The AMS Experiment on the International Space Station

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AMS-02 is the main phase of the Alpha Magnetic Spectrometer experiment and is to be installed on the International Space Station in 2004 for a three-year exposure. The motivations and capabilities of AMS-02 will be reviewed.

1. Introduction

The Alpha Magnetic Spectrometer (AMS) is a charged particle in space, with a main goal of studying cosmic rays with energies up to TeV. The basic idea is simple: a high dipole magnetic field allows momentum and charge sign measurements in a precision tracker. Several sub-detectors, including time-of-flight scintillator counters, a transition radiator detector, a ring-imaging Cherenkov detector and an electromagnetic calorimeter provide additional and redundant information to identify particle types and improve the measurements.

2. Physics Motivations

Some physics motivations for studying the composition and spectra of cosmic rays above the atmosphere are given below.

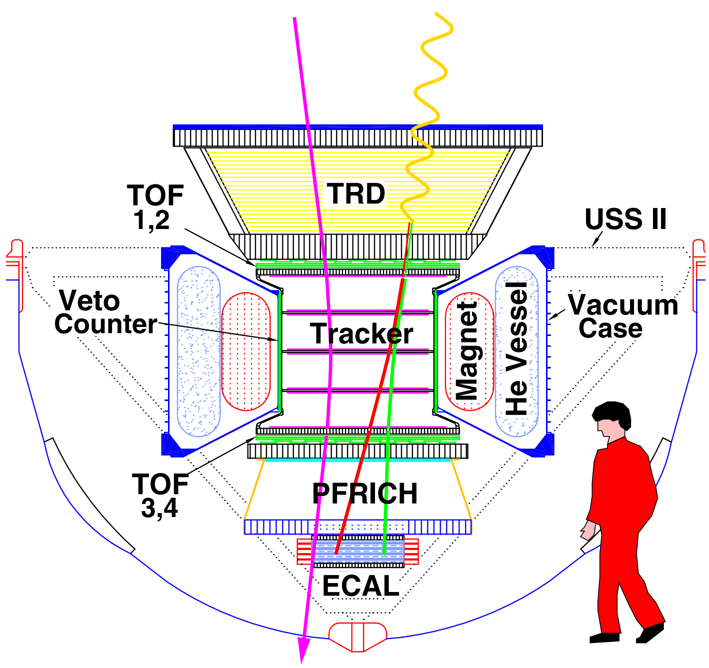

Figure 1: The AMS detector, shown in the Space Shuttle payload bay.

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Search for primordial antimatter. The apparent asymmetry between matter and antimatter is a long-standing mystery of cosmology. A possible solution to the puzzle is a universe which does in fact contain distant domains of antimatter. Even for an asymmetric universe, small nearby pockets of antimatter created by an early phase transition are not ruled out. A smoking-gun signature of primordial antimatter would be antinuclei such as $\overline{\mathrm{He}}$ (or heavier elements) observed above the atmosphere.

Indirect search for SUSY dark matter. Another long-standing puzzle is the nature of the dark matter of the universe; some sort of non-baryonic dark matter is now thought to make up to ~30% of the critical density of the universe. Neutralinos (χ), neutral particles predicted by supersymmetric theories, are prime candidates. If neutralinos comprise the our galaxy's dark halo, they may annihilate, with antimatter ($\bar{p}$, e^+ or γ-rays) among the direct or indirect annihilation products. Such "primary" χ annihilation antimatter could be distinguished from "secondary" antimatter produced in cosmic ray collisions by an anomalous energy spectrum. For instance, a bump in the observed e^+ spectrum at around 10 GeV/c could be the signature of $\chi\bar{\chi}$ annihilation (see e.g. [1]).

Cosmic Ray Propagation. A precision, high-statistics measurement of the ^{10}Be to ^{9}Be ratio in the cosmic ray flux, and its energy dependence, would be a powerful method of distinguishing between Galactic cosmic ray propagation models. These isotopes are "clocks" which measure the confinement time of charged cosmic rays in the galaxy.

Exotic Particles. Exotic matter such as "strangelets" (a possibly stable state of matter consisting of u, d, and s quarks) or fractionally charged particles may manifest itself as particles with anomalous charge-to-mass ratio in a spectrometer.

The Unexpected? Finally, since high-statistics cosmic ray measurements of this type have never been made before above the atmosphere, one can never rule out the possibility of surprising new observations.

3. The AMS-01 Precursor Mission

The AMS-01 precursor experiment flew on Space Shuttle Discovery in June of 1998 for a period of 10 days, recording 100 hours of data and 10^8 particles. The orbit was 51.7°, and the altitude 320–390 km. The precursor mission employed a permanent Nd-Fe-B magnet with a 0.15 T field, in addition to six planes of silicon tracker, time-of-flight scintillator counters, and a threshold Cherenkov counter. This successful flight produced a number of published results. In particular the limit on the $\overline{\mathrm{He}}/\mathrm{He}$ ratio was pushed down to nearly 10^{-6} for rigidities up to 20 GV [4]. No $|Z| > 2$ nuclei were found. Unprecedented high-statistics measurements of protons [5, 8], leptons [6, 7], and helium isotopes [5] were made.

4. The AMS-02 Experiment

The AMS-02 experiment is to be installed on ISS in March 2004 for a three-year exposure. A significant upgrade with respect to AMS-01 is the superconducting magnet with a field of 0.9 T, allowing spectral measurement up to TeV energies. The acceptance of the tracker will be about 0.5 m^{2}sr. A few notes on the major AMS-02 sub-detectors are given below.

Silicon tracker: there will be eight layers of Si strip tracking planes, with a total of 196,000 channels covering 6.45 m^2. Proton rigidity resolution is 20% at 0.5 TV and He rigidity resolution is 20% at 1 TV.

Time of flight scintillator counters: four layers of scintillator counters provide time of flight (~20 picoseconds) and dE/dx information.

Transition radiation detector: there will be 20 layers of polypropylene radiator interspersed with Xe/CO_2 drift tubes to detect the resulting TR from traversing charged particles. Since transition radiation depends on the relativistic γ of the charged particle, the TRD improves p/e^+ separation with a proton rejection factor of $\sim 10^2$–10^3 up to about 300 GeV/c.

Table I AMS-02 capabilities.

Particle Type	Momentum Range (GeV/c)	Expected data collection/capability
e^-	$\sim$ 0.3–3000	10^7 events > 10 GeV/c
e^+	$\sim$ 0.3–300	4×10^6 events > 5 GeV/c
p	$\sim$ 0.3–3000	3×10^6 events > 1 TeV/c
$\bar{p}$	$\sim$ 0.3–3000	10^6 events > 5 GeV/c
$\overline{\mathrm{He}}$,$\overline{\mathrm{C}}$	$\sim$ 0.3–1500	10^9 He events
Ions A<4	$\sim$ 1–20	mass ID
A < 4 < 20	$\sim$ 1–12	mass ID
Ions Z < 20	0.3-1500	charge ID

Ring-imaging Cherenkov detector: the RICH, which is sensitive to charge and velocity, will provide nuclear isotope identification up to 13 GeV for isotopes up to carbon.

Electromagnetic calorimeter: the $15X_0$ 3D sampling lead-scintillation fiber ECAL can measure energies of γ-rays and leptons, and improve p/e^+ separation up to TeV energies, with a proton rejection factor of $\sim 10^4$.

AMS-02 will be able to do studies of e^+, e^-, p, $\bar{p}$, d, t, ^{3}He and ^{4}He with statistics three or four orders of magnitude greater than previous ones. It can search for anti-ions, such as $\overline{\mathrm{He}}$ and $\overline{\mathrm{C}}$; in particular the $\overline{\mathrm{He}}$/He sensitivity will be 1 in 10^9, giving limits some orders of magnitude beyond current ones.

The sensitivity of AMS-02 for different particle types is summarized in Table I[2].

In addition, AMS-02 may have some γ-ray sensitivity [3] in the $\sim$ 10–100 GeV range, via pair conversions in the upper layers of the detector, and shower production in the ECAL.

5. Summary

In summary, the AMS-02 experiment will measure cosmic rays with momenta between 300 MeV/c and 3 TeV/c with unprecented statistics and precision over a three-year period starting in 2004. This will allow an antihelium search with $\bar{\mathrm{H}}$e/He sensitivity of 10^{-9}, a SUSY dark matter annihilation product search, tests of cosmic ray propagation models, exotic matter searches and more.

References

[1] E. A. Baltz et al. The cosmic ray positron excess and neutralino dark matter. 2001.
[2] M. Buenard. The gamma ray detection capabilities of the alpha magnetic spectrometer. *Proceedings of the XXIV Symposium on Nuclear Physics, in Taxco, Mexico January 3-6, 2001*, 2001.
[3] R. Battiston. The gamma ray detection capabilities of the alpha magnetic spectrometer. *Astropart. Phys.*, 13:51, 2000.
[4] The AMS collaboration, J. Alcaraz *et al.* Search for antihelium in cosmic rays. *Phys. Lett. B*, 461:387, 1999.
[5] The AMS collaboration, J. Alcaraz *et al.* Cosmic protons. *Phys. Lett. B*, 490:23, 2000.
[6] The AMS collaboration, J. Alcaraz *et al.* Erratum to leptons in near earth orbit. *Phys. Lett. B*, 495:440, 2000.
[7] The AMS collaboration, J. Alcaraz *et al.* Leptons in near earth orbit. *Phys. Lett. B*, 484:10, 2000.
[8] The AMS collaboration, J. Alcaraz *et al.* Protons in near earth orbit. *Phys. Lett. B*, 472:215, 2000.