The AMS Silicon Tracker: construction and performance

G. Ambrosi

on behalf of the AMS Tracker Group

VCI 2007

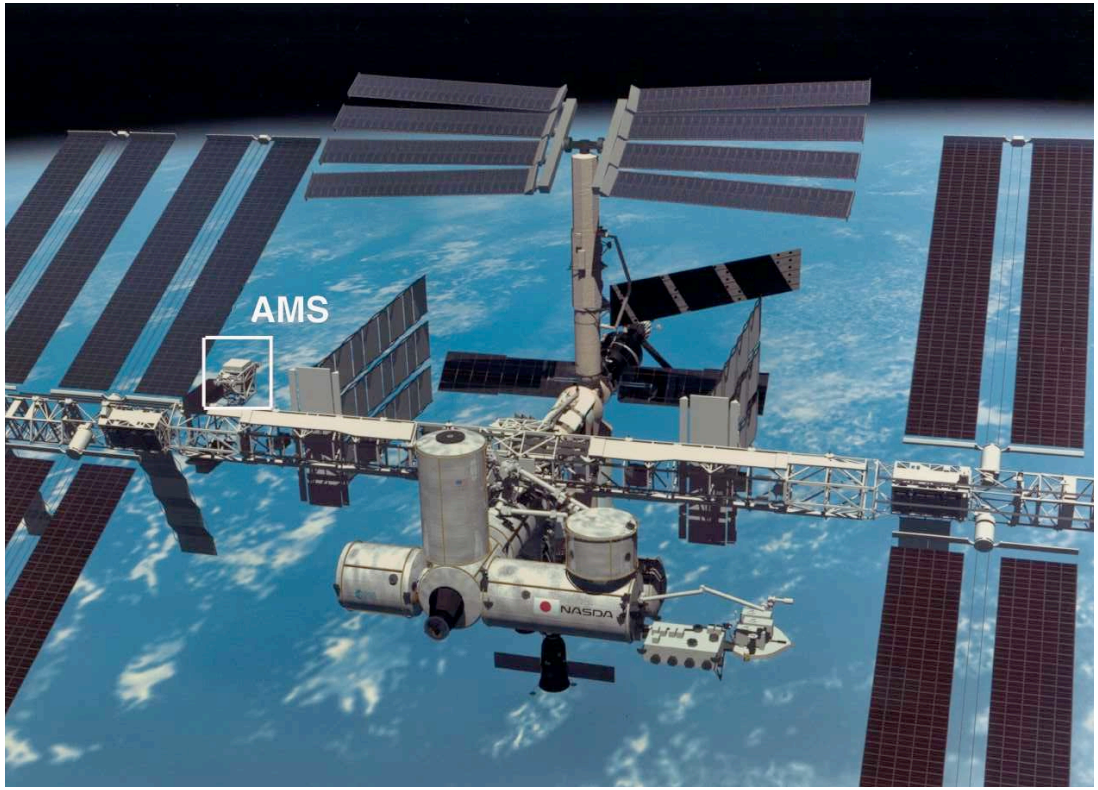
Outline

Perugia
INFN
Istituto Nazionale di Fisica Nucleare

- The Alpha Magnetic Spectrometer
- The Silicon Tracker
- Construction and qualification
- Performance with particle beams
- Summary

AMS on the International Space Station

- Cosmic Antimatter search with 10^{-9} sensitivity
- Indirect Dark Matter search (e^+, $\bar{p}$, γ)
- Relative abundance of nuclei and isotopes in primary cosmic rays
- γ ray astrophysics

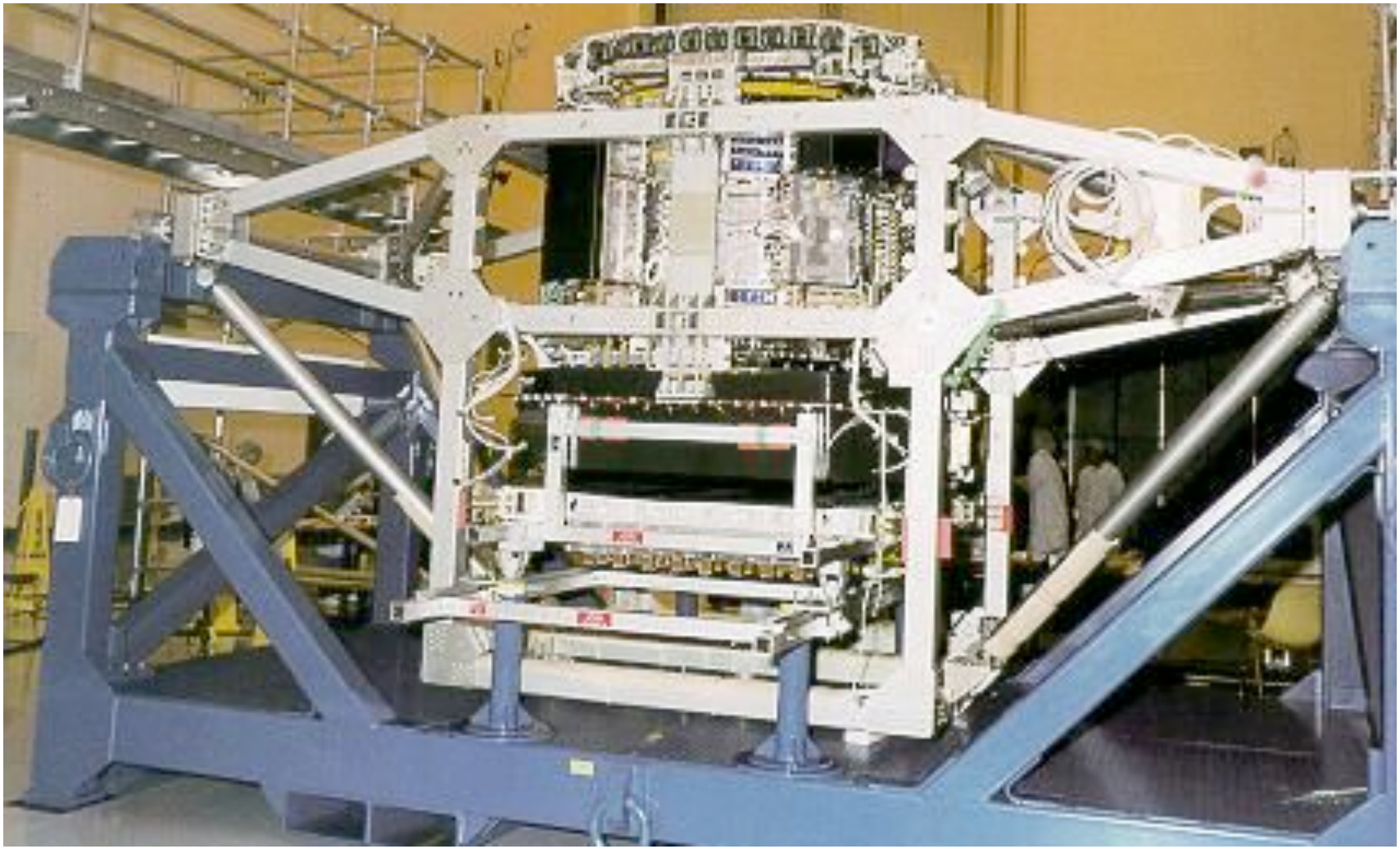


The purpose of the AMS experiment is to perform accurate, high statistics long measurements of charged (0.5 GV - 1 TV) cosmic rays and γ rays (E>1GeV)

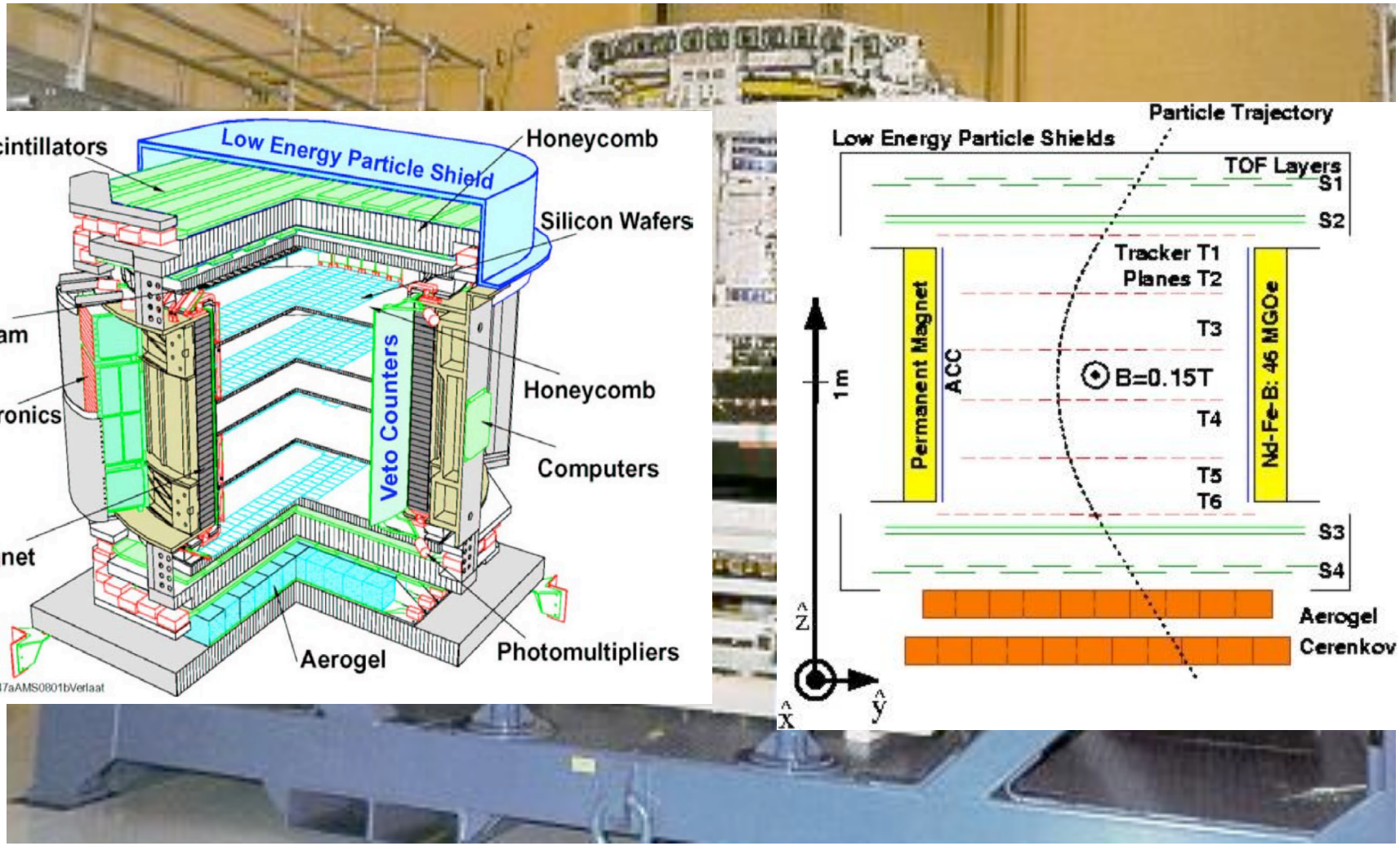
The instrument we need has …

- performance a la 'particle physics':
  - high resolution measurements of momentum, velocity, charge and energy
- characteristics to properly work in the space environment:
  - Vibration (6.8 G rms) and acceleration (17 G)
  - Temperature variation (day/night $\Delta T = 100^{o}C$)
  - Vacuum (10^{-10} Torr)
  - Orbital debris and micrometeorites
  - Radiation (Single Event Effect)
- limitation in weight (15000 lb), power (3KW), bandwidht and maintenance
- Compliant with EMI/EMC specs

AMS-01 at KSC before installation on the Shuttle

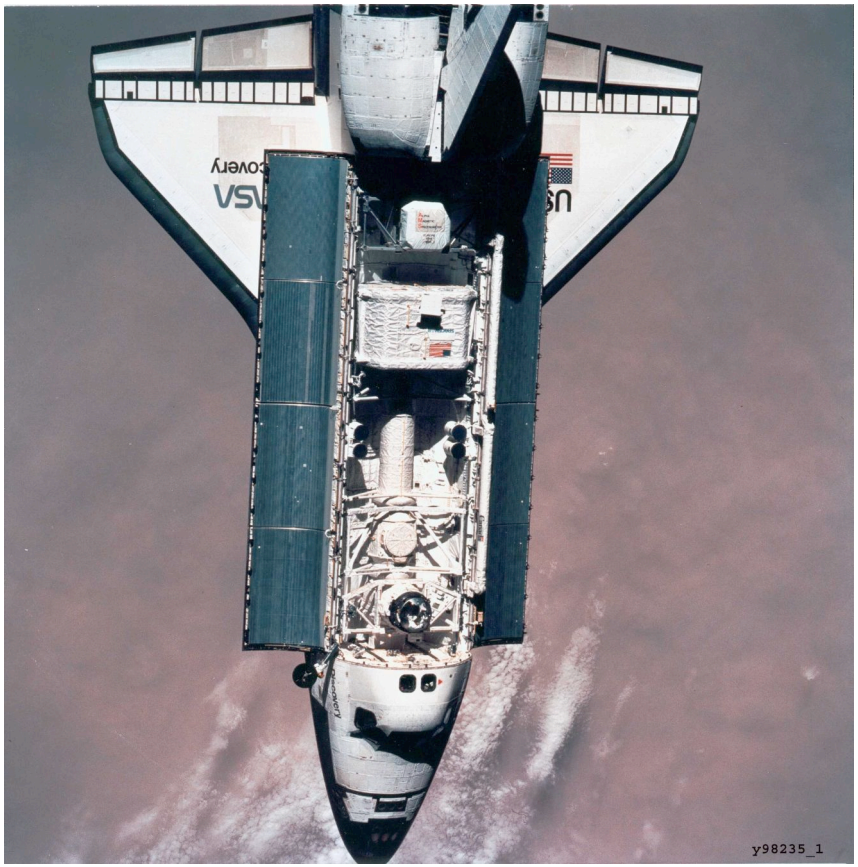


AMS-01 at KSC before installation on the Shuttle

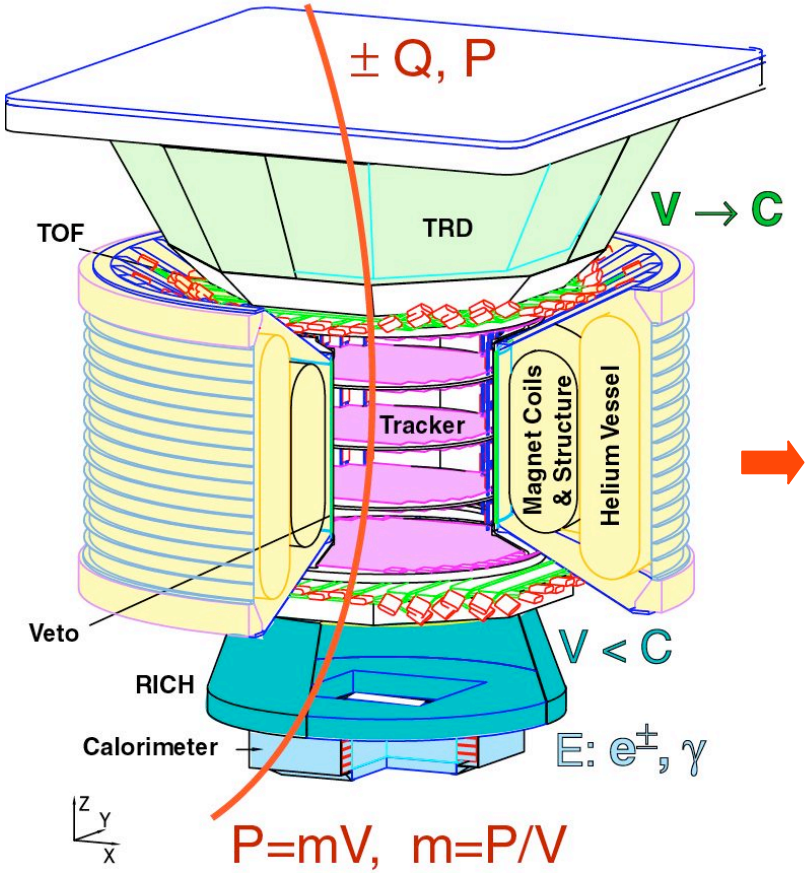


AMS-01 pilot experiment: STS91, June 2nd - 12th 1998

- 10 days of data taking in orbit:
  - 400 Km altitude
  - latitudes +51.7°
  - all longitudes
- 10^8 events recorded
- Physics results
  (Phys. Rep. 366 (2002) 331)
  - precise measurements of primary fluxes
  - detection of secondary fluxes (quasi trapped)
  - antimatter limit at 10^{-6}



The AMS-02 detector



→TeV	e⁻	P	He,Li,Be,..Fe	γ	e⁺	$\bar{P}$, $\bar{D}$	$\bar{He}$, $\bar{C}$
TRD							
TOF							
Tracker							
RICH							
ECAL							
Physics example	Cosmic Ray Physics Strangelets				Dark matter		Antimatter

Silicon spectrometer design goals:

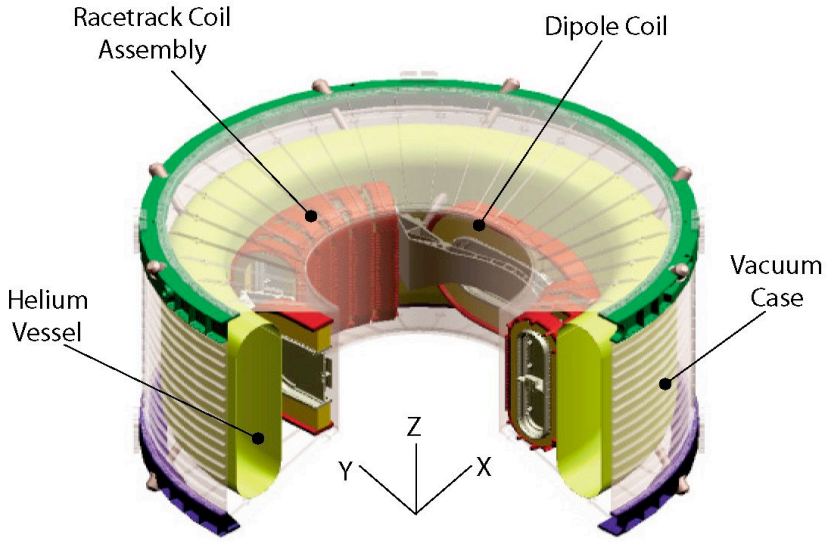
dP/P ~ 1% up to 100 GeV

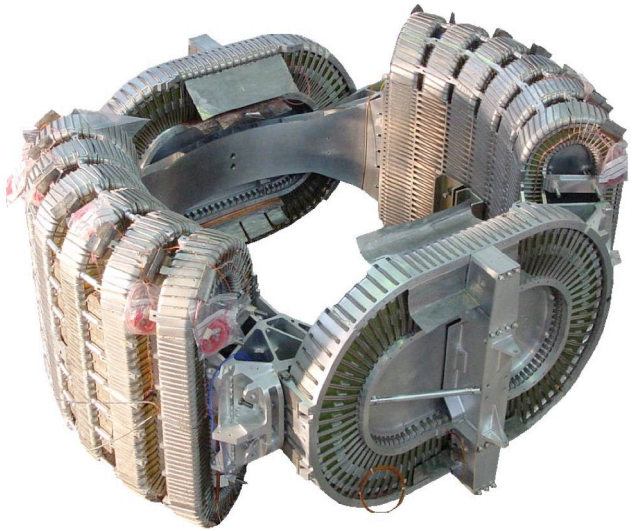
MDR ~ 1 TV

Z measurement up to Iron

Superconducting magnet

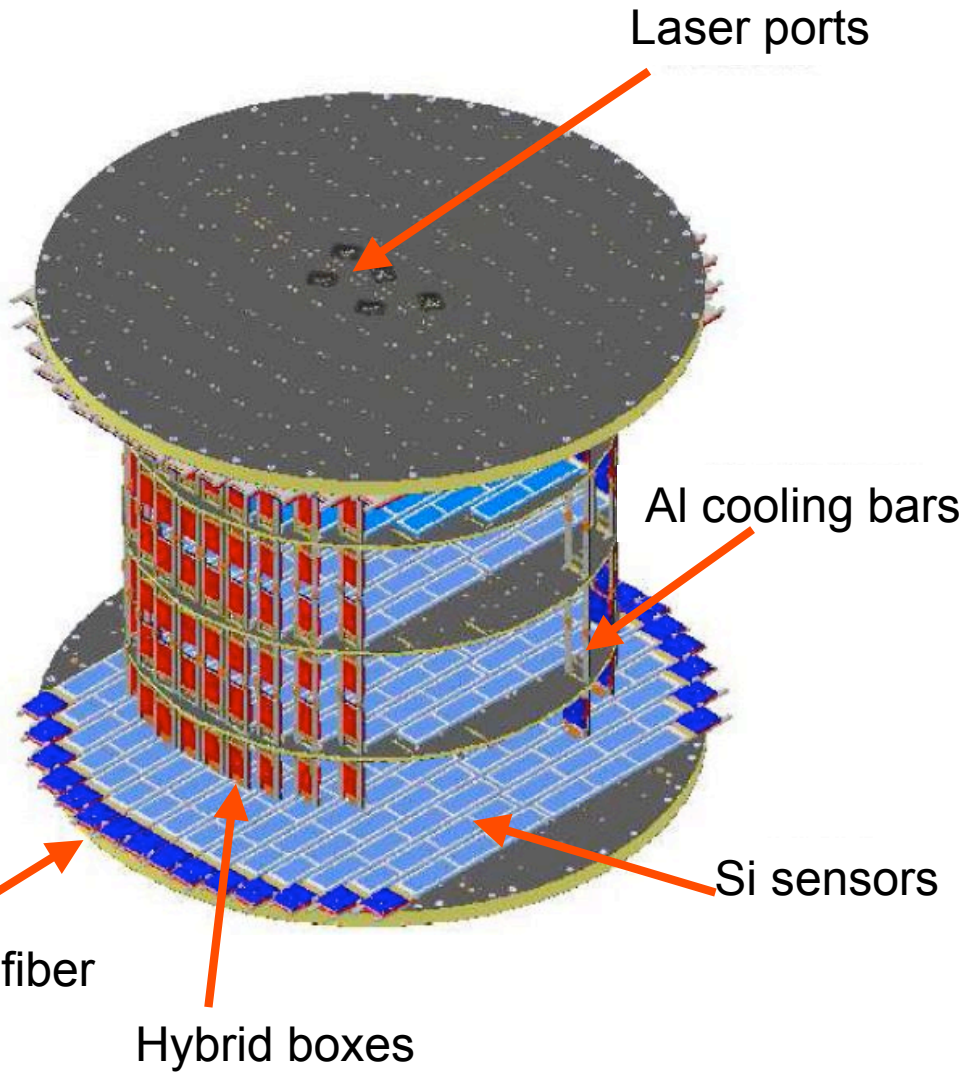
- 2 'dipole' coil, 12 'racetrack' coil (~ no magnetic dipole moment)
- B~0.9 T, 1.1 m inner diameter, 2360 Kg weight
- 55 Km of superconducting wire (NbTi/Cu embedded in pure aluminium)
- Indirect cooling with superfluid helium (1.8 K)
- 2500 liters helium vessel plus cryocuulers for 3 years operation





Silicon Tracker

- 8 layers of double sided silicon detectors arranged in 192 ladders
- 5 honeycomb carbon fiber plane
- detector material ~ 0.04 Xo
- total of 200 kchannels 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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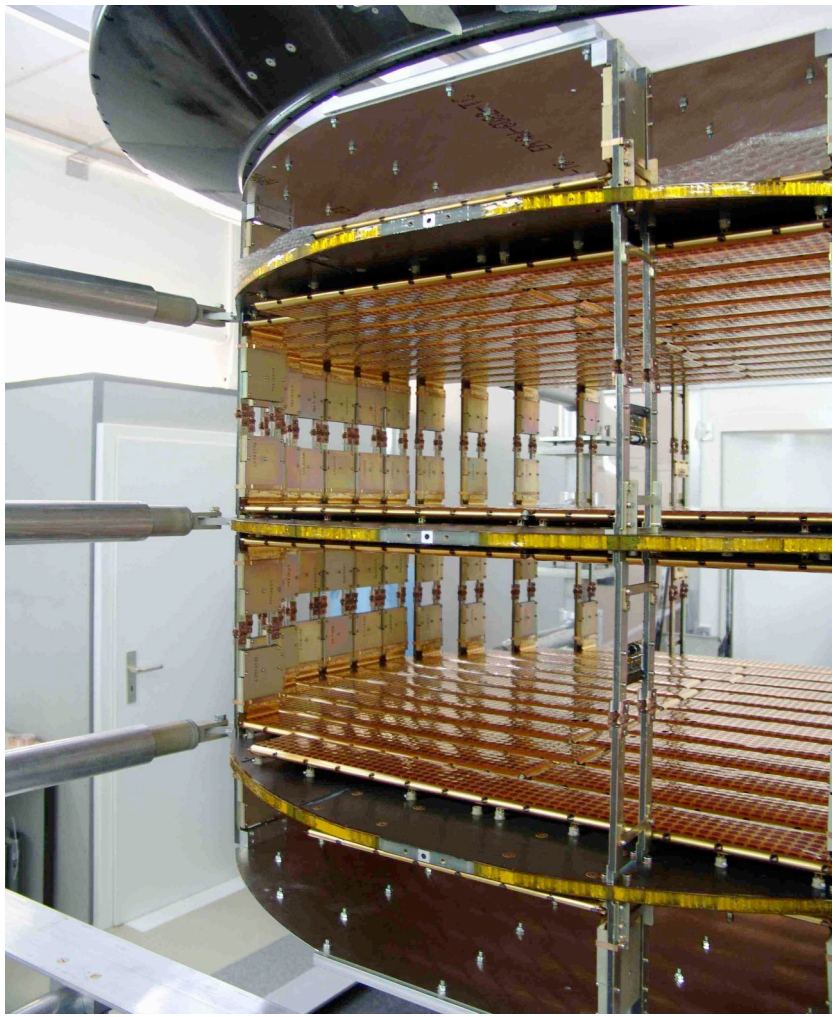
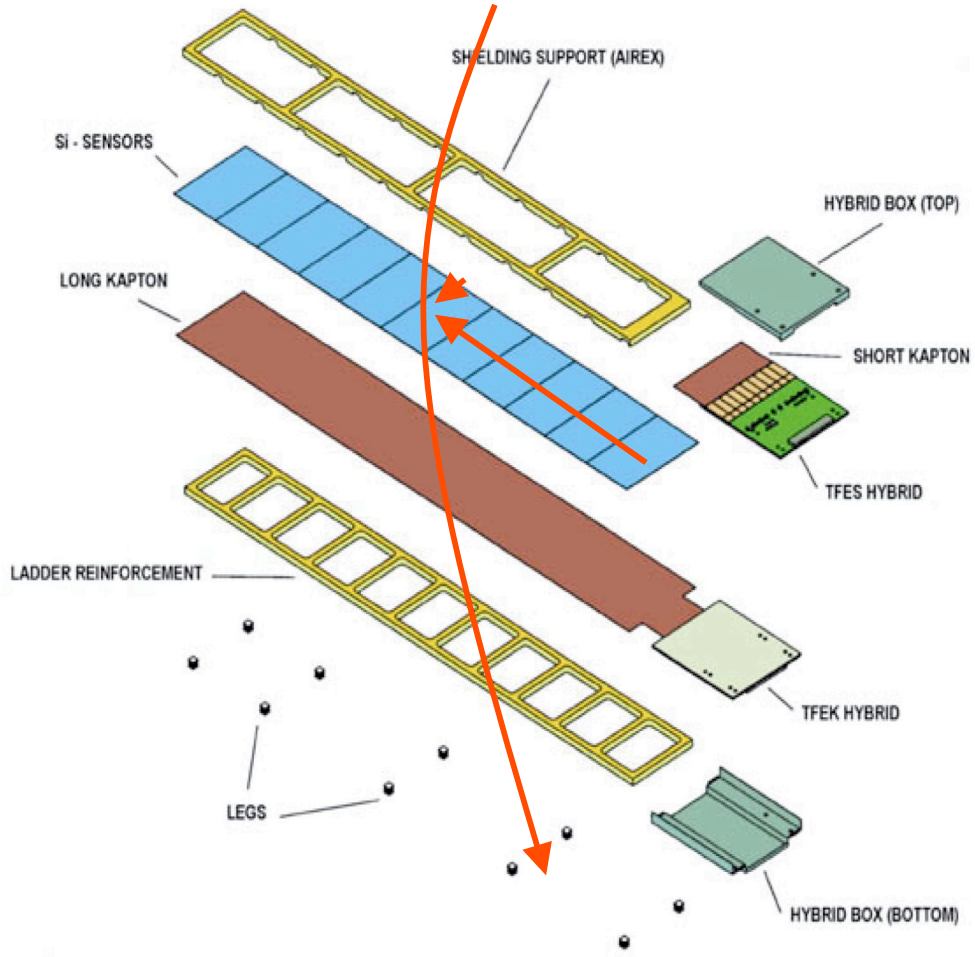


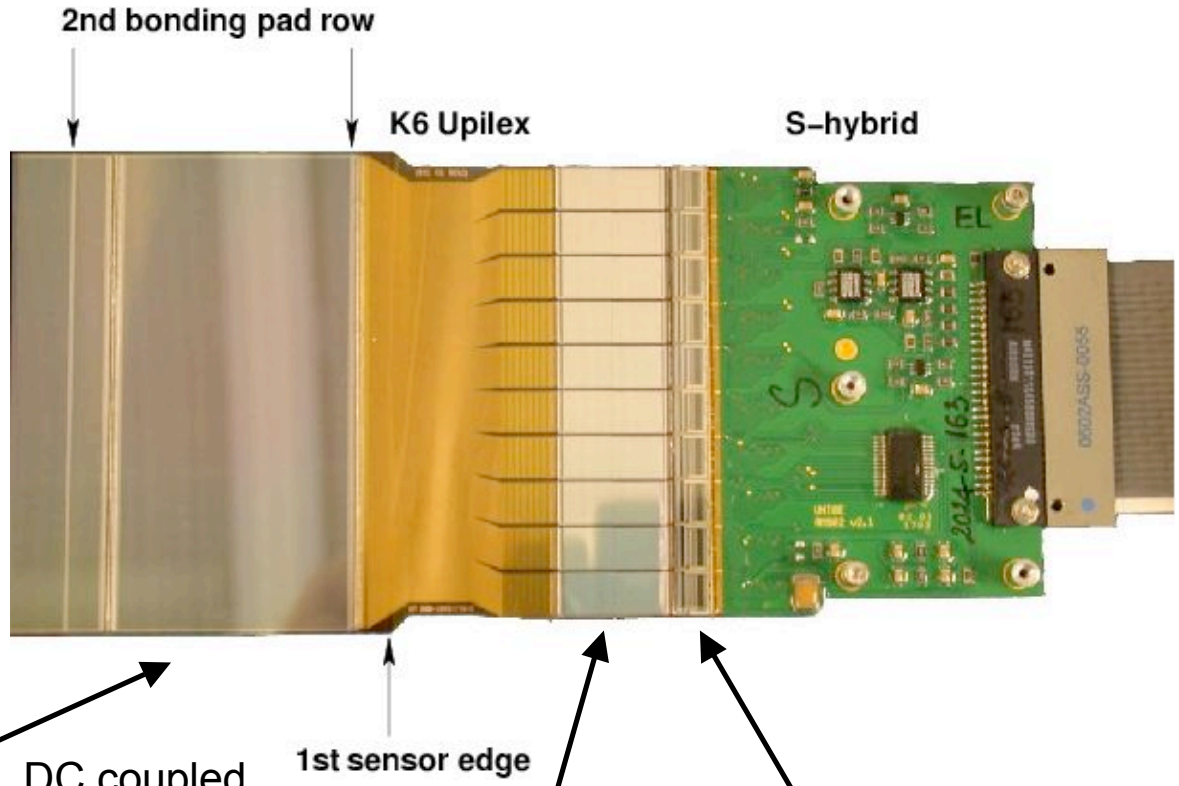
AMS silicon ladders



- 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)

Ladder components (p side)

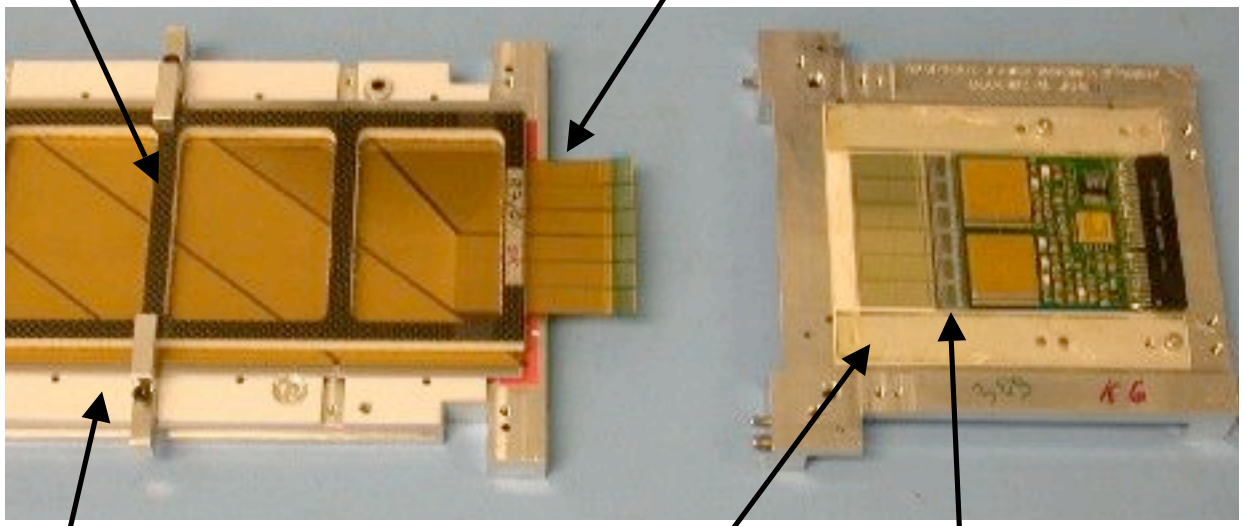


double sided, DC coupled
300 μm thickness
7 - 15 sensors in a ladder
produced at:
- Colybris (CH)
- IRST (IT)

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)

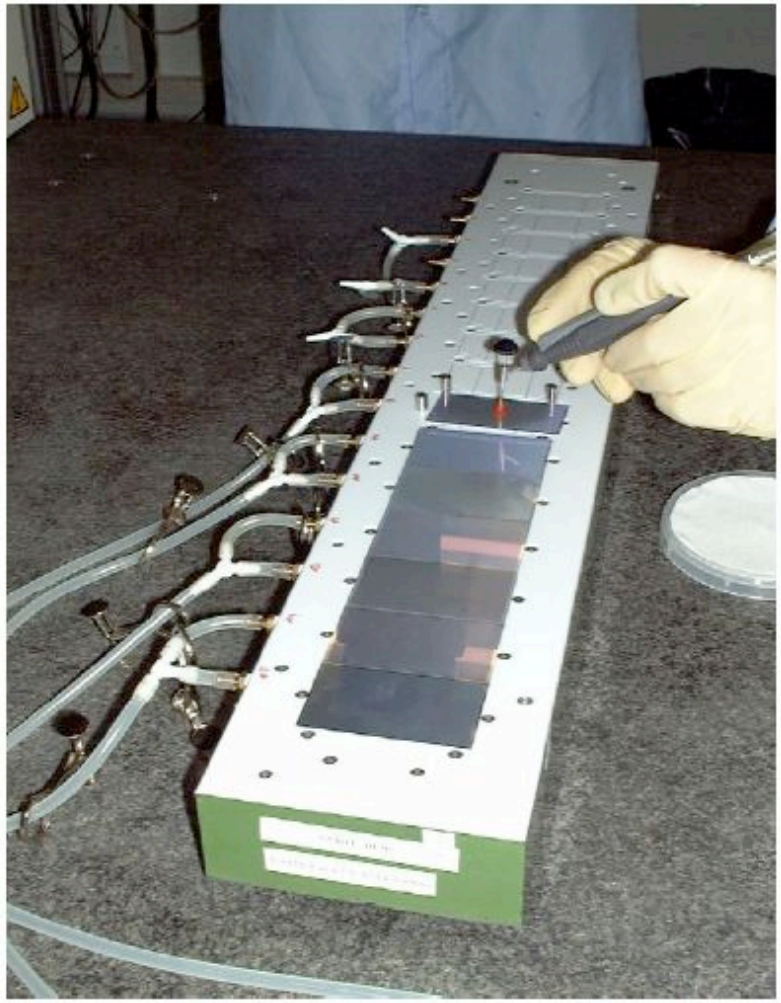


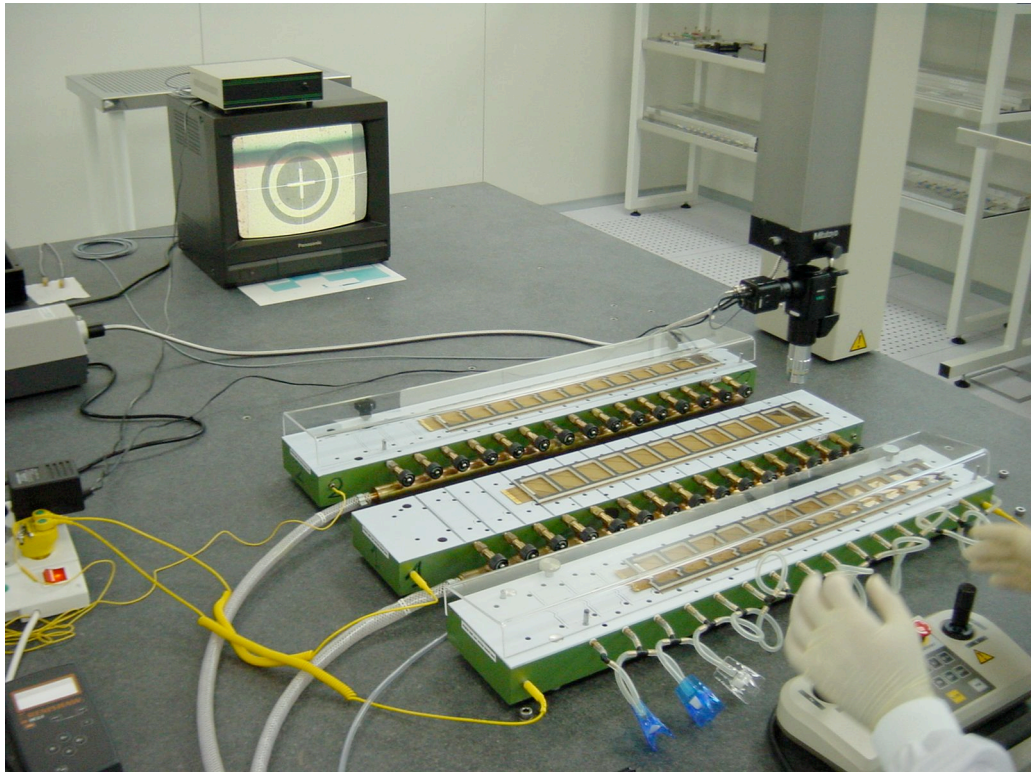
double sided, DC coupled
300 μm thickness
7 - 15 sensors in a ladder
produced at:
- Colybris (CH)
- IRST (IT)

700 pF coupling capa

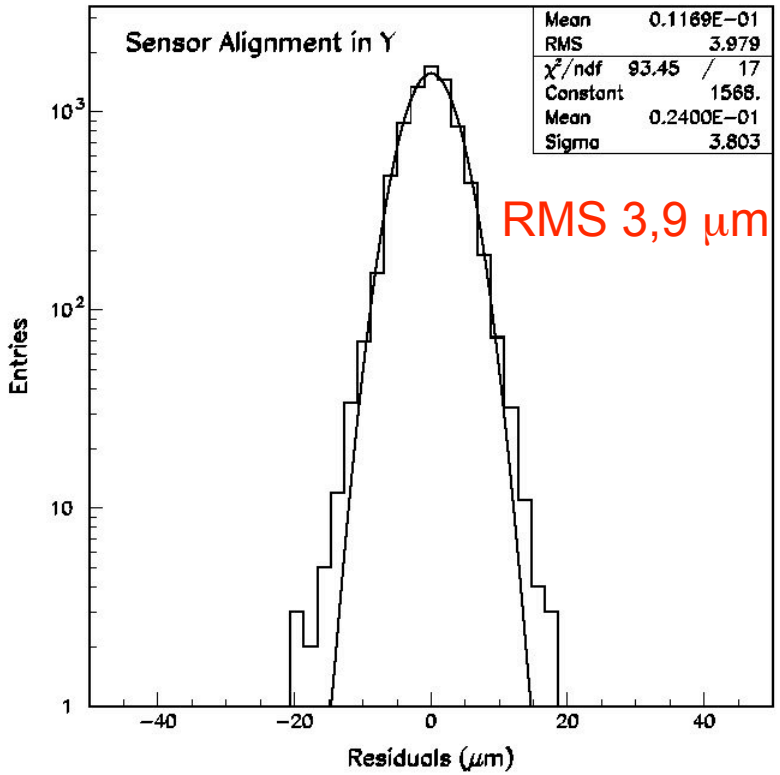
6 VA_hdr64a (IDEas, NO)
384 channels, 0.7 mW power each
CR-RC shaper and S&H
4 μs shaping time
100 MIP dynamic range

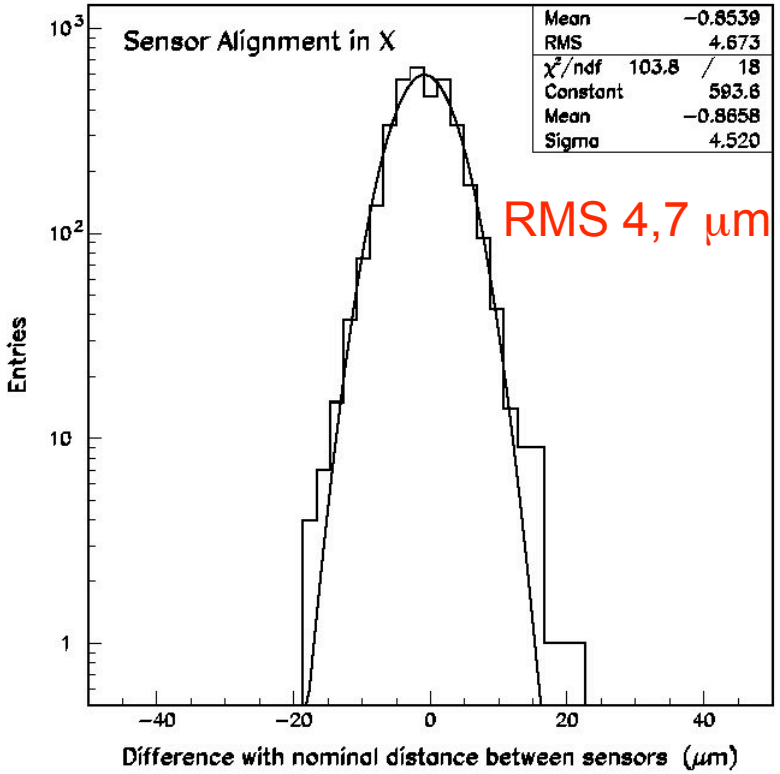
Silicon positioning and metrology



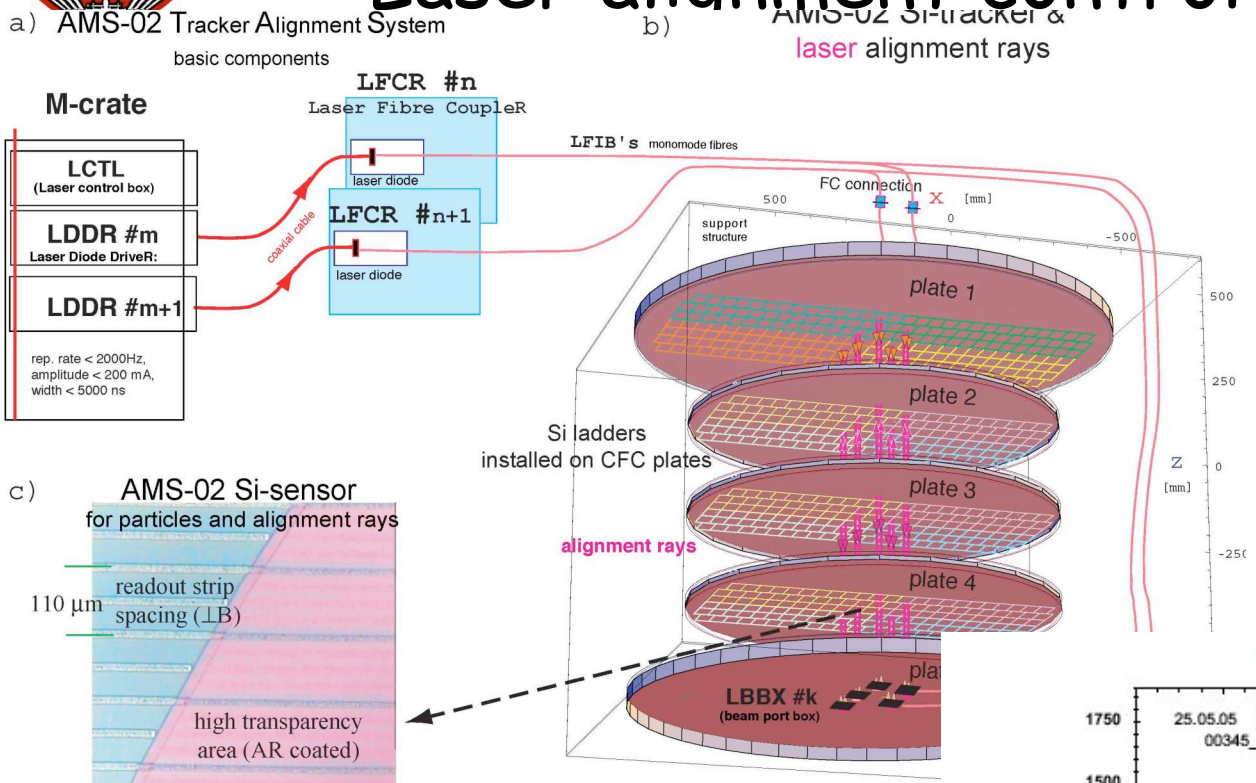


Sensor alignment in ladders





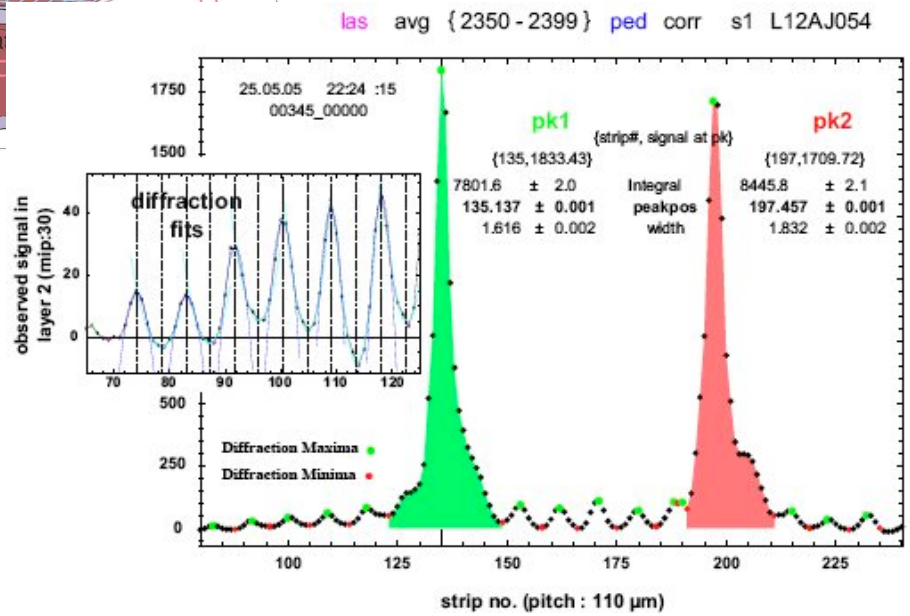
Laser alignment control system



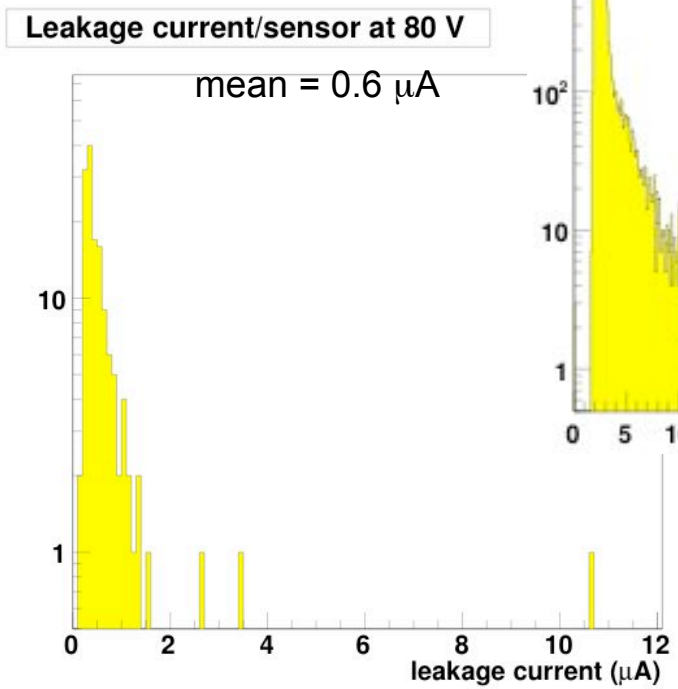
TAS properties

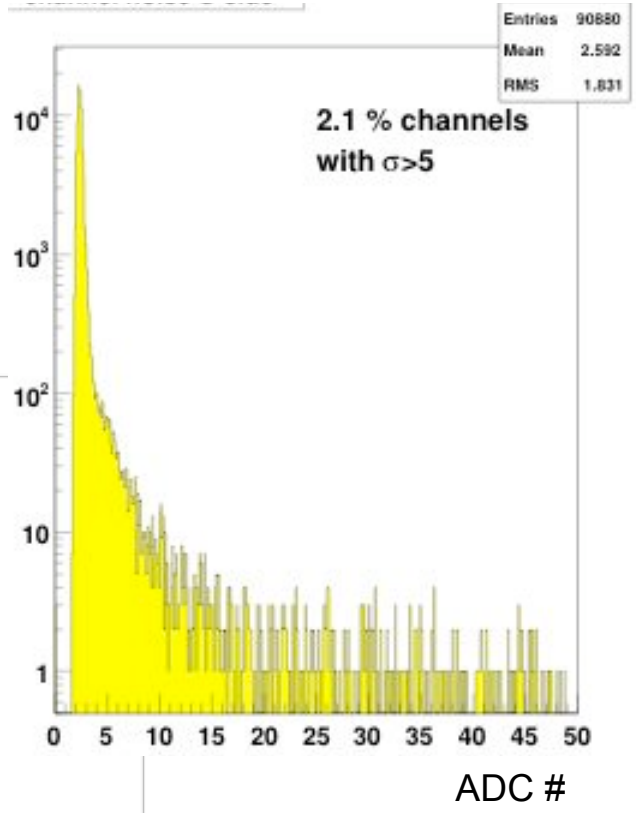
Light weight (3 kg)
Low power (< 0.1 W)
Fast data taking (20s)
Highly accurate (< 5µm)

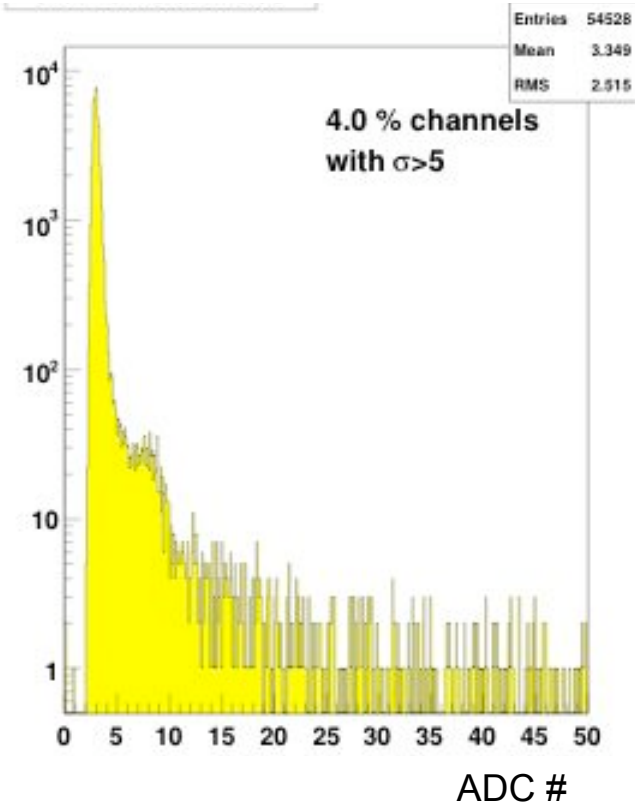
Low power laser diodes (1082nm)
100 nJ pulses



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



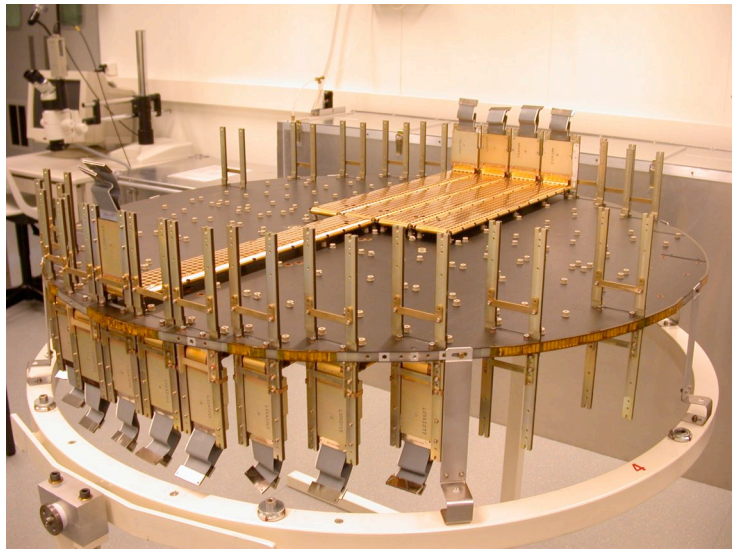


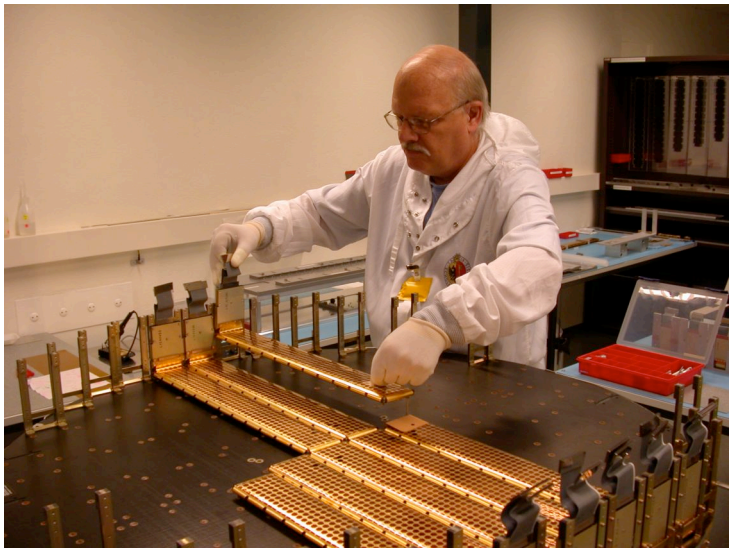


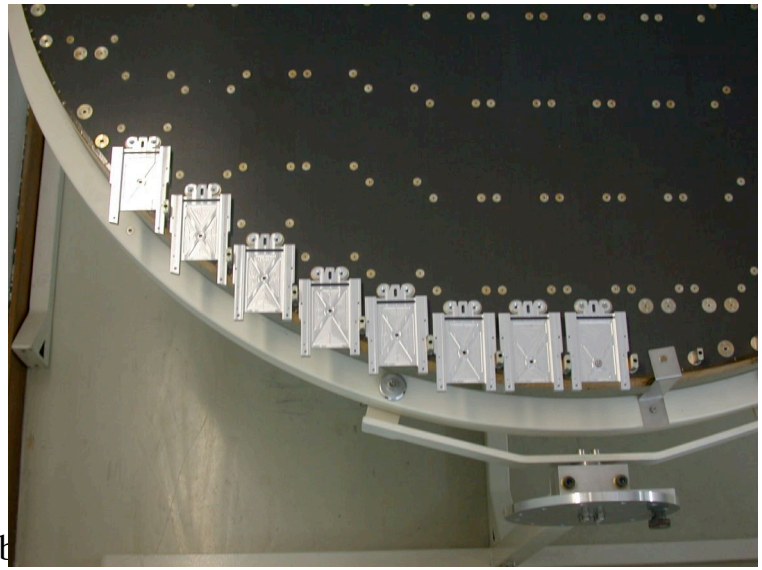
Landau MPV for MIPs ~ 30 ADC#

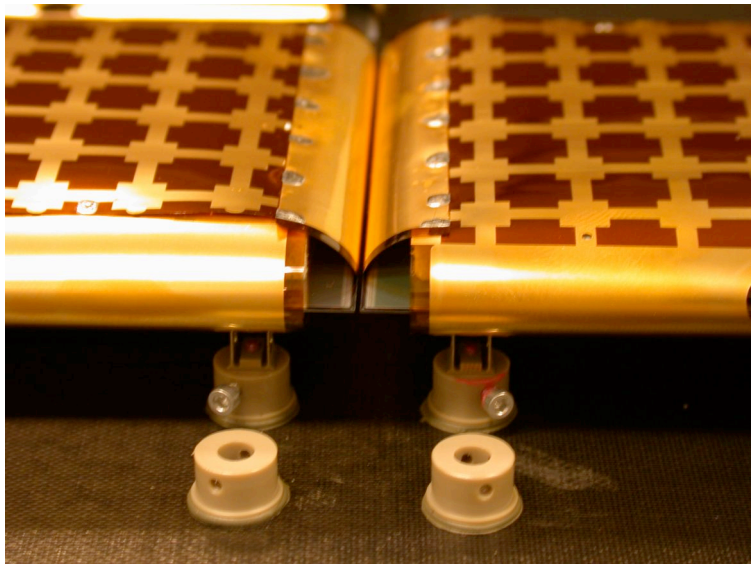
single wafer current was ~ 400 nA

Mounting ladders on plane



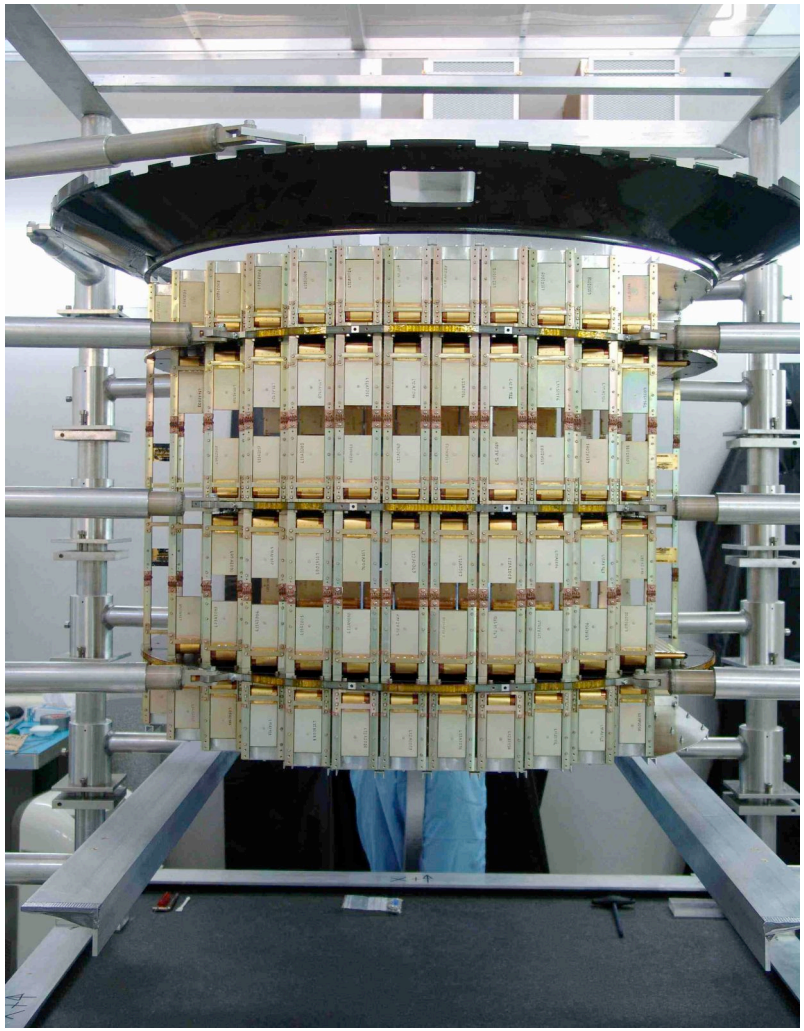


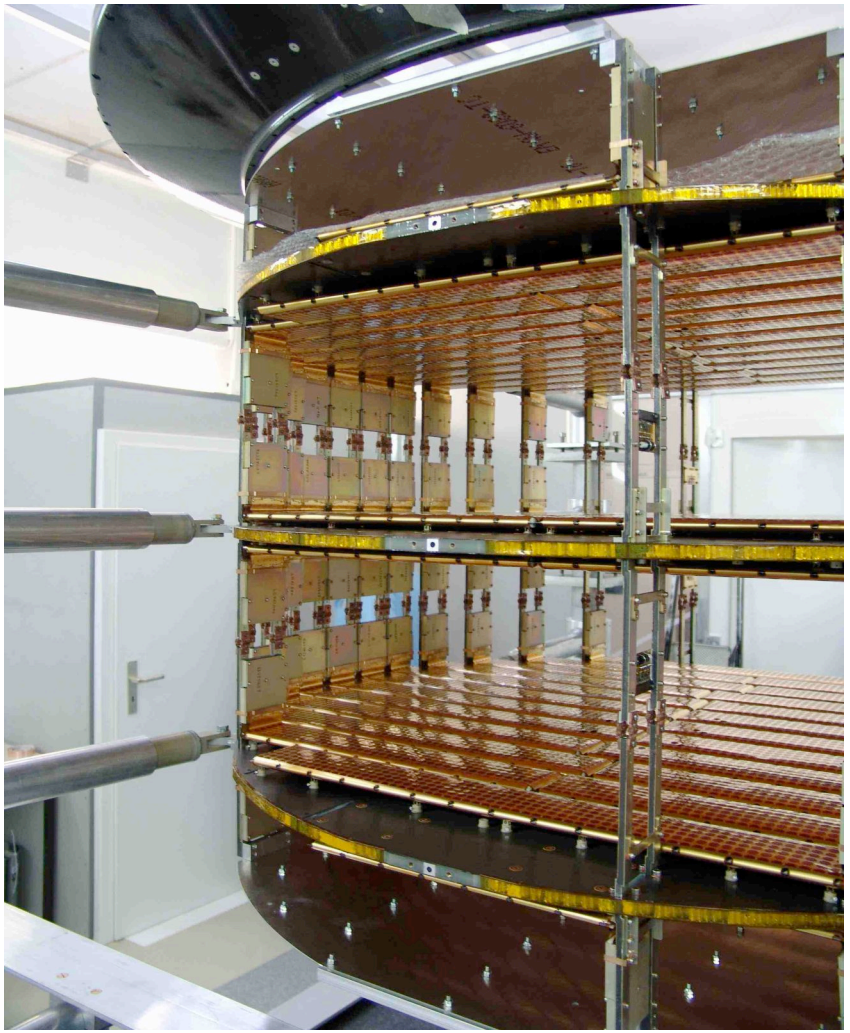




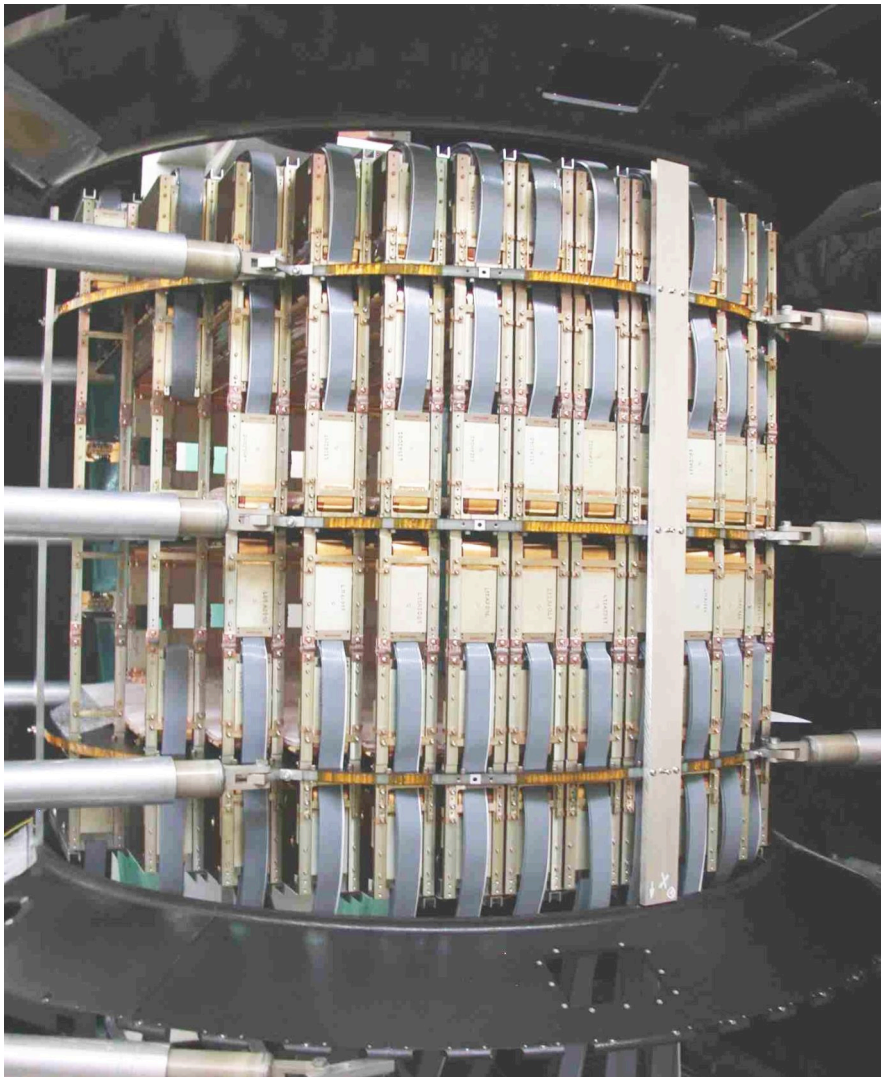
Tracker integration

Inner Tracker (plane 2, 3 and 4)

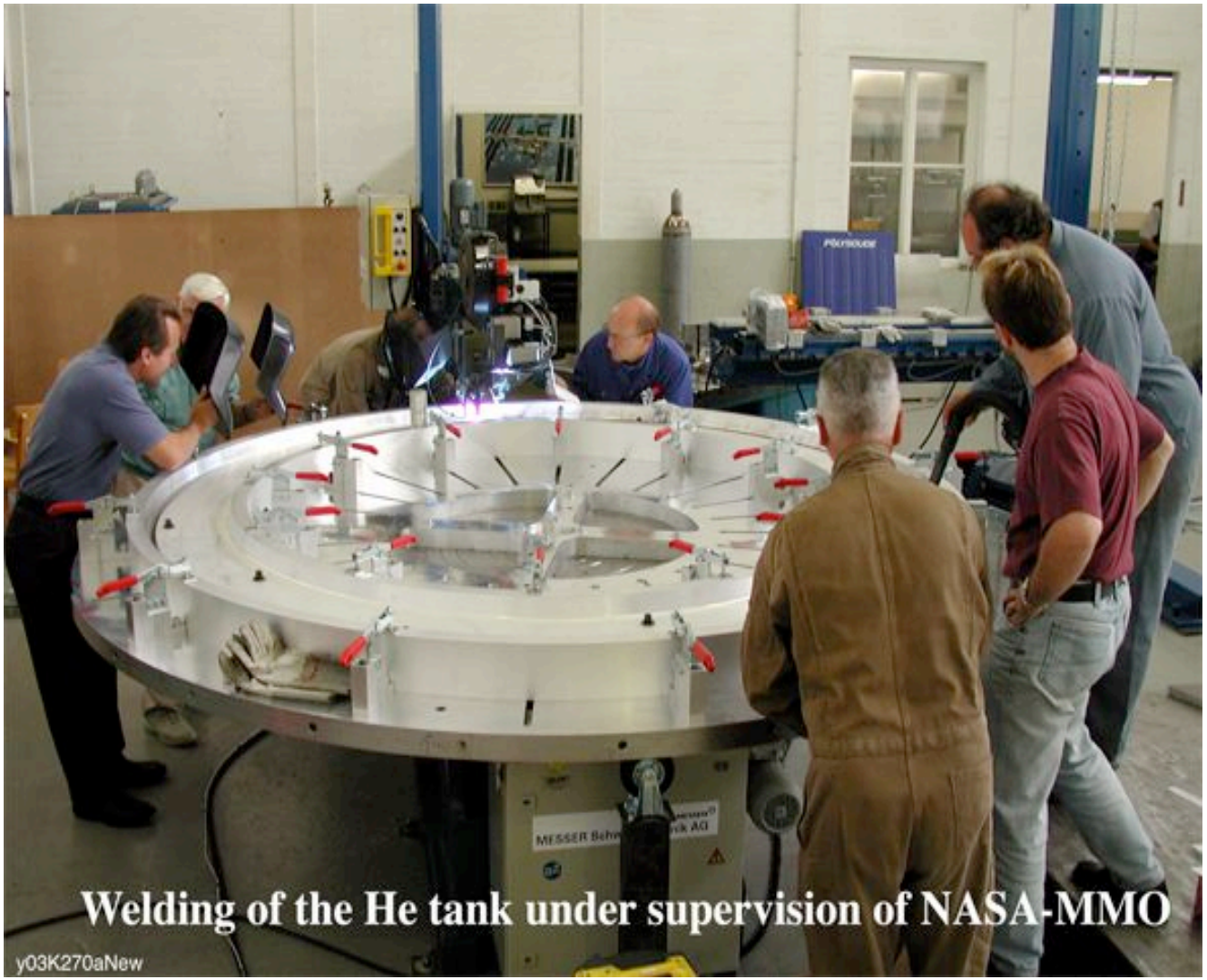




Tracker ready for cosmic test

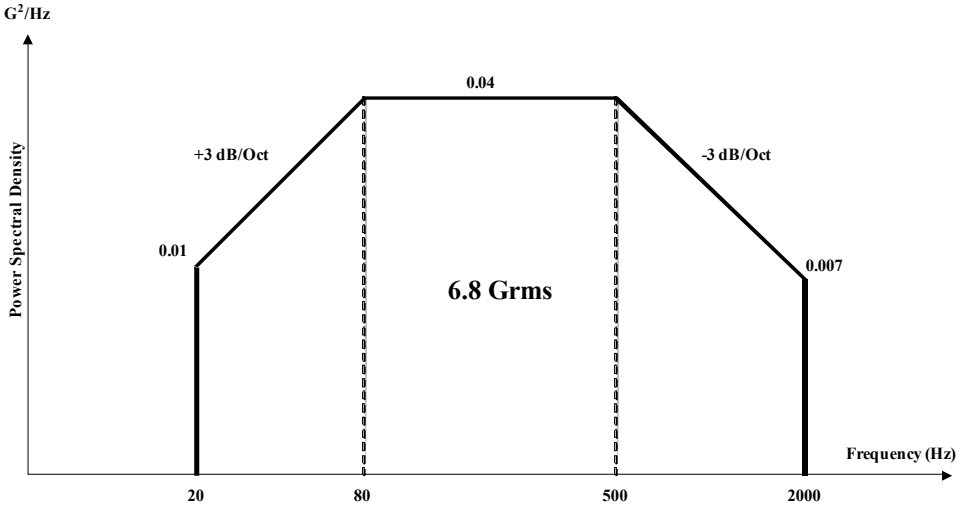


Space qualification

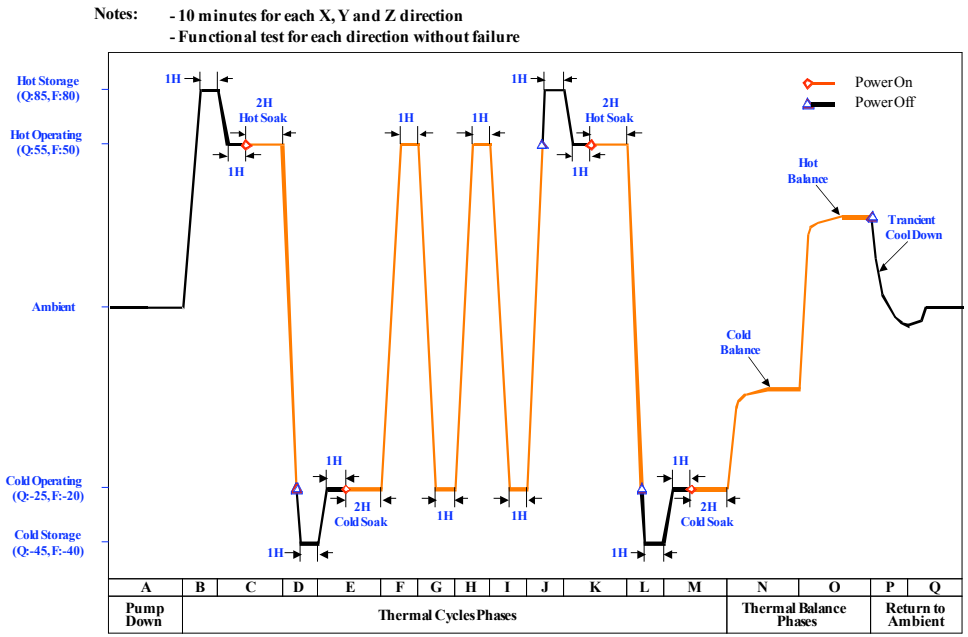


Stress Profile

Vibration
power spectrum

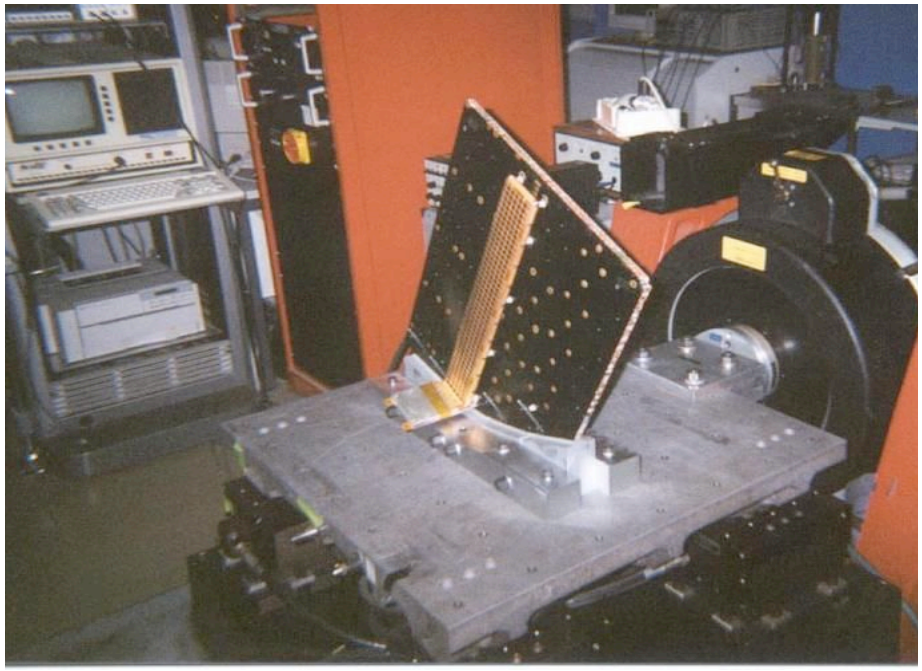


Thermal and
thermo-vacum cycles



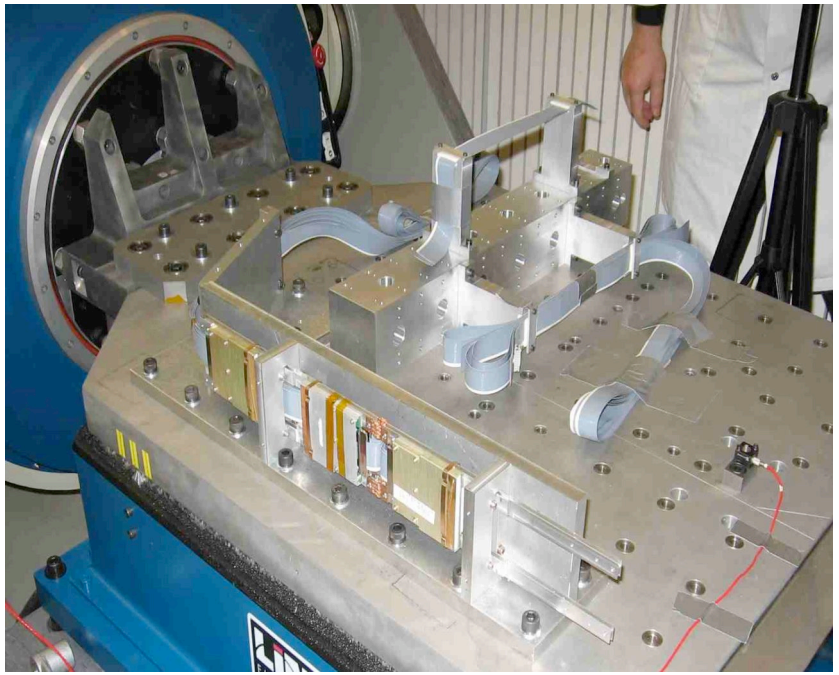
Vibration tests

ladder on plane



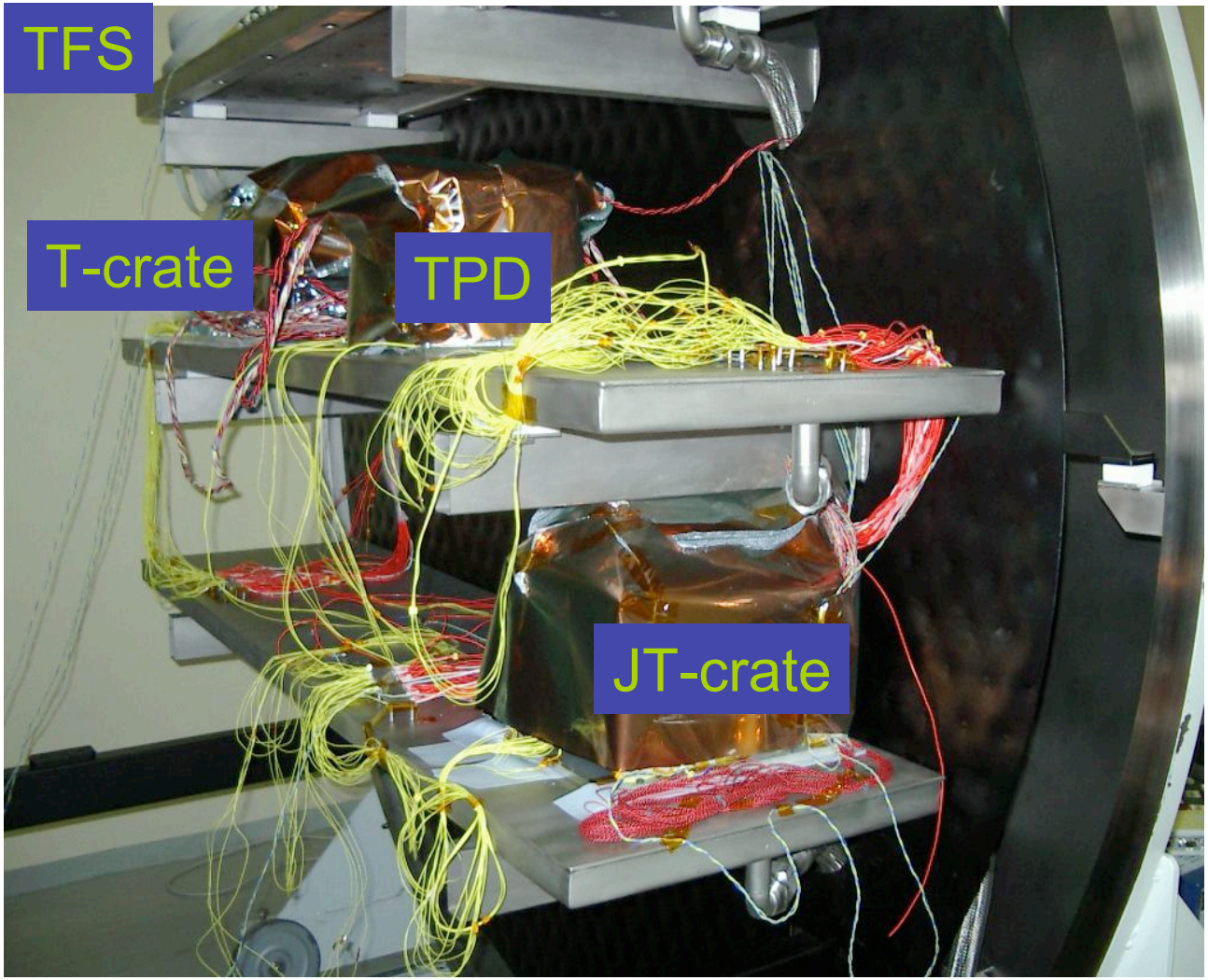
no missing bonds after ladder
and test structure vibration

cables and cables support



definition of cabled fixation

TV test set-up



Radiation 'hard' electronics

The problem are the SEE (Single Event Effect)

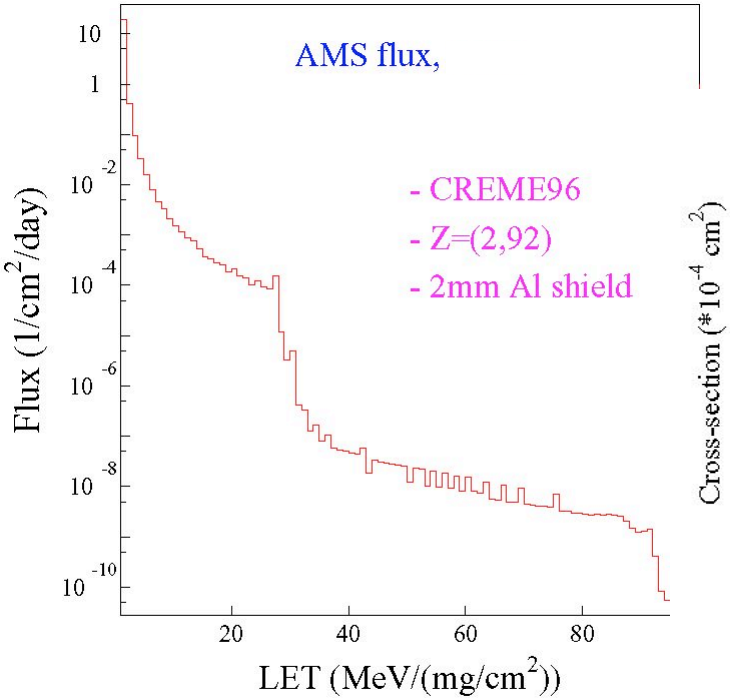


Figure 5: Expected fluxes on ISS in 2003.

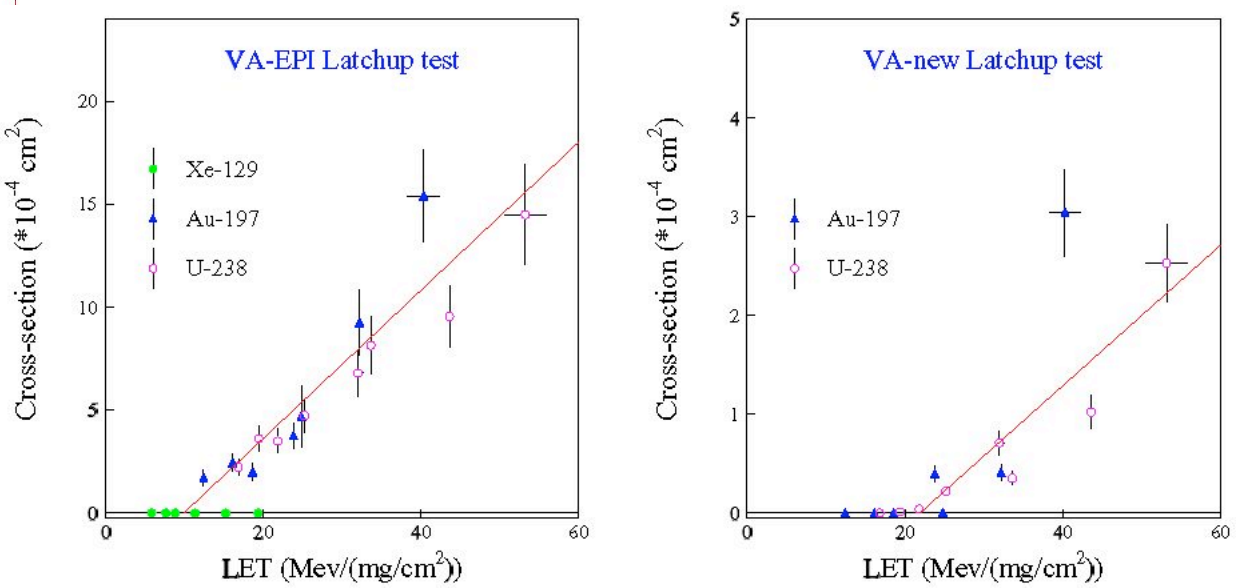
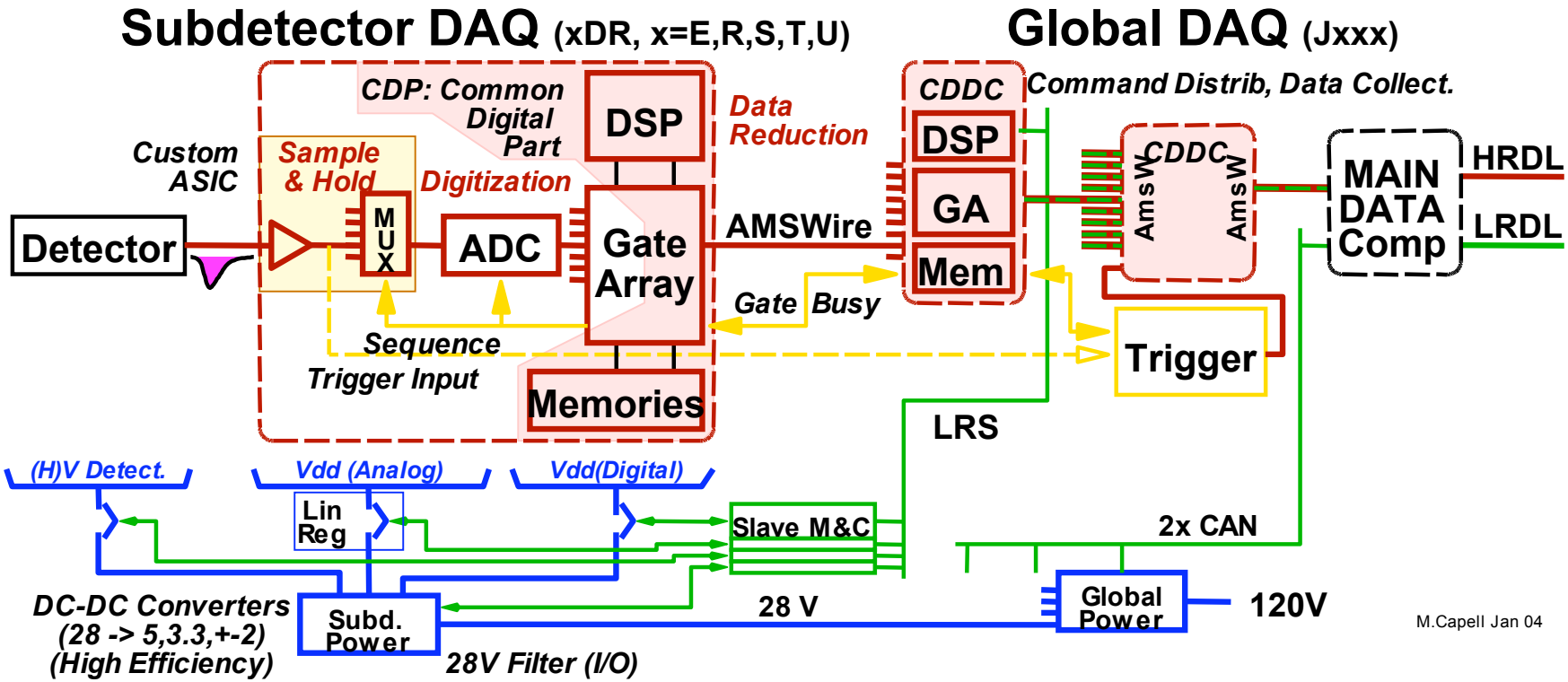


Figure 12: The new VA – SEL rates as measured in GSI

current limit protection is present for all active components

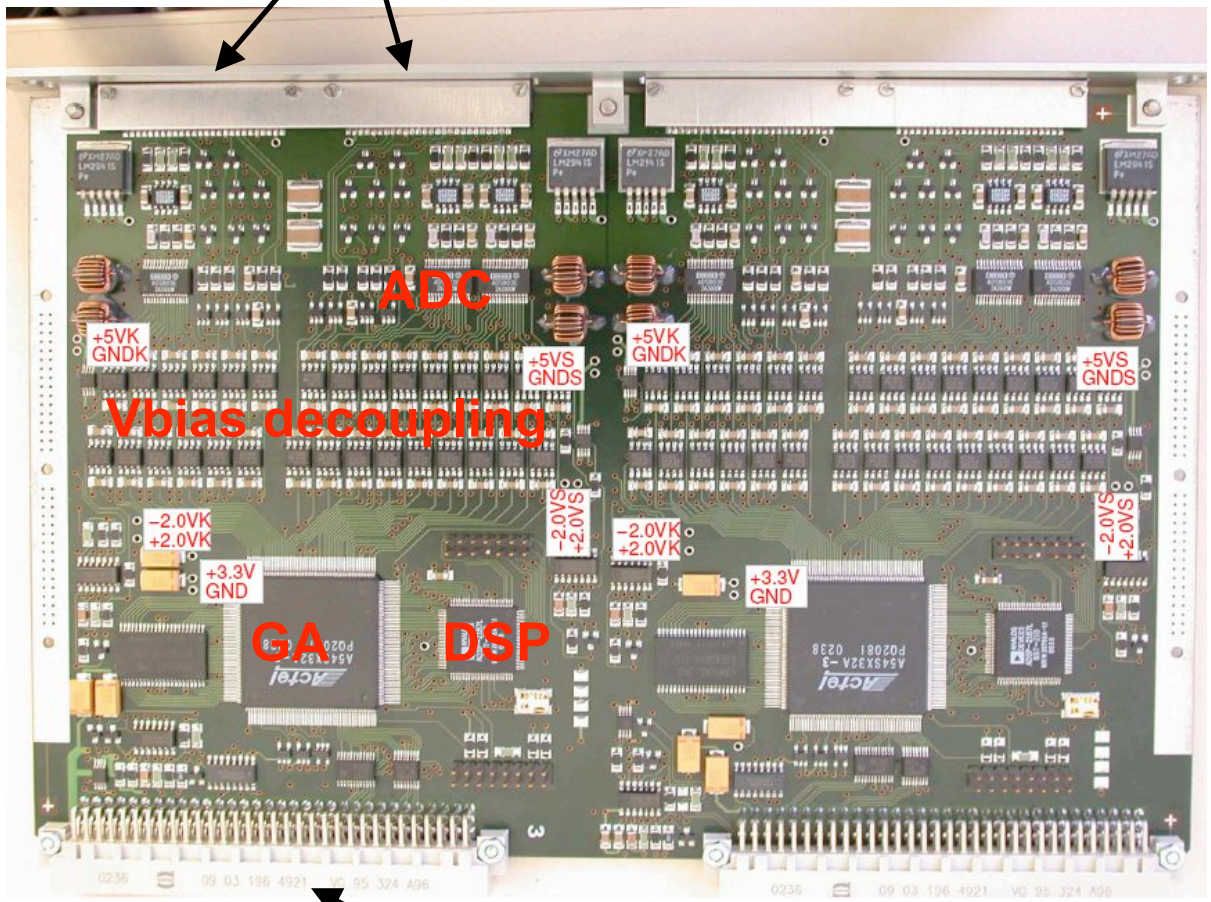
AMS-02 Custom/Common Readout Unit



- Cust/Comm processing unit, software, links.
  - DSP (ADSP-2187L), Gate Array (Actel A54SX-2A), SRAM (Samsung K6R-016V1C), Flash (AMD Am29LV004), LVDS Tx/Rx (TI SN65LVD-39-), etc.
- Cust/Comm monitor & control interfaces.
- Cust/Comm power supplies w/high efficiency.

Data Reduction Board (TDR2)

analog signal in



compressed digital out

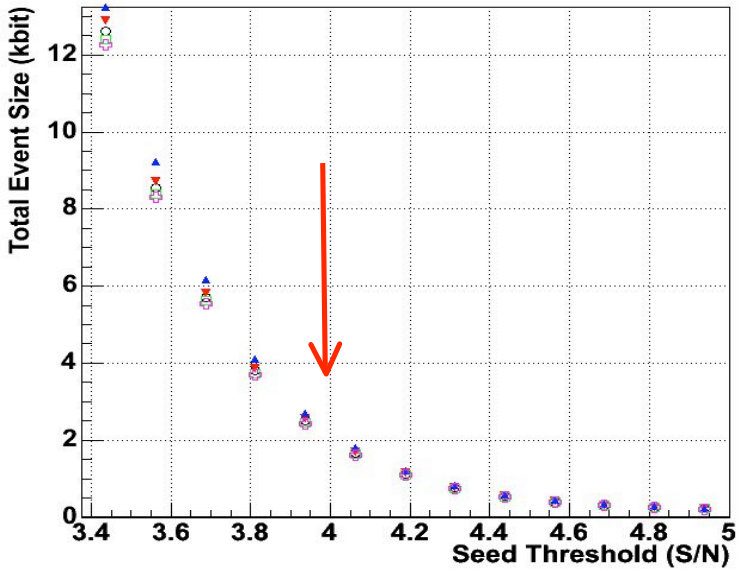
Collect analog data and digitize it (100 μs irred. dead time)

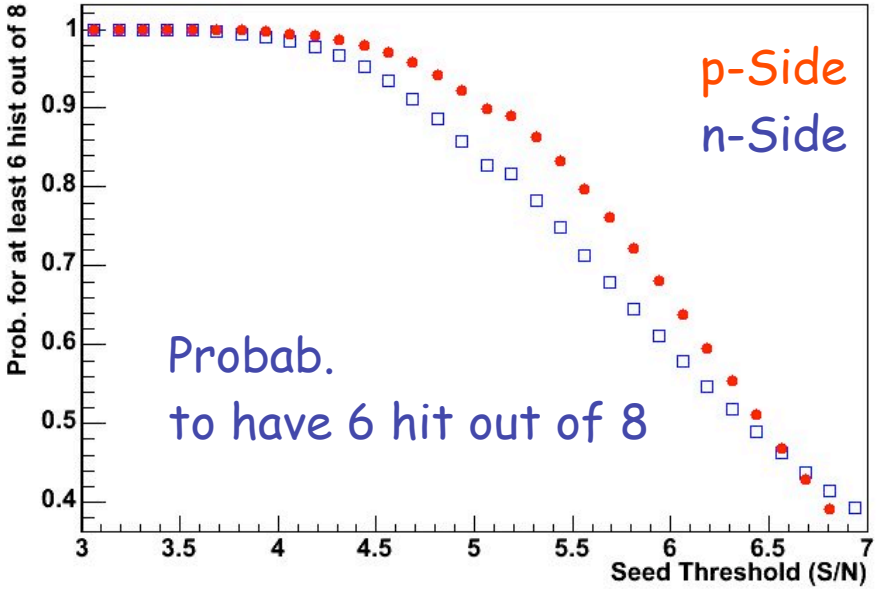
Perform online data compression

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

Up to 5 KHz trigger rate in compressed mode

Data size and efficiency



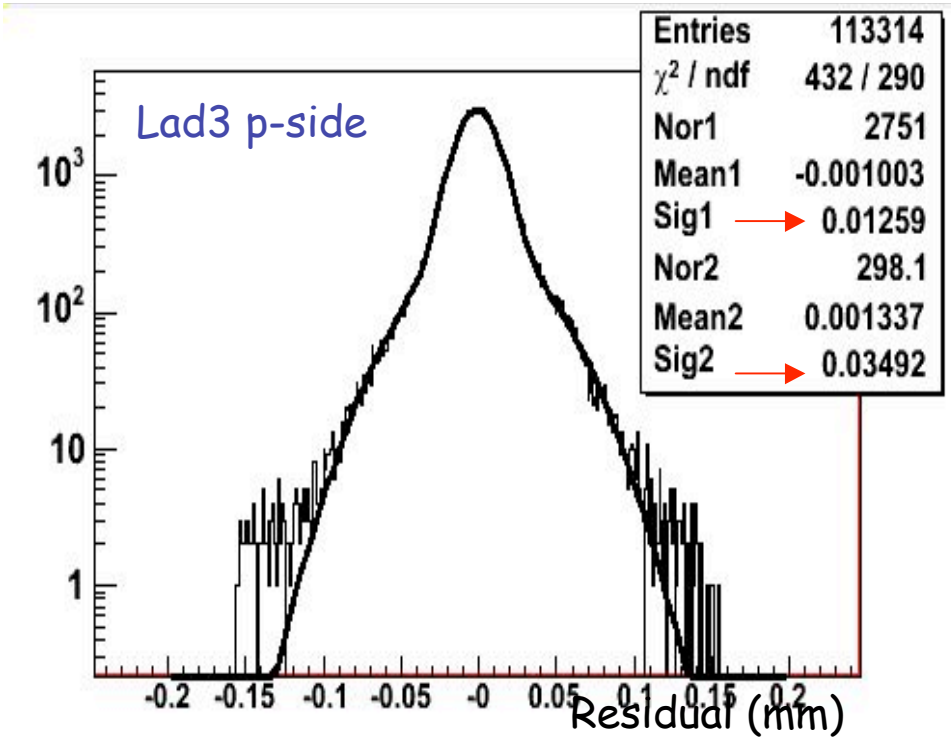


total bandwith is 2Mbit/s
max trigger rate is 2 KHz

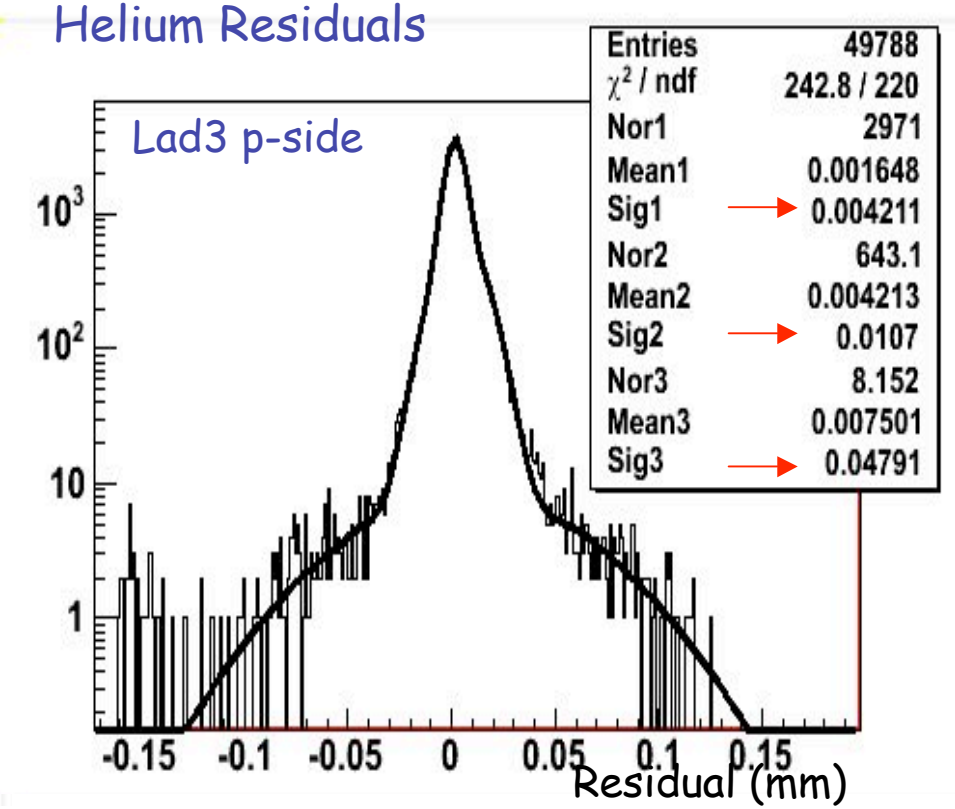
Subdetector	Req'ments	Channels	Raw Kbits
U: TRD	Gas gain	5,248	84
S: ToF+ACC	100 ps	48*4*8	49
T: Tracker	few fC	196,608	3,146
R: RICH	Single gamma	680*16*2	348
E: ECAL	1:60,000	324*(4*2+1)	47
Σ Raw Kbits/event			3,674
* Event Rate			≤ 2 Khz
= Total Raw Data Rate			~7 Gbit/sec

Residual Distributions

Proton Residuals



Helium Residuals



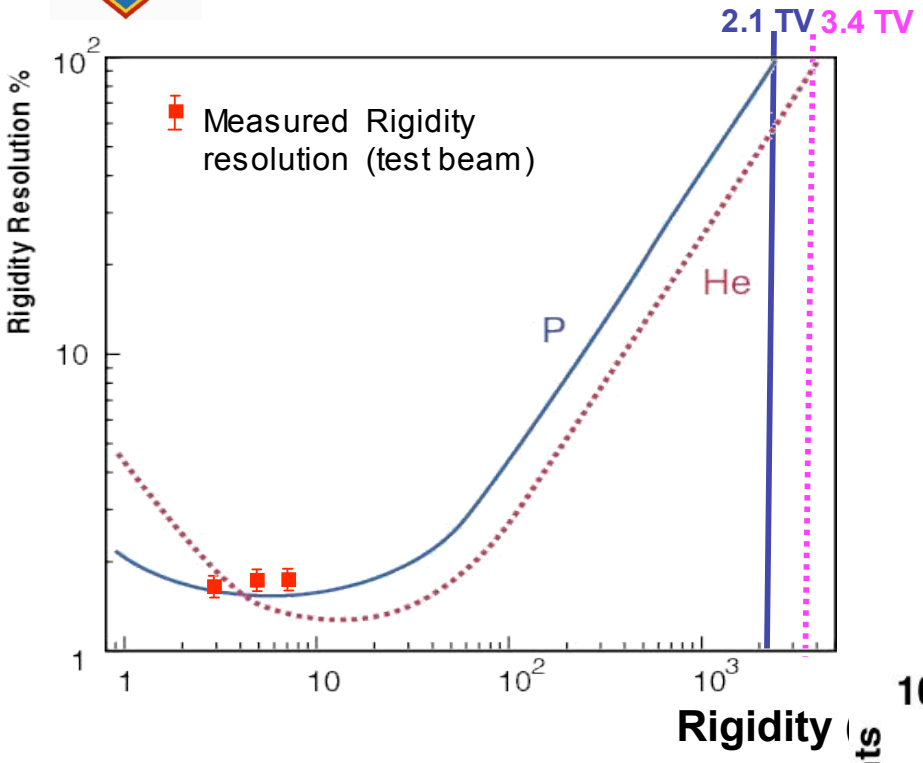
2 gaussian Fit

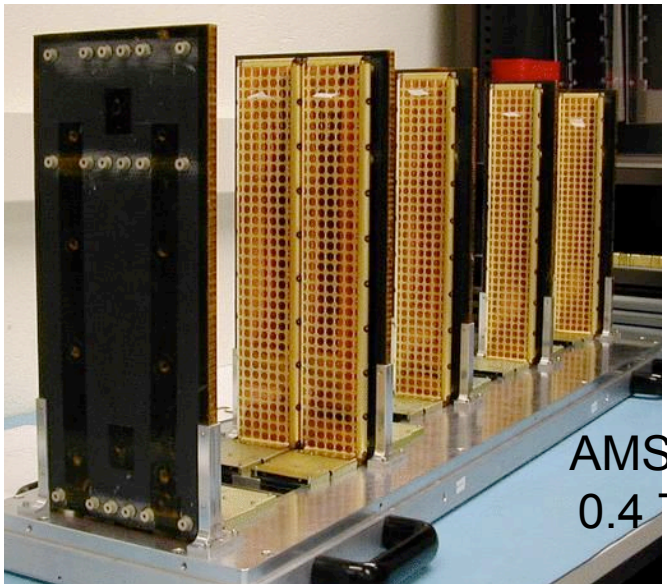
1st Gaussian 70% of events
2nd Gaussian 30% of events

3 Gaussian Fit

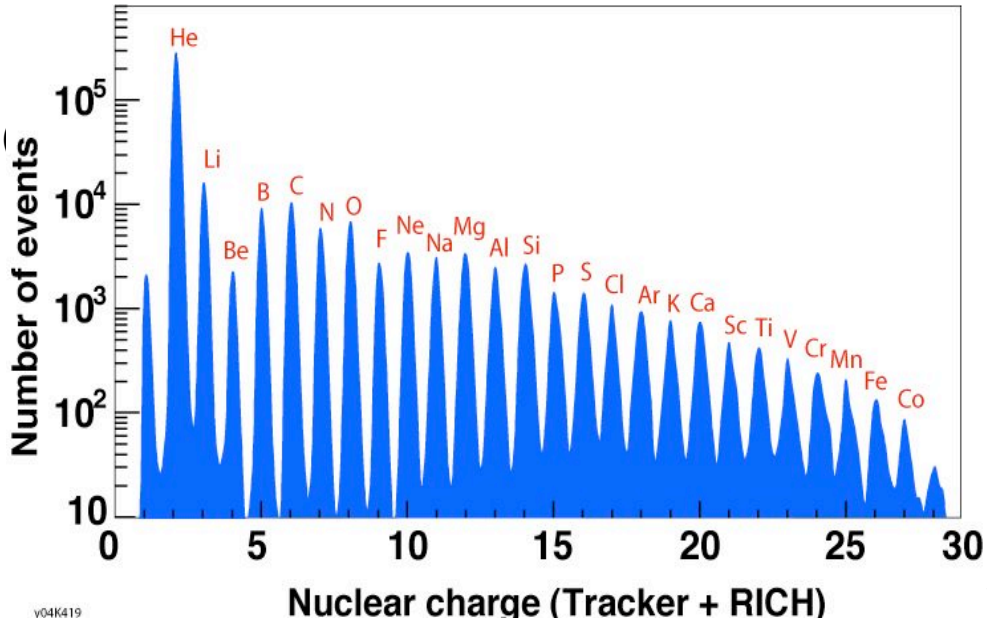
1st Gaussian 63% of events
2nd Gaussian 34% of events
3th Gaussian 3% of events

Rigidity res. and charge id.





AMS like config.
0.4 T mag. fiels



Conclusions

- After the successful test flight on board the Space Shuttle Discovery on June 1998, the AMS-02 Tracker capabilities have been extended
- The detector construction is completed
- Design requirements have been fulfilled
- In September 2007 the Tracker will be integrated in the AMS-02 magnet
- In autumn 2008 the whole AMS-02 detector must be delivered to Cape Canaveral (Florida) ready to launch for 3 years (and more) operation on board the ISS

ISS status on orbit