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Particle Identification with the HEAT dE/dx vs. Rigidity Detector System

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Abstract

The HEAT–pbar instrument uses a multiple dE/dx vs. Rigidity technique to identify cosmic rays by mass and charge. In particular, the detector system provides unambiguous discrimination between protons/antiprotons, positive and negative pions or muons, and positrons and electrons. A key element in the system is a stack of 140 Xenon filled multiwire proportional chambers for measurements of the ionization energy loss of particles. We will describe the design and construction of this system, and we shall discuss its performance and particle identification power, based on measurements in the laboratory and on data from a balloon flight in Spring 1999.

1 Introduction:

The HEAT–pbar experiment is a magnet spectrometer experiment designed to measure the antiproton spectrum and antiproton/proton ratio from ~4 GeV to ~50 GeV (Bower et al., 1999). Given the low antiproton abundances expected at these energies, rejection of background caused by other negatively charged particles is critical.

Unambiguous particle identification in a magnet spectrometer experiment can be attained with precise measurement of momentum or magnetic rigidity, charge, and velocity. The superconducting magnet and drift tube hodoscope employed by HEAT–pbar have been described previously and used on the previous version of the HEAT payload (Barwick et al., 1997). This spectrometer provides a characteristic maximum detectable rigidity (MDR) of 170 GV. The time–of–flight (TOF) system is similar to that used on previous HEAT flights, with a lower set of TOF paddles substituting for the electromagnetic calorimeter used in the earlier HEAT payload.

In order to provide mass discrimination between antiprotons and other negatively charged particles at energies above a few GeV, a precise measurement of velocity other than by TOF must be made. Multiple ionization sampling for particle identification has been used in accelerator experiments (Allison & Cobb 1980). This technique exploits the logarithmic rise in the mean rate of energy loss of a relativistic charged particle in a medium, as given by the Bethe–Bloch equation:

$$\frac{dE}{dx} = -K \frac{Z_{med}}{A_{med}} \frac{z^2}{\beta^2} \left[\frac{1}{2} \ln\left(\frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} \right) - \beta^2 - \frac{\delta}{2} \right] \quad (1)$$

where Z_{med} and A_{med} are the charge and mass numbers of the medium, I is the mean excitation energy of the medium, z is the charge of the incident particle, β and γ are the velocity and Lorentz factors for the incident particle, T_{max} is the maximum kinetic energy that the particle can impart to an electron in the medum, and K is a proportionality constant. The third term in the parenthesis is a density correction factor, which will have some effect on the choice of gas and which may be parametrized according to the treatment of Sternheimer (1952), and the first term in the parenthesis is the relativistic logarithmic rise in energy loss by which particles of different masses but equal velocities may be distinguished.

The net effect of the constants outside of the parenthesis, is that energy resolution in an ionization measurement increases with the electron number density of the medium. A primary choice of gas for a multiwire proportional counter would be xenon mixed with a small amount of quench gas. For HEAT–pbar, we chose 95-5% Xe–CH_4 gas at 1 atmosphere as the ionizing medium.

Because the signal for passage through a 1 atm-cm thickness of Xe gas can be as wide as 80% FWHM, a large number of samples is necessary to distinguish different particles by the logarithmic rise in dE/dx signal. On board a balloon instrument, such a detector stack is further constrained by the available space and weight limitations and by the limited power available for electronics and high voltage. Furthermore, the detectors must be large enough to provide adequate geometry factor to attain the scientific objectives of the flight. In the case of HEAT–pbar, the geometry factor must be large enough to detect the low intensity of high energy antiprotons over a 24 hour flight.

2 Design and Construction of the Wire Chambers:

The HEAT-pbar wire chamber stacks are composed of 140 xenon filled multiwire proportional chambers, divided into two stacks of 70 chambers each, above and below the magnet. The chambers are divided into 10 modules, or chamber sets, of 14 wire chamber layers each, coming in three sizes (Figure 1). The largest chambers have ~96x96 cm^2 active area, the intermediate sized chambers have ~78x78 cm^2 active area, and the smallest chambers have ~60x60 cm^2 active area.

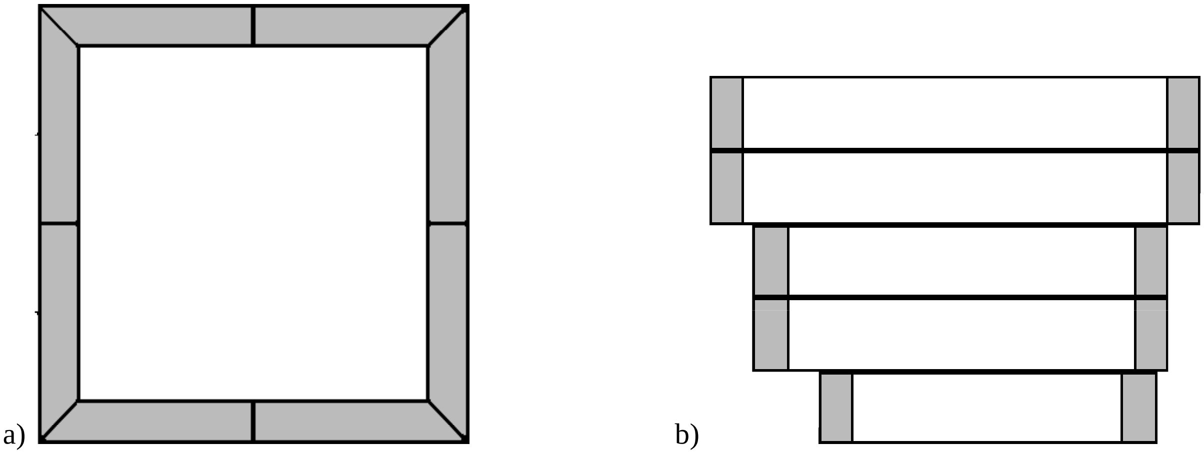

Figure 1: a) Cross–section of wire and window support aluminum frame. Shaded areas are filled with vented hexagonal honeycomb core. Small tabs on the left side help align and attach readout electronics boards. b) Stackup diagram for top wire chamber stack, showing the three chamber sizes.

Each module is composed of layers of aluminum frames alternately holding cathode windows or anode wire planes. The frames are made of 0.48 cm thick 6061–T6 aluminum, water–cut and deburred to provide the interior chamber. The outer walls of the frames were also water–cut to provide outer cavities, which are filled with vented aluminum hexagonal honeycomb core to provide vertical mechanical rigidity at less weight cost than solid aluminum would require. These outer cavities are also vented to the outside of the chambers while maintaining the inner gas seal. The aluminum frames and the hexagonal core are laminated above and below with 0.028cm thick G10, bonded to the frames with HB Fuller Resiweld epoxy. The G10 layers provide electrical insulation of the anode wires and cathode windows from the electrically grounded aluminum frames. The average thickness of a wire– or cathode–support frame is ~0.55 cm, so that the vertical cathode spacing when assembled is ~1.1 cm.

The anode wires are 20 µm diameter gold–plated tungsten, spaced at intervals of 0.51 cm and attached with a tension of 50 g to the wire support frames. The high voltage (~-1400 V to ~-1600 V) cathode windows are 13 μm thick mylar, aluminized on both sides to 2 optical depths, and stretched onto the window support frames to an average tension of around 200±50 g/cm.

Alternating layers of wire– and cathode–support frames are stacked with primed RTV silicone to form one module. The modules are closed out above and below with "closeout" support frames made of 0.64 cm thick aluminum, which provide gas inlets and outlets, outer cathode windows, and outermost gas–sealing windows. The closeouts also provide the mechanical attachment points for mounting the modules into the payload. The closeout interior (cathode) windows are 25 μm thick mylar aluminized on inward facing side and stretched to tensions similar to those of the inner windows, while the outer gas–sealing windows are 51 μm thick clear mylar stretched to greater than 400 g/cm.

3 Wire Chamber Electronics:

The anode wires in each wire chamber are connected in 30 groups of 4, 5, or 6 adjacent wires, depending on the size of the chamber. Each group of wires in a chamber is connected to one input channel of a multiplexed charge amplifier. These amplifier electronics are based on the CERN AMPLEX chip (Longoni et al., 1990). The amplifier circuit boards were previously used in the RICH experiment (Buckley et al., 1992) and were rebiased for the negative charge signals expected for the HEAT experiment. The AMPLEX chips used in this experiment provide an average gain of 6 mV/fC and a shaping time of 700–800 ns. With additional buffering electronics and voltage limits on the amplifier cards, we have a dynamic range of ~200 fC. Each AMPLEX chip can read 16 channels, so two AMPLEX chips read 30 wire groups per wire chamber. The 1st and 32nd channels of the AMPLEX chip pair are unattached and are fed to the data stream to provide electronic noise measurement. Custom electronics were built to control the amplifier cards, one set of control electronics each for both the top wire chamber stack and the bottom wire chamber stack. Each wire group within a wire chamber is read in sequence by the amplifier electronics, but the wire chambers themselves are read in parallel. The total time for the amplifiers to read the signals from all of the wire groups is ~185 μs.

The amplifier card output signals are read by custom ADC cards built for this experiment. The ADCs digitize the signals with 8–bit resolution. Pedestals are stored on pedestal FIFOs on these ADC cards, up to 8 pedestal measurements per wire group. When all wire group signals are loaded into data FIFOs, the signals are then compared with their corresponding pedestals. Any signal which exceeds the pedestal level plus a programmable threshold is passed to the data acquisition computer; those signals at or below pedestal plus threshold are suppressed. Pedestal FIFOs may be reloaded during flight, and zero suppression may also be turned off for selected wire chambers.

Digitized signals passing zero–suppression are formatted into variable length data frames by custom–built electronics and are passed in parallel, for the top and bottom stacks, to two Lecroy 1190 dual port memory modules. When the wire chamber data frames for both the top and the bottom stacks are complete, they are passed to the onboard data acquisition computer. When the data acquisition system has read the data frames, it resets the wire chamber readout electronics, allowing for receipt of new event data. The strobe rate from the data acquisition electronics to the Lecroy 1190 is 0.4 μsec per wire signal so that, if every wire were to yield a positive signal for a given trigger — for example, if zero–suppression were turned off for calibration — the data could be transmitted to the dual port memory modules in 0.9 ms.

4 Performance:

Wire chamber responses are being mapped as of this writing. Figure 2 shows a signal histogram for one wire group in a wire chamber at the top of the top stack, using the first–pass wire chamber response map to normalize the peak of the signal to 1. The chambers were filled with 95–5% argon–methane gas and run at -1600 V. The lower histogram in Figure 2 shows a histogram of the average of signals from the entire wire chamber stack, with the highest 20% of signals eliminated to reduce contributions from the Landau tail and with other rudimentary cuts to eliminate multi–particle events.

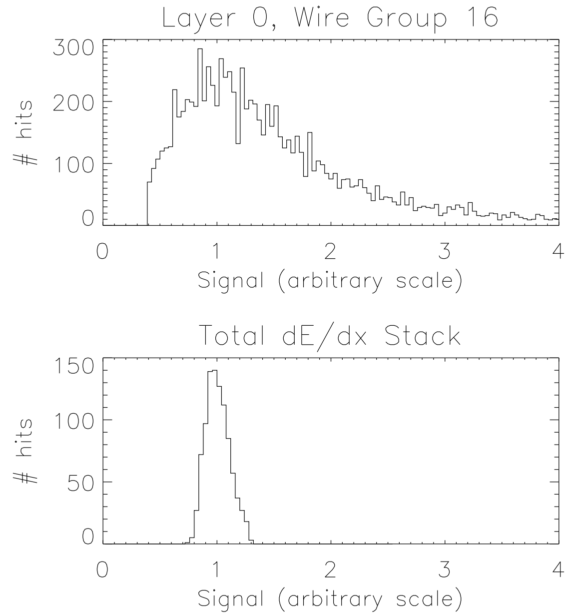

Figure 2: Signal histogram for single wire chambe (top) and total stack (bottom).

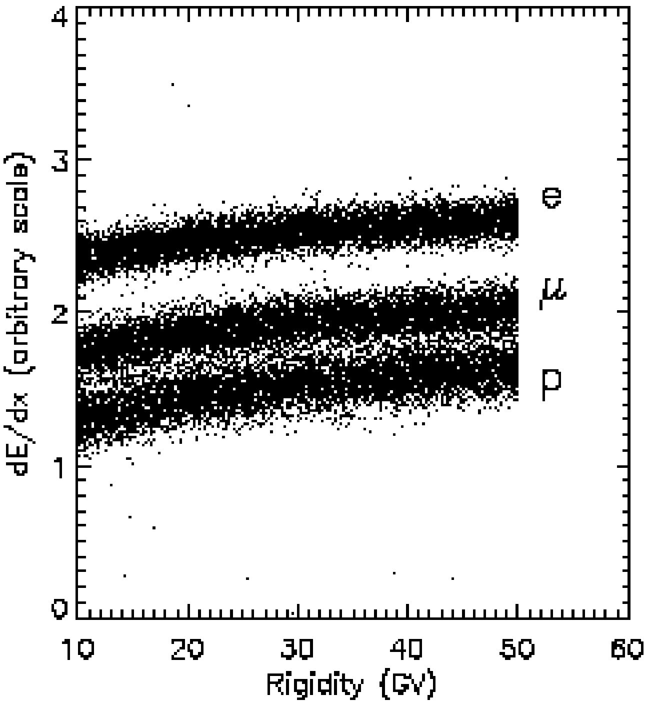

Figure 3: dE/dx vs. Rigidity, simple Monte Carlo.

Figure 3 shows a scatter plot of total dE/dx vs. Rigidity based on the results shown in Figure 2, with proton, muon, and electron signals shown. The simulated spectra are flat, and because the density correction is small for gases, it is neglected here. Rigidity uncertainty is also neglected in order to isolate uncertainty due to the dE/dx measurement. Particle tracks are clearly evident in the simulation. A more detailed simulation is shown by Bower et al. (1999), in these proceedings.

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