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The **PAMELA** Time-of-Flight system: status report

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The **PAMELA** (Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics) satellite-borne experiment, scheduled to be launched in 2003, aboard a Soyuz TM2 rocket, is designed to provide a better understanding of the antimatter component of cosmic rays. In the following we report on the features and performances of its scintillator telescope system which will provide the primary experimental trigger and time-of-flight particle identification.

1. The PAMELA experiment

The primary objective of **PAMELA**[1] is to measure the energy spectrum of antiprotons and positrons in the cosmic radiation. At least 10^5 positrons and 10^4 antiprotons are expected per year. These data set will allow significant comparisons between competing models of antimatter production in our galaxy. Distortions to the energy spectra could originate from exotic sources, such as the annihilation of supersymmetric neutralino particles - candidates for the dark matter in the universe. Another experimental goal is to measure the antihelium to helium ratio with a sensitivity of the order of 10^{-7}.

PAMELA (in Fig.1) is built around a 0.48 T 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 (anticounters) that will reject particles that do not pass cleanly through the acceptance of the tracker. Above the tracker is a TRD made of proportional straw tubes and carbon fiber radiators. This will allow electron-hadron separation through threshold velocity measurements. 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 pro-

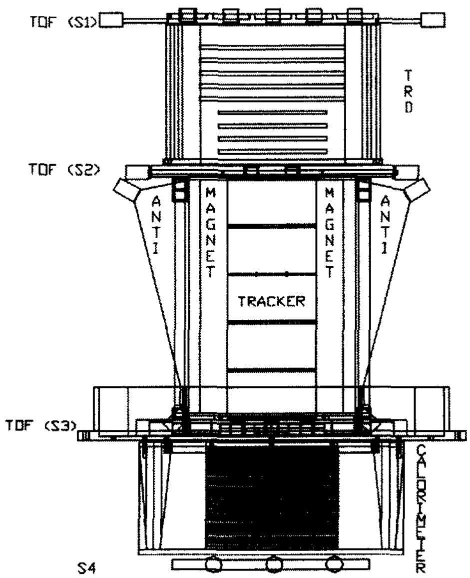

Figure 1. The **PAMELA** apparatus (1050 mm high) consists of a transition radiation detector (TRD), a magnetic spectrometer equipped with silicon micro-strip detector, a silicon/tungsten calorimeter, a time-of-flight detector (TOF), and an anti-coincidence system (ANTI).

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vide 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 detection system for the selection of very high energy electrons and positrons (up to 3 TeV).

2. The PAMELA's ToF

The Time-of-Flight (ToF) system of **PAMELA** is composed of several layers of plastic scintillators read out by Photo-Multiplier 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 incident particles through the multiple measurement of energy loss dE/dx in the scintillator counters.

Additionally, segmentation of each detector layer in strips can provide a rough tracking of particles, thus helping the magnetic spectrometer to reconstruct their trajectory outside the magnet volume.

2.1. ToF layout

The ToF, as showed in Fig. 2, will be divided in 6 layers, arranged in three planes, each plane composed of two layers. The first plane, S1, is placed on top of the instrument: its first layer, S11, is divided in 8 strips, each 330 mm long and 51 mm wide, while the second layer, S12, is divided in 6 strips, each 408 mm long and 55 mm wide. The overall sensitive area of each layer of S1 is 330×408 mm^2. The second plane, S2, is placed between the TRD and the spectrometer: its first layer, S21, is divided in 2 strips, each 150 mm long and 90 mm wide, while the second layer, S22, has the same number of strips, each 180 mm long and 75 mm wide. The overall sensitive area of each layer of S2 is 150×180 mm^2. The last plane, S3, is placed between the spectrometer and the calorimeter, just below the magnet: its first layer, S31, is divided in 3 strips, each 180 mm long and 50 mm wide, while the second layer, S32, has the same number of strips, but 150 mm long and 60 mm wide. The overall sensitive area of each layer of S3 is 150×180 mm^2. The layers of S1 and S3 are 7 mm thick, while those of S2 are only 5 mm thick.

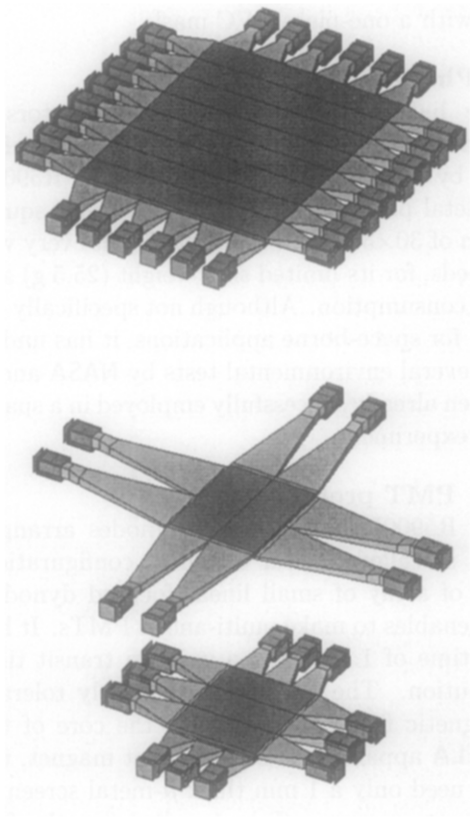

Figure 2. Isometric drawing of the full ToF.

2.2. Mechanical structure

Both ends of each scintillator paddle are glued to a one-piece adiabatic UV-transparent Plexiglas light guide. This is in turn mechanically coupled to a PMT by means of optical pads, mod. BC-634A manufactured by BICRON. The pads are 25.7×25.7 mm^2 wide and 3 mm thick in the case of S1 and S2, 6 mm for S3. Scintillators and light-guides are wrapped in a 25 μm thin Mylar foil. The S3 plane will be housed directly in the base plate of **PAMELA** and kept in place by a set of steel frames. The other two planes will be enclosed in light-proof boxes. The external shell of these boxes is 300 μm thick Avional[1], and the space between the box and the scintillators is filled with a one-piece PVC mask.

2.3. Photo-multiplier tubes

The light produced by the scintillators is viewed by mod. R5900U [2] PMTs, manufactured by Hamamatsu Photonics. The R5900U is a metal package head-on PMT, with a square section of 30×30 mm^2. This PMT suits very well our needs, for its limited size, weight (25.5 g) and power consumption. Although not specifically designed for space-borne applications, it has undergone several environmental tests by NASA and it has been already successfully employed in a space-borne experiment.

2.3.1. PMT properties

The R5900U PMT has 10 dynodes arranged in the so-called "metal channel" configuration, a sort of array of small linear focused dynodes, which enables to make multi-anode PMTs. It has a rise time of 1.5 ns and a uniform transit time distribution. The R5900U is relatively tolerant of magnetic fields and although the core of the **PAMELA** apparatus is a permanent magnet, the PMTs need only a 1 mm thick μ-metal screen.

The parameters in Tab. 1 well define the features of the PMT.

The R5900U PMTs for the **PAMELA** ToF are selected with a Quantum Efficiency Q.E.> 21%.

Redundant 900V HV supplies are connected to each PMT through a regulator circuit capable of 800V swing. This is used to trim the individual PMT gains and to compensate for differential aging of the PMTs and scintillators. Voltage is distributed within each PMT by a resistive voltage divider designed to accommodate the largest particle rates to be measured.

parameter	value
Quantum Efficiency	20%
Cathode Luminous Sensitivity	70 μA/lm
Cathode Blue Lum. Sens.	8.0 μA/lm-b
Anode Lum. Sensitivity	140 A/lm
Anode to Cathode voltage (DC)	800 V
Anode current (av.)	0.1 mA

Table 1
Characteristics (at 25 ° C) of a R5900U PMT.

2.4. Scintillator

The plastic scintillator used for the **PAMELA** ToF is the BICRON BC-404 which has a pulse rise time of 0.7 ns, a decay time of 1.8 ns and an attenuation length of 160 cm. Strip widths have been chosen to match the exit areas of the scintillators to 3.24 cm^2 active areas of the PMTs.

2.5. Readout electronics

The readout electronics of the ToF system must be capable of time resolution better then 100 ps using a very limited power budget. Each PMT anode is coupled to a pair of discriminators that fire at two different thresholds. The first threshold is set to a very low value to insure optimum timing and the second to 15-20 % of the expected signal from a minimum-ionizing singly-charged particle. The discriminator output pulse is sent to the instrument trigger logic, to rate scalers and to the control logic of a double ramp time expander. This signal starts the charging of a low loss, low thermal drift capacitor through a precision constant-current source, the capacitor is then discharged at the arrival of the trigger signal with a current 200-fold lower. The time expansion factor of 200, obtained in this way, allows to measure 50 ps delay using a 100 MHz TDC custom designed and implemented on a ACTEL 54SX32A

[1] A high strength, low weight Aluminum alloy (95% Al, 4% Cu, 1% Mg) of limited weldability, used in aircraft and aerospace applications.

FPGA. The full scale range of this system is 200 ps and the resolution is 50 ps/count.

The amplitude of each PMT pulse is measured integrating the signal on a capacitor and measuring the time need to discharge it by a constant-current with the same 100 MHz TDC. Six boards are need to readout all the ToF PMTs. A serial link (Data Strobe) allows the communication of the six front-end ToF boards with the so called DSP board, a board equipped with a DSP AD 2187 which collects data, performs zero-suppression and organizes data packets before to transmit them to main **PAMELA** DAQ.

3. PMT qualification tests

In the laboratory of the Department of Physics at the University of Siegen (Germany) during Winter 2001–2002 several tests were performed to select and characterize PMTs to be employed in the Flight Model[1] of the ToF.

For the gain the method described in [3] was used. Illuminating the PMT with a pulsed LED, the mean and the width of the ADC distribution for different LED voltages were measured. Then a plot of ΔADC^2 vs. ADC_{mean} was made and a linear fit to the data done. The slope of the linear fit gives the gain of the PMT at the given voltage.

To test the linearity, the Double Pulse Method was employed (as described in [4]). The PMT response to the LED before and after placing a filter is measured for different LED light yield, in order to check for deviation from linearity.

Finally, to measure the photocathode homogeneity, the PMT has been illuminated with LED light fed through an optical fiber. The fiber could be moved across the photocathode with two stepper motors, and for each position of the fiber the PMT signal was measured.

4. Counter qualification tests

In the laboratory of the Department of Physics at the University of Napoli (Italy), since Spring 2002 a series of tests on the ToF paddles are being performed. Purpose of these tests is the measurement of the intrinsic time resolution and the charge distribution of each ToF paddle in different experimental situations. Each paddle is housed is a custom-made light-proof box, placed on top of a drift chamber (DC). The whole apparatus is triggered by the coincidence of the signals coming from the two PMTs of the paddle. The DC can reconstruct the tracks of ionizing particles passing through its sensitive volume ($47 \times 47 \times 33.3$ cm^3) with a precision of 300 μm along the x-direction. Evaluation of the timing resolution of the paddles is performed comparing the impact point reconstruction done by the scintillator with the one done by the DC. Assuming that the contribution from the DC finite precision is negligible, the width of the residual distribution gives us the intrinsic timing resolution of the paddle. Preliminary tests give the following results

S1	$\Delta T \approx 100$ ps
S2	$\Delta T \approx 150$ ps
S3	$\Delta T \approx 130$ ps

A typical time resolution plot is shown in Fig.3.

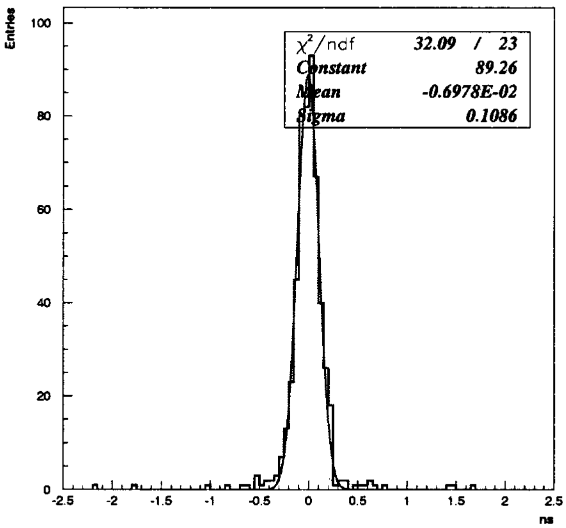

Figure 3. Result of time resolution measurements on a counter of the S1 layer.

5. Thermal tests

In order to estimate the PMT behaviour during the flight of **PAMELA**, gain measurements are performed at different temperatures (in the range 0° ÷ 50° C). The gain is measured by modulating the light from a green LED, with a low yield when the single photoelectron peak has to be estimated. The data have been analyzed with three different methods for gain calculation but, the result is the same in all three cases and does not show any strong dependence on temperature variations in the range of interest.

Scintillators too, equipped of light guides and PMTs, are submitted to thermal test to characterize the whole dispositive. Data acquisitions of cosmic ray events have been made by keeping counters at fixed temperature in an insulated box. The results is shown in Fig.4.

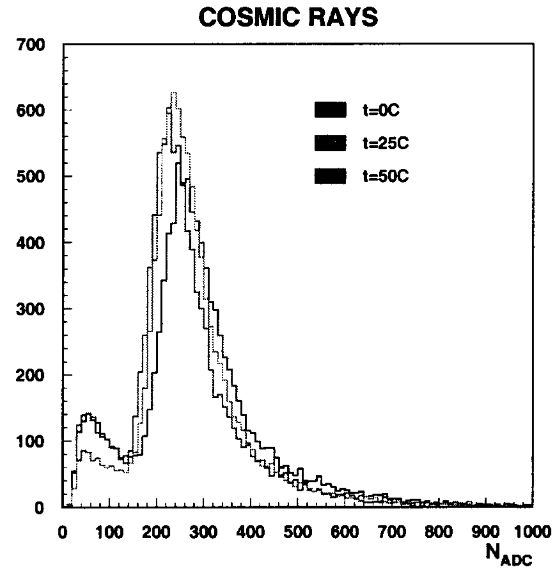

Figure 4. Result of counter performance measurements at different temperatures.

6. Readout electronics tests

The performances of the timing electronics chain have been tested using a 660 MHz pulse generator. Start and stop pulses have been generated with delay in the range between 15 ps and 100 ps with 10 ps step. For each delay about 10000 events have been collected. The NLI error obtained in the whole range is < ± 50 ps (± 1 LSB). The standard deviation of each point is always lower than 50 ps as shown in Fig.5.

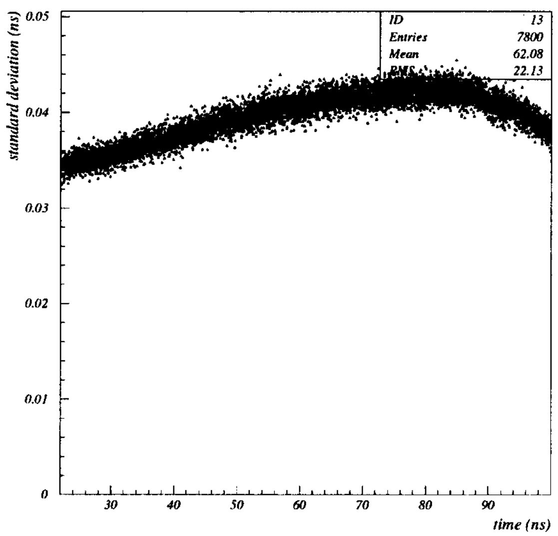

Figure 5. Standard deviation distribution (see text)

7. Environmental tests

The engineering models of the ToF planes S1,S2,S3 have been tested simulating the random vibration spectrum of the satellite launch on a shaker machine located at Officine Galileo in Florence. The qualification spectrum used is about 3-fold bigger the real one to insure maximum reliability of the system. For all the planes the models withstand the qualification test without crash or worsening of the performances.

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