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Investigation of the $dp \rightarrow {}^3\text{He}\, X$ (X=η,$\pi^+\pi^-$) reactions at COSY-ANKE

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Abstract

Differential and total cross sections for the $dp \rightarrow {}^3\text{He}\,\eta$ reaction have been measured in a high precision, high statistics COSY–ANKE experiment near threshold using a continuous beam energy ramp up to an excess energy Q of 11.3 MeV. The very rapid rise of the total cross section to its maximum value within 0.5 MeV of threshold implies a very large $\eta\,{}^3\text{He}$ scattering length and hence the presence of a quasi–bound state extremely close to threshold. Simultaneously, data on the reaction $dp \rightarrow {}^3\text{He}\,\pi^+\pi^-$ have been measured which are investigated with respect to the still poorly understood ABC effect.

1 The reaction $dp \rightarrow {}^3\text{He}\,\eta$

The anomalous energy dependence found at low excess energies in the $\eta\,{}^3\text{He}$ system suggests that the strong $\eta\,{}^3\text{He}$ final state interaction (*fsi*) might lead to the formation of an $\eta\,{}^3\text{He}$ quasi–bound state [1] for nuclei much lighter than originally postulated [2]. However, this question is far from being settled and further high quality data are required. Therefore, the reaction $dp \rightarrow {}^3\text{He}\,\eta$ has been investigated using the ANKE spectrometer situated at an internal position of the COoler SYnchrotron COSY–Jülich [3]. During each of the beam cycles of 277 seconds, the deuteron beam energy was ramped slowly and linearly in time, from an excess energy of $Q = -5.05$ MeV to $Q = +11.33$ MeV. The produced ^{3}He nuclei 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 η meson production was subsequently identified using the missing–mass technique. The geometrical acceptance for the ^{3}He nuclei of interest was $\sim 100\%$, so that systematic uncertainties from acceptance corrections are negligible.

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The η center of mass (c.m.) momentum p_η was derived from the radius of the ^{3}He momentum locus in the c.m. frame for each of the one second time bins during the COSY ramp. It was found that the value of $Q = p_\eta^2/2m_{red}$ (m_{red} is the η^3He reduced mass) increases perfectly linear with ramp time. From this distribution the uncertainty in the determination of the mean value of the excess energy itself was derived and found to be ± 9 keV for each time bin. This method is described in more detail in [4].

The total cross sections for $dp \to {}^3\mathrm{He}\,\eta$ obtained at 195 bins in excess energy are compatible with those of SPESII [5] and COSY-11 [6], though the other data sets do not define firmly the energy dependence in the near threshold region. At ANKE it was found that the total cross section reaches its maximum within 0.5 MeV of threshold and hardly decreases for higher enegies. This is in complete contrast to phase space expectations and indicates a strong final state interaction.

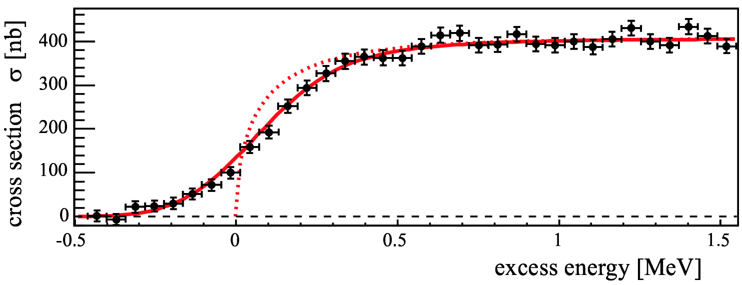

Figure 1: Total cross section data extracted in the vicinity of the threshold.

With p_d as the initial c.m. momentum the angular average of the amplitude-squared is derived from the total cross section σ_{tot} through

$$\overline{|f|^2} = \frac{p_d}{p_\eta} \cdot \frac{\sigma_{tot}}{4\pi}. \tag{1}$$

We parametrize the s-wave component f_s in the form

$$f_s = \frac{f_B}{(1 - p_\eta/p_1)(1 - p_\eta/p_2)}. \tag{2}$$

In the presence of a strongly attractive final state interaction there should be a pole of f_s where $|p_1|$ is very small, while the second singularity has no direct physical meaning.

The shape of the η production below the nominal threshold as shown in Fig. 1 is a very sensitive measure of the momentum width of the COSY beam. This resolution has to be taken into account in any phenomenological analysis [3]. The effect of the beam smearing can easily be seen in Fig. 1, where the unsmeared parameterization is shown as the dotted curve. The fit to the whole energy range up to $Q = 11\,\mathrm{MeV}$ provided

$$\begin{aligned} p_1 &= [(-5 \pm 7^{+2}_{-1}) \pm i(19 \pm 2 \pm 1)]\,\mathrm{MeV/c} \\ p_2 &= [(106 \pm 5) \pm i(76 \pm 13^{+1}_{-2})]\,\mathrm{MeV/c} \end{aligned} \tag{3}$$

and this results in a scattering length of

$$\begin{aligned} a &= -i(p_1 + p_2)/p_1 p_2 \\ &= [\pm(10.7 \pm 0.8^{+0.1}_{-0.5}) + i(1.5 \pm 2.6^{+1.0}_{-0.9})]\,\mathrm{fm}, \end{aligned} \tag{4}$$

where the first errors are statistical and the second (where given) systematic, including effects associated with the fitting range assumed.

The results show that a is dominantly real with large errors on the imaginary part. The value of $|a|$ is much larger than that found in earlier work [5,7] or in the later COSY-11 experiment [6]. This is due, in part, to the treatment of energy–smearing effects, whose need is very evident in our data with the fine energy steps near threshold.

In order to affect the cross section variation over a scale of less than 1 MeV, there must be a pole of the production amplitude in the complex plane that is typically only 1 MeV away from $Q = 0$. From our fit values we found a stable pole at $Q_0 = p_1^2/2m_{\mathrm{red}} = [(-0.30 \pm 0.15 \pm 0.04) \pm i(0.21 \pm 0.29 \pm 0.06)]\,\mathrm{MeV}$.

Additionally, differential cross sections have been extracted from the data. The observed asymmetry implies contributions of higher partial waves in the near threshold region [3]. Defining an asymmetry parameter α through $(d\sigma/d\Omega)_{c.m.} = \sigma_{tot}(1 + \alpha \cos\theta_{c.m.})/4\pi$, this is seen to become positive above $p_\eta = 40$ MeV/c ($Q = 1.7$ MeV) and increase monotonically with p_η much faster than observed at SPESII [5]. This effect could originate from a rapid variation of the phase of the near-threshold s-wave amplitude and might be connected to a possible η^3He quasi-bound state [8].

2 The reaction $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$

Simultaneously to the η production, data on the pion pair production in the reaction $dp \to {}^3\mathrm{He}\,\pi^+\pi^-$ have been recorded in order to investigate the still poorly understood ABC-effect, which shows up as a strong enhancement at low $\pi^+\pi^-$ invariant masses. The identification of this reaction channel was performed by detecting the ^{3}He nuclei in the forward detector and the π^- meson in the negative system of the ANKE spectrometer. The undetected π^+ meson was identified using the missing-mass technique.

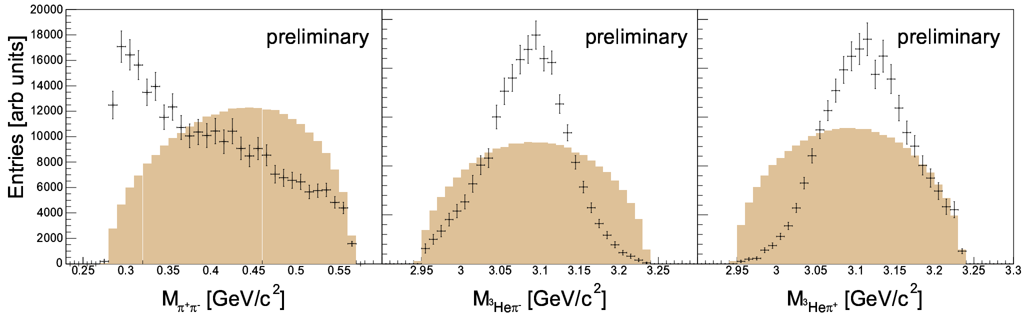

Figure 2: Invariant mass distributions of the $\pi^+\pi^-$ and ${}^3\mathrm{He}\pi^\pm$ systems

In Fig. 2 the obtained invariant mass distributions of the $\pi^+\pi^-$ and ${}^3\mathrm{He}\pi^\pm$ systems are displayed and compared with phase space Monte-Carlo simulations. The observed deviations from phase space are in good agreement with recent results from the CELSIUS/WASA experiment [9]. Currently, the data are under final evaluation and will be investigated with respect to possible production mechanism, such as the the double pion production via a double Δ resonance production ($\Delta\Delta \to N\pi N\pi$) or the excitation of an N^* resonance ($N^* \to \Delta\pi \to N\pi\pi$) [10].

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