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Scintillation Time Profiles of Slow Organic and Water-Based Liquid Scintillators using a Pulsed Neutron Beam

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Slow organic and water-based liquid scintillators are currently developed and characterized for future large-scale neutrino experiments such as THEIA. One goal of these new scintillators is to separate Cherenkov light from scintillation light in a detector. By this, the spatial information improved while keeping the excellent energy resolution of proven organic mixtures. This contribution focuses on scintillation time profile studies of novel liquid scintillators. We performed liquid scintillator characterization experiments using a pulsed neutron beam at the CN accelerator of INFN Laboratori Nazionali di Legnaro. At different quasi-monoenergetic neutron beam energies, ranging from 1.86 MeV to 3.86 MeV, the fluorescence time profile of recoil protons was recorded. Differences in the time profiles after gamma and neutron excitation open the window to perform pulse shape discrimination and therefore advance the ability to distinguish the neutrino signal from backgrounds.

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1. Introduction

For future large-scale neutrino experiments such as THEIA [1], two approaches are currently under investigation to separate Cherenkov radiation from scintillation light [2]. While the one is via the development of water-soluble scintillators, so-called water-based liquid scintillators (WbLSs), in which the ratio of Cherenkov light to the otherwise dominant fraction of scintillation is increased, the second is via the formulation of so-called slow organic scintillators, in which the characteristic fluorescence times are intentionally retarded so that separation via timing using fast photosensors becomes possible. In this work the combination of conventional solvents such as linear alkylbenzene (LAB) and diisopropylnaphthalene (DIN), and fluors such as 2,5-diphenyloxazole (PPO) are used to develop such novel detection media.

2. Experimental Setup

Several glass spheres, each with a volume of approximately 150 mL, are filled with liquid scintillators (LS) and protected by nitrogen atmospheres. Figure 1 illustrates the experimental setup at the end of the beamline of the CN accelerator at INFN Legnaro. The experiment uses the widely-used technique of time-correlated single photon counting (TCSPC) such as in [3, 4].

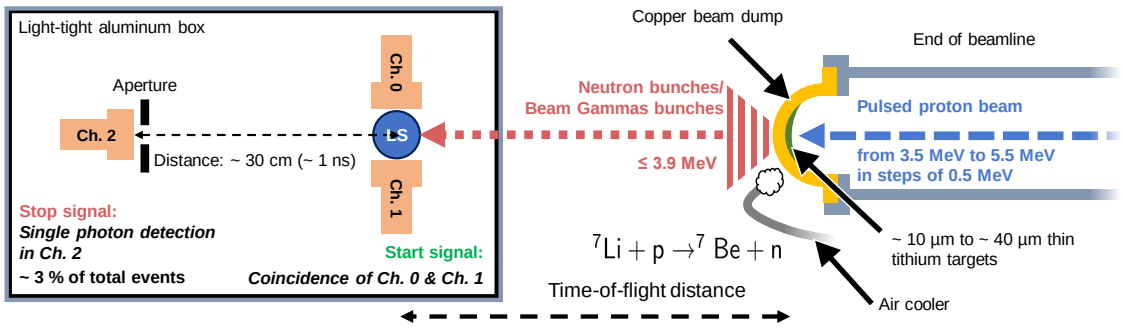


Figure 1: Illustration of the scintillation time profile experiment at the end of the beamline of the CN Van de Graaff accelerator at INFN Legnaro.

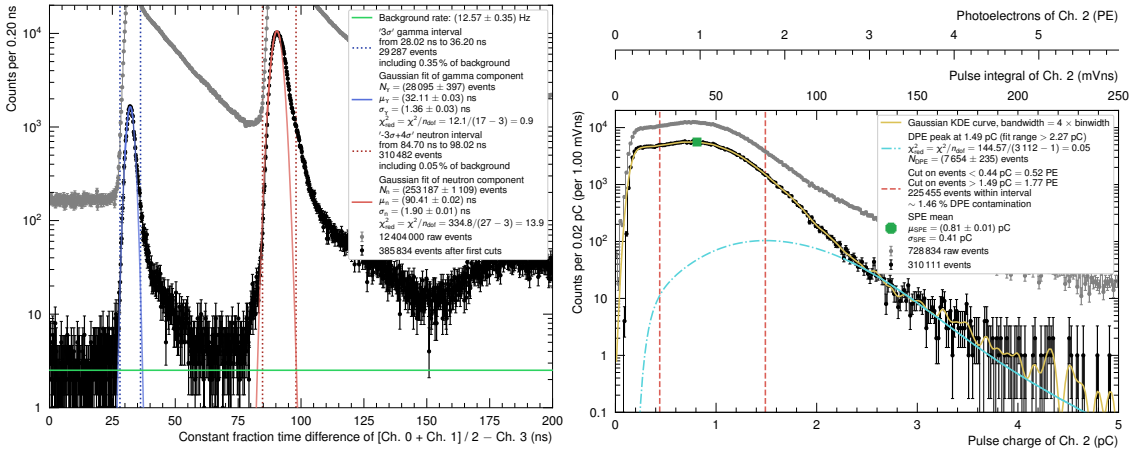
Inside a light-tight box two near photomultiplier tubes (PMTs) (Ch. 0 & Ch. 1) monitor one LS glass vessel and will detect multi-photon pulses from one excitation of the LS and whose coincidence provides the start signal of a time measurement. A third PMT (Ch. 2) is placed behind an adjustable aperture and in a certain distance to ensure only the detection of single photon signals from the same excitation, which provides the stop signals of the time measurements. Signals are only recorded when Ch. 2 detects a signal within a gate created by the start signal. Recording many of these time measurements allows to obtain the scintillation time profile. The trigger logic and readout electronics comprises a flexible and fast NIM system, which can be adjusted for efficiently working with radioactive sources such as ^{137}Cs or at particle accelerators to include beam trigger signals. The system is adjusted that time differences of the start and stop signals are possible up to 650 ns.

At the CN accelerator monoenergetic pulsed proton beams with energies from 3.5 MeV up to 5.5 MeV can be guided onto a thin lithium target. In this nuclear reaction neutrons as well as

beam correlated gammas will be created, which can enter the time profile experiment and interact with protons and electrons of the scintillator, respectively. The experiment is placed around 1.5 m away from the lithium target to have a sufficiently large distance for time-of-flight measurements of the beam bunches.

3. Results and Discussion

As Figure 2a shows neutron data can be distinguished from beam gammas using the time information of the beam bunches. The recorded data is going through several quality checks such as ensuring the coincidence of signals of Ch. 0 & Ch. 1 being within a few nanoseconds and containing multi-photoelectrons while signals of Ch. 2 only contain single photoelectrons as Figure 2b shows.

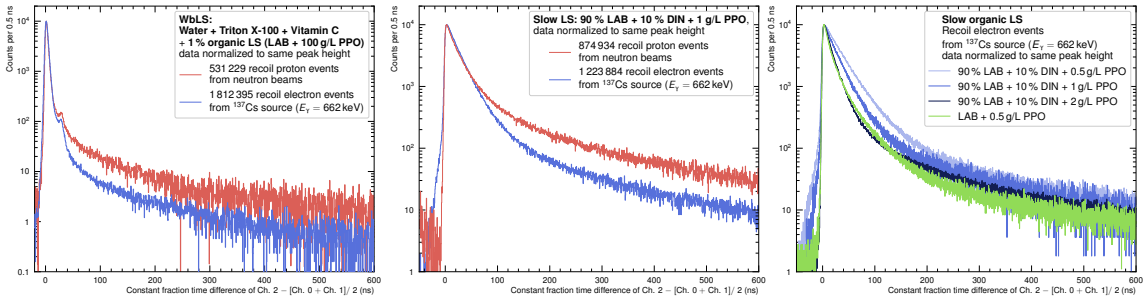


(a) Time of flight spectrum

(b) Pulse integral spectrum of Ch. 2

Figure 2: **(a)** Neutron and gamma data can be selected using the time-of-flight information. **(b)** Quality cuts on the pulse integral spectrum of the far PMT (Ch. 2) are applied to ensure single photoelectron charges.

Figure 3 shows the recorded time profiles of liquid scintillators excited by recoil electrons induced by a ^{137}Cs source and recoil protons induced by neutron beams. While Figure 3a shows the fast relaxating time profiles of a water-based liquid scintillator, Figure 3b shows the slowly relaxating time profiles of a slow organic LS. Note that the secondary bump to the right of the maximum of the distribution is due to unavoidable late pulses in the far PMT (Ch. 2). The time profiles of both LSs are clearly different when excited by different particles. This different emission of light over time demonstrates the potential to perform pulse shape discrimination with these novel LSs in next-generation neutrino detectors. Figure 3c shows the time profiles of different slow mixtures. Samples containing larger amounts of PPO relaxate faster as expected [3]. Qualitatively, the mixture containing 90 % LAB and 10 % DIN with 2 g/L PPO is as slow as the mixture containing only LAB with 0.5 g/L PPO. The moderate admixture of DIN to LAB is therefore responsible for the retarded light emission and proves that the combination of conventional solvents and fluors can be used to develop slow media.



(a) Water-based liquid scintillator **(b)** Slow organic liquid scintillator **(c)** Comparison of slow organic LSs

Figure 3: The scintillation time profiles after particle excitation by recoil protons (red) and recoil electrons (blue) of water-based liquid scintillators **(a)** as well as slow organic liquid scintillators **(b)** are clearly distinguishable. **(c)** Comparison of time profiles of different slow LS mixtures.

4. Conclusion and Outlook

TCSPC together with a pulsed neutron beam has shown for the first time that the novel slow organic and water-based LSs indeed have PSD capabilities. Using a pico-second laser system the three PMTs were characterized at SPE intensity concerning gains and transit time spectra. This allows to build an instrumental response function (IRF) taking into account the late pulse contribution of the far PMT. By that, the data can be properly fit by the convolution of the IRF with a scintillation model that is similar to [5]. Results for the slow LSs will be presented in a future publication [6].

Acknowledgments

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