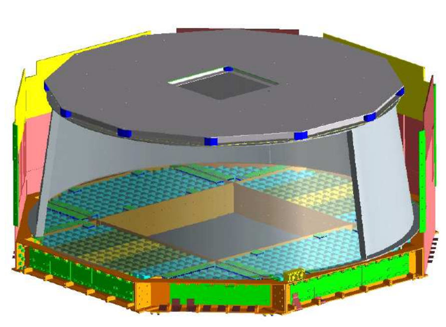
The AMS-RICH velocity and charge reconstruction

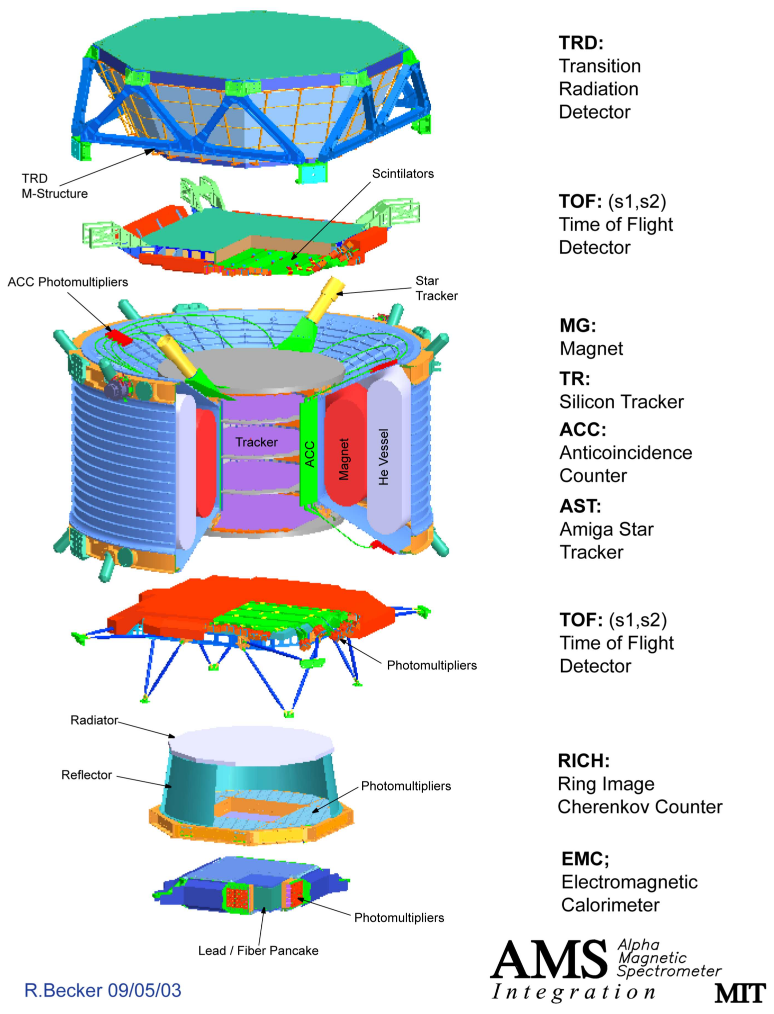
F. Barao for the AMS/RICH collaboration

barao@lip.pt



1 The AMS experiment

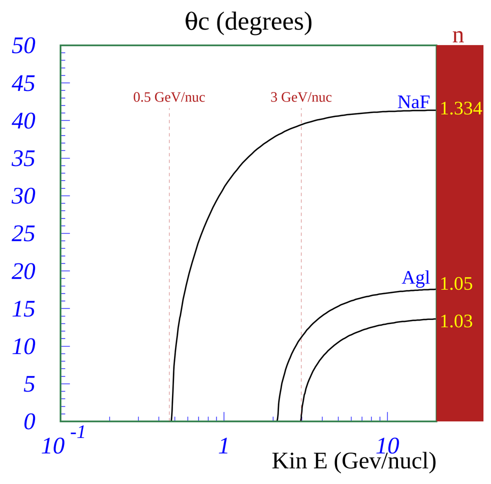
The Alpha Magnetic Spectrometer (AMS) is a particle detector to be installed in the International Space Station (ISS) for at least three years. It is a large acceptance ($\sim 0.5\ m^2.sr$) detector equipped with a superconducting magnet that detects cosmic rays in a large range in energy (from MeV up 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.

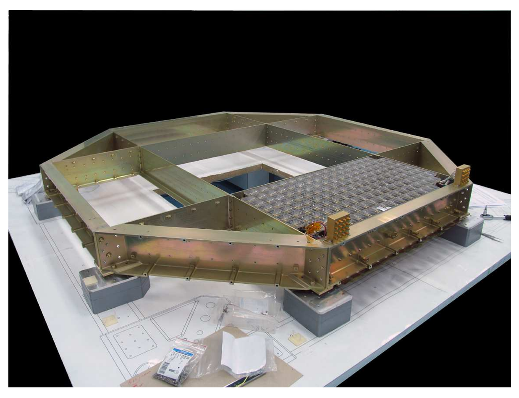


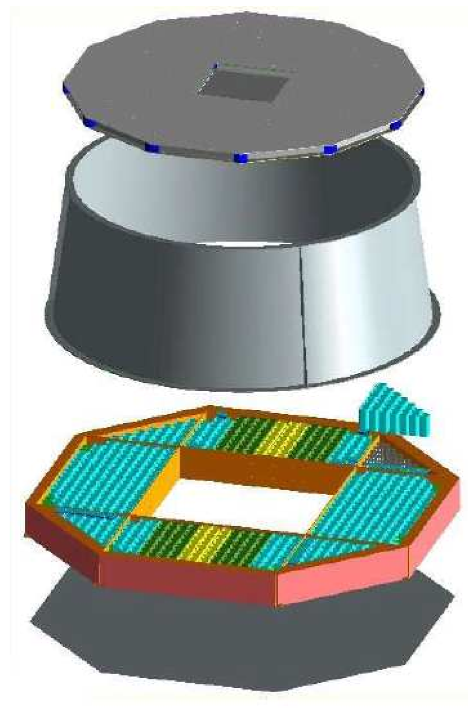
2 The RICH detector

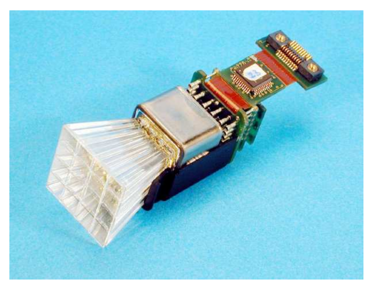
AMS will be equipped with a Ring Imaging CHerenkov detector (RICH), enabling measurements of particle electric charge ($\mathbf{Z}$) and velocity ($\beta \equiv \mathbf{v}/\mathbf{c}$). The RICH is composed of a dual radiator, a lateral conical mirror of high reflectivity and a detection matrix with 680 photomultipliers coupled to light guides.

When crossed by a particle with a velocity greater than the light speed in the medium ($\beta > \mathbf{c}/\mathbf{n}$), 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.







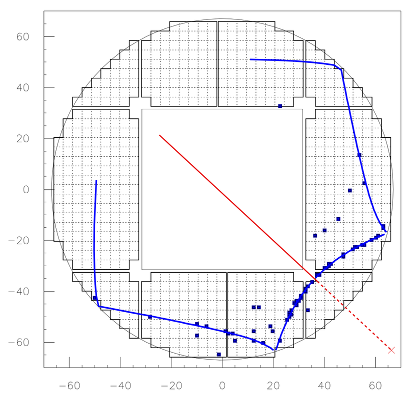


3 Velocity (β) reconstruction

Charged particles crossing the radiator material of refractive index n and with a velocity larger than $1/\mathbf{n}$, emit photons. The aperture angle ($\theta_\mathbf{c}$) of the photons with respect to the radiating particle direction depends on the particle velocity β,

$$\beta = \frac{\mathbf{1}}{\mathbf{n}\cos\theta_\mathbf{c}}$$

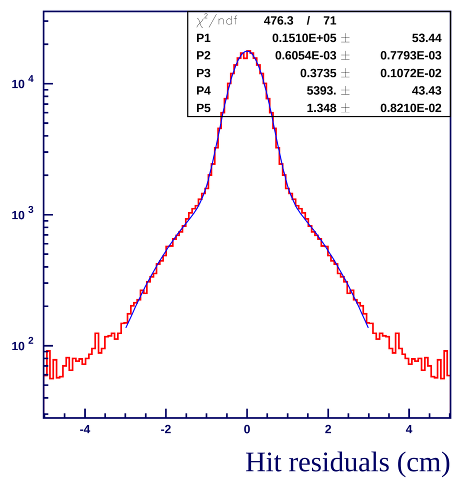
The detected ring photon pattern reflects the geometry of the photomultiplier detection matrix and the interactions suffered by the emitted photons along their path to the readout matrix: radiator interactions (Rayleigh scattering, absorption), surface optical effects (reflection and refraction) and light guide efficiency. Consequently, from the point of view of the expected Čerenkov pattern, a typical event will be composed of aligned photons, strongly uncorrelated scattered photons and detector noise.



Two different approaches were implemented for the Čerenkov ring reconstruction. One was based on **single hit reconstruction** and the other on a **maximum likelihood method**.

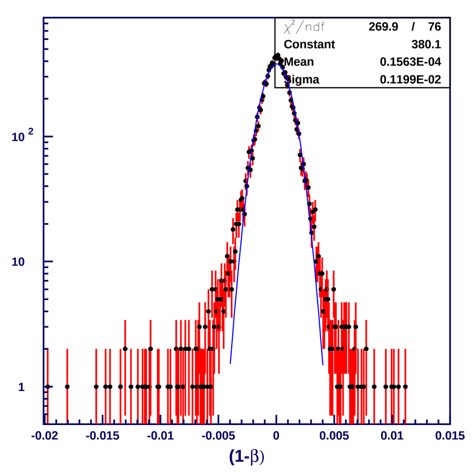
In the former method a value of β is reconstructed for every detected hit. The method is purely geometrical and relies in a set of analytical equations that relate the detection point with the Čerenkov angle ($\theta_\mathbf{c}$) and the particle coordinates. The possibility of the photon being reflected is taken into account. Next, the most probable cluster of hits is searched and the final velocity is computed as a mean of the clusterized hit β values, weighted with measured signal amplitude (photon multiplicity).

In the other reconstruction approach, the algorithm incorporates a probability density function for the detected hits. The residuals of the signal hits distribute according to a double gaussian function whose widths are directly related to the pixel size and granularity, radiator thickness, chromaticity effects and aerogel forward scattering. The existence of the second gaussian, accounting for a natural enlargement of the hit residuals from forward scattering, makes possible the description of the signal to larger hit distances and endows a better algorithm efficiency and a lower sensitivity to noisy hits. The signal probability density function $\mathbf{S}(\mathbf{r})$:

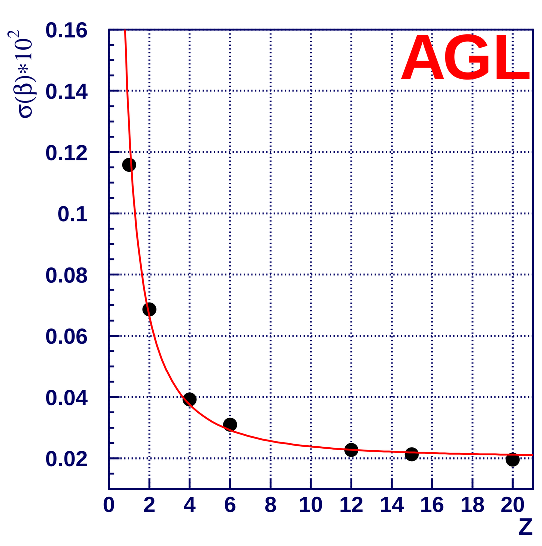


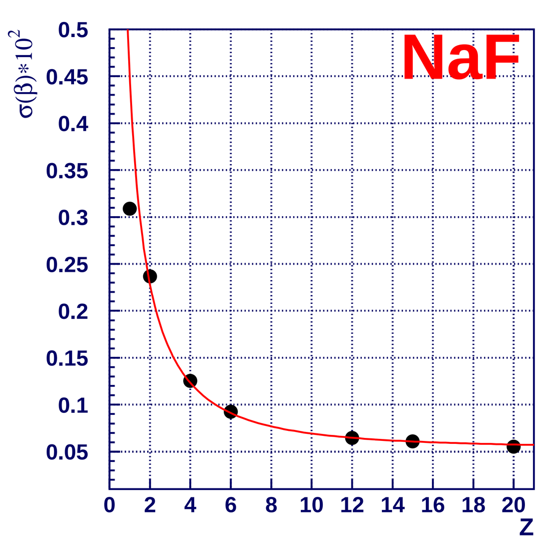
$$\mathbf{S}(\mathbf{r}) = \alpha_\mathbf{1}\ \mathbf{G_1}(\sigma_\mathbf{1}) + \alpha_\mathbf{2}\ \mathbf{G_2}(\sigma_\mathbf{2})$$

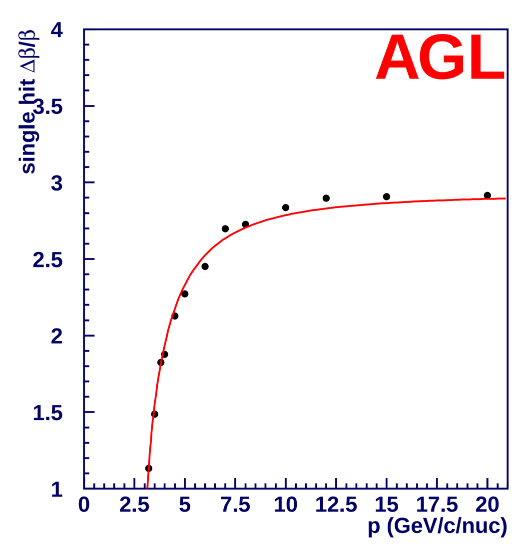
where α_1 and α_2 are respectively $\sim \mathbf{3/4}$ and $\sim \mathbf{1/4}$ and σ_1 and σ_2, $\sim \mathbf{0.37}$ **cm** and $\sim \mathbf{1.35}$ **cm**. For distances larger than $\sim \mathbf{2.1}$ **cm**, the detected hits are tagged as background and a uniform probability density function is associated, $\mathbf{B}(\mathbf{r}) = \frac{\mathbf{b}}{\mathbf{D}}$, where $\mathbf{D}$ is an effective distance in the detector corresponding to $\mathbf{134}$ **cm** and $\mathbf{b}$ the background fraction estimated as $\mathbf{77}\%$. The overall probability density function is therefore defined as:



$$\mathcal{P}(\mathbf{r}) = (\mathbf{1} - \mathbf{b})\ \mathbf{S}(\mathbf{r}) + \mathbf{B}(\mathbf{r})$$







AMS-RICH collaboration: M. Aguilar-Benitez[1], L. Arruda[2], F. Barao[2], B. Baret[3], A. Barrau[3], G. Barreira[2], E. Belmont[4], J. Berdugo[1], J. Borges[2], M. Buenerd[3], D. Casadei[5], J. Casaus[1], E. Cortina[1], M. Costado[7], D. Crespo[1], C. Delgado[7], C. Diaz[1], L. Derome[3], P. Gonçalves[2], R. Garcia-Lopez[7], C. de la Guia[1], A. Herrero[7], E. Lanciotti[1], G. Laurenti[5], A. Malinin[6], C. Mana[1], J. Marin[1], M. Mangin-Brinet[3], G. Martinez[1], A. Menchaca-Rocha[4], C. Palomares[1], R. Pereira[2], M. Pimenta[2], A. Putze[3], Y. Sallaz-Damaz[3], E.S. Seo[6], I. Sevilla[1], A. Torrento[1], M. Vargas-Trevino[3], O. Veziant[3]

[1]CIEMAT, Madrid, Spain; [2]LIP, Lisboa, Portugal; [3]LPSC, IN2P3/CNRS, Grenoble, France; [4]Inst. de Fisica, UNAM, Mexico; [5]U. of Bologna and INFN, Bologna, Italy; [6]U. of Maryland, USA; [7]IAC, Tenerife, Spain

4 Charge (Z) reconstruction

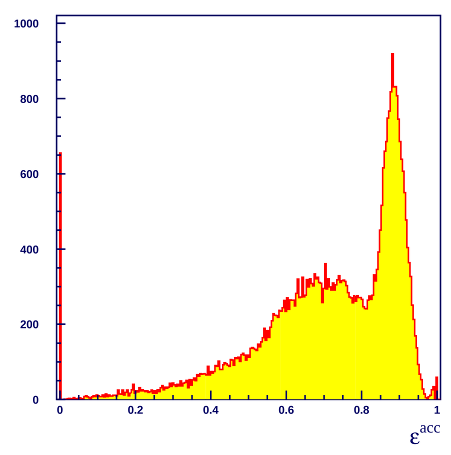
Photons are uniformly emitted along the particle path (L) and their number depends on the particle charge (z) and velocity (β) and on the refractive index of the medium (n):

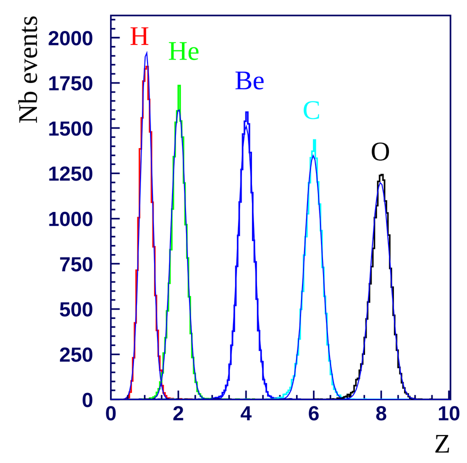
$$\frac{dN_\gamma}{dE} \propto z^2\ L\ \left(1 - \frac{1}{\beta^2\ n^2}\right)$$

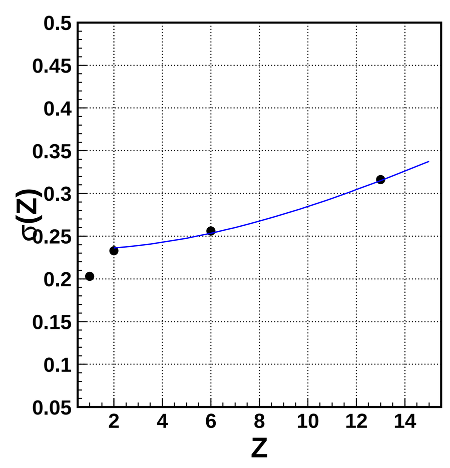
The fraction of photons in the ring pattern that are lost in every event depends on their topology (impact point and particle direction and velocity) and other factors. Therefore, charge reconstruction relies on the reconstructed Čerenkov angle and on measurements of the path length crossed by the particle, of the number of ring associated photoelectrons detected on the readout matrix and finally on the evaluation of the photon detection efficiency. The efficiency factors involve the radiator interactions, the photon ring acceptance including the mirror reflectivity and the light guide and photomultiplier quantum efficiencies.

Therefore, applying the correction factors on an event-by-event basis, the detected signal for singly charged particles (N_0) can be estimated and the charge of the incident particle is obtained according to:

$$Z^2 = \frac{N_{p.e.}}{N_0} \propto \frac{N_{p.e.}}{\varepsilon_{TOT}}\frac{1}{\Delta L}\frac{1}{\sin^2\theta_c}$$



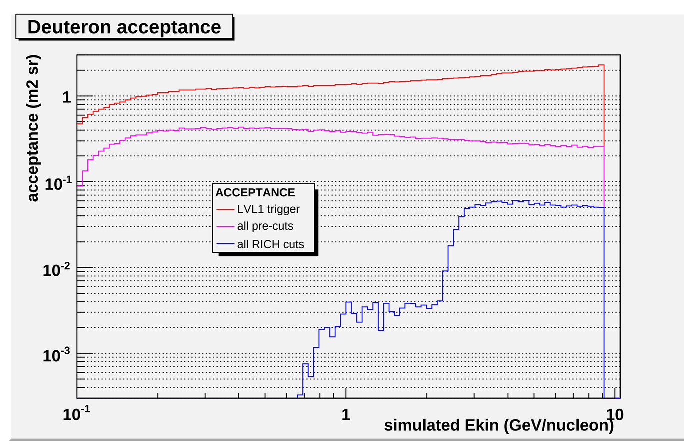




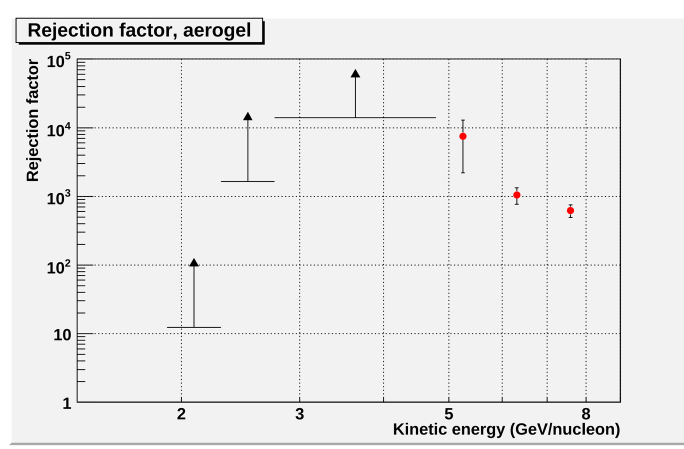
5 Physics prospects: D/p separation

The measurement of the deuteron/proton ratio provides information on cosmic-ray production and propagation and is particularly challenging due to the low deuteron abundance (D/p ~ 1%). The extremely accurate velocity measurement provided by the RICH ($\Delta\beta/\beta \sim 10^{-3}$) is crucial to reduce the background level. A full-scale simulation of the AMS detector was used to evaluate the capabilities of AMS-02 for mass separation.

Pre-selection cuts using readings from different subdetectors of AMS-02 were applied to reduce the fraction of events badly reconstructed in momentum. The set of events passing these cuts corresponds to an acceptance of $\sim$ 0.3 $m^2 sr$ and $\sim$ 0.2 $m^2 sr$, respectively for protons and deuterons.



The reconstruction of particle masses was then performed for events having a signal in the RICH detector. A series of event selection cuts were introduced, namely a minimum of 3 hits in the reconstructed Cerenkov ring, an upper limit on the number of noisy hits and compatibility between two independent velocity measurements. After all cuts, an acceptance of $\sim$ 0.07 $m^2 sr$ and $\sim$ 0.05 $m^2 sr$ was obtained, respectively for protons and deuterons for $E_{kin} >$ 3 GeV/n.



Results show that mass separation of particles with Z=1 is feasible even if one species is orders of magnitude more abundant than the other. It is possible to obtain good estimates for the D/p ratio in the few GeV region. D/p separation is possible up to $E_{kin} \sim$ 8 GeV/nucleon. In the optimal region immediately above the aerogel radiation threshold (up to 5 GeV/nucleon) rejection factors above 10^4 were attained.