Online calibration of neutrino liquid scintillator detectors above 10 MeV

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Abstract. Online calibration of neutrino liquid scintillator detector at energies above 10 MeV is very important for study of such rare process as supernova and for correct calculation of backgrounds if spectral properties is the focus of researches. The traditional procedure implies the usage of radioactive sources with well-known spectral properties but such approach is limited by available radioactive sources, upper possible energies (~10–11 MeV) and dangerous for ultra low background environment of modern detectors. The approach we propose is based on simulation of events with controllable UV double LED pulser. The LED’s main wavelength fits the scintillator excitation wavelength. This technique allows to simulate physical events within the detector in very wide energy range from a few hundred keV to about 50 MeV. Additional studies like pile-up analysis can be performed due to double-LEDs scheme which generates two delayed signals with different adjustable amplitudes. The delay time is also adjustable parameter.

The large liquid scintillator neutrino detectors have been created in recent decades. To exploit them for study of various rare processes that take place in the energy range from 10 to 100 MeV and for correct account of backgrounds in the same energies online calibration is strongly necessary. But the traditional method based on the usage of radioactive sources with well-known spectral properties cannot be applied. There are several main problems in this case. First of all, the source must be small. It means the dimensions are not much more than the accuracy of the spatial reconstruction of events in the detector. Therefore only the sources which are based on natural radioactivity can be used. But all of them including complex sources like AmBe have energies of radiation below 10 – 11 MeV. Finally the radioactive sources are very dangerous for ultra low background environment of modern detectors. The way out is to use a powerful light pulses with adjustable amplitudes.

During recent years the different light sources have been actively applied in large volume liquid scintillator detectors for technical purposes. For example, the condition of photomultipliers can be tested with a laser. Another example is a definition of the spatial position of a radioactive source in the detectors during a calibration campaign. It can be done by using a few cameras attached to the inner surface of central tank and a small light source (laser or LED) placed in immediate vicinity from the radioactive one. These instances of works have been performed in the Borexino experiment [1,2].

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The concept of the online calibration above 10 MeV by light sources implies an assumption that the energy of simulated signal is directly proportional to the number of emitted photons. There are three light sources: a laser, laser diode and LED. The laser has two main advantages. The first one is a power of radiation. For example, one laser could be used to calibrate simultaneously plenty PMTs by dividing the signal with a splitter. The high power provides a sufficient number of photons if the laser is exploited for reconstruction of the radioactive source position. The second advantage is a duration of pulses. It should be about \(10^{-200}\) ns like a typical duration of real events. On the other hand the main disadvantage of the laser is the high cost of components of the calibration system if it’s planned to control some signal parameters like amplitude, duration, rate of pulses and delayed time between them. It’s especially a huge problem in case of UV lasers. The last one is useful when the task is to simulate real events which produce the primary radiation that is invisible for PMTs. Thus the UV laser doesn’t suit for calibration. Moreover the systems with any type of laser diode are expensive as well.

Another solution is to use a LED as a source of light. LEDs are cheap. Since the beginning of the 1990s the new types of LEDs, in particular blue and UV, have appeared. But it was impossible to make the calibration system due to the power of LEDs was insufficient and there were no blue and UV LED drivers. The situation has changed over time.

A standard blue or UV LED has a power about 0.1–1.0 mW. It’s easy to understand whether this value is high or not. Let \(P\) denotes the power of the LED, \(E = 50\) MeV – the maximum energy of simulated event, \(n_{\text{eff}} = 10\) – the attenuation of the pulse in the system, \(\tau = 20\) ns – the signal duration, \(m\) – the number of photons per pulse and \(\lambda = 250\) nm – the wavelength. Then

\[
P = \frac{E \cdot n_{\text{eff}}}{\tau} \approx 4\text{ mW} \tag{1}
\]

and

\[
m \approx \frac{2\pi \lambda n_{\text{eff}} E}{\hbar c} \approx 4 \cdot 10^9 \tag{2}
\]

It’s important to note that the assessment is conservative and rough. On the other hand, it is implied that the LED worked in continuous mode. If the pulses are rare (i.e. the pulsed mode) the maximum diode current may be higher by an order. But the power of a few mW is preferred for the calibration above 10 MeV.

The scheme of easily controllable, reliable, compact and very cheap driver for nanosecond LED pulser was proposed by J.S.Kapustinsky and his colleagues in 1985 [3]. It has become relatively popular since that time. For instance, the pulsers are based on this scheme were applied for time and amplitude calibration in the Baikal experiment NT-200 [4] and in the ANTARES experiment [5] located in the Mediterranean Sea. The scheme was called "Kapustinsky’s driver". Lubsandorzhiev and Vyatchin adapted it for InGaN/GaN ultraviolet and blue LEDs produced by Nichia Chemical [6]. So that the way to construct a cheap system for online calibration with LED pulser has been opened.

The common simplified scheme of the proposed system is presented in figure 1. Borexino is indicated since the system is expected to be implemented in this detector and for completeness of the illustration. There are three main ideas which formed the basis of the method.

1. **Adjustable input of the LED pulser.** It means that the amplitude, rate and delayed time of the simulated signals are adjustable parameters. They are set remotely by operator. The duration of pulses is specified during the design. On hardware level a generator produces starting pulses that define two parameters – the rate and delayed time, and a control circuit manages the supply voltage of the LED driver that influences to the amplitude.

2. **Double-LEDs scheme.** The LED driver has two diode so that it’s possible to generate two close peak. The delayed time between them can be changed up to 0. It’s useful for simplified pile-up analysis and for simulation of inverse \(\beta\) - decay events.
3. **Controllable output of the LED pulser (line of control or power meter).** It allows to measure the pulse energy. One uses the method of relative measurements. For calibration of the line of control a few test set of the pulser signals are written and compared with the other calibration data collected during the cycle of measurements with radioactive sources. The energy scale up to 10 MeV is built. It must be linear. Then the scale is extrapolated implementing the main assumption of the proposed procedure that the energy of simulated signal is directly proportional to the number of emitted photons. The structure of the power meter is very simple. This is an optic system that consists of an attenuator, focusing lens/collimator, photodiode with a preamplifier and amplifier. A trigger and ADC are absent due to the line of control naturally integrates into the DAQ of the detector.

The current design of the calibration system implies the use of UV LEDs with wavelength $265 \pm 5$ nm and the maximum pulse power of 6 mW at 200 mA. The parameters of the diodes were fitted to properties of the Borexino scintillator (PC+PPO). The LED driver is slightly modified Lubandsorzhiev’s LED driver. The first prototype that was made a year ago is shown in figure 2. A typical oscillogram obtained on a test stand is shown in figure 3. The test stand is a black box with one PMT (ETE 9823B) and the prototype of the device.

It’s worth noting that the off-axis calibration can be performed with the new system. It depends on the source insertion mechanism. The sketch of the off-axis calibration in case of Borexino is presented in figure 4. One detail should be taken into account: a small diffuser must be placed at the end of the fiber to reduce anisotropy of radiation.

The new calibration system is quite universal. Therefore it’s planned to apply it in other...
experiments. The system will be useful for hyper projects like JUNO [7] and Hyper-Kamiokande [8]. Also the further research and technological development of the method will be based on the iDREAM [9] and Borexino experiments.

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