Measuring transfer reaction particle correlations with FAUST to improve stellar models

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The ^{12}C(α, γ)^{16}O reaction in stellar nucleosynthesis is considered to be the most significant aside from the triple-α process as it directly influences the ^{12}C/^{16}O elemental ratio and the properties of stars beyond helium burning [1]. Despite this importance, the relative uncertainty associated with the reaction cross section at stellar energies is large as direct measurements are Coulomb-inhibited and two dominant multipolar contributions exist rather than one. Estimating the cross section is only possible through extrapolation of models which are parameterized and constrained by resonance properties of ^{16}O and thus a comprehensive understanding of ^{16}O* as a function of energy is needed to perform accurate extrapolations.

One of the most significant uncertainties associated with the extrapolation is the measurement of relative contribution between the E1 and E2 transitions at energies approaching the stellar regime. As with the production of ^{16}O, absolute measurements result in contributions from all available transition multipolarities; this alone does not aid in the constraint of models as independent contributions must be known. Conventional measurements rely on extraction of contributions via angular correlations, i.e., taking advantage of the angular distribution of emitted radiations of given multipolarity to preferentially isolate yield. An example of this is shown in Fig. 1; as shown, the isolation of E1 contribution from superposed E1-E2 can be performed by measuring the amplitude of radiations emitted at 90° then using this information in conjunction with an extended angular fit to extract E2 contributions. However, this E2 measurement is a single indirect extrapolation. With the proper detector apparatus and reaction, a more comprehensive determination of the E2 magnitude can be made.

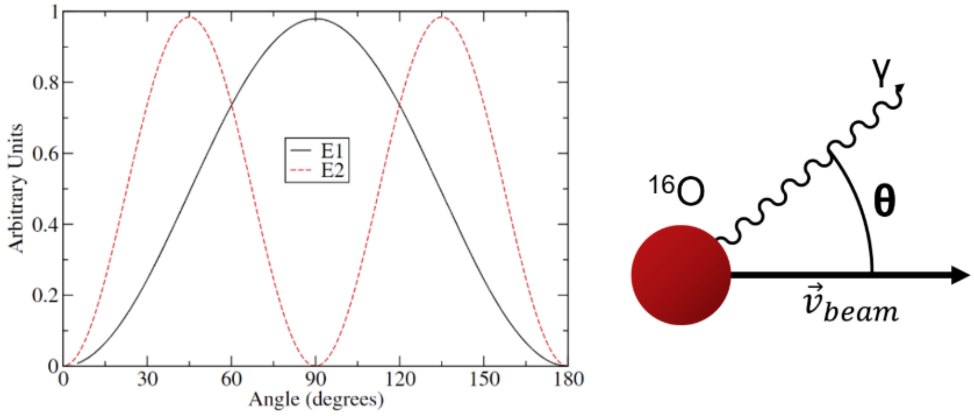

Fig. 1. (Left) Comparison of E1 and E2 angular distributions in the system center of mass for transitions of ^{12}C(α, γ)^{16}O [2]. (Right) A simplified figure showing the described angle for this process.

Due to the difficulty associated with direct reaction measurements, indirect methods are often used in the study of astrophysical reactions to supplement the extraction of residual nucleus or reaction properties; in the case of ^{12}C(α, γ)^{16}O, α-transfer reactions are most frequently used. The reaction relevant in this context is ^{7}Li(^{12}C, t)^{16}O*(α)^{12}C with coincidence measurements made between the triton, α, and

^{12}C. A triple-coincidence measurement permits the measurement of emitted α particles with respect to the reaction plane, thus allowing the type of measurement discussed in the previous paragraph.

The Forward Array Using Silicon Technology (FAUST) at TAMU is a position-sensitive charged particle array that covers most of 1.6-45.5° of forward angles via 68 ΔE-E telescopes (Fig. 2). Capable of providing sub-mm continuous position information (depending on particle ID and energy) in addition to ~1-2% energy resolution, this array is currently being investigated for studying particle correlations of an α-transfer reaction to obtain information about the properties of ^{16}O relevant for (α, γ). As a large-area silicon array, FAUST is capable of performing high-count measurements with the intent of further clarifying E1-E2 contributions as a function of E* for energies relevant to the (α, γ) process via an indirect probe.

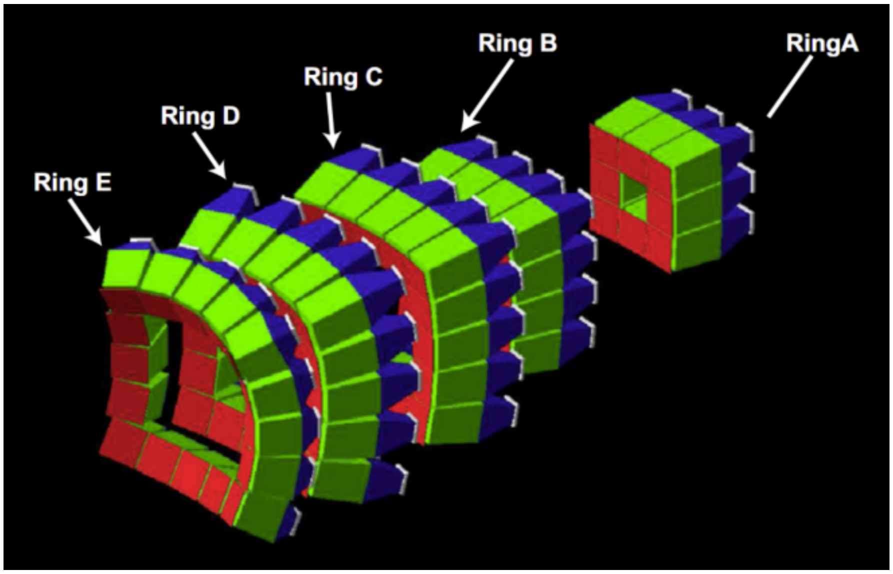

Fig. 2. Isometric projection render of FAUST [3]. The target position is located upstream such that the detector faces are oriented perpendicular.

The current plan involves augmenting FAUST with an upstream position-sensitive annular S3 silicon detector [4] for capturing particle yield behind the target position and performing a measurement of $^{7}Li(^{12}C, t)^{16}O^{*}(\alpha)^{12}C$ with incident energy of 15 MeV/nucleon. Using FAUST for this measurement provides access to the φ degree of freedom for angular correlations which is typically not possible due to detector constraints. Several simulations have been performed judging the viability of this measurement, primarily focusing on the imposed particle multiplicity and energy-momentum discretization methods that are employed in place of universal particle identification. As an illustration, Fig. 3 demonstrates that reactions of (^{6}Li, d) and (^{7}Li, t) can be separated using these requirements (given proper placement of the S3) despite not possessing comprehensive PID; the left figure depicts the centroids and 3σ widths of the Gaussian momentum distributions for a given S3 distance and that comprehensive separation is attainable with proper placement while the right reconsolidates that information in the form of peak separation (absolute difference between centroids) in addition to solid angle subtended by the S3 at a given distance. Regarding preliminary simulations, considerations of variable beamspot location, alternate reaction

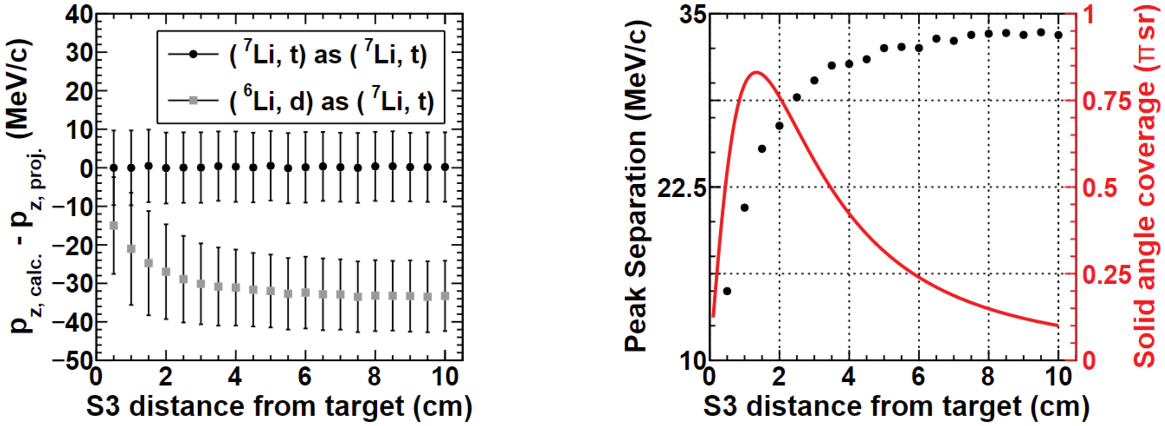

Fig. 3. (Left) Difference between the calculated beam axis momentum for exit channel particles and the initial projectile momentum between phase-space simulated (^{6}Li, d) and (^{7}Li, t) reactions analyzed as (^{7}Li, t) versus S3 distance from the target; error bars are 3σ of the corresponding distribution. (Right) Comparison between solid angle coverage (red) and separation of the distribution peaks (black) as a function of the S3 distance.

channels, and yield/coincidence estimates have also been performed; for the former two, the analysis method proposed satisfied all necessary requirements, and for the latter, an estimated 10% triple-coincidence yield was predicted (Fig. 4). Additional auxiliary detectors upstream could be used to improve efficiency.

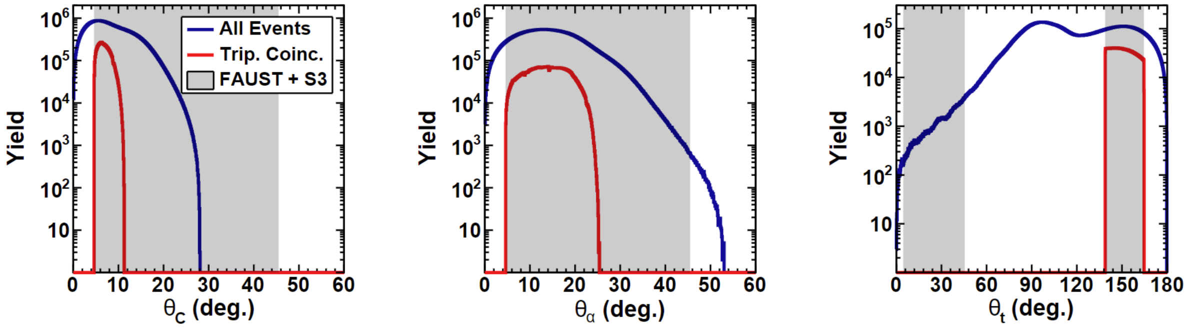

Fig. 4. Yield plots for all (blue) and triple coincidence (red) events for the three particles to be detected in experiment as a function of incident laboratory θ. The triton angular distribution was generated from a preliminary distorted-wave Born approximation (DWBA) calculation [5] for the reaction and energy of interest.

Given success with preliminary simulations, a series of test runs in various running configurations and a full-length experiment in the finalized configuration are being planned for the next calendar year of beam.

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