Examination of supernova nucleosynthesis with CRIB: measurement of the ^{13}N$(\alpha, p)^{16}$O reaction

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Stars with initial masses exceeding $\sim 8\ M_\odot$ end their lives in core-collapse supernovae, producing radioactive isotopes, such as ^{44}Ti and ^{56}Ni, via nuclear reactions in the ejected material. These isotopes, observed in supernova remnants, provide insights into explosion conditions. The ^{13}N(α, p)^{16}O reaction has been identified as a bottleneck in explosive nucleosynthesis, influencing the yields of ^{44}Ti, ^{56}Ni, and short-lived isotopes (^{48}V, ^{52}Mn, ^{55}Fe) detectable by future X- and γ-ray missions.[1,2]

The ^{13}N(α, p)^{16}O reaction, critical for core-collapse supernova nucleosynthesis ($T = 2-5$ GK), remains largely unexplored in the relevant energy range. Two recent studies were attempted to address this gap: one study used a (^{7}Li, t) transfer to investigate mirror states in analog ^{17}O,[3] and the other study directly measured the reaction with an active-target system at center-of-mass energies $E_{c.m.} \sim 3.3-6$ MeV.[4]

We performed a new direct measurement of ^{13}N(α, p)^{16}O reaction with the low-energy radioactive ion beam facility CRIB[5] using thick-target in inverse kinematics (TTIK) method. We produced radioactive ^{13}N beam using a primary ^{13}C^{6+} 200 particle nA beam at 6.0 MeV/nucleon (78 MeV) from the AVF cyclotron and cryogenic hydrogen target with 300-Torr H_2 gas at an effective temperature of 90 K via ^{13}C$(p,n)^{13}$N reaction in inverse kinematics. After the production target, the primary and secondary beams were separated using two electric dipoles and a velocity (Wien) filter. Close to the final focal plane, the secondary beam passed through a pair of position-sensitive Parallel-Plate Avalanche Counter (PPAC) detectors to track its position and intensity, event by event. The ^{13}N beam had an average intensity of $I = 8\ \times 10^5$ pps, which is the highest recorded, with >90% purity. Finally, the ^{13}N beam entered a helium-filled target chamber (P = 250 Torr) which had a 10 μm Havar foil window to contain the gas in the chamber. The helium gas was sufficiently thick to completely stop the secondary beam, and thereby, can scan the excitation function of ^{17}F at the center of mass energies between 1.5–6 MeV. We used five silicon telescopes to detect protons from ^{13}N(α, p)^{16}O reaction and elastically scattered α-particles. Each telescope conmprised ΔE and E layers with thicknesses of 41–300 μm and 1500 μm, respectively. The ΔE layer featured an orthogonal, double-sided layout for x- and y-position determination.

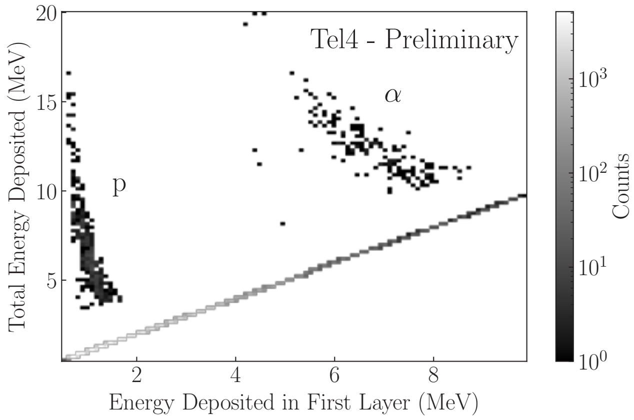

Fig. 1. ΔE-E plot from Telescope 4 ($\theta = 62°$). The two particle groups—p & α—are clearly separated.

Figure 1 shows preliminary results from the telescope at $\theta = 62°$ relative to the beam direction, clearly identifying protons from the (α, p) reaction and elastically scattered α-particles. The next steps include reconstructing reaction positions within the target chamber and subtracting background events using argon gas data. These results will improve the ^{13}N$(\alpha, p)^{16}$O reaction rate and allow us to explore its role in core-collapse supernova nucleosynthesis.

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