EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Experiments Committee for experiments with HIE-ISOLDE

Study of the nature of the low-lying strength in nuclei with neutron skin

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Abstract

With this LoI, we propose to study the nature of the pygmy resonances in the Sn isotopes via Coulomb and different mixtures of isoscalar and isovector nuclear interactions at HIE-ISOLDE beam energies.

1. Introduction

In the neutron rich side of the Segré chart, as the number of neutrons increases a neutron skin starts to develop and, as a result, new excitation modes become possible.

Recent studies of the nuclear structure of very neutron-rich nuclei with pronounced neutron skin have revealed the presence of low-lying E1 strength at energy excitation around neutron threshold and below the usual Giant Dipole Resonance (GDR) observed also in less exotic nuclei. While the GDR is attributed macroscopically to a resonant oscillation between the neutrons and the protons forming the nucleus, the macroscopic description of the low-lying strength is a resonant oscillation between the inert core of the nucleus and its neutron skin, called Pygmy Dipole Resonance (PDR).

Although most of the microscopic models predict the existence of this low-lying strength around neutron threshold, the collective or non collective nature of the strength, as well as the real thickness of the neutron skins, are still under discussion. Beyond their new and very exciting nuclear structure, neutron skin thicknesses can reveal important information on the equation of state of asymmetric nuclear matter and the nuclear symmetry energy at saturation and sub-saturation densities. Such information is of crucial importance in understanding the structure of neutron stars.

We propose to study experimentally the dipole strength distribution below and above neutron threshold in the Sn isotopic chain via Coulomb excitation and different mixtures of isoscalar and isovector nuclear interactions to characterize the nature of the strength.

2. Physics case

From an experimental point of view, our insight of the pygmy dipole resonances in heavy neutron-rich nuclei, in particular $^{130\text{-}132}$Sn, comes mainly from measurements of electric dipole transition rates $B(E_1)$ in Coulomb excitation reactions at high energy, ~500 MeV/nucleon [1]. Very little is known however about the wave-functions and transition densities that characterize these resonant states.

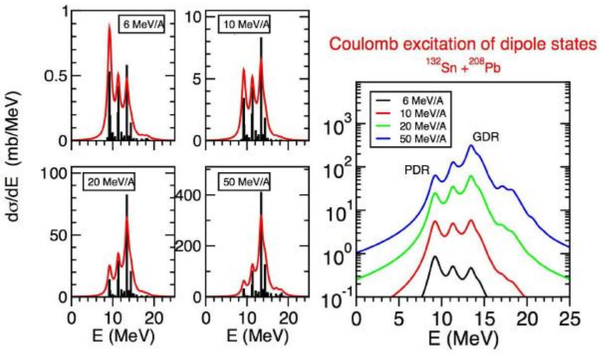

Figure 1: taken from ref. [2]

One of the benefits of Coulomb excitation studies at high beam energy is the high cross-section for the dipole strength distribution around and above neutron threshold. As a consequence, provided a good experimental setup, the issue of low intensities that usually characterizes radioactive ion beams can be overcome. The results presented in ref. [1] which shows clearly the pygmy dipole strength at excitation energy around 10 MeV within the tail of the GDR, were obtained with a ^{132}Sn beam intensity of 10 ions per seconds only and for a period of 4 days. Recent cross-section calculations of the Coulomb excitation of dipole states in the reactions ^{132}Sn+^{208}Pb at beam energies 50, 20, 10 and 6 MeV/nucleon [2] illustrate the reduction of the cross-section as the beam energy decreases (fig.1). Beyond the reduction in cross-section, the calculations also show the effect of the kinematical cut off which reduces the GDR cross-section faster than the PDR one. As a result, for beam energies at 10 and 6 MeV/nucleon the probability to excite the PDR state is expected to equal and exceed, respectively, the probability to excite the GDR state.

At HIE-ISOLDE, high intensity ^{132}Sn beams at 10 MeV/nucleon are expected. This will give the opportunity to carry-out measurements of PDR strengths that are no longer hidden in the tail of the GDR. Parameters of the symmetry energy and neutron skin thicknesses for the $^{130\text{-}132}$ Sn isotopes reported in [3] are based on Relativistic Quasiparticle Random Phase Approximation (RQRPA) calculations and the measured PDR/GDR strength reported in [1]. New experimental data on the PDR/GDR strength ratios at HIE-ISOLDE beam energies would allow these theoretical calculations to be tested and the deduced symmetry energy parameters and neutron skin thicknesses to be confirmed.

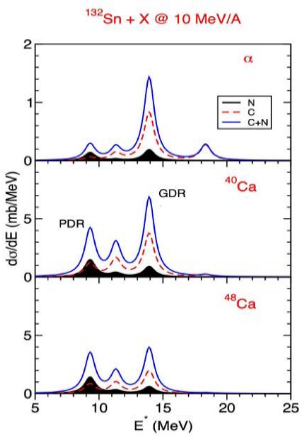

Figure 2 : taken from ref. [2]

Additional calculations reported in [2] suggest that a better insight of the properties of the pygmy states can be extracted from different reactions involving different contributions of the Coulomb and Nuclear excitations. Those calculations based on Hartree-Fock plus RPA formalism and Skyrme interactions were performed for the reactions ^{132}Sn+^{4}He, ^{132}Sn+^{40}Ca and ^{132}Sn+^{48}Ca at 10 MeV/nucleon. By changing the reaction partner one changes the Coulomb and nuclear contributions to the total excitation processes as well as the isoscalar and isovector nuclear component. Those changes results in a change of the relative intensity of the PDR and GDR states (see fig. 2). Similar changes have already been observed in the PDR of ^{140}Ce when experimental results obtained from (γ,γ') and (α,α'γ) reactions were compared [4]. The cross sections in figure 2 can be analyzed in term of Coulomb and nuclear contributions. The nuclear formfactors describing the nuclear excitation process can then be extracted. By using a reaction

partner purely isoscalar (alpha or N=Z nuclei) and a reaction partner with a mixture of isoscalar and isovector components (N≠Z nuclei), the isoscalar and isovector components of the nuclear formfactor can be extracted. Since the nuclear formfactors are constructed from the transition densities [2, and references therein], information of the corresponding isoscalar/isovector mixture in the transition densities of the states can be deduced and, consequently, the nature of the pygmy resonance can be revealed.
Therefore, we are extremely interested in taking advantage of the HIE-ISOLDE ^{132}Sn beam in order to check experimentally these reaction cross sections calculations and these PDR/GDR strength ratios.

3. Experimental setup

In ^{132}Sn, the PDR lies about 3 MeV above the neutron threshold (S_n=7.3 MeV) and this leads to important constraint on the experimental setup. The reconstructed excitation energy distribution can be reconstructed by summing the relative energy between neutron and recoil nucleus and the energy of the gamma-rays emitted by the recoil. Therefore, the experimental setup has to be capable of characterizing in coincidence the recoil nucleus; the corresponding gamma-rays and the neutrons emitted during the Coulomb and nuclear excitation processes. Such experimental setup remains to be identified but new generation of detectors are currently being investigated and could be suitable and possibly available to be used at HIE-ISOLDE for the proposed measurements. A calorimeter of LaBr such as the PARIS array for instance could possibly be used to detect both gamma-rays and neutrons. Time of flight could be used to discriminate between the neutrons and gamma-rays, as well as to provide the neutron energy. The detection of the recoil would require an array at forward angles and would certainly benefit from a separator.

4. Beam requirements

Although this letter of intent focuses on the ^{132}Sn isotope, other neutron rich nuclei with neutron skin that would become available at HIE-ISOLDE would be of interest in the future.
A 10 MeV/nucleon beam of ^{132}Sn is preferable as the calculated cross sections are one order of magnitude higher than at 6 MeV/nucleon. A beam intensity of 10^8 pps should keep the beam time request within the typical range of 5-10 days. Beam purity would certainly be advantageous, and a good quality beam is important if one has to avoid using beam tracking detectors.

5. Safety aspects

No particular safety concern or issue has been identified at this stage.

6. References

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