Convenzione Quadro INFN PAT Progetto MEMS

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Giornata INFN Spazio

LNF

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Programmi di ricerca nell' ambito della Convenzione PAT- INFN

L' INFN e la Provincia Autonoma di Trento (PAT), tramite il Comitato paritetico presieduto da P.Dal Piaz, hanno preparato 2003 il progetto esecutivo di due programmi di ricerca, nell' ambito della convenzione sottoscritta il 31 luglio 2001.

I due programmi sono:

1- "SAE" finalizzato allo sviluppo di sistemi di calcolo avanzatoin ambito GRID;

2 "MEMS" finalizzato allo sviluppo di microsistemi innovativi per la realizzazione per esperimenti di alta energia, attivita' spaziali, applicazioni medicali ed altro.

Il Direttivo dell' INFN ha approvato nella riunione del settembre 2003 una lettera di intenti per l'attuazione di questi programmi nella misura fino al 40% del costo complessivo.

La Giunta Provinciale di Trento, nella riunione del 30 dicembre 2003, ha approvato un impegno di spesa di **3.690.000,00 Euro**, per la realizzazione di tali programmi comprendendo il finanziamento di sei borse di studio triennali.

Il progamma MEMS

Il **programma MEMS** prevede inizialmente i seguenti quattro sottoprogetti di interesse congiunto INFN/ITC-irst:

1. Sviluppo di rivelatori di radiazione in silicio ad alta resistività con elettrodi tridimensionali .
2. Sviluppo di matrici di microfotomoltiplicatori al silicio per la rivelazione di luce .
3. Sviluppo di matrici di microbolometri.
4. Sviluppo di una Time Projection Chamber (TPC) basata su silicio a bassa temperatura.

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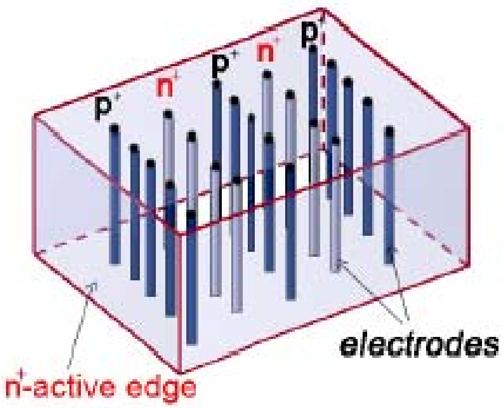
Programma MEMS
P1. Rivelatori al silicio 3D

3D SILICON DETECTORS

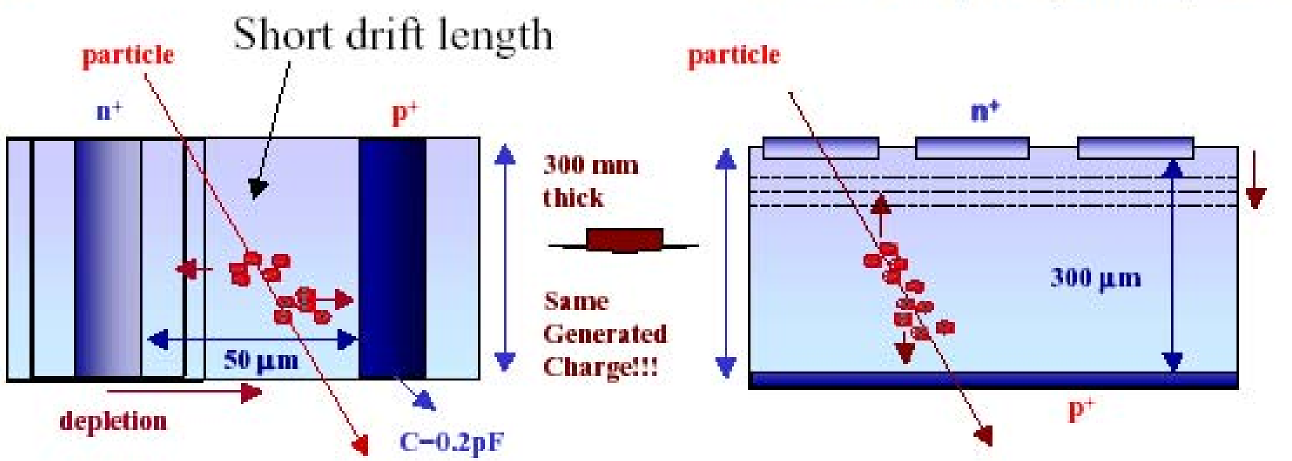
S. Parker, C. Kenney
Stanford 1995

combination of VLSI and micromachining technologes (MEMS MicroElectroMechanicalSystems)



- FZ silicon
- n- and p-type substrates
- High resistivity kΩ-cm
- <100> orientation

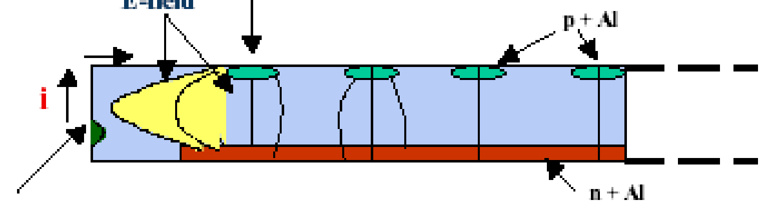
- IEEE Trans Nucl Scie 46 4 (1999) 1224
- IEEE Trans Nucl Scie 48 2 (2001) 189
- IEEE Trans Nucl Scie 48 6 (2001) 2405
- IEEE Trans Nucl Scie 48 5 (2001) 1629
- CERN Courier, Vol 43, Number 1, Jan 2003



3D ACTIVE EDGES

PLANAR TECHNOLOGY
E-field lines need to be contained
TO PREVENT HIGH SURFACE
LEAKAGE CURRENT

EDGE SENSITIVITY ~ 500 μm

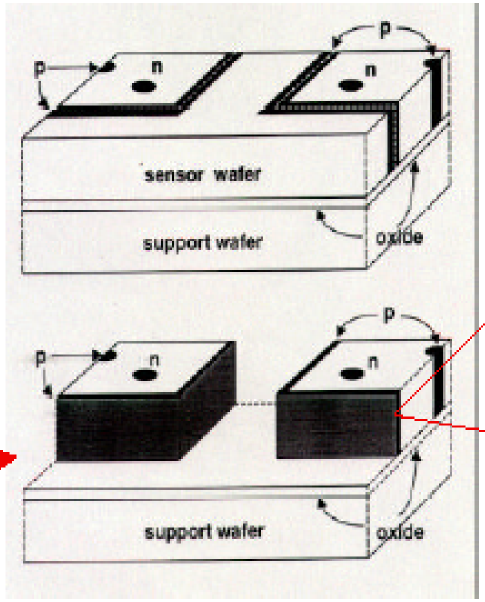


3D TECHNOLOGY
E-field line ends into the
edge (p) electrode

EDGE SENSITIVITY <10 μm

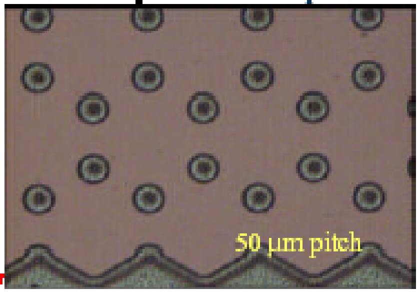
AFTER PROCESSING THE MATERIAL SURROUNDING THE DETECTORS IS ETCHED AWAY: NO SAWING NEEDED!!!

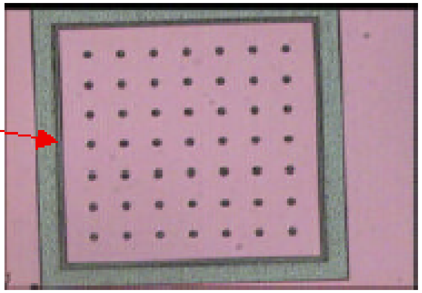
Side view



Pictures of processed structures
Brunel, Hawaii, Stanford Jan. 2003

Top view





Interesse duale dei Silicon 3D

-Imaging ad alta velocita' in presenza di alte dosi e alti rates

-Resistenza alla radiazione

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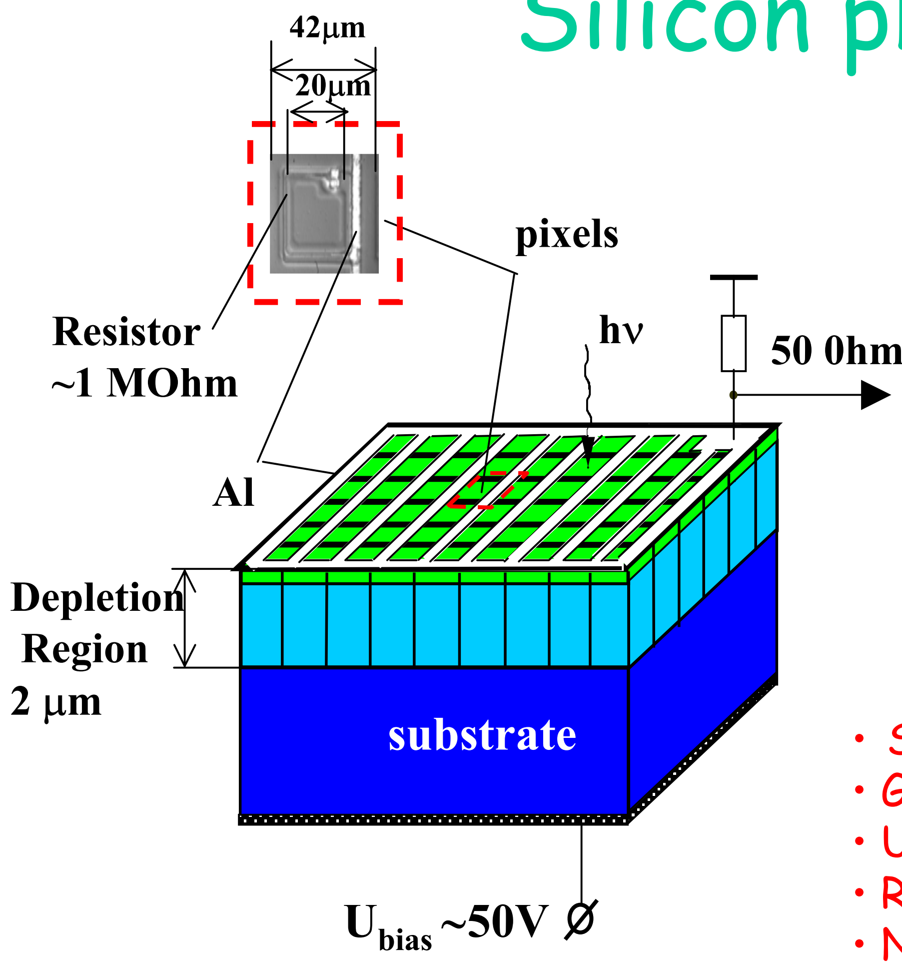
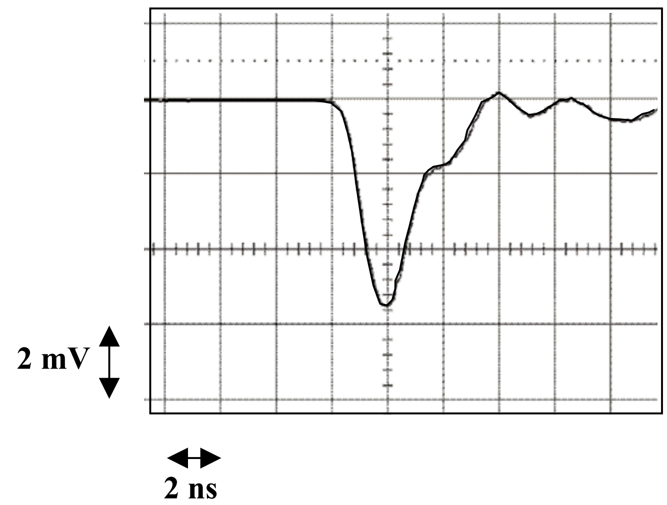
Programma MEMS

P2. Sviluppo di matrici di SiPM

Silicon photomultiplier (SiPM)



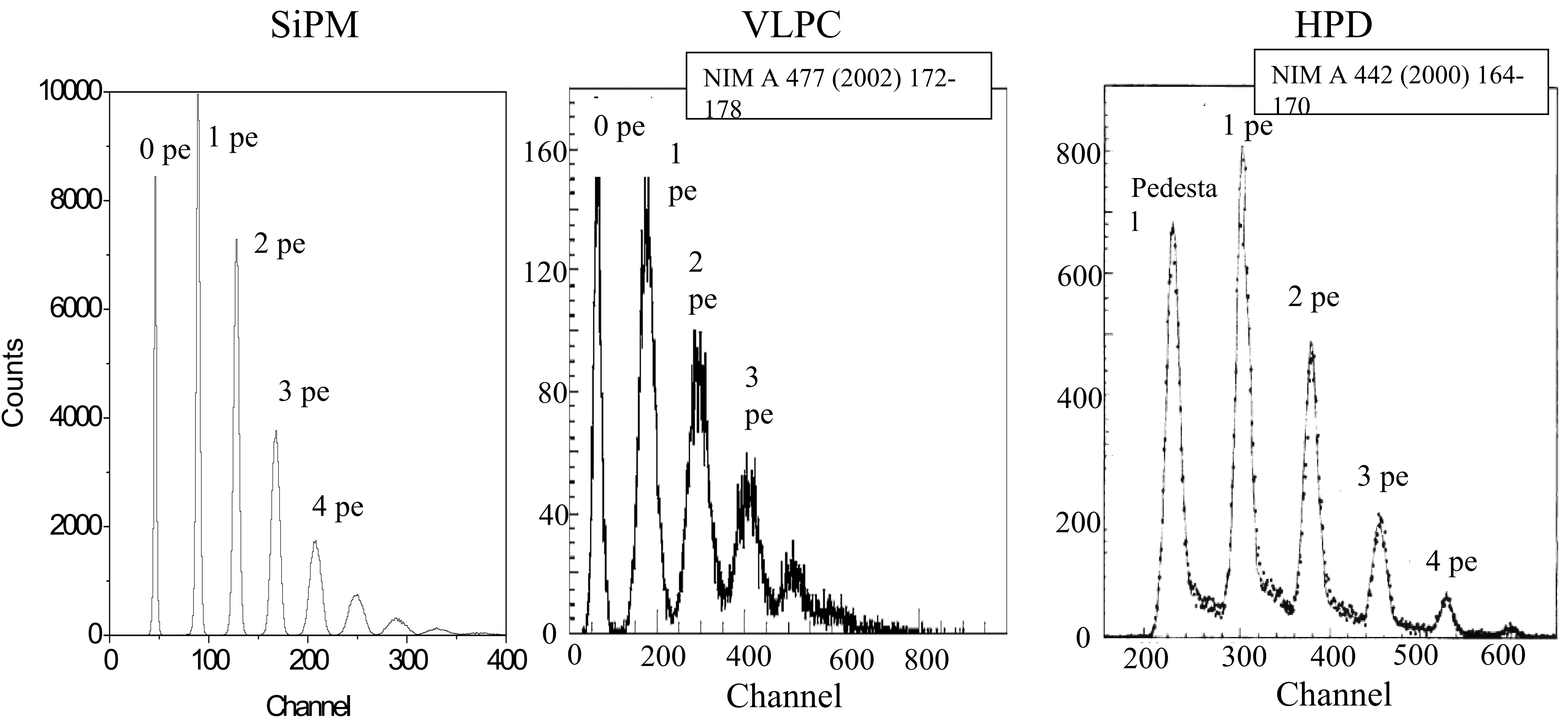


SiPM main features:

- Sensitive size $1x1mm^2$ on chip $1.5x1.5\ mm^2$
- Gain $2{\cdot}10^6$
- U_{bias}~50V
- Recovery time < 100 ns/pixel
- Number of pixels: ~ $1000/mm^2$
- Nuclear counter effect: negligible (due to Geiger mode
- Insensitive to magnetic field
- Dynamic range ~$10^3/mm^2$

for details: NIMA 504(2003)48

Single photoelectron (single pixel) spectra



SiPM:

- excellent single photoelectron resolution
- low ENF expected

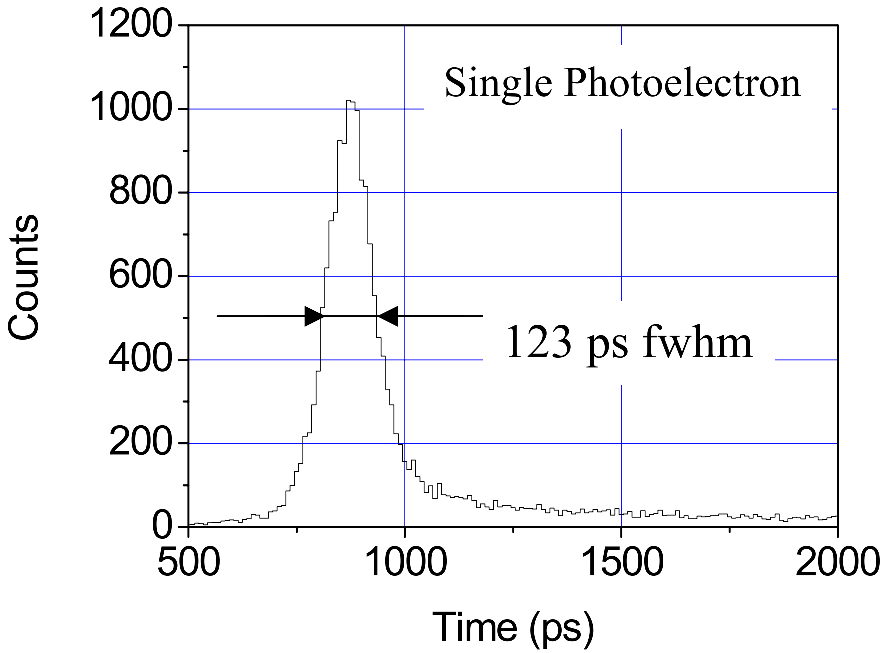
SiPMT characterstics compared

Table 1:

	PMT	APD	HPD	SiPM
Photon detection efficiency:				
blue	20%	50%	20%	12%
green - yellow	a few %	60-70%	a few %	15%
red	<1%	80%	<1%	15%
Gain	10^6-10^7	100-200	10^3	10^6
High voltage	1-2 kV	100-500 V	20 kV	25 V
Operation in the magnetic field	problematic	OK	OK	OK
Threshold sensitivity S/N$\gg$1	1 ph.e.	$\sim$10 ph.e.	1 ph.e.	1 ph.e.
Timing /10 ph.e.	$\sim$100 ps	a few ns	$\sim$100 ps	30 ps
Dynamic range	$\sim10^6$	large	large	$\sim10^3/\text{mm}^2$
Complexity	high (vacuum, HV)	medium (low noise electronics)	very high (hybrid technology, very HV)	relatively low

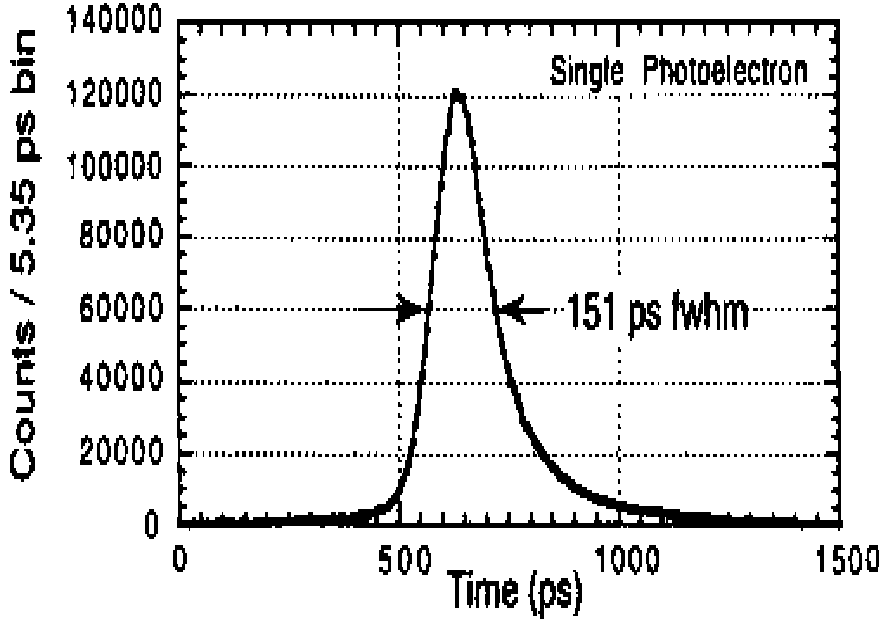
Timing by SiPM

SiPM



The best

PMT R-5320



FWHM: Laser (40 ps) + electronics (40 ps) => SiPM (100 ps)

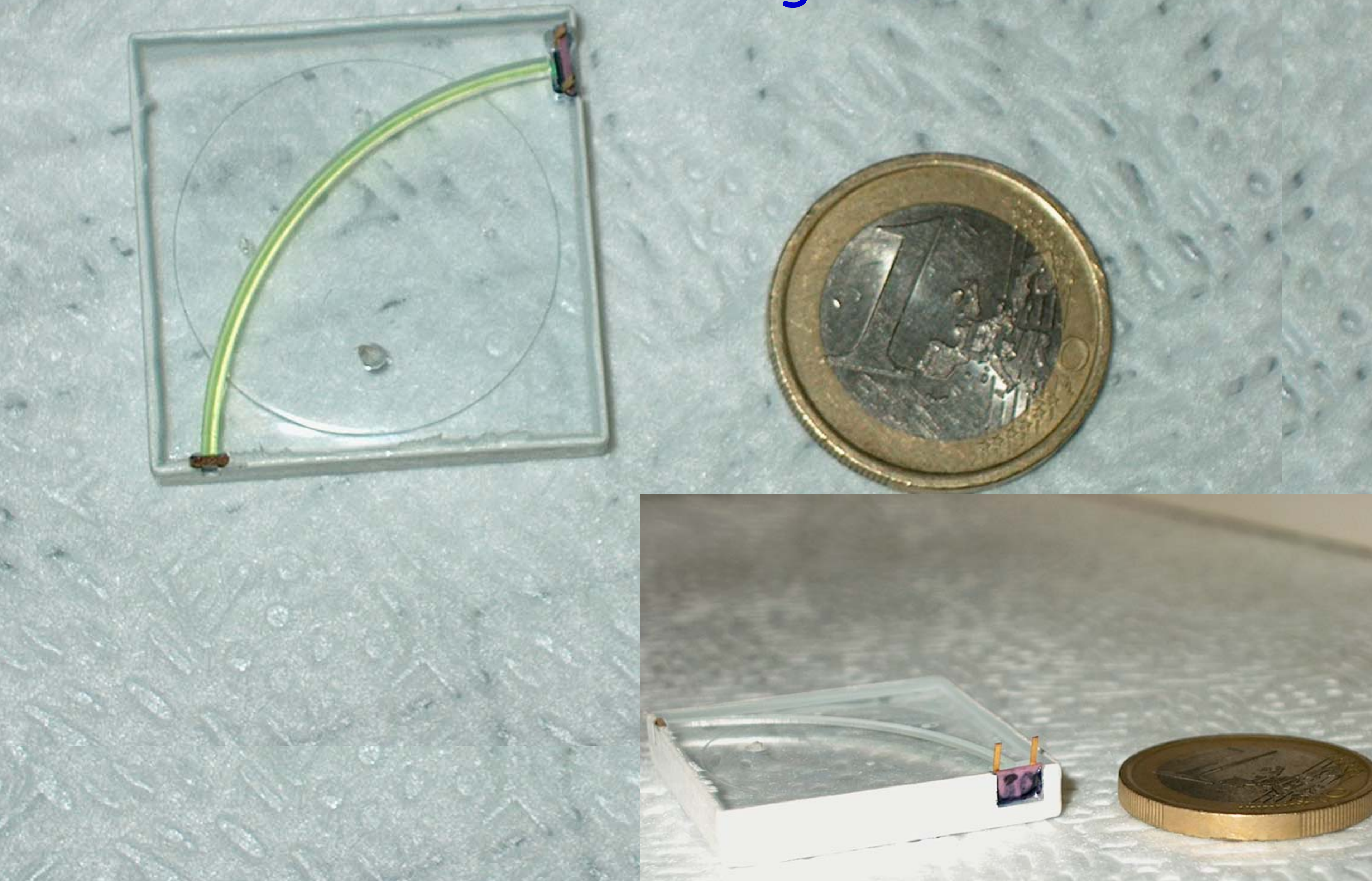
50 ps sigma for single ph.e. by leading edge discriminator

- SiPM timing performance competes with MCP PM

SiPM: arguments in favour

- ✓ Low noise,high gain
- ✓Good single electron resolution
- ✓Very good timing
- ✓Small recovery time
- ✓Low charge particle/photon sensitivity
- ✓Insensitivity to B
- ✓Low bias voltage
- ✓Low power consumption
- ✓Compactness
- ✓Room temperature operation
- ✓Good temperature and voltage stability
- ✓Simplest electronics
- ✓Relatively low cost(low resistivity Si,simple technology)

MEMS Silicon Photomultipliers for the LAZIO-SiRad scintillating tiles



SiPM for a single photon counting: Possible application for EUSO experiment

EUSO-

Extreme Universe Space Observatory

EUSO on the ISS

EUSO Geometry

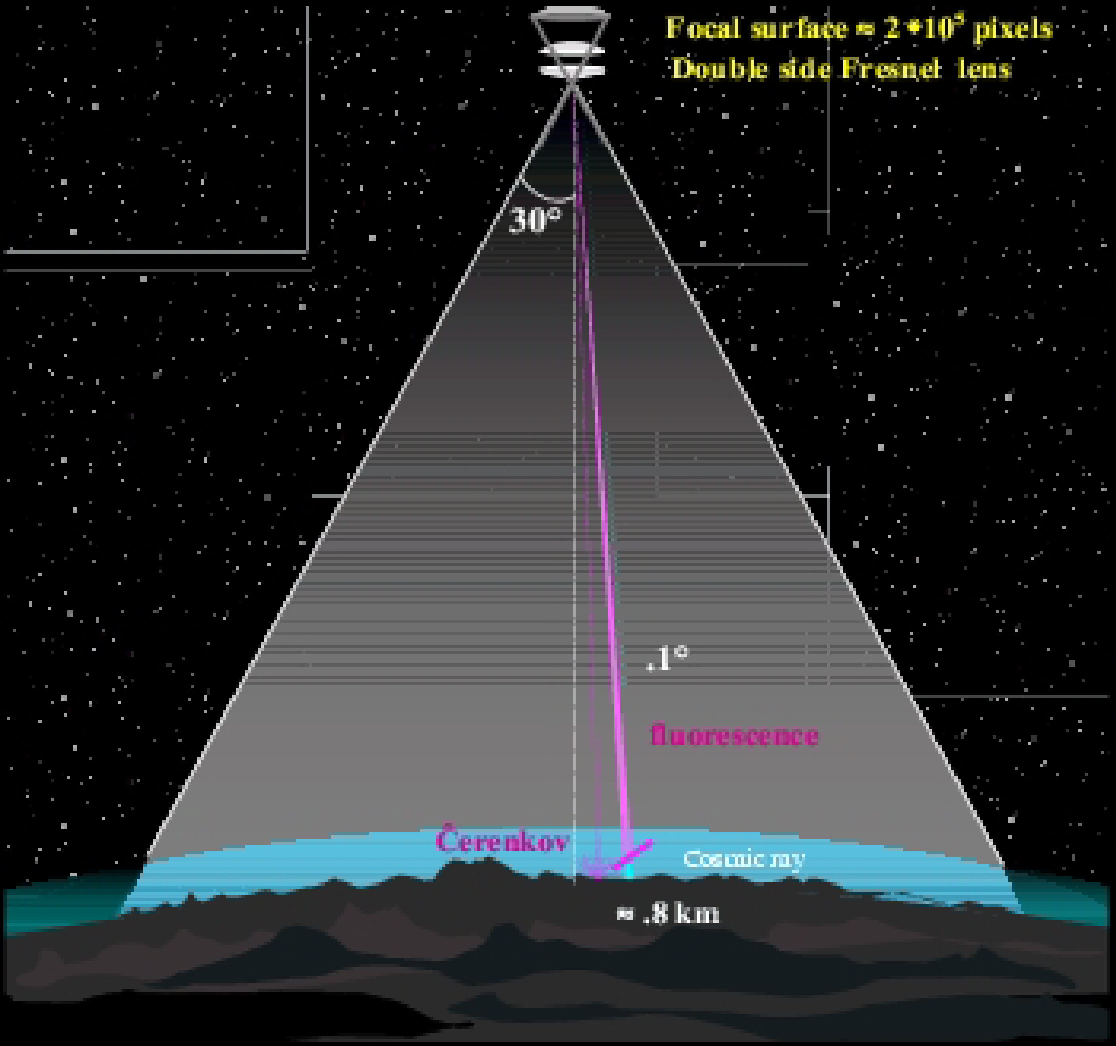
Detector distance = 400 km

Total field of view = 60°

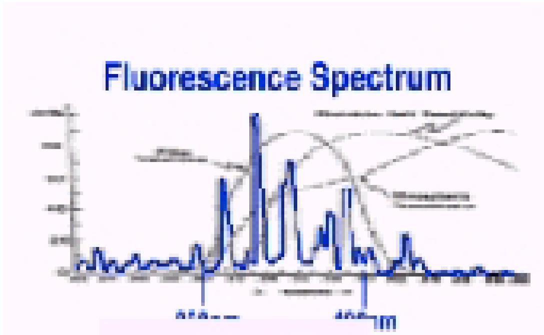
Geometrical factor = $5 \cdot 10^5$ km^2 sr

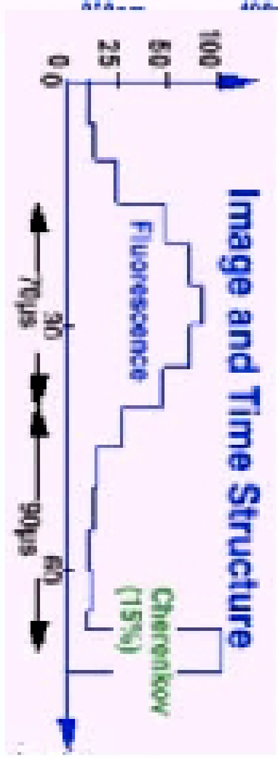
Target air mass = $2 \cdot 10^{12}$ tons

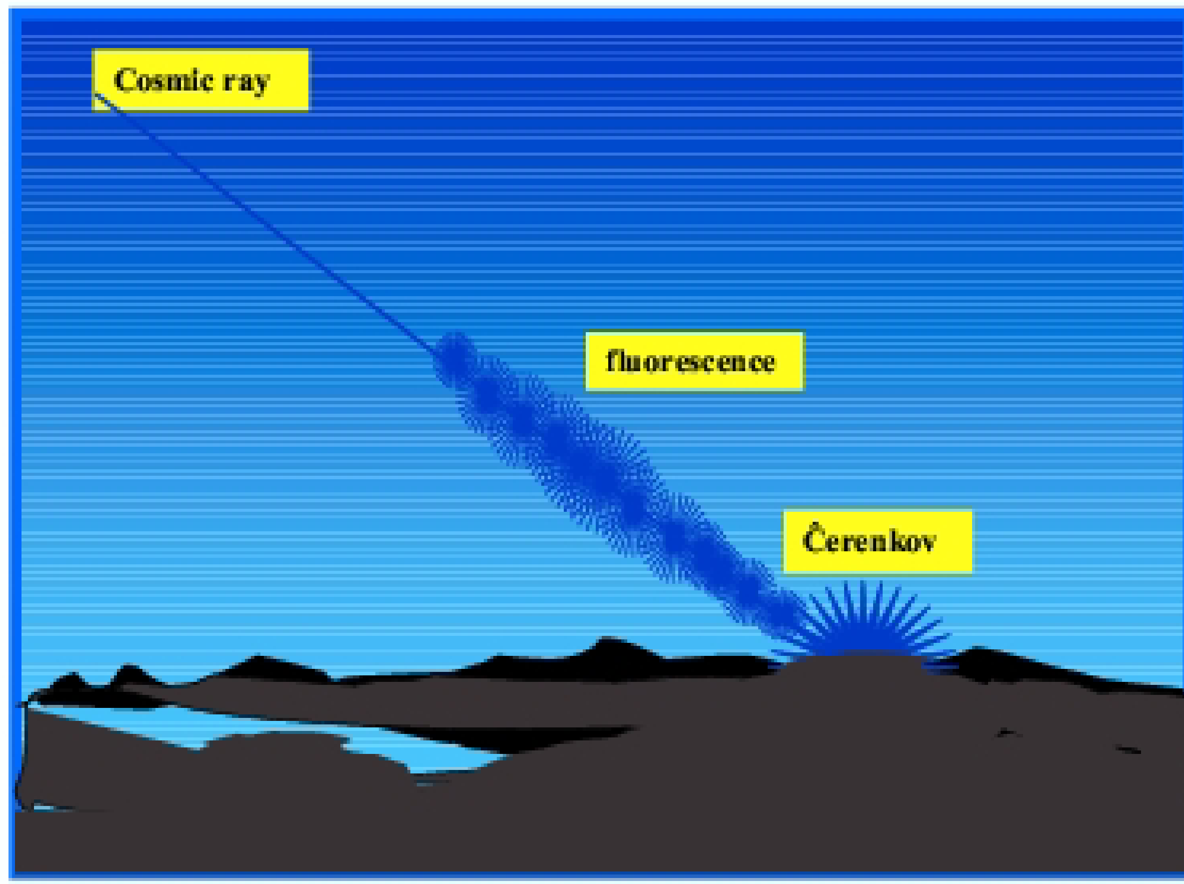
Pixel size = $(.8 \cdot .8)$ km^2



EUSO Approach







EUSO needs:

- 300000 Photodetectors,working in a single photon counting mode("TPC Calorimeter")
- Sensitivity in 300-400 nm range,PD eff 30-40%
- Fast(<10 ns), compact,low weight, low power consuming
- Size 4x4(5x5) mm

Baseline option is MAPMT's
(weght?power consumption?packing eff?QE?)

- SiPM's ?

SiPM's for EUSO: limitations for today

1. Photon detection efficiency for 300-400 nm is too low(a few %)

2. Size 1x1 mm is only carefully studied

3. Single ph.e. dark rate should be less than dark sky rate(~1 MHz/5x5 mm)

SiPM: Example for superfast timing

TOF Positron Emission Tomography(TOF PET) with 3D reconstruction of each event

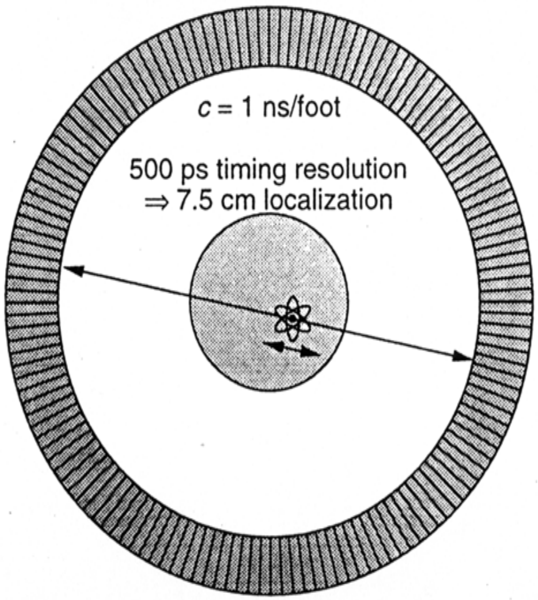


Figure 1. Time-of-Flight PET Camera. Annihilation photons are detected by a ring of scintillation crystals. With a conventional PET camera, this localizes the position of the positron to the line segment joining the two crystals. With a TOF PET camera, the arrival time difference is used to further restrict the position.

GEANT based simulation gives

FOR

ZnO(In) crystal size (4.5 mm^3)

SiPM size 4.5x4.5 mm

Sigma of SiPM 50 ps

Sigma electronics 5 ps

Photon Detection eff. 30%

3D TOF PET resolution of 2 mm(sigma) can be achieved

(TOF timing of 13 ps for ~400ph.e)[1,2]

SiPM: Limitations: * Size 4.5x4.5mm, * PD efficiency 30%

Interesse duale dei SiPM

-*Imaging 3d, terza coordinata spaziale ottenuta con la temporizzazione*

-*applicazioni automobilistiche (con illuminazione attiva)*

10 ps = 3 mm / 2 = 1.5 mm

-*applicazioni mediche (senza illuminazione attiva) 10 ps = 3 mm*

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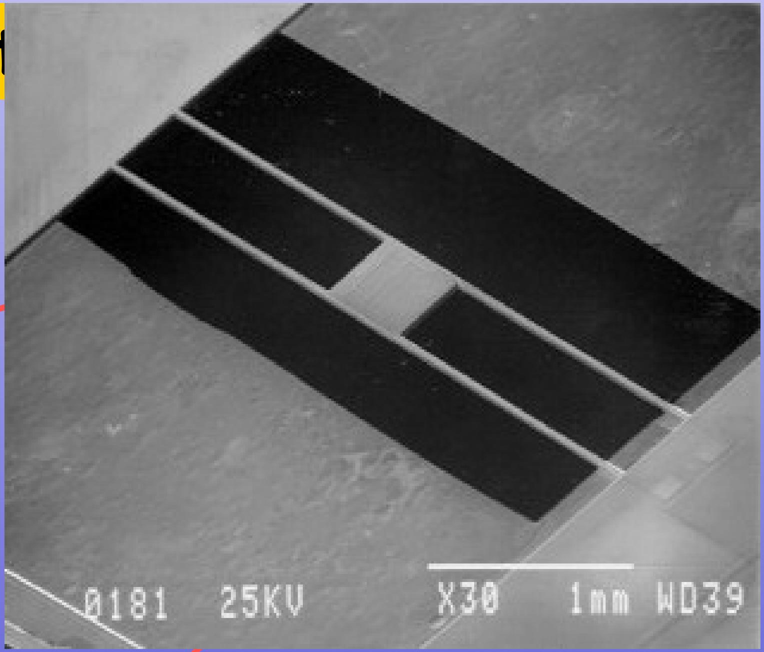
Programma MEMS

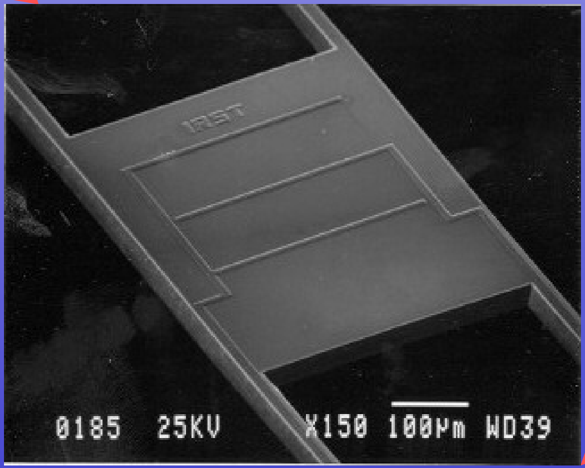
P3. Sviluppo di matrici di Microbolometri

Bolometri criogenici

Tecnologia per microbolomet

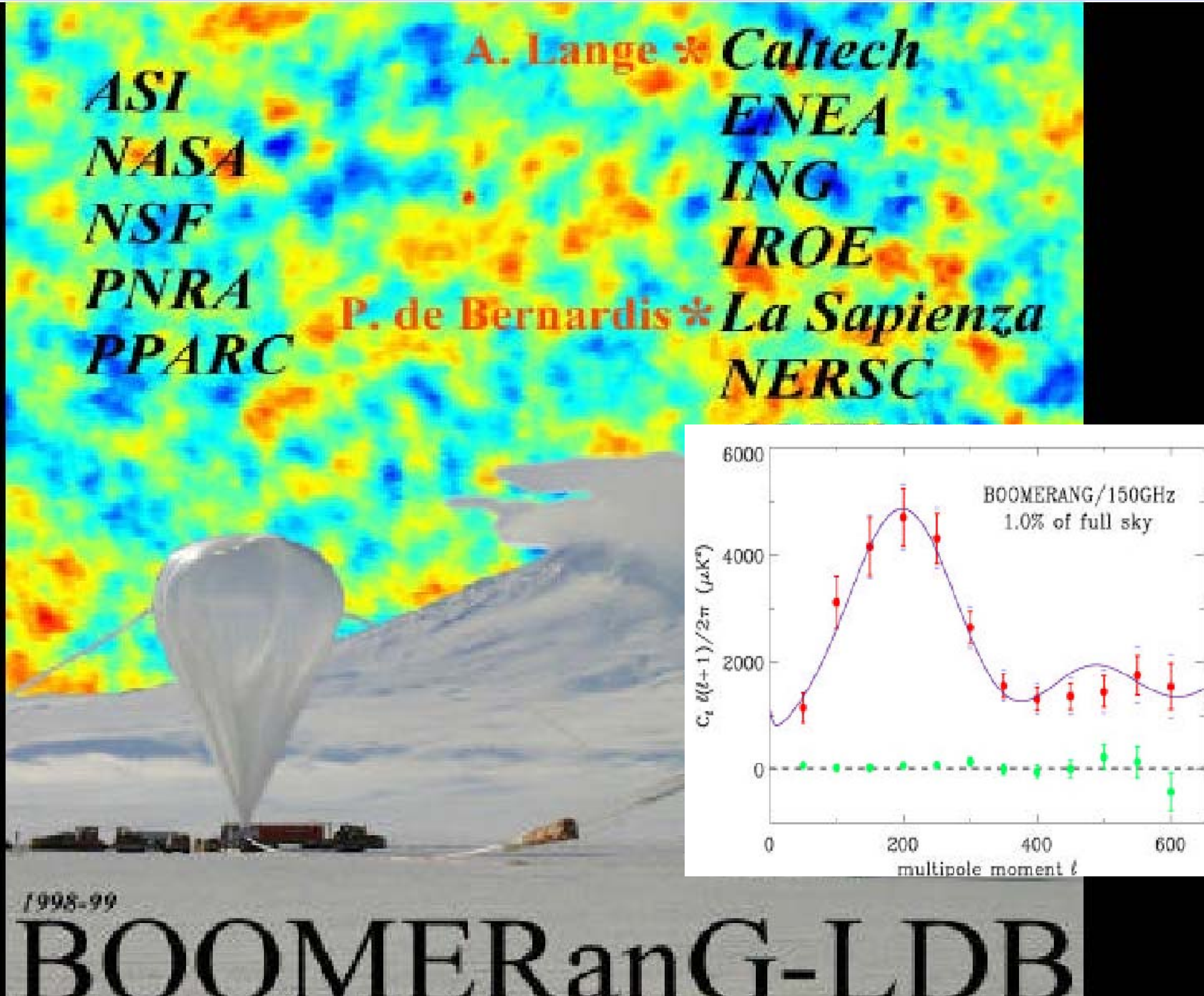


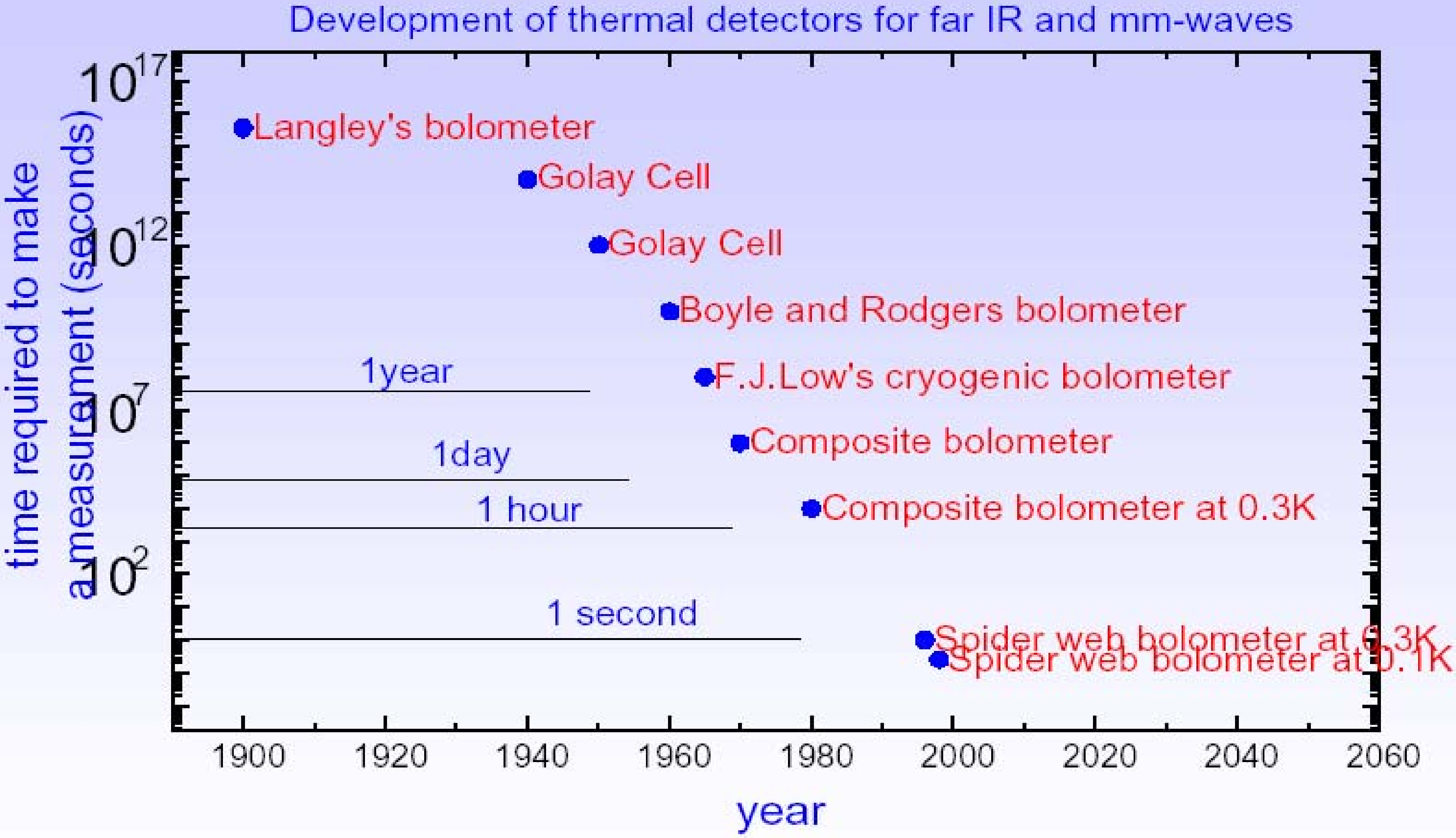
Con il micromachining e possibile integrare il link termico



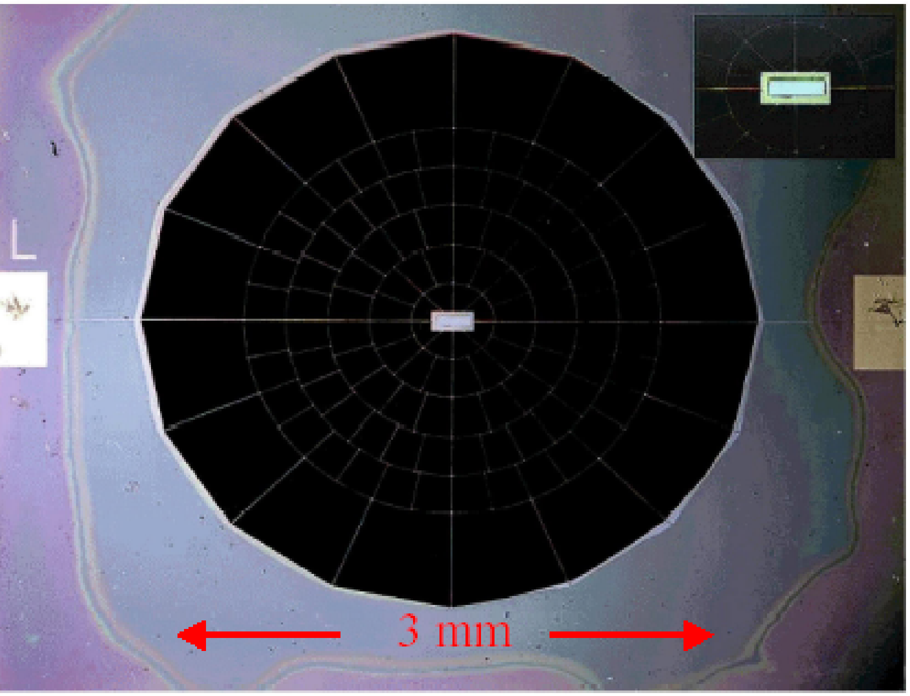
Microcalorimetro integrato realizzato con impianto multiplo in silicio e lavorazione micromeccanica

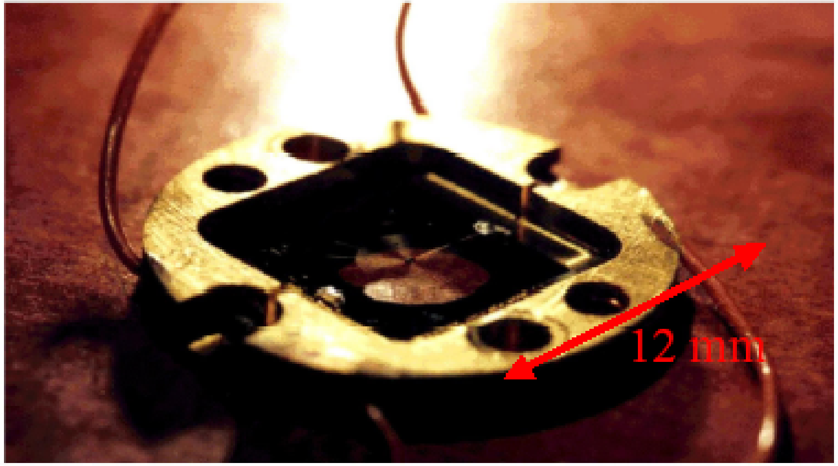
http: // oberon.roma1.infn.it / boomerang
http: // www.physics.ucsb.edu / ~boom




Development of thermal detectors for far IR and mm-waves
time required to make a measurement (seconds)
10^17
10^12
10^7
10^2
1year
1day
1 hour
1 second
Langley's bolometer
Golay Cell
Golay Cell
Boyle and Rodgers bolometer
F.J.Low's cryogenic bolometer
Composite bolometer
Composite bolometer at 0.3K
Spider web bolometer at 0.3K
Spider web bolometer at 0.1K
1900
1920
1940
1960
1980
2000
2020
2040
2060
year

1) the detectors (Caltech/JPL)





Cosmic Rays events are 10 times more frequen than at temperate latitudes

Spider web bolometers have been custom developed at JPL-Caltech for this application.

The absorber is micromachined as a web of metallized Si_3N_4 wires, 2 μm thick, with 0.1 mm pitch. This is a good absorber for mm-wave photons and features a very low cross section fo cosmic rays. Also, the heat capacity is reduced by a large factor with respect to the solid absorber.

NEP ~ 2 10^{-17} W/$Hz^{0.5}$ is achieved @0.3K

In the focus of our telescope the sensitivity is enough to detect the heat of a coffee-maker on the moon in 1 second. (150μK_{CMB} in 1 s)

They have been selected for the ESA mission Planck.

Mauskopf *et al.* Appl.Opt. **36**, 765-771, (1997)

Uncooled InfraRed Sensors

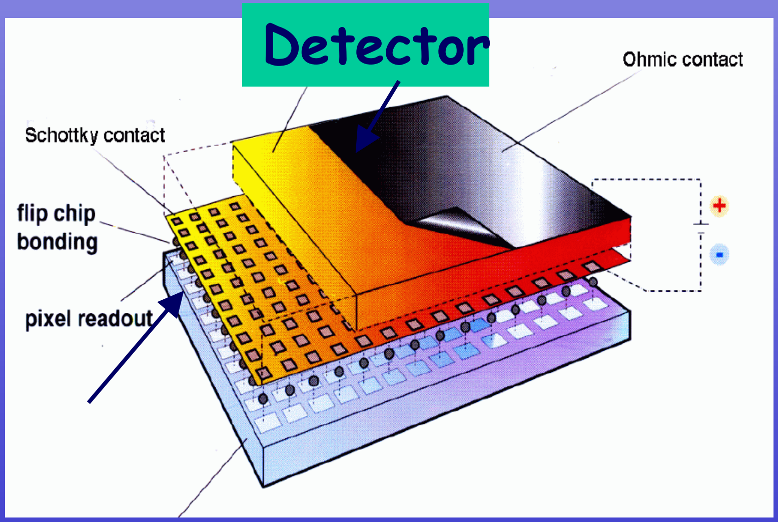
InfraRed Imaging System

Option A: a single device in CMOS compatible technology

- Integration of bolometer and readout circuits at pixel level

Option B: bolometer array in dedicated technology readout circuits in standard CMOS technology

- 2D array of bolometers in IRST technology
- 2D array of readout circuits in standard CMOS technology
- Bump bonding and flip chip assembly technologies



Electronic chip

Interesse duale delle matrici di bolometri

-Imaging IR a temperatura ambiente

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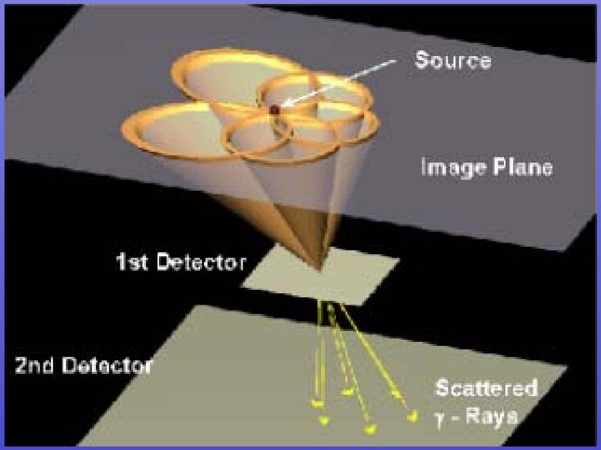
Programma MEMS
P4. Sviluppo Silicon TPC (freddo)
e silicio spesso
(temperatura ambiente)

The measured quantities in Compton imaging are:

- x, y, z-co-ordinates in the first detector
- x, y, z-co-ordinates in the second detector
- Energy of recoil electron in first detector
- Energy of scattered photon in second detector

- **Not measurable** with Compton Cameras for medical applications: Direction of recoil electron, which leads to the conical ambiguity. This leads to more complicated image reconstruction algorithms.

Illustration of conical ambiguity in the reconstruction of a point source



Interesse duale del Silicio spesso

- ***Applicazioni mediche (high resolution PET)***
- ***Applicazioni astrofisiche***