Viareggio

July 13th, 2021

Abstract

In this Application Note (AN) we present the results of measurements performed with the CAEN A5202 board **[1]**, the first member of the FERS-5200 family. In particular, a single A5202 board was used to readout Hamamatsu S13360-6050CS SiPMs coupled to tiles of small plastic scintillators, in order to perform a measurement of relativistic cosmic ray loss of energy within the scintillators. The measurement was performed using both Pulse Height Analysis (PHA) and Time over Threshold (ToT) information and offers one example of the wide variety of applications in which the board can be used. The A5253 FERS-5200 header adapter **[2]** and A5261 SiPM remotization cables, allowing low signal degradation and attenuation, were also used to perform such measurement.

Introduction

It is well known that the Bethe-Bloch formula describes the average energy lost by charged particles when travelling through matter, while the fluctuations of energy loss by ionization of a charged particle in a thin layer of matter was theoretically described by Landau in 1944 **[3]**. In particular, for thin absorbers **[4]**, where the total energy lost by the particle is well below its total energy ($\Delta E \ll E_{max}$), strong fluctuations around the average energy loss exist. The resulting energy-loss distribution is asymmetric and is well described by the *Landau Distribution*. The distribution is defined as the inverse Laplace transform of the function s^s, but a reasonable approximation is given by the following relation:

$$L(\lambda) = \frac{1}{\sqrt{2\pi}} \cdot \exp\left[-\frac{1}{2}(\lambda + e^{-\lambda})\right] \tag{1}$$

where λ characterizes the deviation from the most probable energy loss,

$$\lambda = \frac{\Delta E - \Delta E^{m.p.}}{\xi}$$

and depends on:

- ΔE, the actual energy loss in a layer of thickness *x*.
- $\Delta E^{m.p.}$, the most probable energy loss value in a layer of thickness *x*.
- ξ, a scale factor.

In particular, $\Delta E^{m.p.}$ and ξ depend on the material density and thickness and on the particle energy. Given the same detector, the value of these parameters is almost constant for Minimum Ionizing Particles (MIP) and ultra-relativistic particles, which will thus give rise to approximately the same Landau distribution.

In the work presented in this AN, the hardest component of cosmic rays (mainly composed of relativistic and ultra-relativistic muons) was selected and their loss of energy in thin ($\approx$ 1 cm) layers of plastic scintillators was measured. A fit via a Landau distribution was finally performed and was demonstrated to well describe the acquired data.

Experimental Setup

The measurement was performed taking advantage of the following setup:

- **A5202** board based on Citiroc-1A chips and specifically designed for the readout of large SiPM arrays;
- **Polystyrene-based Scintillators**, each one having a dimension of $47 \times 47 \times 10$ mm^3, with reflective coating and leaving only a 6×6 mm^2 window open at 45 degrees for the coupling to the SiPMs. The scintillators are the same used in the CAEN SP5608 **[5]** and having the characteristics listed in Tab. **1** **[6]**.

Scintillator Type	UPS-923A
Density [g/cm^3]	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. 1: Properties of the scintillators used for the measurement.

- **Hamamatsu S13360-6050CS SiPMs**, each one having an active area of 6×6 mm^2 and with the characteristics listed in Tab. **2** **[7]**.

Properties	Values
Package Type	Ceramic
Number of Pixels	14400
Pixel Pitch [µm]	50
Spectral Response Range [nm]	270-900
Peak sensitivity wavelength [nm]	450 (typ.)
Dark Count/ch [kcps]	2000 (typ.)
Terminal capacitance/ch [pF]	1280 (typ.)
Gain	$1.7 \cdot 10^6$ (typ.)
Measurement Condition	25 °C

Tab. 2: Properties of the SiPMs used for the measurement.

- **Lead Blocks** of ≈ 5 cm height to reduce environmental background and select relativistic and ultra-relativistic cosmic rays.
- **A5253** 3-pin header adapter for FERS-5200 **[2]**.
- **A5261** SiPM remotization cables (0.7 m) for A5253 adapter.
- **SiPM Coupling**. In order to connect the cables to the SiPMs, the same 3-102203-4 (3-pin) AMPMODU connectors installed in the A5253 adapter were used. Moreover, a filter capacitor (with a capacitance >10 nF and a voltage rating >100 V) was soldered between the cathode and ground lines as suggested in **[2]**.

In Fig. **1** a picture of the experimental setup is presented. Two scintillators are placed one on top of the other and within a structure of lead blocks. Two A5261 cables connect the SiPMs coupled to the scintillator tiles to the A5253 adapter inserted in the A5202 board.

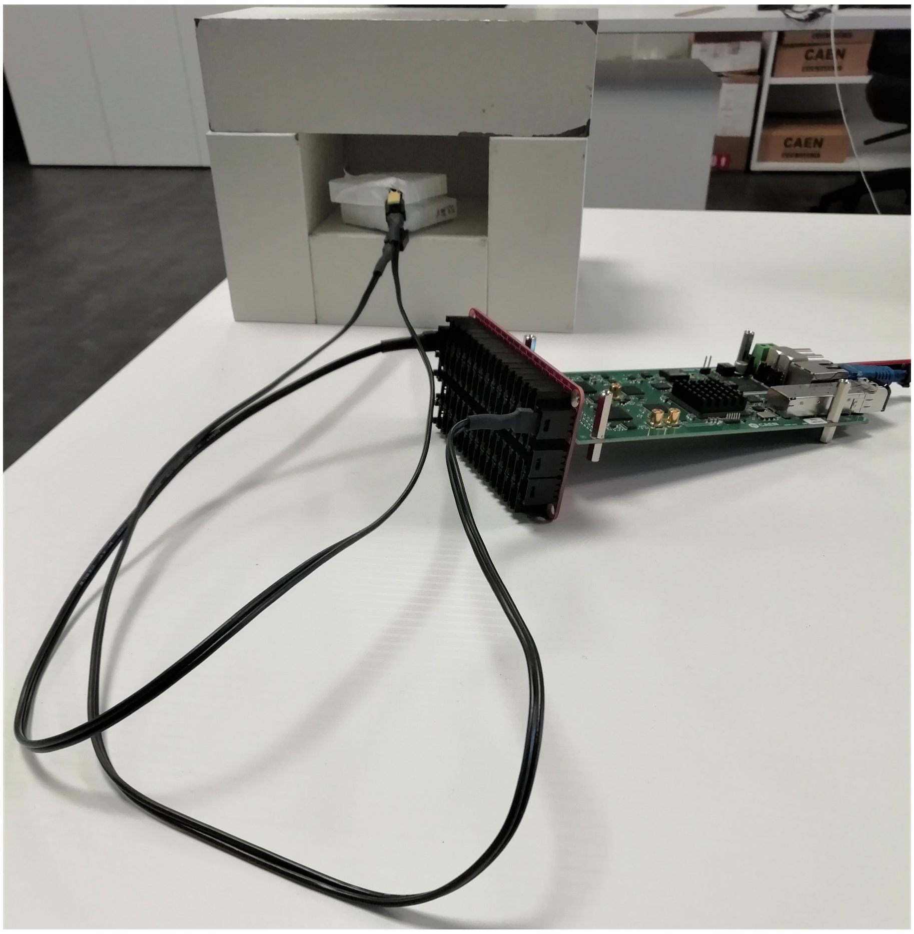

Fig. 1: Picture of the experimental setup used for the measurement.

Study of the signal degradation along the cables

Before performing the cosmic ray loss of energy measurement, a characterization study of the cables was performed, in order to understand if a significant signal attenuation or degradation (i.e. loss of resolution) was expected in the propagation of the signal along the cables. For such purpose, three A5261 cables were produced having variable lengths (up to 3 m) and connected to an Hamamatsu S13360-6050CS SiPM **[7]**. The SiPM was then connected to the A5202 board via the cables and irradiated with an SP5601 LED driver **[8]**. Several acquisitions were performed varying the intensity of the light and the cables.

Fig. **2** shows the spectra acquired with the three cables of different length. Each of the presented spectra was obtained with a different LED light intensity. As it is well visible in Fig. **2**, no significant differences were observed when using different length cables at different values of light intensity.

This result is a proof that the A5261 cables and connectors chosen were completely adequate to perform the measurement proposed in this Application Note. Moreover, it is a demonstration that other measurements where the SiPMs have to be placed far away (up to 3 m) from the readout board are feasible with this setup and should not be affected by significant signal losses or degradations.

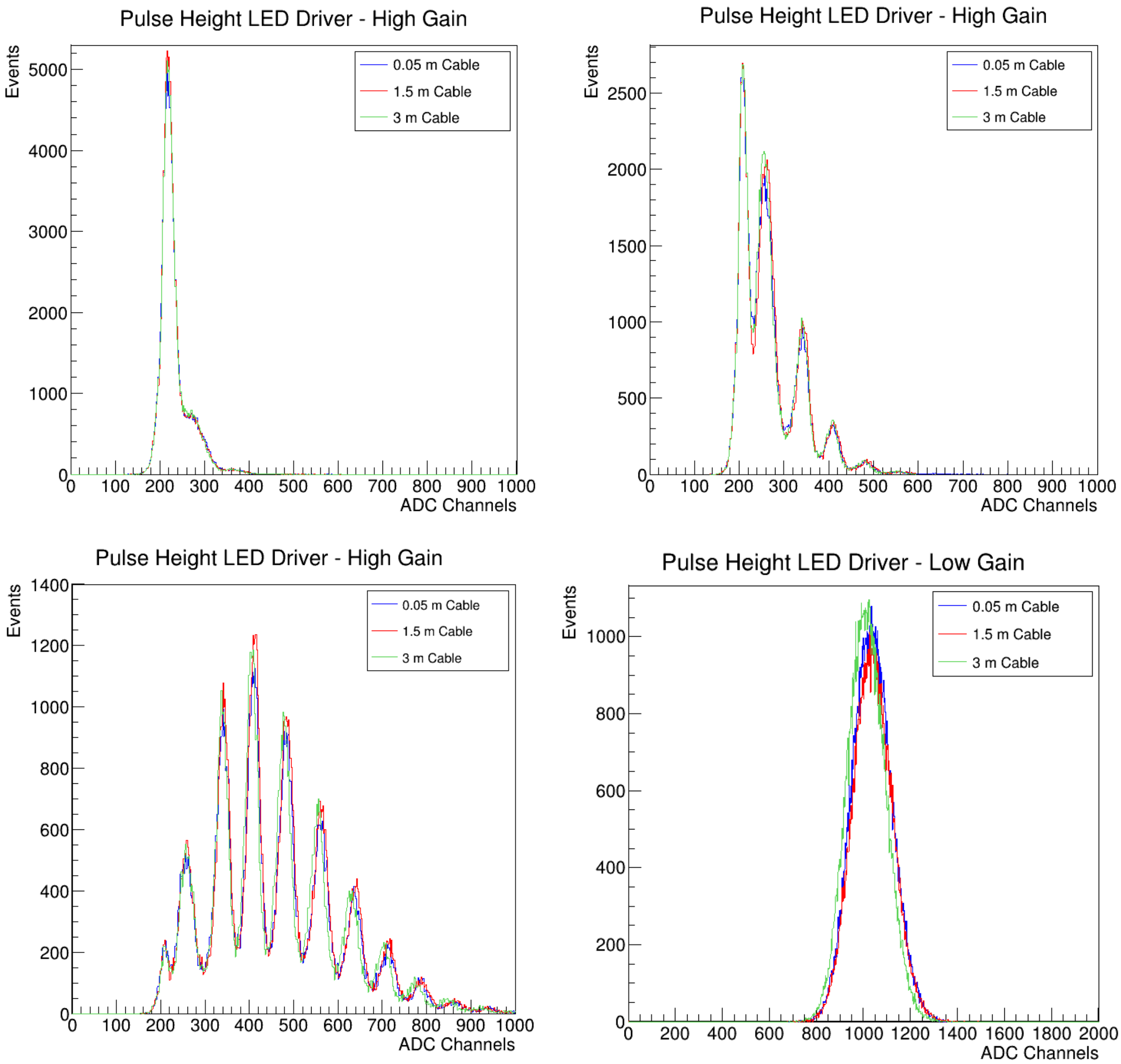

Fig. 2: LED light spectra acquired with the three cables allowing the remotization of the SiPMs. From left to right and from top to bottom the light intensity was increased.

Acquisition Configuration and Results: PHA

The Janus software **[9]** (release 1.1.5) was used to control the A5202 board and to define all the relevant settings of the data acquisition. The first measurement was performed in Spectrosocopy Mode and the PHA values of the incident particles were saved to an Ascii list file to perform an offline analysis.

A first measurement was performed using as ”Bunch Trigger Source” the T-OR option, i.e. every time one of the two tiles (placed one on top of the other) triggered, the A/D conversion of PHA values from both channels was started. This acquisition was performed in order to test the correct functioning of the experimental setup used and to define the composition of the single channel spectrum when acquiring PHA data from cosmic rays. In Tab. **3**, the list of the most relevant parameters and the corresponding values set for this acquisition are presented.

The result of the acquisition is visible in Fig. **3** and shows the presence of a rapidly decreasing spectrum with a bump

Parameter	Value
Acquisition Mode	SPECTROSCOPY
Bunch Trigger Source	T-OR
Trigger Logic	Irrelevant
Ch Enable Mask Chip 0	0x0
Ch Enable Mask Chip 1	0xC0000000 (Only CH62 and CH63 enabled)
Fast Shaper Input	LG-PA
TD Coarse Threshold	185
Gain Selection	LOW
LG Gain	15
LG Shaping Time	25 ns
Hold Delay	100 ns
MUX Clock Period	300 ns

Tab. 3: Janus software settings for the first cosmic ray acquisition in Spectroscopy Mode (T-OR used as "Bunch Trigger Source").

positioned at $\approx$ 1500 ADC Channels. The low energy cut is a consequence of the chosen threshold.

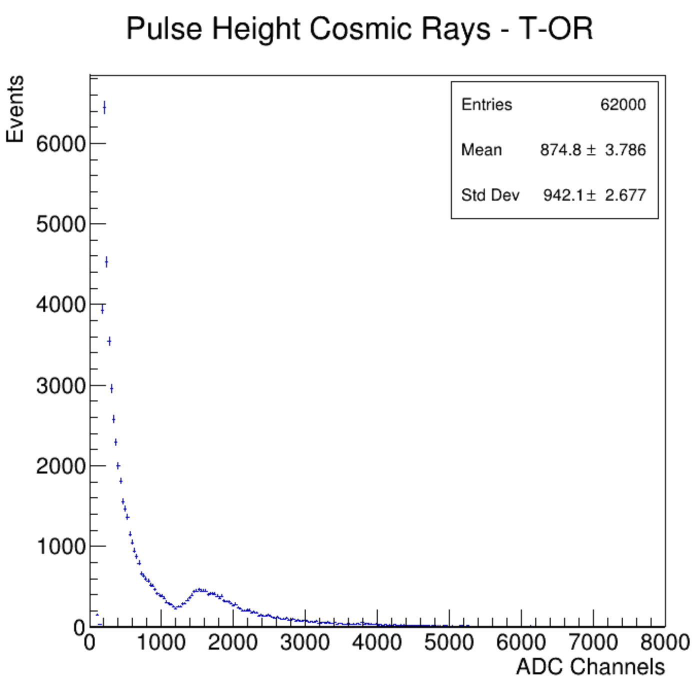

Fig. 3: Cosmic ray LG PHA spectrum when using the T-OR trigger logic to trigger the pulse height acquisition.

Once the correct functioning of the experimental setup was tested, the measurement was repeated with the same settings as those presented in Tab. **3** but using as "Bunch Trigger Source" the TLOGIC option and selecting for the "Trigger Logic" parameter the AND2_OR32 option [1] **[1]**. In this case, the bunch trigger source is no longer the OR between the enabled channels, but it corresponds to the logic AND between the two enabled channels (see "Ch Enable Mask" and "TLogic Mask" parameters)".

The complete list of settings used for the measurement is presented in Tab. **4**.

The same number of events as those acquired in the first measurement was collected. As it is well visible in Fig. **4**, the coincidence request increased the contribution to the total spectrum of the PHA values positioned at $\approx$ 1500 ADC

[1] For the "Trigger Logic" parameter, also the MAJ64 option could have been used with a "Majority Level" parameter value of 2 and the result would have been the same.

Parameter	Value
Acquisition Mode	SPECTROSCOPY
Bunch Trigger Source	TLOGIC
Trigger Logic	AND2_OR32
Ch Enable Mask Chip 0	0x0
Ch Enable Mask Chip 1	0xC0000000 (Only CH62 and CH63 enabled)
Fast Shaper Input	LG-PA
TD Coarse Threshold	185
Gain Selection	LOW
TLogic Mask Chip 0	0x0
TLogic Mask Chip 1	0xC0000000 (Only CH62 and CH63 enabled)
LG Gain	15
LG Shaping Time	25 ns
Hold Delay	100 ns
MUX Clock Period	300 ns

Tab. 4: Janus software settings for the cosmic ray acquisition in Spectroscopy Mode (TLOGIC used as ”Bunch Trigger Source”).

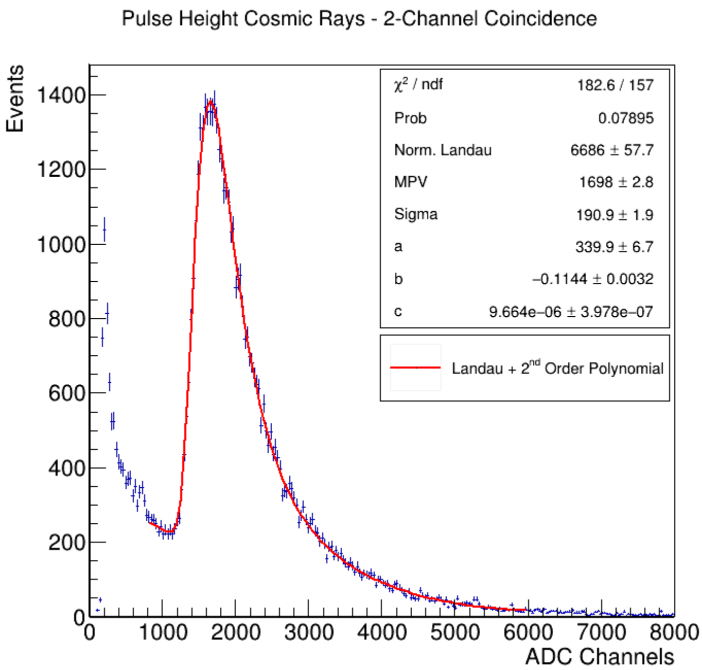

Fig. 4: Cosmic ray PHA spectrum with a 2-channel coincidence.

Channels, i.e. the contribution from relativistic and ultra-relativistic muons.

An offline analysis of the output Ascii file was realized with ROOT **[10]** and a binned maximum likelihood fit was performed to the PHA values with a Landau distribution (see Eq. **1**) summed to a 2^{nd} order polynomial. This function was arbitrarily chosen to parametrize the rapidly decreasing background on the left part of the PHA spectrum and below the Landau distribution. As the fit results show (see Fig. **4**), the chosen background and signal model well describes the data over a wide (≈5000 ADC Channels) range.

Acquisition Configuration & Results: ToT

The Time over Threshold (ToT) information in the A5202 board provides information regarding the energy released by the particles traversing the plastic scintillator as well. Despite the lower resolution ($\approx 1/3^{rd}$) and the lower linearity response expected with respect to the PHA **[1]**, these two effects are not supposed to significantly affect the measurement.

A distinct Landau distribution was then expected to appear also in the ToT spectrum.

To perform the acquisition, another SiPM coupled with a scintillator tile (as those described in Sec. **Experimental Setup**) was used and placed just above the lead shielding. The SiPM was then connected to the A5253 header adapter via another A5261 0.7 m long cable.

For this measurement, the board operated in Timing Mode (Common Start) and the T-OR signal was used as time reference for the acquisition: every time one of the three enabled channels had a signal over threshold, a gate of 1 µs width was opened.

In Tab. **5**, the list of the main settings used to perform the ToT acquisition is presented.

Parameter	Value
Acquisition Mode	TIMING_CSTART
Tref Source	T-OR
Tref Window	1.0 us
Ch Enable Mask Chip 0	0x0
Ch Enable Mask Chip 1	0xC0008000 (CH62, CH63 and CH47 enabled)
Fast Shaper Input	HG-PA
TD Coarse Threshold	290
Gain Selection	HIGH
HG Gain	30

Tab. 5: Janus software settings for the cosmic ray acquisition in Timing Mode (T-OR used as T_{ref}).

The Time of Arrival (ToA) of the channel hits falling in the gate was saved together with the ToT information in an Ascii file and further analyzed with ROOT. In this case, no logic coincidence of the channel hits could be required at trigger level and for this reason a 3-channel coincidence was applied offline at analysis level. Indeed, for each saved event, it was required the presence of the ToT information for all the three enabled channels. Fig. **5** shows the resulting ToT spectrum.

To be noticed the small component of background present in the spectrum when requiring a 3-channel coincidence (with one scintillator placed above the lead covering). A binned maximum likelihood fit with a Landau distribution (see Eq. **1**) summed to a 2^{nd} order polynomial was performed and demonstrated to properly model the acquired data also in this case. The lower linearity of the ToT response with respect to the PHA seemed not to affect at all the distribution and thus the fit results. Acquisitions with the same settings as those presented in Tab. **5** with radioactive sources could be performed in order to calibrate the ToT scale and to better establish the linearity of response of the ToT for the chosen settings.

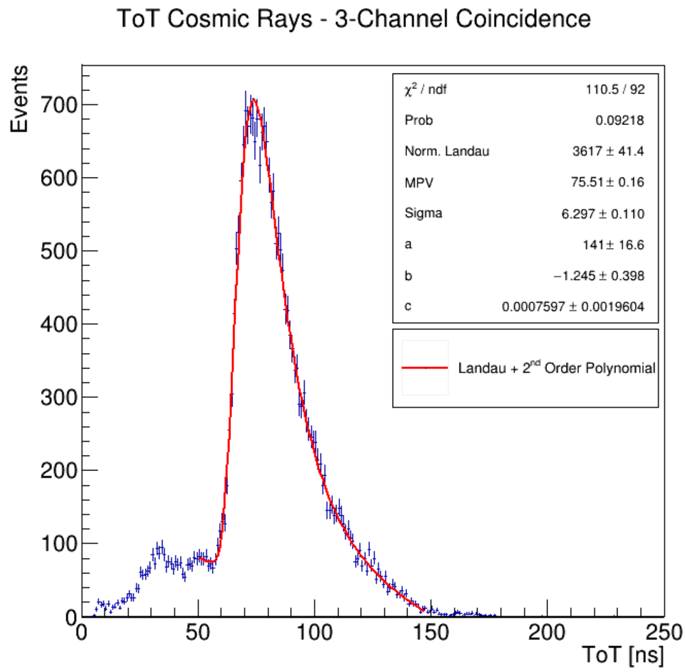

Fig. 5: Cosmic ray ToT spectrum with a 3-channel coincidence.

Conclusions

In this AN, a measurement of cosmic ray loss of energy performed with an A5202 board and SiPMs coupled to plastic scintillators was presented. The A5253 header adapter, A5261 cables and dedicated SiPM connections were used to perform such measurement with remote detectors. Tests carried out prior to the measurement of cosmic energy loss demonstrated the adequacy of the chosen experimental setup. Measurements of cosmic ray loss of energy were then performed in Spectroscopy Mode (PHA) using as trigger source two channel coincidences performed at firmware level. The measurement was then performed using the Time over Threshold (ToT) information and performing 3 channel coincidences at analysis (offline) level. A fit with a Landau distribution summed to a 2^{nd} order polynomial to model the background was performed to the data acquired both in Spectroscopy Mode (PHA) and in Timing Mode (ToT) and showed up to well describe the acquired data in both acquisitions.

References

[1] UM7945 – A5202/DT5202 User Manual.

[2] DS8147 – A525X Adapters for FERS-5200 Board Inputs.

[3] L. Landau, On the Energy Loss of Fast Particles by Ionization, J. Phys. USSR 8 (1944) 201.

[4] Grupen, Claus, et al. Particle detectors. Vol. 11. Cambridge: Cambridge university press, 2008.

[5] https://www.caen.it/products/sp5608/.

[6] http://detecsciences.com/scintillation-materials.html.

[7] https://www.hamamatsu.com/eu/en/product/type/S13360-6050CS/index.html.

[8] SP5601 - LED Driver.

[9] UM7946 – Janus Software User Manual.

[10] Rene Brun and Fons Rademakers. “ROOT - An Object Oriented Data Analysis Framework”. In: *Proceedings AI-HENP’96 Workshop, Lausanne, Sep. 1996, Nucl. Inst. and Meth. in Phys. Res. A*. Vol. 389. 1997, pp. 81–86. URL: `http://root.cern.ch/`.

CAEN SpA
Via Vetraia 11
55049 – Viareggio Italy
Tel +39.0584.388.398
Fax +39.0584.388.959
info@caen.it www.caen.it