THE ALPHA MAGNETIC SPECTROMETER (AMS)*

Jorge Casaus

On behalf of the AMS Collaboration

Unidad de Física de Partículas, CIEMAT
Avda. Complutense 22. 28040 Madrid, Spain

(Received May 6, 1999)

The Alpha Magnetic Spectrometer (AMS) is a large acceptance magnetic spectrometer to search in space for antinuclei in cosmic rays with a sensitivity 10^4 times better than achieved previously. In its first mission, AMS went into a ten day orbit on the Space Shuttle Discovery in June 1998. In this paper we briefly report on the detector performance during this first flight.

PACS numbers: 95.55.Vj, 98.70.Sa

1. Introduction

There is strong experimental evidence supporting the *Big Bang* origin and evolution of the Universe (for example from cosmic microwave background measurements [1]). According to this model, the evolution of the Universe is based to a large extent on the interactions of the elementary particles at very high energy ($\gg 1$ TeV). The current description of the interaction between elementary particles (*Standard Model*), which has been successfully checked up to energies $O(1$ TeV$)$, suggests that matter and antimatter where equally abundant at the very hot beginning of the Universe. However, experimental evidence excludes to date the presence of antimatter within a distance of 10 Mpc from the earth [2].

Attempts to reconcile these observations with cosmological models that do not require new physics have failed [3]. In order to describe the evolution of an initially symmetric universe to an asymmetric universe (baryogenesis), it is mandatory to extend the *Standard Model* with new interactions between elementary particles, mediated by very massive intermediate vector bosons

* Presented at the XXVII International Meeting on Fundamental Physics, Sierra Nevada, Granada, Spain, February 1–5, 1999.

($M > 10^{14}$ GeV), which violate the baryonic number conservation as well as the symmetries C and CP [4].

Modern baryogenesis models either predict an universe free of antimatter or deal with the possibility that the Universe contains matter and antimatter domain structures larger than the sizes of clusters of galaxies ($\sim$ 20 Mpc). Since different models may involve different sorts of CP violating mechanisms, the determination of whether the Universe does or does not contain domains of antimatter beyond our local supercluster of galaxies is of great importance to particle physics. Moreover, the structures which would be implied by a positive detection of antimatter would be related to a number of issues, such as inflation and domain walls, that have deep implications for both cosmology and particle physics. However, the available matter-antimatter models are experimentally disfavoured and even excluded in great generality with the current understanding of cosmology [5].

2. Previous antimatter searches

Limits on the abundance of antimatter have been obtained by two methods in the past:

1. Searches for γ-ray excess from annihilation of matter and antimatter particles in the interstellar or intergalactic gas.

2. Searches for antiparticles in the cosmic rays.

The first technique requires a knowledge of the gas density, and is therefore limited to scales less than the size of clusters of galaxies. Negative results from this indirect method establish that if antimatter is to exist in substantial quantities in the Universe it must do so on the scale of clusters of galaxies or larger ($\gtrsim$ 20 Mpc).

Concerning the second technique, in the last 20 years balloon-borne experiments have searched for antimatter in the cosmic rays. The output of these searches is:

1. Small excess above the Leaky Box model [6] for secondary production of positrons [7] and antiprotons [8].

2. Limits at the level of $10^{-4} - 10^{-6}$ for antinuclei to nuclei ratios [9] with $Z \geq 2$.

Of all the techniques used to search for antimatter, direct searches of cosmic rays, particularly cosmic ray nuclei with atomic number greater than or equal to 2, are probably the most reliable. Unlike the secondary production of antiprotons, it is exceedingly difficult to produce heavy antinuclei in collisions involving ordinary cosmic rays and interstellar material [10].

3. The AMS experiment

The Alpha Magnetic Spectrometer (AMS) [11, 12] is a space-borne particle physics detector designed to measure the amount of antimatter nuclei present in cosmic rays to a much higher precision than achieved to date. The improvement in the sensitivity is critical to the goal of detecting cosmic rays from antimatter domains.

The AMS research program is organised in two different phases. On June 1998, a first version of the detector was launched on the Space Shuttle Discovery (STS-91). During the ten day mission, AMS was allocated 100 hours of primary time to perform system checks. In year 2003, the final version of AMS will be installed in the International Space Station (ISS). AMS will continuously operate during a minimum period of three years. Several modifications are foreseen in order to improve the resolution and identification range of charged particles as well as photon detection.

In addition to the antinuclei search, the AMS particle identification capabilities also allow to measure the abundances of positrons and antiprotons in cosmic rays. An anomalous yield above the expectations from secondary production could be the signal of non-baryonic cold dark matter annihilation in the halo of our galaxy [13, 14].

On the ISS, AMS will also operate as a γ-ray telescope within a wide energy range. Due to its design features, AMS will be able to continue the study of galactic and extragalactic γ-ray sources begun by the EGRET experiment [15].

Finally, AMS will improve the current measurements of the isotopic composition of the light elements in the cosmic rays and thus increase our understanding of cosmic ray production and propagation in our galaxy.

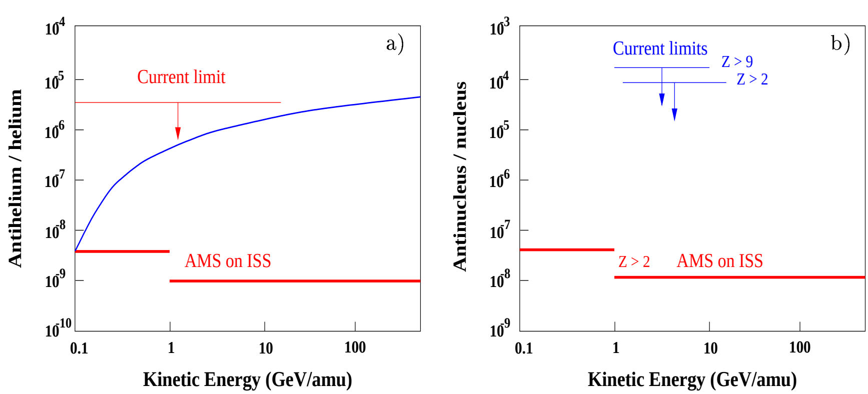

Fig. 1. Sensitivity of AMS after 3 year exposure in the search for (a) $\overline{\mathrm{He}}$; (b) $Z > 2$ antinuclei (95% C.L.). $\overline{\mathrm{He}}$ sensitivity is compared to a prediction of a matter-antimatter symmetric universe.

Figures 1a,b show the current limits for antinuclei to nuclei ratios in cosmic rays together with the AMS sensitivity after a three year exposure. In figure 1a we have included the prediction for a matter-antimatter symmetric model [16] including the cosmic ray propagation from its origin to the AMS detector [12]. As seen in the figure, the current limits are not sensitive enough to test the existence of clusters of galaxies made of antimatter, whereas AMS will be able to detect an antimatter concentration typically one thousand times less than the prediction based on this model.

4. The AMS detector

The AMS configuration for the Shuttle flight (figure 2) consists of

1. a cylindrical permanent magnet with a geometrical acceptance of 0.6 $m^2 \cdot sr$ which provides a rather uniform magnetic field of 0.15 T perpendicular to the bore,
2. a set of six layers of double sided silicon microstrip detectors with a resolution of 10(30) μm in the (non-)bending plane,
3. a counter system consisting of four planes of time of flight (TOF) with a resolution of 100 ps and a set of anticoincidence counters (ACC) covering the magnet inner wall,
4. an aerogel threshold Čerenkov counter (ATC) with a refraction index n=1.035.

The detector is covered with a low energy particle shield and rests in an aluminum support structure. The weight of the experiment plus the support system is 4100 Kg and the total power consumption of the AMS electronics and subdetectors is below 1 KW.

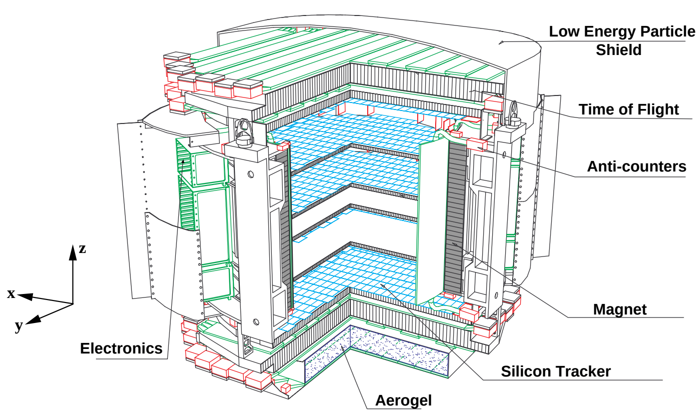

Fig. 2. AMS experimental setup for the STS-91 flight

When a charged particle goes through the magnet bore, its trajectory is bended. The silicon tracker allows to determine the rigidity (p/Z) of the incoming particle providing up to six precise three dimensional points to reconstruct the trajectory. The momentum resolution is 7% for 10 GeV protons. In addition, the energy deposition in each plane by the particle allows a determination of the charge absolute value. Finally, the curvature direction fixes the charge sign of the particle.

The tracker response is identical for a downward going particle and for its corresponding upward going antiparticle. Precise time of flight measurements prevent this confusion and allow a determination of the particle velocity with a resolution better than 3%. In addition, TOF counters also measure the energy deposition and thus provide another measurement of the charge magnitude. Finally, the coincidence of fast signals in several layers is used to trigger the event.

The remaining subdetectors are used either to reject backgrounds coming from particles which go through the magnet (ACC) or to extend the ranges of particle identification (ATC).

The foreseen detector upgrades for the AMS second phase are

1. a superconducting magnet which will increase the magnetic field,
2. a transition radiation detector to improve positron identification,
3. a ring imaging Čerenkov counter which will extend the range of precise velocity measurements,
4. a three-dimensional calorimeter to measure the energy of electromagnetic particles and to reduce the hadronic contamination.

Detailed Monte Carlo studies for the new subdetectors have been performed and their final design and construction has already started.

5. AMS performance on the Space Shuttle

On June 2, 1998 AMS was launched on the Space Shuttle Discovery for a 10 day flight into an orbit similar to the one foreseen for the ISS (380 Km altitude and 51.6 ° inclination).

The AMS main goals were the full detector performance verification and the study of the background for the antimatter search coming from downward going and upward going misidentified nuclei (*albedo* [1]).

[1] The *albedo* nuclei are cosmic rays deflected by the interaction with the earth atmosphere and magnetic field. The previous knowledge of the yield and momentum distribution was based on short duration measurements with balloons at a height of 40 Km.

Four hours after the liftoff, AMS went into normal data taking. Data collection spanned 200 hours (90% of the total mission duration) with a total of 100 million events recorded on tape.

The excellent AMS performance is illustrated with a few examples obtained on a small sample of flight data.

Figure 3a shows the time difference between the particle hits on bottom and top TOF planes. Negative values correspond to upward going particles (*albedo*). The discrimination power between positive and negative time differences can be clearly seen in this figure. The particle velocity derived from this measurement (figure 3b) is consistent with the expected resolution [1].

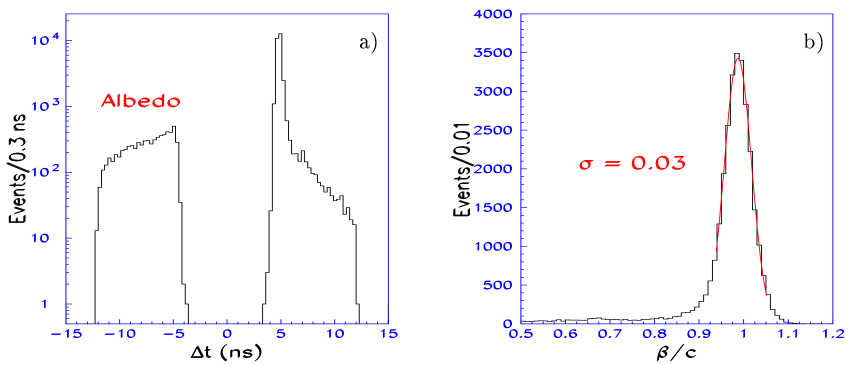

Fig. 3. Particle time of flight differences (a) and reconstructed particle velocity distributions (b) as described in text.

Figures 4a and 4b illustrate the AMS particle identification capabilities using the measured energy deposition in the scintillators and in the silicon tracker as a function of the reconstructed particle rigidity. In addition to proton and helium, electron and secondary pion bands can be also distinguished at low rigidities. Finally, tracker dE/dx measurements allow to determine the absolute charge of light nuclei heavier than helium.

Out of the total sample of collected events during the ten day flight, no antinuclei candidate has been found. Preliminar analysis shows that the corresponding antimatter limits are already competitive with the best limits to date.

Final results on $p, \bar{p}, e^-, e^+$ and nuclei fluxes at different geomagnetic latitudes as well as antinuclei limits are in progress and will be available soon.

[1] The bulk of the data in this specific sample are ultrarelativistic particles. Therefore, the main contribution to the velocity distribution width comes from the resolution in the measurement.

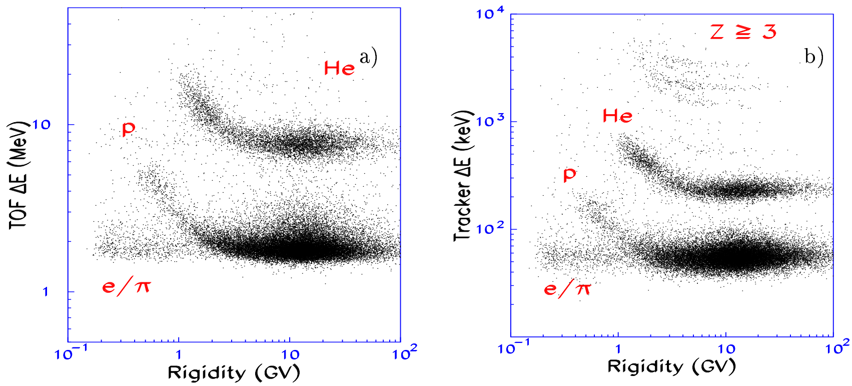

Fig. 4. Energy deposition in (a) TOF and (b) tracker as a function of the measured particle rigidity.

6. Conclusions

AMS is the first sensitive magnet spectrometer in space designed to carry out the most intensive search ever done for cosmic rays made of antimatter.

The first mission, a ten day flight on the Space Shuttle in June 1998, was mainly devoted to detector performance verification and background measurements.

During its first flight AMS recorded 100 million events with an excellent overall performance. No antinuclei candidate has been found. Final results on cosmic ray fluxes and antimatter limits are in progress and will be available soon.

The successful completion of the first flight has provided us with the needed experience to face the long term exposure on the International Space Station starting in year 2003.

REFERENCES

[1] D. Fixsen *et al.*, *Astrophys. J.* **486**, 623 (1997); G. Hinshaw *et al.*, *Astrophys. J.* **464**, L17 (1996).

[2] G. Steigman, *Ann. Rev. Astron. Astrophys.* **14**, 339 (1976).

[3] P.J.E. Peebles, *Principles of Physical Cosmology* (Princeton University Press, Princeton, 1993).

[4] A.D. Sakharov, *JETP Lett.* **5**, 24 (1967).

[5] A.G. Cohen, A. de Rújula, S.L. Glashow, *Astrophys. J.* **495**, 539 (1998).

[6] R.J. Protheroe, *Astrophys. J.* **251**, 387 (1981); R.J. Protheroe, *Astrophys. J.* **254**, 391 (1982).

[7] R.L. Golden *et al.*, *Astrophys. J.* **436**, 769 (1994); G. Barbiellini *et al.*, *Astron. and Astrophys.* **309**, L15 (1996); R.L. Golden *et al.*, *Astrophys. J. Lett.* **457**, L103 (1996); S.W. Barwick *et al.*, *Astrophys. J. Lett.* **482**, L191 (1997).

[8] J.W. Mitchell *et al.*, *Phys. Rev. Lett.* **76**, 3057 (1996); A. Moiseev *et al.*, *Astrophys. J.* **474**, 479 (1997); M. Boezio *et al.*, *Astrophys. J.* **487**, 415 (1997); H. Matsunaga *et al.*, *Phys. Rev. Lett.* **81**, 4052 (1998).

[9] G.F. Smoot, A. Buffington, C.D. Orth, *Phys. Rev. Lett.* **35**, 258 (1975); N. Lund, M. Rotenberg, *Proc. 19th Int. Cosmic Ray Conf.* **3**, 330 (1985); T. Saeki *et al.*, *Phys. Lett.* **B422**, 319 (1998).

[10] R. Hagedorn, *Cargese Lectures in Physics* **6**, 643 (1973).

[11] S. Ahlen *et al.*, *Nucl. Instrum. Methods* **A350**, 351 (1994).

[12] *The Alpha Magnetic Spectrometer*, MIT, 1995.

[13] E. Diehl *et al.*, *Phys. Rev.* **D52**, 4223 (1995).

[14] G. Jungman, M. Kamionkowski, *Phys. Rev.* **D49**, 2316 (1994).

[15] D.J.Thomson *et al. Astrophys. J. Suppl.* **86**, 629 (1993).

[16] S. Ahlen *et al.*, *Astrophys. J.* **260**, 20 (1982).