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The Electron Spectrum above 20 GeV Measured by ATIC-2

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The Advanced Thin Ionization Calorimeter (ATIC) Balloon Experiment has been flown from McMurdo, Antarctica in 2000-01 (test flight) and 2002-03 (science flight). ATIC is composed of a segmented BGO calorimeter following a carbon target with scintillator tracking layers and a Silicon matrix detector at the entrance. ATIC measures the composition and energy spectra of the nuclei plus electrons. We present the electron spectrum derived from the ATIC-2 science flight, from 20 GeV to 1.5 TeV, and compare it to existing very high energy measurements from emulsion chambers and to the results of galactic propagation calculations. The good energy resolution and high statistics in the ATIC data allow detailed astrophysical interpretation of the results.

1. Introduction

Cosmic ray electron (including positron) observations have been carried out by many different instruments during the last 40 years. Because of their low intensity (below 0.01 of the proton flux), the accuracy of the energy spectrum is still not sufficient. At high energy (above hundreds of GeV), only Emulsion Chamber (EC) experiments have been successful, as magnetic spectrometers are limited by the field intensity and can not extend their energy sensitivity to hundreds of GeV.

ATIC is an ionization calorimeter for measurement of the composition and energy spectra of cosmic rays including heavy primaries up to 100 TeV. A full description of the instrument can be found in separate papers[1, 2]. Very briefly, ATIC consists of a graphite / plastic scintillator target section of 3/4 proton interaction lengths (int.l.), followed by about 18 electron radiation lengths (r.l.) of Bismuth Germanate (BGO) scintillator. The graphite target, comprising only 1.6 r.l., is there to force as many protons and heavier nuclei as possible to interact early in the instrument so that the conditions for the ensuing shower development are similar for the majority of the events.

From beam tests at CERN, along with simulations, we find that ATIC can observe the cosmic ray electron (including positron) spectrum by identifying the shower differences between electrons and protons. While identifying about 85% of electrons as such, only about 2 in 10,000 protons (@ 150 GeV) will mimic electrons. For high energy electron observationS from balloons, another background is gamma-rays produced in the residual atmosphere. Because of backscattering, some of these atmospheric gamma-rays will mimic electrons. At the top of ATIC, there is a silicon matrix detector plus two layers of plastic scintillator strips which act as charge detectors. If we use these charge detectors as a segmented anticoincidence detector, ATIC can observe electrons and atmospheric gamma-rays at the same time. Because gamma-ray showers are very similar to electron showers, we can use gamma-rays as a shower calibration for the electron event selection. In the 2000/2001 ATIC antarctic test flight, the electron observation ability has been checked very well. This paper presents the spectrum of high energy electrons observed in the second ATIC flight (2002/2003).

2. Electron event selection

After trajectory reconstruction, most of the backgrounds incident on the sides of ATIC have been rejected. We then select, as electron candidates, events with single charge and a shower performance like gamma-rays. Fig.1 shows the shower parameter distribution in X-Z plane and Y-Z plane for 'gamma-ray like' events and 'electron-like' events. The peaks at the left of the histograms are the electron or gamma-ray 'signal', and the shower parameter distribution for 'electron-like' and 'gamma-ray like' events agree very well.

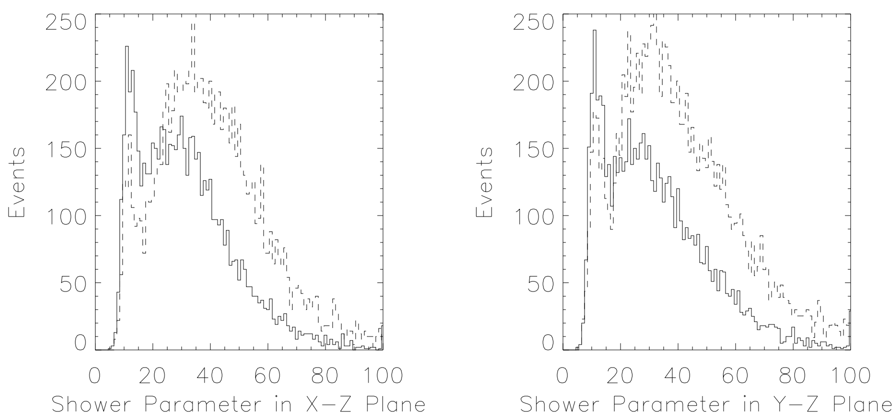

Figure 1. The shower parameter distribution in X-Z plane (top) and Y-Z plane (bottom) for 'electron-like' (solid line) events and 'gamma-ray like' (dashed line) events from 100 GeV to 200 GeV

To reduce the atmospheric electron background, the zenith angle of the shower axis is constrained to be less than about 37 degree (cos(theta) $\geq$ 0.8). In addition, to reduce the atmospheric gamma-ray background some of the BGO crystals along the edge of the calorimeter are used as a segmented anticoincidence. Within these limits we find the electron detection efficiency above 50 GeV is a almost constant 84%. For the ATIC-2 flight, the total observation time is about 396 hours, and the geometry factor is about 0.14 sr.m^2.

On top of ATIC the silicon matrix detector is used to measure the charge of the incident particle. Fig.2 shows the charge distribution observed in that detector for all good geometry ATIC events (energy deposit above 50 GeV) and peaks at charge 2 (He), 6 (C), and 8 (O) are clearly seen. After electron selection we find that almost all such heavy ions have been rejected and the remaining charge distribution agrees well with that measured for muon events. One should note for this background study we did not set any cut for the charge detector. The proton backgrounds can be estimated from fig.2, after considering the shower difference between proton and heavy ions from the flight data. It is about 1/300 for proton energy deposit spectrum. Figure 3 shows the measured electron fluxes together with the estimated background at flight altitude.

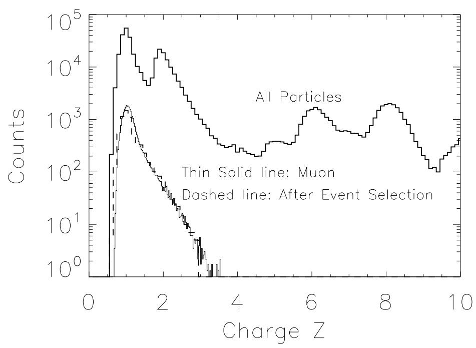

Figure 2. Charge distribution from the Silicon matrix detector.

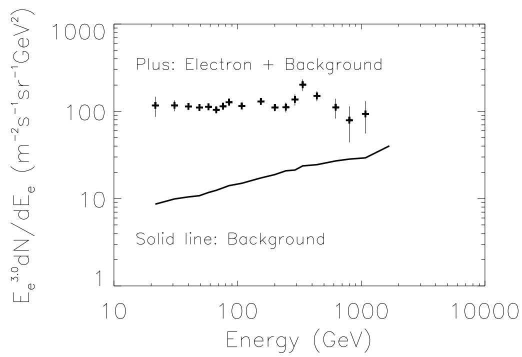

Figure 3. The ATIC electron flux and background at flight altitude.

3. Electron Spectrum

After subtracting the backgrounds (proton, secondary atmospheric electrons and atmospheric gamma-rays), we can calculate the absolute primary electron spectrum at the flight altitude. The secondary electron (including positron) and gamma-ray backgrounds are calculated by FLUKA2002 [3, 4]. According to present measurements (AMS, BESS below 100 GeV, ATIC above 100 GeV), we assume the proton flux is $1.75E^{-}2.75$ (m^2 s sr$)^{-}1$, and that the heavy ion contribution is 0.2 [5]. The calculated gamma-ray flux at flight altitude agrees well with both ATIC and EC measurements.

The residual atmosphere above ATIC during flight is 5.18g/cm^2. From simulations we find that, if the primary spectrum has the form of a power law $E^{-\alpha}$, the detected spectrum at this altitude retains the same power law but will be reduced in intensity by a factor 0.78. This value agrees with that Nishimura calculated for their EC experiment [6].

Because the energy resolution for ATIC is much better than previous detectors, 2% at 150 GeV, the 'spillover'of the events in adjacent energy bins can be neglected. According to the spectrum shape at flight altitude, we assume the spectrum index is -3.0 to get the mean energy in each energy bin. This energy spectrum is then corrected by the factor 1/0.78 to get the spectrum at the top of atmosphere, which is shown in Fig.4. Below 100 GeV, ATIC agrees well with AMS, HEAT, and BETS results. Above 100 GeV, the ATIC measurement agrees, in general, with that from the EC experiment.

4. Discussion

Some authors have calculated the electron spectrum by using a diffusion model[11] and considering the effects of nearby sources. Fig.5 shows the electron spectrum from ATIC-2 compared with this model. If we assume that supernovae occur uniformly on the Galactic disk at the rate of 1/40 year, the ATIC-2 electron spectrum agrees with this model very well except around 300 to 400 GeV where a "bump" appears in the ATIC-2 observations.

According to present models, the electron spectrum should be smooth with no prominent features in the high energy regime, except possibly above 1000 GeV due to the effects of nearby sources. However, some dark

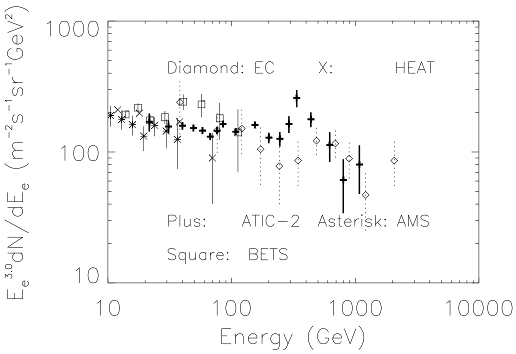

Figure 4. Electron Spectrum at the top of atmosphere, AMS Data [7], HEAT Data[8], BETS Data [9], EC Data[10]

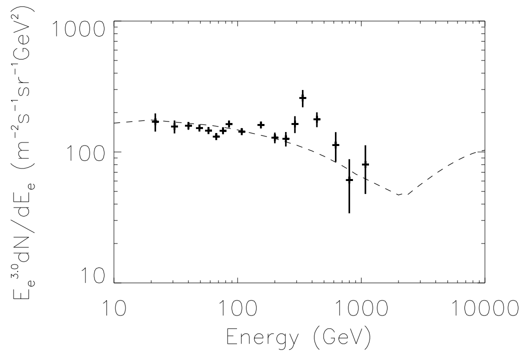

Figure 5. Absolute electron spectrum spectrum comparison with calculated model by a diffusion coefficient of $D=2.0\times10^{29}(E/TeV)^{0.3}$ $cm^2 s^{-1}$ and a power index of injection spectrum 2.4.

matter particle models predict an ”excess” in the electron + positron spectrum due to annihilation or interaction of these particles in the galactic halo[12]. A third flight of ATIC is currently scheduled for 2005-2006 and for this flight the BGO calorimeter will be increased to more than 22 radiation lengths. This increased calorimeter depth will improve the electron energy resolution and background rejection capability in order the investigate this issue more fully.

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