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$K\bar{K}$ Production at COSY

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Near threshold $K\bar{K}$ production has been studied in several hadronic reactions at COSY. Data on $pp \rightarrow ppK^+K^-$ and $pd \rightarrow {}^3HeK^+K^-$ are available at several excess energies. ϕ mesons are clearly observed whereas the contribution from the scalar resonances $a_0/f_0(980)$ is unclear. Data on $pp{\rightarrow}dK^+\bar{K}^0$ were measured at two excess energies and for the lower energy the total cross section as well as differential distributions have been extracted. The main contribution to this reaction is identified as the a_0^+ channel. Furthermore, the differential distributions may give information on the $d\bar{K}^0$ FSI and scattering length. The data at the higher energy are still under analysis, and a preliminary value for the total cross section is given. $K\bar{K}$ production in pn reactions is also investigated in a recently performed measurement.

Keywords: Meson production; Proton induced reactions.

1. Introduction

The constituent quark model is a very successful model in hadron physics. It well describes, e.g., the composition of the pseudoscalar mesons or the light baryons. However, in other cases - like for the scalar mesons - the situation seems to be more complicated. Many more resonances have been observed than would fit into the scalar nonet. The scalar $a_0/f_0(980)$ belong to those resonances which might be $q\bar{q}$ states (see e.g. Ref. 1). However, they have also been identified with $K\bar{K}$ molecules[2] or compact qq–$\bar{q}\bar{q}$ states[3]. Even the existence of a complete nonet of 4–quark states at masses below 1.0 GeV has been suggested[4].
In the baryon sector possible deviations from the constituent quark model are currently attracting much interest, e.g., the vividly discussed θ^+[5] being interpreted as a 5-quark state or the $\Lambda(1405)$ which might be a $\bar{K}N$ bound state[6].
At the Cooler SYnchrotron Jülich (COSY)[7] a program has been started in order to gain additional information about the light scalar resonances $a_0/f_0(980)$ from pp, pn, pd, and dd interactions[8]. In contrast to the existing data (see e.g. Ref. 9)

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these experiments are close to the $K\bar{K}$ threshold where the a_0/f_0 are produced directly, i.e. not via higher lying resonances. The final goal of this program will be the extraction of the charge-symmetry breaking a_0/f_0 mixing amplitude which is predicted to be large[10] but no unambiguous signal has been observed up to now.

2. The Experimental Facilities

COSY, the 184 m long synchrotron accelerator at the research center Jülich, provides (stochastically or electron cooled) polarized and unpolarized proton and deuteron beams in the momentum range 300 to 3700 GeV/c for internal and external experiments. With the highest energy mesons up to the $\phi(1020)$ can be produced. Intensities of up to 10^{11} particles are available in case of unpolarised beams. The experimental setups where $K\bar{K}$ production has been studied are ANKE[11] and COSY-11[12] at internal and MOMO[13] at an external target station.
ANKE is a magnetic spectrometer comprising three dipoles. The target is placed in front of the central dipole D2 which separates charged ejectiles from the circulating beam. D2 has a gap height of 20 cm and a horizontal and vertical acceptance of $\pm 12°$ and $\pm 7°$, respectively. An H_2/D_2 cluster jet target[14] has been used providing areal densities of up to $5 \cdot 10^{14} cm^{-2} s^{-1}$. Positively charged ejectiles are detected in the forward and side detection systems. The forward system consists of multiwire proportional chambers (MWPCs) for track reconstruction and a two-layer hodoscope of scintillation counters for time-of-flight (TOF) and energy loss measurements. The side system is composed of TOF-start scintillation counters, dedicated range telescopes in the focal plane of D2 for TOF (stop) and energy loss measurements. An additional layer of scintillation counters for TOF measurements and two MWPCs for track reconstruction is available, covering higher momenta than the telescopes. Negatively charged ejectiles are detected in TOF-start and -stop counters and two MWPCs.
COSY-11 also is an internal magnetic spectrometer. The target station is placed in front of one of the COSY ring dipoles in which the reaction ejectiles are separated from the beam and are momentum analyzed. The 4-vectors of positively charged ejectiles are measured with TOF-start and -stop counters and drift chambers. For negatively charged particles an additional silicon pad detector, mounted inside the dipole magnet, can be used to identify possible K^- candidates and therefore to reduce the background. For the discussed measurements a similar H_2 cluster jet target as at ANKE has been used.
The setup of the external experiment MOMO comprises a scintillating fiber vertex detector for meson identification near a liquid D_2 target with an opening angle of $\pm 45°$. The high resolution magnetic spectrometer BIG KARL[15] is used for ^3He identification, accompanied with two drift chambers for track reconstruction and two scintillation hodoscopes for TOF and energy loss measurements.

3. The Data

Several experiments on $K\bar{K}$ production have been performed at COSY and are listed in Table 1.
At COSY-11 and ANKE data on the reaction $pp \rightarrow ppK^+K^-$ have been measured at six different excess energies from 10 to 108 MeV above the K^+K^- threshold. From the experiment at $Q = 17$ MeV a total production cross section of 1.8 nb and angular distributions have been extracted[16]. In the missing mass distribution $m_X(pp)$[17] resonant K^+K^- production via the f_0 or a_0 cannot be distinguished from nonresonant production and the statistical uncertainty is too large to be able to perform a partial wave analysis of the angular distributions. Two more measurements at COSY-11 are being analyzed, at $Q = 10$ and 28 MeV[18], both below the ϕ threshold. Total cross sections as well as angular distributions will be determined. At ANKE three pp measurements above the ϕ threshold are being analyzed. Also for them the total cross section and angular distributions will be available soon.

Table 1. Data on $K\bar{K}$ production from COSY. The excess energy is given relative to the corresponding $K\bar{K}$ threshold.

Reaction	$pp \rightarrow ppK^+K^-$	$pp \rightarrow dK^+\bar{K}^0$	$pn \rightarrow dK^+K^-$	$pd \rightarrow {}^3HeK^+K^-$
Detector	COSY-11, ANKE	ANKE	ANKE	MOMO
Excess Energy $[MeV]$	10, 17, 28, 51, 67, 108	48, 105	30 - 90	35, 40, 56

At MOMO the reaction $pd \rightarrow {}^3HeK^+K^-$ has been studied at three different excess energies[13]. The total cross sections for ϕ production and K^+K^- production not via the ϕ were determined. Also here, the contribution from the scalar resonances a_0/f_0 is not obvious.
At ANKE the reaction $pp \rightarrow dK^+\bar{K}^0$ has been investigated at $Q = 48$ and 105 MeV excess energy[19]. For the lower energy the total cross section as well as differential spectra have been obtained, see Fig. 1. These distributions have been fitted assuming that only s- and p-waves contribute. S-waves everywhere are forbidden due to principal conservation laws, thus at least one p-waves contributes. Higher partial waves are suppressed close to the production threshold. The data are described well by the fit with the result that approx. 83% of the $K\bar{K}$ pairs are in a relative s-wave while the $K\bar{K}$ system is in a relative p-wave to the deuteron. Since the a_0 is a scalar resonance, decay kaons have to be in an s-wave. Thus, the a_0 channel dominates this reaction. In Ref. 20 it has been suggested to investigate the $d\bar{K}$ FSI which influences the invariant mass distribution $m_{inv}(d\bar{K})$. However, two arguments are put forward against a strong $d\bar{K}$ FSI. First, the partial wave fit describes the data quite well without any $d\bar{K}$ FSI. Second, any $d\bar{K}$ FSI would move the center of gravity of the distribution $m_{inv}(d\bar{K})$ towards low invariant masses which is not supported by the

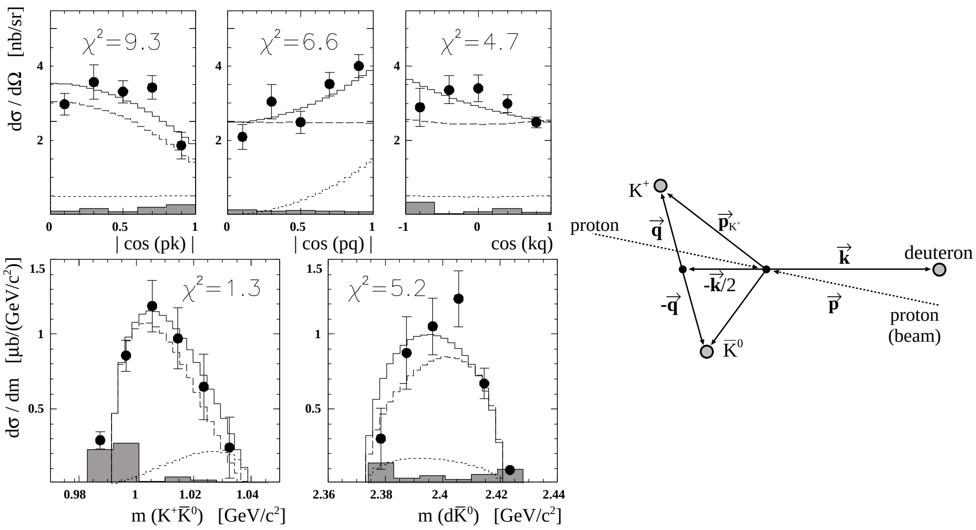

Fig. 1. Differential cross section of the reaction $pp \to dK^+\bar{K}^0$ at $Q = 48$ MeV with statistical (error bars) and systematic (shades area) uncertainties[19]. The angles are described in the right sketch.

data. Recently, Sibirtsev *et al.*[21] have included the FSI via the Watson factor and refitted the data with the real and imaginary part of the scattering length as free parameter. The best agreement is achieved for small scattering lengths, Im $a \leq 1.3$ fm and $|\text{Re } a| \leq 1.3$ fm.

The data at the higher energy are still being analyzed. Since the excess energy is more than twice as large as for the lower energy the accessible range of the invariant mass distribution $m_{inv}(K\bar{K})$ is also more than twice as large. The preliminary total cross section has been extracted[22] and is shown in Fig. 2 together with the lower energy data and a prediction of the model from Ref. 23. According to the model the contribution from nonresonant $K\bar{K}$ production increases and is as large as resonant production.

Early this year an experiment on the reaction $pn \to dK^+K^-$ has been performed at ANKE. Since free neutron targets are not available a deuterium cluster jet target has been used. Whereas in the reaction $pp \to dX^+$ the a_0^+ must be produced, a $pn \to dX^0$ reaction may lead to the production of a_0^0, f_0 and $\phi(1020)$. All three particles dK^+K^- have been detected. The missing mass $m_X(dK^+K^-)$ shows a peak at the mass of the spectator proton (see Fig. 3, left side). After the selection of this proton, the invariant mass $m_{inv}(K^+K^-)$ exhibits a peak at the ϕ mass (Fig. 3, right side). This measurement is the first on ϕ production from neutrons. The total cross section as well as differential distributions will be extracted. Also, possible contributions from a_0/f_0 production will be investigated.

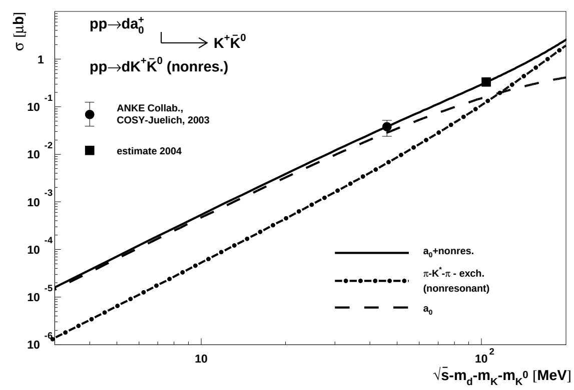

Fig. 2. Prediction for the total cross section[23] for the reaction $pp \to dK^+\bar{K}^0$ together with the ANKE result at $Q = 48$ MeV and the estimate for $Q = 105$ MeV.

4. Outlook

The final goal of the a_0/f_0 production studies will be the extraction of the a_0/f_0 mixing amplitude. This quantity has not yet been measured but might shed further light on the nature of these resonances. The next step into this direction is a planned measurement of the reaction $dd \to \alpha K^+K^-$ to determine the total and differential cross section for $S = I = 0$ $K\bar{K}$ production. The final step will be an experiment on the reaction $dd \to \alpha\pi^0\eta$. Any signal of this reaction is a direct observation of isospin violation since the deuterons in the initial and the alpha particle and π^0 in the final state are all isoscalar particles. The reaction $dd \to \alpha f_0$ is allowed by isospin. Mixing of the f_0 with the a_0 and a subsequent decay into $\pi^0\eta$ would explain the signal, and it has been shown that this is the dominant isospin violating effect[25]. The invariant

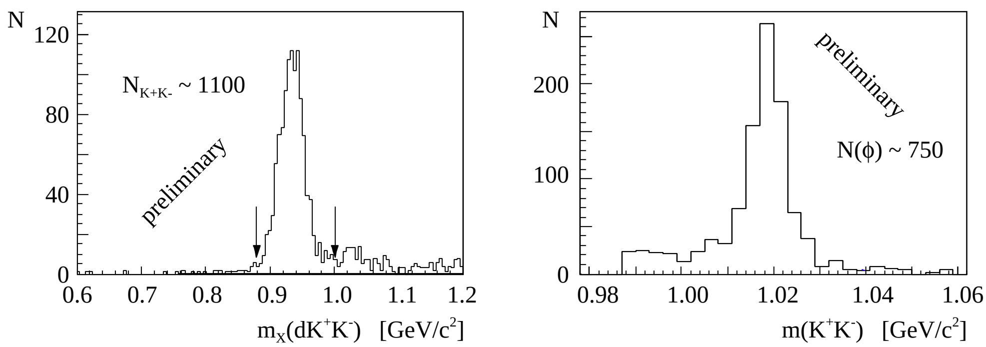

Fig. 3. On the left side, the missing mass distribution $m_X(dK^+K^-)$ is shown. The prominent peak is at the mass of a proton - the spectator proton. The invariant mass $m_{inv}(K^+K^-)$ shows a clear peak from ϕ-production (right side). This spectrum is shown after a gate on the spectator proton (indicated by the arrows). These spectra[24] show roughly 40% of the available statistics.

mass distribution $m_{inv}(\pi\eta)$ together with $m_{inv}(K^+K^-)$ of the previously described experiment would then allow to extract the a_0/f_0 mixing amplitude. Since the $\alpha\pi^0\eta$ experiment requires a photon detector it cannot be performed at an existing detector at COSY but has to await the WASA detector soon to be moved to Jülich.

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