Cosmic ray and gamma astrophysics with the AMS-02 experiment

Sonia Natale
DPNC - University of Geneva, 24, Quai Ernest-Ansermet , 1211 Genève 4 - Switzerland
E-mail: Sonia.Natale@cern.ch

Abstract. The Alpha Magnetic Spectrometer (AMS) is a particle physics detector designed to operate on the International Space Station (ISS) for a minimum period of three years. The aim of AMS is the direct detection of charged particles in the rigidity range from 0.5 GeV to few TeV to perform high statistics studies of cosmic rays in space and a search for antimatter and dark matter. AMS will provide precise gamma measurements in the GeV range. In addition, the good angular resolution and identification capabilities of the detector will allow clean studies of galactic and extra-galactic sources, the diffuse gamma background and gamma ray bursts.

1. AMS detector
AMS is a magnetic spectrometer equipped with several sub-detectors devoted to identification and precise measurement of particles in the GeV-TeV energy range. The detector strategy is based on redundant measurements which ensure a proper background rejection for rare signal searches. In addition, the design has to meet the specific constraints imposed by the launch and operational environment conditions [1]. The main components of the detector are:

- A cryogenic super-conducting magnet that consists of an arrangement of two Helmholtz coils and two series of six racetrack coils cooled by superfluid helium at 1.8 K (BL² = 0.9 Tm²).
- A Silicon Tracker detector made of eight double-sided micro-strip silicon sensor layers, six of them located inside the magnet, to localize charged particles. Particle rigidity is measured with an accuracy better than 2% up to 10 GV.
- A time of flight system (ToF) consisting of two double planes of scintillator counters which is able to reach a precision in time of about 120 ps.
- A transition radiation detector (TRD) which detects the transition radiation light produced by ultra-relativistic particles in a set of polypropylene fiber radiators by means of 5248 straw tubes filled with Xe/CO₂ mixture. It provides lepton-hadron separation (≥ 100 : 1) up to 300 GeV.
- A Ring Imaging Cerenkov counter (RICH) which measures the velocity of relativistic particles from the opening angle of the Cerenkov cone. It consists of a dual radiator (silica aerogel and NaF) and a detection plane instrumented with multi-anode photo-multipliers. Typical accuracy is σ(β)/β ∼ 10⁻³ for Z= 1 and σ(β)/β ∼ 10⁻⁴ for Z> 10.
- An electromagnetic calorimeter (ECAL) that consists of layers of lead foils with glued scintillating fibers resulting into a total radiation depth of 16X₀ for shower development.
Figure 1. Left plot: projected AMS-02 limits on antihelium-helium flux ratio compared with previous measurements. Right plot: projected AMS-02 one year measurements of the $^{10}\text{Be} : ^9\text{Be}$ ratio energy dependence compared with a diffusion model prediction (solid line) together with the results from satellite measurements.

provides further ($10^3 : 1$) lepton discrimination power and an energy resolution better than 3\% above 10 GeV.

The charge is determined by a combined measurement of the deposited energy in the ToF and Silicon Tracker planes and by the Cerenkov light detected in the RICH from $Z = 1$ to $Z \leq 26$ with very small charge confusion.

2. Physics Goals and Predictions

The AMS program includes a search for cosmic antimatter, a search for dark matter, precision measurements on the relative abundance of different nuclei and isotopes of primary cosmic rays, as well as measurements of high-energy gamma rays. Furthermore, it has been recently estimated that AMS will allow a direct test of the strange quark matter hypothesis [1].

2.1. Antimatter

The search for antimatter is motivated by the conjecture that at the time of the Big Bang equal amounts of matter and antimatter were produced. Nowadays only a small flux of anti-protons is observed in the cosmic rays, compatible with secondary production from the interaction of primary cosmic rays with the interstellar medium: the antiproton to proton ratio is $10^{-4}$ to $10^{-5}$ in the energy range between a few hundred MeV and a few tens of GeV. Furthermore the baryon-to-photon ratio in the Universe is about $10^{-10}$, while a value of the order of $10^{-19}$ would be expected from a symmetric Universe. With an expected effective statistics of more than $10^9$ events collected by AMS-02 in three years, an upper limit of $10^{-9}$ would be set for the ratio antihelium/helium at the 95\% confidence level, if no antihelium nucleus were observed (Figure 1).

2.2. Dark Matter

There is evidence for a large quantity of non-baryonic dark matter in the Universe. The lightest supersymmetric particle, the neutralino, is a good candidate to be the Weakly Interacting Massive Particle required to explain this observation. Annihilation of neutralino pairs in the galactic halo would provide good signatures in the form of anomalous production of anti-protons, positrons, or high energy gamma rays [2].
2.3. Cosmic Rays

Precise measurements of the fluxes of H, He and other nuclei that are believed to have a primary origin (C, N, O) provide information about the acceleration mechanisms of cosmic rays. The detection of secondary nuclei, such as Li, $^9$Be, B (absent at the cosmic ray sources), produced by the primaries through their path in the interstellar medium, provides information about the propagation of the cosmic rays in the galaxy. The ratio of unstable to stable nuclei can be used to determine the confinement time of cosmic rays in the galaxy. In particular AMS will be able to separate $^{10}$Be, with $t_{1/2} = 1.6$ Myr, from the stable $^9$Be isotope (Figure 1).

2.4. High-energy Gamma Rays

To measure high energy gamma rays, two complementary methods can be applied in AMS. The “conversion mode” consists in the identification and reconstruction of positron-electron pairs from photons converting in the material upstream of the Silicon Tracker. The “calorimetric mode” is based on the detection of photons in the electromagnetic calorimeter. Both modes are characterized by different energy and angular resolutions as is shown in Figure 2. Many known and unknown sources will be in the field of view for a long-term observation. Though optimized for detection of charged cosmic rays, AMS will also collect competitive and complementary data on high energy gamma rays. It is sensitive to photons in the poorly explored range from 1 GeV up to a few hundred GeV. Due to its large acceptance it will play an important role in the squad of gamma ray observatories already placed or planned to be placed in orbit in the near future. A possible AMS-02 measurement is shown in Figure 2. AMS-02 data on the spectrum of Vela pulsar in the energy range from 5 to 50 GeV, where there is not enough statistics from EGRET, will allow to distinguish between two models of gamma ray emission [3].

References

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