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The Ring Imaging Cherenkov detector (RICH) of the AMS experiment

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The Alpha Magnetic Spectrometer (AMS) experiment to be installed on the International Space Station (ISS) will be equipped with a proximity focusing Ring Imaging Cherenkov (RICH) detector for measuring the electric charge and velocity of the charged cosmic particles. A RICH prototype consisting of 96 photomultiplier units, including a piece of the conical reflector, was built and its performance evaluated with ion beam data. Preliminary results of the in-beam tests performed with ion fragments resulting from collisions of a 158 GeV/c/nuc primary beam of Indium ions (CERN SPS) on a Pb target are reported. The collected data included tests to the final front-end electronics and to different aerogel radiators. Cherenkov rings for a large range of charged nuclei and with reflected photons were observed. The data analysis confirms the design goals. Charge separation up to Fe and velocity resolution of the order of 0.1% for singly charged particles are obtained.

1. Introduction

The Alpha Magnetic Spectrometer [1] (AMS) is a high energy physics experiment that will be installed on the International Space Station (ISS) by the year 2008, where it will operate for a period of at least three years. It is a large acceptance (~ 0.5 m^{2}sr) superconducting magnetic spectrometer able to detect in a wide kinematic range (from a few hundred MeV up to TeV region) singly charged particles, charged nuclei and γ rays. The long time exposure in space will allow AMS to collect an unprecedented large data sample and to extend by orders of magnitude the sensitivity reached by previous experiments on dark matter and antimatter searches. In addition, the measurement of the cosmic-ray abundances up to the TV region and in a wide charge range (up to Z$\sim$ 26) will contribute to a better description of cosmic ray production, acceleration and propagation mechanisms, essential for a full understanding of the background spectra on dark matter searches. Information about the density of the interstellar medium traversed by the cosmic rays and their confinement time can be derived from the isotopic composition of secondary cosmic rays, produced by fragmentation during the cosmic ray transport in the galaxy. For instance, the relative abundances of deuterium and helium-3 isotopes reflect the transport history along the galaxy of protons and heliums, while the beryllium-10 radionuclide accounts for the time confinement. Current measurements are performed at relatively low energies (T $\lesssim$ 1 GeV/n) and based on small statistics.

Particle identification with AMS-02 relies on a very precise determination of the magnetic rigidity, energy, velocity and electric charge. In the AMS spectrometer, the momentum is obtained from the information provided by the silicon tracker with a relative accuracy of $\sim$1% up to 10 GeV/c/n. Isotopic mass separation over a

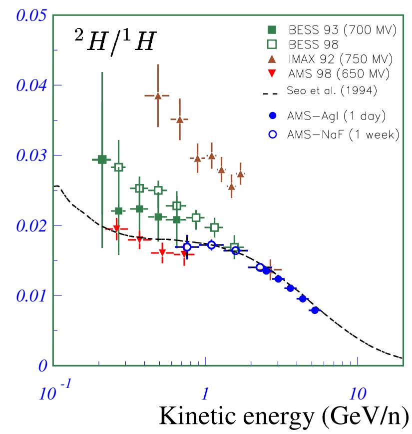

Figure 1. AMS expected isotopic ratio for $^2H/^1H$ (open and full dots) as compared with AMS01 measurements obtained during a shuttle flight in 1998 and two balloon experiments. The expected results are based on simulated data equivalent to 1 week statistics for events passing through the RICH central radiator (NaF) and 1 day for events passing elsewhere. The events were simulated according to the reacceleration model of reference [3] represented by the dashed line.

wide range of energies requires, in addition to an accurate momentum measurement, a velocity determination with low relative uncertainty in as $\Delta m/m = (\Delta p/p) \oplus \gamma^2(\Delta\beta/\beta)$. For this purpose, the AMS spectrometer includes a Ring Imaging Cherenkov detector (RICH) operating between the time-of-flight and electromagnetic calorimeter (ECAL) detectors. It was designed to provide measurements of the velocity for singly charged particles with a relative uncertainty of 0.1% and of the nuclei electric charge up to Fe. Moreover, it will provide AMS with an additional contribution to the electron/proton separation. For the isotopic separation, the RICH detector will cover a kinetic energy region ranging from 0.5 GeV/n up to around 10 GeV/n for A $\lesssim$ 10. Figure 1 shows the expected isotopic deuterium-proton ratio to be measured by AMS, based on a simulated data sample of $\sim 10^7$ events [2]. Although there is an upper boundary around 6 GeV/n, imposed by the low fraction of deuterium signal in comparison with the dominant proton mass tail ($d/p \sim 10^{-2}$), the current kinematic region is clearly extended.

2. The AMS RICH detector

The RICH design was driven by a set of constraints imposed by the launch and the long duration flight environment on one hand, and by the integration in AMS and the envisaged physics aims, on the other hand. Therefore, the RICH options had to deal with restrictions on size, weight, power consumption and materials. In addition, it had to take into account the AMS stray magnetic field, reaching $\sim$ 300 G in some locations, and the minimization of matter in front of the electromagnetic calorimeter.

The RICH has a truncated conical shape with a top radius of 60 cm, a bottom radius of 67 cm, and a total height of 60.5 cm. It covers 80% of the AMS magnet acceptance [4]. A general view of the RICH detector is shown in figure 2. It is a proximity focusing device with a dual solid radiator configuration on the top, an expansion height of 46.9 cm and, at the bottom, a matrix of 680 multipixelized photon readout cells. A high reflectivity mirror with a conical shape surrounds the whole set in order to increase the device acceptance. The radiator is made of 80 aerogel 27 mm thick tiles with a refractive index 1.05, and sodium fluoride (NaF) tiles with a thickness of 5 mm in the center covering an area of 34 × 34 cm^2. The NaF placement prevents the loss of photons in the hole existing in the center of the readout plane (64 × 64 cm^2), in front of the ECAL calorimeter located below. Figure 2 shows a NaF event display. The radiator tiles are supported by a 1 mm thick layer of methacrylate (n=1.5) free of UV absorbing additives.

To prevent a large fraction of RICH radiated photons ($\sim$ 33%) to escape through the lateral surface of the expansion volume, a conical reflector was designed. It consists of a carbon fiber reinforced composite sub-

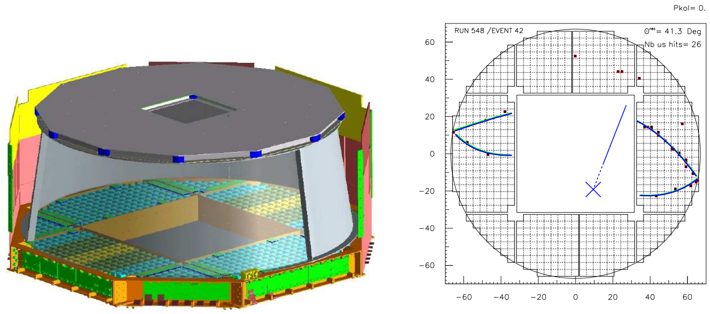

Figure 2. Schematic view of the RICH detector. Display of a reconstructed photon ring for a simulated beryllium event crossing the NaF radiator.

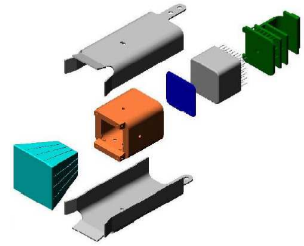

Figure 3. Detailed view of a readout cell.

strate with a multilayer coating made of aluminium and SiO_2 deposited on the inner surface. This ensures a reflectivity higher than 85% for 420 nm wavelength photons.

The photon detection is made with an array of multianode Hamamatsu tubes (R7600-00-M16) with a spectral response ranging from 300 to 650 nm and a maximum at $\lambda \sim 420$ nm. The choice of the phototube was driven, among other factors, by its response to the photoelectron signal and its low sensitivity to the magnetic field. Nevertheless, the strength of the residual field from the superconducting magnet imposes the need to shield the photomultipliers with a permalloy thickness varying from 0.8 to 1.3 mm. To increase the photon collection efficiency, a light guide consisting of 16 solid acrylic pipes glued to a thin top layer (1 mm) was produced. It is optically coupled to the active area of phototube cathode through a 1 mm flexible optical pad. With a total height of 31 mm and a collecting surface of 34×34 mm^2, it presents a readout pixel size of 8.5 mm. The light guide is mechanically attached through nylon wires to the photomultiplier polycarbonate housing.

The detected photons are converted into a charge signal in the photomultiplier with a typical gain of $\sim 10^6$. A low consumption 80 MΩ high voltage divider was chosen. The charged signal is then shaped and amplified ($\times 1$ or $\times 5$) in a front-end chip in order to both cope with a dynamic range of 10^2 and to keep a high sensitivity to the photoelectron signal. Finally the signal is digitized on a 12-bit ADC. The RICH data acquisition system deals with a total number of $10,880$ readout channels. Figure 3 shows an exploded view of a complete readout cell with all the chain from the light guide to the front-end electronics.

RICH assembling activities started in September 2003. The final detector is scheduled to be operational at the beginning of 2006 for functionality tests and further integration into AMS.

3. The RICH prototype

A prototype of the RICH detector consisting of an array of 9×11 cells filled with 96 photomultiplier readout units was constructed. Its performance was evaluated with cosmic muons and fragmented ions from CERN SPS beams in 2002 [4] and 2003. The light guides used were prototypes with a slightly smaller size (31 mm). An adjustable supporting structure was used to test different sets of aerogels at variable expansion heights. The setup was completed with AMS silicon tracker layers placed upstream in the beam, two multi-wire proportional chambers and scintillator counters. Secondary fragments with charges $Z < 49$ from the fragmentation of a 158 GeV/c indium beam were used in the 2003 run. Given the small angular acceptance of the beam line, a rigidity accuracy of 1.5% was provided. A total number of 11 million events were recorded during seven days.

The evaluation of the aerogel samples in order to make a final radiator choice was one of the key issues of these tests. Different production batches from two manufacturers, Matsushita Electric Co. (MEC) and Catalysis

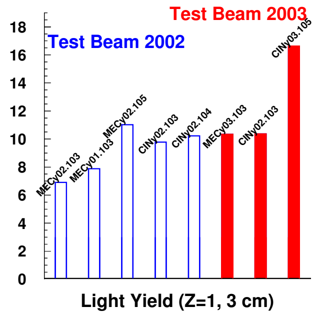

Figure 4. Comparison of the aerogel light yield for 3 cm thickness.

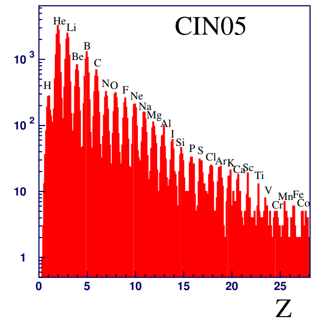

Figure 5. Charge reconstructed ions from a 158 GeV/c primary In beam.

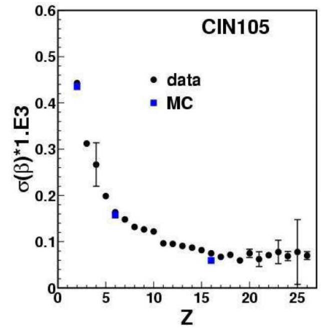

Figure 6. Velocity accuracy dependence on the charge.

Institute of Novossibirsk (CIN) were analyzed. The required criteria for a good candidate were a high photon yield, in order to ensure a good ring reconstruction efficiency, and accurate β and charge measurements. The aerogel light yield depends on the tile thickness and its optical properties, i.e refractive index and scattering effects (clarity). Figure 4 shows the normalized to 3 cm thickness light yield for the different aerogel samples tested in 2002 and 2003. The highest signal comes from a CIN sample produced in 2003 with 1.05 refractive index reflecting the very good clarity ($\sim 0.0055\ \mu$m^4/cm) of the aerogel batch. The hydrophilic nature of this aerogel implies the sealing of the radiator container with a neutral gas like nitrogen in order to keep humidity below 50%.

Reconstruction of velocity and charge were made with two independent methods [5]. A charge resolution around 0.15 is observed for low Z ions together with a systematic uncertainty, scaling with the charge, of 1.2% due to non-uniformities. Charge peaks up to iron were identified as shown in figure 5. The velocity resolution scales with the detected signal ($\propto z^2$) as is shown on figure 6. A relative accuracy $\Delta\beta/\beta \simeq 0.45\ 10^{-3}$ for heliums is obtained for the aerogel chosen (n=1.05). Similar clarity 1.03 aerogels tested in 2003 had essentially the same resolution but lower photon yields. Runs with a prototype mirror were also performed. The mirror reflectivity derived from data analysis is in good agreement with the design value.

4. Conclusions

A RICH detector is being constructed, and its assembling with the AMS spectrometer is scheduled for the beginning of 2006. Cosmic muon and in-beam tests with fragmented ions validated the detector design and its goals; i.e, a singly charge resolution of 0.1% and charge separation up to iron. A refractive index 1.05 aerogel was chosen for the radiator accommodating well both the demand for a large light yield and good velocity resolution.

5. Acknowledgments

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