

HRFLEXTOT

High Resolution Flexible Time over Threshold ASIC

App Note

Tutorial on how to perform SPTR, Energy resolution and CTR measurements

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1 Introduction

In this tutorial, users will be able to operate, in small groups and with the help of the monitors, different PET prototype setups. Using these setups, they will be able to register energy spectra for a few radioactive sources, produce Single Photon Time Resolution measurements with state-of-the-art electronics and a basic Coincidence Time Resolution measurement.

1.1 Overview of a PET system

Positron Emission Tomography (PET) is a well-established nuclear medicine technique for visualization and quantification of metabolism and different biological processes at the cellular level. Advances in PET technology result in regular performance improvements and sensitivity increase. PET imaging works as follows. The molecule to be imaged is marked with a radioactive isotope emitting low energy positrons. The positrons will annihilate in the presence of electrons producing a pair of 511 keV gammas. Those two gammas, produced back-to-back, are the base of PET. By detecting both of them in opposite detectors in our scanner one can reconstruct the position where the positron annihilated and thus where the marked molecule is located.

PET can be divided into pre-clinical imaging, organ dedicated imaging and whole-body imaging depending on the application. Spatial resolution is a key parameter of the performance of the equipment for these applications. Pre-clinical and dedicated organ PET imaging requires resolution around 1 mm³. Whole body PET imaging can, in general, relax this figure. A motivation for even better clinical sensitivity is to open the way to a drastic reduction of absorbed dose to the patient. Thus, the technological implementation of PET requires fast and efficient detectors coupled to fast readout electronics.

1.2 Scintillators

A scintillator is a material with the ability to absorb ionizing radiation, such as x- or γ -rays (like the 511 keV gammas produced in positron annihilation), and to convert a fraction of the absorbed energy into visible, or ultraviolet, photons. The conversion process typically takes place in a time scale of nanoseconds to microseconds, thus introducing a brief pulse of photons for each x- or γ -ray that interacts with the scintillating material.

The light pulse, whose intensity is usually proportional to the energy deposited in the scintillator, is typically sensed by a photosensor that converts it into an electrical signal. Inorganic solid scintillators such as NaI, BGO, LSO, GSO, LYSO are the most commonly used for PET applications, because of their generally higher atomic number and mass density compared to organic scintillators (typically faster), which leads to better detection efficiency.

LSO, LYSO or LSF offer some of the best combinations of properties for PET. They have high atomic number and mass density for good γ -ray detection efficiency, a short decay constant for good coincidence timing, and a large light output that permits a good energy resolution. Additionally, they are mechanically rugged and non-hygroscopic, thus allowing relatively simple fabrication of detectors.

1.3 Photosensors: SiPM

A SiPM (Silicon Photo-Multiplier, also known as Multi-Pixel Photon Counter, MPPC) is a device obtained by connecting in parallel many miniaturized SPADs (Single Photon Avalanche Diode),

each one with an area of a few tens of μm^2 (also known as Geiger-mode Avalanche Photo-Diode, G-APD) belonging to the same silicon substrate.

The small SPAD plus its quenching element (to stop the avalanche) is named microcell. A typical SiPM consist of hundreds or thousands of such microcells, each one producing an almost identical signal in response to a photon impinging in its active volume. The output signal of the SiPM is, thus, proportional to the number of SPADs microcells that the incident photons fire.

The overvoltage (i.e., the difference between the applied bias and breakdown voltage) and microcell capacitance uniformity can be quite accurate in modern production processes and therefore an excellent separation between peaks in the charge spectrum is achieved, at least in the limit of a low number of incident photons. This makes it possible to count even tens of photons, which is clearly impossible with PMTs.

Nevertheless, PMTs still have some advantages, namely: lower temperature dependence and lower dark count rate. It is worth to keep in mind that the temperature dependence of the SiPM is related to the breakdown voltage temperature dependence and, therefore, it can be corrected by a smart supply voltage control.

1.4 Fast readout electronics

This tutorial will focus on the usage of non-conventional fast readout electronics, making use of different ASICs (Application Specific Integrated Circuits) developed for the fast readout of SiPM. The EHEP (experimental High-Energy Physics) group of the University of Barcelona has developed these ASICs for future PET scanners and/or other scientific applications.

The setups that you will be using are based on the evaluation setups developed to characterize the functionality of the different ASICs. We have chosen those that have a direct relation with their application in future PET scanners.

In each section, the relevant information about the ASIC being used is provided. In case you are interested, datasheets with complete details can be provided upon request.

In general terms all ASICs provide at least the following functionality:

- Multichannel SiPM readout.
- Possibility to adjust, within a certain range, the overvoltage applied to each individual channel to correct for gain differences if necessary.
- Fast low impedance input stage that can be masked in case of problems in a particular SiPM channel.
- Several configurable signal shaping options to allow their usage with different SiPM families and scintillating materials (with different light yields and decay time constants), and different use cases (trade off between measurement precision and readout speed).
- Low power, low noise and radiation tolerant implementations to ensure their usability in harsh environments.
- Depending on the case, analog or digital output with configurable gains and thresholds.

In all cases, ASICs are controlled by FPGAs (Fully Programmable Gate Arrays) that in turn are controlled from a computer that orchestrates the setup.

1.5 Manipulation instructions

The following instructions must be considered when manipulating any of the test benches proposed for this tutorial. In case of doubt, ask the monitors and follow their instructions:

- **IMPORTANT:** You will be handling radioactive sources, but they have low activity. Precautions should be taken to minimize the exposure time and maximize the distance.
- **CAUTION!** *Electrostatic discharge (ESD) can cause board damage. Wear an anti-static bracelet when handling the board or when plug-in the SiPMs.*
- **IMPORTANT:** *Please do not **POWER ON** the board without limiting the LV and HV supply source current.*
 - a. *Maximum current limit for **LV** supply source is **0.5 A (max.)**.*
 - b. *Maximum current limit for **HV** supply source is **1 mA (max.)**.*
- **IMPORTANT:** *Please do **not** power the board only from the USB port.*
- **IMPORTANT:** *Please do not turn ON the LV when the **HV** is at 0 V, always make sure that **HV** is at 2 V, never lower.*
- **IMPORTANT:** *Never leave the board power ON with **HV** at 0 V.*
- **IMPORTANT:** *Please never short circuit the diode **ANODE & CATHODE** pins of the SiPM readout board during any kind of measurement.*

2 Laboratories

2.1 Single Photon Time Resolution

Single Photon Time Resolution (SPTR) or time jitter is used to evaluate the fast response of an electronic circuit in combination with a photosensor. The SPTR is defined as the variability of the observed time difference (jitter) between the arrival of a photon to the photosensor and the detection by the front-end electronics. In practice SPTR is a combination of the jitter introduced by the photosensor, the electronics noise and the jitter from the light source (typically a pulsed laser that can be neglected). Moreover, the result of a given measurement depends on the detailed configuration of your setup:

- Choice of the excess bias or over-voltage applied to the SiPM.
- The discriminating threshold applied to the SiPM signal.
- Laser wavelength (diffusion tail), which also affects to the Photon Detection Efficiency (PDE) of the sensor.
- Temperature: for instance, dark count noise directly depends on the temperature, thus affecting the SPTR measurement.
- Front-end circuit (input capacitance) and other sources of electronic noise.

The setup employed to perform SPTR measurements consists of the following elements, as shown in Figure 1:

1. An external trigger at 50 kHz that sends a signal to both the laser driver and the oscilloscope.
2. The laser driver that sends a pulse to the laser (PicoQuant LDH at 641 nm, 50 ps pulse width).
3. The laser that generates a photon package that passes through a diffuser layer, which increases the light homogeneity that reaches the SiPM, HPKK single channel S13360 MPPC of 3x3 mm² and 50x50 μm² microcell size.
4. The HRFlexToT ASIC demonstrator board that processes the SiPM signal and sends it to the oscilloscope.
5. The oscilloscope, Agilent Technologies InfiniiVision MSO-X 3034A, that is used to record the measurements and to send them to the control computer for its further analysis.

To obtain reproducible results the temperature should be stabilized to avoid gain variations and to diminish dark count noise. For simplicity, temperature stabilization will not be used in this setup.

Figure 2 illustrates two measurements on the oscilloscope while performing an SPTR study. The “Laser Trigger” (in yellow) indicates when the photon pulse is emitted. The “Shaper monitoring” (in red) output is used to visualize the analog response of the SiPM. The green signal is the “Time” output, where the rising edge indicates the time arrival of the photons. The FlexToT ASIC, used for the readout, provides two outputs. A programmable threshold is compared to the output of the shaper producing a fast binary output providing, with its leading edge, precise timing information. While a second programmable threshold is set to produce a linear Time Over Threshold (ToT) output that encodes in its duration a precise measurement of the integrated charge. This is the blue or “Ch Out:Energy” signal.

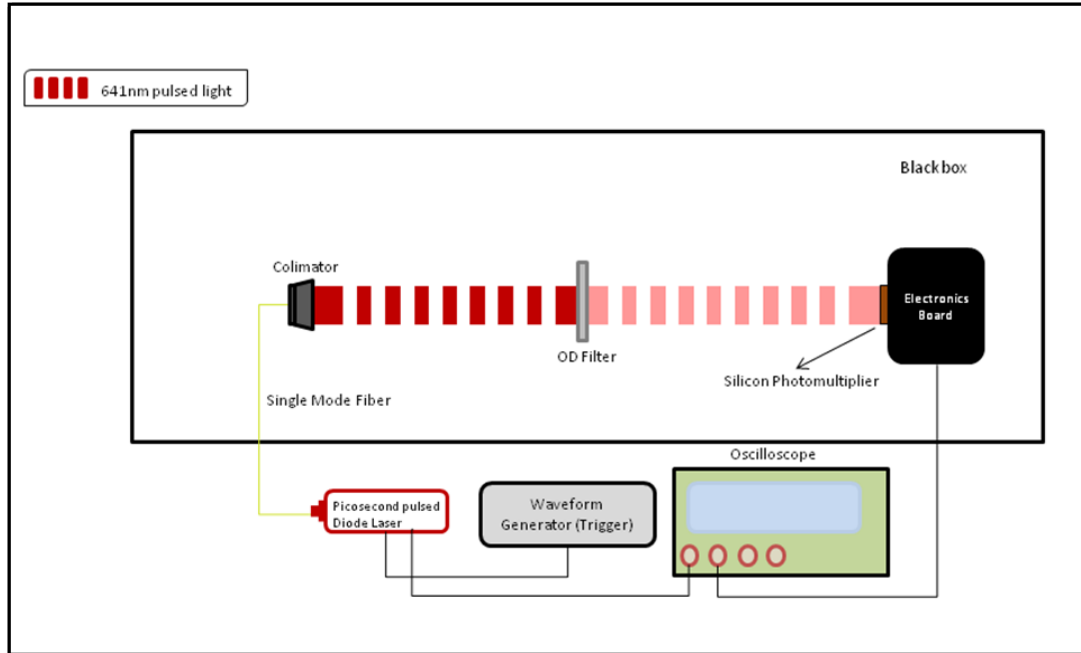


Figure 1: Single Photon Time Resolution set up.

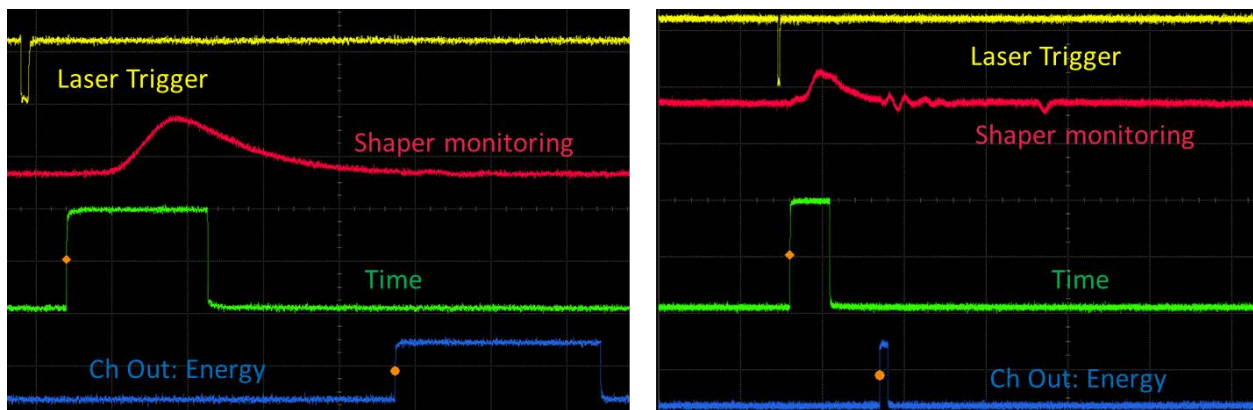


Figure 2: Typical signals of the HRFlexToT for measurements. Left: high input signal (many photons). Right: low input signal (close to single photon).

The time response of the system can be computed by obtaining the distribution of time delays between the falling edge of the “Laser Trigger” and the rising edge of the “Time” signal. Figure 3 shows an example of a shaper charge and time width histogram to distinguish the first photoelectron. Selecting the events corresponding to each peak allows to select one, two, etc., photon pulses. Then, the standard deviation of the delay distribution when single photon events are selected, i.e., the jitter corresponding to the single photon events, is known as the Single Photon Time Resolution (SPTTR). The distribution of time delays for those events is also presented in Figure 3.

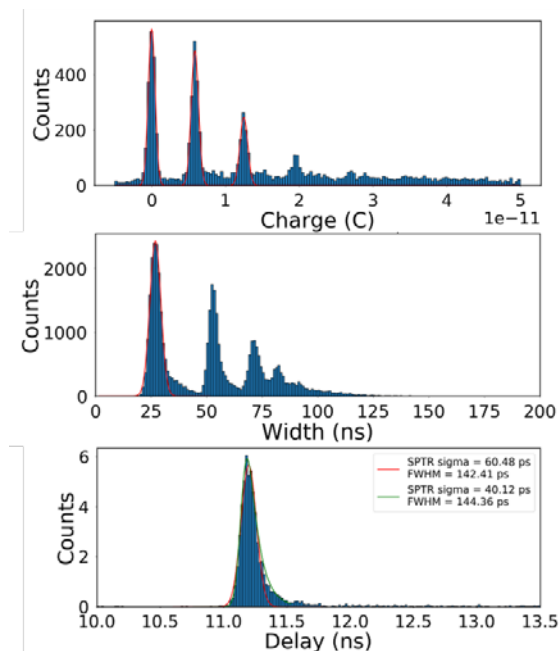


Figure 3: Top: Shaper charge distribution for low light laser intensity. Middle: time width distribution for low light laser intensity. Bottom: delay time distribution for single photon events. Sensor used: LCT4 of 3x3 mm² and 75 μm of pixel pitch, bias voltage of 59 V (over-voltage around 7 V).

2.1.1 TUTORIAL TASKS

Objective: Performing an SPTR measurement using the current setup and trying to get the best possible time resolution.

Take into account the following considerations.

1. Set the laser intensity at the proper level to detect a single photon. You can use an external attenuator or the “intensity level” of the laser driver. Connect the SiPM in the desired channel. In this example, channel 15 is used.

Trick: Use the persistent mode in the oscilloscope with an analog signal and try to see zeros (events without signal) and events with one or two photons.

2. Modify the time threshold to obtain the best SPTR. The fast pulse from the SiPM is converted into a binary pulse using a level defined by the time thresholds. This produces a non-linear time over threshold binary pulse. The threshold should be set above noise level and below the second photoelectron to capture the single photon events.

Trick: Move the threshold around 1st and 2nd photoelectron to find the optimal value.

- a. Select the gain (\$gain and \$gain_rl) configuration most suitable for the application. For SPTR measurements is recommended the highest gain for both values; both gains can be configured from 0 to 3 where 0 corresponds to the lower gain and 3 the highest.
- b. Perform a threshold scan to obtain the fine (\$value3 and \$value4) and coarse threshold corresponding to the pedestal. Important, switch off the high voltage and configure the board first.

```

./hrflectot threshold_scan -r th_scan_new_pcb_test.txt -w 1000
-e 15 1
  
```

- c. Coarse Threshold (`$coarse_thld`) can be set between 0 to 63. This value is normally set to the minimum threshold which is 63.
- d. Fine Threshold (`$fine_thld`) can be set from 0 to 63. Normally this value is set between 20 and 45, but the fine threshold depends on the SiPM employed and the ASIC.
- e. Using the information from the threshold scan, adjust the fine threshold to set the threshold at the first photon, but above noise level.
- f. The range where the 1st and 2nd photon is placed (or any photoelectron in general) can be found by performing a Dark Count Rate analysis. This study is not considered in this lab session, but if you want to know how to do it ask the monitor.
- g. Configure the board, using the desired threshold to capture the first photon.

```
>./hrflexTot config -s --trg_sel_fpga 2 -D 200 -m 15 0 -M 15 1
-e 15 0 -i 15 1 -S --gain $gain --gain_rl $gain_rl
-T $coarse_thld -t 15 $fine_thld
```

NOTE: The following steps (data acquisition and data processing) are performed using the MSO9254A oscilloscope from Agilent Technologies and thus the python scripts are adapted for this instrumentation. For other instrumentation, used your own scripts or modify the following ones according to your needs.

3. Perform a data acquisition using 2000 samples with the desired configuration.

```
>python sptr_acquire.py
```

4. Process the data acquired following this instructions.
 - a. Use the following command to process the data:

```
>python sptr_results.py data_HRFlexToT.csv
```

- b. Set the upper limit of the distribution of pulse widths (i.e., 15 ns).
 - c. Observe the histogram of time widths to discover the range of time widths where the first photoelectron is captured. "*cut_initial*" represents the minimum width which might correspond to the first photon and "*cut_final*" the largest time width which still corresponds to the first photon.
 - d. Obtain the jitter from the corresponding delay time histogram, i.e., the Single Photon Time Resolution.
5. Change the bias voltage to see how it affects to the time resolution. Do not increase the bias voltage beyond 62 V and ask the monitor before doing it.

2.2 Spectroscopy

The HRFLEXToT enables the possibility to measure the energy deposited by the gammas in the scintillator. Using this feature, experimental spectroscopic measurements can be done to study the spectra from different radioactive sources as well as the linearity of our setup.

Radioactive nuclei are unstable and decay emitting various types of ionizing radiation: alpha, beta, gamma, etc. In this tutorial we will focus on gamma radiation. It is important to notice that

radioactive sources may present different activity (number of disintegrations per unit of time) and therefore different exposure times might be required. The unit to measure the activity is the becquerel (Bq) that corresponds to one decay per second. In this lab we will only use sources with low activities that are authorized for manipulation by users.

Here there is a list of some typical sources with gamma emission that will be used in our setup (there are other sources that could be used upon demand):

- Cobalt 60 (^{60}Co):** Emits two gammas with energies of 1.17 and 1.33 MeV. Depending on the energy resolution of your system and the configuration of your setup, you might be able to distinguish the two photo-peaks in an energy spectrum or you will see a single broader peak.

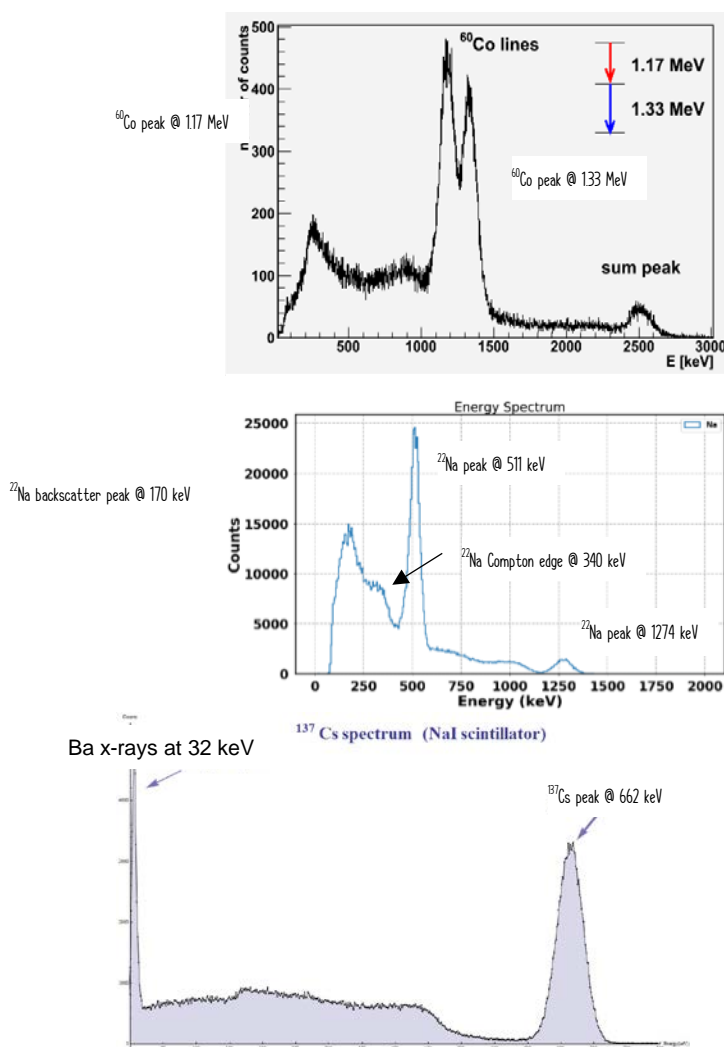


Figure 4: Spectra of various radioactive sources: (top) Co-60 (extracted from https://groups.nsl.msu.edu/SuN/SuN_spectra.php); (center) Na-22; (bottom) Cs-137 (extracted from <http://enacademic.com/dic.nsf/enwiki/1459031>).

- Sodium 22 (^{22}Na):** This source emits a positron and subsequently a gamma with 1274 keV. The positron will annihilate in the presence of electrons producing a pair of 511

keV gammas. These two gammas, produced back-to-back, are the base of PET scanners. By detecting both of them in opposite detectors in our scanner one can reconstruct the position where the positron annihilated. The spectrum of ^{22}Na presents other characteristic points that can be used to check the energy calibration of our system: the Compton edge at 340 keV and the backscatter peak at 170 keV.

- **Caesium 137 (^{137}Cs):** Radionuclide that emits a gamma with 662 keV. This source generates a single peak that can be clearly identified in the spectrum.

Figure 4 shows the spectra of the radioactive sources previously outlined. Note that the photons captured at low energies for the ^{137}Cs sample corresponds to the characteristic x-rays at around 30 keV.

As mentioned above, the HRFlexToT provides a measurement of the deposited energy encoded in the length of a binary signal. In the present setup this output is sent to the readout FPGA where a Time to Digital Converter (TDC) captures detected events and provides a digital representation of the pulse width of the energy detected. The evaluation board used for this tutorial includes a TDC implemented in a FPGA with enough resolution (around 40 ps jitter) to measure the energy pulse width of the individual channels.

In our setup, a single channel S13360 MPPC of $3 \times 3 \text{ mm}^2$ and $50 \times 50 \mu\text{m}^2$ microcell size is used. The crystal is an LFS of size $3 \times 3 \times 20 \text{ mm}^3$ wrapped in Teflon and a thin metal layer. A crystal with a relatively large height is used to maximize the probability of capturing the produced gammas, especially those of higher energies. Different radioactive sources will be used to obtain energy spectra.

Figure 5 shows the set up used to obtain the energy spectrum. Figure 6 shows an example of an energy spectrum of a Na-22 source when applying an over-voltage of 5 V.

The peaks corresponding to the full energy deposition of the 511 keV as well as the 1274 keV gammas are clearly visible. Note that the number of counts or samples used in this example is high enough to distinguish the latter gamma of the radioactive source, which is produced with lower probability than the 511 keV. Moreover, the Compton edge and even the backscatter peak can be distinguished. Note that the TDC is calibrated before performing this measurement to have the pulse width in nanoseconds.

Several factors can affect the linear response of the system:

1. The ASIC can respond non-linearly if the input signal is larger than its dynamic range. Note that the ASIC has different gain configurations depending on the application, so be sure that the lowest gain is selected to extend the dynamic range.
2. The number of photons that arrives to the sensor is larger than its dynamic range. In this case the sensor will present a saturated response.
3. The scintillator might also present non-linear responses for large energy depositions.

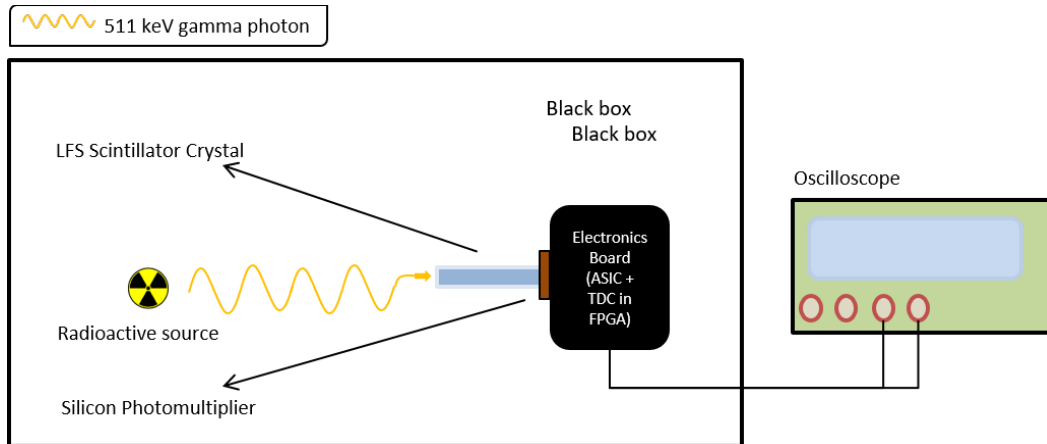


Figure 5: Set up used to perform energy spectroscopy.

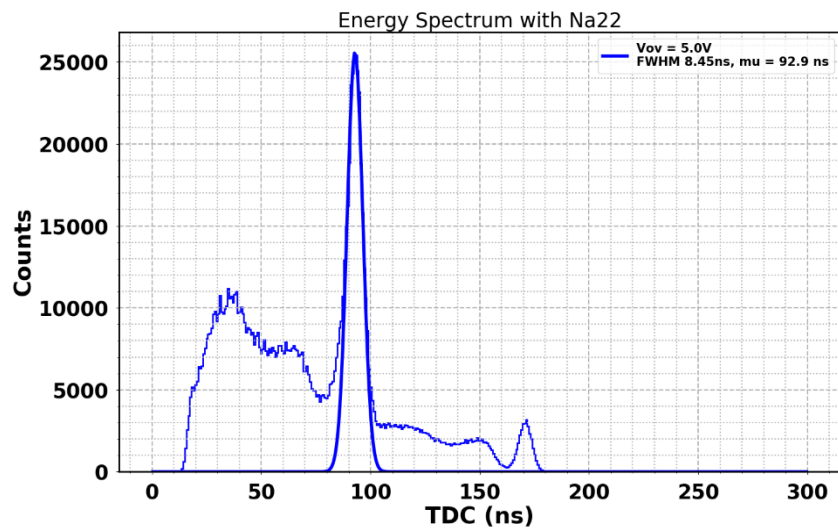


Figure 6: Na-22 spectrum using the TDC.

Observe that the distance between zero and the 511 keV photo-peak is significantly bigger than the distance between the 511 and the 1274 keV peaks.

Figure 7 shows the linearity of the readout electronics when gain is set to 0 and load resistance (RL) is set to 0. Given the range of input signal we can be sure it is not saturating. Hence, this means that very likely the SiPM is saturated owing to the limited number of SPADs.

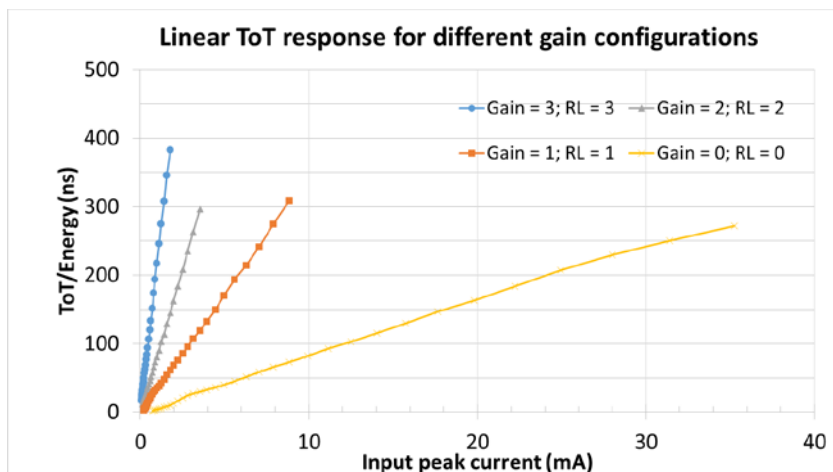


Figure 7: Dynamic range and linear behavior of the energy ToT channel for different gain and load resistance (RL) configurations.

This SiPM model has $60 \times 60 = 3600$ microcells and it starts to show saturation effects at around 2000 fired microcells, as can be seen in Figure 8. This effect is due to the fact that, being in Geiger mode, the single SPADs will produce identical signals for one or more converted photons arriving simultaneously. At the same time, the expected number of photons reaching the surface of the scintillator in this configuration might be as large as 7000. Therefore saturation effects might be observed, depending on the efficiency to detect those photons (a combination of fill factor and quantum efficiency).

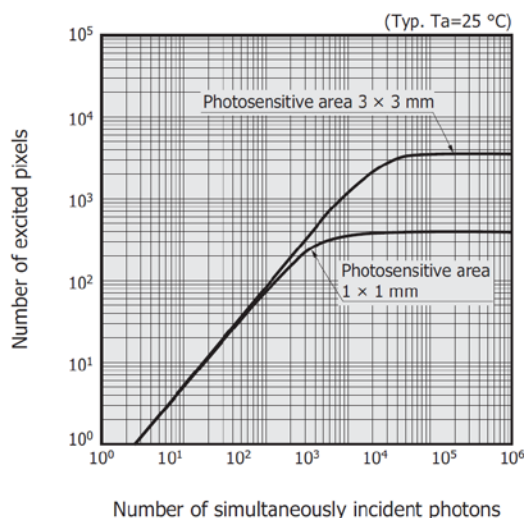


Figure 8: Dynamic Range for simultaneously incident photons (pixel pitch: $50 \mu\text{m}$). Courtesy of HPKK photonics.

The following equation considers this saturation effect to linearize the scale of the system:

$$N_{\text{photon}} \cdot \text{PDE} = -N_{\text{total}} \cdot \ln \left[1 - \frac{N_{\text{fired}}}{N_{\text{total}}} \right] \quad \text{Eq. (1)}$$

where N_{photon} is the number of photons arriving to the sensor, PDE stands for Photon Detection Efficiency (that combines fill factor of the active volume as well as the quantum efficiency of a photon to produce a signal once it impinges the active volume), N_{total} is the total number of

microcells, and N_{fired} is the number of fired microcells (directly related to the pulse width, TDC in nanoseconds, multiplied by a calibration factor f):

$$N_{fired} = TDC[ns] \cdot f$$

where $TDC[ns]$ is the width of the energy signal in nanoseconds and f is the inverse of the pulse width corresponding to a single microcell firing (i.e., the number of fired microcells per nanosecond of the energy pulse width), thus, the energy gain in photons/nanosecond units.

Using the correct f factor, you can generate the calibrated energy spectrum in terms of detected photons (N_{photon} ·PDE) from Eq. (2). The calibrated energy spectrum should look like the one in Figure 9.

The final step is to calibrate the detected photons (N_{photon} ·PDE) in terms of energy (electronvolts). The following equation can be used to finally calibrate the system, since N_{photon} ·PDE follows a linear behavior.

$$N_{photon} \cdot PDE = a + b * Energy \quad Eq. (2)$$

Figure 10 shows the energy spectrum calibrated using the equations above.

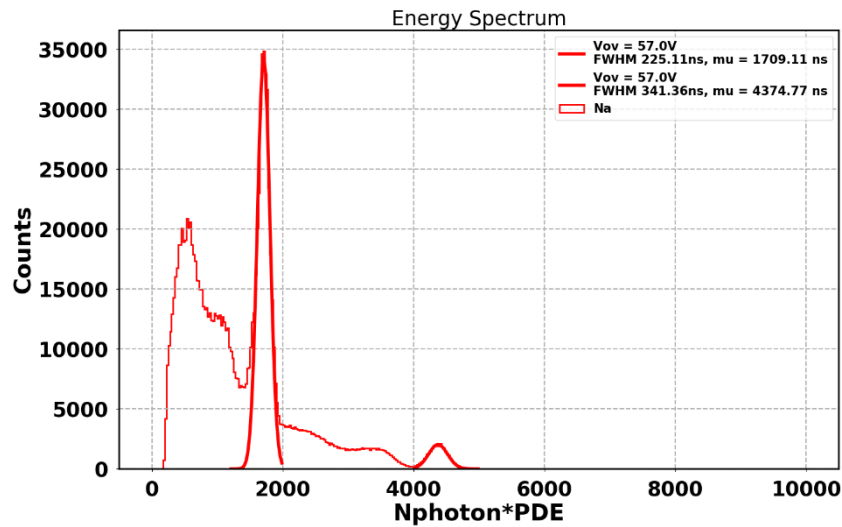


Figure 9: Na-22 spectrum calibrated correcting for the non-linear behavior of the SiPM.

TASK 2: Can you identify the peaks of the different radioactive sources in terms of TDC units (nanoseconds)? Take note of the corresponding expected energies and positions in the distribution. Is the relation between energies and measured widths linear? You may use the prepared excel file “energy_calibration.xls” to visualize the results. Use the “Overview” tab.

From now on, you may use your own data or use the spectra files provided in the folder “spectroscopy_Lab” in the working directory that have a large number of samples for each acquisition.

TASK 3: Check the non-linearity. Set the empirical factor f (use an initial value of 5) in the “f Factor” tab of excel file “energy_calibration.xls” to calibrate the system using your data or the data from the files found in the “spectroscopy_Lab” folder in the working directory. Vary the f factor until the Energy and Number of Photon ratio coincide.

TASK 4: Find the parameters (a , b) of the Eq. (2) to calibrate the system. Use the “Calibration” tab of the excel file. This calibration can be done using the data in Table 1 where measurements from a ^{60}Co source are included to have additional points to calibrate the system. These data is taken on this tab from the corresponding entries in “Overview” tab.

Reference points	TDC [ns]	Energy [keV]
^{22}Na backscatter peak		170
^{22}Na Compton edge		340
^{22}Na annihilation peak	169	511
^{137}Cs peak	203	662
^{60}Co first peak	281	1173
^{22}Na peak	296	1274
^{60}Co second peak	299	1333

Table 1: TDC and energy correspondence for ^{22}Na , ^{60}Co and ^{137}Cs using the HRFlexToT ASIC.

TASK 5: Obtain the energy resolution of your system (Crystal + Sensor + Electronics) for the 511 keV peak. The “energy_result.py” executable will ask for the values of the (a , b) parameters and the ^{22}Na spectrum will be calibrated. Use the cursor to determine the width of the 511 keV peak and calculate the resolution R using Eq. (3).

2.3 Coincidence Time Resolution

The Coincidence Time Resolution (CTR) is a key parameter for the operation a PET scanner. On the one hand, it defines the coincidence window that has to be used to acquire the data and reject random coincidences, i.e. it reduces spurious noise in the image as the CTR improves. On the other hand, beyond a certain point, a good enough CTR allows to move from a Line of Interest (LoI) to a Segment of Interest (SoI) that could eventually become a point in the space where the positron annihilation occurred. The smaller the CTR becomes, the better the spatial resolution will be; i.e., smaller the spot that can be resolved.

Commercial full-body PET scanners (like the one shown in Figure 11) currently achieve a CTR of around 500 ps FWHM. Although there is a lot of effort in decreasing this number, nowadays the best values are around 200 ps FWHM with scintillator crystal lengths of about 10-15 mm. This time resolution corresponds to a segment of about 3 cm around the annihilation point, sufficient to remove events outside the organ of interest.

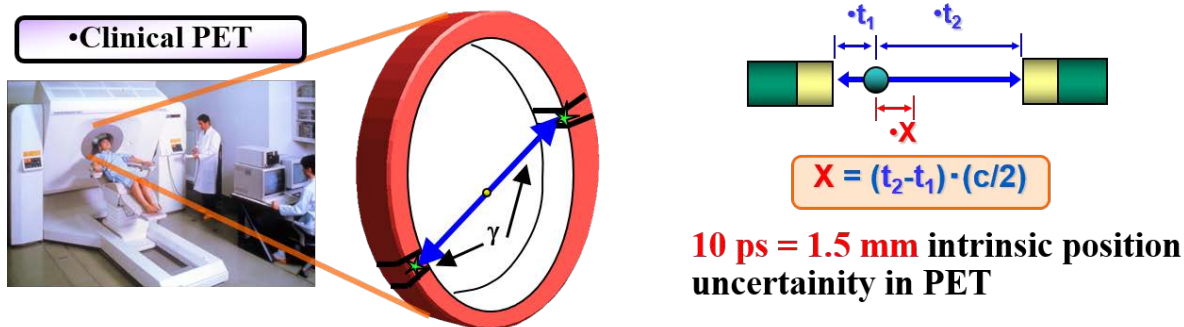


Figure 11: Clinical PET system using radioactive source emitting two gammas in coincidence. Image from PET system extracted from: <https://www.hivehealthmedia.com/types-medical-equipment/>

The CTR value depends on the scintillator coupling to the photosensor, the scintillator geometry and composition, the selected sensor, as well as the electronics used to process the signal coming from the photosensor (a SiPM in our case).

The setup used to perform CTR measurements is illustrated in Figure 12. The basic steps to obtain a CTR measurement are the following:

1. The ^{22}Na radionuclides decay by means of a β^+ process, emitting a positron.
2. Once the positron has lost most of its kinetic energy, it annihilates with an electron, generating two gammas of 511 keV along the same line but with opposite directions (back-to-back).
3. These two gammas impinge on the scintillator crystals, where each gamma ray starts to transfer all or part of its energy to the crystal.
4. Then, the scintillator crystal reemits part of the gamma energy as an avalanche of optical photons with a wavelength around 400 nm. Depending on the scintillator material, one gamma ray of 511 keV may generate up to ~ 15000 optical photons.
5. The optical photons arrive to the photodetector (SiPM in our case). The SiPM generates a voltage signal whose amplitude depends on the number of photons detected.
6. This signal is then processed by the electronics and extracted to the oscilloscope in the form of Charge and Time.

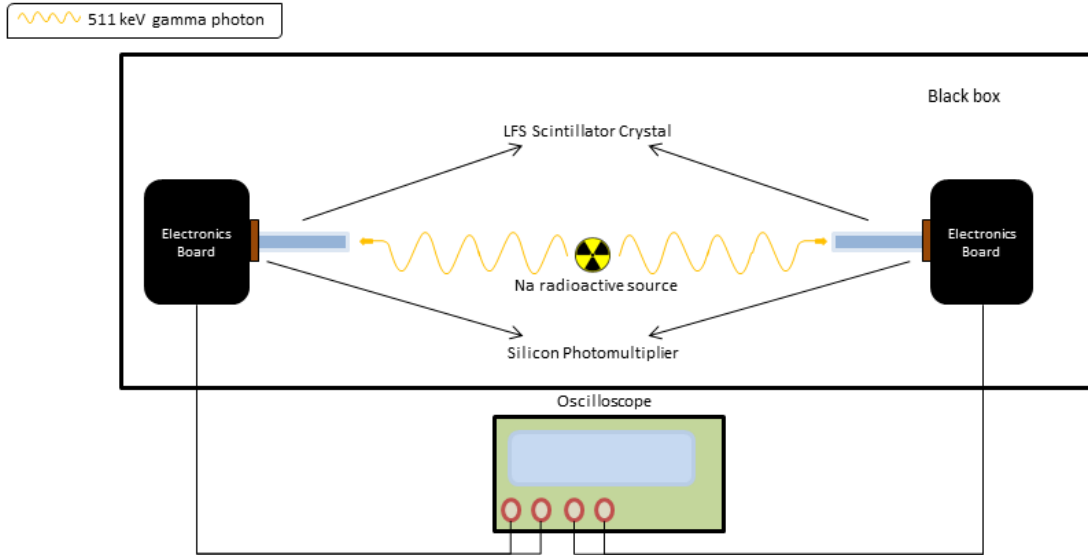


Figure 12: Coincidence time resolution setup.

The entire setup is typically housed in a thermally insulated black box at a fixed temperature. Temperature fluctuations induce SiPM gain variations, which means that the temperature should remain constant during a CTR measurement.

The pulse width and the arrival time of the 511 keV gammas measured simultaneously by both FlexToT boards are acquired using a high bandwidth and high sampling rate oscilloscope, in this case an Agilent MSO9404 at 20 GSa/s.

The CTR is obtained measuring the time difference between selected events in the total absorption peak of the 511 keV gammas as can be seen in Figure 13.

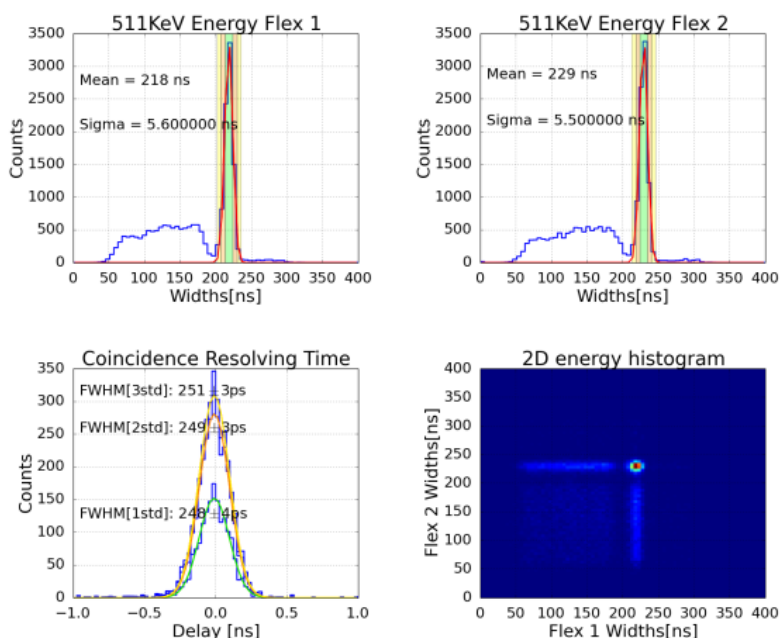


Figure 13: Top: Na-22 energy spectrum for both FlexToT boards. Bottom left: arrival time difference distribution for the events corresponding to the photo-peak coincidences between both modules. Bottom right: 2D correlation plot of the energy (in pulse width) for both FlexToT boards.

2.3.1 TUTORIAL TASKS

Objective: See how a CTR measurement is performed.

See how a CTR measurement is performed using the current setup and understand the whole process involved in the acquisition.

1. Setting the boards at the correct position to record coincident events (alignment).
2. Radioactive source manipulation and positioning for the optimization of the event rate acquisition.
3. Proper configuration of the oscilloscope: coincidence time window, trigger, data acquisition, etc.
4. Proper configuration of both modules:
 - a. Time threshold for each FlexToT board (the lower the threshold, the better CTR in an ideal system, until hitting by the dark current).
 - b. Bias-voltage of each SiPM (the bigger the voltage, the better the CTR in an ideal system, until hitting the crosstalk).
5. Analysis and understanding of the obtained results. Think about different ways to improve the system.