ENERGY SPECTRA OF ELECTRONS AND POSITRONS FROM 5 TO 100 GeV


1 Enrico Fermi Institute and Department of Physics, University of Chicago, Chicago, IL 60637
2 Department of Physics, University of California, Irvine, CA 92717
3 Department of Physics and Astronomy and Astrophysics, Pennsylvania State University, University Park, PA 16802
4 Department of Physics, Indiana University, Bloomington, IN 47405
5 Department of Physics, University of Michigan, Ann Arbor, MI 48109
6 Institut für Experimentalere Kernphysik, Universität Karlsruhe, Germany
7 Physics Department, University of California, Berkeley, CA 94720
8 Department of Physical Sciences, Eastern New Mexico University, Portales, NM 88130

ABSTRACT

We report and discuss new measurements of the intensities and energy spectra of cosmic-ray electrons and positrons over the energy range 4.5 to 50 GeV, and of the all-electron flux to 100 GeV. These measurements were obtained with the first balloon flight of the HEAT magnet spectrometer in 1994. The results are consistent with an essentially secondary origin of galactic positrons.

INTRODUCTION

Previous measurements of electrons (e^- + e^+) up to roughly 1000 GeV (Prince 1979, Nishimura et al. 1980, Golden et al. 1984, Tang 1984) have shown that their intensity amounts to about 1% of the flux of protons around 10 GeV, but decreases more rapidly with energy (~E^{-3.5}) than the proton spectrum (~E^{-2}). Separate measurements of positrons and electrons have only been possible at much lower energies and have indicated a "positron fraction" (n(e^-)/n(e^- + e^+)) around 10% in the region 1-50 GeV (Fanselow et al. 1969, Agrinier et al. 1969, Buffington et al. 1975, Müller and Tang 1987, Golden et al. 1987, 1994, and 1996, Barbieri et al. 1996, Barwick et al. 1995 and 1997a). These observations have led to a number of conclusions, but have also left some key questions unanswered:

1. The predominance of negative electrons requires acceleration in primary sources.
2. The steepness of the observed energy spectrum is usually explained as a consequence of radiative energy losses during propagation through the interstellar medium. However, there are several problems: the energy spectrum of electrons at the source is not known a priori, nor is it known that electrons and nuclei originate at the same acceleration sites; the energy dependence ~E^{-0.6} of the containment of nuclei may be difficult to reconcile with the observed shape of the electron spectrum (Tang 1984); and the "leaky box" approximation which is usually used, assumes an unreasonably high density of electron sources in the galactic disk (Cowick and Lee 1979).
3. The small flux of positrons appears to be essentially consistent with a secondary origin. However, a small primary contribution of positrons cannot be excluded with certainty. This question is discussed by Couto et al. at this conference (paper Q9 71.13).

Progress in our understanding of these issues requires measurements of electrons and positrons separately, and over as large an energy range as possible. This was the motivation for the construction of the High-Energy Antinatter Telescope (HEAT) which was flown on balloons in 1994 and 1995. In the following, we shall present and discuss results from the 1994 flight, but by the time of the conference, we hope to also have the analysis of the 1995 flight available.

---

TRI: EXPERIMENT

The first balloon flight took place in May 1994, from Fort Sumner, New Mexico, (vertical rigidity cutoff 4.5 GV), with float altitudes between 3.8 and 7.4 g/cm² for about 29 hours. The flight instrument consists of a combination of a superconducting magnet spectrometer (using a drift-tube hadroscope (DTH) tracking chamber), with particle identifiers employing time-of-flight scintillators (TOF), a transition-radiation detector (TRD), and an electromagnetic calorimeter (EC). A detailed description of the instrument is given by Barwick et al. 1997b.

For each event in flight, the following quantities are measured:

1. magnitude of the particle charge (top TOF scintillator and TRD)
2. sign of the charge and particle momentum (DTH)
3. trajectory and direction of traversal (DTH, TOF, TRD)
4. energy (EC)
5. electron/hadron characteristics from shower profile (EC)
6. Lorentz factor for electron/hadron discrimination (TRD)

These measurements provide a high degree of redundancy in particle identification and permit hadron rejection power in excess of 10^5. Specifically, for a particle to be accepted as electron or positron, we require that a well reconstructed downwards trajectory through the instrument be identified, that the particle be singly charged, that the momentum be defined with good precision, and that the momentum be consistent, within experimental resolution, with the energy measured with the EC. In addition, the event must be characterized by a "good" shower profile starting within the first radiation length of the EC, and it must exhibit a saturated transition radiation signal in the TRD. Key to the success of the data analysis procedure is the fact that the response functions of all detector elements are accurately determined from accelerator calibrations, from the flight data themselves, and from Monte Carlo simulations.

---

<table>
<thead>
<tr>
<th>Energy (GeV)</th>
<th>Electrons ΔNΔE</th>
<th>Positrons ΔNΔE</th>
<th>All-electrons ΔNΔE</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.5 - 6.0</td>
<td>1931 ± 45</td>
<td>176 ± 14</td>
<td>2097 ± 47</td>
</tr>
<tr>
<td>6.0 - 8.9</td>
<td>1787 ± 45</td>
<td>165 ± 14</td>
<td>1949 ± 45</td>
</tr>
<tr>
<td>8.0 - 14.8</td>
<td>921 ± 31</td>
<td>75 ± 10</td>
<td>997 ± 33</td>
</tr>
<tr>
<td>14.8 - 26.5</td>
<td>344 ± 20</td>
<td>18 ± 1</td>
<td>363 ± 70</td>
</tr>
<tr>
<td>26.5 - 50.0</td>
<td>75 ± 10</td>
<td>6.1 ± 1</td>
<td>81.2 ± 10</td>
</tr>
<tr>
<td>50.0 - 100.0</td>
<td>19 ± 2</td>
<td>1.9 ± 0.1</td>
<td>21.2 ± 1</td>
</tr>
</tbody>
</table>

---

Table 1. Raw numbers of electrons

---

RESULTS

The absolute differential energy spectra are obtained from the counts ΔN of Table 1 as:

\[ j_{\text{abs}}(E) \approx \frac{\Delta N}{\Delta E \Omega \Delta t} \]

where \(\text{ΔN}\) is the instrumental acceptance, \(\Omega\) is the solid angle, \(\Delta t\) is the weighted average energy, and \(\text{ΔE} \text{ΔΩ} \text{Δt}\) is the power-law spectral index. An atmospheric secondary contribution \(\text{ΔE} \text{ΔΩ} \text{Δt}\) is subtracted to obtain the primary component \(\text{ΔE} \text{ΔΩ} \text{Δt}\). This contribution is determined from Monte Carlo simulations, as well as growth curves measured for different altitudes during the balloon flight. It is small for electrons but at a level of about 30% for positrons.
The detection efficiency $\epsilon$ is comprised of contributions from all selections made in the simulation of the instrument is made, based on the GEANT software package, and including geometric factor $A \Omega$ of the instrument, $A \Omega = 495$ cm$^2$sr. Whenever possible the efficiencies data. Finally, small corrections to the resulting spectrum are applied which are due to the limited to the transformation from the measured energy $E$ to energy $E$ at the top of the atmosphere.

Table 2 shows the resulting energy intervals, acceptances, and differential intensities for $e^+, e^-$, and $(e^+ + e^-)$.

<table>
<thead>
<tr>
<th>$E$ (GeV)</th>
<th>$\Delta E$ (GeV)</th>
<th>$\epsilon A \Omega$ (cm$^2$sr)</th>
<th>$\varphi(E)$</th>
<th>$\varphi(E)^*$</th>
<th>$\varphi(E)^{**}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.14</td>
<td>1.47</td>
<td>198 ± 12</td>
<td>1.54 ± 0.16</td>
<td>0.118 ± 0.20</td>
<td>1.66 ± 0.18</td>
</tr>
<tr>
<td>7.25</td>
<td>5.78</td>
<td>188 ± 15</td>
<td>0.159 ± 0.049</td>
<td>0.032 ± 0.105</td>
<td>0.135 ± 0.053</td>
</tr>
<tr>
<td>11.3</td>
<td>5.06</td>
<td>175 ± 13</td>
<td>0.110 ± 0.014</td>
<td>0.032 ± 0.105</td>
<td>0.135 ± 0.053</td>
</tr>
<tr>
<td>16.9</td>
<td>10.7</td>
<td>158 ± 12</td>
<td>0.097 ± 0.032</td>
<td>0.032 ± 0.105</td>
<td>0.135 ± 0.053</td>
</tr>
<tr>
<td>26.5</td>
<td>21.1</td>
<td>132 ± 12</td>
<td>0.097 ± 0.032</td>
<td>0.032 ± 0.105</td>
<td>0.135 ± 0.053</td>
</tr>
<tr>
<td>66.4</td>
<td>44.0</td>
<td>174 ± 15</td>
<td>0.097 ± 0.032</td>
<td>0.032 ± 0.105</td>
<td>0.135 ± 0.053</td>
</tr>
</tbody>
</table>

DISCUSSION

In Figure 1, we compare our results with previous measurements for which absolute intensities have been given for positrons and electrons separately, and in Figure 2, we compare the all-electron energy spectrum ($e^+ + e^-$) with previous results, also including measurements which did not employ a magnet spectrometer for charge separation (Meegan & Earl 1975, Silverberg 1976, Freier et al. 1977, Prince 1977, Nishimura et al. 1980, Tang 1984). We find that all results individually exhibit similar spectral slopes over the energy range of concern, but that our overall ($e^+ + e^-$) intensity is lower than that of some of the previous investigations by a factor of about 1.5. There are two likely contributors to this systematic discrepancy. First, the absolute energy calibration of individual experiments may be uncertain by up to 10%. Multiplication of the intensities with $E^3$ (as in Figure 2), accentuates this uncertainty to about 30%. Second, the assessment of the absolute detection efficiency of the instrument is notoriously difficult and does involve some intuitive judgment, although the more recent investigations, such as ours, benefit in this respect from more detailed Monte Carlo simulations than were previously available.

If we fit the spectra to single power laws, we find spectral indices $\alpha = 3.4 \pm 0.2$ and $3.1 \pm 0.1$ for positrons and electrons, respectively, over the energy range 4.5 to 50 GeV. Thus, the positron spectrum appears to be slightly steeper than that of electrons. If all positrons are of interstellar secondary origin, one expects that radiative energy losses lead to a power-law index at high energy that is larger by unity than that of the production spectrum, i.e., $\alpha = 3.7$ for production spectra of the form $E^{-\alpha}$. The spectrum of electrons, on the other hand, should steepen less.

This work was supported by NASA. We acknowledge the services of the NOSB balloon crew.

REFERENCES

Barwick, S. W. et al. Nucl. Instr. & Meth., submitted (1997b)