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Associated strangeness production at threshold

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Abstract. The associated strangeness dissociation at threshold has been studied at the COSY-11 facility measuring the hyperon and the K^+K^- meson pair production. Measurements of the near-threshold Λ and Σ^0 production via the $pp \to pK^+\Lambda/\Sigma^0$ reaction (S. Sewerin *et al.*, Phys. Rev. Lett. **83**, 682 (1999)) at COSY-11 have shown that the Λ/Σ^0 cross-section ratio exceeds the value at high excess energies ($Q \geq 300\,\mathrm{MeV}$ (A. Baldini *et al.*, *Total Cross-Sections for Reactions of High-Energy Particles, Landolt-Börnstein, New Series*, Vol. **I/12** (Springer, Berlin, 1988))) by an order of magnitude. For a better understanding additional data have been taken between 13 MeV and 60 MeV excess energy. The near-threshold production of the charged kaon-antikaon pair is related to the discussion about the nature of the scalar states in the $1\,\mathrm{GeV}/c^2$ mass range, *i.e.* the $f_0(980)$ and $a_0(980)$ (O. Krehl, R. Rapp, J. Speth, Phys. Lett. B **390**, 23 (1997)). The interpretation as a $K\overline{K}$ molecule is strongly dependent on the K-$\overline{K}$ interaction which can be studied via the production channel. A first total cross-section value on the reaction $pp \to ppK^+K^-$ at an excess energy of 17 MeV (C. Quentmeier *et al.*, Phys. Lett. B **515**, 276 (2001)), *i.e.* below the ϕ production threshold, was measured.

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1 The Λ/Σ^0 production ratio close to threshold

One of the main investigations of the COSY-11 Collaboration is the associated strangeness production of the neutral Λ and Σ^0 hyperons in the reactions $pp \to pK^+\Lambda/\Sigma^0$. Since the quark structures of these hyperons are analogous to each other, one can expect similar production mechanisms. In such a case the cross-section ratio $\mathcal{R}_{\Lambda/\Sigma^0} \equiv \frac{\sigma(pp\to pK^+\Lambda)}{\sigma(pp\to pK^+\Sigma^0)}$ should be mainly determined by the isospin relation which leads to $\mathcal{R}_{\Lambda/\Sigma^0} = 3$. That is consistent with the ratio of about 2.5 observed at high excess energies ($Q \geq 300\,\mathrm{MeV}$) [1]. Very close to threshold, in the range of excess energies $Q \leq 13\,\mathrm{MeV}$, the total cross-sections for the Λ- and Σ^0-hyperon production were measured exclusively at the COSY-11 facility [2,3] at COSY Jülich [4]. The most remarkable feature of the data [5,6] was that at the same excess energy the total cross-section for the Σ^0 production appeared to be about a factor of 28^{+6}_{-9} smaller than for the Λ-particle.

Enhancements in the missing mass distribution at the Λp and ΣN thresholds observed in inclusive K^+ production data, taken at SPES 4 [7] in proton-proton scattering at $Q = 252\,\mathrm{MeV}$, both having about the same magnitude, suggest a strong $\Sigma N \to \Lambda p$ final-state conversion. This conversion might be responsible for the decrease of the Σ^0 production yield close to threshold as seen in the COSY-11 data. Strong $\Sigma N \to \Lambda p$ conversion effects are also suggested when interpreting the results of K^- scattering on deuterons [8]. Here a sharp peak is clearly seen at an effective mass of the Λ-proton system $m_{\Lambda p} = 2131\,\mathrm{MeV}/c^2$ corresponding exactly to the $\Sigma^0 p$ threshold.

However, in calculations within the Jülich meson exchange model [9], the final-state conversion is rather excluded as a dominant origin of the observed Σ^0 suppression. In these calculations both the π and the K exchange

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are taken into account with inclusion of final-state interaction (FSI) effects. Λ production is found to be dominated by kaon exchange, which is consistent with the experimental results obtained by the DISTO Collaboration [10] at higher excess energies ($Q = 430\,\mathrm{MeV}$). Here the importance of the K exchange is confirmed by a measurement of the polarisation transfer coefficient. On the other hand, in the case of Σ^0 production both the π and the K exchanges are found to contribute with about the same strength. A destructive interference of the π and K exchanges, suggested by Gasparian *et al.* [9], is able to describe the suppression of the Σ^0 production observed in the close-to-threshold data.

Studies of the production ratio in [11] consider two different models: either a π plus K exchange approach or the excitation of intermediate N^*-resonances via an exchange of π- and heavier non-strange mesons, where the N^*'s couple to the K^+Y channel [12], but any interference of the amplitudes is neglected.

The latter mechanism is also taken into account in an effective Lagrangian approach [13] where the strangeness production mechanism is modeled by the exchange of π, ρ, ω and σ mesons, which excite the nucleon resonances $N^*(1650)$, $N^*(1710)$, and $N^*(1720)$. In both calculations experimental data are reproduced within a factor of two.

The one-boson exchange calculation performed by Laget [14] takes into account interference effects of pion and kaon exchange by selecting the relative sign for these two mechanism to maximise the cross-section and reproduce not only the data of the Λ/Σ^0 ratio within a factor of two, but also the polarisation transfer results of the DISTO experiment [10].

Recent COSY-11 measurements [15] extend the Λ/Σ^0 production ratio in proton-proton collisions up to an excess energy $Q = 60\,\mathrm{MeV}$. This allows the study of the behaviour of the cross-section ratio in the transition region between the low-energy range $Q \leq 13\,\mathrm{MeV}$ and data at high excess energies $Q \gg 60\,\mathrm{MeV}$. Together with the new [15] and earlier [5] experimental data, calculations obtained within the approach of Gasparian *et al.* [9] are presented in fig. 1. Here a destructive interference of π and K exchange is assumed, with different choices of the hyperon-nucleon interaction model for low-energy scattering in the final state. The results of the calculations are very sensitive to the off-shell properties of the microscopic hyperon-nucleon interaction.

Both the rather good description of the experimental data very close to threshold by the Jülich model A [16] and the fair agreement for the Nijmegen model (dashed line in fig. 1) with the right tendency of the cross-section ratio should not be regarded as being very conclusive. In the case of the Nijmegen model an explicit isospin symmetry breaking had to be introduced [17]. As a consequence, the relation between amplitudes of the $\Sigma^{\pm}p$ and $\Sigma^0 p$ channels is not uniquely defined [18].

As already emphasised in [19], constant elementary amplitudes and S-waves alone in the final state may not be justified for excess energies above 20 MeV and thus the calculation based on the new Jülich model [20] (solid line in fig. 1) does not reproduce the excitation function of the experimental cross-section ratios.

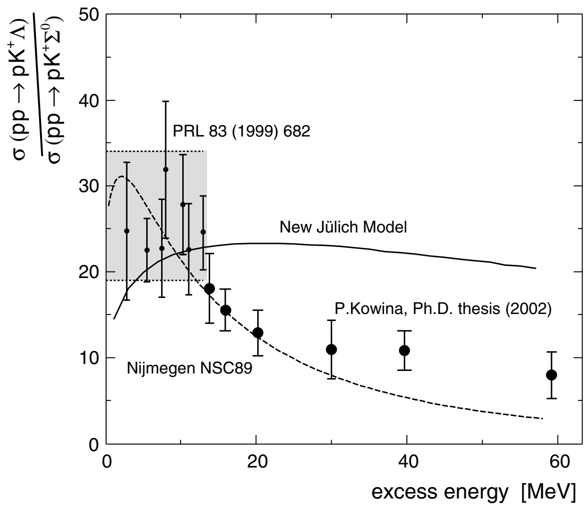

Fig. 1. Energy dependence of the cross-section ratio for Λ/Σ^0 production in proton-proton collisions. Experimental data within the range up to 13 MeV are from [5], data at higher excess energies from [15]. Calculations are performed within the Jülich meson exchange model, assuming a destructive interference of K and π exchange [19] and employing the microscopic YN interaction models Nijmegen NSC89 (dashed line [17]) and the new Jülich model (solid line [20]), respectively.

The data for the Λ production in the excess energy range up to 60 MeV are described fairly well by calculations of the phase space behaviour, which is modified by the p-Λ FSI [15] consistent with the scattering parameters from [21]. In contrast, in the case of Σ^0 there is almost no deviation from the phase space behaviour in the energy dependence of the cross-section for Σ^0 production, which might indicate a very weak p-Σ^0 FSI [15]. However, it should be noted that the apparently weak influence of the p-Σ^0 FSI could be feigned by either higher partial-wave contributions or an energy dependence of the elementary amplitude [19]. Therefore further measurements at an excess energy of $Q \approx 60\,\mathrm{MeV}$ are highly desirable to study the angular distribution of the produced Λ and Σ^0 hyperons.

2 Exclusive kaon-antikaon production at COSY-11

Different interpretations of the structure of the scalar resonances $f_0(980)$ and $a_0(980)$ are known [22,23]. Some motivations for measurements of the K^+K^- production were calculations within the Jülich meson exchange model for the $\pi\pi$ and $\pi\eta$ scattering. The results of these calculation are very sensitive on a strength of the $K\overline{K}$ interaction [24]. Therefore, measurements of the energy dependence of the cross-section can help to confirm or exclude the hypothesis, that the production of K^+K^- occurs via the excitation of the intermediate resonance. Unfortunately those calculations are done only for $\pi\pi$ scattering. However,

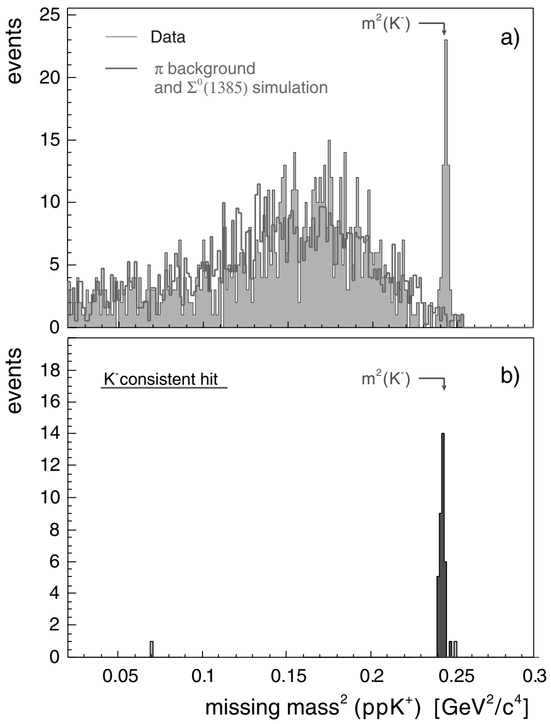

Fig. 2. Missing-mass distribution with respect to an identified (ppK^+) subsystem at an excess energy of 17 MeV above the $pp \to ppK^+K^-$ production threshold without (a) and with (b) K^- detection [25].

similar effects are expected in the case of the pp interaction [26].

From the reconstruction of the full four-momentum vectors for all positively charged ejectiles one obtains the missing-mass spectrum of the (ppK^+) system shown in the upper part of fig. 2, where a clear peak with a resolution (FWHM) of $\approx 2\,\mathrm{MeV}/c^2$ is seen at the mass of the charged kaon. The physical background shown is mainly due to the excitation of the hyperon resonances $\Lambda(1405)$ and $\Sigma(1385)$, where the proton originating from the hyperon resonance decay is detected.

Requiring an additional K^- hit in the dedicated negative particle detector installed at the COSY-11 facility [2] one obtains an almost background-free spectrum of the missing mass of the ppK^+ system shown in the lower part of fig. 2. The number of entries in the K^- peak is slightly reduced compared to the upper figure due to the influence of the kaon decay and acceptance. The analysis resulted in a first total cross-section for the elementary K^+K^- production below the Φ threshold at $Q = 17\,\mathrm{MeV}$, measured in proton-proton scattering. Its value is $\sigma = 1.80 \pm 0.27^{+0.28}_{-0.35}\,\mathrm{nb}$ with statistical and systematical errors, respectively [25]. The cross-section for the $pp \to pK^+\Lambda$ [5,6,15] reaction, which is the elementary K^+ production is two orders of magnitude larger compared to the cross-section for the elementary K^- production in the $pp \to ppK^+K^-$ reaction at corresponding excess energies.

At the present stage it is not possible to judge whether K^+K^- proceeds via a resonant production with the excitation of the $f_0(980)$ and $a_0(980)$ scalar resonances.

The energy dependence of the total cross-section for K^+K^- below [25] and above [27] the Φ threshold might be compared to data for η' [1,28] production, where for an excess energy range $100 \le Q \le 1000\,\mathrm{MeV}$ the excitation function is well described by a three-body phase space ($\sigma \propto Q^2$). To describe the data below 100 MeV at least the FSI between the final-state protons and possibly even the FSI between the final-state proton and meson have to be considered.

This is not the case for the K^+K^- production, where calculations based on a one-boson exchange [29] neglecting FSI effects give significantly different results than simply assuming a four-body phase space behaviour. Contrary to the $\pi N \to \eta' N$ amplitudes, the K^+p and especially the K^-p amplitudes are strongly energy dependent [30]. The reason might be a compensation of the interaction of the two strongly interacting subsystems pp and K^-p in the final state or an additional degree of freedom given by the four-body exit channel. In such a case the influence of the FSI effects should be more pronounced at the K^+K^- production threshold [30].

Additional data were taken at the COSY-11 facility at excess energies 10 MeV and 28 MeV, *i.e.* close to the K^+K^- production threshold and slightly below threshold for the Φ production. The data analysis is presently in progress.

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