Rev. 1 - 5th December 2022

SP5600AN

Educational Kit - Premium Version

CAEN Educational

Guide

GD5484

1.1 Purpose of this Guide

This QuickStart Guide contains basic information and examples that will let you use Educational kit - Premium Version in few steps.

1.2 Change Document Record

Date	Revision	Changes
September 2016	00	Initial release.
December 2022	01	Updated §Getting started, §Basic Measurements, §Educational Experiments and §Technical Support. Added New §PID (Product Identifier), §Hardware Description, §Software Description, §Appendix, §Instructions for Cleaning, §Device decommissioning and §Disposal.

1.3 Symbols, abbreviated terms and notation

AMC FPGA	Acquisition & Memory Controller FPGA
DPP	Digital Pulse Processing
FPGA	Field Programmable Gate Array
OS	Operating System
PSAU	Power Supply & Amplification Unit
ROC FPGA	ReadOut Controller FGPA
SiPM	Silicon Photo-Multiplier
GUI	Graphical User Interface
PSAU	Power Supply and Amplification Unit

1.4 Reference Documents

[RD1] DT5720 User Manual

[RD2] UM1935 – CAENDigitizer User & Reference Manual

[RD3] GD2783 - First Installation Guide to Desktop Digitizers & MCA

[RD4] GD7873 - Digital Pulse Processing for SiPM kit

[RD5] DS2626 – SP5600 Power Supply and Amplification

[RD6] DS2628 – SP5650 Sensor Holder for SP5600

[RD7] DS2477 – SP5601 Led Driver Data sheet

[RD8] ED3127 - An educational kit based on a Modular silicon Photomultiplier System

[RD9] A. A. Ivanov et al., JETP letters, V69 N4(1999)288

https://www.caen.it/support-services/documentation-area/

1.5 Manufacturer Contacts

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1.6 Limitation of Responsibility

If the warnings contained in this manual are not followed, CAEN will not be responsible for damage caused by improper use of the device. The manufacturer declines all responsibility for damage resulting from failure to comply with the instructions for use of the product. The equipment must be used as described in the user manual, with particular regard to the intended use, using only accessories as specified by the manufacturer. No modification or repair can be performed.

1.7 Disclaimer

The information contained herein has been carefully checked and is believed to be accurate; however, no responsibility is assumed for inaccuracies. CAEN spa reserves the right to modify its products specifications without giving any notice; for up to date information please visit www.caen.it.

1.8 Made in Italy

We remark that all our boards have been designed and assembled in Italy. In a challenging environment where a competitive edge is often obtained at the cost of lower wages and declining working conditions, we proudly acknowledge that all those who participated in the production and distribution process of our devices were reasonably paid and worked in a safe environment (this is true for the boards marked "MADE IN ITALY", while we cannot guarantee for third-party manufactures).

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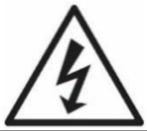
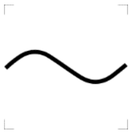
1 Safety Notices

<u>N.B. Read carefully the "Precautions for Handling, Storage and Installation" document provided with the product before starting any operation.</u>

The following HAZARD SYMBOLS may be reported on the unit:

	Caution, refer to product manual
	Caution, risk of electrical shock
	Protective conductor terminal
	Earth (Ground) Terminal
	Alternating Current
	Three-Phase Alternating Current

The following symbol may be reported in the present manual:

	General warning statement

The symbol could be followed by the following terms:

- **DANGER**: indicates a hazardous situation which, if not avoided, will result in serious injury or death.
- **WARNING**: indicates a hazardous situation which, if not avoided, could result in death or serious injury.
- **CAUTION**: indicates a situation or condition that, if not avoided, could cause physical injury, or damage the product and / or its environment.

CAUTION: To avoid potential hazards

USE THE PRODUCT ONLY AS SPECIFIED.
ONLY QUALIFIED PERSONNEL SHOULD PERFORM SERVICE PROCEDURES

CAUTION: Avoid Electric Overload

TO AVOID ELECTRIC SHOCK OR FIRE HAZARD, DO NOT POWER A LOAD OUTSIDE OF ITS SPECIFIED RANGE

CAUTION: Avoid Electric Shock

TO AVOID INJURY OR LOSS OF LIFE, DO NOT CONNECT OR DISCONNECT CABLES WHILE THEY ARE CONNECTED TO A VOLTAGE SOURCE

CAUTION: Do Not Operate without Covers

TO AVOID ELECTRIC SHOCK OR FIRE HAZARD, DO NOT OPERATE THIS PRODUCT WITH COVERS OR PANELS REMOVED

CAUTION: Do Not Operate in Wet/Damp Conditions

TO AVOID ELECTRIC SHOCK, DO NOT OPERATE THIS PRODUCT IN WET OR DAMP CONDITIONS

CAUTION: Do Not Operate in an Explosive Atmosphere

TO AVOID INJURY OR FIRE HAZARD, DO NOT OPERATE THIS PRODUCT IN AN EXPLOSIVE ATMOSPHERE

Do Not Operate with Suspected Failures. If you suspect this product to be damaged, please contact Technical Support.

THIS DEVICE SHOULD BE INSTALLED AND USED BY SKILLED TECHNICIAN ONLY OR UNDER HIS SUPERVISION

DO NOT OPERATE WITH SUSPECTED FAILURES.
IF YOU SUSPECT THIS PRODUCT TO BE DAMAGED, PLEASE CONTACT THE TECHNICAL SUPPORT

THE SAFETY OF ANY SYSTEM THAT INCORPORATES THE DEVICE IS UNDER THE RESPONSIBILITY OF THE ASSEMBLER OF THE SYSTEM

See Chap. 13 for the Technical Support contacts.

⚠Carefulness with Radioactive Sources

The Physics experiments related to Beta spectroscopy proposed in this manual needed radioactive sources.

There are two radioactive source types for educational purpose: sealed and unsealed sources. In the following experiments, sealed sources have been used. This source type is typically easier to use because the radioactive material is deposited in a plastic disk and sealed inside with a durable epoxy. Problems related to possible spills or decontamination are negligible.

Sealed gamma or beta sources of low activity, such as 0,1 µCi or a little bit more, can be handled directly without significant risk, although it is good practice to utilize tongs. Otherwise, sealed gamma sources with high activity, such as 10 µCi or more, should only be handled with tongs.

Nevertheless, when working with radioactive sources, mitigation of radiation exposures is very important. The basic principles of ALARA can give instructions. ALARA (As Low As Reasonably Achievable) is a radiation safety principle for minimizing radiation doses and releases of radioactive materials by employing all reasonable methods. ALARA is not only a sound safety principle for all radiation safety programs but is a regulatory requirement.

The three main principles are related to:

- Time**:** minimizing the time of exposure is the simplest way to directly reduce radiation exposure;
- Distance: doubling the distance between the radiation source and human body means to reduce radiation exposure by a factor of 4;
- Shielding: using absorber materials, such as lead for X-rays and gamma rays and Plexiglas for beta particles, to reduce the radiation reaching the body from a radioactive source is an effective way to reduce radiation exposures.

The radioactive sources for educational purpose have a low level of activity and them storing is a relatively simple matter. Solid sealed sources can be safely stored in the own plastic containers of shipment and then they can be put together in a locked cabinet, possibly with an additional shielding of lead sheets or bricks.

Important Note: Beta and Gamma Radioactive Sources are not included in the SP5600AN Educational Kit – Premium Version.

2 Introduction

CAEN brings the experience acquired in more than 40 years of collaboration with the High Energy & Nuclear Physics community into the University educational laboratories. Thanks to the most advanced instrumentation developed by CAEN for the major experiments Worldwide, together with the University teaching experience at the University of Insubria, a series of experiments covering several applications has been carried out.

CAEN realized different modular Educational Kits. The set-ups are all based on Silicon Photomultipliers (SiPM) state of-the-art sensor of light with single photon sensitivity and unprecedented photon number capability.

The **Educational Kit – Premium Version**, **SP5600AN**, is the system solution that includes all the components of the three kits: SP5600C, SP5600D and SP5600E. The kit can be configured to perform several experiments, covering different Physics fields. What is being proposed has to do with light quanta, radioactive decays (β and γ rays) and cosmic rays. The experiments address the essence of the phenomenon as well as exemplary illustrations of their use in medical imaging and industry, complemented by basic and advanced statistical exercises. The goal to inspire students and guide them towards the analysis and comprehension of different physics phenomena.

The Educational Kit – Premium Version comprises:

- Nr. 1 Power Supply & Amplification Unit (PSAU, ID code SP5600). The PSAU supplies the bias for the sensors, features a variable amplification factor up to 50 dB and integrates a feedback circuit to stabilize the sensor gain against temperature variations. Moreover, the PSAU includes one leading edge discriminator/channel and a coincidence circuit for flexible event trigger logic. Sensors housed in dedicated mechanical holders can be directly connected to the PSAU. The PSAU technical specifications are reported in the relevant data sheet, together with the front and rear panel description.
- Nr. 1 Desktop Waveform digitizer (ID code DT5720A), with 2 input channels sampled at 250 MS/s by a 12-bit ADC. The DT5720A runs the Digital Pulse Processing for enhanced triggering and integration capabilities. The Digitizer technical specifications are reported in the relevant User's manual, together with the front and rear panel description.
- Nr. 1 SiPM Holder (ID code SP5650C), housing a Hamamatsu MPPC 1.3 x 1.3 mm^2 model S13360-1350CS. The mechanical structure of the holder allows an easy coupling of the holder itself with the PSAU.
- Nr.1 Ultra-fast LED Driver (ID code SP5601) with pulse width at ns level, tunable intensity, pulsing frequency internally/externally generated and FC interface to either a clear or a Wave Length Shifting (WLS) fiber. The LED technical specifications are reported in the relevant data sheet, together with the front and rear panel description.
- Nr. 1 Mini-Spectrometer for gamma ray detection (ID code SP5606) composed of a mechanical structure that houses a scintillating crystal, coupled to a dedicated SiPM. Three different crystals are available: CsI, LYSO and BGO. The spectrometer is equipped with a bottom support to allows an easy connection to the SP5600 via the splitter A315, to avoid saturation effects. The spectrometer head was designed to make easy a full range of basic gamma spectrometry educational experiments. The main features of the spectrometer are reported in the data sheet.
- Nr.1 The Gamma absorption tool (ID code SP5607) allows to perform gamma attenuation measurements. It is a modular tool, and its design allows an easy connection to the SP5606 bottom support. The SP5607 is composed of spacers, Aluminium and PMMA absorbers (one 4 mm thick, five 10 mm thick).
- Nr.1 The Splitter (ID code A315) divides one input on two output signals. The splitter is used to connect the SP5606 to the SP5600 by avoiding saturation effects. The A315 technical specifications are reported in the data sheet.

- The Scintillating Tile (ID code SP5608) composed of a support with a embedded plastic scintillating tile, directly coupled to a SiPM. The tile is the ideal tool for tests with beta emitting isotopes and cosmic rays. It is provided by paper and aluminium sheets and source holder in order to perform beta attenuation measurements.
- External AC/DC stabilized 12 V power supplies (Meanwell GS40A12-P1J 40 W, 12 V DC Output, 3.34 A).
- Nr.1 Kit cables (ID code FKITSP56) composed of: n.1 LEMO-LEMO cable, n.2 MCX-LEMO cables, n.1 MCX-MCX cables, n.1 Power Cord Adapter (1IN / 3 OUT).
- Nr.1 Pen-Vac Vacuum Pickup Tool (VPV) is an ideal tool for manually offloading absorbers from SP5607. The pickup tool is a self-contained unit and can lift up to 500 grams.
- Nr.1 Optical grease.
- USB cables.
- A LabView™ based software: HERA (Handy Educational Radiation Application).

The different building blocks of the kit can be assembled in a customized configuration, according to the specific application and the user’s requirements.

The purpose of this guide is to provide a hands-on primer on the use of the essential functionalities of the kit.

Item description	Code	Image	SP5600AN Educational Premium kit	SP5600C Educational Gamma kit	SP5600D Educational Beta kit	SP5600E Educational Photon kit
SP5600 Power Supply and Amplification Unit	WSP5600XAAAA		yes	yes	yes	yes
DT5720A Desktop Digitizer	WDT5720AXAAA		yes	yes	yes	yes
SP5601 Led Driver	WSP5601XAAAA		yes	no	no	yes
SP5650C Sensor Holder with SiPM	WSP5650XCAAA		yes	no	no	yes
SP5606 - Mini Spectrometer	WSP5606XAAAA		yes	yes	no	no
SP5607 Absorption Tool	WSP5607XAAAA		yes	yes	no	no
SP5608 Scintillating Tile	WSP5608XAAAA		yes	no	yes	no
A315 - Splitter	WA315XAAAAAA		yes	yes	no	no

Tab. 2.1: Building blocks of the kits.

CAUTION: to manage the product, consult the operating instructions provided.

When receiving the unit, the user is strictly recommended to:

- Inspect containers for damage during shipment. Report any damage to the freight carrier for possible insurance claims.
- Check that all the components received match those listed on the enclosed packing list as in Tab. 2.1. (CAEN cannot accept responsibility for missing items unless we are notified promptly of any discrepancies.)
- Open shipping containers; be careful not to damage contents.
- Inspect contents and report any damage. The inspection should confirm that there is no exterior damage to the unit such as broken knobs or connectors and that the front panel and display face are not scratched or cracked. Keep all packing material until the inspection has been completed.
- If damage is detected, file a claim with carrier immediately and notify CAEN service.
- If equipment must be returned for any reason, carefully repack equipment in the original shipping container with original packing materials if possible. Please, contact CAEN service.
- If equipment is to be installed later, place equipment in original shipping container and store in a safe place until ready to install

DO NOT SUBJECT THE ITEM TO UNDUE SHOCK OF VIBRATIONS

DO NOT BUMP, DROP OR SLIDE SHIPPING CONTAINERS

DO NOT LEAVE ITEMS OR SHIPPING CONTAINERS UNSUPERVISED IN AREAS WHERE UNTRAINED PERSONNEL MAY MISHANDLE THE ITEMS

USE ONLY ACCESSORIES WICH MEET THE MANUFACTURER SPECIFICATIONS

3 PID (Product Identifier)

PID is the CAEN product identifier, an incremental number greater than 10000 that is unique for each product[1]. The PID is on a label affixed to the kit suitcase by the opening mechanism (Fig. 3.1).

Fig. 3.1:PID location taking a CAEN Educational kit as an example (the number in the picture and the device model are purely indicative).

The PIS is even stored on each educational kit subparts as shown in Fig. 3.2,Fig. 3.3,Fig. 3.4 and Fig. 3.5.

Fig. 3.2: The PID position is located on the plastic black case for SP5606 - Mini Spectrometer, SP5607 - Absorption Tool and SP5608 - Scintillating Tile.

[1] The PID substitutes the serial number previously identifying the boards.

Fig. 3.3: SP5600 - Power Supply and Amplification Unit: PID position is located on the back panel of the module hosting the power input. Same location is adopted for DT5720A - Desktop Digitizer also.

Fig. 3.4: PID position: on the metal shield for the A315 . Splitter or around the holder for the SP5650C - Sensor Holder with SiPM.

Fig. 3.5: SP5601 – LED Driver PID position: in the back panel of the module hosting the power input.

Note: The serial number is still valid to identify older boards, where the PID label is not present.

4 Hardware Description

As previously mentioned, the Educational Kit- Premium Version is composed of a lot of hardware devices. To better understand their use, this section provides a brief description of the main kit units.

SP5600 - Power Supply and Amplification Unit

- Variable amplification gain (up to 50 dB)
- Low noise, to guarantee high performances of the sensor even with small signals
- Wideband, to comply with the fast sensor response
- Fast leading-edge discriminator and time coincidence
- Provides the bias for the sensors with gain stabilization
- USB 2.0 interface
- Dimension: 150 x 50 x 70 mm^3 (WxHxD)

The SP5600 is a general-purpose Power Supply and Amplification Unit, integrating up to two SiPMs in a mother & daughter architecture allowing easy mounting and replacement of the sensors. The basic configuration features two channels with independent gain control up to 50 dB and provides the bias voltage (up to 130 V) to the sensors with gain stabilization. Each channel can provide a digital output generated by the fast-leading edge discriminators. A timing coincidence of the two channels is also available [RD5].

DT5720A - Desktop Digitizer

- 2 Channel 12 bit 250 MS/s Digitizer
- Digital Pulse Processing for Charge Integration DPP-CI for SiPM
- Best suited for PMT and SiPM/MPPC readout at low and high rates
- Mid-High speed signals (Typ: output of PMT/SiPM)
- Good timing resolution with fast signals (rise time < 100 ns)
- Optical Link and USB 2.0 interfaces
- Dimension: 154 x 50 x 164 mm^3 (WxHxD)

The DT5720A is a 2 Channel CAEN Waveform Digitizers able to perform waveform recording and run online advanced algorithms of charge integration (DPP-CI), i.e. the digital version of the traditional QDC (Charge-to-Digital Converter) [RD4].
Data is read by a Flash ADC, 12-bit resolution and 250 MS/s sampling rate, which is well suited for mid-fast signals as the ones coming from liquid or inorganic scintillators coupled to PMTs or Silicon Photomultipliers. The acquisition can be either channel independent or common through an external signal and the acquired data can be saved for offline analysis.
The acquisition in DPP-CI mode for SiPM is fully controlled by the Hera software, which manages the algorithm parameters, builds plots and saves the relevant information through the USB 2.0 interface of the digitizer (data transfer up to 30 MB/s).
The digitizer runs on real time:

- Self-Trigger using CR-RC digital Time filter algorithm
- Input signal baseline (pedestal) calculation
- Charge Integration (with programmable gate parameters) with pedestal subtraction for energy calculation.

SP5601 – LED Driver

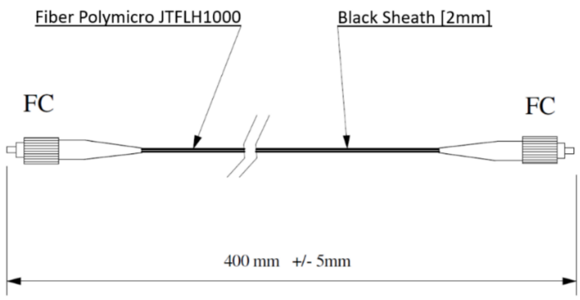
- Width of pulse: 8 ns
- LED color: violet (400nm) 1500 mcd
- Pulse generator: internal/external
- Optical output connectors: FC
- Optical fiber included
- Dimension: 79 x 42 x 102 mm^3 (WxHxD)

The SP5601 is an ultra-fast LED Driver and represents the ideal tool for SiPM tests and characterization, through a triggered light burst of intensity down to a few photons and up to a number saturating the sensors. The SP5601 features tuneable intensity and repetition rate: the LED driver can be triggered either via the internal pulse generator, or via an external source [RD7].

Optical Fiber

The optical signal coming from LED Driver is routed to the sensor through an *optical fiber*, FC interfaced.

Here below, some details about the optical fiber.



Characteristics:

- Step Index;
- Numerical Aperture: 0.37 ± 0.02;
- Full Acceptance Cone: 43.4 degrees;
- Low -OH Silica Core, Hard Polymer Clad;
- Low -OH Core for Vis-NIR Transmission;
- Operating Temperature: –65 ºC to +125 ºC;
- Proof Tested from 100kpsi to 150 kpsi;
- Optional Acrylate, Nylon, or Hytrel® Buffer;

Product Descriptor	Core (µm)	Clad (µm)	Buffer (µm)	Proof Test (kpsi)
JTFLH100010351400	1000 ± 15	1035 ± 15	1400 ± 50	100

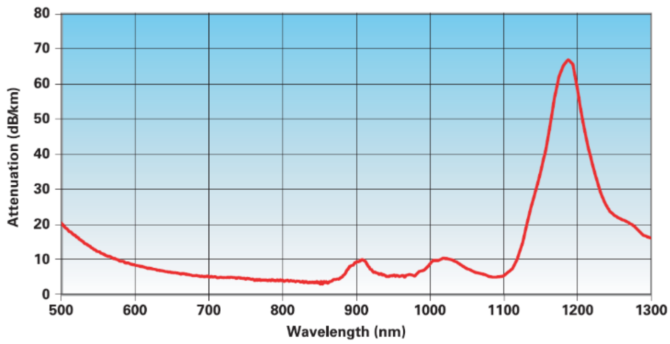


Fig. 4.1: Typical attenuation of the optical fiber.

Optical Grease

The optical coupling grease is a non-curing colourless coupling gel, clear and colourless having moderate viscosity and providing excellent transmission properties well into the near-ultraviolet region. It should be stored at temperatures below 26 °C, preferably above 5 °C, but it retains clarity and fluid property down to -60 °C.

Typical Properties	Value	
Colour	Clear	
Refractive Index @25 ºC	1.466	
Specific Gravity	1.06	
Penetration	300	
Light Transmittance @ 1 cm	300 nm	99.45%
	400 nm	99.99%
	450 nm	99.99%
	500 nm	99.99%
	633 nm	99.99%
	850 nm	99.99%
	1310 nm	99.65%
	1550 nm	99.38%

Tab. 4.1: Typical properties of the optical grease.

SP5650C – Sensor Holder

- Size 20 mm (diameter) x 6 mm (height)
- Analog Out Connector RADIALL: R113425000 (MCX MALE)
- Bias Connector M22-7140542 Female Vertical Socket
- Embedded Hamamatsu MPPC S13360- 1350CS:
- 1.3 x 1.3 mm^2 Active Area
- 667 Number of pixels
- 50 µm Pixel Pitch

The SP5650C holder hosts a 1.3 x 1.3 mm^2 Silicon Photomultipliers. A probe inside the holder senses temperature variations, thus allowing the user to compensate for possible gain instability. The SP5650C is made of a mechanical structure providing an FC fiber connector and a PCB where the SiPM is soldered. Bias voltage for the SiPM and temperature probe output are provided through a 10 pin female socket, while the analog output connector is MCX [RD6].

SP5608 – Scintillating Tile

- Sensitive volume: 47 x 47 x 10 mm^3
- Scintillator: polystyrene
- Directly coupled to a SiPM 6 x 6 mm^2
- 20 Paper and Aluminium sheets

The SP5608 is a support with an embedded plastic scintillating tile, directly coupled to a SiPM. The tile is the ideal tool for tests with beta emitting isotopes and cosmic rays. The support structure allows to use the SP5608 stand-alone or two tiles in cosmic telescope configuration via the SP5609 - Telescope mechanics. A special source holder allows the user to perform beta attenuation measurements with a thin thickness material that can be located at 2 mm distance from the scintillating tile. Absorbing material included in the kit are paper and aluminium sheets. Moreover, the user can study how the light collection improves by using optical grease or interface sheet to do the optical matching between detector and tile, and by reducing the light losses via tile coating with Teflon tape.

Plastic Scintillator

The main features of the Polystyrene-based scintillator used in the SP5608 are described in the following table.

Scintillator type	UPS-923A
Density	1.06
Refractive index	1.60
Absorption coefficient [cm^{-3}]	0.01-0.003
Softening [K]	355-360
Hygroscopic	no
Emission peak [nm]	425
Light Output [% of anthracene]	60
H/C ratio	1.0
Rise time [ns]	0.9
Decay time [ns]	3.3
Light attenuation length [cm]	400
Important Properties	• High light output • Good transparency • Short decay time

Tab. 4.2: Plastic Scintillator Properties.

Silicon Photomultiplier

The embedded detector is the Hamamatsu Silicon Photomultiplier (SiPM), S13360-6050CS. A small printed circuit board inside the SP5608 hosts the 6 x 6 mm^2 detector.

The main features of the S13360-6050CS SiPM are summarized in the following table.

Properties	Value
Package type	Ceramic
Active Area	6 × 6 mm^2
Number of pixels	14400
Pixel Pitch	50 µm
Spectral response range	270 to 900 nm
Peak sensitivity wavelength (typ.)	450 nm
Dark count/ch (typ.)	2000 kcps
Terminal capacitance/ch (typ.)	1280 pF
Gain (typ.)	1.7×106
Measurement condition	Ta=25 ℃

Tab. 4.3: S13360-6050CS Features.

Optical interface sheet

An alternative to optical grease, a little square of EJ-560 silicone rubber can be employed for making a better optical join between the SiPM and the plastic scintillator. The EJ-560 optical transmission and its general features are summarized in table Tab. 4.4.

Properties	EJ-560
Density (g/cc)	1.03
Hardness, Shore A	16-24
Refractive Index	1.43
Operating Temperature Range (°C)	-40 to 70
Thermal Expansion Coefficient (cm/cm per °C)	3 x 10^{-4}

Tab. 4.4: Optical Interface sheet features.

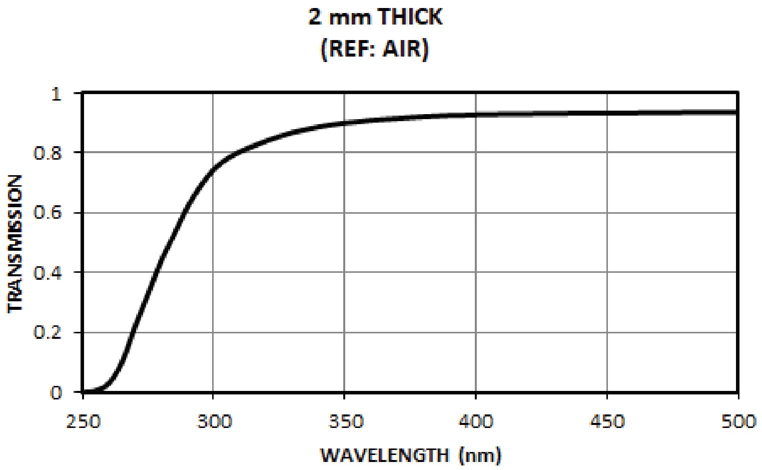


Fig. 4.2: EJ—560 Optical Transmission.

Teflon Tape

The quality of a detection measurement is determined primarily by the quality of the scintillator material and the detector wrapping.

Teflon tape is the wrapping solution proposed by CAEN for educational purposes. It is a polytetrafluoroethylene (PTFE) film tape commonly used for several applications. It has a white colour and good characteristics of sealing, corrosion resistance, anti-aging.

The main property is the high reflection rate, and it allows the system to have a very good light collection even for the small signals.

SP5606 - Mini Spectrometer

- Mechanical structure for optimal SiPM to crystal coupling
- Included crystals: LYSO, BGO, CsI
- Crystals dimension: 6 x 6 x 15 mm^3
- One SiPM 6 x 6 mm^2 embedded

SP5606 is a mini spectrometer for gamma ray detection. The spectrometer is composed of a mechanical structure that houses a scintillating crystal, coupled to a dedicated 6 x 6 mm^2 SiPM. Three different crystals are available: CsI, LYSO and BGO. The spectrometer is equipped with a bottom support for an easy connection to the SP5600 via the splitter A315, to avoid saturation effects.

More details about the mini spectrometer are listed here below.

Scintillating Crystals

The SP5606 is provided with three different crystals: BGO (Bismuth Germanate [$Bi_4Ge_3O_{12}$]), LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate), CsI(Tl) (Thallium-doped Cesium Iodide). The crystals are polished on all sides and coated with white epoxy on 5 faces. One 6 x 6 mm^2 face is open in order to be coupled with the Silicon Photomultiplier.

- <u>BGO information:</u>

A relatively hard, high density, non-hygroscopic crystal with good gamma ray absorption. Often used for PET imaging and high energy physics applications as Compton shields. The main characteristics of the crystal are summarized in the Tab. 4.5.

Properties	Value
Cleavage Planes	None
Decay Constant (ns)	300
Density (g cm^{-3})	7.13
Emission Spectral Range (nm)	350-650
Melting Point (K)	1323
Peak Scintillation Wavelength (nm)	480
Photons/MeV	8500
Radiation Length (cm)	1.13
Refractive Index at Peak Emission	2.15
Solubility (g/100g H_2O @ 300K)	Insoluble
Stability	Good
Structure	Cubic
Transmission Range (nm)	470-7500

Tab. 4.5: BGO Scintillator Properties.

- <u>LYSO(Ce) information:</u>

Non-hygroscopic scintillator that is both bright and fast. It is often employed in applications where fast timing is needed such as PET and TOF PET. The main characteristics of the crystal are summarized in the Tab. 4.6.

Properties	Value
Cleavage Planes	None
Decay Constant (ns)	40
Density (g cm^{-3})	7.1
Emission Spectral Range (nm)	380-480
Melting Point (K)	2323
Peak Scintillation Wavelength (nm)	420
Photons/MeV	32000
Radiation Length (cm)	1.15
Refractive Index at Peak Emission	1.81
Solubility (g/100g H_2O @ 300K)	Insoluble
Stability	Good
Structure	Cubic

Tab. 4.6: <u>LYSO(Ce)</u> Scintillator Properties.

- <u>CsI(Tl) information:</u>

This scintillator offers a high light yield and emits at a wavelength very suitable for silicon photomultipliers (SiPMs). Typical applications include arrays of this material used in security imaging systems, such as baggage scanners. The main characteristics of the crystal are summarized in the Tab. 4.7.

Properties	Value
Cleavage Planes	None
Decay Constant (ns)	1000
Density (g cm^{-3})	4.51
Emission Spectral Range (nm)	350-725
Gamma and X-ray absorption coefficients (cm^{-1})	0.48 at 660keV 10.00 at 100KeV
Melting Point (K)	894
Peak Scintillation Wavelength (nm)	550
Photons/MeV	52000
Radiation Length (cm)	1.86
Refractive Index at Peak Emission	1.78
Solubility (g/100 g H_2O @ 300 °K)	44.0
Stability	Slightly Hygroscopic
Structure	BCC
Thermal Conductivity ($W \cdot m^{-1} \cdot K^{-1}$) @ 300K	1.13
Transmission Range (nm)	240-70000

Tab. 4.7: CsI(Tl) Scintillator Properties.

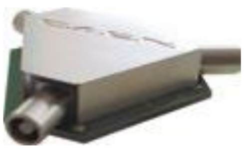
Silicon Photomultiplier

The embedded detector is the Hamamatsu Silicon Photomultiplier (SiPM), S13360-6050CS. A small printed circuit board inside the mini-spectrometer hosts the 6 x 6 mm^2 detector.
The main features of the S13360-6050CS SiPM are listed in Tab. 4.8.

Properties	Value
Package type	Ceramic
Active Area	6 × 6 mm^2
Number of pixels	14400
Pixel Pitch	50 µm
Spectral response range	270 to 900 nm
Peak sensitivity wavelength (typ.)	450 nm
Dark count/ch (typ.)	2000 kcps
Terminal capacitance/ch (typ.)	1280 pF
Gain (typ.)	1.7×106
Measurement condition	Ta=25 ℃

Tab. 4.8: S13360-6050CS Features.

A315 - Splitter



The Mod. A315 splits one input on two output signals. All the connectors are LEMO female type. The splitter is adapted for 50 Ohm lines to avoid reflections of the signal. The device is completely passive (no power supply is required); the amplitude on each output is one half of that on the input.

SP5607 - Absorption tool

- Spacers: one 4mm thick, five 10 mm thick
- Aluminium Absorbers: one 4mm thick, five 10 mm thick
- PMMA Absorbers: one 4mm thick, five 10 mm thick

The Gamma absorption tool allows performing gamma attenuation measurements. It is a modular tool, and thanks to its design, it can be easily connected to the SP5606 bottom support. This tool includes several spacers and two different absorber materials: Aluminium and Polymethyl methacrylate (PMMA).

As well known, the Aluminium is lightweight, durable, malleable, and corrosion-resistant metal and it is widely used in the aerospace, transportation, and construction industries.
Out of scientific community, the PMMA is more known as Plexiglas and acrylic. The first use of PMMA as a dental device was for the fabrication of complete denture bases. Its qualities of biocompatibility, reliability, relative ease of manipulation, and low toxicity were soon seized upon and incorporated by many different medical specialties. PMMA has been used for bone cement, contact and intraocular lens, screw fixation in bone, filler for bone cavities and skull defects. Moreover, it is widely used in medical dosimetry as a water equivalent solid-state organic material. Water and PMMA are found to be the closest soft-tissue and water substitutes, respectively. Soft-tissue and water equivalence of dosimetry materials need to be evaluated for a range of photon energies and field sizes before their application in complex radiation beams. The behaviour of the PMMA under the action of gamma radiation is generally studied to measure the absorbed dose rate to water using a PMMA phantom.

The following table summarizes additional information on Aluminium and PMMA.

Material	Mass Density (g cm^{-3})	(Z/A)eff	Mole fraction (%)
PMMA	1.185	0.539	H 53.333, C 33.333, O 13.333,
Aluminium	2.698	0.482	Al 100

5 Getting started

This chapter will guide you through the drivers installation of PSAU and Digitizer, as well as the installation of HERA (Handy Educational Radiation Application) software and the first measurements.

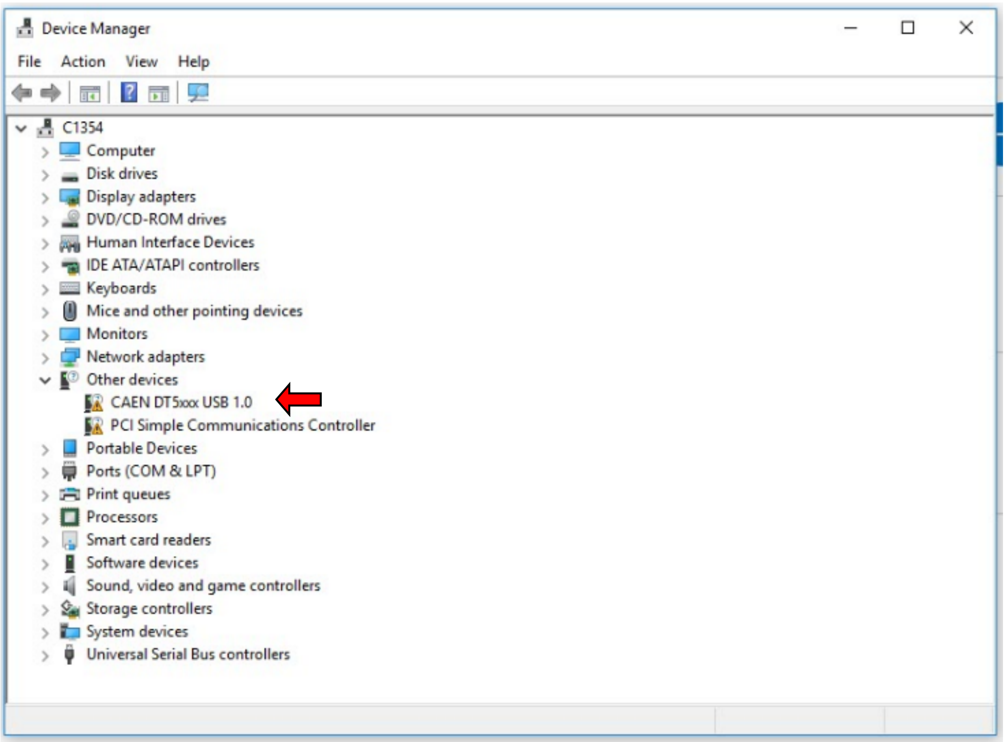
5.1 Software Installation Requirements

OS	Hardware	CAEN drivers required
Microsoft Windows 10 (64-bit)	2 available USB2.0 ports	DT5720 USB driver (32/64-bit) SP5600 USB driver (32/64-bit)

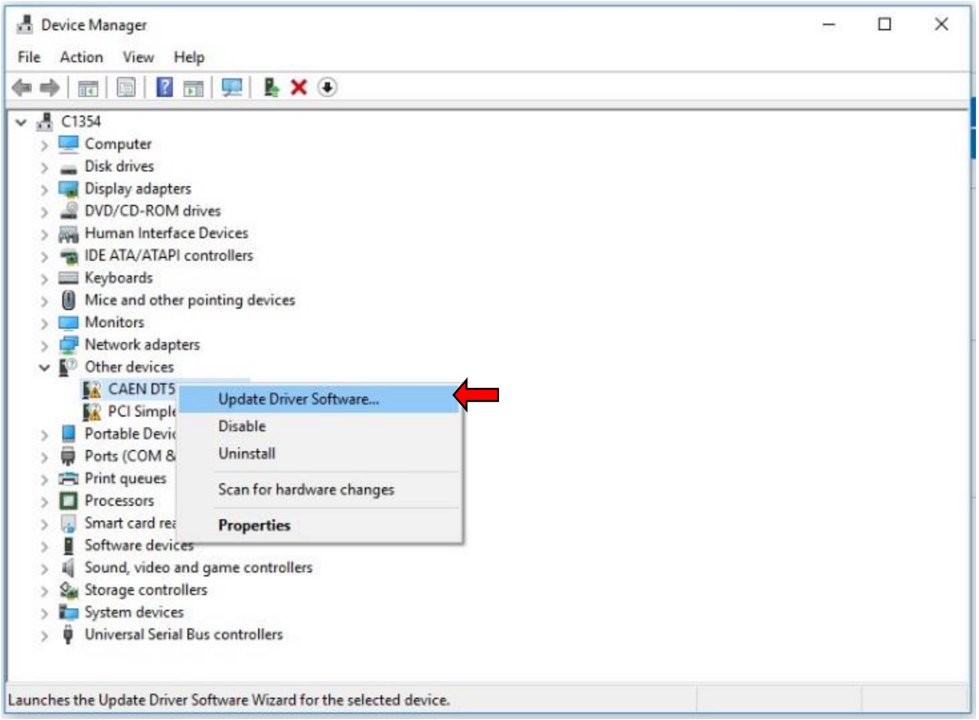
Tab. 5.1: Host PC requirements.

- Download the USB drivers for both DT5720 and SP5600 compliant to the Windows version 64-bit on CAEN website: Educational kit webpage > “Download” > “Software” tab > Driver section (login is required before the download).
- **Install the DT5720 drivers** following the instruction of the setup wizard. The OS will automatically recognize the DT5720 when it is connected to the PC. If the automatic installation fails, perform it manually from the Device Manager by selecting the driver update and pointing to the driver folder you downloaded from CAEN website.

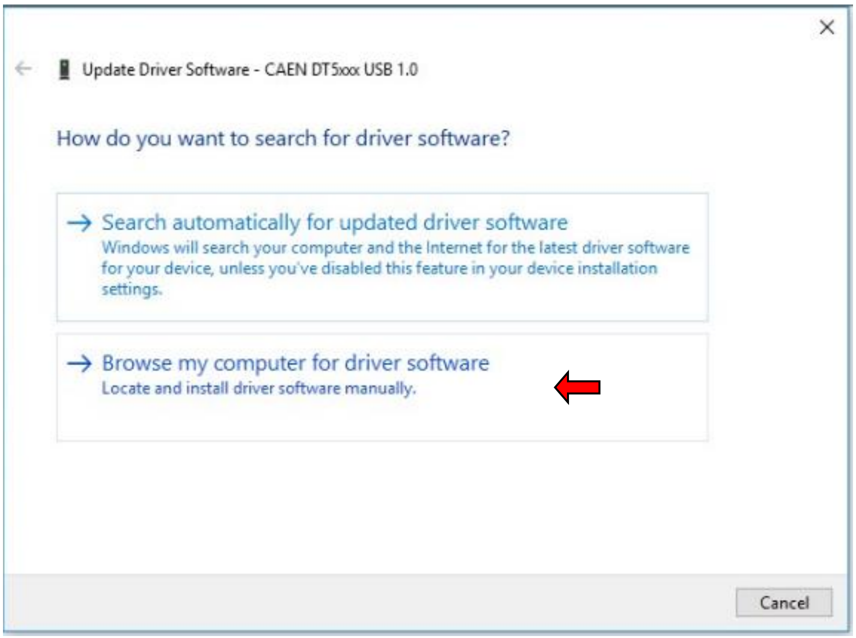
  For example, once connected and powered on the digitizer, you can do it going to Control Panel -> System & Security -> System -> Device Manager. In the Device Manager window, find the unknown **CAEN DT5xxx USB 1.0** in the list **Other Devices**:



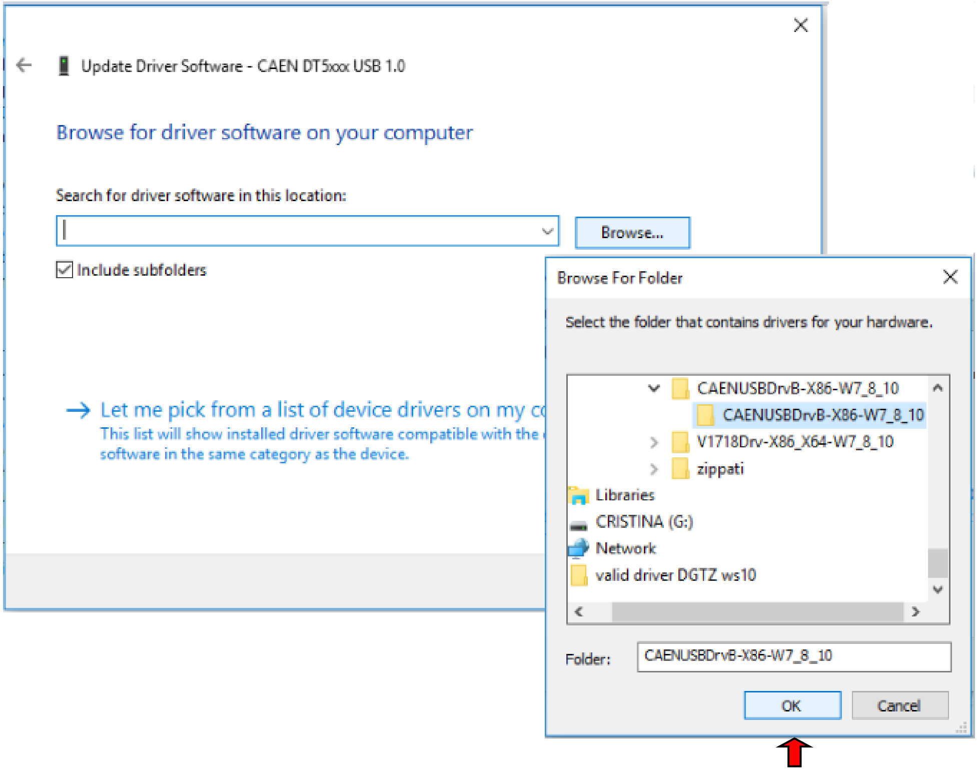
Right click on **CAEN DT5xxx USB 1.0** and select **Update Driver Software** option in the scroll menu.



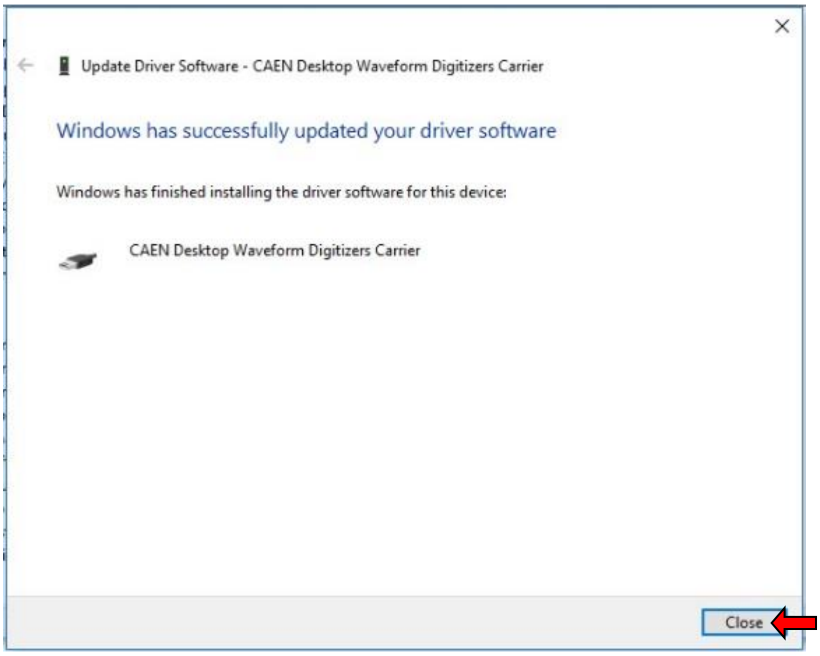
Select **Browse My Computer for driver software**.



Click **[Browse]** to point to the Windows drivers' folder you have previously unpacked, click **[OK]** to include the path in the search and click **[Next]** to continue.



When the driver installation will be completed, click **Close** to close the window.

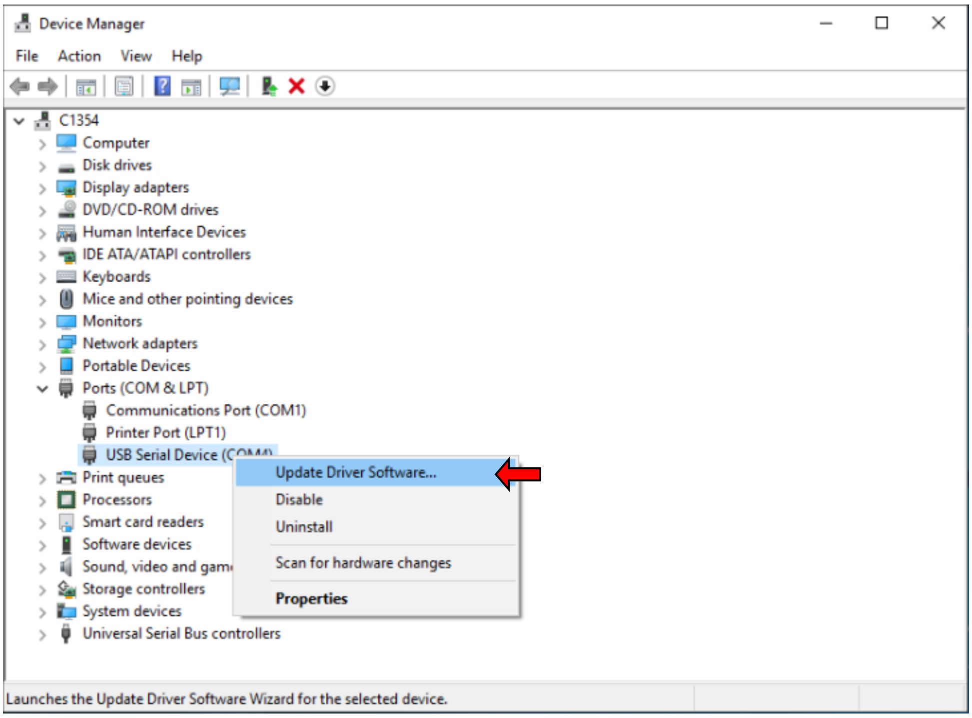


Refer to [RD3] for detailed installation OS-dependent.

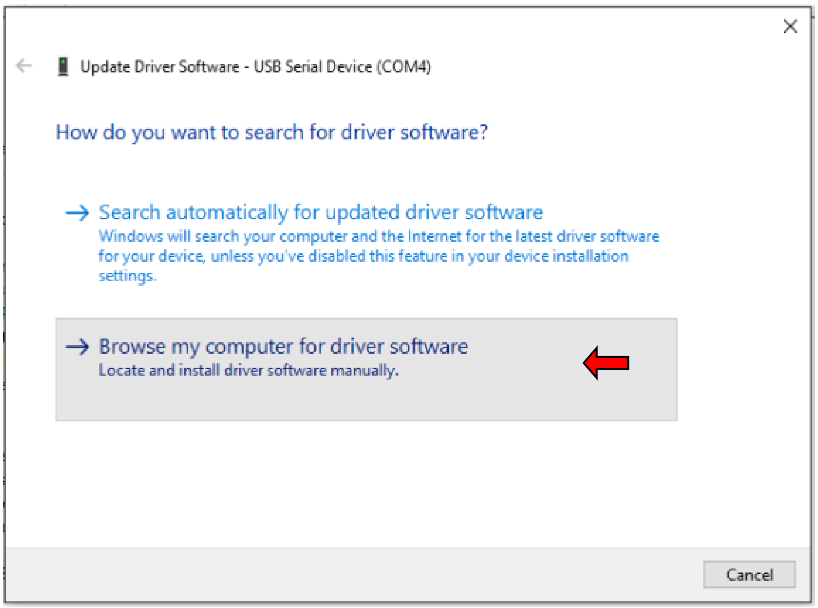
- Connect to the PC and power ON the **SP5600**; the PC will recognize as a new peripheral by the OS. Perform the driver installation manually from the Device Manager by selecting the driver update and pointing to the driver folder you downloaded from CAEN website. Finally, a COMM port will be associated to SP5600.

For example (Windows 10 – 64bit), once connected and powered on the SP5600, you can follow the previous instructions going to Control Panel -> System & Security -> System -> Device Manager -> Controller USB [Ports (COM)] Manager.

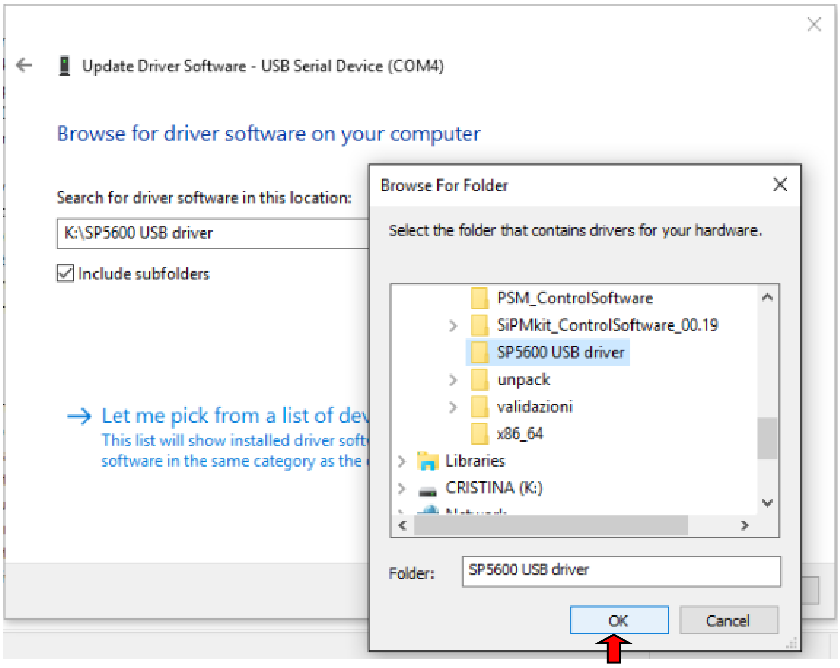
Right click on **USB Serial Device** and select **Update Driver** Software option in the scroll menu.



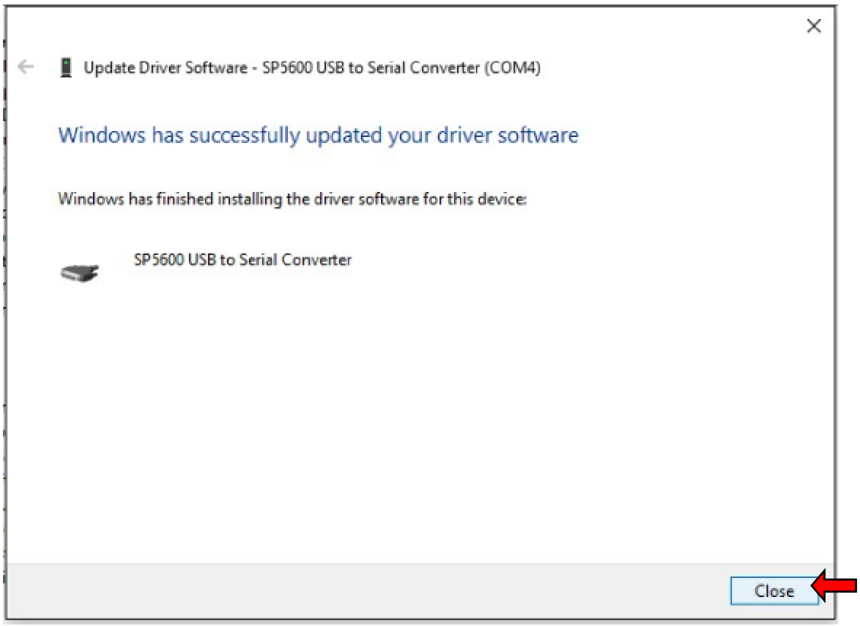
Select **Browse My Computer for driver software**.



Click **[Browse]** to point to the Windows drivers' folder you have previously unpacked, click **[OK]** to include the path in the search and click **[Next]** to continue.



When the driver installation will be completed, click **Close** to close the window.



Finally, a COM port will be associated to SP5600; please check the port number as shown in Fig. 5.1.

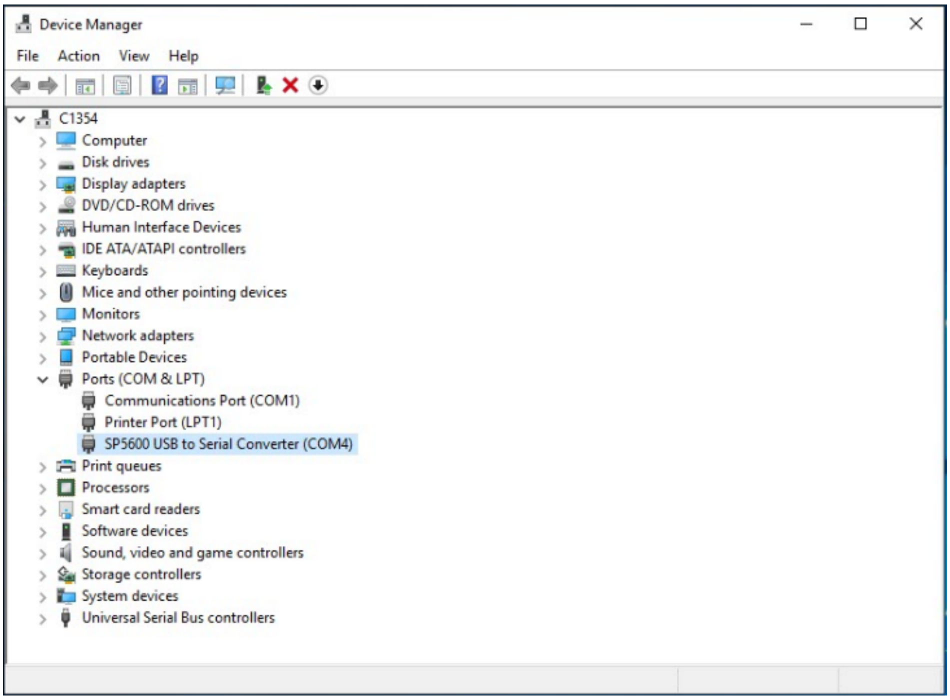


Fig. 5.1: Tracking the PSAU port assignment on a PC running Windows 10.

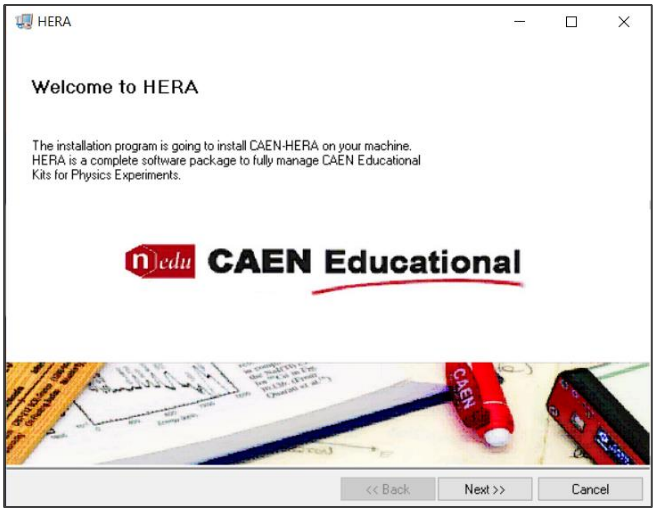
Important Note: HERA rel. 1.0.0 Build: 1.5.21.0103 or higher:

- does not require LabVIEW™ Run-Time Engine. or LabView™ version 2018 (or higher). The installation of LabVIEW™ Run-Time Engine 2018 is already implemented in the HERA.
- does not work with a digitizer USB Driver release < 3.4.7, if running in a 32-bit Windows environment.

5.2 Software Installation

Download the standalone HERA Software full installation package on CAEN website: Educational kit webpage > “Download” > “Software” tab > Application SW section (login is required before the download).

Unpack the installation package, login as administrator, launch the setup file, and complete the Installation wizard.



The setup automatically creates a link on the PC Desktop.

6 Software Description

When the installation procedure has been completed, the user can run the program by clicking the correspondent icon.

HERA (Handy Educational Radiation Application) is a user-friendly software platform allowing the user to manage the following CAEN Educational kits: SP5600E – Photon kit, SP5600D – Beta kit, SP5600C – Gamma kit, SP5600AN – Premium Version kit.

The simple graphical interfaces help the user to perform its own experimental activity. As shown in the opening window in Fig. 6.1, several ways of operative openings are available. This initial access multiplicity makes the software very flexible and suitable both for expert users as well as for beginner ones. With a simple selection, the user can decide how to execute the activity by choosing the direct access to the suggested experiments or access to devices management.

Via this main GUI, it is possible to visualize the devices status, server messages and, to access to data (log file, data stored, configuration files, etc.).

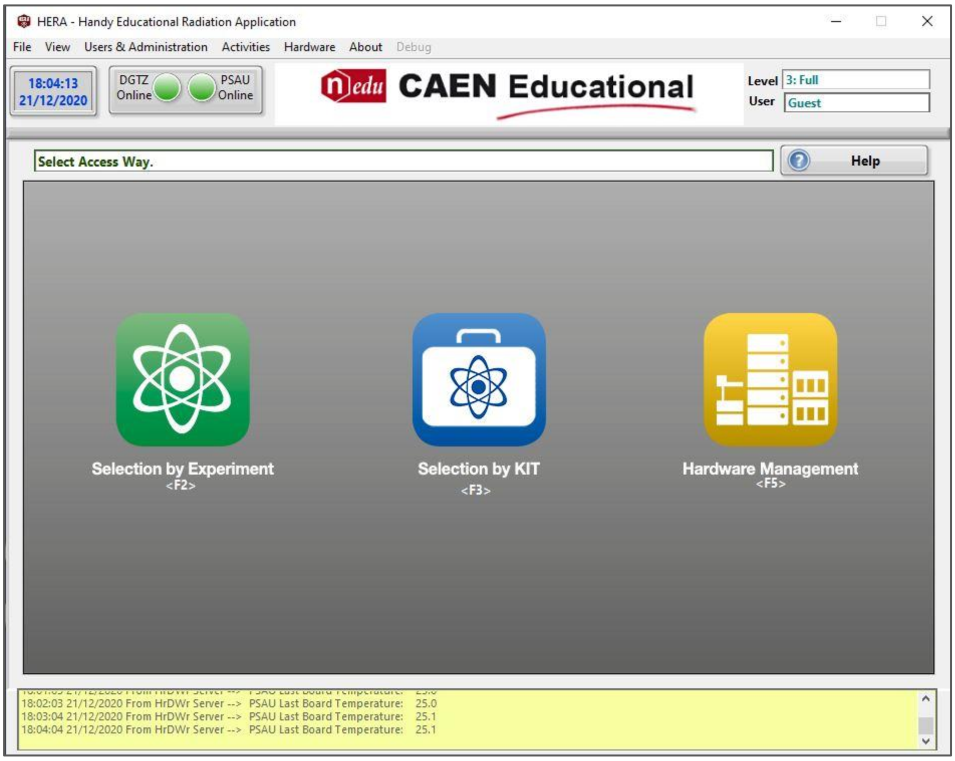
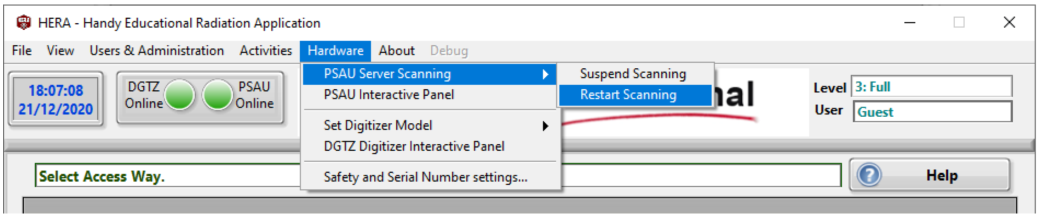


Fig. 6.1: Main GUI of the HERA software.

Before running the software, the user should wait the hardware connection. The software recognises the hardware automatically and start the connection. Two connection indicators, "Online Hardware", are present on the opening window:

- **Green light** means that the connection is ok.
- **Red light** means that there is no connection.
  If the PSAU is power on, but the light colour is red, the software can be forced to search for a new connection via the rescanning procedure from the Verbose Menu: Hardware-> PSAU Server Scanning -> Restart Scanning.



- **Yellow light** means that either the DGTZ is not a DT5720A/C, or its firmware is not compliant with Hera software, and another firmware type is probably running on the board.

The special firmware compatible with HERA Software is the Digital Pulse processing for Charge Integration for SiPM Kit (DPP-CI for SiPM) for DT5720A and the Digital Pulse Processing for Charge Integration and Pulse Shape Discrimination (DPP-PSD) for DT5720C [COMING SOON]. The firmware can be download from CAEN Website. Without any licenses, it will run in a 30-minute-per-power-cycle fully functional trial version.

To upload the firmware on the digitizer, use the CAENUpgrader Software (free download on CAEN Website): https://www.caen.it/products/caenupgrader/

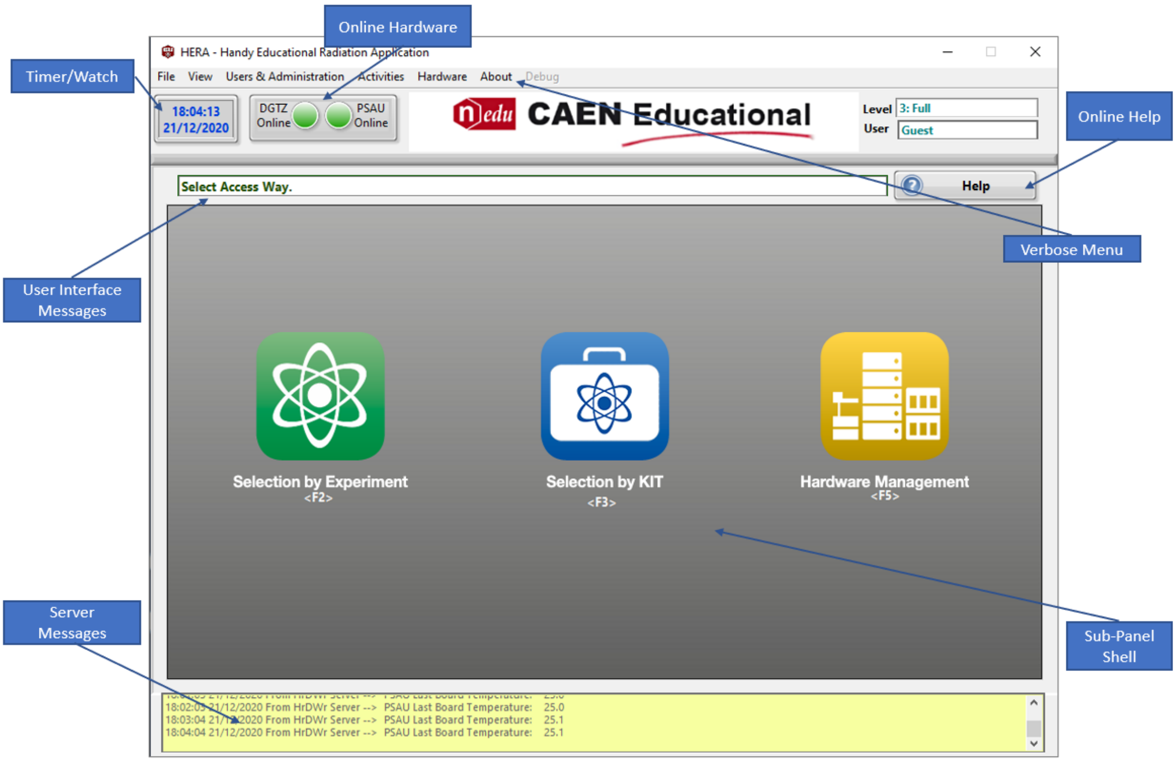


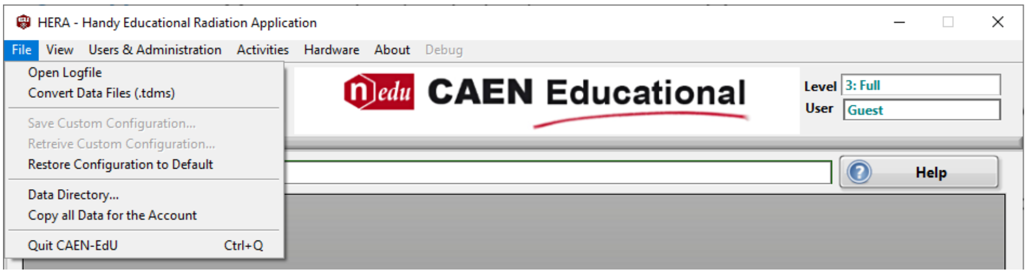
Fig. 6.2: Main GUI Description.

The main features of the GUI are:

- **Timer/Watch:** Time and Date.
- **Online Hardware:** Indicators of the Digitizer (DGTZ) and Power Supply and Amplification Unit (PSAU) status.
- **User Interface Messages:** Operation messages related to user activity.
- **Server Messages:** Messages related to the hardware server activity.
- **Sub-panel shell:** Sub-panel of the initial menu choice.
- **Online Help**: QuickStart guide available for each software window and experimental activity.
- **Verbose Menu:** It is organized into several items (File, View, User & Administration, Activities, Hardware, About menus), each one allowing the user to perform several actions.

- **File Menu**

The user can assess further functionalities by pressing the “File” label on the top left of the GUI. As shown in the picture below, the File Menu is composed by four sections.



The first section gives access to the logfiles and to a special tool for the data file conversion in .txt format. The second section allows the user to save and retrieve a configuration file containing the parameters settings for the DGTZ and the PSAU and, moreover, the default configurations recovery. The third section is focused on data storage management. The user can open the data directory located in ProgramData folder or copy it in another PC location.
The fourth section allows closing the software.

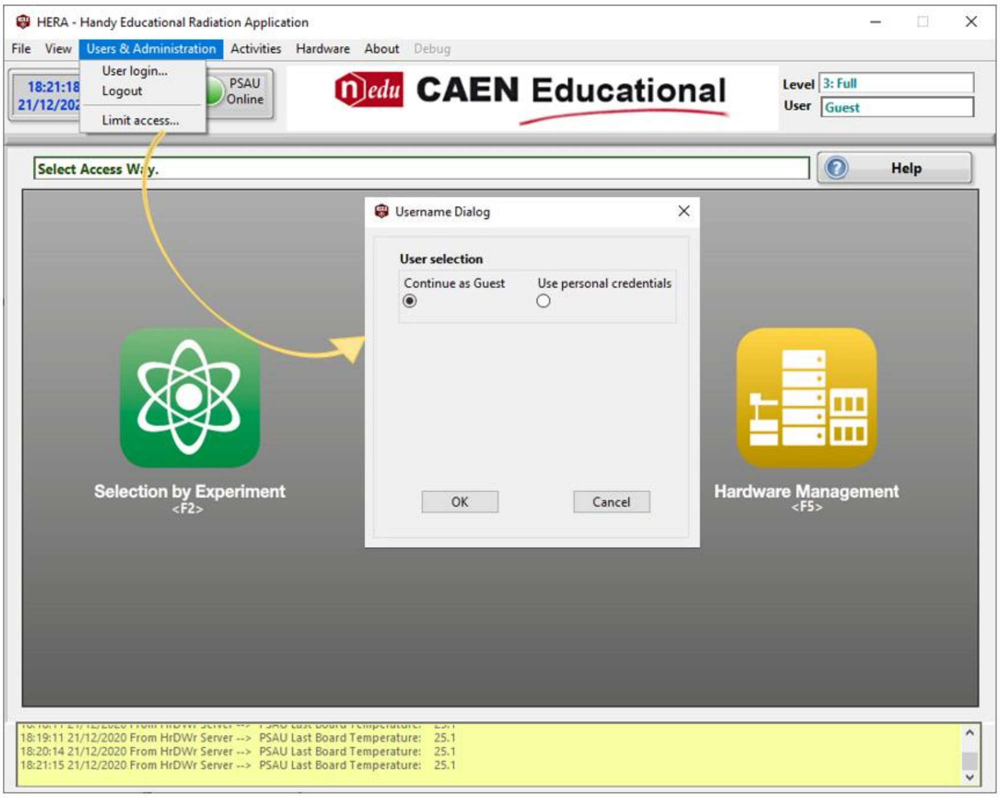
- **View Menu**

Through this menu, the user can enable/disable the display of the server messages in the bottom part of the window.

- **User & Administration Menu**

This menu section gives high flexibility to the user in managing the accounts and deciding what each user can access of the software.

For this purpose, two interesting functionalities are available:
User Account
The software can create several accounts via the "User Login" selection. This procedure is advantageous when several people or groups work on the same computer. Once created the account, the software automatically produces the related folder in which data, configuration files, and images can be saved and stored.
Via “Logout” selection, the account goes back to the default "Guest" user.



Software Access Mode

Three access levels to the software are implemented and are available through the “Limit Access...” selection in the drop-down menu. The first one, “Level 1”, just gives access to the Hardware Management. The second one, “Level 2”, allows the user to access the Hardware Management and the guided procedures to perform the experiments listed in the CAEN Educational Handbook. This access level does not include analysis tools. The third one, “Level 3”, gives full access to all software functionalities and all the analysis tools are included.

The initial option, “Selection by Kit”, is accessible by all the three access levels.

The user needs the Master Password to change the access mode. The Password is unique, not changeable, and not declared in the embedded Help to give this type of modification power to the tutors only.

This functionality allows to the tutors deciding what each user can access and therefore, structuring the courses depending on the course attendee levels.

The Master Password is the build of the HERA release in use. The build is displayed in the "About HERA" window via the about label in the GUI verbose menu.

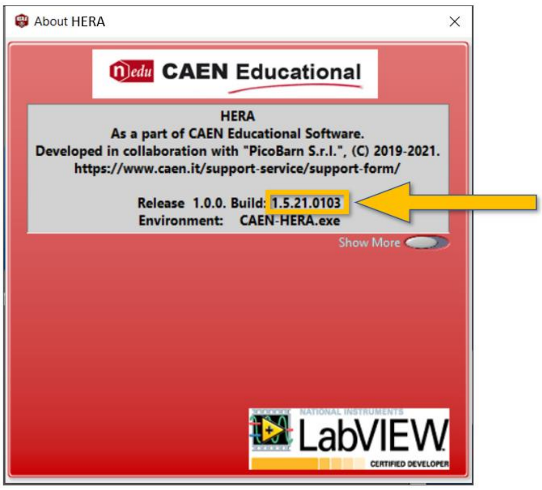
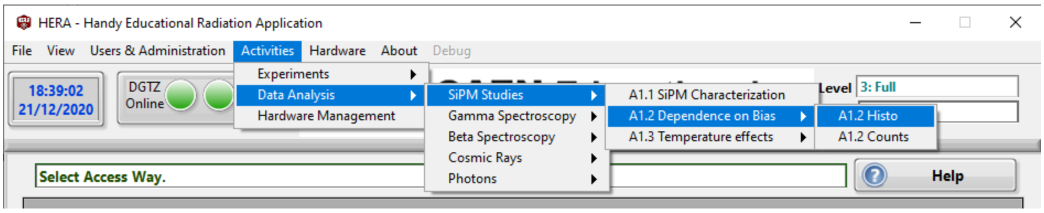


Fig. 6.3: About window.

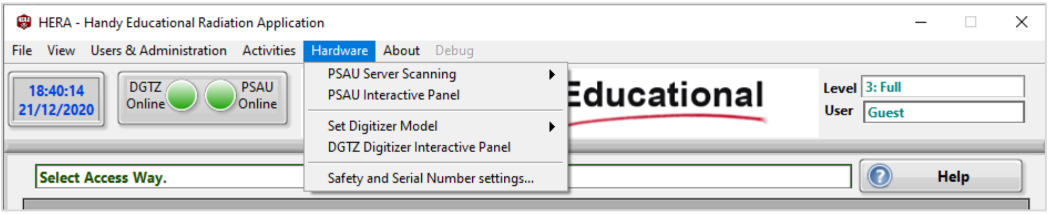
– **Activities Menu**

The “Activities” drop-down menu allows the user to direct access to the experimental activities and to the hardware control panels. Moreover, through it, it is possible the use the analysis tools without connecting to the devices.



– **Hardware Menu**

The “Hardware” drop-down menu is made of three sections useful for the hardware management. The first section gives access to the PSAU Control Panel and to launch again the rescanning procedure when its connection is lost.



Through the second section it is possible to select the digitizer model (DT5720A or DT5720C) and to access the DGTZ Control Panel.

The last section is very important for its preventing action related to the possible detectors damaging:

Detector Safety

The Bias Voltage Limits can be modified from the main window of the GUI only, before selecting the experiment or hardware. The user can set the detector safety condition via the “Hardware” drop-down menu.

This functionality is very important for preventing action related to the possible detectors damaging.

The SP5600 module houses two detectors (SiPM). The module provides independent bias voltages (up to 130 V) to the sensors with gain stabilization. The user can apply a safety measure to prevent detector damage due to a wrong and too high bias voltage. Via “Safety and Serial Number Setting…” selection, the user can set the recommended operating voltage for each channel and, discretionary, the serial number to identify the detector itself. The software stabilizes the maximum value of bias voltage that can be applied to the sensor as a percentage (2,5%) of the operating one. To change the voltage limit is requested to modify the value in the “Bias Setting window” (see Fig. 6.4).

– **About**

The “About” leads to a new window including all information related to the software (release, build, etc).

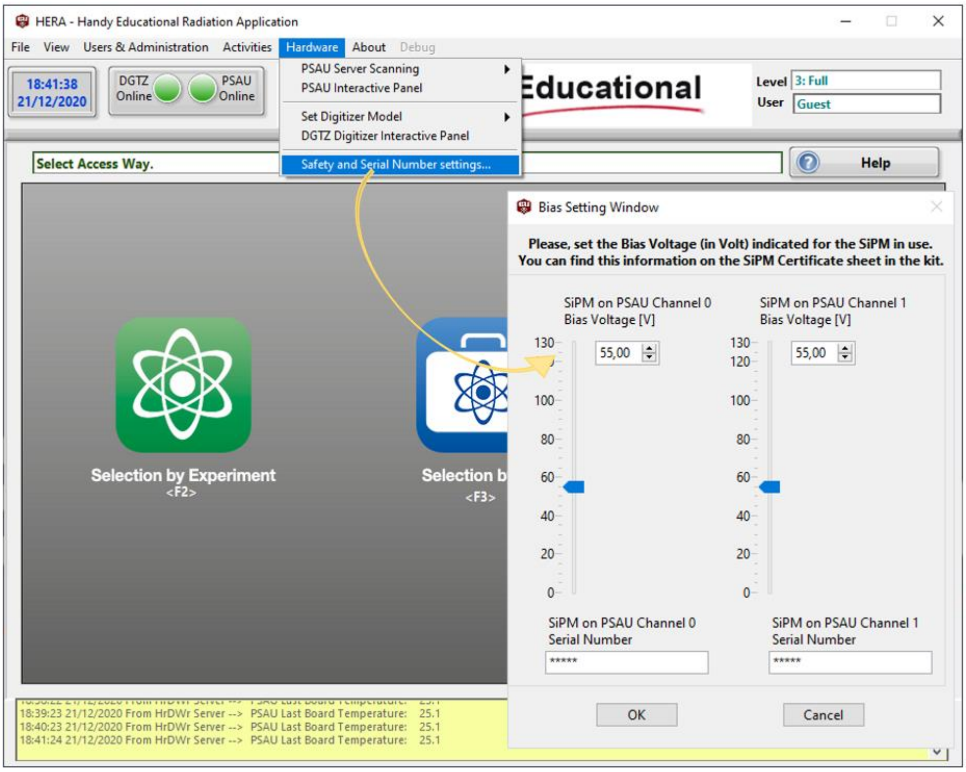


Fig. 6.4: Bias Setting Window.

The Main GUI clearly shows that several ways of operative openings are available:

- "**Selection by Experiment**": access to experiments frame covering Nuclear and Particle Physics fields.
- "**Selection by Kit**": access to operative options allowed by the educational kit in use.
- "**Hardware Management**": direct access to the management of the device parameters and data readout.

The chosen option can be run by double clicking on the relative box or by selecting it and then by the press on the "Select" button.

The user can easily access to the GUI description via the "Help" button. Each window of the software is equipped with a dedicated "Help" button that must be closed before starting any activity.

Selection by Experiment

This option allows the user to access the experiment menu listed in the CAEN Educational Handbook.
By selecting the Physics topic of interest, a series of experiments can be performed. The software programs a predefined settings of the devices and gives a detailed guide into the “Help” button.
The option “Selection by Experiment” can be run by double click on the relative icon or by selecting it and then by pressing the “Select” button.

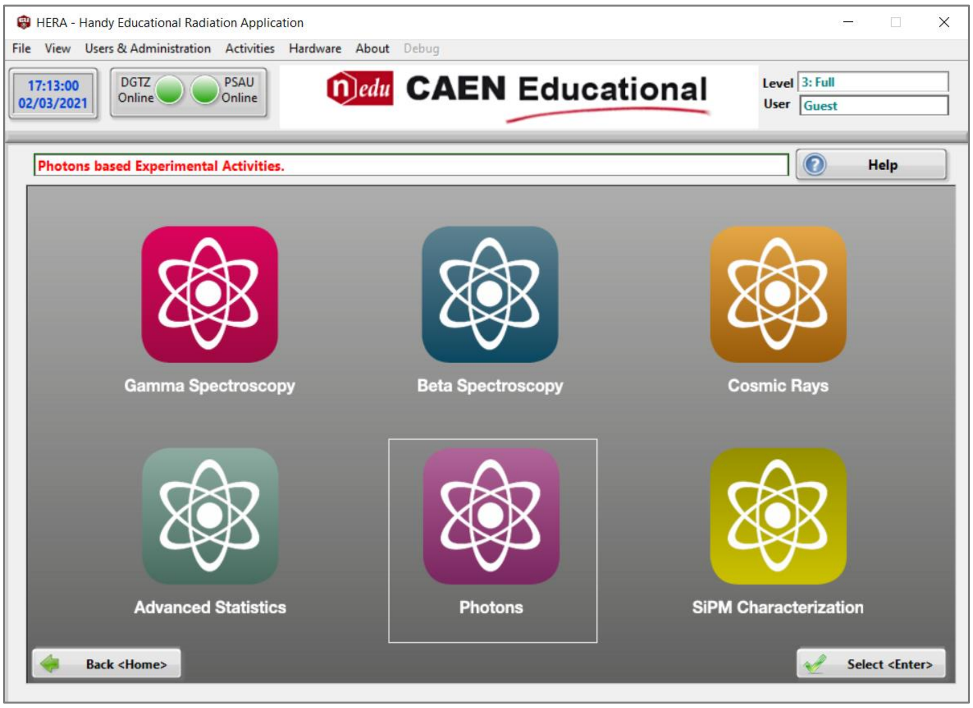


Fig. 6.5: Selection by Experiment.

The “Help” button is present in all the windows in use and provides guides and advice about the experimental procedures.

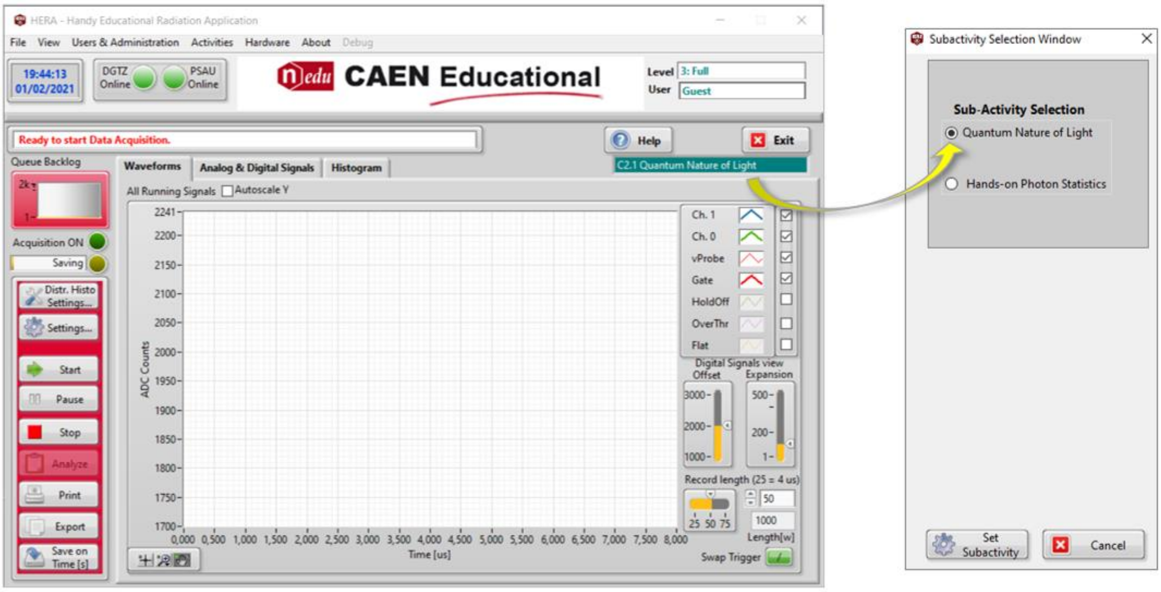


Fig. 6.6: Example of experimental activity.

Selection by Kit

This option allows the user to access the experiment menu listed in the CAEN Educational Handbook.
By selecting the Physics topic of interest, a series of experiments can be performed. The software programs a predefined settings of the devices and gives a detailed guide into the “Help” button.
The option “Selection by Experiment” can be run by double click on the relative icon or by selecting it and then by pressing the “Select” button.
The “Help” button is present in all the windows in use and provides guides and advice about the experimental procedures.

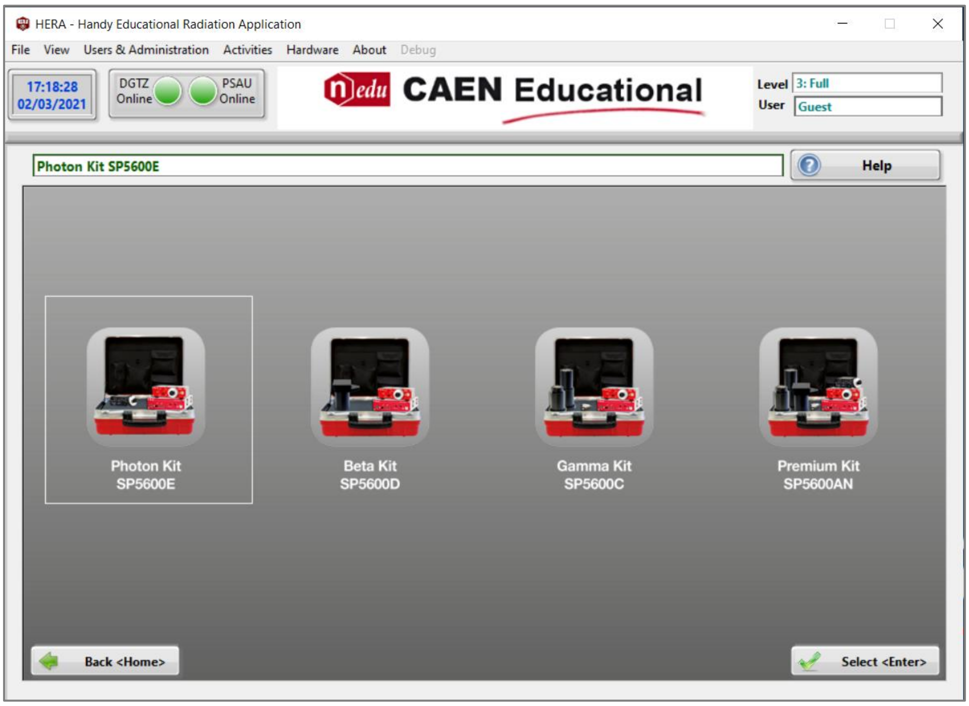


Fig. 6.7: HERA: Selection by kit.

Hardware Management

The main units of the Educational kit, which are common among all the systems, are:

- Power Supply and Amplification Unit (PSAU) - SP5600
- Desktop Digitizer (DGTZ) - DT5720A

The “Hardware Management” section allows the user to manage all the parameters of both PSAU and DGTZ giving the highest flexibility in the operating modes.

With few easy steps, the setting of bias voltage, gain, thresholds, and digital outputs are possible. The digitized signals can be monitored for a real-time fine-tuning of the set-up. Energy spectra, trends of the charge as a function of the time, signal frequency versus threshold, and frequency counting are also displayed in the visualization tabs of the main GUI.

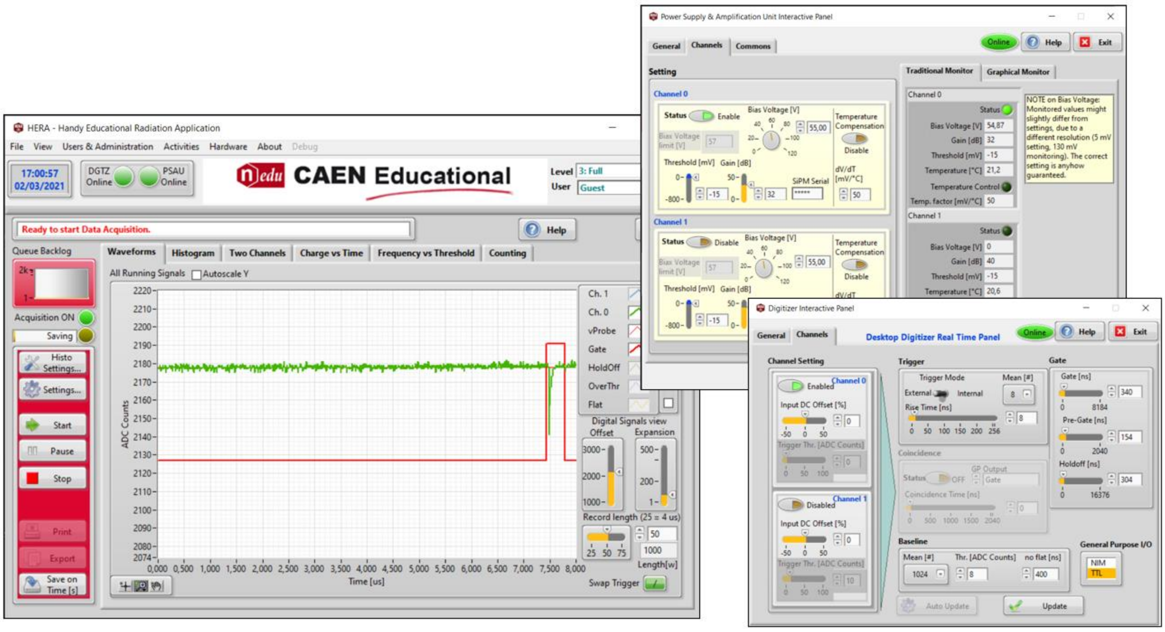


Fig. 6.8: Hardware Management.

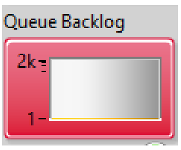
All tabs allow the user to save plots and data on file for the offline analysis processes.

- Main GUI Description

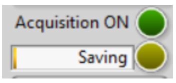
The Main GUI of the HERA software consists of several visualization tabs. These tabs allow the user to visualize and manage the signals of the detector. The “Waveform”, “Histogram”, “Two Channels” and “Charge vs Time” tabs refer to the digitizer (DTGZ). The other two, “Frequency vs Threshold” and “Counting”, refer to the Power Supply and Amplification Unit (PSAU).

Control keyboard

The keyboard on the left side of the GUI allows the user to control and manage the acquisition tabs and to monitor the system status.



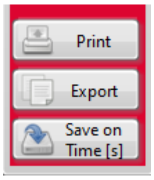
“*Queue Backlog*” indicates the number of acquired data (elements) that are waiting for displaying or saving to file, for both the "Waveforms" tab and "Histogram" tab. This element number should normally be equal to zero unless some extra time-consuming operation occurs.



Two *light indicators* provide the system status related to Data Acquisition and Storage.

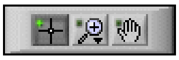
“*Histo Settings...*” button makes available the selection of the different types of histograms for the “*Histogram*” tab.
“*Settings…*” button leads to an additional window providing the options for the channels enabling/disabling for both PSAU and DGTZ, and for setting the run preset according to a fixed time or number of events.

"*Start*" button must be used to launch the acquisition and to visualize the results on the related tabs. To stop the acquisition and/or change to another visualization tab, the user can press the "*Stop*" button. The single shot mode of the waveform can be activated via "*Pause*" button, then the "*Start*" button will change its name to "*Single shot*". In that case, the plot will be updated and frozen with a single trigger. The continuous data stream can be activated again by pressing the "*Pause*" button.



The last three buttons of the keyboard are related to data storage. The "*Print*" button sends the result visualized in the tab to the selectable printer. The "*Export*" button opens an additional window to export data in two formats. If the "Clipboard" box is selected, a bitmap image to the Clipboard is exported. If the "Excel" box is selected, just numerical data are exported. "*Save on Time*" (or "*Save on #Events*") button saves data according to the setting previously defined via "*Settings…*" button.

The display of the tabs is equipped with a Graph Palette that allows the user to interact with a graph.



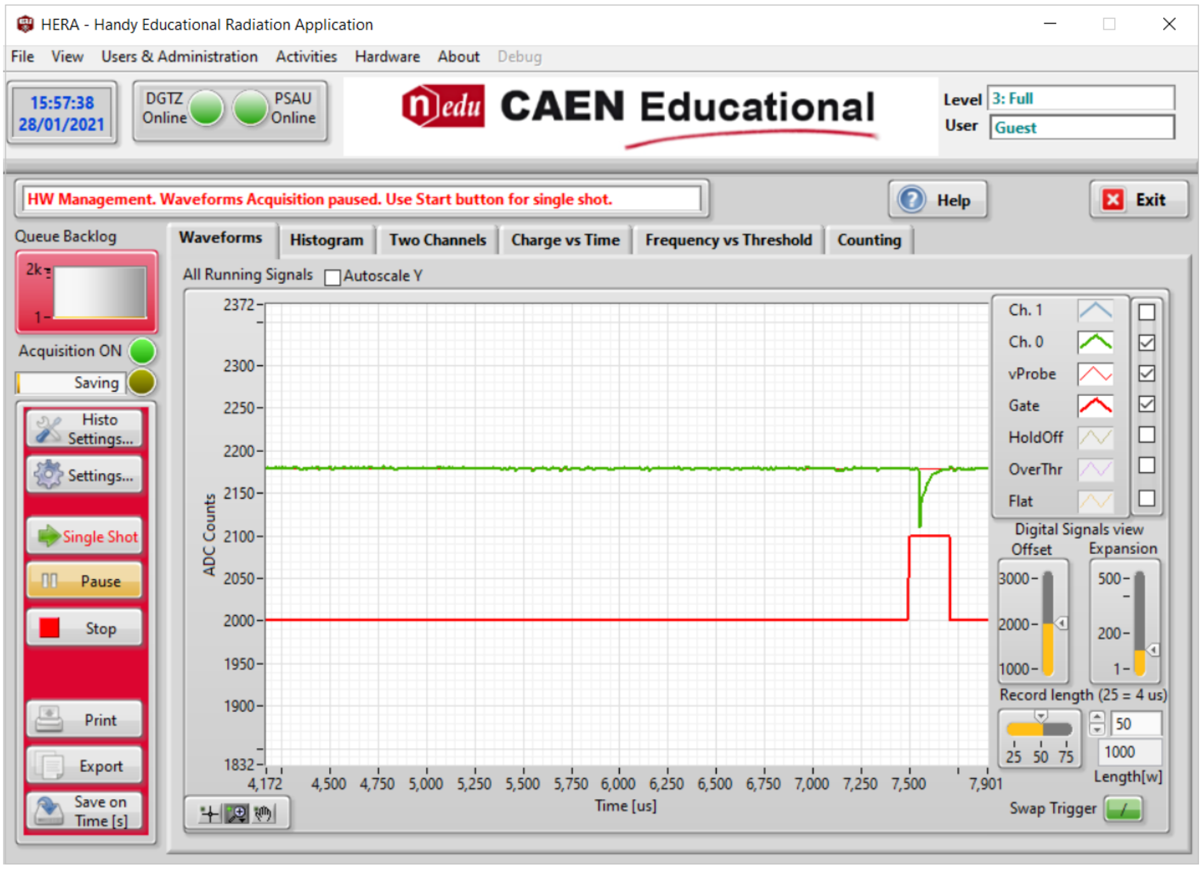
This palette appears always with the following buttons, in order from the left to the right:

- Cursor Movement Tool moves the cursor on the display. If the cursor is not present, it does not work.
- Zoom acts by zooming in and out the display.
- Panning Tool picks up the plot and moves it around on the display.

Note: If one of the controls of the Graph Palette does not work, that interaction type is not permitted for the specified graph. The graph palette is always composed of the three controls, even if not all of them are used.

Waveform tab

The “Waveform” tab shows the traces of the analog and digital signals read out from the digitizer. The signals visualization can be enabled/disabled by selecting the related box on the legend on the right side.



The analog signals are the traces of the input channels (Ch.1 and Ch.0) and the virtual probe, i.e. the baseline signal.

The digital signals are the Gate (red), the Over Threshold (violet), the HoldOff (brown) and the Flat (yellow):

- “Gate” represents the width of the signal integration.
- “Holdoff” means the veto width for the generation of other gates.
- “Over Threshold” is generated when the signal is over the set threshold.
- “Flat” stands for the veto width for the baseline calculation.

The “Digital Signal View” section on the window right side includes the graphical controls for the digital traces. These traces can be amplified via the “Expansion” cursor and moved in a vertical direction via the “Offset” cursor.

The “Record length” control allows the user to change the time scale of the acquisition window, from 4 µs to 12 µs.

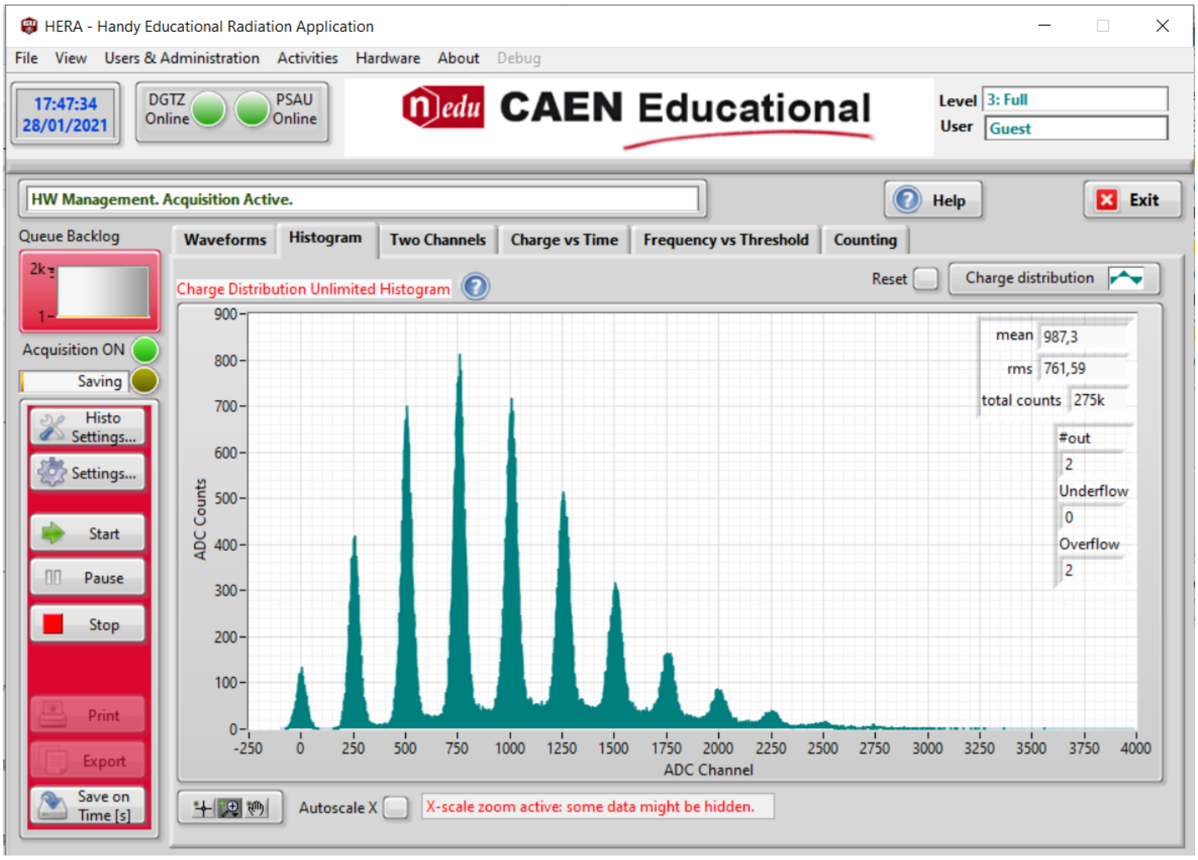
The “Swap Trigger” button enables/disables the rising edge stabilization of the gate on the time scale.

The acquisition conditions for the data saving, previously set via the "Setting…” button on the control keyboard, can be applied simply by pushing the “Save on…” button during the acquisition run.

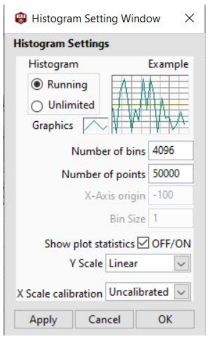
If the system is not in acquisition mode, the "Save on..." button only allows the data storage of the displayed waveform without any constraints in time or in events. The data will be saved in .TDMS format. The waveforms data format is described in detail in the Appendix.

Histogram tab

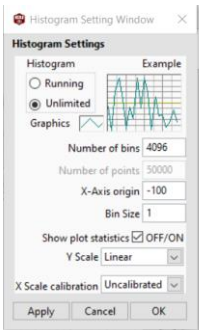
The “Histogram” tab shows the histogram of the active channel according to the PSAU and DGTZ settings.



Via “Histo Settings...” button, the user can enable/disable the general statistics on the display right side, choose the Y scale as linear or logarithmic, and the histogram types. HERA software supports two different histograms:



The "*Running Histogram*" accumulates data until the number of entries defined in the "*Number of points*" parameter is reached. The user can set this value in the Histogram Setting Window via "*Histo Settings...*" button of the Control keyboard. Data is overwritten by the new events. The number of bins, bin size and starting X point are automatically set by the software.
This kind of histogram processing is useful when the hardware conditions are changed during the measurement, to check how the system response evolves. For example, the user can try to change the L.E.D. intensity during the acquisition and observe how the histogram changes.



The "*Unlimited Histogram*" accumulates data with no limits in the number of entries of the Y-axis. Differently from the "Running Histogram", the user must provide the properties of the X scale in order to determine the histogram range:

- the *origin* of the histogram means the minimum plotted charge value;
- the *number of bins* determines the end of the plotting window;
- the *bin size*, i.e. bin width.

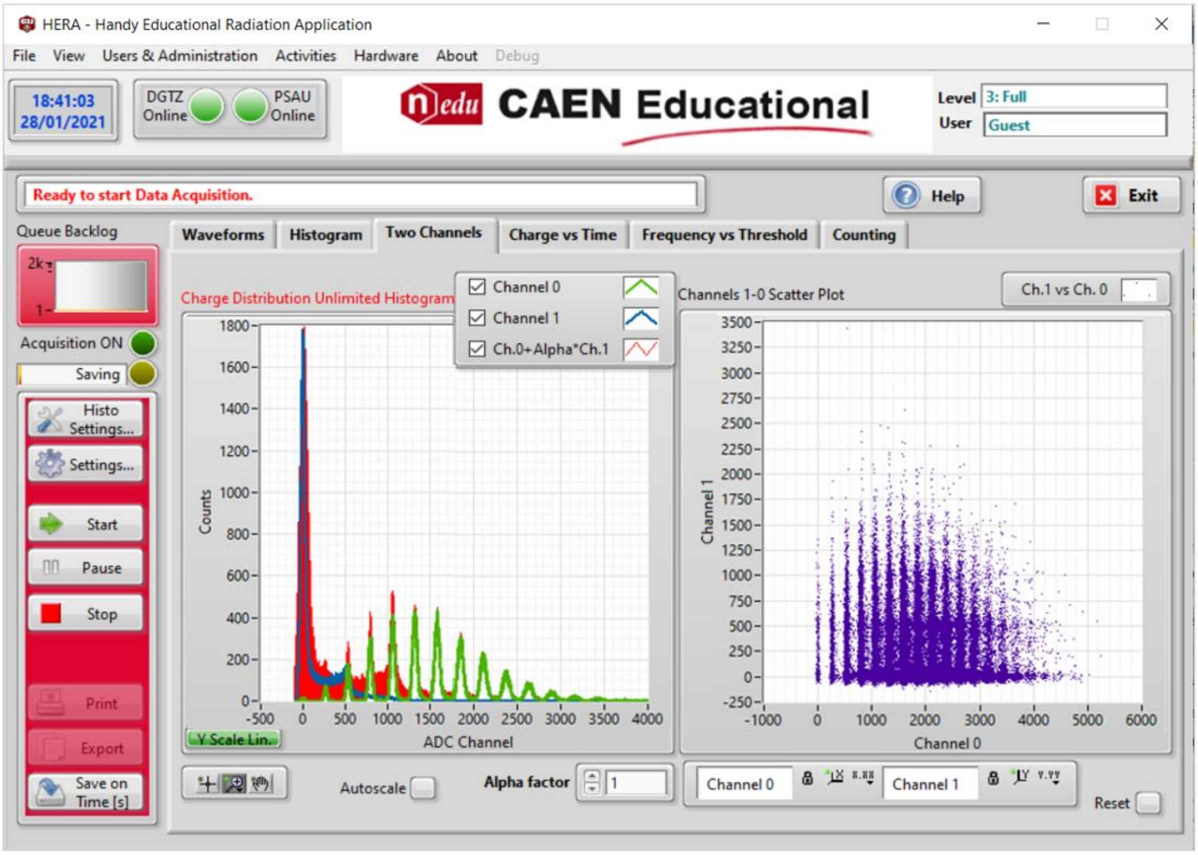
The Unlimited Histogram can be used to make comparisons between measurements taken in the same setup conditions. Note: the hardware setup must not be changed during the measurement.

The acquisition conditions for data saving, previously set via the "Setting…" button, can be applied through the "Save on…" button during the acquisition run.
If the system is not in acquisition mode, the "Save on..." button allows the data storage without any constraints in time or in events. The data will be saved in .TDMS or ASCII formats. The histograms data format is described in detail in the Appendix.

Note: Because of the automatic and variable setting of the bin size, the *Running Histogram* is not suitable for comparison purposes. This histogram type does not guarantee the same acquisition conditions.
Conversely, the *Unlimited Histogram* is suitable for comparison among spectra due to its setting properties in terms of the number of bins, bin size and starting X point.

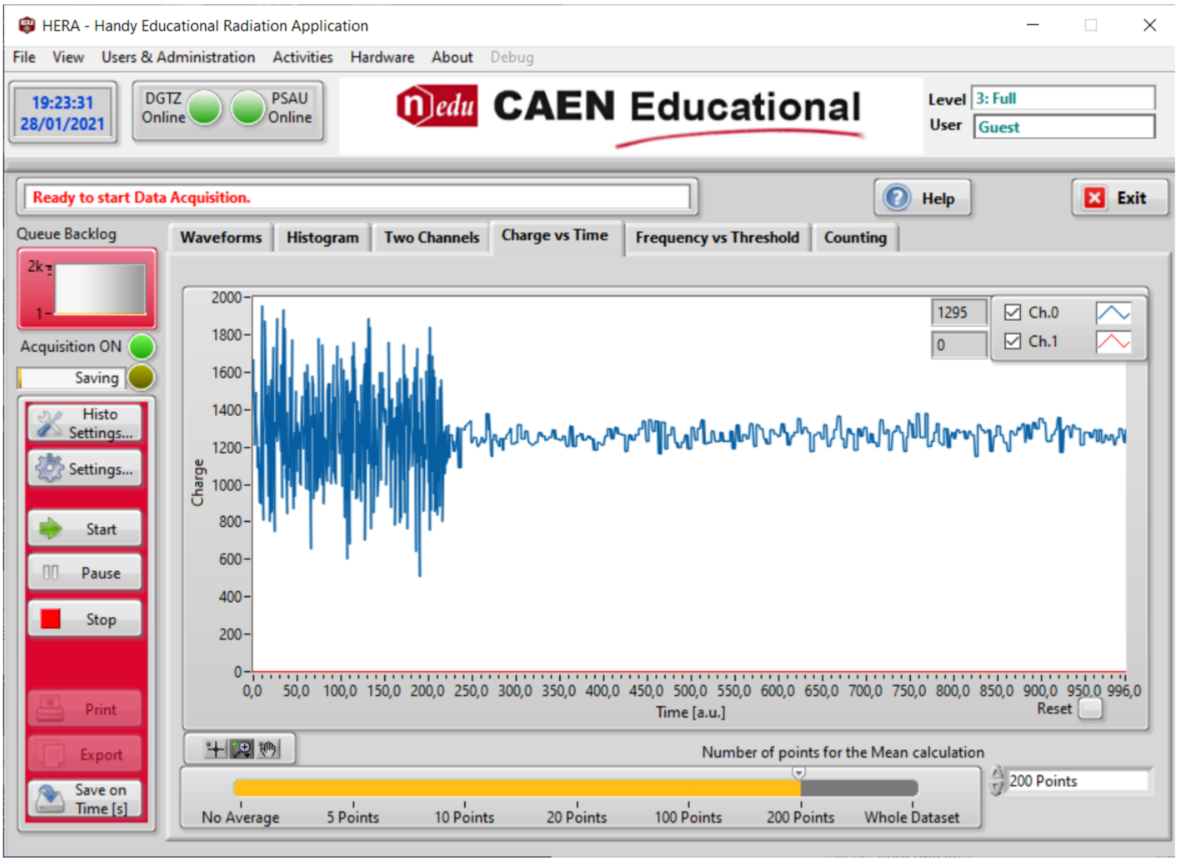
Two Channels tab

The "*Two Channels*" tab allows the user to manage the histogram plots from the two channels of the digitizer simultaneously. It is possible to plot and reset the two histograms, the histogram sum, and their correlation.
The *graph on the left side* contains the histogram plots of both channels and the sum plot. Each plot can be enabled or disabled trough the relative box in the legend. The sum of the histograms is defined as the histogram resulting from adding channel0's histogram to channel1's histogram multiplied by an *alpha factor*. Common x-axis origin, number of bins and bin size can be set via "*Histo Settings...*" button for all the spectra. All graphs can be reset at the same time via the "*Reset*" button in the lower part of the window.
The *graph on the right side* shows a scatter plot of the signals from the two sensors, after being integrated in the specified time window (look at the displayed "*Gate*" in the *Waveforms tab*). This tab might help for specific applications relying on simultaneous use of the two detectors, e.g. when using the scintillator tiles for cosmic ray experiments or two spectrometry heads for ^{22}Na positron annihilation detection.
The histograms saving is described in detail in the Appendix.



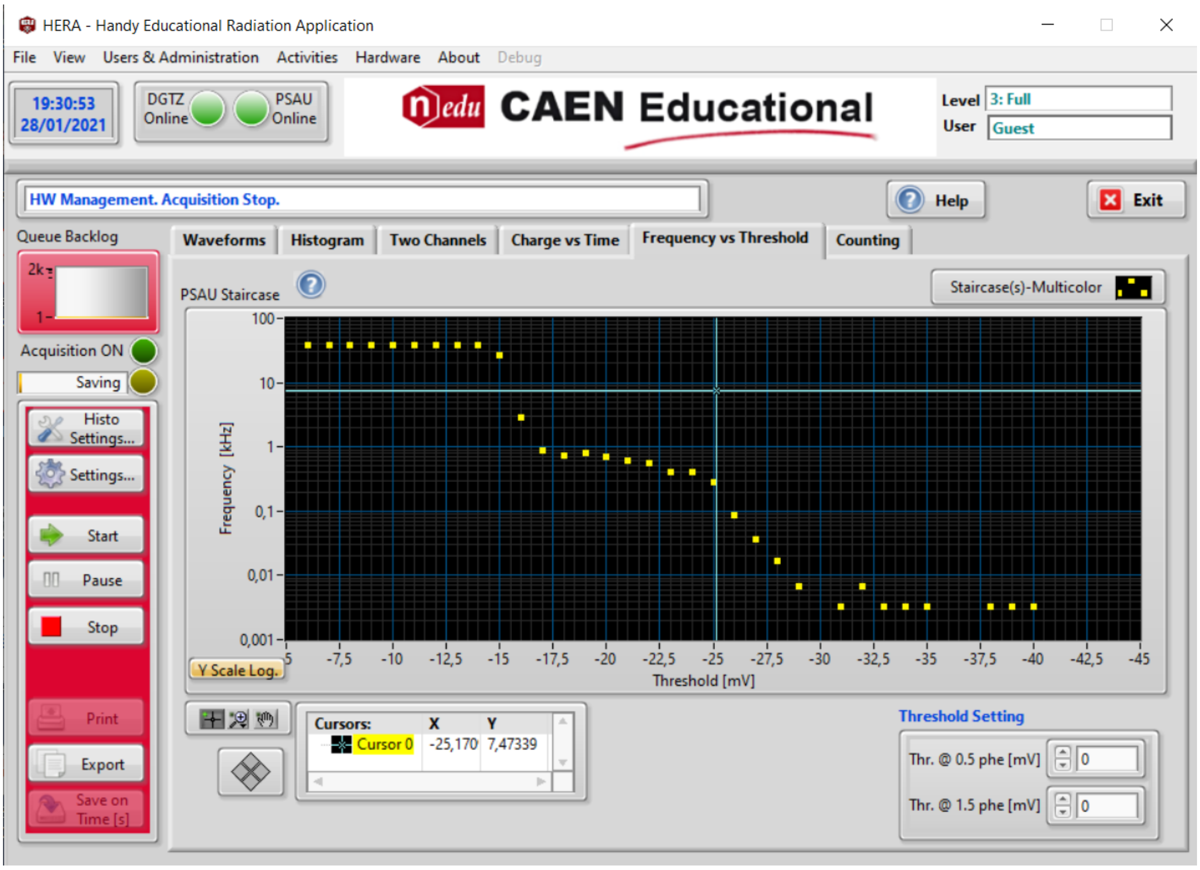
Charge vs Time tab

The "*Charge vs time*" tab plots the signal charge versus time. The user can change the number of charges for the plotted mean. The plot can be stored pushing the "*Save on..*" button.
During the acquisition, the conditions for data saving, previously set via the "*Setting…*" button, can be applied simply by pushing the "*Save on...*" button. If the system is not in acquisition mode, the "*Save on...*" button allows the user to storage the data of the displayed plot without any condition related to the number of entries or acquisition time and the data will be saved in .TDMS format. The Charge vs Time data format is described in detail in the Appendix.

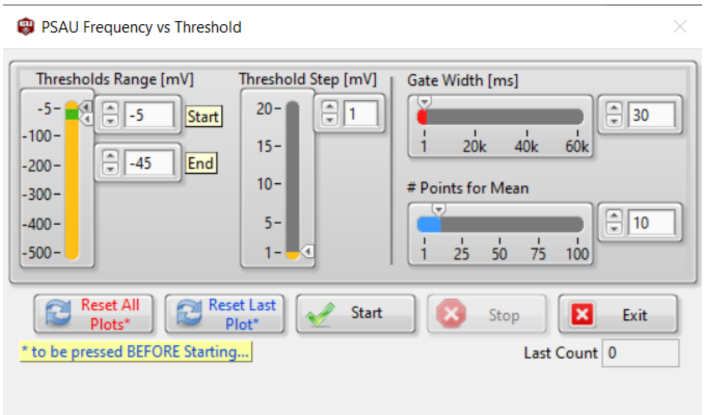


Frequency vs threshold tab

The “*Frequency vs Threshold*” tab allows the user to interact with the PSAU in order to produce the so-called “SiPM staircase”: the plot shows the frequency of the signals which are over the threshold, during a threshold scan from the minimum up to maximum threshold value.



After pressing the “*Start*” button on the control keyboard, the user can change the *limits of the scan*, the *step*, the number of read point which produces the *mean* plotted value and the *gate width* for the counting via an additional window, *“Frequency Scan Setting”*.

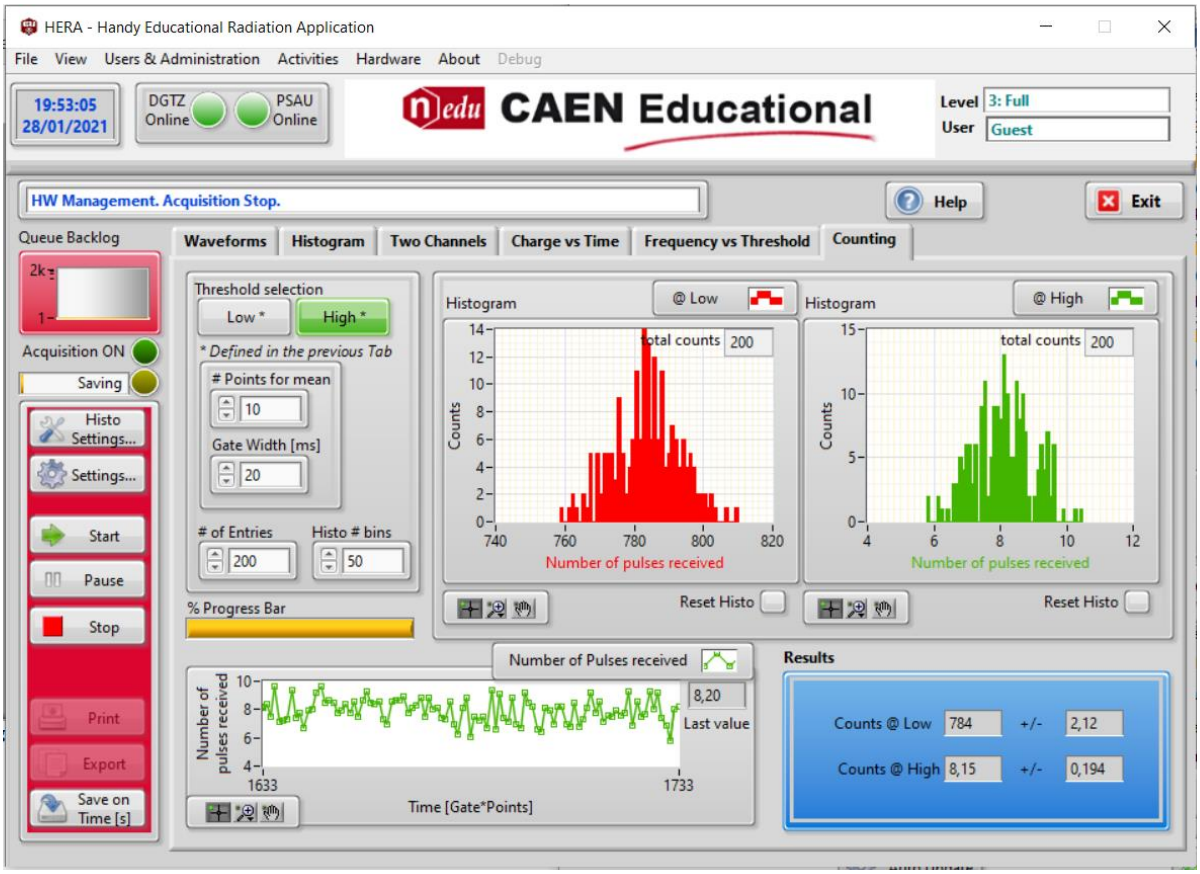


Once the acquisition is completed, the user can choose two threshold values and respectively write them in the two boxes, in the lower part of the window. These two threshold values will be transmitted to the *“Counting”* tab for further analysis.

To store the information included in this tab, the user can employ the *“Export”* button on the control keyboard.

Counting tab

The “Counting” tab shows three plots for which the user can change the number of points for the plotted mean value and the gate width for the counting.
The graph in the lower part plots the frequency trend of the signals over the threshold set in the PSAU Interactive Panel for the active channel or over the threshold value corresponding to the Low/High button selection, set in the previous tab. The two histograms show the distribution of the mean number of counts referred to the two threshold values (Low and High). The mean values of these distributions are displayed in the blue box, together with their uncertainty. The number of histogram entries and bins can be set by the controls “# of Entries” and "Histo # bins".



The “Save on..” button allows the user to save the plots content at the end of the acquisition. The data format is described in detail in the Appendix.

- Power Supply & Amplification Unit (PSAU) Interactive Panel

The PSAU Interactive Panel is fully dedicated to the management of the Power Supply and Amplification Unit (PSAU). It is composed of three tabs: "General", "Channels" and "Commons".

General tab

The "General" tab contains "Board ID and Global Status" frame with information about the PSAU firmware release, Serial Number and COM Port. The "Last PSAU Hardware Error" frame shows the last Error Code of the library which the PSAU stands on. Moreover, the Temperature History plot shows the temperature of the board and of both two detectors.

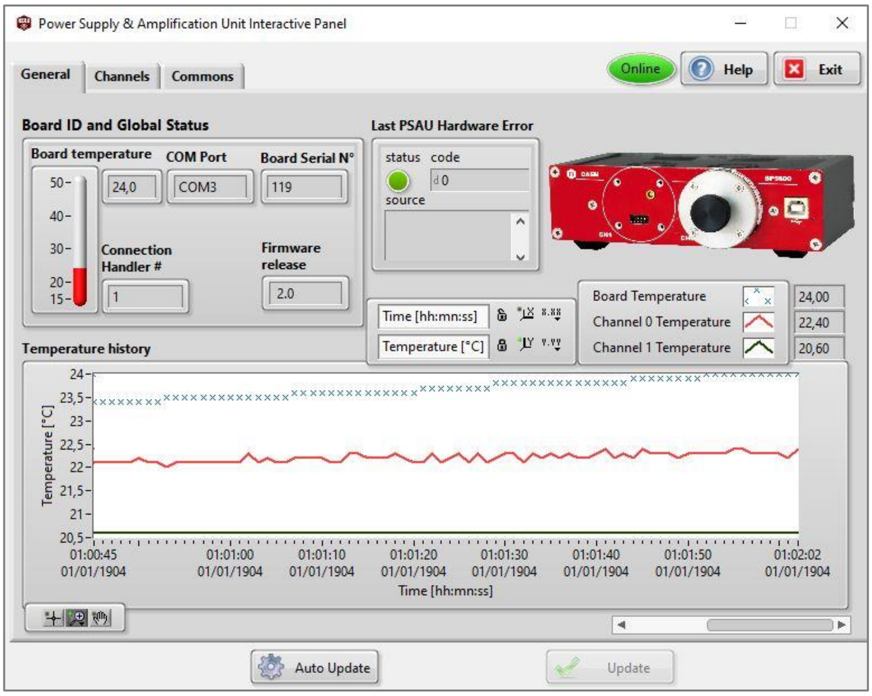


Fig. 6.9: PSAU General Tab.

The PSAU library return codes displayed in the General tab are summarized in the following table.

Error code	Value	Meaning
PSAU_Success	0	Operation completed successfully
PSAU_InvalidComPortError	-1	Error related to the COM port
PSAU_TooManyClientsError	-2	Max. nr. of PSAUs simultaneously manageable exceeded
PSAU_CommunicationError	-3	Communication error
PSAU_InvalidHandleError	-4	Invalid device handler
PSAU_InvalidHandleError	-5	Unspecified error
PSAU_InvalidCommandError	-6	Invalid command error
PSAU_InvalidParameterError	-7	Invalid parameter error
PSAU_DeviceNotFound	-8	Device error (i.e., hardware or firmware issue)

Tab. 6.1: PSAU library return codes.

Channels tab

The "Channels" tab is composed of two sections: Setting and Monitor. The first one, on the left side, provides the switchers for the two channels enabling the settings of the bias voltage, the gain, the discriminators threshold, and the temperature compensation. The temperature compensation requires the setting of the coefficient "dV/dT" for both the channels. The compensation acts on the bias of the sensor to keep its gain constant, according to the voltage linear dependence as a function of the temperature. For both channels, the SiPM serial number is visualized according to the initial setting via "Safety and Serial Number Setting…" selection in the "Hardware" drop-down menu.

Two different graphical visualizations are provided to monitor the set parameters and verify channels status. An important note is shown to underline that the setting and monitoring of Bias Voltage have different resolutions due to the hardware.

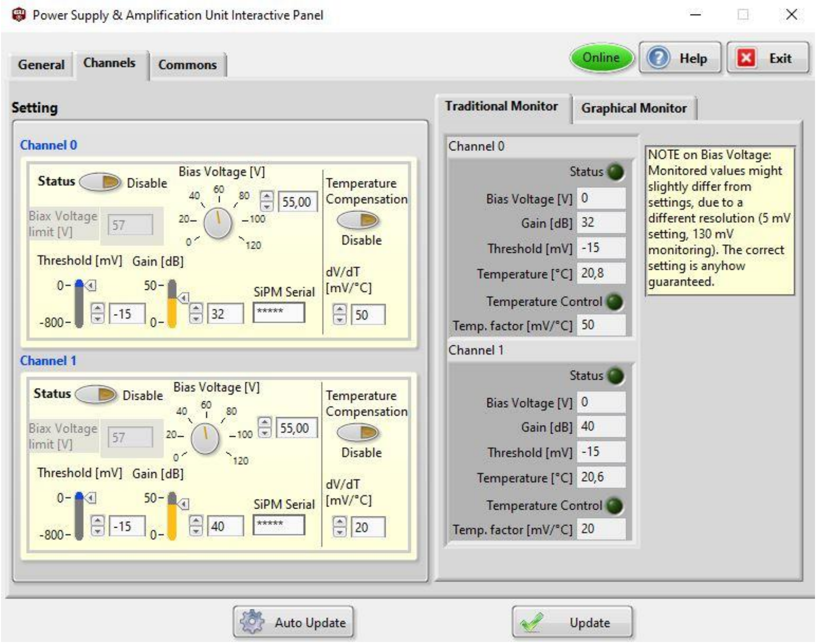


Fig. 6.10: PSAU Channels Setting Tab.

Commons tab

The "Common" tab allows to user to set the width of both signals produced as digital outputs. The output level can be set as NIM or TTL standard and the polarity of the discriminator edge can be selected. The coincidence can be activated when both PSAU channels are switched on. The coincidence signal is provided on digital output of the selected channel and its width can be set in the Coincidence section of this tab.

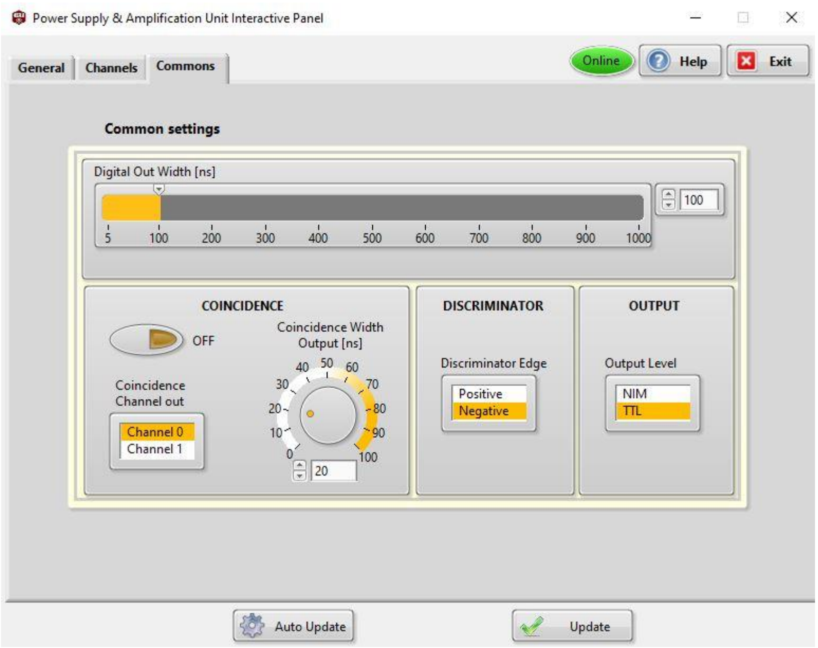


Fig. 6.11: PSAU Commons Setting Tab.

Important Note: The “Update” button must be selected for all settings change to apply them correctly. The lack of this operation leaves the default settings unchanged.
The “Auto Update” button executes the updating process automatically.

- Desktop Digitizer Interactive Panel

The Digitizer Interactive Panel allows the user to:

- check the digitizer connection and status (online/offline)
- check the model and serial number, revision, and firmware of the device
- overwrite default values with new ones for both input channels
- set Coincidence, Trigger mode, Gate and Baseline parameters.

The Digitizer Window is composed of two tabs: “General” and “Channels”.

General tab

The “General” tab contains the “*Unit ID and Characteristics*” and “*Last Digitizer Error received*” frames:

- *Handle Number*: once the device is opened, the function returns a handle that becomes the unique identifier of that device; any access operation to the device will take place according to its handle.
- *ROC & AMC Firmware release*: these fields contain the current firmware release running on the mainboard (i.e. on the ROC FPGA) and on the mezzanine (i.e. on the AMC PFGA). Moreover, a message box related to firmware compatibility.
- *Serial* and *Model Number*, *PCB revision*
- *Last DGTZ Error received:* any error given back by the CAEN Digitizer library which the program stands on, is reported in the field code.

The DGTZ library return codes are summarized in the Tab. 6.2.

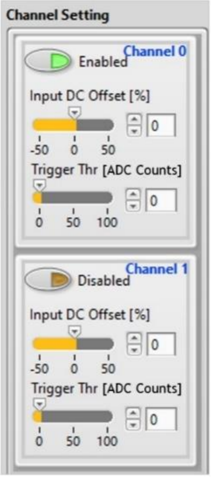
Error code	Value	Meaning
CAEN_DGTZ_Succes	0	Operation completed successfully
CAEN_DGTZ_CommError	-1	Communication error
CAEN_DGTZ_GenericError	-2	Unspecified error
CAEN_DGTZ_InvalidParam	-3	Invalid parameter
CAEN_DGTZ_InvalidLinkType	-4	Invalid Link Type
CAEN_DGTZ_InvalidHandler	-5	Invalid device handler
CAEN_DGTZ_MaxDevicesError	-6	Maximum number of devices exceeded
CAEN_DGTZ_BadBoardType	-7	Operation not allowed on this type of board
CAEN_DGTZ_BadInterruptLev	-8	The interrupt level is not allowed
CAEN_DGTZ_BadEventNumber	-9	The event number is bad
CAEN_DGTZ_ReadDeviceRegisterFail	-10	Unable to read the registry
CAEN_DGTZ_WriteDeviceRegisterFail	-11	Unable to write into the registry
CAEN_DGTZ_InvalidChannelNumber	-13	The Channel is busy
CAEN_DGTZ_ChannelBusy	-14	The channel number is invalid
CAEN_DGTZ_FPIOModeInvalid	-15	Invalid FPIO Mode
CAEN_DGTZ_WrongAcqMode	-16	Wrong acquisition mode
CAEN_DGTZ_FunctionNotAllowed	-17	This function is not allowed for this module
CAEN_DGTZ_Timeout	-18	Communication Timeout
CAEN_DGTZ_InvalidBuffer	-19	The buffer is invalid
CAEN_DGTZ_EventNotFound	-20	The event is not found
CAEN_DGTZ_InvalidEvent	-21	The event is invalid
CAEN_DGTZ_OutOfMemory	-22	Out of memory
CAEN_DGTZ_CalibrationError	-23	Unable to calibrate the board
CAEN_DGTZ_DigitizerNotFound	-24	Unable to open the digitizer
CAEN_DGTZ_DigitizerAlreadyOpen	-25	The Digitizer is already open
CAEN_DGTZ_DigitizerNotReady	-26	The Digitizer is not ready to operate
CAEN_DGTZ_InterruptNotConfigured	-27	The Digitizer has not the IRQ configured
CAEN_DGTZ_DigitizerMemoryCorrupted	-28	The digitizer flash memory is corrupted
CAEN_DGTZ_DPPFirmwareNotSupported	-29	The digitizer DPP firmware is not supported in this lib version
CAEN_DGTZ_InvalidLicense	-30	Invalid Firmware License
CAEN_DGTZ_InvalidDigitizerStatus	-31	The digitizer is found in a corrupted status
CAEN_DGTZ_UnsupportedTrace	-32	The given trace is not supported by the digitizer
CAEN_DGTZ_InvalidProbe	-33	The given probe is not supported for the given digitizer's trace
CAEN_DGTZ_UnsupportedBaseAddress	-34	The Base Address is not supported, as in case of DT and NIM devices
CAEN_DGTZ_NotYetImplemented	-99	The function is not yet implemented

Tab. 6.2: Digitizer library return codes.

Channels tab

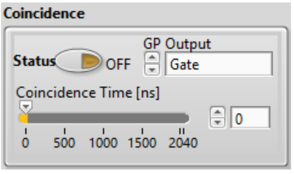
The “Channels” tab consists of five sections: *Channel Setting, Coincidence, Trigger, Gate,* and *Baseline*.

- *Channel Setting Section*



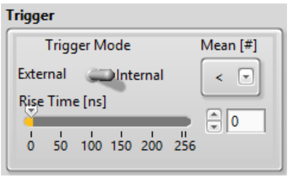
The *Channel Setting* section contains:
the switches to enable/disable the two channels of the digitizer.
“Input DC Offset” is a percentage shift of the input range scale (=2 V_{pp}), allowing the dynamic range to be shifted from -2.0/0 V up to 0/2.0 V. -50% is its minimum value and it corresponds to -2.0/0 V dynamic range. 0% corresponds to a -1.0/+1.0 V dynamic range, and +50% corresponds to 0/2.0 V dynamic range.
“Trigger Threshold” is related to the settings of the *Trigger* section of this software panel, and it is available only when the internal trigger mode is selected.
The internal trigger mode uses a CR-RC digital filtering algorithm. After digitalization, the DPP applies the digital filter to the raw input pulse to create a shaped bipolar pulse (called *DELTA*). The trigger and internal gate are generated as soon as the *DELTA* signal is greater than a programmable digital threshold, which is the “trigger threshold”.

- *Coincidence Section*



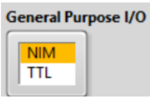
The *Coincidence* section allows the user to select the coincidence mode if both the channels are switched on.
“Coincidence Time” represents the width of the discriminator signal of each channel. Two signals are in coincidence if all of them exceed their own threshold during this time width.
“GP Output” allows the user to choose the signal output on the "GPO" of the digitizer front panel between: *Coincidence*, *Gate* and *Discrimination*.

- *Trigger section*



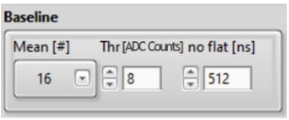
The *Trigger* section allows the user to select external or internal trigger mode. If “*External Mode*” is selected, the digitizer waits for a trigger signal on the “TRG IN” front panel connector. If the “*Internal Mode*” is selected, the digitizer is able to self-detect the signals, according to the trigger parameters.
The purpose of the digital filter is to improve the signal-to-noise ratio by attenuating the low frequencies, (using a numerical differentiator filter) and to smooth out the high frequency noise (using a smoothing function). This filter averages a certain number of samples within a moving window.
“Mean” represents the number of sampling used by the average window; the selectable values are 1, 2, 4, 8, 16 and 32.
Rise Time is the rise time of the input signal, used in the calculation of the signal *DELTA*.

- *General Purpose I/O section*



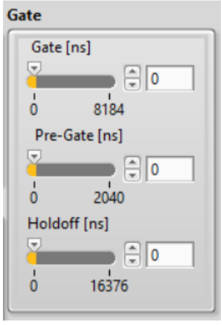
General Purpose I/O section allows the user to set input and output levels as NIM or TTL.

- *Baseline Section*



The *Baseline* section contains the controls for the baseline evaluation.
The *“Mean”* parameter is the number of samples for the average calculation of the baseline. The value 0 disables the baseline restoration. The “Threshold” represents the value on DELTA, over that the baseline calculation is frozen, and *“no flat”* is the veto for the calculation of baseline.

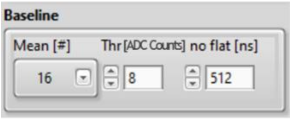
♦ *The Gate Section*



The *Gate* section consists of three parameters.

- *"Gate"* represents the width of the gate signals.
- *"Pre-Gate"* is the time between the gate generation and the trigger leading edge.
- "*Holdoff*" is a veto for the generation of other gates.

♦ *Baseline Section*



The *Baseline* section contains the controls for the baseline evaluation.
The "*Mean"* parameter is the number of samples for the average calculation of the baseline. The value 0 disables the baseline restoration. The "Threshold" represents the value on DELTA, over that the baseline calculation is frozen, and "*no flat"* is the veto for the calculation of baseline.

Important Note: The "Update" button must be selected every time to communicate and apply the selected parameters to the DGTZ. The lack of this operation leaves the default settings unchanged.
The "Auto Update" button executes the updating process automatically.

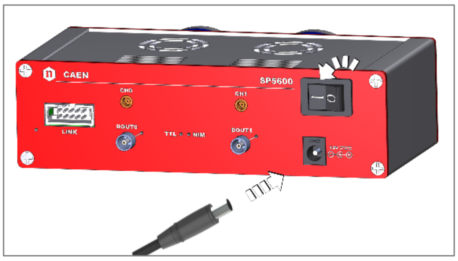
7 Basic Measurements

This manual section is dedicated to the simple and practical use to perform the first basic measurements by using the Educational Kit – Premium Version.

7.1 Enjoying the first SiPM spectrum & measuring the Dark Count Rate

7.1.1 Kit Configuration

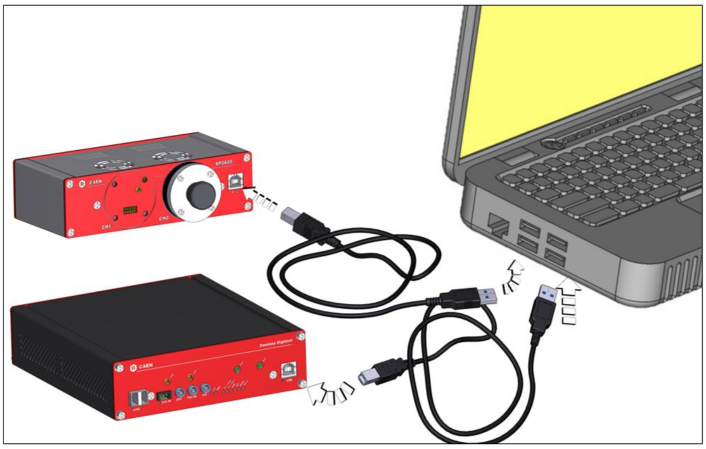
- Required elements: PSAU + Digitizer + Oscilloscope
- Cabling instructions:
  - The main units of the kit must be power on.



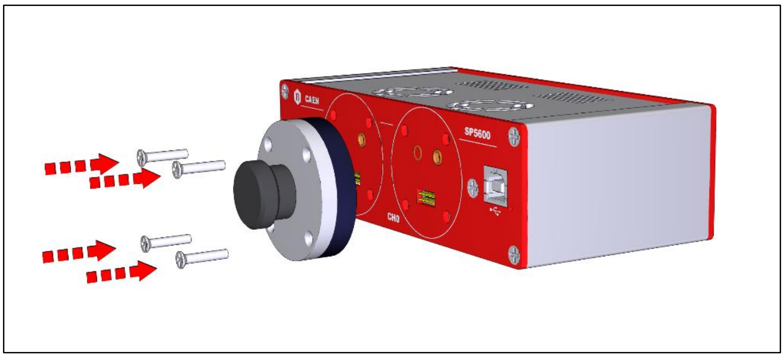
SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

  - SP5600 (PSAU) and DT5720A (DGTZ) shall be connected to the PC via USB cables.



  - The sensor (included in the SP5650C) shall be plugged on a PSAU input channel (for example channel 0, as default in the software pre-settings).



- The output analog signal from the PSAU ("CH0" on the rear panel) must be connected to the input channel of the DGTZ.

- Getting the system alive:
  - Run the program by clicking the HERA icon.

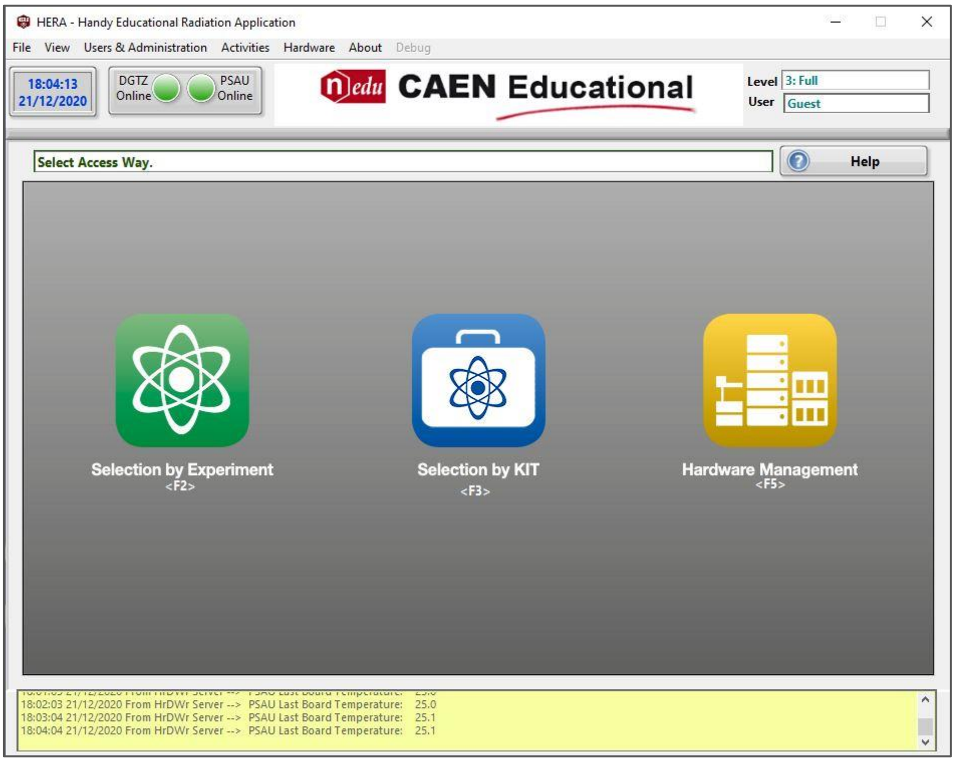


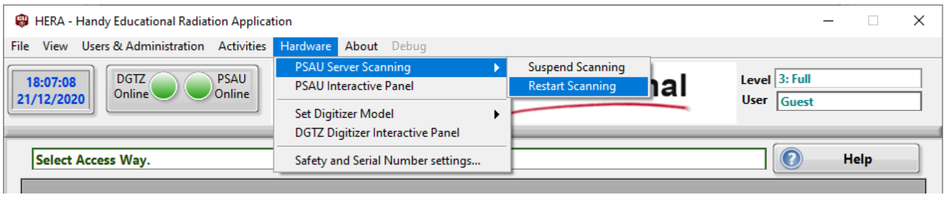
Fig. 7.1: Main GUI of the HERA software.

  - Before running the software, wait the hardware connection. The software recognises the hardware automatically and start the connection. Two connection indicators, "Online Hardware", are present on the opening window:

    Green light means that the connection is ok.

    Red light means that there is no connection.

If the PSAU is power on, but the light colour is red, the software can be forced to search for a new connection via the rescanning procedure from the Verbose Menu: Hardware-> PSAU Server Scanning -> Restart Scanning.



Yellow light means that either the DGTZ is not a DT5720A/C, or its firmware is not compliant with Hera software, and another firmware type is probably running on the board.

Once the system is running, the first action to take is properly biasing the detector and setting the right gain to avoid saturating the PSAU amplifier.

As far as the optimal bias voltage of the sensor, it is suggested to stick to the value reported on the sensor ID card, which may be set in the Power Supply & Amplification Unit Interactive Panel (Fig. 7.2). The Panel can be easily opened via "Hardware" drop-down menu or via the "Hardware Management" access.

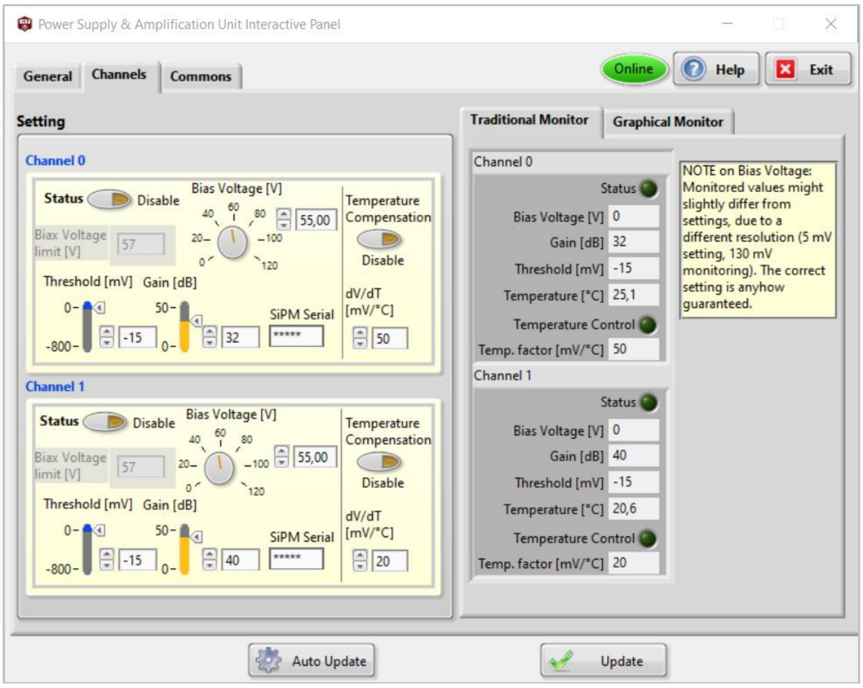


Fig. 7.2: Power Supply & Amplification Unit Interactive Panel.

Enable the channel in use and set the optimal bias voltage. At the same time, the amplification factor can be set and, since the SiPM for the current measurement will not be illuminated and only a few cells are expected to fire, a high value can be used, e.g. 40 dB.

Moreover, for the sake of clarity, the feedback system for the SiPM gain stabilization against temperature variations can be disabled.

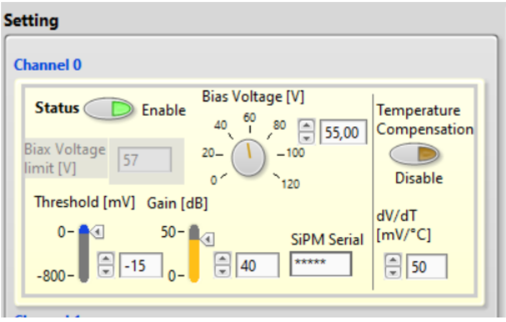


Fig. 7.3: PSAU - Channel 0 Settings.

Important Note: The "Update" button must be selected for all settings change to apply them correctly. The lack of this operation leaves the default settings unchanged.
The "Auto Update" button executes the updating process automatically.

As long as the SiPM is biased and the oscilloscope is properly triggered (an edge trigger, in manual mode, with a threshold at the -10 mV level should be suitable), the SiPM signal is expected to appear on the oscilloscope display, with a waveform similar to what is shown in Fig.7.4**.**

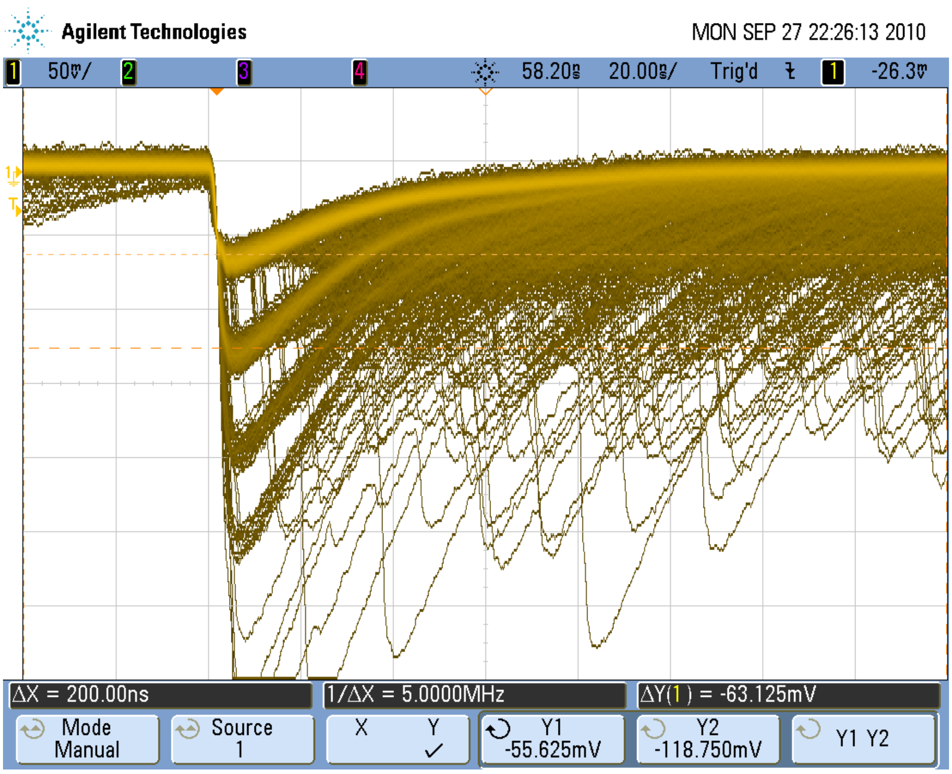


Fig.7.4: SiPM output signal for a not illuminated sensor. Bias: 55 V; Gain: 40 db. Peak-to-peak distance: 63.13 mV.

The different bands in the signal output correspond to avalanches in the cells triggered by the thermal generation of the charge carriers or by the photons associated to the avalanche development (optical cross-talk).

The SiPM Geiger-Mueller multiplication factor is actually corresponding to the area underneath the single cell signal. However, the peak-to-peak distance provides a fair indication of the overall system gain, useful for

- checking the SiPM gain dependence on the over-voltage with respect to the breakdown
- set the amplification factor and avoid saturation effects

- set the discriminator threshold to generate a trigger condition and integrate the signal or perform counting experiments.

A useful entry-level parameter is the Dark Count Rate (DCR) of the SiPM under study, namely the frequency with which avalanches occur for thermal or optical crosstalk (OCT) effects. It is a standard procedure to quantify the DCR as the counting frequency with a threshold corresponding to 0.5 x single photo-electron (p.e.) peak ($DCR_{0.5}$) and to measure the OXT as

$$OCT = \frac{DCR_{1.5}}{DCR_{0.5}}$$

Being the numerator the Dark Count Rate with a threshold at 1.5 photoelectron peak.

The DCR vs threshold can be precisely measured with the Kit. However, a fair indication can be obtained with the Oscilloscope, if the option to measure the triggering frequency is offered. In case, it is worth to exploit this feature to cross check the values against the factory measurements and as reference value for the most advanced procedures. As exemplary illustration, the DCR measurement at 0.5 Photoelectron threshold is shown in Fig. 7.5.

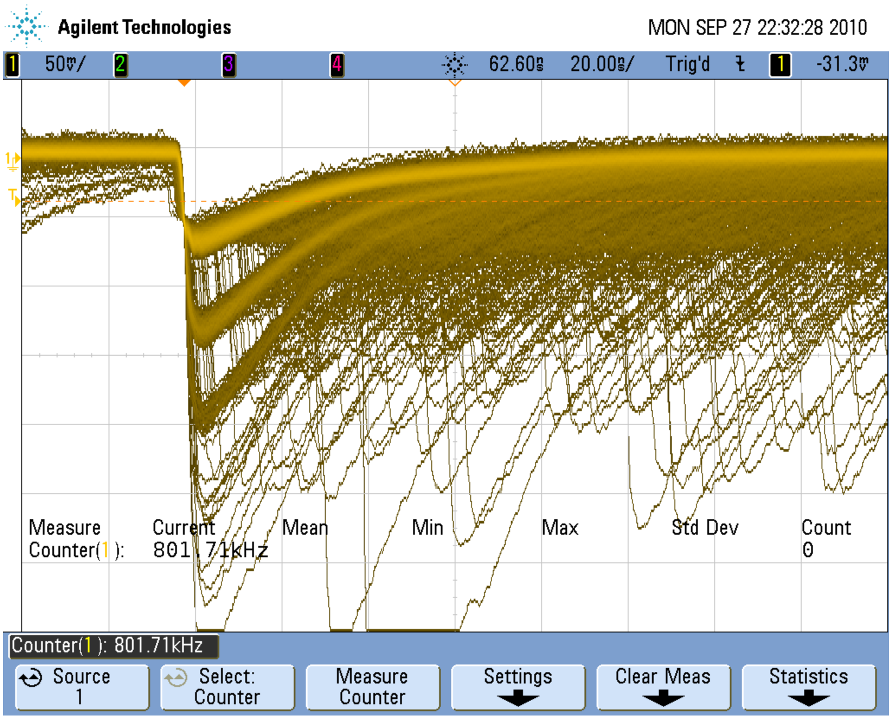


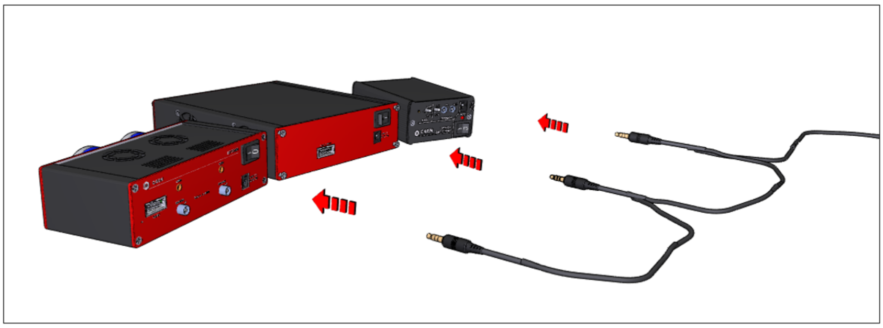
Fig. 7.5: DCR 0.5 measurement at the oscilloscope. The frequency drops to ~206 kHz increasing the threshold to 1.5 p.e. (not shown).

By now and before moving to the next step, the user can gain further knowledge on the system, playing with the bias and the amplification factor and measuring the peak-to-peak and DCR variations.

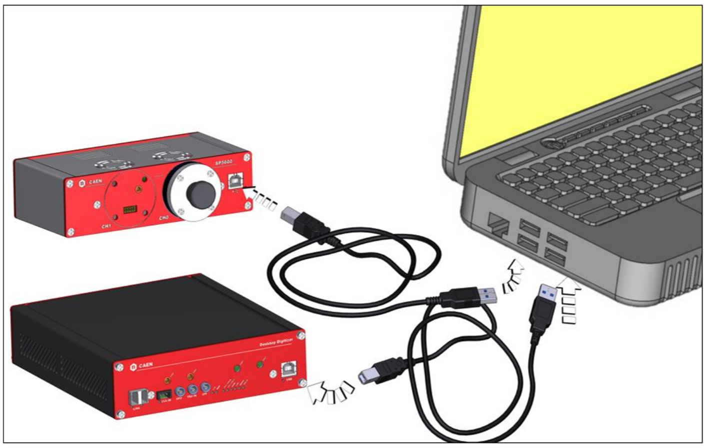
7.2 Can you see the light? SiPM illuminating; triggering & integrating

7.2.1 Kit Configuration

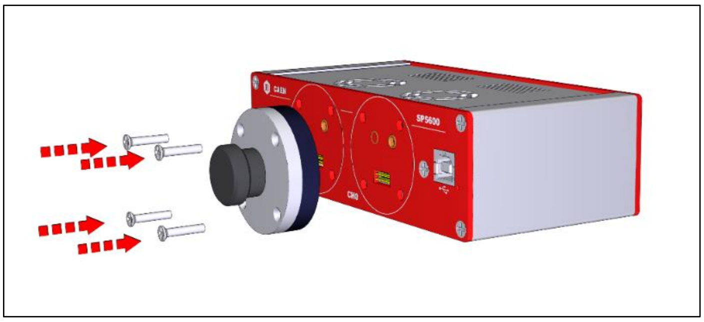
- Required elements: PSAU + Digitizer + LED driver + Oscilloscope
- Cabling instructions:
  - The 12V power supply is able to power PSAU, DGTZ, and SP5601 (LED) thanks to the power cord adapter (1 IN / 3 OUT).



  - SP5600 (PSAU) and DT5720A (DGTZ) shall be connected to the PC via USB cables.

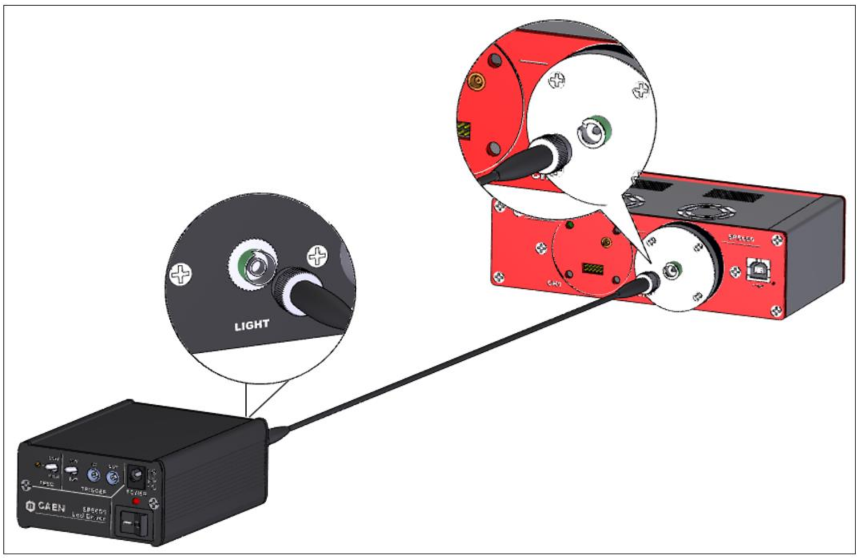


  - The sensor (included in the SP5650C) shall be plugged on a PSAU input channel (for example channel 0, as default in the software pre-settings).

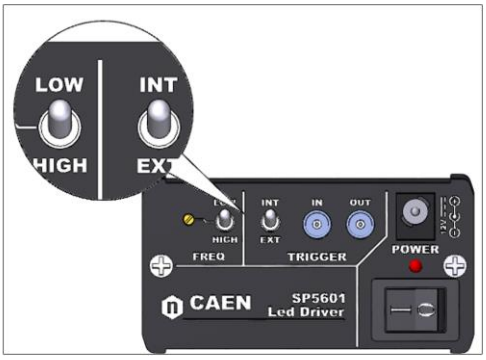


  - Remove the black cap of the LED output light on the front panel and the black cap of the sensor holder SP5650C.
  - The fiber caps must be removed to have the connection between light source and photodetector.

- The LED output light (front panel) shall be directed to the SiPM through the FC terminated clear fiber.

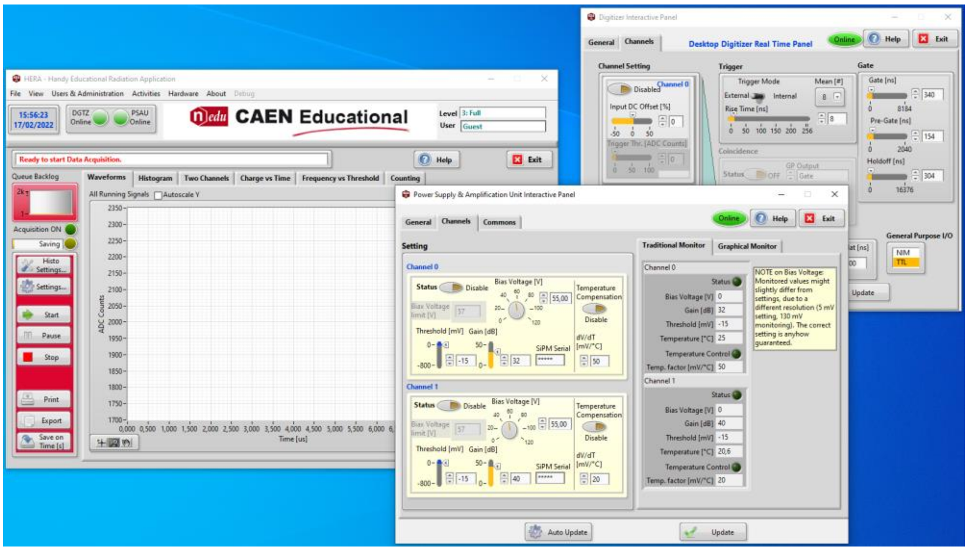


- Low frequency and internal trigger must be set on the rear panel of the LED Driver.



- Cabling among the kit elements depend on the undertaken measurement (see below).

- Getting the system alive:
  - Power on the kit elements
  - Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
  - Select the Hardware Management access.



- Bias the SiPM via Power Supply & Amplification Unit Interactive Panel ("Hardware" drop-down menu). Set an initial amplification factor as of 0.
- Initially no setting of the Digitizer and Main GUI windows are required.

7.2.2 Obtaining a multi-photon peak spectrum

The multi-photon peak spectrum fully exploits the SiPM potential, and it is the reference quantity for the detector characterisation and qualification. It corresponds to the output signal spectrum for an illuminated SiPM and carries information about the detector gain and noise, the photon number resolving capability and even the DCR and the cross talk; concerning the light source, it allows to characterize the statistics of the emitted photons. More will be reported in the following, after the first spectrum is obtained through a two-step procedure:

- **Step 1: amplification factor and intensity tuning [LED driver + PSAU + Oscilloscope]**

The LED driver features the possibility to generate internally or externally the light pulse frequency; for the sake of simplicity, internal generation is considered here and the toggle switch on the back plane of the LED driver shall be set accordingly. The pulse frequency can be selected via a multi-turn rotary meter in the [6;500] kHz range.

When internal generation is chosen, a synchronization output signal in TTL logic is provided from the DOUT plug on the back panel. In order to know the frequency and as a trigger for the SiPM output visualization, it is recommended to look at the synch signal at the oscilloscope.

Once this is done, the SiPM output from the PSAU can be properly displayed showing a number of fired cells by far exceeding what is due to the DCR and cross-talk.

Looking at the scope track, the LED intensity can be tuned and the amplification factor regulated to avoid saturating the dynamic range and inducing an artefact in the spectrum (Fig. 7.6 and Fig. 7.7).

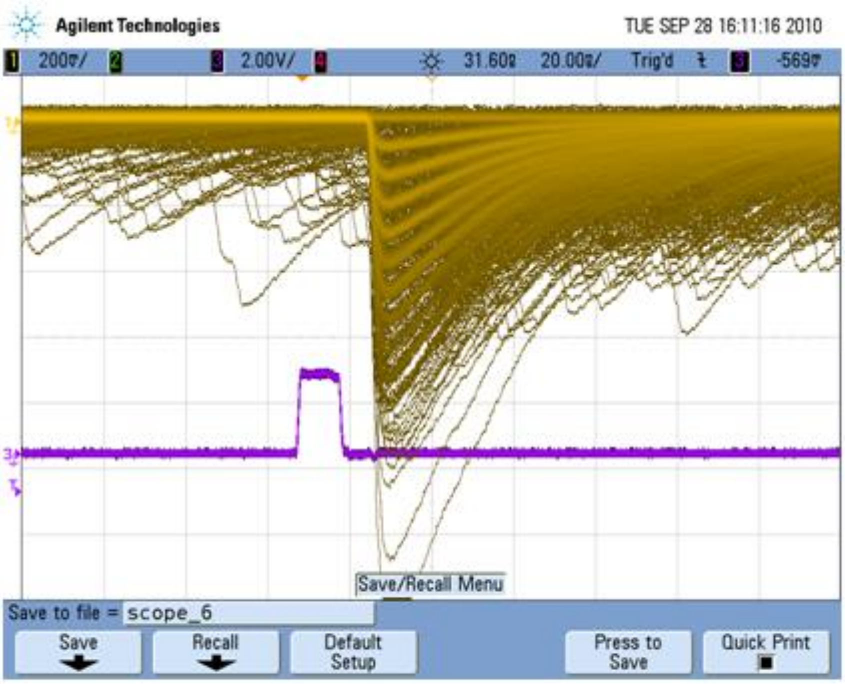


Fig. 7.6: Analog output from the SiPM under test, illuminated the LED. The purple track, used as a trigger, corresponds to the synchronization signal form the LED driver.

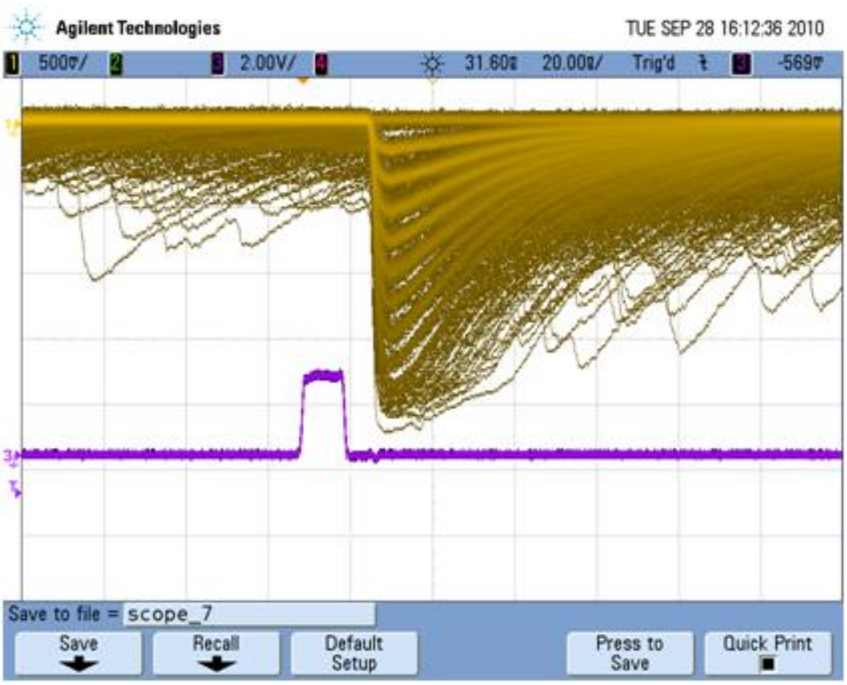


Fig. 7.7: Analog out from SiPM under test, showing onset of saturation due to a too large amplification factor.

- **Step 2: signal digitization**

In order to digitize the SiPM output, the kit has to be configured as follows:

- Cabling:
  - The output signal form the PSAU has to be connected to the input of the Digitizer, either channel 0 or 1

- The output analog signal from the PSAU ("CH0" on the rear panel) must be connected to the input channel of the DGTZ.

- The Synchronization signal from the LED will provide the trigger edge to the Digitizer. The Trigger Out signal of the LED must be connected to the TRG IN plug of the DGTZ. On the rear panel of the LED, take care to verify that the trigger switch to “INT”, which means internal mode, and to plug the LEMO cable in the Trigger “OUT” hole.

- HERA Software: in the Digitizer Interactive Panel (Fig. 7.8).
  - Select EXTERNAL trigger mode.
  - Enable the channel (for example ch 0).
  - Accept default values for the GATE and BASELINE sub-panels.

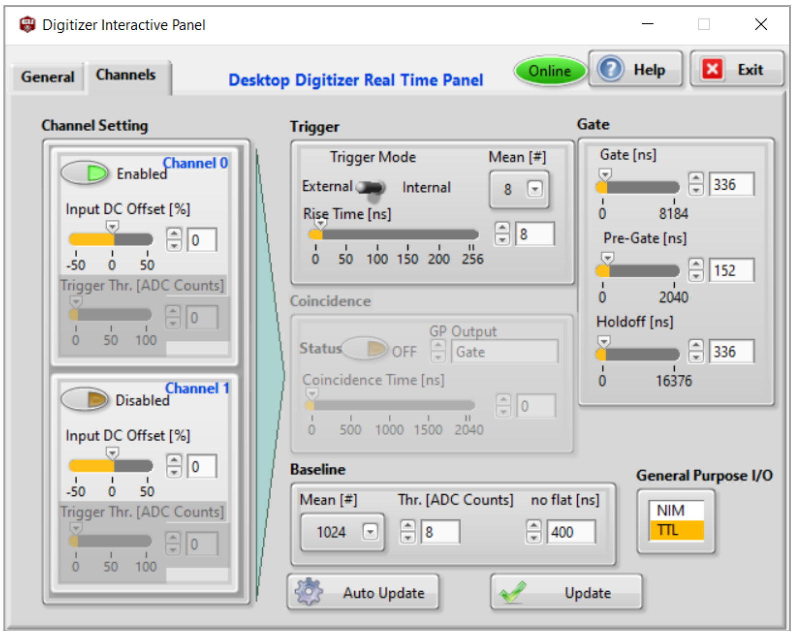


Fig. 7.8: The DIGITIZER control panel.

By now, the system is ready for digitizing the signal but, rather than doing it in a blind way, it is worth taking a guided tour of the system features, going to the visualization panel and switching on the Waveforms tab.

The Waveform tab displays the most relevant information:

a. The digitized analog Input;

b. The signal Baseline (labeled as vProbe);

c. The integration Gate triggered externally or internally by the Digital Pulse Processor.

The *baseline* can be calculated according to the parameters specified in the corresponding sub-panel, namely (Fig. 7.8):

- The number of samples used to calculate the *mean* value
- The *threshold,* used to avoid including in the mean value signals which could bias the baseline value. Whenever the signal exceeds the threshold while the baseline is being updated, the averaging procedure is frozen
- The *no flat time*, specifying the time interval between two updates of the baseline value. The flat time can also be shown in the WAVE display.

The *GATE* actually defines the integration time, and its edge may be triggered in different ways. Once the gate is open, its characteristics are associated to three parameters, specified in the gate sub-panel (Fig. 7.8):

- *gate*[ns] represents the width of the gate signals
- The *pre-gate*, fully exploiting the digital power for the optimal timing with respect to the signal. It defines the position of the gate with respect to the trigger edge, with the possibility to anticipate it, to compensate for the different timing in the signal routing.
- The *holdoff* time, a user's defined veto following a gate opening. The holdoff can also be shown in the waveform display.

For the sake of clarity in the display, every signal can be offset and magnified, enabled or disabled via the commands located on the right side of the waveform tab.

Fig. 7.9 is showing the waveform tab for the SiPM illuminated by the LED, for optimal tuning of the baseline and notably of the pre-gate and the gate width, depending on the time development of the SiPM signal. It is worth remarking here that the LED driver was designed to provide light pulses with a few ns duration (see the technical specifications), so the time development is dominated by the sensor response.

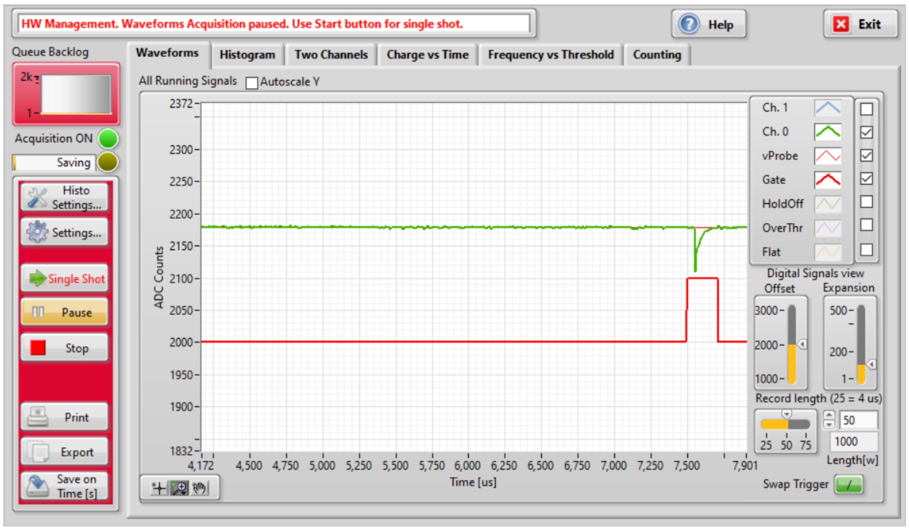


Fig. 7.9: The WAVE display of the GUI.

As long as the GATE is properly defined, the system is ready to record the spectrum, displayed in the HISTOGRAM tab. Exemplary illustration of the multi-photon peak spectrum are shown in Fig.: 7.10.

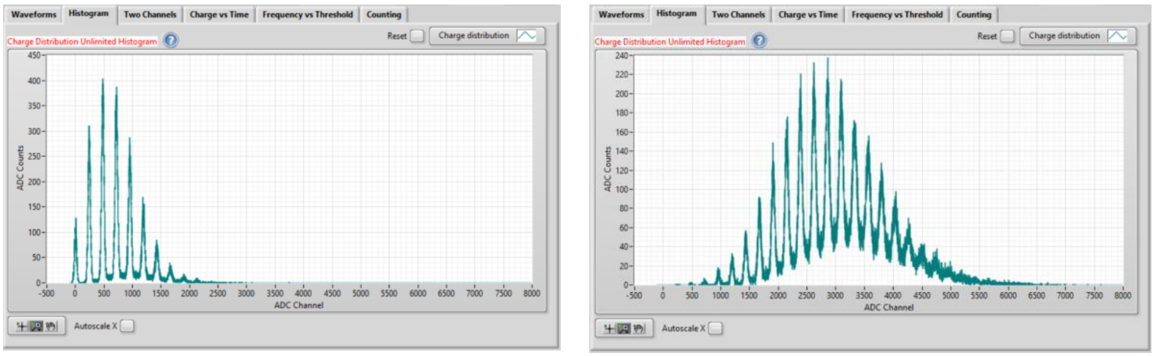


Fig.: 7.10: Multi-photon peak spectrum at two different LED intensities.

The multi-photon peak spectrum provides several information about the system in use; it is worth recalling here the fundamentals:

- The SiPM multiplication factor can be measured by the peak-to-peak distance, knowing that the system is characterized by a charge LSB of 40 fC/ADC channel and the SiPM signal is amplified by an amplification factor set by the user. The linearity and the dynamic range of the sensor can be studied as well.
- The photon number resolving power can be obtained at glance and its dependence on the SiPM biasing conditions studied
- A genuine multi-photon peak spectrum fit can provide further insight, namely:
    - A measurement of the width of the Gaussian peaks against the number n of cells, where a trend of the form

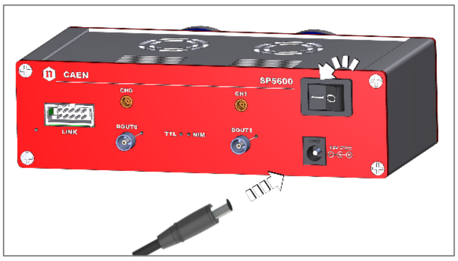
      $$\sqrt{\sigma_0^2+\sigma_1^2 \times n^2}$$

      Is expected, being σ_0 related to the zero-photon peak width, so to the system noise, and σ_1 provides an indication of the cell-to-cell variation of the characteristics.
    - An independent measurement of the DCR and the crosstalk, as long as these terms are included in the fitting function
    - An information on the statistics of the emitted photons, usually retained to be Poissonian.
- Moreover, the SiPM biasing can be optimized, trading-off the avalanche triggering efficiency and the spectrum quality, possibly affected by the spurious dark counts in the gate window.

7.3 Can you see γ spectrum?

7.3.1 First Kit Configuration

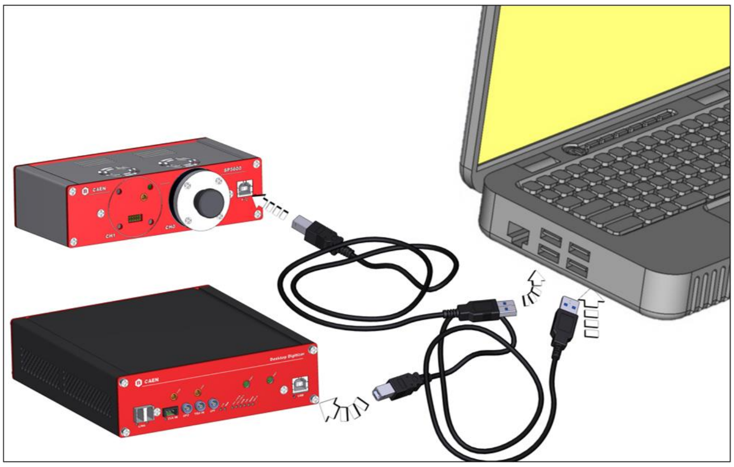
- Required elements: PSAU + Digitizer + Spectrometer + [Oscilloscope].
- Cabling instructions:
  - The main units of the kit must be power on.



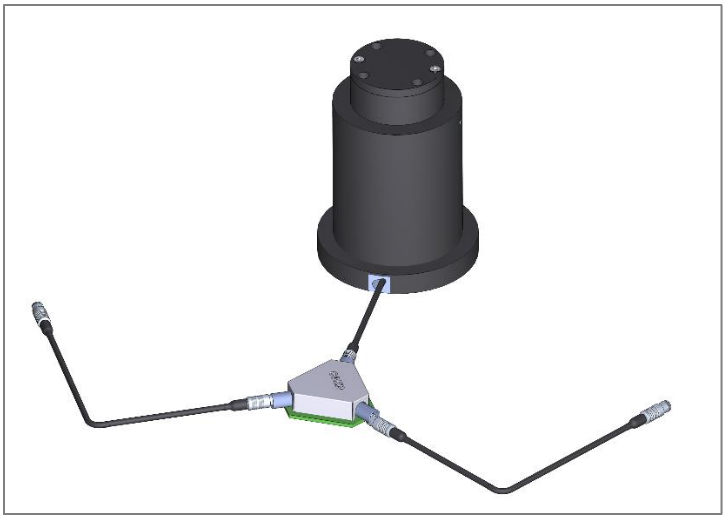
SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

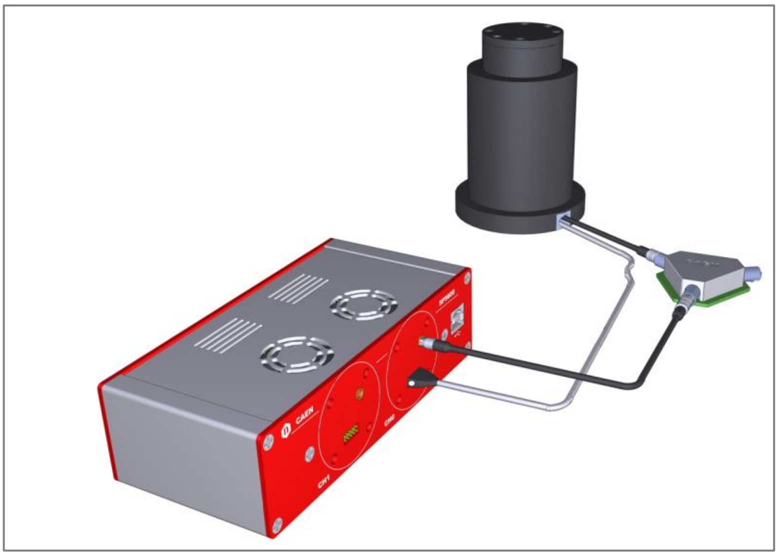
  - SP5600 (PSAU) and DT5720A (DGTZ) shall be connected to the PC via USB cables.



  - In order to avoid saturation during the spectroscopy measurements, the output signal of the spectrometer is divided using the A315 splitter.

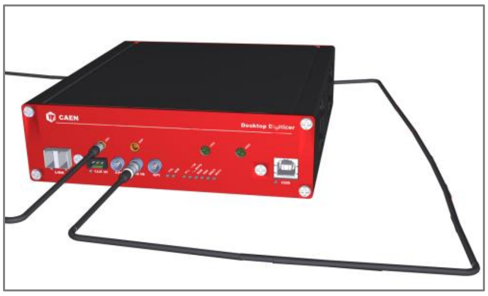


  - Power Cable of the Spectrometer shall be connected to the PSAU channel (for example channel 0).



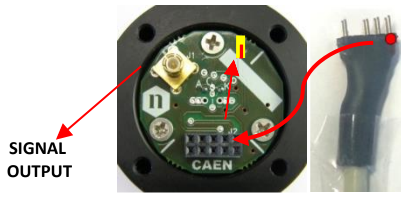
- One splitter branch shall be connected to PSAU channel 0 in order to be amplified by the module. The other splitter branch shall be connected to channel 0 input on the front panel of the digitizer and will be digitized.

- The Digital Output of the used PSAU channel shall be connected to the TRG IN on the front panel of the Digitizer.



Important Note: How can you connect the *Power Cable* of the Spectrometer board to SP5600?

-



Normally, the board power cable is already connected to the bottom part of the spectrometer. If the connection doesn't exist, take careful to attach the marked extremity of the cable connector to the "J2" side of the board connector as shown in picture.

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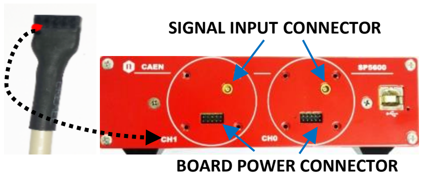
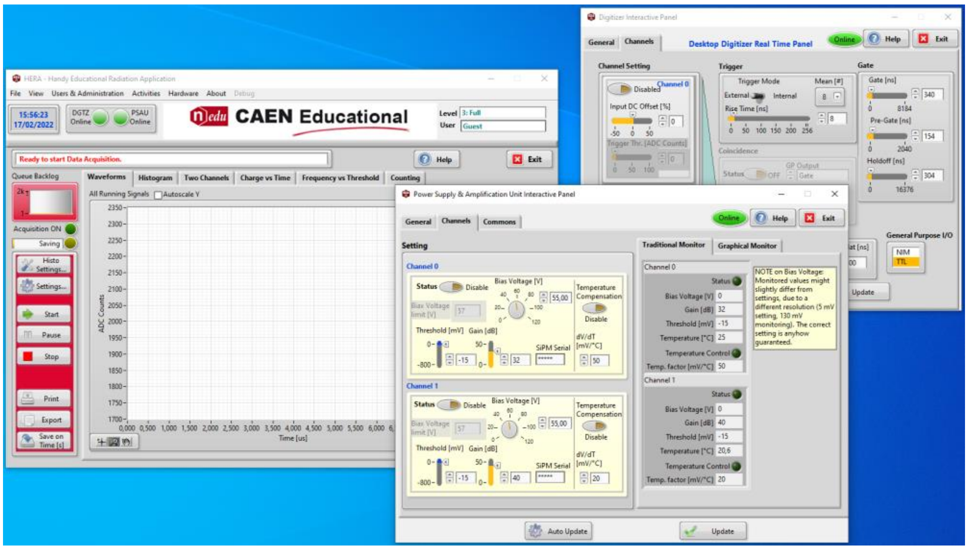


To connect the board power cable to the SP5600 channel, put the marked cable side close to the channel label.

- Getting the system alive:
  - Power on the kit elements
  - Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
  - Select the Hardware Management access.



  - Activate the connected PSAU channel and Digitizer channel

Once the system is running, the first action to take is properly biasing the detector and setting the gain to the PSAU amplifier.

As far as the optimal sensor bias, it is suggested to stick to the value reported on the sensor ID card, which may be set in the Bias & Gain tab of the PSAU panel (Fig. 7.11).

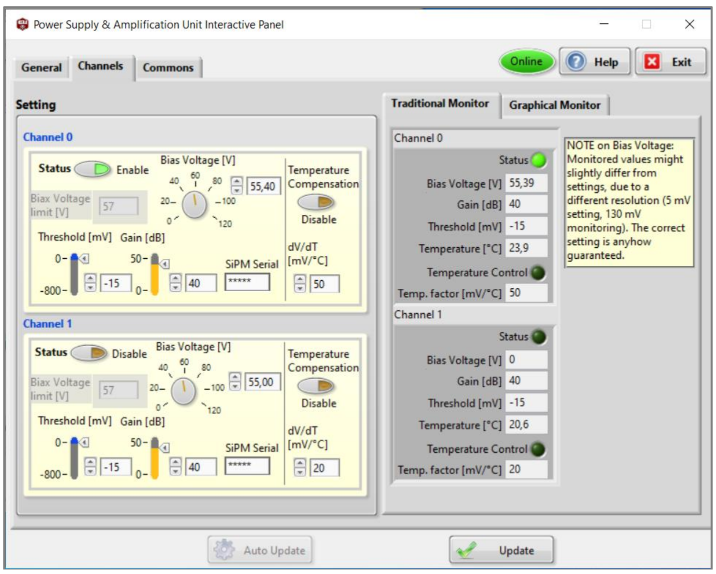


Fig. 7.11: Power Supply & Amplification Unit Interactive Panel – Gamma spectroscopy settings.

At the same time, the amplification factor can be set at high values, e.g. 40 dB, due to the PSAU digital output works only as trigger.

Moreover, for the sake of clarity, the feedback system for the SiPM gain stabilization against temperature variations can be disabled.

Putting on the oscilloscope the spectrometer signal output before (Fig. 7.12) or after the splitting, it's hard to distinguish the different traces corresponding to avalanches in the cells triggered by the thermal generation of the charge carriers or by the photons associated to the avalanche development (optical cross-talk). This fact is due to a combination of factors: no signal amplification and big cells number.

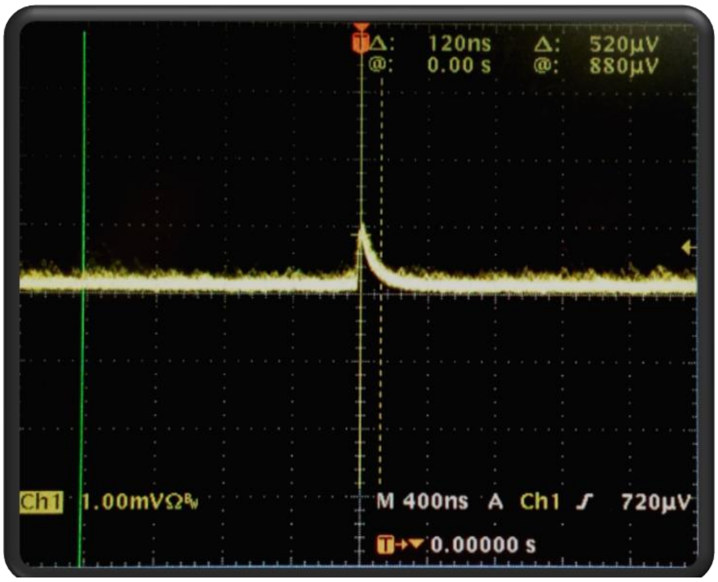


Fig. 7.12: Scope trace of the spectrometer.

Important Note: In order to see multiple traces, it is better to put the spectrometer signal into the PSAU, set the gain and use the analog output to see the bands on the oscilloscope.

The intensity of the light measured by the detecting system (SIPM + scintillating crystal) is proportional to the γ source activity. However, this information is affected and biased by stochastic effects characteristic of the sensor and occurring within the time window: spurious avalanches due to thermally generated carriers (a.k.a. Dark Count Rate (DCR)).

Before to acquire a γ source spectrum, take care to measure this entry-level parameter of the SiPM. It is a standard procedure to quantify the DCR as the counting frequency with a threshold corresponding to 0.5 x single photo-electron (p.e.) peak ($DCR_{0.5}$). The DCR of the mini spectrometer SiPM is 2÷6 MHz.

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. The DCR vs discriminator threshold can be precisely measured by using the "PSAU Staircase" tab in the SiPM Kit Control Software.

The Fig. 7.13 shows the DCR staircase: once the SiPM is biased, and a convenient gain is chosen, through the "Frequency vs Threshold" tab in the right part of the GUI, the threshold scan of the signals frequency can be performed.

Through two staircases it is possible to choose a right cut-off threshold: one acquired with the source and one acquired without it.

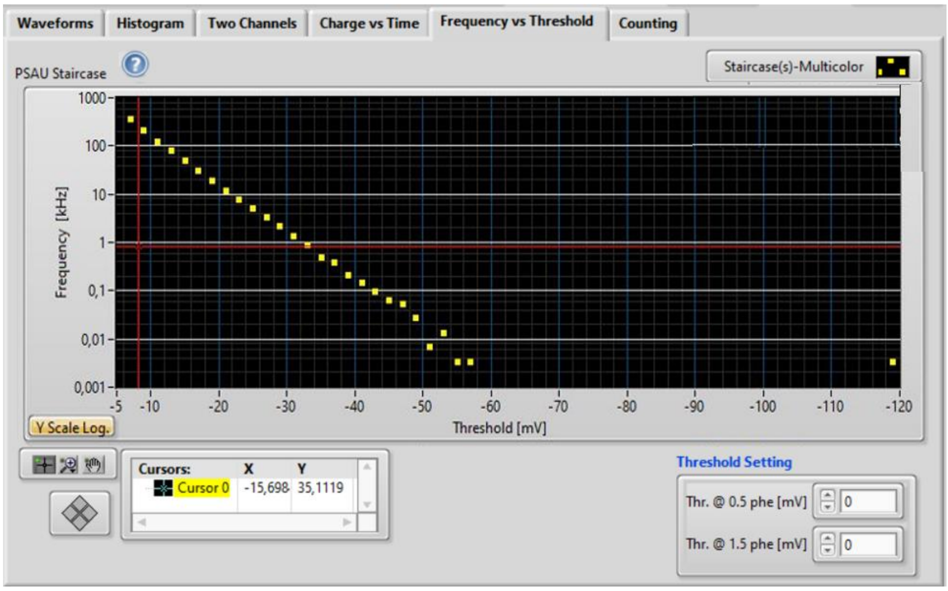
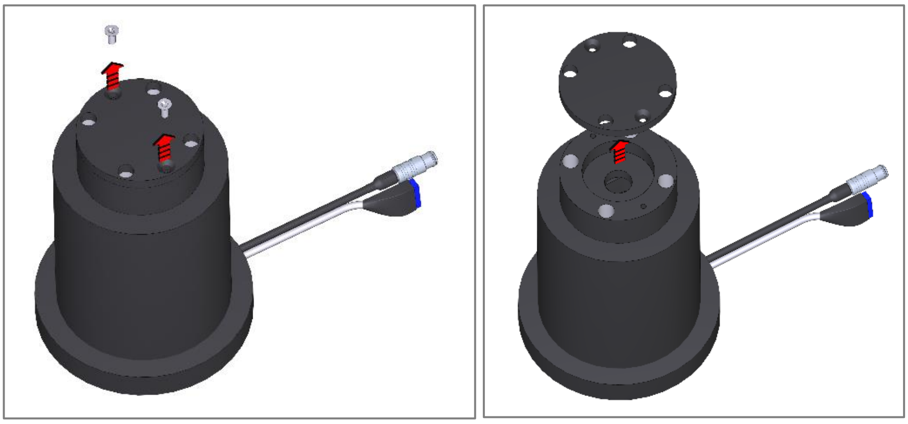


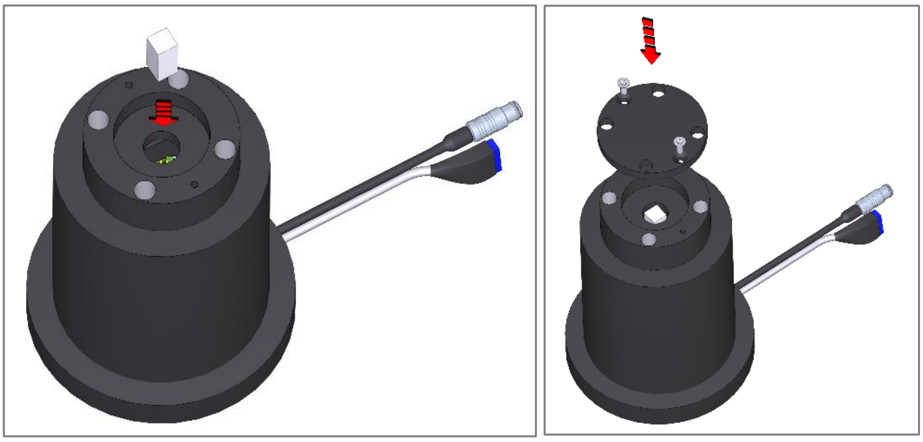
Fig. 7.13: Dark Counts Rate frequency versus Discriminator threshold.

7.3.2 Second Kit Configuration

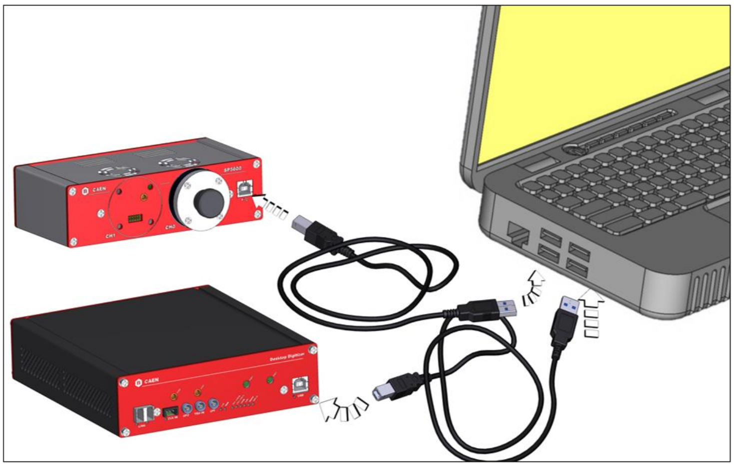
- Required elements: PSAU + Digitizer + Spectrometer + Splitter + Radioactive Source + [Oscilloscope]
- Mechanical instructions:
  - In the educational Gamma kit, there are one mini spectrometer and three scintillating crystals.
  - Before starting any application with radioactive sources, remove the screws and open the spectrometer.



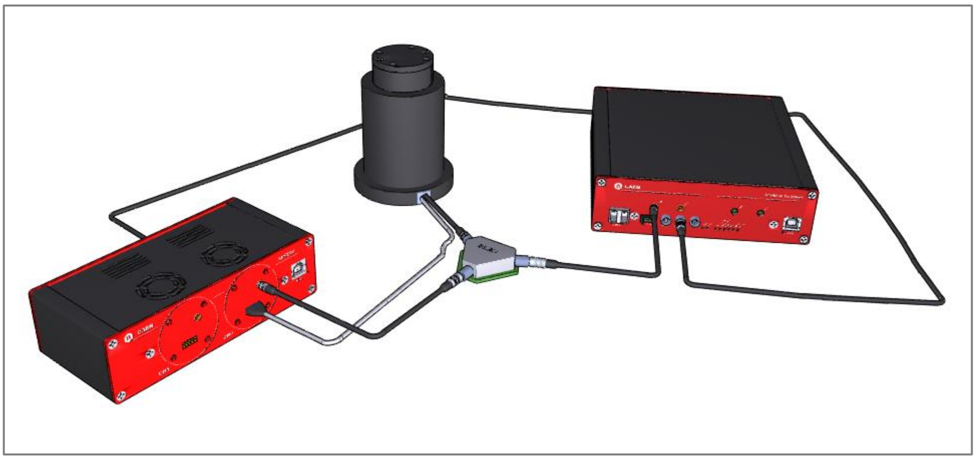
  - Choose the scintillating crystal for the application (It doesn't matter if you use the hands to manage the crystal, but a small pliers could help you).
  - Take care to spread homogeneously optical grease on the open face of the scintillating crystal (the only one not polished).
  - Insert the crystal greased side in the spectrometer, put on top the radioactive source, close it with the screws and start the application.



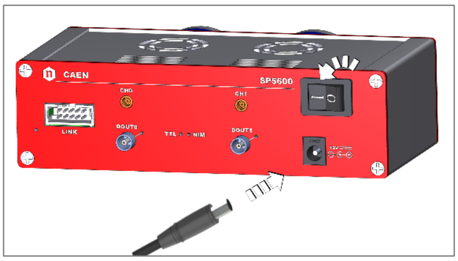
- Cabling instructions:
    - The PSAU and the Digitizer shall be connected to the PC via the USB.



    - The Power Cable of the Spectrometer shall be connected to the PSAU in ch0 position (for example).
    - In order to avoid saturation, the output signal of the spectrometer is divided using the A315 splitter: one branch shall be connected to channel 0 input on the front panel of the digitizer and will be digitized. The other branch will be amplified by the SP5600 module (ch0) and the digital output shall be used as DT5720A "trigger IN" for the integration signal by the on-board leading edge discriminator.



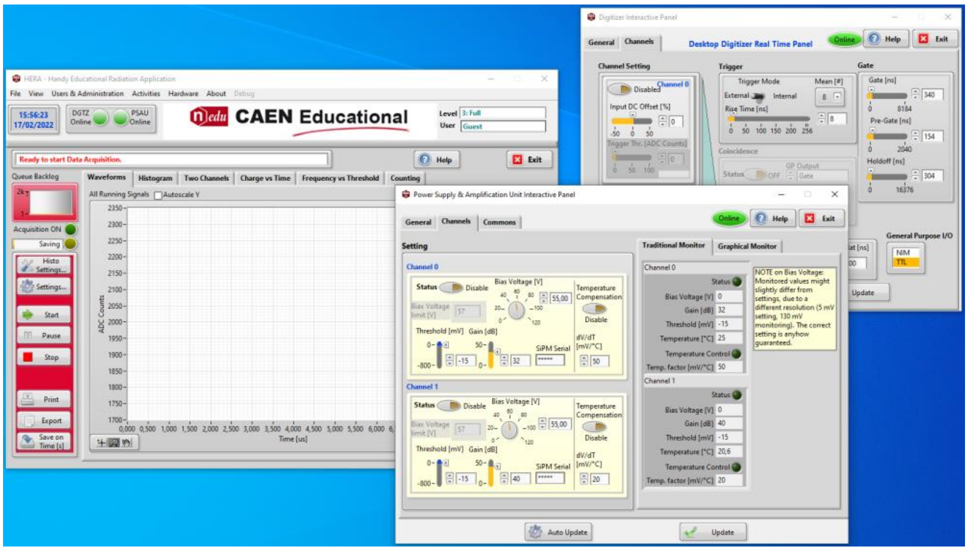
- Getting the system alive:
    - Power on the kit elements



SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

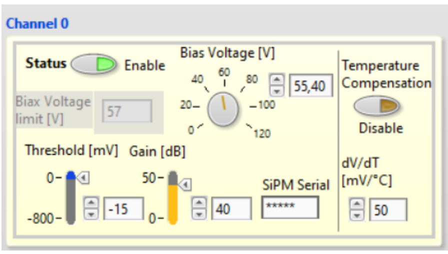
- Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
- Select the Hardware Management access.



- Activate the connected PSAU channel and Digitizer channel.

7.3.3 Correctly bias the SiPM and set the gain

- The first action to take is biasing the SiPM and setting the gain: set the bias according to the detector datasheet (in this example bias = 55.4 V, as before). For the gain, since the SiPM signal in the spectrometer application will be split, a high value can be used (e.g. 40 dB, as before).



- The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once fixed threshold if the radioactive source is properly positioned the spectrum can be recorded.

  In Fig. 7.14 a typical scope trace of the spectrometer with ^{22}Na source.

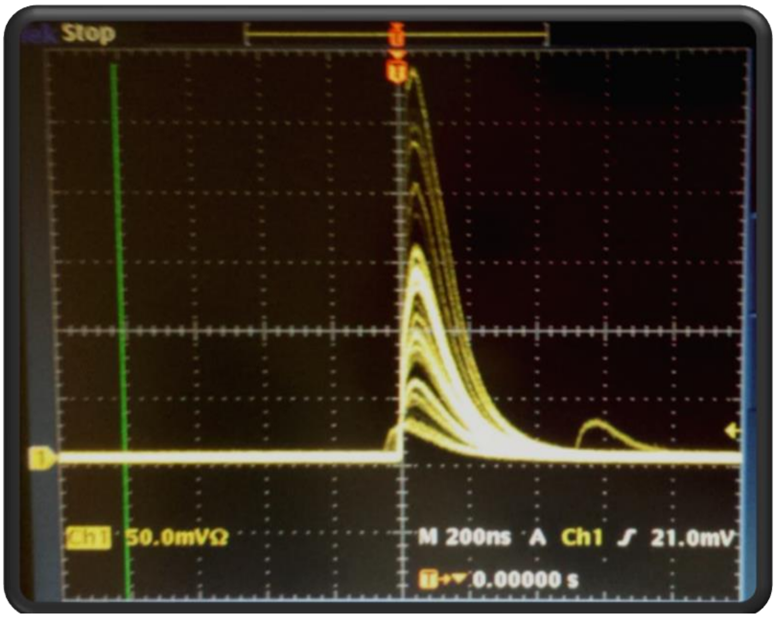


Fig. 7.14: Scope trace of the spectrometer with a ^{22}Na source.

- Software: in the Digitizer Interactive Panel (Fig. 7.15).
- Select EXTERNAL trigger mode.
- Select the active channel (for example channel 0).
- Accept default values for the Gate and Baseline sub-panels.

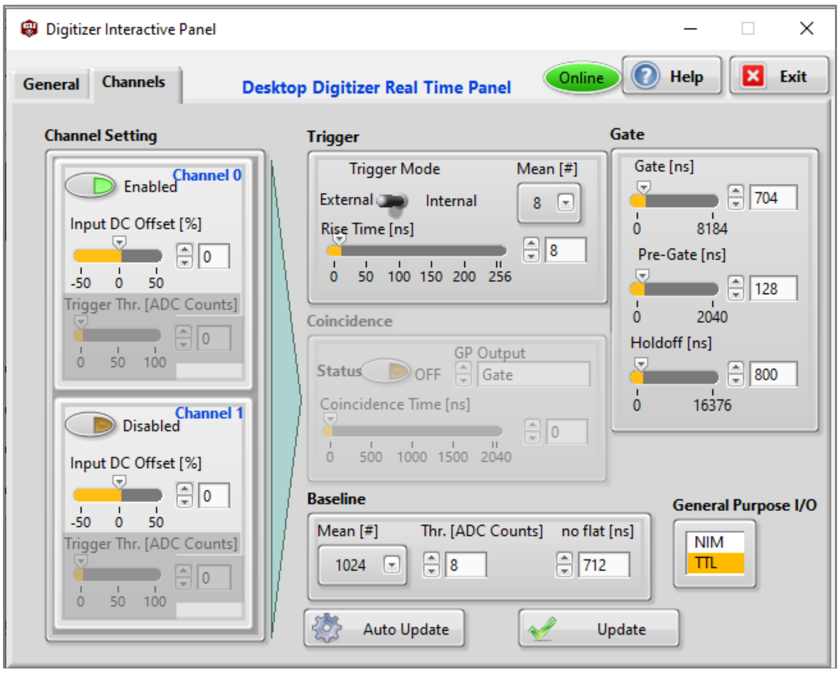


Fig. 7.15: The DIGITIZER control panel.

7.3.4 External and internal trigger

The kit allows the user to trigger the digitizer for the acquisition of a source spectrum in two different ways: internally to the digitizer, selecting an appropriate threshold value (on delta signal) or externally to the digitizer, setting the discriminator threshold in the PSAU, through the PSAU discriminator tab, and using the correspondent NIM/TTL signal produced by the PSAU as a trigger signal for the digitizer itself.

If the digitizer external trigger mode is selected, a threshold value on the PSAU discriminator tab shall be selected, as suggested in this application. With a wrong choice of this value, the PSAU triggers the signal on its noise. Increasing the threshold value, the particle signal shall be clear, becoming similar to the wave of Fig. 7.16.

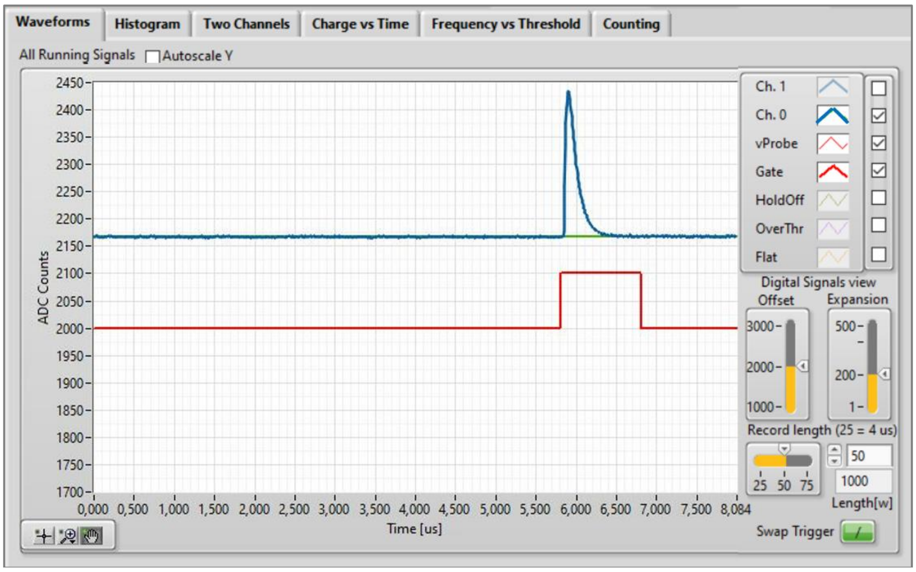


Fig. 7.16: Wave for a right PSAU trigger threshold.

How select the “right” external threshold value?
Running a staircase (in the Frequency vs Threshold tab) from -5 mV to -110 mV, the Dark Count Rate decreases drastically from ~ 0.6 MHz to a value around 1 kHz (as shown in Fig. 7.17). This example is performed with a ^{22}Na source of an activity of 16 kBq, so, in order to remove all the dark count rate due to the nature of the sensor, a threshold bigger than 60 ÷ 70 mV can be selected. In fact, the frequency measured with source remains constant over this threshold value, while the Dark Count Rate drops to zero.

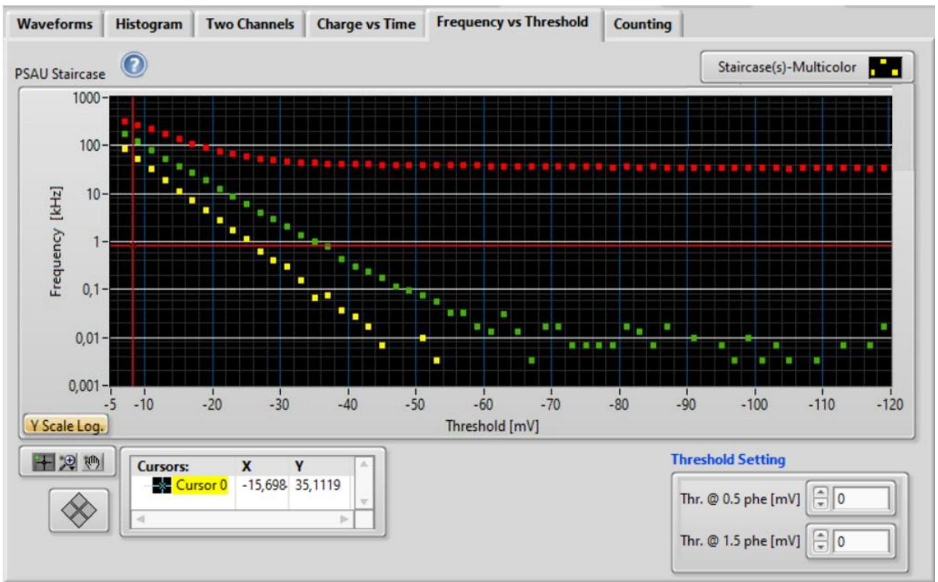


Fig. 7.17: Frequency vs Threshold for SiPM 6x6 mm^2 of spectrometer, in a run without crystal, with crystal and with Crystal and radioactive source.

If digitizer internal trigger mode is selected, set the digitizer trigger parameters and the channel threshold in the Digitizer Interactive Panel: before the calculation of delta (see the "Digital Pulse Processing for SiPM kit" document [RD4]), 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. The Fig. 7.18 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.

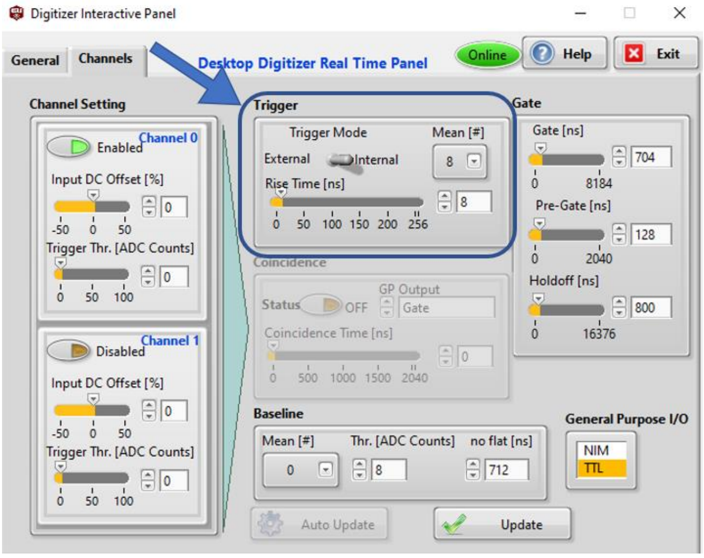


Fig. 7.18: The Trigger digitizer parameters.

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

By now, the system is ready for digitizing the signal but, rather than doing it in a blind way, it is worth taking a guided tour of the system features, going to the Visualization panels of the HERA Main GUI and switching ON the Waveform Tab.

Important Note: Putting 0 as number of samples used to calculate the mean, the baseline restoration is disabled, therefore the histogram doesn't start from zero [ADC channels].

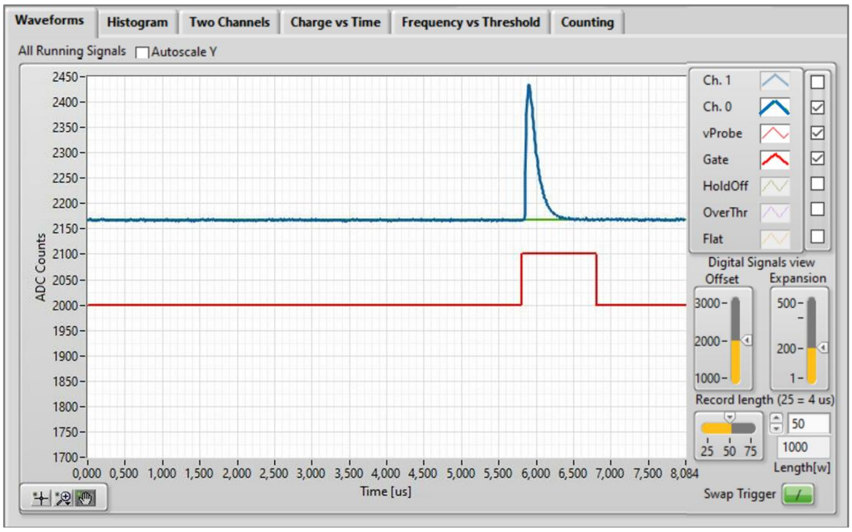


Fig. 7.19: The Waveform tab of the HERA Main GUI.

The Gate actually defines the integration time. For the sake of clarity in the display, every signal can be offset and magnified, enabled or disabled.

Fig. 7.19 is showing the WAVE panel for the SiPM coupled to LYSO crystal and ^{22}Na source, for optimal tuning of the pre-gate and the gate width, depending on the time development of the signal. The signal time development is dominated not only by the sensor response, but also by the decay time of the scintillating crystal. Moreover, the waveform is positive because the digitized signal comes directly from the spectrometer (after splitting). This configuration allows to avoid saturation effects and overshoot due to AC coupling of the SP5600.

As long as the Gate is properly defined, the system is ready to record the spectrum, displayed in the Histogram tab. As exemplary illustration**,** Fig. 7.20 shows a spectrum of ^{22}Na. It was obtained with the mini-spectrometer with the Hamamatsu S13360- 6050CS SiPM coupled with a 6 x 6 x 15 mm^2 LYSO crystal.

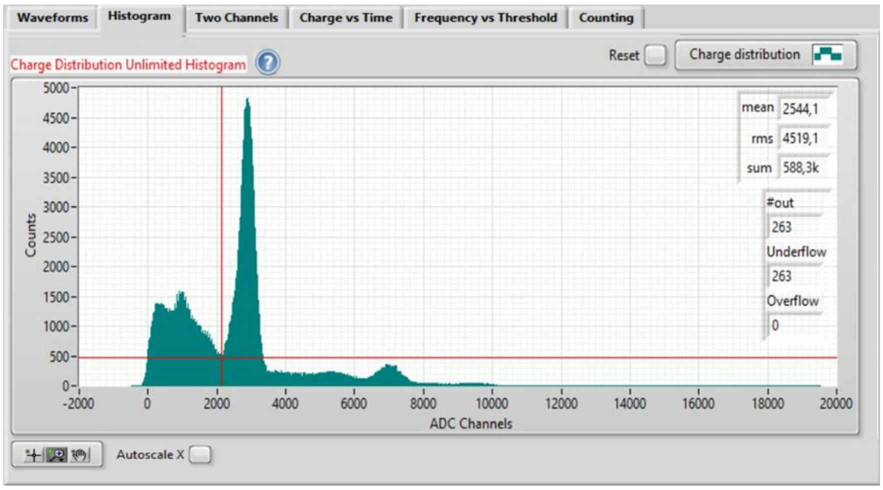


Fig. 7.20:^{22}Na spectrum.

The threshold is fixed in order to cut the system noise peak, so the spectrum shows the following peaks:

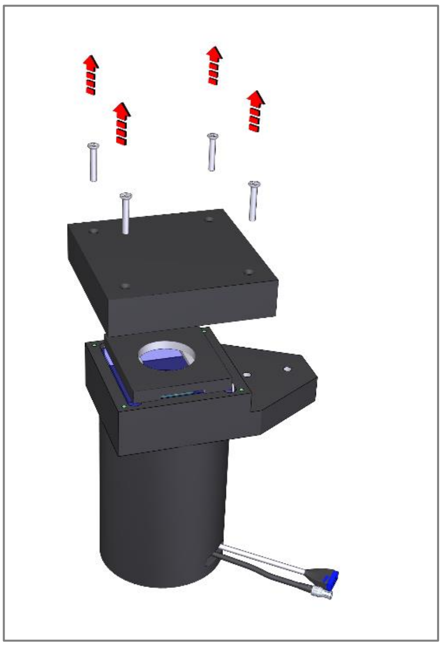
- The backscatter at the low energy and the Compton distribution for the first peak;
- First γ peak @ 511KeV: Electron-positron annihilation;
- Compton distribution for the second peak;
- Second γ peak @ 1275KeV: Nuclear Energy Transition.

The energy resolution of the peaks represents the spectroscopic capability of the detector at different energy values.

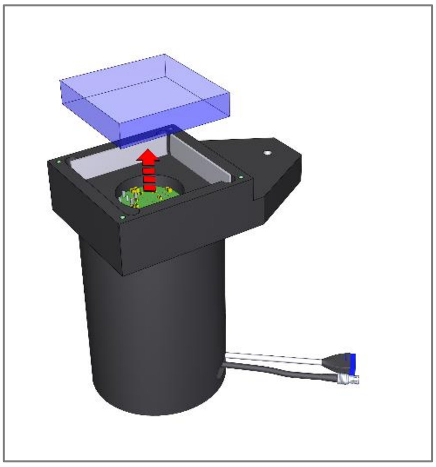
7.4 Can you see a β particle?

7.4.1 First Kit Configuration

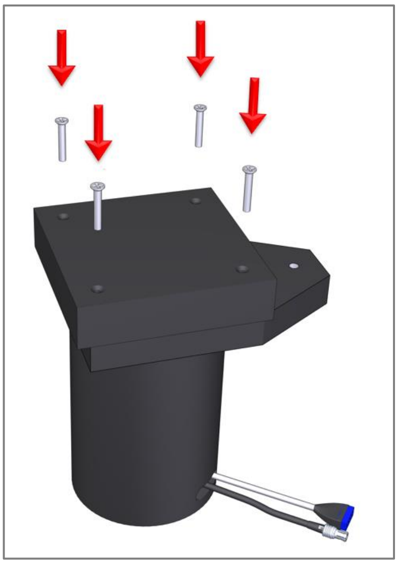
- Required elements: PSAU + Digitizer + SP5608 + [Oscilloscope].
- Mechanical instructions:
  - Before starting any application with beta radioactive sources or cosmic rays, remove the screws and open the SP5608.



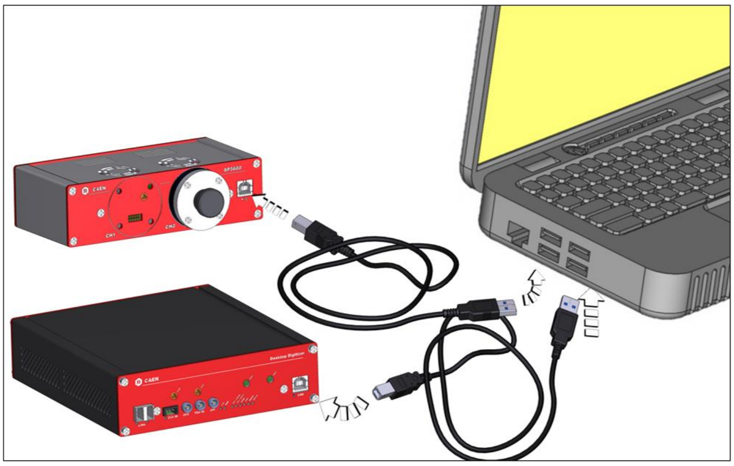
  - Use a flat-blade screwdriver or small lever to remove the scintillating tile from the SP5608.



  - Close the SP5608 with the screws and start the application.



- Cabling instructions:
  - The PSAU and the Digitizer shall be connected to the PC via the USB.

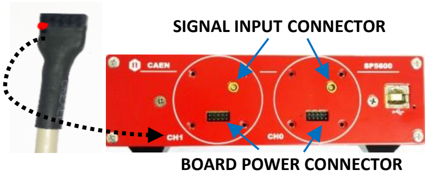


  - Output Signal of the SP5608, means the black cable, shall be connected to the PSAU channel (for example channel 1). Connect the SP5608 power cable to the same PSAU channel.

  - The Digital Output of the Used PSAU channel shall be connected to the TRG IN on the front panel of the Digitizer.

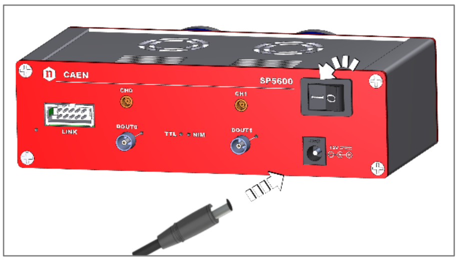
- The Output signal from the PSAU has to be connected to the input of the Digitizer. (To avoid mistakes, use the same number channel of the SP5600 module.)

Important Note: How can you connect the power cable of the SP5608 to SP5600?



To connect the board power cable to the SP5600 channel, put the marked cable side close to channel label on the PSAU front panel.

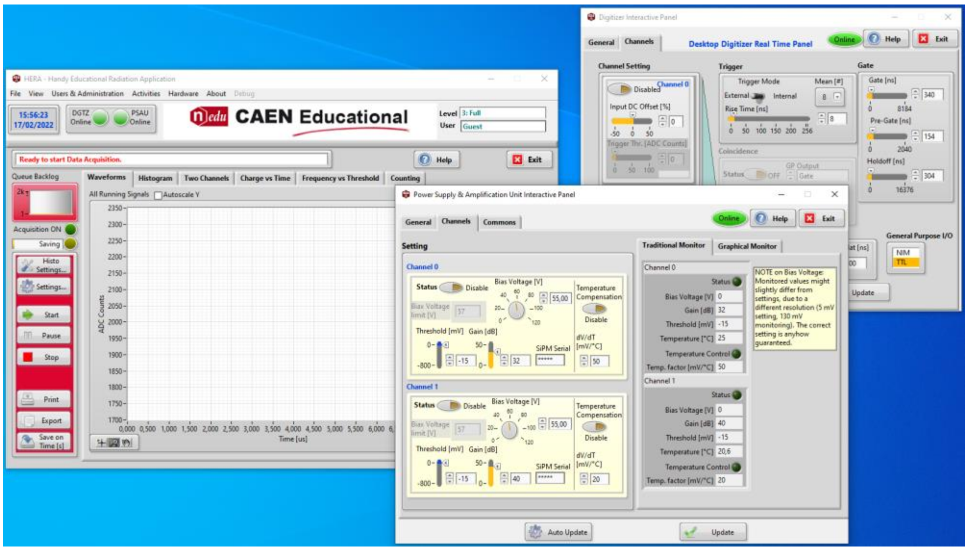
- Getting the system alive:
  - The PSAU and the Digitizer shall be powered on



SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

  - Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
  - Select the Hardware Management access.



- Activate the connected PSAU channel and Digitizer channel.

Once the system is running, the first action to take is properly biasing the detector and setting the gain to the PSAU amplifier.

As far as the optimal sensor bias, it is suggested to stick to the value reported on the sensor ID card (in this example V_{bias} = 55.4V), which may be set in the Bias & Gain tab of the PSAU panel (Fig. 7.21).

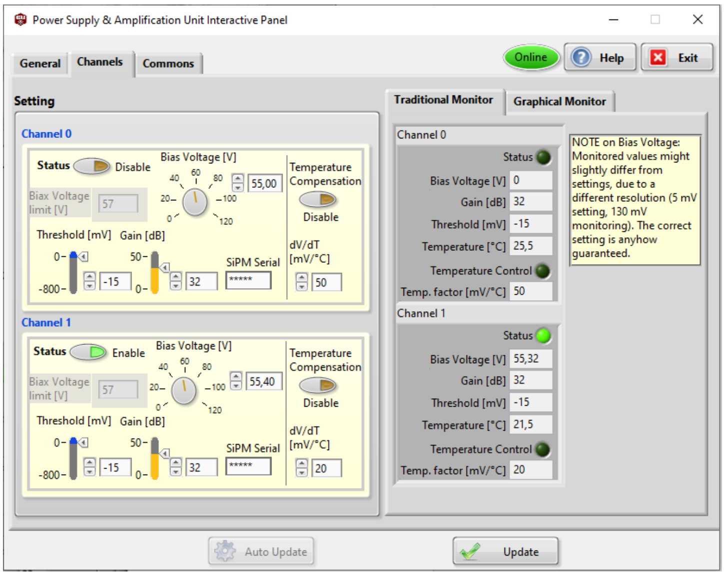


Fig. 7.21: Power Supply and Amplification Unit Interactive panel.

At the same time, the amplification factor can be set at high values. In this example, it is 32 dB.

Moreover, for the sake of clarity, the feedback system for the SiPM gain stabilization against temperature variations can be disabled.

Putting on the oscilloscope the SP5608 signal output before (Fig. 7.22), it's possible to distinguish the different traces corresponding to avalanches in the cells triggered by the thermal generation of the charge carriers or by the photons associated to the avalanche development (optical crosstalk).

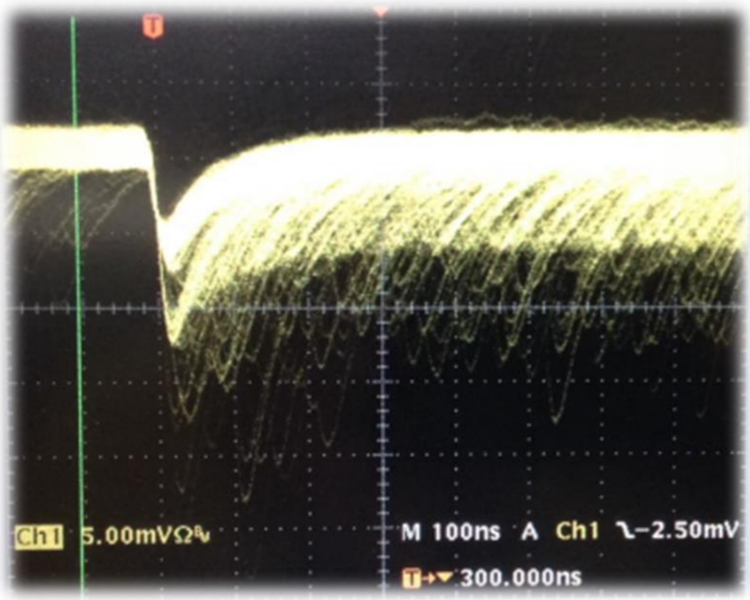


Fig. 7.22: Scope trace of the sensor.

The intensity of the light measured by the detecting system (SIPM + scintillating tile) is proportional to the source activity. However, this information is affected and biased by stochastic effects characteristic of the sensor and occurring within the time window: spurious avalanches due to thermally generated carriers (a.k.a. Dark Count Rate (DCR)).

Before to acquire a β source spectrum or a cosmic rays spectrum, take care to measure this entry-level parameter of the SiPM. It is a standard procedure to quantify the DCR as the counting frequency with a threshold corresponding to 0.5 x single photoelectron (p.e.) peak ($DCR_{0.5}$). The DCR of the system is about 2÷6 MHz.

In order to avoid the system be blind to the radioactive source or cosmics, due to this high DCR, a proper cut-off threshold has to be selected. The DCR vs discriminator threshold can be precisely measured by using the "Frequency vs Threshold" tab in the HERA Software.

The Fig. 7.23 shows the DCR staircase: once the SiPM is biased, and a convenient gain is chosen, through the "Frequency vs Threshold" tab of the Main GUI, the threshold scan of the signals frequency can be performed.

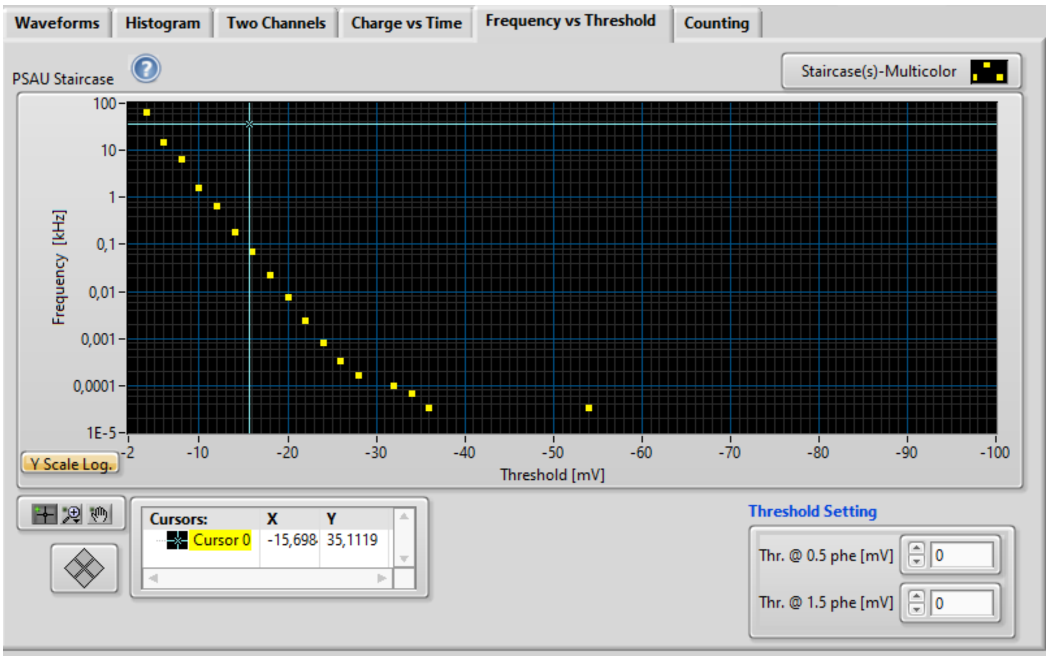
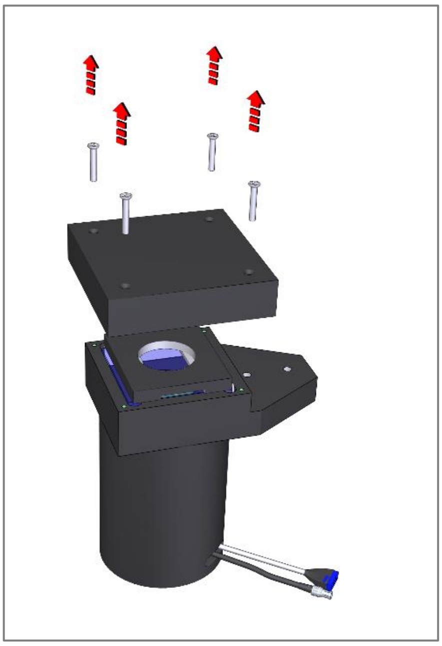


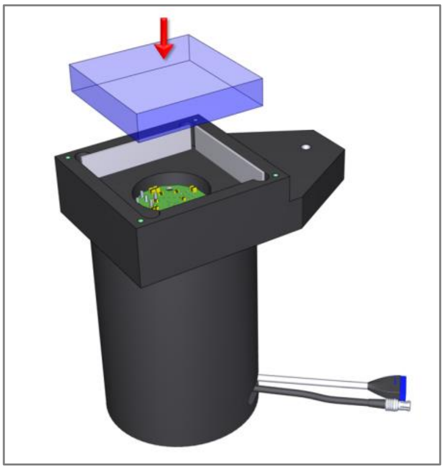
Fig. 7.23: Dark Counts Rate frequency versus Discriminator threshold.

7.4.2 Second Kit Configuration

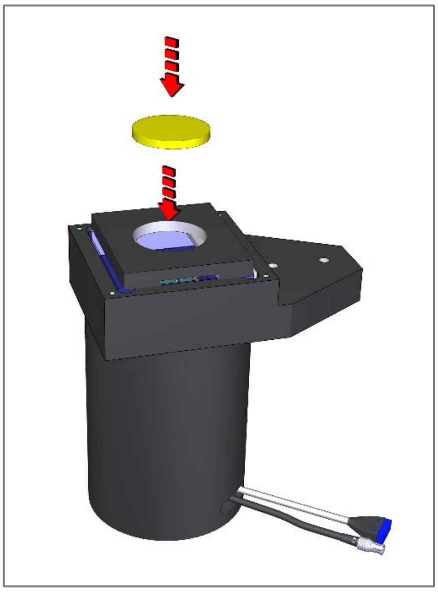
- Required elements: PSAU + Digitizer + SP5608
- Mechanical instructions:
  - Before starting applications related beta and cosmics acquisition, remove the screws and open the SP5608.



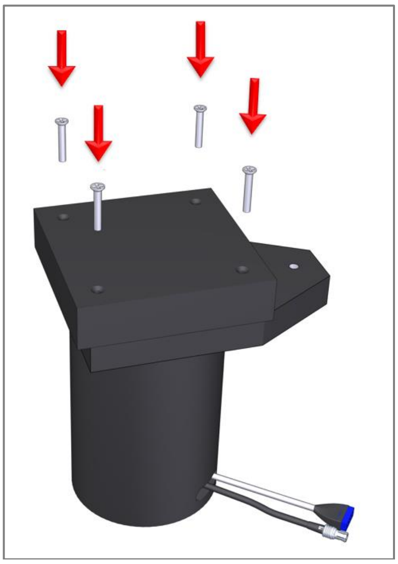
  - Take care to spread homogeneously optical grease on the sensor.
  - Insert the Scintillating tile inside the SP5608 suitable housing up to reach the perfect match with the sensor.



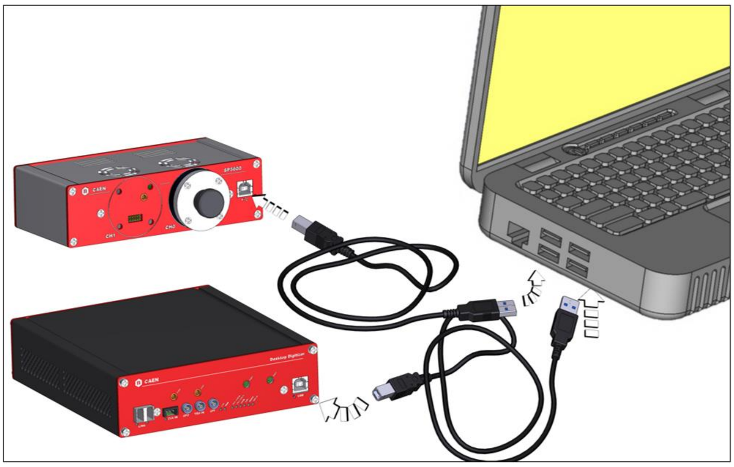
  - Put on Tile top the source holder and the radioactive source as well.



- Close the SP5608 with the screws and start the application.



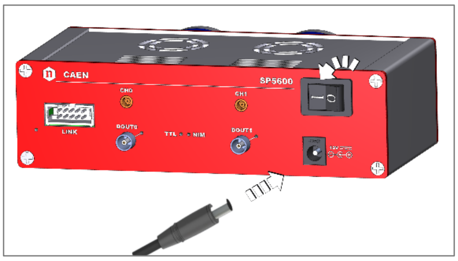
- Cabling instructions:
  - The PSAU and the Digitizer shall be connected to the PC via the USB.



- Output Signal of the SP5608, means the black cable, shall be connected to the PSAU channel (for example channel 1). Connect the SP5608 power cable to the same PSAU channel.

- The Digital Output of the Used PSAU channel shall be connected to the TRG IN on the front panel of the Digitizer.
- The Output signal from the PSAU has to be connected to the input of the Digitizer. (To avoid mistakes, use the same number channel of the SP5600 module.)

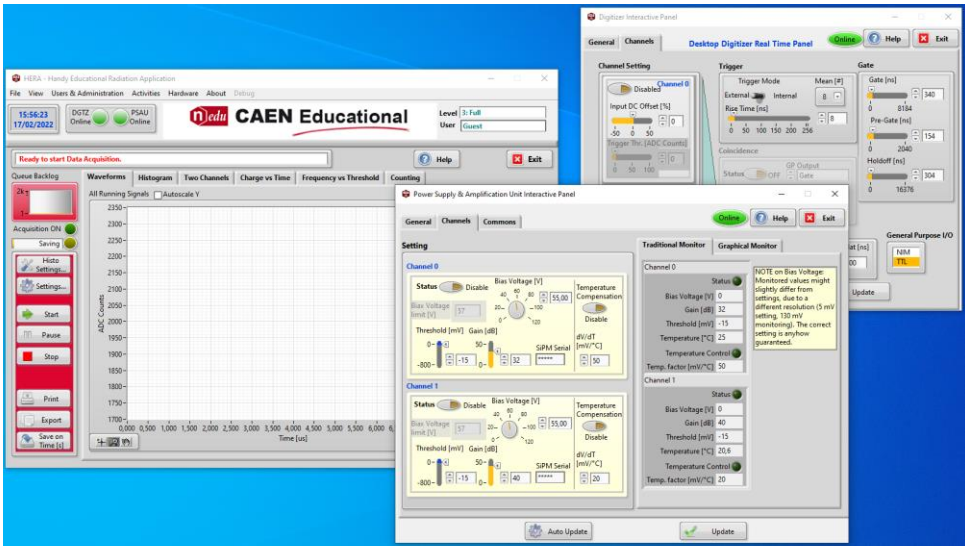
* Getting the system alive:
  - The PSAU and the Digitizer shall be powered on



SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

- Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
- Select the Hardware Management access.



- Activate the connected PSAU channel and Digitizer channel.
- Bias the two SiPM and set an amplification factor as in the previous case.

The frequency scanning in discriminator threshold allows to observe the beta source contribution. It can be precisely measured by using the “Frequency vs Threshold” tab in the HERA Software.

The Fig. 7.24 shows the beta radioactive source staircase: once the SiPM is biased, and a convenient gain is chosen (same parameters as in DCR measurement), through the “Frequency vs Threshold” tab, the threshold scan of the signals frequency can be performed.

Through the two staircases, DCR and β source, it is possible to chooce the right cut-off threshold to acquire the spectrum. Running a staircase (Freq. vs Thr tab) from -5mV to -100 mV, the Dark Count Rate decreases drastically from ~0.1 MHz to a value below Hz level (as shown in Fig. 7.23**)**. This example is performed with a ^{90}Sr source of an activity of 3 kBq, so, in order to remove all the dark count rate due to the nature of the sensor, a threshold bigger than 50 ÷ 60 mV can be selected. In fact, the frequency measured with source remains constant over this threshold value, while the Dark Count Rate drops to zero.

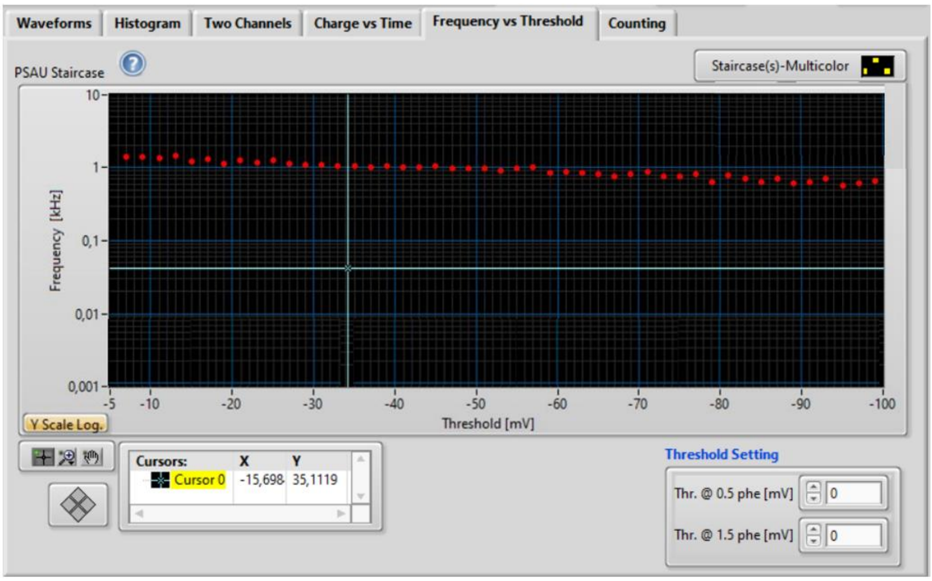
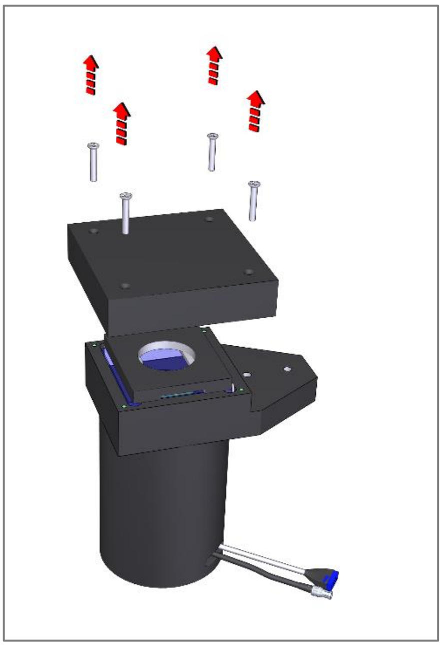


Fig. 7.24: Counting frequency versus Discriminator threshold with a ^{90}Sr source.

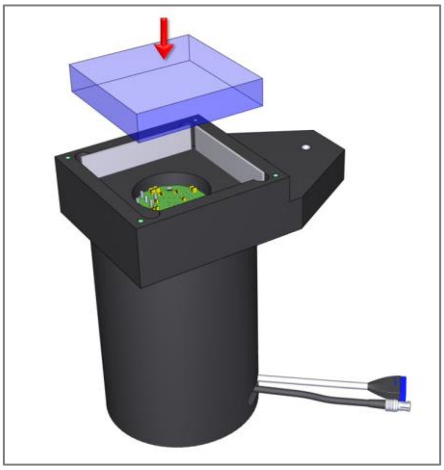
7.5 Can you see Cosmic rays?

7.5.1 Kit Configuration

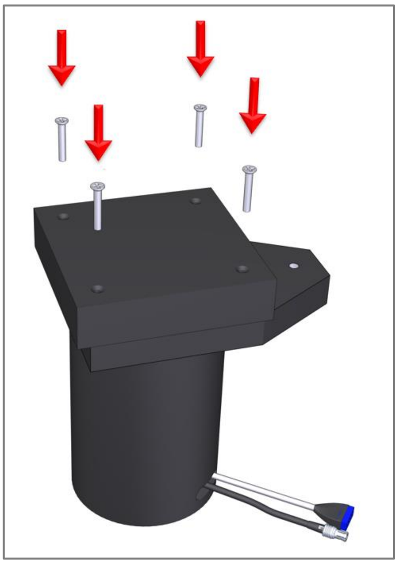
- Required elements: PSAU + Digitizer + SP5608
- Mechanical instructions:
  - Before starting applications related beta and cosmics acquisition, remove the screws and open the SP5608.



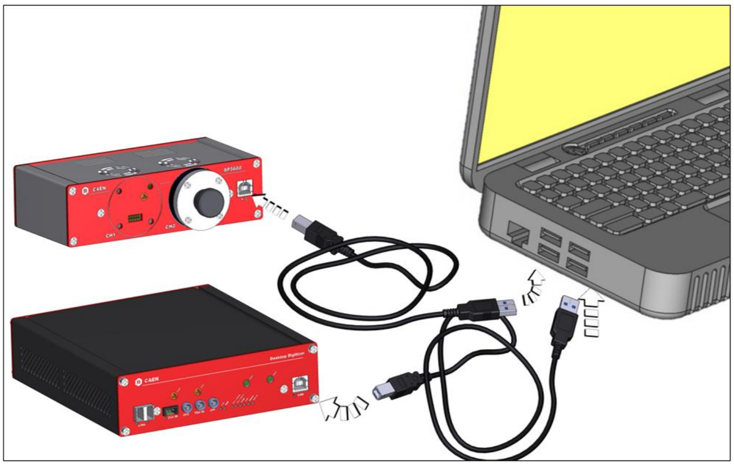
  - Take care to spread homogeneously optical grease on the sensor.
  - Insert the Scintillating tile inside the SP5608 suitable housing up to reach the perfect match with the sensor.



  - Close the SP5608 with the screws and start the application.



- Cabling instructions:
    - The PSAU and the Digitizer shall be connected to the PC via the USB.

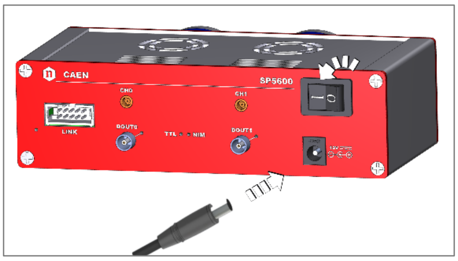


    - Output Signal of the SP5608, means the black cable, shall be connected to the PSAU channel (for example channel 1). Connect the SP5608 power cable to the same PSAU channel.

    - The Digital Output of the Used PSAU channel shall be connected to the TRG IN on the front panel of the Digitizer.

- The Output signal from the PSAU has to be connected to the input of the Digitizer. (To avoid mistakes, use the same number channel of the SP5600 module.)

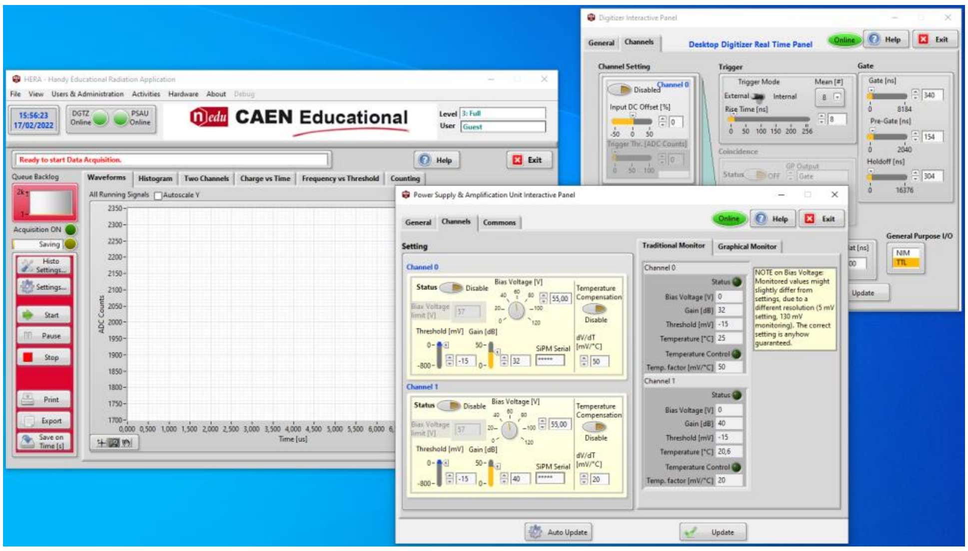
- Getting the system alive:
  - The PSAU and the Digitizer shall be powered on



SP5600 – Power Supply and Amplification Unit

DT5720A – Desktop Digitizer

  - Run the program by clicking the HERA icon and wait for the hardware connection. The software recognises the hardware automatically and starts the connection. Keep attention to the two connection indicators status.
  - Select the Hardware Management access.



- Activate the connected PSAU channel and Digitizer channel.
- Bias the two SiPM and set an amplification factor as in the previous case.

As in the previous measurement, the frequency scanning in discriminator threshold allows also to observe the cosmics contribution. It can be precisely performed by using the “Frequency vs Threshold” tab in the HERA Main GUI.

The Fig. 7.25 shows the cosmic rays staircase: once the SiPM is biased, and a convenient gain is chosen, through the “Frequency vs Threshold” tab in the Main GUI, the threshold scan of the signals frequency can be performed.

Through the two staircases, DCR and cosmic rays staircases, it is possible to choice the right cut-off threshold to acquire the spectrum of cosmic rays. The discriminator threshold shall be indeed defined looking at the spectrum and evaluating the dark count rate. Once fixed threshold, the spectrum can be recorded.

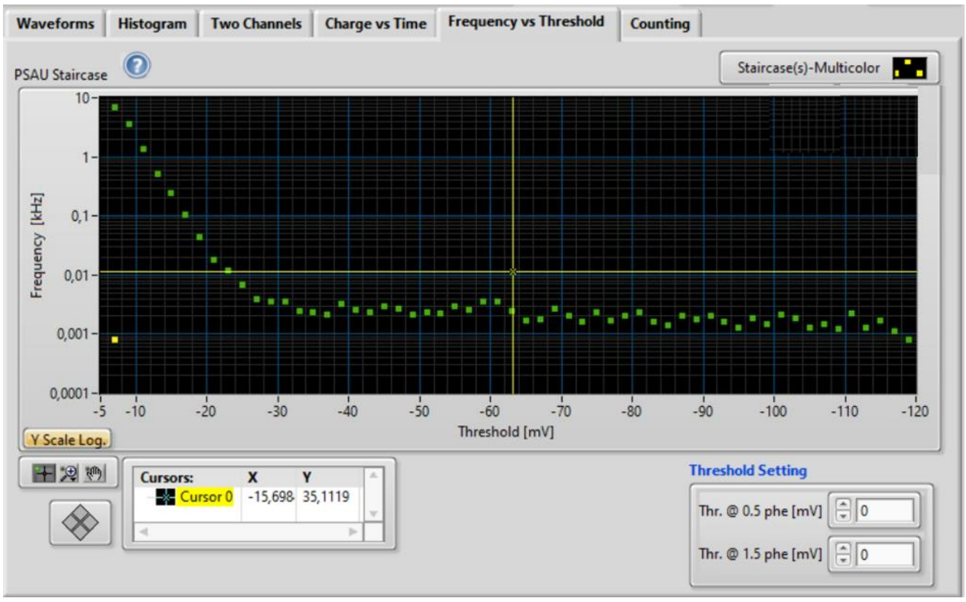


Fig. 7.25: Counting frequency of Cosmic rays versus Discriminator threshold.

7.5.2 To acquire the Spectrum

The kit allows the user to trigger the digitizer for the acquisition of a spectrum in two different ways: internally to the digitizer, selecting an appropriate threshold value (on delta signal) or externally to the digitizer. In this example the external trigger mode is suggested in order to acquire the spectrum. Please don’t forget the connection of the LEMO cable between the digital output of the PSAU and the trigger input of the digitizer.

By now, the system is ready for digitizing the signal but, rather than doing it in a blind way, remember to tune the gate and baseline parameters in the Digitizer Interactive Panel (Fig. 7.26), according to the signal waveform displayed in the Waveform tab.

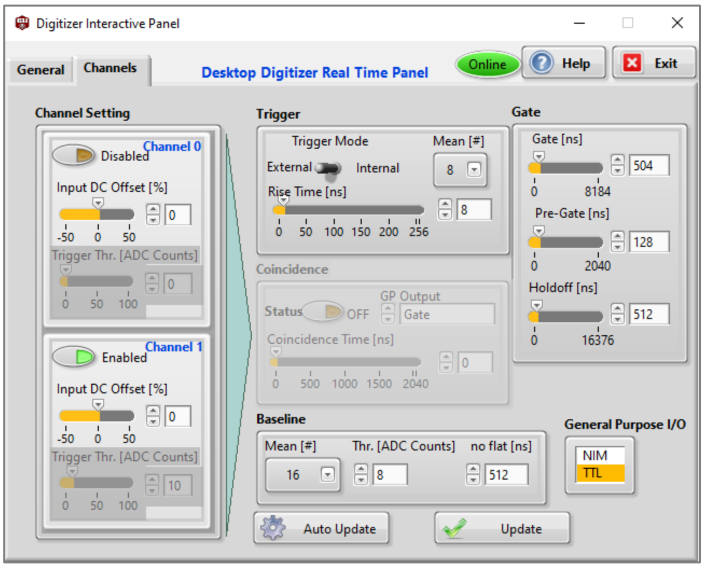


Fig. 7.26: The DIGITIZER Interactive panel.

For the sake of clarity in the display, every signal can be offset and magnified, enabled or disabled.

Fig. 7.27 is showing the Waveform tab for the SiPM coupled to a scintillating tile, for optimal tuning of the baseline and notably of the pre-gate and the gate width, depending on the time development of the signal. The signal time development is dominated not only by the sensor response, but also by the decay time of the scintillating crystal.

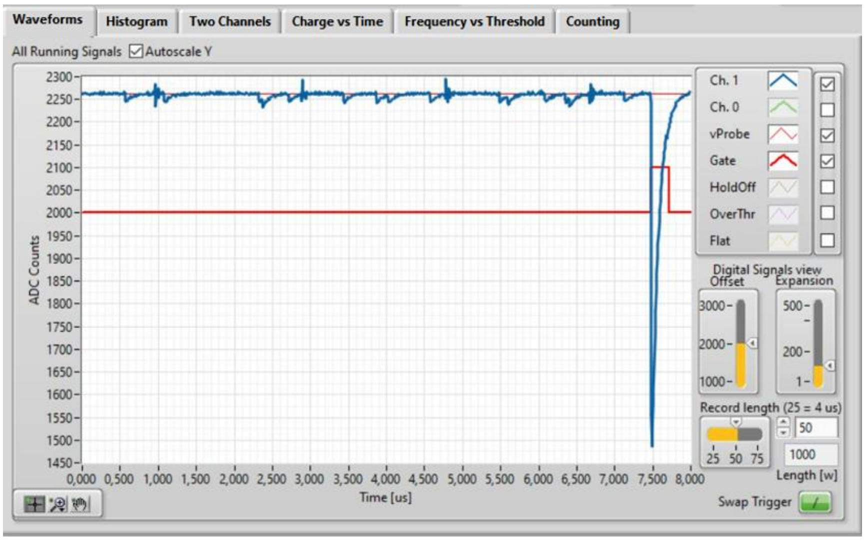


Fig. 7.27: The Waveform tab of the HERA Main GUI.

As long as the gate is properly defined, the system is ready to record the spectrum, displayed in the Histogram tab. The cosmic rays spectrum, during the acquisition phase, is shown in Fig. 7.28, while the beta source spectrum is shown in Fig. 7.29.

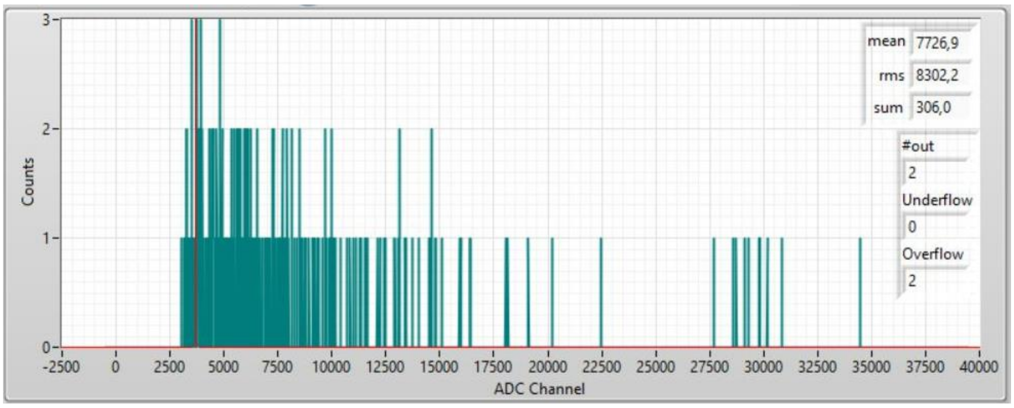


Fig. 7.28: Cosmics spectrum.

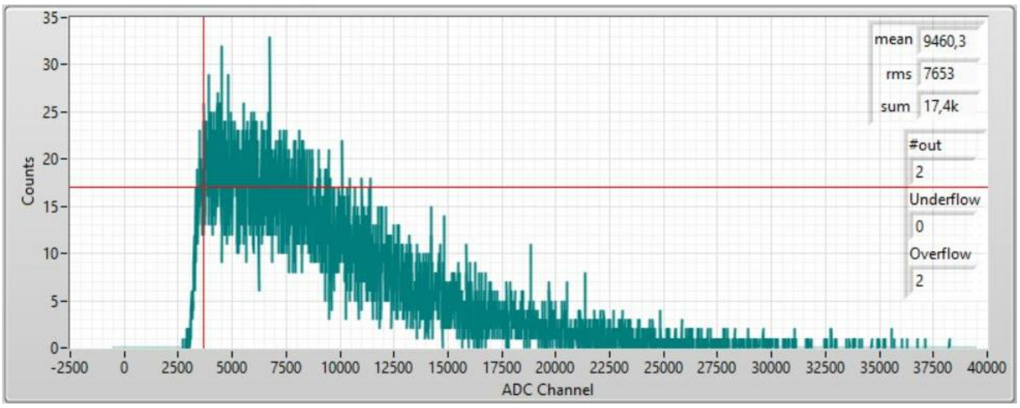


Fig. 7.29: ^{90}Sr source spectrum.

A nice exercise is to apply a Teflon tape coating to the plastic scintillating tile (Fig. 7.30) to reduce the light loss and upgrade the spectrum acquisition (Fig. 7.31).

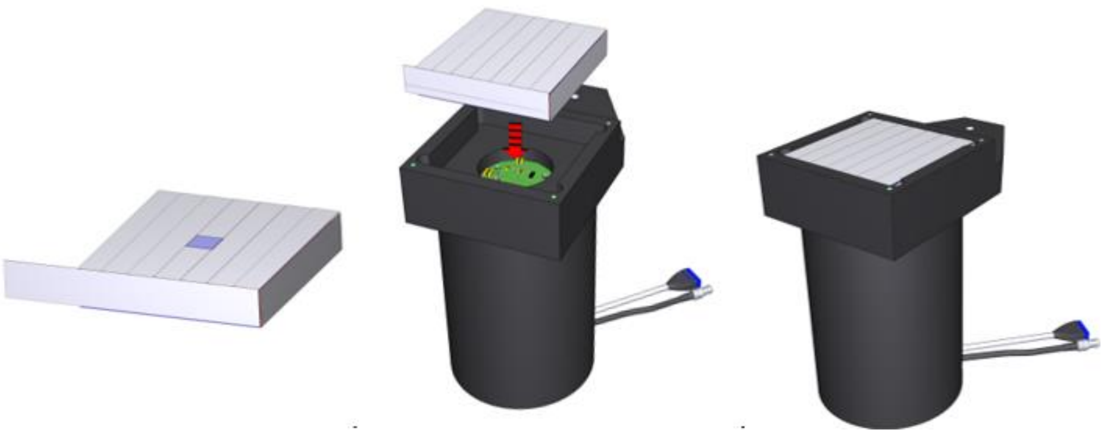


Fig. 7.30: Teflon coating of the plastic scintillating tile.

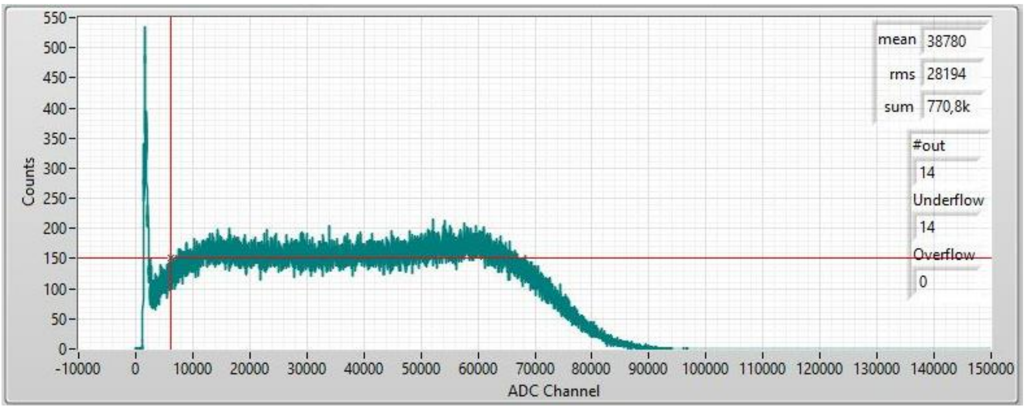


Fig. 7.31: Beta spectrum acquired through a plastic scintillating tile coated with Teflon tape.

8 Educational Experiments

The Educational kit – Premium Version allows to perform experiments in different Physics fields.
What is being proposed has to do with light quanta, radioactive decays (β and γ rays) and cosmic rays. The experiments address the essence of the phenomenon as well as exemplary illustrations of their use in medical imaging and industry, complemented by basic and advanced statistical exercises.
Exploring the quantum nature of phenomena is one of the most exiting experiences a physics student can live, together with the detection of Cosmic rays, energetic and subatomic particles constantly bombard the Earth's atmosphere from all directions.
Radioactivity is around us and getting to know it experimentally is essential for physics students.
When an unstable nucleus decays in a cascade leading to a stable nuclide, it emits α or β or γ quanta or a combination of them. The spectroscopy of the emitted γ or β rays is instrumental for understanding the mechanism of the interaction with matter, the fundamentals about detection and the underlying nuclear physics. Moreover, it is relevant in basic and applied fields of science and technology, from nuclear to medical physics, from archaeometry to homeland security.
Beta spectroscopy, furthermore, introduces the student into the field of special relativity and weak interactions of radioactive decays.
This section represents an overview of the experiments proposed by CAEN using the Educational kit of your choice. Each experiment has its own identification code (reference ID). For each ID, a step by step guide that includes a detailed description to perform the data analysis of the physical process is available on the CAEN Educational web page. The experiments address the essence of the phenomenon as well as exemplary illustrations of their use in medical imaging and industry, complemented by basic and advanced statistical exercises.
The experiments proposed by CAEN in Modern Physics field are listed in Tab. 8.1.

Section	Subsection	Reference ID	Experiment
Particle Detector Characterization	**Silicon Photomultiplier (SiPM)**	6011A	SiPM Characterization
		6012A	Dependence of the SiPM Properties on the Bias Voltage
		6013A	Temperature Effects on SiPM Properties
Nuclear Physics and Radioactivity	**Gamma Spectroscopy**	6111A	Detecting γ-Radiation
		6112A	Poisson and Gaussian Distributions
		6113A	γ Spectrum and Energy Resolution
		6114A	System Calibration: Linearity and Resolution
		6115A	Scintillator Crystals Comparison: Light Yield and Decay Time
		6116A	γ-Radiation Absorption
		6117A	Photonuclear cross-section/Compton Scattering cross-section
		6118A	Study of the ^{137}Cs spectrum: the backscatter peak and X rays
	Beta Spectroscopy	6121A	Response of a Plastic Scintillating Tile
		6122A	β Spectroscopy
		6123A	β-Radiation: Transmission through Matter
		6124A	β-Radiation as a Method to Measure Paper Sheet Grammage and Thin Layer Thickness
		6125A	Coating effect on the Light Collection
Particle Physics	**Cosmic Rays**	6210A	Statistics
		6211A	Muons Detection
		6212A	Muons Vertical Flux on Horizontal Detector
		6216A	Zenith Dependence of Muons Flux
	Photons	6221A	Quantum Nature of Light
		6222A	Hands-on Photon Counting Statistics

Tab. 8.1: Physics Experiments performed via the Educational Kit – Premium version.

8.1 SiPM Characterization (SG6011A)

Purpose of the experiment:

Characterization of a SiPM detector using an ultra-fast pulsed LED. Estimation of the main features of the detector at fixed bias voltage.

Fundamentals:

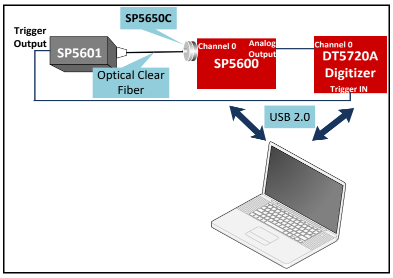
Silicon Photomultipliers (SiPM) consist of a high-density (up to ~10^4/mm^2) matrix of diodes connected in parallel on a common Si substrate. Each diode is an Avalanche Photo Diode (APD) operated in a limited Geiger-Müller regime connected in series with a quenching resistor, in order to achieve gain at level of ~10^6. As a consequence, these detectors are sensitive to single photons (even at room temperature) feature a dynamic range well above 100 photons/burst and have a high Photon Detection Efficiency (PDE) up to 50%. SiPM measure the light intensity simply by the number of fired cells. However, this information is affected and biased by stochastic effects characteristic of the sensor and occurring within the time window: spurious avalanches due to thermally generated carriers (a.k.a. Dark Counts), delayed avalanches associated to the release of carriers trapped in metastable states (a.k.a. Afterpulses) and an excess of fired cells due to photons produced in the primary avalanche, travelling in Silicon and triggering neighbouring cells (a phenomenon called Optical Cross Talk). The typical SiPM response to a light pulse is characterized by multiple traces, each one corresponds to different numbers of fired cells, proportional to the number of impinging photons. Because of the high gain compared to the noise level, the traces are well separated, providing a photon number resolved detection of the light field.

Requirements:

No other tools are needed.

Carrying out the experiment:

The light pulse from the SP5601 ultra-fast LED-Driver is driven through an optical clear fiber into the SP5650C SiPM holder housing the sensor under test and connected to the SP5600. The output signal (from the SP5600) is connected to the input channel of the DT5720A Desktop Digitizer equipped with the charge integration firmware and triggered by the SP5601 LED-driver. The SP5600 and the DT5720A are connected to the PC through the USB. Use the default software values or optimize the bias voltage and discriminator threshold. The horizontal axis of the acquired spectrum is the ADC channels, therefore ADC channel conversion ($ADC_{c.r.}$) factor can be calculated to perform the experiment and determine the main features of the SiPM.



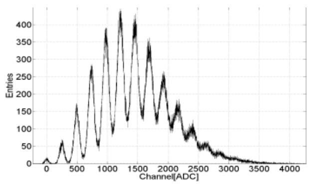
Experimental setup block diagram.

Results:

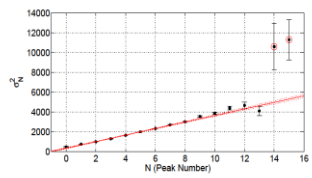
The gain of the SiPM is evaluated from the output charge of the sensor. After the estimation of the ADC channel conversion factor ($ADC_{c.r.}$) and the distance between adjacent peaks (ΔPP(ADC_ch)), the SiPM gain can be calculated according to the following equation:

$$Gain = \frac{\Delta PP(ADC\_ch) * ADCc.r.}{e}$$

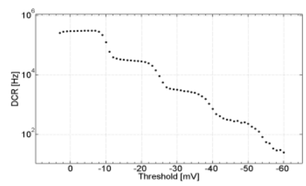
The resolution power of the system can be evaluated plotting the σ of each peaks versus the number of peaks. The counts frequency, in absence of light, at 0.5 p.e. threshold represents the DCR. The ratio between the dark count at 1.5 p.e. threshold ($DCR_{1.5}$) and the value at 0.5 p.e. threshold ($DCR_{0.5}$) give the crosstalk estimation of the detector.



Spectrum of Hamamatsu S10362-11-100C.



Peak σ versus peak number for Hamamatsu S10362-11-100C.



Sensor Dark Count frequency versus discrimination threshold.

8.2 Dependence of the SiPM Properties on the Bias Voltage (SG6012A)

Purpose of the experiment:

Study the dependence of the main SiPM figures of merit on the bias voltage. Measurement of the breakdown voltage and identification of the optimal working point. The experiment requires the use of the LED source included in the kit.

Fundamentals:

The main features of the SiPM are expected to depend on the bias voltage or, more specifically, on the overvoltage, the voltage in excess of the breakdown value:

- The gain is expected to depend linearly on the overvoltage
- The triggering efficiency, i.e. the probability for a charge carrier to generate an avalanche by impact ionization, increases with the overvoltage till a saturation value is achieved. As a consequence, the Photon Detection Efficiency (PDE) increases together with the stochastic events (Dark Count Rate, Cross Talk and After Pulses) affecting the sensor response.

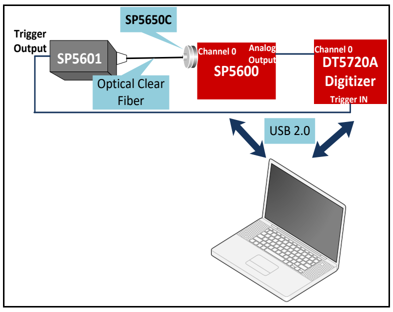
Actually, spurious events are expected to grow super-linearly and the determination of the optimal working point requires the definition of a proper figure of merit. Referring to the photon number resolving capability of the SiPM, the bias can be set to optimize the resolution power, i.e. the maximum number of resolved photons.

Requirements:

No other tools are needed.

Carrying out the experiment:

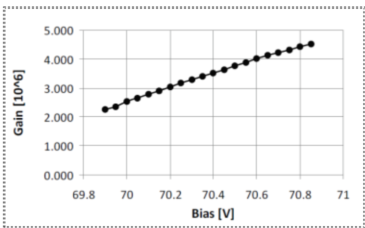
Mount one of the sensors (SP5650C) on the SP5600 and connect the analog output to the input of the DT5720A digitizer. Optically couple the LED and the sensor via the optical fiber, after having used the index matching grease on the tips. Set the internal trigger mode on the SP5601 and connect its trigger output on the DT5720A trigger IN. Connect via USB the modules to the PC and power ON the devices. Through the HERA graphical user interface (GUI), properly synchronize the signal integration and, for every voltage value, record the photon spectrum and measure directly the Dark Count and the Optical Cross talk. The measurement of the After Pulse is also possible but it requires most advanced analysis techniques.



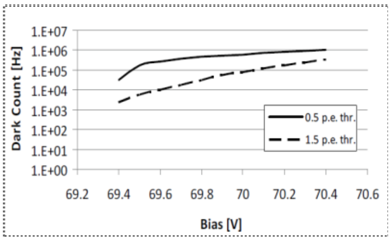
Experimental setup block diagram.

Results:

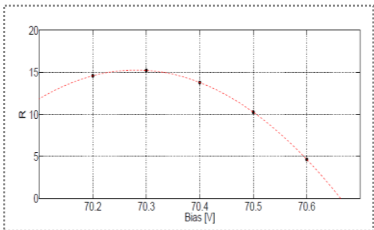
As exemplary illustration, the trend of the gain vs. the bias voltage is shown, allowing as well the measurement of the breakdown voltage corresponding to the value at zero gain. The optimal working point by a measurement of the resolution power on the multi-photon peak spectrum is also shown.



SiPM gain versus bias voltage.



Dark count versus bias voltage.



Scan of the resolution power R as a function of the bias voltage.

8.3 Temperature Effects on SiPM Properties (SG6013A)

Purpose of the experiment:

Gain, noise and photon detection efficiency (at fixed bias voltage) are affected by temperature. The student is driven through the measurement of the dependence of these critical figures.

Fundamentals:

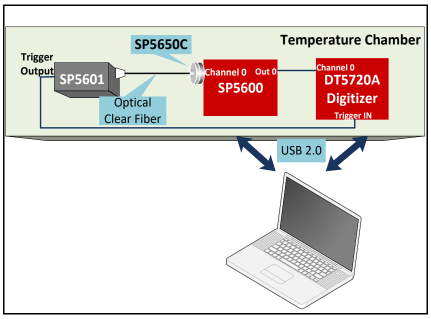
The gain in a SiPM biased at fixed voltage changes with temperature since the breakdown voltage V_{br} does it. Gain stabilization is a must and can be pursued tracking the V_{br} changes and adjusting the bias voltage accordingly. The rate of variation depends on the sensor, through the material properties. Noise depends on the thermal generation of charge carriers, so a significant dependence is expected as well.

Requirements:

A temperature-controlled box/room is essential.

Carrying out the experiment:

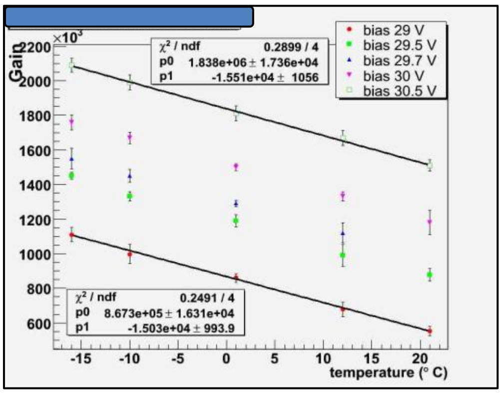
In a temperature-controlled box, mount one of the sensors (SP5650C) on the SP5600 and connect the analog output to the input of the DT5720A digitizer. Optically couple the LED and the sensor via the optical fiber, after having used the index matching grease on the tips. Set the internal trigger mode on the P5601 and connect its trigger output on the DT5720A trigger IN. Connect via USB the modules to the PC and power ON the devices. Through the HERA graphical user interface (GUI), properly synchronize the signal integration and, for every temperature & voltage value, record the photon spectrum and measure directly the Dark Count and the Optical Cross talk.



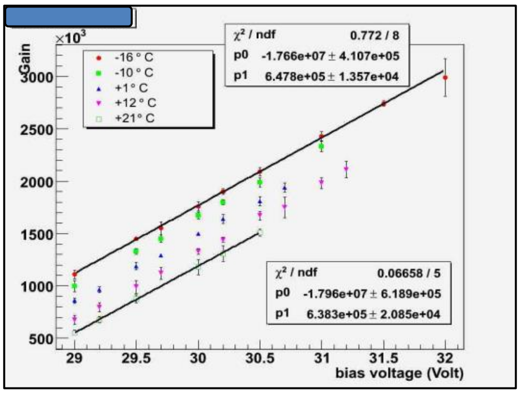
Experimental setup block diagram.

Results:

Figures show the dependence of the gain upon temperature at various voltages and the voltage dependence at various temperatures. By the two set of results, the temperature coefficient of the sensor, i.e. the variation of the breakdown voltage with temperature, can be measured.



SIPM gain as a function of temperature, at different bias voltage values.



SiPM gain as a function of the bias voltage, at different temperature values.

8.4 Detecting γ-radiation (SG6111A)

Purpose of the experiment:

Gamma radioactivity detection by using a system composed of a scintillating crystal coupled to a photon detector.

Fundamentals:

Gamma rays interact with matter by three processes: Compton Scattering, Photoelectric Effect and Pair Production (whenever the energy exceeds the 1.022 MeV threshold corresponding to the e^+e^- rest mass). The cross section of each process depends on the energy of the gamma ray.

The Compton Effect is the inelastic scattering between the incoming photon and an atomic electron. In the Photoelectric Effect, the incident gamma ray transfers all of its energy to a bound electron which acquires a kinetic energy equal to the incoming gamma energy decreased by the binding energy.

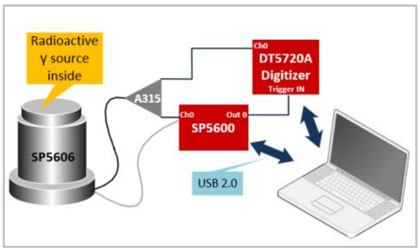
These processes convert, totally or partially, the gamma ray energy into kinetic energy of electrons (or positrons, in case of pair production). The interaction of the charged particles with the atomic and molecular systems of the medium results in excited states whose decay, possibly mediated, leads to light in the visible or UV region, eventually detected by the light sensor. A wide range of scintillator products is available today, differing for the light yield, the material properties, the time characteristics of the scintillation light and, last but not least, cost. The choice of the scintillator is essentially dependent on the specific targeted application.

Requirements:

Gamma Radioactive Source.

Carrying out the experiment:

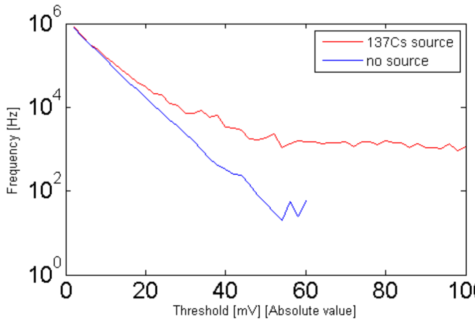
The selected scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator or simply counting the pulses induced by the detected gamma ray.



Experimental setup block diagram.

Results:

The student may get acquainted with the presence of radioactivity with a simple preliminary measurement, namely comparing the counting frequency as a function of the discriminator threshold with/without the source. Presuming the source, essentially in contact to the crystal, to be point like with respect to the crystal surface, and assuming its activity is known, the student may estimate for every threshold value the detection efficiency and the signal over noise ratio, building up an efficiency-purity plot. Exemplary results obtained with a ^{137}Cs Source are shown. Moving away the source from the crystal, the law governing the variation of the flux can also be investigated.



Sensor output frequency as a function of the threshold in mV, with and without ^{137}Cs source.

8.5 Poisson and Gaussian Distribution (SG6112A)

Purpose of the experiment:

Study the statistical distribution of the counting rates of a gamma radioactive source. Comparison of the data to the Poisson distribution, turning into a Gaussian as the mean number of counts grows. The study can be performed both experimentally, with the SiPM kit or simulating it with the emulation kit.

Fundamentals:

The number of radioactive particles detected over a time Δt is expected to follow a Poisson distribution with mean value μ. It means that for a given radioactive source, the probability that n decays will occur over a given time period Δt is given by:

$$P_\mu(n) = \frac{\mu^n}{n!} e^{-\mu}$$

Where μ is proportional to the sample size and to the time Δt and inversely proportional to the half-life $T_{1/2}$ of the unstable nucleus. As long as μ grows, the probability $P_\mu(n)$ is well approximated by a Gaussian distribution:

$$P(n) = \frac{1}{\sqrt{2\pi\sigma}} e^{\frac{-(n-\mu)^2}{2\sigma^2}}$$

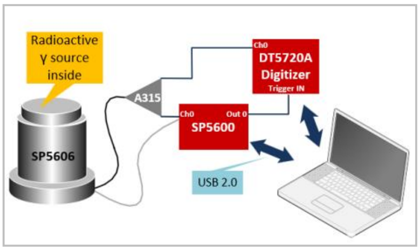
Where $\sigma = \sqrt{\mu}$ is the standard deviation.

Requirements:

Gamma Radioactive Source

Carrying out the experiment:

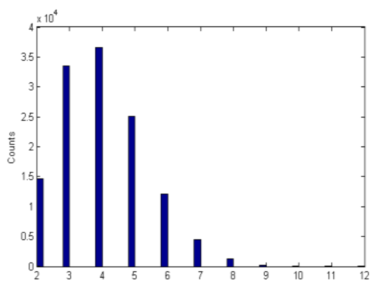
The selected scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator or simply counting the pulses induced by the detected gamma ray. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is properly set, the counting experiment shall be performed.



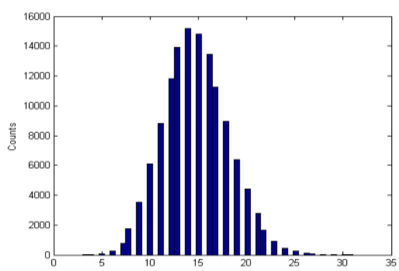
Experimental setup block diagram.

Results:

Changing the counting window and/or the activity of the source or the threshold, the number of counts changes, with a probability density function moving form a Poissonian to a Gaussian shape. The student may play with the data, fitting them and comparing the expectations to the measurement.



Poissonian distribution.



Gaussian distribution.

8.6 Energy Resolution (SG6113A)

Purpose of the experiment:

The analysis of the spectrum of the deposited energy by a γ ray in a detector discloses the essence of the interaction of high energy photons with matter and allows to learn by doing the detector related effects.

Fundamentals:

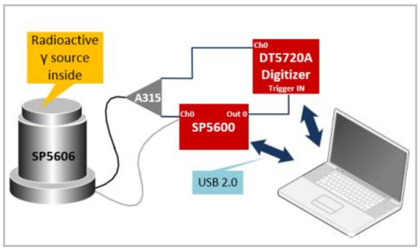
For γ-energy less than 2 MeV, the interaction with matter is dominated by Compton scattering and Photo-absorption. The analysis of the Compton continuum of the deposited energy and of the photo-peak conveys information on the characteristics of the decaying isotope as well as the effects due to the system noise, the detected photon statistics, the stochastic terms in the detector and the intrinsic resolution of the scintillator. The experiment presumes to use ^{137}Cs with its decays detected by a CsI crystal coupled to a Silicon Photomultiplier. The ^{137}Cs source is particularly interesting due to its low energy X ray line at 33 keV and the high energy gamma emission at 662 keV. The former is relevant to optimize the lower detection limit of the system; the latter is a standard to evaluate the energy resolution. The use of the 2 lines and the analysis of the Compton spectrum characteristics allow to perform a rough measurement of the linearity with a single isotope.

Requirements:

Gamma Radioactive Source.

Carrying out the experiment:

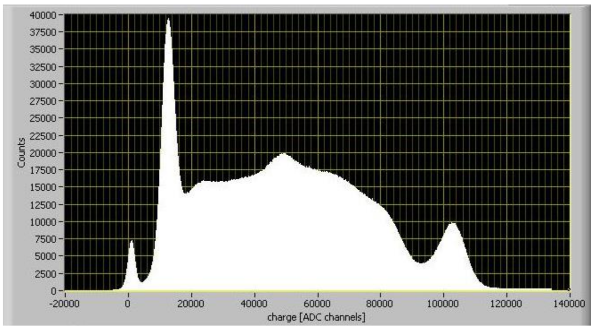
The CsI scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is properly set and the radioactive source is properly positioned, the spectrum can be recorded.



Experimental setup block diagram.

Results:

The figure shows a typical gamma spectrum, recorded with a very low energy threshold. The left over from the system noise is clearly visible, as well as the low energy line at 33 keV and the photo-peak. For this specific spectrum, the energy resolution on the 662 keV peak corresponds to



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

$$\text{Energy Resolution} = \frac{\text{FWHM}_{\text{peak}}}{\mu_{\text{peak}}} * 100 \sim 10\%$$

$\text{FWHM}_{\text{peak}}$ = full width at half maximum of the peak

μ_{peak}= channel number of the peak centroid.

8.7 System Calibration: Linearity and Resolution (SG6114A)

Purpose of the experiment:

Recording and comparing the γ energy spectra of several radioactive sources is the main goal of the experiment. The photo-peaks are used to calibrate the response of the system and to measure the energy resolution.

Fundamentals:

Linearity and energy resolution are the main figures of merit of a spectrometric system. In the proposed experiment, based on a scintillating crystal coupled to a Silicon Photomultipliers, deviations in the linearity may be due to the sensor or the front-end electronics saturation. The student is guided through the analysis of the response curve using a series of isotopes up to the MeV energy by a ^{60}Co source and to disentangle the different effects.

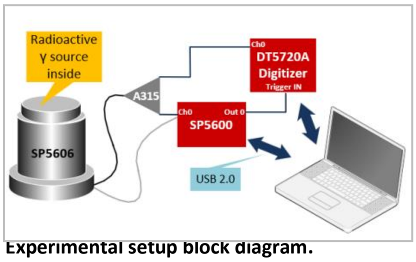
At the same time, the energy resolution of the system is measured by the width of the photo-peaks and the results compared to what is expected by the fluctuations in the number of detected scintillation photons, the system noise, the sensor stochastic effects, the intrinsic resolution of the scintillator.

This is following an initial activity on the optimization of the operating parameters by an analysis of the photo-peak position and the resolution for a single isotope.

Requirements:

Gamma Radioactive Sources.

Carrying out the experiment:

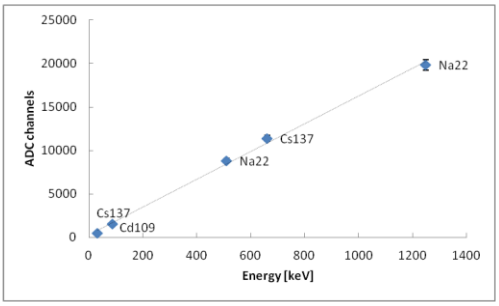


Experimental setup block diagram.

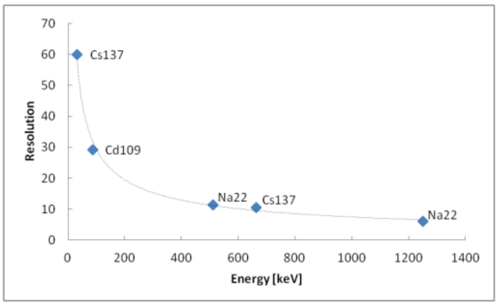
The scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is set and the radioactive source is properly positioned, the spectrum can be recorded.

Results:

By fitting the photo-peaks with a Gaussian curve, the system linearity as a function of energy is verified. The peak widths are determining the energy resolutions. At more advanced level, the interpretation of the results accounting for the system properties may be performed.



Energy calibration.



Energy dependence of the system resolution.

8.8 A comparison of different scintillating crystals: Light Yield , Decay Time and resolution (SG6115A)

Purpose of the experiment:

Compare the basic characteristics of different scintillating crystals, namely the light yield and the decay time of the scintillation light. Verify the effect on the energy resolution.

Fundamentals:

Scintillating materials have different characteristics related to the light yield and the characteristics time of the emission. The CAEN spectrometer is provided with three different crystals: BGO (Bismuth Germanate), LYSO(Ce) (Cerium-doped Lutetium Yttrium Orthosilicate), CsI(Tl) (Thallium-doped Cesium Iodide). All of them have the same volume (6 x 6 x 15 mm^3), are polished on all sides and coated with a white epoxy on 5 faces. One 6 x 6 mm^2 face is open in order to be coupled with the Silicon Photomultiplier. The main characteristics of the crystals are summarized in the following table:

	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

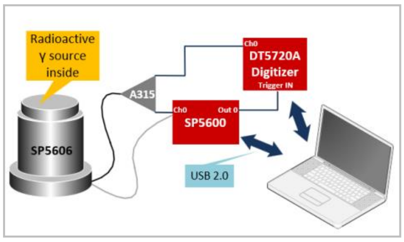
The light yield is having an impact on the energy resolution. This is also affected by the decay time, constraining the integration time and implying a different effect of the sensor stochastic effects (dark counts and afterpulses).

Requirements:

Gamma Radioactive Source.

Carrying out the experiment:

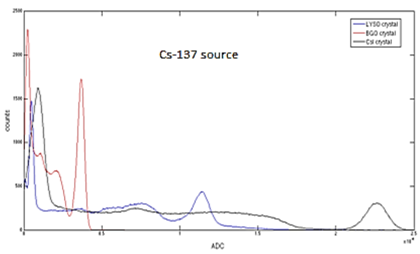
The scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is set and the radioactive source is properly positioned, the spectrum can be recorded. The procedure shall be repeated for every crystal.



Experimental setup block diagram.

Results:

The crystal characteristics are investigated recording a source spectrum (for example ^{137}Cs) with the three different crystals, optimizing the integration time as a function of the scintillation decay time. According to table, the Light Yield of the three crystal is very different. LYSO(Ce) has a light yield three times greater than the BGO, and CsI(Tl) light yield is twice than LYSO(Ce). The analysis of the signal waveform or the trend of the charge vs integration time leads to the measurement of the time characteristics of the scintillator.



^{137}Cs energy spectra. Blue spectrum corresponds to the acquisition through LYSO crystal, the red and black ones respectively with BGO and CsI crystals.

8.9 γ-Radiation Absorption (SG6116A)

Purpose of the experiment:

The main goal of the experiment is the measurement of the γ radiation attenuation coefficient for different materials and different energies.

Fundamentals:

The attenuation of a γ radiation flux passing through matter is described by the exponential law:

$$I(x) = I_0 * e^{-\mu x}$$

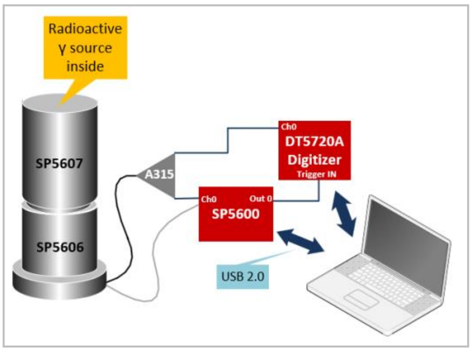
where I_0 is the incident photon flux and I(x) measures the flux of γ rays emerging from a layer x of material without having interacted. The coefficient μ depends on the material properties (atomic number, density) and on the energy of the impinging photon. The student is guided towards the development of complementary measurement techniques based on counting and on the analysis of the spectrum, performing the experiment for different materials (including PMMA, a water equivalent solid state organic material used in medical dosimetry).

Requirements:

Gamma Radioactive Source.

Carrying out the experiment:

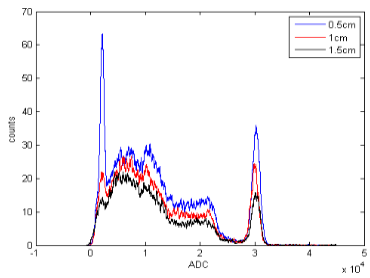
The scintillator crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is set the SP5609 absorption tool shall be mounted. The experiment can be performed for every absorber thickness in counting mode and analysing the spectrum, measuring the events in the photo-peak for a constant pre-defined time interval.



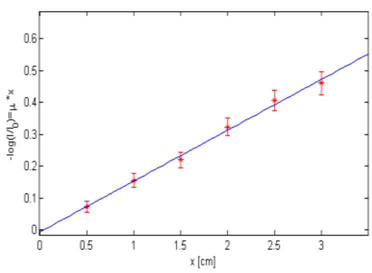
Experimental setup block diagram.

Results:

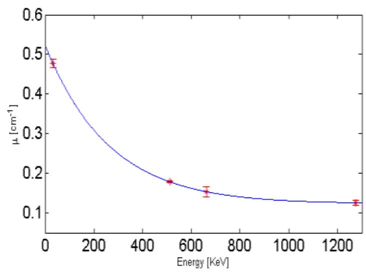
Exemplary results are shown below, reporting the variation of the events in the photopeak for different absorber thickness, a plot verifying the exponential absorption law and the dependence of the absorption coefficient on the energy.



Gamma spectra acquired with different absorber thicknesses.



Linear dependence of logarithmic intensity of gamma rays as a function of penetration thickness.



Gamma attenuation coefficient as a function of energy.

8.10 Photonuclear cross-section/Compton Scattering cross-section (SG6117A)

Purpose of the experiment:

Determination of the ratio of the effective cross-sections due to Compton and Photoelectric effects as a function of photons energy.

Fundamentals:

In the energy range up to 2 MeV, gamma rays interact with matter by two processes:

- Photoelectric Effect, dominant at energy less than 100 KeV. In this process the photon energy is completely transferred to atomic electron bounded

$$\gamma + \text{atom} \rightarrow \text{ion} + e^-$$

- Compton Scattering, linked to the elastic collision between electrons and photons and relevant at 1 MeV energy level

$$\gamma + e^- \rightarrow \gamma' + e^{-\prime}$$

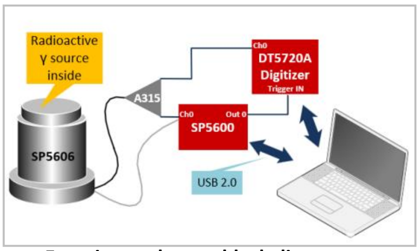
The predominant mode of interaction depends on the energy of the incident photons and the atomic number of the material with which they are interacting. From the acquired γ-spectrum, it is possible to estimate the fraction of events due to Compton scattering and those caused by the photoelectric. The ratio of the event fractions is used to determine the ratio of the two effective cross-sections that depends on the detector size.

Requirements:

Gamma Radioactive Source.

Carrying out the experiment:

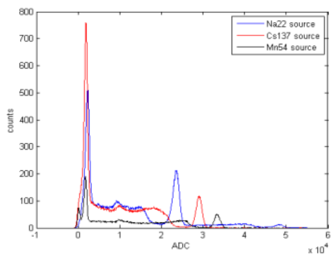
Spread the optical grease on the open face of the scintillating crystal, insert this crystal side in the SP5607 spectrometer. Connect the power cable to the SP5600 module and connect the other cable of the spectrometer to the splitter A315. Connect the two split outputs to SP5600 channel 0 and DT5720A channel 0. Use the SP5600 digital output as DT5720A "trigger IN". Use the default software values or optimize the parameters to choose the discriminator cut-off threshold in mV. Switch off the power supply, open the spectrometer and insert the radioactive gamma source to acquire the first spectrum. After that, switch off the power supply, open the spectrometer, change the radioactive gamma source and repeat the measurement.



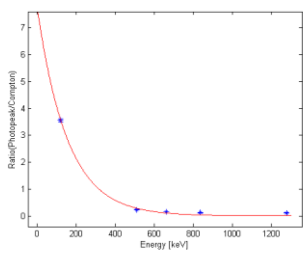
Experimental setup block diagram.

Results:

By using several radioactive sources, the energy dependence of the ratio between the cross-sections of two phenomena can be examined, by verifying that the Photoelectric Effect cross section decreases with increasing energy compared to the Compton Scattering cross section for the used detector size.



Spectra of radioactive sources used to estimate the ratio of Photonuclear and scattering Compton cross sections.



Behaviour of the ratio between Photo-Peak and Compton contributions as a function of energy.

8.11 Study of the ^{137}Cs spectrum: the backscatter peak and X rays (SG6118A)

Purpose of the experiment:

Study the characteristics of the ^{137}Cs spectrum, with special relevance given to the low energy spectrum. The student can learn effects related to the experimental observation of a gamma decay and have basic information about the experimental setup used in gamma spectroscopy. Estimate the energy of the backscatter peak and of the K_α line.

Fundamentals:

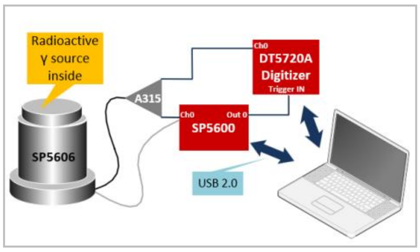
The Compton effect is linked with experimental issues, since it is caused by the interaction of photons with the electrons instrument that measure the gamma radiation. In a real detector setup, some photons can and will undergo one or potentially more Compton scattering processes (e.g. in the housing material of the radioactive source, in shielding material or material otherwise surrounding the experiment) before entering the detector material. This leads to a peak structure, the so-called backscatter peak.
The basic principle for the backscatter peak formation is the following: gamma-ray sources emit photons isotropically, some photons will undergo a Compton scattering process with a scattering angle close to 180° and some of these photons will subsequently be detected by the detector. The result is an excess of counts in the Compton part of the spectrum, the so-called backscatter peak. This peak has an energy approximately equal to the photopeak energy minus the Compton edge energy.

Requirements:

Gamma Radioactive Source: ^{137}Cs

Carrying out the experiment:

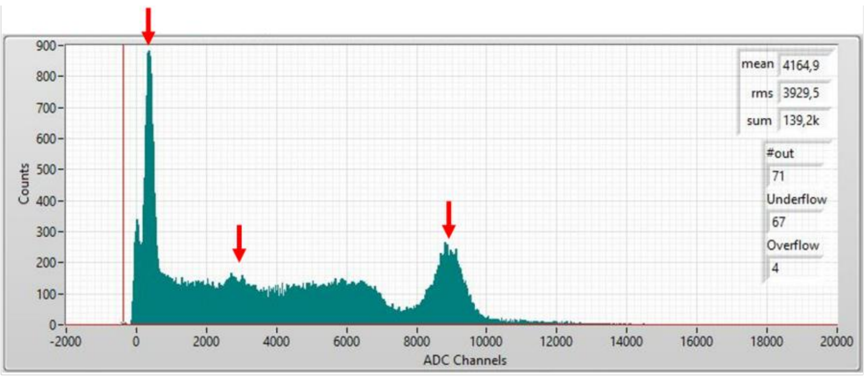
The scintillating crystal shall be coupled to the SiPM in the SP5607, through a thin layer of index matching grease to maximize the light collection. In order to avoid saturation, the output of the SiPM is divided using the A315 splitter: one branch is connected to the DT5720A and will be digitized. The other branch will be amplified by the SP5600 module, generating the trigger for the integration signal by the on-board leading edge discriminator. The discriminator threshold shall be defined looking at the spectrum and evaluating the dark count rate. Once this is properly set and the radioactive source is properly positioned, the spectrum can be recorded.



Experimental setup block diagram.

Results:

The user can calibrate the system by using the spectrum itself. The backscatter peak and the K_α line can be identified. After calibrating the spectrum, it is possible to estimate the energy of the two peaks and compare them with theoretical predictions.



Plot of the ^{137}Cs spectrum acquired by HERA software. The backscatter peak and the K_α line are indicated with the red arrows.

8.12 Response of a Plastic Scintillating Tile (SG6121A)

Purpose of the experiment:

To get acquainted with a set-up based on a plastic scintillator tile coupled to a Silicon Photo-multiplier.

Fundamentals:

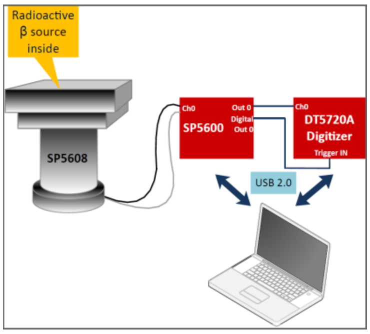
Particle detectors based on scintillating material coupled to a photosensor are in common use in nuclear and particle physics, medical, industrial and environmental applications. The choice of the scintillator is dependent on the end-user specifications but for a large set of applications plastic scintillators represent a cost-effective viable solution. The CAEN kit comprises a plastic scintillator tile of 5 x 5 x 1 cm^3 volume, directly coupled to a 6 x 6 mm^2 SiPM. The sensitive area is a trade-off between the requests for some of applications (e.g. cosmic ray detection or inspection of thin layers or filters) and the homogeneity of the response of the system. Before addressing a variety of lab applications, the student is guided through the basics of the system.

Requirements:

Beta Radioactive Source.

Carrying out the experiment:

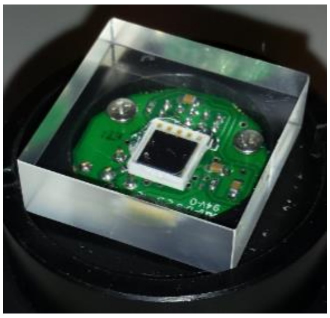
Connect the power and the MCX cables of the SP5608 tile to one channel of the SP5600. Connect the two channel outputs to DT5720A: the analog output to the channel 0 and the digital output to "trigger IN" of the digitizer. Use the GUI to optimize the system parameters (bias, gain, discriminator threshold). Once this is done, switch off the power supply, open the SP5608 top cover and position the beta source on the scintillating tile in the center. Close the support top, switch ON the power supply and measure the counting rate. Repeat the measurement moving the source in several positions over the tile and acquiring the signal/background ratio.

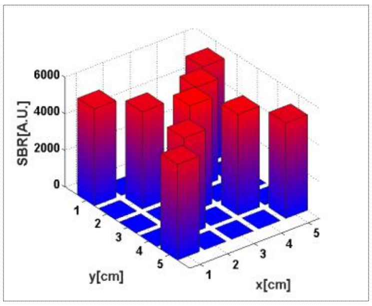


Experimental setup block diagram.

Results:

In response to the incoming beta particles, the system is designed to deliver a high signal. However, the student shall consider the optimal setting of the discriminator threshold, taking into account the dark count rate, the variation in the beta source counts, the signal to noise ratio and the quality of the recorded beta spectrum. Moreover, for the optimal setting it is significant to monitor the homogeneity of the response as the source is moved across the tile.


Scintillating tile coupled to a sensor.



Homogeneity of tile response to a beta source.

8.13 β Spectroscopy (SG6122A)

Purpose of the experiment:

After gamma spectrometry, the student is introduced to the measurement and interpretation of β spectra, using a plastic scintillator tile.

Fundamentals:

There are three different beta decays:

- β^- decay (electron emission): $n \rightarrow p + e^- + \nu$
- β^+ decay (positron emission): $p \rightarrow n + e^+ + \nu$
- Electron capture (EC): $p + e^- \rightarrow n + \nu$

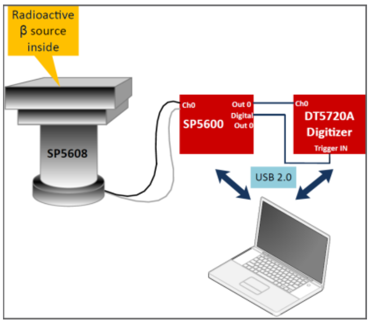
Where p identifies the proton, n the neutron and ν the weakly interacting neutrino. Because of the three body kinematics and the energy associated to the neutrino, the β spectrum is continuum up to a maximum energy depending on the isotope under study (and the neutrino mass).

Requirements:

Beta Radioactive Source.

Carrying out the experiment:

Connect the power and the MCX cables of the SP5608 tile to one channel of the SP5600. Connect the two channel outputs to DT5720A: the analog output to the channel 0 and the digital output to "trigger IN" of the digitizer. Use the default software values or optimize the parameters to evaluate the contribution not coming from the beta source and choose the discrimination threshold in mV. After that, switch off the power supply, open the SP5608 top and place the beta source on the scintillating tile. close the support top, switch ON the power supply and acquire the beta spectrum.



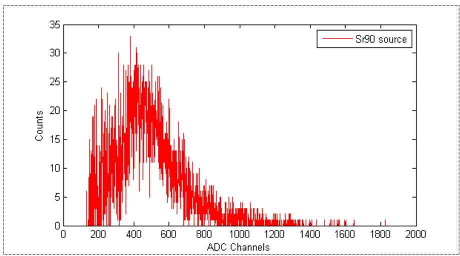
Experimental setup block diagram.

Results:

Measurement and interpretation of β spectra introduce the student into the field of special relativity and weak interactions of radioactive decays. Observation of the beta spectrum is very important to understand the theory of beta decay. Historically, experimental beta-ray spectra introduced enormous problems in the interpretation of beta decay due to the ostensible violation of the energy conservation. The introduction of neutrinos explaining the continuous beta-ray spectra solved not the problem conservation of energy, momentum, and lepton number. As first approach to beta spectroscopy, it is interesting to determine the maximum energy available in the decay process and to verify that the most probable energy value E_{avg} can be expressed as:

$$E_{avg} \cong 1/3 * E_{max}$$

By using several β-sources, different energy values E_{avg} can be estimated, each one corresponds to the total energy released in the specified β decay. An example of ^{90}Sr spectrum is shown in the figure. For a most complete analysis on beta spectrum, other application notes are recommended.



Experimental beta spectrum of ^{90}Sr radioactive source.

8.14 β-Radiation: Transmission through Matter (SG6123A)

Purpose of the experiment:

Attenuation measurement of the intensity of β radioactive source as a function of the absorber thickness by using two absorber materials: aluminium and paper sheets.

Fundamentals:

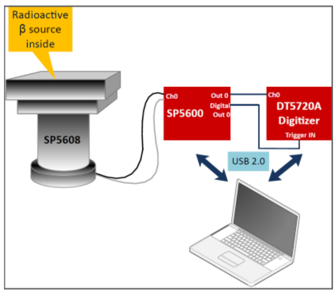
β-particle is a charged particle that interacts with matter in several ways depending on its initial energy: ionization process, Bremsstrahlung process, Cherenkov and Transition radiation. When β-radiation crosses a matter thickness, it releases completely or part of its energy due to collisions with absorber atoms; this phenomenon depends on the initial β-energy and on the crossed material density. Beta particles are less massive than alpha particles and only carry a charge of 1 e; consequently, beta particles can appreciably penetrate many potential shielding materials although their penetrating capacity is considerably lower compared with γ-rays. These different radiation behaviours are essential for those attempting to shield locations from gamma radiation, either for sensitive experiments or for the safety of humans. The transmission of beta particles is frequently calculated in the same fashion as that of gamma rays, where the mass attenuation coefficient is defined by the slope of the exponential function. Due to the fact that the β-particles with lower energies are less penetrating hence they are completely absorbed at smaller values of thickness, the initial decrease of the absorption curve is too rapid to be fit by exponential function. This approximation is verified only in a particular region of the transmission curve: a minimal absorber thickness so that the beta counting are very well separated from the "background level".

Requirements:

Beta Radioactive Source

Carrying out the experiment:

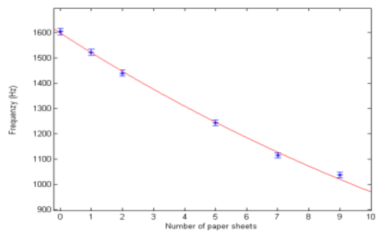
Insert the beta source support in the SP5608 and connect power and MCX cables to one channel of the SP5600. Connect the two channel outputs to DT5720A: the analog output to the channel 0 and the digital output to "trigger IN" of the digitizer. Use the default software values or optimize the parameters to evaluate the contribution not coming from the beta source and choose the discrimination threshold in mV. After that, switch off the power supply, open the SP5608 top and place the beta source on the plastic support and close the support top. Switch ON the power supply and measure the counting rate. Repeat the measurement by adding layers of the same absorber and later change the absorber type.



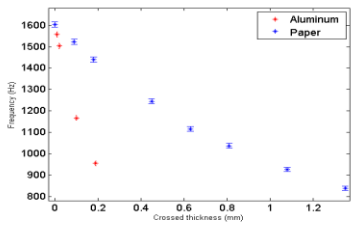
Experimental setup block diagram.

Results:

By using different absorber thicknesses, the near-exponential decreasing of β-radiation intensity I as a function of the absorber thickness x, is verified. This behaviour does not have a fundamental basis like gamma rays attenuation, but it is very well described by: $I = I_0 * e^{-nx}$,where n is the absorption coefficient. This coefficient correlates the endpoint energy of beta source for a particular absorbing material. From absorption curves of beta particles, the absorption coefficients and ranges of β particles in aluminium and in paper sheets can be determined.



Exponential behaviour of the transmitted counting rate of ^{90}Sr source with respect to number of paper sheets.



Behaviour of the transmitted counting rate of ^{90}Sr source as a function of different absorbing materials.

8.15 β-Radiation as a Method to Measure Paper Sheet Grammage and Thin Layer Thickness (SG6124A)

Purpose of the experiment:

Estimate of the instrument sensitivity in the measurement of thin layer thickness by beta particle attenuation.

Fundamentals:

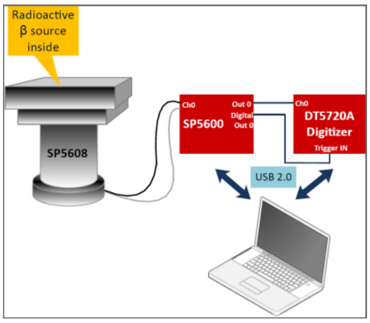
Beta attenuation represents a golden standard in the quality control of paper industry and in the measurement of thin layer thickness. The latter has several applications, including the concentration of fine particulate matter deposited on a filter. The use of high activity sources with relatively soft spectrum and highly efficient detectors guarantees that this technique, used since the 50's, is yet today a standard.

Requirements:

Beta Radioactive Sources

Carrying out the experiment:

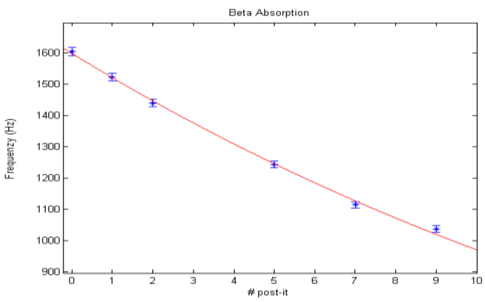
Insert the beta source support in the SP5608 and connect power and MCX cables to one channel of the SP5600. Connect the two channel outputs to DT5720A: the analog output to the channel 0 and the digital output to "trigger IN" of the digitizer. Use the default software values or optimize the parameters to evaluate the contribution not coming from the beta source and choose the discrimination threshold in mV. After that, switch off the power supply, open the SP5608 top and place the beta source on the plastic support and close the support top. Switch ON the power supply and measure the counting rate. Repeat the measurement by adding paper sheets.



Experimental setup block diagram.

Results:

The industrial results are provided by using high activity β source (1 GBq). This experiment allows to estimate the instrument sensibility and the time needed to obtain a certain percentage of sensibility through the attenuation curve of a β source with "student compliant" activity. The results are very surprising: 3σ of confidence level to distinguish one or two post-it in 250 ms and 25 seconds to reach sensibility 10%.



Counting frequency of the beta rays as a function of the number of crossed paper sheets.

8.16 Coating effect on the Light Collection (SG6125A)

Purpose of the experiment:

This experiment investigates the impact of a reflective coating on the light collection efficiency in a plastic scintillating tile.

Fundamentals:

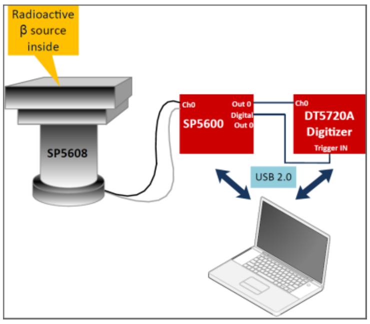
Scintillating materials are commonly used in high energy physics and medical applications because of their capability to convert high energy radiation into optical photons and they are usually coupled with a photosensor. Scintillator has a key role in the detection chain, and it is often mandatory to extract and detect the generated scintillation light as efficiently as possible. The amount of light generated during the scintillation process is, in standard configurations, only a small percentage of this light reaches the photodetector. Extracting as much light as possible from the crystal becomes thus crucial, given that both energy and time resolution depend strongly on the amount of detected light. Indeed, extracting more light enables a more accurate estimation of the energy deposited in the crystal by the incoming radiation. Several phenomena limit the amount of light that can be extracted from the scintillator and then detected by a photodetector: the scintillator-photodetector interface, the light collection efficiency, the light absorption in the scintillator itself, and, moreover, if not covered by any material, the scintillator can let light escape through its lateral surfaces, thus losing a significant number of optical photons.

Requirements:

Beta Radioactive Sources.

Carrying out the experiment:

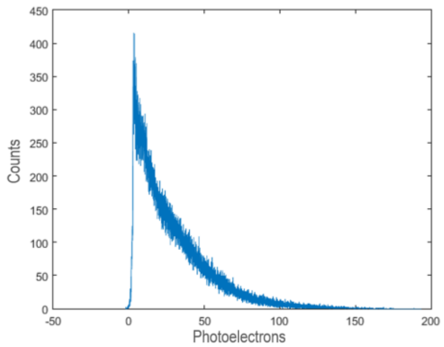
Connect the power and the MCX cables of the SP5608 tile to one channel of the SP5600. Connect the two channel outputs to DT5720A: the analog output to channel 0 and the digital output to “trigger IN“ of the digitizer. Use the default software values or optimize the parameters to evaluate the contribution not coming from the beta source and choose the discrimination threshold in mV. After that, switch off the power supply, open the SP5608 top and place the beta source on the scintillating tile. Close the support top, switch ON the power supply and acquire the beta spectrum. Repeat the spectrum acquisition after having uniformly covered the scintillator with the Teflon tape leaving only a window open for the optical coupling with the SiPM.



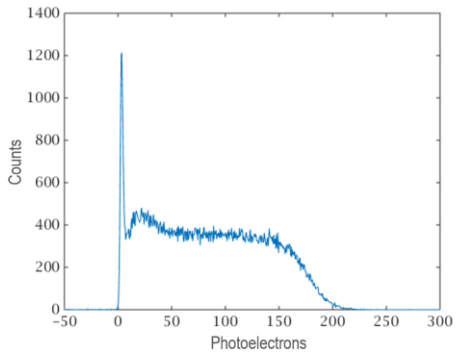
Experimental setup block diagram

Results:

The presence of a white coating allows the user to observe the improvement of the light collection via the acquisition of ^{90}Sr spectrum.



^{90}Sr spectrum acquired just by using optical grease as coupling between scintillator and SiPM.



^{90}Sr spectrum acquired by using Teflon coating and Optical interface sheet between scintillator and SiPM.

8.17 Statistics (SG6210A)

Purpose of the experiment:

Statistical properties of the cosmic rays.

Fundamentals:

The event number in a given time interval is one of the most interesting points in many Physics phenomena. This number is often affected by statistical fluctuations around an average value determined by the type of phenomenon. Multiple factors may cause fluctuations and influence the measurement result. Thus, the exact value is not always the same (as in the case of particles that decay may derive from space or from a radioactive source).

The most important goal in the experimental approach is to understand which values can occur in a series of measurements as well as their probability, i.e. the probability distribution. The Poisson distribution describes with good approximation events comings from radioactive phenomena or from counting cosmic rays. This distribution expresses the probability of a given number of events occurring in a fixed interval of time or space, and can be expressed as:

$$P_{\mu}(n) = (\mu^n / n!) \cdot e^{-\mu}$$

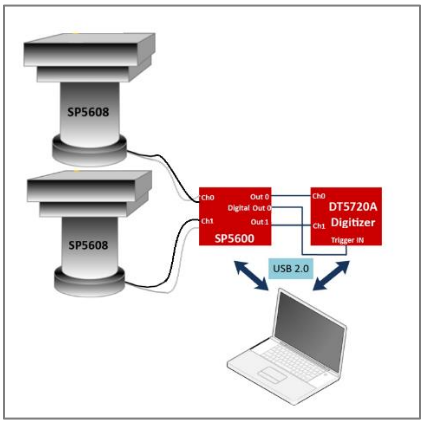
where μ is the average number of events in a fixed interval and n is the number of events.

Requirements:

Optional: Additional SP5608 - Scintillating tile.

Carrying out the experiment:

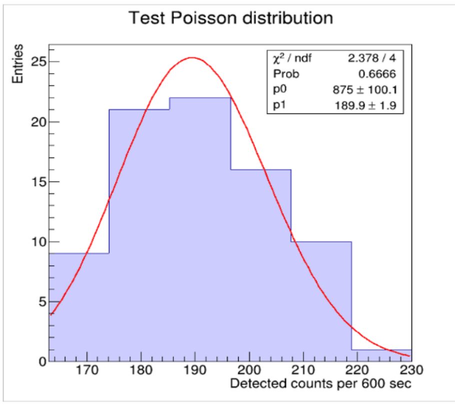
Connect the SP5608 power cable and its MCX cable to one channel of the SP5600. Connect the two outputs of the chosen channel to DT5720A: the analog output to channel 0 and the digital output to "trigger IN" of the digitizer. Use the default software values or optimize the operating voltage of the sensor to reach a higher photon detection efficiency (PDE). Switch ON the power supply and run cosmic experiments of HERA software. The photons produced are detected by the photosensor and converted into an electrical signal. The first measurement step is the evaluation of the default threshold setting. The number of counts is displayed in the counting tab. Note that spurious electrical signals will likely also be detected by the photosensor, thus producing noise. Take and record more data to obtain statistical significance. Using two SP5608 in coincidence mode will greatly reduce the number of spurious events.



Experimental setup block diagram.

Results:

The Poisson distribution of cosmic rays can be experimentally verified via data analysis and the treatment of their statistical uncertainty.



Poissonian distribution of cosmic rays [Fit: $y = p0 * (p1^x/x!) * e^{-p1}$].

8.18 Muons Detection (SG6211A)

Purpose of the experiment:

Cosmic rays detection by using a system composed of a plastic scintillating tile directly coupled to a Silicon Photomultiplier detector.

Fundamentals:

The muons, produced by the decay of pions and kaons generated by the hadronic interaction of the primary cosmic rays with atmospheric nuclei, are the most cosmic rays at sea level.

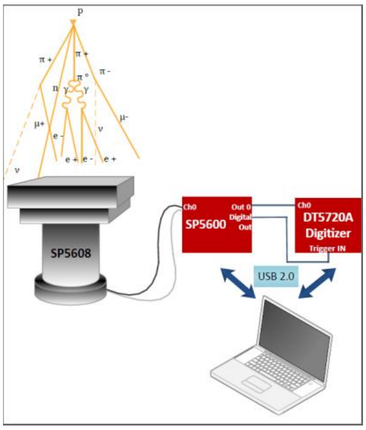
Cosmic muons are charged particles, produced high in the atmosphere (typically 15 km) with highest penetration capability in matter. Their mass (~ 200 times the electron mass), the absence of strong interactions and their long lifetime ($\tau \sim 2{,}2 \times 10^{-6}$ s), allow muons to cross the atmosphere and reach the Earth's surface.
The muon average energy at sea level is around 4 GeV.

Requirements:

No other tools are needed.

Carrying out the experiment:

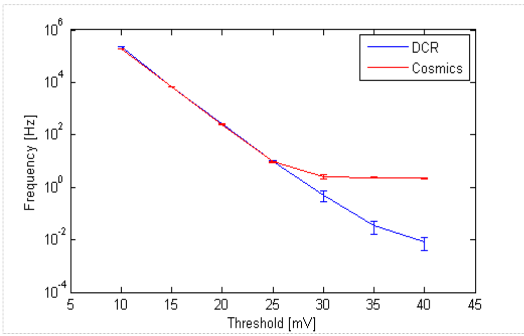
Open the SP5608 and remove the plastic scintillating tile. Close the SP5608 and connect its power cable and its MCX cable to one channel of the SP5600. Connect the two outputs of the chosen channel to DT5720A: the analog output to the channel 0 and the digital output to “trigger IN“ of the digitizer. Use the default software values or optimize the parameters to evaluate the noise contribution of the sensor, called Dark Count Rate (DCR). Measure the DCR as a function of the discrimination threshold in mV. Because of the DCR, the system has to be made sensitive to the cosmic ray flux relying on the acquisition time of the sensor signal. Switch off the power supply, open the SP5608 top, spread the optical grease on the SiPM and insert the scintillating tile. Close the support top, switch ON the power supply and restore the previous configuration parameters. Measure the counting rate scanning the values of the threshold.



Experimental setup block diagram.

Results:

The cut-off threshold has a key role in the cosmic ray detection, and it shall be set to reduce the random coincidence rate below the Hertz level and measure the cosmic rate.



Signal frequency as a function of discriminator threshold. The red line represents the cosmic contribution, the black one the noise.

8.19 Muons Vertical Flux on Horizontal Detector (SG6212A)

Purpose of the experiment:

Measurement of the muon vertical flux on a plastic scintillating tile. Estimation of the detection efficiency of the system by comparison between the expected rate and the measured one.

Fundamentals:

Muons lose about 2 GeV to ionization before reaching the ground with average energy around 4 GeV. The production spectrum, energy loss in the atmosphere and decay of the muons are convoluted in their energy and angular distribution. The integral intensity of vertical muons is:

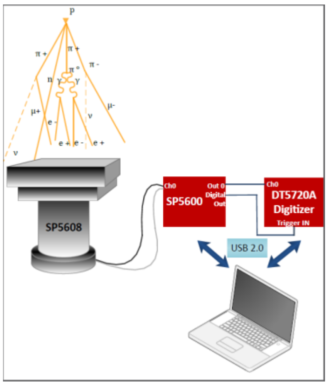
$$I_V \approx 82\ m^{-2}s^{-1}sr^{-1}$$

and their flux for horizontal detectors is ≈ 1 $cm^{-2}min^{-1}$ at energies higher than 1 GeV at sea level, as known in literature[2].

Requirements:

No other tools are needed

Carrying out the experiment:

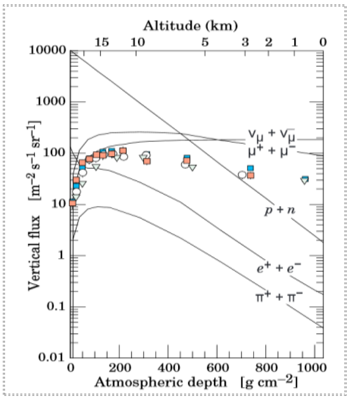


Experimental setup block diagram.

Open the SP5608 and remove the plastic scintillating tile. Close the SP5608 and connect its power cable and its MCX cable to one channel of the SP5600. Connect the two outputs of the chosen channel to DT5720A: the analog output to the channel 0 and the digital output to "trigger IN" of the digitizer. Use the default software values or optimize the operating voltage of the sensor to reach an higher photon detection efficiency (PDE). The first measurement step is the evaluation of the noise (Dark Count Rate) as a function of the discriminator threshold. Because of the DCR, the system has to be made sensitive to the cosmic ray flux relying on the acquisition time of the sensor signal. The thresholds shall be set to reduce the random coincidence rate below the Hertz level. Switch off the power supply, open the SP5608 top, spread the optical grease on the SiPM and insert the scintillating tile. Close the support top, switch ON the power supply and reset the previous configuration parameters. Measure the muons counting rate and estimate the cosmic flux.

Results:

Exemplary results are shown below, reporting the variation of the events in the photo-peak for different absorber thickness, a plot verifying the exponential absorption law and the dependence of the absorption coefficient on the energy.



Cosmic vertical flux as a function of altitude and atmospheric depth[2].

[2] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014)

8.20 Zenith Dependence of Muons Flux (SG6216A)

Purpose of the experiment:

The goal of the experiment is to analyse zenith dependence by performing a series of measurements at different zenith angle values.

Fundamentals:

Most muons are produced in the upper atmosphere, typically 15km above the surface of the earth. Muons typically lose about 2GeV to ionization before reaching the ground. The average energy of muons on the ground is around 4GeV. When their decay ($E_\mu > 100 / \cos\theta$ GeV) and the curvature of the Earth (for $\theta > 70°$) can be disregarded the flux of cosmic muons can be expressed as follows:

$$\frac{dN_\mu}{dSdtdE_\mu d\Omega} = 0.14E_\mu^{-2.7}\left\{\frac{1}{1+\frac{1.1E_\mu cos\theta}{115GeV}} + \frac{0.054}{1+\frac{1.1E_\mu cos\theta}{850GeV}}\right\}[cm^2\ s\ GeV\ sr]^{-1}$$

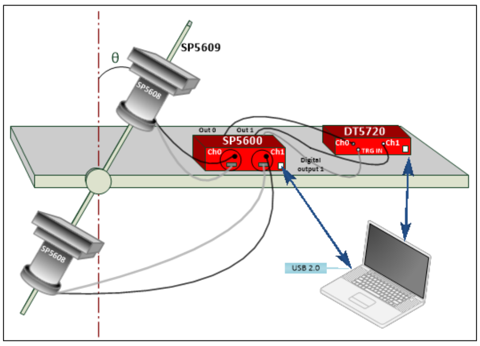
Where θ is the zenith angle, and the two terms in the brackets indicate the contribution of the charged pions and kaons. For $E_\mu \sim 3$GeV, the angular distribution of muons is proportional to $\cos^2\theta$ at sea level. The intensity of cosmic muons is only determined by the angular dependence of the zenith on their energy spectrum and their energy. As first approximation, the dependence of the muon flow from φ is considered negligible, which is in fact less than 10%**Errore. L'origine riferimento non è stata trovata.** [RD9].

Requirements:

The SP5609 - Telescope Mechanics and SP5608 – Scintillating Tile are needed.

Carrying out the experiment:

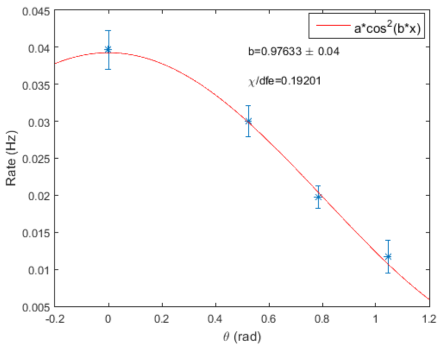
Assemble the cosmic telescope as described in **Errore. L'origine riferimento non è stata trovata.**.
Connect the SP5608 power cables and their MCX cables to the input channels of the SP5600. Connect the channel outputs to DT5720: the SP5600 analog outputs to digitizer channel inputs and one of the two digital outputs to "trigger IN" of the digitizer. Use the default software values or optimize the setting parameters for your application. Switch ON the power supply and run cosmic experiments with HERA software. The photons produced are detected by the photosensor and converted into an electrical signal. The first measurement step is the evaluation of the default threshold setting. The number of counts is displayed in the counting tab. Note that spurious electrical signals will likely also be detected by the photosensor, thus producing noise. Manually rotate the telescope to set the zenith angle value via the SP5609 and acquire the data. Repeat the procedure for different zenith angle values.



Experimental setup block diagram.

Results:

The following plot shows the result obtained by positioning the two detectors at 10 cm distance. The count rate was measured at 8 photoelectrons threshold for the zenith angles θ= [0, 30°, 45°, 60°] to verify the $\cos^2(\theta)$ theoretical trend of the muons flux.



Zenith angle dependence of the muons flux [Fit: $y = a*cos^2 (b*x)$].

8.21 Quantum Nature of Light (SG6221A)

Purpose of the experiment:

Exploring the quantum nature of light thanks to bunches of photons emitted in a few nanoseconds by an ultra-fast LED and sensed by a state-of-the-art detector, a Silicon Photomultiplier (SiPM).

Fundamentals:

In the XVII century the concept of wave-particle duality was developed, starting from the wave nature of light postulated by Huygens to the Einstein Photoelectric Effect, which postulates light quanta existence.

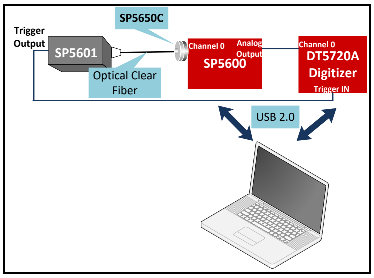
A basic principle of quantum mechanics is complementarity: each quantum-mechanical object has both wave-like and particle-like properties. With this approach the photon is at the same time wave and particle, but they can never be observed simultaneously in the same experiment, not even if the uncertainty principle is successfully bypassed.

Requirements:

No other tools are needed.

Carrying out the experiment:

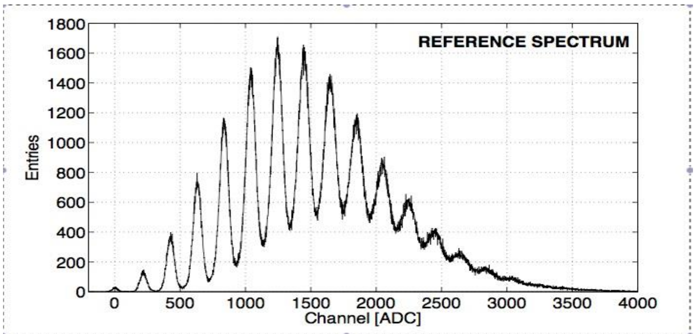
Plug in the SP5650A into one channel of SP5600 and connect the analog output to DT5720A channel 0. Remove the protection cover of the SP5601 and SP5650A, spread the optical grease on both ends of the optical fiber and connect them. Use internal trigger mode on SP5601 and connect its trigger output on the DT5720A trigger IN. Connect via USB the modules to PC and power ON the devices. Use the default software values or optimize the parameters to acquire the light spectrum. In the spectrum of the SiPM response to a light pulse, every entry corresponds to the digitized released charge, measured integrating the electrical current spike during a pre-defined time interval. The peaks correspond to different number of cells fired at the same time by incoming photons.



Experimental setup block diagram.

Results:

This detector can count the number of impacting photons, shot by shot, allowing to observe how the light is composed by photons. Moreover, the SiPM measures the light intensity simply by the number of fired cells.



Spectrum of the photons emitted by a LED Driver and detected by a Silicon Photomultiplier.

8.22 Hands-on Photon Counting Statistics (SG6222A)

Purpose of the experiment:

Statistical properties of the light pulses emitted by a LED driver.

Fundamentals:

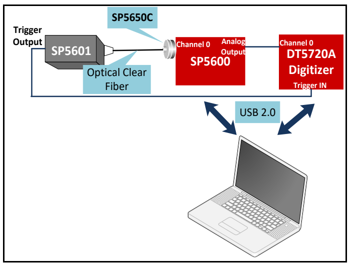
The typical SiPM response to a light pulse is characterized by multiple traces, each one corresponds to different numbers of fired cells, proportional to the number of impinging photons. Because of the high gain compared to the noise level, the traces are well separated, providing a photon number resolved detection of the light field. Spontaneous emission of light results from random decays of excited atoms and it is expected to be Poissonian. SiPM can count the number of impacting photons, shot by shot, opening up the possibility to apply basic skills in probability and statistics while playing with light quanta displaying the spectrum of the SiPM response to a high statistics of pulses. The spectrum is composed by a series of peaks, each ones correspond to different number of cells fired at the same time. Each peak is well separated and occurs with a probability linked at first order to the light intensity fluctuations. In SiPM the homogeneity of the response is quite high, however, since fired cells are randomly distributed in the detector sensitive area residual differences in the gain become evident broadening the peak. A key point in the analysis technique was the estimation of the area underneath every peak, essential to reconstruct the probability density function of the emitted number of photons per pulse. An easy procedure is to consider each peak as a gaussian, so spectra recorded in response to photons impacting on the sensor can be seen as a superposition of Gaussians, each corresponding to a well defined number of fired cells

Requirements:

No other tools are needed.

Carrying out the experiment:

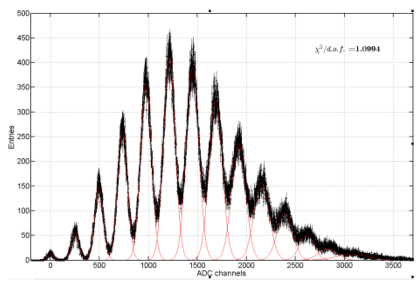
Plug in the SP5650A into one channel of SP5600 and connect the analog output to DT5720A channel 0. Remove the protection cover of the SP5601 and SP5650A, spread the optical grease on both ends of the optical fiber and connect them. Use internal trigger mode on SP5601 and connect its trigger output on the DT5720A trigger IN. Connect via USB the modules to PC and power ON the devices. Use the default software values or optimize the parameters to perform the experiment.



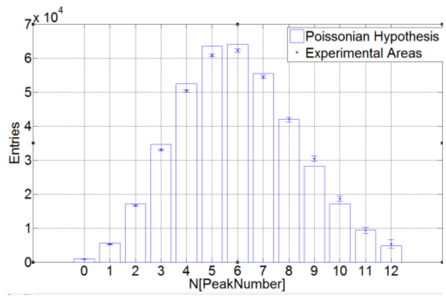
Experimental setup block diagram

Results:

The probability density function of the emitted number of photons per pulse can be estimated by the evaluation of the area underneath every peak. Two different hypothesis can be investigated to evaluate the statistical model and mean number of photoelectrons: Model Independent (the mean photon number is nothing but the mean) and Poissonian hypothesis (mean value obtained by presuming a pure Poissonian behaviour and by referring to the probability P(0) of having no fired cell when the expected average value). A complete and more complex analysis that include also considerations about detector structure is reported in the Educational Note [RD8].



Photoelectron spectrum probing a LED source measured with a Hamamatsu SiPM. The Individual Gaussians are shown in red..



Data from the light spectrum compared to a simple Poissonian.

9 Appendix

Data Storage

The HERA system allows the user to save data in several ways:

- Save data during the run (streaming mode).
- Save the data for an offline run (snapshot mode).
- Save an image.
- Export data in Excel.

The generation of the files due to the experimental activity deserves a dedicated discussion and it is referred to the step-by-step guides of each experiment.
All directories and files are generated under the following path: *C:\ProgramData\HERA\UserName .*
Where *UserName* is the name of the logged user. If no specific username is chosen, the default name used is “Guest”.
The list of the directories created by the HERA system during Hardware Management usage is the following:

- PSAU Temperatures
- Waveform
- Histograms
- Charge-Time
- TDMS

HERA generates several file formats: ASCII (.txt), binary (.dat), and another special file format of Labview (.TDMS) format.
National Instruments defined a new flexible technical data management (TDM) data model, which is accessible through LabVIEW, LabWindows™/CVI™, Measurement Studio, SignalExpress, and DIAdem.
The TDMS file format saves both the raw data and the metadata in the binary format in one file with the .TDMS extension.
When creating or opening a .TDMS file, HERA automatically creates a .TDMS_index file, used to speed up random access to the .TDMS file.
The .TDMS files can be open via a simple Add-In for Microsoft Excel (https://www.ni.com/example/27944/en/) or by using the "Convert data files (.TDMS)" in the File Menu.

PSAU Temperature

Regardless of the type of acquisition and the tab in use, a new file (ASCII format) is stored at every change of date (Log file type).

.txt Structure			
Typical Filename	PSAU_Temperature_*date(mmm-dd-yy)*.txt	Ex.: *PSAU Temperature_ Jan-15-21.txt*	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:		***Name***	***Type***
Structure	5 columns		
Separation character	TAB		
Channels	Channel(s): 5	Date	Date (O.S. format)
		Time	24 h format
		Board Temperature	Decimal float
		Ch.0 Temperature	Decimal float
		Ch.1 Temperature	Decimal float
Data Format	Decimal separator: point (.)		
Data Type Recorded	Single points of measures		
Length	Depends on the running time of the Main Program		

Waveform tab

In addition to the waveforms export in a Bitmap Image to the Clipboard or "Excel" numerical data via the “Export" button, the Waveforms can be saved in both modes, streaming, and snapshot. The generated files are in .TDMS format (see Tab. 9.1).

Folder	Streaming Mode	Snapshot Mode
Waveform	.TDMS *streaming*	--
TDMS	--	*.TDMS*

Tab. 9.1: Waveforms saving scheme.

- *Streaming Mode*

TDMS Structure

Typical Filename	*Activity Acronym_*Wave*(Time or events xx)_date(mm-dd-yy)*-T-*time(hhmm).TDMS*	Ex.: *HRDW_Wave(#Evn 1000)_01-08-21-T-1155.TDMS*
General	TDMS Structure (NI standard), readable by Excel with “TDM Importer Plugin”.	
File Properties recorder	**Dataset Conditions:** string record (*)	
Organisation:		**Name**
Existing Groups	Group(s): 1	Analog Waveforms
Channels	Channel(s): 2	Trace Ch. 1
		Trace Ch. 0
Channel Range	0..4095	
Data Format	DT_Float (floating point double precision, 64 bits)	
Data Type	Array	
Length	Depends on the acquisition time or # of triggers	

- *Snapshot Mode*

TDMS Structure

Typical Filename	*Activity Acronym _Wave.TDMS*	Ex.: *SiPM_Wave.TDMS*
General	TDMS Structure (NI standard), readable by Excel with “TDM Importer Plugin”.	
File Properties recorder	**Dataset Conditions:** string record (*)	
Organisation:		**Name**
Existing Groups	Group(s): 2	Analog Waveforms
		Digital Waveforms
Channels	“Analog Waveforms” Channels: 2	Trace Ch. 1
		Trace Ch. 0
	“Digital Waveforms” Channels: 5	Virtual Probe
		Gate
		Hold Off
		Over Threshold
		Flat
Channel Range	0..4095	
Data Format	DT_Long (Long 32 bits integer)	
Data Type	Arrays	
Length	Depends on the x scale extension of the Waveform plots originating the file	

Histogram tab

The histograms can be export in a Bitmap Image to the Clipboard and in "Excel" numerical data via the “Export" button. Moreover, as the waveforms saving, the histograms can be saved in streaming and snapshot mode. The generated file formats are summarized in Tab. 9.2.

Folder	Streaming Mode	Snapshot Mode
Histogram	*.txt* (ASCII)	*.txt* (ASCII) [Under request]
TDMS	--	*.TDMS* [Under request]

Tab. 9.2: Histograms saving scheme.

- *Streaming Mode*

.txt Structure

Typical Filename	*Activity Acronym*_Charge_Histo*(*Time *or* events xx)_*date(mm-dd-yy)*—Time *(hhmm)*.txt	Ex.: *HRDW_Charge_Histo(Time 10)_02-10-21 Time 1610.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

- *Snapshot Mode*

.txt Structure

Typical Filename	*Activity Acronym*_Charge_Histo_*date(mm-dd-yy)*-Time-*time(hhmm)*.txt	Ex.: *HRDW_Charge_Histo_01-25-21 Time 1048.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

TDMS Structure

Typical Filename	*Activity Acronym*_Charge_Histo.*TDMS*	*Ex.:* *HRDW_Charge_Histo.TDMS*
General	TDMS Structure (NI standard), readable by Excel with "TDM Importer Plugin".	
File Properties recorder	**Dataset Conditions:** empty	
Organisation:		***Name***
Existing Groups	Group(s): 1	Charge Histogram
Channels	Channel(s): 2	X coord
		Histo(X)
Data Format	DT_Float (floating point double precision, 64 bits) DT_Long (long 32 bits integer)	
Data Type Recorded	Array	
Length	Depends on the number of bins present in the Histograms	

<u>**Two Channels tab**</u>

The storage of the histograms in the *Two Channels tab* can be occurred in snapshot mode only, as showed in Tab. 9.3.

Folder	Streaming Mode	Snapshot Mode
Histogram	--	.txt (ASCII), 2 separate files
TDMS	--	.*TDMS* (2 files) [Under request]

Tab. 9.3: Two channels saving scheme.

- <u>*Snapshot Mode*</u>

.txt Structure

Typical Filename	Hardware Management (generic)Ch*x*(channel number)_*date(mm-dd-yy)*-Time-*time(hhmm)*.txt A file is generated for each channel.	Ex.: *Hardware Management (generic)Ch1_02-09-21 Time 1238.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	Rate bin	Decimal float
		Counts/bin	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histograms		

TDMS Structure		
Typical Filename	*Activity Acronym*_2Ch_Charge_Histo.*TDMS*	Ex.: *HRDW_2Ch_Charge_Histo.TDMS*
General	TDMS Structure (NI standard), readable by Excel with “TDM Importer Plugin”.	
File Properties recorder	**Dataset Conditions:** empty	
Organisation:		***Name***
Existing Groups	Group(s): 2	Channel 0 Histogram Channel 1 Histogram
Channels	Channel(s): total 4, (2 per group)	X coord Histo(X)
Data Format	DT_Float (floating point double precision, 64 bits) DT_Long (long 32 bits integer)	
Data Type Recorded	Array	
Length	Depends on the number of bins present in the Histograms	

<u>**Charge vs Time tab**</u>

The Charge vs Time data can be saved in streaming and snapshot mode. The generated file formats are summarized in Tab. 9.4.

Folder	Streaming Mode	Snapshot Mode
Charge-Time	.TDMS streaming	--
TDMS	--	*.TDMS* (2 files) [Under request]

Tab. 9.4: Charge vs Time saving scheme.

- <u>*Streaming Mode*</u>

TDMS Structure		
Typical Filename	*Activity Acronym*_ChargeVSTime(Time *or* events xx)_*date(mm-dd-yy)*-T-*time(hhmm).TDMS*	Ex.: *HRDW_ChargeVSTime(Time 5)_02-09-21-T-1245.TDMS*
General	TDMS Structure (NI standard), readable by Excel with “TDM Importer Plugin”.	
File Properties recorder	**Dataset Conditions:** string record (*)	
Organisation:		***Name***
Existing Groups	Group(s): 1	ChargeVSTime
Channels	Channel(s): 2	Charge DGTZ-Ch.0 Charge DGTZ-Ch.1
Data Format	DT_Float (floating point double precision, 64 bits)	
Data Type Recorded	Array	
Length	Depends on the acquisition time or # of triggers	

- *Snapshot Mode*

TDMS Structure

Typical Filename	*Activity Acronym*_ChargeVSTime.*TDMS*	Ex.:*HRDW_ChargeVSTime.TDMS*
General	TDMS Structure (NI standard), readable by Excel with "TDM Importer Plugin".	
File Properties recorder	**Dataset Conditions:** empty	
Organisation:		***Name***
Existing Groups	Group(s): 1	ChargeVSTime
Channels	Channel(s): 2	Trace Ch. 0
		Trace Ch. 1
Channel Range	Full range	
Data Format	DT_Float (floating point double precision, 64 bits)	
Data Type	Array	
Length	Depends on the acquisition time or # of triggers	

Counting tab

The Counting tab data can be saved in snapshot mode only. The generated file formats are summarized in Tab. 9.5.

Folder	Streaming Mode	Snapshot Mode
Histogram	--	3 files *.txt* (ASCII)
TDMS	--	*.TDMS*

Tab. 9.5: Counting saving scheme.

- *Snapshot Mode*

.txt Structure

Typical Filename	• *ActivitymAcronym*_Counts_HistoFrequency_*date(mm-dd-yy)* Time *time(hhmm)*.txt • *ActivityAcronym*_Counts_HistoLeft_*date(mm-dd-yy)* Time *time(hhmm)*.txt • *ActivityAcronym*_Counts_HistoRight_*date(mm-dd-yy)* Time *time(hhmm)*.txt	Ex.: • *HRDW_Counts_HistoFrequency_01-23-21 Time 1219.txt* • *HRDW_Counts_HistoLeft_01-23-21 Time 1219.txt* • *HRDW_Counts_HistoRight_01-23-21 Time 1219.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns (all)		
Channels	Channels: 2 (Histo Left and Right)	X coord	Decimal float
		Histo(X)	Integer
Channels	Channels: (HistoFrequency)	Freq. or #of pulses	Decimal float
		Event Index	Integer
Data Format	Decimal separator: point (.)		
Data Type	Array(s)		
Recorded Length	Depends on the number of events present in the Plot		

TDMS Structure		
Typical Filename	*ActivityAcronym*_Counts_Histo.*TDMS*	Ex.: *HRDW_Counts_Histo.TDMS*
General	TDMS Structure (NI standard), readable by Excel with “TDM Importer Plugin”.	
File Properties recorder	**Dataset Conditions:** empty	
Organisation:		***Name***
Existing Groups	Group(s): 3	Count Histogram Left Count Histogram Right Frequency
Channels	Channel(s): total 6, (2 per group)	X coord
		Histo(X)
Data Format	DT_Float (floating point double precision, 64 bits) DT_Long (long 32 bits integer)	
Data Type Recorded	Array	
Length	Depends on the number of bins present in the Histograms	

(*) Dataset Conditions description

STRING Structure	
type	ASCII STRING, readable by any text editor. Variable. Terminated by \n (new line == 0x13 character). The string can be read abruptly until footer, and reproduced in any desirable context (comment, reports, screen fields,…)
HEADER	*** Start of Header ***
FOOTER	*** End of Header ***
Number of Records	56
Structure of records	*Description* <tab> *value* <nl> .OR. *Description* <nl> *Value* <nl>
Data Type Recorded	Single points of measures
Length	Fixed: 56 + 5 lines.
Contents	Example of a typical Dataset Condition header follows (with sample values) *** Start of Header *** Signature: HERA Writer V 1.0 Separator TAB Decimal Separator . Date: 05/01/2021 Time: 10.51.45 Username: Description: Dataset Channels: 2 Dataset Samples: 200 Data taking Conditions: Dataset metadata Date / Time creation: 20210105-T105144 User:

```
Activity code:	25
Sub-Activity code:		0
Sub-Activity:	D2 After-Pulses studies

PSAU settings:
 Channel in use:	0

Channels setting follow:
Ch.:	0
SiPM Serial:	*****
Bias Voltage [V]:	55,00
Gain [dB]:	32,00
Threshold [mV]:	-15,00
Channel Temperature [°C]:		25,50
T Compensation:		Off
dV/dT	50,00
Ch.:	1
SiPM Serial:	*****
Bias Voltage [V]:	55,00
Gain [dB]:	32,00
Threshold [mV]:	-15,00
Channel Temperature [°C]:		21,00
T Compensation:		Off
dV/dT	20,00

DGTZ settings:
 Model:	DT5720A
Model #:	9
Serial #:	812
Channel 0 Status:		On
Channel 1 Status:		Off
DC Offset 0:	0
DC Offset 1:	0
Trigger Mode:	FALSE
Trigger Rise Time:		8
Trigger Mean:	8
Trigger 0 Thresh.:		0
Trigger 1 Thresh.:		10
Gate Mode:	FALSE
Gate Width|Pre|Hold:		340 | 154 | 304
Baseline Mean|Thresh.|NoFlatTime:		1024 | 8 | 4008
Coincidence Status:		FALSE
Coincidence on GPO|Time:		0 | 0
*** End of Header ***
```

Notes: <nl> stays for "new line character". <tab> stays for Tab character.

Important Note:
Legend of the *Activity Acronyms*

- *HRDW:* Hardware Management
- *SiPM:* SiPM Experiments
- *ADV-AfterP:* Advanced Statistics Experiment (After-Pulses)
- *BETA:* Beta Spectroscopy Experiments
- *GAMMA*: Gamma Spectroscopy Experiments
- *PHOTONS*: Photons Experiments
- *COSMICS:* Cosmic Rays Experiments

Files generated during experimental activities.

The files generated during experimental activities are saved in different data formats. In addition to the previous data saving, each experimental activity generates a directory every time the activity is undergoing or has been completed. The file and directory names, the structure, and contents of these directories must not be changed. Moreover, no files can be added to those directories because it would affect data analysis procedures with different issues, including wrong results or the inability in performing the analysis.
The file formats are ASCII (.txt) and binary (.dat).
The .dat files contain direct binary copy of data in memory. Data represent a single histogram and is composed of two arrays of the same number of elements. This number depends on the number of bins included in the Histogram saved.
Arrays represent respectively the bin values sequence (float) and the counts per bin (integer).
No header or footer is present, so no data length information is present.
Arrays are aligned one after the other and data representation is, in the order: Double Precision Float (64 bits) and Long integer (32 bits). Therefore, the physical structure of the file is the following:

First array	Element 0	DB_F 7	DB_F 6	DB_F 5	DB_F 4	DB_F 3	DB_F 2	DB_F 1	DB_F 0
First array	Element 1	DB_F 7	DB_F 6	DB_F 5	DB_F 4	DB_F 3	DB_F 2	DB_F 1	DB_F 0
First array	Element 2	DB_F 7	DB_F 6	DB_F 5	DB_F 4	DB_F 3	DB_F 2	DB_F 1	DB_F 0
First array	…	DB_F 7	DB_F 6	DB_F 5	DB_F 4	DB_F 3	DB_F 2	DB_F 1	DB_F 0
First array	Element n	DB_F 7	DB_F 6	DB_F 5	DB_F 4	DB_F 3	DB_F 2	DB_F 1	DB_F 0
Second array	Element 0	I32 3	I32 2	I32 1	I32 0				
Second array	Element 1	I32 3	I32 2	I32 1	I32 0				
Second array	Element 2	I32 3	I32 2	I32 1	I32 0				
Second array	…	I32 3	I32 2	I32 1	I32 0				
Second array	Element n	I32 3	I32 2	I32 1	I32 0				

Tab. 9.6: Physical structure of the .dat files. Each coloured box indicates a single byte (8 bits).

Since no array length is prepend, the only way to locate and separate the two blocks is to consider that the first one must occupy the 2/3 of the total number of bytes and the second one the remaining 1/3.
Data are in Little Endian coding (Windows). Double Float is in 64-bit IEEE double-precision format.
For example, a .dat file of 72,000 bytes, contains:

1. The DB_Float array in the first 48,000 bytes
2. The I32 array in the following 24,000 bytes

And this principle must be used to locate and separate them.

- **Section A1: Silicon Photomultipliers**

The following table reports the organization of the data files generated by HERA during the experimental activities of Section A: Silicon Photomultipliers.

File generating experiment	Folder	Generation during the run	Description
A1.1 *Histogram TAB*	**20-1-DateTime-Histo_aaaa..**	• .dat (histogram binary) • .txt (ASCII) • Dataset Condition .txt	• Histogram of charge in binary • ASCII translation of the histogram • Dataset Condition.txt logfile
A1.2 *Histogram TAB*	**20-2-DateTime-Histo_aaaa..**	• ***n*** .dat (histogram binary) + • ***n*** .txt (ASCII) + • Dataset Condition .txt	• Histogram of charge in binary • ASCII translation of histogram • Dataset Condition.txt logfile.
A1.2 *Counting TAB*	**20-2-DateTime-Count_aaaa..**	• ***n*** .txt (counts summary) • Dataset Condition .txt	• Summary of measured counts • Dataset Conditions.txt logfile
A1.3 *Histogram TAB* (generates a series of directories. User can flag the directories with a mnemonic to find them during analysis)	**20-3-DateTime-Histo_aaaa..**	• ***n*** .dat (histogram binary) • ***n*** .txt (ASCII) • Dataset Conditions .txt • Temperat. Monitor.wvf • Temperat. Monitor.txt	• Histogram of charge in binary • ASCII translation of histogram • Dataset Condition.txt logfile • Temperature trends (binary waveform) • Temperature trends (ASCII)
A1.3 *Counting TAB* (generates a series of directories. User can flag the directories with a mnemonic to find them during analysis)	**20-3-DateTime-Count_aaaa..**	• ***n*** .txt (ASCII) • Dataset Condition .txt • Temperat. Monitor.wvf • Temperat. Monitor.txt	• Summary of measured counts • Dataset Condition.txt logfile • Temperature trends (binary waveform) • Temperature trends (ASCII)
in background for **all experiments**	**PSAU Temperatures**	.txt (ASCII) New file at every change of date (Log file type	

Tab. 9.7: Data saving scheme of the Experiments Section A1.

Activity 20.1: A1.1- SiPM Characterization

.txt Structure

Typical Filename	20-1-Raws_SiPM Basic.txt		
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	20-1-Raws_SiPM Basic.dat		
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 20.2: A1.2 - Dependence of the SiPM Properties on the Bias Voltage [Histogram TAB]

.txt Structure

Typical Filename	20-2-Raws_Bias[V] xx,xx.txt	Ex.: *20-2-Raws_Bias[V] 55,20.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	20-2-Raws_Bias[V] xx,xx.dat	Ex.: *20-2-Raws_Bias[V] 55,20.dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Conditions are replicated in the file names. Never change the names of the .bin files.

<u>Activity 20.2: A1.2 - Dependence of the SiPM Properties on the Bias Voltage [Counting TAB]</u>

.txt Structure (Dark Count vs Bias) *Summary of measured counts*

Typical Filename	20-2 Dark_Bias[V]*xx,yy*.txt *<u>Never change filename and contents of this file.</u>*	Xx,yy indicates Bias conditions in Volts	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Channels	Channel(s):	Rate 0.5	Decimal float
		Rate 0.5 error	Decimal float
		Rate 1.5	Decimal float
		Rate 1.5 error	Decimal float
		OCT	Decimal float
		OCT Error	Decimal float
Data Format	Decimal separator: O.S. dependent (" , " or " . ")		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 20.3: A1.3 - Temperature Effects on SiPM Properties [Histogram TAB]

.txt Structure

Typical Filename	20-3-Raws_Bias[V] xx,xx -Temp[°C] xx.txt	Ex.: *20-3-Raws_Bias[V] 55,00 -Temp[°C] 30.txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	20-3-Raws_Bias[V] xx,xx -Temp[°C] xx.dat	Ex.: *20-3-Raws_Bias[V] 55,00 -Temp[°C] 30.dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Conditions are replicated in the file names. <u>Never change the names of the .bin files.</u>
The file "*Temperature Monitor.wvf*" is used internally by the Analysis procedure. Not provided for custom analysis. <u>Never change the name file of this file.</u>
The "Temperature Monitor.txt" file = ASCII translation of the Waveform TM file.

.txt Structure (Temperature Monitor)

Filename	Temperature Monitor.txt		
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:		***Name***	***Type***
Structure	4 columns		
Separation character	TAB		
Channels	Channel(s): 4	Timestamp	Date Time (O.S. format)
	PSAU Board	Y[0]	Decimal float
	PSAU Ch. 0	Y[1]	Decimal float
	PSAU Ch. 1	Y[2]	Decimal float
Data Format	Decimal separator: O.S. dependent (" , " or " . ")		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Depends on the running time of the Experiment		

Activity 20.3: A1.3 - Temperature Effects on SiPM Properties [Counting TAB]

Summary of measured counts

Typical Filename	20-3-Dark_Bias[V] xx,xx -Temp[°C] xx *Never change filename and contents of this file.*	Ex.: *20-3-Dark_Bias[V] 55,00 - Temp[°C] 28.txt*	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Channels	Channel(s):	Rate 0.5	Decimal float
		Rate 0.5 error	Decimal float
		Rate 1.5	Decimal float
		Rate 1.5 error	Decimal float
		OCT	Decimal float
		OCT Error	Decimal float
Data Format	Decimal separator: O.S. dependent (“ , “ or “ . “)		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

- **Section n B1: Gamma Spectroscopy**

The following table reports the organization of the data files generated by HERA during the experimental activities of Section B1: Gamma Spectroscopy.

<table>
<tr><th>File generating experiment</th><th>Folder</th><th>Generation during the run</th><th>Description</th></tr>
<tr><td>B1.1
Counting TAB</td><td>21-1-DateTime-Count_aaaa..</td><td>• .txt (ASCII)
• Dataset Condition .txt</td><td>• Summary of measured counts
• Dataset Condition.txt logfile</td></tr>
<tr><td>B1.2
Counting TAB</td><td>21-2-DateTime-Count_aaaa..</td><td colspan="2">Not yet implemented!</td></tr>
<tr><td>B1.3
Histogram TAB</td><td>21-3-DateTime-Histo_aaaa..</td><td>• .txt (ASCII)
• .dat (histogram binary)
• Dataset Condition .txt</td><td>• Histogram of charge in binary
• ASCII translation of the histogram
• Dataset Conditions.txt logfile</td></tr>
<tr><td>B1.4
Histogram TAB</td><td>21-4-DateTime-Histo_aaaa..</td><td>• n .dat (histogram binary)
• n .txt (ASCII)
• Dataset Conditions .txt</td><td>• Histogram of charge in binary
• ASCII translation of histogram
• Dataset Condition.txt logfile</td></tr>
<tr><td>B1.5
Histogram TAB</td><td>21-5-DateTime-Histo_aaaa..</td><td>• n .dat (histogram binary)
• n .txt (ASCII)
• Dataset Conditions .txt</td><td>• Histogram of charge in binary
• ASCII translation of histogram
• Dataset Condition.txt logfile</td></tr>
<tr><td>B1.6
Histogram TAB</td><td>21-6-DateTime-Histo_aaaa..</td><td>• n .dat (histogram binary)
• n .txt (ASCII)
Dataset Conditions .txt</td><td>• Histogram of charge in binary
• ASCII translation of histogram
• Dataset Condition.txt logfile</td></tr>
<tr><td>B1.7
Histogram TAB</td><td>21-7-DateTime-Histo_aaaa..</td><td>• n .dat (histogram binary)
• n .txt (ASCII)
Dataset Conditions .txt</td><td>• Histogram of charge in binary
• ASCII translation of histogram
• Dataset Condition.txt logfile</td></tr>
<tr><td>in background for all experiments</td><td>PSAU Temperatures</td><td>.txt (ASCII) New file at every change of date (Log file type</td><td></td></tr>
</table>

Tab. 9.8: Data saving scheme of the Experiments Section B1.

Activity 21.1: B1.1- Detecting γ-Radiation

.txt Structure	*Summary of measured counts*		
Typical Filename	20-2 Dark_Gamma Spectroscopy.txt *Never change filename and contents of this file.*		
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Channels	Channel(s):	Rate Src	Decimal float
		Rate Src error	Decimal float
		Rate NO Src	Decimal float
		Rate NO Src error	Decimal float
Data Format	Decimal separator: O.S. dependent (“ , “ or “ . “)		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)	
Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 21.3: B1.3- γ Spectrum and Energy Resolution

.txt Structure

Typical Filename	21-3-Raws_En.Spectrum –(Time or Events *xxx*).txt	Ex.: *21-3-Raws_En. Spectrum -(Time 300).txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	21-3-Raws_En.Spectrum –(Time or Events *xxx*).dat	Ex.: *21-3-Raws_En. Spectrum -(Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 21.4: B1.4- System Calibration: Linearity and Resolution

.txt Structure

Typical Filename	21-4-Raws_Source *-nnn-AAA* (Time *xxx*).txt	Ex.: *21-4-Raws_Source -22-Na (Time 300).txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	21-4-Raws_Source *-nnn-AAA* (Time *xxx*).dat	Ex.: *21-4-Raws_Source -22-Na (Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

Activity 21.5: B1.5- Scintillator Crystals Comparison: Light Yield and Decay Time

.txt Structure

Typical Filename	21-5-Raws_Crystal -*AAA* (Time *xxx*).txt	Ex.: *21-5-Raws_Crystal-BGO (Time 300).txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	21-5-Raws_Crystal -*AAA* (Time *xxx*).dat	Ex.: *21-5-Raws_Crystal-BGO (Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

Activity 21.6: B1.6- γ-Radiation Absorption

.txt Structure

Typical Filename	21-6-Raws_ Tower[mm] *xx Thick.yy* (Time *zzz*).txt	Ex.: *21-6-Raws_Tower[mm] 50 Thick.20 (Time 300).txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	21-6-Raws_ Tower[mm] *xx Thick.yy* (Time *zzz*).dat	Ex.: *21-6-Raws_Tower[mm] 50 Thick.20 (Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

<u>**Note:**</u> Conditions are replicated in the file names. <u>*Never change the names of the .bin files.*</u>

Activity 21.7: B1.7- Photonuclear cross-section/Compton Scattering cross-section

.txt Structure

Typical Filename	21-7-Raws_ Source -*xxx-AAA* (Time *zzz*).txt	Ex.: *21-7-Raws_Source -22-Na (Time 300)txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	21-7-Raws_ Source -*xxx-AAA* (Time *zzz*).dat	Ex.: *21-7-Raws_Source -22-Na (Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

- **Section B2: Beta Spectroscopy**

The following table reports the organization of the data files generated by HERA during the experimental activities of Section B2: Beta Spectroscopy.

File generating experiment	Folder	Generation during the run	Description
B2.1 *Counting TAB*	**22-1-DateTime-Count_aaaa..**	• .txt (ASCII) • Dataset Condition .txt	• Summary of measured counts • Dataset Condition.txt logfile
B2.2 *Histogram TAB*	**22-2-DateTime-Histo_aaaa..**	• .txt (ASCII) • .dat (histogram binary) • Dataset Condition .txt	• Histogram of charge in binary • ASCII translation of the histogram • Dataset Conditions.txt logfile
B2.3 *Counting TAB*	**22-3-DateTime-Count_aaaa..**	• ***n*** .txt (ASCII) • Dataset Conditions .txt	• Summary of measured counts • Dataset Condition.txt logfile
B2.4 *Counting TAB*	**22-4-DateTime-Count_aaaa..**	• ***n*** .txt (ASCII) • Dataset Conditions .txt	• Summary of measured counts • Dataset Condition.txt logfile
in background for **all experiments**	**PSAU Temperatures**	.txt (ASCII) New file at every change of date (Log file type	

Tab. 9.9: Data saving scheme of the Experiments Section B2.

Activity 22.1: B2.1- Response of a Plastic Scintillating Tile

.txt Structure	*Summary of measured counts*		
Typical Filename	20-2 Dark_Gamma Spectroscopy.txt *Never change filename and contents of this file.*		
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***

.txt Structure	*Summary of measured counts*		
Typical Filename	20-2 Dark_Posn[i].txt *Never change filename and contents of this file.*	*i* indicates position of the radioactive source on the detector	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Header	Positional: Rates[Hz], Ratio[%]		
Channels	Channel(s):	Rate Src	Decimal float
		Rate Src error	Decimal float
		Rate NO Src	Decimal float
		Rate NO Src error	Decimal float
		Ratio	Decimal float
		Ratio error	Decimal float
Data Format	Decimal separator: O.S. dependent (“ , “ or “ . “)		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)	
Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 22.2: B2.2- β Spectroscopy

.txt Structure

Typical Filename	22-2-Raws_En.Spectrum –(Time or Events *xxx*).txt	Ex.: *22-2-Raws_En. Spectrum -(Time 300).txt*	
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	22-2-Raws_En.Spectrum –(Time or Events *xxx*).dat	Ex.: *22-2-Raws_En. Spectrum -(Time 300).dat*	
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Activity 22.3: B2.3- β-Radiation: Transmission through Matter

.txt Structure	*Summary of measured counts*		
Typical Filename	22-3 Dark_NumS[n] *x*-Mpp MAI[mm]*y,yy*.txt *Never change filename and contents of this file.*	*x* indicates number of layers used; y,yy width in mm Ex.: *22-3-Dark_NumS[n] 0-MPp[mm]1,00*	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Header	Radiation Transmission: Rate[kHz], Dev[kHz]		
Channels	Channel(s):	Rate [kHz]	Decimal float
		Rate [kHz]	Decimal float
Data Format	Decimal separator: O.S. dependent (“ , “ or “ . “)		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)	
Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

Activity 22.4: B2.4- β-Radiation as a Method to Measure Paper Sheet Grammage and Thin Layer Thickness

.txt Structure	*Summary of measured counts*		
Typical Filename	22-3 Dark_NumS[n] *x*.txt *Never change filename and contents of this file.*	*x* indicates number of layers used. Ex.: *22-4-Dark_NumS[n] 0.txt*	
General	ASCII File, readable by any text editor. Fixed length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** absent		
Organisation:	Name and value per line	***Name***	***Type***
Structure	2 columns, 7 rows (fixed)		
Separation character	TAB		
Header	Radiation Transmission : Rate[kHz], Dev[kHz]		
Channels	Channel(s):	Rate [kHz]	Decimal float
		Rate [kHz]	Decimal float
Data Format	Decimal separator: O.S. dependent (“ , “ or “ . “)		
Data Type Recorded	Single points of measures during execution of the experiment		
Length	Fixed		

.txt Structure (Dataset Conditions)	
Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

- **Section C2: Photons**

The following table reports the organization of the data files generated by HERA during the experimental activities of Section C2: Photons.

File generating experiment	Folder	Generation during the run	Description
C2.2 *Histogram TAB*	**24-2-DateTime-Histo_aaaa..**	• .txt (ASCII) • .dat (histogram binary) • Dataset Condition .txt	• Histogram of charge in binary • ASCII translation of the histogram • Dataset Conditions.txt logfile
in background for **all experiments**	**PSAU Temperatures**	.txt (ASCII) New file at every change of date (Log file type	

Tab. 9.10: Data saving scheme of the Experiments Section C2.

Activity 24.2: C2.2- Hands-on Photon Counting Statistics

.txt Structure

Typical Filename	24-18-Raws_LEDS[n] 0,00.txt		
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).		
File Properties recorder	**Dataset Conditions:** string record (*)		
Organisation:		***Name***	***Type***
Structure	2 columns		
Channels	Channel(s): 2	ADC Channel	Decimal float
		Counts	Integer
Data Format	Decimal separator: point (.)		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.dat Structure (histogram Binary)

Typical Filename	24-18-Raws_LEDS[n] 0,00.dat		
General	Direct Binary. Used by Analysis procedure only. Not recommended for custom analysis.		
File Properties recorder	**Not applicable**		
Organisation:		***Name***	***Type***
Structure	Cluster of 2 elements		
Elements	Arrays	Not applicable	Decimal float
		Not applicable	Long Integer
Data Format	Not applicable		
Data Type Recorded	Array(s)		
Length	Depends on the number of bins present in the Histogram		

.txt Structure (Dataset Conditions)

Filename	Dataset Conditions.txt
General	ASCII File, readable by any text editor. Variable length records. Terminated by \n (new line == 0x13 character).
File Properties recorder	**Dataset Conditions:** string record (*) without Header and Footer
Organisation:	No further structures are present
Data Format	Decimal separator: point (.)

Note: Conditions are replicated in the file names. *Never change the names of the .bin files.*

10 Instructions for Cleaning

The equipment may be cleaned with isopropyl alcohol or deionized water and air dried. Clean the exterior of the product only.
Do not apply cleaner directly to the items or allow liquids to enter or spill on the product.

10.1 Cleaning the Touchscreen

To clean the touchscreen (if present), wipe the screen with a towelette designed for cleaning monitors or with a clean cloth moistened with water.
Do not use sprays or aerosols directly on the screen; the liquid may seep into the housing and damage a component. Never use solvents or flammable liquids on the screen.

10.2 Cleaning the air vents

It is recommended to occasionally clean the air vents (if present) on all vented sides of the board. Lint, dust, and other foreign matter can block the vents and limit the airflow. Be sure to unplug the board before cleaning the air vents and follow the general cleaning safety precautions.

10.3 General cleaning safety precautions

CAEN recommends cleaning the device using the following precautions:

1) Never use solvents or flammable solutions to clean the board.
2) Never immerse any parts in water or cleaning solutions; apply any liquids to a clean cloth and then use the cloth on the component.
3) Always unplug the board when cleaning with liquids or damp cloths.
4) Always unplug the board before cleaning the air vents.
5) Wear safety glasses equipped with side shields when cleaning the board.

11 Device decommissioning

After its intended service, it is recommended to perform the following actions:

- Detach all the signal/input/output cable
- Wrap the device in its protective packaging
- Insert the device in its packaging (if present)

THE DEVICE SHALL BE STORED ONLY AT THE ENVIRONMENT CONDITIONS SPECIFIED IN THE MANUAL, OTHERWISE PERFORMANCES AND SAFETY WILL NOT BE GUARANTEED

12 Disposal

The disposal of the equipment must be managed in accordance with Directive 2012/19 / EU on waste electrical and electronic equipment (WEEE).

The crossed bin symbol indicates that the device shall not be disposed with regular residual waste.

13 Technical Support

To contact CAEN specialists for requests on the software, hardware, and board return and repair, it is necessary a MyCAEN+ account on www.caen.it:

https://www.caen.it/support-services/getting-started-with-mycaen-portal/

All the instructions for use the Support platform are in the document:

A paper copy of the document is delivered with CAEN boards.

The document is downloadable for free in PDF digital format at:

https://www.caen.it/wp-content/uploads/2022/11/Safety_information_Product_support_W.pdf

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GD5484 - SP5600AN rev. 1 - 5th December 2022 00100-0-SIPM0-G000