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AMS—Alpha Magnetic Spectrometer on the International Space Station

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On behalf of the AMS-02 collaboration

Abstract

The Alpha Magnetic Spectrometer (AMS) is a particle physics detector designed to measure charged cosmic ray spectra up to the TeV region, with high-energy photon detection capability up to a few hundred GeV. After the successful precursor flight on STS-91 in 1998 the detector was redesigned (AMS-02) to operate for 3 years on the International Space Station (ISS). With its large acceptance, the long flight duration and its state-of-the-art particle identification techniques, AMS-02 will increase substantially the sensitivity on antimatter and dark matter searches. In addition, AMS-02 will provide measurements of cosmic ray fluxes with unprecedentedly large statistics and over a wide kinematic range.

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1. Introduction

The Alpha Magnetic Spectrometer [1] (AMS) is a high-energy physics experiment that will be installed on the International Space Station (ISS) by the year 2007, where it will operate for a period of at least 3 years. It is a large acceptance ($\sim 0.5\,\mathrm{m}^2\,\mathrm{sr}$), superconducting magnetic spectrometer able to detect over a wide kinematic range (from a few hundred MeV up to the TeV region) singly charged particles, charged nuclei (up to iron) and γ rays. The long-term exposure in space will allow AMS to collect an unprecedentedly large data sample and to extend by orders of magnitude the sensitivity reached by previous experiments.

The future installation of AMS on the ISS has been preceded by a successful 10-days engineering test flight on board the Space Shuttle Discovery (STS-91) in June 1998, at a mean altitude of 370 km. Although the purpose of this experimental flight was to test the spectrometer design princi-

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ples, about 100 million events were collected along a total of 154 orbits inclined at 51.7°. This large statistics of data have allowed both to improve the antimatter search sensitivity to 10^{-6} and to perform a systematic study of the cosmic ray fluxes arriving on earth in the rigidity ($R \equiv pc/Z$) ranging from 0.1 to 200 GV [2]. For each detected particle or nucleus two distinct spectra were observed depending on its rigidity: a higher energy spectrum made of particles with a rigidity above the geomagnetic cutoff and a substantial second spectrum of below-cutoff particles. The galactic proton, electron, positron, helium, antiproton and deuterium spectra were accurately measured. In particular, precision measurements of the primary proton and helium fluxes are very important for correctly estimating fluxes of particles produced in the atmosphere, in particular neutrino fluxes.

The search for antimatter and the identification of the nature of dark matter are among the outstanding physics issues AMS will deal with. The amount of observed antimatter (antiprotons, positrons) is several orders of magnitude lower than the corresponding amount of matter and moreover, is essentially explained by secondary matter interactions. In addition, there is a huge discrepancy between the measured baryon–photon ratio ($n_B/n_\gamma \sim 10^{-10}$) and the value predicted by the Big Bang Nucleosynthesis model ($\sim 10^{-19}$). Although there are clues for a matter–antimatter asymmetric universe, the existence of small domains of antimatter is not excluded [3]. A large fraction of the universe is composed of non-baryonic, non-luminous matter. The quest for its nature needs a precision instrument capable of identifying different particle species such as positrons, antiprotons and photons and showing up possible anomalies in their primary spectra. The measurement of the cosmic ray abundances over both a large rigidity range (hundreds of MV up to TV) and in a broad charge interval (up to $Z \sim 26$) will largely contribute to a better understanding of cosmic ray production, acceleration and propagation mechanisms in the galaxy. Besides, the measurement by AMS of the isotopic abundances of light nuclei (up to $A \sim 10$), which are essentially of a secondary nature, will provide information about the galactic halo and the confinement time and will help to decide among different propagation models.

2. The AMS-02 detector

The AMS spectrometer capabilities have been reviewed and extended with respect to those of the STS-91 experimental flight by the inclusion of new subdetector systems and the completion of others. The AMS-02 spectrometer design includes a superconducting magnet, a Time-of-Flight (TOF) system, a Silicon Tracker, Veto Counters, a Transition Radiation Detector, an Electro-magnetic Calorimeter and a Ring Imaging Cherenkov Detector. A full view of the detector with its main components is shown in Fig. 1. Together with a larger acceptance, the new detector design extends the rigidity coverage from ~100 GV to the TV region and particle identification has been significantly improved.

The superconducting magnet [4] consists of a pair of large racetrack-shaped coils together with two series of six smaller racetrack coils distributed over the circumference in order to ensure a null magnetic moment and to reduce the magnitude of

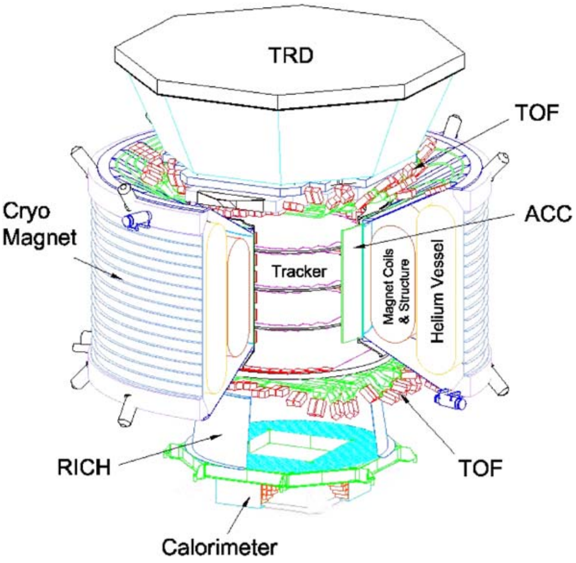

Fig. 1. Full view of the AMS Spectrometer.

the stray field outside the magnet. The coils are situated inside a vacuum case and operated at 1.8 K with superfluid helium. The magnet provides a magnetic field reaching 0.8 T in the center, corresponding to slightly more than six times the value of the AMS-01 permanent magnet.

The tracking system [5] is made of double-sided silicon sensors (~2500) arranged in eight layers placed inside the magnet and on a total of 192 ladders. The distance between the outermost layers is 1 m. The position of the charged particles crossing the tracker layers is measured with a precision of ~10 μm along the bending plane and ~30 μm on the transverse direction. With a bending power (BL^2) of around 0.9 T m^2, particle rigidity is measured with an accuracy better than 2% up to 20 GV and the maximal detectable rigidity is around 1 TV.

The TOF system [6] is made of four scintillator planes placed at the magnet end-caps and will provide a fast trigger within 200 ns, charge and velocity measurements as well as information on particle incidence direction. The TOF operation in regions having very intense magnetic fields forces the use of shielded fine-mesh phototubes and the optimization of the light guides geometry. A time resolution for protons of ~140 ps is expected.

At the ends of the AMS spectrometer, there are the Transition Radiation Detector (TRD) [7] at the top and the Electromagnetic Calorimeter (ECAL) [8] at the bottom. Both these detectors contribute to discriminate leptons from hadrons. Additionally, the calorimeter gives AMS the capability to detect photons. The TRD consists of modules made of a fleece radiator 23 mm thick and straw tubes filled with a Xe/CO_2 gas mixture, arranged in 20 layers. A rejection power against protons greater than 200 for energies below 200 GeV was obtained with a prototype. The ECAL is a sampling device with a lead-scintillating fibers structure providing a three-dimensional reconstruction of the shower. The expected energy resolution is $\Delta E/E \simeq 10.6\%/\sqrt{E(\mathrm{GeV})} \oplus 2.6\%$.

The Ring Imaging Cherenkov detector (RICH) [9] will operate between the TOF and the ECAL detectors. It is a proximity focusing device with a dual radiator configuration on the top (low refractive index 1.03 aerogel and sodium fluoride) and multipixelized photomultipliers at the bottom, where Cherenkov photons are collected. A conical shaped, high-quality reflector surrounds the whole set.

Particle identification on AMS-02 relies on a very precise determination of the magnetic rigidity, energy, velocity and electric charge. The velocity of low-energy particles (up to ~1.5 GeV) is measured by the TOF detector while for kinetic energies above the radiator thresholds (0.5 GeV for sodium fluoride and 3 GeV for aerogel) the RICH will provide very accurate measurements; a target resolution of ~1% and ~0.1% for singly charged particles is expected for sodium fluoride and aerogel radiators, respectively. The electric charge is measured by the silicon tracker and TOF detectors through dE/dx sampling and by the RICH through the Cherenkov signal integration. Charge identification at least up to iron is expected. Fig. 2 shows the reconstructed charge peaks from a RICH prototype with an aerogel radiator, using fragmented lead ions of 20 GeV per nucleon.

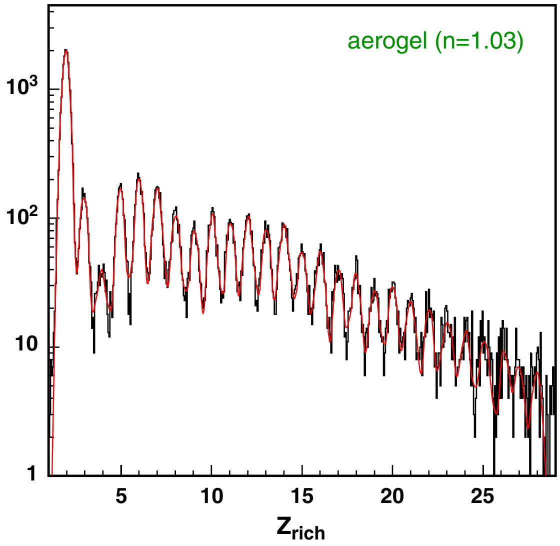

Fig. 2. Reconstructed charge peaks obtained with the Ring Imaging Cherenkov detector prototype of AMS-02.

3. Physics prospects

The search for cosmological antimatter is one of the main physics issues for the AMS experiment. Different from singly charged antimatter, antiprotons and positrons, which are produced through the propagation of dominant cosmic ray components, antinuclei ($Z \geqslant 2$) production from matter collisions is strongly suppressed. Therefore, the detection of a single antinucleus ($Z \geqslant 2$) would be a major indication for the existence of antimatter clusters somewhere in the universe. Over 3 years of data taking AMS will gather more than 10^9 helium events up to a few TV of rigidity.

Supersymmetry provides a possible framework to solve the dark-matter puzzle. The lightest supersymmetric particle, the neutralino (χ), is a natural candidate for non-baryonic matter in the galactic halo. Neutralino annihilations enhanced by the halo's clumpiness can provide detectable anomalies in the spectra of antiprotons, positrons, antideuterons and photons. For instance, AMS will detect positrons up to around 400 GeV, collecting around 50 e^+/year/GeV with an energy of ~50 GeV. Background, essentially composed of misidentified protons ($\Phi_p/\Phi_e^+ \sim 10^3$) and electrons ($\Phi_e^-/\Phi_e^+ \sim 10$), is rejected by factors of 10^6 and 10^4, respectively.

The measurement of the elemental and isotopic fluxes of cosmic rays is fundamental for a better understanding of the creation, acceleration and propagation of cosmic rays. Primary cosmic ray abundances will provide information about the sources, once propagation effects have been evaluated and taken into account. Secondary cosmic rays such as lithium, beryllium and boron nuclei, which result from CNO spallation, allow to determine the quantity of matter traversed by cosmic rays. The study of radioactive secondaries such as ^{10}Be provide information about the confinement time of cosmic rays in the galaxy. Over 1 year of data taking AMS will collect around 10^5 ^{10}Be events in the energy range $0.15 \lesssim E \lesssim 10$ GeV/nuc. Fig. 3 shows a compilation of ^{10}Be/^{9}Be measurements together with the expected AMS sensitivity based on the statistics of 1 year and taking into account only the RICH measurements.

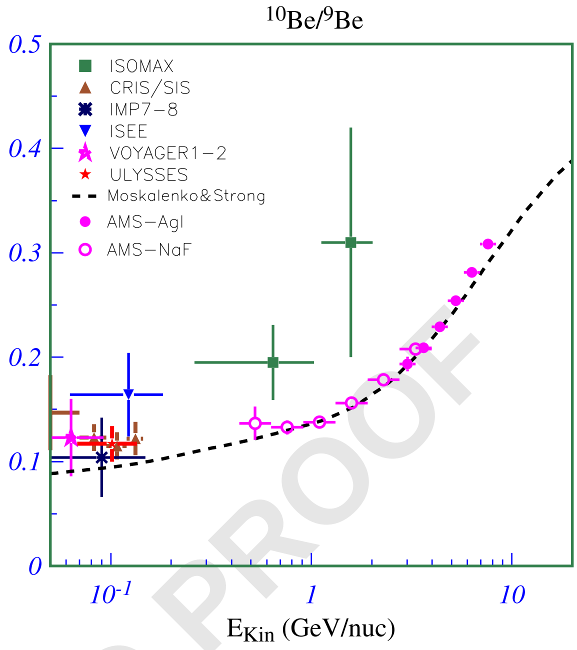

Fig. 3. AMS-02 expected sensitivity on ^{10}Be/^{9}Be measurements together with previous measurements and the simulated model (dashed curve) from [10].

4. Conclusions

AMS is a magnetic spectrometer designed for antimatter and dark-matter searches and for elemental and isotopic measurements of cosmic rays. Its installation on the International Space Station is scheduled for 2007, where it will operate for at least three years. The long-term exposure in space will allow AMS to collect an unprecedentedly large amount of data and to extend by orders of magnitude the sensitivity reached by previous experiments on various physics issues.

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