High Energy Cosmic Ray Electron Spectra measured from the ATIC Balloon Experiment

J. Chang,[1,2] W. K. H. Schmidt,[2] J.H. Adams,[5] H.S. Ahn,[4] G. Bashindzhagyan,[7] K. E. Batkov,[7] M. Christl,[5] A.R. Fazely,[6] O. Ganel,[4] R. M. Gunasingha,[6] T.G. Guzik,[3] J. Isbert,[3] K.C. Kim,[4] E. Kouznetsov,[7] M. Panasyuk,[7] A. Panov,[7] E.S. Seo,[4] N. Sokolskaya,[7] J.Z. Wang,[4] J.P. Wefel,[3] J. Wu,[4] V. Zatsepin [7]

(1) Purple Mountain Observatory, Chinese Academy of Sciences (CAS), China
(2) Max-Planck-Institut für Aeronomie, D-37191 Katlenburg-Lindau, Germany
(3) Louisiana State University, Baton Rouge, LA 70803
(4) University of Maryland, College Park, MD 20742
(5) Naval Research Laboratory, 4555 Overlook Ave., S.W. Washington
(6) Southern University, Baton Rouge, Louisiana 70813
(7) Moscow State University, Moscow 119899, Russia

Abstract

The Advanced Thin Ionization Calorimeter Balloon Experiment (ATIC) is specifically designed for high energy cosmic ray ion detection. From simulation and a CERN beam test exposure we find that the design consisting of a graphite target and an energy detection device, a totally active calorimeter of BGO scintillator, gives us sufficient information to distinguish electrons from protons up to the TeV energy range. Balloon observations were successfully carried out over Antarctica in both 2000/2001 and 2002/2003 for a total of more than 35 days. This paper presents preliminary results on the spectrum of high energy electrons observed in the first ATIC flight.

1. Introduction

Up to now, emulsion chambers (EC) have been most successful in observing the absolute flux of electrons above 100 GeV. However, the EC technique is very difficult, as electrons are found by naked-eye survey of emulsion plates. It is not easy to find electrons in a large amount of background tracks, especially for long time exposure. ATIC is an ionization calorimeter for the measurement of the composition and energy spectra of cosmic rays including heavy primaries up to very high energy (100 TeV). It consists of a target of 3/4 proton interaction lengths (30 cm of graphite plus scintillators and other materials) followed by about 18 radiation lengths (20 cm, equivalent to about 0.9 proton interaction lengths) of Bismuth Germanate (BGO) scintillator consisting of an assembly of 2.5 cm x 2.5 cm x 25 cm bars viewed individually by a PM tube each [1,2]. From beam tests

pp. 1817–1820

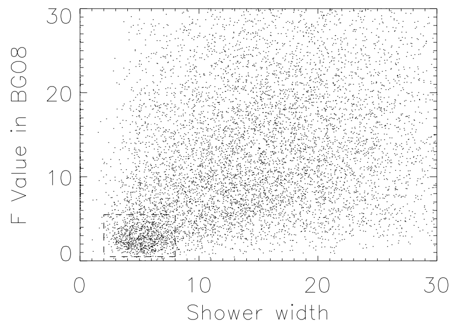

Fig. 1. All singl charged 'good geometry' events of 50-100 GeV after χ^2 cut.

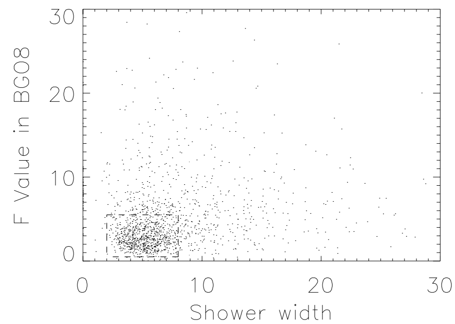

Fig. 2. After χ^2 cut, shower width of BGO2 cut and F value of BGO7 cut.

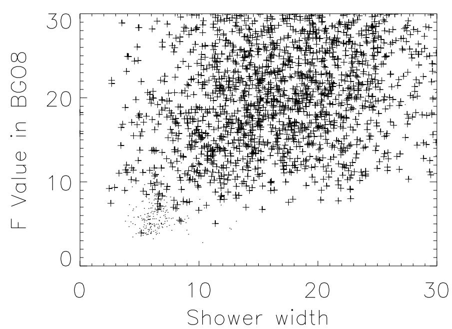

Fig. 3. Dot: 150GeV electrons, plus: 375 GeV protons, from CERN test.

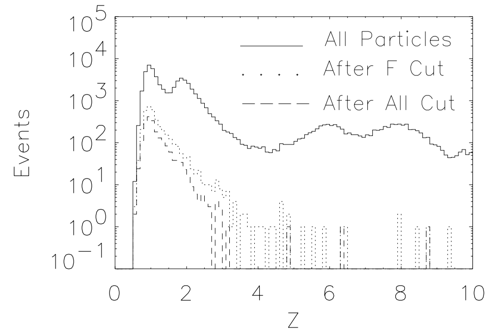

Fig. 4. Charge distribution from silicon detector

at CERN and simulation computations we find that ATIC can observe the cosmic ray electron spectrum up to at least 1 TeV by identifying the shower differences between electrons and protons [3]. Balloon observations were successfully carried out over Antarctica in both 2000/2001 and 2002/2003 for a total of more than 35 days. This paper presents preliminary results on the spectrum of high energy electrons observed in the first ATIC flight.

2. Electron event selection

First we compute the trajectory of the incoming particle from the three dimensional shower information inside the calorimeter. Because of backscattering we did not use the top plastic scintillator information. Then we try to fit the longitudinal shower curve of an event with a particular energy deposit to the average shower curve corresponding to an electron event of the same total energy deposit. By requiring a goodness of fit as expressed by χ^2 smaller than 1.5 per degree of freedom we lose several percent of the electrons but reject about 60% of the protons. Second we make use of the lateral distribution (shower width) of the energy deposit in the first and second BGO layers. The shower width is expressed as the r.m.s. value which is calculated in each individual layer around the scintillator bar with the highest energy deposit. From simulation and the CERN beam test we find that the shower width difference between electron and proton induced showers is very clear in the first and second layers of the BGO. In a next step we look at the last two layers BGO7 and BGO8. We assign a parameter $F = (En/Sum) * r.m.s.^2$ to the shower in BGO7 and BGO8, where En is the energy deposit in that layer, and Sum is the total energy deposit. According to the CERN calibration it is very powerful for proton rejection.

Figure 1 and 2 are scatter plots which show two steps of our method to isolate electrons (50 to 100 GeV total eneregy deposit). There we plot the shower width in BGO1 on the x-axis, and the F-value in BGO8 on the y-axis. Figure 1 shows all singly charged ($Z \leq 1.5$) 'good geometry' events, i.e. events with tracks that pass through the top and bottom of ATIC, after rejecting the most obvious non-electron events by virtue of the χ^2 criterion. The events in the island in the lower left corner are mostly electrons; that is borne out well by CERN beam test results shown in Fig.3 (the energy deposit range in BGO of protons and electrons is the same). One cannot expect exact congruence between Fig.s 1 and 3 because at CERN we had monoenergetic beams impinging perpendicularly on the front surface of ATIC, while in flight we have isotropic incidence of particles from wide energy spectra; but qualitatively it is clear that electron and proton events occupy clearly different areas in the scatter plot. Figure 2 shows what is left after application of cuts on shower width in BGO1, and on F-value in BGO7. About 70 % of the electrons are still there but most of the proton induced events have been rejected. Any extension of the proton population distribution into the electron 'island' area is obviously small as compared to the electron population. Our final cut on the data is the dashed line rectangle. Everything inside we assume to be electron like events, and our last task is to find out quantitatively how many of these may be fake events really caused by protons.

On top of ATIC there is a silicon matrix detector to measure the charge of the incident particle. Figure 4 shows the charge distribution observed in that detector for all ATIC events. Several features are clearly discernible, e.g. the He (alpha particle) peak and peaks around charge 6 and 8 corresponding presumably to primary C and O nuclei, respectively. We now apply the same procedure as in Fig1-2 without making use of the charge information in any way. It can be seen that after the F-cut more than 99% of the heavy primaries (charge above 3) have been rejected; even the He peak cannot be found with statistical significance. After step by step selection it can be seen that in the last charge distribution only very few counts of heavier primaries (4 out of 10300 events) are left. There

Table 1. Electron flux at the top of the atmosphere

Energy (×100GeV)	2-3	3-4	4-6	6-8	8-10	10-15
Observed Ne	89	28	13	6	3	2
Expected Ne	89	28	19	6.1	2.67	2.67

are two more charge detectors with somewhat lower charge resolution on top of the target, Scintillators 1 and 2; the result (not shown here) from them looks very similar to that of the silicon matrix. From the few heavy primaries left we can determine a rejection rate or left-over fraction of the nucleonic component quantitatively. Assuming now that heavy primaries and protons are rejected in the same proportion due to the similarities in their shower development, we estimate the background level due to protons in the electron observation as a function of energy as statistics allow. By this way at 150 GeV about 5 % of the 'electron events' are presumably due to protons. That agrees with the value as derived from the CERN calibration as well as simulations [3].

3. Observation result

Table 1 shows the electron flux on the top of the atmosphere. For comparision we get the expected flux on the top of the atmosphere from emulsion chamber observations including secondary electrons. After considering the different flight altitude and geomatry factor, the emulsion chamber data are normalized to the flight data [4]. It can be seen that the electron flux from ATIC agrees with the emulsion chamber observations well. Detailed cosmic ray electron fluxes will be published later.

4. Summary

This paper presents preliminary results on the spectrum of high energy cosmic ray electrons observed from the first ATIC flight; it agrees with the Emulsion Chamber observational results.

This work was supported by the exchange program between the CAS and the Max-Planck-Society. J. Chang thanks the funding agency: Ministry of Science and Technology of China (2002CB713905, 2002AA732021, 2002AA732022).

1. Guzik T. G. 1999, Proc. 26th ICRC 5 6
2. Ganel, O. et al. 2001, AdSpR 27, 819
3. Schmidt, W. K. H. 1999, Proc. 26th ICRC 5, 41
4. Nishimura, J. et al. 1980, ApJ 238, 394