A High Resolution Gas Cerenkov Detector for the Superconducting Magnet Facility

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ABSTRACT

A high resolution gas Cerenkov imaging detector for Cosmic Ray heavy ions is described. The performances of this detector are evaluated in view of its association with a Superconducting Magnet.

1 - Introduction

The project of implementing a Superconducting Magnet Facility (SCMF) in orbit, with its associated tracking hodoscope, is currently considered by NASA for the future Space Station /1/. Such an instrument, performing accurate rigidity measurements in the range from a few tens to several hundreds of GV, is likely to open a new field in Cosmic Ray research. Measurements of electron and positron spectra could be extended over the 100 GeV region where synchrotron losses in galactic magnetic fields dominate /2/. Long exposures in orbit would enable an extensive search for antinuclei heavier than Hydrogen. The measurement of the antiproton/proton ratio in the 30-500 GeV range would surely help unravel the controversial situation brought up by the few existing data at lower energy. The isotopic composition of Cosmic Rays around 100 GeV/n is also of utmost interest. A refined study of the decrease of the escape length with increasing energy could be performed over the whole charge range from H to Fe. Primaries could be searched more accurately for source isotopic anomalies since the secondary component is expected to be less important than at lower energy because of the escape length shortening. For those anomalies already discovered at lower energy (Ne22, Mg25+26) the question is whether they still show up at 100 GeV/n or more.

However these goals could be met only if, in addition to an accurate rigidity measurement, the particle momenta are also measured with a good resolution. In the following we describe a high resolution gas Cerenkov detector which can perform this measurement with a few percent accuracy over extended charge and energy ranges. We also evaluate the performances of an assembly composed of this detector associated to a SCMF.

2 - The Gas Cerenkov Imaging Detector

Gas Cerenkov detectors have been used in several space experiments either as a threshold device to discriminate between electrons and pions or protons /3/ or to effectively measure the momentum of Cosmic Ray nuclei /4/,/5/. These experiments essentially recorded the number of Cerenkov photons collected by photomultipliers with using either a diffusing light box or a focussing mirror arrangement. This technique however is plagued by a rather poor momentum resolution especially at the highest energies of interest here. With Cerenkov gases appropriate to the SCMF energy range the number of photoelectrons is hardly in excess of a few units for a $Z=1,\beta=1$ particle so that statistical errors are overwhelming. In addition background light originating either from Cerenkov radiation in the material on the particle path or from delta-ray electrons contribute to further degrade the resolution.

Here we propose to rather measure the particle momenta by the angle of Cerenkov emission θ which is related to the particle velocity $\beta=v/c$ and the gas index of refraction n through $\cos\theta = 1/\beta n$.

The Cerenkov light radiated by the charged particles in the radiator gas is focussed by a spherical mirror onto a position sensitive photon detector at the focal plane. In the absence of optical distortions, the Cerenkov photoelectrons are distributed along a circle with radius r. Let f be the focal length of the mirror, then the Cerenkov angle θ is inferred from the measurement of r through $\theta=\mathrm{atan}(r/f)$. In addition the position of the circle center gives a measurement of the arrival direction of the primary particle. Accelerator experiments were successful at recording Cerenkov ring images with using various types of position sensitive photon detectors (see /6/ for a review).

In the next section we discuss the performances of a gas Cerenkov having the characteristics given in Table 1.

3 - The detector performances

The momentum resolution of a gas Cerenkov imaging detector depends primarily on the following factors:

(i) the granularity of the focal detector: a reasonable trade-off between spatial resolution and the number of readout channels leads to a pixel pitch of a few mm i.e. an angular resolution of less than a milliradian for individual photons.

(ii) the dispersion of the gas refractive index: for Ar it is of the order of the pixel resolution in the VUV range while being negligible in the visible.

(iii) the optical distortions arising from the large aperture of the optical system and the fact that Cerenkov photons travel at relatively large angles to the optical axis.

In practice effect (iii) is the most severe as far as the momentum resolution is concerned. The Cerenkov images are no more circles but rather ellipses which greatly complicates the analysis.

The resolution of the detector having the characteristics given in Table 1 was investigated by a Monte-Carlo simulation. The Cerenkov images of Cosmic Ray charged particles impinging randomly on the telescope at an angle up to 5° to the axis were first generated. The adopted value for the average number of photoelectrons generated by a $Z=1,\beta=1$ particle was 3 per meter of Argon, a figure valid in the VUV but probably pessimistic for the visible range. Then a second computer program was designed to analyze each image and assign the most likely energy to the primary particle. Optical distortions could be successfully handled by the program as is shown in figure 1 where the expected resolution for H and He nuclei is displayed as a function of momentum/nucleon. The particle trajectories through the gas radiator are also fitted to an accuracy of the order of 0.1 mrad.

A great advantage of the imaging technique is that background photon hits can be removed as being not part of the well defined Cerenkov image. Although the present study was restricted to Ar at STP as the radiator gas, with an energy threshold of 35 GeV/n, the energy range can be adjusted by varying the gas pressure. Finally we note that the energy resolution should improve for higher Z nuclei since more photoelectrons are available.
In the next section we estimate the performances of a SCMF fitted with a gas Cerenkov imaging detector.

4 - The imaging gas Cerenkov coupled to the SCMF

The rigidity resolution of the SCMF can be roughly estimated from the Maximum Detectable Rigidity (MDR), with the r.m.s error $\sigma(R)$ on a rigidity measurement R being given by:

$$\sigma(R)/R \simeq R/MDR \qquad \text{eq. (1)}$$

In order to estimate the isotopic resolution of a gas Cerenkov+SCMF association we simulated the response of both instruments to a Cosmic Ray beam containing equal amounts of He3 and He4. The rigidity R of the particles was sampled according to eq.(1) while the momentum/nucleon p was assigned as described in the preceding section. The observed mass A of He isotopes, computed from A=R/2p, is displayed in fig.2a and 2b for a MDR value of 1500 and 5000 GV respectively. It is clear that the factor limiting the isotopic resolution is the MDR rather than the momentum resolution. This is quite important for the design of the future SCMF which should have a high MDR value. Concerning the e/p separation it is seen from fig.1 that the gas Cerenkov has the capability of discriminating protons from electrons with equal rigidities up to at least 200 GeV/c. The e/p mass difference is so large that the difficulty in identifying $\overline{p}$'s and e+'s is not with the MDR but rather with the spill-over of p's and e-'s due to a wrong magnetic deflection measurement. The evaluation of this effect requires careful simulations and possibly calibrations of the SCMF alone.

5 - Conclusions

The performances of a gas Cerenkov imaging detector are well matched to the high rigidity resolution expected for the SCMF. Accurate isotopic measurements in the 50-100 GeV/n range and e+/e-/$\overline{p}$ measurements up to 200 GeV/c can be achieved with combining these instruments. The Cerenkov imaging technique is actively developed at Saclay in a joint effort with particle physicists at CERN. Prototypes of multineedle detectors and multianode photomultipliers, with a granularity of a few mm, are currently under testing together with a compact low power readout electronics. Such detectors, suited for long exposures in space environment,are likely to become available within a few years.

References

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Mirror:
- spherical
- focal length 2.4 m
- diameter 1.2 m

Radiator:
- Argon at STP
- maximum Cerenkov angle 1.5°
- energy threshold 35 GeV/n

Focal detector:
- 45 cm diameter
- full field of view 10.7°
- cell size 3x3 mm²
- number of cells 18,000

Table 1 - Physical parameters of the Cerenkov imaging telescope.

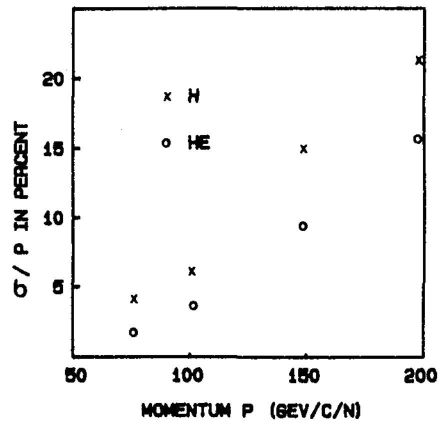

Figure 1- Momentum resolution of the telescope.

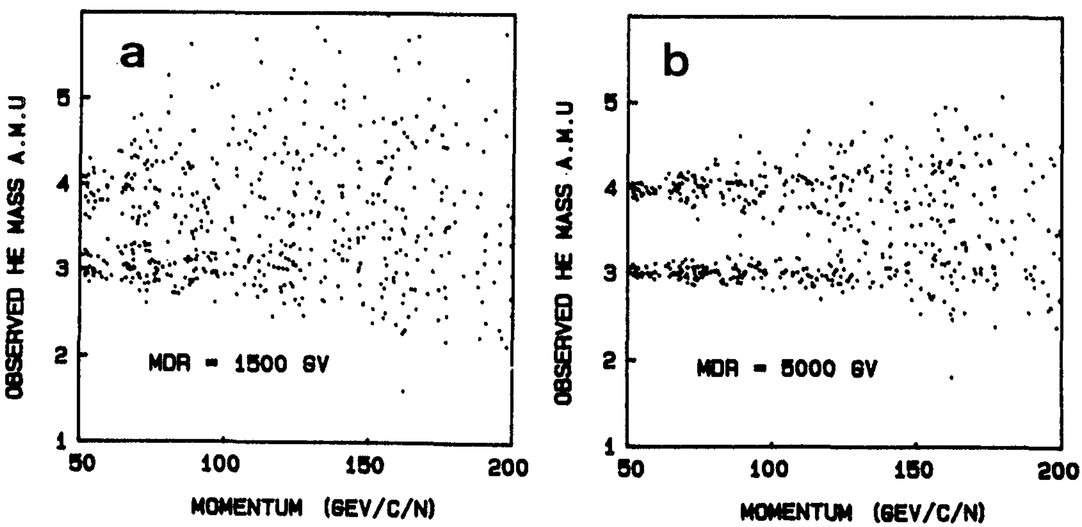

Figure 2 - The separation of He isotopes as determined from a simulation which takes into account the resolution of both the Cerenkov and the SCMF ; a) MDR=1500GV ; b) MDR=5000GV.