Energy Dependence of the pp $\rightarrow$ ppK$^+$K$^-$ Total Cross Section Close to Threshold

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

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Abstract

The strangeness dissociation in the elementary nucleon–nucleon scattering via the pp $\rightarrow$ ppK$^+$K$^-$ reaction is of fundamental interest.
At the COSY–11 installation, a first preliminary absolute total cross section value of $2.1\,(\pm\,0.8)$ nb at an excess energy of $Q = 17\,\mathrm{MeV}$ has recently been determined from a total of 60 identified events. In order to continue studies on the energy dependence of the total cross section close to threshold at two different excess energies we request five weeks of beam time in total, two weeks during the second half of 2000.

COSY–11 Results on the Reaction pp $\rightarrow$ ppK$^+$K$^-$

While early studies on the reaction pp $\rightarrow$ ppK$^+$K$^-$ at the COSY–11 installation resulted in upper limits on total production cross sections [1, 2], a significant increase in luminosity due to both an improved cluster target performance and an increase in the COSY beam intensity allowed to determine an absolute value of the total cross section close to threshold for the first time [3]. Preliminary results from a running period in September 1998 on the basis of COSY Proposal 61 [4] at an excess energy of $Q = 17\,\mathrm{MeV}$ have been presented to the PAC in April 1999 (see also Proposal 61 for a detailed description of the physics motivation). In order to confirm the result at higher statistics two weeks of beam time have been granted (Proposal 61.1 [5]).

Experimental Technique

At the experimental facility COSY–11 four–momenta of positively charged reaction products are directly available combining momentum and time–of–flight information.
The internal magnetic spectrometer allows a momentum determination via ray tracing back particle trajectories measured using two sets of drift chamber stacks (D1,D2 in fig. 1) through the precisely known dipole field to the target position. A time–of–flight measurement between the scintillator hodoscopes S1,S2 and a large area scintillation wall S3 allows a particle identification and hence provides the full four–momentum information.
In view of the short kaon lifetime an indirect time–of–flight measurement is used to identify a third charged ejectile in addition to two detected protons in the exit channel: The (start) time of production in the target is intrinsically provided by tracing back the proton trajectories towards the target location with the stop signal being generated by the "start" scintillator S1.
Negatively charged particles — as indicated for a K$^-$ consistent hit in figure 1 — are detected by a dedicated part of the detection system consisting of granulated silicon pad detectors and a scintillation counter both mounted inside the dipole gap.

Total Cross Section at $Q = 17\,\mathrm{MeV}$

For the combined result from three running periods in September 1998, May 1999 and July 1999, the missing mass with respect to an identified (ppK$^+$) subsystem is shown in figure 2.
A sharp peak at the charged kaon mass — as expected for a (ppK$^+$K$^-$) final state — is clearly separated from a broad background structure which is explained by the excitation of the hyperon

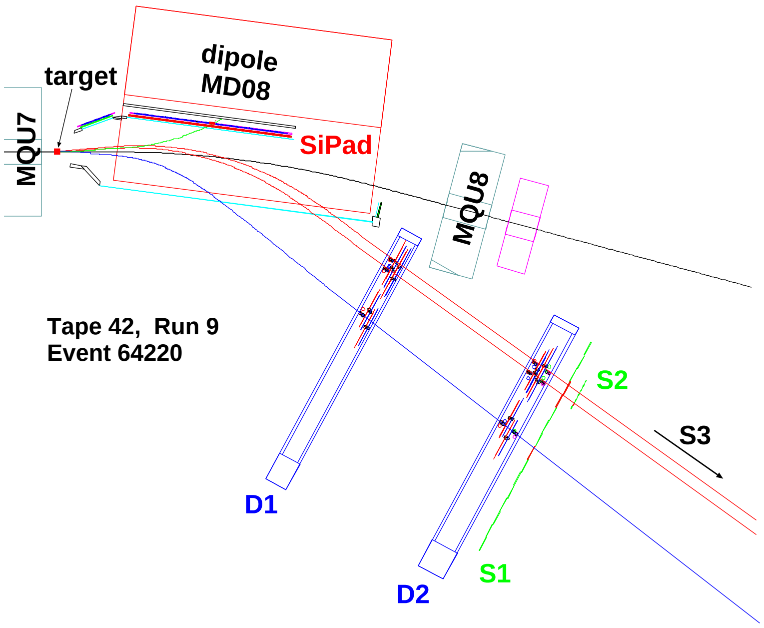

Figure 1: Schematic sketch of the COSY–11 installation including particle trajectories of a reconstructed (ppK^+K^-) event measured during the beam time in September 1998.

resonances $\Lambda\,(1405)$ and $\Sigma\,(1385)$: One of the identified protons may originate from the weak decay of a previously produced hyperon Y via $pp \to pK^+Y \to pK^+pX$ where X denotes a system of one or more undetected particles. In consequence, the missing mass with respect to the identified (ppK^+) subsystem may shift to values too small for a (ppK^+K^-) hypothesis. Qualitatively, the background structure is reproduced in Monte Carlo simulations of the hyperon resonance channels. Experimentally, in order to directly discriminate between a possible hyperon resonance excitation and the production of charged kaon pairs, a K^- hit in the dedicated part of the detection system is required in addition to an identified (ppK^+) subsystem in figure 3. While the broad background structure of figure 2 appears effectively suppressed, the strong signal at the charged kaon mass remains. Quantitatively, the number of events with an additional K^- hit agrees well with expectations from Monte Carlo simulations taking into account the acceptance of the negative particle detection system. In consequence, the peaking structure at the charged kaon mass in the (ppK^+)

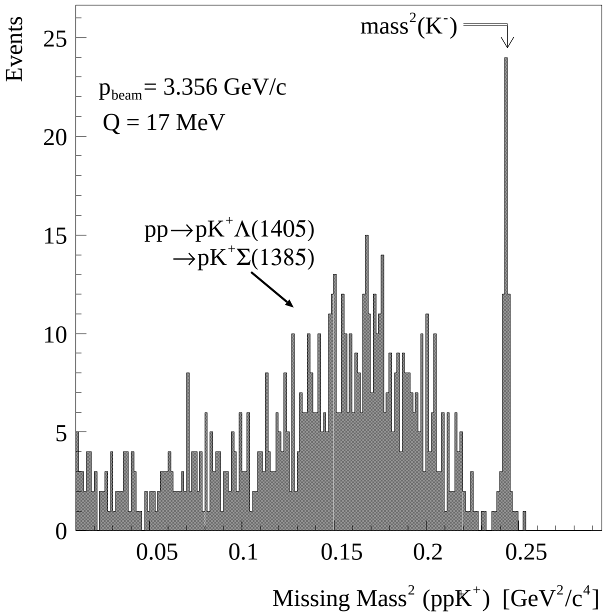

Figure 2: Missing mass distribution with respect to an identified (ppK^+) subsystem at a nominal excess energy of 17 MeV ($p_{beam} = 3.356$ GeV/c) from three running periods in 1998 and 1999 (see text).

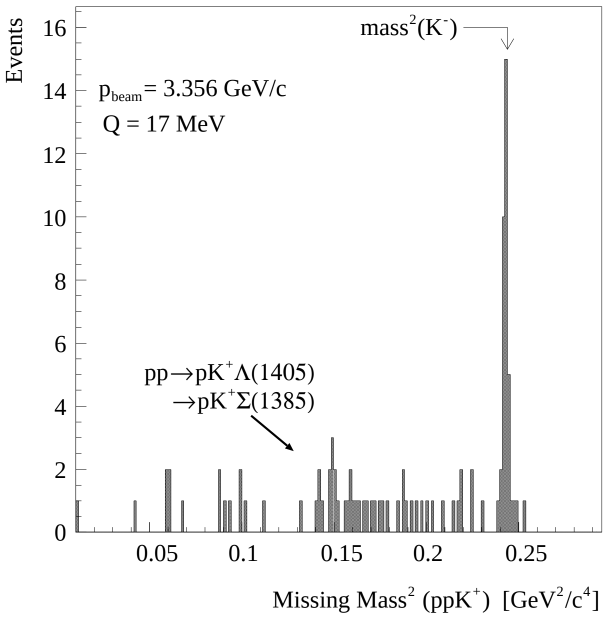

Figure 3: Missing mass distribution with respect to an identified (ppK$^+$) subsystem at a nominal excess energy of 17 MeV ($p_{beam} = 3.356$ GeV/c). In addition, a K$^-$ hit is required in the negative particle detection system.

missing mass distribution is identified with the (ppK$^+$K$^-$) final state. Taking into account both the luminosity determined from a simultaneous measurement of pp elastic scattering and the acceptance of the detection system studied by means of a Monte Carlo simulation, a first total cross section value for the reaction pp $\rightarrow$ ppK$^+$K$^-$ can be derived from the number of 60 identified events at a nominal excess energy of 17 MeV [3]:

$$\sigma_{\mathrm{pp}\rightarrow\mathrm{ppK^+K^-}}\ (\mathrm{Q} = 17\,\mathrm{MeV}) \ = \ 2.1 \pm 0.8\,\mathrm{nb} \qquad (1)$$

The total error of 38 % will be reduced in the final analysis. Although event selection, luminosity determination as well as acceptance studies have been almost finalized, the error given for the total cross section value in equation (1) still contains uncertainties due to the actual beam momentum values during the three different running periods. Systematic studies on the true beam momenta are presently performed and will conclude the analysis, with the total cross section value to be published in the near future.
As a further check of consistency, results for the pp $\rightarrow$ ppK$^+$K$^-$ total cross section are reported separately for the three running periods in September 1998, May 1999 and July 1999 in table 1:

Running Period	Integrated Luminosity [cm^{-2}]	Total Cross Section [nb]
September 1998	1.02×10^{36}	2.6 ± 0.8
May 1999	1.51×10^{36}	1.8 ± 0.5
July 1999	1.62×10^{36}	2.2 ± 0.7

Table 1: Integrated luminosities and derived total cross section values for the reaction pp $\rightarrow$ ppK$^+$K$^-$ at a nominal excess energy of 17 MeV listed separately for the three running periods in 1998 and 1999, the results should be considered as being preliminary.

Within the given errors, consisting of statistics and uncertainties in luminosity as well as systematic contributions, the results from different beam times appear to agree well. These errors don't include the uncertainty of the beam momentum which effects the acceptance of the detection system, in the error given for the sum of the three running periods (equation (1)) this effect is included.

Study of the Energy Dependence of the Total Cross Section

The combined result for the total cross section at Q = 17 MeV from equation (1) is depicted in figure 4.

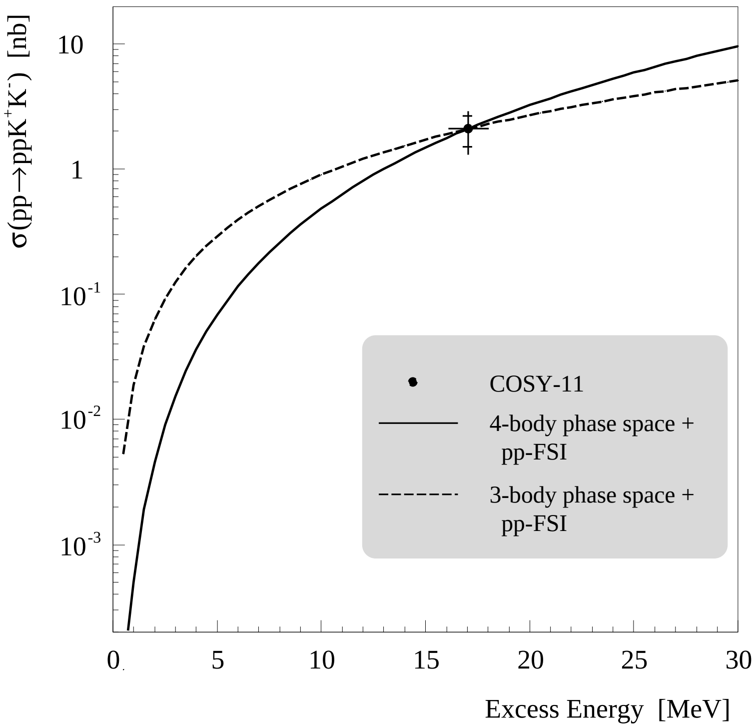

Figure 4: Total cross section for the reaction $pp \to ppK^+K^-$ close to threshold as a function of the excess energy. Horizontal and vertical error bars denote the current uncertainty in the nominal beam momentum and the total cross section value, respectively, obtained at the COSY–11 facility. Horizontal bars on the vertical error bars indicate the expected size of the error on the total cross section in the final analysis (see text). Calculations of the energy dependence of the total cross section according to a four– (solid line) and three–body phase space behaviour (dashed line), respectively, modified by the proton–proton final state interaction according to [6], are normalized to the cross section value at 17 MeV.

The energy dependence of the total cross section close to threshold is generally expected to be determined by the four–body phase space volume modified by the proton–proton final state interaction (solid line in figure 4 [6]) in case of a non-resonant production process. Any deviation from this behaviour might be attributed to either changes in the primary production amplitude or effects of final state interaction in the kaon–nucleon, antikaon–nucleon or kaon–antikaon subsystems.
An understanding of both the scale and the energy dependence of the kaon–antikaon production cross section in proton–proton scattering of course has to await detailed microscopic theoretical calculations. It should be noted, however, that possible interpretations of scalar resonances in the 1 GeV/c^2 mass range crucially depend on the strength of the poorly known kaon–antikaon interaction [7]. A significant influence of scalar resonances on $K\overline{K}$ production should modify the energy dependence of the total cross section, as tentatively indicated by the corresponding three–body phase space dependence in figure 4 (dashed line).
Experimentally, the exclusive identification of the ppK^+K^- final state has been demonstrated by the presented results, showing the feasibility of future measurements on $K\overline{K}$ at the COSY–11 facility. A measurement of the total cross section at different excess energies should put further constraints on the excitation function and trigger off more detailed theoretical investigations of the strangeness dissociation mechanism into the kaon–antikaon channel.

Beam Request

In order to study the energy dependence of the pp $\to$ ppK^+K^- total cross section it is proposed to add two total cross section values (see table 2) to the data point obtained at Q = 17 MeV at the COSY–11 facility. The choice of beam momenta below and above the excess energy of 17 MeV is motivated by the intention to cover an energy range as large as possible, taking into account the need of obtaining valuable physics results within a reasonable amount of time. At both beam momenta, upper limits on the total cross section have been determined by the COSY–11 collaboration [2]. In view of the significant increase in luminosity since those early studies the determination of absolute total cross section values has become feasible.
The integrated luminosity given in table 2 is based on the average value achieved during the running periods in September 1998, May 1999 and July 1999. The number of expected events results from the total cross section value of 2.1 nb at Q = 17 MeV assuming a four–body phase space behaviour of the total cross section modified by the proton–proton final state interaction [6] and taking into account the acceptance of the COSY–11 detection system.

Beam Momentum [GeV/c]	Excess Energy[a] [MeV]	Integrated Luminosity [cm^{-2}]	Expected Number of Events[b]	Days to Run
3.333	10	4.2×10^{36}	24	21
3.390	28	2.8×10^{36}	80	14

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

Table 2: Beam time parameters for the proposed measurement of the reaction pp $\to$ ppK^+K^- close to threshold at the COSY–11 installation.

In total, we ask for five weeks of beam time, two weeks we would like to have scheduled for the second half of 2000, for the measurement at P_{beam} = 3.39 GeV/c.

References:

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[2] T. Lister, PhD thesis (1998), Westfälische Wilhelms–Universität Münster.

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[5] Beam Time Request 61.1, Total Cross Section of the Reaction pp $\to$ ppK^+K^- at COSY–11, April 1999.

[6] G. Fäldt, C. Wilkin, Phys. Lett. B 382 (1996) 209 and C.Wilkin, private communications.

[7] O. Krehl, R. Rapp, J. Speth, Phys. Lett. B 390 (1997) 23.