The Search for Cluster Structure in $^{14}$C with the Prototype Active Target-Time Projection Chamber (pAT-TPC) *

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One of the five key questions in nuclear physics and astrophysics proposed by the Long Range Plan of NSAC (Nuclear Science Advisory Committee) in 2007 are the origin and evolution of nuclear matter and the origin of simple patterns in complex nuclei. In order to understand the entire process a big puzzle needs to be solved. In this sense, nuclear physics is of great importance in the building of a coherent picture of the production and evolution of the constituents of the Universe.

By studying how certain nuclear phenomena evolve as nuclei get more asymmetric in their proton to neutron ratio we can get a better understanding of how nucleons interact inside the nucleus. Unfortunately the stable nuclei present on Earth do not show this characteristics, so we need to produce exotic nuclei that are not stable and study them in radioactive beam facilities such as the Cyclotron Lab of Michigan State University.

Regarding the origin of simple patterns in nuclei, we know that certain light nuclei have inherent cluster structure, meaning that the protons and neutrons that form the nucleus are not completely independent but they appear in subclusters of 2 or more of them together. A very famous case is the triple-alpha structure in the Hoyle state of $^{12}$C. This nucleus has 6 protons and 6 neutrons but in this state they appear as 3 different alpha particles (2 protons and 2 neutrons) that are bound together. The discovery of this triple alpha cluster helped us understand how the $^{12}$C was produced in the universe. The fact that it is produced through a triple alpha resonance explains why this element is so abundant as compared to the neighboring nuclei. Thus, the existance of this Hoyle state might be related to the foundations of carbon-based life. Further studies of clustering in neutron-rich nuclei could also shed light on how neutrons affect alpha clustering, making $^{14}$C a logical candidate for study [1]. In this sense, we performed an experiment at the University of Notre Dame with the pAT-TPC [2] (Fig. 1 a.) to study the elastic and inelastic scattering of a 40 MeV secondary $^{10}$Be beam on a $^4$He gas active target. The pAT-TPC combines the active target and time projection chamber techniques allowing for the study of reactions induced by secondary beams with high resolution and efficiency. The $^{10}$Be+$^4$He reaction populates the excited states of $^{14}$C allowing for us to calculate the angular distribution of resonant states in this nucleus (Fig. 1 b). Theoretical predictions show the existance of cluster structures in this nucleus too, but it has not been observed in experiments before. Our results will shed light to the problem and help us better understand the production and evolution of C in the universe.

![Schematic view of the pATTC](image1.png)

![$^{14}$C excitation energy versus angle for the elastic scattering events](image2.png)

FIG. 1: a) Schematic view of the pATTC. b) $^{14}$C excitation energy versus angle for the elastic scattering events.


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