IL NUOVO CIMENTO Vol. 34 C, N. 3 Maggio-Giugno 2011
DOI 10.1393/ncc/i2011-10853-6

Colloquia: Scineghe2010

The AMS-02 experiment status

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(ricevuto il 25 Febbraio 2011; pubblicato online il 26 Aprile 2011)

Summary. — The Alpha Magnetic Spectrometer (AMS) is a high-energy physics experiment built to operate in space. The prototype of the AMS detector was AMS-01, flown in 1998 on-board of the space shuttle Discovery (mission STS-91). Starting from the experience acquired in the high successful AMS-01 mission the detector AMS-02 has been designed improving the AMS-01 energetic range, geometric acceptance and particle identification capabilities. In 2010 the AMS-02 detector has been validated for the space/scientific operations by means of a wide test campaign (including beam tests, TVT test and EMI test). A major change in the design of AMS-02 has been decided after the thermo-vacuum test to extend as much as possible the endurance of the experiment, profiting also of the extended endurance of the International Space Station (ISS) program toward 2020. The final AMS-02 configuration has been integrated during summer 2010, then tested on the H8 beam-line at CERN, and finally delivered to the launch site (Kennedy Space Center, Florida) at the end of August. AMS-02 is planned to be installed on the International Space Station in 2011 by the space shuttle Endeavour (mission STS-134).

PACS 07.87.+v – Spaceborne and space research instruments, apparatus, and components (satellites, space vehicles, etc.).
PACS 95.55.Vj – Neutrino, muon, pion, and other elementary particle detectors; cosmic ray detectors.
PACS 29.30.Aj – Charged-particle spectrometers: electric and magnetic.

1. – The AMS scientific goals

The AMS project is devoted to the precise positive-to-negative particle charge distinction up to high energies, for the accurate discrimination between matter and antimatter. Thanks to the high particle identification power and the wide measurement energetic range, AMS will be able to make a precise measurement of the absolute fluxes and relative abundances of almost all the charged cosmic-rays (CRs) species over a wide energetic range, from fractions of GeV to few TeV.

(*) http://www.ams02.org/partners/who-is-who-2/.

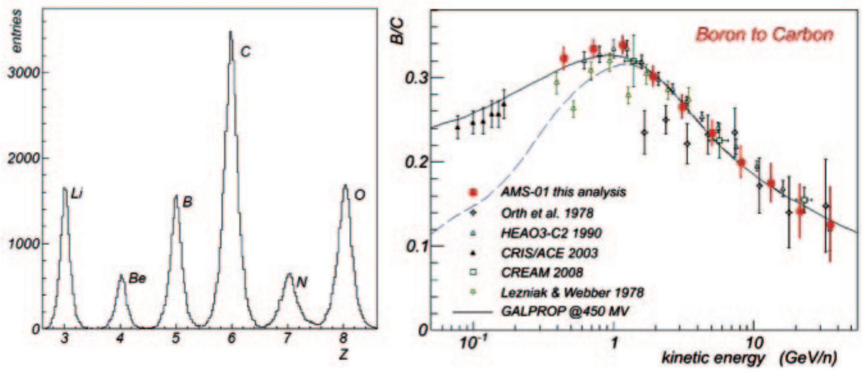

Fig. 1. – On the left the AMS-01Tracker measured charge spectrum: a distinction of less than 0.15 charge units has been measured. On the left the boron-to-carbon ratio measured by AMS-01 [6].

The prototype of AMS, AMS-01 [1], flew in 1998 on-board of the space shuttle Discovery. In the 10 days of data acquisition AMS-01 was able to set new limits on the primordial antimatter searches [2], to precisely measure many CRs spectra species such as protons, electrons, positrons and nuclei [3-6], revealing also new details of the dynamics of secondary particles trapped in the geomagnetic field [7, 8]. As an example of the capabilities of AMS-01, in fig. 1 the measured charge spectrum and the boron-to-carbon ratio are shown. The B/C ratio is one of the most sensible observables of the CRs diffusion in our Galaxy. The AMS-01 measurement is able to give an important constraint on the existing propagation models. This measurement will be easily extended in the energetic range (up to TeV) and in statistics (up to 10^7 carbons) by AMS-02.

The major improvements of the AMS-02 design are: a) the extended period of data taking—indeed AMS-02 will be installed on the International Space Station in 2011 and will operate for more than 10 years; b) the collection area a factor 5 bigger; c) a wider momentum range measurement, from fractions of GeV up to few TeV; d) the improved particle identification capabilities, in terms of chemical separation (up to $Z = 26$) and proton/electron separation (a 10^6 rejection is expected). Thanks to the extended exposure time and the wide geometrical acceptance of about $0.5\,\mathrm{m}^2\,\mathrm{sr}$, AMS-02 will be able to collect more than 10^{10} particles, an amount of statistics never covered by previous experiments. Such a big statistic will have a two-fold implication. On one side, the spectral shape of many CRs species will be measured with high accuracy, even in the case of the most rare components of CRs as e^+ or $\overline{\mathrm{p}}$. On the other side, the high statistics permits an extended search of primordial antimatter such as $\overline{\mathrm{He}}$, never found before. The upper limit on the $\overline{\mathrm{He}}$ flux with respect to He flux is given by the the BESS experiment as $6.8 \cdot 10^{-7}$ [9]. This limit could be extended from AMS-02 to $\sim 10^{-9}$ as presented in fig. 2. The detection of a never seen presence of anti-nuclei in GCRs, as a nucleus of $\overline{\mathrm{He}}$, can be a direct proof of the existence of antimatter domains, since the probability of a spallation production of $\overline{\mathrm{He}}$ is very low [10].

The accurate distinction between hadrons and leptons, realized by two independent techniques, *i.e.* transition radiation and electromagnetic calorimetry, will give the rejection power needed to distinguish $\overline{\mathrm{p}}$ from e^-, $\overline{\mathrm{p}}/\mathrm{e}^- \sim O(10^{-2})$ and e^+ from p,

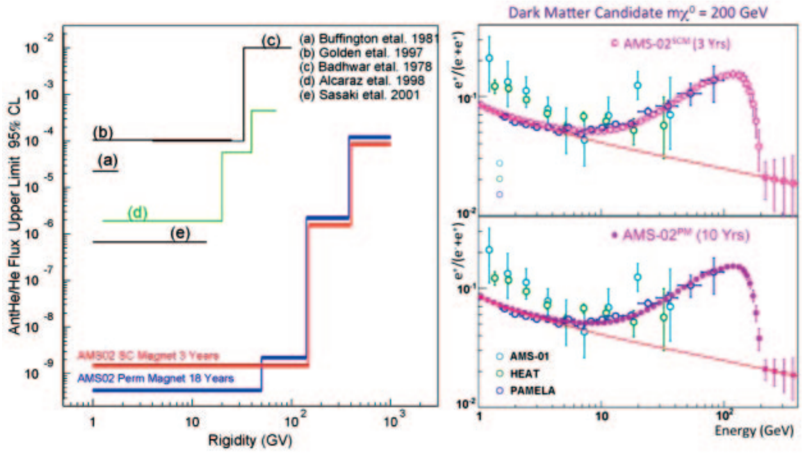

Fig. 2. – In these plots are compared the measured antihelia sensibility upper limit (left) [13-15, 2, 9] and the positron spectrum (right) [12, 11, 5] compared with the AMS-02 new design expected performances. The AMS02 first design performances were reported as a comparison.

p/e$^+$ $\sim O(10^{-4})$ up to the TeV scale. The detailed separation of rare components of CRs as e$^+$ and $\overline{\mathrm{p}}$ could reveal possible traces of Dark Matter annihilation and contribute to solve the puzzle of the PAMELA [11] positron data, a problem also pointed out in the past by HEAT [12] and AMS-01 [5] and reported in fig. 2 compared to the expected AMS-02 performances.

Among the most abundant cosmic-rays species, as protons and electrons, heavy hadrons are of the fundamental importance for the understanding of the cosmic rays propagation, as for example the already discussed B/C ratio. AMS-02 will be able to distinguish charges up to Fe ($Z = 26$) with a very little contamination thanks to the 14 independent measurements of charge on different sub-detectors.

2. – The AMS-02 detection system

AMS-02 has been designed and built taking advantages from the experience of the high-energy particle physics experiments. The main structural component of AMS-02 is Permanent Magnet (PM), a cylindrical shaped volume of diameter and height of about 1 m, able to generate a field of about ~ 0.15 T almost uniform along the X-axis inside the cylinder volume. Seven layers of double-sided silicon detectors inside the magnet bore together with 2 detection layers placed at the edges of AMS (see fig. 3), measure the coordinate of the points used to reconstruct the track with a resolution of 10 (30) μm for $Z = 1$ particles [16]. From the curved trajectory the sign of the particle can be detected and the rigidity ($R = pc/Ze$) measured. The magnetic spectrometer is able to measure rigidities from fractions of GVs to few TVs, with a resolution of $\Delta R/R \sim 8\%$ in the 10 GV region.

A system based on scintillating counters encloses the inner Tracker. Two pairs of scintillator planes, placed on the top and at the bottom of the spectrometer, constitute the Time-of-Flight system (TOF), which provides the charged particle fast trigger of the whole experiment and measures the velocity of the impinging particles with a resolution of $\Delta\beta/\beta \sim 3\%$. The ToF system is designed to perform a rejection of 10^9 among downward-

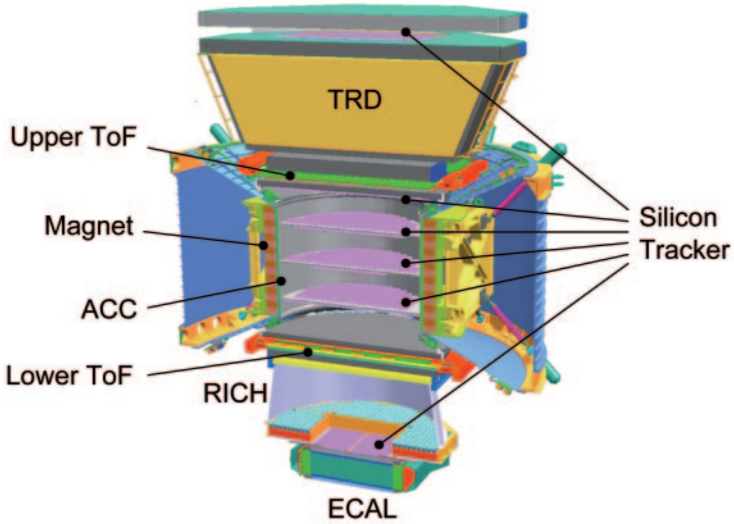

Fig. 3. – A CAD sketch of the AMS-02 final design.

going and upward-going (albedo) particles [17]. Veto for high-inclination particles is given by the Anti-Coincidence Counter (ACC) system, a set of 16 scintillator counters placed around the inner tracker in a cylindrical geometry.

AMS-02 is able to reconstruct the mass of the particle from the combination of the rigidity and velocity measurement ($m = R\sqrt{1-\beta^2}/\beta$). The mass identification is improved by the use of a high-precision velocity measurement detector, the Ring Image Cherenkov (RICH). The RICH is placed just below the PM and performs a very precise measurement of the particle velocity of $\Delta\beta/\beta \sim 0.1\%$ for protons and $\sim 0.01\%$ for ions [18].

The spectrometer particle identification capabilities are increased by the add of two additional detectors able to perform the hadron-to-lepton separation to a level of 1 particle over 10^6. The Transition Radiation Detector (TRD) placed on top of the AMS detector is able to reject e/p of a factor 10^{-3} up to a kinetic energy of about $\sim 500\,\mathrm{GeV}$ [19]. At such energy protons start to emit transition radiation as the ultra-relativistic electrons and the distinction starts to be less effective. The Electromagnetic Calorimeter (ECAL), a 17 radiation length calorimeter, placed at the bottom of AMS is able to measure the energy of electromagnetic particles ($e^{\pm}$, γ) with a resolution of $\sigma_E/E = (10/\sqrt(E)+2)\%$ up to few TeV. The ECAL is able to distinguish hadrons and leptons of a factor 10^{-4} [20].

AMS-02 has a powerful chemical separation up to Fe ($Z = 26$) realized by the combined measurement of the energy deposition on the 9 Silicon Tracker layers and 4 ToF planes together with the RICH single measurement from the number of photons in the Cherenkov ring [21, 17, 18].

The AMS-02 detector has also γ-rays astronomy capabilities. The γ are detectable in two ways: by the simultaneous measurement of two tracks, one negative and one positive, produced by the $\gamma\, e^+/e^-$ pair conversion in the material over the Tracker; or by an electromagnetic shower initiated in the electromagnetic calorimeter (in this case ECAL is used as a stand-alone detector). A star tracker gives the orientation of the detector with respect to the fixed stars with an accuracy of few arc seconds.

3. – The AMS-02 design change

The first AMS-02 design involved the use of a Superconducting Magnet (SCM) instead of the PM. The SCM has an operating temperature of 2.8 K maintained by a vessel of 2500 l of superfluid cryogenic helium. The unavoidable heat load from external world to the cryogenic vessel would have boiled off the superfluid helium after a nominal endurance of 3 years, determining the overall endurance of the magnetic system [22]. In April 2010 the fully integrated AMS-02 in SCM configuration was tested in a thermo-vacuum test in ESTEC and the expected endurance of the cryogenic system was estimated to be 22 ± 8 months. Due to this measurement and the extension of the ISS mission endurance of 10 years [23], the AMS Collaboration decided to exchange the SCM with the AMS-01 Permanent Magnet in order to fully profit the wider time window, thus increasing the AMS collectable statistics.

Since the AMS-02 subsystems were originally designed to support both the PM and the SCM options, the two vacuum cases structures are mechanically identical and integration has been very similar. The only drawback in using the PM consists in a reduced magnetic field strength, namely 5 times weaker than the SCM one. This means that charged particles of the same energy are bent less by the PM field. To cope with this fact, an optimization of the geometry of the AMS Silicon Tracker has been implemented. The optimization of the Silicon Tracker has been obtained adding the 2 external planes at the beginning and at the end of the detector, extending the lever arm from ~ 1 m to ~ 3 m. These two planes are built reshuffling some already existing silicon detectors and no new electronics was needed. An implication of the new Tracker design is the reduction of the geometrical acceptance by a factor ~ 3. The expected improvement in statistics due to the extended lifetime will balance and exceed the problem.

To promptly check the main characteristics of the new design a beam test was performed in August 2010 after the full integration. The 20 days test beam campaign was mainly focused on the Tracker system rigidity measurement performances, since this is the system most affected by the new design. The system was illuminated by proton, pions, electrons and positron beams of various momenta (from 20 GeV/c to 400 GeV/c). The preliminary analyses of beam test data confirm the expected momentum range of the Tracker system.

In fig. 2 we present the expected results comparing the AMS-02 SCM configuration and PM configuration for the two most important physics goals of AMS, the search of the $\overline{\mathrm{He}}$ and the measurement of the positron-over-electron ratio, the most promising channel for the Dark Matter indirect measurement.

4. – Conclusion

The AMS-02 experiment is ready and fully tested for the scientific/space application. It will be launched in 2011 with the space shuttle Endeavour (mission STS-134) and then installed on the ISS. Due to the large geometric acceptance and the long period of data taking AMS-02 will profit of a large statistics collection power (more than 10^{10} particles). AMS-02 is expected to measure with high accuracy the most abundant cosmic-rays species such as protons, electrons and light ions improving the knowledge of CRs origin, acceleration and propagation mechanism and reducing the astrophysical uncertainties on diffusion models. The comparison between more realistic predictions of fluxes for the less abundant CRs species, $\overline{\mathrm{p}}$ and e^+, and their accurate direct measurements with AMS-02 could reveal the presence of structures due to exotic contributions as Dark Matter WIMP annihilation signatures.

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