Study of dynamics and correlations from semi-conjugate nuclear reaction systems

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Research studying alpha-conjugate nuclei–that is, nuclei with a number of protons and neutrons such that the total nucleus is equal to an N-alpha conglomerate–is immensely prevalent. In comparison, measurements of semi-conjugate systems–those in which the combined projectile and target form an alpha-conjugate nuclide despite neither independently being one–are far more lacking. As a result, these reactions may offer a wealth of nuclear structure and clustering information, especially as a compliment to existing alpha-conjugate data.

The semi-conjugate ^{14}N + ^{10}B reaction is attractive as a first investigation. In addition to both reactants being stable, the reference alpha-conjugate system is ^{12}C + ^{12}C, one of the most studied systems, both experimentally and theoretically, in the field of nuclear physics. Existing research on the former system at intermediate energies is limited; previous works focus primarily on either the relationship and competition between complete and incomplete fusion processes [1] or the statistical properties of nuclear decay from reaction products [2]. For these reasons, these reactions were selected for the following study.

Both the ^{14}N + ^{10}B and ^{12}C + ^{12}C reactions were measured with the Forward Array Using Silicon Technology (FAUST) at Texas A&M University. FAUST covers most of 1.6-45.5° in the forward direction via 68 ΔE-E telescopes [3]. The position-sensitive dual-axis duo-lateral silicon ΔE detectors provide continuous sub-mm position information (depending on the energy deposited in the detector), thus granting excellent momentum resolution and precise event reconstruction [4]. For this work, the ^{12}C + ^{12}C reaction was conducted at 30 MeV/u while the ^{14}N + ^{10}B reaction was conducted at a lower energy of 28.3 MeV/u; this difference was chosen to account for the higher entrance channel excitation energy of ^{14}N + ^{10}B. Both beams were supplied by the TAMU CI K500 cyclotron and impinged upon the corresponding targets; the carbon target used was fabricated from a standard foil obtained from Arizona Carbon Foil [5], while the 10B target was an isotopically enriched, freestanding target obtained from the Center for Accelerator Target Science at Argonne National Laboratory [6]. The experiment was conducted in Q4 2024 and, including the 11 MeV/u 4He calibration beam, spanned two weeks.

Unfortunately, prior to experiment, an electronics issue resulted in the inclusion of aperiodic noise which could not be resolved. This noise manifested ubiquitously across FAUST silicon detectors with amplitude on the order of ±100 mV. While this noise was slow enough to not depreciate signal resolution (the baseline remained essentially constant on the timescale of silicon signals and FAUST data acquisition performs baseline subtraction on a signal-by-signal basis), the noise did influence the trigger threshold. Rather than having a < 1 MeV equivalent threshold as in previous FAUST experiments, the global threshold had to be raised to 2-3 MeV depending on the FAUST detector ring. This led to the loss of the majority of $Z = 1$ isotopes and high velocity $Z = 2$ isotopes, as these deposit very little energy in the silicon. The source of the electronic noise has since been identified, and a repeat of this experiment has been scheduled. Fortunately, the stability of FAUST means that the data already collected can be used to accelerate the final array calibration and verify the analysis chain ahead of the experiment.

Future direction for this work involves comparing experimental results with antisymmetrized molecular dynamics [7] simulations, both including and excluding cluster correlations. This dynamical model is to be paired with the statistical afterburner HFl [8] through a collaboration with the INFN Florence group; HFl is of particular interest for this work as it was originally developed to study the decay of excited light nuclei.

[1] M.E. Ortiz, Phys. Rev. C **25**, 1436 (1982).
[2] L. Morelli *et al.*,. Eur. Phys. J. Web of Conf. **66**, 03064 (2014).
[3] F. Gimeno-Nogues, *et al.*, Nucl. Instrum. Methods Phys. Res. **A399**, 1 (1997).
[4] S. N. Soisson, *et al.*, Nucl. Instrum. Methods Phys. Res. **A613**, 240 (2010).
[5] The Arizona Carbon Foil Co., Inc., https://www.acf-metals.com/.
[6] Center for Accelerator Target Science (CATS), https://www.anl.gov/phy/cats.
[7] A. Ono and H. Horiuchi, Prog. Theor. Phys. **87**, 1185 (1992).
[8] G. Baiocco, Ph.D. Thesis, Università di Bologna and University of Caen- Lower Normandy (2012), https://amsdottorato.unibo.it/4295/1/baiocco_giorgio_tesi.pdf