OG 1.3-4

A MEASUREMENT OF THE ANTIPROTON FLUX IN THE COSMIC RAYS

Andrew Buffington and Stephen M. Schindler
California Institute of Technology
Pasadena, California, 91125
U.S.A.

ABSTRACT

A balloon-borne instrument has been used to detect cosmic-ray antiprotons. These are identified topologically by the appearance of annihilation prongs in a thick lead-plate spark chamber. The initial recording of the data is enriched in potential antimatter events by a selective trigger. After a small subtraction for background, 14 identified antiprotons yield a flux of $1.7 \pm 0.5 \times 10^{-4}$ $\bar{P}/(m^2$ster sec MeV) between 130 and 320 MeV at the top of the atmosphere. When combined with higher energy antiproton flux measurements, this result indicates that the antiprotons have a spectrum whose shape is the same as that of the protons, but with a magnitude reduced by a factor of 1/3000.

1. Introduction

A small flux of antiprotons ("$\bar{P}$") is expected to occur in the cosmic rays due to the production of these particles in collisions between high energy cosmic rays, mostly protons, and the interstellar gas. A number of calculations predict a cosmic-ray $\bar{P}$/P ratio of about 2×10^{-4} above several GeV (Gaisser and Maurer 1973; Gaisser and Levy 1974; Badhwar et al. 1975; Szabelski et al. 1980; Stephens 1980). Golden et al. (1979) and Bogomolov et al. (1979) recently reported measurements of finite $\bar{P}$ fluxes somewhat above this expected level. We report here a new $\bar{P}$ flux measurement at low energy, where the secondary $\bar{P}$ spectrum is expected to drop dramatically.

2. Apparatus and Balloon Flight

The apparatus and its mountaintop calibration were described in the previous conference of this series (Buffington et al. 1979; Pennypacker et al. 1979). Figure 1 shows a schematic diagram. The apparatus selects $\bar{P}$ events from the larger background of normal-matter cosmic rays by combining a selective trigger with a detailed spark-chamber visualization. The top scintillators (S_1, S_2, and S_3) and the Cerenkov counter "C" select events typically having an incident velocity $\lesssim$ 300 MeV/nucleon. The trigger requirement is S_1 through S_4 in coincidence, and C in anticoincidence. The threshold settings on the top three scintillators require more than about twice minimum ionizing energy deposition, which is important in rejecting charge Z=1 background events with velocity just above the Cerenkov counter threshold. To penetrate the 150 g/cm^2 lead-plate spark chamber, thus satisfying the S_4 trigger requirement, a proton must have a kinetic energy $\geqslant$ 400 MeV, which corresponds to a velocity safely above the 0.65c limit. However, antiprotons slower than this can annihilate within the lead-plate chamber, with resulting daughter pions penetrating through to S_4. Once the trigger criteria are satisfied, the spark chambers are operated, giving a photographic record of the detailed event topology. The selective trigger provides an approximately 1000-fold rejection against normal cosmic-ray events, with an efficiency of about 10% for recording $\overline{P}$ annihilations. An oscilloscope record of the scintillator and Cerenkov counter responses (pulse height and timing) also appears on the film.

In addition to the selective trigger, further rejection of normal-matter background is required. The spark-chamber pictures are first selected for the multiprong topology characteristic of $\overline{P}$ annihilations. From this sample, about half of potential recorded $\overline{P}$ events are able to satisfy the final requirement imposed upon event topology, timing, and pulse height response for the scintillators. The timing permits selection of downward going particles, and the pulse height distinguishes charge Z=1 particles from those with $Z\geq 2$. To reduce background contributions to the $\overline{P}$ signal from fragmentation reactions of deuterons, tritons, and helium nuclei, the accepted $\overline{P}$ candidates had to have at least three charged prongs showing in the lead-plate chamber. To be counted as a prong, at least three spark-chamber gaps had to be penetrated. In the case of only three prongs, one of them had to travel backwards in the apparatus.

The expected properties of the apparatus were calculated by a Monte-Carlo program. The program assumed an isotropic distribution of annihilation pions in the apparatus, and calculated the geometry factor including all trigger and data analysis acceptance criteria. There is a potential for systematic error in this calculation, because the assumptions characterizing the annihilation process may in fact not be correct for $\overline{P}$-lead annihilations. However, within the 10% accuracy appropriate for the statistics of this experiment, the calculation was found not to be particularly sensitive to the assumptions. If one were to plan on a future version of this experiment with a larger exposure factor, it is clear that an accelerator calibration would be important for determining the geometry factor and generating authoritative expected distributions needed for the various cross-checks

The experiment was flown from The Pas, Canada, on 18 June 1980, at an average residual atmospheric depth of 11 g/cm^2. The live time was 4.6×10^4 sec., yielding an exposure factor of 550 m^{2}ster sec. 20,562 events were recorded with the full trigger criterion. Taking into account energy loss in the atmosphere, the instrument covers 130 to 320 MeV for antiprotons. The residual atmosphere both attenuates the cosmic antiproton signal and can potentially add a few extra antiprotons created in collisions of high energy cosmic rays with the air nuclei. The attenuation correction factor which results from an assumed mean free path in air of 50 g/cm^2 is 1.25. Low energy antiprotons created in the atmosphere are greatly suppressed due to the kinematics of the production process. The expected number of atmospheric antiprotons for this experiment is a negligible 0.1 event.

3. Data Analysis and Results

About 1500 events were found by scanners to satisfy initial selection criteria: an incident track which connects to three or more straight or kinked prongs in the lead-plate chamber. When we examined these events, most proved to have either more than one energetic particle present, or some other topological uncertainty which the scanners felt deserved further analysis. However, 64 events were found to satisfy all the topological requirements (three or more prongs, with one penetrating through to S_4; in the case of only three prongs, one of them backwards). Of the 64, 28 were rejected because the measurement of timing showed that they were caused by a particle incident from the side, which looked like one of the prongs, and whose interaction satisfied the trigger criterion entirely with secondary particles. Analysis of the energy deposition in scintillator S_3 showed that 19 of the remaining events were induced by helium nuclei which underwent fragmentation reactions in the lead. Although this removed the bulk of the helium-induced background, studies of other helium-induced events that had too few prongs to satisfy the above topological requirements showed that a single background helium-induced event is expected to remain in the $\bar{P}$ data sample. This must be subtracted to get a proper $\bar{P}$ flux. An additional two events were discarded due to an accompanying particle which presumably assisted in meeting the trigger criterion. Thus, for flux calculation purposes, the experiment observed fourteen antiprotons.

Numerous crosschecks were carried out to be sure that no identifiable background process could be responsible for these $\bar{P}$ events. The distribution of prong number, isotropy of daughter prongs, and energy deposition in the lead-plate chamber were in adequate agreement with the Monte-Carlo predictions. The distribution of Cerenkov counter response below trigger threshold, as recorded by the oscilloscope, was as expected. Additional details of the apparatus and data analysis will be presented elsewhere (Buffington, Schindler, and Pennypacker 1981).

Figures 2 and 3 present the measured flux and $\bar{P}$/P ratio, together with other $\bar{P}$ measurements and calculations of expected fluxes if the $\bar{P}$'s are entirely secondary. Considerable questions have been raised about the calculation of Badhwar et al. ("B" on the figures) (Szabelski et al. 1980; Stephens 1980). The data do not show the expected drop in $\bar{P}$ flux at low energy; instead the $\bar{P}$/P ratio could well be flat. Moreover, the integral flux of $\bar{P}$'s is substantially larger than that predicted by the calculation of, e.g., Stephens (1980). This unexpected result suggests a substantially different history for cosmic-ray protons compared with that for the medium or heavy elements.

This work was supported by grants NGR 05-003-553 and NGR 05-002-160 from the National Aeronautics and Space Administration.

References

Apparao, M.V.K. 1968, Can. J. Phys., 46, S654.
Badhwar, G.D., et al. 1975, Astrophys. and Space Sci. 37, 283.
Bogomolov, E.A., et al. 1979, Proc. 16th Int'l C.R. Conf., I, 330.
Buffington, A., et al. 1979, ibid, 337.
Buffington, A., et al. 1981, submitted to Astrophys. J.
Gaisser, T.K., and Levy, E.H. 1974, Phys. Rev., D-10, 1731.
Gaisser, T.K., and Maurer, R.H. 1973, Phys. Rev. Lett., 30, 1264
Golden, R.L., et al. 1979, Phys. Rev. Lett., 43, 1196

Stephens, S.A. 1980, "Secondary Production of Antiprotons in Cosmic Radiation", preprint SP/IR-80-2, Tata Institute, submitted to Astrophysics and Space Science, August 1980.
Szabelski, J., et al. 1980, Nature, 285, 386.

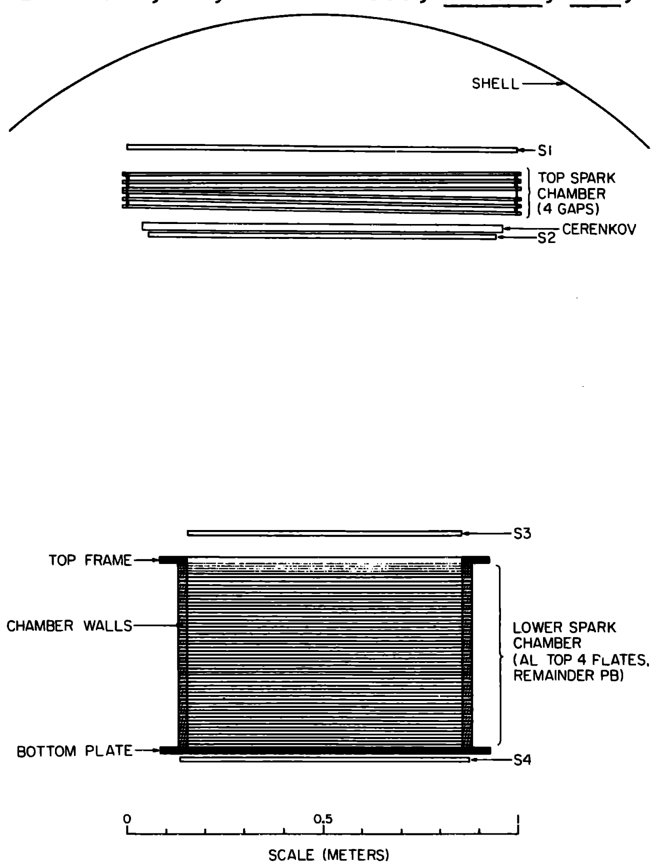

Figure 1. Apparatus.

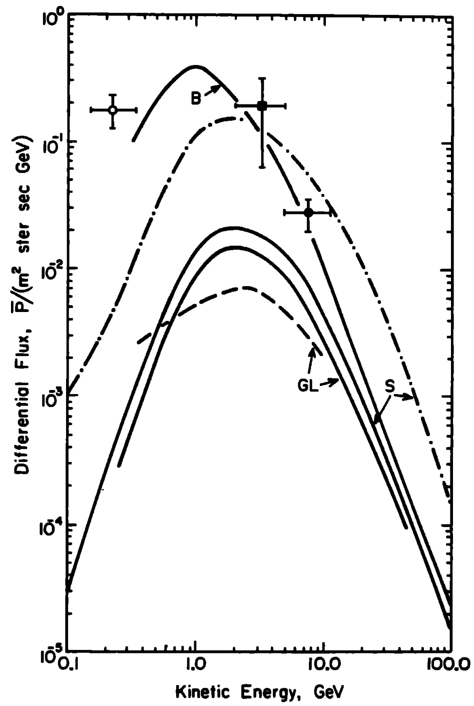

Figure 2. $\overline{P}$ flux vs. energy. (⊕) This experiment. (□) Golden et. al. (1979). (■) Bogomolov et. al. (1979). S= Stephens (1980). GL = Gaisser and Levy (1974). (—·—·) closed galaxy model. (——) leaky box models. (— — —) includes solar modulation for 1969. B = Badhwar et al. (1975).

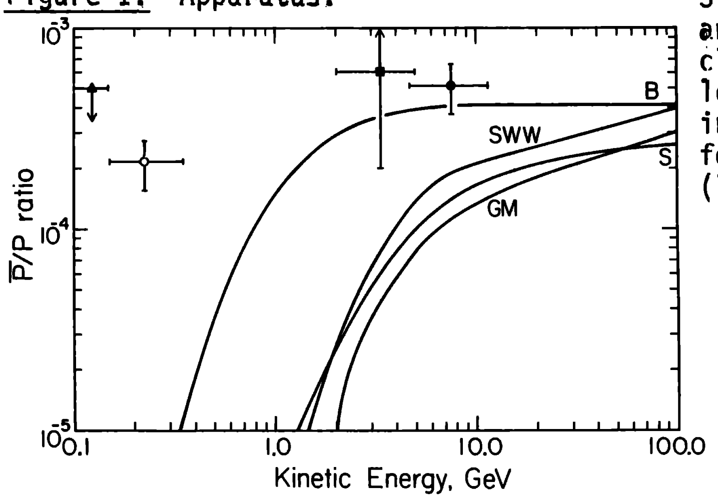

Figure 3. $\overline{P}/P$ ratio vs. energy. Data points as above, but also including a low-energy upper limit by Apparao (1968). GM=Gaisser & Maurer (1973). SWW=Szabelski et al. (1980).