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Research with the Alpha Magnetic Spectrometer (AMS)

-Research report-

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Abstract

The apparent asymmetry between matter and antimatter, and the presence of non-luminous component of matter (the dark matter) are two of the most intriguing puzzles in the current understanding of the evolution of the universe.

In order to try to solve them we propose to use the Alpha Magnetic Spectrometer (AMS), which is an installation, dedicated to the study of these problems in space. AMS (approved in 1994) is scheduled for installation on the International Space Station (ISS) in 2004. The goal of AMS is to perform a three-year long run in order to measure with the highest accuracy the composition of Cosmic Rays in the rigidity range 10^{-3} to several TV.

As a first, preparatory stage for this long duration mission a operating model (AMS-1) was flown on the Discovery shuttle (STS-91) in a 10 days precursory mission.

The obtained data enabled us, for the first time, to perform the study of the behavior of CR near earth in the rigidity interval 0.1 to 200 GV at all longitudes and at latitude up $\pm 51.7^{o}$

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Introduction

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The AMS-1 Detector

The search of antimatter requires the capability of identifying, the mass the momentum and electric charge of the particles traversing the active part of the detector.

The overall design of the device took advantage of current high-energy detector technology, which had to be transferred to space conditions. This means that the detector must remain operational in vacuum and resistant to mechanical stress during launching and landing of the Discovery shuttle. Also it has to resist to temperature changes between –60° and 40° C. Additional design conditions were also imposed such as total power consumption less than 1.8 kW and a weight limit of 3.157 kg.

Post flight the AMS detector was extensively calibrated [5,7] with helium and carbon beams at GSI Darmstadt and with proton beams at CERN PS

The AMS-1 (1998) configuration (fig 1) includes a permanent magnet, a high accuracy large area tracker (T1 – T6) made from microstrip silicon detectors, an anticounter (ACC) and a time of flight (ToF) scintilator systems, an aerogel threshold Cherenkov counter, a low energy shielding (LEPS).

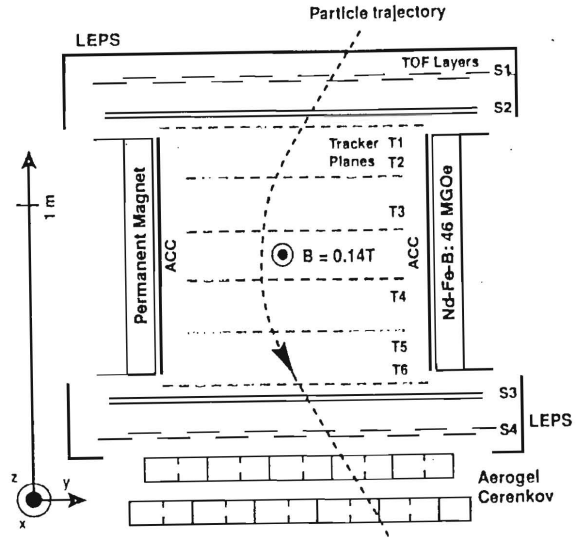


Fig 1 Schematic view of AMS [1] as flown on STS-91 (explanations in the text)

The magnet

The magnetic field was produced by a cylindrical shell shape, permanent magnet with the dimensions H/ ϕ_i/ ϕ_o of 800/557/1200 mm. It was made from 1024 blocks of $Nd_2Fe_{14}B$ magnetic material with a maximal energy density of 46 MGOe. It provides a dipole field along the x-axis of the AMS. By careful arrangement of the individual blocks, a fairly uniform magnetic dipole field of 0.14 Tesla was reached inside the magnet. At 2.6 meters outside the magnet, the field drops to 3 Gauss. The total weight of the magnet was 1900 kg.

The silicon tracker

The silicon tracker consists of six horizontal planes of which four T2 to T4 were within the magnet and two T1 and T6 above and below the magnet. Each plane was formed of elements of 4*7 cm^2 double sided microstrip silicon wafers of 300 μm thickness assembled side by side in two half "ladders". To fill out the circle of the plane the half ladders contained between 8 and 15 silicon elements.

For the 1998 flight only half of ladders were installed. The accuracy was determined in a test beam exposure and it was determined to be 10 μm in the bending plane and 30 μm in the non-bending plane.

The best resolution, which was limited by multiple scattering, was in the vicinity of 5 GeV/c/nucleon

Time of Flight system (ToF)

There were four planes of scintilator located above and below the tracker planes. Each plane consists of 14 plastic scintilator of 1 cm thickness and 11 cm width mounted on a 10 cm thick honeycomb panel. To reduce the effective least count by a factor of 10 a time stretcher is used giving a 100-ps. resolution. The common stop is delayed after the event to allow the time stretcher to finish.

In addition to the time measurement (resolution better than 120 ps) which allows the velocity and flight direction of the particle to be determined, the ToF counters measure the energy deposition and thus provide a measurement of the charge magnitude of the particles

Cherenkov counter

Two Planes of Aerogel located below the magnet formed a Cherenkov threshold counter. The cells are arranged in 8x10 matrix layer in the upper plane and in 8x11 matrix in the lower plane. Each cell was made from 8 aerogel cell (n=1.036) 1x10x100 viewed by Hamamatsu R5900 photo multiplier tubes.

The Cherenkov counter supplements the measurements by providing direct information of the particle velocity above or below the threshold. The total electron rejection was around 100. The refraction index ensures antiproton identification up to 4 GeV/c. Furthermore an independent determination of the direction (up/down) of the particle was made.

Anticoincidence scintilator counters (ACC).

For rejecting the particles exiting detector through the magnet, 16 anticoincidence counters made of 10 mm plastic scintilator were mounted, just outside the inner part of the tracker. The read-out was done by wavelength sifter bars coupled at both ends to flexible fiber light guides viewed by Hamamatsu R2490-1 photo multiplier tube.

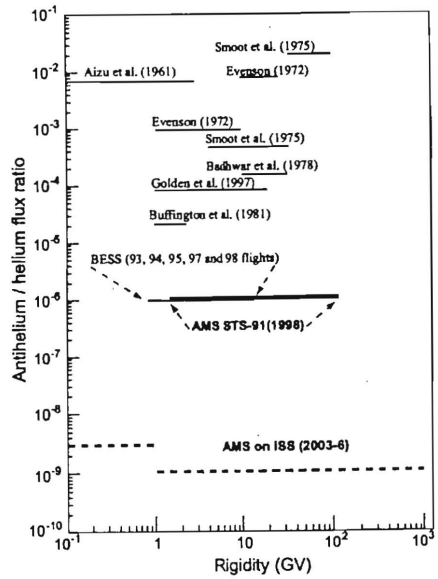
Low energy shielding (LEPS)

The detector was also shielded against low energy (up to several MeV) particles coming from above and below by thin carbon fibers shield as shown in fig 1. The amount of material at normal incidence was 1.5 g/cm^2 in front of the ToF system and 3.5 g/cm^2 in front of the tracker

AMS on the STS-91 flight

During the period 2-12 June 1998 the Discovery STS-19 shuttle performed 154 orbits at an inclination 51.7 ° at an altitude between 320 and 390 km. During 184 hours time the AMS- collected about 10^8 events, which were analyzed for electron, protons, nuclei and their antiparticles. A comparison, of the results obtained by AMS in 10 days flight, with all other existing data (fig 2) show that even in such short flight our data compete with all the existing till this moment data. An extrapolation of the results convinces us that in the flight on ISS it is to be expected for example for Anti-He data an improvement of three orders of magnitude.

The behavior of the electrons, protons and helium nuclei in cosmic rays and in near earth orbits were studied. For the analysis three coordinates systems were used. One (x, y, z) connected with the position of the AMS system in the shuttle bay, one (r, θ, Φ)



Eig 2 Compilation of limits of AntiHelium in C.R. [6]

connected with the geographical position of the shuttle and other (R, θ_M, Φ_M) connected with the geomagnetic position of the shuttle, to describe the movement of the particles in the field

The particle charge, type, magnetic rigidity R= pc/|Z|e = Hρ [8], and energy were determined. The spectrum of the electrons, positrons (fig 3) protons (fig 4) and He nuclei (fig 5) were also established for downward and upward particles. Both the hard, and the soft particles are clearly seen as well as the geomagnetic cut-of for all particles. The decreasing of geomagnetic cutoff with increasing $|\theta_M|$ is seen.

The higher part (above the geomagnetic cut-of) represents the contribution of primary CR. In addition to the primary CR there is a substantial second spectrum below the geomagnetic cutoff due to particles produced essentially in the atmosphere. This spectrum extends to much lower energy and exhibit some significant latitude dependence close to the equator. Above the cutoff, the flux spectra are identical for downward and upward cases.

For sufficiently low rigidity the particles can be trapped in the magnetic field of the earth and form belts along the magnetic field lines, roughly symmetric in latitude with respect to the geomagnetic equator. The motion of trapped particles can be factorized in three components namely:

the revolution around the guiding center of gyration,
the bouncing between mirror points (with a B mirror field) as in a magnetic bottle.
and longitudinal drift around the earth.

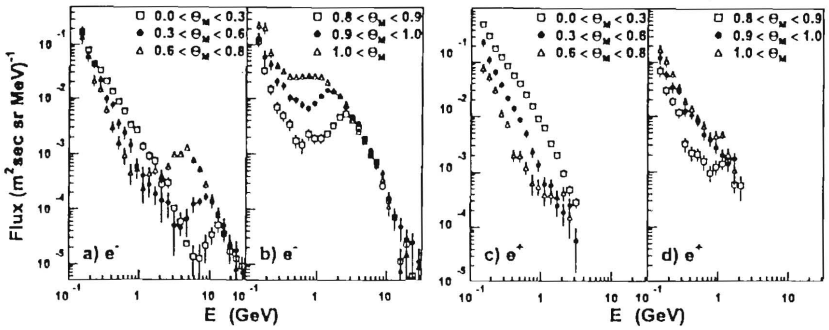


Fig 3 Electrons and positron spectra at different geomagnetic latitudes measured by AMS-1 [6]

Reconstruction of the particle trajectories inside the AMS and extrapolation outside the AMS of each particle for the time in flight, following it in the forward as well as the backward directions was done. The results show the existence of a substantial second spectrum of high energy particles trapped within the low altitude belts. These new

belts are dominated by positively charged particles mainly positrons, protons, deuterium and helium 3

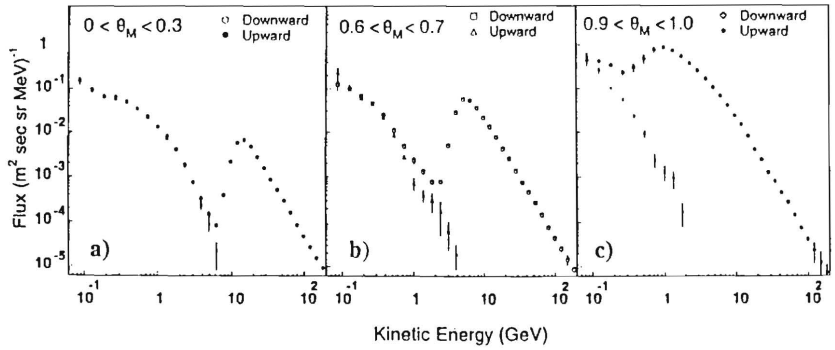


Fig. 5. Spectrum of protons taken by AMS 1 at different geomagnetic latitudes [6]. For comparison on the same plot you can see the downward (open circles) and upward (full circles.)

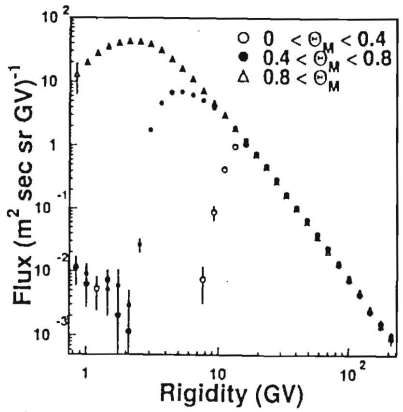


Fig 6 Helium flux spectra for different geomagnetic latitude [5].

According to the momentum and the time length of their life, two categories of particles were identified. The long time (> 0.2-0.3 sec) and the short time live (< 0.2-0.3 sec).

The origins of short time lived particles are consistent with a uniform distribution around the globe.

The long time lived particles appear to have their origin from two geographical restricted regions (the same for positrons, protons and He nuclei (fig 6)). So the positive long-lived particles have the same origin independent of their mass and the negative another which differ from the origin of the positive ones and are complementary to it.

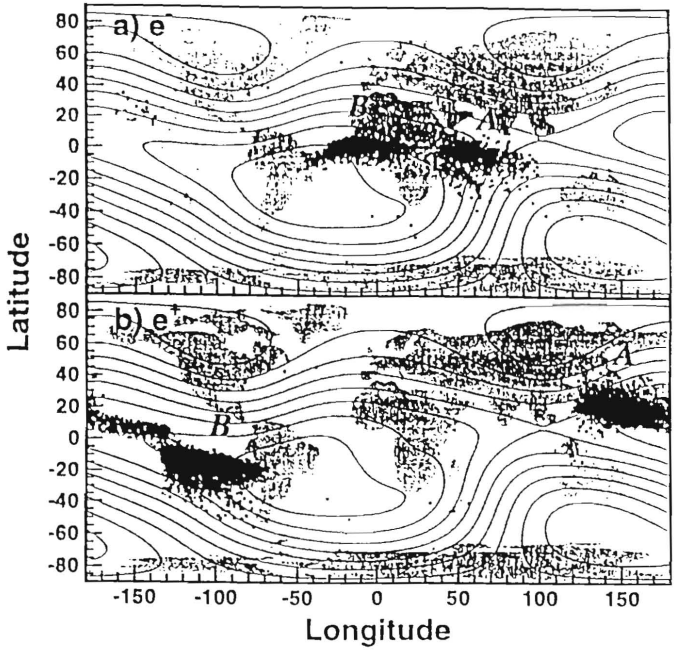


Fig 7 The extrapolated origin of long lived a) electrons, b) positrons. [3]

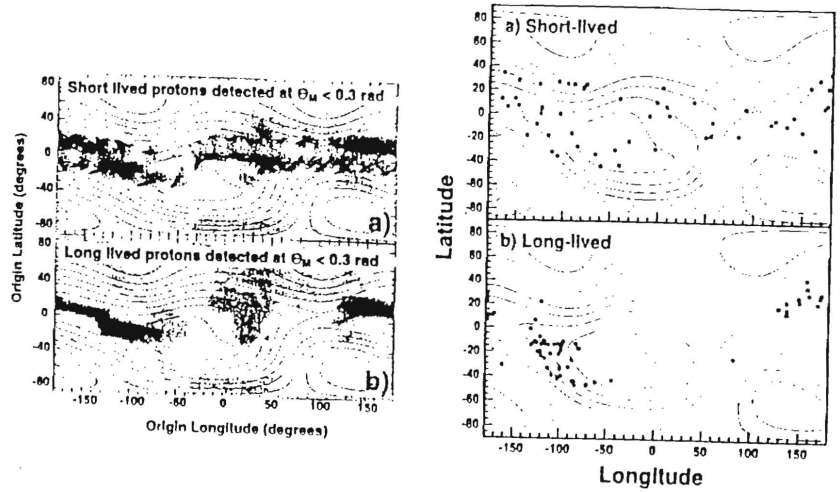


Fig 9 The extrapolated origin of long time lived protons [2] and ^{3}He [5] nuclei

Adding all the data collected above the geomagnetic cutoff, and integrating for all directions it was possible to estimate the primary Cosmic Ray flux as $\Phi(R) = \Phi_0 R^{\gamma}$ where R ($R = pc / |Z|e$) is in GV The results of performed fits for γ for different primaries are in the range $\gamma = 2.78 - 2.74$ with an error of about 0.02.

The existence of primary antimatter (antinuclei of ^{3}He and ^{4}He as well as ^{12}C) was also tested. Function of the assumptions made about the anti He spectrum over the rigidity interval 1-140 GV our analysis allow to established a limit of:

$$N_{anti\,He/He} < (1.1 - 3.9) \times 10^{-6}$$

The shortly mentioned results show the wide possibilities opened for the astronomy, astrophysics and the physics of the earth, by the researches done with the flight of the AMS installation on ISS.

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