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ANTIPROTON AND ANTIHELIUM SEARCH

Carl R. Pennypacker, A. Buffington, Phil M. Lubin, and George F. Smoot

Space Sciences Laboratory and Lawrence Berkeley Laboratory,
University of California,
Berkeley, California 94720, USA

ABSTRACT

The apparatus described in the above paper (OG-6-20) has been calibrated at sea level and mountaintop (about 3000 m). We describe the various processes which have been seen to circumvent the trigger criteria. The efficiency of the apparatus has been calculated for antiprotons and antihelium with a Monte Carlo program. We plan to fly the apparatus by balloon at a residual atmospheric depth of about 15 gm/cm^2, hopefully before the conference. If the flight is successful, we may be able to report preliminary results.

1. Introduction

A mountaintop calibration of the experiment (described in OG-6-20) to fly at 28.5 km to search for low-energy cosmic antiprotons and antihelium provided a check of the apparatus response, with substantially larger particle fluxes than at sea level. The basic trigger rejection against background to the antimatter signal was verified to be satisfactory for the experiment, and the non-antimatter processes meeting the trigger were identified. This paper describes the calibrations and crosschecks that were carried out both at sea level and at mountaintop.

2. Trigger

The apparatus has a selective low energy (80-360 MeV) anti-matter trigger which requires coincident pulses larger than minimum ionizing from the top three scintillators, no pulse from the Cerenkov counter, and any pulse greater than 0.5 times minimum ionizing from the scintillator underneath the lead. For protons and helium nuclei, a coincidence from all four scintillators is almost always (>99%) accompanied by a veto pulse from the Cerenkov counter; conversely slow anti-matter and its annihilation pions can satisfy the trigger with reasonable efficiency.

3. Proton Fluxes at Sunspot, New Mexico

The apparatus was tested at the New Mexico State University mountaintop laboratory at 730 g/cm^2 of residual atmosphere. Mountaintop proton fluxes have been measured by several groups (e.g., Kocharian 1959, and Barber 1976) and can be well-approximated within our energy range by a constant 10 events/m^2-ster-sec-GV/c. Protons between about 80 and 360 MeV should meet all but the final-scintillator portion of the trigger, and the measurement of this flux with this apparatus provides a good check on much of the experimental concept and trigger criterion. The incident flux is somewhat vertically collimated by the atmosphere and is reduced to approximately half for wide angles where the apparatus geometry factor begins to drop off. The average flux reduction due to this anisotropy is a factor of 0.6 times the vertical flux. (In addition, fluctuations in delta rays and scintillation in the Cerenkov counter, and scintillator thresholds cutting into the Symon-Landau ionization curve, contribute 90% and 80% detector efficiencies respectively.) Combining these numbers along with our .5 m^2-ster geometry factor and .5 GV/c rigidity acceptance give an expected 1.1 events/sec satisfying the trigger criterion (minus the bottom scintillator). We measure, after scanning the film to reduce the non-proton component, .9 ± .1 events/second, which is in satisfactory agreement.

4. Apparatus Performance

The trigger performance of the apparatus is set by the ability of the Cerenkov counter to reject events above its threshold, and by the ability of the four scintillator telescope to reject events with small values of dE/dx. The Cerenkov counter was found to yield an average of 16 photoelectrons for a vertical relativistic muon. We set the anti-coincidence threshold at effectively 4 photo-electrons, after subtraction of the expected scintillation in the Pilot 425 Cerenkov radiator. We also confirmed that the scintillation in our particular piece of Pilot 425 is the expected 3% of the Cerenkov light of a relativistic particle. The threshold of 4 photo-electrons allows the equipment to stay safely above any scintillation fluctuations of anti-matter, but still provides a good rejection of common matter cosmic rays.

The thresholds of the discriminators on the three scintillators preceding the lead-plate spark chamber affect the trigger rate strongly. Figure 1 shows the trigger rate per hour as a function of Cerenkov threshold in equivalent photo-electrons for several scintillation threshold settings (in units of minimum ionizing). There is roughly a factor of 10 difference in trigger rate between a threshold of 1.5 times minimum ionizing and of 1.75 times minimum ionizing. These trigger rates agree qualitatively with expected proton induced triggers. The higher energy protons can penetrate the lead better, but have difficulty meeting the scintillation threshold.

The two spark chambers recorded the topology of each event meeting the trigger criteria. The topologies of the processes that have met the full trigger criterion are tabulated below for two scintillator threshold settings:

TABLE I. BACKGROUND PROCESSES MEETING THE TRIGGER CRITERION

Process	Scintillator Thresholds	
	1.5X(33hrs)	1.75X(22hrs)
Single penetrating particle	215	1
Non-penetrating particles:		
(a) never seen in lower chamber	26	4
(b) stop in first 6 gaps of lower chamber	61	9
(c) stop in middle half of lower chamber	72	8
(d) go out side of lower chamber	6	3
Extra particle in top chamber	7	2
Extra particle in lower chamber	9	3
Multiple particles	11	2
Interaction in spark chamber frame	1	0
No recognizable tracks	6	1
Total	414	33

The non-penetrating particles are probably protons which met the penetration requirement through production of a neutron in the lead or close above (the probability of this is about 5%, using a 3000 gm/cm^2 mean free path for neutron production) which then hits a proton in the bottom scintillator (2% probability). The above rate for protons (1/sec) times these probabilities, which apply for the 1.5X scintillator thresholds, yield about 4 events/hour, or an expected sum total of non-penetrating events in the left-hand column above of about 130, which corresponds well with the 160 seen. Since most of these protons are well below the 420 MeV minimum energy to penetrate the lead, the higher scintillator threshold setting does not reduce them as dramatically as it does the penetrating protons. We should also note that atmospheric deuterons are probably included in this topology, since they apparently all fragment before reaching S_4.

The other backgrounds in Table I are modest in number, corresponding to about 1/hour in the lower threshold data, and 0.3/hour in the higher threshold data. We do not understand in every case how these events met the trigger, but their numbers are so low that there would have to be a very strong scaling to balloon altitudes for them to give us trouble.

In 55 hours of running at Sunspot, we observed at most a single antiproton event, consistent with Barber's calculation of the expected atmospheric background in our energy range. He predicted about 10^{-5} antiprotons per m^2 ster sec GeV/c.

5. Scaling to Altitude

Using the calculations of Barber, we find that protons just above 420 MeV should increase by 60 times to balloon altitudes, for the vertical flux, and by about 100 times when the anisotropy effect is included. Lower energy protons increase only about 50 to 70 times, since the mountaintop proton spectrum peaks at a somewhat lower energy than the cosmic one. Thus the lower threshold setting would indicate a flight trigger rate of about 1 event/3 seconds, while the higher one would indicate 1 event/30 seconds. A setting somewhere in between the two scintillator thresholds would seem to give a manageable trigger rate, with some protection from the uncertainty of the present solar modulation cycle, and from the potentiality of discriminator threshold drift with time or temperature, which is common at the 5 → 10% level with our particular circuits.

6. Antiproton Efficiency

Antiprotons and protons alike can be rejected by Cerenkov counter and scintillator thresholds. At a threshold setting for scintillators of 1.5X, the efficiency for including a 430 MeV antiproton is about 0.2, while at 320 MeV it has risen to about 0.5, and at 250 MeV nearly to unity. Assuming a flat spectrum for antiprotons, and that they are at 10^{-4} of the protons in flight, and that we achieve an exposure factor of 2.5×10^4 m^2 ster sec (about 12 hrs), and a 250 MeV bandpass for the experiment (about 80 MeV to 330 MeV), we should have 5×10^6 protons stop in the apparatus, and about 10^6 heliums. If 500 antiprotons enter the apparatus, their fate as a function of energy bin is outlined in the table below:

TABLE II. ANTIPROTON EFFICIENCY STUDY - ESTIMATED NUMBERS OF EVENTS

			Events after threshold cuts applied			
Starting Events #	Energy Bin	Events After S4 Geometry Efficiency	1.5X + 4 pe's in C	1.75X + 4 pe's in C	1.5X + 2 pe's in C	1.75X + 2 pe's in C
100	80-130 MeV	15	13	13	7	7
100	130-180 MeV	20	20	18	10	10
100	180-230 MeV	25	23	15	15	10
100	230-280 MeV	35	25	12	16	8

100	280-330 MeV	50	25	10	16	6
		Totals	103	68	64	41
Average Threshold Efficiency (%)			71	47	44	28

These numbers show that there is not a really great sensitivity of antiproton efficiency to the various thresholds, and that the scintillator thresholds particularly should be chosen conservatively to reduce trigger backgrounds. The background reduction as a function of Cerenkov setting is about the same as the loss in efficiency, so the 4 pe's setting seems sufficient, since it is nearly fully efficient for antiprotons in this energy range. (We should note also, that the numbers chosen above are for a flight somewhat shorter than we hope to get, and the $\bar{P}/P$ ratio of 10^{-4} may be low by as much as a factor of 4, or of course it may also be too high!

7. Balloon Flight

The experiment is in a flight-ready state in Thompson, Canada, and is scheduled to fly sometime after 10 August 1979.

References

Barber, H., Thesis, Univ. of Arizona, 1976.
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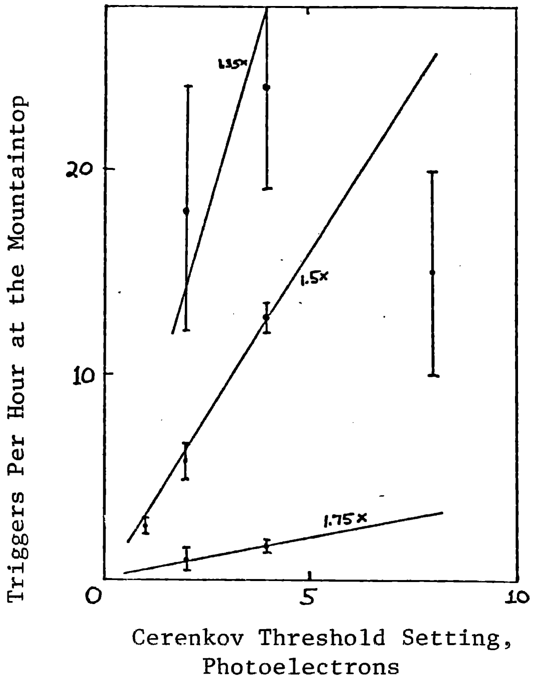

Figure 1. A plot of observed trigger rates for various scintillator threshold settings as a function of Cerenkov threshold setting. The lines guide the eye, but also are compatible with calculated expected trigger rates for proton-induced triggers. Trigger rates at balloon altitudes are expected to be about 100 times larger.