ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Catania

INFN/TC-06/04
17 February 2006

TESTS WITH GPS CAMAC UNITS FOR EDUCATIONAL EXPERIMENTS ON COSMIC RAY PHYSICS

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Abstract

Educational and professional experiments in cosmic ray physics usually require the use of GPS units for a precision time-stamp of the collected events, in order to correlate events measured with independent detectors. As a part of an educational program aimed to carry out experiments in collaboration with high school teams, several tests of a time-stamp system based on the use of CAMAC GPS units was performed. Position and time information for periodic as well as for random events were collected, to check the reliability of the method and the achievable resolution, in view of on-going experiments with extended arrays of cosmic ray detectors.

PACS.: 96.40.-z, 01.40.Ej, 01.50.Pa

Published by ***SIS–Pubblicazioni***
Laboratori Nazionali di Frascati

1 INTRODUCTION

Cosmic ray experiments which make use of multiple detectors separated by large distances require event time synchronisation for the off-line correlation of measured events. The time information on the arrival of each individual event may be used for the reconstruction of extended air showers in large array of detectors, or even to search for possible correlation with other independent installations over huge distances. Basically, when a particle generated by a high energy cosmic ray event crosses a local detector system, it is stamped with its GPS time, and by comparing the particles arrival times and angles at different sites it is possible to look for correlated showers.

A method which has become the standard in recent years is the use of the Global Positioning System (GPS), which provides the dissemination of precise time and position information anywhere on the Earth. Such system allows to correlate events within time intervals in the order of 100 ns or less, thus representing a significant step forward with respect to previous systems, based on radio broadcasting of time reference signals.

Apart from experiments which are devoted to professional measurements in high energy cosmic rays, several educational projects, which involve collaborations between high-school teams and university or research centers, have also started in recent years to design, build and operate extended arrays for cosmic ray detections [1]. All such projects require the use of GPS devices for each local installation, in order to compare the time information associated to far events. A recent project aiming at the deployment of an extended area array in high schools over all Italy is the EEE (Extreme Energy Event) project [2], which will also be able to look for coincident events over large distances.

GPS devices are also useful tools to carry out several educational investigations with cosmic ray detectors on a local basis. For instance, recording the arrival time of cosmics in a single detector may provide interesting data to understand the time distribution of events following the Poisson distribution [3] or even to search for non random components in the cosmic flux [4].

As a part of extended tests concerning all such projects, we carried out a series of measurements with GPS devices providing position and time information for periodic as well as for random events, in order to check the reliability of such information over extended time intervals and from different locations. This report provides a first set of results.

2 THE GLOBAL POSITIONING SYSTEM

The Global Positioning System (GPS), funded by and controlled by the U.S. Department of Defense (DOD), is a navigation system which provides specially coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time anywhere in the world. It consists of a constellation of satellites which follow 12 hour orbits distributed in 6 orbital planes (inclined by 55° to the equator), at an altitude approximately of 18000 km. The distribution of satellites is organized in such a way that 4 or more satellites, which allow to accurately determine the position, are visible at any time. Each GPS satellite has an atomic clock being synchronized daily with respect to the UTC (Universal Time Coordinate) to within 100 ns, and continuously transmits its current position in space. GPS receivers may obtain their position by measuring the distance to each of the four satellite. If the receiver is motionless and its position is accurately known, it can obtain accurate timing information by tracking a single satellite [5] .

3 THE EXPERIMENTAL SET-UP

Preliminary tests of a GPS-based time-stamp system, to be used in educational experiments on cosmic ray physics, were carried out in our Institution using two Hytec GPS modules (GPS92) in CAMAC standard [6]. Another GPS module from Trimble (Mod. GTS8000) was used to provide an additional source of 1 pulse/s (1 PPS) signal [7]. In Fig. 1 we show the hardware configuration used to carry out the tests of a single GPS CAMAC unit. The 1 PPS signal produced by the GTS8000 module was sent to a gate and delay generator, which provided two signals: the first was sent to the event input of the GPS92 module, while the second provides a LAM (Look At Me) signal on the trigger unit of the acquisition system. Each event consists of some information provided by the GPS92 module (altitude, longitude, latitude of the receiver; year, day, second and nanoseconds, in 10-ns increment, of the event with respect to the UTC).

The addition of a second GPS92 unit in the system is shown in Fig. 2. Such configuration was used to carry out the correlation tests between the information provided by the two modules. For these tests we used both the GTS8000 unit as before (providing a periodic signal at 1 Hz) and physical signals from detectors (a small Geiger or a scintillator telescope) which provide cosmic signals with random arrival times.

The CAMAC modules under tests were two units from Hytec Electronics Ltd. These are double-width modules, performing event time-stamping through the GPS system. A small antenna/preamplifier must be located out-of-doors with a clear view of the sky. Through the antenna, the receiver may track up to 6 satellites simultaneously. In standard accuracy mode, the unit automatically determines its position and provides an event time-stamp within 100 ns with respect to UTC.

4 RESULTS AND DATA ANALYSIS

4.1 Position information

The first tests were carried out in December 2004, covering a period of about 4 days. About 3×10^5 1PPS events from GTS8000 were recorded on a single GPS92 module. We focused first on position measurements provided by the GPS module. In Fig. 3 we show the histograms of the latitude, longitude and altitude recorded by the GPS for each individual event. We obtained the following mean values: latitude 37° N 31.4798 min, with a RMS=0.0038 min; longitude 15° E 4.3248 min (RMS=0.0042 min), altitude 218.3 m (RMS=15.2 m)[1].

To check the fluctuations from event to event and over an extended time period, we report in Figs. 4-6 the plots of latitude, longitude and altitude, measured over a period of approximately 4 days with the antenna located in a fixed position. As it can be seen, small fluctuations are observed in the latitude and longitude (in the order of thousandths of minute), with the occasional presence of some larger variations, which may reach 0.01 minute. Such variations however are not correlated in the two variables. Somewhat larger variations (in the order of 20-40 m) are noticed in the altitude. Looking at the scatter plot of the x-y geographical position (Fig.7), most of the events lie in a spot whose widths are of the order of 10 m, with some fraction of the events spanning a wider area, up to 20-30 m with respect to the centroid.

In order to verify how accurate is the position information over long time periods, some of the measurements were repeated six months later, with the antenna located in the same position. The results, which are shown in Fig.8, demonstrate that the differences between the two sets of measurements are quite negligible (0.001 minute in the average values of longitude and latitude and 0.5 m in altitude) and may be considered compatible with the resolution.

By sending the same 1PPS signal from the GTS8000 unit to two twin GPS92 units, each having its individual antenna located at a few cm distance, we verified that the position information provided by the two units is quite comparable, with differences within the expected resolution (Fig.9).

4.2 Time information

To test the GPS units with respect to the time information, which is the most

[1] Note that 0.001 min latitude are equivalent to 1.55 m , and 0.001min longitude to 1.95 m.

important piece of information for cosmic detectors localized at far distances, we employed both the 1PPS periodic signal provided by an additional GPS unit or physical signals derived from small cosmic ray detectors. Extended investigations were carried out to check the overall reliability of the technique, including the time resolution, systematic differences between the information provided by two different units, possible variations over extended time periods and occasional loss of events. Since some of these measurements are still in progress, here we only report a typical reslt concerning the time resolution. Fig. 10 shows the distribution of the time differences obtained when the two GPS92 modules stamp the same event originating from cosmics traversing a Geiger counter, with an approximate rate of 0.3 Hz. The RMS of the distribution is close to 60 ns, which corresponds to $60/\sqrt{2} = 42$ ns for the individual unit. Similar values were obtained by the use of other counter detectors (single scintillators or scintillator telescopes) with slightly different counting rates. Contrary to what happens for periodic signals, as those derived from the 1 PPS information of an additional GPS unit, the arrival of cosmics in a real detector is a random process, and even with a very low counting rate, there is a finite probability that two events may come very close to each other. Such situation may produce an incorrect readout of the events, if it is not taken into account with proper veto techniques during the acquisition readout process.

5 CONCLUSION

One of the goals of extended arrays for cosmic detection, as the EEE network, is to look for time correlated events at different detector sites, which can be separated by as little as a few kilometres or as much as a few hundred kilometres. To do this, all recorded events have to be tagged with a time information derived from GPS modules placed at the detector sites. The cross correlation between two GPS receivers, used in such investigation, was showed to provide an RMS timing error of about 40 ns. Is this value compatible with the performance required to set up a suitable network of cosmic detectors? If the trigger rate from the single station is r counts/s, then a spurious rate in the order of $8 \times 10^{-8}\, r^2$ /s is expected in this situation. For r=10 Hz, this gives about 10^{-5} coincidences/s, or a false coincidence per day. This could be certainly a problem when looking for rare events, as those expected for distant detectors. However, the possibility to include additional local detectors close each other could reduce the individual rate from a single station, still detecting the local cosmic shower with a high probability. An alternative solution is to introduce an additional degree of freedom in the reconstruction of correlated showers, for instance looking at their incoming orientation, with detectors able to give information on the direction of the shower.

6 REFERENCES

[1] See for instance the relevant links on the site of Cosmic Ray Educational Observatory in Catania (http://www.ct.infn.it/rivel/cosmic.html)
[2] The EEE project, http://www.centrofermi.it
[3] F.Arqueros et al., Eur. J. Phys. 25(2004)399.
[4] Y.Katayose et al., Nuovo Cimento C21(1998)299.
[5] B.Hofman-Wellenhof, H.Lichtenegger and J.Collins, GPS: Theory and Practice, Springer-Verlag, Wien, New York, 1993.
[6] HYTEC, http://www.hytec-electronics.co.uk
[7] TRIMBLE, http://www.trimble.com

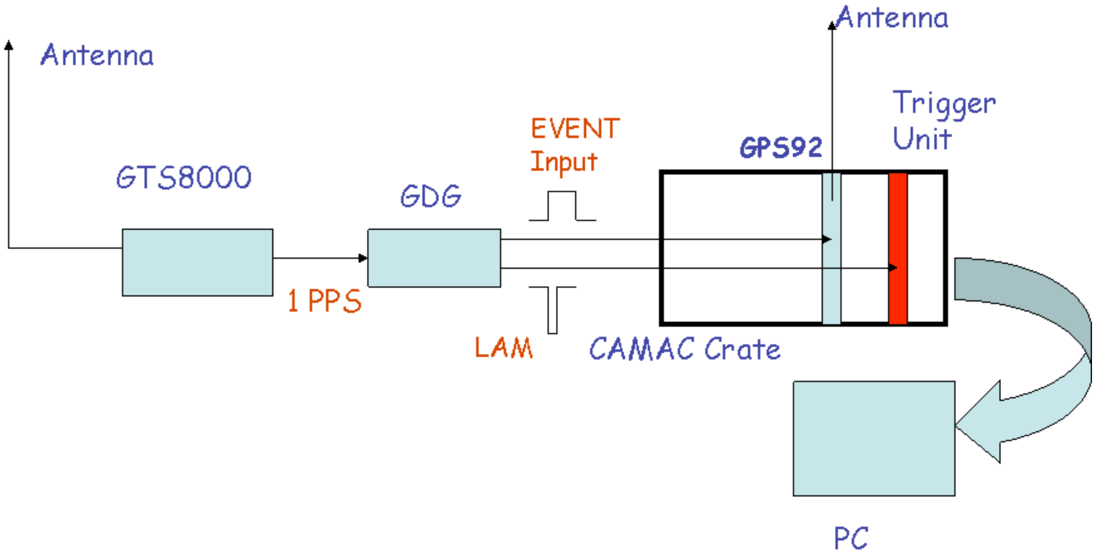

FIG. 1: Hardware configuration for tests with 1PPS signals from GTS8000.

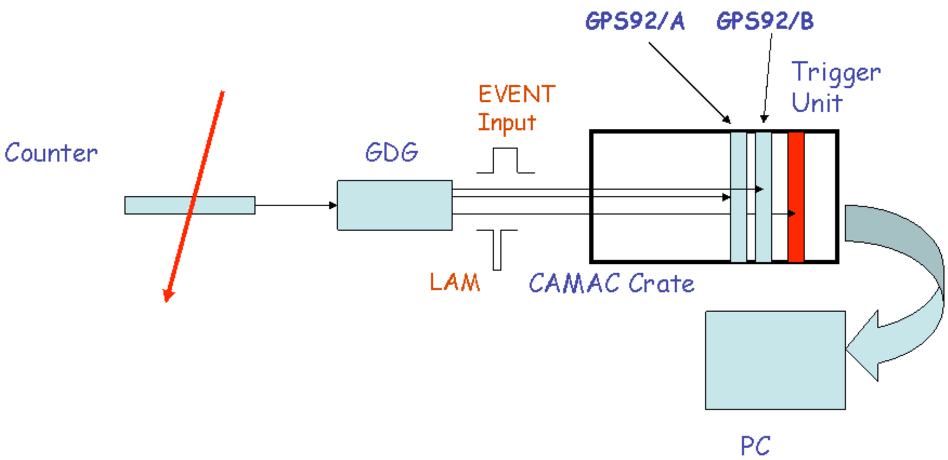

FIG. 2: Hardware configuration for tests with 2 GPS92 modules.

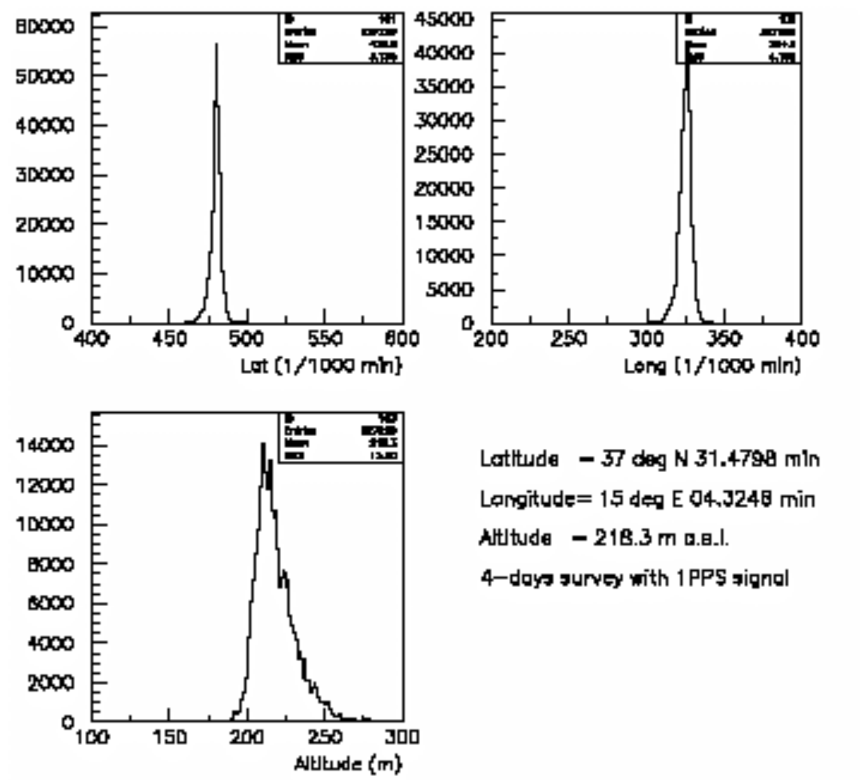

FIG. 3: Latitude, longitude and altitude recorded by a single GPS92 module during a period of 4 days.

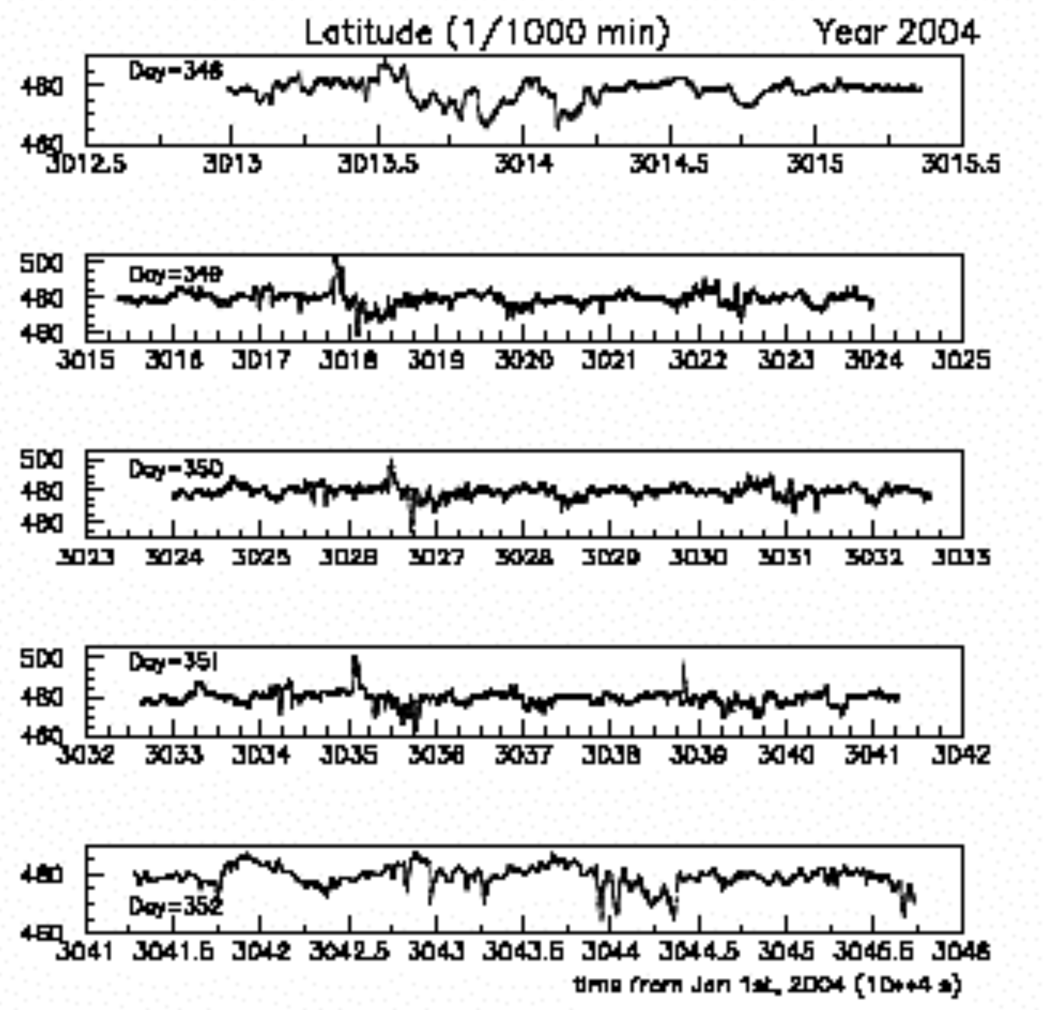

FIG. 4: Fluctuations observed in the latitude information (expressed as thousandths of minute) over a period of approximately four days.

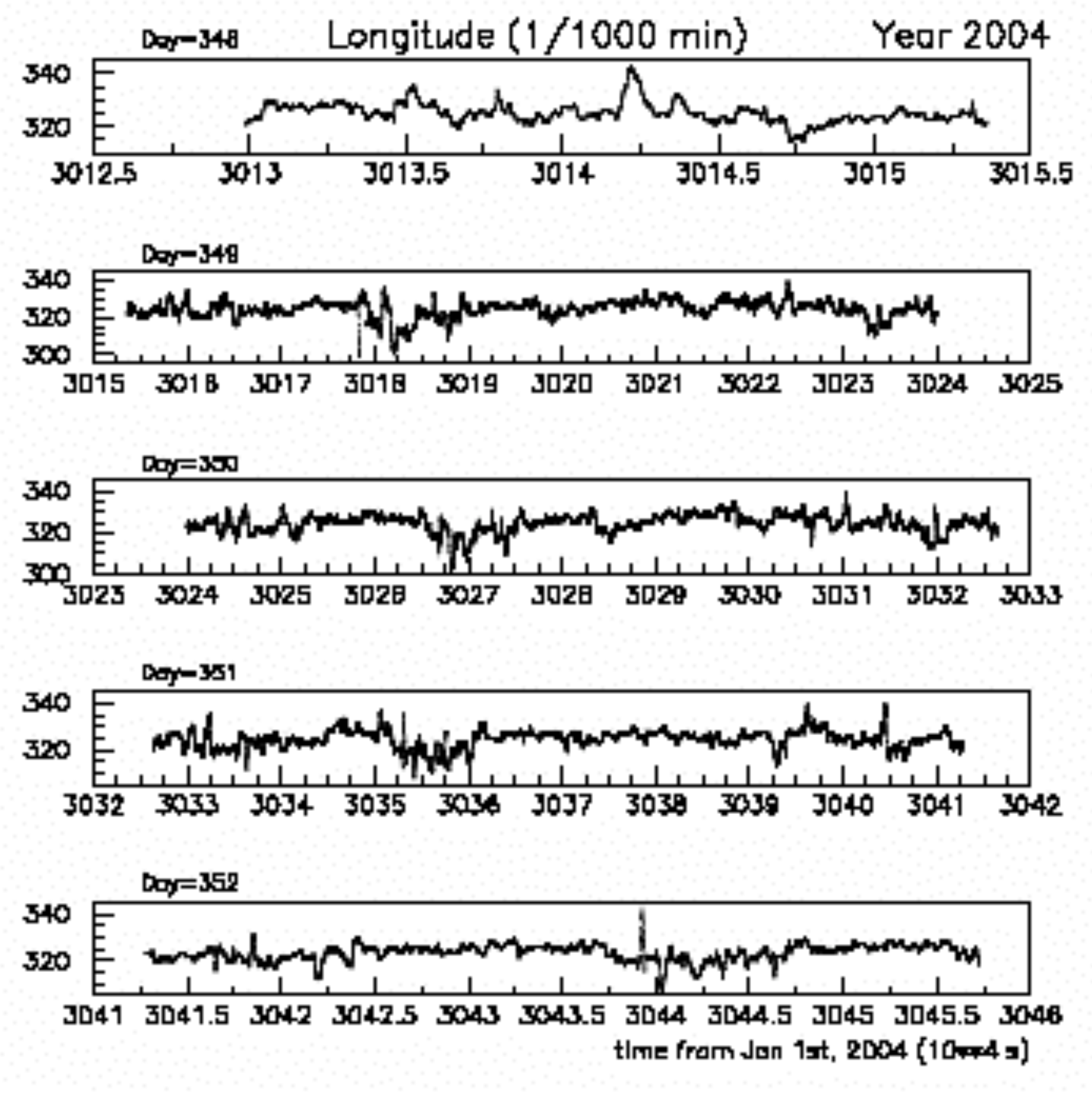

Fig.5: Same as fig.4, for the longitude.

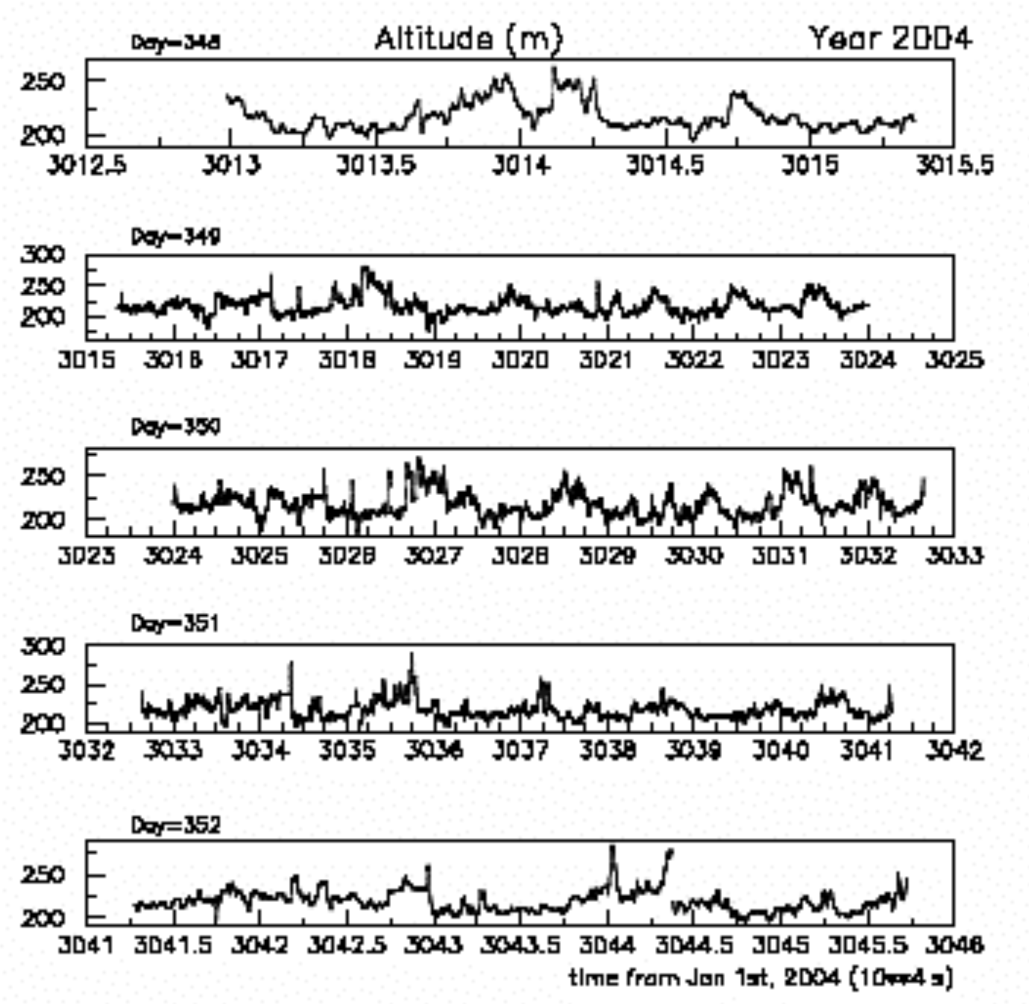

Fig.6: Same as fig.4, for the altitude.

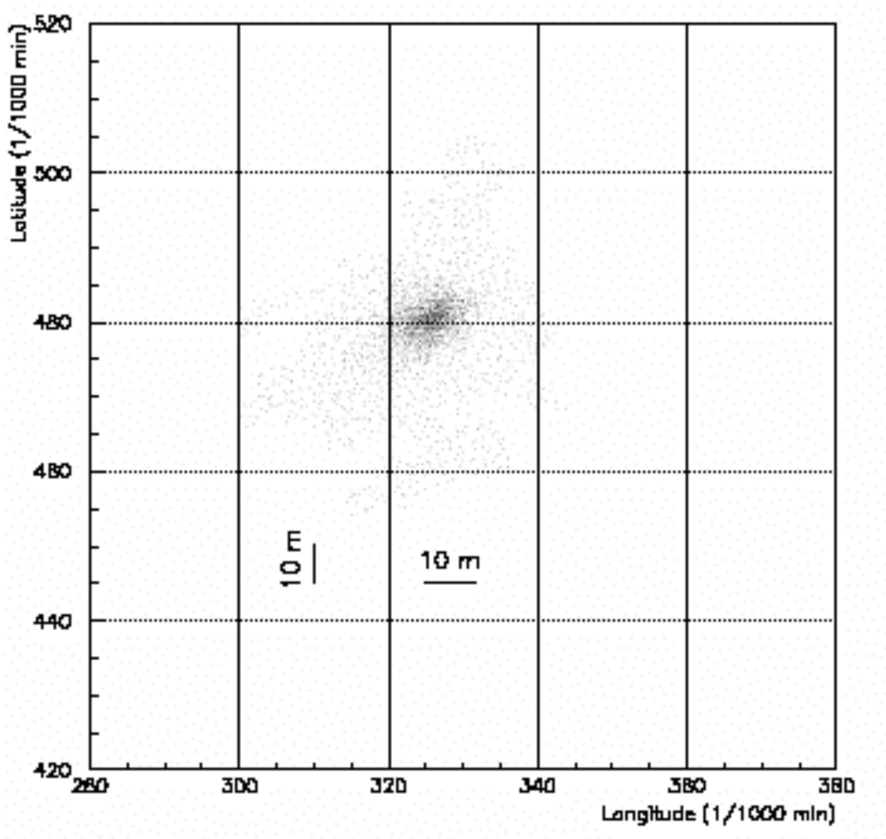

Fig.7: Scatter plot of the x-y geographical position, recorded from a GPS unit at intervals of 1 second over a period of approximately four days.

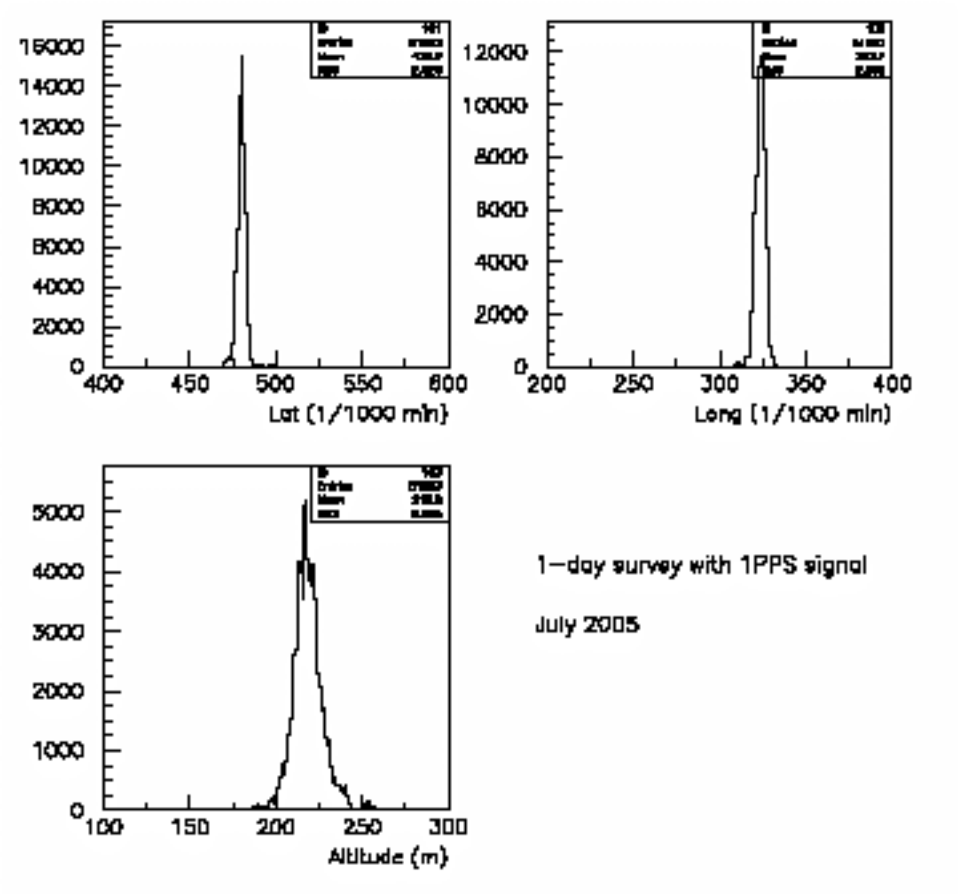

Fig.8: Distribution of the position information (latitude, longitude and altitude)as measured six months later with respect to the data shown in fig.3.

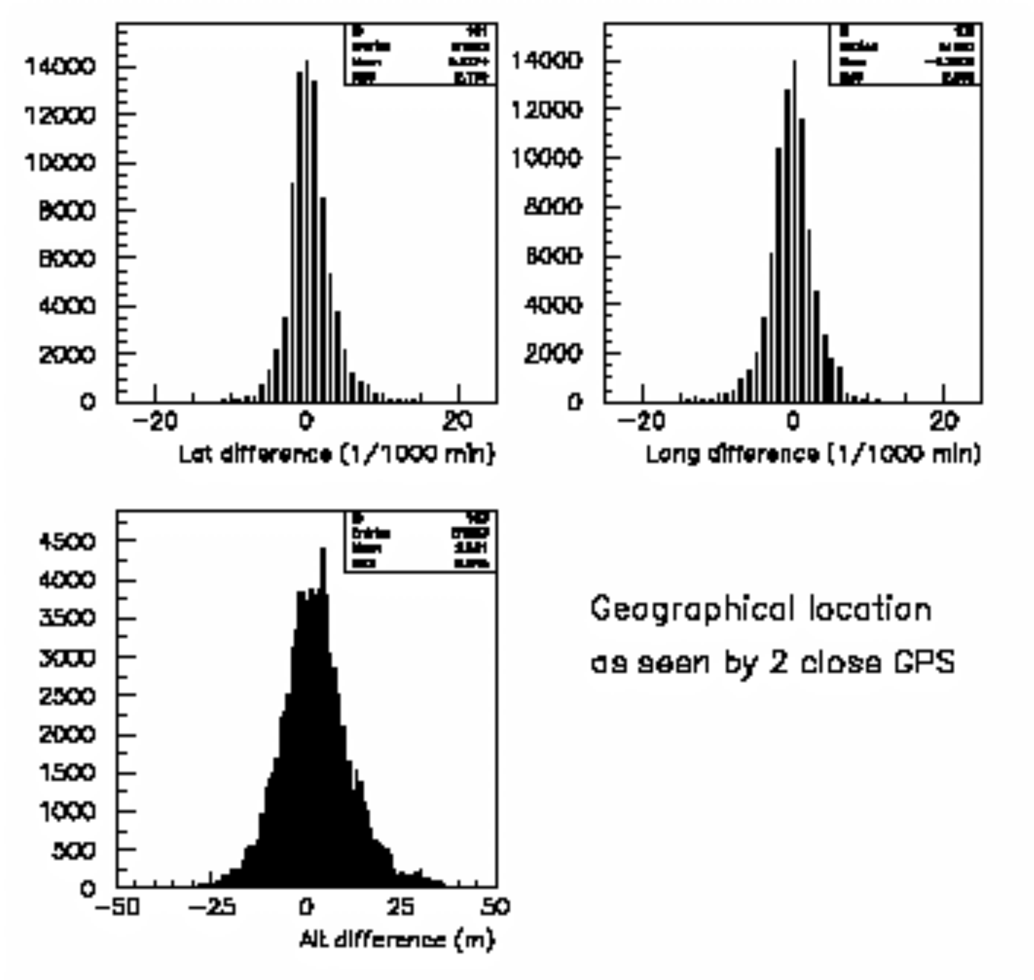

Fig.9: Differences between the position information extracted from two GPS92 modules feeded with the same 1PPS event.

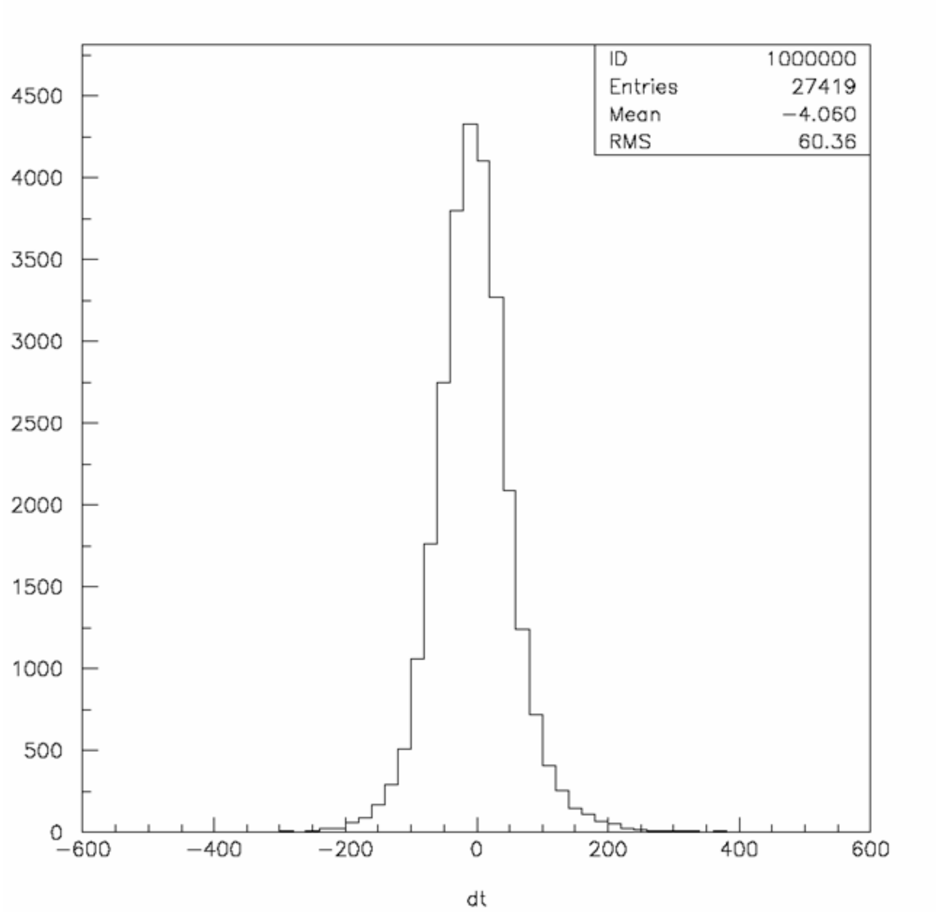

Fig.10: Distribution of the time difference (in ns) provided by the two GPS92 modules in response to a random signal due to cosmics traversing a Geiger counter.