8th International Conference on Large Scale Applications and Radiation Hardness of Semiconductor Detectors
27/29 June 2007 Florence, Italy

The AMS Silicon Tracker: construction and performance

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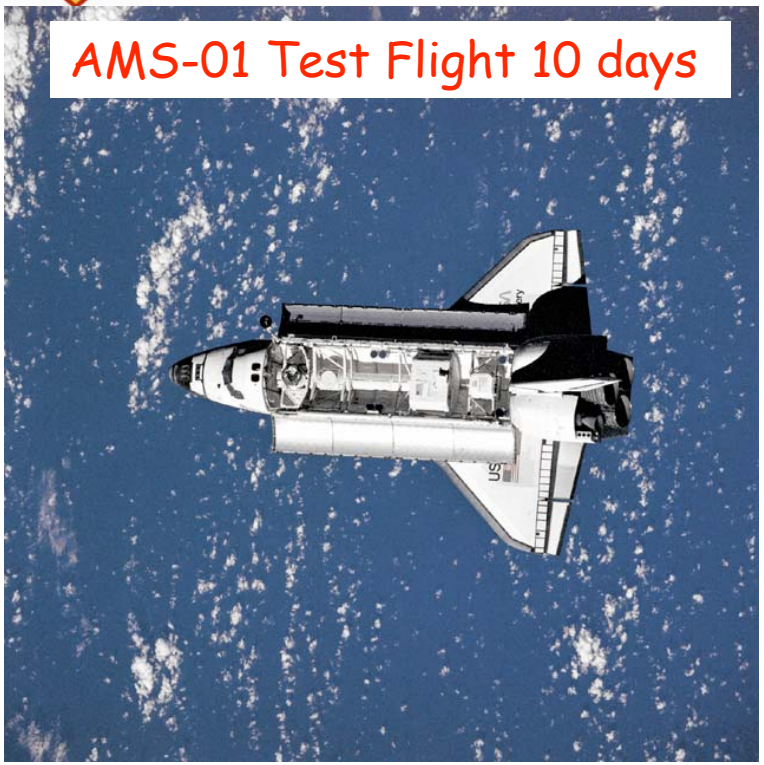
INFN - Sezione di Perugia

on behalf of the **AMS Tracker** group

The Alpha Magnetic Spectrometer experiment



- **AMS** is a broad international collaboration (~ 500 members) for the detection of primary cosmic rays in space
- Successful test flight aboard space shuttle Discovery in June 1998
- Detector integration at CERN starting August 2007

Final detector to be installed on the International Space Station

*ready for launch date

AMS Astrophysics Goals

Accurate measurement of cosmic rays fluxes from 0.5 GV up to 2 TV rigidity

→Hadronic component gives information on production, acceleration and propagation mechanisms

- Secondary-to-primary ratios (d/p, ^{3}He/^{4}He): test to propagation models
- Confinement times (^{10}Be/^{9}Be): constraint to galactic halo models
- Long period of observation will give information on solar cycle variations

→Dark matter signatures may be found in cosmic rays

→ Existence of antimatter domains might be inferred from direct detection of antinuclei

AMS Requirements

Astrophysics → *Nuclei fluxes*

- Charge identification in large Z range
- Precise velocity measurement
- Rigidity measurement
- Ability to identify different isotopes

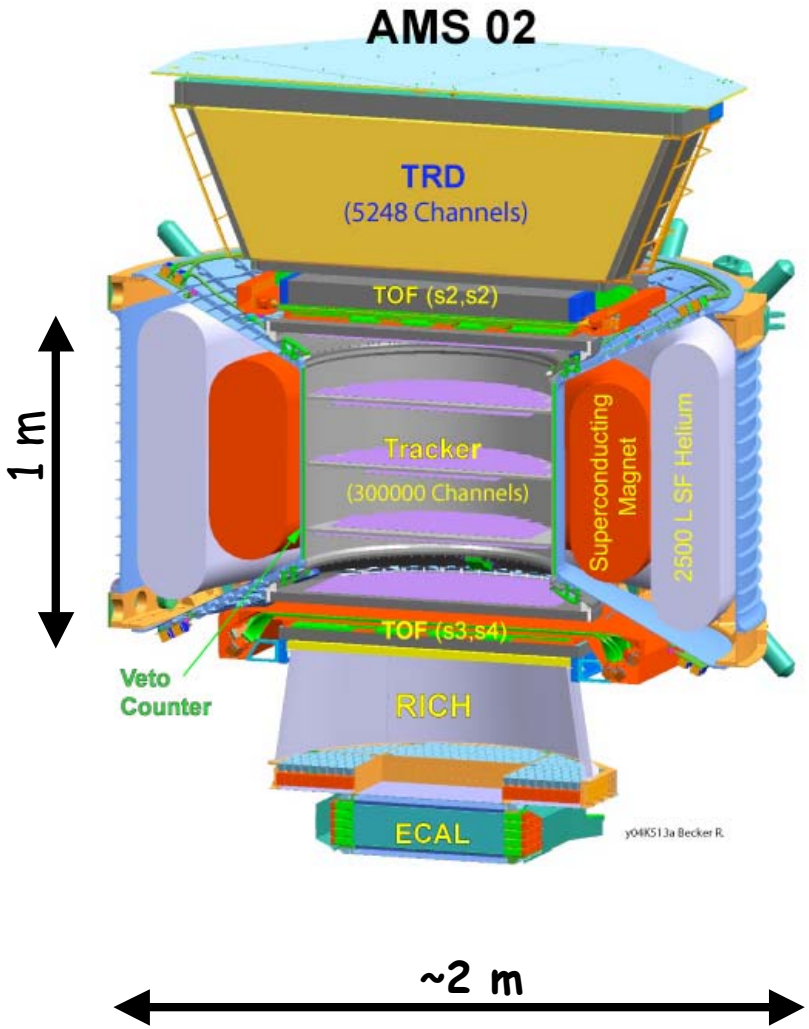
Anti-matter & Dark matter Signals → *Rare CR components*

- Large Statistic
- Charge identification
- Velocity & rigidity measurements
- Albedo rejection
- γ detection

Operation in Space:

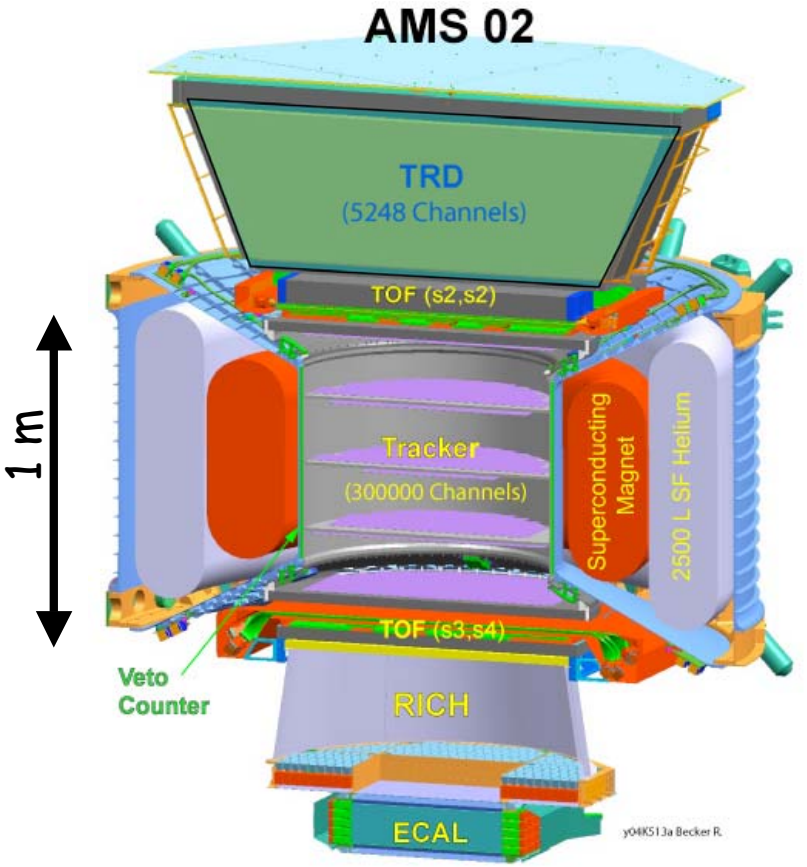
- Space qualification
- Redundancy
- Low power consumption
- Weight budget
- Bandwidth for data

The AMS detector



AMS Weight: 7 Tons

The AMS detector

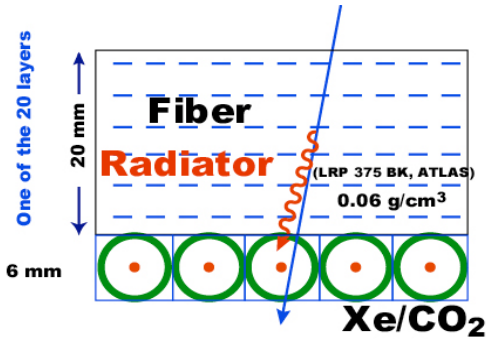


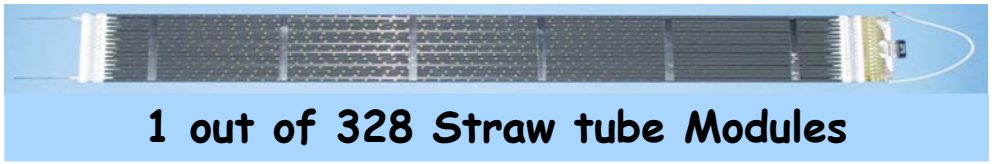
AMS Weight: 7 Tons

TRD (Transition Radiation Detector):

20 layers of Foam + Straw Drift Tubes (Xe/CO_2)

3D tracks, e/h separation>10^2 rej. up to 300 GeV





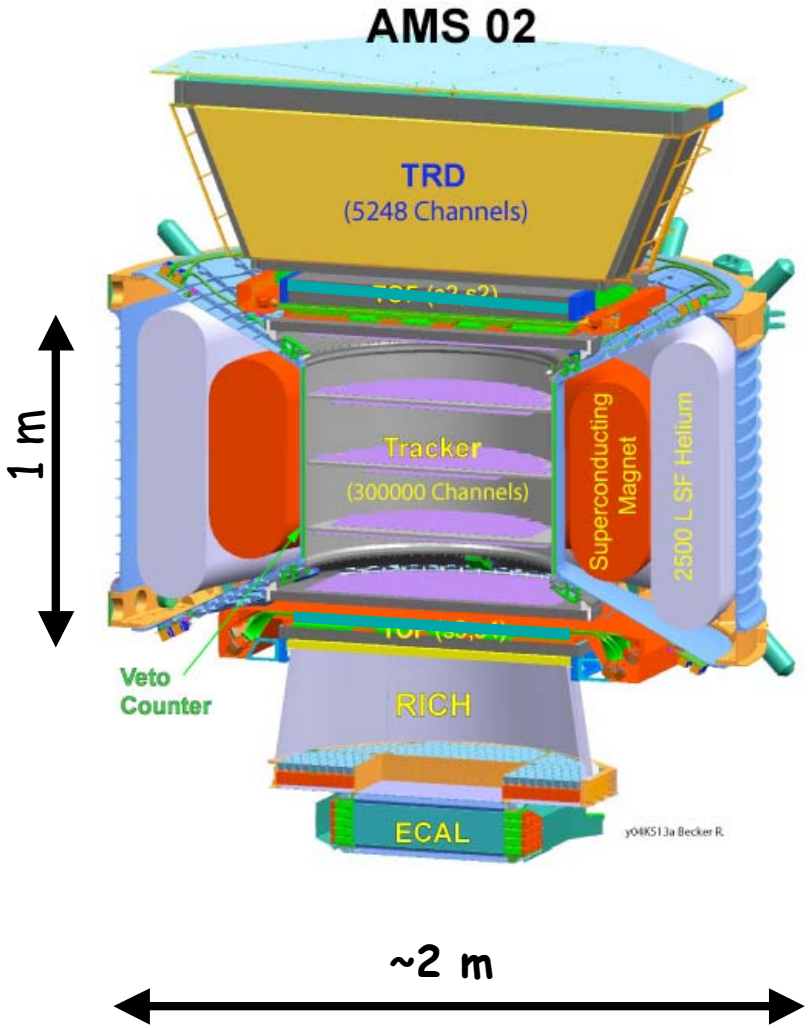
1 out of 328 Straw tube Modules

The AMS detector

TOF (Time of Flight):

2+2 layers of scintillators, Δt =~160ps

Trigger, Z separation, β with few % precision



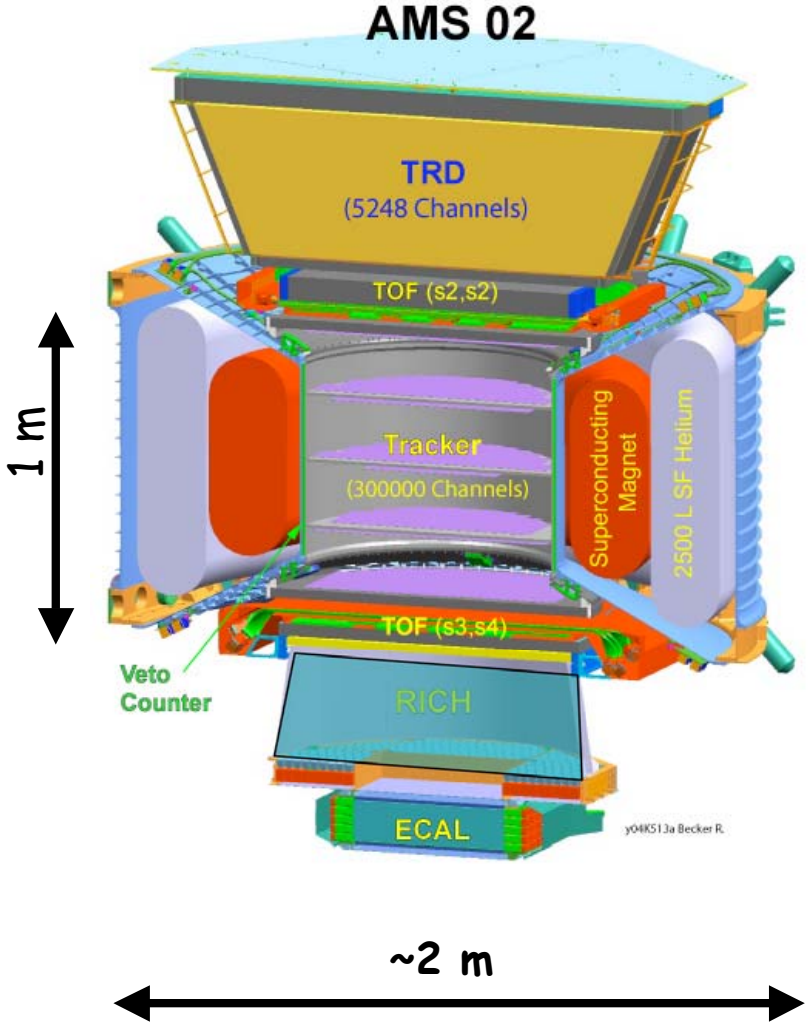
2 out of 4 layers

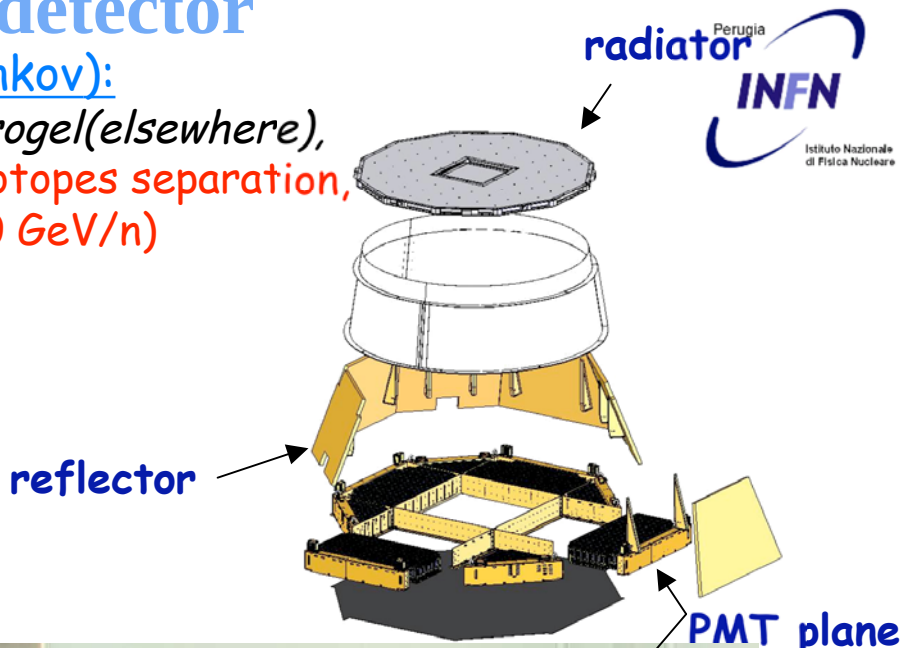
The AMS detector

RICH (Ring Imaging CHerenkov):

2 Radiators: NaF (center), Aerogel(elsewhere),

β with 0.1% precision, Z and isotopes separation,
(2% precision on mass below 10 GeV/n)





The AMS detector

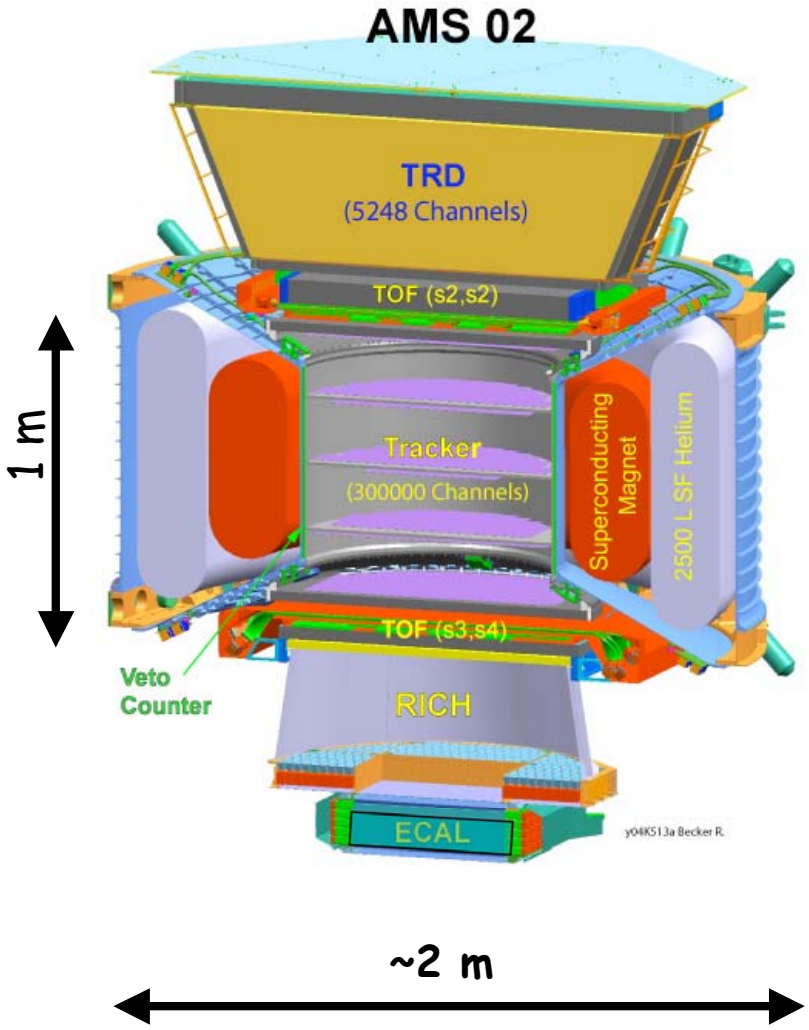
Perugia INFN Istituto Nazionale di Fisica Nucleare

ECAL (Electromagnetic Calorimeter):

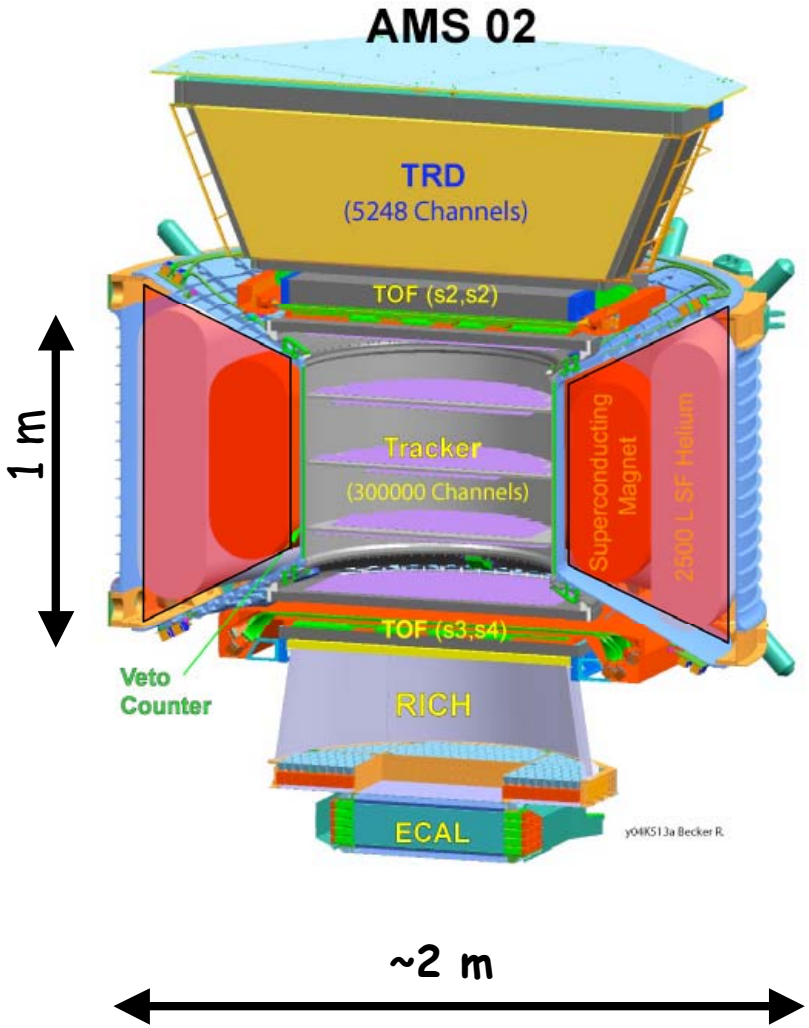
Sampling: 9 superlayers of Lead+Scint. Fibers

trigger, $e^{\pm}$, γ detection: $\sigma_{E(nergy)}$ **<3%** for E>10 GeV,

3D imaging: e/h separation>10^3 rej



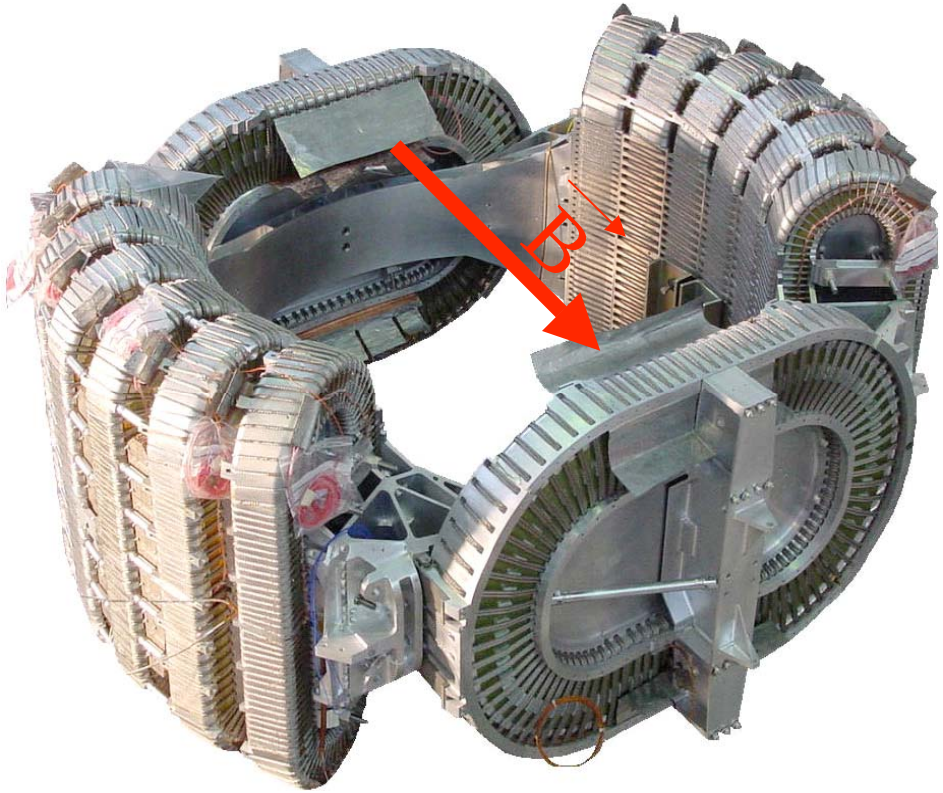
The AMS detector



Superconducting Magnet:

12 racetrack coils & 2 dipole coils cooled to 1.8° K by 2.5 m^3 of superfluid He

Contained dipolar field: $BL^2 = 0.85\ Tm^2$

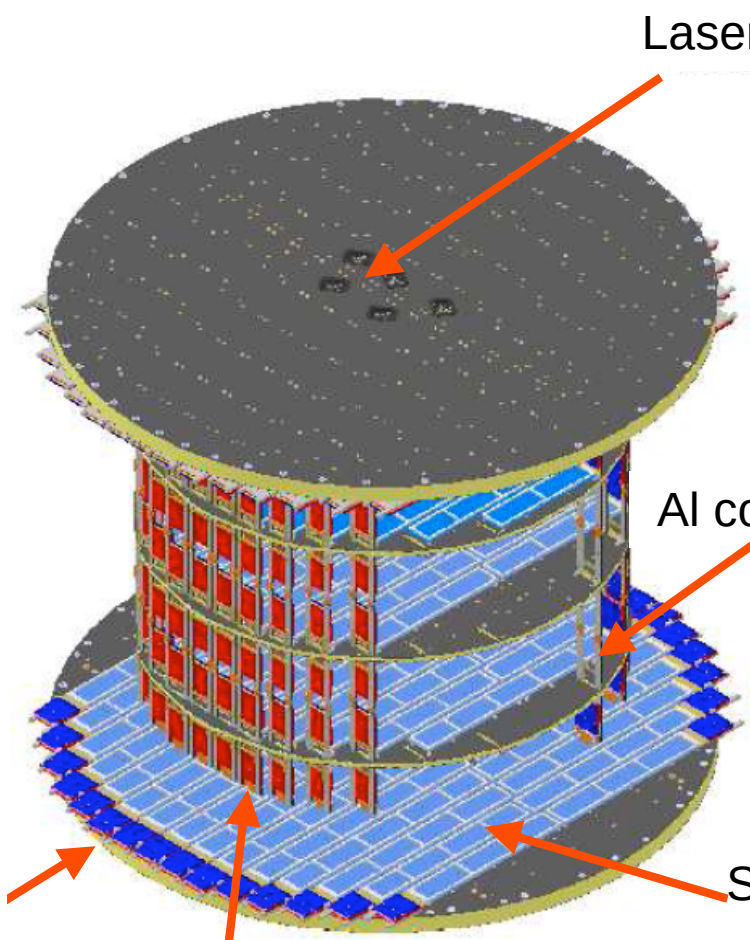


Technological challenge:

first superconducting magnet operating in space

Silicon Tracker

- 2264 Double sided silicon sensors ~4x7 cm mechanicaly and electrically grouped in ladders (7-15 sensors)
- Ladders arranged on 8 layers of circular shape
- 5 honeycomb carbon fiber plane
- detector material ~ 0.04 Xo
- total of 200k channels for 192 watt dissipated inside the magnet volume
- 10 μm (30 μm) spatial resolution in bending (non bending) plane
- momentum resol 1.5% at 10 GeV
- high dynamic range front end for charge measurement
- wide temperature range (-20/+40 survival, -10/+25 oper.)



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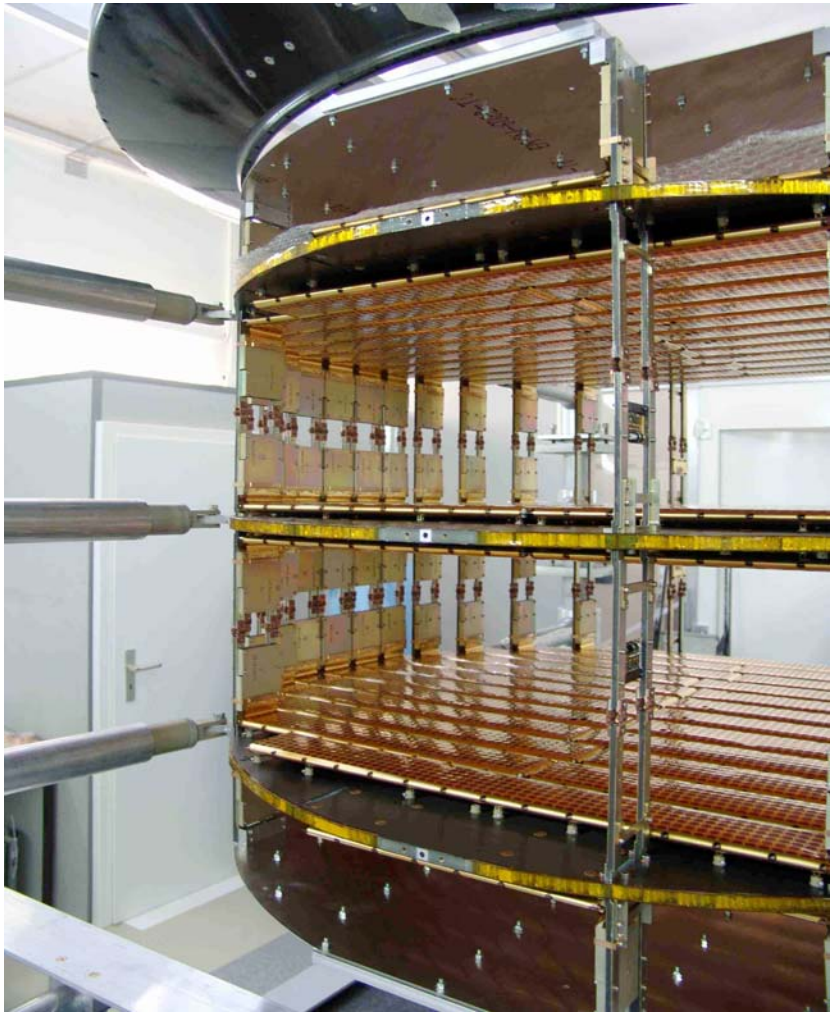
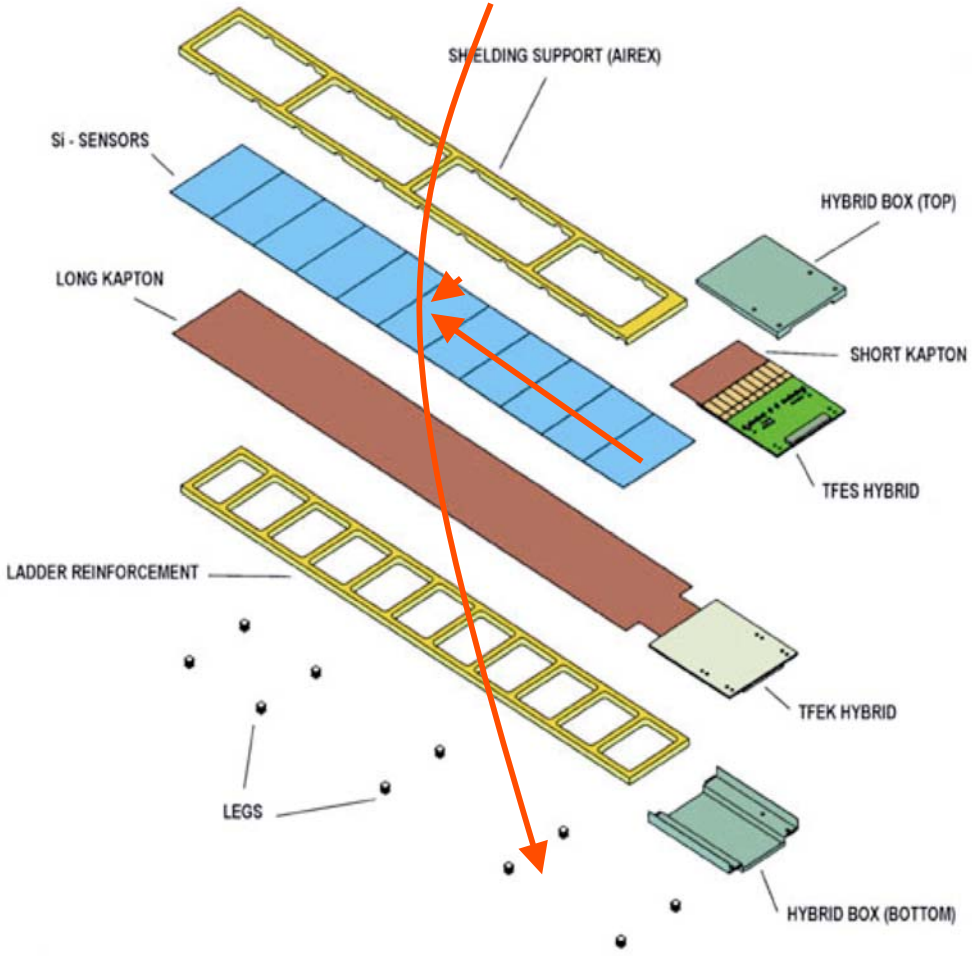


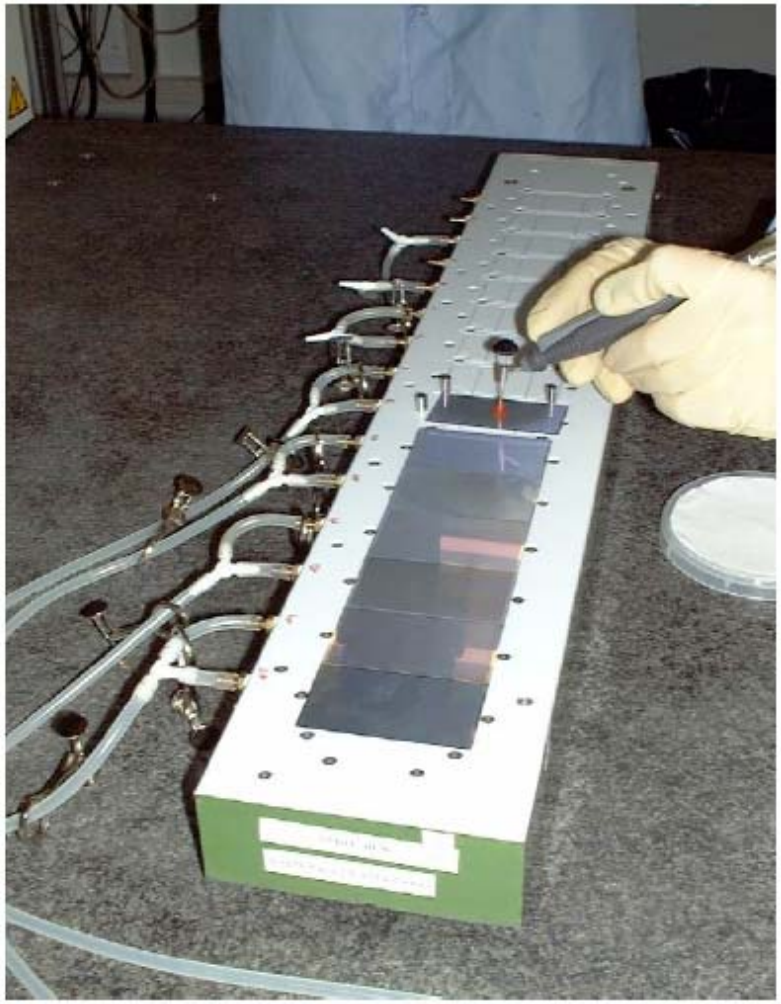
AMS silicon ladders

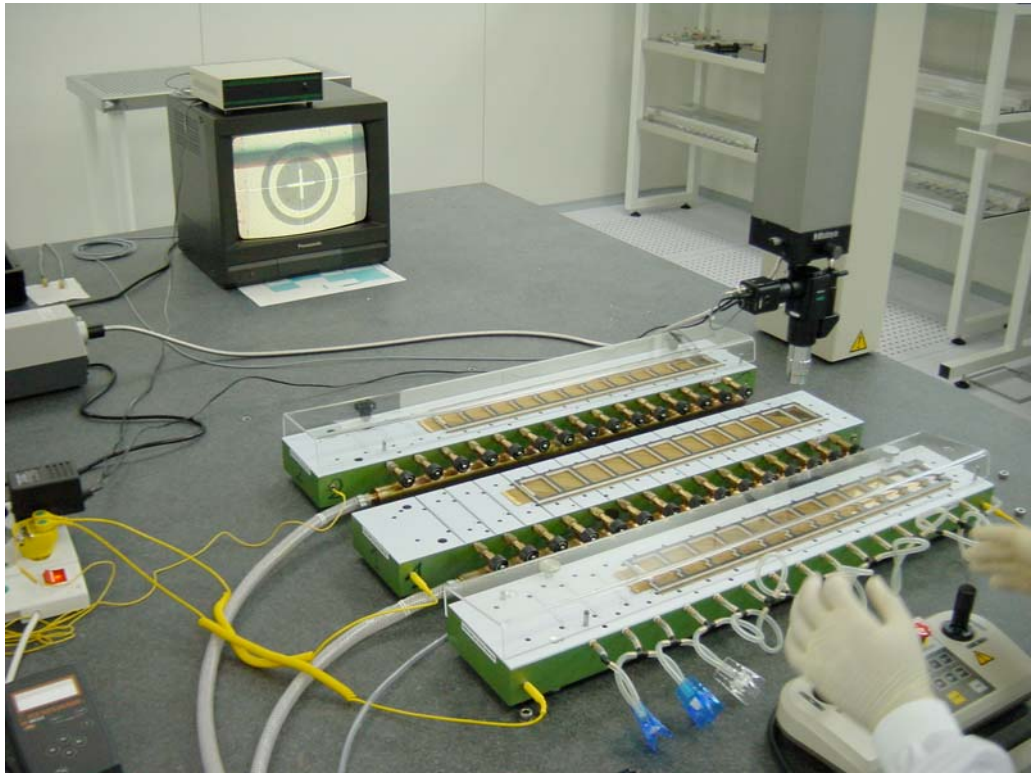


- 1024 high dynamic range, AC coupled readout channels:
  - 640 on junction (S) side
  - 384 on ohmic (K) side
- Impl/readout pitch:
  - 27.5/110 μm (S side)
  - 104/208 μm (K side)
- 7 – 15 wafers (28 – 60 cm)

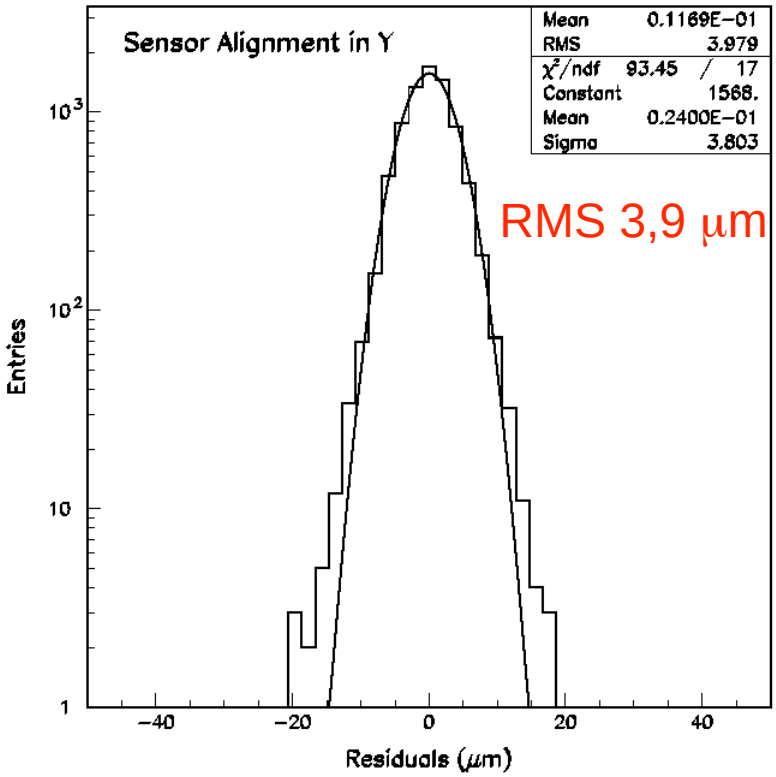
192 flight units, 210 assembled in 3 lines:
Perugia (I), Geneva-ETHZ (CH), G&A (Carsoli, I)

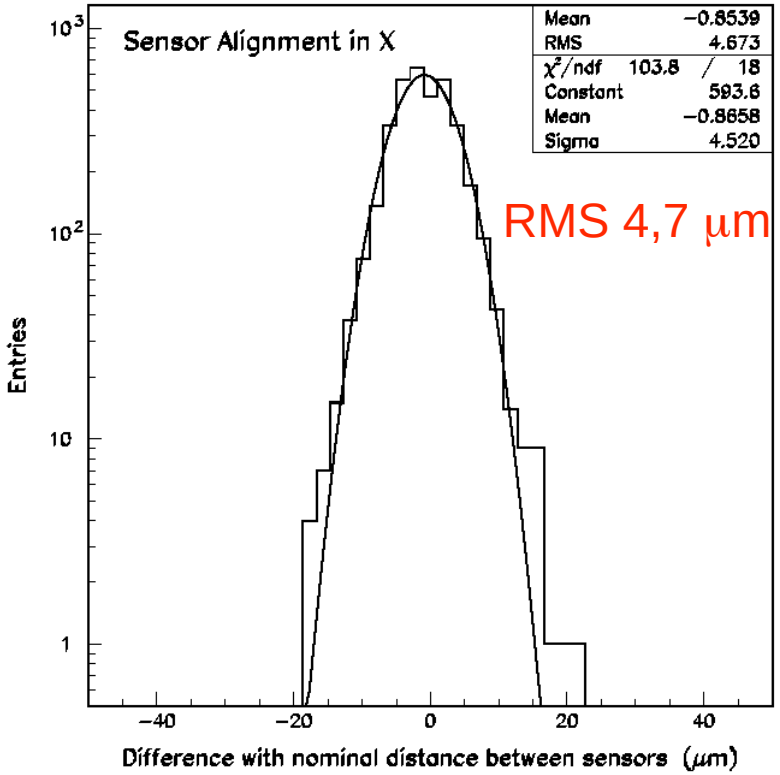
Silicon positioning and metrology



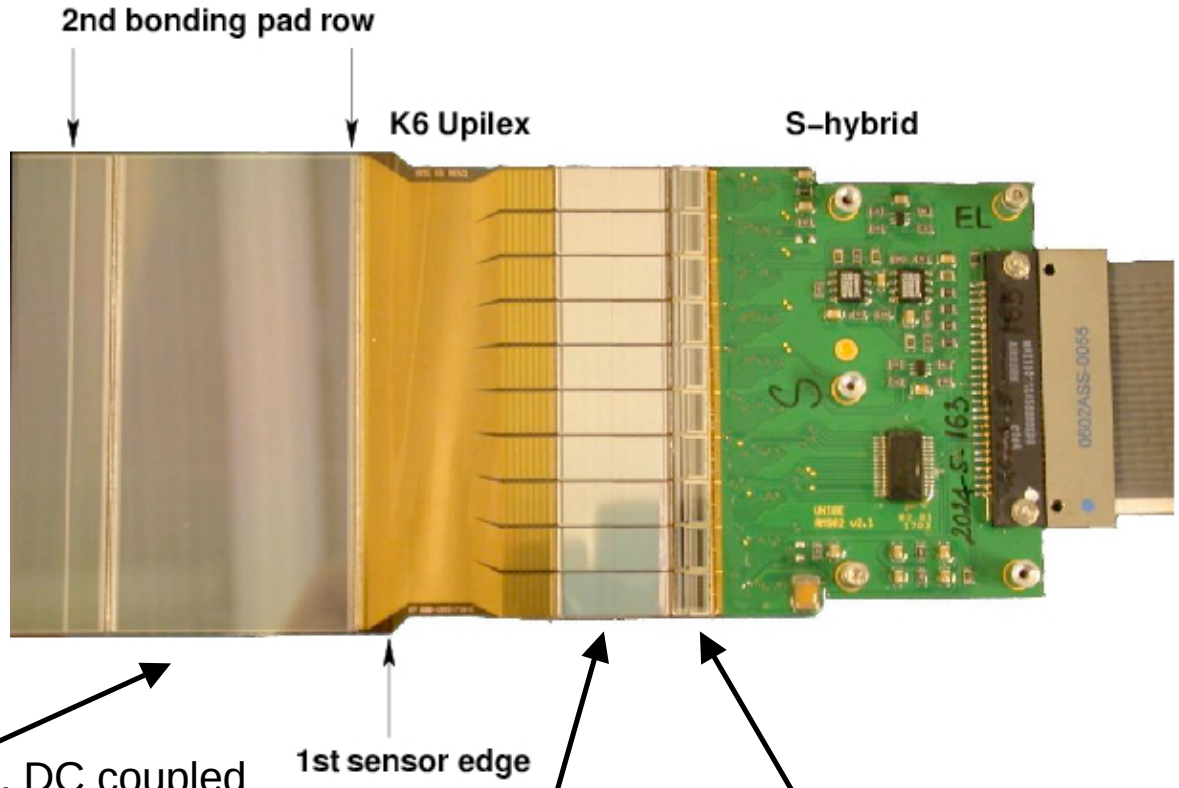


Sensor alignment in ladders





Ladder components (p side)

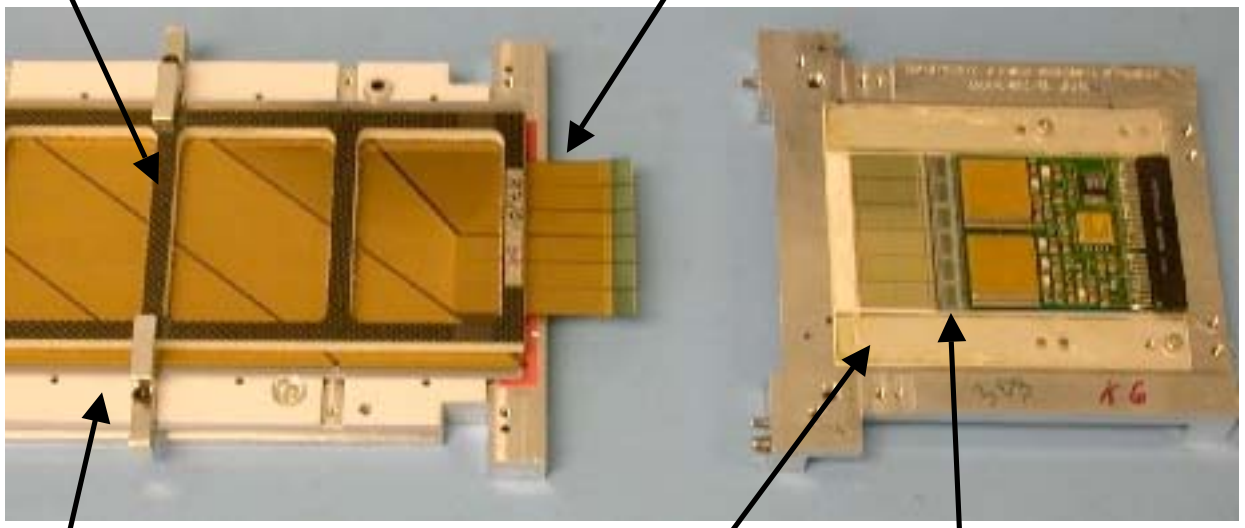


double sided, DC coupled
300 μm thickness
7 - 15 sensors in a ladder
produced at:
- Colybris (CH)
- IRST (IT)

700 pF coupling capa

10 VA_hdr64a (IDEas, NO)
640 channels, 0.7 mW power each
CR-RC shaper and S&H
4 μs shaping time
100 MIP dynamic range

Ladder components (n side)

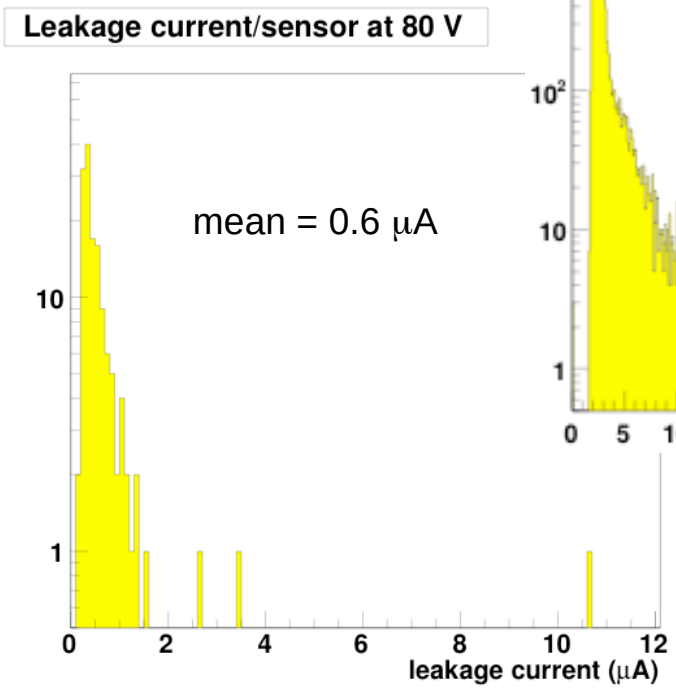


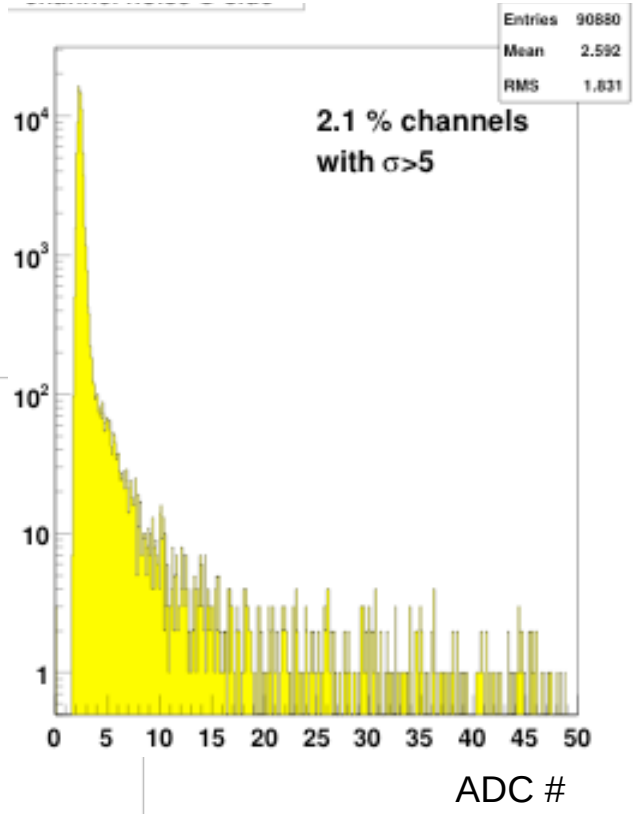
double sided, DC coupled
300 μm thickness
7 - 15 sensors in a ladder
produced at:
- Colybris (CH)
- IRST (IT)

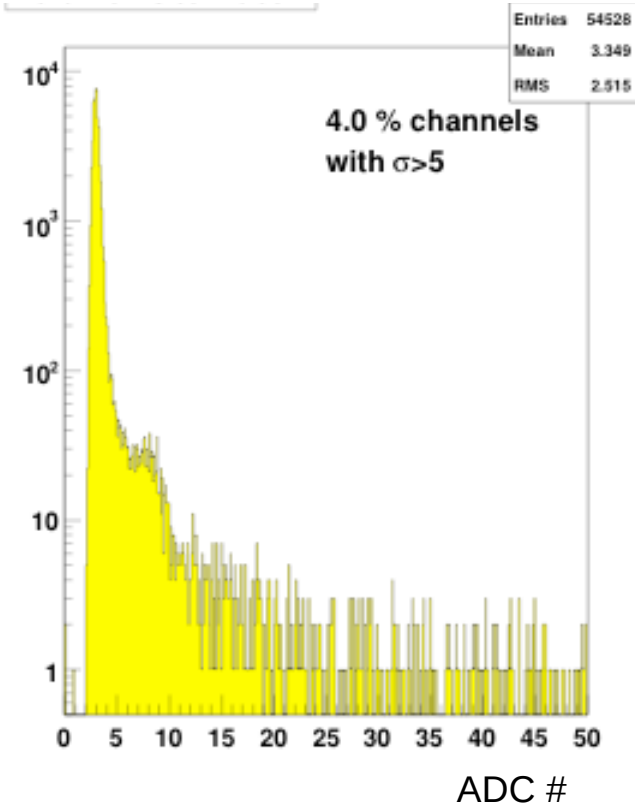
700 pF coupling capa

6 VA_hdr64a (IDEas, NO)
384 channels, 0.7 mW power each
CR-RC shaper and S&H
4 μs shaping time
100 MIP dynamic range

Noise and currents
(after ~ 3 10^6 bonds)





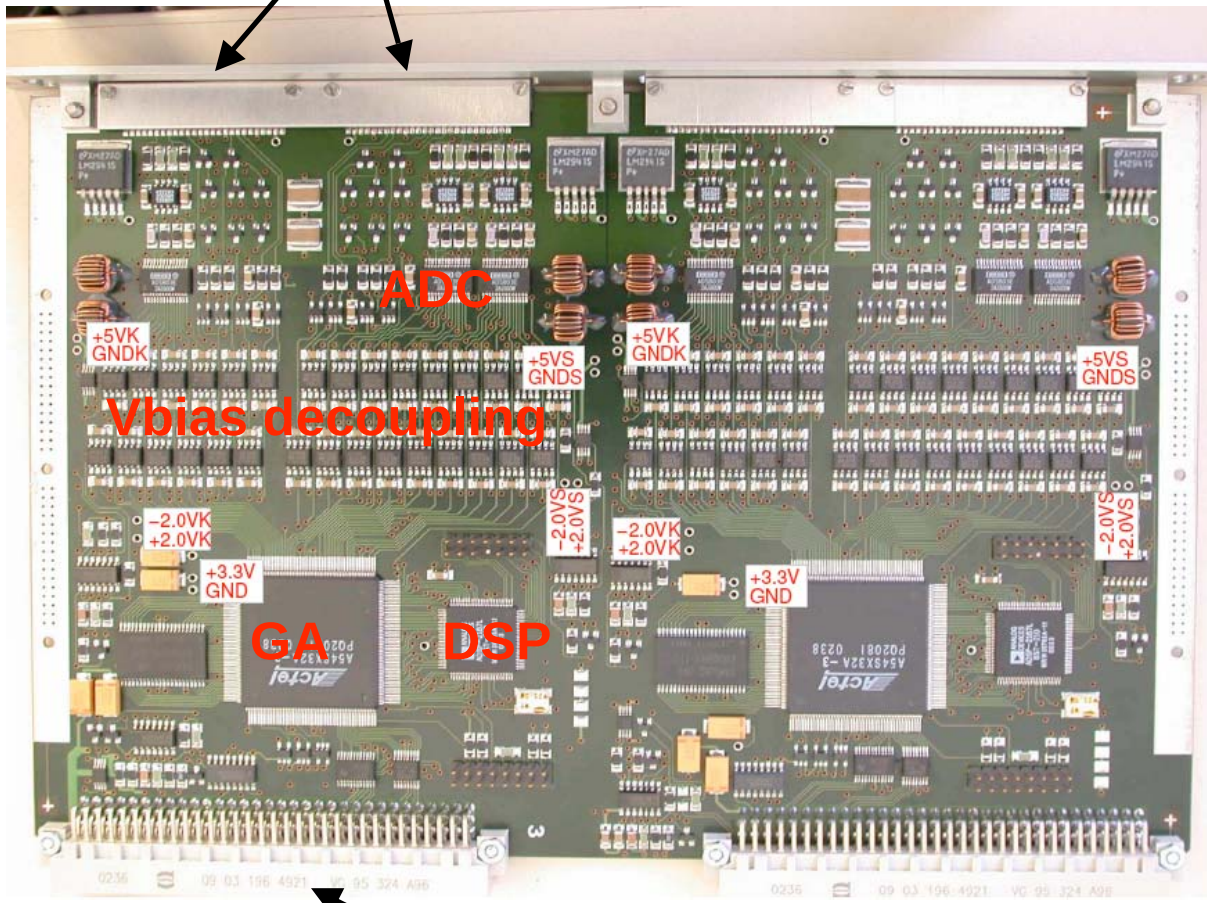


Landau MPV for MIPs ~ 30 ADC#

single wafer current was ~ 400 nA

Data Reduction Board (TDR2)

analog signal in



compressed digital out

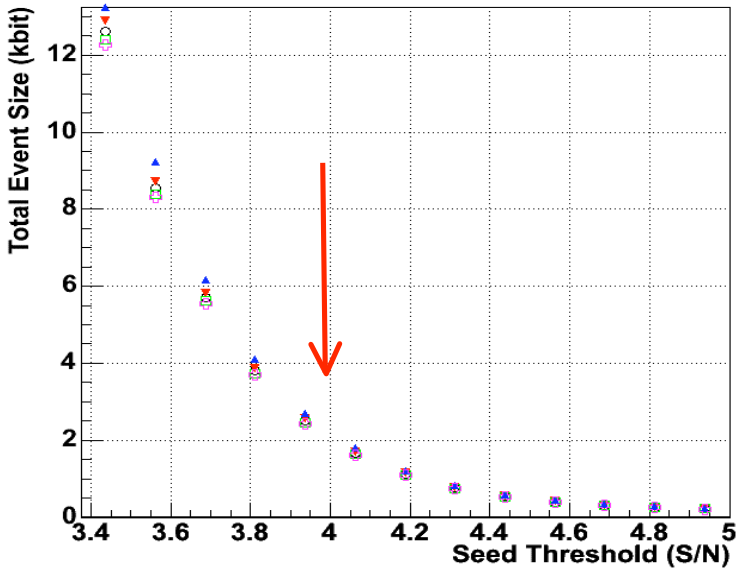
Collect analog data and digitize it (100 μs irred. dead time)

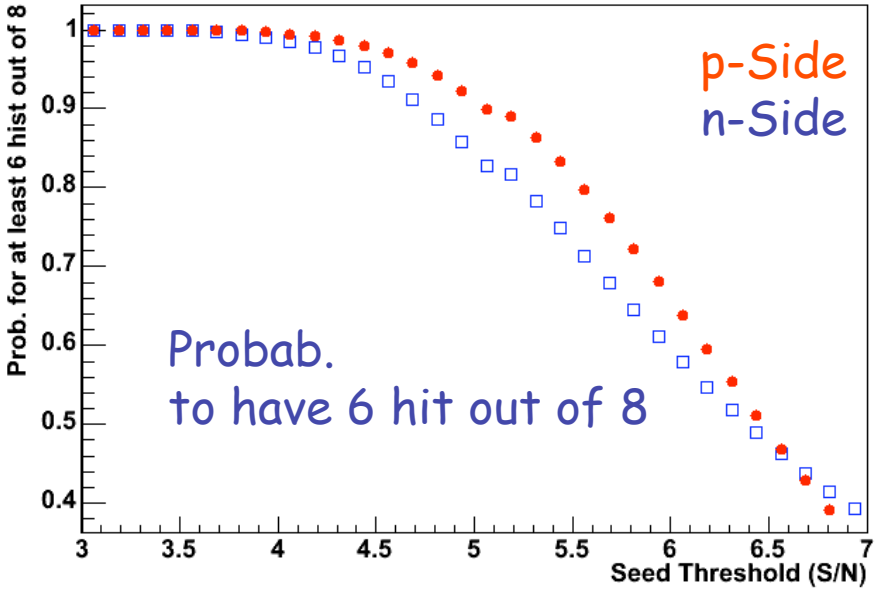
Perform online data compression

- Remove Pedestals
- Calculate and Remove Common Noise
- Search Clusters

Up to 5 KHz trigger rate in compressed mode

Data size and efficiency

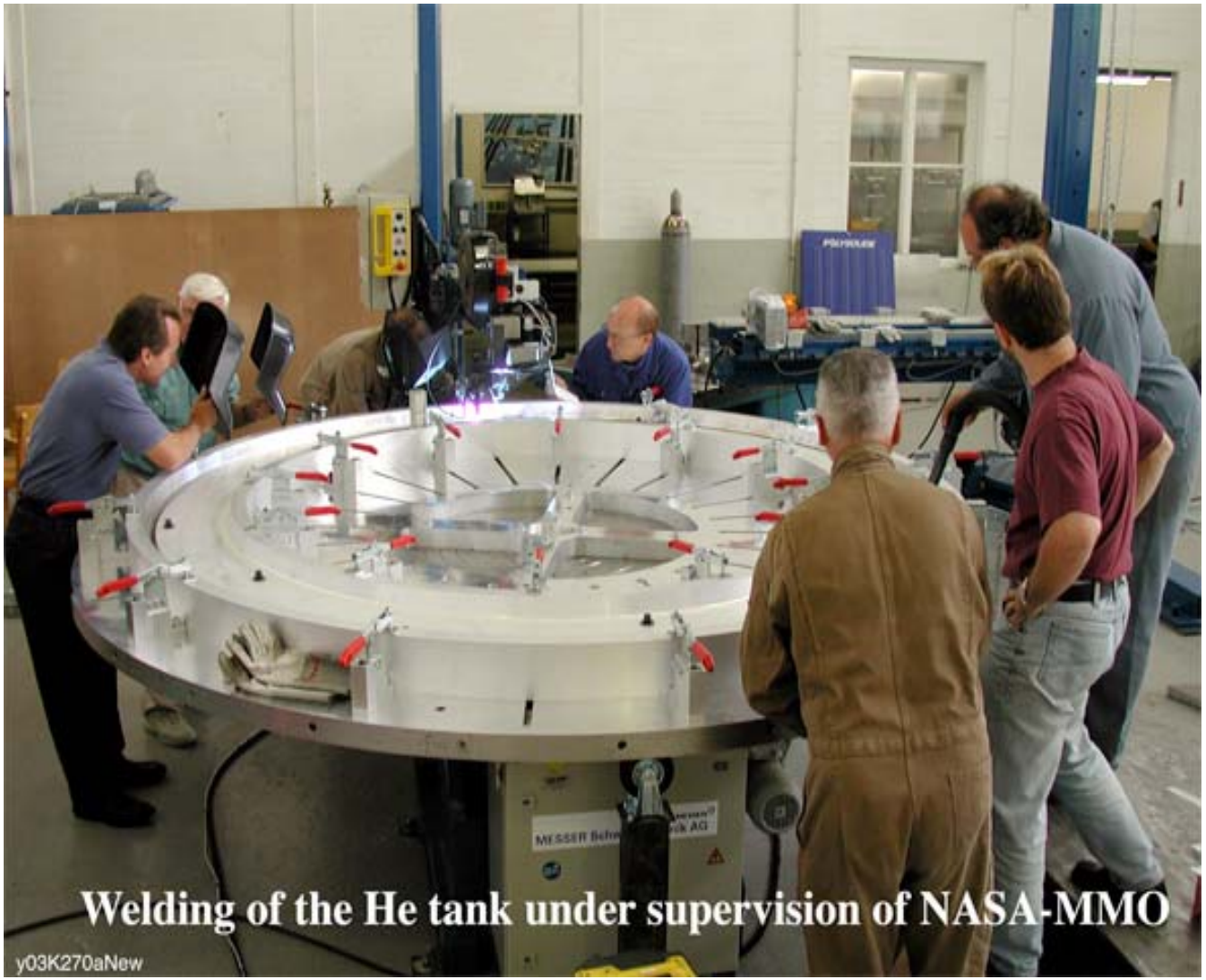




total bandwith is 2Mbit/s
max trigger rate is 2 KHz

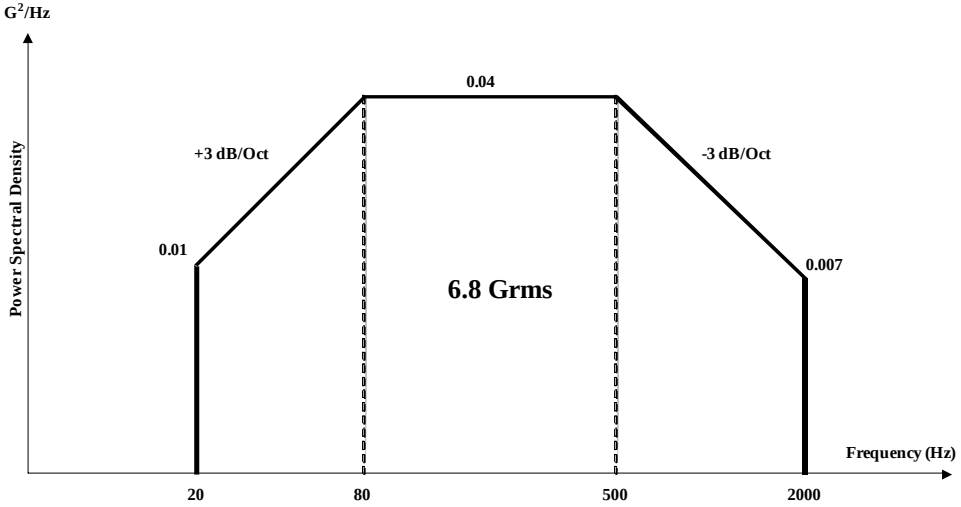
Subdetector	Req'ments	Channels	Raw Kbits
U: TRD	Gas gain	5,248	84
S: ToF+ACC	100 ps	48*4*8	49
T: Tracker	few fC	196,608	3,146
R: RICH	Single gamma	680*16*2	348
E: ECAL	1:60,000	324*(4*2+1)	47
Σ Raw Kbits/event			3,674
* Event Rate			≤ 2 Khz
= Total Raw Data Rate			~7 Gbit/sec

Space qualification

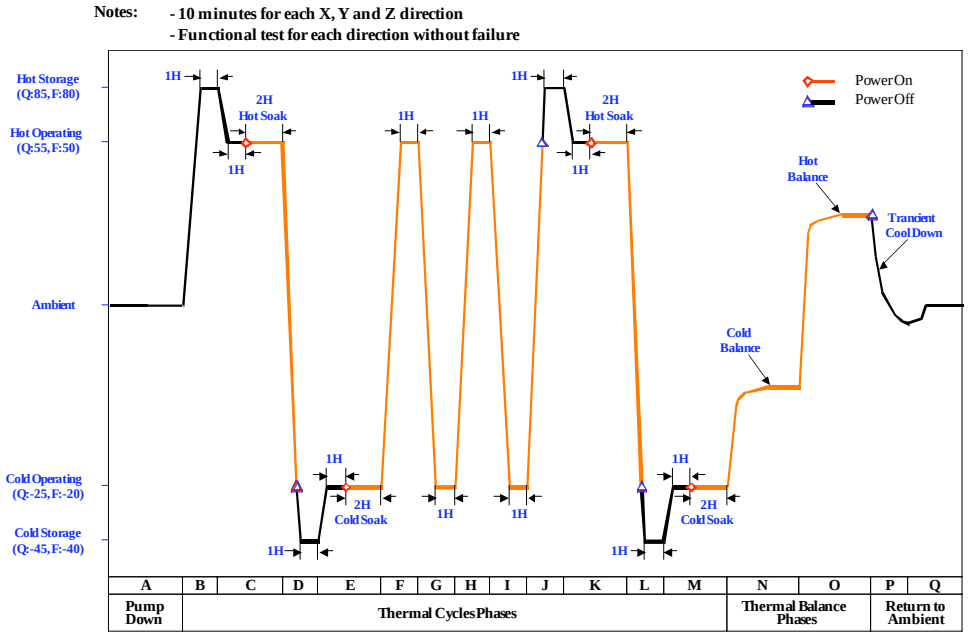


Stress Profile

Vibration
power spectrum

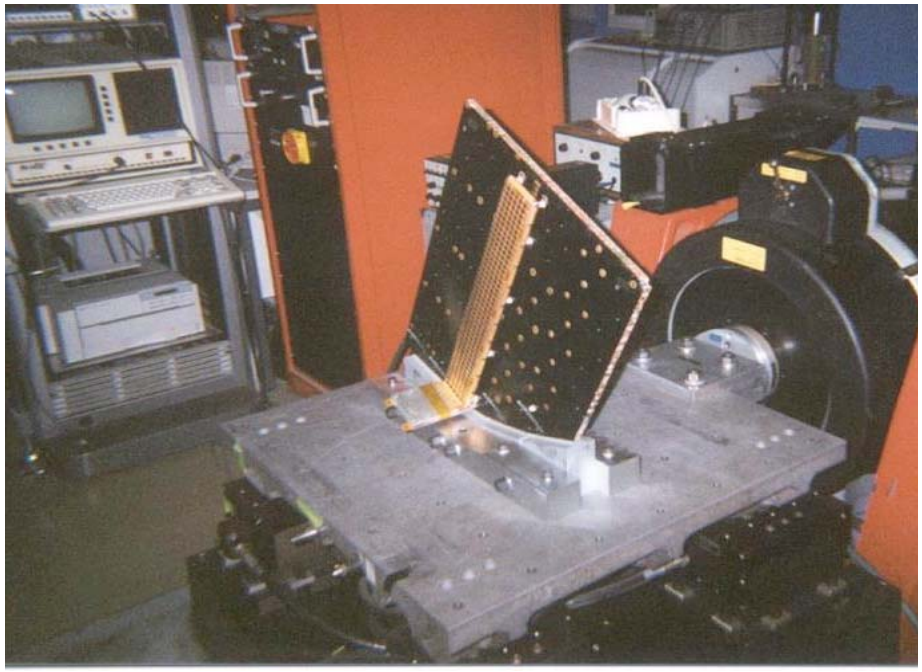


Thermal and
thermo-vacum cycles



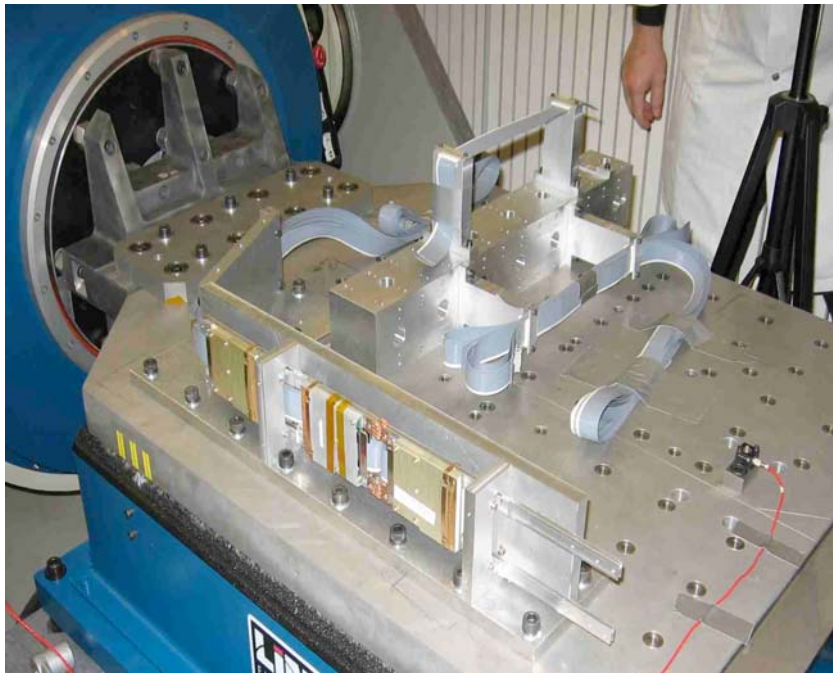
Vibration tests

ladder on plane



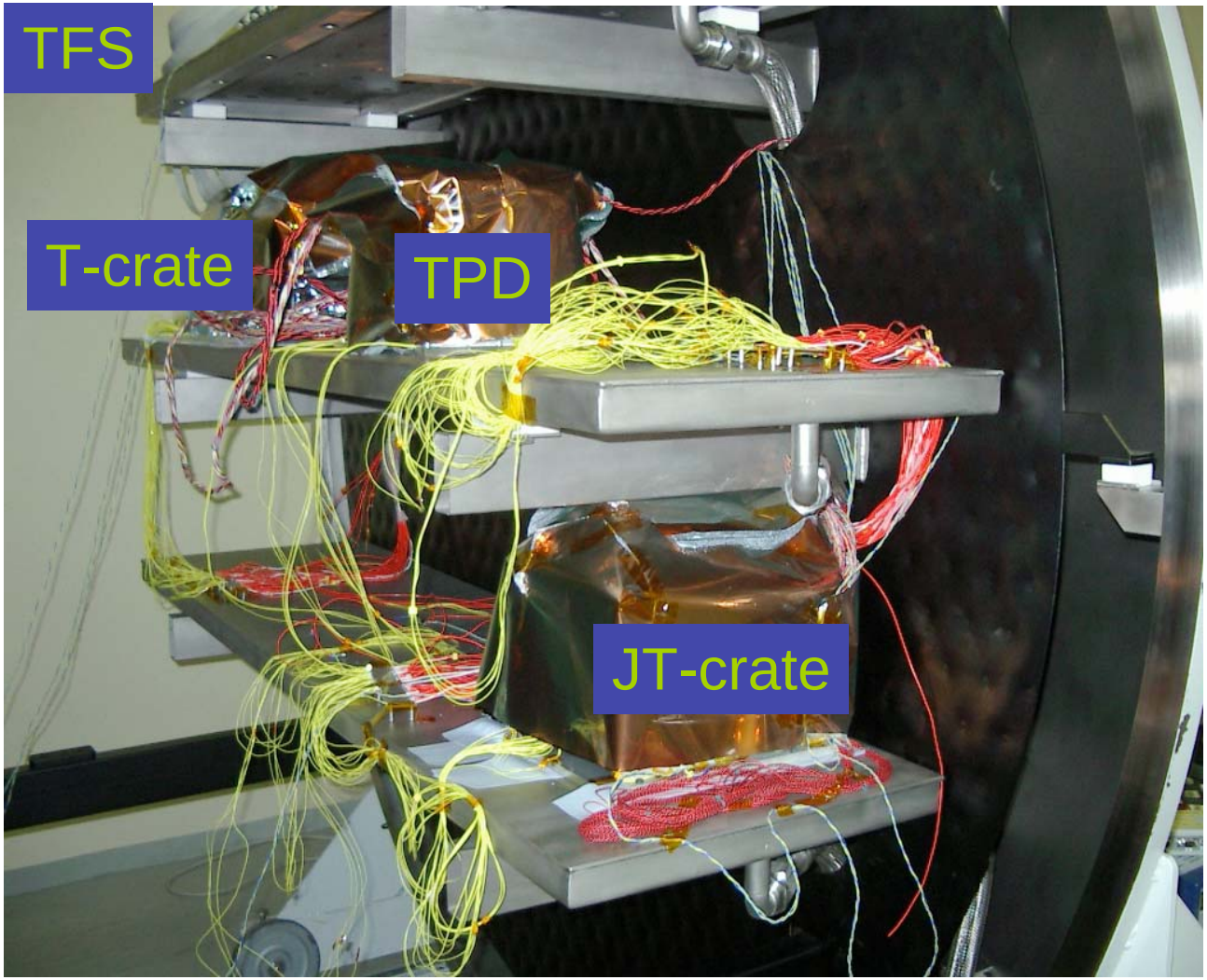
no missing bonds after ladder
and test structure vibration

cables and cables support



definition of cabled fixation

TV test set-up



Radiation 'hard' electronics

The problem are the SEE (Single Event Effect)

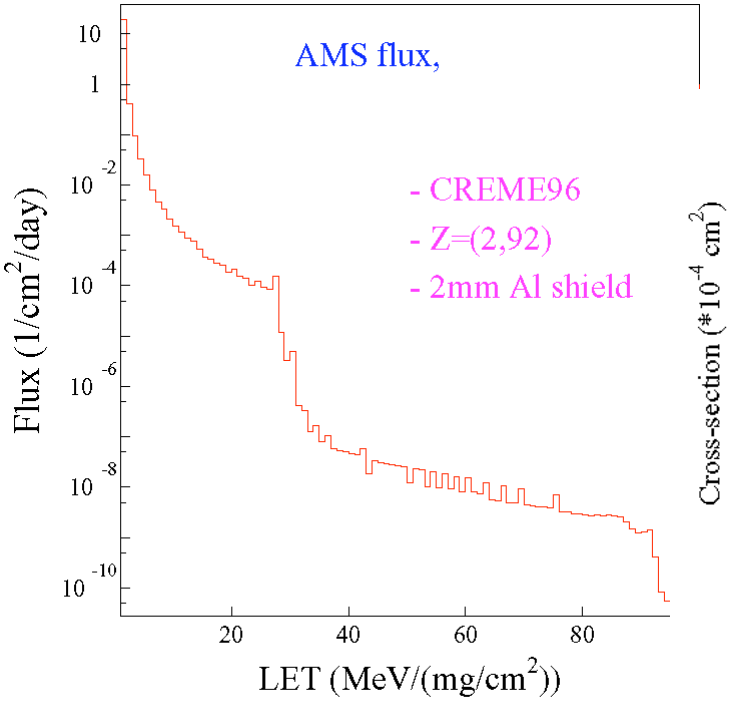


Figure 5: Expected fluxes on ISS in 2003.

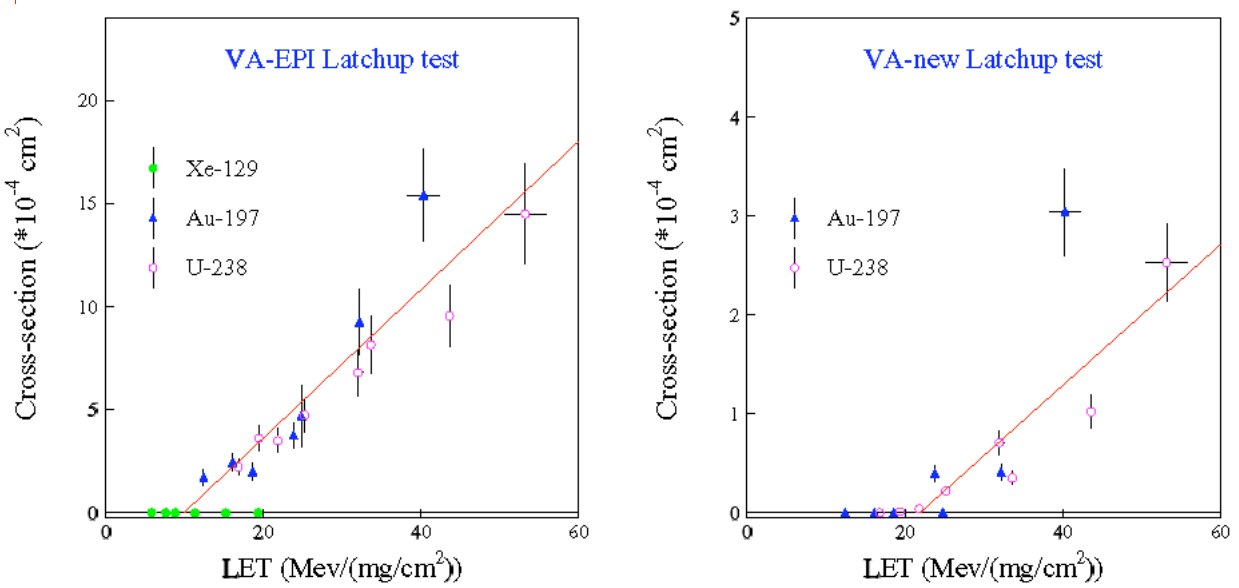


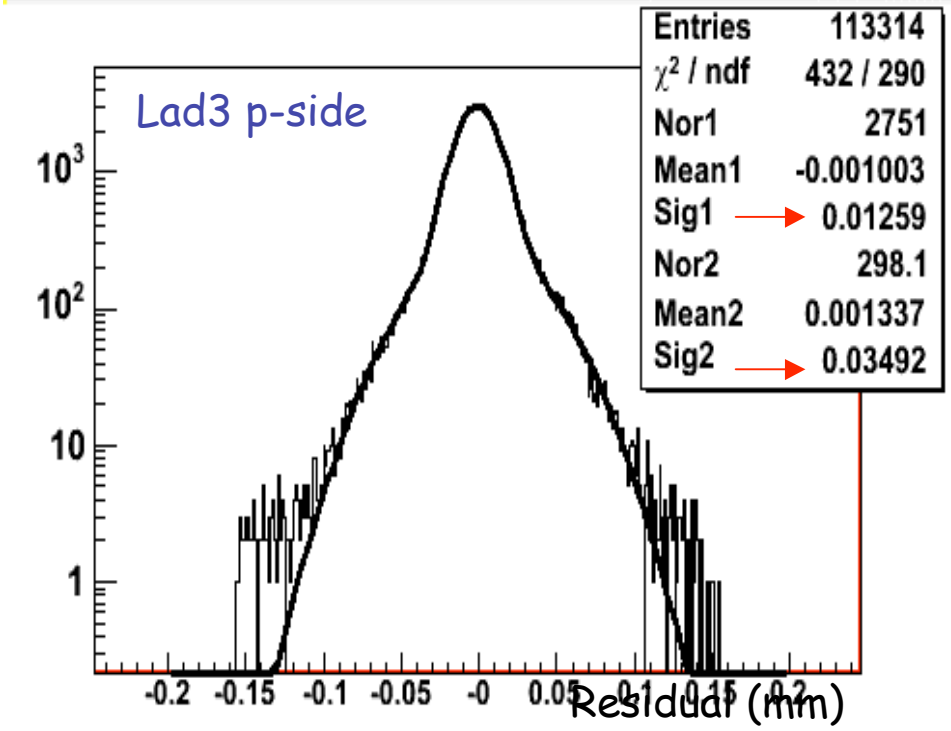
Figure 12: The new VA – SEL rates as measured in GSI

current limit protection is present for all active components

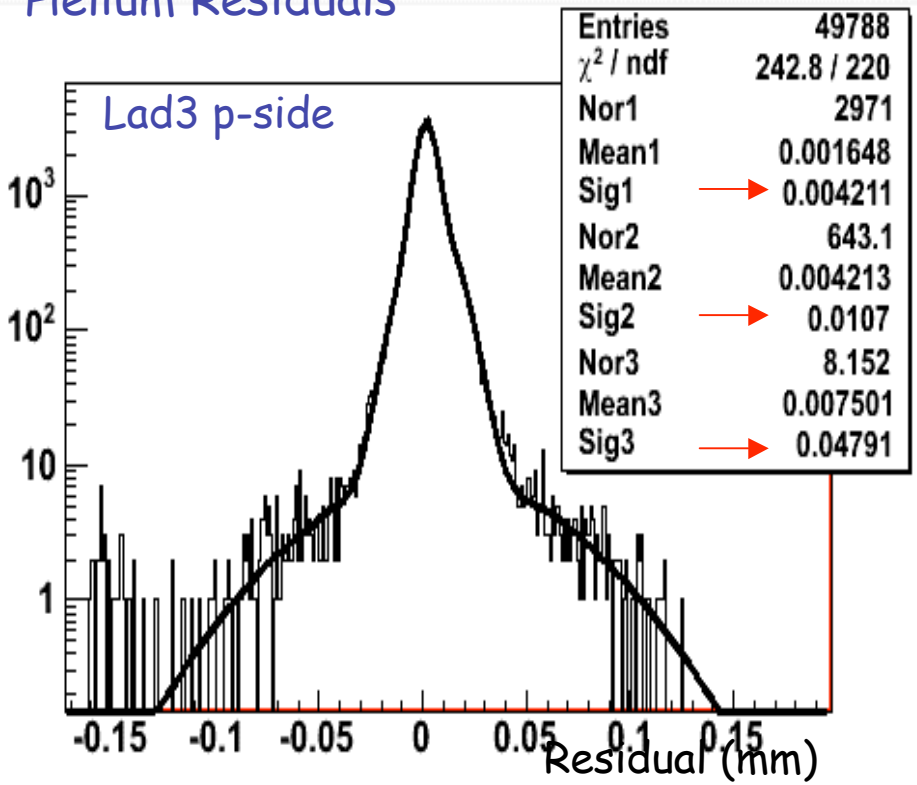
Test beam results

Residual Distributions

Proton Residuals



Helium Residuals



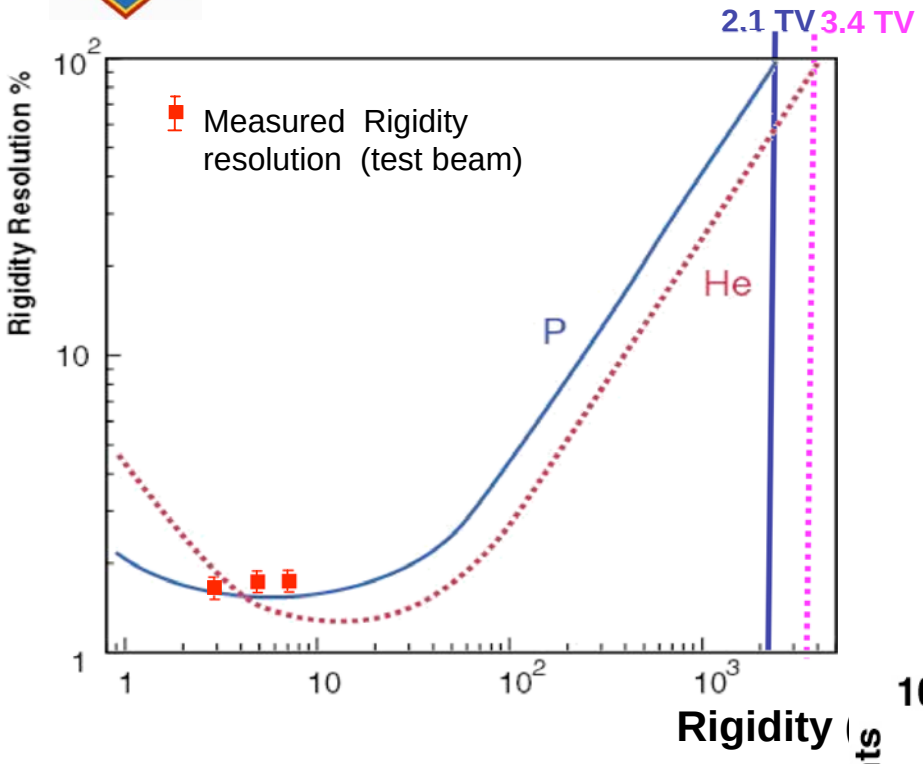
2 gaussian Fit

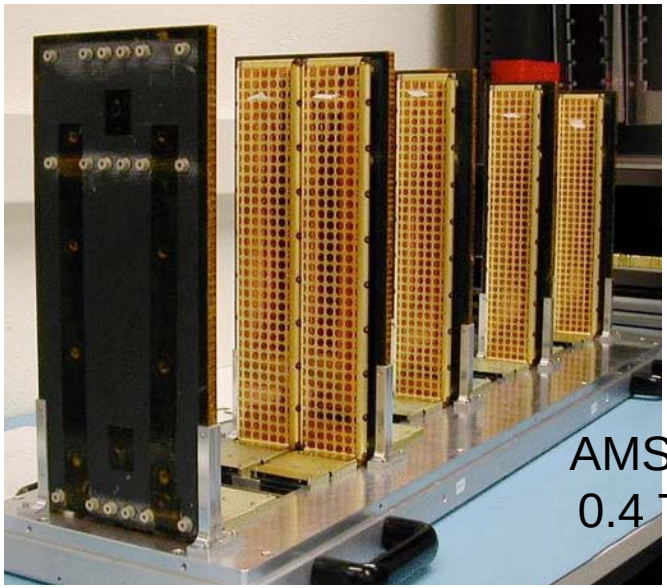
1st Gaussian 70% of events
2nd Gaussian 30% of events

3 Gaussian Fit

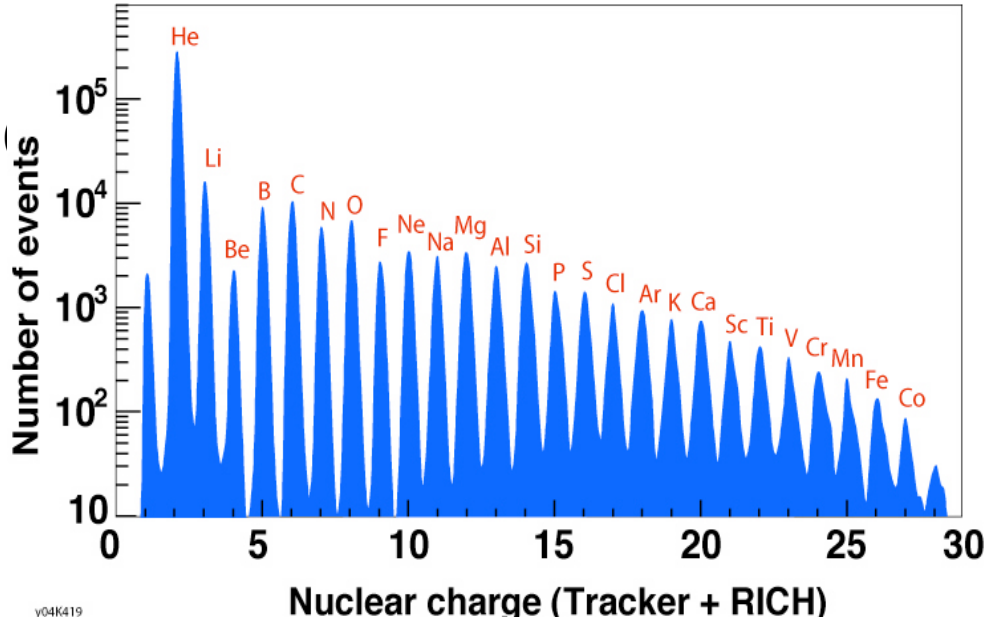
1st Gaussian 63% of events
2nd Gaussian 34% of events
3th Gaussian 3% of events

Rigidity res. and charge id.

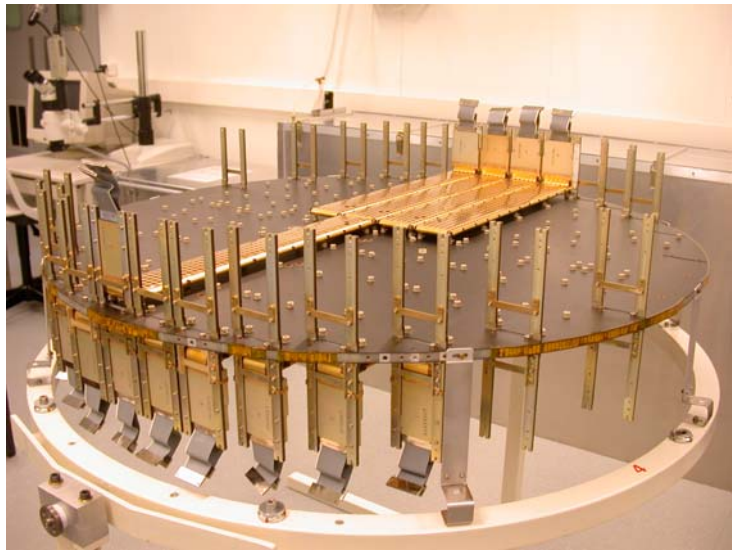


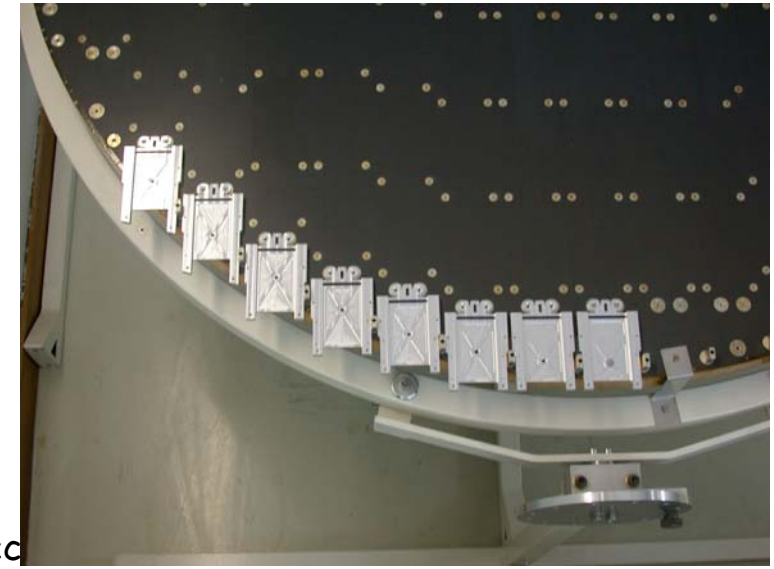


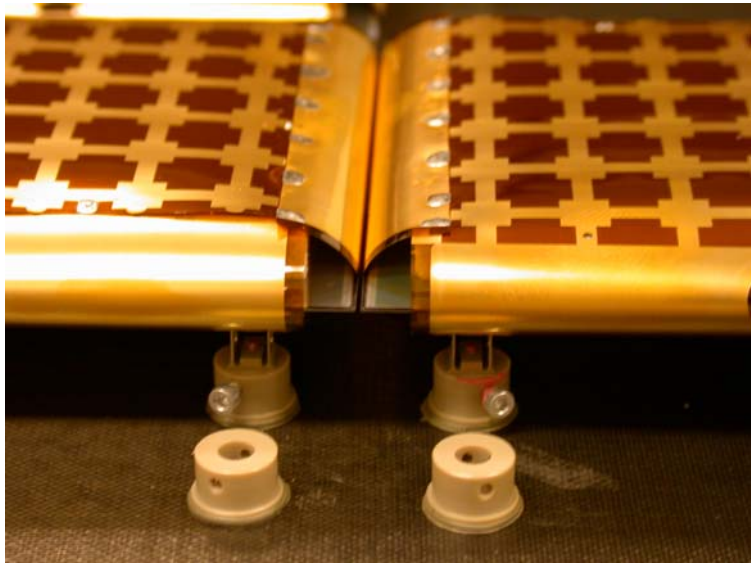
AMS like config.
0.4 T mag. fiels



Integration: mounting ladders on plane

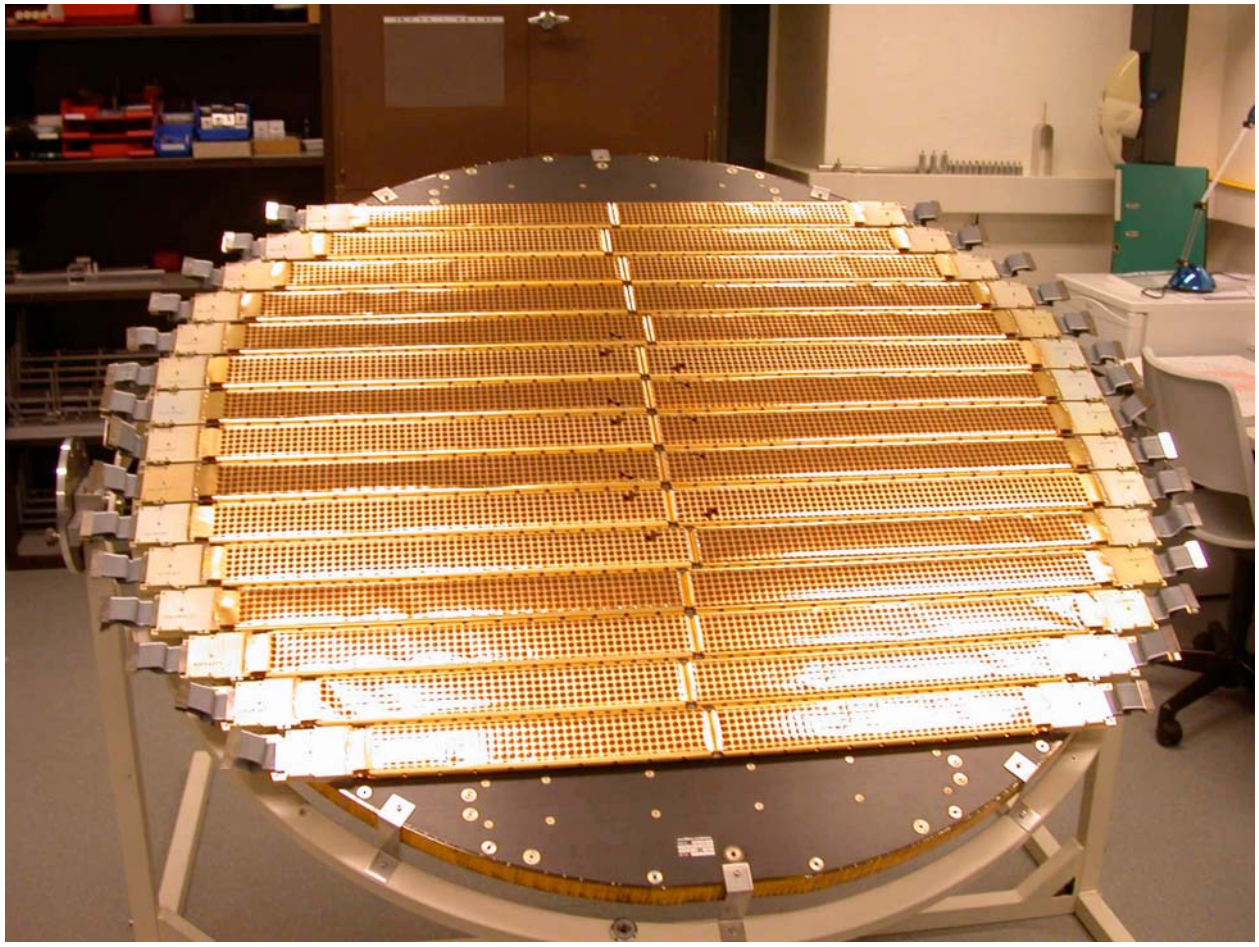






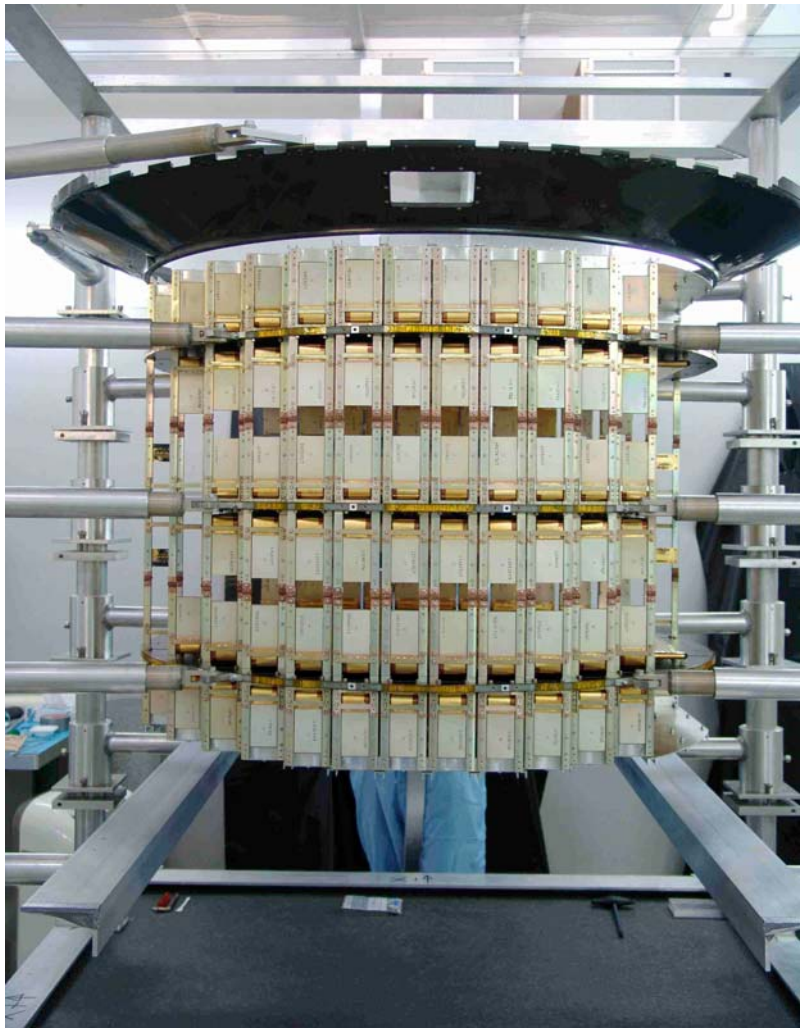
Tracker integration

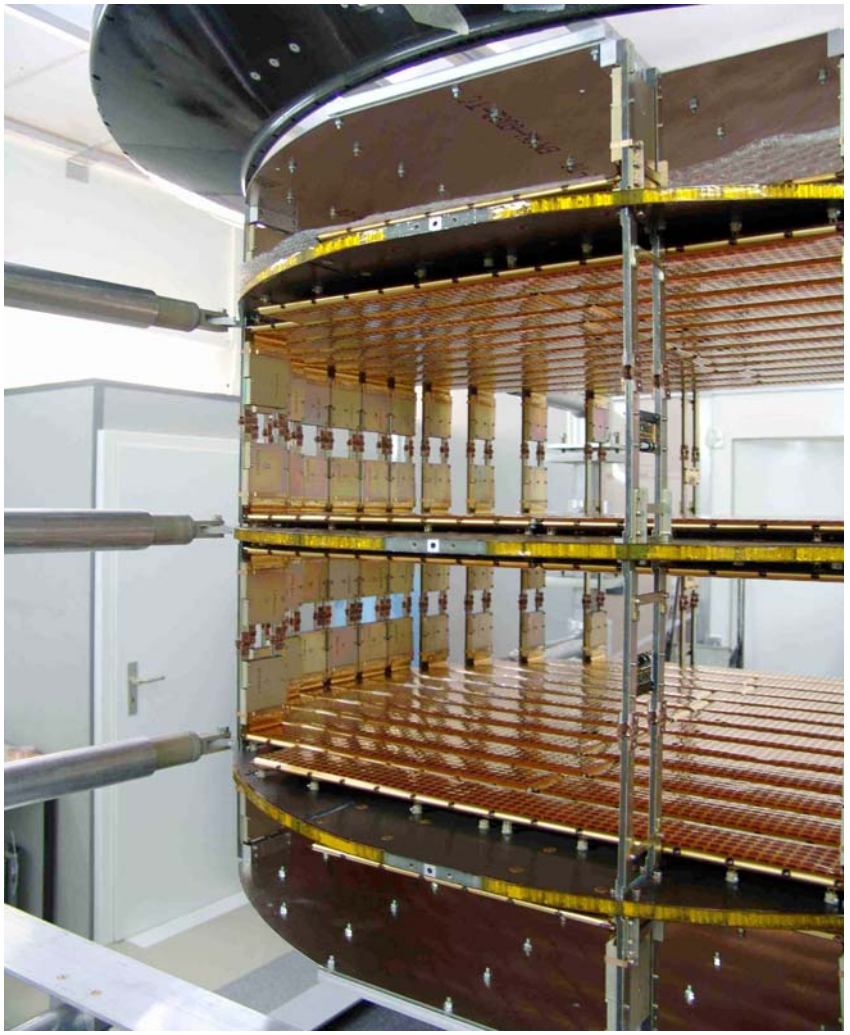
Plane 1



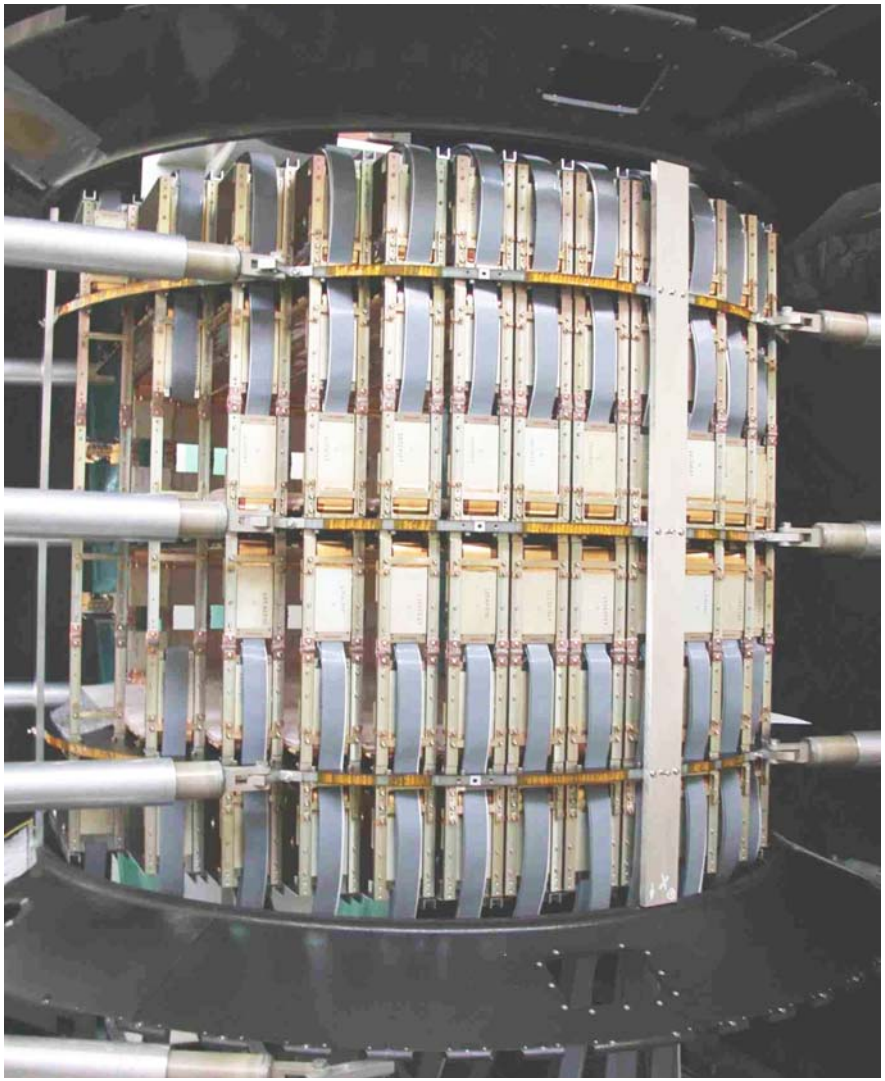
Inner Tracker

layers 2,3(plane2) 4,5(plane 3) 6,7(plane 4)





Inner Tracker Cabled

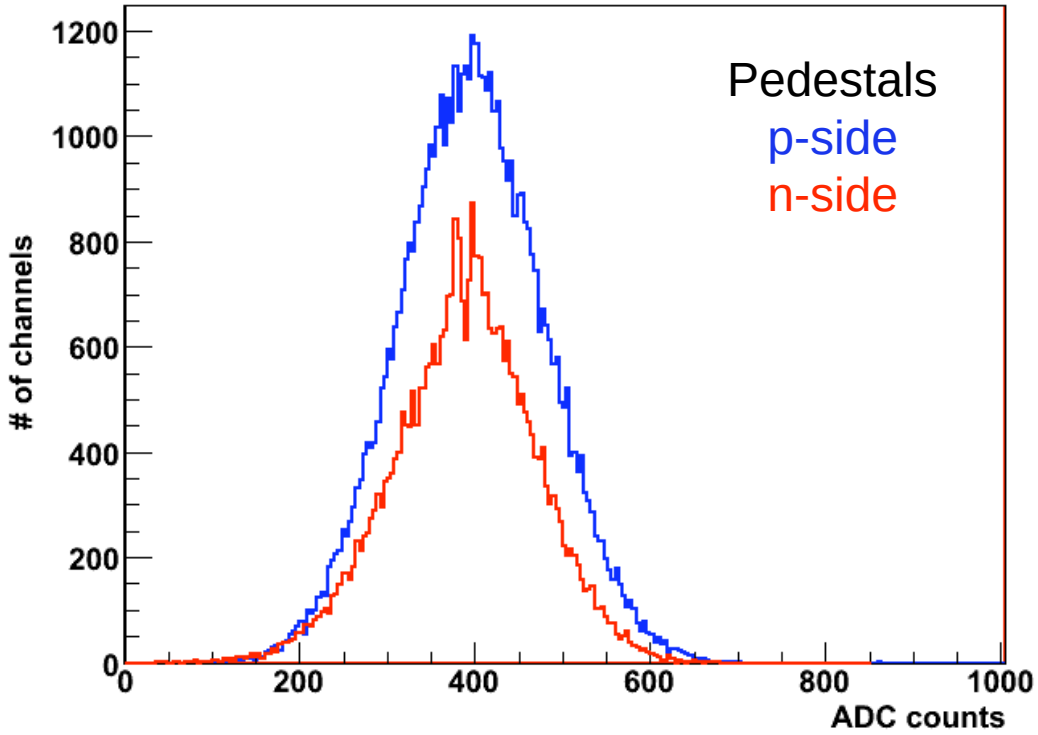


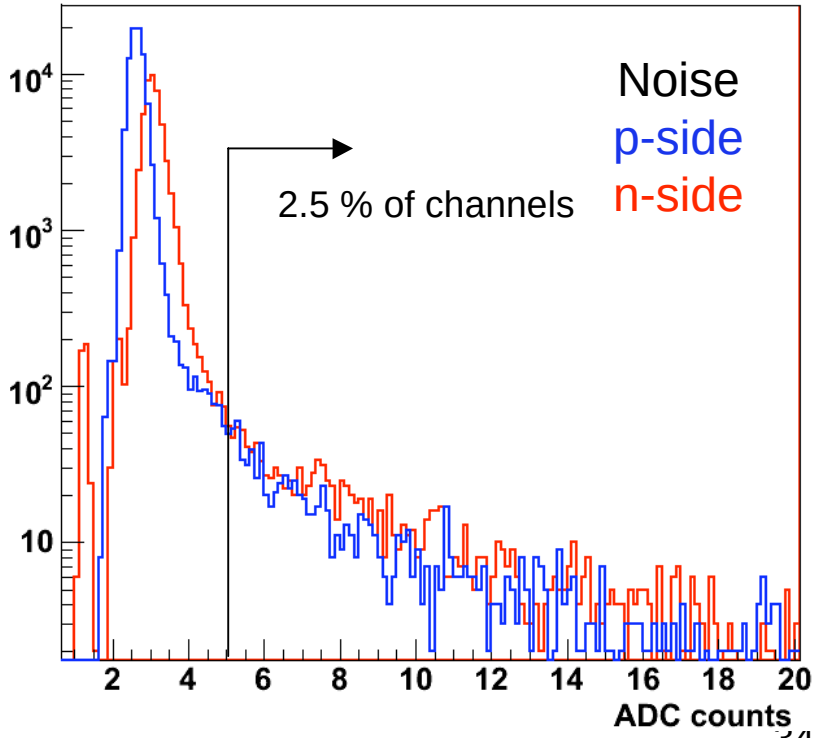
Tracker ready for cosmic test

Cosmic test allow for …

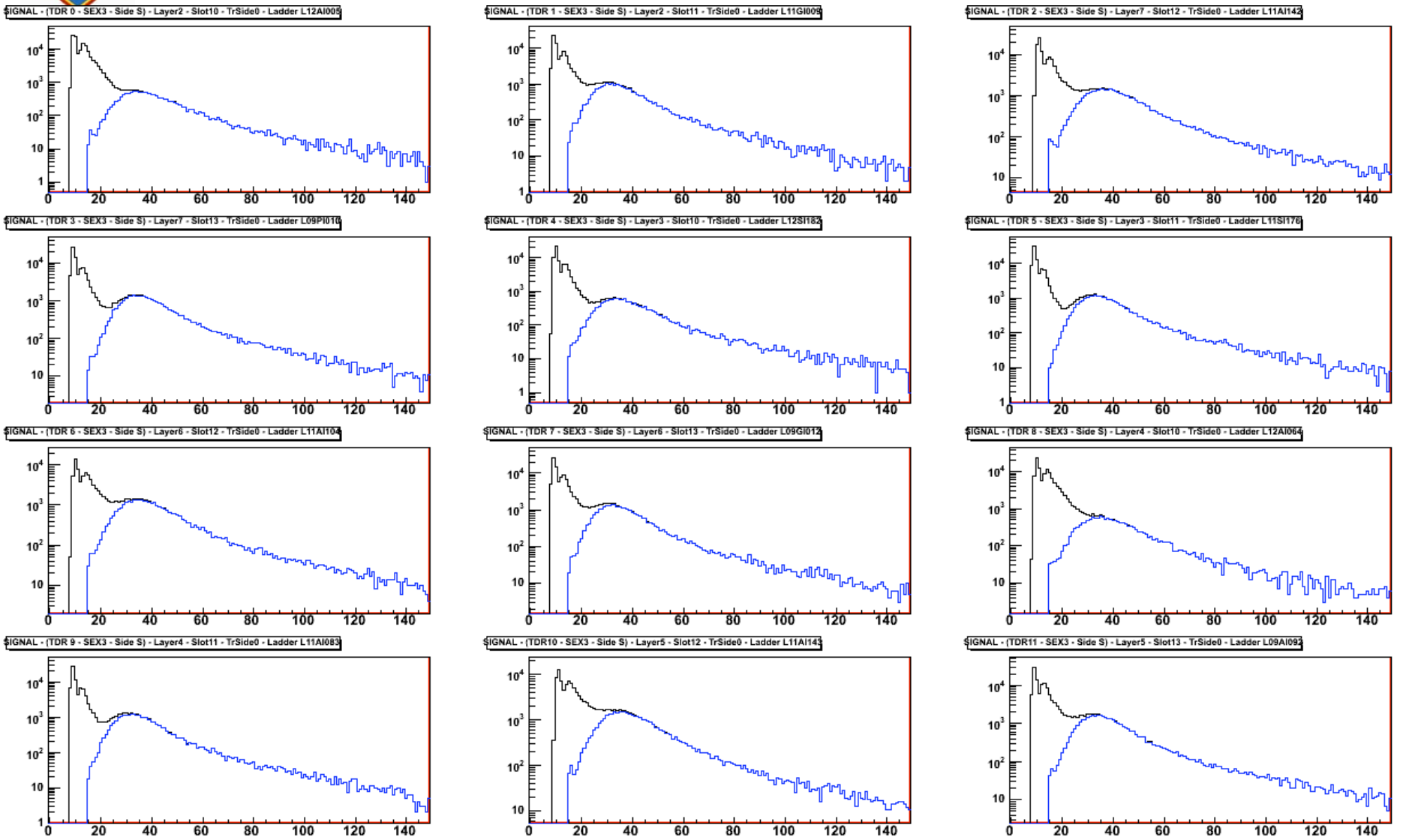
Testing the 132 ladders of the inner tracker in the final configuration and with the final electronics:

- Calibration
- Signal amplitude (gain)
- Tracks

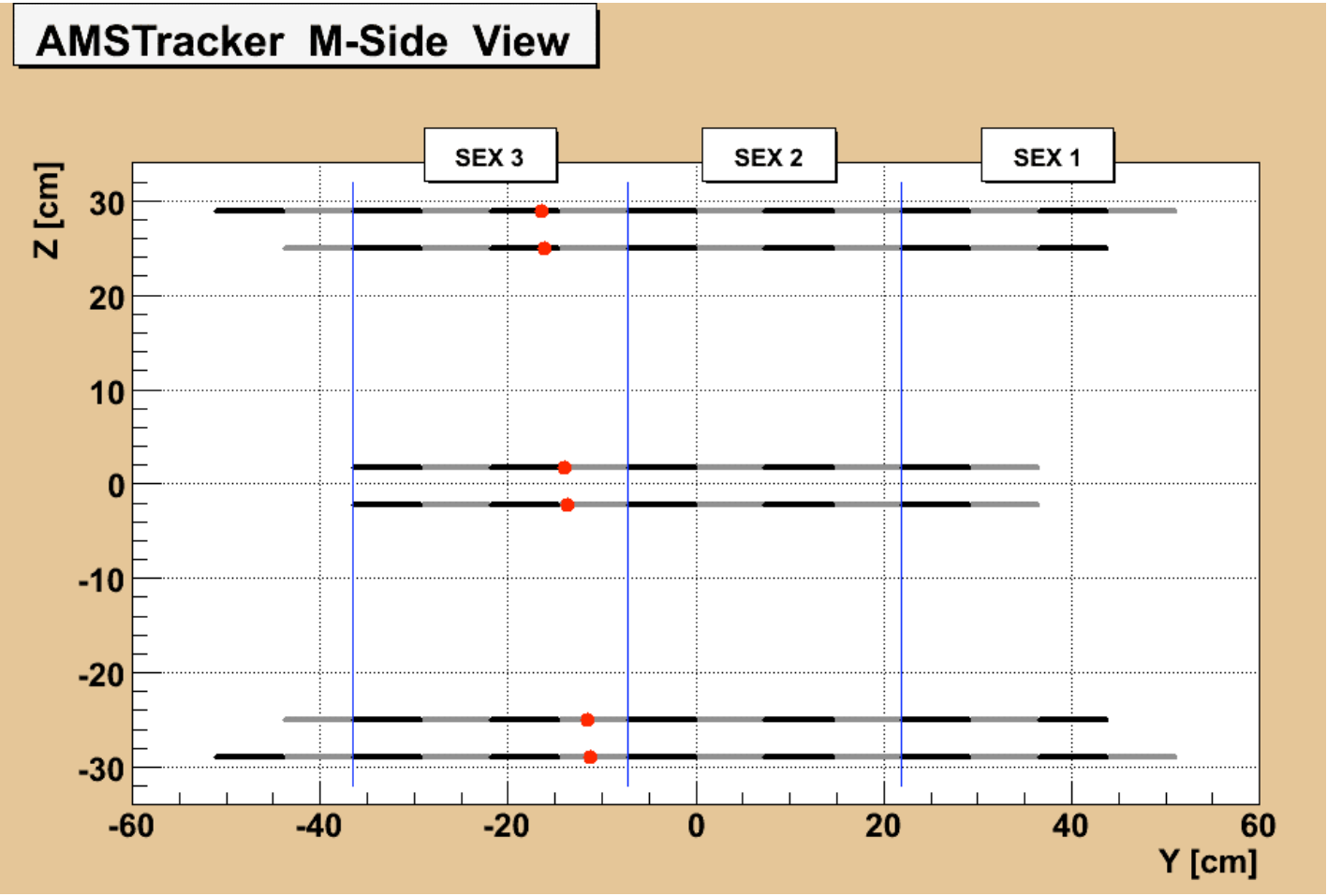




MIP Signals


SIGNAL - (TDR 0 - SEX3 - Side S) - Layer2 - Slot10 - TrSide0 - Ladder L12AI005
SIGNAL - (TDR 1 - SEX3 - Side S) - Layer2 - Slot11 - TrSide0 - Ladder L11GI009
SIGNAL - (TDR 2 - SEX3 - Side S) - Layer7 - Slot12 - TrSide0 - Ladder L11AI142
SIGNAL - (TDR 3 - SEX3 - Side S) - Layer7 - Slot13 - TrSide0 - Ladder L09PI010
SIGNAL - (TDR 4 - SEX3 - Side S) - Layer3 - Slot10 - TrSide0 - Ladder L12SI182
SIGNAL - (TDR 5 - SEX3 - Side S) - Layer3 - Slot11 - TrSide0 - Ladder L11SI176
SIGNAL - (TDR 6 - SEX3 - Side S) - Layer6 - Slot12 - TrSide0 - Ladder L11AI104
SIGNAL - (TDR 7 - SEX3 - Side S) - Layer6 - Slot13 - TrSide0 - Ladder L09GI012
SIGNAL - (TDR 8 - SEX3 - Side S) - Layer4 - Slot10 - TrSide0 - Ladder L12AI064
SIGNAL - (TDR 9 - SEX3 - Side S) - Layer4 - Slot11 - TrSide0 - Ladder L11AI083
SIGNAL - (TDR10 - SEX3 - Side S) - Layer5 - Slot12 - TrSide0 - Ladder L11AI143
SIGNAL - (TDR11 - SEX3 - Side S) - Layer5 - Slot13 - TrSide0 - Ladder L09AI092

TRACKS: a cosmic muon

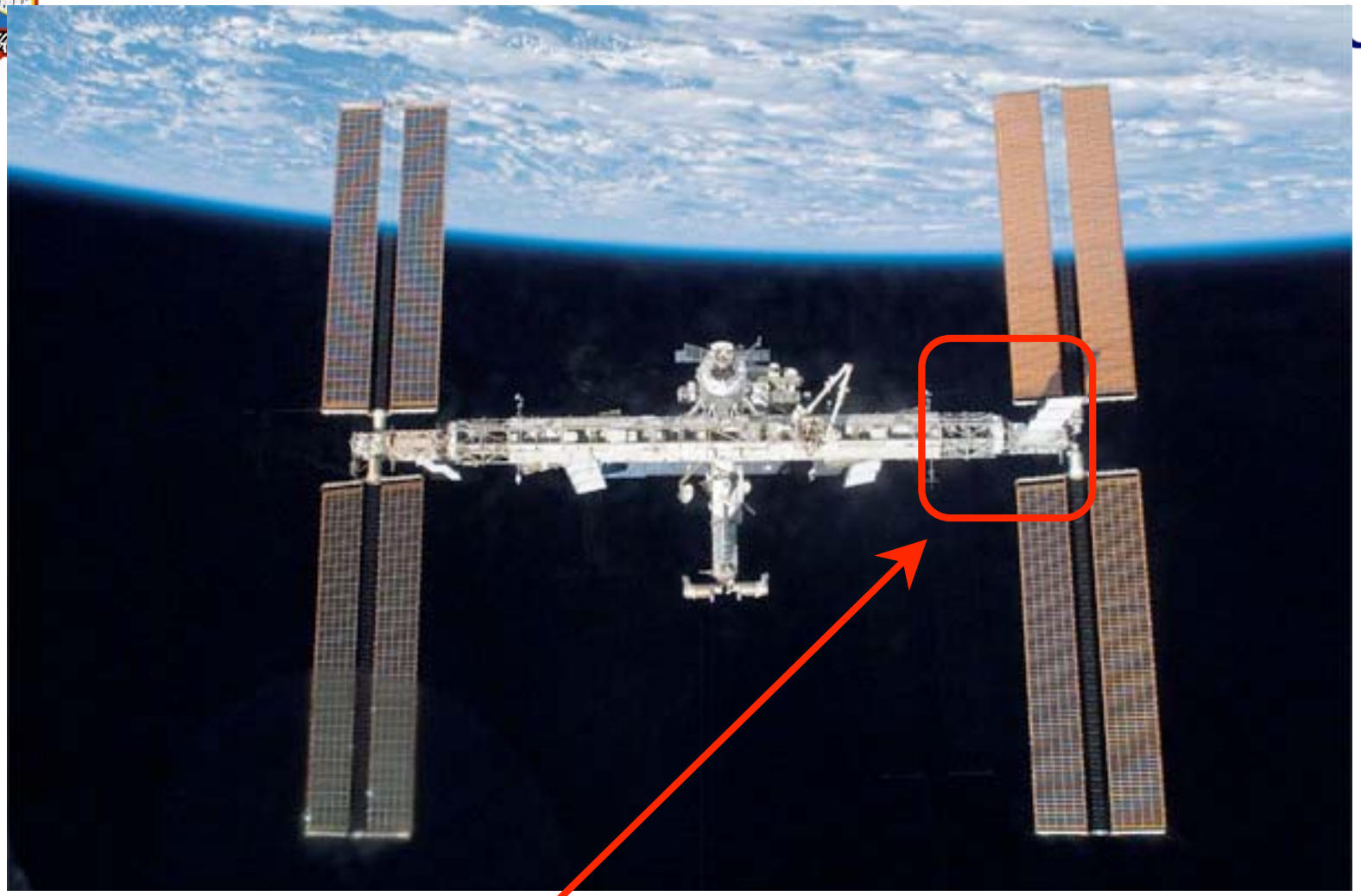


Conclusions

- A silicon tracker of about 6.4 m^2 has been designed, produced and space qualified
- Test beam and cosmic runs showed that design requirements have been fulfilled
- In September 2007 the Tracker will be integrated into the AMS-02 magnet
- In autumn 2008 the whole AMS-02 detector will be delivered to Cape Canaveral (Florida) ready to launch for 3 years (and more) operation on board the ISS

Latest news about ISS →

ISS status on orbit (June 2007)



A couple of weeks ago the S3 Truss has been installed!
S3 truss is equipped with the “socket” to plug-in AMS