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STUDY OF THE LOW ENERGY DYNAMICS IN THE ppK^+K^- SYSTEM WITH THE COSY-11 MAGNETIC SPECTROMETER*

Michał Silarski, Paweł Moskal, Damian Gil, Jerzy Smyrski

on behalf of the COSY-11 Collaboration

M. Smoluchowski Institute of Physics, Jagiellonian University
Reymonta 4, 30-059 Kraków, Poland
and
Institute for Nuclear Physics and Jülich Center for Hadron Physics
Research Center Jülich, 52425 Jülich, Germany

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The near threshold production of K^+K^- pairs in proton–proton collisions has been investigated at the cooler synchrotron COSY below and above the threshold for the ϕ meson. The experimental excitation function determined for the $pp \to ppK^+K^-$ reaction differs from theoretical expectations including proton–proton final state interaction. The discrepancy may be assigned to the influence of K^+K^- or pK^- interaction. In this article we present distributions of the cross-section for the $pp \to ppK^+K^-$ reaction as a function of the invariant masses of two and three particle subsystems at excess energies of $Q = 10$ MeV and 28 MeV.

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1. Introduction

The basic motivation for investigating the $pp \to ppK^+K^-$ reaction near the kinematical threshold was comprehensively reviewed by Oelert at the very first Cracow Workshop on Meson Production and Interaction [1]. The main reason for such studies is an attempt to understand the nature of scalar resonances $f_0(980)$ and $a_0(980)$, whose masses are very close to the sum of K^+ and K^- masses. Besides the standard interpretation as a $q\bar{q}$ mesons [2], these resonances were also proposed to be $qq\bar{q}\bar{q}$ states [3], $K\bar{K}$ molecules [4, 5], hybrid $q\bar{q}$/meson–meson systems [6] or even quark-less gluonic hadrons [7]. The strength of the $K\bar{K}$ interaction is a crucial quantity

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regarding the formation of a $K\bar{K}$ molecule, whereas the KN interaction is of importance in view of the vigorous discussion concerning the structure of the excited hyperon $\Lambda(1405)$ which is considered as a three quark system or as a KN molecular state [8]. Additionally, these interactions appear to be very important also with respect to other physical phenomena, like for example a modification of the neutron star properties due to possible kaon condensation [9] or properties of strange particles immersed in the dense nuclear medium studied by means of the heavy ion collisions [10–13]. In our approach [14–16] we endouver to learn about the K^+K^- and Kp interactions from the excitation function and from invariant mass distributions of cross-sections for the $pp \to ppK^+K^-$ reaction.

2. Excitation function for the near threshold K^+K^- production

The measurements of the $pp \to ppK^+K^-$ reaction were conducted at low excess energies by collaborations ANKE [17], COSY-11 [18–20] and DISTO [21]. The achieved results are presented in Fig. 1 together with curves representing three different theoretical expectations [17] normalized to the DISTO data point at $Q = 114\,\mathrm{MeV}$.

The dashed curve represents the energy dependence from four-body phase space, when we assume that there is no interaction between particles in the final state. These calculations differ from the experimental data by two orders of magnitude at $Q = 10\,\mathrm{MeV}$ and by a factor of about five at $Q = 28\,\mathrm{MeV}$. Hence, it is obvious, that the final state interaction effects in the ppK^+K^- system cannot be neglected [22].

Inclusion of the pp–FSI (dashed-dotted line in Fig. 1), by folding its parameterization known from the three body final state [23] with the four body phase space, is closer to the experimental results, but does not fully account for the difference [19]. The enhancement may be due to the influence of K^+K^- or pK interaction which was neglected in the calculations. Indeed, as shown by authors of reference [17,24] the inclusion of the pK^-–FSI (solid line) reproduces the experimental data for the excess energies down to the point at $Q = 28\,\mathrm{MeV}$. These calculations were accomplished under the assumption that the overall enhancement factor, originating from final state interaction in ppK^+K^- system, can be factorised into enhancements in the pp and two pK^- subsystems [17]:

$$F_{\mathrm{FSI}} = F_{pp}(q)\, F_{p_1K^-}(k_1)\, F_{p_2K^-}(k_2)\,, \tag{2.1}$$

where k_1, k_2 and q stands for relative momenta of particles in the first pK^- subsystem, second pK^- subsystem and pp subsystem, respectively. Factors describing the enhancement originating from pK^-–FSI are parametrised using the scattering length approximation:

$$F_{p_iK^-} = \frac{1}{1 - i\ k_i a_{pK^-}}\,, \qquad i = 1, 2\,, \tag{2.2}$$

where a_{pK^-} is a complex parameter describing the interaction, called effective scattering length. It is important to note that the inclusion of the pp and pK^- final state interaction is not sufficient to describe data very close to threshold (see Fig. 1). This enhancement may be due to the influence of the K^+K^- interaction, which was neglected in the calculations[1].

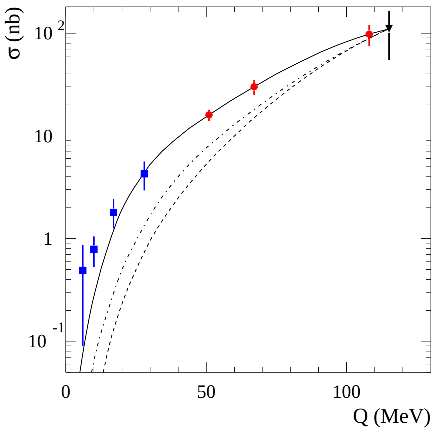

Fig. 1. Total cross-section as a function of the excess energy Q for the reaction $pp \to ppK^+K^-$. Triangle and circles represent the DISTO and ANKE measurements, respectively. The four points nearest threshold are the results from COSY-11 measurements. The curves are described in the text.

3. The differential observables for COSY-11 data measured at $Q = 10$ MeV and $Q = 28$ MeV

The authors of publication [17] pointed out that the observed enhancement of the total cross-section near threshold may be, at least partially, due to the neglect of the pK^-–FSI in the calculations of the COSY-11 acceptance. As a consequence the obtained total cross-sections might decrease, if the interaction would have been taken into account during the analysis of the experimental data. This suggestion encouraged us to check quantitatively the influence of the interaction in pK^- subsystem on the acceptance of the detection setup. To this end we derived the distributions of the differential cross-section for data at both excess energies assuming that the acceptance

[1] It is worth mentioning, that in the calculations also the pK^+ interaction was neglected. It is repulsive and weak and hence it can be interpreted as an additional attraction in the pK^- system [17].

depends only on the pp–FSI. Then we calculated the acceptance with inclusion of the pK^-–FSI and derived analogous distributions. The results are presented in Fig. 2 for data at $Q = 10$ MeV and in Fig. 3 for $Q = 28$ MeV. As one can see, distributions obtained under both assumptions are almost identical, which shows that the acceptance of the COSY-11 detection setup is only very weakly sensitive to the interaction between K^- and protons.

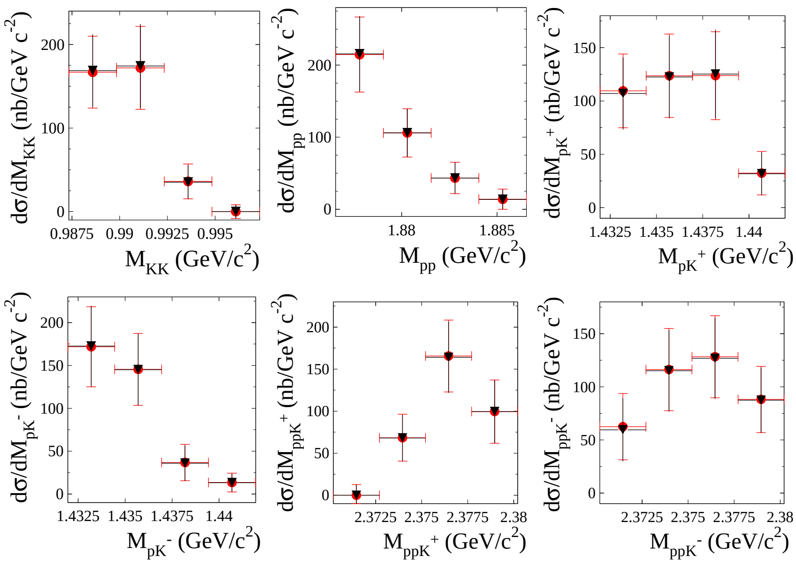

Fig. 2. The differential cross-sections for the $pp \to ppK^+K^-$ reaction at $Q = 10$ MeV. Circles denote spectra where acceptance was determined taking into account only the pp–FSI, and triangles denote results where additionally pK^-–FSI was taken into account in the acceptance calculations. They are hardly distinguishable.

The spectra shown in Figs. 2 and 3 constitute an additional information to the total cross-sections published previously [19], where the values of the cross-sections were determined using the total number of events identified as the $pp \to ppK^+K^-$ reaction and the total acceptance of the COSY-11. The acceptance was calculated assuming the pp–FSI described by the on shell proton–proton scattering amplitude. Now after the determination of the absolute values for the differential distributions one can calculate the total cross-sections in a less model dependent manner regardless of the assumption of the pp–FSI. The cross-sections, calculated for both excess energies as a integral of the M_{pp} distribution derived with inclusion of the pK^-–FSI in the acceptance calculations:

$$\sigma_{\rm tot} = \int \frac{d\sigma}{dM_{pp}}\, dM_{pp}\,,$$

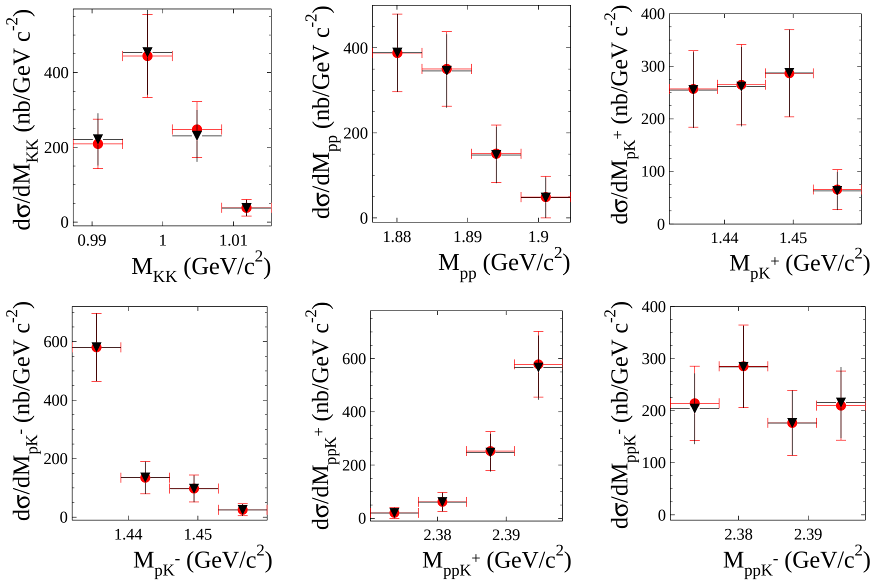

Fig. 3. The differential cross-sections for the $pp \to ppK^+K^-$ reaction at $Q = 28$ MeV. Circles denote spectra where acceptance was determined taking into account only the pp–FSI, and triangles denote results where additionally pK^-–FSI was taken into account in the acceptance calculations. They are hardly distinguishable.

amount to $\sigma_{\text{tot}} = (0.95 \pm 0.17)$ nb for measurement at $Q = 10$ MeV and $\sigma_{\text{tot}} = (6.5 \pm 1.1)$ nb for $Q = 28$ MeV. These results are larger than the previously obtained total cross-sections by about 20 % for $Q = 10$ MeV and 50 % for $Q = 28$ MeV, which strengthen the confidence to the observed enhancement at threshold. However, the total cross-sections obtained in these two different analyses are statistically consistent. The determination of the absolute values for the differential cross-sections permitted us to establish the absolute values for the following ratios at the close to threshold region:

$$R_{pK} = \frac{d\sigma/dM_{pK-}}{d\sigma/dM_{pK+}},$$

$$R_{ppK} = \frac{d\sigma/dM_{ppK-}}{d\sigma/dM_{ppK+}}.$$

If pK^+ and pK^- interactions were the same, the distribution of R_{pK} as well as R_{ppK} should be flat and equal to unity. But as one can see in Fig. 4 and as presented already in the previous publication by the COSY-11 [19] and ANKE [17] R_{pK} for both excess energies is far from constant and increases towards the lower M_{pK} invariant masses. This effect might be

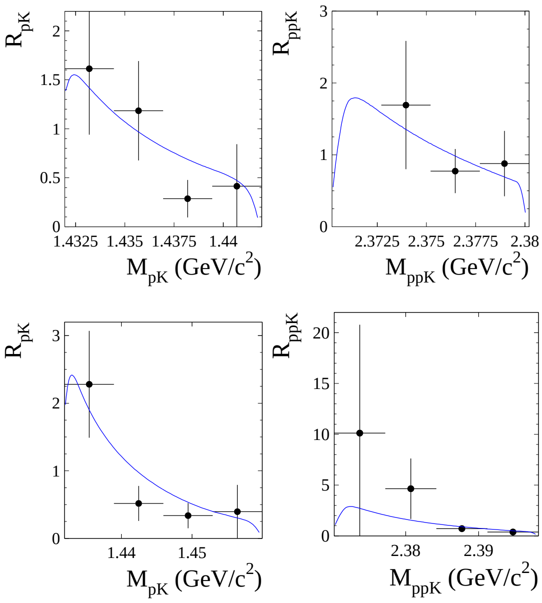

Fig. 4. The distributions of ratios R_{pK} and R_{ppK} for data at $Q = 10$ MeV (upper panel) and $Q = 28$ MeV (lower panel). Solid curves represent theoretical expectations calculated taking into account pp and pK^- final state interaction.

connected with the influence of the pK^- final state interaction. Similarly the distributions of R_{ppK} differs from expectations assuming only interaction in pp system. This is a confirmation of effects found also by the ANKE Collaboration at higher excess energies [17].

As one can see in Fig. 4 simulations taking into account the pK^- final state interaction with the scattering length determined by the ANKE group for the data at significantly higher excess energies reproduce very well the distributions of R_{pK} and R_{ppK} near the threshold. The results presented by the curves in Fig. 4 were determined assuming that the pK^- scattering length amounts to: $a_{pK^-} = (0 + 1.5i)$ fm [17][2].

[2] In this calculations we used the following parametrization of the proton–proton scattering amplitude:

$$F_{pp} = \frac{e^{-i\delta_{pp}(^1\mathrm{S}_0)}\,\sin\delta_{pp}(^1\mathrm{S}_0)}{C\,q}\,,$$

where C stands for the square root of the Coulomb penetration factor [23]. The parameter $\delta_{pp}(^1\mathrm{S}_0)$ denotes the phase-shift calculated according to the modified Cini–Fubini–Stanghellini formula with the Wong–Noyes Coulomb correction [26–28]. A more detailed description of this parametrization can be found in references [23, 25–28].

4. Conclusions

We concluded, that a reanalysis of the COSY-11 data with the inclusion of the pK^- interaction did not change significantly the shape of the previously determined differential distributions of the cross-section. Moreover, the determination of the total cross-sections from the differential M_{pp} distributions even increased the observed enhancement at threshold. Regarding the comparison of the interactions in the pK^-, pK^+, ppK^- and ppK^+ subsystems, the absolute ratios determined from COSY-11 data measured at $Q = 10$MeV and $Q = 28$ MeV are consistent with the predictions based on parametrisation introduced in reference [17] and on the values of the scattering length a_{K^-p} extracted from the ANKE data at higher excess energies [17].

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