A STRATOSPHERIC MAGNETIC SPECTROMETER INVESTIGATION OF THE SINGLY CHARGED COMPONENT SPECTRA AND COMPOSITION OF THE PRIMARY AND SECONDARY COSMIC RADIATION.

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ABSTRACT

The results of balloon investigations carried out with a magnetic spectrometer at middle latitudes during 1972-1977 are presented.

The aim of the experiments was to measure the flux of antiprotons within the 2-5 Gev range, the flux of deutrons with the energy of $\sim$ 1 Gev/nucl. and the spectra of the secondaries.

The measured antiproton-proton flux ratio, $\bar{p}/p$ (2-5 Gev), is equal to (6 ± 4)$\times 10^{-4}$.

The spectra of electrons and muons above 50 Mev measured at 11 g/cm^2 residual atmosphere are presented. The problem of reentrant albedo electrons at middle latitudes is discussed.

1. Introduction

Measurements of the singly charged component of the cosmic radiation at balloon altitudes with a magnetic spectrometer allow one to investigate simultaneously different problems concerning this component. One of the most interesting problems during the recent years has remained the search for antiprotons in the primary cosmic radiation. This search was inspired by the fundamental question about the charge symmetry of the Universe. The experimental upper limit for the antiproton-proton flux ratio in the 2-5 Gev energy range found to be 8x10^{-3} at the 95 % confidence level (Bogomolov et al., 1971) could be considered as an evidence for the absence of condensed antimatter in our Galaxy. The theoretical limit for the $\bar{p}$/p-ratio at energies below 10 Gev due to the interactions of cosmic rays with interstellar gas lies between 2x10^{-5} (Gaisser et al., 1974) and 3x10^{-3} (Bhattacharyya et al., 1978).

The flux of antinuclei from these interactions is$\sim$10^{-8} of the flux of the antiprotons, therefore the best present result in the search for antimatter is the upper limit for the $\bar{Z}$/Z -

ratio obtained in (Smoot et al.,1975). It is equal to $8x10^{-5}$ for $Z \geqslant 3$ in the 4-33 Gev/c range (at 95 % confidence).

So now the cosmic ray antiprotons are regarded mostly as a test for the amount of material traversed by cosmic rays in the Galaxy and as a test for the validity of some calculations (Shen et al.,1968; Suh,1971; Gaisser et al.,1973; Gaisser et al.,1974; Badhwar et al.,1975; Steigman,1977; Bhattacharyya et al.,1978) connected with different models of cosmic ray propagation. The major results obtained in $\bar{p}$/p-ratio calculations and the experimental search (Brooke et al.,1964; Apparao,1968; Golden et al.,1978) for antiprotons in the cosmic rays are shown in Figure 1 (the experimental upper limits are given at 95 % confidence level).

2. Method

For some years we have searched for antiprotons in the primary cosmic radiation with a balloon-borne magnetic spectrometer. It consists of a deflecting magnet, a system of optically viewed spark chambers and a triggering Čerenkov-scintillation counter telescope for restricting the solid angle and separating particles by their velocity and charge. A detailed description of the device is given elsewhere (Bogomolov et al., 1971).

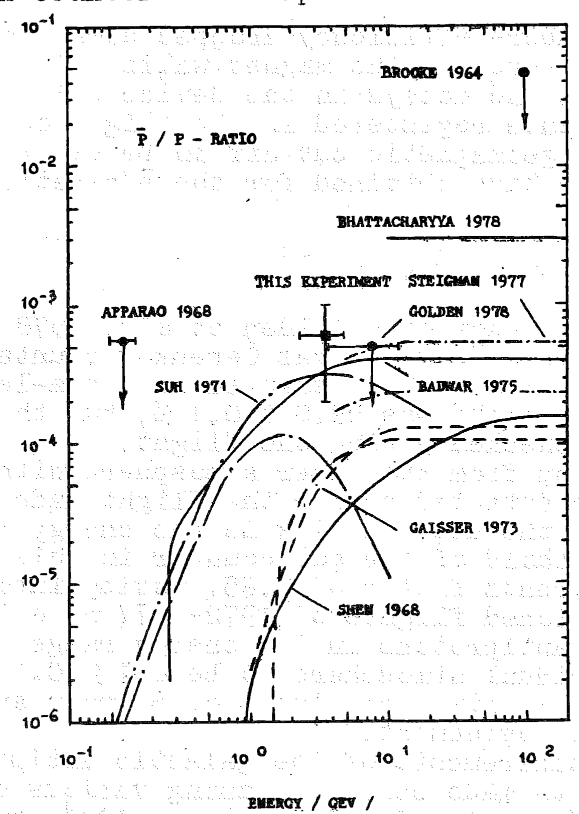

Fig. 1.
The theoretical and experimental data for the $\bar{p}$/p flux ratio in the primary cosmic radiation.

3. Results

Antiprotons. In the three flights of the spectrometer made on October 19-20,1972, on September 20-21,1974, and on October 18-19,1977 at 10-12 g/cm^2 residual atmosphere and cut-off rigidity $\sim$ 3.5 Gv there were recorded 3400 ± 40 of primary protons in the 2-5 Gev energy range. The deflection distribution of all singly charged particles obtained in these experiments is shown in Figure 2. All events with deflections corresponding to that of antiprotons were thoroughly analysed. Most of them (after exluding ambiguous events connected with operator

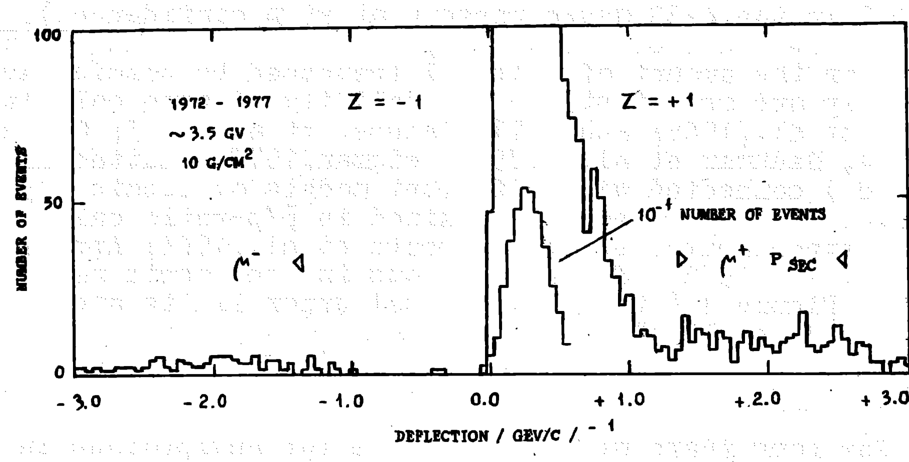

Fig. 2.
The deflection distribution for the singly charged particles measured with a magnetic spectrometer.

mistakes when the spark chambers efficiency dropped down) are due either to particles scattered on the magnet walls (11 events); or to interactions and decays in the device (17 events). We believe two events registered in the flight on September 20-21, 1974 above geomagnetic cut-off to be due to primary antiprotons. Thus we have obtained for the $\bar{p}$/p-ratio in the 2-5 Gev energy range:

$$\bar{p}/p \text{ (2-5 Gev) } = (6 \pm 4)\times 10^{-4}.$$

Our result is comparable with that of (Golden et al., 1978).

The efficiency of the veto from the gas Čerenkov counter (the threshold Lorentz factor = 6.07) measured with sea-level muone before and after this flight was 99.8 ± 0.1 %, but this critical parameter was not checked during the flight.

One secondary antiproton from the upper atmosphere with the energy of ~ 0.7 Gev was detected during the flight made on December 2, 1975 to measure the deutron flux in the energy region ~ 1 Gev/nucl. The threshold of the gas counter in this flight corresponded to a Lorentz factor of 2.65. Taking into consideration the abovementioned flights of 1972-1977 we estimate the flux of secondary antiprotons in the energy range 0.5-1.5 Gev at 10 g/cm^2 residual atmosphere to be 0.1 ± 0.1 (m^2 sec ster Gev)$^{-1}$. Our experimental fluxes of primary and secondary antiprotons are in agreement.

The accuracy of our measurements of the galactic antiproton flux does not allow us to made selection among various calculations leading to the $\bar{p}$/p-ratio of a few units x 10^{-4}, but the observation of primary antiprotons may serveas evidence that the lifetime of antiprotons at rest is at least as great as the age of the cosmic rays, that is about 10^7 years (Steigman, 1977). It is perhaps of interest to note that the discovery of positrons in the cosmic rays gives for the lower astrophysical limit for the lifetime of the positrons at rest also about 10^4-10^5 years.

Deutrons. The deutron flux measured in the flight on December 2, 1975 in the energy range 0.9-1.6 Gev/nucl. is 16 ± 6 (m^2 sec ster Gev/nucl. $)^{-1}$. The upper and lower energy limits are determined by the threshold of the gas Čerenkov counter and the cut-off rigidity, respectively. This result corresponds to the $^2H/^1H$-ratio of 0.020 ± 0.008 at the top of the atmosphere.

Electrons. In the flight on September 20-21, 1974 we measured the spectra of electrons and positrons in the energy range 50-600 Mev as well. In these experiments, the gas counter (the threshold Lorentz factor = 6.07) was connected in coincidence with the other counters so that only electrons and positrons could be detected in the momentum region below 600 Mev/c. Figure 3 shows the measured spectrum of downward-moving electrons at 11 g/cm^2 residual atmosphere.

After comparing these results with calculations (Daniel et al., 1974) we have obtained a spectrum of the reentrant albedo electrons in the energy region under consideration. The available reentrant albedo experimental data have a small spread at energies below 0.2-0.3 Gev which can be partly due to the modulation effects as the experiments were carried out at the threshold rigidity ~0.25 Gv. The data obtained at middle latitudes are scanty and the results obtained for greater energies (Verma, 1967; Israel, 1969) differ by almost an order magnitude. Only upper limits for the reentrant albedo electron fluxes were obtained in (Israel, 1969) after corrections for the secondary electrons in the residual atmosphere. These corrections were made using calculations (Perola et al., 1966)

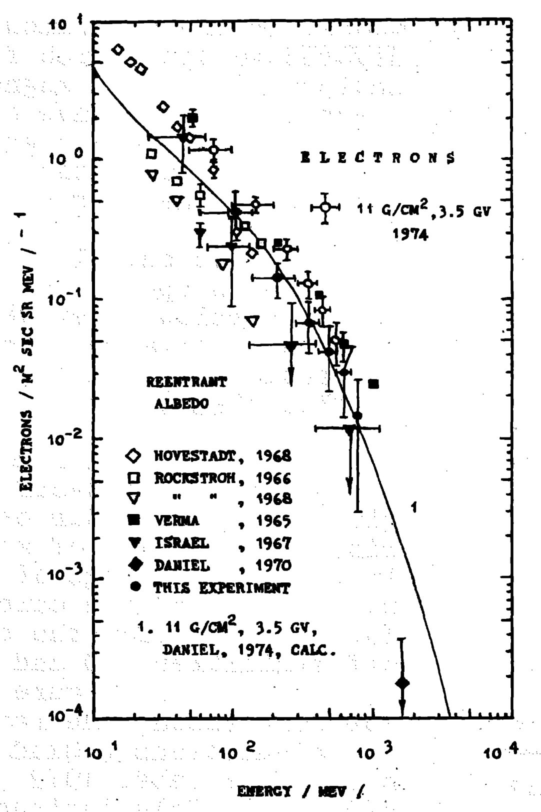

Fig. 3.
Differential energy spectra of reentrant albedo electrons at various latitudes and the spectra of downward-moving electrons at 11 g/cm^2 atmospheric depth.

yielding overestimated values for the electron flux. If one uses the calculations of the secondary electron flux of (Daniel et al., 1974) then the results of (Israel, 1969) yield a finite flux of reentrant albedo electrons. In Figure 3 we compare the improved result of (Israel, 1969), the experimental data of (Verma, 1967; Rockstroh et al., 1969; Hovestadt et al., 1970) and our results for reentrant albedo electrons at the top of the atmosphere. We have obtained reentrant albedo fluxes of 430 ± 160, 140 ± 40, 67 ± 27, 43 ± 21, 30 ± 16, and 15 ± 12 (m^2 sec ster Gev $)^{-1}$ in the energy intervals 0.07-0.14, 0.14-0.28, 0.28-0.43, 0.43-0.57, 0.57-0.71, and 0.71-0.85 Gev, respectively.

A comparison of the vertical fluxes of the splash albedo and reentrant albedo electrons seems to show that they are not equal. Exact equality should be obtained after integrating over all directions, as it is correctly pointed out in (Israel, 1969). It would be interesting to check this point by measuring the reentrant albedo flux at various zenith angles.

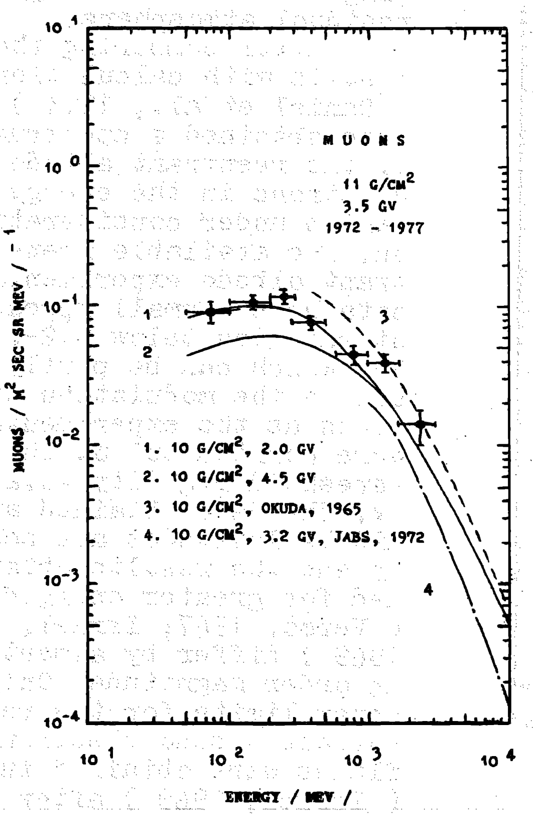

Fig. 4.
Differential energy spectra of downward-moving muons at 11 g/cm^2 atmospheric depth and vertical cut-off rigidity 3.5 Gv.

Muons. In the experiment devoted to the search for antiprotons with a magnetic spectrometer, we have also measured the spectra and the charge composition of muons with energies above 50 Mev.

For the calculation of the muon spectra at energies below 1 Gev we used the available pion generation spectra (Perola et al., 1966) and calculated the spectra at 5-100 g/cm^2 residual atmosphere and the cut-off rigity of 0-16 Gv. Our experimental spectrum of muons in the energy range of 0.05-3 Gev and the calculated spectra for the cut-off rigidities 2.0 and 4.5 Gv are shown in Figure 4. For comparison, the results of calculations (Okuda et al., 1965; Jabs, 1972) made for middle latitudes and for energies above 0.4 Gev are also shown. Our experimental and calculated results are in good agreement.

The μ^+/μ^--ratio is constant within experimental errors in the energy range under consideration. We have obtained for averaged μ^+/μ^--ratio a value of 1.26 ± 0.12.

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