14\textsuperscript{TH} WORKSHOP ON RESISTIVE PLATE CHAMBERS AND RELATED DETECTORS
19–23 FEBRUARY, 2018
PUERTO VALLARTA, JALISCO STATE, MEXICO

Long term experience in Autonomous Stations and production quality control

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Abstract: Large area arrays composed by dispersed stations are of major importance in experiments where Extensive Air Shower (EAS) sampling is necessary. In those dispersed stations, detectors that require very low maintenance and show good resilience to environmental conditions are mandatory. In 2012, our group started to work in Resistive Plate Chambers that could become acceptable candidates to operate within these conditions. Since that time, more than 30 complete detectors were produced, tested and installed in different places, both indoor and outdoor. The data and analysis presented here are mainly related to the tests made in the Auger site in real conditions, where two Resistive Plate Chambers have been under test for more than two years. The results confirm the capability to operate such kind of Resistive Plate Chambers for long time periods under harsh conditions at a stable efficiency. In the last years, Laboratório de Instrumentação e Física Experimental de Partículas and USP—São Carlos have led a collaboration with the aim of installing an Engineering Array at BATATA (Auger) site to learn in more detail and improve the resilience and performance of the Resistive Plate Chambers in outdoor conditions. The organization of such collaboration and the work done so far will be presented.

Keywords: Large detector systems for particle and astroparticle physics; Muon spectrometers; Particle tracking detectors (Gaseous detectors); Resistive-plate chambers

ArXiv ePrint: 1806.11455
1 Introduction

Resistive Plate Chambers (RPCs) [1] can be found in a large number of experiments, mainly in indoor but also in outdoor environments [2–5]. Six years ago [6, 7], we started to research on the development of a chamber able to operate outdoors with residual maintenance, low power and gas consumption. At this point, we believe to be close to a robust and mature detector solution.

In the framework of the Pierre Auger Observatory upgrade, RPCs have been proposed as a dedicated muon detector to better estimate the muonic component of Extensive Air Showers (EAS), further constraining the nature of the cosmic rays and hadronic interactions that take place in the EAS development. In the main Auger array, each water-Cherenkov station distances 1500 m from his neighbors. The Infill array consists of an area of 23.5 km² with additional water-Cherenkov stations on a denser grid. The additional stations are set out forming a hexagonal spacing with sides of 750 m, compared to the spacing of 1500 m of the main array. The upgrade of seven water-Cherenkov stations with a precast structure and four trigger (counting) RPCs [7, 8], one at the center and the other six at each corner of a hexagon defines the Engineering Array. Although this array will only allow the collection of a limited sample of moderate energy cosmic ray showers, it will be of extreme importance to set a calibration point since it provides a direct measurement of the muonic component of the showers. Furthermore, the Engineering Array will be installed in the same region as AMIGA, an underground muon detector, allowing to cross-calibrate the two detectors. Additionally, it will allow to study and improve the performance of RPCs in an inhospitable outdoor environment.

In the first part of this work, we present results taken over more than one year in the infill region, confirming the stable performance of the RPC detectors in outdoor conditions. In the second part, we will describe, from the point of view of R&D, production and test, the organization of a collaboration between LIP and São Carlos Physics Institute, Brazil, with the aim of installing an Engineering Array at the BATATA (Auger) site.

2 Long term outdoor results

The environmental conditions at the Pierre Auger Observatory situated on the vast plain known as the Pampa Amarilla (yellow prairie) in western Argentina [9] are well known and described in [8].
A detailed description of the detector module can be found within the same reference. The detector operates with a mono-component gas R-134a, at a flow rate of 4 cc/min.

To assure a stable efficiency over the time, the automatic HV adjustment, which compensates any temperature and/or pressure variations with an equivalent high voltage variation, was implemented. In this way, the reduced electric field and subsequent gain, charge spectrum and efficiency are kept independent of temperature and/or pressure variations. Further information can be found in [8].

The setup used to monitor the efficiency in real field conditions is located in Tierra del Fuego (TdF) site, see figure 1. It consists of two detector modules placed inside a precast structure underneath one water-Cherenkov station. This way, we can use the station and one RPC as a trigger and study the performance of the other RPC. Besides supporting the tank, the precast structure protects the RPC modules from the environment and helps to filter the electromagnetic component of the shower.

![Figure 1](image)

*Figure 1.* Picture of the Tierra del Fuego station. The two RPC modules (not visible) are inside the precast structure underneath the tank.

The Front End Electronics (FEE) installed is not able to measure the charge information, it just counts the number of times each pad triggers within a certain time window. This way, it is not possible to access the charge spectrum to check the gain stability. The reduced electric field (E/N, [8]) is the only controllable variable that will allow to operate at a stable gain and consequently (hopefully) at a stable efficiency. For this propose, continuous monitoring of temperature and absolute pressure is mandatory to adjust the HV (every 15 minutes) and keep E/N as constant as possible.

The two RPCs were turned on in November 2015, and in March 2016 the automatic HV adjustment was started. Figures 2 and 3 clearly show the capability to operate at a stable E/N
only by compensating the HV setting to correct for temperature and/or pressure variations. The dependence of the reduced electric field (1 Td (Townsend) is equal to $1 \times 10^{-17} \text{ V cm}^{-2}$) on the temperature, absolute pressure and effective voltage is shown in the equation

$$\frac{E}{N} = 0.0138068748 \times \frac{V_{\text{eff}}, \text{Volts}}{d_{\text{cm}}} \times \frac{(T + 273.15)}{P_{\text{mbar}}} \text{[Td]}. $$

In the first approximation, due to the low currents flow in the chambers, it is possible to neglect the contribution of the potential drop across the glass electrodes and consider that all the applied voltage will be available within the gap, this is $V_{\text{eff}} \equiv \text{HV}$.

**Figure 2.** RPC on the trigger, most part of the time at 250 Td as reference $E/N$, the rest at 254 Td. On the left side, the reduced electric field and the three variables considered for its determination via the automatic adjustment of the applied high voltage. This detector operates at a gas flow rate of 4 cc/min. On the right side, the distribution of the reduced electric field since March 2016.

In both figures, it is clear the seasonal variation of temperature and the inverse effect that causes in the HV. Despite the large temperature daily excursions in the site, the large inertia from tank, precast and soil strongly reduces the effect of temperature in the detectors, decreasing also the daily temperature variations by a factor 10 [8]. Under these temperature conditions, the HV adjustments will be very small, just a few tens of Volts at most at each step. This is also important because, in the adjustment process, the effect of temperature on the electrodes is not taken into account. In situations in which it is necessary to correct large (more than 10 °C) temperature variations, it is impossible to keep the assumption of a negligible effect of the glass (or any resistive electrode) resistivity on the potential drop and consequently in the effective voltage. This is even more significant if the operation temperature is above the room temperature. In those situations, the background and leakage currents increase faster than the glass resistivity decreases, causing an increase in the drop potential, that reduces the effective potential resulting in a loss of gain. For
temperatures between zero degrees and room temperature, the situation should be better once the background rate is less than 0.1 Hz/cm² and the leakage currents are absent. Even the increase by one order of magnitude in the glass resistivity will not produce a considerable effect on the potential drop, once it is balanced by the very low currents flow through the chamber.

Concerning absolute pressure, the daily and seasonal excursions are below 5% at the most, which corresponds to a maximum of 50 V adjustment in the HV. These small variations in the HV for a constant temperature will produce negligible background and leakage currents, making the absolute pressure much less important than the temperature for situations in which the automatic HV adjustment is applied. Operation at stable E/N is visible from the data extracted from both detectors. As a consequence, an almost constant efficiency is expected, which is crucial for extensive air shower sampling experiments.

![Figure 3](image)

**Figure 3.** RPC under study. The chosen reference value for E/N was 255 Td. On the left side, the reduced electric field and the three variables considered for its determination via the automatic adjustment of the applied high voltage. This detector operates at a gas flow rate of 4 cc/min. On the right side, the distribution of the reduced electric field since March 2016.

The two RPCs are separated by 36 mm, and each one is readout with 64 signal pickup pads. Coincident signals in one chamber and the water-Cherenkov station define the trigger. An efficient event on the pad n in the RPC under study is defined when the trigger RPC is on the same pad or in the side pads in the RPC used as a trigger, as illustrated in figure 4 left side. Due to the efficiency definition, all the border cannot be taken into account. The four missing pads in the right side of figure 4 correspond to dead channels in the FEE. In reference [8], it is proven that both RPCs had similar dependence of efficiency on E/N. There it is also explained why it is not possible to reach the same efficiency plateau as in the laboratory. This is due to the different operation pressures. At Tierra del Fuego site the pressure is 15% lower than at sea level (laboratory conditions). It is
Figure 4. Left side: scheme of the efficiency measure setup. A certain pad n in the RPC under study is defined as efficient if the trigger RPC shows a signal in the same pad or in the side pads. Right side: efficiency as a function of the area. All measured pads show very similar efficiency values around 85%. This is an acceptable value for a chamber with two gaps of 1 mm at an absolute pressure of 850 mbar at room temperature.

It is not possible to compensate the pressure drop only by increasing the high voltage since the pressure reduction also affects the detector gain through the gas density. To mitigate this effect, the gas thickness must be increased either by increasing the gap(s) width or the number of gaps. In other words, it is necessary to keep constant the ratio between the number of ionization clusters and the number of ionization steps.

Figure 5 summarizes the field results over more than a year. The plot illustrates that the operation of trigger RPC chambers in standalone remote stations with low gas consumption at a
stable efficiency is perfectly viable. It is important to mention that the electronics used in this setup were not prepared to work in harsh outdoor conditions. As a consequence, the data taking period was interrupted several times, and unfortunately, in the middle of 2017 a major malfunction ended up with the permanent interruption of the data taking although the RPCs were switched on and in operation during the whole period. New electronics, prepared for these conditions, were already manufactured, tested and will be installed in the field within this year.

3 Engineering array

Although the Auger Collaboration did not adopt the RPCs for the upgrade, it was considered important to continue the study and development of RPCs for astrophysics. In this sense, in the framework of a Portugal-Brazil collaboration, it was decided to instrument seven water-Cherenkov stations with the same design proposed for the Auger upgrade. The tasks were distributed between both institutes. The project, sensitive volume and supporting systems were developed and delivered by Portugal. The structural, shielding and “tight” aluminum box, the pickup pads and RPC module integration were developed and assembled in Brazil. The sensitive volume is described in detail in reference [8]. Before sending the sensitive volumes to Brazil, they needed to get approved in two tests: argon discharge, where it is possible to clean and check the uniformity of the gap; efficiency and charge maps at the working point with R-134a. Figure 6 shows the correlation between the current and HV with argon in the gaps. At NTP (normal temperature and pressure) conditions and close to 3000 V, the discharge becomes permanent over all the area and, it is possible to exploit the linear dependency to extract the glass resistivity. Below 3000 V, the proportional regime dominates as expected. The observation of these dependencies and the determination of the glass resistivity are the first steps to confirm the correct chamber assembly. The chamber is then left at 3000 V for at least 3 days to “clean” the gap surfaces. Because of this procedure, the conditioning period after the fill of the RPC with tetrafluoroethane is shorter.

After the argon test, the sensitive module is placed in a muon telescope where the filling with tetrafluoroethane takes place. The muon telescope allows testing three detectors simultaneously. For each sensitive module, the background current and rate, temperature, pressure and relative humidity are monitored. After the replacement of the argon by the tetrafluoroethane, the HV is turned on, and with the current limit set to 1 µA, the HV rumps up until it reaches the working point (middle of the efficiency plateau). At NTP and at a gas flow rate of 10 cc/min, this process normally takes between two and three days. Then the automatic HV adjustment is turned on to keep the reduced electric field “constant” around 238 Td (in the middle of the efficiency plateau), and the data taking starts. Figure 7 shows the 2D efficiency map and charge median. Both are requirements for the sensitive volume to be approved in the tests. The efficiency is close to 100% over all the scanned area (five pads are missing due to limited electronic channels). The charge median in ADC bins is also quite uniform over all the area. By comparing the two plots in figure 7, it can be seen that the charge measurement is more sensitive than the efficiency one. This is an effect of the detector module construction and the signal induction.

The first twenty sensitive volumes are already in Brazil being integrated inside the aluminum boxes. Production and tests of the remain twenty detectors are in progress and should be finished by July 2018. The supporting subsystem as gas distribution and monitoring systems, HV power
Figure 6. Argon discharge quality test. With this test, it is possible to check the gap uniformity, clean the gap surfaces and have an evaluation of the detector assembly quality. Apply for the first time the HV in an inert gas also prevents the possibility of some dust polymerization and reduces the conditioning period after the RPC is filled with tetrafluoroethane.

Figure 7. Efficiency and charge median 2D plots. These two plots are the final quality control test to approve each sensitive volume before sending to Brazil. At E/N = 238 Td, the efficiency should be above 90% over all the area. The charge median should be above 100 ADC units. The charge measurement is very sensitive to the signal induction, which turns into charge variability over the area.

Supplies and FEE are also under production and, some units are already in Brazil to be integrated into the detector modules. All these subsystems present very low power consumption and were entirely developed and assembled at LIP.

In the Physics Institute of São Carlos, our colleagues started the integration of the first ten detector modules in the second half of 2017. Figure 8 shows the 3D CAD of the structural/shielding aluminum box. The sensitive volume, pick up pad plane, and environmental sensors are assembled inside. This volume is then sealed to minimize contamination by moisture and dust. The sealing
box receives the gas output from the sensitive volume to improve the removal of moisture. A second/small aluminum box is assembled on the top of the first one to house all the electronic subsystems. This box should also be sealed (as much as possible), as shown in figure 9. The bubbler block has three monitoring columns to measure the gas flow rate, temperature and relative humidity in all the 3 volumes described above. To summarize, each detector module will be a closed aluminum structure with five connections, three for communications, one for power and one for gas. The monitoring and safety columns of the bubbler block can be seen/checked by naked eye to better assist local staff during any gas checking or bottle exchange.

Figure 8. 3D CAD of the aluminium shielding box where the sensitive module and the pick up pad plane are assembled. The small extra volume will house the subsystems: HV power supply (red); gas monitoring bubbler block (yellow), MAROC front-end board (centre green board); LV power supply, multiplexer and gas system communication (left green boards).

Figure 9. Picture of the subsystems already installed in a detector module. 1. LV power supply, 2. raspberry pi, only used for test, 3. gas system communication board, 4. I2C multiplexer, 5. Maroc board, 6. HV power supply and 7. gas monitoring bubbler block. Together all these subsystems consume less than 10 Watts.

The first activities to construct the precast structures, which will support the tanks and house the RPC modules has already started at Malargüe. The installation of the Engineering Array are scheduled to start in the last quarter of this year.
4 Conclusion

Since 2012, when the development of RPCs for outdoor applications started, we have experienced some difficulties. Most of them were only discovered in the field. During this process, we also learned that our experience in an indoor/controlled environment is important but far from enough for this challenge. Despite all these barriers, it is clear that the use of RPCs for outdoor, standalone applications are possible under harsh operation conditions, with very low gas flow rate at a stable proofs efficiency. This is important for experiments where EAS sampling is necessary because they need to cover large remote areas. To improve the robustness and resilience of the detectors, it is very important to monitor all the environment variables and prepare the system in a way to minimize their influence in the detector operation.

The possibility to install an Engineering Array with seven stations in the infill region of the Auger site was embraced by us together with our Brazilian colleagues as a unique opportunity to improve the performance of RPCs for outdoor operation and increase their contribution to the understanding of the physics in EAS experiments. The collaboration between Portugal and Brazil in the development, construction, installation and operation of this array of stations should be considered as an important step in the RPCs technology growth in South America. The first ten detector modules should be completely assembled in Brazil in the next months. Their installation in Malargüe is scheduled for the last quarter of this year.

Acknowledgments

This work is supported by Portuguese national funds OE, FCT-Portugal, CERN/FIS-PAR/0023/2017 and OE, FCT-Portugal, FAPESP #2014/19946-4. The author R. Luz thanks the FCT-Portugal and IDPASC Portugal for the grant PD/BD/113488/2015.

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