Study of near-threshold π^0- and η-meson production in proton-neutron reactions at ANKE

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Abstract

We propose to measure the cross section for $pn \to d\eta$ near threshold by studying the reaction $pd \to d\eta p_{sp}$ in deuterium in a region of quasi-free kinematics where the spectator proton p_{sp} has low momentum, typically 100 MeV/c. The deuteron will be measured in the forward detector of ANKE and the spectator proton by solid state counters placed in the reaction chamber at angles around $\vartheta \approx 90°$, thus allowing the π^0- and η-mesons to be identified as a missing-mass peak. A range of excitation energies can be covered by identifying Q on an event-by-event basis with the help of the spectator information. For a better understanding of the acceptance corrections, it is also planned to perform measurements of the reaction $pd \to d\pi^0 p_{sp}$ at comparable values of Q.

1 The $pn \to d\,\eta$ reaction near threshold

Data on the energy dependence of the production of η-mesons in the $pd \to {}^3\mathrm{He}\,\eta$ [1] and $dd \to {}^4\mathrm{He}\,\eta$ [2] reactions near threshold show that the $\eta\,{}^3\mathrm{He}$ and $\eta\,{}^4\mathrm{He}$ scattering lengths are very large, and that this in turn might indicate the existence of quasi-bound η-helium nuclei [3], possibly driven by the presence of the $N^*(1535)$ resonance that overlaps the $\eta\,N$ threshold. Of great interest is the $\eta\,d$ system, which is susceptible to more microscopic calculations than is the case for heavier nuclei. The theoretical results are rather uncertain, due to the limited knowledge of the low energy η-nucleon interaction, but it seems likely that this is not strong enough to give a quasi-bound state, but still a large $\eta\,d$ scattering length [4]. Experimental data of high quality are required to settle the question.

The $\eta\,{}^3\mathrm{He}$ case is under investigation in photoproduction data currently being analysed at Mainz [5]. However the coupling of isoscalar photons to the $N^*(1535)$ is rather weak so that the $\gamma\,d \to \eta\,d$ reaction is not a very promising means to investigate the $\eta\,d$ system, and the production with pions is even less hopeful. One is therefore led to study the production of the system in neutron-proton collisions.

In the absence of free neutron targets, the η has been detected in quasi-free production off the neutron in the deuteron. Data taken in an inclusive $d(p,d)X$ experiment close to the $NN\,\eta$ threshold [6] have been interpreted in terms of $pn \to d\,\eta$ [7] and the cross section deduced is large and rapidly varying with excess energy Q. In a much more refined experiment at CELSIUS [8, 9], the η-meson in the $pd \to p_{\mathrm{sp}}\,d\,\eta$ reaction was measured through its two-photon decay products. The direction, but not in general the energy, of a fast charged particle was also detected.

With certain simplifying assumptions, kinematical fits allowed one to identify the underlying $pn \to d\eta$ reaction with a spectator proton (p_{sp}), and deduce the cross section as a function of Q from a single experiment carried out at a fixed beam energy corresponding to $Q \approx 35$ MeV for a stationary target (Fig.1). The binning in Q in the range $15 \leq Q \leq 115$ MeV was 10 MeV. The CELSIUS group simultaneously measured $pd \to n_{\mathrm{sp}}\,pp\,\eta$ and obtained an excitation function in Q which agreed in both normalisation and shape with that obtained in free proton-proton collisions. This gives confidence in identifying quasi-free measurements with free ones.

The method could not be extended directly to the very low values of Q because, very close to threshold, the deuteron escapes down the beam-pipe. This fact was exploited in a second CELSIUS experiment [10], where the fast deuteron was measured in a small spectrometer which used the subsequent CELSIUS bending magnet. The normalisation was achieved by looking at

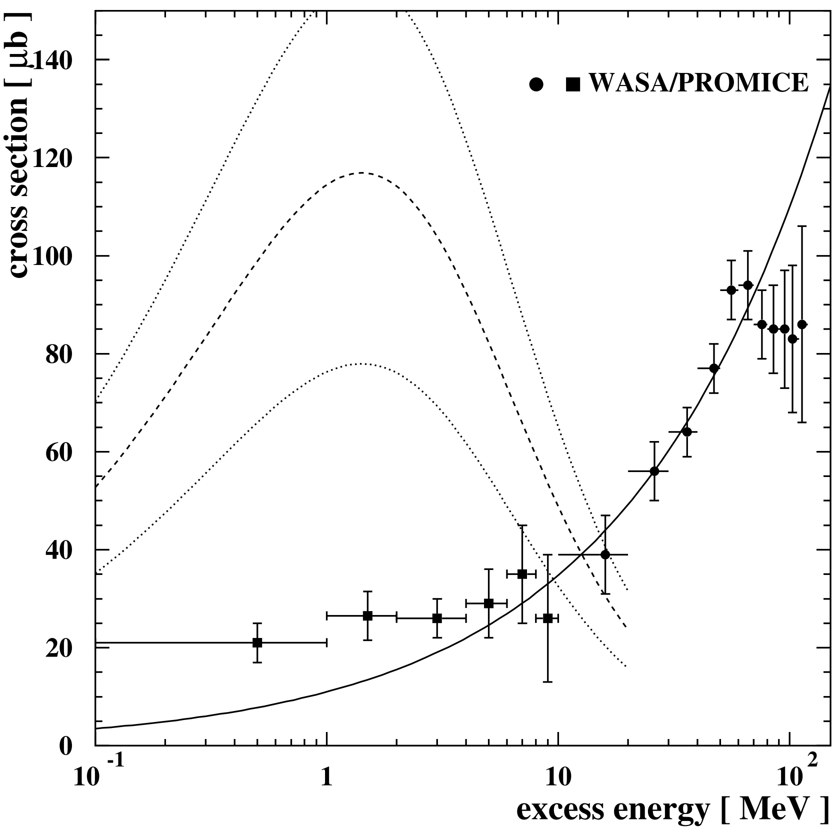

Figure 1: Energy dependence of the total cross section for the quasifree $pn \to d\eta$ reaction at threshold [8, 9]. The solid line indicates a fit to the data based on pure phase space expectations. The dashed and dotted lines show the parametrization of the cross section from [7] and the corresponding quoted errors.

events in the overlap region with the earlier experiment [8, 9]. Though a threshold enhancement was observed, its magnitude does depend upon the relative normalisation of the two CELSIUS experiments and the energy calibration. It seems, though, that the effect is far smaller than that suggested by the inclusive Saclay measurement [6, 7].

As an alternative procedure, which offers the potential of far better resolution in Q, it is possible at storage rings to measure directly the direction and energy of the spectator proton in quasi-free interactions on the deuteron. A test experiment of this method in the case of $pd \to p_{\rm sp}\, d\,\pi^0$ has been carried out successfully at CELSIUS [11]. With solid state counters to detect the spectator protons covering only a small part of 4π solid angle, the group were able to show that the energy dependence obtained for the $pn \to d\pi^0$ cross section is consistent with direct $np \to d\pi^0$ measurements or deduced from $pp \to d\pi^+$ using isospin invariance. Spectator tagging led to a resolution in Q which was about a factor of two better than the CELSIUS $pn \to d\eta$ measurement [8, 9]. The improvements that they proposed (larger solid-angle coverage and the use of ultra-thin Si ΔE counters) could not be implemented because spectator detection is not compatible with the new CELSIUS/WASA scattering chamber arrangement. We therefore want to exploit this methodology in refined experiments at the ANKE spectrometer in the COSY ring.

Specifically, we propose to investigate the $pd \to p_{\rm sp}\, d\eta$ reaction, and hence extract the $pn \to d\eta$ cross section, by measuring the fast deuteron in the forward wall of ANKE in coincidence with the spectator proton in a solid-state detector placed only few cm from the interaction region. Unlike the CELSIUS experiments, the η will be reconstructed through the missing-mass in the reaction. For a fixed beam energy, the range in Q is determined by the characteristics of the spectator counter, and the accuracy in Q primarily by the counter's angular precision. We would like to obtain total and differential cross sections from threshold to about $Q \approx 200$ MeV, so that, unlike at CELSIUS, we will scan the whole width of the $N^*(1535)$ resonance. Particular attention will be paid in the present proposal to the near-threshold region in order to get a good determination of the $\eta\, d$ scattering length. It is shown in the following that for values of Q up to ~ 30 MeV, data can be obtained at a single beam energy, $T = 1.290$ GeV. For higher Q, we request no dedicated beam time but refer to the beam-time request on ω production in $pd \to p_{\rm sp}\, d\omega$ reactions (COSY proposal #75, also presented for this PAC meeting) where it is foreseen to take data at $T = 2.0$ GeV. Although the acceptance of ANKE for $pd \to p_{\rm sp}\, d\eta$ events is rather low at high beam energies, it is hoped that some information about η production at large Q values can be obtained from those data.

It is obvious that a precise knowledge of the detector acceptances as function of Q is crucial to extract the energy dependence of the η-production cross section. Usually, these acceptances are deduced from simulation calculations which might result in rather large systematic uncertainties. As an alternative approach, we would like also to run an experiment just above the π^0 threshold at comparable values of Q. By a comparison to known data on the cross section for $pn \to d\pi^0$ reactions, this will allow to determine the acceptances and to prove that we can reliably extract the cross sections for η-production.

2 Detection scheme

Simulated trajectories of deuterons and spectator protons are shown in Fig. 2 for the reaction $pd \to p_{\rm sp}\, d\,\eta$, generated at a beam energy of 1.290 GeV and an deflection angle of the circulating COSY beam $\alpha = 9.4°$ at the ANKE installation. The deuterons will be detected in the forward detector, consisting of multiwire proportional chambers, a scintillation wall and Čerenkov counters (not shown). It has already been shown in earlier proposals (see, e.g. [14, 15]) that the deuterons can be discriminated against protons and other background particles by TOF and ΔE measurements and with the help of the Čerenkov counters.

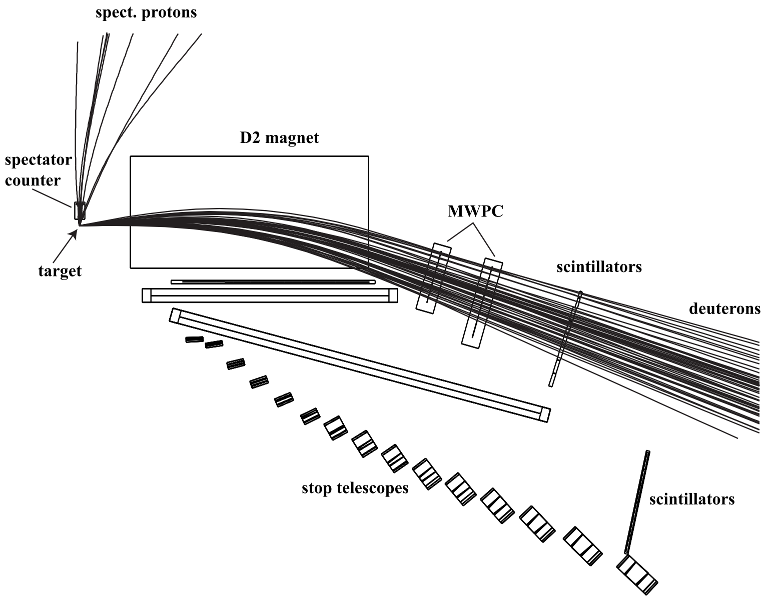

Figure 2: Layout of the ANKE facility at COSY.

The spectator protons will be detected in a three-layer Silicon detector close to the target with an active size of ~ 10 cm^2 and thicknesses of 60 μm, 300 μm and 5 mm. The counters are located at distances of 5, 6 and 12 cm from the target. The orientation relative to the target can be adjusted such that different angular ranges for the detection of spectator protons are accessible, according to the experimental requirements. The counters have already been successfully used at ANKE for target monitoring and first data on $pd \to p_{\rm sp}\, d\,\omega$ reactions have been taken during the last ANKE beam time. First results of analyses will be presented during the PAC meeting. The second layer of the spectator counter has a spatial resolution of better than

1 mm. Thus the measurement error for the emission angles of the spectator protons is mainly given by the uncertainty of the point of interaction, i.e. by the length of the cluster target in the beam direction.

Through the detection of the fast deuteron in coincidence with the spectator proton, the 4-monenta of these ejectiles will be accessible, leading to full event reconstruction for reactions of the type $pn \to d\,X$ with X being the unobserved meson. Note that the missing mass resolution Δm_X at ANKE is better than 10 MeV/c^2. This value is significantly smaller than the invariant mass resolution $\Delta m_{\gamma\gamma} \sim 50$ MeV/c^2 of the η-decay photons detected in the CELSIUS measurements [8, 9, 10].

3 Results of simulation calculations

Monte-Carlo simulations have been undertaken at different beam momenta for the reactions $pn \to d\,\pi^0$ and $pn \to d\,\eta$. In Fig. 3 the result of a simulation is shown for η-production at a beam energy of $T = 1.290$ GeV, corresponding to a Q-value of 15 MeV in the case of a motionless neutron target.

Dashed lines indicate kinematical distributions of generated Monte-Carlo events at the target while the dashed histograms show the corresponding distributions of events seen from the ANKE facility. For a better visibility the latter spectra have been scaled up by arbitrary factors. As can be seen by the upper spectra of Fig. 3, nearly the complete range of deuteron momenta and angles is covered. In the lower spectra of that figure the energy and the angle of the corresponding spectator protons are shown. The sharp cut in the angular distribution is given by the geometrical size of the spectator detector, leading to a limitation of the accessible range of excess energies to $Q = 0 - 30$ MeV for this particular choice of the counter position and beam energy. In order to achieve an opportune resolution for the determination of the Q-value, target dimensions of $\Delta z = 2$ mm in beam direction and $\Delta x = 5$ mm perpendicular to the beam will be chosen. From this a resolution ΔQ of better than 3 MeV (FWHM) will be achieved.

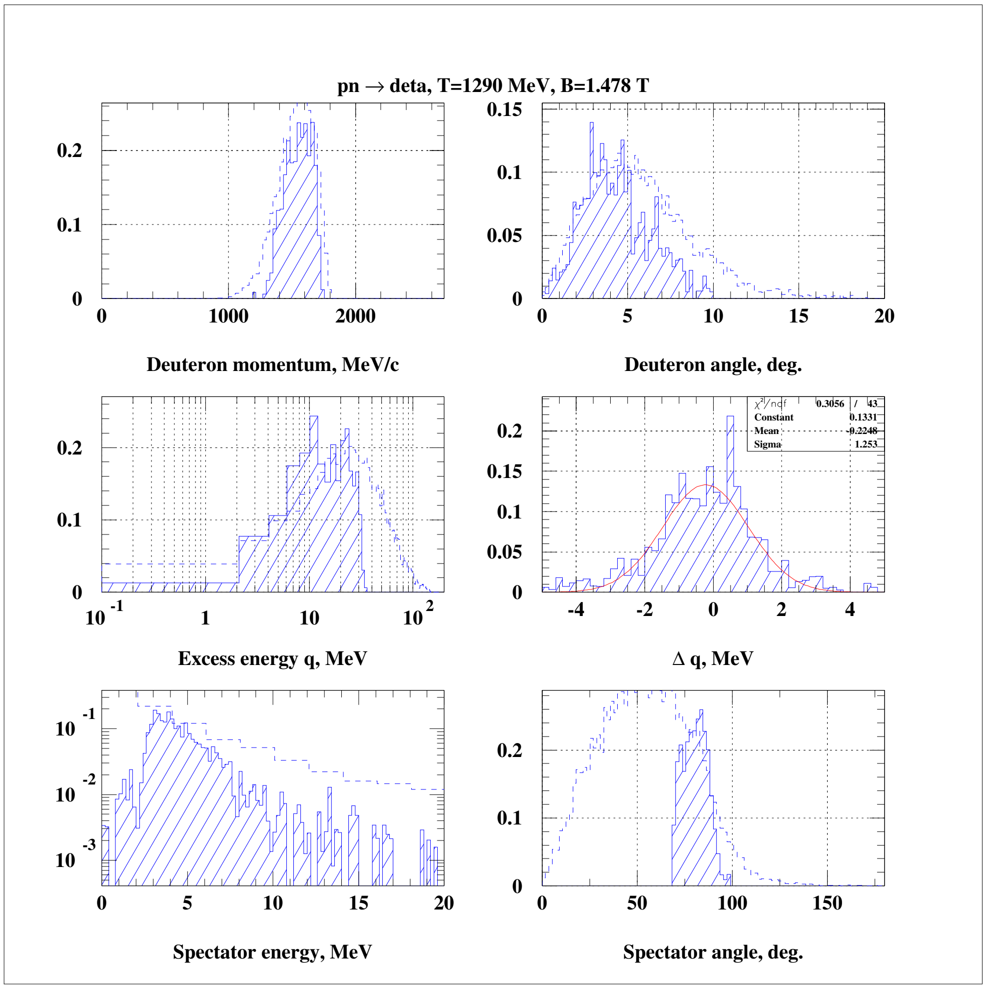

Figure 3: Kinematical distributions of Monte-Carlo events for spectator protons and deuterons of the reaction $pd \to p_{\rm sp}\, d\, \eta$ at a beam energy of 1.290 GeV. Dashed lines indicate distributions of the generated events and dashed histograms represent the (scaled) distributions of accepted events.

Referring to experiences from earlier beam times at ANKE using a deuterium cluster beam target, the modification of the target beam diameter in the scattering chamber will lead to luminosities in the order of up to $L \approx 5 \cdot 10^{29}$ cm^{-2}s^{-1}. For a conservative estimation of the expected counting rates we consider a mean luminosity of only $L = 2 \cdot 10^{29}$ cm^{-2}s^{-1}. The cross section is estimated from the parametrisation indicated as the solid line in Fig. 1. On the basis of these assumptions, and taking into account the results of Monte-Carlo simulations (Fig. 3), effective cross sections of 50 nb and 160 nb have been determined for the regions of excess energies of $Q < 10$ MeV and $Q = 10 - 30$ MeV, respectively. This leads to expected counting rates of 860 events/day and 2800 events/day for the quoted regions. Therefore, six days of beam time will allow us to collect in total $\sim$ 22000 events of the reaction $pn \rightarrow d\,\eta$ and to divide the measured excitation function in bins of $\Delta Q = 2$ MeV.

As discussed above it is planned to start with a test measurementof the reaction $pn \rightarrow d\,\pi^0$ at comparable Q-values where the angular distribution of the detected ejectiles (spectator proton and deuteron) are almost identical. Since the absolute value of the cross section and the angular distribution in the center-of-mass system are known (Fig. 4), these data will allow us to check the acceptance corrections which are necessary to determine the excitation function for the reaction $pn \rightarrow d\eta$. Above $Q \approx 6$ MeV, the cross section for the π^0 are larger than in the case of the η. Our simulations for $T = 317$ MeV (corresponding to $Q = 15$ MeV for a neutron target at rest) show that count rates comparable to the case of η-production can be expected and, thus, six days of beam time will be needed to collect a sufficient amount of events for the discussed purpose.

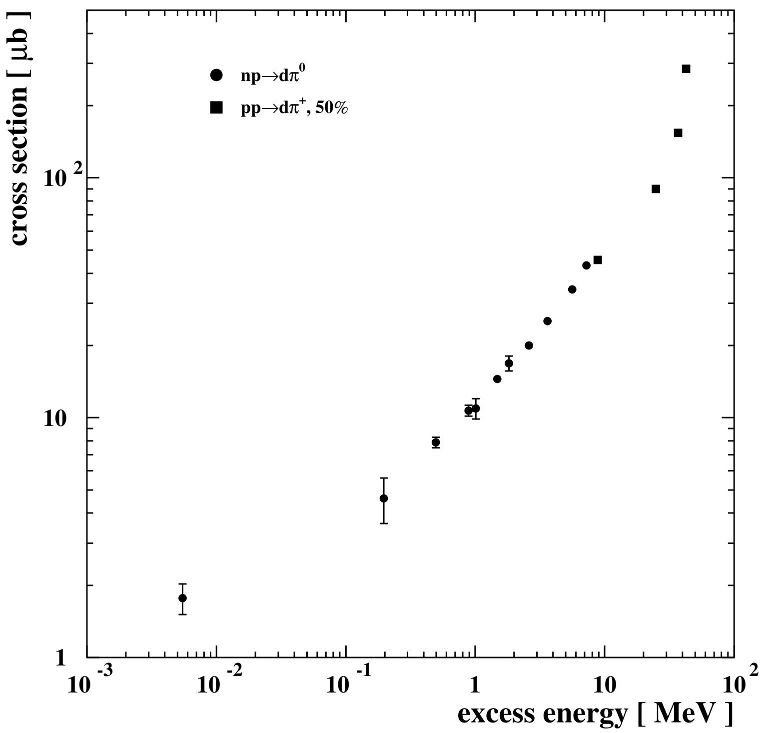

Figure 4: Energy dependence of the total cross section for the quasifree $pn \to d\pi^0$ reaction at threshold. Data marked by filled circles are from [12]; data marked by filled squares have been deduced from data of the reaction $pp \to d\pi^+$ [13] using charge independence.

4 Requested time for measurements

Summarizing, we apply for **two weeks** of beam time in total. One week will be used for detailed studies on the reaction $pn \to d\pi^0$ including one day for beam developement and trigger adjustment. The second week will be used for measurements on the reaction $pn \to d\eta$ at a beam energy of 1.290 GeV, including one day for beam developement and trigger adjustment. For an optimized utilisation of the beam time and, to minimize systematical uncertainties, it will be advantageous to perform these measurements in one continuous block of beam time.

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