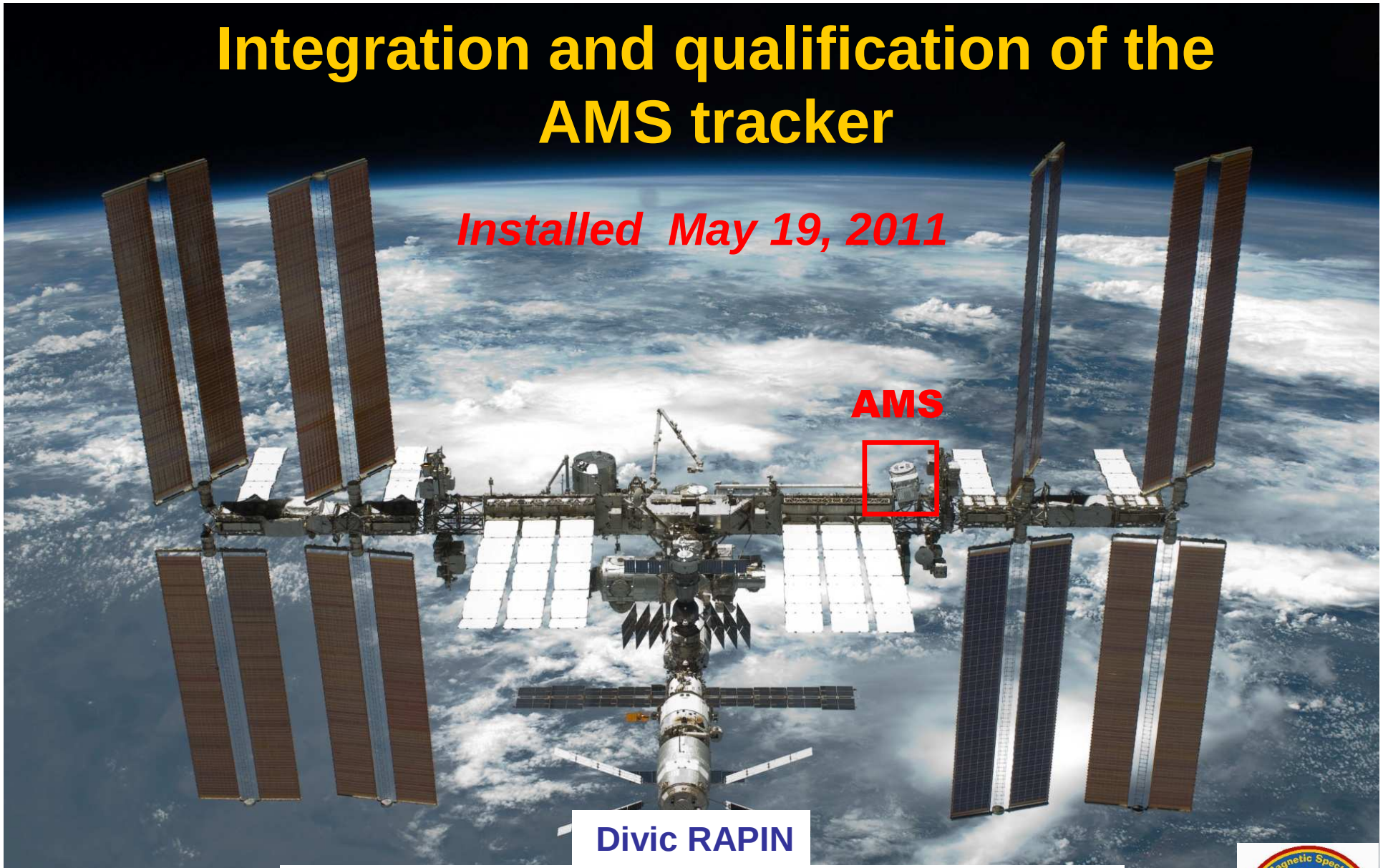
Integration and qualification of the AMS tracker



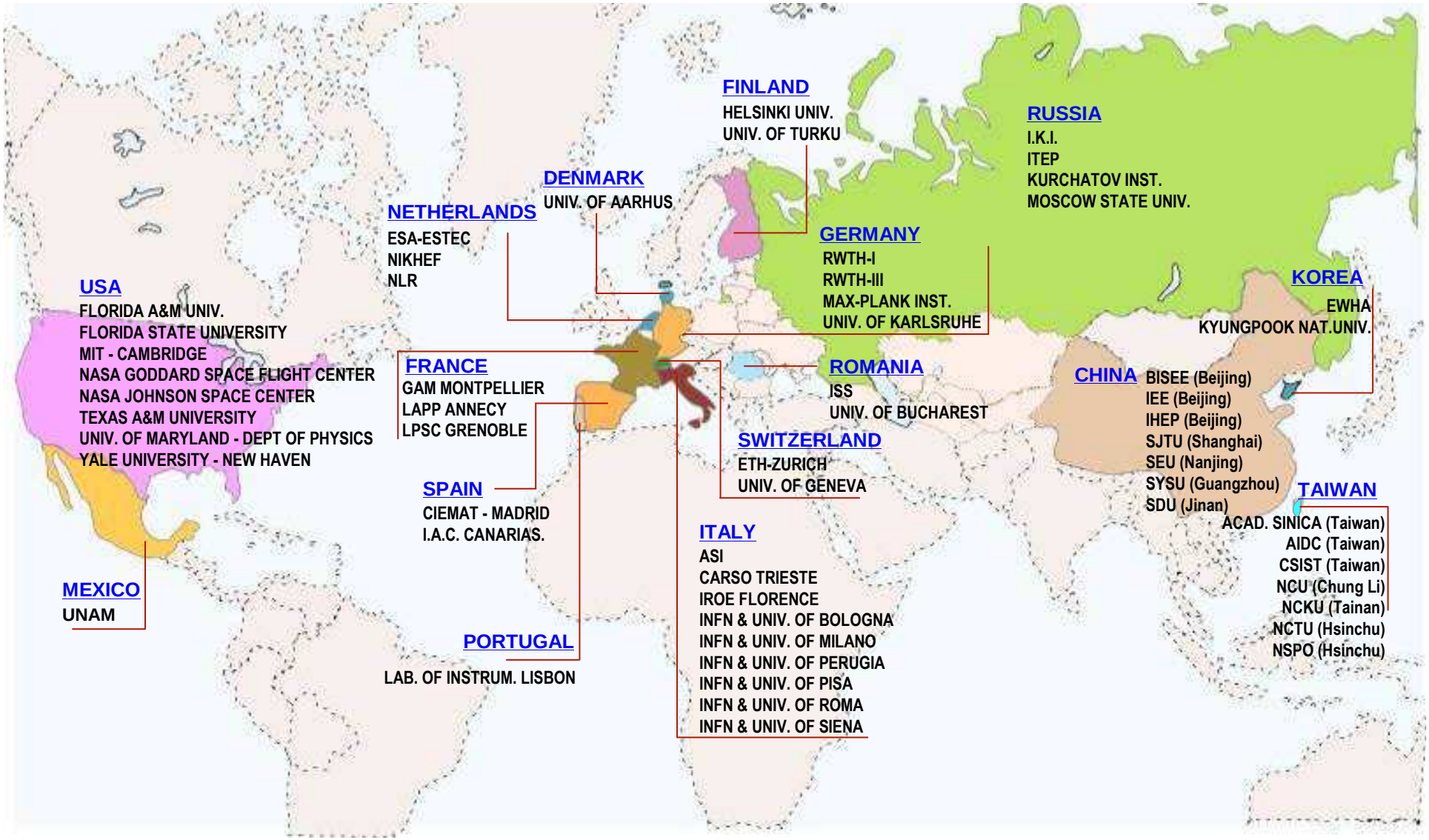
Divic RAPIN

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

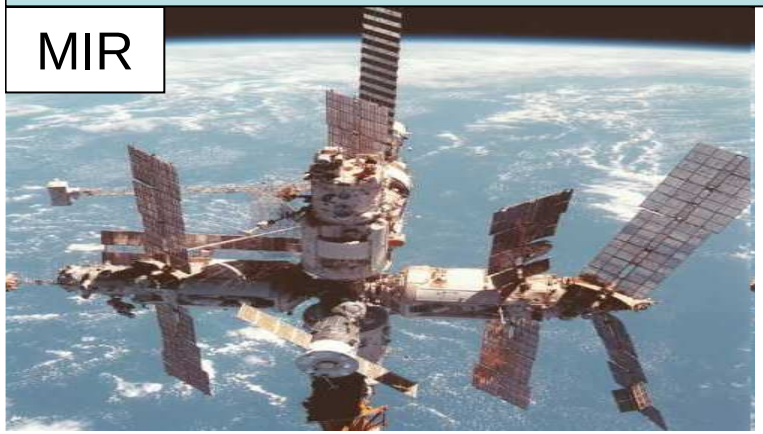
AMS is a spectrometer installed on International Space Station (ISS) devoted to systematic studies of cosmic ray spectra up to 1TV rigidity and $1 \leq |Z| \leq 26$

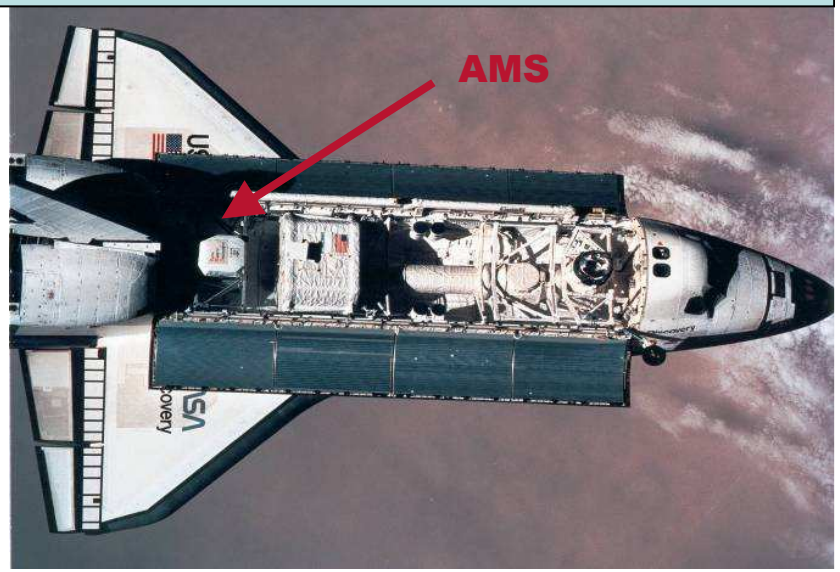
OUTLINE OF THE TALK

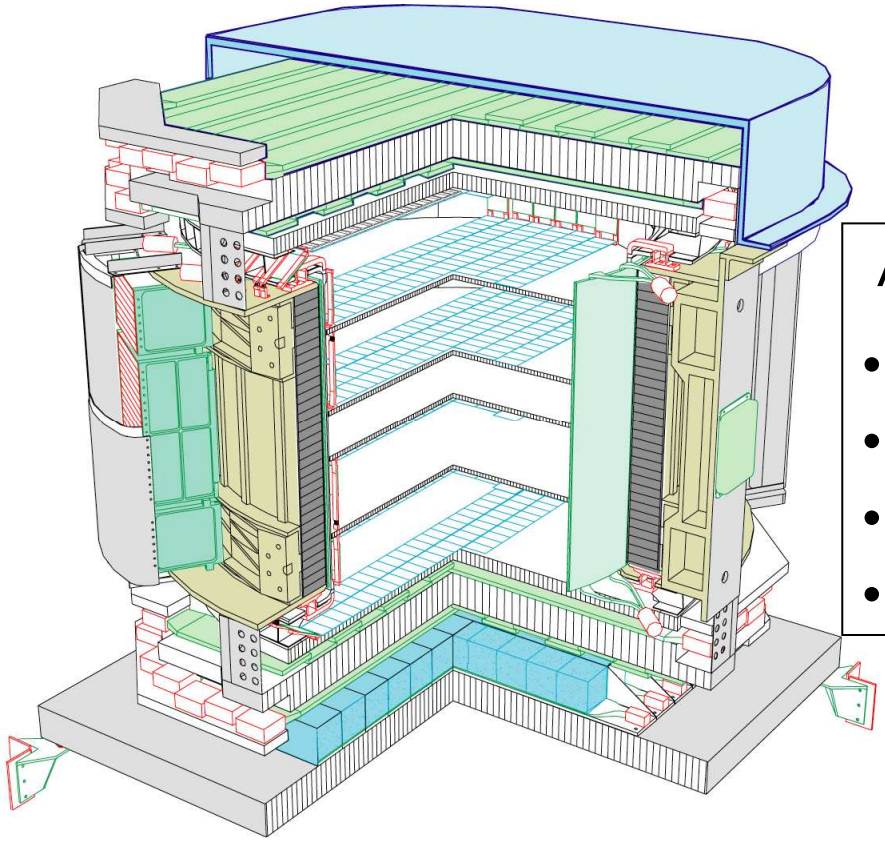
- History & Description of AMS
- Constraints for experiment in space
- Tracker hardware description (+ cooling)
- Space qualification (components, prototypes)
- Pre-integration of ladders
- Integration of ladders on planes
- Integration of planes into tracker
- Integration of tracker into AMS.
- System qualification
- Last minute changes
- System qualification

Twelve days test flight on board *Discovery* june 1998

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



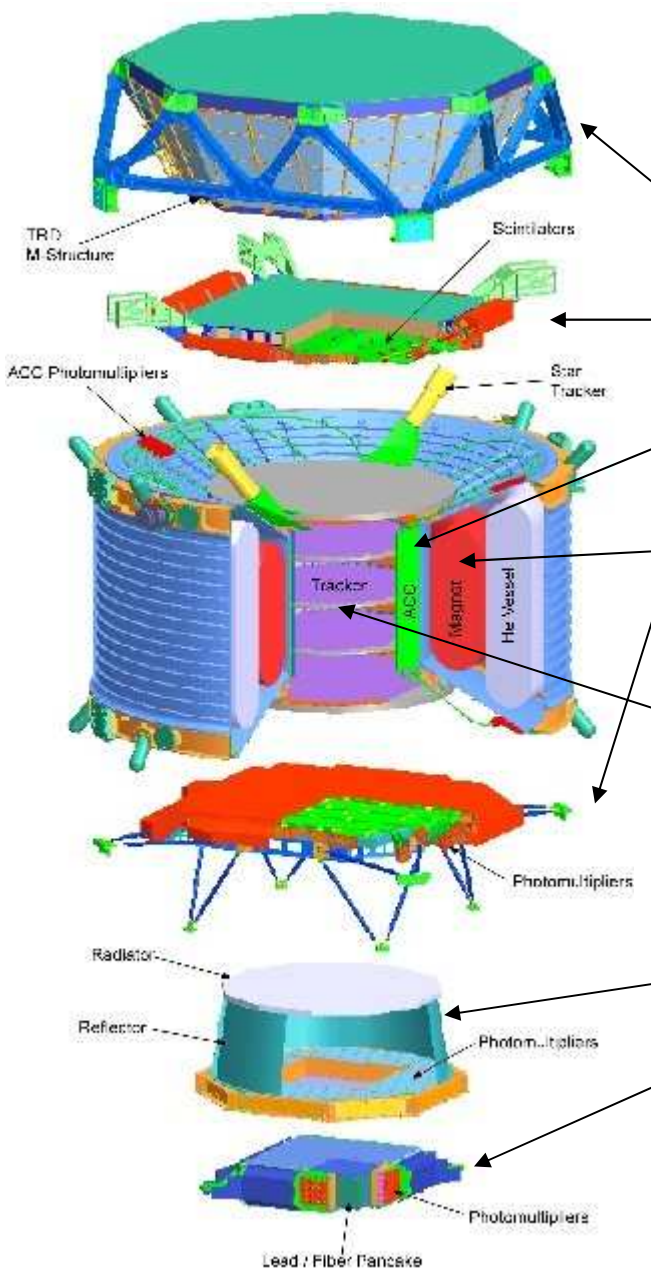




AMS-01 PROTYPE DETECTOR

- Permanent magnet ($\vec{m} = 0$)
- Transversal field B=0.13 [T], L=1[m]
- 2 m^2 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 sideway 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* γ *triggering + energy meaurement.*

Constraints for a detector in space, design principles

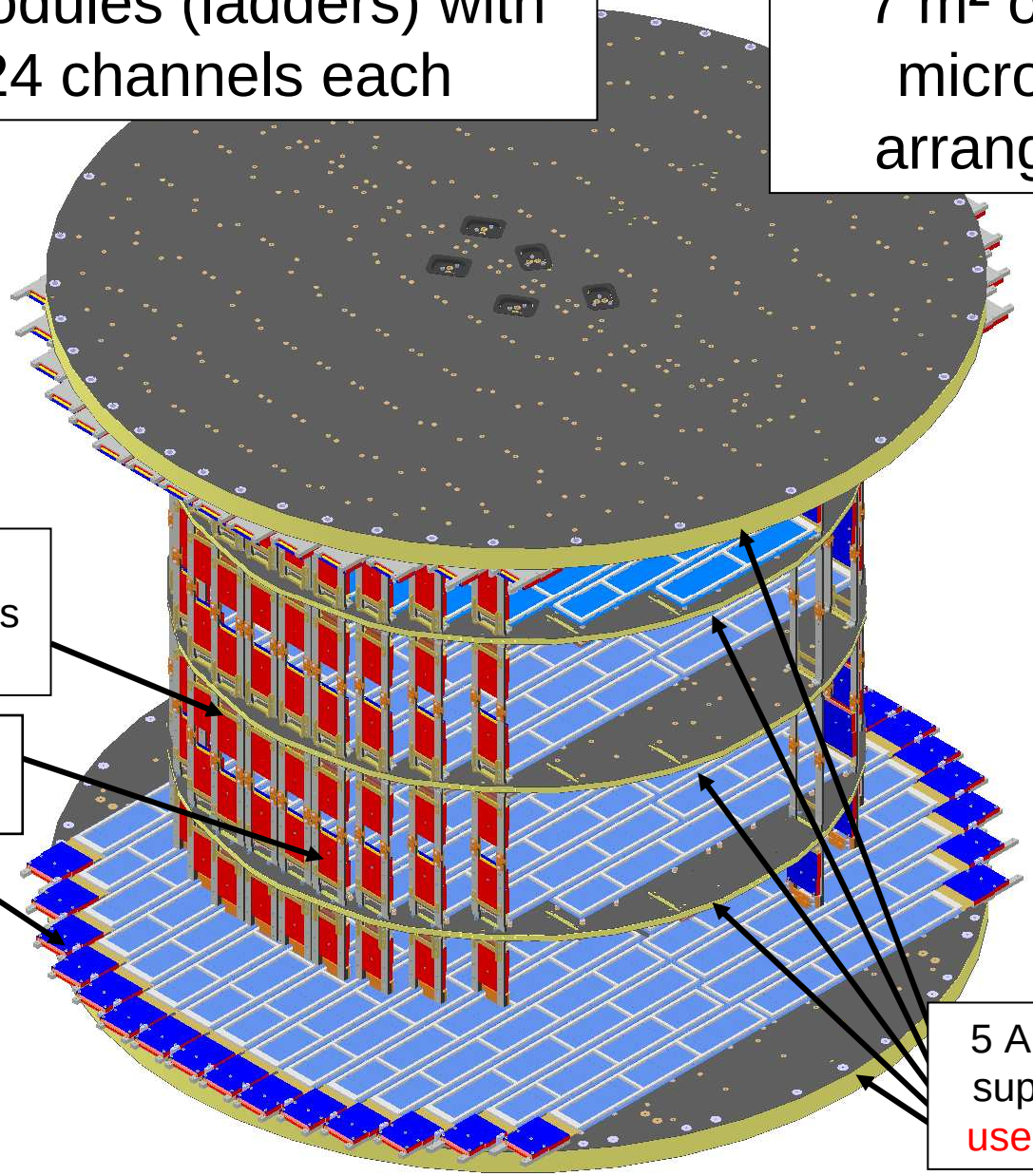
- Cooling of electronics is difficult in vacuum (PCB design)
- Mechanical stress due to vibrations (launch: up to 9 G)
- Fast venting ($\Delta P \approx 1$ bar in 1 minute)
- Large variation (~100^0) of thermal environment
- No repair possible
- Power and weight are expensive
- Limited control possibilities 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 supervison)*
  - 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



Vertical thermal bars Al+TPG

Front-end electronics

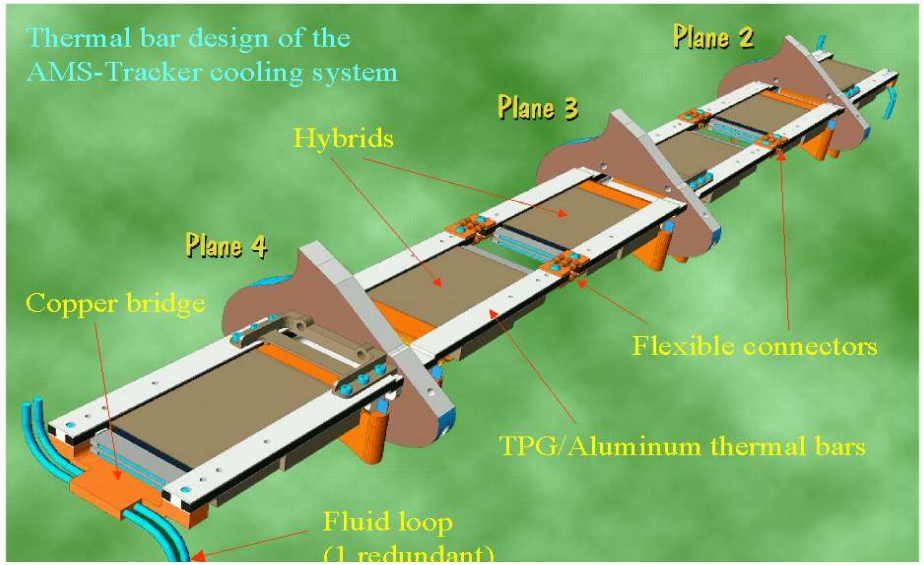
- **Layer 1**
- **Layers 2-3**
- **Layers 4-5**
- **Layers 6-7**
- **Layer 8**

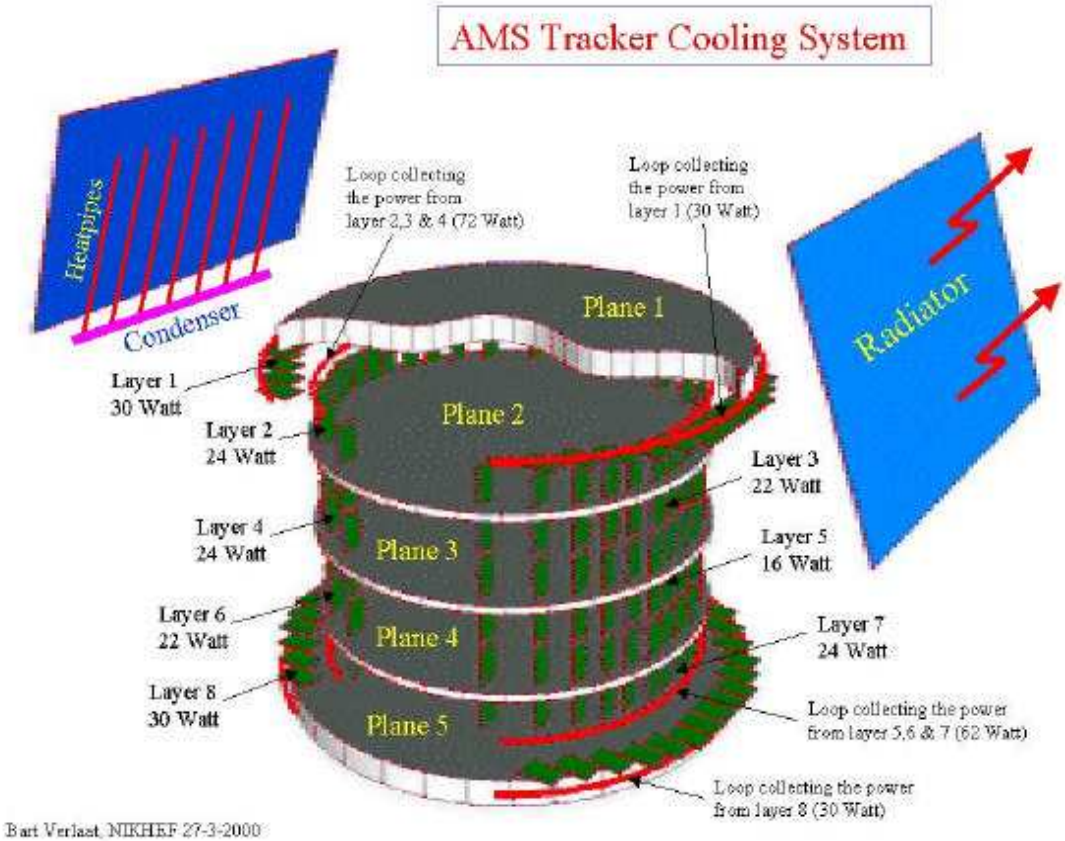
5 Al/C honeycomb support planes re-used from AMS-01

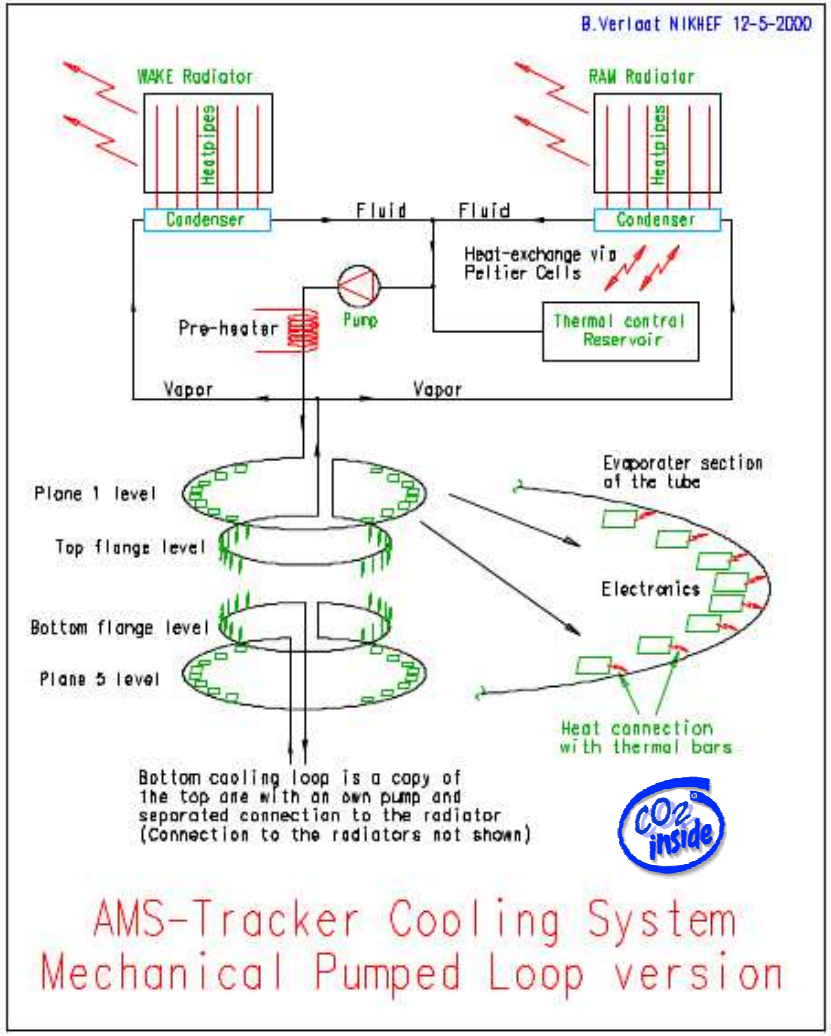
Tracker cooling system

Mechanically pumped two phases CO2 proposed by B.Verlaat in 2000.

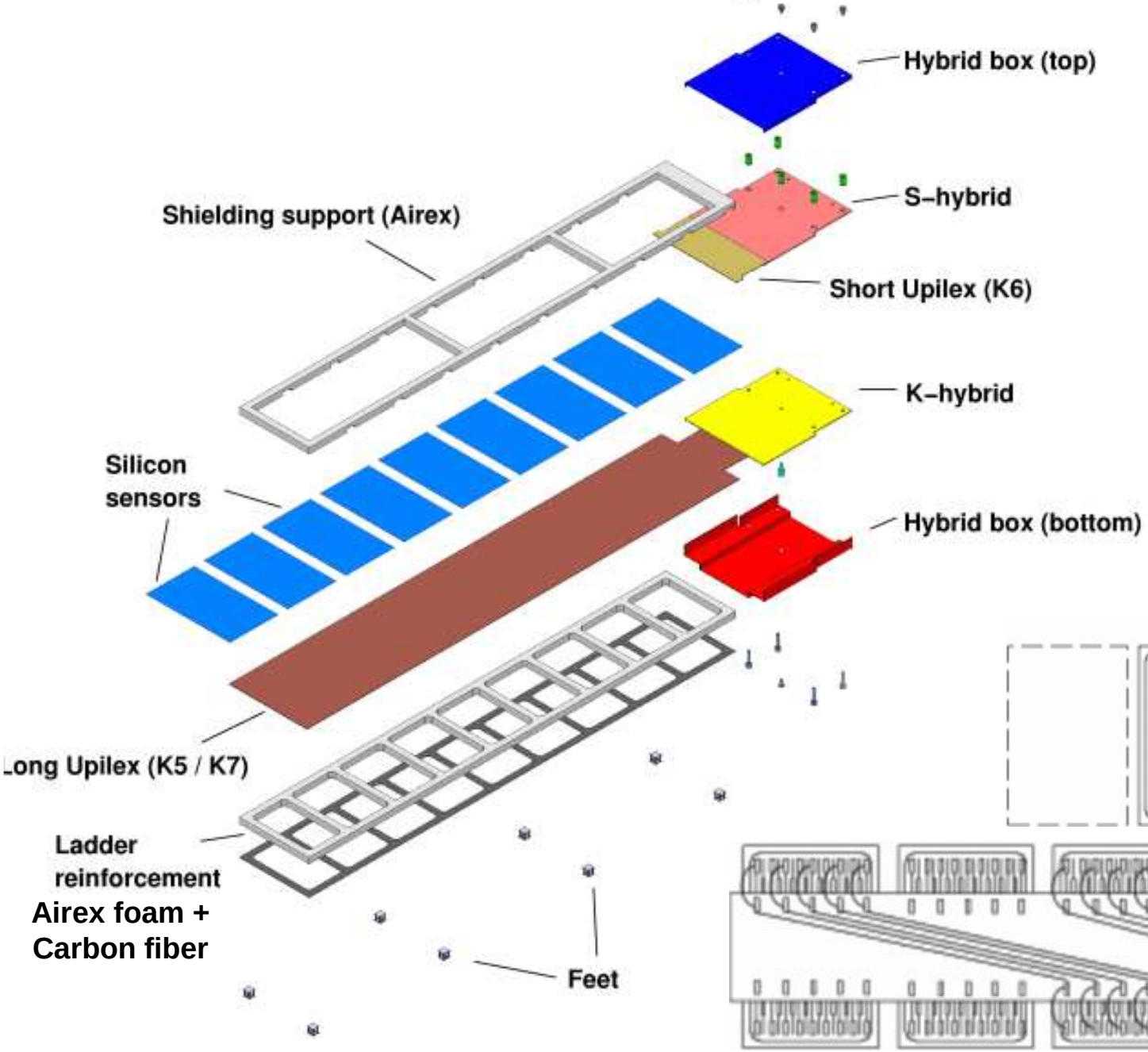
Two circuits with 2 pumps each



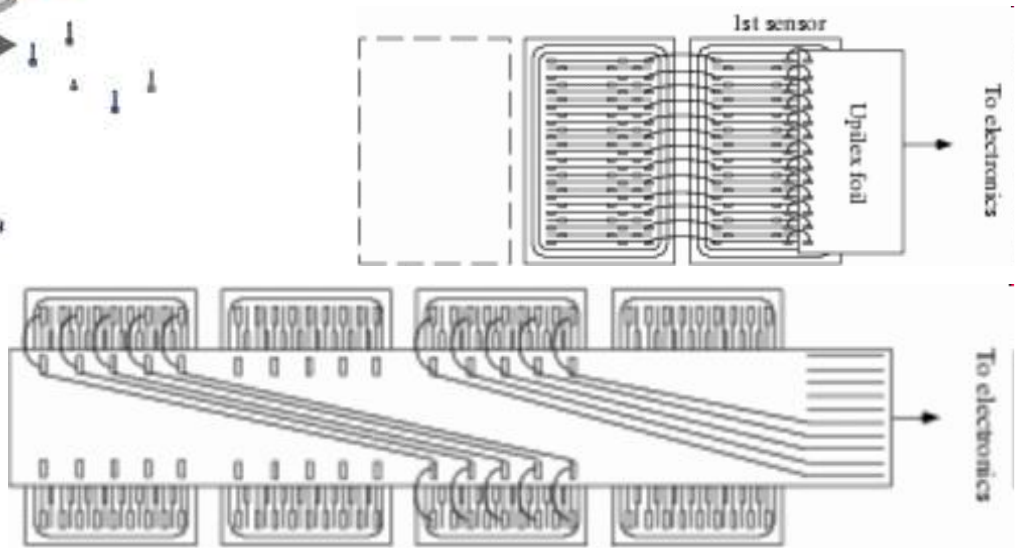




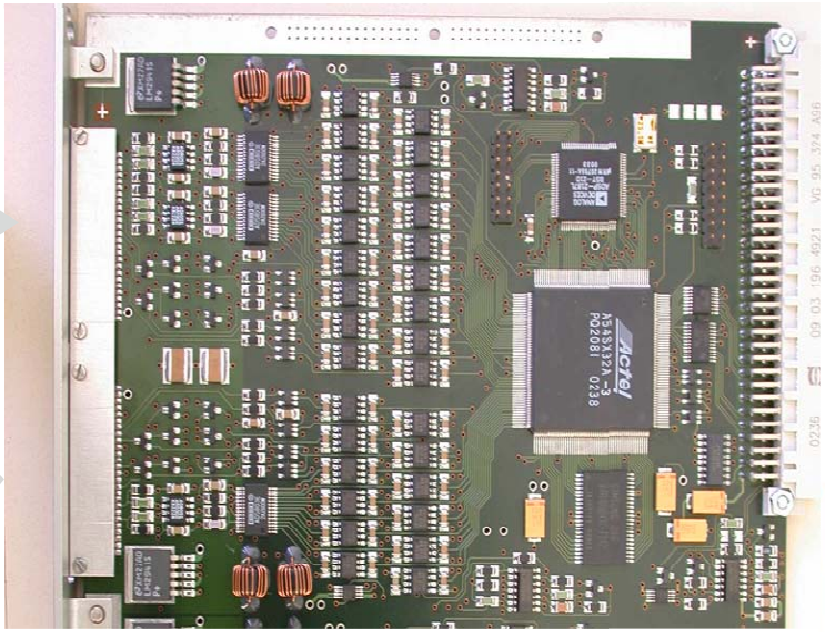
AMS-02 Ladders *(tracker modules with 7 to 15 sensors)*



Daisy chaining

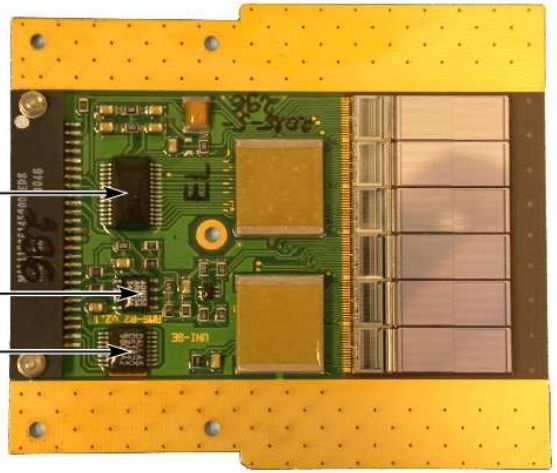


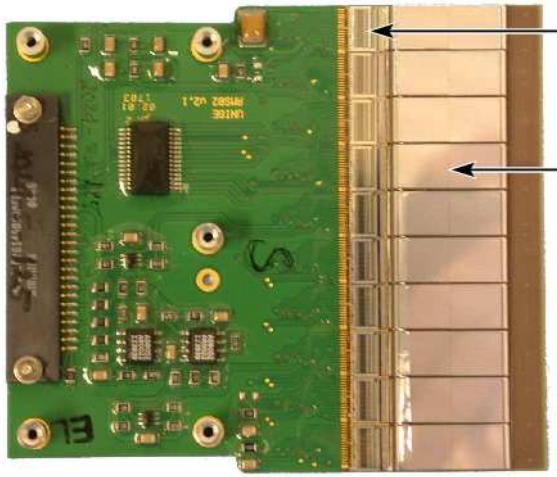
AMS-02 tracker electronics



½ TDR (in Tcrate)

Front-end (hybrids)





L_{GND}: 80V

Shield: 0V

L_{GND}: 0V

GORE RibbonAX quasi-coax. 2-3 m

Qualification at component, prototype or production levels

Electronic components:

- *VA_{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 haevy 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.

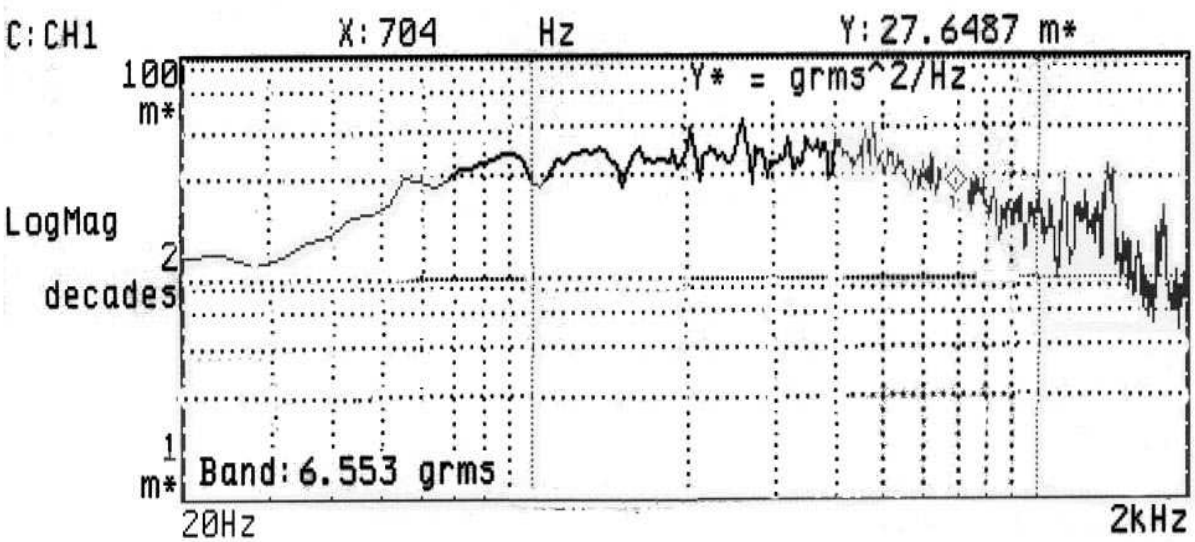
Detectors: (thermal)

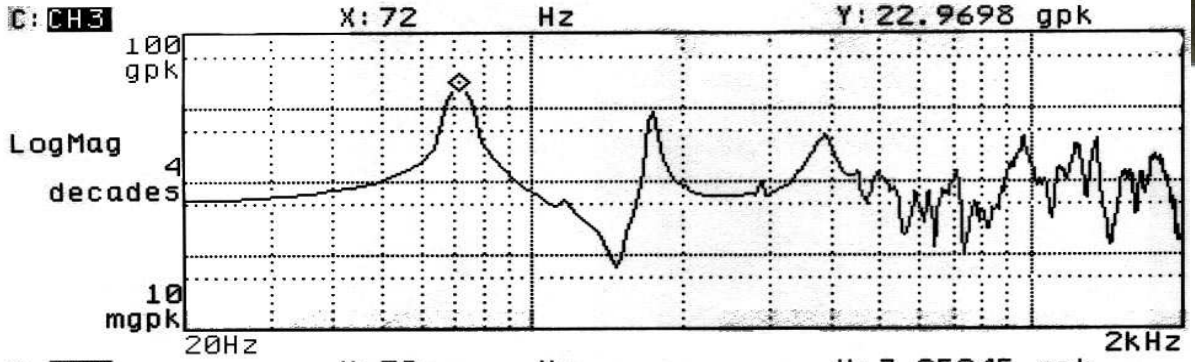
- TVT of one prototype.
- Thermal behavior of hybrids PCBs, box and thermal bars assembly under high vacuum (10^{-6}bar).

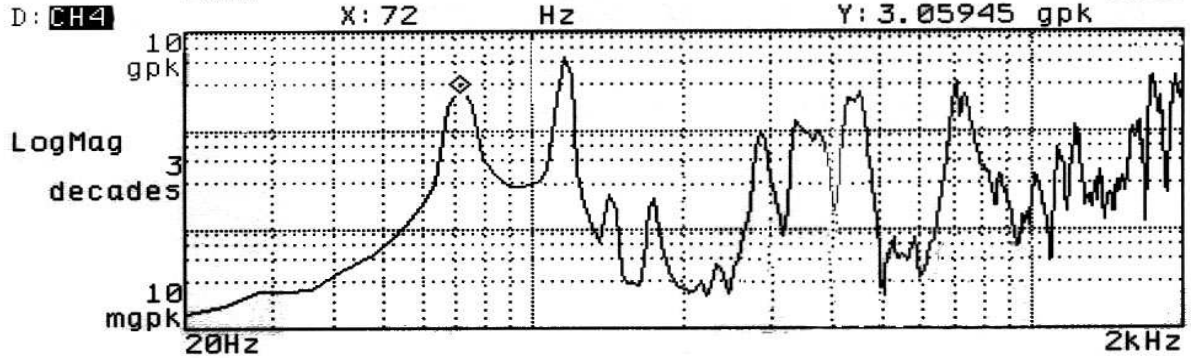
Mechanics: (vibrations)

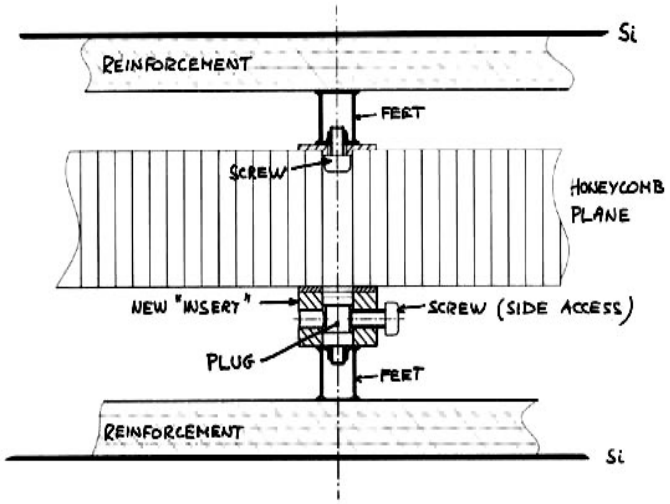
- FE analysis, tests.

AMS-02 ladder vibration (at EPFL 2001)



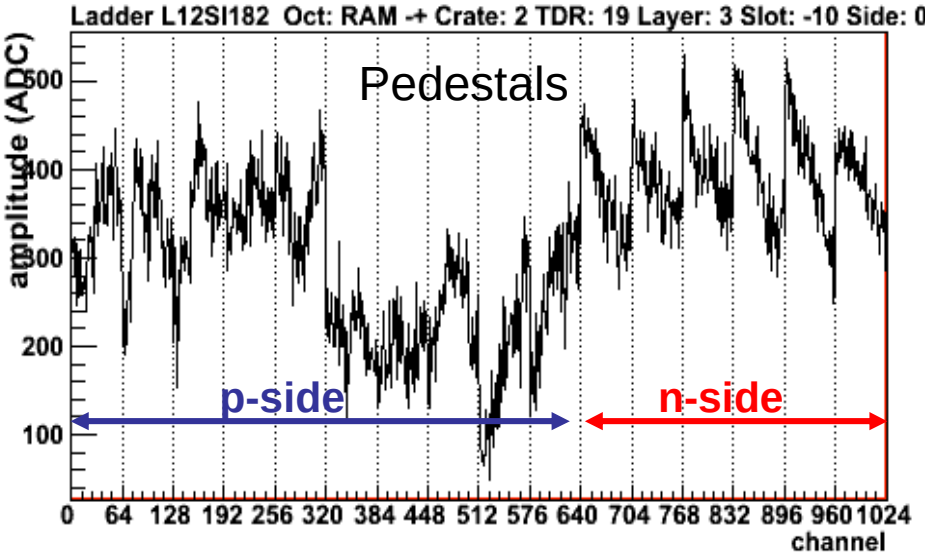




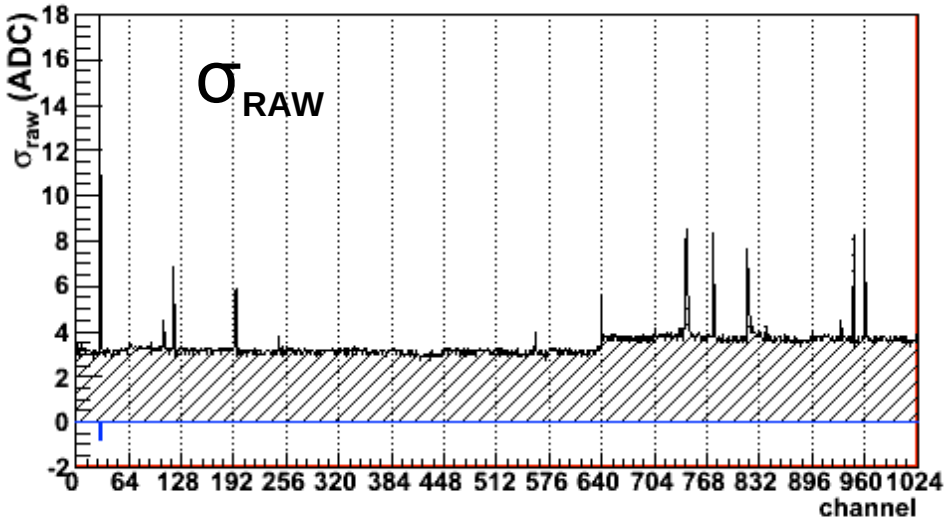


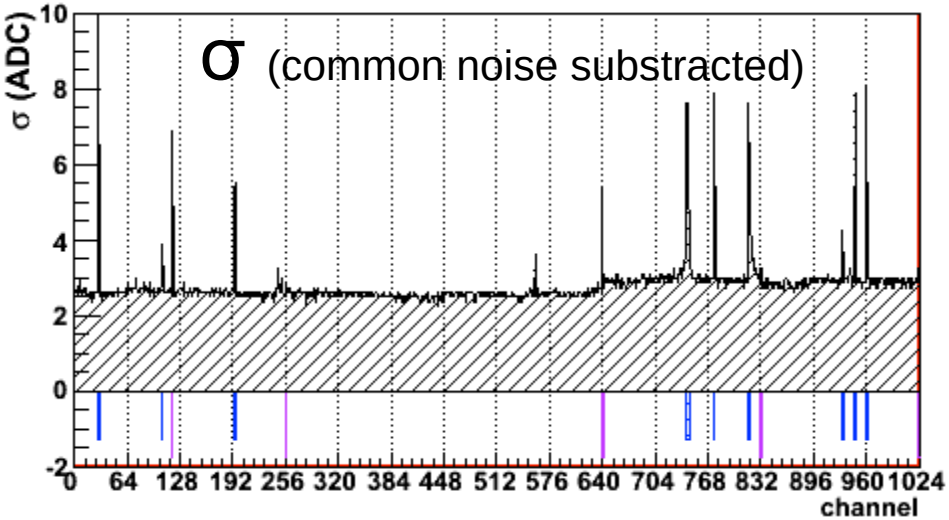
Test system for production and integration

A PC based system was developed for the test of ladders at various locations and stages of the production and integration



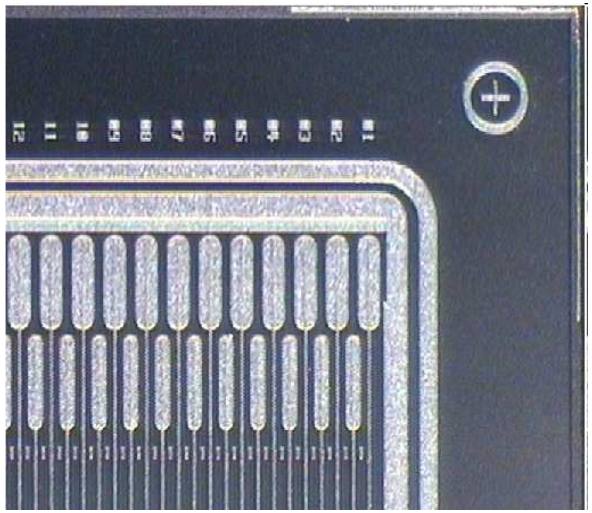
Basic test: calibration





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

Production: Sensors and Upilex cable



41 mm x 72 mm sensors

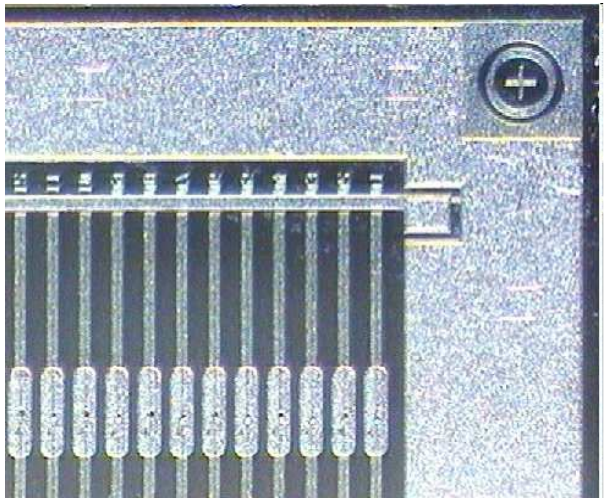
Thickness: 300 µm

Colibrys SA (+IRST Trento)

Cut: Selmic

Tests: INFN-Perugia

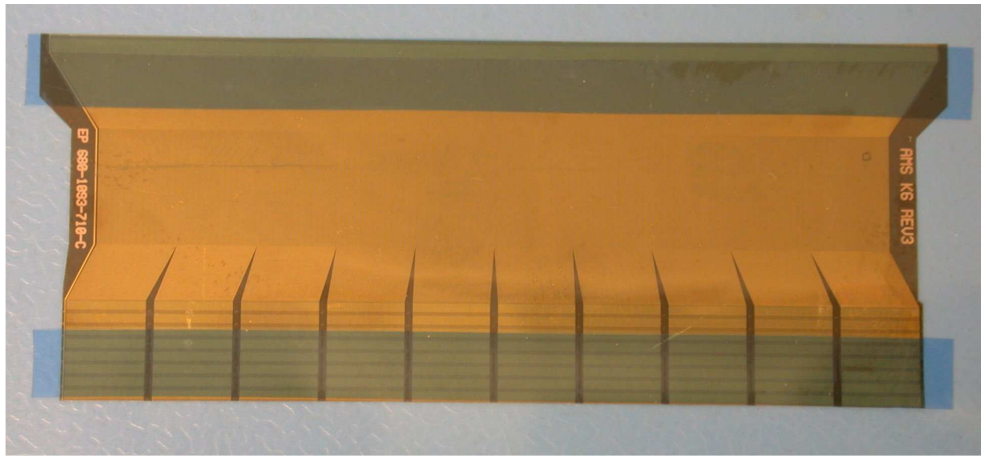
(*Visual*, I_{Leak}, I_{strip}, V_{Depl})



Bending coord: P-side, Resol: ~8µm
Strips pitch: 27.5 µm, Read-out: 1/4

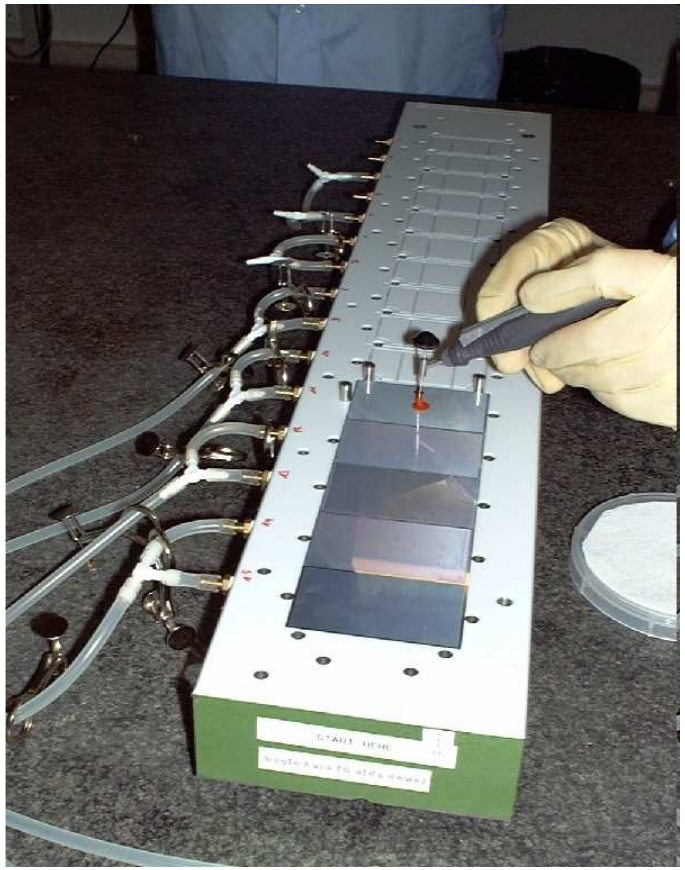
Non-bending: N-side, Resol: ~8µm
Strips pitch: 104 µm, Read-out: 1/2

Upilex cables manufactured by CICOREL after CERN AMS1 prototypes

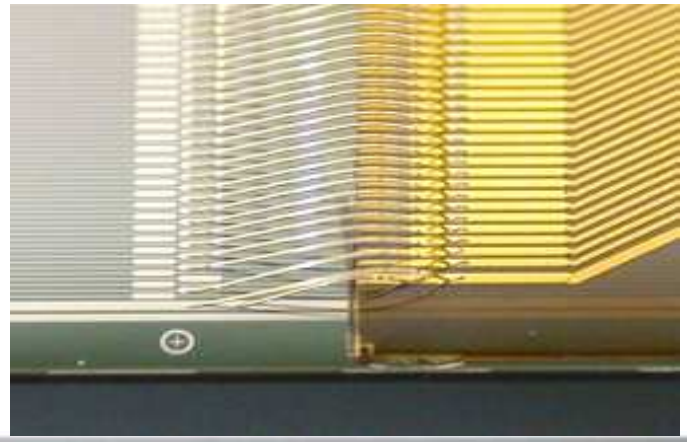


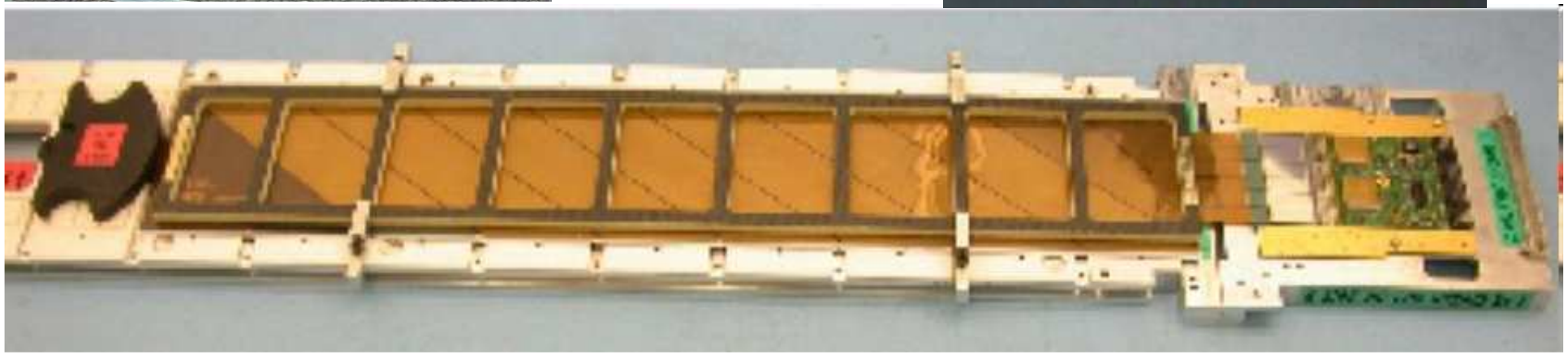
- Double bonding pads allowed several gluing/ungluing and bonding operations.
- Tested at INFN-PG for continuity and shorts.
- Evtl. repaired by bonding.

AMS-02 ladder production

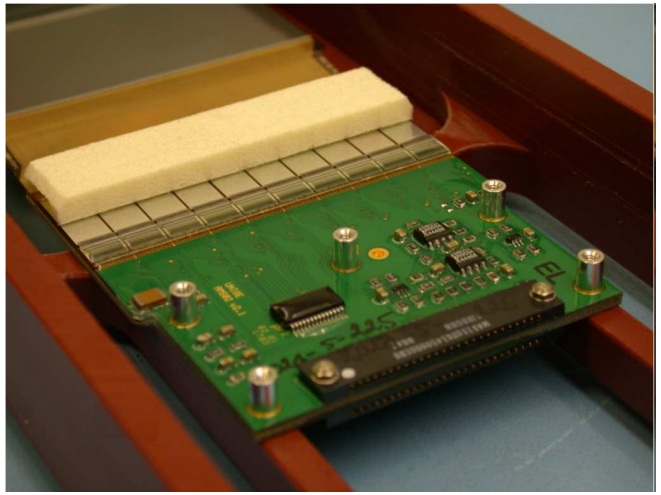


- Gluing: Sensors+Upilex_cables+ reinforcement
- Gluing front-end and bonding of both sides
- Assembly jigs build by INFN PG and UniGe
- 80 % ladders assembled by G&A company
- 20 % by INFN Perugia and UniGe

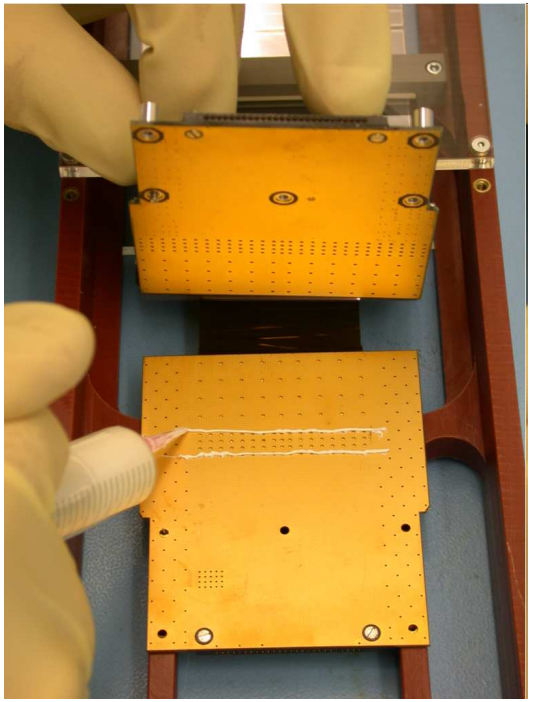


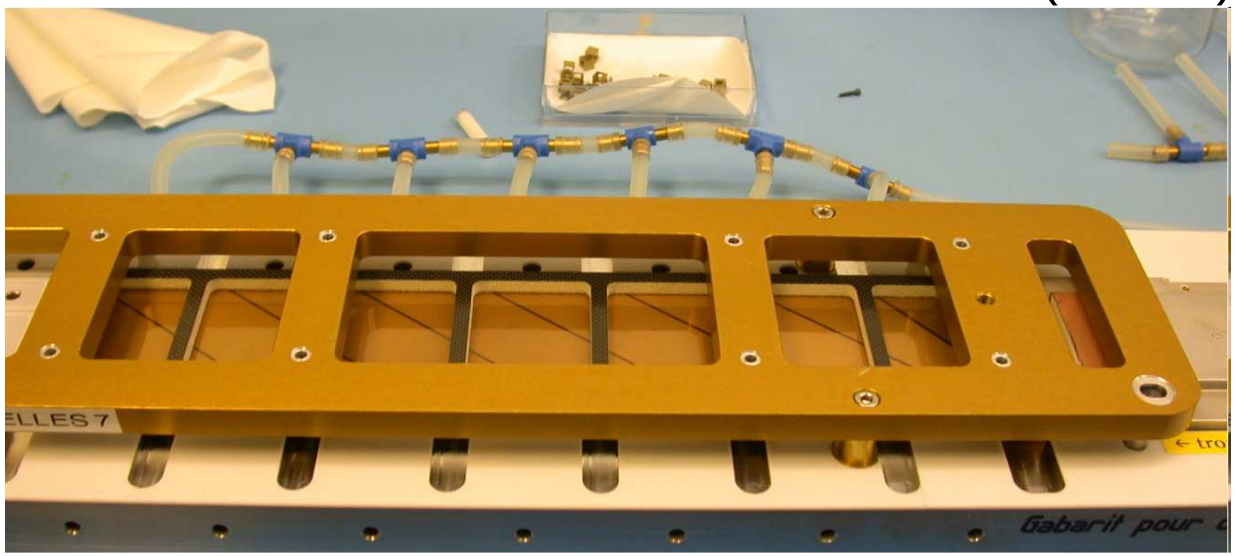


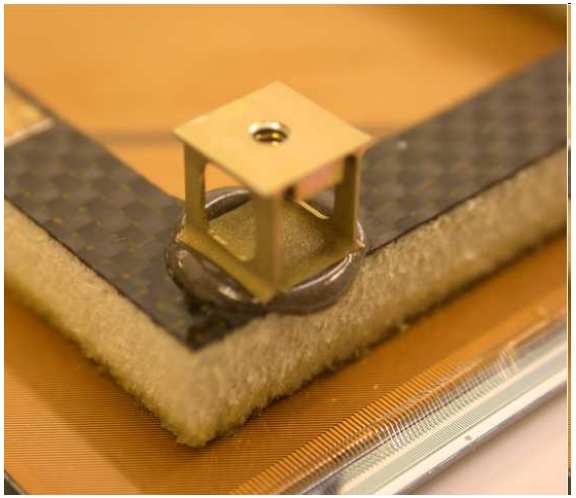
AMS-02 ladder pre-integration (UniGe) Phase 1



- Visual and electrical test
- Conformal coating and bond gluing
- Add *hybrid box* and *thermal grease*
- Gluing of feets
- Electrical test (+ Sr90)

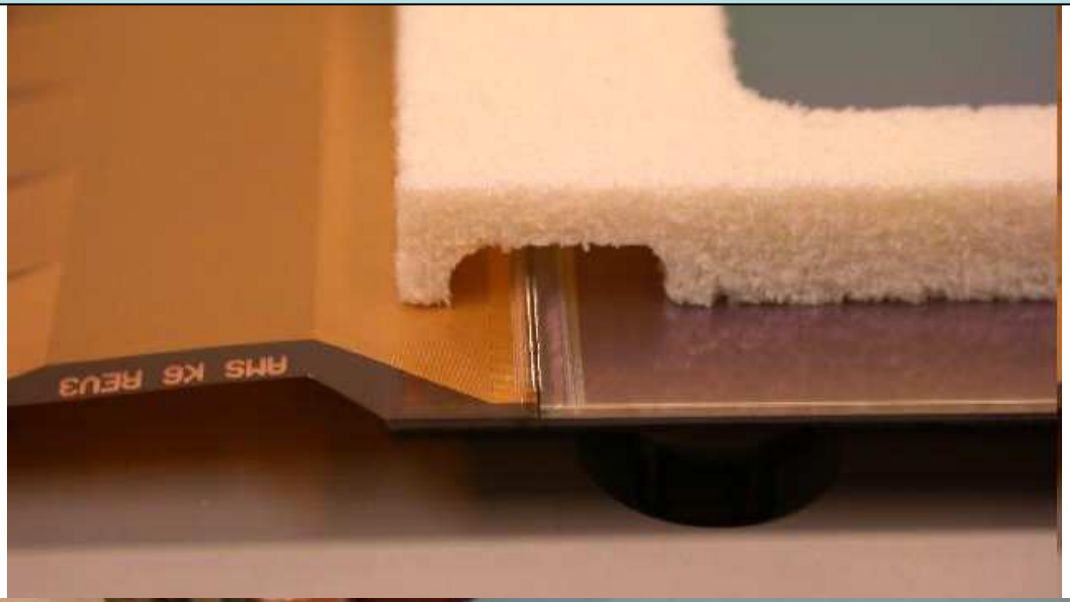


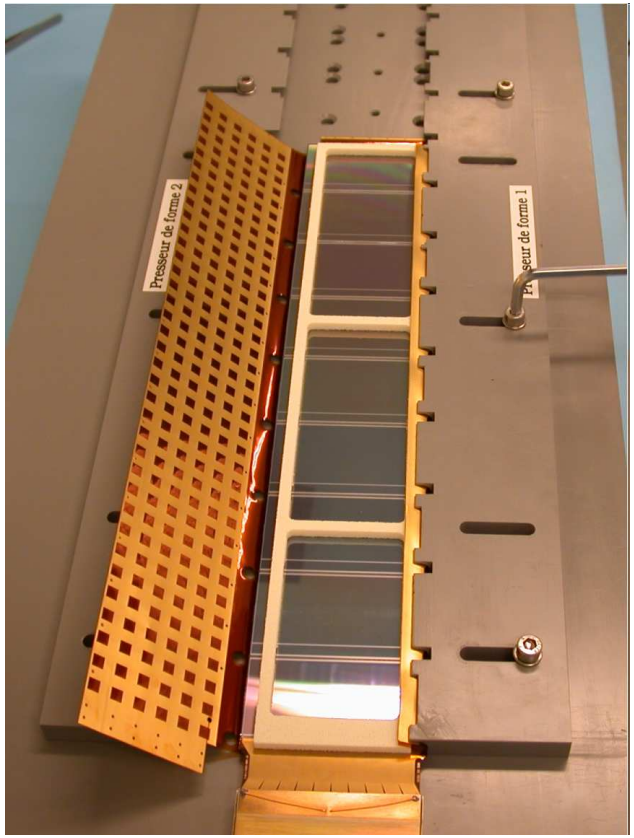


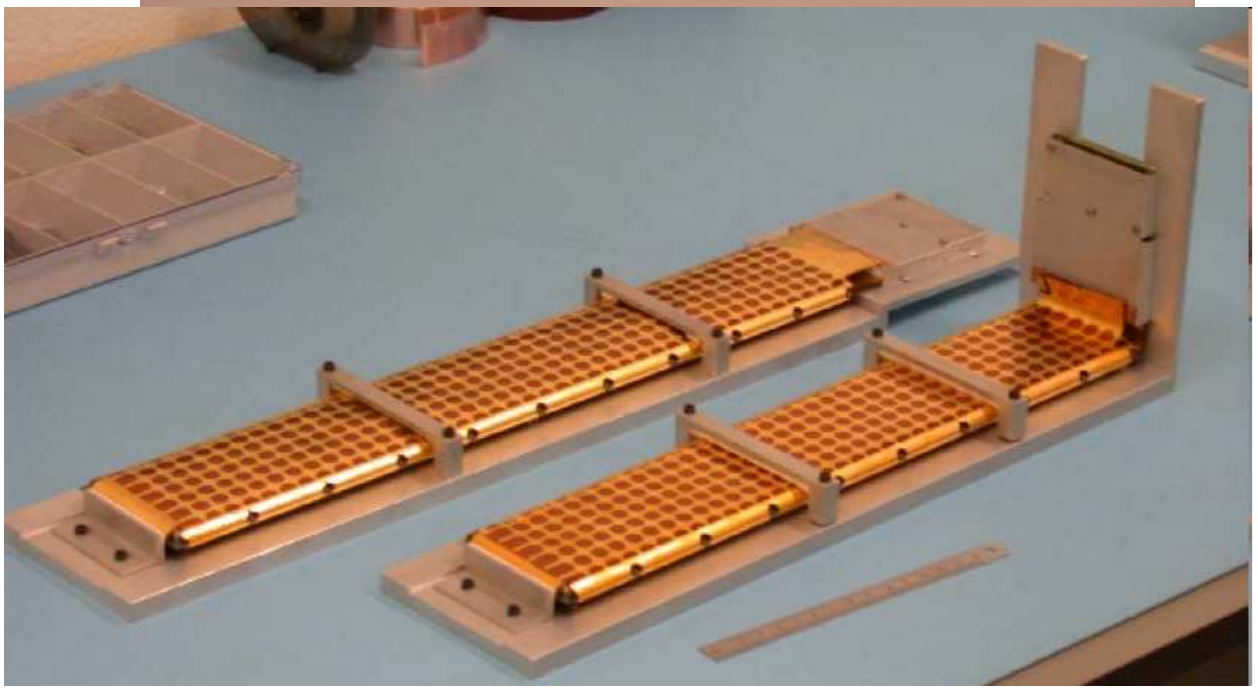


AMS-02 ladder pre-integration (UniGe) Phase 2

- Gluing Airex spacer and wrapping of EM shielding foil
- Storage on *storage jig* and test (+ Sr90)



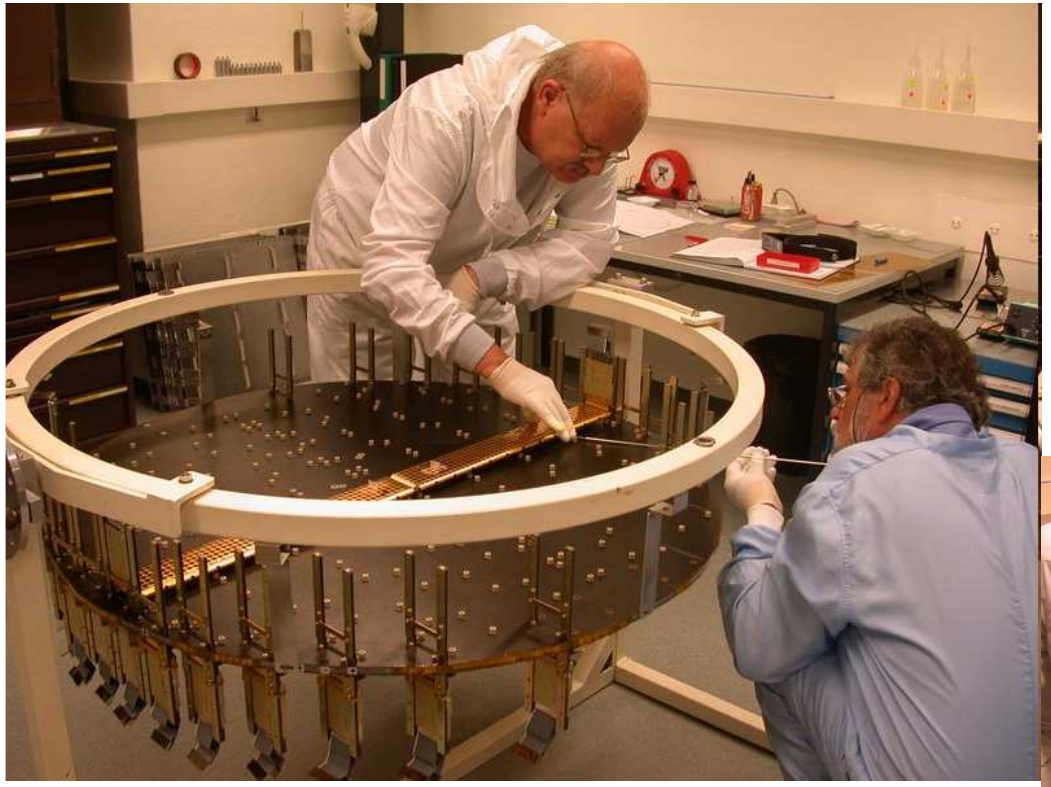


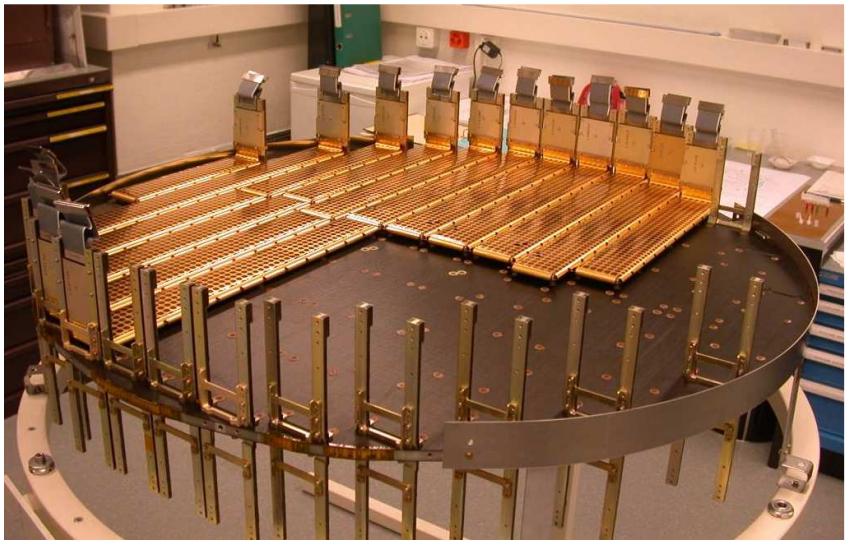


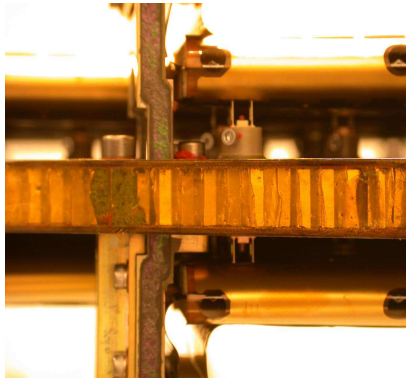
AMS-02 ladder repair

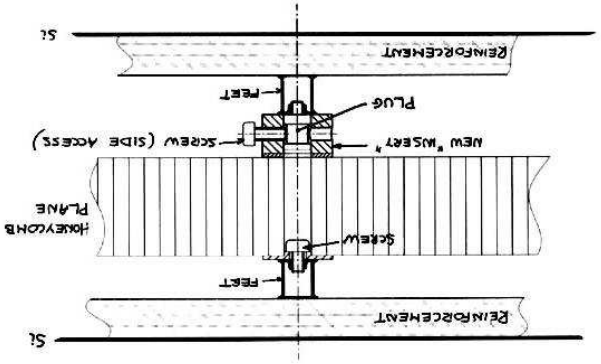
- Due to accidents, misplaced sensors or low gain VA's, repairs were needed and possible (*thanks to double bonding pads*):
- About 200 ladders were built and passed the phases1-2 of pre-integration.
    - ~20 hybrids front-end were changed
    - ~8 changes of sensors (*de-bond, unglue, re-glue, re-bond*)
    - hybrids repair (*change of VA or capacitors*)

Integration of ladders on support planes

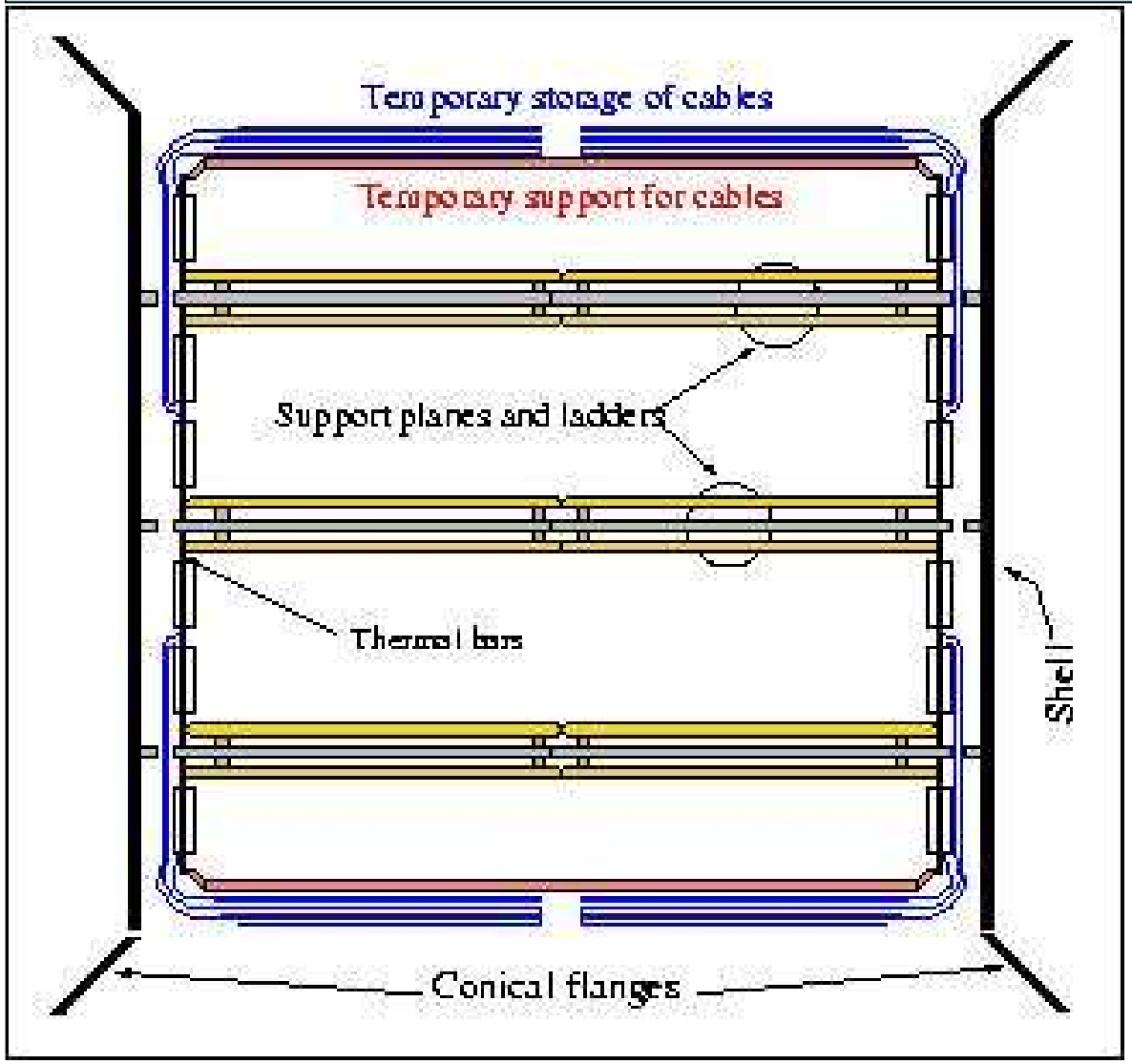




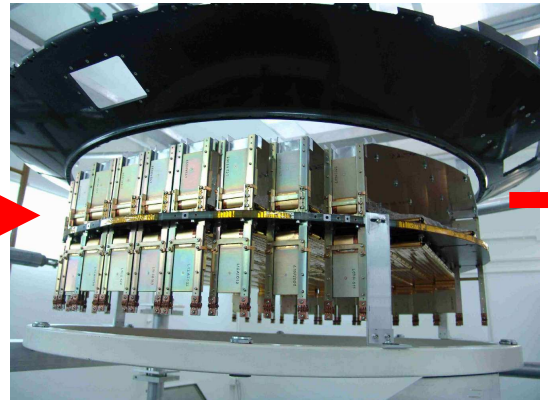


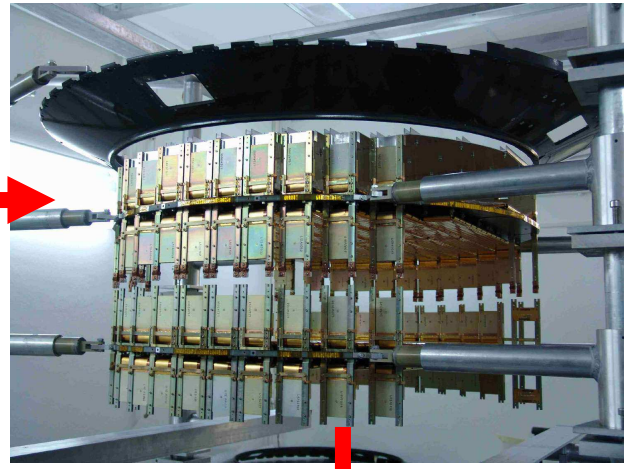


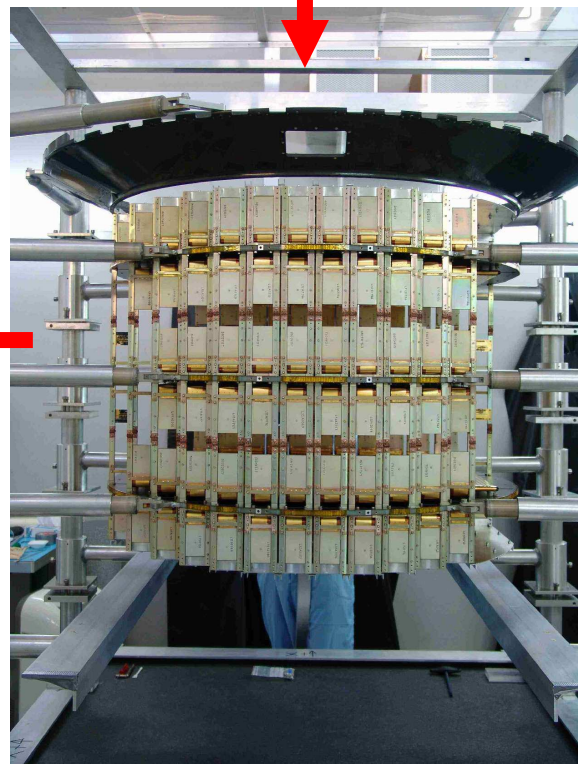
Assembly of the inner tracker (3 inner planes, 6 layers)(**UniGe**)

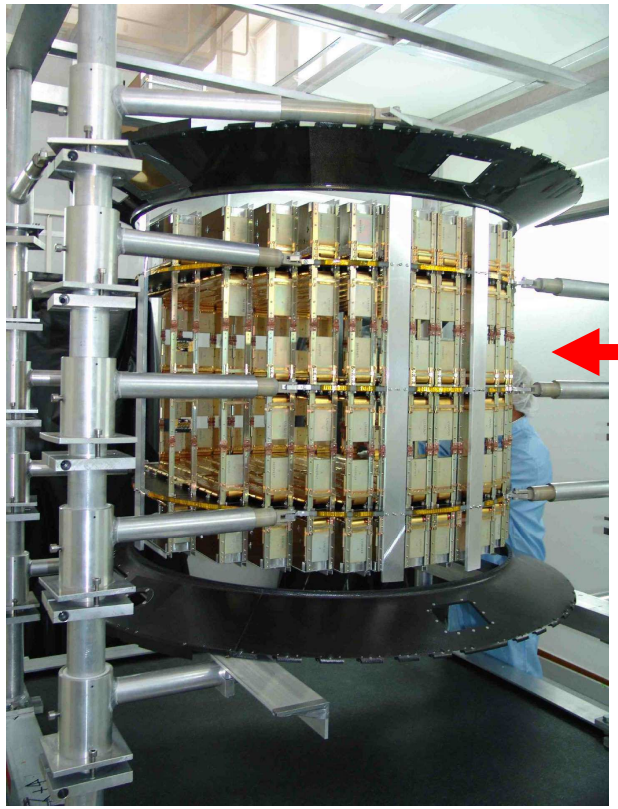


Assembly of the inner tracker (3 inner planes, 6 layers)

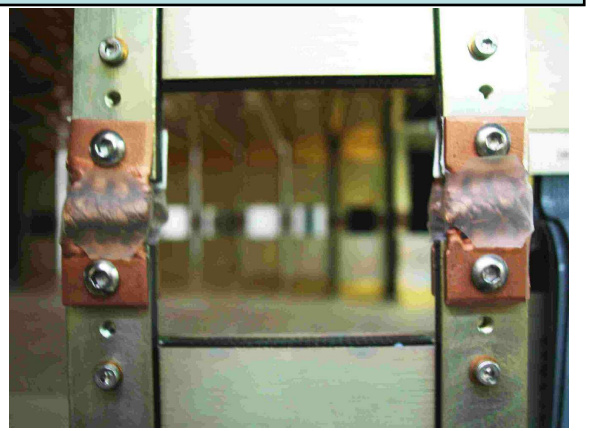








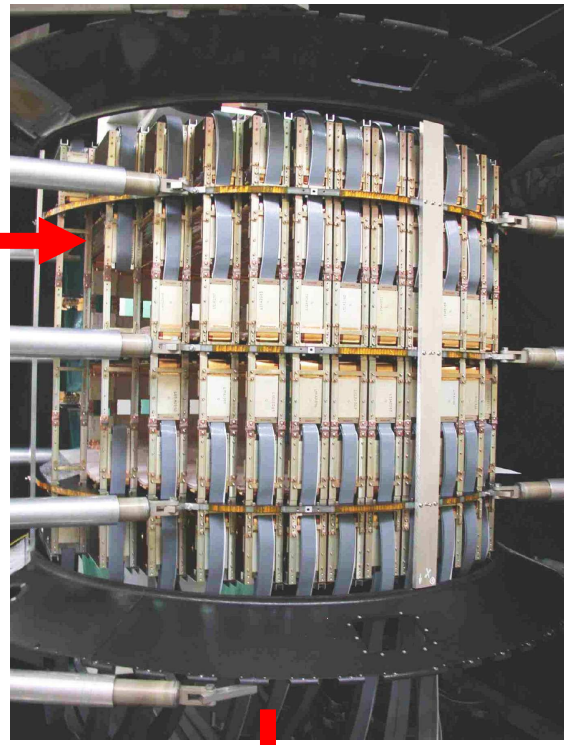
Thermal connections

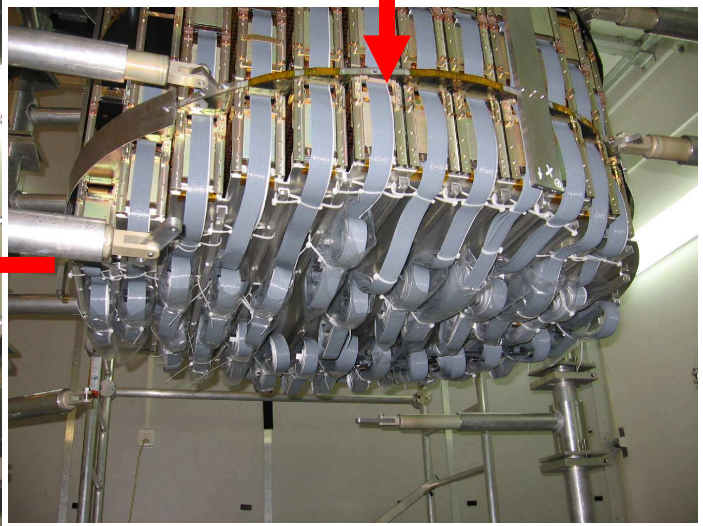


Inner cabling

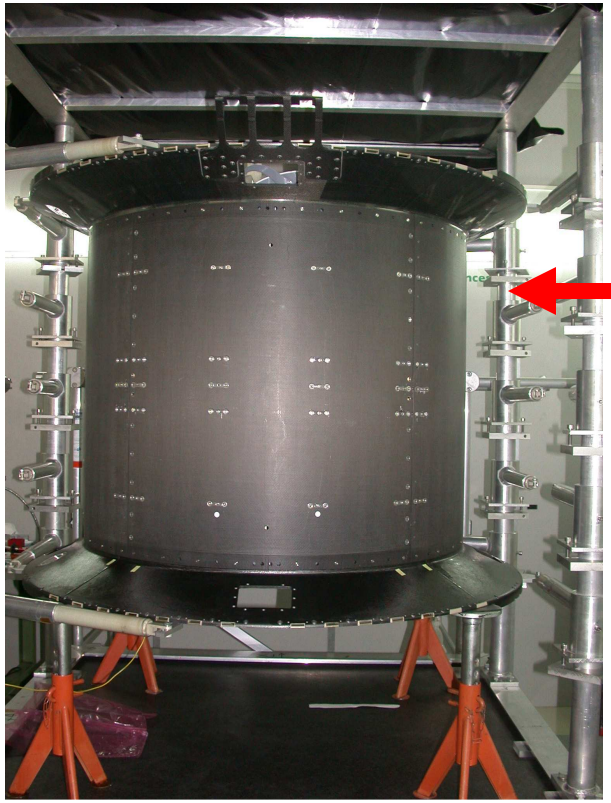
Shell mounting

Remove from jig



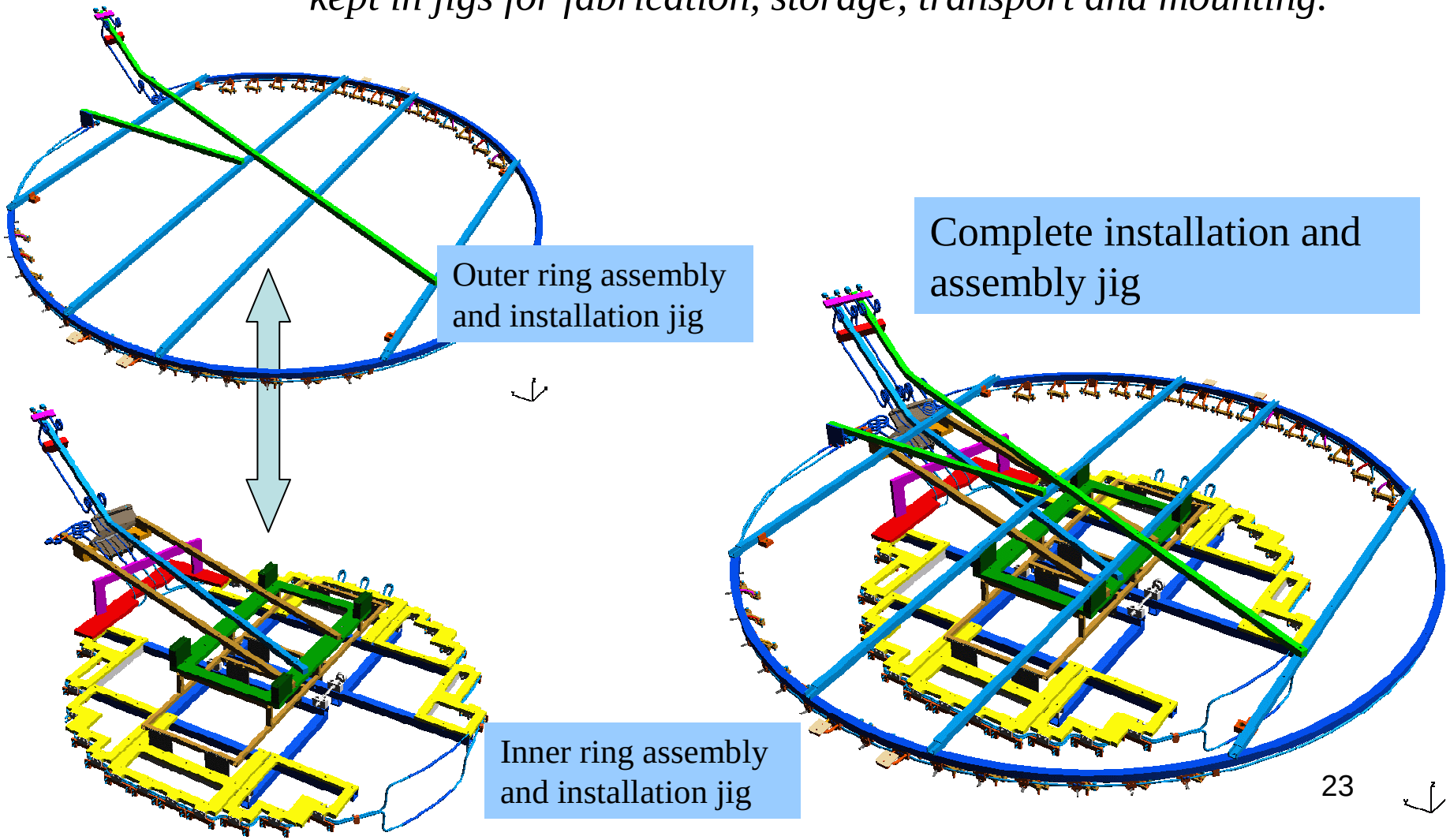


Temporary storage of cables

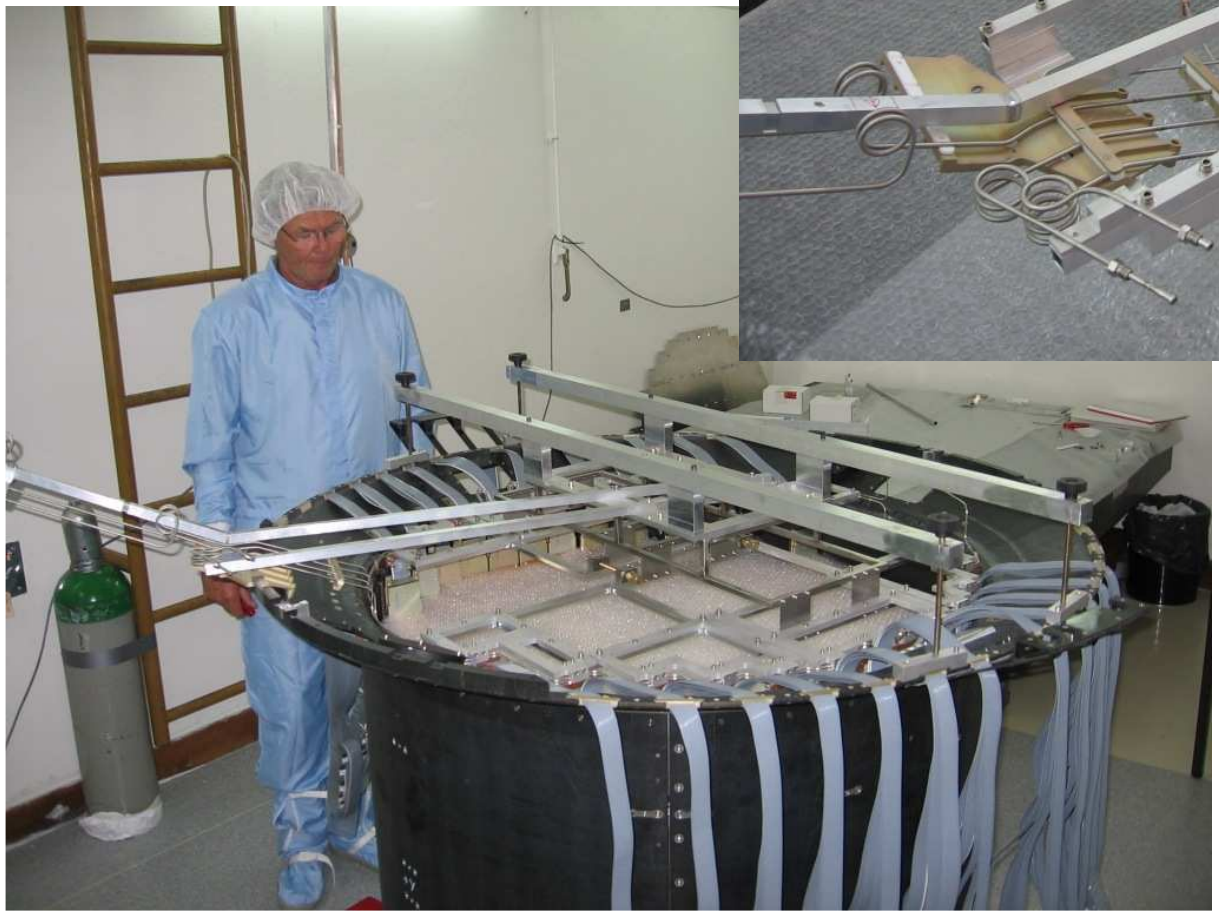


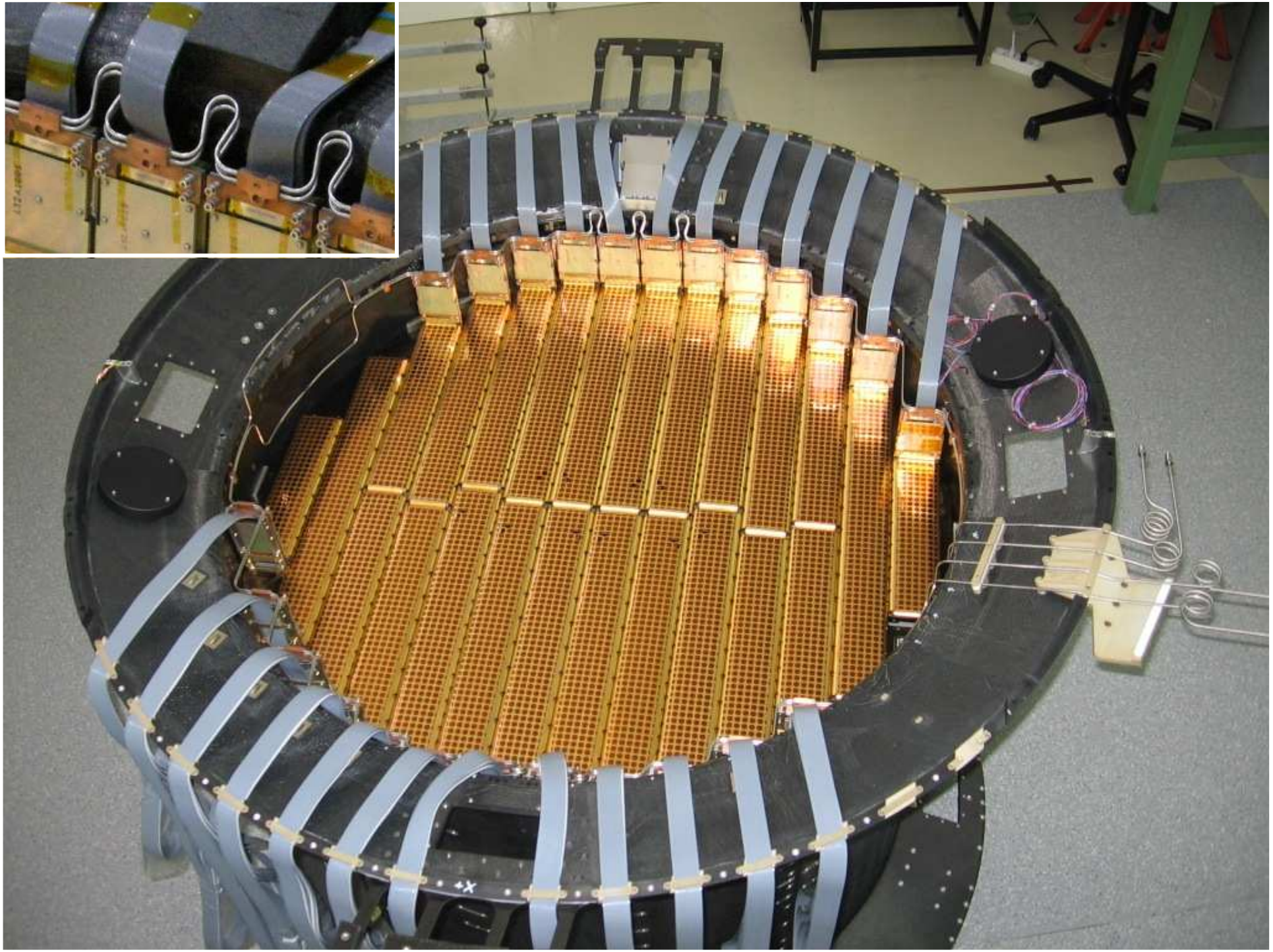
Integration of cooling loops (evaporators) on outer planes and on top side of inner tracker (UniGe)

Cooling loops are fragile and not self supporting. They were kept in jigs for fabrication, storage, transport and mounting.

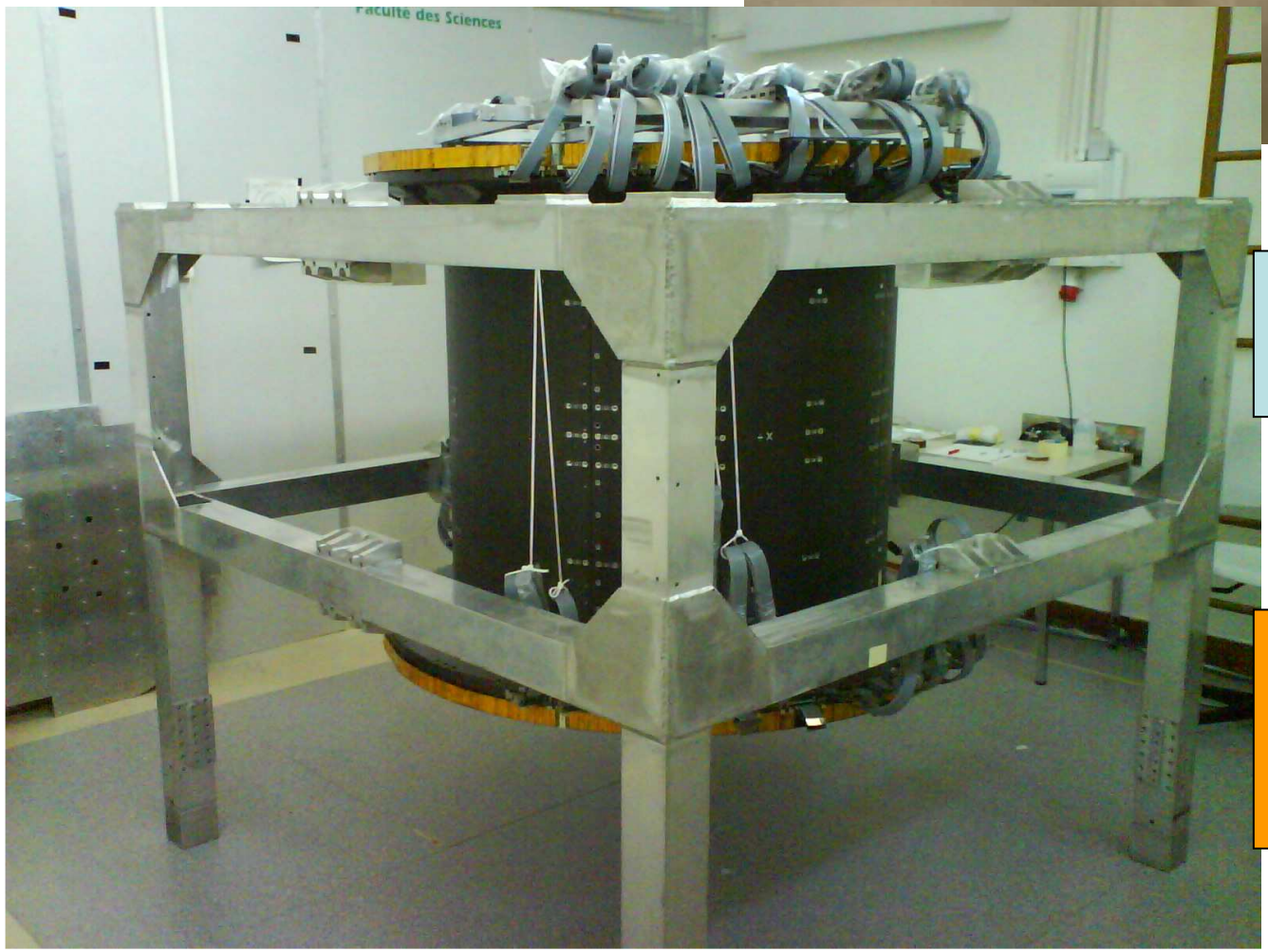


Installation of top inner cooling loop (evaporator)





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.

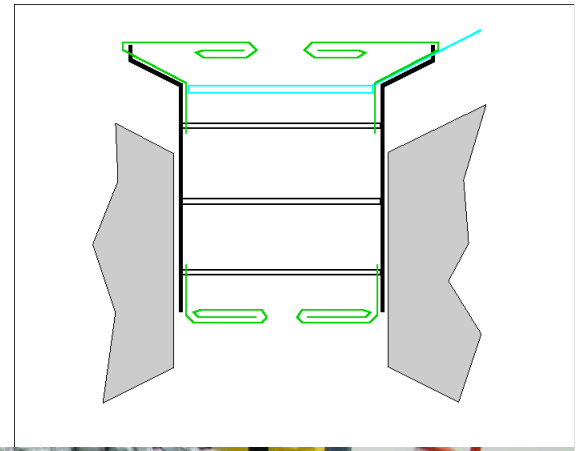
It gave the opportunity to solve and to pinpoint various issues at the interfaces between the components built by various institutes and to test the detector and the DAQ at system level.

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

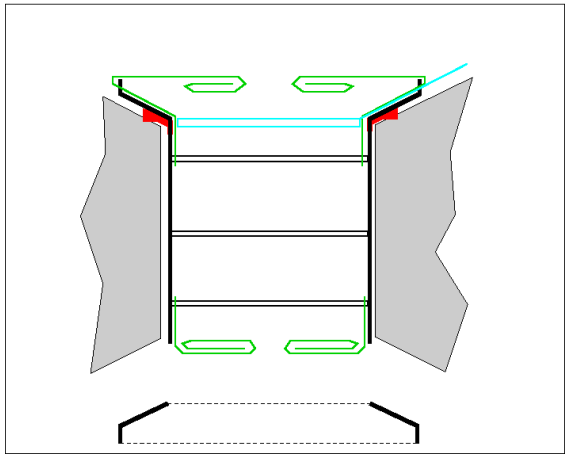
- Fall 2007: pre-integration
- June 2008: de-integration

  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



1. PROJECT CODE: SA-AMS
2. JPIC CODE: AMS

AMS-02 TASK SHEET (ATS)

3. TYPE: A CONFIGURATION CHANGE ☒ — PERMANENT ☒ TEMPORARY ☐ — B NONCONFIGURATION CHANGE ☐
4. ATS NO. TRKMEC0610draft-v1
5. PAGE 1 OF 38
6. MOD SHEET(S) NUMBER(S)

10. PART NAME: AMS
11. Sub Detector Name: TRACKER
12. SERIAL/LOT NO.: ST02

14. APPLICABLE DOCUMENTS

18. ATS TITLE: SILICON CENTRAL TRACKER - BASELINE INTEGRATION PROCEDURE-DRAFTv1

20. OPER SEQ. NO. | 21. OPERATIONS (Print, Type, or Write Legibly) | VERIFICATION 22. TECH | 23. QA/DV

NOTE CAUTION WARNING

THIS ATS COVERS ALL THE INTEGRATION STEPS NEEDED FOR THE SILICON TRACKER MECHANICAL INTEGRATION WITH VACUUM CASE AT ATMOSPHERIC PRESSURE.

AS A GENERAL REQUIREMENTS ALL STEPS SHALL BE DONE:

- IN A CONTROLLED ENVIRONMENT (CLEAN ROOM);

- BY USING THE AMS02 PLATFORM SYSTEM (SCAFFOLDING);

- BY USING GROUND SUPPORT EQUIPMENT.
- BY THE TRACKER TEAM ENGINEERS AND TECHNICIANS.

This ATS authorizes lifting operations. All safety regulations and procedures shall be followed.

No personal equipment shall be brought within the Tracker storage area and/or within the AMS02 assembly area, during the integration; for example: mobile phone, money, key and all items not identified as integration tools.

24. ORIGINATOR: E.PERRIN / F.CADOUX — DATE: 15 JUNE '10
25. FINAL ACCEPTANCE STAMP AND DATE

APPROVALS (Printed or Typed and Signed)

26. PROJECT ENGINEER: Eric PERRIN / Franck CADOUX — DATE: 15 June '10
27. QUALITY ENGINEER — DATE
28. Johannes van ES
29. Divic RAPIN — 15 June 2010
30. Corrado GARGIULO
31. Sonia NATALE

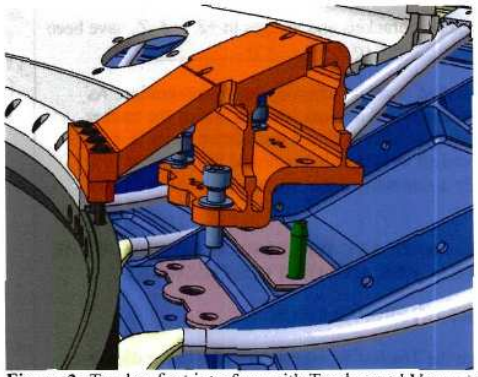
AMS Assembly Task Sheet (ATS) Rev 9/25/06 JH

Bolting the 4 upper tracker feet (ATS)

5. Page 4 of 4

AMS-02 TASK SHEET (ATS)
CONTINUATION PAGE

4. ATS NO. TRKMEC0610
6. MOD NO.

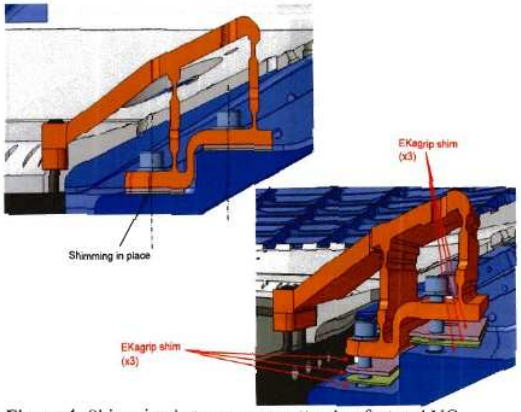
20. OPER SEQ. NO.	21. OPERATIONS (Print, Type, or Write Legibly)	VERIFICATION 22. TECH	VERIFICATION 23. QA/DV
	 **Figure 2:** Tracker foot interface with Tracker and Vcase + guiding pin.		
3.3	Add long sliding protections to the cylindrical tracker shell	15 June 10 FC	15 JUNE 10 CY
3.4	Lift the tracker. 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) Part # N/A Lot # N/A Part # N/A Lot # N/A  BASED ON VC PHOTOGRAMMETRY NO SHIMS ARE REQUIRED ATS # 1911TK100JA-79 15 JUNE 10 CY **Figure 3:** Interface block fastened below the top feet	15 June 10 FC	15 JUNE 10 CY

AMS Assembly Task Sheet (ATS) Continuation Rev 9/25/06 JH

5. Page 5 of 5

AMS-02 TASK SHEET (ATS)
CONTINUATION PAGE

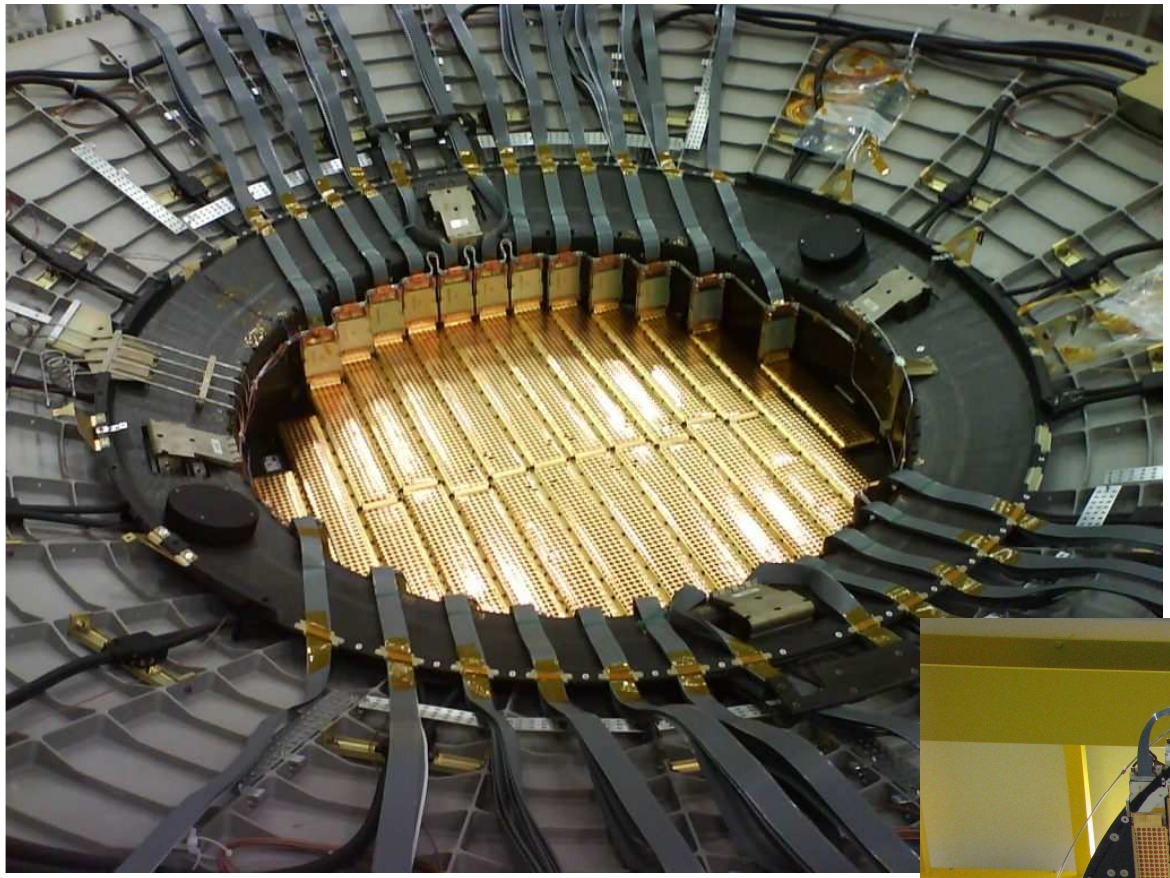
4. ATS NO. TRKMEC0610
6. MOD NO.

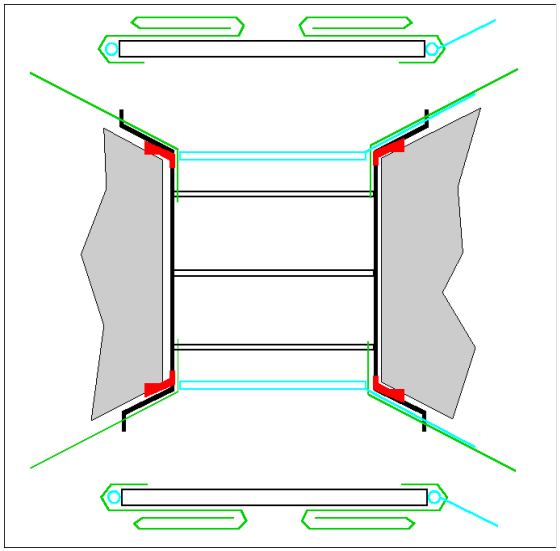
20. OPER SEQ. NO.	21. OPERATIONS (Print, Type, or Write Legibly)	VERIFICATION 22. TECH	VERIFICATION 23. QA/DV
	 **Figure 4:** Shimming between op top ttracker feet and VC		
3.5	Lift and insert the inner tracker in the VC bore, with the crane. Somebody has to watch the insertion clearances from below.	15 June 10 FC	15 JUNE 10 CY
3.6	Dock the Inner tracker to the VC without transferring the weight of the tracker to the VC.	15 June 10 FC	15 JUNE 10 CY
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: Joint#1 tracker feet to Vacuum Case flange. This installation is temporary and the bolts will be tightened by hand. Bolts part # N/A lot# N/A qty 8 Apply Braycote on the threads. Lot # 135999 Exp date: 05/2023 60155	15 June 10 FC	15 JUNE 10 CY

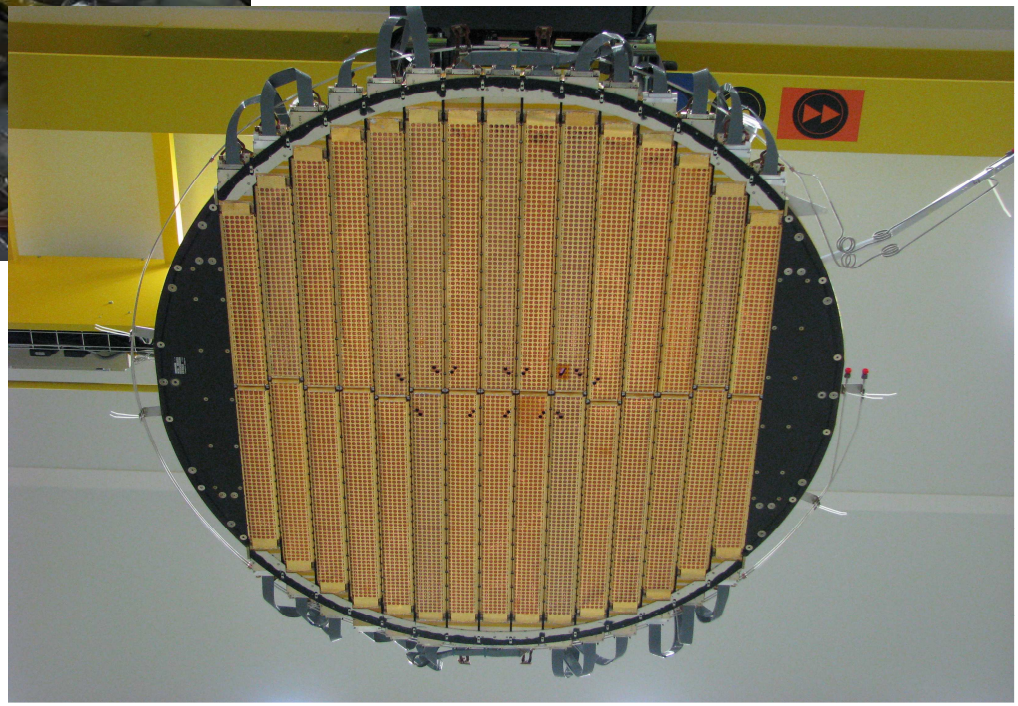
FOOT	Shim package description	Shim total Thk (mm)
X +	NO SHIM	0
Y +	" "	0
X -	" "	0
Y -	" "	0

AMS Assembly Task Sheet (ATS) Continuation Rev 9/25/06 JH

Deploy inner cables and install outer planes

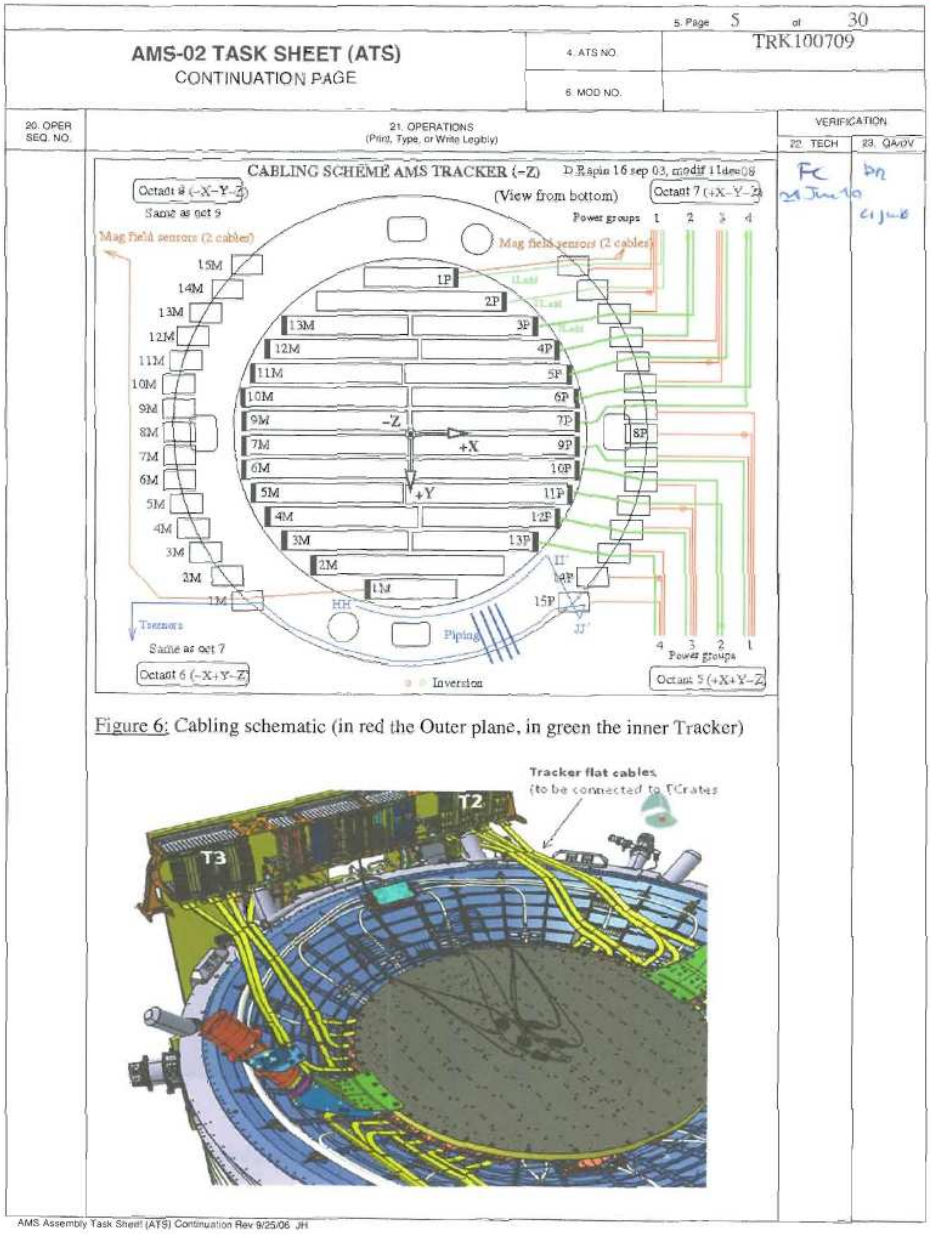


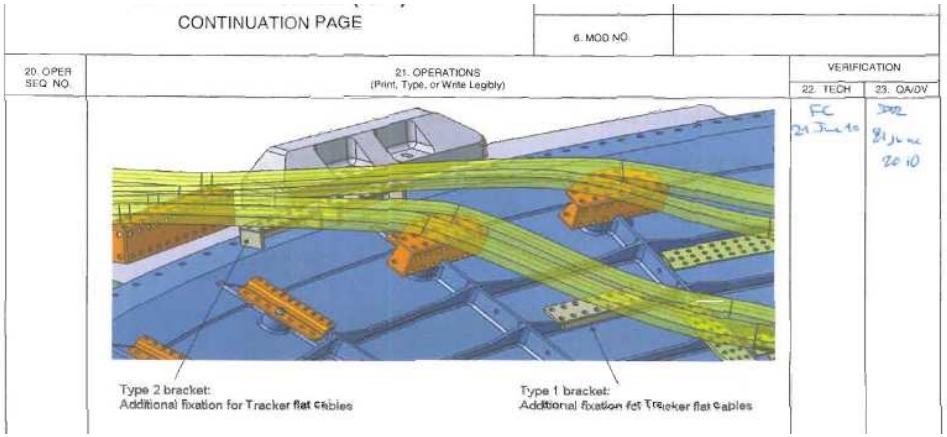




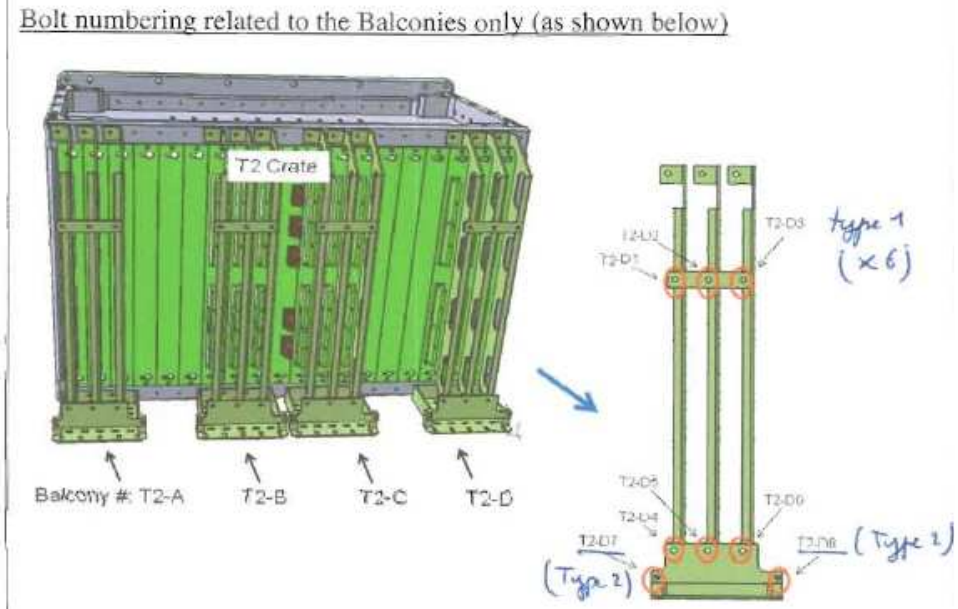
Then, connect evaporator tubing together and to CO2 cooling …

Connect flat cables to the crates (ATS)

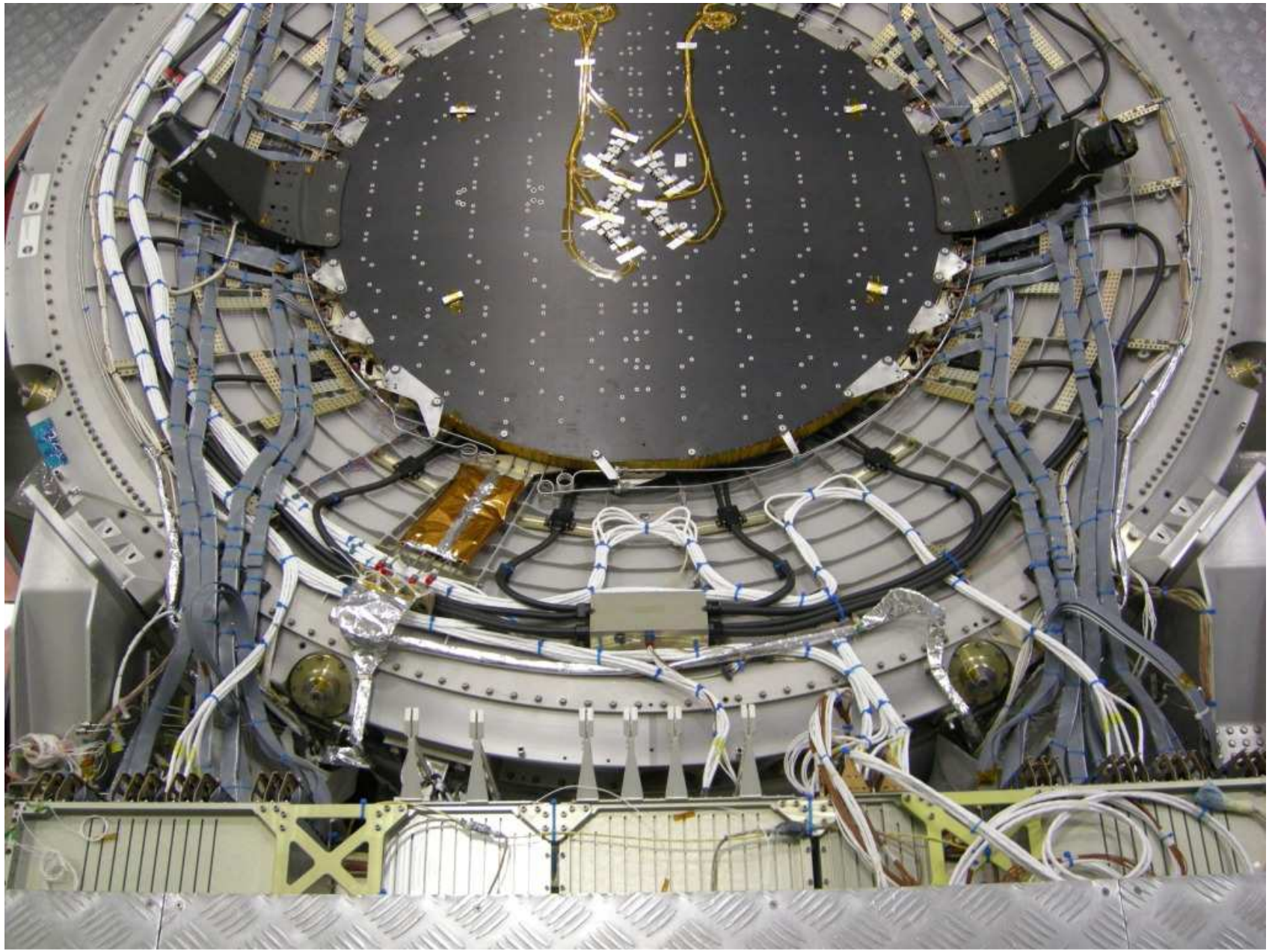




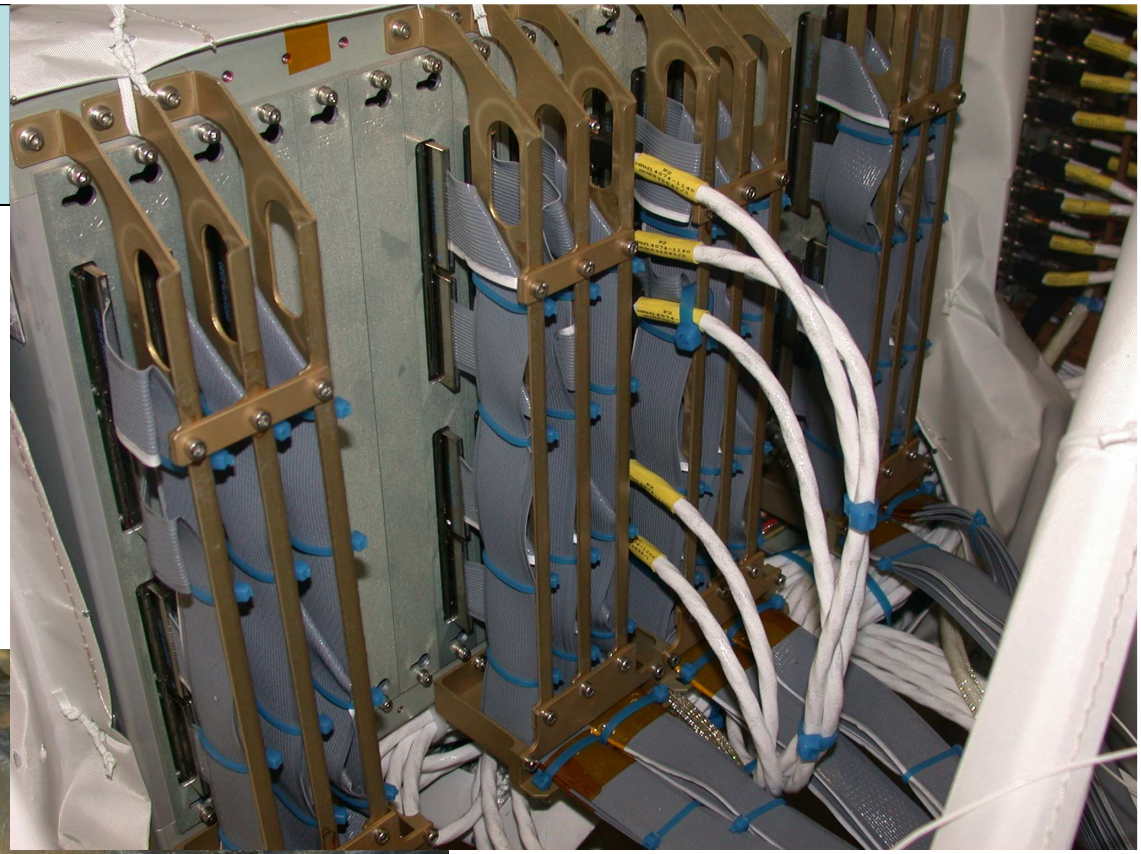
"*Balcony*" to fix the cables to crates

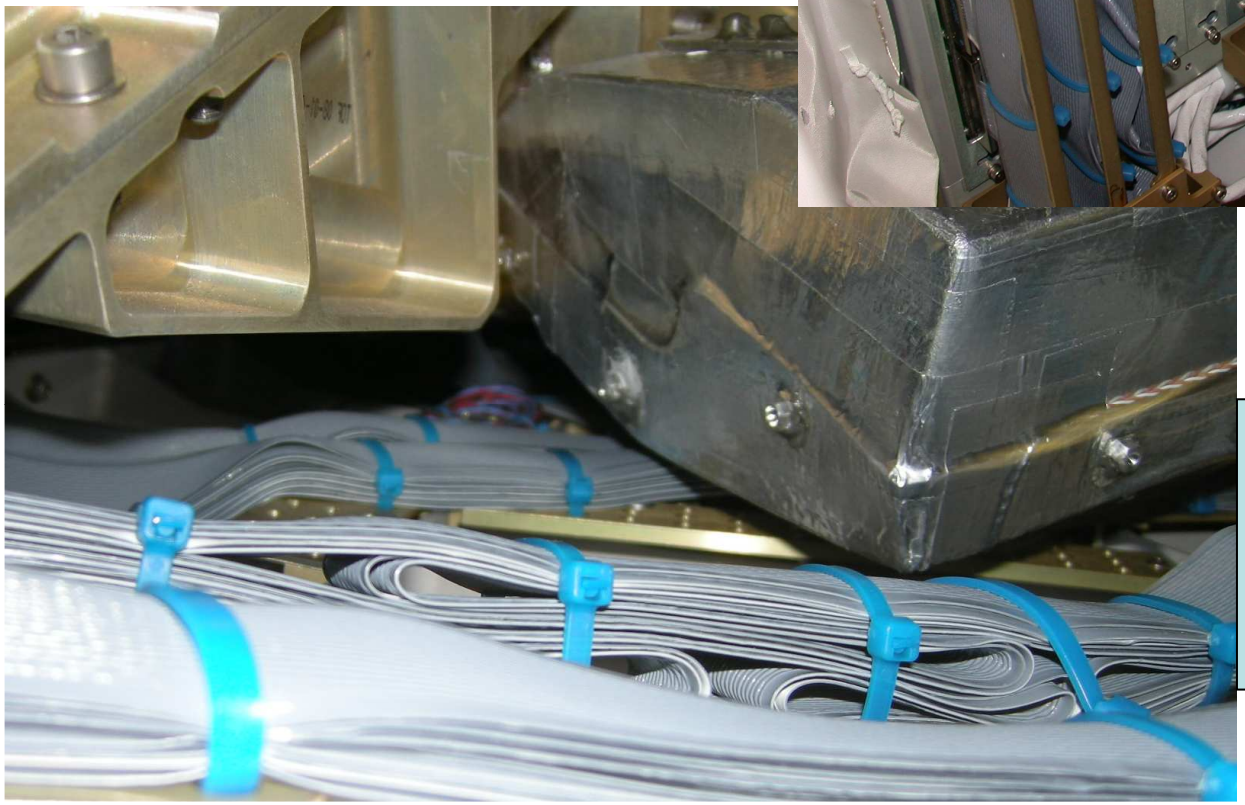


Connect and fix flat cable



Connect flat cables to the crates

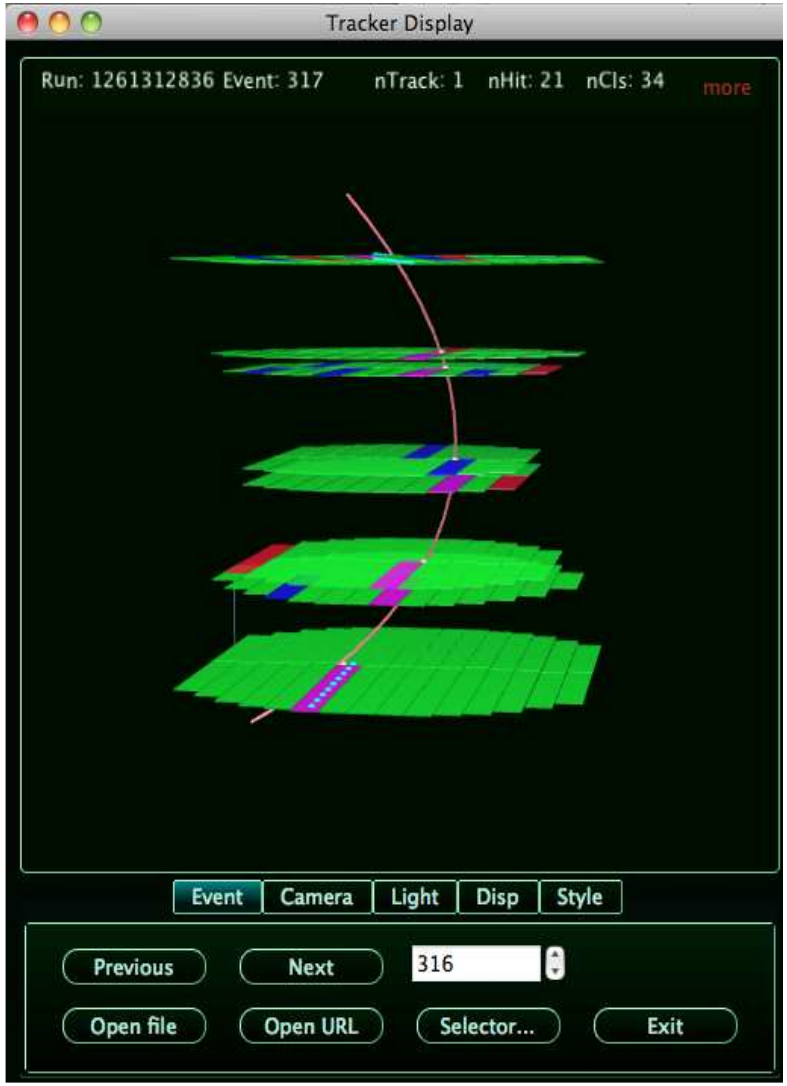


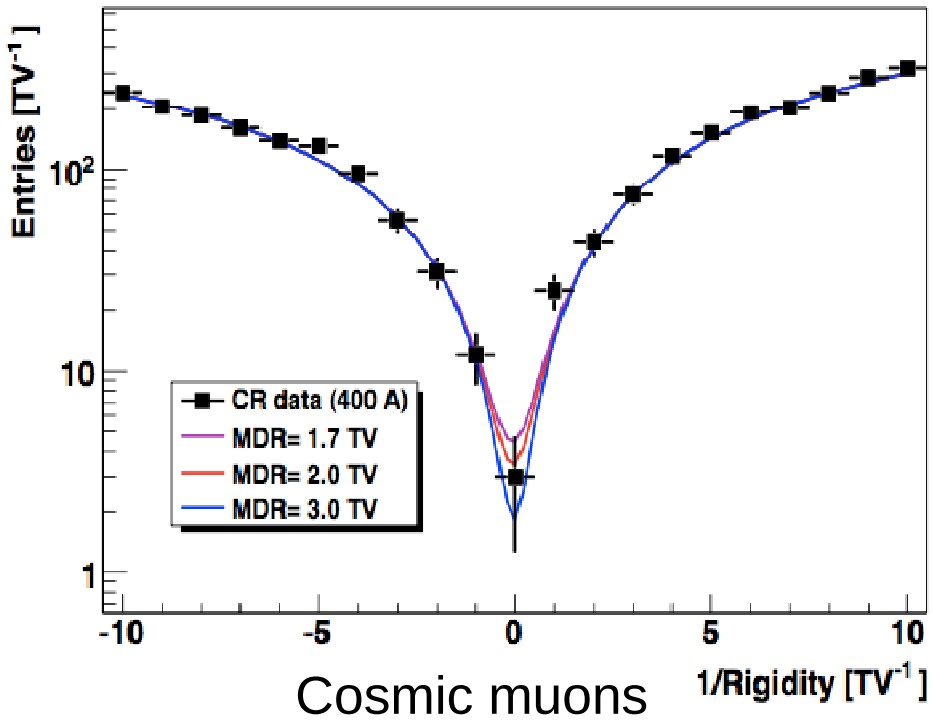


Fit check with next equipment (without MLI)

SYSTEM QUALIFICATION:

December 20th, 2009: SC magnet at 400 A

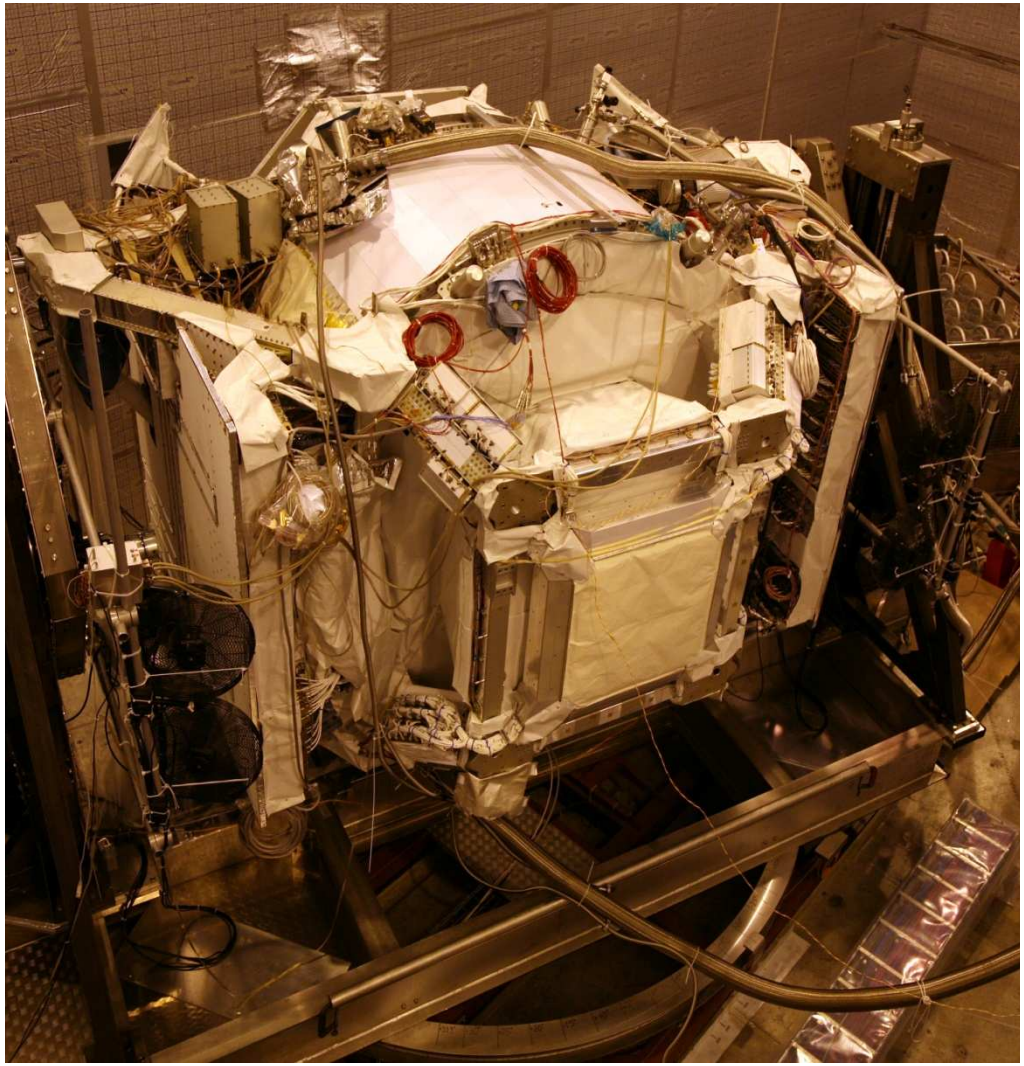


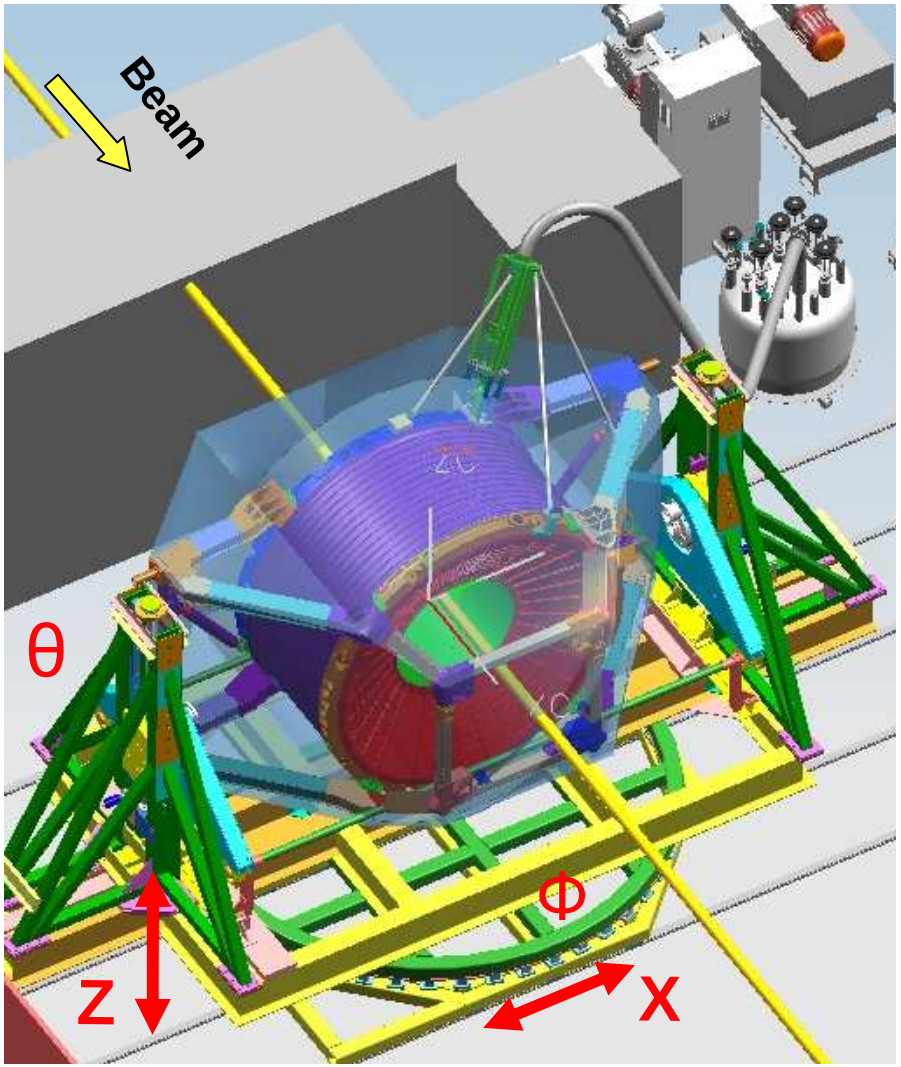


Cosmic muons

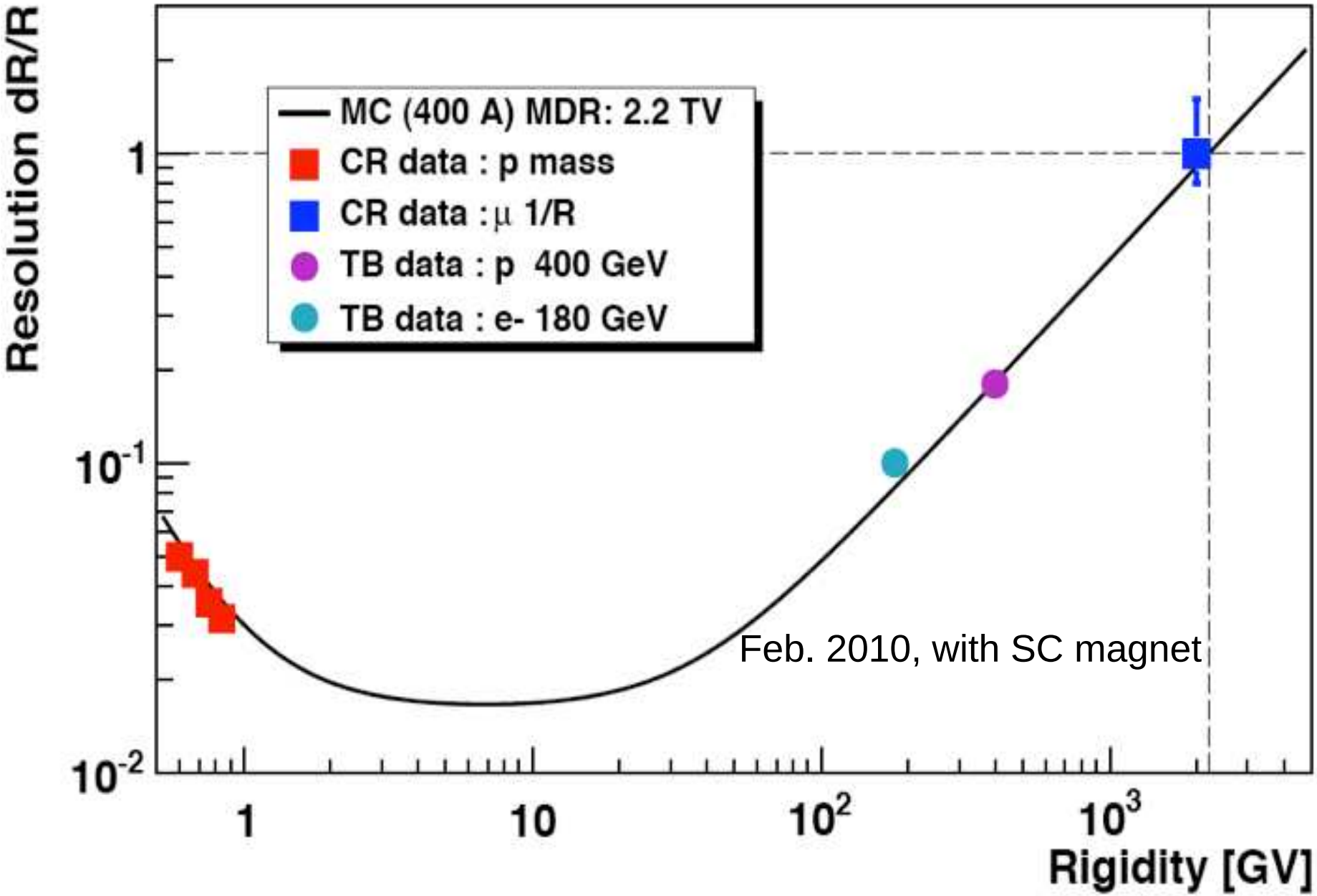
Systen qualification: AMS in Test Beam (CERN)

Feb 4-8, 2010



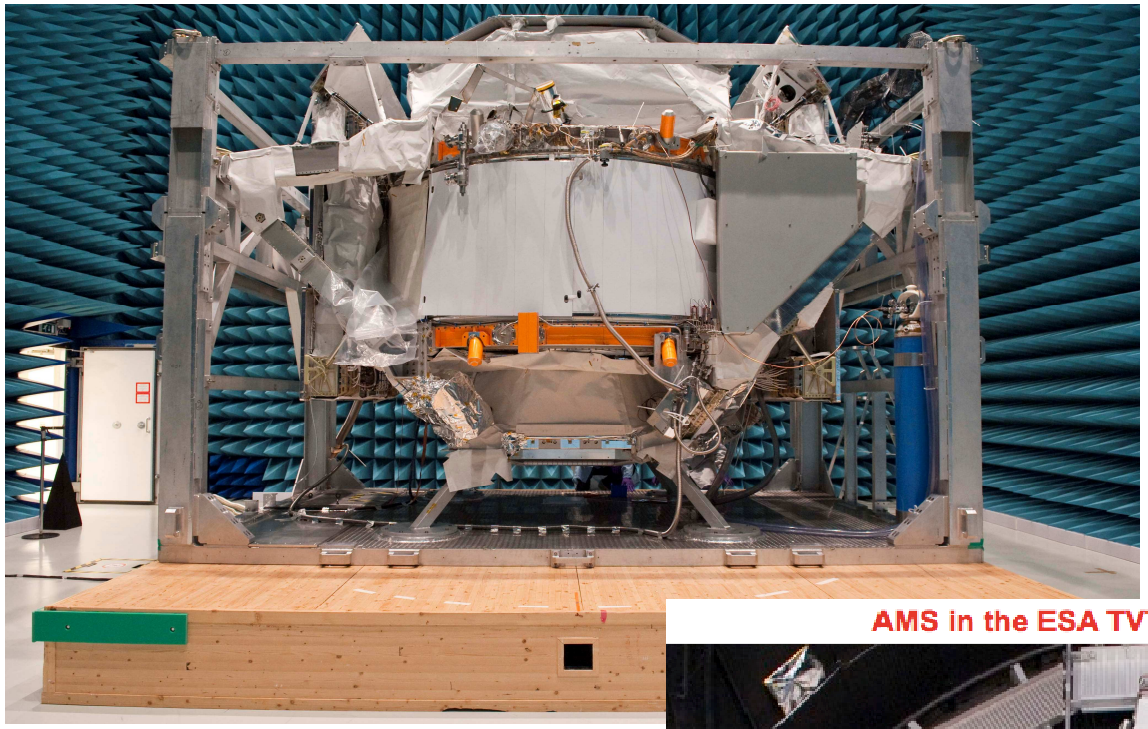


Test Beam 2010 : momentum resolution of the spectrometer



Journey from CERN to ESTEC

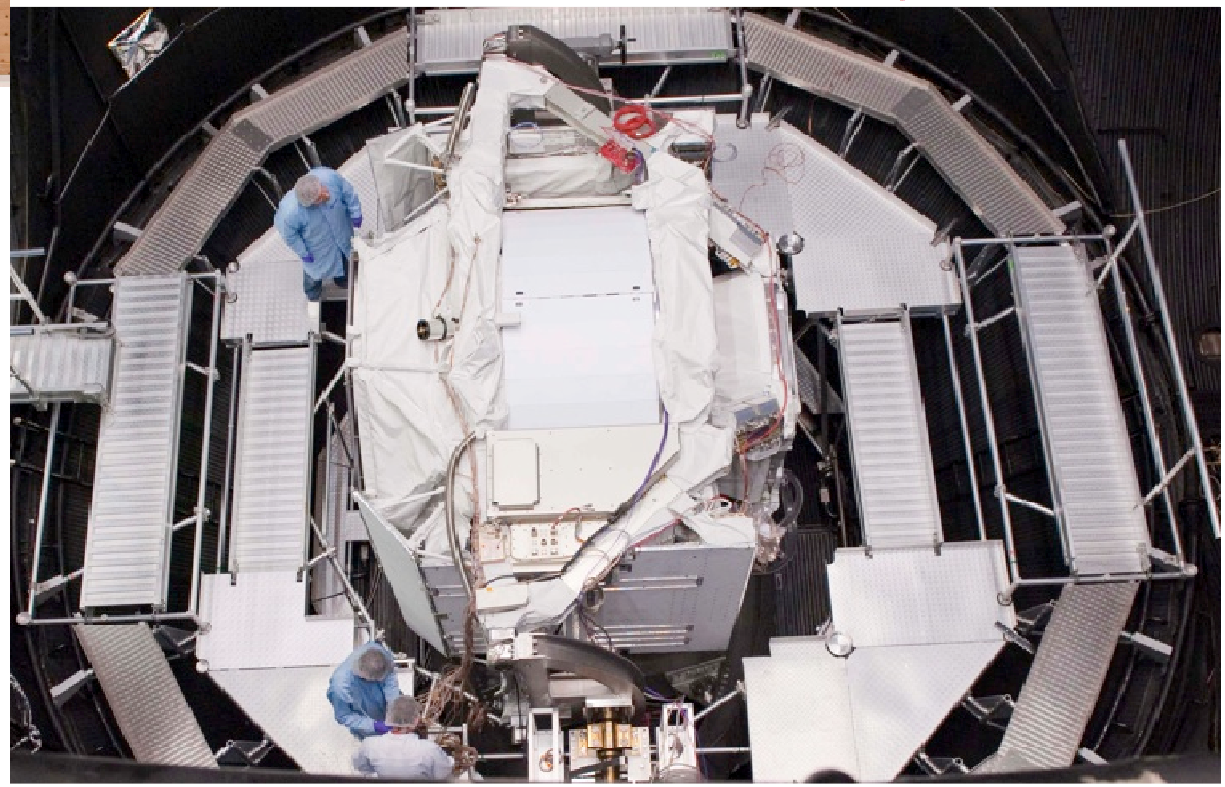
(ESA center at Noordwijk, NL)



AMS in Maxwell EMI test chamber at ESTEC

AMS in TVT chamber at ESTEC

AMS in the ESA TVT Chamber in the horizontal position



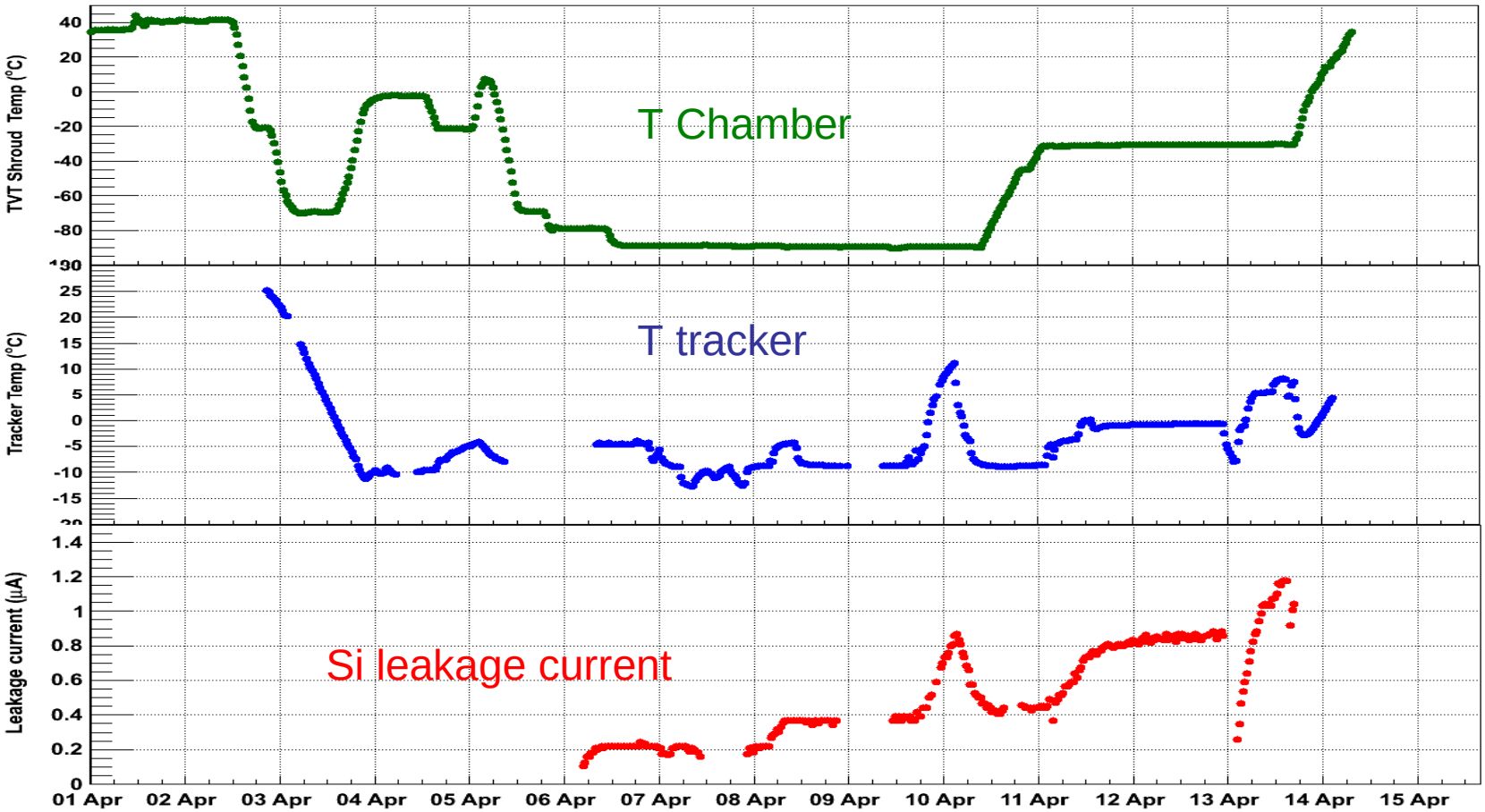
Simulation of space conditions (vacuum, temperature and solar radiation)

Feb, March, April 2010

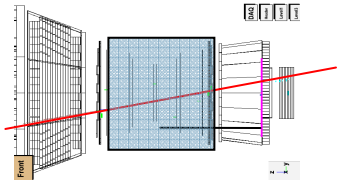
CO2 Cooling (TTCS):

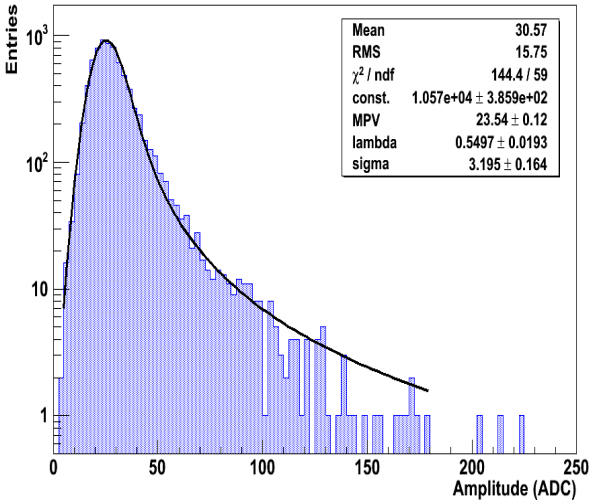
- Functional checks successful
- Condenser: freezing and defrosting tests successful
- Unbalanced radiator temperatures do not influence stability

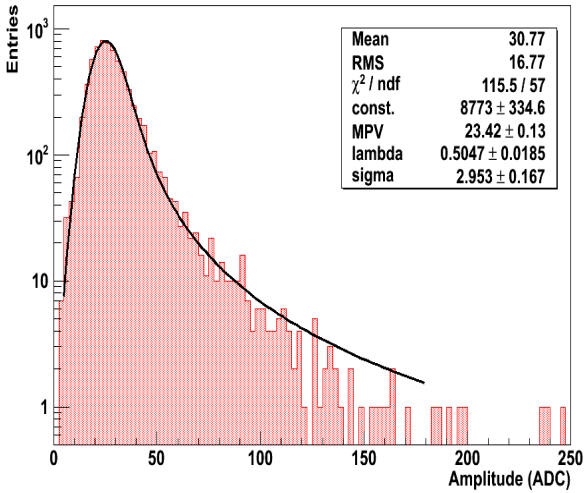
TRACKER: leakage currents evolution with temperature

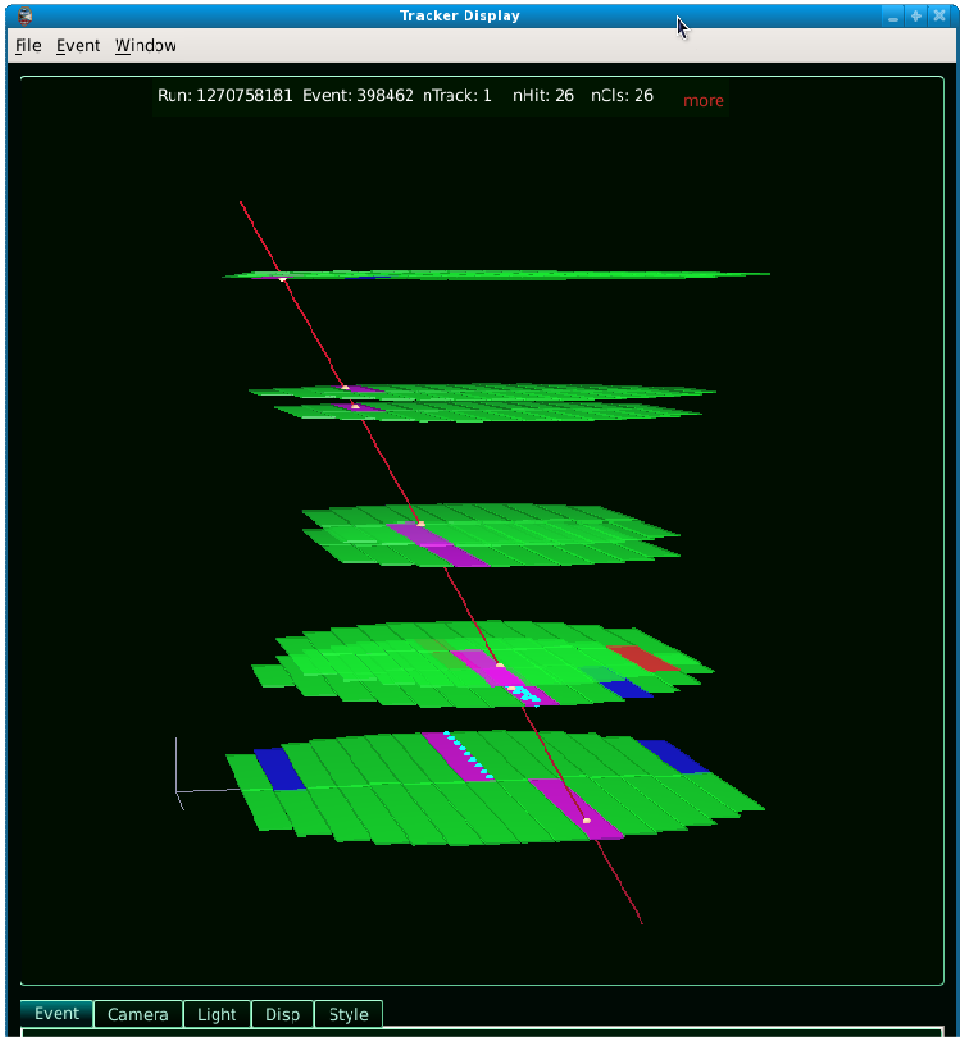


TRACKER PERFORMANCES:
a cold muon track & mip signal in silicon

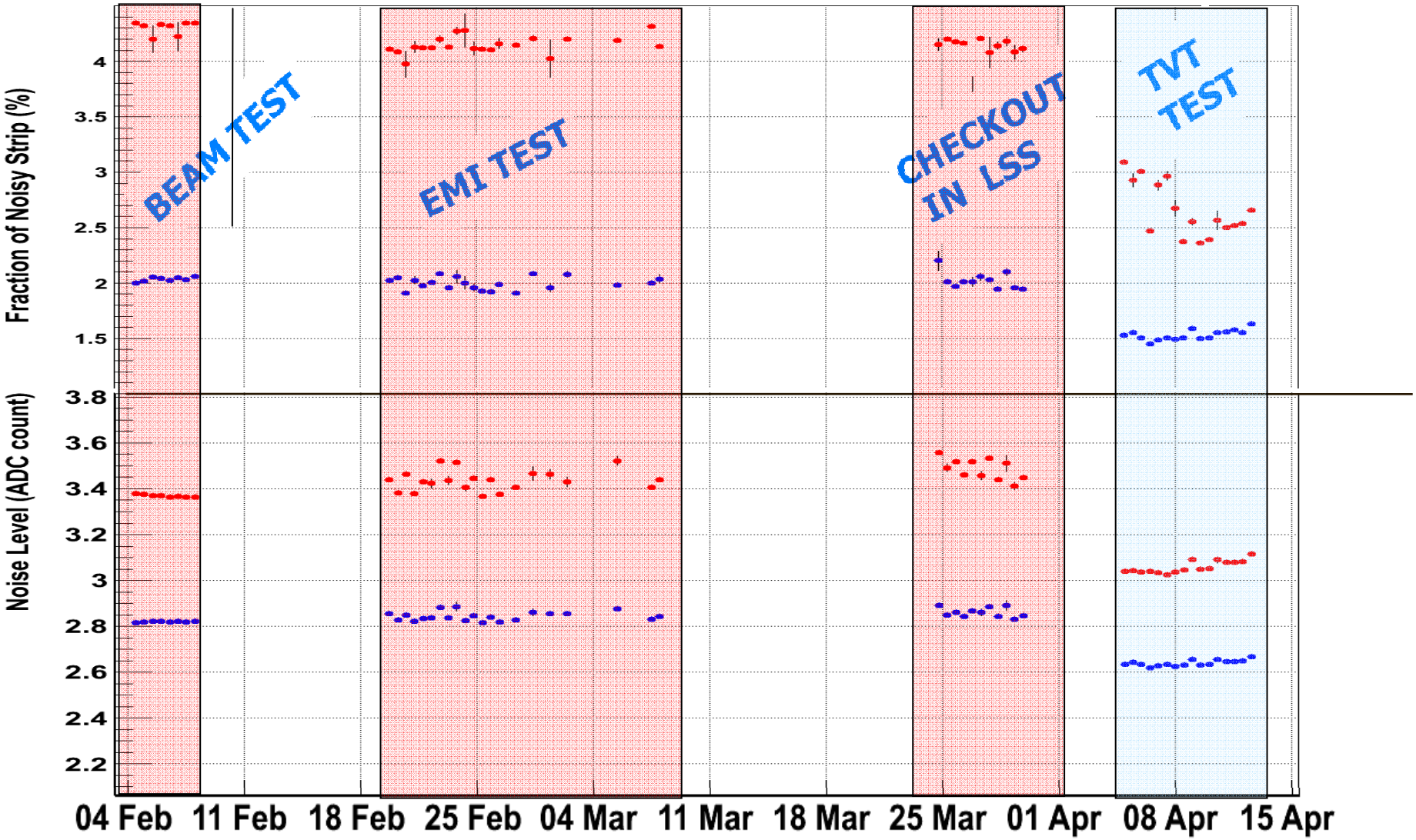






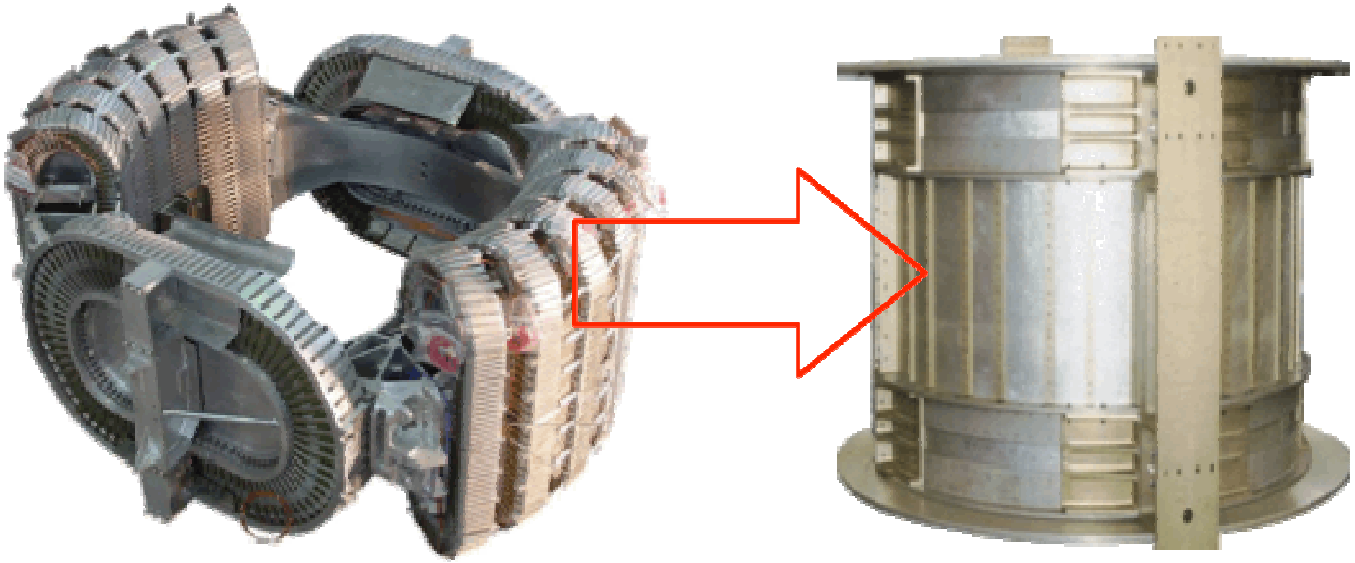


Tracker Performances:
noise in different ambient conditions



Change of Strategy after test at ESTEC *(april 16, 2010)*

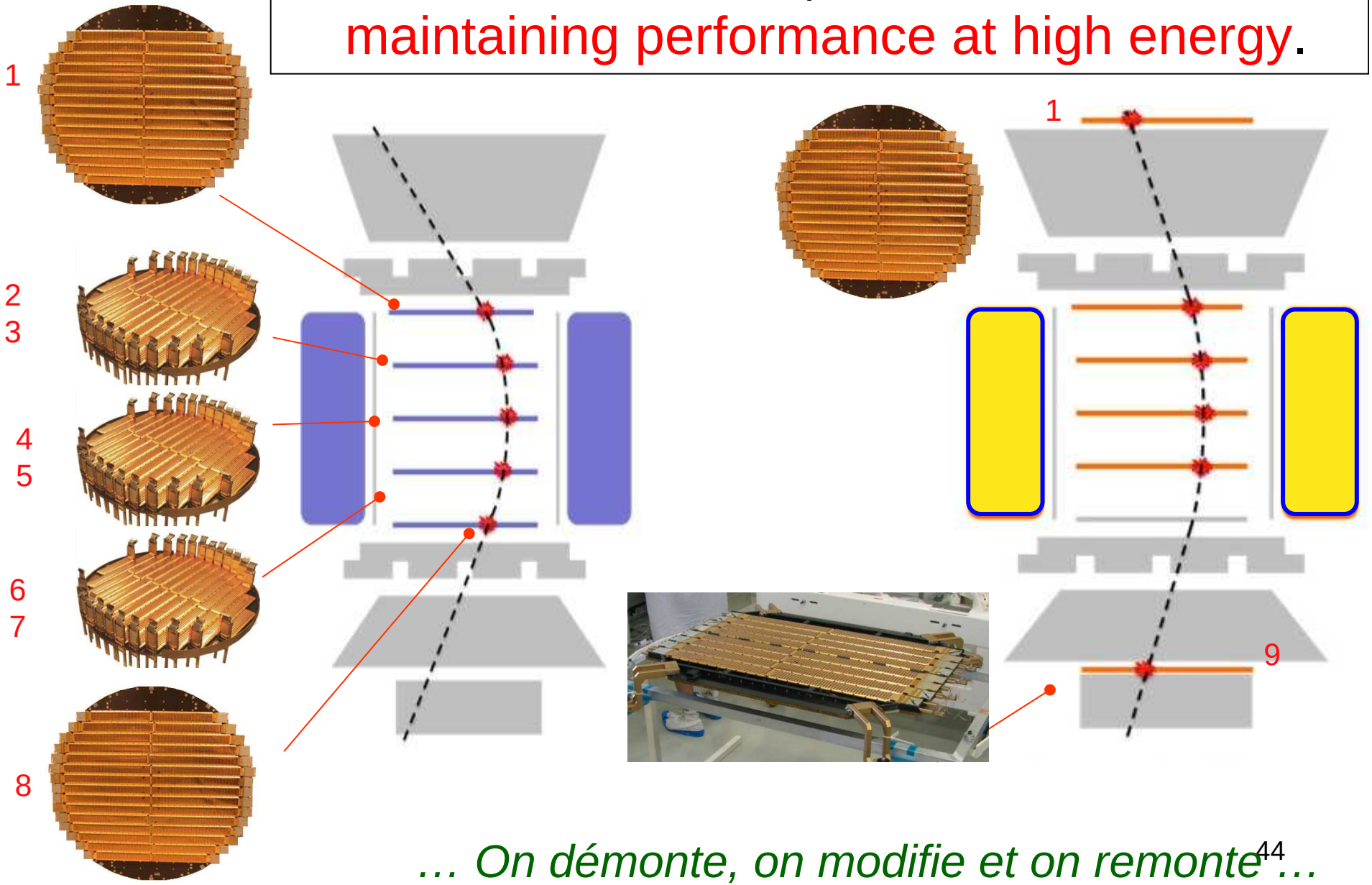
- Measured Helium consumption: → 20 ±4 months of SC magnet operation
- Refilling is not an option (AMS will stay on ISS)
- ISS life and operation time is extended (→ 2020, 2028 ?)
- Availability of a 2nd cylindrical support (spare vacuum tank) + AMS-1 magnet
- → The exposure time can be multiplied by a large factor.



Superconducting Magnet: B= 0.8 T

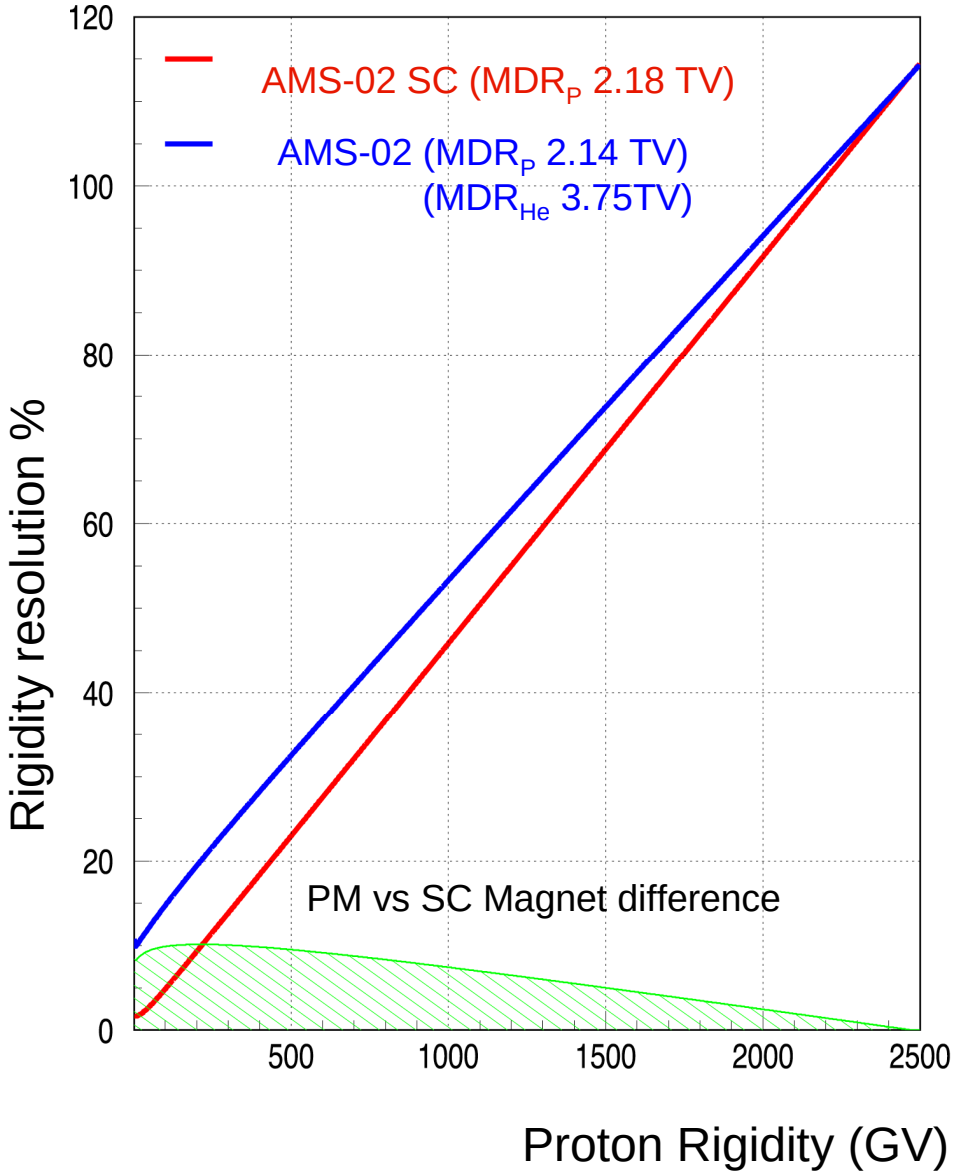
Permanent Magnet: B= 0.8 T

Tracker geometry is modified in order to increase the lever arms to compensate the lower field, maintaining performance at high energy.

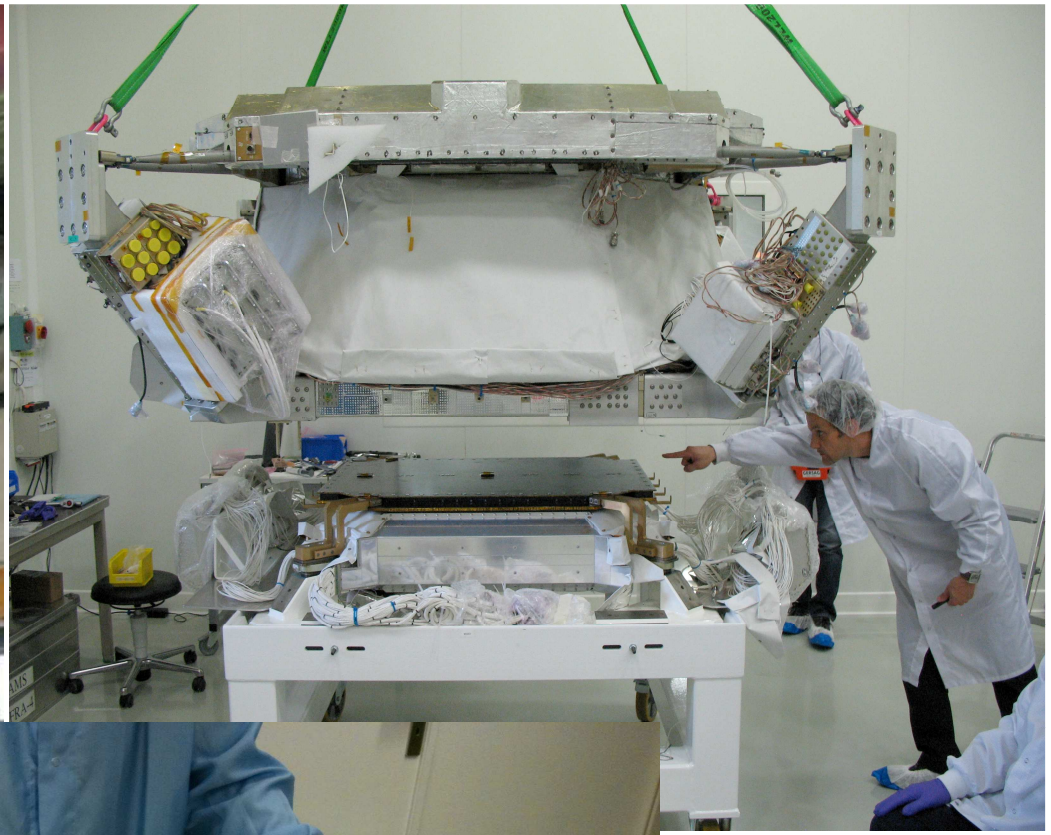


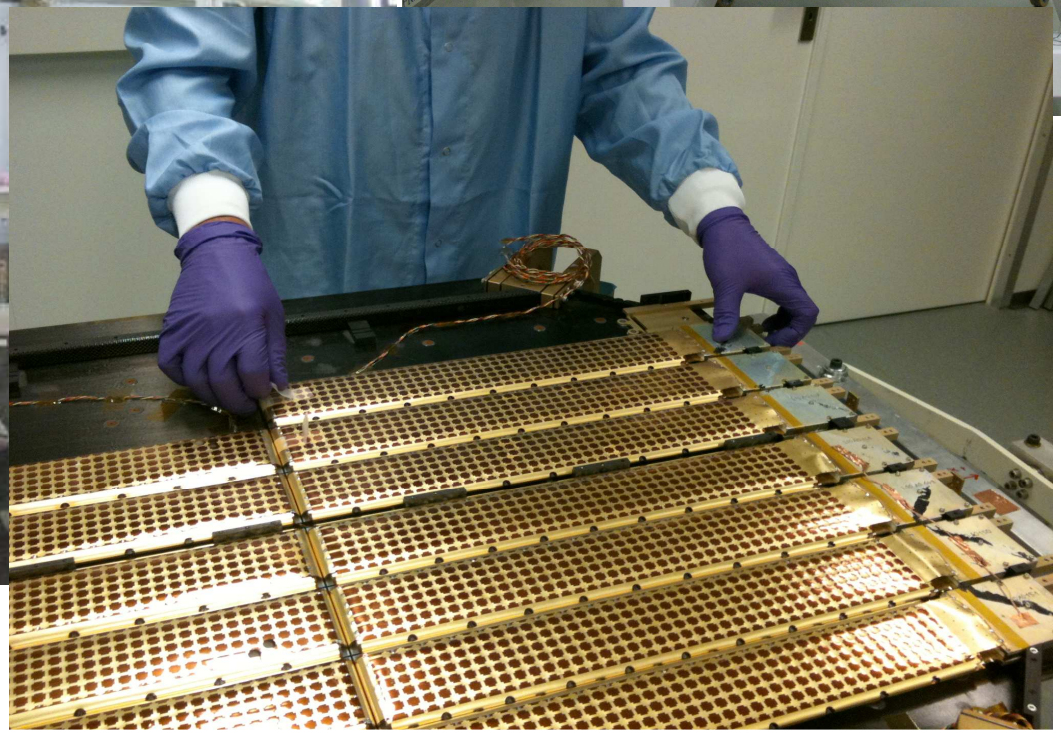
… On démonte, on modifie et on remonte…

Design curves for SC and PM tracker resolution ….



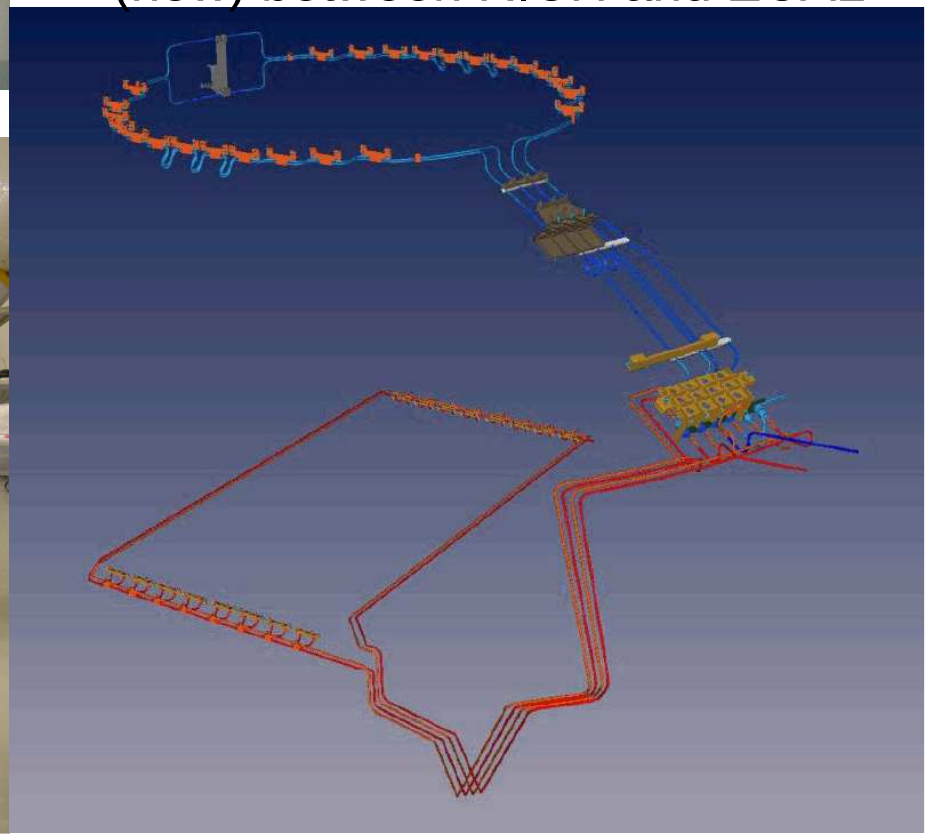
Real curves after beam test final analysis and muon data taking





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

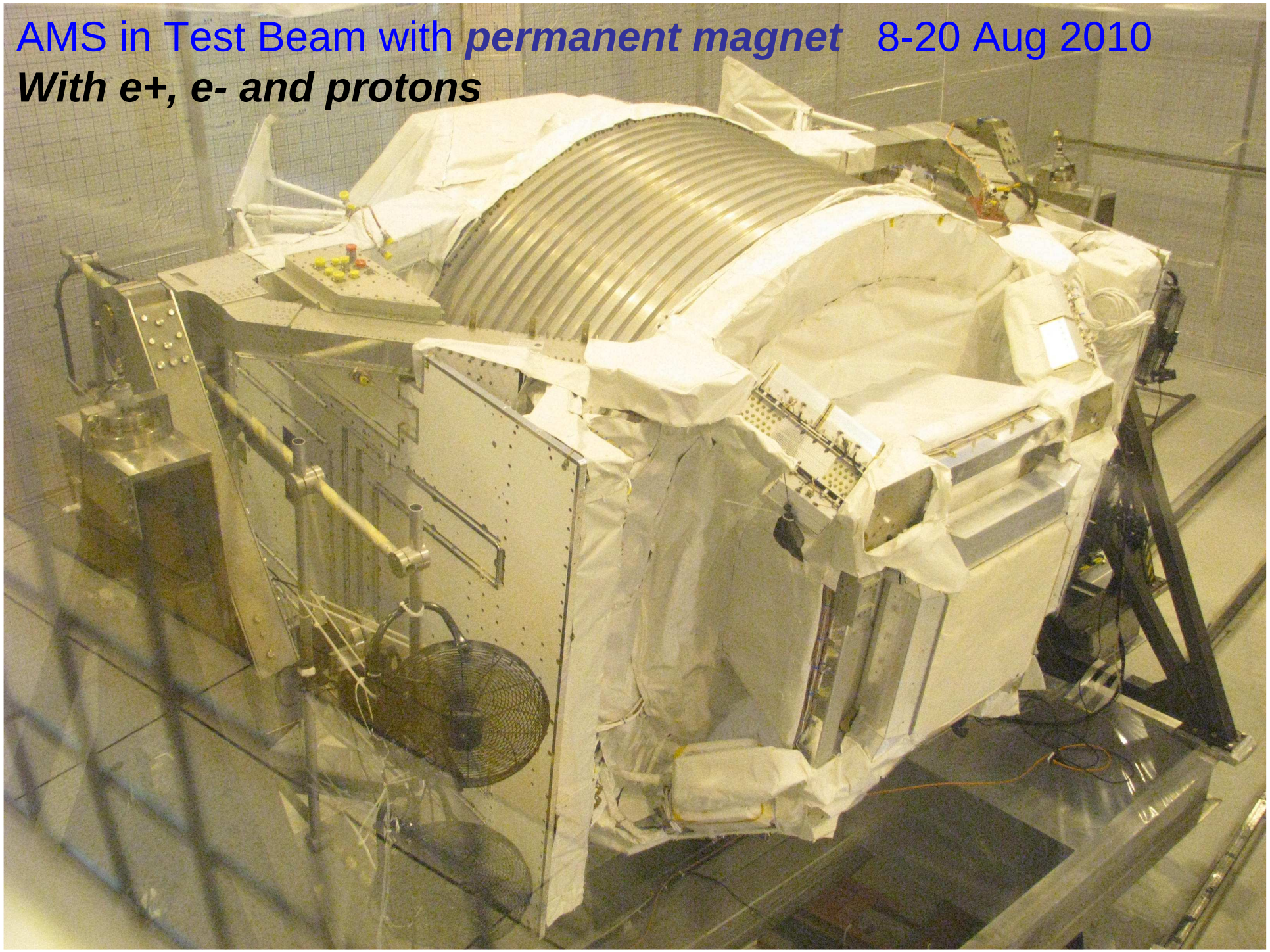


7 août 2010

(après modification de l'arrangement des plans du tracker)

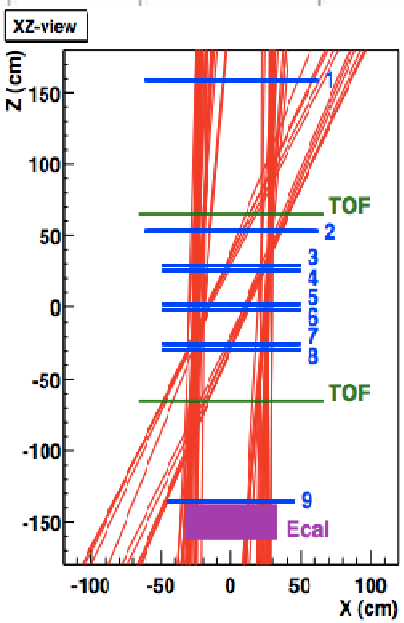
AMS in Test Beam with ***permanent magnet*** 8-20 Aug 2010

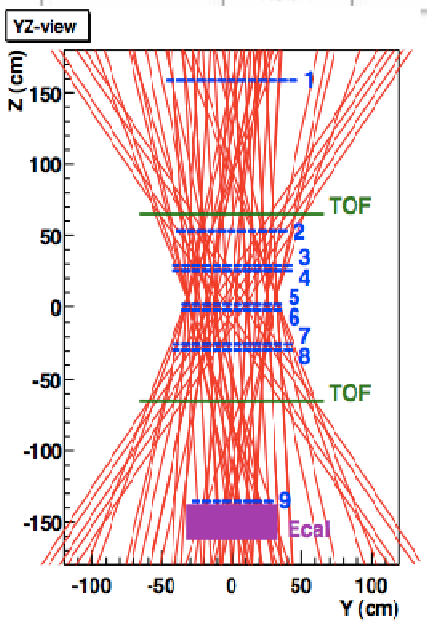
With e+, e- and protons

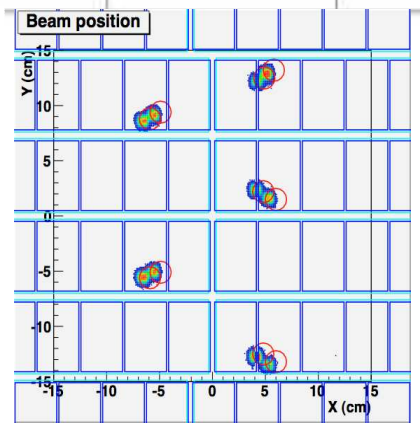


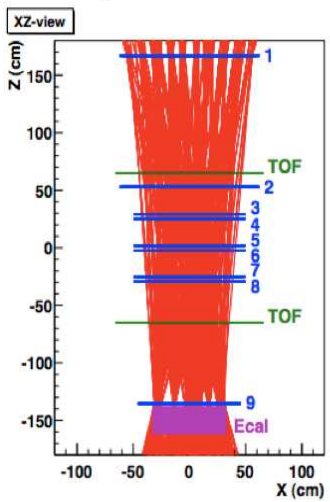
Calibration with 400 GeV protons

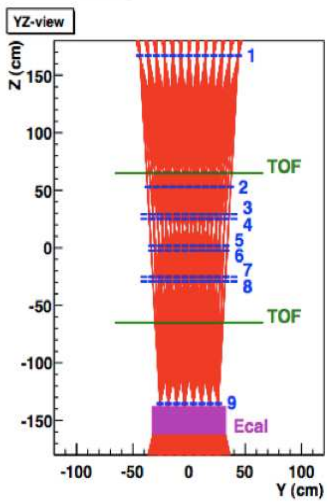
Particle	Momentum	C1/C2 Pr (Bar)	Min Events Per Pos	Spills Per Pos	Time (hrs) Total	Positions	Rate (p/sp) Expected	Comment
Protons	400 GeV	2/2	10^6	75	1	Center, 5°	20k	Initial Setup
Protons	400 GeV	2/2	10^4	3	5	TRACKER60	20k	Inner Tracker Alignment
Protons	400 GeV	2/2	10^4	7	1	TRACKER10	20k	Laser Correlation
Protons	400 GeV	2/2	10^4	3	30	TRACKER416	20k	Layers 1/9 Alignment
Protons	400 GeV	2/2	10^4	3	6	TRACKER80	20k	Layers 2/9 Alignment
Protons	400 GeV	2/2	10^4	3	24	TRACKER280	20k	Layers 1/8 Alignment
				67				



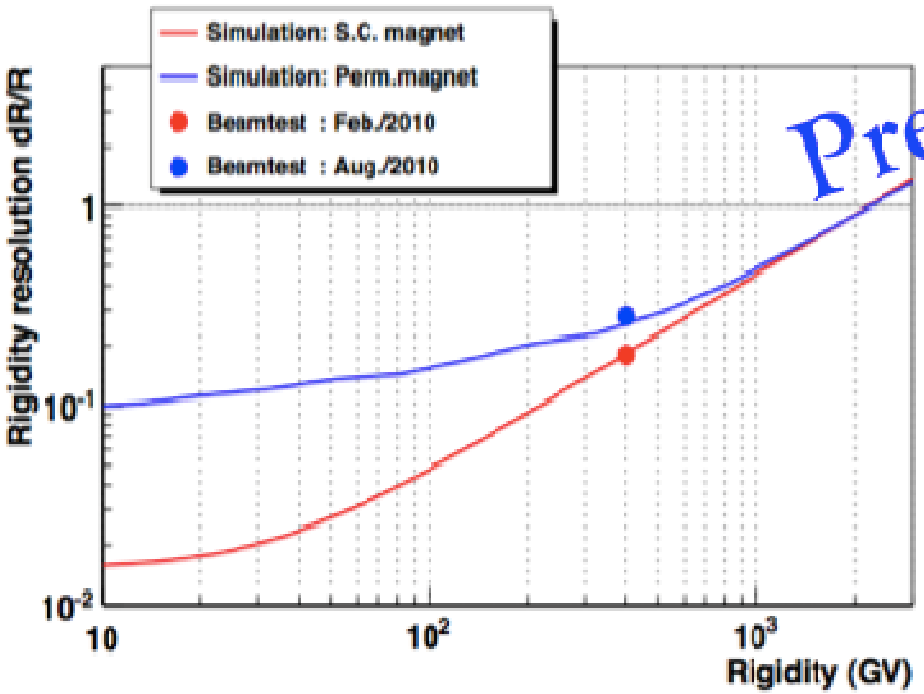


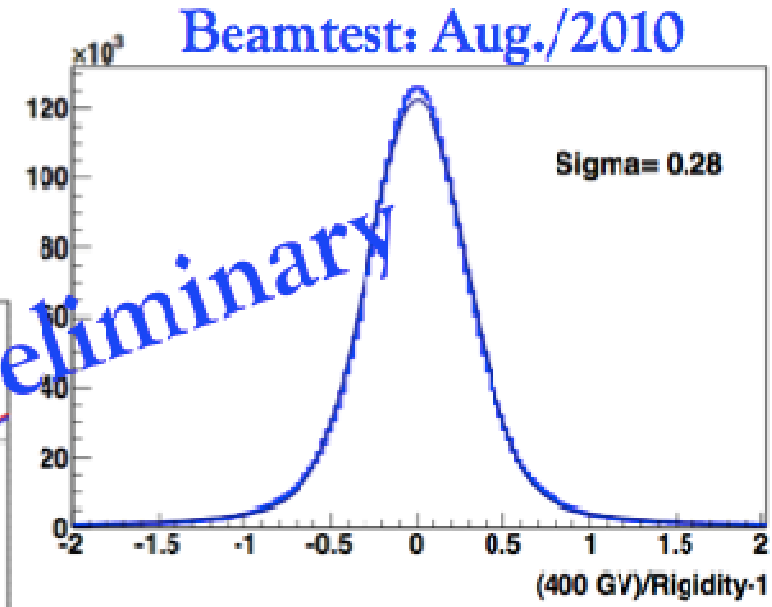


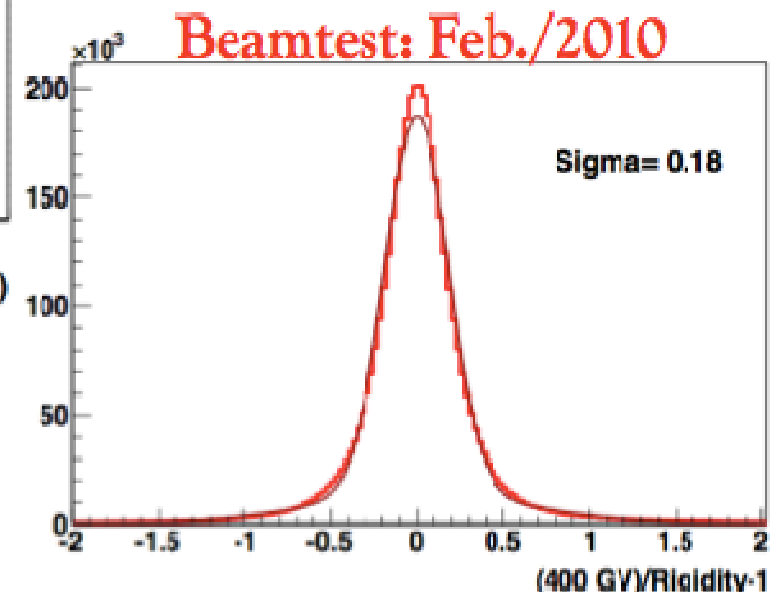




Preliminary results : TRACKER





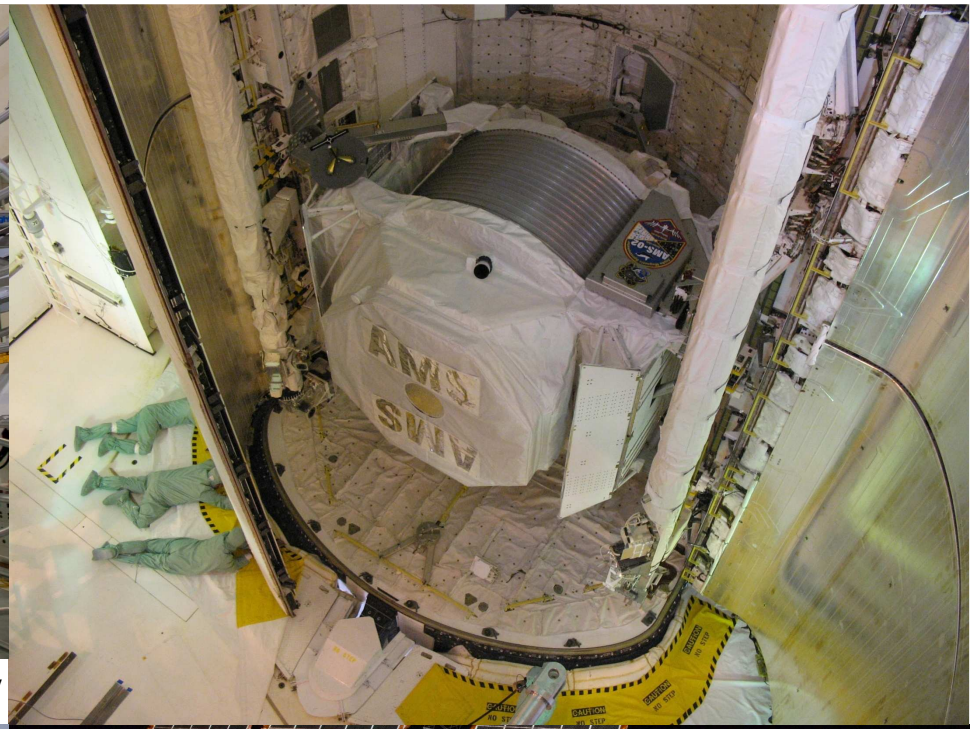


Other detectors performances did not change

23-24 août 2010: departure from CERN to GVA airport and loading in a C5-Galaxy airplane.

Direct flight to Kennedy Space Center

In SSPF ready to be installed in cargo bay



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

AMS installed on the ISS Truss
and taking data
May 19, 2011