Portuguese collaboration in the AMS experiment

RICH standalone reconstruction

An algorithm for finding the particle direction and velocity from a set of 2-dim points

Fernando Barão, Rui Pereira

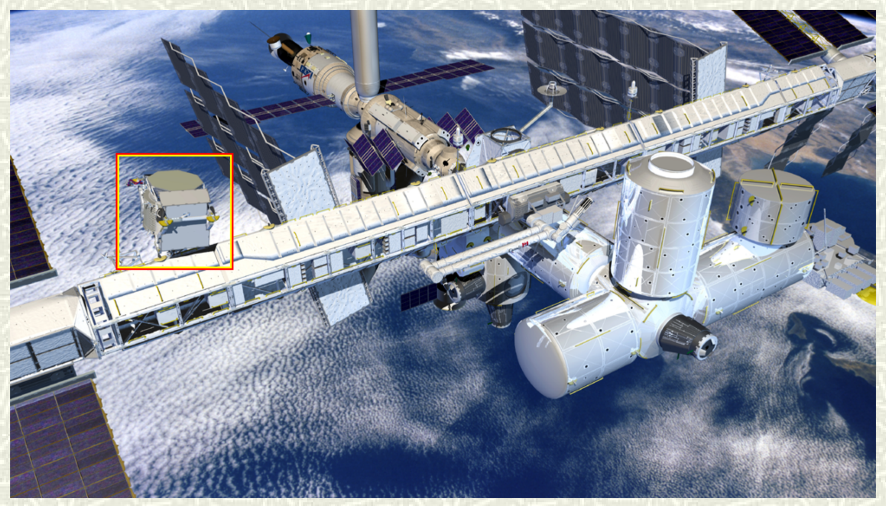
LIP (Laboratório de Instrumentação e Física Experimental de Partículas)
Av. Elias Garcia, 14, 1º, P-1000-149 Lisboa

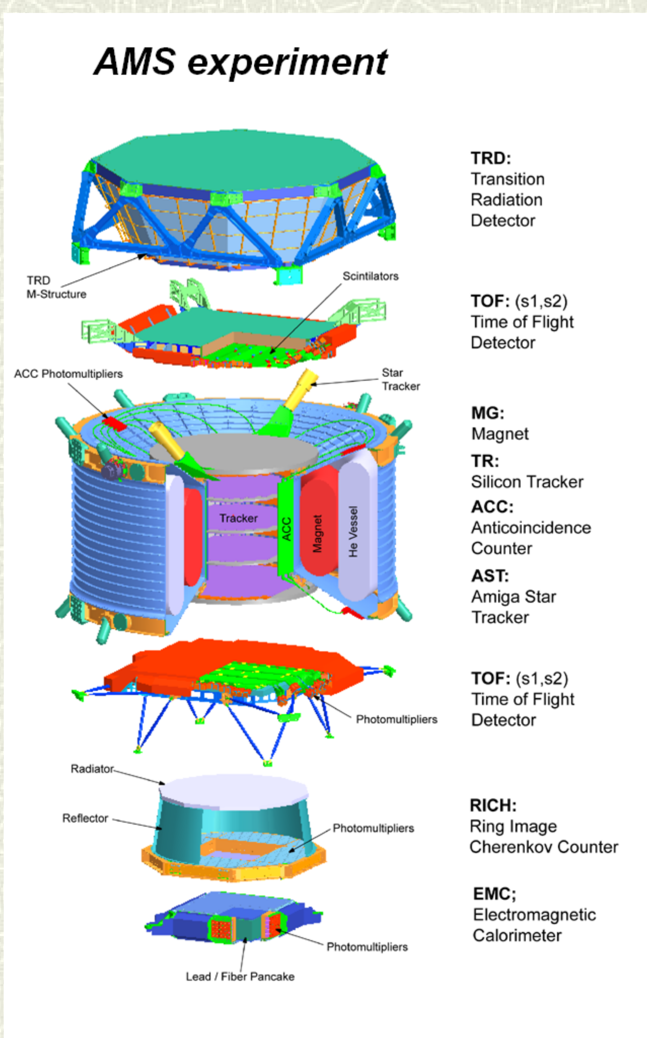
AMS EXPERIMENT

AMS (Alpha Magnetic Spectrometer) is an international experiment to be installed in the International Space Station in 2006. It is scheduled to operate for a minimum of 3 years, collecting an unprecedented amount of data on charged Cosmic Rays, allowing for:

A major improvement on the current knowledge of cosmic ray spectra;

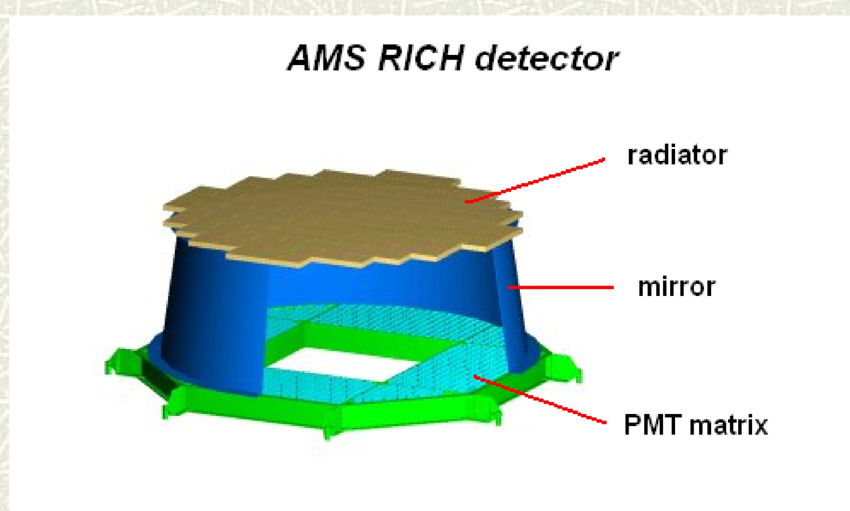
A search for new particles (including anti-nuclei and dark matter).





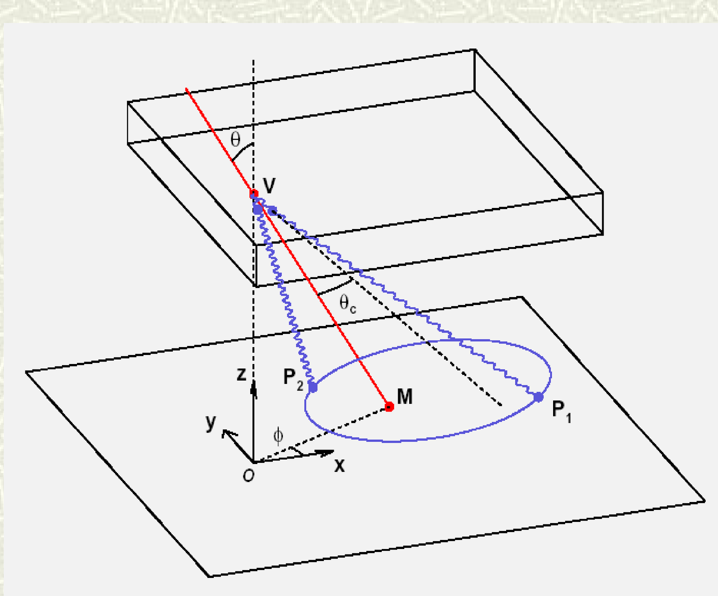
RICH DETECTOR

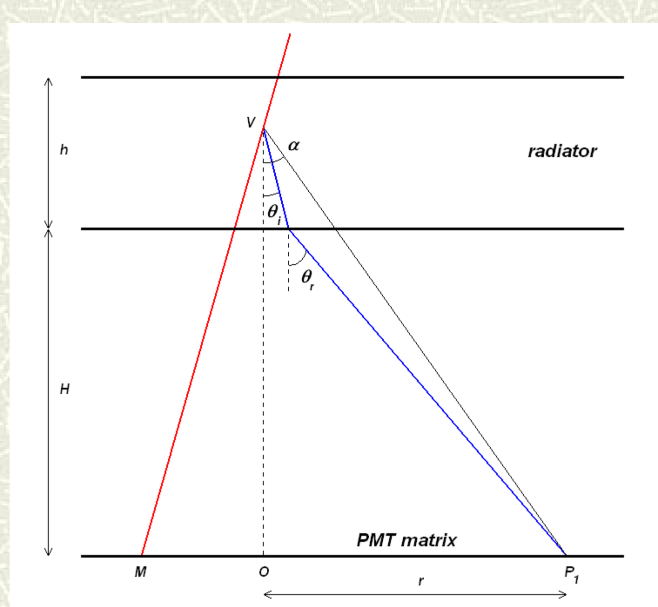
Included in AMS is a RICH (Ring Imaging Cherenkov) detector composed of a radiator material (aerogel) on the top, a matrix of 680 multianode photomultipliers at the bottom and a large conical mirror around for increasing the detector's geometrical acceptance.



CHERENKOV EFFECT

When a charged particle (red line) crosses a medium with a velocity greater than the velocity of light in that medium (given by c/n, where n is the medium's refraction index), it radiates in the UV/visible part of the spectrum. This is known as Cherenkov effect. Cherenkov photons (blue lines) are emitted at a fixed angle θ_c in respect to the particle's path VM. This angle is a function of the particle's velocity, given by cos $\theta_c = 1 / n\beta$, where $\beta = v/c$.





PATTERN RECONSTRUCTION

A Monte Carlo algorithm was developed using CERN's ROOT package to simulate the emission of Cherenkov radiation in aerogel by charged cosmic ray particles, and reconstruct the particle's direction (polar and azimuthal angles) and the Cherenkov angle from a small number of photons collected in the RICH detector. Only direct photon paths were considered in this simulation. Photon reflection due to the conical mirror was not taken into account.

Each particle crosses only a small length of aerogel, meaning that the reconstruction problem may be simplified by considering all photons generated by a given particle as emitted at the same point V. Under this assumption, potential photon paths define a conical surface with V as its vertex. This surface is then distorted as photons change direction when refracted at the aerogel-vacuum interface.

Impact points for the charged particle and three photons are needed to obtain a reconstruction for all parameters. This reconstruction is not unique, however.

NEWTON-RAPHSON METHOD

Newton-Raphson method was used to find possible reconstructions for 3-photon sets. This was achieved by creating a set of three functions f_k which relate the three unknowns θ, ϕ, θ_c:

$$f_k(\theta,\phi,\theta_c;P_k,M) = \cos\theta\cos\theta_i + \sin\theta\sin\theta_i\cos(\phi-\varphi_r) - \cos\theta_c$$

• φ_r is the photon's azimuthal angle (which remains unchanged after refraction), given by

$$\tan\varphi_r(\theta,\phi;P_k,M) = \frac{(y_{P_k}-y_M)+(h+H)\tan\theta\sin\phi}{(x_{P_k}-x_M)+(h+H)\tan\theta\cos\phi}$$

• θ_i is the photon's polar angle before refraction, a function of the angle α, calculated by numerical inversion of

$$\tan\alpha = \frac{h\tan\theta_i + H\tan\theta_r}{h+H} \qquad \text{where} \qquad \sin\theta_r = n\sin\theta_i$$

The angle α is given by the formula

$$\tan\alpha = \frac{\sqrt{\left[(x_{P_k}-x_M)+(h+H)\tan\theta\cos\phi\right]^2+\left[(y_{P_k}-y_M)+(h+H)\tan\theta\sin\phi\right]^2}}{h+H}$$

Starting values are given for θ, ϕ, θ_c. Newton-Raphson method is applied for solving the following system of linear equations:

$$\sum_{j=1}^{3}\frac{\partial f_k}{\partial w_j}\delta w_j = -f_k \qquad (k = 1, 2, 3) \qquad \text{where} \quad w_1 \equiv \theta \quad w_2 \equiv \phi \quad w_3 \equiv \theta_c$$

Derivatives for f_k are numerically calculated. The next step values are given by

$$w_k^{(n+1)} = w_k^{(n)} + \delta w_k$$

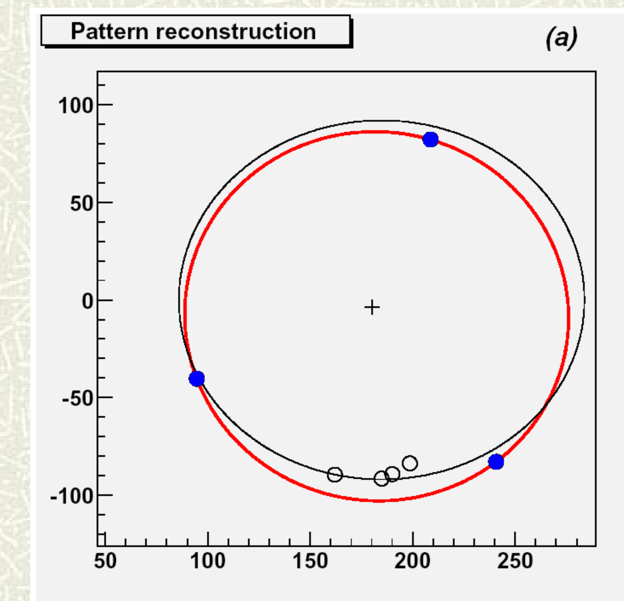
This procedure is repeated until δw_k are negligible, meaning a solution was found.

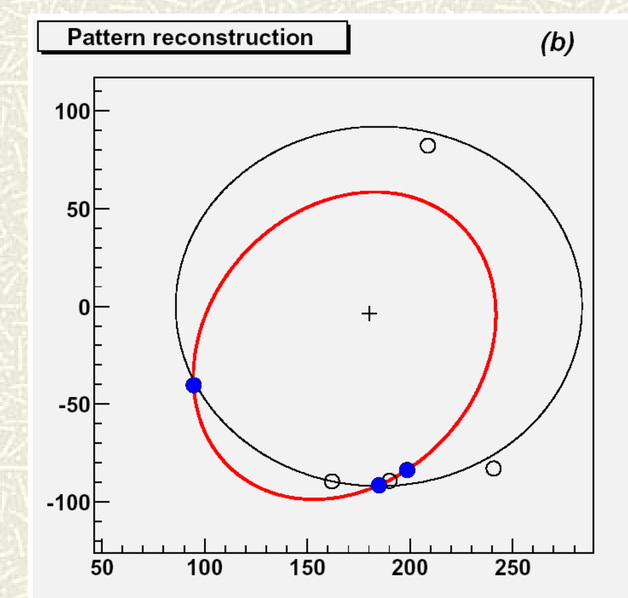
More than one reconstruction may be obtained from the same 3-photon set. Most bad patterns may be excluded based on physical reasonings.

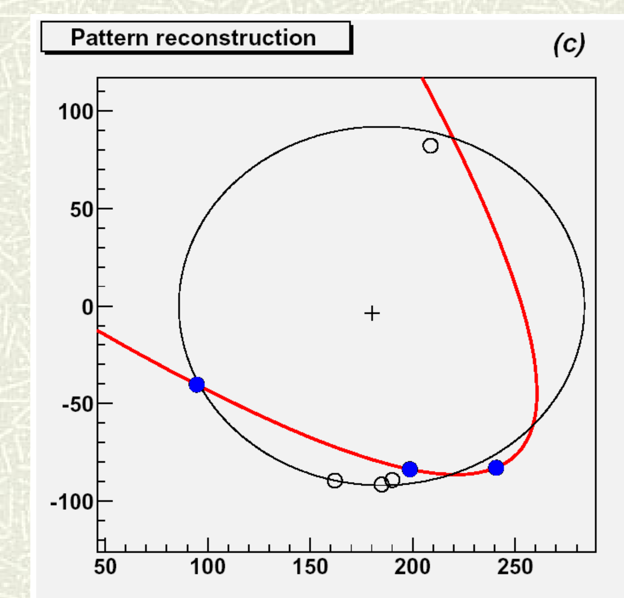
Taking a sample of events with 4 or more photons detected., Newton-Raphson's method was applied to all sets of 3 photons. Assuming no errors on photon positions, there is a reconstruction (the correct one) that is found for all 3-photon sets. Experimental errors imply that good reconstructions are not entirely coincidental, meaning that an average must be taken over the results obtained. Sets containing photons that are very close to each other are excluded due to their high sensitiveness to error. A clustering algorithm may be used as a final test to exclude reconstructions too far from average to be considered as variations of the same pattern. Average values are then calculated over the remaining patterns, giving the final result.

RECONSTRUCTION EXAMPLE

Three different reconstructions (red lines) for the same theoretical Cherenkov pattern (black line) as a result of different choices of 3 out of 7 photon impact points (filled dots): (a) a good reconstruction; (b) excluded for containing two close photons; (c) excluded based on θ cut. The cross near the centre marks the charged particle's impact point.







RECONSTRUCTION RESULTS

Reconstruction spectra for θ (right), ϕ (bottom) and θ_c (bottom right) for simulated particles with θ = 20º, ϕ = 0º, θ_c = 10º obtained from 3-photon sets as a function of the smallest photon distance. Best results are obtained for d_{min} > 15 cm.