Clustering in ^{10}Be

S. Upadhyayula, G.V. Rogachev, E. Koshchiy, E. Uberseder, V.Z. Goldberg, J. Hooker,
H, Jayatissa, C. Hunt, and B.T. Roeder

There is a strong experimental evidence that some states in ^{10}Be exhibit molecular-like α:2n:α configuration [1-3]. Theoretically these exotic structures can be explored microscopically in the antisymmetrized molecular dynamics plus Hartree-Fock approach [4] or in Molecular Orbital model [5]. Based on these theoretical studies it appears that the 6.179 MeV 0^+ state in ^{10}Be has a pronounced α:2n:α configuration with an α-α inter-distance of 3.55 fm. This is 1.8 times more than the corresponding value for the ^{10}Be ground state. The 2^+ at 7.542 MeV in ^{10}Be is believed to be the next member of this rotational band [6]. The state at 10.2 MeV was identified as a 4^+ member [1, 3]. The algebraic model [7] predicts that a 6^+ state at around 13 MeV is the next member of this band. It would be of paramount importance to identify this 6^+ state experimentally and to conclusively establish the α:2n:α rotational band. This would become the most striking and well established case of molecular-like configurations in nuclei and an important step towards better understanding of clustering phenomena in atomic nuclei.

We performed an experiment to search for the 6^+ state in ^{10}Be at around 13 MeV excitation energy in the excitation function for ^{6}He+α scattering. The Cyclotron Institute Momentum Achromat Recoil Separator (MARS) facility was used to produce a secondary ^{6}He beam at 7.0 MeV/u from the production reaction of ^{7}Li(d,^{3}He). The sketch of the experimental setup is shown in Fig. 1. Modified thick target inverse kinematics approach [8] was used to measure the ^{6}He+α excitation function. Details of the

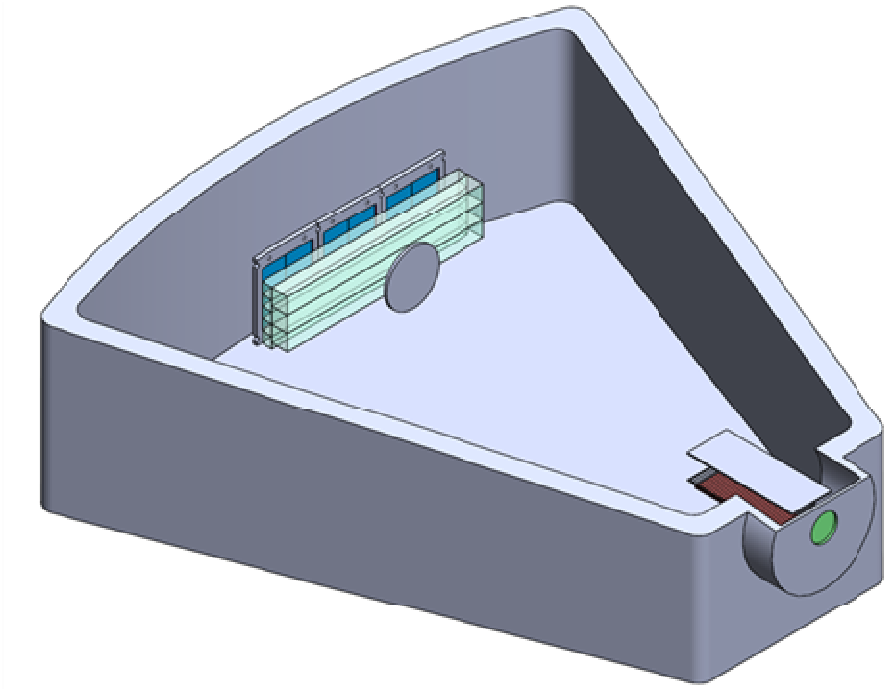

FIG. 1. Sketch of the experimental setup to measure the ^{6}He+α excitation function of ^{10}Be excitation energy.

experimental setup can be found in [9]. The energy of the ^{6}He beam was reduced down to 22 MeV by the thick scintillator foil located in front of the scattering chamber filled with Helium+CO_2 96:4 gas mixture at pressure of 1700 Torr.

We have observed a distinct peak of α particles that could be a result of resonance in the ^{6}He+α excitation function which we were looking for. This peak in the α spectrum was verified to be associated with the incoming ^{6}He beam particles and not the other secondary beam components, the dominant of which is tritium. Given the nature of the set up, we expect the highest energy α particles (between 12 and 15 MeV) to correspond to pure elastic scattering. At lower energies, admixtures from α particles due to inelastic scattering and breakup are possible. Based on the shape of the spectrum compared to Monte Carlo simulations (Fig. 2), the experimental yield and angular dependence of the cross section, we can conclude that the α spectrum is dominated by the breakup of ^{6}He into α+2n at energies below 8 MeV.

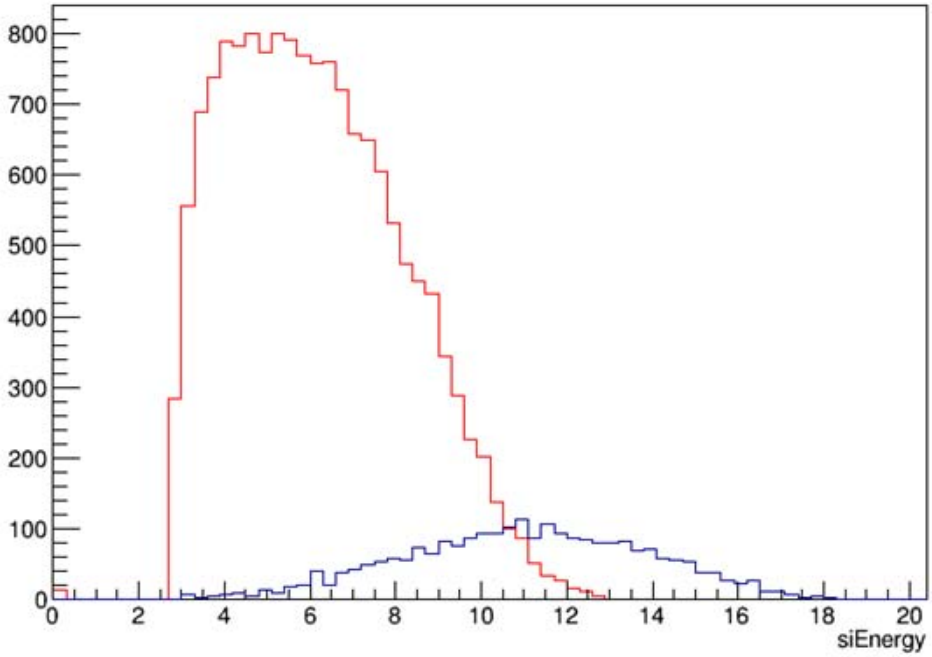

FIG. 2. Monte Carlo simulation of α particles spectrum due to breakup of ^{6}He. The (red) curve at lower energy shows α particles from ^{6}He decay. The (blue) curve at higher energy shows α particles due to elastic scattering.

For analysis purposes, we have divided the three different angles in our set up into regions. The detector at the forward angles correspond to Region 1. The other two angles (170° and 162° in the center of mass frame) correspond to Region 2 and Region 3 respectively. The peak in the α spectrum due to the hypothetical 6^{+} state at 13.5 MeV [10,11,12] would appear in the vicinity of 8 MeV in the Lab. frame of reference in Region 2 and 6.5 MeV in Region 3 (Fig. 3). There is no indication for a resonance-like structure in our spectrum at that energy at any angle. Since we can't conclusively claim the origins of the α particles in the entire spectrum, we were not able to extract a clean excitation function for ^{6}He+α

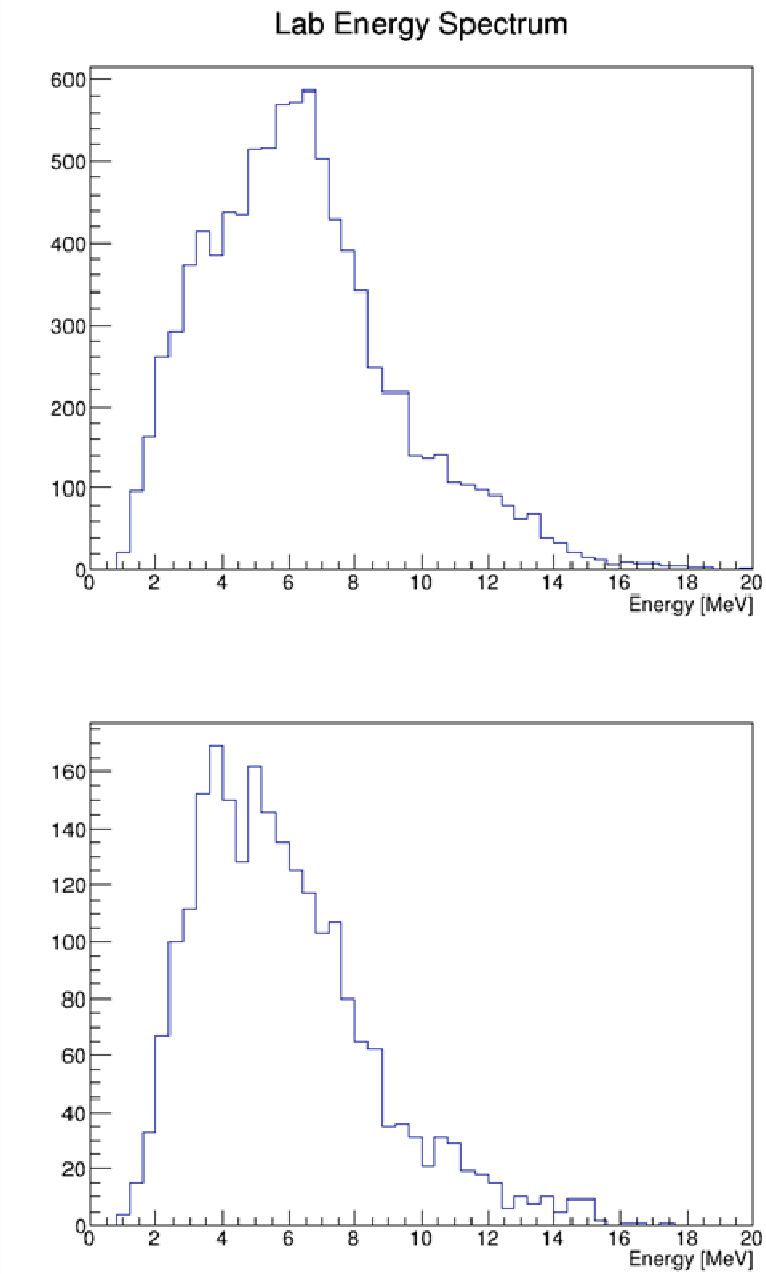

FIG. 3. Spectrum of α particles measured by the off-center Si detectors. The peak at 7 MeV is a result of ^{6}He decay into α + 2n (see text for details).

elastic scattering. However, based on the number of ^{6}He ions accumulated during the run and using 6^{+} resonance cross section calculated by AZURE2 R-Matrix software package with R-matrix parameters taken from [12], the effect of the hypothetical cluster 6^{+} state can be evaluated. The blue histogram in Fig. 4 demonstrates the expected spectrum of α-particles, compared to the one observed experimentally. There

is no indication of the 6^+ state in both Region 2 and Region 3. In fact, there is no indication for any resonance structures in the excitation function for ^{6}He+α, consistent with conclusions of Ref. [3].

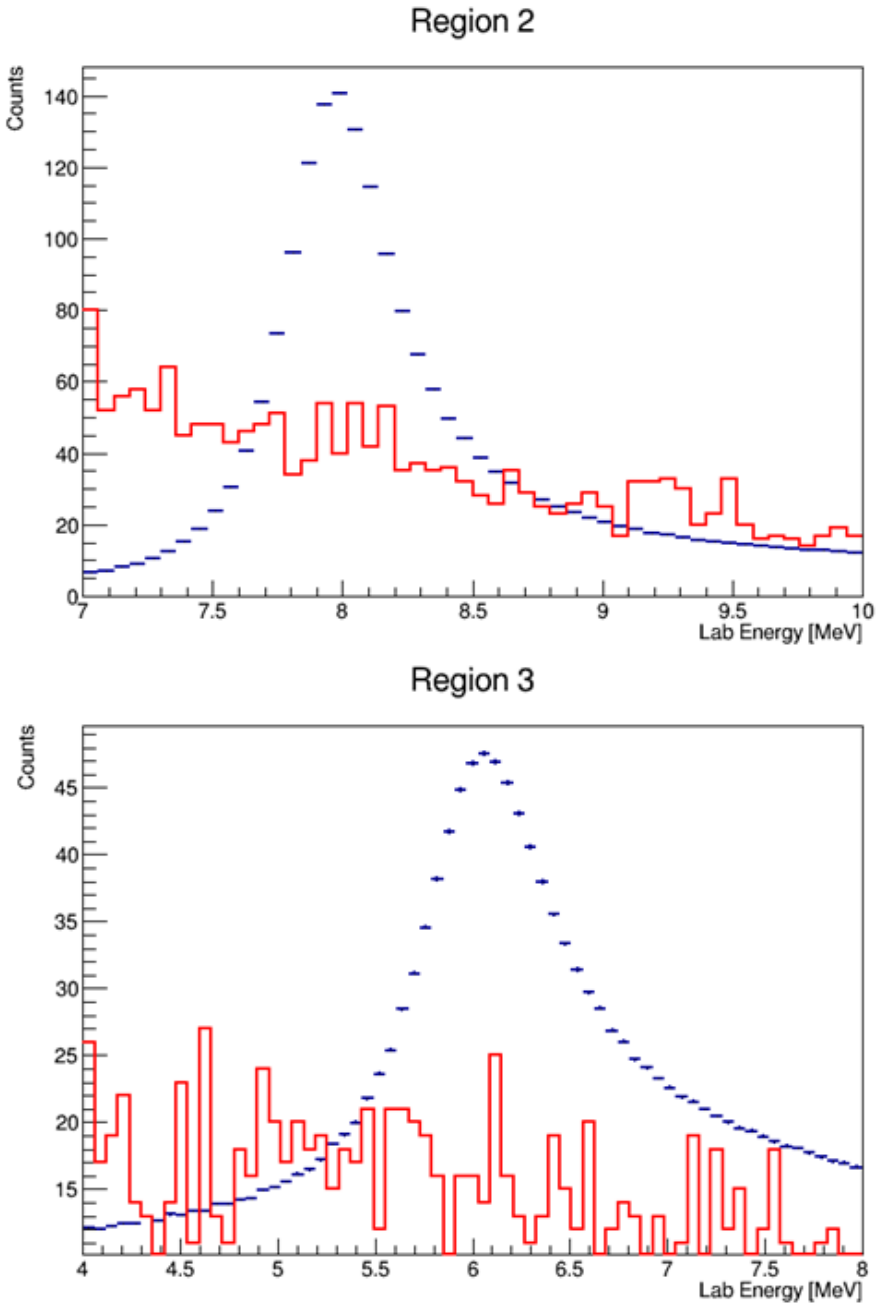

FIG. 4. Blue curve represents the calculated cross section from AZURE2 converted to counts. Red is the alpha spectrum for the respective regions.

In summary, we have performed a search for the lowest 6^+ state in ^{10}Be, which was assumed to be the next member of the molecular α:2n:α rotational band, in the excitation function for ^{6}He+α. No evidence for this state have been observed in the energy range between 11 and 15 MeV (it was expected

at 13 MeV). Either the states does not exist, or it has small coupling to the ^{6}He(g.s.)+α exit channel (small ^{6}He(g.s.)+α dimensionless reduced width). This experimental information provides important constraints on the theoretical models describing clustering in ^{10}Be.

[1] M. Freer *et al.*, Phys. Rev. Lett. **96**, 042501 (2006).

[2] M. Milin *et al.*, Phys. At. Nucl. **69**, 1360 (2006).

[3] D. Suzuki *et al*., Phys. Rev. C **87**, 054301 (2013).

[4] A. Doté, H. Horiuchi, and Y. Kanada-Enýo, Phys. Rev. C **56**, 1844 (1997).

[5] N. Itagaki and S. Okabe, Phys. Rev. C **61**, 044306 (2000).

[6] A.N. Kuchera *et al.*, Phys. Rev. C **88**, 054615 (2011).

[7] R. Wolsky *et al.*, Phys. At. Nucl. **73**, 1405 (2010).

[8] K. Artemov *et al.*, Sov. J. Nucl. Phys. **52** 408 (1990).

[9] S. Upadhyayula *et al.*, Progress in Research, Cyclotron Institute, Texas A&M University (2016-2017) p. I-54.

[10] D. Dell'Aquila *et al.*, Phys. Rev. C **93** 024611 (2016).

[11] E. Koshchiy *et al.*, Nucl. Instrum. Methods Phys. Res. **A870**, 1 (2017).

[12] A.N. Kuchera, Ph.D. Thesis, Florida State University, 2013.