An approach to pure scintillator-based detector for *Neu-LAND*

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*There are two proposals for the next generation of LAND (**L**arge **A**rea **N**eutron **D**etector): a detector based on Resistive plate chambers (RPCs) or on pure plastic scintillator material. The time resolution of the second option has been tested.*

Motivation

The detection of neutrons, derived from heavy ion collisions, is LAND's mission. The current resolution of this detector is: $\sigma = 250$ ps (time resolution) and $\sigma = 3$ cm (spatial resolution). Future applications require to improve the detector up to a time resolution of less than 100 ps and less than 1 cm in position resolution. This will allow to measure high-energy neutrons (from 200 MeV to 1000 MeV) at the R^3B experiment at FAIR. [1]

Why does one need to detect neutrons? It is essential for the study of most of the reactions that currently take place at the LAND/FRS setup (multifragmentation, collective flow of nuclear matter, etc.[1]) and also for future experiments like R^3B which will allow many kinds of studies: knockout reactions, electromagnetic excitations and so on [2].

1 Physics in the experiment.[2]

1.1 Neutron detection with scintillators.

Since neutrons have no charge they can not interact by means of the Coulomb force with matter. When they undergo an interaction it is due to the presence of the nuclear force, i.e by means of **nuclear reactions**. In these reactions one could expect to have scattering, excitation of the nuclei (and the corresponding deexcitation), transformation of the nuclei into new particles like protons, alpha particles, fission fragments, etc. These charged secondary particles can easily be detected. *This conversion from neutrons to charged particles is the basic principle used to detect neutrons.* Later we will explain how to measure the charged particles with plastic scintillators.

For high energetic neutrons the probability of having a nuclear reaction in which we get secondary particles coming from the fragmentation of the original nuclei is very low. Therefore, the method currently used in the LAND is based on the excitation of passive material (Iron) and afterwards the nuclei emit charged particles which are detected with plastic material. The disadvantage of this kind of detector is that the neutron can interact several times and also that the charged particles sometimes do not come out of the passive material.

What other method can we use? The answer could be using **elastic scattering** without this passive component. In this interaction the neutron transfers a portion of its kinetic energy to the scattering nucleus which gives rise to a *recoil nucleus.* When the neutron transfers an energy on the range of a few hundreds keV, the recoil nucleus can be detected. The most widely used target nucleus to produce this mechanism is Hydrogen; the main reason for this is that a neutron can transfer most of its energy to the proton in **one single** interaction.

As mentioned before, a high concentration of Hydrogen is desired to produce elastic scattering of neutrons. It is possible to get a scintillator material with this characteristic, for example the so-called **organic scintillators**. A lot of the physics involved in the process of generat-

[1] R^3B: Reactions with Relativistic Radioactive beams, FAIR: Facility for Antiproton and Ion Research.
[2] For further details see [3].

ing light with these materials can be mentioned but it is not the aim of this work. Nevertheless, we remind you that the fundamental process involved is **fluorescence** while **phosphorescence** is a process which we want to avoid since it is much 'slower'.[3]

1.2 Photomultipliers.

These elements are a very important piece of the setup. They register the light of the scintillator and transform it to an electric signal. The fundamental physical process involved is the **Photoelectric effect**. The **Quantum Efficiency** (QE) of the photocathode is a function of the photons wavelength; this is why it is very important to match as good as possible the wavelength of the photons emitted by the scintillator material with the wavelength at which we get the highest QE.

2 Experiment.

2.1 Material employed.

Electronics	TRIVA6 module, constant fraction module (*CF*), delayer, coincidence unit, time to digital converter (*TDC*), charge to digital converter (*QDC*), scope.
Scintillators	One 2x0.05x0.05 m^3 bar, two scintillator cubes of 0,02 m edge. Material details: [4]
Photo-multiplier tubes (PMT)	R9800 and R9779 made by Hamamatsu
Radioactive sources	Gamma source: 22Na 370 kBq, 60Co 370 kBq, electron source: 90Sr 40 kBq.

2.2 Test setup.

In order to measure the time resolution of the scintillator bar we need particles that produce light inside this bar. This light is collected by the PMTs and recorded by the Data Acquisition System (*DAQ* from now on).

Several setups are possible. One could think of using a radioactive source and a collimator. However, PMTs have a certain spread in the *electron transit time* [4]. The behaviour of such spread with the number of photons is a linear decreasing function. Therefore, since gamma rays from sources used for our tests leave at maximum 1.3 MeV and cosmic rays around 10 MeV[5], it is expected that the first would give ten times less photons (larger spread) than the latter, and no good results were obtained with this setup.

Another option would be using cosmic rays. Since we can not control this source we have to create a way to measure only certain events we consider appropriate. In order to do so we place two scintillator cubes (S1 and S2 in Fig. 1) on top and below the scintillator which will be tested. This will allow us to determine when a cosmic ray passes through both of them, and consequently, through the long bar inside a region of 2x2 cm^2 (the area covered by the cubes).

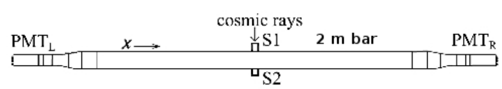

Fig. 1: *Experimental setup.*

2.3 Detailed description of the DAQ.

Using the two scintillator cubes and the CF we make a coincidence in order to get a 'trigger' which has, yet, to be accepted by the TRIVA6 module (see *(a)* in Fig. 2). As we have already mentioned in 2.2, this trigger simply means that a cosmic ray has passed through both of our cubic scintillators, and we take that as a valid event. The accepted trigger is taken into a coincidence module to restore the right timing. This 'timing' is given by the latest of the two signals from the scintillator cubes, i.e. it has to define the coincidence (see *(b)* in Fig. 2). Finally, we have generated our 'Master trigger'. This signal gives the order to the TDC and QDC modules to measure the time and the charge of the desired signals.

The time and charge signals are taken from the CF logic and analog output correspondingly. Each signal has to be delayed, depending on the purpose required. In order to get a time measure the data has to come after the master trigger within the range of the TDC (200 ns in our case). For the charge measurement the trigger has to be taken as a 'gate'. This means that while the gate is open, the QDC can read the analog singals (see *(c)* and *(d)* in Fig.2).

[3] By this we mean that the emission of photons takes a longer time.

[4] The time interval between the arrival of a photon and the collection of the photoelectrons at the anode.

[5] A cosmic ray leaves roughly 2 MeV/cm and it travels through 5 cm of plastic scintillator in our setup.

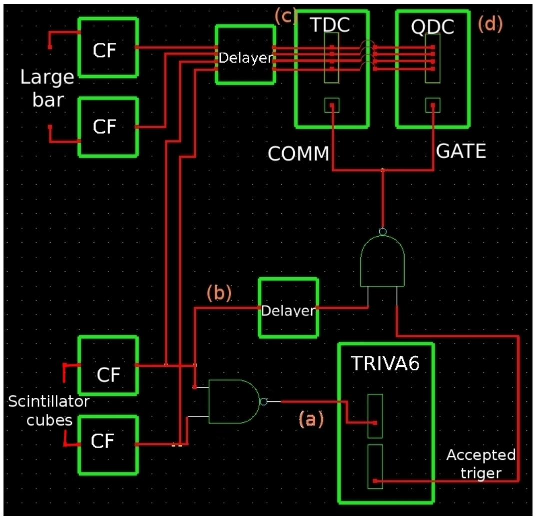

Fig. 2: *Scheme of the DAQ system used.*

3 Data analysis.

Were we only taking the signals from the PMTs we would measure the total resolution, that is, including the one from the electronics and the one from the cubes used to generate the Master trigger. To estimate this contribution we have to consider the electronics, the distribution for each cube (Gaussian type) and a rectangular distribution related to the physical dimensions of the cube[6]. The last is an important contribution, but the mathematical treatment is extensive and will not be done here. Instead, we fit such data as a Gaussian and we give an upper limit of the time resolution.

We will calculate a weighted average of the time: T_{av} according to the formulas[7] :

$$T_{av} = \frac{T_L \sigma^2(T_R) + T_R \sigma^2(T_L)}{\sigma^2(T_R) + \sigma^2(T_L)} \quad (1)$$

$$\frac{1}{\sigma^2(T_{av})} = \frac{1}{\sigma^2(T_L)} + \frac{1}{\sigma^2(T_R)} \quad (2)$$

Where T_L and T_R are the mean values recorded by PMT_L and PMT_R. The sigma value: $\sigma(T_L)$ $(\sigma(T_R))$ is obtained as the quadratic difference between the one given by the PMT_L (PMT_R) and the sigma value given by the signal *(b)* in Fig. 2 which we name $\sigma(T_S)$. As an example of the plots used, we now show those corresponding to the position 120 cm.

[6] Cosmic rays have the same probability to go through any point of the 2x2 cm^2 of the cube.
[7] Taken from [5].
[8] Actually, we have 4096 channels which correspond to a range of 200 ns. This gives us 48,8 ps/ch

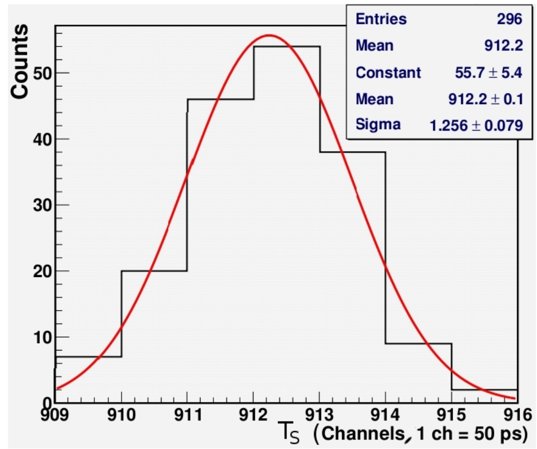

Fig. 3: T_S.[8]

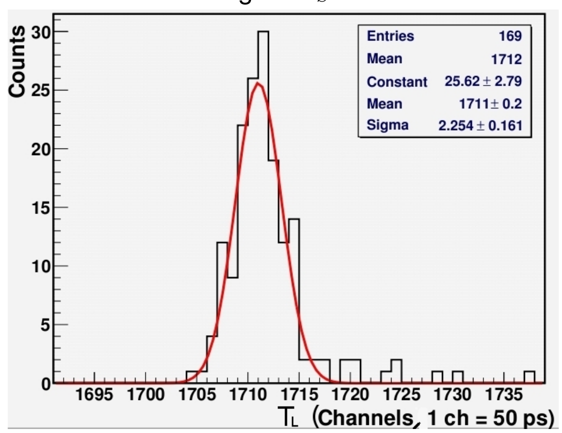

Fig. 4: *Time resolution of PMT_L.*

In most of the cases it is necessary to make a restriction in the data points. This restriction could be done directly in the plot; for example on Fig. 3 we have restricted the fitting range since we had random data surrounding. On Fig. 4 we have represented only the data points from PMT$_L$ which correspond to the values inside the range in Fig. 3, this is why we only have 169 counts instead of the total: 296. In other cases we could restrict on the energy. This allows us to select the most energetic signals in order to obtain more photons and therefore a lower spread in the times as already explained in Sec. 2.2.

4 Results.

4.1 Estimation of the speed of light.

With the data we have measured we can give an approximate value of the speed of light in our material. First, from the measure at x = 100 cm we get the *offset* value: we plot the difference T_R - T_L. This plot should be centered in channel 0 since we assume that light gets to both PMTs at the same time. We fit the data and take the mean value as our *offset*. Later, we take the data recorded at a different position and substract the offset value. This is all we need to calculate the desired value.

Position (cm)	Mean value (ch)
100	-215.8 ± 1,1
150	-336,02 ± 0,53

Tab. 1: *Mean value of* $T_R - T_L$ *fit for some positions.*

The mean value of the data at 150 cm without the offset is: -120.2 ± 1.2 ch. Considering that we have 48,8 ps/ch we can obtain the speed of light as follows:

$$v = \frac{2(150-100)}{120,2 * 48,8 * 10^{-3}} = 17,05 \pm 0,17\ cm/ns \tag{3}$$

We can compare this value with the one given by the manufacturer of the scintillator material: Refractive index: 1.58. This means: $v = \frac{c}{n} = 18,99\ cm/ns$. The estimation agrees.

4.2 Time resolution.

We have already mentioned how to obtain the time resolution T_{av} for each position in the bar. We have only tested one half of the bar: from x = 100 cm to x = 200 cm. It is important to mention that several tests have been done, but the external conditions were not always the same. This is why not all the tests can be studied together. The external conditions we refer to might be for example the beam at 'Cave C'. During beam time the magnet ALADIN[9] is turned on and it can disturb the PMTs' performance. We tried that the data presented had been taken under the same external conditions.

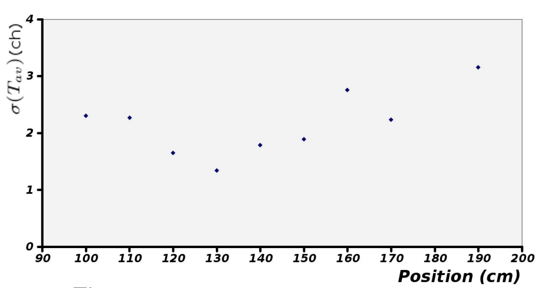

Fig. 5: $\sigma(T_{av})$ *vs position in the bar.*

It is very important to mention that we have observed a systematic error during all the tests. The sigma values given by PMT$_R$: $\sigma(T_R)$ were always much larger than the corresponding values for PMT$_L$: $\sigma(T_L)$[10]. Therefore, if we look at Eq. 2, it is expected that $\sigma(T_{av})$ would have the 'same' behaviour as $\sigma(T_L)$. This is exactly what we observe comparing Fig 5 and 6.

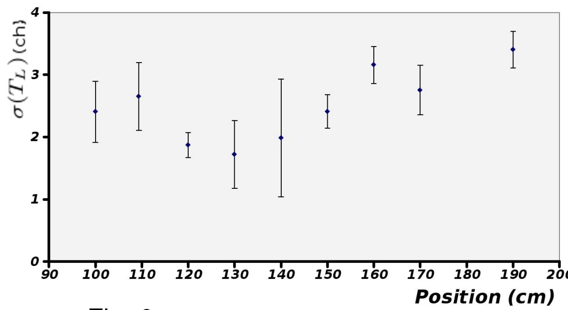

Fig. 6: $\sigma(T_L)$ *vs position in the bar.*

5 Conclusions.

It has been showed that the organic scintillator used can be implemented in a neutron detector. We have established an upper limit of the time resolution near $\sigma = 100\ ps$. The real resolution can only be better than this value for the following reasons:

1- We have not taken into account the error introduced by the physical size of the scintillator cubes used to create our trigger of the DAQ.

2- It is expected for neutrons to produce more photons which will improve the performance of the PMTs.

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References

[1] URL: http://www.gsi.de/forschung/kp/kp2 /collaborations/land/aim.html
[2] URL: http://www.land.gsi.de/R3B/docu/LoI-R3B-final.pdf
[3] Glenn F. Knoll, *Radiation Detection and Measurement.* Chapters 8, 9, 15.
[4] URL: http://www.rexon.com/RP_408.pdf
[5] Denisov S, Dzierba A, Heinz R et al. Nucl. Instrum. Methods A, 2002, 478: 440.

[9] A LArge DIpol magNet.
[10] That is why no error bars are shown in Fig. 5, the uncertainty introduced by PMT$_R$ is not statistical but due to malfunction.