ISOTOPIC MASS SEPARATION WITH THE RICH DETECTOR OF THE AMS EXPERIMENT

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The Alpha Magnetic Spectrometer (AMS) to be installed on the International Space Station (ISS) will be equipped with a proximity focusing Ring Imaging Čerenkov detector (RICH). Reconstruction of the Čerenkov angle and the electric charge with RICH are discussed. A likelihood method for the Čerenkov angle reconstruction was applied leading to a velocity determination for protons with a resolution around 0.1%. The electric charge reconstruction is based on the counting of the number of photoelectrons and on an overall efficiency estimation on an event-by-event basis. The isotopic mass separation of helium and beryllium is presented.

1. The AMS02 and the RICH detector

AMS (Alpha Magnetic Spectrometer) [1, 2] is a precision spectrometer designed to search for cosmic antimatter, dark matter and to study the relative abundances of elements and isotopic composition of the primary cosmic rays. It will be installed in the International Space Station (ISS), in 2008, where it will operate for a period of at least three years. It will be equipped with a Ring Imaging Čerenkov detector (RICH). This detector was designed to measure the velocity of singly charged particles with a resolution $\Delta\beta/\beta$ of 0.1%, to extend the electric charge separation up to the iron element, to contribute to the albedo rejection and to contribute to the e/p separation.

The RICH of AMS is a proximity focusing Čerenkov radiation detector. Its radiator is composed by aerogel (n=1.05) and a sodium fluoride (NaF

1.334) squared region placed at the center and covering an acceptance of ∼10%. The whole detector set will be covered by a high reflectivity conical mirror increasing the reconstruction efficiency. Photons will be detected in a matrix with 680 photomultipliers (PMTs) coupled to light guides. There will be a large non-active area at the center of the detection area due to the insertion of an electromagnetic calorimeter. For a more detailed description of the RICH detector see reference [3]. Figure 1 shows a view of the RICH and a beryllium event display with a view of the PMT detailed matrix.

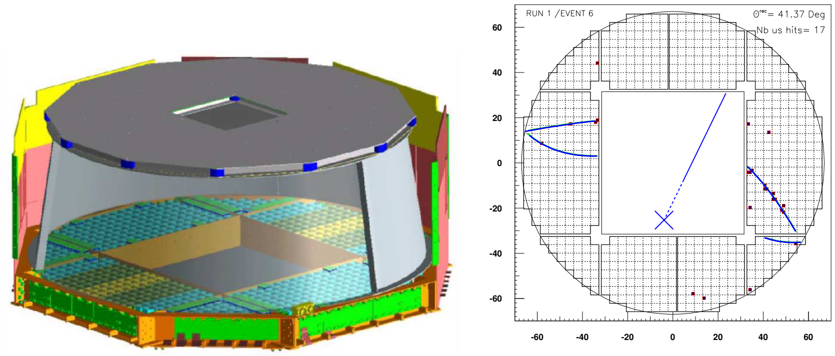

Figure 1. *On the left:* View of the RICH detector. *On the right:* Beryllium event display generated in a NaF radiator. The reconstructed photon pattern (full line) includes both reflected and non-reflected branches. The outer circular line corresponds to the lower boundary of the conical mirror. The square is the limit of the non-active region.

2. Velocity reconstruction

A charged particle crossing a dielectric material of refractive index n, with a velocity β, greater than the speed of light in that medium emits photons. The aperture angle of the emitted photons with respect to the radiating particle track is known as the Čerenkov angle, θ_c, and it is given by (see [4]):

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

It follows that the velocity of the particle, β, is straightforward derived from the Čerenkov angle reconstruction, which is based on a fit to the pattern of the detected photons. Complex photon patterns can occur at the detector plane due to mirror reflected photons, as can be seen on right display of Figure 1. The event displayed is generated by a simulated beryllium nuclei in a NaF radiator.

The Čerenkov angle reconstruction procedure relies on the information of the particle direction provided by the tracker. The tagging of the hits signaling the passage of the particle through the solid light guides in the detection plane, provides an additional track element, however, those hits are excluded from the reconstruction. The best value of θ_c will result from the maximization of a likelihood function, built as the product of the probabilities, p_i, that the detected hits belong to a given (hypothesis) Čerenkov photon pattern ring,

$$L(\theta_c) = \prod_{i=1}^{nhits} p_i^{n_i} \left[r_i(\theta_c) \right] . \tag{2}$$

Here r_i is the closest distance of the hit to the Čerenkov pattern. For a more complete description of the method see [5]. The resolution achieved for protons of 20 GeV/c/nuc is ∼4 mrad. The evolution of the relative resolution of beta with the charge can be observed on the left plot of Figure 2. It was extracted from reconstructed events generated in a test beam at CERN in October 2003 with fragments of an indium beam with a momentum per nucleon of 158 GeV/c/nuc, in a prototype of the RICH detector.

3. Charge reconstruction

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 depends on the particle's charge, Z, and velocity, β, and on the refractive index, n, according to the expression:

$$\frac{dN_\gamma}{dE} \propto Z^2 L \left(1 - \frac{1}{\beta^2 n^2}\right) = Z^2 L \sin^2 \theta_c \tag{3}$$

So to reconstruct the charge the following procedure is required:

- Čerenkov angle reconstruction.
- Estimation of the particle path, L, which relies on the information of the particle direction provided by the tracker.
- Counting the number of photoelectrons.
  The number of photoelectrons related to the Čerenkov ring has to

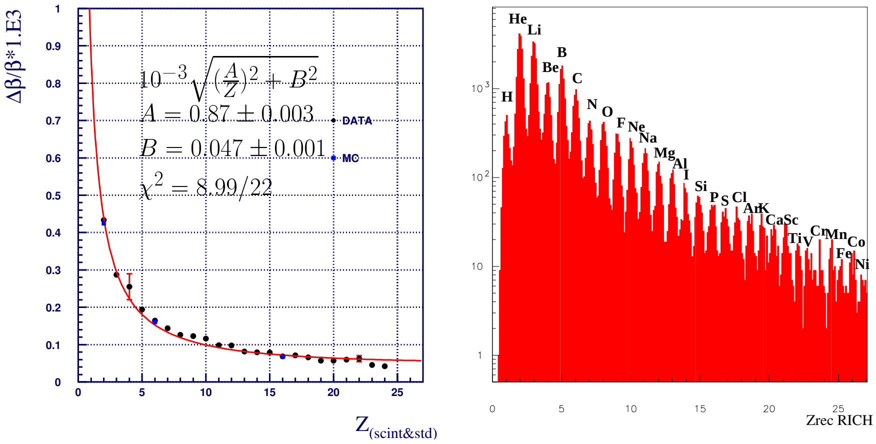

Figure 2. At left evolution of the relative resolution on beta with the charge and at right the reconstructed charge peaks. Both are reconstructions with data from a test beam at CERN in October 2003, using an indium beam of 158 GeV/c/nuc.

be counted within a fiducial area, in order to exclude the uncorrelated background noise. Therefore, photons which are scattered in the radiator are excluded. A distance of 15 mm to the ring was defined as the limit for photoelectron counting, corresponding to a ring width of ∼4 pixels.

- Evaluation of the photon detection efficiency. The number of radiated photons (N_γ) which will be detected ($n_{p.e.}$) is reduced due to the interactions with the radiator (ε_{rad}), the photon ring acceptance (ε_{geo}), light guide (ε_{lg}) and photomultiplier efficiency (ε_{pmt}).

$$n_{p.e.} \sim N_\gamma \; \varepsilon_{rad} \; \varepsilon_{geo} \; \varepsilon_{lg} \; \varepsilon_{pmt} \tag{4}$$

The charge is then calculated according to expression 3, where the normalization constant can be evaluated from a calibrated beam of charged particles. In the right plot of Figure 2 are visible reconstructed charge peaks from the mentioned test beam at CERN in October 2003. These results were obtained with aerogel radiator 1.05 and 2.5 cm thick. A charge resolution for helium events slightly better than $\Delta Z \sim 0.2$ was observed together with a systematic of 1%. A clear charge separation up to Z=27 was achieved. For a more complete description of the charge reconstruction method see [5].

4. Isotopic Element Separation

Isotopic separation and particularly the ratios ^{3}He/^{4}He and ^{10}Be/^{9}Be is a major part of the physics goals where the RICH plays a fundamental role within AMS. The presence of a mixed radiator with a NaF radiator at the center will allow AMS to cover a kinematic energy range from 0.5 GeV/nucleon up to around 10 GeV/nucleon.

Samples of helium and beryllium nuclei corresponding to 1 day and 1 year of data taking, respectively, were simulated. These samples were generated according to [6] for helium and [7] for beryllium nuclei. Afterwards, the spectra was modulated taking into account the geomagnetic field. The masses were reconstructed using a momentum uncertainty $\sim$2%.

The reconstructed masses were fitted with a sum of two gaussian functions:

$$f(m) \propto \alpha\,(G_1(M_1, \sigma_1) + G_2(M_2, \sigma_2))$$

where M_i, σ_i and α are respectively the isotopic mass central value, the mass width and the relative weight of the two distributions.

Figure 3 presents the isotopic ratios obtained from the fits as function of the kinetic energy. Isotopic ratios from events crossing the sodium fluoride radiator are fairly measured up to the aerogel threshold. From there on, the aerogel allows to measure the isotopic ratios up to around 10 GeV/nucleon of kinetic energy. Above 10 GeV/nuc the mass relative resolution is greater than 8.5% for He and greater than 6% for Be.

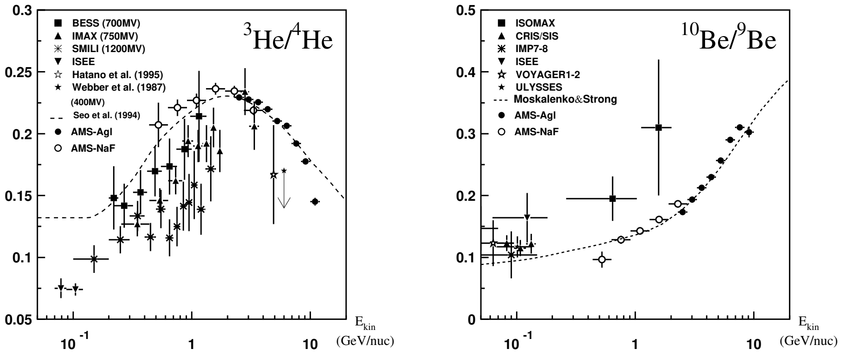

Figure 3. Reconstructed isotopic ratios of helium and beryllium simulated events as function of kinetic energy per nucleon. The aerogel in study has a refractive index of 1.050.

5. Conclusions

AMS is a spectrometer designed for antimatter, dark matter searches and for measuring relative abundances of nuclei and isotopes. The instrument will be equipped with a proximity focusing RICH detector based on a mixed radiator of aerogel and sodium fluoride, enabling velocity measurements with a resolution of about 0.1% and extending the charge measurements up to the iron element. Velocity reconstruction is made with a likelihood method. Charge reconstruction is made in an event-by-event basis. Both algorithms were successfully applied to simulated data samples with flight configuration. Evaluation of the algorithms on real data taken with the RICH prototype was performed at the LPSC, Grenoble in 2001 and in the test beam at CERN, in October 2002 and 2003. The RICH radiator will allow AMS to perform helium and beryllium isotopic separation up to 10 GeV/nucleon.

References

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