The New Trigger/GPS Module for the EEE Project

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Abstract

The EEE (Extreme Energy Event) Project is an experiment devoted to the study of high energy Extensive Air Showers (EAS) over a very large area, using an array of muon telescopes. At present the array is composed of more than 50 stations, most of them distributed all over the Italian territory, on a total area of 3×10^5 km^2. The telescopes are based on position-sensitive Multigap Resistive Plate Chambers (MRPCs) segmented in strips, read by using two TDC (Time to Digital Converter) units. A GPS unit provides the *Pulse Per Second* signal (PPS) which is used to create a timestamp at UTC time and to reset the internal counters of the TDCs. The absolute time of an event is built as the TDCs event time plus the GPS timestamp for each PPS. With the aim to improve the stability of the timestamp a novel VME trigger unit for the EEE telescopes was developed, including an embedded GPS receiver for precision timing application. This allows extracting the event time stamping at level of the trigger unit, avoiding any time drifts. The trigger/GPS unit will be presented, including some measurements of its time resolution.

Keywords: Multigap RPC, EAS detection, Muon detections, Trigger system, Time stamping, Timing GPS
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1. The EEE Project

Frontier studies in cosmic rays physics on ground require large detection areas: in fact the main difficulty in studying higher energy components is their extremely low intensity, whereas studies as the search for coincidences over long distances and multi-messenger physics need a huge amount of data collection. These can be done with sparse EAS arrays, which make use of vast detection areas for several years. The global positioning system (GPS) technology makes possible to perform precision timing over large areas, enabling several detectors to act as a very extensive network. Densely populated areas are the ideal locations for measurement stations, because the necessary infrastructures, such as Internet and mains voltage, are available there. With the aim to increase the area

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coverage, an EAS detector arrays can use high schools sites as detection nodes. Besides offering suitable locations, high schools can provide sufficient enthusiastic manpower (teachers, technical assistants and pupils) to monitor the detectors and keep them operational.

The EEE Extreme Energy Event Project [1] [2] aims to detect EAS over a very large surface, using an array of muon telescopes. The Project involves several Italian High Schools: the stations are located in high schools buildings, in INFN sections, plus two at CERN, and they are operated by teachers and students of these schools under the supervision of researchers from scientific institutions. The detection of an EAS is operatively achieved by measuring the coincidences in time among events recorded at different sites of the EEE network. In addition to EAS, the EEE network studies other phenomena, as the upward charged particles [4], the correlations between distant EASs [3], the secondary cosmic ray flux variations correlated with meteorological parameters and solar activity [5] [6] [7].

2. The EEE telescope

The tracking telescope of the EEE Project consists of three Multi-gap Resistive Chambers (MRPCs) [8] with an active area of 82 cm × 158 cm, placed at a relative vertical distance of ∼ 50 cm. A detailed description of the EEE MRPC is reported in [9]. Each chamber is segmented into 24 copper strips with a readout board (FEA card, Front End Analog card) placed at both the ends, with full differential outputs (LVDS standard) [10]. Each FEA card forms an OR-signal from the 24 readout strips, moreover it feed the strip signals, amplified and formed, into a multi-hit Time-to-Digital converter (TDC) through a 24-Pair cable. The particle impact point in each MRPC is defined by the fired strips and the difference of the signal arrival time at the strip ends measured by the TDCs. The telescopes spatial resolution has been evaluated about 1 cm and 1.5 cm along the transversal and longitudinal direction respectively [11] [12]. The chambers operate in avalanche mode with a typical operating voltage around 18 kV The raw data from all telescopes are transferred regularly to CNAF (the Italian National Center for Research and Development about Information and Data transmission Technologies), where they are reconstructed and stored.

The VME-based data acquisition includes a trigger card, 144 TDC channels (grouped in two modules) and a GPS receiver based unit for remote synchronization. The schematic design of a station of the EEE Project, *EEE station*, is shown in Figure 1.

3. The Data Acquisition system

Each EEE station is equipped with a VME Crate who supplies the VME modules:

- ⋄ VME *bridge* (CAEN V1718): the data acquisition is controlled by a LabView program running on a PC connected to the VME crate via a VME *bridge*, through a USB standard port.

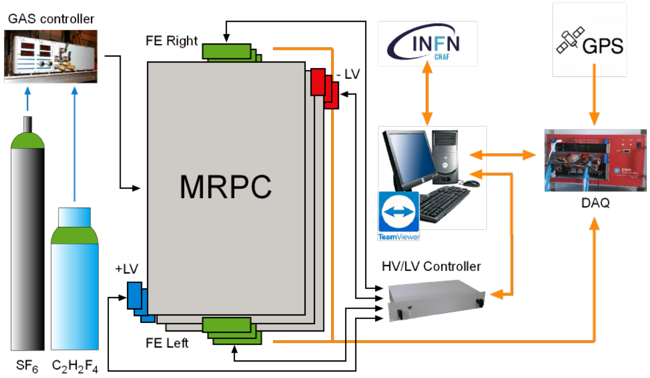

Figure 1: A schematic design of the EEE station.

- ⋄ Two multi-hit TDCs (CAEN V1190A-V1190B): the differential signals from 144 channels (24 channels from each MRPC side) are fed into the TDCs modules, V1190A with 128 channels and V1190B with 64 channels.

- ⋄ Trigger card: one or more custom modules generate the data acquisition trigger [14].

- ⋄ EEE Clock Distribution & Trigger shape cards (*Clock Card*): the card improves the time performance of the EEE telescope, allowing the synchronization of the internal clock of the two TDCs.

When a charged particle crosses the EEE telescopes and induces signals in the MRPC strips, the FEA card forms an OR-signal from the 24 readout strips. These six signals (differential LVDS), each one produced from a MRPC side of the telescope, are collected and elaborated by the trigger card, and their six-fold coincidence generates the data acquisition trigger. It is not possible to read data syncronically at each trigger, using a VME bridge, because the USB cycle time limits the VME reads, imposing an unacceptable dead time on the system; therefore the data are read out asynchronously. The absolute time of each event in the EEE telescope is recorded and synchronized by means of Global Positioning System modules, in order to get the event timestamp in UTC time, and to correlate the information collected by different telescopes. Due to the same dead time considerations, the absolute timestamp of an event is obtained by adding the UTC time once per second, provided by the GPS receiver (t_{GPS}) at every PPS signal, to a time offset (t_{TDC}) with respect to the PPS signal, measured by the TDCs counters, as it is described in the next section.

Two different kinds of GPS receivers have used in the EEE station:

- *HYTEC VME*, placed in the VME Crate and connected to the trigger board by means of a GPS-Interface board [14].

- *Spectracom TSync GPS*, placed directly in the Data Acquisition PC mainboard.

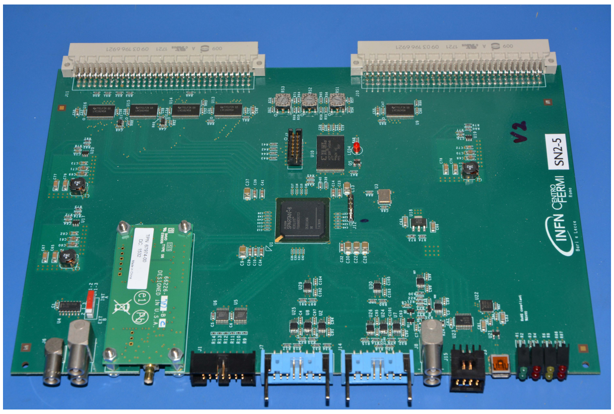

Figure 2: The Trigger/GPS Card.

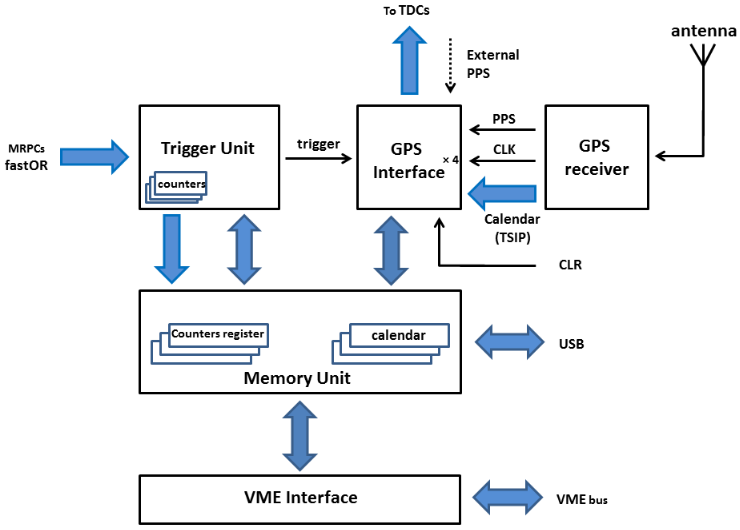

Figure 3: The block diagram of the Trigger/GPS unit.

The time information is read by the Data Acquisition (DAQ) software in LabView.

The new trigger card has been developed, with an embedded engine GPS for timing application to implement the event time stamping at level of the trigger card itself.

4. The Trigger/GPS Card

The new Trigger/GPS Card is the evolution of the trigger system used in the EEE station so far. The board (Figure 2) has designed to integrate in a double Eurocard board both a trigger logic and a GPS receiver for time stamping purpose. The GPS receiver is the ICM SMT 360^{TM} mounted on a carrier board in an open PCB assembly without enclosure, specifically designed to be integrated in host systems. This receiver is able to receive GNSS signals from GPS, GLONASS, Galileo, or Beidou satellite constellations [15]. The Trigger/GPS card has designed for a full compatibility with the previous DAQ system, therefore it is able to operate with an external GPS receiver as well.

A block diagram of the Trigger/GPS Card is presented in Figure 3. The main logic of this unit is implemented into a FPGA (Field Programmable Gate Array) Xilinx Spartan-6 for matter of flexibility. The trigger unit forms the six-fold coincidence signals (*triple*) from the OR-signals originate by the six MRPC FEAs, moreover it generates 3 *double* coincidences for each MRPC couples, the *single* signals from the MRPCs (the coincidence of the left and right FEAs signals) and 6 signals for all the FEAs. The *triple* signal and the 3 *double* signals are also available at front panel level. The trigger unit also performs the counts of all these signals; these counts are stored and available on request via VME bus and USB bus both. The *triple* signal triggers the transmission of the event signal (*trigger event*) to the TDCs, through the GPS interface, thus the TDCs store data into their FIFOs. Through a specific VME command sent by the DAQ software it is possible to modify the trigger event logic using the double chambers or single chamber coincidences for testing purposes.

The GPS receiver provides the PPS signals to create a timestamp and to reset the internal counters of the TDCs; jointly with the PPS signal, the receiver send to the GPS Interface all the calendar and position raw data (UTC time, latitude, longitude, altitude, number of visible satellites, etc) in Trimble Standard Interface Protocol (TSIP) [16]. The GPS receiver generates also a 10 MHz clock, disciplined to the PPS signal, which is multiplied by 4 in the GPS Interface and fed into both TDCs, in order to generate the 40 MHz clock which TDCs need for their counters synchronization. At each PPS the GPS interface sends a clear command to the TDCs to reset their internal counters, and two pulses to both the TDCs, one in time with the PPS signal and the other delayed by 1.5 μs, which generate two empty events (*trigger* events with no hits in TDCs channels). This delay in the TDCs counters is used by the DAQ system to identify a *GPS event* from the trigger events and to insert the UTC time into the data stream. The absolute time of an event, t_{event}, is obtained by adding data stored into TDCs FIFOs at each trigger event, t_{TDC} and the GPS event t_{GPS} ($t_{event} = t_{TDC} + t_{GPS}$).

Due to searching for satellites and almanac download, the GPS side of the Trigger/GPS Card is inoperative for about 15 minutes after a cold start. Then the GPS receiver performs a survey by averaging a configurable number of valid position fixes (2000 by default). After this phase, the GPS receiver stores the surveyed reference position to a non-volatile memory and automatically switches in a time-only mode (over-determined clock mode). In this mode the GPS receiver do not update position, but maintains the PPS output and 10 MHz disciplining, solving only for the receiver clock error and error rate [15].

5. Time resolution measurements

The resolution σ_{PPS} of the Trigger/GPS board, has been estimated from the difference in time ΔT_{PPS} between the PPS signals for 2 different modules supplied by the same VME Crate. Their GPS receivers have been connected to equal antennas, placed at a distance of 40 cm from each other in an area clear of obstacles, to avoid any GNSS signal reflections. If we assume the same time resolution σ_{PPS} for both the modules, this value can be calculated from the sigma of a gaussian fit from the distribution of $\Delta T_{PPS} = T_{PPS\,ref} - T_{PPS\,N}$, the difference between the PPS signal from a reference module (SN005 module), PPS_{ref}, and the PPS signal from the other modules, PPS_N, as $\sigma_{PPS} = \sigma_{\Delta T_{PPS}} / \sqrt{2}$. The difference ΔT_{PPS} has been measured with a 4 GHz, 40 GS/s oscilloscope (LeCroy WaveRunner 640ZI). 16 Trigger/GPS modules have been tested. As an example the distribution ΔT_{PPS} for one of

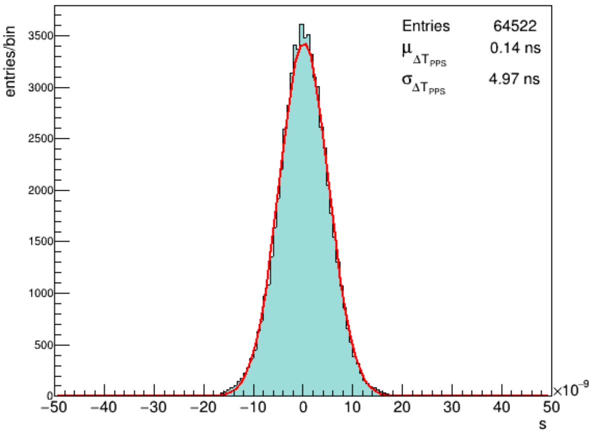

Figure 4: Distribution for $\Delta T_{PPS} = T_{PPS\,ref} - T_{PPS\,N7}$, the difference between the PPS signal from SN005 module, PPS_{ref} (the reference module,) and the PPS signal from the module SN007 PPS_{N7}. The gaussian fit presents a mean value $\mu_{\Delta T_{PPS}} \sim 0,1$ ns with a std dev. $\sigma_{\Delta T_{PPS}} \sim 5,0$ ns.

these module (SN007 module) is shown in Figure 4 and its time resolution for PPS signal is $\sigma_{PPS} \sim 3.5\,ns$. The distribution profile with a bin value of 10 minutes, obtained during a day of data acquisition (when the receiver was in over-determined clock mode) is presented in Figure 5. It shows an adequate stability in time. The σ_{PPS} values for all the modules tested

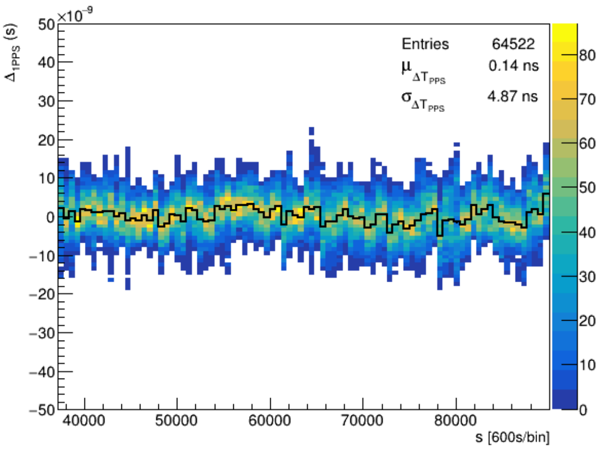

Figure 5: Profile over time of the distribution ΔT_{PPS} for the module SN007 using the module SN005 as reference.

show uniformity and same stability in time, as it is shown in Figure 6. The mean value for the set is 3.7 ns. The

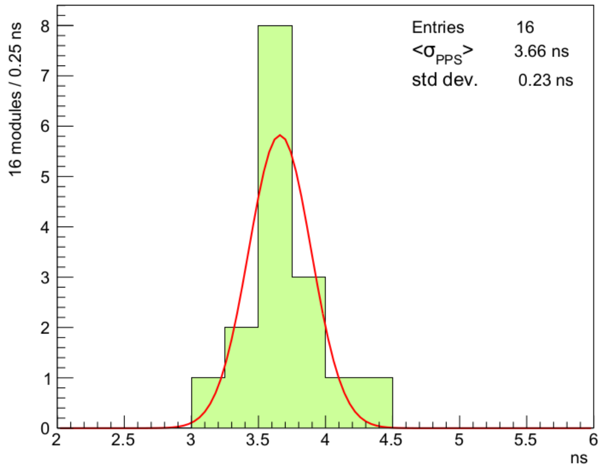

Figure 6: Distribution of the time resolution values for the PPS signal σ_{PPS} obtained with 16 Trigger/GPS modules.

mean value $\mu_{\Delta T_{PPS}}$ of the ΔT_{PPS} distribution, for each module tested, is presented in Figure 7, the observed variation for this parameter, 12.11 ns, is compatible with the specification for the GPS receiver, when the device is operating in over-determined clock mode [15].

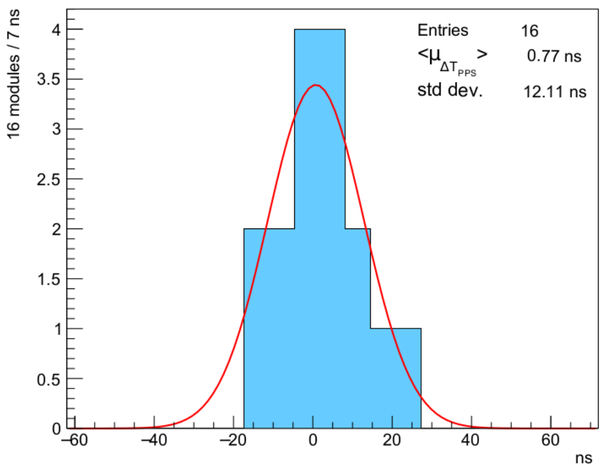

Figure 7: Distribution of the mean values $\mu_{\Delta T_{PPS}}$, obtained with 16 Trigger/GPS modules.

6. Conclusion

A new board which integrate both the functions of trigger and timing unit has been presented. It was extensively tested, showing that its performances are adequate to the requirements of the EEE Project [19] [3]. The board is currently in production phase and soon it will be distributed to all the EEE stations for matter of uniformity.

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