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# Construction of the AMS-02 Transition Radiation Detector for the International Space Station

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The Alpha Magnetic Spectrometer AMS-02 will be equipped with a large transition radiation detector (TRD) to achieve the proton background suppression necessary for dark matter searches. The AMS-02 TRD consists of 20 layers of fleece radiator each with proportional wire straw tubes read out by a dedicated low-power data acquisition system. The tubes are filled with a 80:20% mixture of Xe:$CO_2$ at 1 bar absolute from a recirculating gas system designed to operate for more than 3 years in space. A space qualified TRD design and the production process are presented. This project is funded by the German Space Agency DLR under contract number 50OO0501.

## 1. Introduction

The Alpha Magnetic Spectrometer AMS-02[1] is a high precision particle detector to be operated for at least three years on the International Space Station (ISS). A primary physics goal will be the determination of the nature of dark matter. As a likely candidate neutralinos are expected to annihilate and enrich the cosmic ray positron fraction above standard model expectations in the momentum range between 10 and 300 GeV. Such a measurement relies on the efficient suppression of the dominant proton background by six orders of magnitude. For particle momenta above 10 GeV a 3D sampling calorimeter will reach a proton rejection factor of $10^3$. Another factor of 10 is reached by matching $E$ and $p$ from calorimeter and tracker, and a transition radiation detector will deliver the remaining $10^2$ to $10^3$.

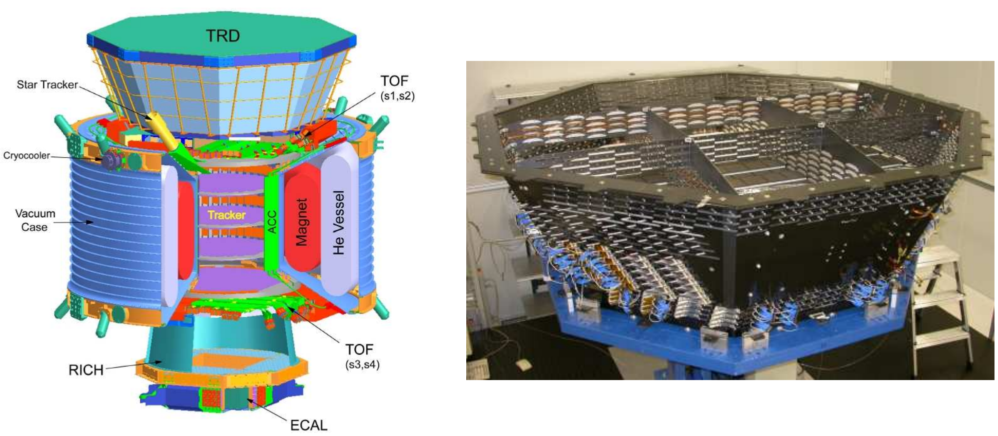

**Figure 1.** Schematic view of the AMS-02 experiment with the TRD on top (*left*), AMS-02 TRD support structure on the assembly stand during module integration (*right*)

Transition Radiation (TR) consists of soft X-rays and is emitted when charged particles traverse the boundary between two materials which differ in their dielectric constant. Since the emission of transition radiation has a threshold of $\gamma \approx 500$ (Lorentz factor), light particles such as positrons have a much higher probability of emitting TR than heavy particles such as protons. This allows for a proton suppression in the momentum range of 10-300 GeV.

The AMS-02 TRD is based on a well proven design[2][3] with multiple irregular boundary crossings in a fleece radiator and strawtube proportional wire chambers filled with Xe/$CO_2$ gas mixture to detect the TR photons. The challenge is to build such a detector in a space qualified way with strict limits on gas tightness, weight, power consumption and outgassing whilst assuring structural safety and gas gain homogeneity in a harsh environment. Furthermore, beyond the payload lift into space, there will be no further access to the device.

## 2. TRD straw tube modules

The sensitive elements of the TRD are formed by straw tubes of 6 mm in diameter and 72 $\mu$m wall thickness. The individual tubes are fabricated from a multilayer foil predominantly made out of kapton material. Two overlapping kapton strips covered with graphite on one side and polyethylene on the backside are wound back-to-back and heatsealed. For production, each straw tube has to be tested individually with He at 2.8 bar for 5 minutes in a setup sensitive to the diffusion limit[4]. Straw tubes exceeding a diffusion limit of $10^{-5}$ mbar/s are rejected. 16 straw tubes are then glued together with 6 longitudinal carbon fiber stiffeners to form a module. Additionally, carbon stiffeners are glued perpendicular to the strawtubes onto the modules with a 10 cm spacing, which further improves mechanical rigidity to withstand launch vibrations. At both ends the tubes are closed with polycarbonate endpieces which provide the gas supply and center the Cu-Te crimp plugs[5] to hold the 30 $\mu$m thick goldplated tungsten wires tensioned with 1 N.

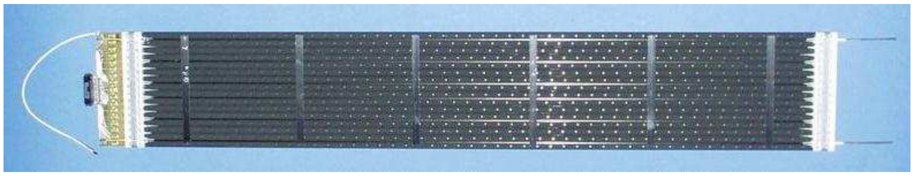

**Figure 2.** An AMS TRD straw tube module

Straw tube modules have been successfully tested in thermovacuum cycles and on a vibration table according to NASA specifications. Each module is tested individually for wire tension[6], leakage current and gas gain homogeneity. Fig.3 *(left)* shows the $CO_2$ gas tightness of the flight modules in units of safety factors. A safety factor of 1 is equivalent to a leak rate of $25.3 \cdot 10^{-5}$ $\ell$ mbar/s for a module of 1 m length, corresponding to the loss of the stored $CO_2$ within the scheduled operation time of 3 years. The gas gain homogeneity is limited by the precision of the wirepositioning. It is monitored before and after detector assembly by analyzing $^{55}Fe$ signals at different positions along the modules. At present, 10 layers with 152 modules have been inserted into the detector with high mechanical precision, i.e. without any degradation of gas gain homogeneity (fig.3, *right*). To verify the reliability of the $^{55}Fe$ method, computer tomography scans of a qualification module have been performed.

## 3. Mechanical structure

The TRD straw modules are supported by a conical octagon structure, built of aluminum honeycomb material with carbon fiber skins and bulkheads. The mechanical precision will provide a module support with a straight-

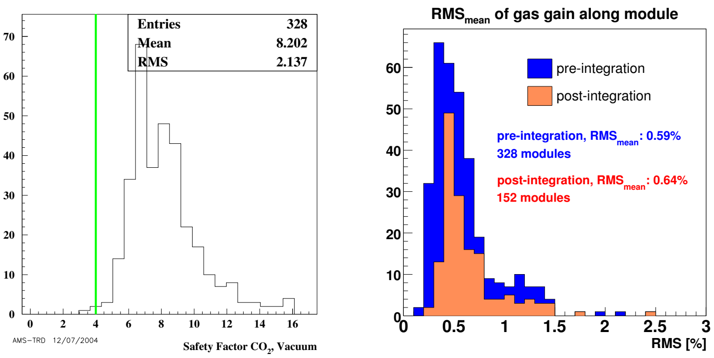

**Figure 3.** CO$_2$ gas tightness (safety factors) of the 328 flight modules (*left*), RMS of gas gain measurements along the straw tube modules before and after the integration (*right*). 152 modules are integrated at present.

ness of below 100 $\mu$m. In total 328 straw modules of lengths between 0.8 m and 2 m will be inserted into the support structure, arranged in 20 layers, each covered with 20 mm of polypropylene/polyethylene 10 $\mu$m fiber fleece. The uppermost 4 and lowermost 4 layers are oriented parallel to the magnetic field lines, whilst the central 12 layers are arranged perpendicular to it, thus providing 3D tracking.

## 4. Gas system and readout electronics

The gas used in the TRD is a Xe/CO$_2$ mixture in the ratio 80/20% at 1 bar. Two storage vessels contain the individual components of the gas mixture, 49.5 kg Xe and 4.5 kg CO$_2$, respectively (fig.4, *left*). The total TRD gas volume of 230 $\ell$ is divided into 41 separate chains each containing 8 modules connected in series. To each chain, the TRD gas system[7][8] supplies a gas flow of 1 $\ell$/h with daily replenishment of diffusion losses and partial refreshment. The gas quality is monitored via spirometer measurements of the CO$_2$ fraction, as well as by extra gas gain monitor tubes with $^{55}Fe$ sources.

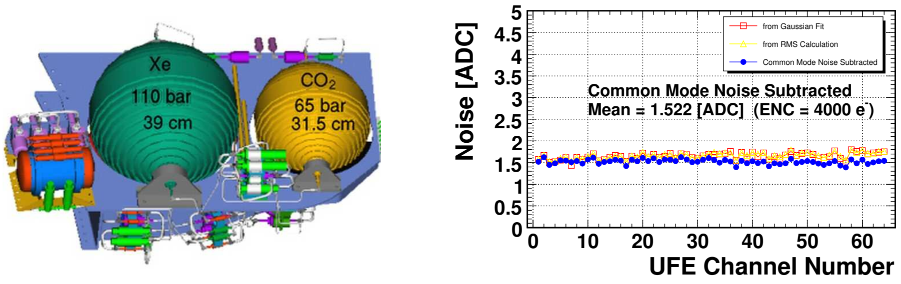

**Figure 4.** The TRD gas supply system (*left*), common mode subtracted noise distribution of a front end board serving 4 modules with 16 channels each (*right*)

To separate protons from positrons, wire signals from ionization losses alone have to be distinguished efficiently from signals caused by both $dE/dx$ and TR photon absorption with an analog pulse height readout. The front end electronics, consisting of 5248 channels, is based on VA analog multiplexers, equipped with a

12-bit AD converter covering a dynamic range of about 60 MIP at gas gain 3000. The noise level is below 2 ADC channels (fig.4, *right*). Each front end board serves four modules and is attached directly to the support structure. In total, the front end electronics consumes 20 W of electrical power. The components of the readout electronics have been space qualified during design. In addition to vibration and thermovacuum tests, the electromagnetic interference was measured, including HF emission and -susceptibility studies.

## 5. TRD performance

A full 20 layer prototype equipped with 40 modules of 40 cm length was tested in the CERN T9, X7 and H6 beam lines to verify the design of the AMS-02 TRD[9]. Three million tracks of electrons, muons and pions up to 100 GeV and protons up to 250 GeV were recorded. Fig.5 *(left)* shows the single straw tube energy spectra for reconstructed tracks caused by the different particles. Protons are separated from electrons with a likelihood algorithm. The proton rejection factor is determined as the inverse proton selection efficiency with a likelihood cut set for an electron efficiency of 90%. For beam energies ranging from 15 to 250 GeV it is between 1000 and 100 as shown in fig.5 *(right)*.

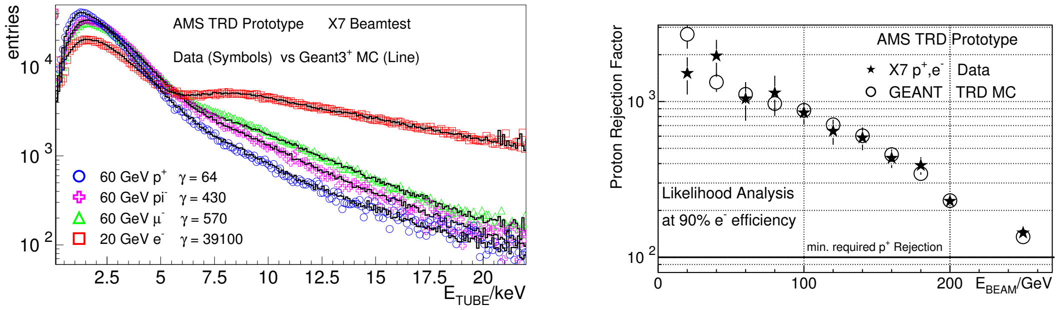

**Figure 5.** Single straw energy spectra (*left*), TRD proton rejection as function of energy (*right*)

## 6. Acknowledgments

We wish to thank the many organizations and individuals listed in the acknowledgments of reference [1].

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