The AMS-02 Electromagnetic Calorimeter - FLIGHT MODEL

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Abstract

In the AMS-02 experiment, the Electromagnetic Calorimeter (ECAL) plays a key role for its high capability to measure $e^{\pm}$ and gamma spectra in the energy range from a few GeV up to 1 TeV. The detector has been designed to fullfill the requirements imposed by the extreme working conditions (vacuum, temperature gradients, radiation) of the Space environment.

After a successfull functional and space qualification test campaign on a full scale prototype, the detector flight model was assembled and tested at CERN in October 2006 using electron and proton beams.

1 Introduction

The AMS-02 experiment will operate on board of the ISS for 3 years looking for antimatter and dark matter signatures by high precision spectra measurement of cosmic rays and gamma rays. The experiment will be equipped with

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an electromagnetic calorimeter measuring $e^{\pm}$ and γ-rays energy in the range between 1 GeV and 1 TeV. The detector is provided with good linearity and energy resolution, while its 3D imaging capability is useful to suppress the CR background, mainly consisting of p and He nuclei.
In designing the calorimeter, many stringent requirements such as very high mechanical and thermal stability, low weight and power consuption as well as radiation hardness were taken into account.
Starting from 2001, an ECAL full-scale qualification model (QM) was assembled and then submitted to space qualification and beam tests with results in full agreement with simulations. Based on this experience, the ECAL flight model assembly began in Autumn 2004.

2 Detector characteristics

The AMS-02 ECAL is a sampling device built employing a lead-glue-scintillanting-fibers composite material with a volume ratio of 1:0.57:0.15 cm^3 and an average density of 6.8 ± 0.3 g/cm^3.
The active volume (called the "pancake") results is a pile-up of 9 "superlayers". Each superlayer, designed as a square parallelepiped with 65.8 cm side length and 1.85 cm thickness, consists of 11 grooved lead foils, 1 mm thick, interleaved with 10 layers of 1-mm diameter Pol.hi.tech. polifi 0244-100 scintillanting fibers.
In manufacturing the detector flight unit, many efforts were spent in selecting the best lead foils set making use of quality checks on the groove dimensions, the weight and the tickness uniformity (the average thickness was 1.01 ± 0.1 mm). Moreover, both single superlayer milling and global volume lateral surface finishing required special machining techniques. This was necessary to obtain the high precision needed to contain the detector weight and to increase the fiber light transmission with respect to the QM. At the end of the manufacturing process, the pancake has a total weight of 487 kg and a thickness of 16.6 cm corresponding to about 17 radiation lengths (see Fig. 1).
The 1296 ECAL readout elements are square areas of 9 mm side, which roughly corresponds to one Moliere radius in transverse dimensions and one radiation length in depth. The multianodes Hamamatsu R7600-00-M4 have been chosen considering the behaviour in magnetic field and the dimension of the anodes. Each photomultiplier accomodates four anodes with a light collecting area of 8.9×8.9mm^2, which fits the ECAL granularity very well.
Due to the tight limits on power consumption and weight, light is collected from one end only of the fibers: each superlayer is equipped with 36 photomultipliers arranged alternately on the two opposite sides. The coupling between fibers and PMT's is realized by means of plexiglass light guides while a 1 mm thick soft-iron housing acts as magnetic shielding to the outer field of 200-300

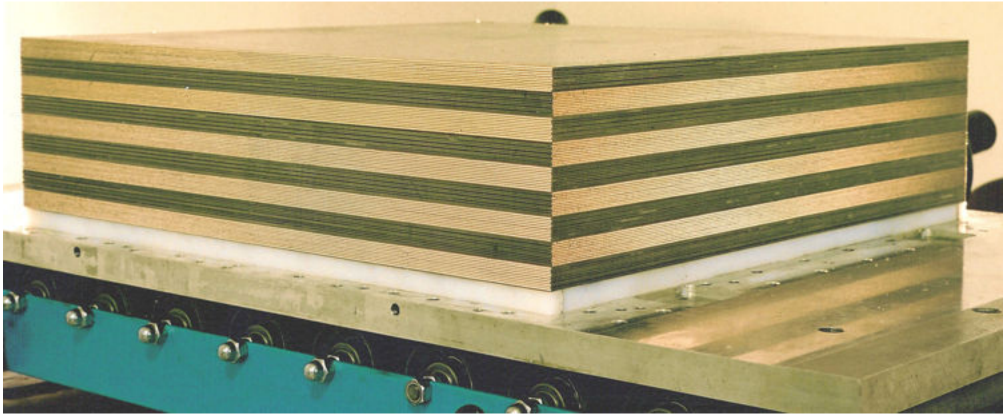

Fig. 1. Active volume of the FM AMS-02 calorimeter.

Gauss [1].
Before the installation on the flight unit, each photomultiplier was fully characterized measuring its gain and linearity curve and its stability under temperature variations and external magnetic fields.
The electronic support system includes a FE section, the data acquisition, high and low voltage supplies and the slow control. With the exception of the FE, each ECAL electronic board is characterized by double redundancy in order to assure a very high system reliability: in case of fault, it is possible to switch between two completely independent sectors, separately powered but capable of the same functionality.
Twelve cards, the EDRs (Ecal Data Reduction), receive the PMT's data digitized by the FE cards; they perform sparsification and pedestal subtraction and send the packets to the upper DAQ level, the JINF board. The slow control system mainly supervises the switching between the board redundant sections and serves to set and monitor the high voltages. The primary slow-control interface is located on the JINF card, which provides serial buses distributed to the HV control modules and to the low voltage control cards (EPSFE). The EPSFE was designed to host the power switches for the FE electronics.
The calorimeter is also equipped with a stand-alone trigger for photons. This trigger, requested to be very efficient down to the lowest possible energies and to have a high directional dependence, is built up with a granularity of 1 photomultiplier: the last dynode signals of the PMT's are first compared to a given threshold and then sent to the full digital board, the ETRG, where the trigger algorithm is computed and its result sent to the AMS-02 Trigger Supervisor [2].

3 Space qualification test campaign

Since the ECAL must be able to operate in Space for a long time without human intervention and under extreme enviromental conditions, accurate

thermal-vacuum and mechanical tests must be carried out on the detector and its subsystems before the flight.
Sine-burst loads and random vibrations were applied to measure the strength of the ECAL structure and to cross-check the finite element model. A first test on the QM was performed at BISEE in 2003 with 12 g sine-burst loads and 3.2 g_{rms} random vibrations. Then, in 2004, a sine sweep test on the flight hardware was sucessfully completed revealing a first resonance frequency much higher than the limit of 50 Hz imposed by NASA. In the meanwhile the light collection system design was validated during the "mission success" test held at SERMS Laboratory: the shuttle launch conditions were simulated and no significant worsening in detector performance was discovered after vibrations. Again at SERMS, the QM underwent a thermal vacuum test. The main objectives were to validate the thermal mathematical models and to test the thermal hardware including the radiator sizing. The detector operating range of $-20°C/+40°C$ was confirmed as well as a temperature variation over one orbit inside 5 °C, which is an important requirement for the PMTs' gain stability.

A test campaign was organized to qualify also the electronics. QM crates

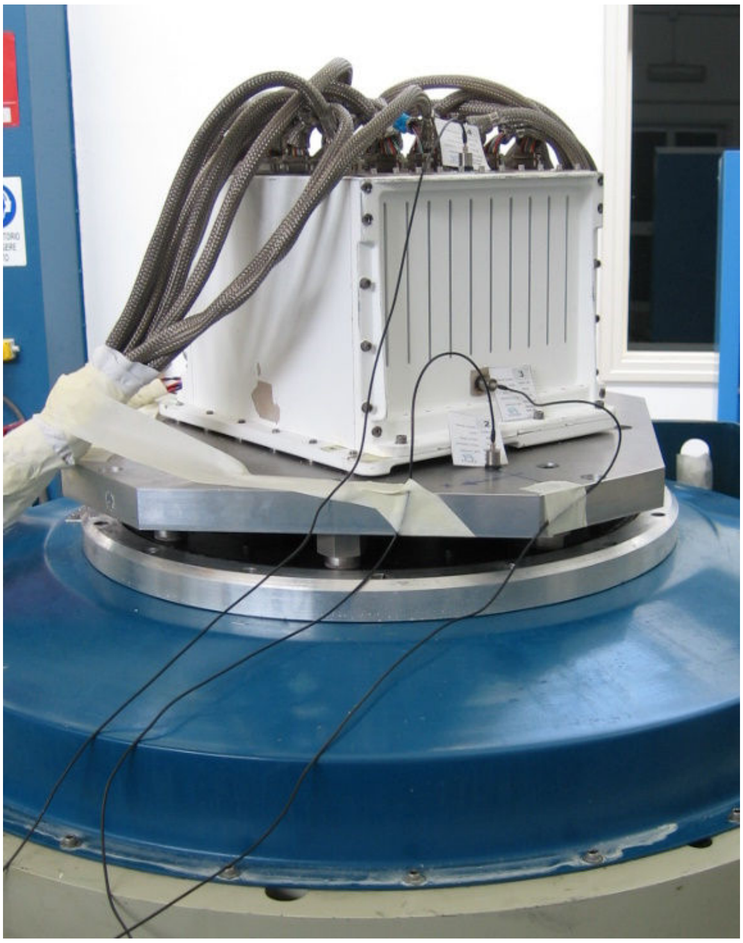

Fig. 2. Space qualification test on QM electronics crate.

and boards were submitted to random vibrations up to 3.2 g_{rms} (see Fig. 2), thermal cycles in air and vacuum from $-45°C$ to $+85°C$, and to electromagnetical compatibility tests where both susceptibility and emission have been verified to be inside NASA limits. All electronic components have been tested for radiation hardness according to space rules.
The whole test campaign has been successfully completed and the production of all FM cards will finish over the next few months.

4 Preliminary results from Test Beam

In October 2006, the ECAL flight unit equipped with QM electronic crates (see Fig. 3) was tested at CERN using electron and proton beams. The whole detector DAQ chain as well as the stand-alone trigger were intensively tested and debugged by means of AMS-02 DAQ.
Data analysis is still ongoing but first results show very promising improvements in the FM performance compared to the QM. As an example, the increase in the minimum ionizing particle signal from 8 ADC channels to about 20 is compatible with an increased detector light yield. Moreover, both the energy and the angular resolution for low-energy electrons (Tab. 1) are well aligned with the value quoted for the QM [3] although no equalization techniques have been applied yet.

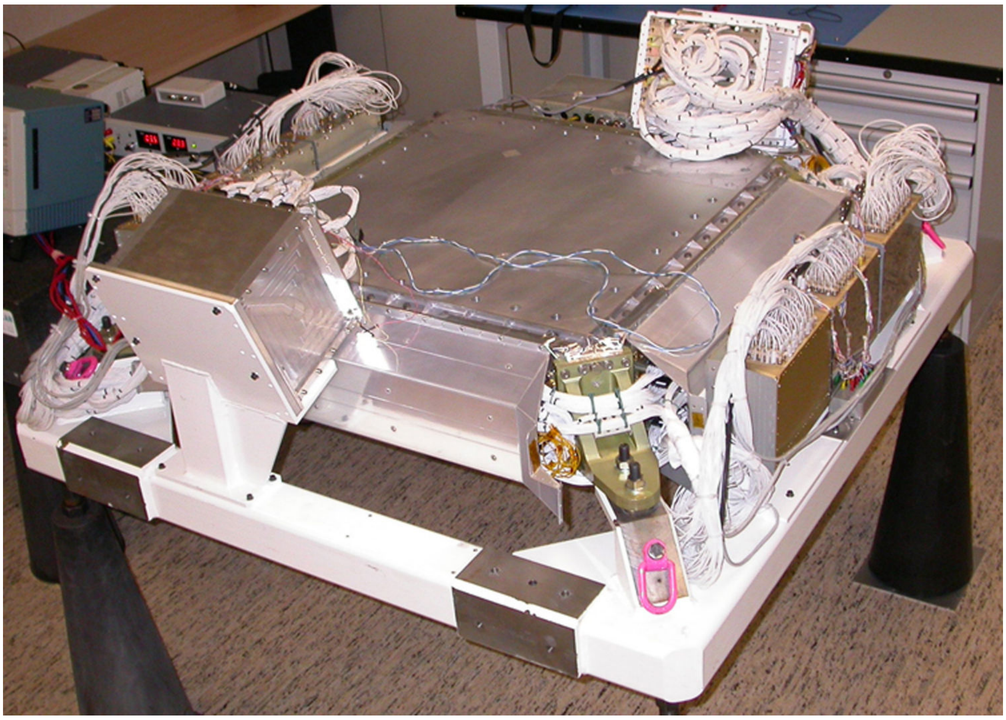

Fig. 3. The FM AMS-02 ECAL ready to be installed in the test beam area.

Table 1
2006 Test beam. Energy and Angular resolution from e^- data.

Energy GeV	Energy Res. [%]	Angular Res. [°]
6	6.0 ± 0.5	3.0 ± 0.3
10	5.5 ± 0.5	2.4 ± 0.3

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