Nuclear Instruments and Methods in Physics Research A 714 (2013) 147–154

Contents lists available at SciVerse ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical Notes

The AMS-02 lead-scintillating fibres Electromagnetic Calorimeter

C. Adloff [a], L. Basara [a], G. Bigongiari [d], F. Bosi [c], P. Brun [a], F. Cadoux [a], F. Cervelli [c], V. Chambert [a], G. Chen [b], G.M. Chen [b], H.S. Chen [b], G. Coignet [a], G. Cougoulat [a], S. Di Falco [c], J.M. Dubois [a], S. Elles [a], E. Falchini [c], A. Fiasson [a], D. Fougeron [a], N. Fouque [a], S. Galeotti [c], G. Gallucci [c], F. Gherarducci [c], L. Girard [a], F. Giuseppe [c], C. Goy [a], R. Hermel [a], M. Incagli [c,*,1], J. Jacquemier [a], L. Journet [a], R. Kossakowski [a], V. Lepareur [a], Z.H. Li [b], B. Lieunard [a], T. Lomtadze [c], Y.S. Lu [b], P. Maestro [d], C. Magazzù [c], M. Maire [a], A. Orsini [c], M. Paniccia [a], E. Pedreschi [c], F. Peltier [a], M. Piendibene [c], F. Pilo [c], J. Pochon [a], T. Rambure [a], S. Rosier-Lees [a], F. Spinella [c], X.W. Tang [b], J. Tassan-Viol [a], A. Tazzioli [c], C. Vannini [c], J.P. Vialle [a], H.L. Zhuang [b]

[a] *LAPP, Université de Savoie, CNRS/IN2P3, Annecy-le-Vieux, France*
[b] *Institute of High Energy Physics, CAS, Beijing 100049, China*
[c] *Istituto Nazionale di Fisica Nucleare, Sezione di Pisa, 57023 Pisa, Italy*
[d] *Universita' degli Studi di Siena, 53100 Siena, Italy*

ARTICLE INFO

Article history:
Received 17 September 2012
Received in revised form
30 January 2013
Accepted 13 February 2013
Available online 14 March 2013

Keywords:
Electromagnetic Calorimeter
Astroparticle
Cosmic rays

ABSTRACT

The Electromagnetic Calorimeter (ECAL) of the AMS-02 experiment is a fine grained lead-scintillating fibres sampling calorimeter that allows for a precise three-dimensional imaging of the longitudinal and lateral shower development. It provides a high ($\geq 10^6$) electron/hadron discrimination with the other AMS-02 detectors [1] and good energy resolution. The calorimeter also provides a standalone photon trigger capability to AMS-02. The mechanical assembly was realized to ensure minimum weight, still supporting the intrinsically heavy calorimeter during launch. ECAL light collection system and electronics are designed to measure electromagnetic particles over a wide energy range, from GeV up to TeV. A full-scale flight-like model was tested using electrons and proton beams with energies ranging from 6 to 250 GeV.

1. Calorimeter

The AMS-02 ECAL [2,3] consists of a lead/scintillating fibre sandwich with an active area of $648 \times 648\ \text{mm}^2$ and a thickness of 166 mm. The calorimeter is composed of *superlayers*, each 18.5 mm thick and made of 11 grooved 1 mm thin lead foils interleaved with layers of 1 mm diameter scintillating fibres glued to the foils by means of optical epoxy. The resulting composite structure has a relative lead-fibre-glue volume composition of 1:0.57:0.15 and an average density of $6.8 \pm 0.2\ \text{g/cm}^3$ (see Fig. 1).

In each superlayer, fibres run in one direction only. The detector imaging capability is obtained by stacking superlayers with fibres alternatively parallel to the x-axis (five superlayers) and y-axis (four superlayers). In AMS, the dipole magnetic field is oriented along the x-axis. The active part of the calorimeter has a weight of 496 kg, for a total weight of 638 kg, including mechanical structure and readout cables. Its thickness corresponds to about 17 radiation lengths.

2. Light collection

Each of the nine superlayers is read out by 36 four anode Hamamatsu R7600-00-M4 photomultipliers (PMTs), arranged alternatively on the two opposite ends in order to read out each fibre with no dead areas. Fig. 2 shows the picture of a superlayer with the PMT disposition: for each PMT both the cathode section and the dimensions of the support system are shown. Each anode covers an active area of $9 \times 9\ \text{mm}^2$, corresponding to 35 fibres: each active area is defined as a "cell". In total ECAL is subdivided into 1296 cells (324 PMTs) allowing a sampling of 18 independent measurements of the longitudinal shower profile and 72 measurements each layer.

To maximize light yield and to reduce cross-talk between cells, photons from the fibres are collected by means of individual Plexiglas light guides. Each light guide has a truncated pyramidal shape and is wrapped in an aluminum foil with chromium and quartz coating (see Fig. 3). Silicon optical joints on both ends of light guides ensure a good optical transmission from the fibres to the PMTs.

As shown in Fig. 4, each PMT is surrounded by a magnetic shield which also contains the light guides, the PMT base and Front End Electronics (FEE). The magnetic shield is required to

* Corresponding author. Tel.: +39 0502214379.
E-mail address: marco.incagli@pi.infn.it (M. Incagli).
[1] Currently at Massachusetts Institute of Technology, MIT, Cambridge, MA 02139, USA.

0168-9002/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.nima.2013.02.020

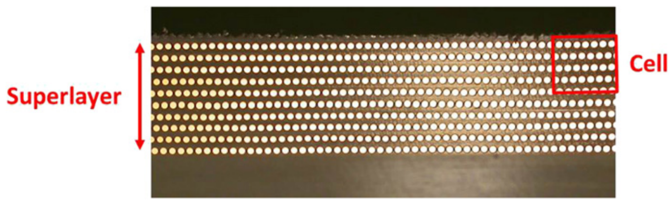

Fig. 1. ECAL structure and cell dimensions. Each fibre has a diameter of 1 mm.

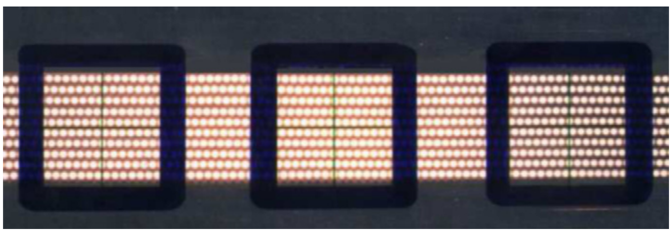

Fig. 2. Picture of a *superlayer* with the PMT positioning. Half of the PMTs are on the opposite side to avoid dead areas.

Fig. 3. Light guides and polycarbonate support.

reduce the residual magnetic field below 20 G and it is made of a 1 mm thick soft iron square tube, 30.5 mm wide and 74 mm long.

3. Mechanical assembly

The ECAL mechanical assembly was required to support the calorimeter and PMTs with the related electronics. Furthermore it was expected: (a) to minimize weight while ensuring a first resonance frequency above 50 Hz; (b) to withstand accelerations up to 12 g in any direction; and (c) to limit temperature gradients at the FEE level to less than one degree during each orbit.

As shown in Fig. 5, the optimization of the mechanical structure through finite element studies led to an aluminum alloy support frame composed of four lateral panels, where PMTs are inserted, and top and bottom honeycomb planes. The structural analysis was cross checked with a full scale, flight like *qualification model* (QM) at the Beijing Institute of Satellite Environment Engineering. The first resonance frequency was found to be higher than 60 Hz, complying with requirements.

4. PMTs and front end electronics

For each cell, the readout system is able to process signals with good linearity over a wide dynamic range, i.e. from a single minimum ionizing particle (~7 MeV/cell) up to about 60 GeV/cell (maximum energy released in a single cell by 1 TeV electromagnetic particles). To this effect, PMTs are provided by a tapered resistor divider (1.5:1.5:1.5:1:1:1:1:1:1:2:3.7), also allowing a reduced power

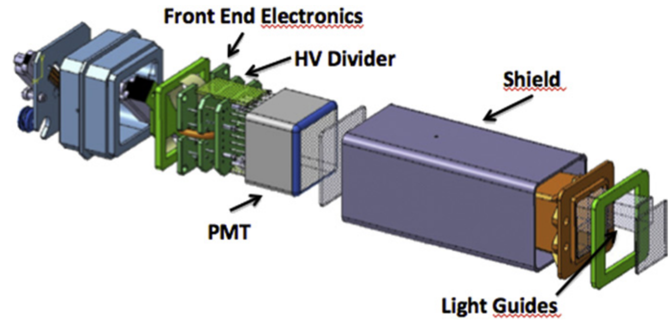

Fig. 4. Scheme of the PMT light collection system.

consumption (100 mW at 650 V). Each anode signal is split into two by voltage dividers and then amplified in two electronics channels with a gain ratio of about 33 (see Fig. 6).

The splitting and amplifying electronics was implemented in a dedicated ASIC chip [4] in BiCMOS 0.8 μm technology with very low power consumption (~5 mW/cell, i.e. 21 mW per PMT). The signal of the last dynode of each PMT is also read out to ensure a redundant measurement of the energy deposition and to provide input to the trigger logic. The nine signals of a PMT (2×4 anodes+1 dynode) are shaped to give a peaking time at 2.2 μs and are held until reading and sequential transmission to a serial ADC (*AD*7476*A*). HV dividers, ASIC and ADC are assembled together behind the PMT (see Fig. 7). The resulting assembly is completely potted to avoid corona effects [4].

The digitized outputs from nine PMTs are sent to an intermediate board (*EIB*) mounted on ECAL mechanical support. From EIB anode signals reach the data reduction boards (*EDR*), while the last dynode signals are sent to the trigger boards (*ETRG*) [5]. EDR and ETRG boards are hosted in two ECAL readout crates (ECRATE).

5. High Voltage power supply

Each HV power is supplied to PMTs by dedicated units. Each unit is composed of one controller module, two elevators and five Linear Regulator (LR) boxes, see Fig. 8. All the elements of each module are dual redundant. The elevators are based on a four-stage Cockcroft–Walton multiplier which raises the 28 V input up to a high voltage in the range of 500–1000 V. The LRs provide HV adjustment with 2 V steps through a discrete "series transistor". Eight independent HV channels are assembled in each LR box, for a total of 40 HV lines for each ECAL High Voltage (EHV) unit. To limit global weight, only six EHVs were installed in AMS-02: therefore only 156 out of 324 PMTs have independent power source, while the other 168 are grouped in 84 pairs, each using the same HV line. The power dissipation is kept below 5 W per EHV.

6. Readout electronics

In addition to the FEE mounted directly on the calorimeter, ECAL is instrumented with several custom developed electronic boards devoted to data reduction, slow control, trigger and high and low voltage setting. Each board is composed of two completely independent sectors that are separately powered and capable of the same functionality. In case of any fault, it is possible to switch from one sector to the other, so to maintain the full functionality of ECAL.

6.1. DAQ system

ECAL readout follows the overall AMS-02 design [6]. The *EDR* cards receive the digitized signals from 27 PMTs (3 *EIB*) over Low