Rev. 1 - March 16th, 2021

SP5620CH

Cosmic Hunter

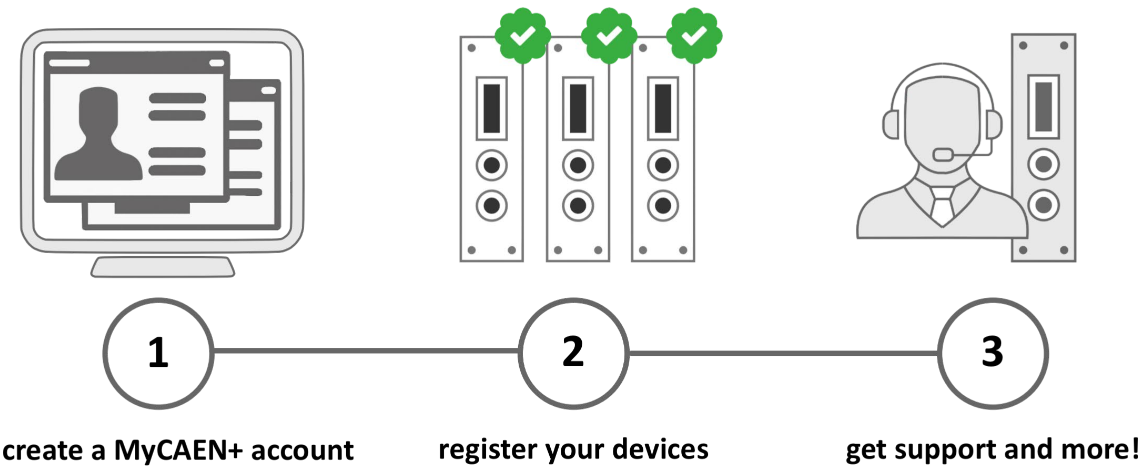
CAEN Educational

Guide
GD7686

Register your device

Register your device to your **MyCAEN+** account and get access to our customer services, such as notification for new firmware or software upgrade, tracking service procedures or open a ticket for assistance. **MyCAEN+** accounts have a dedicated support service for their registered products. A set of basic information can be shared with the operator, speeding up the troubleshooting process and improving the efficiency of the support interactions.

MyCAEN+ dashboard is designed to offer you a direct access to all our after sales services. Registration is totally free, to create an account go to https://www.caen.it/become-mycaenplus-user and fill the registration form with your data.



https://www.caen.it/become-mycaenplus-user/

Purpose of this Guide

This QuickStart Guide contains basic information and examples that will let you use Educational Cosmic Hunter in a few steps.

Change Document Record

Date	Revision	Changes
September 14th, 2020	00	Initial release
March 16th, 2021	01	Modified "Data Storage" paragraph in Chapter 3.

Symbols, Abbreviated Terms and Notation

DC	Direct Current
USB	Universal Serial Bus

Reference Documents

[RD1] GD7330 - Assembling Instructions

[RD2] https://www.espressif.com/en/products/devkits

[RD3] K.A. Olive et al. (Particle Data Group), Chin. Phys. C, 38, 090001 (2014)

[RD4] Cosmic Rays, Oxford, Clarendon Press, 1948 (https://archive.org/details/cosmicrays029757mbp/page/n9/mode/2up).

[RD5] A. A. Ivanov et al., JETP letters, V69 N4(1999)288.

[RD6] Frank G.Schröder, Radio detection of cosmic-ray air showers and high-energy neutrinos, 2017 (https://doi.org/10.1016/j.ppnp.2016.12.002)

[RD7] http://cosmicrays.oulu.fi/links.html

All CAEN documents can be downloaded at: www.caen.it/support-services/documentation-area

CAEN S.p.A.
Via Vetraia, 11 55049 Viareggio (LU) - ITALY
Tel. +39.0584.388.398 Fax +39.0584.388.959
info@caen.it
www.caen.it

Index

List of Figures

List of Tables

Introduction

CAEN is proud to bring our more than 40 years of collaborative experience with the High Energy & Nuclear Physics community into University educational laboratories. In redesigning our highly advanced acquisition and high voltage instrumentation into kits which are ideally suited to the University-level teach experience a series of experiments covering several applications can be performed.

CAEN has developed a family of modular Educational Kits, each designed to perform a number of physics experiments. The set-ups are all based on Silicon Photomultipliers (SiPM), state of-the-art light sensors with single-photon sensitivity and unprecedented photon number capability.

The CAEN Educational branch includes several kits suitable for a wide range of laboratory teaching needs. In designing these kits, our goal is provide instructors with the tools necessary to teach the scientific method to the students, guiding them towards the realization of critical, foundational experiments based on modern Physics.

The **Cosmic Hunter, SP5620CH**, is a user-friendly system for cosmic-ray detection. It can be used as an external trigger system for a separate experimental application or as a didactic instrument. The user friendly design makes it suitable for students who have not yet developed strong technical knowledge about electronic instrumentation. As a result, Cosmic Hunter is well suited to not only university-level physics labs, but also to high school level physics programs.

The Cosmic Hunter Kit contains:

- Nr. 1 Coincidence Module (ID code SP5621). This is a counter device which allows a user to supply bias voltage to the scintillating tiles and count the hits produced by muons on each tile.
- Nr. 2 Detection System (ID code SP5622). Included are two tiles composed of plastic scintillator directly coupled to a SiPM. Documentation which includes information about detection efficiency and the applied bias voltage is provided for each system.
- Nr.1 External AC/DC stabilized 5*V* power supplies (Multicomp MCEXT5V15WC1, 5*V* DC Output, 2.4*A*).

The various building blocks of the kit can be assembled in customized configurations according to the specific applications 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.

Code	Description
WK5620CHAAAA	SP5620CH - Cosmic Hunter
Related Products	**Description**
WSP5622XAAAA	SP5622 - Detection System
Accessories	**Description**
WSP5609XAAA	SP5609 - Telescope Mechanics

Tab. 1.1: Table of models and related items.

1. Power Requirements

The SP5621 is powered by the external AC/DC stabilized power supply provided with the SP5620CH and included in the delivered kit. Please use only the power supply shipped with this instrument and certified for the country of use.

Input: *100-240 VAC*, *47-63 Hz*; Output: *5.0 V*, *2.4 A*.

Fig. 1.1: AC/DC power supply provided with the Cosmic Hunter – SP5620CH.

Alternatively, a mobile phone power bank or a computer can be used to power the module via the micro-USB connector on the rear panel of the SP5621.

2. General Description

The **Cosmic Hunter - SP5620CH**, shown in **Fig. 2.1**, is composed of two *Detection Systems - SP5622* and one *Coincidence Module - SP5621.*

Fig. 2.1: Cosmic Hunter, the educational system to detect and study the cosmic rays. On the left is the coincidence module, and on the right are the detection systems.

The system allows you to perform almost all the experiments described in the kit guide. However, for some specific applications additional tools are required: An additional *Detection Systems – SP5622* and the *Telescope Mechanics - SP5609*. More details are given in **Chapter 3**.

The following section is dedicated to a complete description of the system components and functionalities.

Detection System

The **Detection System – SP5622** (size: *18.4 x 18.4 x 2.7* cm^3 - weight: *860g*), called "scintillating tile" in this document, consists of a plastic scintillator, a photodetector, and a small front-end electronic boards.
The charged particles that pass through the unit deposit part of their energy inside the scintillators, producing a light signal. The light produced in the scintillator is then collected and converted into an electrical signal via a photosensor unit.

The plastic scintillator, Polystyrene-based, is a tile with dimensions *15 x 15 x 1* cm^3. The following table describes the main features of this material.

Feature	Value
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. 2.1: Plastic Scintillator features.

The scintillating tile is characterized by excellent temporal resolution, with rise times of light pulses less than 1 *ns* and duration equal to about 2.5 *ns*. The light yield allows cosmic electrons and muons to produce light signals that are sufficiently intense to be detected by the photosensor with very high efficiency.

As already mentioned, the light produced by the incident radiation is detected by a photodetector, the Silicon Photomultiplier (SiPM). The SiPM is a high-density matrix of diodes with a common output, working in Geiger-Müller regime. A common bias is applied to all cells connected in parallel. The output is a fast signal which corresponds to the sum of signals produced by the individual cells. The SiPM may be seen as a collection of binary cell which “fire” when a photon is absorbed, and the cells “counting” provides information about the intensity of the incoming light.

The SiPM is an AdvanSiD NUV-SiPM (4 x 4 mm^2). ASD-NUV SiPM is based on the “P-on-N” silicon technology for the detection of Near Ultraviolet Light. It has peak efficiency at 420 *nm* and a detection spectrum extending from 350 *nm* to 900 *nm*. The Operating Temperature Range is between -25*°C* and +40 *°C* and its breakdown voltage temperature dependence is about 25 *mV/°C*.

The following table summarizes the main features of the ASD-NUV4S-P.

Feature	Value
Effective active area	4 x 4 mm^2
Number of cells	9340
Cell size	40 *µm* × 40 *µm*
Cell fill-factor	60 %
Quenching resistance	800 *kΩ*
Cell capacitance	90 *fF*
Recharge time constant	70 *ns*
Photon Detection Efficiency	43 %
Breakdown voltage	Typical: 26 *V* Min: 24 *V* Max: 28 *V*
Recommended Overvoltage range	Min: 2 *V* Max: 6 *V*
Dark Count Rate	< 50 kHz/mm^2 @ 2 *V* OV < 100 kHz/mm^2 @ 6 *V* OV
Gain	$3.6{\times}10^6$

Tab. 2.2: Geometrical, Electrical and Optical Typical Characteristics of ASD-NUV4S-P @ 20°*C.*

Because scintillation photons are emitted in all directions with the same probability it is necessary to focus them towards the area of the scintillator surface which is coupled to the SiPM.
Concerning design, one corner of the scintillating tile is cut at 45 degrees in order to assemble the detector via the very small electronics board. Two screws guarantee correct board and SiPM alignment. The application of optical grease between the SiPM and scintillator further improves optical light transmission.

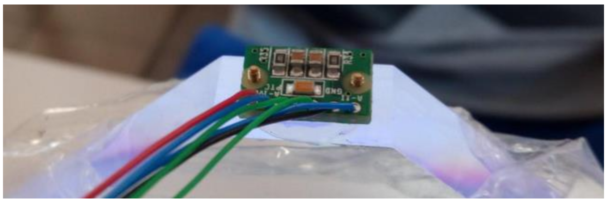


Fig. 2.2: Coupling example between the SiPM and the plastic scintillator.

To enhance the collection of the light the plastic scintillator is covered by a sheet of metalized mylar. The mylar sheet reflects the photons and enhances the detection of light produced by the charged particles crossing the scintillator, thus increasing the number of photons on the SiPM. The whole described system is wrapped in black cardboard and then enclosed in a black plastic cover. The black cardboard prevents ambient light and ensures that all the detected photons are derived from the interaction between the cosmic rays and the scintillator.

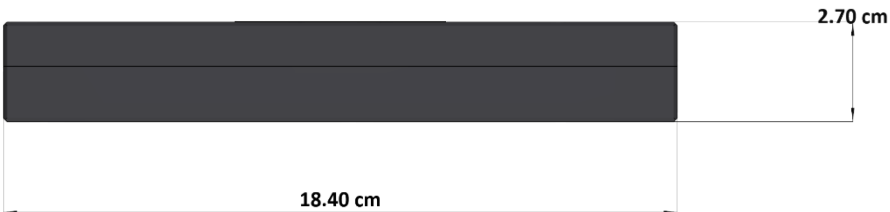


Fig. 2.3: Detection Systems – SP5622 side view.

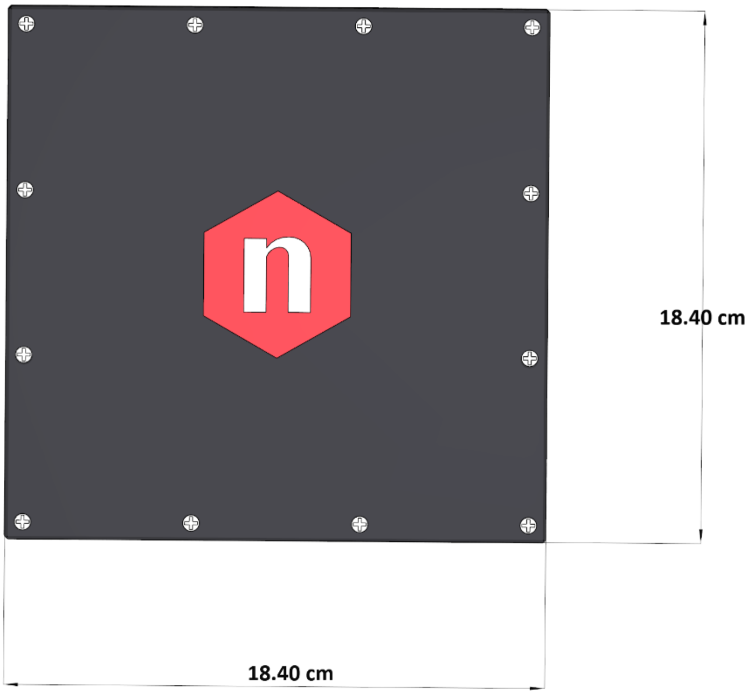


Fig. 2.4: Detection Systems – SP5622 top view.

The front-end electronics of the SP5622 consists of a transconductance amplifier and a fast discriminator. The scintillating tile is power supplied by 5*V* via the SP5621 module, and the electronics output signals are LVDS type.

Each SP5622 is supplied with a datasheet containing information about the detection efficiency value at the fixed SiPM bias voltage. The SiPM bias Voltage cannot be modified by the user.

Coincidence Module

The **Coincidence Module – SP5621** (size: *18.13 x 16.52 x 6.62 cm³* - weight: *660g)* provides information about the device status and coincidence counts. The module hosts an esp32-based microcontroller, "DOIT Esp32 DevKit v1"**[RD2]**, which allows the user to select the events to count: either the signals coming from only one scintillating tile or the coincidence signals between the two tiles. The number of events acquired is shown in real-time on the display, together with the related information about the measurement in progress.

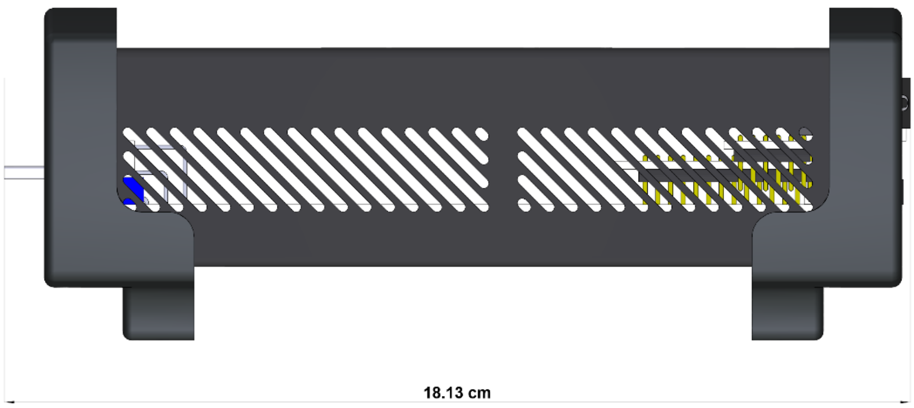


Fig. 2.5: Coincidence module – SP5621 side view.

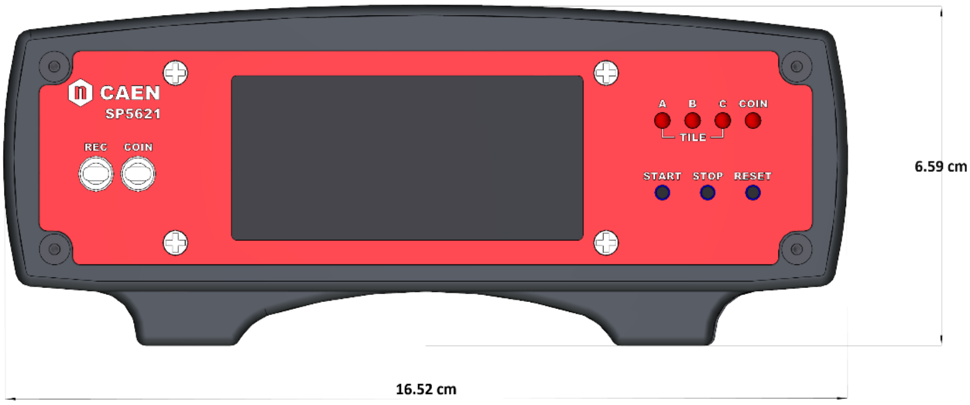


Fig. 2.6: Coincidence module – SP5621 front view.

The front panel, shown in **Fig. 2.6**, houses the e-book display and the control buttons.
The first three LEDs on the front panel light up when a signal is detected in the A, B and/or C scintillating tiles. Each SP5622 tile is identified by the label of the input connector on the rear panel (**Fig. 2.8**).
The fourth LED lights up when there is a coincidence signal. The coincidence type can be selected via the button (COIN) and it is visualized on the display panel. The button on the left side of the display allows the user to activate automatic recording on a microSD card and to choose the integration time. The buttons on the right side of the display allow the user to start, stop, and reset the counting mode.

Note: For correct device operation please press buttons for approximately two seconds or until the corresponding status changes on the display.

The display is graphically divided into different areas which contain quantitative information about the measurement in progress (see **Fig. 2.7**).

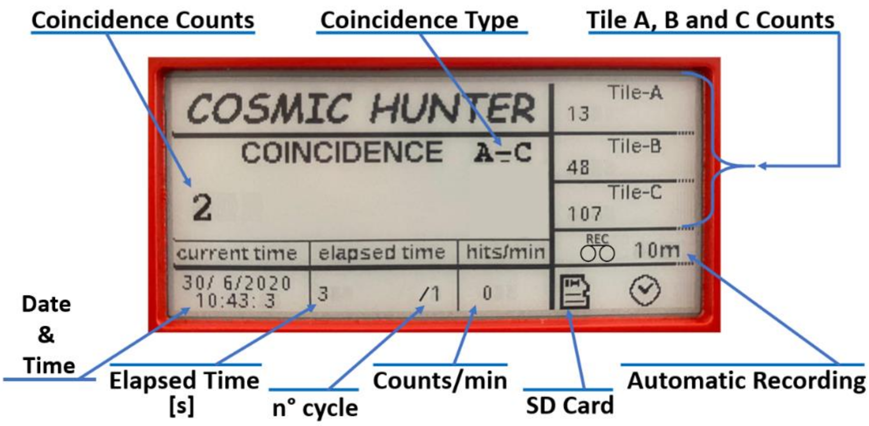


Fig. 2.7: Display description.

On the rear panel of the module, shown in **Fig. 2.8**, several inputs/outputs are present: the input connector for 5 *V* power supply, the connector for microSD memory card, three connectors for the scintillating tiles inputs and a 16 pin connector with the LVDS outputs of the three tiles and of the coincidence, and generic outputs labelled as LVDS OUT (see **Fig. 2.9**).

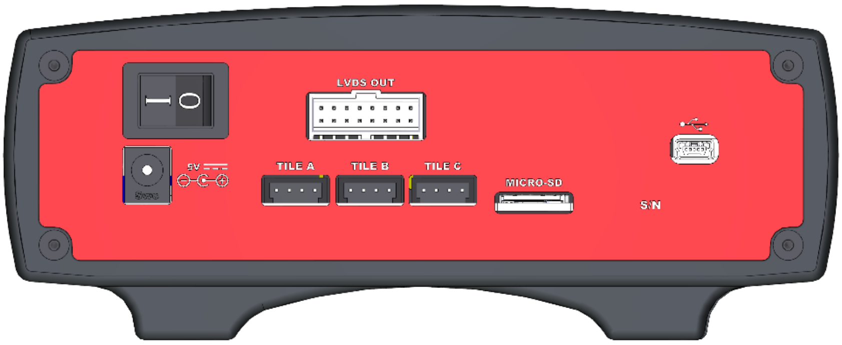


Fig. 2.8: SP5621 Rear Panel.

The rear panel also hosts a micro-USB connector which was utilized to program the esp32 microcontroller during module production. However, this micro-USB connector can also be used to power the "Cosmic Hunter" via computer or via mobile phone power bank.

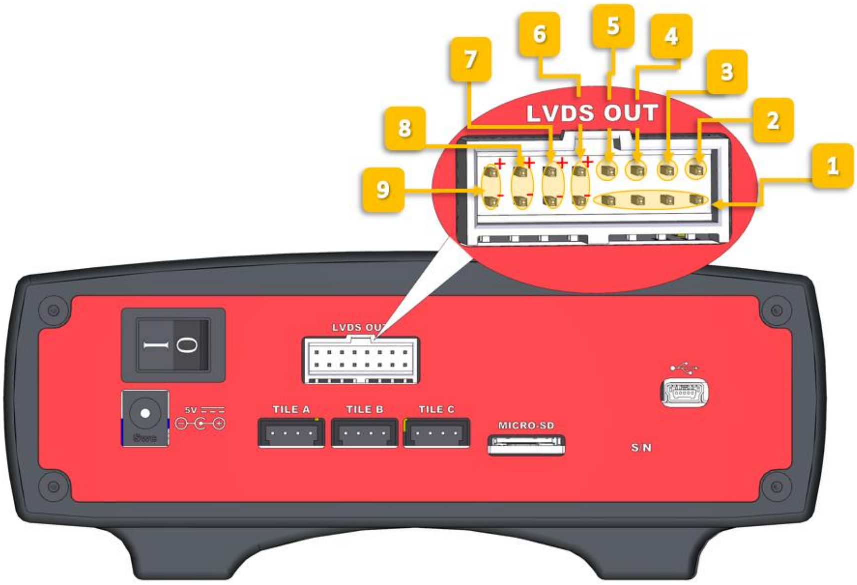


Fig. 2.9: LVDS OUT – Outputs description: 1) Ground; 2) 5V; 3) Start; 4) Stop; 5) Reset; 6) Tile A; 7) Tile B; 8) Tile C; 9) Coincidence.

Operational features

The **Cosmic Hunter** allows the user to select the coincidence type, the count integration time, and the data saving.

Coincidence Type

The default coincidence is between tile A and tile B. The Coincidence button, Up/Down type, allows the user to change and select among the following options:

- **A-C:** Tile A & Tile C - double tile coincidence;
- **A:** Tile A - single tile coincidence;
- **C:** Tile C – single tile coincidence;
- **B:** Tile B – single tile coincidence;
- **A-B:** Tile A & Tile B – double tile coincidence;
- **C-B**: Tile C & Tile B - double tile coincidence;
- **ABC:** Tile A & Tile B & Tile C - triple tile coincidence.

The coincidence type is selectable by moving the up/down button "COIN" and by keeping that position for about two seconds or until the status changes on the display. Toggle the button up to reach the triple coincidence ("ABC") option. Triple coincidence is the last attainable value by moving the button up. Once this selection is reached, the user can go back and move the button down to change and select another coincidence type up to "A-B" double selection. The "A-B" and "ABC" coincidences represent the extremes of the selection options.

Integration Time

Via the up/down button "REC" on the left side of the display, it is possible to select the integration time and to activate automatic recording on a microSD card, located on the rear side of the SP5621. When recording is activated the (REC) icon and the selected integration time appear on the display.

The available recording times are as follows: 10 minutes, 30 minutes, 1 hour, 2 hours, 4 hours, 6 hours, 12 hours, 18 hours, and 24 hours.

Automatic data saving can be activated only if the SD card is inserted in the SP5621 module. Correct insertion of the SD card is verified on the display by the ( ) icon. If the card is not present the icon disappears. The time of integration (s) and the recording cycle number are shown in the "elapsed time" section of the front display. The cycle number increases (no limit) while the time of integration decreases to zero starting from the selected time value. When the "elapsed time" becomes zero the counters reset, the data is recorded on the microSD, and the cycle begins again.

If the SD card is not inserted then the "elapsed time", shown on the front display (see **Fig. 2.7**), increases without an upper limit. The START, STOP, RESET buttons allow the user to start, stop, and reset the counters and the elapsed time, but no data is stored and the user must take note of it manually.

Important Note: Switch OFF the SP5621 before inserting or removing the SD card.

Data Storage

The microSD insertion must be done before powering on the module. The microprocessor recognizes the card and enables data saving. Simultaneously, the microSD card icon ( ) appears on the front display. Via the up/down button "REC" selection data files can be produced.

The files name has the following general format: *CSMHUNT_SN_yyyy-mm-dd_hh-mm-ss*

Where "*SN*" stands for the serial number of the SP5621, while "*yyyy-mm-dd_hh-mm-ss*" represents respectively the year, the month, the day, the hour, the minute and the second of data acquisition.

Note: Power cycle (switch off and on) is required to close a file and open a new one. If no reboot is performed then all data collected, regardless of possible changes to the settings, will be written in a single file.

The data format is .csv (comma separated values), compatible with Excel, Open Office, etc.
For each cycle a row of values separated by commas is saved and appended to the previous row:

num #1, coinc #1, date #1, time #1, sec #1, RecTime #1, A #1, C #1, B #1, COINC #1, Pressure #1, Temp #1, Humidity #1, Altitude #1
num #2, coinc #2, date #2, time #2, sec #2, RecTime #2, A #2, C #2, B #2, COINC #2, Pressure #2, Temp #2, Humidity #2, Altitude #2,
……

The data file of the measurement is a matrix (see **Fig. 2.10**), whose columns represent respectively: the cycle number (num), the selected coincidence type (coinc), the recording data (date), the recording time (time), the number of seconds from the measurement beginning (sec), the integration time in seconds (RecTime), the number of signals of the scintillator A (Tile A), the number of signals of the scintillator B (Tile B), the number of signals of the scintillator C (Tile C), the number of coincidence signals (COINC,) the pressure, the temperature, the humidity, and the altitude.

CSMHUNT_1_2020-6-30_8-21-31

num	coinc	date	time	sec	RecTime	A	B	C	COINC	Pressure	Temp	Humidity	Altitude
1	A-B	15/06/2020	08:21:31	0	600	0	0	0	0	982.54	23.88	47.96	258.86
2	A-B	15/06/2020	08:31:40	601	600	3215	3765	0	326	982.54	23.88	47.96	258.86
3	A-B	15/06/2020	08:41:40	1201	600	3228	3878	0	348	982.58	24.16	47.38	258.55
4	A-B	15/06/2020	08:51:40	1801	600	3094	3712	0	317	982.58	24.16	47.38	258.55

Fig. 2.10: Example of data stored with 10 minutes of integration time.

The sensor accuracy is about ±3% for measuring humidity, about ±1 hPa for barometric pressure, and about ±1.0°C for temperature. Because pressure changes with altitude, and the pressure measurements are so good, the sensor can be also used as an altimeter with ±1 meter accuracy.
However, the sensor can only infer altitude based on pressure and need a set calibration point. The stored altitude values are indicative only. Once measured a stable pressure, the user must estimate the offset between the corresponding altitude value and the location quote where the measurement takes place. Then this offset must be applied to all the altitude values to obtain significant value of altitude. Moreover, It is important underline that the barometric pressure changes daily based on the weather therefore the altitude could fluctuate based on these changes too. In conclusion, once estimated the offset, the altitude can be considered a reliable data in stable pressure condition, namely few hours during the same day.

Stored Data				**Right Altitude Values**
Pressure [hPa]	*Altitude [m]*	*Known altitude [m a.s.l.]*	*offset [m]*	*a.s.l. [m]*
1018,25	-41,58	2	43,58	2
1018,06	-39,95			5
1016,57	-27,61			17

Fig. 2.11: Calculating example of the correct altitude value.

3. Experiments

The CAEN Cosmic Hunter is designed to facilitate and support cosmic ray experiments.
Cosmic rays are energetic subatomic particles which are constantly bombarding the Earth's atmosphere from all directions. Cosmic radiation, discovered by Victor Hess in 1912, includes all stable charged particles and is composed of two components: "primary" and "secondary" cosmic rays. Primary cosmic rays are composed of heavy nucleus protons (~90%) and helium (~10%), as well as electrons, neutrinos, photons, some light nucleus and antimatter (positron and antiprotons). These particles are accelerated by astrophysical sources and by interacting with the terrestrial atmosphere. They mainly produce the "secondary" cosmic rays: pions, kaons and electromagnetic showers. Muons and neutrinos are products of the decay chain of charged mesons, while electrons and photons originate in decays of neutral mesons.

This section represents an overview of the experiments proposed by CAEN using the Educational kit Cosmic Hunter. 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 experiment is or will be available on the CAEN Educational web page very soon. The experiments address the essence of the phenomenon as well as exemplary illustrations of their use in different application fields, complemented by basic and advanced statistical exercises. Nice applications of the cosmic rays are represented by the muons radiography and tomography (see **Absorption Measurements (ID.6219)** experiment). The muons radiography and tomography are based on the measurement of the absorption undergone by high energy muons when they cross large size objects. These measurement technics provide precise maps of the average density of the object under investigation and they are used in several fields, from the geophysical application (volcanoes, caves, etc.) to the control of illicit traffic of radioactive materials, and much more.

The experiments proposed by CAEN are listed in **Tab. 3.1** and some of them, identified by (✱) symbol, require extra tools. For example, the ID. 6214 and ID. 6217 experiments need an extra scintillating tile, SP5622 - Detection System, while for the ID. 6216 experiment, the SP5609 - Telescope Mechanics is strongly suggested.

Section	Reference ID	Experiment	Additional tool
Particle Physics Cosmic Rays	6210	Statistics	No
	6211	Muons Detection	No
	6212	Muons Vertical Flux on Horizontal Detector	No
	6213	Random Coincidence	No
	6214✱	Detection Efficiency	n.1 SP5622 - Detection System n.1 DT1081A - Four-Fold Programmable Logic Unit and n.1 Cable Adapter
	6215	Cosmic Flux as a function of the altitude	No
	6216✱	Zenith Dependence of Muons Flux	n.1 SP5609 - Telescope Mechanics
	6217✱	Cosmic Shower Detection	n.1 SP5622 - Detection System
	6218	Environmental and Cosmic Radiation	No
	6219	Absorption Measurements	No
	6220	Solar Activity Monitoring	No

Tab. 3.1: Physics Experiments performed via the Cosmic Hunter Kit. If the symbol (✱) is present, extra tools are needed to perform the experiment.

Statistics (ID.6210)

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:

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

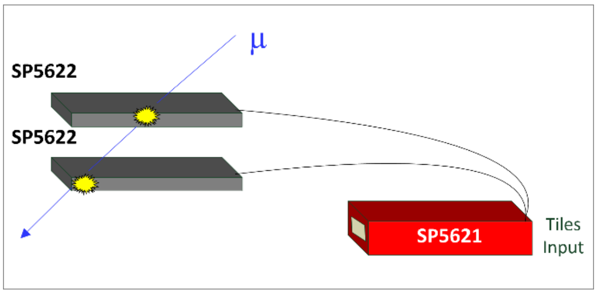
where μ is the average number of events in a fixed interval and n is the number of events.

Requirements:

No additional tools or components are required.

Carrying out the experiment:

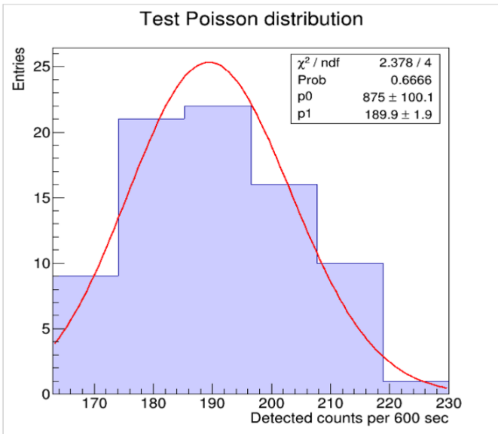
Connect the cable connector from each SP5622-Detection System to the input located on the rear panel of of the SP5621 module. Power on the SP5621 module and start acquisition via the START button on the front panel. When a charged particle crosses the black tile its energy is converted into scintillation light. The photons produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator is available via the SP5621 display. Note that spurious electrical signals will likely also be detected by the photosensor, thus producing noise. Coincidence between two SP5622 will greatly reduce the number of spurious events. However, the statistical fluctuations cannot be totally removed.
Select the scintillators coincidence via the related button on the front panel, then select the integration time of the measurement. Before starting acquisition choose the system geometry. Be sure to keep this geometry constant for the duration of the experiment. Take and record more data to obtain statistical significance.



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: $y = p0 * (p1^x/x!) * e^{-p1}$].

Muons Detection (ID.6211)

Purpose of the experiment:

Cosmic ray detection using a system composed of two plastic scintillating tiles directly coupled to a Silicon Photomultiplier detector.

Fundamentals:

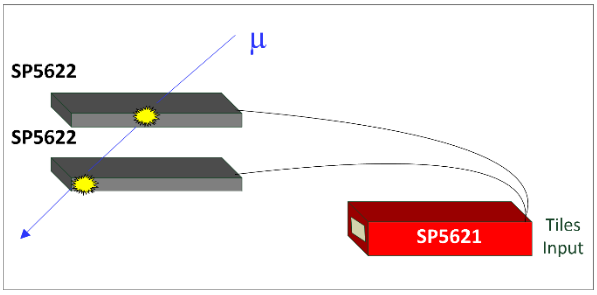
Muons are produced by the decay of pions and kaons generated by the hadronic interaction of the primary cosmic rays with atmospheric nuclei. They are the most common cosmic rays at sea level.
Cosmic muons are charged particles which are produced high in the atmosphere (typically 15 km) and with very high penetration capability in matter. Their mass (~200 times the mass of an electron), the absence of strong interactions, their long lifetime ($\tau \sim 2{,}2x10^{-6}$ s) and the time dilation effect due to their highly relativistic velocities allow muons to cross the atmosphere and reach the Earth's surface.
The average energy of a muon at sea level is around 4 GeV.

Requirements:

No additional tools or components are required.

Carrying out the experiment:

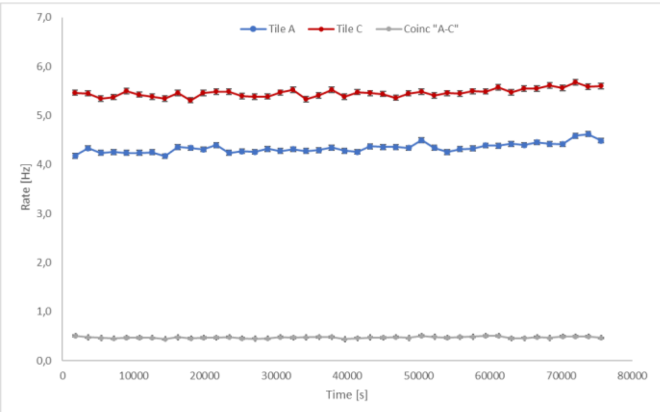
Connect the cable connectors of the two SP5622 to the inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator is available via the SP5621 display. Note that also spurious electrical signals are likely to be detected by the photosensor, thus increasing the noise. Putting two SP5622 in coincidence will greatly reduce the number of these spurios events. Because acquisition of the events will take place only in the presence of the coincidence, all events coming from a cosmic particle that crosses only one scintillating tile will be automatically discarded.
A muon telescope can be realized by playing with the geometry of the two SP5622. For example, by increasing the distance between the two scintillating tiles the direction of the particles will be more defined and the solid angle will be reduced. Conversely, by reducing the distance between the two scintillating tiles the solid angle will become greater and the direction of the particles will be less defined.



Experimental setup block diagram.

Results:

Double tile coincidence plays a key role in cosmic ray detection. It should be used to reduce the random counts, select the solid angle, and measure the cosmic rate.



Counts Rate of the single tiles and their coincidence as a function of the time.

Muons Vertical Flux on Horizontal Detector (ID.6212)

Purpose of the experiment:

The purpose of this experiment is to measure muon vertical flux upon the plastic scintillating tiles and to estimate the detection efficiency of the system by comparing the expected rate with the measured one.

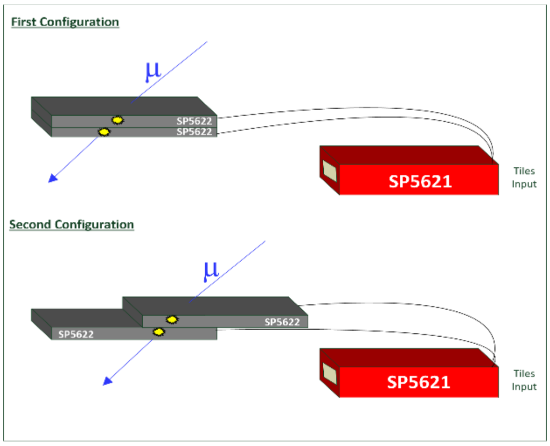
Fundamentals:

Muons with an average energy of approximately 4 GeV lose about 2 GeV to ionization before reaching the ground. 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 **[RD3]**.

Requirements:

No additional tools or components are required.

Carrying out the experiment:



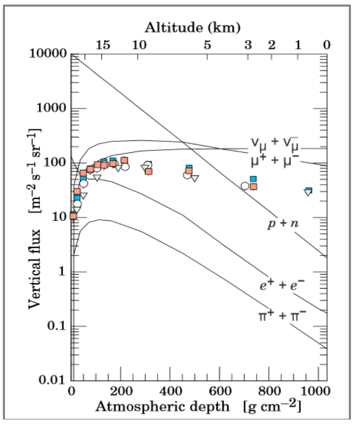
Experimental setup block diagram.

Connect the cable connectors of the two SP5622 to the inputs located on the rear panels of the SP5621 modules. Power on the SP5621 module and start acquisition via the front panel START button. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator is available via the SP5621 display. Select the scintillators coincidence via the related button on the front panel, then select the integration time of the measurement. Because acquisition of the events will take place only in the presence of the coincidence, all events coming from a cosmic particle that crosses only one scintillating tile will be automatically discarded.

An initial geometry may be realized by placing one SP5622 tile on top of the other. Be sure that the corners overlap exactly. This simple configuration allows us to consider the greater solid angle which may be achieved by applying system geometry. In this configuration one may measure the muon counting rate and estimate the cosmic flux on the total surface of the system. Another interesting measurement of the muon vertical flux can be performed by reducing the overlapping area of the scintillating tiles (see figure above).

Results:

Considering the integration over the solid angle, the expected cosmic rate due to the geometry system can be estimated and the detection efficiency can be evaluated. For a more accurate estimation of the cosmic rate it is suggested surround the detector tiles with lead bricks.



Cosmic vertical flux as a function of altitude and atmospheric depth [RD3].

Random Coincidence (ID.6213)

Purpose of the experiment:

To understand the potential for accidental counts coming from double tile coincidence.

Fundamentals:

Once the geometry of the detectors has been defined and coincidence is confirmed it becomes important to estimate the number of random coincidences. Random coincidences derive from simultaneous or nearly-simultaneous pulses caused by accidental discharges (i.e. noise), and not by particles with a trajectory within the volume determined by the solid angle of the geometry. The probability that a particle crosses the detector is a function of the surface of the tile itself and of the average rate. Therefore, the probability of a random coincidence is proportional to the pulse duration. An evaluation of random coincidence contribution [R_{random}] can be obtained by a simple theoretical calculation, Janossy method based **[RD4]**:

$$R_{random} = 2 * R_A * R_C * \tau$$

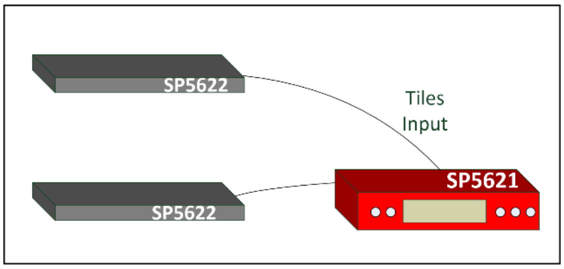
Where τ is the pulse duration (*700 ns*), and R_A and R_C are the event rate of each scintillating tile.

Requirements:

No additional tools or components are required.

Carrying out the experiment:

Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select the scintillators coincidence via the related button on the front panel, then select the integration time of the measurement.

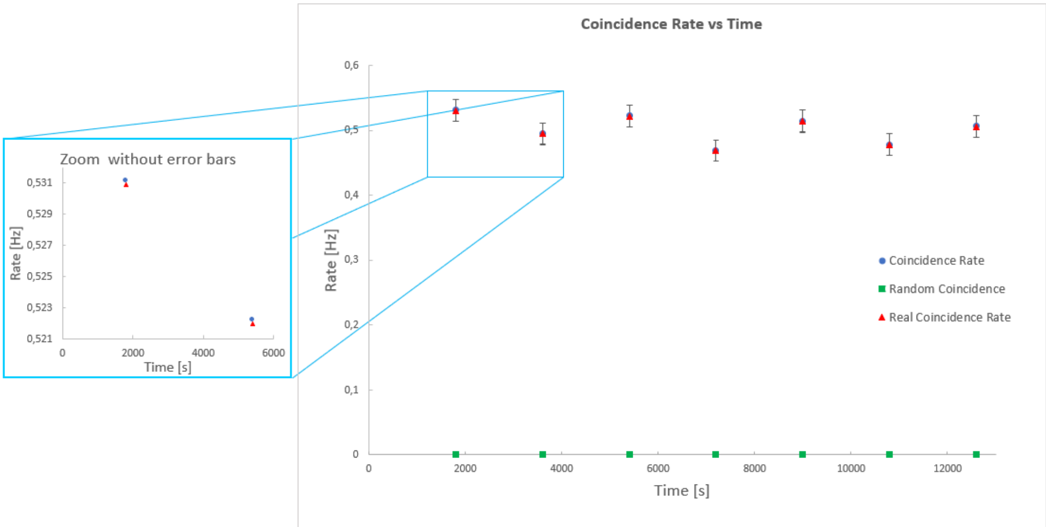


Experimental setup block diagram.

Before starting acquisition choose the system geometry. Be sure to keep this geometry constant for the duration of the experiment. Take and record more data to obtain statistical significance.

Results:

Double tile coincidence plays a key role in a great many Physics experiments. The random coincidence rate allows you to evaluate the data quality via estimation of the Signal to Background ratio [SBR].



Trend of the Count Rate and Random Rate as a function of the time. The plot on the left side is an enlargement of the main plot and underlines the deviation between the measured coincidence rate and the real one, obtained via the random rate subtraction.

Detection Efficiency (ID.6214)

Purpose of the experiment:

To goal of the experiment is the evaluation of the detection efficiency of the scintillating tiles that make up the system.

Fundamentals:

Detection efficiency is the probability that a particle is detected after crossing the sensitive volume of the detector. Detection efficiency is dependent upon the incidence angle, the cross-section through which the particle interacts with the scintillator, and on its physical dimensions. The efficiency of a detector can change depending upon the bias voltage applied and upon the particle type and energy. The efficiency (ε) is defined experimentally as the ratio between the number of detected particles (N_0) and the number of particles incident upon the detector surface (N):

$$\varepsilon = N_0 / N$$

The number of the particles detected in coincidence between additional detectors can be expressed as the product between the impinging particles and the efficiency of each detector. The following expressions can be assumed for the double and triple coincidences:

$$N_{AC} = \varepsilon_A * \varepsilon_C * N_0 \qquad \text{and} \qquad N_{ABC} = \varepsilon_A * \varepsilon_B * \varepsilon_C * N_0$$

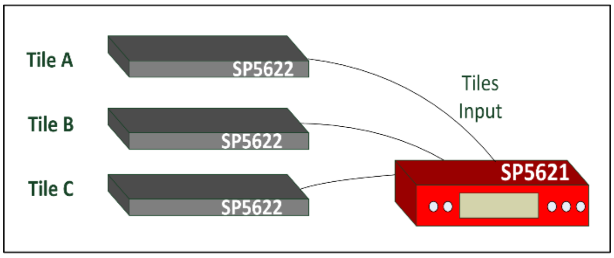
Thus, the detection efficiency of the scintillating tile positioned in the middle can be expressed as:

$$\varepsilon_B = N_{ABC} / N_{AC}$$

Requirements:

Additional SP5622 - Detection System , DT1081A Four-Fold Programmable Logic Unit (Discriminator, Coincidence and Scaler modules in one solution) and a Cable Adapter are needed.

Carrying out the experiment:

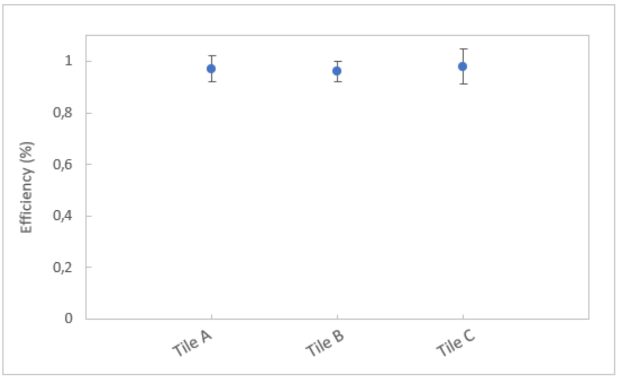


Experimental setup block diagram.

Connect the cable connectors of the three SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select triple scintillator coincidence mode via the related button on the front panel, then select the integration time of the measurement. Arrange the geometry of the detectors as depicted in the diagram above. Be sure to keep this geometry for the duration of the experiment. This system configuration allows the user to test the efficiency of the central scintillating tile.
Connect the signal outputs of the three scintillating tiles to an external apparatus in order to identify double and triple counts at the same time, which correspond to the same cosmic ray.
To estimate the detection efficiency of the upper and lower scintillating tiles change the detector positions and repeat the measurement.

Results:

The efficiency value for each detector should be very close to one another.



Detection efficiency of the three scintillating tiles – SP5622.

Cosmic Flux as a function of the altitude (ID.6215)

Purpose of the experiment:

The measurement of cosmic ray flux as a function of altitude. The goal of this experiment is analyse muon rate behaviour by performing measurements at different altitude levels. For example, one may perform such measurements on different floors of a building, at different elevations of a hill, or even by using a hot-air balloon.

Fundamentals:

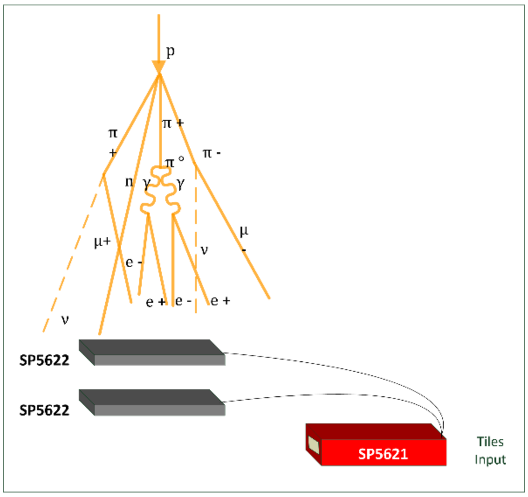
The origin of cosmic radiation represents one of the most fascinating Physics discoveries of the 20th century. The first evidence of natural and non-terrestrial ionizing radiation in the atmosphere was observed in the early 1900s and subsequently studied via different typology of electroscopes by several scientists: from the Jesuit monk Theodor Wulf to the Italian physicist Domenico Pacini, to the Austrian-American physicist Victor Hess (Nobel Prize in 1936).
The measurement of the cosmic ray flux as a function of the altitude played a key role in the comprehension of the nature of both primary and secondary cosmic rays. The Earth's atmosphere acts as a filter by absorbing most of the secondary particles produced by the interaction of the primary ones with the external layers of the atmosphere itself. Muons and Pions are the most have the greatest penetrating capability and can reach the Earth's surface. For that reason they constitute the hard component of the secondary cosmic radiation. The soft component consists mainly of gamma, positrons, and electrons that are easily absorbed by the Earth's atmosphere. Initially, the flux of the secondary cosmic rays as a function of the altitude endures a slight decrease due to the loss of the contribution of natural radioactivity from the terrestrial crust. However, evident increase in the flow of revealed particles is then observed.

Requirements:

No additional tools or components are required.

Carrying out the experiment:

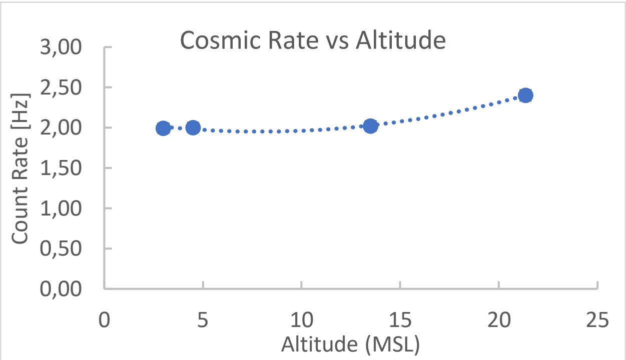
Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select double scintillators coincidence mode via the related button on the front panel, and then select measurement integration time. Because the acquisition of events takes place only in the presence of the coincidence, all such events coming from a cosmic particle that crosses only one scintillating tile will automatically be discarded.
Before starting acquisition choose the system geometry. Be sure to keep this geometry constant even at different altitude levels. Take and record more data to obtain statistical significance.



Experimental setup block diagram.

Results:

This experiment is a simple way to identify and prove the non-terrestrial origin of cosmic radiation. For better comprehension of the cosmic flux behaviour as a function of the altitude the user may cover the floor with lead bricks.



Cosmic flux as a function of altitude.

Zenith Dependence of Muons Flux (ID.6216)

Purpose of the experiment:

Measurement of the zenith dependence of the cosmic ray flux as a function of altitude. 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_μ> 100 / cosθ GeV) and the curvature of the Earth (for θ> 70°) can be disregarded the flux of cosmic muons can be expressed as follows:

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

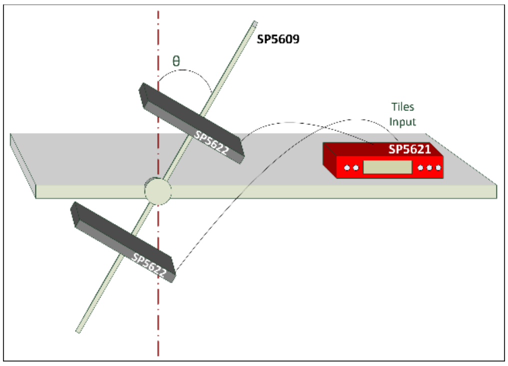
Where θ is the zenith angle, and the two terms in the brackets indicate the contribution of the charged pions and kaons. For $E_\mu \sim$ 3GeV, the angular distribution of muons is proportional to $\cos^2\theta$ at sea level. The intensity of cosmic muons is only determined by the angular dependence 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% **[RD5]**.

Requirements:

The SP5609 - Telescope Mechanics or a similar structure is needed.

Carrying out the experiment:

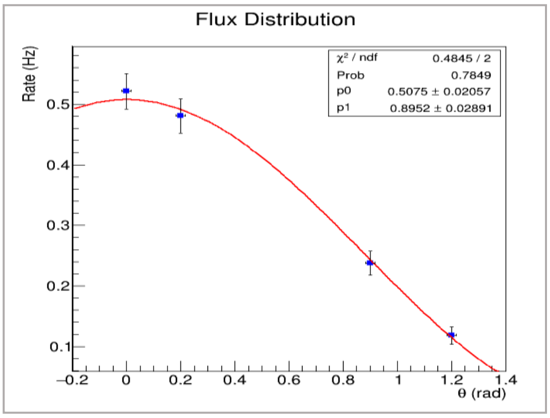
Set up the SP5609 on a desk or table and assemble the two SP5622 on the vertical arm **[RD1]**. Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select double scintillators coincidence mode via the related button on the front panel, and then select measurement integration time. Because the acquisition of events takes place only in the presence of the coincidence, all such events coming from a cosmic particle that crosses only one scintillating tile will automatically be discarded. Determine the solid angle of the muon telescope by fixing the distance of the two scintillating tiles. Be sure to keep this orientation for the duration of the acquisition. Perform the cosmic flux measurement at the first zenith angle value, then rotate the structure to change the angle value and acquire new measurements.



Experimental setup block diagram.

Results:

The following plot shows the result obtained by positioning the two detectors at 20 cm distance. The count rate was measured at four values of the zenith angle, θ= [0, 10°, 50°, 70°], to verify the cos²(θ) theoretical trend of the muons flux.



Zenith angle dependence of the muons flux [Fit: *y = p0*cos² (p1*x)*].

Cosmic Shower Detection (ID.6217)

Purpose of the experiment:

Detection of the cosmic showers by using the coincidence of three scintillating tiles located adjacent to one another on a flat surface.

Fundamentals:

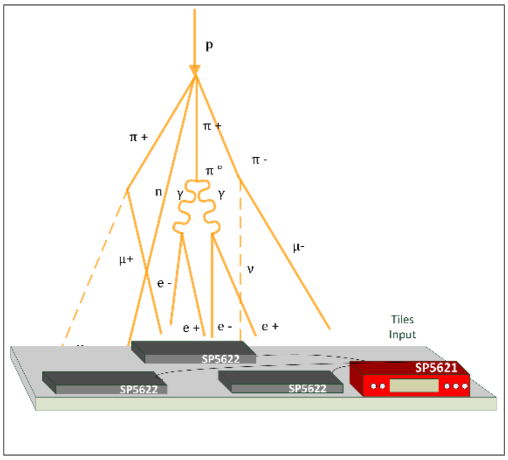
Cosmic ray showers are cascades generated by cosmic rays interacting with the atmosphere. They were originally discovered by chance during the application of coincidence counters for the study of the cosmic rays. In some of these experiments coincident events were detected when the detectors were not assembled in telescopic structure, but rather were organized near one another on a flat surface.
The intuition of this new physical phenomenon was formulated by Bruno Rossi in 1934 and is considered to be the first evidence of the existence of extended atmospheric showers. The Italian physicist was the first to deduce that the multiplicative processes made by the cosmic rays produced in the atmosphere are identical to those observed in dense materials such as lead. Several groups of scientists studied this phenomenon. In particular, Auger and Maze undertook a campaign of systematic studies of these showers and even managed to measure coincident events between detectors as far apart as 300 meters! Auger and collaborators discovered the Extensive Atmospheric Showers [EAS] of very high energy, i.e. the energy of the primary particles at the origin of these events is around 10^{16} eV.

Requirements:

Additional SP5622 - Detection System is needed.

Carrying out the experiment:

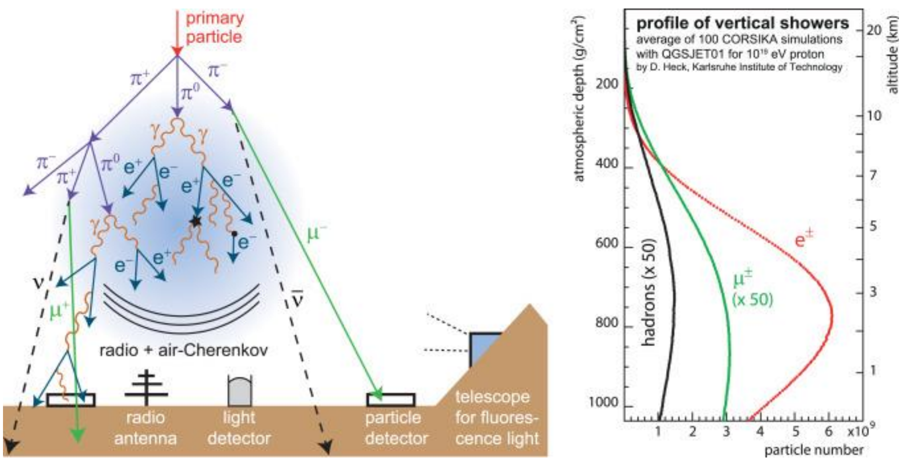
Connect the cable connectors of the three SP5622 to the tile inputs located on the rear panel of the SP5621 module. Arrange the tiles on a flat surface some distance apart from one another. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select triple scintillator coincidence mode via the related button on the front panel, then select the integration time of the measurement. Because event acquisition will only take place only in the presence of the coincidence, all those events coming from a cosmic particle that crosses only one scintillating tile will be automatically discarded.
An extended geometry can be realized simply by using additional Cosmic Hunter. Additionally, it could be interesting to observe Air Showers as a function of the altitude.



Experimental setup block diagram.

Results:

Observation of the cosmic shower phenomenon.



Scheme of an air shower detected by several detectors and its vertical profile[RD6] .

Environmental and Cosmic Radiation (ID.6218)

Purpose of the experiment:

To estimate the contribution of environmental radiation during the detection of the cosmic radiation.

Fundamentals:

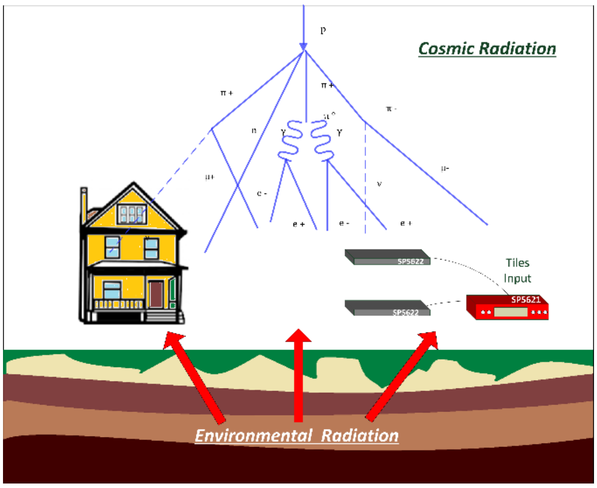
Natural radiation is composed of two components: Environmental (primarily derived from soil, but also water, air and food) and Cosmic radiation. Gamma rays coming from soil will have mean energy lower than 2MeV and will descend from the decay chains of three natural radioactive elements: Potassium [^{40}K], Thorium [^{232}Th] and Uranium [^{238}U]. However, there is a not null probability that a soil-derived gamma interacts with the scintillating tile and deposits 1MeV of energy. This potential could cause confusion or inaccuracies in cosmic rays counting measurement. However, the high threshold of the electronics and the low probability of this phenomenon, when compared to the cosmic ray high detection probability, should typically avoid this inconvenient situation.

Requirements:

A large iron or lead tile is strongly suggested.

Carrying out the experiment:

Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select double scintillators coincidence mode via the related button on the front panel, and then select measurement integration time.

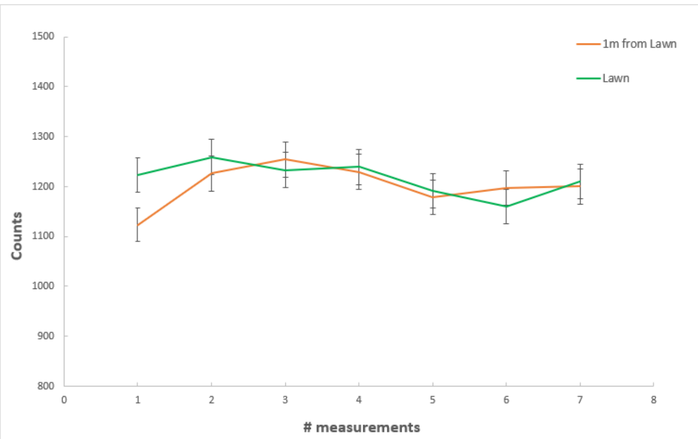


Experimental setup block diagram.

Before beginning acquisition the geometry of the system must be determined. Be sure to keep this geometry for the duration of the experiment. To get acquainted with environmental radiation detected by the Cosmic Hunter place the system over bare soil and record data. Once complete, place the detectors a few meters above bare soil and place an iron or lead shield between the soil and the tiles. Acquire the data again with identical tile geometry and compare the results.

Results:

Students may become acquainted with the presence of natural radioactivity by identifying environmental and cosmic contributions via simple comparison of the counting measurements at different heights.



Comparison between the count rates of the measurements acquired on soil and again 1 meter above soil. The comparison plot demonstrates that the parameter settings (Bias Voltage and Threshold) are such that cosmic ray detection is not affected by environmental radiation.

Absorption Measurements (ID.6219)

Purpose of the experiment:

The main goal of this experiment is verify the absorption of the cosmic rays passing through solid matter and understand related observations about the material which has been traversed by the cosmic rays.

Fundamentals:

Before reaching the ground cosmic muons lose energy by ionization and through processes such as bremsstrahlung, creation of pairs ($e^+ e^-$), and nuclear interactions. If a detector is located within a building or below the earth's surface the detected muon flux decreases in relation to the thickness of the crossed rock/material. The expression of the average energy lost by a muon through matter is:

$$-dE / dx = k(E) + b_b(E)\,E + b_p(E)\,E + b_n E$$

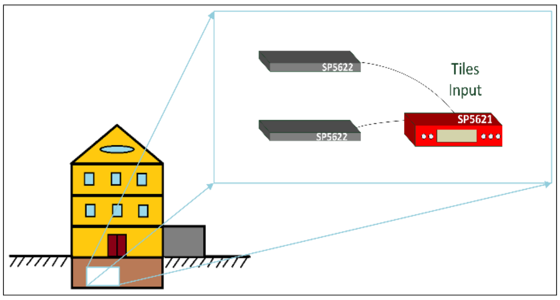
where the $b_b(E)$, $b_p(E)$ and b_n are proportionally connected to the losses due to bremsstrahlung, to pairs creation, and to the nuclear interactions respectively. Interesting applications which explore the absorption of cosmic rays are represented by muon radiography and tomography. Muon radiography and tomography are based on the measurement of the absorption undergone by high energy muons when they cross solid objects. Good measurement techniques can provide precise maps of the average density of the object under investigation. These methods are used in several fields, from the geophysical application (volcanoes, caves, etc.) to the control of illicit traffic of radioactive materials, and much more. Typically, the average energy loss is about *1.7 MeV* $g^{-1}cm^2$, therefore in the case of *1 Km* of crossed rock whose density is equal to $2\ g\ cm^{-3}$, the muons lose about *0.5 TeV*.

Requirements:

A large iron or lead tile is strongly suggested.

Carrying out the experiment:

Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select double scintillators coincidence mode via the related button on the front panel, and then select measurement integration time.

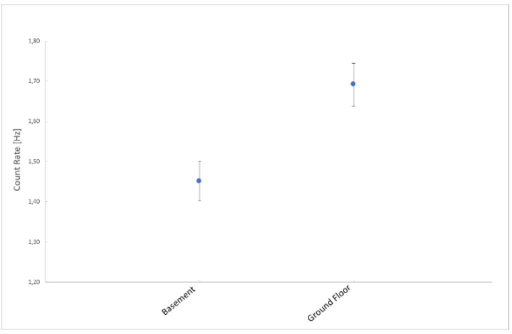


Experimental setup block diagram.

Before beginning acquisition the geometry of the tile must be determined. Be sure to keep this geometry for the duration of the experiment. Acquire data in a cave or solid structure. Then repeat acquisition, keeping the tiles in an identical geometric orientation, outside of the structure or cave.

Results:

Students can estimate absorption extent by comparing the results of the measurements performed underground or inside a cave to measurements performed outdoors and without any solid obstructions. Additionally, if the thickness of the overburden material or structure is known then some hypothesis about the average density of the material can be determined.



An example of absorption measurement has been performed in the basement of a building. As shown in the plot, the counting rate in the basement is reduced by 14%.

Solar Activity Monitoring (ID.6220)

Purpose of the experiment:

Observation of cosmic flux variation due to solar activity.

Fundamentals:

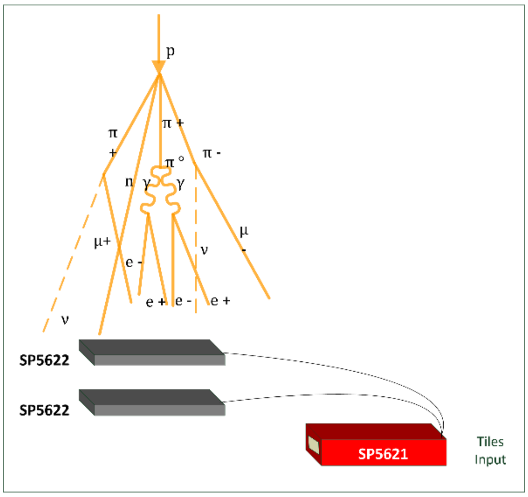
The intensity of the cosmic rays observed at the surface of the Earth is influenced and modulated by geomagnetic effects, by the location where the measurement takes place, and by the solar activity. There is a strong connection between the Sun and its effects on the Earth. The most visible effect relates to sunlight. But another effect relates to cosmic rays. Cosmic rays can be divided into two types: galactic cosmic rays and extragalactic cosmic rays (high-energy particles originating outside the solar system), and solar energetic particles (high-energy particles emitted by Solar activity). The solar wind which is continuously produced by the Sun is not constant due to changes in solar activity. The unsteady nature of the solar wind is responsible for the flux variations of incoming cosmic rays observed at the top of the Earth's atmosphere. Multiple studies have shown that the sunspot cycle is not correlated with cosmic rays detected. This is caused by the solar magnetic field being stronger at the solar maximum which lets fewer cosmic rays penetrate into the Earth's atmosphere. Hence, cosmic rays are at a minimum when solar activity is at a maximum.

Requirements:

No additional tools or components are required.

Carrying out the experiment:

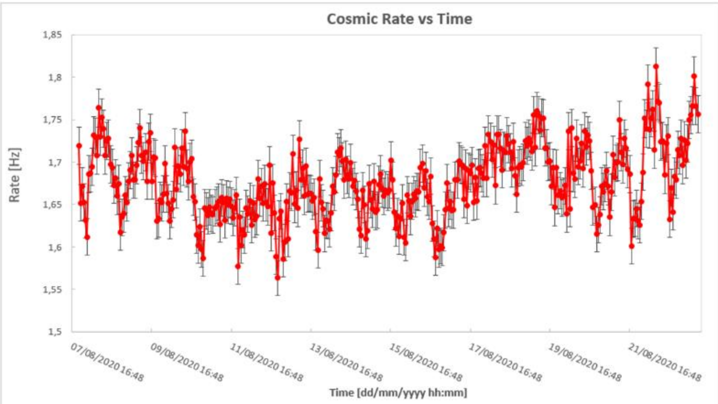
Connect the cable connectors of the two SP5622 to the tile inputs located on the rear panel of the SP5621 module. Power on the SP5621 module and start the acquisition via the front panel START button. When a charged particle crosses the black tile it's energy is converted into scintillation light. The photons which are produced are detected by the photosensor and converted into an electrical signal. The number of counts for each scintillator may be viewed via the SP5621 display. Select double scintillators coincidence mode via the related button on the front panel, and then select measurement integration time. Because the acquisition of events takes place only in the presence of the coincidence, all such events coming from a cosmic particle that crosses only one scintillating tile will automatically be discarded. Determine the system geometry and keep this geometry constant the duration of the measurement. Try to collect as much data as possible, over the period of days or even weeks, in order to perform and understand several theoretical considerations about the night-day trend, the solar wind, etc.



Experimental setup block diagram.

Results:

This experiment leads the students to an intriguing and critical analysis of acquired data. Collected data can be compared to data from several websites which are designed allow the user to monitor the solar activity in real-time **[RD7]**.When comparing such data it is possible to find correlations between the trend of the cosmic rays detected by the system and the solar activity itself, the solar wind speed, the geomagnetic field, etc.



The typical cosmic rate night /day trend can be sometimes modified due to solar activity changes.

4. Technical Support

CAEN makes available the technical support of its specialists for request concerning the software and the hardware. Use the support form available at the following link:

https://www.caen.it/support-services/support-form/

Scan me

CAEN GmbH
Brunnenweg 9
64331 Weiterstadt
Germany
Tel. +49 (0)212 254 4077
Mobile +49 (0)151 16 548 484
info@caen-de.com
www.caen-de.com

CAEN Technologies, Inc.
1 Edgewater Street - Suite 101
Staten Island, NY 10305
USA
Phone: +1 (718) 981-0401
Fax: +1 (718) 556-9185
info@caentechnologies.com
www.caentechnologies.com

CAEN S.p.A.
Via Vetraia 11
55049 - Viareggio
Italy
Phone +39 0584 388 398
Fax +39 0584 388 959
info@caen.it
www.caen.it

CAENspa INDIA Private Limited
B205, BLDG42, B Wing,
Azad Nagar Sangam CHS,
Mhada Layout, Azad Nagar, Andheri (W)
Mumbai, Mumbai City,
Maharashtra, India, 400053
info@caen-india.in
www.caen-india.in