Perfomances and space qualification tests of the AMS Time Of Flight

L.Amati, D.Baldassari, V.Bindi, A.Contin, F.Giovacchini, G.Levi, R.Martelli, A.Oliva, F.Palmonari, L.Quadrani, L.Villa , A.Zichichi,

Dep. of Physics, Bologna Universtity (Italy)

D.Casadei, F.Cindolo, G.Laurenti, C.Sbarra,

INFN-Bologna, Italy

G.Castellini

CNR-Iroe, Florence, Italy

***Abstract*— The AMS-02 Time Of Flight system is in construction at the INFN laboratories of Bologna and it will cover an angulare aperture to match the need of the AMS-02 spectrometer. The counters of the four TOF planes have a time resolution of 150 ps for 1 mip and of 60-70 ps for Z = 10 . The detector will give the fast trigger to the DAQ of the whole experiment and will perform up/down particle separation at a level of 10^{-9}; it will also measure the charge of the particles passing through, up to Z about 20 . The space operation for at least three years imposes several requirements on the TOF. For this reason some space qualification tests have been done and their results are shown.**

***Index Terms*— TOF, space qualification.**

I. Introduction

The TOF apparatus of the AMS-02 experiment [8] 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 those measured by the silicon tracker and by the RICH. The geometrical acceptance of the TOF has been fixed at $0.4\ m^2 sr$ and, to avoid inefficiencies, the scintillator paddles of the TOF planes are slightly overlapped ($0.5\ cm$). The AMS-02 detector is based on a superconducting magnet which will provide a field six times higher than the field produced be the permanent magnet of AMS-01 [2]. For this reason, the photomultipliers chosen are the Hamamatsu fine-mesh R5946 [4], that can substain field up to 1-2 kG. 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 specifications. For this reason vibrational and thermal-vacuum tests on the structure components should be performed.

C.Sbarra is the corresponding author

Fig. 1. Exploded view of the AMS-02 TOF subdetector.

II. The TOF design

The TOF sub-detector of AMS-02 is sketched in the figure 1 were the TOF planes and the light cover, with all the mechanical structure supports, are shown in an exploded view.

The first problem in designing the TOF of AMS-02 has been the high absolute value of the magnetic field ($1.5 - 2$ kG) in the photomultipliers position, which forced to choose a special kind of photomultiplier (PMT), the Hamamatsu "fine mesh" R5946 [4]. 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 [1] [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 2.

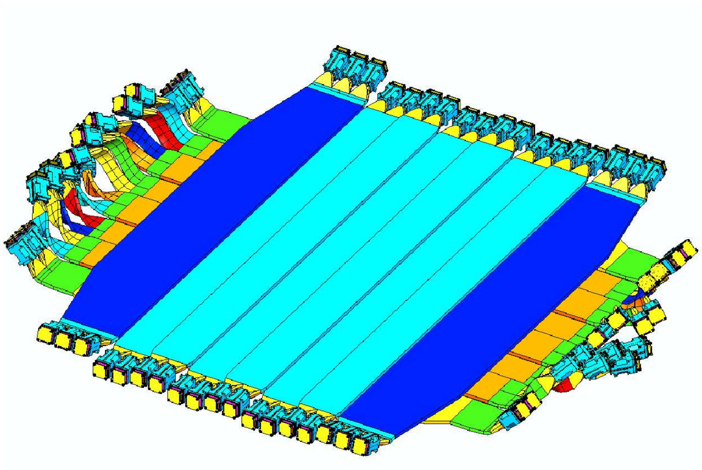

Fig. 2. A view of two TOF upper planes with counters, light guides and PMTs.

A. The fine mesh PMTs

To study the behaviour of the Hamamatsu fine mesh PMT in the magnetic field, significant tests were performed in the Bologna laboratories: the PMT response to a red light emitting diode (LED) was measured inside the poles of an electro-magnet [1] on a movable stand which could be rotated at a maximum angle of $90°$. The photomultiplier response was measured for different values of the magnetic field $\vec{B}$ and of the angle between the tube axis and the field direction [1].

A complete simulation of the fine mesh phototubes has also been developed [3] and the results of the simulation are in good agreement with the data taken, both for the fine mesh response in time and for the gain response, at various inclination of the PMT inside the magnetic field. Figures 3 and 4 show the data taken together with the simulated events. The results of both measured data and simulation show that the fine mesh cannot work for $\theta > 30°$, because of their time response degradation and because their gain has an abrupt fall [1].

III. 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 and mechanical tests must be carried on with each subdetector and with the full AMS-02 configuration, before the flight.

[1]maximum field 4 kG

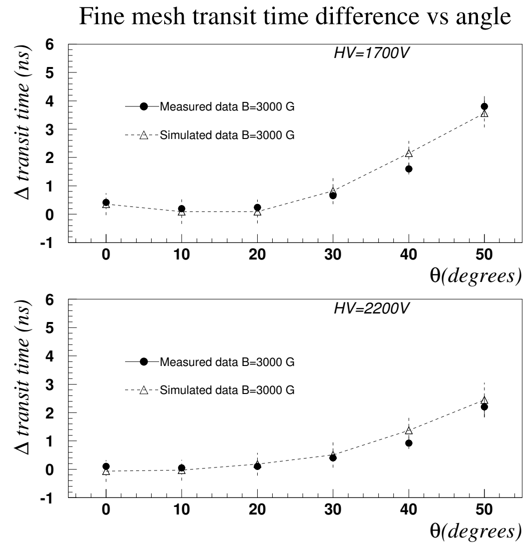

Fig. 3. Measured and simulated transit time difference $(t_{B>0} - t_{B=0})$ for fine mesh photomultipliers in a magnetic field B=3000 G, as a function of the angle θ between $\vec{B}$ and the PM axis [3].

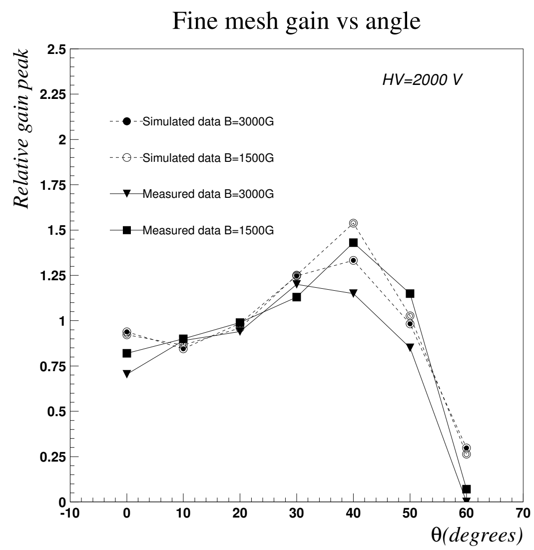

Fig. 4. Measured and simulated PMT gain versus the angle between the magnetic field and the PM axis [3]: the fine mesh response drops down above $\theta \sim 30°$, both in the data and in the simulation.

A. PMT thermovacuum tests

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 (the temperature cycle is shown at the bottom of figure 5).

Four PMTs were equipped with a radioactive β source and a small scintillator, that was used as a very stable reference.

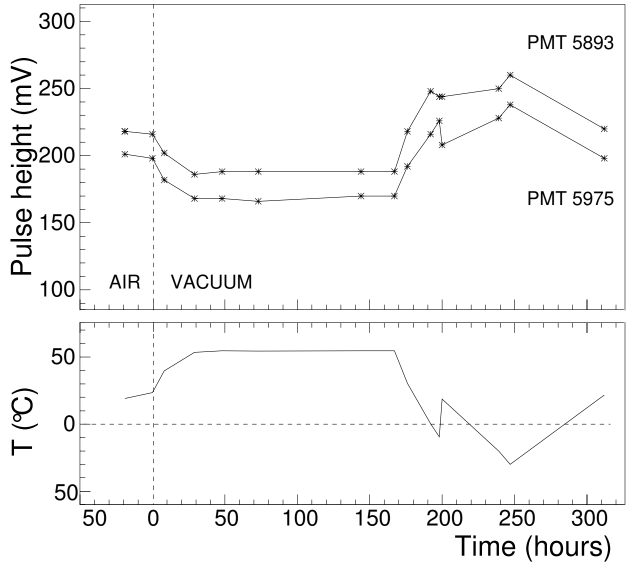

Fig. 5. The PMTs response as a function of time during the thermal-vacuum test (above). The temperature variation as a function of time (below).

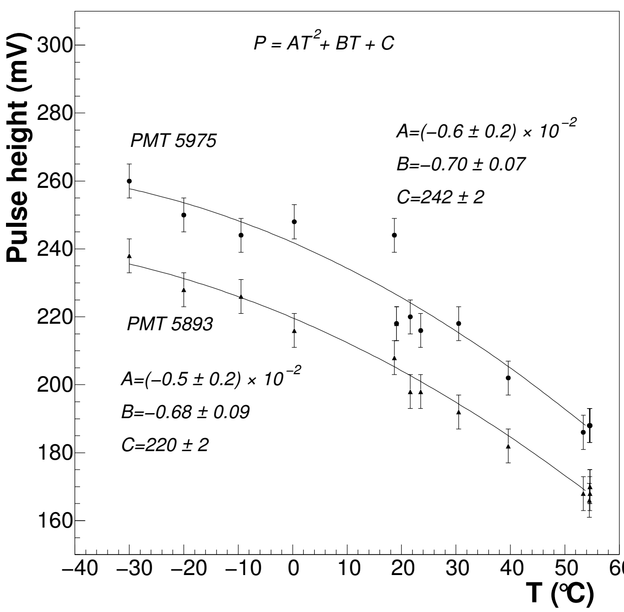

Fig. 6. The PMTs response as a function of the temperature, superimposed is a parabolic fit.

Other six PMTs were monitored for the dark current. Figure 5 shows the variation of the 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 6, 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 [4]. Figure 7 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 [7].

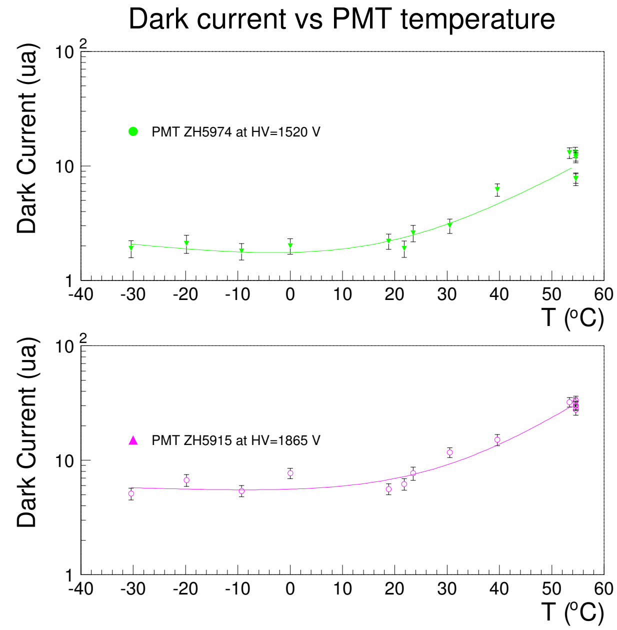

Fig. 7. PMTs dark current as a function of the temperature.

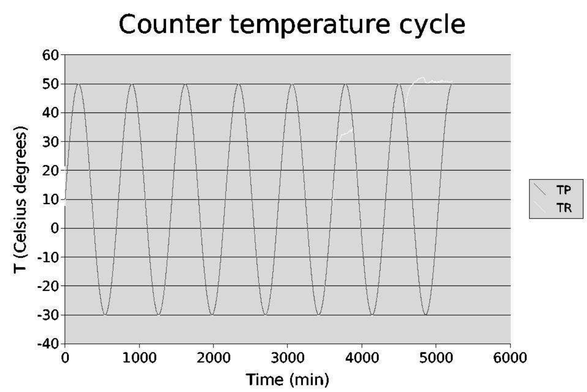

Fig. 8. Counter thermo-vacuum test: cycle of temperature.

B. TOF counter thermovacuum test

A complete TOF counter (the whole of a scintillator, light guide and photomultipliers) thermovacuum test was also performed. The temperature cycle for the counter test is shown in figure 8.

The counter was characterized with the AMS-Bologna cosmic ray telescope (at the Bologna INFN laboratory) before and after this test [6]. The most peculiar counter characterization parameters remained the same (at a level of few percent). The test results are shown in figure 9: the overall cosmic ray triggered pulse height turned out to be slightly decreasing as a function of temperature (but more studies on this are to be done).

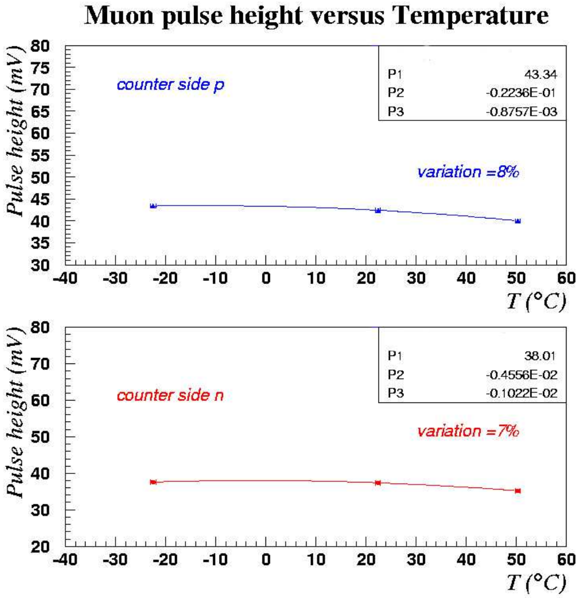

Fig. 9. Mean pulse height as a function of the temperature, triggering the counter on cosmic rays. The variation are at a level of 8 percent (more studies on this are needed).

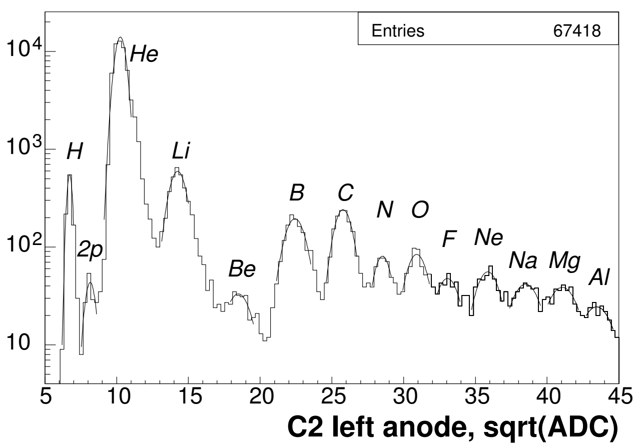

Fig. 10. Square root of the integrated charge measured with left anode of C2 counter. Peak "2p" is produced by two singly charged particles crossing in time the scintillator.

IV. The TOF performances: beam test results

In 2003, four scintillators [2] 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 10. 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. 12.

From the time of flight measurements between different

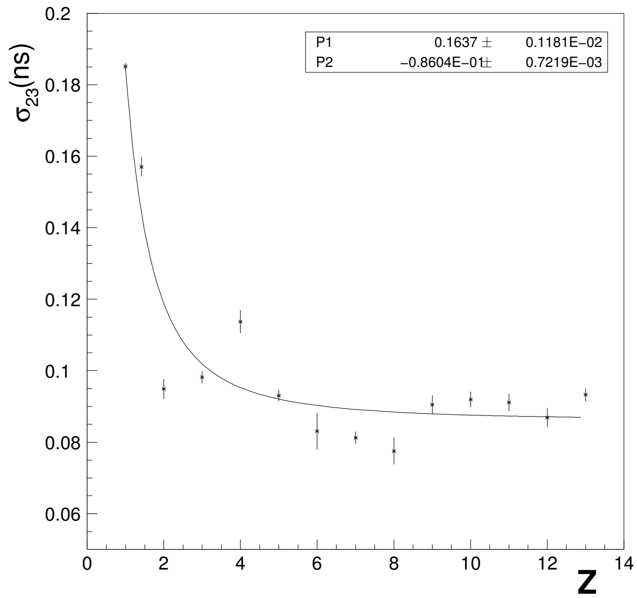

Fig. 11. Resolution on the time of flight between C2 and C3 as function of the particle charge.

counters (for example C2-C3 is shown in figure 11) it is possible to infer the TOF resolution, that turns out to be of the order of 130 ps for singly charged particles [3].

A. Trigger acceptance

In the AMS experiment, 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 13 shows the average effect on the real cosmic ray spectrum taken with AMS-01 experiment [2].

V. Conclusions

From the thermal-vacuum tests performed, it was proved that the photomultipliers can operate from -40 to $+50$ Celsius degrees without major problems. Nevertheless, some more studies are needed to understand the complete counter behaviour during a cycle of temperature. From the TOF performances studies made on the TOF-01 data, it turns out that 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 PMTs 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.

[2] named C1,C2,C3,C4

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

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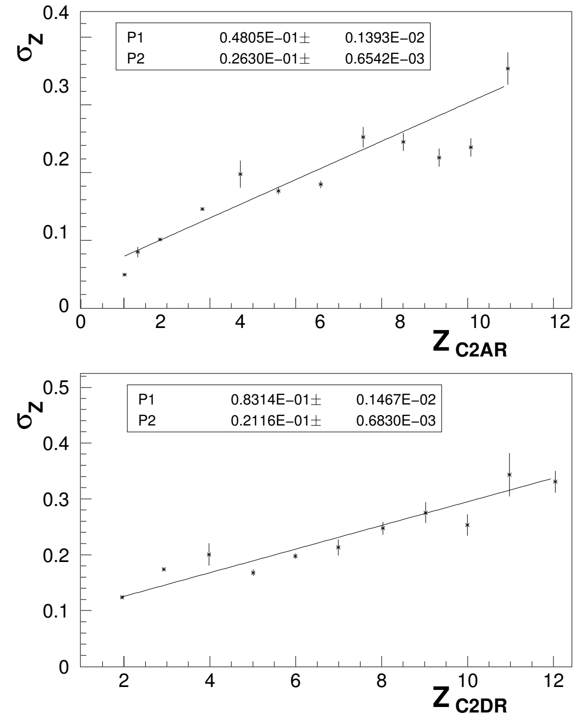

Fig. 12. C2 charge resolution as function of the particle charge for anode (above) and dynode (below) signals.

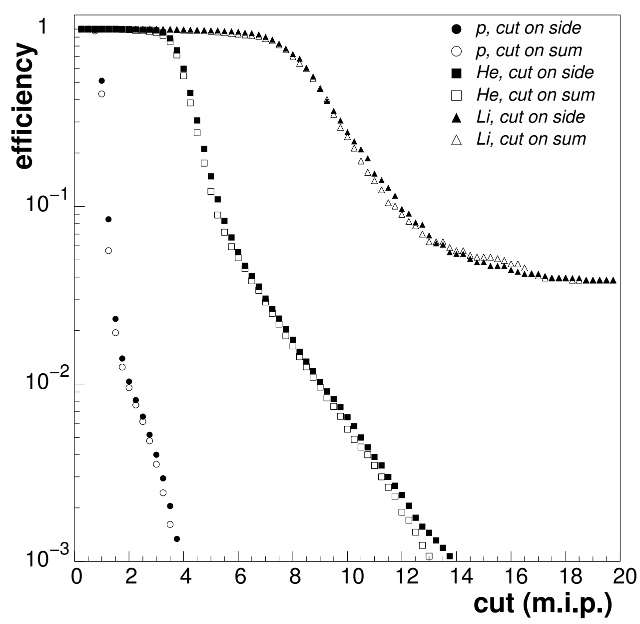

Fig. 13. Trigger efficiency for different particles, as a function of the threshold (in mip units) applied on the energy lost measured by a single counter side or by both ends (AMS-01 data [2]).