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Investigation of the $a_0^+(980)$-resonance with ANKE

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Abstract. Two experiments on the production of the $a_0^+(980)$-resonance in the reaction $pp \to da_0^+$ were performed with the ANKE spectrometer at COSY-Jülich. The decay channels $a_0^+ \to K^+\overline{K^0}$ and $a_0^+ \to \pi^+\eta$ were measured simultaneously at energies $T = 2.65$ GeV and $T = 2.83$ GeV. For the reaction $pp \to dK^+\overline{K^0}$ a total production cross-section of ~ 50 nb has been deduced for $T = 2.65$ GeV. Further goals of the data analysis are to determine differential cross-sections like angular distributions and the branching ratio $a_0^+ \to K^+\overline{K^0}/\pi^+\eta$.

PACS. 13.75.Cs Nucleon-nucleon interactions (including antinucleons, deuterons, etc.) – 25.40.Ve Other reactions above meson production thresholds (energies > 400 MeV)

1 Introduction

The $a_0(980)$- and $f_0(980)$-resonances are the focus of experimental and theoretical studies because their structure is not yet understood. According to different theoretical works [1–5] they could be $q\overline{q}$ states, four-quark states, $K\overline{K}$ molecules, or be of dynamical origin, *i.e.* generated via strong final-state interaction effects. Due to a possible mixing between the neutral $a_0^0(980)$- and the $f_0(980)$-resonances via the coupling to $K\overline{K}$ intermediate states [6], the unmixed, pure isospin-1 state $a_0^+(980)$ was studied in a first series of experiments with ANKE [7,8]. Simultaneous detection of the two main decay channels $a_0^+ \to K^+\overline{K^0}$ and $a_0^+ \to \pi^+\eta$ has been achieved. The most important benefits of such measurements are

- The a_0^+ was measured at energies $T = 2.65$ GeV and $T = 2.83$ GeV. This is close to the $K^+\overline{K^0}$ threshold and allows to study the a_0^+-resonance in direct production, and not via the decay from higher-lying resonances.
- The simultaneous measurement of both decay channels reduces systematic errors, *e.g.* for the determination of their branching ratio.
- The deuteron in the final state is a spin-isospin filter that might simplify the interpretation of the data.
- Meson-meson and meson-deuteron FSI can be studied.
- ANKE allows to measure absolute production cross-sections.

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2 Event identification with ANKE

The first measurement of $a_0^+(980)$ production was performed in Jan./Feb. 2001 at a beam energy of $T = 2.65$ GeV. All spectra shown in this article have been obtained from these data. The ANKE spectrometer [9,10] is located at an internal target position of the proton synchrotron COSY-Jülich. The experimental setup of ANKE is shown in fig. 1. A hydrogen cluster-jet target built at the University of Münster was used for our measurements.

For the detection of K^+- and π^+-mesons the positive detector system was exploited, which consists of 23 TOF-start counters, 2 MWPCs, 6 side-wall counters and 15 range telescopes located in the focal plane of the ANKE dipole. Kaons (pions) were selected from the background by using their time-of-flight (TOF) between the start counters and the telescopes (side-wall counters) as well as their energy losses. The information from the MWPCs was used to reject particles scattered at the pole shoes of D2. Figure 2(a) shows the TOF spectra for particles in the positive-particle detectors. After the cuts mentioned above, a clear peak from K^+-mesons is visible (inset in fig. 2(a)). The remaining background under the kaon peak is suppressed subsequently by requiring the coincidence with a deuteron.

Deuterons were detected in the forward detection system (3 MWPCs and a 2-layer scintillator hodoscope).

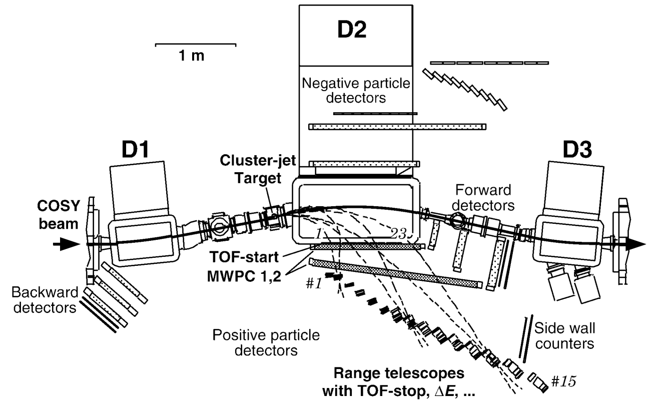

Fig. 1. The ANKE facility comprises the spectrometer dipole D2 and four detection systems: backward detectors, forward detectors, negative- and positive-particle detectors. For the investigation of the $a_0^+(980)$-resonance the forward detectors (2 layer scintillator hodoscopes, 3 MWPCs) and the positive-particle detectors (23 TOF-start counters, 2 MWPCs, 6 side-wall counters, 15 range telescopes) were used.

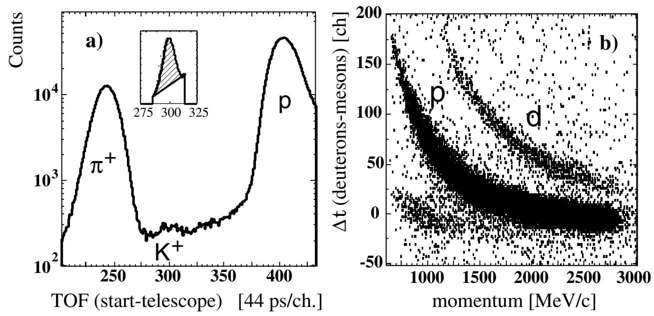

Fig. 2. Particle identification: a) TOF of K^+/π^+ in the positive-particle detectors. After TOF, energy loss and MWPCs cuts a clear peak of K^+-mesons becomes visible (small inset). b) Selection of deuterons in the forward detectors via 2d spectrum, Δt (between mesons and d) *versus* momentum. Bands corresponding to protons and deuterons are seen. The cut along deuteron band allows to separate them from protons.

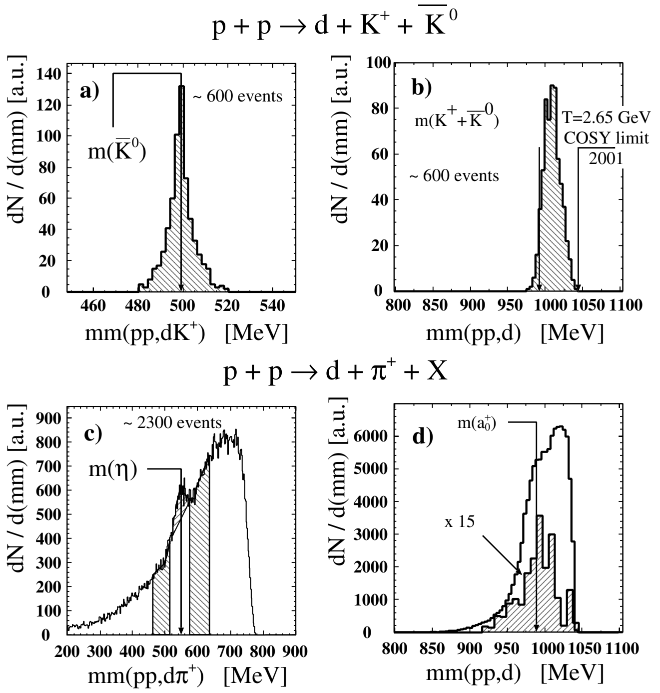

Fig. 3. Missing-mass spectra for the selected dK^+ (upper row) and $d\pi^+$ (lower row) pairs at $T = 2.65$ GeV. The spectra are not efficiency and acceptance corrected. The hatched distribution in picture (d) presents the remaining events after background subtraction.

They were separated from the more abundant protons by a cut in a 2d spectrum of Δt (between K^+/π^+ and d) *versus* momentum (fig. 2(b)).

3 Missing-mass spectra

Figure 3 presents the missing-mass distributions for the selected deuteron-meson pairs. The upper row shows the results for the dK^+-events, the lower for $d\pi^+$. All spectra are not yet efficiency and acceptance corrected. Corresponding simulations are in progress. The (pp, dK^+) missing-mass distribution is shown in fig. 3(a). It exhibits a narrow peak around the $\overline{K^0}$ mass, which confirms the clean selection of the reaction channel $pp \to dK^+\overline{K^0}$. The missing mass of the (pp, d) system is shown in fig. 3(b). This distribution is limited at the left side by the $K^+\overline{K^0}$ threshold and at the right side by the maximum accessible mass for $T = 2.65$ GeV. For such a narrow missing-mass range it is difficult to separate resonant (via the a_0^+) and non-resonant components of the $K^+\overline{K^0}$ channel, because the shapes of both distributions are very similar [11]. According to model calculations [12–15], the resonant part should dominate ($\approx 85\%$) at $T = 2.65$ GeV. The predicted cross-section for the reaction $pp \to da_0^+ \to dK^+\overline{K^0}$ [15] is in good agreement with our preliminary value of ~ 50 nb for the reaction $pp \to dK^+\overline{K^0}$, which is based on the determination of the luminosity described in sect. 4 and on simulation calculations of the ANKE acceptance. After acceptance correction of the missing-mass (pp, K^+) spectrum (not shown) it should be possible to obtain information about the $d\overline{K^0}$ final-state interaction, which is expected to be strong close to the $K\overline{K^0}$ threshold [5].

The $(pp, d\pi^+)$ missing-mass spectrum (fig. 3(c)) exhibits a peak around the η mass containing ~ 2300 events on top of background from multi-pion production $pp \to d\pi^+ (n\pi)$ $(n \geq 2)$. The corresponding deuteron missing-mass distribution $\mathrm{mm}(pp, d)$ from fig. 3(d) has a shoulder around 980 MeV/c^2. Assuming a smooth behavior of the background in $\mathrm{mm}(pp, d\pi^+)$, the events in the shaded areas of the lower left figure are used for background subtraction. The remaining events show a clear peak structure around 980 MeV/c^2 with a width of ~ 40 MeV. This corroborates the interpretation that the peak in $\mathrm{mm}(pp, d\pi^+)$ at ~ 550 MeV/c^2 is connected with the $pp \to da_0^+ \to d\eta\pi^+$ reaction. For the extraction of the cross-section value

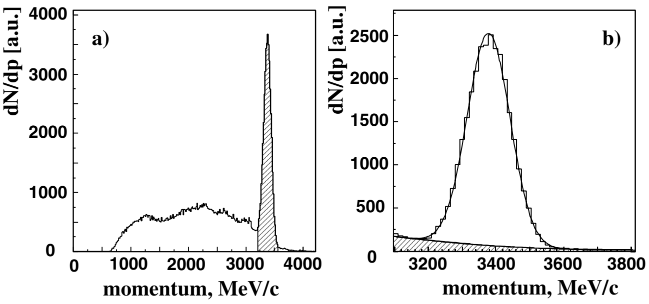

Fig. 4. Luminosity determination via the *pp* elastic scattering reaction. (a) Raw momentum spectrum of particles detected in the forward counters. (b) Peak of elastically scattered protons with emission angles $\vartheta = (5.5\text{–}9)^\circ$ after correction for the MWPC efficiencies. A Gaussian fit of the peak and a polynomial fit for the background are shown.

a careful investigation of the shape of the multi-pion background below the η peak is in progress.

4 Luminosity determination

The luminosity during the a_0^+ beam times was determined with the help of *pp* elastic scattering events taken simultaneously with the a_0^+ data [16]. A peak from this reaction is seen in the momentum distribution of protons detected inclusively with the forward detectors (fig. 4(a)). For the luminosity determination protons scattered into the angular range $\vartheta = (5.5\text{–}9)^\circ$ were selected, since GEANT simulations show that the ANKE acceptance changes smoothly for these angles and the elastic peak in the momentum distribution is easily distinguished from the background. The elastic peak region was fitted by a Gaussian distribution, and events were selected within 2σ from the fitted average value. The background was fitted by a polynomial and subtracted. For the detector-efficiency correction of these data two-dimensional efficiency maps for each MWPC plane were created. Figure 4(b) shows the peak from elastically scattered protons in the $\vartheta = (5.5\text{–}9)^\circ$ angular range after this correction. Finally, an average luminosity $L \sim 2.7 \times 10^{31}$ s^{-1}cm^{-2} for the a_0^+ measurement at $T = 2.65$ GeV was obtained. This corresponds to an areal target density of $\sim 5 \cdot 10^{14}$ cm^{-2} [17].

5 Summary

The ANKE spectrometer has been exploited for a simultaneous measurement of the $K^+\overline{K^0}$ and $\pi^+\eta$ decay channels of the $a_0^+(980)$-resonance.

At $T = 2.65$ GeV the measured cross-section for the reaction $pp \to dK^+\overline{K^0}$ is ~ 50 nb. The separation between resonant (via the a_0^+) and non-resonant $K^+\overline{K^0}$ production is difficult due to the narrow available $K^+\overline{K^0}$ mass interval. According to model calculations [12–15], the resonant contribution into the kaon channel is expected to be dominant.

For the $\pi^+\eta$ channel a peak from η-mesons on a broad background from multi-pion production is seen in the missing-mass distribution $\mathrm{mm}(pp, d\pi^+)$. After background subtraction a peak structure in $\mathrm{mm}(pp, d)$ at 980 MeV/c^2 with a width of about 40 MeV/c^2 is obtained. A detailed analysis of this channel, in particular simulations of the multi-pion background, is in progress.

In Febr./March 2002 a second measurement on a_0^+-resonance production was performed at $T = 2.83$ GeV, which currently is the upper energy limit of the COSY accelerator. Due to the higher energy, the range of accessible missing masses becomes significantly wider. This should allow a model-independent separation of resonant and non-resonant contributions also in the kaon decay. The data analysis is in progress.

In the future we intend to investigate neutral a_0/f_0 resonances at ANKE, using a neutron (*i.e.* deuteron) target and detecting three decay channels, $\pi^0\eta, K^+K^-$ and $\pi^+\pi^-$ [18]. A photon detector for the study of the $\pi^0\eta$ channel is under development [19]. The detection system for negatively charged particles was installed at ANKE and successfully tested in spring 2002.

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