# Fast-timing study of the $l$-forbidden $1/2^+ \rightarrow 3/2^+$ $M1$ transition in $^{129}$Sn

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The levels in $^{129}$Sn populated from the $\beta^-$ decay of $^{129}$In isomers were investigated at the ISOLDE facility of CERN using the newly-commissioned ISOLDE Decay Station (IDS). The lowest $1/2^+$ state and the $3/2^+$ ground state in $^{129}$Sn are expected to have configurations dominated by the neutron $s_{1/2}$ ($l = 0$) and $d_{3/2}$ ($l = 2$) single particle states, respectively. Consequently, these states should be connected by a rather slow $l$-forbidden $M1$ transition. Using fast-timing spectroscopy we have measured the half-life of the $1/2^+$ 315.3-keV state, $T_{1/2} = 19(10)$ ps, which corresponds to a moderately fast $M1$ transition. Shell-model calculations using the CD-Bonn effective interaction, with standard effective charges and g-factors, predict a 4 ns half-life for this level. We can reconcile the shell-model calculations to the measured $T_{1/2}$ value by the renormalization of the $M1$ effective operator for neutron holes.

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## I. INTRODUCTION

Experimental information on nuclei far from the stability line is of great importance for the development of nuclear models describing the structure of nuclei at or close to the drip lines. As the N/Z ratio increases, several aspects of the effective interaction between protons and neutrons are revealed, providing unique views into the nuclear structure. In this context, the predictive power of nuclear models is subject to a stringent scrutiny, especially when the measurement of the electromagnetic transition probabilities connecting nuclear states can be achieved. These are, in fact, key observables for a reasonably fine tuning of the nuclear models.

The regions around doubly-magic nuclei attract strong interest both from the point of view of experiment and theory, since they are the best testing ground for the shell-model effective Hamiltonian. Crucial information

* Deceased.

on single-particle energies, two-body matrix elements of the residual interaction and effective electromagnetic operators can be obtained, which can then be applied to an extended range of the nuclear chart. Nuclei in the proximity of the doubly-magic $^{132}$Sn (Z=50 and N=82) have a special impact, as their study provides information on the neutron-rich side of the long tin isotopic chain, which is currently known from the doubly-magic $^{100}$Sn up to $^{138}$Sn [1].

A good description of nuclear structure around $^{132}$Sn has been achieved by recent realistic shell-model calculations [2], where the two-body matrix elements of the effective Hamiltonian were constructed via many-body perturbation theory, starting from a low-momentum interaction derived from the CD-Bonn nucleon-nucleon potential.

In the framework of the nuclear single-particle shell model, the magnetic dipole ($M1$) transitions are allowed only between initial and final states for which the change in orbital angular momentum is $\Delta l = 0$ [3]. Therefore $M1$ transitions between $\Delta l = 2$ states are considered to be $l$-forbidden, such as $s_{1/2} \leftrightarrow d_{3/2}$ and $g_{7/2} \leftrightarrow d_{5/2}$. Measurements, however, have shown that in certain cases these transitions appear to be experimentally allowed, thus providing a motivation to develop more elaborate nuclear models to understand this behaviour. The breakdown of the $\Delta l = 0$ selection rule can be explained by configurational mixing [4] and/or by considering an effective $M1$ operator, resulting from the renormalization of the free operator induced by core excitations.

In the case of the $^{135}$Sb system ($^{132}$Sn+2$n$+1$p$), for example, the B($M1$; $5/2^+ \rightarrow 7/2^+$) transition rate from the first-excited 281.7-keV level to the ground state calculated with free $g$-factors is two orders of magnitude larger than the experimental value. This discrepancy cannot be removed by using effective $g$-factors, but only by considering an effective $M1$ operator. This is due to core-polarization effects leading to a non-zero off-diagonal matrix element of the effective $M1$ operator between the $1d_{5/2}$ and $0g_{7/2}$ proton orbitals that compensates the diagonal $0g_{7/2}$ matrix element [5, 6].

An interesting case to study the $l$-forbidden character of $M1$ transitions is represented by the $^{129}$Sn nucleus, with three-neutron holes with respect to $^{132}$Sn. The low-lying state of spin $1/2^+$ at an excitation energy of 315 keV and the $3/2^+$ ground state in $^{129}$Sn are expected to have configurations dominated by the neutron $2s_{1/2}$ ($l = 0$) and $1d_{3/2}$ ($l = 2$) single particle states. These states are directly connected by a 315-keV $\gamma$ transition. Since the $M1$ transition between them is $l$-forbidden and the electric quadrupole collectivity is very small for a weakly deformed nucleus, one expects a very retarded $M1$ transition from the 315-keV level to the ground state, characterized thus by a small $B(M1)$ value.

In this paper, the half-life measurement of the first excited state of $^{129}$Sn populated in the $\beta^-$ decay of $^{129}$In at the ISOLDE facility is reported, along with a comparison to shell-model calculations. Previous measurements of the $\beta^-$ decay of $^{129}$In established in great detail the level scheme of $^{129}$Sn [7, 8] and determined half-lives for microsecond isomers [9] which are in good agreement with shell-model calculations. Here we concentrate on the half-life of the 315-keV level, for which there are no previous experimental data available.

## II. EXPERIMENTAL DETAILS

The excited states in $^{129}$Sn were populated in the $\beta$ decay of $^{129}$In at the ISOLDE-CERN facility. A beam of $^{129}$In was produced by the 1.4 GeV proton beam from the PS-Booster directly impinging on a uranium carbide ($UC_x$) target. The $^{129}$In atoms thermally diffused out of the target matrix, were surface ionized [10], then separated using the ISOLDE General Purpose Separator (GPS) and finally brought to the centre of the experimental setup at the newly-commissioned ISOLDE Decay Station (IDS). IDS is positioned in a well-shielded area, more than 40 m away from the production target. The estimated $^{129}$In yield was $1.2 \cdot 10^4$ ions/$\mu$A, and the average proton current during the run was $\sim$1 $\mu$A. Three $\beta$-decaying states coexist in $^{129}$In [8]: the $J^\pi = 9/2^+$ ground state with $T_{1/2} = 0.61(1)$ s, a 459-keV isomer with $J^\pi = 1/2^-$ and $T_{1/2} = 1.23(3)$ s and a high-lying $J^\pi = 23/2^-$ state with $T_{1/2} = 0.67(10)$ s. The corresponding 2118.3-, 315.4- and 2189-keV transitions in $^{129}$Sn which uniquely decay from each isomer were used for estimating the isomeric mixing of $^{129}$In. Based on our data and the $\gamma$-ray decay intensities in the literature [8], the population of each isomeric state was found to be 56(6)%, 37(3)% and 7(1)% for the $9/2^+$, $1/2^-$ and $23/2^-$ states, respectively.

The $^{129}$In ions were implanted on the aluminium-coated Mylar transport tape at the center of the IDS, where the decay products were measured using $\gamma$ and $\beta$ detectors. The detection system consisted of 4 HPGe Clover-type detectors, 2 $LaBr_3$(Ce) crystals coupled to fast-timing Hamamatsu R9779 photomultiplier tubes (PMT) [11], and a thin plastic scintillator disk coupled to a fast PMT, which was employed as a fast time response $\beta$ detector. The Nutaq [12] digital data acquisition system (DAQ) was used. The Clover signals and the scintillator energy signals, taken from the PMT last dynodes, were directly fed into the DAQ. The PMT anode signals were used for the timing. The signals processed by analog Constant Fraction Discriminators (CFD) were optimized for external delay and time walk. The processed signals were sent to Time to Amplitude Converters (TAC), which were used to determine the time interval between coincident signals coming from the $\beta$ and $LaBr_3$(Ce) detectors. Events were constructed off-line in order to correlate the time differences and the detector signal amplitudes.

Energy and efficiency calibrations were performed using standard sources of $^{152}$Eu, $^{133}$Ba and $^{60}$Co. The time-response calibration, essential for our measurements, was obtained using a source of $^{138}$Cs, which, via $\beta$ decay, populates several short-lived excited states in $^{138}$Ba that have well-known half-lives [13, 14].

The analysis of $\gamma - \gamma$ coincidences confirmed the $^{129}$Sn level scheme reported earlier [8]. A partial level scheme

which contains the main $\gamma$ rays from the decay of $^{129}$In isomers is shown in Fig. 1. No other new transitions could be identified and placed in the existing level scheme. The $\gamma$-ray intensities are also in agreement with Ref. [8], provided that we measured the mixture of all three isomers of $^{129}$In mentioned earlier.

Fig. 2 shows the $\beta$-gated $LaBr_3$(Ce) (a) and HPGe (b) summed spectra. The most intense peak corresponds to the 315-keV ($1/2^+ \rightarrow 3/2^+$) transition in $^{129}$Sn. At this energy, the Full-Energy Peak (FEP) to background ratio is 4:1 for the HPGe and 1.5:1 for the $LaBr_3$(Ce) $\beta$-gated spectra. The intensity difference of the X-rays recorded by the $LaBr_3$(Ce) and HPGe detectors is mostly due to the extra thickness of the material in front of the HPGe detectors.

The half-life of the 315-keV $1/2^+$ state in $^{129}$Sn was investigated by using the advanced time-delayed method (*fast-timing*) for measuring nuclear half-lives in the picosecond-nanosecond range [15, 16]. For very short half-lives, down to a few picoseconds, the method is based on the analytic result that the offset between the time distribution centroid and the prompt detector response is the first moment of the time distribution, and therefore it is equal to the lifetime of the exponential decay. In the case of a long half-life in the nanosecond range, the de-convolution of the decay slope can also be employed.

The time difference between $\beta$ particles and $\gamma$ rays was studied by analyzing the $\beta$-gated $LaBr_3$(Ce) spectra independently for both $LaBr_3$(Ce) detectors. Fig. 3 shows the TAC time distribution of the 315-keV $\gamma$ rays relative to the $\beta$ decay. No Compton subtraction was done at this stage as the main purpose of this investigation was just exploratory in order to have an estimative value for the decay half-life. The time distribution shows a symmetric quasi-Gaussian response and the absence of any significant exponential decay slope rules out a lifetime in the nanosecond range. The time distribution can be fitted by a Gaussian function, which suggests that the 315-keV state in $^{129}$Sn has a half-life well below the time resolution of the $\beta$-$LaBr_3$(Ce) combination at this energy. The upper limit was obtained by analyzing the $\chi^2$/d.o.f. (degrees of freedom) variation relative to the half-life when the time distribution is fitted with a convolution of a Gaussian and an exponential function. The $\chi^2$/d.o.f. variation of $< 0.1$ around the minimal value suggests a half-life of 30(+7-13) ps, yielding an upper limit of $\sim$40 ps.

Once a long lifetime was discarded, the full analysis by the centroid-shift method was performed [15, 16]. For calibration purposes, the data set containing transitions from the $\beta$ decay from $^{138}$Cs to $^{138}$Ba [13, 14] was used. Triple $\beta\gamma\gamma(t)$ events involving HPGe, $LaBr_3$(Ce) and $\beta$ detectors were employed. Owing to the good energy resolution of the $LaBr_3$(Ce) detectors it was possible to select the FEP in $^{129}$Sn and apply the timing corrections in double $\beta\gamma(t)$ events involving the $LaBr_3$(Ce) and $\beta$ detectors. The statistics were not large enough to perform a similar $\beta\gamma\gamma(t)$ analysis. As shown in Fig. 1, the 973.5- and 907.3-keV transitions which populate the 315-keV $1/2^+$ state have low intensities.

TABLE I. $\gamma$-ray transitions used for determining the walk curves. Data for $^{138}$Ba were taken from [13, 14]

| Nucleus | $E_{level}$ (keV) | $T_{1/2}$ (ps) | $E_\gamma$ (keV) | HPGe gate (keV) |
|---|---|---|---|---|
| $^{129}$Sn | 769.0 | | 769.3 | |
| $^{129}$Sb | 645.1 | | 645.2 | |
| $^{138}$Ba | 2307.6 | 7(3) | 409.0 | 462.8 |
| | 2445.6 | 5(4) | 138.1 | 871.8 |
| | | | 227.8 | 2218.0 |
| | | | 547.0 | 462.8 |
| | | | 1009.8 | 1435.8 |

The first step of the analysis involved the walk correction for the $\beta$ detector. Although the $\beta$ detector is thin and has a time response relatively independent of the incident $\beta$ energy, there is still a residual time dependence that needs to be accounted for. The correction was performed relative to an intense prompt peak in the $LaBr_3$(Ce) spectra for each data set corresponding to $^{129}$In. A similar treatment was done for the time calibration source of the $^{138}$Cs decay.

Next, the time-energy response curves of the $LaBr_3$(Ce) detectors were determined both for Compton events and FEP, by using the timing information of transitions in $^{138}$Ba which de-excite short-lived levels that are directly fed in the $\beta$ decay of $^{138}$Cs [13, 14]. The transitions used as prompt reference are listed in Table I. The time distributions were determined using HPGe gated coincidences between the plastic scintillator and the $LaBr_3$(Ce) detectors in the triple $\beta\gamma\gamma(t)$-event data set. For the Compton walk correction an individual transition in the $LaBr_3$(Ce) detectors was selected by a suitable HPGe gate and the centroid position of the time distribution is obtained for several energy regions in the $LaBr_3$(Ce) spectra, corresponding to Compton events. The correction is used to account for the Compton time response under FEP.

The corrected FEP prompt response curves for the two $LaBr_3$(Ce) detectors are shown in Fig. 4. Each point represents the centroid of $\beta$-$LaBr_3$(Ce) FEP time distributions with the Compton background subtracted. The $^{138}$Cs decay walk curve could be fitted using a quadratic polynomial thanks to the smooth time-energy response of the detectors. The 769.3-keV transition in $^{129}$Sn, listed in Table I, was used as prompt reference. The 645.2-keV transition in $^{129}$Sb was independently corrected for the $\beta$ detector walk and used as cross-check. The time centroids in the A=129 decay chain were shifted to match the 769.3-keV and 645.2-keV points to the curve. The difference between the centroid of the 315-keV transition and the curve is due to the lifetime of the 315-keV level.

The average of residuals from Fig. 4 for both $LaBr_3$(Ce) detectors is shown in Fig. 5. The reference error of $\pm$10 ps was deduced by averaging the error bars of all the prompt $\gamma$-ray time centroids. The only statistically significant difference (offset) between the time distribution centroid and the prompt detector response, of $\tau$ =28(15) ps, cor-

responds to the 315-keV transition. This translates into a decay half-life of $T_{1/2} = 19(10)$ ps for the 315-keV $1/2^+$ state in $^{129}$Sn.

In order to extract the $B(M1)$ value, the 315-keV transition from $^{129}$Sn was corrected for the internal conversion. The M1 coefficient is 0.025 [17]. According to the calculations (see below) the $E2$ branch amounts to only ∼2%, therefore the $E2$ component was neglected. This yielded a $B(M1)$ transition rate of $6.4(30) \times 10^{-2}$ $\mu_N^2$=3.6(19) $\times$ $10^{-2}$ W.u. indicating a relatively fast transition, contrary to the expected retarded transition.

## III. THEORETICAL INTERPRETATION

With the assumption of dominant $2s_{1/2}$ and $1d_{3/2}$ configurations for the $1/2^+$ and $3/2^+$ ground state in $^{129}$Sn, respectively, one would expect a small value of the $B(M1)$ transition rate between them, due to the $l$-forbidden nature of the $\Delta l$=2 ($2s_{1/2} - 1d_{3/2}$) $M1$ transition, in contrast to our measurement of a rather fast transition.

In order to understand the properties of these two low-lying levels and the measured half-life, shell-model calculations have been performed for $^{129}$Sn using a realistic two-body effective interaction. This interaction has been derived [18] in the hole-hole formalism starting from the CD-Bonn potential [19], renormalized by means of the $V_{\rm low-k}$ approach with a cut-off momentum $\Lambda$=2.2 fm$^{-1}$. In our calculations, $^{132}$Sn is considered as a closed core with neutron holes occupying the five orbitals $0g_{7/2}$, $1d_{5/2}$, $1d_{3/2}$, $2s_{1/2}$, $0h_{11/2}$ of the 50-82 shell. The single-hole energies were taken from the experimental spectrum of $^{131}$Sn. Proton and neutron excitations across the 50 and 82 shells were not explicitly included in the calculations but accounted for by the core polarization contributions to the effective interaction. Based on previous studies in the region, the matrix elements for the $J^\pi = 0^+$ channel were reduced by a factor of 0.9. More details about the derivation of the effective interaction can be found in [20]. No other adjustable parameters were needed in the calculations.

The calculated excitation energy of the yrast $1/2^+$ state is 294 keV, which is in very close agreement with the experimental value of 315 keV. Its wave function configurations as well as those of the $3/2^+$ ground state are provided in Table II. Only configurations with a percentage $\geq 5\%$ are reported for the $3/2^+$ and $1/2^+$ state, both of which are characterized by one neutron hole in the $1d_{3/2}$ and $2s_{1/2}$ orbital, respectively. It can be observed that the wave functions of both states are essentially composed of the configurations with the two remaining neutron holes in the $0h_{11/2}$ and $1d_{3/2}$ orbitals, the former being the dominant one.

With an effective neutron charge $e^{\rm eff} = 0.7e$ and $g$-factors equal to $g_l^{\rm free}$, $g_s = 0.7 g_s^{\rm free} = -2.68$ [20], the resulting reduced transition probabilities are $B(E2, 1/2^+ \to 3/2^+) = 32.89$ $e^2$fm$^4$ and $B(M1, 1/2^+ \to 3/2^+) = 0.58 \times 10^{-4}$ $\mu_N^2$. Then, using the conversion coefficients 0.030 and 0.025 for the $E2$ and $M1$ transition, respectively [17], as well as the experimental excitation energy for the $1/2^+$ state, we obtain the transition probabilities $T(E2) = 0.13 \times 10^9$ s$^{-1}$ and $T(M1) = 0.03 \times 10^9$ s$^{-1}$, leading to a half-life of $T_{1/2} = 4$ ns, which clearly overestimates the experimental value by two orders of magnitude.

TABLE II. Percentage of the wave-function configurations for the $3/2^+$ ground state and the $1/2^+$ 315-keV state in $^{129}$Sn. One of the three neuron holes is always occupying the $1d_{3/2}$ and $2s_{1/2}$ orbitals in the case of the $3/2^+$ and $1/2^+$ states, respectively (see text for details).

| $J^\pi$ | $(nl_j)^{-2}$ | | | | |
|---|---|---|---|---|---|
| | $(0h_{11/2})^{-2}$ | $(1d_{3/2})^{-2}$ | $(2s_{1/2})^{-2}$ | $(1d_{5/2})^{-2}$ | $(0g_{7/2})^{-2}$ |
| $3/2^+$ | 69% | 12% | 8% | 6% | 5% |
| $1/2^+$ | 60% | 27% | 7% | | 5% |

TABLE III. Comparison between the single-hole neutron $M1$ matrix elements (in $\mu_N$) obtained using $g_l^{\rm free}$, $g_s = -2.68$ and those of the effective $M1$ operator (see text for details).

| $a$ | $b$ | $\langle a\|\|M1\|\|b\rangle$ | $\langle a\|\|M1\|\|b\rangle_{\rm eff}$ |
|---|---|---|---|
| $0g_{7/2}$ | $0g_{7/2}$ | 1.65 | 1.36 |
| $0g_{7/2}$ | $1d_{5/2}$ | 0 | 0.15 |
| $1d_{5/2}$ | $1d_{5/2}$ | -1.92 | -1.89 |
| $1d_{5/2}$ | $1d_{3/2}$ | 2.05 | 1.88 |
| $1d_{3/2}$ | $1d_{3/2}$ | 1.02 | 1.05 |
| $1d_{3/2}$ | $2s_{1/2}$ | 0 | 0.10 |
| $2s_{1/2}$ | $2s_{1/2}$ | -1.62 | -1.61 |
| $0h_{11/2}$ | $0h_{11/2}$ | -2.49 | -2.48 |

An effective $M1$ operator has been devised in order to reconcile experiment and theory. In fact, due to the structure of the $3/2^+$ and $1/2^+$ wave functions, no substantial changes can be produced by modifying the $E2$ operator. The calculation of the matrix elements of the $M1$ effective operator is performed by means of many-body perturbation theory, which is consistent with our derivation of the effective two-body interaction. In this way, the single-particle matrix elements (ME) of the free $M1$ operator are modified, and in particular the off-diagonal $\langle 1d_{3/2}||M1||2s_{1/2}\rangle$ ME becomes different from zero. It is worth noting that even a slight modification of this ME would entail a significant change in the $M1$ transition rate because of the sizeable value of the corresponding one-body transition density ($\sim 0.9$).

The calculated effective $M1$ matrix elements are listed in Table III and compared to those obtained using $g_l^{\rm free}$, $g_s = -2.68$. The $\langle 1d_{3/2}||M1||2s_{1/2}\rangle$ effective ME is $0.10\,\mu_N$, whereas the other ME are only slightly modified.

With these $M1$ matrix elements, we obtain $B(M1, 1/2^+ \to 3/2^+) = 0.55 \times 10^{-2}$ $\mu_N^2$, which leads to the transition probability $T(M1) \sim 3.42 \times 10^9$ s$^{-1}$. Using for the T(E2) the value reported above, the half-life of the $1/2^+$ becomes 195 ps, which is still an order of magnitude larger compared to the experimental data, but clearly different from the previous calculated value indicating that the short half-life of the $1/2^+$ level

in $^{129}$Sn can be explained as due to the renormalization of the bare $M1$ operator induced by core-polarization effects.

## IV. SUMMARY AND CONCLUSIONS

The half-life of the lowest $1/2^+$ state in $^{129}$Sn populated in the $\beta^-$ decay of $^{129}$In is reported for the first time. The measurement was carried out at the recently-commissioned ISOLDE Decay Station.

The 315.3-keV $1/2^+$ state is expected to have a configuration dominated by the $\nu s_{1/2}$ single particle orbit while the $3/2^+$ ground state is expected to be predominantly the $\nu d_{3/2}$ state. Therefore it is expected that they are connected by a retarded $l$-forbidden $M1$ transition. The advanced time-delayed $\beta\gamma\gamma(t)$ fast-timing method has been used to measure the 315.3-keV level half-life, yielding a value $T_{1/2}$ =19(10) ps, and implying an enhanced transition rate of $B(M1)$ =0.036(19) W.u.

Realistic shell-model calculations, with an effective interaction derived from the CD-Bonn nucleon-nucleon potential lead to a 4 ns half-life for the $1/2^+$ level, when standard effective charge and g-factors are employed. However, by using an effective $M1$ operator derived within the same framework of the effective interaction, we calculate a half-life that is 20 times shorter, closer to the experimental value.

In conclusion, the short half-life of the $1/2^+$ level in $^{129}$Sn does not necessarily imply a change in the shell structure, but can be explained as due to the renormalization of the $M1$ operator.

It will be of great interest extending this investigation to the next odd Sn isotope, $^{131}$Sn, the nearest neighbour below $^{132}$Sn in the 50−82 shell. Furthermore, it will be important to probe the interactions for neutron particles in the 82−126 shell for $^{133}$Sn, across the N=82 gap.

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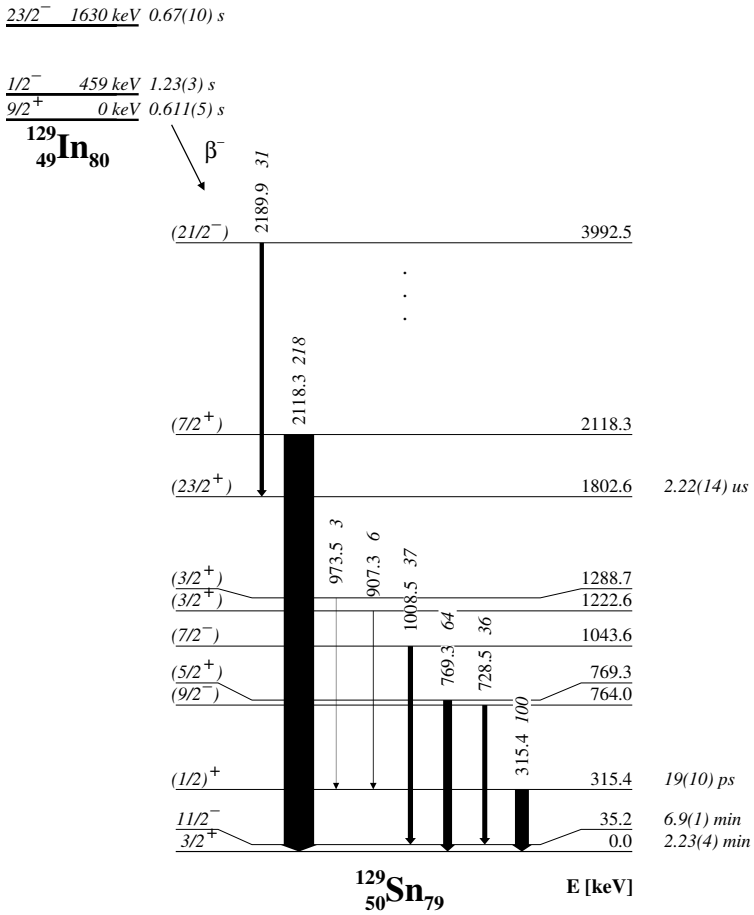


FIG. 1. Partial level scheme of $^{129}$Sn [8] populated from the mixture of the three $\beta$-decaying isomers of $^{129}$In indicating the $\gamma$-rays relevant to the analysis. The intensities obtained in the present experiment are given relative to the 315-keV $\gamma$ ray.

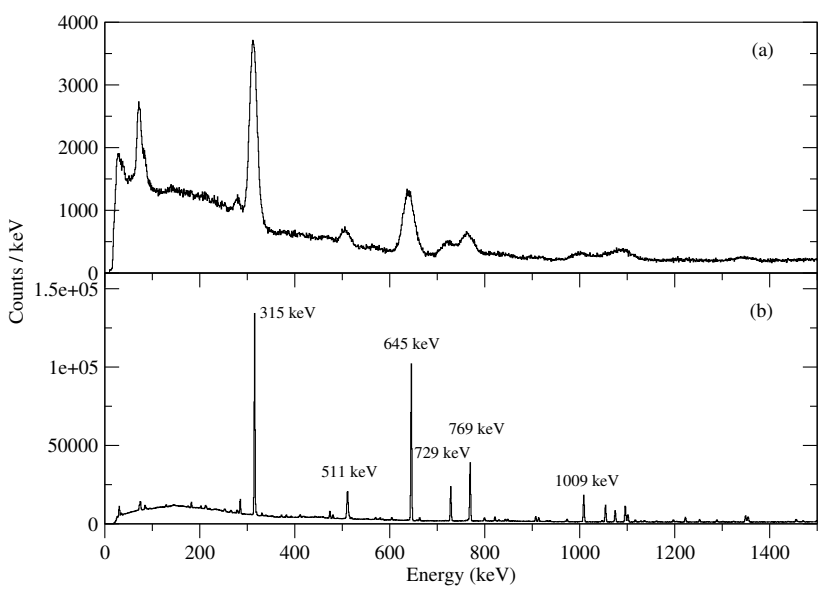


FIG. 2. $\beta$-gated $\gamma$-ray energy spectra recorded by (a) the $LaBr_3$(Ce) and (b) the HPGe $\gamma$-ray detectors. The main $\gamma$ rays belong to the decay of $^{129}$In. No contaminants were observed.

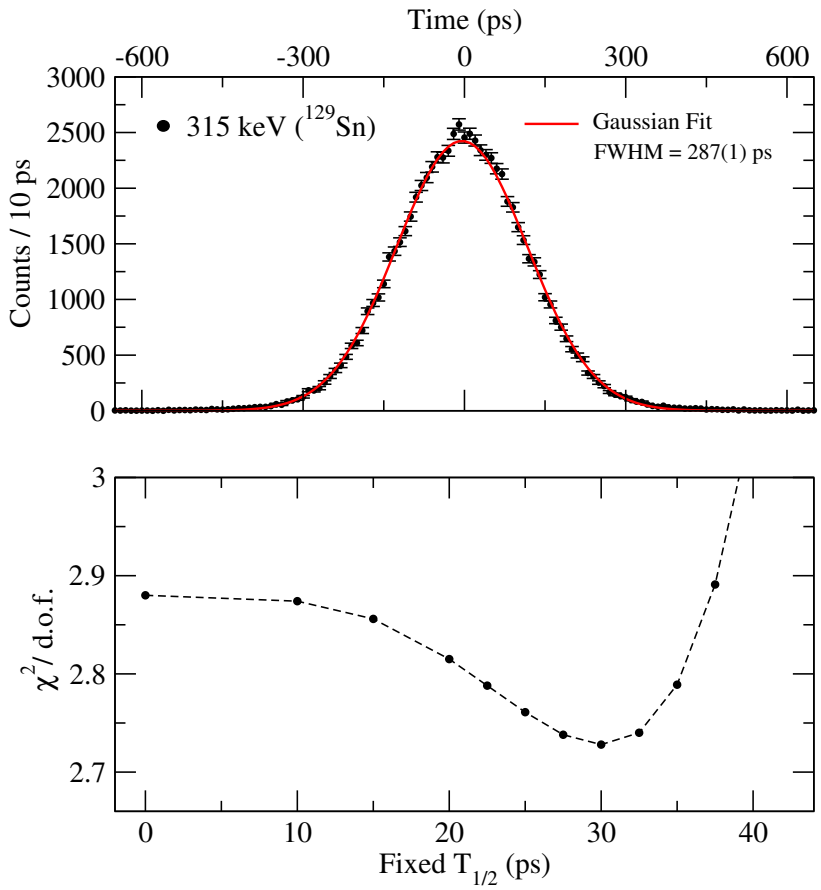


FIG. 3. (Color online) Time distribution and Gaussian fit of the 315-keV $\gamma$ ray in the $LaBr_3$(Ce) detectors relative to the $\beta$ particles recorded by the plastic scintillator. The Compton background is not subtracted (due to a different energy-time response of the neighbouring regions) and not considered in the fit. The second plot shows the $\chi^2$/d.o.f. vs. half-life dependence when the time distribution is fitted with a convolution of a Gaussian and an exponential function.

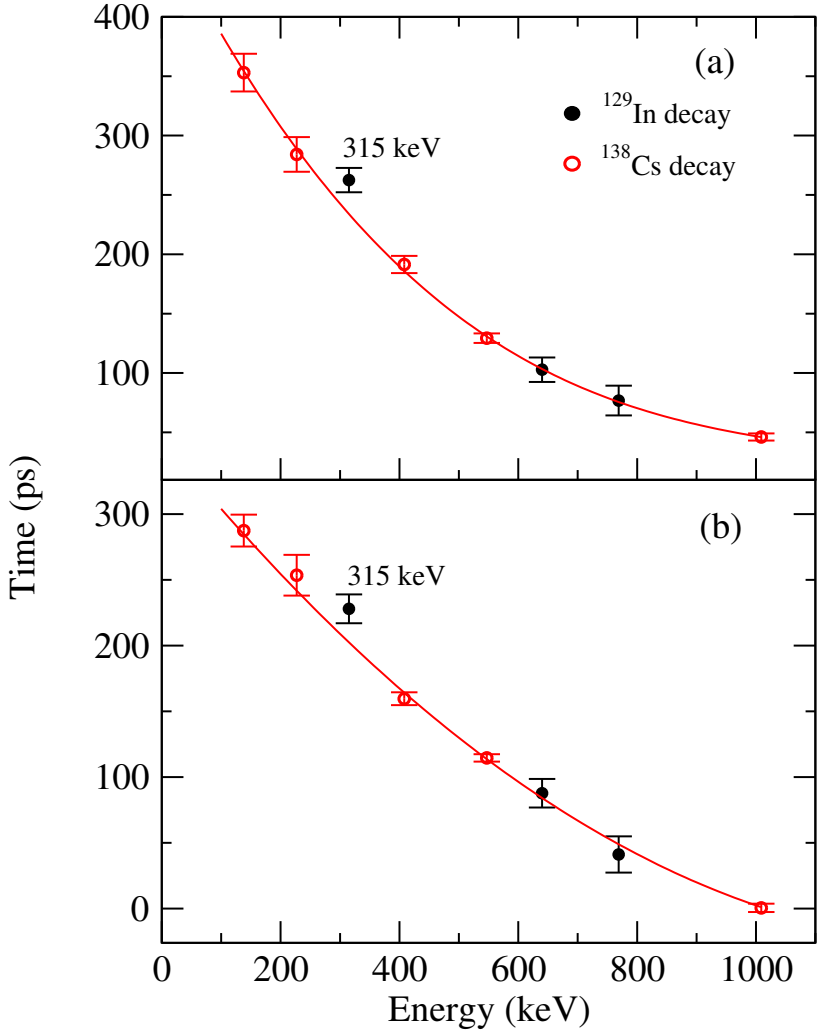


FIG. 4. (Color online) The red curve is a quadratic fit of the prompt time response of each $LaBr_3$(Ce) detector, (a) and (b), relative to the plastic scintillator. The time centroids were determined using the transitions from $^{138}$Ba listed in Table I. For both $LaBr_3$(Ce) detectors, the 315-keV centroid is slightly shifted with respect to the red curve due to the lifetime of the level.

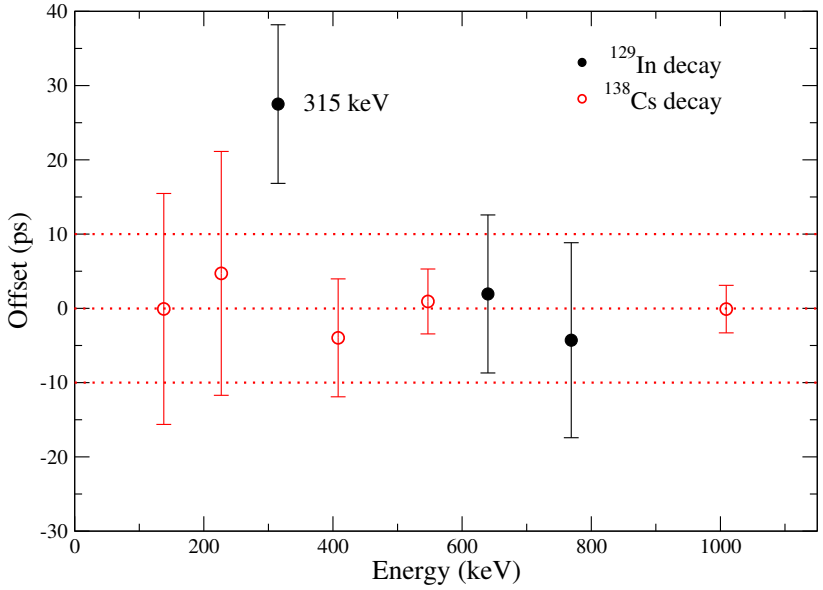


FIG. 5. (Color online) Difference (offset) between each $\gamma$-ray time distribution centroid and the quadratic fit representing the prompt detector response shown in Fig. 4. Each point is the average of the values obtained from the two $LaBr_3$(Ce) detectors. The only point with a significant offset $\tau = 28(15)$ ps is the 315-keV centroid which translates into a half-life of $T_{1/2} = 19(10)$ ps.