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The AMS microstrip silicon tracker

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Abstract. The Alpha Magnetic Spectrometer is designed for anti-matter and dark matter searches and for cosmic ray measurements in the GeV to TeV range. Its central part is a silicon tracker with 10 μm spatial resolution and a dynamic range of 1 to 100 MIPS for dE/dx measurements. An operational period of 3 years is scheduled on the International Space Station (ISS) starting in 2004. A precursor flight on a Space Shuttle occured in 1998 with a reduced silicon surface of 2 m^2. The construction of the 7 m^2 second phase is in progress. We discuss the design, construction and performance of the detector.

1 Introduction

The AMS will measure the charged particle composition of cosmic rays with an unprecendented sensitivity due to the large acceptance of the magnetic spectrometer (0.5 m^{2}sr) which will be installed on the ISS for three years operation. The AMS has the potential to address such fundamental questions as the existence of antimatter and supersymmetric dark matter. For the detection of antimatter, or a conclusive non observance, the AMS must be able to distinguish a potential antihelium nuclei from $\sim 10^{10}$ particles which will be recorded during 3 years operation.

Figure 1 shows a sketch of the apparatus. A 20-layer transition radiation detector (TRD) will be able to distinguish positrons from protons (or electrons from antiprotons) up to 300 GeV.

Four layers of plastic scintillators (S1, S2, S3 and S4) will provide the fast triggering and a time a flight (ToF) measurement.

Eight layers of double sided Silicon microstrip detectors (Tracker) will measure the trajectories in a 1 Tesla field provided by a superconducting magnet with a zero dipole moment (BL^2 = 1 Tm^2). The tracker also provides charge identification by energy loss (dE/dx) measurement up to Z$\simeq$10. The rigidity resolution $\Delta R/R$ is expected to be at its minimum 2 % at 10 GV and to reach 100 % at 3 TV.

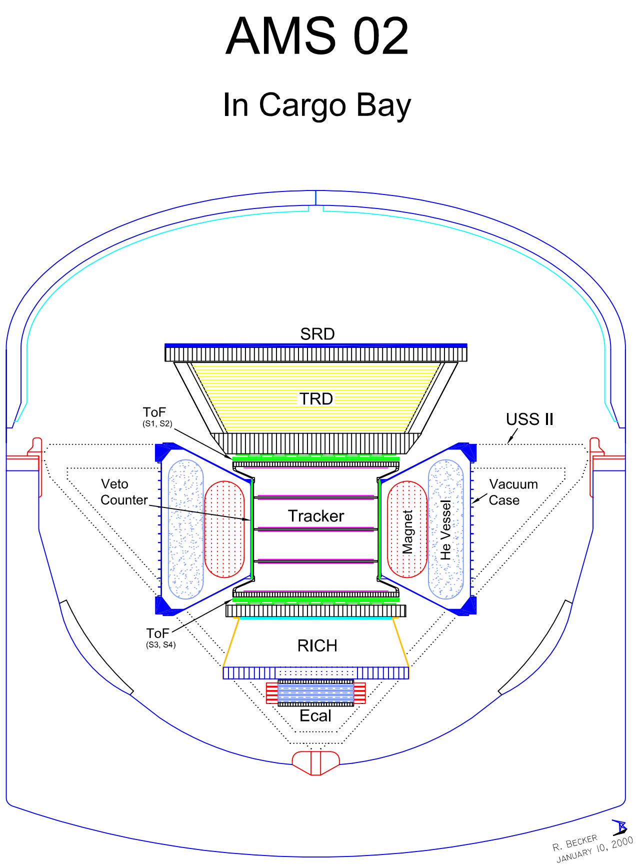

Fig. 1. The AMS02 detector with its support in the cargo bay of the Space Shuttle

Anticoincidence counters (Veto) surrounding the tracker will reject background induced by the passage of charged particles through the magnet.

A ring image Cherenkov counter (RICH) with an Aerogel radiator is foreseen for isotope identification by a precise

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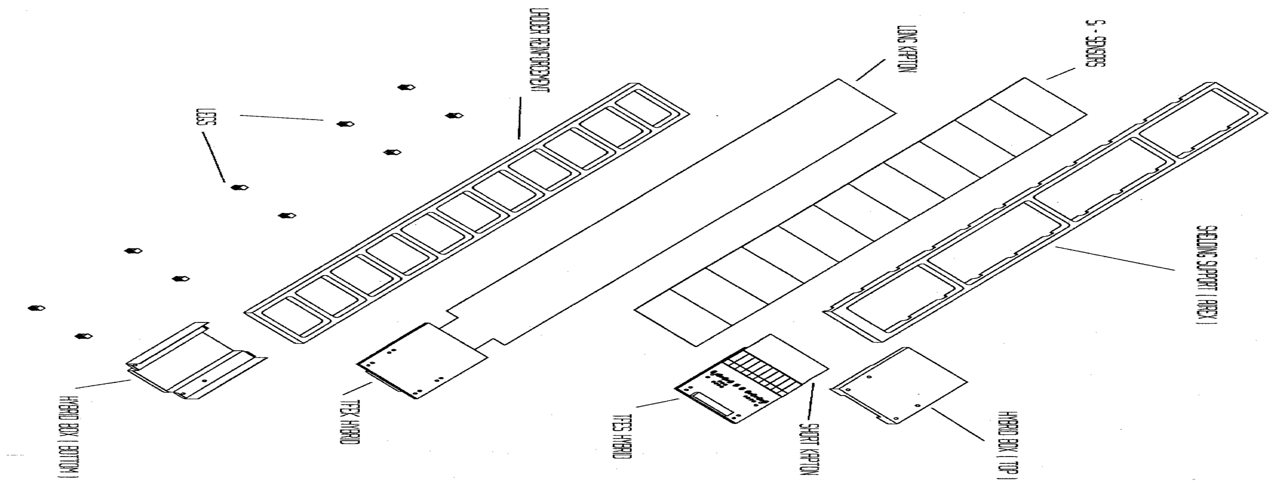

Fig. 2. Exploded view of an AMS silicon module (ladder)

velocity measurement. It will also provide charge identification.

Finally, a 3-D sampling electromagnetic calorimeter (ECAL) will allow, with a reduced acceptance, to separate $e^{\pm}$ from hadrons and to detect photons up to 1 TeV.

A successful 10 days precursor flight (STS-91) on a Space Shuttle occured in 1998 with a reduced detector (AMS-01) without TRD, ECAL and RICH. A magnetic field of 0.14 T was provided by a permanent magnet, the 6-layer tracker had half surface equipped and a threshold Cherenkov counter was installed. The main goal of the mission was MIR docking with AMS as second objective. The detector behaved as expected. Physics results from this flight can be found in ref (Alcaraz, 1999a, 2000a,b,c,d) and at the present conference.

2 The AMS Tracker design

The design of the detector was guided by the severe conditions of space such as mechanical stress at launch, large temperature range and relatively low electrical power available ($\sim$ 2 kW) for the whole experiment. Detailed descriptions of AMS-01 tracker are available in (Alcaraz, 1999b; Burger, 1999).

The AMS-02 tracker (see figure 3) consists of 8 layers of double sided silicon microstrip detectors mounted on very light supporting disks made of carbon fiber and Al honeycomb ($X/X_o = 0.65$ % per layer). Six inner layers of 1 m diameter, mounted on 3 supporting disks, are in the 1 Tesla magnetic field. Two outer layers, with a diameter of 1.25 m, are placed outside the field. The total sensitive Silicon surface is of the order of 7 m^2.

The microstrip sensors are based on the design used for the ALEPH and L3 microvertex detectors at CERN: double-sided sensors of n-type material, with p^+ blocking strips on the ohmic side.

The sensors ($40 \times 72 \times 0.3$ mm^3) have an implantation

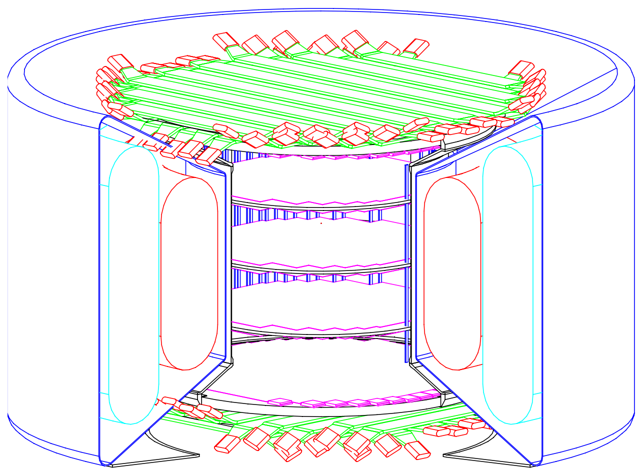

Fig. 3. The AMS02 tracker surrounded by the ToF scintillators and the vacuum tank of the magnet

strip pitch of 27.5 μm on the p-side (bending coordinate) and 52 μm on the n-side (non-bending). The interstrip capacitive coupling allows read-out pitches of 110 and 208 μm.

For biasing and read-out, sensors are organized in 192 modules called ”ladders” (see fig 2) connecting serially up to 15 wafers to the front-end electronics (TFE hybrids). The routing of lines from sensor to sensor is made by 50 μm kapton (Upilex) microstrip cables directly glued on the silicon. The connections (shown in figure 4) are made by microbonds.

The mechanical rigidity is provided by a reinforcement made of Airex foam and carbon fiber sandwich. A thin EMI shielding is wrapped around the ladder.

The front-end electronics (TFE) is protected by an Al box and is fixed to Alu profile bars filled with a highly thermo-conductive material (TPG). These ”thermal bars” provide mechanical fixation and cooling of the TFEs (1 W per ladder). They will be connected to a two phase cooling loop working

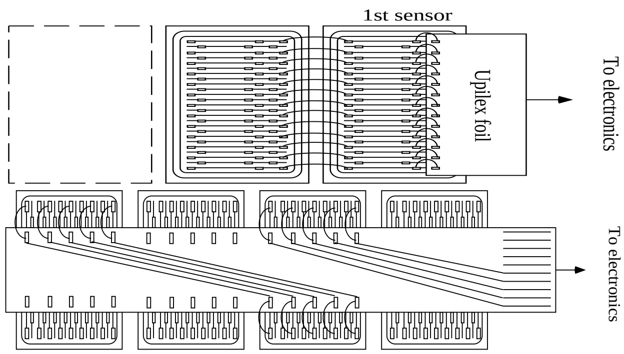

Fig. 4. Sensor to sensor connections

with high pressure CO_2.

3 Electronics

The signal of each connected strip is amplified, stretched and memorized on the front-end board (TFE). In-chip analog multiplexing allows then to route the signal to reduction boards (TDR) where sequential read-out and digitalization take place. The number of channels is 640 for p-side (bending) and 384 for the n-side (non-bending), leading to a total of 196’608 channels for the AMS-02 tracker.

The relative large input capacitance (33-72 pF) and the need of a high dynamic range ($\sim$100 MIP) led to the development of the 64 channel VA_hdr chip based on the Viking. A detailed description of AMS-01 tracker electronics can be found in (Ambrosi, 1999).

Slight improvements are made for AMS-02 by introducing an AD8052 amplifier and a custom-made control circuit on TFE board. The TDR will use BB-ADS803S ADCs allowing a 5 MHz read-out speed. All components were tested for radiation dose of 30 krad representing a safety factor of 10. Tests with heavy ion beams were made for Single Event Effects (SEE).

4 AMS-01 Performance

AMS-01 prototypes were tested with 50 GeV electrons at CERN (Alpat, 1999) and with C ions at GSI (Alpat, 2000; Hou, 1999) for dE/dx studies. We obtained position resolutions better than 10 μm for the p-side, 30 μm for the n-side and a *signal/noise* $\simeq$ 8 for MIPs.

This performance was confirmed for the whole tracker during the STS91 shuttle flight of 1998 (Alcaraz, 1999b; Burger, 1999) and by subsequent tests with particle and ion beams at CERN and GSI. No failure occured during the 10 days of mission in space.

The rigidity resolution for ^4He is shown in figure 5 where the sample contains mainly 4 hit tracks due to the reduced acceptance of AMS-01. Good agreement is seen between the expected resolution for flight data (histogram) and from ^4He beam of known momentum (points). Figure 6 shows the momentum resolution as measured at CERN with 10 GeV/c protons.

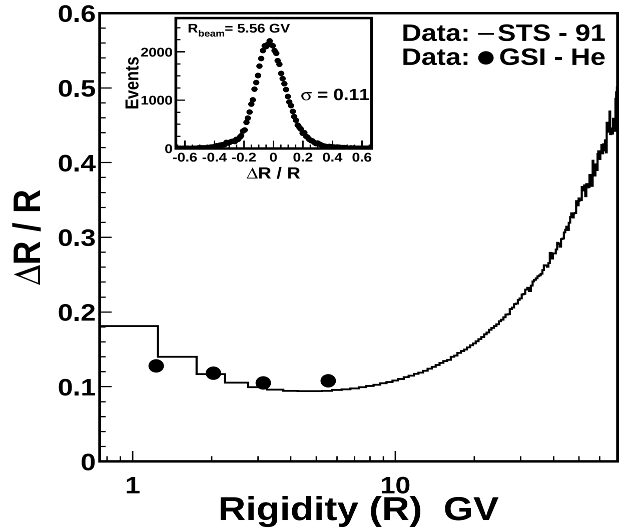

Fig. 5. AMS-01 Rigidity resolution for ^{4}He. Curve is the resolution computed for STS-91 flight events. Dots are measurements from ^{4}He beam at GSI

The particle identification capability using dE/dx can be seen from figure 7, where the agreement between the tracker and the scintillators is shown for proton-Helium separation. Figure 8 shows the quality of the dE/dx measurement of both sides of the detector for the identification of cosmics nuclei.

5 AMS-02 expected performance

Based from the excellent behaviour of the 2 m^2 AMS-01 tracker, only slight design modifications are introduced for its extension to 7 m^2 for AMS-02. The surface of the silicon wafers is now passivated to protect sensitives surfaces during the assembly phases. In order to get a better charge collection, the number of strips on n-side is now divided by two, with a pitch of 104 μm for implantation, keeping 208 μm for read-out.

The electronics is replaced keeping the same philosophy. Slight changes of VA_hdr and of the TFE will simplify the control.

Prototypes of AMS-02 ladders were recently tested in a muon beam at CERN. The expected performance on *signal to noise* ratio and spatial resolution was reached as shown on figure 9.

Thank to the increase of a factor 7 of the magnetic field, of the extension from 6 to 8 layers and of the full coverage of the magnet aperture, the rigidity resolution of AMS-02 will be increased by a factor 7 to 10 compared to AMS-01.

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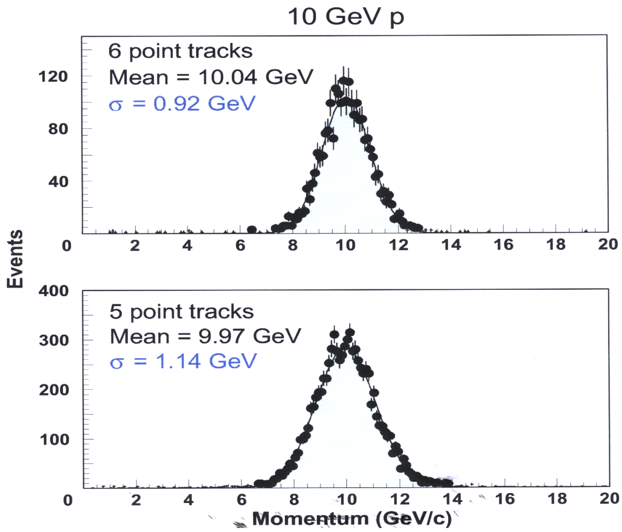

Fig. 6. AMS-01 momentum resolution for 10 GeV/c protons at CERN

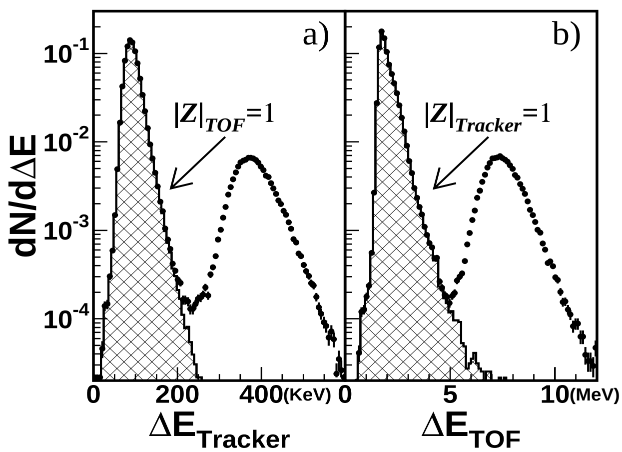

Fig. 7. Proton-Helium separation using Tracker or scintillators dE/dx measurements

Aachen (Germany) and Space Research Laboratory University of Turku (Finland).

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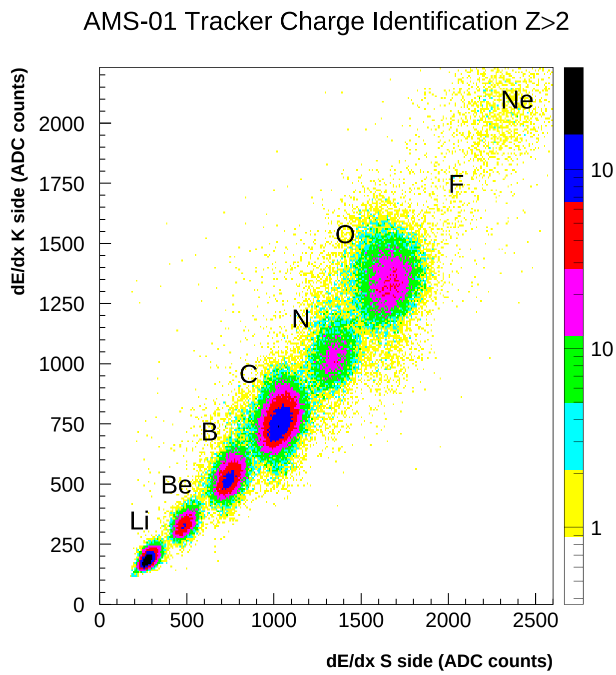

Fig. 8. p-side(S) and n-side(k) charge identification

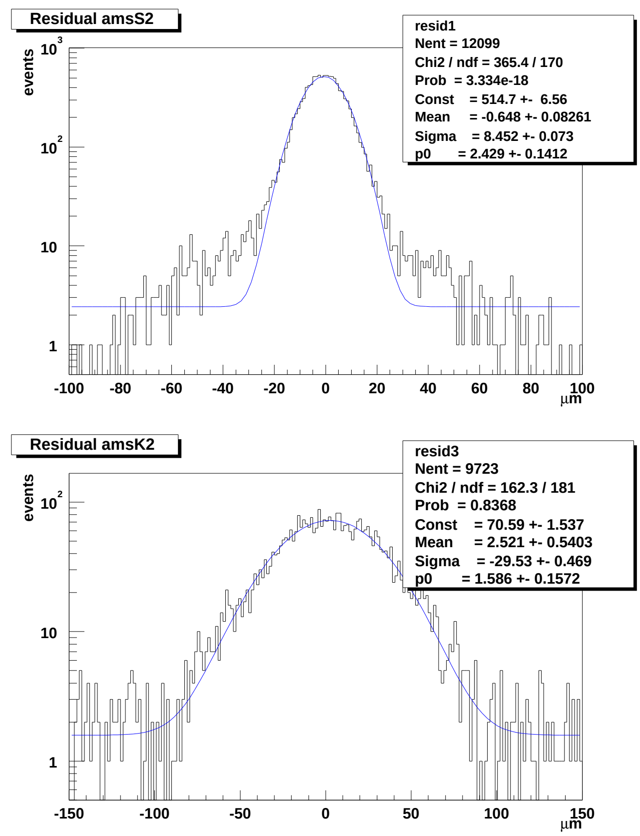

Fig. 9. Residual distribution of hits on a AMS-02 ladder prototype. The resolutions are 8.5 μm and 30 μm on p- and n-side respectively