# The TOF counters of the AMS-02 experiment: space qualification tests and beam test results.

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The scintillator counters of the TOF system of AMS-02 is beeing constructed to match the needs of the AMS-02 experiment that is armed by a high aperture superconducting dipole magnet. The goals of the TOF-02 hodoscopes actually are: to give the fast trigger to the all sub-detectors of AMS-02; to measure the particle velocity ensuring a $1 \times 10^9$ albedo rejection; to measure the absolute charge by particle energy loss, up to at least Z=20. In spring of 2005 all the TOF counter planes will be assembled and the space qualification tests will be performed. A description of the first test results and of the TOF performances will be given.

## 1. INTRODUCTION

The TOF apparatus of the AMS-02 experiment[1] is being built at the INFN laboratories of Bologna. Two of the four planes of the TOF will be ready and will undergo vibration and thermal vacuum tests early in 2005. The TOF system will provide: the fast trigger to the whole AMS; the measurement of the time of flight of the particles traversing the detector with a resolution sufficient to distinguish upward from downward going particles at a level of $10^{-9}$; the measurement of the absolute particle charge in addition to the one measured by the silicon tracker and the RICH. In order to provide the general data acquisition system (DAQ) with the fast trigger signal (FT), the TOF must give a very fast and reliable response to the energy lost by charged cosmic rays. Moreover the system will provide a measurement of the particles charge with a resolution to distinguish nuclei up to $Z \leq 20$. The resolution of the TOF to satisfy these physical requirements is about 120 ps. The choice to have 1 cm thick scintillator pads is a compromise between minimum weight and enough light to reach this resolution. Given the strong limitations in the total weight of the AMS detector, the TOF system was allotted about 240 kg and it was allowed to use a maximum power of about 150 W. The operation in space imposes several requirements on the mechanical design and on the servicing electronics for the TOF system. The modules have to be housed in a light-tight and robust cover and the support structure of the modules has to conform NASA specification and vibrational and thermal-vacuum tests on the structure components have to be done.

## 2. The TOF design

The first problem in the design of the TOF of AMS-02 has been the high absolute value of the field at the position of the photomultipliers (1.5 : 2 kG) which forced to choose a special kind of photomultiplier (PMT), the “fine mesh” Hamamatsu R5946[2]. The second problem has been the direction of the field with respect to the PMT axis, because the response in time of the PMTs is strongly affected by this angle, as seen from both the data and the simulation[3]. Thus, tilted light guides were designed in order to minimize this angle. The four TOF planes equipped with guides and PMTs are shown in figure 1.

### 2.1. The fine mesh photomultipliers

The cylindrically shaped, “fine mesh”, Hamamatsu R5946 PMT has been chosen for its good performance in high magnetic field. The PMT

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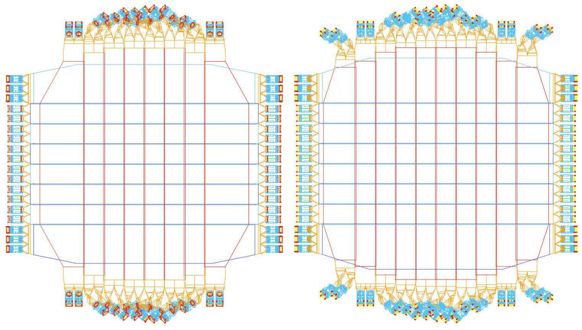

Figure 1. A top view of the planes with counters, light guides and PMTs. Upper TOF planes (left) and lower TOF planes (right).

has a bialkali photocathode, a borosilicate glass window and 16 bialkali dynodes. The spectral response ranges from 300 to 600 nm with a maximum response at ∼ 420 nm (corresponding to a quantum efficiency of about 20%). The PMTs were tested in magnetic field [2] and the most critical parameter was found to be the time response of the phototube. In fact for $\theta \geq 35°$ the transit time and the transit time resolution worsen badly (see fig. 2). The curved light guides keep the angles of the TOF PMTs below this critical value. All PMTs have been calibrated using the method described in [4]. The two (or three) PMTs on each side of the counters are chosen so as to have similar responses and operating HV (and therefore transit times). A genetic algorithm [5] is used to determine the best placement of each PMT in the apparatus, by means of a likelihood function that contains some parameters like the voltage supply, the slope of the calibration curve and the anode-to-dynode ratio, the magnetic field intensity and direction, and the light guides transmission. Moreover, high gain PMTs are put at the critical positions, so that their voltage supply can be increased, if necessary, to compensate for the worsening of their timing response [3].

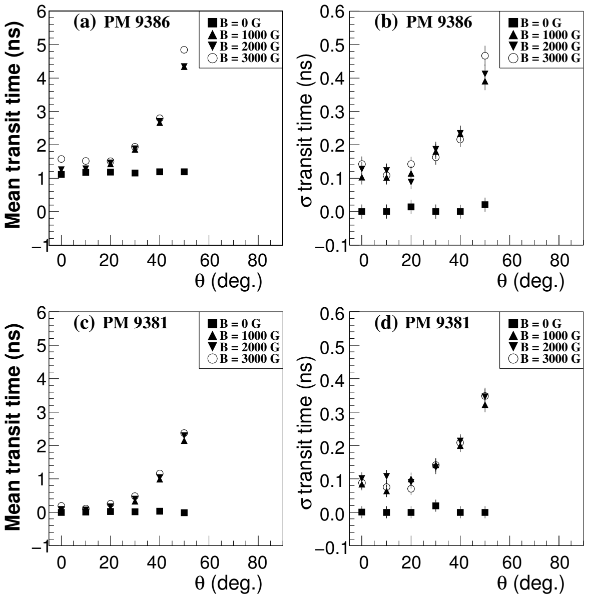

Figure 2. Magnetic field effect on the time measurement.

## 2.2. The counters

The scintillator counters of the TOF system are constructed by Eljen-Technology(Texas-USA) Type: EJ-200, 120 mm width 10 mm thick for rectangular counters, variable width (185 - 269 mm) for trapezoidal[2] counters and variable lenght (between 117-134 cm) for all. The CR telescope for counters characterization in the Bologna laboratory was optimized and some of them were taken to the beam test of 2003. Each counter is coupled to 4 PMTs (6 for the trapezoidal ones) through light guides that are tilted to account for the magnetic field direction.

## 3. Space qualification tests

The TOF system must be able to operate in space for a long time without human intervention and with temperature ranging from −20°C to +50°C. In addition, the detector must survive the strong acceleration produced by the shuttle launch, and its measurements should not be affected by this vibration. Hence, thermal-vacuum

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[2] In order to reduce weight and power, the side counters of each plane have a trapezoidal shape and are slightly larger than the other counters.

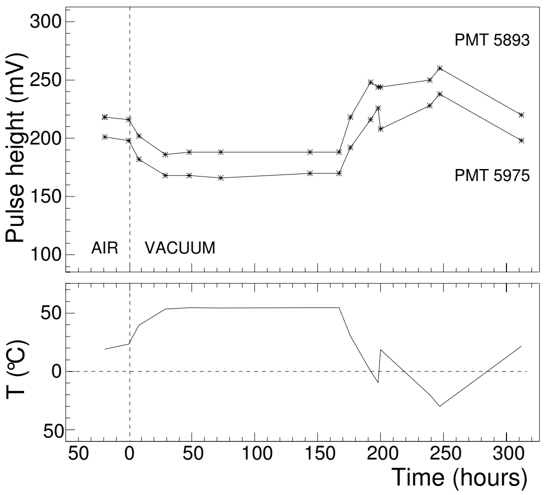

Figure 3. The PMTs response as a function of time during the thermal-vacuum test (above). The temperature variation as a function of time (below).

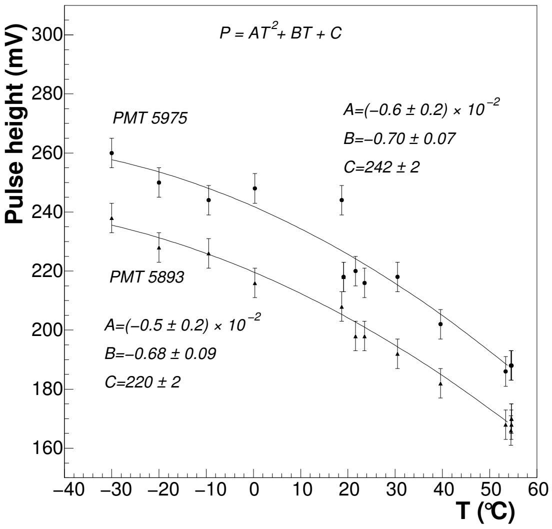

Figure 4. The PMTs response as a function of the temperature, superimposed is a parabolic fit.

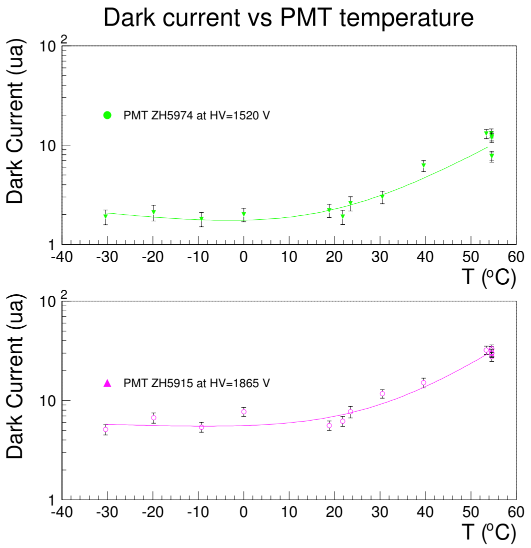

Figure 5. PMTs dark current as a function of the temperature.

and mechanical tests must be carried on with each subdetector and with the full AMS-02 configuration, before the flight. A group of 10 photomultipliers was tested in a thermo-vacuum simulator at a pressure of $10^{-7} \div 10^{-6}$ mbar with temperature varying between $-30°$C and $+55°$C. Four PMTs were equipped with a radioactive $\beta$ source and a small scintillator, that was used as a very stable reference. Other six PMTs were monitored for the dark current. Figure 3 shows the variation of pulse height as a function of time for 2 PMTs. Each point corresponds to the average of 5000 events measured with an oscilloscope. As shown in figure 4, the pulse height (i.e. the gain) of the PMTs is well described by a parabolic dependence as a function of the temperature. The data are in good agreement with the PMT characteristics as given by Hamamatsu. Figure 5 shows the variation of the dark current versus temperature for 2 PMTs. Even if an increase is clearly measured at high temperature, the dark current is always negligible [6].

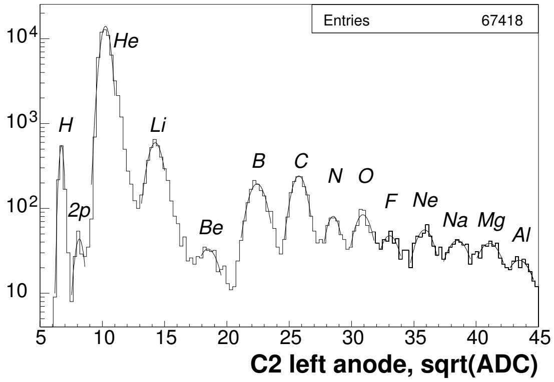

Figure 6. Square root of the integrated charge measured with left anode of C2 counter. Peak "2p" is produced by two singly charged particles crossing in time the scintillator.

## 4. Beam test results

In 2003, four scintillators were used with a 158 GeV/$c$/A ion beam obtained from the primary In SPS beam and tuned with the H8 selection line. Data analysis is still in progress for this beam test run. Two of the scintillators used represented the worst situations, with twisted and bended light guides. The charge peaks of the most problematic counter (C2) are clearly seen in figure 6. The charge resolution was also computed, both for the anode signal and for the dynode signal (passive sums of the two PMTs), as you can see in fig. 7.

From the time of flight measurements between the different counters (for example C2-C3 is shown in figure 8) it is possible to infer the TOF resolution, that turns out to be of the order of 130 ps for singly charged particles [3].

## 5. Trigger acceptance

The FT is generated when at least three planes out of four produce signals above a fixed threshold. In addition to the FT, the TOF system will also flag cosmic rays with charge greater than one, in order to allow for proton suppression at the trigger level, if necessary, without strongly affecting the measurement of the flux of higher charge ions (figure 9 shows the average effect on the real cosmic ray spectrum taken with AMS-01 [1]).

## 6. Conclusion

From the thermal-vacuum tests made, it was proved that the photomultipliers can operate from −40 to +50 Celsius degrees without major problems. The trigger acceptance will allow to suppress 99% of the proton flux at level-1 trigger. From the last beam test results it can be inferred a good charge resolution and time of flight resolution. The calibration of all the PMs and of their behaviour in the magnetic field, together with the light guide characterization for all the counters, will allow us to optimize the TOF system configuration to obtain the above mentioned performances during the space mission.

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[3] for the four planes $\sigma_{tof} \simeq \frac{\sigma_{23}}{\sqrt{2}}$

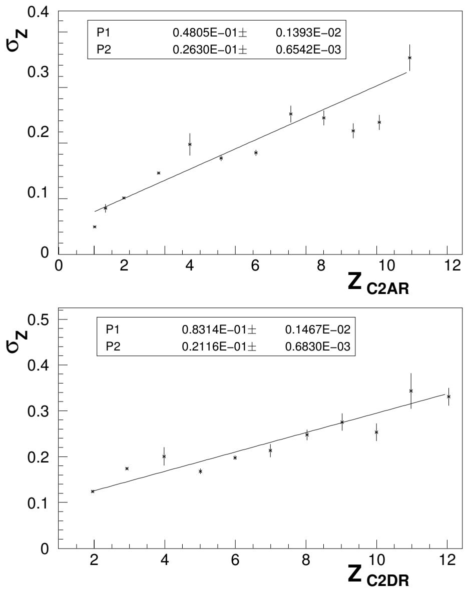

Figure 7. C2 charge resolution as function of the particle charge for anode (above) and dynode (below) signals.

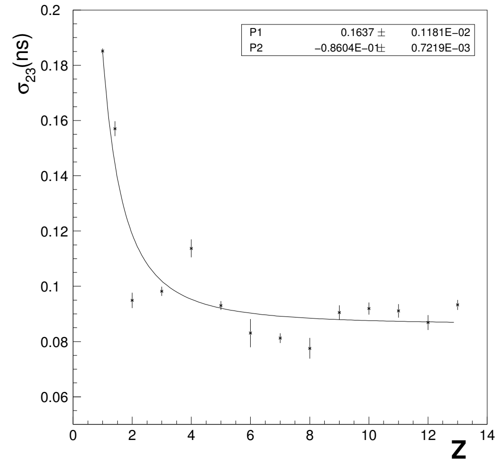

Figure 8. Resolution on the time of flight between C2 and C3 as function of the particle charge.

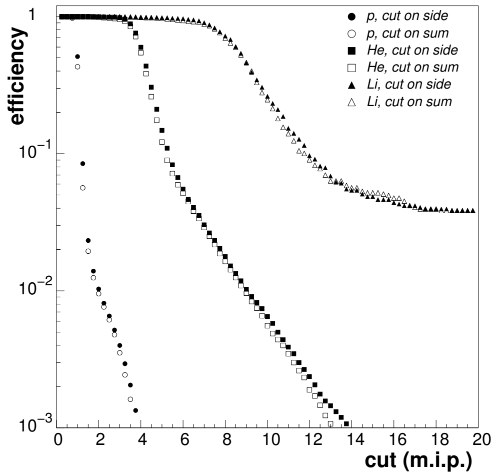

Figure 9. Trigger efficiency for different particles, as function of the threshold applied on the energy lost measured by a single counter side or by both ends.