Threshold Kaon Production in the Proton-Proton Interaction at COSY-11

COSY-11 Collaboration:

IKP -, ZEL -Forschungszentrum Jülich, Germany
IKP, Westfälische Wilhelms-Universität, Münster, Germany
Institut of Physics, Jagellonian University, Cracow, Poland
Institut of Nuclear Physics, Cracow, Poland
IUCF, Bloomington, Indiana, USA
NRC, Atomic Energy Authority, Cairo, Egypt

Spokesperson: Magnus Wolke

Abstract
Experimental results of strangeness production at threshold of the K^+K^- meson pair production in the elementary proton-proton interaction are presented. Additional data are needed to determine more accurate questions concerning the reaction mechanism.

1. INTRODUCTION

The focus of the experiments performed at COSY-11 is to explore the physics of strange-antistrange quark production and the role of these quarks in the configuration of the emerging hyperons and/or mesons. In view of the attempts to understand the nature of the quark-flavour composition, its structure, and its creation process, the associated strangeness production is of fundamental interest. It is essential that different complementary tools are used for the understanding of the complex hadronic systems. At the COler SYnchrotron COSY-Jülich the COSY-11 collaboration investigated the associated strangeness production via two channels. In the $pp \to pKY \quad (Y = \Lambda,\ \Sigma^0)$ reaction [1–5] the strangeness is dissociated into a hyperon and a meson and in the $pp \to ppK^+K^-$ reaction [6,7] the antistrange-strange quark pair is divided between two mesons. Total cross sections have been determined and lead to the first physics interpretations.

Theoretical models in nuclear physics, in particular heavy-ion physics, depend critically on input from elementary particle interactions. Meson-nucleon and meson-meson interactions dominate the nucleus-nucleus scattering mechanisms. Therefore, knowledge of the kaon production cross section in the elementary NN interaction is important for studies of the production of hypernuclei in nucleon scattering on nuclei, and for investigations of the strangeness production mechanism in heavy-ion collisions, which may provide information about hot, dense nuclear matter and eventually the existence of a quark-gluon plasma.

The production threshold region offers the advantage that
i) experimentally the reaction products are confined in a forward cone, whereas background reactions populate the phase-space more homogeneously and
ii) the momentum transfers are relatively large with only the lowest partial waves contributing, which should simplify the theoretical framework.

2. Strangeness Production into $pp\ K^+K^-$

The production of a K^+K^- meson pair is very interesting in view of the existence of $K\bar{K}$ molecules and especially for the structure of the objects $f_0(980)$ and $a_0(980)$. The structure of these two resonances has provoked a long-standing discussion in the literature describing them as normal $q\bar{q}$ states, exotic hybrids, hadronic K^+K^- molecules and even glueball candidates. Again, they have been at the center of attention during the recent HADRON'97 [8] conference where the controversial discussion could best be summarized by three presentations given

i) by Lafferty [8] from the OPAL collaboration, which observed the decay $Z^0 \to f_0(980)$, $f_2(1270)$, and $\phi(1020)$, and conclude that all features of the $f_0(980)$ are consistent with a pure $q\bar{q}$ scalar-meson description,

ii) by Lebrun [8] from the FERMILAB E-687 collaboration, which found a strong $f_0(980)$ resonance in the invariant mass of two oppositely-charged pions in the $D_s \to \pi^+\pi^-\pi^+$ decay, but observed no such resonance in the $D^+ \to \pi^+\pi^-\pi^+$ channel, an indication of a significant strangeness component in the $f_0(980)$ resonance. However, for final conclusions additional data would be required,

iii) by Kirk [8] from the OMEGA collaboration, which measured central proton-proton collisions and found that "the $f_0(980)$ acts in an opposite fashion from all known $q\bar{q}$ states". This observation is based on a small momentum transfer to the produced resonance state, as typically expected for gluon-rich mechanisms.

For a general review of the present stage of speculations about the scalar mesons and glueballs from the theoretical and experimental point of view see ref. [9,10].

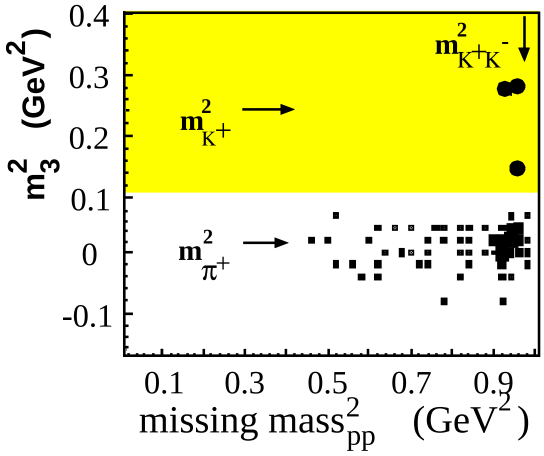

Figure 1. Squared invariant mass of the third charged ejectile versus the squared missing mass in the pp system for data at 3.321 GeV/c beam momentum.

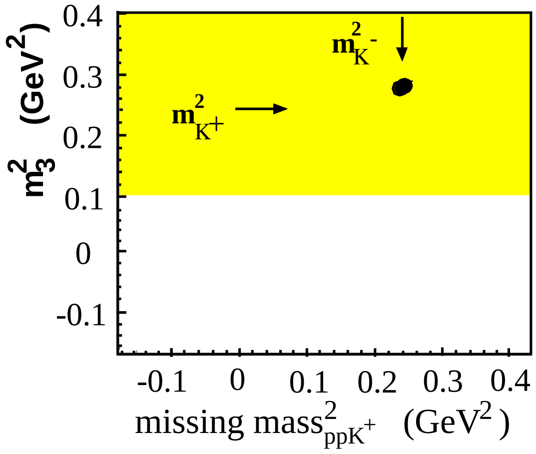

Figure 2. Squared invariant mass of the third particle vs. the missing mass in the ppK^+ system. Two events remain consistent with a $pp \to ppK^+K^-$ hypothesis.

The first results of the COSY-11 collaboration on K^+K^- meson pair production in the $pp \to pp\, K^+K^-$ reaction are given in Figs. 1 and 2 [6], which show the invariant mass of the third positively-charged particle versus missing masses of identified subsystems pp (left) and ppK^+ (right hand side). The shaded region indicates the invariant mass range which is accepted for the kaons in the further analysis. The data result from a run (April 96) at 3.321 GeV/c, which corresponds to an excess energy of 6.1 MeV. Two events could be selected with a clear signature for the K^+K^- production. The resulting cross section is $\approx$ 500 pb. In the measurement below threshold, made with comparable luminosity, no events were observed.
It should be stressed that experimentally available luminosities have increased by more than one order of magnitude since then.
At COSY-11, further data on K^+K^- production have been taken at different excess energies (according to the beam request Exp. No. 46.1 presented at the PAC meeting April 1997) with an extracted yield of some ten events for each momentum setting. The data are under evaluation and will give an excitation curve in the threshold region which might serve for a first comparison to theoretical expectations.
These preliminary results are shown in Fig. 3 [6,7], and seem to indicate that the relative cross section increase with increasing excess energy ($4 \to 27$ MeV) is much

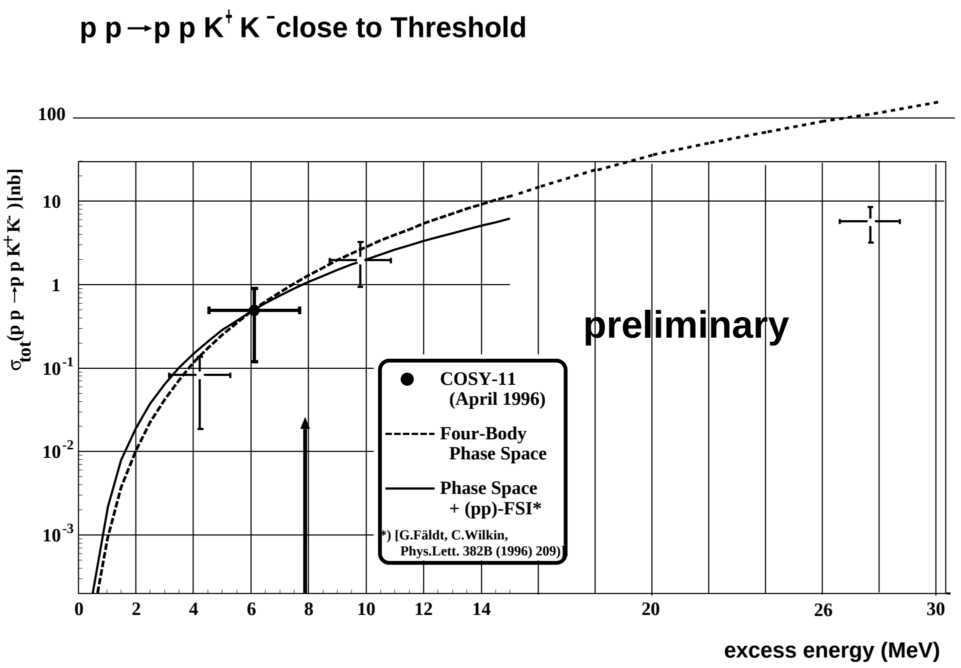

Figure 3. Cross sections for the $pp \rightarrow pp\ K^+K^-$ reaction at different excess energies in the threshold region. The K^- was not observed directly but rather determined by the missing mass method.

smaller than would be expected by a four-body phase-space distribution for the reaction $pp \rightarrow pp\ K^+K^-$. On an absolute scale, no theoretical cross section predictions to which the present data could be compared are available.

However, since the phase-space distribution does not predict an absolute cross section, the curves shown in Fig. 3 could be adjusted to the cross section at Q = 27.4 MeV as well in which case we would observe experimental cross sections in the range of Q = 4 $\rightarrow$ 10 MeV which are at least an order of magnitude too high. There are two experimental and two physics indications which are in favour of such an interpretation that at least a large fraction of the observed cross section yield is not due to a non-resonant K^+K^- production:

a) The silicon-pad detectors at the inner region of the dipole magnet should observe hits from the negatively charged K^-, with a relative probability of about 80 % after setting the geometrical acceptance of the $pp\ K^+$ identification to unity. However, we observe only about 30 %, i.e. we miss more than 50 % of the expected K^- signature. With a statistics of some ten events this argument is certainly rather limited.

b) With a resolution of $\pm \approx 50\ MeV/c^2$ the missing mass spectrum of the assumed K^- is much wider than we are used to observe from other reactions in which we identify the third particle via the missing mass method as e.g. in the reactions $pp \to pp\eta(\eta')$ or $pp \to pK^+\Lambda$ where the $\eta(\eta')$ or Λ particles are determined via the missing mass.

c) Physics wise it has to be taken into account that we might produce the K-meson pair via the intermediate f_0 (or a_0) resonances as $pp \to ppf_0 \to ppK^+K^-$, where a phase-space behaviour according to a four-body phase-space distribution is not to be expected but rather a three-body phase-space or at least a four-body phase-space which is strongly modified by a K^+K^- final state interaction. In an extreme consideration the phase-space distribution should even follow a three-body pattern including the proton-proton final state interaction.

d) Figure 4 represents the possibility of observing either the ejectiles i) pK^+pK^- with less than 3 % probability or the ejectiles ii) pK^+p with a major probability if the intermediate resonance Λ^{1405} is excited.

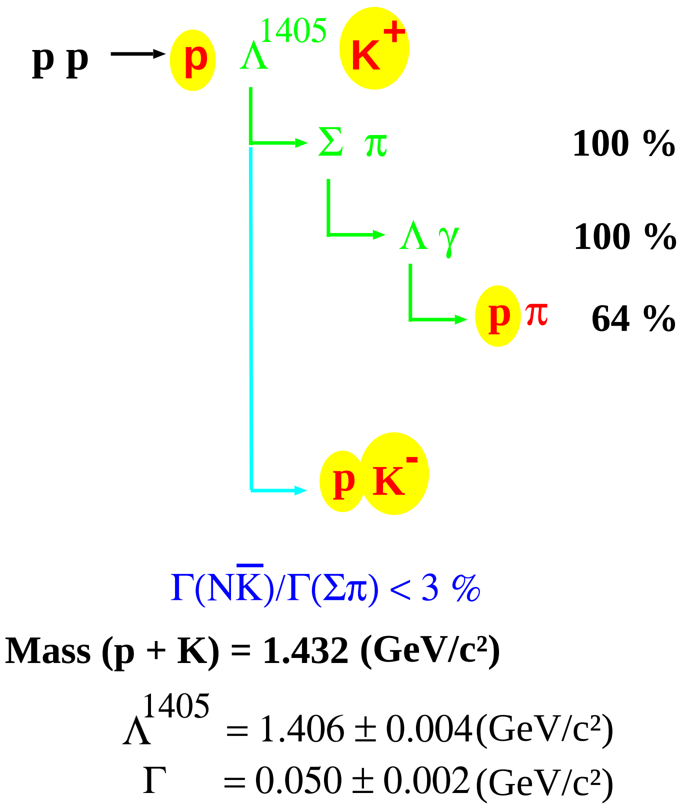

Figure 4. Possible decay modes of the Λ^{1405} after its production via the $pp \to p\,\Lambda^{1405}\,K^+$ reaction.

On the other hand, if the possibility ii) plays a significant role the ppK^+ final state reaction products should be observable below the ppK^+K^- threshold, since the mass of the system $p\Lambda^{1405}K^+$ is 2838 MeV and falls below the mass of the system pK^+pK^- with 2864 MeV.

2.1. BEAM TIME REQUEST

In order to clarify the outlined questions we are asking for the following beam time:

a) cross section measurements of the $pp \to ppK^+K^-$ reaction at
Q = 14, 17, 21, 26 MeV to fill in the gap obvious in Fig. 3, in order to observe the cross section behaviour in the threshold region,

b) cross section measurements of the $pp \to ppK^+(K^-)$ reaction at
Q = -3, 3, -26 MeV, to verify the possibility of an intermediate Λ^{1405} resonance.

See the order as presented in the table for our priorities among these Q - values.

In order to make use of the achievements from our last experiment for the $pK^+\Lambda(\Sigma)$ production we would like to run again in a supercycle with equivalent beam optics of COSY.

The first five listed beam momenta are subject of this proposal and amount to four weeks. The last two should be done, depending on a) the performance of the run and b) for Q = - 26 MeV the result of the measurement below threshold at Q = - 3.
The expected integrated luminosity is based on already achieved experimental conditions with 2×10^{10} stored protons in COSY.

Beam time parameters				
Beam momentum [GeV/c]	**Q [MeV]**	**integrated Luminosity**	**expected events**	**days to run**
3.292	**- 3**	$\mathbf{14 \times 10^{35}}$	**? no ?**	**8**
3.311	**3**	$\mathbf{14 \times 10^{35}}$	**10**	**8**
3.346	**14**	$\mathbf{9 \times 10^{35}}$	**44**	**5**
3.356	**17**	$\mathbf{7 \times 10^{35}}$	**44**	**4**
3.369	**21**	$\mathbf{5 \times 10^{35}}$	**39**	**3**
3.385	26	5×10^{35}	42	3
3.220	- 26	14×10^{35}	- ?? -	8
Sum:				**28** + 11 = 39

REFERENCES

1. J. Balewski et al., Phys. Lett. **B 388** (1996) 859.
2. J. Balewski et al., Phys. Lett. **B**., in press.
3. J. Balewski et al., JEP **A**., in press.
4. G. Schepers, PhD thesis, in preparation, University Münster, 1998
5. S. Sewerin, PhD thesis, University Bonn, probably in 1999.
6. M. Wolke, PhD thesis, University Bonn, 1997.
7. T. Lister, PhD thesis, in preparation, University Münster, 1998.
8. HADRON'97, BNL, August 25 - 30 1997, Conference Proceedings to be published.
9. F. E. Close, hep-ph/9701290 - RAL-97-004 and see summary talk in ref. [8].
10. E. Klempt, see summary talk in ref. [8].