THE TIME OF FLIGHT DETECTOR AND TRIGGER FOR THE PAMELA EXPERIMENT IN SPACE

S. RUSSO, G. BARBARINO, D. CAMPANA, G. OSTERIA
Dip. Scienze Fisiche Università Federico II and INFN Sez. di Napoli
Via Cintia Napoli 80126, Italy

M. BOSCHERINI, W. MENN, M. SIMON
Universitat-GH Siegen, FB Physik
Siegen 57078, Deutschland

The electronics of the Time of Flight telescope and trigger of PAMELA experiment are described. The time resolution requested by the ToF system must be less than 120 ps. The contribution of the digitization electronics is negligible if the TDC resolution is < 50 ps. The peculiarity of the developed electronics arises from the need to obtain such a time resolution associated to a wide dynamic range for charge measurements, operating in satellite environment, which implies low power consumption, radiation hardness, redundancy and high reliability

1. Introduction

The PAMELA [1] (a Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) is a satellite born experiment scheduled to be lunched at the end of 2005. The primary objective of PAMELA is to measure the energy spectrum of cosmic ray protons and electrons with a special care on their antiparticle counterparts and the search for antimatter covering an energy range and with a sensitivity unreachable by previous similar experiments. Another experimental goal is to measure the antihelium to helium ratio with a sensitivity of the order of 10^{-7}.

PAMELA is built around a permanent magnet spectrometer equipped with double-sided silicon sensor tracker, which will be used to measure the sign, absolute value of charge and momentum of particles. The tracker is surrounded by a scintillator veto shield (called anticounters) that will reject particles that do not pass cleanly through the acceptance of the tracker. Below the tracker is a silicon-tungsten calorimeter, to measure the energy of electrons and allow topological discrimination between electromagnetic and hadronic showers. A scintillator telescope system will provide the primary experimental trigger and time of flight particle identification. A scintillator mounted beneath the calorimeter will provide an additional trigger for high-energy electrons. This is followed by a neutron detector system for selections of very high-energy electrons and positrons (up to 3 TeV).

2. The PAMELA ToF

The Time-of-Flight (ToF) system [2] is composed by 6 layers of fast plastic scintillators arranged in 3 groups (S1, S2 and S3) read out by 48 photo-multipliers tubes (PMTs). The ToF must fulfill the following goals:

- Provide a fast signal for triggering data acquisition in the whole instrument;
- Measure the flight time of particles crossing its planes; once this information is integrated with the measurement of the trajectory length through the instrument their velocity β can be derived. This feature enable also the rejection of albedo particles;
- Determine the absolute value of charge z of the incident particles through the multiple measurement of the specific energy loss dE/dx in the scinitllator counters.

Additionally, segmentation of each detector layers in strips can provide a rough tracking of particles, thus helping the magnetic spectrometer to reconstruct their trajectory outside the magnet volume.
The ToF is divided in 6 layers, arranged in 3 planes (S1, S2, S3), each plane composed of 2 layers (S11, S12, S21, S22, S31, S32). The overall geometry of the ToF for PAMELA is summarized in tab. 1

Plane	No. of strips	Strip dim. (mm x mm)	Thickness (mm)	Section area (mm^2)
S11	8	330 x 51	7	357
S12	6	408 x 55	7	385
S21	2	180 x 75	5	375
S22	2	150 x 90	5	450
S31	3	150 x 60	7	420
S32	3	180 x 50	7	350

3. The ToF and Trigger electronics

The ToF and trigger electronics is a complex system made by 9 boards. These are the 6 Front-End (FE) boards, the DSP board and the two identical trigger boards (one called “hot” and one called “cold”). The purpose of this system is to collect the signals coming from 48 PMTs of the ToF, measure their arrival time with respect to the trigger pulse and their charge, generate signal for the trigger, handle the busy logic for all subsystems and interfacing the ToF system with the general data acquisition system of the PAMELA apparatus.
The ToF electronics has to comply to the following requirements:

- Guarantee a wide dynamic range in the charge measurement to allow the measurement of energy release of $z > 1$ particles up to Carbon;
- Add a negligible contribution to the overall ToF time resolution. This implies a contribution from time digitalization, which has to be less or equal than 50 ps.

In the mean time, the electronics must ensure low power consumption, a high reliability in terms of radiation hardness and temperature range. Therefore a great effort has been paid in implementation both hardware and software redundancy, that is to mean the replication of at last all critical components.

3.1. *Front-End boards*

Each front end board receives the analog signals coming from 8 PMTs. For each channel the input is split in two branches, which are fed into the time and charge section respectively. The first section measures the arrival time of the signal with respect to the trigger pulse, and generates signal for trigger information. The other section measure the charge of the PMT signal.

3.1.1. *Time section*

In the time section of the FE board, each anode line is coupled to a fast discriminator. Each discriminated signal is in turn split: on one side, the signal is shaped ad sent to trigger board. On the other side, it is fed to a double-ramp Time-to-Amplitude-to-Time converter (TAT).
The fixed level of our discriminator threshold generates a pulse height dependency of the measured time due to the finite rise time of the pulses. Simply stated, signals which are generated at the same time, but with different amplitude, will cross the discriminator threshold at different times, the

difference being greater the higher the threshold level is set. To minimize this time-walk effect, one should use a threshold as low as possible; but lowering the threshold the comparator increases the probability to be crossed by noise pulse. The double-ramp time expansion works in the so called COMMON STOP mode: the arrival of the PMT pulse produces the start of the fast ramp, while the trigger signal (COMMON STOP) starts the slow ramp. The moment when the PMT pulse crosses the threshold corresponds to the START of the ramp: a low loss, low thermal drift capacitor C is charged with a high stability constant current source I_c. The charging of the capacitor continues until a STOP signal arrives, namely the trigger pulse. The time interval T_c (typically around 60-65 ns, mainly due to the trigger signal generation and propagation) between the START and STOP signals is the one of the interest, and is given by

$$T_c = \frac{VC}{I_c}$$

Where V is the voltage across the capacitor. With the arrival of the STOP signal, the capacitor is slowly discharged with a much lower constant current I_d. The discharge time td is given by

$$T_d = \frac{VC}{I_d}$$

This time interval is measured by a Time-to-Digital Converter (TDC), which has an internal clock at 100 MHz. Therefore the time digitalization resolution related to the TDC least significant bit (LSB) is 10 ns.

The ratio between the discharging and charging currents sets an expansion factor (independent of the capacitor's value) $\alpha=I_c/I_d$. Form the equation follows that the relationship between the expanded time and the time to measured is

$$T_d = \frac{I_c}{I_d} T_c = \alpha T_c$$

Hence, if the expanded time T_d is measured with a resolution of 10 ns, T_c is measured with a resolution which is α time lower. In our case α=200 and the intrinsic time resolution of our electronics is 50 ps.

3.1.2. *Charge section*

The anode current coming from PMT is collected by a charge amplifier which provides an output voltage which is proportional to the total current. This peak will quickly discharge exponentially, therefore the output of the amplifier is connected to a so-called "pulse stretcher", where a J-FET charges up rapidly a capacitor at the peak value of the input waveform. The capacitor is linearly discharged with a (quite low) constant current source. Clearly, the discharge time is once again proportional to peak voltage, and therefore to the PMT total current. Likewise the time section, also in the charge section of the FE board the discharge time is measured with the TDC, whose gate is opened by trigger signal.

4. The Performance

4.1. *Qualification test*

The performances of the ToF and Trigger electronics has been subject to extensive test. The time resolution and integral non-linearity of the flight model of the FE boards have been measured with an AGILENT 81132 pulse generator (RMS jitter of the time base = 15 ps +/- 0.001 % of the delay). The results, shown in fig.1, fully satisfy the design specifications.

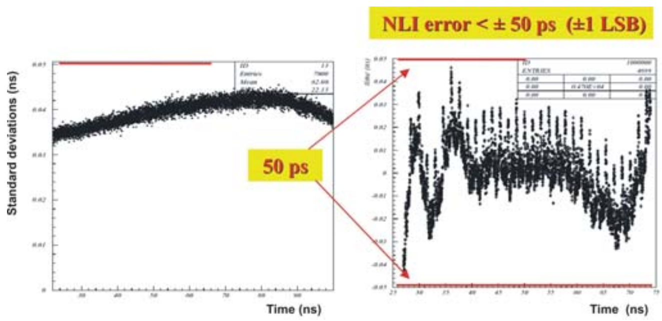

Figure 1. Time resolution measurement results of the PAMELA FE boards

4.2. *Flight model test*

The performance of the ToF system and trigger are measured in the PAMELA integrated flight model. Cosmic muons are acquired using the ToF scintillators and trigger board in order respectively to detect the particles passing through the apparatus and to trigger and to manage the data acquisition.
Data are taken in different working conditions relative both to the HV values as well as to the threshold values of the ToF system in order to evaluate the trigger efficiency and the time resolution as function of the working conditions.

4.2.1. *Efficiency measurement*

The efficiency of single paddle is evaluated using a set of perfectly reconstructed tracks pointing in the paddle. The tracks selection criteria requires a good reconstructed track from the tracker in agreement whit the position of the track as reconstructed from the timing information of the ToF in the planes different from the one under study. The overall measured efficiency is more than 98%

4.2.2. *Time resolution measurement*

In order to obtain a first evaluation of the time resolution of the single paddle, the position of the track along the paddle is measured from the tracker and compared to the one obtained from the difference of the TDCs. Fig.2 shows the result for a paddle of S2.

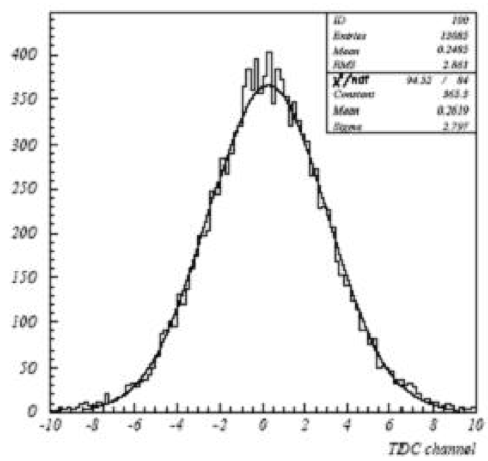

Figure 2. Time resolution, in unit of 50 ps, for a S2 paddle measured in flight conditions

Acknowledgments

We thank to M. Boscherini and S. Ricciarini. We also thank V. Marzullo, R. Rocco, E. Vanzanella, for help in construction of ToF system and its integration in the PAMELA apparatus

References

1. O. Adriani et. Al., IEEE Transaction on Nuclear Science *Vol 51 n.3 854 (2004).*
2. G. Osteria et. al., Nuclear Instrumentation and Methods A535 (2004), 152,157.