A Thin Electronic Calorimeter for Galactic Cosmic Ray Spectral Measurements

J.H. Adams, Jr.[1], N.L. Grigorov[2], M.I. Panasyuk[2], and V.I. Zatsepin[2]

[1]Naval Research Laboratory, Washington DC, USA; [2]Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, Russia

Abstract

In this paper we describe a concept for a balloon-borne electronic calorimeter to measure the individual elemental energy spectra of galactic cosmic rays over a broad energy range. It utilizes application-specific integrated circuits to achieve a large weight and power savings that make its collecting power per unit mass competitive with passive calorimeters.

1 Introduction

A high priority objective in cosmic ray research is to measure the galactic cosmic ray elemental spectra to energies that approach the "knee" in the cosmic ray all-particle spectrum. Such measurements would be used to: test models for cosmic ray acceleration by supernova remnants; determine the parameters needed to extract composition information from air shower measurements; and explore galactic containment of cosmic rays to the highest possible energies.

The best technique for making such measurements over the broad range of energies required is cosmic ray calorimetry [1]. Because of the back-scattered electrons coming from the cascades, an ionization calorimeter (IC) needs to be a picture device. The IC must acquire data on each individual event in a sufficient number of detector elements to obtain a image of the cascade in the calorimeter. This image is needed to project the trajectory of the incident cosmic ray back to the particle identification plane (PIP) at the top of the instrument. This projection must be sufficiently accurate to unambiguously locate the pixel in the PIP containing the track of the the incident cosmic ray. This requirement has lead to the use of passive calorimeters employing photographic materials which provide high resolution images of the cascades. These devices, however, have a detection threshold in the several TeV range and the data they produce is labor-intensive to analyze.

In this paper we describe a concept for an active electronic instrument, based on the Proton and Sokol satellite-borne electronic calorimeters [2,3], with a threshold of of several 10's of GeV. The use of modern electronics makes it possible to construct such an instrument with a large number of active detector elements which has minimal power requirements.

2 The Thin Electronic Calorimeter

Figure 1 shows the conceptual design of the calorimeter. The instrument consists of two parts, the IC and the PIP. We will discuss each of these below.

The IC is the energy measuring element of the instrument. It must must

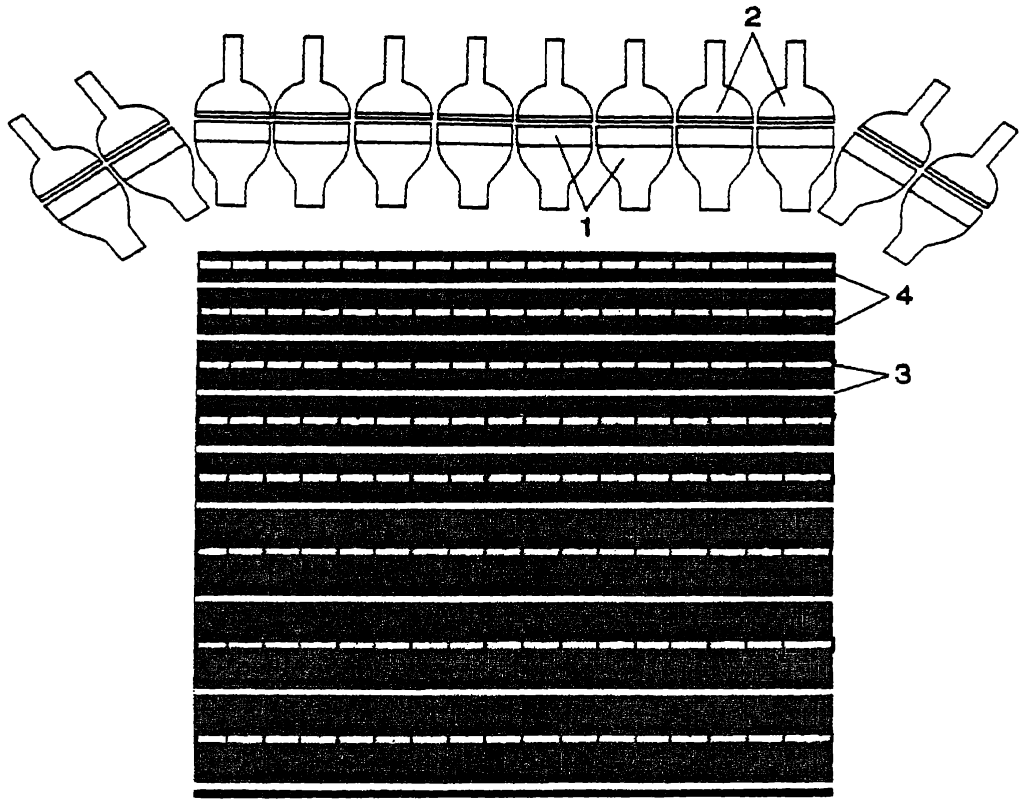

Figure 1: *This figure shows the concept of an instrument for measuring the elemental spectra of high-energy cosmic rays. The instrument consists of: (1)Cherenkov counters for measuring the charge in the* $1 < Z < 10$ *range; (2)scintillator counters for registering charge in the* $6 < Z < 30$ *range; (3)scintillator strips; and (4)absorber of the ionization calorimeter. (Note: this drawing is not to scale)*

be as thin as possible to save weight and yet thick enough to measure the particle energy. Experience has shown that this requires an IC with a thickness 1.5 to 2 proton interaction mean free paths. As shown in figure 1, the IC must be segmented into many absorber layers so that the longitudinal profile of the shower can be observed. It is this profile that gives the location of the initial interaction vertex. Figure 1 shows an IC concept consisting of 16 detector planes, each comprised of 16 scintillator strips. The successive planes are oriented at 90 degrees to eachother in order to form the image of the cascade that is used to project the trajectory of the incident cosmic ray back into the PIP. Each of the scintillator strips is viewed on each end by a photodiode. The specific number of planes and strips per plane will be adjusted using computer simulations.

The PIP shown in figure 1 consists of 144 pixels (the actual number required will be determined from computer simulations). Each pixel is composed of two detector elements, a scintillator and a Cherenkov detector. The Cherenkov detector is made strongly direction sensitive by blackening the top while viewing it from the bottom with a phototube. These detectors are used primarily for protons and helium ions. Their strong directional sensitivity suppresses the signal from back-scattered electrons that are upward bound. The pixels of the PIP are made sufficiently small so that they contain only a few backscattered electrons even in the worst cases. For this reason the signal from ions with $Z \geq 3$ can be measured in the scintillator. The signals of such ions are sufficiently large to be resolved in the presence of a few election signals. Uniform light collection from the scintillator is essential in resolving the atomic numbers of the elements near Fe, therefore a hemispherical light diffusion box is used.

3 Application Specific Integrated Circuits

The instrument concept contains 800 detector elements. Each of these must have analog electronics, also ADC's and trigger logic must be provided. All this can be accomplished with 100 pairs of application specific integrated circuits (ASIC's) which require 70 watts and can be mounted in 6 pc boards. A suitable ASIC pair has been developed for the calorimeter of the WA98 experiment at CERN [4] and is described below.

The preamp ASIC has 8 charge-sensitive pre-amplifiers, each followed by two amplifiers with gains of X1 and X8 respectively. The second of the these covers a dynamic range of 125 and the first extends that range to 1000. The preamp ASIC also contains a pulser and programable trigger logic based on the sum of 16 signals, as the first step in creating a master coincidence. This chip also contains a serial computer bus that permits many of the functions of the chip to be controlled by an onboard computer.

The second chip of the ASIC pair contains 16-sample analog memories. These memories store samples of each of the 16 amplifier outputs at the rate on one every 50 nsec, for a revolving record of 800 nsec. This continues until a master event trigger is received. At that point a 10 bit ADC digitizes two samples from each amplifier outputs The choice of which two samples to digitize is also programmable through the serial interface. One sample before the pulse and a second one at the peak of the pulse are differenced to measure the pulse height. The serial interface is also used to extract the digitized data from the on-chip registers after the digitization is completed.

In addition to the ASIC pairs, the electronics, a logic array to generate the master event trigger and a computer is used to control the ASIC's, collect and compress the data, and handle the telemetry interface. The power requirement of the electronics will be about 80 watts.

4 Discussion

We have presented here concept for an electronic instrument to measure high cosmic ray elemental spectra which is a high resolution picture device using ionization calorimetry. The proposed instrument design is based on experience with the SOKOL satellite and SOKOL data will be used to validate the computer simulations for this instrument. We estimate the instrument will weigh 1 metric ton and require 80 watts. This is within the current capabilities of the long duration balloon program in the US.

The authors would like to acknowledge support from ISF grant NCP000.

References

[1] Murzin, V.S. Prog. in Elementary Particle and Cosmic Ray Physics **9**(1967)247.

[2] Grigorov N.L. JETP Lett **49**(1989)83 and 246.

[3] Akimov, V.V., et al. 11th ICRC, Budapest, **OG-99**(1969).

[4] Wintenberg, A.L., et al., 1995 (private communication)