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

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Beam Time Request for the COSY–11 Proposal 61.2:
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Abstract

At the COSY–11 installation, a first value of the total cross section for the reaction pp $\rightarrow$ ppK$^+$K$^-$ below the Φ production threshold has been determined at an excess energy of $\epsilon = 17\,$MeV.
To study the energy dependence of the total cross section, at $\epsilon = 28\,$MeV data have been taken successfully. Due to severe problems with the internal cluster jet target used at the COSY–11 installation during the measurement at an excess energy of 10 MeV, the respective data taken so far do not allow to deduce a total cross section value. Thus, to conclude our investigations on the energy dependence of the close–to–threshold K$^+$K$^-$ production we ask for two weeks of additional beam time.
Preliminary results are presented, and further physical motivation is given from recent theoretical investigations for the importance of a measurement close to the production threshold.

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

Introduction

Close to threshold, the energy dependence of the total cross section for reactions pp $\rightarrow$ ppX, where X denotes a single meson or a mesonic system being produced, is determined by phase–space behaviour modified by final state interactions (FSI) of the outgoing particles, predominantly the strong proton–proton FSI. Any deviations from the expected behaviour might be attributed to either changes in the primary production amplitude or effects of final state interactions, i.e. in the kaon–nucleon, antikaon–nucleon or kaon–antikaon subsystems in case of the ppK$^+$K$^-$ final state.

range crucially depend on the strength of the poorly known kaon–antikaon interaction [1]: Within the framework of the Jülich meson exchange model, the $K\overline{K}$ interaction determines both scale and shape of $\pi\pi \rightarrow K\overline{K}$ cross sections. However, up to now microscopic calculations within this model for the four–body final state of K^+K^- production in proton–proton scattering have not been carried out.

Experimental Technique

At the COSY–11 facility [2] four–momenta of positively charged reaction products are directly available combining momentum and time–of–flight information.

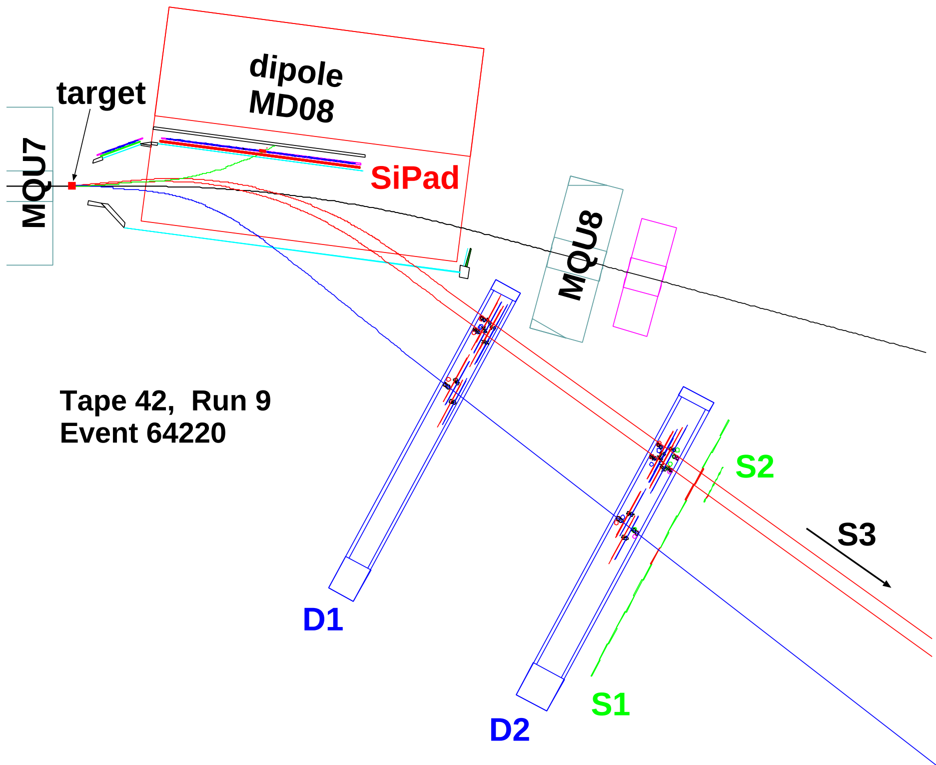

Figure 1: Schematic sketch of the COSY–11 installation including particle trajectories of a reconstructed (ppK^+K^-) event measured during the beam time at an excess energy of 17 MeV.

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 figure 1) through the precisely known dipole field to the target position. Time–of–flight measurements using the scintillator hodoscopes S1, S2 and a large area scintillation wall S3 result in a particle identification and hence provide the full four–momentum information.
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 a highly granulated silicon pad detector and a scintillation counter both mounted inside the dipole gap.

Total Cross Section at 17 MeV Excess Energy

For the measurement at an excess energy of $\epsilon = 17$ MeV the missing mass squared with respect to an identified $\left(ppK^+\right)$ subsystem is shown in figure 2 [3–5].

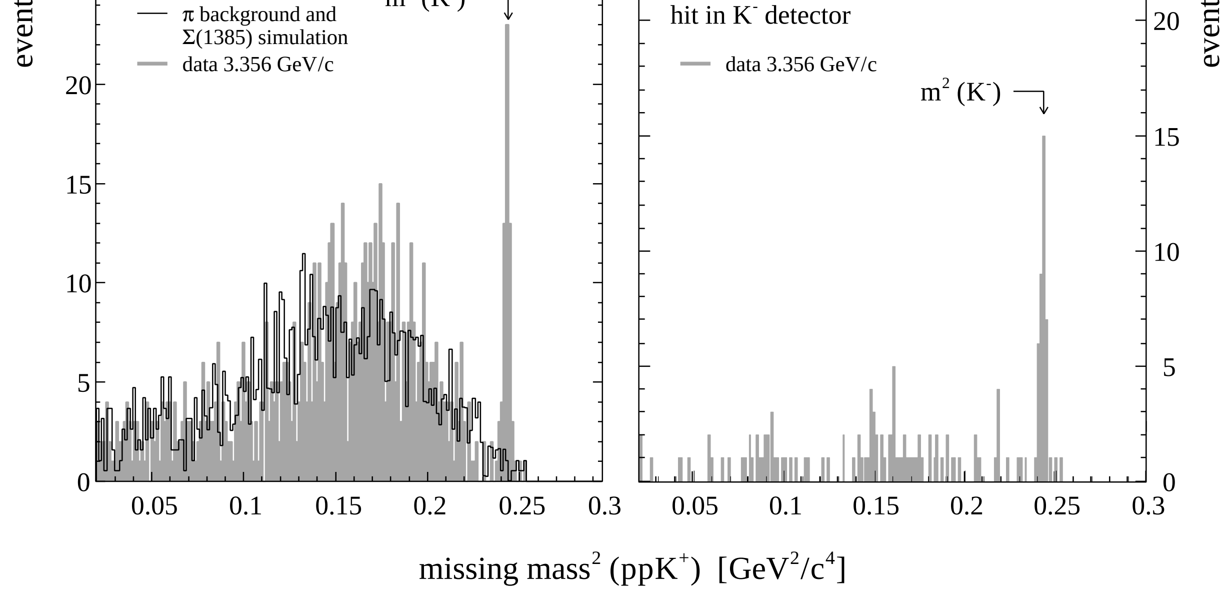

Figure 2: Missing mass distribution with respect to an identified $\left(\mathrm{ppK}^{+}\right)$ subsystem at an excess energy of 17 MeV ($p_{beam} = 3.356\,\mathrm{GeV/c}$) without (left, taken from [5]) and with (right) the additional requirement of a registered hit in the negative particle detection system.

A sharp peak at the charged kaon mass — as expected for a $\left(\mathrm{ppK}^{+}\mathrm{K}^{-}\right)$ final state — is clearly separated from a broad background structure (figure 2 left), which is well reproduced by contributions from misidentified pions and the excitation of the hyperon resonances $\Lambda\,(1405)$ and $\Sigma\,(1385)$: In the latter case one of the identified protons may originate from the weak decay of a previously produced hyperon Y via $\mathrm{pp} \rightarrow \mathrm{pK}^{+}\mathrm{Y} \rightarrow \mathrm{pK}^{+}\mathrm{pX}$, where X denotes a system of one or more undetected particles. In consequence, the missing mass with respect to the identified $\left(\mathrm{ppK}^{+}\right)$ subsystem may shift to values too small for a $\left(\mathrm{ppK}^{+}\mathrm{K}^{-}\right)$ hypothesis.

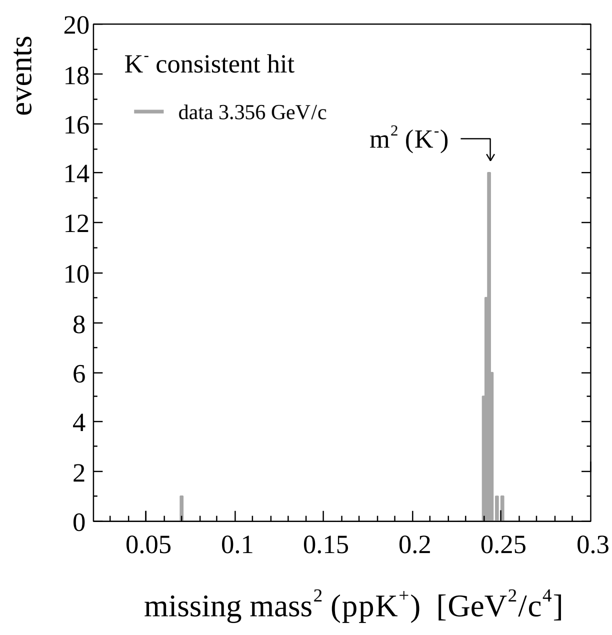

Figure 3: Missing mass distribution with respect to an identified $\left(\mathrm{ppK}^{+}\right)$ subsystem at an excess energy of 17 MeV. In addition to figure 2(right) the hit position in the highly granulated negative particle detection system has been checked for consistency with the reconstructed K^{-} momentum information (figure taken from [5]).

The signal at the charged kaon mass with a missing mass resolution of FWHM $\approx 2\,\mathrm{MeV/c^2}$ already demonstrates the unambiguous detection of events from the reaction $\mathrm{pp} \rightarrow \mathrm{ppK}^{+}\mathrm{K}^{-}$ with a final number of $61\,^{+0}_{-5}$ identified events. However, in order to directly discriminate between either of the two contributions to the background structure discussed above and a

$\left(\mathrm{ppK^-}\right)$ final state, an associated hit in the negative particle detection system is required in addition in the picture on the right hand side of figure 2: While the broad background structure appears effectively suppressed, the strong signal at the charged kaon mass remains. With the four–momentum vector of the $\mathrm{K^-}$ being accessible via the complete four–momentum information from the identified $\left(\mathrm{ppK^+}\right)$ subsystem, the measured hit position in the dedicated highly granulated silicon pad detector mounted inside the dipole gap can be compared to the prediction from the reconstructed $\mathrm{K^-}$ momentum (for details see [5]). The resulting missing mass distribution depicted in figure 3 is obviously (almost) free of any background, and gives independent and additional proof for the exclusive $\mathrm{K^+K^-}$ detection. Quantitatively, the reduction in the $\mathrm{K^+K^-}$ counting rate compared to figure 2(left) is in very good agreement with Monte Carlo simulations taking into account both acceptance and decay losses.
At an excess energy of 17 MeV a first total cross section for the reaction $\mathrm{pp \to ppK^+K^-}$ has been deduced [4, 5]:

$$\sigma\left(\mathrm{pp \to ppK^+K^-}, \epsilon = 17\,\mathrm{MeV}\right) = \left(1.80 \pm 0.27 {}^{+0.28}_{-0.35}\right)\ \mathrm{nb} \tag{1}$$

including statistical and systematical errors.

Preliminary Results at $\epsilon = 28\,$MeV (August 2000)

In order to investigate the energy dependence of the total $\mathrm{pp \to ppK^+K^-}$ cross section close to threshold, five weeks of beam time have been granted by the PAC on the basis of the COSY beam time request No. 61.2 [6]. During two weeks in August 2000, the elementary $\mathrm{K^-}$ production channel in proton–proton scattering was studied at an excess energy of 28 MeV.

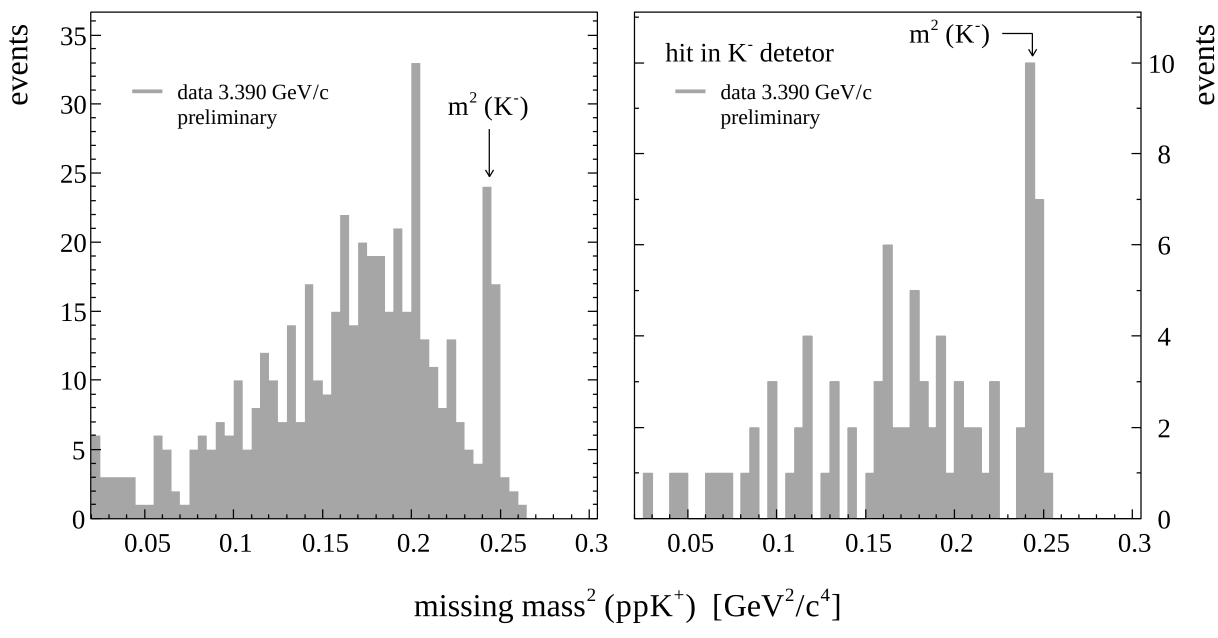

Figure 4: Missing mass squared with respect to an identified $\left(\mathrm{ppK^+}\right)$ subsystem at an excess energy of 28 MeV ($p_{beam} = 3.390\,\mathrm{GeV/c}$) without (left) and with (right) the additional requirement of a registered hit in the negative particle detection system.

Preliminary missing mass distributions with respect to an identified $\left(\mathrm{ppK^+}\right)$ subsystem are presented in figure 4.
As for the previously discussed result at $\epsilon = 17\,$MeV, a clear signal is visible at the expected position of the charged kaon mass, giving again unambiguous evidence for the detection of events corresponding to a $\mathrm{ppK^+K^-}$ final state (figure 4 left). Requiring an additional hit in

of the background structure in the region of lower missing masses and a clean signal at the K^- mass, the latter with a reduction quantitatively in good agreement with Monte Carlo simulations. Although measured and expected hit positions of the associated K^- have not yet been compared at this preliminary stage of the analysis, we expect the final result to be as free of background as shown for the measurement at $\epsilon = 17\,\mathrm{MeV}$ in figure 3.

Report on the Beam Time March 2001

During the beam time in March 2001 dedicated to measurements on K^+K^- production at an excess energy of 10 MeV several problems in the operation of the cluster jet target occured resulting in a very low integrated luminosity. We deeply regret this poor performance both in view of the missing physics result and the costs associated with COSY beam time.
In the beginning of the beam time the nozzle of the cluster target was blocked several times which was at that time a known but not severe problem induced by impurities in the gas system. Additionally — independently of the impurity problem — the displacer of the cold head for the nozzle was broken. Consequently, the target cooling had to be removed for a repair, which took a few days. After the re–installation of the repaired cold head the target was running reasonably stable but with a low density, which might have been caused by the at that time still existing impurity problem and/or the complete opening of the gas system during the inevitable repair.
At no time during the first two weeks it was clear that we would not reach standard target densities and thus the physics goals of the beam time, which would have allowed to ask other collaborations at COSY to stand in.
After the beam time the whole system was removed and checked. Some parts of the gas system which apparently showed some leakage have been replaced. Furthermore, the nozzle and the skimmer have been exchanged, as they had been slightly deformed during the several installations and removals during the beam time.
During the past maintenance week 40, the target system has been fully tested and first results show that the system again runs at the performance, which has been available with high stability at COSY–11 during the past years of operation.
However, from a preliminary analysis of the data taken during the beam time, it is evident that it will not be possible to deduce a total cross section value from the statistics measured in March 2001. In view of the importance of the close–to–threshold cross section, herewith we would like to ask the PAC for a possibility to repeat the measurement and to conclude our investigations on the energy dependence of the total cross section. Further physical motivation arises from results obtained in very recent theoretical investigations by A. Sibirtsev, which are outlined in the next section.

Physical Motivation

The detailed experimental studies of the reactions $pp \to pp\eta$, $pp \to pp\omega$ and $pp \to pp\eta'$ indicate three following general features:
First, the total η, ω and η' production cross sections σ show very similar dependences on the excess energy, defined as $\epsilon = \sqrt{s} - 2\,m_N - m_X$ with s, m_N and m_X being the squared invariant collision energy and the nucleon and meson masses, respectively.
Second, at $100 \le \epsilon \le 1000\,\mathrm{MeV}$ the energy dependence of the total cross section is dominated by three–body phase space ($\sigma \propto \epsilon^2$).
Third, the deviation of data from an ϵ^2 dependence below 100 MeV arises from the interaction between the final state protons and possibly between the final state proton and meson.

The latter was clearly observed in case of the pp → ppη' reaction.

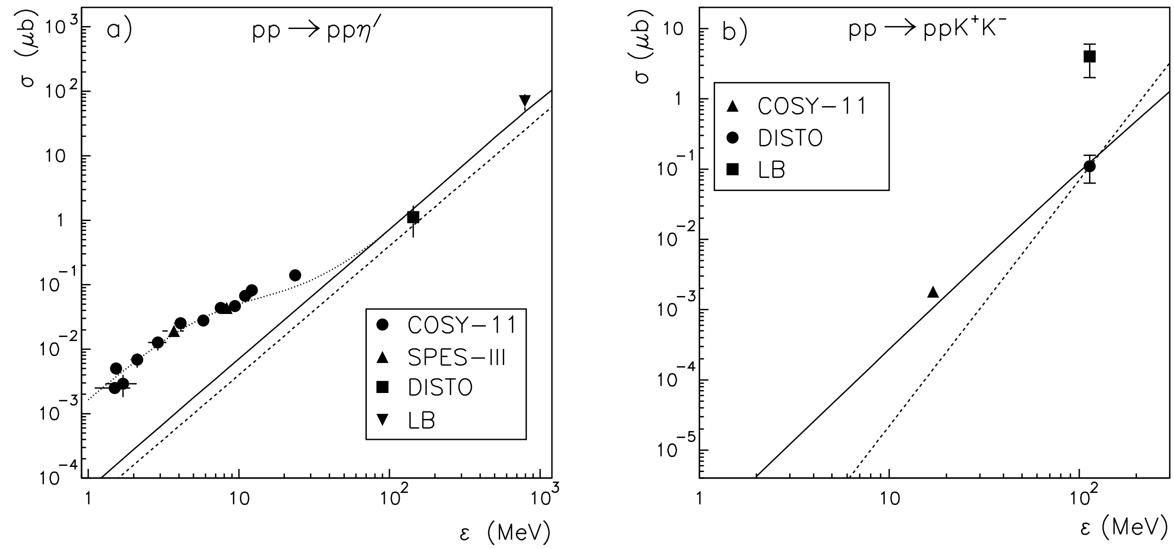

Figure 5: a) The pp → ppη' cross section as a function of excess energy. The data are from [7–12], the dashed line shows the phase space ϵ^2–dependence, the solid line indicates calculations without FSI [13, 14], the dotted line shows the parameterization of the pp FSI. b) The pp → ppK$^+$K$^-$ cross section. The data are from [5, 12, 15], the solid line shows the calculations of [16], the dashed line indicates the phase space $\epsilon^{7/2}$–dependence.

The features listed above can be well illustrated by the data [7–12] on the reaction pp → ppη', where the possible effect due to the pη' final state interaction (FSI) is expected to be almost negligible. Figure 5a) shows the data available for the pp → ppη' cross section as a function of excess energy ϵ. The dashed line indicates the phase space dependence as $\sigma \propto \epsilon^2$, which apart from the normalization constant reproduces the data at $\epsilon > 100\,$MeV. The solid line shows the calculations [13, 14] without pp FSI, which explicitly follows the phase space dependence. The dotted line in figure 5a) indicates the effect due to the pp FSI.

Now, the very recent pp → ppK$^+$K$^-$ measurement by COSY–11 [5] as well as the DISTO result [15] are shown in figure 5b). The data are in a reasonable agreement with the theoretical calculations without FSI [16] shown by the solid line. In contrast to the η, ω and η' production, the calculations for the pp → ppK$^+$K$^-$ reaction substantially deviate from the 4–body phase space dependence given as $\epsilon^{7/2}$ and shown by the dashed line in figure 5b).

This nontrivial energy dependence of the pp → ppK$^+$K$^-$ cross section can be understood in terms of the scattering diagrams shown by figure 6a-b). In that case the energy dependence of the pp → ppη' and pp → ppK$^+$K$^-$ cross section is driven by the energy dependence of the relevant scattering amplitudes.

The π^0p → η'p, K$^-$p → K$^-$p and K$^+$p → K$^+$p scattering amplitudes squared $|\mathrm{M}|^2$ can be evaluated from experimental data [12] on relevant cross sections as

$$\frac{d\,\sigma}{d\,\Omega} = \frac{1}{64\,\pi^2\,s}\,\frac{q_f}{q_i}\,|\mathrm{M}|^2, \qquad (2)$$

where s is squared invariant energy of the interacting particles, while q_i and q_f are their momenta in the initial and final states, respectively, taken in the center of mass system.

Now, figure 6c) shows the data [12] on the π^-p → η'n and π^+n → η'p amplitudes squared that almost do not depend on the invariant πN collision energy and can be well fitted by a constant value, shown by the solid line.

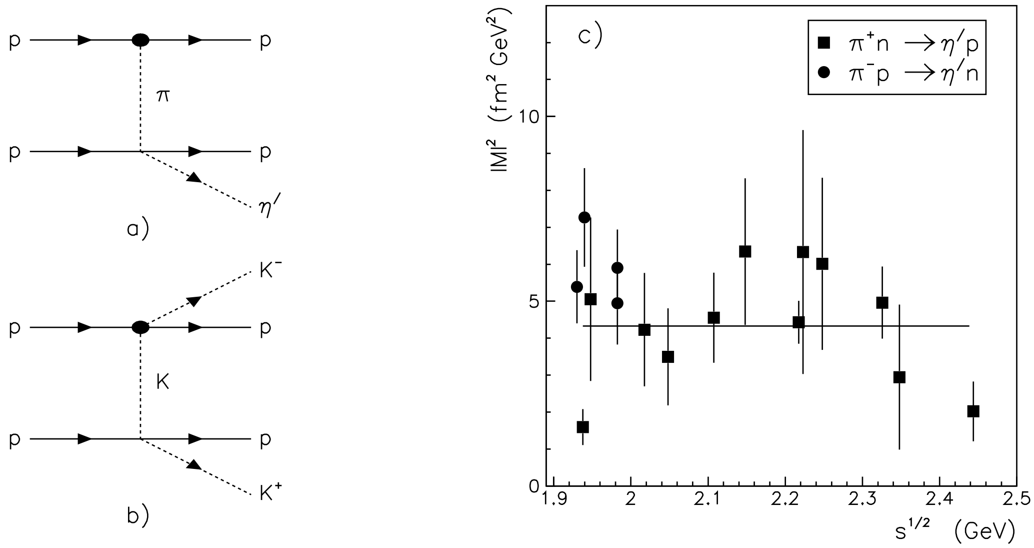

Figure 6: a-b) The scattering diagrams for the reactions pp $\to$ ppη' and pp $\to$ ppK$^+$K$^-$. The squared amplitude for the πN $\to$ η'N scattering as a function of the πN invariant collision energy. The solid line shows a fit by a constant value.

In opposite, the K$^+$p $\to$ K$^+$p and K$^-$p $\to$ K$^-$p scattering amplitudes [12] indicate a substantial energy dependence, as illustrated by figure 7.
Obviously, it is necessary to collect more pp $\to$ ppK$^+$K$^-$ data in order to clarify whether such reaction dynamics lead to the deviation of the near threshold K$^+$K$^-$ production cross section from a trivial phase space $\epsilon^{7/2}$–dependence.
Moreover, by comparing the recent COSY–11 result [5] with the calculations shown by the solid line in figure 5b) one might detect no room for the FSI. The calculations were performed neglecting FSI. Note that the three body reaction with η, ω and η' production indicate strong FSI at excess energies $\epsilon \leq 100\,$MeV. It is not clear whether the absence of the FSI effect in the pp $\to$ ppK$^+$K$^-$ reaction can be explained by partial compensation of the pp

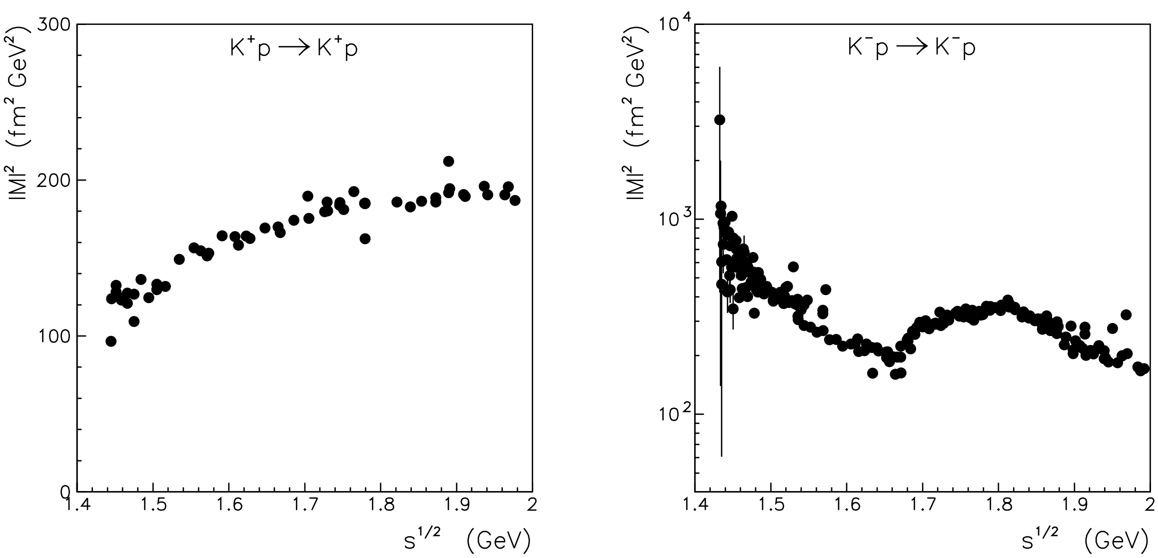

Figure 7: The K$^+$p $\to$ K$^+$p and K$^-$p $\to$ K$^-$p scattering amplitudes squared as a function of the KN invariant collision energy.

the 4–body final state. In the latter case the FSI can be more pronounced at energies very close to the pp $\rightarrow$ ppK^+K^- reaction threshold and it would be of specific interest to measure the cross section at ϵ below that 17 MeV data point investigated recently by COSY–11 [5]. Furthermore, it might be possible that the presence of two pairs of strongly interacting particles as pp and K^-p in the final state could no longer be considered by the factorization in terms of two–body different interactions and one would be faced with the four–body problem. In that case the pp $\rightarrow$ ppK^+K^- measurements provide a unique opportunity to get insight into the problem experimentally.

Summary and Beam Time Request

The internal COSY–11 facility allows to identify the ppK^+K^- uniquely, without any significant experimental background, and is well suited for close–to–threshold production studies. The reaction pp $\rightarrow$ ppK^+K^- has been studied successfully at excess energies of 17 and 28 MeV, respectively. Problems in the cluster target operation during the dedicated measurement at an excess energy of 10 MeV have been solved, allowing a performance of the internal target as during previous beam times. A measurement closer to the production threshold is further motivated by recent theoretical investigations, which demonstrate discrepancies in the FSI effects when comparing close–to–threshold K^+K^- production to reaction channels in proton–proton scattering with hidden strangeness.

In order to conclude studies on the energy dependence of the total cross section of the reaction pp $\rightarrow$ ppK^+K^- below the Φ production threshold, we ask for **two additional weeks of beam time in the first half of 2002** to repeat our measurement from March 2001.

Beam time parameters [6] are listed in table 1. The integrated luminosity is based on the average luminosity during the COSY–11 measurement at ϵ = 17 MeV [5]. The number of expected events results from the corresponding total cross section value assuming a four–body phase space behaviour of the total cross section modified by proton–proton final state interaction [17] and taking into account the acceptance of the COSY–11 detection system.

Beam Momentum	[GeV/c]	3.333
Excess Energy	[MeV]	10
Integrated Luminosity	[cm^{-2}]	4.2×10^{36}
Expected Number of Events		16
Days to Run		14

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

Acknowledgements

We gratefully acknowledge stimulating discussions with A. Sibirtsev in preparation of this beam time request, and especially his enthusiasm and contribution in providing further theoretical motivation for K^+K^- production studies close to threshold.

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