Eur. Phys. J. A **31**, 503–505 (2007)
DOI 10.1140/epja/i2006-10276-4

THE EUROPEAN PHYSICAL JOURNAL A

Special Article – QNP 2006

Hyperon production at COSY-TOF

W. Schroeder[a]

For the COSY-TOF Collaboration
University of Erlangen-Nuremberg, Germany

Received: 23 November 2006
Published online: 23 March 2007 – © Società Italiana di Fisica / Springer-Verlag 2007

Abstract. The strangeness production program at the COSY-TOF experiment is discussed. The apparatus is shown emphasizing the technique to measure delayed decays. Results obtained for the reactions $pp \to K^+\Lambda p$ and $pp \to K^0\Sigma^+p$ are discussed.

PACS. 13.75.-n Hadron-induced low- and intermediate-energy reactions and scattering (energy ≤ 10 GeV) – 14.20.Gk Baryon resonances with $S = 0$ – 14.20.Jn Hyperons

1 Introduction

The main interest in the investigation of the associated strangeness production in elementary reactions close to threshold is to get insight into the dynamics of the production. The questions especially concern the role of N^*-resonances and the hyperon-nucleon final-state interaction which is known to be of special importance close to threshold. To get to conclusive results precise observables are needed, concentrating on exclusive data, covering the full phase space.

2 Experimental setup

The external experiment COSY-TOF [1] is a wide-angle, non-magnetic spectrometer. A cross-section is shown in fig. 1. A few millimeters behind the very small liquid-hydrogen target the start (inner) detector system, which is optimized for strangeness production measurements, is installed. The stop detector with a length of about 3 m consists of various scintillator detectors (quirl, ring and barrel).

Except for small beam holes, the inner detector system, as well as the outer detector system covers the full angular range of the reaction products for the channels $pp \to K^+\Lambda p$ and $pp \to K^0\Sigma^+p$. This allows a complete reconstruction of the events, including a precise measurement of the delayed decay of the Λ-hyperon and the K^0, respectively. A schematic view of the start detector system, consisting of the start torte (two layers of wedge-shaped scintillators), a double-sided microstrip detector and two scintillating fibre hodoscopes is shown together with events of the type $pp \to K^+\Lambda p$ (fig. 2) and $pp \to K^0\Sigma^+p$ (fig. 3), respectively.

[a] e-mail: schroeder@physik.uni-erlangen.de

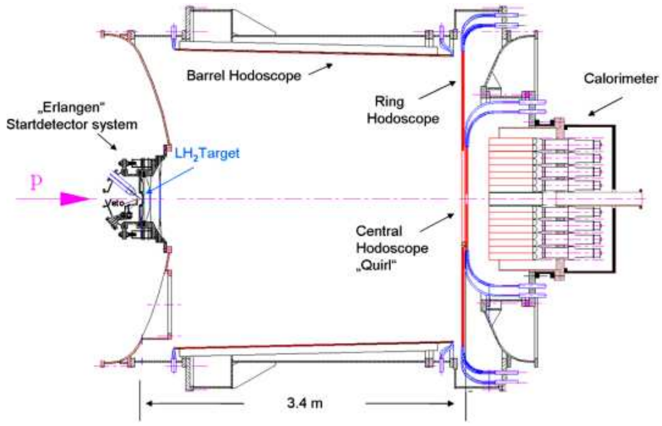

Fig. 1. Cross-section of the COSY-TOF spectrometer.

3 Results

A particular focus in the investigation of the reaction $pp \to K^0\Sigma^+p$ was laid on the search for the possible exotic pentaquark resonance Θ^+ for which evidence was reported for the first time by the LEPS Collaboration [2]. Among other experiments COSY-TOF found evidence for a peak at $1.53\,\mathrm{GeV}/c^2$ with a statistical significance of about 4σ in the K^0p invariant-mass spectrum at a beam momentum of $2.95\,\mathrm{GeV}/c$ [3], which is shown in fig. 4. To get to a final decision on the existence of the Θ^+ in the investigated channel recently COSY-TOF performed a measurement that will give results with a significantly improved statistical accuracy.

The reaction $pp \to K^0\Lambda^+p$ has been investigated at several beam momenta between $2.5\,\mathrm{GeV}/c$ and $3.3\,\mathrm{GeV}/c$ [4,5], that means from close to threshold up to nearly the COSY limit for the external beam. For reactions with more than two particles in the final state, as

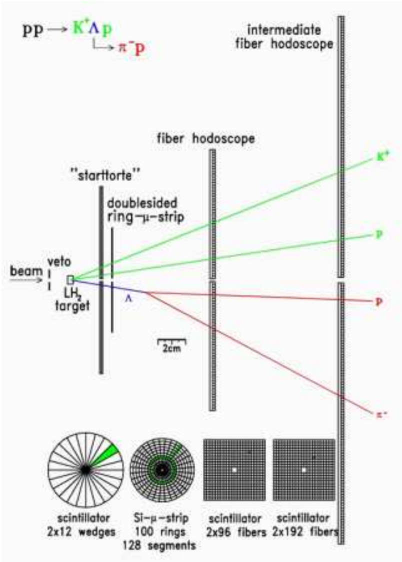

Fig. 2. Schematic view of the start detector with an event of type $pp \to K^+\Lambda p$.

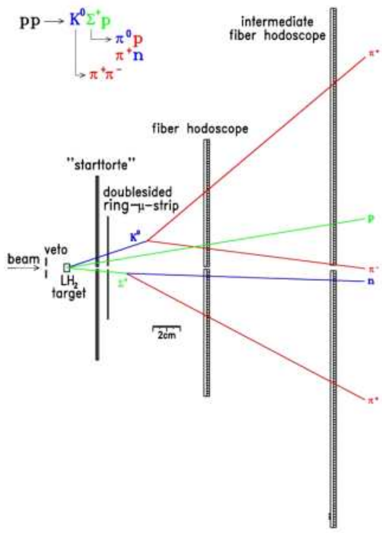

Fig. 3. Schematic view of the start detector with an event of type $pp \to K^0\Sigma^+ p$.

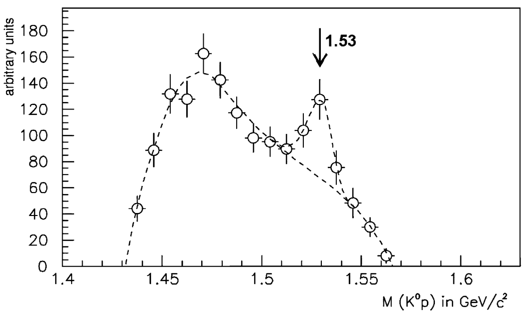

Fig. 4. $K^0 p$ invariant-mass spectrum of the reaction $pp \to K^0\Sigma^+ p$ at a beam momentum of 2.95 GeV/c.

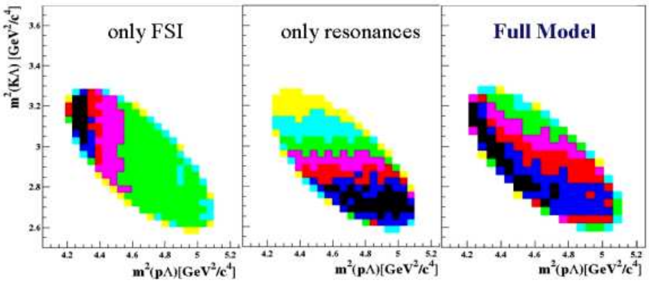

Fig. 5. Model calculations using parametrization of Sibirtsev [7] without resonances (left), without FSI (middle) and full calculation (right) for 2.95 GeV/c.

in the case of the reaction $pp \to K^+\Lambda p$, Dalitz plots are a powerful tool to extract information about the reaction mechanism. Whereas pure phase-space leads to a homogeneous distribution of the strength, in particular resonances should lead to significant deviations from this.

In fig. 6 (upper part) Dalitz plots for experimental data at beam momenta of 2.95 GeV/c, 3.20 GeV/c and 3.30 GeV/c, respectively are shown. They obviously show strong deviations from phase space. Monte Carlo simulations show that higher partial waves influence the Dalitz plot distributions only in a minor way. The strength coefficients of these partial waves have been extracted from the experimental angular distributions, which show some anisotropy for all three ejectiles. From theoretical work and our previous investigations [4], it is most likely that the observed anisotropy has its origin in the influence of the $p\Lambda$ final-state interaction and/or N^*-resonances. To obtain more insight into the various contributions, the data were compared with a model parametrization prepared by A. Sibirtsev [6], which includes the $N^*(1650, 1710, 1720)$-resonances, a non-resonant term and the $p\Lambda$ final-state interaction on the amplitude base (see eq. (1)):

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}m^2_{K\Lambda}\mathrm{d}m^2_{p\Lambda}} = fl\Phi\left|\left(\sum_R (C_R \cdot A_R) + C_N\right) \cdot (1 + C_{FSI} \cdot A_{FSI})\right|^2. \quad (1)$$

The quantity fl gives the normalization to the total cross-section, Φ is a phase-space factor. The third factor gives the deviation from an equally distributed Dalitz plot. A_R are the amplitudes of the Breit-Wigner-shapes of the three considered N^*-resonances. A_{FSI} denotes the amplitude of the $p\Lambda$ final-state interaction as given by the Juelich YN-model [7]. The strength of the individual resonances C_R, of the non-resonant contribution C_N (which includes the kaon exchange) and of the $p\Lambda$ final state C_{FSI} can be adjusted individually. For illustration the results of the model, obtained without resonances ("only FSI"), without FSI ("only resonances"), and the full calculation ("full model") are shown in fig. 5. Obviously only the full model can reproduce the data (see also fig. 6).

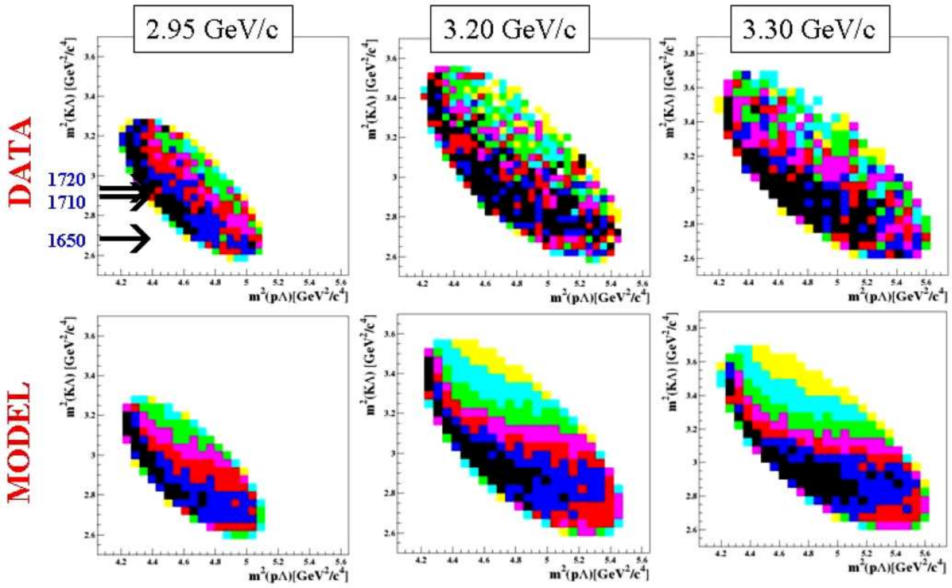

Fig. 6. Dalitz plots of the reaction $pp \to K^+\Lambda p$; data (upper) compared to model fits (lower).

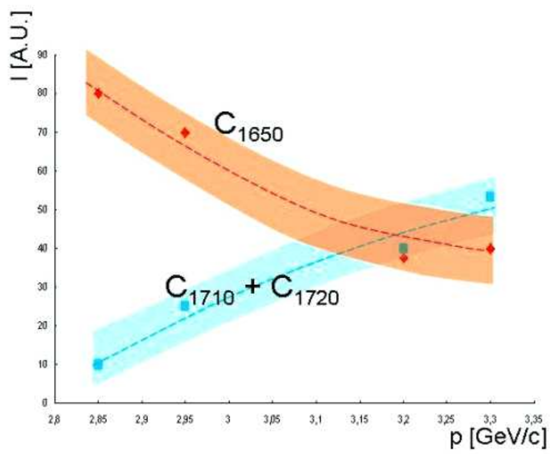

Fig. 7. Contribution of $N^*(1650)$ compared to the sum of $N^*(1710) + N^*(1720)$ as a function of the beam momentum.

The strengths of the various contributions were adjusted individually to achieve a best fit for the various Dalitz plots. The results are shown in fig. 6 (lower part). The data are well described by the model fits. The obtained reduced χ^2-values are between 1.4 and 2.0. The most interesting result is that the strength of the contribution of the $N^*(1650)$-resonance compared to the sum of the contributions of the $N^*(1710)$ and $N^*(1720)$ changes dramatically with the beam momentum. This is shown in fig. 7. The given bands correspond to a 3σ-error interval of the extracted strengths of the resonances. The amplitude of the non-resonant contribution is smaller by a factor of about ten compared to the sum of the three contributing resonances. The influence of the $p\Lambda$ final-state interaction is significant even for the highest momentum; within errors is the corresponding amplitude independent of the beam momentum. From these results it has to be concluded that there is a dominant exchange of non-strange mesons. Only these are able to contribute to the observed leading mechanism via N^*-resonances.

4 Summary and outlook

The COSY-TOF experiment is well suited for hyperon production experiments.

A final decision on the existence of the Θ^+ should be possible by using the extended data set of the reaction $pp \to K^0\Sigma^+p$, which is analyzed at the moment.

For the reaction channel $pp \to K^+\Lambda p$ a strong influence of N^*-resonances was observed.

Data with much larger event samples, which are under investigation, will allow to study the resonance parameters in detail and to search for unknown resonances. In this context the inclusion of other reaction channels accessible through np-reactions by the use of a deuterium target, and the use of a polarized beam, which have already been started (tested), will be of special importance.

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