MARTA front-end electronics and readout systems

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Cosmic Rays and the Pierre Auger Observatory

• When a cosmic ray particle reaches the atmosphere creates a cascade of particles called Extensive Air Shower (EAS).

• There is a correlation between the particles sampled at ground and the primary cosmic particles.

• The Pierre Auger Observatory is a 3000 km$^2$ cosmic ray detector, located in Argentina.

• There is a need to get a more precise and independent measurement of the EAS’ muon content.

• This measurement would allow to:
  • Distinguish FE and proton showers.
  • Understand the discrepancy between the muon models and data.
Muon Array with RPCs for Tagging Air showers

- Use RPCs to detect muons.

Place 4 RPCs under the water Cherenkov tank (that would work as an absorber for the electromagnetic component).
MARTA requirements

- MARTA was designed to fulfill the requirements of large scale UHECR array experiments:
  - Low cost detector units.
  - Standalone.
  - Must operate in outdoor environment.
  - Have minimal maintenance.
  - Low power consumption.

An isolated water Cherenkov tank
RPC (Resistive Plate Chamber)

• Widely used gaseous detector.
• Gas is contained in the 3 glass plates.
• High voltage is applied to the gas creating a uniform electric field.
• When a charged particle crosses the gas an avalanche is created.
• A current signal is induced on the pickup electrode by the avalanche.
• Developed at LIP Coimbra.

1 mm gap between plates
Efficiency above 95 %
8 x 8 pad (14 x 18 cm²) matrix
Time resolution below 1 ns
Low gas flux
Low cost per unit area
Readout systems: PREC

- Discrete electronics for particle counting applications
- Low noise 8 channel Front-End, that amplifies and discriminates the signals
- Motherboard that controls the system (up to 13 Front-Ends) and aggregates the data
- Developed as a proof of concept without any concerns about power consumption
- Can be used with other kind of detectors with fast negative pulse charges such as silicon photomultipliers
Readout systems: MARTA DAQ

- Readout system based on the MAROC ASIC by OMEGA:
  - Able to do both charge and count measurements.
  - Low power ASIC.
  - 64 input channels.
  - Complex with more than 800 parameters and it has a complicated trigger system.
The main features of the MARTA DAQ are the FPGA, MAROC ASIC, input stage and USB port.

Based on the recommended design by omega.

Equilibrated input stage to minimize noise.

The signals come through the input stage to the MAROC where the analogue electronics are performed.

Its digital outputs go to the FPGA where the digital electronics are implemented.

The data is then sent to the a PC via the USB port.
DAQ V4

- New prototype design incorporating the experience acquired.
- Recent FPGA with more space.
- LVDS links for communication.
- Additional charge measurement using a fast external ADC.
- Low power.
- New mezzanines where the inputs are now soldered.
My main contributions to this development are the following:

- FPGA firmware development and testing, including data aggregation, communication protocols and ASIC configuration
- Software development
- Test benches to assess the performance of this system

Firmware debugging using SignalTap

Old software interface using C#
Test benches setups

• A setup for firmware and software development.
• An hodoscope used to trigger another RPC instrumented with MARTA DAQ.
• Two setups where two RPCs, both instrumented with MARTA DAQ, are in coincidence.
• A setup to test newly build RPCs for the future engineering array.
• Two RPCs in the Auger field.
• An hodoscope of RPCs with PREC studying the tank response.
Efficiency studies

• Using an hodoscope to trigger the RPC being studied.

• HADES FEE and MARTA DAQ were connected to the RPC being tested.

• The efficiency was studied for different HV Tensions. Both DAQs follow the same patterns.
Coincidence setup

- This setup consists of 2 RPCs instrumented with MARTA DAQ in coincidence.
- Ready to be implemented at Auger to perform the validation of new detectors.
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Coimbra setup

RPCs one on top of the other

Rio setup

RPCs with a 73 cm gap

LVDS daughterboard

Used for development and validation
Coincidence setup

- This setup consists of 2 RPCs instrumented with MARTA DAQ in coincidence.
- Ready to be implemented at Auger to perform the validation of new detectors.
Charge studies

- Several slow shaper configurations were tested.

- Since the SS peak is proportional to the charge induced on the RPC, it is important to know where to place the sample and hold.

- A charge spectrum of an RPC was obtained using self trigger.

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1. L. Lopes et al., Resistive Plate Chambers for the Pierre Auger array upgrade, JINST 9 (2014) C10023
Future

• Continue the R&D of the electronics and test benches.

• Deployment of the MARTA engineering array in 8 Auger tanks:
  • 8 stations -> 4 MARTA units per station.
  • 32 units + 8 spare.
  • Hexagonal unitary cell (baseline design).

Twin stations in the center

Area = 1.46 km²

MARTA engineering array

750 m
Thank You
EXTRA SLIDES
Pierre Auger Observatory

- The Pierre Auger Observatory is a hybrid cosmic ray detector. It is the biggest in the world doing this kind of measurements;
- Located in the pampas region of Argentina, It is a collaboration of 16 countries, with LIP being the Portuguese representative.
Cosmic Rays

• When a primary cosmic ray particle with high energy reaches the top of Earth’s atmosphere it interacts giving birth to a cascade of particles - an Extensive Air Shower (EAS);

• These air showers are mainly composed by particles like electrons, positrons, photons and muons;

• EAS allows to establish a correlation between the particles sampled at ground and the high energy primary cosmic particles reaching the top of the atmosphere.
Hybrid Detector

Hybrid detector:

• 1600 Cherenkov water tanks covering an area of 3000 km$^2$ make the Surface Detectors (SD);

• 27 Fluorescence Detectors (FD) on 4 sites overlooking the SD array.
Surface Detector

- The Cherenkov water tanks make this detector sensible both to the electromagnetic and to the muon component of the cascade;

- The array makes it possible to determine the trajectory of the incoming cosmic rays;

- Operate regardless of the atmospheric conditions.
Fluorescence Detectors

• This detectors measure the ultraviolet light produced by the electromagnetic component of the cascade when the air shower crosses the atmosphere. This way is possible to track the development of the air shower.
• Only available in clear dark nights giving an uptime of only 10% and reducing greatly the statistics of the most energetic events.
MARTA - Measurements technique

• MARTA proposes to measure the number of muons detected under the tank using two different techniques:
  • For small numbers of muons, far from the air shower core, a counting technique through the use of a simple threshold can be used;
  • For a large number of muons, close to the air shower core, the total charge is estimated and divided by a reference value.
MARTA – Physics

Have a precise and independent measurement of the air showers’ muon content

- New muonic variables would allow to:
  - Distinguish FE and proton showers
  - Understand the discrepancy between the muon models and data
- Cross-calibration between detectors:
  - Improve the understanding of systematic effects and therefore reduce the uncertainties associated with the detection
– MARTA measurement
  • MARTA will have two main kinds of measurements
  • It will count particles far from the shower core and measure the charge for high multiplicity events
  • A second charge measurement, using an external ADC to the ASIC, using the SUM output of the MAROC
  • This measurement will give us a permanent monitorization of total RPC charge value
  • It is also possible to choose which and how many channels we want to monitor
A MARTA station will have:

- 4 RPCs
- 4 DAQs
- A central unit:
  - Data concentrator unit
  - Control of the RPC’s HV board
  - Trigger and communications
  - FPGA with an ARM processor

When connected to the central unit, the DAQ will communicate through LVDS instead of USB.

Several triggers are possible with this setup. The tank triggering the RPCs will be most likely the most used trigger type.
Front-end electronics

- Due to the remote and isolated location of the water tanks, the operation of needs to be low power.

- Two different front-end electronics were developed for this application:
  - PREC (Prototype Readout Electronics for Counting particles)
  - MARTA DAQ

Main focus of my work

An isolated water Cherenkov tank

PREC system
PREC

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PREC Front-End

PREC Motherboard
• The design and characterization are presented in a paper already submitted

• Being used in several setups, including the Gianni Navarra setup that is using the MARTA RPCs to study the water tank

Submitted paper

1 P. Assis et al., Measurement of the water-Cherenkov detector response to inclined muons using an RPC hodoscope, ICRC 2015
• To understand if this chip would be compatible with RPC signals a measurement was performed with a development board provided by OMEGA.

![First measurement](image1.png)
![MAROC 3 development board](image2.png)

• This development board was also used to test and study the different features of this ASIC.
The MAROC is sensible enough to read RPC signals.
Slow Shaper

RC Buffer

SLOW SHAPER
Fast Shaper studies
Optimization of the slow shaper constants

Rising time: 100 ns to 300 ns
Different input signal amplitudes
Overlapped signals

CAP_FC = 300 ff
CAP_BUF = 2250 ff

Indistinguishable for $\Delta t < 100$ ns