Measurement of the Cross Section Ratio for Λ and Σ^0 Production

Abstract

In recent threshold studies of hyperon production at COSY-11 the cross section ratio of $\sigma(pp \to pK^+\Lambda)/\sigma(pp \to pK^+\Sigma^0)$ was found to be in the order of 30 in contradiction to a ratio of about 2.5 measured at higher excess energies ($\epsilon > 350$ MeV). Different scenarios were proposed to explain this unexpected behaviour, but the present data are not sufficient to discriminate between possible explanations. Therefore it is proposed to study the transition of the cross section ratio of Λ/Σ production in the pp interaction from threshold values to the high energy level.

1 Introduction

Recently the cross section ratio $\sigma(pp \to pK^+\Lambda)/\sigma(pp \to pK^+\Sigma^0)$ was measured at equivalent excess energies up to about 13 MeV [1]. In contrast to the ratio of 2.5 given at high excess energies ($>$ 350 MeV [2]) a value of $28\,^{+6}_{-9}$ is seen close to threshold.

A possible explanation of this strong Σ suppression (or Λ enhancement) could be a strong $p\Lambda - p\Sigma$ coupling resulting in a conversion of the $p\Sigma$ to the $p\Lambda$ system. Experimentally effects of a $p\Lambda - p\Sigma$ coupling have been observed in K^- capture on a deuteron target [3]. In the Dalitz plot of the $K^-d \to \pi^- p\Lambda$ reaction a strong enhancement is seen in the invariant mass of the $p\Lambda$ system at the Σ threshold. Also in the COSY-TOF data for the $pp \to pK^+\Lambda$ reaction at 2.75 GeV/c [4] an indication for a sharp enhancement at the Σ threshold is given.

The Jülich theory group has recently performed calculations for the reaction channels $pp \to pK^+\Lambda$ and $pp \to pK^+\Sigma$ including π^0 and K^+ exchange [5]. In their approach the interaction between the emerging hyperons (Λ, Σ) and the nucleon is described by a microscopic (ΛN-ΣN) coupled channel model [6], 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. More detailed calculations are presently being performed to increase the reliability of the theoretical results.

In other investigations of the hyperon production additional production mechanisms like heavy meson exchange (ρ, ω and K^*) and/or production via nucleon resonances are considered [7], [8]. If their contributions are significant, as the results in [7] and [8] indicate, they might also have a strong influence on the Λ and Σ production.

A complete calculation should include all possible exchange graphs but apart from the complexity due to the large number of involved channels partly the coupling constants are completely unknown as well as the phases of the different amplitudes. More data are needed to figure out the contributions of different exchange graphs.

A way to distinguish between the different possibilities resulting in a threshold suppression of the Σ production are more detailed experimental information like the energy dependence of the cross section ratio. The Λ-Σ coupling is a strong threshold effect which should be limited to the close to threshold region. If, however, the $\pi - K$ interference is responsible for this effect a more smooth transition is expected because the amplitudes for the elementary production mechanisms ($KN \to KN$, $\pi N \to KY$) show a weak energy dependence.

A first preliminary result employing the Jülich-YN model A, neglecting the energy dependence of the $KN \to KN$ and $\pi N \to KY$ amplitudes, was calculated by Gasparian and Haidenbauer [9]. In this calculations a smooth decrease is observed where at an excess energy of 60 MeV a cross section ratio $\sigma_\Lambda/\sigma_\Sigma$ of about 18 is reached, see fig.3.

2 Experiment

The experiment will be performed at the COSY-11 facility using the standard missing mass technique by measuring the outgoing proton and the K^+. The feasibility of such studies has been demonstrated by the near threshold measurements of the Λ [10] and Σ production [1]. At higher excess energies the efficiency at COSY-11 is reduced. However, our Σ^0 production data prove that the Λ cross section can be well extracted at $\epsilon \sim 80$ MeV. Even more, in fig.1 a preliminary missing mass spectrum for data at 2.994 GeV/c (extracted from a measurement for the ω production) is shown which corresponds to an excess energy of 142 MeV in the $pK^+\Sigma$ and 218 MeV in the $pK^+\Lambda$ system.

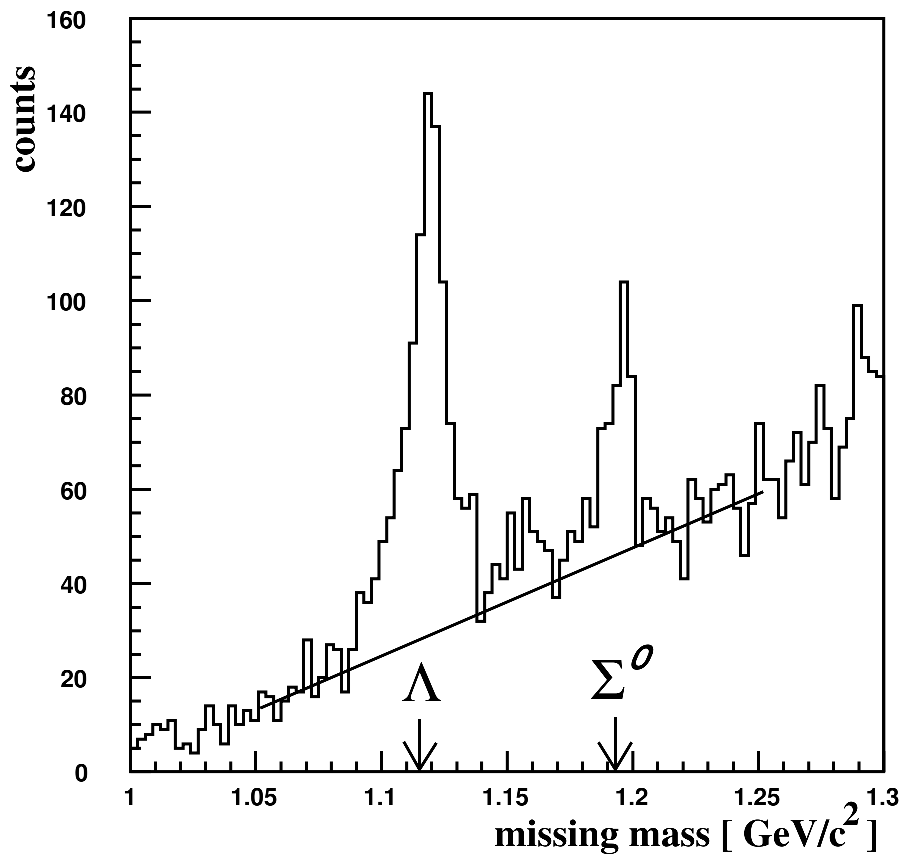

Figure 1: Missing mass spectrum calculated from 2-track events assumed to be one proton and one kaon.

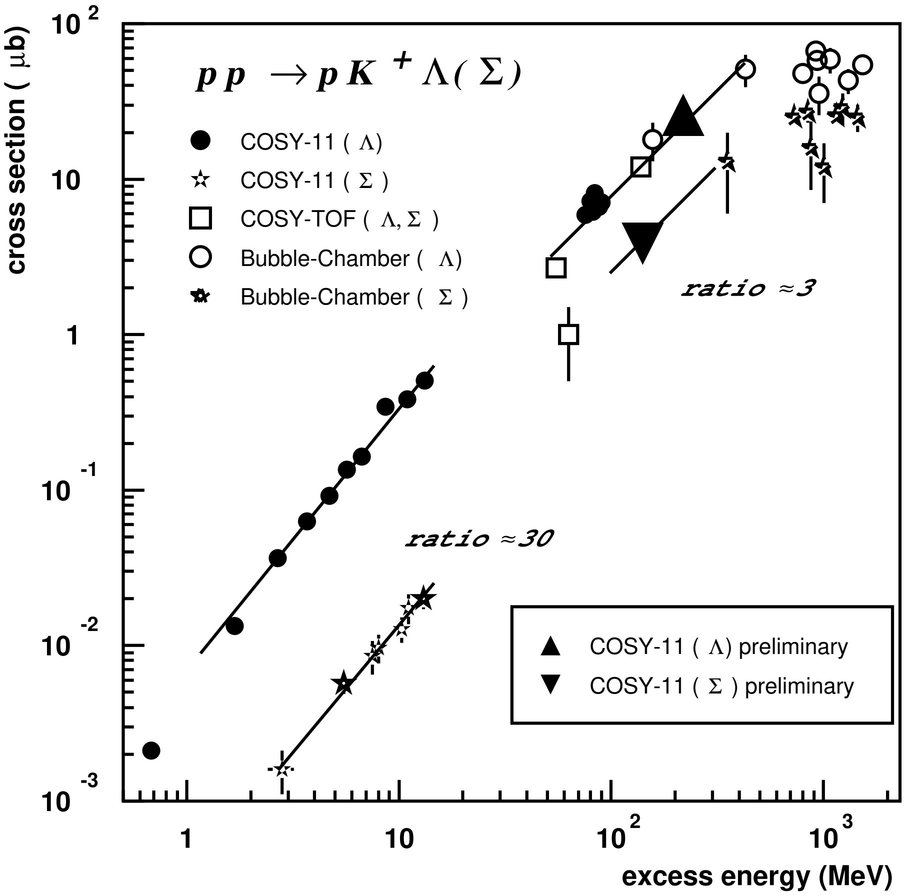

Figure 2: Compilation of the total cross sections in the hyperon channels $pp \rightarrow pK^+\Lambda$ and $pp \rightarrow pK^+\Sigma^0$ including the old bubble chamber data [2] and the results from COSY-TOF [4] and COSY-11 [10], [1].

Events with two reconstructed tracks are selected, one track with an invariant mass in the proton range and the other with an invariant mass in the K^+ range. The Λ and Σ peaks are clearly identified in spite of the low efficiency of $\sim 2 \cdot 10^{-4}$ in the Λ and $\sim 4 \cdot 10^{-4}$ in the Σ case. A rough estimate of the cross section ratio at $\epsilon = 142$ MeV results in a value of about 3 which is very close to the high energy value. The cross section for the Λ production at $\epsilon = 142$ MeV used in this calculation results from an interpolation of the existing data, (fig.2).

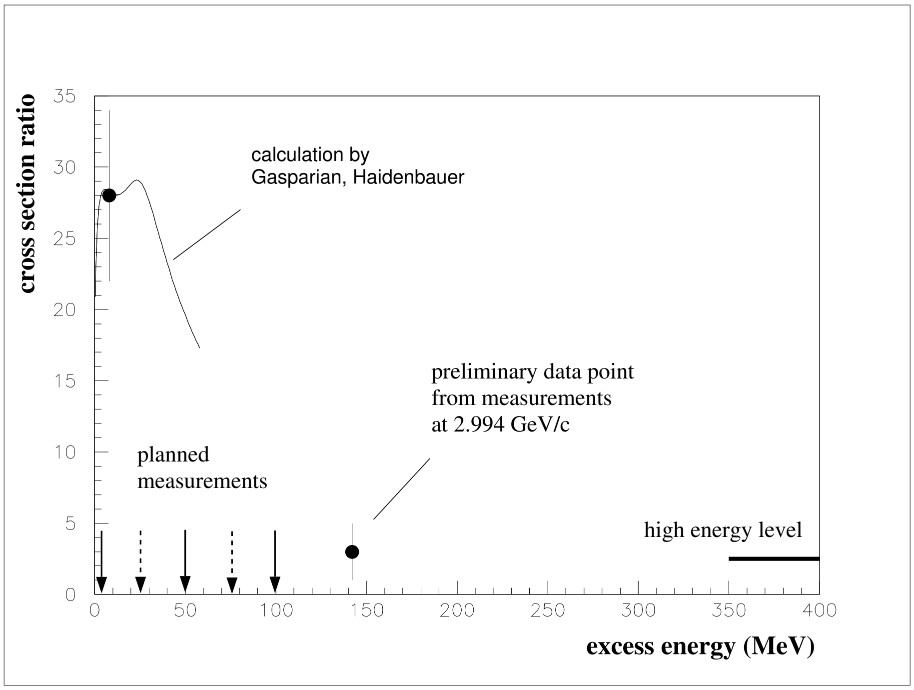

Figure 3: Ratio of the hyperon production cross section $\sigma_\Lambda/\sigma_{\Sigma^0}$ as a function of the excess energy ϵ.

The triangles in figure 2 represent the number of Λ and Σ events corrected by the acceptance which were detected in the measurement at 2.994 GeV/c. The cross section for the Σ-channel results by fixing the Λ-value to the interpolation line. The Λ-data follow a rather smooth line but in the Σ-data there seems to be a change in the behaviour between 20 - 100 MeV excess energy. In fig.3 the cross section ratio $\sigma_\Lambda/\sigma_{\Sigma^0}$ is given.

The solid line in figure 3 gives the calculated behaviour expected from the calculations in [9] where only s-waves are included. The limit of the model is at the Σ-threshold in the Λ-channel. The enhancement at around $\epsilon = 25$ MeV is a peculiar feature of the employed YN model (Jülich A) resulting from a spurious bound state in the ΣN channel and is not expected in reality. More refined calculations including an extension of the reliable excess energy range of the model are in preparation [11].

Indicated in fig.3 are the excess energies of the planned measurements. We want to fill up the region from $\epsilon = 20$ MeV to $\epsilon = 150$ MeV and measure three additional data points very close to threshold.

In total we propose to take data at 7 different excess energies which will be possible within three weeks of beamtime. The typical luminosity achieved at COSY-11 is $2 \cdot 10^{30}\, cm^{-2}s^{-1}$.

At low excess energies the cross section for the Σ^0-production is known to be 20 nb at ϵ = 13 MeV which results in about 100 Σ^0 events from four days of data taking with regard to the efficiency of $\sim$ 1 %. The cross section increase exceeds the decrease of the detection efficiency resulting in an increase of counting rate with rising excess energy. The data in fig.1 have been taken in about 40 hours of effective beam time resulting in 200 Σ^0-events and 750 Λ-events. Therefore a beam time of about four days for each data point (Λ and Σ) will be sufficient to extract cross section ratios with an accuracy better than 10 %.

Due to the uncertainty in the excess energy dependence of the cross section ratio the excess energies for the measurements will be determined during the beam time. COSY will be operated in the supercycle mode, i.e. switching between different momenta for each cycle. We want to start with ϵ = 50 MeV for four days, using 10 spills at 2.714 GeV/c (ϵ = 50 MeV for Σ^0-production) followed by one spill at 2.487 GeV/c (ϵ = 50 MeV for Λ-production). Then we switch for four days to ϵ = 100 MeV, 4-5 spills at 2.866 GeV/c (Σ^0) and one spill at 2.64 GeV/c (Λ). At COSY-11 a preliminary 'online' analysis of the data is possible with one day delay. Thus during this measurements the data at ϵ = 50 MeV will have been analyzed and depending on the extracted cross section ratio the next beam momenta will be chosen at ϵ = 25 MeV or at ϵ = 75 MeV. The procedure will be performed also for the fourth data point. All measurements should be performed with a stochastically cooled beam. After completion of the excess energy range ϵ > 20 MeV we would like to follow the same procedure for three data points at ϵ < 10 MeV. At excess energies below 10 MeV a decrease of the cross section ratio is expected from the calculations in [9]. The lowest excess energy in existing data for the Σ production [1] is about 3 MeV but the statistics is too low (39 events) to see an indication for a reduction of the cross section ratio.

3 Beam request

Three weeks of beam time are requested for the measurement of the cross section ratio $\sigma_\Lambda/\sigma_\Sigma$ in the excess energy range between ϵ = 20 - 150 MeV and ϵ = 1 - 10 MeV. Data taking is planned for seven different excess energies, i.e. 14 different beam momenta settings are necessary with a stochastically cooled beam. In order to reduce the systematic errors COSY should be operated in the supercycle mode.

Starting with 2.487 GeV/c (Λ) / 2.714 GeV/c (Σ^0) and 2.64 GeV/c (Λ) / 2.866

GeV/c (Σ^0) the third and fourth momentum settings will be determined from the analysis of the cross section ratios during the measurement before going to the low excess energy range.

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