Development of a PMT Readout System with Viking Chips for the SciFi Detector of CALET

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Abstract

The CALET (CALorimetric Electron Telescope) experiment on the International Space Station (ISS) is designed to observe cosmic-ray electrons, γ-rays, and heavy nuclei. The CALET detector will comprise an imaging calorimeter (IMC) and a total absorption calorimeter (TASC). The IMC part will be assembled with several ten thousand scintillating fibers (SciFi). In order to read the SciFi's, we have been developing a readout system for multi-anode PMT (MA-PMT). We assembled a test detector using 512 SciFi's and a MA-PMT readout unit composed of "Viking" chips (VA32HDR2). We report the performance of the readout unit as proved by beam tests.

1. Introduction

We propose the CALET experiment to observe cosmic-ray electrons up to an energy around 10 TeV, γ-rays between 20 MeV and 10 TeV, and heavy nuclei between 1 TeV and 1000 TeV [5]. The IMC part of the CALET will be assembled with several ten thousand SciFi's. It can provide information on the charge and direction of the incident particle as well as the stating point of the cascade shower [6]. The method was proved to be effective to distinguish the incident particles by the electron observations [7] and the atmospheric γ-ray observations [2] with the BETS (Balloon-borne Electron Telescope with Scintillating fibers).

We had established a way to read the SciFi with an image intensifier (I.I.) coupled to a CCD [6]. As an advanced method, we have been developing a readout system with the MA-PMT's and the Viking chips. It will enable the data acquisition at a higher rate ($\sim$1 kHz) and reduce the volume of system in comparison with the I.I.-CCD system previously developed. Dynamic range in the

pp. 2189–2192

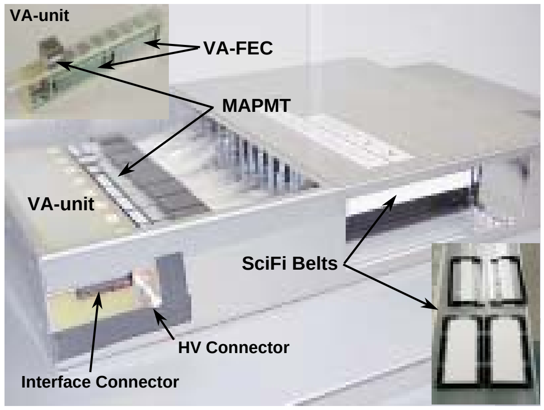

Fig. 1. Prototype detector.

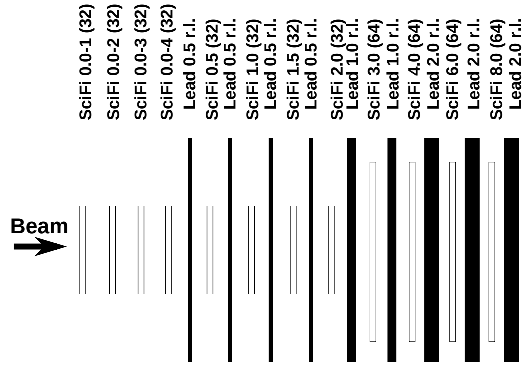

Fig. 2. Detector configuration.

readout system is required to be about 3000 for the current structure of detector, in which the SciFi's are deployed within 4 radiation lengths (r.l.) [1]. The dynamic range of the present prototype is nearly 230 as expected for the VA32HDR2. The required range will, however, be achieved by a new chip developed now.

2. Experiments

We have made a prototype readout unit to which 8 MA-PMT's can be attached [4]. One MA-PMT has 64 anodes and the number of dynodes was reduced from 12 to 8 stages to adjust the amount of input charge to the chip and to keep the dynamic range of PMT as well as possible [8]. Sixteen of Viking chips (VA32HDR2, 32ch for each) were implemented as the front-end circuit and a total of 512 ch is read out with one unit. In order to evaluate performance of the readout unit, we constructed a SciFi detector with the unit as shown in Fig. 1.

Figure 2 shows an outline of the prototype detector for beam test. It has 512 SciFi's of 1 mm square in cross-section for each. We assembled two types of SciFi belts, narrower and wider, consisted of 32 and 64 fibers, respectively. We used 8 narrower belts at shallower layers and 4 wider belts at deeper layers. Lead plates of total thickness of 8 r.l. were inserted between the SciFi belts and lead of 2 r.l. was set at the bottom.

The beam test for shower particles was carried out at T2-H4 beam line at CERN in 2002. We collected 0.60 million events of muon (150 GeV/c), 0.93 million events of electron (10,20,50,100 and 200 GeV/c), and 0.17 million events of proton (350 GeV/c). The test for dynamic range was done by using the heavy nuclei at Heavy Ion Medical Accelerator (HIMAC) in Japan. We obtained 57k events of He (230 MeV/n), 86k events of C (430 MeV/n), 44k events of Si (800 MeV/n), 53k events of Fe (500 MeV/n). For this test, we used the detector in which the lead plates were removed.

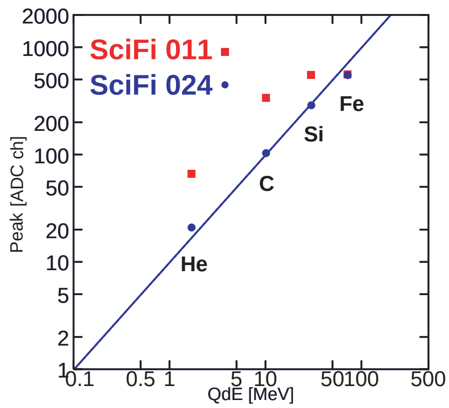

Fig. 3. Peak response to He, C, Si and Fe. Two typical examples are shown.

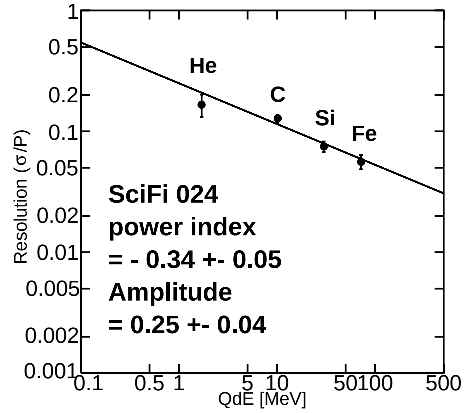

Fig. 4. Peak resolution (σ/peak) of the 24th SciFi for He, C, Si and Fe.

3. Data Analysis and Result

By using the data in HIMAC, we have examined the linearity of the ADC values to the energy deposits. The ADC distributions from the 32 SciFi's at the top layer might be fitted by a Gaussian distribution, and the peak value and the standard deviation, σ, were obtained. The peak value should be proportional to the light output from the SciFi. The output is , however, not proportional to the energy deposit of heavy particle traversing the SciFi due to quenching effect. We estimated the energy deposits, dE, in the SciFi of 1 mm to be 1.70, 10.9, 47.3, 192 MeV by the equation of Bethe-Bloch for He, C, Si, Fe, respectively. By adopting the quenching factor, Q, by Matsufuji *et al.* [3], we acquired the corrected energy deposits, QdE, of 1.70, 10.1, 29.9, 71.6 MeV for He, C, Si, Fe, respectively.

Figure 3 shows two examples of the peak values versus QdE at a high voltage (HV) of -600 V for typical examples. The peak values of the 11th SciFi indicate a saturation effect at larger QdE due to the insufficient dynamic range of the VA32HDR2. As for the 24th SciFi, the linearity is established mostly up to Fe. The linearity is much better with a lower HV of -550 V.

Figure 4 shows the dependence of the resolution (defined as a ratio of the σ to the peak value) on QdE. It can be fitted by a power-law function with an index of -0.34. We might derive the charge (Z) resolution, e.g. the best charge resolution of iron ($Z = 26$) at 1 GeV/n turned out to be $\Delta Z = 0.82$ among the several SciFi's. Figure 5 shows an expected result for the cosmic abundance.

The main purpose of the beam test at CERN was the confirmation of ability of the readout system for high-energy showers. In Fig. 6, we present an example of ADC values for the 512 ch by 200 GeV/c electron and the shower image reconstructed in the detector space. As seen in the figure, the purpose is successfully achieved. We have, furthermore, made some image analyses on

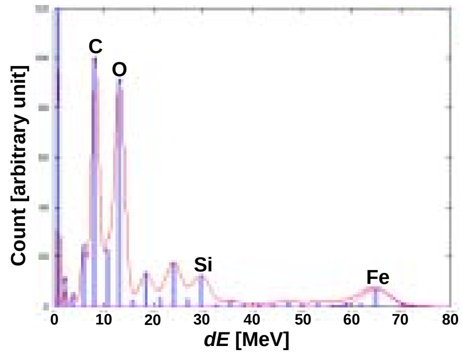

Fig. 5. Expected observation result.

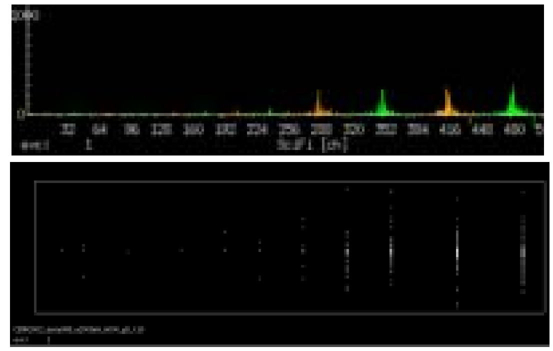

Fig. 6. ADC's and a shower image.

an angular resolution to determine shower axis, concentration of energy deposits around shower axis, and so forth. These detailed results will be presented at the conference after applying the gain corrections.

4. Discussion and Summary

We have successfully developed a prototype system of 512 ch read-out of SciFi with MA-PMT by using a conventional Viking chip of VA32HDR2. The full dynamic range of the chip, 230, is confirmed by the heavy ion beam tests, and the charge resolution by one layer of SciFi is effective to resolve the cosmic abundance. The shower measurement at CERN bring us a conclusion that the readout system is very useful if we can extend the dynamic range. We are developing a new front-end board for the new chip which has the dynamic range exceeding 1000. The board will also include a digitization circuit to reduce a noise as low as possible.

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