OG 4.2.28

The Imaging Calorimeter for ACCESS (ICA)

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Abstract

A mission concept study to define the "Advanced Cosmic-ray Composition Experiment for Space Station (ACCESS)" is being sponsored by the National Aeronautics and Space Administration (NASA). The ACCESS instrument complement contains an ionization calorimeter to measure the spectrum of protons, helium, and heavier nuclei up to $\sim 10^{15}$ eV to search for the limit of S/N shock wave acceleration. Several calorimeters are under study, including the "baseline" totally active bismuth germanate instrument and sampling calorimeters utilizing various detectors. The ICA comprises a carbon target and a high atomic number absorber sampled approximately each radiation length (rl) by thin scintillating fiber (SCIFI) detectors. The main features of the ICA instrument concept are described in this paper.

1 Introduction

The Imaging Calorimeter for ACCESS (ICA) is a design study to define a sampling calorimeter for proton and helium spectral measurements up to the "knee" ($\sim 10^{15}$ eV). In ACCESS, energy measurements on heavier nuclei would be made in concert with a transition radiation detector over the calorimeter. The collecting power, energy range, and energy resolution of the calorimeter will be sufficient to detect a predicted break in the proton and helium spectra near 100 TeV. (Lagage,1983). The measurement of the spectra of all elements Z =1-28 would also test multi-source models for cosmic rays (Biermann,1994).

Since the ACCESS calorimeter has a mass allocation of 2700kg and an exposure time (3 years), "total absorption" calorimeters are not practical. A calorimeter that rapidly develops and absorbs the first interaction electromagnetic cascade (along with a fraction of secondary interactions) appears to be the best choice for ACCESS and was selected for ICA. This "ultra thin" approach has extensive heritage in emulsion chambers (Burnett,1986), and more recently the SOFCAL instrument (Christl 1996,1999).

The ICA is a sampling calorimeter employing thin (~0.5mm) scintillating fiber detectors in hodoscopic X,Y planes, spaced approximately each radiation depth throughout the calorimeter. The main components are a carbon target with up to one proton interaction length thickness and lead or tungsten plates, 0.5 to 1 rl thick, with a total depth of 25-60 rl. The optimum configuration of target and absorber will be chosen following an extensive ICA simulation effort (Watts,1999), and calibration of a small ICA model with 450 GeV protons at CERN.

Figure 1 is a schematic of the ICA configuration. Table 1 gives the results of geometry-efficiency factor calculations for several configurations of carbon target and calorimeter depth and area, and which meet the ACCESS mass constraints. These calculations include particles with up to 68^o zenith angle and which interact anywhere in the target. The calculation includes events that interact in the calorimeter that have a cascade path length of >29 rl in the calorimeter. The event numbers given are for a 3-year mission, and a spectral index of 2.7 breaking to 3.1 above 100 TeV. A trade study of energy resolution and event statistics (Watts,1999) will determine the final configurations.

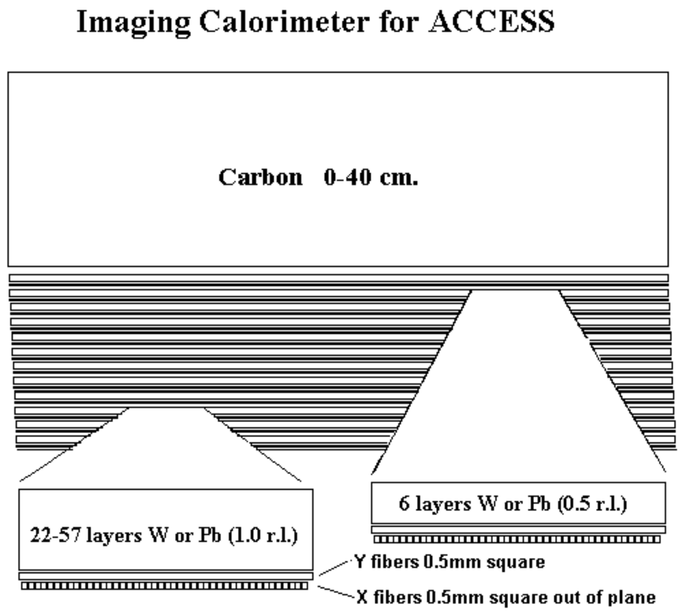

Figure 1 Schematic of the ICA configuration

Target Material	Target Depth(cm)	Instrument Width(cm)	Incident Protons (E>500 TeV)	Interaction Location		Interactions Above 29 rl
1 λ Carbon	40	99	122	Target Calorimeter	71 13	**84**
½ λ Carbon	21	107	145	Target Calorimeter	64 19	**83**
None	0	119	183	Target Calorimeter	00 46	**46**
1 λ Lead	19	84	82	Target Calorimeter	52 7	**59**
½ λ Lead	10	97	111	Target Calorimeter	51 14	**65**

Table 1 Event rates for five different ICA configurations for cosmic ray protons above 500 TeV

2. Design Features of ICA

Thin (0.5mm) square scintillator fibers have been selected as the detector for the initial ICA studies. This is the thinnest practical SCIFI detector with adequate optical attenuation characteristic (~1m) and light output (> 80% detection efficiency for relativistic singly charged particles). Thin detectors introduce the least dilution of the high Z absorber and allow the physically thinnest calorimeter. They also give the best "point back" angular resolution (<1^o) from the cascade to the pixelated primary charge detectors in the target, mitigating effects of back-scattered particles. Sampling within the cascade with high resolution (Watts,1999) could find use in analysis of flight data, such as better separation of primary electrons from proton events. Smaller fibers result in less photocathode area, which reduces the cost and complexity of the readout system.

The 0.5mm square fibers used in the present ICA simulation study have a polystyrene based scintillating core with a 6% total thickness acrylic cladding. Fibers with thinner cladding (2.6% total thickness) have recently been developed and are used in the ICA prototype calorimeter. The simulations presently use hodoscopic XY planes of fibers at 0.5 rl depth for the first 3 rl, and at each following rl. Other hodoscopic configurations, sampling frequency and fiber sizes may result from the simulations, calibrations, and engineering trade-off studies.

The ICA performance simulations show that the dynamic range required to recover fiber signals, from single relativistic particles through 1000 TeV proton cascade maxima, (at various positions and zenith angles) is nearly 10^7:1, as would be expected from the "one MIP per primary GeV rule of thumb" for shower maximum in lead calorimeters. Cascade maximum cores from 10-1000 TeV primaries would be confined to one or two fibers, although the "wings" at cascade maximum cover several cm. The spreading of the cascade among the ~20 fibers reduces the dynamic range requirements somewhat. Several strategies to handle the large dynamic range are part of the fiber read-out trade studies.

The ICA study has selected the image intensifier-CCD camera (IICCD) as the principal candidate for its imaging device, since it is the presently available technology with the best combination of image resolution, dynamic range (~10^3 with standard CCDs), and record of successful application. Fast phosphors with decay times ≤ 10 microseconds and intensifier gating give them adequate speed. The image data handling system is well understood and practical. Instrumenting IICCD's on each end of the fibers offer a dynamic range of near 10^6. Figure 2 shows the candidate IICCD. Figure 3 is a schematic of the ICA calorimeter with the IICCD system attached to the fiber bundles. Non-scintillating light guides would be used from the calorimeter to the IICCD's to reduce image degradation from out-of-geometry particles.

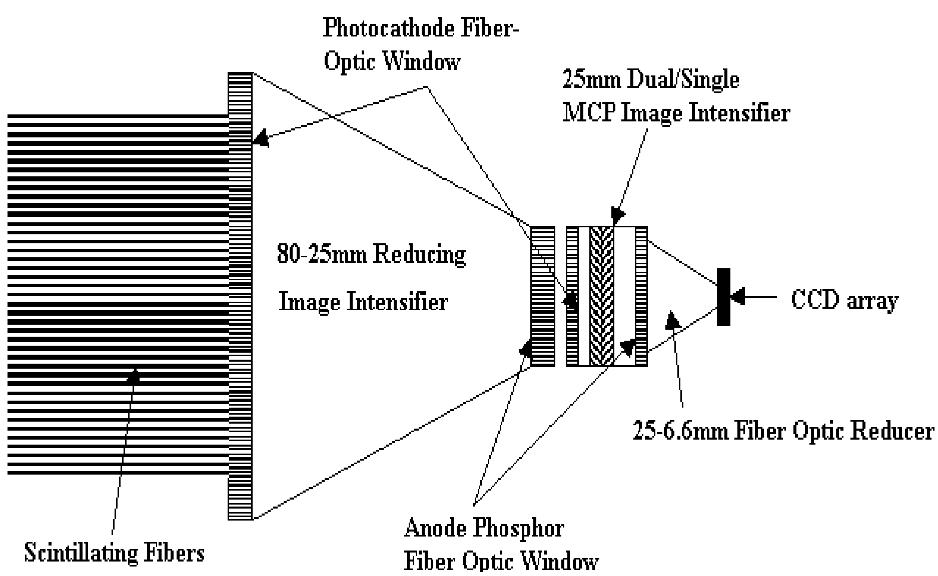

Figure 2 ICA image intensified CCD read-out system.

Alternate approaches to the fiber signal read-out are being examined in the study, with particular attention to dynamic range, imaging capability, engineering complexity and technology readiness. Compact multi-anode photomultiplier tubes (MAPMT) (eg HAMMAMATSU R5900-64) are the closest competitor to the IICCD's. They offer equal (or slightly superior) imaging capability, a practical dynamic range of about 500, a larger electronic system parts count, and more complexity in on-board gain adjustment. If the high resolution imaging requirement for ICA should be relaxed, other read-out options are available.

3 Discussion

The ICA study of a sampling calorimeter for ACCESS utilizes a high Z absorber (Pb,W) and the thinnest practical scintillating fibers to achieve high resolution "imaging" of the shower. The small fibers confer some practical advantages to an "ultra thin" calorimeter, and the utility of high resolution imaging in date analysis is being investigated with simulations. The principal candidate imaging system of IICCD's has a successful history of use in the laboratory, on balloons, and in space. The final configuration of the target, calorimeter, fibers, and read-out system will depend upon the results of the simulations, calibrations and engineering trade-off studies.

4 References

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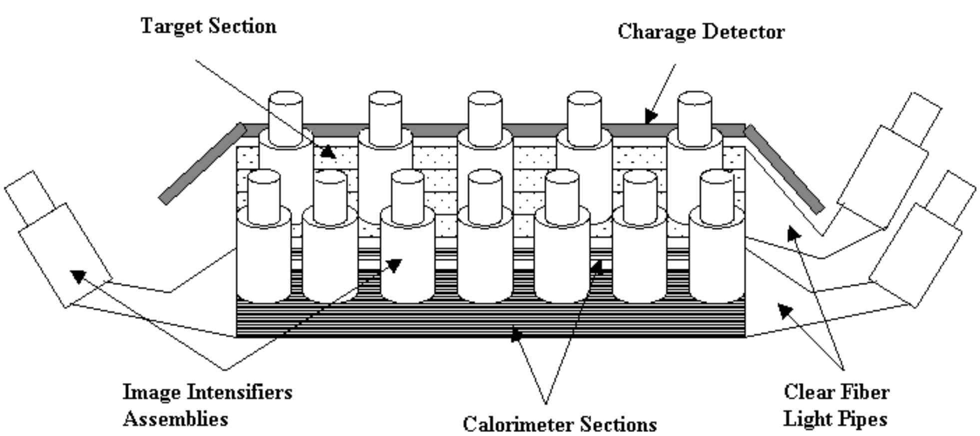

Figure 3 Schematic of the ICA instrument and IICCD read-out.