The AMS-02 experiment on the ISS: status and perspectives

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***Abstract*. The Alpha Magnetic Spectrometer 02 is a large acceptance ($\sim 0.5\, m^2 sr$) particle physics detector designed to perform an accurate measurement of the charged cosmic rays fluxes for rigidities ranging from 500 MV to 4 TV.**

AMS-02 is currently being integrated at CERN and it is scheduled to be installed on the International Space Station during a Space Shuttle mission in 2010.

***Keywords*: Spectrometer, anti-matter, dark-matter**

I. Introduction

AMS-02 is a large acceptance ($\sim 0.5\, m^2 sr$) magnetic spectrometer designed to measure the cosmic rays fluxes in the rigidity range from 0.5 GV to 4 TV.

The AMS-02 launch on the Space Shuttle is scheduled for September 2010 and the detector is now in its final integration phase at CERN. After a beam test, to be performed in fall 2009 at CERN, the fully assembled AMS-02 will be moved to the Netherlands to undergo the final thermo-vacuum qualification test in the space simulator at the ESA/ESTEC facility. In the beginning of 2010 it will be shipped to the NASA Kennedy Space Center, ready for launch.

Foreseen mission duration is at least three years, limited by the liquid helium reserve used to cool the superconducting magnet. When the liquid helium will be consumed and the magnet will be off, AMS-02 will be still capable to use the Electromagnetic Calorimeter (ECAL), the Transition Radiation Detector (TRD), the Ring Image Cerenkov (RICH) and the Time Of Flight (TOF) detectors for the energy measurement.

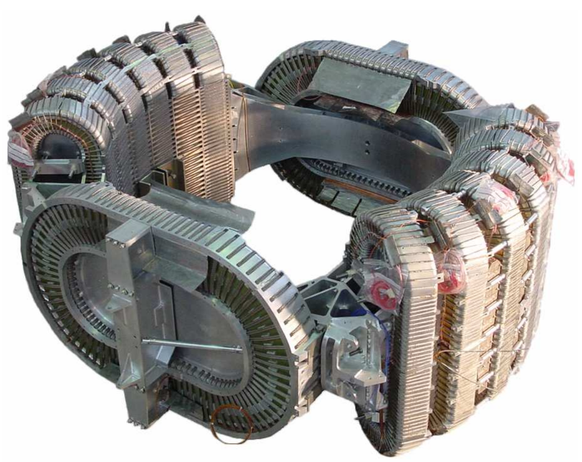

Fig. 1. The AMS-02 superconducting magnet.

AMS-01 successfully flew in June 1998 aboard the Space Shuttle Discovery (NASA, STS-91 flight) for ten days. The detector had been operational for about 180 hours collecting more than one hundred million cosmic ray events which led to signicant results (ref. [1] to [6]).

II. The AMS-02 detector

The most challenging part of AMS-02 is the superconducting magnet which will be the first one flown in the Space.

The magnetic field has a dipole structure and it is pretty uniform (0.8 T) within the volume determined by the magnet toroidal structure but of very small intensity out of it, the overall magnetic moment is also very small. These features, which are required to operate on the ISS, are achieved by the peculiar geometry of the coils (fig. 1): two main coils facing each other are producing the main component of the dipolar field while the others, called ”racetrack” coils, are shaping the field to the desired features.

The magnet coils and an helium vessel are held within a toroidal enclosure called the vacuum case (VC). The VC is the main mechanical structure of AMS-02, the subdetectors are attached to it either directly either through aluminum beams, figure 2 present a schematic view of the detector, figure 6 shows a photo of the pre-integration.

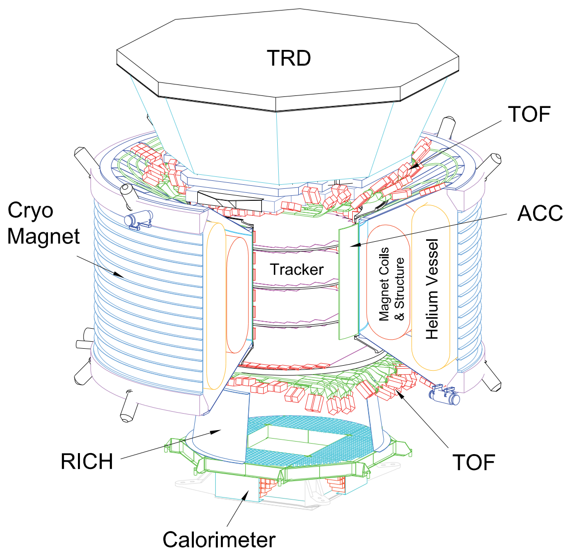

Fig. 2. Scheme of the AMS-02 detector.

The Silicon Tracker is made of five circular planes hosted into the VC bore. The planes are instrumented with silicon microstrip detectors to perform accurate position measurements, the three internal planes are equipped both sides and in total there are eight layers of silicon detectors.

The silicon tracker is capable to measure the particle trajectory within the magnetic field with a resolution better than 12(30) μm in the bending(not-bending) coordinate for $Z = 1$ particles and 5(25) μm for particles with $Z \geq 2$. Using up to eight measures of the energy deposition in the silicon, the tracker is also able to recognize the particle charge up to Iron [7].

The internal walls of the VC bore are covered by scintillator pads (Anti Coincidence Counters) used to veto the particles entering from the sides.

At the top and at the bottom of the VC, a set of scintillator pads is measuring the time at which a particle cross the spectrometer with a resolution of $150\,ps$ $(Z = 1)$ and $60\,ps$ $(Z \geq 4)$, allowing for a time of flight measurement over a base of about 1 m. The scintillators pads are disposed orthogonally on two layers both above and below the tracker providing also a rough measurement of the particle coordinate and direction.

Placed on top of AMS-02, the Transition Radiation Detector is made of a fleece material interleaved by 20 planes of straw tubes of about 6 mm in diameter. The planes are disposed along the X and Y axis the way the TRD can act also as a tracker with a resolution of the size of the straw tube. By the repeated measurement of the transition radiation the TRD is capable to separate electrons and protons with a rejection power of 10^3 up to 400 GeV.

Below the VC a Ring Image Cerenkov detector (RICH) is made of a layer of aerogel radiator, a conic mirror and a photomultiplier detector array. The reconstructed Cerenkov ring allow for a precise measurement of the particle velocity $\delta\beta/\beta \simeq 0.1\%$ and $\delta\beta/\beta \leq 0.03\%$ for $Z = 1$ and $Z > 1$ particles respectively. The high resolution β measurement of the RICH will allow for the isotope identification up to kinetic energies of several tens of GeV/n. The signal intensity allow for a precise measurement of the particle charge up to Iron.

At the bottom of the AMS-02 detector there is an imaging electromagnetic calorimeter (ECAL) made as a pancake of lead and scintillating fibers. The ECAL is $16.7\,X_0$ thick and covers about the 25% of the spectrometer acceptance, its energy resolution is:

$$\frac{\delta E}{E} = \frac{10.2\%}{\sqrt{E(GeV)}} \oplus 1.6\%$$

and its rejection power proton versus electron is better than 10^3 up to TeV region. The ECAL can also operate as standalone gamma detector with an angular resolution of about $\sim 1°$.

Gamma rays that convert into a e^+e^- in the upper part of AMS-02 can be detected in the Tracker [8]

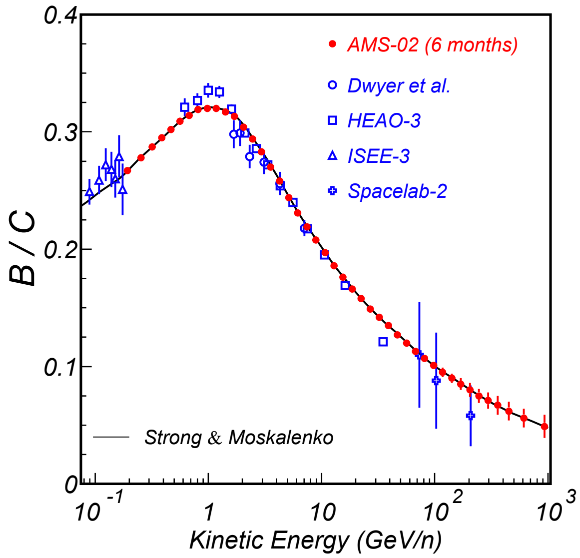

Fig. 3. Available measurements of the B/C flux ratio and the expected AMS-02 resolution, statistical errors only.

III. AMS-02 PHYSICS GOALS

The main goal of the AMS-02 experiment is to search for anti-nuclei of primordial origin into the cosmic rays flux. The detector design allows to reject almost all the background to an anti-Helium nucleus signal, the large acceptance and the long duration of the mission will allow for large statistic and hence for a very high sensitivity to the presence of anti-nuclei in the cosmic rays flux.

During its three years mission onboard the International Space Station (ISS) AMS will collect and unprecedented statistics of cosmic rays fluxes, it is foreseen to collect $\sim 10^{10}$ charged particles in the energy range from 500 MeV/n to few TeV/n. The most aboundant ion samples (Carbon, Oxygen and Nitrogen) will count for $10^{6\div 7}$ events with kinetic energies above 10 GeV/n, an energetic interval where present measurements suffer from limitations coming from short exposure time, intrinsic instrumental limitations and restricted energy range [9] [10] [11].

Figure 3 reports a simulation of the AMS-02 sensitivity to the Boron over Carbon ratio with a statistic corresponding to six month of data taking. The comparison with existing data show how the AMS-02 contribution will be relevant. It is worth to cite that preliminary results about a new analysis of AMS-01 data on the B/C ratio have been presented at this conference [12].

The accurate measurement of the cosmic rays chemical and isotopic composition will provide better constraints to the theoretical models on the cosmic rays origin and propagation through the galaxy. Once fully exploited in a simulation code as for example GALPROP [13] it will be possible to produce more accurate predictions on light anti-matter fluxes produced in the interstellar medium.

The third and nowadays most interesting goal of AMS

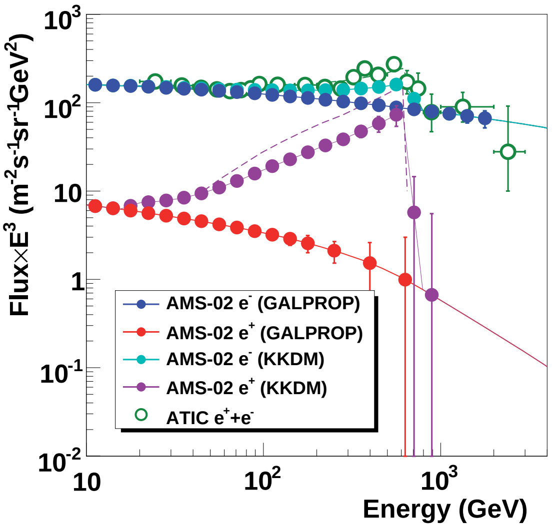

Fig. 4. The ATIC all electron data [14] compared to a model of Dark Matter made of Kaluza-Klein particles [15], AMS-02 foreseen sensitivity for positron and electron spectra is also shown.

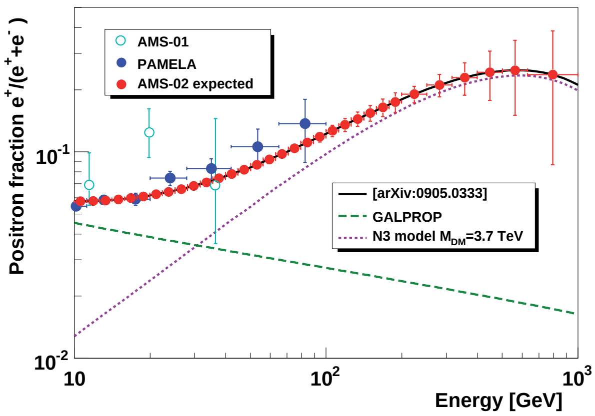

Fig. 5. The PAMELA $e^+/(e^+ + e^-)$ data [17] compared to AMS-01 data [1], AMS-02 foreseen sensitivity for the ratio measurement in the case of a M_{DM} =3.7 TeV is also shown.

is the search for signatures of dark matter annihilations by the study of the rare cosmic rays components, as anti-protons and positrons, and of the gamma rays flux.

The Dark Matter counts for about the 30% of the energy density of the Universe, all the recent data point to weak interacting massive neutral particle (WIMP) as its main component. These particles produced during the evolution of the Universe should have decoupled from the rest of the matter and should constitute the galactic halos. Even though WIMPs are stable particle, they may undergo an annihilation reaction that produce ordinary particles, among which protons, anti-protons, electrons and positrons. These products of the annihilation reaction may be accelerated and then can contribute to the cosmic rays fluxes. Such a contribution is foreseen to be negligible for protons and electrons while could be significant for anti-protons and anti-electrons. The Dark Matter signature will then appear as a deviation of the anti-proton and/or positron fluxes from the expected power law spectrum.

Recent measurement from the ATIC [14] collaboration shows some deformation in the overall electron $(e^+ + e^-)$ spectrum, which may be compatible with a Dark Matter made of a Kaluza-Klein particle [15]. Figure 4 shows the sensitivity of AMS-02 to such a Dark Matter signal. Being able to distinguish positron and electrons AMS-02 should be also able to identify without ambiguity the large deformation of the positron spectrum as well as the smaller one on the electron spectrum.

The FERMI collaboration also published recently [16] a quite precise measurement of the overall electron spectrum which seems not compatible with the ATIC measurements.

The PAMELA experiment, which is very similar to AMS-02 although with an acceptance $\sim$ 200 times smaller, also published [17] recently a measurement of the positron over all electrons ratio, which is quite different from what expected (fig. 5).

As a consequence of the large errors and of the limited energy range of those measurements their interpretation is difficult and controversial, the large statistic of AMS-02 will allow to confirm the presence of a deformation and to carefully describe its features. In figure 5 we report the foreseen AMS-02 measurement for the case of a Dark Matter made of neutralinos of mass 3.7 TeV [18], that seems compatible with PAMELA data.

The AMS-02 capability to measure also the anti-proton flux in a wide energy range combined with the capabilities to detect gamma-rays would help to constrain Dark Matter signatures in a multi-channel analysis approach.

IV. AMS (PRE)INTEGRATION

In the first half of the 2008 AMS-02 detector went through a pre-integration phase where all the detectors have been assembled in their final configuration on the mechanical support structure of the super-conducting magnet. This phase whereall the components have been assembled together has been essential, and gave a good opportunity to debug the electronics and the control procedures.

By the mid of April all the sub-detectors were installed and cabled, figure 6 shows a photo of the fully assembled AMS-02 detector. Starting from April a two months period of cosmic muons data taking took place. The cosmic muon data allowed to study the performance of the sub-detectors and to develop and improve the reconstruction software especially for what concerns the algorithms.

Contributions to this conference are reporting on the performace of the AMS-02 subdetector or subsystem: Tracker performance [19], Tracker Laser Alignement System [20] and TRD performance [21].

Fig. 6. The (pre) assembled AMS-02 detector.

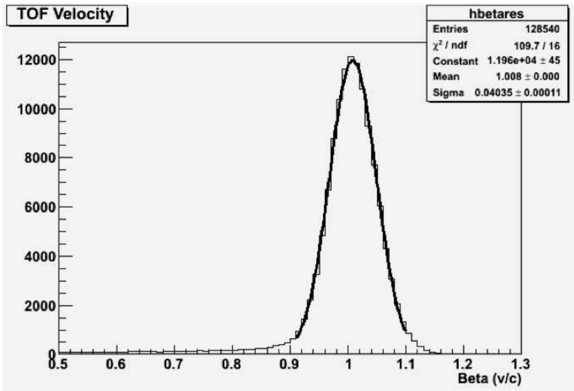

Fig. 7. The β measurement resolution of the TOF sub-detector.

As example figure 7 shows the measured β resolution of the Time Of Flight detector of 4%.

V. Conclusions

The AMS-02 detector has been finally scheduled for a launch on board the Space Shuttle in 2010, the detector is completing the integration phase and will undergo a qualification test at the ESTEC ESA facility by the end of the 2009. New cosmic rays fluxes measurement are expected to be ready few months after the launch while the full exploitation of the three year mission statistic will provide data extended to very wide energy ranges and of very high accuracy.

After the recent results about the lepton fluxes from the PAMELA and the FERMI experiments, the availability of new and accurate measures as the AMS-02 ones is more and more interesting and could lead to a final answer about the features of the lepton spectra.

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References

[1] J. Alcaraz et al., Phys. Lett. B 484, 10 (2000).
[2] J. Alcaraz et al., Phys. Lett. B 490, 27 (2000).
[3] J. Alcaraz et al., Phys. Lett. B 472, 215 (2000).
[4] J. Alcaraz et al., Phys. Lett. B 494, 193 (2000).
[5] J. Alcaraz et al., Phys. Lett. B 461, 387 (1999).
[6] M. Aguilar et al., Phys. Rep. 366, 331 (2002).
[7] B. Alpat et al., Nucl. Instrum. Meth. A540, 121 (2005).
[8] B. Bertucci et al., Proceedings of ICRC 2001, 2777(2001).
[9] E. Juliusson, Ap.J. 19, 331(1974).
[10] J. J. Engelmann et al., A&A 233, 92 (1990).
[11] D. Muller et al., Ap. J. 374, 356 (1991).
[12] N. Tomassetti these proceedings.
[13] A. W. Strong, I. V. Moskalenko and O. Reimer, Astrophys. J. 613, 962 (2004).
[14] J. Chang et al., Nature 456, 362 (2008).
[15] D. Hooper, K. Zurek, arXiv:0902.0593v1 [hep-ph] .
[16] A. A. Abdo et al., Phys. Rev. Lett., 102, 181101 (2009).
[17] O. Adriani et al., Nature 458, 607 (2009).
[18] L. Bergström, J. Edsjö and G. Zaharijas, arXiv:0905.0333v1 [astro-ph.HE].
[19] A. Oliva, these proceedings.
[20] S. Natale, these proceedings.
[21] C. Chung, these proceedings.