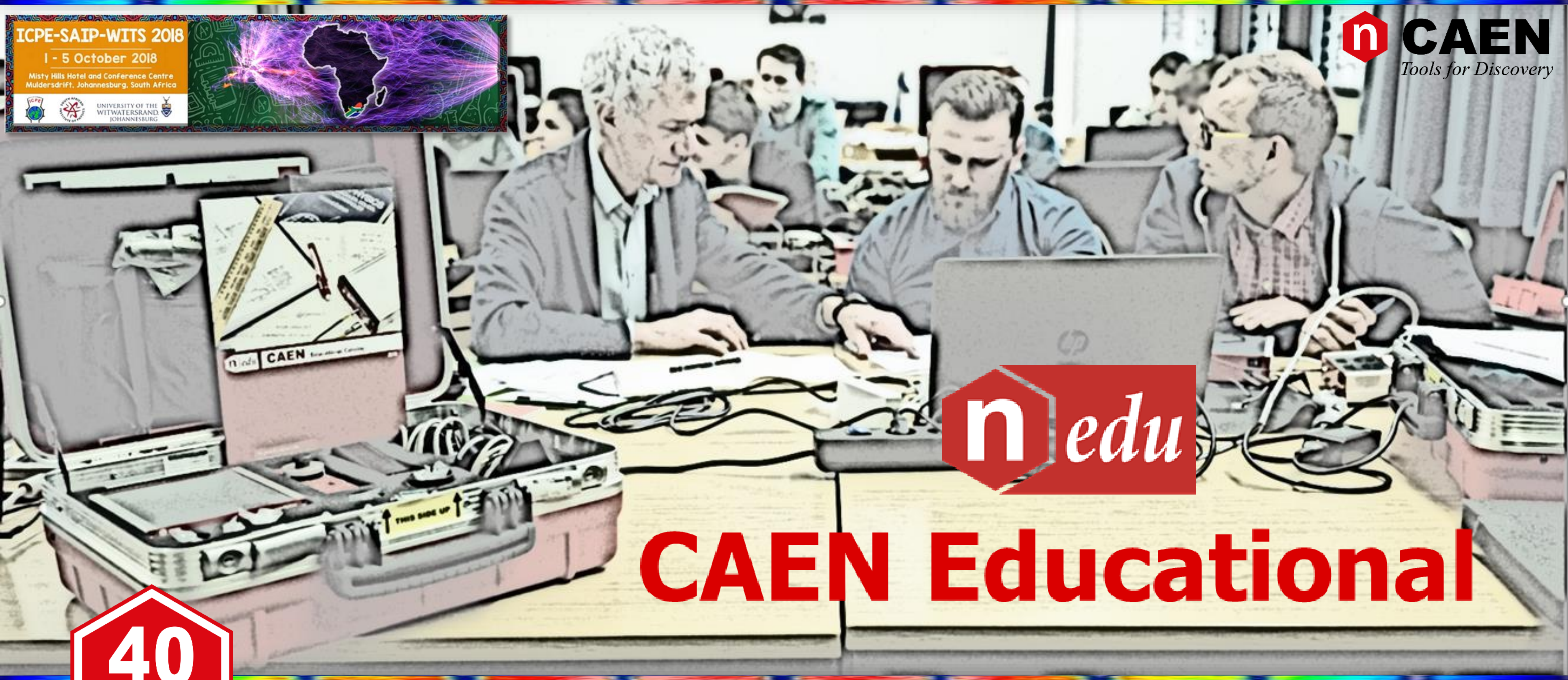


CAEN Educational

40 YEARS of INNOVATION 1979-2019

The 16th IPPOG meeting

CERN, 4th – 6th October

Massimo Venaruzzo – Cristina Mattone

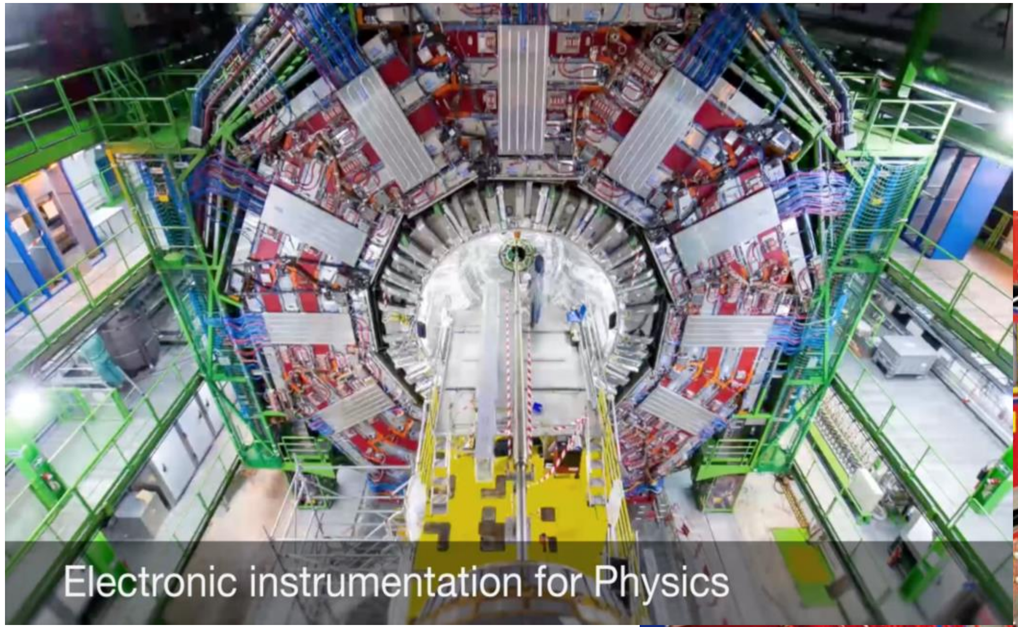
CAEN Tools for Discovery

CAEN Company

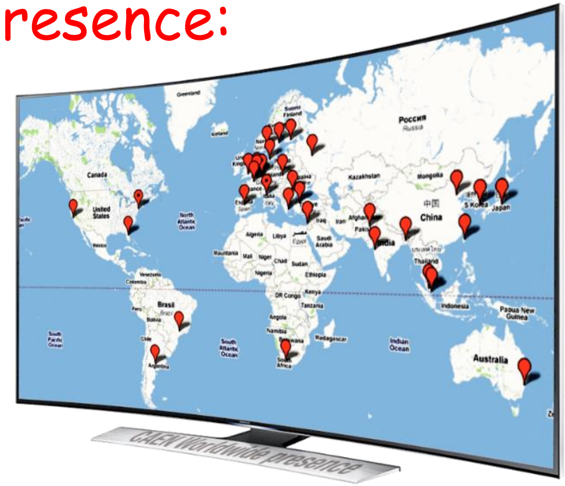
Founded in 1979, CAEN SpA (Costruzioni Apparecchiature Elettroniche Nucleare) is an important industrial spin-off of the INFN.

CAEN SpA

Core business:
Electronic Instrumentation for physics experiments (world leader)

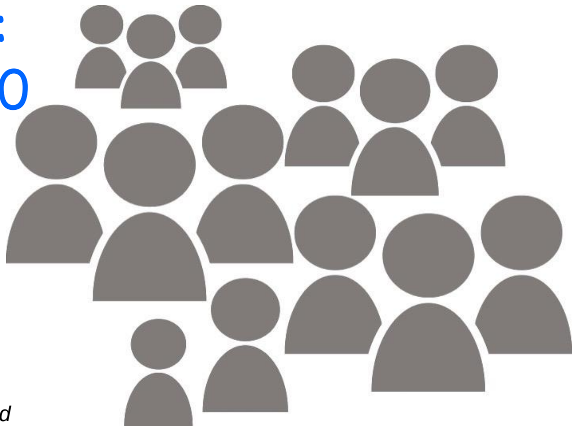


Worldwide Presence:



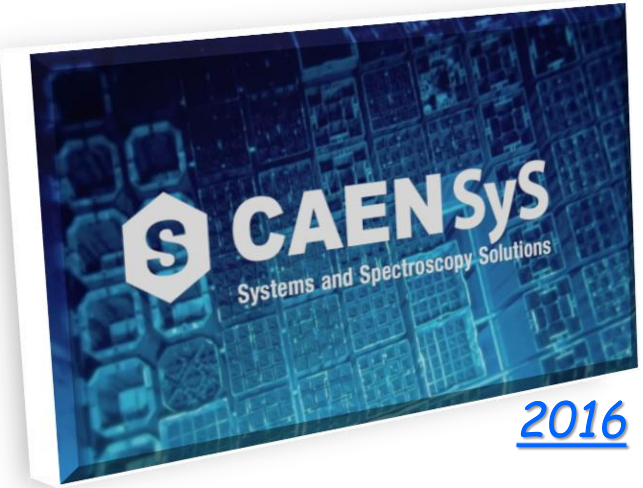
Sales network offices in Italy, Germany, USA, Distributors in more than 30 countries.

Total Emploee: 120



CAEN Network

CAEN SpA



2016

- ✓ Safety
- ✓ Security
- ✓ Laboratories

2003

- ✓ UHF RFID Readers
- ✓ RFID Tags

2010

- ✓ Magnet Power Supplies
- ✓ Precision Current Measurement
- ✓ DCCTs
- ✓ Beamline Electronic Instrumentation
- ✓ FMC and mTCA.4

2012

- ✓ Information Security
- ✓ Managed Security Services
- ✓ Technologies Consulting
- ✓ Risk Assessment & Vulnerability
- ✓ Compliance Consulting

CAEN brings the experience acquired in almost 40 years of collaboration with the High Energy & Nuclear Physics community into the University educational laboratories.

CAEN enters the world of learning and training by providing modern physics experiments for University advanced labs based on the latest technologies and instrumentation.

Main Scientific Collaborations:

University of Insubria (IT)

University of Aveiro (PT)

A series of educational notes and scientific papers!

CAEN Tools for Discovery

CAEN Educational

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CAEN enters the world of learning and training by providing modern physics experiments for University advanced labs based on the latest technologies and instrumentation.

Goals

Inspire students and guide them towards the analysis and comprehension of different physics phenomena with a series of experiments based on state-of-the art technologies, instruments and methods

Target the experiment depending on the student educational level. With this approach, the experiments proposed can be performed at high school level (grade 11,12) science classes up to undergraduate physics laboratory and PhD courses.

CAEN
Tools for Discovery

CAEN Educational

Be part of the project: develop your own experience and send an email to **educational@caen.it**

Goals

Help the tutors in exploiting the most advanced capabilities of our educational product and create a community in which they can share their own experiment and make it available for everyone.

Inspire students and guide them towards the analysis and comprehension of different physics phenomena with a series of experiments based on state-of-the art technologies, instruments and methods

Target the experiment depending on the student educational level. With this approach, the experiments proposed can be performed at high school level (grade 11,12) science classes up to undergraduate physics laboratory and PhD courses.

CAEN Tools for Discovery

University of Insubria

CAEN Educational History

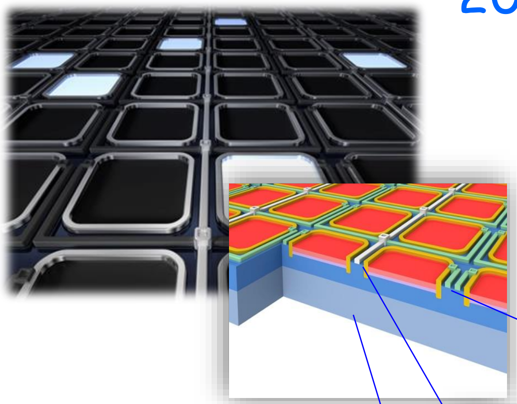
The project was born as a by-product of **RAPSODI** (*RAdiation Protection with Silicon Optoelectronic Devices and Instruments*): FP6 founded project.

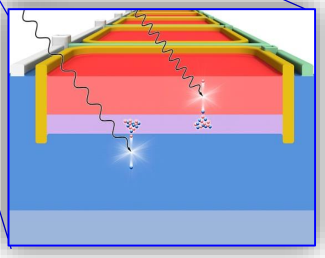
RAPSODI Main objectives ⟶ SiPM development and optimization for three different applications: Dosimetry in Mammography, Radon Monitoring, illicit traffic of radioactive material

"Prototypes of an easy-to-use, flexible, modular kit for the characterization of SiPM"

2009/10 ⟶ Licensing of the background knowledge to CAEN

SiPM Evaluation & Educational Kit



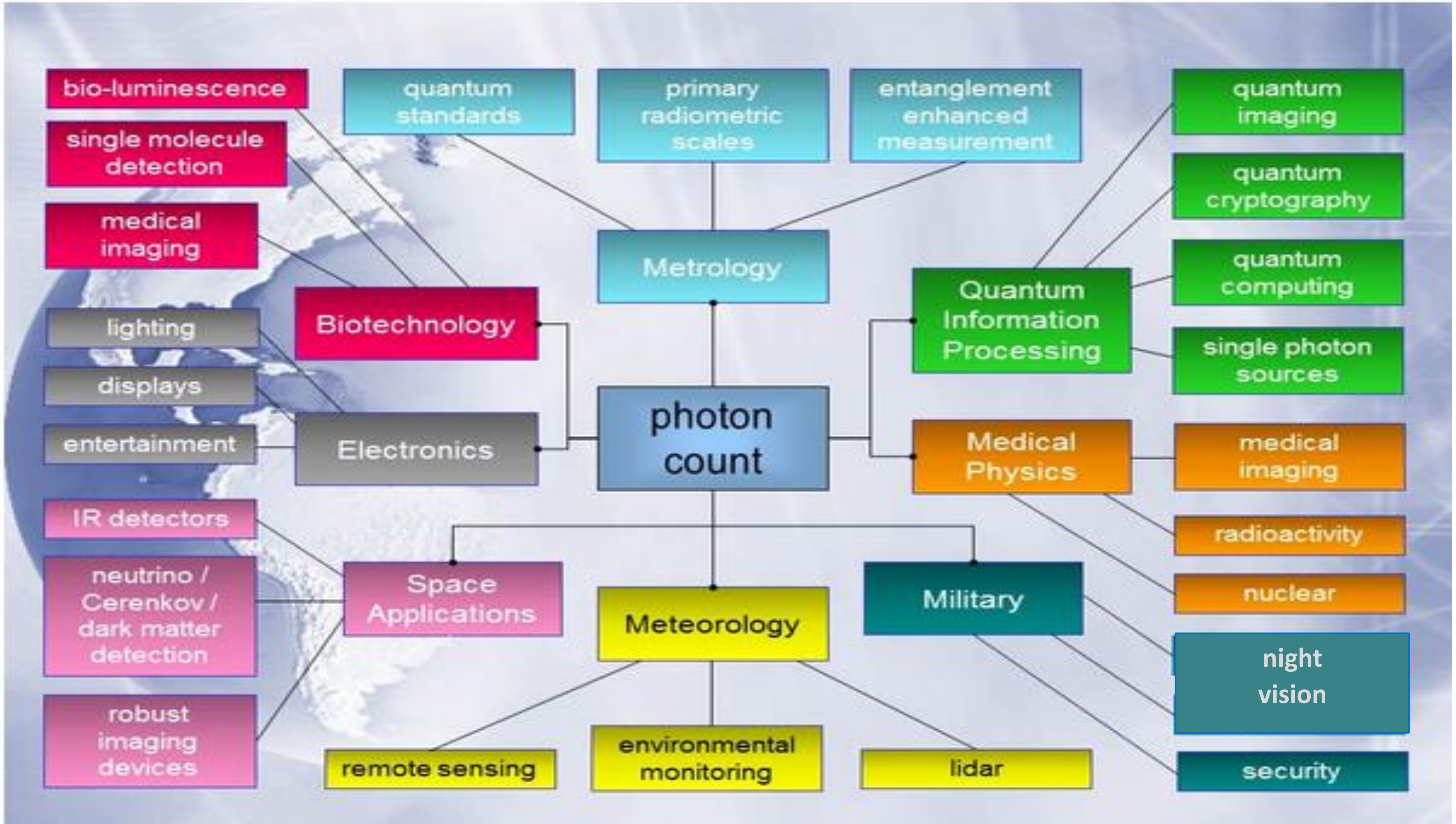


Silicon Photomultiplier (SiPM) is a high density (up to $10^4/mm^2$) matrix of diodes with a common output, working in Geiger-Müller regime with 10^6 gain

- High Gain
- Low Voltage
- High photon number resolving power
- Wide dynamic range
- Good timing capability
- Low cost
- Withstanding to magnetic field

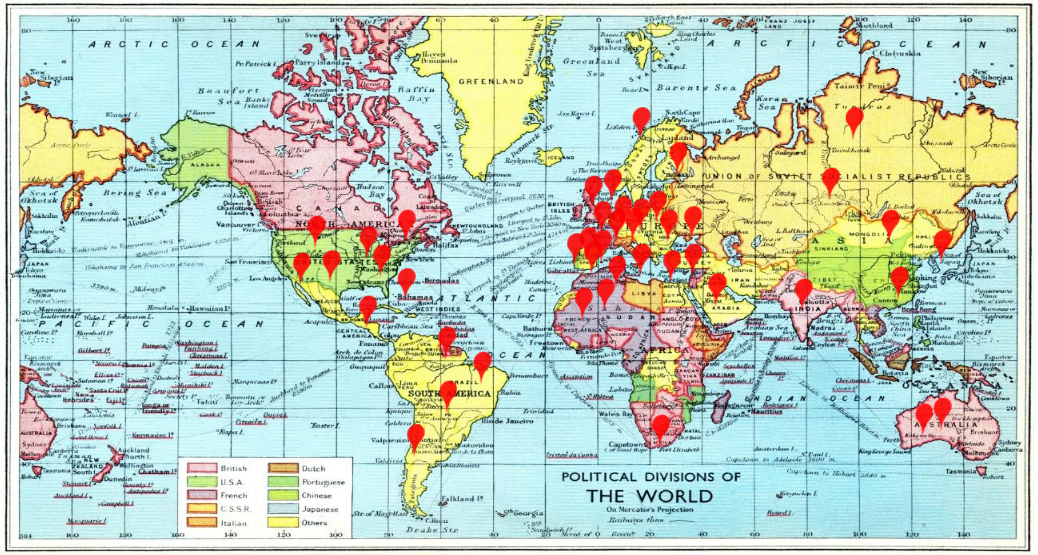
Dark Counts (DCR)
Optical Cross Talk (OCT)
After Pulse (AP)

Latest Technology - SiPM



Summary Table from http://www.photoncount.org

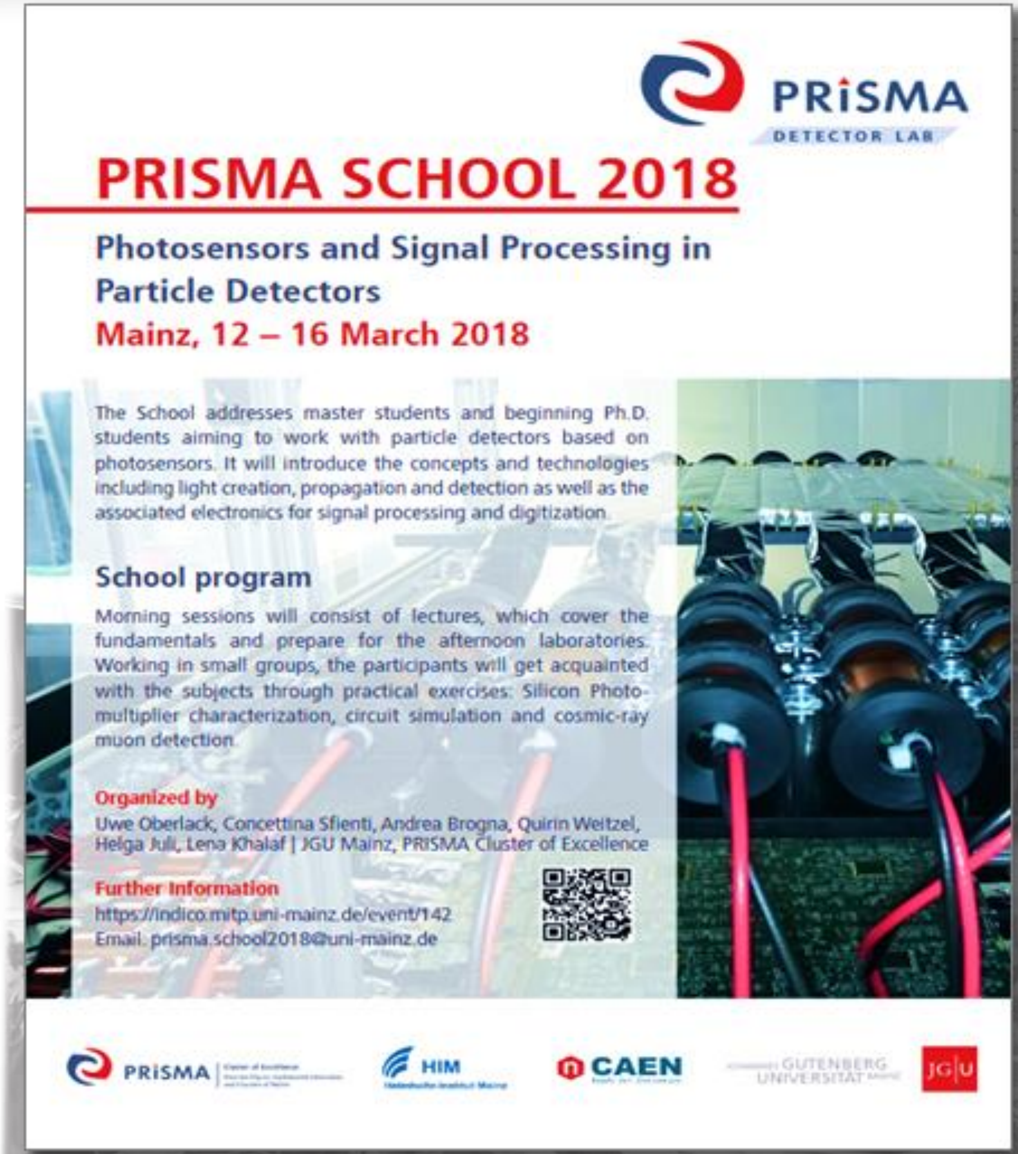
Market diffusion



Universities & Research Institutes:

- Outreach and Masterclass
- Training courses for High School teachers
- High school Laboratory courses
- University and PhD Laboratory courses
- PhD schools
- Research tools

Market diffusion


PRISMA DETECTOR LAB

PRISMA SCHOOL 2018

Photosensors and Signal Processing in Particle Detectors

Mainz, 12 – 16 March 2018

The School addresses master students and beginning Ph.D. students aiming to work with particle detectors based on photosensors. It will introduce the concepts and technologies including light creation, propagation and detection as well as the associated electronics for signal processing and digitization.

School program

Morning sessions will consist of lectures, which cover the fundamentals and prepare for the afternoon laboratories. Working in small groups, the participants will get acquainted with the subjects through practical exercises: Silicon Photomultiplier characterization, circuit simulation and cosmic-ray muon detection.

Organized by

Uwe Oberlack, Concettina Sfienti, Andrea Brogna, Quirin Weitzel, Helga Jull, Lena Khalaf | JGU Mainz, PRISMA Cluster of Excellence

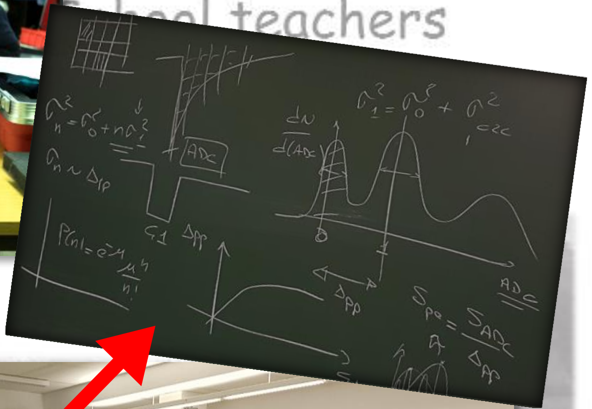
Further Information

https://indico.mitp.uni-mainz.de/event/142

Email: prisma.school2018@uni-mainz.de

Institutes:

- ...hool teachers
- Research tools



Prof. Massimo Caccia
Dr. Andrea Brogna
Dr. Quirin Weitzel

CAEN Tools for Discovery

Market diffusion

Training Course for ERASMUS Mundus Program

Viareggio
Italy, July 2018

Erasmus Mundus JMD on Nuclear Physics

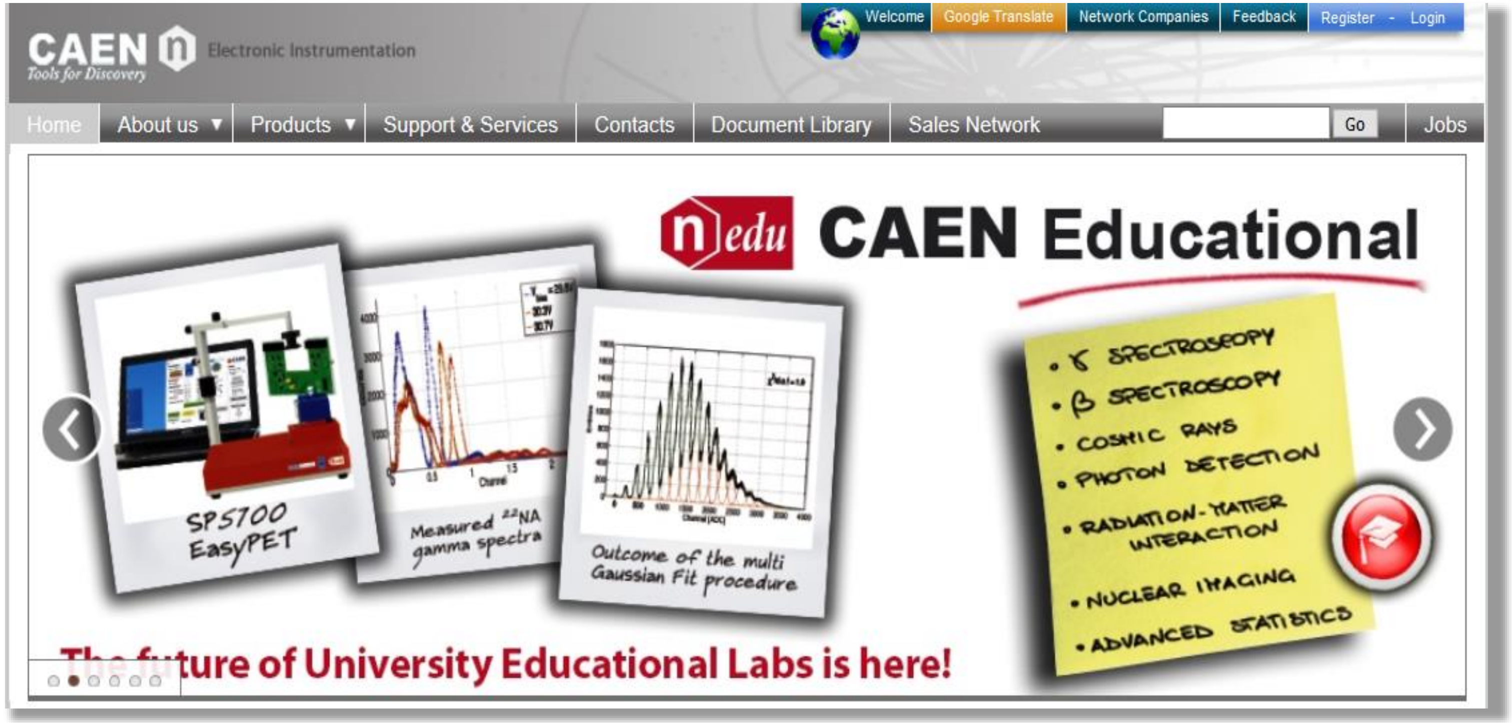
Market diffusion

IEEE Educational Collaboration

"IEEE NPSS International School for Real Time Systems in Particle Physics 2018"

Cape Town, July 2018

Website



Info:
educational@caen.it

A dedicated Web Page
www.caen.it/educational

Physics Experiments

Particle Detector Characterization

Silicon Photomultiplier (SiPM)

- ✓SiPM Characterization
- ✓Dependence of the SiPM Properties on the bias voltage
- ✓Temperature Effects on SiPM Properties

Nuclear Physics and Radioactivity

γ Spectroscopy

- ✓Detecting γ-Radiation
- ✓Poisson and Gaussian Distributions
- ✓Energy Resolution
- ✓System Calibration: Linearity and Resolution
- ✓A comparison of different scintillating crystals: Light Yield , Decay Time and resolution
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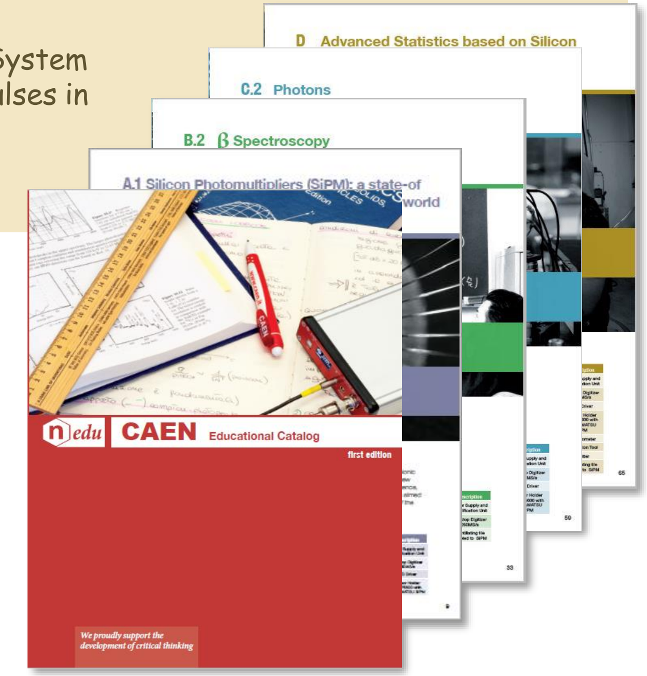

nedu CAEN Tools for Discovery

Physics Experiments

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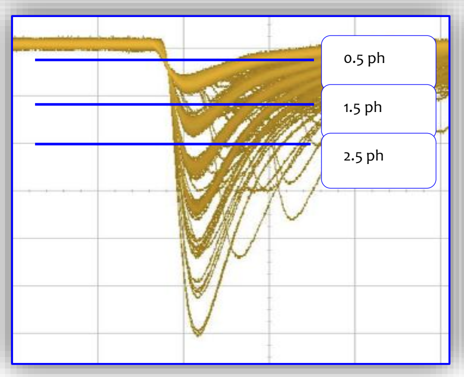
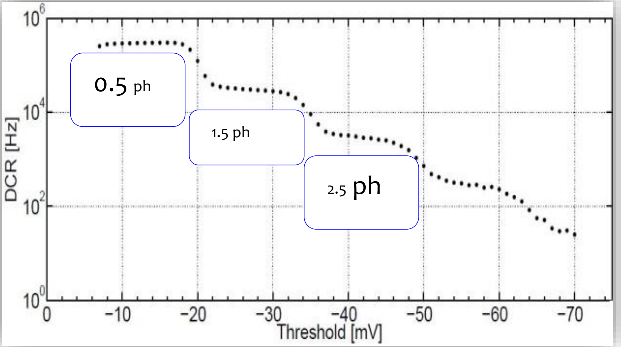
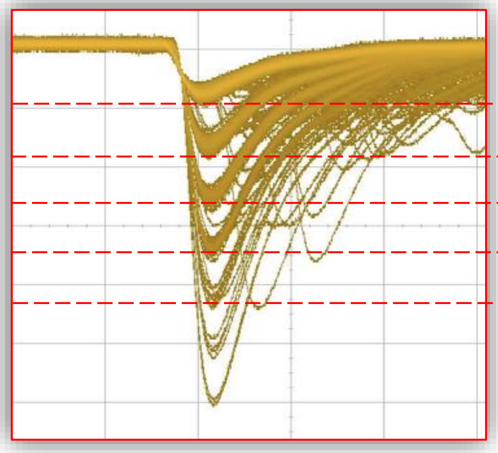
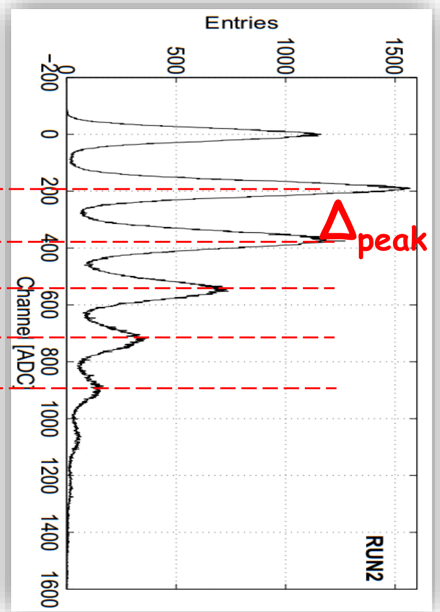




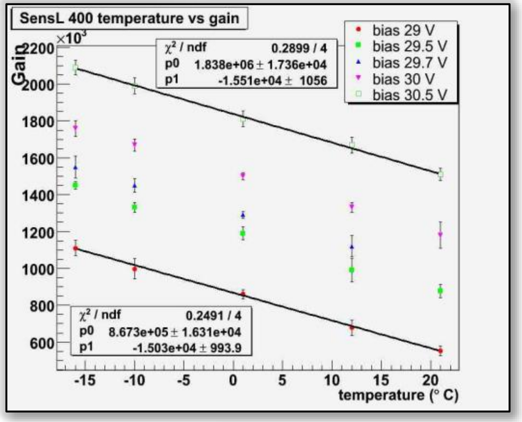
DCR & OCT

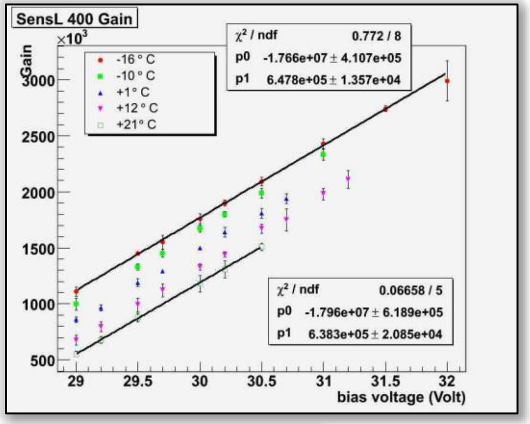
$\Delta_{peak} \propto$ gain



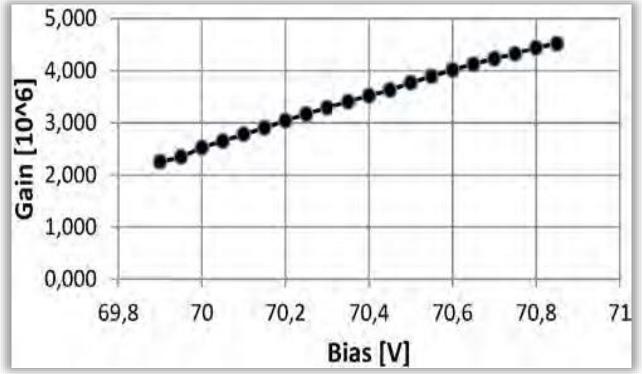


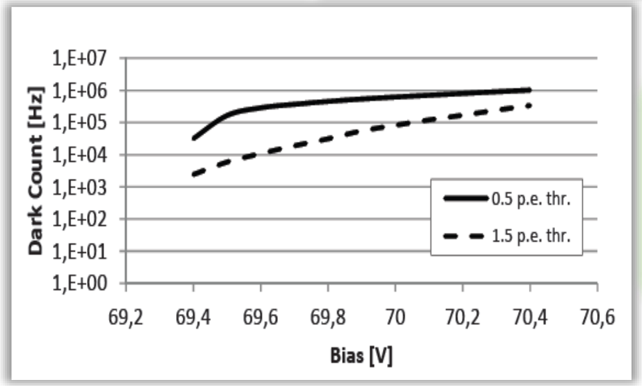
T Effects





- Peak width:
  - System noise
  - Cell-to-cell gain variation (process uncertainties)
  - I_{leak} fluctuations
  - Spurious hits in the QDC integration time





Vbias

Physics Experiments

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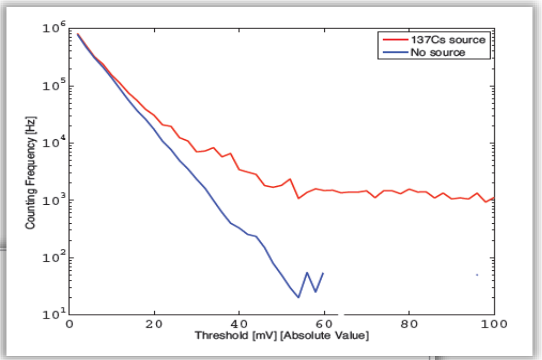

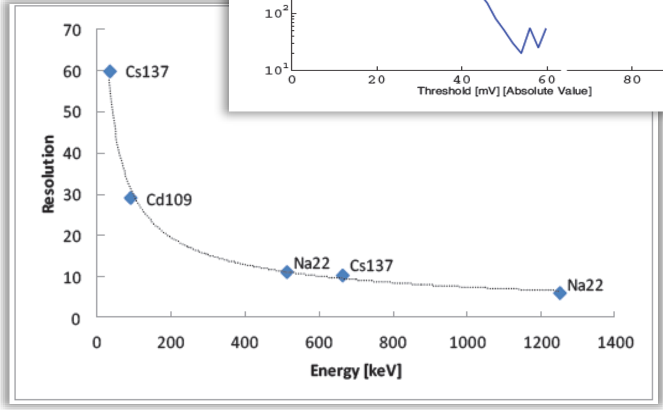

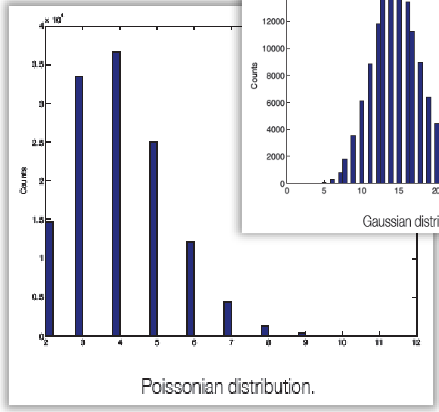

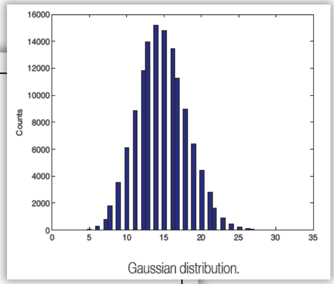

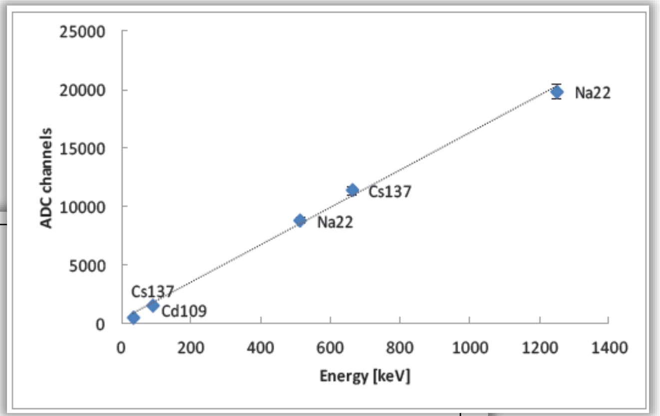

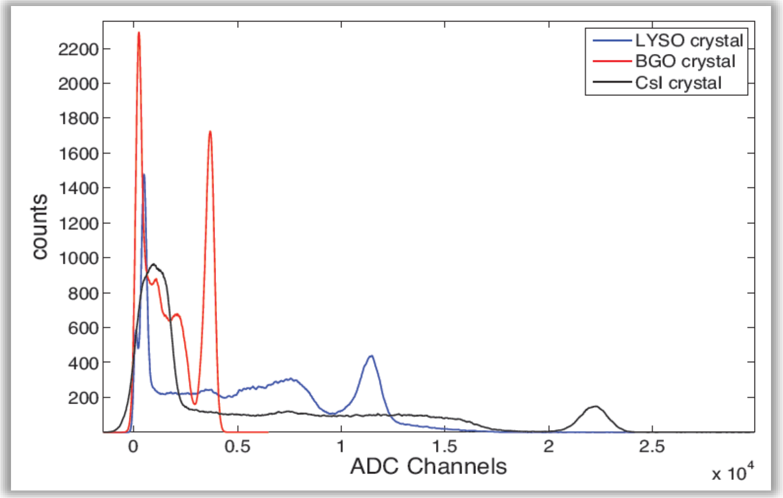

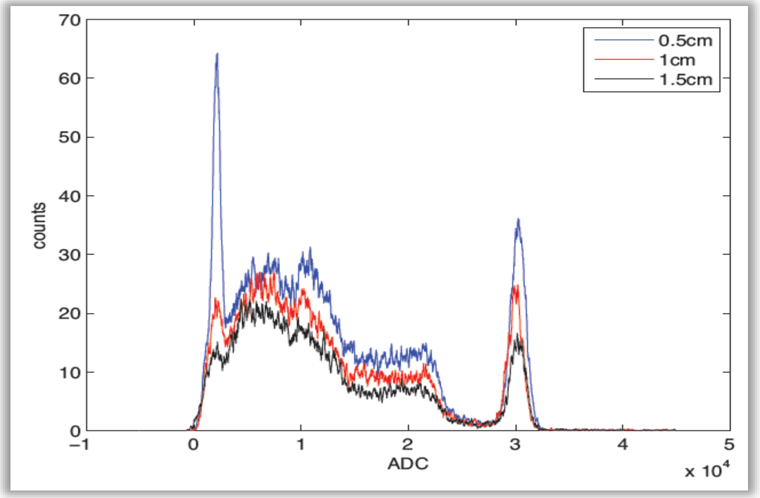

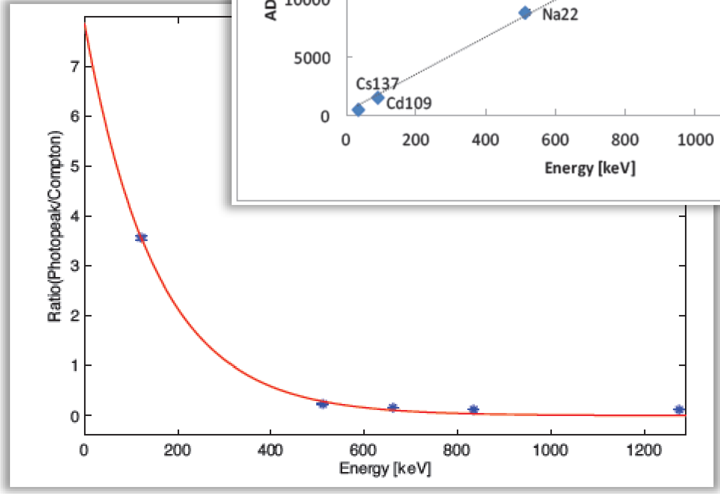

Physics Experiments

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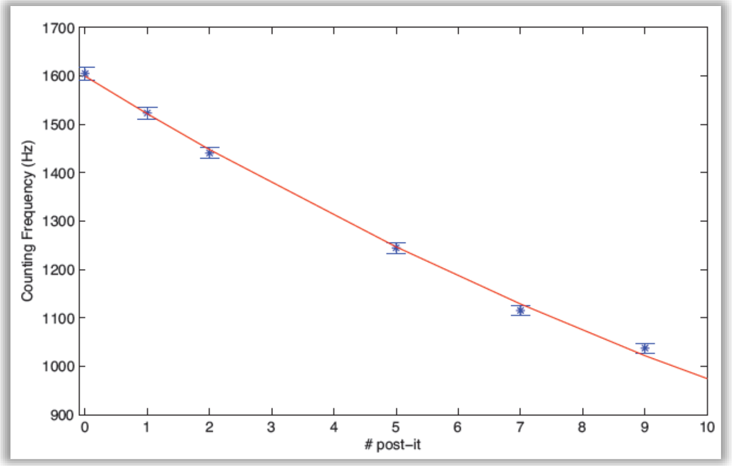
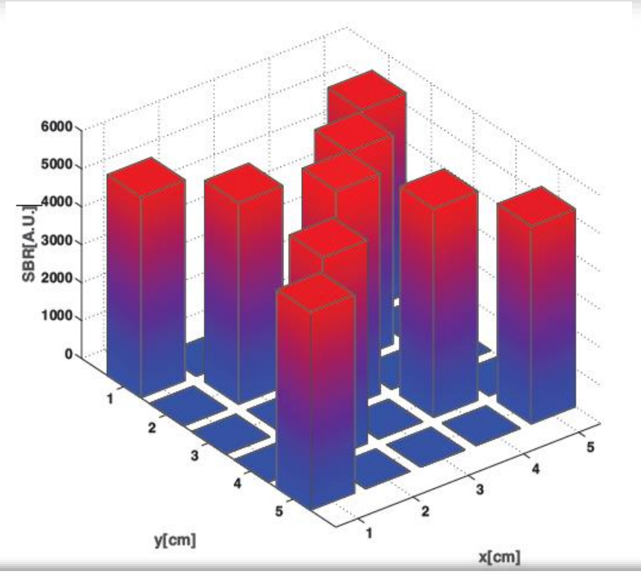
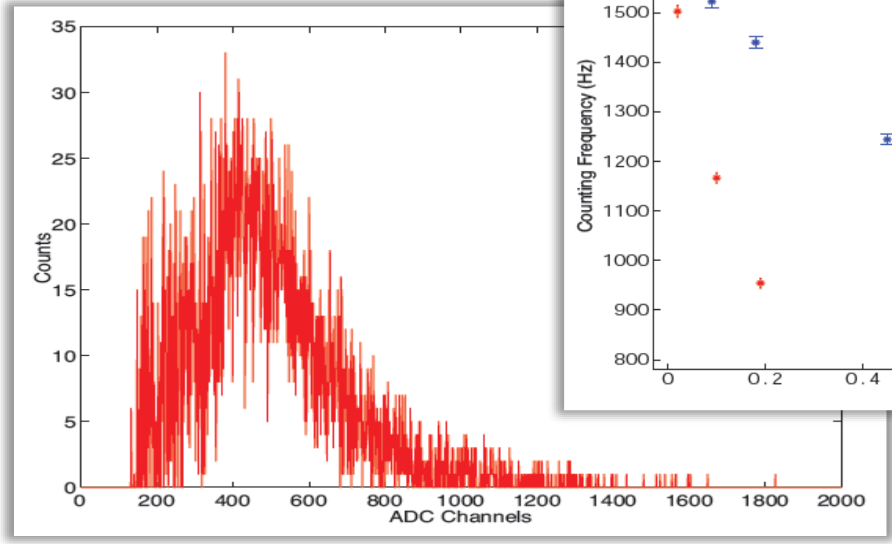
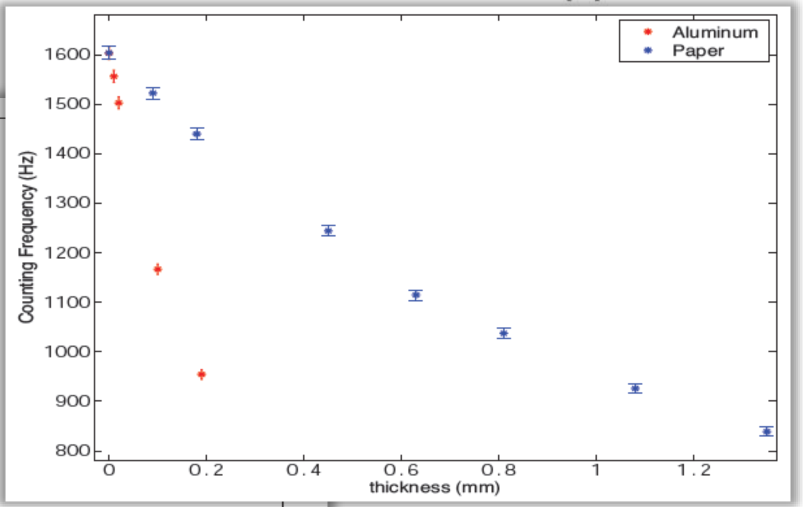


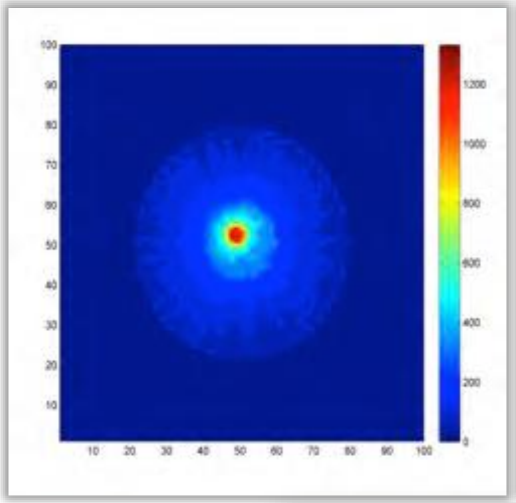


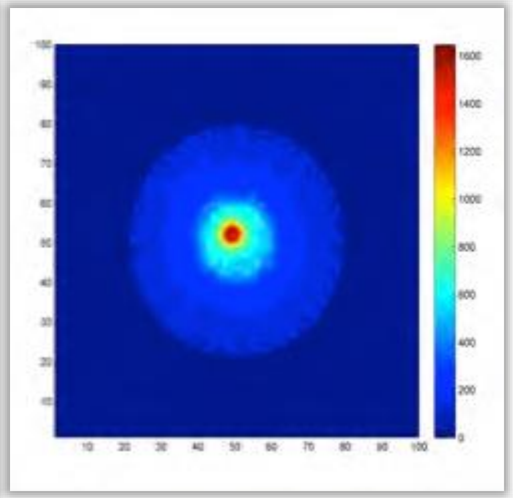


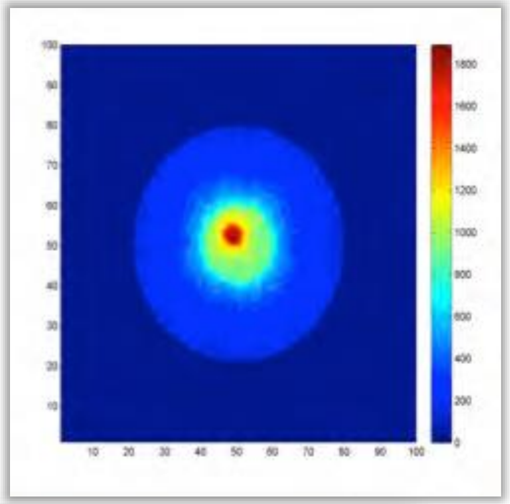


CAEN Tools for Discovery

Physics Experiments







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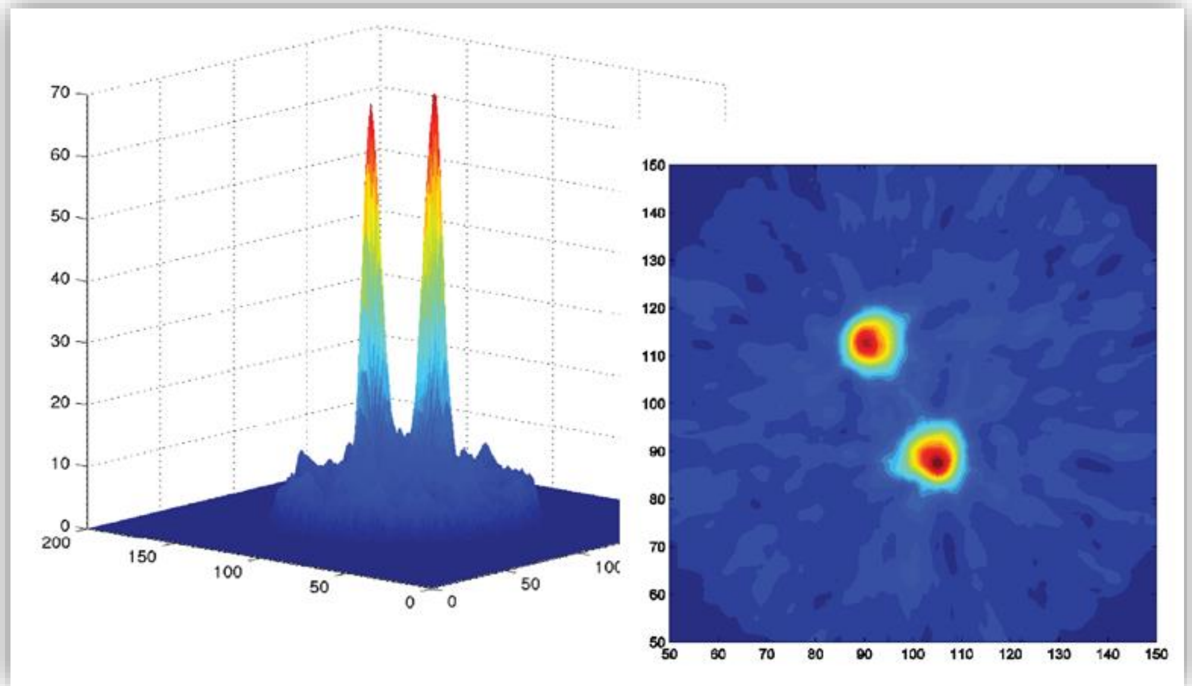
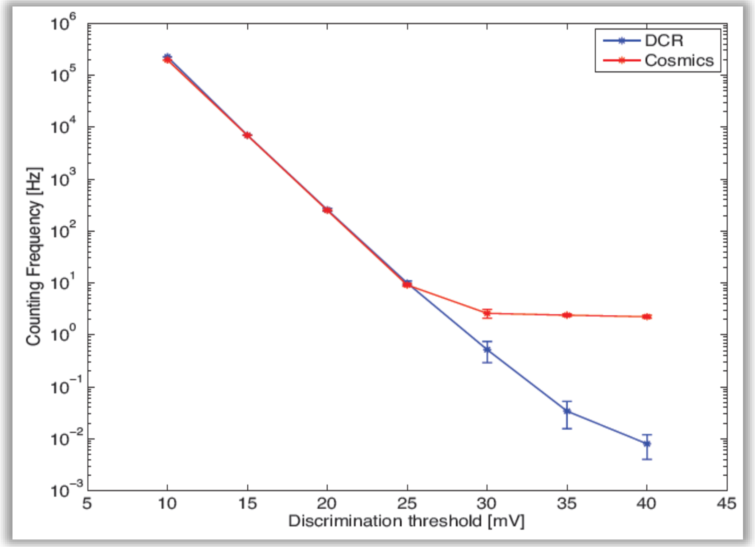


Physics Experiments



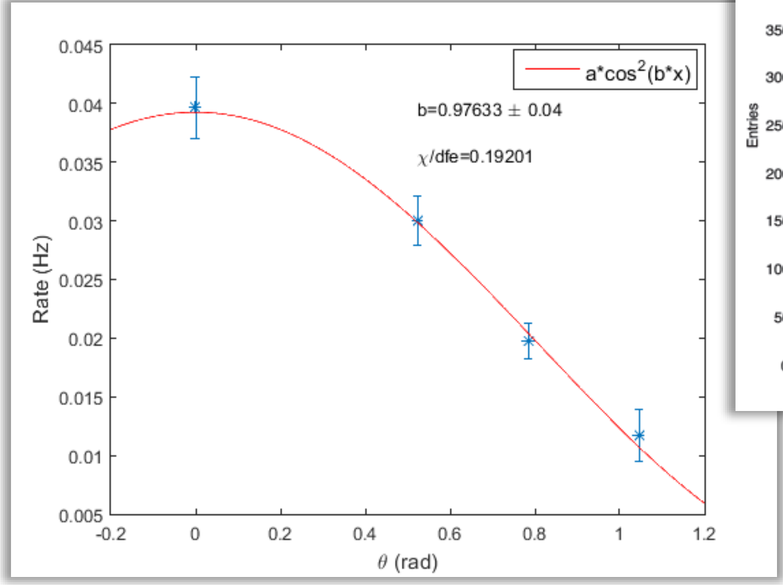
Particle Physics

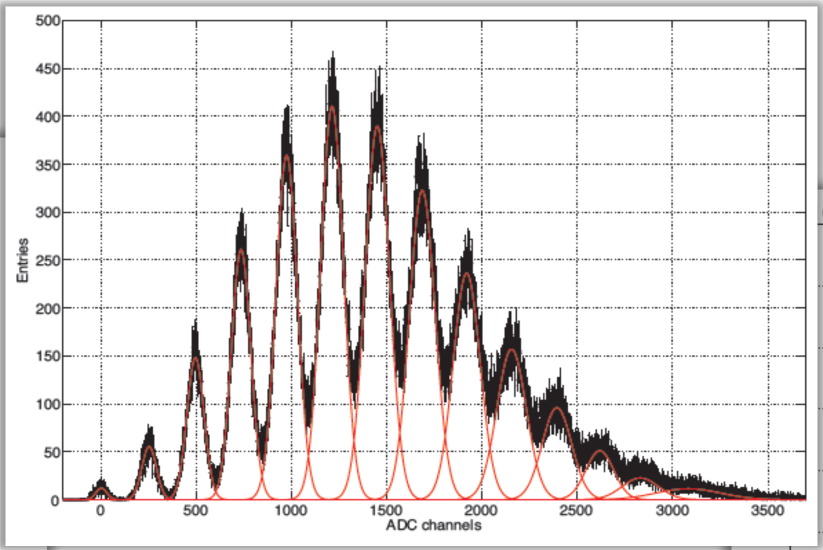
Cosmic Rays

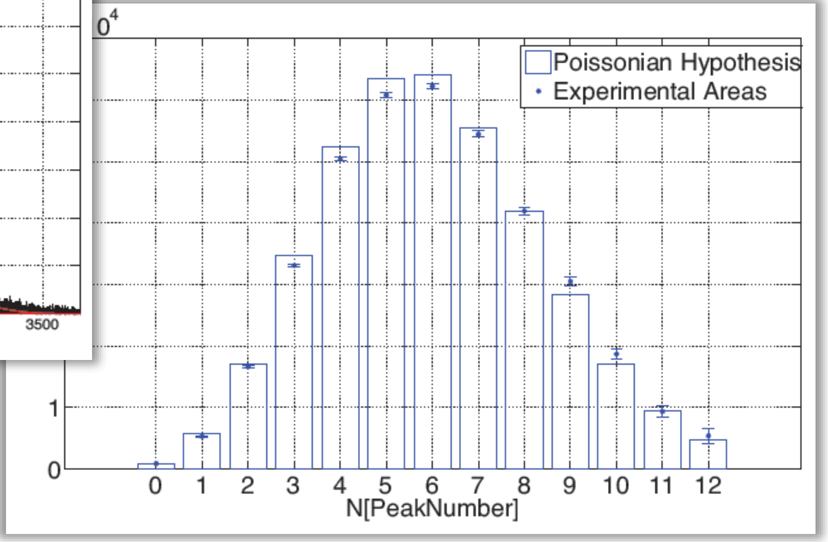
- ✓Muons Detection
- ✓Muons Vertical Flux on Horizontal Detector
- ✓Zenith Dependence of Muons Flux

Photons

- ✓Quantum Nature of Light
- ✓Hands-on Photon Counting Statistics



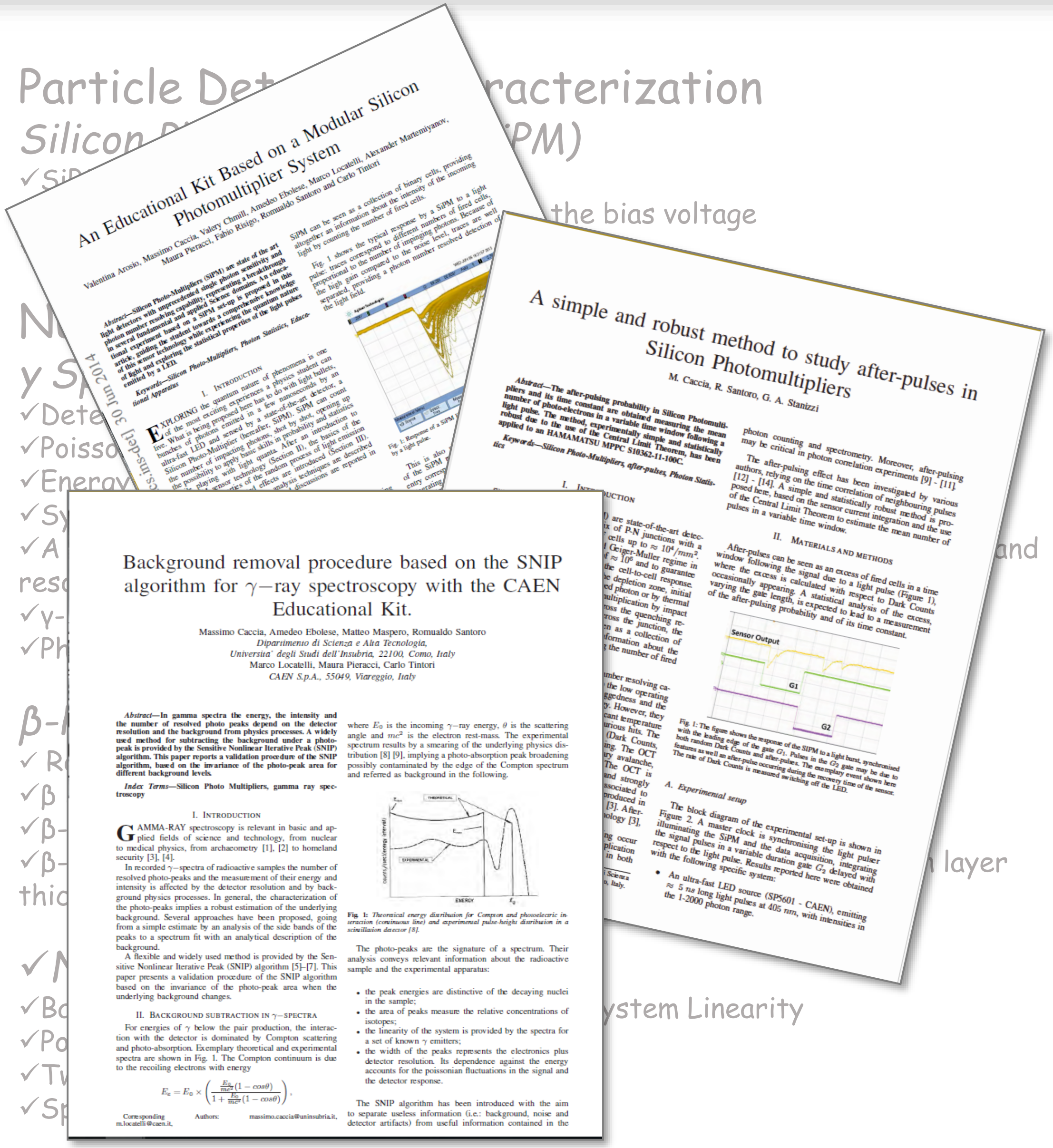




CAEN edu Tools for Discovery

Physics Experiments

Particle Det... racterization
Silicon P... PM)
✓SiP... the bias voltage



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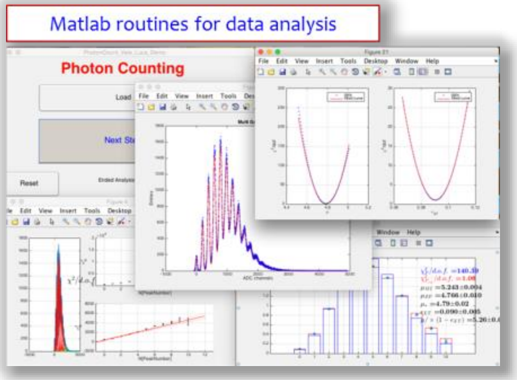
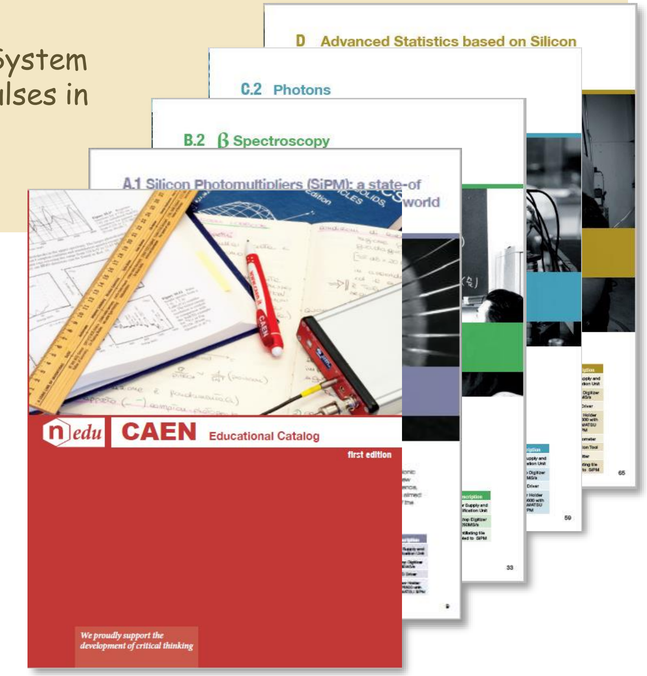
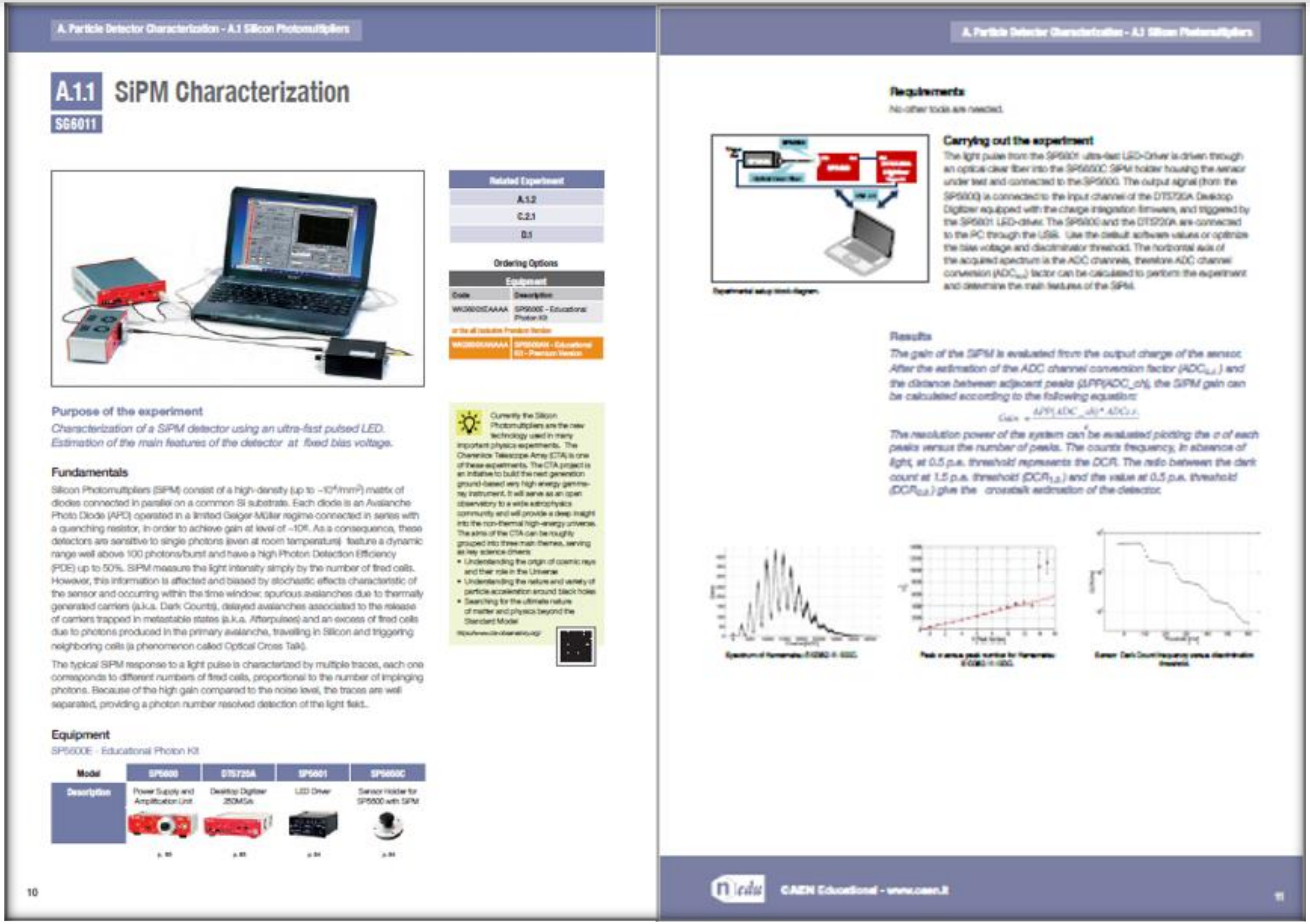
- ✓Background removal procedure based on the SNIP algorithm for γ-ray spectroscopy

Matlab routines for data analysis





Structure of Experiment Pages


A. Particle Detector Characterization - A.1 Silicon Photomultipliers

A.1.1 SiPM Characterization

SG6011

Related Experiment
A.1.2
C.2.1
D.1

Ordering Options

Code	Description
WK5600XEAAAA	SP5600E - Educational Photon Kit

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 neighboring 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.

Currently the Silicon Photomultipliers are the new technology used in many important physics experiments. The Cherenkov Telescope Array (CTA) is one of these experiments. The CTA project is an initiative to build the next generation ground-based very high energy gamma-ray instrument. It will serve as an open observatory to a wide astrophysics community and will provide a deep insight into the non-thermal high-energy universe. The aims of the CTA can be roughly grouped into three main themes, serving as key science drivers:

- Understanding the origin of cosmic rays and their role in the Universe
- Understanding the nature and variety of particle acceleration around black holes
- Searching for the ultimate nature of matter and physics beyond the Standard Model

Equipment

SP5600E - Educational Photon Kit

Model	SP5600	DT5720A	SP5601	SP5650C
Description	Power Supply and Amplification Unit	Desktop Digitizer 250MS/s	LED Driver	Sensor Holder for SP5600 with SiPM

10

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 ($ADC_{c.f.}$) 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 ($ADC_{c.f.}$) and the distance between adjacent peaks (ΔPP(ADC_ch)), the SiPM gain can be calculated according to the following equation:

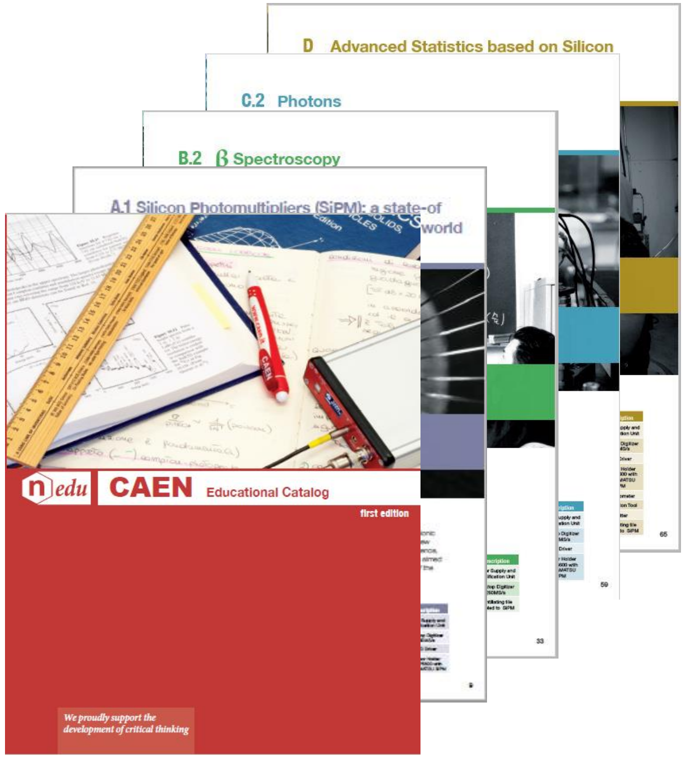
$$Gain = \frac{\Delta PP(ADC\_ch) * ADC_{c.f.}}{e}$$

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.

CAEN Educational - www.caen.it

11

Products – Educational Kits



Products – Educational Kits

PRODUCTS

This section is dedicated to a short description of the advanced instrumentations developed by CAEN and used to perform the experiments proposed in this catalogue.

The devices are put together to form educational kits, suitable to a specified application in Nuclear and Modern Physics fields. Moreover three educational kits, "Educational Gamma Kit", "Educational Beta Kit" and "Educational Photon Kit", are included in a "Educational Kit – Premium Version" that allows to perform almost entirely the catalogue experiments.

The "Emulation Kit" allows to perform a series of lab experiments related to gamma spectroscopy with no radioactive source and detector, but simulating the signals produced by interaction of particle with the detecting unit.

The "EasyPET" is the only not modular system. It is a user friendly and portable PET system that allows to perform nuclear imaging experiments.

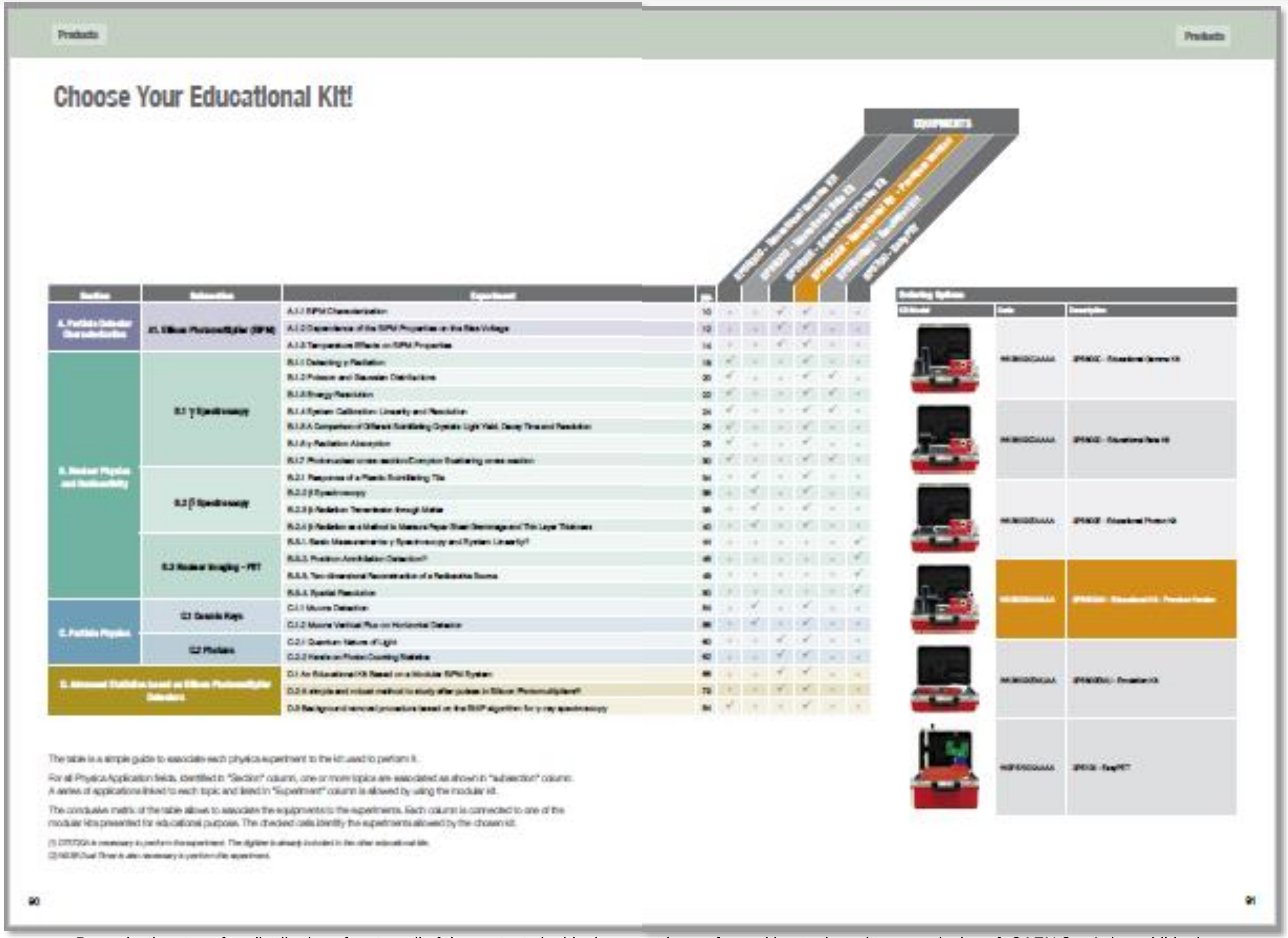
All the experimental setups are provided by a complete software suite for remote control of the system and data analysis.

The complete list of Physics Experiments and the concerning CAEN Educational Systems is reported in the following table.

edu

CAEN Tools for Discovery

Products – Educational Kits



Choose Your Educational Kit!

The table is a simple guide to associate each physics experiment to the kit used to perform it.

For all Physics Application fields, identified in "Section" column, one or more topics are associated as shown in "subsection" column. A series of applications linked to each topic and listed in "Experiment" column is allowed by using the modular kit.

The conclusive matrix of the table allows to associate the equipments to the experiments. Each column is connected to one of the modular kits presented for educational purpose. The checked cells identify the experiments allowed by the chosen kit.

Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

5. SP5600EMU – Emulation kit
6. SP5700 – EasyPET

Products – Educational Kits

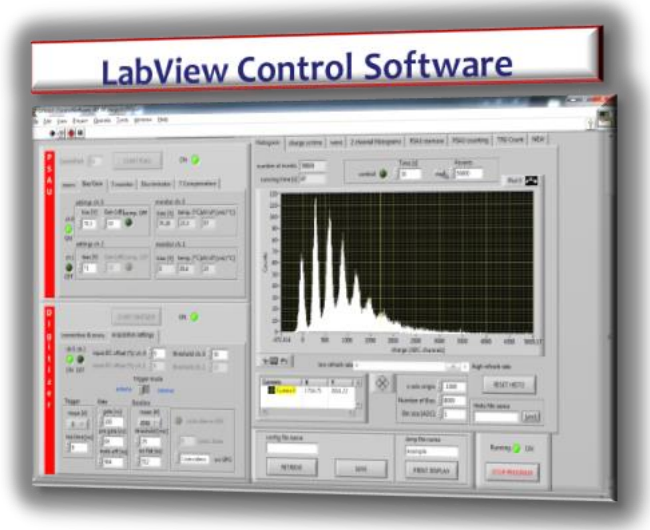
1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit
Premium Version



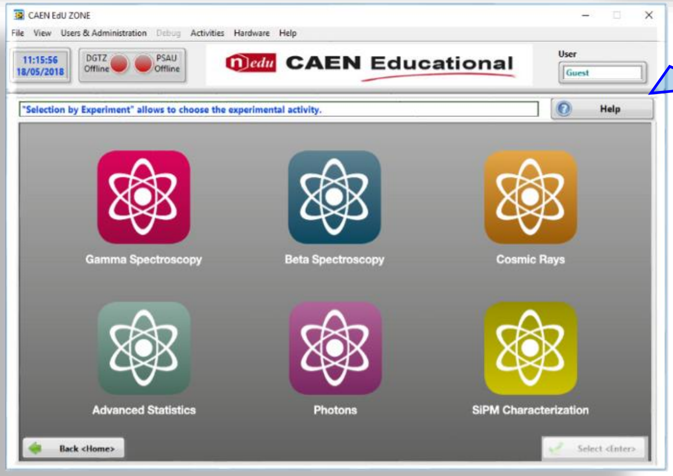
Products – Educational Kits

A New Software Platform that allows to manage 4 Educational kits and perform the experiments described in the CAEN Educational Catalog…

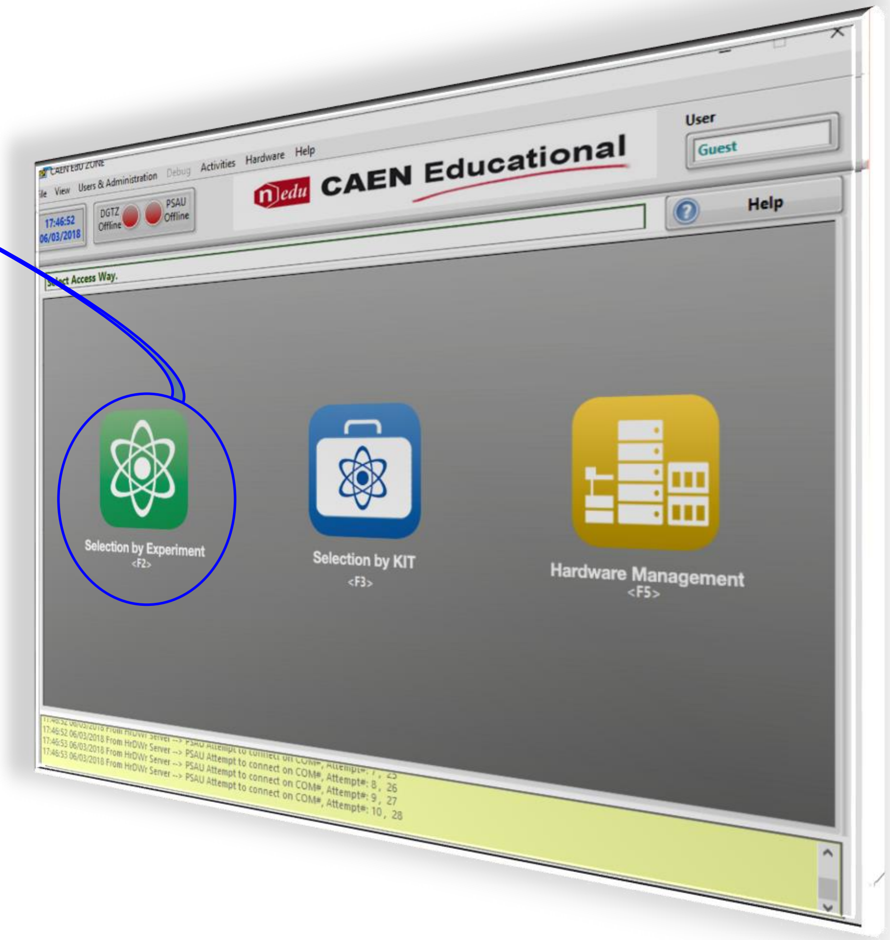
Suitable to several customers needs!

CAEN Tools for Discovery

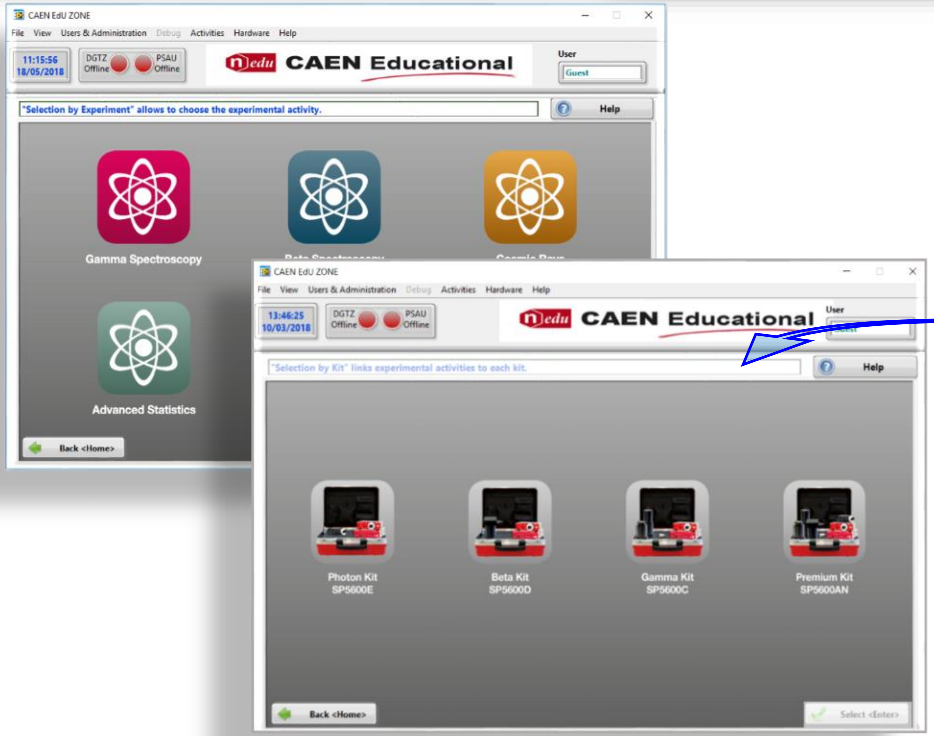
Products – Educational Kits



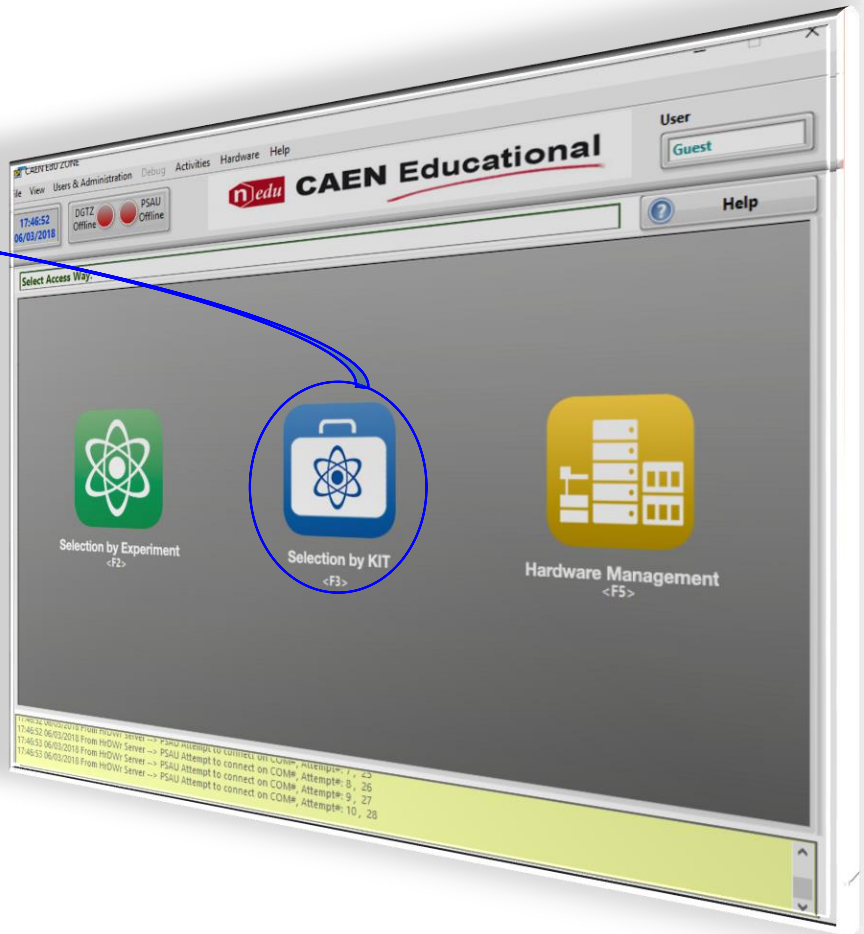
"Selection by Experiment"



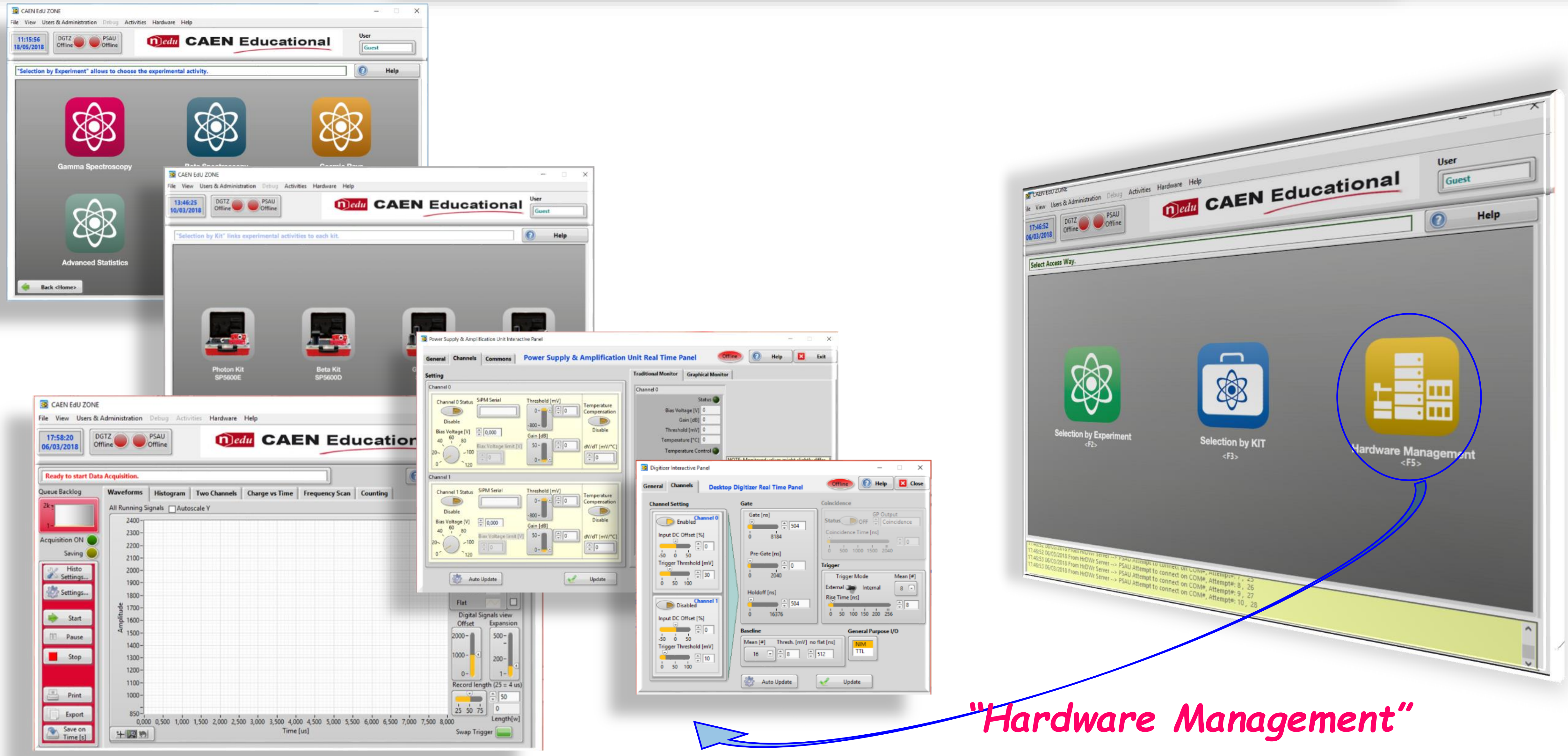
Products – Educational Kits



"Selection by Kit"



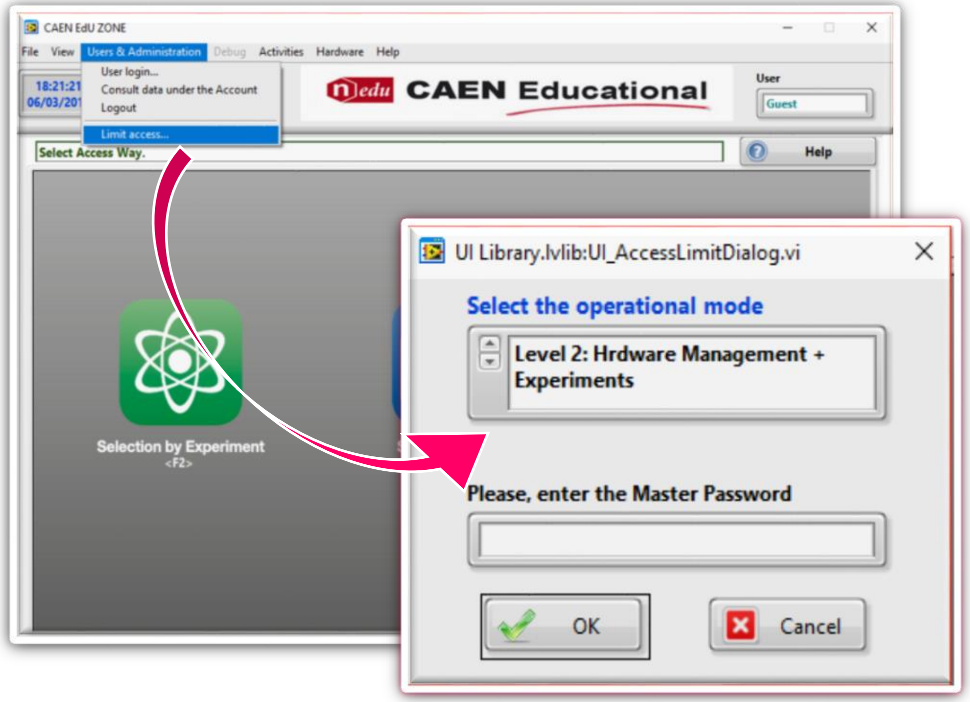
Products – Educational Kits



"Hardware Management"

Software Features:

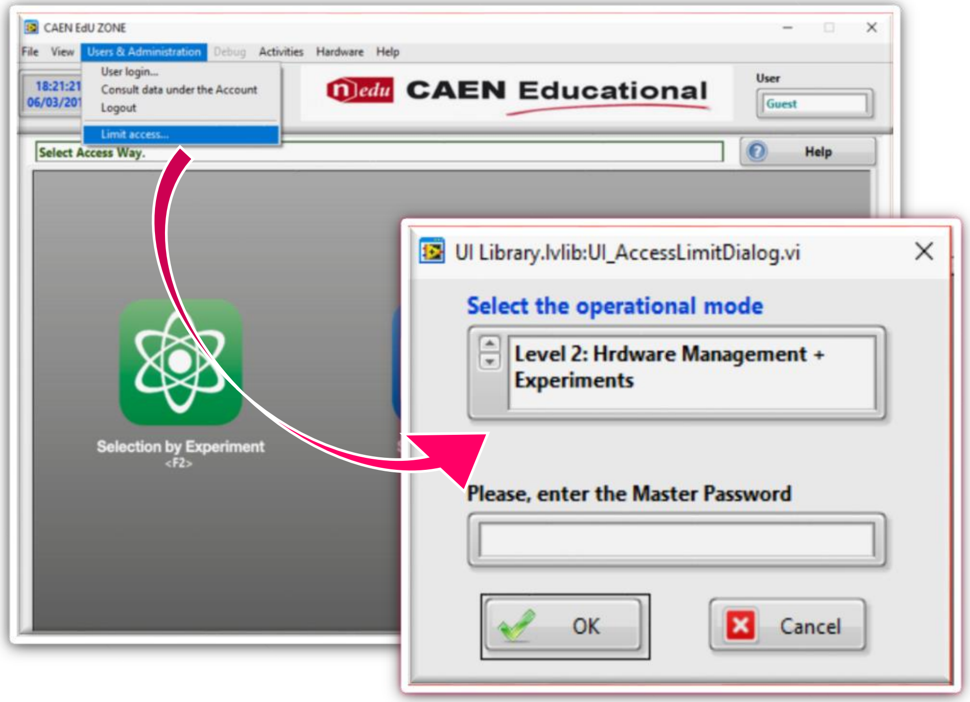
- Three Access Levels to the software functionalities:
  - ➢ Level 1 - Hardware Management
  - ➢ Level 2 - Hardware Management + Experiments
  - ➢ Level 3 - Full Access (Analysis Tools)

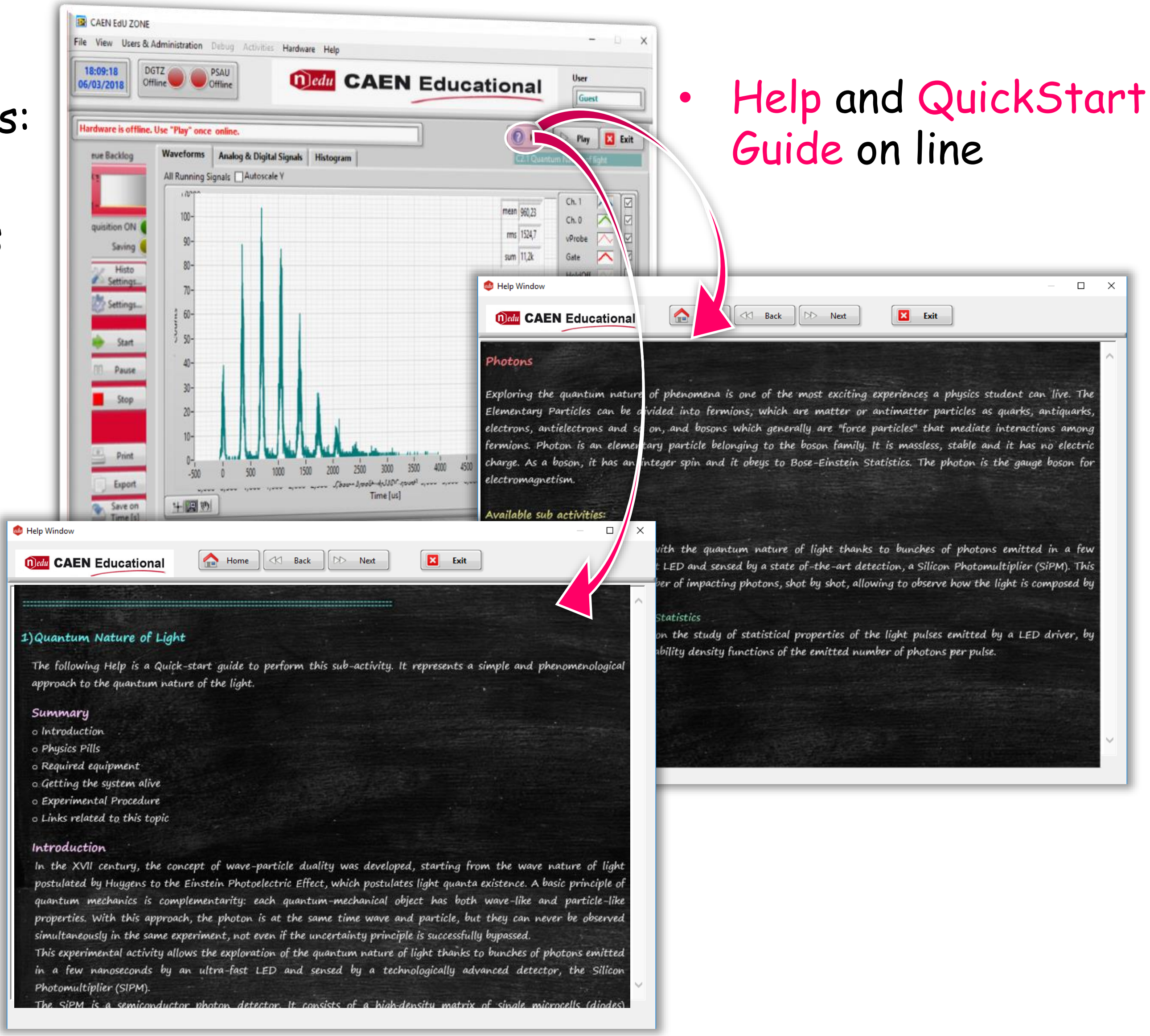


Software Features:

- Three Access Levels to the software functionalities:
  - ➢ Level 1 - Hardware Management
  - ➢ Level 2 - Hardware Management + Experiments
  - ➢ Level 3 - Full Access (Analysis Tools)

- Help and QuickStart Guide on line



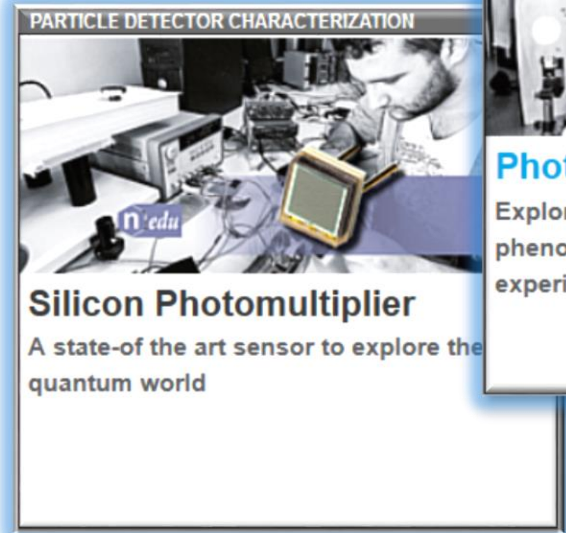


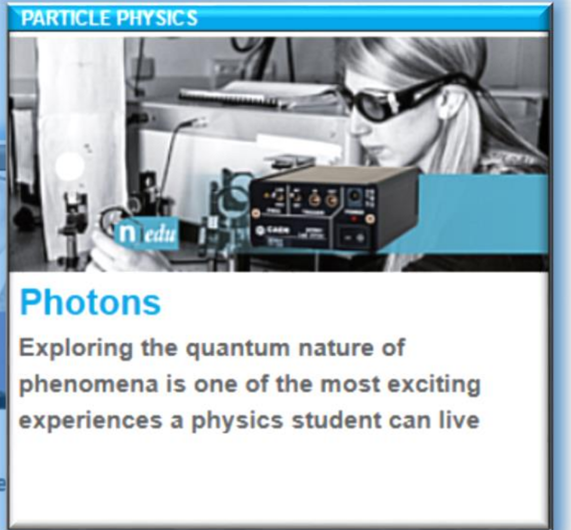
Products – Educational Kits

1. SP5600E – Educational Photon kit

2. SP5600D – Educational Beta kit

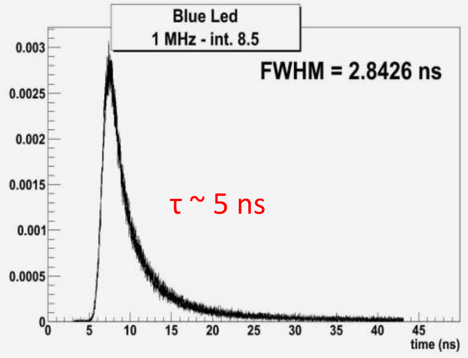
3. SP5600C – Educational Gamma kit





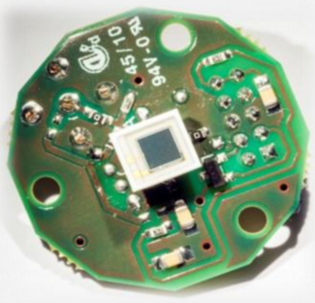
Model	SP5600	DT5720A	SP5601	SP5650C
Description	Power Supply and Amplification Unit 	Desktop Digitizer 250MS/s 	LED Driver 	Sensor Holder for SP5600 with SiPM 

SP5601 – LED Driver



- LED color: violet (λpeak = 420 nm)
- Peak current 120 mA
- Luminous intensity = 9500 mcd @20mA
- Width of pulse: 8ns
- 30° half-view angle
- Pulse generator: internal/external
- Optical fiber included

SP5650C-Sensor holder with SiPM



HAMAMATSU
MPPS S13360- 1350CS

- *Effective photosensitive area* : 1.3x1.3mm^2
- *Pixel pitch* : 50 μm
- *Number of pixels* : 667

Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

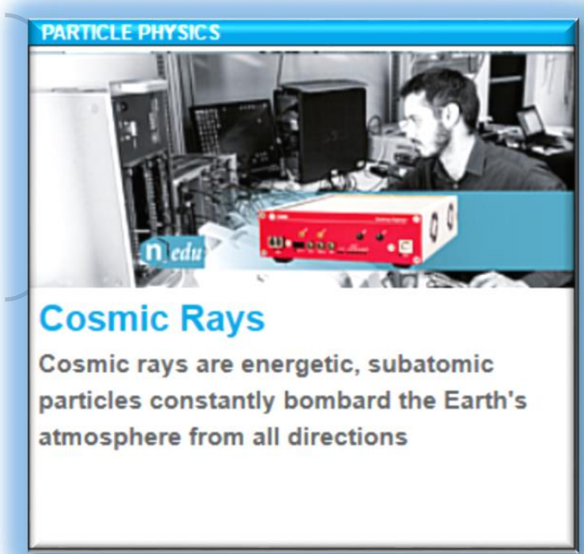
4. SP5600AN Educational kit
   Premium Version

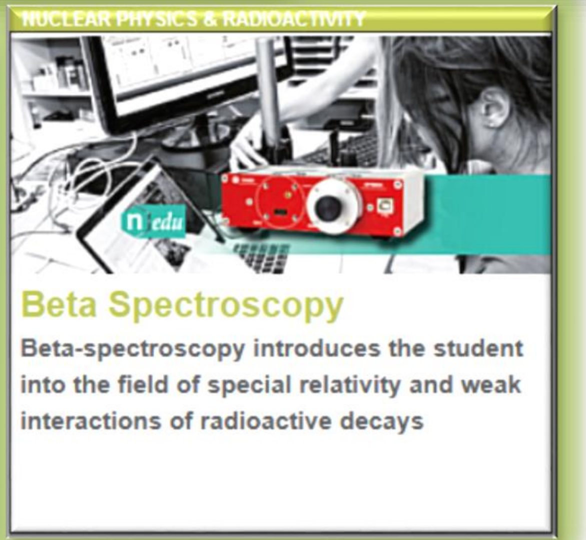
CAEN Tools for Discovery

2. SP5600D Products – Educational Kits

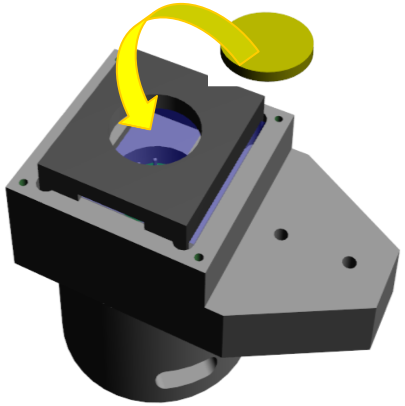
1. SP5600E – Educational Photon kit
2. **SP5600D – Educational Beta kit**
3. SP5600C – Educational Gamma kit

Model	SP5600	DT5720A	SP5608
Description	Power Supply and Amplification Unit 	Desktop Digitizer 250MS/s 	Scintillating tile 





SP5608 - Scintillating tile

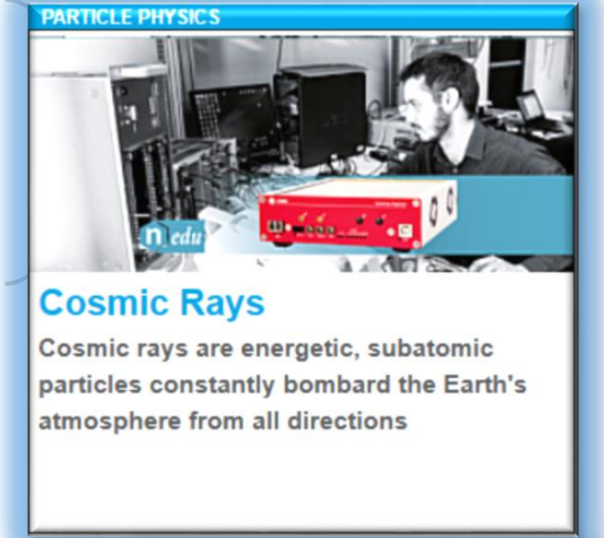


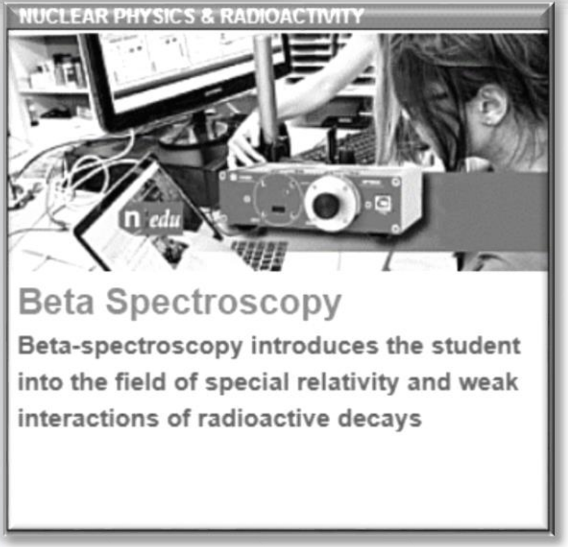
- Sensitive volume: 47x47x10 mm^3
- Scintillator: polystyrene
- Directly coupled on HAMAMATSU MPPS S13360- 6050CS
  - Effective photosensitive area : $6x6mm^2$
  - Pixel pitch : 50 µm
  - Number of pixels : 14400
- 20 Paper and Aluminum sheets

2. SP5600D Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

Model	SP5600	DT5720A	SP5608
Description	Power Supply and Amplification Unit	Desktop Digitizer 250MS/s	Scintillating tile
			





Build a Muons Telescope

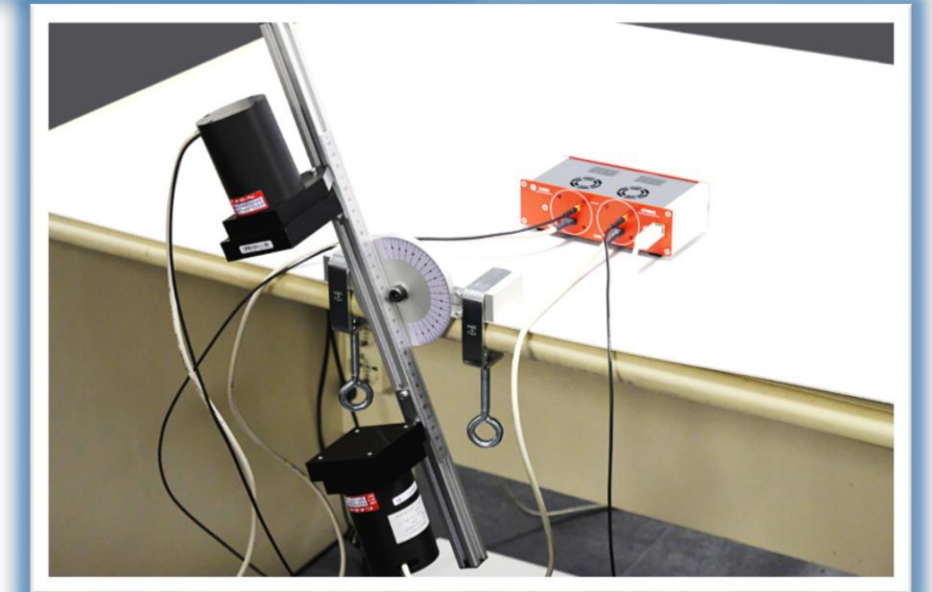
SP5600D - Educational beta kit

+

SP5608 - Scintillating Tile

+

SP5609 - telescope mechanics



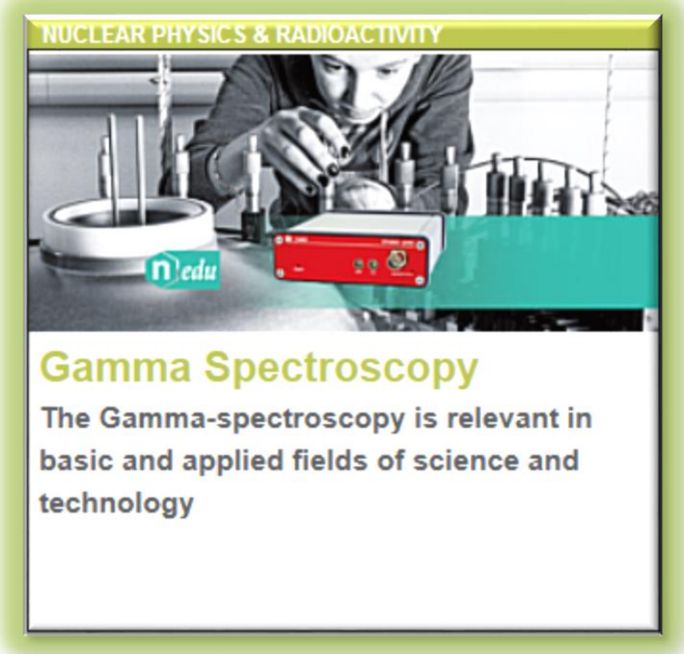
Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

3. SP5600C Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. **SP5600C – Educational Gamma kit**



Model	SP5600	DT5720A	A315	SP5606	SP5607
Description	Power Supply and Amplification Unit 	Desktop Digitizer 250MS/s 	Splitter 	Mini-Spectrometer 	Absorption tool 

SP5606 Mini-Spectrometer

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

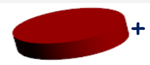
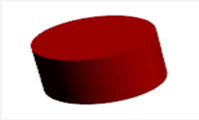
SP5607 – γ Absorption tool

- **Spacers:** one 4mm thick, five 10 mm thick;
- **Aluminum Absorbers:** one 4mm thick, five 10 mm thick;
- **PMMA Absorbers:** one 4mm thick, five 10 mm thick.

6 Spacers

1x  + 5x 

12 Absorbers

1x  + 5x 

Products – Educational Kits

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2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

Products – Educational Kits

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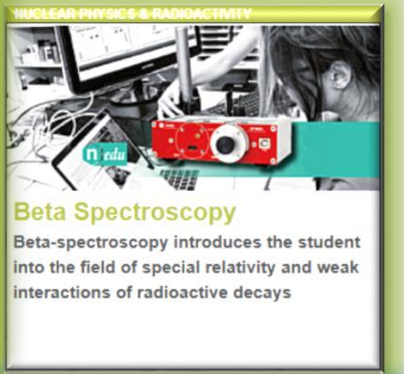
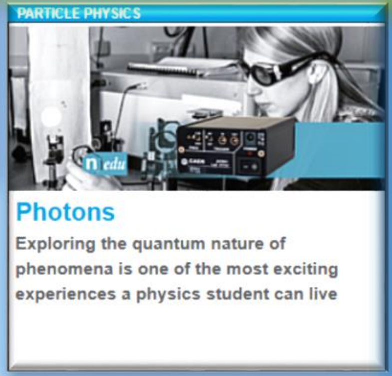
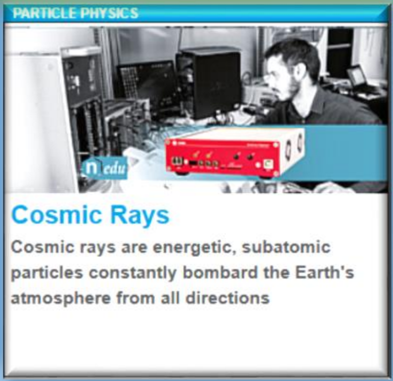
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

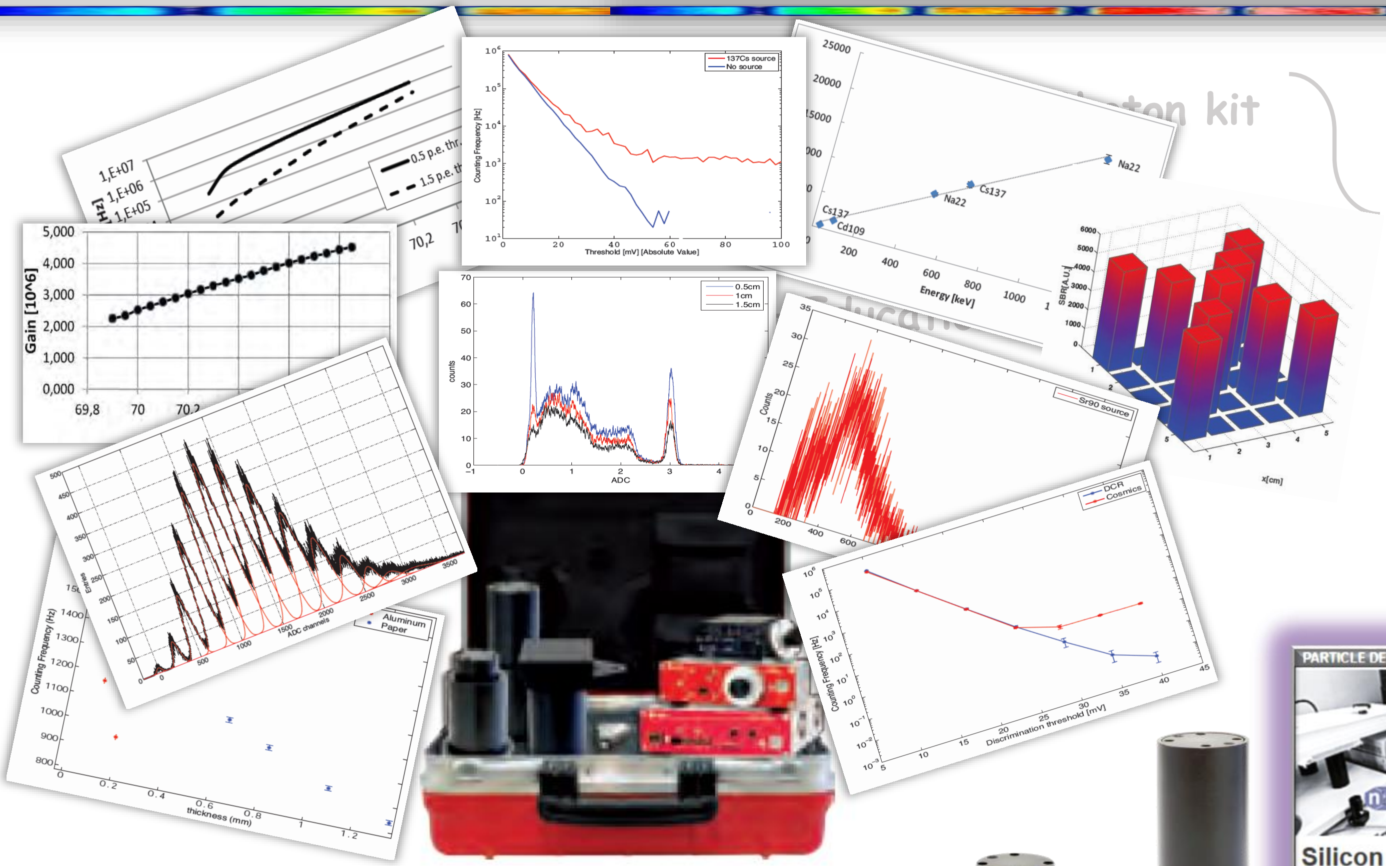






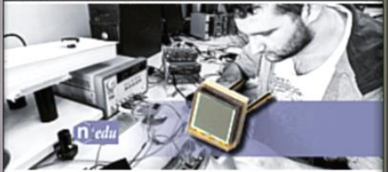
CAEN Tools for Discovery

4. SP5600AN Products – Educational Kits



4. SP5600AN Educational kit Premium Version

PARTICLE DETECTOR CHARACTERIZATION



Silicon Photomultiplier

A state-of the art sensor to explore the quantum world

NUCLEAR PHYSICS & RADIOACTIVITY

Gamma Spectroscopy

The Gamma-spectroscopy is relevant in basic and applied fields of science and technology

NUCLEAR PHYSICS & RADIOACTIVITY

Beta Spectroscopy

Beta-spectroscopy introduces the student into the field of special relativity and weak interactions of radioactive decays

PARTICLE PHYSICS

Photons

Exploring the quantum nature of phenomena is one of the most exciting experiences a physics student can live

PARTICLE PHYSICS

Cosmic Rays

Cosmic rays are energetic, subatomic particles constantly bombard the Earth's atmosphere from all directions

Additional Product – Educational Kits

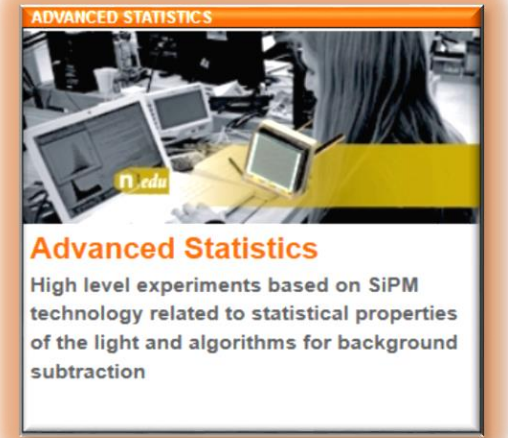
DT993 Timing Unit

The Model Dual Timer is a 1-unit module housing two identical triggered pulse generators

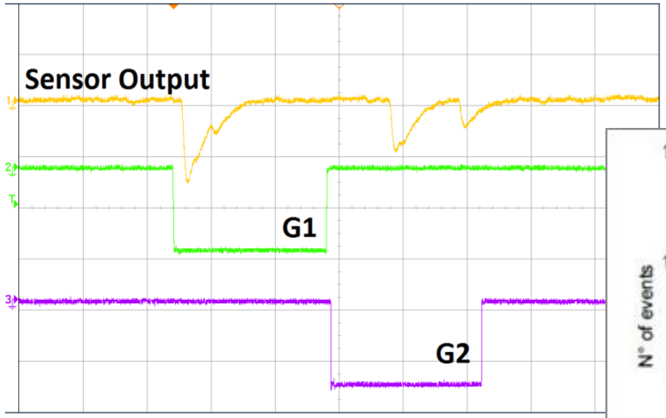
- Manual or pulse triggered START (NIM, TTL or ECL)
- NIM, TTL and ECL output pulses from 50 ns to 10 s
- Manual or pulse triggered RESET
- (NIM, TTL and ECL) END-MARKER pulse
- VETO input

Educational Photon Kit
Edu Kit – Premium Version

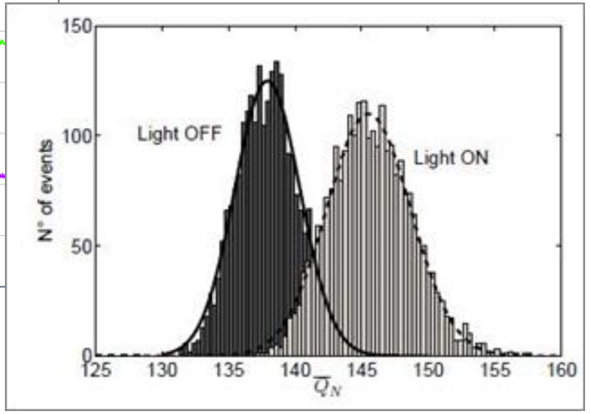
After-pulses studies



The method for the after-pulse and its time constant measurement is based on the analysis of the charge distribution in a variable time window.



The experimental procedure starts by defining two gates



Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

4. SP5600AN Educational kit Premium Version

5. SP5600EMU – Emulation kit
6. SP5700 – EasyPET

Products – Educational Kits

1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

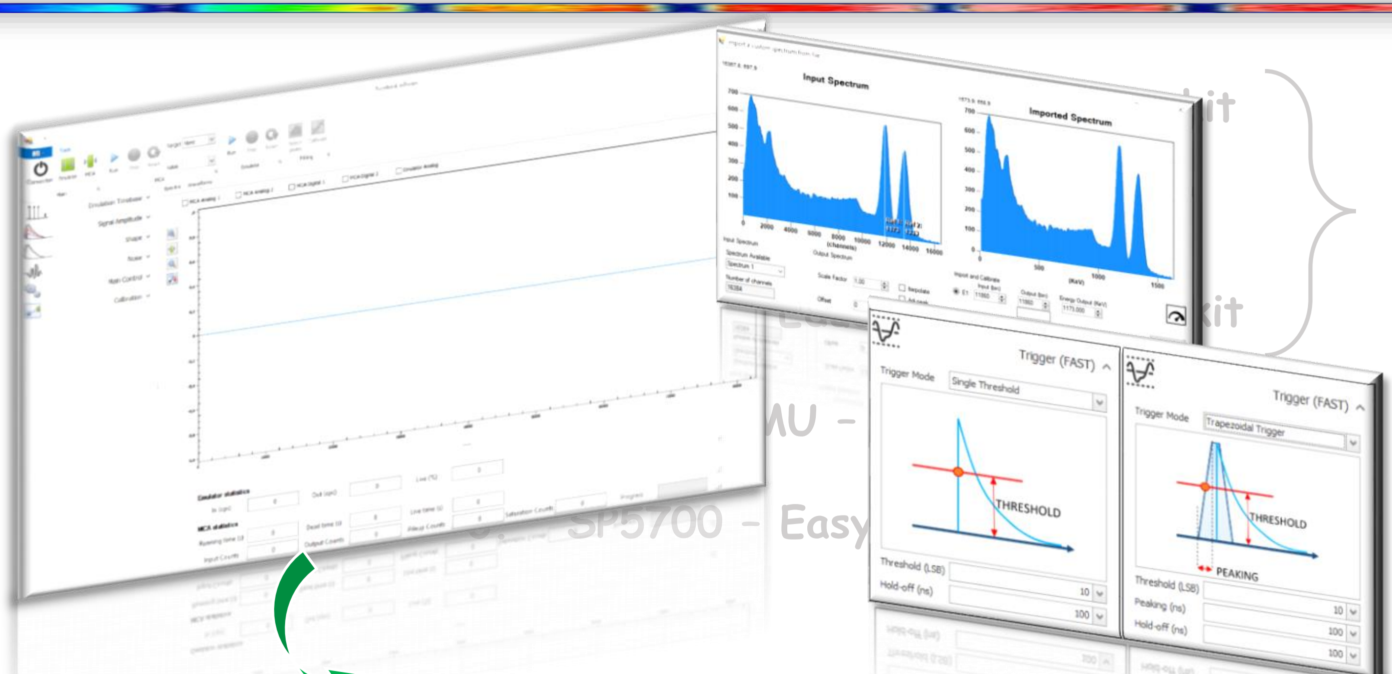
4. SP5600AN Educational kit Premium Version

5. **SP5600EMU – Emulation kit**
6. SP5700 – EasyPET

CAEN Tools for Discovery

5. SP5600EMU

Products – Educational Kits



Emulation and Detection Educational Software

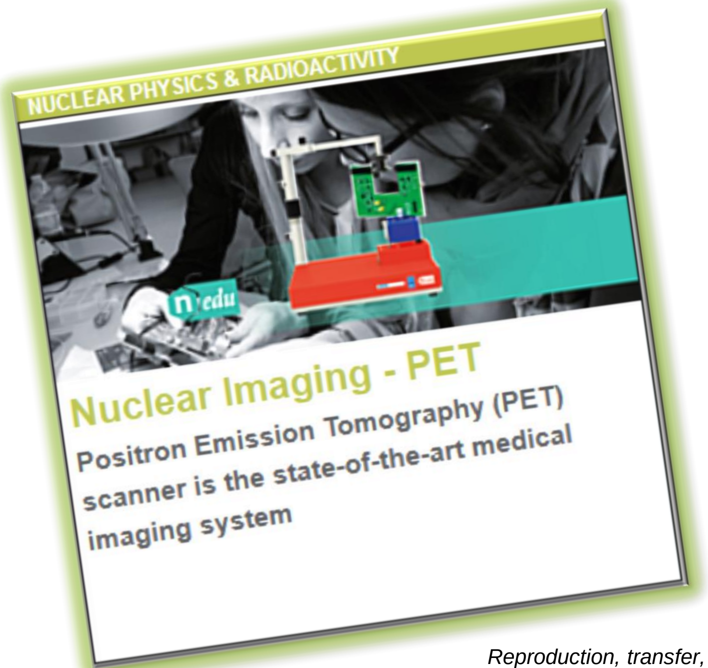
- Poisson and Gaussian Distributions
- Energy Resolution
- System Calibration: Linearity and Resolution
- Photonuclear cross-section/Compton Scattering cross-section

6. SP5700 Products – Educational Kits

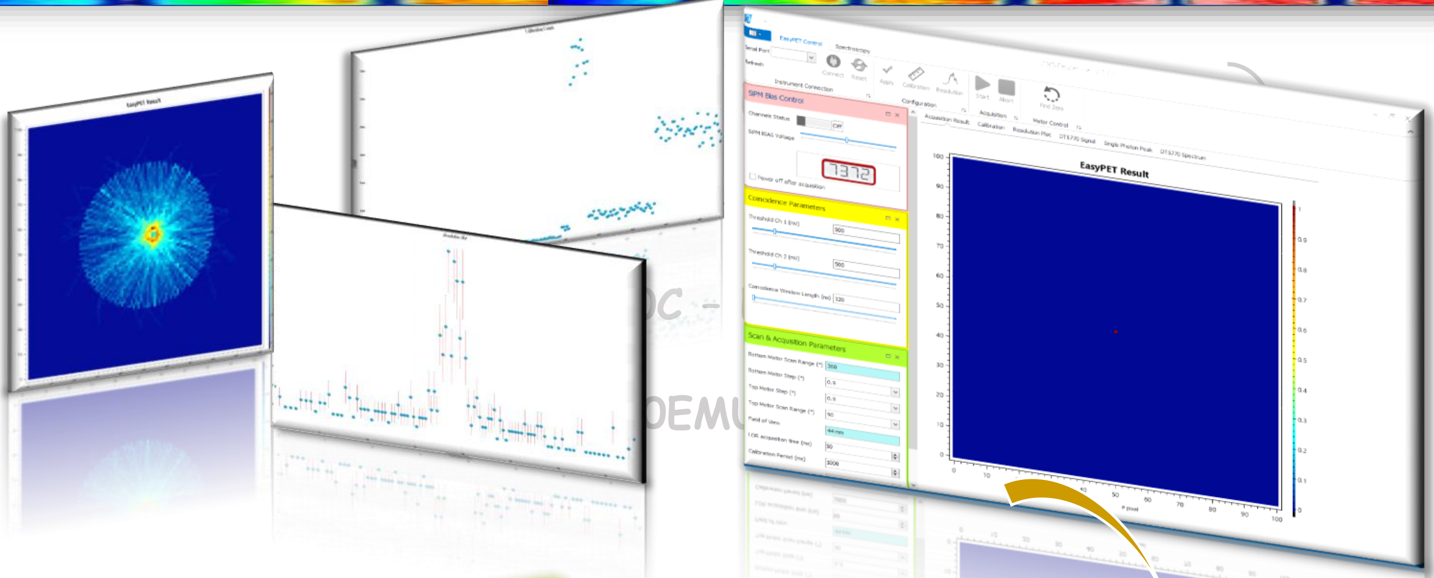
1. SP5600E – Educational Photon kit
2. SP5600D – Educational Beta kit
3. SP5600C – Educational Gamma kit

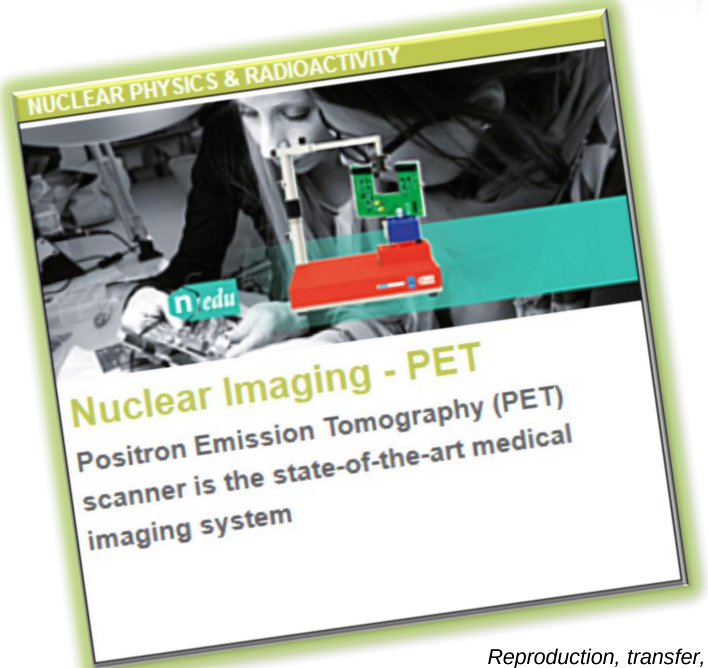
5. SP5600EMU – Emulation kit

6. **SP5700 – EasyPET**



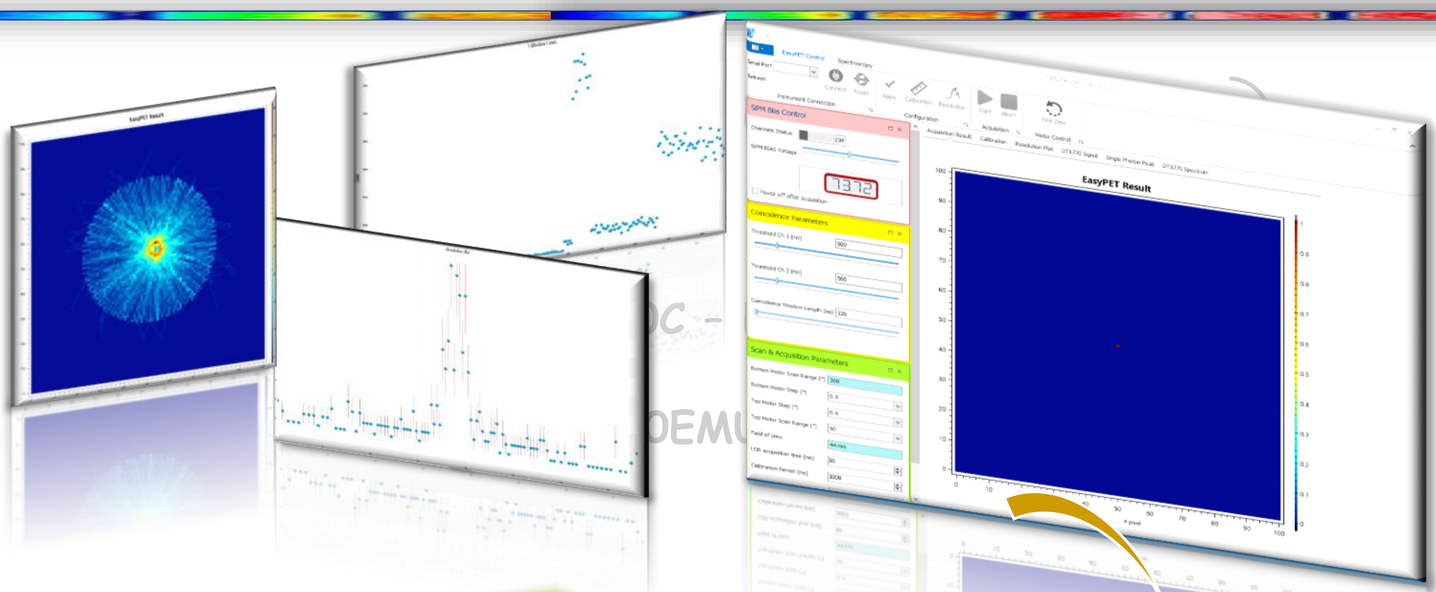
6. SP5700 Products – Educational Kits

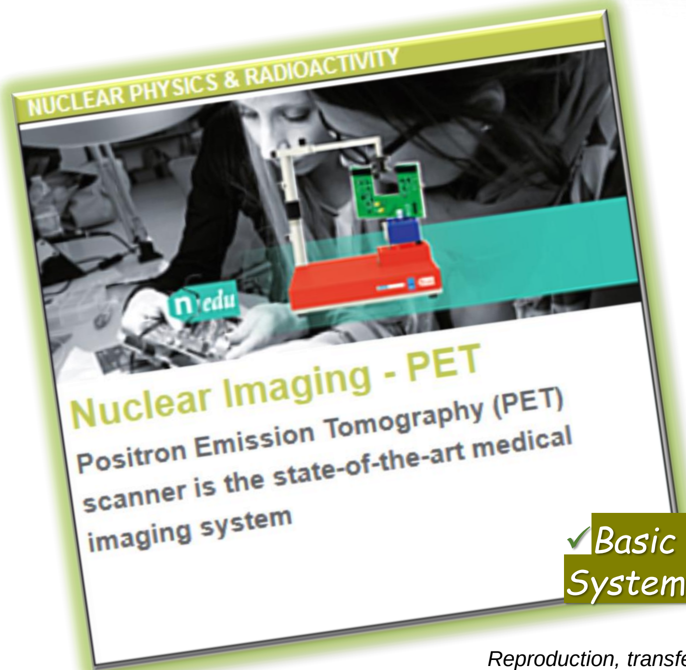




EasyPET Control Software

6. SP5700 Products – Educational Kits





EasyPET Control Software

✓ *Basic Measurements: γ Spectroscopy and System Linearity*

SP5701 EasyPET kit → **SP5700 + DT5770**

CAEN Tools for Discovery

Next Steps

New Projects:

- Environmental kits
  - Active & passive Radon Measurements
  - PM10 Particulate Matter Measurements
  - Sulphates, CO & CO_2 Analysis
  - T, P & H monitoring
  - etc….

Università degli Studi di Napoli Federico II

- Kinematics kit
  - Kinematics Experiments

Università degli Studi dell'Insubria

Dissemination:

- Documentation & Video Tutorial
- Webinars & Seminaries
- Dedicated Conferences/Schools

i-Spector Family
PMT Replacement

Canisters of Activated Carbon

… & New Collaborations!

CAEN Tools for Discovery

ISO 9001:2000
CERT. N. 9105.CAEN

Thanks for your attention…

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Mobile: +39 348 6001513

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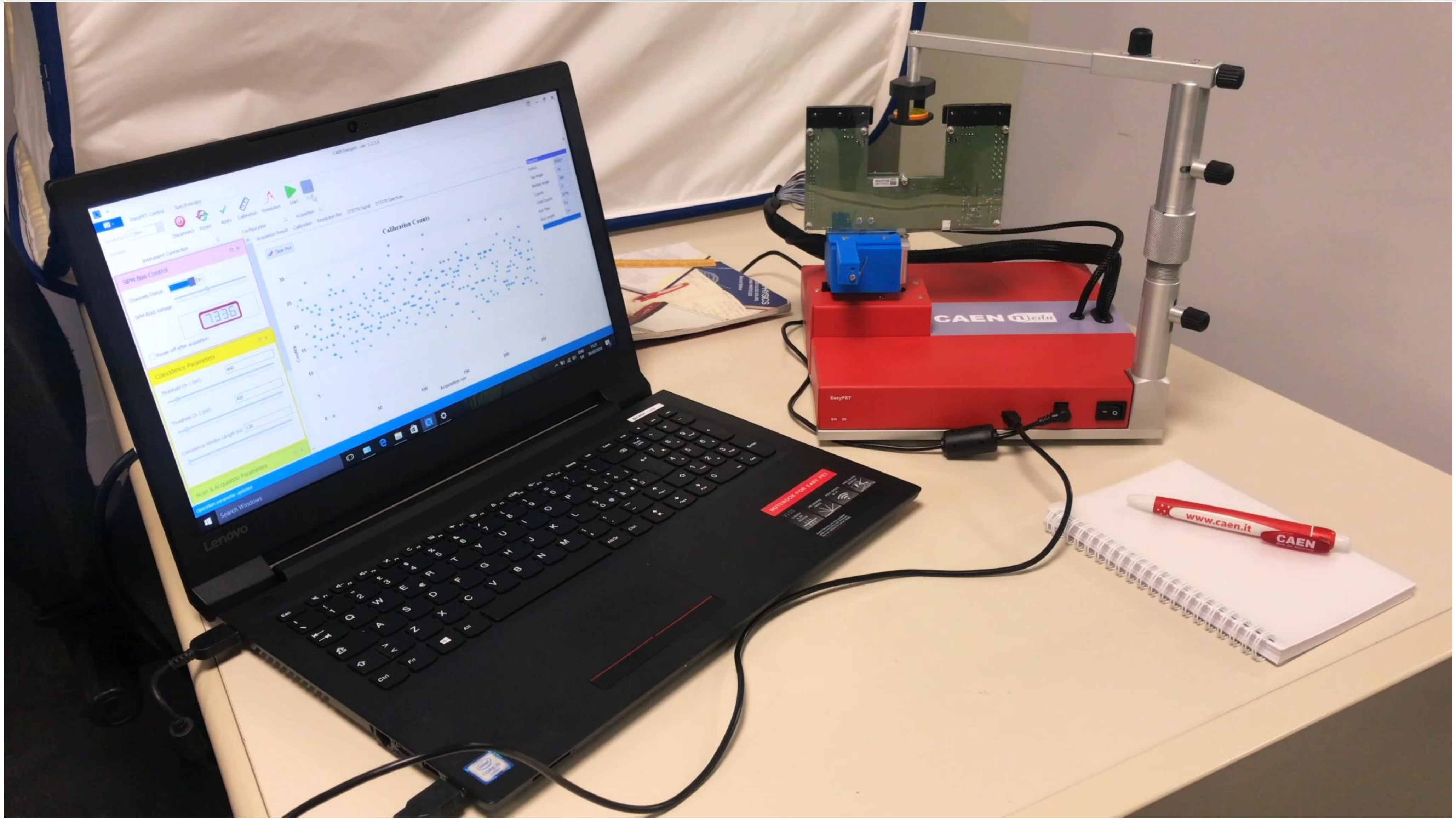
Skype: cristinamattone
Mobile: +39 348 9156856

40 YEARS OF INNOVATION 1979-2019

SPARES

Products – Educational Kits

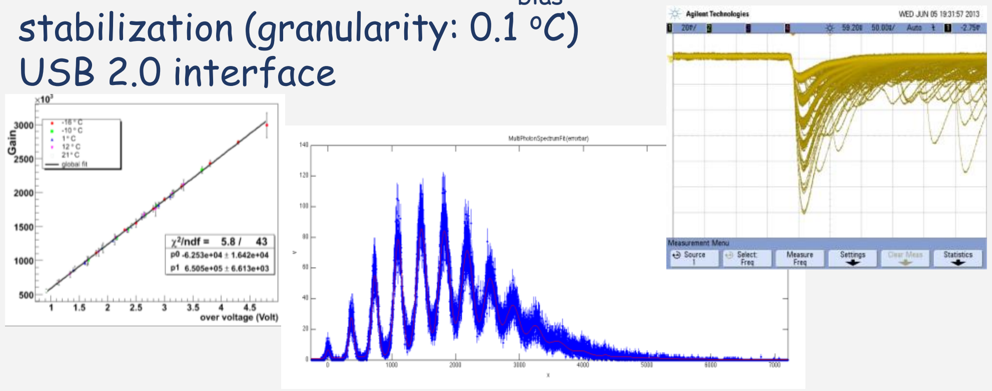


Products – Educational Kits

SP5600 - Power Supply and Amplification Unit

Two channels:

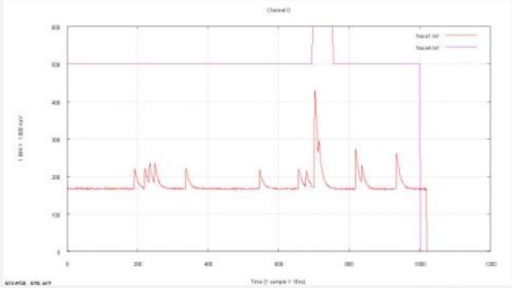
- Independent biasing (max 100 V, 100 μA)
- 2 stage amplification [500 MHz bandwidth, tunable gain up to ~ 50 dB]
- Fast leading edge discriminator (±2V)
- Coincidence logic
- active feedback control on V_{bias} for Gain stabilization (granularity: 0.1 °C)
- USB 2.0 interface



DT5720A - desktop Digitizer Signal recording —> digitization

Main characteristics:

- Digital Pulse Processing for Charge Integration DPP-CI
- Good timing resolution with fast signals (rise time < 100 ns)
- 2 channels
- stand-alone
- 250 Ms/s, 12 bits
- ±1V input range
- Optical Link and USB 2.0 interfaces

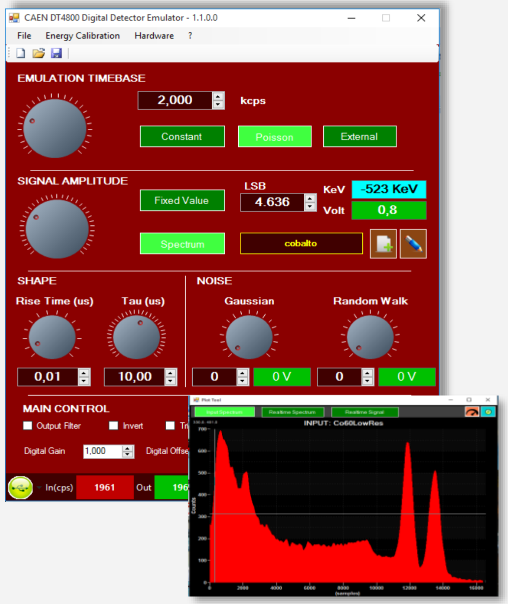


CAEN
Tools for Discovery

5. SP5600EMU — Products – Educational Kits

DT4800
Micro Digital Detector Emulator

- Pulser/Emulator operating modes
- Real Energy spectrum emulation
- Time distribution emulation (Poissonian)
- Noise emulation
- Continuous pre-amplifier emulation
- Nuclides database
- User Friendly Control SW with Graphical User Interface



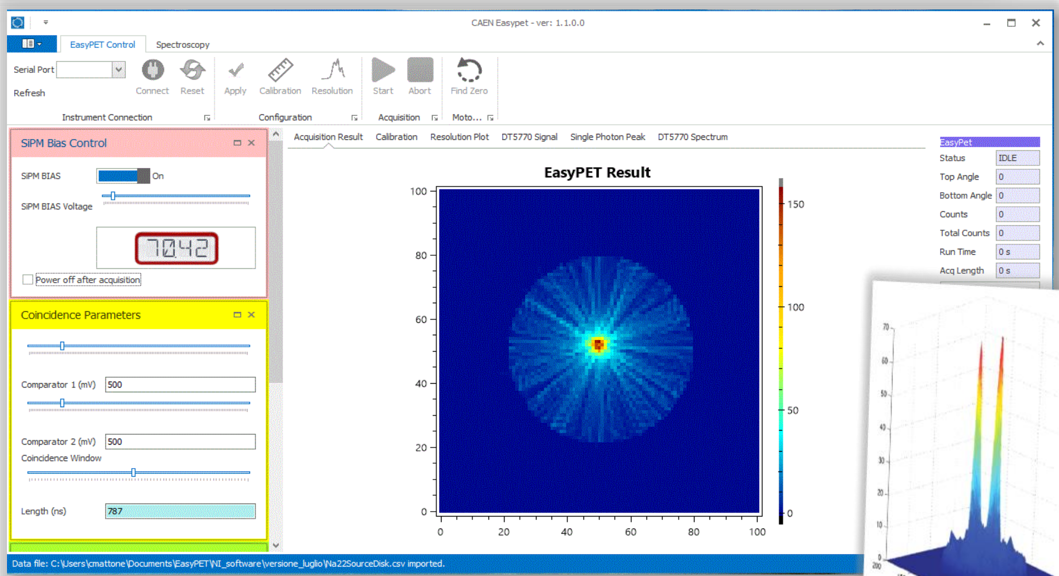
DT5770
Digital Multichannel Analyzer

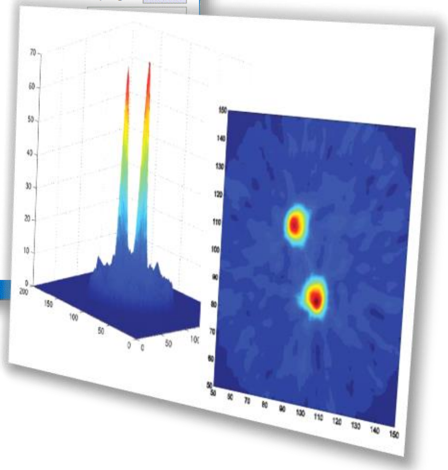
- Compact portable 16k Digital MCA
- Suited for high resolution Gamma Spectroscopy
- Support continuous and pulsed reset preamplifiers
- Software selectable coarse and fine gain
- DB9 connector for preamplifier power supply
- Features Pulse Height Analysis firmware for energy calculation
- Different acquisition modes available: PHA and signal inspector for an easy setup and signal monitoring
- USB and Ethernet communication interfaces
- *Ordering Option:*
- MC^{2}Analyzer software to manage the acquisition and perform basic spectrum analysis

SP5700 – EasyPET

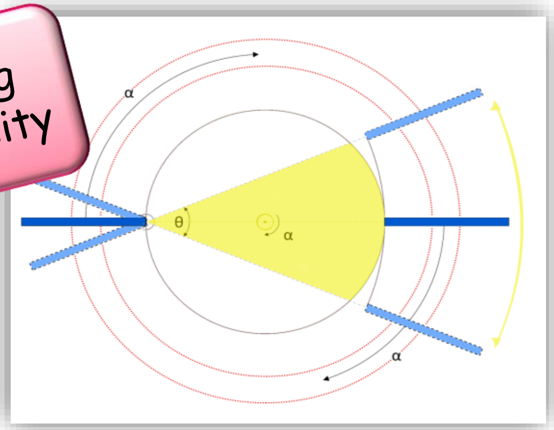
Main EasyPET components:

- Two detectors, each composed of a LYSO scintillator crystal optically coupled to a SiPM;
- Printed Circuit Board (PCB) equipped with electronics used for SiPMs supply voltage, signal readout and coincidence detection;
- Two stepper motors;
- Microcontroller unit responsible for controlling EasyPET parameters, driving the stepper motors and communicating with the computer;
- Holder for radioactive source;
- User Friendly Control Software.





Patent pending
Aveiro University

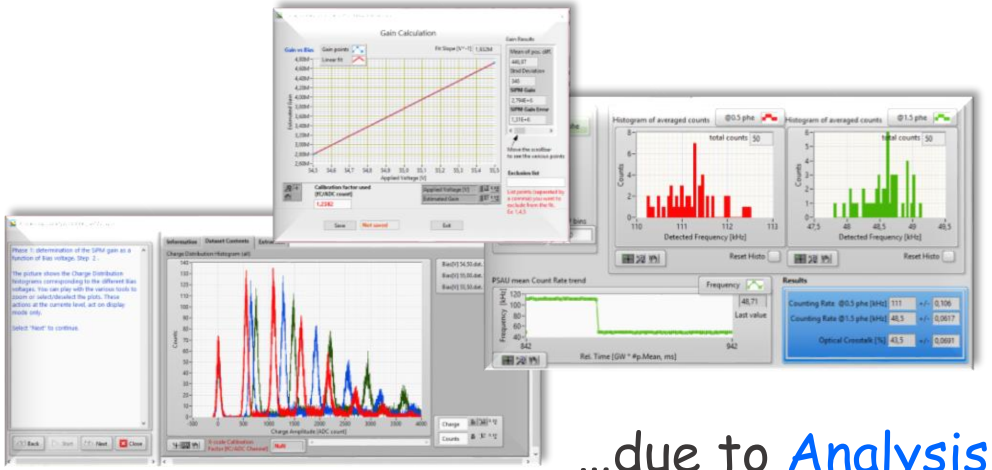


- Single pair of detectors oppositely aligned
  - ✓ Parallax error is eliminated
- Mechanical rotating system executing two types of independent movements to simulate the entire PET ring
  - ✓ 360° rotation (axis ≡ center)
  - ✓ θ scan (axis ≡ one detector)
  - ✓ Off-center source imaging
  - ✓ Spatial resolution uniform over the field of view

CAEN
Tools for Discovery

Products – Educational Kits

A New Software Platform that allows to manage 4 Educational kits and perform the experiments described in the CAEN Educational Catalog…

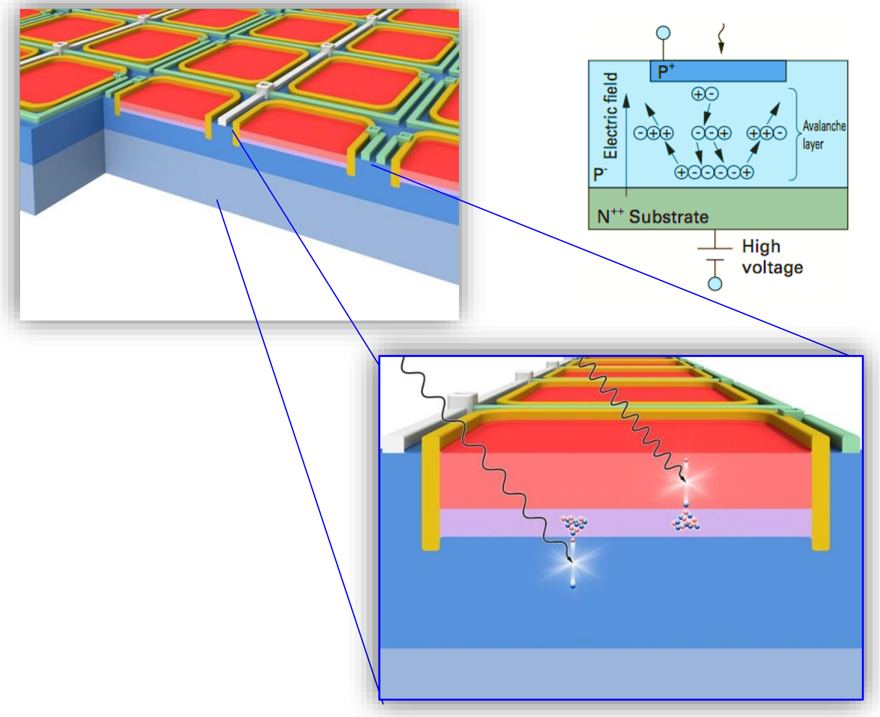


…due to Analysis Tools implemented in the software itself!

Suitable to different customers needs!

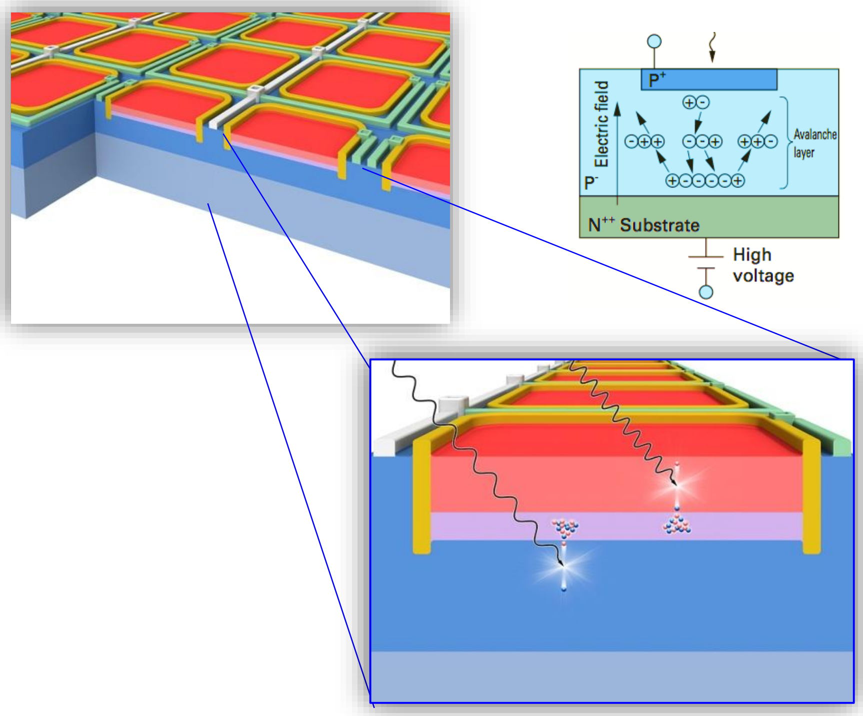
- Three Access Levels to the software functionalities:
- Help and QuickStart Guide on line

Silicon PhotoMultipliers - SiPM



- SiPM is a High density (up to 10^4/mm2) matrix of diodes with a common output, working in Geiger-Müller regime
- Common bias is applied to all cells (few % over breakdown voltage)
- Each cell has its own quenching resistor (from 100kΩto several MΩ)
- When a cell is fired an avalanche starts with a multiplicative factor of about 10^5-10^6
- The output is a fast signal (t_{rise}~ ns; t_{fall} ~ 50 ns) sum of signals produced by individual cells
- SiPM works as an analog photon detector

Silicon PhotoMultipliers - SiPM



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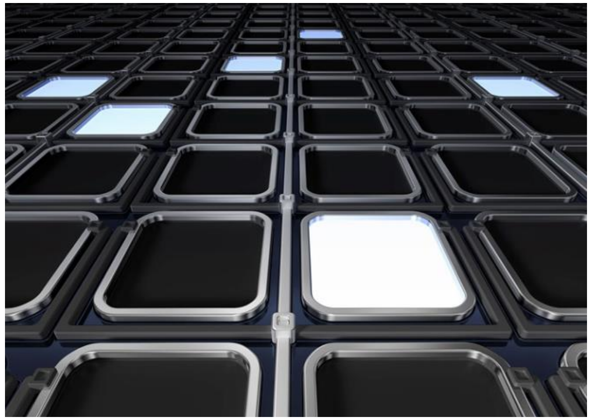
- SiPM works as an analog photon detector

$$A_i \sim C\,(V_{breakdown} - V_{bias})$$

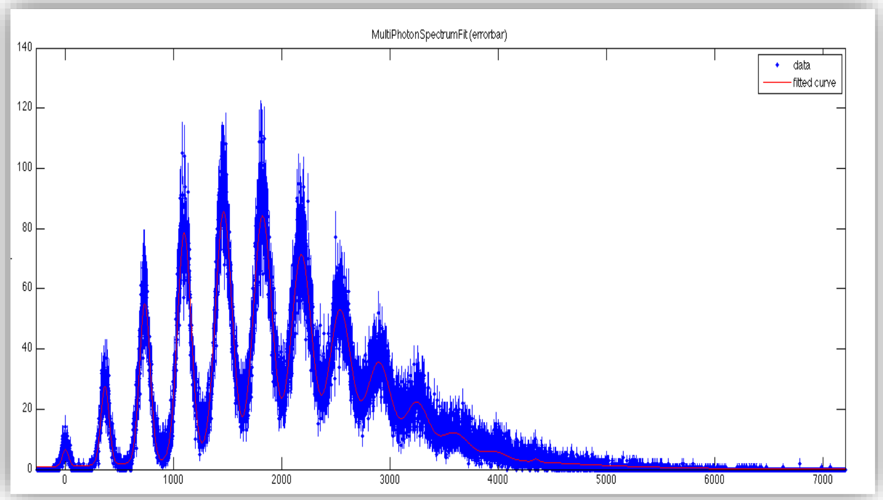
$$A = \Sigma A_i$$

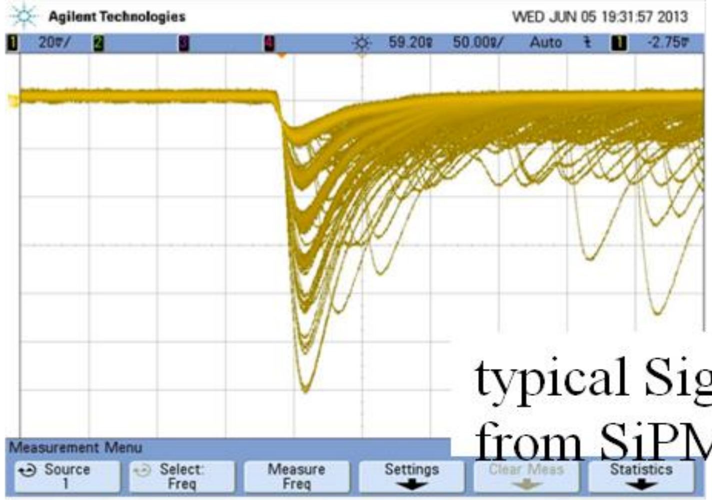
- SiPM may be seen as a collection of binary cells, fired when a photon in absorbed
- "counting" cells provides an information about the intensity of the incoming light



Silicon PhotoMultipliers - SiPM

The high uniformity of pixel structure guarantees no avalanche fluctuations

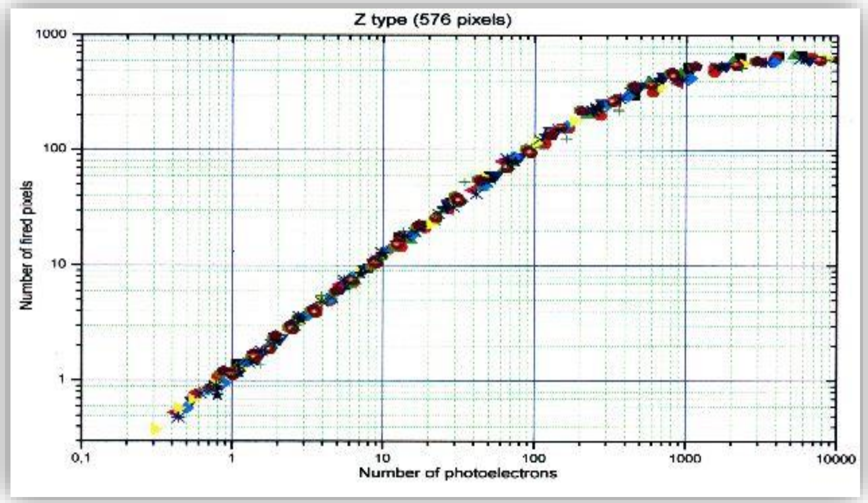




typical Signal from SiPM

excellent resolution

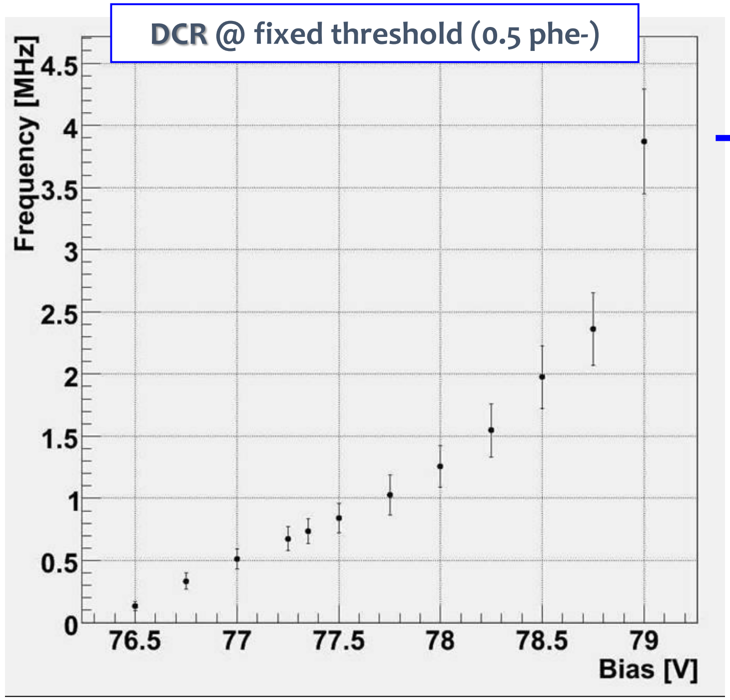
Linear response if the average number of photoelectrons/pixel is less than one

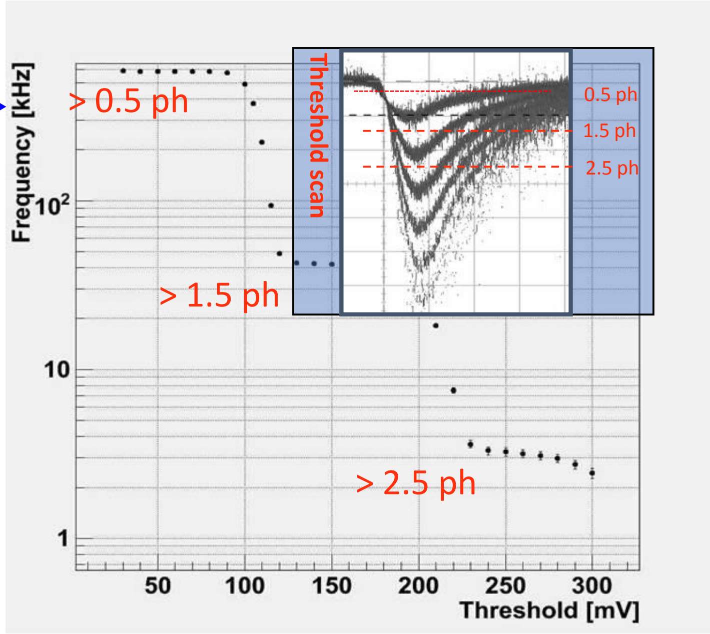


Number of pixel determines the SiPM **dynamic range**

Silicon PhotoMultipliers - SiPM

The **Dark Counts** (**DCR**) measure the rate at which a Geiger avalanche is randomly initiated by thermal emission.



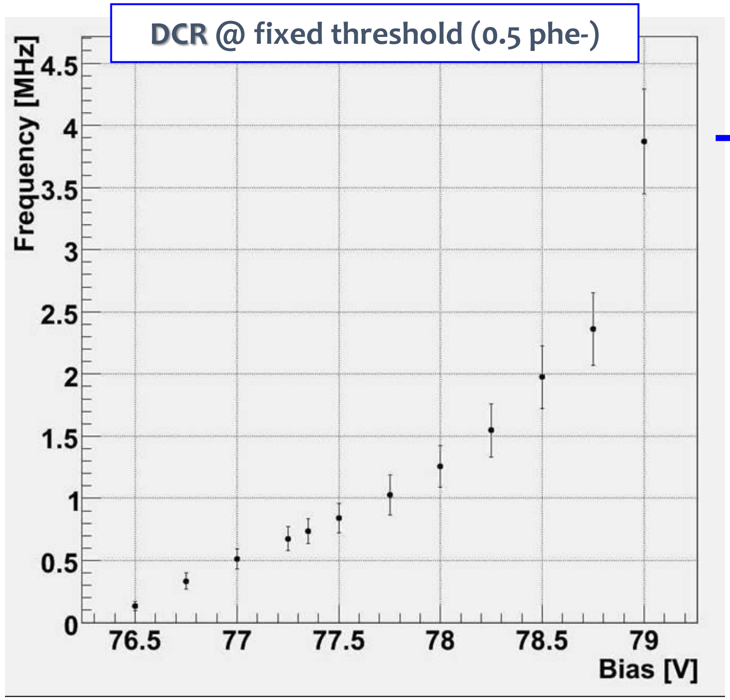


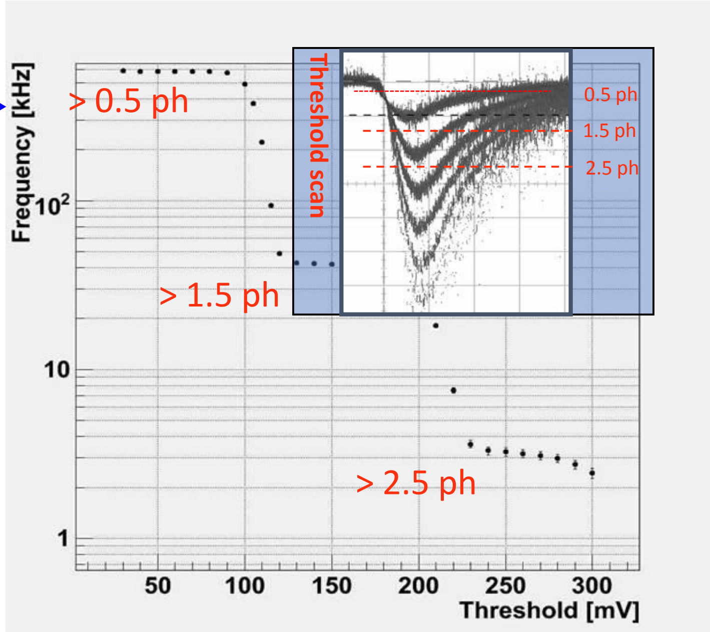
Decrease DCR:

- lowering temperature
- lowering active volume – decrease V_{bias}
  – small area

Silicon PhotoMultipliers - SiPM

The **Dark Counts** (**DCR**) measure the rate at which a Geiger avalanche is randomly initiated by thermal emission.



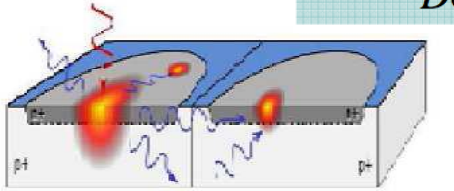


An avalanche generation can fire another cell by a photon; measuring the DCR for different thresholds is possible to define and evaluate the **Optical Cross Talk** (**OCT**) as:

$$X_{talk} = \frac{DCR(1.5\,ph)}{DCR(0.5\,ph)}$$

Decrease DCR:

- lowering temperature
- lowering active volume – decrease V_{bias}
  – small area

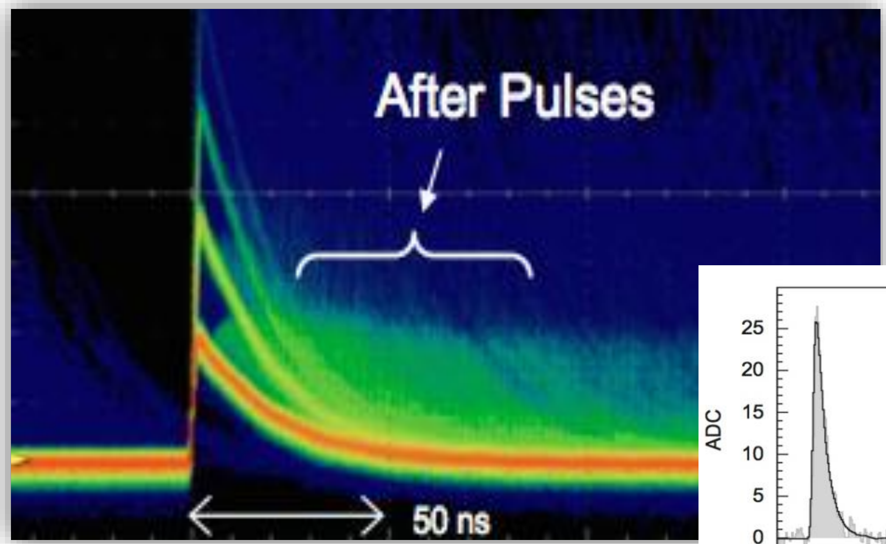


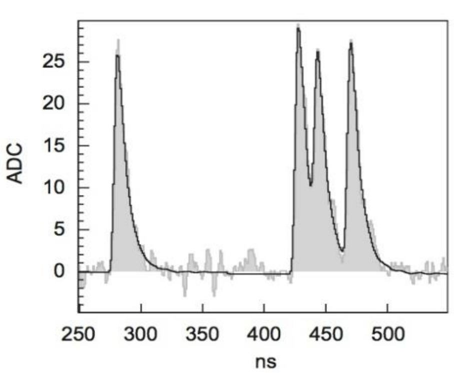
Decrease OCT:

- low gain/V_{bias}
- big pixel size
- trench for optical isolation

Silicon PhotoMultipliers - SiPM

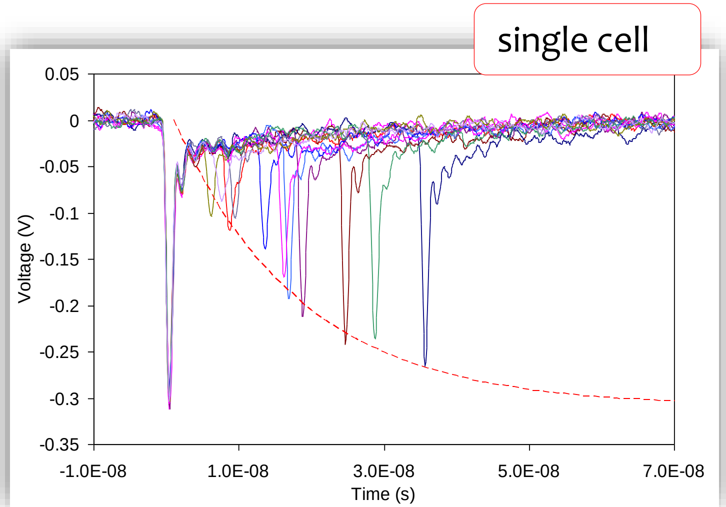
After Pulse: It is a delayed avalanches triggered by the release of a charge carrier that has been produced in the original avalanche and has been trapped on an impurity





- limiting the photon counting resolution

- The release of the trapped carriers is characterized by a typical decay time ~200 ns



The pulse amplitude depends on the pixel recovery state

$$\xi(\Delta t) = 1 - exp(-\Delta t/\tau_r)$$

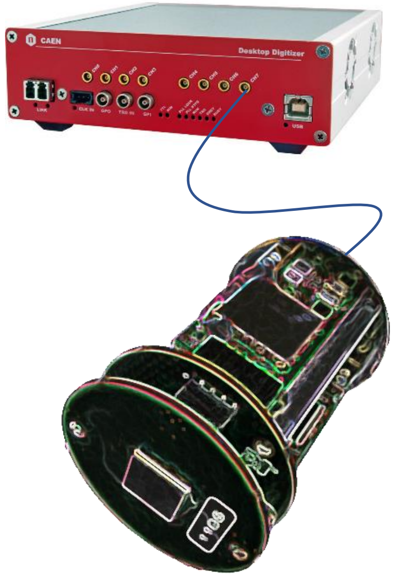
Decrease AP:

- low V_{bias}
- small pixel

CAEN Educational

i-Spector: PMT replacement with integrated digital pulse processing

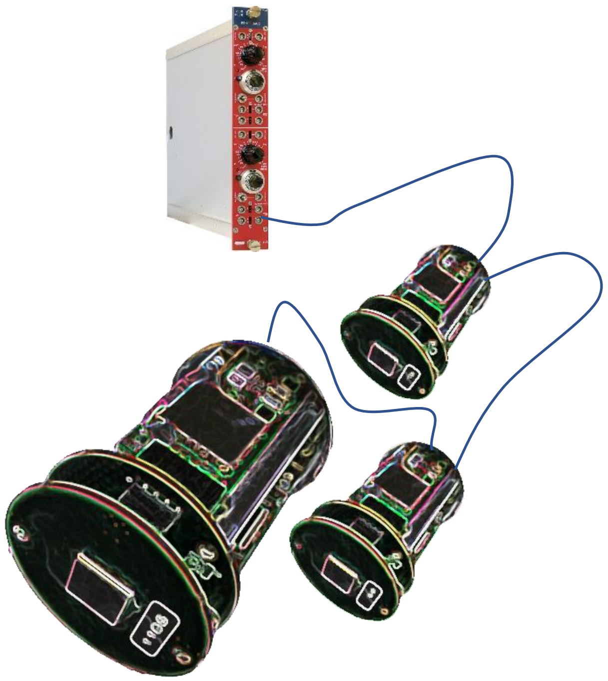
i-Spector



Analog Out

Replace PMT in Experiments

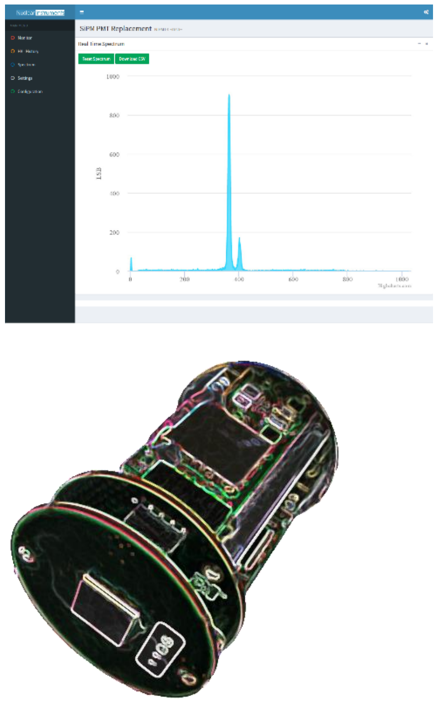
i-Spector PLUS



Logic And TMU

Trigger/Veto Logic/Time Stamping
Neutron Beam Monitor / TOF measurement

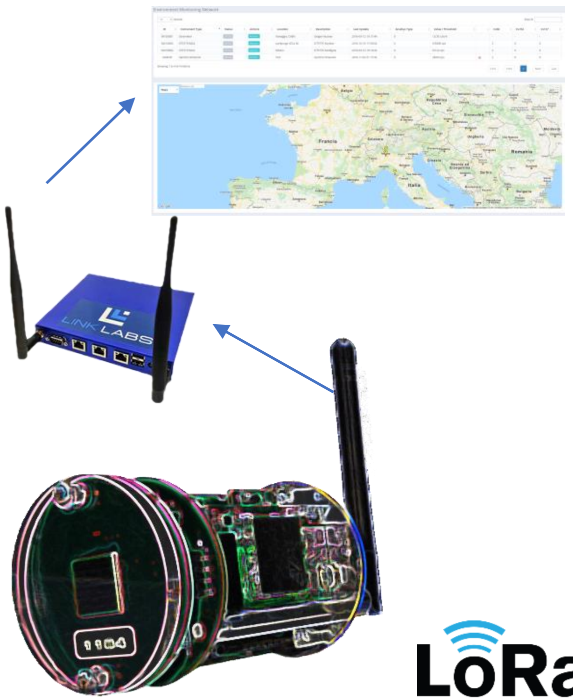
i-Spector Digital



Digital MCA

Laboratory Monitoring

i-Spector Digital LoRa



MCA + LORA

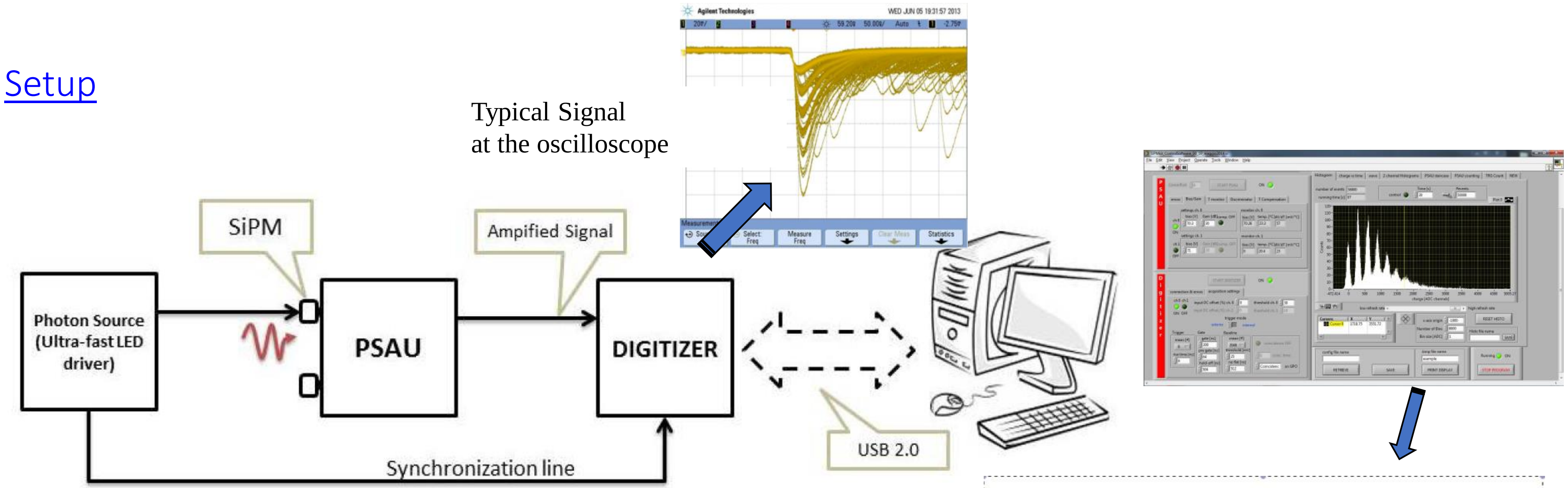
LoRa™

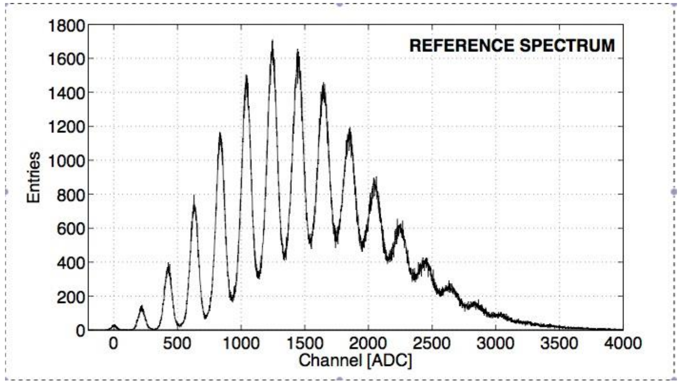
Large Area Environmental Monitor

Physics Experiments

D.1 An Educational kit based on Modular SiPM System

Setup



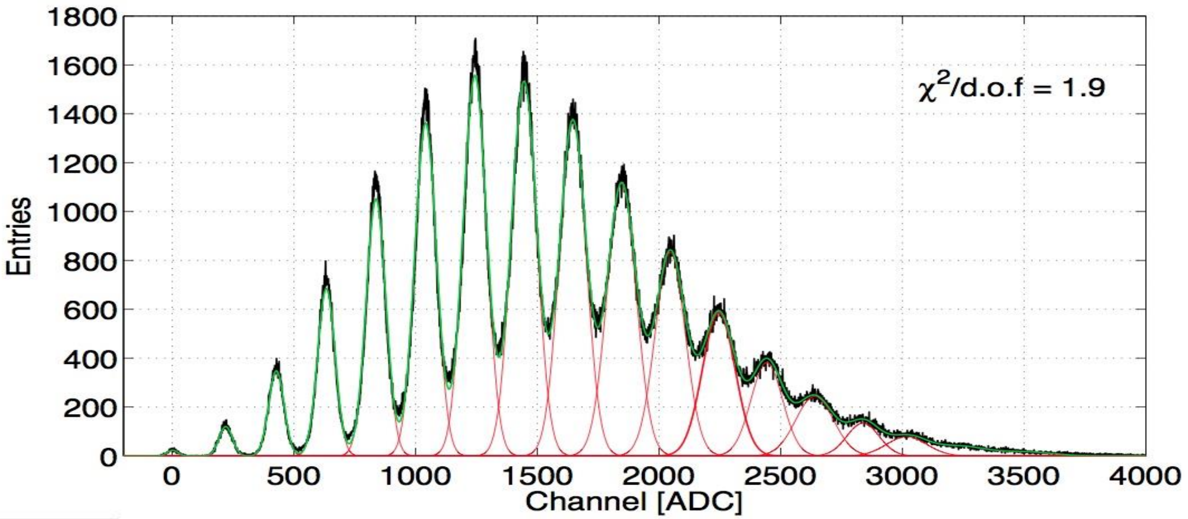


Goal:

- ✓ Can we investigate the statistical model underlying the emitted light?
- ✓ Can we investigate the detector performances trying to quantify its impact on the statistical model?

D.1 An Educational kit based on Modular SiPM System

Step 1: estimate the area under every peak

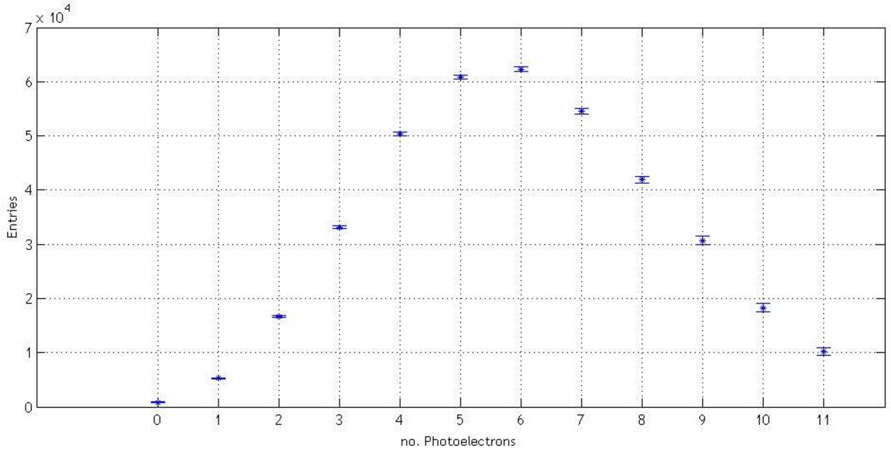


	PeakPosition[ADC]		*PeakWidth[ADC]*		*Exp. Probability*	
N	*P&P*	*MGF*	*P&P*	*MGF*	*P&P*	*MGF*
0	3 ± 1	2.1 ± 0.9	22 ± 1	21.7 ± 0.8	0.092 ± 0.006	0.09 ± 0.01
1	220 ± 1	220.1 ± 0.4	25 ± 1	27.3 ± 0.3	0.53 ± 0.02	0.56 ± 0.01
2	427 ± 1	428.0 ± 0.3	30 ± 1	31.5 ± 0.2	1.75 ± 0.06	1.86 ± 0.02
3	635 ± 1	633.6 ± 0.2	32 ± 1	36.0 ± 0.2	3.8 ± 0.1	4.17 ± 0.02
4	838 ± 2	837.5 ± 0.2	38 ± 1	40.5 ± 0.2	7.0 ± 0.2	7.21 ± 0.04
5	1044 ± 2	1041.3 ± 0.2	41 ± 1	44.7 ± 0.2	9.9 ± 0.2	10.30 ± 0.04
6	1247 ± 2	1243.7 ± 0.2	45 ± 1	48.2 ± 0.2	12.2 ± 0.3	12.67 ± 0.05
7	1449 ± 3	1445.6 ± 0.2	50 ± 3	51.9 ± 0.3	13.4 ± 0.8	13.43 ± 0.06
8	1650 ± 4	1645.8 ± 0.3	57 ± 2	54.8 ± 0.4	13.3 ± 0.5	12.71 ± 0.07
9	1853 ± 4	1846.4 ± 0.4	67 ± 2	59.5 ± 0.6	12.9 ± 0.4	11.2 ± 0.1
10	−−	2046.5 ± 0.6	−−	62.0 ± 0.9	−−	8.7 ± 0.1
11	−−	2245 ± 1	−−	66 ± 2	−−	6.6 ± 0.2
12	−−	2445 ± 1	−−	68 ± 2	−−	4.4 ± 0.2
13	−−	2632 ± 2	−−	65 ± 3	−−	2.4 ± 0.1

By a *point&click procedure*
(P&P for Pick&Play)
or
By a MultiGaussian Fit (MGF)

Physics Experiments

D.1 An Educational kit based on Modular SiPM System



Step 2: plot the probability function for the number of observed photo-electrons

Step 3: Different hypothesis to investigate the statistical model

1. Estimate the mean number of Ph.e. (model independent):
2. Poissonian hypothesis
   a. Compare it to what you get by the 0^{th} photon peak
   b. Fit the full distribution
3. Poissonian + Binomial to account for the cross-talk

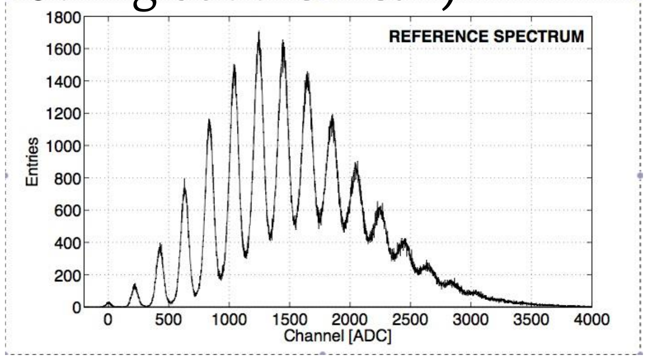
Physics Experiments

D.1 An Educational kit based on Modular SiPM System

Step 3: Different hypothesis to investigate the statistical model

1. Model independent: estimate of the mean number (nothing but the mean):

$$\mu_{MI} = \frac{\overline{ADC}}{\overline{\Delta_{pp}}}$$ with $$\overline{ADC} = \frac{\Sigma_i y_i ADC_i}{\Sigma_i y_i}$$



D.1 An Educational kit based on Modular SiPM System

Step 3: Different hypothesis to investigate the statistical model

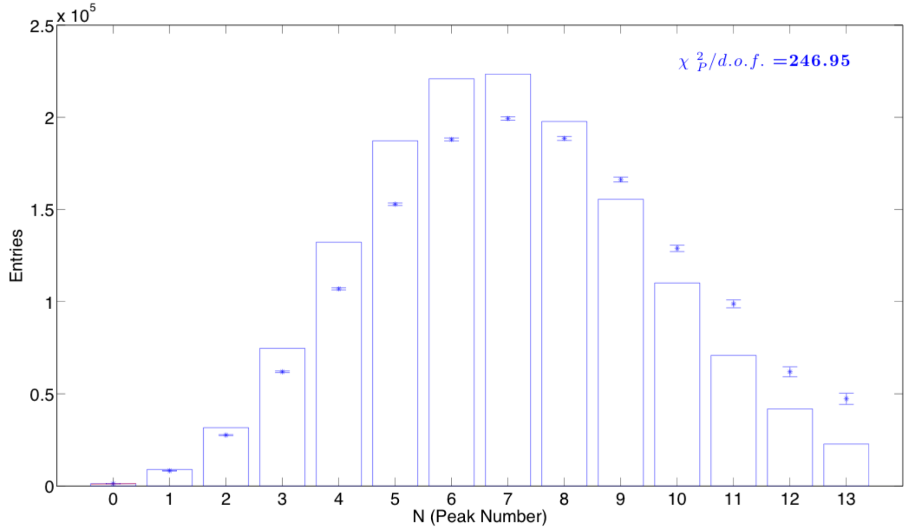
1. Model independent: estimate of the mean number (nothing but the mean):

$$\mu_{MI} = \frac{\overline{ADC}}{\Delta_{pp}} \quad \text{with} \quad \overline{ADC} = \frac{\Sigma_i y_i ADC_i}{\Sigma_i y_i}$$

2. Poissonian model:
   a. Estimate by the 0th Ph.e. peak

$$\mu_{ZP} = -ln(P(0)) = -ln(\frac{A_0}{A_{tot}})$$

   b. Fit the full distribution



D.1 An Educational kit based on Modular SiPM System

Step 3: fit the full distribution with the PxB model

[2014 update: Xtalk accounted for at all orders, following Vinogradov et al., DOI: 10.1109/NSSMIC.2009.5402300]

$$P \otimes B = \sum_{k=0}^{floor(m/2)} B_{k,m-k}(\epsilon_{XT}) P_{m-k}(\mu)$$

Probability to observe m Ph.e.

Probability for the incoming photons to fire (m-k) cells

Binomial Probability for the (m-k) primary cells to trigger k cells by optical cross-talk

The P⨉B distribution is characterized by the first & second order momenta given by:

$$\bar{m}_{P\otimes B} = \frac{\mu}{1-\epsilon_{XT}}$$

$$\sigma^2_{P\otimes B} = \mu(1+\epsilon_{XT})$$

Physics Experiments

D.1 An Educational kit based on Modular SiPM System

Step 3: fit the full distribution with the PxB model

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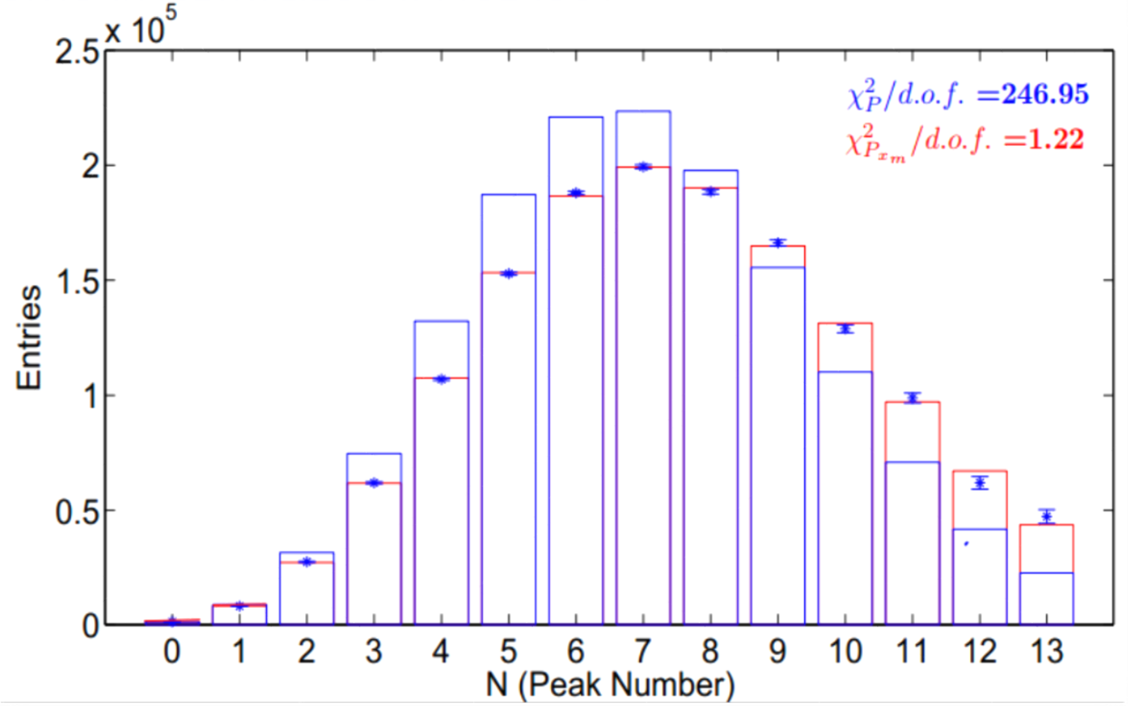
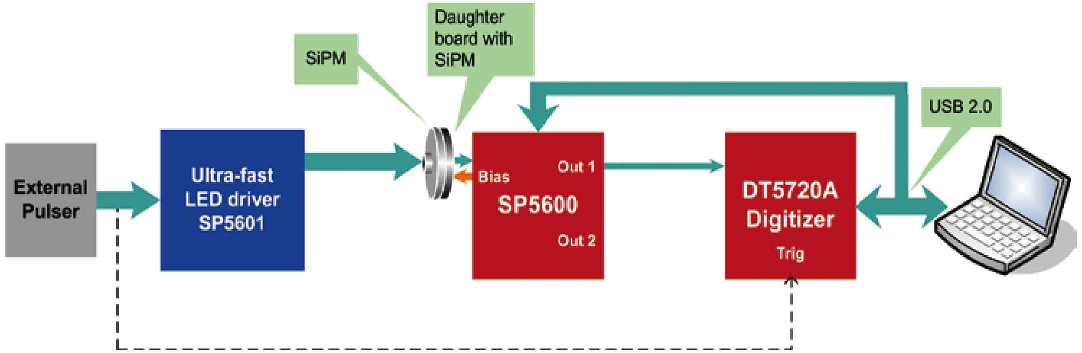


Simple Poissonian

Poisson & Xtalk

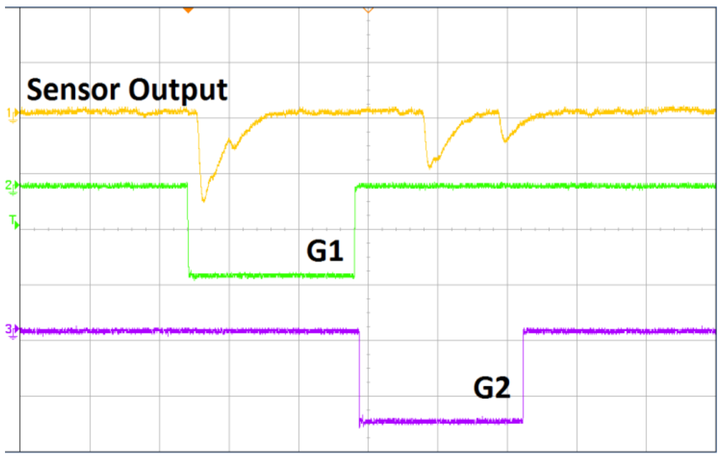
Definitely showing a better agreement and confirming the validity of the model (and the relevance of detector effects)

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

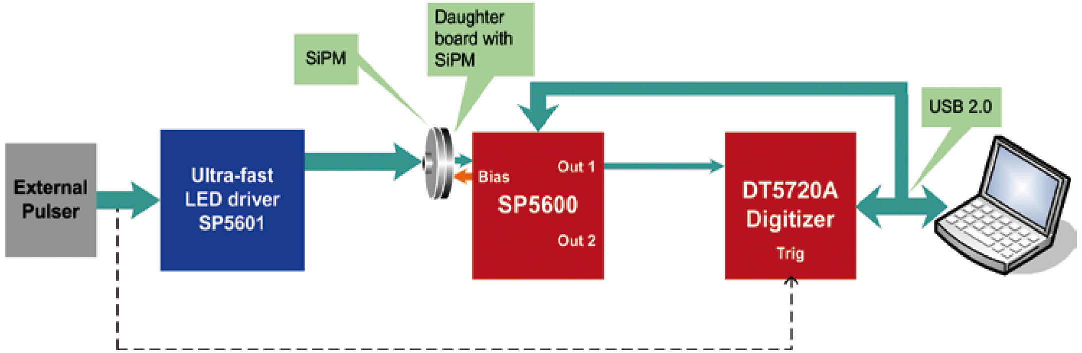


The method for the after-pulse and its time constant measurement is based on the analysis of the charge distribution in a variable time window.

The experimental procedure starts by defining two gates



D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers



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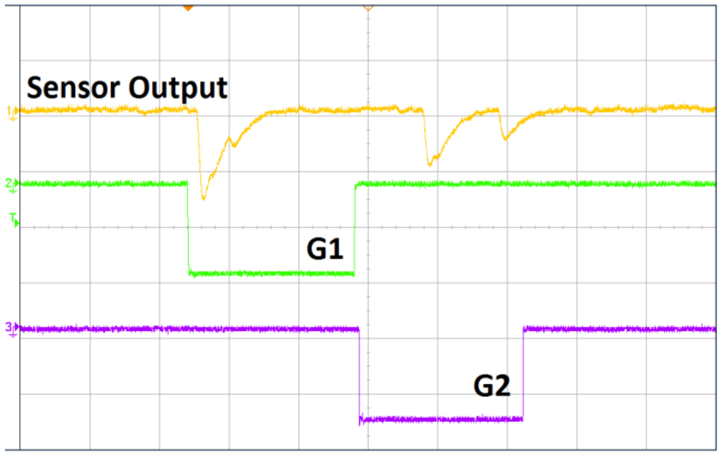
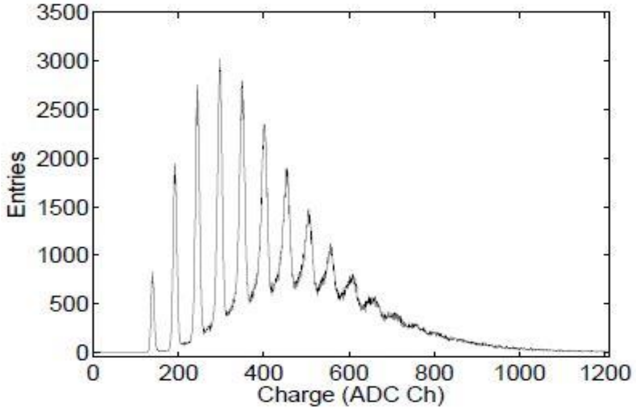


G1 is synchronized with the light burst.

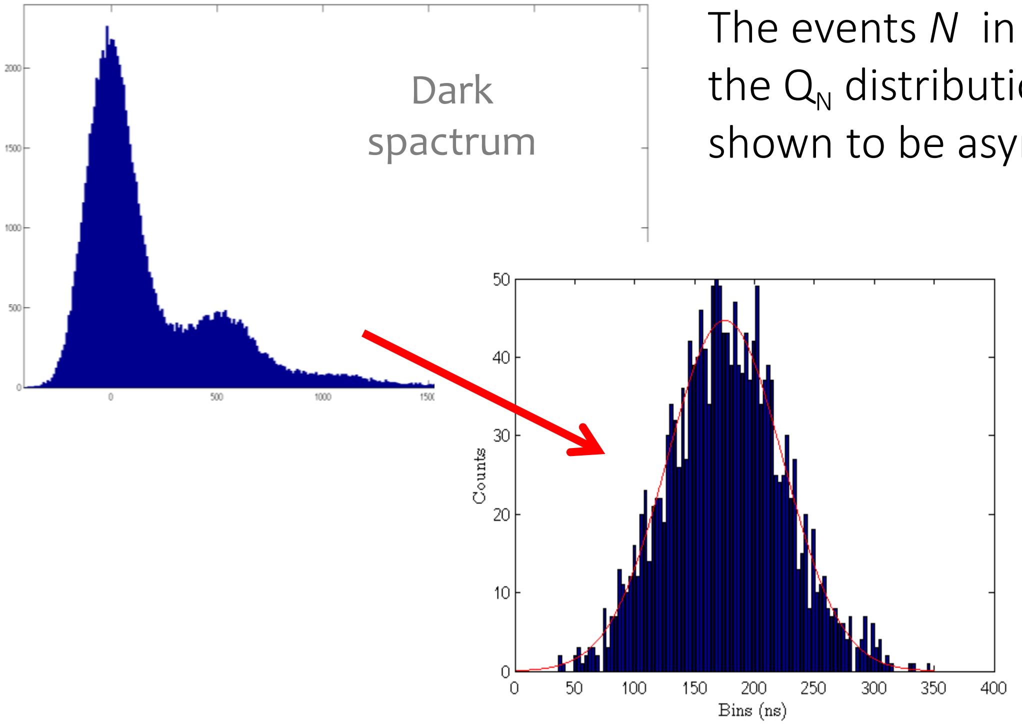


Light spectrum acquired to calibrate the charge in photo-electrons.

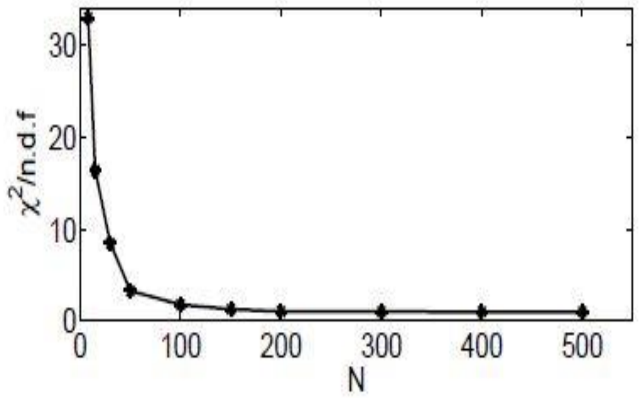
(M, Δ_{pp})

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

Switch OFF the light to estimate the DCR average charge Q_N in G2



The events *N* in a sequence are determined studying the Q_N distribution vs. N and fixing its value when it was shown to be asymptotically gaussian



D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

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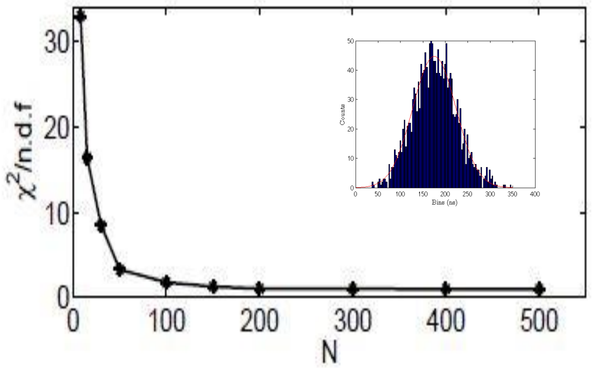


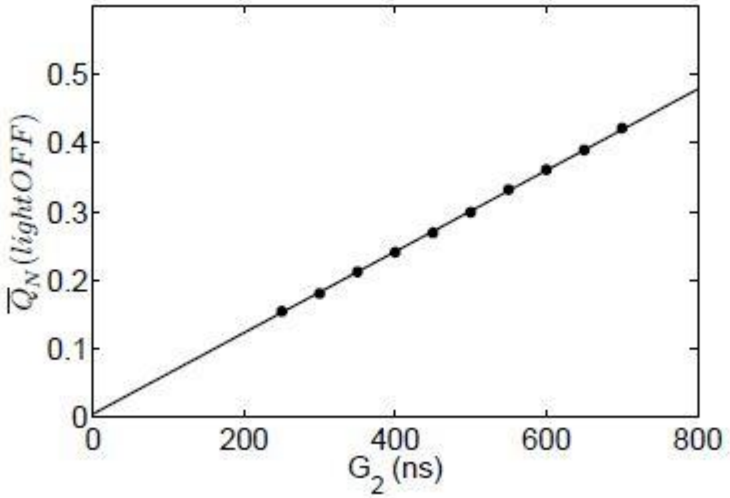
The events *N* in a sequence are determined studying the Q_N distribution vs. N and fixing its value when it was shown to be asymptotically gaussian

DCR measurement

- ❖ trend $<Q_N$(light OFF)$>/\Delta pp$ ~~vs~~ → time slope (m)

- ❖ considering OCT → $<Q_N>/\Delta_{pp} = n_{p.e}.x(1+\varepsilon)$

- ❖ DCR= m/(1+ε)

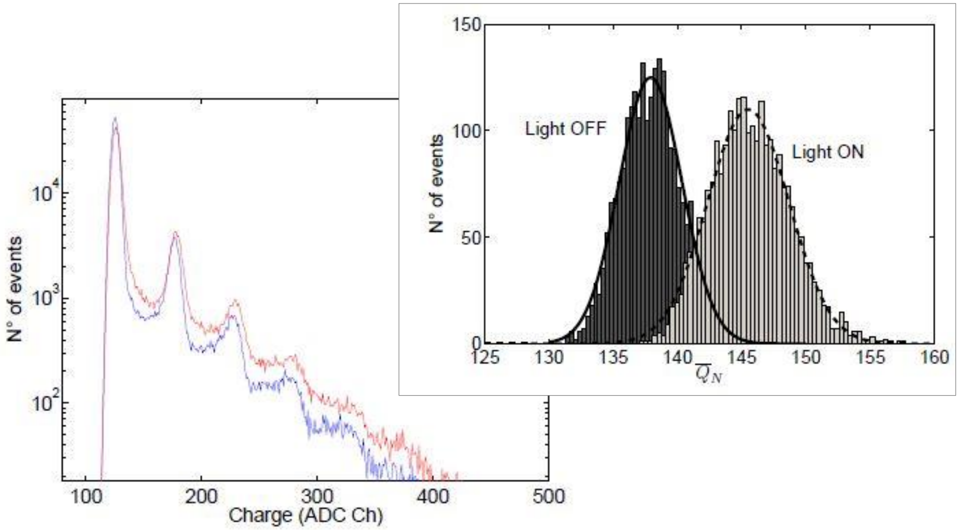


D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

Switch ON the light and estimate the average charge in G2 gate

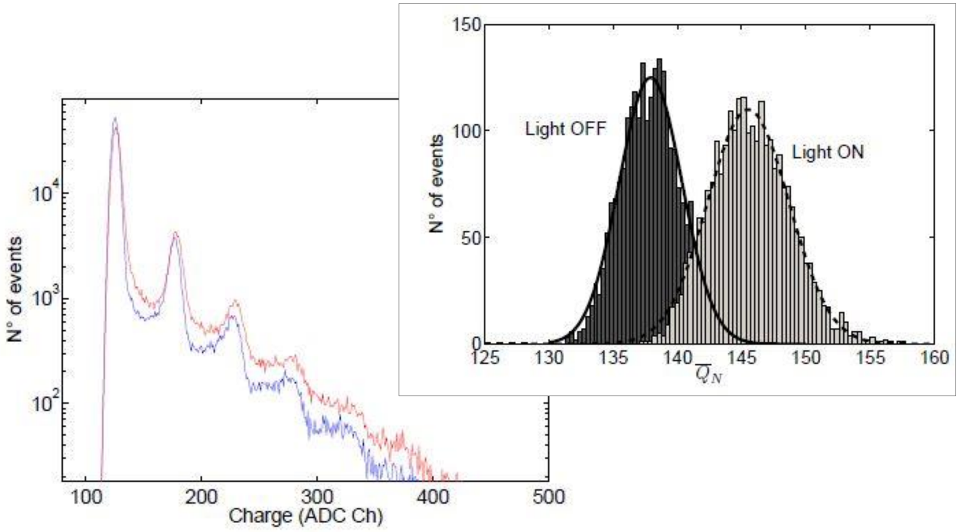
$$\Delta_{QQ}(G_2) = \frac{\langle \overline{Q}_N(light\ ON, G_2)\rangle - \langle \overline{Q}_N(light\ OFF, G_2)\rangle}{\overline{\Delta}_{pp}}$$

measures the excess of avalanches due to after pulses associated to the light burst with respect to Dark Counts.



D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

Switch ON the light and estimate the average charge in G2 gate



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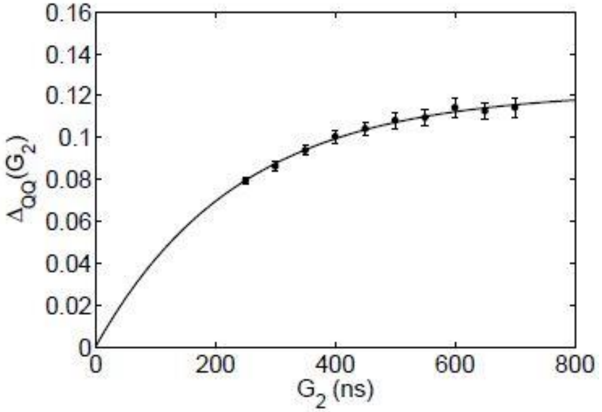
measures the excess of avalanches due to after pulses associated to the light burst with respect to Dark Counts.

After-pulse measurement

$$y(t) = \frac{P}{\tau} e^{-\frac{t}{\tau}} \rightarrow \Delta_{QQ}(G_2) = \int_{G1}^{G1+G2} \frac{M \times P}{\tau} e^{-\frac{t}{\tau}} dt = a(1 - e^{-\frac{G_2}{\tau}})$$

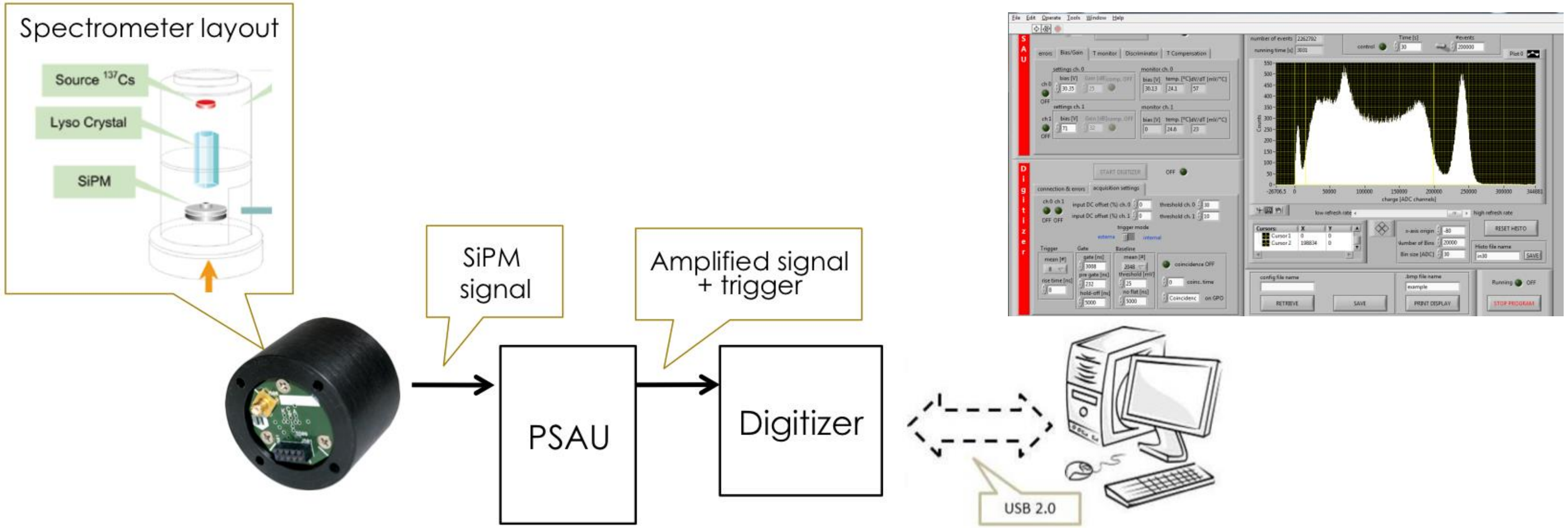
a and τ are estimated from fit curve

$$a = M \times P e^{-\frac{G_1}{\tau}}$$ → ***P** after-pulsing probability*



Physics Experiments

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers



Goal:

- ✓ Qualify the SiPM for spectrometry (i.e. energy resolution optimization, linearity response and resolution dependence)
- ✓ SNIP introduction: algorithm for background subtraction under the photopeak

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

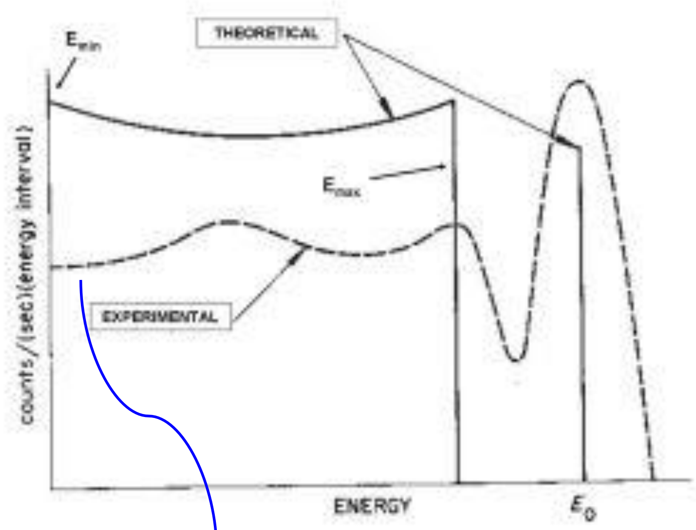
$FWHM_{peak}$ = full width at half maximum of the peak
μ_{peak} = channel number of the peak centroid

Physics Experiments

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

The photo-peaks are the signature of a spectrum. Their analysis conveys relevant information about the radioactive sample and the experimental apparatus:

- the peak energies are distinctive of the decaying nuclei in the sample;
- the area of peaks measure the relative concentrations of isotopes;
- the linearity of the system is provided by the spectra for a set of known γ emitters;
- the width of the peaks represents the electronics plus detector resolution.



$$E_e = E_0 \times \left(\frac{\frac{E_0}{mc^2}(1-\cos\theta)}{1+\frac{E_0}{mc^2}(1-\cos\theta)}\right)$$

E_0: incoming γ-ray energy
Θ : scattering angle
mc^2: electron rest-mass

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

The SNIP: an algorithm for background subtraction under the photopeak

❖ The SNIP (Statistics sensitive Non-linear Iterative Peak clipping) is not new and it is actually a quite popular [and implemented in Root (Tspectrum) & R] algorithm for automated (or semi-automated) background subtraction

❖ originally introduced for the treatment of PIXE (Proton Induced X-ray Emission) (ref.1), has been adapted for bckg elimination in coincidence γ-ray spectra (ref.2)

❖ developed to account for spectra with poor & large statistics (extended dynamic range), searching for a solution with the minimal number of parameters, aiming for a “full” automation

1. C.G. Ryan et al., NIM B34 (1988) 396-402
2. M Morac et al., NIM A401 (1997) 113-132

SNIP fundamentals

1. Start by a spectrum y(i), where *i* is the ADC/Energy bin identifier and y is the corresponding number of events

2. transform the original spectrum in $v(i) = \log[\log(\sqrt{y(i)+1}+1)+1]$

   where the log(s) compress the dynamic range and the sqrt enhances the small peaks

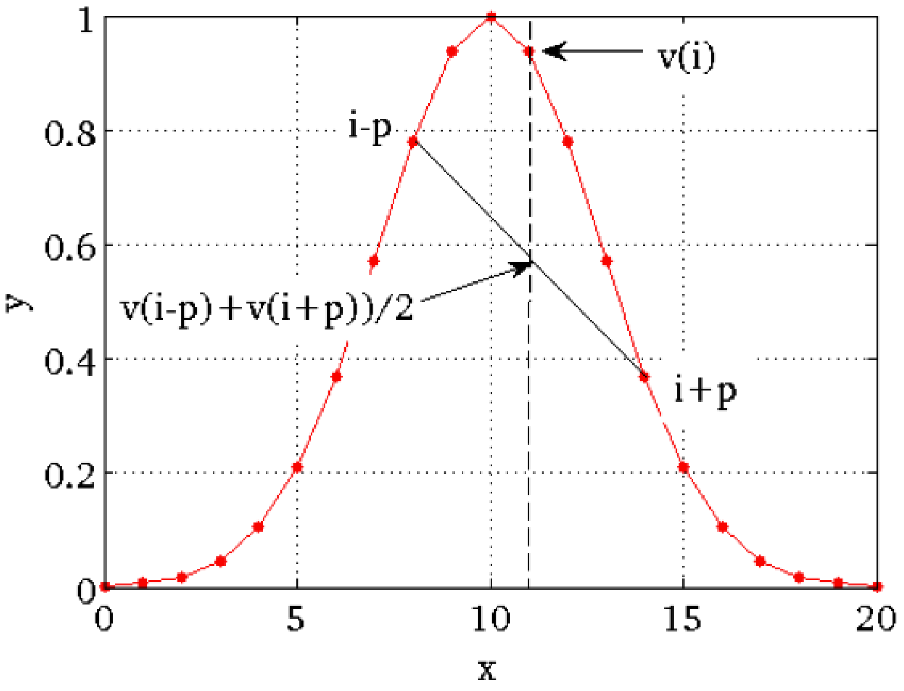
3. Replace v(i) with $v_p(i) = \min(v_{p-1}(i), \frac{1}{2}(v_{p-1}(i-p) + v_{p-1}(i+p)))$

4. Iterate on p till when it is "convenient" [this is the hard part]

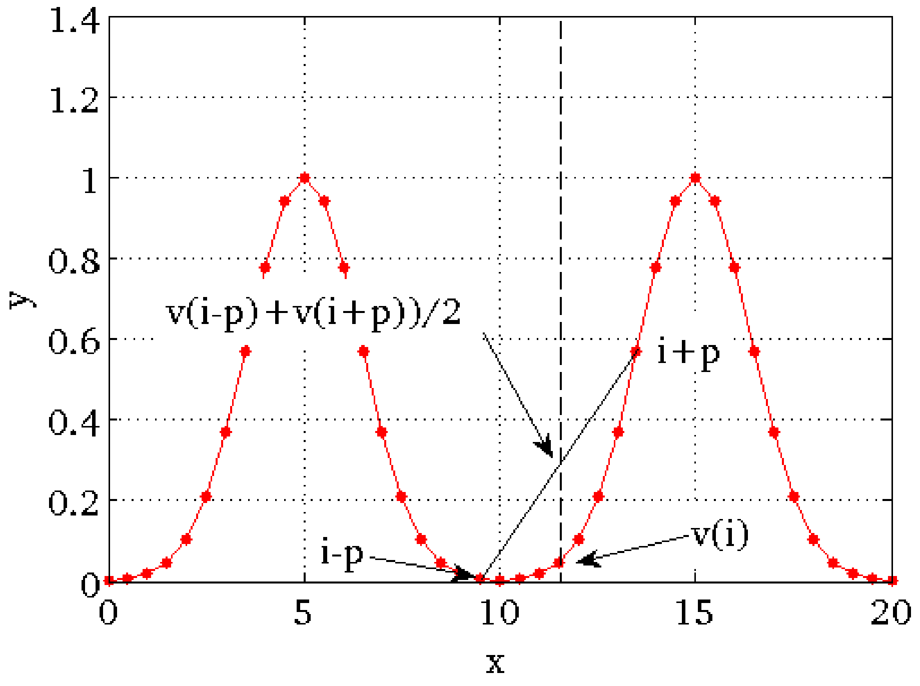
5. anti-transform & subtract from the original spectrum

D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

SNIP in action



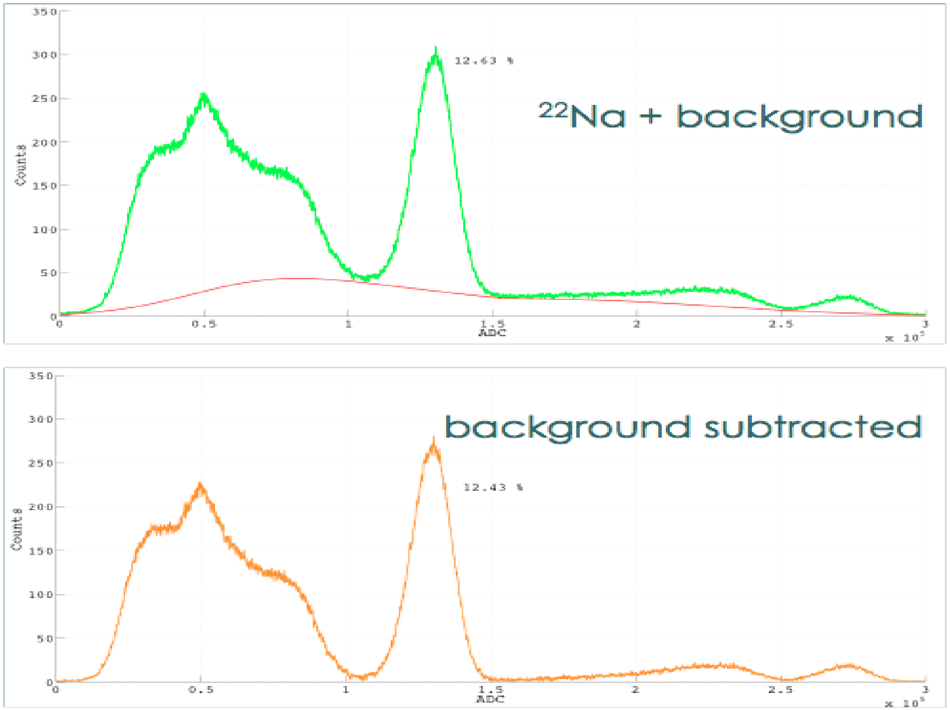
On a peak, p = 3



On a valley, p = 3

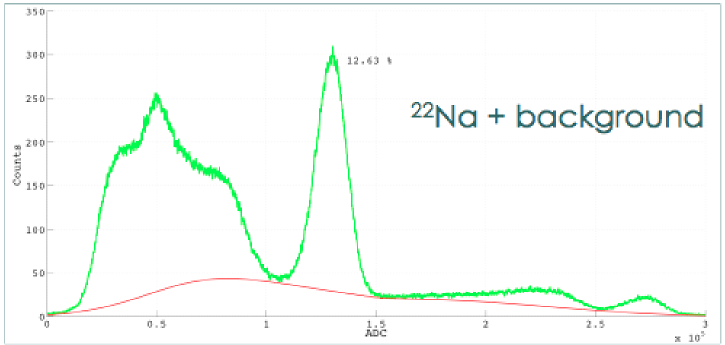
D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

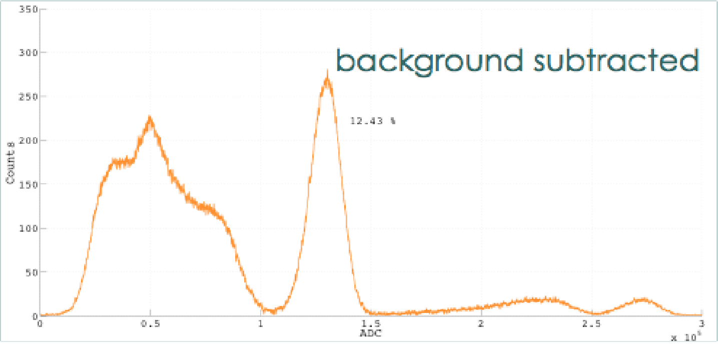
The SNIP has been implemented in a MATLAB routine for the subtraction of the smeared Compton shoulder under the photo-peak, to improve the estimate of the Peak Position, Peak Width and Peal



D.2 A simple and robust method to study after-pulses in Silicon Photomultipliers

The SNIP has been implemented in a MATLAB routine for the subtraction of the smeared Compton shoulder under the photo-peak, to improve the estimate of the Peak Position,





Followed by a measurement of the linearity & resolution: