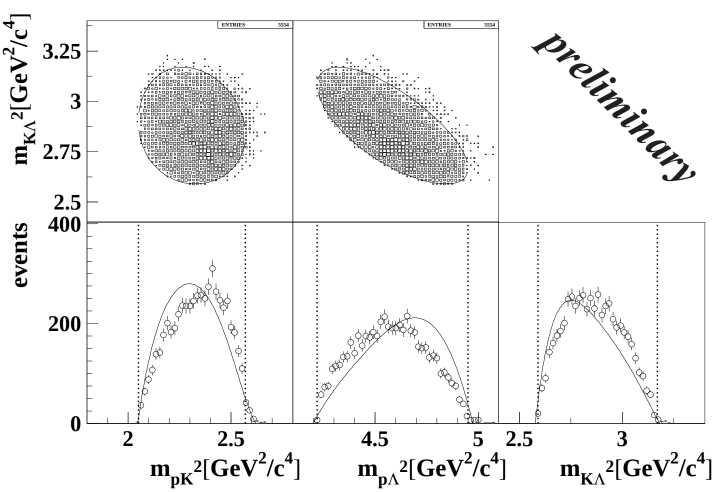

Fig. 6. Dalitz plots and projections for the reaction $pp \to K^+ \Lambda\, p$ at 2.85 GeV/c

For the Λ-channel the preliminary Dalitz plots and their projections (figure 6) again show an enhancement at low $p\Lambda$-masses which has to be attributed to the $p\Lambda$-final state interaction. And again there is an enhancement in the $K\Lambda$-subsystem around the $N^*(1710)$ and $N^*(1720)$ resonances, corresponding to values of $m^2_{K\Lambda}$ between about 2.75 and 3.10 GeV$^2/c^4$.

4. Summary

The COSY-TOF experiment obtained exclusive data for the Λ- and Σ-production in proton–proton collisions. The improved precision and the possible comparison of the different channels including the hyperon production in pn-reactions using a deuterium target together with the future use of a polarized beam and a polarized target will allow further insight into the structure and dynamics of the involved hadronic objects.

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