

STUDY OF THE NEAR THRESHOLD
 $pp \rightarrow ppK^+K^-$ REACTION IN VIEW OF
THE K^+K^- FINAL STATE INTERACTION*

M. SILARSKI, P. MOSKAL

on behalf of the COSY-11 Collaboration

M. Smoluchowski Institute of Physics, Jagellonian University
Reymonta 4, 30-059 Kraków, Poland
and

Institute for Nuclear Physics and Jülich Center for Hadron Physics
Research Center Jülich, 52425 Jülich, Germany

(Received August 9, 2010)

Measurements of the $pp \rightarrow ppK^+K^-$ reaction, performed near the kinematical threshold with the experiment COSY-11 at the Cooler Synchrotron COSY, reveal a significant discrepancy between obtained excitation function and theoretical expectations neglecting interactions of kaons. In order to deepen our knowledge about the low energy dynamics of the $ppKK$ system we investigated population of events for the $pp \rightarrow ppK^+K^-$ reaction as a function of the invariant masses of two particle subsystems. Based for the first time on the low-energy K^+K^- invariant mass distributions and the generalized Dalitz plot analysis, we estimated the scattering length for the K^+K^- interaction.

PACS numbers: 13.75.Lb, 13.75.Jz, 25.40.Ep, 14.40.Aq

1. Introduction

The basic motivation for investigation of the $pp \rightarrow ppK^+K^-$ reaction near the kinematical threshold at COSY was an attempt to understand the nature of the scalar resonances $f_0(980)$ and $a_0(980)$. In addition to the standard interpretation as $q\bar{q}$ states [1], these particles were also proposed to be $qq\bar{q}\bar{q}$ tetraquarks [2], $K\bar{K}$ molecules [3,4], hybrid $q\bar{q}$ /meson–meson systems [5] or even quark-less gluonic hadrons [6]. With regard to the formation

* Presented at the Workshop “Excited QCD 2010”, Tatranská Lomnica/Stará Lesná, Tatra National Park, Slovakia, January 31–February 6, 2010.

of the molecule the strength of the $K\bar{K}$ interaction becomes a crucial quantity, and it can be probed for example in the near threshold $pp \rightarrow ppK^+K^-$ reaction. First measurements of this reaction were conducted at cooler synchrotron COSY by the COSY-11 Collaboration [7, 8]. A precise determination of the collision energy, in the order of fractions of MeV, permitted us to deal with the rapid growth of cross-sections [9] and thus to take advantage of the threshold kinematics like full phase space coverage achievable with dipole magnetic spectrometer being rather limited in geometrical acceptance. These experiments revealed, however, that the total cross-section at threshold is by more than seven orders of magnitude smaller than the total proton–proton production cross-section making the study difficult due to low statistics. A possible influence from the f_0 or a_0 on the K^+K^- pair production appeared to be too weak to be distinguished from the direct production of these mesons on the basis of the COSY-11 data [8]. However, the combined systematic collection of data obtained by the collaborations COSY-11 [7, 8, 10], ANKE [11] and DISTO [12] reveal a significant signal in the shape of the excitation function which may be a manifestation of the interaction among particles in the final state.

2. Total cross-sections for the $pp \rightarrow ppK^+K^-$ reaction near threshold

Results of all the measurements are presented in Fig. 1 together with curves representing three different theoretical expectations normalized to the DISTO data point at $Q = 114$ MeV [11]. 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 by two orders of magnitude from data at $Q = 10$ MeV and by a factor of about five at $Q = 28$ MeV. Inclusion of the pp -FSI (dashed-dotted line in Fig. 1), using parametrization known from the three body final state [13] with the four body phase space, is closer to the experimental data, but does not fully account for the difference [10]. The enhancement may be due to the influence of pK and K^+K^- interaction which was neglected in the calculations. Indeed, the inclusion of the pK^- -FSI (solid line) reproduces the experimental data for excess energies down to $Q = 28$ MeV. These calculations of the cross-section were accomplished under the assumption that the overall enhancement factor, originating from final state interaction in the ppK^+K^- system, can be factorised into enhancements in the pp and two pK^- subsystems [11]

$$F_{\text{FSI}} = F_{pp}(q) \cdot F_{p_1K^-}(k_1) \cdot F_{p_2K^-}(k_2), \quad (1)$$

where k_1 , k_2 and q stand for the relative momenta of the particles in the first pK^- subsystem, second pK^- subsystem and pp subsystem, respectively. Factors describing the enhancement originating from the pK^- -FSI are parametrized using the scattering length approximation, with the pK^- scattering length amounting to $a_{pK^-} = (0 + 1.5i)$ fm [11]. However, the inclusion of the pp and pK^- final state interaction fail to describe the data very close to threshold (see Fig. 1). This indicates that in this energy region the influence of the K^+K^- interaction is significant and cannot be neglected¹. Therefore, we decided to perform more detailed analysis of the COSY-11 data at excess energies of $Q = 10$ MeV and 28 MeV including studies of both the differential cross-section distributions [14] and the strength of the final state interaction between the K^+ and K^- [15].

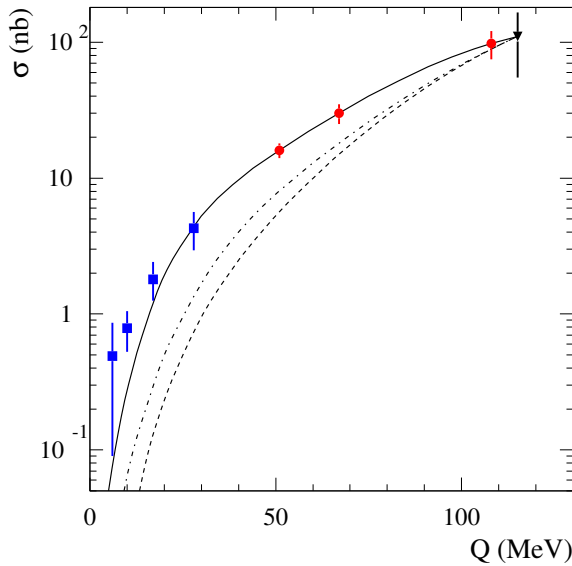


Fig. 1. Excitation function for the $pp \rightarrow ppK^+K^-$ reaction. Triangle and circles represent the DISTO and ANKE measurements, respectively. The four points close to the threshold are results from the COSY-11 measurements. The curves are described in the text.

3. Analysis of the K^+K^- final state interaction

The final state interaction may manifest itself even stronger in the distributions of the differential cross-sections than in the shape of the excitation function [9]. Thus, we have performed an analysis of the generalized

¹ In this 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 [11].

Dalitz plots [15, 16] for the low energy data at $Q = 10$ MeV (27 events) and $Q = 28$ MeV (30 events), in spite of the quite low statistics available. Complementary to previous derivations [17–20] here we estimate the K^+K^- scattering length directly from the low energy differential mass distributions of K^+K^- and pp pairs from the ppK^+K^- system produced at threshold. The raw data (represented by black points in Figs. 2(a) and 2(b)) were first binned and then for each bin corrected for the acceptance and detection efficiency of the COSY-11 facility [21]. The resulting Goldhaber plots

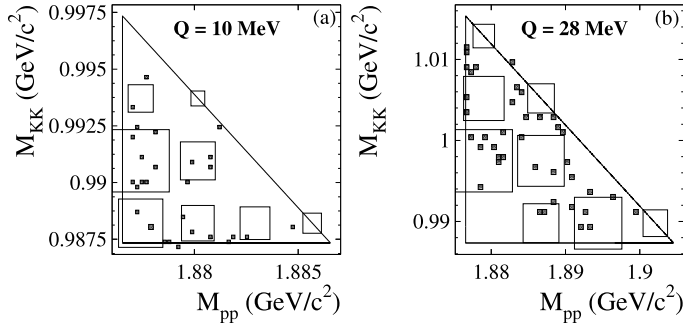


Fig. 2. Goldhaber plots for the $pp \rightarrow ppK^+K^-$ reaction. The solid lines of the triangles show the kinematically allowed boundaries. Raw data are shown in Figs. (a) and (b) as black points. The superimposed squares represent the same distributions but binned into intervals of $\Delta M = 2.5$ MeV/ c^2 ($\Delta M = 7$ MeV/ c^2) widths for an excess energy of $Q = 10$ MeV (28 MeV), respectively. The size of the square is proportional to the number of entries in a given interval.

are presented together with the raw distributions in Figs. 2(a) and 2(b). In order to estimate the strength of the K^+K^- interaction, the derived cross-sections were compared to results of simulations generated with various parameters of the K^+K^- interaction taking into account strong final state interaction in the pp and pK^- subsystems. To describe the experimental data in terms of final state interactions between (i) the two protons, (ii) the K^- and protons and (iii) the K^+ and K^- , the K^+K^- enhancement factor was introduced such that Eq. (1) changes to

$$F_{\text{FSI}} = F_{pp}(q) \cdot F_{p_1K^-}(k_1) \cdot F_{p_2K^-}(k_2) \cdot F_{K^+K^-}(k_3). \quad (2)$$

As for the case of the pK^- -FSI, the $F_{K^+K^-}$ was calculated in the scattering length approximation

$$F_{K^+K^-} = \frac{1}{1 - i k_3 a_{K^+K^-}}, \quad (3)$$

where $a_{K^+K^-}$ is the effective K^+K^- scattering length and k_3 stands for the relative momentum of the kaons in their rest frame. Using this parametrization we compared the experimental event distributions to the results of Monte Carlo simulations treating the K^+K^- scattering length as an unknown parameter, which has to be determined. In order to estimate the real and imaginary part of $a_{K^+K^-}$ we constructed the Poisson likelihood χ^2 statistic derived from the maximum likelihood method [22, 23]. Data collected at both excess energies have been analysed simultaneously [15]. The best fit to the experimental data corresponds to $|\text{Re}(a_{K^+K^-})| = 0.5^{+4}_{-0.5}$ fm and $\text{Im}(a_{K^+K^-}) = 3 \pm 3$ fm. The final state interaction enhancement factor $F_{K^+K^-}$ in the scattering length approximation is symmetrical with respect to the sign of $\text{Re}(a_{K^+K^-})$, therefore only its absolute value can be determined.

4. Summary

The analysis of the $pp \rightarrow ppK^+K^-$ reaction measured by COSY-11 Collaboration at excess energy $Q = 10$ MeV and $Q = 28$ MeV has been extended to the determination of the differential cross-sections in view of the K^+K^- final state interaction. The extracted K^+K^- scattering length amounts to

$$\begin{aligned} |\text{Re}(a_{K^+K^-})| &= 0.5^{+4}_{-0.5} \text{ fm}, \\ \text{Im}(a_{K^+K^-}) &= 3 \pm 3 \text{ fm}. \end{aligned}$$

Due to the low statistics the uncertainties are rather large. In this analysis we cannot distinguish between the isospin $I = 0$ and $I = 1$ states of the K^+K^- system. However, as pointed out in [24], the production with $I = 0$ is dominant in the $pp \rightarrow ppK^+K^-$ reaction independent of the exact values of the scattering lengths.

The work was partially supported by the European Commission under the 7th Framework Programme through the ‘‘Research Infrastructures’’ action of the ‘‘Capacities’’ Programme. Call: FP7-INFRASTRUCTURES-2008-1, Grant Agreement N. 227431, by the PrimeNet, by the Polish Ministry of Science and Higher Education through grant No. 1202/DFG/2007/03, by the German Research Foundation (DFG), by the FFE grants from the Research Center Jülich, and by the virtual institute ‘‘Spin and strong QCD’’ (VH-VP-231).

REFERENCES

- [1] D. Morgan, M.R. Pennington, *Phys. Rev.* **D48**, 1185 (1993).
- [2] R.L. Jaffe, *Phys. Rev.* **D15**, 267 (1977).
- [3] D. Lohse *et al.*, *Nucl. Phys.* **A516**, 513 (1990).
- [4] J.D. Weinstein, N. Isgur, *Phys. Rev.* **D41**, 2236 (1990).
- [5] E. Van Beveren, *et al.*, *Z. Phys.* **C30**, 615 (1986).
- [6] R.L. Jaffe, K. Johnson, *Phys. Lett.* **B60**, 201 (1976).
- [7] M. Wolke, PhD thesis, IKP Jül-3532 (1997).
- [8] C. Quentmeier *et al.*, *Phys. Lett.* **B515**, 276 (2001).
- [9] P. Moskal *et al.*, *Prog. Part. Nucl. Phys.* **49**, 1 (2002).
- [10] P. Winter *et al.*, *Phys. Lett.* **B635**, 23 (2006).
- [11] Y. Maeda *et al.*, *Phys. Rev.* **C77**, 01524 (2008).
- [12] F. Balestra *et al.*, *Phys. Lett.* **B468**, 7 (1999).
- [13] P. Moskal *et al.*, *Phys. Lett.* **B482**, 356 (2000).
- [14] M. Silarski *et al.*, *Acta Phys. Pol. B Proc. Supp.* **2**, 97 (2009).
- [15] M. Silarski *et al.*, *Phys. Rev.* **C80**, 045202 (2009).
- [16] P. Nyborg *et al.*, *Phys. Rev.* **140**, 914 (1965).
- [17] R. Kamiński, L. Leśniak, *Phys. Rev.* **C54**, 2264 (1995).
- [18] V. Baru *et al.*, *Phys. Lett.* **B586**, 53 (2004).
- [19] S. Teige *et al.*, *Phys. Rev.* **D59**, 012001 (2001).
- [20] D.V. Bugg *et al.*, *Phys. Rev.* **D50**, 4412 (1994).
- [21] M. Silarski, FZ-Jülich report, Jül-4278, (2008).
- [22] S. Baker, R.D. Cousins, *Nucl. Instrum. Methods Phys. Res.* **A221**, 437 (1984).
- [23] G.J. Feldman, R.D. Cousins, *Phys. Rev.* **D57**, 3873 (1998).
- [24] A. Dzyuba *et al.*, *Phys. Lett.* **B668**, 315 (2008).