Viareggio
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Introduction

Even if a SiPM is able to detect very low light intensity, it can be used for detecting a large amount of light in radiation detection with scintillators. The CAEN Mini Spectrometer is based on a Hamamatsu 3x3 mm^2 SiPM, model MPPC[(1)] S10362-33-050C, coupled to a scintillating crystal. This sensor, with its 3600 cells, provides a wide dynamic range, allowing the building of a mini spectrometer. Its Dark Count Rate (DCR), due to the large amount of pixels, is one order of magnitude higher than that of the 1x1 mm^2; its Dark Count Rate at 0.5 ph. is 3÷4 MHz: this is not a problem for the spectrometer application because we are not interested in counting photons, but in measuring the electrical charge of the large pulse obtained by the pixels signal overlap. A right threshold will remove all the spurious hits.

[(1)]MPPC® (Multi-Pixel Photon Counter) is a trademark of Hamamatsu Photonics.

The mini spectrometer is a holder able to keep the right coupling between the sensor and the crystal in a dark environment. The Fig. 1 shows the CAEN set-up diagram for this application.

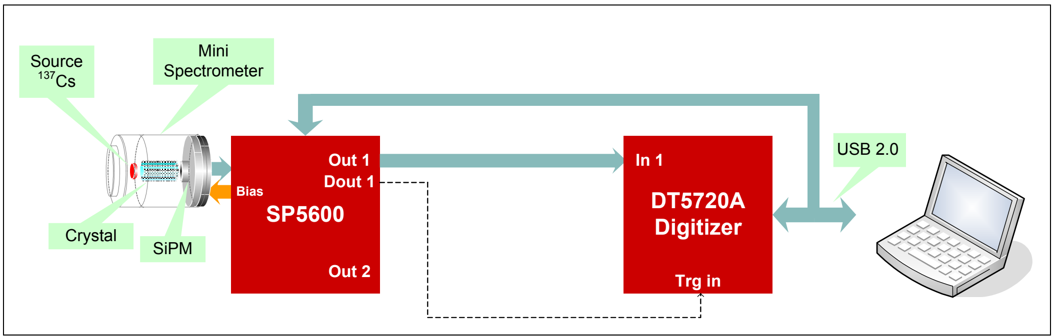

Fig. 1: The CAEN set-up diagram for mini spectrometer application.

Crystals

The CAEN mini spectrometer is provided with three different crystals: BGO (Bismuth Germanate), LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate) and CsI(Tl) (Thallium-doped Cesium Iodide). This selection of scintillator crystals gives a wide scope of evaluation.

Table 1 summarizes their main characteristics. All of them are 3 x 3 x 15 mm^2, polished on all sides and coated with a white epoxy on 5 faces. One 3 x 3 mm^2 face is open in order to be couple with the SiPM.

	BGO	LYSO(Ce)	Csi(Tl)
Density (g/cm^3)	7.13	7.4	4.51
Decay Time (ns)	300	40	1000
Light Yield (ph./MeV)	8200	27000	52000
Peak emission (nm)	480	420	560
Radiation length (cm)	1.13	1.14	1.85
Reflective index	2.15	1.82	1.78

Tab. 1: Crystals properties.

Interaction of γ-ray with scintillating crystals

In the energy range up to 3 MeV, gamma rays interact with matter by three processes: Compton Scattering, Photoelectric Effect and Pair Production (possible for energies greater than 1.022 MeV). The Compton Effect is the collision between a photon and a free electron. The energy of the incoming photon is shared between the scattered photon and the recoiling electron. In the Photoelectric Effect, the incident gamma ray transfer all its energy to a bound electron, which acquire a kinetic energy equal to the incoming gamma energy less the energy necessary to free the electron from its bound state.

All these processes convert gamma ray energy into electrons or positrons which collide with the the scintillators atoms, raising the atomic electrons into excited states. The de-excitation of these states cause the emission of photons in the visible or near UV region. The amount of light produced in the scintillator is proportional to the energy of the initial gamma ray.

The recombination of the electrons and holes, generated by the incident gamma ray on the scintillating crystal, provides the light the SiPM detects. The average photon energy of the light from the recombination depends on the nature of the crystal (Tab. 1 shows different peak emission for the three different crystals).

Acquiring the ^{137}Cs spectrum

The ^{137}Cs emits a single γ-line of 662 keV, produced by ^{137m}Ba, the dacay product of ^{137}Cs, which is in secular equilibrium with ^{137}Cs. Figure 2 shows the decay scheme of ^{137}Cs.

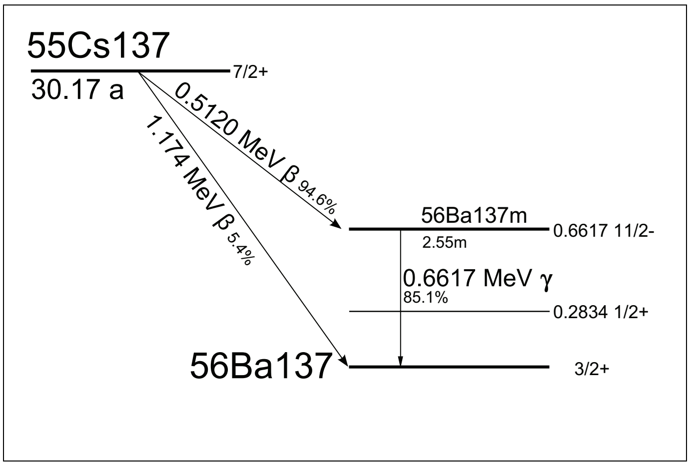

Fig. 2: The ^{137}Cs decay scheme.

Choosing the right cut-off threshold

The DCR of the mini spectrometer SiPM is 3÷4 MHz, one order of magnitude greater than the respective 1x1 mm^2 SiPM. In order to avoid the system be blind to the radioactive source, due to this high DCR, a proper cut-off threshold has to be selected. For example through two stair cases it is possible to choice a right cut-off threshold: one acquired with the source and one acquired without it. The Fig. 3 shows the two staircases: once the SiPM is biased, and a convenient gain is chosen, through the “PSAU staircase” tab in the right part of the GUI, the staircase run can be performed.

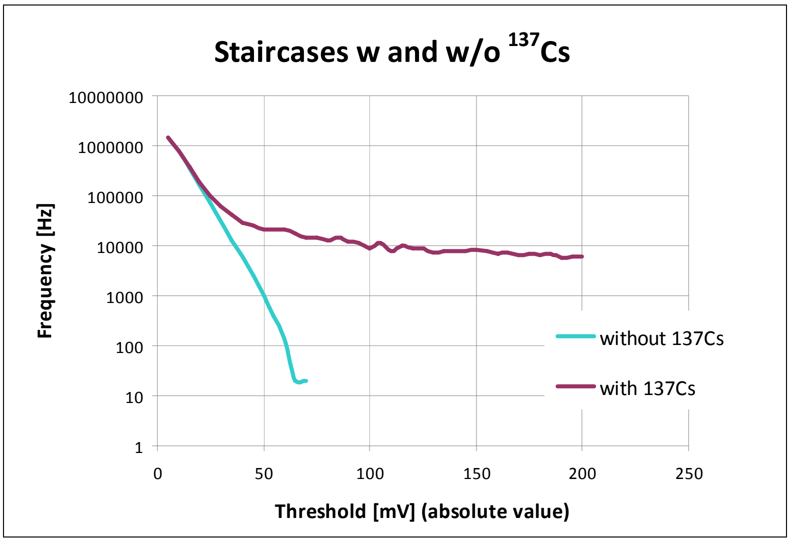

Fig. 3: Staircases acquired with and without ^{137}Cs source.

Step by step:

- Start the SP5600 - 2 Channels Power Supply and Amplification Unit (PSAU) clicking on “START PSAU” (the green light ‘ON’ switches on);
- Switch on the channel where the mini spectrometer is mounted;
- Bias the SiPM (in this example the bias is set at the nominal value, 70.85 V);
- Set the PSAU gain (in this example is 32 dB);
- Start the Digitizer, clicking on “START DIGITIZER” (the green light ‘ON’ switches on);
- Click on “PSAU StairCase” tab and run the two staircases clicking on “REFRESH” button.

In this example the SiPM is coupled with the LYSO crystal. Without the radioactive source, Fig. 3 shows that the count rate over a threshold of 60-70 mV drops to zero, while it remains constant when the source is present. Setting a threshold of 70 mV in the "Discriminator" panel of the PSAU (Fig. 4 shows the panel), allows the acquisition of a spectrum without the DCR contribution. Using the PSAU discriminator the acquisition can start in external trigger mode.

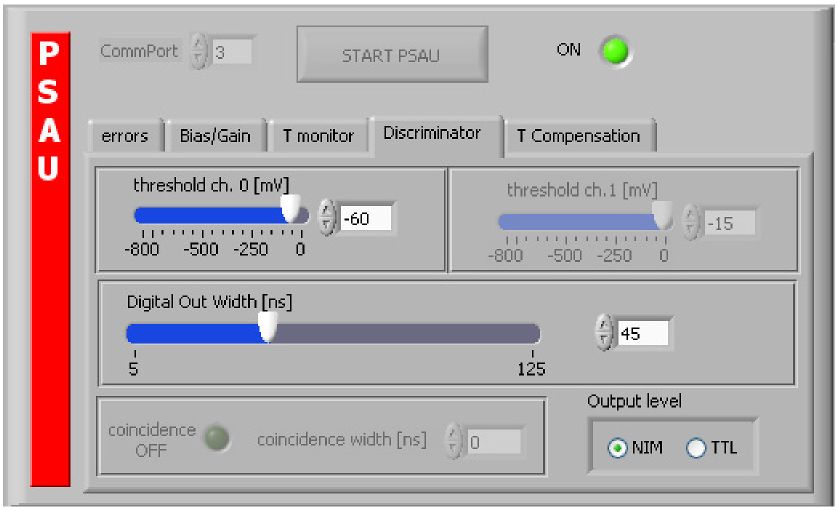

Fig. 4: The PSAU "Discriminator" control tab.

Alternatively it is possible to use the digitizer internal trigger mode, setting the digitizer trigger parameters and the channel threshold in the digitizer "Acquisition settings": before the calculation of delta (see the "Digital Pulse Processing for SiPM kit" document), the input signal is filtered in order to reduce the high frequency noise, using a low pass filter that averages a certain number of samples within a moving window. **Errore. L'origine riferimento non è stata trovata.** shows the trigger parameters the user can set.

"mean[#]" represents the number of double sampling periods used by the average window.

"rise time [ns]" is the rise time of the input signal, used in the calculation on delta

Fig. 5: The trigger digitizer parameters

In the external trigger mode don't forget the connection of the LEMO cable between the digital output of the PSAU and the trigger input of the digitizer.

^{137}Cs spectrum and the energy resolution

Fig. 6 shows a typical ^{137}Cs spectrum acquired coupling the CsI crystal to the 3x3mm^2 SiPM. The spectrum shows the following peaks:

- The noise peak of the system;
- The low energy X radiation (due to the internal conversion of γ-ray);
- The backscatter at the low energy and the Compton distribution;
- The photo peak at 662 keV.

The energy resolution of the peak, representing the spectroscopic capability of the detector, can be calculated, according to the following equation:

$$Energy\ resolution = \frac{FWHM_{peak}}{\mu_{peak}} \cdot 100$$

$FWHM_{peak}$ = full width at half maximum of the peak

μ_{peak} = channel number of the peak centroid

The peak at 662 keV is resolved with a resolution of 6.7 %, while the 32keV peak has a resolution of about 29 %.

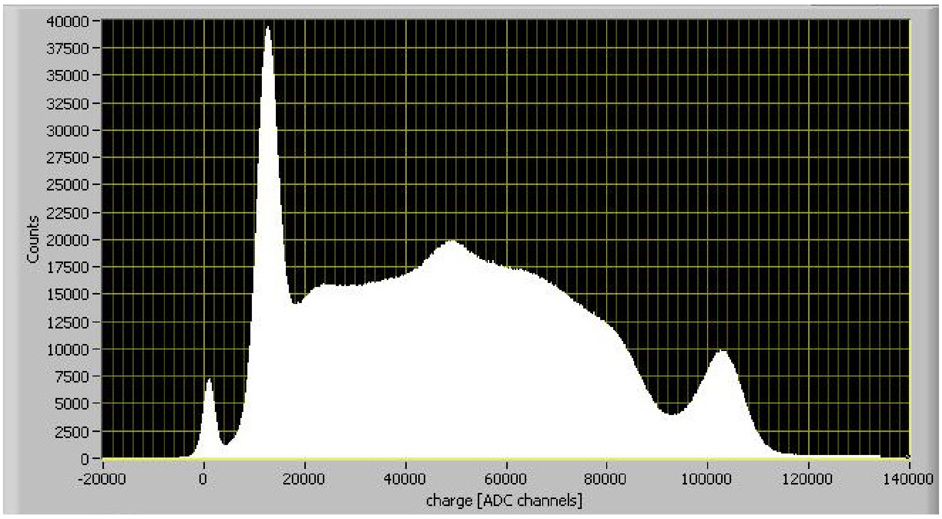

Fig. 6: The ^{137}Cs spectrum; activity of the source: 180 kBq

By keeping the same set-up and acquiring different spectra with different energy sources, a linearity plot can be assessed.

The three crystals in action

According to Tab. 1, each scintillator has a different balance of properties. For instance the Light Yield of the three crystal is very different. Lyso(Ce) has a light yield three times greater than the BGO, and the CsI(Tl) light yield is twice than Lyso(Ce). This crystal characteristic can be investigated acquiring a source spectrum with the three different crystals in the same PSAU and Digitizer conditions. This is show in Fig. 7.

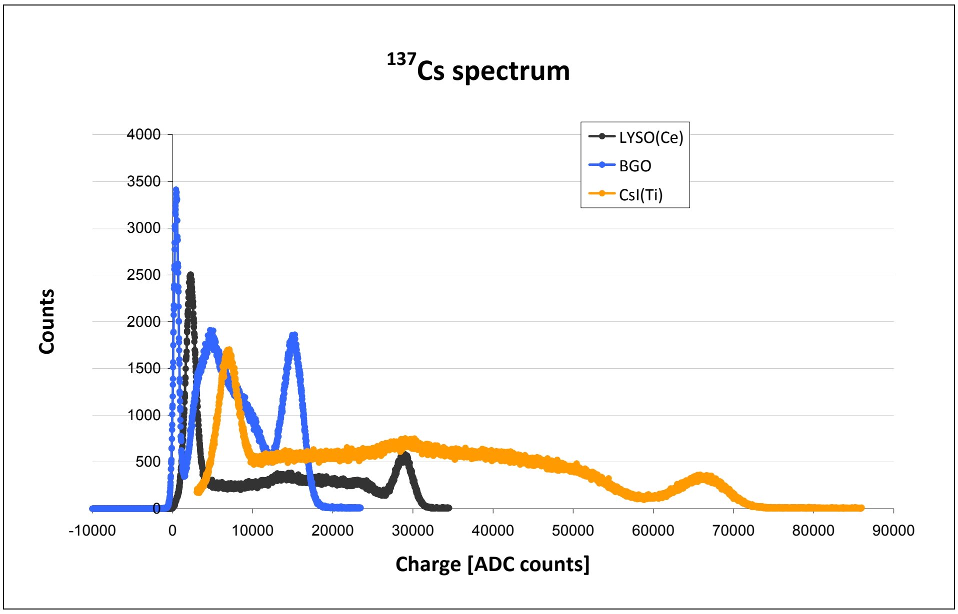

Fig. 7: ^{137}Cs spectrum with the three crystals. The plots are not normalized.

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