PROCEEDINGS OF SCIENCE

The AMS-02 detector operation in space

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The Alpha Magnetic Spectrometer is a large acceptance instrument conceived for the search of primordial anti-matter and dark matter on board the International Space Station (ISS) orbiting at $\sim$400 km from the earth surface. Nine layers of double sided silicon microstrip detectors track with a single point resolution of 10 μm the charged particle trajectories bent in the magnetic field of a permanent magnet. Redundant measurements of the charge magnitude, velocity, momentum and energy of the cosmic rays are performed by the different detectors integrated in AMS-02. The large acceptance and a long exposure time, matching the ISS operational lifetime, will allow AMS-02 to collect a wealth of data to study with unprecedented accuracy the composition and the energy spectrum of charged CRs and gammas up to the TeV energy scale. Launched with the STS-134 mission of the Shuttle Endeavour on May 16^{th} 2011, AMS-02 has been installed on May $19^{t}h$ on the ISS and it is continuously taking data since then. In this contribution we will revue the characteristics of the instrument and report on the AMS-02 status in orbit.

The 2011 Europhysics Conference on High Energy Physics-HEP 2011,
July 21-27, 2011
Grenoble, Rhône-Alpes France

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PoS(EPS-HEP2011)067

1. The instrument

The AMS-02 instrument is a magnetic spectrometer conceived to perform cosmic ray measurements in space, on board of the International Space Station (ISS). Search for anti-matter, either anti-nuclei of primordial origin or light anti-matter from exotic sources, is the primary goal of this experiment; thanks to its large acceptance (0.45 m^2sr) and the long exposure time (>10 yrs) AMS-02 will allow to study the composition and energy spectra of CR components up to iron in the GV-TV energy range with unprecedented statistical accuracy. The AMS project started in mid 90's with the proposal of a large acceptance spectrometer to be operated in space, making use of the detection techniques used in the high energy particle physics experiments at colliders. The proof of concept of the AMS tracker system, made of thin layers of double sided microstrip silicon sensors, was at the basis of the AMS-01 detector [1], successfully flown in 1998 on board of the Space Shuttle Discovery. Based on the AMS-01 flight experience, the AMS-02 detector was designed and constructed in the last decade, with a large effort put in testing each single component both in terms of its required performance and its qualification for operating in the harsh environmental conditions of space. A schematic view of the apparatus and the assembled instrument before installation on board of the Space Shuttle are presented in In Fig.1.

The core of the detector is the magnetic spectrometer: nine layers of double sided silicon microstrip detectors [2] are used to reconstruct the trajectory of charged particles bent by the 0.15T magnetic field provided by a permanent magnet [3]. With a $\approx 10\mu m$ position resolution on the bending coordinate, the TRACKER system is able to measure the charged particle rigidity in the GV - TV range. At both ends of the magnet two pairs of segmented scintillator planes are placed to measure the Time Of Flight (ToF) of the impinging particles and to provide the main trigger of the experiment [4]. An Anti-Coincidence scintillator Counter (ACC) system surrounds the TRACKER planes installed within the magnet volume: it provides the veto signal to the trigger in order to reject multi-particle events generated in the interaction of cosmic rays entering the detector through

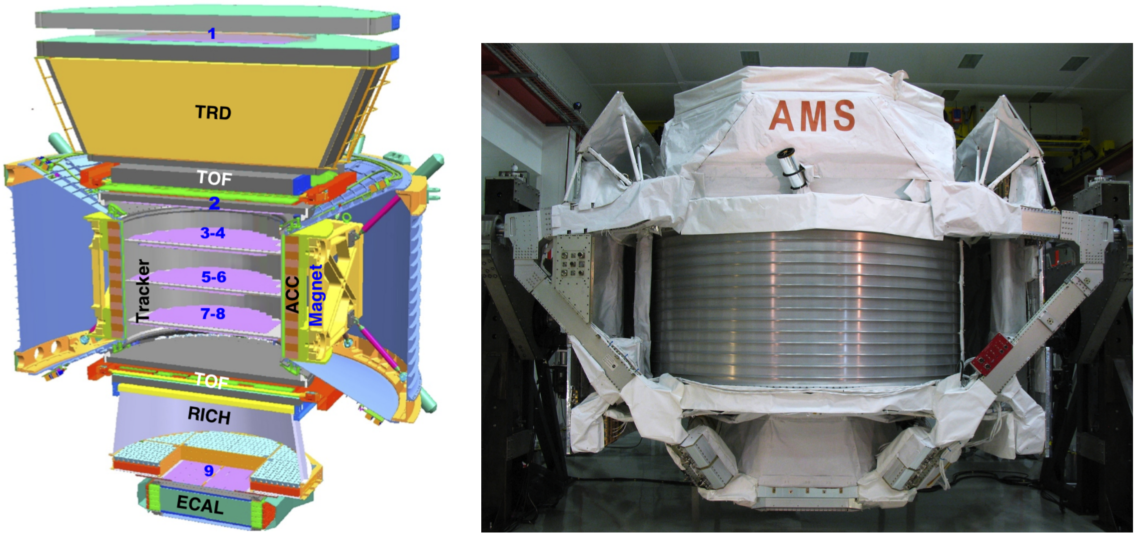

Figure 1: The AMS-02 detector: schematic view (left) and the assembled detector (right) in the clean room at CERN

the sides. The AMS-02 detector is completed by other three sub-detectors which provide redundant measurements of the particle charge magnitude and complete the particle identification: the Ring Image CHerenkov (RICH) detector dedicated to the precise measurement of the particle velocity and absolute charge magnitude [5]; the Transition Radiation Detector (TRD) and the Electromagnetic CALorimeter (ECAL) to ensure an accurate separation between leptons and hadrons [6, 7]. With its 17 r.l. depth, the ECAL allows to determine electron and photon energy at the % level. Precise measurements of the time and pointing direction of AMS are performed by a GPS system and a Star Tracker system made of two CCD cameras placed on the upper part of the mechanical structure enveloping the magnet.

Fig.2 shows AMS-02 on May 19^{th} after its installation on the main ISS truss: the experiment is directly exposed to the vacuum and to the temperature variations of the spatial environment. To reach is final destination, AMS-02 has been hosted in the cargo bay of the Space Shuttle Endeavour in its last flight, the STS-134 mission, being exposed to the severe mechanical stress of the launch. Since its first switch on, AMS-02 has been fully functional and has operated continuously without major failures in the detectors and Data Acquisition system (DAQ). Careful mechanical, thermal and electronic design, detailed assembly procedures and extensive qualification tests of the single subsystems against the mechanical and thermal stresses have been the key points in order to insure the functionality of the instrument in space. Radiation hard components have been selected for all the electronics; the detectors and each sub-system, prior to integration, have passed different mechanical and thermal tests to verify their most critical points as assessed by structural and thermal analysis. Three months were spent by the whole AMS-02 in the ESTEC facility of ESA to test the thermal control system and the full functionality of the detector in vacuum as well as the electromagnetic compatibility of the electronics and power systems with the requirement for operating on board of the Shuttle and the ISS.

Produced all over the world, in the 57 research institutes participating to the International Collaboration, the different AMS-02 sub-systems have been assembled in a dedicated clean room at CERN.

Figure 2: The AMS-02 detector installed on the ISS. On both sides of the experiment are clearly visible the radiator panels where readout and power supply electronic crates are hosted to dissipate in space the $\sim 2\,KW$ needed to operate the instrument.

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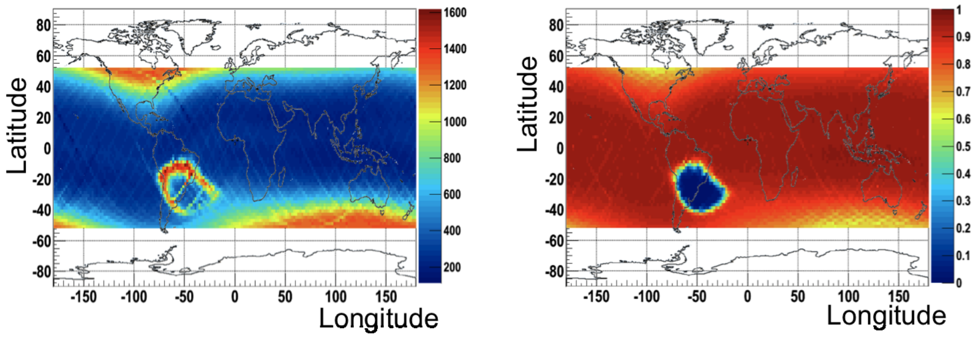

Figure 3: DAQ trigger rates (Hz, left) and livetime (right) in different geographical locations of the AMS-02 orbit

Calibration with beams of protons, electrons and positrons at different energies was performed in August 2010 prior to the AMS shipment to the Kennedy Space Center for final processing with the integration of the mechanical and electrical interfaces to the Space Shuttle and ISS. During the integration phases and in the seven months spent in the Space Shuttle Processing Facility, extended periods of data taking were performed in order to verify the DAQ procedures and to perform calibration on ground with atmospheric muons.

2. The data taking

In Fig.3 the average trigger rates collected in different geographical location along the 51.7° inclined orbit of the ISS are shown on the left and the corresponding livetimes are presented on the right: higher rates are corresponding to regions with lower values of the geomagnetic cutoff, in the equatorial region is clearly visible the effect of the South Atlantic Anomaly. Along the 93 minutes long orbit, the average livetime is 85%. A tree-like modular structure with full redundancy of the critical components is at the basis of the the Data Acquisition System: 300 computational nodes based on ADSP-2187L Digital Signal Processors (DSP) and a Main DAQ Computer based on PPC750 processor (JMDC) process the $\sim$ 300.000 channels coming from the whole AMS.
All the nodes are hosted in 21 electronic crates located on two radiators (vertical panels on the two sides of AMS-02 in Fig.1) to allow the exchange of heat with the outer space. The nodes are interconnected with point-to-point LVDS serial links and a dedicate protocol (AMSWire) is used for communication. The data throughput per link is 100 Mbits/s.

The AMS experiment operates at input trigger rates up to 2 kHz with an average event size of about 2 KBytes. In order to minimize the dead time due to data processing, event buffering is used at every level of DAQ hierarchy. Data are continuously transmitted from space to the AMS-02 Front End Processors (FEPs) located in the Marshall Space Flight Center in Alabama, at an average rate of 9 Mbit/s, and buffered during Loss of Signal (LOS) periods. A backup of the data before transmission to ground is provided by the AMS laptop system on the ISS. From Marshall, data are retransmitted in real time to the Payload Operation Control Center (POCC) located in CERN, where the data monitoring and AMS-02 control is performed since June 23^{rd}.

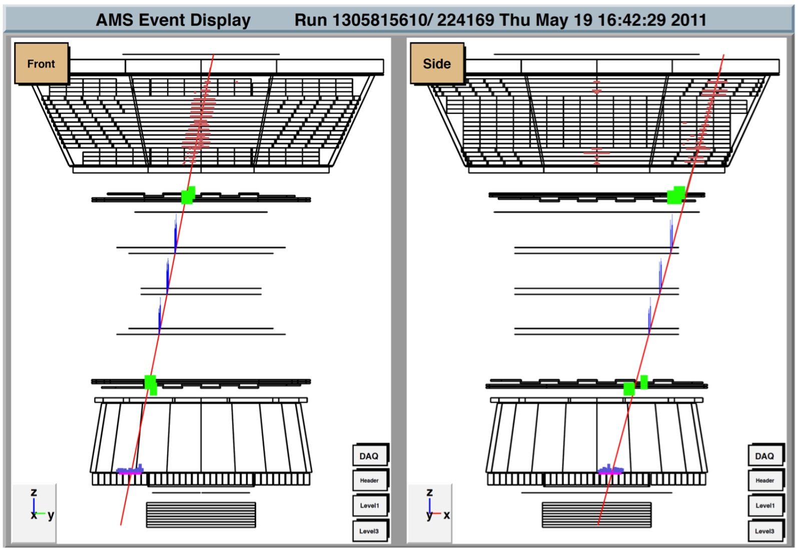

Figure 4: A carbon nucleus with a momentum of 42 GeV/c revealed in the AMS-02 during the first hours after the activation: the event is presented in the bending (yz, left) and non bending views (xz,right) separately.

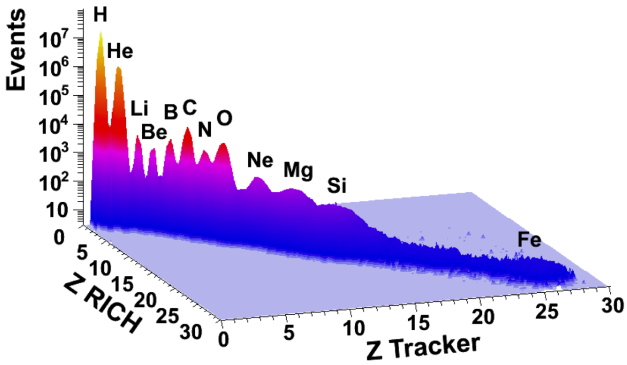

Figure 5: Correlation of the charge magnitude (Z) measurements from RICH and TRK systems

3. Operation in space

In Fig.4 the event display of a carbon nucleus as reconstructed in AMS-02 after few hours from its activation in space. Different subdetectors are used to reconstruct the particle characteristics, from the energy deposit in Tracker and TOF and the intensity of the signal in RICH the charge magnitude could be clearly established. In Fig.5 the correlation between the complementary charge measurements in the Tracker and the RICH is shown, nuclei up to iron are clearly visible.
In spite of the harsh spatial environment, no major malfunctioning of the AMS-02 detectors has appeared since their first switch on. Fig.6 (left) shows how the percentage of the tracker channels declared bad (noisy or dead) is at the level of few %, both for the bending (y) and non bending (x) sensor sides and does not exhibit appreciable variation with time after the first month devoted

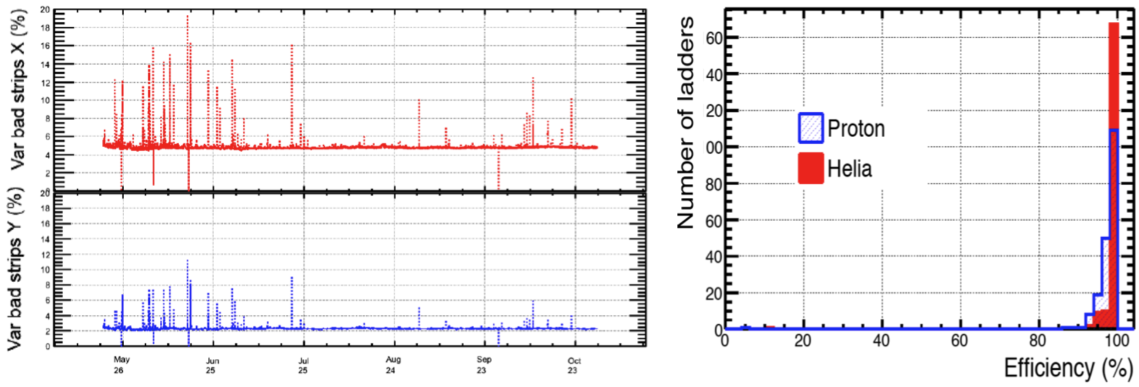

Figure 6: Left: the time behaviour of the noisy and dead channels of the silicon tracker is shown as a function of time. Right: the efficiency of the 192 tracker units is shown for proton and helium particles

to optimization of calibration procedures. In the right panel, the efficiency of the 192 ladder units constituting the tracker is shown for proton and helium particles.

4. Conclusions

The AMS-02 instrument has been successfully operated in orbit since May 19^{th} 2011. Up to the end of January 2012 $\sim 10^{10}$ triggers have been collected for a total of $\sim$ 25 TB of raw data transferred on ground; the sub-detectors are functional within the expectations and their calibrations are being finalized in order to study the cosmic ray radiation with the instrument nominal perfomance.

5. Acknowledgments

The success of the AMS-02 mission is due to many individuals and organizations outside the collaboration. The support of DOE was vital in the inception, development and operation of the experiment. CERN is the host of the AMS-02 Control Center and its infrastructures have been precious for the detector integration. The support of the space agencies from USA (NASA), Italy (ASI), France (CNES), Germany (DLR), China and the support of CSIST, Taiwan, made possible the realization of this experiment and continue to be of primary importance for its operation.

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