# RING Imaging Cherenkov Detector (RICH) For the AMS Experiment

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**Abstract:** 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 charge and velocity of incoming cosmic-ray nuclei. From top to bottom, the detector consists of a radiator plane made of 1.05 aerogel and sodium fluoride (NaF) materials, an expansion volume enveloped by a high reflectivity conical shaped mirror, and a matrix of 680 16-anode photomultipliers coupled to light guides. A RICH prototype consisting of 96 photomultiplier units was tested in a secondary beam of ion fragments from a 158 GeV/c per nucleon primary beam of Indium ions (CERN SPS). The results of this prototype beam test, which confirmed the RICH design goals, will be presented. Charge separation of elements from protons to iron nuclei was observed. Velocity resolution on the order of 0.1% was obtained for singly charged particles. Recent results from the RICH physics performance analysis, integration status, and preflight tests will be reported.

## 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 2009. It will operate for a period of at least three years and will become the first large acceptance (~0.5 $m^2$sr) superconducting magnetic spectrometer in space able to detect cosmic-ray particles in a wide rigidity range (from a few hundred MV to ~1 TV). The long time exposure will allow AMS to extend by orders of magnitude the sensitivity reached by previous experiments on antimatter and dark matter searches. In addition, the measurements of the cosmic-ray fluxes up to the TV region and in a wide charge range (up to Z~26) will contribute to a better description of cosmic ray production, acceleration and propagation mechanisms, essential for a full understanding of the background spectra in dark matter searches. AMS–02 will allow to test propagation models through the precise measurements of secondary-to-primary ratios as D/p, $^3$He/$^4$He in the energy range from few hundreds MeV to tens of GeV, and B/C, sub-Fe/Fe up to ~1 TV. In particular, the accurate measurement of $^{10}$Be/$^9$Be in a wide energy range will allow to understand the age of the cosmic-ray confinement in the galaxy and will constraint the size of the galactic halo [2]. Current $^{10}$Be/$^9$Be ratio measurements are performed at relatively low energies ($T \leq 1$ GeV/n) and based on small statistics. Particle identification in AMS 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 ~1% up to 10 GeV/c/n.

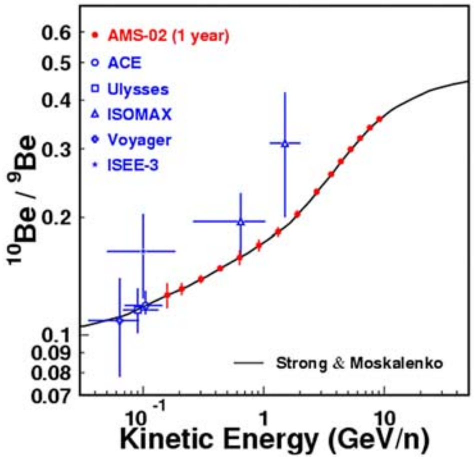

Figure 1. Expected performance of the AMS on the $^{10}$Be/$^{9}$Be ratio after 1 year data taking compared to recent measurements. The ratio has been simulated according to the propagation models described in [2].

Isotopic mass separation over a wide range of energies requires, in addition to an accurate momentum measurement, a velocity determination with low relative uncertainty. For this purpose, the AMS spectrometer includes a Ring Imaging Cherenkov detector (RICH) placed between the time-of-flight and electromagnetic calorimeter (ECAL) detectors. It was designed to provide the measurements of the charged particles velocity with a relative uncertainty of 0.1% (for *Z*=1) and of the nuclei electric charge up to Fe. The RICH data for mass separation will help to eliminate a fake anti-He background in antimatter searches. Moreover, it will provide AMS with redundant electron/proton separation to further reduce the background in dark matter searches. 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≤10. Figure 1 shows the expected $^{10}$Be/$^{9}$Be ratio to be measured by AMS, after 1 year exposition. An improvement over the previous measurements both in accuracy and the kinetic energy range is apparent.

## The AMS RICH detector

The AMS RICH detector 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 magnetic acceptance. 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 16-anode photomultiplier 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 x 34 cm$^{2}$. The NaF placement prevents the loss of photons in the hole existing in the center of the readout plane (64 x 64 cm$^{2}$), in front of the ECAL calorimeter located below. The radiator tiles are supported by a 1 mm thick layer of methacrylate (n=1.05) free of UV absorbing additives. The constraints imposed on RICH design by the space flight and launch conditions, its duration, as well as compromises with other AMS detectors and systems required to deal with the restrictions on size, weight, power consumption and materials. In addition, one had to take into account the AMS stray magnetic field, reaching ~300 G in some locations, and to minimize the amount of material in front of the electromagnetic calorimeter, mounted under the RICH.

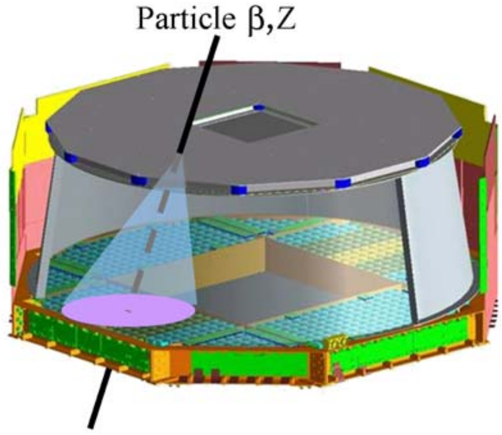

Figure 2. Schematic view of the RICH detector.

Figure 3. Detailed view of a readout cell.

To prevent a large fraction of RICH radiated photons (~33%) to escape detection through the lateral surface of the expansion volume, a conical reflector was designed. It consists of a carbon fiber reinforced composite substrate with a multilayer coating made of aluminum and $SiO_2$ layer deposited on the inner surface. This ensures a reflectivity higher than 85% for 420 nm wavelength photons. The photons are detected by a large array of multi-anode 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 residual field from the superconducting magnet imposes the need to protect the photomultipliers by the magnetic shielding mu-metal cases of thickness varying from 0.8 to 1.3 mm, depending on the local stray field strength and orientation. To increase the photon collection efficiency, the light guides consisting of 16 solid acrylic elements glued to a top acrylic 1 mm window were produced. Each is optically coupled to the active area of phototube cathode through a thin elastic optical pad. With a total height of 31 mm and a collecting surface of 34 x 34 $mm^2$, it has a readout pixel size of 8.5 mm. The light guides are mechanically attached to the photomultiplier polycarbonate housing by means of nylon threads.

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 (x1 or x5) 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 a detailed view of a complete readout cell and its main components containing all the chain from the light guide to the front-end electronics.

## The RICH prototype

A prototype of the RICH detector consisting of an array of 9 x 11 cells filled with 96 photomultiplier readout units was constructed. Its performance was evaluated on cosmic muons and fragmented ions from CERN SPS beams in 2002 and 2003 [3]. Secondary fragments with charges $Z < 49$ from the fragmentation of a 158 GeV/c indium beam were used in the 2003 run. A total number of 11 million events were recorded during seven days. The test beam data was used to make a final radiator choice. Different aerogel production batches from two manufacturers, Matsushita Electric Co. (MEC) and Catalysis Institute of Novosibirsk (CIN) were analyzed and the aerogel with 1.05 refractive index providing a very good clarity (~0.0055 $\mu m^4/cm$) made by CIN was selected. Reconstruction of velocity and charge were made with two independent methods [4]. A charge resolution around 0.15*Z* is observed for low *Z* ions together with a systematic uncertainty, scaling with the charge, of 1.2% due to non-uniformities, Figure 4. The velocity resolution $\Delta\beta/\beta \approx 0.45 \times 10^{-3}$ for helium is obtained with chosen aerogel (n=1.05). The mirror reflectivity derived from the data analysis was found in a good agreement with the expected design value.

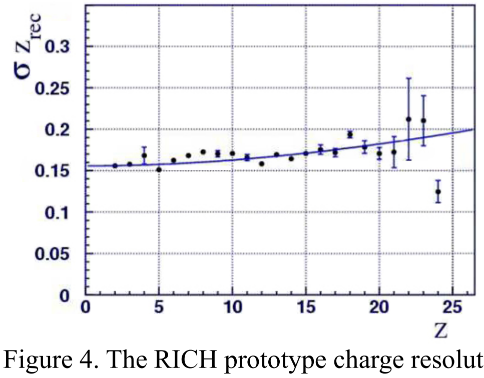

Figure 4. The RICH prototype charge resolution

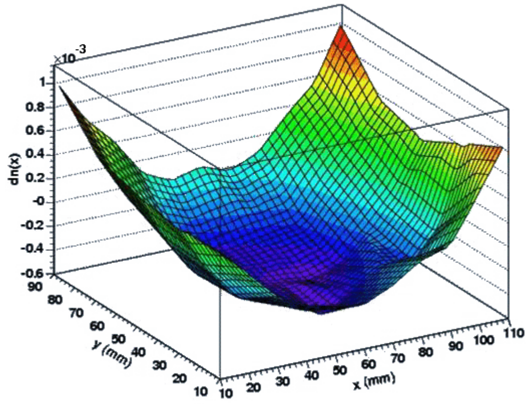

Figure 5. Example of the measured RICH aerogel refraction index uniformity.

## Integration and tests

RICH assembling activities started in September 2003. The final detector is scheduled to be operational in summer of 2007 for functionality tests and further integration into AMS. First, each readout cell and radiator tile passed a series of characterization tests to extract the information on gain, efficiency and refractive index variations. The data was used to obtain a maximum uniformity of the radiator and detector plains and to create the database of mapped elements performance. The precise determination of the refractive index for each tile required the elaboration of a dedicated measurement method, by laser beam deviation, done at LPSC, Grenoble. The vertical and horizontal deviation of the laser beam entering normally to the tile surface, allows a measurement of the refractive index gradient at a given position on the tile. The refractive index variation is obtained by integration of this gradient (see Figure 5). The detector plane elements and the radiator tiles then were assembled together using the manufactured mechanical structures. The alignment was carefully controlled and the radiator plane as well as one of the detection matrix rectangular "boxes" passed a successful vibration test. The matrix functionality was checked before and after the vibration, the result is shown in the Figure 6. No significant performance change was observed. The RICH electronics functionality and thermal stress tests were successfully accomplished at Madrid and CSIST, Taiwan. The integration of the RICH is nearing its completion at CIEMAT, Madrid.

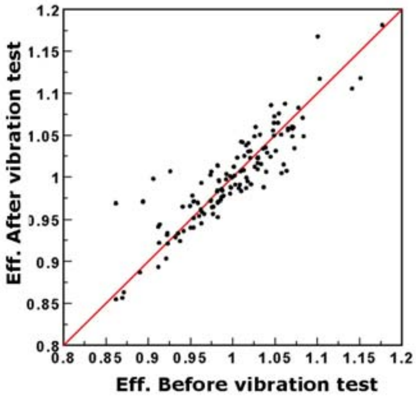

Figure 6. The detection matrix efficiency comparison before and after the vibration test.

## Conclusions

A RICH detector is being assembled, and its integration in the AMS spectrometer is scheduled to start in summer of 2007. Cosmic muon and accelerator beam tests with fragmented ions validated the detector design goals. A detailed characterization of the detector plane parameters as well as the radiator tails small refractive index variations mapping was performed before the final assembly. The vibration tests confirmed the detector performance stability during the launch.

## Acknowledgements

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