Operation of the AMS-02 TRD in Space

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Abstract

The AMS-02 detector was installed on May 2011 on the International Space Station and has since collected billions of cosmic ray events. AMS will measure with unprecedent precision cosmic ray spectra up to the TeV energy scale, achieving a sensitivity to the presence of anti-nuclei of one part in a billion, as well as providing important information on the origin of dark matter. A Tranisiton Radiation Detector (TRD), filled with a Xe/CO_2 mixture, is used to reach the sensitivity to positron identification needed for the detection of a neutralino dark matter candidate. The control of a gaseous detector in Space is a challenging task: the operational procedures, and the performances achieved, will be described.

Keywords: Dark Matter, Cosmic Rays, Transition Radiation, Detector operation in Space

1. The AMS-02 TRD and Gas System

An ultra-relativistic charged particle crossing the interface between two media with different dielectric constants has a probability of the order of 1% to emit a photon in the soft X-ray region [Alcaraz et al. (1999); Burger (2002)].

The probability of transition radiation emission can be maximized increasing the number of boundaries that a particle has to cross. This is why the radiator material in the AMS-02 TRD is a fleece of 10 μm thick propylene fibres (LRP 375 BK), with a density of 0.06 g/cm^3. The transition radiation emission probability at each radiator layer thus increases to 50% for a high-γ particle.

The transition photons are detected in proportional straw tubes of 6 mm diameter filled with a Xe:CO_2 [80:20] gas mixture, grouped in 328 modules of 16 straws each [Toker et al. (1994); Alpat et al. (2000)]. The proton-positron separation capability increases with the number of radiator–detector layers that the particle has to cross. This, due to weight requirements, has been limited to 20.

The detector configuration is shown in figure 1. The TRD layers are arranged into an octagonal structure made of aluminum honeycomb walls and carbon fiber skins and bulkheads. To provide tracking capabilities with the desired spatial resolution, the relative alignment of the modules is a key issue.

The gas mixture circulated in the TRD is periodically refilled from a supply box containing the gas tanks. The electronic control of the Gas System includes a control board and three dedicated boards that supervise the electromechanical devices and the 490 sensors used to continuously monitor pressure and temperature [Delil et al. (2001)]. The gas storage guarantees at least 20 years of operation.

The DAQ system includes the front-end electronics, two crates hosting the acquisiton and the slow-control, and two crates that provide low voltage transforming the 28 V DC supplied by the power distribution system. The digitization of the signals from the 5,248 straw tubes and a first filtering step take place in the 30 onboard computers of the front-end electronics.

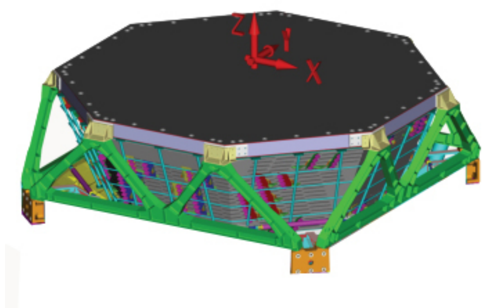

Figure 1: The AMS-02 Transition Radiation Detector.

2. Detector operation

Being in Space, the detector is exposed to very large environmental temperature variations, that are strongly mitigated by the thermal insulation, but not completely wiped out. Therefore, the TRD is continuously moving on top of the inner Tracker by up to 1 mm, and the modules are internally displaced, following temperature gradients.

The same temperature fluctuations, and additional changes of pressure, gas composition and high voltage applied, cause time-dependent variations of the detector response at the single tube level, that are even more pronounced at the time of gas refills. Figures 2 and 3 show the results of offline alignment and calibration obtained using samples of (very abundant in Cosmic Rays) protons: each straw module is aligned with an accuracy

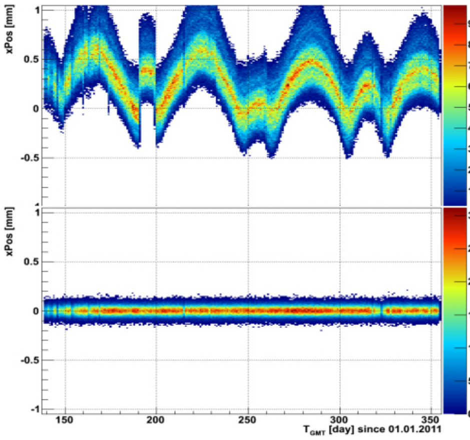

Figure 2: Displacement of the TRD modules before (top) and after (bottom) the offline alignment.

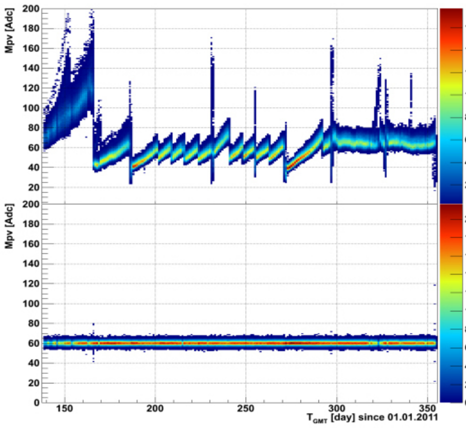

Figure 3: MPV of each channel before (top) and after (bottom) the offline calibration. The ”spikes” correspond to the periodic gas refills.

of 0.04 mm, and the response (parametrized by the most probable value, or MPV, i.e. the peak position of the Landau distribution for a tube) is equalized to a homogeneity within 3%, even during gas refills.

3. Detector response

The AMS Tracker [Rapin (2012)] and Electromagnetic Calorimeter [Cadoux et al. (2002)] can be used to define separate, clean electron and proton samples. This allows the study of the TRD performance in Space, and the detrmination of the particle identification power, from flight data directly. The different response of the TRD to protons and electrons at the single layer level, shown in figure 4, is due to transition radiation.

The data analysis is based on a likelihood method that exploits the response of each of the 20 layers, and quantifies the difference in the typical event profiles of the two samples, giving the probability to observe a proton or an electron, on an event-by-event basis. The resulting rejection power for protons, as a function of the efficiency on electron identification, is shown in figure 5. The result obtained ensures the AMS-02 capability to reach the desired sensitivity on the positron spectrum on the whole interesting energy range, even at the TeV scale.

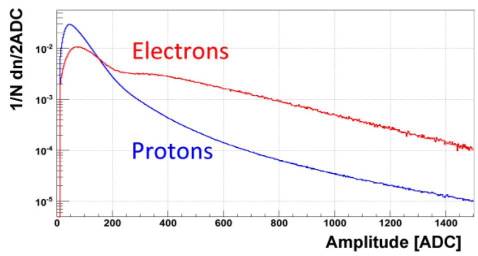

Figure 4: Single layer response to protons (blue) and electrons (red).

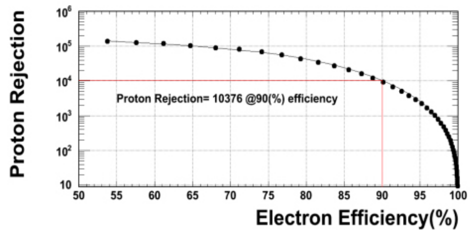

Figure 5: Standalone TRD proton rejection factor as a function of electron efficiency.

4. Conclusions

AMS-02 was installed on May 19th, 2011 on the International Space Station and has since collected $1.6{\cdot}10^{10}$ cosmic ray events, at a rate of one TeV event per day.

The Transition Radiation Detector is functioning smoothly and its performance measured on flight data exceeds the one determined with test-beams. This reflects the higher purity of the electron and proton samples used in the flight data analysis, with respect to the electron and positron beams provided by a proton accelerator as the CERN SPS, that always suffer from a pion contamination.

In Space, the TRD provides a 10^4 proton rejection factor at an electron identification efficiency of 90%.

The overall AMS-02 particle identification power allows the indirect search of a dark matter candidate in the positron channel with unprecedent sensitivity, in the energy region where other experiments [Adriani et al. (2009); Ackermann et al. (2011)] have shown a possible signal, and beyond.

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