# Invariant-mass spectroscopy for light proton-rich isotopes*

R. J. Charity and L. G. Sobotka
*Departments of Chemistry and Physics, Washington University, St. Louis, 63105, USA*

Proton-rich beams of $^{7}$Be, $^{9}$C, $^{13}$O, $^{15}$O, $^{17}$Ne, and $^{20}$Mg from the National Superconducting Cyclotron Laboratory have been used to produce resonant states at or beyond the proton drip line. We will discuss some highlights of these studies. Resonances beyond the proton drip line continue to shed their excess protons until the final residue is particle bound and thus lies within the proton drip line. Because of the odd-even staggering of the drip line caused by nucleonic superfluidity, the shedding of unbound protons is usually terminated at an even-Z particle-bound residue. Thus just beyond the proton drip line, one is likely to find single-proton emitters for odd-Z nuclei and two-proton emitters for even-Z nuclei. Even further removed, one finds 3p and 4p emitters. The quest for the most proton-rich isotopes at the edge of the chart of nuclides thus involves decays with large proton multiplicities. We will show examples of ground-state 2p emitters ($^{6}$Be, $^{11,12}$O, $^{16}$Ne), 3p emitters ($^{13}$F, $^{18}$Na) , and 4p emitters ($^{8}$C , $^{18}$Mg). Finally we will present evidence for $^{9}$N, a ground state 5p emitter. This is a very exotic resonance with more than half of the constitute nucleons unbound. The invariant-mass spectrum show evidence for probably 2 $^{9}$N levels which involve initial proton decays to the ground state of $^{8}$C which subsequently decays by two steps of prompt 2p emission. Comparison will be made to predictions of the Gamow Shell Model and there is some possibility that the lowest-energy state is not a real resonance, but a subthreshold resonance, the mirror of a virtual state in $^{9}$He.

The nucleus $^{10}$Be is well known for having a highly deformed rotational band associated with strong $\alpha$-cluster structure where the two valance neutrons occupy molecular-like orbitals. An analog of this band should exit in the mirror $^{10}$C where most excited states decay into the $2p$+$2\alpha$ exit channel. This exit channel can be produced in multiple ways: via an initial $\alpha$ decay to the two-proton emitter $^{6}$Be; via an initial proton emission to the unbound $^{9}$B intermediate state; or via an initial prompt $2p$ decay to the $^{8}$Be intermediate state. We show how these various decay modes can be isolated from the correlations between the decay products. The second $0^{+}$ state in $^{10}$C was identified from the correlations associated with its prompt $2p$ decay branch and the rotational band is tentatively identified up to the $4^{+}$ state.

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