OG 4.2.33

A Silicon-Tungsten Imaging Calorimeter for PAMELA

The PAMELA Collaboration

Abstract

An imaging calorimeter has been designed and is being built for the PAMELA experiment. The calorimeter acts as a powerful particle identifier by measuring the deposited energy and reconstructing the spatial development of the interacting events. The physics tasks are the measurement of the flux of antiprotons, positrons and light isotopes in the cosmic rays. The calorimeter is made by 23 layers of tungsten, each of them sandwiched by two views of silicon strip detectors (X and Y). The detectors are 8x8 cm^2 each and have 32 strips with a pitch of 2.4 mm. Each view consists of a square matrix of 3x3 detectors. The signals are read out by a custom VLSI front-end chip, with a dynamic range of 7.14 pC or 1400 MIPs (Minimum Ionizing Particle).

1 Introduction:

The PAMELA experiment (The PAMELA Collaboration, OG 4.2.04 this Conference) is a part of the Russian Italian Mission (RIM) program, which foresees several space missions with different scientific programs. The RIM-1 experiment studies the isotopic composition of cosmic nuclei by means of the silicon telescope NINA (Bakaldin et al., 1997), carried by the russian polar orbit satellite Resource-04. The NINA instrument has been launched succesfully from Bajkonur on July 10^{th}, 1998 and is currently taking data. The RIM-2 mission is the PAMELA experiment while the RIM-3 project, called GILDA (Morselli et al., 1995), is supposed to study high energy cosmic gamma rays.

The PAMELA apparatus will be installed onboard of a russian Resource-05 satellite and will be launched in the 2002. The sun-synchronous, 680 km polar orbit will allow studying the low energy cosmic rays, close to the poles. The main scientific objectives of the experiment are the precise measurement of the positron and antiproton fluxes at energies from 100 MeV to above 100 GeV, as well as the search for antihelium with a sensitivity of 10^{-7} in the antiHe/He ratio.

The PAMELA apparatus has an overall height of about 1 m and consists of:

- a Transition Radiation Detector (TRD) to identify electrons and positrons;
- a spectrometer based on a permanent magnet equipped with a silicon microstrip tracker to measure particle tracks and momenta;
- an imaging calorimeter (see next section);
- a Time of Flight (TOF) and first level trigger system based on plastic scintillators;
- an anticoincidence system, also based on plastic scintillators.

The Maximum Detectable Rigidity (MDR) is 400 GV/c, the geometric factor of the apparatus is about 21 cm^2 sr, the total weight is about 380 kg and the overall power consumption is less than 340 W.

2 The Imaging Calorimeter:

The PAMELA calorimeter is a sampling one made of silicon sensor planes interleaved with plates of tungsten absorber. The calorimeter has to perform a precise measurement of the total energy deposited, to reconstruct the spatial development of the shower both in the longitudinal and in the transverse directions, and to precisely measure the energy distribution along the shower itself. The main physics tasks of the imaging calorimeter are the following:

- extraction of the antiproton signal from the large background generated by the electron flux, with an efficiency of ≈ 90 % and a rejection power of 10^{-3} - 10^{-4};

_ identification of the positrons in the background generated by protons having p ≥ 1 GeV, with an efficiency of ≈ 70 % and a rejection power better than 10^{-4}.

2.1 General Characteristics: To accomplish the above mentioned tasks, the PAMELA calorimeter has to have a high granularity, both in the longitudinal (z) and in the transversal (x and y) directions. In the z direction, the granularity is determined by the thickness of the layers of the absorbing material (tungsten); each tungsten layer has a thickness of 0.26 cm, which corresponds to 0.7 X_0 (radiation lengths). The total depth is 16 X_0 (i.e. 0.9 interaction lengths), since there are 23 layers of tungsten.

The transversal granularity is given by silicon strip (see Subsection 2.3). Each tungsten layer is sandwiched between two layers of silicon detectors, i.e. the stratification of a single plane is Si-X/W/Si-Y. For each view (X or Y) there are 9 silicon detectors, arranged in a square matrix of 3x3 detectors. Since each silicon detector has a surface of 8x8 cm^2, the total sensitive area is 24x24 cm^2. The total sensitive volume is 24x24x18 cm^3. Each detector has 32 strips and each strip is connected to the corresponding ones belonging to the two detectors of the same row (or column), so that the number of electronics channel per plane is 32 x 3 x 2 = 192 and the total number of channels is 192 x 23 = 4416.

2.2 Mechanics: The mechanical structure is based on a modular concept. The basic unit is called a "detection plane", and it consists of an absorber plate, two PCBs (X and Y, supporting the silicon detectors as well as the fron-end and part of the read-out electronics) and the two matrices of silicon sensors (the first and last detection planes have only one layer of silicon sensors). Two detection planes form a "detection module". In a module, the two detection planes are kept together by a frame to which they are bolted at the edge of the absorber plate (Figure 1). The 12 modules are independent and fully extractable; they are inserted like "drawers" in the main mechanical structrure and then locked by a cover (Figure 2).

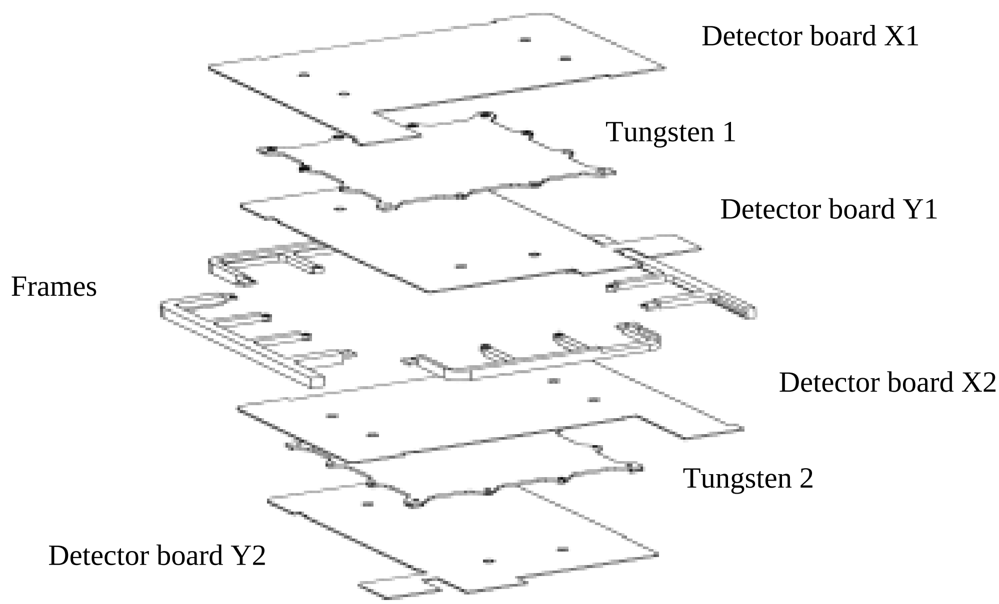

Figure 1: Exploded view of one detection module, showing the tungsten plates, the detector printed circui boards and the supporting frames.

The total calorimeter mass (including electronics and cables) is 114 kg. The whole calorimeter structure has been modelled and numerically analysed by means of the finite element method.

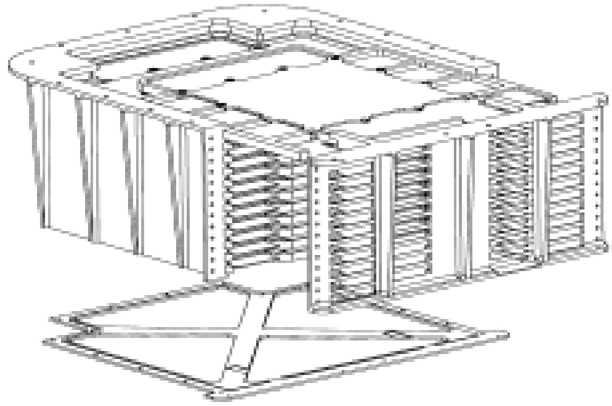

Figure 2: An assembly view of the mechanical structure of the calorimeter, showing also the locking front cover.

The finite element models have been analysed for static and dynamic loads, using the same values that were specified for the NINA experiment for load power spectral density (random vibrations) and for mechanical shock along the three axes. Experimental vibration and shock tests have also been performed on a pre-prototype, made by 2 plates of tungsten and, hence, 4 views of silicon sensors (2 X and 2 Y). The prototype was complete of supports, main frame and cover. One of the two tungsten plates has been equipped with printed circuit boards and silicon detectors. During all these tests, the leakage current of the detectors was continuously monitored. The test results showed the full compliance of the pre-prototype with the design characteristics and the effectiveness of the interconnection techniques (see next Subsection).

2.3 Silicon detectors and interconnection technique: The interconnection technique to realize the detection planes have been defined through numerous tests, in collaboration with the firm Mipot (Cormons, Italy), using both "mechanical" and "real" silicon detectors. As a first step, the printed circuit boards are fixed to the corresponding tungsten plates. The detectors are glued, in rows of 3, on a specially designed 75 μm thick kapton layer with a siliconic glue. Then, the wire bonding of the corresponding strips on each detector is performed. Afterwards, 3 such rows are glued on the supporting printed circuit board, again by using a special siliconic glue, to form the 3x3 silicon detector matrix of one view (either X or Y).

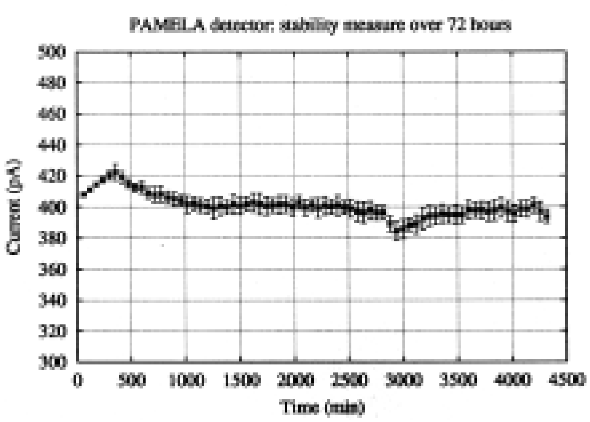

Figure 3: Stability measurement (at a depletion Voltage of 90 V) of the leakage current for a PAMELA detector over 72 hours.

The silicon detectors for the PAMELA calorimeter are very large area devices (8 x 8 cm^2 each), 380 μm thick and segmented into 32 strips with a pitch of 2.4 mm. They feature an innovative bias technique (Kemmer \& Lutz, 1988), adopted in order to bring the bias voltage with a wire bonding directly on the junction side of the devices. To accomplish that, the bulk contact is realised via a forward biased p$^+$ implant running at the edge of the device. In this way, we can avoid the use of a conductive epoxy glue for gluing the detectors on the PCB, therefore preserving the devices from the large mechanical stress that these type of glues can induce during polymerization.

Several pre-series detectors, from two manufacturers, have been completely characterised in the laboratory. The test results are very good: the average value of strip leakage current is about 400 pA, which corresponds to an average current per unit area of 0.17 nA/cm^2. Figure 3 shows the result (for one strip) of an I-V measurement performed over 72 hours on a pre-series detector. As one can see, the stability of the current, which is a crucial item in space applications, is excellent.

2.4 Front-end and read-out electronics: The front-end electronics is based on a VLSI ASIC: the CR-1 chip (J. H. Adams et al, OG 4.1.18 this Conference). The use of an ASIC allows to gain considerably in weight reduction and compactness with respect to the discrete preamplifiers previously used in balloon flights. The main design characteristics of this chip are the very large dynamic range (1400 MIPs), the ability to cope with a very large (up to ≈ 180 pF) detector capacitance, the good noise performance (≈ 3500 e^- rms + 6 e^-/pF) and the low power consumption (< 100 mW/chip). Each circuit has 16 channels and each channel comprises a charge sensitive preamplifier, a shaping amplifier, a track-and-hold circuit and an output multiplexer. A self-trigger system and an input calibration circuit are also integrated on chip. Figure 4 displays a scope picture of the output of a CR-1 circuit (trace 2) when stimulated by an input calibration signal (trace 1) injecting a charge corresponding to ≈ 300 MIPs (Minimum Ionizing Particles, 1 MIP ≈ 5.1 fC for 380 μm thick silicon detectors).

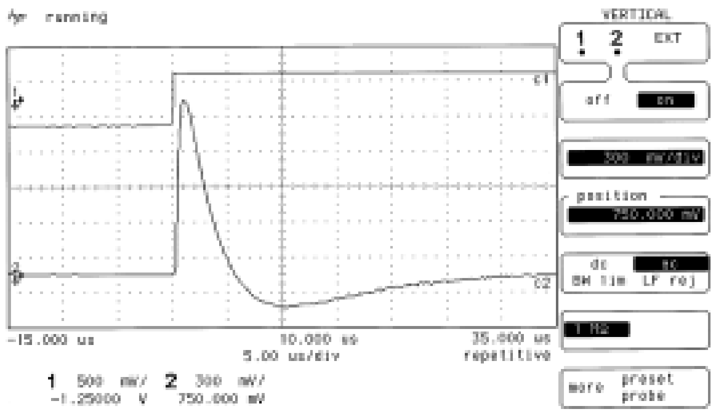

Figure 4: Scope picture showing the analog output of one channel of a CR1.3 chip (trace 2) corresponding to an input calibration signal (trace 1) equivalent to about 300 MIPs.

The design of the read-out electronics is divided into two main parts: ADC electronics (on the detector boards) and Data Processing electronics (on external read-out boards).

On each detector board, the 6 CR1 outputs are connected to a 16-bit ADC (with serial digital output) through an analogue multiplexer and an operational amplifier. On the read-out boards the collection and analysis of the events, prior to their transmission to the main CPU, is performed. The whole calorimeter is divided, from the point of view of the read-out, into four independent sections. An FPGA parallelize the data of the ADCs, controls the generation of the multiplexer address and performs the self trigger coincidence. Four DSPs (Digital Signal Processors, one for each section of the calorimeter), read and process the data and control the acquisition procedure.

3 Conclusions

The Silicon-Tungsten Imaging Calorimeter for PAMELA has been completely defined through careful tests and simulations. The results show that the instrument can fulfil its scientific objectives in the framework of the apparatus. The launch of PAMELA is foreseen in 2002 onboard of the Resource-Arktika satellite, and the scheduled mission duration is three years.

References

The PAMELA Collaboration, Proc. 26th ICRC (Salt Lake City, 1999), The PAMELA experiment.

Bakaldin, A. et al., 1997, Astrop. Phys. 8/1-2, 109\\.

Morselli, A. et al., Proc. 24th ICRC (Rome, 1995), 3, 669\\.

Kemmer, J. \& Lutz, G., 1988, Nucl. Instr. Meth., A 273, 588\\.

Adams, J.H. et al., Proc. 26th ICRC (Salt Lake City, 1999), The CR-1 chip: Custom VLSI Circuitry for Cosmic Rays.