COSMIC RAY VELOCITY AND ELECTRIC CHARGE MEASUREMENTS IN THE AMS EXPERIMENT

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The Alpha Magnetic Spectrometer (AMS) is a particle physics detector designed to measure charged cosmic ray spectra with energies up to the TeV region and with high energy photon detection capability up to few hundred GeV. It will be installed on the International Space Station (ISS) in 2008 and will operate for more than three years. Due to its large acceptance, the flight duration and the state-of-art of particle identification techniques, AMS will have a remarkable sensitivity on antimatter and dark matter searches.
The addition of different detector systems provide AMS with complementary and redundant electric charge and velocity measurements. The velocity of singly charged particles is expected to be measured with a precision of 0.1% and charge separation up to iron is attainable. The AMS capability of measuring a large range of electric charges and accurate velocities, will largely contribute to a better understanding of cosmic ray production, acceleration and propagation mechanisms in the galaxy.

1. The AMS02 detector

AMS [1] (Alpha Magnetic Spectrometer) is a precision spectrometer designed to search for cosmic antimatter, dark matter and to study the relative abundance of elements and isotopic composition of the primary cosmic rays with an energy up to $\sim$1 TeV. It will be installed in the International Space Station (ISS), in 2008, where it will operate for more than three years.

The spectrometer will be able to measure the rigidity ($R \equiv pc/|Z|e$), the charge (Z), the velocity (β) and the energy (E) of cosmic rays within a geometrical acceptance of $\sim$0.5 m^2.sr. Figure 1 shows a schematic view of the AMS spectrometer. At both ends of the AMS spectrometer exist the Transition Radiation Detector (TRD) (top) and the Electromagnetic Calorimeter (ECAL) (bottom). Both will provide AMS with capability to discriminate between leptons and hadrons. Additionally the calorimeter

will trigger and detect photons. The TRD will be followed by the first of the four Time-of-Flight (TOF) system scintillator planes. The TOF system [2] is composed of four roughly circular planes of 12 cm wide scintillator paddles, one pair of planes above the magnet, the upper TOF, and one pair bellow, the lower TOF. There will be a total of 34 paddles. The TOF will provide a fast trigger within 200 ns, charge and velocity measurements for charged particles, as well as information on their direction of incidence. The TOF operation at regions with very intense magnetic fields forces the use of shielded fine mesh phototubes and the optimization of the light guides geometry, with some of them twisted and bent. Moreover the system guarantees redundancy, with two photomultipliers on each end of the paddles and double redundant electronics. A time resolution of 130 ps for protons is expected [3].
The tracking system will be surrounded by veto counters and embedded in a magnetic field of about 0.9 Tesla produced by a superconducting magnet. It will consist on a Silicon Tracker [4] made of 8 layers of double sided silicon sensors with a total area of $\sim$6.7 m^2. There will be a total of $\sim$2500 silicon sensors arranged on 192 ladders. The position of the charged particles crossing the tracker layers is measured with a precision of $\sim 10\,\mu$m along the bending plane and $\sim 30\,\mu$m on the transverse direction. With a bending power (BL^2) of around 0.9 T.m^2, particles rigidity is measured with an accuracy better than 2% up to 20 GV and the maximal detectable rigidity is around 1-2 TV. Electric charge is also measured from energy deposition up to Z$\sim$26.
The Ring Imaging Čerenkov Detector (RICH) [5] will be located right after the last TOF plane and before the electromagnetic calorimeter. It is a proximity focusing device with a dual radiator configuration on the top made of a low refractive index aerogel 1.050, 2.7 cm thick and a central square of sodium fluoride (NaF), 0.5 cm thick. Its detection matrix is composed of 680 photomultipliers and light guides and a high reflectivity conical mirror surrounds the whole set. RICH was designed to measure the velocity of singly charged particles with a resolution $\Delta\beta/\beta$ of 0.1%, to extend the charge separation up to iron, to contribute to e/p separation and to albedo rejection.
Particle identification on AMS-02 relies on a very precise determination of the magnetic rigidity, energy, velocity and electric charge. Velocity of low energy particles (up to $\sim$ 1.5 GeV) is measured by TOF detector while for kinetic energies above the radiator thresholds (0.5 GeV for sodium fluoride and 2 GeV for aerogel) the RICH will provide very accurate measurements;

a target resolution of ∼1% and ∼0.1% for singly charged particles is expected, respectively for sodium fluoride and aerogel radiators. The electric charge is measured by the silicon tracker and TOF detectors through dE/dx samplings and on the RICH through the Čerenkov ring signal integration. Charge identification, at least, up to the iron element is expected.

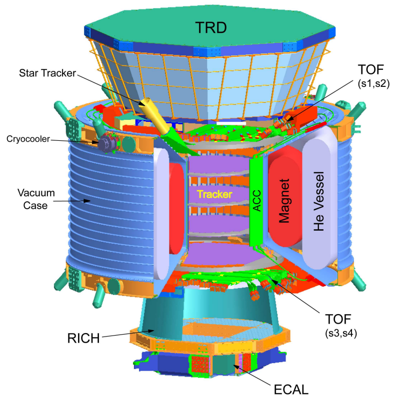

Figure 1. A whole view of the AMS Spectrometer.

2. Velocity measurement

TOF measures the crossing time between two scintillator planes and extracts the velocity through β=ΔL/Δt. The time of flight resolution for two scintillators, tested in a test beam at CERN in October 2003 with fragments of an indium beam of 158 GeV/c/nuc, is shown in figure 2 as function of the particle charge. One of the tested scintillators had bent and twisted light guides (C2) while the other one had bent light guides (C3). A time resolution of 180 ps was estimated for this conservative configuration. However, as the measurement in AMS-02 will be done with four independent measurements, the time resolution which can be inferred is of the order of 130 ps for a minimum ionizing particle.

In the RICH detector the velocity of the particle, β, is straightforwardly derived from the Čerenkov angle reconstruction ($\cos\theta_c = \frac{1}{\beta\ n}$). Two reconstruction methods were developed: a geometrical method based on a hit-by-hit reconstruction and a method based on a likelihood fit to the pattern of the detected photons. The best value of θ_c will result in the former case from the average of the hit velocities after hit clusterization and in the latter from the maximization of a Likelihood function $L(\theta_c)$ given by,

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

where the probability of a hit belonging to a Čerenkov ring of angle θ_c (p_i) is function of the closest distance of the hit to the Čerenkov pattern (r_i). In both methods the hits position is weighted by the detected signal n_i. For a more complete description of the method see [6]. The resolution expected for $\beta \sim 1$ singly charged particles crossing the aerogel radiator is around $4\,mrad$ while for those crossing the NaF radiator is around $8\,mrad$. The accuracy of the velocity determination improves with the charge. Figure 2 (right plot) shows the evolution of the velocity resolution for indium beam fragments of 158 $GeV/c/n$ detected with a RICH prototype corresponding to 1/6 of the final RICH detector. The radiator plane was placed perpendicular to the beam direction. The photon expansion length between the radiator and the detection matrix was adjusted to 42.3 cm, allowing fully contained Čerenkov rings.

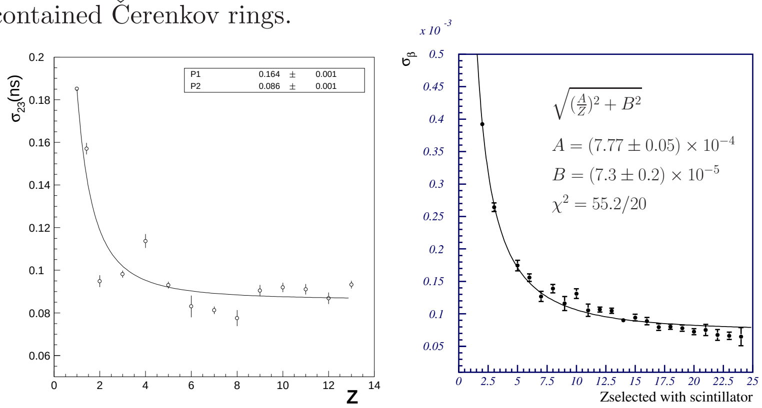

Figure 2. Time of flight resolution for a set of two scintillators and different charged nuclei (left), and evolution of the β resolution with the charge obtained for a RICH prototype with an aerogel 1.03 radiator, 3 cm thick. Both results are from nuclei fragments of an indium beam of 158 GeV/c/nuc taken at CERN in October 2003.

3. Charge measurements

As it was said previously, TOF and tracker measure the charge (Z) through dE/dx samplings. Figure 3 a) shows the charge measurement from the anode signal of one of the TOF counters (C2) tested in ion beam at CERN in 2003, in principle the most unfavourable one. Charge separation up to the aluminium is visible. Figure 3 b) shows the combined measurements for

4 or more ladders on the tracker K side. The ion species can be distinguished up to Z=26.

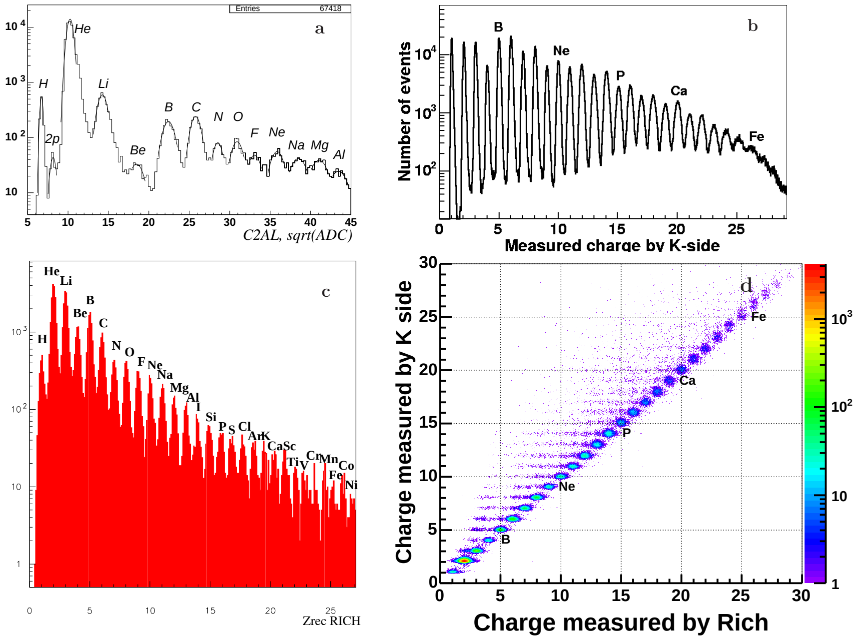

Figure 3. Charge measurements with TOF, Tracker and RICH prototypes tested at CERN in October 2003, with fragments of an indium beam of 158 GeV/c/nuc. (a) The square root of the integrated charge measured with TOF scintillator's anode show different peaks corresponding to charges up to aluminium. (b) Combined Z measurements for 4 or more ladders on the tracker K side. (c) Charge peaks distribution measured with the RICH prototype having an n=1.05 aerogel radiator, 2.5 cm thick. (d) Comparison of the charge measurements made by the tracker and by the RICH.

RICH charge measurement is based on the fact that the number of Čerenkov photons produced in the radiator depends on the particle charge through $N_\gamma \propto Z^2 L \sin^2\theta_c$ where L is the radiator thickness. Once the total number of photoelectrons ($N_{p.e}$) associated to a Čerenkov ring is computed one has to correct it by the photon ring overall efficiency in order to derive the charge. The uncertainty on charge determination results from two distinct contributions. One of statistical nature independent of the nuclei charge and depending essentially on the amount of Čerenkov signal detected for singly charged particles ($N_{p.e} \sim 10$). Another one of systematic nature scaling with the charge and coming essentially from non-uniformities on the radiator plane and photon detection efficiency. The RICH goal of a good charge separation in a wide range of nuclei charges implies a good mapping and monitoring of the potential non-uniformities present on the detector.

Charge peaks reconstructed with the RICH prototype for data taken at CERN during October 2003, are shown in figure 3 c). The RICH configuration included an aerogel radiator of n=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 uncertainty of 1%. A clear charge separation up to Z=28 was achieved. For a more complete description of the charge reconstruction method see [6]. Finally figure 3 d) presents the comparison of charge measured by tracker and RICH. Ions can be distinguished and identified up to Z=26, an excellent correlation is obtained.

4. Acknowledgements

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5. Conclusions

AMS is a spectrometer designed for antimatter and dark matter searches and for measuring relative abundances of nuclei and isotopes.The velocity of singly charged particles is expected to be measured with a precision of 0.1% and charge separation up to iron is attainable. Real data analysis was done with data collected with prototypes of TOF, tracker and RICH in test beams at CERN, in October 2002 and 2003

References

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