Isoscalar response of $^{68}\text{Ni}$ to $\alpha$-particle and deuteron probes

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Isoscalar giant resonances have been measured in the unstable $^{68}\text{Ni}$ nucleus using inelastic alpha and deuteron scattering at 50$A$ MeV in inverse kinematics with the active target MAYA at GANIL. Using alpha scattering, the extracted isoscalar giant monopole resonance (ISGMR) centroid was determined to be $21.1 \pm 1.9$ MeV and the isoscalar giant quadrupole resonance (ISGQR) to be $15.9 \pm 1.3$ MeV. Indications for soft isoscalar monopole and dipole modes are provided. Results obtained with both ($\alpha$,$\alpha'$) and (d,d') probes are compatible. The evolution of isoscalar giant resonances along the Ni isotopic chain from $^{56}\text{Ni}$ to $^{68}\text{Ni}$ is discussed.

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I. INTRODUCTION

Measurement of the isoscalar giant resonances (ISGR), and in particular the isoscalar giant monopole resonance (ISGMR) plays an important role in constraining the nuclear equation of state [1]. More precisely, the energy of the ISGMR, that corresponds to a succession of compression/expansion phases of the atomic nucleus, also called the breathing mode, where all the protons and neutrons oscillate in phase, can be linked to the nuclear-matter incompressibility. The nuclear-matter incompressibility has been constrained in the last decades using measurements in stable nuclei that are made up only with symmetric matter or slightly asymmetric matter (in a local density approximation picture). However, measurements in unstable nuclei are lacking in order to study the evolution of the nuclear-matter incompressibility as a function of the neutron-proton asymmetry. Recently, it has been shown that measuring the energy of the ISGMR provides information on the ability to compress the matter around the average density of nuclei, which is typically 70\% of the saturation density. The present work emphasizes the importance of measuring the ISGMR in different nuclei at several neutron-proton asymmetries and several densities.

Moreover, an isoscalar monopole mode at lower energy, called soft monopole mode, has been predicted in neutron-rich nuclei by several relativistic and nonrelativistic models. Recently calculations with an exact treatment of the continuum have also predicted monopole strength in the same energy region. However, this mode is found to be characterized with a larger width and turns out to originate mainly from the continuum background. Such a soft monopole mode has not yet been observed.

Experimentally, the measurement of giant resonances in unstable nuclei is a challenging task which has until now been mainly dedicated to the study of the isovector giant dipole resonance (IVGDR) and the isovector pygmy dipole resonance (IVPDR). Photons are a relevant probe to excite the IVGDR and the IVPDR, thus Coulomb excitation with absorption of a virtual photon has been used, for example, to study the IVGDR and IVPDR in neutron-rich O, Ne, Sn isotopes and in $^{68}\text{Ni}$ [8]. In these studies, the invariant-mass method was used, requiring the detection of all the decay products. These experiments yielded evidence for the appearance of a low-energy dipole mode, the nature of which is still under discussion; it may correspond to an oscillation of a neutron skin against a nucleus core, possibly mixed with isoscalar dipole strength.

In the case of the isoscalar response, the first measurement was performed on the $N = Z$ unstable $^{56}\text{Ni}$ nucleus with deuterons as probe. The ISGMR has been measured at $19.3 \pm 0.5$ MeV and the isoscalar giant quadrupole resonance (ISGQR) at $16.2 \pm 0.5$ MeV [11]. The isoscalar giant dipole resonance (ISGDR), a second-order mode corresponding to the so-called squeezing mode, has never been measured in an unstable nucleus. It should be noted that in Ref. [14] relativistic random-phase approximation (RRPA) calculations indicate some substantial isoscalar dipole strength in $^{68}\text{Ni}$.

Measuring the scattering of radioactive nuclei from light probes requires the use of inverse kinematics and the detection of very low-energy light charged particles. Therefore, a