T-535: Antiproton Beam Testing of the Gaseous Antiparticle Spectrometer (GAPS)

The goal of this experiment was to test a novel concept for space-based antimatter detection. When antimatter is slowed down in a target it is captured and forms an exotic atom. The exotic atom deexcites and in the process emits X-rays. When the antiproton reaches the ground state it annihilates with the nucleus producing pions. The signature of an antiparticle is multiple X-rays of precisely defined energies and one or more pions, all occurring within a sub-10 nanonsecond time window. GAPS great improvement in sensitivity over the current premier techniques for antimatter searches, such as the BESS experiment, which uses a superconducting magnet. As such GAPS is a next generation concept for antimatter detection.

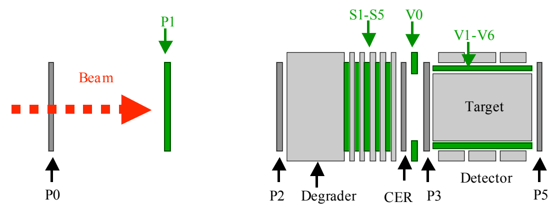

Figure 1: Experimental layout: The detectors highlighted in green are new for the 2005 experiment.

The experimental setup is in Figure 1. The GAPS gas target is designed so that antiprotons with kinetic energy below 100 MeV will be captured into exotic atoms with nearly unity probability. The 1 GeV/c (433 MeV) antiprotons were slowed passively using a lead degrader. The TOF and energy deposited in a third beam counter after the degrader is used to tag the antiprotons that survive passage through the degrader and enter the GAPS target. A Cerenkov detector is also used to veto highly relativistic charged particles – both in-flight antiproton annihilation products and accidental beam particles (pion, kaon, muon and electrons). Together, these four counters efficiently tag antiprotons entering the GAPS target.

GAPS as employed at KEK in the pi2 beamline is shown in Figure 2. The gas target cell was built using carbon fiber reinforced plastic (CFRP). Sets of 2x4 NaI crystals (25mm diameter, 5 mm thick) are housed in 16 panels arranged in a hexagonal array. Each of the 128 crystals is coupled to a Hamamatsu RM1924a photomultiplier tube (PMT). The system achieves sufficient energy resolution to resolve the X-ray transitions of interest and 200 ns time resolution for coincidence rejection of background. An open ended cylindrical geometry is required for the beam entrance and exit.

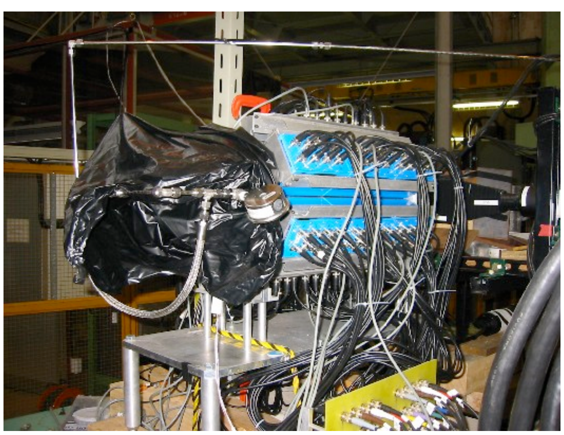

Figure 2: Photograph of the Gaps detector with the gas target in pi2 beamline

We measured the antiproton rate to be 27 antiprotons per spill. This rate was extracted from the GAPS data. Nearly 50 exotic atoms formed every hour of run time. A histogram of the antiparticle TOF is in Figure 3.

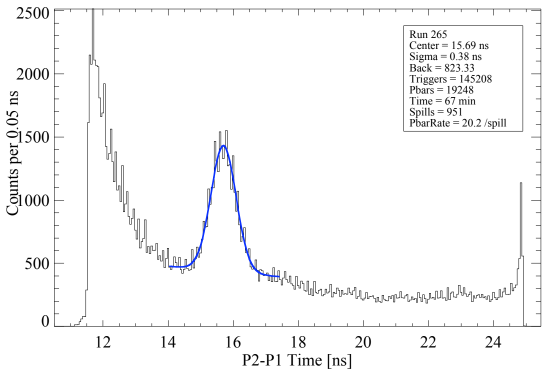

Figure 3: Histogram of the antiparticle TOF from P1 to P2. The blue Gaussian fit to the antiproton peak on top of accidental pions and muons generated from kaon decay

During the 31 hours in which we ran with the C_2F_6 target, approximately 1500 exotic atoms were formed. A histogram of all X-rays detected in this C_2F_6 target dataset is plotted in Figure 4. The X-ray spectrum with the target removed is also plotted (1.5 hours equivalent data scaled to the C_2F_6 data). A line fitting this data indicates a flat background with low energy component.

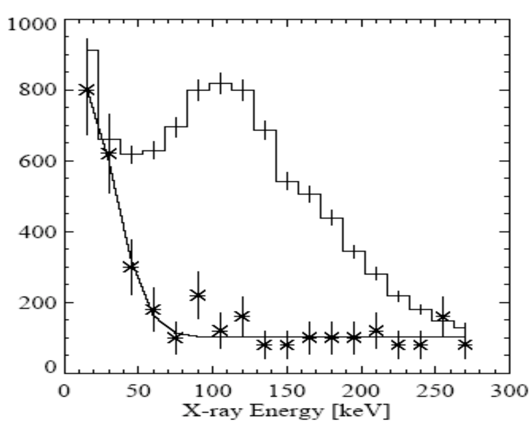

Figure 4: Histogram of X-rays for C2F6 target (31 hours). The X-ray spectrum with the target removed is also plotted (1.5 hours equivalent data scaled to the C2F6 data0. A line fitting this data indicates a flat background with low energy component.

In addition to the antiprotonic X-rays, we expect to see several charged and neutral pions (5 on average) emitted from this annihilation. The charged pions will leave an enormous amount of energy as they pass through the NaI crystal (~2 MeV) that will be recorded as a pion star event (π*). As an example of the power of the technique is shown in Figure 5. The cylindrical detector has been unfolded to show the 16 NaI detector modules each containing 8 independent X-ray detectors. A GAPS event is shown with three X-rays and a pion star. This is considered a clean signature of a $\overline{p}F$ atom since the three X-rays are consistent with expected transitions at 93, 43 and 23 keV and are observed together with a pion star. This is the first time a detector has ever been made whose purpose is to detect antimatter through a coincident exotic atom signature. Our detection rates and efficiencies as inferred from experiment are consistent with simulations.

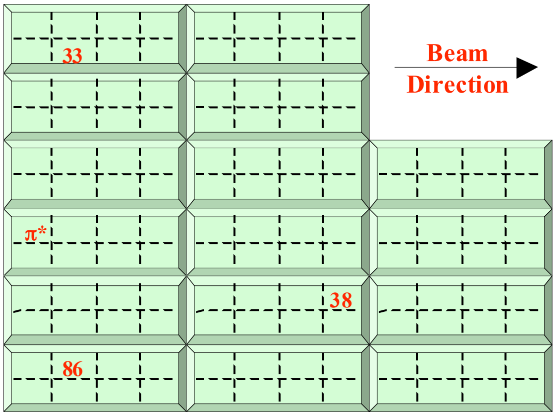

Figure 5: Antiprotonic event in Fluorine indicating correct signature of pion star and 3 X-rays.

The GAPS experiment succeeded in completely confirming the validity of the exotic atom approach to antimatter detection.