Hyperon and Kaon–Antikaon Production in Proton–Proton Scattering Close to Threshold at the COSY–11 Facility

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In exclusive production of hyperons via the $pp \to pK^+\Lambda/\Sigma^0$ channels the Λ to Σ^0 production ratio at low ($Q \leq 13\,\mathrm{MeV}$) and equal excess energies is enhanced by an order of magnitude compared to the high energy regime ($Q \geq 300\,\mathrm{MeV}$). Data on low excess energy Σ^0 production and preliminary results on the energy dependence of the Λ/Σ^0 ratio are shown and physics implications of the observed suppression are discussed.

In studies of the strangeness dissociation to charged kaon–antikaon pairs via $pp \to ppK^+K^-$ a first total cross section value at an excess energy of 17 MeV, i.e. below the Φ production threshold, is presented.

1. THE Λ/Σ^0 PRODUCTION RATIO CLOSE TO THRESHOLD

The production of Λ and Σ^0 hyperons has been compared via the associated strangeness production channels $pp \to pK^+\Lambda/\Sigma^0$ exclusively at the COSY–11 facility [1,2] at COSY Jülich [3,4]. The striking feature of the cross section data [5–7] taken at excess energy pairs ($Q_{pK^+\Lambda} = Q_{pK^+\Sigma} \leq 13\,\mathrm{MeV}$) is the suppression of the Σ^0 signal with

$$\sigma\left(pp \to pK^+\Lambda\right)/\sigma\left(pp \to pK^+\Sigma^0\right) = 28\,^{+6}_{-9}, \tag{1}$$

while at higher energies ($Q \geq 300\,\mathrm{MeV}$) this ratio is known to be about 2.5 [8].

At an excess energy of 170 MeV inclusive K^+ production data in proton–proton scattering show enhancements at the Λp and ΣN mass of similar magnitude [9]. Thus, qualitatively, effects of a strong $\Sigma N \to \Lambda p$ final state conversion, which are known for example from fully constrained $K^-d \to \pi^- p\Lambda$ data at rest [10], might account for both the inclusive SPES4 data as well as the depletion of the Σ^0 signal in the COSY–11 measurements.

In a microscopic approach within the framework of the Jülich meson exchange model, calculations considering both π and K exchange as well as rigorously treating possible FSI effects in a coupled channel approach, a final state conversion is concluded to be of minor importance for the observed cross section ratio [11]. While Λ production is found to be dominated by K exchange — experimentally confirmed at higher excess energies ($Q = 430\,\mathrm{MeV}$) from exclusive polarization transfer measurements at SATURNE [12] — both π and K exchange graphs turn out to contribute to Σ^0 production with similar strength. In result of these exploratory calculations, only a destructive interference of the π and K exchange diagrams might explain the enhancement of the Λ/Σ^0 production ratio close to threshold.

It should be noted, that the experimental data are reproduced within a factor of two by recent calculations within boson exchange models considering π and K exchange or meson exchanges and the virtual excitation of baryon resonances [13,14].

The same holds for calculations by Laget considering one boson exchange as well as nucleon–hyperon final state effects [15]. Both the inclusive SPES4 data [9] and the polarization transfer measurements [12] are well reproduced by this model at the same time.

Studies on the energy dependence of the Λ/Σ^0 production ratio have been extended at the COSY–11 facility to cover the energy range up to excess energies of 60 MeV. Although data analysis is still in progress, preliminary values are shown in figure 1 together with the earlier result obtained close to threshold [7].

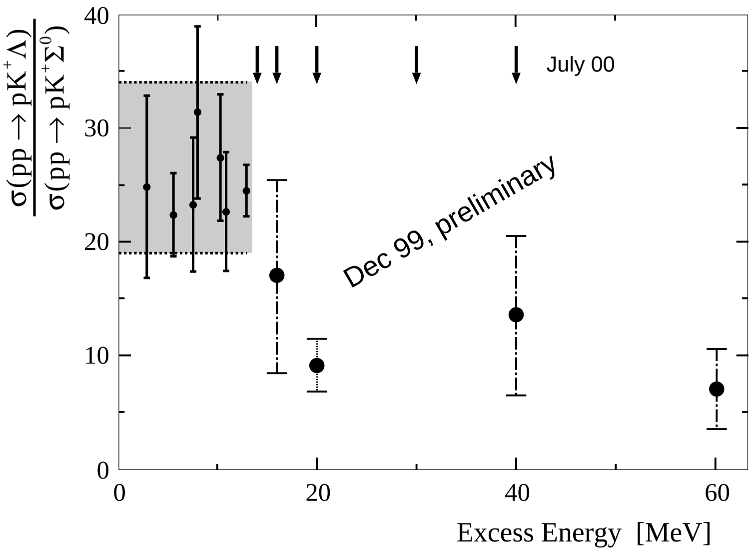

Figure 1. Energy dependence of the Λ/Σ^0 total cross section ratio. The shaded area denotes the close–to–threshold ratio (1) from [7], including measurements up to $Q \leq 13$ MeV (solid error bars). Additional preliminary data are marked by dash–dotted and dotted error bars corresponding to preliminary and final luminosity determination, respectively. Arrows indicate further data recently taken at the COSY–11 facility.

So far, only for the preliminary result at $Q = 20$ MeV, the luminosity has been determined accurately, indicating the size of the error bars to be expected in the final analysis at the other excess energies. At this stage of analysis, the result obtained at 60 MeV exceeds the Λ/Σ^0 ratio at high energies by a factor of three. However, the ratio's strong decline seems to be located in the range of 10 MeV $-$ 20 MeV above the hyperon production thresholds. Further statistics have been added in July 2000, thus the final precision for the Λ/Σ^0 production ratio in the near future from the COSY–11 data set will be in the order of $10 - 15\,\%$. Unless the reaction mechanism changes, these data might provide a sensitive testing ground especially for the off–shell properties of microscopic hyperon–nucleon models [11].

2. EXCLUSIVE KAON–ANTIKAON PRODUCTION AT COSY–11

Studies on the reaction $pp \to ppK^+K^-$ close to threshold have been motivated by the continuing discussion on the nature of the scalar resonances $f_0\,(980)$ and $a_0\,(980)$, which have been interpreted as conventional $q\overline{q}$ states [16], two–quark–two–antiquark states [17], or as $K\overline{K}$ molecules [18,19]. Within the Jülich meson exchange model for $\pi\pi$ and $\pi\eta$ scattering the $K\overline{K}$ interaction dominated by vector meson exchange gives rise to a bound state in the isoscalar sector identified with the $f_0\,(980)$ [20]. Both shape and absolute scale of $\pi\pi \to K\overline{K}$ transitions crucially depend on the strength of the $K\overline{K}$ interaction, which, in turn, is a prerequisite of a $K\overline{K}$ molecule interpretation of the $f_0\,(980)$. Similar effects might be expected for the elementary kaon–antikaon production in proton–proton scattering, although no microscopic calculations are presently available.

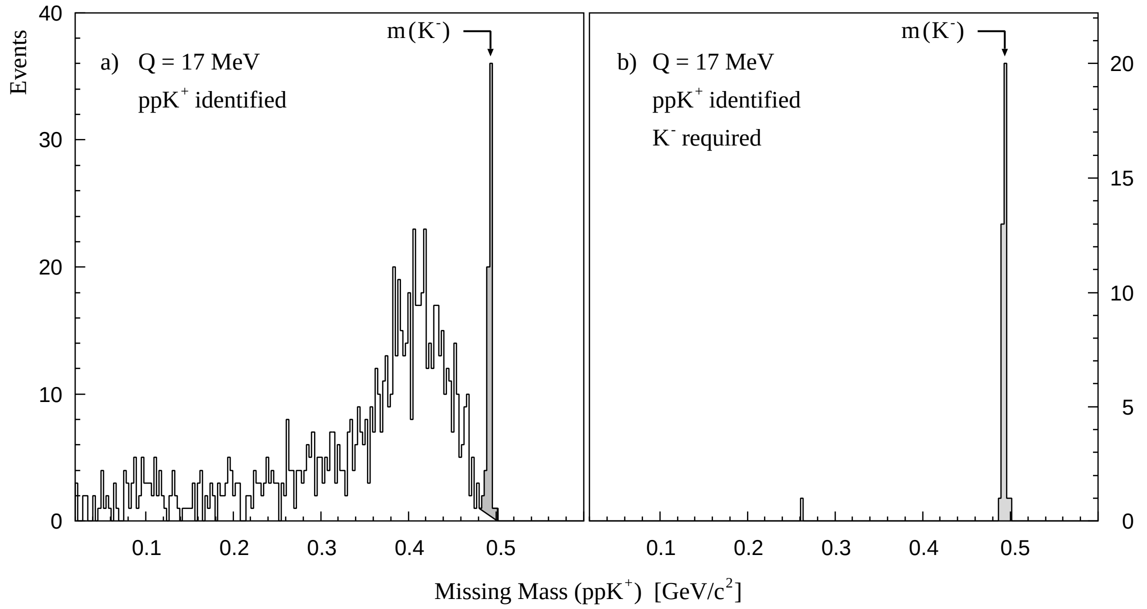

Figure 2. Missing mass distribution with respect to an identified (ppK^+) subsystem at an excess energy of 17 MeV above the $pp \to ppK^+K^-$ production threshold without (a) and with (b) K^- detection.

From the measured complete four–momentum vector information of positively charged ejectiles, the missing mass distribution with respect to an identified (ppK^+) subsystem is shown in figure 2a. A sharp peak at the charged kaon mass with a resolution (FWHM) of $\approx 2\,\mathrm{MeV/c^2}$ is clearly separated from a broad background structure between 0.3 and $0.5\,\mathrm{GeV/c^2}$ superimposed on a small continuous background. At least the broad structure is explained by the excitation of the hyperon resonances $\Lambda\,(1405)$ and/or $\Sigma\,(1385)$: One of the identified protons may originate from the decay of the originally produced resonance Y via $pp \to pK^+Y \to pK^+pX$, with X denoting a system of one or more undetected particles. In consequence, the missing mass is shifted to values too low for a (ppK^+K^-)

interpretation. Qualitatively, the structure is well reproduced in Monte Carlo simulations.

In addition, a K^- consistent hit in the dedicated part of the detection system is required in figure 2b: While the background is effectively suppressed, the signal at the charged kaon mass remains, giving additional and independent proof of a background free identification of the ppK^+K^- final state. Quantitatively, the number of events in figure 2b is in very good agreement with expectations taking into account acceptance and kaon decay.

In result, a total cross section value for the reaction $pp \to ppK^+K^-$ has been extracted at an excess energy of $Q = 17\,\mathrm{MeV}$ ($p_{beam} = 3.356\,\mathrm{GeV/c}$)

$$\sigma_{\mathrm{pp}\to\mathrm{ppK^+K^-}}(\mathrm{Q} = 17\,\mathrm{MeV}) \;=\; 1.87 \pm 0.28\,^{+0.28}_{-0.36}\,\mathrm{nb}, \tag{2}$$

taking into account both statistical and systematical errors [21].

For the first time, the scale of the exclusive K^+K^- production in proton–proton scattering is fixed by this value for the total cross section at excess energies below the Φ production threshold (see also [22]). Compared to K^+ production via $pp \to pK^+\Lambda$ [5–7] the elementary K^- production appears to be suppressed by two orders of magnitude.

In the near future, the energy dependence of the $pp \to ppK^+K^-$ total cross section will be studied at the COSY–11 facility by measurements at two execess energies below and above the present value of 17 MeV, respectively, to investigate possible deviations from the expected phase space behaviour modified by proton–proton and, eventually, $K\overline{K}$ final state interactions.

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