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Exploring unbound states of ^{18}C in inverse kinematics with the R^{3}B experimental setup

Since the advent of radioactive ion beam facilities, excited states in exotic neutron-rich carbon isotopes have been an interesting object of study. In the late 90's, three ^{17}C resonant states above the ^{16}C+n threshold were observed using the beta-delayed neutron decay of ^{17}B [Raimann96]. More resonances were observed in later works using transfer [Bohlen07], proton inelastic scattering [Satou07] and neutron-removal [Kim23] reactions. More recently, other studies have started investigating ^{18}C unbound states [Revel18, Murillo22], both via proton knockout reactions in the R3B/LAND setup. This work aims to extend the aforementioned analysis by using the new state-of-the-art R3B setup, which offers higher neutron-detection efficiency.
Moreover, by using ^{X}N(p,2p)$^{X-1}$C reactions, with protons being removed from the $1p_{1/2}$ or $1p_{3/2}$ orbitals, and comparing the energy difference between the centroids of the resulting states in ^{14}C and ^{18}C, provides insight into a potential reduction of the Z=6 gap caused by the p-splitting towards the neutron dripline. While some studies suggest a constant gap along the isotopic carbon chain [Tran18], a previous R3B/LAND work [Syndikus20] has found an increase in the proton component and moderate quenching of the Z=6 gap towards the neutron dripline, which could be explained within a seniority-inspired scheme to the neutron component [Machiavelli14]. However, both experiments are indirect observations of the evolution of the gap.
The GSI/FAIR facility was used to produce a beam of neutron-rich light isotopes near nitrogen at a relativistic kinetic energy of 540 MeV/u. The projectiles, impinging on a 5 cm liquid hydrogen target, populate unbound states of neutron-rich carbon isotopes, including as ^{18}C, which are produced via a quasi-free (p,2p) scattering reaction. The 1n and 2n decaying system ^{18}C* is studied by detecting the evaporated neutron(s), the fragment, and emitted gamma-rays in coincidence. The invariant mass method in inverse kinematics is employed to reconstruct the excitation energy spectrum above S_n and S_{2n}. The study is conducted using the R3B setup, which provides high efficiency, acceptance, and resolution for kinematically complete measurements. Key detectors include the CALIFA calorimeter [Califa14] made of CsI(Tl) crystals and the NeuLAND neutron detector [Neuland21], along with tracking detectors for both incoming isotopes and fragments [Tofd22]. Preliminary results reveal that the (p,2p) strength can be extracted up to E*(^{18}C) ~ 15 MeV, observing from the one-neutron emission new unbound states at high energies. The discussion will be based on the correlation of the gamma-ray energies with the reconstructed relative energies between the evaporated neutron and the final fragment. The distribution of the unbound populated states can be compared to those observed in the selective ^{15}N(d,^{3}He)^{14}C reaction [Ajzenberg76], bringing direct information about the change of the amplitude of the p-splitting. Results from the two-neutron unbound system will be discussed as well, particularly exploring the sequential vs. direct emission of the two emitted neutrons.

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