Scintillator-SiPM Lab

NAT/HEPCAT Summer School
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This activity involves the use of a tabletop test bed that utilises Silicon PhotoMultipliers (SiPMs) and scintillators to assess the Pulse Shape Discrimination (PSD) capabilities of the scintillator using a mixed neutron and gamma source. For a description of the physics processes relating to the emission of light from scintillators the reader is directed to Organic Scintillators for Fast Neutron Detection[1]. For a very complete overview on SiPMs the reader is directed to The Silicon Photo-Multiplier Status and Perspectives[2]

The learning outcomes of this lab are:

- Understanding of data collection using a digitizer.

- Fitting models to data using lmfit (python library).

- Understanding of metrics used to assess PSD.

Introduction

Devices capable of conducting PSD between fast neutrons and gammas have widespread use in the development of neutron cameras for application towards field measurements, neutron physics and nuclear nonproliferation. In general, they tend to utilise simple algorithms to ensure the fast determination of particle type, allowing for highly portable and low-powered devices. Efficient discrimination between fast neutrons and gammas is vital when trying to observe a weak neutron flux in a high gamma background.

What exactly is PSD? The emission spectra from a scintillator can be dependent on the type of interacting particle. Therefore, the resultant electronic pulse output by an optical sensor has characteristics (timing and intensity) depending on the particle type. This allows for the discrimination of particles by their induced pulse shape. Examples of the normalised emission spectra from an organic, EJ-276, and a crystalline, Stilbene, scintillators are given in Figure 1.

The PSD capabilities of the scintillator will be assessed using the "Q-ratio" method. This is traditionally taken as the integral of the tip of the pulse against the ratio of the tail. This activity will use a slightly altered version of the Q-ratio method, where the ratio of a partial integration (from start time t_0 to time t_1) divided by a total integration of the pulse (from the same start time t_0 to time t_2), as shown in Figure 2.

$$PSD = \frac{\int_{t_0}^{t_1} Waveform(t)\ dt}{\int_{t_0}^{t_2} Waveform(t)\ dt}. \tag{1}$$

[1] https://drive.google.com/file/d/1YO5gVDlNd4Lqe4LQjOg0F5ht-JfXfSCd/view?usp=sharing

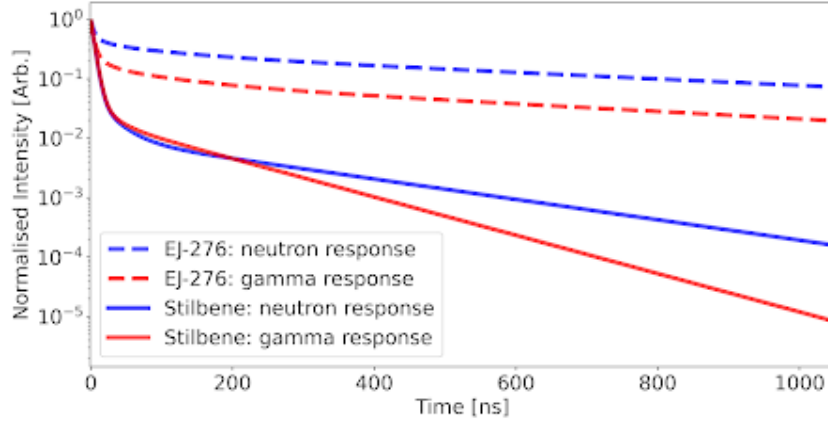[2] https://indico.cern.ch/event/716539/contributions/3251239/attachments/1797750/2931272/VCI19_-_SiPM_-_GCollazuol_-_v8.pdf

Figure 1: Normalised emission spectrum for neutron (blue) and gamma (red) responses of EJ-276 (dashed lines) and Stilbene (solid lines).
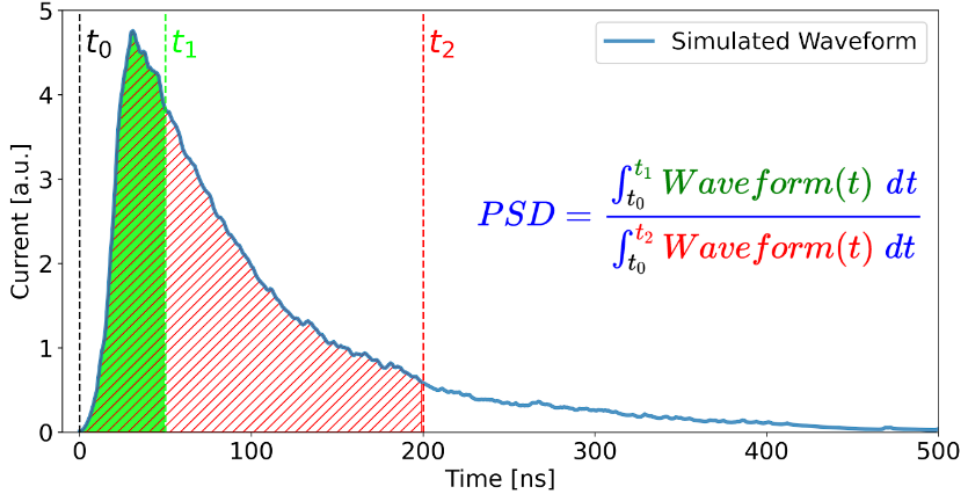

$$PSD = \frac{\int_{t_0}^{t_1} Waveform(t)\ dt}{\int_{t_0}^{t_2} Waveform(t)\ dt}$$

Figure 2: Definition of the Q-ratio pulse shape discrimination method. The ratio of the areas from t_0, the start of the triggered pulse, to t_1, and from t_0 to t_2 define the PSD metric.

In the analysis stage of this lab, the PSD capabilities of the scintillator being studied will be assessed for different combinations of t_1 and t_2. To assess these combinations two metrics will be used: a Figure Of Merit (FOM) and gamma leakage. Where the FOM is a measure of the separation between the resultant neutron and gamma distributions within the PSD parameter. The FOM use the mean, μ, and standard deviation, σ, of the distribution of PSD values obtained for neutrons and gammas:

$$FoM = \frac{\mu_\gamma - \mu_n}{2.355\,(\sigma_\gamma + \sigma_n)}. \tag{2}$$

The larger the value of the FOM, the greater the separation between the distribution, thus a better performance at distinguishing between neutrons and gammas. A FOM of >1.27 indicates the distributions are sufficiently separated for PSD between neutrons and gammas.

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The second metric, gamma leakage, is assessed by determining the per cent of the gamma events which lie in the same region of PSD space at and above the value corresponding to the PSD value of the 99.9% neutron acceptance. The optimal combination of t_1 and t_2 will maximise the FOM and minimise the gamma leakage.

Activity

Assessing the dark count rate and finding a suitable threshold

Before collecting data, a suitable threshold needs to be established. This is to ensure that the scope is not triggering on dark count pileups; which would result in a data-set dominated by dark count.

- Ensure only the SiPM array is in the black box, and tightly close the black box.

- Turn on the power supply. Slowly raise the power to 29 V (be careful to not accidentally overshoot 29 V as bias voltages above 31 V are detrimental to the SiPMs).

- Open the CaenScope application on the desktop and make sure it recognizes the digitizer.

- On the right-hand side of the application, enable channels 0 (SOUT) and 1 (FOUT)

- Set the trigger on channel 0 and ensure that "E" is disabled.

- On the bottom left-hand side of the application, make sure the position, dc offset, and record length are correct. The position should be at -49 for 10 ADCC/bin, DC offset should be 65536 for SOUT/CH0 and 50000 for FOUT/CH1 and record length should be 2000 samples

- Make sure to press enter after changing/entering any of the above values (the software is finicky and doesn't register a new entry otherwise)

- Force trigger on a few events

- Find the baseline value, (y2-y1)/2 will be our baseline.

- Trigger threshold is approximately baseline + 2 (in ADC counts). But to ensure the threshold is true, ensure no more than 20 events occur within 10 minutes.

- If 20 events are surpassed in under 10 minutes, raise the threshold by 1 ADC counts and try again. The reason for this is to prevent excessive triggering on dark count pileups from the SiPMs

- Once the threshold has been determined. Turn the power supply off

Collecting data with a scintillator and source

This section will cover the steps required to obtain the raw waveform information required to perform the PSD analysis. The length of time to complete this section will be dependent on the activity of the source. For very low activity sources, the number of events recorded in the data-set may need to be reduced to fit the time-frame of the activity.

- Place the scintillator on the SiPM array after applying a small amount of optical grease on the SiPM pixel first. Move the scintillator in two perpindicular figure of eight pattern to ensure even coverage of the optical grease.

- Place the source on top of the scintillator.

- Close the black box carefully to ensure the source stays on the scintillator.

- Bias the SiPM array to 29 V.

- Start recording the data as a text (xml) file.

- Set to record 100,000 events and check the box ensuring that CaenScope will immediately stop taking data after acquiring these 100,000 events.

- Once the scope has finished recording the files, turn the power off to the SiPM

- Remove the source and scintillators from the test-bed and wipe off remaining optical grease with Kim-tech wipe from SiPM.

Conducting the analysis to assess the PSD capabilities of the scintillator

This stage of the lab will use a Jupyter notebook containing the necessary procedure to conduct the assessment of the PSD capabilities of the scintillator.

LINK TO NOTEBOOK WITH SCREENSHOT

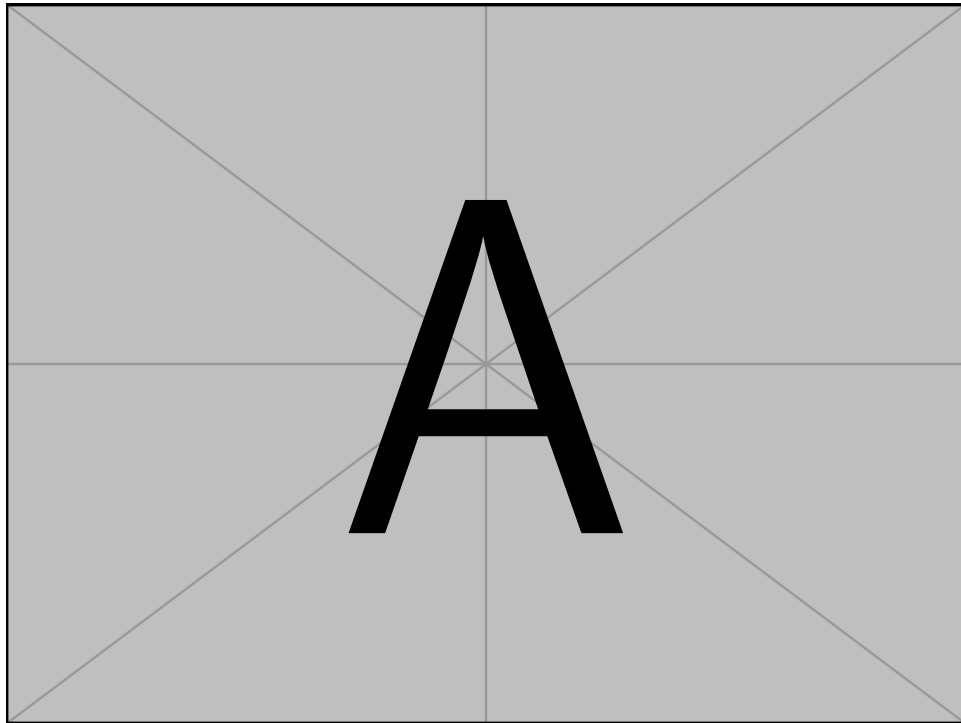Each stage of the notebook has a clear description of what is happening and the code is commented throughout.

Figure 3: Screenshot of the Jupyter notebook used to conduct the analyses.