Analysis of the differential cross-sections for the reaction $pp \to ppK^+K^-$ in view of the K^+K^- interaction

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Measurements of the total cross section of the reaction $pp \to ppK^+K^-$ were performed at the cooler synchrotron COSY near the kinematical threshold by the COSY-11 collaboration [1, 2], and for higher energies by the ANKE collaboration [3]. This reaction channel was studied also by the DISTO collaboration [4] at Q = 114 MeV at the SATURN accelerator. The results indicate that near threshold data points lie significantly above theoretical expectations.

The enhancement may be due to the influence of K^+K^- or Kp interactions which were neglected in the calculations. This interaction should manifest itself also in the distributions of the differential cross-sections [5]. A significant effect observed for the excitation function for the $pp \to ppK^+K^-$ reaction encourages us to carry out the analysis of double differential cross sections in spite of the fact that the available statistics is quite low. In our investigation we use experimental data obtained from two COSY-11 measurements at excess energies of Q = 10 MeV (27 events) and 28 MeV (30 events) [2]. At present we are, however, at the early stage of the analysis.

For three particles in the final state the process of analysing data by plotting them in the space of two internal parameters is a very convenient way to study the interaction. It was originated by Dalitz in a nonrelativistic application. In the original paper [6] Dalitz let the distances to the sides of an equilateral triangle be the energies of the three particles in the center-of-mass system. Another convenient coordinate is the squared invariant masses of the two-body subsystems. Using such coordinates we obtain event distributions bounded by a well defined smooth closed curve [7]. The area of the Dalitz Plot is proportional to the phase space volume. Moreover, for no dynamics and the absence of any final state interaction, the occupation of the Dalitz plot would be fully homogeneous because the creation in any phase space interval would be equally probable. Thus, final state interactions should show up as a modification of the event density in the Dalitz plot.

For four particles in the final state the analysis is more complex, because one needs five variables to fully describe a relative movement of particles. Nevertheless, there are many different types of generalization of the Dalitz plot for four-particle final states, which make possible to study interaction between particles in the exit channel. For studying the K^+K^- or Kp interaction we use two convenient generalizations proposed by Chodrow [8] and Goldhaber [9, 10].

In his work [8] Chodrow assumed, that the invariant matrix element for the process depends only on the energies of the particles. For four particles with masses m_i and total energy E in the center-of-mass frame, the probability of a reaction yielding a state with the ith particle in the energy range dE_i (when two of the particles are identical) is:

$$d^3P = 32\pi^2 |M|^2 dF_1 dE_2 dE_3, \qquad (1)$$

where $dF_1 = \sqrt{E_1^2 - m_1^2} dE_1$ and M denotes the invariant matrix element for the process. This implies that $F_1 = \frac{1}{2}\left[E_1\sqrt{E_1^2 - m_1^2} - m_1^2 cosh^{-1}\left(\frac{E_1}{m_1}\right)\right]$. The distribution of events can then be plotted in the F_1E_2-plane, and resonances may be directly read off this part of the plot, where $E_1 < E_2$. Similarly as in the case of three particle final states the physically allowed region in a Chodrow plot is bounded by a well defined curve, but the event density is not homogeneous and the area of the plot is not proportional to the phase space volume.

According to Nyborg, several other extensions of the Dalitz plot can be obtained if one assumes, that the matrix element M depends only on invariant masses of two- and three particle subsystems [7]. Suppose that M depends at most on M_{12}^2, M_{34}^2, and M_{124}^2, which corresponds to the situation were only two two-particle or one three-particle resonances are present [7]. The distribution of events is then given by:

$$d^3P = \frac{\pi^3}{8E^2M_{12}^2}|M|^2 g\left(M_{12}^2, m_1^2, m_2^2\right) dM_{12}^2\, dM_{34}^2\, dM_{124}^2 \qquad (2)$$

where:

$$g\left(M_{12}^2, m_1^2, m_2^2\right) = \sqrt{\left[M_{12}^2 - (m_1+m_2)^2\right]\left[M_{12}^2 - (m_1-m_2)^2\right]}.$$

The projection of the physical region on the (M_{12}, M_{34})-plane, referred to as a Goldhaber plot, gives a right isosceles triangle within which the area is not proportional to the phase space volume. It is worth mentioning that the event density in the Goldhaber plot is not homogeneous and goes to zero on the entire boundary of the plot given by following equations: $M_{12} + M_{34} = E$, $M_{12} = m_1 + m_2$, $M_{34} = m_3 + m_4$ [7].

So far we conducted Monte Carlo simulations of the $pp \to ppK^+K^-$ reaction [11] using a FORTRAN-based code, called GENBOD [12]. The simulations were first made assuming that there is no final state interaction, then the pp-FSI was included [13]. The pp-FSI was taken into account as weights proportional to the inverse of a squared Jost-function of the Bonn potential [14]. In order to compare these spectra with the experimental distributions we need to correct them for the acceptance and detection efficiency of the COSY-11 facility. This will be the next step of the ongoing investigations.

References:

[1] C. Quentmeier, et al., Phys. Lett. B **515**, 276-282 (2001).

[2] P. Winter, et al., Phys. Lett. B **635**, 23-29 (2006).

[3] Y. Maeda, et al., Phys. Rev. C **77**, 015204 (2008).

[4] F. Balestra, et al., Phys. Lett. B **468**, 7-12 (1999).

[5] P. Moskal, et. al., Prog. Part. Nucl. Phys. **49**, 1-90 (2002).

[6] R.H. Dalitz, Phil. Mag. **44**, 1068 (1953).

[7] P. Nyborg, et al., Phys. Rev. **140**, 914 (1965).

[8] D. Chodrow, Nuovo Cimento **50**, 674 (1967).

[9] G. Goldhaber, et al., Phys. Rev. Lett. **9**, 330 (1962).

[10] G. Goldhaber, et al., Phys. Rev. Lett. **6**, 62 (1963).

[11] M. Silarski, P.Moskal, AIP Conf. Proc. **950**, 77 (2007).

[12] F. James, Monte Carlo phase space, CERN 68-15 (1968).

[13] P. Moskal, et. al., Phys. Lett. B **482**, 356-362 (2000).

[14] B. L. Druzhinin, et al., Phys. A **359**, 205 (1997).

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