Simulations of Performance for the Imaging Calorimeter for ACCESS

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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 spectra of protons, helium, and heavier nuclei up to $\sim 10^{15}$ eV to search for the limit of the S/N shock wave acceleration. Several calorimeters are under study, including the "baseline" totally active bismuth germanate instrument and several sampling calorimeters utilizing various detectors. Since direct calibration is not possible, the best approach must be decided from simulations of calorimeter performance. This paper presents some simulation results on the performance of the Imaging Calorimeter for ACCESS (ICA) instrument.

1 Introduction:

The Imaging Calorimeter for ACCESS is a "mission concept study" to define a sampling ionization calorimeter for proton and helium energy spectrum measurements up to the "knee," ($\sim 10^{15}$ eV). Energy measurements on heavier nuclei would be made in concert with a transition radiation detector above the calorimeter. The candidate ICA instrument would contain thin (~0.5 mm) scintillating fiber (SCIFI) detectors in hodoscopic X,Y planes spaced approximately each radiation depth in the calorimeter. The concept builds on experience from the SOFCAL instrument (Christl 1996, 1999). In order to explore the full imaging capability of ICA and its potential benefits in data analysis, it is necessary to simulate each element of the detector system including target, absorbers, and each fiber (including the non-scintillating cladding). The advantages of such imaging for a cosmic-ray calorimeter are discussed in paper OG 4.2.28 of this conference (Parnell, 1999).

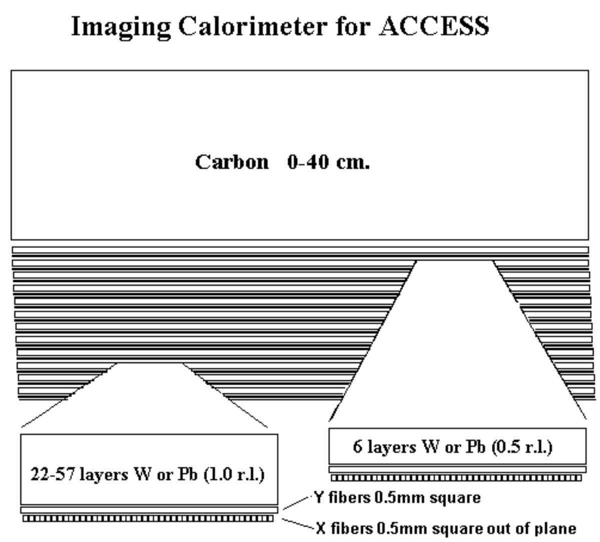

Figure 1. Imaging Calorimeter for ACCESS

The ICA detector geometry was modeled in GEANT (Brun et al, 1984) and interaction/cascade simulations were performed in GEANT / FLUKA. The geometry modeled so far is shown schematically in Figure 1. The exploratory simulations reported here were performed for calorimeters of 25 rl and 60 rl below a carbon target of $0.7\lambda_p$. Since the number of detector elements and array sizes are so large the area of the simulated calorimeter has been confined to 30 x 30 cm, although a Space Station ICA would have an area of ~ 1 m^2. Typical simulation data output array sizes of 50 megabytes result from each "event." The simulations are run on the Silicon Graphics Power Challenger and the Silicon Graphics Orion 2000 computers at MSFC. The GEANT codes and the large number of elements to be stored obviously require much CPU time and massive storage. The average time required for an "event" on the SGI Power Challenger is 800 and 3000 seconds, for a 100 and 1000 TeV event respectively. The run-time has been decreased significantly by creating new efficient hit structures in GEANT /FLUKA.

2 Results on Individual Cosmic Ray Events and Event Average Behavior

In order to explore the potential for imaging calorimetry the full data for each simulated "event" (cascade) is stored. Then the set of events for a given condition (particle, energy, zenith angle, position of entry, etc.) can be analyzed with various methods. Figure 2 shows a cascade from a vertically incident proton at 100 TeV which interacts in the $0.7\lambda_p$ target, and Figure 3 shows the lateral energy deposition at four fiber layers for a 100 TeV proton event. For results presented here the energy deposition is in 0.5 mm square fibers with 6% cladding.

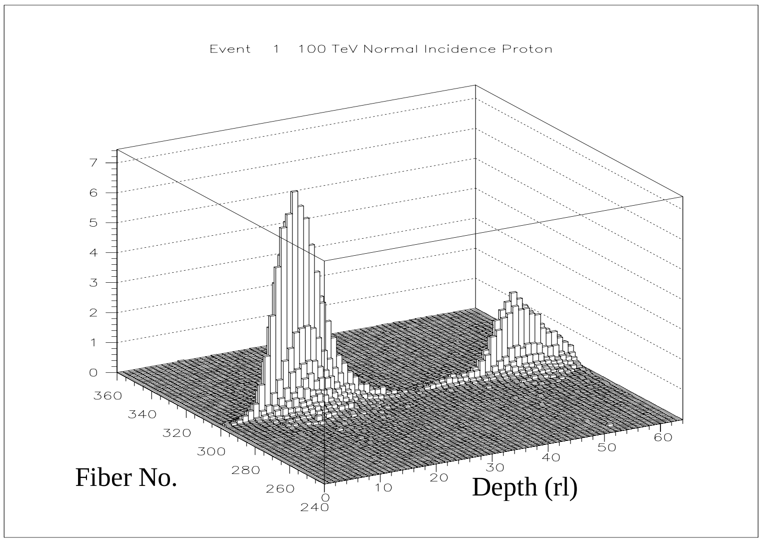

Figure 2. A cascade from a 100 TeV proton in a 60-rl calorimeter; energy per fiber in GeV

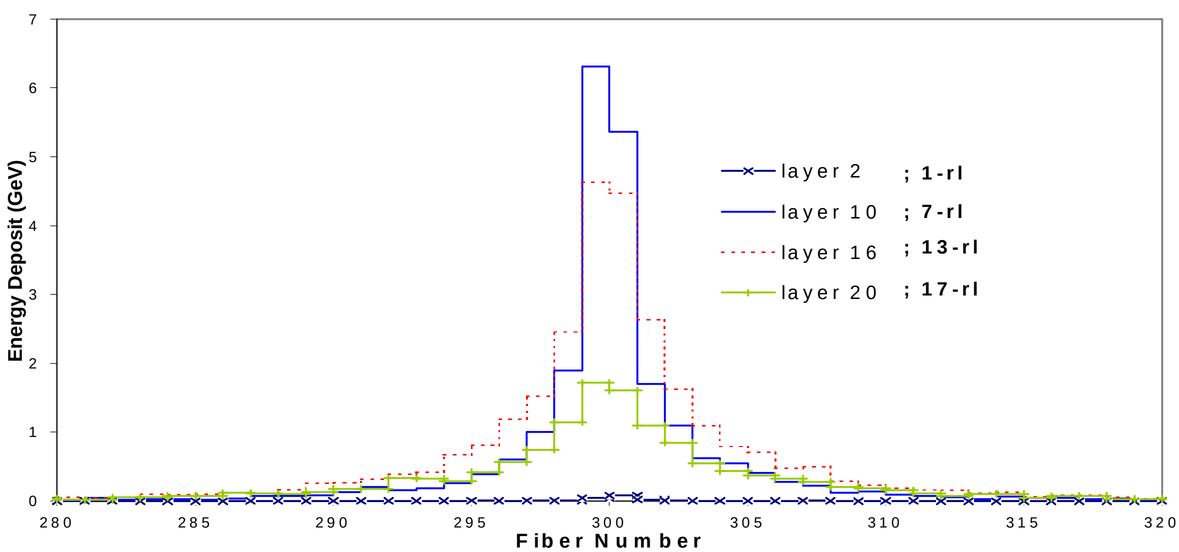

Figure 3. Energy deposition per fiber in GeV at various depths for a 100 TeV proton

Figure 4 shows the normalized average behavior of vertically incident proton cascades at 0.1, 10, and 1000 TeV, indicating that a vertical depth of 25-rl may be adequate for the ACCESS calorimeter.

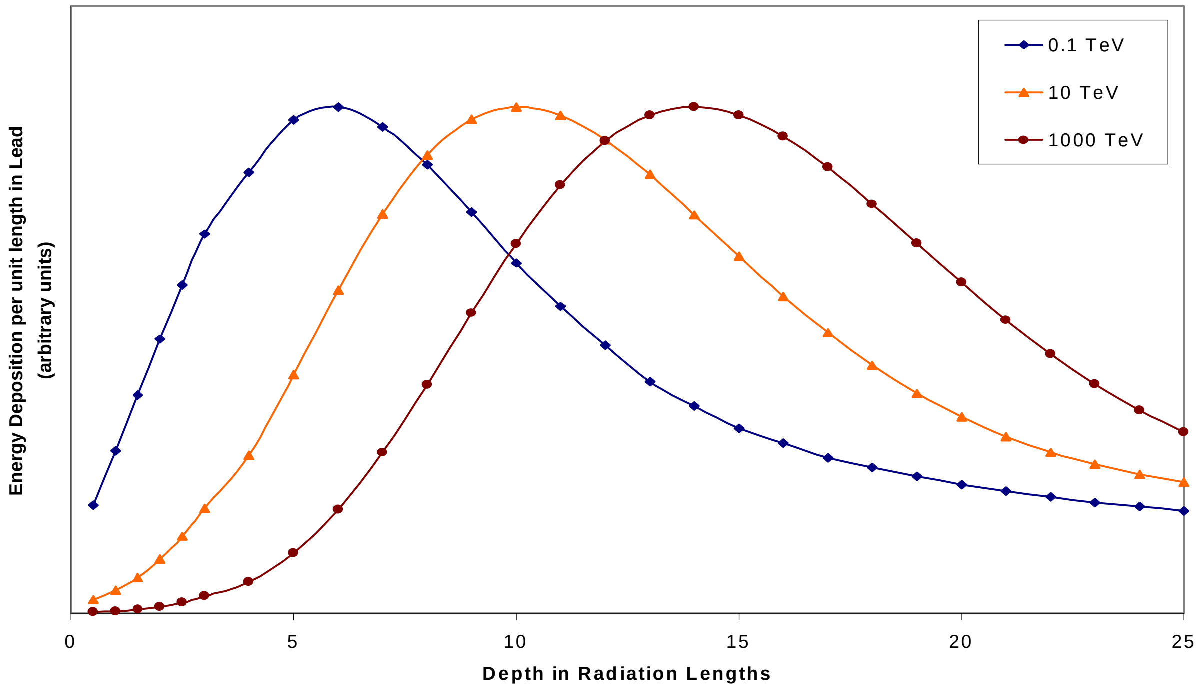

Figure 4. Average shower profiles for proton energies 0.1, 10, and 1000 TeV, with cascade maxima normalized. Deposited energy in calorimeter lead layers.

3 Energy Deposition and Energy Resolution

The mass allowed for the ACCESS calorimeter (2,700 kg), coupled with the need for an adequate exposure factor ($\geq$ 500 m^2 sr-day) dictates a "thin" calorimeter (< $3\lambda_p$), including carbon target. The ICA study explores several signatures of the "size" of the energy deposition in the calorimeter. These include the total energy deposition in the fibers of the calorimeter (ΔE), the maximum energy deposition (height of the cascade development from a Greisen cascade curve fit) and the maximum energy deposition of any fiber in the calorimeter (somewhat analogous to $\sum E_\gamma$ derived from emulsion chamber measurements (Burnett, 1986)). The results of these analyses for vertical cascades are shown in Figure 5 for 25 and 60-rl calorimeters. The 40% energy resolution for the ΔE method meets the ACCESS requirement. We note that σ (ΔE) will vary with the cascade path length (zenith angle). The cascade maximum methods are expected to be independent of zenith angle. The detector response (average energy deposition signature) for each of these methods is linear with primary energy from 0.1 – 1000 TeV (within present sampling statistics).

Except at the lowest energy, there is little difference in the resolution of various shower maximum methods. In particular the resolution based on the shower maximum is no different for a 60-rl calorimeter than for a 25-rl calorimeter. This is expected since the maximum is well contained even with only 25 rl. Also as expected, the ΔE method gives better resolution for both 25 and 60-rl cases, and substantially better resolution with the deeper calorimeter.

4 Discussion

A sample of the present exploratory results have been shown. These results indicate that the ICA configuration used for these simulations will meet the ACCESS energy resolution requirements for a calorimeter depth of 25-rl. The resolution by the ΔE method will improve with zenith angle. For the higher energies the other energy estimation methods might be used to augment event statistics for inclined, deeply interacting events.

Work is in progress to perform isotropic flux calculations for fiber sampling calorimeters from 30 to 60-rl with about 5000 events per energy. Work is also in progress to further determine the resolution of various methods for primary energy estimation, to explore electron versus proton cascade differences, to predict the back scatter of particles into the ACCESS charge detectors, and to study the effect of various scintillating fiber sampling configurations. A statistical study is also underway to define the probability of detecting spectral breaks near 100 TeV, with the break energy, spectral indices above and below the break, number of detected particles and calorimeter energy resolution as parameters.

References

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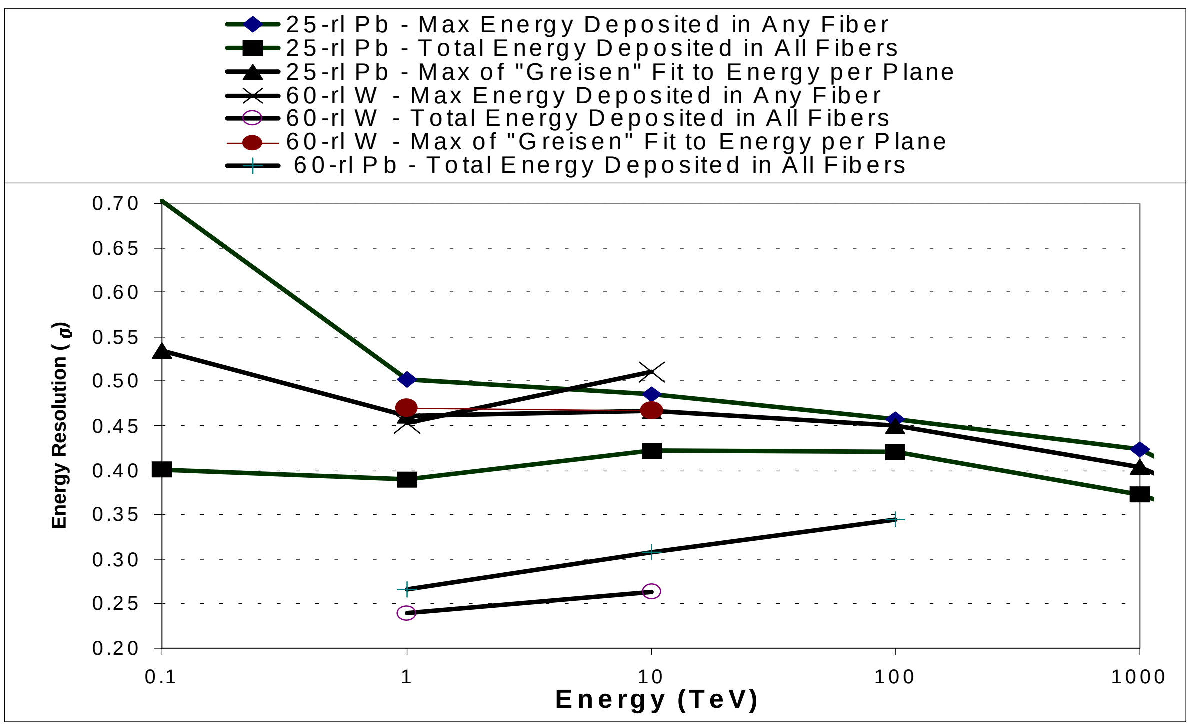

Figure 5. The calculated energy resolution for 25-rl lead and 60=rl lead and tungsten calorimeters, using three different methods for estimating energy.