PROCEEDINGS OF SCIENCE

Improved measurements of timing and optical properties of the JUNO liquid scintillator with SHELDON

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JUNO (Jiangmen Underground Neutrino Observatory) is a 20 kton scintillation detector aimed to study fundamental properties of neutrinos such as neutrino mass ordering and oscillation parameters. The experiment is currently under construction in Kaiping, China and is expected to be commissioned next year. To reach its goals, JUNO will strongly rely on the accurate description of the scintillator. This includes the emission spectrum of the scintillator, the contribution of Cherenkov light and the characteristic times and weights of the fluorescence components.

SHELDON (Separation of cHErenkov Light for Directionality Of Neutrinos) is a small-scale setup developed to determine the contribution of Cherenkov light in the scintillator cocktail used in JUNO, as well as to measure its fluorescence parameters more accurately than ever before.

Here we show the preliminary work towards a new accurate measurement of the characteristic times and weights included in the description of the fluorescence process, with an emphasis on the impact of Cherenkov light separation and a thorough characterization of the setup. The steps that enable the evaluation of the Cherenkov contribution are presented, as well as the next steps that will allow the separation of Cherenkov light and its possible use to determine the direction of neutrinos interacting in JUNO.

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1. Introduction

Scintillators convert part of the energy deposited by charged particles into visible light. Liquid organic scintillators are widely used in nuclear and particle physics experiments due to good performances, ease of deployment in very large volumes and cost-effectiveness. They are often composed by mixtures including an organic solvent, a scintillation fluor and a wavelength shifter.

The scintillation process in organic scintillators involves excited electrons in the π-orbitals of the solvent [1]. Their de-excitation takes place via non-radiative processes to the first excited singlet state and via radiative processes (fluorescence) from the first excited singlet state to the ground state. The spectrum of fluorescence light is often in the ultraviolet region and its time distribution involves characteristic times of the order of hundreds of ns. Radiative processes involving triplet states (phosphorescence) are characterized by larger times. The inclusion of a fluor and a wavelength shifter in the mixture improves the yield, the timing and the spectral features of emitted light. The resulting light has a spectrum that extends in the visible region, where the quantum efficiency of PMTs is higher and its time distribution can be described by a superposition of different exponential contributions with characteristic times of the order of few ns to hundreds of ns.

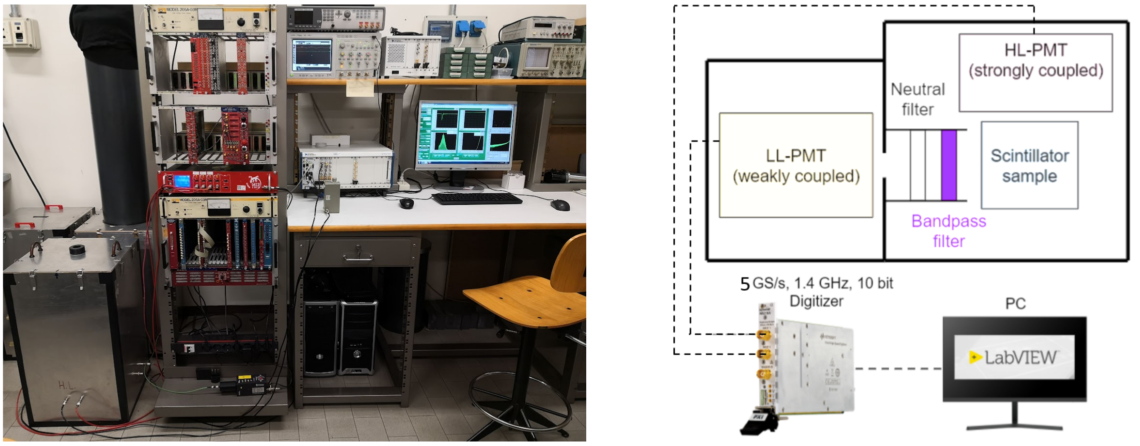
Apart from fluorescence, charged particles travelling in the scintillator can cause the emission of a small amount of Cherenkov light, provided that their speed is high enough to overcome the Cherenkov threshold. The most notable feature of Cherenkov light is its direction, which is closely correlated to the direction of the charged particle causing its emission [2, 3]. Moreover, both the spectral and timing features of Cherenkov light greatly differ from those of fluorescence light [4–6]. Cherenkov light is emitted instantaneously as the particle moves in the liquid scintillator and its spectrum is proportional to λ^{-2}, extending both below and above the fluorescence spectrum.

The short-wavelength part of the Cherenkov spectrum is rapidly absorbed by the components of the scintillator mixture and subsequently re-emitted as fluorescence light. Unfortunately, this process does not preserve any directional information, nor conserve the fast timing properties of Cherenkov light. The long-wavelength part of the Cherenkov spectrum above the endpoint of the fluorescence spectrum, though, is still present. This contribution to the total light emission has to be considered in the measurement of fluorescence times and can possibly provide useful information.

2. Experimental setup

The experimental setup allows the measurement of the time distribution of emitted light via the time-correlated single photon counting (TCSPC) technique [7]. It consists of two photomultiplier tubes (PMTs) detecting the light emitted by the liquid scintillator, contained in a small cuvette made of optical glass. One PMT is placed very close to the cuvette so that its optical coupling to the scintillator is strong, so as to generate a large output signal with a sharp leading edge and a precise start time. To satisfy the conditions required by the TCSPC technique and detect at most one photon for each event, the second PMT is placed further away from the scintillator and either a neutral filter or a bandpass filter is placed in between them.

The output signals of the two PMTs are digitized by two NI PXI-e 5162 digitizers (10 bit, 5 GS/s, 1.5 GHz). A LabVIEW software implements constant fraction discrimination for the signals, calculates the time difference for each event detected by both of the two PMTs and measures



(a) Picture of the setup, including the dark box (bottom-left), power supply (center-left), digitizers (center-right) and monitor with the LabVIEW front panel (middle-right).

(b) Sketch of the setup for the separation of Cherenkov light and the measurement of the fluorescence times.

Figure 1: Picture and sketch of the setup of the SHELDON experiment.

the amplitude and charge spectra. The spectra of the weakly coupled PMT allow to confirm the conditions needed for the TCSPC technique to correctly work.

Scintillation events are generated by means of ^{60}Co, ^{244}Cu and AmBe radioactive sources. The ^{60}Co placed above the cuvette generates 1.33 MeV and 1.17 MeV photons that can produce Compton electrons in the scintillator. The ^{244}Cu implanted in a gold substrate and placed inside the cuvette (below the scintillator surface), generates α particles. The AmBe source placed in a 2 cm thick lead container above the cuvette produces both gamma rays and fast neutrons. Using this set of sources is possible to see the effect of different radiations on the time distribution of light and possibly use this information to improve pulse shape discrimination in future experiments.

The Impulse Response Function (IRF) of the system was measured using a pulsed laser source (402 nm, 75 ps). The light was brought inside the blackbox via an optical fiber and diffused by a teflon cylinder placed in the middle of the cuvette. To better emulate the effect of reflections and refractions, the diffuser was immersed in pure LAB during the measurement of the IRF.

3. Analysis method and preliminary measurements

To measure accurately the time distribution of emitted light, we used a 1.6 μs long acquisition window and we included four exponential contributions in the model as already shown in a previous work using a similar setup [8]. When it can be present, our model also considers a Cherenkov contribution, included in the model as an impulse (a Dirac delta distribution). Both fluorescence and Cherenkov contributions were analytically convoluted with a function that best fits the IRF. The IRF was fitted to a superposition of seven gaussian distributions, so that the analytical convolution results in a reasonably simple formula. To take into account the finite length of the acquisition window, the normalization factors applied to the exponential contributions had to be rescaled.

Thanks to a systematic analysis of several Monte Carlo simulations, we demonstrated that both the long acquisition window and the inclusion of the Cherenkov contribution determine an improvement in the sensitivity to the fluorescence times and the relative weight of each exponential component. On the other hand, a shorter acquisition window and the neglection of the Cherenkov contribution result in biased results on the fluorescence times and the relative weights.

Initially we used a set of optical bandpass filters to select different regions of the spectrum of emitted light. This allowed us to recognise the time distribution of Cherenkov light and fluorescence light effectively, fitting each contribution separately to verify the model that we implemented. Subsequently, we measured the time distribution using a neutral filter and we were able to determine the magnitude of the subdominant Cherenkov contribution when present.

Our preliminary results [9] provide the most accurate measurement of the fluorescence times and weights available today for the scintillator mixture that will be used in JUNO.

To suppress a possible contribution of cosmic-ray induced muons in our measurements and further improve their accuracy, we are now implementing a veto system consisting of two scintillator slabs placed above and below the blackbox. The new measurements are ongoing and will be presented in a forthcoming paper.

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