THRESHOLD ETA PRODUCTION IN pN REACTIONS AT CELSIUS *

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The quasi-free p+n→d+η reaction cross section has been measured at threshold using 1295 MeV protons in the CELSIUS storage ring and an internal cluster-jet deuterium target [1]. Excess energies from threshold to 10 MeV in the center of mass of the final $d\eta$ system were covered. Approaching the threshold the cross section is enhanced compared to phase-space expectations. This behaviour is typical for a strong final state interaction.

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1. Introduction

The experimental programme at the CELSIUS cooler-storage ring of The Svedberg Laboratory, Uppsala, has during the last years included η meson production in proton-proton and proton-deuteron collisions as a main subject. For these studies, a detector setup [2] was developed by the CELSIUS/WASA collaboration. The setup allows for a kinematically complete determination of the meson production events in most cases. In addition, its photon detection capability has enabled measurements very close to threshold *e.g.* of the $p + p \to p + p + \pi^0$ and the $p + p \to p + p + \eta$ [3] reactions. The excitation functions for the quasi-free reactions $p + n \to p + n + \eta$ and $p + n \to d + \eta$ [4] have been measured for excess energies in the CM system from 15 MeV up to 115 MeV using a deuterium target.

The strength of the η-N interaction lead to speculations on the existence of a quasi-bound η-nuclear state even in the two-nucleon system [5–7]. Such a quasi-bound state would be a new phenomenon and should also show up as a threshold enhancement of η-meson production in nucleon–nucleon collisions. A first indication of such an enhancement at threshold came from a Saclay study of the $n+p \to d+\eta$ reaction [8]. However, in that experiment, only the deuteron was measured and furthermore the cross section had to be unfolded from the high-energy tail of a wide band neutron beam.

2. The threshold experiment

To be able to cover the region of very low CM excess energies and check the Saclay results, we modified the detector setup, so that deuterons going forward inside the beam pipe could be detected. Charged particles scattered at angles below 1°, and with a magnetic rigidity in the range 0.71–0.91 of the beam, were detected in a plastic scintillator telescope placed 7.6 m downstream of the target region (Fig. 1). A run with a proton beam at 1295 MeV energy and a deuterium cluster-jet target was made in September 1996. The decay γ's from the η are selected by means of the hit pattern in the two CsI(Na) arrays of the CD (Fig. 1) and an associated deuteron is identified by means of the signals from the three planes in the downstream scintillator telescope. The particle identification, illustrated in Figs 2 and 3, results in cleanly identified $d + \eta$ final state events. This means that one can neglect the background from the reaction $p + n \to p + n + \eta$ which together with $p + n \to d + \eta$ dominates η production in the threshold region.

The events selected for the final analysis are those consistent with the $p+n \to d+\eta$ two-body reaction kinematics. From the direction of the deuteron together with the energy and direction of the η meson it is straightforward to calculate, the CM excess energy ($Q_{\mathrm{CM}} = \sqrt{s} - (m_d + m_\eta)c^2$), assuming that the spectator proton is on the mass shell.

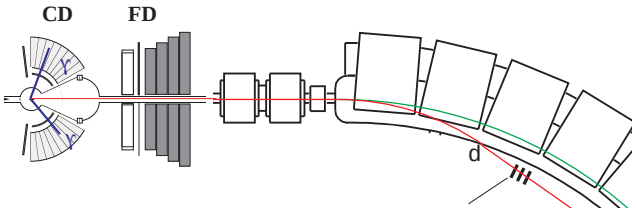

Fig. 1. Layout of the experiment at CELSIUS. To the left is shown the detector setup at the cluster-jet target [2]. It consists of a central part (CD), used for the detection of η decay γs and a forward part (FD) for charged particles. The scintillator telescope for detection of 0° deuterons is situated outside the beam pipe at the 3rd of the CELSIUS bending magnets downstream of the target.

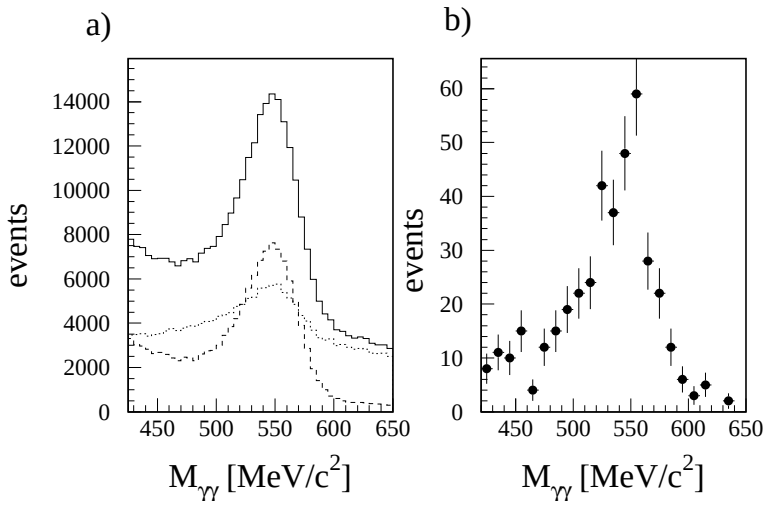

Fig. 2. (a) Invariant 2γ mass from the CsI(Na) information. The solid line corresponds to all events. The dashed and dotted lines correspond to events with and without a charged particle detected in the FD (4-20^0), respectively. (b) The distribution of the events with a signal in the downstream telescope.

Fig. 4(a) shows the excitation function for the quasi-free $p + n \rightarrow d + \eta$ reaction at threshold together with our earlier result at higher Q_{CM} [4]. The normalisation of our data is obtained from data simultaneously acquired at higher Q_{CM} where the cross section has been determined in the earlier measurement. The overall systematic error, including a 20% uncertainty in the relative normalisation, is estimated to be around 30%.

The cross section is fairly constant, about 30 μb in the whole range from threshold to 10 MeV. The resolution in Q_{CM} is 1 MeV (rms) at threshold and

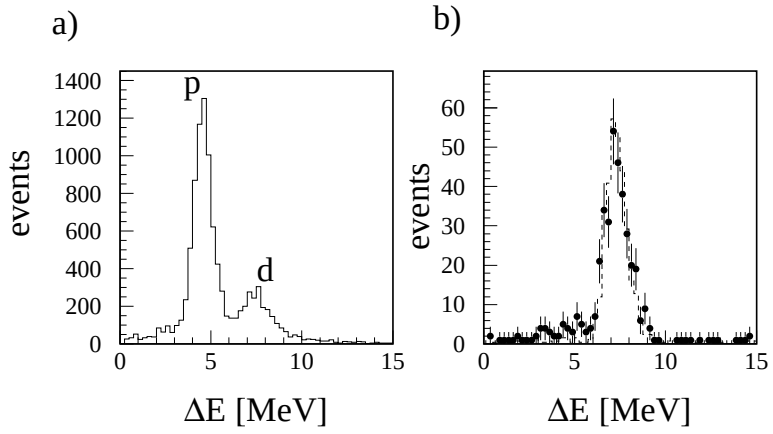

Fig. 3. (a) Energy deposition in one of the telescope planes. The peaks correspond to the expected depositions of protons and deuterons. (b) The distribution of the events where in addition, 2γ having an invariant mass in the η region are detected. Dashed curve — Monte Carlo data for the $p + n \to d + \eta$ events.

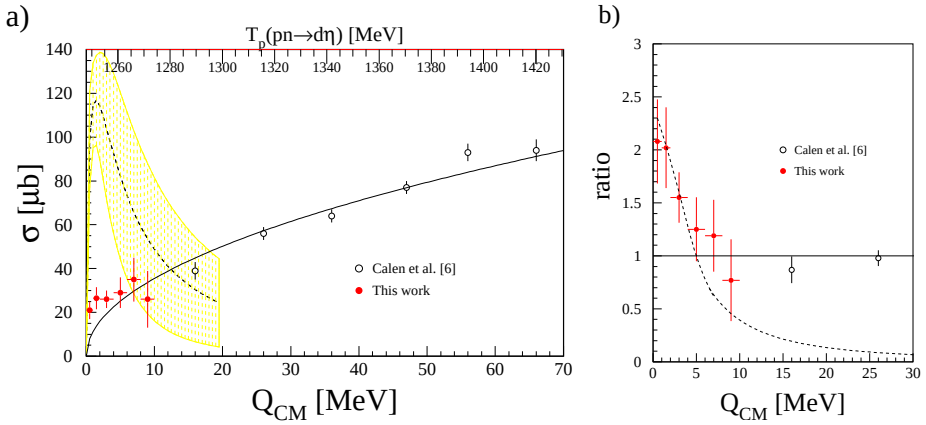

Fig. 4. (a): Excitation function for the quasi-free p+n→d+η reaction at threshold together with our earlier results at higher CM energies. Vertical bars — statistical errors. Horizontal bars — bin width. Solid line — phase-space curve. Dashed line — parameterisation from Ref. [8]. (b): Ratio of the measured cross section and the expectation for a two-body phase-space behaviour (solid line in (a)). Dashed curve — expectations for a cross section behaviour according to the renormalized parameterisation of Ref. [8].

it decreases to 2 MeV at $Q_{\mathrm{CM}} = 10$ MeV. The result implies a rapid increase of the cross section from zero to around 30 μb very close to threshold. Our cross section close to threshold is clearly much below the curve representing

the earlier Saclay measurements. Fig. 4(b) shows the ratio of the measured cross section relative to what is expected from phase-space. Below $Q_{\rm CM} = 3$ MeV there is a significant deviation from phase-space which is typical for a strong final-state interaction and could be consistent with the existence of a quasi-bound state or a resonance in the ηd system [5–7]. The observed signal agrees in magnitude and shape with predictions of such effects [5] which correspond to ηd scattering lengths of a few fermi.

3. Summary

We present results of the first exclusive measurement of the energy dependence of the quasi-free $p + n \to d + \eta$ reaction at threshold. The cross section rises to about 30 μb already at 1 MeV above threshold and is constant within errors in the range up to 10 MeV. This is clearly at variance with a pure phase-space behaviour and is most likely explained by a strong final state interaction. Whether this is strong enough to make possible the formation of an $NN\eta$ resonance or a quasi-bound state remains to be seen.

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