Test and calibration of the IDS fast-timing electronics

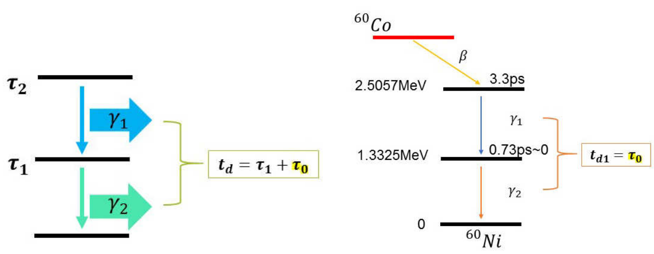
Jindaratsamee Phrompao
Chiang Mai University, Thailand

Supervisor
Razvan Lica
ISOLDE Decay Station at ISOLDE, CERN

Abstract
The ISOLDE decay station(IDS) is one of the permanent experimental setups at the ISOLDE facility of CERN. IDS is used to study decay properties of radioactive nuclei. Thus, fast-timing electronics are necessary for extracting nuclear half-lives. The aims of this work are testing and optimization of the IDS fast-timing electronics as well as measuring a nuclear level half-life in the decay of ^{152}Eu. The energy resolution of $LaBr_3$ γ-detectors was characterized and optimized. A nuclear level lifetime of ^{152}Eu was measured after obtaining the best parameters for energy resolution and time walk. Dedicated sorting scripts were developed in ROOT [1] in order of perform the characterization and optimization automatically.

1 Introduction

An approach to investigate nuclear structure is nuclear level lifetime measurement. Generally, level lifetimes are extremely short, on the order of nanoseconds or picoseconds and nuclear lifetime measurement is based on $\gamma - \gamma$ or $\beta - \gamma - \gamma$ coincidences. To achieve this, the only requirement is combination of fast beta and gamma detectors with fast-timing electronics:"the fast-timing technique" [2]. Consider figure 1(a), which shows a two-level decay. There are two sequential γ-transitions and τ is the lifetime of the nuclear level. When γ_1 and γ_2 are detected by fast-timing γ detectors then time difference t_d between γ_1 and γ_2 represents the lifetime τ_1 of the second excited state and the time delay τ_0 between fast-timing detectors. First of all, time delay between fast-timing detectors must be measured by using a calibration source for which the lifetime of the first excited state can be approximated as zero. Experimentally, ^{60}Co is used because, from the nuclear level scheme on figure 1(b), the state's lifetime is almost zero. Other important steps are testing and calibration of fast-timing electronics to optimize energy resolution, time walk and time resolution, performed using ^{60}Co because the nuclear level scheme is well known.

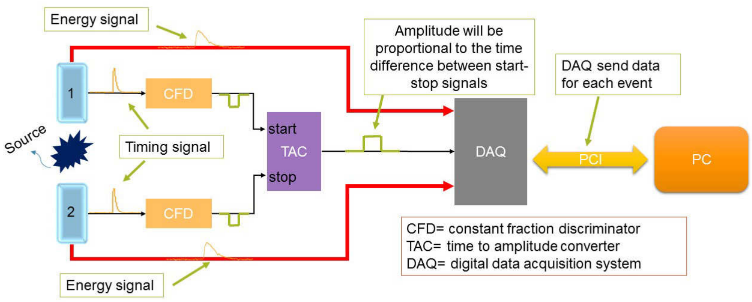


(a) (b)

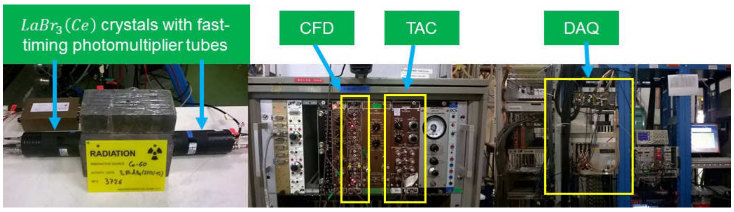
Fig. 1: (a) A two γ-transitions with time delay t_d between γ-rays. (b) A part of the nuclear level scheme of ^{60}Co [4]

2 Experimental set-up

The experimental set-up, consists of two fast-timing scintillation detectors($LaBr_3$(Ce)) and electronic modules. The detectors generate two types of signal output: energy and timing signals. The timing signals have a faster rise-time than the energy signals. The energy signals will be directly recorded by data acquisition(DAQ) but the timing signals will be analysed by constant fraction discriminator(CFD). The timing signals from detector 1 represents the start of the time to amplitude converter(TAC) unit and the timing signals from detector 2 represents the stop of the TAC unit. Then, the time difference between the start and stop signals will be extracted by TAC unit. The amplitude of TAC output will be proportional with the time difference between the two signals [4]. Figure 2(b) shows the experimental set-up, where ^{60}Co is placed between the two $LaBr_3$ γ-detectors.



(a)

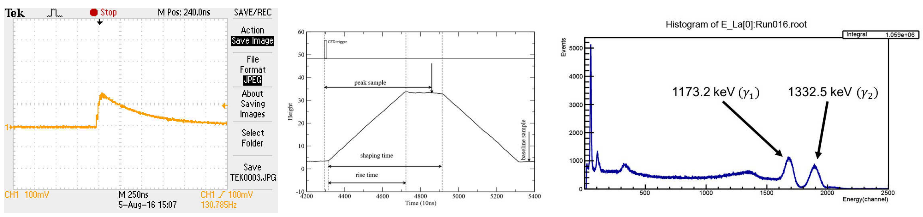


(b)

Fig. 2: (a) Schematic diagram of the experimental setup.(b) The experimental set-up for calibration of the IDS fast-timing electronics

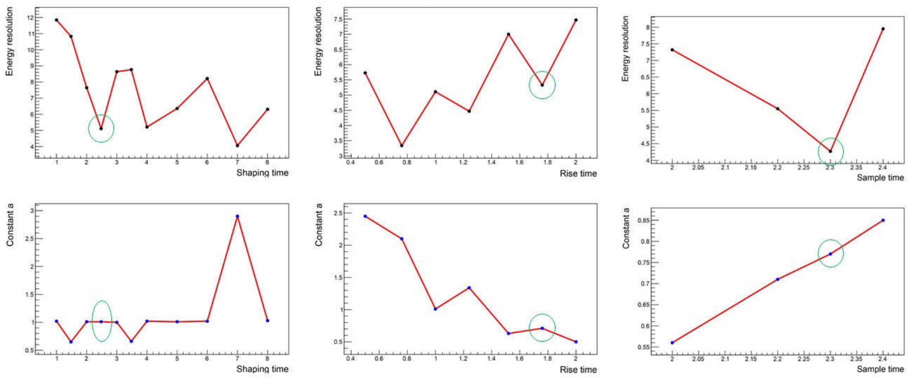
3 Optimization of the energy resolution

All the signals will register as events by the data acquisition running in a triggerless mode and each event will consist of energy and timestamp. Generally, the energy signals have fast rise time and exponential fall time as shown in figure 3(a). The data acquisition filters out random noise by using the "moving window deconvolution method" [7]. There are three main shaping parameters: rise time, shaping time and peak sample as shown in figure 3(b). The parameters also affect energy resolution and distribution of energy spectrum. Thus, optimization of the parameters is needed to have good energy resolution and proper energy distribution. A linear dependency between the channel number and the corresponding energy was considered, can be written $E(keV) = aE(channel) + b$, the constant a being the gain factor, having a desired value <1. The energy resolution is defined as $\frac{\Delta E}{E}$. ^{60}Co was used as a calibration source, which has γ-rays of 1322.5 and 1173.2 keV as shown in figure 3(c). Figure 4 shows the results from varying shaping parameters in order to optimize the energy resolution and gain, the optimal parameters were chosen as: shaping time= 2.48, rise time= 1.76, peak sample=2.3, which provided the energy resolution of 4.27% and energy gain of 0.77.



(a) (b) (c)

Fig. 3: (a) A energy signal from the $LaBr_3$ detector. (b) The shaping parameters: shaping time, rise time, sample peak (c) The energy spectrum of ^{60}Co



(a) (b) (c)

Fig. 4: Energy resolutions and gain factors (a) Varying of shaping time. (b) Varying of rise time with 2.48 of shaping time. (c) Varying of sample peak with 2.48 shaping time and 1.76 rise time.

4 Time walk optimization

First of all, the TAC is calibrated by varying the length of the delay cable between the same start and stop signal. The figure 5 shows the time delay as function of channel and the error from fitting. The time walk is the dependence of time delay with energy. There are two important parameters for the CFD, which plays an important role for time walk and time resolution. One of the parameters is external delay(Δ) and another is zero-crossing(Z_c). The time resolution will be more sensitive to external delay than zero-crossing and the time walk with very short external delay is sensitive to the Z_c [3]. In this study only the zero-crossing of the signals from a $LaBr_3$ detector was varied and both time walk and time resolution was extracted for a with 2 ns external delay. To extract the time walk, the start peak of the $LaBr_3$ γ_2 is gated and plotted between time difference and energy of the $LaBr_3$ detector. Then, the time walk is shown in a 2D representation of Time (Y) vs. Energy (X) in figure 6(a). The time walk must be corrected such that the centroid position will not depend on energy. The centroid positions are fitted with fourth order polynomial function and the time walk time walk will be corrected by using the fit function. Figure 6(a) shows time walk at Z_c=2.3 mV without correction and figure 6(b) is corrected to be time walk independent with energy. The Figure 7(a) shows the centroid position of the time distribution as a function of energy of $LaBr_3$ γ-detector with different zero-crossing values. A setting of Z_c=0 mV has the smallest walk and a small curve at low energy. When zero-crossing was changed, time resolution also slightly changed as shown in figure 7(b). The time resolution will be smaller when the CFD operates by leading edge at minus Z_c values.

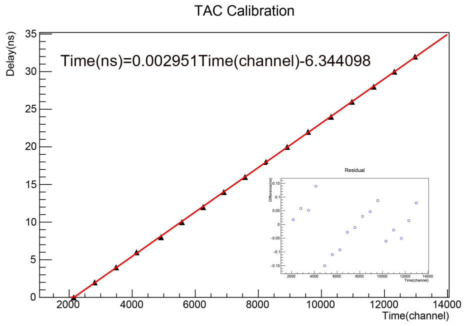
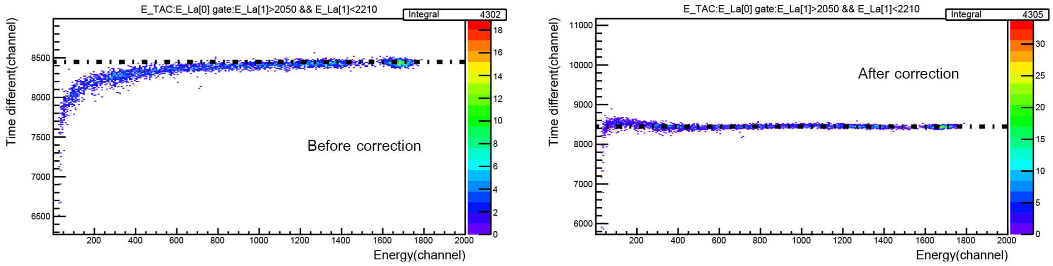
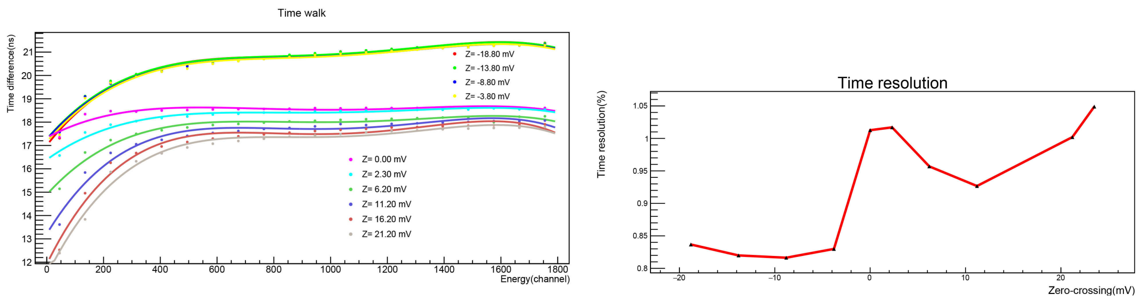


Fig. 5: The time delay as function of channel and residual plot of the linear fit



(a) (b)

Fig. 6: A setting of Z_c= 2.3 mV (a) The time walk without correction. (b) The time walk after correction by fitting with a fourth order polynomial function

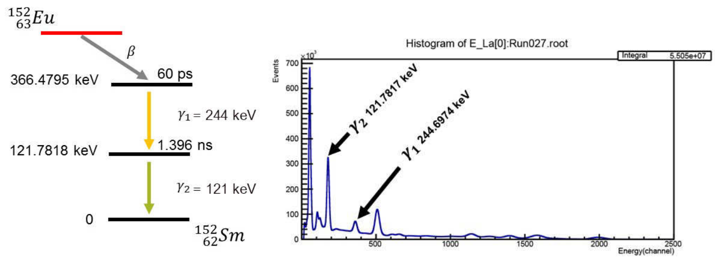


(a) (b)

Fig. 7: The time walk curves and time resolutions corresponding to different Z_c values.

5 Half-life measurement of ^{152}Eu

The zero-crossing was set at zero for both detectors and the data was collected 24 hours for good statistic in measuring a known half-life in the decay of ^{152}Eu in order to test the fast-timing setup. A part of the of ^{152}Sm level scheme populated in the decay of ^{152}Eu is illustrated in figure 8(a), the level of interest at 121.8 keV with an adopted half-life of $T_{1/2}$=1.403(11) ns [8]. The ^{152}Eu energy spectrum of $LaBr_3$ detectors is plotted in figure 8(b). The time distribution of the start(γ_1=244 keV) and stop(γ_1=121 keV) was extracted in order to determine the desired halflife. Figure 9 shows the time difference curve and was fitted with both a Gaussian and exponential function. The decay constant can be extracted from the fitting and therefore the half-life of the level is 1.419(14) ns, in very good agreement with the literature value.



(a) (b)

Fig. 8: (a) A part of nuclear level scheme of ^{152}Sm populated in the decay of ^{152}Eu. (b) Energy spectrum of the ^{152}Eu decay.

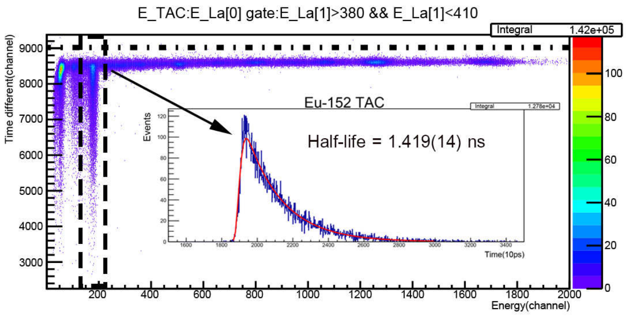


Fig. 9: The 2D time walk of ^{152}Eu and distribution of time difference by gating the 244 keV full peak

6 Conclusion

The characterization and optimization of the fast-timing setup was completed using dedicated codes in ROOT. After optimization of shaping time parameters, the best energy resolution is 4.27% and constant $a = 0.77$. At Z_c=0 mV provides the best shape for the time walk and can be easily corrected by using a polynomial function. The average time resolution for ^{60}Co of FWHM=180 ps is not very sensitive to modifying the zero-crossing, depending mainly on the CFD delay. The half-life of 121 keV in the decay of ^{152}Eu is $T_{1/2}$=1.419(14) ns in very good agreement with the adopted $T_{1/2}$=1.403(11) ns.

References

[1] https://root.cern.ch/, ROOT

[2] H. Mach, R.L Gill and M. Moszynski, A Method for Picosecond Lifetime Measurements for Neutron-Rich Nuclei, Nuclear Instruments and Methods in Physics Research Section A280(1989)49-72.

[3] V. Vedia, H. Mach, L.M. Fraile, J.M. Udias and S. Lalkovski, Enhanced Time Response of 1-Inch $LaBr_3$(Ce) Crystals by Leading Edge and Constant Fraction Techniques, Nuclear Instruments and Methods in Physics Research Section A,2015.

[4] K. Muraleedhara Varier, Nuclear Radiation Detection Measurements and Analysis, Book.

[5] Razvan Lica, Gamma Spectroscopy Following the Beta-Decay of Neutron Rich Nuclei at ISOLDE, Master thesis, University of Bucharest, 2014.

[6] Razvan Lica, Analysis Algorithm for Digital Data Used in Nuclear Spectroscopy, Bachelor thesis, University of Bucharest, 2012.

[7] Operation manual for Lyrthech digital data acquisition system at York.

[8] M. J. Martin Nuclear Data Sheets 114, 1497 (2013) 31-Aug-2013