Silicon Detectors in Space: the INFN experience

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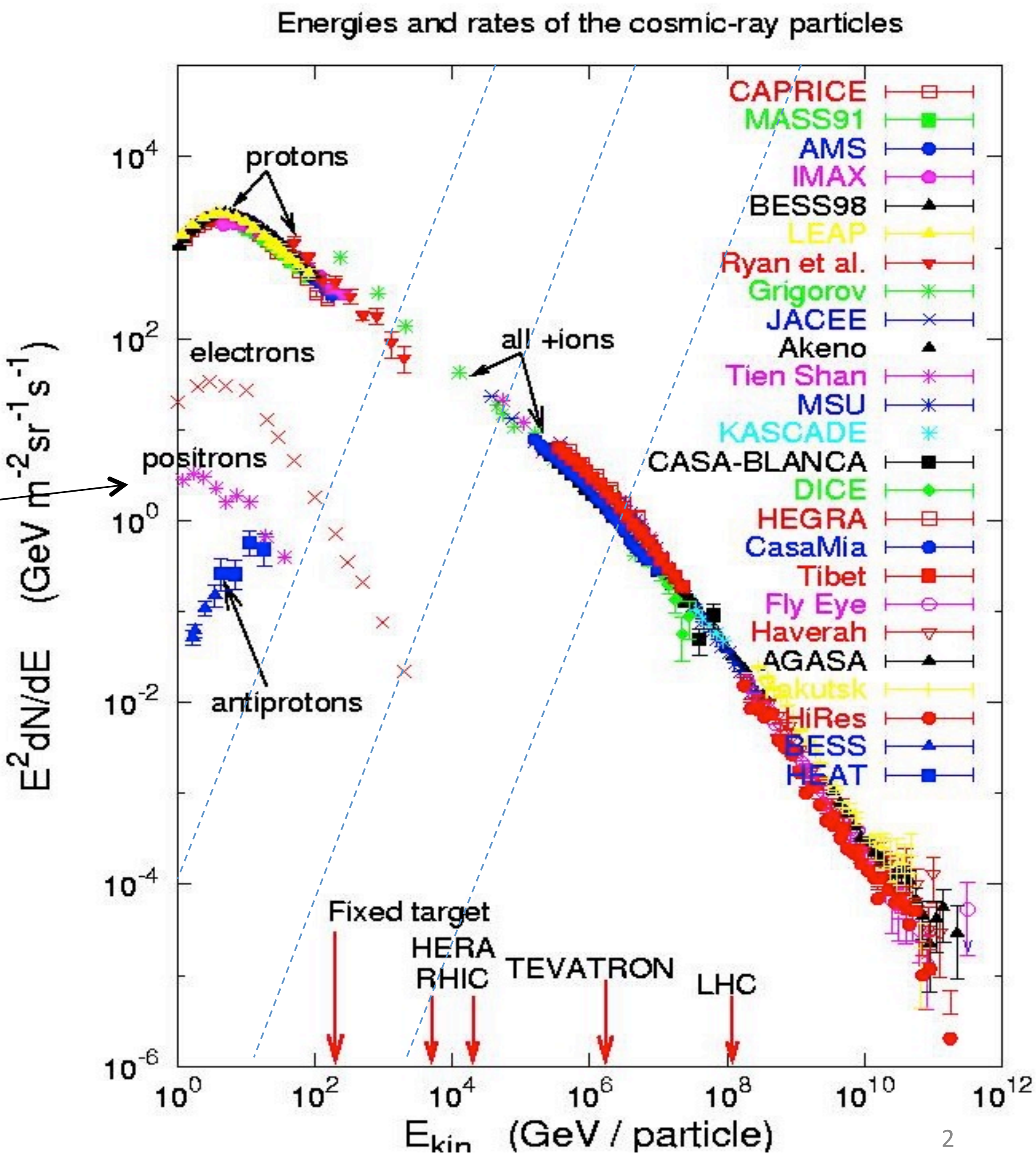
Istituto Nazionale di Fisica Nucleare

LNS, 7 Aprile 2016

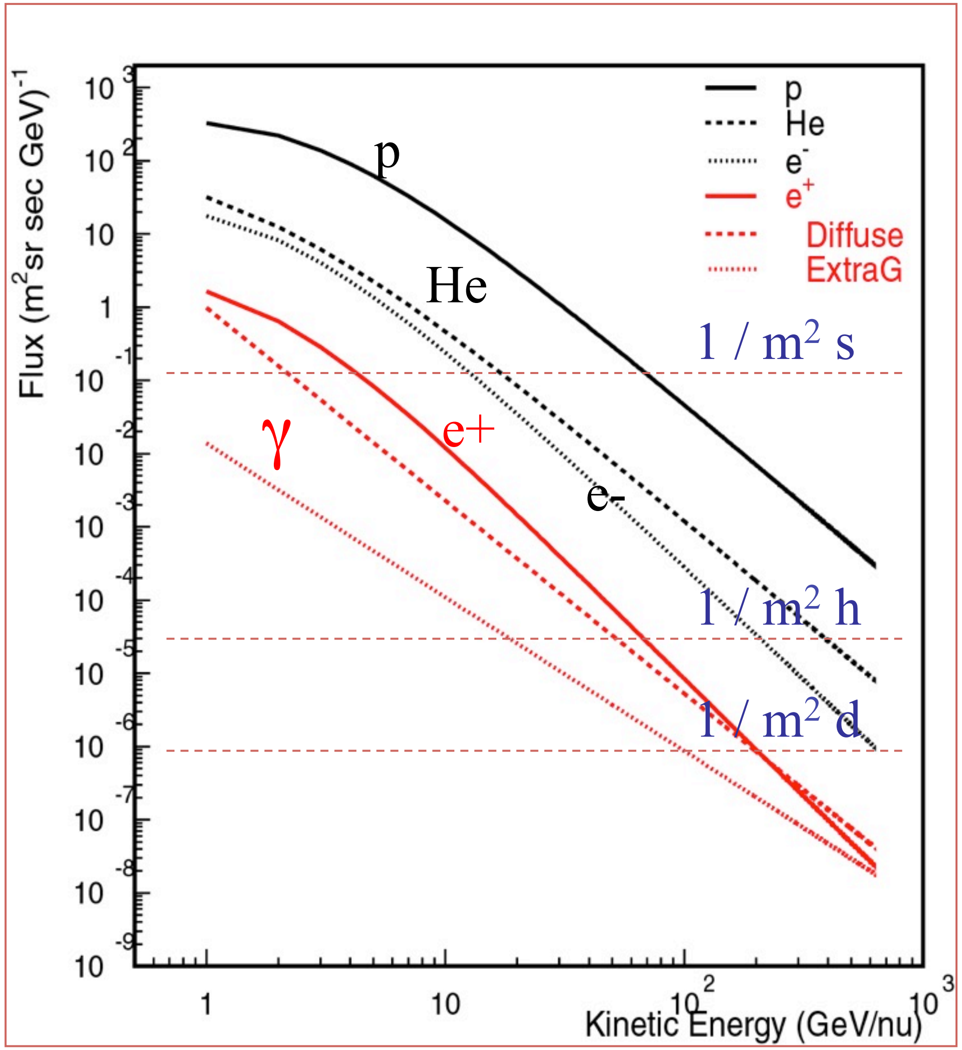
The beam !

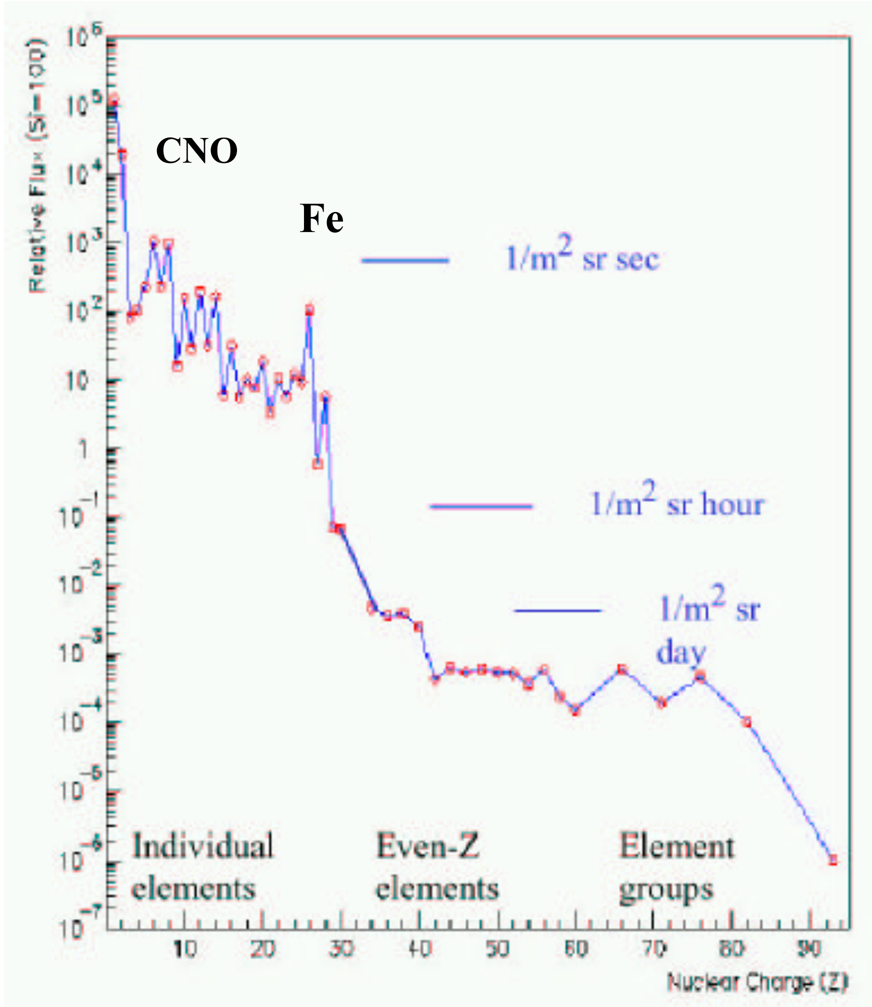
(charged particles)

A few years-old scenario

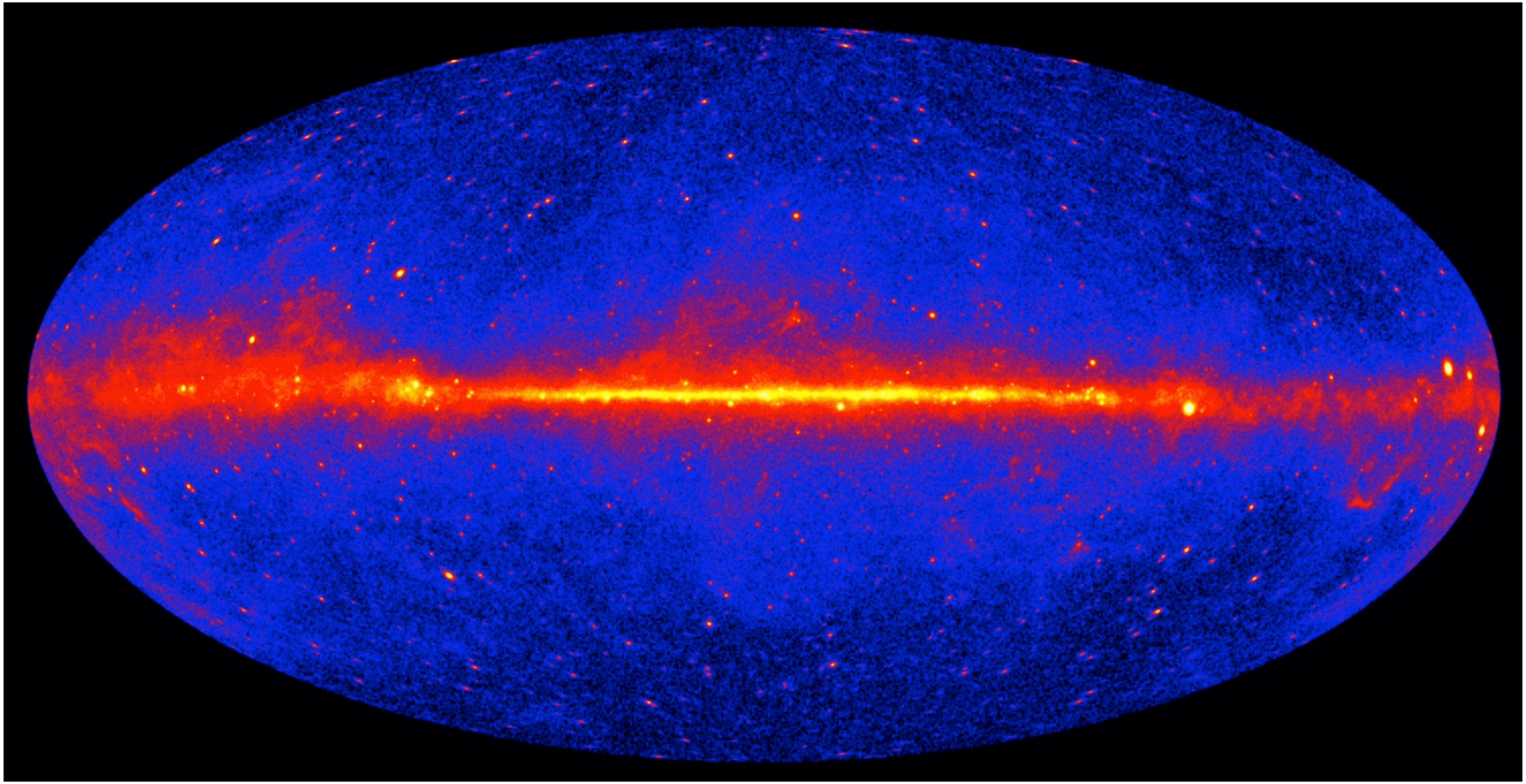


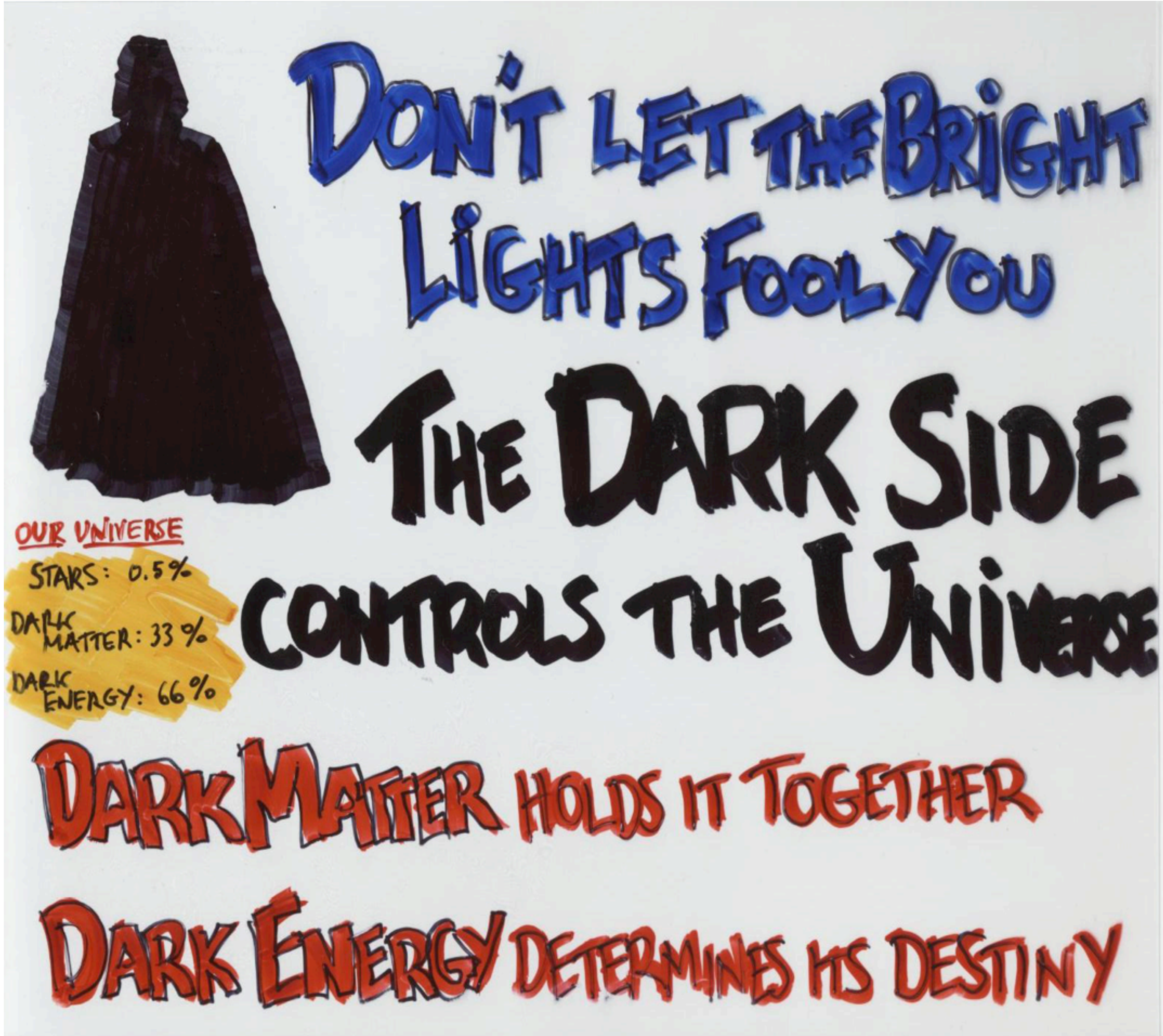
High Energy CR flux and composition





FERMI all sky map





Turner @ ICRC 2003

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

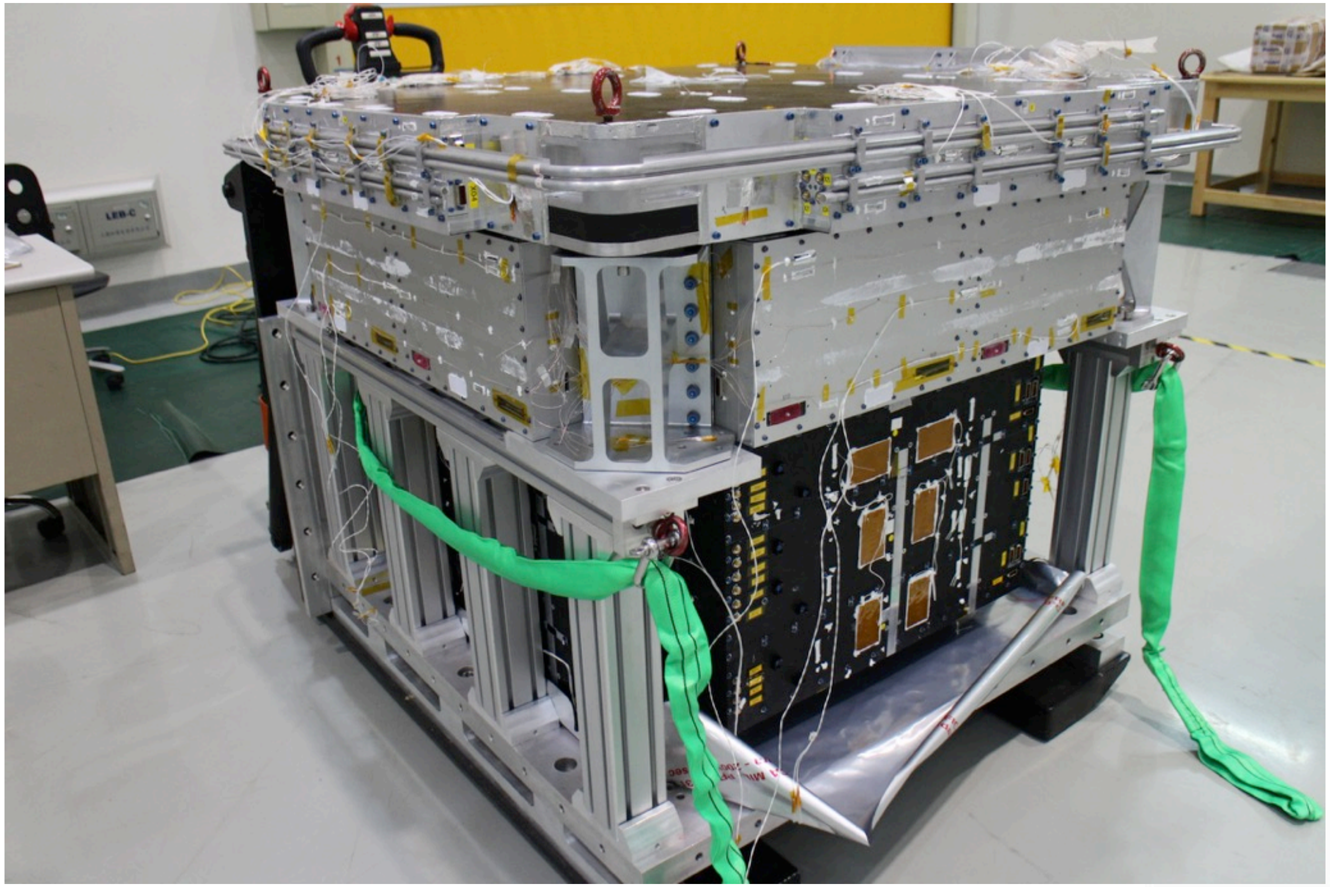
exact stress numbers depend from the detail of the mission,
here AMS-02 values are reported

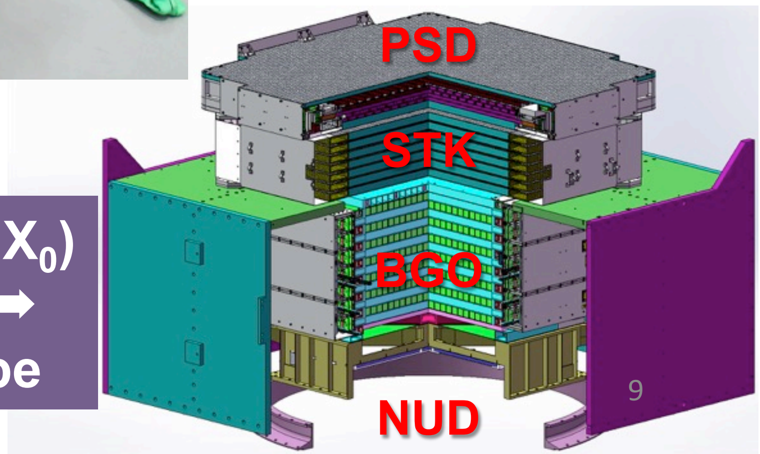
INFN HEP detector in space

- 1998: AMS-01
  - permanent magnet with silicon tracker
  - 10 days flight on Space Shuttle
- 2006: PAMELA
  - permanent magnet with silicon tracker
  - taking data since launch, satellite
- 2007: AGILE
  - Silicon-Tungsten tracker
  - taking data since launch, satellite
- 2008: FERMI
  - Silicon-Tungsten tracker
  - taking data since launch, satellite
- 2011: AMS-02
  - permanent magnet with silicon tracker
  - taking data since launch, International Space Station
- 2015: DAMPE
  - Silicon-Tungsten tracker
  - taking data since launch, satellite


2015年12月17日8时12分

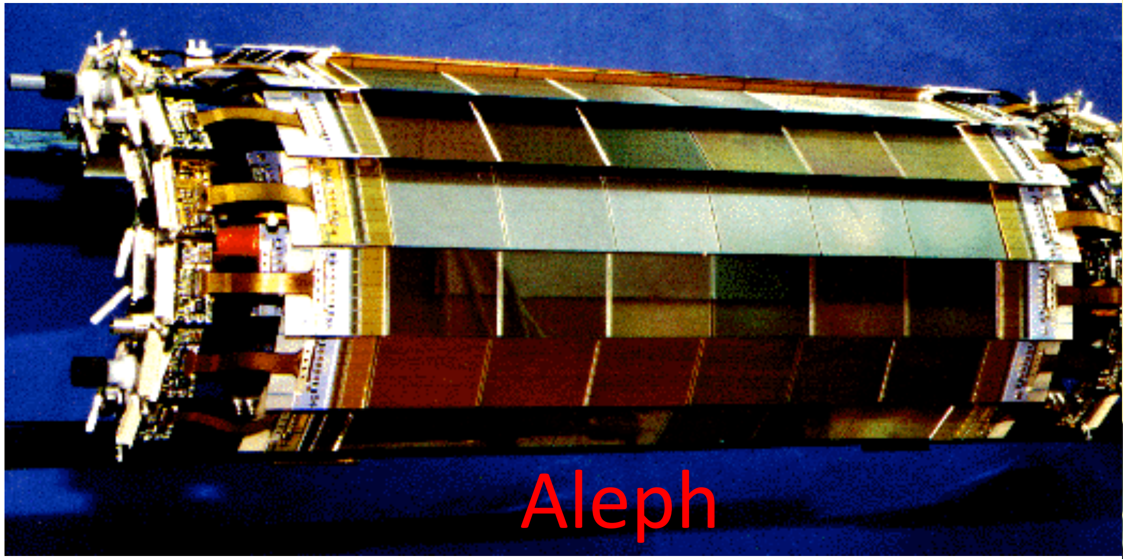
The DAMPE Detector

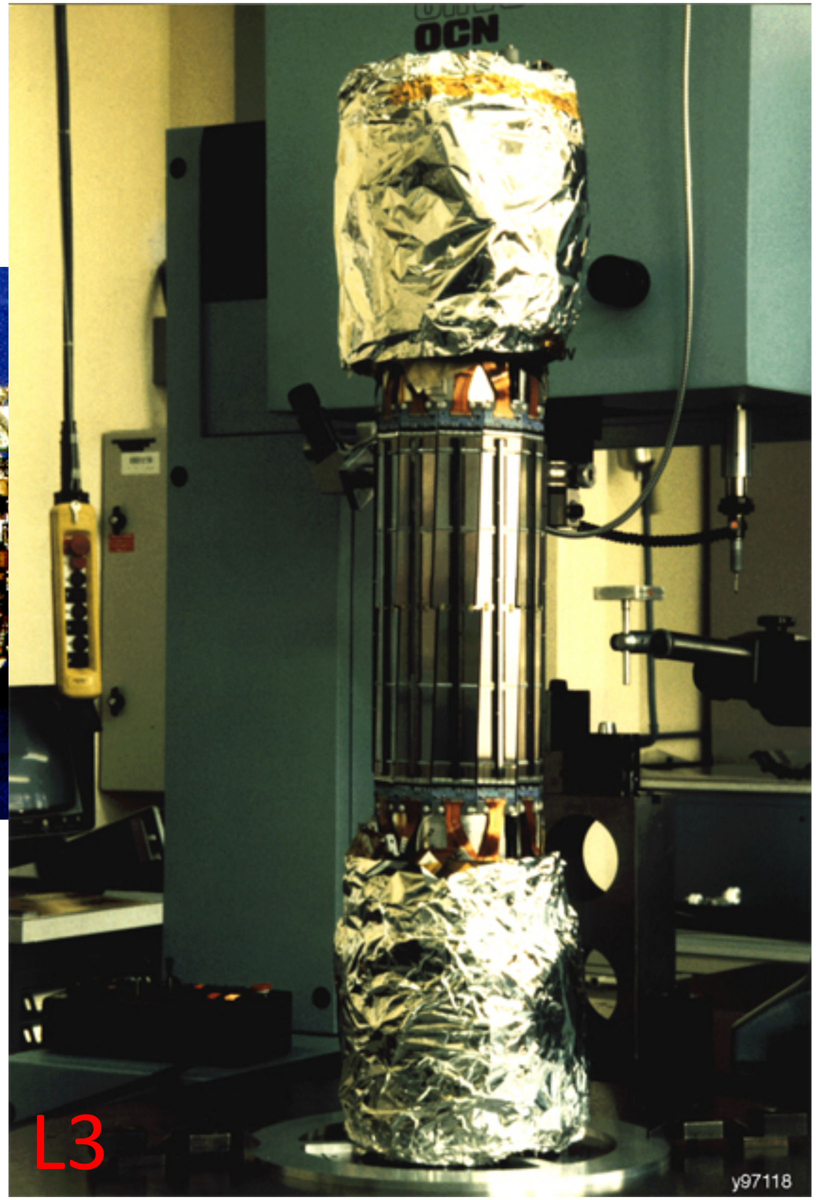




W converter (1.43 X_0) + thick calorimeter (31 X_0) + precise tracking + charge measurement ➡ high energy γ-ray, electron and CR telescope

Silicon detectors in the '90s





LEP accelerator @ CERN

INFN HEP detector in space

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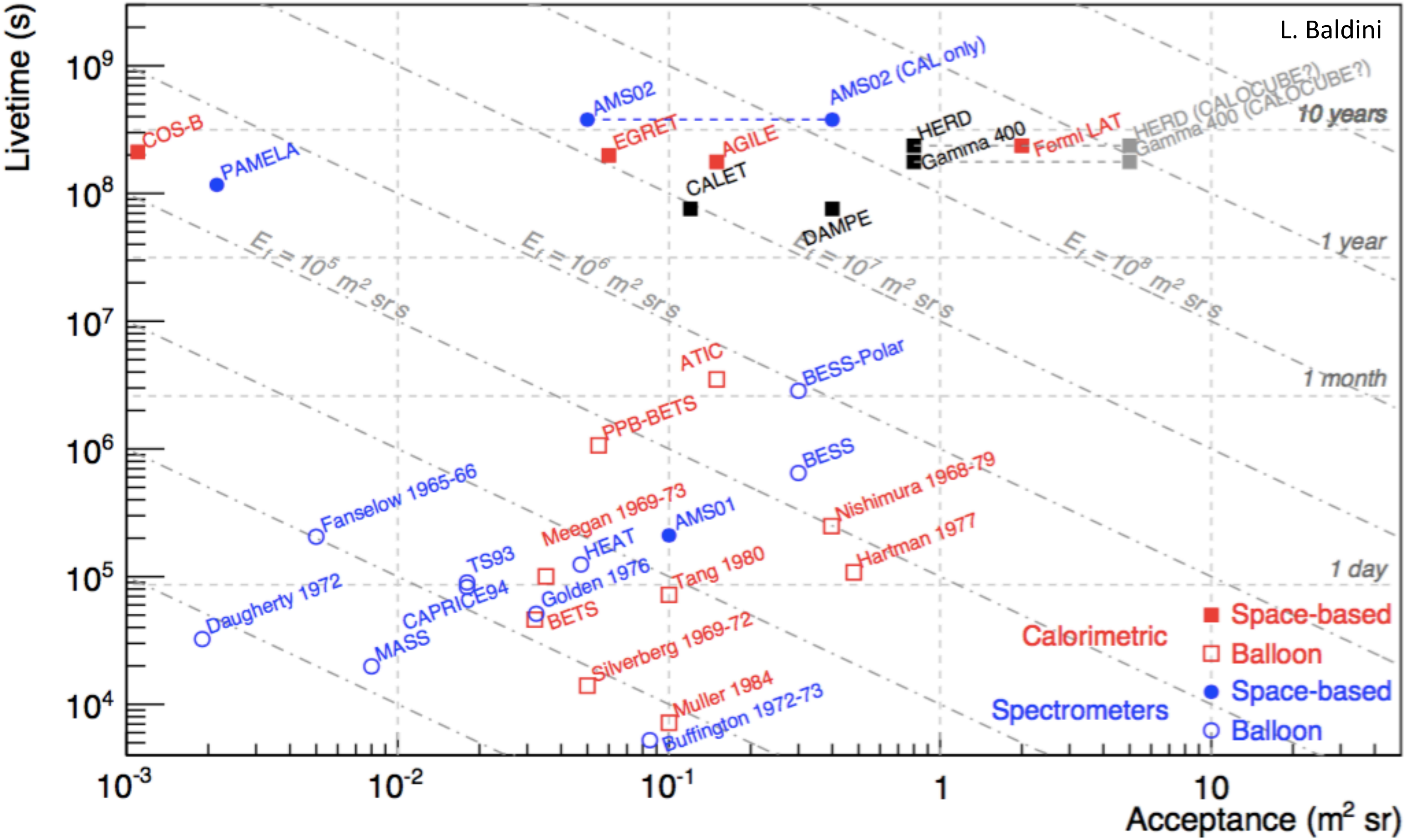
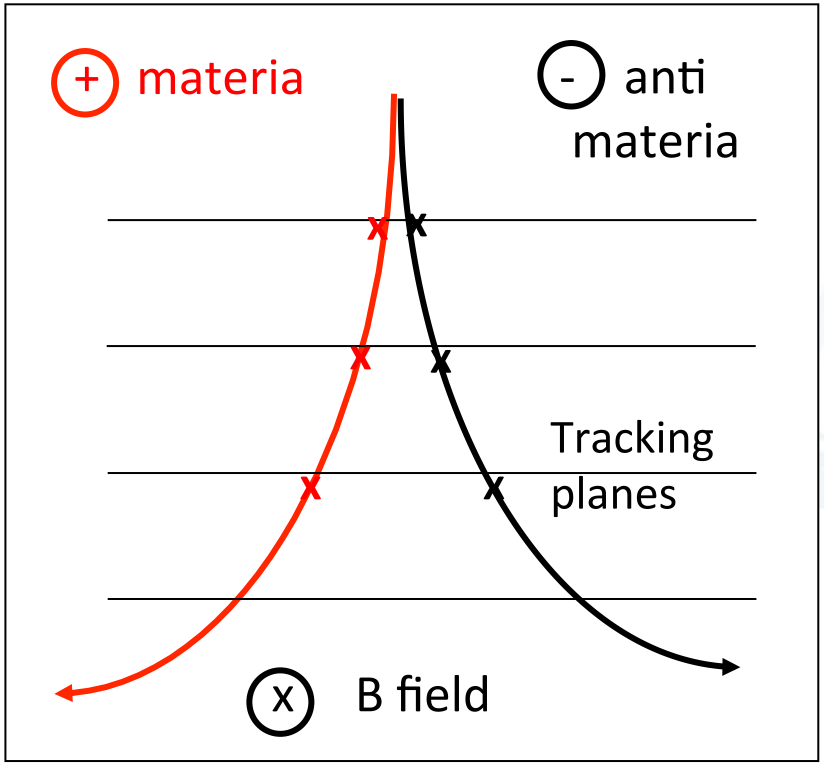
  - Silicon-Tungsten tracker
  - taking data since launch, satellite

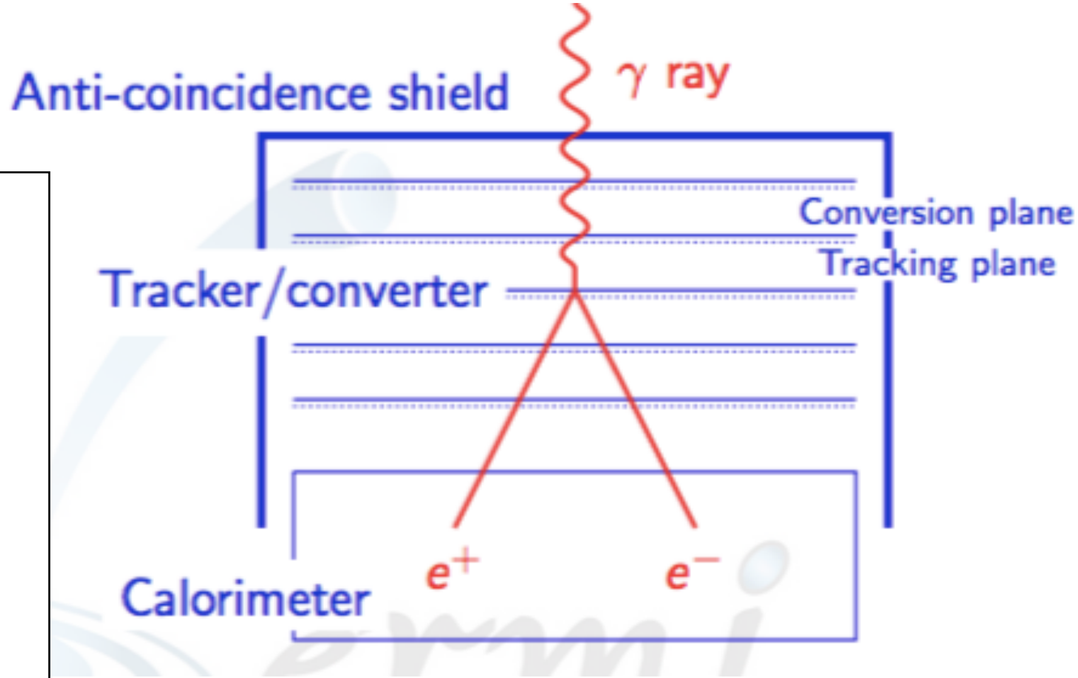
Accettanza (m^2 sr)



Spectrometer vs Calorimeter

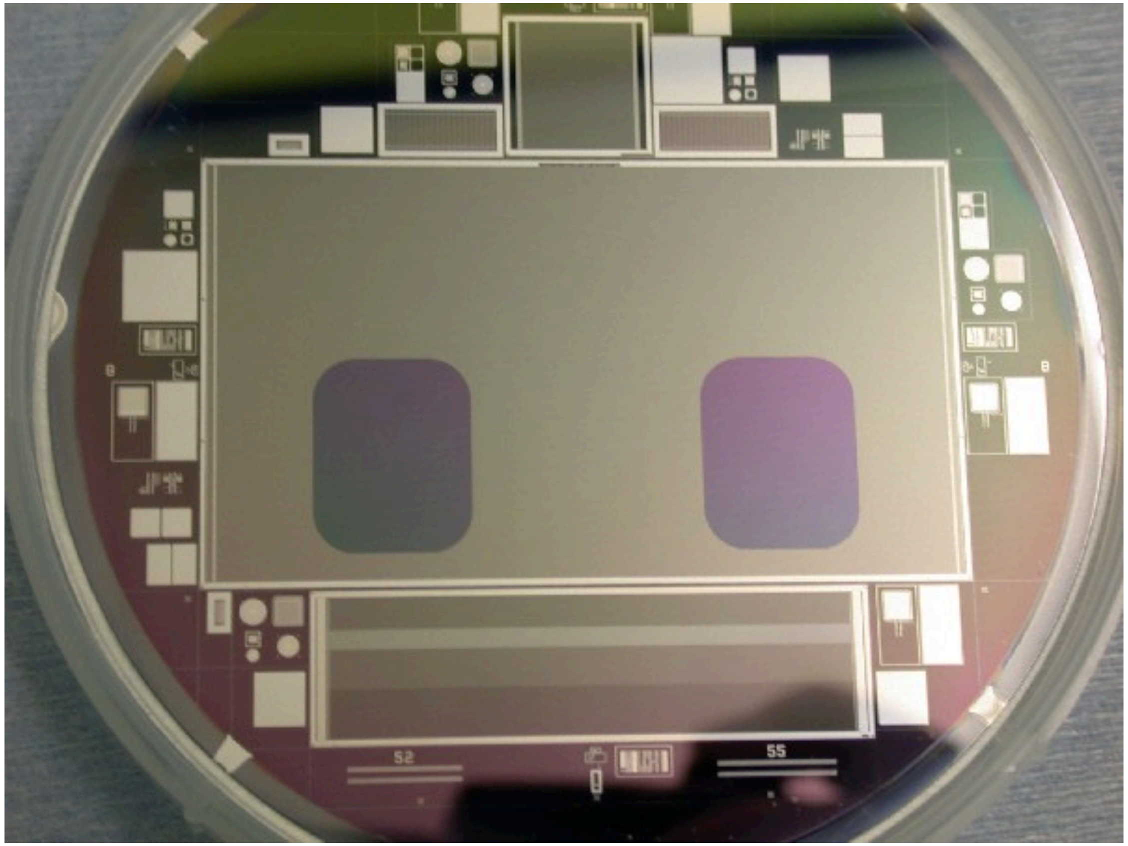
Magnetic spectrometer

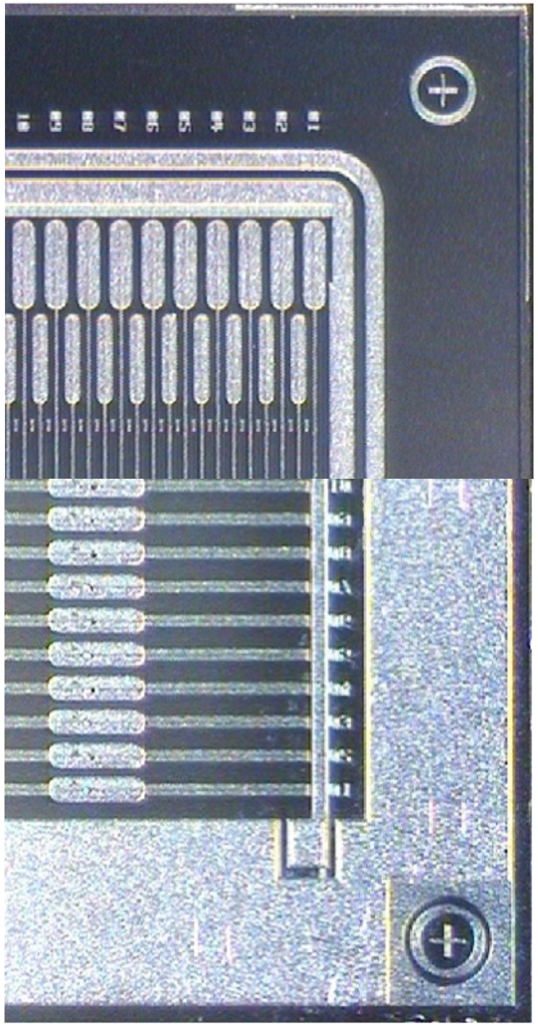




Spatial resolution:
- 3 – 10 µm spectrometer
- 30 – 70 µm calorimeter

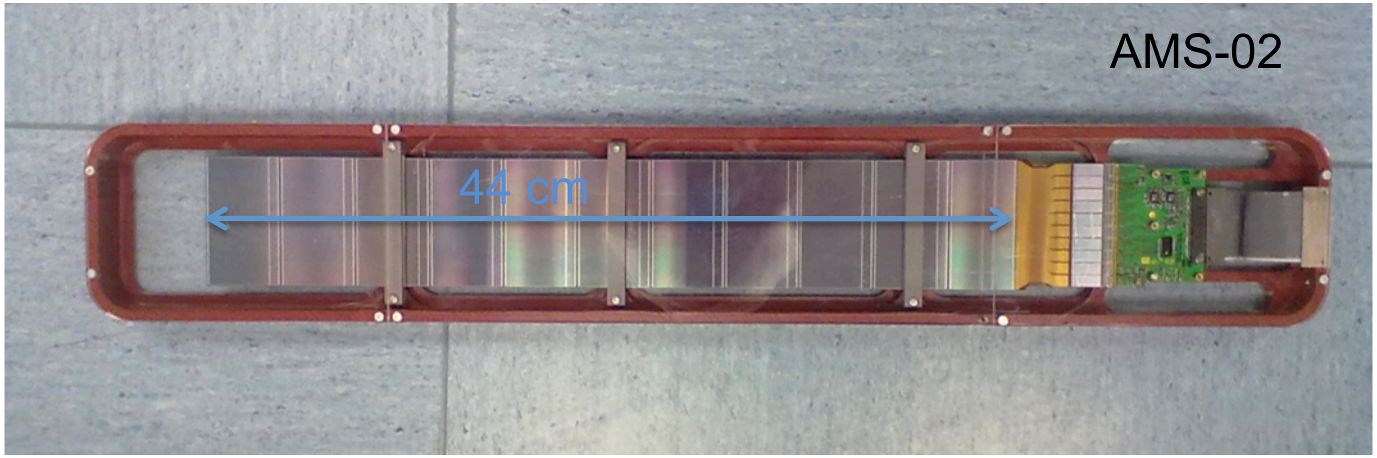
Silicon microstrip detector

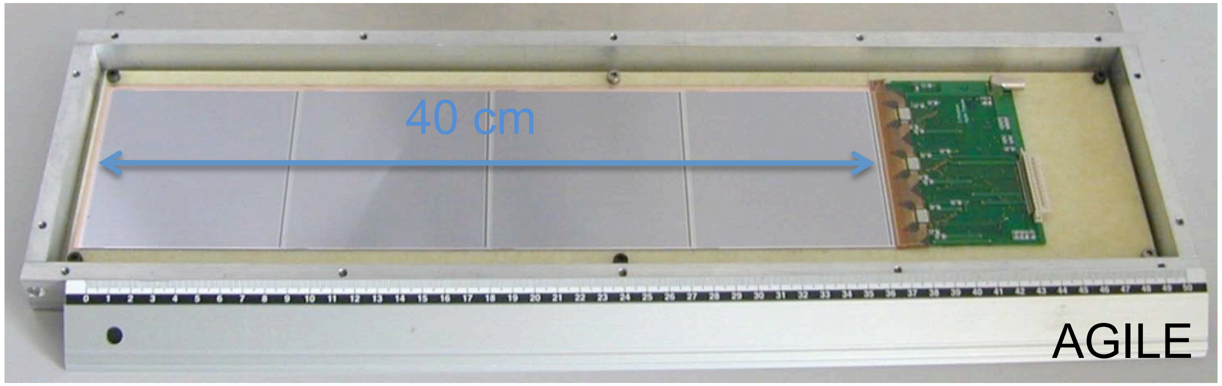




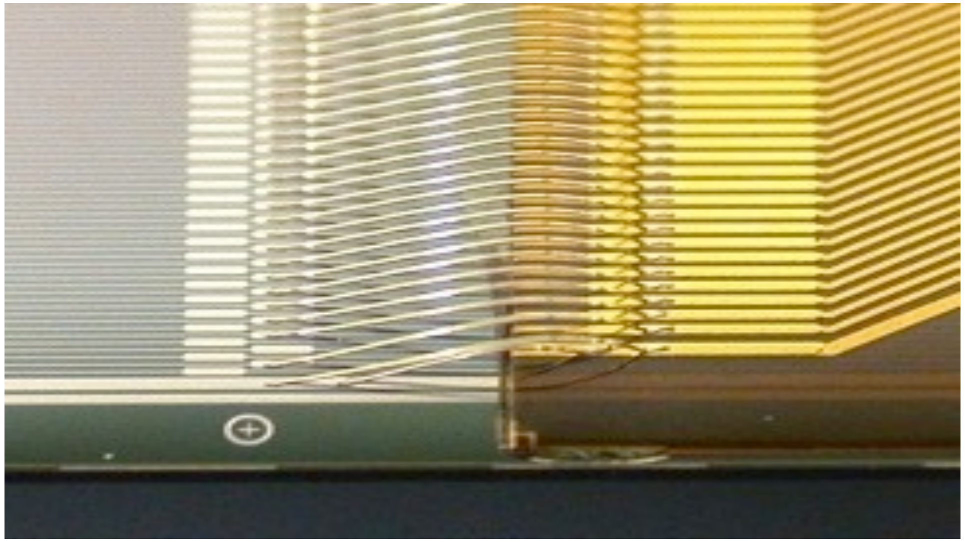
Spatial resolution:
- Strip pitch 25 – 200 μm
- Readout pitch 100 – 300 μm

Silicon ladder

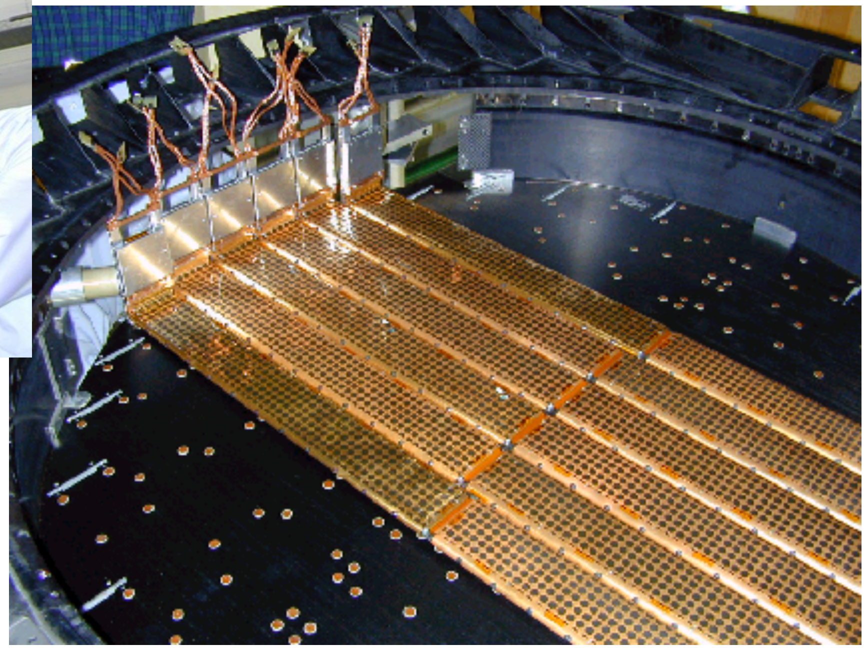




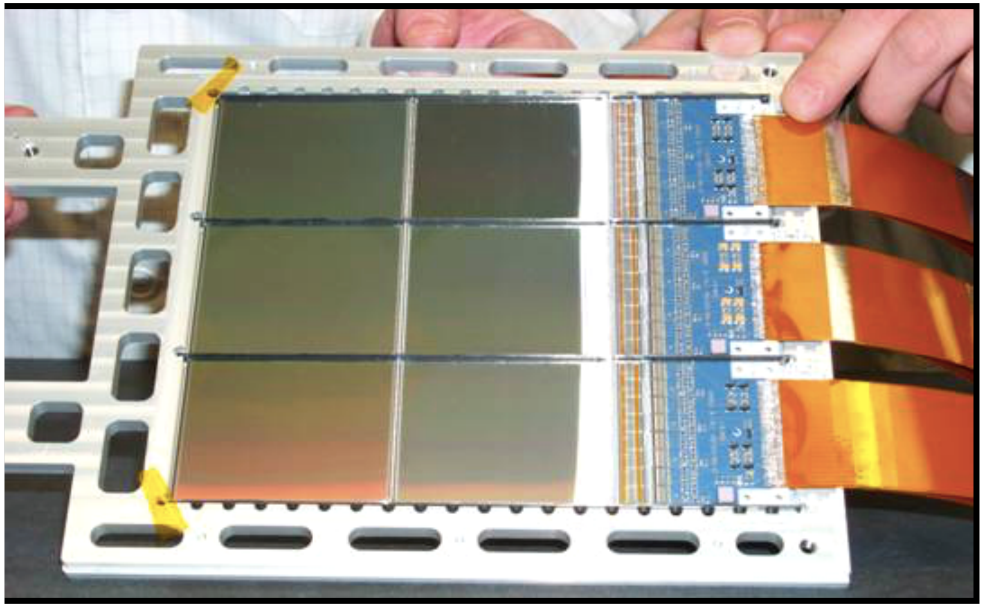
Silicon Tracker

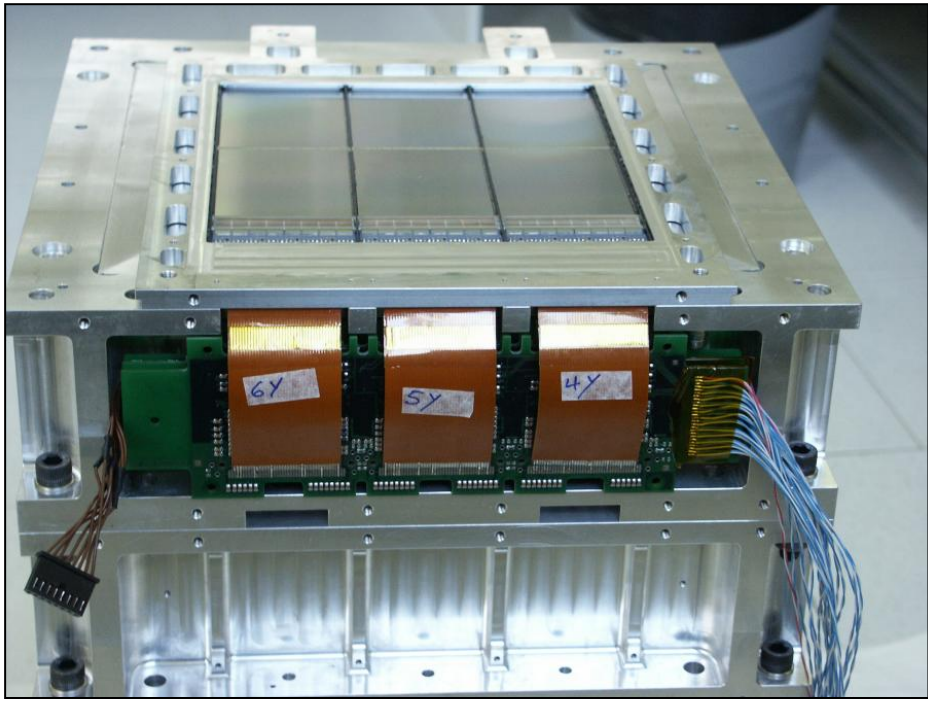


AMS-01 Silicon Tracker



PAMELA 2006





Silicon detectors with electronics

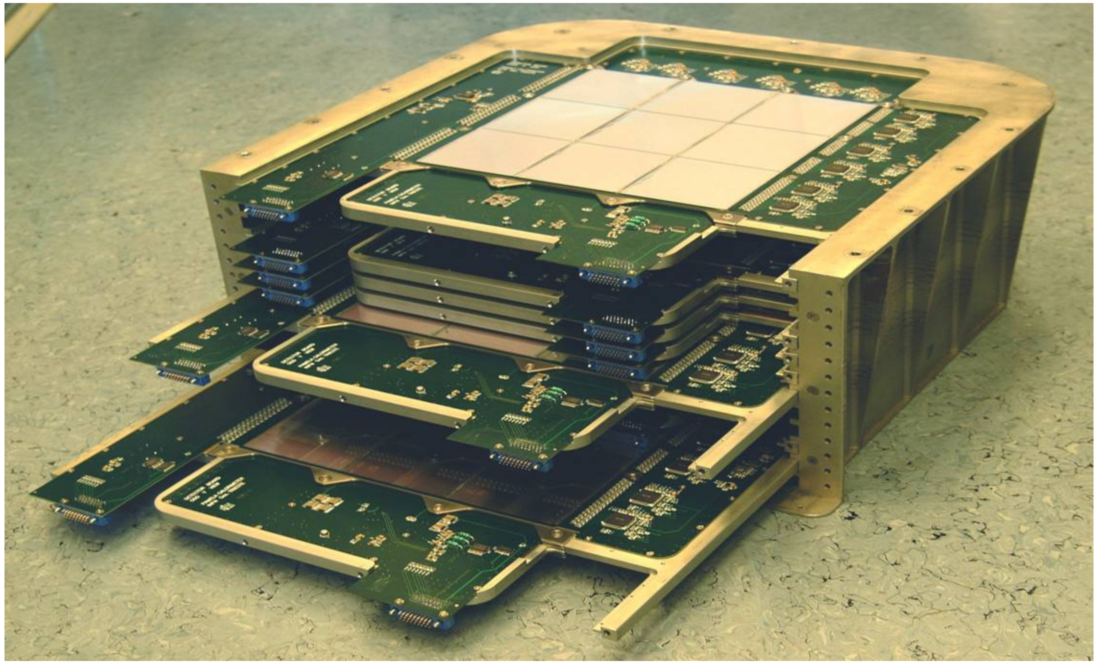
PAMELA Calorimeter

Si-W Calorimeter

- Measures energies of $e^{\pm}$.

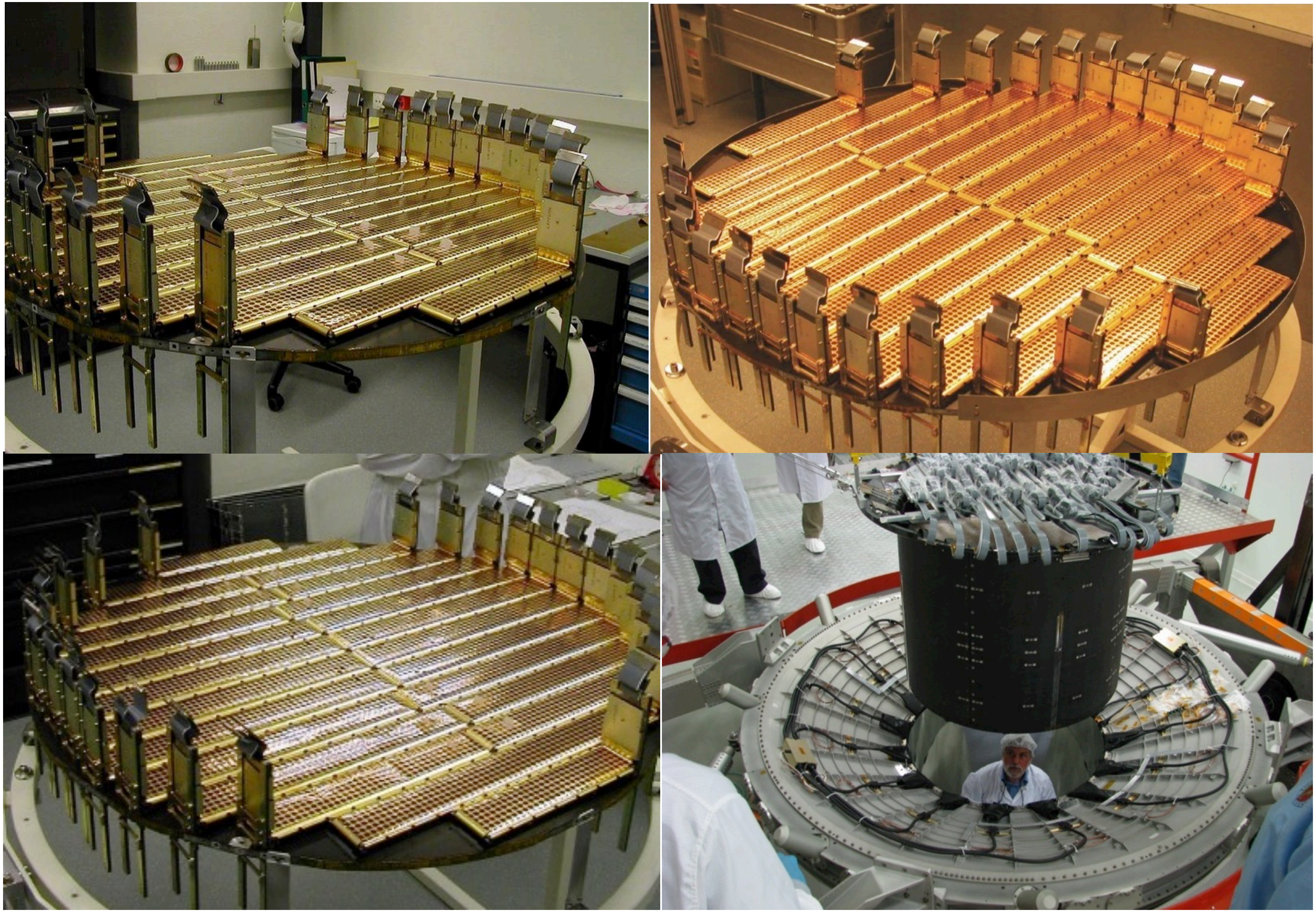
  $\Delta E/E = 15\% / E^{1/2} + 5\%$

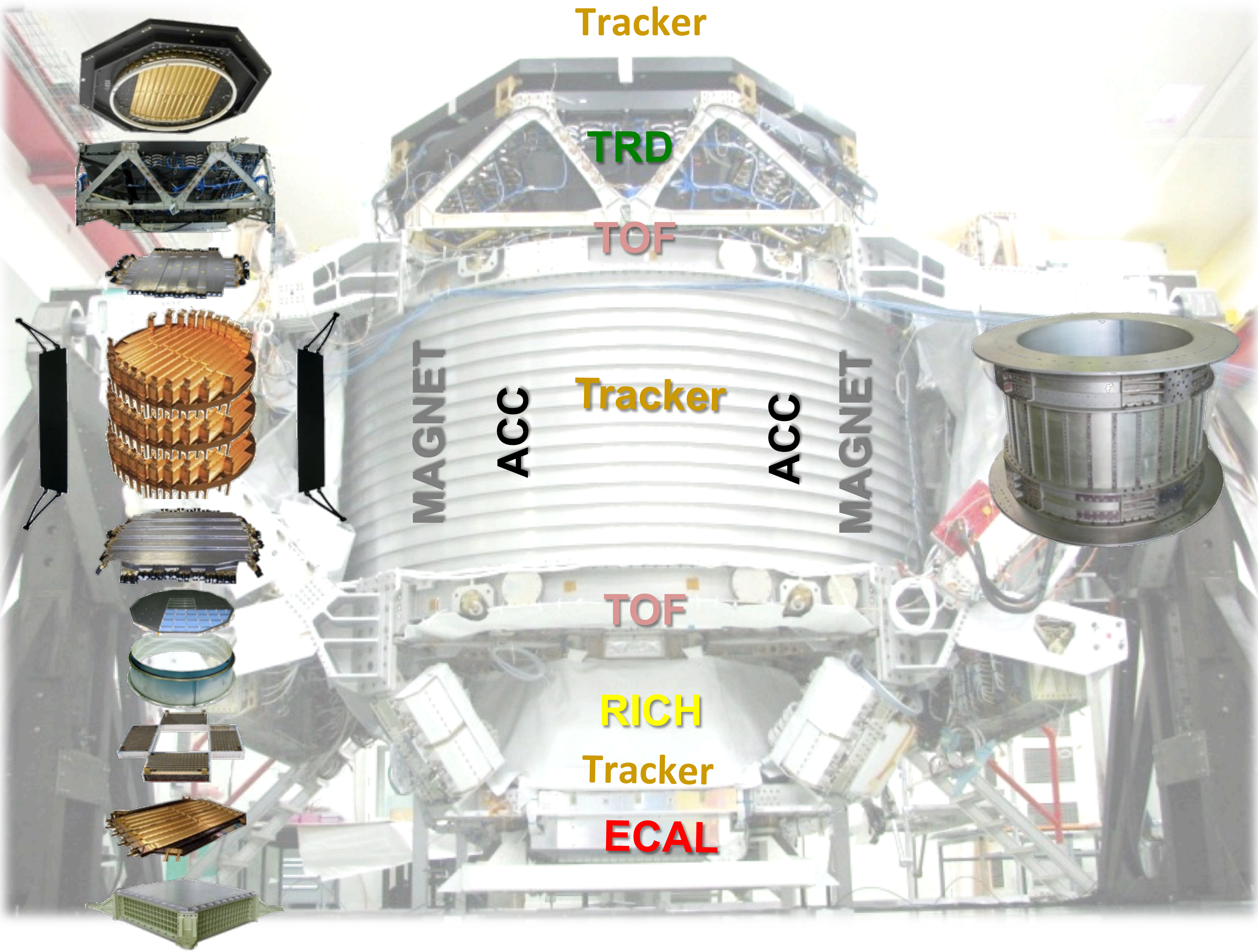
- Si-X / W / Si-Y structure.
- 22 Si / 21 W $\Rightarrow$ $16X_0$ / $0.9\lambda_0$
- Imaging: EM - vs- hadronic discrimination, longitudinal and transverse shower profile
- Total number of channels 4224
- Wide dynamic range $\cong$ 1 - 1000 MIP



Calorimeter Requirements:
- p/e^{+} selection eff. ~ 90%
- p rejection factor ~ 10^5
- e^{-} rejection factor > 10^4

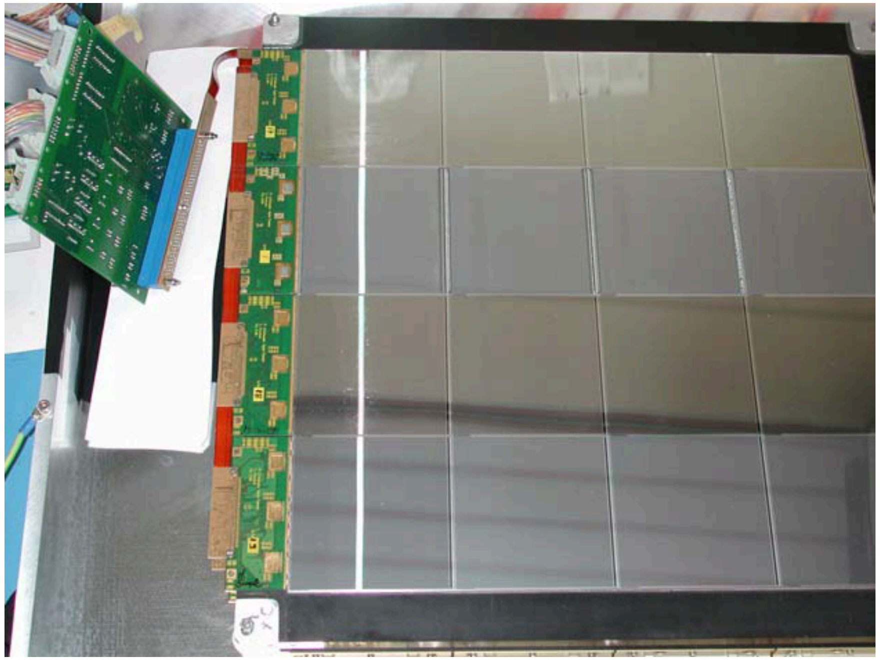
AMS-02: 9 planes with 200,000 channels aligned to 10 microns

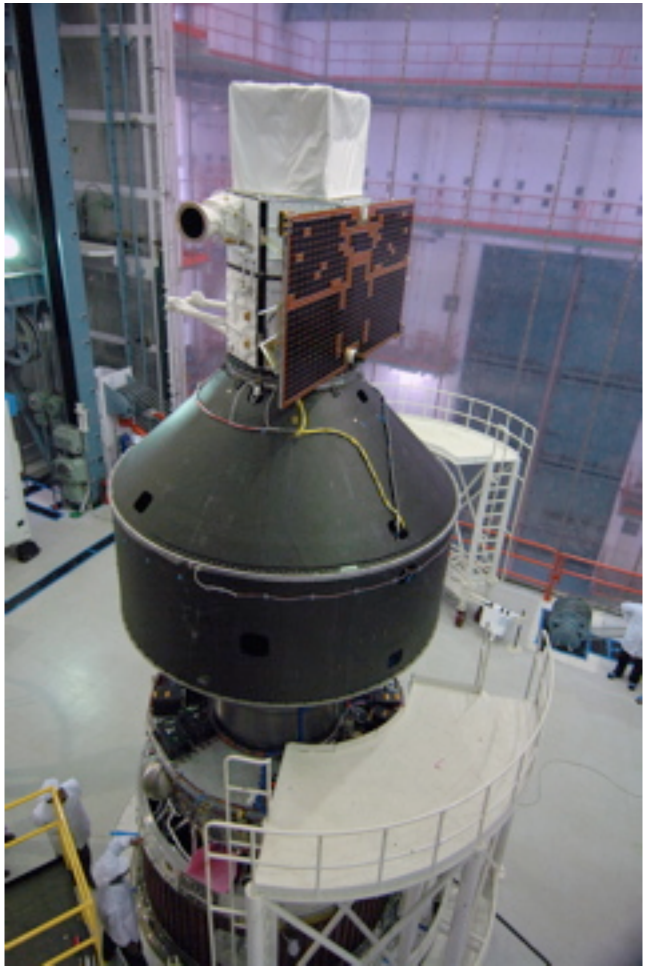




Tracker
TRD
TOF
MAGNET
ACC
Tracker
ACC
MAGNET
TOF
RICH
Tracker
ECAL

AGILE 2007

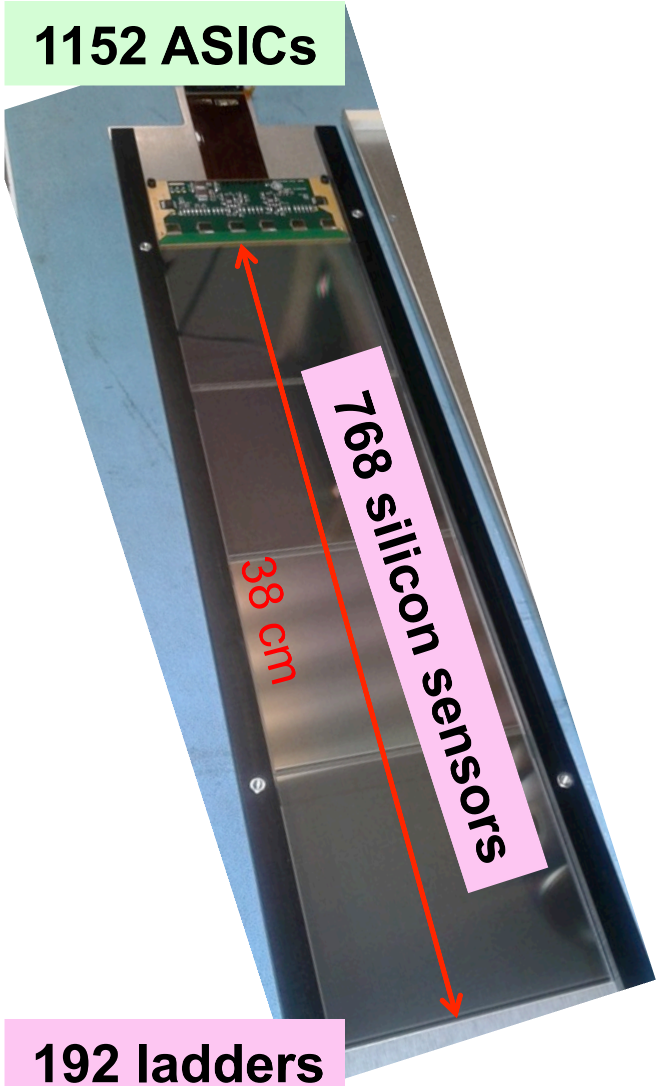




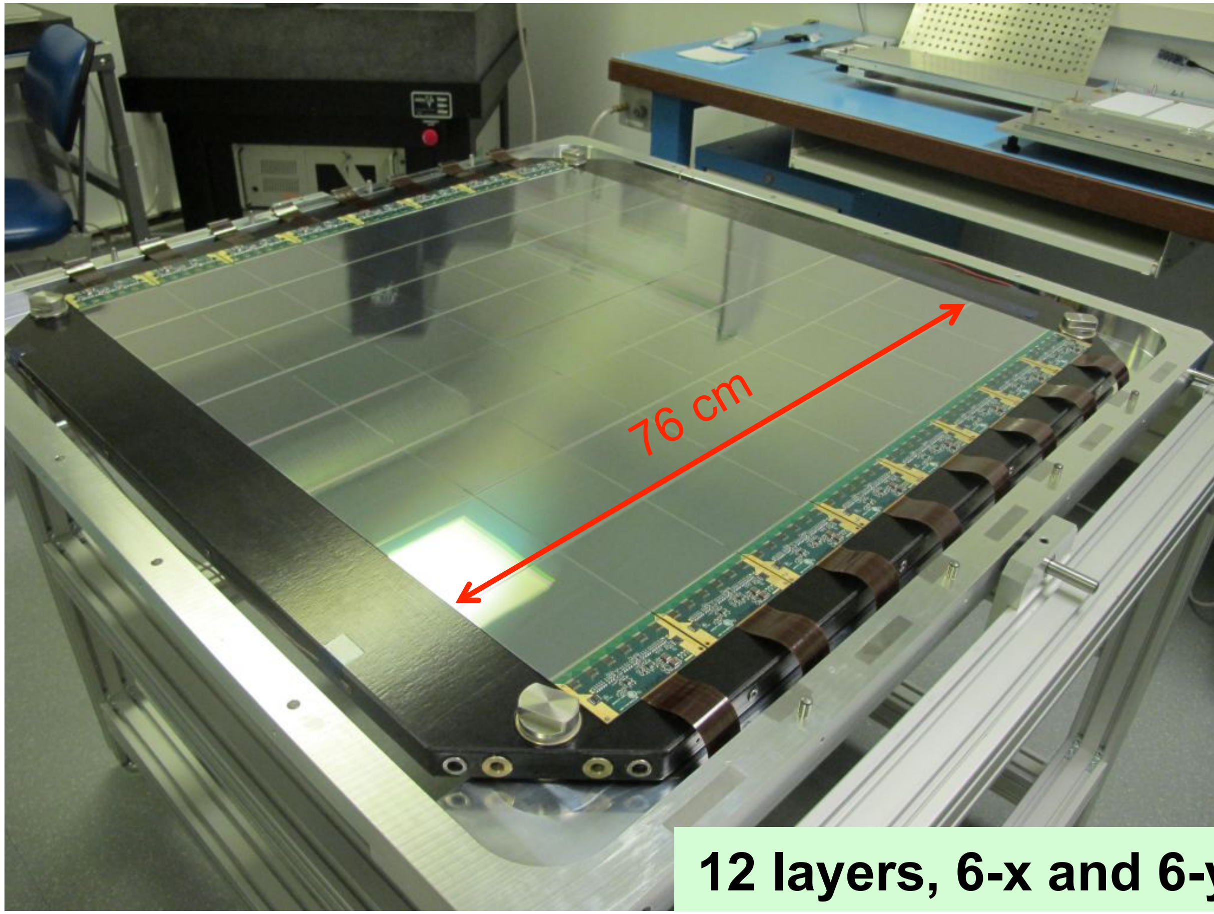
FERMI 2008

DAMPE Si Ladder and Layer

1152 ASICs



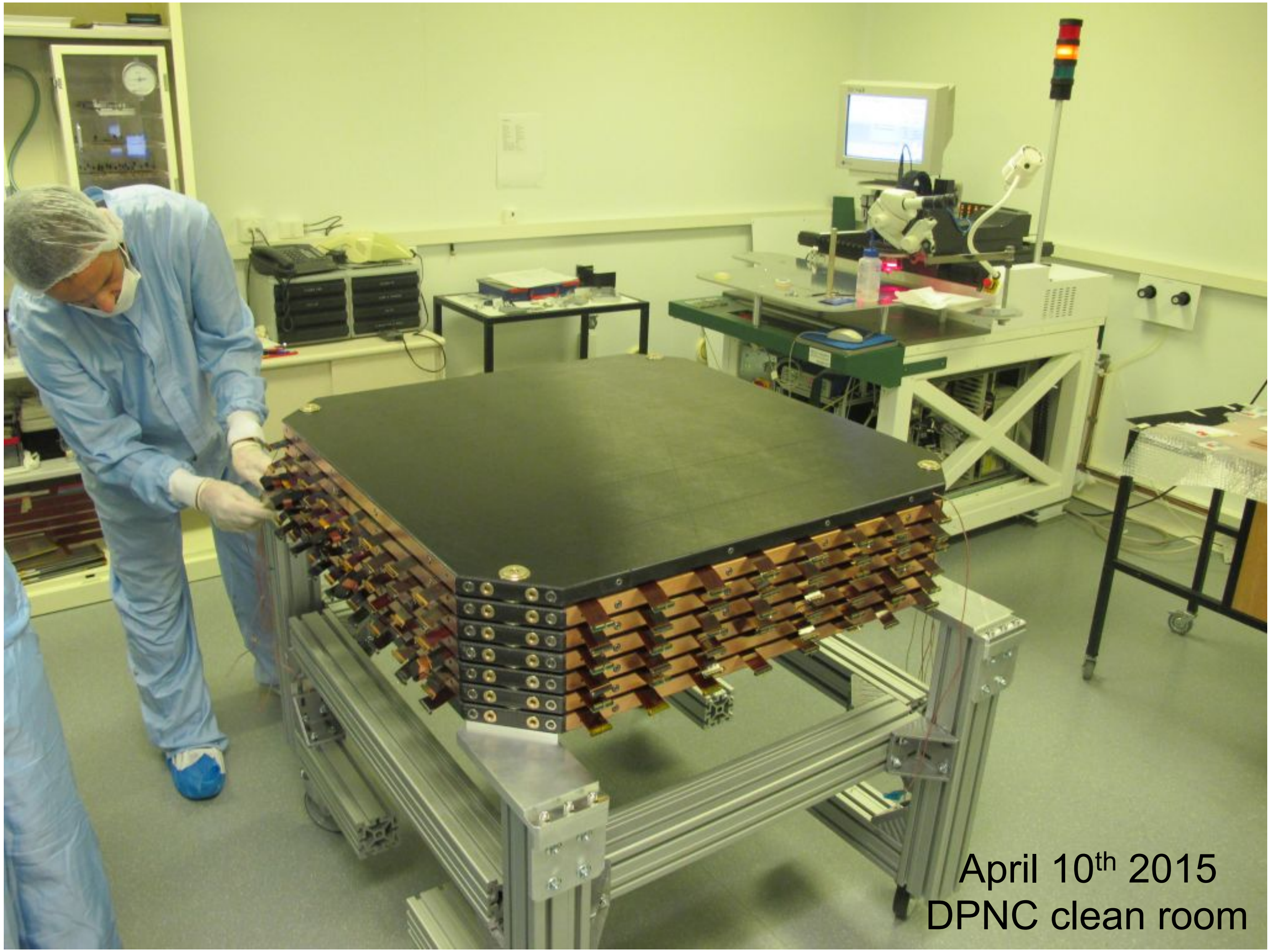
192 ladders



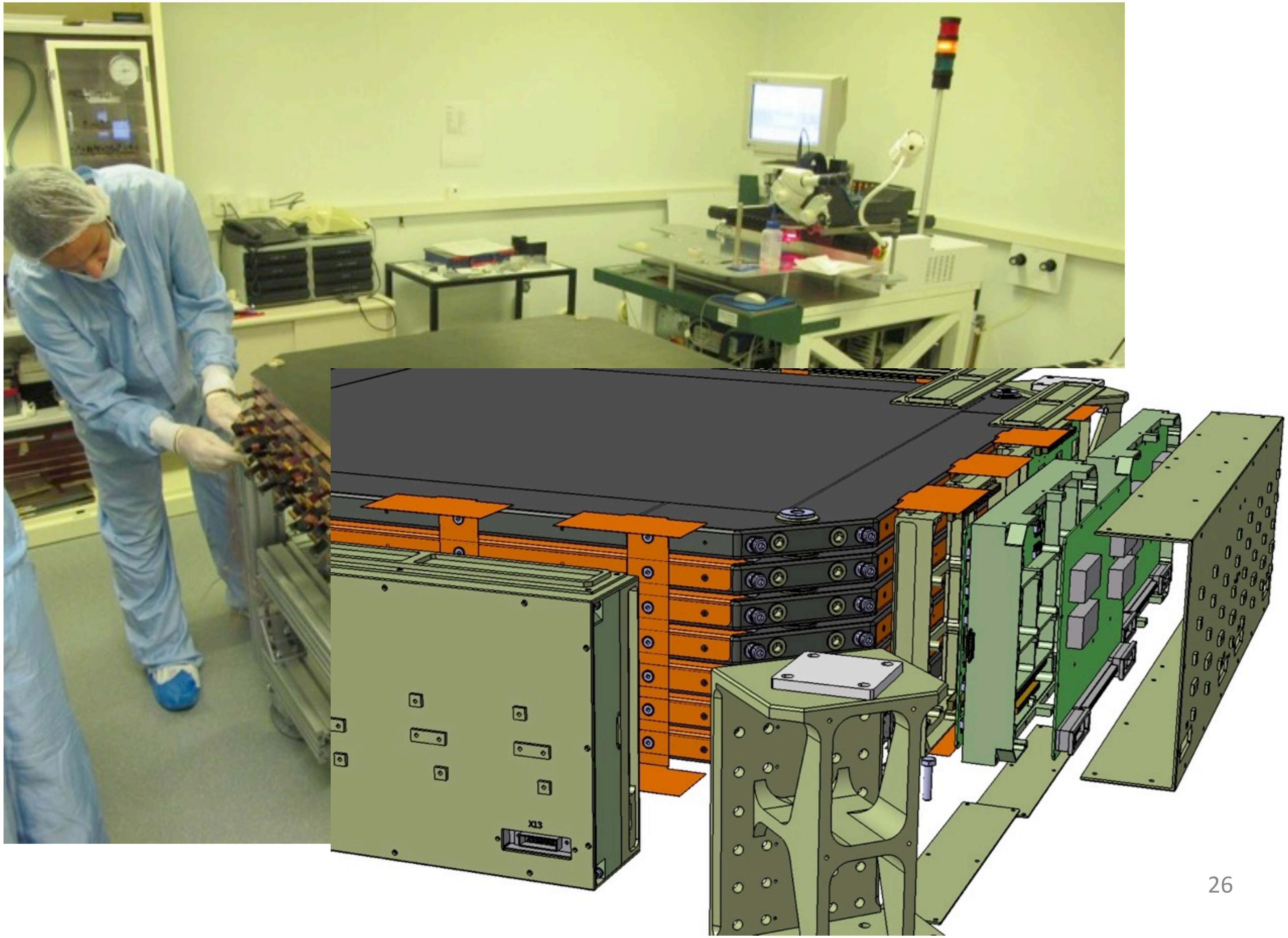
12 layers, 6-x and 6-y

73728 channels

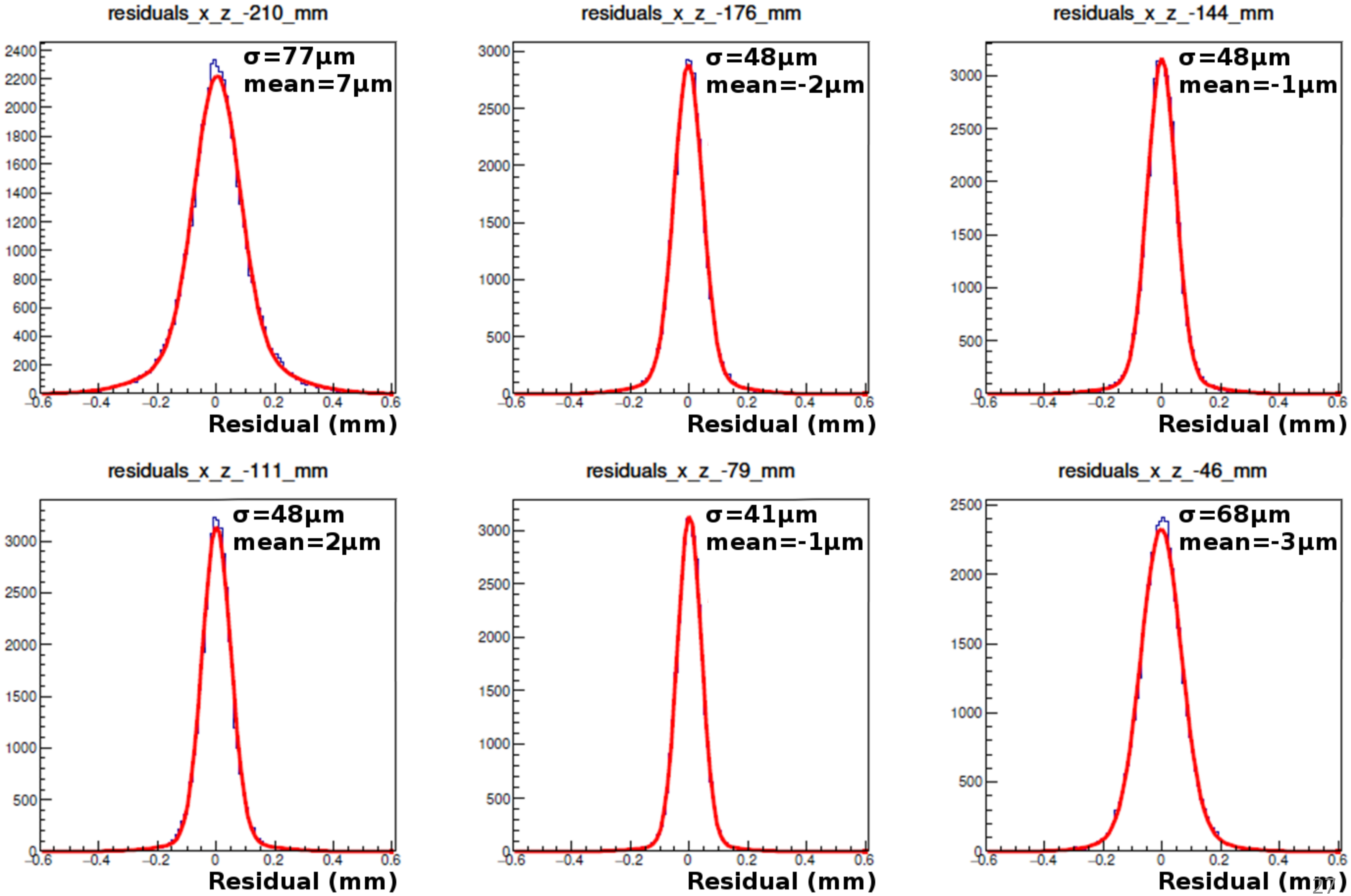
the Dampe Silicon Tracker



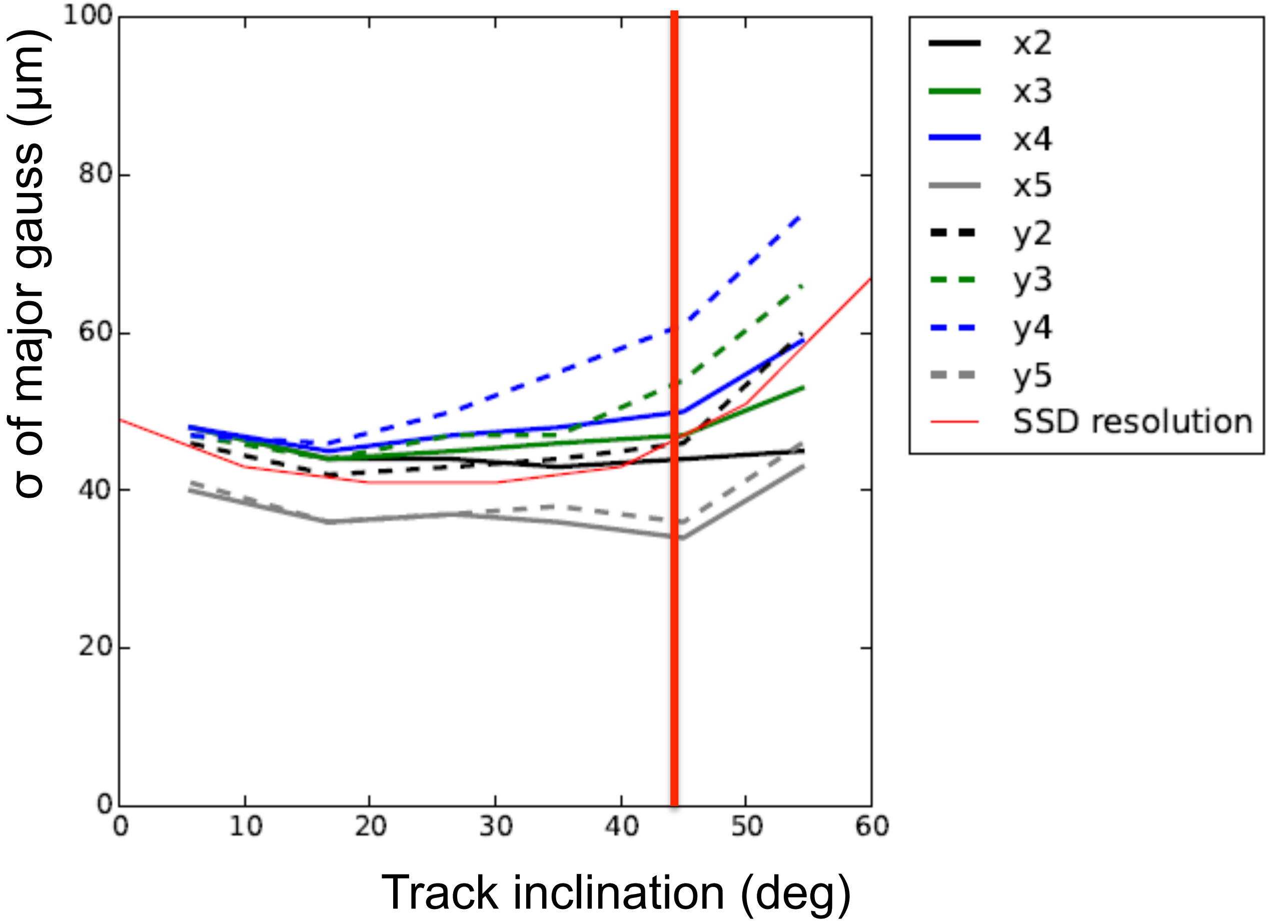
the DAMPE Silicon Tracker



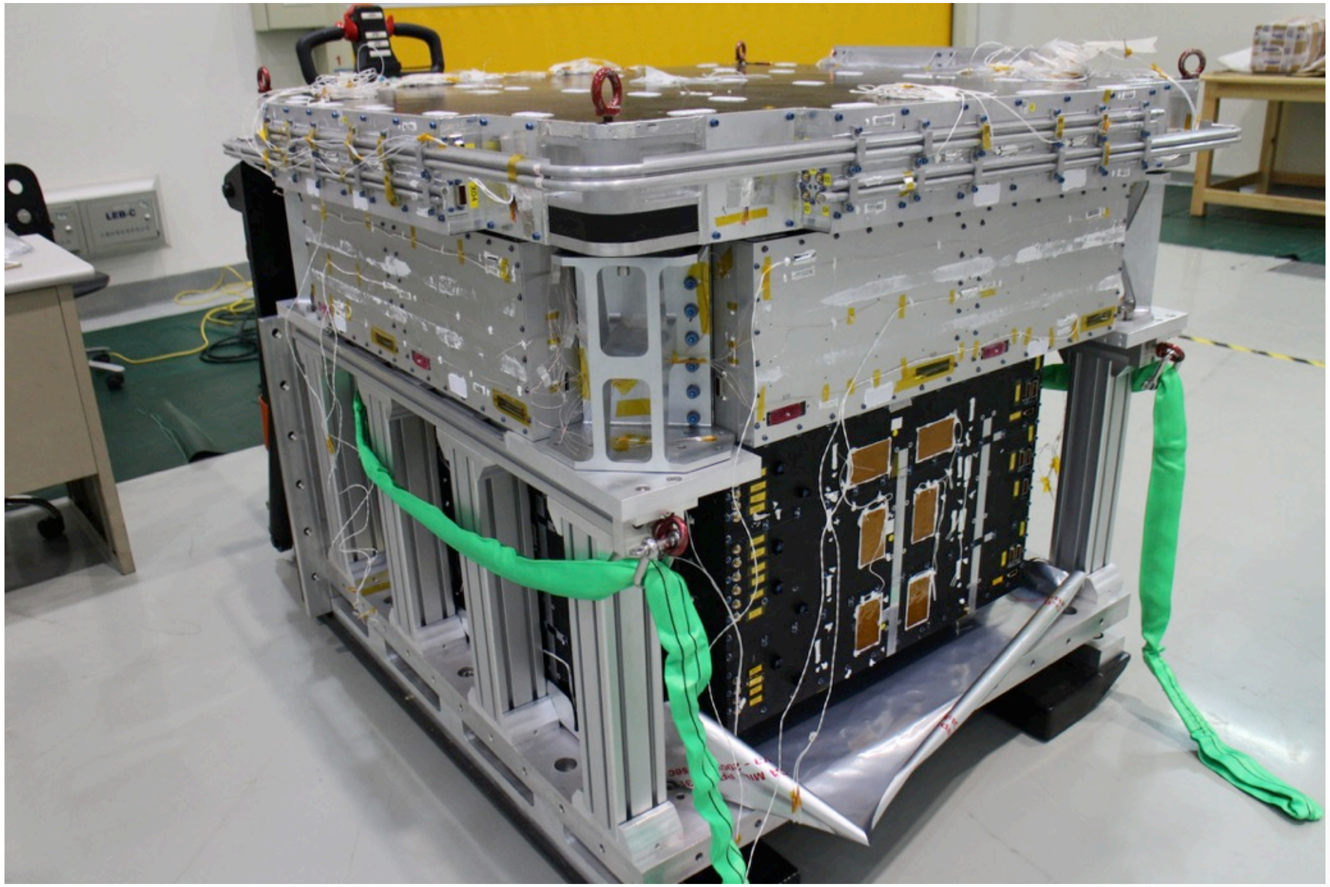
DAMPE STK resolution after alignment



DAMPE STK resolution vs angle



The DAMPE Detector



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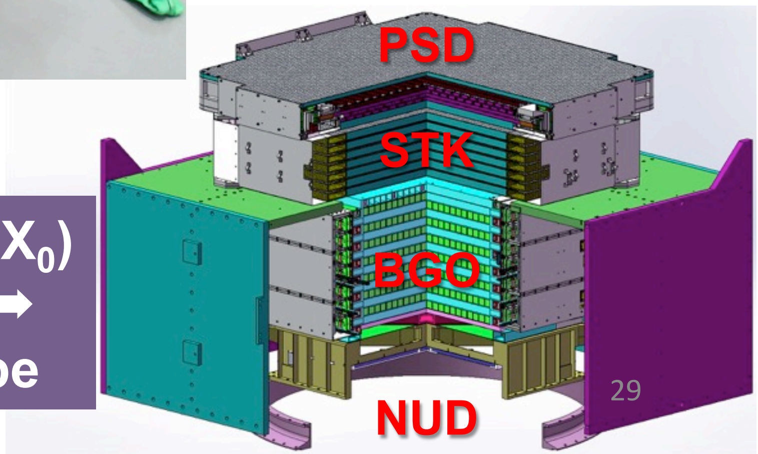
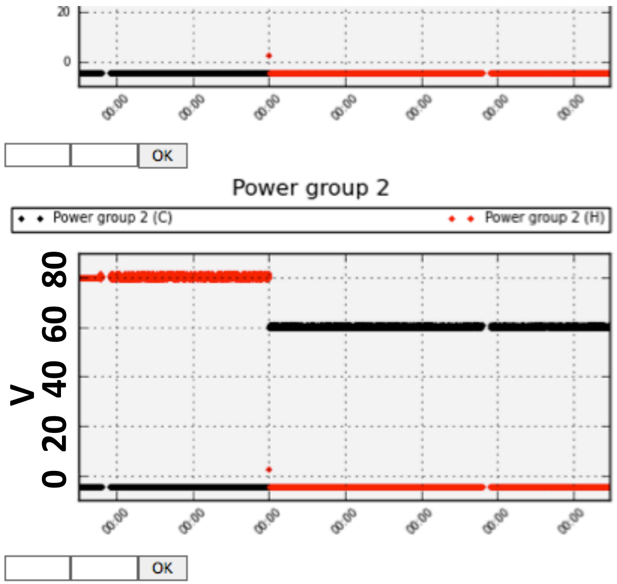
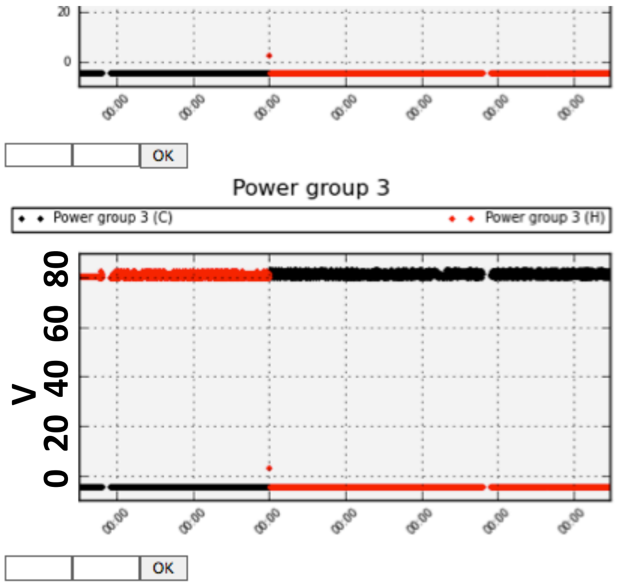
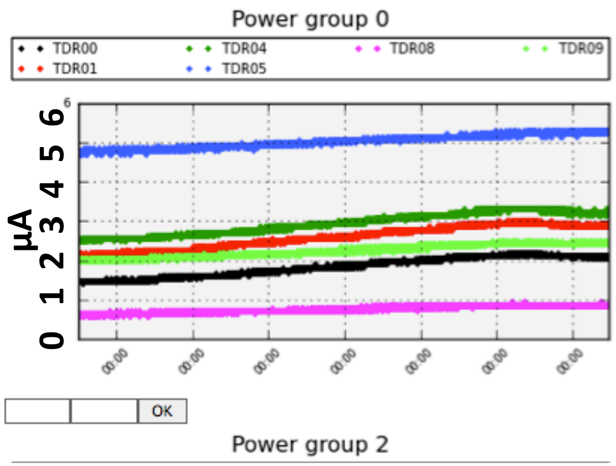


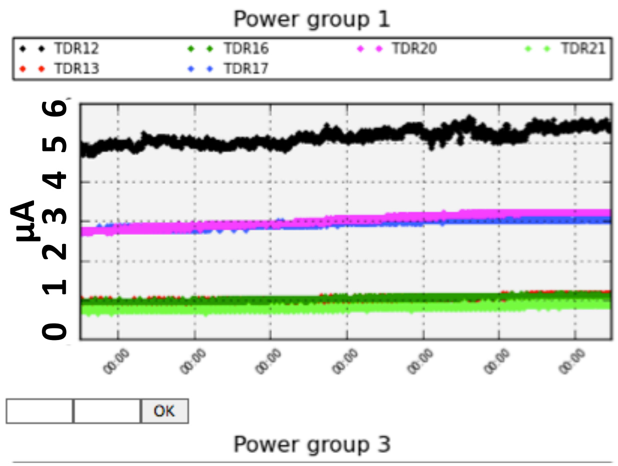
Ladder biases and currents (AMS-02)





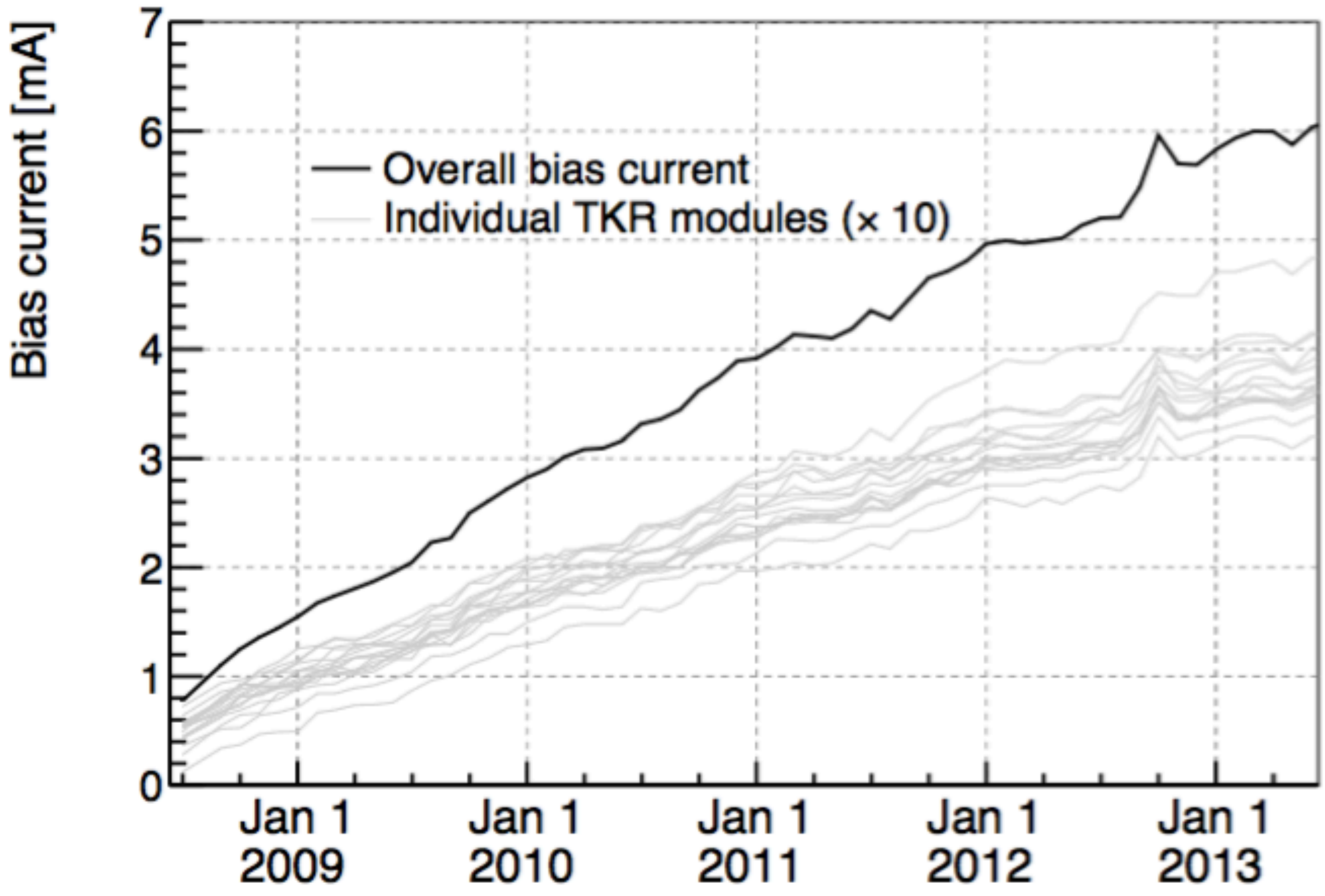
Silicon fully depleted at ~ 40V
→ nominal bias for ladder at 80V
→ possibility to operate at 60V





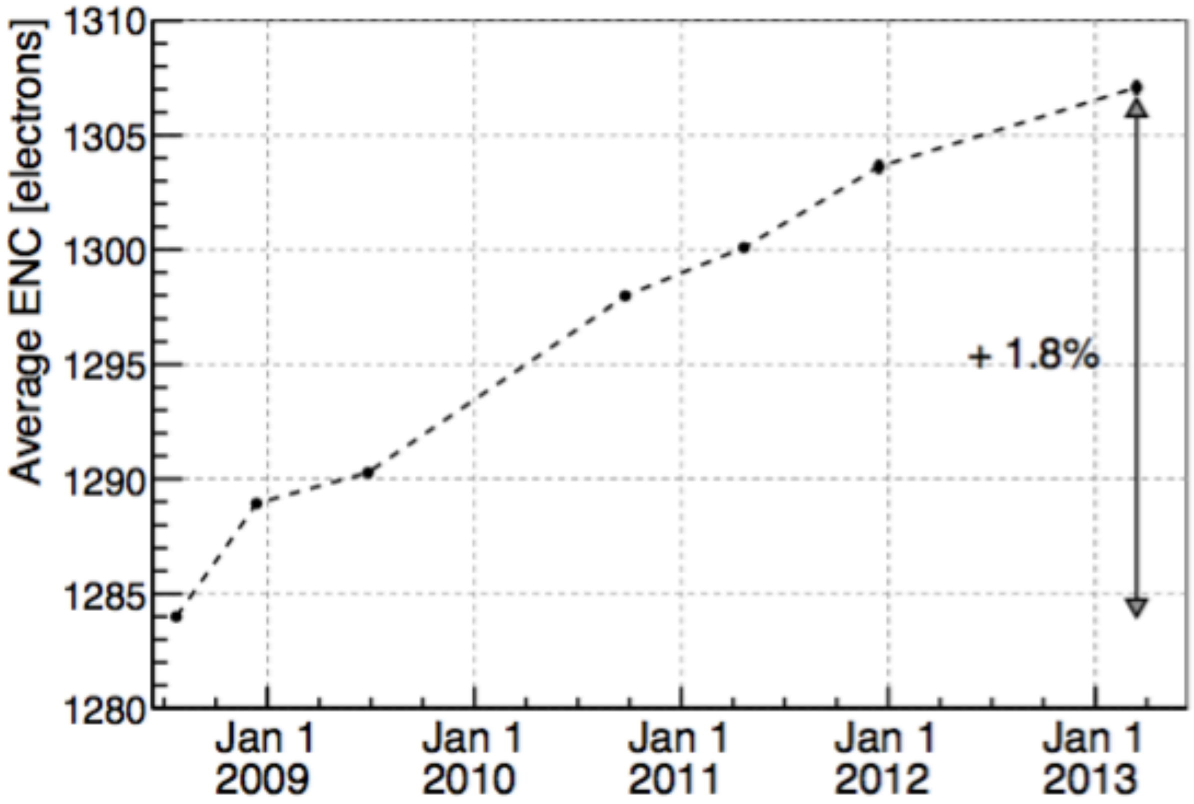
Leakage current at the level of nA per channel
→ few μA per ladder

Telemetry data trending: bias current



FERMI

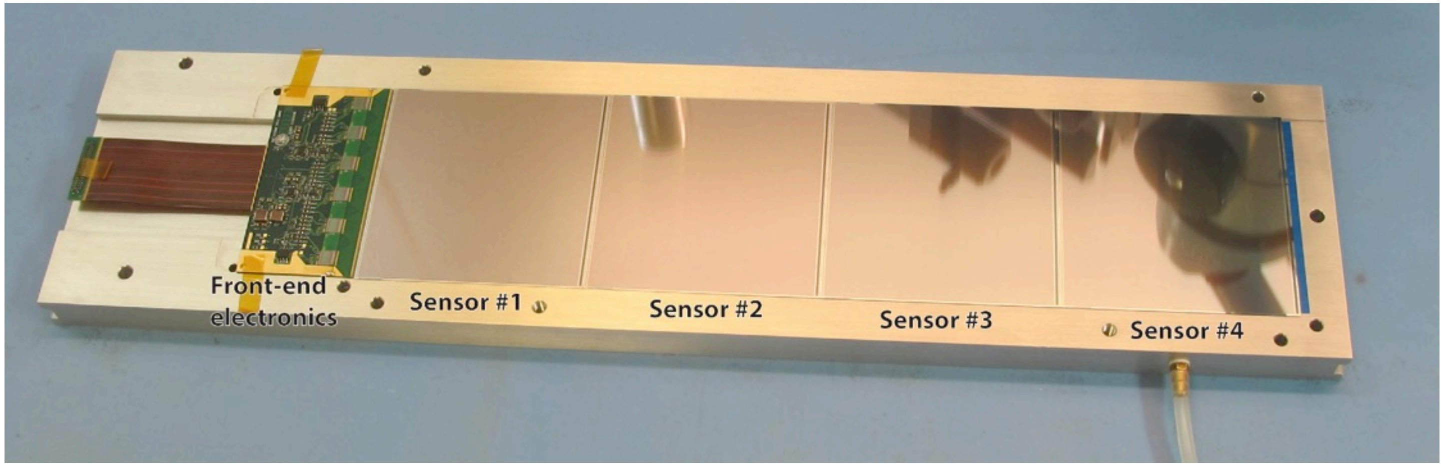
Noise trending

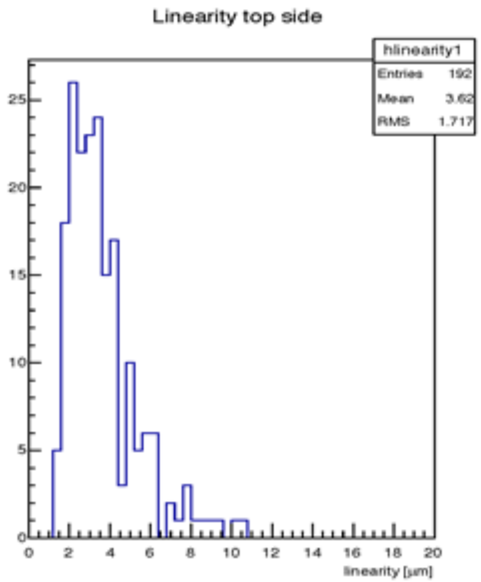


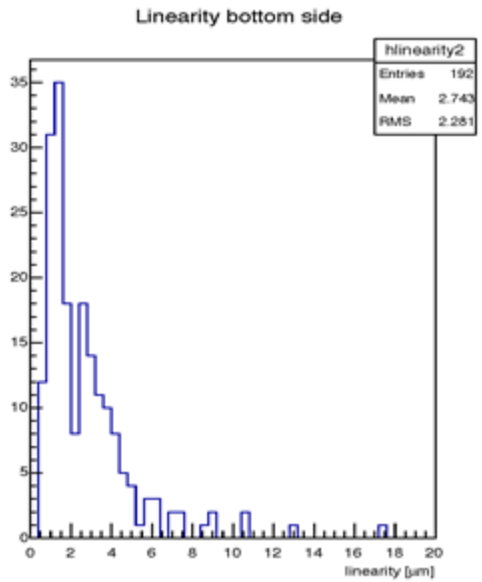
- This is roughly in agreement with what expected from the increase in the bias current from radiation damage.
  - Projects to a negligible noise increase after 10 years.

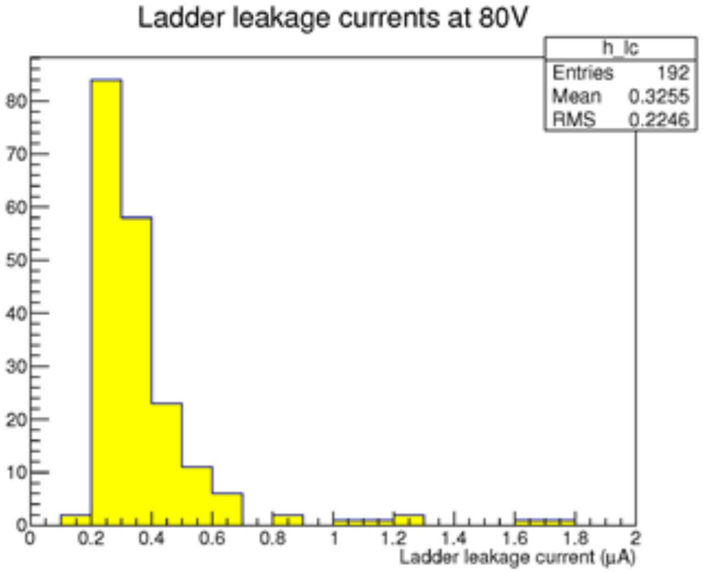
FERMI

DAMPE Silicon Ladders









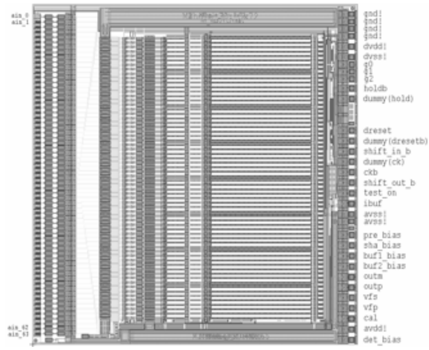
- **Alignment precision required: 20 μm**
- **97% of ladders < 10 μm**

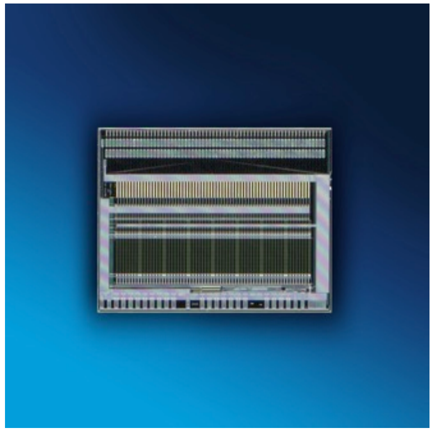
Total leakage current for the 192 installed ladders is excellent

Readout ASICs

- Use updated version of the ASIC used by AMS-02: VA64HDR9a → VA140
  - By Gamma Medica-Ideas (Oslo), 0.35 µm (was 0.8) CMOS technology
  - Improved performance in noise, power and radiation tolerance

Parameter	VA64HDR9A	VA140
Noise, Cd=0pF (eRMS)	290	100
Noise, Cd=50pF (eRMS)	520	430
Noise, Cd=100pF (eRMS)	810	780
DNR	+100fC,-200fC	±200fC
Linearity ± 72fC		
Negative:	±6%	±2%
Positive:	±12%	±5.5%
Power cons. (mW/channel)	0.8	0.29
Peaking time (µs)	4.5	7.5





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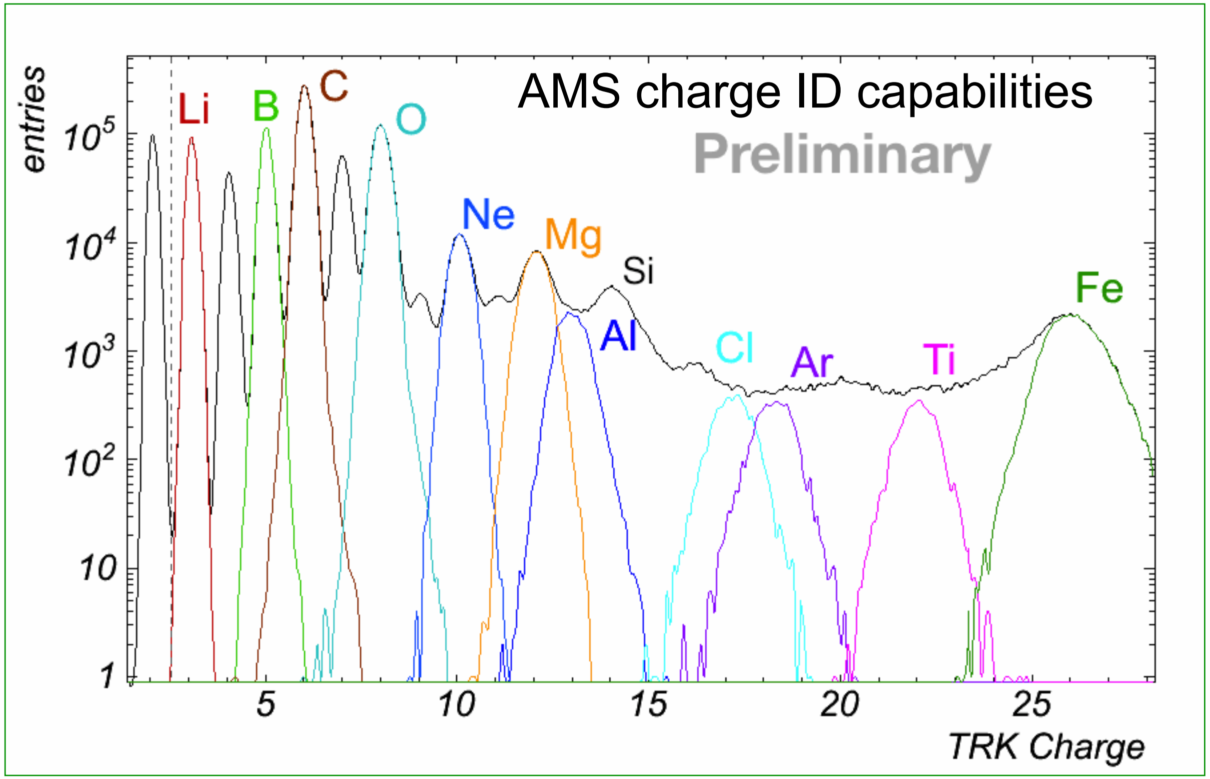
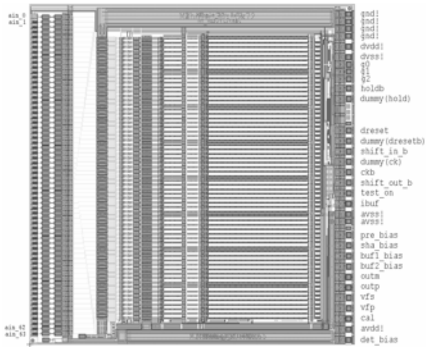
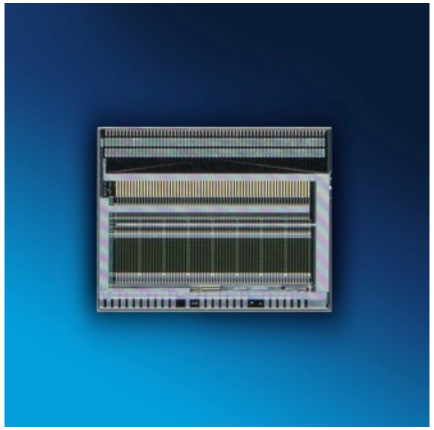
  - Improved performance in noise, power and radiation tolerance
  - 10 chips already available in Perugia







Radiation 'hard' electronics

The problem are the SEE (Single Event Effect)

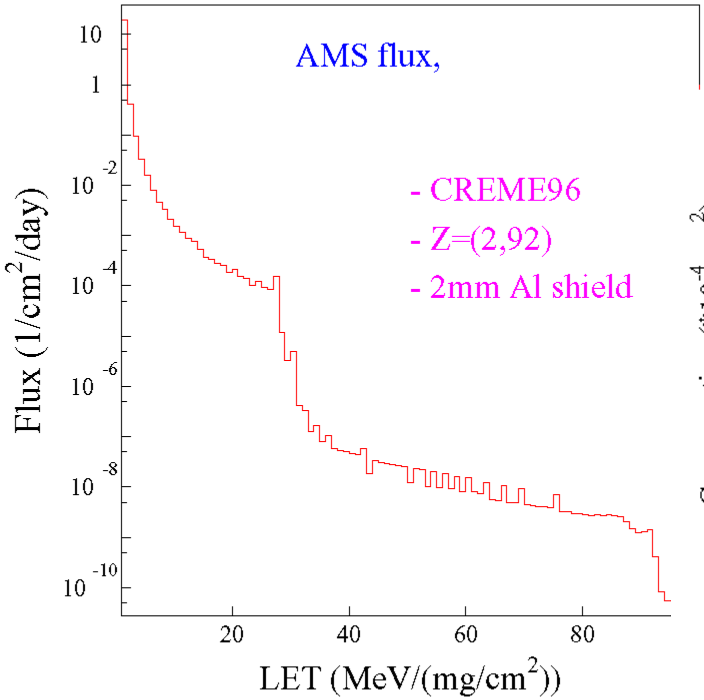


Figure 5: Expected fluxes on ISS in 2003.

Example: AMS-02 Tracker front end chip

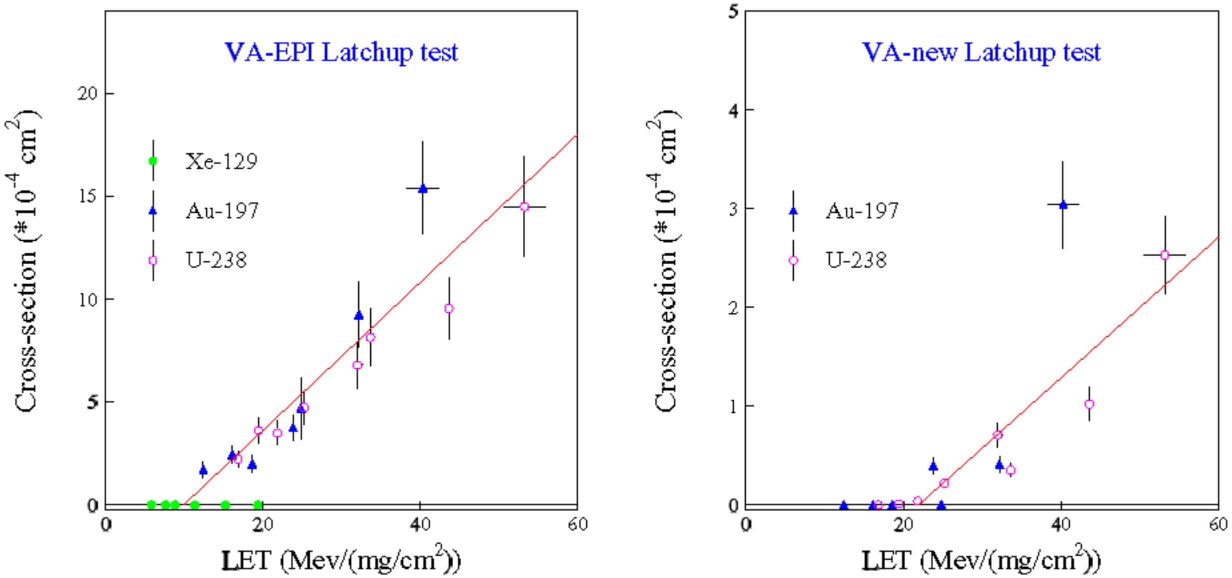
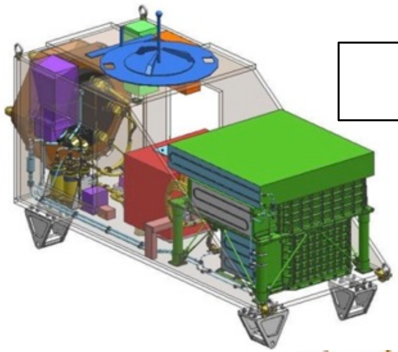


Figure 12: The new VA – SEL rates as measured in GSI

similar test on all active components

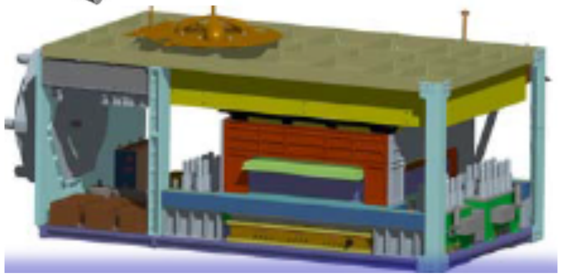
current limit protection is present for all active components

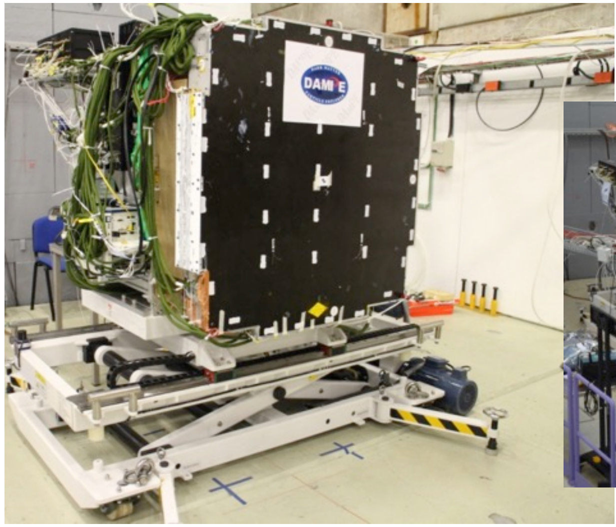
Current and Future projects (space)



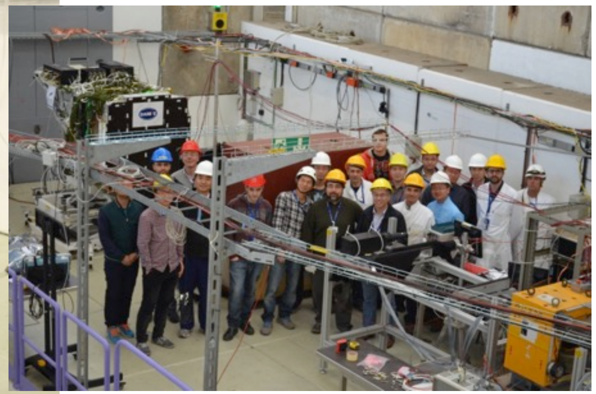
CALET

ISS_CREAM

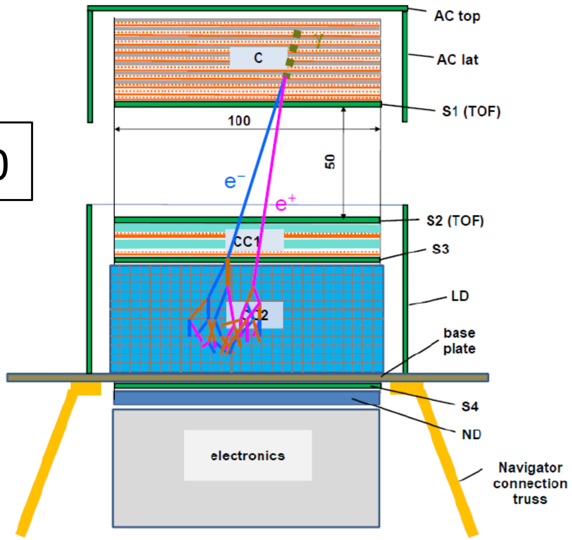




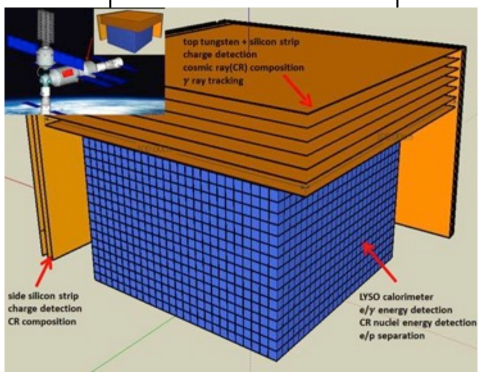
DAMPE



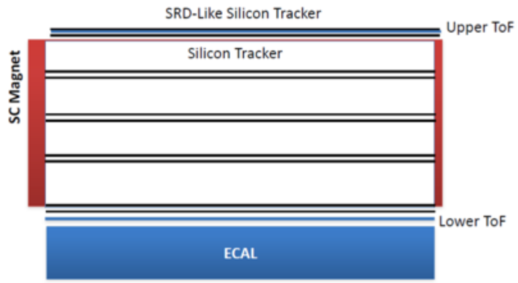
Gamma-400



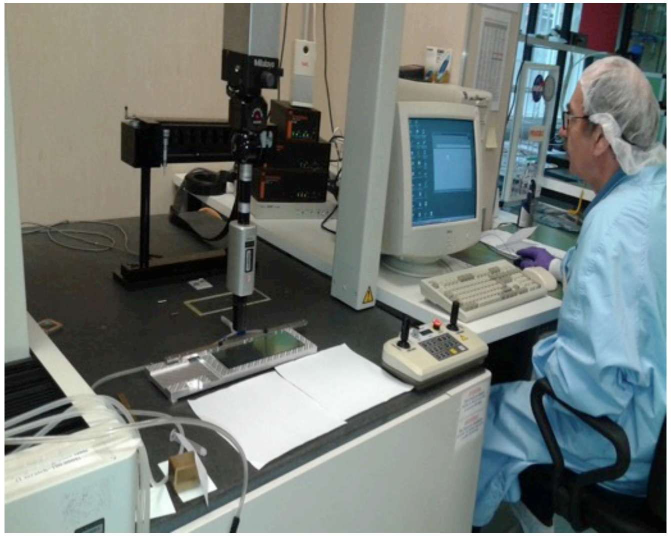
HERD

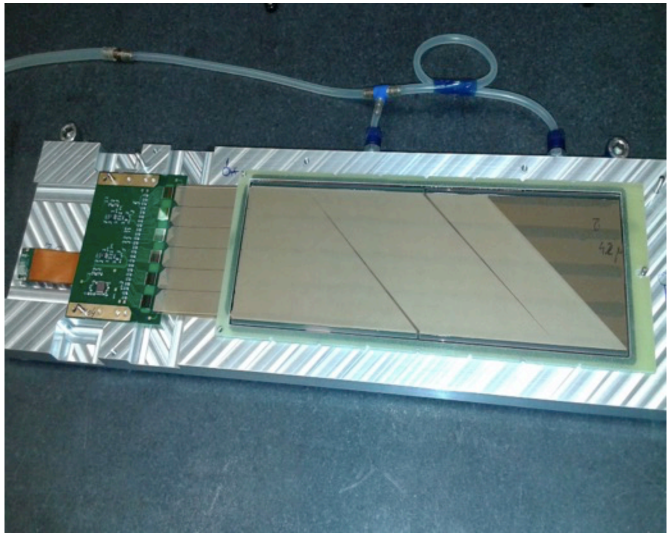


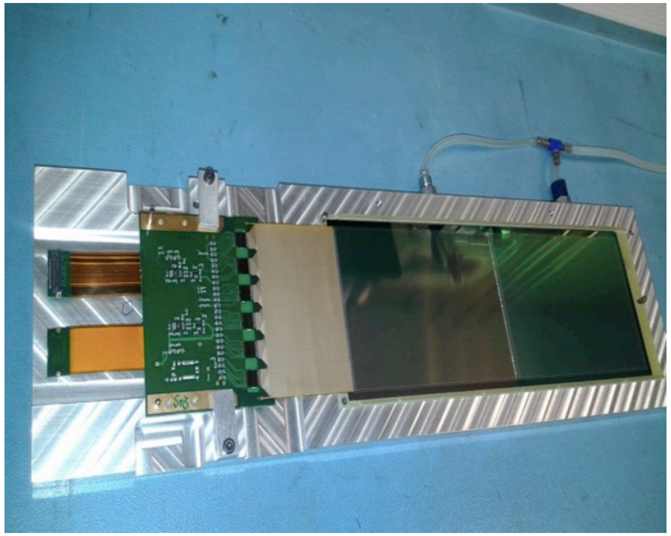
AMS-03



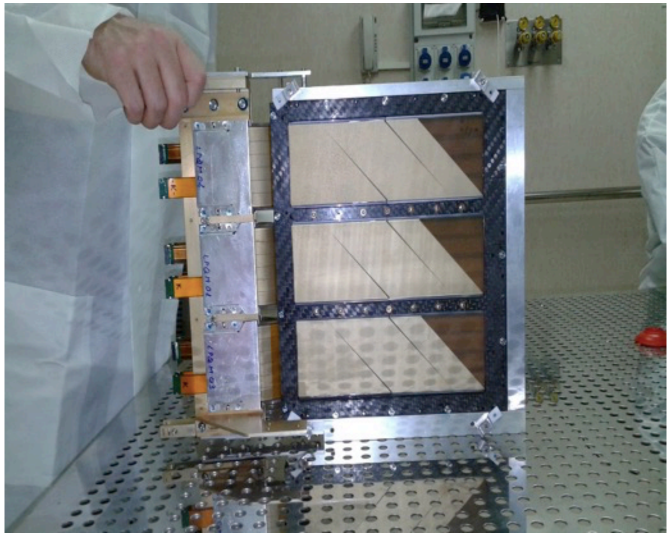
LIMADOU

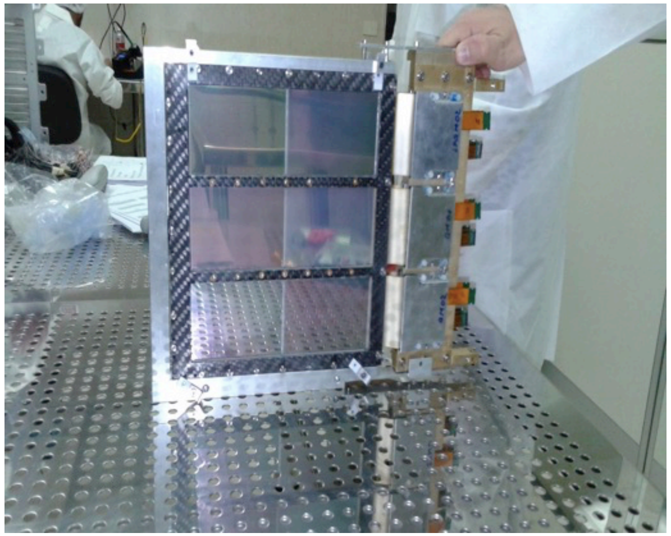






LIMADOU





Conclusions

- In space applications there is a massive use of 'old technology'
- Silicon Strips Detector fulfill the requirements of particle detector in space (Low Earth Orbit)
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- Opportunities for new technologies in the photon detection (X-rays, bolometers)

- New technologies open opportunity for new physics

- It is (not) difficult to put HEP detectors in space