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Cosmic ray velocity and electric charge measurements with the AMS/RICH detector: prototype results

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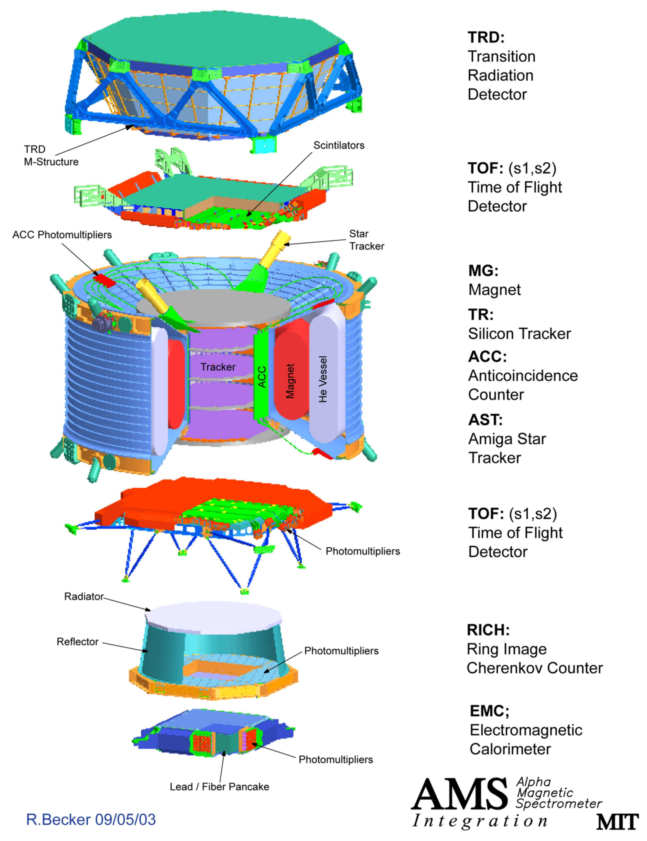
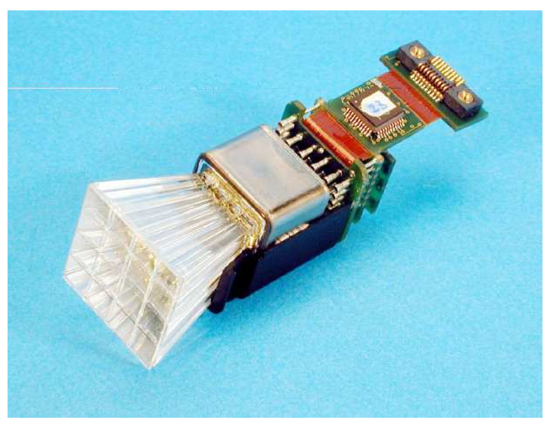
1 The AMS experiment

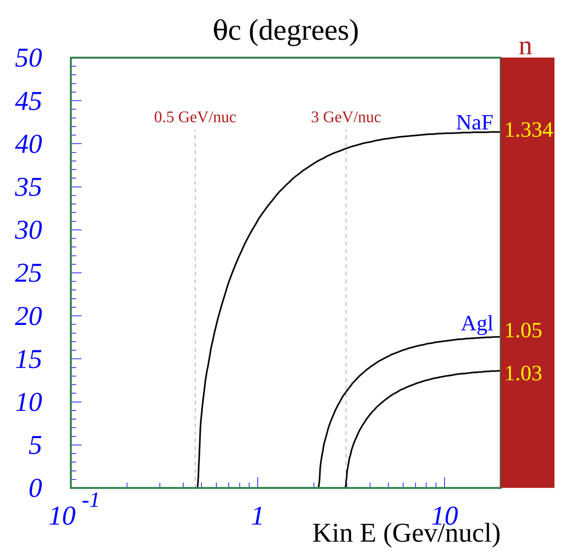
The Alpha Magnetic Spectrometer (AMS) is a particle detector to be installed in the International Space Station (ISS) for at least three years. It is a large acceptance ($\sim 0.5\ m^2.sr$) detector equipped with a superconducting magnet that detects cosmic rays in a large range in energy (from MeV up to TeV) and electric charge (up to Iron). The long stay of AMS in space will allow the accumulation of a large statistic of events increasing in several orders of magnitude the sensitivity of the proposed physical measurements. With an average collection rate of 1000 events per second, a total of 10^9 protons per year and around 10^4 antiprotons will be accumulated.

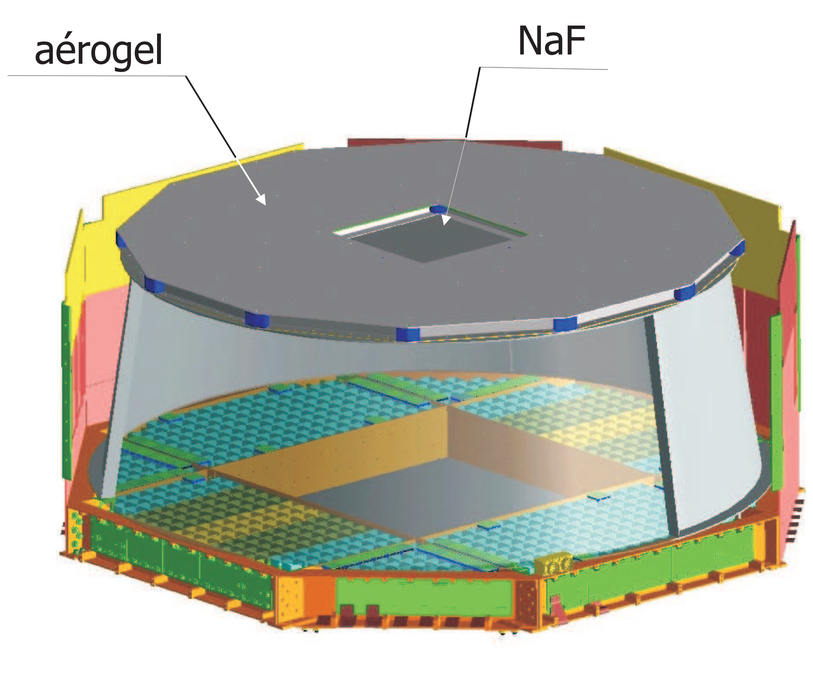


2 The RICH detector

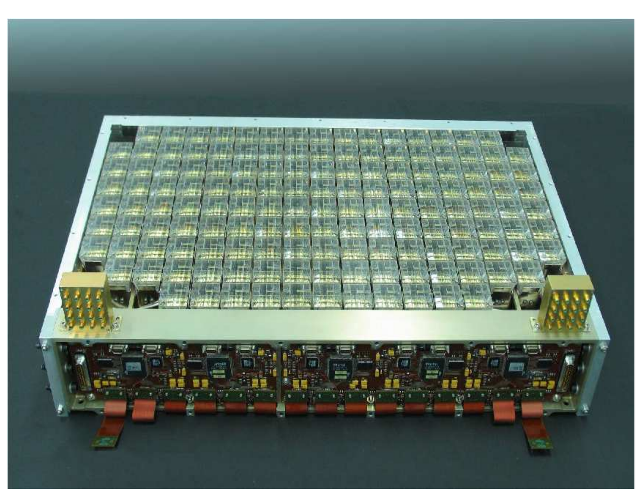
AMS will be equipped with a Ring Imaging CHerenkov detector (RICH), enabling measurements of particle electric charge (Z) and velocity ($\beta \equiv v/c$). The RICH is composed of a dual radiator, a lateral conical mirror of high reflectivity and a detection matrix with 680 photomultipliers coupled to light guides.
When crossed by a particle with a velocity greater than the light speed in the medium ($\beta > c/n$), the radiator made of aerogel and sodium fluoride with a refractive index of 1.05 and 1.334 respectively, emits an electromagnetic cone of radiation along the particle direction.
In order to validate the design of the AMS-02 RICH, a prototype with an array of 96 photomultiplier units similar to part of the matrix of the final model was constructed. The performance of this prototype has been tested with cosmic muons and with a beam of secondary ions at the CERN SPS produced by fragmentation of a primary beam. Different samples of the radiator materials were tested, as well as a segment of a conical mirror with 1/12 of the azimuthal coverage of the final one.

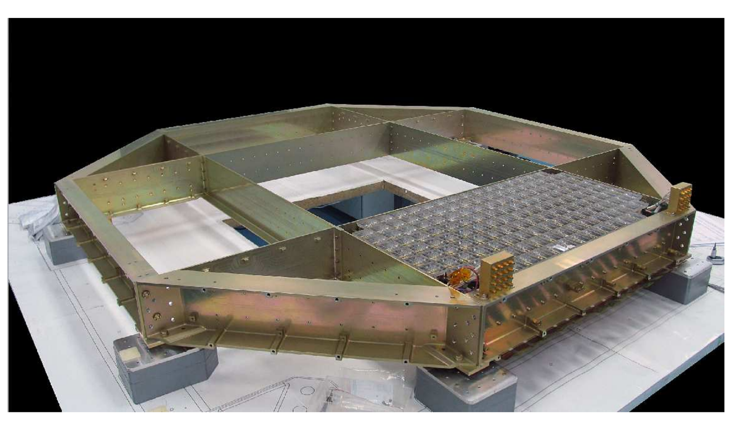






The RICH assembly has already started at CIEMAT in Spain and is foreseen to be finished before the end of 2006. A rectangular grid has already been assembled and has been subject to a mechanical fit test, functional tests, vibration tests and vacuum tests. The other grids will follow. The refractive index of the aerogel tiles has been measured and the radiator container was subjected to a mechanical test. The final integration of RICH in AMS will take place at CERN in 2007.



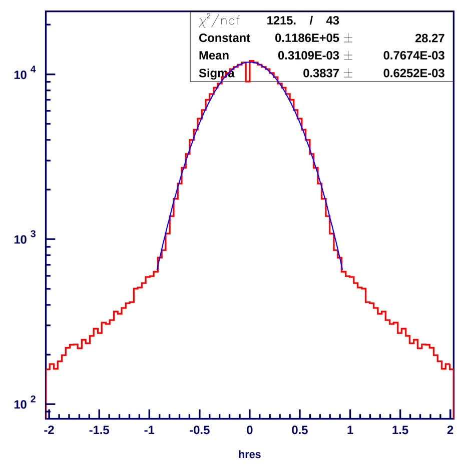


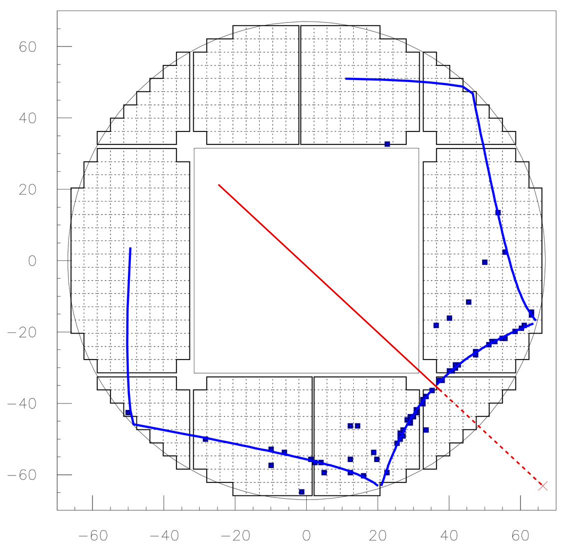
3 Beta (β) and charge (Z) reconstruction

The aperture angle of the emitted photons with respect to the radiating particle is known as the Čerenkov angle, θ_c, and since there is a relation between the charged particle velocity (β) and this aperture, β is straightforward derived from the Čerenkov angle reconstruction, which is based on a fit to the pattern of the detected photons in the photomultipliers matrix.

$$\beta = \frac{1}{n\cos\theta_c}$$

The Čerenkov angle reconstruction procedure relies on the highly accurate information ($10\mu m$) of the particle direction (θ, ϕ) provided by the Tracker. For each detected hit can be associated a probability p_i to belong to the Čerenkov pattern.
The maximum likelihood function $P(\theta_c)$ can be built as the product of the probabilities, p_i, that the detected hits (excluding the particle hits) belong to a given (hypothetical) Čerenkov photon ring. This probability takes into account r_i, the closest distance of the hit to the Čerenkov pattern, and n_i the signal strength. The best value of θ_c will result from the maximization of a likelihood function.





$$P(\theta_c) = \prod_{i=1}^{nhits} P_i^{npe}\{r_i(\varphi_i;\theta_c)\}$$

The probability of a hit belonging to the pattern is obtained by taking into account that it can either be part of the noise (essentially flat) or of the Čerenkov pattern (Gaussian distributed). Expressing b as the photon background fraction, D as the detector's dimensions and σ as the width of the residuals distribution, we can write:

$$P_i = \frac{(1-b)}{\sqrt{2\pi}\sigma}\, e^{-\frac{1}{2}\left(\frac{r_i}{\sigma}\right)^2} + \frac{b}{D}$$

where $b = 0.5122$ for AGL105 and $b = 0.105$ for NaF.

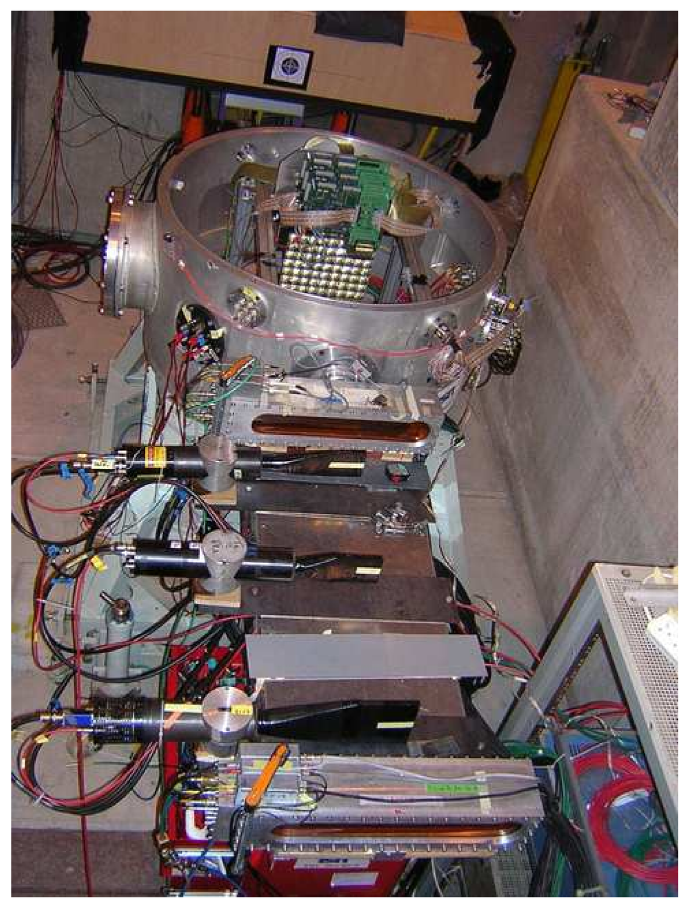
D	
Flight	Prototype
100 cm	20 cm

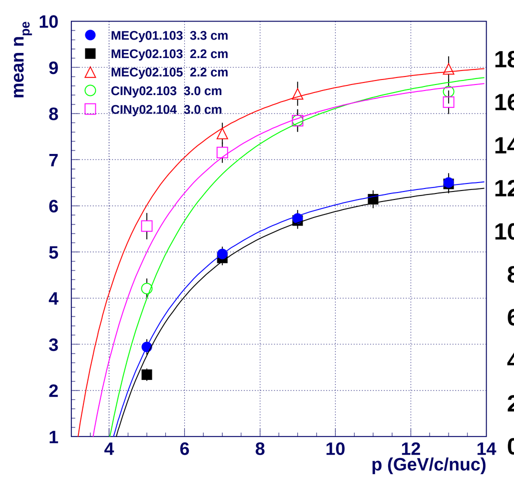
The Čerenkov photons produced in the radiator are uniformly emitted along the particle path inside the dielectric medium, L, and their number per unit of energy (N) depends on the particle's charge, Z, and velocity, β, and on the refractive index, n.
Therefore electric charge (Z) is determined from the signal evaluation and taking into account the different detection efficiencies.

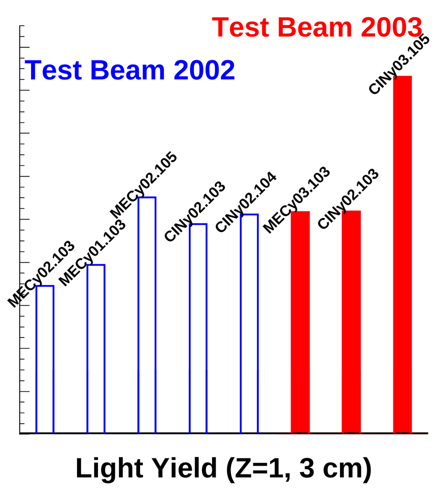
$$N \propto Z^2\,\Delta L\left(1 - \frac{1}{\beta^2 n^2}\right)$$

4 Results with the RICH prototype

The large amount of collected data in the last test beam at CERN, in October 2003, performed with ion fragments resulting from the collision of a 158 GeV/c/nucleon primary beam of indium ions (CERN SPS) on a lead target, allowed to test the beta and charge reconstruction algorithms, as well as to characterize the used radiators and perform a comparative study with the radiators used in the test beam of 2002.







A clear charge separation up to approximately the iron element was achieved. The beta and charge resolution were also evaluated. The accuracy of the velocity determination improves with the charge being 0.9×10^{-3} for $Z = 1$ and reaching an assymptotic value of 4.7×10^{-5}.
A charge resolution for proton events slightly better than 0.17 charge units is obtained together with a systematic uncertainty of $\sim 1\%$. In order to keep the precision uncertainties bellow this value the aerogel tile thickness, the refractive index and the clarity should not have a spread greater than $0.25\,mm$, 10^{-4} and 5%, respectively; at the detection level a precise knowledge ($< 5\%$ level) of the single unit cell photo-detection efficiency and gains is required.