Strangeness Production in Proton–Proton Collisions Close to Threshold*

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Exclusive data on the reactions $pp \to ppK^+K^-$ and $pp \to pK^+\Lambda/\Sigma^0$ have been taken at the cooler synchrotron COSY close to threshold.

At equal excess energies, an enhancement of the Λ/Σ^0 ratio by one order of magnitude has been observed compared to data at higher excess energies. New results obtained at the COSY–11 facility explore the transition region between this low–energy Σ^0 suppression and excess energies of 60 MeV.

A first total cross section for elementary antikaon production below the ϕ threshold has been determined, two orders of magnitude smaller compared to kaon production at the same excess energy.

1. ELEMENTARY ANTIKAON PRODUCTION

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 $a_0(980)$ [1]. Within the Jülich meson exchange model the $K\overline{K}$ interaction gives rise to a bound state in the isoscalar sector identified with the $f_0(980)$ [2]. 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 in proton–proton scattering, and first results of exploratory microscopic calculations have recently been presented [3].

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A first total cross section value for the elementary antikaon production below the ϕ threshold in proton–proton scattering has been extracted from exclusive data taken at the COSY–11 installation at an excess energy of Q = 17 MeV with $\sigma = 1.80 \pm 0.27^{+0.28}_{-0.35}$ nb including statistical and systematical errors, respectively [4]. The experimental technique is based on the measurement of the complete four–momenta of positively charged ejectiles. Requiring furthermore a K^- consistent hit in the dedicated negative particle detection system of the COSY–11 facility [5], the identification of the four particle final state becomes (almost) completely free of background (fig. 1).

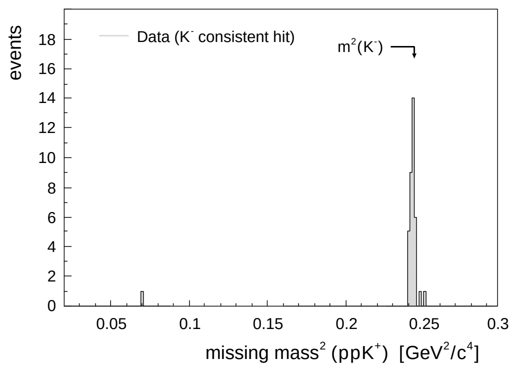

Figure 1. Missing mass squared with respect to an identified (ppK^+) subsystem 17 MeV above the K^+K^- threshold. The bin width corresponds to an experimental resolution of $\approx 2\,\mathrm{MeV/c^2}$ (FWHM).

However, the presently available statistics of K^+K^- events is not sufficient to distinguish non–resonant K^+K^- production and resonant production via the scalar resonances $f_0(980)$ and $a_0(980)$ from differential observables, e.g. the $K\overline{K}$ invariant mass distribution.

Considering the energy dependence of the total cross section, η, ω and η' production indicate strong imprints of final state interaction (FSI) at excess energies Q $\leq$ 100 MeV in the proton–proton and, in case of η, in the proton–meson subsystems. Contrary to this, $pp \to ppK^+K^-$ cross section data obtained at COSY–11 [4] and DISTO [6] below and above the ϕ threshold, respectively, are in reasonable agreement with one–boson exchange calculations [7] neglecting FSI effects. Presently it is not clear whether the absence of the FSI influence in the $pp \to ppK^+K^-$ reaction might be explained by a partial compensation of the pp and K^-p interaction in the final state or by the additional degree of freedom given by the four–body final state. In the latter case FSI effects are expected to be more pronounced at energies very close to the K^+K^- production threshold [8].

Data taking at excess energies closer to threshold and slightly below the Φ production threshold, i.e. at excess energies of 10 MeV and 28 MeV with respect to the K^+K^- threshold, has been successfully completed early this year at the COSY–11 facility and data analysis is presently in progress.

2. EXCLUSIVE KAON–HYPERON FINAL STATES

The most striking feature of the exclusive close–to–threshold data on Λ and Σ^0 production in proton–proton scattering taken at the COSY–11 facility [9, 10] is the Σ^0 suppression with $\sigma\,(pp \to pK^+\Lambda)\,/\sigma\,(pp \to pK^+\Sigma^0) = 28^{+6}_{-9}$ observed at equal excess energies below Q = 13 MeV. At excess energies $\geq$ 300 MeV this ratio is known to be about 2.5 [11].

Inclusive K^+ production data in pp scattering from the SPES 4 facility at an excess energy of 252 MeV with respect to the $pK^+\Lambda$ threshold show enhancements at the Λp

and ΣN thresholds of similar magnitude [12]. Qualitatively, a strong $\Sigma N \to \Lambda p$ final state conversion might account for both the inclusive SATURNE results as well as the Σ^0 depletion in the COSY–11 data. Evidence for such conversion effects is known e.g. from exclusive hyperon data via $K^- d \to \pi^- \Lambda p$ [13].

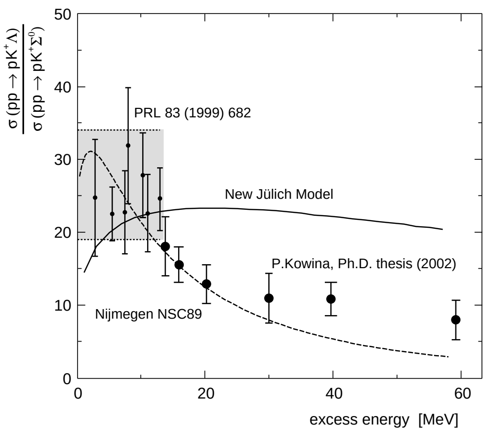

Figure 2. Λ/Σ^0 production ratio in proton–proton collisions as a function of the excess energy. Data within the shaded area are from [10], results at higher excess energies from [18]. Calculations [19] within the Jülich meson exchange model assume a destructive interference of K and π exchange and employ the microscopic YN interaction models Nijmegen NSC89 (dashed line [20]) and the new Jülich model (solid line [21]), respectively.

However, in exploratory calculations performed within the framework of the Jülich meson exchange model [14], taking into account both π and K exchange diagrams in a coupled channel approach, a final state conversion is rather excluded as origin of the experimentally observed ratio. While Λ production is found to be dominated by kaon exchange both π and K exchange turn out to contribute to the Σ^0 channel with similar strength. It is concluded [14], that a destructive interference of π and K exchange might explain the close–to–threshold Σ^0 suppression.

An experimental study of Σ production in different isospin configurations should provide a crucial test for the above interpretation, as for the reaction $pp \to nK^+\Sigma^+$ an opposite interference pattern is found as compared to the $pK^+\Sigma^0$ channel. Measurements close to threshold are planned at the COSY–11 facility in the near future.

Contributions from direct production as well as heavy meson exchanges have been neglected so far in these calculations [14] but might influence the Λ/Σ^0 production ratio [15]. For complementary theoretical studies — considering strangeness production close to threshold to proceed by one–boson exchanges or one–boson exchange followed by the excitation of nucleon resonances — we refer to refs. [16] and a recent review [17].

Measurements on the Λ/Σ^0 production ratio in proton–proton collisions have been extended up to excess energies of Q = 60 MeV at the COSY–11 installation [18]. In comparison to the experimental data, in figure 2 calculations are included obtained within the approach of [14] assuming a destructive interference of π and K exchange with different choices of the microscopic hyperon nucleon model to describe the interaction in the final state [19]. The result depends on the details — especially the off–shell properties — of the hyperon–nucleon interaction employed. At the present stage both the good agreement found in [14] for Jülich model A [22] with the close–to–threshold result and for the Nijmegen model (dashed line in fig. 2) with the energy dependence of the cross section ratio should rather be regarded as accidental[4]. Calculations using the new Jülich model (solid line in fig. 2 [21]) do not reproduce the tendency of the experimental

[4]In the latter case an SU(2) breaking in the $^3S_1$ ΣN channel had to be introduced [20] resulting in an ambiguity for the $\Sigma^0 p$ amplitude [23].

data. It is suggested in [19] that neglecting the energy dependence of the elementary amplitudes and higher partial waves might no longer be justified beyond excess energies of 20 MeV.

The energy dependence of the total cross section for Λ production up to excess energies of Q = 60 MeV is much better described by a phase space behaviour modified by the $p\Lambda$ final state interaction than by pure phase space [18]. However, unlike the findings of [10] based on data up to Q = 13 MeV, in the energy range up to 60 MeV Σ^0 production is equally well described neglecting any FSI effect. One reason for this qualitatively different behaviour might be, that the $\Sigma^0 p$ FSI is much weaker compared to the Λ–proton system. On the other hand, a fit to the energy dependence based on a phase space behaviour implies dominant S–wave production and energy independent reaction dynamics as discussed above. Within the statistics of the present experiment, P–wave contributions can be neither ruled out nor confirmed at higher excess energies for Σ^0 production. Consequently, high statistics Σ^0 data would be needed in future to study the onset of different partial waves experimentally.

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