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The HEAT-pbar Cosmic Ray Antiproton Experiment

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Abstract

The HEAT-pbar high altitude balloon experiment has been designed and constructed to detect cosmic ray antiprotons in the energy range 4-50 GeV. The instrument uses the novel technique of multiple energy loss measurements in thin gas layers combined with a superconducting magnet spectrometer to identify particle masses. This produces a detector system with a wide range of response energies from a single device. The first flight of HEAT-pbar is planned from New Mexico in Spring 1999.

1 Introduction

The HEAT-pbar instrument is designed to detect the rare antiparticle species, antiprotons ($\overline{p}$) in the cosmic rays. The measurements of the $\overline{p}$ flux arriving near Earth serves as an important diagnostic tool for the understanding of the propagation of cosmic rays through the Galaxy and for the understanding of the diffuse gamma radiation produced by cosmic ray interactions in the Galaxy (Moskalenko, Strong, & Reimer, 1998). As is the case for positrons, unusual contributions to the source intensities of antiprotons may include exotic phenomena, such as the annihilation of cold dark matter particles (Moraal et al.,1991; Baltz & Gondolo, 1998), for example, weakly interacting massive particles (WIMPs) which are thought to be gravitationally bound in the halo of the Galaxy. Thus, the unique identification of even the slightest deviation of the observed e^+ or $\overline{p}$ intensity from that expected for purely interstellar secondary origin could have far-reaching implications.

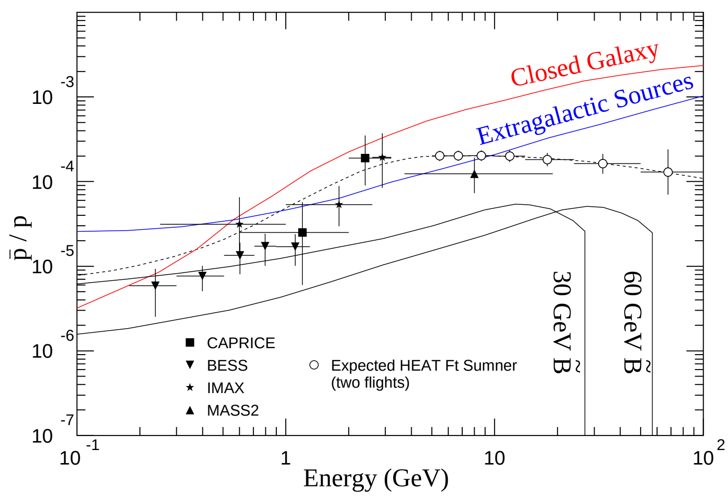

Figure 1: *Antiproton/proton measurements together with simulated HEAT $\overline{p}/p$ results (open circles). Data points are from: CAPRICE (Boezio et al., 1997), BESS (Matsunaga et al., 1998; Moiseev et al., 1997), IMAX (Mitchell et al., 1996), and MASS2 (Hof et al., 1996). "Closed Galaxy" is from Peters & Westergaard, 1977 and Rasmussen & Peters, 1975. "Extragalactic Sources" is from Stecker & Wolfendale, 1984. The standard Leaky Box (dashed curve) is from Labrador & Mewaldt, 1997 and Webber & Potgieter, 1989. Supersymmetric particle annihilation curves ($\tilde{\mathrm{B}}$) are from Jungman & Kamionkowski, 1994.*

There have been several measurements of antiprotons in recent years (Matsunaga et al., 1998; Moiseev et al., 1997; Boezio et al., 1997; Mitchell et al., 1996; Hof et al., 1996). Instruments using time-of-flight vs. rigidity and Čerenkov vs. rigidity for efficient particle identification and utilizing continuous tracking to reject hard scatter background have mapped out the the energy region between 200 MeV and several GeV. The results of these experiments are shown in Figure 1.

Through repeated balloon flights at low geomagnetic cutoff rigidity, the BESS experiment (Matsunaga et al., 1998; Moiseev et al., 1997) continues to accumulate new data in this energy region. However, there is very little information available at higher energies. Precise spectral measurements over a wide energy range above a few GeV, where the $\overline{p}/p$ ratio is expected to decline, are clearly needed.

2 The HEAT-pbar Detector: Scope and Overview

The HEAT-pbar detector (as of this writing, awaiting a high altitude balloon flight in Fort Sumner, New Mexico) is designed to measure the cosmic ray antiproton flux up to at least 50 GeV. In addition, this detector is able to identify cosmic ray positrons over much of this energy interval, complementing earlier measurements with the HEAT $e^{\pm}$ instrument (DuVernois et al., 1999; Barwick et al., 1998; Barwick et al., 1997a; Barwick et al., 1995). A schematic drawing of the instrument is shown in Figure 2. This detector uses multiple ionization loss measurements (multiple dE/dX), along with a superconducting magnet spectrometer to determine the mass, energy, and charge sign of cosmic ray particles. This combination of measurements provides excellent separation of antiprotons from other (more abundant) negatively charged particles, and is the only practical technique which allows true identification of all singly-charged particle species over this energy range. The magnet spectrometer determines the particle's momentum and charge sign. The dE/dX detectors determine the particle's velocity by exploiting the relativistic rise of the ionization loss in gaseous media. The particle's charge magnitude is obtained from layers of scintillators at the top and bottom of the instrument. Finally, timing measurements from these scintillators are used to reject upward going particles, which would mimic antiparticles in the spectrometer.

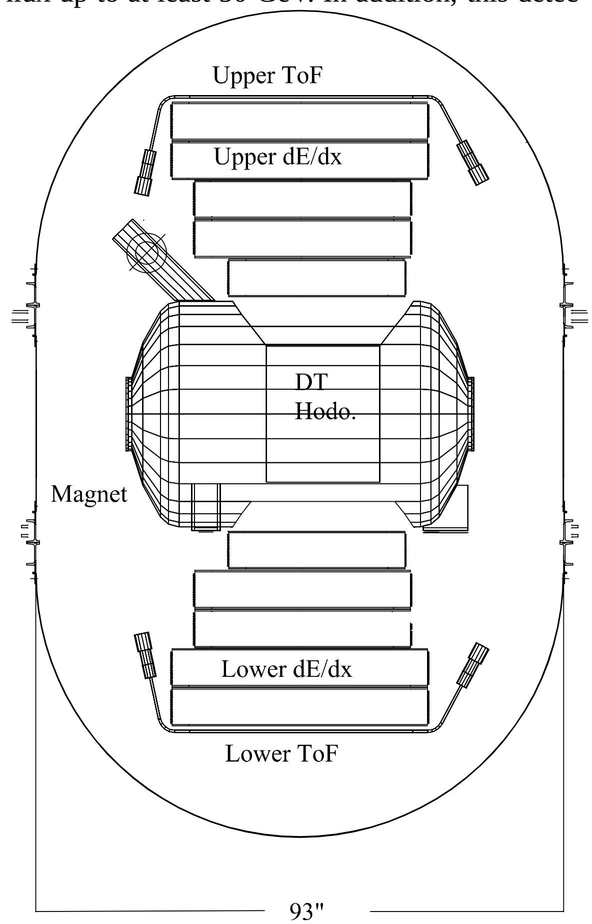

Figure 2: *Cross-section drawing of the HEAT magnet spectrometer showing the placement of the drift-tube hodoscope in the magnet dewar.*

The choice of a velocity measurement made by multiple dE/dX sampling rather than the more conventional ring imaging Čerenkov (RICH) technique is based on the following consideration: a RICH detector would be restricted to a more limited range of particle energies. Previous RICH detectors have used either solid NaF radiators (Barbiellini et al., 1996), with a threshold $\overline{p}$ energy ~0.5 GeV, or gaseous fluorocarbons (Barbiellini et al., 1997; Diehl et al., 1997), at a threshold $\overline{p}$ energy ~ 18 GeV. Thus the solid counters cannot provide measurements above $\overline{p}$ energies of ~ 5 GeV and the gases do not respond below ~ 18 GeV, leaving a significant energy 'gap' in particle identification which is unavoidable with present RICH devices. As measurements of the antiproton flux in this energy interval are critical in determining the energy dependence of the $\overline{p}/p$ ratio at high energy, we have chosen the dE/dX technique as an attractive alternative. This technique has been used extensively in accelerator experiments (Allison & Cobb, 1980; Lehraus et. al.,1978), and in space for heavy nuclei with the HEAO-3 mission (Binns et al., 1988). It is a natural choice for a cosmic ray antiproton flux measurement, but could not previously be used in balloon flights because of the required large number of electronic channels. Only recently has low-power VLSI instrumentation become available that makes this measurement possible. The following sections describe HEAT-pbar in more detail.

3 Magnet Spectrometer

For HEAT-pbar, we employ the same rigidity spectrometer that was successfully flown for HEAT-e$^{\pm}$ in 1994 and 1995. The spectrometer has been described in detail (Barwick et al., 1997b), and consists of 479 precision drift tubes mounted in the room-temperature bore of a superconducting magnet. It has a most-probable field integral of ~ 0.42 T-m, a single-point tracking accuracy of 70 μm, an average track length of 58 cm, and typically measures 15 points along a particle trajectory. The continuous-tracking approximation then yields a mean Maximum Detectable Rigidity (MDR) of 170 GV, and the rigidities of particles up to $\sim$60 GV can be reliably measured. For a fraction of the trajectories, much higher values of MDR (up to $\sim$400 GV) can be obtained. The geometrical factor for the spectrometer alone, without the constraints imposed by outlying counters, is 920 cm^2-sr.

4 Multiple dE/dX Detector

The HEAT-dE/dX detector consists of a stack of 140 segmented proportional chambers, each providing a measurement of the specific ionization loss of the particle. In order to maximize the particle identification power of the instrument, the proportional chambers are filled with a gas consisting of 95-5% Xe-CH_4, which exhibits an increase in ionization loss rate of 70% (Fischer et al., 1975) between minimum ionization and relativistic saturation. The details of the dE/dX detector are more fully discussed in an accompanying paper (Labrador et al., 1999). The overall acceptance geometry of the complete instrument is $\sim$500 cm^2-sr.

The primary sources of background to the antiproton flux measurement are negatively charged electrons, muons, pions, and kaons which are produced in the atmosphere and local material above the detector, and which appear as single isolated particles in the detector. We have used data from previous HEAT flights to determine the flux of muons and pions relative to protons. A detailed simulation of kaon production in the ≈ 1 g/cm^2 of material in the gondola shell and thermal insulation predicts the expected kaon contamination. Based on the HEAT data, we find that the combined negatively charged muon/pion flux through the instrument is roughly 0.7% of the proton flux. The results of the kaon production simulation indicate that one K$^-$ is produced in the shell for every 1.4×10^4 protons, but that 85% of these kaons have an energy below the geomagnetic cutoff, and would be rejected on that basis. Of the remaining kaons, the vast majority are associated with events with a high particle multiplicity, which would also result in the rejection of the event. The results of this study indicate that kaons represent a negligible background to the antiproton measurement after application of minimum energy and event cleanliness selections.

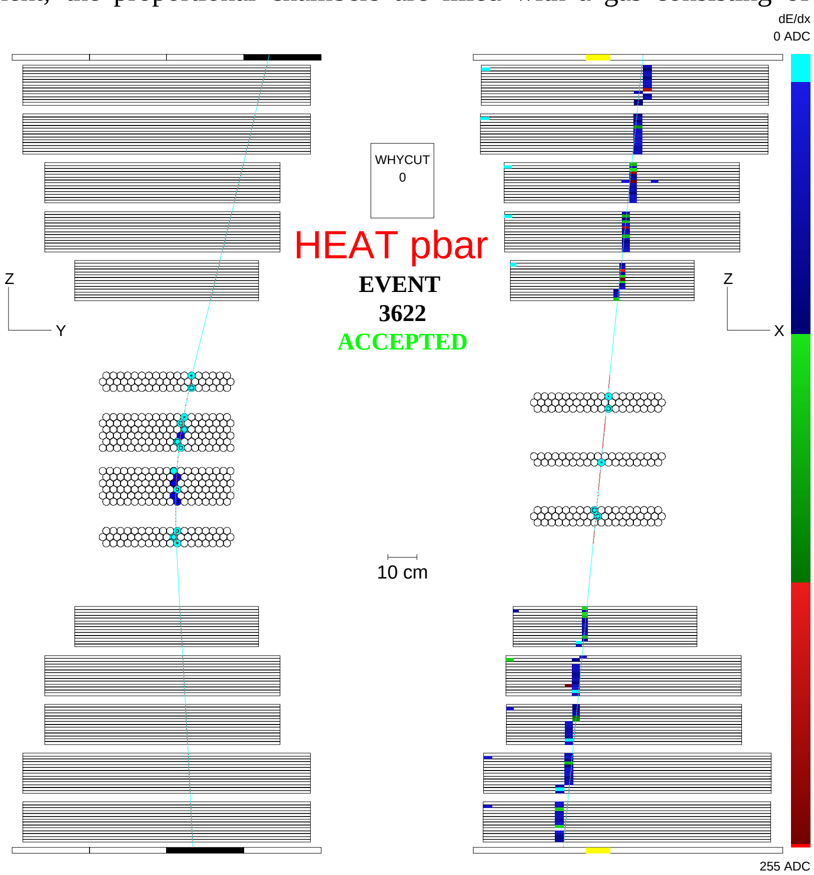

Figure 3: *Orthogonal views of a sea-level muon passing through the HEAT-pbar instrument with the 1T (central field) magnet on.*

5 Instrument Performance

Figure 3 shows a reconstructed sea-level muon event taken with the full instrument and magnet on. The efficient, clean track in the dE/dX wire chambers and drift tube hodoscope is evident. Figure 4 is a Monte Carlo simulation of the expected mass resolving power of the HEAT-pbar instrument. Such delineation of particle species over a wide range of energies is anticipated for real data. The instrument will be able to separate the muon-pion mass region from the more interesting proton/antiproton and electron/positron bands. Since the experiment is currently awaiting flight, cosmic ray data from balloon altitudes cannot be included in this paper. Assuming a successful flight in May, 1999, we anticipate being able to present preliminary results at the conference. Just to illustrate the statistical quality we expect from two flights of this instrument, we have included simulated data in figure 1.

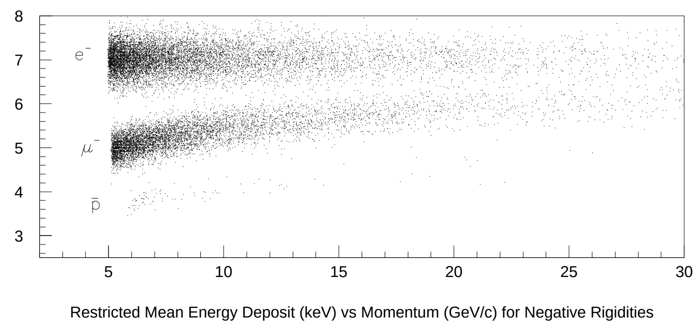

Figure 4: *Simulated scatter plots of negatively charged cosmic rays at balloon altitudes based on our expected resolution.*

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