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A Gas RICH for Cosmic Ray Studies

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Abstract

A newly developed gas Ring Imaging Cherenkov (RICH) detector for cosmic ray studies was used in the WiZard/CAPRICE98 balloon-borne experiment. The performance of the gas-RICH will be presented. The detector was built for identifying charge one particles and specifically antiprotons and positrons in a large background of cosmic ray particles. This is the first time cosmic ray antiprotons above 18 GeV can be mass resolved on an event by event basis.

1 Introduction

The scientific goals of the CAPRICE98 experiment are to measure precisely the energy spectra of cosmic ray particles, and in particular the flux of antiprotons and positrons. The instrument included a gas radiator RICH detector, a time-of-flight system, a super conducting magnet spectrometer equipped with three drift chambers (Hof et al. 1994), and an electromagnetic silicon-tungsten calorimeter (Ricci et al. 1999). Performance of the spectrometer during the flight are described elsewhere (Cafagna et al. 1999).

The NMSU-WiZard/CAPRICE98 flight took place on 28-29 May 1998 from Ft Sumner (34.3 N, 104.13 W), New Mexico to Heber, Arizona. The geomagnetic cut-off at these latitudes is about 4.2 GV/c. About 4.1 M events were collected during the 21 hour long flight above an altitude of 35 km, corresponding to an atmospheric overburden of approximately 5.5 g/cm^2.

The CAPRICE98 gas RICH detector was build in order to accurately identify antiprotons and positrons in the energy range between 3-40 GeV in a large background of electrons, muons, pions and protons. It is the first RICH detector used in a space experiment that is able to mass resolve antiprotons with an energy above 18 GeV.

The identification is done by detecting Cherenkov photons produced in a gas, C_4F_{10}, with a threshold Lorentz factor of 18.9 corresponding to an electron (proton) momentum of 0.01 (17.7) GeV/c at a refractive index for C_4F_{10} of 1.001401 (911 mbar and 45^{o}C). The Cherenkov light produced in the gas radiator is reflected by a spherical mirror back onto a photo sensitive MWPC. From this the Cherenkov angle and the beta (β) of the particle are determined.

2 The RICH detector

The RICH detector is shown in figure 1 (Barbiellini et al. 1997, Francke et al. 1998). When a cosmic ray particle enters the detector through the MWPC it ionizes the ethane gas. Thereafter it goes through a quartz window into the radiator volume. Cherenkov light is emitted along the trajectory of the particle in the C_4F_{10} gas at atmospheric pressure in the 1 m tall gas radiator. The cone of light is reflected back and focused by a spherical mirror towards a MWPC situated in the focal plane of the mirror, where it interacts with a photosensitive gas (TMAE) and produces photoelectrons. These are then amplified and detected by induced pulses in a matrix pad plane, where the cone of Cherenkov light will give a ring-like image. The radius of the ring depends on the velocity of the particle. The ring radius increases from 0 at threshold (17.7 GeV/c for protons) to about 5.5 cm for a $\beta \simeq 1$ particle. To collect and focus the Cherenkov light on the MWPC a 6 mm thick spherical glass mirror was used. The reflectance was measured to be 85 % in the wavelength region 140-250 nm. The MWPC is operated at low gain ($2 \cdot 10^4$ electrons per photoelectron) with pure ethane as amplifying gas and TMAE vapour for photosensitivity. The quartz window is transparent for wavelengths longer than 170 nm. The TMAE is heated to 35^{o}C which gives an absorption probability of more then 80 %. The quantum efficiency for TMAE is about 30 % for wavelengths shorter than 200 nm (Arnold et al. 1992).

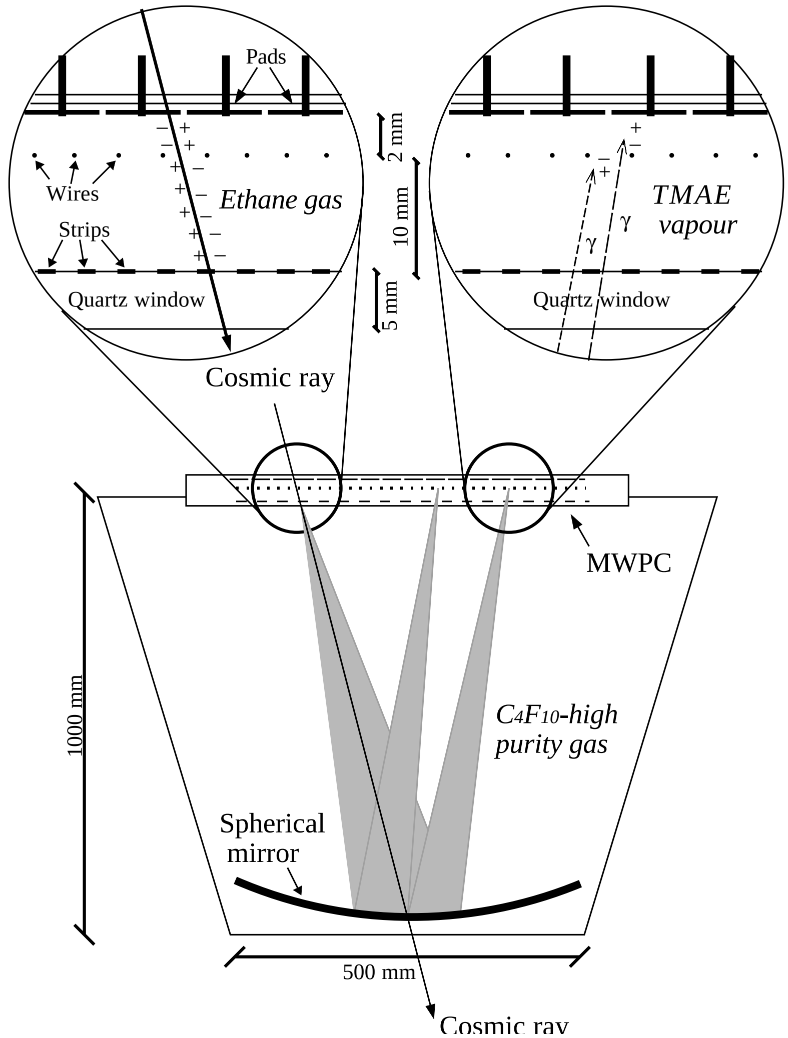

Figure 1: Schematic view of the CAPRICE98 RICH detector. At the top are two expanded views of the MWPC. Cherenkov light is emitted in the C_4F_{10} gas along to the particle track, indicated by the shaded area, and is reflected by a spherical mirror back up onto the photosensitive MWPC.

The front-end electronics used the 16 channel, low noise, VLSI chip AMPLEX developed at CERN (Beuville et al. 1990). The readout time was 3 μs per channel giving a total readout time of approximately 1.5 ms. The trigger rate during the flight was 65 Hz.

A typical signal in the pad plane from a single photo electron is 70 fC (spread out over an average of 4.5 pads). The noise level of the electronics was normally 7 fC (r.m.s.). Above 400 fC the AMPLEX saturates. Both the pedestals and thresholds were adjusted individually for each channel.

The detector performance can be expressed by the observed number of photoelectrons, $N = N_0 L\, sin^2\theta_{max}$ where θ_{max} is the maximum Cherenkov angle, L the path length and N_0 is the detector response parameter. The observed number of photoelectrons was derived experimentally by making a strict selection on a large sample of particles (200 k) from flight data. We selected a well defined single track in the spectrometer with a good momentum resolution, characterized by acceptable chi-squares and small uncertainty in deflection. A good reconstruction of the Cherenkov angle was required together with the condition that the center of the ring of Cherenkov light should be contained in the MWPC. The calorimeter was used to select electrons with $\beta \simeq 1$ in the rigidity range above 1 GeV/c. For the surviving 149 events the Cherenkov pad hits were identified, clusterized (2-5 pads per photoelectron) and counted, which gave an average of 12 photoelectrons per event. This gives a detector response parameter, N_0, of 44 photons per cm for the path length of about 1 m and θ_{max} = 52.2 mrad.

3 Particle identification

Figure 2 shows the measured Cherenkov angle for about 9000 particles in a deflection region up to 0.6 (GeV/c)$^{-1}$. These events were chosen for having a good tracking reconstruction and good reconstruction of the Cherenkov angle. The lines in the figure are the theoretical Cherenkov angle for protons, pions and muons. A dense band of about 6500 protons is extending from approximately 0.056 (GeV/c)$^{-1}$ to higher energies (smaller deflection) and increasing Cherenkov angles. The main bulk of electrons and positrons are located at at maximum Cherenkov angle ($\approx$ 52 mrad). This is the first time that, in a balloon-borne experiment, muons and pions can be separated in the rigidity region 2-6 GeV/c.

The Cherenkov angle is calculated for each pad that is not included in the 5×5 pad ionization area closest to the track, using an iterative geometrical method. Then a Gaussian potential method (Ullrich et al. 1996) is used to calculate the Cherenkov angle for that event. This method assigns a weight to the Cherenkov angle calculated for each pad, depending on how much it differs from the mean angle for all pads. Pads with Cherenkov angles far from the mean value are therefore suppressed.

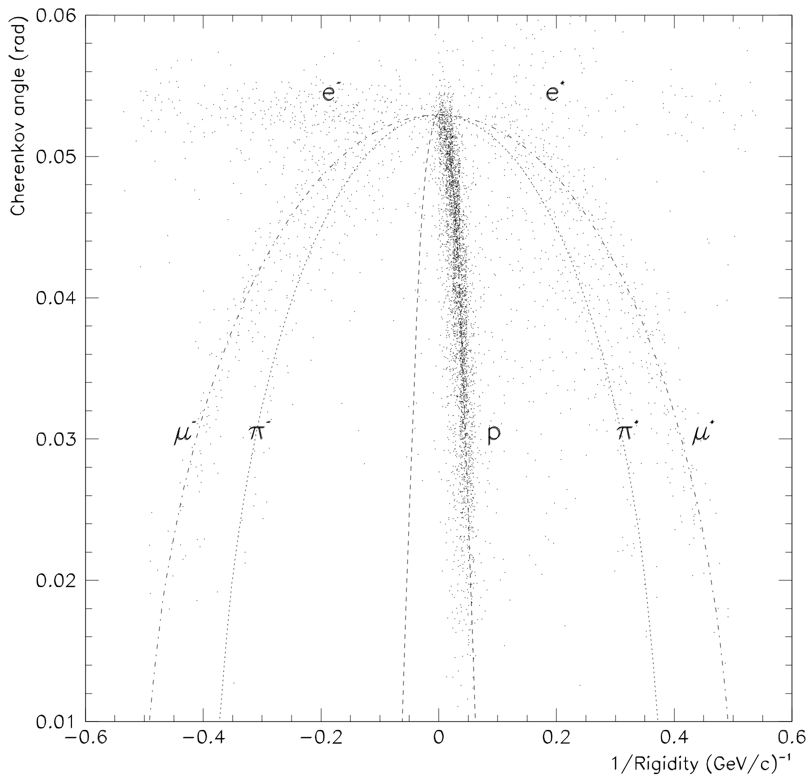

Figure 2: The measured Cherenkov angle distribution versus deflection for about 9000 events.

The weight is assigned to each pad calculated Cherenkov angle assuming a Gaussian distribution, which has its maximum at a fitted mean of the Cherenkov angles. For the calculation a measured average resolution of 7.6 mrad is used. The error of an individual pad is rather independent of β and the incidence angle of the particle.

The reconstructed Cherenkov angle has a resolution of 1.6 mrad for muons with a maximum Cherenkov angle, see figure 3(b).

4 Selection efficiency

To get a good estimation of the RICH selection efficiency for protons, the background of positrons, muons and heavier particles like alphas are removed by using both the time-of-flight and calorimeter information.

Figure 3(a) shows the proton selection efficiency for the RICH in the rigidity region 4-50 GeV/c. Below 17 GeV/c protons are selected by requiring that they should give no Cherenkov light. At 17 GeV/c they start to give light and therefore the efficiency drops. Above 17 GeV/c a selection is made on the measured Cherenkov angle θ_{meas} that should not deviate from the theoretical value for protons by more then 3 standard deviations.

Furthermore, θ_{meas} is required to be more than 3 standard deviations away from the expected Cherenkov angle for pions. This causes the decrease in efficiency above 35 GeV/c.

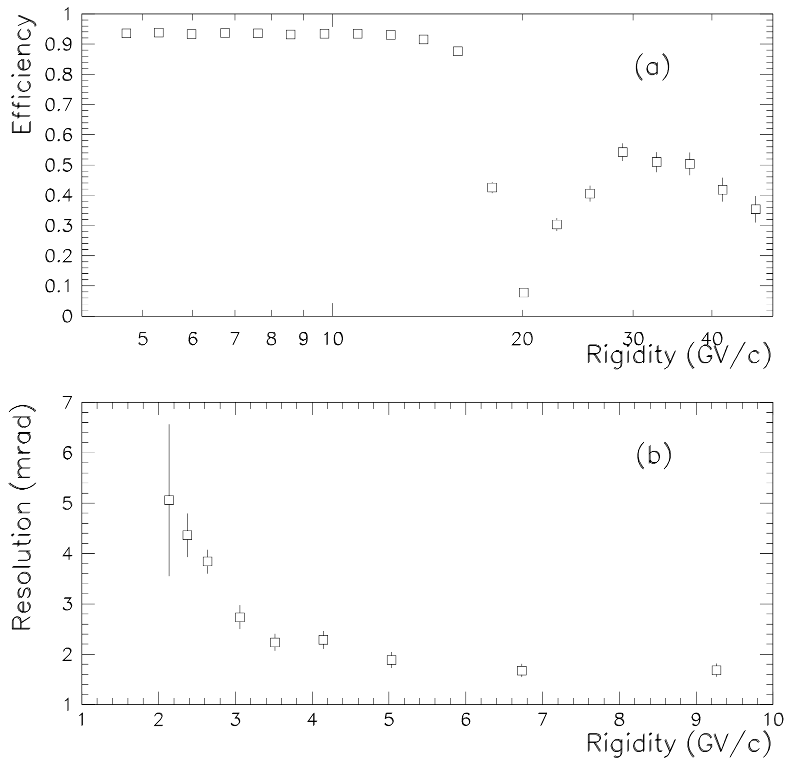

Figure 3: (a)The proton selection efficiency for the RICH. (b)The Cherenkov angle resolution for muons as a function of rigidity.

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