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Comparison of resolving time values of different scintillation detectors in the coincidence experiments

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Abstract The resolving time values of the coincidence spectrometers composed by NaI(Tl) inorganic, BC408 type and BC418 type organic scintillation detectors were obtained in this work. For this purpose, fast–fast coincidence measurements were carried out. Best timing performance was obtained by BC418 type plastic scintillator for various source-detector distances.

Keywords NaI(Tl) scintillation detector · BC408 type plastic scintillation detector · BC418 type plastic scintillation detector · Fast–fast coincidence measurement

Introduction

Experiments such as mean lifetime measurements and time of flight (TOF) measurements require to measure short time intervals with a good resolution. Improving the timing resolution of a TOF measurement is directly related to better signal to noise ratio [1]. Scintillation detectors are widely used in timing experiments due to their fast responses. Investigations of their time properties have been the subjects of extensive studies in many physics experiments [2]. Organic scintillators such as BC408 and BC418 types give best timing resolution because of their fast decay times (2.1 and 1.4 ns, respectively). These are two of the polyvinyltoluene based plastic scintillators. They are low costs and have high light outputs [3]. The most commonly used inorganic material is NaI(Tl), where thallium (Tl) is the impurity activator. In general, inorganic scintillators are 2–3 orders of magnitude slower in response than organic scintillators [4].

The time resolution of a timing system can be determined by measuring the distribution of the time delays between prompt events. The figure of merit of a system is usually characterized by the full width at half maximum (FWHM) (Fig. 1) [2].

The corresponding time to 61 % of the peak amplitude is called shaping time (Fig. 1). The time required for the shaped pulse to reach its maximum amplitude is also called as the peaking time (Fig. 1) [1]. The peaking time is about three or five times greater than the shaping time for an ideal pulse shape [5].

For the time spectroscopy, the coincidence unit performs the equivalent function and selects among all the intervals only those for which the time difference between inputs is less than a circuit parameter, known as the resolving time. A coincidence unit, in its simplest form, has two identical logic inputs [1]. In practice, a coincident unit is designed to register the coincident pulses arriving within a finite but short time interval. This time interval is called resolving time or width of the coincidence timing pulse. Typical resolving time values are 1–5 μs for slow coincidence and 1–10 ns for fast coincidence measurements [6]. A fast–fast coincidence measurement system uses fast signals from the detectors in coincidence process, and this system, then, combines the signals from each detector.

Sanyal et al. [7] used different plastic scintillators and photomultiplier tubes in order to obtain time resolution values by means of leading edge and constant fraction timing methods. The coincidence timing resolution values were obtained by using high purity germanium detectors (HPGe) by Abuelhia et al. [8]. Khamzin and Valentine

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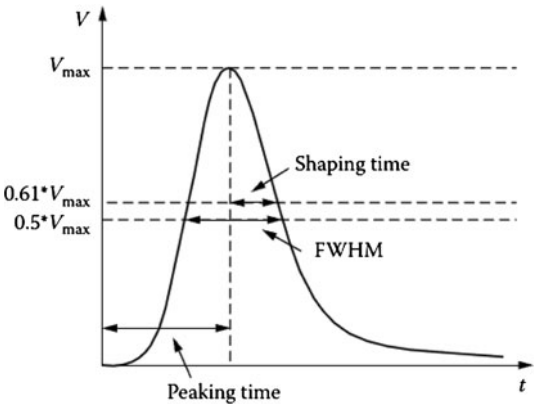


Fig. 1 Definitions of shaping and peaking times

reduced the walk effect in NaI(Tl) detectors by using leading edge discriminators in a coincidence spectrometer [9]. Alpha energy resolutions of the spectrometers consisted of BC400 type plastic scintillation and Si surface barrier detectors were achieved by Celiktas and Ermis through constant fraction timing method [10, 11].

In this work, the coincidence time resolutions (resolving time values) for BC408 and BC418 type plastic and NaI(Tl) scintillation detectors were achieved by using constant fraction timing method. These detector crystals are used in medical imaging, and the time resolution of the crystals and source-detector distance are effective on the best imaging performance [12–14]. For this reason, we compared the obtained time resolution results using these detectors in different source-detector distances.

Experimental

A ^{137}Cs radioactive source with 5 μCi activity was used for these measurements. Its half-life is 30.07 year. Two Bicron NaI(Tl) scintillation detectors manufactured by REXON Inc., having 3 in. by 3 in. dimensions in cylindrical shapes, two Bicron BC408 type plastic scintillation detectors of 1 in. by 1 in. by 4 in. dimensions in rectangular prism shapes and two Bicron BC418 plastic scintillators of 1 in. by 0.75 in. by 1.5 in. dimensions in truncated cone shapes were used. BC408 and BC418 type plastic scintillators have decay times of 2.1 and 1.4 ns, respectively. NaI(Tl) scintillator's decay time is 250 ns at room temperature [3]. These plastic scintillators were mounted on the entrance window of the photomultipliers of 2 in. width. The distances between the detectors were 5, 10, 15, 20 and 25 cm, respectively. The used isotope was placed between the two detectors for each measurement. Data acquisition time was chosen 600 s during the measurements.

The input signal is firstly delayed in constant fraction timing method. A fraction (f) of the undelayed pulse is then

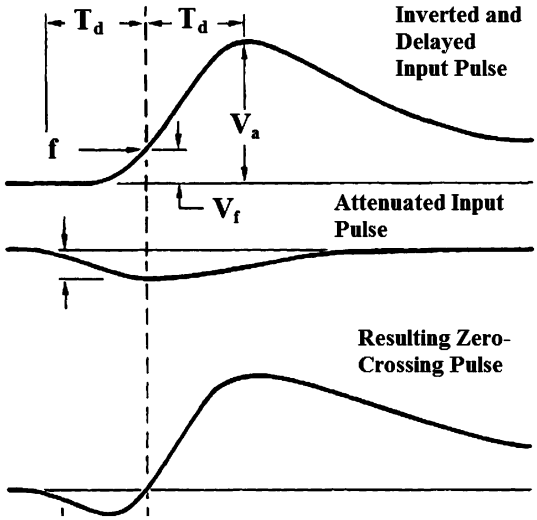


Fig. 2 Constant fraction timing method [16]

subtracted from input signal. A bipolar timing pulse is generated, and its zero-crossing is detected and used to produce an output logic pulse (Fig. 2) [15].

We obtained the time spectra of ^{137}Cs by means of fast–fast coincidence measurement for each distance for NaI(Tl) scintillation, BC408 and BC418 type plastic scintillation detectors. Used spectrometer for both NaI(Tl) scintillation, BC408 and BC418 plastic scintillation detectors is illustrated in Fig. 3.

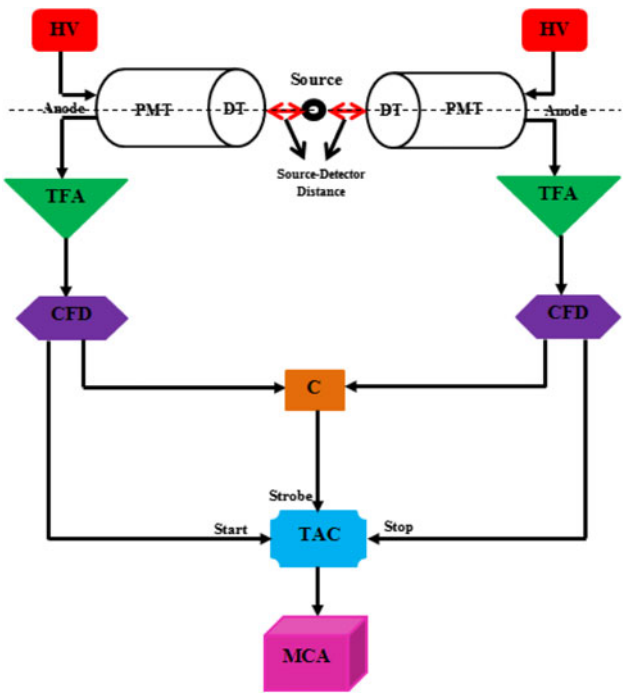


Fig. 3 Used spectrometer in the fast–fast coincidence method. *HV* High voltage supplier, *DT* detector, *PMT* photomultiplier tube, *TFA* timing filter amplifier, *CFD* constant fraction discriminator, *C* universal coincidence, *D* delay, *TAC* time to amplitude converter, *MCA* multichannel analyzer

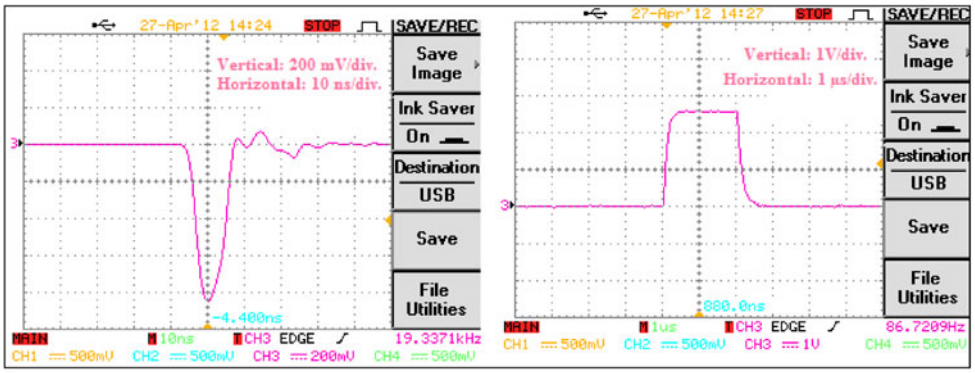


Fig. 4 Output signal shapes of **a** CFD **b** TAC for NaI(Tl) detector

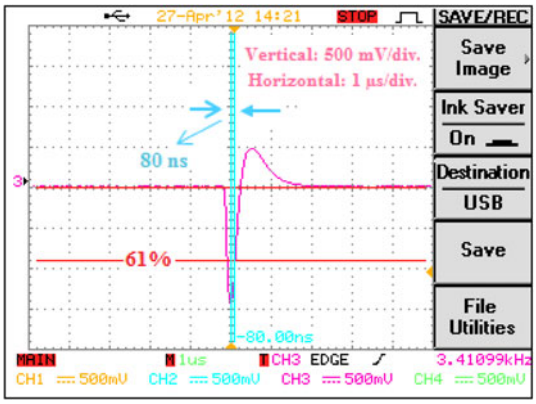


Fig. 5 Shaping time of the NaI(Tl) detector from TFA

The anode outputs of photomultipliers (PMT, ORTEC 266) were sent to timing filter amplifiers (TFA, ORTEC 454). The TFA provides additional amplitude before the timing discriminator. Integration in the TFA can be used to reduce high frequency noise [17]. Their outputs were forwarded to constant fraction discriminators (CFD, ORTEC 463). The CFD module triggers at a fixed fraction of the input signal amplitude to produce a logic marker [18]. One of the CFDs' outputs was directly sent to start input of a time to amplitude converter (TAC, ORTEC 566). The TAC is an electronic device that converts the time difference between two input signals into a voltage pulse between 0 and 10 V. The height of the TAC output pulse is proportional to the time difference between the two events [6]. The output of the other CFD was connected to the stop input of the TAC via a delay unit (D, ORTEC 425A) in order to generate significant time difference between the start and the stop inputs of the TAC. The positive outputs of the CFDs were connected to a universal coincidence module (C, ORTEC 418A). The output of this module was forwarded to strobe input of the TAC to trigger it. Time spectra of the used isotope were obtained by connecting the MCA to the TAC output.

The output signal shapes of the CFD and the TAC in the spectrometer consisted of NaI(Tl) scintillation detectors are shown in Fig. 4.

The signal shape of the NaI(Tl) detector via TFA is given in Fig. 5. From this figure, shaping and peaking times of the TFA output signal of the NaI(Tl) detector was determined as 80 and 240 ns, respectively.

CFD and TAC output signal shapes of the BC408 type plastic scintillation detectors are given in Fig. 6.

The signal shape of the BC408 type plastic detector through the TFA can be seen in Fig. 7. The shaping time

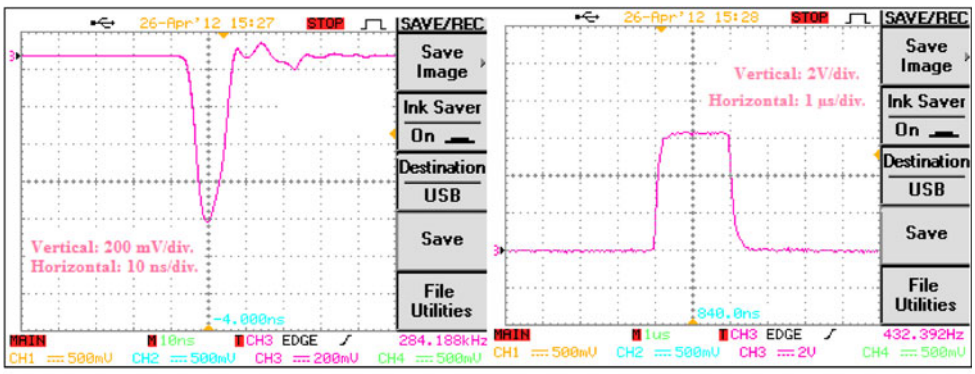


Fig. 6 Output signal shapes of **a** CFD **b** TAC for BC408 type plastic scintillation detector

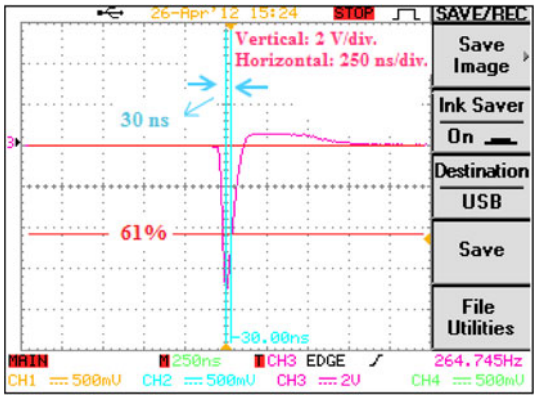


Fig. 7 Shaping time of BC408 type plastic scintillation detector from TFA

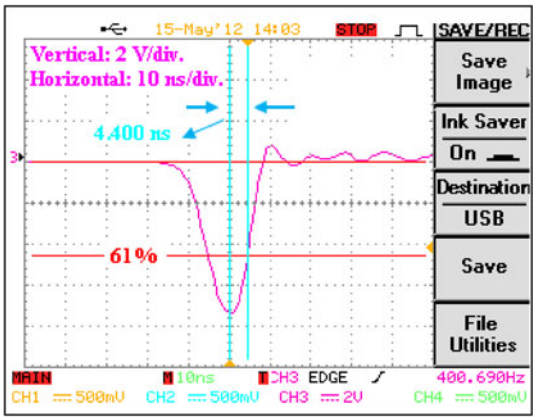


Fig. 9 Shaping time of BC418 type plastic scintillation detector from TFA

was found as 30 ns from this figure, and the peaking time was calculated as 90 ns.

The output signal shapes of the CFD and the TAC are given in Fig. 8 from the spectrometer consisted of the BC418 type plastic scintillation detectors.

Figure 9 shows the signal shape of the BC408 type plastic detector from the TFA. From this figure, the shaping and peaking times of the TFA output signal of the BC418 type plastic scintillation detector was obtained as 4.40 and 19.60 ns, respectively.

The obtained shaping and peaking time results are in accordance with the information depicted in the previous section [5].

Before obtaining time resolution values, the channels of the MCA were calibrated for each detector. We plotted a time calibration graph as shown in Fig. 10 according to the results from the spectrometer with NaI(Tl) detector. The inverse of the slope of this fitted graph gives approximately time value (97.499 ± 0.157 ps) of each channel of the MCA. The time per each channel of the MCA was the same in whole data acquisition process.

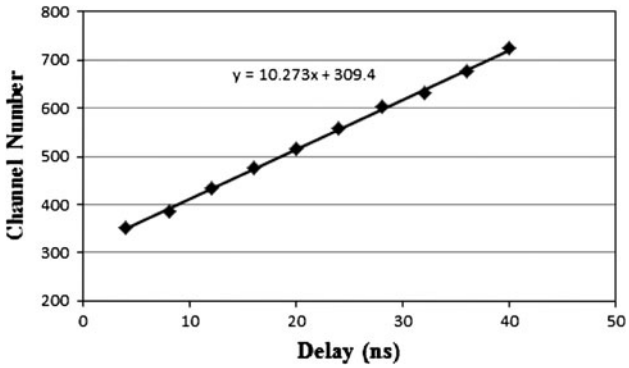


Fig. 10 Time calibration graph (fitted time calibration = 97.499 ± 0.157 ps/ch)

Results

The obtained resolving time values calculated from the time spectra for NaI(Tl) scintillation, BC408 and BC418 type plastic scintillation detectors are shown in Table 1.

In Fig. 11, resolving time values correspond to the distances between two detectors are shown.

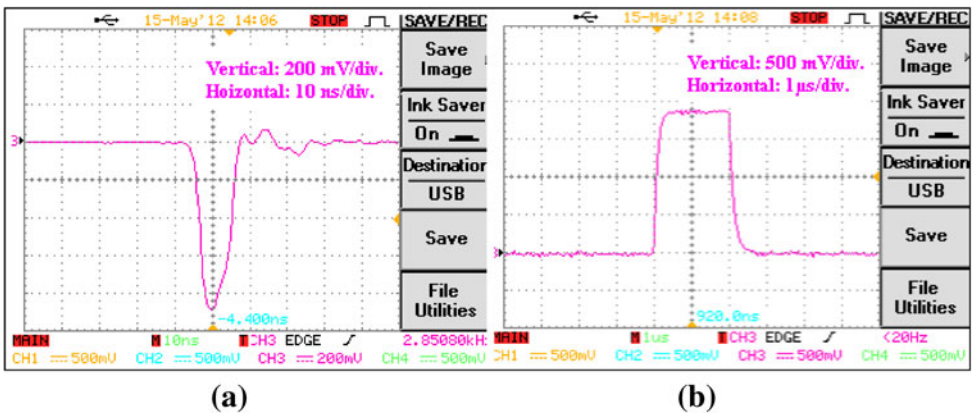


Fig. 8 Output signal shapes of **a** CFD **b** TAC for BC418 type plastic scintillation detector

Table 1 Obtained resolving times of NaI(Tl) scintillation, BC408 and BC418 type plastic scintillation detectors

Detector distances (cm)	Resolving times by NaI(Tl) scintillation detector (ns)	Resolving times by BC408 plastic scintillation detector (ns)	Resolving times by BC418 plastic scintillation detector (ns)
5	7.486 ± 0.326	6.492 ± 0.438	4.328 ± 0.277
10	8.170 ± 0.065	7.519 ± 0.879	5.891 ± 0.261
15	8.365 ± 0.033	8.251 ± 0.732	6.379 ± 0.325
20	9.439 ± 0.162	9.277 ± 0.879	4.914 ± 0.554
25	10.741 ± 0.455	10.693 ± 0.927	–

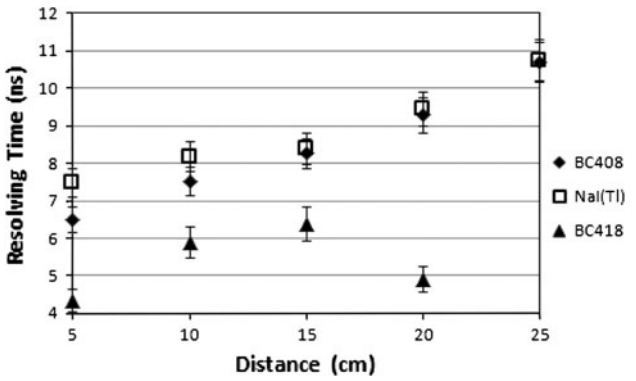


Fig. 11 Resolving time versus detector distance variation

Obtained time spectra for all spectrometers for the apart of 5 cm between the detectors are shown in Figs. 12, 13 14.

The time spectra were achieved by means of the MCA. The time range of the timing device (TAC) and the number of counts were corresponded to abscissa and ordinate of the MCA screen, respectively.

It can be concluded that any pile-up and spectrum distortion effects were not included in the obtained time spectra since the dead time of the MCA is lower than 30–40 % level as can be seen in Figs. 12, 13 14. This level is the threshold level for the dead time, pile-up and spectrum distortion [1, 4].

Conclusion and discussion

We investigated the effect of the source-detector distances in the resolving time values obtained for NaI(Tl) scintillation, BC408 and BC418 plastic scintillation detectors to determine the optimum resolving time values.

The optimum resolving time values were found at the source-detector distance of 5 cm for NaI(Tl) and BC408 type detectors. As the distance between the source and the detectors increased, the counts per channel in the MCA decreased. For this reason, the resolving time values deteriorated for NaI(Tl) and BC408 type detectors since enough counts were not recorded in the MCA. In the BC418 spectrometer, the resolving time for the distance of 20 cm between the detectors was acquired lower than the other small distances (Fig. 11) because of the fact that the counts at the distance of 20 cm were very low (43.928 s^{-1}) without any change in the rise time. Consequently, distance of 15 cm was decided as the threshold distance for the spectrometer with BC418 plastic scintillation detectors.

The resolving time values which were obtained by using BC418 plastic scintillation detectors were smaller than those of BC408 plastic scintillation and NaI(Tl) scintillation detectors because the decay time of BC418 type scintillator is lower than those of the others. The smaller decay time, that is, the best time resolution is.

In the present work, the effect of the variations of the distances between the source and the detectors on the time resolution values were determined in order to obtain the

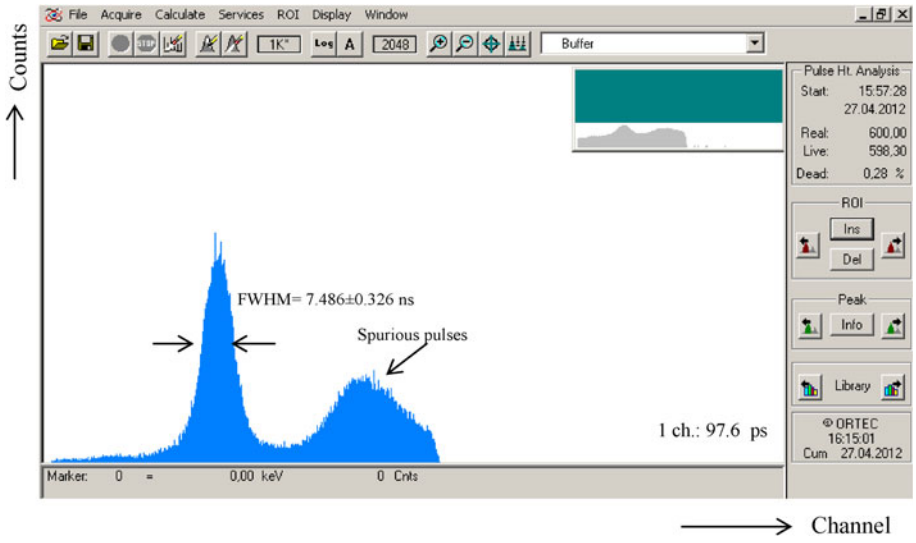


Fig. 12 Obtained time spectrum for the apart of 5 cm between NaI(Tl) scintillation detectors

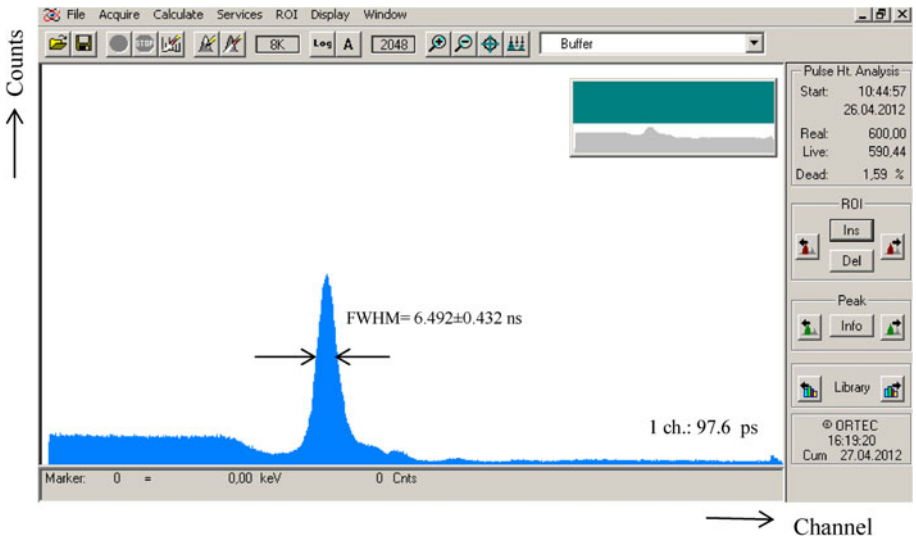


Fig. 13 Obtained time spectrum for the apart of 5 cm between BC408 plastic scintillation detectors

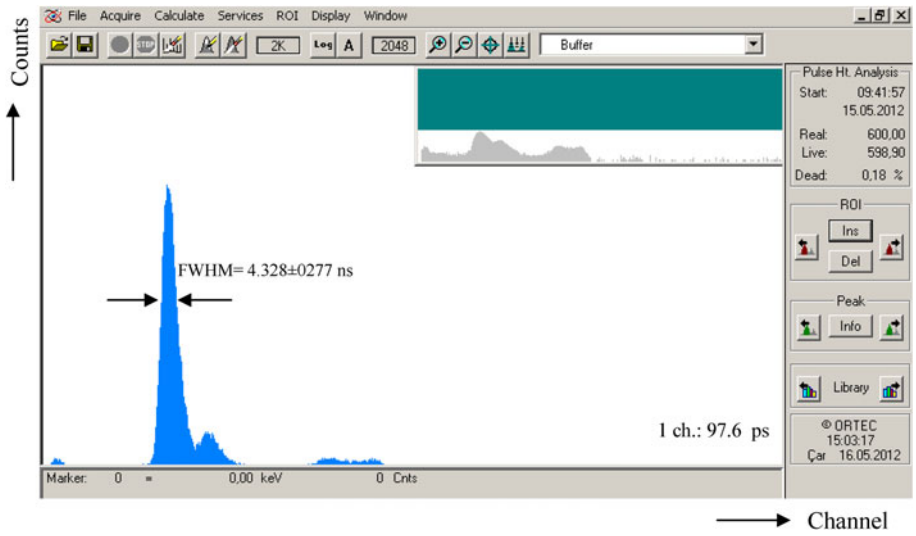


Fig. 14 Obtained time spectrum for the apart of 5 cm between BC418 plastic scintillation detectors

optimum resolving time values for NaI(Tl) scintillation, BC408 and BC418 plastic scintillation detectors since these types of crystals are widely used in the medical imaging. The time resolution values of the detectors are the most important factors in medical imaging. Because the smaller time resolution leads to a better imaging, this work was carried out to compare their timing performances. It was thought that this comparison would be useful to obtain best signal to noise ratio in TOF and mean lifetime measurement experiments. Future works will be focused on the improving the time resolutions of the crystals via timing techniques.

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