EPJ manuscript No.
(will be inserted by the editor)

Measurement of the isospin-filtering $dd \to {}^4\mathrm{He}\,K^+K^-$ reaction at $Q = 39$ MeV

X. Yuan[1,2], M. Büscher[2], D. Chiladze[2,3] S. Dymov[4,5], A. Dzyuba[2,6], V.Yu. Grishina[7], C. Hanhart[2,8], M. Hartmann[2], A. Kacharava[2], A. Khoukaz[9], L.A. Kondratyuk[10], V. Koptev[6], P. Kulessa[11], M. Mielke[9], S. Mikirtychiants[2,6], M. Nekipelov[2], M. Papenbrock[9], K. Pysz[11], V. Serdyuk[2,4], H. Ströher[2], C. Wilkin[12a], and H. Xu[1]

[1] Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou 730000, P.R. China
[2] Institut für Kernphysik and Jülich Centre for Hadron Physics, Forschungszentrum Jülich, D-52425 Jülich, Germany
[3] High Energy Physics Institute, Tbilisi State University, GE-0186 Tbilisi, Georgia
[4] Laboratory of Nuclear Problems, Joint Institute for Nuclear Research, RU-141980 Dubna, Russia
[5] Physikalisches Institut II, Universität Erlangen-Nürnberg, D-91058, Erlangen, Germany
[6] Petersburg Nuclear Physics Institute, RU-188300 Gatchina, Russia
[7] Institute for Nuclear Research, RU-117312 Moscow, Russia
[8] Institute for Advanced Simulations, Forschungszentrum Jülich, D-52425 Jülich, Germany
[9] Institut für Kernphysik, Universität Münster, D-48149 Münster, Germany
[10] Institute of Theoretical and Experimental Physics, RU-117218 Moscow, Russia
[11] H. Niewodniczański Institute of Nuclear Physics PAN, PL-31342 Kraków, Poland
[12] Physics and Astronomy Department, UCL, London, WC1E 6BT, UK

February 22, 2013

Abstract. The total cross section for the $dd \to {}^4\mathrm{He}\,K^+K^-$ reaction has been measured at a beam momentum of 3.7 GeV/c, corresponding to an excess energy of 39 MeV, which is the maximum possible at the Cooler Synchrotron COSY-Jülich. A deuterium cluster-jet target and the ANKE forward magnetic spectrometer, placed inside the storage ring, have been employed in this investigation. We find a total cross section of $\sigma_{\mathrm{tot}} < 14$ pb, which brings into question the viability of investigating the $dd \to {}^4\mathrm{He}\,a_0(980)$ reaction as a means of studying isospin violation.

PACS. 14.40.Cs Other mesons with $S = C = 0$, mass < 2.5 GeV – 25.45.-z 2H-induced reactions

1 Introduction

Since the deuteron and the α-particle both have isospin $I = 0$, the $dd \to {}^4\mathrm{He}\,X$ reaction provides an "isospin filter" that favours $I = 0$ states X. The first definitive measurement of the $dd \to {}^4\mathrm{He}\,\pi^0$ cross section near threshold [1] has therefore provided clear evidence for isospin violation in the form of charge symmetry breaking (CSB).

Within the standard model there are two dominating sources of isospin violation, namely the electromagnetic interaction and the differences in the masses of the quarks [2]. One way in which the quarks may play a role is through inducing a mixing between $I = 0$ and $I = 1$ mesons, such as that between the η and the π^0. In this sense the observed mesons are not pure isospin eigenstates and one contribution to the CSB reaction would be through the virtual production of η meson which mixes to emerge as a π^0. However, as a result of the relatively large mass of the strange quark, which leads to a significant mass splitting of π^0 and η, the effect of the η/π^0 mixing is not expected to be dominant in isospin-violating pion production [3]. For a discussion and exploratory calculations for the $dd \to {}^4\mathrm{He}\,\pi^0$ reaction, see Refs. [4,5].

On the other hand the $a_0(980)$ and $f_0(980)$ scalar mesons, which have $I = 1$ and $I = 0$ respectively, are rather narrow but overlapping resonances. This alone already enhances the effect of meson mixing in the final state compared to isospin violation in the production operator [6,7]. In addition, since both mesons couple strongly to $K\bar{K}$ [8], a particularly large contribution coming from kaon loops [9,10] significantly enhances the mixing amplitude. Therefore one might hope to get a direct experimental access to the a_0/f_0 mixing amplitude.

The main decay channel of the $I = 1$ meson is through $a_0(980) \to \eta\pi$ [8] and so a promising measurement of CSB might be through the study of $dd \to {}^4\mathrm{He}\,f_0(980) \to {}^4\mathrm{He}\,a_0(980) \to {}^4\mathrm{He}\,\eta\pi^0$ [11], with an isospin-allowed $f_0(980)$ production in the first step. Whether this promise can be fulfilled or not would depend to a large extent on the production cross section for the $f_0(980)$ meson in this channel. It is the primary aim of the current work to provide

[a] e-mail: cw@hep.ucl.ac.uk

experimental data on this through a measurement of the $dd \to {}^4\mathrm{He} f_0 \to {}^4\mathrm{He}\,K^+K^-$ cross section.

The conditions of the experiment, which was carried out using the ANKE spectrometer at COSY-Jülich, are described in sect. 2. The strict conditions on the particle selection necessary to identify the desired reaction against a much larger background are here explained in some detail. Two methodologies that remove almost all the background are discussed but, in view of the consequent low acceptances, they could only provide upper limits on the production rate. By relaxing the criteria, it proved possible to extract events with a reasonable background and hence to evaluate the total cross section which is reported in sect. 3. The smallness of the resulting value suggests that the $dd \to {}^4\mathrm{He}\,\eta\pi^0$ reaction might in fact not be a useful way of investigating isospin violation and this is reflected in our conclusions of sect. 4.

2 Identification of dd → ^{4}He K$^+$K$^-$ events with ANKE

2.1 Experimental setup

The COSY COoler SYnchrotron of the Forschungszentrum Jülich can accelerate and store deuterons with momenta of up to 3.7 GeV/c [12], which corresponds to an excess energy of $Q = 39\,\mathrm{MeV}$ for the $dd \to {}^4\mathrm{He}\,K^+K^-$ reaction. The studies of this reaction were carried out at the ANKE facility [13], a magnetic spectrometer located in one of the straight sections of COSY. ANKE has three dipole magnets, D1 – D3. D1 deflects the circulating COSY beam onto a target in front of D2, and D3 bends it back into the nominal orbit. The C-shaped spectrometer dipole D2 separates forward-going reaction products from the COSY beam and allows one to determine their emission angles and momenta.

The deuterium cluster-jet target [14] used with ANKE had an areal density of a few times $10^{14}\,\mathrm{cm}^{-2}$ which, combined with a typical deuteron beam intensity of $(3-6)\times10^{10}\,\mathrm{s}^{-1}$, yields an average luminosity of $L = [2.6 \pm 0.1(\mathrm{stat}) \pm 0.8(\mathrm{syst}) \pm 0.3(\mathrm{syst})] \times 10^{31}\,\mathrm{s}^{-1}\mathrm{cm}^{-2}$ [15]. This gave an integrated luminosity of $L_{\mathrm{int}} = 35\,\mathrm{pb}^{-1}$ over the course of the experiment. The two systematic errors are due mainly to the uncertainty in the quasi-elastic $dd \to dX$ cross section used for the normalisation and to a possible error in the determination of the angle-momentum acceptance for that process in ANKE.

2.2 Particle selection criteria

In order to isolate the $dd \to {}^4\mathrm{He}\,K^+K^-$ events, two well-identified final-state particles, *viz* the K^+ and ^{4}He, could be detected in coincidence, with the remaining K^- meson being recognised through the missing-mass in the reaction. Alternatively, all three final particles could be measured with rather looser criteria. Both approaches have been implemented in this work.

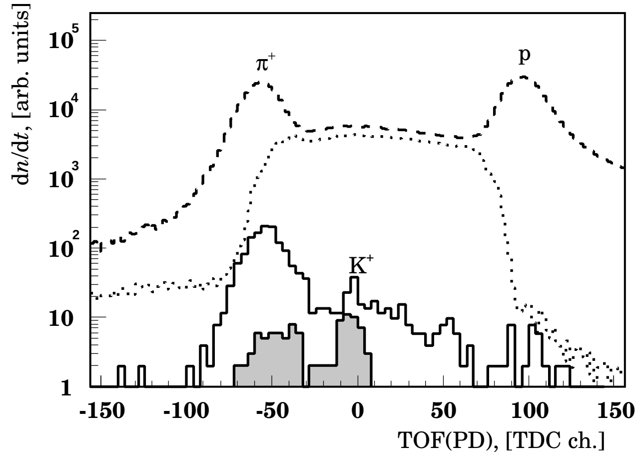

Fig. 1. Time-of-flight spectrum in the ANKE positive detector (PD) for increasingly stringent on-line trigger settings and K^+ selection criteria. Dashed line: open trigger run; dotted line: on-line TOF trigger for the detection of K^+ mesons; solid line: same as dotted plus a K^+-cut on the time difference between the PD and forward detector (FD); shaded histogram: same as solid plus the delayed veto criterion in the ANKE range telescopes. In all cases a valid track (reconstructed from the MWPC information) in the PD and FD was required and an energy-loss cut on deuterons (and heavier particles) in the FD (cf. Fig. 2) has been applied. The spectra are normalised to the relative luminosities and dead times.

Positively charged kaons can be identified in the positive side detection system (PD) [13,16] of ANKE by a time-of-flight (TOF) measurement, as illustrated in Fig. 1. The TOF start counters, consisting of one layer of 23 scintillation counters, are mounted next to the large exit window of the vacuum chamber in D2. Positive kaons from the $dd \to {}^4\mathrm{He}\,K^+K^-$ reaction with momenta between 390 and 625 MeV/c stop in the range telescopes located along the focal surface of D2. These telescopes serve as the TOF stop counters and provide further, extremely effective, kaon-*versus*-background discrimination through the measurement of delayed signals from the K^+ decay products, μ^+ and π^+ [16]. A drawback of this method is its relatively low K^+-detection efficiency of only about 15%. Two multi-wire proportional chambers (MWPCs) positioned between the TOF start and stop counters allow one to deduce the ejectile momenta and to suppress the background from secondary scattering.

A rather strict K^+ TOF criterion was already included in the on-line trigger that suppresses π^+ mesons and protons. In order to collect data for the calibration of the ^{3}He and ^{4}He energy losses, several runs were taken with an open TOF trigger (cf. Fig. 1).

High momentum particles, such as protons, deuterons and He nuclei, that are produced in coincidence with the K^+ mesons, as well as scattered deuterons and protons from the breakup of the beam deuterons, were detected in the forward-detector (FD) [15,17]. This contains three layers of scintillation counters for TOF and energy-loss (ΔE) measurements. In addition, there are three MWPCs that are used for momentum reconstruction and background suppression.

Negatively charged particles can be measured in the negative-particle detection system (ND) [18], comprising scintillators for TOF measurements and two MWPCs for tracking. The K^- are separated from the π^- background by TOF criteria and, in addition, a reconstructed track from the ND MWPCs is required.

In addition to the above mentioned K^+ TOF criterion, the energy loss in the FD was already used at the trigger level. The ΔE thresholds were set such that events with ^{4}He particles as well as deuterons were retained for further analysis. The latter were used for a fine-tuning of the K^+ selection criteria, since dK^+ pairs are produced at a much higher rate than the ${}^4\mathrm{He}\,K^+$ events of interest.

Events with a K^+ meson in the PD and a deuteron in the FD can be identified from the relative detection times in these counters. This time difference, $\Delta t_{\mathrm{FD,PD}}(d, K^+)$, can be determined either directly from the calibrated TDC data or reconstructed from the particle trajectories and momenta, as deduced from the MWPC track information. For particles arising from the same reaction vertex, these values are correlated [18]. The solid line in Fig. 1 shows the PD TOF spectrum after the application of the $\Delta t_{\mathrm{FD,PD}}(d, K^+)$ cut. A clear K^+ peak from the dK^+ events is seen, though a substantial background from secondary particles remains.

Figure 1 shows that, when the delayed-veto cut for the K^+ mesons is applied in addition to the $\Delta t_{\mathrm{FD,PD}}(d, K^+)$ criterion, a background-free identification of dK^+ correlations is possible.

Since the ^{4}He particles have both twice the charge and almost twice the mass of the deuterons, their time correlations with the kaons are indistinguishable. Therefore, some of the nominally K^+d events in Fig. 1, selected on the basis of the $\Delta t_{\mathrm{FD,PD}}(d, K^+)$ cut, may stem from the $dd \to {}^4\mathrm{He}\,K^+X$ reaction. In order therefore to discriminate between ^{4}He and deuterons, a rigidity-dependent ΔE cut has been applied in all FD scintillators, as shown in Fig. 2. The exact locations of the ΔE-*versus*-$|\boldsymbol{p}_{FD}|/Z$ bands have been determined from events with a coincident π^+ meson in the PD (open TOF trigger runs). Their positions are in good agreement with those obtained from Monte-Carlo simulations.

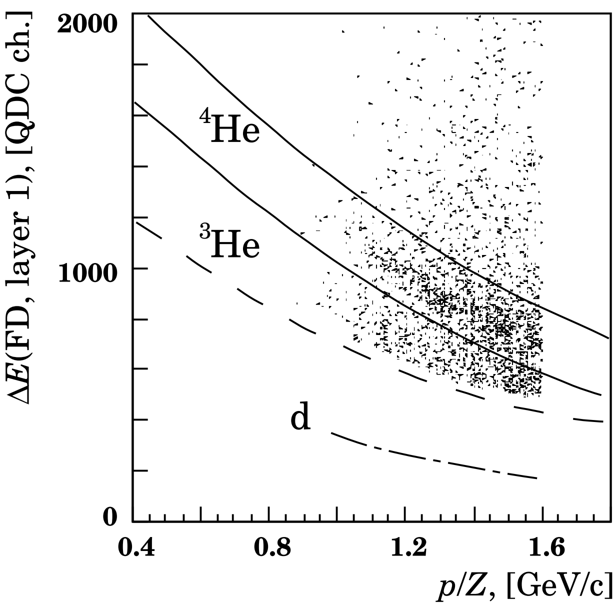

Fig. 2. Identification of ^{4}He particles (selected in coincidence with π^+ mesons) using energy losses in the FD scintillation counters (shown here for scintillator layer 1). The solid lines show the boundaries of the ΔE cut used for ^{4}He selection. The dashed and dash-dotted lines indicate the positions of the centres of the ^{3}He and deuteron bands, respectively. For a better visibility of the ^{4}He energy-loss band, only those events are shown that fulfil the following criteria: *i*) an energy loss above the ^{3}He band in layer 1; *ii*) a valid $\Delta t_{\mathrm{FD,PD}}$ for ${}^4\mathrm{He}\,\pi^+$ events for layers 1 and 2; *iii*) a cut on the energy loss of layer 2 for the ^{4}He candidates.

2.3 Event selection with maximum background suppression

For the identification of the $dd \to {}^4\mathrm{He}\,K^+K^-$ events the following K^+ and ^{4}He selection criteria are jointly used, as described above:

i) TOF for K^+ mesons in the PD;
ii) time difference between particle detection in the PD and FD, $\Delta t_{\mathrm{FD,PD}}({}^4\mathrm{He}, K^+)$;
iii) ΔE *versus* $|\boldsymbol{p}_{FD}|/Z$ in the FD;
iv) delayed-veto signal in the range telescopes.

These combined criteria offer the maximum possible background suppression at ANKE, though at the expense of having the low efficiency ($\sim 15\%$) of the delayed-veto criterion. However, it turned out that no events survive these criteria and this procedure only leads to an upper limit on the production cross section.

Another possibility to provide an efficient background suppression with comparable detection efficiency is to abandon the delayed-veto criterion and to search directly for K^- mesons in correlation with the detected ${}^4\mathrm{He}\,K^+$ pairs. The additional demands imposed to ensure that any signal comes from a K^- meson reduces the total acceptance by a factor ~ 5. One event was found by this method and this is clearly consistent with the zero events obtained with the delayed-veto procedure.

The above considerations show that only upper limits on the total $dd \to {}^4\mathrm{He}\,K^+K^-$ production cross section can be deduced by using "background-free" methods and that some of the criteria must be relaxed in order to obtain a signal.

2.4 Event selection with relaxed cuts

Figure 3a) shows the $(dd, {}^4\mathrm{He})$ missing-mass distribution for the events remaining after imposing the following criteria:

i) TOF for K^+ mesons in the PD;

ii) time difference between particle detection in the PD and FD, $\Delta t_{\mathrm{FD,PD}}({}^4\mathrm{He}, K^+)$;
iii) ΔE *versus* $|\boldsymbol{p}_{FD}|/Z$ in the FD.

Figures 3b)–d) show the remaining events after additionally demanding that the $(dd,{}^4\,\mathrm{He})$ missing mass must be above the K^+K^- threshold:

iv′) $mm(dd,{}^4\,\mathrm{He}) > m(K^+K^-)$ (arrow in Fig. 3a).

Compared to the "background-free" selection from the previous section, we do not impose the delayed-veto criterion and use the missing-mass cut on the ^{4}He instead.

In order to suppress the residual background, an additional stronger cut on the TOF between the start and stop counters in the PD has been applied to select the K^+ mesons (arrows in Fig. 3b) with efficiency $\varepsilon_{\mathrm{TOF(K^+)}} = 90\%$. The results are shown in Figs. 3e) and 3f). Virtually identical distributions are obtained for a narrower $\Delta t_{\mathrm{FD,PD}}({}^4\mathrm{He}, K^+)$ time gate.

Under the assumption that the background distribution for the ^{4}He missing-mass is flat and is at a level of 0.5 events per bin (Fig. 3f), we find evidence for about 5 events coming from the $dd \to {}^4\mathrm{He}\, K^+K^-$ reaction. This number is consistent with the upper limits derived using the "background-free" methods described in the previous section.

3 Total production cross section

In order to evaluate the total $dd \to {}^4\mathrm{He}\, K^+K^-$ production cross section, the geometrical acceptance of ANKE, the detector resolutions and efficiencies, dead times, and kaon-decay probabilities were taken into account in a Monte Carlo simulation, written using the GEANT4 code [19]. Two possibilities for the input distributions have been considered, *viz* three-body phase space and a Flatté K^+K^- mass distribution [20], where the $f_0(980)$ parameters were those obtained by the BES collaboration [21]. The simulated results for these two scenarios are basically identical and the average total acceptance for the $^4\mathrm{He}\, K^+$ detection is estimated to be $A_{^4\mathrm{He},K^+} = 8.5\%$.

Taking the dead time into account, the efficiency of the ANKE data acquisition system is $\varepsilon_{\mathrm{DAQ}} = 70\%$, while the SD and FD efficiencies are $\varepsilon_{\mathrm{SD}} = 95\%$ and $\varepsilon_{\mathrm{FD}} = 70\%$.

The two methods described in sect. 2.3 as being "background-free" are almost independent statistically and their simultaneous measurement allows one to deduce an upper limit for the $dd \to {}^4\mathrm{He}\, K^+K^-$ cross section at $Q = 39\,\mathrm{MeV}$:

$$\sigma_{\mathrm{tot}} < 14\,\mathrm{pb} \qquad (92\%\mathrm{CL}) \tag{3.1}$$

On the other hand, the five events obtained after background subtraction shown in Fig. 3f) lead to a total production cross section of

$$\sigma_{\mathrm{tot}} = (5 \pm 2_{\mathrm{stat}} \pm 1_{\mathrm{syst}})\,\mathrm{pb}. \tag{3.2}$$

with an additional overall uncertainty of about 50% coming from the luminosity determination. The two approaches give consistent results and show that the $^4\mathrm{He}\, K^+K^-$ production cross section in deuteron-deuteron collisions near threshold is very low indeed.

4 Discussion and outlook

In order to investigate the production of the upper tail of the f_0 meson in deuteron-deuteron collisions, we have undertaken a measurement of the $dd \to {}^4\mathrm{He}\, K^+K^-$ reaction at an excess energy of 39 MeV. The production cross is surprisingly low such that the techniques which we used to eliminate the background essentially eliminated the very weak signal as well. By relaxing the selection criteria and subtracting the background, it was possible to find five events that corresponded to a cross section of a mere 5 pb.

One of the principal advantages of the reaction studied is that the selection rules require the K^+K^- pair to be in isospin $I = 0$ but, in view of the poor statistics, there is no way of knowing whether the five events arise from the production of scalar (f_0) pairs or vector (ϕ) pairs. There is evidence from the $pd \to {}^3\mathrm{He}\, K^+K^-$ reaction that even at $Q = 35\,\mathrm{MeV}$ the production of the ϕ-meson represents a significant fraction of the total cross section [22].

Since no theoretical models exist for K^+K^- production in this reaction, it is perhaps permissible to make a crude estimate based upon the factorisation ansatz whereby

$$\sigma_{\mathrm{tot}}(dd \to {}^4\mathrm{He}\, K^+K^-) = \frac{\sigma_{\mathrm{tot}}(dd \to {}^4\mathrm{He}\,\eta)}{\sigma_{\mathrm{tot}}(pd \to {}^3\mathrm{He}\,\eta)} \times \sigma_{\mathrm{tot}}(pd \to {}^3\mathrm{He}\, K^+K^-). \tag{4.1}$$

The production of the η meson via $dd \to {}^4\mathrm{He}\,\eta$ has only been measured up to $Q = 16.6\,\mathrm{MeV}$, where the total cross section is about 16 nb [23]. Interpolating the $pd \to {}^3\mathrm{He}\,\eta$ data [24,25] to this energy gives $\sigma_{\mathrm{tot}}(pd \to {}^3\mathrm{He}\,\eta) \approx 340\,\mathrm{nb}$ so that the simplistic approach of Eq. (4.1) would predict

$$\sigma_{\mathrm{tot}}(dd \to {}^4\mathrm{He}\, K^+K^-) \approx 0.05 \times \sigma_{\mathrm{tot}}(pd \to {}^3\mathrm{He}\, K^+K^-). \tag{4.2}$$

Although the data are more sparse, a roughly similar ratio is obtained if one uses the results on $pd \to {}^3\mathrm{He}\,\omega$ [26] and $dd \to {}^4\mathrm{He}\,\omega$ [27], though with larger uncertainties.

It was shown in Ref. [22] that the non-ϕ production cross section varies as

$$\sigma_{\mathrm{tot}}(pd \to {}^3\mathrm{He}\, K^+K^-) \approx 5\,(Q/\mathrm{MeV})^2\,\mathrm{pb}, \tag{4.3}$$

which gives 7.5 nb for our excess energy. These considerations would lead us to expect a total cross section for $dd \to {}^4\mathrm{He}\, K^+K^-$ of about 370 pb, which is almost two orders of magnitude larger than our measurement and does not even allow for the contribution from ϕ production. This vast discrepancy suggests that the dynamics governing the production of the η or ω meson and K^+K^- pairs in these reactions are intrinsically different and this may come about from the kaons being produced at different vertices whereas a solitary meson must originate from a single one.

Independent of the underlying dynamics, if one assumes that the five events are products of the decay of the $f_0(980)$ resonance, which has a branching ratio of 0.12 ± 0.06 into K^+K^- [21], the total cross section for

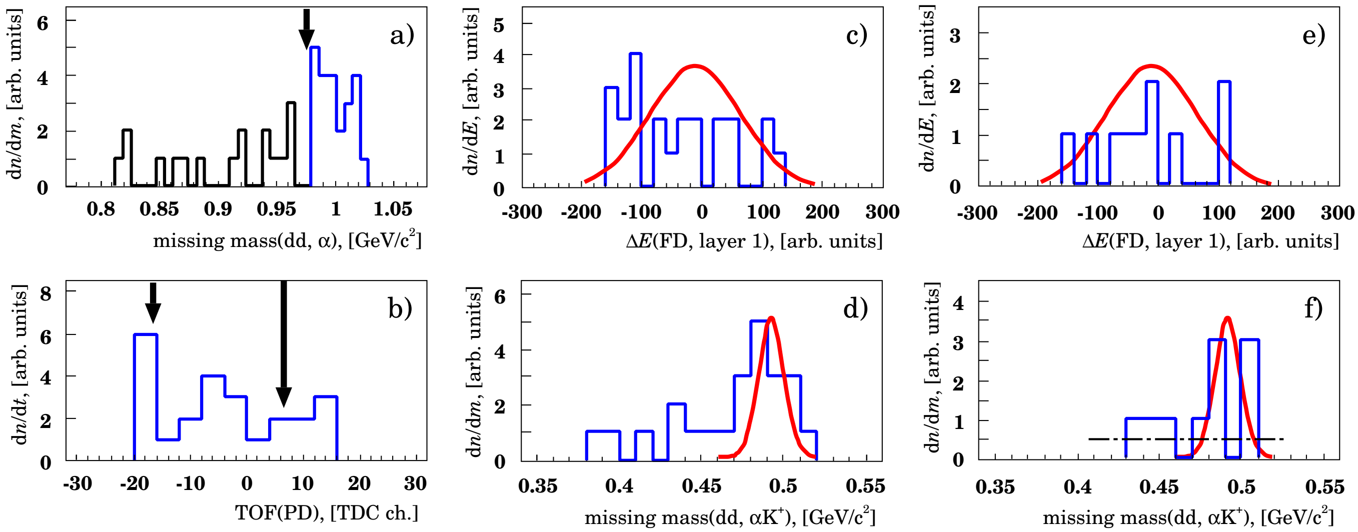

Fig. 3. a)–d) Events remaining after the application of the K^+ TOF cut (Fig. 1), the time correlation between the PD and FD, and the ^{4}He energy-loss criterion (Fig. 2). For panels b)–d) an additional (dd, ^{4}He) missing-mass cut $m > 980\,\mathrm{MeV}/c^2$ has been used, as indicated in panel a). Panels e) and f) show the residual events after the use of the stronger TOF cut indicated in panel b) by the arrows. Panels c) and e) show the difference between the measured and expected ^{4}He energy loss. The curves represent the shapes of the expected signals, as derived from Monte-Carlo simulations.

the production of this state through $dd \to {}^4\mathrm{He}\,f_0(980)$ is only about 40 pb at our energy. This low value must bring into question any attempt to measure charge symmetry breaking in the $dd \to {}^4\mathrm{He}\,\pi^0\eta$ reaction generated through $a_0(980)/f_0(980)$ mixing.

The authors wish to record their thanks to the COSY machine crew for producing the good experimental conditions needed for this experiment and also to other members of the ANKE collaboration for their help. We are grateful to A. Nogga for a careful reading of the manuscript. This work was supported by DAAD, DFG (436 RUS 113/630, 787, 940), RFFI (06-02-04013), the JCHP-FFE programme, and the HGF-VIQCD.

References

1. E.J. Stephenson *et al.*, Phys. Rev. Lett. **91**, 142302 (2003) [arXiv:nucl-ex/0305032].
2. G. A. Miller, B. M. Nefkens, and I. Šlaus, Phys. Rept. **194**, 1 (1990).
3. U. van Kolck, J. A. Niskanen, and G. A. Miller, Phys. Lett. B **493** (2000) 65 [arXiv:nucl-th/0006042].
4. A. Gårdestig *et al.*, Phys. Rev. C **69** (2004) 044606 [arXiv:nucl-th/0402021].
5. A. Nogga *et al.*, Phys. Lett. B **639**, 465 (2006) [arXiv:nucl-th/0602003].
6. V. Grishina *et al.*, Phys. Lett. B **521**, 217 (2001) [arXiv:nucl-th/0103081].
7. C. Hanhart, Phys. Rept. **397** (2004) 155 [arXiv:hep-ph/0311341].
8. C. Amsler *et al.* [Particle Data Group], Phys. Lett. B **667**, 1 (2008).
9. N. N. Achasov, S. A. Devyanin, and G. N. Shestakov, Phys. Lett. B **88**, 367 (1979).
10. C. Hanhart, B. Kubis, and J. R. Pelaez, Phys. Rev. D **76**, 074028 (2007)[arXiv:0707.0262 (hep-ph)].
11. WASA-at-COSY Collaboration (H.-H. Adam *et al.*), arXiv:nucl-ex/0411038.
12. R. Maier *et al.*, Nucl. Inst. Meth. A **390**, 1 (1997).
13. S. Barsov *et al.*, Nucl. Inst. Meth. A **462**, 364 (2001).
14. A. Khoukaz *et al.*, Eur. Phys. J. D **5**, 275 (1999).
15. X. Yuan, A. Dzyuba, and M. Büscher, Chin. Phys. C **33**, 20 (2009).
16. M. Büscher *et al.*, Nucl. Inst. Meth. A **481**, 378 (2002).
17. S. Dymov *et al.*, Part. Nucl. Lett. **1**, 40 (2004).
18. M. Hartmann *et al.*, Int. J. Mod. Phys A **22**, 317 (2007).
19. S. Agostinelli *et al.*, Nucl. Inst. Meth. A **506**, 250 (2003); http://geant4.web.cern.ch/geant4/
20. V. Baru *et al.*, Eur. Phys. J. A **23**, 523 (2005) [arXiv:nucl-th/0410099].
21. M. Ablikim *et al.* [BES Collaboration], Phys. Lett. B **607**, 243 (2005) [arXiv:hep-ex/0411001].
22. F. Bellemann *et al.*, Phys. Rev. C **75**, 015204 (2007) [arXiv:nucl-ex/0608047].
23. A. Budzanowski *et al.* [GEM Collaboration], Nucl. Phys. A **821** (2009) 193 [arXiv:0811.3372 (nucl-ex)].
24. T. Mersmann *et al.*, Phys. Rev. Lett. **98**, 242301 (2007) [arXiv:nucl-ex/0701072].
25. R. Bilger *et al.*, Phys. Rev. C **69**, 014003 (2004).
26. R. Wurzinger *et al.*, Phys. Rev. C **51**, R443 (1995).
27. J. Banaigs *et al.*, Nucl. Phys. B **105**, 52 (1976).