Integration and qualification of the AMS tracker

Installed May 19, 2011

Divic RAPIN
Département de Physique Nucléaire et Corpusculaire, Université de Genève
Workshop on Quality Issues in Current and Future Silicon Detectors
CERN, Nov 4, 2011
AMS International Collaboration
16 Countries, 60 Institutes and 600 Physicists

based on NASA’s commitment to deploy AMS on the ISS
AMS is a spectrometer installed on International Space Station (ISS) devoted to systematic studies of cosmic ray spectra up to 1TV rigidity and $1 \leq |Z| \leq 26$
Twelve days test flight on board *Discovery* june 1998

*Mission STS-91, last space shuttle docking to MIR space station*

AMS-01 PROTOTYPE DETECTOR

- Permanent magnet (\( m = 0 \))
- Transversal field \( B=0.13 \, [T], L=1[m] \)
- 2 m² of double sided Silicon microstrips
- 6 partially equipped layers
AMS-02 detector designed with a superconducting magnet

- **TRD**: for electron/protons separation at HE
- **TOF**: Scintillators (trigger, TOF and charge ID)
- **ACC**: anti-counters to reject sideways events

- Superconducting magnet (B=0.7 Tesla) with superfluid He cryostat

- **TRACKER** for momentum and Z identification (large dynamic range of energy deposition)

- **RICH**: for Z and isotope identification

- **ECAL**: EM calorimeter for $e^\pm$ ID and $\gamma$ triggering + energy measurement.
Constraints for a detector in space, design principles

- Cooling of electronics is difficult in vacuum (PCB design)
- Mechanical stress due to vibrations (launch: up to 9 G)
- Fast venting ($\Delta P \approx 1$ bar in 1 minute)
- Large variation (~1000) of thermal environment
- No repair possible
- Power and weight are expensive
- Limited control possibilities during operations

- Used of approved material (outgassing, aging, …)

**Mission success:** *(AMS collaboration)*
  - Full reliability of AMS in space environment
  - System design: redundancy in critical components

**Mission safety:** *(AMS + NASA supervision)*
  - Structural plan, thermal design, e.m. compatibility
  - Mechanical, Thermal, Thermo-Vac, EMI/EmC: test on all AMS sub-system prior integration and final TVT/EMI test in the ESTEC ESA facility
  - Detailed integration procedures (ATS) submitted to NASA.
AMS-02 microstrips Silicon Tracker

192 modules (ladders) with 1024 channels each

7 m² of double sided microstrip sensors arranged in 8 layers

- Layer 1
- Layers 2-3
- Layers 4-5
- Layers 6-7
- Layer 8

Vertical thermal bars Al+TPG
Front-end electronics

5 Al/C honeycomb support planes re-used from AMS-01
Tracker cooling system
Mechanically pumped two phases CO2 proposed by B.Verlaat in 2000.

Two circuits with 2 pumps each
AMS-02 Ladders *(tracker modules with 7 to 15 sensors)*

- Hybrid box (top)
- S-hybrid
- Short Upilex (K6)
- K-hybrid
- Hybrid box (bottom)
- Shielding support (Airex)
- Silicon sensors
- Long Upilex (K5 / K7)
- Ladder reinforcement
- Airex foam + Carbon fiber
- Daisy chaining
- Feet
AMS-02 tracker electronics

1/2 TDR (in Tcrate)

L_{GND}: 80V
Shield: 0V
L_{GND}: 0V

GORE RibbonAX quasi-coax. 2-3 m
Qualification at component, prototype or production levels

Electronic components:
  • $V_{A_{HDR}}$: tested with Co60 at SERMS-Terni for total dose.
  • *DSPs, ADCs, OpAmplif, Memories, …*: total dose and SEE+LatchUp cross-sections versus LET were measured at GSI with heavy ions beams. (same batch possible)

Electronic modules: (built at CSIST-Taiwan)
  • Followed the EM, QM, FM scheme.
  • Each piece thermo-cycled and vibrated at manufacturer.
  • Each piece thermo-vacuum and vibration at SERMS-Terni.

Detectors: (thermal)
  • TVT of one prototype.
  • Thermal behavior of hybrids PCBs, box and thermal bars assembly under high vacuum ($10^{-6}$bar).

Mechanics: (vibrations)
  • FE analysis, tests.
AMS-02 ladder vibration (at EPFL 2001)
A PC based system was developed for the test of ladders at various locations and stages of the production and integration.

Tests with Sr90 were also performed on all ladders (UniGe).

Basic test: calibration
Production: Sensors and Upilex cable

41 mm x 72 mm sensors
Thickness: 300 µm
Colibrys SA (+IRST Trento)
Cut: Selmic
Tests: INFN-Perugia
\( \text{(Visual, } I_{\text{Leak}}, I_{\text{strip}}, V_{\text{Depl}}) \)

Bending coord: P-side, Resol: \(~8\mu m\)
Strips pitch: 27.5 µm, Read-out: 1/4

Non-bending: N-side, Resol: \(~8\mu m\)
Strips pitch: 104 µm, Read-out: 1/2

Upilex cables manufactured by CICOREL after CERN AMS1 prototypes

- Double bonding pads allowed several gluing/ungluing and bonding operations.
- Tested at INFN-PG for continuity and shorts.
- Evtl. repaired by bonding.
AMS-02 ladder production

- Gluing: Sensors+Upilex_cables+ reinforcement
- Gluing front-end and bonding of both sides
- Assembly jigs build by INFN PG and UniGe
- 80 % ladders assembled by G&A company
- 20 % by INFN Perugia and UniGe
AMS-02 ladder pre-integration (UniGe) Phase 1

• Visual and electrical test
• Conformal coating and bond gluing
• Add hybrid box and thermal grease
• Gluing of feets
• Electrical test (+ Sr90)
AMS-02 ladder pre-integration (UniGe) Phase 2

- Gluing Airex spacer and wrapping of EM shielding foil
- Storage on storage jig and test (+ Sr90)
AMS-02 ladder repair

- Due to accidents, misplaced sensors or low gain VA’s, repairs were needed and possible (*thanks to double bonding pads*):
- About 200 ladders were built and passed the phases 1-2 of pre-integration.
  - ~20 hybrids front-end were changed
  - ~8 changes of sensors (*de-bond, unglue, re-glue, re-bond*)
  - hybrids repair (*change of VA or capacitors*)
Integration of ladders on support planes
Assembly of the inner tracker (3 inner planes, 6 layers) (UniGe)
Assembly of the inner tracker (3 inner planes, 6 layers)

Thermal connections
Inner cabling
Shell mounting
Remove from jig

Temporary storage of cables
Integration of cooling loops (evaporators) on outer planes and on top side of inner tracker (UniGe)

Cooling loops are fragile and not self supporting. They were kept in jigs for fabrication, storage, transport and mounting.
Installation of top inner cooling loop (evaporator)
Cooling loop on outer planes

Tracker in transport frame.

Test with cosmics with QM electronics Summer 2007
Integration of tracker into AMS spectrometer (CERN)

Two identical vacuum cases were built. During the completion of the manufacturing of the SC magnet, we had the opportunity to make a test integration of all the sub-detectors (without magnet), using the spare vacuum case.

It gave the opportunity to solve and to pinpoint various issues at the interfaces between the components built by various institutes and to test the detector and the DAQ at system level.

*All integration operations at this level had to be described previously in “ATS” documents and approved by NASA.*

- Fall 2007: pre-integration
- June 2008: de-integration
- SC magnet reception and tests
- Fall 2009: Integration
- Feb 2010: Test beam at CERN
- March 2010: EMI/TVT at ESTEC
- April 2010: ....................
Insertion of tracker in the vacuum case bore
Bolting the 4 upper tracker feet
Bolting the 4 upper tracker feet (ATS)

3.3 Add long sliding protections to the cylindrical tracker shell.

3.4 Lift the tracker. Remove the interface blocks fastened below the 4 top feet. Add shims and a layer of high-friction material at each interface below the 4 top feet (as defined by tracker group from VC survey measurements).

Figure 2: Tracker foot interface with Tracker and V-case + guiding pin.

Figure 3: Interface block fastened below the top feet.

Table: Shim package description

<table>
<thead>
<tr>
<th>FOOT</th>
<th>Shim package description</th>
<th>Shim total Thk (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>X+</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Y+</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>X-</td>
<td>0.5</td>
<td>0</td>
</tr>
<tr>
<td>Y-</td>
<td>0.5</td>
<td>0</td>
</tr>
</tbody>
</table>

3.5 Lift and insert the inner tracker in the VC bore, with the crane. Somebody has to watch the insertion clearances from below.

3.6 Deck the inner tracker to the VC without transferring the weight of the tracker to the VC.

3.7 Remove the 2 long guiding pins and mount 4 x 2 fastening bolts to the VC. Temporary tighten the 4 x 2 (8) bolts by hand (use stainless steel non-flight bolts).

Note: longitudinal tracker feet to Vacuum Case flange. This installation is temporary and the bolts will be tightened by hand.

Bolts part # S120-01. Lot # 11611 Exp date: 05.28.23

Apply Bracote on the threads. Lot # 45899 Exp date: 05.28.23
Deploy inner cables and install outer planes

Then, connect evaporator tubing together and to CO2 cooling …
Connect flat cables to the crates (ATS)

“Balcony” to fix the cables to crates

Bolt numbering related to the Balconies only (as shown below)
Connect and fix flat cable
Connect flat cables to the crates

Fit check with next equipment (without MLI)
SYSTEM QUALIFICATION:
December 20th, 2009: SC magnet at 400 A
Systen qualification: AMS in Test Beam (CERN)

Feb 4-8, 2010
Test Beam 2010: momentum resolution of the spectrometer

Feb. 2010, with SC magnet
Journey from CERN to ESTEC
(ESA center at Noordwijk, NL)
Simulation of space conditions (vacuum, temperature and solar radiation)

Feb, March, April 2010
CO2 Cooling (TTCS):
- Functional checks successful
- Condenser: freezing and defrosting tests successful
- Unbalanced radiator temperatures do not influence stability

TRACKER: leakage currents evolution with temperature
TRACKER PERFORMANCES:
a cold muon track & mip signal in silicon

AMS-02 TIM, April 16th 2010, ESTEC
Tracker Performances:
noise in different ambient conditions
Change of Strategy after test at ESTEC (april 16, 2010)

- Measured Helium consumption: $\Rightarrow 20 \pm 4$ months of SC magnet operation
- Refilling is not an option (AMS will stay on ISS)
- ISS life and operation time is extended ($\Rightarrow 2020, 2028$ ?)
- Availability of a $2^{nd}$ cylindrical support (spare vacuum tank) + AMS-1 magnet
- $\Rightarrow$ The exposure time can be multiplied by a large factor.
Tracker geometry is modified in order to increase the lever arms to compensate the lower field, maintaining performance at high energy.

… On démonte, on modifie et on remonte …
Design curves for SC and PM tracker resolution ….

Real curves after beam test final analysis and muon data taking
First tracker plane above the TRD (cooled by deep space)

Modification of the lower evaporator to cool the last plane (new) between RICH and ECAL
7 août 2010
(après modification de l'arrangement des plans du tracker)
AMS in Test Beam with permanent magnet  8-20 Aug 2010
With e+, e- and protons
Calibration with 400 GeV protons

<table>
<thead>
<tr>
<th>Particle</th>
<th>Momentum</th>
<th>C1/C2 Pr (Bar)</th>
<th>Min Events Per Pos</th>
<th>Spills Per Pos</th>
<th>Time (hrs) Total</th>
<th>Positions</th>
<th>Rate (p/sp) Expected</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^6$</td>
<td>75</td>
<td>1</td>
<td>Center, 5°</td>
<td>20k</td>
<td>Initial Setup</td>
</tr>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^4$</td>
<td>3</td>
<td>5</td>
<td>TRACKER60</td>
<td>20k</td>
<td>Inner Tracker Alignment</td>
</tr>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^4$</td>
<td>7</td>
<td>1</td>
<td>TRACKER10</td>
<td>20k</td>
<td>Laser Correlation</td>
</tr>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^4$</td>
<td>3</td>
<td>30</td>
<td>TRACKER416</td>
<td>20k</td>
<td>Layers 1/9 Alignment</td>
</tr>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^4$</td>
<td>3</td>
<td>6</td>
<td>TRACKER80</td>
<td>20k</td>
<td>Layers 2/9 Alignment</td>
</tr>
<tr>
<td>Protons</td>
<td>400 GeV</td>
<td>2/2</td>
<td>$10^4$</td>
<td>3</td>
<td>24</td>
<td>TRACKER280</td>
<td>20k</td>
<td>Layers 1/8 Alignment</td>
</tr>
</tbody>
</table>
Preliminary results: TRACKER

Other detectors performances did not change
23-24 août 2010: departure from CERN to GVA airport and loading in a C5-Galaxy airplane. Direct flight to Kennedy Space Center
AMS installed on the ISS Truss and taking data
May 19, 2011

In SSPF ready to be installed in cargo bay

STS-134 launch
May 16, 2011
@ 08:56 AM