The AMS-02 Transition Radiation Detector

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***Abstract*. AMS-02 is a large acceptance precision particle spectrometer approved for installation on the International Space Station (ISS). A key feature of AMS-02 is precise particle identification for measurements of primary cosmic ray anti-particle spectra with negligible background up to a momentum of 500 GeV to allow indirect searches for dark matter. To efficiently separate positrons/electrons from protons/anti-protons, AMS-02 will be equipped with a Transition Radiation Detector (TRD) with 5248 straw tube proportional counters filled with a Xe/CO_2 (80/20) mixture. The AMS-02 TRD was fully assembled and integrated into AMS-02 in 2007. In 2008 AMS-02 had recorded cosmic ray particles on ground to demonstrate full functionality of the device. For the AMS-02 TRD it will be shown that the detector response is as expected and the gas tightness will allow operation in space for 20 years with a gas supply of 25 kg.**

***Keywords*: AMS-02, Dark Matter, Transition Radiation Detector**

I. INTRODUCTION

Recently published data from ATIC[4], PPB-BETS[5], Fermi-LAT[6] and H.E.S.S.[7] instruments have opened a new window in the study of Cosmic Ray (CR) electrons as shown in Fig. 1. These experiments report spectral deviations from the conventional CR propagation model and imply the presence of unknown primary sources such as nearby pulsars or exotic dark matter annihilation in the Galatic halo. However, a lack of accurate measurement of high energy CR positrons is a major disadvantage for understanding their origin and propagation in the local interstellar medium. Positron fraction data from PAMELA[3] and electrons data from other experiments are not consistent with any CR propagation model.

The Alpha Magnetic Spectrometer (AMS-02) is a large acceptance precision particle spectrometer approved for installation on ISS to measure primary CR spectra in space. It will precisely determine the fluxes of elemental abundances with charge separation up to Z = 26 (Fe) in the energy range from 100 MeV/nucleon to 1 TeV/nucleon. As shown in Fig. 2 the spectrometer uses a Superconducting Magent at its core and consists of a Silicon Microstrip Tracker, a Transition Radiation detector (TRD), a Time of Flight (ToF) system with Anti-Coincidence Counter (ACC), a Ring Image Cherenkov Counter (RICH) and an Electromagnetic Calorimeter (ECAL). For details refer to [9].

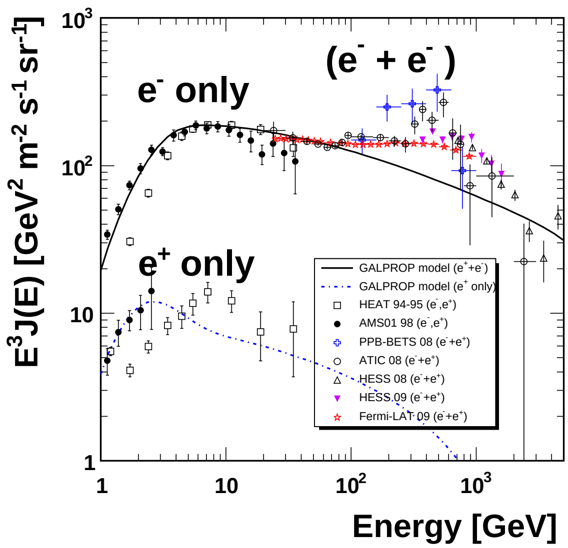

Fig. 1. The energy spectrum of CR electrons as measured by AMS[1], HEAT[2], ATIC[4], PPB-BETS[5], Fermi-LAT[6] and H.E.S.S.[7] experiments. A CR conventional model based on GALPROP codes [8] is included to compare the electron and positron spectra.

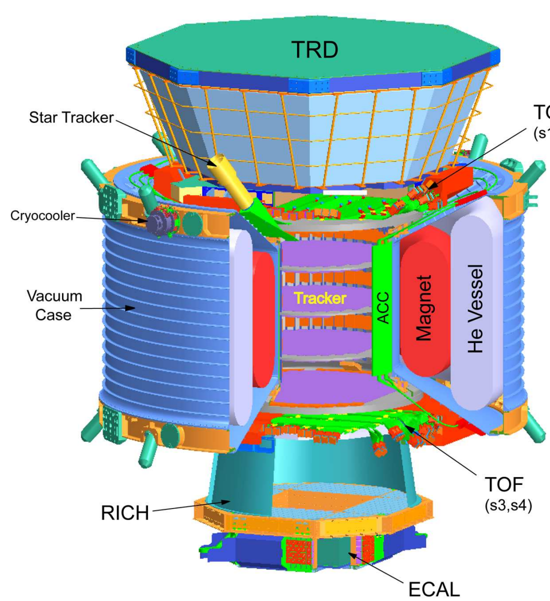

Fig. 2. AMS-02 detector

In AMS-02 the TRD is a key element to improve positron identification from the dominant proton background in a momentum range from 10 to 500 GeV by a proton rejection factor of $10^3 \sim 10^2$ at 90% positron efficiency [10], [11]. In conjunction with the ECAL and Tracker, overall rejection power can be improved to better than 10^6 by distinguishing lateral shower development between electromagnetic showers and wider hadronic showers and matching between shower energy and momentum.

II. AMS-02 TRD

Transition Radiation (TR) is observed as X-rays when a highly relativistic charged particle ($\gamma \equiv E/m > 10^3$) passes through a material with varying index of refraction. In practice, the TRD is used to provide electron separation for 1 GeV $\leq p \leq$ 500 GeV because electrons emit TR whereas protons do not. To provide an efficient X-ray photon absorption a high-Z gas mixture of Xe:CO_2 (80:20) is used.

A. Mechanical Structure

The TRD consists of 20 layers of straw modules interleaved with 20 mm thick fleece radiators supported in a conical octagon support structure. The upper four and lower four layers (yz plane in the AMS-02 coordinates) are parallel to the magnetic field, and the middle 12 layers (xz plane) are perpendicular in order to provide 3D tracking of the CRs.

This detector has 328 individual straw modules and 5248 readout channels. Each straw module is composed of 16 single straw tubes with a diameter of 6 mm and a straw wall thickness of 72 μm. A straw module is closed with two polycarbonate endpieces for gas supply and signal readout. Its mechanical structure is re-enforced by longitudinal and transversal stiffeners. The radiator is made of 10 μm polypropylene/polyethylene fiber fleece with a density of 0.06 g/cm^3. The octagon wall made of carbon-fiber-aluminium honeycomb is the main support structure for radiators and straw modules. It is manufactured with a precision better than 100 μm to center the wires for a gas gain homogeneity better than 2% for 5248 straw tubes in total.

B. Quality Control of Straw Module Production

For use in space, all flight straw modules have to comply with the following requirements: gas-tight, low dark current and high gas gain homogenity performed with an ^{55}Fe radioactive source. A detailed description of the straw module production can be found in Ref.[12].

C. DAQ and Slow Control Electronics

The electronics for the TRD is divided into the 82 Front-End boards (UFE) mounted on the octagon walls, two U-Crates for data acquisition, and one UG-Crate to control the gas supply system.

Each UFE has two VA32 charge sensitive amplifiers to multiplex the analog signals from four straw modules to serial ADCs (AD7476). It has a peaking time of 2.4 μs and the input is linear up to 2000 fC, corresponding to 50 MIPs signals at gas gain of 3000. The nominal gain of the UFE is 2 ADC/fC and its uniformity between channels of the same chip is better than 1%.

The U-Crate [13] includes three UFE power supply boards (UPSFEs), six data reduction boards (UDR2s), six high voltage supply boards (UHVGs) and a high rate interface board (JINF). The power for the UFE is controlled and regulated by the UPSFE. Each UPSFE consists of 14 linear regulators, two Actel FPGAs and slow control circuitry to switch on and off other U-Crate boards. Due to limited usable bandwidth of high level data link (HRDL) interface to the ISS each subdetector uses its own data reduction board based on a common digital part (CDP). The UDR2 comprises two CDPs for redundancy and an interface for 7 UFEs. Each CDP consists of a FPGA and a DSP where data is zero-subtracted and buffered. The UHVG can supply up to 1600 V using 16 stages of Cockroft-Walton voltage mulitplier controlled by LeCroy MHV100 chips.

On request, the JINF sends commands, collects the data from all UDR2 boards and transfers it to the main AMS DAQ system by AMSWire[1]protocol for storage or direct downlink to earth. The time to readout 5248 channels is less than 80 μs and the data processing time is faster than 230 μs/event capable of handling a 10 kHz peak and 4 kHz average trigger rate. Also JINF is connected in parallel by LeCroy links to the UPSFE, UHVG boards and UPD control electronics to control and monitor the crate status.

The power for TRD electronics is generated by custom-made DC/DC converters housed inside the UPD which is connected to the AMS-02 main power distribution system (PDS). Power consumption of the complete TRD electronics is less than 100 W.

To meet the NASA requirements, all of the flight front-end/crate electronics boards went EMI, vibration and thermal vacuum tests without any failure.

D. Gas Supply System

The gas system stores 20.0 kg Xe and 5.0 kg CO_2, filters, mixes, transfers and circulates a weekly resupply of Xe:CO_2 gas losses for at least three years. It can be divided into a supply system (Box S), a circulationn system (Box C) and four gas distribution manifolds. Two mixing circuits from Xe and CO_2 vessels (Box S) convey the gases to the mixing vessel where the required mixture is made using partial pressures. A system of valves allows the transfer of gas from the mixing vessel to Box C. In Box C, two redundent pumps circulate the gas through the TRD volume in order to keep the gas mixed. The CO_2 fraction is monitored with a spirometer by measuring the speed of sound in Box C. Manifolds distribute the gas to the 5248 straw tubes segmented into 10 parallel loops. Each loop has two valves and one differential pressure sensor across a flow restrictor

[1]AMSWire: a serial point-to-point protocol based on IEEEE-1355

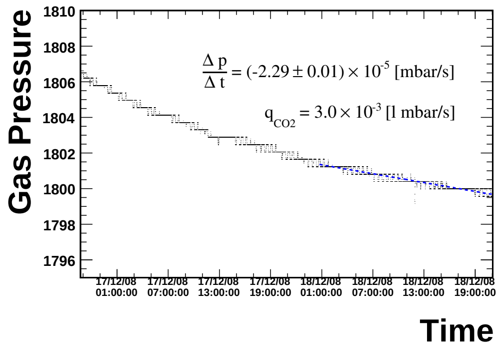

Fig. 3. Gas tightness testing for a TRD gas volume of 230 liter with $ArCO_2$ (80/20) at 1800 mbar and constant temperature of 23.0 $^{\circ}C$. Pressure sensors monitor on both gas inlet(upper black dots) and outlet sides.

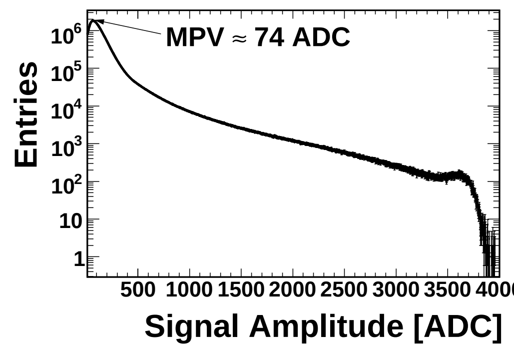

Fig. 4. Distribution of energy deposited on single straw tube by single muon track events. The $ArCO_2$ gas is supplied at a constant flow rate of 1 l/h and the same high voltage of 1400 V is applied after calibration of each UHVG channel.

on inlet and outlet. The manifold pressure sensors are constantly monitored and relevant valves are closed to isolate a loop in case a leak is detected.

III. Performance of TRD during Preintegration

The TRD was fully assembled at RWTH Aachen and successfully integrated into AMS-02 at CERN in 2007. The Tracker, ToF, ACC, RICH and ECAL were also integrated in the main DAQ system for complete detector/trigger operations and data quality monitoring as a whole. From December 2007 to June 2008, AMS-02 has recorded cosmic muons on ground to demonstrate full functionallity of the instrument except of the magnet. The full software chains have been developed in order to reconstruct and analyse the recorded events as well as detector alignment and calibration. Within the framework of the AMS-02 data scheme, slow control data indicating the state of TRD such as measured voltages, currents, pressures, temperatures and performance statistics with operational information were also produced to asses the condition of the experiment. The excellent noise performance, position resolution, occupancy and signal homogeneity is verified by analyzing the collected cosmic muon data.

A. Gas Tightness

The gas leak rate of the TRD is measured by increasing the $ArCO_2$ pressure to 1.8 bar and monitoring the pressure drop as a function of time. Fig. 3 shows the pressure drop as a function of time. Precise pressure sensors with a precision of 0.4 mbar are used to monitor pressure drop at both inlet and outlet. The TRD has a volume of about 230 liters and its leak rate of $(0.30 \pm 0.01) \times 10^{-2}\ l \cdot mbar/s$ is in agreement with individual He pressure drop measurments during module production. This result confirms that the TRD is still gastight to the diffusion level and allows TRD operation in space for 20 years with a gas supply of 25 kg.

B. Muon Signal, Position Resolution and Noise Performance

The muon signal is obtained by using a tracking algorithum, based on a statistical approch for all hit pairs found in the TRD, within the AMSRoot offline software framework. AMSRoot is a CVS standalone distribution for user analysis of AMS data and it provides an object oriented framework for event simulations and reconstructions in the AMS-02 detector [14]. The event selection requires 4/4 layers in ToF, no hit in ACC and track events in Tracker. The implemented tracking algorithm detects single cosmic muon tracks with a tight constraint on number of hits in both xz and yz planes.

Fig. 4 shows a distribution of energy deposited on single straw tubes for selected cosmic muon events. The most probable value (MPV) of the Landau distriubtion is about 74 ADC counts and its monotonic tail extends to the limit of the Frontend dynamic range.

A position resolution is calculated from the width of the residual distribution of the reconstructed hits at tube center with respect to the track fit as shown in Fig. 5. Regardless of the incident particle angles all reconstructed events are included. At signal to noise ratio of 45, the achieved single hit resolution of 2.0 mm is already close to the expected 1.8 mm for a pitch of 6.2 mm. In both xz and yz planes, the position resolution is the same value as designed.

In the normal operation, a noise measurement gives an average value of less than 2 ADC counts corresponding to an equivalent noise charge of 4000 e^{-}. The spread of the noise with common mode noise of 1.6 ADC counts subtracted is in the order of 5% as shown in Fig. 6.

C. Occupancy and Homogeneity

In Fig. 7-(a) an occupancy plot of reconstructed tracks from cosmic muons shows the homogeneous acceptance of the detector.

To examine the signal homogeneity of the TRD, the energy deposited on single straw tube is calculated by considering only good single track events in a subset of

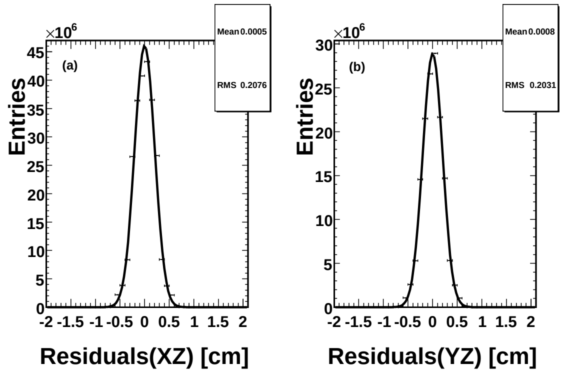

Fig. 5. Distribution of the residuals of the straw tubes from the reconstructed particle tracks in both xz (a) and yz (b) planes. Two resiudal plots are almost identical in the position resolution of 2.0 mm

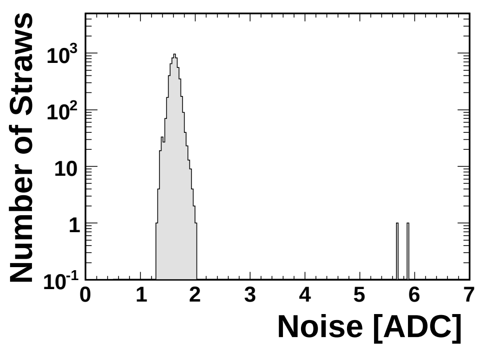

Fig. 6. The distribution of noise for all straw tubes. The average noise is 1.62 ± 0.08 ADC and spread of the noise is within 5% except of two noisy channels out of 5248 channels.

good runs. The homogeneous response to cosmic muons is improved after corrections of HV and UFE calibrations as well as gas density variations in straw modules. As shown in Fig. 7-(b) the signal inhomogeneity is 2.5% which is negligible for the positron/proton separation.

IV. Summary and Milestone

AMS-02 is approved for lauch to the ISS in 2010 and its new data with increased statistics, excellent particle identification and wide energy coverage promise significant advances in the study of CR origin and propagation.

The AMS-02 TRD is designed to achieve excellent positron identification in conjunction with ECAL and Tracker with a proton rejection of better than 10^6 at 90% positron efficiency up to 500 GeV, and 3D particle tracking in 20 layers with a single hit resolution of about 2 mm as well as a signal homogeneity better than 3%.

During preintegration of the detector from December 2007 to June 2008, AMS-02 has continuously recorded cosmic muons without any sign of performance deterioration. The results of a performance study with cosmic muons prove that the TRD fulfills the design requirements.

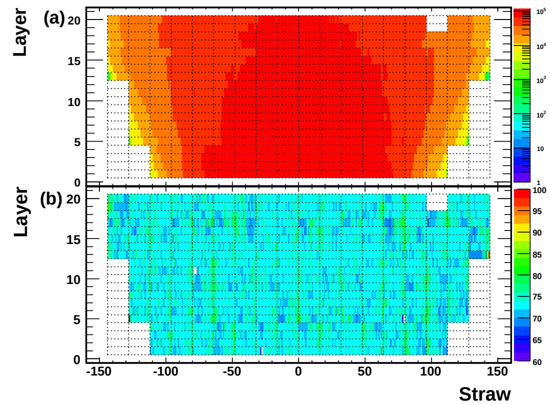

Fig. 7. Track ocupancy (a) and gas gain homogenity (b) with cosmic muons. The obtained average deposited energy is 73.56 ± 1.81 ADC counts and overall signal inhomogeneity is 2.5% after corrections. The palette scales show the number of hit per straw tube (a) and the most probable value of the Landau fit on each straw tube (b). Two straw modules mounted 19th and 20th layers are excluded due to an unstable preamplifier chip which was replaced after preintegration stage.

In 2009 AMS-02 is scheduled to conduct a beam test at CERN and thermal vacuum tests at ESA-ESTEC in the Netherlands. Afterwards it will be delivered to NASA-KSC to prepare for the lauch on flight (STS-134) scheduled for September 2010.

V. Acknowledgment

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