Investigation of the ^{3}He+η system with polarised beams at ANKE*

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Differential and total cross sections for the $dp \to {}^3\mathrm{He}\,\eta$ reaction have been measured with both unpolarised and tensor/vector polarised deuteron beams at the COSY–ANKE experiment near threshold. The data have been taken by using a continuous beam energy ramp up to an excess energy Q of 10 MeV with essentially 100% acceptance of the detection system. The data allowed the determination of the energy dependence of the tensor analysing power t_{20} and hence of the two s-wave production amplitudes at threshold. The observed very weak energy dependence of these quantities supports the hypothesis that the rapid energy variation of the scattering amplitude for this reaction is dominantly given by a strong s-wave η^3He final state interaction, which is discussed to be a signal for the existence of a possible quasi-bound eta-mesic state.

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1. Introduction

Earlier high-precision measurements performed at the COSY–ANKE facility on the reaction $dp \to {}^3\mathrm{He}\,\eta$ resulted in a rich data set of differential cross sections as well as in 195 total cross sections for the first 11 MeV excess energy above threshold [1]. The very small relative systematic errors resulting from the measurement of the excitation function in a single experiment led to a robust data set for detailed analyses on the final state interaction of the $\eta -^3$ He system. In Fig. 1 the total cross sections for the very near threshold region, i.e. for $Q < 4.5$ MeV, are presented. The solid line starting in the sub-threshold region corresponds to a fit to the results considering a strong final state interaction as well as the finite COSY beam

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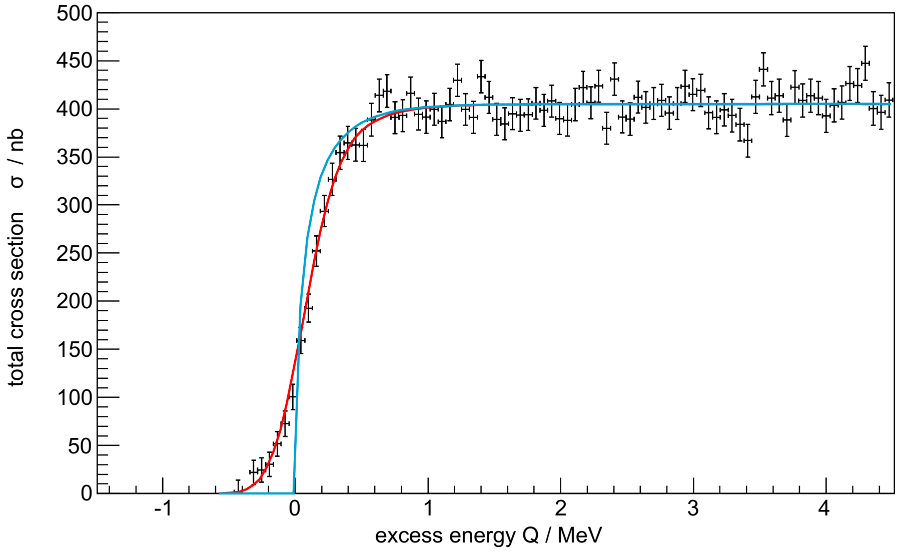

Fig. 1. Total cross sections for the $dp \to {}^3\mathrm{He}\,\eta$ reaction in the very near threshold region, i.e. for $Q < 4.5\,\mathrm{MeV}$. The solid line starting in the sub-threshold region corresponds to a fit to the results considering a strong final state interaction as well as the finite COSY beam momentum width, while the other one is the result to be expected without the 180 keV smearing in Q.

momentum width, while the other one is the result to be expected without the 180 keV smearing in Q. Obviously the total cross section reaches its maximum value within 0.5 MeV of threshold and hardly decreases after that. This behavior is in complete contrast to phase–space expectations and indicates a very strong final state interaction and a possible pole in the production amplitude close to threshold [2].

The underlying theoretical description of the total and differential cross section data presented in Ref. [1] considers s- and p-waves in the final state as well as a strong final state interaction. Here it can be shown that there are two independent $dp \to {}^3\mathrm{He}\,\eta$ s–wave amplitudes (A and B) [3] and five p–wave amplitudes close to threshold. However, in order to discuss the data phenomenologically, only two of these were retained (C and D) that give a pure $\cos\theta_\eta$ dependence in the cross section. Here the production operator can be written as

$$\hat{f} = A\,\vec{\varepsilon}\cdot\hat{p}_p + iB\,(\vec{\varepsilon}\times\vec{\sigma})\cdot\hat{p}_p + C\,\vec{\varepsilon}\cdot\vec{p}_\eta + iD\,(\vec{\varepsilon}\times\vec{\sigma})\cdot\vec{p}_\eta \tag{1}$$

with $\vec{\varepsilon}$ as the polarisation vector of the deuteron. The corresponding unpolarised differential cross section depends upon the spin-averaged value of

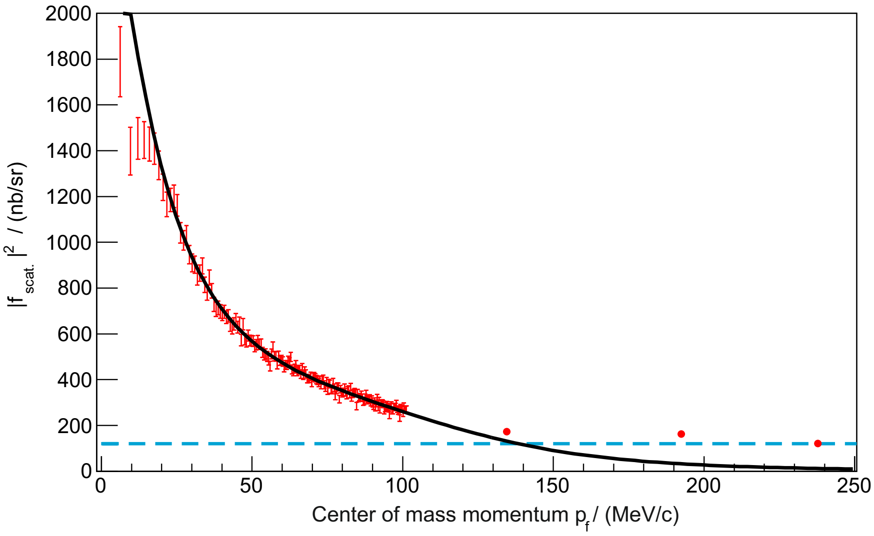

Fig. 2. Scattering amplitude squared extracted from the unpolarised data obtained at ANKE as function of the η c.m. momentum. The solid line shows the result of a fit to the near-threshold data, whereas the dashed line shows an expectation according to pure phase space behavior, arbitrarily fixed to the highest energy data point.

the amplitude square $|f|^2$

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{p_\eta}{p_p}\,\overline{|f|^2} = \frac{p_\eta}{3p_p}\,I\,. \tag{2}$$

Using the amplitudes of Eq. (1) this yields

$$I = |A|^2 + 2|B|^2 + p_\eta^2|C|^2 + 2p_\eta^2|D|^2 + 2p_\eta Re(A^*C + 2B^*D)\cos\theta_\eta, \tag{3}$$

which has the desired linear dependence on $\cos\theta_\eta$ observed in the data [1].

The scattering amplitudes $|f|^2$ extracted from the unpolarised data close to threshold as well as a fit to the data up to Q=11.3 MeV, i.e. p_f=102 MeV/c, are presented in Fig. 2. The rapid decrease of the amplitude with increasing momentum indicates the presence of a very strong η^3He final–state interaction (FSI) which should affect the two s–wave amplitudes A and B in a similar way. Thus, detailed information on the magnitude and energy variation of these amplitudes is of great interest and these can be obtained by the investigation of the deuteron tensor analysing power t_{20} as function of the excess energy. While existing data on the deuteron tensor analysing power t_{20} are compatible with A and B being of similar size and only a weak energy variation [4], the data base is not sufficient to draw final conclusions on this question. Therefore, additional experiments to measure the deuteron tensor analysing power have been performed at COSY–ANKE [5] using the same experimental facility and method but using tensor polarised deuteron beams [6].

2. Experiment

Similar to the earlier measurements using unpolarised beams the experiment presented here was performed with a polarized deuteron beam on a hydrogen cluster-jet target [7] using the ANKE spectrometer [8] placed at an internal station of the COoler SYnchrotron COSY–Jülich. The deuteron beam energy was ramped slowly and linearly in time, from an excess energy of $Q = -5\,\mathrm{MeV}$ to $Q = +10\,\mathrm{MeV}$. After each COSY cycle with a duration of approximately 300 s the beam was alternated between an unpolarised and a tensor polarised one. The tensor polarisation itself was determined by the analysis of the reaction $d + p \to (pp) + n$ for which the analysing powers are known [9].

The ^{3}He produced were detected in the ANKE forward detection system, which consists of two multi-wire proportional chambers, one drift chamber and three layers of scintillation hodoscopes. The geometrical acceptance for the ^{3}He of the $dp \to {}^3\mathrm{He}\,\eta$ reaction was $\sim 100\%$, so that systematic uncertainties from acceptance corrections are negligible. The tracks of charged particles could be traced back through the precisely known magnetic field to the interaction point, leading to a momentum reconstruction for registered particles. The relative luminosity required to compare polarised and unpolarised data was determined by simultaneously measuring the spectator protons with a Fermi momentum $p_{spec} \leq 60\,\mathrm{MeV}/c$.

3. Determination of tensor analysing powers

It is plausible to assume that very close to the production threshold the s-wave amplitudes A and B dominate the observed total cross section data. Thus in good approximation the near–thresold data can be described by

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{p_\eta}{p_p}|f_{scat}|^2 = \frac{1}{3}\frac{p_\eta}{p_p}\left[|A|^2 + 2|B|^2\right]. \tag{4}$$

Information on these two s-wave amplitudes A and B itself can be gained by studying the tensor analysing power t_{20} [10] which itself can be determined by the comparison of data obtained with tensor polarised deuterons and unpolarised ones:

$$t_{20} = \frac{2\sqrt{2}}{p_{zz}} \cdot \frac{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta)\right)_0 - \left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta)\right)_\uparrow}{\left(\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega}(\vartheta)\right)_0} = \sqrt{2}\left[\frac{|B|^2 - |A|^2}{|A|^2 + 2|B|^2}\right]. \tag{5}$$

Here the differential cross sections obtained with unpolarised beams are denoted by the index "0" while the polarised ones are indicated by an arrow as index. The deuteron tensor polarisation is denoted here by p_{zz}. The extracted preliminary deuteron tensor analysing powers t_{20} are presented in Fig. 3 and compared to existing data from Ref. [4]. Although preliminary the analysing powers are obviously comparatively small and show only a very weak energy dependence in the near threshold region. In more detail with good approximation the data can be described well by assuming a constant analysing power (solid line), however, within the uncertainties the data might allow also for a weak variation with energy as indicated by the linear fit (dashed line).

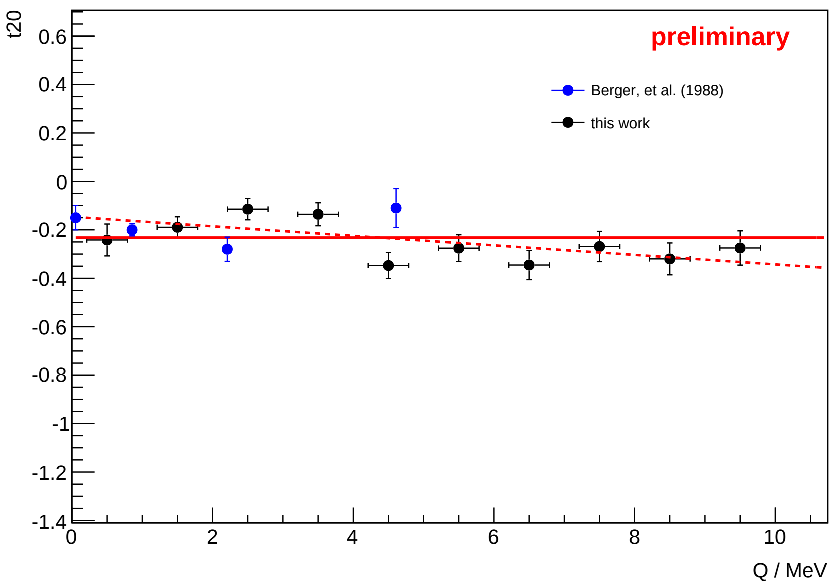

Fig. 3. Energy dependence of the deuteron tensor analysing power t_{20} close to the production threshold. The solid line corresponds to a fit to the data assuming a constant analysing power while the fit indicated by the dashed line allows for a linear.

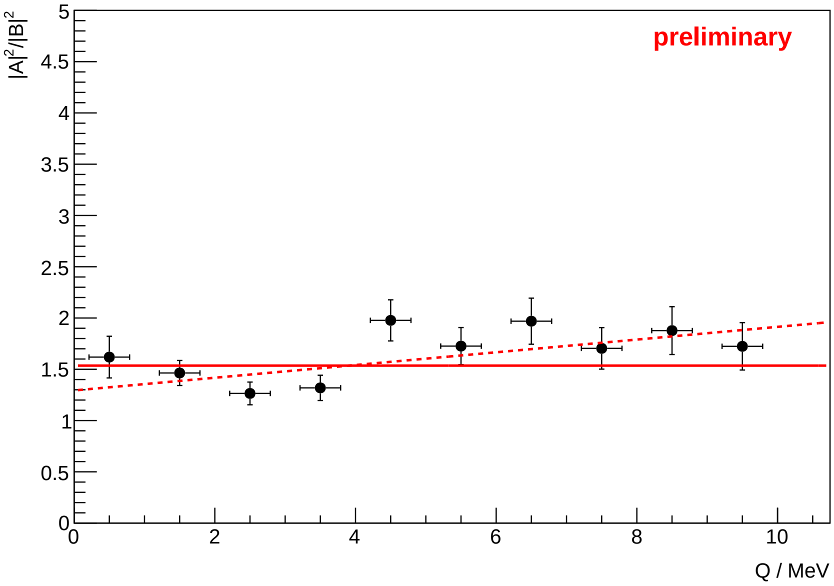

Fig. 4. Ratio of the squared amplitudes $|A|^2/|B|^2$ as function of the excess energy. The solid and dashed lines correspond to a constant fit and a first order polynomial fit, respectively.

Exploiting Eq. (5) the extracted analysing powers t_{20} allow for the determination of the ratio of the squared amplitudes $|A|^2/|B|^2$. In Fig. 4 the preliminary data determined at ANKE for this ratio are shown as function of the excess energy Q. As expected from the small magnitude of t_{20} and its energy dependence, both amplitudes are similar in size, i.e. $|A|^2 \sim |B|^2$, and can be described well near threshold by assuming a constant ratio (solid line). Combining this information on the energy dependence of the amplitude ratio $|A|^2/|B|^2$ with the already known absolute magnitude and energy dependence of the scattering amplitude $|f_{scat}|^2$ from the earlier unpolarised measurements of Ref. [1], information on the absolute magnitude of the individual amplitudes $|A|^2$ and $|B|^2$ can be derived by applying Eq. (5). In Fig. 5 the correspondingly obtained data are presented. In addition the solid lines indicate the individual amplitude squared $|A|^2$ and $|B|^2$ as function of the final state momentum in the center of mass system, obtained by using Eq. (5), assuming a constant ratio $|A|^2/|B|^2$ as shown in Fig. 4, as well as using the fit function for $|f_{scat}|^2$ for the unpolarised data (see Ref. [1]). Similar to the amplitude square $|f_{scat}|^2$ both individual amplitudes $|A|^2$ and

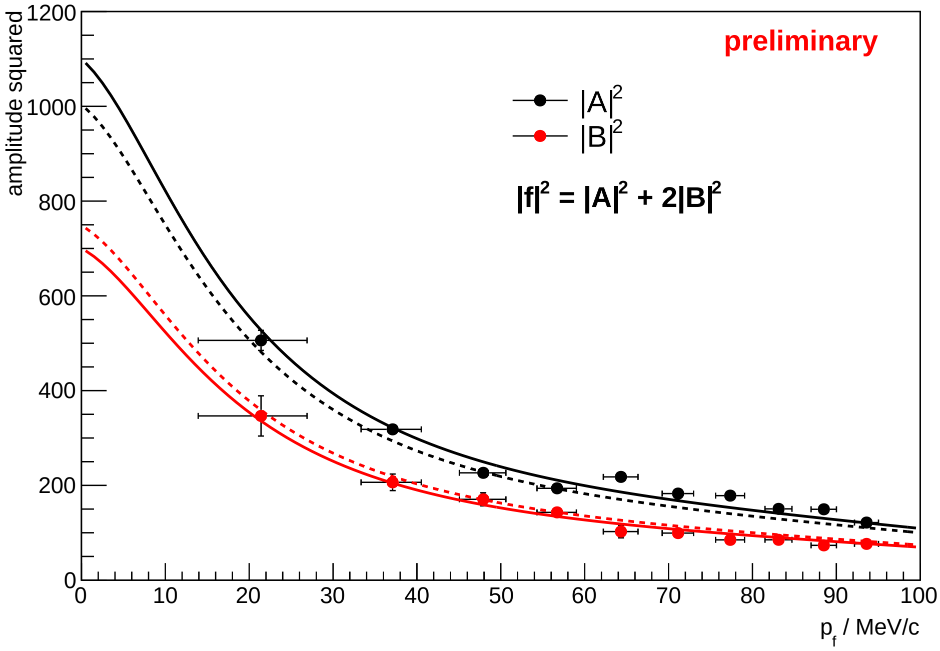

Fig. 5. Energy dependence of the amplitudes $|A|^2$ and $|B|^2$ as function of the final state momentum p_f. The solid lines have been obtained by the assumption of a constant ratio $|A|^2/|B|^2$ close to threshold and using the squared amplitudes $|f_{scat}|^2$ from unpolarised data.

$|B|^2$ show a strong decrease with increasing final state momentum p_f. However, if one allows for an energy variation of t_{20} or $|A|^2/|B|^2$, i.e. shown by the dashed lines in Fig. 3 and Fig. 4, the amplitudes $|A|^2$ and $|B|^2$ might show a different energy dependence, which would indicate contributions to these amplitudes different from pure final state interaction. In Fig. 5 this effect is demonstrated by the dashed lines. Although preliminary, the presented data indicate that such additional contributions to the scattering amplitudes $|A|^2$ and $|B|^2$ are only of minor relevance can not explain the surprisingly strong decrease of the scattering amplitudes close to threshold. Due to this the present data strongly support the presence of a strong $\eta -^3$He final state interaction and a pole close to the production threshold.

4. Conclusions

Data on the deuteron tensor analysing power t_{20} as function of the excess energy have been taken for the reaction $dp \to {}^3\mathrm{He}\,\eta$. The obtained data show only a small variation with the excess energy and support the presence of a strong $\eta -^3$ He final state interaction. In contrast, contributions different from the FSI were found to play only a minor role close to threshold and can not explain the observed strong energy dependence of the production amplitude. Therefore, the presented data strongly support the hypothesis of the presence of a pole close to the reaction threshold.

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