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

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Beam Time Request for the COSY–11 Proposal 61.4:
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Abstract

At the COSY-11 installation, the total cross section for the reaction pp → ppK$^+$K$^-$ has been determined at four excess energies below the Φ production threshold: $\epsilon = 6$ MeV (with very low statistics), 10 MeV, 17 MeV, and 28 MeV. To complete the COSY-11 study on the K$^+$K$^-$ mesons, we propose to measure the pp → ppK$^+$K$^-$ reaction at $\epsilon = 3$ MeV and $\epsilon = 6$ MeV in order to test the interaction in the four-body ppK$^+$K$^-$ system, which is expected to show up at ϵ lower than 10 MeV.

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

As a demonstration of the feasibility to study the pp → ppK$^+$K$^-$ reaction, Figure 1 shows the essential background free observation of the final state, where in the three missing mass plots the raw data (left), the requirement of any hit in the K$^-$-detector (center) and finally the identified K$^-$ mesons are shown.

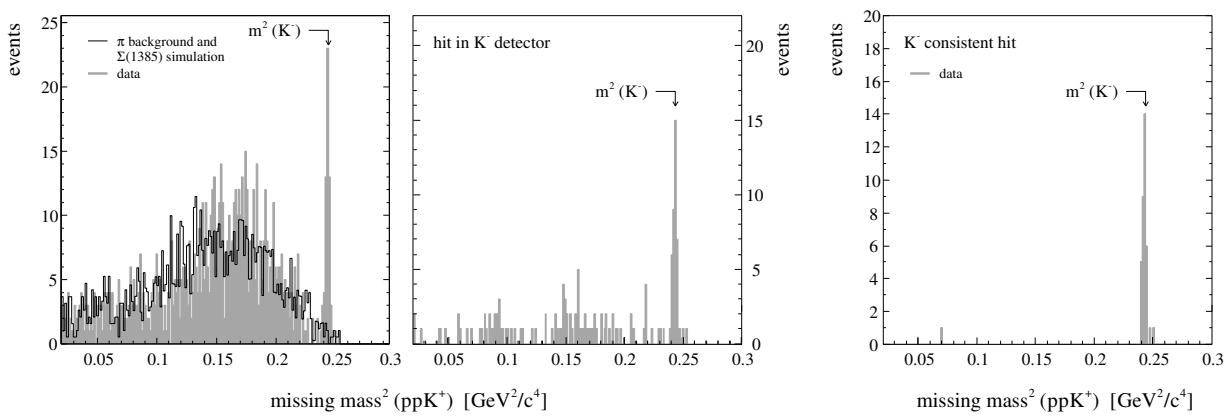

Figure 1: From the raw data to the background free observation of the pp → ppK$^+$K$^-$ reaction.

Similar results were observed for all experiments at the above mentioned beam momenta. In Figure 2 the cross section data measured by COSY-11 are presented and compared to simple three body and four body phase space distributions, not including proton-proton final state interactions, which should be done and will be discussed later.

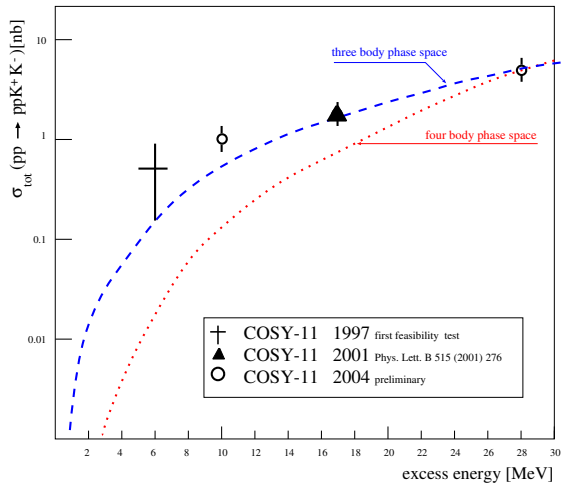

Figure 2: The four COSY-11 data points for the reaction pp $\rightarrow$ ppK$^+$K$^-$ at $\epsilon = 6$ MeV (with a rather large uncertainty), 10 MeV, 17 MeV, and 28 MeV, compared to phase space expectations without final state interaction.

The figure is predominantly meant to show the cross sections below the Φ production threshold observed till now by the COSY-11 collaboration. However, without any sophisticated analysis one sees that there is an interesting physics behind, since the data obviously follow much more the three body phase space distribution rather than the four body one, in spite of the four particle final state.

Physical Motivation

The detailed experimental studies of the reactions pp $\rightarrow$ ppη, pp $\rightarrow$ ppω, and pp $\rightarrow$ ppη' indicate three general features:

1. The total η, ω, and η' production cross sections σ show 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.

2. At $100 \leq \epsilon \leq 1000\,$MeV the energy dependence of the total cross section is dominated by the three–body phase space, i.e. $\sigma \propto \epsilon^2$.

3. The deviation of the data from an ϵ^2 dependence below 100 MeV arises mainly from the interaction between the final state protons and additionally a small contribution due to the final state interaction between proton and meson. The latter is clearly visible in case of the pp $\rightarrow$ ppη reaction.

The features listed above can be well illustrated by the data [1–7]. Exemplarily, figure 3a) shows the data available for the pp $\rightarrow$ ppη' cross section as a function of the excess energy ϵ, where the possible effect due to the pη' final state interaction (FSI) is almost negligible [15]. 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 calculations [8,9] without pp-FSI, which follow the phase space dependence. The dash-dotted line in figure 3a) indicates the effect due to the pp-FSI.

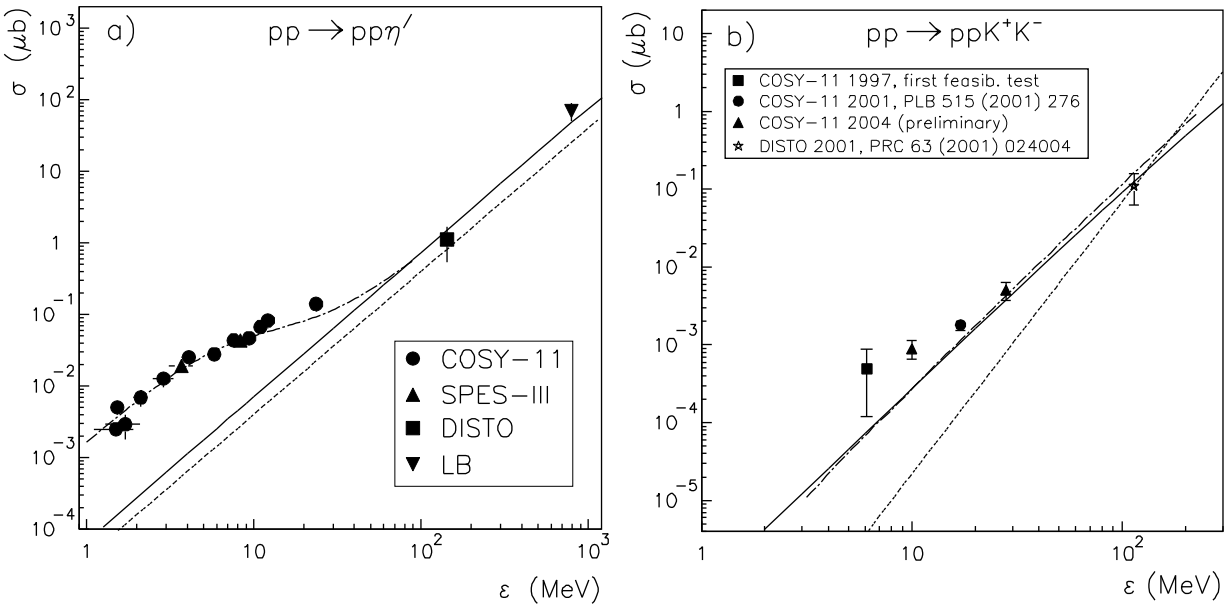

Figure 3: a) The pp → ppη' cross section as a function of the excess energy. The data are from [1–7], the dashed line shows the phase space ϵ^2–dependence, the solid line indicates calculations without FSI [8, 9], the dash-dotted line includes a parameterization of the pp-FSI.
b) The pp → ppK^+K^- cross section. The data are taken from [10–13], the solid line shows the calculations of [14], the dashed line indicates the phase space $\epsilon^{7/2}$–dependence, whereas the dash-dotted line results from a parametrization of the pp-FSI.

In case of the four-body final state reaction pp → ppK^+K^- the situation is somehow different. The final [10, 11] and very recent preliminary data by COSY–11 [13] as well as the DISTO result [12] are shown in figure 3b). The deviation from the phase space prediction normalized to the DISTO point indicates a much higher discrepancy close to threshold for the KK data than for the data on the η'. For example at $\epsilon = 10\,\mathrm{MeV}$, it is about one order of magnitude in case of the η' and almost two orders of magnitude in the case

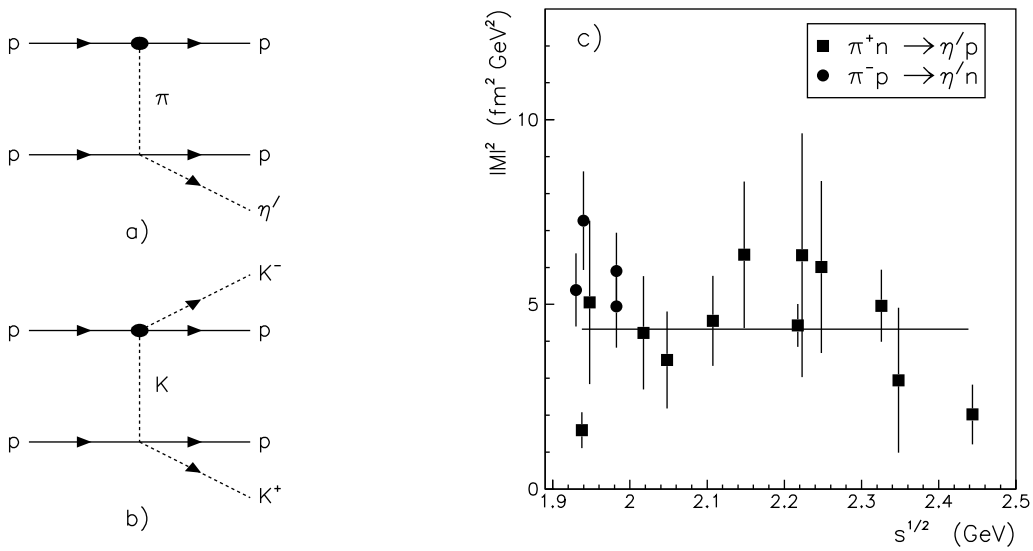

Figure 4: a-b) The scattering diagrams for the reactions pp → ppη' and pp → ppK^+K^-.
c) The squared amplitude for the πN → η'N scattering as a function of the πN invariant collision energy. The solid line shows a fit to a constant value.

of the K^+K^- production. Also on the theoretical side, in contrast to the η, ω, and η' production, calculations [14] for the $pp \to ppK^+K^-$ reaction substantially deviate from the 4–body phase space dependence given as $\epsilon^{7/2}$ and shown by the dashed line in Figure 3b). In addition, a parametrization of the pp-FSI (dash-dotted line) is equally well describing the data compared to the calculation, which does not include the proton-proton final state interaction. The preliminary data by COSY-11 (black triangle at $\epsilon = 10\,\mathrm{MeV}$) indicates in addition with the low statistics feasibility test (black square) that there is an enhancement at energies below 10 MeV. We will come back to this issue later again.
Let's first concentrate on the energy dependence in the range of $10 < \epsilon < 100\,\mathrm{MeV}$. The non trivial discrepancy to the pure phase space is understood by the authors of reference [14] in terms of the scattering diagrams shown in Figure 4a) and Figure 4b), where the energy dependences of the $pp \to pp\eta'$ and $pp \to ppK^+K^-$ cross sections are driven by the energy dependences of the relevant scattering amplitudes.
The $\pi^0 p \to \eta' p$, $K^-p \to K^-p$, and $K^+p \to K^+p$ scattering amplitudes squared $|M|^2$ can be evaluated from experimental data [6] on relevant cross sections via

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

where s is the 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. Figure 4c) shows the data [6] on the $\pi^-p \to \eta' n$ and $\pi^+n \to \eta' p$ 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.

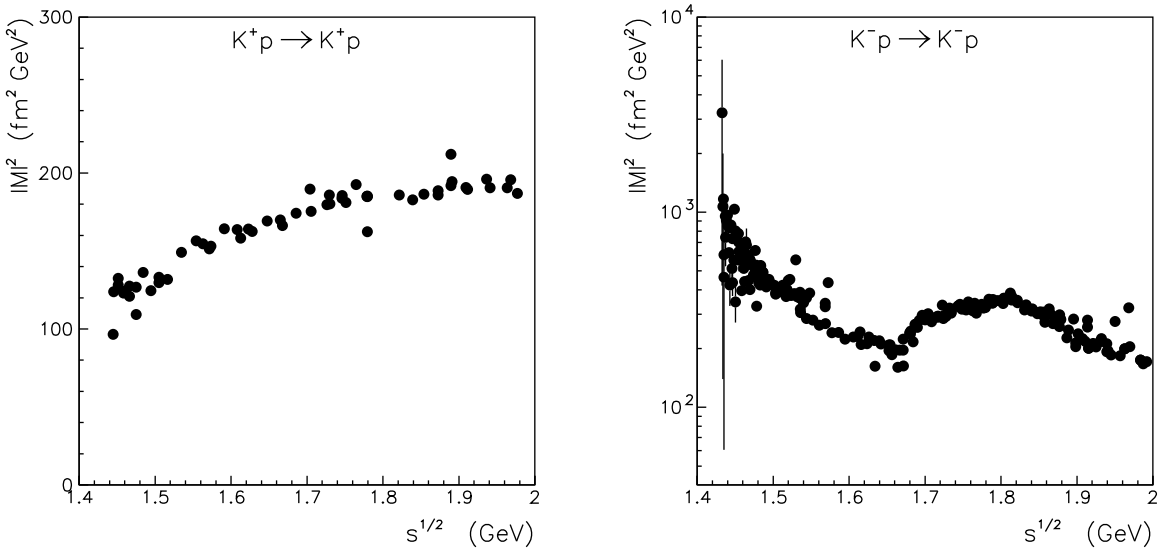

Figure 5: The $K^+p \to K^+p$ and $K^-p \to K^-p$ scattering amplitudes squared as a function of the KN invariant collision energy.

In contrast, the $K^+p \to K^+p$ and $K^-p \to K^-p$ scattering amplitudes indicate a substantial energy dependence, as illustrated by the two plots in Figure 5 and leading to the difference to the pure phase space expectations.
For the excess energy region below 10 MeV, the cross section data seem to be enhanced compared with the calculation [14] and the parametrization of the pp-FSI. Regarding the low statistics at $\epsilon = 6\,\mathrm{MeV}$ of only two counts, it is necessary to have further data closer to the threshold in order to prove this enhancement. In such a case, it will be necessary to include the pp-FSI and the K^-p interactions simultaneously to theoretical calculations in a

rigorous way in order to eliminate the discrepancy below 10 MeV.
Additionally, the pp $\rightarrow$ ppK$^+$K$^-$ reaction allows to measure the K$^-$p invariant mass spectrum. The differential cross section at low K$^-$p masses can be strongly affected by the $\Lambda(1405)$ hyperon and/or by the K$^-$p final state interaction. Therefore, it is important to collect more data and to scan the K$^-$p mass spectrum close to the threshold in order to determine the K$^-$p scattering length [16].
The role of the $\Lambda(1405)$ hyperon in low energy K$^-$p interaction is still in debate and most significant theoretical progress was achieved only recently [17]. Unfortunately there is no significant experimental progress and the data available close to the K$^-$p threshold are very scarce due to the lack of antikaon beams. A direct measurement of the low energy K$^-$p interaction can be done by analysing the ratio of the K$^-$p and K$^+$p invariant mass spectra. Such an analysis will provide a clean separation of the final state interaction since due to the ratio, the phase space dependence cancels out.
Motivated by the items above, it is proposed to increase the statistics at $\epsilon = 6$ MeV and to add another last data point at $\epsilon = 3$ MeV since for both energies an increase of the cross section above presently available predictions is very likely, but its degree has to be determined.

Beam time request

In order to finish the COSY-11 project to determine the energy dependence of the total cross section in pp $\rightarrow$ ppK$^+$K$^-$ close to threshold, we would like to take final data at two energy settings of ϵ–values of 6 MeV (remeasurement) and 3 MeV.
For these two excitation energies the total acceptance is **5%** and **10%** and the cross sections should be in the order of **0.5 nb** and **0.1 nb**, respectively. Presently the standard luminosity at COSY-11 is in the order of $\mathbf{5 \times 10^{30}\ cm^{-2}s^{-1}}$.
Altogether, we expect 11 identified events/day at a cross section of 0.5 nb and 4 events/day for 0.1 nb. Aiming for 60 events at each momentum setting we would like to ask for:
7 days at $\epsilon = 6$ MeV and 16 days at $\epsilon = 3$ MeV, including 1 day for each energy for COSY, target, and COSY-11 setup optimization. We would like to be granted for **three weeks of beam time at COSY-11 to finalise the low energy pp $\rightarrow$ ppK$^+$K$^-$ programme**.

Acknowledgements

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