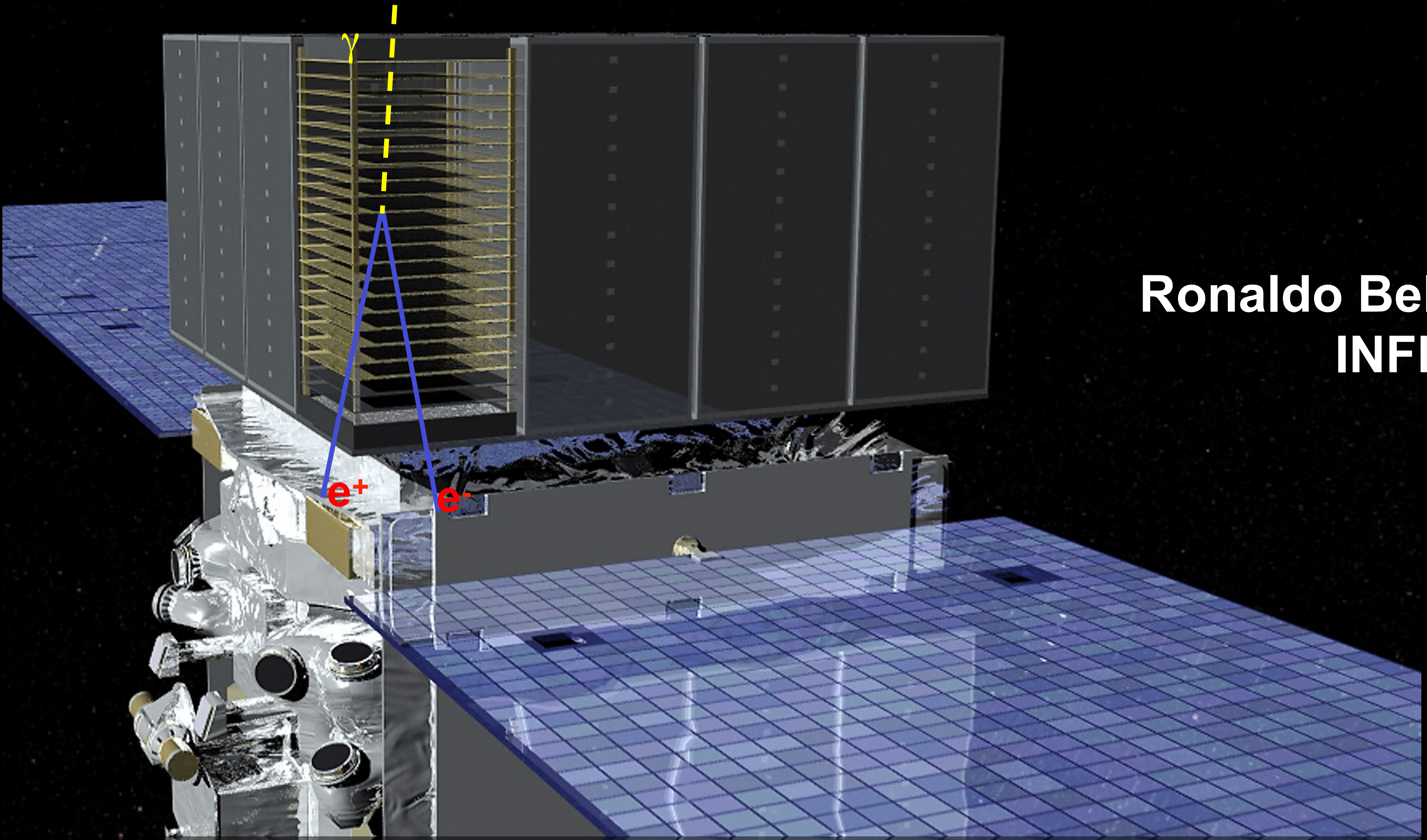
The construction of the largest silicon tracker in space on-board the Fermi Large Area Telescope



Ronaldo Bellazzini
INFN- Pisa

Outline

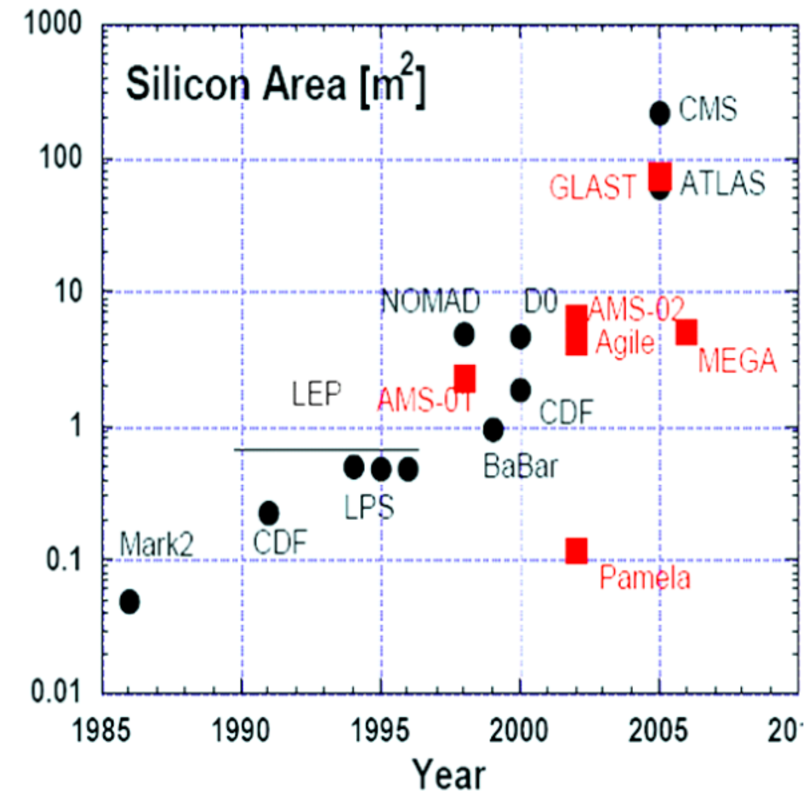
- Science requirements
- Silicon strip detectors for the LAT
- The Tracker subsystem
- LAT Tracker status

LAT TKR Requirements flowdown

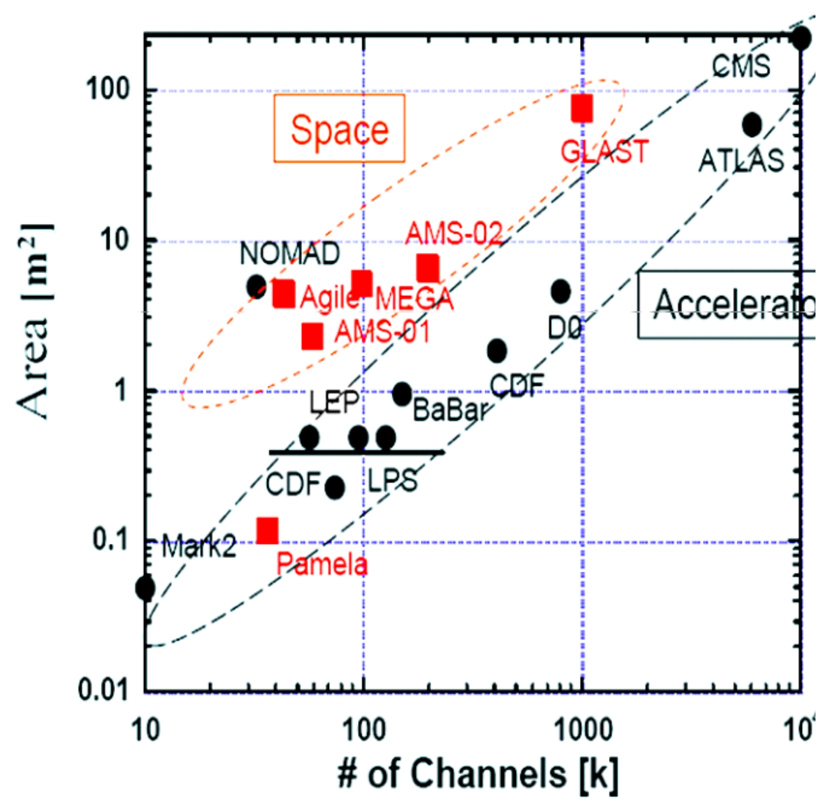
- **30-100x EGRET sensitivity O(10)MeV - O(100)GeV**
  - High efficiency
  - Large area
    - low cost per unit area
    - low power
- **Large field of view for transients**
  - Many thin converting layers
- **Long stable operations**
  - No consumables
  - High reliability
  - Uniform and stable response
  - Low operating voltage (~100V)

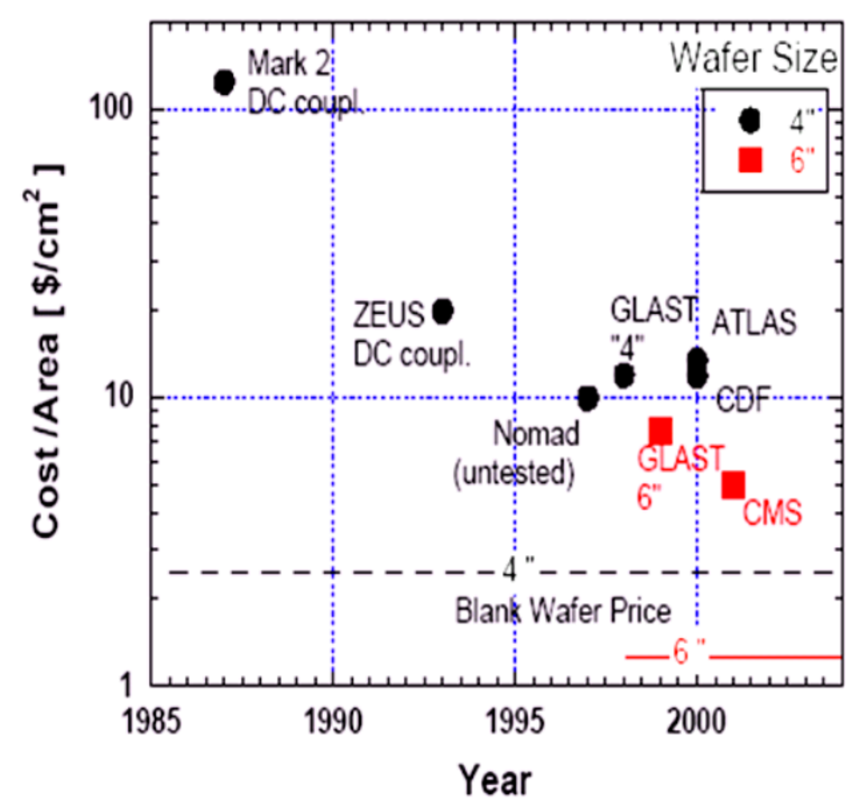
TKR Challenges - SSD

- **Cost at < 10$/cm^2**
  - simple robust design
  - large scale production
- **Power at ~ 180 μW / channel**
  - digital readout
  - custom ASICs for Front-End and control



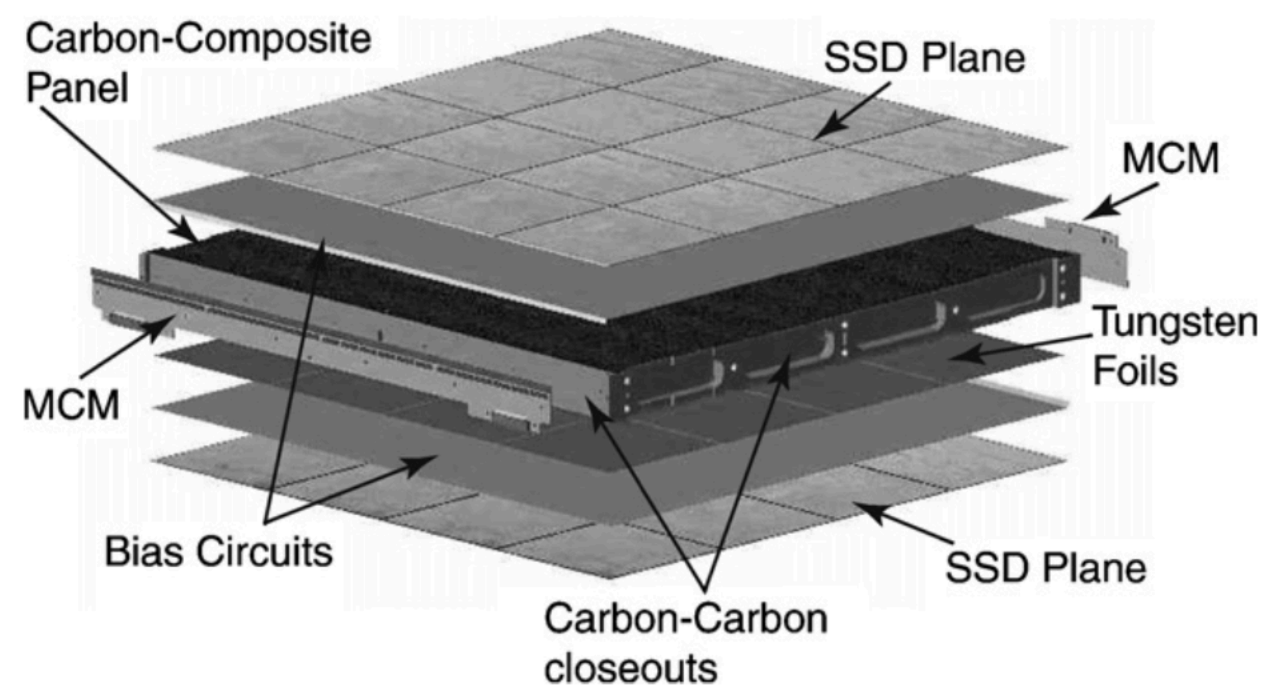
The fabrication of the GLAST-Fermi Silicon wafer paved the way to the Silicon Trackers of the CERN LHC Experiments

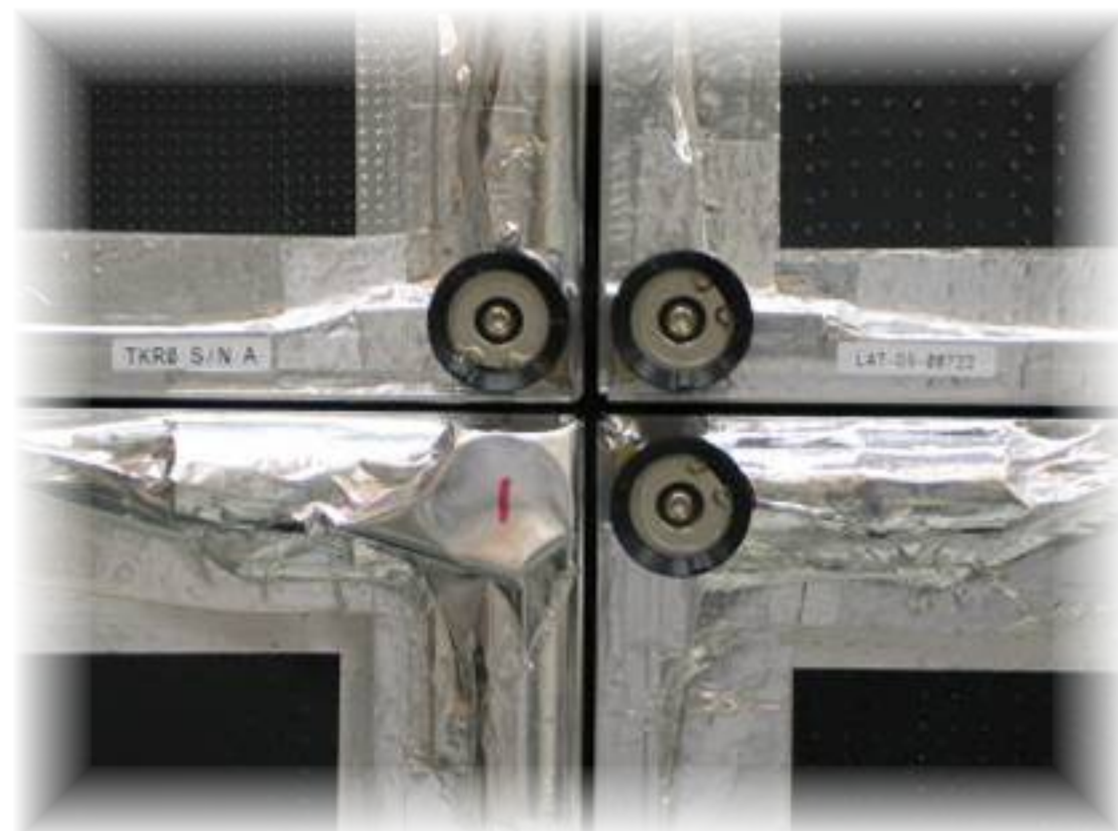




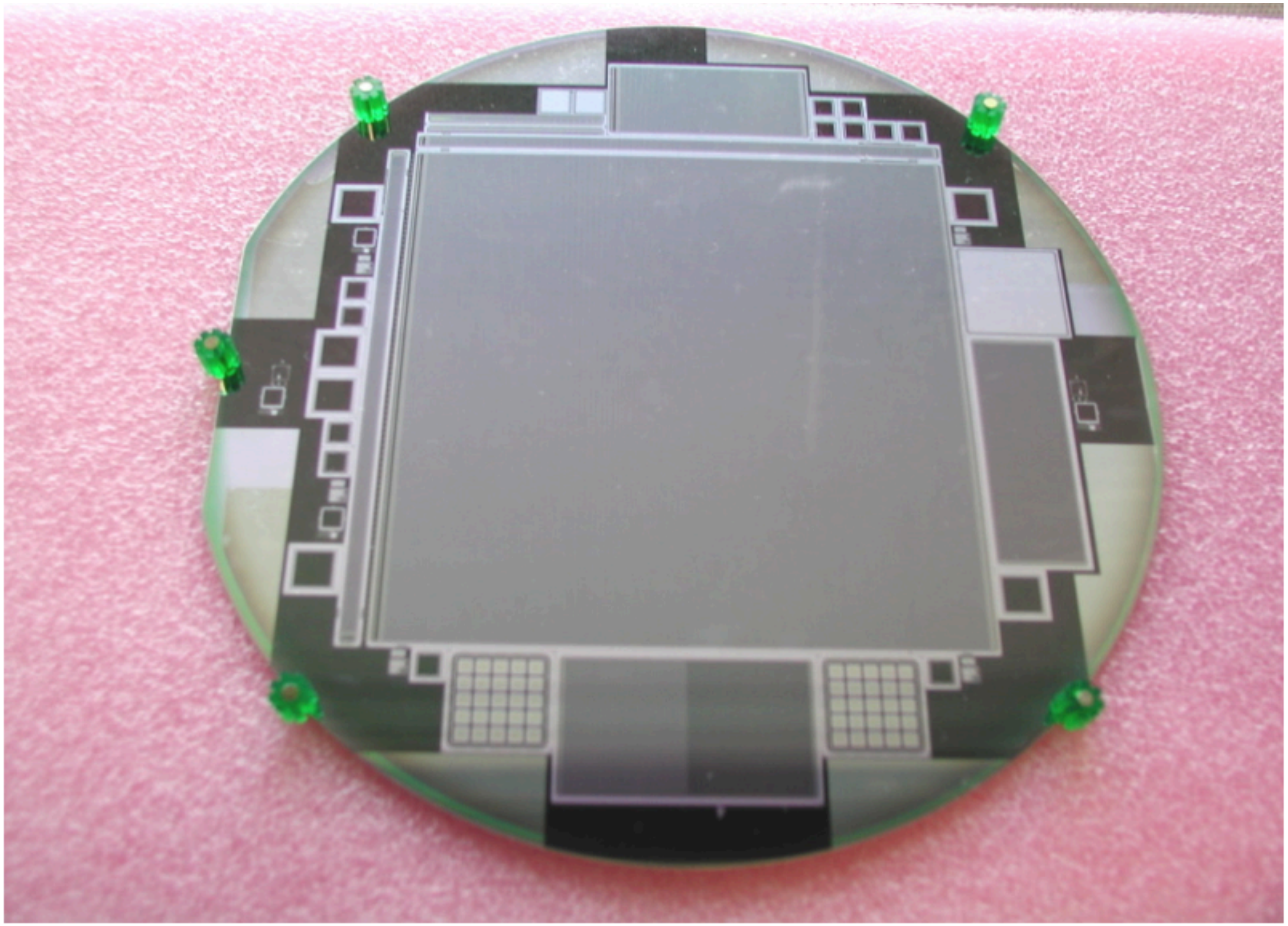
TKR Challenges - Mechanics

- **Carbon composite materials**
  - higher transparency to charged particles wrt standard aluminum
- **Tight mechanical tolerances**
  - minimize dead areas
    - < 2mm between Si layers
    - < 2mm between adjacent towers
- **RO electronics at 90° on the tray side**





In the beginning was the wafer ….

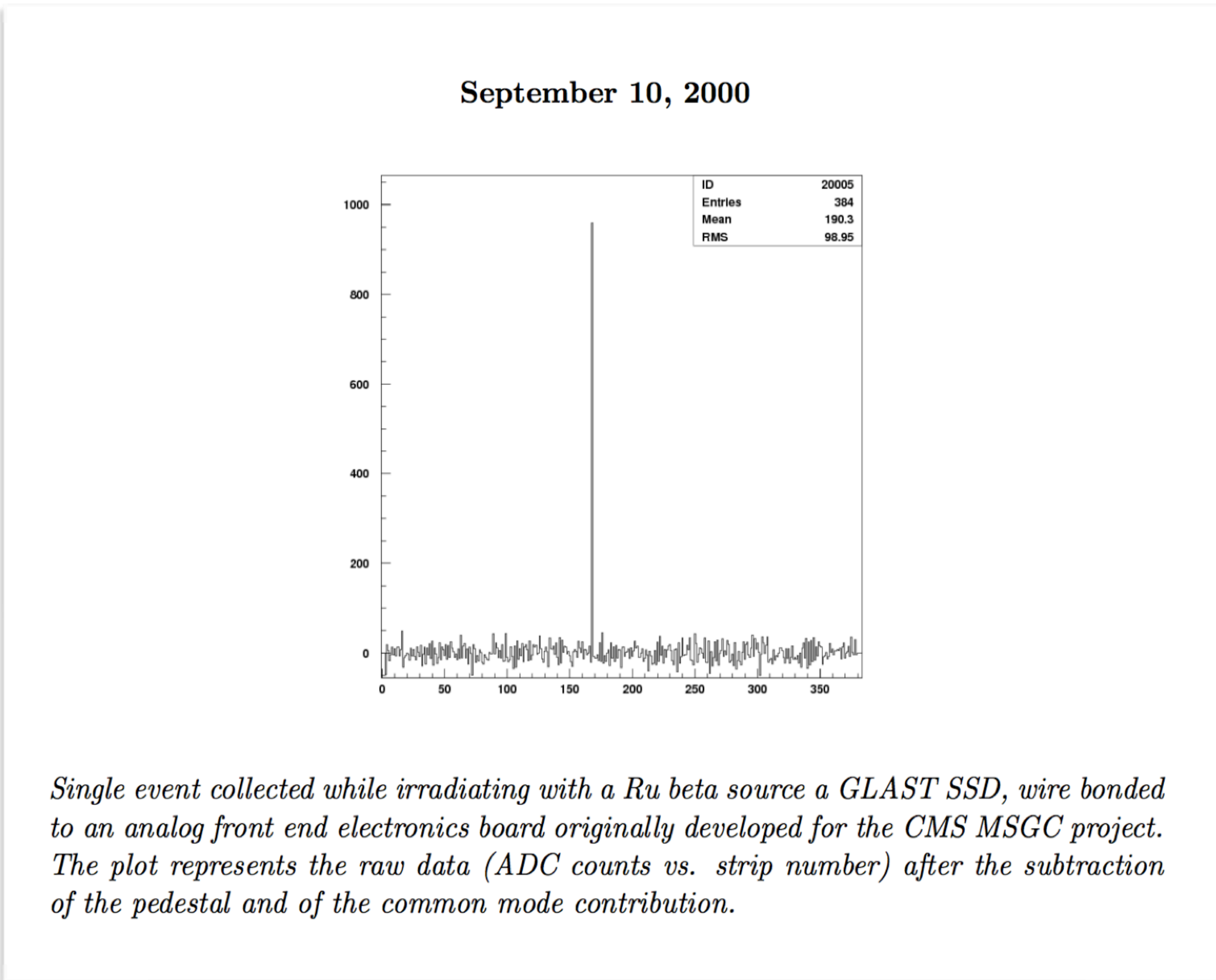


LAT Silicon sensors design

Wafer size	6”
Sensor size (cmxcm)	8.95X8.95
Thickness (μm)	400
Doping	n-type
Implant	p+
Read-out	Single-sided
Coupling	AC
Bias	Poly-Si
Strips	384
Strip pitch (μm)	228
Implant width (μm)	56
Bias voltage	< 120V
Breakdown	> 175V
Current (@150V)	< 500 nA < 200 nA (averaged any 100 SSD)
Bad strips rate	0.2%
Dicing precision	< 20 μm each corner

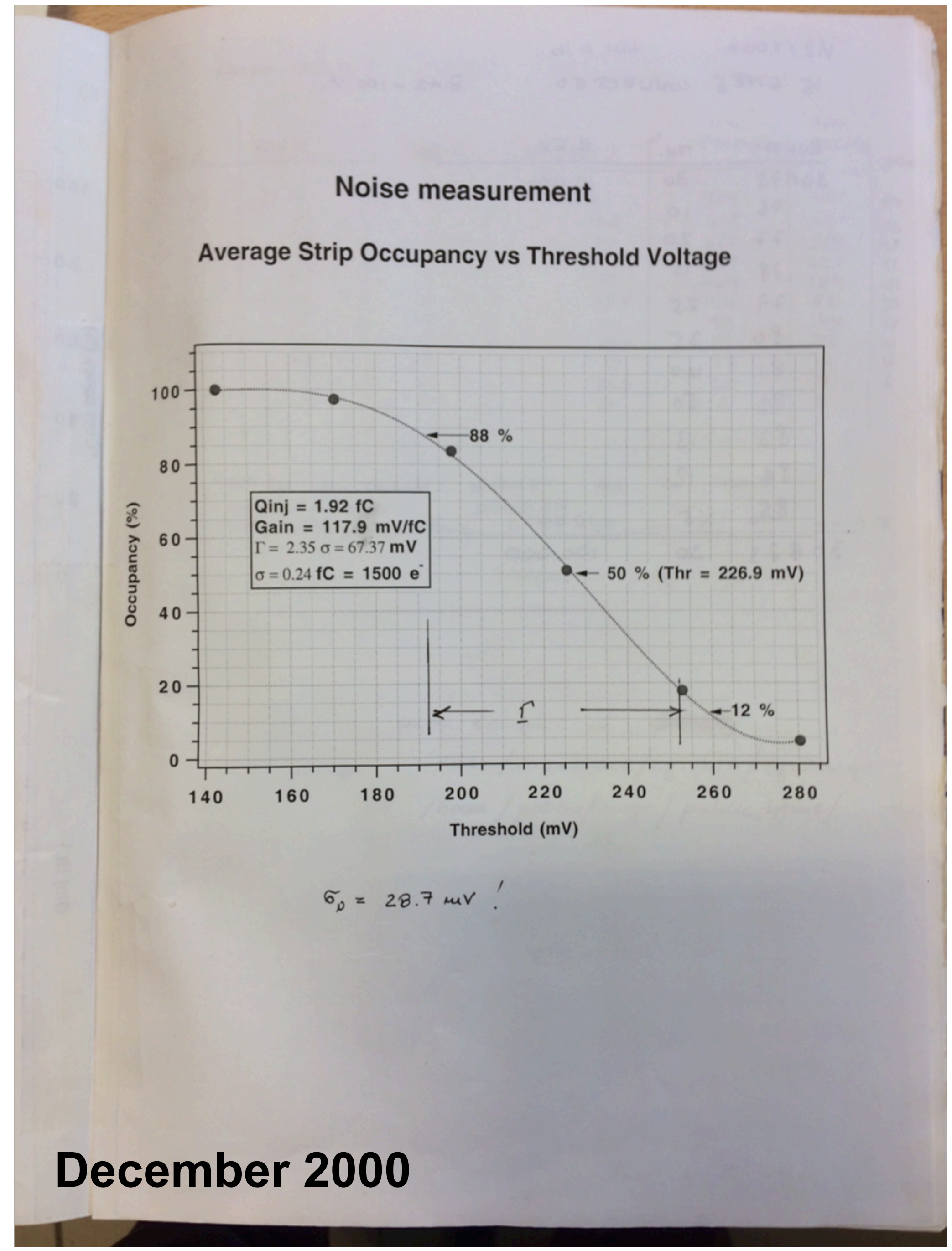
SSD initial tests in Pisa

First noise measurement of the digital electronics of GLAST-BTEM



Single event collected while irradiating with a Ru beta source a GLAST SSD, wire bonded to an analog front end electronics board originally developed for the CMS MSGC project. The plot represents the raw data (ADC counts vs. strip number) after the subtraction of the pedestal and of the common mode contribution.

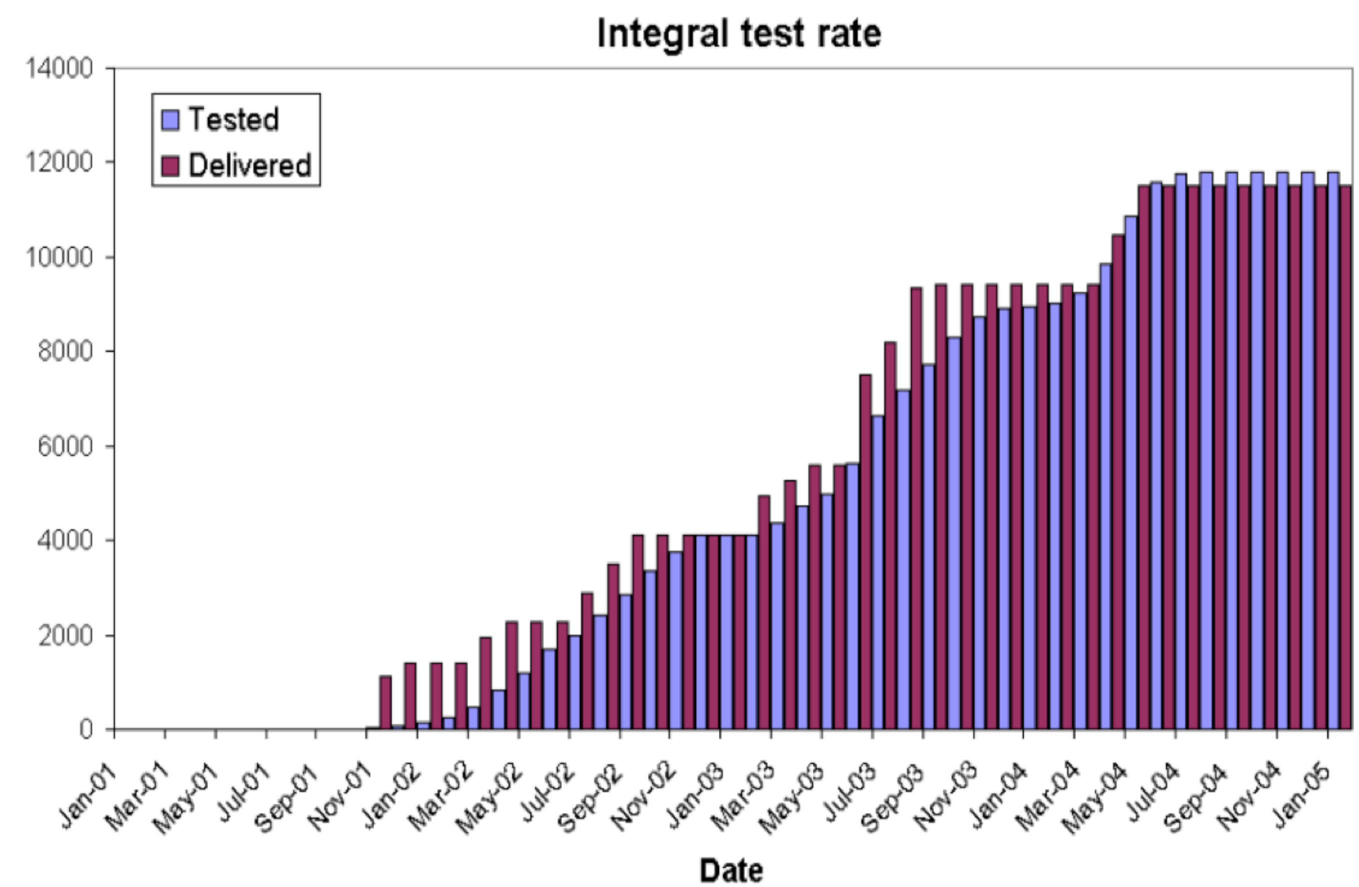
First signal from a GLAST SSD with the analog electronics of CMS-MSGCs

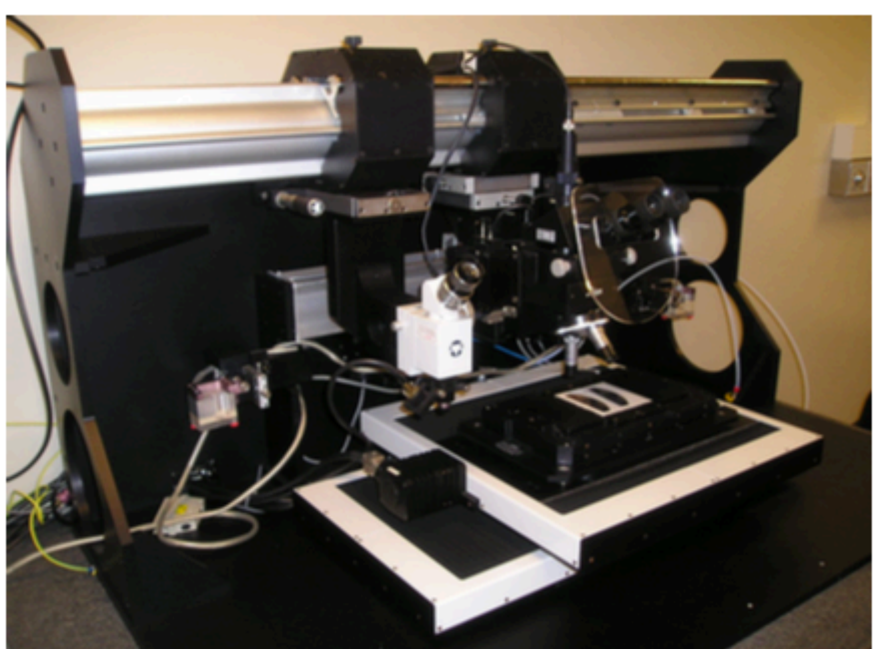


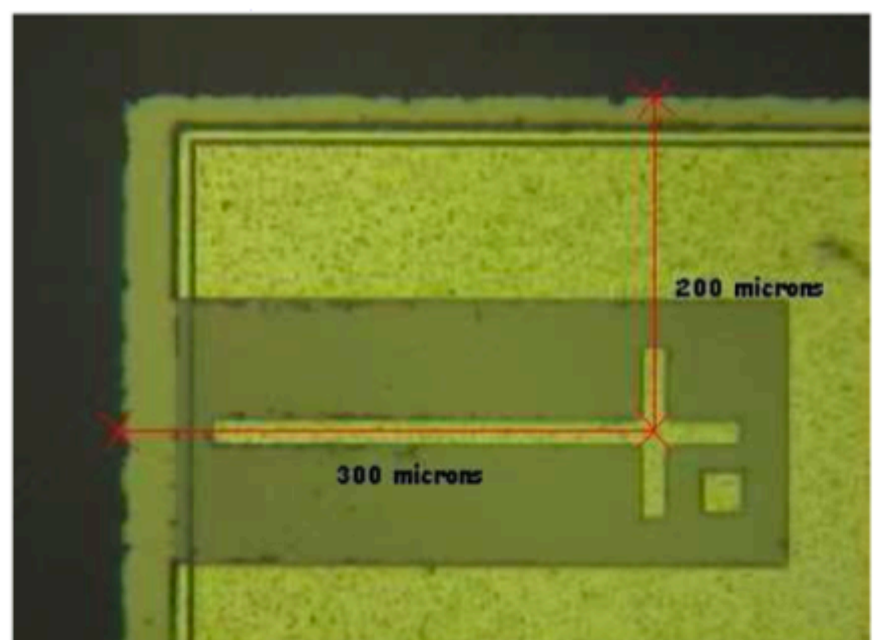
December 2000

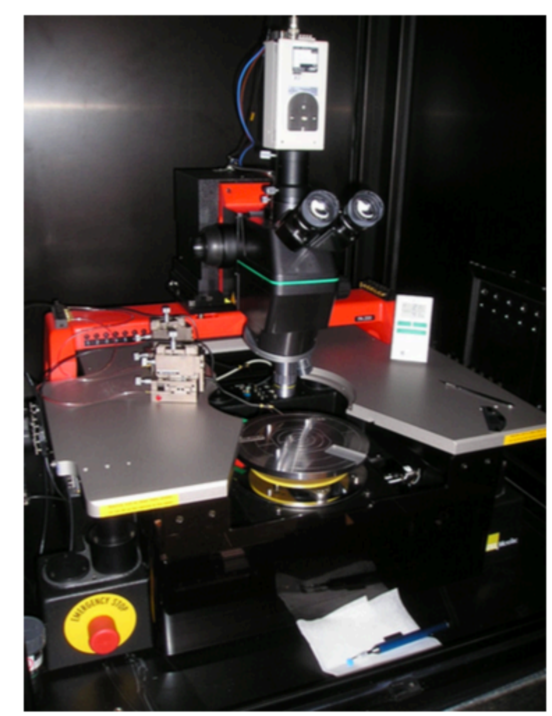
LAT SSD Production & Test

- **12500 SSDs produced by Hamamatsu Phot. in 3 yrs**
- **>90 m^2 of active Si**
  - 10368 for 18 towers + spare wastage, prototype
- **up to 700 SSD/month**
- **fully tested at HPK**
- **bulk IV, CV at INFN**

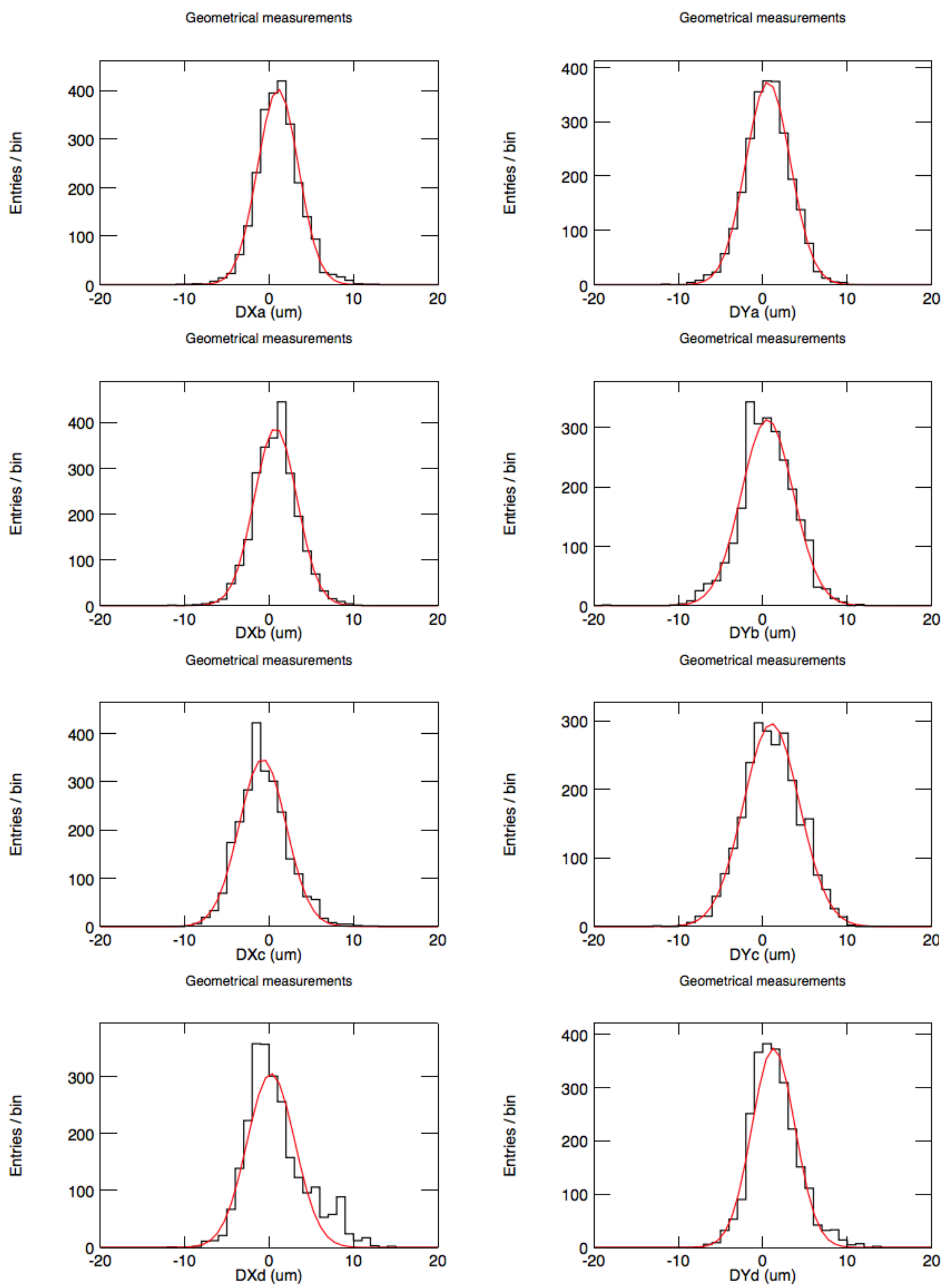




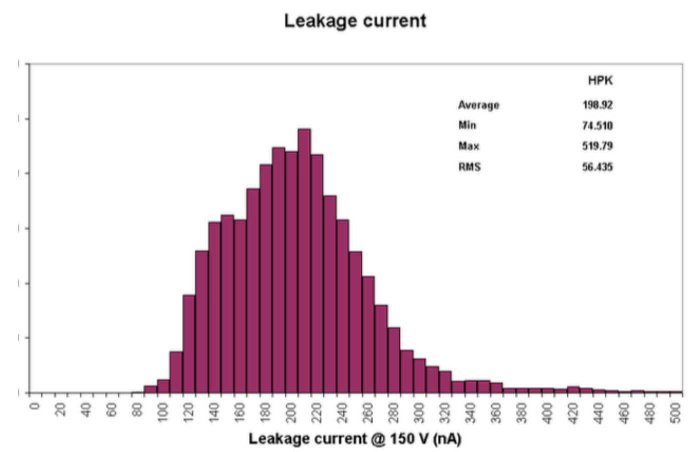


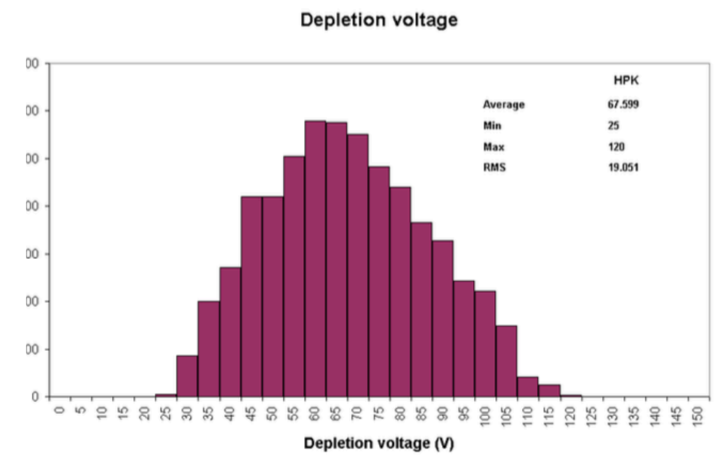


LAT SSD test results



few μm dicing accuracy





~nA/cm^2 current

~70V depletion voltage

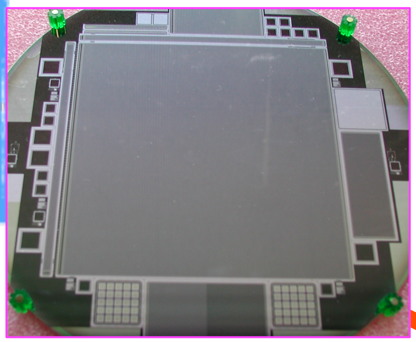
Final rejection rate		
Non conformance	**Number of rejected wafers**	**Fraction**
High leakage current	30	0.26%
High depletion voltage	3	0.03%
Low breakdown voltage	29	0.25%
Mishandling/transportation	10	0.09%
Large cut error	0	0%
Total rejected	67	0.58%

SSD overall rejection rate ~0.6%

Tracker construction workflow

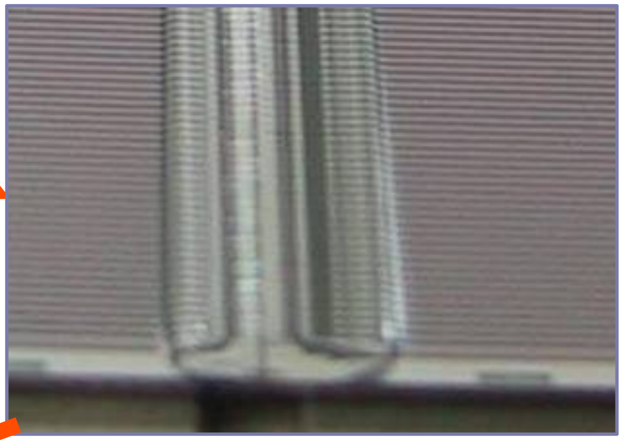
Module Structure Components
SLAC: Ti parts, thermal straps, fasteners.
Italy (Plyform): Sidewalls

SSD Procurement, Testing
SLAC,Japan, Italy (HPK)



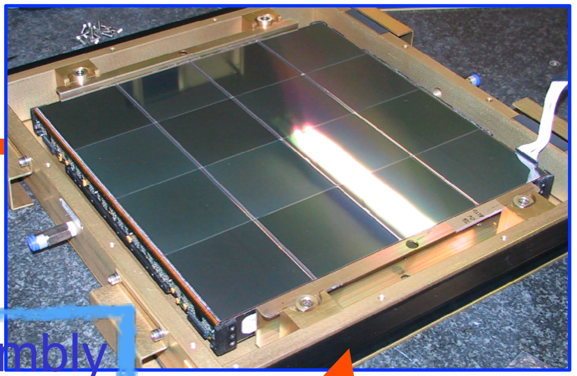
10,368

SSD Ladder Assembly
Italy (G&A, Mipot)

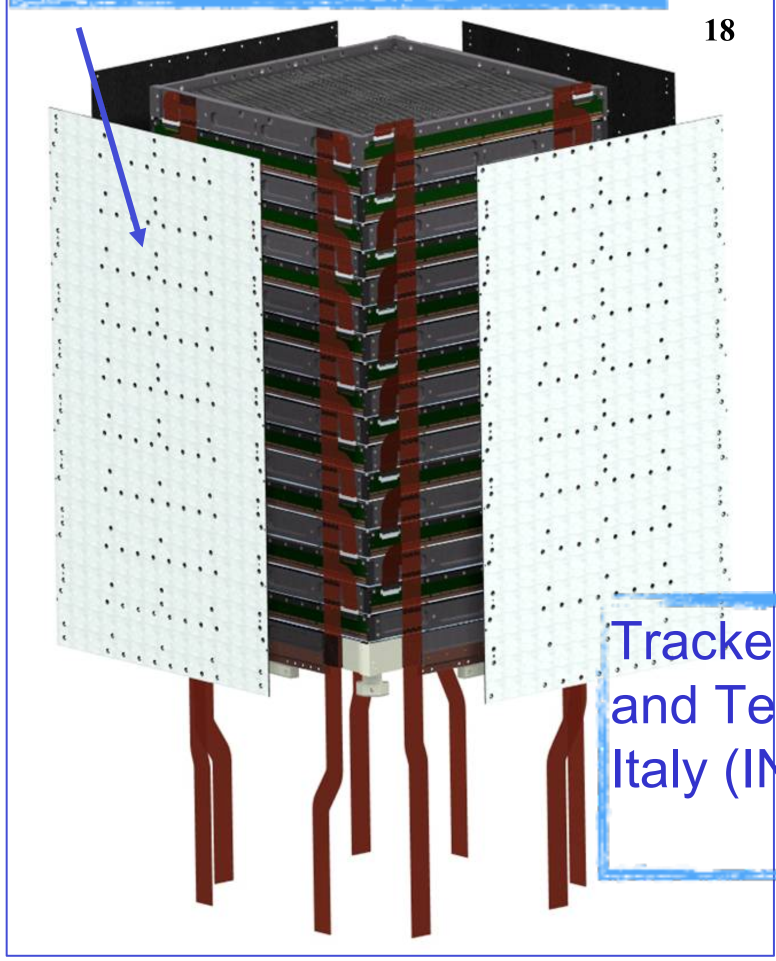


2592

342 inter-ladder // 100µm



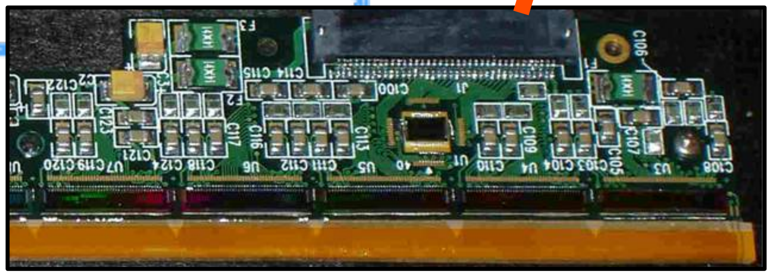
Tray Assembly and Test
Italy (G&A)



inter-tower stay-clear 2mm

Tracker Module Assembly and Test
Italy (INFN, Alenia Spazio)

648



342

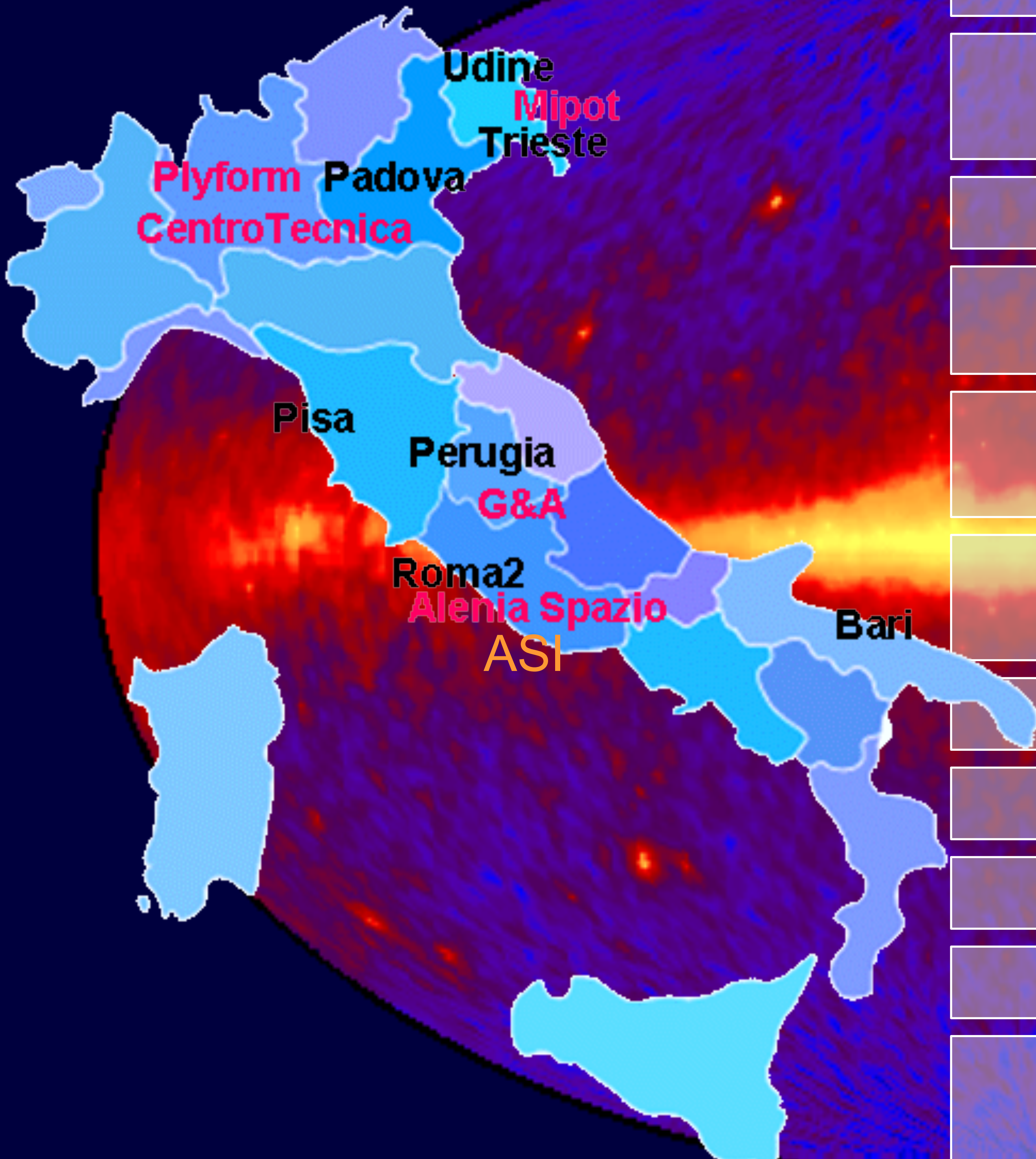
Readout Cables
UCSC, SLAC
(Parlex)

Electronics Fabrication, burn-in, & Test
UCSC, SLAC (Teledyne)

Composite Panel, Converters, and Bias Circuits
Italy (Plyform): fabrication
SLAC: CC, bias circuits, thick W, Al cores

Italian responsibilities for the LAT-TKR construction

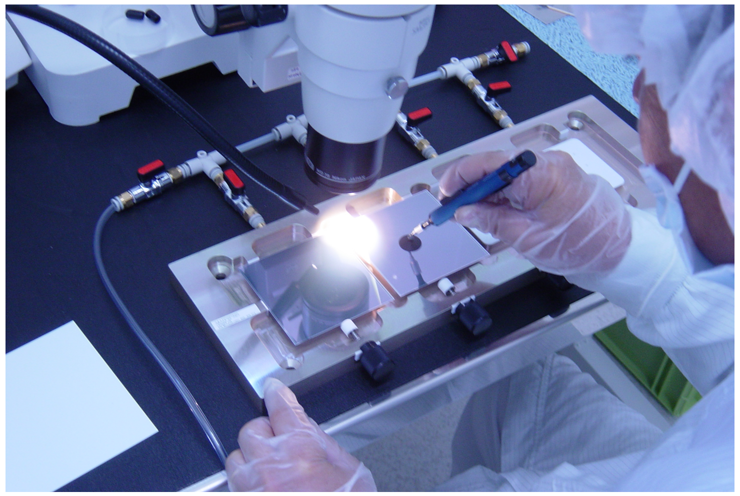
delivery of the GLAST TKR detector,16 towers, assembled and tested, by 09/2005

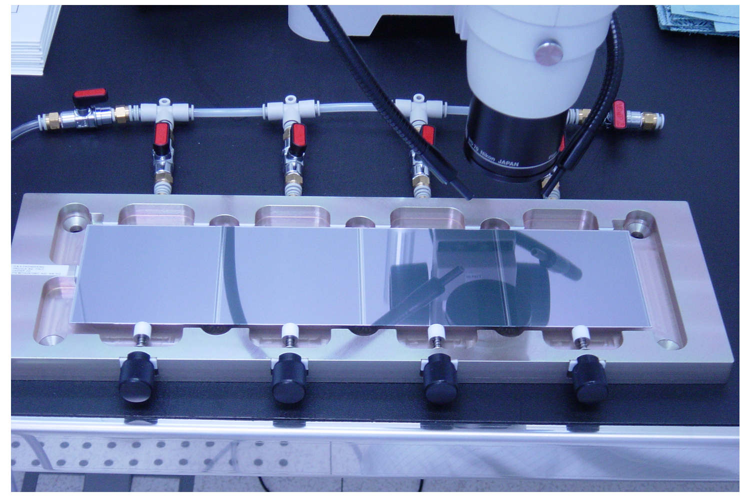


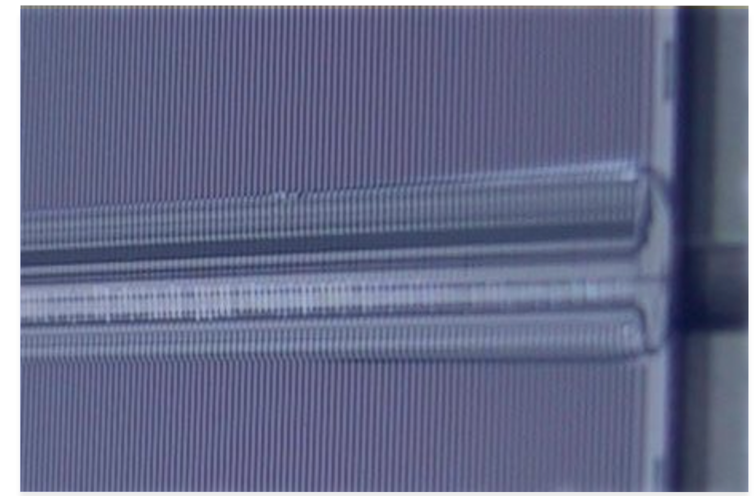
- SSD procurement and test (INFN/ASI)
- Ladder assembly (G&A/Mipot) and test (INFN/ASI)
- Trays panels production (Plyform)
- Trays panels structural test (ESPI/static) (INFN-Pisa)
- Trays panels thermal-vacumm test (INFN/ASI)
- Trays panels integration with ladders and electronics (G&A)
- Trays functional test (INFN/ASI)
- Trays C.R. burn-in test (INFN/ASI)
- Tower assembly (INFN/ASI)
- Tower functional test (INFN/ASI)
- Tower environmental test (Alenia/INFN/ASI)

From 2001 to 2005 – 60 INFN people involved: physicist, engineers, technicians

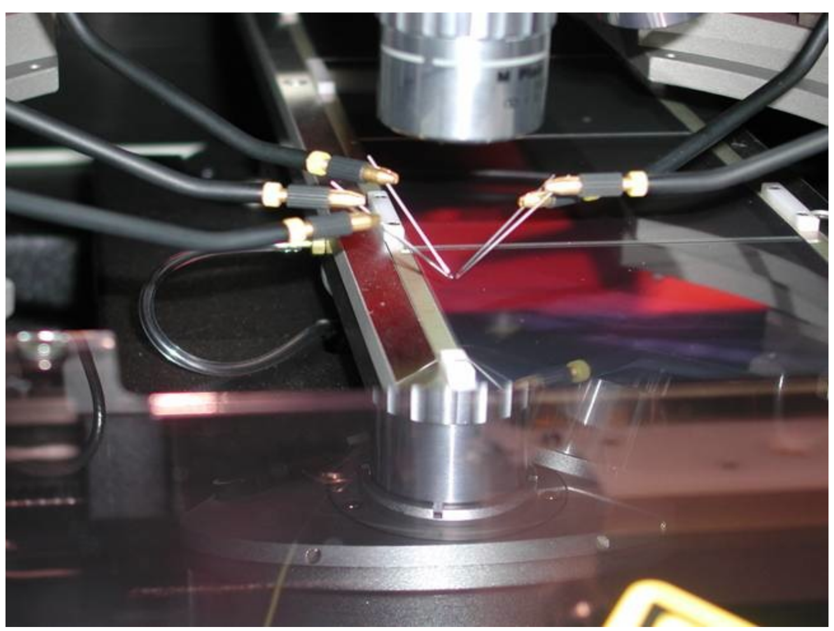
G&A for GLAST

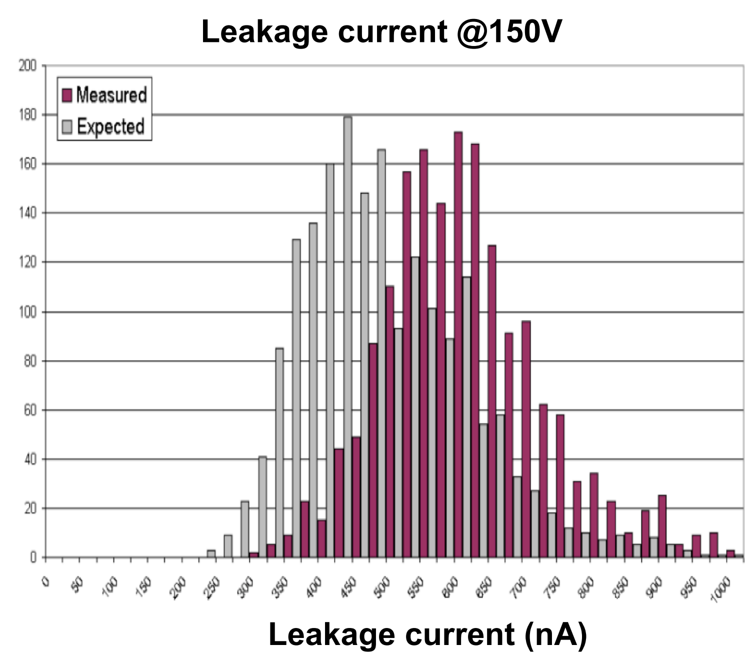


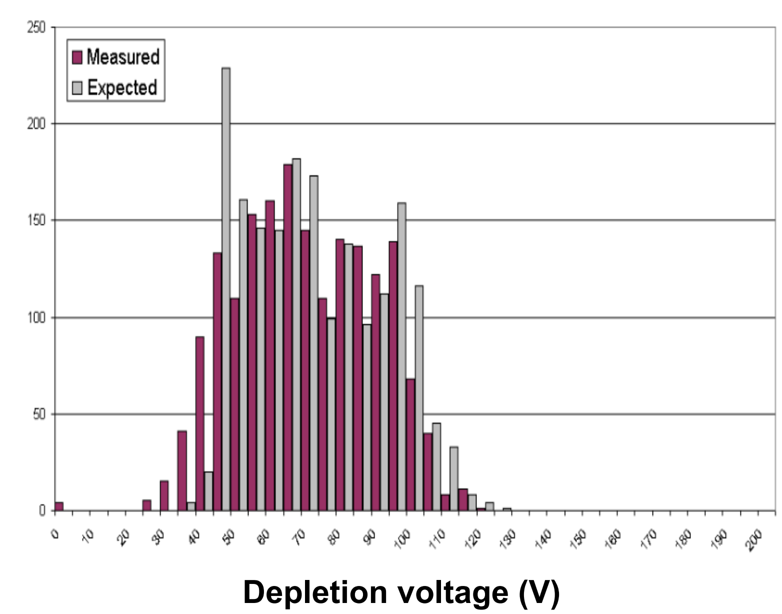




Ladder Assemblig & Bonding



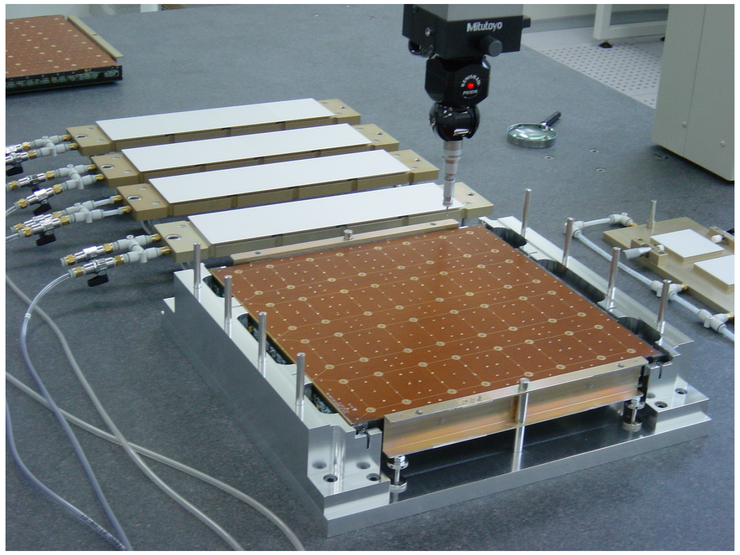




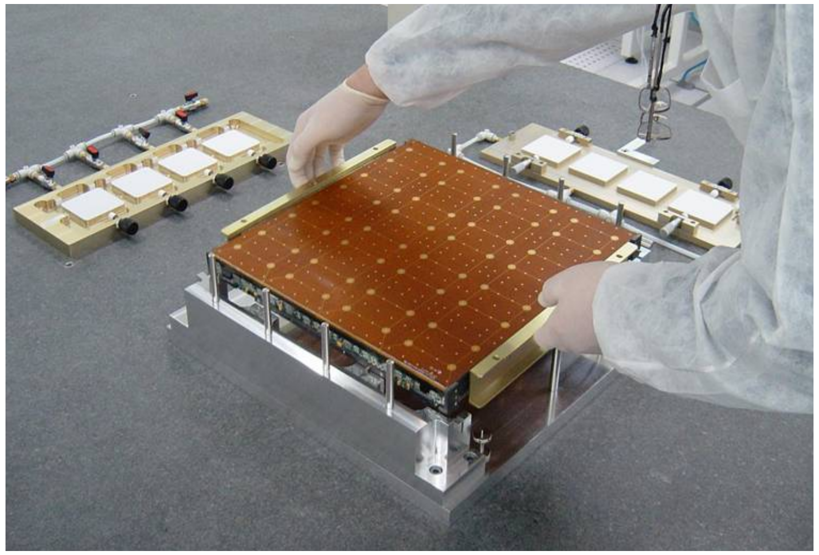
Ladder Testing

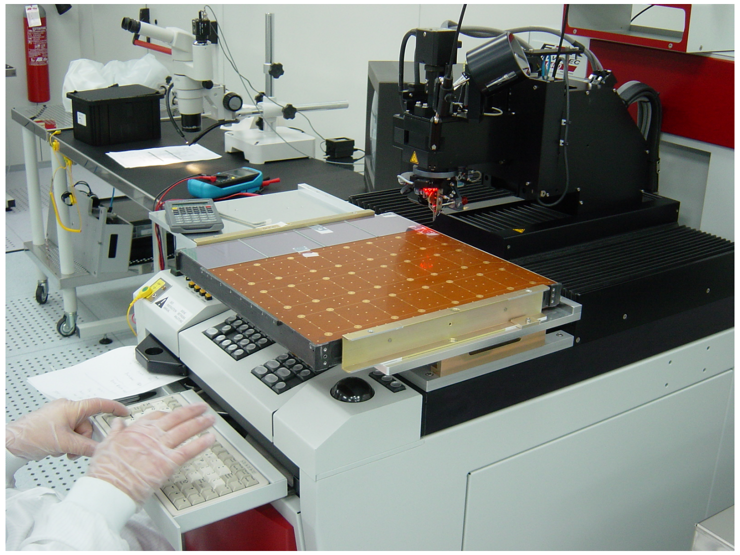
G&A for GLAST

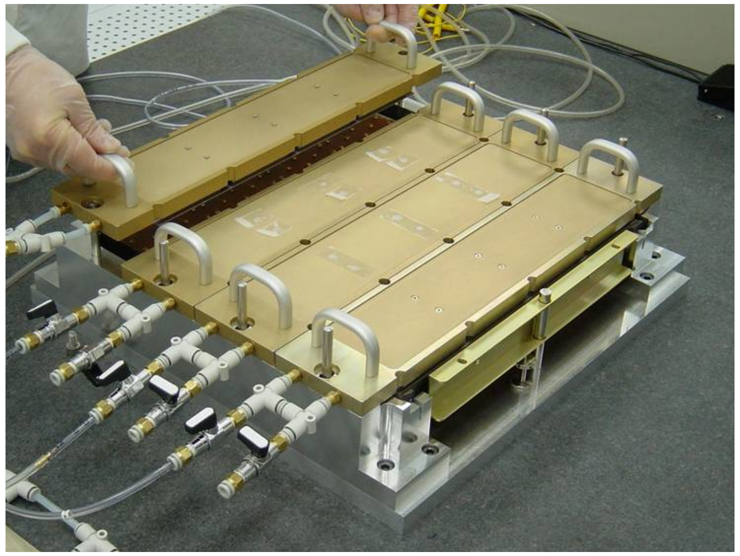
Tray Metrology



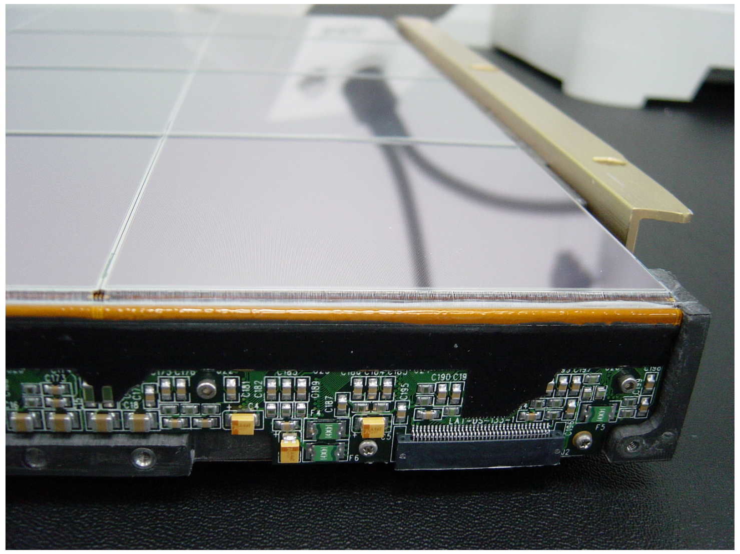
Tray Bonding preparation







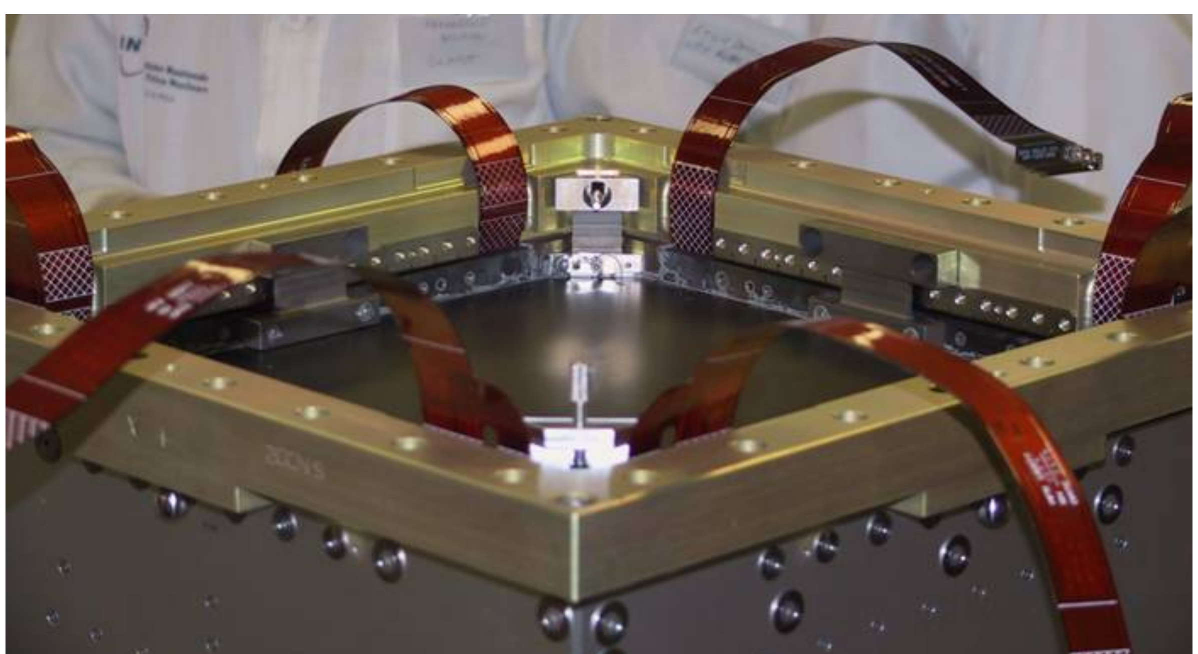
Tray Assembly

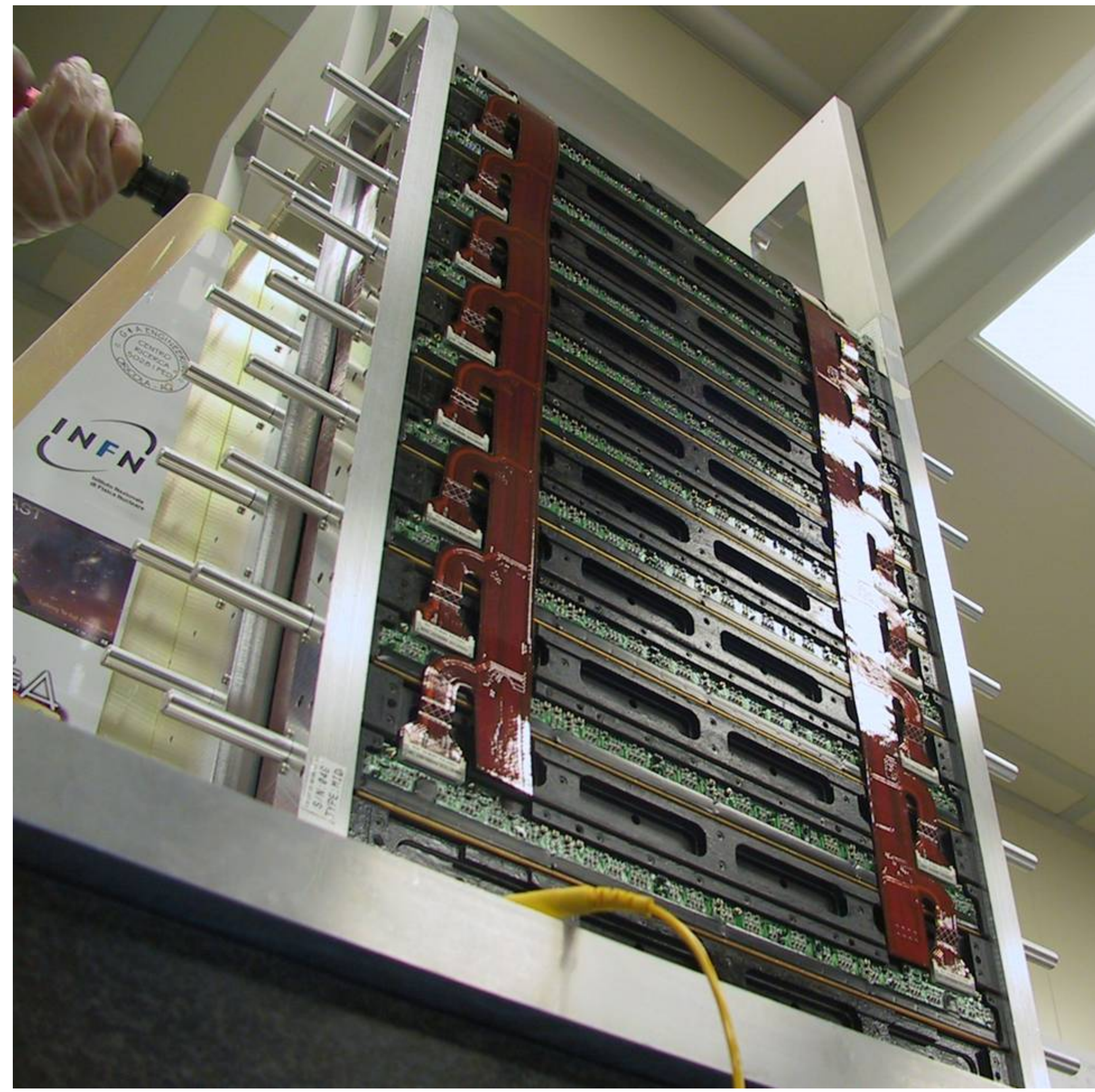


Tray Bonding

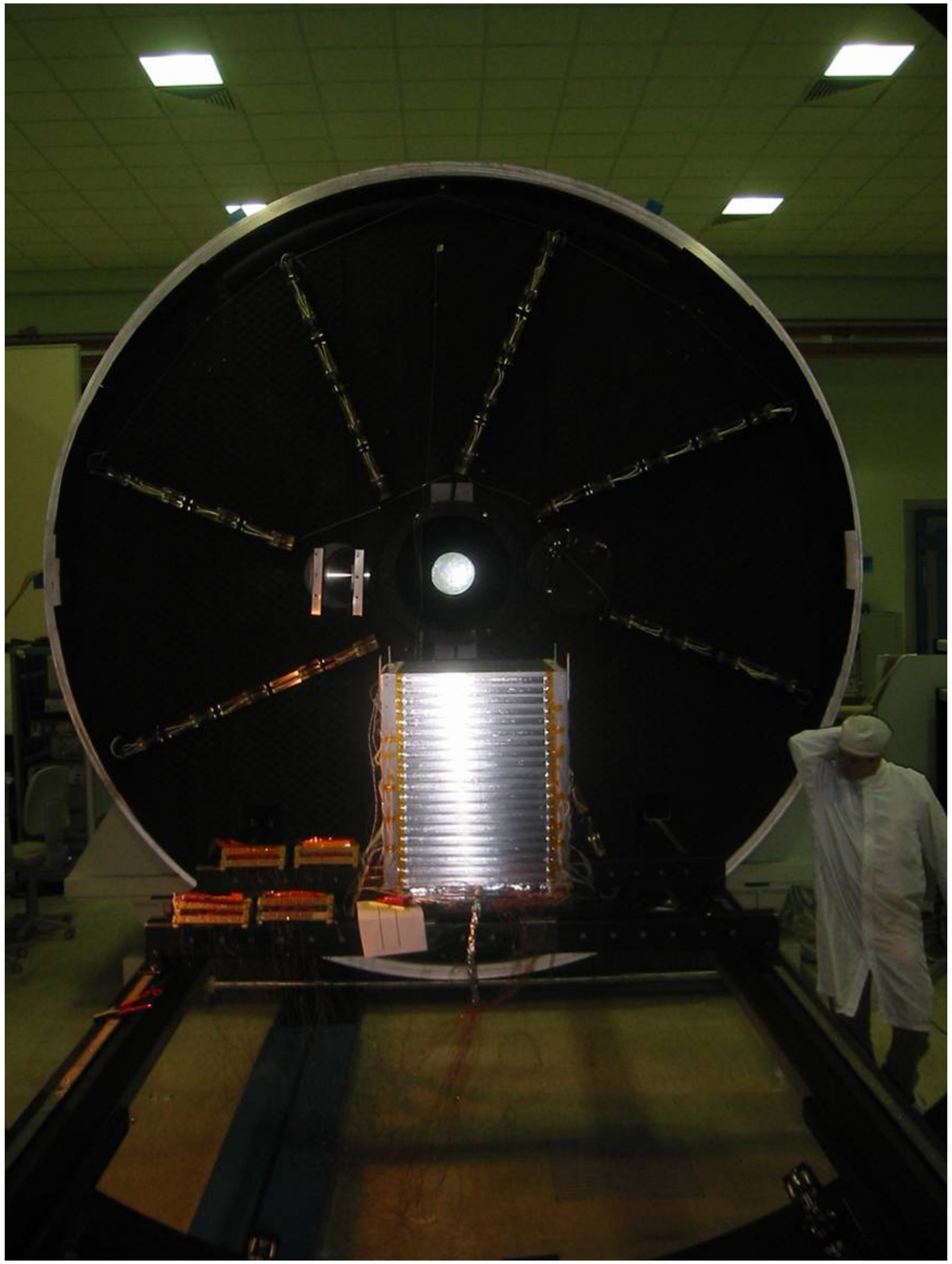
Functional test in Pisa

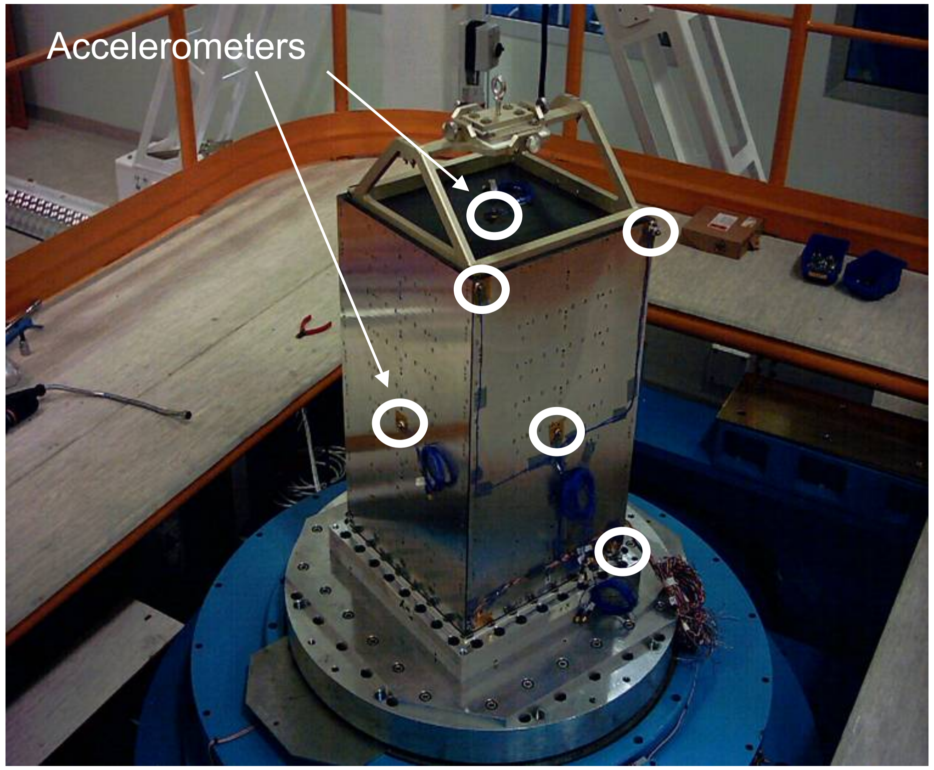
Tower Integration





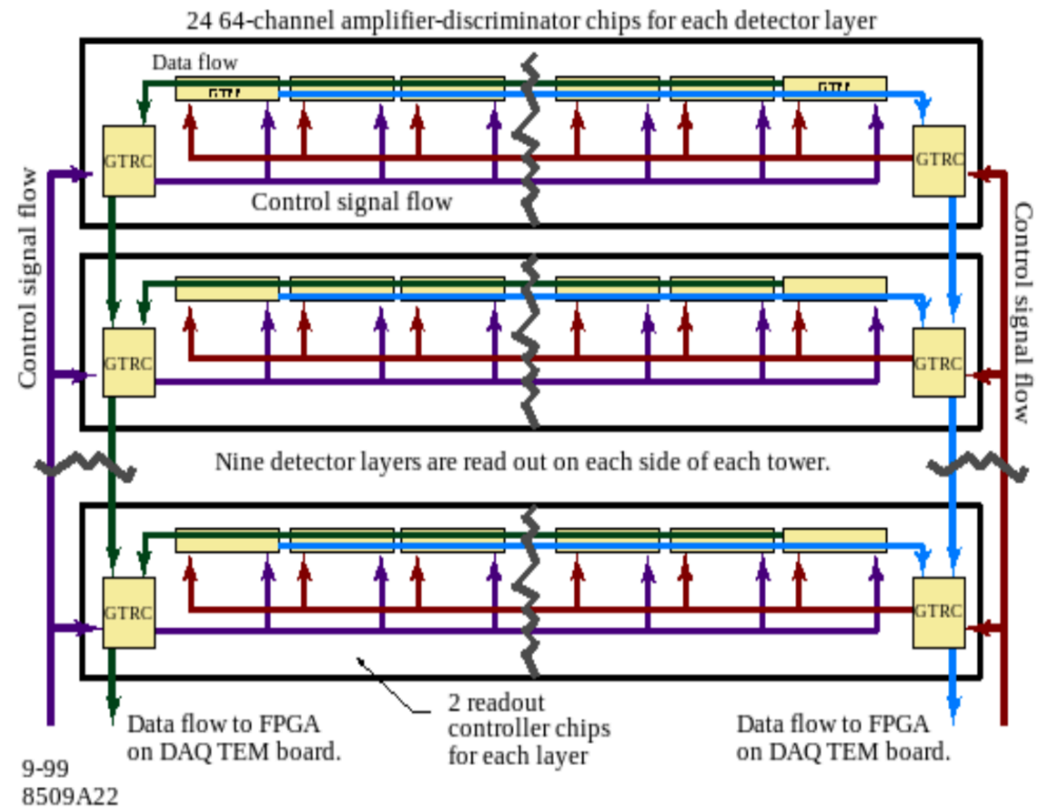
TKR Tower Environmental testing





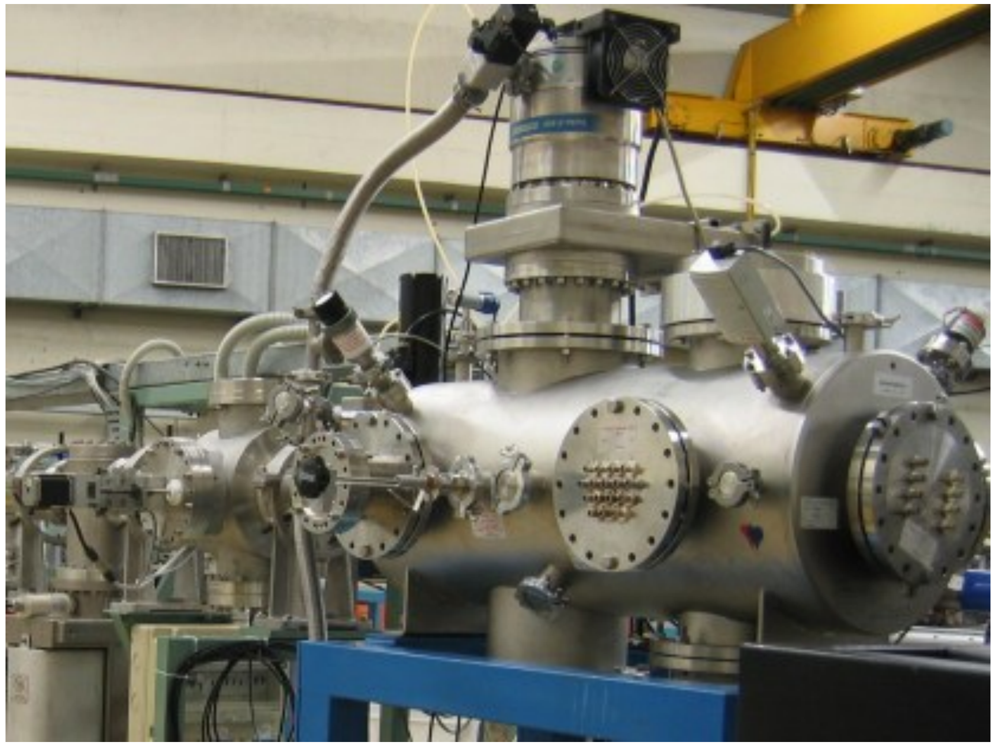
TKR Electronics

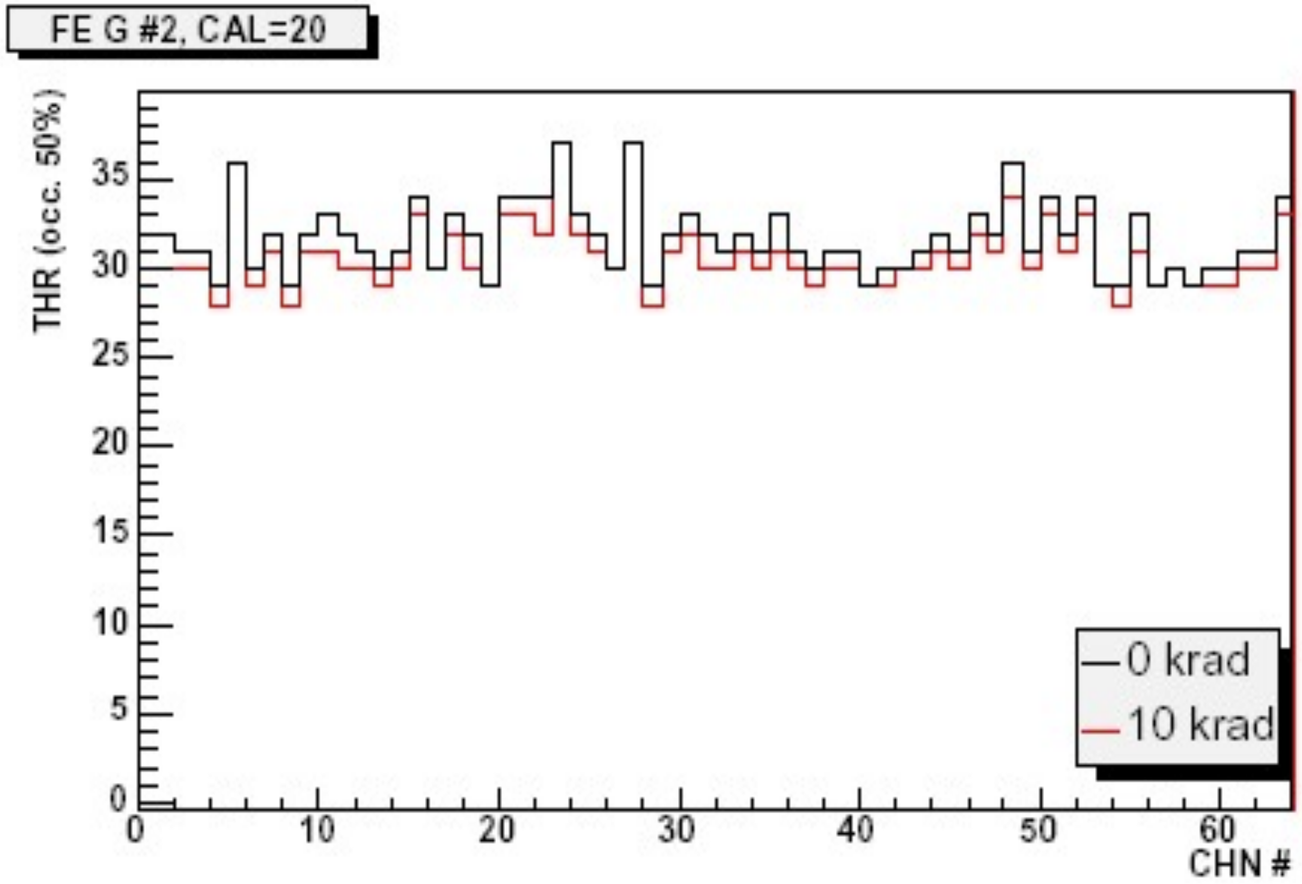
- **~14k Front End ASICs for charge amplification**
- **+1k Control ASIC for signal processing**
  - zero suppression
  - trigger generation
  - signal transmission
- **Demanding compact mechanical arrangement**



Radiation test of LAT TKR electronics in Padova

SIRAD facility in Legnaro



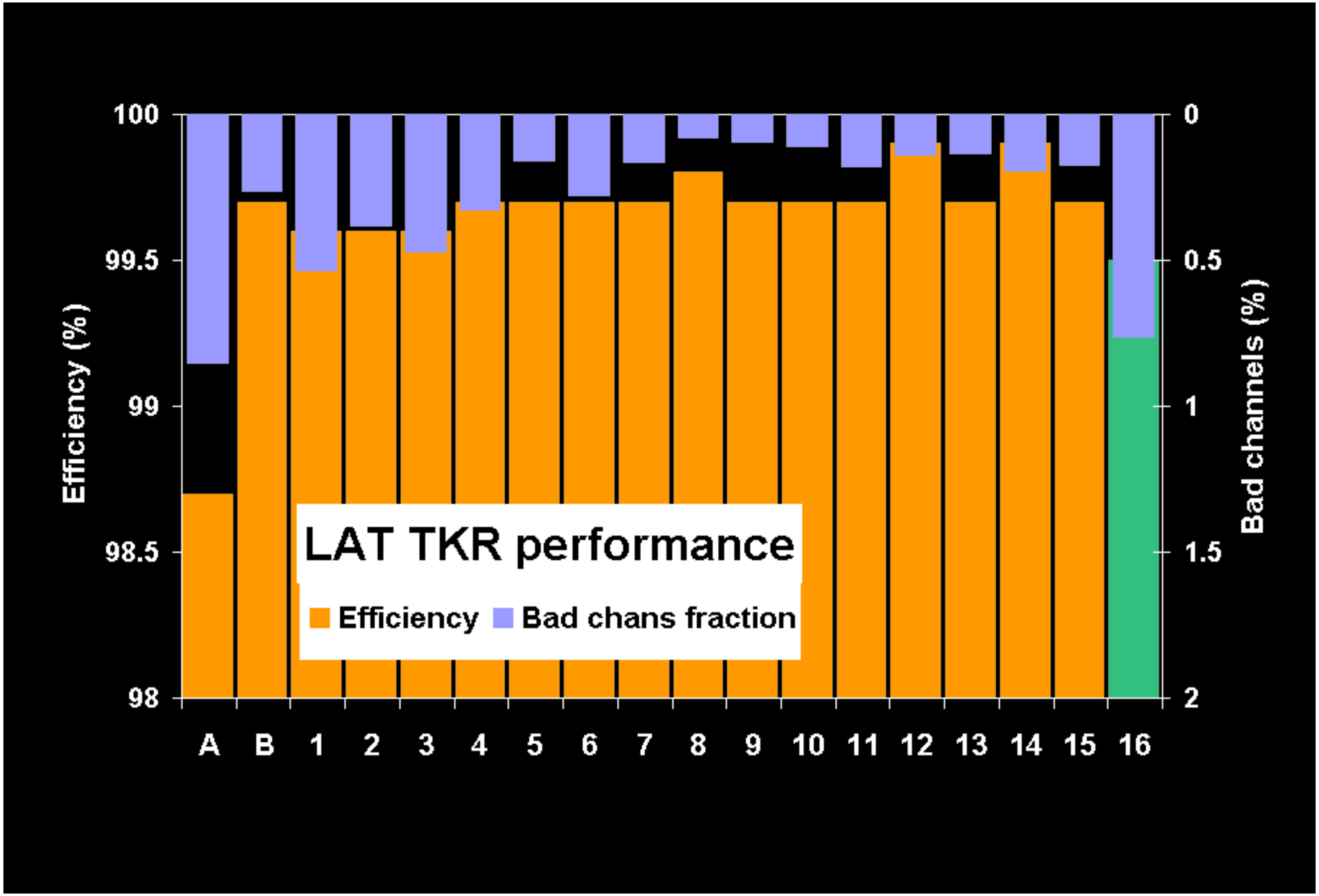


THR at 50% occupancy at 0 and 10 krad

TKR Performance Metric

Metric	Measurement
Active area at normal incidence	1.96 m^2
γ-ray conversion probability	63%
Active area fraction within a Tracker module	95.5%
Overall Tracker active area fraction	89.4%
Single-plane hit efficiency in active area	$\geq$ 99.4%
Dead channel fraction	0.2%
Noisy channel fraction	0.06%
Noise occupancy	$< 5 \times 10^{-7}$
SSD strip spacing	0.228 mm
Power consumption per channel	180 μW
Tower-module mass	32.5 to 33.0 kg
Maximum misalignment at top of module	0.59 mm
Maximum misalignment at bottom of module	0.29 mm

The LAT TKR Numbers

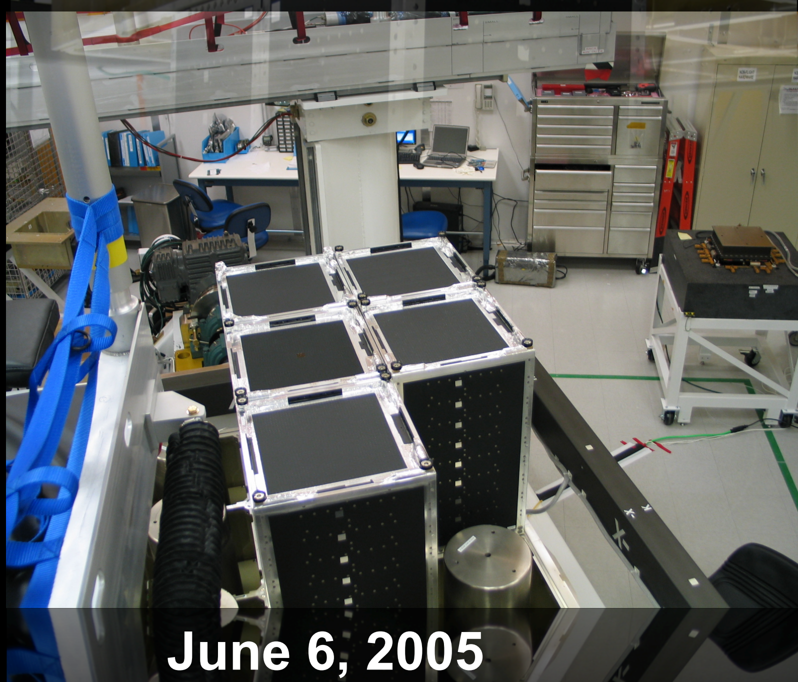


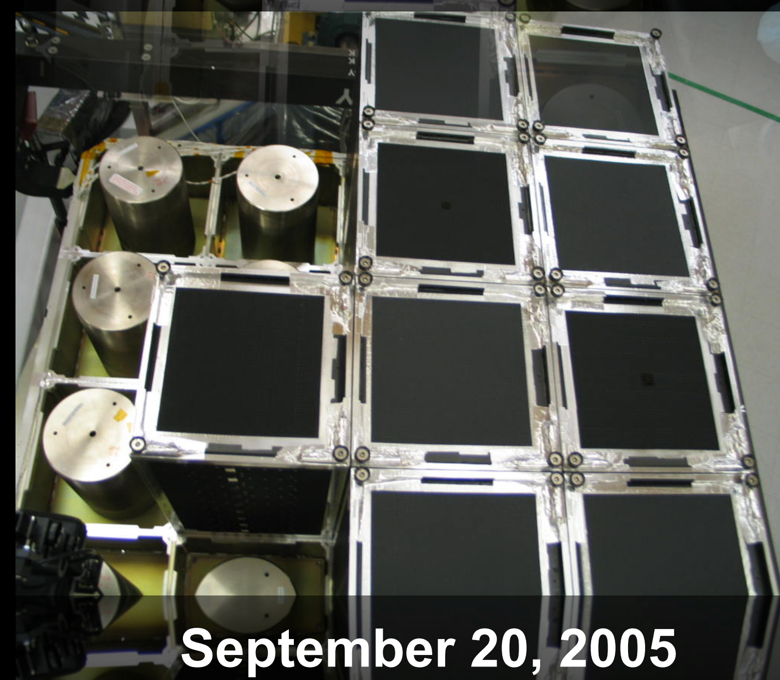
The last flight TKR Tower!

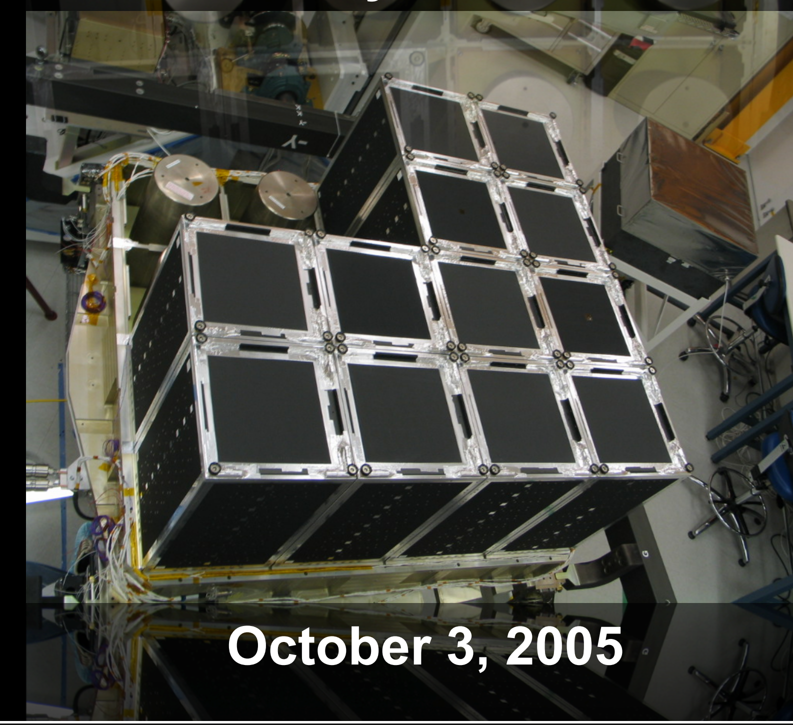

April 8, 2005

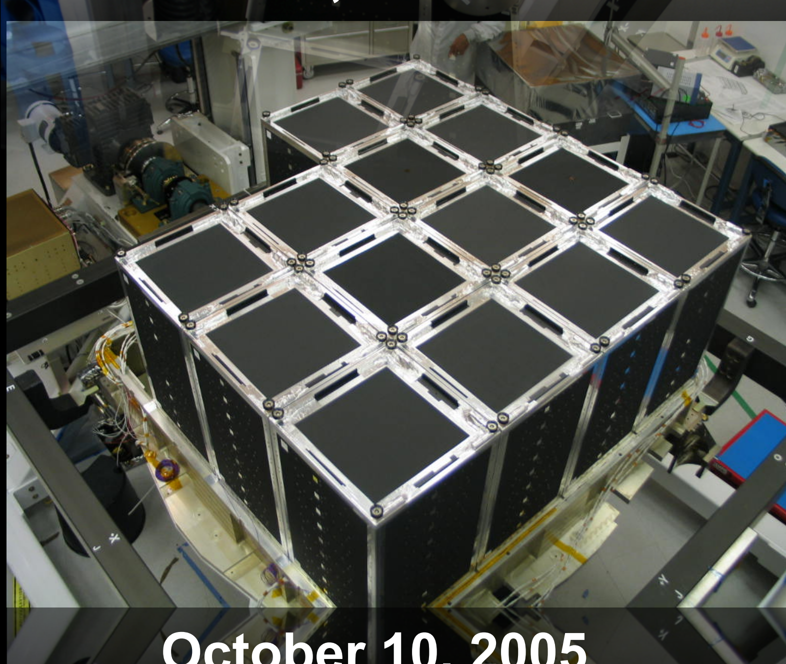

May 17, 2005


May 19, 2005

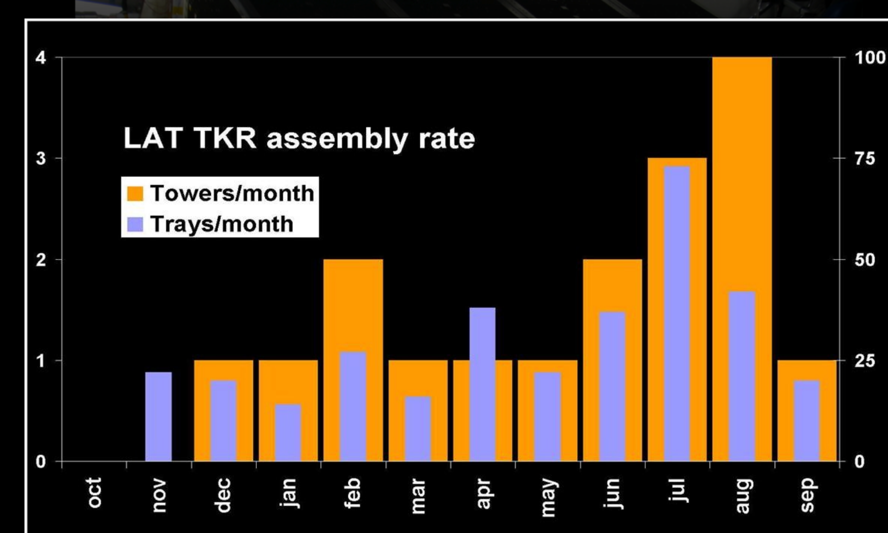

June 6, 2005


September 20, 2005

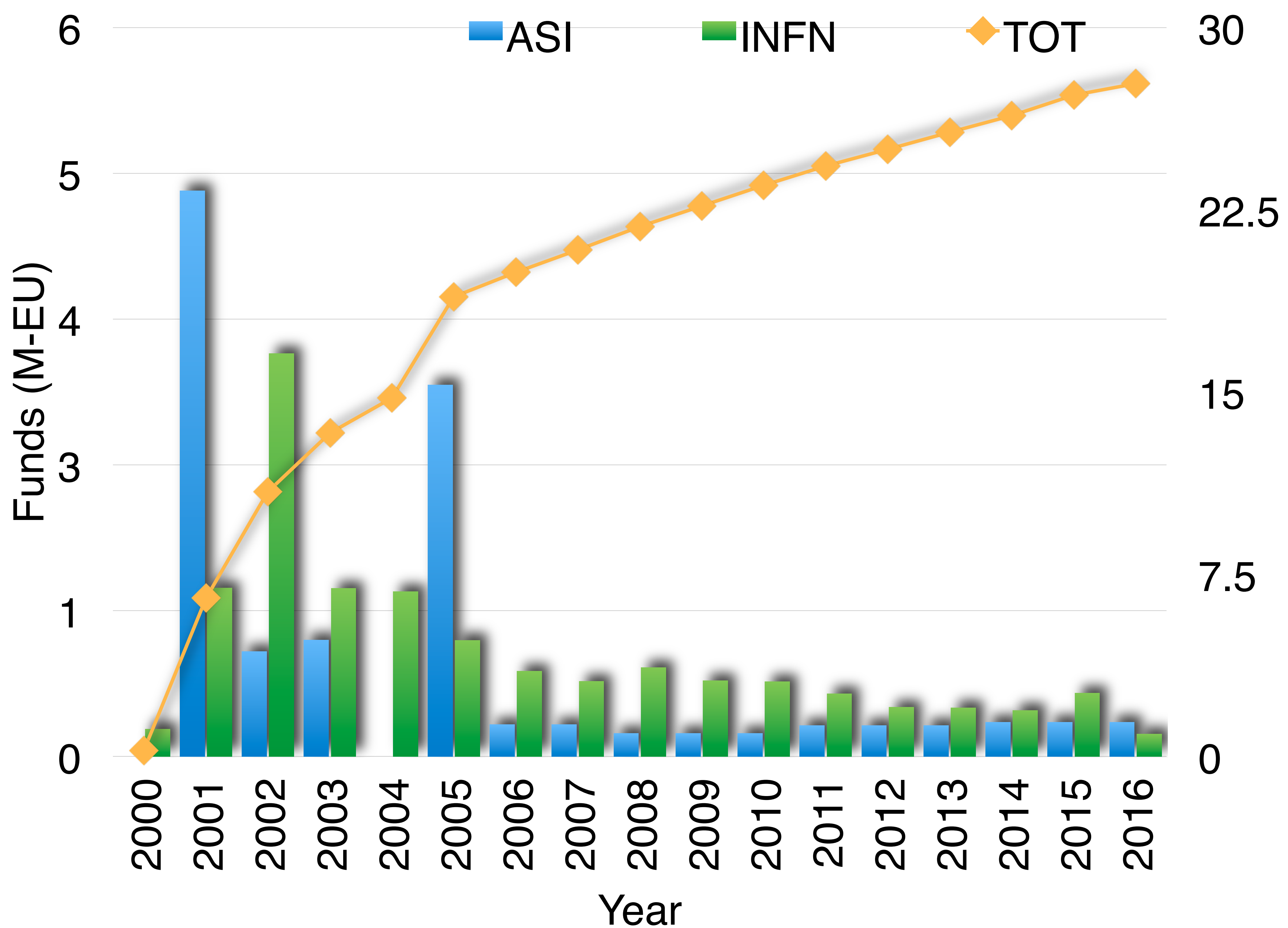

October 3, 2005


October 10, 2005


October 19, 2005: TKR integration complete!



Italian agencies investement



Awards for the LAT TKR construction completion

STANFORD UNIVERSITY
STANFORD UNIVERSITY, CALIFORNIA 94305-4060

ISTITUTO NAZIONALE DI FISICA NUCLEARE
PRESIDENZA
3/10/05 Prot. n° 4892 Arch. 9.15
Orig. Copia

DEPARTMENT OF PHYSICS

September 26, 2005

Professor Roberto Petronzio
President
Istituto Nazionale di Fisica Nucleare
Piazza dei Caprettari 70
00186 Roma
ITALY

Dear Professor Petronzio,

On the occasion of the completion of the GLAST Large Area Telescope (LAT) construction in Italy, I am writing to thank you and all of the INFN scientists and technical staff for achieving this very important milestone for the GLAST project. The entire GLAST Collaboration is grateful to our collaborators in Italy, led by Ronaldo Bellazzini, for this magnificent achievement.

Completion of the tracker construction required exceptional planning, skill, dedication, and team effort by Ronaldo and all of the scientists, engineers, and technicians in Italy who made it happen. The tracker flight towers meet or exceed the design requirements, insuring that the LAT will be a powerful instrument with great discovery potential when GLAST is launched in 2007. The LAT tracker now holds several records: i) the largest silicon tracker ever constructed (83 square meters of silicon-strip detectors), ii) the most efficient detector of its kind ever built, and iii) among the lowest noise occupancies of any silicon tracker. All of this and each module has been rigorously tested to verify that it will meet the demanding requirements of a space launch.

Between now and the end of this year the integration and testing of the LAT will be completed at SLAC. Already, more than 50% of the tracker and calorimeter modules are integrated and tested. So far the hardware is performing beautifully!

As the LAT nears completion, the collaboration is focusing more attention on data analysis and science preparation. These were the main topics at our collaboration meeting in early September. I am pleased to report to you that there is growing activity in all of the 9 science groups of the collaboration. These groups cover a broad range of science that GLAST will address. Italian scientists are active in all of these groups and are playing key leadership roles in several of the groups as coordinating leads.

Again, thank you so very much. If you have the opportunity to visit SLAC before we ship the instrument in early January for integration to the spacecraft, I would be happy to show you the LAT.

Regards,

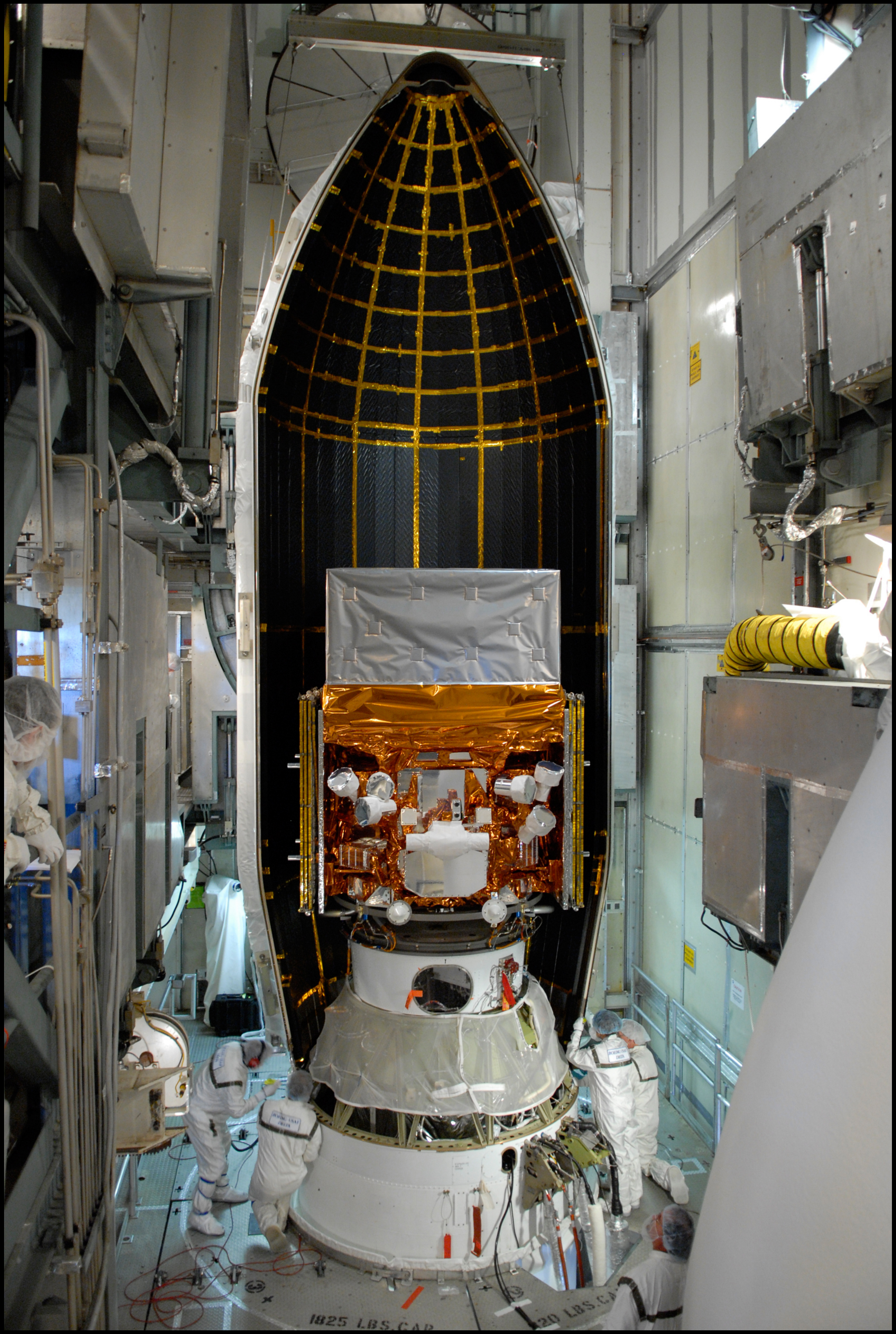
Peter F. Michelson
Professor of Physics and Professor SLAC (courtesy)
GLAST LAT Collaboration Spokesperson

The LAT Tracker records:

- largest Si tracker ever constructed ($83 m^2$) *(for the moment)*
- most efficient detector of its kind ever built
- among the lowest noise occupancies of any Si tracker

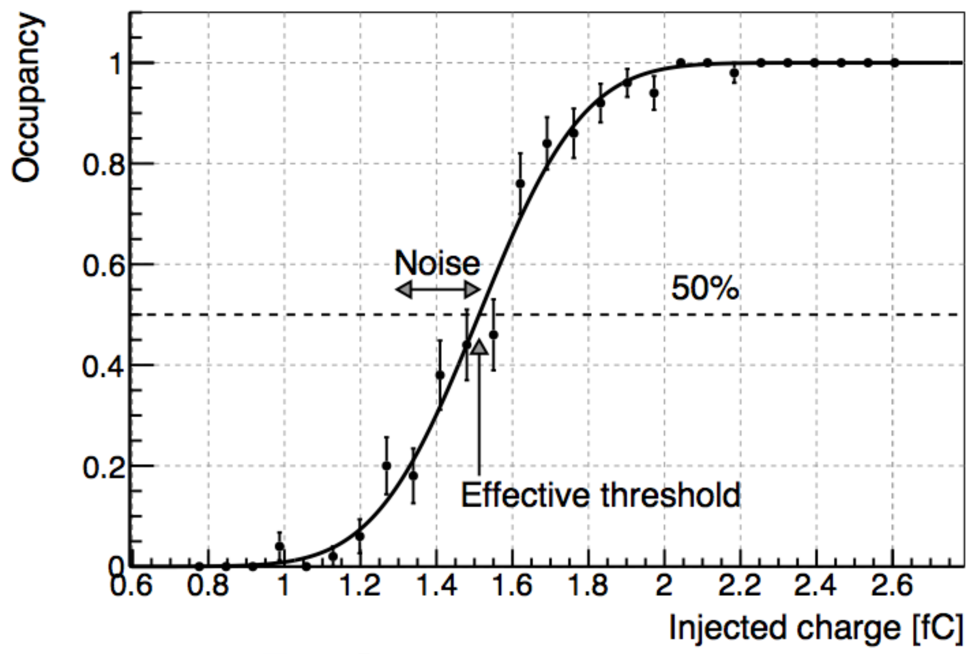
The contributions to GLAST by the entire italian team are enormous …. The spirit of collaboration established by the tracker team has been an example for the entire collaboration. Congratulations and thank to all!

Peter Michelson, GLAST PI

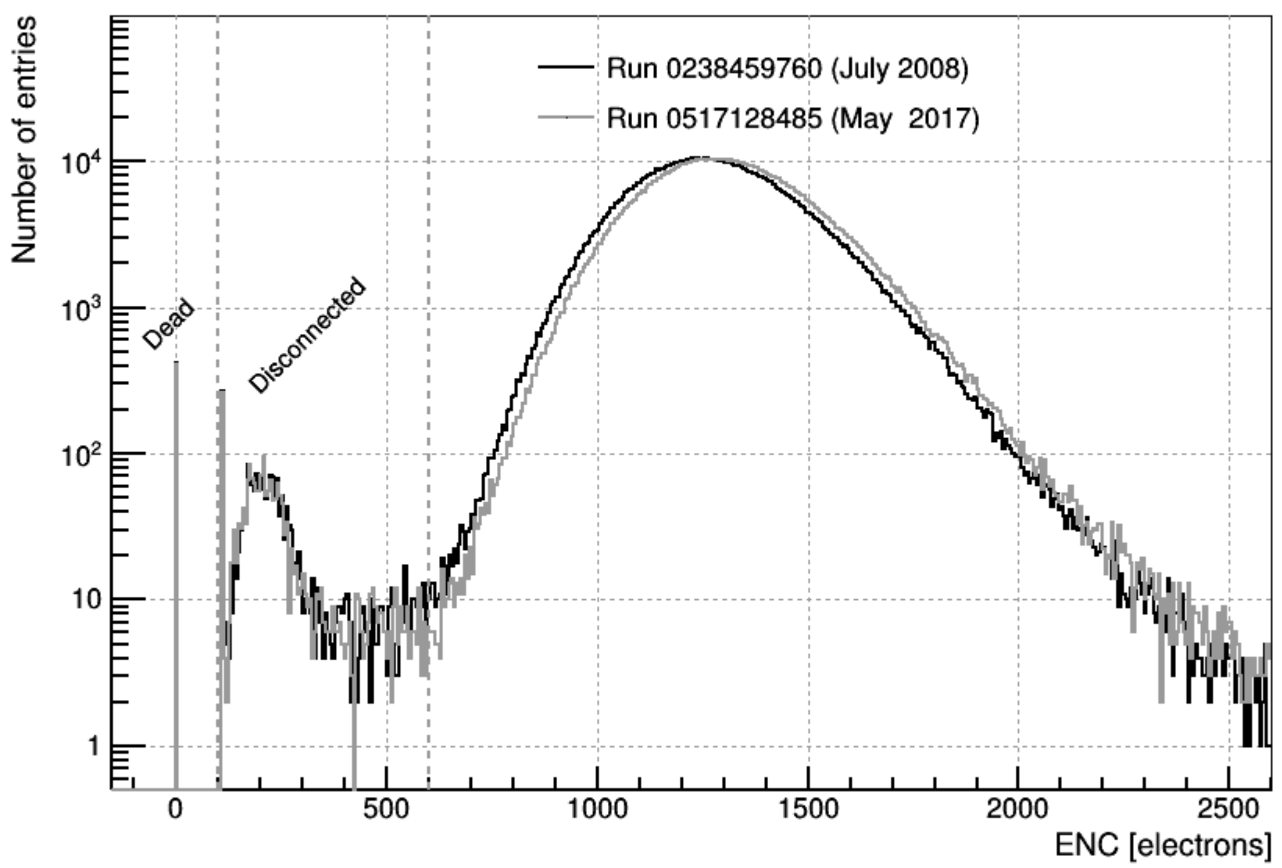


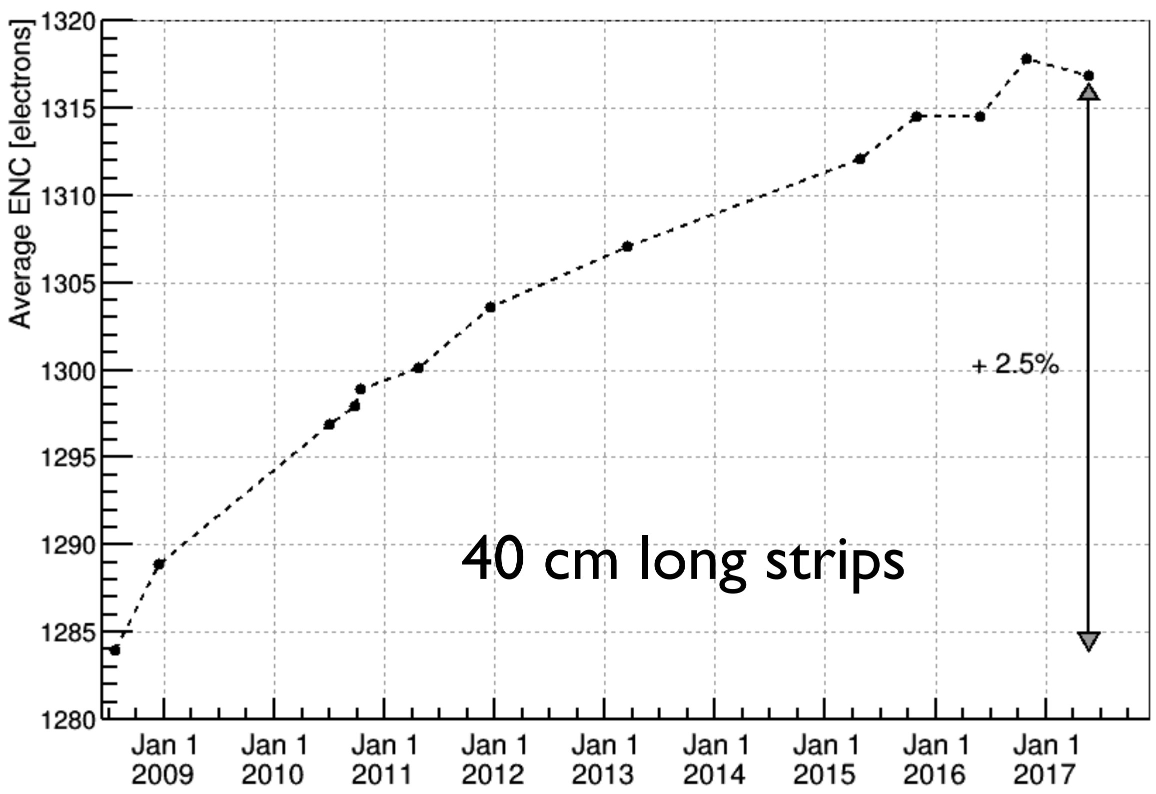
GLAST - Cape Canaveral - June 2008

Status of the LAT TKR

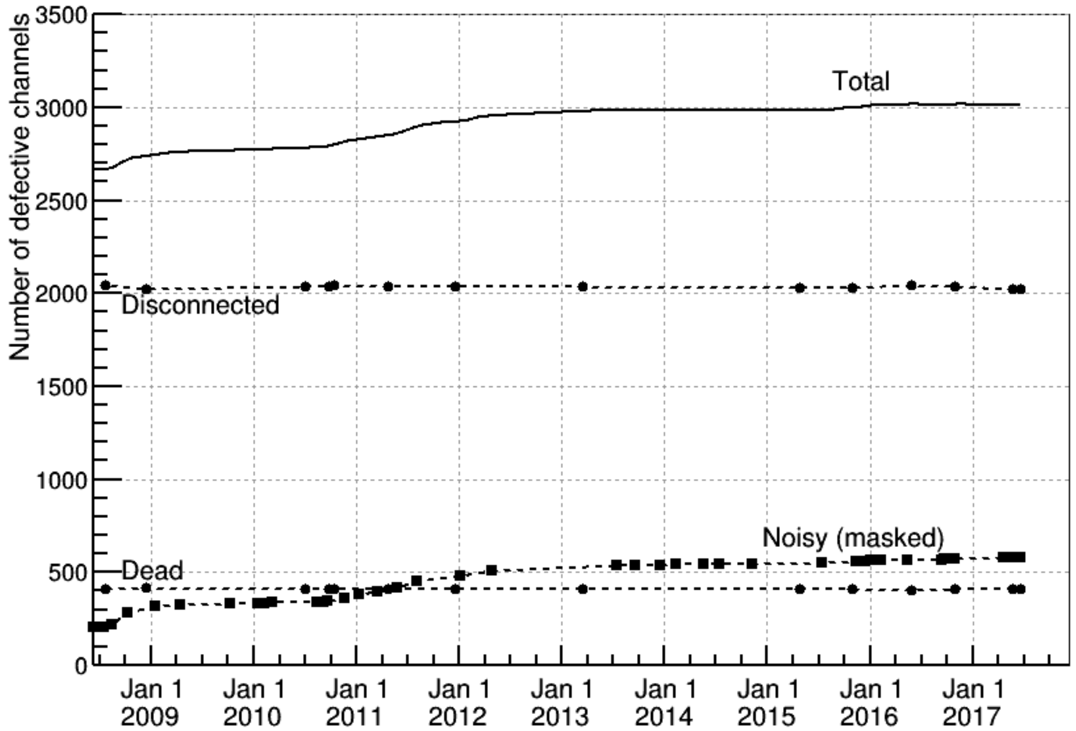


single TKR channel noise calibration

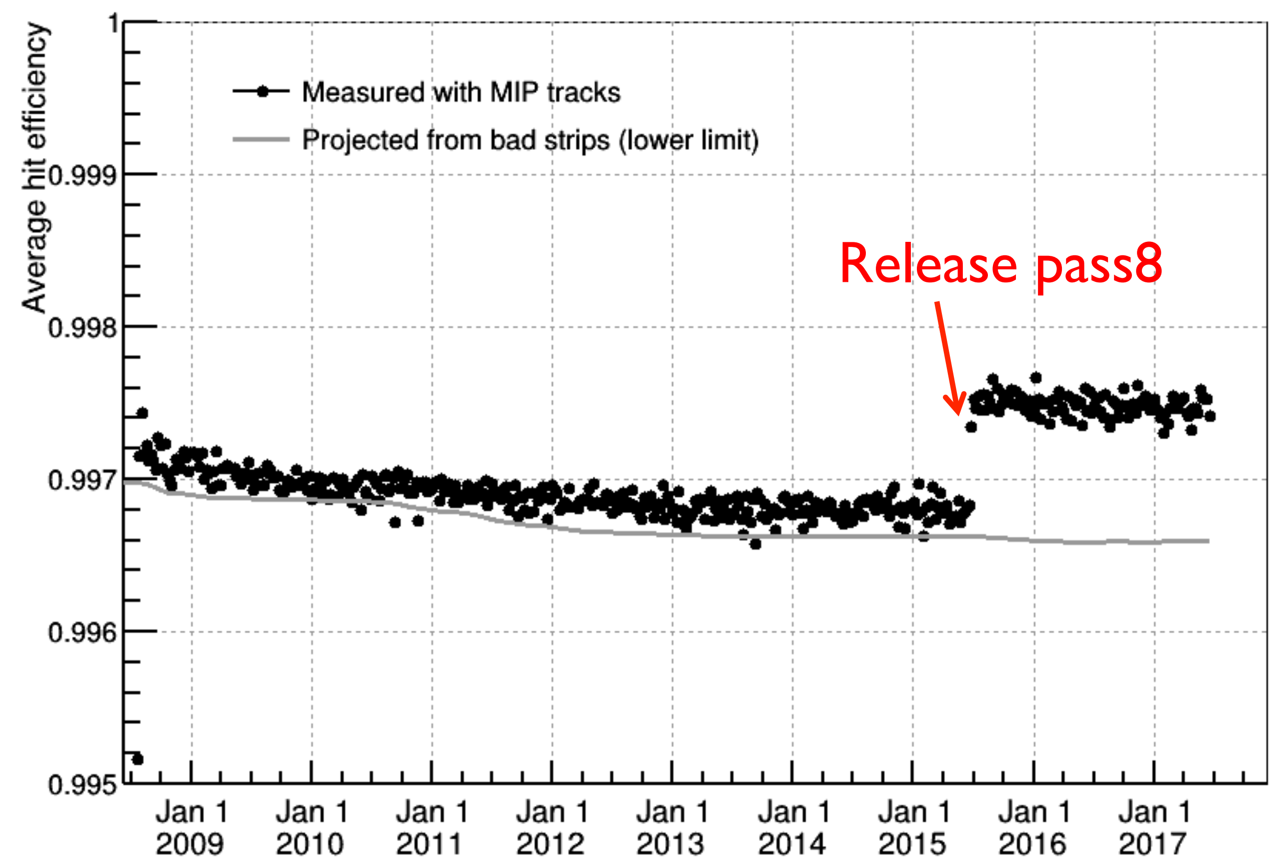




Status of the LAT TKR



Bad channels trending



Conclusions

- **The LAT tracker is the largest solid-state tracker ever built for space application:**
  - 73 m^2 of single-sided silicon strip detectors in space;
  - Almost 900,000 independent electronics channels.
- **All design goals met with large margins:**
  - Single-plane hit efficiency in excess of 99%;
  - Noise occupancy at the level of < 1 channel per million;
  - 160 W of power consumption;
  - No noticeable degradation of performance observed in the years.
- **10-years mission goal achieved**