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A GEANT STUDY OF THE SCINTILLATING OPTICAL FIBER (SOFCAL) COSMIC RAY DETECTOR

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Introduction

Recent energy measurements by balloon-borne passive emulsion chambers (3) indicate that the flux ratios of protons to helium nuclei and of protons to all heavy nuclei decrease as the primary cosmic ray energy per nucleon increases above ~ 200 GeV/n, and suggest a "break" in the proton spectrum between 200 GeV and 5 TeV (1,2,8). However, these passive emulsion chambers are limited to a lower energy threshold of ~ 5 TeV/n, and cannot fully explore this energy regime. Because cosmic ray flux and composition details may be significant to acceleration models (7), a hybrid detector system called the Scintillating Optical Fiber Calorimeter (SOFCAL) has been designed and flown. SOFCAL incorporates both conventional passive emulsion chambers and an active calorimeter utilizing scintillating plastic fibers (6) as detectors. These complementary types of detectors allow the balloon-borne SOFCAL experiment to measure the proton and helium spectra from ~ 400 GeV/n to ~ 20 TeV.

The fundamental purpose of this study is to use the GEANT simulation package to model the hadronic and electromagnetic shower evolution of cosmic rays incident on the SOFCAL detector. This allows the interpretation of SOFCAL data in terms of charges and primary energies of cosmic rays, thus allowing the determinations of cosmic ray flux and composition as functions of primary energy.

Detector Description

SOFCAL consists of four functional detector modules and the electronics required to operate the instrument, and to telemeter and record the data (5).

The upper detector module is a Cerenkov radiator in a diffusion box viewed by six photomultiplier tubes. The radiator is virgin Teflon™ with a refractive index of 1.36 and dimensions of 60 cm X 50 cm X 1.27 cm. The main purpose of this detector component is to resolve the primary cosmic ray as a proton, helium, or Carbon-Nitrogen-Oxygen (CNO) nucleus for lower energy (below ~ 5 TeV/n) events.

The second detector module is the upper emulsion chamber with an area of 50 cm X 40 cm, which consists of two major sub-components: a target section, and a passive emulsion calorimeter. The target section consists mostly of double coated (proton and helium sensitive) emulsion plates, 0.51 mm thick lead sheets, acrylic plates, and dividing layers of paper. Two sheets of plastic nuclear track detectors (CR-39) are used for identifying the charge of higher energy (above ~ 5 TeV/n) or heavy ($Z \geq 6$) primary particles. The target section has 0.11 interaction lengths for vertical protons and 0.9 radiation lengths. The emulsion calorimeter section is composed of five 1.1 mm and ten 1.95 mm thick lead plates separated by double-coated emulsion plates, x-ray films, and sheets of paper. This emulsion section has 0.13 interaction lengths for vertical protons and 4.3 radiation lengths. The x-ray film sets a threshold of ~ 1 TeV on the energy (ΣE_γ) of a detected cascade, thus fixing a lower scale on the observed primary cosmic ray energy of ~ 5 TeV/n. The emulsion plates do not have this limitation, but locating the numerous small cascades randomly distributed throughout the emulsion chamber would require a tremendous amount of microscope scanning without the scintillating fiber hodoscope.

The next detector module is the scintillating optical fiber calorimeter containing a stack of ten 4.0 mm thick lead plates separated by two orthogonal layers of 0.5 mm square scintillating optical fibers. These are BICRON polystyrene base fibers (BC-12) with acrylic cladding and coated with an extramural absorber to reduce signal cross talk between fibers. Two layers of 1.0 mm square scintillating optical fibers near the top and middle of the module serve as triggers and discriminators. Data processing is accomplished by coupling the fiber bundles to two dual-stage image intensifying 8-bit CCD camera systems. This detector module has an area of 50 cm X 50 cm, and has 0.39 interaction lengths for vertical photons and 7.1 radiation lengths.

The final detector module is a thin passive emulsion calorimeter consisting of five 1.95 mm thick lead plates separated by double-coated emulsion plates, x-ray films, and sheets of paper. This detector module has an area of 50 cm X 40 cm, and is 2.0 radiation lengths thick.

Simulation Packages

Aside from thorough experimental testing with beams of known composition and momenta (which could take years!), the best way to determine the propagation of cosmic rays through a complex detector geometry such as SOFCAL (SOFCAL contains over 21,000 detector elements) is via computer-generated simulations. Past SOFCAL simulations have employed a combination of electromagnetic simulators: EGS3 by the Stanford Linear Accelerator Center (SLAC), and SIBATA by the Japanese-American Cooperative Emulsion Experiment (JACEE); and a hadronic simulator, MCM2, also by JACEE. However, this study will utilize the GEANT simulation package, compare with previous studies, and attempt to extend the details of SOFCAL detector simulations.

The GEANT *Detector Description and Simulation Tool* (4) was written by and is maintained by CERN, the European Organization for Nuclear Research. GEANT is designed to be able to simulate all of the dominant hadronic, electromagnetic, and muonic processes in the energy range from 10 keV to 10 TeV. GEANT simulates the following hadronic interactions: decay in flight, multiple scattering, ionization and δ-ray production, hadronic interactions, and Cerenkov radiation. Simulated photonic interactions include: electron-positron pair production, Compton scattering, the photoelectric effect, photo-fission, and Rayleigh scattering. Simulated processes involving electrons and positrons include: multiple scattering, ionization and δ-ray production, bremstrahlung, positron annihilation, Cerenkov radiation, and synchrotron radiation. And simulated muonic interactions include: decay in flight, multiple scattering, ionization and δ-ray production, ionization by heavy ions, bremstrahlung, electron-positron pair production, nuclear interactions, and Cerenkov radiation.

The GEANT detector description package allows a thorough definition of detector materials, tracking parameters, geometries, and cuts. GEANT subroutines permit the definition of any type of cosmic ray, its initial momenta, and decay modes. And the GEANT graphics package allows the visualization of detector components and geometrical dimensions, particle trajectories, and hits recorded in the sensitive elements of the detector. An interactive version called GEANT++ is also available.

Results

For this initial stage of the study, the entire SOFCAL geometry was programmed and linked with the GEANT++ interactive simulation package. Figure 1 is a simulated example of a 400 GeV proton normally incident at the top of the upper emulsion chamber. For clarity, only a 8 cm X 8 cm area of the detector is shown, and the Cerenkov detector module and "filler" materials such as styrofoam, plywood and air are omitted. The solid (red) lines are charged particles and virtually all of the dashed (blue) lines are photons. The shower consists of many photons and charged particles (only distinguishable in the color version). The left frame view is parallel to the x-axis, the right frame view is parallel to the y-axis, and the top of the detector is "up" in both views. Note that some of the square cross-sections of the scintillating fibers are discernible at this scale.

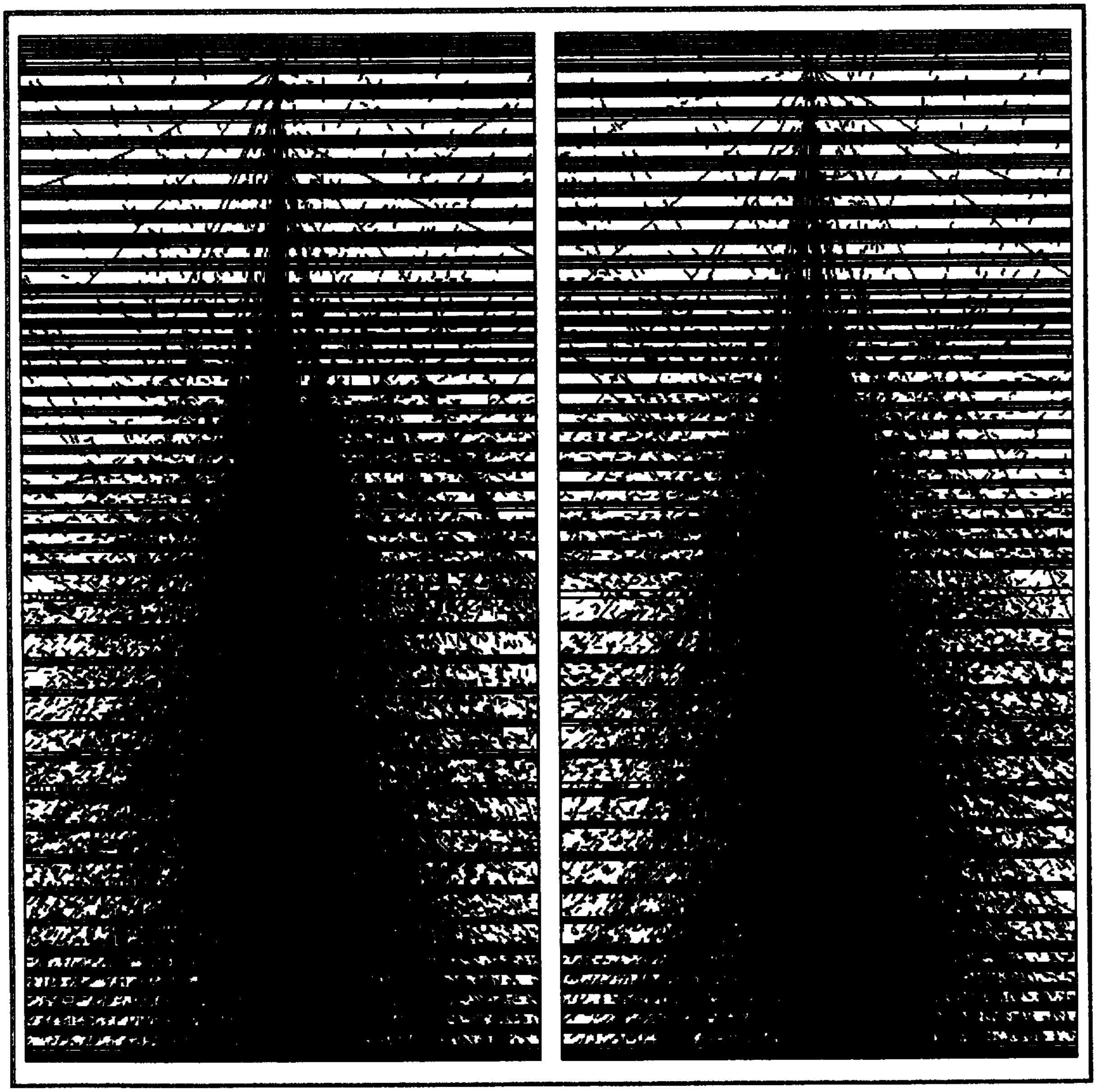

Figure 1 - A GEANT simulation of a 400 GeV proton incident on the SOFCAL detector.

Conclusions

GEANT is a convenient and comprehensive simulation package that can be applied to the study of lower energy cosmic ray detectors. The initial stage of this study highlights only one of GEANT's many capabilities and more detailed simulations of the SOFCAL detector are anticipated.

Proposals are ongoing for the design of and research on the Advanced Cosmic-ray Composition Experiment on the Space Station (ACCESS). Because standard emulsion chamber experiments are not designed for long exposures, at least one of the proposals for ACCESS will utilize a scintillating optical fiber calorimeter. So a modified version of SOFCAL may have a bright future!

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References

1. Asakimori, K. et al., 22nd International Cosmic Ray Conference Papers (Dublin), 2, 97-99 and 57-60 (1992).
2. Asakimori, K. et al., 23rd International Cosmic Ray Conference Papers (Calgary), 2, 21-24 and 25-29 (1993).
3. Burnett, T.H. et al., NIM, A251, 583-595 (1986).
4. CERN, GEANT - Detector Description and Simulation Tool (Geneva) (1993).
5. Christl, M.J., Fountain, W.F., Parnell, T.A., Roberts, F.E., Benson, C., Berry, F.A., Gregory, J.G., and Takahashi, Y., SPIE - The International Society for Optical Engineering Proceedings (Denver), 2806, 155-163 (1996).
6. Connell, J.J., Binns, W.R. et al., NIM, A294, 325-350 (1990).
7. Ellison, D.C. et al., Publication of the Astronomical Society of the Pacific, 106, 780-797 (1994).
8. Muller, D. et al., Ap. J., 374, 356 (1991).