Reply to the referee report on experiment #140 presented during the 28$^{\text{th}}$ session of the COSY-PAC

M. Büscher, C. Hanhart, S. Krewald, F.P. Sassen

Report on exp. #140 from the minutes of the PAC meeting:
This proposal is motivated by the isospin violating process $dd \to \eta\pi^0\alpha$. This process is interesting because it is expected to be dominated by the reaction chain $dd \to \alpha f_0 \to \alpha a_0 \to \alpha K^+K^-$ or $\to \alpha(\eta\pi^0)$. Hence, it is expected to give valuable information on a_0-f_0 mixing and a possible exotic nature of these mesons. This experiment is considered a very important topic for WASA at COSY, since WASA will be able to detect both neutral ($\eta\pi^0$) and charged final states (K^+K^-). However, this experiment only aims at a measurement of $dd \to K^+K^-\alpha$ using the ANKE detector. Several questions were raised: 1) what new insight into the nature of the a_0-f_0 puzzle could be obtained from the new (αK^+K^-) data alone, within the limited available phase space? 2) Would these data still be useful once WASA is measuring the complete process (i.e. both K^+K^- and $\eta\pi^0$)? If yes, how would the ANKE data be compared with WASA, in view of the very different detector acceptances?
The PAC decided to defer the discussion of P140 until these questions have been clarified.

1 Overview

We share the viewpoint of the COSY-PAC that a measurement of the isospin-violating a_0-f_0 mixing will be one of the key experiments for WASA at COSY. A necessary first step into this direction is the proposed study of the process $dd \to K^+K^-\alpha$ (Sect. 3). However, a measurement of this reaction alone can already give valuable information about the properties of the f_0 resonance (Sect. 4). In principle, the $K\bar{K}$ channel could also be measured with WASA, but ANKE is much better suited for these measurements (Sect. 5).

2 General remarks

1. ANKE has measured (in 2001) the reaction $pp \to dK^+\bar{K}^0$ at an excess energy of $Q = 46$ MeV. The data (so far) are the basis for three papers, two of them published and one submitted to refereed journals (in addition there are several conference proceedings): i) "*a_0^+(980)-resonance production in $pp \to dK^+\bar{K}^0$ reactions close to threshold*" [1] (experimental data, cross sections, partial wave decomposition); ii) "*Near threshold production of a_0(980)-mesons in the reaction $pp \to dK^+\bar{K}^0$*" [2] (theoretical description of the data in terms of scalar meson production; iii) "*Determination of the $\bar{K}^0d$ scattering length from the reaction $pp \to d\bar{K}^0K^+$*" [3].

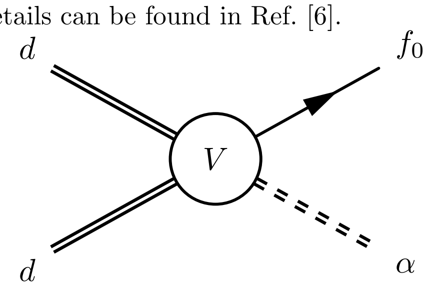
2. The $pp \to dK^+\bar{K}^0$ reaction leads to a_0^+ production (i.e. the isospin=1 scalar meson), a pn interaction is not isospin selective and both the a_0 ($I = 1$) and f_0 ($I = 0$) states may be produced, whereas the $dd \to \alpha X$ reaction — neglecting small isospin violating contributions — is a filter for the f_0 resonance. Thus, from the proposed experiment we expect data of

comparable quality on the f_0 resonance as for the isospin 1 channel [1]. We consider the dd experiment as the most important from the three initial states, pp, pn and dd, the former two have in the past received very strong support by PAC, and have been successfully measured at ANKE.

3. The current proposal on $dd \to \alpha K^+K^-$ foresees a measurement at an excitation energy of $Q = 39$ MeV above the K^+K^- threshold, i.e. about the same excitation energy as for the pp reaction. Thus the model independent partial wave analysis from Ref. [1] can also be applied to the data from the proposed experiment. There is an important difference, however, namely that for the pp reaction there must be a mixture of s and p waves in the final state, whereas for the dd case only the s wave is expected. This allows for a stronger effect of the $\bar{K}\alpha$ interaction that is an interesting issue in itself (see below).

3 A first step towards a_0-f_0 mixing

In 1979 Achasov and collaborators [4] pointed out that the leading term to the f_0-a_0 mixing amplitude in between the charged and neutral kaon thresholds is dominated by the unitary cut of the intermediate two-kaon system. This allows one to determine the product of the couplings of the two-kaon systems to the f_0 and a_0 model independently[1]. However, the cross section will be proportional to the product of the mixing amplitude and the production operator and therefore it is compulsory to determine the latter in an independent measurement in order to extract the mixing amplitude. The reaction $dd \to \alpha K^+K^-$ allows one to extract the $dd \to \alpha f_0$ production operator with the presently existing equipment. More details can be found in Ref. [6].



4 Analysis of the reaction $dd \to \alpha K^+K^-$

Recently, proton-antiproton annihilation (LEAR) and the study of radiative ϕ-decay (KLOE) have increased the experimental knowledge of scalar mesons [7, 8, 9, 10]. Hadronic Z^0-decays (OPAL) find the mass of the $f_0(980)$ meson to be $m = 953$ MeV [11]. In charmed-meson decay (FermiLab E791), the mass is determined to be $m = 975$ MeV, close to the KLOE-value $m = 973$ MeV. In theoretical analyses, the pole position of the $f_0(980)$ may be even larger (≈ 1015 MeV), see e.g. Refs. [12, 13].

The reaction $dd \to \alpha K\bar{K}$ serves as an isospin filter and therefore is a unique opportunity to study the $\bar{K}K$ decay channel of the isoscalar $f_0(980)$. The

[1]The uncertainties of the coupling constants g_{a_0KK} and g_{f_0KK} are illustrated e.g. in a recent compilation [5].

question remains, whether the small excess energy of ≈ 40 MeV available at COSY is sufficient to distinguish between various pole positions. To study this question we developed a model for the kaon production in $dd \to K\bar{K}\alpha$ using the Jülich $\pi\pi$-$K\bar{K}$ coupled channel model [14, 15, 16] to generate the final state interaction of the produced mesons either with the $f_0(980)$ pole located at 1022 MeV or at 981 MeV. To calculate the production amplitude M we use

$$M = C_{KK}^{\rm prod} T_{KK\to KK} + C_{\pi\pi}^{\rm prod} T_{\pi\pi\to KK} \ . \tag{1}$$

This expression would be exact, if the ranges of the production operator and of the scattering potential were equal (this is the case in the approach taken by J.A. Oller et al. [17], where both are point like). We expect that a more microscopic calculation will not change this picture significantly. We found that changing the ratio $C_{\pi\pi}^{\rm prod}/C_{KK}^{\rm prod}$ over a wide range changed the m_{KK} dependence of the production cross sections by 5% only.

Our predictions for the differential production cross sections are shown in Fig. 1. One can see how the phase space (dashed) is modified by the final state interaction. The pole situated at 1022 MeV produces a strong enhancement close to threshold and a strong transition from $\pi\pi\alpha$ to $K\bar{K}\alpha$. In the case of the pole being closer to the threshold (981 MeV) this enhancement is not that pronounced anymore. Corresponding calculations for pole positions at even lower masses (as measured, e.g., by E791, KLOE or OPAL) would lead to shapes which are more similar to the phase-space distribution. Consequently, a close to threshold measurement will give valuable input to study the production and properties of the scalar isoscalar meson.

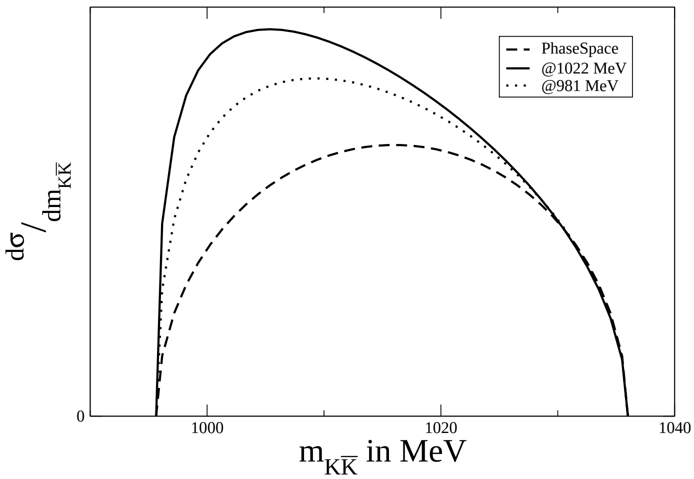


Figure 1: Production cross section for $dd \to \alpha K\bar{K}$ as a function of the invariant mass of the $K\bar{K}$-system for $Q = 40$ MeV/c^2. The blue line shows phase space, where as the green and the red curves show how phase space gets modified by final state interaction in the meson-meson channel corresponding to different pole positions of the $f_0(980)$.

5 Comparison of ANKE and WASA

ANKE — a forward magnetic spectrometer — allows one to detect and identify charged ejectiles emitted at 0° relative to the circulating COSY beam. WASA with its forward scintillator arrangement can only detect charged ejectiles with emission angles larger than 3°. In an experiment aiming at the detection of fast α particles from a $dd \to \alpha X$ reaction at COSY this has severe consequences for the maximum detectable masses m_X. According to our simulations, the maximum achievable missing mass m_X at WASA is ~ 15 MeV/c^2 lower than at ANKE (at the *same beam momentum*), i.e. $Q \sim 24$ MeV instead of $Q \sim 39$ MeV. It should be noted that this intrinsic restriction of the WASA detector is not a severe drawback for the foreseen measurement of the $dd \to \alpha(\eta\pi^0)$ channel since *i)* the $\eta\pi^0$-mass distribution is not restricted at lower masses by the $K\bar{K}$ threshold and *ii)* the isospin violating signal from the kaon loops is expected to be very narrow and concentrated around the mass region $987 - 995$ MeV/c^2, see Fig. 2 of the proposal.

ANKE is the best detector at COSY for the detection of charged kaons, whereas WASA is well suited for $K_s^0(\to 2\pi^0 \to 4\gamma)$ detection. Good K^+/K^- identification with WASA (in particular in forward direction) is currently *not* possible and would call for major upgrades of the detector. Consequently, with ANKE one would measure $dd \to \alpha K^+K^-$, with WASA $dd \to \alpha K_s^0 K_s^0$. The corresponding minimum invariant masses of the kaon-antikaon systems are 987.4 and 995.3 MeV/c^2, respectively, which further reduces the maximum achievable Q value for WASA by 8 MeV/c^2. At a beam momentum of 3.70 GeV/c we thus have $Q = 39$ MeV for ANKE and ~ 16 MeV for WASA!

As demonstrated in Fig. 2 the $K\bar{K}$-mass distributions calculated for different values of the f_0 pole position become less distinct if measured at an excitation energy of only $Q = 16$ MeV. In addition, due to the smaller total cross section closer to threshold, such a measurement would require significantly longer beam times. This shows that the proposed measurements of the $K\bar{K}$ channel must be performed at ANKE ($Q = 39$ MeV, Fig. 1) where the curves can be distinguished. A further increase of the beam momentum would not significantly improve the situation. This is also shown in Fig. 2 where the result of our calculations for $Q = 100$ MeV is presented.

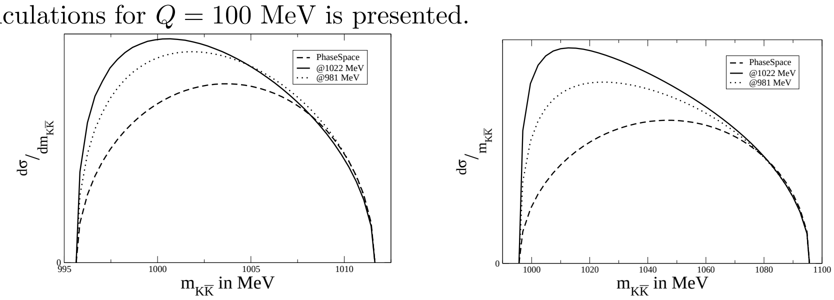


Figure 2: Same as Fig. 1 for excitation energies of $Q = 16$ and 100 MeV/c^2.

We finally recall the result of our simulation calculations presented in the proposal that the total geometrical acceptance of ANKE for the reaction $dd \to \alpha K^+K^-$ is 10% (including decay in flight). This large value is due to the reaction kinematics at $Q = 39$ MeV. According to simulations the acceptance of WASA for $dd \to \alpha K_s^0 K_s^0(\to 4\pi^0 \to 8\gamma)$ is about 8%.

6 $\bar{K}N$ final state interaction

From the data on the pp reaction we were able to extract the $\bar{K}d$ scattering length in a basically model independent way. This quantity is not well known yet, however of great importance, e.g. in view of formation of bound kaonic states [3]. As shown in the proposal the sensitivity of the (αK^+K^-) final state on the scattering length is significantly larger than for $(dK^+\bar{K}^0)$. Unfortunately, the PAC did not comment at all on this point yet.

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