THE IMPLEMENTATION OF BOOLEAN LOGIC CONCEPTS IN A LEARNING-BY-DOING PROJECT FOR MEASURING THE EFFICIENCY OF THE DETECTOR MRPCs

Lucia Garritano, PhD; Andreea Loredana Cretu, MSc; Marco Schioppa, Full Prof;

Corresponding Author: Lucia Garritano, lucia.garritano@tin.it, Department of Physics, University of Calabria, **ITALY**
Andreea Loredana Cretu, andreea.cretu@hest.ethz.ch Neural Control of Movement Lab, Department of Health Sciences and Technology, ETH Zurich, **SWITZERLAND**
Marco Schioppa, marcoschioppa@fis.unical.it, Department of Physics, University of Calabria, **ITALY**

ABSTRACT

The laboratory activities are essential in order to guarantee the student an active and aware participation in learning technical and scientific topics. These also contribute to developing skills to the collaboration and work sharing. At the Fermi High School of Catanzaro (Italy), within the project EEE (Extreme Energy Events), we conducted a laboratory experiment for measuring the efficiency of the MRPCs (Multigap Resistive Plate Chambers)- which are part of the telescope used in the study of cosmic rays. This experiment is an application of the operators of Boolean logic, the concepts of triggers, data acquisition and analysis. The good work done by the students and the fruitful discussions favored the assimilation of new concepts and helped to strengthen organizational and teamwork skills. All this underlines the educational value of this project. In the long run, being involved in a real scientific experiment with the purpose of performing research in an advanced field of investigation, is a way to improve the acquisition of scientific topics and can bring valuable knowledge to students.

Keywords: Detector, efficiency, Boolean logic, students, learning.

INTRODUCTION

The EEE Project, a national project carried out by a collaboration of several research institutes, aims to study Ultra High Energy extensive air showers of cosmic rays over a very large surface, using an array of muon detectors located inside Italian High School buildings [1]. The main goal of the EEE-Project is to involve students in a research project with a muon telescope made of three Multigap Resistive Plate Chambers (MRPCs) [2], which were built at CERN by teams composed of high school students and teachers under the supervision of researchers and technicians. One of these telescopes is located at High School "E. Fermi" in Catanzaro, which is involved in the Extreme Energy Events (EEE) project. Many didactic activities have been carried out while proceeding with the assembling and commissioning of the telescope, one example being the measurements related to the efficiency of the detector. In the next sections we will give a brief description of the telescope used for studying the cosmic rays and afterwards we will continue with the description of the activity.

MRPC description

The telescope is made of three Multigap Resistive Plate Chambers (MRPC), located at a distance that can be varied from 40 to 100 cm allowing to reconstruct with good precision the orientation and arrival time of cosmic ray secondary muons. A MRPC (80 x160 cm^2 active area) is a gaseous detector with six gaps obtained by a stack of glass plate, spaced 300 μm

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each by means of commercial fishing line [3,5]. Each chamber is filled with a mixture of $C_2F_4H_2$ (98%) and SF_6 (2%) and is operated in "avalanche" mode [4]. The electrodes are connected to a high voltage provided by DC-DC converters packed in small boxes and connected directly to the electrodes of the detector. These converters can give voltages up to ±10 kV for each electrode, with low power 0-5 V [5]. Each MRPC is equipped with copper strips, glued on two vetronite panels placed on top and bottom of the external glass electrodes. The relative signals are sent to NINOASIC chips based on Front-End electronics, where they are amplified, discriminated and subsequently transmitted to the appropriate acquisition boards [6]. Since readout strips lie longitudinally on the chambers, the coordinate x of the muon impact point on the chamber is directly obtained from the heated strip, while the coordinate y is obtained by the difference of the signal arrival times at the two strip extremities. The signals coming from the Front-End cards are collected and processed when a triple coincidence of the MRPCs generates the trigger for the data acquisition. At the operating voltage of 18 kV the measured MRPC efficiency is around 95% and the time resolution is of the order of 100 ps [7,8]. It is very important to periodically determine the efficiency of MRPCs for a proper functioning of the detector itself. Efficiency tests are made in order to check that everything is working correctly.

METHODOLOGY

The authors involved the students by using the IBSE methodology (Inquiry Based Science Education) [9], in all steps of planning, observation, exploration, discussions, data processing and analysis, which allowed them to acquire scientific concepts, that sometimes were rather hard and difficult. This methodology allows acquiring the experimental mode of scientific research, with an increase of self-esteem, especially in the students considered lazy and less proactive in the classroom, confirming the importance of laboratory activities to improve the learning of scientific topics. The "inquire process" consist in the following steps:

- Engage
- Explore
- Explain
- Elaborate
- Evaluate

The methodology is based on three major dimensions:

- Scientific and technological practices
- Transversal concepts that put together the study of science and technology through their common implementation.
- Basic ideas in the four subject areas: Physical Sciences, Human Sciences, Earth Sciences and Space, Engineering and Technology and application of Sciences.

This methodology increases the cognitive ability and changes the dynamics of learning, since it makes cerebral integration processes more flexible for both memory and information processing [10]. The methodology is also characterized by a strong educational and outreach aspect since the experience is managed by students and teachers who operate effectively in a team. This practice allows each student to share responsibility within the group, and to acquire the methods of how to use a scientific approach to understanding and problems solving. This methodology has also further educational value for the students because it creates a greater self-esteem that comes from perceiving their progress, and from putting into practice the acquired theoretical concepts, giving room for creativity and intuition. The laboratory is therefore the place where they learn by doing [11].

Management and Organization

Students who participated in the activity and are involved in EEE project set up multiple working groups using a management of teamwork according to scheme in Figure 1.

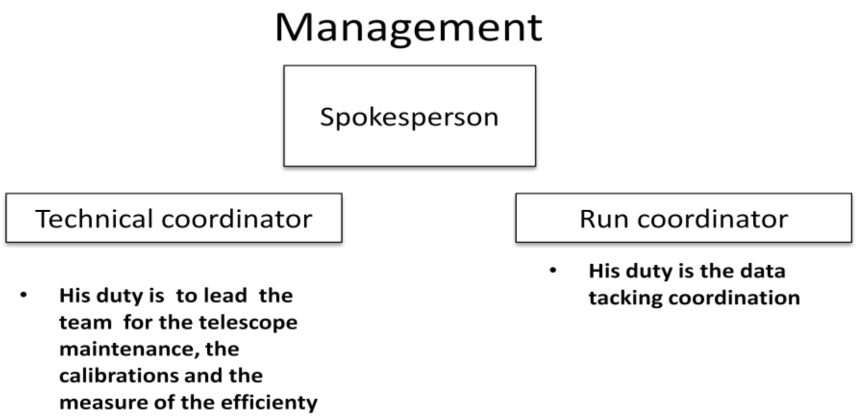


Figure 1. Management of teamwork.

The organization of the team work is shown in Figure 2.

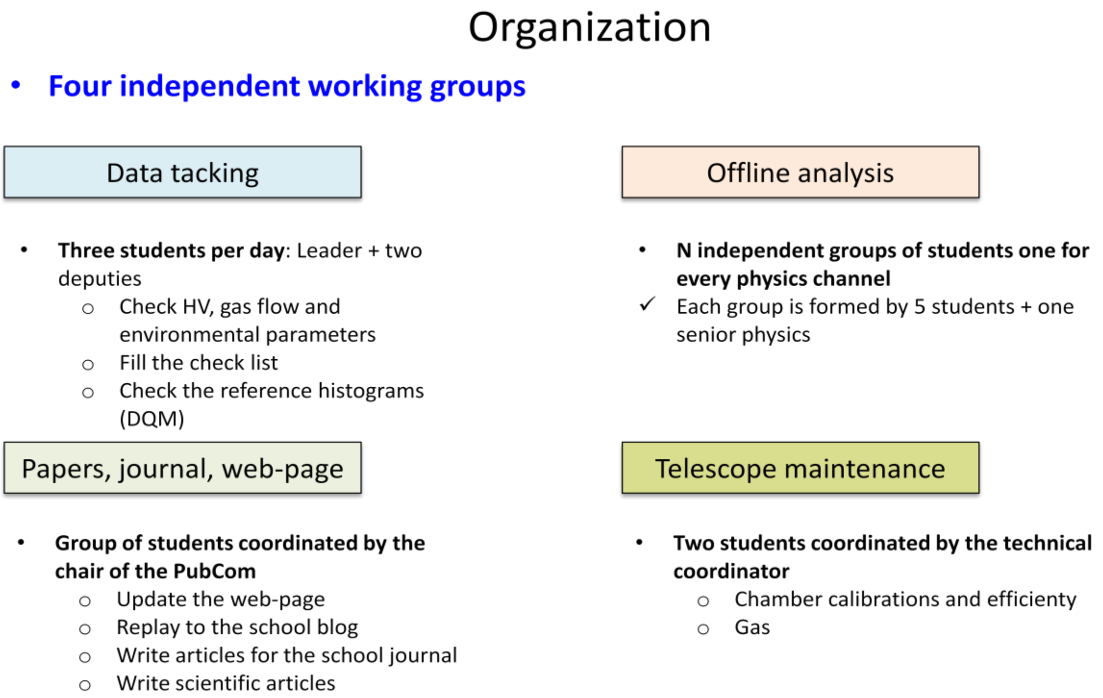


Figure 2. Organization working groups

Measure the efficiency of the detector

One of the basic requirements for a detector is a high detection efficiency. In the first phase of the activity, the students investigated and discussed about how to measure the efficiency of the detector. The detector efficiency is the number of incident particles detected, compared to the total number of incident particles on the detector. Not all particles that strike the detector can be measured. Each detector has a detection efficiency that can be expressed by :

$$\varepsilon = \frac{N_r}{N_i} \qquad (1)$$

where N_r is the number of particles signaled by the detector, and N_i is the number of incident particles. The efficiency depends, in general, on:

- Type of particle
- Energy particle
- Detector type
- Capacity detector

The detector might produce noise signals not related to the particle in question, but caused by intrinsic fluctuations of the system, such as the electronic noise. In an ideal detector we would like to be able to detect all incident particles without any noise. The efficiency, in theory, should have a value close to one.

To make a measurement of efficiency, a coincidence circuit with two other detectors of the same or a different type must be built. The students choose to use, for this part of the experiment, two plastic scintillators. A MRPC detector should be placed in the middle between the two scintillators, which allows defining the signal (trigger) of cosmic muons. The efficiency is a function of the supply voltage of the same detector, therefore it is necessary to determine the optimum working point through the research of the so-called "characteristic curve" in HV or "**curve plateau**". When both of the scintillators produce a signal, it means that a particle has passed through them, therefore there is a " good trigger", meanwhile the MRPC also has to detect the particle. It must, therefore, determine the number of incident particles N_i, those identified by the two external scintillators, and the number of particles N_r revealed by the detector. The events reported by the detector at the center, but not reported by the two external scintillators, are considered being "not good" events for the counting of efficiency.

Counter and logic circuits of coincidences

The students, in the second step, are engaged in the study and in the realization of circuits coincidence to capture events.
A particle counter is always made with three basic elements:

- A detector, which generates observable signals when it interacts, through energy exchange, with a particle or with a beam of radiation.
- An amplifier that increases the intensity of the signal produced by the detector.
- An analyzer, which has the function of "selection" and counting of the number of detections performed by the first component.

The basic scheme, made for acquisition of signals, is shown in Figure 3.

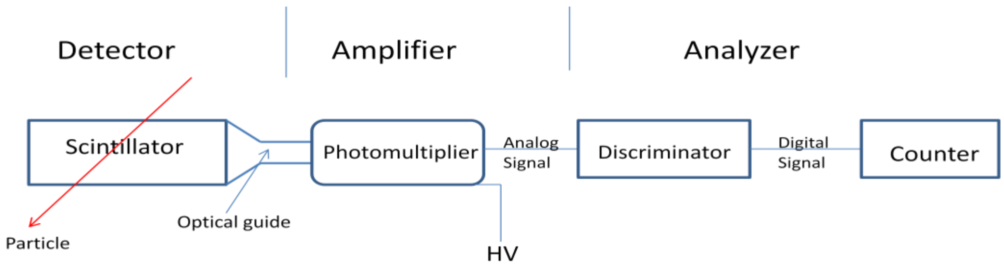


Figure 3. Basic scheme for acquisition of signals

Afterwards, it is necessary to determine the conditions for which two pulses produced by two different scintillators are coincident, that is, when they arrive simultaneously at the analyzer. For this purpose, a coincidence circuit with double coincidence between two scintillators and triple coincidence with MRPC was built and its diagram is shown in Figure 4.

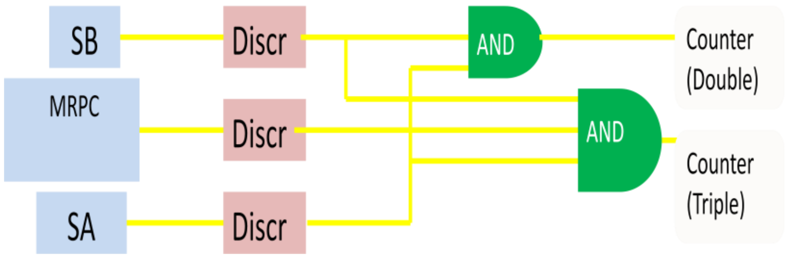


Figure 4. Scheme of logic circuits in double coincidence between the two scintillators SA and SB
and coinciding with triple MRPCs

These are logic circuits. The pulses, produced by detectors, are amplified and converted, through appropriate module, into NIM (Nuclear Instrumentation Module) signals. Subsequently, signals SA and SB are analyzed by a module coincidence. Output signal from the module of double coincidence between the two scintillators is sent to a counter. At the same time, the signals SA, SB and MRPC are sent to another module of coincidence. In this way it is possible to realize a triple coincidence circuit between the SA, SB, and MRPC detector, and the output signal is sent to a second counter. The ratio between the counts in double coincidence (particles detected by SA and SB) and counts in triple coincidence (particles detected by SA, SB and MRPC) gives the value of MRPC efficiency. The efficiency of a detector, is in fact defined, as shown in formula (1), by using the ratio between the number N_r of particles detected and the number N_i of incident particles on the detector surface. The number of particles detected in coincidence by several detectors can be expressed as the product between the number of incident particles and the values of the individual detectors efficiency, which is indicated by the letter ∈. So we can write, for two detectors:

$$N_{12} = \in_1 \in_2 N_i \qquad (2)$$

The same way for the three detectors:

$$N_{123} = \in_1 \in_2 \in_3 N_i \qquad (3)$$

From (2) and (3) the efficiency formula is achieved:

$$\in_2 = \frac{N_{123}}{N_{12}} \qquad (4)$$

where $\in_2$ is the efficiency of the detector placed in the middle, N_{123} indicates counts triple coincidence, and N_{12} indicates counts double coincidence.

Boolean operators between two signals

The activity, during the implementation phase of the logic circuits, allows to acquire and enhance the concepts of Boolean operators. The module of coincidence, is actually represented by the same symbol used for the AND outputs of the logic circuits. The elementary processing blocks are logical ports, which allow to perform the basic operations: in this case AND and OR (Figure 5).

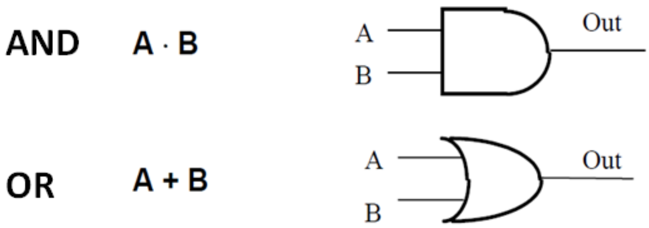


Figure 5. Boolean operators: AND, OR

The elaboration of the signals, shown in Figure 6, is realized following Boolean algebra.

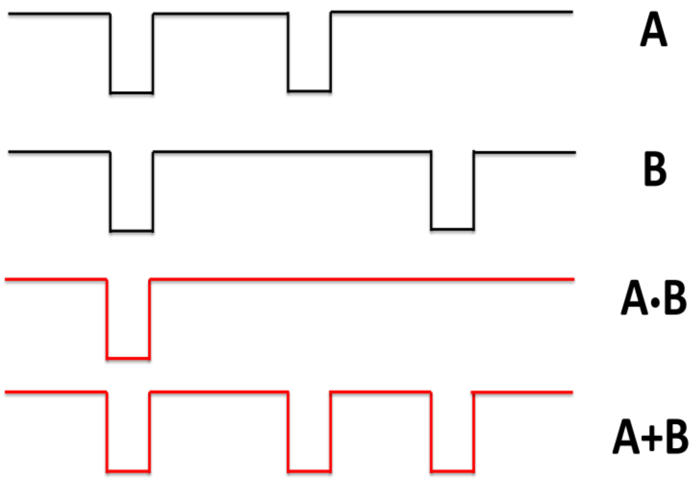


Figure 6. AND, OR between the signals A and B

The negation of the same signals is shown in Figure 7.

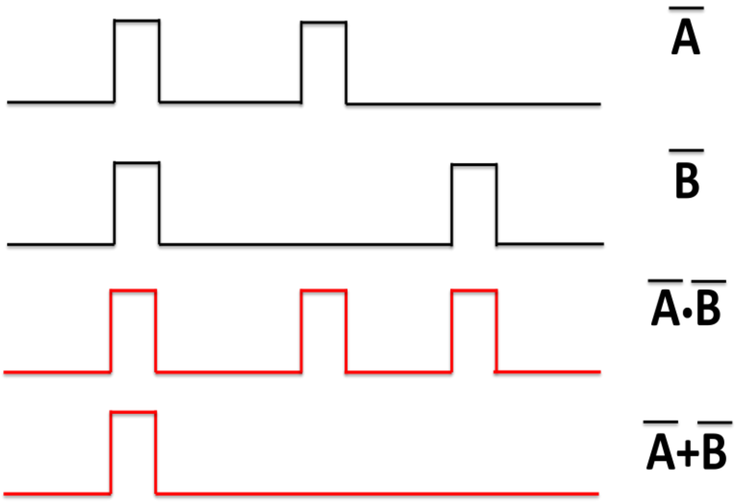


Figure 7. AND, OR between NOT A, NOT B

We make it clear for the students that if the cables that carry signals are inverted, NIM signals are inverted too and, consequently, the AND of these signals becomes an OR, and viceversa. The base Sheffer stroke [12] or NAND it is based on operations NOT, AND through which you can obtain all the Boolean operations:

a AND b = NOT (NOT a OR NOT b) (5)
a OR b = NOT (NOT a AND NOT b) (6)

Materials

Materials used are:

- A pair of plastic scintillators SA, SB, assembled with relative photomultipliers.
- A Crate with following electronic modules in standard NIM:
  - HV generator
  - Discriminator
  - Coincidence Logic Unit
  - Scaler
- Coaxial cables
- Digital oscilloscope

A scintillator is a material able to detect the passage of a particle that passes through it. The phenomenon on which it is based is the *fluorescence*, and has its origin in the exchange of energy that happens when the particle interacts with luminescent material [13]. The scintillator used in this experiment are organic plastic type, and have a surface area of (14x80) cm^2. They are covered entirely by black adhesive tape so as to make them insensitive to low energetic radiation, such as those produced by light of the same laboratory. The light produced by the scintillator is conveyed to the amplifier by means of an optical guide, whose principle of functioning is the total reflection of the light in the inside. The amplification signal occurs by means of the photomultiplier (PMT**,** PhotoMulTiplier), a device that converts a light pulse into an electrical signal and bases its operation on the photoelectric effect. The electrical impulse, produced by the photomultiplier, is sent to the electronic modules by means of the waveguides formed by flexible coaxial cables, which are characterized by variable travel times. In this experiment we used cables of 0.5, 2, 4, 8, 10 ns. Finally, the discriminator performs a selection between the analog signals coming from the amplifier and sends out a digital signal, whose characteristics belong to the standard NIM. It has a dual function: to eliminate background noise and make the signal analyzed by the counter. The module of coincidences sends an output pulse when the logic signal, corresponding to two or more detectors at the input, arrives at the same instant. The output signals are sent to the Scaler, or counter, which acquires digital signal at a specific time interval, indicated on the display. The electronics used is developed by CAEN [14]. The same signals are transmitted to the oscilloscope for visualization.
Experimental setup is shown in Figure 8.

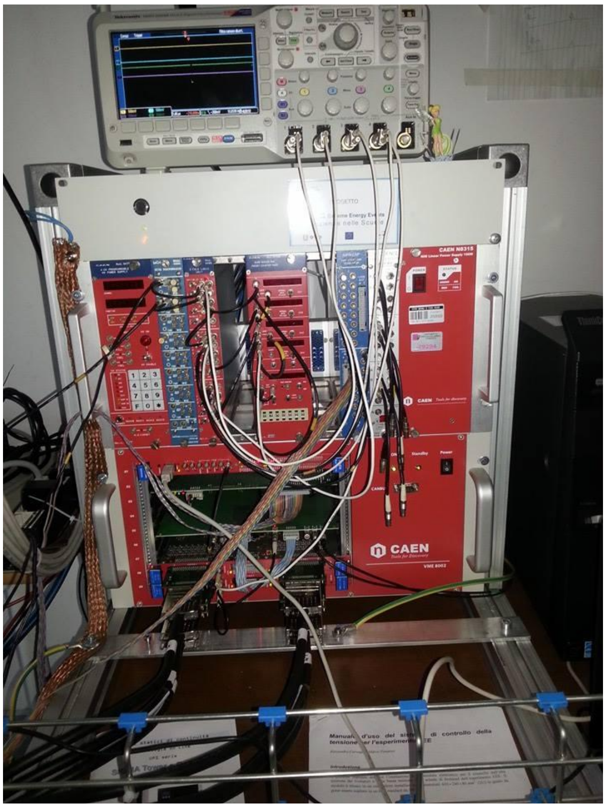


Figure 8. Experimental setup for acquisition and display signals

Experiment execution

Two scintillators are mounted on a support column so MRPC can be placed between the two scintillators SA and SB. (Figure 9).

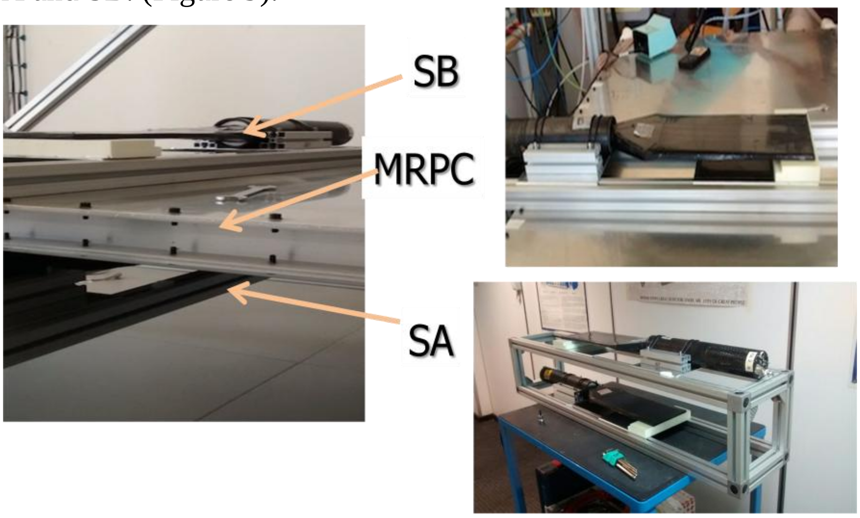


Figure 9. Installation of scintillators with MRPC in the center.

The photomultipliers and MRPC to Crate are connected through appropriate channels. The threshold of the discriminator is adjusted (Figure 10), by acting on the adjustment screw, to the smallest possible value. Then, the channel to which the MRPC is connected is selected, using the number keypad in the module specific (Figure 10). The experiment begins with the chamber 1, namely the one located at the bottom in the telescope. Finally, a time base for counts is set, initially 10s, to be repeated at least 5 times and for values of low voltage ranging from 0 V to 5V, which correspond to values in HF from 0 to 10 KV. The group of students assigned notes of counts to coincide double and triple, provided by scaler (Figure 10). Same operations are repeated in subsequent steps for the other MRPCs that constitute the detector.

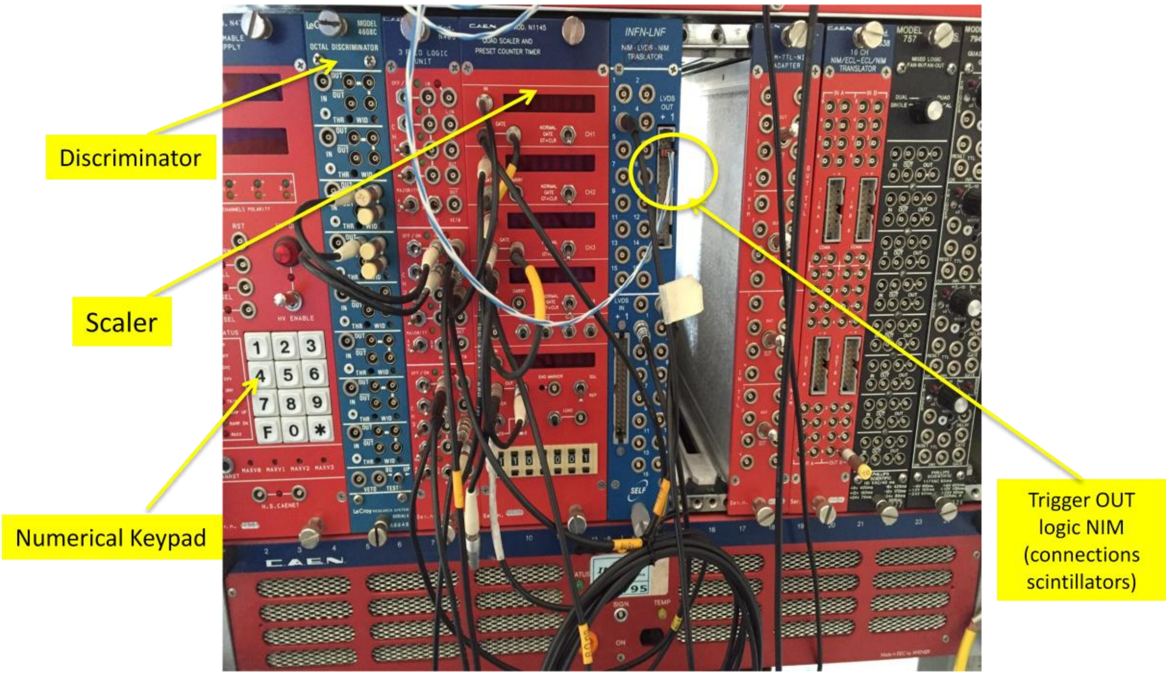


Figure 10. Modules which form the experimental setup.

RESULTS AND DISCUSSION

Table 1 shows the counts detected for bottom MRPC for different voltage values.

Supply Voltage (V)	HV (-) (KV)	HV(+) (KV)	ΔV (KV)
3,5	7,59	7,88	15,47

Counts Double	Counts Triple
44	29
42	35
35	31
29	24
33	22

Supply Voltage (V)	HV (-) (KV)	HV(+) (KV)	ΔV (KV)
3,5	7,59	7,88	15,47

Counts Double	Counts Triple
44	29
42	35
35	31
29	24
33	22

Supply Voltage (V)	HV (-) (KV)	HV(+) (KV)	ΔV (KV)
3,8	8,16	8,48	16,64

Counts Double	Counts Triple
28	27
42	37
38	35
33	32
36	34

Supply Voltage (V)	HV (-) (KV)	HV(+) (KV)	ΔV (KV)
4,0	8,59	8,93	17,52

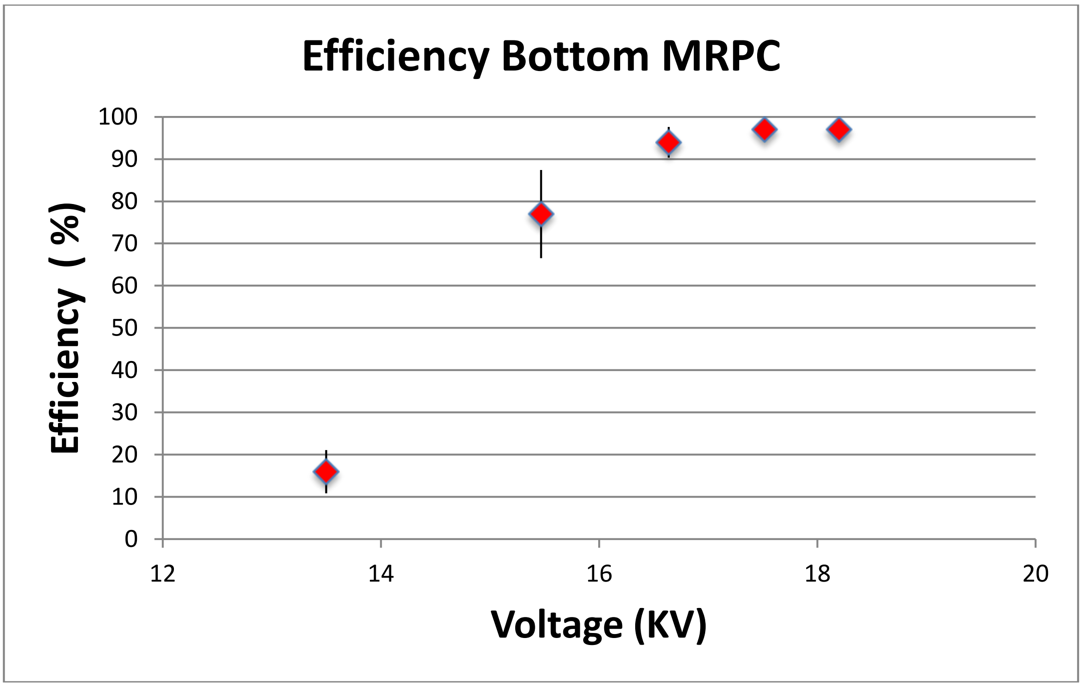
Counts Double	Counts Triple
36	34
38	36
30	30
37	37
31	30

Supply Voltage (V)	HV (-) (KV)	HV(+) (KV)	ΔV (KV)
4,2	8,95	9,25	18,20

Counts Double	Counts Triple
47	46
34	33
32	30
27	27
54	50

Table 1. counts in double and triple coincidence for different voltage values

First, the average of counts related to a specific voltage value is calculated, then the corresponding efficiency, according to the formula (4), and finally the respective curve in function of voltage. (Graph 1)



Graph 1. Efficiency curve bottom MRPC

Graph 1 indicates that the area between 18-20 kV tends to approximate a horizontal line and is called " **efficiency plateau** ". It is the region in which the efficiency stabilizes at its maximum level and specifies the **optimum working point.** Bottom MRPC denotes an efficiency around 97%.

The data is presented in Excel. At a later phase, it used the ROOT framework, a data analysis software developed at CERN [15]. Using the same methodology, but with a count number in a predetermined time equal to 300s, we obtained the relative efficiency curves for the three chambers which form the telescope, shown in Figure 11, with the relative counts.

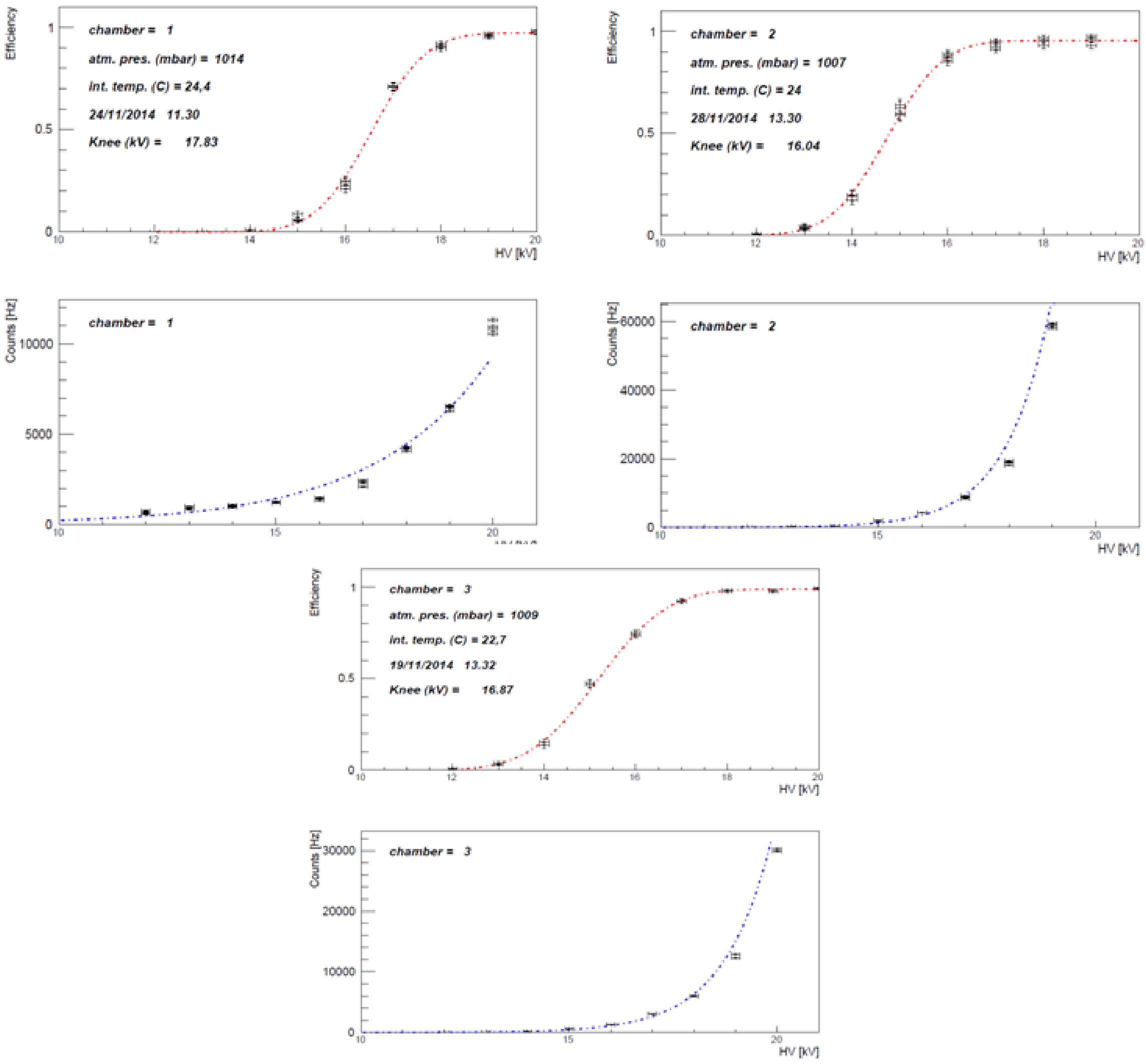


Figure 11. Efficiency curves and counts with ROOT framework for the three chambers.

Important to observe in these plots is that the efficiency is close to the value 1 for the three chambers. This indicates a good functioning of the telescope used for the detection of cosmic rays.

CONCLUSIONS

The activity allowed the students involved to benefit from the following:

- Learning by doing
- Cooperative learning
- Experience the cooperation between students and teachers as one team
- Teach the data acquisition mechanisms typical for professional research

It was a fruitful experience for the team giving each student the opportunity to acknowledge their skills and it created the basis for:

- A careful and creative motivation

- Critical thinking
- More autonomy
- More confidence in self abilities

The way in which students worked in teams (Figure 12), and the fruitful discussions with them have shown a real assimilation of the new concepts and an improvement resulting in scientific learning.

Figure 12. Students engaged in teamwork

The activity has not been seen as a simple executive assignment, but more as a procedural knowledge to be acquired through the planning, the observation, the manipulation, and the discussion. The exploration, which has been the main element in the various steps of the design, implementation and interpretation, has encouraged the motivation and interest of students and has given them the opportunity to express and achieve their ideas in a system of communication and collaborative learning. All the things considered, this activity has allowed the students to learn not only new physics topics but also a team-working methodology which might be useful in their future work.

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