The Time-of-Flight System of the PAMELA Experiment

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Abstract

The PAMELA satellite-borne experiment, scheduled to be launched in 2004, 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. Detector description

The Time-of-Flight (ToF) system of PAMELA experiment [1] 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 $\mathrm{d}E/\mathrm{d}x$ in the scintillator counters.

1.1. ToF layout

The ToF, as showed in Fig. 1., will be divided in 6 layers, arranged in three planes, each plane composed of two layers. The overall geometry of the ToF layers is summarized in Tab. 1..

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

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PMT by means of optical pads. 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, and the space between the box and the scintillators is filled with a one-piece PVC mask.

Table 1. Summary of ToF planes geometry.

plane	no. of strips	strip dim. (mm×mm)	thickness (mm)	section area (mm^2)
S11	8	330×51	7	357
S12	6	408×55	7	385
S21	2	180×75	5	375
S22	2	150×90	5	450
S31	3	150×60	7	420
S32	3	180×50	7	350

Photo-multiplier tubes

The light produced by the scintillators is viewed by mod. R5900 [3] PMTs, manufactured by Hamamatsu Photonics. The R5900 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. The R5900 PMTs for the PAMELA ToF are selected with a Quantum Efficiency QE $> 21\%$.

The R5900 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.

Redundant 900 V HV supplies are connected to each PMT through a regulator circuit capable of 800 V 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.

Scintillator

The chosen plastic scintillator 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 the 3.24 cm^2 active areas of the PMTs.

The readout electronics of the ToF system, which must be capable of time resolution better than 100 ps, are discussed in [5].

2. Qualification tests

2.1. PMT qualification tests

Several qualification tests were performed in order to select a "good" sample of PMTs to be employed in the Flight Model [1] of the ToF. The gain was measured applying the method described in [2]. To test the linearity, the Double Pulse Method was employed (as described in [4]). Finally to measure the photocathode homogeneity, the PMT has been illuminated with LED light fed through an optical fiber, and moved with a stepper motor.

2.2. Counter qualification tests

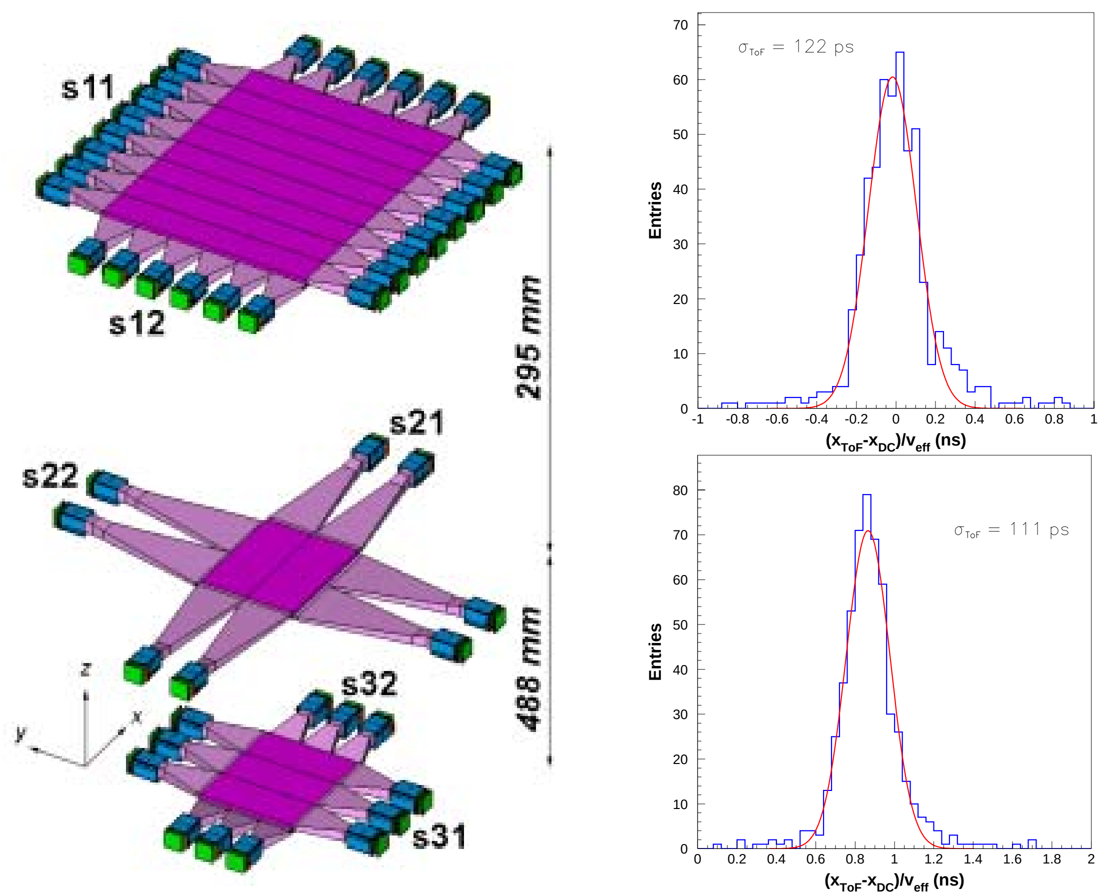

Fig. 1. Left: isometric view of the ToF. Right: sample time resolution of a ToF paddle before (above) and after (below) time-walk correction.

The intrinsic time resolution and the charge distribution of each ToF paddle were measured in different experimental situations. Each paddle was housed in a custom-made light-proof box, placed on top of a drift chamber (DC). The whole apparatus was triggered by the coincidence of the signals coming from the two PMTs of the paddle. Evaluation of the timing resolution of the paddles is performed comparing the impact point reconstruction done by the scintillator with the one obtained by the DC. Since the DC can reconstruct the tracks of ionizing particles passing through its sensitive volume with a precision of 300 μm, we can assume that the contribution from the DC finite precision is negligible, therefore the width of the residual distribution gives us the intrinsic timing resolution of the paddle. Preliminary tests give the following results

S1	110 ps $< \Delta T <$ 120 ps
S2	140 ps $< \Delta T <$ 150 ps
S3	120 ps $< \Delta T <$ 140 ps

A typical time resolution plot is shown in Fig.1. before and after corrections for the time-walk effect.

2.3. Environmental tests

In order to estimate the PMT behavior during the flight of PAMELA, gain measurements were performed at different temperatures (in the range $0 \div 50^{\circ}$ C). The gain was 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. Full paddles were also submitted to thermal test to characterize the whole apparatus. Data acquisitions of cosmic ray events have been made by keeping counters at fixed temperature in an insulated box.

Mechanical tests on the engineering models of the three ToF planes have been performed applying the expected random vibration spectrum of the satellite launch on a shaker machine. The qualification spectrum is about 3-fold bigger than the real one to ensure maximum reliability of the system. For all the planes the models withstood the qualification test without damages or worsening of the performances.

3. References

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