Design and construction of the AMS silicon tracker

The AMS silicon tracker collaboration

Abstract

The AMS (Alpha Magnetic Spectrometer) is a detector designed to analyse the cosmic radiation at an altitude of 400 km above the Earth, once installed in a few years on the International Space Station.
A precursor flight took place in June 1998. At the heart of this detector is a $6\ m^2$2 silicon tracker. The design and the construction of the silicon tracker will be described.

1 Introduction:

The measurement of the presence of antimatter in cosmic rays has not yet reached a precision capable of really being a challenge to theories of the Big Bang. The reason lies in the fact that such a measurement needs to be performed out (or near the end) of the atmosphere, and requires the presence of a large magnetic volume. To address this very important measurement, the Alpha Magnetic Spectrometer (AMS)[1] has been approved by NASA to operate on the International Space Station Alpha (ISSA). A precursor flight with mission STS91 in June 1998 has been successfully completed to demonstrate the detector capabilities[2].
AMS has been proposed and built by an international collaboration involving China, Finland, France, Germany, Italy, Portugal, Rumania, Russia, Spain, Switzerland, Taiwan and the US.

AMS consists mainly of four parts (see figure): a large magnet ($0.15\,T$, $0.14 T\,m^2$), a silicon tracker, a time of flight system and an aerogel $\check{C}$erenkov counter.
The silicon tracker was preferred against a Time Projection Chamber mainly because of concerns of gas leaks during a very long unattended stay in space.

2 The silicon tracker of AMS:

AMS needs a detector capable of reconstructing very precisely the path of a charged track in a constant magnetic field. The measurement of the $|Z|$ is also needed.
Three planes of double sided silicon are sufficient for reconstructing the helix parameters of a charged track trajectory. As AMS is an experiment aimed at a very precise counting of antimatter particle, it is essential that we never make any mistakes on the sign of the charge of a track. Therefore, we chose to build six planes so that we are able to perform the curvature measurement twice independently. Monte Carlo simulations showed that this will be sufficient for the required maximum misidentification probability (10^{-10}).
The weight allowed by NASA combined with the requirement of maximum possible acceptance determined the size and the shape of the magnet. This fixed the size of each tracker plane to about 1 m^2.
The task was then to design a 6 m^2 silicon tracker able to function in the vacuum of space. The time to the precursor flight being very short (less than 3 years), we decided to re use as much as possible our design for the L3 silicon micro-vertex detector[3] but adapting it to space constrains.
We chose: 70 X 40 X 0.3 mm^3 CSEM[4] double sided silicon detectors. We bonded up to 15 detectors together to form “ladders” (see figure 2), using capton to route the readout of the bottom strips to the end of the ladder. DC decoupling was achieved by CSEM quartz 600 pF capacitors.
The Silicon detectors were delivered by CSEM to Perugia university where they where tested. They were then sent to Finland for a very precise cut. We relied on this cut as a fiducial reference for the assembly of each ladder. The cut sensors could then be distributed to three different places where bonding and gluing was performed: ETH Zurich, Perugia university and Geneva university. All assembled ladders with electronics went then to Geneva for wrapping in the electrical shield, installation on support planes and metrology of the finished planes. Each completed plane was sent to ETH for the tracker final installation inside AMS.
Cosmic rays are not composed of charge 1 particles only. Most particle momentum is below the minimum

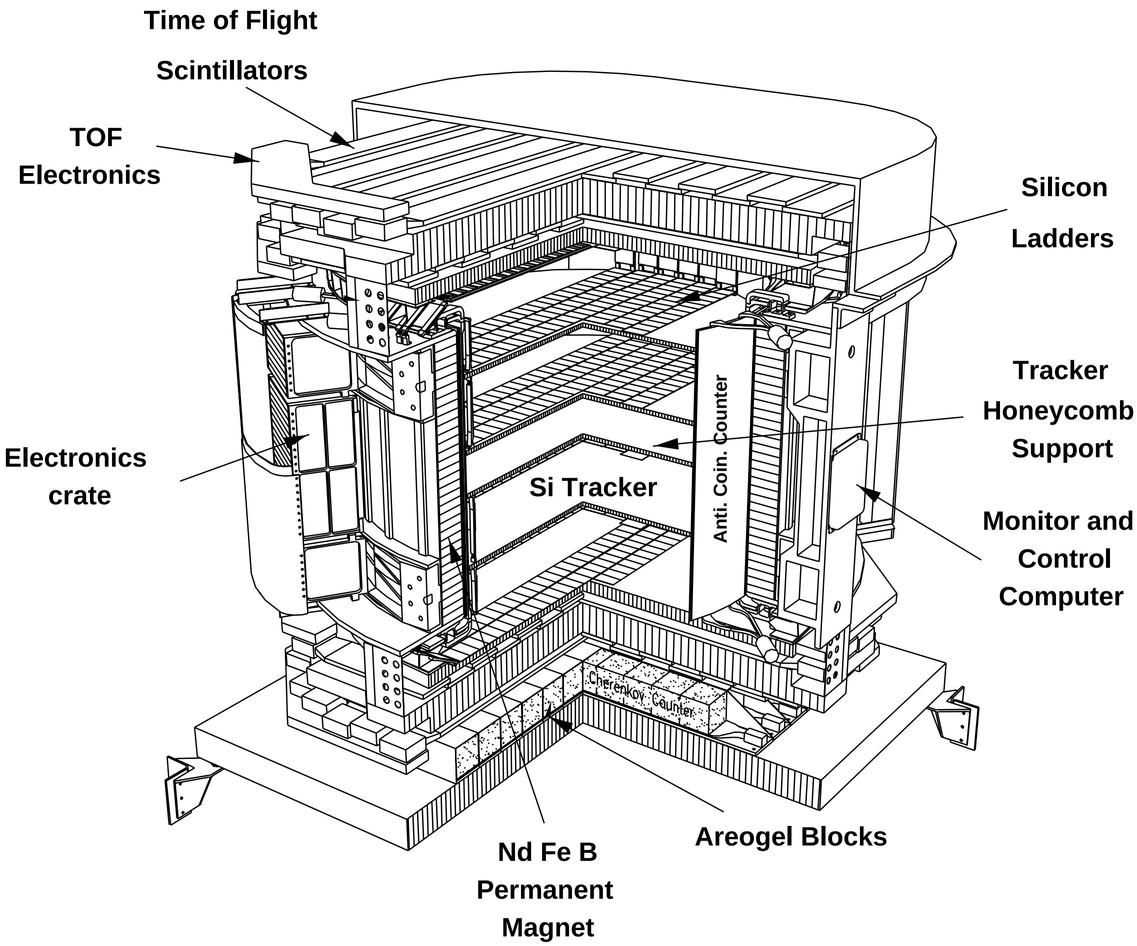

Figure 1: The AMS detector artistic view.

ionisation range. The VA1[5] chip was designed with minimum ionisation particles so not appropriate because of lack of dynamic range. The IDE company built for us the VA HDR (for High Dynamic Range) which basically is the VA1 design, but with less amplification ($0.5\ \mu A/fC$). This allowed us to extend the dynamic range to 100 MIPs. Noise performance was enhanced by a very long ($6\ \mu s$ shaping time). Irradiation tests of this chip showed that it can be subject to latch-ups. This was not a real worry for the precursor flight but we are considering to replace it for the future.

To reduce the power consumption of the tracker (NASA allowed us 1 kW for the full detector of witch 365 W was allocated to the tracker) we decided to read the p side with a pitch of 110 μm and the n side with a pitch of 220 μm. Test beam results showed us that the position resolution was not significantly degraded by the big readout pitch, in particular in the direction where we do not have bending due to the magnetic field.

A big worry was the vibration during the launch. The alignment of a silicon tracker must be understood at the same level as its intrinsic resolution. We decided to vibrate every subcomponent and some partially assembled parts. We have proven for example that micro-bonds do not suffer because of a typical shuttle launch.

As we expected big temperature variations during the flight, the tracker ladders where mounted on a carbon fibre support plate with a zero thermal expansion coefficient. This structure ensured a very solid and stable mechanical assembly with a minimal (0.3$\%$ radiation length) amount of material. Hygroscopic deformation studies where also performed.

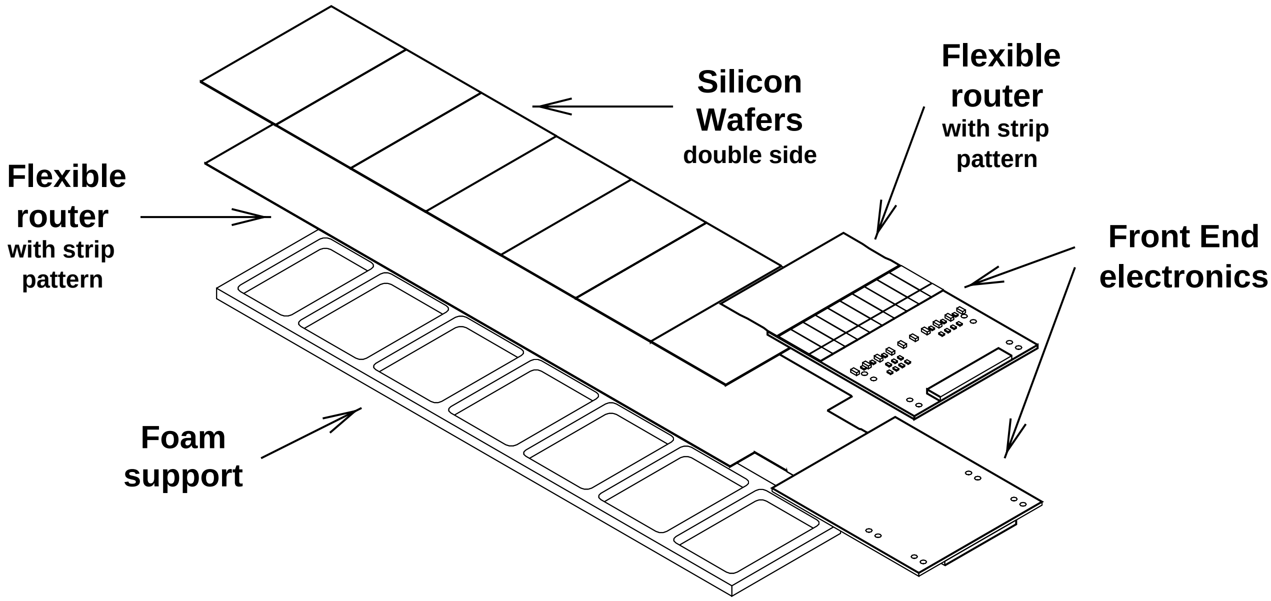

Figure 2: Exploded view of an AMS ladder

The thermal design of the front end electronics had to take into account that no convection exists in space. Contrary to the common belief, ceramic substrates are not needed where power dissipation is not large. A Printed Circuit Board (PCB) substrate with some generous portions of copper devoted to thermal conduction showed a perfect performance. A PCB has many advantages over ceramic: weight, ease of use and cost. Even 100 μm bonding pad pitch on an exposed second layer was possible. PCBs behave very well under vibrations due to their flexibility and lightness.

Possible corona discharges were an initial worry, but the typical voltages found in silicon tracker electronics are not of real concern[6] if the standard practices of conformal coating are followed. Conformal coating of the bonding wires and of the sensors was out of question. The electrical field around a silicon sensor edge does reach the critical level for corona discharge but we insured that the residual gas pressure was low in selecting only low out-gassing materials.

A low electrical power available, power dissipation and minimization of dead time required a completely new data acquisition scheme. Digitizing was done by a CLC949[7]. This ADC is really ideal for space applications: 12 bit 30 MHz for a consumption of less than 70 mW at 5 MHz. We irradiated it to 3 Gray, using a medical cobalt source, and saw no degradation of performance. Unfortunately, its production was discontinued so we will have to find a replacement for the future.

Data compression and acquisition was designed using Analog Devices DSPs and XILINX FPGA. Electrical decoupling between the two sides of the silicon was realized after the data compression, using optocouplers on the digital serial lines.

For the precursor flight, we decided, because of time and budget restrictions, to complete only 2 m^2 of the full tracker. The ladders built where disposed as to maximise the useful acceptance. The performance of the tracker is described in another talk in this conference.

3 Conclusions:

A 2 m^2 silicon tracker for space was constructed. The design started from ”off the shelf” parts from high energy physics. Adaptation to space environment required a lot of extra testing and major changes in the electronics and in the mechanics.

References

[1] S.Ahlen et al., Antimatter Study Group. An antimatter spectrometer in space. NIM A350:351-367,1994.
[2] W.J. Burger, Proc.26th ICRC (Salt Lake City, 1999)
[3] M. Acciarri et al., L3 SMD Collaboration, THE L3 SILICON MICROVERTEX DETECTOR. NIM A360:103-109,1995.
[4] CSEM, Centre Suisse d'Electronique et de Microtechnique SA, Neuchâtel, Switzerland.
[5] CMOS low noise amplifier for microstrip readout, Design and results. NIM A301:506-516,1991.
[6] Requirements for Conformal Coating and Staking of Printed Wiring Boards and Electronic Assemblies. NASA NHB 5300.4(3J) (April 1985)
[7] CLC949 Comlinear, A National Semiconductor Company. 1995.