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# TANGO Array I: An air shower experiment in Buenos Aires

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**Abstract.** The TANGO Array is an air shower experiment which has been recently constructed in Buenos Aires, Argentina. It became fully operational in September, 2000. The array consists of 4 water Čerenkov detector stations enclosing a geometrical area of $\sim$ 30.000 m$^2$ and its design has been optimized for the observation of EAS produced by cosmic rays near the "knee" energy region. Three of the detectors have been constructed using 12000-liter stainless steel tanks, and the fourth has been mounted in a smaller, 400-liter plastic container. The detectors are connected by cables to the data acquisition room, where a fully automatic system, which takes advantage of the features of a 4-channel digital oscilloscope, was set for data collection without the need of operator intervention. This automatic experiment control includes monitoring, data logging, and daily calibration of all stations. This paper describes the detectors and their associated electronics, and details are given on the data acquisition system, the triggering and calibration procedures, and the operation of the array. Examples of air shower traces, recorded by the array, are presented.

## 1 Introduction

A new Extended Air Shower (EAS) Experiment has been built during 1999 and measured a first shower on March 22$^{th}$ 2000, becoming fully operational on September 13$^{th}$ 2000. It consists of 4 Water Čerenkov Detectors (WCD) and the system has been optimized for energies around the "knee" region. This array is a project which grew up from the first 1:1 scale prototype of a WCD built in 1995 by members of the local Pierre Auger Project Collaboration (P. Bauleo et al. , 1998).

The TANGO (**TAN**dar **G**round **O**bservatory) Array has been constructed in Buenos Aires, Argentina, 35° 34' 21" S and 58° 30' 50" W, at $\sim$ 15 m.a.s.l. (average yearly overburden of $\sim$ 1000 gr/cm$^2$), in the Campus of the Constituyentes Atomic Center, belonging to the Argentinean Atomic Energy Commission (CNEA). The data acquisition (DAQ) room was set inside the TANDAR Accelerator Building. Three detectors are placed on the vertices of an almost isosceles triangle, and a fourth detector was installed in a convenient position close to the center of the triangle, as shown in Figure 1. The final configuration encloses a geometrical area of 31286 m$^2$.

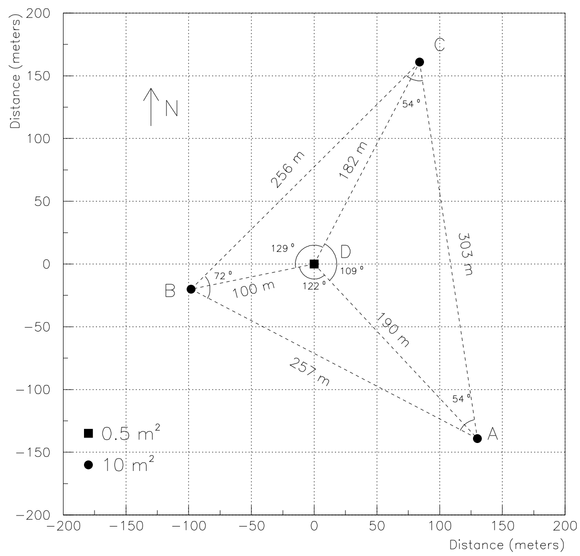


**Fig. 1.** TANGO Array Layout. Circles indicate the positions of the three 10 m$^2$ stations, whereas the square shows the position of the central, 0.5 m$^2$ detector.

During an EAS event the DAQ system measures both, the intensities of the Čerenkov photons emitted by the water when crossed by the secondary particles of an EAS, and also, the arrival time of these particles to each station. The threshold energy of the array, resulting from the geometry and from the particular detector conditions, (noise present, trigger levels,

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etc) is close to $10^{14}$ eV for vertical showers. The detector stations are connected by low attenuation (RG-213) coaxial cables to the DAQ room, where the signals are recorded using a 4-channel digital oscilloscope connected to a computer. Depending on the selected trigger conditions, which are generated by standard NIM electronic modules, the number of accepted events ranges from $\sim$ 250 to $\sim$ 1500 per day.

## 2 The Detector Stations

The first detector prototype of the array (labelled **A** in Figure 1) was construced in a cylindrical tank, made of 0.68 mm stainless steel plate, with a footprint area of 10 m$^2$. The effective water depth is 120 cm. Three, 8-inch photomultipliers (Hamamatsu R1408), symmetrically placed at 120 cm from the tank axis (See Figure 2 were installed looking down on the top of the detector, having only the photocathodes immersed in the water working as Čerenkov radiator.

The two other detectors sitting in the vertices of the triangle (**B** and **C** in Figure 1) have the same general dimensions quoted previously. They are made of 1 mm thick stainless steel, and the external walls are shaped as a dodecagon. In these detectors we used Hamamatsu R5912, 8-inch diameter PMTs, arranged with the same geometry used in the first detector tank. The fourth detector (**D**) is smaller, it was made using a fiberglass-reinforced polyestyrene tank, with a footprint of 0.5 m$^2$ and an effective water depth of 80 cm. Only one, 3-inch PMT, was installed centered on the top of the tank. In order to improve the optical properties of the inner surfaces all the detectors were fully lined with Tyvek which is a highly UV-diffusive and reflective material (A. Filevich et al. , 1999).

All PMTs used in the WCDs were mounted in water-tight enclosures that protect from moisture their voltage dividers and only the photocathode areas of the glass bulbs are immersed in the water radiator (See Figure 2). The glass bulbs of the PMTs were glued to the PVC housings using an elastic silicone compound to reduce mechanical stresses that could break the glass. Local high voltage power supplies, fed from the AC mains, were installed near each station. The bias configuration of all PMTs was adopted as grounded cathode, to prevent eventual noise produced by electrical leaks or discharges through the glass.

The water used to fill the tanks was treated in a reverse-osmosis plant, producing an average final water resistivity of about 1 M$\Omega$-cm. Before filling the tanks they were carefully degreased, brushed with water and mild detergent and rinsed abundantly with the same water used as the detector material. These precautions, together with the darkness and the fact that the water used as Čerenkov radiator has a very low level of bacteria nutrients, virtually blocked any extensive biological activity (O. Bernaola et al. , 1996). After more than 1 year since the filling of the detectors, no significative decrease in the signal strength has been observed.

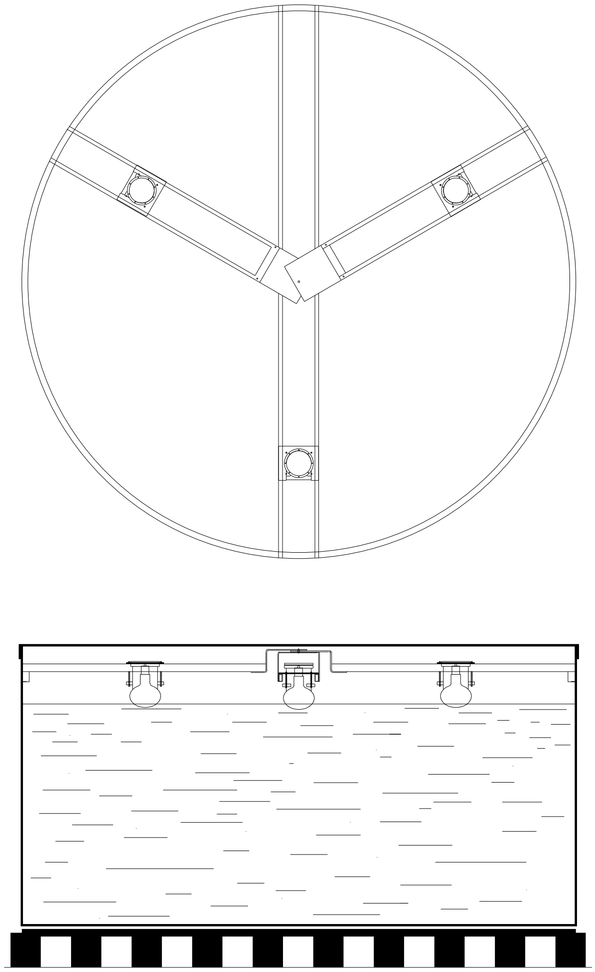

**Fig. 2.** Top (a) and side (b) view of the first 10 m$^2$ WCD used in the experiment.

### 2.1 Gain Settings and Detector Calibration

It is important that the gains of the 3 PMTs installed in each detector station are matched to each other to avoid unbalances in charge collection. Unmatching could impair the homogeneity in the response of the detector. We have used a common high voltage supply in each detector station. Because of this, and provided that the observed differences in gains were small (less than 15 % within the PMTs of each station), we compensated the differences in gain by using passive, constant-impedance variable attenuators to reduce as necessary the output pulse amplitudes of the two tubes having larger gains in each station.

In order to determine the relative gains we adopted a procedure based on the measurement of the signal from each PMT produced by background muons (T. Kutter et al. , 1997). Once the average relative gains are obtained for the three tubes, the attenuators are set in the two PMTs with higher gains, matching the peak position produced by the PMT with lowest gain.

In addition to this periodic gain matching monitoring procedure (perfomed on a monthly basis), a daily routine for monitoring the overall calibration of the 4 detector stations has been adopted. It also uses the natural background muons impinging in the detectors as the source of signals for calibration. It has been found that the spectra of the summed signals of the three PMTs within each peripheral detector station, and also the response of the 3” PMT installed in the small central detector show clearly a peak when they are triggered by themselves. The position of this “background” muon peak is very closely the same as the position of the similar peak obtained when a pair of external plastic scintillators are used to select vertical and central muons for triggering. This experimental result, which might be due to the remarkable uniformity in the light distribution produced by the Tyvek liners, provides a simple and reliable procedure for remote monitoring and calibration of the station gain (P. Bauleo et al. , 2000).

This peak value has been called VEM (**V**ertical **E**quivalent **M**uon), and is defined as the charge (or voltage) peak produced by singly charged, energetic particles, crossing vertically the detector along its axis. This VEM-value is a characteristic parameter of each detector, and depends on its components, geometry, construction, and also on its operation conditions (transparency of the water radiator, bias voltage, etc). The VEM-value provides a practical way of normalizing the signals from different detectors and moreover, to express the total signal produced in each station by an EAS (*i.e.* muons, electrons, gamma-rays, etc., hitting the station) in terms of an “equivalent reference particle”. Muons have been selected in this case as they are present everywhere and proved to be very convenient for calibration.

In previous studies(J. Rodríguez Martino et al. , 1997) performed with the prototype detector, very good homogeneity in charge collection was obtained by using the sum of the signals of the three PMTs. This behavior, which might be again attributed to the excellent light spread produced by the Tyvek liners, is kept almost independently of the entrance points and directions of the muons.

According to these results, our design included fast active adder circuits installed in the peripheral detectors. The operational amplifier employed (CLC 452) works also as the driver for the relatively long RG-213 cable, carrying the signals from each detector to the DAQ room. Because there is only one PMT in the central detector, and the cable length to the DAQ room is relatively short ($\sim$ 45 m), its anode signal was directly sent without summing circuit nor attenuator, and hence without the limitation in the dynamic range present in the outer detectors.

## 3 Trigger System and Data Acquistion

The signals from the four stations arriving to the electronics front panel are split using linear fan-in/fan-out (FIFO) modules (see Figure 3). Then, they are fed directly to the input connectors of a four-channel digital oscilloscope (Tektronix TDS 3034 set at 500 Ms/s). The oscilloscope is the core of our DAQ system and works as the digitizing stage for detector signals under control of a STROBE pulse. The detector signals are at this point unsynchronized after travelling different lengths of cables (206, 196, 310 and 44 m, for detectors **A**,**B**, **C**, **D**, respectively). Thus, in order to generate valid trigger conditions, it is essential to compensate these different transit times. With this purpose, we use the second signals from the FIFOs to generate logical pulses in analog discriminators (discrimination level $\sim$ 1 VEM), then these pulses are delayed accurately to compensate for these differences in time and then they are fed to a majority logic coincidence unit to select the desired trigger condition. The time window in this module is set to 1.1 $\mu$s, covering safely the maximum time used by the EAS front to go across the array, even for the case of almost horizontal directions.

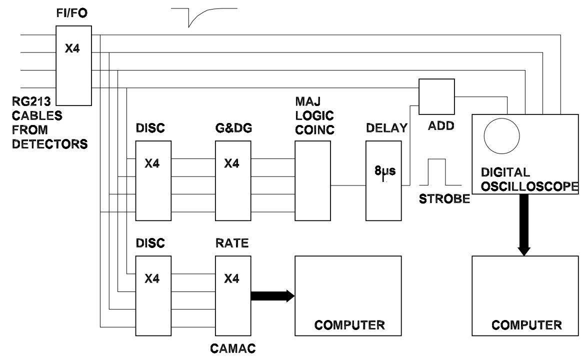


**Fig. 3.** Simplified block scheme of the Trigger and DAQ system.

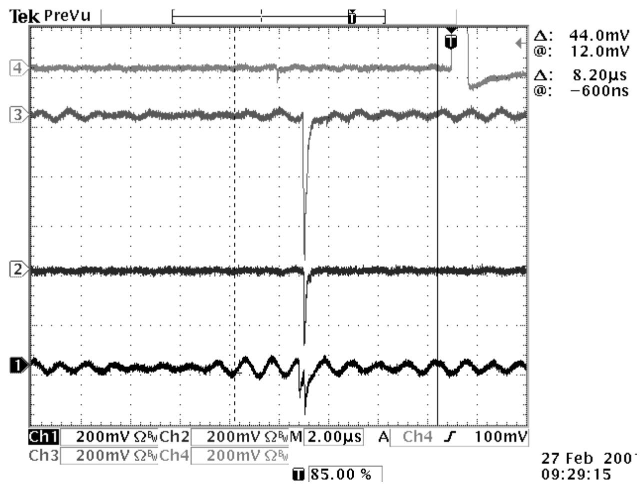


**Fig. 4.** Oscilloscope screen during the capture of a real shower. In Channel 4 the STROBE signal is summed to the signal from detector **D** and indicated with the symbol “T”. In the time region between cursors the signals form a typical shower can be observed. The individual traces has been shifted vertically for clarity.

The digital oscilloscope available does not feature external trigger. For this reason one of the analog channels had to be used for triggering purposes, in addition to its signal digitizing function. With this purpose the STROBE signal generated by the coincidence unit, indicating the production of an event of interest (in practice 3 or 4-fold coincidences) is delayed about 8 $\mu$s after arrival of the last detector signal and then summed to one of the detector channels (channel 4 in Figure 3 and 4). Because of the relatively low singles counting rates and with the introduced delay of 8 $\mu$s no overlaps are produced in practice. Provided that the STROBE pulse is summed with opposite polarity respect to the detector signals the Advanced Trigger feature of the oscilloscope could be safely used for triggering.

The system dead time (digitalization, data transfer and PC storage) is 22 seconds for event. This relatively long dead time is primarily produced by the transfers. This dead time is considered acceptable in comparison with the average time between events, which is of the order of 6 minutes.

The first time region of 8192 ns (up to the first cursor in Figure 4) is used to compute the bias level at the time of presentation of the detector signals. The typical pick up noise appears as a dominant oscillation with a period of the order of 1 $\mu$s, corresponding mainly to the AM broadcasting stations. The following 8192 ns region, between the cursors, is the time region where the detector signals are stored. The last region which contains the STROBE signal is not saved to disk. The internal 150 MHz bandwidth low-pass filter built-in the oscilloscope is active in order to reduce the amplitude of higher frequency signals. A fast Fourier analysis of the detector signals indicated that their main harmonic components extend up to only $\sim$ 100 MHz, thus little distortion in the detector signals is introduced by the filter.

A special program was written to drive the data acquisition system in a completely automatic way. Normal collection of shower events is performed when the program runs in “Survey Mode”. When the STROBE pulse is detected by the oscilloscope, the SAVE procedure is initiated, *i.e.*, the traces stored in the four channel memories corresponding to the last 16384 ns, are frozen and transferred to the PC disk. This time slice allows us to obtain a good measurement of both, the desired detector signals and the unavoidable radio noise pick-up in the long cables carrying the signals. Together with the digitized signals of all channels, information on the year, day, and local civil time of the events is recorded to disk, which allows to reconstruct the equatorial or galactic coordinates of the shower arrival direction.

In addition, every day the program switches at a predetermined time to the “Calibration Mode”. In this mode, the collection of data from each detector station is self-triggered, in order to record background events to calibrate the stations, *i.e.* to determine the daily VEM value for each station. The four detectors are measured sequentially in this mode, under program control. The data are stored to disk and analyzed off-line. Roughly, one hour and a half is required to acquire 3000 background events (found to be sufficient to obtain the VEM values with an error of $\sim$ 5%) for each station and to save the calibration data from the four detectors. The starting time for the calibration procedure, and the total amount of background events for each detector, are set in an ASCII file. Once the calibration is completed, the program automatically switches to the “Survey mode” described above. This mode of operation is kept until the “Calibration Mode” is called up again, at the programmed time next day.

The singles counting rates of the four detector stations are permanently recorded using a CAMAC scaler with a refreshing time of 1 s, and are also saved to disk. This information is valuable for monitoring the status of each station. It helped discarding particular data sets when the operating condition of a particular station became unstable due, for instance, to a high level of pick up noise, or gave an alert signal for the need of maintenance of a station, in occasional cases of light leaks. The recording procedure of the counting rates is also program-controlled and does not require operator action to run, once it is launched.

## 4 Summary

A new Extended Air Shower Experiment consisting in 4 surface detector stations (Water Čerenkov Detector) and optimized for measurements in the “knee” energy region has been commissioned in September 2000 and data has been taken since. A fully automated system for calibration, monitoring and data acquisition has been built using standard NIM and CAMAC modules and a 4-channel oscilloscope connected to a PC. The system has proved to be stable and highly reliable with a duty cycle close to 80% during its first 6 months of full operation.

The simulations performed to obtain its resolution are described in an accompanying paper. The shower reconstruction analysis will be published in a forthcoming paper.

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