A Search for Antiproton Decay at the Fermilab Antiproton Accumulator

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Abstract. We report on the search for anti-proton decay at the Fermilab Antiproton Accumulator Ring. Experiment 868 (APEX) was designed to search for two-body $\overline{p}$ decay modes containing an electron in the final state ($\overline{p} \rightarrow e + X$) and to conduct an exploratory search for decays with a muon in the final state ($\overline{p} \rightarrow \mu + X$). Data were taken for three months in the Spring of 1995. Preliminary results yield lower limits on $\tau_{\overline{p}}$/BR in the range of $10^5 - 10^6$ years for selected channels having an electron in the final state, improving on previous results by approximately 3 orders of magnitude. Additionally, we report the first preliminary results for the $\overline{p} \rightarrow \mu\gamma$ and $\overline{p} \rightarrow \mu\pi^0$ decay channels.

INTRODUCTION

CPT invariance implies that the lifetimes of a particle and its corresponding antiparticle should be equal. Measurements of the half-life of the proton have set (mode dependent) limits on the lifetime of the proton in the range of $\tau_p/BR > 10^{31-33}$ years. Laboratory measurements of the half-life of the antiproton have not yielded limits anywhere near this. Prior to the APEX run, the most sensitive laboratory measurements of the antiproton lifetime were made in the APEX test run (T861) [1], and ranged from $\tau_{\overline{p}}/BR_(\overline{p} \rightarrow e^- K_L^0) > 9$ years to $\tau_{\overline{p}}/BR_(\overline{p} \rightarrow e^-\gamma) > 1849$ years at 95% C.L..

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The APEX experiment (E868) was designed to search for antiproton decay with a single-event sensitivity for the simplest mode ($\overline{p} \rightarrow e^{-}\gamma$) of approximately 10^6 years. It was installed on the 474 m circumference Antiproton Accumulator Ring at Fermilab, where it kept watch over an average of 10^{12} 8.9 GeV/c antiprotons during periods in which there was no stacking. Data was collected over a period of approximately three months (1 April - 30 June 1995) parasitic to CDF and D0 collider running. In all, APEX recorded some 10 Million triggers over 135 runs, totaling $\frac{\int N_{\overline{p}}\, dt}{\gamma_{\overline{p}}} = 3.31 \times 10^9 \overline{p}$-years, where $N_{\overline{p}}$ is the number of antiprotons circling in the accumulator, $\gamma_{\overline{p}}$ is the relativistic correction factor for the antiprotons (9.5), and the integral is taken over the lifetime of the experiment.

HARDWARE

To minimize the effects of our most likely source of background, beam-gas events, APEX installed an approximately 4 m long vacuum tank just upstream of the APEX detector. Titanium sublimation pumps were used to achieve a vacuum of 2.0×10^{-11} Torr within a conically shaped fiducial region. A removable wire target was mounted at the upstream end of the tank, which could be inserted into the beam line for the purpose of aligning and calibrating the detector components (see Figure 1).

Immediately downstream of the tank was the 1.5 m long tracking region of the APEX detector. Within this region there were three dE/dX counter stations used for triggering and crude identification of singly-charged relativistic particles. Each station was made up of four large (50 cm x 100 cm) scintillating planes, arranged such that there were horizontally-oriented planes above and below and vertically-oriented planes on each side of the beam line. The station located furthest downstream was situated behind a 1.27 cm thick lead preradiator, and was used primarily for identifying electromagnetic tracks.

The Scintillating Fiber Tracker was also located in this tracking region. The tracker consisted of 12 L-shaped panels, similar in size and orientation to the dEdX counters, arranged in groups of four to create three tracking stations. There were 384 2 mm diameter Bicron scintillating fibers on each L-shaped panel. The fibers were placed in two staggered layers. Each layer had an average center-to-center spacing of 2.6 mm, thus providing a pitch of 1.3mm. On each panel, the fibers were equally divided between two Hamamatsu R4135A multi-anode phototubes. The average track residual within a plane was observed to be about 620 μm. At the far end of the fiducial region (near the target) the vertex resolution along the beam line was measured to be about 13 cm for a track originating about 4 m upstream of the tracker, and the typical impact parameter for one of these tracks was somewhat less than 1 cm.

An electromagnetic calorimeter was placed just beyond the tracking region. It was made up of 144 cells (each measuring approximately 10 cm high by 10

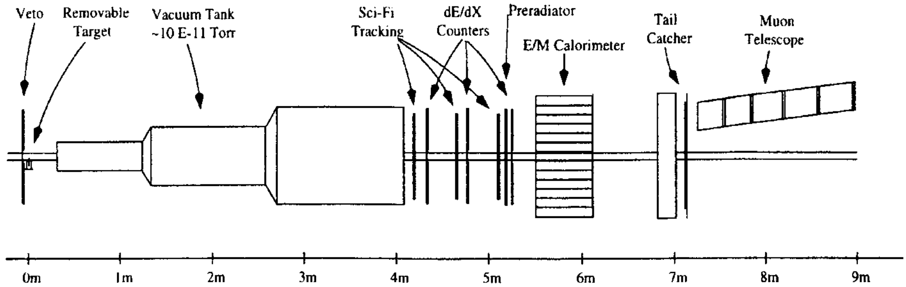

FIGURE 1. Side view of the APEX detector

cm wide by 60 cm deep) arranged so as to fill a 13 by 13 array with 6 cells missing from each corner and once cell missing around the beam line. The calorimeter was calibrated by reconstructing π^0's from beam-target events. It is also possible to see an η peak in the two-photon target data. The calorimeter was followed by a tail-catcher (scintillation counters behind a 20 cm thick lead wall), for identifying tracks that had punched-through the calorimeter (hadrons or muon candidates).

Finally, a muon telescope was located at the far downstream end of the detector. It was comprised of 5 alternating sections of iron (each 30.3 cm deep) and scintillator (each 1.91 cm deep). The telescope had a 30 cm by 30 cm cross section, and its central axis pointed towards the center of the vacuum tank. It was used for triggering and offline identification of muon candidates.

DIRECT SEARCHES

Using the tracker for kinematic reconstruction, the dE/dX counters and preradiator for particle identification and the calorimeter for energy reconstruction (and location of photons), the APEX collaboration has obtained limits on $\tau_{\overline{p}}/\text{BR}$ for four channels by direct searches:

Summary of Direct Search Results

Mode	**Surviving Events**	**Preliminary Result (90 % C.L.)**
$\overline{p} \to e^-\gamma$	0	$> 1.3 \times 10^6$ years
$\overline{p} \to e^-\pi^0$	1	$> 3.3 \times 10^5$ years
$\overline{p} \to \mu^-\gamma$	0	$> 4.2 \times 10^4$ years
$\overline{p} \to \mu^-\pi^0$	0	$> 1.9 \times 10^4$ years
		NO SYSTEMATICS

It should be noted that the analysis is not yet fully optimized, and so these numbers should be considered preliminary. It is also worth noting that the one event that survives the $e^-\pi^0$ analysis cuts is not without its problems when viewed in the event display (it appears that the tracking algorithm may have been tricked by some extraneous hits in a tracking plane). This event may vanish in the final analysis, and the $e^-\pi^0$ limit would then go up accordingly.

INDIRECT SEARCHES

The $\overline{p} \rightarrow e^-\gamma$ analysis has been applied to Monte Carlo simulations of other decay channels containing an electron. One may infer the following limits on $\tau_{\overline{p}}/$ BR from the absence of surviving events in the $e^-\gamma$ analysis:

Summary of Indirect Search Results

Decay Channel	Lifetime Limit 90 % C.L.
$\overline{p} \rightarrow e^-\pi^0$	$> 6.4 \times 10^5$ years
$\overline{p} \rightarrow e^-\eta$	> 17000 years
$\overline{p} \rightarrow e^-\omega$	> 1700 years
$\overline{p} \rightarrow e^-K^0_L$	> 3600 years
$\overline{p} \rightarrow e^-K^0_S$	> 4700 years
$\overline{p} \rightarrow e^-\rho^0$	> 120 years
	NO SYSTEMATICS

Again, these numbers are to be considered preliminary. In particular, optimizing the analysis for each channel should improve the limits for the heavier decays.

REFERENCES

1. Geer S. *et al. Phys. Rev. Lett.* **72** (1994) 1596.