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# The AMS-02 transition radiation detector

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**Abstract**

The Alpha Magnetic Spectrometer (AMS-02) experiment will be mounted on the International Space Station (ISS) for 3 years to perform precision cosmic particle spectroscopy in space. The search for dark matter candidates requires precise $e^+$-spectroscopy in the energy range from 10 GeV up to 300 GeV. Therefore, the dominating p-background has to be reduced by a factor of $10^6$. This will be achieved with the AMS-02 electromagnetic calorimeter delivering 3–4 orders of magnitude and the transition radiation detector with proton rejection between 100 and 1000.

The AMS-02 TRD consists of 20 layers of 6 mm diameter straw modules alternating with 20 mm layers of polyethylene/polypropylene fleece radiator. The straws are filled with a 80%:20% $Xe/CO_2$ gas mixture at 1.0 bar absolute from a recirculating gas system designed to operate $>3$ years. The straw modules will be operated in proportional mode at a gas gain of 3000. For the readout a dedicated low-power data-acquisition system based on VA analog multiplexers has been developed.

The completed construction and assembly of the detector is presented with special emphasis on space qualification, long flight duration aspects and calibration of the AMS-02 TRD. This project is funded by the German Space Agency DLR (contract 50OO0501), the US Department of Energy DOE and NASA.



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## 1. Introduction

The AMS-02 experiment is a large acceptance particle spectrometer (0.5 $m^2sr$) designed to operate and to measure cosmic-ray fluxes for at least 3 years on the International Space Station (ISS). AMS-02 uses a superconducting magnet ($\sim$0.8 T magnetic field), silicon strip tracker, time-of-flight scintillators, a RICH and a sampling calorimeter to detect cosmic-ray nuclei and antimatter and to search for exotic dark matter candidates in the energy range from 1 GeV up to 1 TeV. To reach the required precision in $e^+$-spectroscopy the dominant proton background has to be reduced by a factor of $10^6$. This will be achieved with the AMS-02 electromagnetic calorimeter delivering 3–4 orders of magnitude and the TRD with proton rejection between 100 and 1000.

Transition radiation (TR) consists of soft X-rays and is emitted when a highly relativistic charged particle (Lorentz factor $\gamma \geqslant 500$) traverses a boundary between two materials with different dielectric constants. The AMS-02 TRD is based on a well-proven design [1,2] with multiple irregular boundary crossings in a 20-mm fleece radiator and straw tube proportional wire chambers filled with $Xe/CO_2$ gas to detect the TR-photons. The TRD consists of 20 layers of fleece and straw tube modules.

The challenge is to build such a detector in a space-qualified way with strict limits on outgassing, gas tightness, weight and power consumption whilst assuring safety and gas gain homogeneity in a harsh environment during payload lift and in orbit without the possibility of further access to the experiment. This involves detailed finite-element calculations as well as subcomponent vibration and thermo-vacuum-cycle tests. The optimized AMS-02 TRD design with 2 m diameter and with 5248 straw tubes weighs less than 500 kg.

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## 2. TRD radiator

The fleece material LRP 375 BK [1] has a density of 0.06 g/cm$^3$ and polypropylene/polyethylene fibers with a thickness of 10 μm. The NASA outgassing rates with respect to the NASA-ASTM E 1595 were reached by cleaning the radiator material with $CH_2/Cl_2$ (Soxhlet extraction method). The cleaning did not affect the TR performance [3].

## 3. TRD straw modules

The TR-photons are detected in proportional mode modules, each consisting of 16 straw tubes. The straw tubes have a diameter of 6 mm, a length of 2.2 m and are made from a double-layer kapton–aluminum foil of 72 μm. For the production of gas tight modules each straw was tested individually with helium at 2.8 bar for 5 min in a setup sensitive to the gas diffusion limit through the straw wall [4]. The straw modules (Fig. 1) are closed with polycarbonate endpieces which serve as gas manifolds and center the Cu–Te-crimp plugs to hold a 30 μm gold-plated tungsten wire tensioned with 1 N. The modules are mechanically stabilized by longitudinal and vertical carbon fiber stiffeners. The wire positioning precision was verified with a high-resolution computer-tomography-scan [5] (Fig. 2). Each flight module is tested individually for wire tension, gas tightness, leakage current and gas gain homogeneity. In total, 328 modules of lengths up to 2 m are supported by a conically shaped octagon structure made of aluminum–honeycomb walls with carbon-fiber skins and bulkheads (Fig. 3). The mechanical precision below 100 μm kept the measured average gas gain

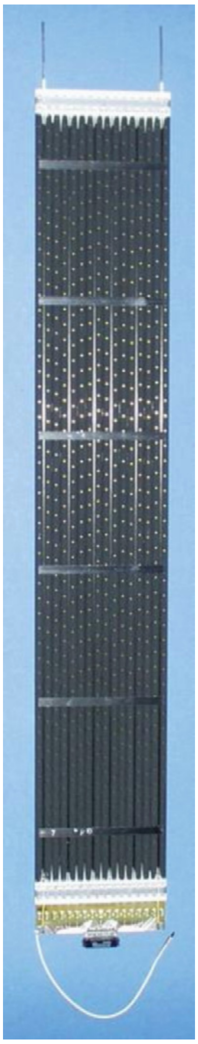

Fig. 1. AMS-02 TRD module with 16 straw tubes.

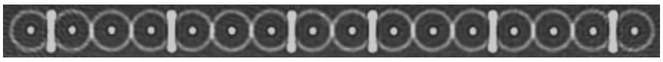

Fig. 2. AMS-02 TRD module computer tomography.

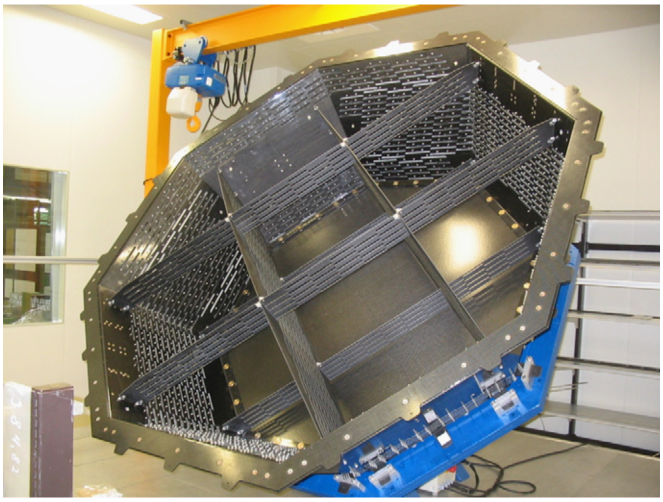

Fig. 3. AMS-02 TRD octagon support structure.

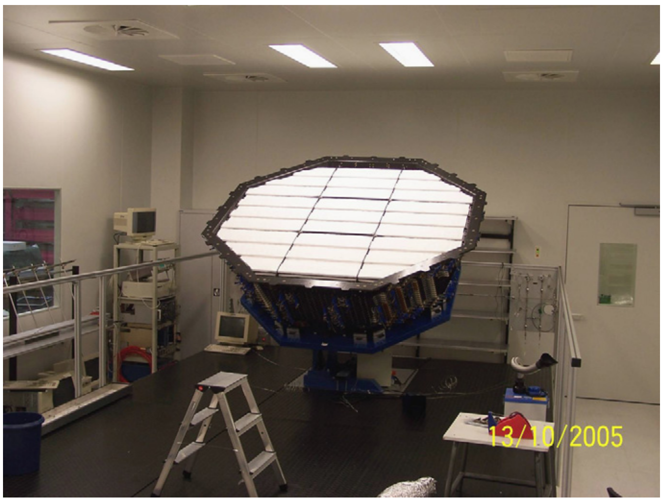


Fig. 4. AMS-02 TRD octagon structure with all 328 straw modules integrated.

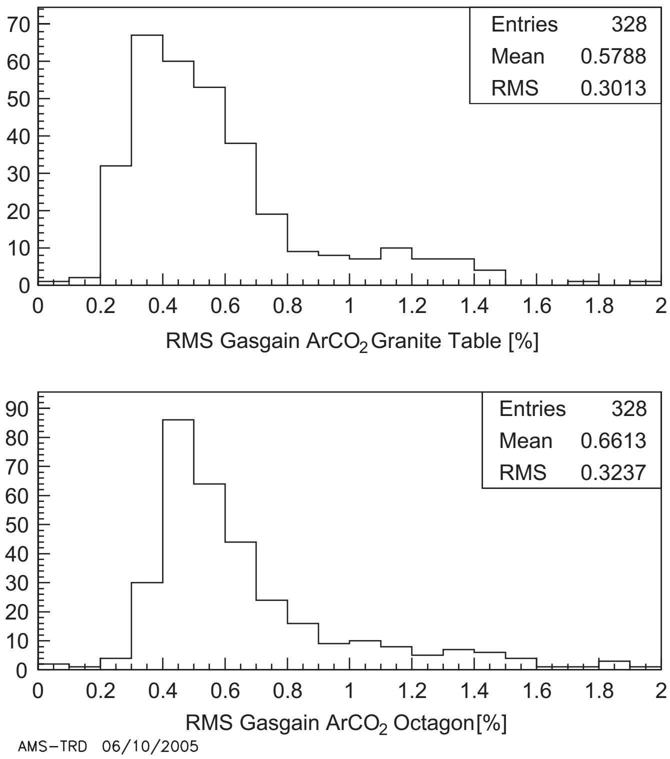


Fig. 5. AMS-02 TRD gas gain homogeneity of the 328 flight straw modules using $Ar/CO_2$ (80/20) at the nominal gas gain of 3000 before and after integration into the octagon support structure.

variations of the integrated 328 straw modules below 0.7% (Figs. 4 and 5). The upper and lower four layers run parallel to the magnetic field, the others perpendicular to provide 3D tracking. The TRD will be fully covered in a multi-layer-insulation (MLI) foil to keep the spatial orbit temperature gradient below 1 K. Space qualification tests have been carried out for eight 0.7 m long straw modules. They underwent vibration tests (0.5 g sine sweep followed by 6.8 g random test followed by 0.5 g sine sweep) as well as thermo-vacuum-cycle tests (between −40 and +60 °C) followed again by vibration tests. No significant changes in eigenfrequencies, gas tightness or gas gain were observed.

## 4. TRD gas system and readout electronics

The TRD gas volume of 230 l is divided into 41 loops each serving eight modules connected in series. The circulating gas system [6,7] supplies a gas flow of 1 l/h of a $Xe/CO_2$ (80%/20%) gas mixture at 1 bar from two storage vessels holding 49.5 kg of Xe and 4.5 kg of $CO_2$. The gas quality is monitored via spirometer measurements of the $CO_2$ fraction and by additional gas gain monitor tubes recording an $^{55}$Fe signal. The gas flow is monitored in each gas loop individually allowing a quick shut-off in case of leakage. Taking into account the amount of $CO_2$ and the gas tightness of the flight straw modules the TRD could be operated for 24 years on the ISS (Fig. 6).

An analog pulse height readout is used to distinguish efficiently wire signals due to pure ionization losses (protons) from signals containing both $dE/dX$ and absorbed TR-photons (positrons). The digitization of the signals from the 5248 straw tubes is done with 82 front-end-boards. Each board serves four TRD straw modules and is attached directly to the octagon support structure. The boards are equipped with 12-bit ADCs covering a dynamic range of 60 mips (at gas gain 3000). The data reduction and low/high voltage supply units are situated in separate crates next to the TRD. In total, the

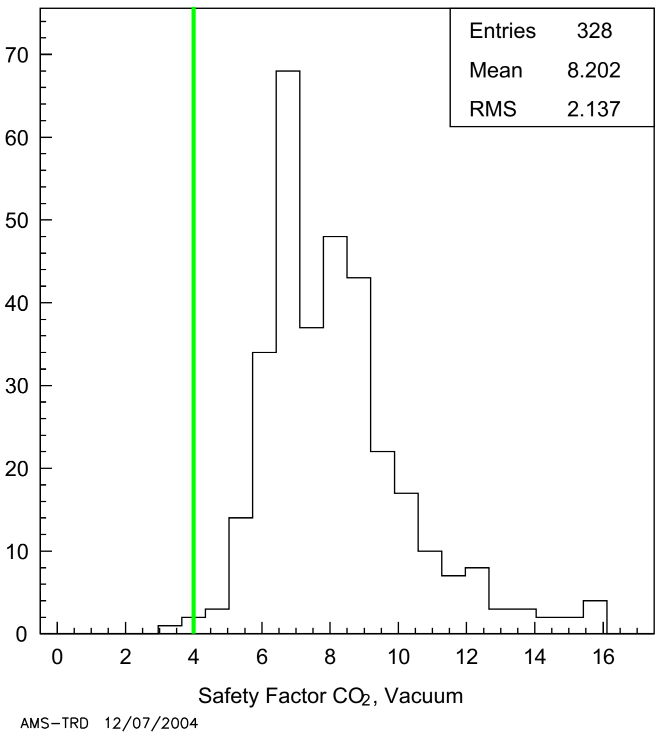


Fig. 6. AMS-02 TRD $CO_2$ gas tightness (safety factors) of the 328 flight straw modules.

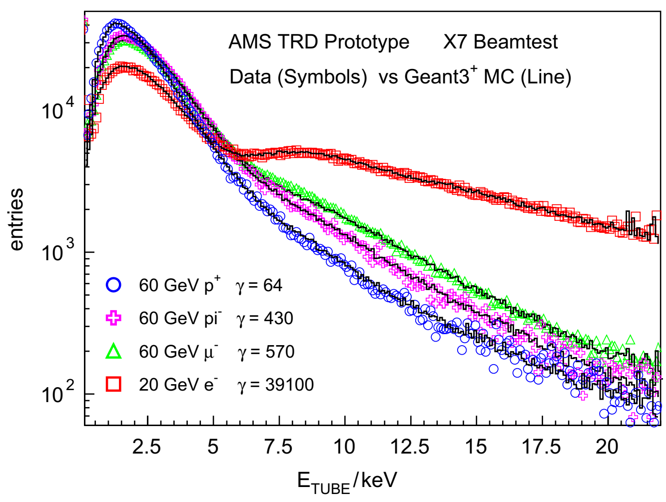


Fig. 7. AMS-02 TRD straw tube energy spectra for clean single tracks.

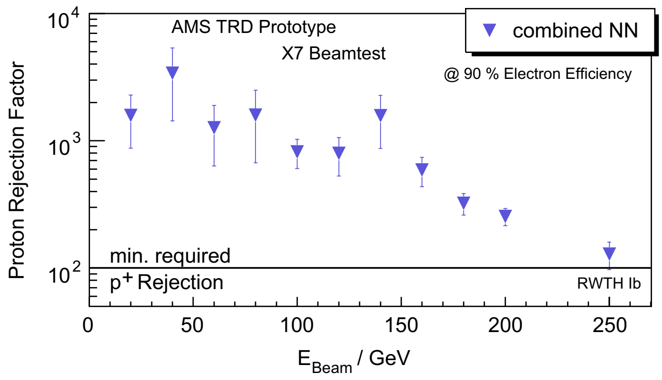


Fig. 8. AMS-02 TRD proton rejection.

front-end-readout consumes 20 W of electrical power. The components of the readout electronics [8] have been space qualified by vibration tests, thermo-vacuum-cycle tests and electromagnetic interference including HF-emission and -susceptibility studies [5].

## 5. TRD performance

The proton rejection power of the AMS-02 TRD design has been verified with a full 20 layer prototype in testbeams [9]. Protons are separated from electrons with a combined neural network analysis. The tube-energy spectra (Fig. 7) are used as probability densities $\rho(E)$. The proton rejection is well above 100 (Fig. 8) at an electron efficiency of 90% for proton beam energies between 15 and 250 GeV.

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