Proceedings of the 30th International Cosmic Ray Conference
Rogelio Caballero, Juan Carlos D'Olivo, Gustavo Medina-Tanco,
Lukas Nellen, Federico A. Sánchez, José F. Valdés-Galicia (eds.)
Universidad Nacional Autónoma de México,
Mexico City, Mexico, 2008

Vol. 2 (OG part 1), pages 75–78

ID 1129

30TH INTERNATIONAL COSMIC RAY CONFERENCE

Comparison of Fluka-2006 Monte Carlo Simulation and Flight data for the ATIC detector

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Abstract: We have performed a detailed Monte Carlo (MC) simulation for the Advanced Thin Ionization Calorimeter (ATIC) detector using the MC code FLUKA-2006 which is capable of simulating particles up to 10 PeV. The ATIC detector has completed two successful balloon flights from McMurdo, Antarctica lasting a total of more than 35 days. ATIC is designed as a multiple, long duration balloon flight, investigation of the cosmic ray spectra from below 50 GeV to near 100 TeV total energy; using a fully active Bismuth Germanate(BGO) calorimeter. It is equipped with a large mosaic of silicon detector pixels capable of charge identification, and, for particle tracking, three projective layers of x-y scintillator hodoscopes, located above, in the middle and below a 0.75 nuclear interaction length graphite target. Our simulations are part of an analysis package of both nuclear (A) and energy dependences for different nuclei interacting in the ATIC detector. The MC simulates the response of different components of the detector such as the Si-matrix, the scintillator hodoscopes and the BGO calorimeter to various nuclei. We present comparisons of the FLUKA-2006 MC calculations with GEANT calculations and with the ATIC CERN data and ATIC flight data.

Introduction

High energy cosmic rays are the only sample of matter from distant regions of our galaxy and possibly elsewhere in the universe, that can be directly observed by balloon-borne or space-based experiments. Understanding the cosmic ray composition, their origin and acceleration, how they propagate, is a fundamental problem with a major impact on our knowledge of the universe. The Advanced Thin Ionization Calorimeter (ATIC) is a balloon-borne experiment designed to investigate the elemental spectra of protons and other nuclei up to $Z = 26$, for energies from 50 GeV to 100 TeV, with a statistical accuracy of better than 30% for protons at the highest energy.[1] The ATIC balloon payload was launched to an altitude of 36 km above sea level from McMurdo, Antarctica in December 2000 and December 2002. The total of these two flights lasted more than 35 days.

In this paper, we discuss a data analysis tool we have developed based on FLUKA-2006. This code provides the capability of simulating high energy interactions well beyond 100 TeV, the highest energy measured by the ATIC detector.

ATIC Detector

The ATIC detector shown in figure 1 is comprised of a fully active $50\ cm \times 50\ cm \times 20\ cm$ deep BGO calorimeter, preceded by three 10 cm thick graphite targets sandwiched between panels of scintillator hodoscopes, having an outwardly projective angle of 24 degrees. It is equipped at the top with a large mosaic of silicon detector pixels capable of charge identification. The construction and commissioning of the detector, the data acquisition system and the software development for the detector, and detector calibration are discussed elsewhere [1].

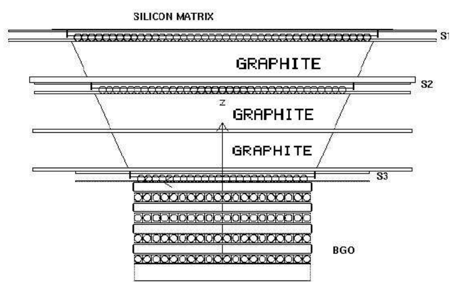

Figure 1: ATIC detector.

GEANT-3.21, ATIC Monte Carlo and CERN Data

We have written a MC code for the ATIC detector using GEANT-3.21, that has the capability to generate events with energies less than 20 TeV for hadrons. Figure 1 was generated by GEANT-3.21 using a geometry input file for the ATIC detector. In 1999, the ATIC detector was calibrated using test beams at CERN. The detector was illuminated with 375 GeV protons, 300 GeV electrons, 150 GeV electrons and 150 GeV pions. Figure 2 shows the energy spectra from data and MC simulations for 375 GeV protons. The data and the simulated results agreed well as expected. Note the MC calculations have been performed for the same number of events as the data. GEANT is widely used in high energy physics for the simulation of primary

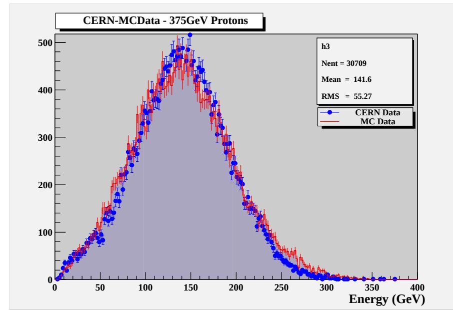

Figure 2: Comparison of CERN 375 GeV proton data with GEANT. The Mean value and the RMS value for MC data(Red line) are 141.64 and 55.27, respectively. The Mean value and the RMS value for CERN data(Blue line) are 138.36 and 50.35, respectively.

particles such as p, e and μ. GEANT has some of limitations for simulations at very high energies (10's TeV to PeV range) and cannot provide simulations of heavy ions.

One of the primary goals of ATIC is to determine the indices for the energy spectrum of heavy ions from He, C, N, O to Fe up to very high energies. For this purpose we chose the FLUKA MC code.

Description of the FLUKA Code, and ATIC-FLUKA

FLUKA is a multi-particle, multipurpose Monte Carlo code used in many different fields such as medical physics, astrophysics and high energy physics. It has been tested and verified with real data[2][3][4]. One of the main reasons for using FLUKA for ATIC is the ability to transport heavy ions at very high energies, approximately 10 PeV. We implemented the ATIC geometry in the FLUKA code. Events were randomly generated in position, direction and energy above the Si-matrix plane. An energy dependence of $E^{-2.7}$ was assumed. Figure 3 shows a 150 GeV proton vertically incident on ATIC very close to the center on top of the detector.

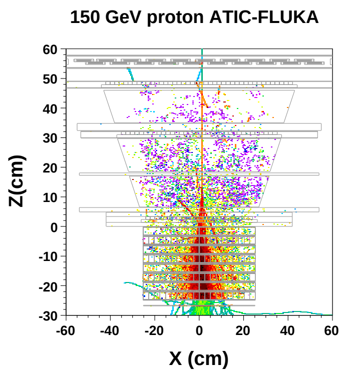

Figure 3: A 150 GeV proton interacting in the ATIC detector. Colors in the plot denote different densities of energy deposit in the detector.

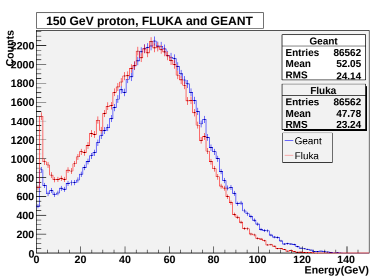

Figure 4: Comparison of the deposited energy spectra in the BGO calorimeter for 150 GeV protons from GEANT and FLUKA calculations.

Heavy Ion Simulation

One of the primary goals of ATIC is to determine the indices for the energy spectra of nuclei such as He,C,N,O up to Fe. For this purpose, we implemented the DPMJET-3 interface to the FLUKA input card file.

Event Generation and Reconstruction

We have written a user code to generate events randomly according to the above power law $\frac{dn}{dE} = CE^{-2.70}$ with energies ranging from 10 GeV to 100 TeV. We ran the ATIC-FLUKA MC for 1,000,000 protons with energies ranging from 50 GeV to 100 TeV. After applying a fiducial volume cut on the particle trajectory 2.5 cm from the edge of the calorimeter in x and y, 250,000 events remained. Figure 5 shows the distribution of the energy deposited in the BGO calorimeter for the events passing the fiducial volume cut. The resulting MC generated data are in the same format as the actual data and can be analyzed in the same manner.

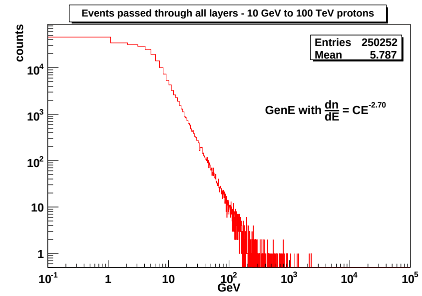

Figure 5: Energy deposited in the BGO calorimeter by events satisfying the fiducial volume cut.

ATIC-FLUKA and Flight Data

The reconstruction of the trajectory of flight data was obtained from a χ^2 fit using the weighted pulse-heights in the BGO crystals. The trajectory was them improved using the position of the hit pixel in the Si-matrix plane as well as any hit scintillator along its intersection with the hodoscope. The charge in the Si pixel with angle correction was compared with the response of FLUKA MC for Si-pixel for elements from H to Fe. This method of analysis readily provides the radiative and relativistic corrections in Bethe-Bloch equation, which is used to determine the Z value of the incident particle on the detector. Also, the detector has a threshold cut of 50 GeV energy deposition in calorimeter. The study of ATIC-FLUKA show that the incident energies of different particles are different for the same threshold energy. Therefore, after determining the deposition energy in the calorimeter for a certain particle, we use the FLUKA calculation to find the primary energy of the particle. Figures 6, 7, and 8 show the primary energy versus the energy deposited in the BGO

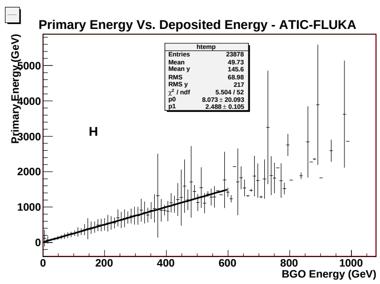

Figure 6: Primary energy versus energy deposited in the BGO calorimeter for H.

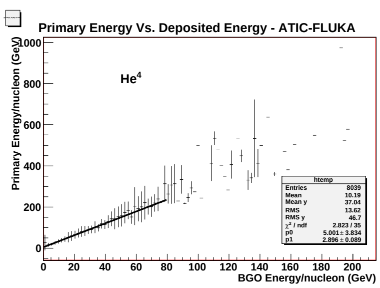

Figure 7: Primary energy versus energy deposited in the BGO calorimeter for He.

calorimeter. The study of elements from H to Fe shows that the fitting parameters (slope and the constant) of primary energy per nucleon versus energy deposit in the calorimeter, are different for different elements.

Conclusion

A simulation code was developed for the ATIC detector using FLUKA-2006. This code can be used to simulate ATIC events for very high energy primary particles (p,e, and μ etc.) and heavy ions. The FLUKA-2006 code provides simulation of particles to the maximum energy $\approx$ 100 TeV measured by ATIC. We compared MC data from standard GEANT-3.21 and FLUKA below 20 TeV. The agreement is reasonable. This ATIC-FLUKA MC code provides an important tool for the analysis of the ATIC flight data.

Acknowledgments
We like to thank Richard L. Imlay for many wonderful discussions regarding this paper. This work was supported in the United States by a grant from the National Aeronautics and Space Administration (NASA), to Southern University under the grant number NNGO4WC06G.

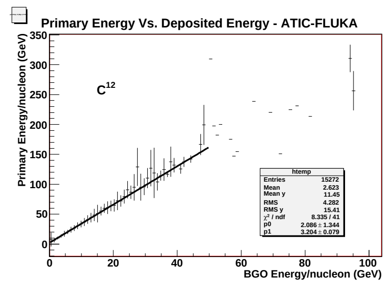

Figure 8: Primary energy versus energy deposited in the BGO calorimeter for C.

References

[1] T. G. Guzik, J. Adams Jr., J. Ampe et. al., The Advanced Thin Ionization Calorimeter (ATIC) for studies of High Energy Cosmic Rays, in proceedings of the 26th ICRC, eds. D. Kieda, M. Salamon and B. Dingus, 5, pp 9-12, Salt Lake City, 1999.

[2] A. Fasso', A. Ferrari, S. Roesler, P. R. Sala, G. Battistoni, F. Cerutti, E. Gadioli, M.V.Garzelli, F. Ballarini, A. Ottolenghi, A. Empl, and J. Ranft, "The physics models of FLUKA: status and recent developments", computing in High Energy and Nuclear Physics 2003 conference (CHEP2003), La Jolla, CA, USA, March 24-28, 2003, (paper MOMT005), eConf C0303241, arXiv:hep-ph/0306267.

[3] A. Ferrari, P. R. Sala, A. Fasso', J. Ranft "Fluka : A multi-particle transport code (Program version 2005)", CERN-2005-00X, INFN TC_05/11, SLAC-R-773, 31 August 2005.

[4] http://www.fluka.org