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Investigations on the tensor analyzing power t_{20} in the reaction $\vec{d} + p \rightarrow {}^3He + \eta$

Michael Papenbrock[a] for the ANKE collaboration

Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Abstract. The reaction $dp \rightarrow {}^3\text{He}\,\eta$ has been investigated at the COSY-ANKE experiment with both an unpolarised and a vector/tensor polarised deuteron beam in an excess energy range of $Q = 0$ MeV up to $Q = 10$ MeV. The determination of the tensor analysing power t_{20} along with the unpolarised cross section allows for the investigation of the s-wave production amplitudes near threshold. The weak energy dependence of t_{20} supports a strong final state interaction of the $\eta\,{}^3\text{He}$ system which might lead to a quasi-bound η-mesic state. Furthermore, the angular dependence of the t_{20} might reveal further insight into the production amplitude.

1. Introduction

The reaction $dp \rightarrow {}^3\text{He}\,\eta$ is known for the anomalous behaviour of its total cross section near the production threshold. Detailed measurements at the COSY-ANKE spectrometer provided a rich data sample consisting of 195 total cross sections within the first 11 MeV of excess energy Q as well as differential cross sections [1]. Since the measurement was done in a single experiment, the relative systematic errors were very small, allowing a detailed analysis on the final state interaction of the η^3He system. The total cross sections are plotted in Fig. 1 against the excess energy Q. The solid line in the inlay corresponds to a fit based on a strong final state interaction, also taking into account the momentum width of the COSY deuteron beam, whereas the dashed line displays the expectation without the beam momentum smearing. As can be clearly seen, the total cross sections rise rapidly to a plateau within 0.5 MeV of excess energy Q, which contrasts the phase space expectations. A description of this excitation function was possible by assuming a pole in the production amplitude near threshold and this behaviour was attributed to a very strong final state interaction [5].

The squared production amplitude $|f|^2$ can be written as

$$\frac{d\sigma}{d\Omega} = \frac{p_\eta}{p_p}\overline{|f|^2} = \frac{p_\eta}{3p_p} I \tag{1}$$

with

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

[a] e-mail: michaelp@uni-muenster.de

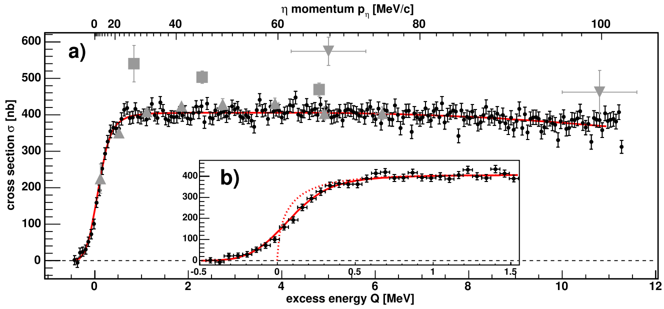

Figure 1. Total cross sections for the $dp \to {}^3\mathrm{He}\,\eta$ reaction. The data up to $Q = 11$ MeV are shown in a), whereas the near threshold region is magnified in b). The solid line shows a fit considering a strong final state interaction, taking also into account the momentum width of the COSY beam. The dashed line corresponds to the expectation without the smearing.

where A and B are the two independent $dp \to {}^3\mathrm{He}\,\eta$ s-wave amplitudes and C and D two of the five corresponding p-wave amplitudes which were retained. In order to be able to quantify possible spin-dependent non-FSI contributions to the total cross section, these amplitudes, in particular A and B close to threshold, have to be investigated. A suitable observable to this is found in the tensor analysing power t_{20}, which can be determined by measuring the reaction with a tensor polarised deuteron beam.

2. Tensor analysing powers

Very close to the production threshold the η^3He system is assumed to be in relative s-wave. In this case the production amplitude can be expressed in terms of just the two s-wave amplitudes A and B, yielding for the differential cross section

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

Access to these amplitudes A and B can be gained via the deuteron tensor analysing power t_{20}, which in turn is determined for collinear kinematics through the ratio of polarised and unpolarised differential cross sections:

$$t_{20} = \frac{2\sqrt{2}}{p_{zz}}\left(1 - \frac{\left(\frac{d\sigma}{d\Omega}(\theta)\right)_\uparrow}{\left(\frac{d\sigma}{d\Omega}(\theta)\right)_0}\right) = \sqrt{2}\left[\frac{|B|^2 - |A|^2}{|A|^2 + 2|B|^2}\right]. \tag{4}$$

Here, the beam tensor polarisation p_{zz} was determined using the reaction $dp \to \{pp\}_s n$, for which the required analysing powers are already well known [3].

The preliminary results for t_{20} are presented in Fig. 2 along with existing data from Ref. [4]. The analysing powers are compatible with existing data and they show only a negligible energy dependence. Thus, the data are very well described by a constant fit (solid line). However, in order to quantify possible spin-dependent contributions to the cross section, the data can also be fitted allowing a linear slope (dashed line). Since the squared production amplitude is known from previous unpolarised measurements [5], equation 4 can be used to extract the absolute amplitude of the individual squared amplitudes $|A|^2$ and $|B|^2$ from the measurement of t_{20}, which is shown in Fig. 3. While the squared amplitudes were determined point by point, the results based on the constant and linear fit in Fig. 2 are also displayed (solid and dashed line, respectively). It is immediately obvious that any spin-dependent contribution, which is allowed by the linear fit, is dwarfed in comparison to the overall variation of the squared amplitudes, which quickly decrease by more than a factor of five close to threshold. Therefore, these non-FSI contributions are considered to be of minor relevance in the rapid decrease of the squared

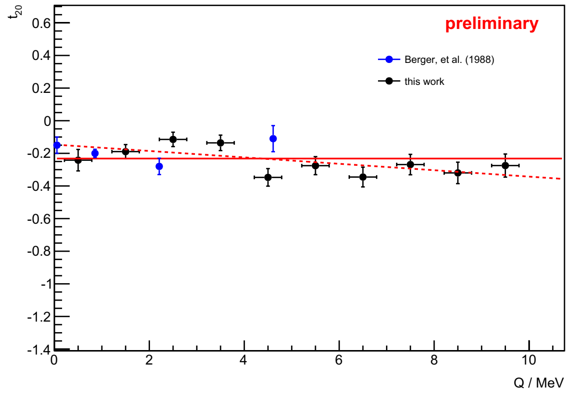

Figure 2. Energy dependence of the tensor analysing power t_{20} up to an excess energy of $Q = 10\,\mathrm{MeV}$. The solid line is based on the assumption that t_{20} is compatible with a constant whereas the dashed line allows a linear slope.

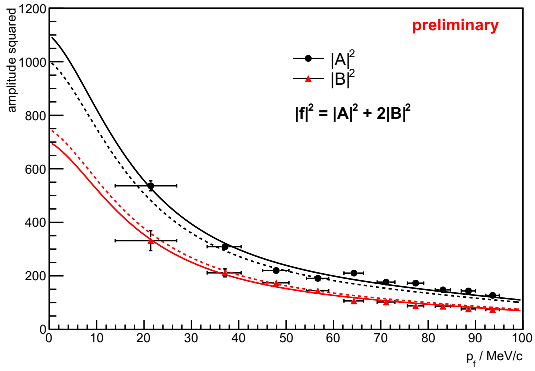

Figure 3. Energy dependence of the individual squared amplitudes $|A|^2$ (black) and $|B|^2$ (red) plotted versus the final state momentum p_f. The solid lines show the dependence on the final state momentum based on the constant fit in Fig. 2 while the dashed lines also allow for a linear slope in the energy dependence of t_{20}.

amplitudes. This behaviour supports a strong final state interaction of the η^3He system and the presence of a pole near the production threshold.

The unpolarised differential cross sections [1] demonstrated an early increase in their asymmetry in $\cos(\theta)$ for $Q < 4\,\mathrm{MeV}$, with θ being the scattering angle, which was interpreted as a rapid variation of the relative phase between the s- and p-wave and is expected from a strong final state interaction. Hence, the angular dependence on the forward/backward hemisphere of the scattered ^{3}He particles was also investigated for t_{20} and is displayed in Fig. 4. The data for either forward and backward hemisphere are plotted versus $< \cos(\theta) > p_f$. Compared to the unpolarised differential cross sections the linear fit shows only little to no asymmetry between the forward and backward hemisphere. Since t_{20} is also sensitive on the interference of the s- and p-wave, this is unexpected. However, this issue might be resolved by introducing a p-wave component in the amplitudes A and B.

3. Conclusion

The deuteron tensor analysing power t_{20} for the reaction $dp \to {}^3\mathrm{He}\,\eta$ has been determined in the excess energy range from $Q = 0\,\mathrm{MeV}$ to $Q = 10\,\mathrm{MeV}$. The data show little to no energy dependence,

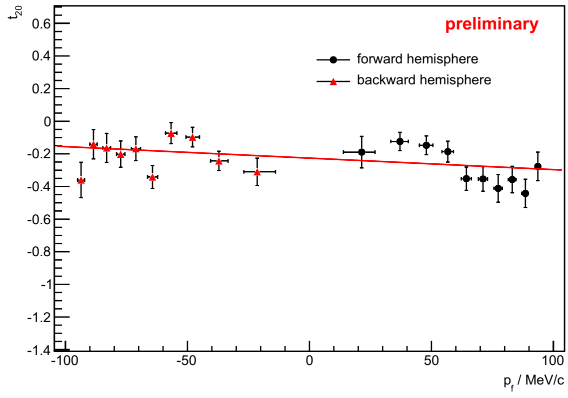

Figure 4. The variation of t_{20} plotted against $< \cos\theta >$ p_f. Also shown is a linear fit to the data.

indicating that spin-dependent non-FSI effects only contribute to the total cross section in a minor way and supporting the strong final state interaction ansatz for the η^3He system. Furthermore, the small angular dependence of t_{20} might reveal more details about the production amplitude.

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