ISOTOPE 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) in 2008, is a cosmic ray detector with several subsystems, one of which is a proximity focusing Ring Imaging Čerenkov (RICH) detector. This detector will be equipped with a dual radiator (aerogel+NaF), a lateral conical mirror and a detection plane made of 680 photomultipliers and light guides, enabling precise measurements of particle electric charge and velocity. Combining velocity measurements with data on particle rigidity from the AMS Tracker it is possible to obtain a measurement for particle mass, allowing the separation of isotopes.
A Monte Carlo simulation of the RICH detector, based on realistic properties measured at ion beam tests, was performed to evaluate isotope separation capabilities. Results for three elements — H (Z=1), He (Z=2) and Be (Z=4) — are presented.

1. The AMS02 experiment

Alpha Magnetic Spectrometer (AMS)[1] is an experiment designed to study the cosmic ray flux by direct detection of particles above the Earth's atmosphere. The deployment of the final detector (AMS-02) to the ISS is scheduled for 2008, for a minimum operating period of 3 years. A preliminary version of the detector (AMS-01) was successfully flown aboard the US space shuttle Discovery in June 1998.

On the ISS, orbiting at an average altitude of 400 km, AMS will collect an extremely large number of cosmic ray particles. Its main goals are *(i)* a detailed study of cosmic ray composition and energy spectrum through the collection of an unprecedented volume of data, *(ii)* a search for heavy antinuclei ($Z \geq 2$) which if discovered would signal the existence of antimatter domains in the Universe, and *(iii)* a search for dark matter constituents by examining possible signatures of their presence in the cosmic ray spectrum.

AMS is a spectrometer equipped with a superconducting magnet. It is composed of several subdetectors: a Transition Radiation Detector (TRD), a Time-of-Flight (TOF) detector, a Silicon Tracker, Anticoincidence Counters (ACC), a Ring Imaging Čerenkov (RICH) detector and an Electromagnetic Calorimeter (ECAL). Fig. 1 shows a schematic view of the full AMS detector. The present work evaluates reconstruction capabilities of the RICH detector of AMS.

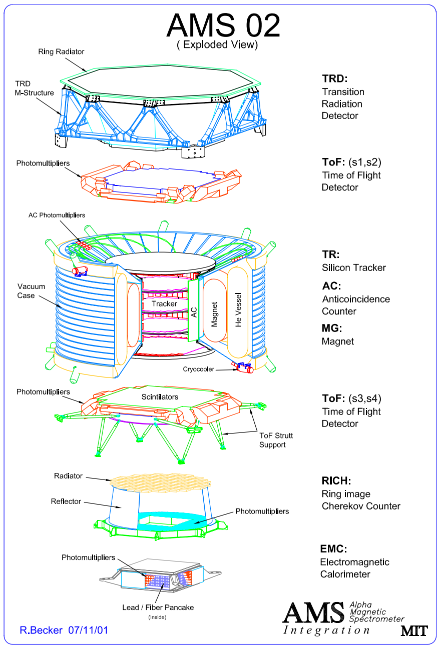

Figure 1. Expanded view of the AMS-02 detector

2. RICH detector simulation

The AMS RICH detector[2] has a dual radiator configuration with a square of sodium fluoride (NaF) with a refractive index n=1.334 at the centre surrounded by tiles of silica aerogel with n=1.05. Detector efficiency is increased by the presence of a highly reflective ($\approx$ 85%) conical mirror surrounding the expansion volume. For additional information on the RICH detector capabilities see also ref. 3.

A full-scale Monte Carlo simulation of the RICH detector was performed to evaluate isotope separation capabilities using the GEANT 3 software package. Data on particle rigidity, which in the experimental setup are expected to come from the AMS silicon tracker, were created by adding a random smearing to the simulated rigidity. The function giving smearing magnitude was adjusted to match real tracker performance.

Table 1 shows the total number of events generated for each simulation. The total number of simulated events corresponds to approximately one day of data, in the cases of H and He, and one year in the case of Be. Simulated distributions were based respectively on ref. 4 for H, ref. 5 for He and ref. 6 for Be and adjusted to the AMS detector acceptance.

Table 1. Statistics for the AMS RICH simulations

Simulations for NaF+aerogel		
H total : $\mathbf{1.63 \times 10^7}$	^{1}H (p) : 1.61×10^7	^{2}H (d) : 1.39×10^5
He total : $\mathbf{2.02 \times 10^6}$	^{3}He : 3.39×10^5	^{4}He : 1.68×10^6
Be total : $\mathbf{8.47 \times 10^5}$	^{9}Be : 6.97×10^5	^{10}Be : 1.49×10^5

Simulation for NaF only		
H total : $\mathbf{1.53 \times 10^7}$	^{1}H (p) : 1.52×10^7	^{2}H (d) : 1.31×10^5

An additional simulation was performed for hydrogen events radiating in NaF, with a total statistics corresponding to approximately one week of data taking. This was due to the relatively low number of NaF events produced by generic simulations (NaF events correspond to only $\sim 10\%$ of the total RICH data).

3. Reconstruction procedure

For each particle, charge and kinetic energy were determined using the procedure described in ref. 7. Since isotopic ratios are a function of energy, the reconstructed spectrum in energy-per-nucleon was divided in narrow regions for which the calculation of isotopic abundances was performed separately. Only events with a minimum of 3 hits in the Čerenkov pattern were considered. In the cases of He and Be, total isotopic abundances for each energy bin were determined by fitting the mass spectrum to a sum of two gaussian functions with an additional constraint on the mass resolutions ($\frac{\sigma_1}{\sigma_2} = \frac{m_1}{m_2}$).

Hydrogen was a special case due to low masses and the small d/p ratio. An inverse mass ($1/m$) spectrum was used, with separate fits being performed for the two mass peaks. A gaussian fit was used for p, while for d a sum of a gaussian and a constant was used to account for proton background.

For all elements, final isotopic ratios were calculated from the gaussian fit integrals corresponding to each peak.

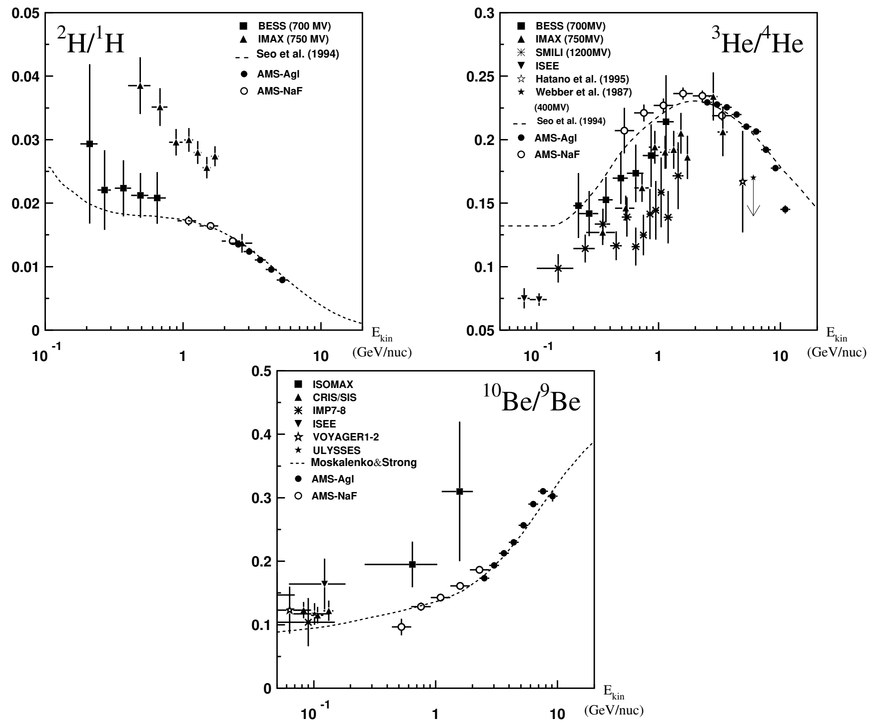

Figure 2. Reconstruction of simulated isotopic ratios in AMS compared with data from other experiments

4. Reconstruction results

Fig. 2 shows the results obtained for isotopic ratios compared with the simulated distributions. Data from previous experiments are also shown for comparison. In the cases of He and Be, satisfactory fits were obtained for the energy regions from the Čerenkov thresholds up to ~ 3 GeV/nucleon (NaF) and ~ 10 GeV/nucleon (aerogel). In the case of H good fits were only obtained for the regions between 0.9 and 3 GeV/nucleon in NaF and from the Čerenkov threshold up to ~ 6 GeV/nucleon in aerogel. These figures clearly show that even a small fraction of the expected AMS statistics will represent a major improvement on existing results for any of the three elements.

For each element, data on mass resolution and separation power for different energies were obtained from fit results. Separation power was defined as the ratio $\frac{\Delta m}{\sigma_m}$. Fig. 3 shows mass resolution and separation power as functions of energy for both radiators. Optimal mass resolutions were reached around 1 GeV/nucleon in NaF and 3 GeV/nucleon in aerogel.

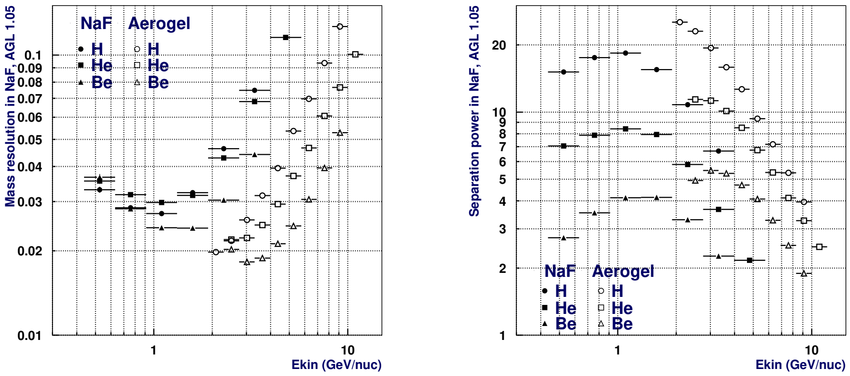

Figure 3. Simulation results for mass resolution *(left)* and separation power *(right)*

Separation power is higher for lighter elements, suggesting isotope separation should be possible up to higher energies in the case of hydrogen. However, the greater difference between proton and deuteron statistics ($d/p \sim 10^{-2}$) compared to the cases of He and Be isotopes eventually leads to the separation being only possible up to $\sim$ 6 GeV/nucleon compared to $\sim$ 10 GeV/nucleon for the other elements.

5. Conclusions

AMS will provide a major improvement on existing data for isotopic abundances in cosmic rays. Simulation results indicate that the separation of light isotopes using the combination of RICH data and tracker rigidity measurements is feasible. The dual radiator configuration of NaF and aerogel makes isotope separation of light elements possible for energies in the range from 0.5 to 10 GeV/nucleon, approximately. Best mass resolutions are $\sim$ 2% at 3 GeV/nucleon for aerogel, and $\sim$ 3% at 1 GeV/nucleon for NaF. Techniques presented here may also be applied in the separation of antimatter isotopes which is of great importance in dark matter studies.

References

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