MEASUREMENT OF THE POSITRON AND ELECTRON SPECTRA WITH THE CAPRICE EXPERIMENT

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ABSTRACT

We report on the absolute energy spectra of positrons and electrons and the positron fraction in the energy range from 0.38 to 14.2 GeV at the top of the atmosphere. The data were collected by the balloon-borne experiment CAPRICE flown from Lynn Lake, Canada, on August 8-9, 1994, at an altitude corresponding to 3.9 g/cm^2 of average residual atmosphere. The experiment used the NMSU-WIZARD/CAPRICE balloon-borne magnet spectrometer equipped with a solid radiator Ring Imaging Cherenkov (RICH) detector and a silicon-tungsten calorimeter for particle identification. A total of 3243 e$^-$ and 803 e$^+$ were identified with very small background of other particles. The resulting positron fraction is consistent with the simple leaky box model.

INTRODUCTION

Detailed measurements of the electron component of the cosmic rays are important to understand the propagation of cosmic rays in the Galaxy. This is because electrons undergo severe energy loss through synchrotron radiation in the magnetic field and inverse Compton scattering with the ambient photons, while these processes do not significantly affect the nucleonic cosmic-ray component. Cosmic ray positrons are believed to be produced in collisions of cosmic ray nucleons with interstellar matter and measurement of the positron spectrum permits to examine propagation models, production mechanism and other possible new sources of its origin. Besides, comparison between the two spectra gives useful information about solar wind effects on the cosmic rays.

Most of the recent measurements on the electron-positron component have been carried out above 5 GeV (e.g. Barwick et al., 1995, Golden et al., 1996). Below 5 GeV just a few results have been published (Clem et al., 1996, Barbiellini et al., 1996b) since early seventies (Fanselow et al., 1969, Daugherty et al., 1975). The unambiguous detection of positrons is difficult because of the vast background of protons. Another problem associated with the balloon borne positron and electron measurements are corrections for the secondaries produced in the residual atmosphere.

DETECTOR SYSTEM

The NMSU-WiZard/CAPRICE spectrometer was flown by balloon from Lynn Lake, Manitoba, Canada (56.5° North Latitude, 101.0° West Longitude), on 8-9 August 1994 at an altitude from 36.0 to

38.1 km and at a low geomagnetic cut off, which varied from about 0.4 to 0.6 GV/c during the flight, for 23 hours. From top to bottom the instrument includes a Ring Imaging Cherenkov (RICH) detector (Carlson et al., 1994, Barbiellini et al., 1996a), a time-of-flight (ToF) system, a magnet spectrometer of multiwire proportional chambers (MWPC) and drift chambers (DC) (Golden et al., 1991, Hof et al., 1994) and a silicon-tungsten imaging calorimeter (Bocciolini et al., 1996) .

DATA ANALYSIS

The analysis was based on 18 hours of data collection for a total acquisition time of 60520 seconds under an average residual atmosphere of 3.9 g/cm^2. The fractional dead time during the flight was 0.7310 ± 0.0006 resulting in a total live time of 16280 ± 36 s. Previous results on the positron to electron ratio in the range from 0.6 to 10 GV/c from the CAPRICE experiment have already been published (Barbiellini et al., 1996b). In this conference we present results over an energy range extended to lower energies and on the absolute spectra.

We selected electrons and positrons in the rigidity range from 0.25 to 10 GV/c. We required a well defined single track in the spectrometer with a good momentum resolution, characterized by acceptable chi-squares and small uncertainty in deflection. We selected singly charged particles with a signal of less than 1.8 mips (minimum ionizing particles) in the top ToF scintillator. Albedo events were rejected using both the ToF and the RICH. Electrons and positrons were selected as particles with negative and positive deflection respectively, $\beta = 1$ as detected by the RICH and an electromagnetic shower in the calorimeter.

The cuts imposed on the calorimeter to identify electromagnetic showers had a logarithmic dependence on rigidity and were based on (a) results from test beams at CERN (Bocciolini et al., 1993), (b) simulations and (c) experience gained from a previous flight with a similar instrument (Golden et al., 1996). An electromagnetic shower was characterized by a narrow shower with most of the energy deposited inside 4 Molière radii around the track. We imposed additional cuts based on the total detected energy, which should match the measured momentum, and on the longitudinal and lateral profiles of the shower. A small number of particles emit a bremsstrahlung photon before entering the calorimeter (e.g. in the RICH or the aluminum cover of the gondola) that was detected in the calorimeter as a parallel shower. These double shower events with a single track in the tracking system are clearly electron/positron events and looser cuts were used. The detection efficiency of the calorimeter using the above cuts is rigidity dependent increasing from 40% at 0.25 GV/c to 85% above 1.0 GV/c.

The RICH was used to measure the velocity (β) of the particles. Due to the high rejection factor of the calorimeter, rather loose cuts were applied on the RICH data in order to maximize the efficiency of selection. Electrons and positrons were selected by the RICH as $\beta = 1$ particles with a well defined Cherenkov light image and a good agreement between the position determined by the RICH and that from the tracking measurement. With these cuts applied, the RICH has a detection efficiency increasing from 58% at 0.25 GV/c to 72% between 0.8 and 5 GV/c. Above 5 GV/c the RICH is not capable of separating protons from positrons and was not used.

RESULTS

Table 1 gives the number of electrons and positrons that passed the cuts applied on the RICH, the ToF and the calorimeter. We estimated the protons passing the calorimeter criteria by selecting proton sample using the RICH, scintillator dE/dx and ToF. Similarly the proton contamination in the RICH selection was estimated using a proton sample selected by the ToF below 1 GV/c and by the calorimeter above 1 GV/c by requiring an hadronic interaction. Assuming that the rejection of protons by the RICH and the calorimeter is independent we got a total proton contamination of 2×10^{-6} for rigidities below 3.0 GV/c increasing to 1×10^{-4} at 5 GV/c. In the energy region from 5 to 10 GV/c, where the selection is performed using only the calorimeter, we assumed that the calorimeter contamination is the same as that of the bin 3 to 5 GV/c , that is: $(1.8 \pm 0.75) \times 10^{-4}$. The rejection factor of the calorimeter and the RICH is high enough to eliminate all proton, pion and muon contamination from the positron sample between 0.25 and 3 GV/c. The proton contamination was found to be 12%, 29% and 37% of the positron sample in the rigidity bins 3 to 4 GV/c, 4 to 5 GV/c and 5 to 10 GV/c respectively. This proton contamination is shown in the parenthesis in Table 1 and was subtracted from the positron sample.

The observed electron and positron spectra were corrected for the efficiencies and were extrapolated to the top of the payload using bremsstrahlung corrections. From these spectra we subtracted the atmospheric secondary e^- and e^+ fluxes, using the theoretical estimates of Stephens (1981).

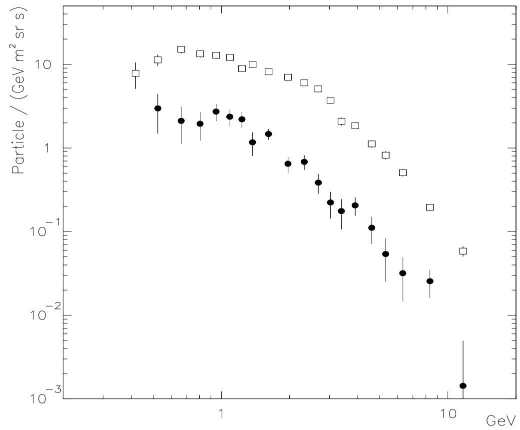

Fig. 1: Extrapolated positron and electron absolute spectra at top of the atmosphere: □ electrons; ● positrons. The positron value in the lowest energy bin is zero.

The corrected electron and positron spectra were propagated backward to the top of the atmosphere (ToA) by simultaneously solving the cascade equations, which describe the propagation of all the electromagnetic components, namely, primary e^- , e^+ and secondary gamma rays that result from bremsstrahlung of the electron component. From this, we obtained the positron and electron spectra,

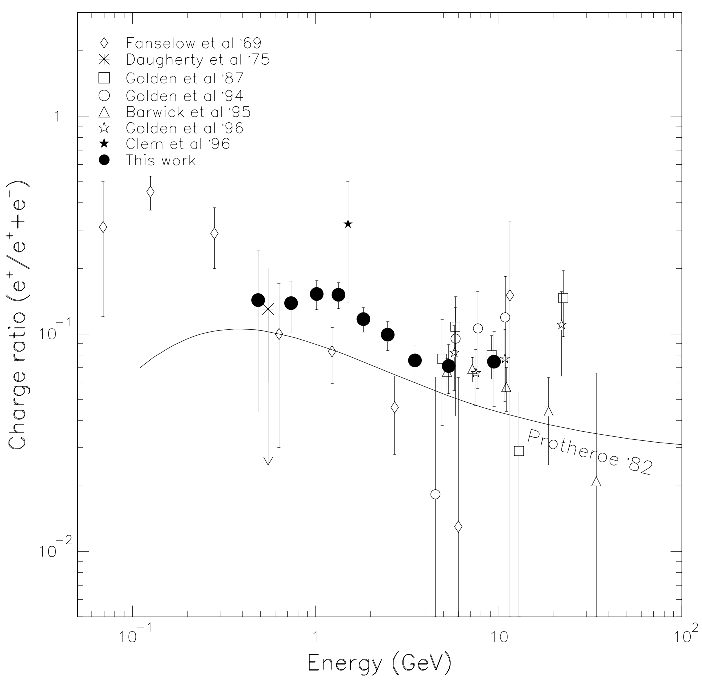

Fig. 2: Positron fraction e^+ / (e^+ + e^-) as observed in this experiment is compared with other published data and simple leaky box model.

shown in Figure 1. The errors shown include both the statistical and the systematic errors. One can

Table 1: Summary of electron - positron results.

Energy bin at spectrometer GeV	Observed number of events[b] e^-	e^+	Median energy at TOA GeV	Flux at TOA[a] $(\text{GeV m}^2 \text{ sr s})^{-1}$ e^-	e^+	$\frac{e^+}{e^+ + e^-}$
0.25-0.4	199	148	0.485	10.1 ± 1.6	1.7 ± 1.3	0.143 ± 0.099
0.4-0.6	419	164	0.73	13.7 ± 1.1	2.2 ± 0.6	0.138 ± 0.036
0.6-0.8	413	128	1.01	13.3 ± 0.85	2.4 ± 0.4	0.152 ± 0.023
0.8-1.05	388	101	1.33	9.72 ± 0.57	1.7 ± 0.26	0.151 ± 0.021
1.05-1.5	539	99	1.82	7.33 ± 0.36	0.97 ± 0.13	0.117 ± 0.015
1.5-2.0	427	60	2.475	5.06 ± 0.28	0.56 ± 0.09	0.099 ± 0.015
2.0-3.0	420	44	3.49	2.21 ± 0.12	0.18 ± 0.03	0.076 ± 0.013
3.0-5.0	279	31(5.6)	5.33	0.79 ± 0.05	0.06 ± 0.02	0.071 ± 0.018
5.0-10.0	159	28(10.4)	9.43	0.114 ± 0.009	0.009 ± 0.004	0.074 ± 0.028

[a]Top of atmosphere.
[b]The numbers shown in the brackets are the estimated proton background.

clearly notice from this figure the effect of the geomagnetic cut-off below 0.7 GeV.

After suitably combining nearby energy bins in order to decrease the statistical errors, we obtained the fraction of positrons that is tabulated in Table 1 and plotted in Figure 2 together with previous measurements . Our results are in agreement with the recent measurements (Barwick et al., 1995, Golden et al., 1996) at the upper energy bins. The observed energy dependence of our results is consistent with that expected from the simple leaky box model (Protheroe, 1982).

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