The search for toroidal high-spin isomers in $^{28}Si + ^{12}C$ at 35 MeV/u using FAUST

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While ground state stable nuclei typically exhibit spherical geometries, given excitation energy and/or angular momentum, they may form $^{4}He(\alpha)$-particle clusters within their bulk and undergo deformation [1,2]. It is predicted that such clustering may promote the production of angular momentum stabilized toroidal nuclei due to local energy minima in the single particle potential [3,4]. An experiment performed on the NIMROD detector array observed evidence of very high excitation states in the same range as predicted toroidal high-spin isomer states in the 7-α disassembly of ^{28}Si in collisions of $^{28}Si + ^{12}C$ at 35 MeV/u [5]. This evidence prompted the recent repeat measurement with improved angular resolution and statistics using the FAUST array. The present experiment measured 93,742 events containing 7 α-particles, a more than order of magnitude improvement over the 6,467 measured in the NIMROD experiment.

Understanding the process of 7-α disassembly, whether by sequential decay through intermediates, or by simultaneous democratic breakup, is of considerable interest. One way to probe the time-evolution of nuclear collisions is to observe states of parent nuclei in the relative energy distributions of the decay products [6]. The ground state and many of the excited states of ^{8}Be decay into 2 α-particles. The decay energy is dictated by the state energy and Q-value for the decay, while the width in the decay energy is dictated by the lifetime. The relative energy between every 2 α-particle pairing in 7-α events is shown in Fig. 1(a(I)). The peak in the relative energy associated with ^{8}Be ground state decay centered at 0.09 MeV has very little background due to uncorrelated α-particles, allowing for an event-by-event determination of the presence of this intermediate. A similar treatment can be performed for every 3-α combination to observe α-decaying ^{12}C excited state intermediates as shown in blue in Fig 1(a(II)). While the 0+ Hoyle state centered at 0.38 MeV has very little background, allowing for event-by-event determination, the 3- excited state centered at 2.35 MeV has roughly 75% uncorrelated background. The 0+ and 3- excited states predominantly decay via α + ^{8}Be ground state. By only calculating the 3-α relative energy containing 2-α pairings that have a relative energy consistent with ^{8}Be ground state (red shaded region in Fig.1(a(I))), the background for the 3- state is reduced by roughly 40%. Relative energy gates around the 0+ (blue shaded region) and 3- (green shaded region) states were made to further characterize the intermediates present. The yields and excitation energy distributions for the intermediate decay pathways consisting of these three states for 7-α events are shown in Fig. 1(b). Roughly 32% of 7-α events contain at least one of these intermediates. For this analysis, the requirement of little background limits the ability to gate on the many higher-lying excited states, however yields associated with them could be obtained through mixed-event subtraction.

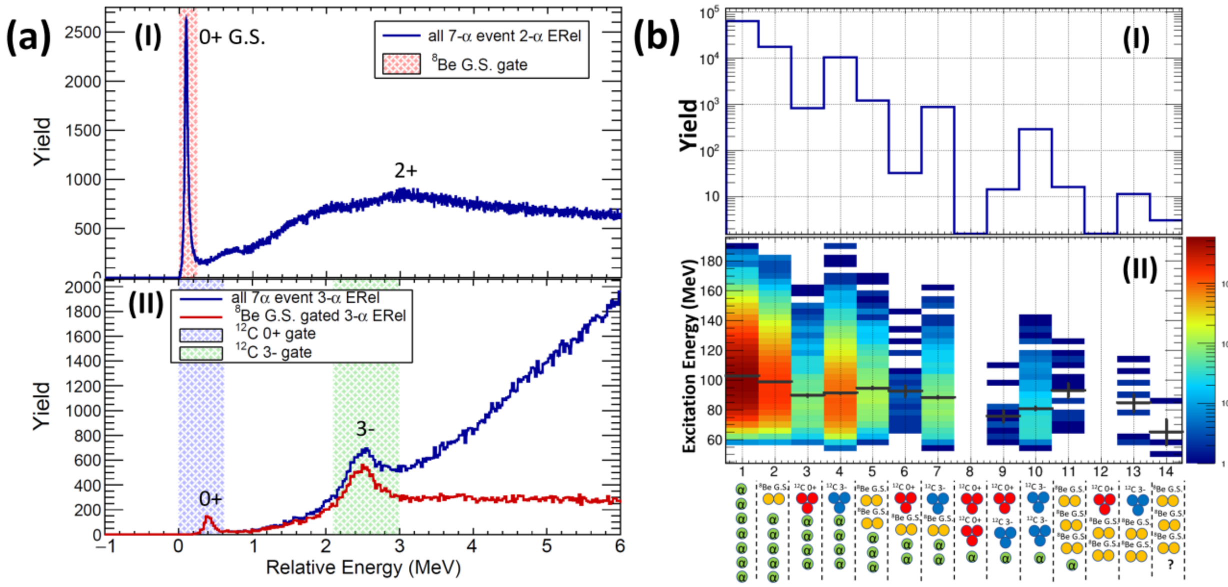

Fig. 1. 2,3-α particle relative energy distributions in 7-α events and the categorization of 7-α events based on intermediate decay pathways. (a(I)) Yield as a function of 2-α relative energy in MeV. The ^{8}Be ground state gate is shown by the red shaded region. (a(II)) Yield as a function of 3-α relative energy in MeV. Distribution for all 3-α pairings (blue line), and when gating on ^{8}Be ground state (red line). 0+ Hoyle state gate is shown by the blue shaded region, and 3- excited state gate is shown by the green shaded region. (b(I)) Yield as a function of intermediate decay pathway. (b(I)) Excitation energy in MeV as a function of intermediate decay pathway.

Evidence of toroidal high-spin isomer states in the NIMROD experiment emerged when studying the excitation energy distribution after mixed-event subtraction for 7-α events. Event mixing is performed

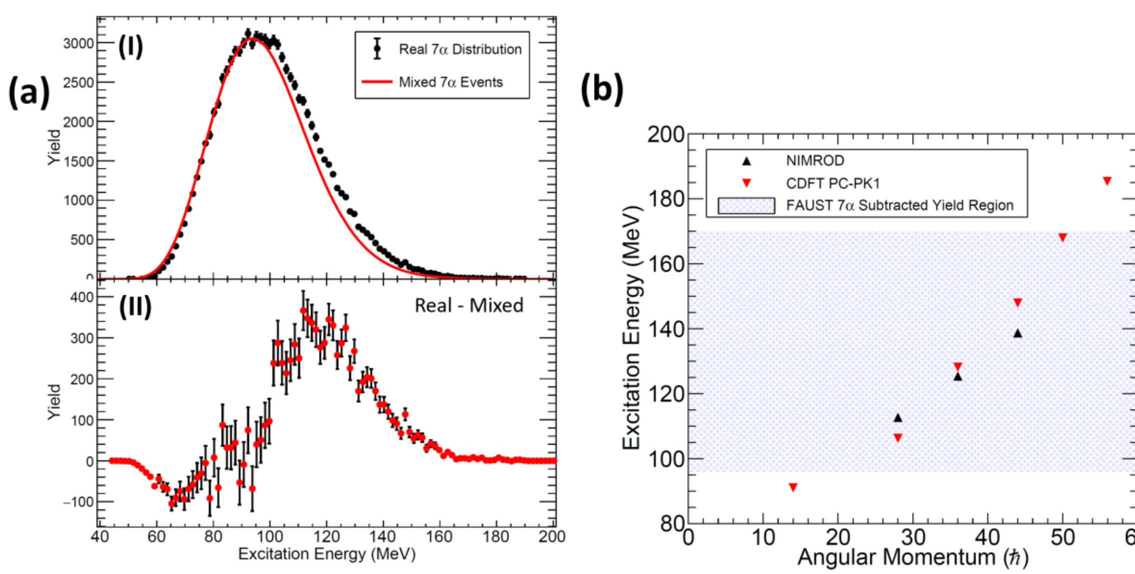

Fig. 2. 7-α excitation energy distribution and subtraction to observe correlated yield with comparison to NIMROD and CDFT results. (a(I)) Real experimental 7-α excitation energy (MeV) distribution is shown in black. Mixed event distribution normalized to real between 75 – 95 MeV is shown in red. (a(II)) Real – mixed excitation energy distribution. (b) Mean excitation energy (MeV) as a function of angular momentum (ħ) as predicted by CDFT calculations (red triangles) and claimed experimentally by the NIMROD experiment (black triangles) [4,5]. The region of correlated yield in the present study is shown by the blue shaded region.

by repeatedly taking 7 α-particles from different events and calculating the excitation energy to account for background associated with 7-α phase space. The real (black) and mixed event (red) distribution for the current study are shown in Fig. 2(a(I)). Mixed events ignore coulomb interactions, causing excess yield at low excitation energy. Due to this, the mixed events are normalized to the real distribution above 75 MeV and below 95 MeV (as predicted states begin at roughly 100 MeV). The subtracted distribution shows yield in a region consistent with the NIMROD results as shown in Fig. 2(a(II)). The region of correlated yield in the current study is compared to the excitation energy and predicted angular momentum for states observed in the NIMROD experiment and calculated using CDFT in Fig. 2(b) [4,5]. Work is ongoing to ensure that the extraction of possible state properties from this distribution is robust.

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