In-flight performance of the AMS-02 silicon tracker

J L Bazo Alba, on behalf of the AMS-02 Tracker Collaboration
INFN-Sezione di Perugia, I-06100 Perugia, Italy
E-mail: JoseLuis.Bazo@pg.infn.it

Abstract. The silicon microstrip Tracker is a key subdetector of the AMS-02 instrument, designed to measure the momentum and charge of cosmic rays. The subdetector is composed of 9 layers of silicon sensors inside a permanent 0.15 T magnetic field. The detector has been installed on board of the International Space Station, at an altitude of 400 km, and is taking data since May 19th 2011. AMS-02 aims to provide a precise measurement of the cosmic-ray spectrum and perform antimatter searches in the GeV-TeV energy range. This review presents the Tracker performances during the first year of operation in space, covering all the most relevant aspects of detector stability, efficiency and capabilities in charge and track reconstruction.

1. AMS-02 and the Silicon Tracker
The Alpha Magnetic Spectrometer 02 (AMS-02) [1] is a particle physics detector in space on board of the International Space Station (ISS). The detector has a volume of 5×4×3 m³ and weights 7.5 tons. It has an acceptance of ~ 0.5 m² and its exposure time will be equal to the ISS lifetime. AMS-02 consists of 5 sub-detectors, of which the Tracker is the focus of this review.

The Tracker [2, 3] has been designed with 9 layers of double-sided microstrip silicon detectors, located inside (7) and outside (2) of the magnet bore (see Fig. 1a). This configuration enables to register the charged particle traversing position with an accuracy on the curvature direction of around ~10 µm and ~30 µm on the not bending direction. The maximum detectable rigidity (MDR) is ~2 TeV for protons, while the rigidity resolution at 10 GeV reaches 10%.

The ladder is the minimum readout unit of the Tracker. It consists of a variable number of 41.360 × 72.045 mm²× 300 µm silicon microstrip sensors bonded along the bending coordinate (y direction). Each ladder has 1024 readout strips, 640 on the p-side (y-side) and 384 on the n-side (x-side). There are in total 192 active ladders. Each ladder is readout by 16 low noise high dynamic range VA chips (64 channels each) integrated in two hybrids circuits, which also provide bias voltage.

1.1. Calibration and Data Compression
The Tracker Data Reduction board (TDR), which consists of 12-bit ADCs and Digital Signal Processors, calibrates [4] and compresses the detector data. The calibration gives for each channel the pedestal, the typical noise fluctuation, which is calculated subtracting the common noise, and the status. A new calibration is performed every 46 minutes, lasting less than 20 seconds, thus the deadtime introduced is negligible. The calibration is done at the equator every other new 23-minute run, avoiding the South Atlantic Anomaly (SAA), since in this area the particle rate is extremely high.
Figure 1: (a) Left: Schematic view of the AMS-02 Tracker with a charged particle traversing the detector. (b) Right: Time evolution of the temperature measured in different sensors.

Due to bandwidth constrains data compression is done applying a zero suppression algorithm, which substracts the pedestal and the common noise inside each VA.

2. Tracker Stability

The time evolution of the most important monitored Tracker quantities is presented next. As a global trend stable conditions are observed.

2.1. Temperatures

Temperatures are measured at different points by Dallas sensors. The Tracker Thermal Control System (TTCS), a mechanically pumped two phases CO$_2$ cooling system, controls the temperature of the Tracker front-end electronics. The operating temperatures range from -10 $^\circ$C to +25 $^\circ$C, for the silicon wafer and the hybrid circuit.

Typical temperatures are shown in Fig. 1b. The inner Tracker temperatures are stable because they are controlled by the TTCS. The upper (layer 1) Tracker show larger fluctuations since its thermal control relies on passive radiation cooling and dedicated heater circuits. Large variations in the first period are due to the commissioning of the TTCS system. Other temperatures changes can be correlated with the Sun exposure of the ISS and the docking/undocking of spacecrafts.

2.2. Signal Pedestal and Noise

The pedestals of each ladder range from 0 to 4095 ADC and most of them depend on temperature. The mean pedestal taking into account the good strips from all good ladders is stable within a margin of 2 ADC (see Fig. 2a). The first days of data taking show fluctuations due to the correlation with temperature changes during the TTCS commissioning (see Fig. 1b). The pedestal RMS shows small variations in the order of 1 ADC. The RMS pedestal difference between calibrations is correlated with the temperature change, which under nominal conditions is less than 1$^\circ$. For this range, the mean pedestal difference is below the noise level.

The evolution of the noise from the good channels is extremely stable. The average noise for the x-side is 2.9 ADC, while for the y-side it is 2.5 ADC.
2.3. Bad Strips

For each calibration the 192×1024 channels (strips) are classified as good or bad, depending if they show a reasonable noise (good) or they are noisy, dead or non-Gaussian (bad). The bad strips are divided into: permanent (masked VA’s) and variable (assigned in each calibration).

In Fig. 2b the variable bad strip evolution is shown. The number of bad strips is steady. The spikes correspond to calibrations taken at the SAA, where the number of noisy channels increases by up to 4 times. The x-side has an average of ~5% bad channels, while the y-side is ~2.3%. Most ladders (95% x-side, 99% y-side) have less than 10% of variable bad strips.

3. Track Reconstruction Performance

The Tracker reconstruction performance is evaluated by analyzing efficiencies at different levels. This calculation is done removing tracks outside the Tracker acceptance and those which do not pass through the active area of the ladders (omitting dead strips and silicon boundaries).

3.1. Ladder intrinsic efficiency

To assess the intrinsic efficiency of a ladder, a window around the track and inside the ladder sensitive area is defined, taking into account possible multiple scattering and keeping the noise cluster probability below 1%. The efficiency is defined as the times a track is passing through a ladder and a cluster is reconstructed in its proximity (i.e. inside the window). The ladder intrinsic efficiency from y-side clusters evaluated using protons and helium is presented in Fig. 3. The signal-to-noise cut done in the compression algorithm at the readout level mostly affects protons since their signal is lower, therefore the efficiency for helium is higher. Most ladders (p > 92%, He > 96%) have an efficiency greater than 95%.
3.2. Hit efficiency
The hit efficiency is the times a track passes through a ladder and a y-side hit is attached to the track, thus includes a convolution of the ladder efficiency and the track reconstruction algorithm.

The y-side hit efficiency by ladder is shown in Fig. 3. Compared to the intrinsic efficiency it is slightly lower due to the pattern recognition algorithm, since only clusters associated to a track are considered. About 90% of the ladders have a hit efficiency greater than 90%.

3.3. Track reconstruction efficiency
To give an unbiased result of the track reconstruction efficiency another sub-detector is used to know if a particle passed through AMS, in this case the Time of Flight (TOF). Clusters in the TOF planes are used to create a simple track. In addition, it is requested that the reconstructed Tracker track geometrically matches the TOF road. The global track reconstruction efficiency is 81%, which includes the effect of the non-sensitive area between ladders, the hit efficiency and the minimum number of hits required for reconstructing a track.

4. Signal Reconstruction Performance

![Figure 4: Signal distribution (y-side) for protons and helia using all ladders.](image)

Each ladder registers the ADC counts corresponding to the ionization energy loss of the charged particle passing through the Tracker. Given the thickness of the silicon strips the expected counts for protons and helia are approximately 30 ADC and 120 ADC respectively. The noise is expected with a lower number of counts and the noise cluster probability is at most a few percent for the external layers and less than 0.1% for the internal layers.

The distribution of the signals registered in the y-side clusters associated to the track of relativistic particles is given for protons and helia in Fig. 4, using all ladders. The signal is corrected for track inclinations. The distributions are described by a Landau function convoluted with a Gaussian noise contribution. The region of the highest signal is better fit by an exponential tail. The result of the Landau fit gives the following MPVs: $32 \pm 0.6$ and $132 \pm 2.2$ ADC for protons and helia respectively.

5. Conclusions
AMS-02 has been deployed on the ISS and is taking data since May 19th 2011. The Tracker shows the expected behavior with high stability of temperatures, pedestals and noise, in addition to a high ladder uniformity, efficiency response and a good signal reconstruction performance.

References
[1] Luebelsmeyer K et al. 2011 Nucl.Instrum Meth A 654 639
[2] Oliva A et al. 2011 Proc. 32nd ICRC Beijing, China
[3] Alcaraz J et al. 2008 Nucl.Instrum Meth A 593 376
[4] Zurbach C 2011 AMS note 2011-02-01