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Measurement of decay time of liquid scintillator

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Abstract

In this paper we describe a single photon method to measure the decay time of two kinds of homemade liquid scintillator. We find that the fast and slow decay time constants of these two samples, with 5 cm diameter and 4 cm height, are about ~4 ns and ~17 ns, respectively. These results are checked through a reference measurement by recording the scintillation pulse shapes at the output of a fast response PMT directly by a digital oscilloscope. The time responses of these two samples are as good as those of commercial liquid scintillator.

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Keywords: Decay time; Single photon method; Liquid scintillator; Reactor neutrino oscillation

1. Introduction

In reactor neutrino oscillation experiments, liquid scintillator (LS) is generally chosen as the target of an antineutrino detector because of its large cross-section in the inverse β decay. Furthermore, an amount of gadolinium is usually loaded in the pure LS to reduce the time interval between the prompt and delay signal and enhance the intensity of delayed signal to increase the ratio of signal to background [1]. We have studied the characteristics of two samples of new experimental LS developed for reactor neutrino oscillation experiments. One sample is normal LS composed of solvents, PPO (5 g/L) and bis-MSB (10 mg/L), and solutions, mesitylene and mineral oil, while the other is gadolinium loaded liquid scintillator (GdLS) whose components are 0.1% Gd, solvents, PPO (3 g/L) and bis-MSB (15 mg/L), and solution, linear alkyl-benzene (LAB) [2]. The short decay time is one of the important characteristics of LS in many physics studies. In this work we construct a specific setup for the single photon method to measure the decay time characteristics of the two samples of our homemade LS, LS and GdLS.

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2. Experimental details and results

The decay time constants of LS and GdLS are measured by the start–stop timing method coupled with single photon detection [3]. The system setup is shown in Fig. 1. In this method, the start signal is derived from the plastic scintillator (PS) which is coupled well to an XP2020 photomultiplier tube (PMT). The single photon detection is achieved by an XP2020Q PMT which collects very weak light emitted from the LS/GdLS under investigation. The scintillation light from the sample pass through an opening in the lead support, reflect on a tyvek film and finally hit on the cathode of the XP2020Q after going through a small aperture in front of the XP2020Q. The signal from the XP2020Q PMT is used as the stop signal. The PS and LS/GdLS are excited by the two back-to-back 0.511 MeV gamma radiations from Na^{22} simultaneously. The decay time distributions of LS and GdLS observed at the output of the TDC C414 are illustrated in Fig. 2.

These distributions $I(t)$ combine the effect of illumination function of LS $i(t)$ and the instrumental response function $g(t)$ of the system [5]:

$$I(t) = i(t) * g(t). \quad (1)$$

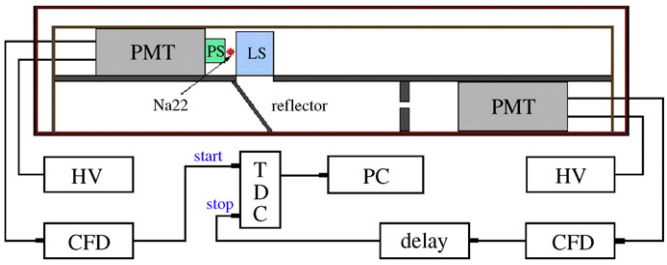

Fig. 1. System setup for the measurement of decay time of liquid scintillator.

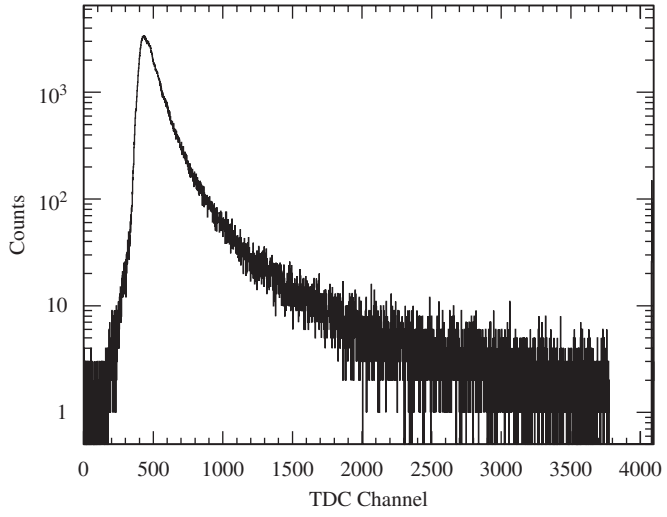

Fig. 2. Decay spectrum of the experimental liquid scintillator, GdLS (after background subtraction [4]).

The decay of light signal $i(t)$ can be described as the sum of two exponential components [6]:

$$i(t) = \frac{\omega}{\tau_0} e^{-t/\tau_0} + \frac{1-\omega}{\tau_1} e^{-t/\tau_1} \quad (2)$$

where τ_0 and τ_1 are the decay time constants of the fast and slow component of a scintillator, respectively, ω is the weight of the fast component. The instrumental response function $g(t)$ of the system can be assumed as a Gaussian shape distribution with the dispersion σ and time delay T ns [5],

$$g(t) = \frac{1}{\sqrt{2\pi}\sigma} e^{-(t-T)^2/2\sigma^2}. \quad (3)$$

This dispersion is mainly due to the energy transfer process in LS, the light collection process from scintillator to detector, and the time jitter of PMT detecting single photons. The decay parameters are derived from the fit with Eq. (1) to the data in different regions of the decay spectrum. All of the χ^2/ndf values in different fit regions are close to unity. The minimum χ^2/ndf are shown in Fig. 3.

In order to implement the unit conversion of the extracted decay parameters, TDC C414 was calibrated by ORTEC 462 with 160 ns range and 10 ns period. Fig. 4 shows the calibration spectrum and linear fit results. With the calibration value 49.7 ps/channel, the final results, fitting parameters in Fig. 3, are concluded in Table 1.

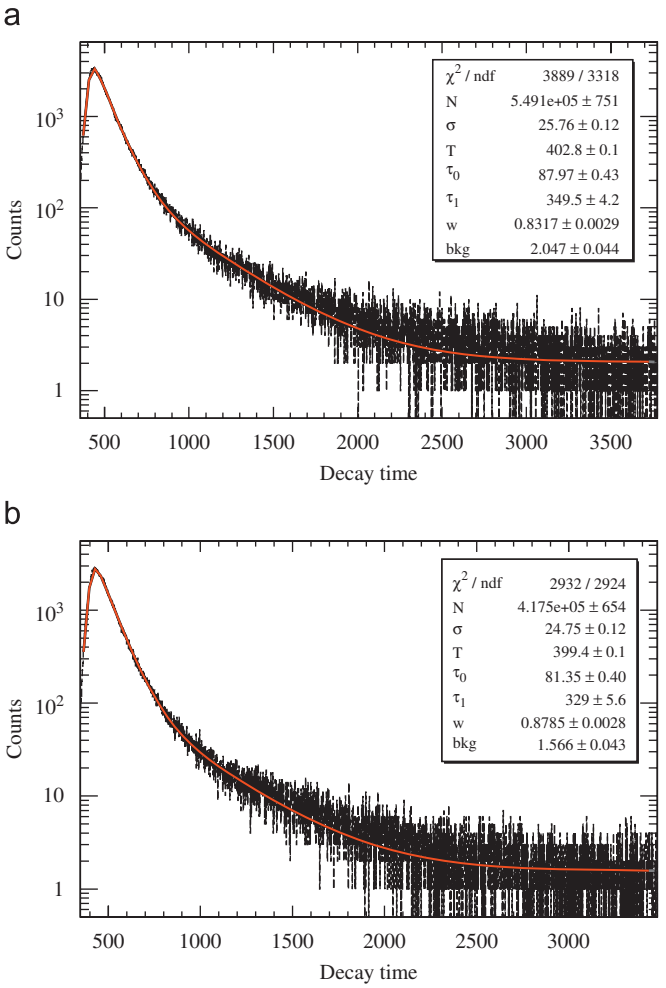

Fig. 3. Fitting results of the two samples of experimental liquid scintillators. (Units of X-axis and the time parameters τ_0, τ_1, T, σ are TDC channel.) Panel (a) is the result of GdLS and panel (b) is the result of LS.

3. Reference measurement

Besides the precise single photon detection, we also use another method to roughly obtain the decay time constants of LS and GdLS as reference. In this method, the LS/GdLS under study is coupled to an XP2020Q PMT and also excited by Na^{22}. Therefore, the scintillation pulse shapes produced from large amounts of photons are collected by the XP2020Q and recorded directly by a LeCroy WavePro 1 GHz digital oscilloscope. The threshold of oscilloscope is set to 50 mV to suppress the small amplitude background. In data analysis, we choose the signals whose amplitudes represent the corresponding scintillation light excited by 1.275 MeV gamma of Na^{22}. Finally, we obtain the pulse shapes of these signals from the samples LS and GdLS, respectively, and use the function as follows to

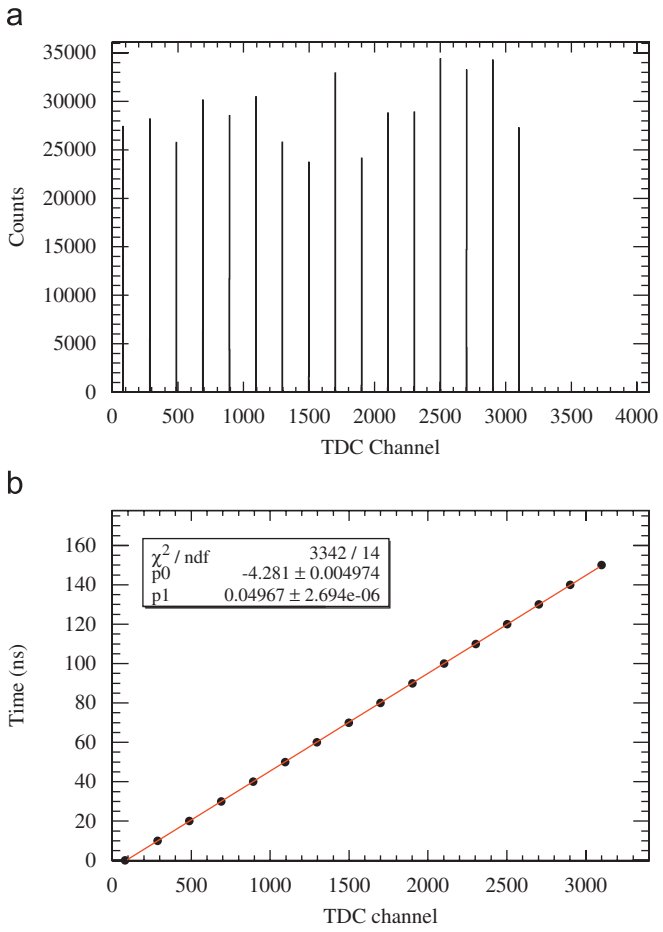

Fig. 4. (a) Calibration spectrum for TDC C414 (200 ns range, 4096 channel) by ORTEC 462 (160 ns range, 10 ns period). (b) Linear fitting results.

Table 1
Scintillation decay parameters of LS and GdLS

Scintillator	τ_0 (ns)	τ_1 (ns)	ω
GdLS	4.37	17.37	0.83
LS	4.04	16.35	0.88

describe them [7]

$$I(t) = i(t) * g(t) * \frac{1}{RC} e^{-t/RC}, \quad (4)$$

where $i(t)$ is the scintillation pulse from sample, according to Eq. (2), $g(t)$ is the instrumental response function, according to Eq. (3), $e^{-t/RC}$ is used to describe the approximation of the RC loop between the output of PMT and input of oscilloscope which result in the aberrance of scintillation pulse shape.

The good fit is obtained in the fitting region from 10% at rise part to 2% at the fall part of the maximum of pulse intensity, as shown in Fig. 5.

Although this method is easy and rough, and not applicable to analyze multiple decay time components,

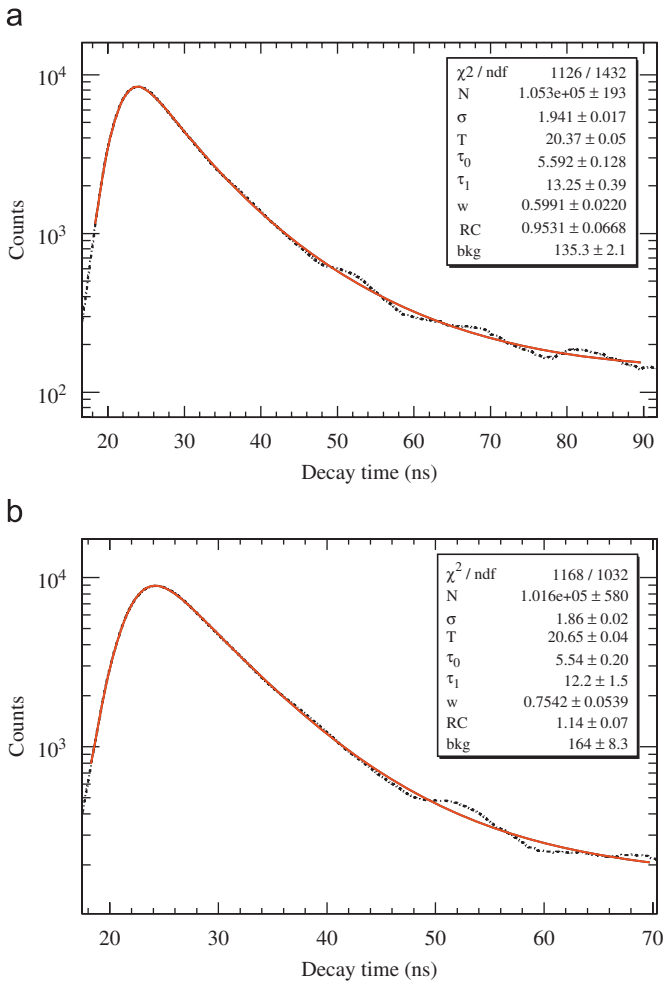

Fig. 5. Pulse shapes of scintillation light recorded by digital oscilloscope and fitting results of parameters. Panel (a) is the result of GdLS and panel (b) is the result of LS.

Table 2
Scintillation decay parameters of LS and GdLS obtained by fitting in the same region of time distributions from single photon method (SPM) and oscilloscope pulse shape method (OPSM)

	GdLS			LS		
	τ_0 (ns)	τ_1 (ns)	ω	τ_0 (ns)	τ_1 (ns)	ω
SPM	4.12	13.01	0.78	3.95	13.22	0.86
OPSM	5.59	13.25	0.6	5.54	12.2	0.75

the fitting results in Fig. 5 illustrate agreements with those of single photon method. The comparison of these two methods are summarized in Table 2. The differences of the results of these two methods are under our expectation and also represent the validity of the results of the single photon method.

4. Discussion

The results of the decay time measurement on these two samples of experimental LS, LS and GdLS, are listed in

Table 1. The fast decay time constant τ_0 of LS is ~4.0 ns and GdLS is ~4.4 ns. In Refs. [8,9], τ_0 of the LS used in Borexino is about 2–3 ns, NE213 and JE301 is about 3.9 and 3.2 ns, respectively. The fast decay time constants we obtained from the GdLS and LS samples are a little longer than those of Borexino, NE213 and JE301 due to the self-absorption and re-emission process of scintillation. The samples of GdLS and LS in our measurement are 5 cm diameter and ~4 cm height cylinders, therefore, compared with a very thin sample, the decay time of scintillation depends on not only the composition of the scintillator, but also the light collection process.

The self-absorption and re-emission process will increase the decay time constant according to [5]

$$\tau_r = \frac{\tau}{1 - \phi q} \tag{5}$$

where q is the probability of re-absorption of fluor solutions, ϕ is the quantum efficiency of scintillator. Taking into account the effect described in Eq. (5), it is clear that the decay time characteristic of GdLS and LS recently developed by IHEP chemists for reactor neutrino oscillation experiments are comparable with the current commercial and experimental LS. The properties of short decay time constant and low cost of these new LS make themselves have a perspective in other experiments such as mean life-time measurements of excited states, angular correlation function, time-of-flight measurements.

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