Beam request for COSY experiment #140
"Investigation of the neutral scalar mesons $a_0/f_0(980)$ in the reaction $dd \to \alpha\, K^+K^-$ with ANKE"

M. Büscher, August 12, 2005
for the ANKE collaboration

1 Status of ANKE beam times

During the last sessions (#28 and #29) of the COSY-PAC, the following decisions regarding ANKE beam times in 2005/06 have been made:

Proposal 104.2, *Investigation of a possible exotic state in the ϕN system*
In total three weeks of beam time were granted, to be scheduled in the coming beam-time period, *i.e.* winter/spring 2006. Due to the high importance of finding a narrow state in the ϕN system, the ANKE collaboration had asked the PAC in proposal #104.2 to consider scheduling of the experiment already in winter 2005. Unfortunately, this request has not even been discussed during the PAC meeting.

Proposal 125.1, *The polarized charge exchange reaction $\vec{d}p \to (pp) + n$*
In total 3 weeks were allocated (two weeks for a measurement of the forward spin-dependent $np \to pn$ amplitudes plus one week for target-cell studies) in winter 2005.

Proposal 140.1, *Investigation of neutral scalar mesons $a_0/f_0(980)$ in the reaction $dd \to \alpha K^+K^-$ with ANKE*
In total four weeks of beam time were given, two of them in the next beam-time period (*i.e.* in Jan./Feb. 2005 due to the high beam energy). The remaining two weeks should be scheduled after results of the first two have been presented to PAC (*i.e.* most likely in winter/spring 2006).

In accord with these decisions, the following ANKE beam times were scheduled during the COSY coordination meeting in Dec. 2004 for the period, Jan. – March 2005:

i) Nothing for exp. 104.2, but three weeks "in the books" for winter/spring 2006

ii) Three weeks for exp. 125.1

iii) Two weeks for exp. 140.1

Early in 2005 the ANKE collaboration was asked by the GEM group whether some days of the scheduled ANKE experiments could be given as a compensation for beam losses due to two acts of sabotage.

In Jan. 2005 the ANKE collaboration — in accord with the management of the IKP — decided to internally re-arrange the three approved beam times listed above. The measurements for exp. 104.2 have been scheduled and successfully been carried out in March 2005 and some days of beam time have been given to GEM. As a consequence, ONE allocated week for exp. 125.1 and the TWO weeks for exp. 140 are now due to scheduling in the next beam period.

With this beam request the ANKE collaboration asks the beam-time coordinator to schedule the canceled two weeks for exp. 140.1 as soon as possible (*i.e.* in winter 2005/06), partially taking the place of the three weeks for exp. 104.2. In addition, **we ask the PAC for the permission to schedule the two remaining weeks for exp. 140.1 in ONE BLOCK (of four weeks)**, *i.e.* without further delay and according to the anticipated time schedule after PAC #29. The purpose of this document is to demonstrate that speedy scheduling of this experiment is mandatory for successfully finalizing the COSY experimental program on scalar mesons, to contribute to the currently intensively discussed problem of $\bar{K}$-nuclear bound states, and is also recommended by the technical boundary conditions at ANKE.

2 Boundary conditions at ANKE

Target installations In summer 2005 the polarized internal target (PIT) has been installed at ANKE, taking the place of the cluster-jet target which is needed for exp. 140. The commissioning of the PIT will be carried out in fall 2005, see beam request submitted for this PAC meeting. After that — during the winter shutdown 2005/06 — the PIT will be taken out again and replaced by the cluster-jet target. Re-installation of the PIT is foreseen for the summer shutdown 2006. This leaves a time slot Feb. – June 2006 for the measurement of the $dd \to \alpha K^+K^-$ reaction.

If the beam time is splitted into two times two weeks, it is unclear when the second block can be taken. Furthermore, according to our experience losses due to "overhead" (beam and target preparation, detector tuning) would *significantly* increase. The expected number of events (our estimate $\sim 100 - 200$) from a two-weeks block would hardly allow one to draw conclusions about the physics issues discussed below, while after four weeks (~ 500, see proposal) this should be possible.

Investigation of in-medium K^-- and ϕ-production At a later stage it is planned to investigate the in-medium production of K^-- and ϕ-mesons at ANKE, using Carbon and heavier target materials (see proposal submitted for this PAC meeting). Clearly, the interpretation of data from these nuclei requires good understanding of lighter systems — like $\bar{K}d$, $\bar{K}\,^3$He and $\bar{K}\,^4$He. The first two have already been measured at ANKE and MOMO and interpreted in terms of the $\bar{K}$-nucleon FSI (see Sect. 3.2), while information about the latter system will be obtained from the measurements requested here.

3 Status of other experiments

3.1 Light scalar mesons

Recently, the BES collaboration has measured resonance production in the decays $J/\Psi \to \phi\,\pi^+\pi^-$ and $J/\Psi \to \phi\,K^+K^-$ [1]. A clear signal from the $f_0(980)$ has been observed in both channels and some Flatté parameters of this resonance have been extracted. After an upgrade of the BES detector also neutral decay products can be measured, making the isospin-violating $J/\Psi \to \phi\,\pi^0\eta$

decay accessible. Then the isospin-violating a_0-f_0 mixing in the reaction chain $J/\Psi \to \phi\, f_0 \to \phi\, a_0 \to \phi\, \pi^0\eta$ can be measured at BES.

The measurement of a_0-f_0 mixing via the isospin-selective $dd \to \alpha\, \pi^0\eta$ reaction with WASA is the main goal of the COSY scalar-meson experimental program [2]. In view of the BES upgrade these measurements should be carried out as soon as possible. Since for the preparation and interpretation of the WASA measurements, the ANKE data on $dd \to \alpha K^+K^-$ are essential (see our proposal) any delay of exp. 140 must be avoided.

3.2 The interaction of $\bar{K}$ mesons with light nuclei

Low energy $\bar{K}N$ and $\bar{K}A$ interactions have gained substantial interest during the last two decades. It is known from the time-honored Martin analysis [3] that the S-wave K^-N scattering length is large and repulsive, $Re\ a_0 = -1.7$ fm, while the isovector length is moderately attractive, $Re\ a_1 = 0.37$ fm. It is clear that such a strong repulsion in $\bar{K}N$ isoscalar channel leads also to repulsion in the low-energy K^-p system, since $Re\ a(K^-p) = 0.5\ Re(a_0 + a_1) = -0.67$ fm. Nevertheless, it is possible that the actual K^-p interaction is attractive. A fundamental reason for such a scenario is provided by the leading order term in the chiral expansion for the K^-N amplitude which is attractive. The analysis of the S-wave kaon-nucleon interactions for strangeness $S = -1$ in the novel relativistic chiral unitary approach based on coupled channels has been performed in Ref. [4]. (See also more recent development of this approach in Ref. [5]). A good description of the data in the K^-p, $\pi\Sigma$ and $\pi\Lambda$ channels has been obtained, and the calculated K^-p scattering length $a(K^-p)$ is in reasonable agreement with results from kaonic-hydrogen X-rays, $a(K^-p) = (-0.78 \pm 0.15 \pm 0.03) + i(0.49 \pm 0.25 \pm 0.12)$ fm [6], and the value of Martin [3], $a(K^-p) = (-0.67 \pm 0.10) + i(0.64 \pm 0.10)$ fm. However, the consistency of the X-ray with the scattering data can be questioned, as first pointed out in Ref. [7], where isospin-breaking corrections to the energy levels and decay widths of kaonic hydrogen were analysed and found to be comparable with the precision of the recent DEAR measurements [8].

The non-trivial dynamics of the K^-N interactions leads to very interesting in-medium phenomena in interaction of antikaons with finite nuclei as well as with dense nuclear matter, including neutron stars, see e.g. Refs.[9, 10]. Thus, to understand the basic features of the K^-N and K^-A physics we need not only data on the shifts and widths of atomic levels, but also new low energy K^-N and K^-A scattering experiments are important to be performed in a nearest future.

The strongly attractive K^-A potential with a depth of -180 MeV has been determined from a phenomenological fit of kaonic-atom data [11]. The microscopic interpretation of such a striking phenomenon — attraction of antikaons in nuclear medium — has been suggested by Waas-Kaiser-Weise [12] and further developed in Refs. [13, 14, 15]. The analysis of the elementary S-wave $\bar{K}N$ interactions (in free space) within the coupled-channel approach is based on SU(3) chiral Lagrangians, where the $\bar{K}N$ amplitude in the $I = 0$ isospin channel has a pole just 27 MeV below the $\bar{K}N$ threshold. This pole corresponds to a $\Lambda(1405)$ resonance. Then, in the presence of nuclear matter, the properties of the $\Lambda(1405)$ as well as K^--mesons should be strongly modified. Due to the so-called dissolution of the $\Lambda(1405)$, the real part of the K^-p scattering length changes sign already at small fraction of nuclear matter density, less than $0.2\rho_0$.

One of the most extensive analysis of the effective $\bar{K}N$ interactions in nuclear medium was done by Ramos and Oset [15] within the latest version of a self-consistent microscopic theory. The resulting K^- attraction in medium has been found to be smaller than predicted by other theories and approximation schemes. The isospin-averaged effective $\bar{K}N$ scattering length is moderately attractive and its real part does not exceed the value of,

$$\mathrm{Re}\; a^{\mathrm{eff}} \simeq 0.3\,\mathrm{fm}\ , \tag{1}$$

at nuclear density $\rho \geq 0.3\rho_0$. The obtained shallow K^--nucleus optical potential with a depth -50 MeV (for the real part of the potential at $\rho = \rho_0$) was succesfully used to reproduce the experimental shifts and widths of kaonic atoms over the periodic table [16].

In contrast to the above discussed studies, Akaishi and Yamazaki have obtained the following effective $\bar{K}N$ scattering lengths for the $I = 0, 1$ channels in the framework of the Brueckner-Hartree-Fock theory

$$\begin{aligned} a_0^{\mathrm{eff}} &= 2.88 + i1.12\,\mathrm{fm}\ , \\ a_1^{\mathrm{eff}} &= 0.43 + i0.30\,\mathrm{fm} \end{aligned} \tag{2}$$

for nuclear medium. For the basic $\bar{K}N$ interactions they exploited a phenomenological potential model, which reproduces the K^-p and K^-n scattering lengths from Martin [3] and the mass and width of the $\Lambda(1405)$ resonance in free space. The strength of the real part for the isospin-averaged attractive $\bar{K}N$ amplitude in nuclear medium was found about 6 times larger than derived in Ref. [15]. According to the Akaishi-Yamazaki approach, such a strong attraction is possible also in the case of light nuclei, and the existence of deeply bound $\bar{K}$-nuclear states has been predicted for few-body systems [17]. Recently two narrow tribaryon states were observed in the reactions ^{4}He(stopped-K^-, p)$S^0(3115)$ and ^{4}He(stopped-K^-, n)$S^1(3140)$ at KEK [18]. In Ref. [19] they were interpreted in terms of deeply bound kaonic states predicted earlier in [17]. To describe the enormously large binding energy, $B_K \geq 130$ MeV, an attractive potential between the $\bar{K}$ and the nuclear core in the case of the K^-ppn system should reach a depth of about -600 MeV. As a result of such strong attraction, the dense nuclear systems can be formed with the average nucleon density, $\rho_N^{\mathrm{av}} = 3.1 \times \rho_0$, which is much larger then normal density, $\rho_0 \sim 0.17$ fm^{-3}.

3.2.1 The K^-A scattering lengths

The question if the strong attraction in systems with K^- mesons and light nuclei exists can be resolved experimentally either using data on $\bar{K}$-nucleus scattering or by analysing final-state interactions in ($\bar{K}$, light nucleus) systems from production data.

Up to now the s-wave $K^-\alpha$ scattering length, which we denote as $A(K^-\alpha)$, has not been measured. Theoretical predictions for $A(K^-\alpha)$ and $A(K^{-3}\mathrm{He})$ have been presented in Refs. [20, 21] within the Multiple Scattering Approach (MSA). The calculations of $A(K^-\alpha)$ and $A(K^{-3}\mathrm{He})$ have been made for five parameters sets of the $\bar{K}N$ lengths, some of them shown in Table 1. Here we discuss the results from a K-matrix fit (Set 1) [22] and the constant scattering-length fit from Conboy [23] (Set 2). The recent predictions for the $\bar{K}N$ scattering

Table 1: The $K^-\alpha$ and $K^{-\,3}$He scattering lengths for various choices of the elementary $\bar{K}N$ scattering lengths $a_I(\bar{K}N)$ $(I = 0, 1)$.

Set	Ref.	$a_0(KN)$[fm]	$a_1(KN)$[fm]	$A(K^-\alpha)$[fm]	$A(K^{-3}\mathrm{He})$[fm]
1	[22]	$-1.59 + i0.76$	$0.26 + i0.57$	$-1.80 + i0.90$	$-1.50 + i0.83$
2	[23]	$-1.03 + i0.95$	$0.94 + i0.72$	$-2.24 + i1.58$	$-1.52 + i1.80$
3	[4]	$-1.31 + i1.24$	$0.26 + i0.66$	$-1.98 + i1.08$	$-1.66 + i1.10$
Ramos	[15]	$0.33 + i0.45$ isospin average		$-1.47 + i2.22$	$-0.43 + i2.33$
AY	[17]	$2.88 + i1.12$	$0.43 + i0.30$	$-3.49 + i1.80$	$-3.93 + i4.03$

lengths based on the chiral unitary approach of Ref. [4] are denoted as Set 3. In order to demonstrate the sensitivity of our result to possible modifications of the $\bar{K}N$ scattering amplitudes in the presence of nuclei we consider also the moderately attractive effective scattering length from Ref. [15] as well as the strongly attractive solution (2) found in Refs. [17, 19].

The results of our calculations are listed in the last two columns of Table 1. The values of $A(K^-\alpha)$ and $A(K^{-3}\mathrm{He})$ are very similar for Sets 1, 3 and are in the range $A(K^-\alpha) = -(1.8{\div}2.)+i(0.9{\div}1.1)$ fm and $A(K^{-3}\mathrm{He}) = -(1.5{\div}1.7)+i(0.3{\div}1.1)$ fm, respectively. The results for Set 2 are quite different: $A(K^-\alpha) = -2.24 + i1.58$ fm and $A(K^{-3}\mathrm{He}) = -1.52 + i1.80$ fm. The calculations with the effective $\bar{K}N$ amplitude from Ref. [15] give the $K^-\alpha$ (K^{-3}He) scattering lengths with an imaginary part two times larger than the result obtained with the vacuum $\bar{K}N$ scattering lengths. Not surprisingly, the exotic set for the elementary amplitudes extracted from Refs. [17, 19] leads to enormously large scattering lengths for $K^-\alpha$ and K^{-3}He systems with real parts of -3.5 fm and -4 fm, respectively.

3.2.2 The $K^-\alpha$ FSI in the $dd\to\alpha K^-K^+$ reaction

In Ref. [20] it has been demonstrated that the reaction $dd \to \alpha K^-K^+$ near threshold is sensitive to the $K^-\alpha$ final state interaction. Here we present calculations of the $K^-\alpha$ invariant mass spectra at excess energy 50 MeV which are shown in Fig. 1(left). The solid line shows the calculations for the pure phase space, *i.e.* for the constant production amplitude and neglecting FSI. All other lines in Fig. 1 (left) show the results obtained with the $K^-\alpha$ FSI calculated using different sets of K^-N parameters presented in Table 1. All lines in Fig. 1 (left) are normalized to the $dd\to\alpha K^+K^-$ cross section of 1 nb. It is clear that the FSI significantly changes the $K^-\alpha$ mass spectra.

Akaishi and Yamazaki [17] argued that the $\bar{K}N$ interaction is characterized by a strong I=0 attraction, which allows the few-body systems to form dense nuclear objects. The optical potential proposed by Akaishi and Yamazaki for deeply bound nuclear states contains the effective $\bar{K}N$ scattering lengths in the medium defined by Eq.(2). We used these modified scattering lengths to calculate the effect of the $K^-\alpha$ FSI in the $dd \to K^+K^-\alpha$ reaction. The short-dashed line in Fig. 1 (left) demonstrates a very pronounced deformation of the $K^-\alpha$ invariant mass spectrum. Such a strong in-medium modification of the $\bar{K}N$ scattering length apparently can be tested with the proposed measurements.

An idea of the sensitivity of this method can be obtained by comparing our

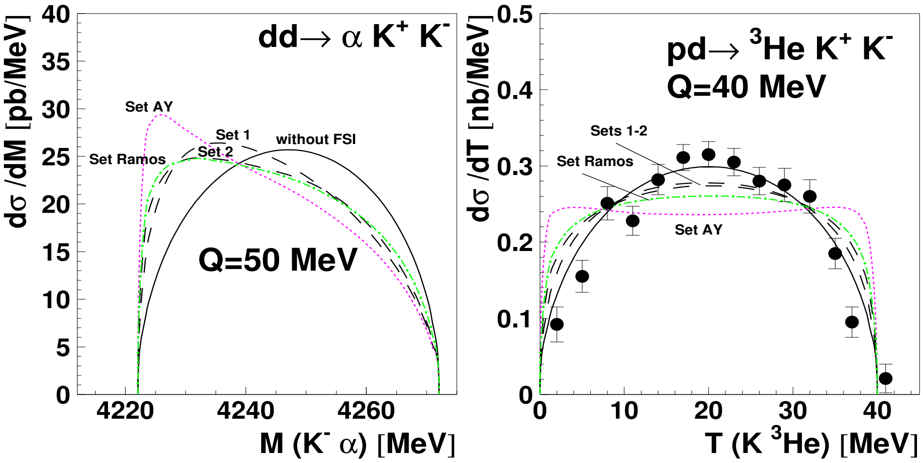

Figure 1: Left: Invariant $K^-\alpha$ mass distribution for the $dd{\to}\alpha K^+K^-$ reaction at an excess energy of 50 MeV. The solid line describes the pure phase space distribution, while the dashed lines show the effect of the $K^-\alpha$ FSI for parameters of Set 1 and 2, respectively. The (green) dashed-dotted line has been calculated for parameters from the Ramos-Oset approach [15] while the (pink) short-dashed line shows the effect for the strongly modified $\bar{K}N$ scattering lengths in nuclear medium [17] leading to deeply bound states. All lines are normalized to the same total cross section of 1 nb. Right: K^3He mass spectrum plotted in units of K^3He relative energy in comparison with the data from MOMO for the reaction $pd{\to}^3\text{He}\,K^+K^-$ at 40 MeV [24, 25]. The model predictions (lines) are symmetric around $T = 20$ MeV since the data do not allow one to determine the kaon charges.

model calculations with the data from MOMO on the reaction $pd{\to}^3\text{He}\,K^+K^-$ [24, 25]. Note that the MOMO experiment does not allow one to measure the charge of the detected kaons and, thus, the mass distribution $M(K,{}^3\text{He})$ shown in Fig. 1 (right) is the sum of the K^+ and K^- contributions. Clearly, an experiment with charge separation like ANKE is better suited for such studies. The effect of the $\phi(1020)$ resonance in the K^+K^- system has not yet been taken into account in the calculations for the MOMO data. The ANKE experiment will be carried out at $Q = 39$ MeV, *i.e.* just below the ϕ threshold.

The proposed measurement at ANKE allows one to distinguish between the different scenarios from Table 1 and to improve our understanding of $\bar{K}$-few-nucleon systems.

References

[1] M. Ablikim *et al.* [BES Collaboration], Phys. Lett. B **607** (2005) 243.

[2] H. H. Adam *et al.* [WASA-at-COSY Collaboration], arXiv:nucl-ex/0411038.

[3] A.D. Martin, Nucl. Phys. B **179** (1981) 33.

[4] J.A. Oller, U.-G. Meißner, Phys. Lett. B **500** (2001) 263.

[5] J.A. Oller, J. Prades and M. Verbeni, arXiv: :hep-ph/0508081.

[6] M. Iwasaki et al., Phys. Rev. Lett. **78** (1997) 3067.

[7] U.-G. Meißner, U. Raha, A. Rusetsky, Eur. Phys. J. C **35** (2004) 349.

[8] C. Guaraldo et al., Eur. Phys. J. A **19** (2004) 185;
G. Beer et al., Phys. Rev. Lett. **94** (2005), 212302.

[9] H. Heiselberg, M. Hjorts, Phys. Rep. **328** (2000) 237.

[10] A. Cieply, E. Friedman, A. Gal, J. Mares, Nucl. Phys. A **696** (2001) 173.

[11] E. Friedman, A. Gal, and C.J. Batty, Phys. Lett. B **308** (1993) 6;
Nucl. Phys. A **579** (1994) 518.

[12] T. Waas, N. Kaiser, W. Weise, Phys. Lett. B **365** (1996) 12.

[13] M. Lutz, Phys. Lett. B **426** (1998) 12.

[14] J. Schaffner-Bielich, V. Koch, M. Effenberger, Nucl. Phys. A **669** (2000) 153.

[15] A. Ramos and E. Oset, Nucl. Phys. A **671** (2000) 481.

[16] S. Hirenzaki, Y. Okumura, H. Toki, E. Oset, and A. Ramos, Phys. Rev. C **61** (2000) 055205.

[17] Y. Akaishi and T. Yamazaki, Phys. Rev. C **65** (2002) 044005.

[18] T. Suzuki, et al., Phys. Lett. B **597** (2004) 167;
M. Iwasaki, et. al., nucl-ex/0310018.

[19] Y. Akaishi, A. Dote, and T. Yamazaki, Phys. Lett. B **613** (2005) 140.

[20] V.Yu. Grishina et al., Eur. Phys. J. A (2005) in print; [arXiv:nucl-th/0503076].

[21] L. Kondratyuk, V. Grishina and M. Büscher, Presented during the 6th International Conference on Nuclear Physics at Storage Rings (STORI2005), Jülich, Bonn, Germany, 23-26 May 2005; [arXiv:nucl-th/0507021].

[22] R. C. Barrett, A. Deloff, Phys. Rev. C **60** (1999) 025201.

[23] J.E. Conboy, Rutherford-Appleton Lab. Report, RAL-85-091 (1985).

[24] H.A. Schitker, *"Zwei-Kaonen-Produktion nahe der Schwelle in der Reaktion* $pd \to {}^3He\,K^+K^-$ *mit dem Experiment MOMO an COSY"*, Dissertation Univ. Bonn (2002).

[25] F. Bellemann et al., Annual Report 2000 of the IKP, p. 63, Berichte des Forschungszentrums Jülich **3852** (2001), ISSN 0944-2952.