Neutron-induced triple-alpha enhancement: measuring neutron-induced reactions with TexAT

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The triple-alpha reaction, by which helium is fused to form carbon, is an important reaction mechanism to overcome the A=5, 8 bottleneck which is facilitated by the Hoyle state at 7.65 MeV. The reaction rate is determined by the radiative width, i.e. how often the Hoyle state decays to end up with carbon-12 in the ground state. As well as the sequential gamma-decay and pair-production, it was demonstrated that in certain astrophysical environments, an alternative decay path can dominate (by up to a factor of 100): that of neutron up-scattering [1]. In this situation, a low-energy neutron interacts with the excited nucleus and carries away a large amount of energy such that the nucleus can de-excite to the ground state (or the first-excited state). The cross section for this interaction is unknown due to the experimental difficulties in measuring it. To determine this cross section, the time-reversed reaction has been studied for the first time using TexAT [2] which will allow for a measurement of the enhancement of the triple-alpha rate via the effect of the neutrons.

The time-reversed reaction is that of $^{12}C(n,n_2)3\alpha$ and must be studied in the astrophysically-relevant energy regime of between the threshold at 8.3 MeV, and 10 MeV. This experiment therefore required a high-intensity, monochromatic, collimated neutron source such as that available at Ohio University [3] via the D(d,n) reaction. This well-suited neutron beam is then incident upon TexAT, filled with 50 Torr CO_2 where the charged-particle products can be measured.

This CENTAUR experiment represented a large collaboration; TAMU, LSU and WashU as well as collaborators at Ohio University, Sheffield Hallam University (UK) and the University of Birmingham (UK). The experiment was finished in August 2021 following COVID-related restrictions easing.

The analysis of this data set has been almost fully completed and a manuscript is currently in production.

The properties of the neutron beam were benchmarked by measuring a single energy with a pulsed beam to measure the neutron energy spectrum using the time-of-flight with an NE213 detector placed at 30 m from the source. The comparison between the expected neutron energy spectrum from a

GEANT4 simulation in comparison to the n-TOF spectrum is shown in Fig. 1 which shows excellent agreement.

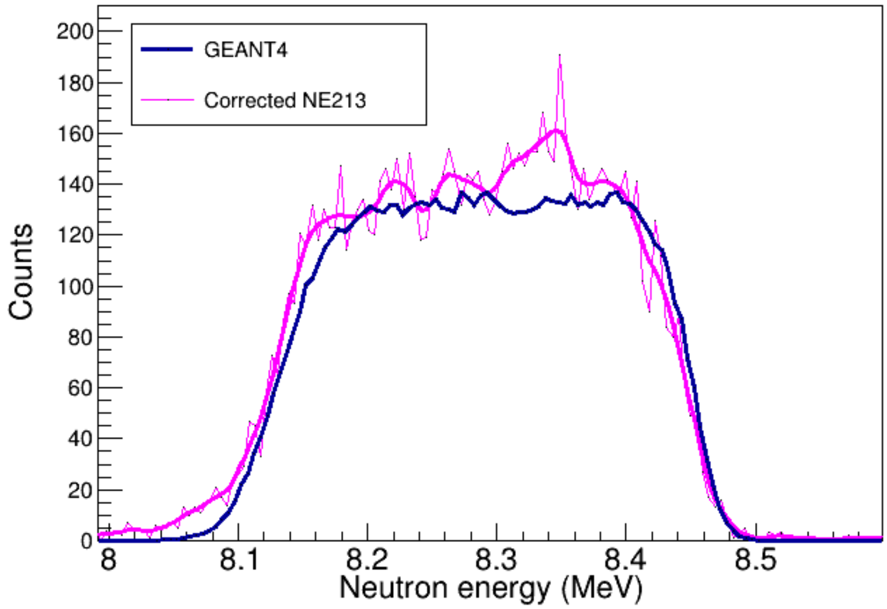

Fig. 1. n-TOF spectrum from the NE213 detector at 30 meters (magenta), in comparison to the GEANT4 simulation (blue) showing excellent agreement.

The $^{12}C(n,n_2)3\alpha$ cross section was seen to have behavior that was at odds with Hauser Feshbach predictions, instead being strongly-fed through a series of states in ^{13}C which also have large $^{12}C(n,a_0)$ widths. The preliminary cross sections are shown in Fig. 2. In addition, the cross sections for the

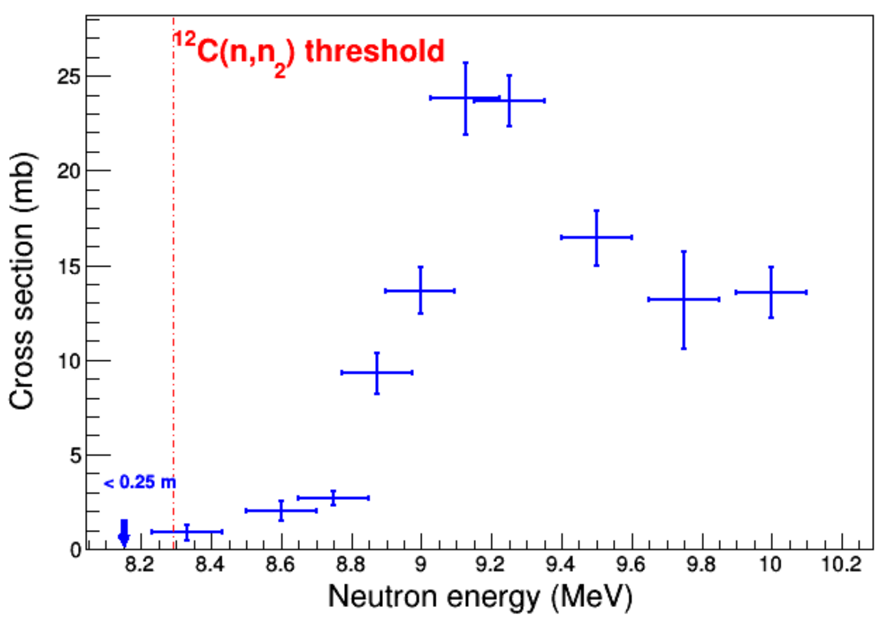

Fig. 2. Preliminary cross section for the population of the Hoyle state via the $^{12}C(n,n_2)3a$ reaction.

$^{12}C(n,a_0)$, $^{12}C(n,a_1)$, $^{16}O(n,a_0)$ and $^{16}O(n,a_1)$ reactions have also been extracted from the data which are not only important for nucleosynthesis calculations but are pivotally important for understanding gas-forming reactions in next-generation nuclear reactors.

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