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PRELIMINARY TESTS OF A SCINTILLATOR-BASED MINI-STATION FOR EXTENSIVE AIR SHOWERS MEASUREMENTS

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Abstract

This Report describes the construction, working conditions and preliminary tests for a mini-station to be employed for educational cosmic ray measurements. The individual detectors are based on small scintillation tiles with a wavelength shifter (WLS) readout. Low cost, dedicated power supplies have been designed for each individual unit. Signal handling, data acquisition and time stamping of the collected events may be provided by dedicated Quarknet cards. The combined use of at least three such detectors placed at a proper relative distance will allow the detection and, to some extent, the reconstruction, of extensive air showers.

PACS.: 01.40.E – Science in school, 01.50.Pa – Laboratory experiments and apparatus, 29.40.-n – Radiation detectors, 96.50.S – Cosmic rays

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1 INTRODUCTION

A variety of educational activities concerned with the study of cosmic ray physics exist worldwide. Over the last decades, several activities in this field have been carried out under various working conditions and with different types of detectors, from small, single detectors (quite often even simple Geiger counters) to scintillation-based detection systems, to complex detectors and arrays for the detection and identification of extensive air showers. A recent review of educational experiments concerned with cosmic ray physics has been reported in Ref.[1].

All of these experiments are a nice way to introduce students and high school teachers to various aspects of modern physics and to related experimental techniques. Scintillation-based detectors offer the possibility of being designed in a variety of sizes and geometrical shapes. While in the past the scintillation light produced in the passage of ionizing particles in the sensitive volume was usually detected by standard photomultipliers, new devices, such as Avalanche Photo Diodes (APD) and Silicon Photomultipliers (SiPM) have been extensively used in recent years, due to their smallness, reduced cost, low voltage and other properties which make them preferable over standard photo-detectors.

Typical educational arrays made up of scintillation detectors employ three or four individual detectors in coincidence, located at relative distances of the order of 5-15 m. Such setup constitutes a station, able to detect extensive air showers in a range of the order 10^{14}-10^{16} eV, depending on the relative distance between the detectors and on trigger conditions. Multiple stations may constitute an array, with relative distances of the order of hundred meters between the single stations. An example of such array is for instance the SEASA Project in Stockolm [2]. With such an array, different physics items may be exploited: the arrival distribution of extensive air showers, the dependence of the detected flux on the weather conditions, and so on. Some of these activities may be pursued even by a single station, provided that the relative distance between the detectors and their time resolution allow the reconstruction of the shower orientation.

This is a preliminary Report to describe the work under development to test the design of a small station to be employed to detect correlated secondary particles from extensive air showers in the atmosphere. The detector must be relatively easy to operate and not too expensive, in order to be used also with high school teams or in undergraduate laboratory courses. For such reasons, small scintillation tiles were used, together with home-made power supplies, and a Quarknet acquisition card, developed at Fermilab for educational activities in cosmic rays physics.

This first Report describes the individual components of the setup and their preliminary tests, together with the result of a first coincidence measurement between two detectors a few meters apart. Additional results, including the measurement of the small-distance decoherence curve, will be the subject of a future work.

2 EXPERIMENTAL SETUP

2.1 Detectors

The detection modules are two plastic scintillation tiles (15 cm x 15 cm, thickness 1 cm) with an electronic readout card mounted on a small board. Such detectors have been also employed to build high-granularity systems for triggering cosmic muons in the test of the ALICE TOF modules at CERN [3]. Each tile is a plastic scintillator, with two coil wavelength-shifter (WLS) optical fibres inserted in it through a circular groove (Fig. 1). Two arrays of avalanche photodiodes (Metal Resistor, MRS APDs) are used at each end of the fibre for the readout. Such devices do not require high voltage power supplies, since they are planned to be operated with a low voltage (about 30 V). An additional power supply of ±5 V is used for the electronic readout card. Since avalanche photodiodes are relatively noisy components, a coincidence (with a time window of the order of 20-40 ns) between the signals provided by the two MRS APDs is made on the board. An adjustable threshold allows to set a working condition in which the coincidence rate between the two MRS APDs is basically equal to the rate given by the passage of true cosmic particles in the tile.

For the measurements of the decoherence curve (number of coincident muons per unit time per unit surface of the two detectors), two detection modules may be arranged on the same horizontal plane and the signals originating from each tile, after conversion from ECL to NIM standard, may be sent to a suitable coincidence unit to record the number of coincident events within a fixed time window. In our case a Quarknet card was employed, which allows not only to record the coincidences, but also includes time-digital converters on each input for a better off-line selection of the events.

2.2 Power supply

The power supply to each detector module needs a ±5 V for the electronic card mounted on the detector and a variable voltage, in the order of 30 V for the APD bias. The use of individual professional power supplies for both voltages might be unnecessarily expensive, since two different power supply are required for each module, and even a small array of 4 detection modules, as it is planned for such activity, might require a large budget compared to the requirements of an educational installation. For such reasons, dedicated, low-cost, power supplies were designed and built in our laboratory, providing both the ±5 V and the 30 V bias, thus constituting a stand-alone tool for the use of a single module. Four equal units were built, to use a corresponding number of individual detectors, even at large relative distances. In view of the possible use of two close detectors however, each unit was designed in order to provide a current high enough to power up two detectors, thus reducing the number of units wherever possible. Commercially, low cost, available electronic kits (an adjustable 1A dual output kit, set at ±5 V and an adjustable single output, 1.5-30 V, 1 A kit) were employed to this purpose, with two small transformers. A suitable box, with standard plugs and a voltage potentiometer allow for an easy use of the units even by students (Fig. 2). The construction of such units may be undertaken in principle even by students with some degree of practical abilities, under the supervision of experts, thus giving the possibility to have a direct approach to the design and mount of simple detection apparatus.

2.3 Electronics and data acquisition

Each individual detection modules provides an ECL signal when either one or both APD sensors mounted at the two ends of the WLS fiber pass the adjustable threshold. A selectable jumper allows the choice of one of three possible operational modes (APD 1, APD 2, APD 1 &2), with a common threshold, which can be adjusted between 30 mV and 250 mV. For a station made by up to 4 individual detectors, a Quarknet [4] card may be used. This card, developed at Fermilab for the purpose to provide a useful tool for educational cosmic ray experiments, may accept up to four signals from photomultipliers or other detectors, and provides discriminator and trigger logic for the four channels. In addition, the relative time between the individual inputs is also provided, which allows to perform time measurements of the rise and fall time associated to each input signal. Other capabilities of the card are the time stamping of the events, provided by a GPS receiver, with a resolution of about 50 ns, an atmospheric pressure sensor, and five built-in scalers (with a 4-digit numerical display), to record the four individual inputs plus the trigger counts. The output stream from the card may be sent to a PC via USB and hyperterminal connection, and produces a set of ASCII lines which can be decoded off-line to extract all the relevant information for the collected events. Event informations on the stream data output report the trigger time according to the UTC standard, with 40 ns resolution (25 MHz clock) and leading and trailing edges for each pulse recorded within the coincidence time window (1 ns resolution). Additional commands allow temperature and barometric pressure to be read, as well as other information on the GPS data (number of satellites visible,…). Trigger logic is implemented using a programmable logic device chip, which allows any trigger logic, from singles to 4-fold coincidences, with a majority logic, i.e. any combination of 3 active channels gives a valid trigger at the 3-fold level. Discriminator output pulses are sent to TDCs, to measure the time associated to leading and trailing edges of each pulse relative to the trigger time. Such information may also be used to evaluate the pulse width, by the use of the Time-Over-Threshold technique. Specific additional information on the Quarknet card may be retrieved from the Quarknet Collaboration [4].

3 PRELIMINARY TESTS OF THE DETECTOR

Preliminary tests of a possible detection setup were first carried out on each individual tile, by measuring its count rate in single mode (APD 1 or APD 2) and in coincident mode (APD 1 & 2). Figs. 3-11 report the results for three such detectors. From these results, it is seen that the single rate is very high at low threshold (up to about 170 mV), where the rate nearly equals that expected for the true cosmic muons traversing the detector (in the order of 10 Hz). When operated in coincident mode (APD 1 & 2), the threshold may be lowered to about 120-130 mV, still maintaining the spurious rate at a negligible level, in the order of 0.01 Hz. When operated in coincidence mode, the experimental count rate was compared to that expected for random coincidences, as estimated from the data measured at very low threshold (Figs. 5, 8 and 11).

A second test was carried out looking at the time difference distribution from two detectors placed very close each other, in order to measure the overall time resolution of the system and understand how to choose an off-line time window to select true coincident events when the detectors are separated by a few meters. Figs. 12-14 show the result for two detectors placed close each other, 120 cm and 480 cm respectively. The rise front of the signals from each detector was considered to build the time difference. The centroid of the distribution is shifted a few ns from zero, simply due to the different cable length in the two channels. The RMS of the distribution increases from about 4-5 ns (when the detectors are very close or separated by about 1 m) to about 11 ns, for a relative distance of 5 m. Such values incorporate both the intrinsic time resolution of the detectors and the associated electronics, as well as the difference in the arrival time of the secondary cosmic particles to the two detectors.

In order to plan a set of high-statistics measurements of coincident events between at least three (or possible four) individual detectors, a preliminary evaluation of the two-fold coincidence count rate at different relative distances was done. Table I reports the working conditions of such measurements. The last value, measured at about 5 m distance, corresponds to about 70 coincidences/day, which is much larger than the expected random coincidence rate, smaller than 1/day in a time window of 50 ns. This gives the possibility to separate the individual detectors of even larger distances, for a better reconstruction of the muon orientation.

Table I: Summary of coincidence measurements at different relative distances.

Relative nominal distance (cm)	Coincidence rate (Hz)	Approximate no. of expected events/day
15	0.06 ± 0.0005	5200
120	0.005 ± 0.0002	430
480	0.0009 ± 0.00007	75

4 CONCLUSIONS

Preliminary tests of the components contributing to a possible design of a station unit to be employed for educational cosmic ray experiments have been carried out. Several individual detectors, based on small scintillation tiles, were tested together with the required electronics and power supplies. Signals from the detectors were collected by means of a dedicated Quarknet card and some basic coincidence measurements at different relative distances were taken, with the purpose to check the overall procedure and estimate realistic count rates at a few meters distance. This will help to design and install a station with three or four detectors, placed at relative distances in the order of 5-15 m, to be employed to detect the arrival of incoming air showers and (possibly) reconstruct their incoming direction through time correlations.

5 REFERENCES

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[2] SEASA Project, http://www.particle.kth.se/SEASA/

[3] A.Akindinov et al., Nuclear Instruments and Methods in Phys. Research **A567**(2006)74

[4] Quarknet Project, http://quarknet.fnal.gov/

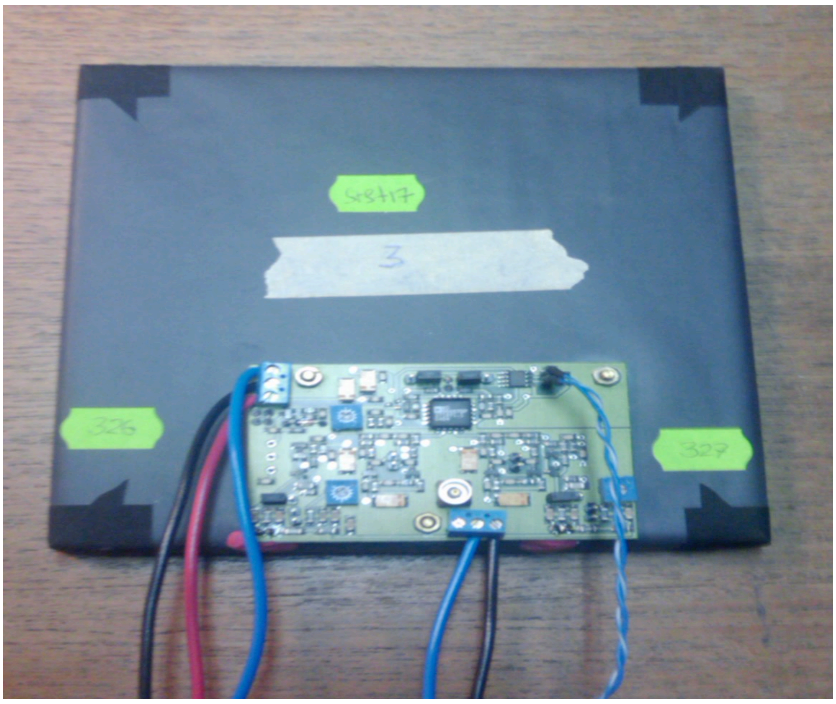

*Fig. 1: One of the scintillation tiles in the present design of a scintillator-based mini-array for cosmic detection***.**

Fig. 2: One of the dedicated, low-cost power supply to bias both the electronics and the APD sensor in each individual detection module.

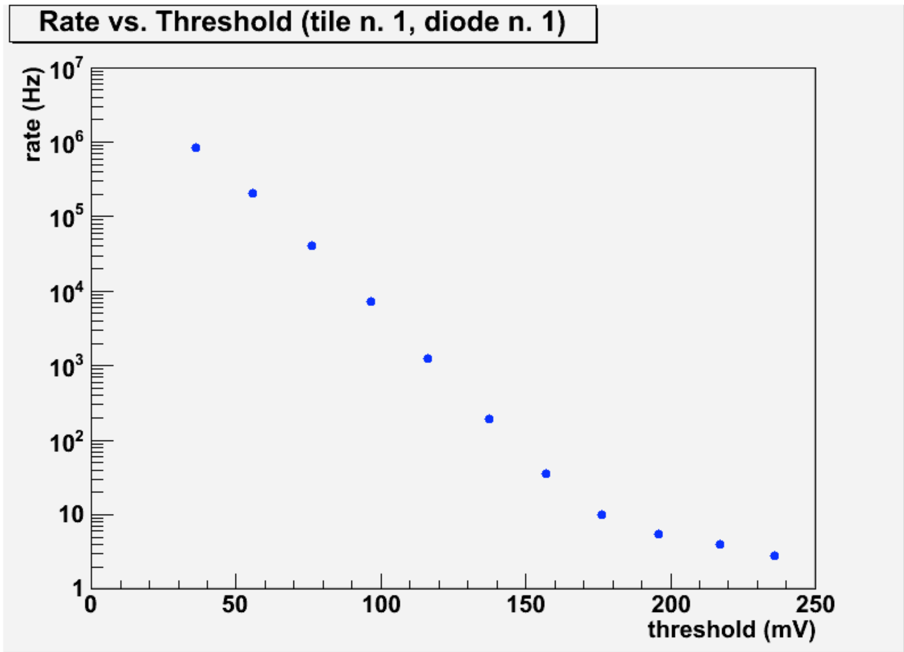

Fig. 3: Count rate of the tile#1 in single mode (APD 1) as a function of the discriminator threshold.

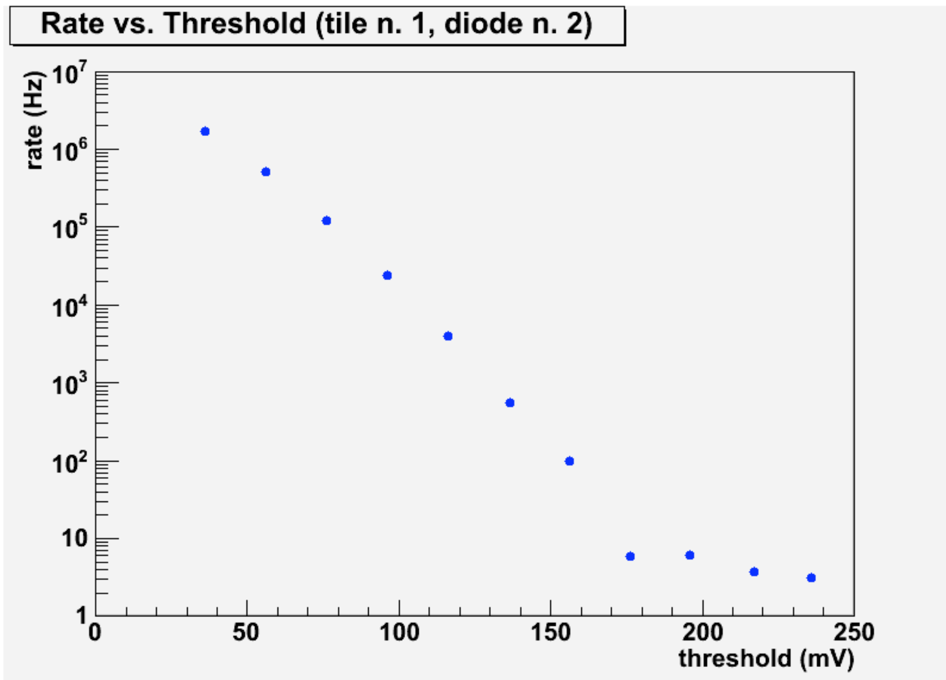

Fig. 4: Count rate of the tile#1 in single mode (APD 2) as a function of the discriminator threshold.

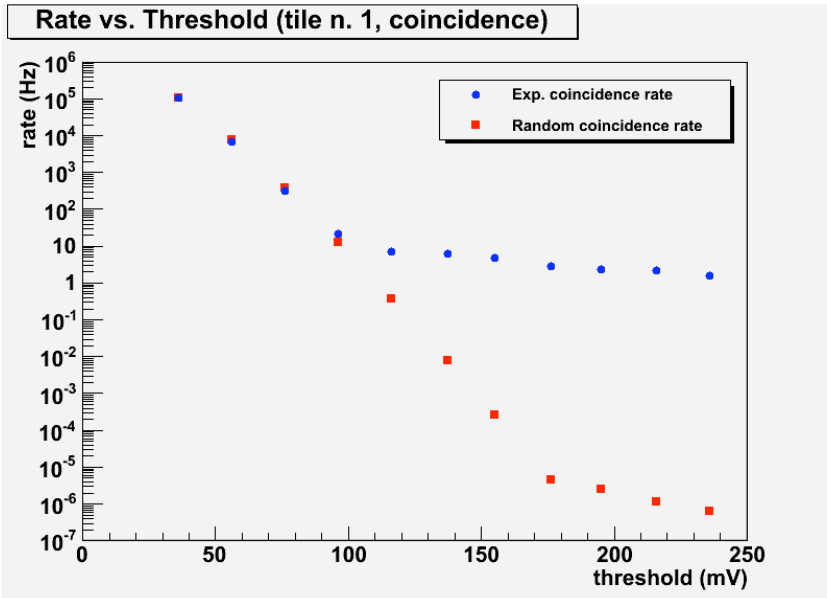

Fig. 5: Count rate of the tile#1 in coincidence mode (APD 1 & 2) as a function of the discriminator threshold. The expected rate for random coincidences is also reported (red squares).

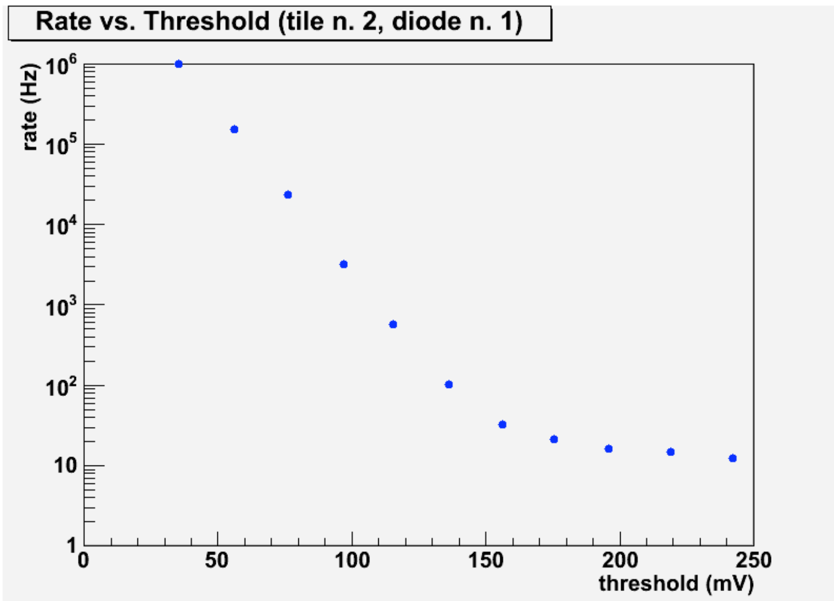

Fig. 6: Count rate of the tile#2 in single mode (APD 1) as a function of the discriminator threshold.

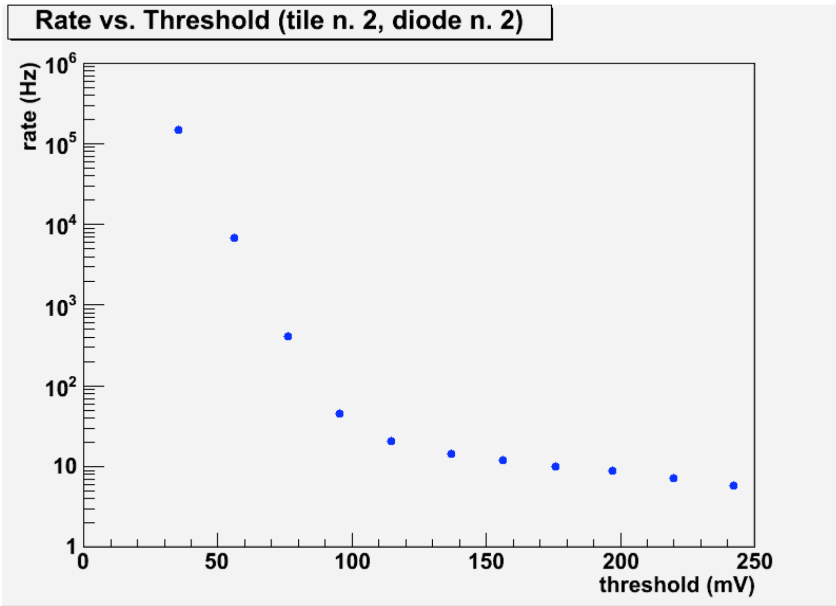

Fig. 7: Count rate of the tile#2 in single mode (APD 2) as a function of the discriminator threshold.

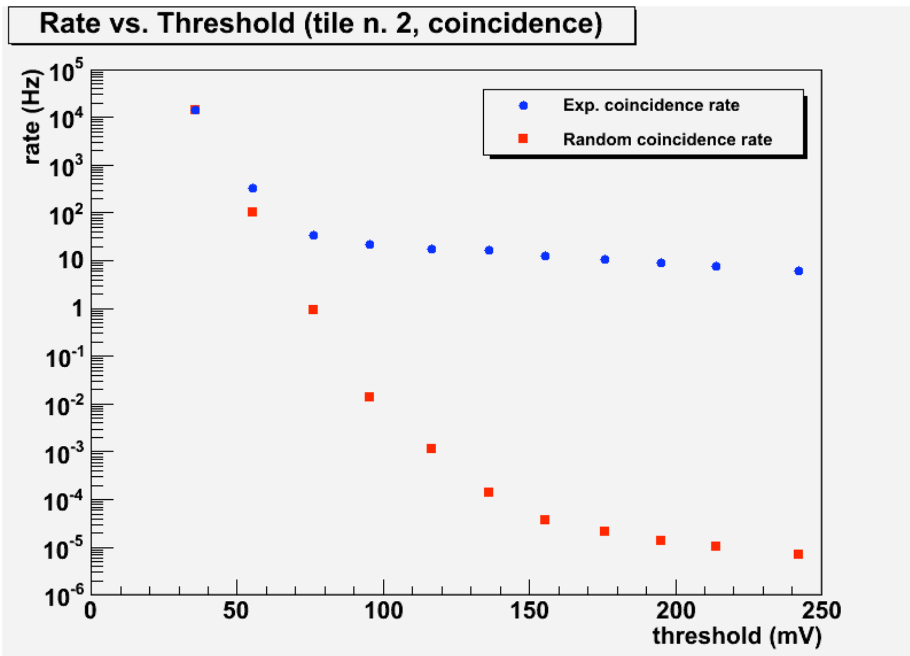

Fig. 8: Count rate of the tile#2 in coincidence mode (APD 1 & 2) as a function of the discriminator threshold. The expected rate for random coincidences is also reported (red squares).

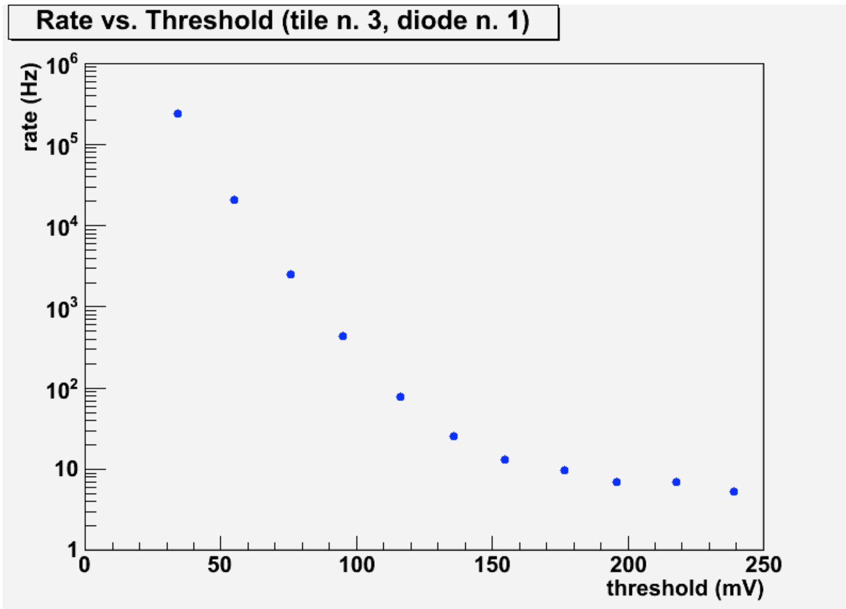

Fig. 9: Count rate of the tile#3 in single mode (APD 1) as a function of the discriminator threshold.

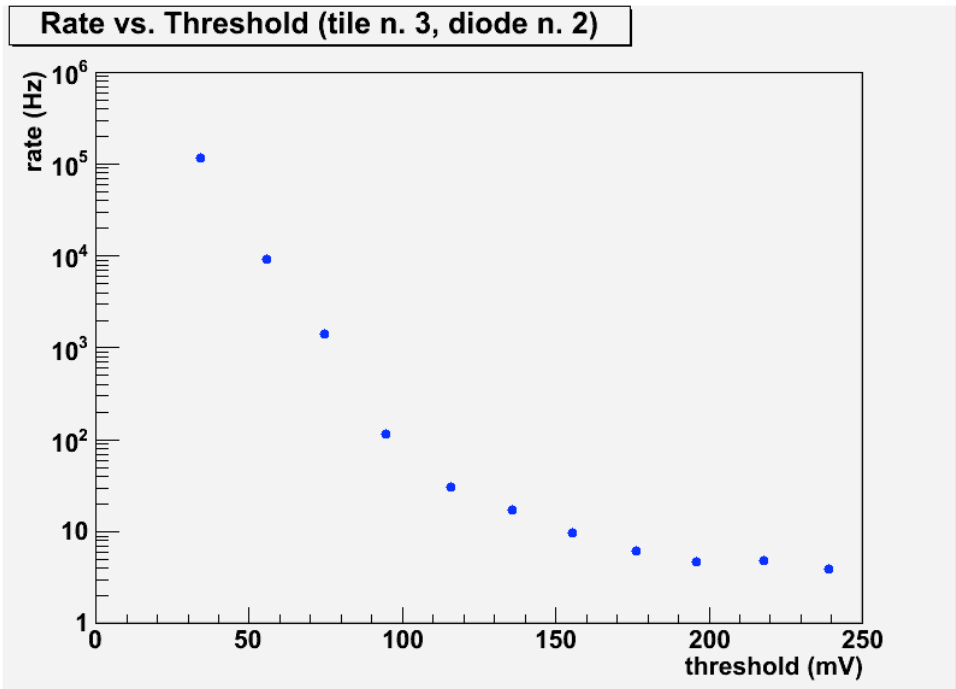

Fig. 10: Count rate of the tile#3 in single mode (APD 2) as a function of the discriminator threshold.

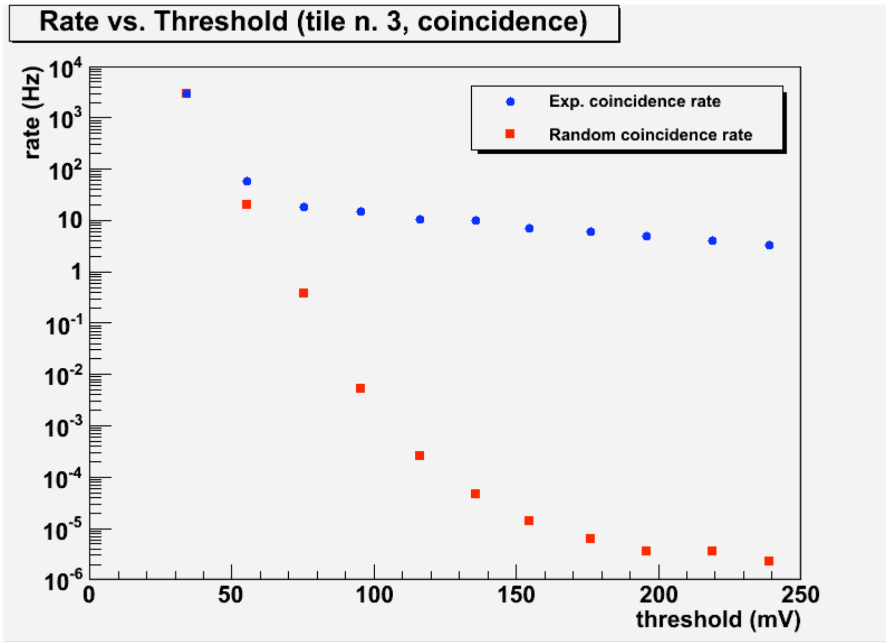

Fig. 11: Count rate of the tile#3 in coincidence mode (APD 1 & 2) as a function of the discriminator threshold. The expected rate for random coincidences is also reported (red squares).

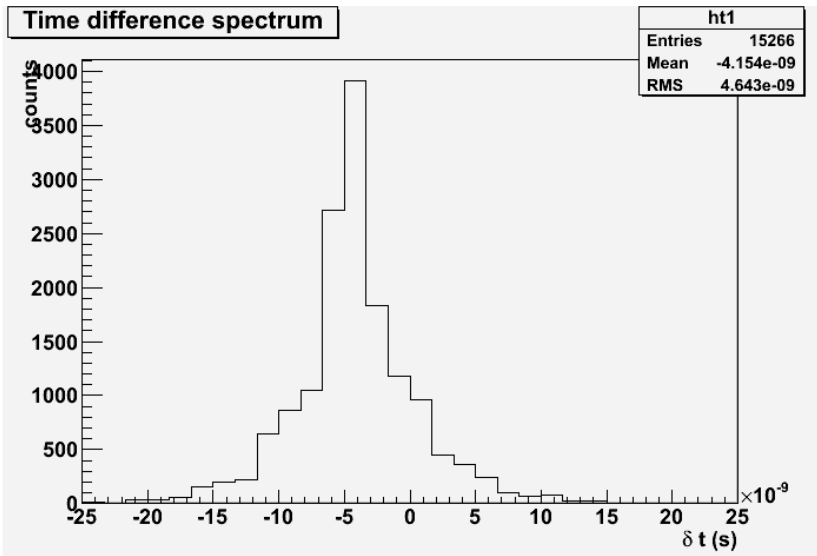

Fig. 12: Time difference spectrum between two individual detectors located close each other. The shift with respect to zero is due to different cable lengths in the two channels.

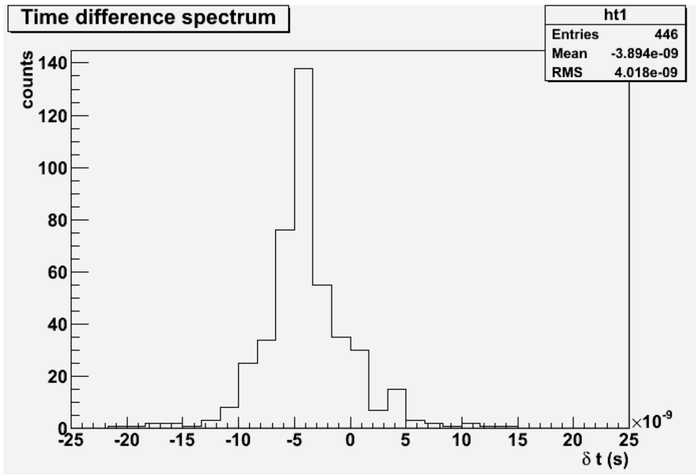

Fig. 13: Time difference spectrum between two individual detectors located at 120 cm relative distance.

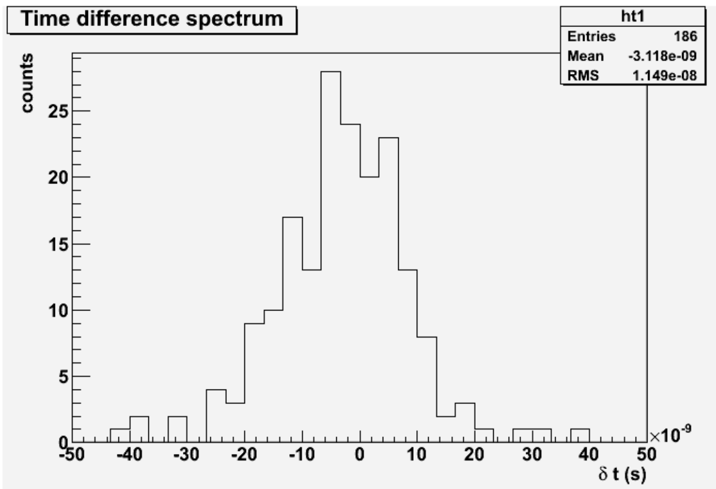

Fig. 14: Time difference spectrum between two individual detectors located at 480 cm relative distance.