Lifetime measurements in A∼100 nuclei using $LaBr_3$(Ce) arrays.

A.M. Bruce[1,*]

[1]School of Computing, Engineering and Mathematics, University of Brighton, Brighton, BN2 4GJ, UK.

Abstract. The region of the nuclear chart around neutron-rich A∼100 nuclei is one where prolate and oblate nuclear shapes are predicted to be in close competition. An indirect measurement of the shape of the nucleus can be obtained from measuring level lifetimes which relate, via transition rates, to β_2 deformation. In order to make measurements of level lifetimes in the sub nanosecond range an array of 36 $LaBr_3$(Ce) detectors has been constructed for use at the FAIR facility in Darmstadt, Germany. This presentation will give an overview of the array and examples of its use in commissioning experiments at the RIKEN Nishina Center in Japan and the Argonne National Laboratory in the USA.

1 Introduction

An array of 36 $LaBr_3$(Ce) detectors [1, 2] has been designed and procured for use at the FAIR facility in Germany. It uses detectors of diameter 38.1 mm and length 50.8 mm, a size selected as a balance between timing resolution (favouring smaller detectors) and efficiency (favouring larger detectors). The array is predicted to have an efficiency of ∼10% at 1.5 MeV [1] and is planned to operate using a digital data acquisition system. In order to ensure correct operation of the array, it has been commissioned in a range of configurations, more details of which are given below.

2 Commissioning experiments with FATIMA

2.1 Lifetimes in $^{102-106}$Zr using FATIMA in coincidence with EURICA

Fission fragments were produced at the Radioactive Isotope Beam Factory, operated by the RIKEN Nishina Center and the Center of Nuclear Study, University of Tokyo using the in-flight abrasion fission of a $^{238}U^{86+}$ beam of average intensity 6.24×10^{10} particles/s accelerated to an energy of 345 MeV/nucleon. The fission fragments were selected and separated by the Big RIKEN Projectile Fragment Separator (BigRIPS) and implanted into the Wide-range Active Silicon Strip Stopper Array for β and Ion detection (WAS3ABi) [3], which detected ion implantations and their subsequent β-decay electrons. For this experiment, WAS3ABi comprised 5 layers of double-sided silicon-strip detectors placed 0.5 mm apart, each with 60 vertical and 40 horizontal strips of width and depth 1 mm.

*e-mail: alison.bruce@brighton.ac.uk

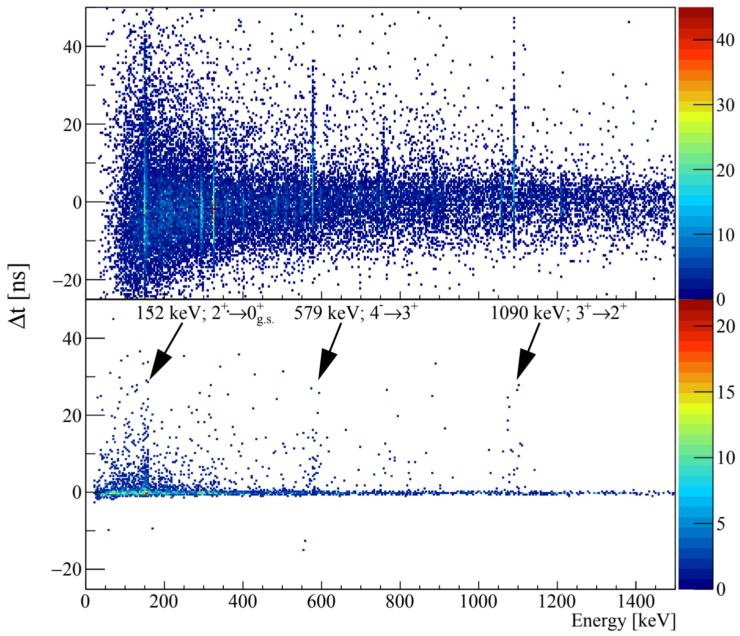

Figure 1. Energies and relative times of γ rays observed in EURICA (top) and the $LaBr_3$(Ce) array (bottom) following the β-decay of ^{102}Y. This figure shows very clearly the power of using $LaBr_3$(Ce) detectors rather than germanium detectors for measuring lifetimes in the sub-nanosecond range.

Fast-timing measurements were carried out by adding an array of 18 $LaBr_3$(Ce) detectors to the EUROBALL-RIKEN cluster array (EURICA) [4]. Figure 1 shows energy-time matrices for transitions in ^{102}Zr produced in the β decay of implantated ^{102}Y ions [5]. For the Δt measurement, the time of the β decay was measured using plastic scintillators placed up-stream and down-stream of WAS3ABi. While the delayed components of the 152-, 579- and 1090 keV peaks are clearly evident in the $LaBr_3$(Ce) spectrum (bottom), they are masked by noise in the spectrum measured in the germanium detector (top). The 152-, 579- and 1090 keV transitions in ^{102}Zr are produced in the decay of the $(\nu\frac{5}{2}[532]\otimes\frac{3}{2}[411])\ 4^-$ state and figure 2 shows the sum of the background-subtracted time-difference projections of the 579- and 1090 keV transitions which have been fitted to give a level lifetime of τ = 9.5(7) ns [5]. The hindrances of the de-exciting γ-ray transitions are consistent with the systematics of the level being a K-isomer and with the decay of the known K-isomer in the isotone ^{100}Sr [6].

In the same experiment, the lifetimes of the 2_1^+ states in ^{104,106}Zr have been measured, following the β decay of implanted ^{104,106}Y ions, to be 2.90^{+25}_{-20} ns and 2.60^{+20}_{-15} ns respectively [7] corresponding to ground-state deformations of $|\beta_2|$ = 0.39(1) and 0.31(1) e^2b^2. The magnitude of these deformations is inconsistent with the oblate solutions of Hartree-Fock-Bogolyubov (HFB) calculations employing the Gogny-D1S interaction which indicate $|\beta_2|$ deformations of $\sim$ 0.1 [8], but supports the conclusion that the neutron-rich Zr nuclei retain a prolate shape.

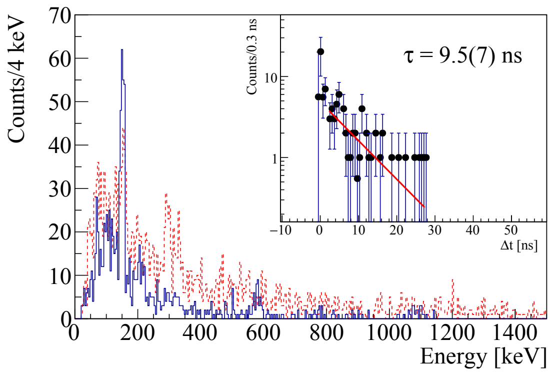

Figure 2. The gamma-ray energy spectra measured in the $LaBr_3$(Ce) detectors in prompt ($\Delta t < \pm 0.5$ ns, red) and delayed ($0.5 < \Delta t < 50$ ns, blue) coincidence with an electron emitted in the β decay of implantated ^{102}Y ions. The inset shows the sum of the background-subtracted time spectra for the 579- and 1090 keV transitions and the associated fit which yields a lifetime of $\tau = 9.5(7)$ ns for the 4^- state at 1821 keV in ^{102}Zr.

2.2 Lifetimes in ^{100}Zr using FATIMA in coincidence with Gammasphere

In a separate experiment at Argonne National Laboratory, fission fragments produced from the decay of a 34.4 μCi ^{252}Cf source, placed at the centre of a hybrid array, were studied. The array comprised 25 $LaBr_3$(Ce) detectors arranged in a hemisphere coupled with half of the Gammasphere [9] germanium detector array (51 detectors). Lead shields were used to avoid crosstalk between neighbouring $LaBr_3$(Ce) detectors. Two separate data sets were collected, one, to be used for spectroscopy, contained fold ≥ 3 events registered in Gammasphere while the other, to be used for lifetime measurements, collected fold ≥ 2 events in the $LaBr_3$(Ce) array which were in coincidence with fold ≥ 1 events in Gammasphere. The coincidence window between Gammasphere and the $LaBr_3$(Ce) array was 500 ns. In addition to the fact that the $LaBr_3$(Ce) detectors have poor energy resolution, γ-ray spectra from fission sources are always very messy. Therefore gates need to be set on transitions in Gammasphere in order to clean the $LaBr_3$(Ce)-$LaBr_3$(Ce) data sufficiently to allow timing measurements to be made. Figure 3 shows an example of one such procedure where a $LaBr_3$(Ce)-$LaBr_3$(Ce) E_γ-E_γ-Δt cube has been constructed gated on the 212- and 626 keV $2^+ \rightarrow 0^+$ and $8^+ \rightarrow 6^+$ transitions in ^{100}Zr. The coincidence between the 351 keV $4^+ \rightarrow 2^+$ and 497 keV $6^+ \rightarrow 4^+$ transitions in ^{100}Zr is clearly evident in the figure. The time spectra shown in figure 4 have then been obtained by subtracting peak/background and background/peak gated (enclosed by 2 black and 2 red lines) time spectra from the peak/peak gated (four black lines) time spectra and adding the background/background gated (four red lines) time spectra to avoid double counting.

Figure 4 shows the delayed and anti-delayed time-difference spectra for the 351 keV $4^+ \rightarrow 2^+$ and 497 keV $6^+ \rightarrow 4^+$ transitions in ^{100}Zr. The difference between the centroids of the distributions ΔC is measured to be 225(15) ps. The prompt response difference (PRD), obtained for this combination of energies from ^{152}Eu calibration data, is 124(7) ps. The lifetime of the level calculated from $2\tau = \Delta C - PRD$ [10] is then 51(9) ps. This value is consistent with the literature value of $\tau = 53(4)$ ps [11] but slightly larger than the value

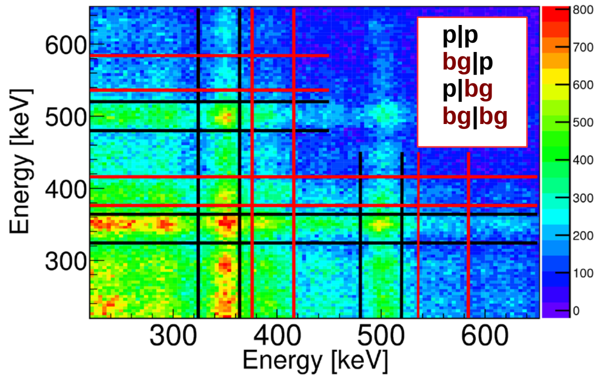

Figure 3. The projection of the $LaBr_3$(Ce)-$LaBr_3$(Ce) E_γ-E_γ-Δt cube measured in coincidence with the $2^+ \rightarrow 0^+$ and $8^+ \rightarrow 6^+$ transitions in ^{100}Zr observed in Gammasphere.

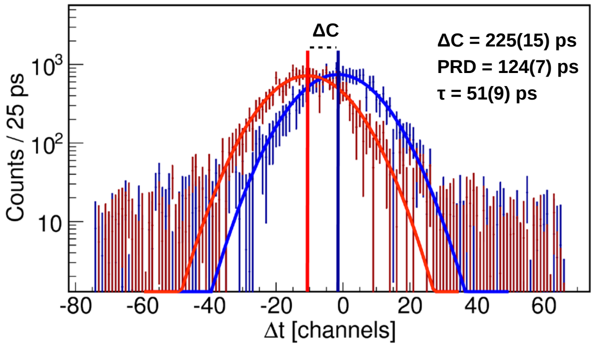

Figure 4. The background-subtracted delayed and anti-delayed time-difference spectra for the 351 keV $4^+ \rightarrow 2^+$ and 497 keV $6^+ \rightarrow 4^+$ transitions in ^{100}Zr.

of τ = 37(4) ps [12] obtained in the recent EXILL-FATIMA campaign at the Institut Laue-Langevin in Grenoble, France.

3 Conclusions

The data presented show that subsets of the 36 element $LaBr_3$(Ce) detector array have been installed, commissioned and tested successfully in coincidence with EURICA and with Gammasphere. An additional configuration has been used successfully during the AGATA campaign at GANIL in 2017 [13]. The full array will now be installed at GSI/FAIR and used for FAIR phase-0 experiments in Sept/Oct 2018.

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