Decay of ^{10}C excited states above the 2p+2α threshold

R. J. Charity1,[1] K. Mercurio,[1] L. G. Sobotka,[1] J. M. Elson,[1] M. Famiano,[1]
A. Banu, C. Fu, L. Trache, and R. E. Tribble
[1]*Washington University, St. Louis, Missouri 63130*

The level structure of ^{10}C is not well known. Only the first excited state, which gamma decays, is fully characterized. All other excited states are particle unstable and above the threshold for decay into the 2p+2α channel. There are a variety of ways one can envision creating this decay channel, either through three sequential binary-decay steps or through a direct three or four-body breakup. In order to investigate these possible decay modes, an experimental study of the correlations between the 4 decay products was initiated.

Using a ^{10}B beam, ^{10}C fragments were created using the ^{10}B(p,n)^{10}C reaction. The fragments at E/A = 10.7 MeV were selected with MARS and were impinged on a ^{9}Be target. Following inelastic excitations, the decay products were detected and identified in four position-sensitive E-ΔE telescopes. The telescopes, part of the HiRA array, each consist of a 65 μm single-sided Si strip detector followed by a 1.5 mm double-sided Si strip detector.

For each detected 2p+2α event, the ^{10}C excitation energy was reconstructed from the summed kinetic energy of the detected fragments in their center-of-mass frame minus the breakup Q-value (-3.726 MeV). The distribution of this reconstructed excitation energy, shown in Fig. 1a, contains two peaks at 5.2 and 6.5 MeV. Levels at these energies are known from a number of previous studies, but their decay modes were not determined.

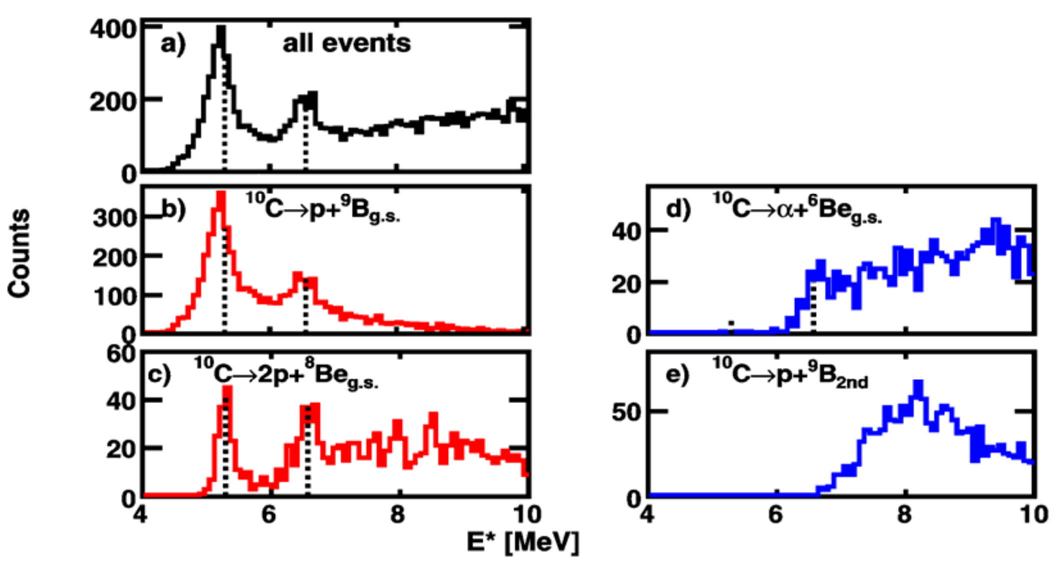

Figure 1. Distribution of reconstructed ^{10}C excitation energy for a) all 2p+2α events and with a b) $^{9}B_{gs}$, d) $^{6}Be_{gs}$, and e) ^{9}B(E*=2.35 MeV) intermediate. c) events with a $^{8}Be_{gs}$, but no $^{9}B_{gs}$ intermediate. To aid in comparing peak energies, the dash lines indicate the centroids of the peaks in c)

To search for the presence of long-lived intermediates associated with possible sequential decay processes, the correlations between the decay fragments were investigated. From the ^{8}Be excitation energy reconstructed from all α-α pairs, most of the events associated with the two peaks were found to involve ^{8}Be ground-state fragment. From the excitation energy reconstructed from *p*-α-α triplets, the ^{9}B ground-state intermediate was also identified. The ^{10}C excitation-energy distribution for events with a ^{9}B ground-state fragment is shown in Fig. 1b. The two peaks are still present and it is clear that these states have a proton decay branch that produces a ^{9}B (ground state) fragment which sequentially proton decays to ^{8}Be (ground state) and which further decays to two alpha particles.

Correlations between the fragments also indicate the presence of ^{6}Be (ground state) and ^{9}B (E*=2.35 MeV) intermediates. However, the ^{10}C excitation-energy distributions, for events containing these fragments, Figs. 1d and 1e, do not show any statistically significant peaks. One further group of events was identified, those containing ^{8}Be (ground state) intermediate, but not a ^{9}B (ground state) fragment. For these events, the ^{10}C excitation-energy distribution, shown in Fig. 1c, also contains two peaks. The lower-energy peak is shifted relative to the low-energy peak in Fig. 1b associated with sequential two-proton decay. Also the width is narrower suggesting that there are two levels in this region (E*=5.18 and 5.3 MeV) The higher-energy peaks in Figs. 1b and 1c have consistent centriods and thus these may represent two branches of a single level.

For the latter group of events, containing an ^{8}Be (ground state) but no ^{9}B (ground state) intermediate, we investigated the possibility of sequential proton decay through the wide first-excited state of ^{9}B rather than the ground state. A Monte Carlo simulation indicated, that for the 6.5 MeV state, the two protons should have similar energies in 2*p*+2α center-of-mass frame. This was not observed experimentally and furthermore the relative emission angles of the two protons (again in the 2*p*+2α center-of-mass frame) shown in Fig. 2 is asymmetric about 90 degrees. This also is inconsistent with sequential emission of the two protons and thus implies the emissions of these protons are more direct and correlated, i.e., both protons are emitted from the same side of the ^{10}C fragment.

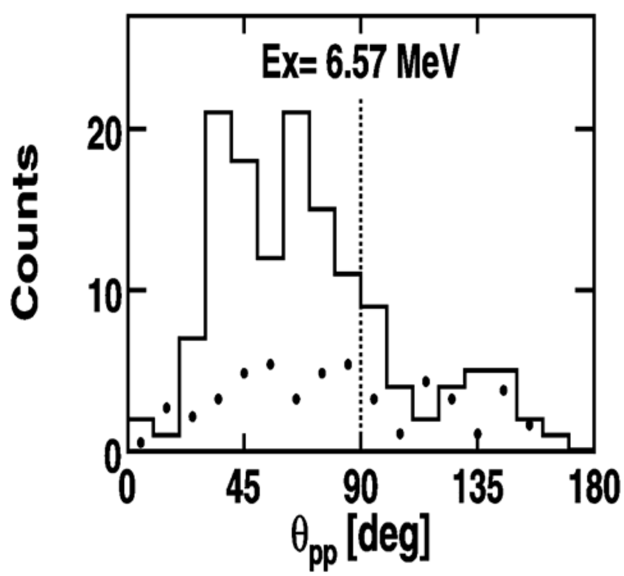

Figure 2. Distribution of relative angle between the two protons in the 2*p*+2α center-of-mass frame for events in the 6.57 MeV level which do not decay through the ^{9}B ground state. The data points are an estimate of the background.

In summary, we have studied ^{10}C levels at 5.18, 5.3, and 6.5 MeV which decay to the $2p+2\alpha$ exit channel. The 6.5 MeV level can decay by two branches. These include a sequential two-proton emission passing through the ^{9}B (ground state) and then the ^{8}Be (ground state) intermediates. In addition we identified a branch where the two protons are prompted emitted from the same side of the ^{10}C fragment, leaving an ^{8}Be (ground state) residue. The 5.18 MeV level also decays via sequential two-proton emission, while the decay of the 5.3 MeV state is still not clear.