Energy dependence of the $pp \to K^+ n\Sigma^+$ reaction at ANKE

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In contrast to neutral light hyperon channels, very little is known about Σ^+ production close to threshold. First values of the total cross section $\sigma(\Sigma^+)$ for the $pp \to K^+ n\Sigma^+$ reaction channel have been obtained at COSY-11 by detecting the K^+ and neutron in the final state [1]. This experiment reports values of $\sigma(\Sigma^+)$ that are factors of 230±70 and 90±40 higher than Σ^0 total cross section at excess energies of $\varepsilon_{\Sigma^+} = 13$ MeV (1.826 GeV) and $\varepsilon_{\Sigma^+} = 60$ MeV (1.958 GeV), respectively. Isospin considerations show that the ratio of the production cross sections $R(\Sigma^+/\Sigma^0)$ should lie in the range $1/6 < R(\Sigma^+/\Sigma^0) < 6$, and this brings into question the large values of $\sigma(\Sigma^+)$ reported in Ref. [1]. In an effort to understand the situation, a study of the $pp \to K^+ n\Sigma^+$ reaction was undertaken at the COSY-ANKE facility that did not rely on the detection of the final neutron [2, 3]. In measurements performed at five excess energies $\varepsilon_{\Sigma^+} = 13$, 47, 60, 82 and 129 MeV, three simultaneously recorded spectra have been analysed. Details of the analysis and values of the Σ^+ cross sections can be found in Refs. [2, 3].

Analysis of inclusive kaon production can lead to estimates of the total Σ^+ production cross section [4]. However, the results depend strongly on the model used for the Λ and Σ^0 contributions to the spectra. In order to obtain upper limits on $\sigma(\Sigma^+)$ at $\varepsilon_{\Sigma^+} = 13$ MeV from inclusive spectra in a less model-dependent way, data on K^+ production below the Σ^+ threshold $\varepsilon_{\Sigma^+} = -11$ MeV ($T_p = 1.775$ GeV) were collected in the same experiment. At $\varepsilon_{\Sigma^+} = 13$ MeV Σ hyperon production can only contribute in a limited ranges of momentum $p_K = 352 - 643$ MeV/c and angle $\vartheta_K < 12^\circ$. Thus, the ratio of the numbers of K^+ mesons detected below $\vartheta_K < 12^\circ$ at 1.826 GeV to those at 1.775 GeV, presented in Fig. 1, represent measurements over a significant part of the Σ production phase space.

$$R\left(\frac{1.826}{1.775}\right) = \frac{\Lambda_{1.826}}{\Lambda_{1.775}} + \frac{\Sigma^0_{1.826} + \Sigma^+_{1.826}}{\Lambda_{1.775}}. \qquad (1)$$

At these close energies the Λ contribution to the K^+ momentum spectra should change only slightly in a momentum range where both Σ can contribute. Since the data were taken during the same experimental run using the same magnetic field in the ANKE D2 magnet, the acceptances and detector efficiencies cancel out. Thus, the ratio of the numbers of K^+ is free from most systematic experimental uncertainties.

In Fig. 1 the shape expected for the contribution from the combined $pp \to K^+ p\Sigma^0/K^+ n\Sigma^+$ channels is indicated, using total cross sections $\sigma(\Sigma^0) = \sigma(\Sigma^+) = 0.021\ \mu$b, $\sigma_{1.826}(\Lambda) = 7.9\ \mu$b and $\sigma_{1.775}(\Lambda) = 6.1\ \mu$b. Depending upon how the Λ level is drawn, this comparison gives a cross section ratio of $(\sigma(pp \to K^+ p\Sigma^0) + \sigma(pp \to K^+ n\Sigma^+))/\sigma(pp \to K^+ p\Lambda) = (4 \pm 2) \times 10^{-3}$, from which we deduce that the total cross section for Σ^+ production at $\varepsilon_{\Sigma^+} = 13$ MeV is below 45 nb at the 98% confidence level. Even if the ratio of the Σ^+/Σ^0 production cross sections were a factor of six, as allowed by the triangle inequality at $\varepsilon_{\Sigma^+} = 129$ MeV, the resulting distribution would greatly overestimate the data shown in Fig. 1.

We have performed measurements of the $pp \to K^+ n\Sigma^+$ reaction at five energies close to threshold. The upper limit on $\sigma(\Sigma^+)$ from the inclusive K^+ spectra at $\varepsilon_{\Sigma^+} = 13$ MeV is two orders of magnitude smaller than the published value [1].

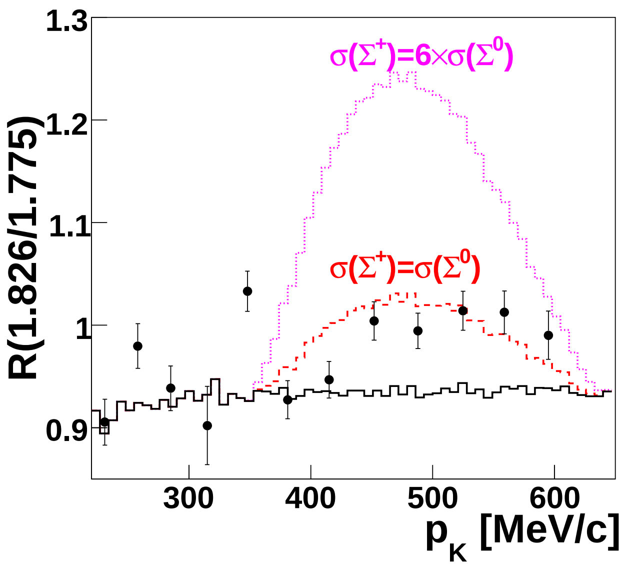

Fig. 1: Ratio of normalised count rates for inclusive K^+ production at 1.826 GeV to those at 1.775 GeV as a function of the momenta in the different telescopes. The data were taken using the ANKE range telescope system with $\vartheta_{K^+} < 12^\circ$ and a 12 MeV/c momentum bite for each telescope. The black solid histogram represents the simulation for the $pp \to K^+ p\Lambda$ reaction, whereas the dashed red one includes also contributions from Σ^+ and Σ^0 production, assuming $\sigma(\Sigma^0) = \sigma(\Sigma^+) = 0.021\ \mu$b, $\sigma_{1.826}(\Lambda) = 7.9\ \mu$b and $\sigma_{1.775}(\Lambda) = 6.1\ \mu$b. The upper magenta dotted histogram represents a simulation where the Σ^+ total cross section is taken to be six times that of Σ^0, which is the limit allowed by the triangle inequality at $\varepsilon_{\Sigma^+} = 129$ MeV.

However, much firmer conclusions could be drawn from the study of K^+p and $K^+\pi^+$ coincidence spectra. These give consistent values of $\sigma(\Sigma^+)$ that are just a little lower than those for $\sigma(\Sigma^0)$. They leave no room for the anomalously high Σ^+ total cross section previously reported [1].

References:

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