Silicon detectors in space: story of a success

OUTLINE

- *Why silicon?*
- *What for?*
- *A brief history of silicon in space*
- *The major silicon-based scientific payloads: from anti-matter to gamma-ray astrophysics*
- *A silicon-based detector for space: from the design to the final integration*
- *The future of silicon in space*

If you think silicon, you think →

- ✓ Optimum spatial resolution
- ✓ Good energy resolution
- ✓ Good timing capabilities
- ✓ Reasonable density
- ✓ No HV and gas
- ✓ Optimum matching with VLSI electronics

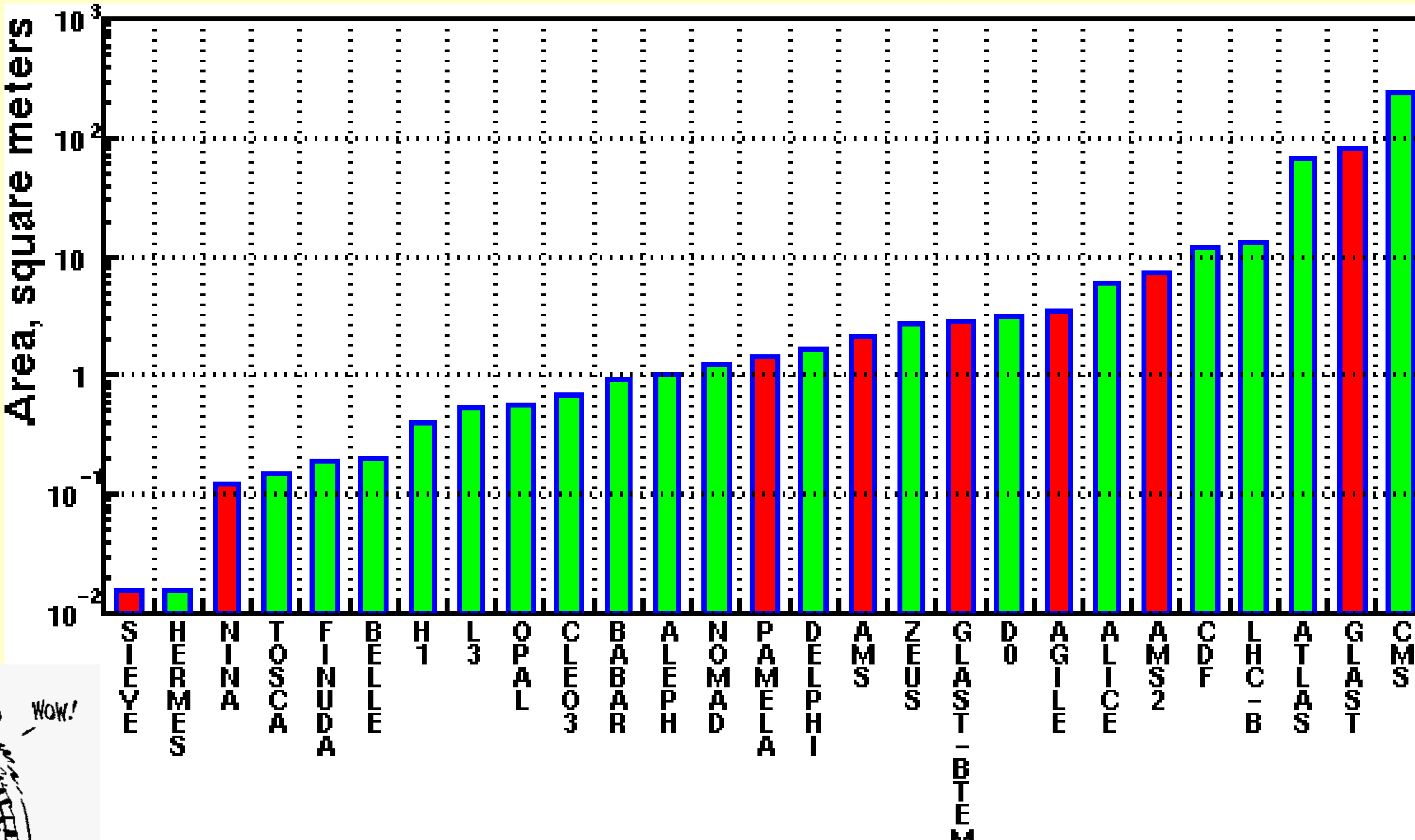
- ✗ No primary charge amplification → low noise high cost amplifiers
- ✗ Expensive
- ✗ Sophisticated and dedicated assembly and test tools
- ✗ Delicate

If you think space, you think →

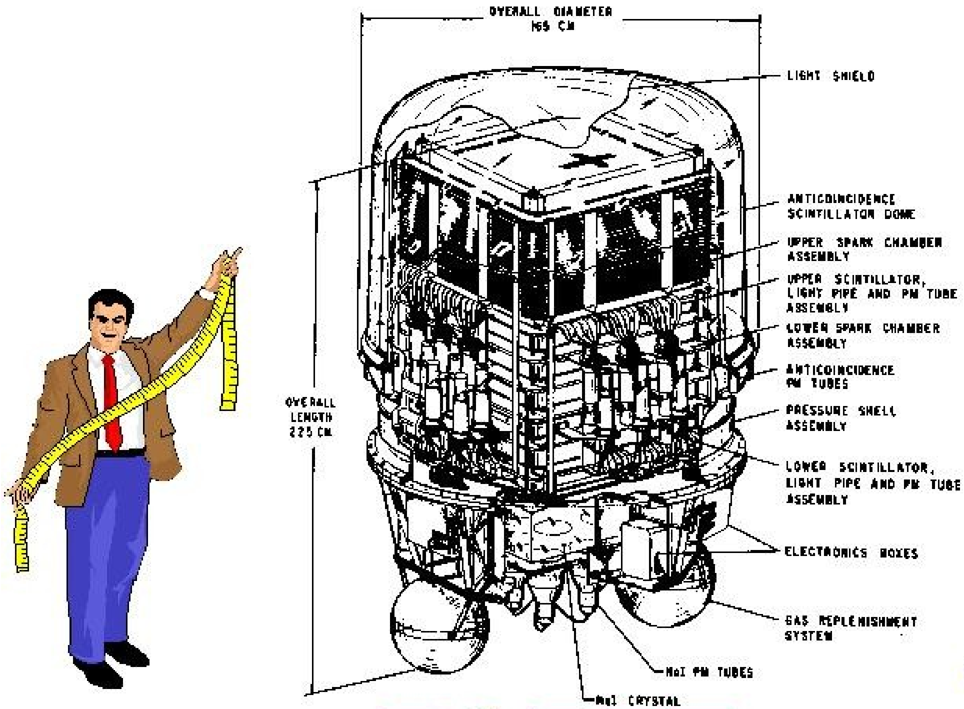
- Fail-proof technology
- Long life
- Resistance in a very hostile thermo-mechanical environment
- Resistance in a hostile radiation environment
- Integration (small weight + small volume → lower launcher cost!)
- Limited power
- Good spatial resolution
- Good timing resolution (burst events!)
- Low deadtime

LOT OF MONEY ....

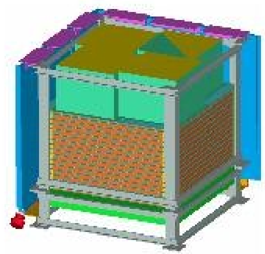
Silicon in space: past, present and near future



Silicon in space: why? Take an example



EGRET



AGILE

- No gas
- Lighter
- Integration
- Low deadtime
- Better performance

Why not?

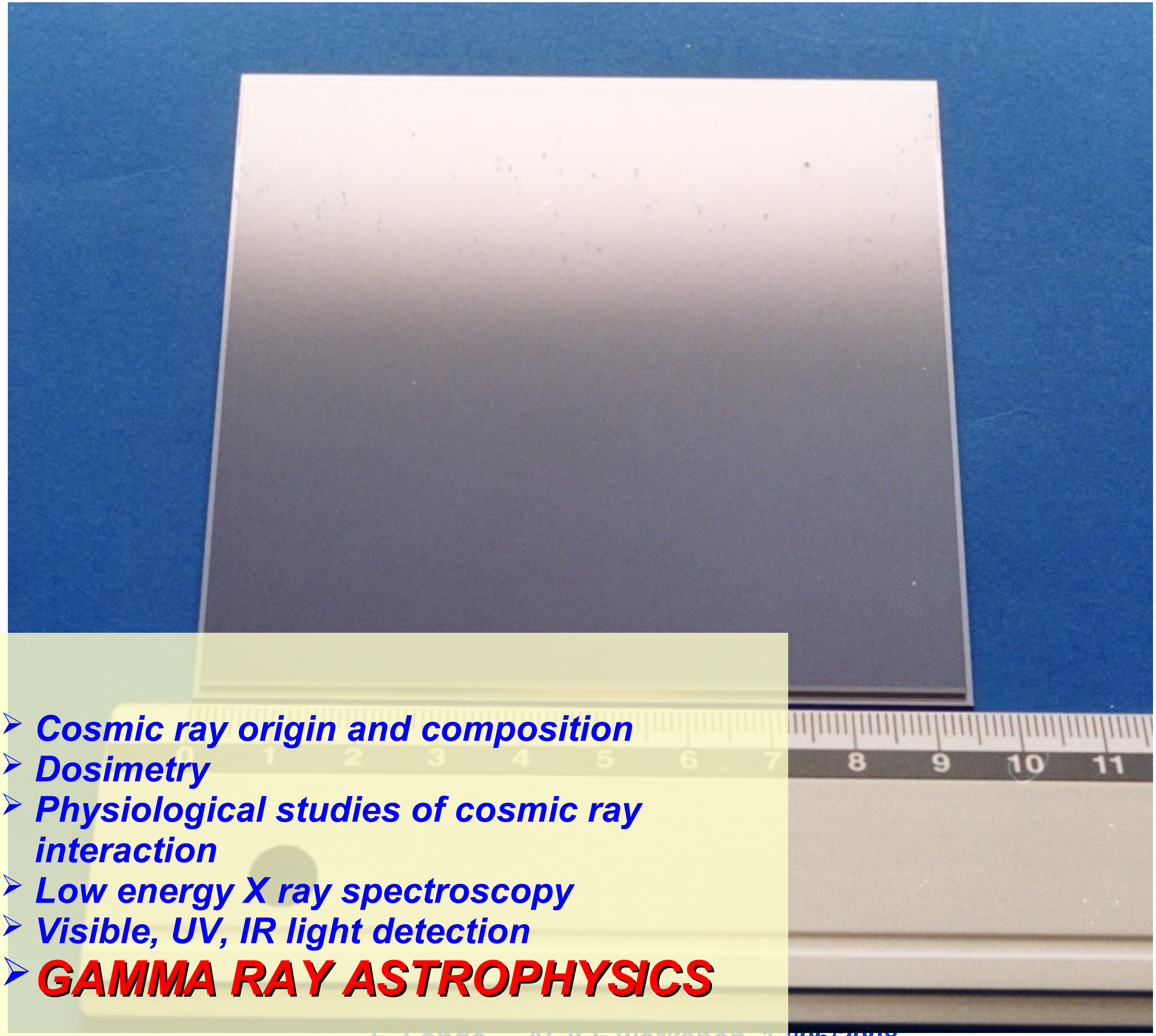
EGRET

✓ Weight	1830 kg
✓ Energy range	30 MeV - 30 GeV
✓ Field of view	0.5 sr
✓ Angular res.	≤1°
✓ Deadtime	≥100 ms

AGILE

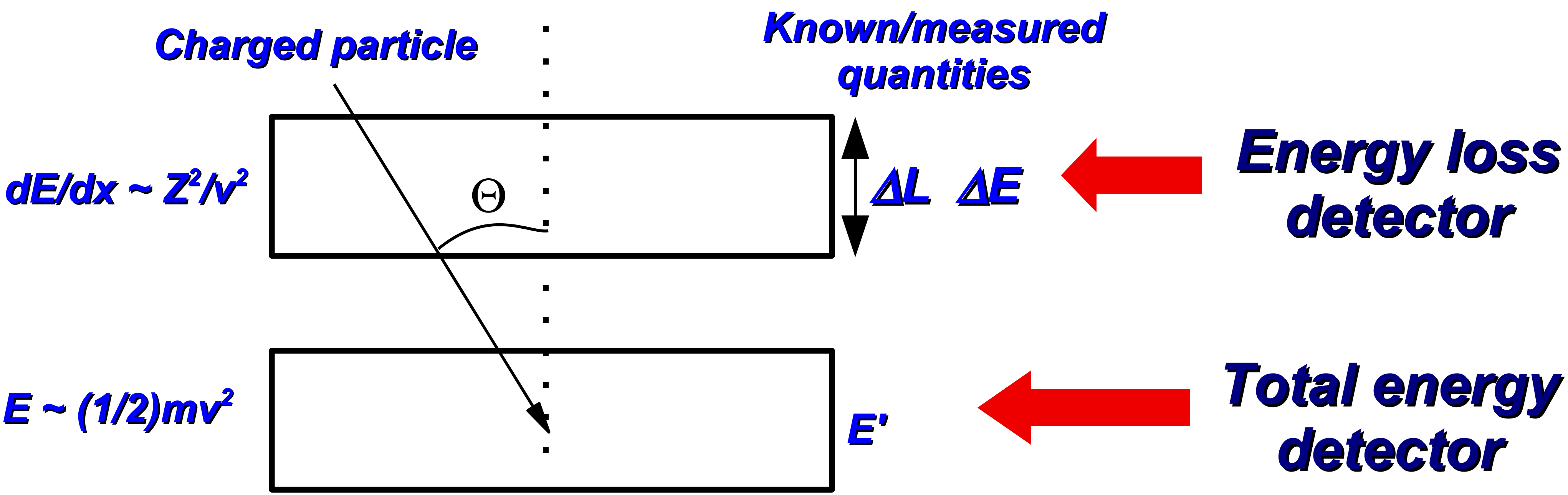
✓ Weight	100 kg
✓ Energy range	30 MeV - 50 GeV
✓ Field of view	3 sr
✓ Angular res.	≤0.5°
✓ Deadtime	≤0.1 ms

Silicon in space: what for?

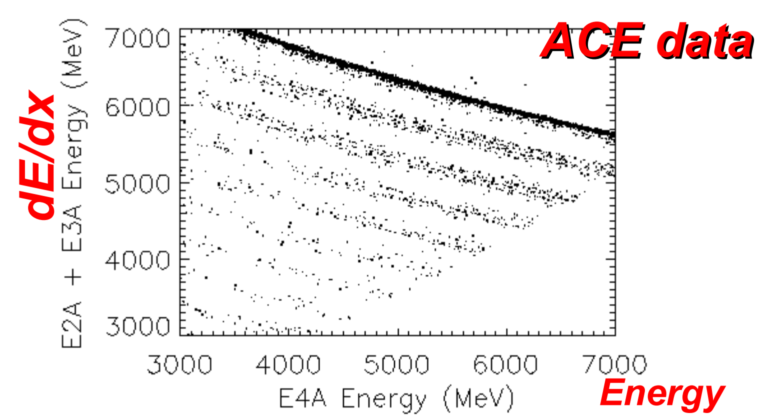


- Cosmic ray origin and composition
- Dosimetry
- Physiological studies of cosmic ray interaction
- Low energy X ray spectroscopy
- Visible, UV, IR light detection
- **GAMMA RAY ASTROPHYSICS**

The Silicon Telescope: the "workhorse" for charged particle measurements in space

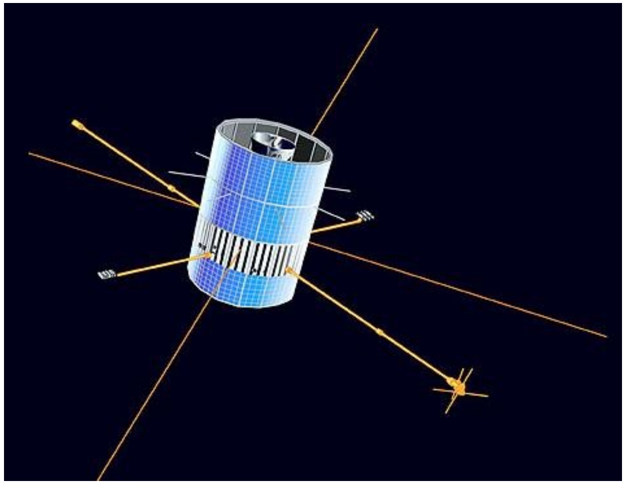


- $dE/dx \sim \Delta E/(\Delta L/\cos\theta)$
- $E \sim E'$
- $(dE/dx * E) \sim Z^2 m/2 \rightarrow$ unique for every nucleus (fully ionized)



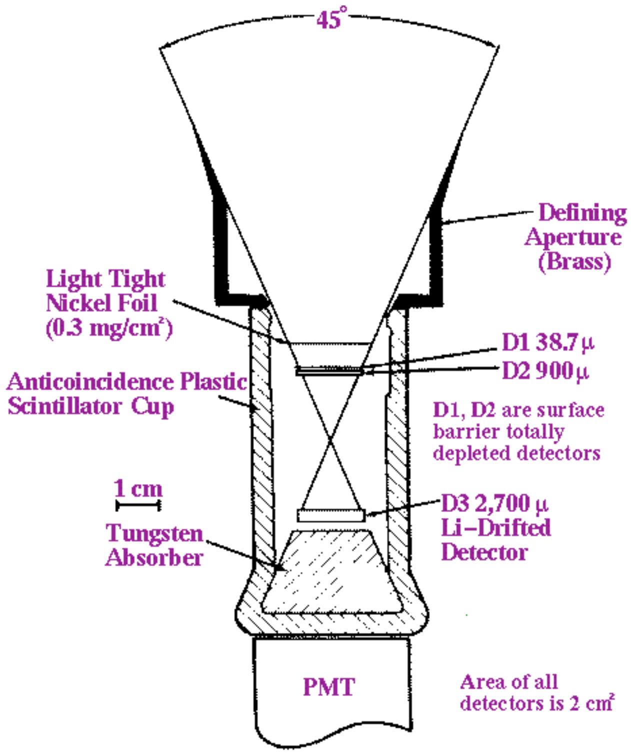
Proposed in 1959 by J. Simpson (Chicago University), deployed on Ranger-1, 1961 and IMP-1, 1963

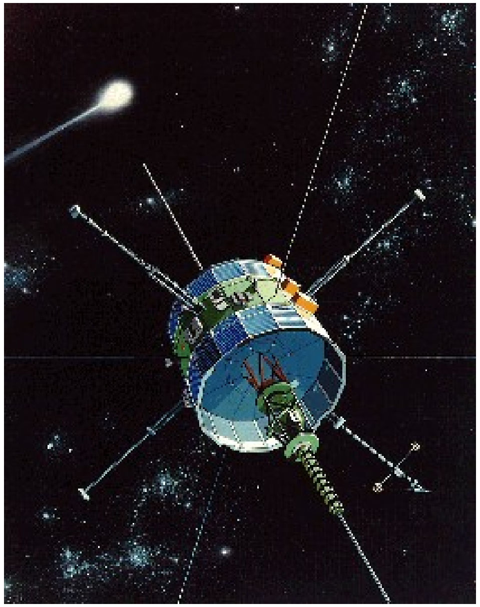
Silicon in space: some of the first



Interplanetary Monitoring Platform IMP-8:

- 26/10/1973
- 371 kg, at 35 Earth rays
- Still working
- Inter-planet cosmic ray studies
- SSB + Si-Li
- Identification with dE/dx+E





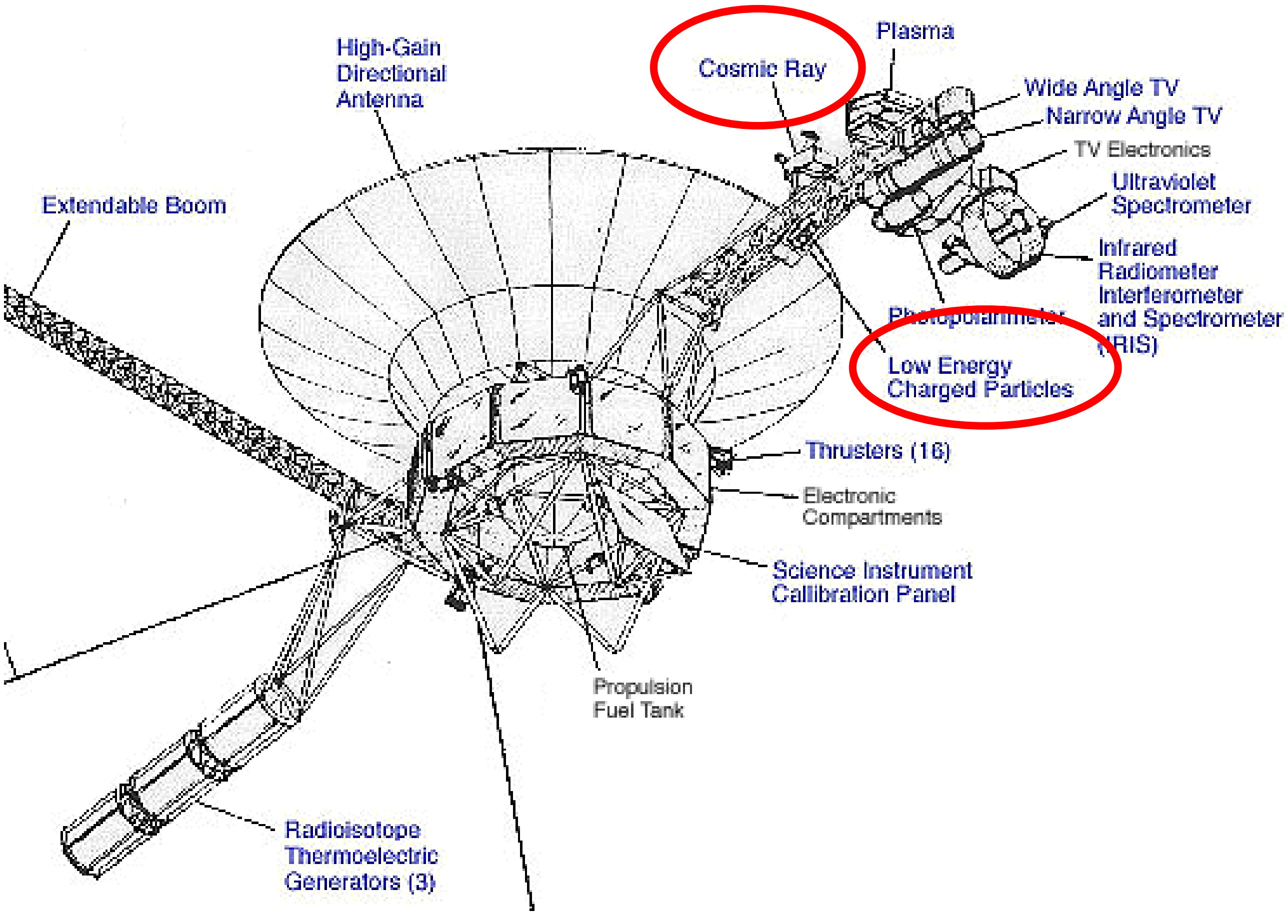
International Sun-Earth Explorer 3 (ISEE-3)

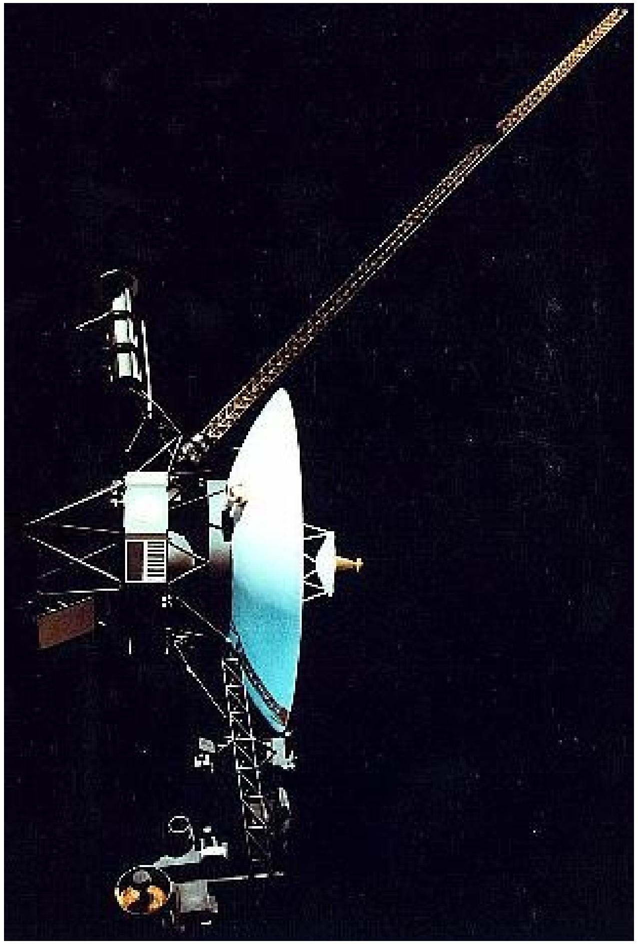
- launch: August 12, 1978
- Mass: 478 kg
- Goal: cosmic rays and emissions during solar flares
- Nov 20, 1978 - Halo Orbit - Earth-Sun L1 Libration Point
  Sep 11, 1985 - Comet Giacobini-Zinner Flyby
  Mar 28, 1986 - Comet Halley Distant Flyby
- 15 Instruments, 5 using Si Detectors (Silicon Surface Barrier & Si-Li)
- First High Purity Germanium detector used in space

Silicon detectors on human-made objects that left the solar-system

Voyager 1 and 2

- *Launched August 20 and September 5, 1977*
- *800 kg each*
- *Two independent cosmic-ray systems*
- *Identification with dE/dx+E*
- *Flyby Jupiter, Saturn, Uranus, Neptune*





Some other missions that used silicon detectors:

- GIOTTO, ESA Mission to Halley Comet, 1986
- Ulysses, Explorer for the polar regions of the SUN,ESA/NASA, 1990
- SAMPEX, Solar Anomalous Magnetospheric Particle Explorer, NASA, 1992
- GEOTAIL, Geomagnetic Tail Laboratory, NASA, 1992
- WIND, Interplanetary Physics Laboratory, NASA, 1994
- SOHO, SOlar Heliosphere Observatory, ESA/NASA, 1995
- POLAR, Polar Plasma Laboratory, NASA, 1996
- CLUSTER2, 4 satellites for Earth Magnetosphere studies, ESA/NASA, 2000
- And many others...

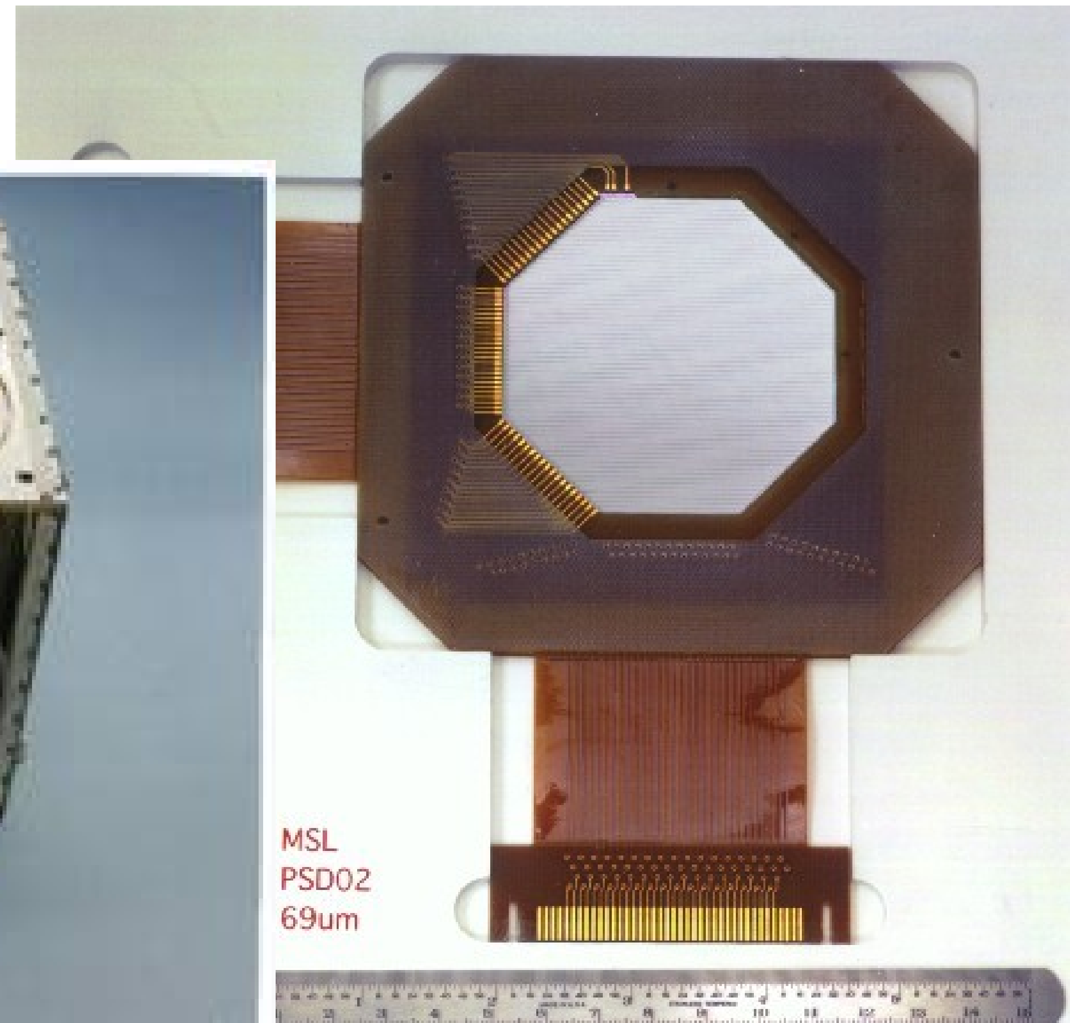
then came strip detectors and HEP technology...

Solar Isotope Spectrometer (SIS, onboard ACE, Advanced Composition Explorer): *isotopic composition from He to Ni over the energy range 10-100 MeV/nucleon :*

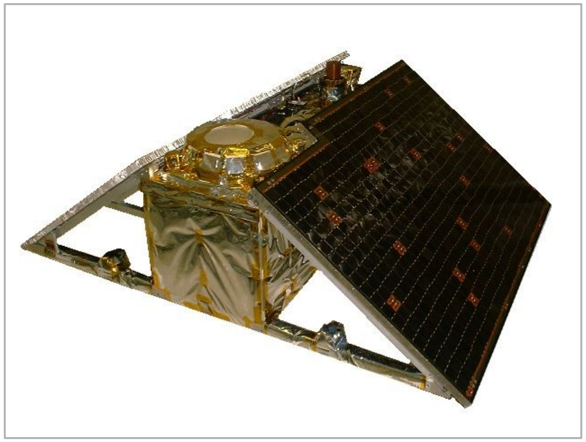
- *Large solar events: isotopic composition of the solar corona*
- *Quiet solar times: isotopes of the Galactic cosmic rays*

2 telescopes with 17 Si:

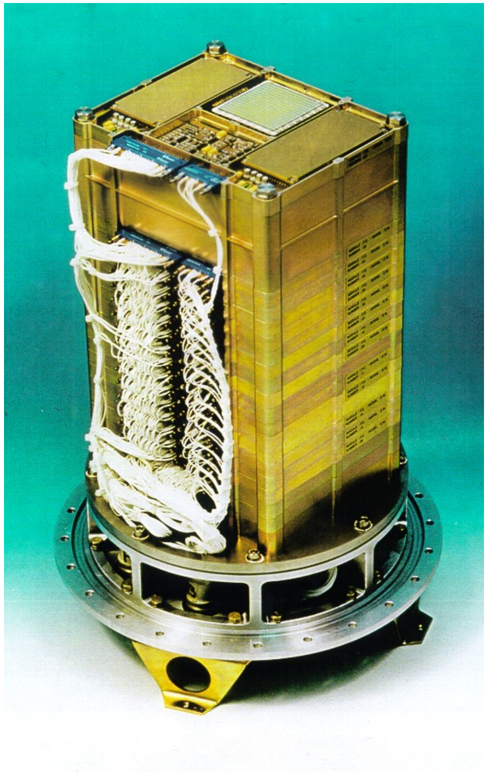
- **2 strip ones for track reconstruction (64 strips each, 1mm pitch)**
- **15 for energy loss**



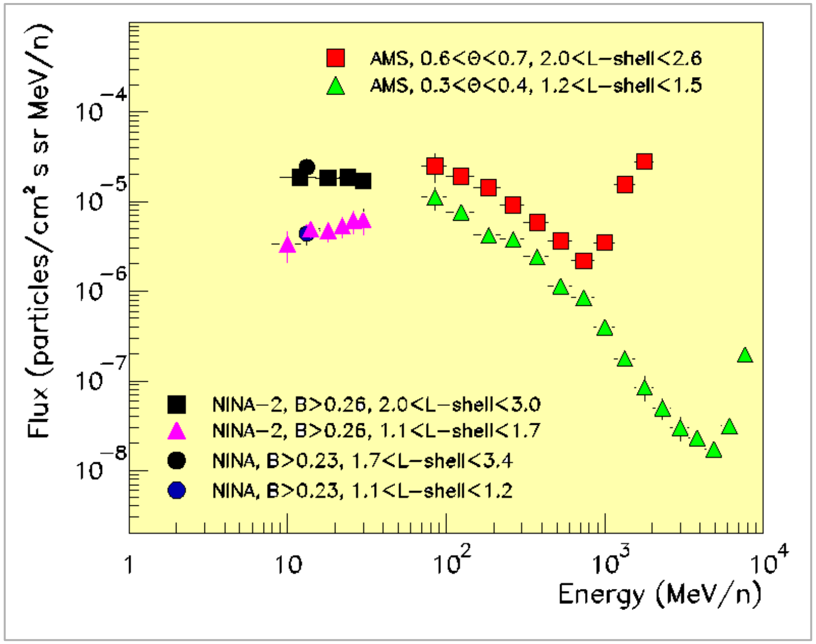
The NINA (New Instrument for Nuclear Analysis) mission



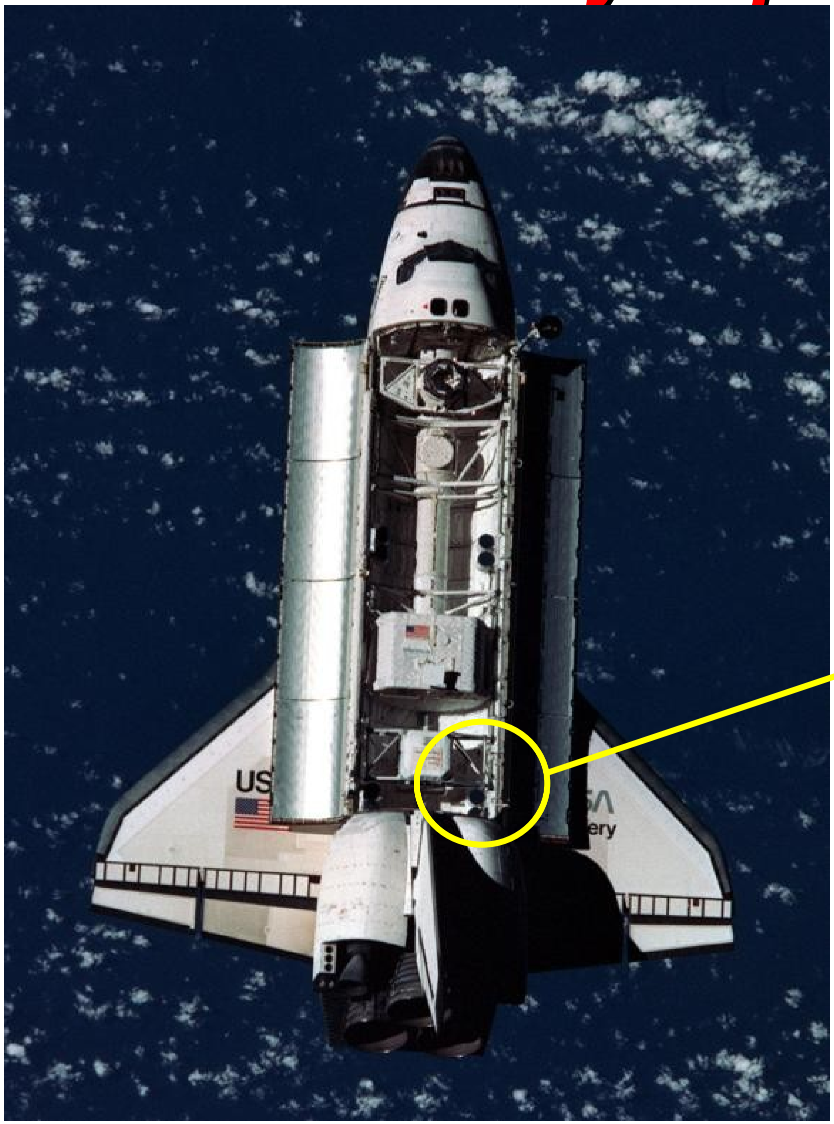
- *NINA1* : 31/8/1998 - 13/4/1999 ($2x10^6$ events)
- Orbit: 840 km, 98.7deg
- Mass = 2500 kg
- Satellite = RESURS-01 nr.4
- *NINA2* : 21/7/2000 - 15/8/2001 (>10^7 events)
- Orbit: 450 km, 87.3deg
- Mass = 200 kg
- Satellite = MITA

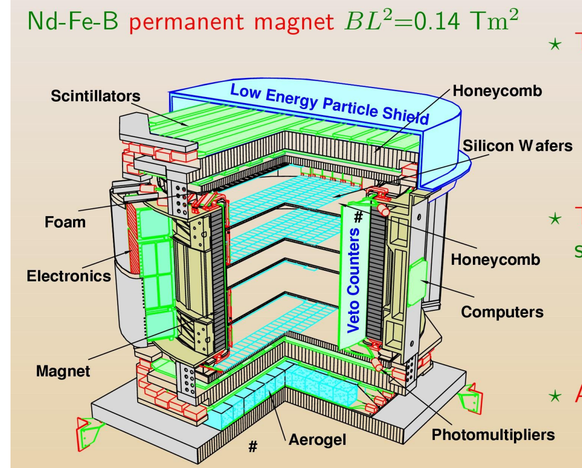


- Basic element:
  - Detector 6x6 cm^2, 150 µm thick (2), 380µm thick (14) with 16 strips (pitch = 3.6 mm)
  - Organized in a x-y mode
- 32 wafers arranged in 16 planes, 1.4 cm apart
- Total weight = 40 kg
- Total power = 40 W



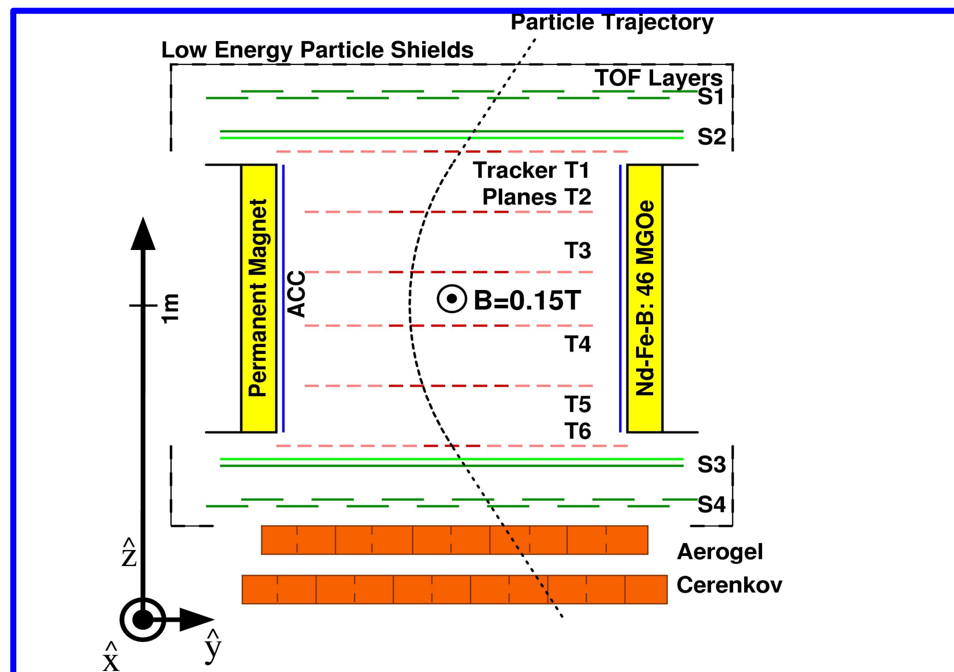
Silicon in space: the breakthrough in cosmic ray experiments → AMS01





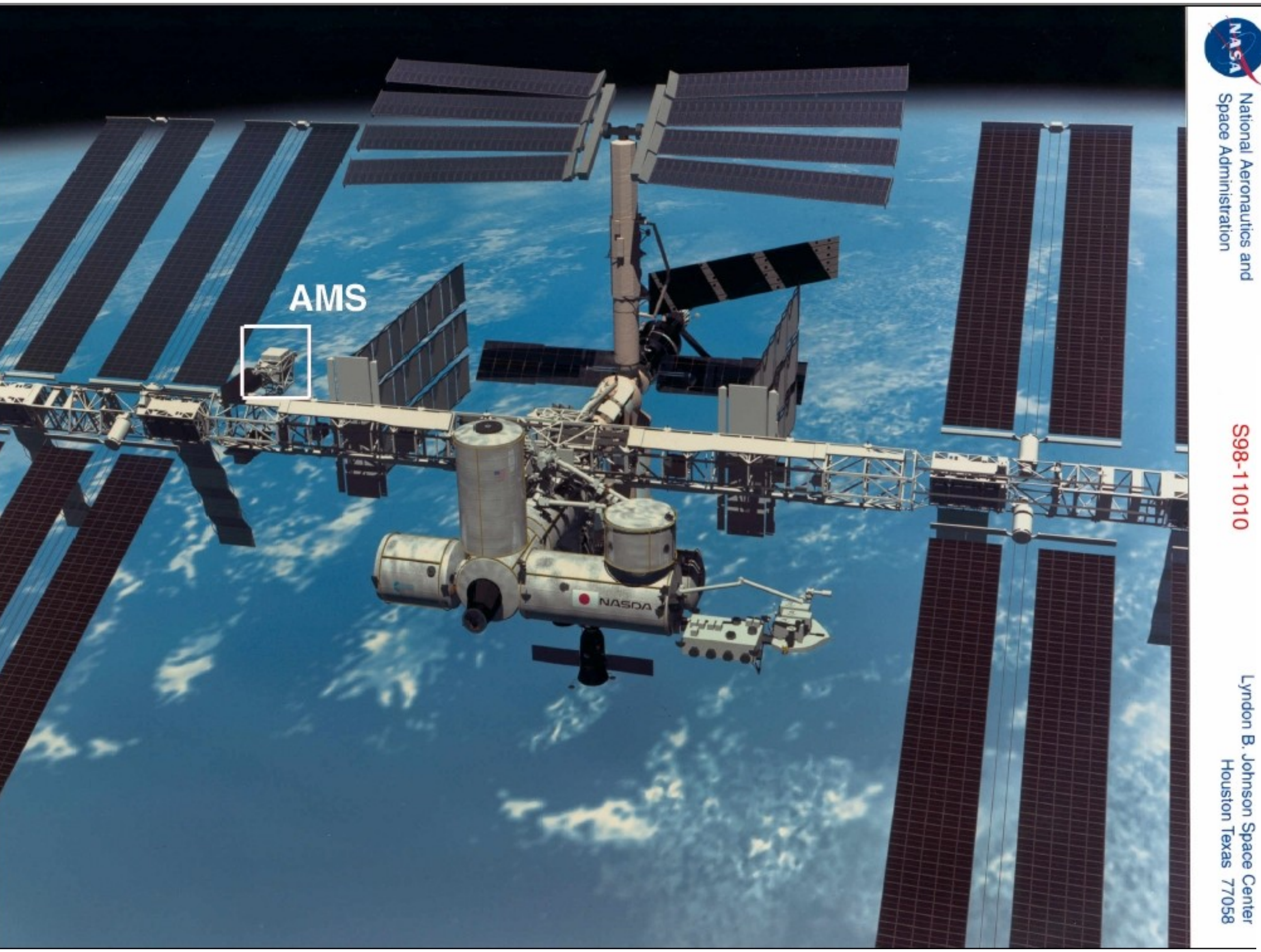
- ⋆ TOF: 4 scintillator planes,
  - ▷ 3D coordinates
  - ▷ dE/dx
  - ▷ time of flight $\sigma_{\mathrm{ToF}} \sim 110$ ps
  - ▷ trigger
- ⋆ Tracker: 2.1m^2 of double side silicon microstrip detectors:
  - ▷ clusters $\sigma_y \sim 10\ \mu m$
  - ▷ trajectory → R
  - ▷ dE/dx
- ⋆ ATC: 2 planes, n=1.035
  - ▷ additional β measurement

Anticounters: reject multiparticle events

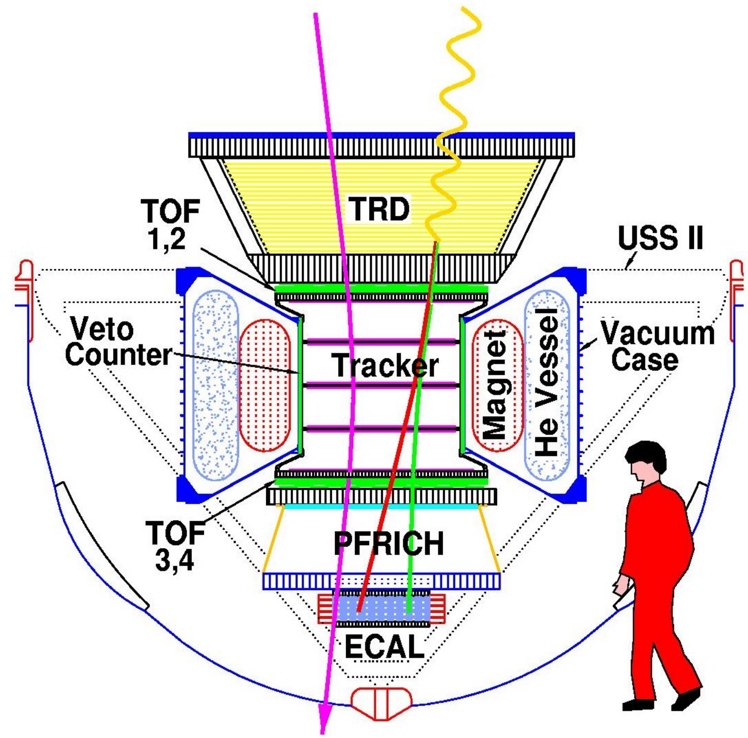


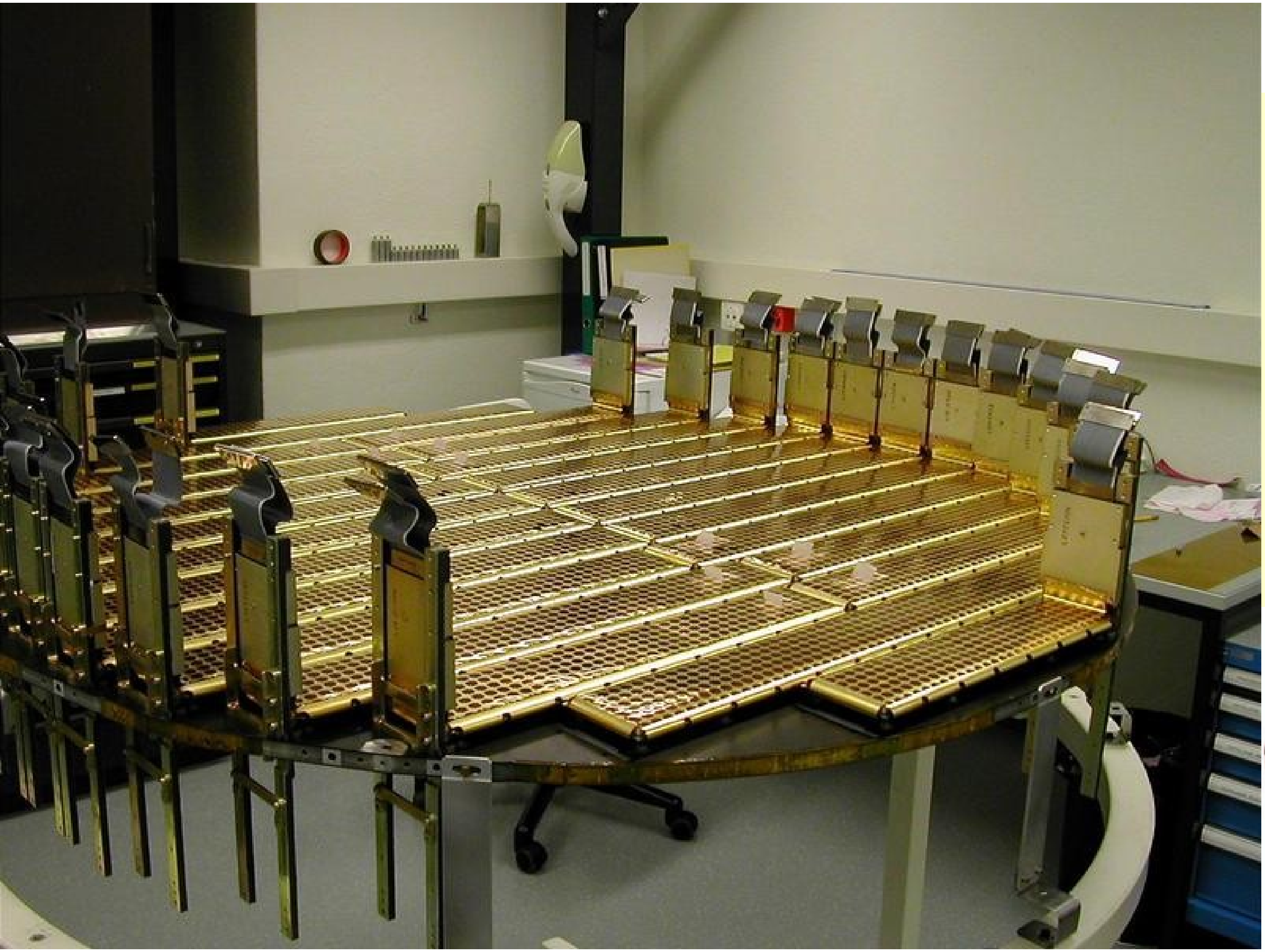
1998

The near future: AMS02

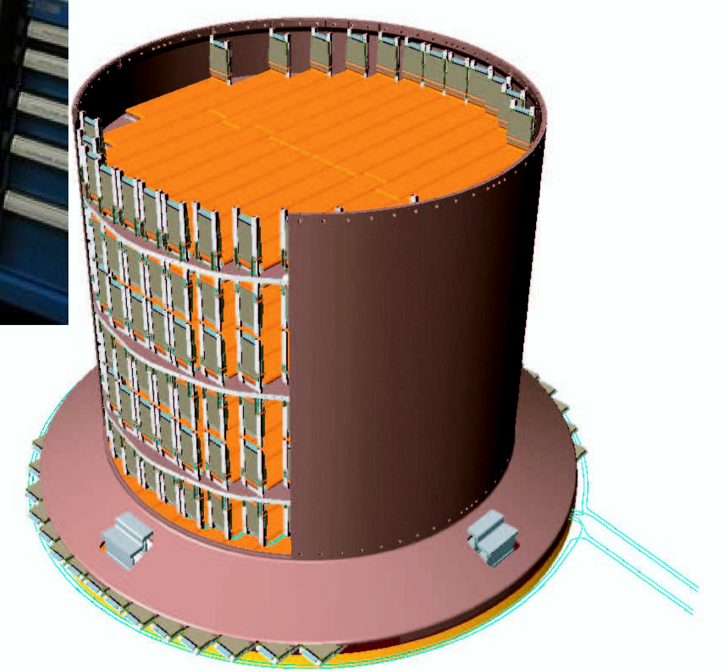


- ✔ *Data taking on ISS*
- ✔ *Superconducting magnet*
- ✔ *Large acceptance*
- ✔ *Long term operation*
- ✔ *Cosmic ray elemental and isotopic fluxes*
- ✔ *Direct search for antimatter*
- ✔ *Indirect search for Dark Matter*

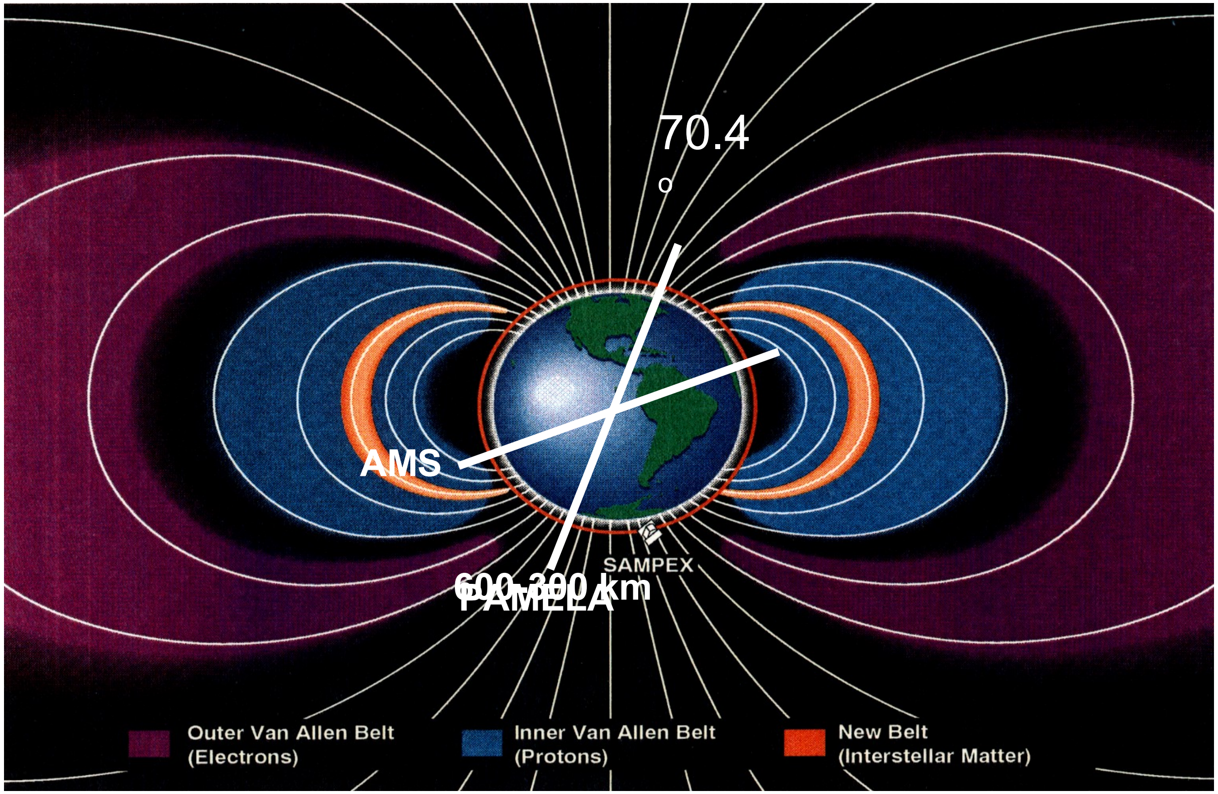




- 8 planes of double side silicon detectors
- Total area ≈ 6 m^2
- Pitch in the bending plane = 110μm
- Pitch in the non-bending plane = 208 μm
- dE/dx measurement
- Readout: VA64HDR (IDEAS)



The present: PAMELA (Payload for Antimatter-Matter Exploration and Light nuclei Astrophysics)

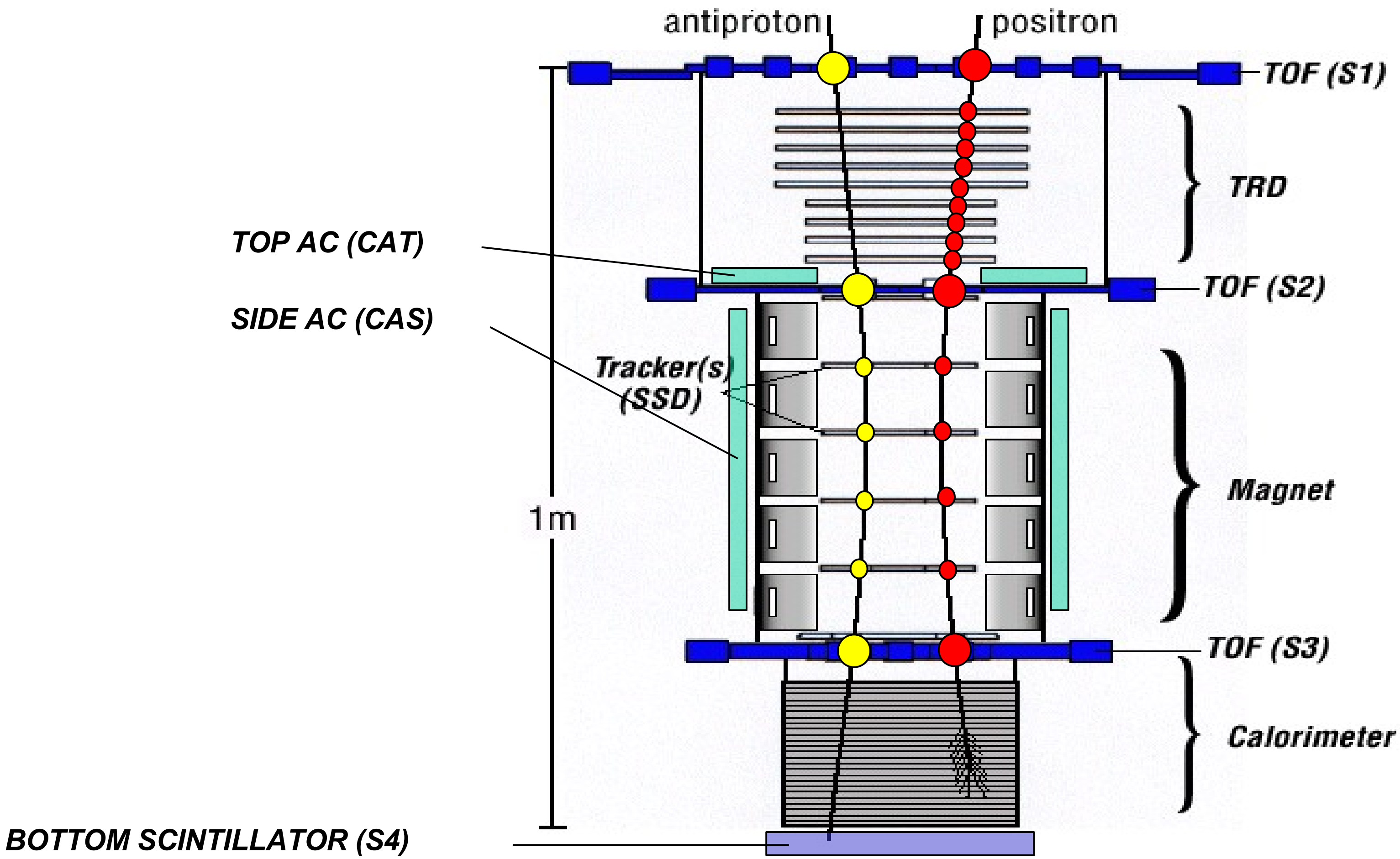


Goal: antiproton and positron fluxes in space:

- ✓ *Wide energy range (80MeV-190GeV for antiproton; 50MeV-270GeV for positrons)*
- ✓ *High statistics: in 2 years, 20k antip and 200k positrons expected*

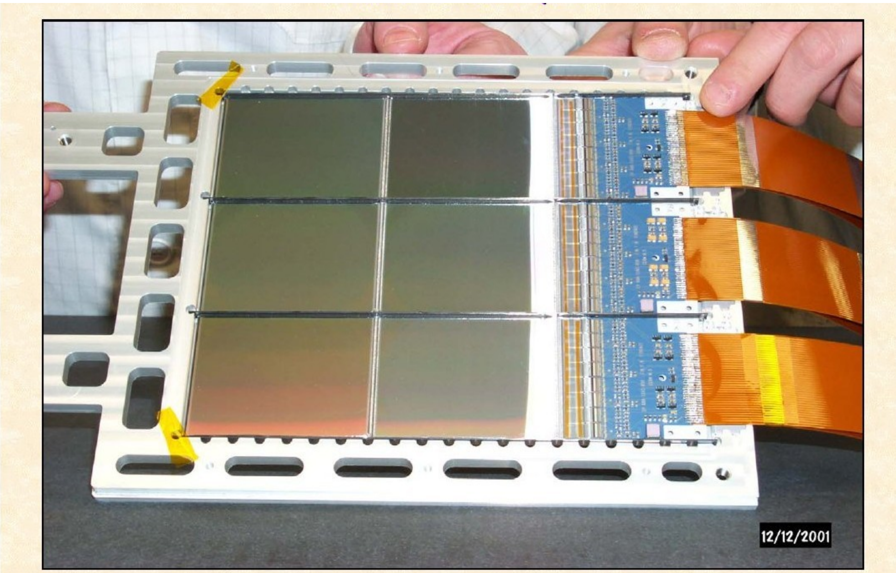
Goal: H→C energy spectrum and search for anti-He

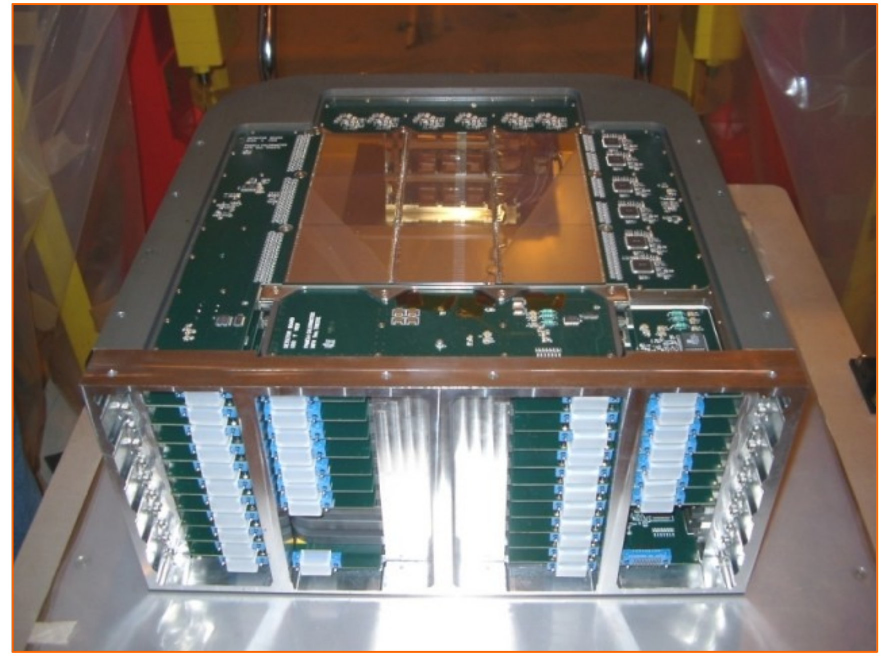
Working principle



Antiproton and positron tracks are shown with exaggerated curvature.

SILICON in PAMELA





Tracking:

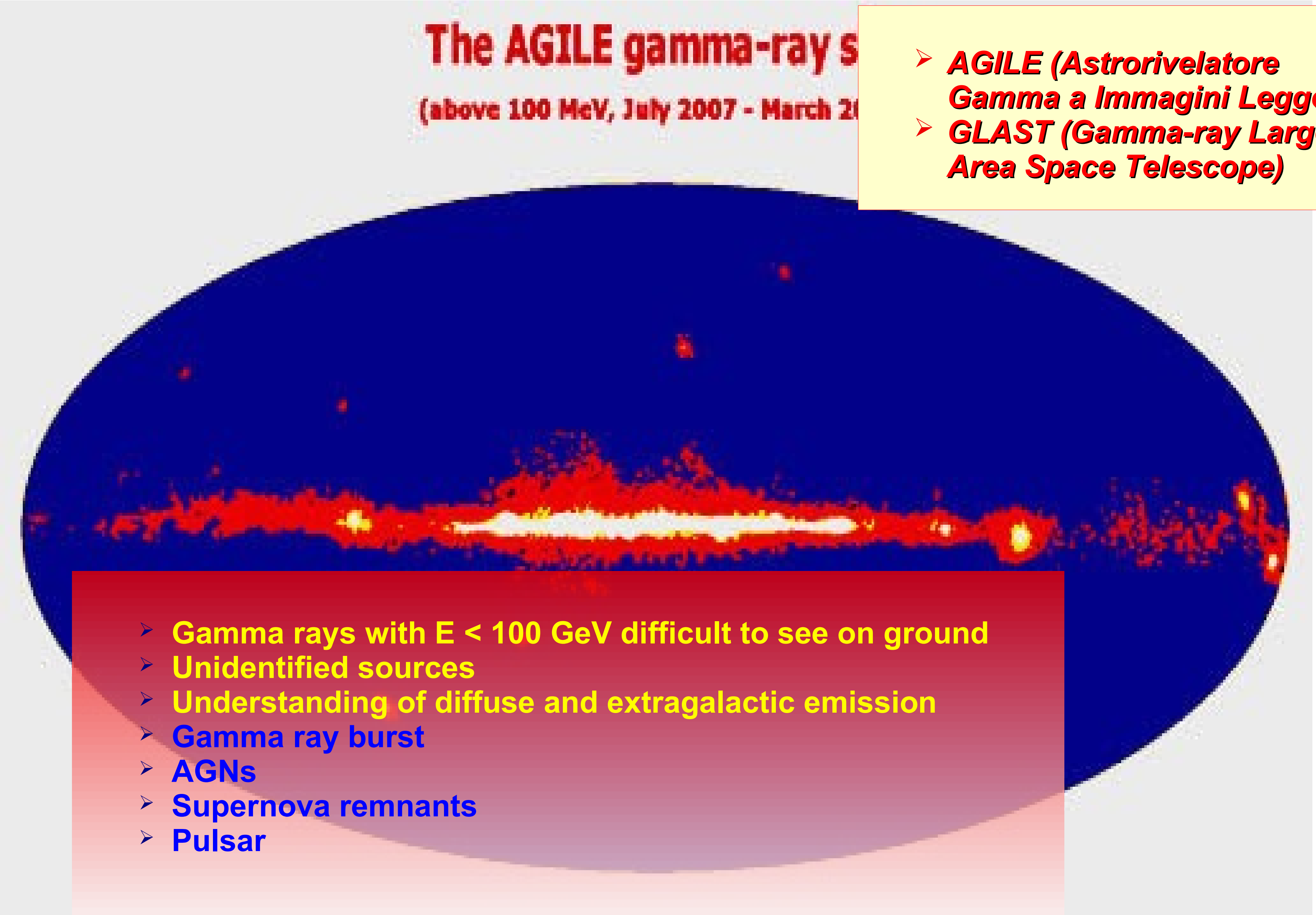
- 6 layers of double side silicon detectors (HAMAMATSU)
- Readout pitch=50µm
- Thickness = 300µm

Calorimeter:

- 22 planes with one tungsten layer of 2.6mm and two layers of silicon detectors (380 µm thick)
- Strip pitch = 2.4 mm
- 16 radiation lengths
- Total number of channels = 4224
- Dynamic range = 1-1000 mips

LAUNCH = 15/06/2006 from Baikonur

Silicon in space: gamma-ray astrophysics

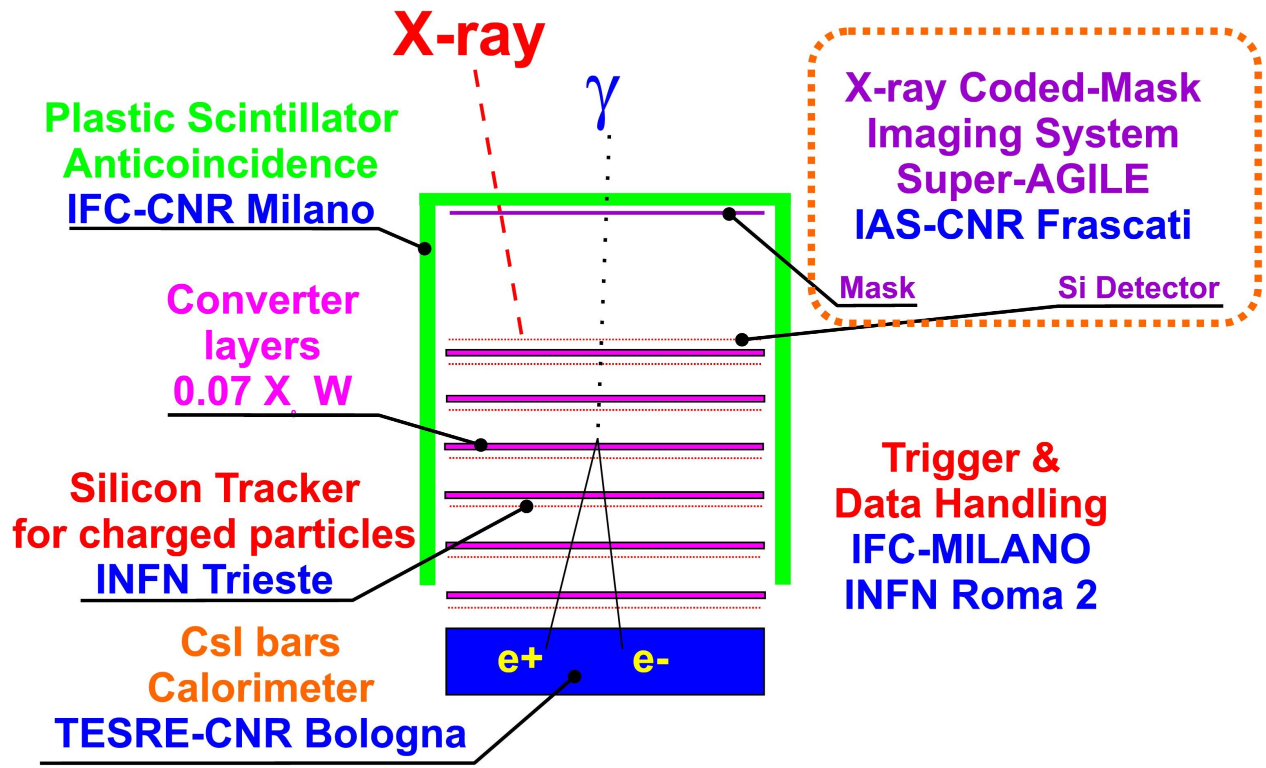


- *AGILE (Astrorivelatore Gamma a Immagini Leggero)*
- *GLAST (Gamma-ray Large Area Space Telescope)*

- Gamma rays with E < 100 GeV difficult to see on ground
- Unidentified sources
- Understanding of diffuse and extragalactic emission
- Gamma ray burst
- AGNs
- Supernova remnants
- Pulsar

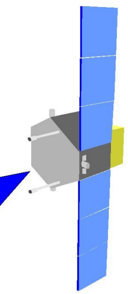
Working principle of AGILE and GLAST

- *Pair conversion telescopes with a calorimeter to measure energy and a scintillator system to veto charged particles*
- *Charged particle background: 10^5-10^6 times larger than γ signal*
- *Trigger based on the silicon planes*
- *Low power electronics*
- *SuperAGILE: X-ray detector with a coded mask imaging system*



Silicon in space: let's build an instrument

TO THE STARS



CONSTRUCTION AND CALIBRATION
- Components test
- Assembly and verification
- Scientific calibration with photons

DESIGN AND PROTOTYPING
- Choice of components
- Performance testbeams
- Vibrational and Thermovacuum tests
- Construction procedures

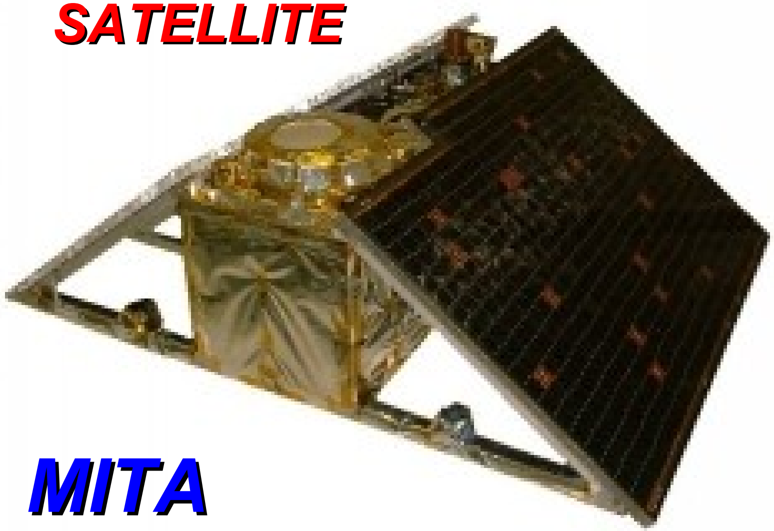
SILICON TRACKER
- Meets SR
- Low Power
- Good angular resolution

SCIENTIFIC REQUIREMENTS
- Wide FOV
- Fast timing
- Excellent back-ground rejection

Procedures procedures procedures ....
Paper paper paper paper paper ......

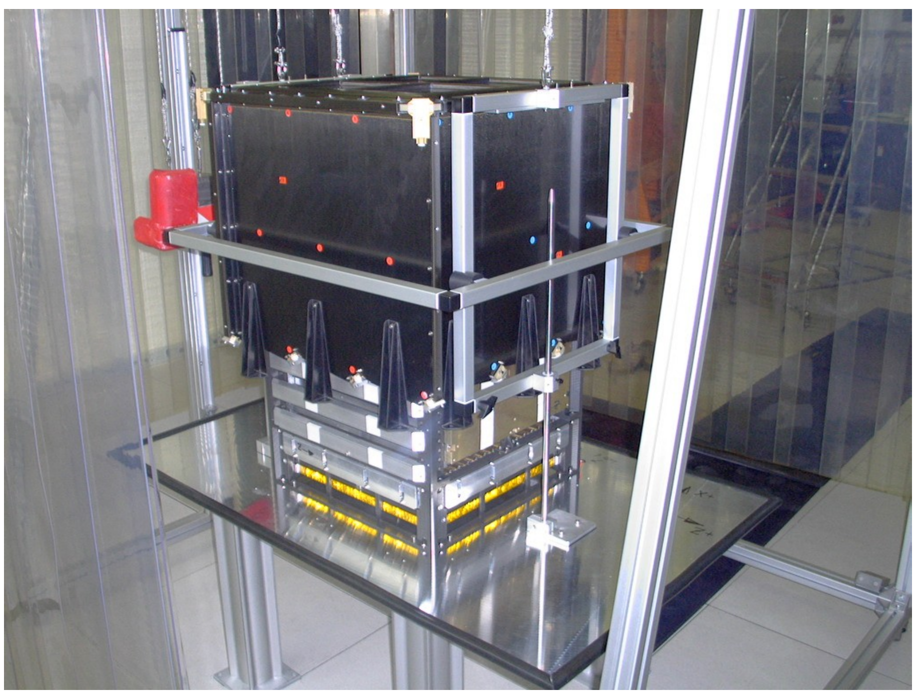
A space mission components

SATELLITE



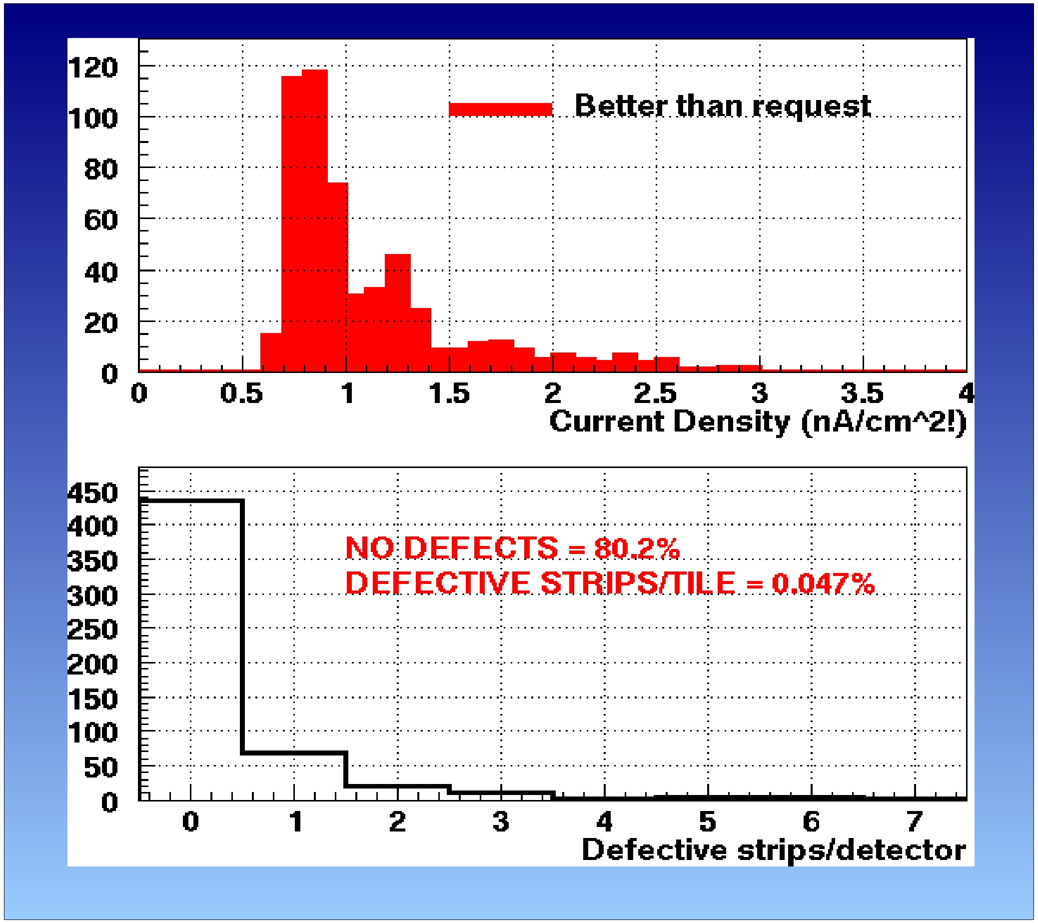
MITA

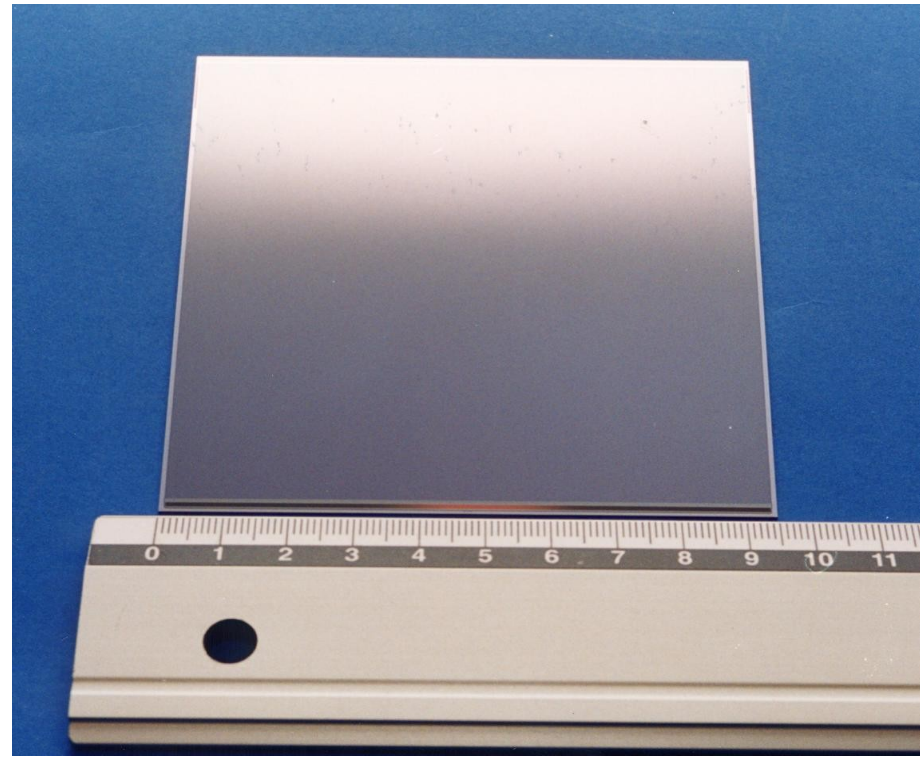
LAUNCHER



SCIENTIFIC PAYLOAD

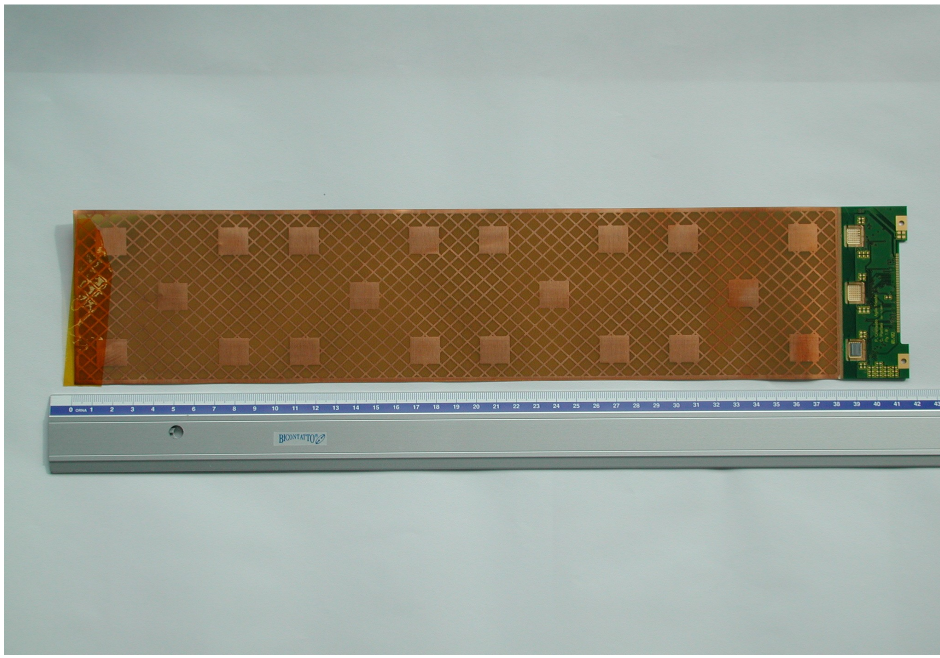
Step 1: design the detector and prove it works

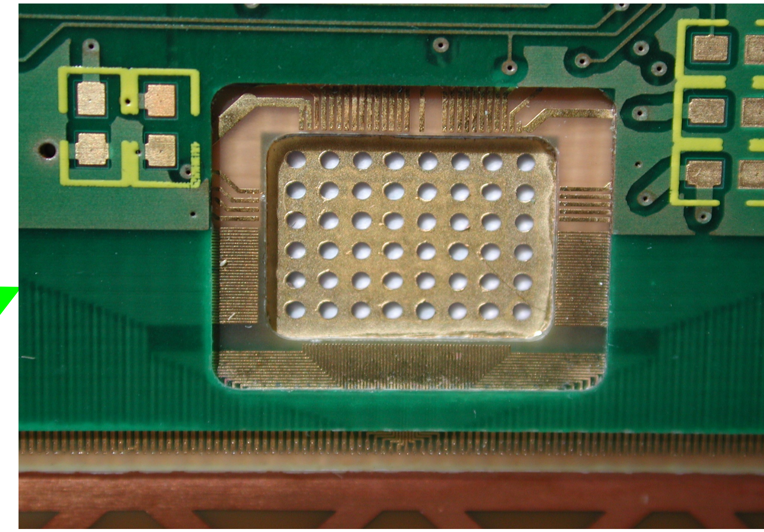


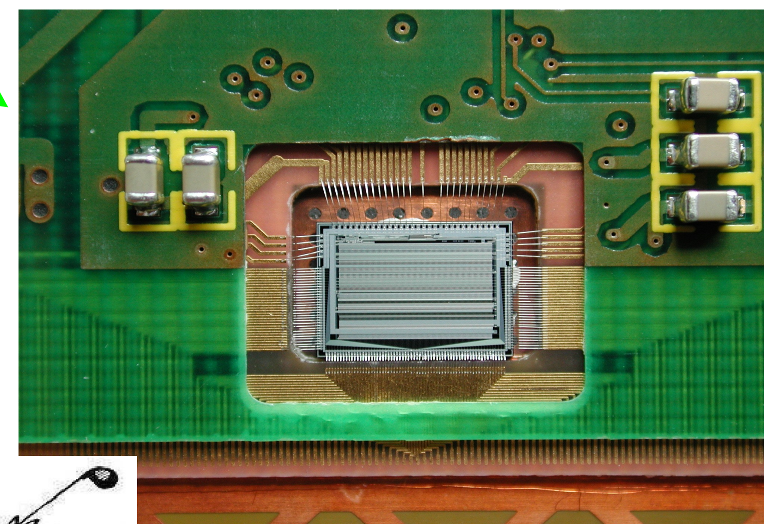


- ✔ *Dimension: 9.5 x 9.5 cm^2*
- ✔ *HAMAMATSU with specifications from INFN-Ts*
- ✔ *Thickness = 410μm, readout pitch = 242 μm*
- ✔ *384 readout strips; 768 physical strips → strip FLOATING → spatial resolution with low power*

Step 2: design/choose the electronics and prove it works



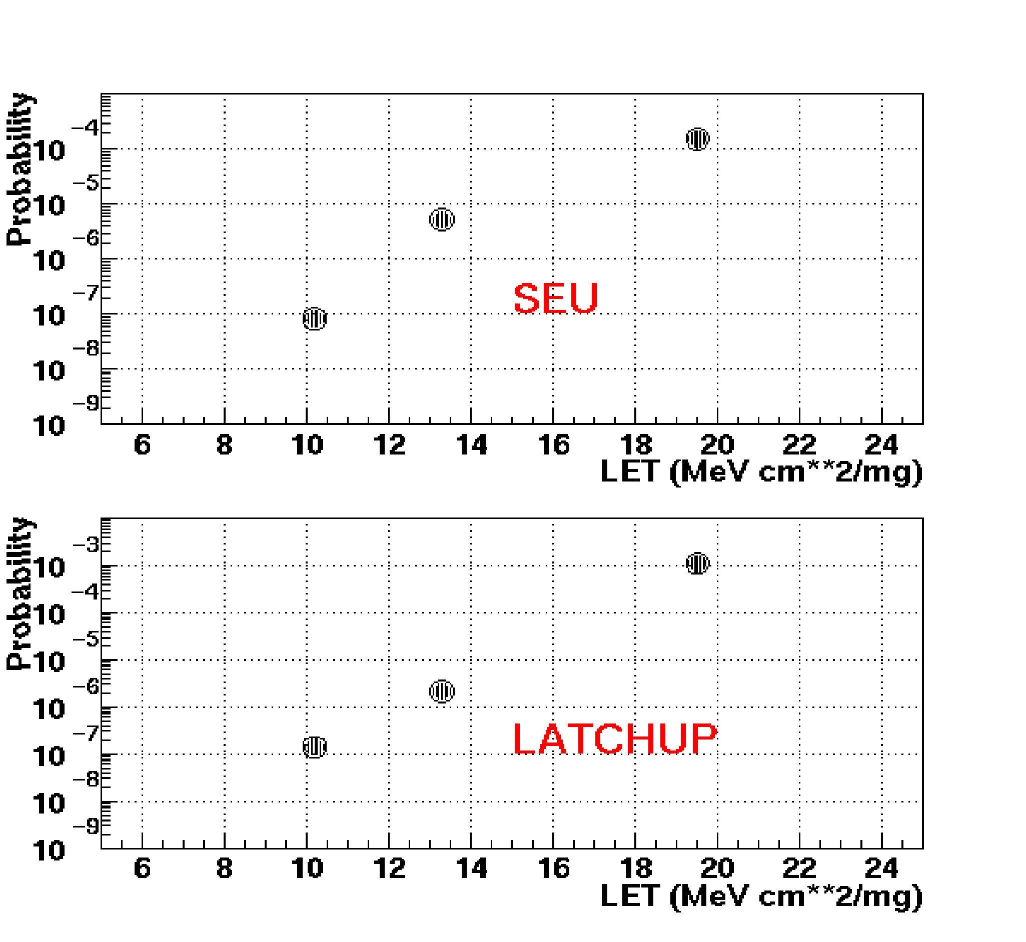


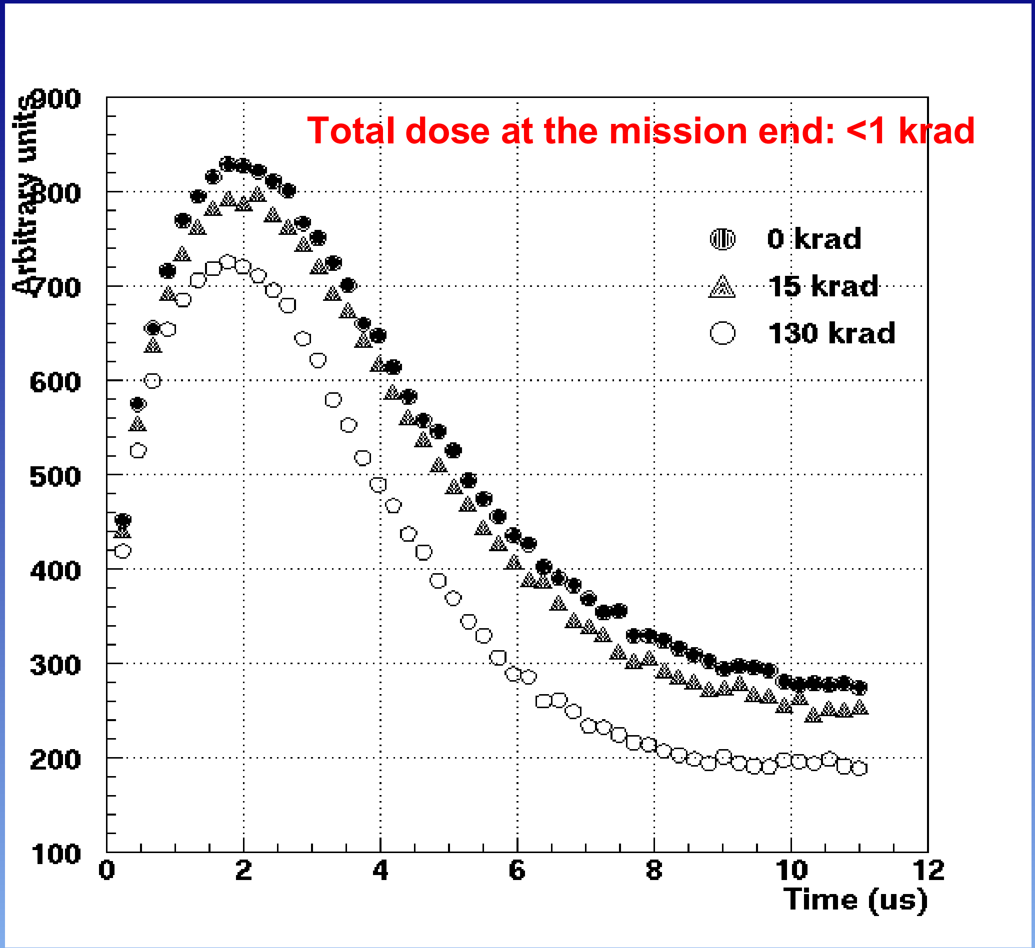


- *ILFA (Hannover), design by INFN-Ts*
- *Unique technology (FR4 based)*
- *ASIC (TAA1, IDE AS) inside the HDI*

Step 3: demonstrate you will not be killed by radiation

Latchup/SEU of TAA1 (SIRAD facility, INFN Legnaro National Laboratory)

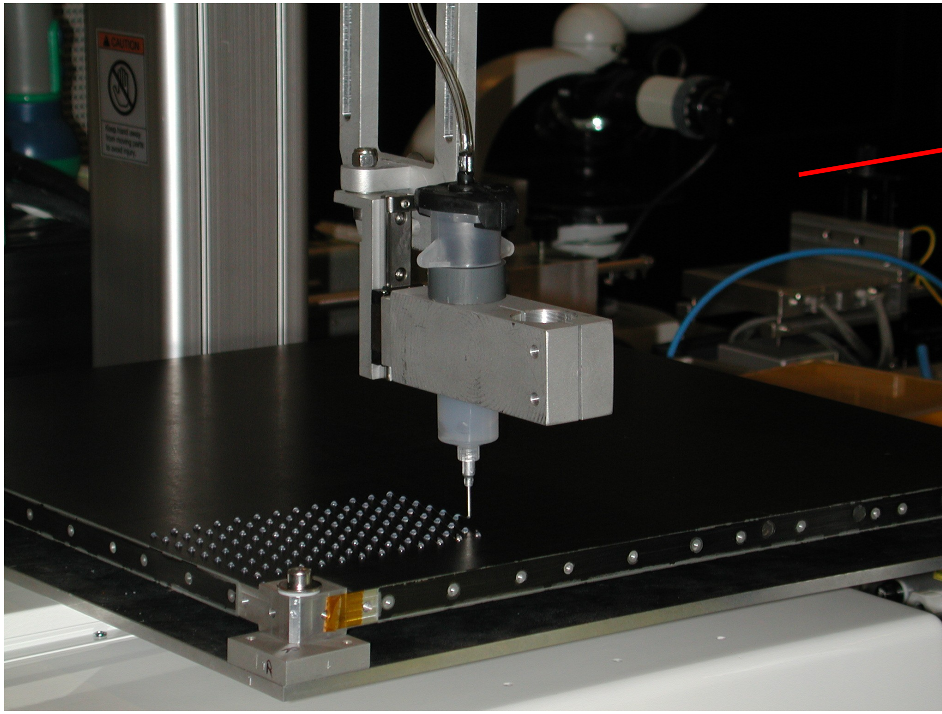




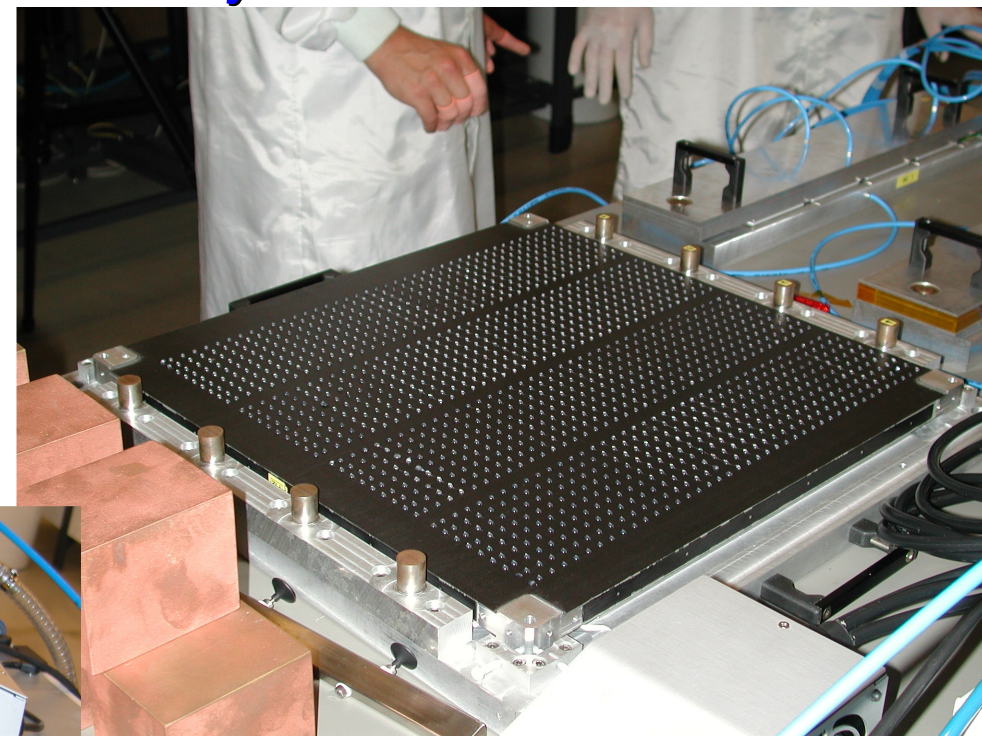
SEU and latchup probability on one ASIC

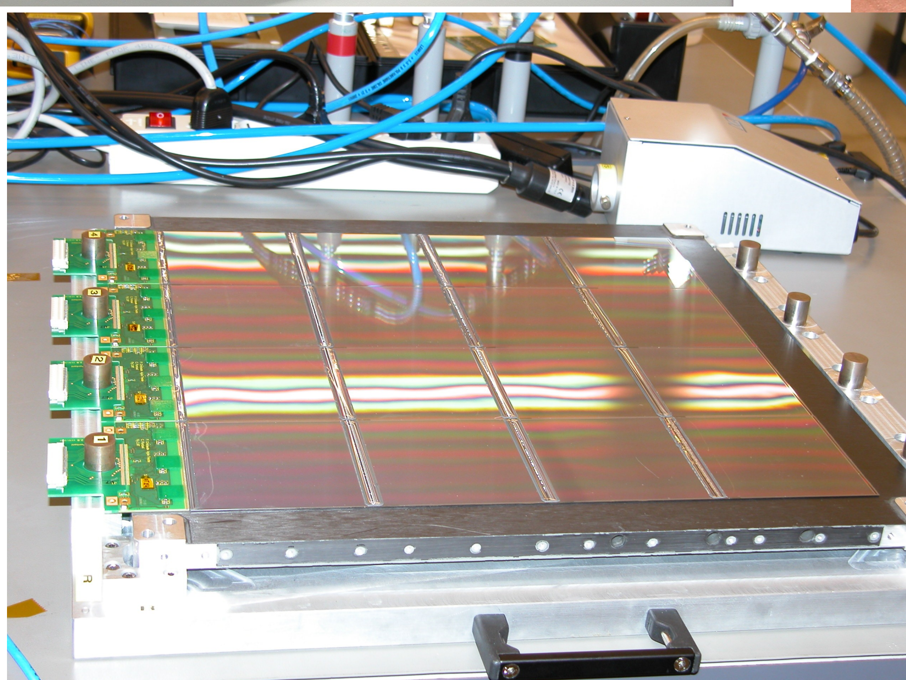
Dose effect on one TAA1 channel

Step 4: build the first block of your tracker - develop tools and procedures

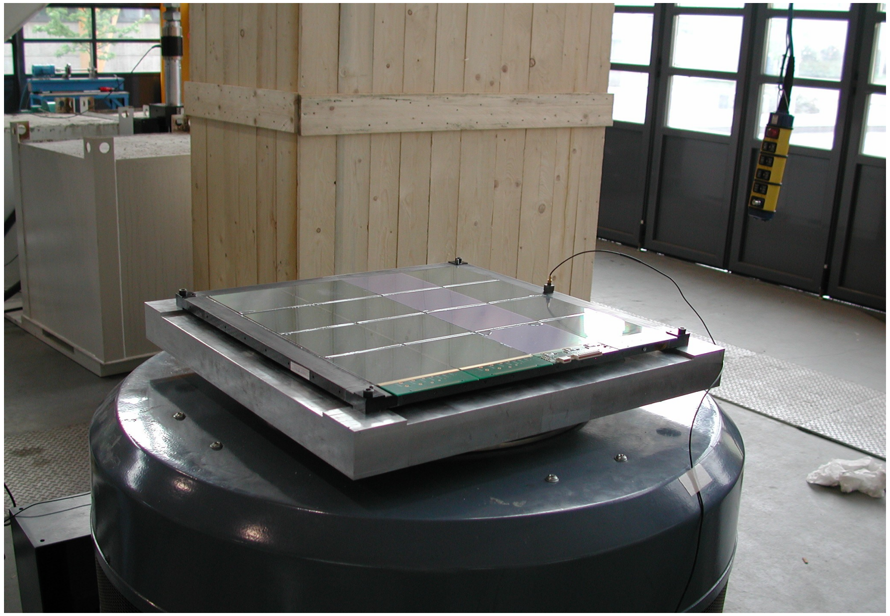


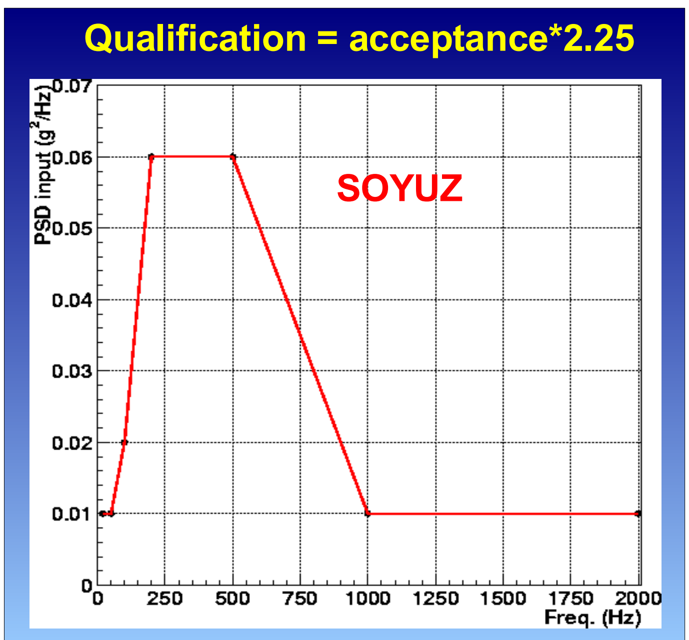
Automatic glue dispensing on a AGILE tracker tray

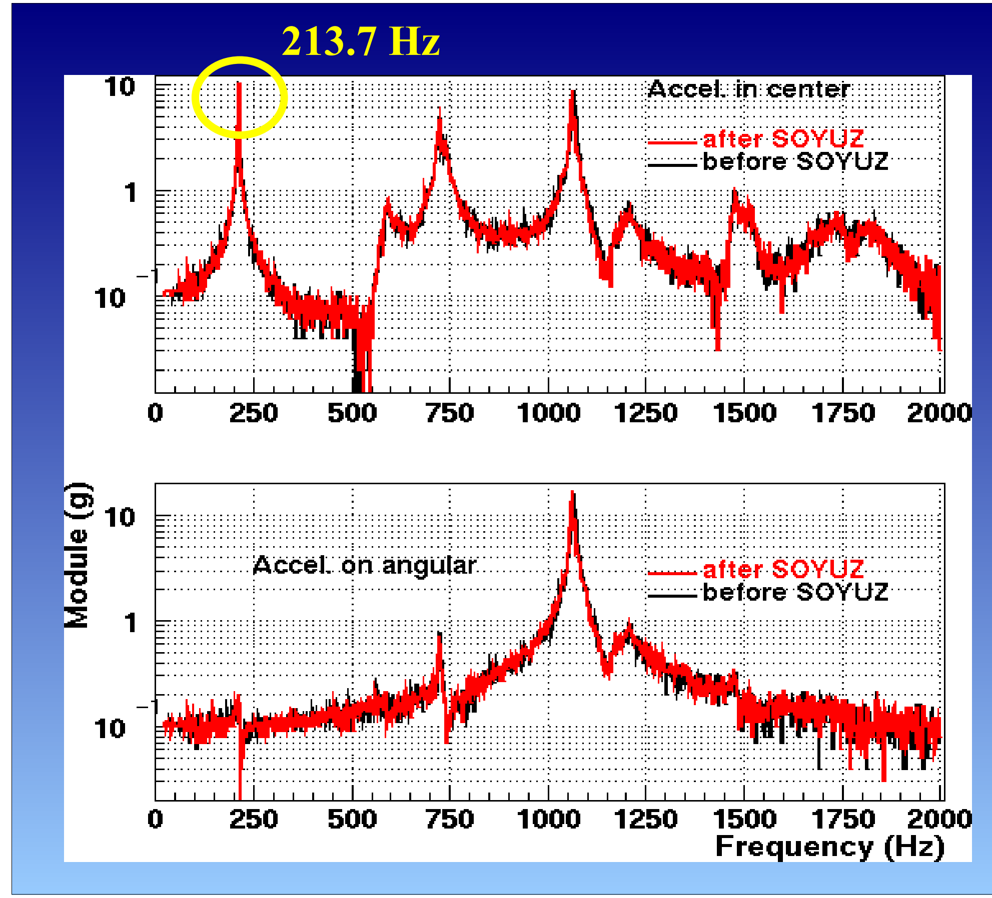




Step 5: "space" tests → thermo-vacuum and vibrations







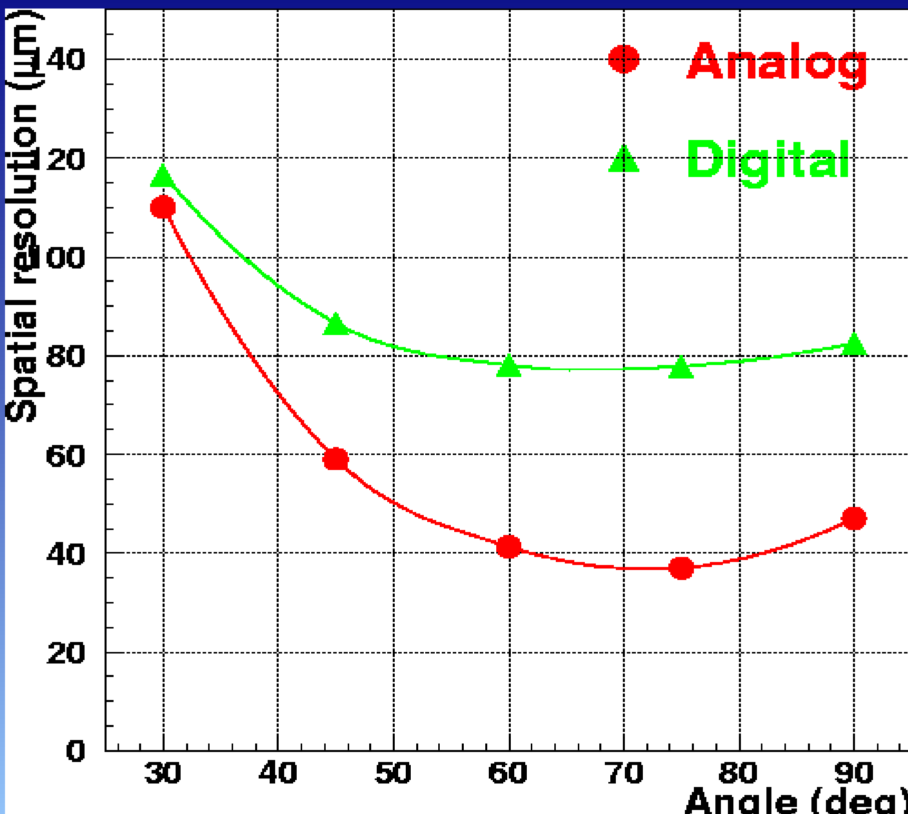
Sinusoidal sweep

Now put everything together ......

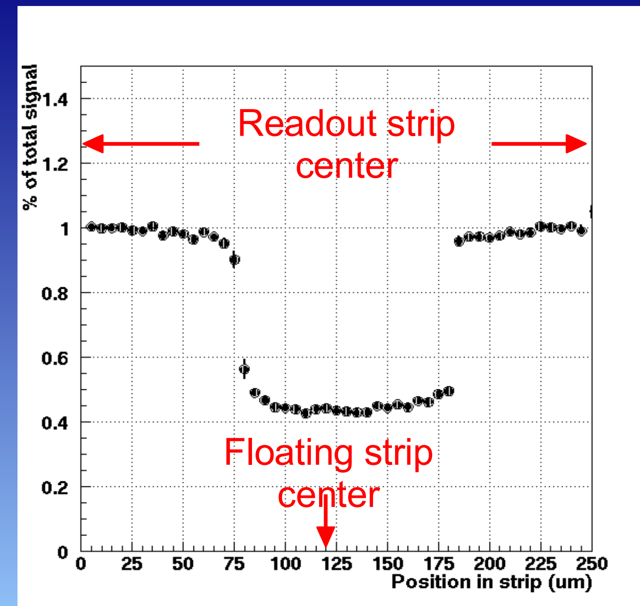
and try it!

Silicon Detectors results

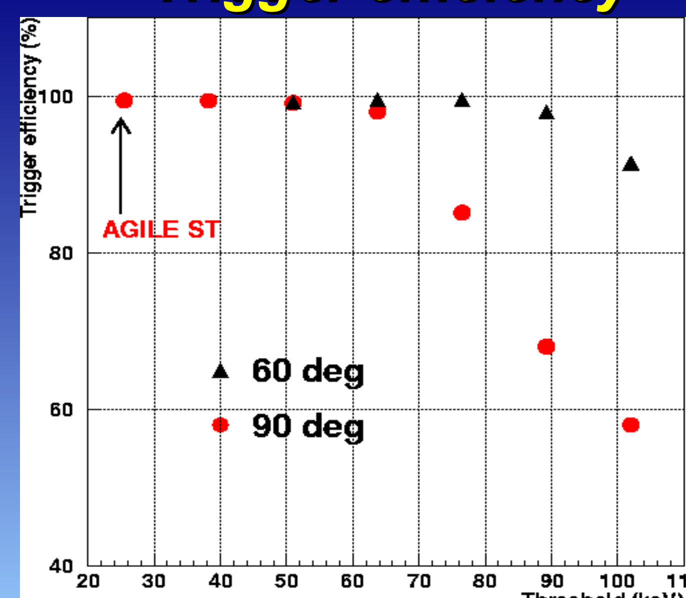
Position resolution



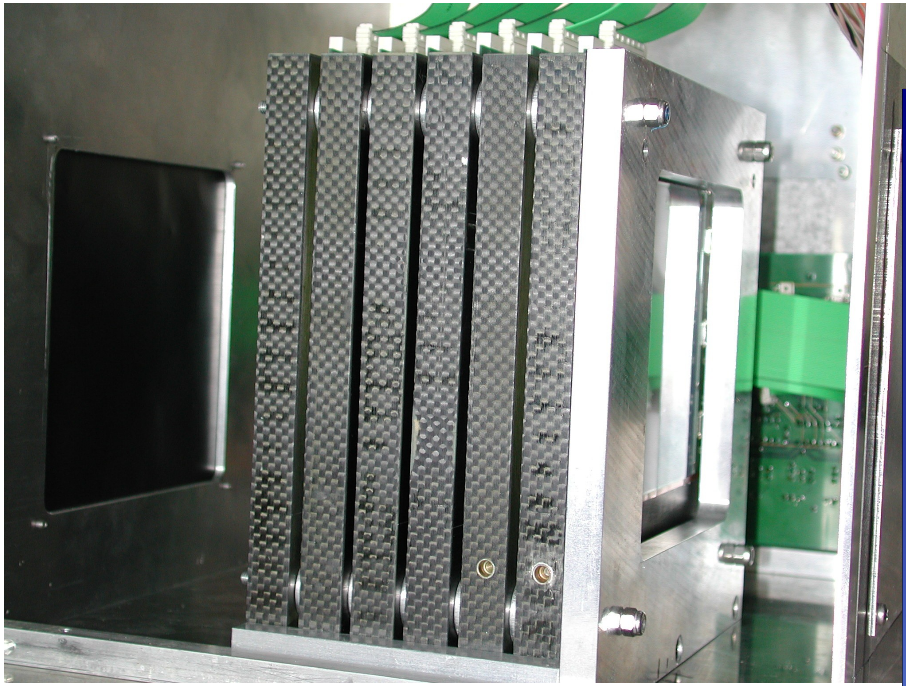
Charge sharing

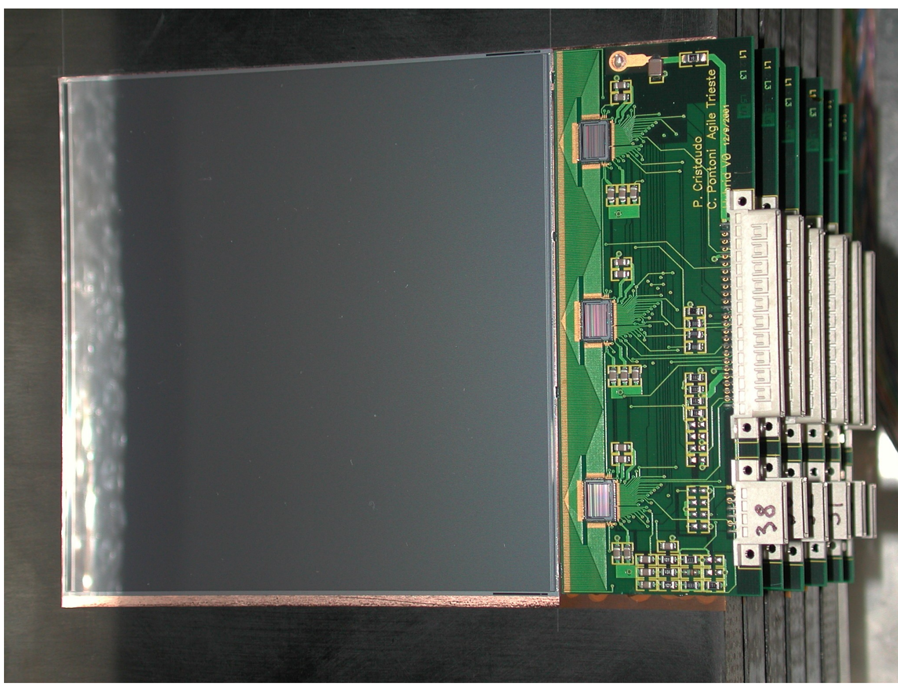


Trigger efficiency

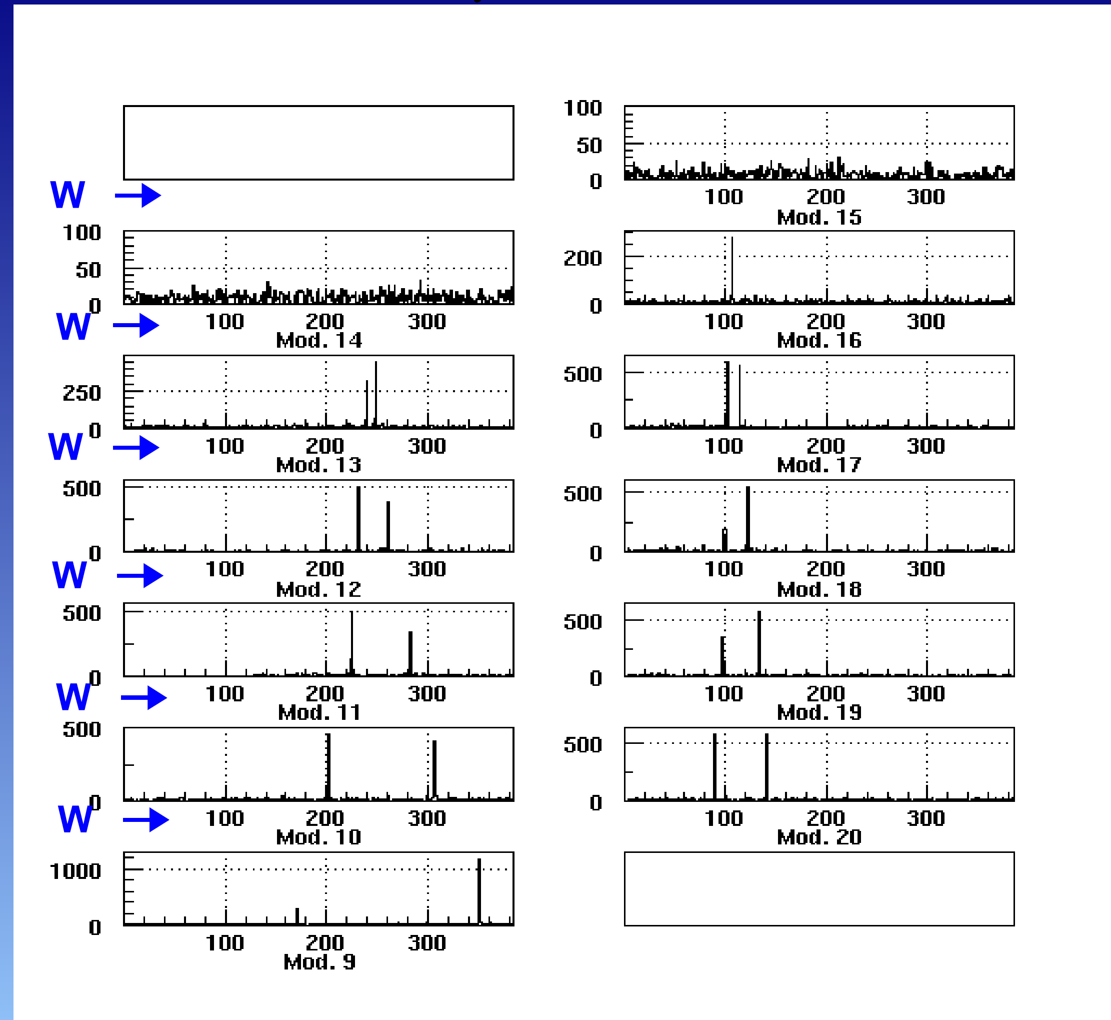


Small Scale prototype for testbeam



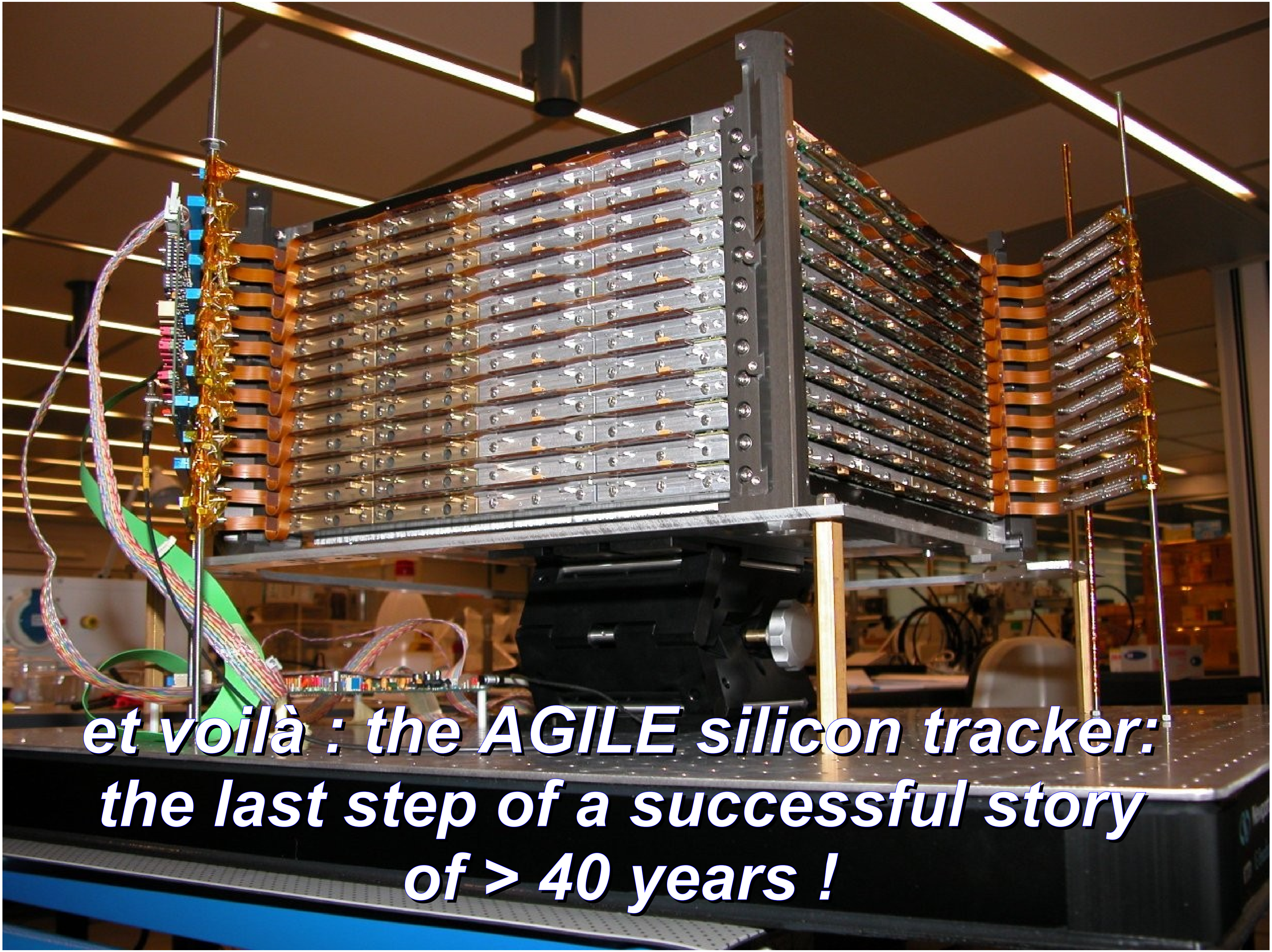


$E\gamma = 107$ MeV



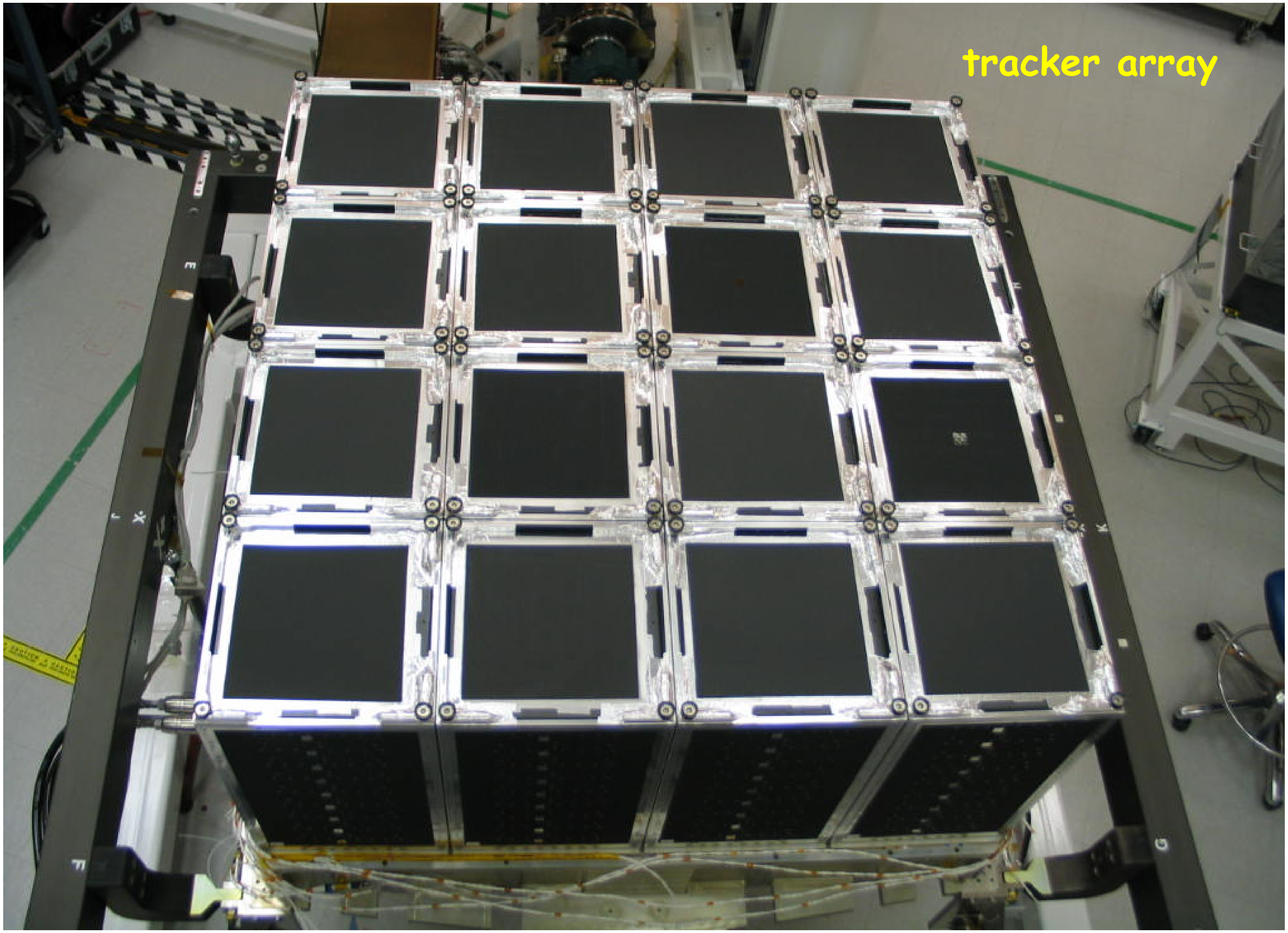
The final touch: a little magic

………………

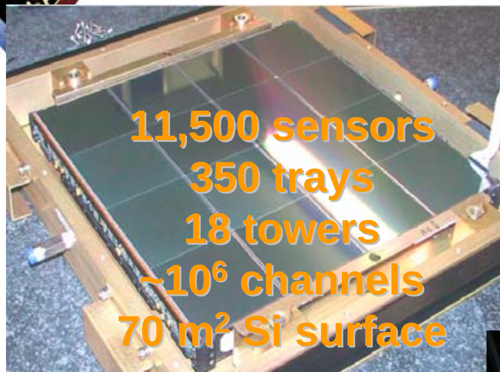

et voilà : the AGILE silicon tracker:
the last step of a successful story
of > 40 years !

Thanks for this fantastic adventure!!!!!!

The Large Area Telescope

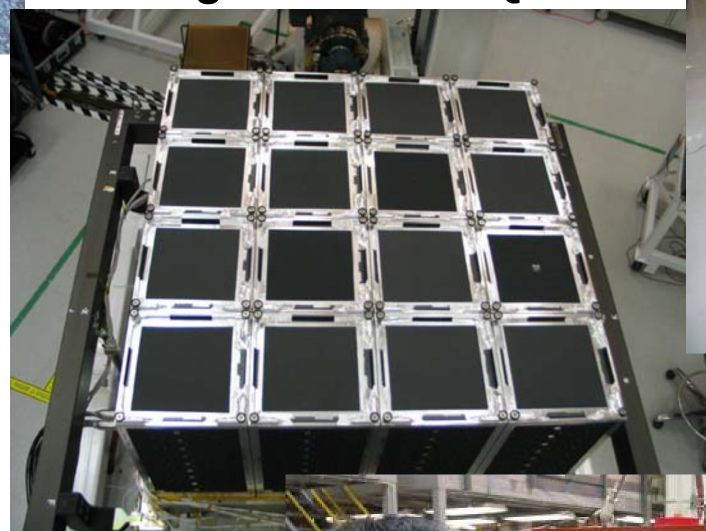


LAT Construction: An International Effort

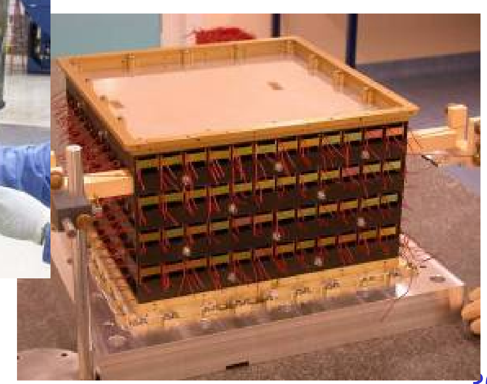


Tracker: US, Italy, Japan

Integration & DAQ: US



ACD: US



Calorimeter: US, France, Sweden

The near future: GLAST in orbit!