IFIN-HH

Proposal for the TANDEM accelerator for the period

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Lifetime measurements in the neutron-rich nucleus ^{67}Cu using mixed HPGe$-$LaBr$_3$:Ce gamma detection array

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We propose to measure the lifetimes of the $E_x = 2503$ keV, $9/2^+$ and of the E_x=3463 keV,$15/2^+$ yrast states in ^{67}Cu using the in-beam fast electronic timing technique, with the Bucharest 8 HPGe and 7 LaBr$_3$:Ce array. The present known values half-lives are $T_{1/2} < 0.3\ ns$ for the $9/2^+$ state and $T_{1/2} < 2.4\ ns$ for the $15/2^+$ state, respectively. The large $E3$ branch to the $3/2^-$ ground state observed in the decay of yrast $9/2^+$ level suggests a possible enhancement of $E3$ strength, which may be due to particle-vibration coupling between single-particle states and the octupole vibration of the even-even core. The hindering of the $15^+ \rightarrow 13/2^+$ $M1$ transition may be due to the dominance of $(\nu g_{9/2} \nu f_{5/2}^{-1})$ configuration in the initial state and of the $(\nu g_{9/2} \nu p_{1/2})$ configuration in the final state. The successful determination of the two lifetimes will provide new insight on the structure of the neutron-rich Cu isotopes near $N = 40$.

I. Scientific motivation

The mixing of single- and few-particle and collective degrees of freedom near closed shells is an interesting subject, because it can shed light on the shell model residual interactions from different nuclear regions. Our proposal concerns the study of the ^{67}Cu nucleus, which, being a neutron-rich nucleus has not not been easily accessible. Several low-lying excited states, and notably, a $9/2^+$ state, were proposed in direct transfer reaction studies: the (α, p) reaction [1], the (t, p) reaction [2], and the $(d,^3He)$ reaction [3]. This level scheme was extended at higher spins by γ-ray spectroscopy in a deep inelastic collision (DIC) study [4]. The level scheme of this last study, relevant for the present proposal, is shown in Fig. 1. There are two isomeric states proposed, the $9/2^+$ level ($T_{1/2} < 0.3$ ns), and the $15/2^+$ level at 3463.5 keV ($0.6 < T_{1/2} < 2.4$ ns). As a result, the $9/2^+$ state decays by a fast E3 transition towards the ground state, which is estimated as larger than 11 W.u.

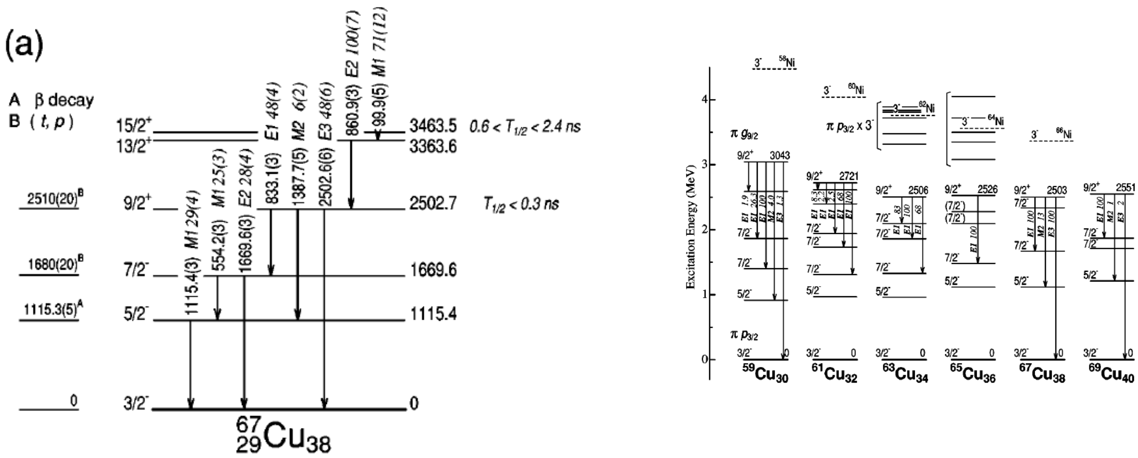

FIG. 1: Relevant level scheme of ^{67}Cu (ref. [4]) and the systematic of $9/2^+$ state and its decay in the Cu isotopes.

Fig. 1 shows also the systematic of the $9/2^+$ state decay in the Cu isotopes. The E3 γ-ray transition was not observed in the isotopes of mass 61, 63, 65, but the B(E3;$9/2^+ \rightarrow 3/2^-$) strength was deduced in ^{63,65}Cu from inelastic scatterings (α, α'), (p, p'), and (e, e'), in the range of ~ 20 W.u. From the systematic of the E1 strengths and from the E3/E1 ratios, one expects for ^{67}Cu a B(E3) value much larger than 11 W.u. That rises interesting questions concerning the structure of this state: the (α, p) experiment [1] showed that it must have a large proton $g_{9/2}$ single-particle component, which led Ref. [5] to assign the enhancement of the $\pi g_{9/2} \rightarrow \pi p_{3/2}$ E3 transition to the particle-octupole vibration coupling. In ^{69}Cu, the same E3 transition is smaller (between 9 and 0.9 W.u.), indicating a change in the structure of this state [6].

The B(M1) value for the $15^+ \rightarrow 13/2^+$ is important as well. The main configurations for the two yrast states are proposed to be $(\pi p_{3/2} \nu g_{9/2} \nu f_{5/2}^{-1})(15/2^+)$ and $(\pi p_{3/2} \nu g_{9/2} \nu p_{1/2})(13/2^+)$ respectively [4]. A M1 transition between these pure configurations being forbidden, the observed 100 keV gamma ray indicates, for instance, the presence of $\nu f_{5/2}^{-1}$ component in the wave function of the $13/2^+$ yrast state.

A precise measurement of the lifetime of these states would allow to better assess the structure of this positive-parity intruder excitation in ^{67}Cu. We propose to determine these lifetimes by populating the excited states in this nucleus with the (α, p) reaction, and measuring by the fast timing technique with the Bucharest mixed array of HPGe and $LaBr_3$:Ce detectors.

II. Experiment

The reaction used will be ^{64}Ni$(\alpha, p)^{67}$Cu. Estimation of the expected reaction cross-sections were performed with the code TALYS-1.2 [7] - Fig. 2. We have chosen an incident energy of 16 MeV; we will integrate over all energies because the available target is thick. The main competing (background reactions) will be the n (^{67}Zn) and $2n$ (^{66}Zn) channels.

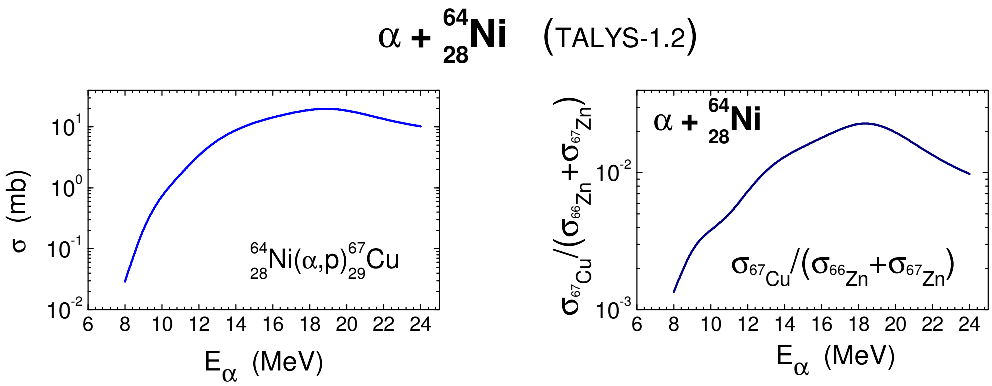

FIG. 2: Production cross section of ^{67}Cu from the ^{64}Ni(α,p) reaction and the yield of ^{67}Cu relative to the dominant reaction channels. The calculations were performed with the TALYS-1.2 code [7].

The gamma-rays will be detected with our array of 8 HPGe detectors and 7 $LaBr_3$:Ce detectors. The high-resolution Ge detectors will be used to gate on the lower transitions of 1115, 554, and 1669 keV (Fig. 1), and thus select in the scintillator detectors the decay γ-ray of 833 keV from the $9/2^+$ state, and, eventually the 861 keV and other gamma-rays feeding this level. The time spectrum of the decay of the $9/2^+$ level can be determined by simply gating on the 833 and 861 keV transitions in the $LaBr_3$ detectors, or by gating only on 833 keV and whatever feeds the $9/2^+$ level.

As shown in our recent work [8], by using a special technique for the processing of the timing information from the $LaBr_3$ detectors, and thus fully use the detection efficiency by adding up the contribution from all the pairs of such detectors, we can measure in this way half-lives down to 30–40 ps by the centroid shift method, therefore there is a very good chance to measure the lifetime of the $9/2^+$ level. The determination of the lifetime of the $15/2^+$ level is more difficult, first because this level will be less populated in the reaction, and second because it may depend on the observation of discrete gamma rays feeding this level. Another practical possibility is also to fit a double-component decay curve taken with STOP on 860 keV transition, START on Compton continuum with the condition to observe with HPGe detectors the 100 keV in coincidence.

On the same experiment the coincidences between HPGe detectors will be used to extend the level scheme of ^{67}Cu.

III. Beamtime request.

Considering the following (minimal) conditions:

- beam intensity of 15 particle-nA;

- thick target (beam stopped in the target);

- a population of about 10% of the average cross-section (about 8 mb) of the (α,p) reaction for states of higher spin (e.g., the $13/2^+$ state) that feed the $9/2^+$ level;

- that the higher spin states are fed with this intensity down to an energy of the incident beam of about 12 MeV;

- efficiencies of about 0.01, and 0.005 for gamma-ray energies of about 800 keV of the HPGe array, and the $LaBr_3$:Ce array, respectively,

we get a rate of about 13 triple Ge-LaBr-LaBr coincidences/hour (total peak coincidences), therefore for a 10 days of beamtime we will get around 3000 events in the time spectrum for the $9/2^+ \rightarrow 3/2^-$ transition. The statistics is estimated for $15/2^+ \rightarrow 13/2^+$ transition to be 10 times smaller, nevertheless it should be enough to obtain a reliable value for the lifetime of the $15/2^+$ state in the nanosecond range.

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