LIFETIME MEASUREMENT OF THE FIRST $9/2^+$ STATE IN ^{65}GE THROUGH THE IN-BEAM FAST TIMING TECHNIQUE

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The paper reports on the experimental investigation of the weak $^{58}Ni(^{12}C,\alpha n)^{65}Ge$ fusion-evaporation channel for a beam energy of 58 MeV. The experiment was performed at the 9MV TANDEM accelerator of IFIN-HH, with the ROSPHERE array configured for in-beam fast timing measurements. The main purpose of this paper is to present an example of lifetime extraction with the use of both fast scintillators and HPGe detectors.

Keywords: gamma spectroscopy, fast timing, lifetime measurements.

1. Introduction

The fast timing method was developed from the beginnings of experimental nuclear physics[1,2], but its usage peaked after more recent developments in the production of fast scintillators and high resolution timing data acquisition systems. Modern experimental setups contain detectors bearing the best compromise between timing and energy resolution. It is also the case of ROSPHERE[3], a 4π gamma radiation detection setup engineered to fit a mixed configuration of $LaBr_3(Ce)$ crystals coupled to fast photomultipliers, for an adequate timing resolution for sub-nanosecond lifetime measurements[4], and a variety of HPGe detectors which can be used, in this case, to apply precise coincidence gates, due to their good energy resolution.

Recently, an experiment concerning the study of E1 transition strengths in ^{67}As was performed at IFIN-HH. Excited states of ^{67}As were populated through a $^{58}Ni(^{12}C,p2n)$ fusion-evaporation reaction at a beam energy of 58 MeV, with a relatively weak cross section representing around 1-2% of the total fusion cross section, based on both CASCADE[5] and PACE4[6] simulations. The reaction yielded many other more favorable exit channels, such as $(n2p)^{67}Ge$, $(3p)^{67}Ga$, $(\alpha np)^{64}Ga$ and $(\alpha 2p)^{64}Zn$. However, among the weaker channels, around half of that of ^{67}As, was $(\alpha n)^{65}Ge$. The statistics for gamma lines of this reaction product

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was sufficient to extract the lifetime of the first $9/2^+$ state in ^{65}Ge through the in-beam fast timing method and the obtained results are reported and compared with previous findings[7].

2. Experimental details

To populate and observe excited states in ^{65}Ge nuclei through a fusion-evaporation process, a few conditions had to be met. Firstly, a target of 5 mg/cm^2 ^{58}Ni on 5 mg/cm^2 Au backing(see Fig. 1) was produced in the target lab of the Department for Nuclear Physics of IFIN-HH[8]. The target was then placed in vacuum in a reaction chamber at the end of the 9MV TANDEM accelerator beam line, where the ROSPHERE array resides. ^{12}C ions were accelerated to an energy of 58 MeV and impinged upon the ^{58}Ni target, where fusion-evaporation processes occurred, with a total interaction cross section of about one barn, as predicted by CASCADE and PACE4 calculations.

Fig. 1. ^{58}Ni target produced for the experiment in discussion.

Excited states of the produced nuclei were observed with the ROSPHERE array, containing at the time of experiment a combination of 14 HPGe detectors and 11 $LaBr_3$(Ce) scintillator crystals coupled to fast photomultiplier tubes. The CAMAC data acquisition system(DAQ) registered the valid time and energy events which were processed with a series of signal amplifiers, constant fraction discriminators(CFD), time-to-amplitude converters(TAC), coincidence modules, time-to-digital converters(TDC) and analog-to-digital converters(ADC). The detection chain is described in detail in Ref. [3]. The DAQ was triggered by fulfilling the condition that at least two $LaBr_3$(Ce) detectors and one HPGe detector would register events within a narrow temporal coincidence window.

Thus, $LaBr_3$(Ce)-$LaBr_3$(Ce) energy coincidence matrices could be cleaned, by applying a precise HPGe energy gate on a coincident transition. The analysis process will be further detailed in the following section.

Lifetime extractions through the in-beam fast timing method imply a number of corrections and calibrations to make sure that energy and time gates are applied precisely. Prior to the experiment, ^{152}Eu source runs have been recorded to perform energy calibrations on the experimental runs up to 1.4 MeV.

Variations in temperature and counting rates during the whole measurement period lead to differences in energy spectrum gains. To eliminate these variances, a run by run energy calibration was performed for each detector using an automatic algorithm for $LaBr_3$(Ce) energy gain corrections[9].

The hardware timing corrections included the delay alignment of all 25 detectors and fine-tuning for the zero-crossing of the CFDs to correct the dependency between the prompt response and the amplitude of the $LaBr_3$(Ce) signal(walk). The temporal alignment and time-energy walk were further corrected in the offline analysis with the use of data recorded from a ^{60}Co source, as well as from prompt coincidences during the experiment.

3. Data analysis

After 14 days of beam time, a total of 162 2-hour runs were collected and the data was analyzed with the aid of the GASPware package. It is important to mention that, due to a significant abundance of exit channels in this reaction, the

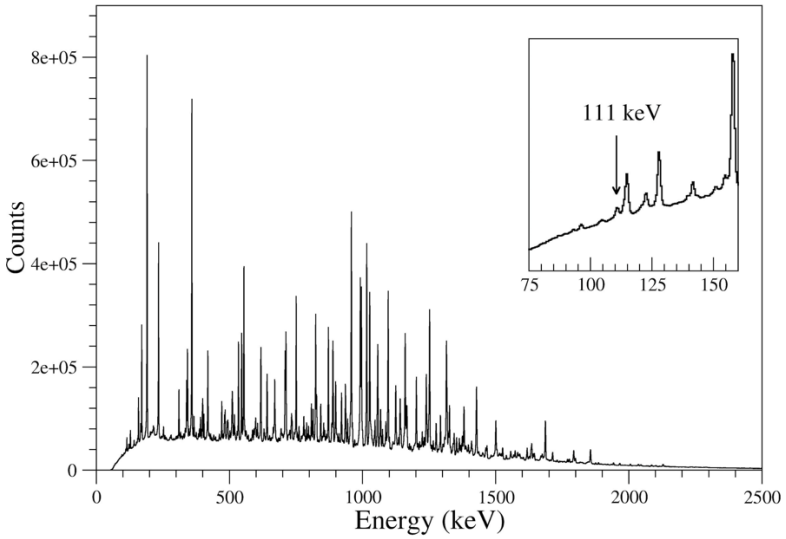

Fig. 2. Total projection of the HPGe energy-energy coincidence matrix representing all events gathered within the 14-day experiment. The inlay graph is an expanded region of the spectrum, where the $5/2^- \rightarrow 3/2^-_{gs}$ transition in ^{65}Ge can be seen emerging from the background.

HPGe-HPGe coincidence energy spectrum was populated with a high amount of gamma lines(Fig. 2). Since the $(\alpha n)^{65}$Ge exit channel had a very weak cross section, it was fairly difficult to distinguish transitions between its excited states.

It is then clear that, for the significantly lower resolution $LaBr_3$(Ce) energy spectra, multiple peaks would overlap, making a precise analysis cumbersome. To obtain much cleaner $LaBr_3$(Ce)-$LaBr_3$(Ce)-time difference matrices, a gate on coincident HPGe events was more than necessary.

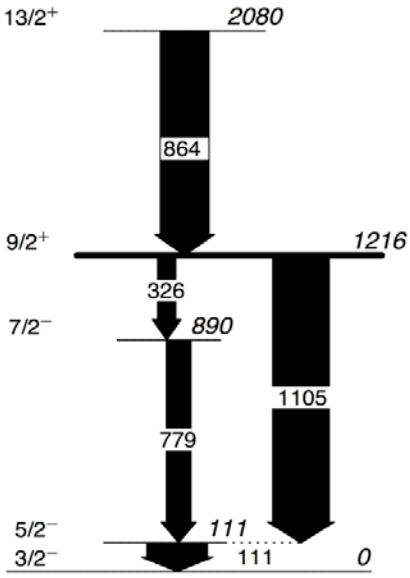

Fig. 3. Partial level scheme of ^{65}Ge.

A careful review of the germanium spectrum revealed the $5/2^- \rightarrow 3/2^-_{gs}$, 111-keV transition(inlay, Fig. 2), making it the primary candidate for a proper coincidence gate. Once the germanium gate was applied, the LaBr spectrum revealed multiple individual gamma lines(Fig. 4) in coincidence which could be used as START and STOP gates to obtain a time difference spectrum for the first $9/2^+$ state in ^{65}Ge. Namely, the 864-keV transition populating the state had the natural START role, while the 326-, 779- and 1105-keV transitions below the isomer were selected individually as STOP. The time distributions for the three cases were then summed to increase the amount of statistics.

Knowing that the $9/2^+$ state is a rather long-lived isomer, the intermediate $7/2^-$ state fed by the 326-keV transition and de-excited by the 779-keV transition would negatively contribute to the time distribution by increasing the number of events in the prompt component, while also increasing the number of events in the exponential decay component associated to the isomer.

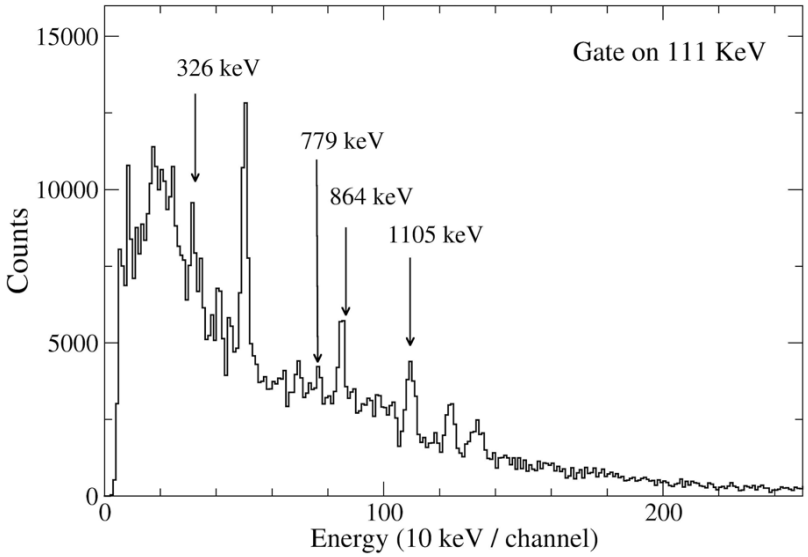

Fig. 4. Total projection of the LaBr energy-energy coincidence matrix after applying the 111-keV HPGe coincidence gate. Due to low statistics and an energy resolution inferior to HPGe detectors, the energy axis was binned down to 10 keV per channel. Peaks associated to transitions in ^{65}Ge used for obtaining a time distribution for the $9/2^+$ isomer are labelled.

The resulting time distribution(Fig. 5) confirmed the presence of an isomer, as stated in Ref. [7]. The rather significant prompt component is justified by the lack of proper background subtraction, due to low peak-to-background ratios. However, the exponential decay component of the time distribution has a single slope, and so, the half-life of the isomer could be validly extracted as $T_{1/2} = 4.2(3)$ ns.

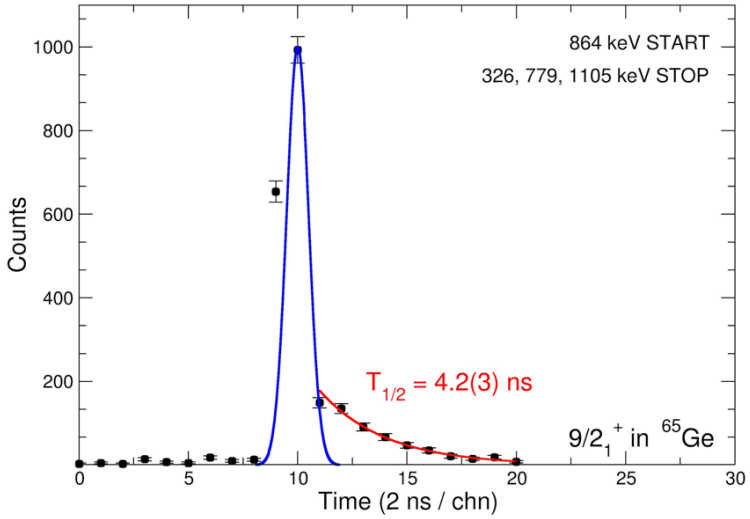

Fig. 5. Experimentally obtained time distribution for the first $9/2^+$ state in ^{65}Ge.

The extracted half-life greatly differs from the previously reported $T_{1/2}$ = 7(1) ns in Ref. [7] and thus points to a new B(M2; $9/2^+ \rightarrow 5/2^-$) value of 0.18(1) Weisskopf units(W.u.). This value, though, is still fairly consistent with the systematics of the $\nu_{9/2}$ states of nuclei in the mass region.

4. Conclusions

The lifetime of the $9/2_1^+$ isomer in ^{65}Ge was extracted for the first time through the in-beam fast timing method applied to fast scintillators, offering a more precise value than was reported in the initial 1987 paper. The current paper demonstrates the usefulness of the method and aims to offer a few brief guidelines through a relevant example.

R E F E R E N C E S

[1]. *T.D. Newton et al.*, Decay constants from coincidence experiments, Physical Review Journal, **Volume 79**, 1950, Page 490.

[2]. *R.E. Bell et al.*, Measurement of a second half-life in Yb^{170}, Physical Review Journal, **Volume 79**, 1950, Page 491.

[3]. *D. Bucurescu et al.*, The ROSPHERE gamma-ray spectroscopy array, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, **Volume 837**, 21 November 2016, Pages 1-10

[4]. *N. Marginean et al.*, In-beam measurements for sub-nanosecond nuclear lifetimes with a mixed array of HPGe and $LaBr_3$:Ce detectors, European Physics Journal A: Hadrons and Nuclei, **Volume 46**, 2010, pages 329-336.

[5]. *V.S. Barashenkov et al.*, CASCADE/INPE code system, Atomic Energy, **Volume 87**, No 4, 1999

[6]. *O.B.Tarasov, D.Bazin*, Nuclear Instruments and Methods in Physics Research Section B, **Volume 266**, 2008, 4657-4664V.

[7]. *J. Görres et al.*, Structure of the very neutron-deficient Ge region: ^{64}Ge and ^{65}Ge, Physical Review Letters, **Volume 58**, Number 7, 16 Feb 1987, 662-665.

[8]. *N.M. Florea et al.*, The status of the target preparation laboratory at IFIN-HH Bucharest, Romania, Journal of Radioanalytical and Nuclear Chemistry, **Volume 305**, Sept 2015, pp. 707-711.

[9]. *R. Lica.*, Gain correction algorithm for $LaBr_3$(Ce) detectors, UPB Scientific Bulletin Series A, **Volume 78**, Issue 3 2016, ISSN 1223-7027.