Threshold Production of Σ^+ at COSY-11

Abstract

It is proposed to measure the total cross section for Σ^+ production via $pp \to nK^+\Sigma^+$ reaction at the COSY-11 installation. The reaction will be identified by detecting the neutron with a recently installed neutron detector and the kaon with the standard COSY-11 setup by adding an additional kaon start scintillator. Data for the threshold production of the Σ^+ hyperon will allow more detailed proofs of the existing models describing the large Λ/Σ^0 cross section ratio at threshold.

1 Introduction

In studies of threshold hyperon production at COSY-11 the cross section ratio of $\sigma(pp \to pK^+\Lambda)/\sigma(pp \to pK^+\Sigma^0)$ was measured to be in the order of 30 in contradiction to a ratio of about 2.5 measured at higher excess energies ($\varepsilon > 350$ MeV) [1]. Different scenarios were proposed to explain this unexpected behaviour, but the present data are not sufficient to discriminate between possible explanations.
In the theoretical models of the hyperon production generally pion and kaon exchanges are included but also additional production mechanisms like heavy meson exchange (ρ, ω and K^*) and/or production via nucleon resonances are considered [2], [3], [4].
Recently the data base was extended by studying the transition of the cross section ratio of Λ/Σ production in the pp interaction from threshold values to the high energy level [5] At COSY-11 the Λ and Σ^0 production cross section have been measured up to excess energies of 60 MeV where almost the high energy level of the ratio is reached. But the data are still not sufficient for an unambiguous identification of the dominant reaction mechanism. Studies on the other isospin projections are promising for a better understanding in this field.
The Jülich theory group has recently performed calculations for the reaction channels $pp \to pK^+\Lambda$ and $pp \to NK\Sigma$ including π^0 and K^+ exchange [2], [6]. In their approach the interaction between the emerging hyperons (Λ, Σ) and the nucleon is described by a microscopic (ΛN-ΣN) coupled channel model [7], so that possible conversion effects can be treated rigorously. They concluded, however, that the $\Lambda - \Sigma$ coupling is by far not sufficient to result in a drastic Σ suppression. On the other hand a destructive interference of the π and K amplitudes can reproduce the observed cross section ratio at threshold. The Λ production is dominated by the K exchange and therefore the influence due to the interference of π exchange is negligible in this hyperon channel. In the Σ production, however, both π and K exchange are of comparable strength resulting in a strong Σ suppression if the destructive interference is used which describes the COSY-11 data very well. At an excess energy of about 13 MeV the cross section ratio $\sigma(\Lambda)/\sigma(\Sigma^0)$ is 9.9 for constructive ($K + \pi$) and 36 for destructive ($K - \pi$) interference compared to the experimental value of 25 $\pm$ 6. For the reaction $pp \to nK^+\Sigma^+$ an opposite behaviour results from the calculations. Here the predicted cross sections at 13 MeV excess energy are 86 nb for constructive and 229 nb for destructive interference. If the model with destructive interference of the kaon and pion exchange amplitudes is valid the cross section for $pp \to nK^+\Sigma^+$ is expected to be a factor 3 higher than the cross section for $pp \to pK^+\Sigma^0$. For a constructive interference it would be a factor of 3 lower.

The measurement of the total reaction cross section of $pp \to nK^+\Sigma^+$ will give a very clear signature for the interference pattern within the Jülich meson exchange model. Also within competing models the knowledge of the cross section in the other isospin channel will allow to check their validity.

2 Experiment

The experiment will be performed at the standard COSY-11 facility extended by a neutron detector and a start scintillator at the dipole exit. In fig. 1 the ejectile tracks at the COSY-11 installation are shown for some $pp \to nK^+\Sigma^+$ events.

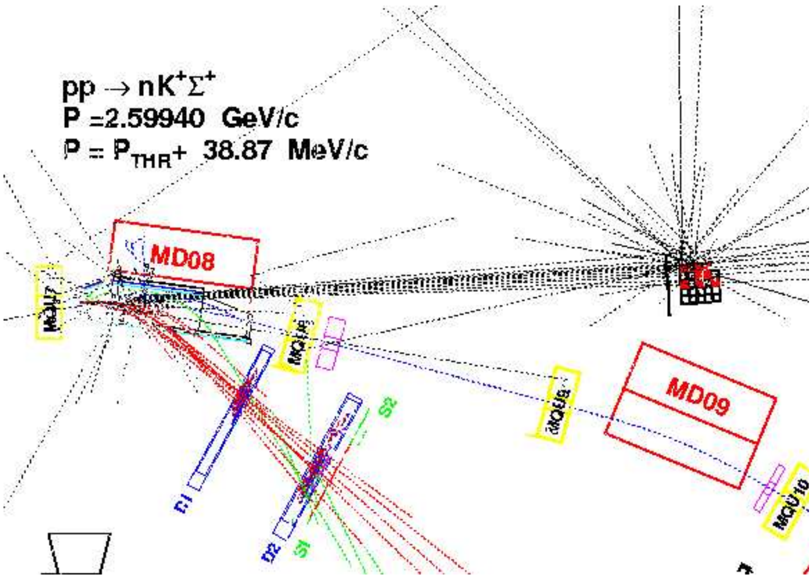

Figure 1: Setup of the COSY-11 detection system for the proposed Σ^+ production study.

The neutron detector covers the neutron laboratory angular range of ± 1.84 deg. in x (in the COSY plane) and ± 1.1 deg. in y direction. It consists of 24 modules readout on both sides by photomultipliers. The dimensions of each modul are 27x9x9 cm^3 and it consists of 11 plastic scintilator plates with lead plates in between. A sketch of the detection system with the neutron detector arrangement and the kaon start scintillator is given in fig. 2. In the lower part the internal structure of one neutron detector moduls with alternating plates of scintillator and lead is sketched.
The start scintillator at the dipole exit consist of several plastic scintillator modules with a width of 20 cm at a height of 45 cm readout on both sides by photomultipliers.
Compared to the standard COSY-11 missing mass technique detecting charged particles the analysis is more difficult here. The neutron detector has a detection efficiency of 50 % for neutron momenta in the relevant range around 900 MeV/c and an information about the neutron energy is practically not available.
The K^+ velocity will be measured with the start and S1 scintillator and the drift chamber information is used for the momentum reconstruction via backtracking to the target. ¿From the kaon velocity and the reconstructed flight path length the start time for the

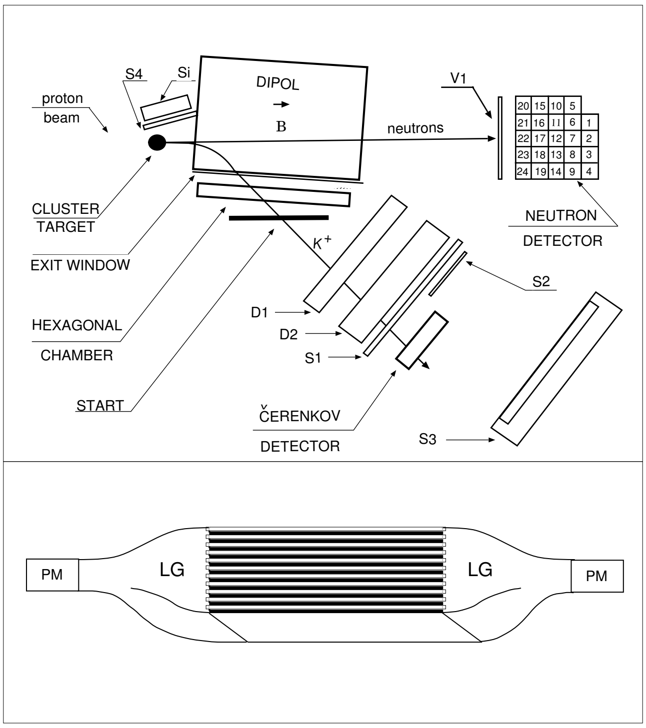

Figure 2: Sketch of detection system showing the arrangement of the neutron detector moduls and the kaon start scintillator. In the lower part of the figure the internal structure of one neutron detector modul is shown with the alternating plates of scintillator (light) and lead (dark), the lightguides (LG) and the photomultiplier on both sides.

neutron can be calculated and the neutron stop time is measured by the neutron detector. Assuming a hit in the neutron detector being due to a neutron, the 4 vector of the neutron is given by the measured velocity, the direction of the neutron which can be reconstructed with an accuracy of at least the modulsize and the known mass. The background from charged particles hitting the neutron detector is discriminated very effectively by veto scintillators around the neutron detector.
Compared to the experimental technique used in the Λ production studies with the detection of a proton and a K^+ mainly the resolution of the missing mass is reduced. The effect on the invariant mass by the different velocity measurement is small. The invariant mass is given by: $m_{inv} = p/\beta\gamma$. The momentum results from the reconstruction using the track information from the drift chambers and is comparable for both measurements. The procedure to determine the velocity is the main error source. The usual way at COSY-11 is to measure the time of flight of a proton with a fligth path of about 9m, calculate the event start time using the reconstructed path through the magnetic field and determine the time of flight for the kaon from the target to the S1 scintillator with a mean path of about 2.5 m. For the proposed Σ^+ study the kaon velocity is measured directly with the additional kaon start scintillator and the S1 scintillator with a reduced path length of about 2 m. The expected σ resolution for the kaons in the invariant mass distribution will be about 6 %.

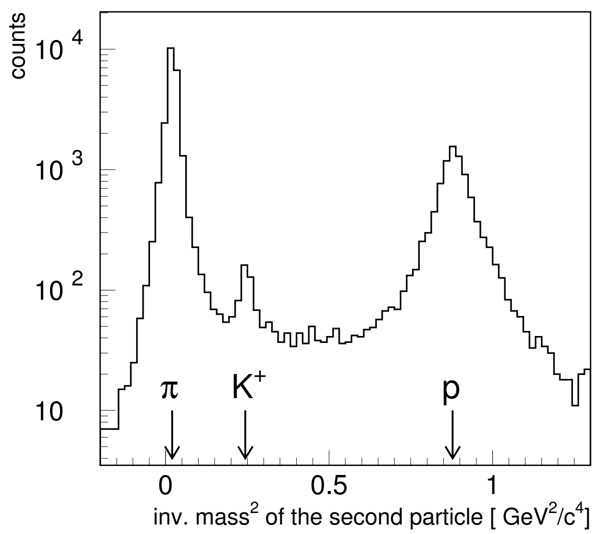

Figure 3: Invariant mass distribution for the charged ejectiles measured at an experiment for Σ^0 production. During these measurements a kaon start scintillator was positioned at the dipole exit.

In fig. 3 the invariant mass distribution is shown for a Σ^0 production experiment with a kaon start scintillator at the dipole exit. In fig. 4 the experimental missing mass distribution for the Σ^0 production at an excess energy of 13 MeV is shown and in fig. 5 the expected missing mass peak for the Σ^+ production is given. The Σ^+ peak was generated by Monte Carlo simulations including all experimental uncertainties.

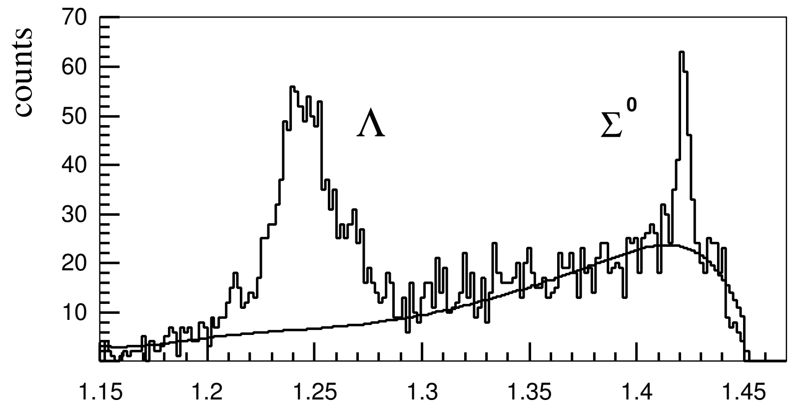

Figure 4: Squared missing mass distribution for the Σ^0 production at an excess energy of 13 MeV.

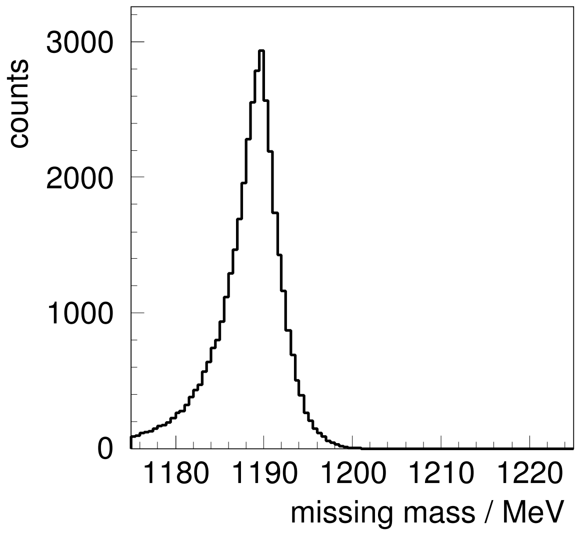

Figure 5: Expected missing mass distribution for the Σ^+ production generated by Monte Carlo simulations.

For the Σ^0 data a missing mass resolution of 3.7 MeV (FWHM) is achieved. In the proposed measurement a missing mass resolution of 5.5 MeV (FWHM) is expected. In the standard technique the momenta of the beam and all ejectiles except the missing one are known or measured with an accuracy in the per mil level. For the neutron such a precise momentum determination is not possible. Here the momentum is given by the direction $(p_x/p, p_y/p, p_z/p)$ and the velocity which is measureable with a drastically lower resolution.

The efficiency for the detection of an $nK^+\Sigma^+$ event at an excess energy of 13 MeV is about 0.4 % which is, including the factor 2 due to the neutron detector efficiency, comparable to the detection efficieny of an $pK^+\Sigma^0$ event with 0,76 % +/- 0,02 (for Q=14 MeV). The $pp \to pK^+\Sigma^0$ production has been sucessfully studied at COSY-11 [1], [5] with event rates of about 20/day. Therefore especially in view of the 3 times higher expected cross section the event rates will be no problem.

The critical point for the measurement could be the background. The dominant background channel is $pp \to pn\pi^+$ with a cross section of about 18 mb at a beam momentum of 2.6 GeV/c [8]. The invaraint mass distribution in fig.4 shows that due to the experimental uncertainties the K^+ peak is located on the tails of the π^+ and the proton. The cross section for $pp \to pn\pi^+$ is about a factor of $1 \cdot 10^5$ higher than the expected 230 nb of the $pp \to nK^+\Sigma^+$ but only a small fraction of the detected pions and protons will be in the invariant mass range which is cutted out to separate the kaons. ¿From fig. 3, a reduction of this background source by a factor of about 100 can be expected. Furthermore at the high excess energy of about 600 MeV for the $pp \to pn\pi^+$ reaction only a small fraction of the neutrons are scattered to reach the neutron detector and the events are distributed over the whole missing mass range. In general the background distribution is expected to be in the same order as for the $pK^+\Sigma^0$ studies where also $pp \to pn\pi^+$ is the main background source. In the Σ^0 production studies (from the background channel) the proton and the pion are measured and in the Σ^+ production studies the neutron and the pion will be measured. The background in the Σ^0 studies

was about 35 events/MeV for an integrated luminosity of $7.5 \cdot 10^{35}(1/cm^2)$. Expecting the same rate for the Σ^+ studies we end up with a total rate of background events of 4 events/MeV/day (for a luminosity of $1 \cdot 10^{30}(1/cm^2/s)$). Within a 2 FWHM region around the Σ^+ peak 44 background events/day are expected.
Beside the Σ^+ production also the Σ^0 production via $pp \to pK^+\Sigma^0$ will be measured simultaneously which would allow to determine the cross section ratio between Σ^0 and Σ^+ without a reduced systematic errors.

3 Beam request

In order to extract the total cross section of Σ^+ production in total one weeks of beam time are requested.
Assuming a luminosity of $10^{30}(1/cm^2/s)$, a cross section of 230 nb and a detection efficiency of 0.4 % a counting rate of 80 events/day is expected. The expected background rate of 4 events/MeV/day will result in a total background rate of about 44 events/day below the Σ^+ peak (2 x 5.5 MeV) in the missing mass distribution. Within one week about 1100 events could be detected with a statistical error of 4 % if the assumed conditions are valid. If the interference between kaon and pion exchange is constructive the cross section and the event rate goes down by a factor of 10 which would still give a significant event number above the background.

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