Exploring exotic α-like emission from α conjugate nuclei collisions with the NIMROD-ISiS array

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J. A. Wheeler had many pioneering ideas. In the 1950s He suggested that the nuclear liquid can assume toroidal shapes under certain conditions, such as excessive charge, excessive angular momentum and shell effects [1]. Early work of C. Y. Wong predicted there was a region of toroidal ground state nuclei near A~330 and Z~ 130 due to the large Coulomb energy [2]. Then Wong extended these investigations to light nuclear systems and predicted that, given sufficient angular momentum, toroidal configurations were also possible for high spin light nuclei [3]. Most recently, various sophisticated Hartree-Fock methods were used to re-examine the possibility of toroidal configurations in light nuclei [4]. From these theoretical studies, we learn that the excitation energy increases with the increase of nuclear quadrupole moment. Spin zero toroids may appear above a threshold excitation energy and potential minima exist for specific higher angular momenta due to internal shell effects.

For toroidal configurations in the heavy region, one can perhaps detect the fission fragments to check the fission fragmentation configuration and see whether there are toroidal potential minima. For light toroidal isomers with large spin and excitation energy investigation of the fragmentation pattern is more difficult.

Macroscopic tori fragment as a result of the development of Plateau-Rayleigh instabilities [5]. This decay mode is dominated by symmetric fragmentations into pieces with equal size. Nuclear toroids might also manifest Plateau-Rayleigh instabilities. However, the nuclear torus is more complicated compared to the macroscopic torus due to the following factors: 1) temperature dependent viscosity of the disassembling nucleus, 2) the existence of Coulomb forces, and 3)shell effects and variations in the fragment binding energies. In addition, the subsequent de-excitations, will smear the signature of the Plateau-Rayleigh instability. Fortunately, α particles can be regarded as quite inert units compared with it's neighbors and quartetting is dominant over deuteron formation at low density and moderate temperature. An experimental exploration with special attention and methodology into observing fragmentation into α particles or α conjugate nuclei offers some possibilities of observing toroidal de-excitations.

A series of experiments were carried out at the Texas A&M University Cyclotron Institute with ^{40}Ca and ^{28}Si beams at 15, 25, 35 MeV/u, provided by the K500 superconducting cyclotron, incident on C, Si, Ca and Ta targets [6], respectively. The reaction products were detected using the 4π array, NIMROD-ISiS (Neutron Ion Multi detector for Reaction Oriented Dynamics with the Indiana Silicon Sphere). The preliminary analysis of the raw data was accomplished by C. Bottosso, E-J Kim and K. Schmidt et al. [6]. Recently, some interesting results regarding α-conjugate neck structures have been obtained for ^{40}Ca+^{40}Ca [7]. In this report, We focus on α-like cluster decay from ^{28}Si+ C@35MeV/u. Binary configurations of excited projectile-like and target-like nuclei dominate in this energy range. Similar results are observed for ^{28}Si+Si and ^{28}Si+Ta, showing that the target effect may be negligible for our exit channel choices. However, the statistics for the ^{28}Si+Ta reaction is much lower than for the other two systems.

For the ^{28}Si+^{12}C reaction, a total of 17 million events were recorded and a significant proportion of events have significant α-conjugate mass emission. The definitions of α-like mass and α-like multiplicity can be found in ref. [8]. There are 7 α-like decay channels for mass 28. For the 7 α exit channel, more than 10 thousand events were obtained. The α-like event composition is shown by Fig. 1.

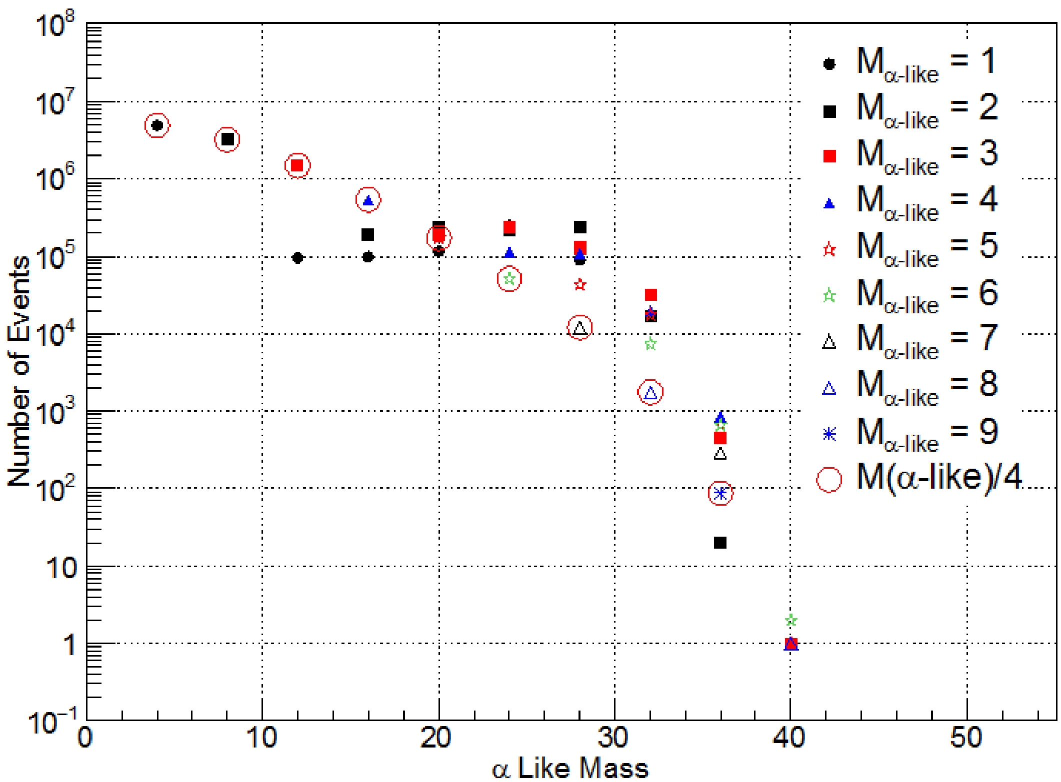

FIG. 1. The α-like event composition from ^{28}Si+^{12}C @ 35MeV/u.

What is the source of these α-like fragments? There is a possibility that these α-like fragments come from some exotic states, such as rod, toroid or disk shapes, or from Bose Einstein condensation.

A hierarchy effect is seen when heavier fragments have larger parallel velocity than the lighter fragments. A hierarchy effect is seen for these α decay channels, indicating lack of complete equilibrium of all degrees of freedom of the α-like emission source [7]. The parallel velocity of α-like fragments of the 7 α-conjugate exit channels from ^{28}Si is shown in Fig. 2.

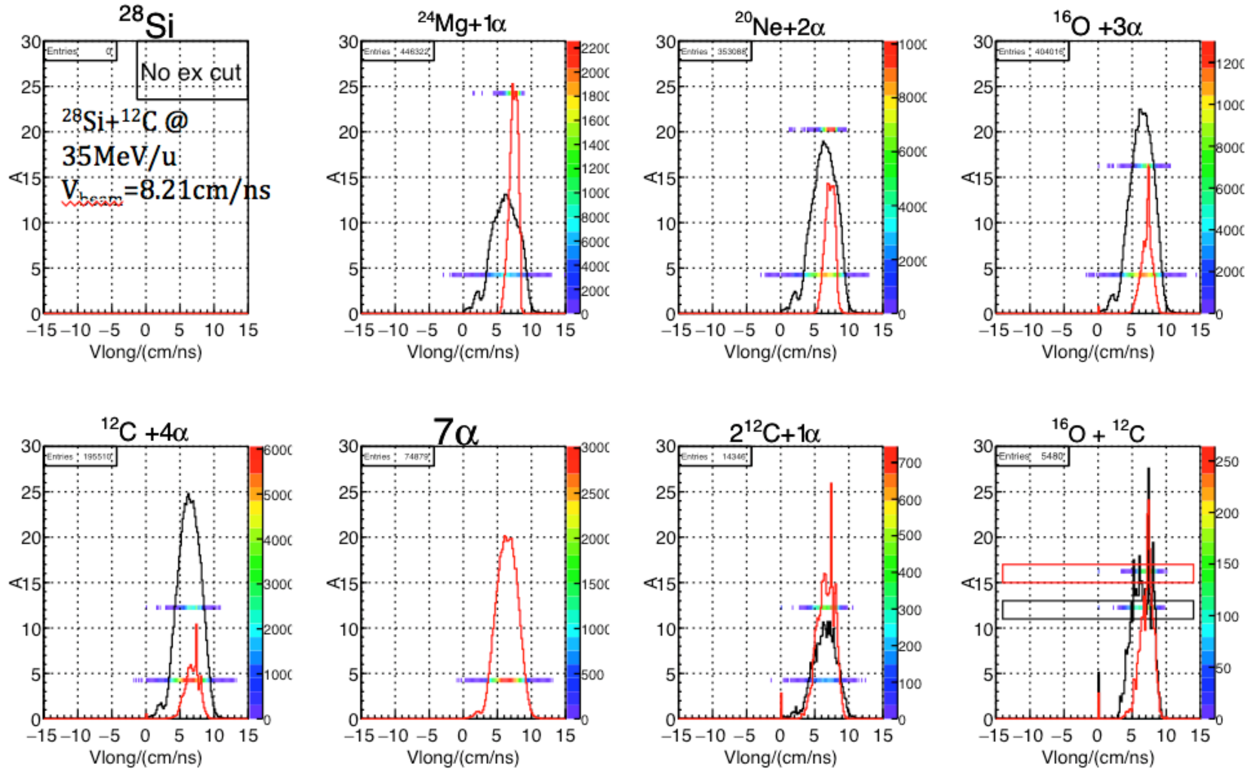

FIG. 2. The parallel velocity of α-like fragments of 7 interesting exit channels from ^{28}Si+^{12}C @ 35MeV/u.

The left panel of Fig. 3 shows that most of the exit channels are far from equilibrium. The right panel shows that the most interesting 7α decay channel has the largest absolute value of Ex_{peak} /Q, which supports the strong dynamical emission of the 7 αs.

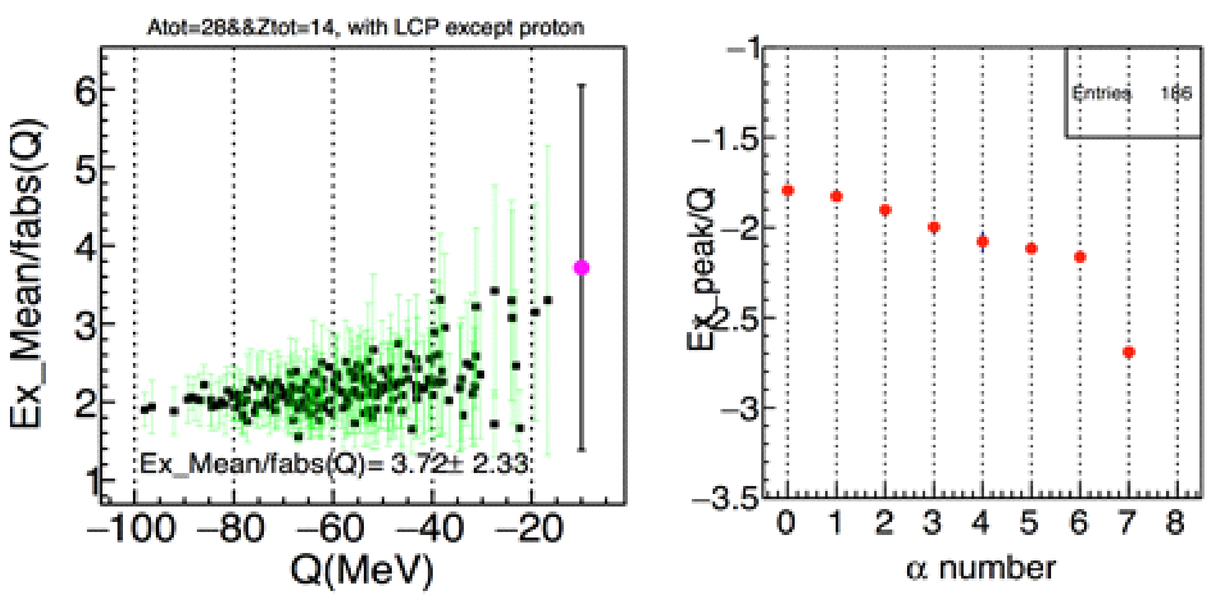

FIG. 3. Left panel: the mean value of excitation energy over absolute value of reaction Q as a function of Q value for all the exit channels satisfying the windows shown in the panel. Right panel: the peak value of excitation energy divided by reaction Q value as a function of number of α particles for the 7 α-like decay channels of ^{28}Si.

Antisymmetrized molecular dynamics (AMD) simulations shown by Fig. 4 help us to confirm that most nucleons in α-like fragments come from the projectile , (colors show the parallel velocity). Further comparison of the results for interesting exit channels such as 7α channel with those of AMD-3.4+Gemini, AMD-New(with cluster correlation) + Gemini and HIPSE + Gemini simulations are in progress.

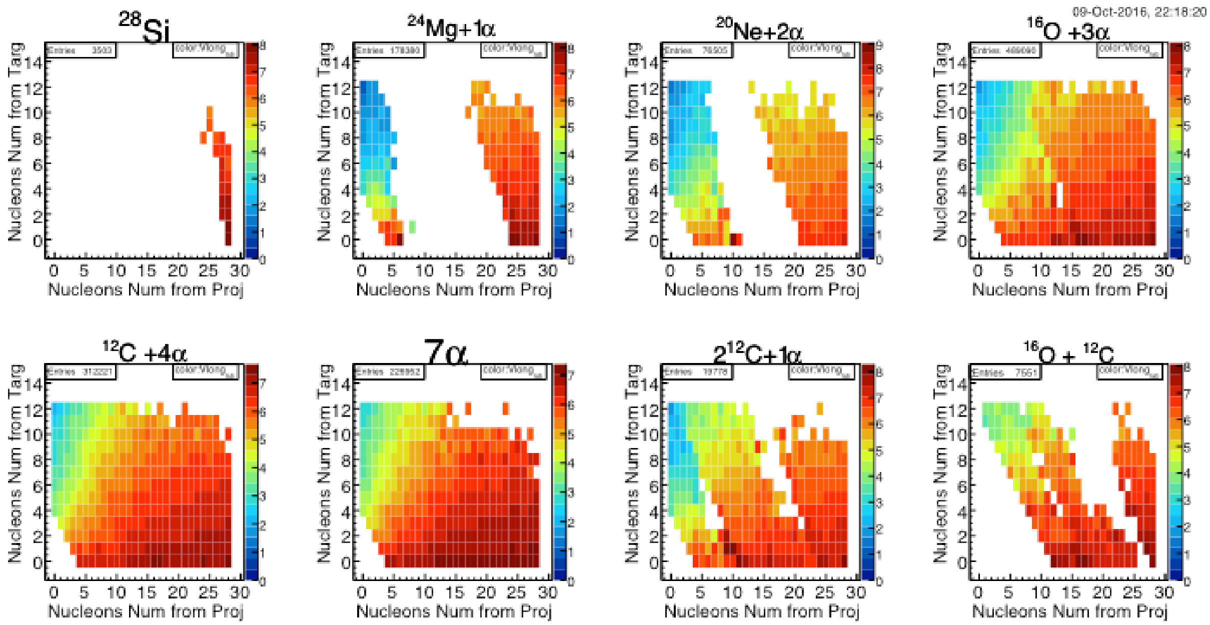

FIG. 4. Nucleon number from target v.s. nucleon number from projectile for α-like channels of ^{28}Si in antisymmetrized molecular dynamics (AMD) calculations.

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