Total Cross Section of the Reaction pp $\rightarrow$ ppK^+K^- at COSY–11

COSY–11 Collaboration

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Beam Time Request for the COSY–11 Proposal 61:
Threshold Kaon Production in the Proton–Proton Interaction at COSY–11

Abstract

The strangeness dissociation into two kaons is interesting on its own as a fundamental process. In addition, predictions of relativistic transport models for subthreshold antikaon production depend on the input of the elementary cross section in nucleon–nucleon collisions close to threshold. Results obtained during the COSY–11 beam time in September 1998 show at an excess energy of 17 MeV a clear signal in the (ppK^+) missing mass spectrum at the K^- mass with six events of the reaction pp $\rightarrow$ ppK^+K^- identified distinctively, i.e. with all final state particles detected. Compared with a measurement below threshold, the method of analysis proves to be unambiguous. In order to confirm the very rough estimate of a total cross section in the order of 900 pb as soon as possible at different beam momenta we request three weeks of beam–time during the second half of 1999.

The Reaction pp $\rightarrow$ ppK^+K^- Close to Threshold

Within the framework of the Jülich meson exchange model [1] a $K\overline{K}$ molecule structure of the scalar object f_0 (980) — still being controversely interpreted from recent experimental data [2] — is closely related to the strength of the $K\overline{K}$ interaction, which is of decisive influence for both shape and absolute value of $\pi\pi \rightarrow K\overline{K}$ excitation functions [3]. Thus, studies of the $K\overline{K}$ channel in proton–proton scattering may contribute to the determination of the strength of the $K\overline{K}$ interaction.
The elementary antikaon production cross section in nucleon–nucleon collisions via NN $\rightarrow$ NN$K\overline{K}$ close to threshold is an important input for the description of subthreshold production in relativistic transport models [4]. At the same time, antikaon production in heavy–ion collisions at subthreshold energies is expected to probe the antikaon properties at high baryon density. Within relativistic transport models [5,6] the antikaon yield has been shown to increase with a decreasing in–medium mass [4]. As a reduced in–medium antikaon mass is consistent with a strong attractive antikaon

potential, the antikaon properties in dense nuclear matter play in addition an important role for astrophysics [7, 8].

Experimental Technique

At the COSY–11 installation (fig. 6) the four–momenta of positively charged particles are directly experimentally available from a momentum determination in combination with a time–of–flight measurement. Trajectories measured by two drift chamber stacks (D1,D2) are traced back in the dipole field to the target position, the time–of–flight is measured between the scintillation hodoscopes S1 or S2 and a large area scintillation wall S3. A detailed description of the detection system is given in [9].
Preselecting two proton final states, the time of the production in the target t_0 is intrinsically provided and an indirect time–of–flight measurement between t_0 and the hodoscope S1 for a third charged particle not hitting the stop scintillator S3 can be applied. Thus, with the momentum reconstructed as described above, a complete four–momentum information is available for a third positively charged ejectile in addition to two identified protons in the exit channel.
Negatively charged particles can be detected with reduced acceptance, which for the K^- detection remains at a level of more than 40 per cent at excess energies of 30 MeV with respect to the $(\mathrm{K}^+\mathrm{K}^-)$ threshold. The dedicated part of the detection system is mounted inside the dipole gap (fig. 6) and consists of highly granulated silicon pad detectors and a scintillator read out on both sides.

Previous Results obtained at COSY-11

With no additional signal from a negatively charged particle being required the identification of a (ppK^+) subsystem leads to the reaction type

$$\mathrm{pp} \rightarrow \mathrm{ppK}^+\mathrm{X}. \tag{1}$$

In this case the underlying reaction mechanism is not unambigous, as one of the identified protons may originate from the decay of a previously produced hyperon Y in $\mathrm{pp} \rightarrow \mathrm{pK}^+\mathrm{Y} \rightarrow \mathrm{pK}^+\mathrm{pX}$. Thus, in reaction type (1), X denotes a system of one or more undetected particles.

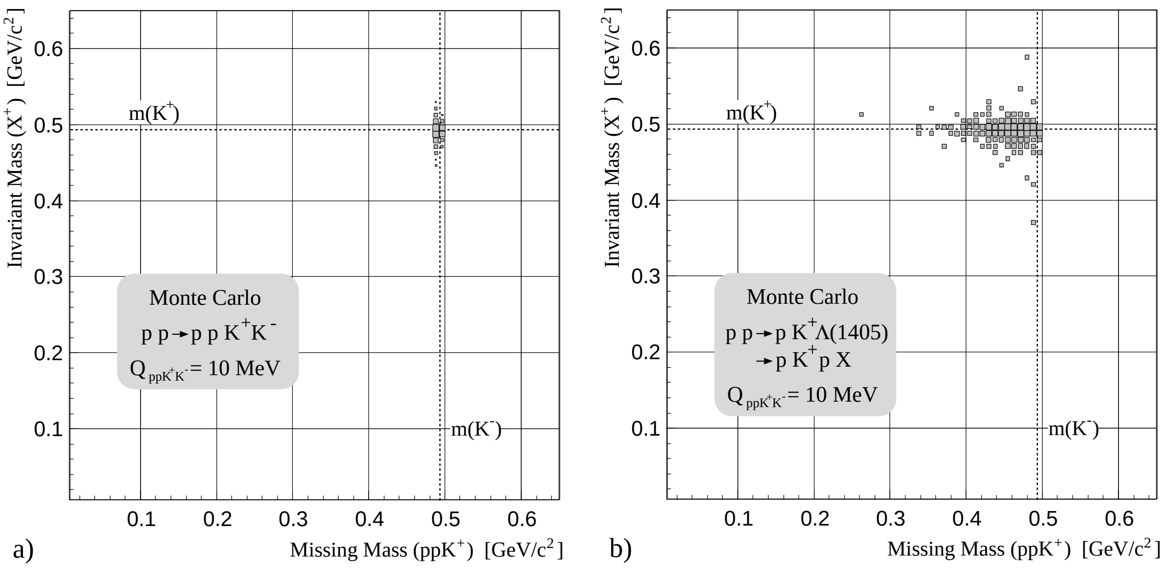

Figure 1: Invariant mass of a third positively charged ejectile besides two identified protons in the exit channel versus the missing mass with respect to the (ppK^+) subsystem at 10 MeV excess energy above the $(\mathrm{K}^+\mathrm{K}^-)$ threshold according to Monte Carlo simulations of the reactions $\mathrm{pp} \rightarrow \mathrm{ppK}^+\mathrm{K}^-$ (a) and $\mathrm{pp} \rightarrow \mathrm{pK}^+\Lambda\,(1405) \rightarrow \mathrm{pK}^+\mathrm{pX}$ (b).

In consequence, the missing mass with respect to the identified (ppK^+) subsystem may shift to values too small for a $(\mathrm{ppK}^+\mathrm{K}^-)$ hypothesis as demonstrated by the simulations in figure 1.

An experimental acceptance decreasing with increasing excess energy favours final states close to threshold, thus a dominant influence of the hyperons $\Sigma^0\,(1385)$ and $\Lambda\,(1405)$ is expected [10]. Furthermore, reactions of the type $pp \to pK^+\Lambda x \to pK^+p\pi^-x$ might contribute, where x denotes a gamma or a neutral pion.
Experimental data at $Q = 10\,\mathrm{MeV}$ in excess of the (K^+K^-) threshold are given in figure 2 and, when compared to the simulations of figure 1, show a clear hint of the significance of the hyperon channels on the (ppK^+) system. Out of ten observed events only two are within the expected mass resolution for being possible $pp \to ppK^+K^-$ candidates.

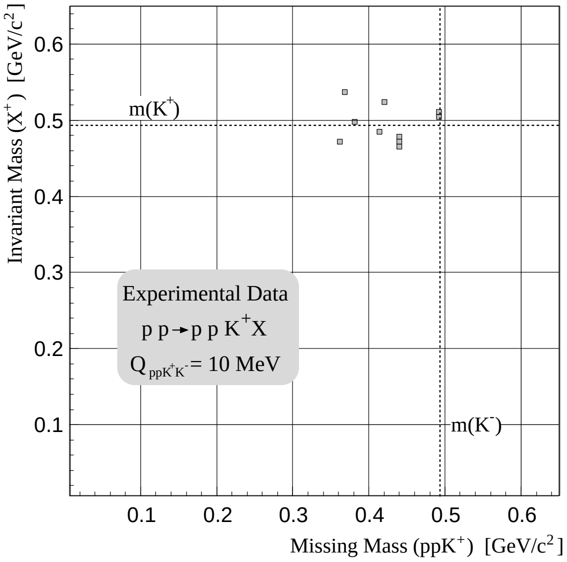

Figure 2: Experimental data at an excess energy of 10 MeV with respect to the (K^+K^-) threshold. Axes are the same as in figure 1.

In addition, none of the events in figure 2 close to the expected mass range for the (ppK^+K^-) hypothesis shows a hit in the negatively charged particle detection system, which provides another piece of evidence for the assumption of dominant hyperon production in final states of the reaction type (1).

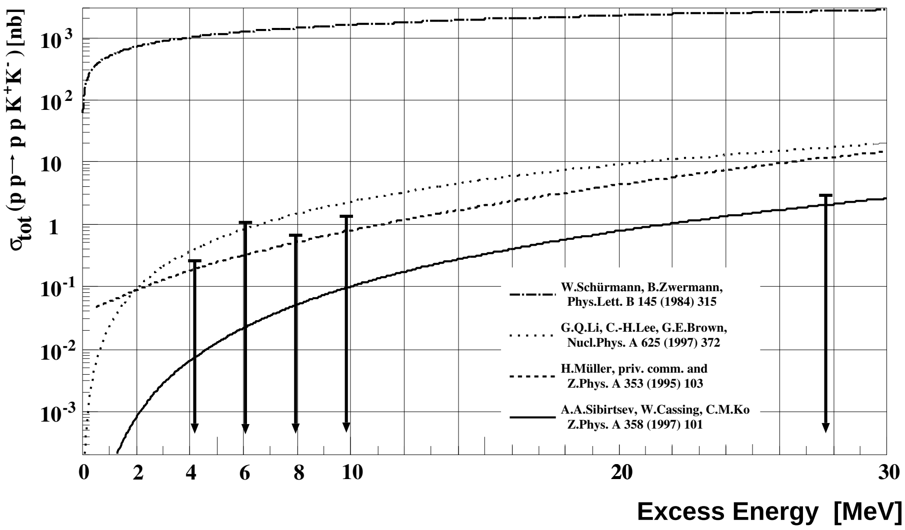

Figure 3: The total cross section for $pp \to ppK^+K^-$: Upper limits at a confidence level of 95 % measured at COSY–11 [10], parametrizations and calculations are given in [12–15].

Earlier data taken by COSY–11 at five different beam momenta up to excess energies of 30 MeV show no enhancement that can be considered a clear exclusive signal of one of the reaction channels discussed, especially not of the K^+K^- production. Thus, from previous measurements [10,11] only

upper limits of the total cross section for the charged kaon pair production have been extracted (fig. 3).
In comparison, a parametrization given by Schürmann and Zwermann [12] for the pp $\rightarrow$ ppK^+K^- total cross section obtained from high energy data, predictions within the *ROC* (*RO*ssendorf *C*ollision Model [13]), results from a one–boson exchange model [15] and a parametrization [14] taking into account the 6 MeV COSY–11 results and the predictions of [15] are included. The high energy parametrization [12] clearly overestimates the experimental results by three orders of magnitude close to threshold, the upper limit at 28 MeV excess energy prefers the one–boson exchange model results [15] to the *ROC* prediction and the parametrization given in [14].

Beam Time September 1998 — Preliminary Results

In May 1998 we asked for four weeks of beam time to clarify the influence of the hyperon channels by measuring at excess energies of Q = −3 MeV and +3 MeV, i. e. symmetrically around the (ppK^+K^-) threshold, and at Q values of 14 MeV, 17 MeV and 21 MeV to compare with the low excess energy results [18]. Three weeks of beam time were granted by the PAC and have been used to measure at the proposed excess energies of −3 MeV, +3 MeV and 17 MeV with respect to the (ppK^+K^-) threshold.

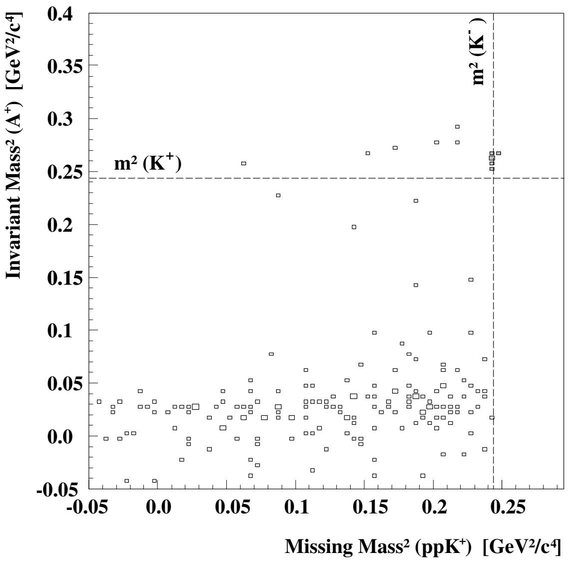

Figure 4: Invariant mass squared for a charged particle A^+ in addition to two identified protons versus the missing mass squared of the corresponding (ppA^+) system at 17 MeV excess energy with respect to the (ppK^+K^-) threshold. For the missing mass with respect to the three particle subsystem the charged kaon mass is assumed for A^+ in the calculation.

Although data analysis is still in progress, preliminary results are presented at this stage [16]. Invariant mass distributions of a third positively charged ejectile versus the missing mass squared with respect to an assumed (ppK^+) subsystem are shown for the excess energy Q = 17 MeV and the corresponding result from the measurement below the (ppK^+K^-) threshold in figures 4 and 5, respectively. Integrated luminosities are comparable.
From the discussion of previous results one has to conclude that the K^- identification is experimentally crucial to discriminate the (ppK^+K^-) final state from hyperon production channels. Therefore, in figures 4 and 5 only events with a corresponding hit in the scintillator of the negative particle detection system are taken into consideration.
A group of six events clearly stands out in figure 4 at the expected values of the charged kaon mass for both the invariant mass of a third charged ejectile after the identification of two protons and the missing mass with respect to the (ppK^+) subsystem. In contrast, no candidates for a (ppK^+K^-) hypothesis are found for the measurement below threshold. In order to substantiate the reaction hypothesis positively the measured hit position in the silicon pad detector has been

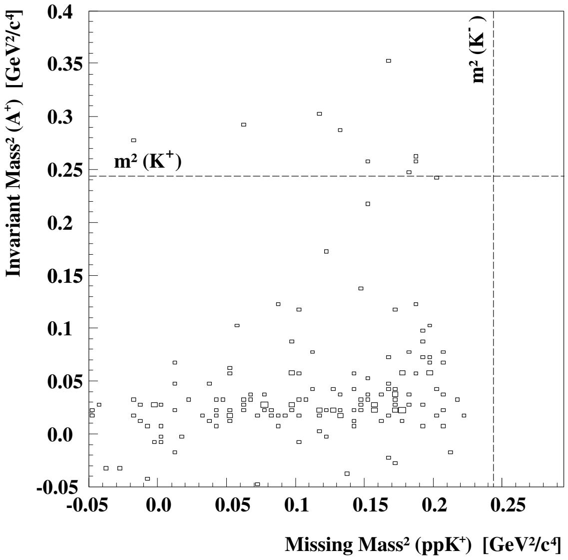

Figure 5: Same as figure 4, but for the measurement 3 MeV below threshold.

checked by tracing negatively charged kaons in the dipole field with a momentum derived from momentum conservation and the directly measured momenta of the (ppK$^+$) system and is found to be in good agreement. In figure 6 one exemplary event — with all four final state particles of the reaction pp $\rightarrow$ ppK$^+$K$^-$ being identified — is displayed schematically to illustrate the experimental technique.

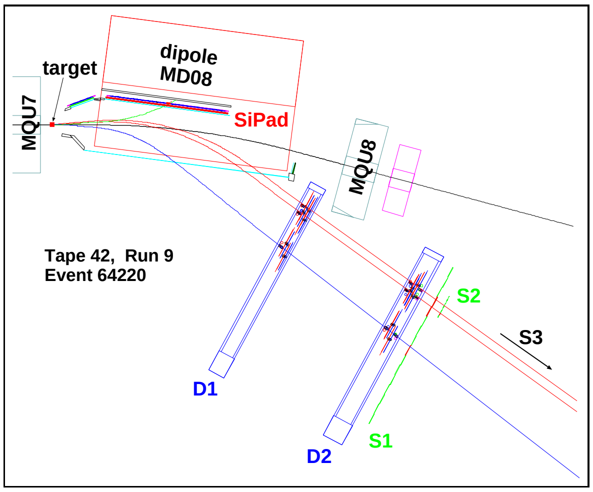

Figure 6: Exemplary (ppK$^+$K$^-$) event in the schematically sketched detector setup of the COSY–11 installation measured in September 1998 at an excess energy of 17 MeV.

As the luminosity determination has not yet been performed accurately, a first estimation of an integrated luminosity of $(1 \pm 0.5) \times 10^{36}\,\mathrm{cm}^{-2}$ results with six events been identified in a first — very preliminary — estimate of the total cross section for the reaction pp $\rightarrow$ ppK$^+$K$^-$ at 17 MeV excess energy of 900 pb. The current uncertainty in the luminosity determination will be reduced to a typical level below 5 % in the final analysis.

Beam Request

In order to confirm this first measured value of the total cross section for the reaction pp $\rightarrow$ ppK$^+$K$^-$ as soon as possible we ask for three weeks of beam time in the second half of 1999.
Beam time parameters are given in table 1. The integrated luminosity is based on already achieved experimental conditions with 2×10^{10} protons stored in COSY, the number of expected events

follows from assuming the energy dependence of the total cross section being determined by phase space modified by the proton–proton final state interaction [17].
It is proposed to run at two beam momenta higher than in the September 1998 beam time, which are from acceptance studies and the assumed energy dependence of the cross section expected to result in a larger counting rate for the (ppK^+K^-) final state. The excess energy of $Q = 21\,\mathrm{MeV}$, close to the September 1998 data point at $Q = 17\,\mathrm{MeV}$, has already been part of the original proposal [18] and is intended to confirm the $Q = 17\,\mathrm{MeV}$ cross section. The data point at $Q = 28\,\mathrm{MeV}$ will replace the previously measured COSY–11 upper limit and, thus, fix the scale of the reaction $pp \to ppK^+K^-$ independently at a higher energy.

Beam Momentum [GeV/c]	Excess Energy[b] [MeV]	Integrated Luminosity [cm^{-2}]	Expected Events[a] with K^- identification	Expected Events[a] without K^- identification	Days to Run
3.369	21	20.7×10^{35}	14	29	12
3.390	28	15.6×10^{35}	15	30	9

[a]assuming a phase space behaviour of the cross section modified by proton–proton final state interaction
[b]with respect to the (ppK^+K^-) threshold

Table 1: Beam time parameters for the proposed measurement of the reaction $pp \to ppK^+K^-$ close to threshold at the COSY–11 installation.

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