Luminosity determination for the $dd \to \alpha K^+K^-$ experiment at ANKE/COSY*

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Abstract High resolution studies of $a_0/f_0(980)$ decays into channels involving open strangeness are currently being performed at COSY-Jülich. As a "filter" for isospin-zero intermediate states, i.e. to selectively produce the $f_0(980)$ resonance, the $dd \to \alpha K^+K^-$ reaction was measured with the magnetic ANKE spectrometer. In order to determine the luminosity of this experiment, the elastically and quasi-elastically scattered deuterons were recorded simultaneously with the αK^+K^- events. Here we report about the luminosity determination via investigating the (quasi-) elastic deuterons at ANKE.

Key words luminosity, ANKE, dd (quasi-) elastic

PACS 13.25.-k, 13.60.Le

1 Introduction

Quantum-chromodynamics (QCD) is the theory of strong interactions. The properties of QCD at low energies or small momentum transfers ("strong QCD") are yet poorly known and are among the few uncharted territories of the Standard Model. A better understanding of strong QCD can be achieved from the investigation of its symmetries and their breaking as well as the spectroscopy of strongly bound quark states (hadrons).

Precise knowledge of the $a_0(980)$ and $f_0(980)$ coupling constants to kaons would allow one to determine the $K\bar{K}$ content of the a_0/f_0. However, the values for $g_{a_0 K\bar{K}}$ and $g_{f_0 K\bar{K}}$ are still poorly known. The Isospin-Violating (IV) a_0/f_0 mixing amplitude is in leading order proportional to the product of $g_{a_0 K\bar{K}}$ and $g_{f_0 K\bar{K}}$[1,2]. Since the a_0 and the f_0 are rather narrow overlapping resonances, a_0-f_0 mixing should give the dominant contribution to the IV effect via the reaction chain $dd \to \alpha f_0(I=0) \to \alpha a_0^0(I=1) \to \alpha(\pi^0\eta)$[2,3].

An experiment on the $dd \to \alpha(\pi^0\eta)$ reaction is under preparation for WASA-at-COSY[4]. As a first step, we aim at the determination of the isospin-conserving $dd \to \alpha f_0$ cross section via a measurement of the $dd \to \alpha f_0 \to \alpha K^+K^-$ process at the magnetic ANKE spectrometer[5] which has been optimized for the detection of charged kaons under forward angles[6,7]. The measurements have been carried out at the maximum COSY beam momentum of $p_d = 3.7$ GeV/c, corresponding to an access energy of $Q_{\alpha K^+K^-} = 39$ MeV. During the experiment two charged particles, K^+ and α, have been detected in coincidence; the missing K^- meson has been reconstructed and identified by a missing-mass criterion.

In order to determine the $dd \to \alpha K^+K^-$ cross section $\sigma_{\alpha K^+K^-}$, one has to determine the luminosity L_{int} integrated over the measurement L according to:

$$\sigma_{\alpha K^+K^-} = \frac{1}{L_{int}} \cdot \frac{N_{exp}}{A_{det} \cdot \varepsilon}. \tag{1}$$

Here N_{exp} is the number of reconstructed $dd \to \alpha K^+K^-$ events, A_{det} is the detector acceptance for the reaction, and ε is the detection efficiency. This lumi-

nosity can be measured by recording the events from reactions with known, sizable and smooth differential cross sections $d\sigma/d\Omega dp$ in the angular-momentum acceptance of the detectors. In our case elastically and quasi-elastically scattered deuterons, which were recorded simultaneously with the αK^+K^- events, have been used.

2   Luminosity determination

ANKE is a magnetic spectrometer located in one of the straight sections of COSY[8] and comprises three dipole magnets, $D1$—$D3$[5]. $D1$ deflects the circulating COSY beam onto the target in front of $D2$, and $D3$ bends it back into the nominal orbit. The C-shaped spectrometer dipole $D2$ separates the forward-going reaction products from the COSY beam and allows one to determine their emission angles and momenta.

The (quasi-)elastic deuterons have been detected using the ANKE Forward-Detection system (FD)[9], which contains two layers of scintillation counters for TOF and ΔE measurements and three multi-wire proportional chambers (MWPCs), each with two sensitive planes, exploited for momentum reconstruction and background suppression[9, 10], to monitor the luminosity. A huge background from breakup proton and fast scattered particles was reduced by an energy-loss threshold in the FD scintillators.

According to Eq. (2) the reconstructed number of dd → dX events N_{exp}, the differential cross section $d\sigma(dX)/d\Omega$ for that reaction in the ANKE acceptance, the detection efficiency ε and spectrometer acceptance A are needed to determine the luminosity:

$$L_{\text{int}} = \frac{N_{\text{exp}}}{\varepsilon \cdot A \cdot \dfrac{d\sigma(dX)}{d\Omega}} . \qquad (2)$$

The differential cross section $d\sigma(dX)/d\Omega$ of dd quasi-elastic scattering has been measured at an angle of $\theta = 103$ mrad (5.9°) for beam momenta $p_{\text{d}} = 4.3, 6.3, 8.9$ GeV/c[11], and in the small-angle Coulomb interference region $\theta = 16.5$—70.5 mrad for $p_{\text{d}} = 1.69$ GeV/c[12]. Fig. 1 shows the results of Monte-Carlo simulations on the ANKE acceptance for dd → dX events at our beam momentum $p_{\text{d}} = 3.7$ GeV/c. The simulations reveal a smooth behavior for the dd → dX acceptance in the angular range $\theta = 5°$—9° with a maximum around 5°. We have therefore selected deuterons in the angular interval $\theta = 5°$—7° and $\phi = -20°$—$+20°$, where the ANKE acceptance amounts to 100%.

For the beam momentum of $p_{\text{d}} = 1.69$ GeV/c the measured differential cross sections from Ref. [12] have to be extrapolated from $\theta = 16.5$—70.5 mrad

to the ANKE acceptance region around 103 mrad. Fig. 2 shows the cross sections from Ref. [12]. The line depicts a fit to these data using a parameterization which can be found in Ref. [12]. In this parameterization, the differential cross section for dd scattering in the small angle Coulomb interference region is dominated by spin-independent scattering amplitude. Meanwhile, Glauber correction has been also included. This fit nicely matches the data and can be used to determine $d\sigma(dX)/d\Omega$ at 103 mrad. This value is shown in Fig. 2 (r.h.s.) together with the cross sections at the higher beam momenta $p_{\text{d}} = 4.3, 6.3, 8.9$ GeV/c[11]. We then make an interpolation for $p_{\text{d}} = 3.7$ GeV/c, using different shapes of the fit function, see Fig. 2. From these fits the differential cross section is deduced to be 30 mb/sr, the error is estimated to be ± 10 mb/sr.

A cross check of the deduced $d\sigma(dX)/d\Omega$ can be obtained by analyzing the t-dependence of our cross section and the ones from Ref. [11]. The square of the four-momentum transfer $|t|$ in our experiment is ~ 0.15 (GeV/c)², i.e. within the range $|t| \sim 0.08$—0.8 shown in Fig. 3 of Ref. [11]. From that figure one deduces a cross section of 25 mb/sr at $|t| = 0.15$ (GeV/c)², which within error bars agrees with our value.
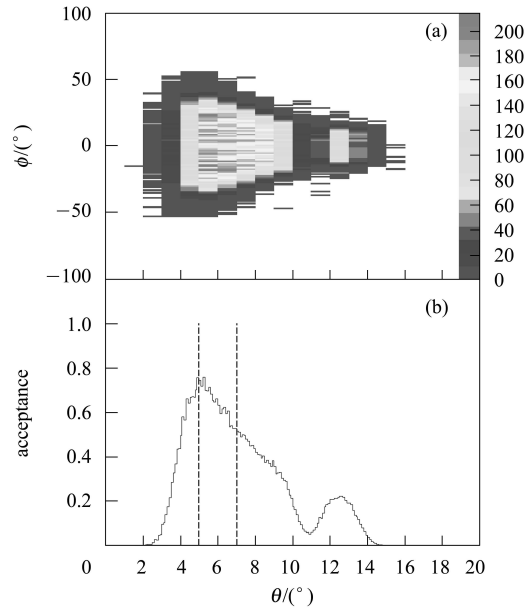

Fig. 1. Monte-Carlo simulation for dd → dX events in the ANKE acceptance at $p_{\text{d}} = 3.7$ GeV/c. (a) Distribution of the events in the polar and azimuthal angles θ and ϕ. (b) Projection on the polar angle. The dashed lines show the θ range that has been used for the luminosity determination.

The FD MWPC efficiencies have been determined for each of the six sensitive planes individually from

events with hits in all other five planes. The information from two horizontal (vertical) planes has been used to reconstruct the intersection point in the remaining plane and, subsequently, to determine the efficiency distribution across the chamber areas, i.e., its angular and momentum dependence. The average FD track efficiency for deuterons is 92%. The data have been corrected for all efficiencies on an event-by-event basis.

Figure 3(a) shows the momentum distribution of particles detected in the ANKE-FD. The particle momenta have been reconstructed from the FD MWPC track information on an event by event basis. The spectrum is dominated by projectile-breakup protons with half the beam momentum. For the selection of quasi-elastic deuterons, the above-mentioned angular criterion has been applied, together with a cut on the particle momentum. This, together with an energy loss threshold for the FD scintillators, allows for a clean deuteron identification, see Fig. 3(b).
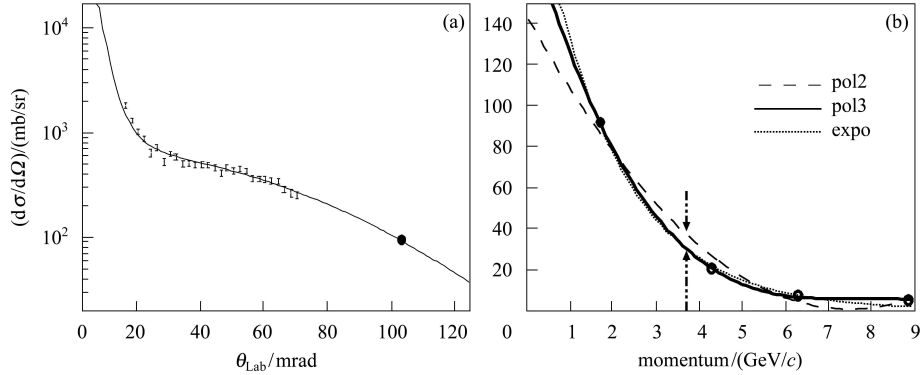

Fig. 2.   (a) Differential cross section for quasi-elastic deuterons at $p_d = 1.69$ GeV/$c^{[12]}$. The error bars represent the statistical uncertainties of the data. The line is a fit to the data using a parameterization from Ref. [12]. The black bullet corresponds to the extrapolated cross section at 103 mrad. (b) Measured (open bullets) and extrapolated (solid) differential cross section for $p_d = 1.69$, 4.3, 6.3, 8.9 GeV/c. Binomial (pol2) trinomial (pol3) and exponential (expo) functions have been fitted to the data in order to interpolate to the p_d value of our experiment (indicated by arrows).
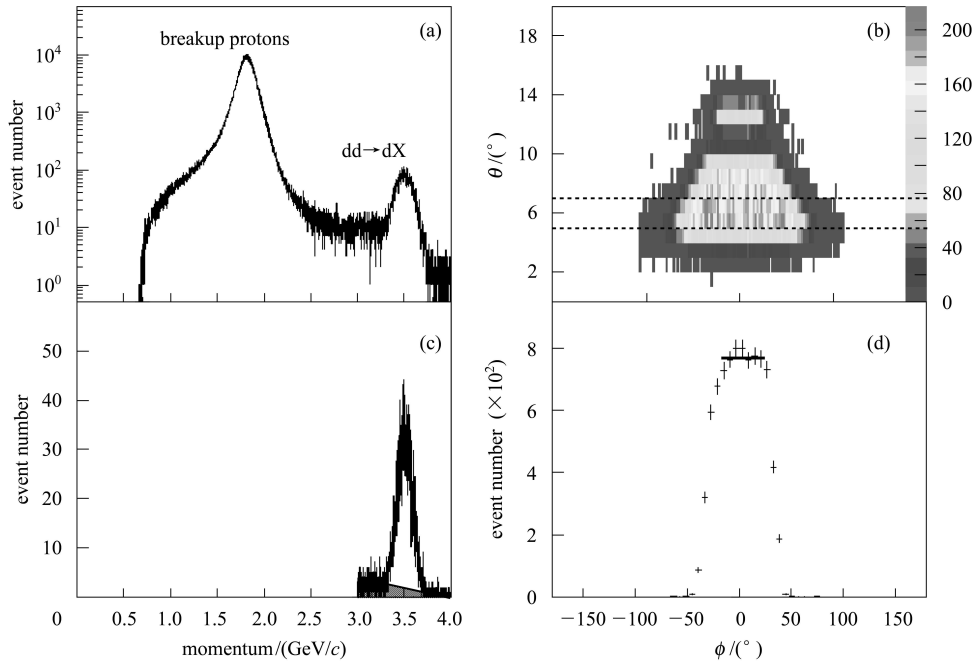

Fig. 3.   (a) Momentum spectrum of particles detected in the ANKE-FD. The spectrum is dominated by protons from projectile breakup, as well as the (quasi-) elastic deuteron peak. (b) The Monte-Carlo simulation result of polar and azimuthal angles θ and ϕ distribution for dd → dX events in the ANKE acceptance at $p_d = 3.7$ GeV/c. The dashed lines show the θ range that has been used for the luminosity determination. (c) The remaining momentum distribution after applying θ and ϕ cuts as well as energy-loss thresholds in the FD scintillators. (d) In the angular interval $\phi = -20°$—$+20°$ the event distribution is flat as expected from the acceptance simulations.

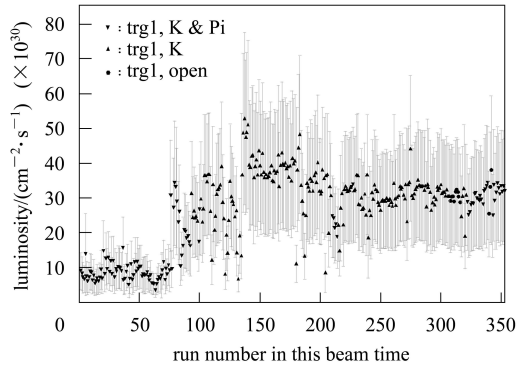Fig. 4.   Run-by-run luminosity over the ANKE dd → d K⁺K⁻ beam time. After some short test runs in the first two days, the luminosity is stable.

The luminosity has been determined for each of the ~ 350 experimental runs individually, see Fig. 4. Starting with Run #100 (where we changed the online trigger conditions) the experimental conditions were more or less constant. The average luminosity over all runs has been determined to be $L = [2.6 \pm 0.1(\text{stat}) \pm 0.8(\text{syst}) \pm 0.3(\text{syst})] \times 10^{31}\,\text{s}^{-1}\text{cm}^{-2}$. The systematic errors are mainly from the dd → dX cross section estimate and the uncertainty of the θ angle reconstruction. This corresponds to an integrated value of $L_{\text{int}} = 35$ pb^{-1}.

3   Result and outlook

An attempt to measure the dd → αK⁺K⁻ reaction has been made at the ANKE spectrometer. As the first step, the dd small-angle (quasi-) elastic scattering at ANKE has been studied. Thus the integrated luminosity of this experiment has been determined to be $L_{\text{int}} = 35$ pb^{-1}. With this value the cross section of the dd → αf₀ → αK⁺K⁻ process will be deduced from an ongoing analysis.

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