New approach for neutrons discovers problems with the understanding of the important astrophysical reaction $^{13}C(\alpha,n)$

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The present work applies the TTIK method [1] to measurements of the excitation function of the $^{13}C(\alpha, n)$ reaction. We used the time-of-flight (TOF) technique (neutron detector time relative to the RF of the beam) for neutron energy measurements. The choice of the reaction was based on the fact that the excitation functions for the $^{13}C(\alpha, n)$ reaction have been studied at a broad range of α-particle energies and because of the importance of this reaction for the nucleosynthetic s process[2]. Additionally, our results can be compared to a very comprehensive and recent analysis of the data relevant to this reaction made by the University of Notre Dame group [3]; this reference also contains a comprehensive review of previous studies.

The experiment was performed at the DC-60 heavy-ion cyclotron in Nur-Sultan (Kazakhstan) using beam energies of 13.0 and 14.3 MeV. The cyclotron parameters were tuned to provide a beam bunch with optimal time resolution at the expense of beam intensity. The beam width was about 2 ns with ≈0.2% energy resolution at a beam intensity of a few nA. The beam parameters were controlled by monitor detectors, described below. The experimental setup is presented in Fig. 1. The cylindrically shaped scattering chamber (15.5 cm diameter and 53.0 cm length) was made of stainless steel with a wall thickness of 0.25 cm and filled with helium of 99.99% purity. The ^{13}C beam from the cyclotron entered the scattering chamber through a thin entrance window made of 1.9-μm Ti foil. Four monitor silicon detectors were mounted on a ring shaped holder inside the chamber in order to detect the ions elastically scattered from the entrance window.

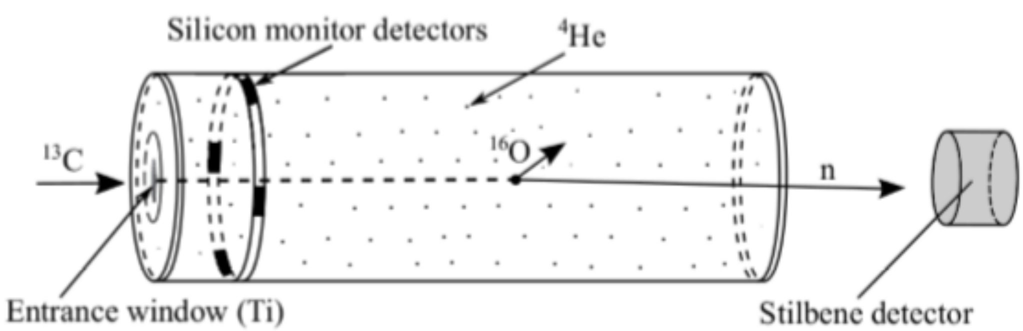

Fig. 1. Experimental layout.

The neutron detector was a stilbene crystal of cylindrical shape (8 cm diameter, 5 cm thickness) optically coupled with Photonis XP 4312/B photomultiplier.

Fig. 2 demonstrates a combined excitation function using both the 13.0 and 14.3 MeV ^{13}C measurements. The overlapping region in these measurements was ~2.73-2.87 MeV c.m. The solid line in Fig. 2 shows R-matrix calculations with the parameters of Ref. [2]. The disagreement between these calculations and our measurements is evident. Finding no obvious mistakes in either our work or that of the comprehensive work of [3], we looked to older experimental data for additional insight. The very old work by Walton et al. [4] did, in fact, provide some insight. These old excitation functions for the $^{13}C(\alpha,n)$ reaction at symmetric forward and backward angles (31° and 149°) were compared with R-matrix calculations with contemporary parameters [3]. We found that the data[4] in the forward hemisphere (31°) agree with the R matrix calculations[3]. However, in the backward hemisphere, the data [4] disagree with the calculations in a similar way as it shown in Fig.2

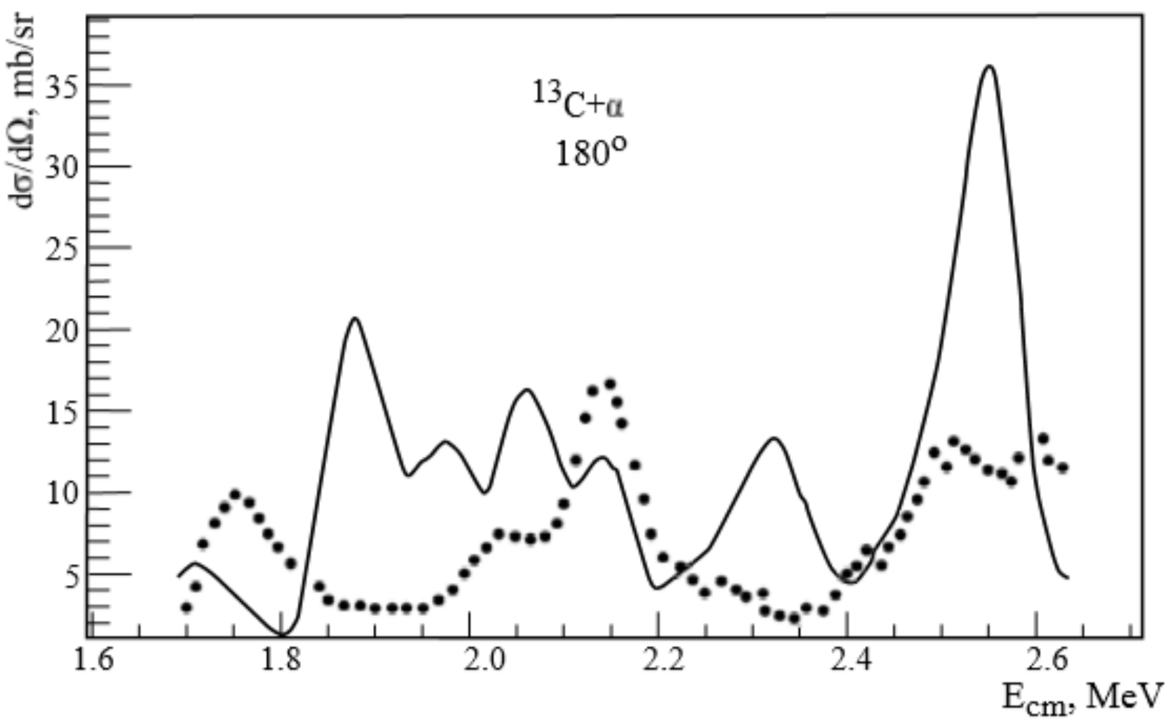

Fig. 2. The excitation function for the $^{13}C(\alpha, n)$ reaction at 180°. The bold curve is R-matrix calculations with parameters of Ref. [3].

The present measurements, planned as a test, revealed an interesting result. Evidently, the new result is related to the unusual geometry. Obtaining equivalent data with the conventional approach would require neutron measurement at angles close to 180°, a difficult measurement. The physical basis of the observed discrepancy likely resides in an unaccounted interference of one or more broad (low spin) level(s) of opposite parity. A manifestation of such levels, if they are broad, might be attributed to a background in an analysis of forward angle data.

It is not easy to predict the eventual applications of the specific TTIK approach described in the present work for the first time. (This was also the case in the original TTIK work [1].) One might imagine that the TTIK technique described here could be used to study (α,n) reactions on gas targets, many of which have not been thoroughly investigated. The simplicity of the TTIK approach is attractive, even more so when the reactions are induced by low-intensity secondary beams. In such cases, each beam particle would be tracked, removing a significant source of the ultimate center-of-mass energy uncertainty. More details of this study one can find in Ref.[5]

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