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An Educational Activity: Building a MRPC

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Abstract This paper describes a teaching laboratory activity conducted at the high school "E. Fermi" of Catanzaro (Italy), within the Extreme Energy Events (EEE) Project, together with an analysis of the obtained results. In Italy the experiment studying cosmic rays is called the EEE Project and is, currently, carried out by a collaboration of several research institutes like Centro Fermi, INFN, CERN and MIUR (the Italian Ministry of Education, University and Research). The project uses telescopes in different secondary schools of the Italian territory for the study of extensive air showers of high-energy cosmic rays through the revelation of the muon component. The telescope consists of three MRPC (Multigap Resistive Plate Chambers). The aim of this educational is to build a model of the above simplified chamber for an improved understanding of its operation and the associated physical-chemical principles.

Keywords: *detector, gas, electrode, strips, school, activity educational*

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1. Introduction

The detector MRPC reconstructs the direction of the particles that pass through it with very high precision and with good time resolution (order around 100ps). This is a gaseous detector that uses the principle of gas ionization. The MRPC (Multigap Resistive Plate Chamber) consists of plans resistive with multiple gas-gap [1]. The main feature of the detectors MRPC is the use of glass planes both as electrodes or as separating elements of the various gas-gap. A uniform electric field is maintained between the planes (electrode): the two plates are electrically charged of opposite sign. A charged particle crossing the detector, ionizes the gas present in the cavity. The electric field generated between the more external two glasses (electrodes), determines that the middle panels also acquire a potential. In this way it is possible to obtain more intervals in which the phenomenon of avalanche ionization by electrons of primary ionization can occur. Ionization is produced by the particle traversing the detector. The electric charges, generated within the gas, move toward the plans electrically charged. The movement of these charges towards the electrodes induces an electric signal. This electrical signal is detected and allows to identify the passage of a particle. The signal must be sufficiently large to detect the passage of each charged particle passing through the gas. For this reason the thickness of the gas in the cavity should be adjusted and the electric field in the chamber very high (high voltage). The intermediate levels are not connected to high voltage, but the effect of the electric field that is created between the external electrodes, even the inner planes assume a voltage value such that it is distributed fairly to each single gap [2]. Glued copper strip allow the reading of the electrical signal. The operation of a MRPC is similar to that of a plate capacitor with gas within gap. For this reason, the container of each chamber must be watertight.

The construction of a MRPC is relatively simple. The materials used are in common use: plastic, glass, fishing line, composite material, copper strips, but each phase must be performed very carefully, so as not to impair the detector functionality.

Thank to the EEE Project has been possible to realize experimental activities to transfer knowledge in a very natural way.

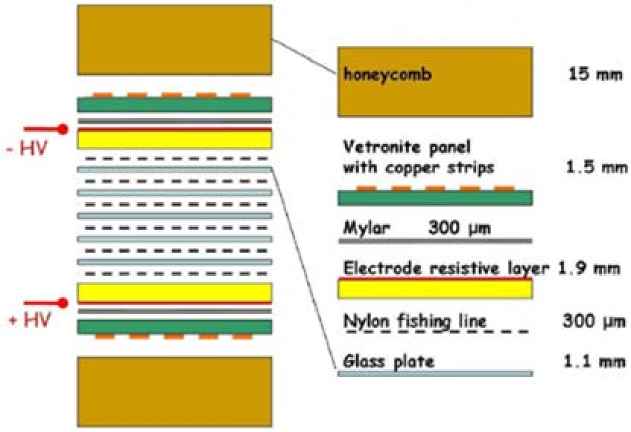

Figure 1. schematic description of a MRPC

1.1. Description MRPC

A MRPC, shown schematically in Figure 1, consists of a structure built with resistive flat electrodes, within which the sensitive volume of gas, a mixture of Freon ecological (98%) and sulfur hexafluoride (2%), is enclosed, The electrodes, manufactured from glass of thickness 1.9 mm, are suitably treated with varnish to create a resistive coating, to which the high voltage is applied. The interspace between the cathode and the anode is divided into 6 intervals (gap) of small thickness (300 mm), with inner glass thickness of 1.1 mm. The distance between the planes is obtained using the common fishing wire suitably positioned. Outside of the electrodes, are placed vetronite panels, on which 24 strips of copper, 2.5 mm wide, are applied for signal collection. The rigidity of the structure is given by two panels of honeycomb.

1.2. Phases of Educational Activity: Building to Learn

In the initial phase the operation of the experimental apparatus together with the physical principles that are the basis of the same, has been described to the students. The theoretical learning is just one of many opportunities for training that is provided for the students. An important role is, however, played by practical activities properly harmonized with the theoretical aspects. The use of such a methodology not only ensures greater involvement and awareness of the students, but allows everyone to make an effective contribution. The practical work carried out by the students has been proposed as executive work after providing them with a scientific knowledge of procedure.

- In the initial phase, after giving only theoretical indications, related to the operation of a MRPC, an entrance test was carried out by the students to evaluate the knowledge gained from the lectures.
- The middle phase has been a pratical activity. The necessary material together with a diagram of the layers that make up a model of the chamber to build, with its dimensions (Figure 2), have been provided for the students. After being divided into groups, they were guided in the design and assembly process, during which they were also asked to reflect on the operation of the experimental apparatus that was to accomplish. At the end of the stage, a student for each working group, outlined the work together with the acquired knowledge [3].
- In the final phase the students have completed the same test administered before the operational phase.

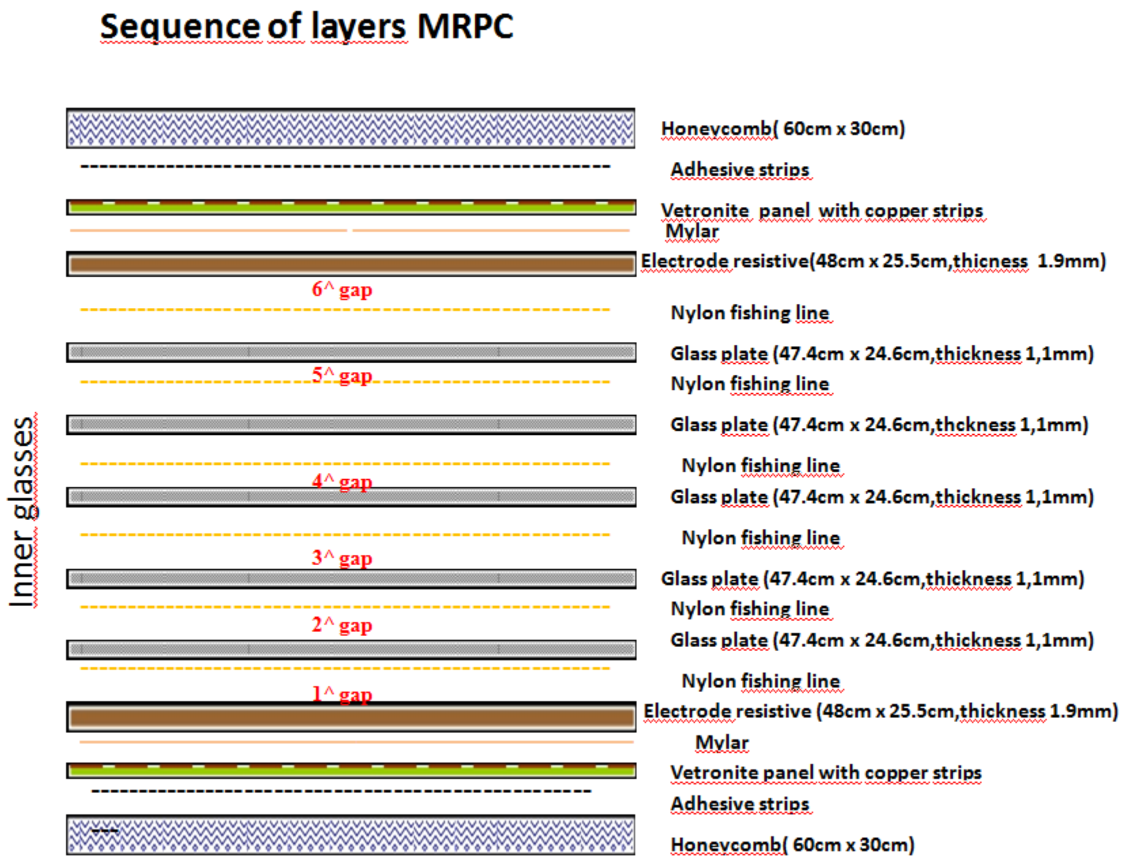

Figure 2. Sequence of layers and dimensions of the model to achieve MRPC

2. Technical and Operational Aspects

The interesting aspect is constituted by the work mode:

- A group has prepared vetronite planes and placed copper strips.
- A group overviewed the glass cleaning steps.
- A group analyzed, selected, provided the material of the components required for the assembly, serving as a guide and support in all phases.

2.1. Preparation of Vetronite

The two vetronite panels constitute the external chamber surfaces (upper and lower), but only one of them was drilled (Figure 3a), according to the scheme shown in Figure 3b. The copper strips were then placed on each of the two vetronite panels (Figure 3c), taking care of making at least 2 cm of bend on each edge to prevent falling, as shown in Figure 3d. The vetronite also serves to isolate the reading strips from the next high voltage plane.

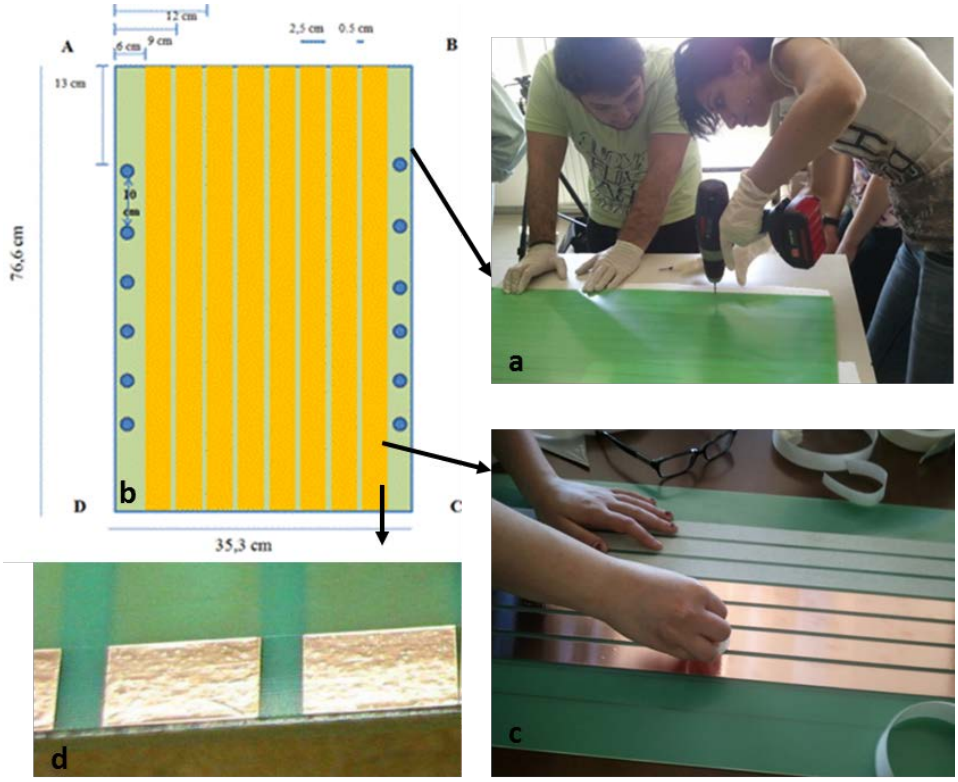

Figure 3. a) Execution of holes on the vetronite panel, b) scheme of vetronite panel with holes and strips, c) positioning of copper strips, d) detail of copper strips folded on the back

2.2. Honeycomb Panels Preparation

The honeycomb panels are designed to support and contain the inner planes of the chamber, but they also serve to give rigidity to the structure.

The dimensions of the honeycomb panels (Figure 4) are equal to those of vetronite.

On both the panels, holes are in correspondence with those in the vetronite and of the same diameter. It is important that the holes match up perfectly with those already operated on vetronite. Then in these holes will be put screws that seal the MRPC.

Figure 4. Preparation of the honeycomb panels

2.3. Cleaning and Preparation Glass

The glass thickness of 1.9 mm act as resistive plans, while the glasses of thickness 1.1 mm are used to form the gas-gap. The glasses were cleaned using fist a solution of water and alcohol, and then only pure alcohol (Figure 5). This operation is important in order not to leave traces of dust that may then create electrostatic phenomena.

Figure 5. glass preparation

2.4. Electrodes Preparation: Resistive Glass

External glasses (thickness 1.9 mm) are resistive plans. This property is achieved by a special paint is sprayed on them. The painting procedure and the relative resistivity measurements are below described:

- The glasses are painted only on the inner face that constitutes the high voltage surface. Resistive paint must be distributed uniformly. (Figure 6a).
  The so obtained resistive layer is very adherent to the glass, with a surface resistivity equal to about 10 MΩ/ m^2.
  A spry gun is required to have on the whole surface of the glass the same potential in the instant when the high voltage will be transmitted to the glass itself by a copper contact which will be applied on it. The glass are allowed to dry.

- In the next step, each resistive glass, covered with resistive layer, is ideally divided into four sections of equal size. The resistance of each sections is then measured using an ohmmeter (Figure 6b) and an average resistance of the whole sheet of glass is calculated.

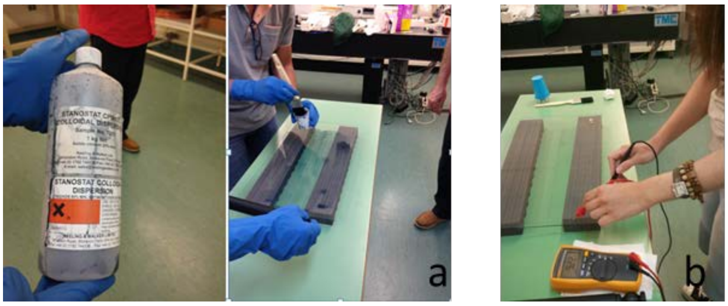

Figure 6. a) painting of the resistive glass; b) resistance measurements

- The glasses, prepared using the above described procedure, act as electrodes for the MRPC, because as it has been said, this chamber, is nothing more than an ionization detector.
  These glasses, that act as electrodes, are then placed at a certain potential difference and hold a definite volume of gas that is ionized (question of primary ionization) by the charged particles that strike the detector. A charged particle passing through the gas-gap gives rise to ionization processes creating electron-positive ion pairs. The average number of these pairs, per unit length, produced by the primary ionization, depends on the energy lost by the particle, per unit length, but is independent of the applied electric field. The probability distribution of the primary ionization to occur, at a distance d from the entry point of the ionizing particle in the gas, considering the average number (m = 1 / d) of the pairs created per unit length, is given by:

$$P(d)=\frac{1}{l}e^{-\frac{d}{t}} \quad (1)$$

where l is the distance covered by the particle and t is the related elapsed time .

In the absence of electric field the ion-electron pairs recombine because of Coulomb's attraction effect. The electric field, in which the gas is held, is used to accelerate and migrate ions and electrons produced by the passage of charged particles towards the two electrodes so allowing them to give rise to a second ionization and the formation of an avalanche ionization (Figure 7), which depends also on choice of the gas mix and on the available space.

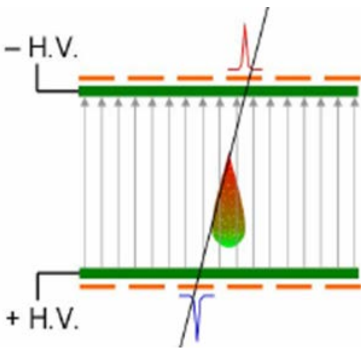

Figure 7. schematic representation of avalanche ionization

If the intensity of the electric field exceeds a certain threshold (10 kV/cm) the electrons produced by the primary ionization can acquire sufficient energy to produce a new ionization and so the process is repeated. The drift velocity of the electrons, or rather negative charge carriers is higher (factor 10^3) than that of the positive charge carriers. This explains the charge's distribution of the avalanche which is drop shaped. The induced signal is due precisely to the movement of the charges towards the electrodes. To have a good signal the avalanches must take place in a limited region and nearby the cathode. These avalanches can develop within a defined space only if they have enough available gas. If the avalanche is originated nearby the anode it hasn't the necessary space to develop and produce a signal strong enough to be revealed. On the contrary, if the avalanche is generated nearby the cathode, the induced signal is very intense, but at the same time may develop lightning inside the chamber. Therefore, to get a good signal the avalanches must originate nearby the cathode, but at the same time must have available enough gas to develop. Furthermore, even minimal variations of voltage and width of the gas-gap can cause variations on the number of electrons in comparison to those of the primary ionization.

2.5. The Function of the Inner Glass and Spacer Wire

For the reasons previously explained there was an evolution from the RPC (Resistive Plate Chambers) [4] to MRPCs (Multigap Resistive Plate Chamber), presenting a subdivision in more gas-gap, created by the inner glass and the spacer wire. Another limitation of the RPC is the low temporal resolution. The time that elapses between the passage of the particle and the revelation of its induced signal is influenced by the point where the avalanche is produced. MRPCs were born, therefore, from the need to improve resolution and efficiency performance of chambers RPC (Resistive Plate Chamber) designed in the eighties by Cardarelli and Santonico. The first prototype of MRPCs was produced in 1996 [5]. In a MRPC the volume of gas is divided into a certain number of gaps, maintaining the overall volume of gas, with appropriate levels of separation that are not connected to the high voltage. However, due to the effect of the electric field created between the external electrodes, they are electrostatically forced to assume a voltage value such that this is divided equally between the individual gap. The subdivision in gaps created with the inner glass (thickness 1.1 mm) and the fishing line (that serves as a spacer element), contributes to restrain the avalanche that grows exponentially with the covered distance. (Figure 8).

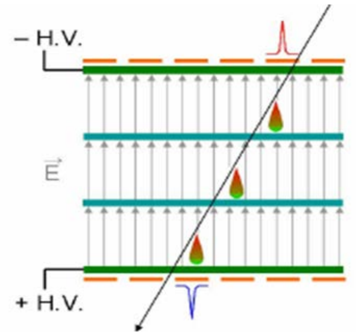

Figure 8. Schematic representation of avalanche ionization in the gas gap

At the same time, this configuration allows to maintain the detector in proportional mode and without reaching the discharge rate. The signal that is obtained is the sum of analog independent signals. Copper strips placed on the vetronite panel pick up the signal and that is then transmitted by "twisted-pair" cables welded at the edge of the strips to the appropriate electronic cards. The overall result you get with MRPCs is an improvement of spatial precision (a few cm) and time (of the order of ps).

2.6. Assembly

- Screws have been tightened on the epoxy glass panel, with their heads on its outer surface. This procedure allows fixing panel to the honeycomb panel through notches previously made on it.
- Vetronite panel was overlapped to honeycomb one, paying attention to align the holes. The surface on which copper strips were placed, facing downwards, must stay within the two panels.
- A sheet of mylar (insulating material) has been fixed on the vetronite panel.
- In one of the corners of the insulating sheet a shape is cut out. It is used to place the contact voltage, that is made of copper fixed with a resistive adhesive tape.
- The same contact is made on the top panel (diametrically opposed). The contacts are used to insert the high voltage connectors. A detail of the copper contact is in Figure 9.

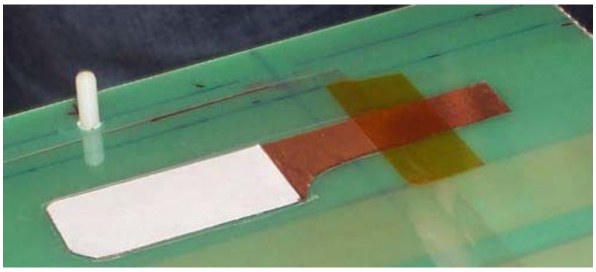

Figure 9. Details of the shaping and the contact

2.7. Glasses Placement

The glass, that acts as an electrode, is placed with the resistive layer facing on mylar so that the film-shaped adhesive tape, placed on the vetronite, achieves an electrical contact with the glass. The fishing line, that acts as a spacer to create the gas-gap, is then positioned. Wire with a zigzag pattern, is wrapped around the screws located along the longitudinal edges of the plans vetronite / honeycomb (Figure 10).

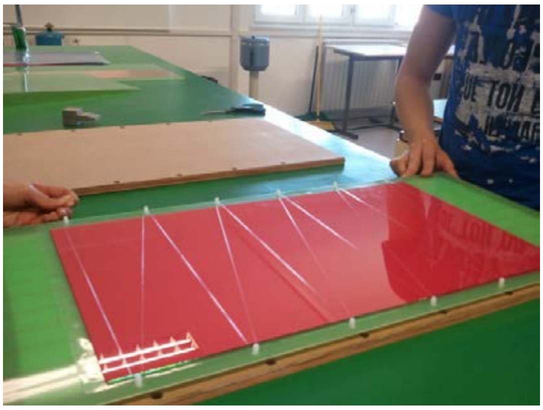

Figure 10. Positioning of wire spacer

We proceeded in same way with the glass of 1.1 mm thickness.

2.8. Cover Top

The chamber can be considered symmetrical with respect to the whole five thin glasses structure. The top epoxy glass panel is without holes and nylon screws, in contrast with the bottom panel. The layers are shown in the diagram Figure 11.

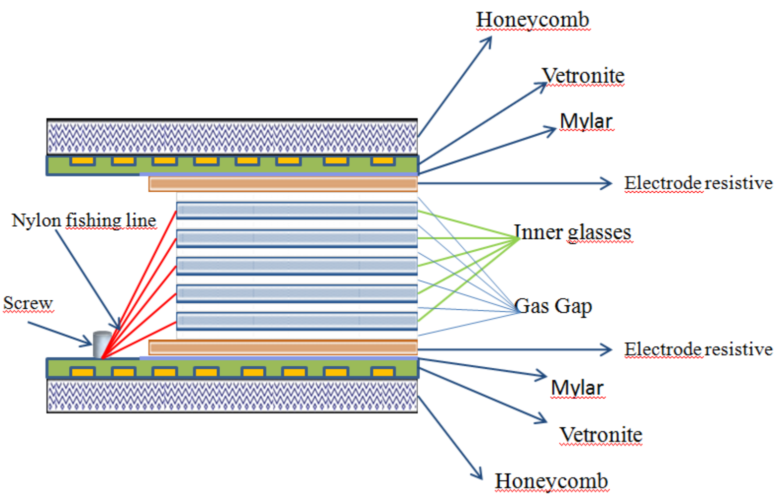

Figure 11. Section of the chamber's layers

The upper part is so assembled:

- The second electrode is positioned in the stack of the five thin glasses, with the resistive surface facing upward.
- The mylar insulation sheet, with the high voltage contact, is placed as stated in paragraph 3.6 (Figure 13).
- The vetronite / honeycomb panels are assembled as in the lower part.
- Top panel is then placed so that the glasses are finally enclosed between the two panels honeycomb /vetronite. In this way the layers that contain the electrodes and the gas-gap are locked.

The so assembled chamber, after being wrapped with insulating sheets, is then placed in a special aluminum box, watertight, that contains gas and high voltage connectors.

2.9. Building of the Metal Container and Closing the Chamber

- Two sheets of metal (aluminum), larger than the assembled chamber and therefore wider and longer than the MRPC, are prepared.
- Along the sides of one sheet four uprights of the same metal are glued and drilled to get in the connectors and the specific screws to form a box that can hold the chamber. (Figure 12)

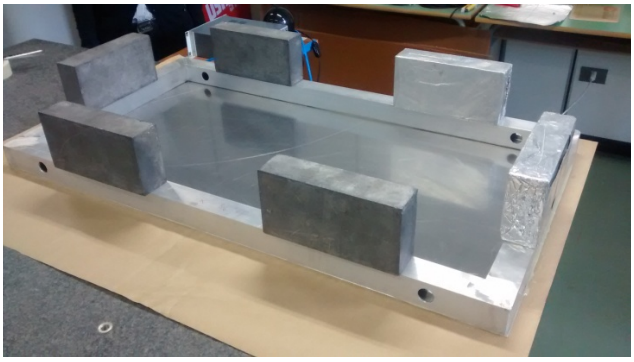

Figure 12. Step gluing of the uprights of the box

- The glue is poured along the sides of the metal box, to avoid gas's losses when it will be injected into the chamber.
- On both "shorts" sides of the box the connectors for the transmission of signals deriving from the twisted pair cables are inserted.
- On the two "long" sides, near the corners, connectors for gas and high voltage are inserted (Figure 13) [6].
- All the joints on the box and connectors are sealed with silicone because the chamber has to be watertight.
- The glue is also poured inside the long sides of the metal box, to avoid gas's losses when it will be injected into the chamber.
- The MRPC is placed inside the "metal structure".
- The MRPC is maintain at a certain distance from the margins and centered.
- The structure is blocked by special spacers placed between the chamber and the metal box.
- The high voltage wire is welded to the output cable (operation has to be repeated twice, because there are two output cables at opposite extremities).
- A sheet of polyethylene, is placed for covering the whole structure and maintaining the watertight container.
- The second sheet metal is deposed for covering.
- The box is closed with the screws placed along the edges of the sheet on the top.

Figure 13. Insertion of HV connectors

The MRPC is so finally ready for flushing gas (Figure 14).

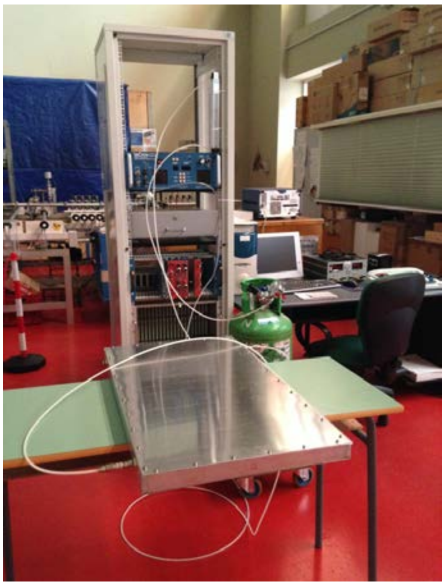

Figure 14. The MRPC is ready for flushing gas

2.10. Used Gas

The choice of the gas mixture to be used for this type of detector is of fundamental importance. The mixture must ensure high values of density of primary ionization, a good sensitivity and a high gain of signal at the passage of the particles, but it has also to prevent the uncontrolled multiplication of the pairs produced by the ionization that result in a electric discharge. In fact, sparks could damage the detector or not ensure a stable gain of signal. A MRPC must operate in free streamer. Typically, gas mixtures with very high-density values of primary ionization, ranging between 2-8 mm^{-1} are used. The main components commonly used gas mixture are:

1. Freon, that is characterized by the high density values of primary ionization (~ 7.5 mm^{-1}) and allow

to reach more easily high values of efficiency, compared to rich mixtures of argon ((~ 2.5 mm^{-1});
2. Sulfur hexafluoride, SF_6, an electronegative gas, that decrease the size of the avalanche absorbing the electrons before they reach the electrodes,
3. Hydrocarbons, such as Isobutane, C_4H_{10}, that act as a quencher, because they absorb the photons irradiated by the processes of recombination within the avalanche.

Moreover, the choice of the type of gas to be used as ionizing medium in the MRPC , has to take account of the fact that it must operate in safety within school buildings, so it is not possible to operate with flammable or toxic gas. So hydrocarbons should be excluded, and a mixture composed of 98% of ecological Freon ($C_2F_4H_2$) which has a primary ionization density equal to 9.2 mm^{-1}, and SF_6 (2%) such as electronegative gas can be used [7]. The latter gas has the task to dampen the shock (quenching). In the initial steps of ignition of the chamber, a flux of ~ 3.5 *l/h* is used to obtain a complete exchange of the gas several times at day. This ensures a more rapid gas recirculation, the cleaning of the inside of the detector in less time and the removing of any impurities remained during the phases of construction of the chamber. Subsequently, the flux is reduced to 1.5 *l/h*. The regularity of the gas's flux can be controlled by inserting a bubbler before the discharge of the gas in output.

3. Test Results

The activity involved 12 students from different classes The test is based on 15 multiple choice questions, focused on the physics of gaseous detectors, on the description of involved physical-chemical process.

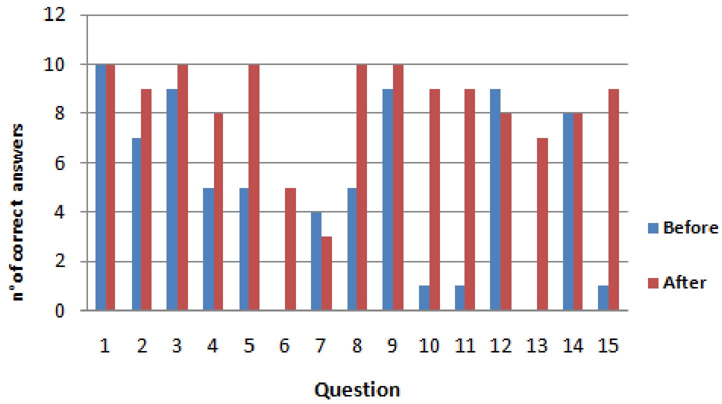

Figure 15. Correct Answers

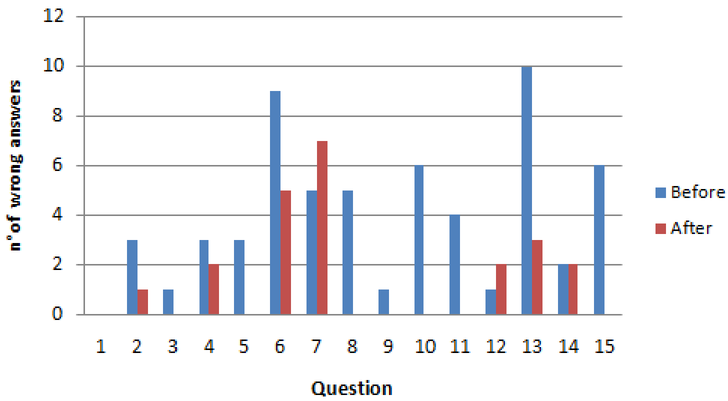

Figure 16. Wrong Answers

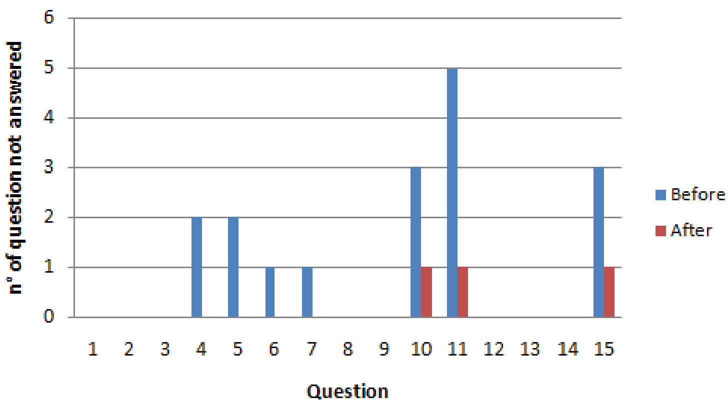

Figure 17. Questions not Answered

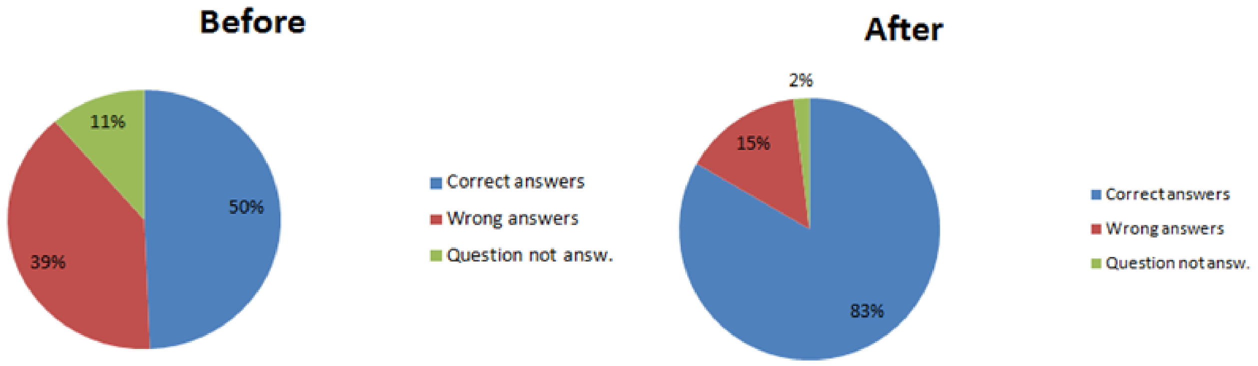

Figure 18. Percentage results before and after MRPC building

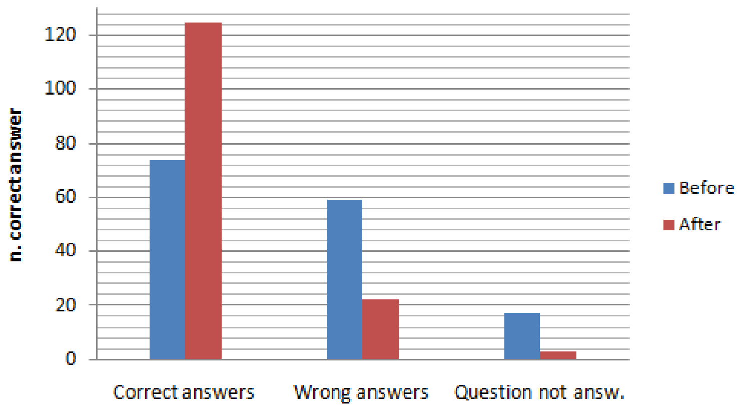

Figure 19. Overall answer results as obtained before and after MRPC building

The obtained tests results of both input and output, are reported in the following histograms, where the blue color is used in the initial phase, while the amaranth color for the same test in the final phase. Figure 15 shows the positivity to the responses in the two phases. Figure 16 shows the negative responses, while Figure 17 shows the given responses, always in two phases: initial and final. The same results are shown in percentage terms, Figure 18. In Figure 19 shows all the answers.

The results show, overall, a positive response that becomes quite higher satisfactory after the practical activity. The number of wrong answer and unanswered questions decreased significantly after the operational phase. Only two answers, namely the n. 7 and n. 12, show a slight increase in wrong answer in the final phase with respect to the initial one. These two answers are purely technical and related to theoretical concepts. The improvements in test results can be ascribed to the fact that in the operational phase the students have given more attention to the procedures, the careful manufacture of the chamber, the observations proposed by external teachers / observers. The activity has involved cognitive processes such as material characterization, precise control of procedures, but also involved creative behaviors.

The test results encourage us to adopt this type of teaching strategy through the practical application of knowledge and understanding of the executive principles that control them. The cooperative learning is, instead, a way focus on learning each other, but above all one for the other. This activity, compared to the traditional learning, allowed a reconstruction process by all the participants, teachers included. Within groups, with the cooperative learning, were able to find a lot of biographies, many forms of involvement, which were expressed, valued and collected as wealth of learning. The results show that just the traditional learning couldn't get knowledge to students about the physics process, which are basics of the working of the detector, and wouldn't have been the moment of the documentation and comparison, as well. The students in the laboratory had put together creativity and concreteness working in an unknown field. The experience it's been useful to students but also to teachers that experimented how it's possible lead a wide and complex theme, like the particles physic working in a concrete way, because the best way to learn something is to build it. The theme it's been very wide and gave a lot of ideas of depth and connection with the other subject.

4. Scientific and Educational Value of All Activity

This educational activity allows students to gain knowledge in different fields. The main training objective is to address the role of science and technology through teamworking and mutual cooperation with the continuous exchange of ideas and comparison [8]. Students gain knowledge and skills in different areas, in particular:

Physics: particle's physic, detector's physics , astrophysics
Electronics: electrical and electronic components
Chemistry: Gas theory
Technique of materials: mechanical devices and materials

This approach has created a environment that resulted beneficial for both learning and strengthening of interpersonal relations in the group. The laboratory activities have, therefore, a pedagogical function, and they led to:

- enhance and strengthen the theoretical acquired knowledge
- encourage the student to the self-assessment of skills
- encourage greater chance to interaction with others.

This experience has also an **educational value** because it creates in the students a greater self-esteem that comes from perceiving their progress in being able to do and, at the same time, gives students and teachers the opportunity to:

- reflect on the learning process
- become aware of the personal potential and limitations
- become more aware of learning strategies
- put into practice the theoretical concepts so give room for creativity and intuition.

This kind of activity isn't only a simple teamwork but a cooperative learning. The teamwork consists only to cooperate to a common aim. The cooperative learning is, instead, a way focus on learning each other, but above all one for the other.

This educational activity, allowed us to obtain important pedagogic and scientific results.

The used approach stimulated students curiosity with respect to a tough matter, such as the investigation of the physics of cosmic rays and particle detectors, creating a challenging and cooperative environment, enabling knowledge sharing and determining a reinforced self-esteem of the students and an increased ability to face complexity by a step by step process.

From a scientific point of view, all activities, selected and planned in order to constitute a valid integration with the theory, represent not only a moment of experimental verification, but also, a basic tool to derive laws, principles and theoretical models starting from the experience, so determining as main result a scientific and technological learning improvement..

5. Conclusions

The activity has been welcomed by all students with positive attitude. It has generated curiosity and interest but it was mostly useful to improve the understanding of physical principles. Most of the students showed, initially, a prudent attitude in dealing with the work, but then they were encouraged by the results, have shown responsibility and ability to run a team working. The practical work is not designed as a simple task but as a procedural knowledge through the planning, observation, manipulation, discussion. Finally teamwork, "the doing together", has allowed to apply problem solving procedures and share tasks to be performed. The experimental activity, however, certainly requires a number of hours greater than that usually school can devote to this type of activities.

Acknowledgements

We thank the students, the teachers and the director of the High School "E. Fermi" of Catanzaro Lido, who accepted the task with enthusiasm and participation. At the same time we thank the Centro Fermi and the entire EEE Collaboration that made this work possible.

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Appendix 1

TEST Costruzione MRPC

Studente:……………………….. Data:…………..………….

1. Che cosa indica la sigla MRPC
   a) Multigap Romantic Plate Channels
   b) Multigap Resistive Plate Channels
   c) Multigap Resistive Plate Chambers
   d) Multigap Romantic Plate Chambers
2. Che cosa è un MRPC ?
   a) Una Scatola di alluminio
   b) Un Rivelatore
   c) Un oggetto molto resistente
   d) Una serie di piani paralleli
3. Quale fenomeno fisico interessa gli MRPC ?
   a) Effetto Doppler
   b) Ionizzazione di un gas
   c) Effetto fotoelettrico
   d) Nessun fenomeno in particolare

4. A cosa può essere assimilato un MRPC?
 a) Un resistore
 b) Un induttore
 c) Un condensatore
 d) Condensatori in serie
5. Quale è il valore della tensione applicata ad un MRPC?
 a) 1000V
 b) 10000V
 c) 100kV
 d) 1000kV
6. Quale è il numero di gap degli MRPC usate nel progetto EEE?
 a) 3
 b) 1
 c) 5
 d) 6
7. Da cosa dipende il guadagno di un MRPC?
 a) Dal numero di elettroni prodotti in una valanga
 b) Da un generico gas utilizzato
 c) Dalla tensione applicata
 d) Dalla geometria degli MRPC
8. I piani di un MRPC sono costituiti da materiale in:
 a) piombo
 b) alluminio
 c) ferro
 d) vetro
9. Come viene realizzata la spaziatura tra un piano e il successivo?
 a) con piccoli supporti in legno
 b) con filo da pesca
 c) con polistirolo
 d) con fogli di alluminio
10. Gli elettrodi degli MRPC sono costituiti da:
 a) due lastre di alluminio
 b) due lastre di vetro trattate con vernice conduttrice
 c) due lastre di vetro trattate con vernice resistiva
 d) due lastre di vetro colorate, una di rosso e l'altra di blu
11. Cosa si pone a contatto con gli elettrodi degli MRPC dalla parte esterna?
 a) distanziatore piani
 b) foglio di mylar
 c) piano di piombo
 d) niente
12. Cosa rappresentano le strip di un MRPC?
 a) elettrodi di lettura
 b) strisce di rame decorative
 c) connettori per introdurre il gas
 d) degli adesivi per mantenere fermi i piani
13. La larghezza di una strip è pari a :
 a) 10cm
 b) 30mm
 c) 25mm
 d) 2cm
14. Ogni strip è connessa a:
 a) ad un pc
 b) al sistema del gas
 c) al sistema elettronico di lettura e acquisizione dati
 d) alla struttura di sostegno degli MRPC
15. Quale è il nome del materiale ricoperto dalle strip?
 a) mylar
 b) vetronite
 c) honeycomb
 d) alluminio