The DAQ System for CORAM (COsmic RAy Mission) Outreach Project

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The CORAM project had as main goal to provide the design, construction and test of a detector for the measurement of the cosmic ray flux as a function of the atmospheric altitude in occasion of the centenary of the cosmic ray radiation discovery.
Today it is well known that the cosmic rays hitting the Earth (primary cosmic rays) are mainly composed by atomic nuclei and a small amount of photons, electrons and positrons. The primary cosmic rays interacting with atmosphere generate particle showers with secondary particles that reach the Earth's surface with a flux of almost $300 Hz/m^2$ at the sea level. The vertical flux of the cosmic rays with respect to the altitude is characterized by a maximum followed by an exponential decay as predicted by the Pfotzer plot from the name of the physicist that first performed various measurements with weather balloon and using particle detectors put into coincidence [1].
The main CORAM goal is to perform several measurements on the cosmic ray flux, by using a setup simple enough to be used for educational and outreach purposes. The detector has been designed to be functional also for measurements performed by students underground or at ground level but at various altitudes and can also be hosted on atmospheric balloon for very high quote measurements.

1. Experimental Setup

Fig.1 shows the final CORAM detector assembly. This is a compact, cheap and user friendly device that is actually used in several public events such as “hand-on” experiments, scientific demonstrations, simulations, debates and for the International Cosmic Day (ICD) [2]. It is made of four tiles of plastic scintillator interposed with iron absorbers. Each tile has dimensions of 14.3×14.3×1.0 cm^3 and density of 1.032 g/cm^3 (BC-412); iron absorbers have the same size but a 2 cm thickness. Scintillation light is detected by two APDs (Avalanche Photo-Diodes) with 1 mm^2 sensitive area and it is collected through a wavelength-shifting (WLS) optical fiber of 1 mm diameter [3]. The flexibility of the fiber allows packing them in circular coils thus increasing the light collection efficiency over the plastic volume. Each detector is provided by an electronics frontend board on top that processes the signals from the two APDs and generates a coincidence LVDS signal.

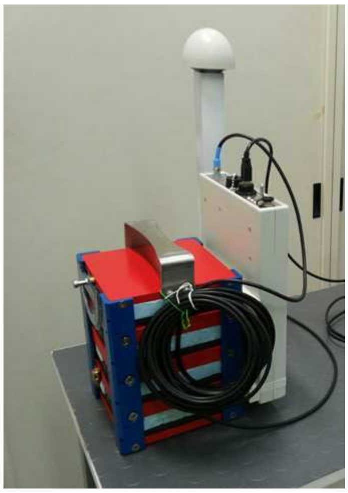


Figure 1. The CORAM detector.

This setup has been chosen because it allows enough stability and avoids the use of high voltage supply as is the case for photomultipliers. Through the coincidence of four horizontal tiles, it is possible to detect cosmic ray muons with minimum energy of about 150 MeV.
Due to the relatively simple setup, we decided to read out just the single rate coming from each detector and the twofold, threefold and fourfold coincidences at $1 Hz$ frequency.

Figure 2. CORAM DAQ board.

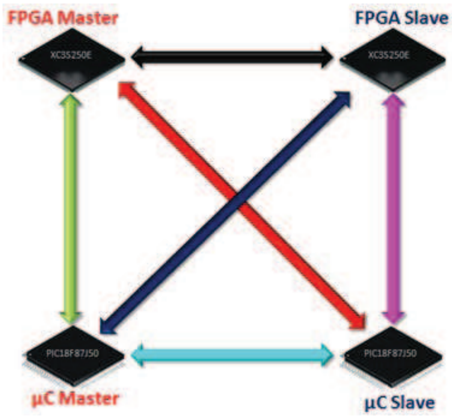
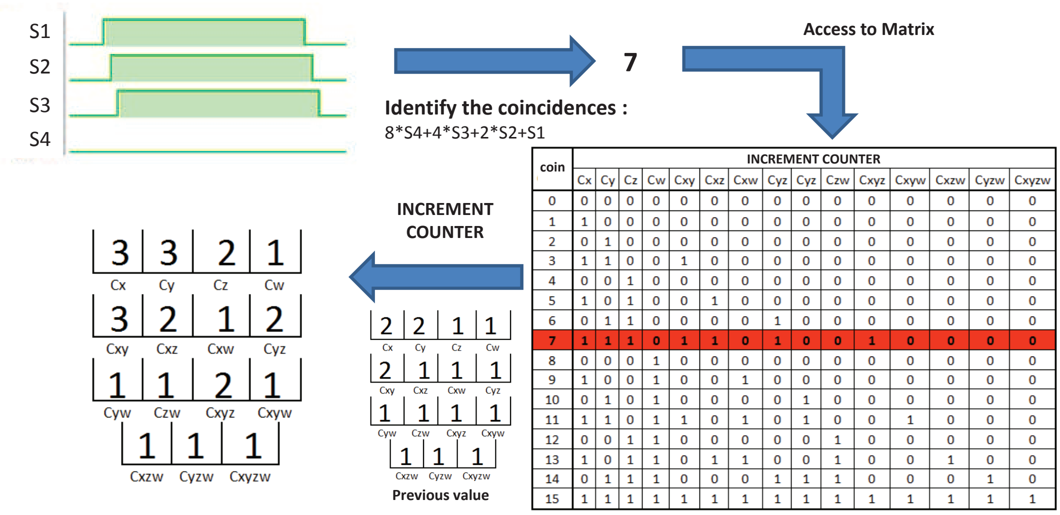


Figure 3. The DAQ system redundance scheme.

2. The DAQ System

The acquisition system has been engineered to create a compact object, redundant and which can be easily used for several measurements in the field.
The DAQ must collect the signals from the detector, digitize and integrate them with the information for geolocation, perform time stamping and transfer such information to the computer.
Each detector is equipped with an electronics frontend board on top that processes the signals from the two APDs. Therefore DAQ system can be simply implemented using a Field-Programmable Gate Array (FPGA) to manage the parallel processes logic and a microprocessor (μC) for the communication with the host computer. Moreover DAQ is provided of a GPS module for the coordinates (latitude, longitude and height) and time stamping. All data will be saved also locally in a mass storage device.
In Fig.2 is shown the DAQ system board. The coincidence calculation is performed by the FPGA (Xilinx Spartan 3E 500K) through the implementation of the counters needed to consider all the possible combinations between the tiles of the detectors. FPGA labels each count with a specific flag (single count plane 1, etc.), increases the event counters and transfers the data to the μC (MicroChip PIC18F87J50). Data are processed by the FPGA in a defined time window through a look-up-table for coincidence counting. The μC provides the timestamp with the time information from the GPS receiver integrated in the DAQ. Moreover, it also provides the environment temperature records (provided by a secondary microcontroller Maxim DS18B20) and the inclination angle (by accelerometer-magnetometer LSM303DLHC), defines the time window for data acquisition, saves data on a SD-Card and finally sends them serially to the host computer for test purpose. FPGA is connected to the detector tiles through four separated bus that host also the power line for each electronics frontend board.
For the matter of flexibility the DAQ system is able to process up to 10 detector signals. Been the detector designed for balloon launch, the system has been made completely redundant, see Fig.3. Therefore DAQ system presents two acquisition chains, master and slave.
A key feature of the DAQ system is the algorithm implemented for the coincidence calculation. Each detector tile produces a 60 ns signal when hit by a particle. At this point the FPGA receives the LVDS signals and registers which and how many tiles detected the particle in a time window of 100 ns. The data are now in a queue, waiting for the μC answer and a new measurement can be performed. In this way we do not have dead time in detection.
The μC converts data from binary in hexadecimal for time and memory space minimization and associates them with the temperature, GPS and magnetometer information.
The coincidence algorithm uses a predefined matrix that take into account all the possible detectors combinations. To every column is associated a counter (single, twofold, threefold and fourfold coincidences with all the possible combinations of the four detector) and to every row one possible event. Using an equation (8*S4+4*S3+2*S2+S1) it is possible to identify the coincidences for one measured event. S1, S2, S3 and S4 are the event flags from each detector. See Fig.4 for details. In this example, three tiles detected a particle. The



coin	INCREMENT COUNTER														
	Cx	Cy	Cz	Cw	Cxy	Cxz	Cxw	Cyz	Cyz	Czw	Cxyz	Cxyw	Cxzw	Cyzw	Cxyzw
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0
4	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5	1	0	1	0	0	1	0	0	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
7	**1**	**1**	**1**	**0**	**1**	**1**	**0**	**1**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
8	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	1	0	0	1	0	0	0	0	0	0	0	0
10	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0
11	1	1	0	1	1	0	1	0	1	0	0	1	0	0	0
12	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
13	1	0	1	1	0	1	1	0	0	1	0	0	1	0	0
14	0	1	1	1	0	0	0	1	1	1	0	0	0	1	0
15	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 4. The DAQ system algorithm.

equation result is 7 (S1, S2, S3 = 1 and S4 = 0) and the correspondent row gives the coincidence. An appropriate graphical user interface was also developed using the LabView [4] software. This allows to monitor data in real time through histograms and to save data in a file.

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