Determination of the time resolution for neutron scintillation detectors by multi-coincidence measurement*

LI Yong-Ming(李永明)[1,2;1)] RUAN Xi-Chao(阮锡超)[2;2)] ZHOU Bin(周斌)[2] MA Zhong-Yuan(马中原)[2]

[1] State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871,China
[2] Science and Technology on Nuclear Data Laboratory, China Institute of Atomic Energy, Beijing 102413, China

Abstract: Based on the multi-coincidence measurement, the time resolution of three liquid scintillation detectors (BC501A) were determined strictly by solving the coincidence equations, where the influence from electronics estimated by self coincidence measurement as well as the background had been considered. The result of this work agreed well with the result that was deduced from the traditional method, and it will be helpful to analyze the energy resolution of neutron time of flight spectra measured by using such detectors at CIAE (China Institute of Atomic Energy).

Key words: BC501A detectors, multi-coincidence measurement, time resolution

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1 Introduction

Liquid scintillation (LS) detectors, such as BC501A and NE213, have been widely used in the measurement of fast neutron time of flight (NTOF) spectra, due to their fast response to the radiation and good capability of neutron gamma discrimination. In order to analyze the energy resolution of the measured neutron spectra with the NTOF method exactly, the time resolution of the spectrometer should be known.

Traditionally, the time resolution of a detector was determined by coincidence measurement with the help of another reference detector whose time resolution was already known [1, 2], or assumed that the two detectors had nearly the same size and under the same detection conditions, thus had equal time resolutions, then the average value of an individual detector could be obtained by dividing the total resolution by a factor of $\sqrt{2}$ [3, 4].

In this work, we extended the above method to multi-coincidence measurement with three neutron liquid scintillation detectors (BC501A). The resolution of each detector was determined more strictly by solving the coincidence equations, where the influences from electronics estimated by self coincidence measurement as well as the background was considered.

2 Experimental details

The experimental setup is shown in Fig. 1. Three BC501A detectors with the same size of ϕ 7”×4” were employed. Each pair of them was placed with an angle of 120°, and the coincidence measurement was performed with a ^{60}Co source, which was located in the center of the detection system. In addition, lead blocks were placed between the detectors to reduce the cross talking effect. The biases were chosen to let the three detectors have the same output signal amplitudes, and the same detection thresholds of 100 keV (electron equivalent energy) were set for all detectors. The timing signals were obtained from the anodes, and the AD conversions with a CAMAC DAQ system were gated by a Gate Generator (ORTEC-CO4020) with the OR signals from Constant Fraction

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1) E-mail: nphliym@gmail.com

2) E-mail: ntof@ciae.ac.cn

Discriminators (CFD ORTEC-935).

In order to estimate the influences from the electronics, a self coincidence measurement was performed, where a module (Phillips 744) was used to fan out the anode signal from one of the detectors to the three CFD modules.

Finally, although the background event rate was very low, we ran the above measurements again without the ^{60}Co source.

3 Result and discussion

Figure 2 shows the coincidence spectra without lead blocks. Due to the extra scattering signals from the other detectors, the event rate of random coincidence increased. One can see that the base of the coincidence peaks were broadened, and the cross talking peaks appeared obviously, which should be reduced for getting the width of the real coincidence peaks.

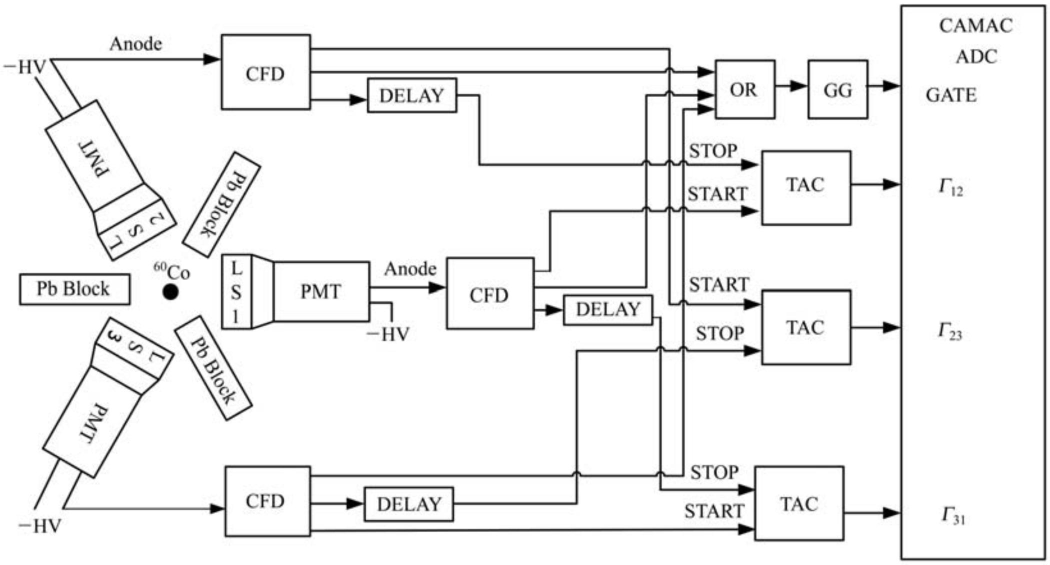

Fig. 1. The experimental setup. LS: Liquid Scintillator (BC501A); PMT: Photomultiplier Tube (XP2041); CFD: Constant Fraction Discriminator (Ortec 935); TAC: Time to Amplitude Converter (Ortec 567); DELAY: Delay line; OR: Fan In Module (Ortec 755); GG: Gate Generator (Ortec CO4020); ADC: Analog to Digital Converter (Phillips 7164).

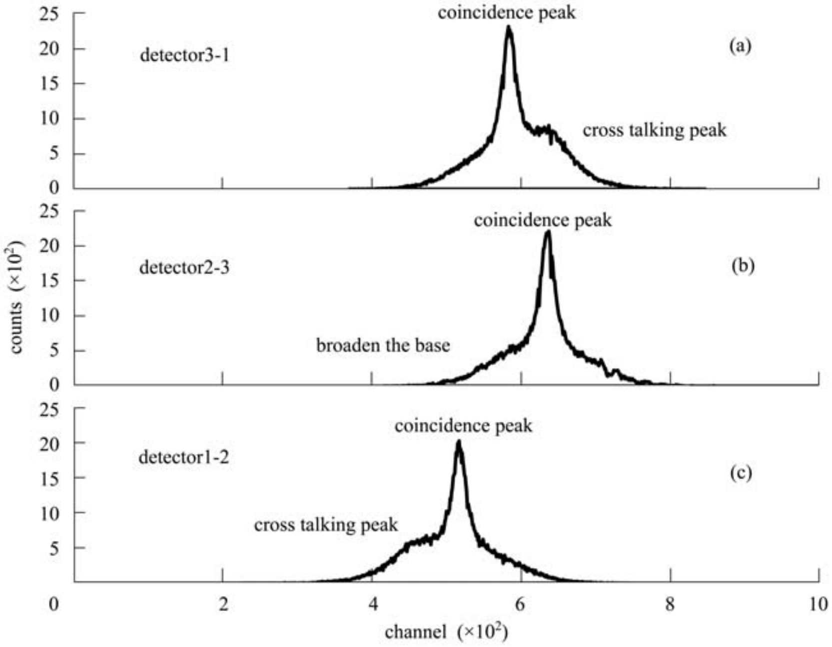

Fig. 2. The coincidence spectra without lead blocks. (a) coincidence between detector 3 and detector 1; (b) coincidence between detector 2 and detector 3; (c) coincidence between detector 1 and detector 2.

Figure 3 shows the final experimental result. Three TACs were calibrated carefully, and the FWHM (Full Width at Half Maximum) of each peak was obtained by Lorenz fitting. The simple relationship between them can be described as

$$\begin{cases} \Gamma_{12\text{pure}} = \sqrt{\Gamma_{12}^2 - \Gamma_{12\text{ele}}^2}, \\ \Gamma_{23\text{pure}} = \sqrt{\Gamma_{23}^2 - \Gamma_{23\text{ele}}^2}, \\ \Gamma_{31\text{pure}} = \sqrt{\Gamma_{31}^2 - \Gamma_{31\text{ele}}^2}, \end{cases} \tag{1}$$

and

$$\begin{cases} \Gamma_1 = \sqrt{\dfrac{\Gamma_{12\text{pure}}^2 + \Gamma_{31\text{pure}}^2 - \Gamma_{23\text{pure}}^2}{2}}, \\ \Gamma_2 = \sqrt{\dfrac{\Gamma_{12\text{pure}}^2 + \Gamma_{23\text{pure}}^2 - \Gamma_{31\text{pure}}^2}{2}}, \\ \Gamma_3 = \sqrt{\dfrac{\Gamma_{23\text{pure}}^2 + \Gamma_{31\text{pure}}^2 - \Gamma_{12\text{pure}}^2}{2}}, \end{cases} \tag{2}$$

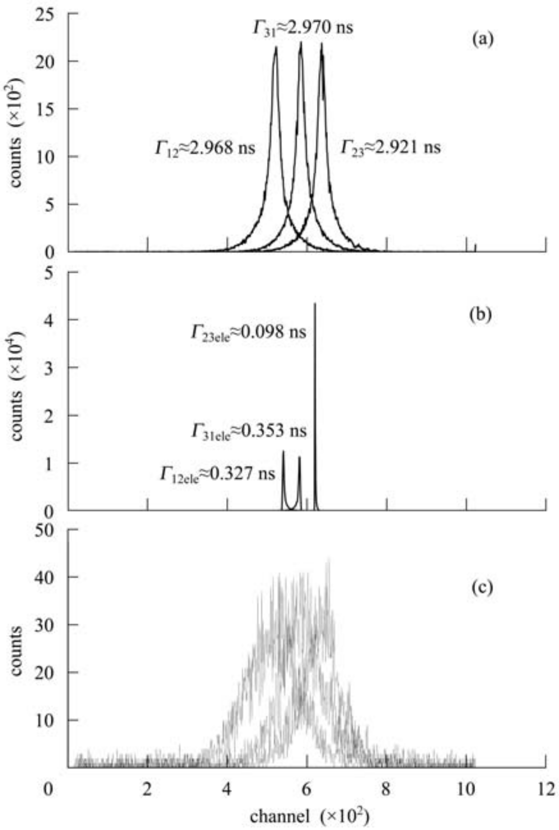

Fig. 3. The final experimental result by adding lead blocks. (a) Total coincidence spectra; (b) contribution from self coincidence; (c) contribution from background.

Where Γ_1, Γ_2, and Γ_3 are the time resolution of the detectors, and each of them consists of the timing uncertainty from scintillator as well as the PMT. After subtracting the background contribution, the pure resolution denoted as $\Gamma_{12\text{pure}}$, $\Gamma_{23\text{pure}}$, and $\Gamma_{31\text{pure}}$ were obtained by deducting the contributions (obtained from the self coincidence measurement) of electronics $\Gamma_{12\text{ele}}$, $\Gamma_{23\text{ele}}$, and $\Gamma_{31\text{ele}}$ from the total resolution of Γ_{12}, Γ_{23}, and Γ_{31}, respectively.

The total and background coincidence measurement were both performed for 8 hours. One can see that the event rate of the background was very low. The Γ_{12}, Γ_{23}, and Γ_{31} of 2.968 ns, 2.921 ns, and 2.970 ns were obtained, while the $\Gamma_{12\text{ele}}$, $\Gamma_{23\text{ele}}$, and $\Gamma_{31\text{ele}}$ were obtained only as 0.327 ns, 0.098 ns, and 0.353 ns, respectively. Therefore, one can neglect the influence from electronics and background if the requirement of precision is not very strict.

In the traditional binary coincidence measurement, if there was not a reference detector, one needs to find a couple of detectors that had the same size and under the same detection condition, and assumed equal time resolution for each of them. Then an individual average value was obtained by dividing the total resolution with a factor of $\sqrt{2}$. Thus, the above requirements limit its applicability.

In this work, we determined three unknown parameters with three equations, and got the time resolution for each detector more precisely. Therefore this method extended the applicable range. However, it should be mentioned that the time characteristics of the detectors used should not differ much from each other, otherwise one could get a minus value when solving the equations, which has no physical meaning.

The result obtained in this work was $\Gamma_1 = 2.106$ ns, $\Gamma_2 = 2.065$ ns, and $\Gamma_3 = 2.063$ ns, and the result of the traditional method was $\Gamma_1 = 2.099$ ns, $\Gamma_2 = 2.065$ ns, and $\Gamma_3 = 2.100$ ns, and the agreement between the two methods is fine.

This work will be helpful to analyze the energy resolution of NTOF spectra measured by using such detectors at CIAE. More research on the neutron scintillator as well as the photomultiplier parameters affecting the time resolution are ongoing, and we are trying to extend this method to the other mixed kinds of radiation detector.

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