Searching for toroidal high spin isomer from resonance decay of ^{28}Si

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Toroidal nuclei were proposed by J. A. Wheeler in 1950s [1]. Then C. W. Wong explored heavy nuclei and light toroidal nuclei and found that large Coulomb energies in heavy mass nuclei and shell effects with sufficiently large angular momentum in light nuclei favor toroidal exotic structure [2-4]. Most recently, various sophisticated Hartree-Fock microscopic methods address this question of light toroidal nuclei [5-7].

Searches for the experimental signal of toroidal high spin isomers (THSI) in collisions of α conjugate nuclei with the NIMROD-ISiS array are still in progress. Partial data analysis progress of the experiments can be found in ref [8][9]. Here we focus on ^{28}Si+^{12}C @35MeV/nucleon since it shows interesting indications and good statistics for possible population and decay of THSI in ^{28}Si*.

It is well verified that the decay of macroscopic tori is dominated by symmetric fragmentations as a result of the development of Plateau-Rayleigh instabilities [10][11][12]. The number of fragments is of the order of the aspect ratio for larger aspect ratio toroids. Nuclear toroid decays might also manifest Plateau-Rayleigh instabilities. However, more factors such as temperature dependent viscosity, Coulomb force and shell effects can largely modify the Plateau-Rayleigh instability. It should be noted that in the Staszczak-Wong, Ichikawa and Meng calculations the minor radius of the toroid is ~1.5fm, essentially the same as the radius of a free α.partice. Ten α in a ring is used as an initial configuration in Ichikawa's cranked Hartree-Fock calculation. Approximately 2/3 of the nuclear saturation density ρ_0 is obtained for the toroidal rings in these calculations. It's already known from theory that quartetting prevails over pairing at $\rho<\rho_0$ /5 [13] for symmetric nuclear matter The TAMU data shows evidence that lots of clusters such as α are produced in low densities and moderate temperatures during the heavy-ion collisions at intermediate energy[14]. In addition, α particles can be regarded as quite inert units due to a large binding energy and very high first excitation energy level. Therefore α particles and α conjugate nuclei can offer some possibilities of observing toroidal de-excitations.For ^{28}Si+^{12}C reaction at 35MeV/nucleon, about 3.19×10^5 events with α-like fragment masses summing to 28 were recorded. Among them, about 8200 events are 7α decay events. Fig 1 shows the excitation energy of 7α events. There are three prominent peaks located around 114MeV, 126MeV and 138MeV after the uncorrelated spectrum subtraction. The uncorrelated background is determined in two ways: one is the standard mixed event method using 7α correlated data and the other is 7α excitation spectrum of an AMD+GEMINI simulation. If the 138MeV state corresponds to the predicted 143.18MeV toroidal state by A. Staszczak and C.Y. Wong [5], its angular momentum would be $44\hbar$. Cranking relativistic density functional calculations [15] predict three toroidal minima in potential energy curves at angular momenta $28\hbar$, $36\hbar$ and $44\hbar$. The associated energies of the three states are within the range suggested by the data although two different interaction parameter sets give slightly different excitation energies.

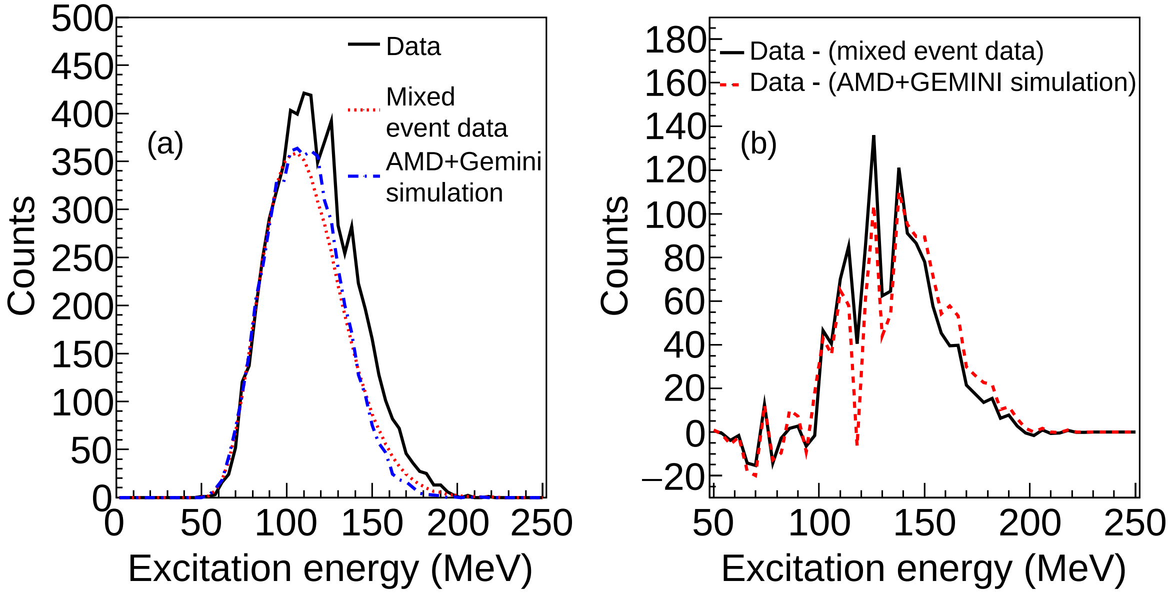

FIG. 1. Excitation function of 7α events, panel (a): experimental correlated spectrum, uncorrelated spectrum derived from event mixing and AMD-Gemini simulation are shown by the solid line, the dashed line, and the dashed and dotted line, respectively. Panel (b): The differences between the experimental spectrum and the other two are shown.

A shape analysis technique [16,17] is used to diagnose the shape of 7α events in momentum space. If the primary fragments are excited or the 7α emission is sequential, the de-excitation process could significantly modify the initial momentum space distribution. GEMINI is used as after burner to simulate the statistical two body decay. The AMD+GEMINI filtered results are similar to the data shown in Fig 2, where most of the events are not in the disk region. The freeze-out momentum distribution @300fm/c predicted by AMD is much more rod to disk like than that observed after de-excitation and filtering. The comparison of data with simulation suggests that 28Si* initially breaks up into larger excited fragments followed by α de-excitation.

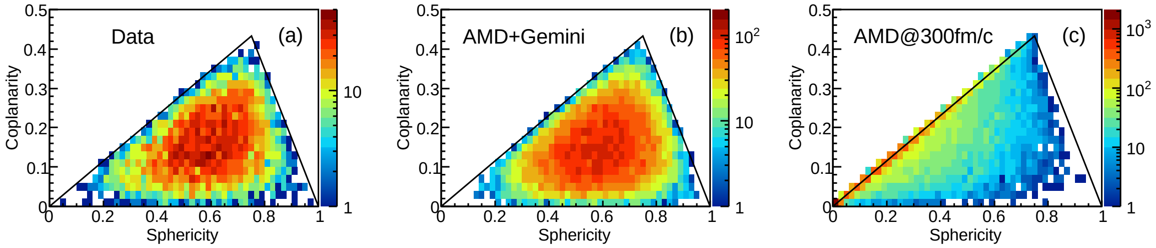

FIG. 2. Shape analysis of 7α exit channels in the de-excitation of 28Si in the 35 MeV/nucleon 28Si + 12C reaction. Panel (a): experimental data. Panel (b): filtered results from AMD+GEMINI simulation. Panel (c): AMD primary fragments at 300 fm/c.

In summary, the 7α resonance structures may indicate the population of high spin toroidal isomers in ^{28}Si+^{12}C @ 35 MeV/nucleon. The several resonance peak energies almost coincide with cranked self-consistent constrained Skyrme–Hartree–Fock and cranked relativistic density functional theory calculations.

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