# Silicon and diamond segmented detectors for imaging and dosimetry in radiotherapy

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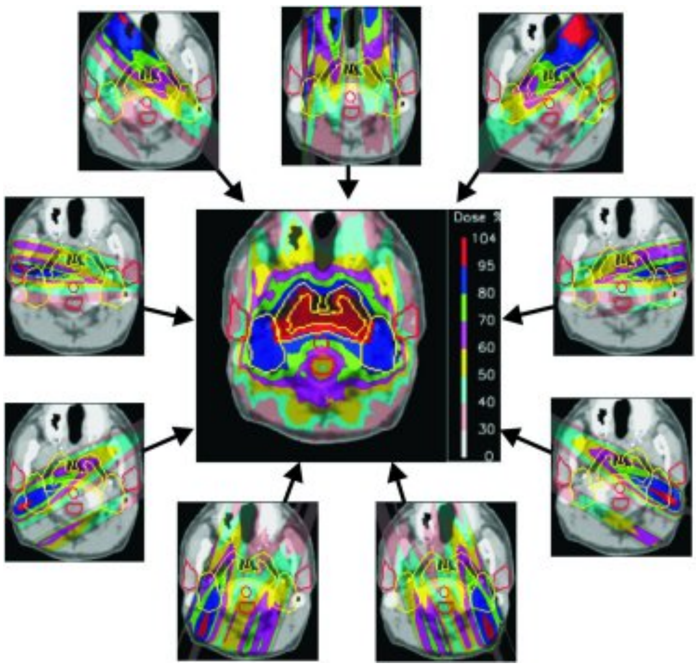
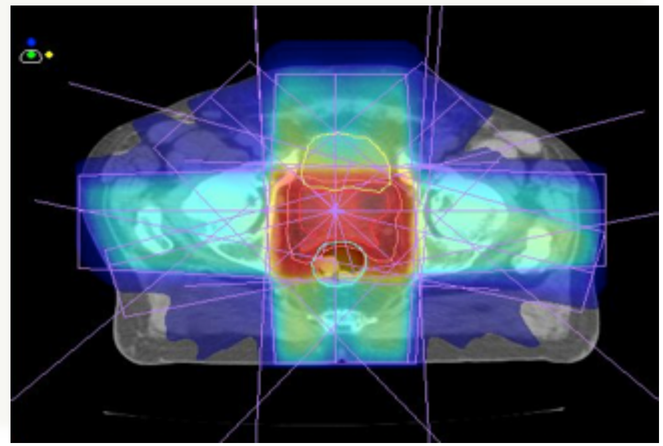
INFN Firenze

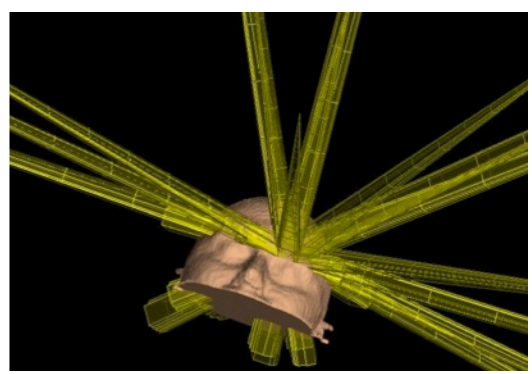
# Outline

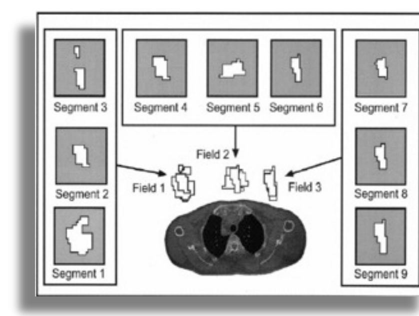
- Development of an innovative 2D Si dosimeter
- Diamond Dosimetry
- Proton Imaging Systems

Clinical dosimetry in radiotherapy is well known matter but high conformal radiotherapy modalities (IMRT, Stereotactic treatments with photons and protons, IMPT) pose problems due to the **small radiation fields** with **high dose gradients**, to the **variation in space and time of the dose rate** and to the **variation in space** and **time of the beam energy spectrum.**

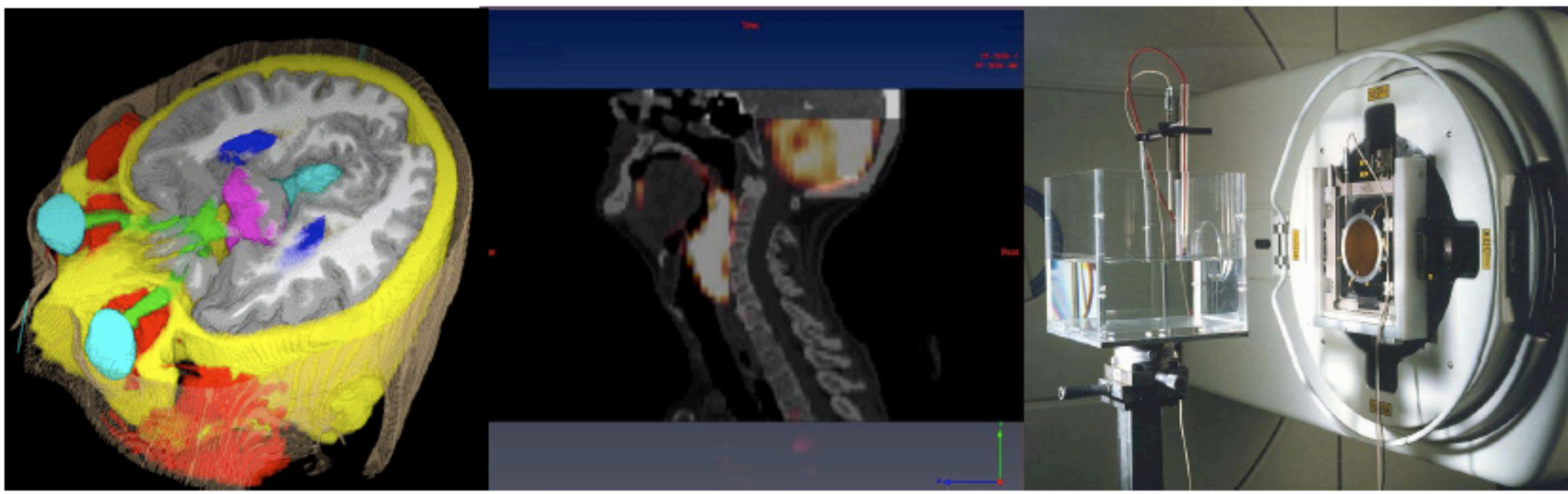






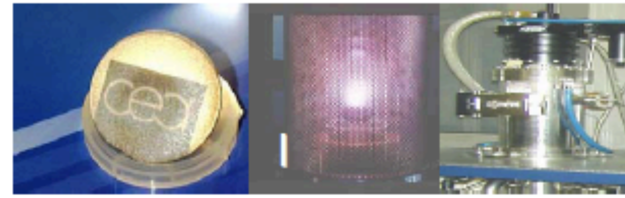
# Methods and Advanced Equipment for Simulation and Treatment in Radio Oncology

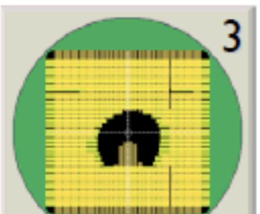


European Integrated project **MAESTRO**
(Methods and Advanced Equipment for Simulation and Treatment in Radio-Oncology, no. LSHC-CT-2004-503564)

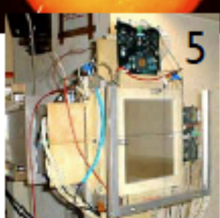
M. Bruzzi, III Seminario Nazionale Rivelatori Innovativi, 4-8 June 2012 INFN Firenze

# 3 - Dosimetric Tools









1. Diamond Dosimeter : ionisation chamber (CEA, IFJ, INFN)
   Thermoluminescence (CEA, IFJ)
2. 16 ways remote OSL dosimeters using optical fibres (CEA)
3. 2D wide surface Si plan imagers (DFC, INFN)
4. 2D dose imager : Gas Electron Multiplier (U-DELFT)
5. Pixelized ionization chamber for IMPT and IMRT (SCX, INFN)
6. TL wide surface Dose imager (IFJ)
7. 3D Fricke gel polymer dosimetry (ISS)
8. 3D Plastic scintillator dosimetry (IN2P3, ELDIM)

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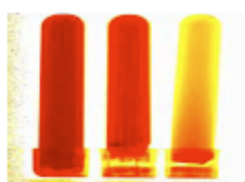

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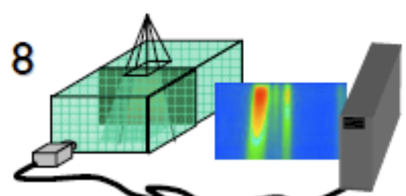


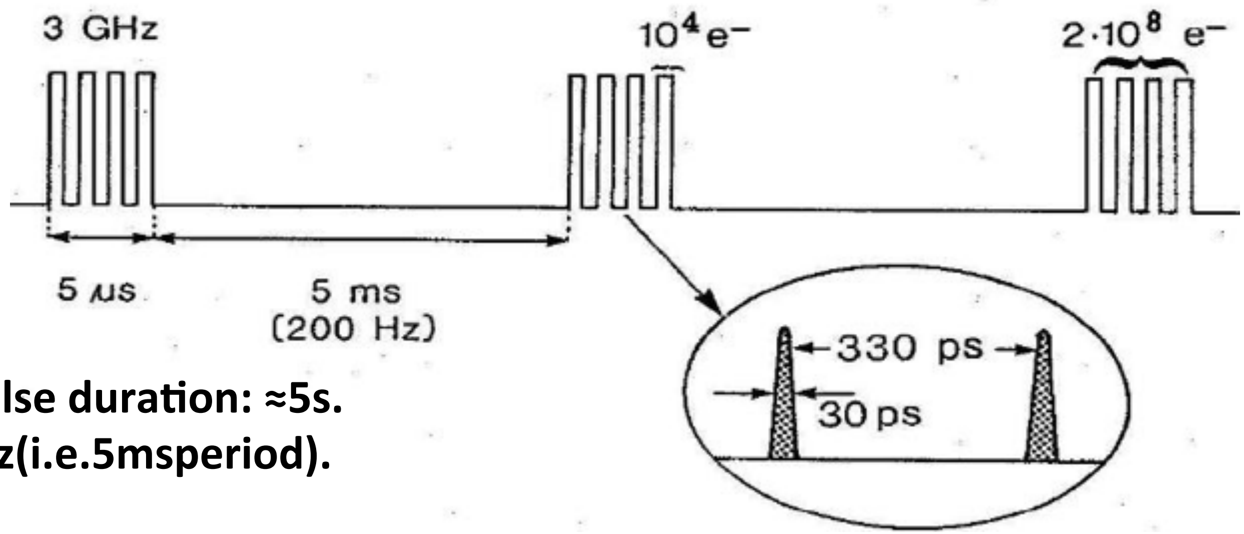
# Goal

**Our goal was to develop a device adequate for 2D pre-treatment in phantom dose verifications in conformal radiotherapy on a beam-by-beam basis.**

For photon IMRT treatments this is possible thanks to a TPS option that permits to export the actual intensity map into the QA phantom. In this procedure the TPS can change, if it is more convenient, the gantry angle and the number of the delivered monitor units.

# LINAC beam structure

**Radiation: electrons or Bremsstrahlung photons**




**(Macro) pulse duration: ≈5s.**
**PRF:~200Hz(i.e.5msperiod).**

**(Micro) pulse frequency:~3GHz(i.e.330ps period).**
**(Micro)pulse duration:~30ps.**

| | | |
|---|---|---|
| **Beam quality:** | **6-18MV (photons)** | |
| | **6-18MeV (electrons)** | |
| **Doserate:** | **3-6Gy/min** | **(flattened).** |
| | **10-50Gy/min** | **(unflattened).** |
| **Dose:** | **0.3-0.5mGy/pulse** | **(flattened)** |
| | **0.8-4mGy/pulse** | **(unflattened)** |

# The silicon choice

**Advantages:**

**- High sensitivity (about 18000 times higher than air filled IC with same active volume).**

**- Well developed manufacture technology.**

-**high spatial resolution.**

- **work in null bias mode ( in-vivo applications possible ).**

**Drawbacks:**

**- Sensitivity decrease with accumulated dose due to increase of concentration of recombination centers (recalibrations needed).**

**- Dose rate dependency due to centers saturation at high dose rates.**

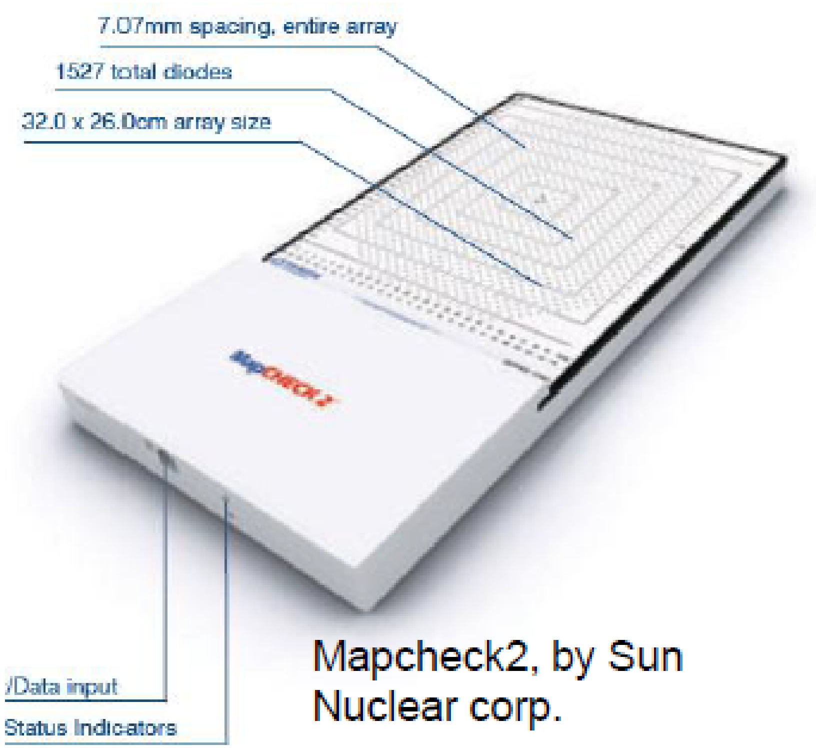
**- Energy dependence, since Si is not "water equivalent" (Z=14).**

**Present use of Si diodes in dosimetry**

**i) Radiation field analysis (especially profile measurement).**

**ii) Direct patient dosimetry ("in vivo" diodes).**

**Arrays of single diodes are already commercially available for 1D and 2D measurements, granuaity is limited due to assembling difficulties.**



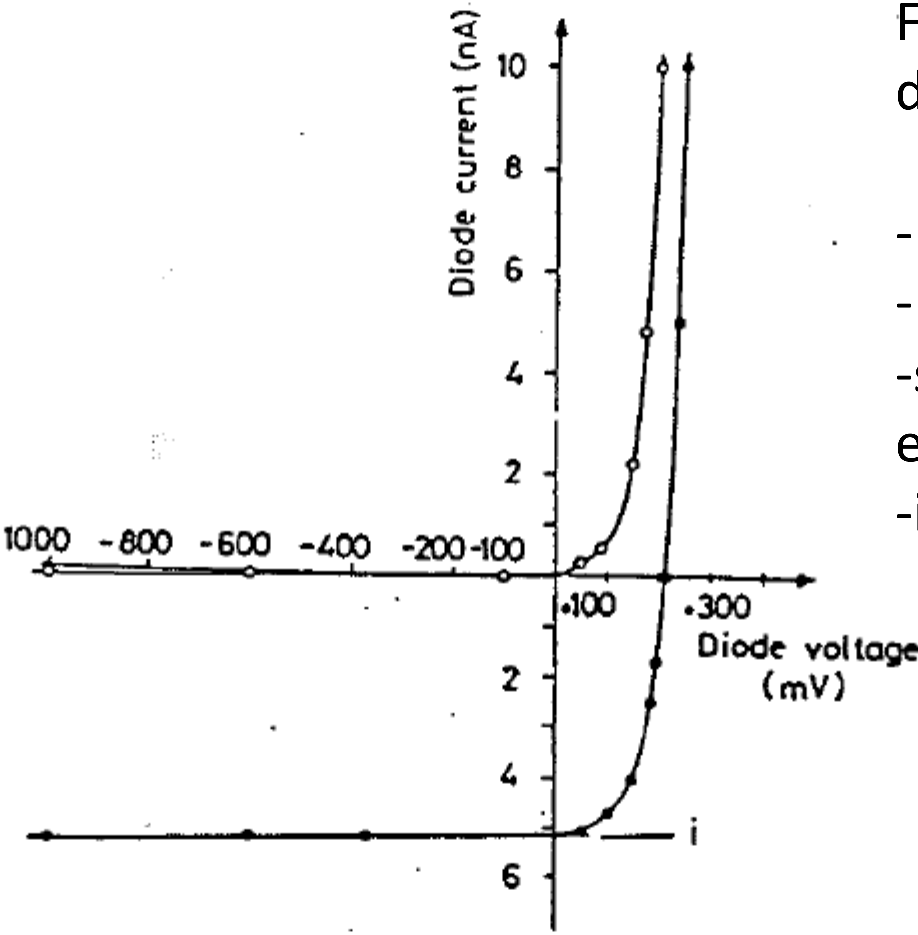

Mapcheck2, by Sun Nuclear corp.

IBA dosimetry LDA99.

| | |
|---|---|
| Sensor: | n-type diode, Pt doped; |
| Detectors active area: | $0.64mm^2$; |
| Active volume: | $0.019mm^3$; |
| Sensitivity: | 32nC/Gy; |

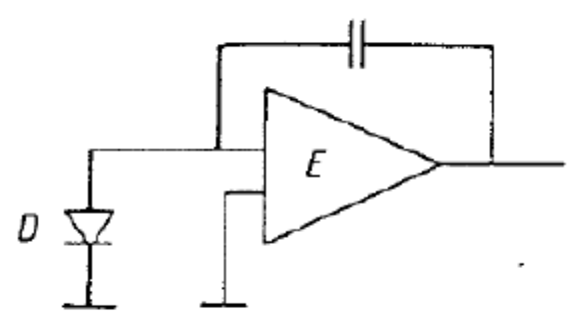
| | |
|---|---|
| Sensor: | p-type; |
| Diode spacing: | 5mm; |
| Detectors active area: | $3mm^2$; |
| Sensitivity: | 35nC/Gy; |

# Working principle

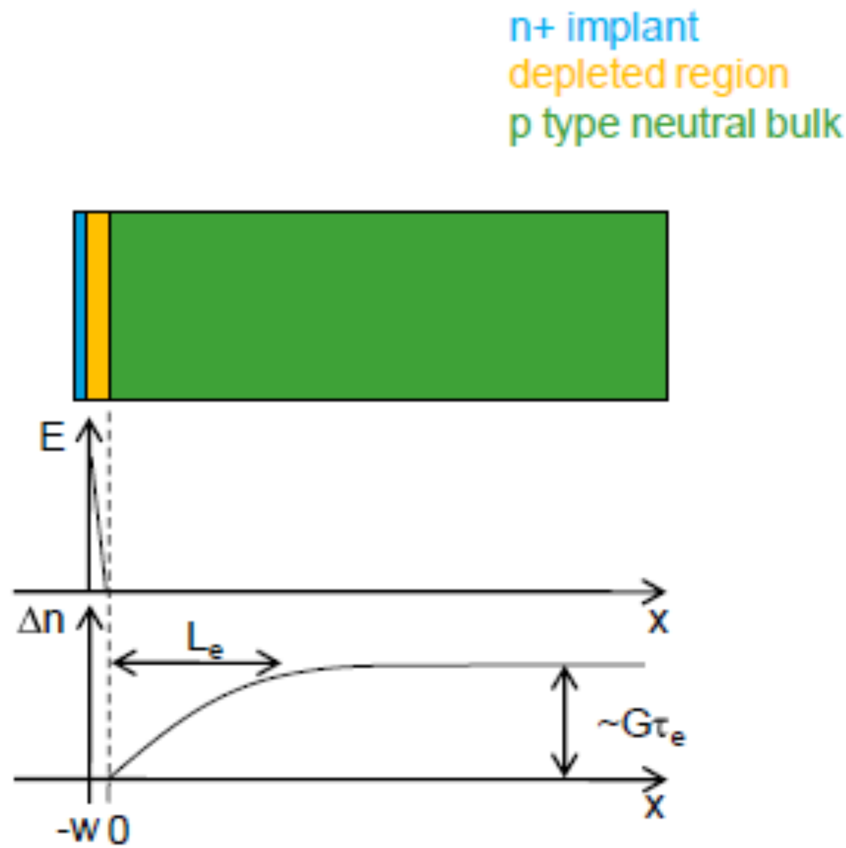



Features different from single event detectors:

-Null bias to minimize leakage current
-DC coupling
-sampling time and reset fixed by digital electronics ( usually T ≥ 10ms)
-integrated signal ( charge) measured



# Diffusion




(a) Excess carriers diffuse in the bulk
(b) diffusion lenght limited by recombinat
(c) minority carriers reaching the deplete region are swept by the electric field ar collected

$$\frac{\partial^2 \Delta n}{\partial x^2} = \left( \frac{\Delta n}{\tau_e} - G \right) \frac{1}{D_e},$$

Diffusion equation

$$D_e = \frac{kT}{q} \mu_e = 37.6 cm^2 / s.$$

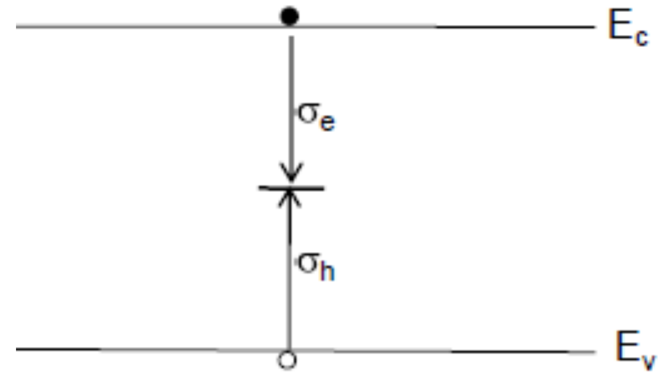
Diffusivity (at 300K)

# Radiation Damage issues

**Indirect recombination via midgap levels is dominant in silicon.**

**Dominant center produced by electron irradiation in silicon has cross sections:**

$\sigma_e = 1.62x10^{-16}$ cm$^2$
$\sigma_h = 8.7x10^{-16}$cm$^2$




So it is more likely to capture holes than electrons. Diffusion is a process dominated by minority carriers so

**… p-type bulk better ( as for HEP detectors!)**

# Sensitivity of standard Si dosimeters changes due to radiation damage

Sensitivity per unit area of the device:

$$S = \frac{j}{R} = sL_e$$

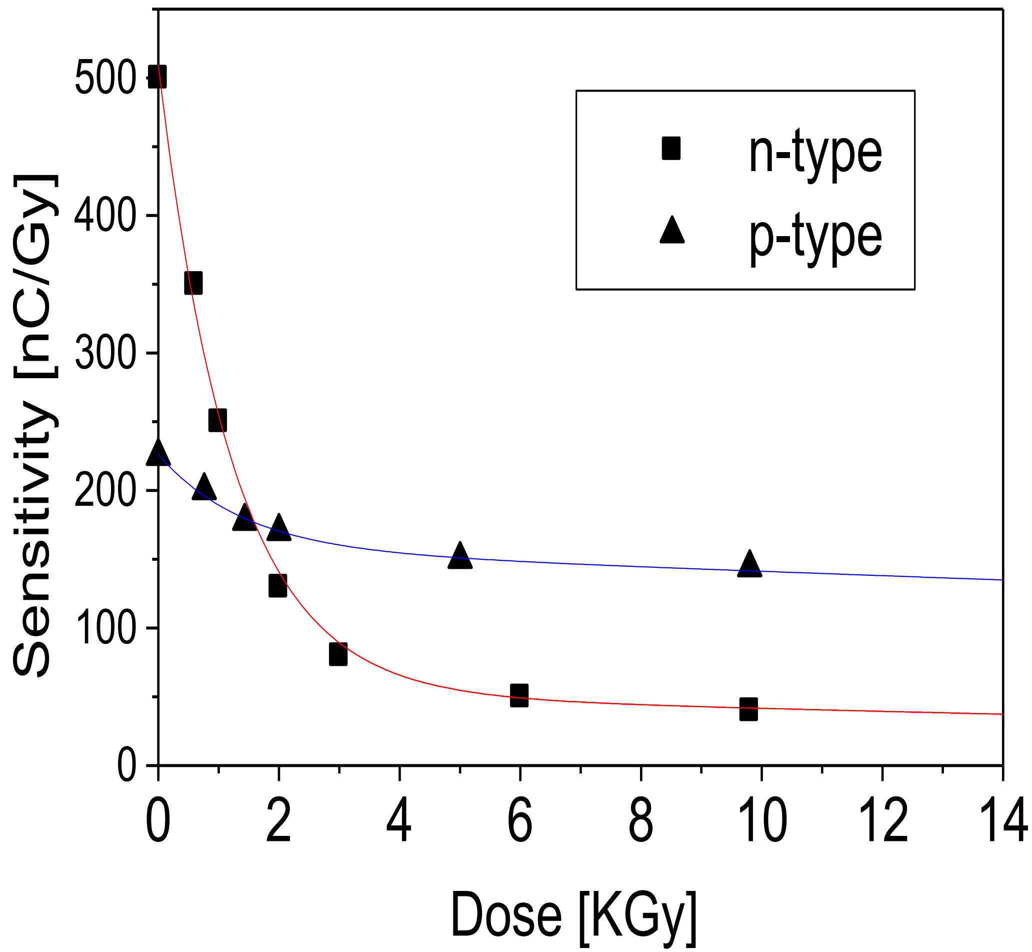
If a single trap dominates:

$$S = \frac{q\rho_{Si}}{E_i}\sqrt{\frac{D_e}{\sigma_e v_e N_t}} \propto N_t^{-1/2}.$$

$N_t$ grows with irradiation: sensitivity changes with the accumulated dose.

**Decrease in sensitivity S during device lifetime**

- Frequent Calibration needed.
- Usually Si devices pre-irradiated up to 10kGy




G.Rikner et al.Phys. Med. Biol. 28, 1983, 1261-1267

# Our Radiation Hardening Choices

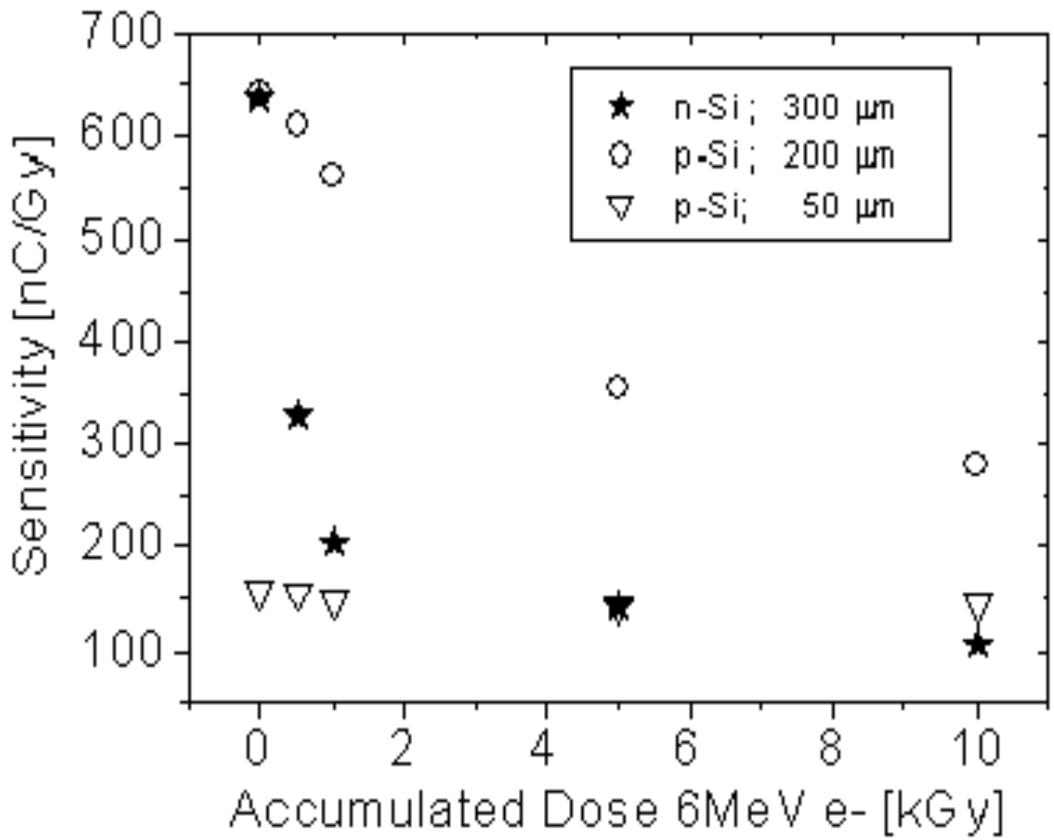
**Constant active volume during irradiation:** epitaxial layer thickness and guard ring distance from active area thinner than minimum diffusion length reached during device lifetime will provide constant sensitivity.

High quality crystalline epitaxial Si of 50μm thickness is now commercially available on large scale at very low costs

Sensitivity of silicon is quite high, and the subsequent reduction in signal strength is of no concern.

- 4” p-type MCz wafer
- Epitaxial layers with 50μm thickness grown by ITME Warsaw Poland
- Manufacturing of the device carried out by ITC-IRST Trento (now FBK)

# Radiation hardening: thin p-type Epitaxial Si




M. Bruzzi et al., "Epitaxial silicon devices for dosimetry applications," Appl. Phys. Lett., vol. 90 (2007) 172109 1-3.

# Development of the 2D Si Matrix

- **Best compromise between bidimensional resolution and electronic read-out efficiency has been achieved by means of a modular device composed by squared matrixes of macropixel sensors. The best geometry of the pixel cell has been determined by investigation of the sensitivity and radiation hardness of single pad diodes with different thickness and active area.**

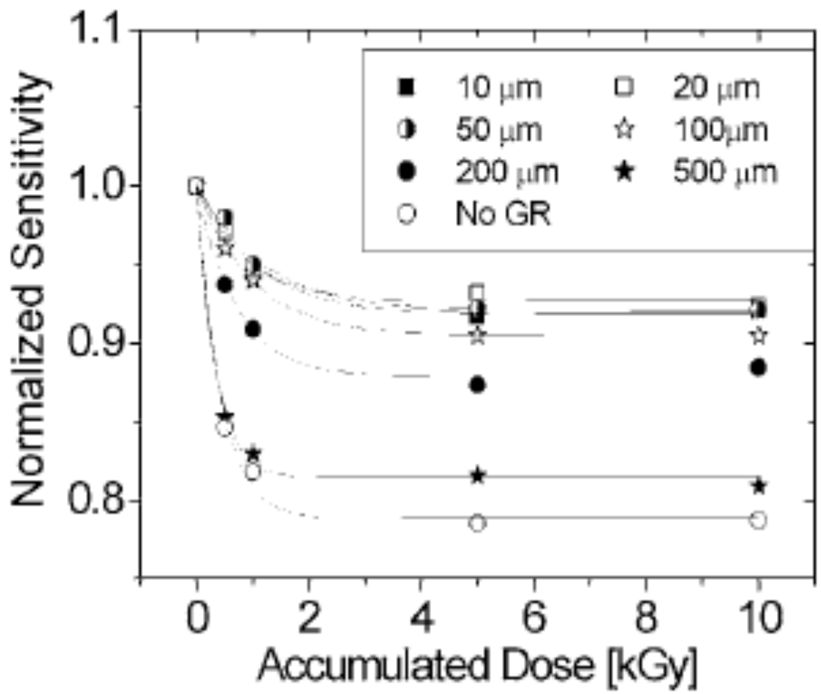
- **We have experimentally studied different guard-ring solutions to confine the lateral extension of each macropixel cell. Best solution is the manufacture of a guard-ring net surrounding each pixel and connected to ground.**

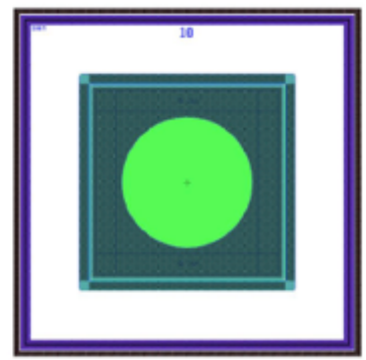
# Pixel Geometry

**n⁺- on-p pixel junction surrounded by a guard-ring structure implanted on an epitaxial p-type Si layer grown on a Czochralski substrate.**

**our choice of epitaxial layer thickness: 50μm ( diffusion length higher than thickness for irradiation doses up to 10kGy )**

**Guard ring choice: 20μm**

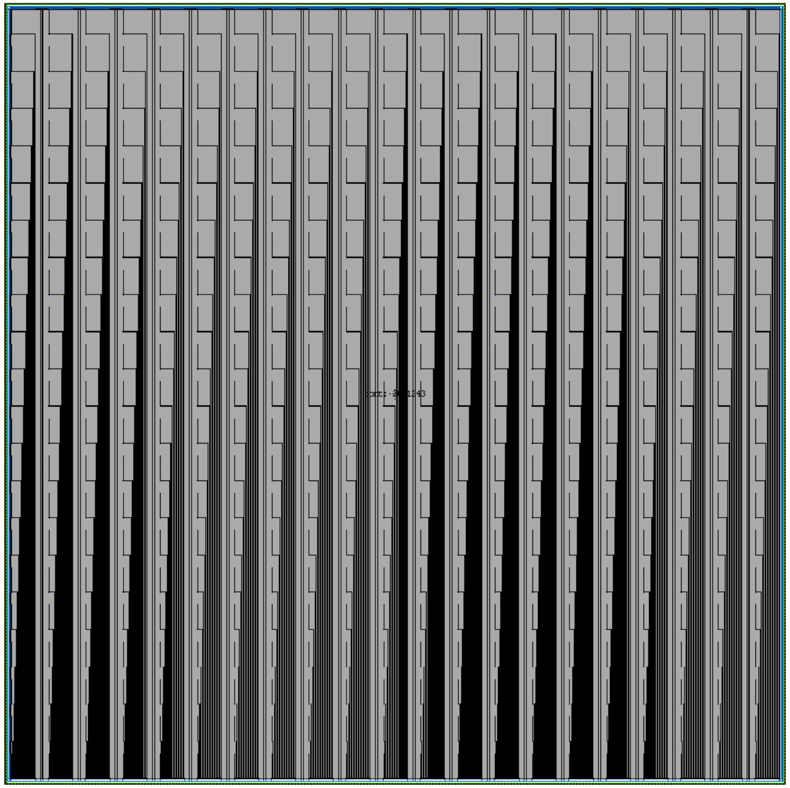



| | |
|---|---|
| Active area | ~9mm² |
| pad-grd distance: | 10-500 μm |
| Epi layer: | 50μm thickness |
| | 50Ωcm resistivity |
| | p type |

M. Bruzzi et al., "Epitaxial silicon devices for dosimetry applications," Appl. Phys. Lett., vol. 90 (2007) 172109 1-3.

# 2D Dosimeter Module   Geometry

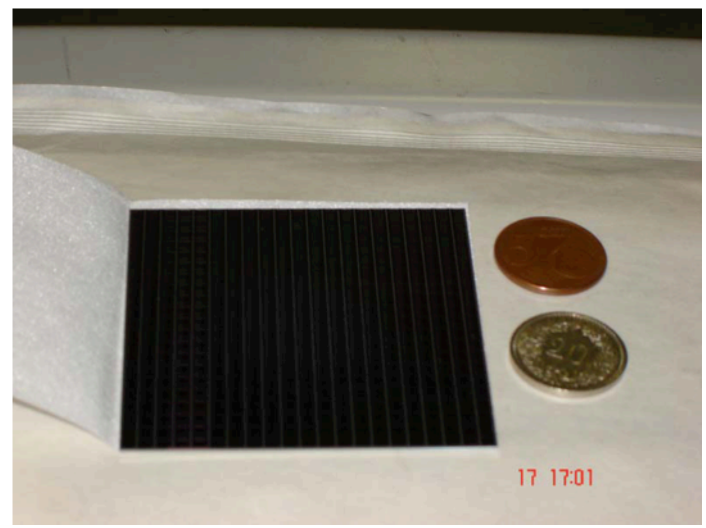


Matrix: 21x21pixels

Pixel: 2x2mm

Pitch: 3mm

Detector size: $6.3 \times 6.3 cm^2$




Tests under probe station:

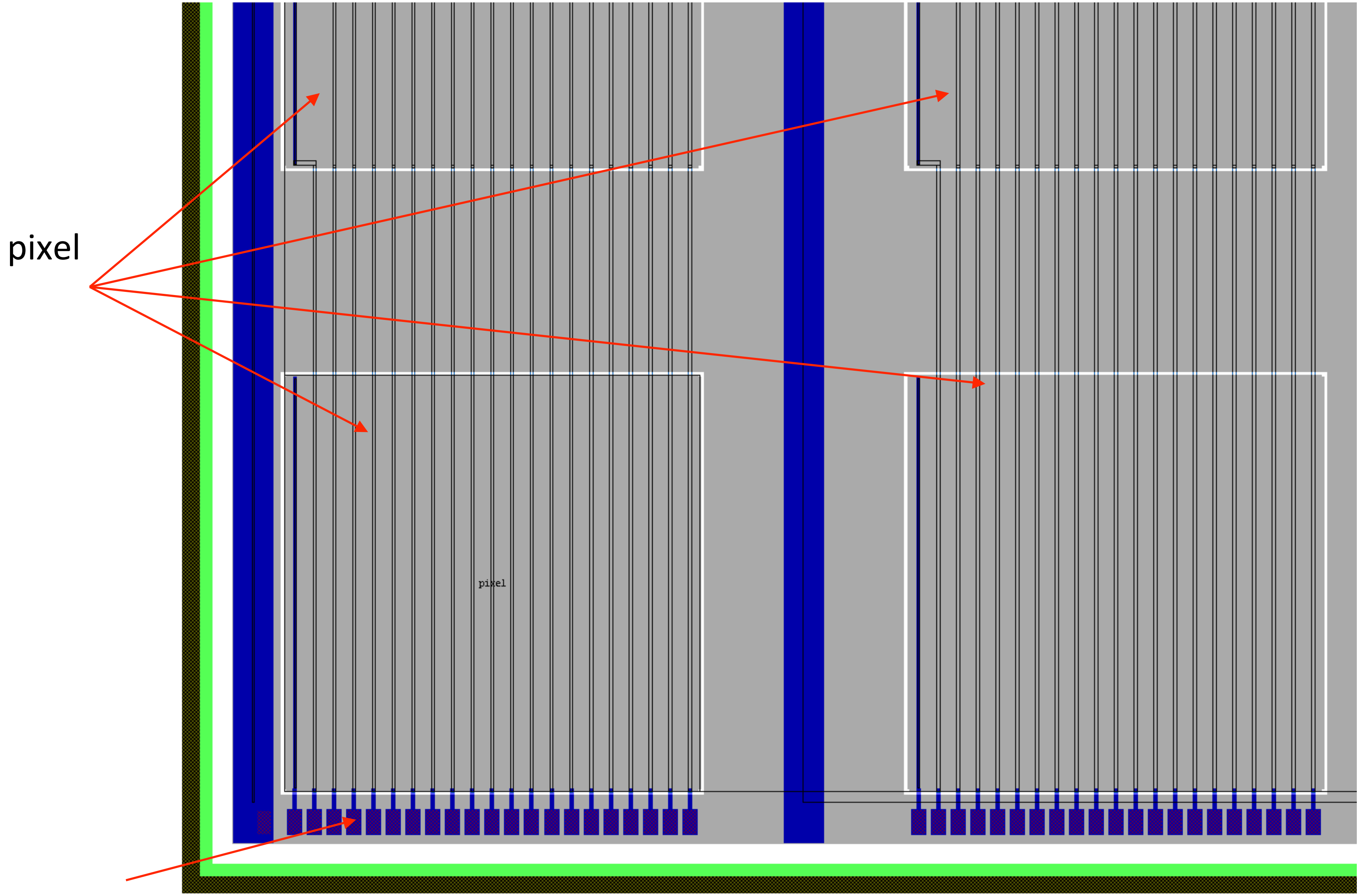
average zero-bias current : $i_0$=13±7 pA

Temperature coeff.: $di_0/dT$=4 pA/°C.

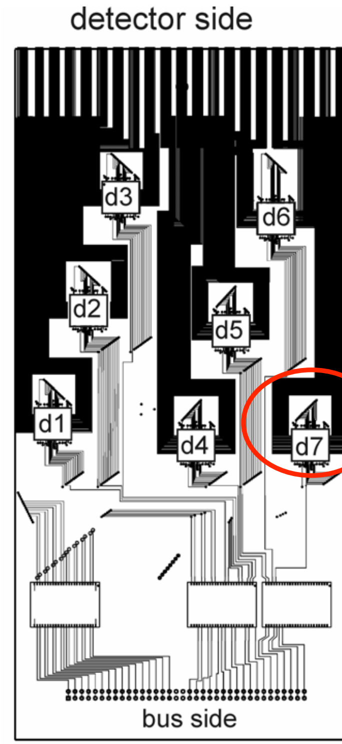
Cross-talk capacitance: $C_c \approx 2$ pF

Bottom corner

Blue=metal; grey=n implant; green=p implant;
Black=scribe line; violet=passivation opening



# 2D Si Module equipped with electronic read-out




TERA06 ASIC

Detector module

**Detector module contains 7 TERA06 chips bonded on a high density 100 μm pitch PCB that read-out the 441 ch of each detector**

- **TERA06 ASICs developed by INFN Turin and produced by Scanditronix**
- **64 channel current to frequency converter**

# Design of the Large Area Prototype

**Specifications:**

**a) Spatial resolution:**

**~1 mm granularity**

**b) Active area:**

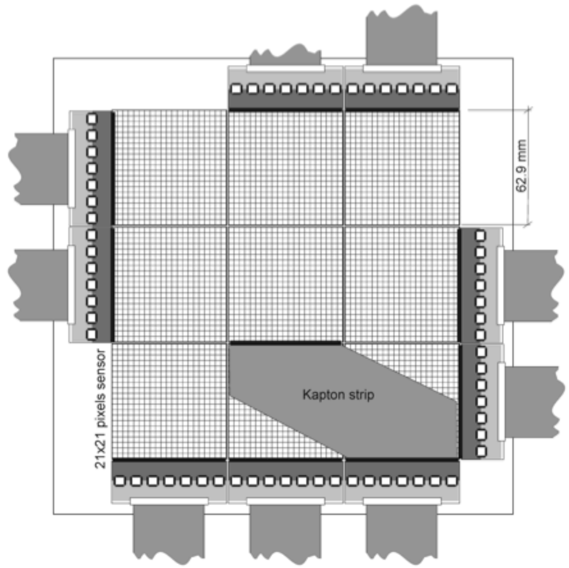
**at least 20x20 cm$^2$**

**c) Low Background signal:**

**< 0.1% of signal**

**(zero bias operation needed)**

**Response speed and signal strength are of no concern**



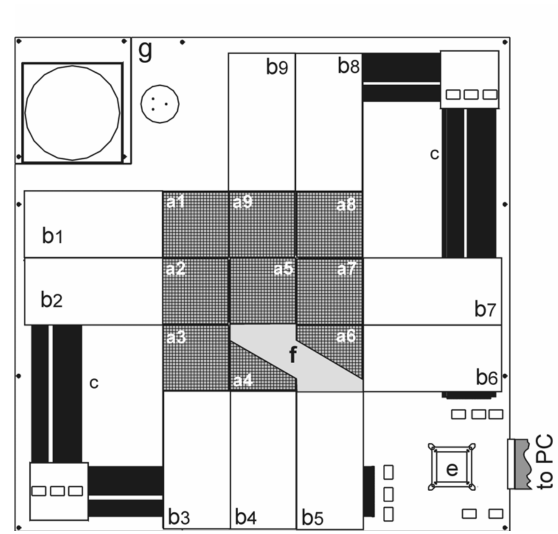

**9-modules design:**

**A single module cut from each wafer.**

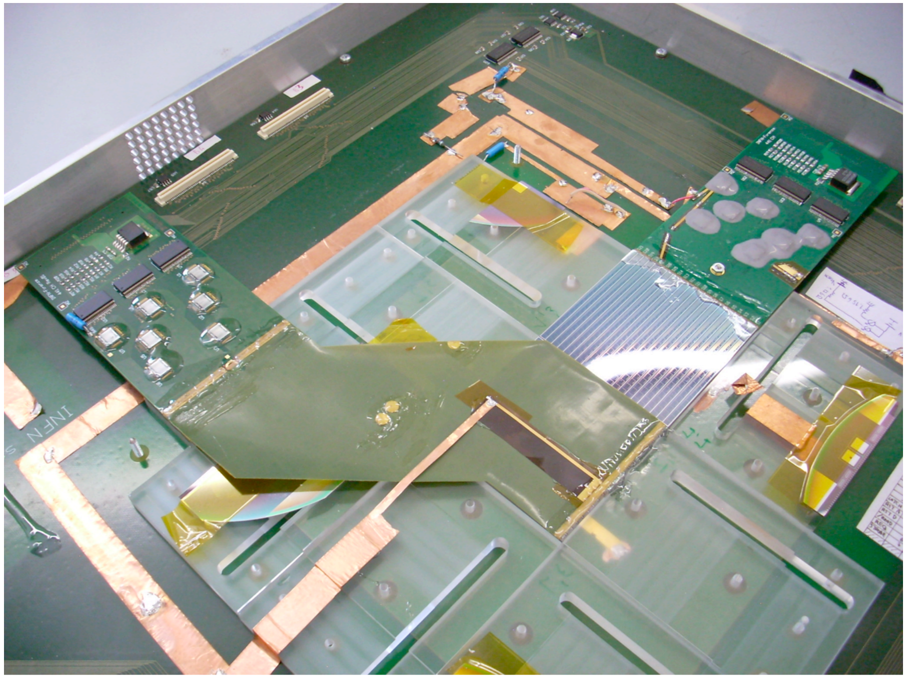
**Nine modules will be used to cover an area of about 20×20 cm$^2$.**

**System complexity: ~4k channels**

The mother board is connected to a digital DAQ board controlled by Labview

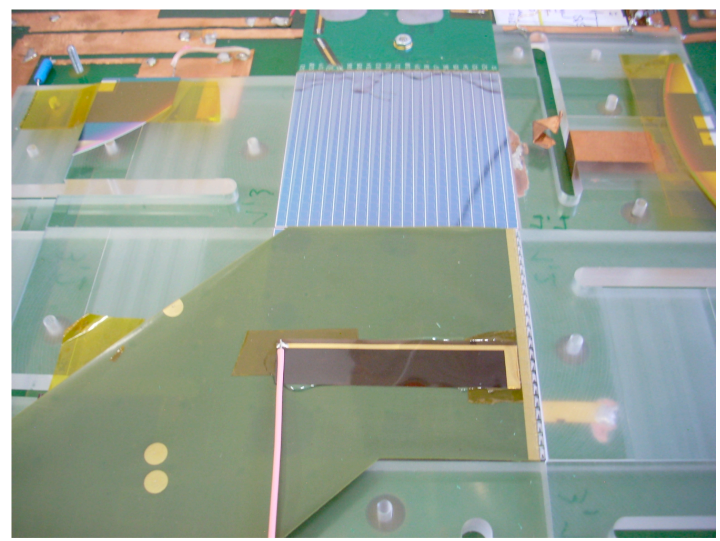


# Work in progress: Large Area Prototype Assembling



4kch detector with two silicon modules out of nine

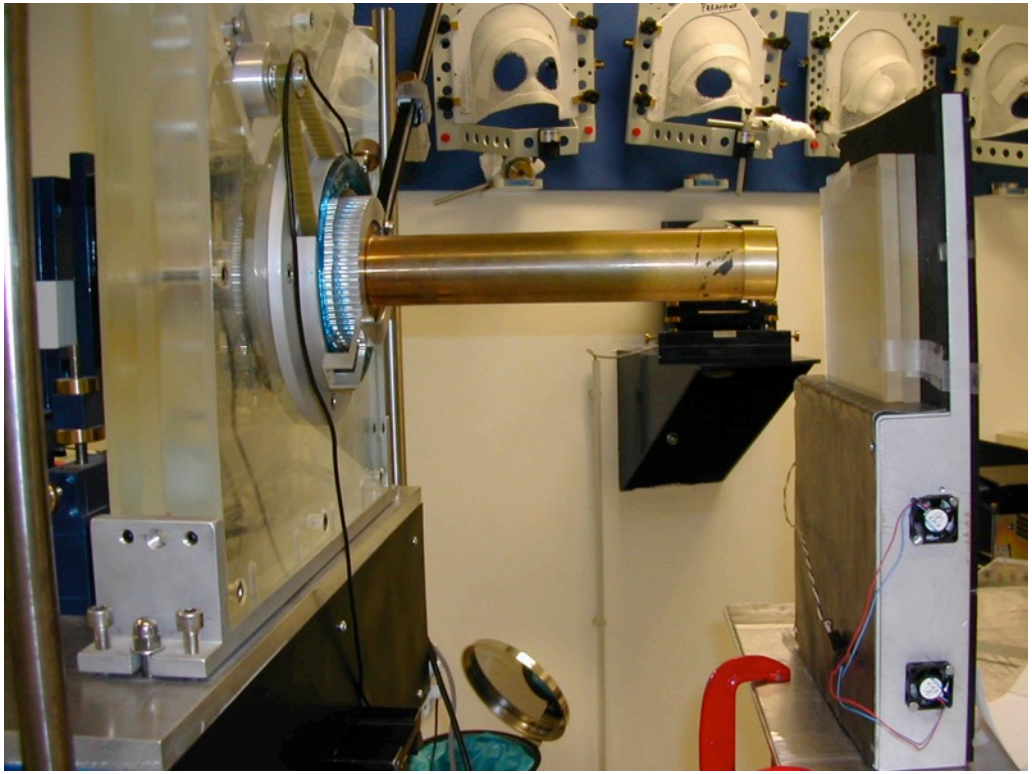
Details of connection between the kapton flexible circuit (pale green) and central silicon module. The central module is almost completely covered by the foil, but its position can be argued from that of the silicon module in the upper side of the image.



# Photon Dosimetric characterization

irradiated with 6, 10, 25 MV photon beams from Precise/Synergy LINAC (ELEKTA) at the **Careggi University Hospital in Florence**.

MAESTRO Prototype was irradiated with 62 MeV protons for medical applications at INFN-LNS Catania



# Results

Almost all the channels exhibit a **repeatability** < 0.5%, **reproducibility** < 1%

•deviation from **linearity is 0.3%** in the dose range 10-550 cGy, and the fraction of channels which have a deviation better than 1% is 98%

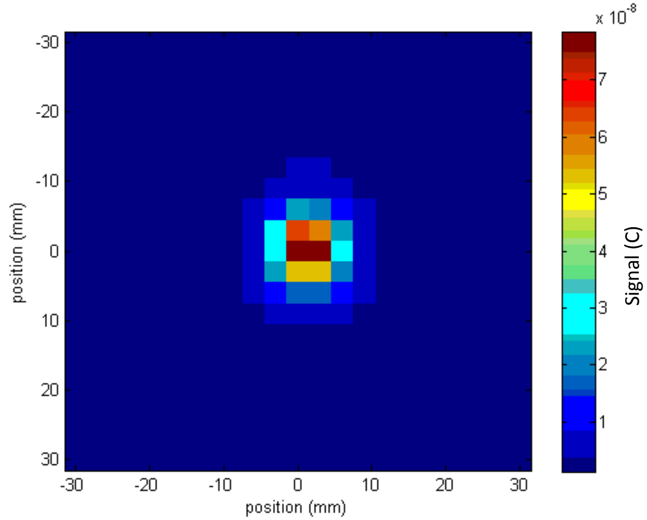
•Measurements in the dose rate range 40-350 cGy/min indicate that there is no dose rate dependence.

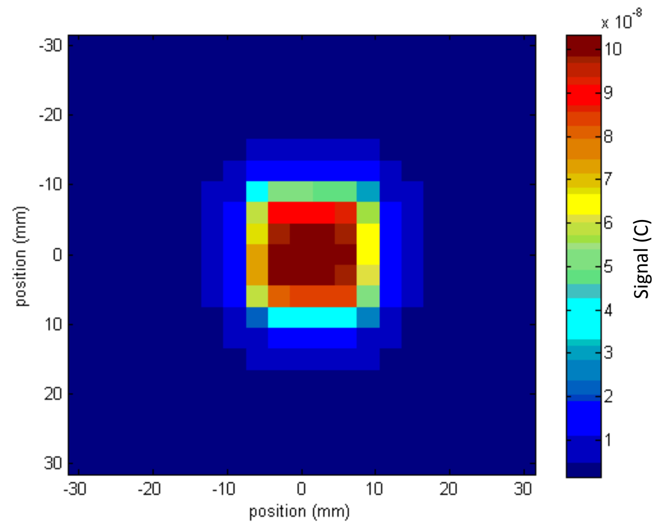
**Mean sensitivity = 1.248 ± 0.004 nC/cGy**

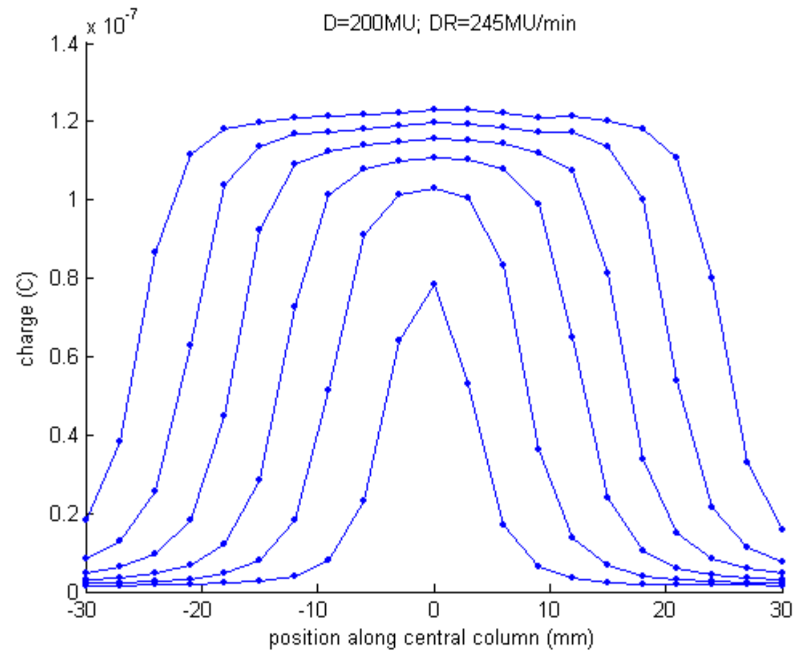
•The energy dependence for assessed for different beam quality and TPR were measured at different depths. As expected a slight energy dependence was observed since silicon is not water equivalent

# Dose maps

# Profiles



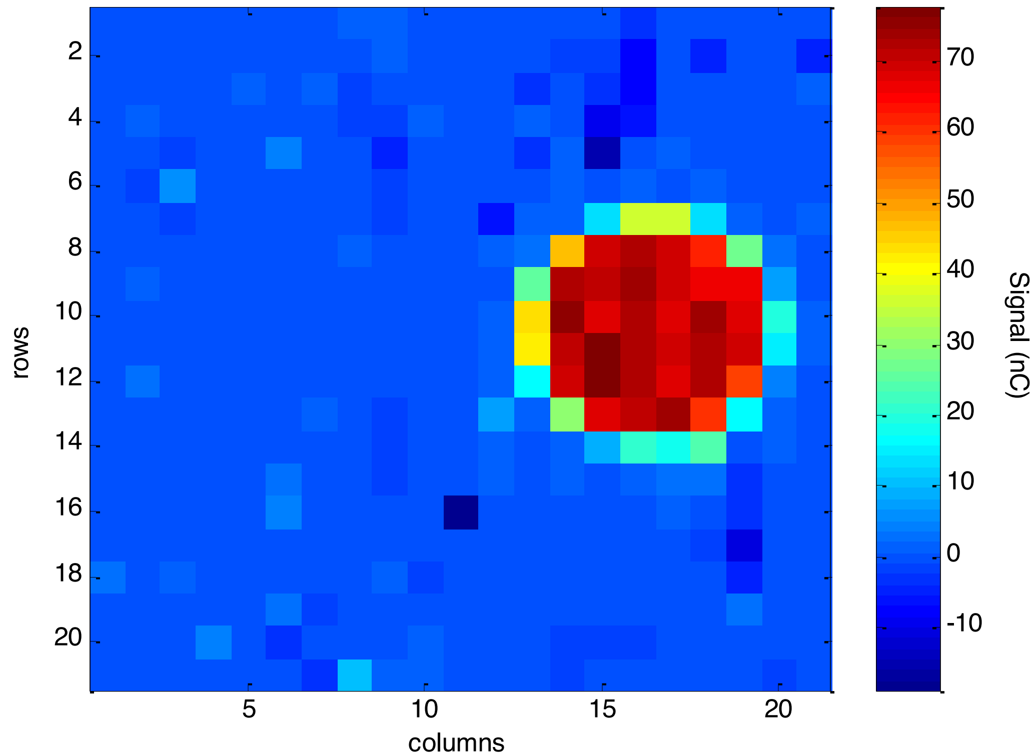

**Profile along the central column for different field size**

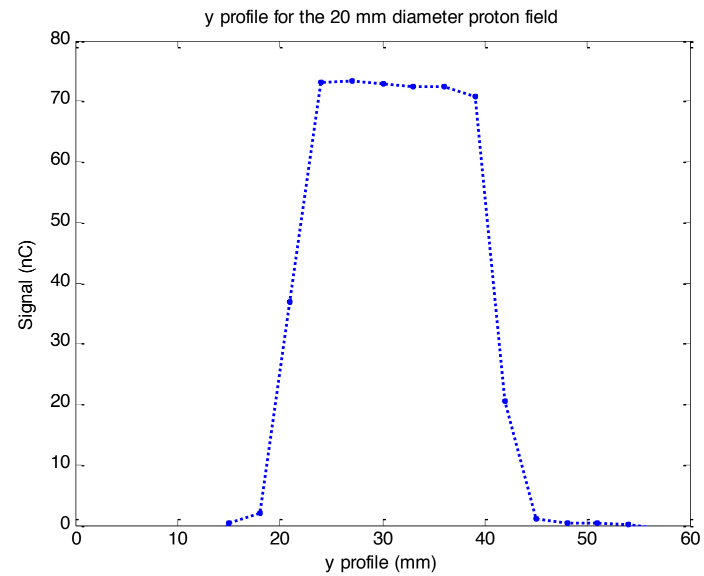
**(0.8X0.8, 1.6x1.6, 2.4x2.4, 3.2x3.2, 4x4, 4.8x4.8)**

6MV photon beam at Careggi Hospital

# Dose map

# Profile

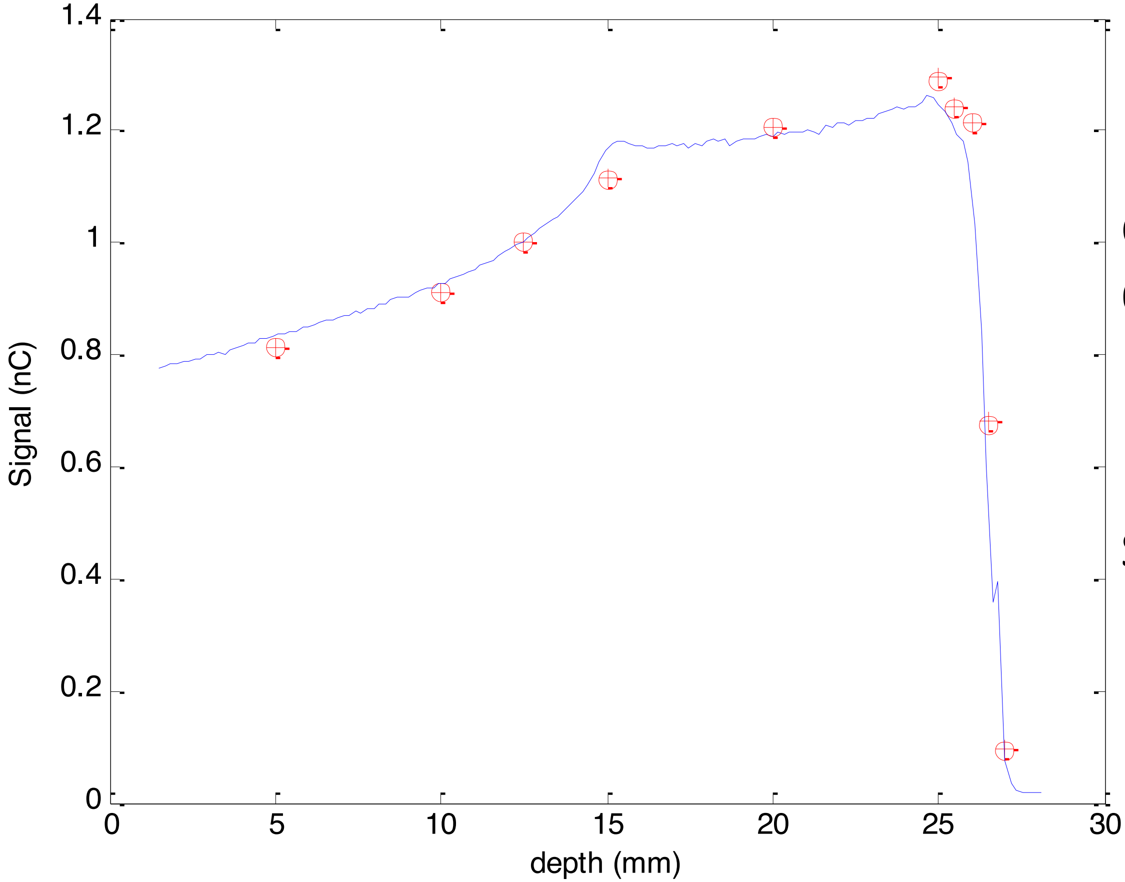



Field size 20 mm diameter

62 MeV proton beam at LNS Catania

# Depth dose measurements (protons)




Spread Out Bragg Peak

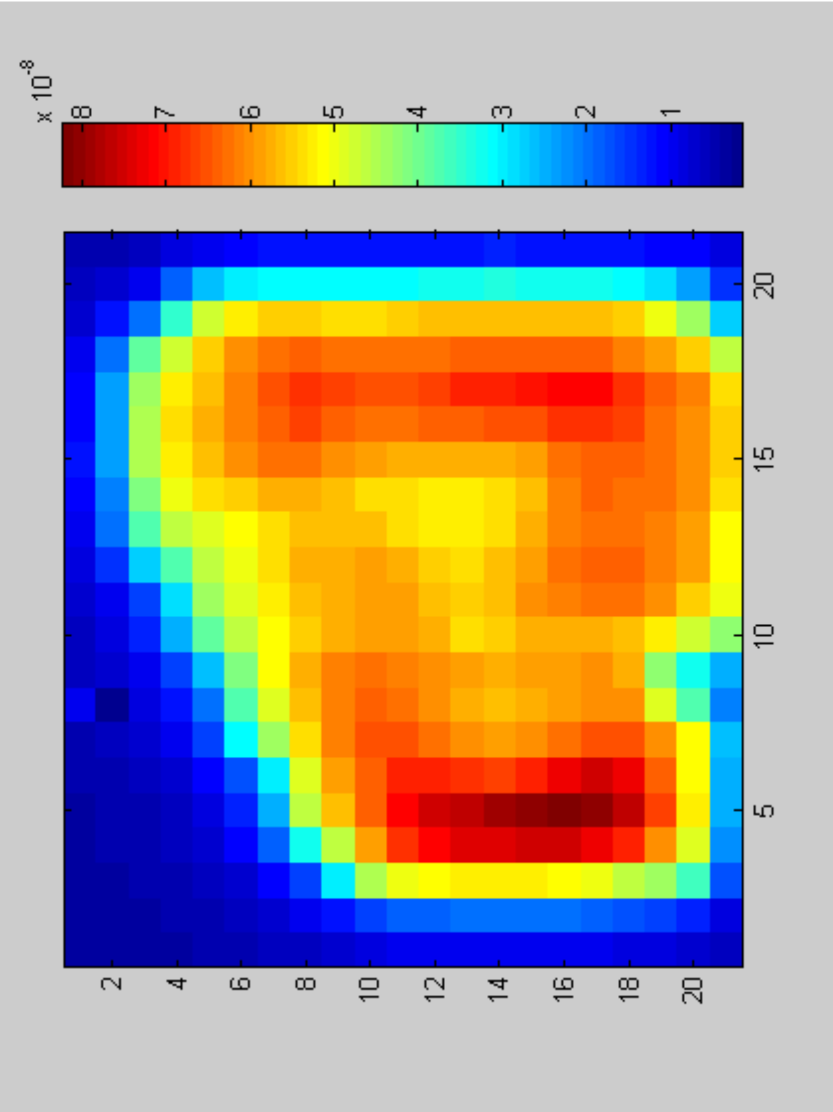
CATANA:
62 MeV proton beam

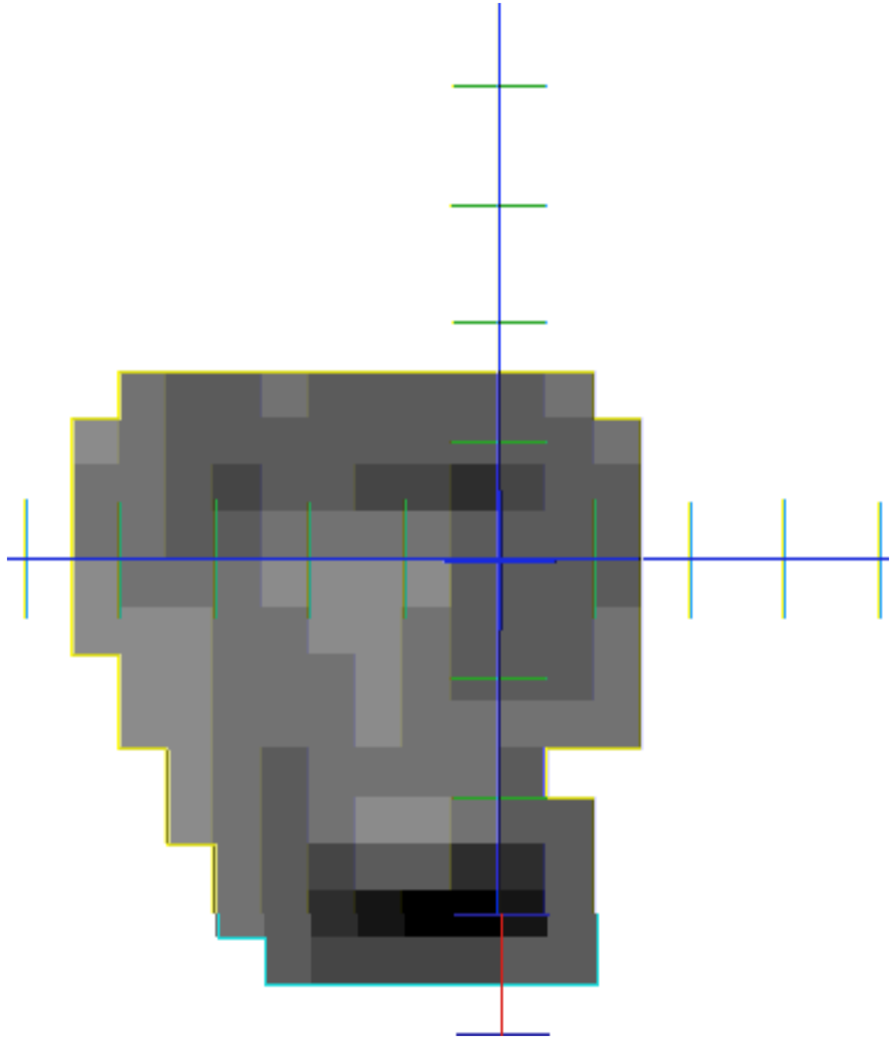
Measurements in PMMA

Signal normalized at 12.5 mm

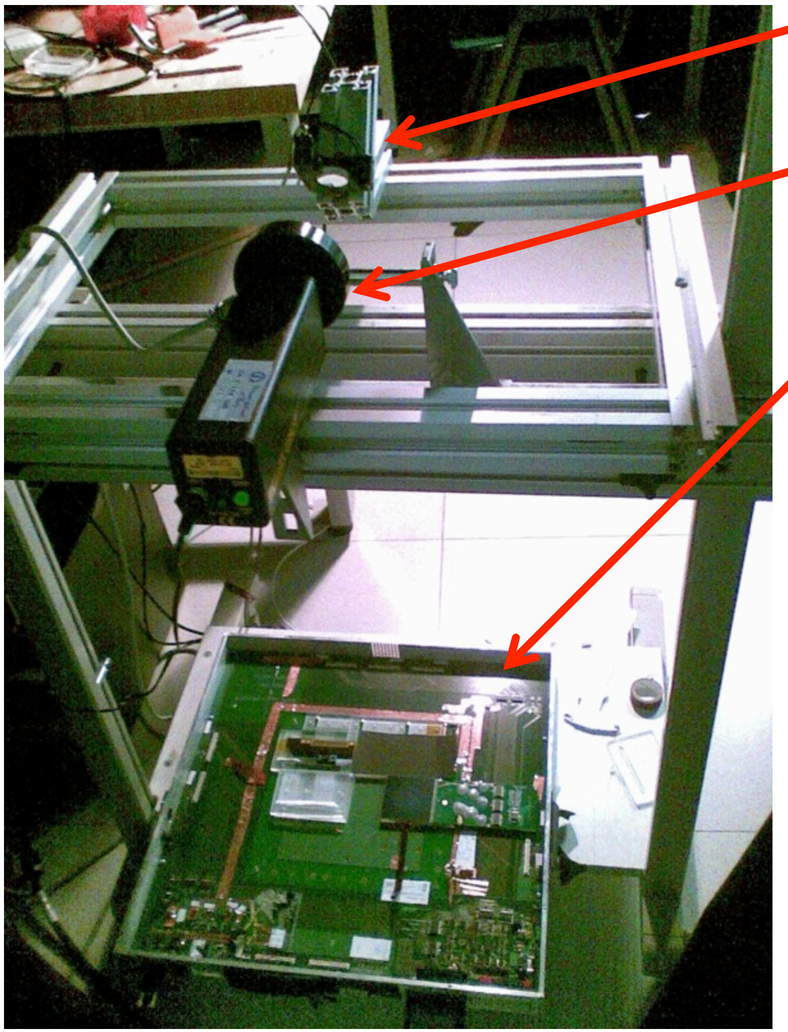
# IMRT Field

10MV photon beam at Careggi Hospital

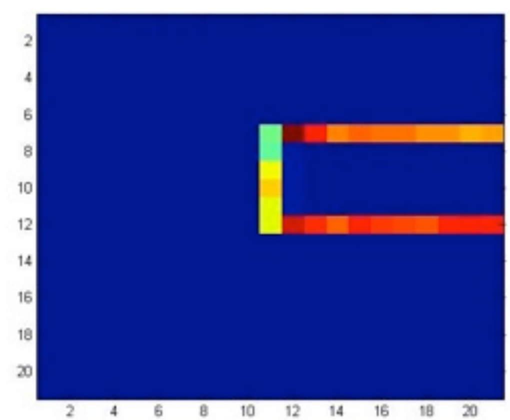


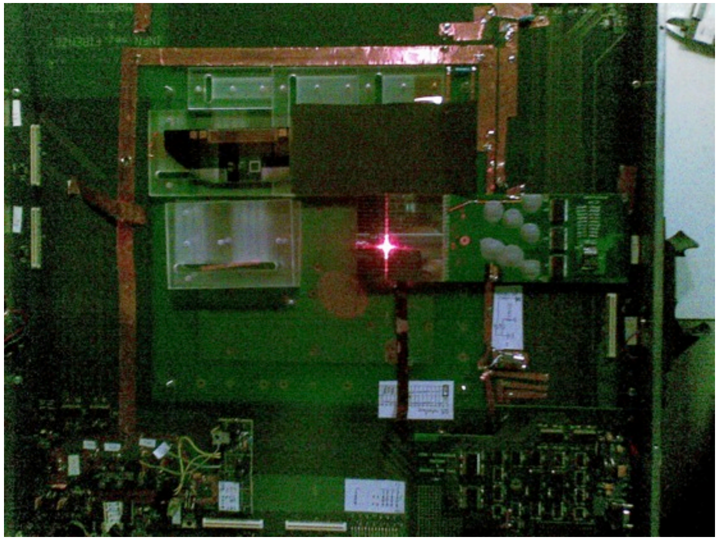
# Experimental Set Up I

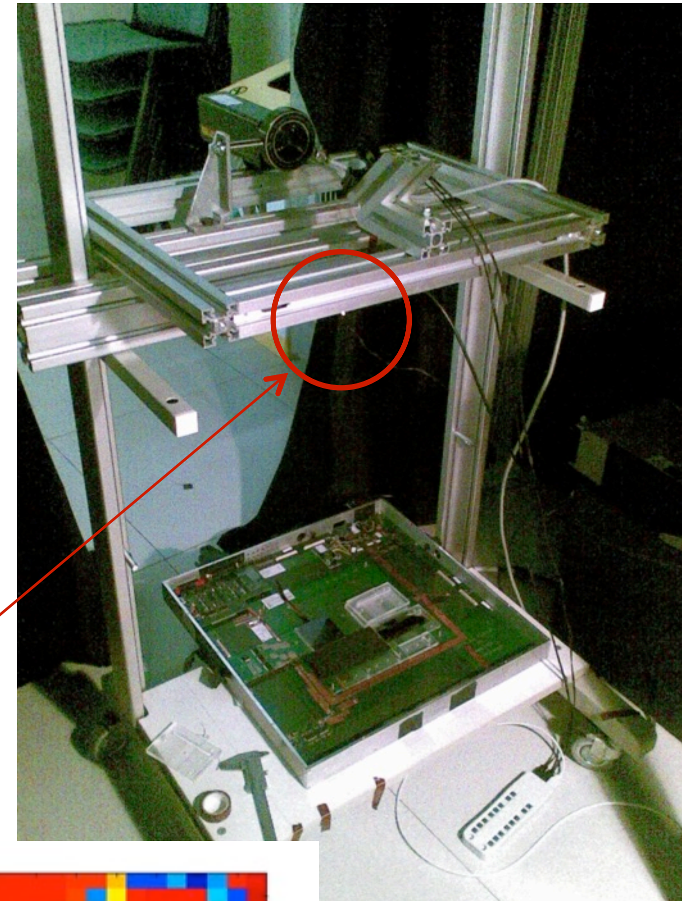


- -Mirror on piezomotor system to move the beam along x-y axes on silicon 2D dosimeter
- -Filtered Laser He-Ne instead of the photon beam
- - 2D Si dosimeter mounted on mother board
- - PC automatized system with reconstruction software



# Experimental Set Up II

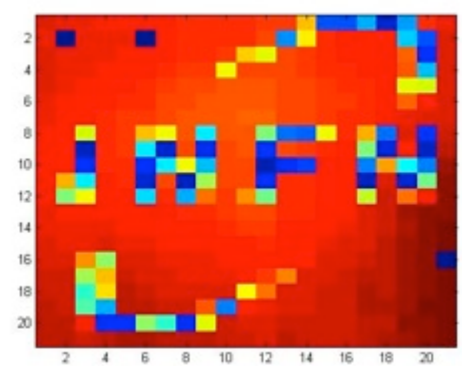




-LED supplied with a pulse generator with variable duty cycles

Slides with different grey-scales to simulate dose conformation

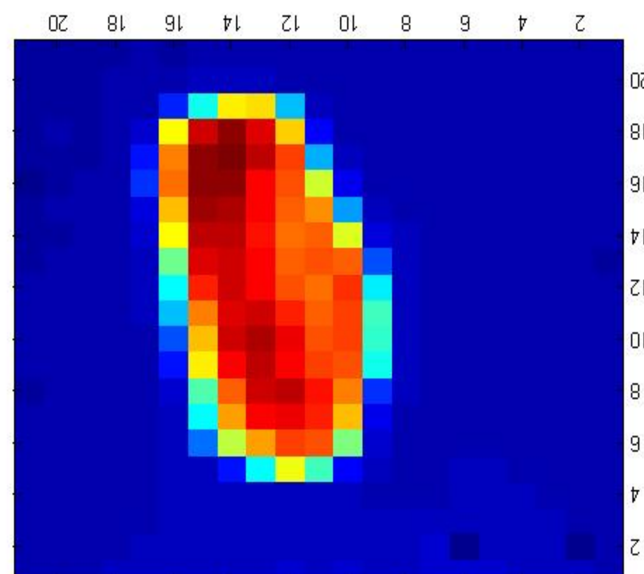
- PC automatized system with reconstruction  software



# Grey-scale to simulate dose maps from TPS

**TPS for IMRT of breast cancer**

**Dose map measured with 2D Si dosimeter**

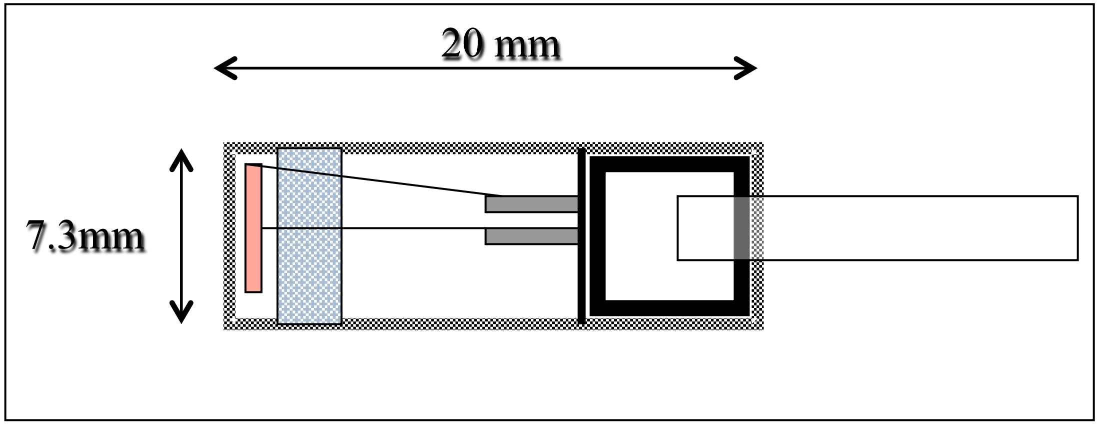


# Diamond Dosimeters

☺
- it is almost water equivalent
  - it doesn't perturb the radiation field → small fields
  - the energy is absorbed as in the water → no correction factors
- high radiation hardness → long term stability
- high density → high sensitivity → small dimensions
- non toxic
- it can be used as TL dosimeter (off-line) or for on-line applications

♠
- high defect density - priming effects – instability of the signal
- high voltage required
- high production costs

# Commercial Devices:PTW




| | |
|---|---|
| •Sensitive area: | 4.3/4.5 $mm^2$ |
| •Sensitive volume: | 1.3/1.4 $mm^3$ |
| •Thickness of sensitive volume: | 0.30/0.31 mm |
| •Operating bias: | 100 V |

# Characterisation of PTW diamond

- Linearity: within 0.5% for absorbed dose up to 5 Gy
- Constant sensitivity for photon beams of different energy:

  ISS: 88.4 nC/Gy, LNS: 85.4 nC/Gy

- Dependence on the dose rate ($D_r$):

Fowler:

$$I = I_{dark} + RD_r^{\Delta}$$

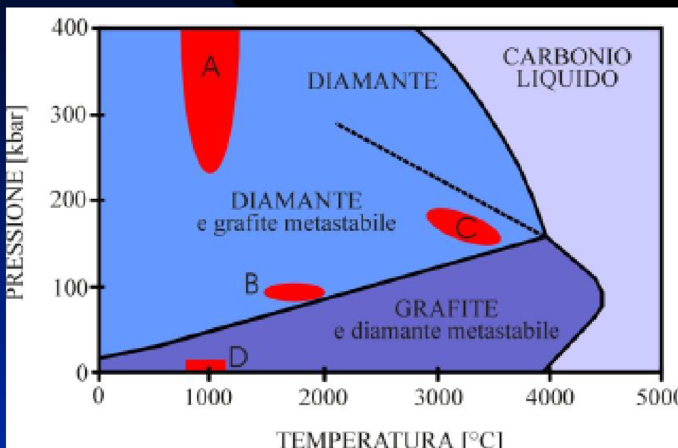
$\Delta$= 0.98

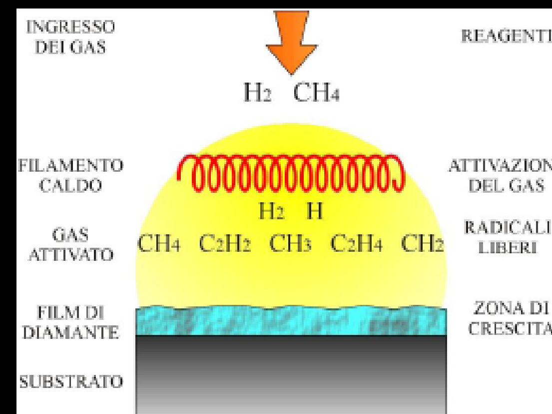
$I_{dark}$ < 1 pA

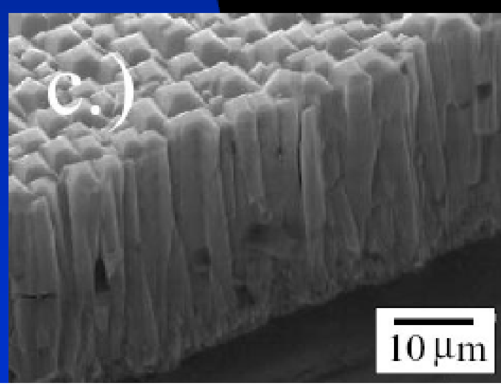
In absence of traps $\Delta = 0.5$

Uniform trap distribution $\Delta = 1$

# Chemical Vapor Deposition



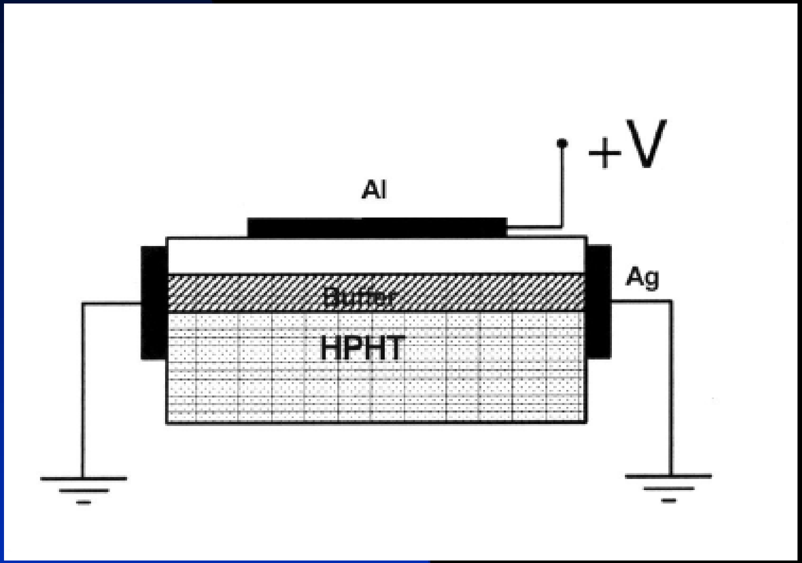




Poly : on Si or other substates

Mono : on HPHT single crystal substrates

## Single crystal diamond dosimeter

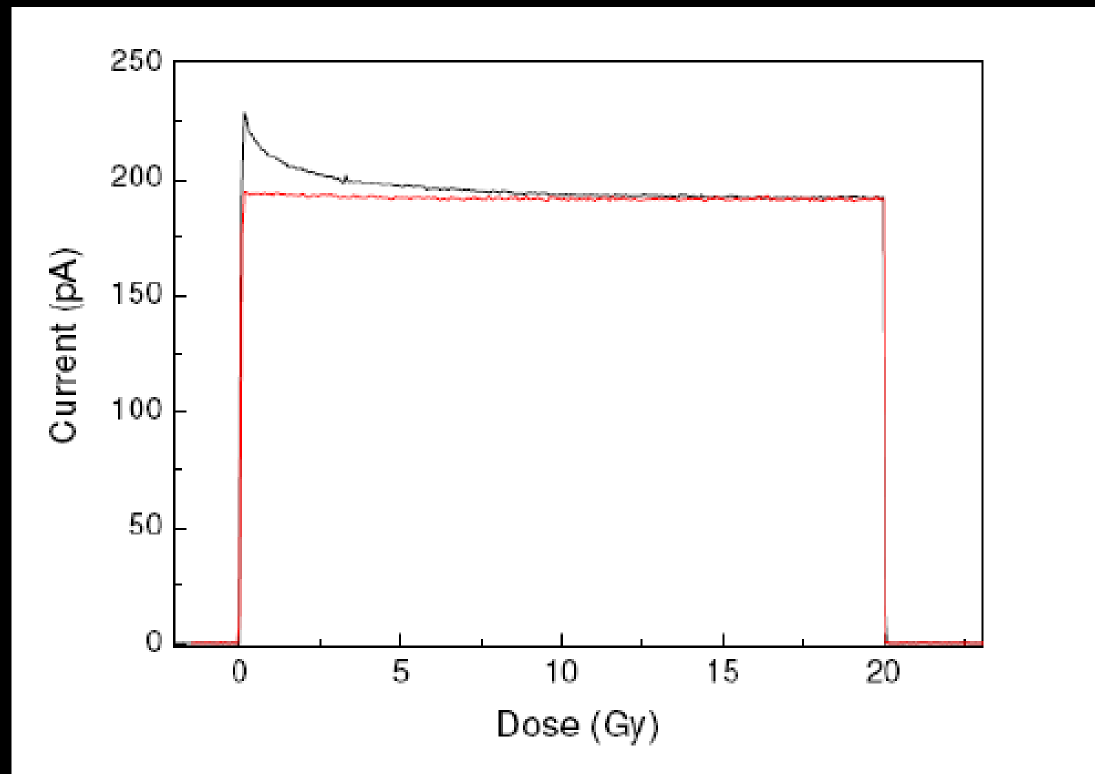
Layout device produced by Università di Roma Tor Vergata



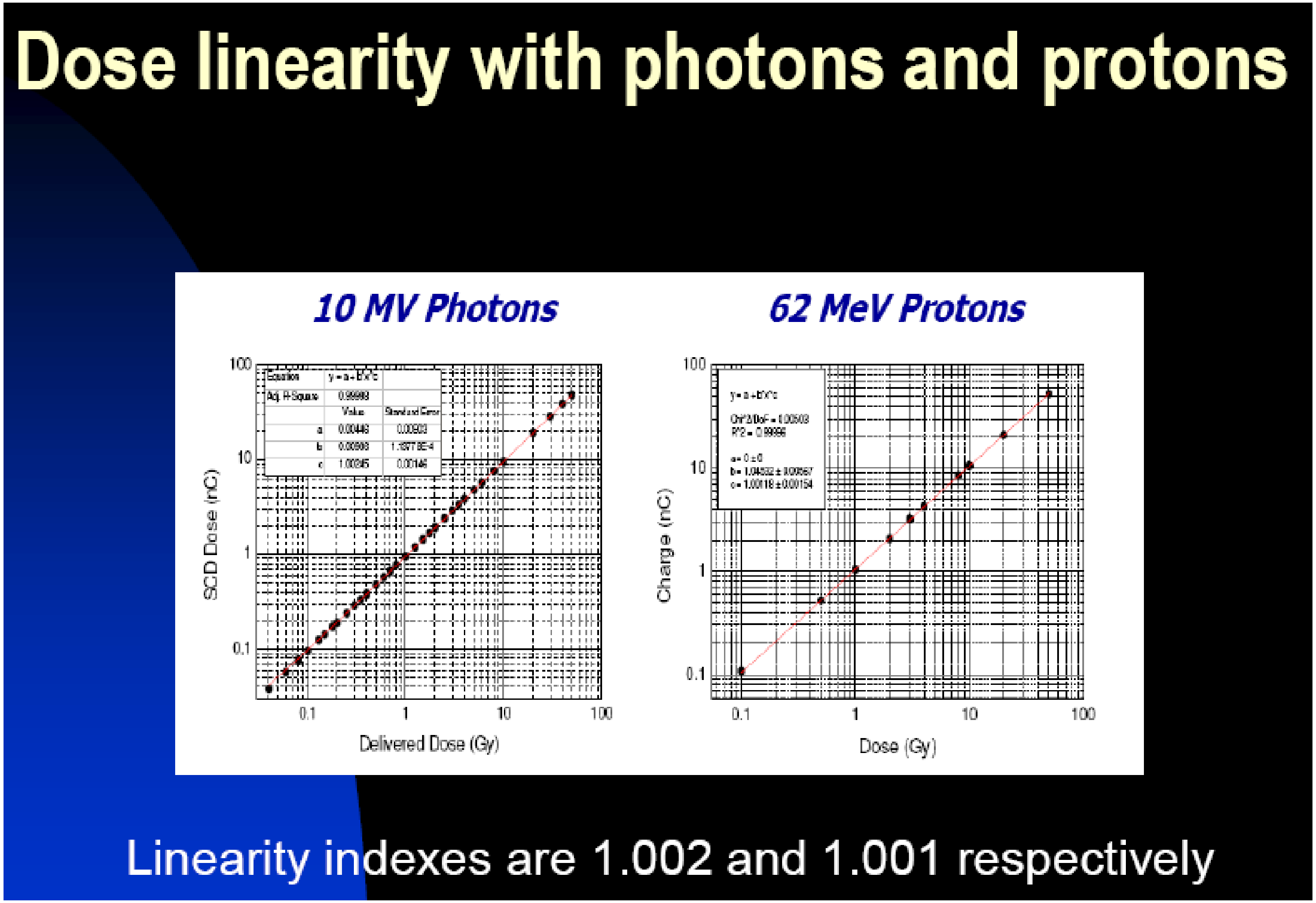

- HPHT p+ boron doped substrate - 300 μm thick
- 35 μm thick p+ buffer layer (CVD)
- Active epilayer 17 μm thick
- Al 100 nm ϕ 2mm upper electrode
- Buffer layer contacted at the perifery with Ag paste

## Priming of a Single crystal diamond dosimeter

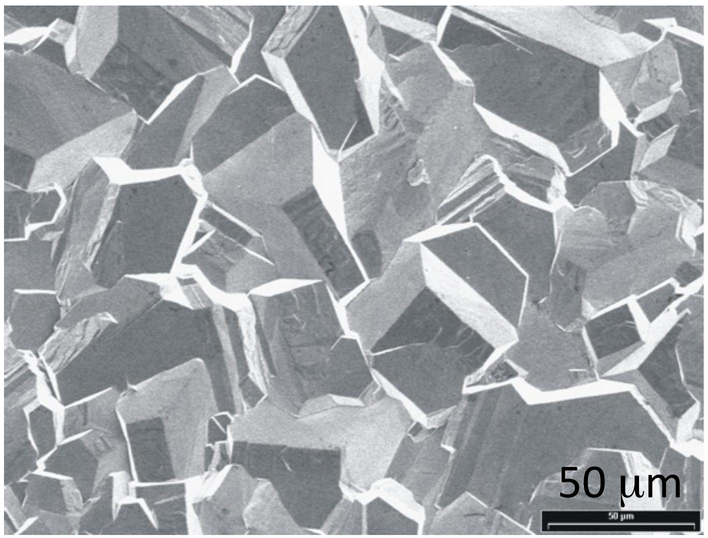
- Priming or pumping up to 15 -20 Gy before daily use ( as natural diamond )
- Fluctuations below 1 % (red curve)



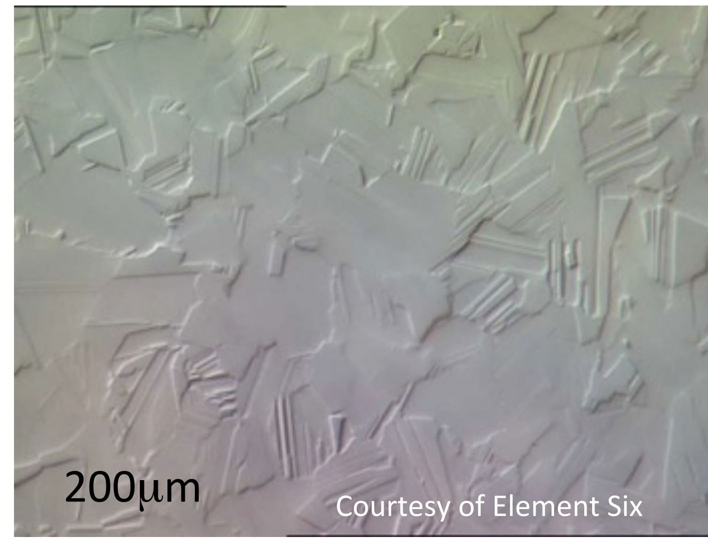
Single crystal diamond dosimeter



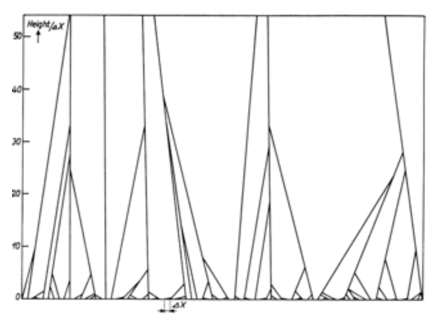
# Chemical Vapour Deposited polycrystalline Diamond



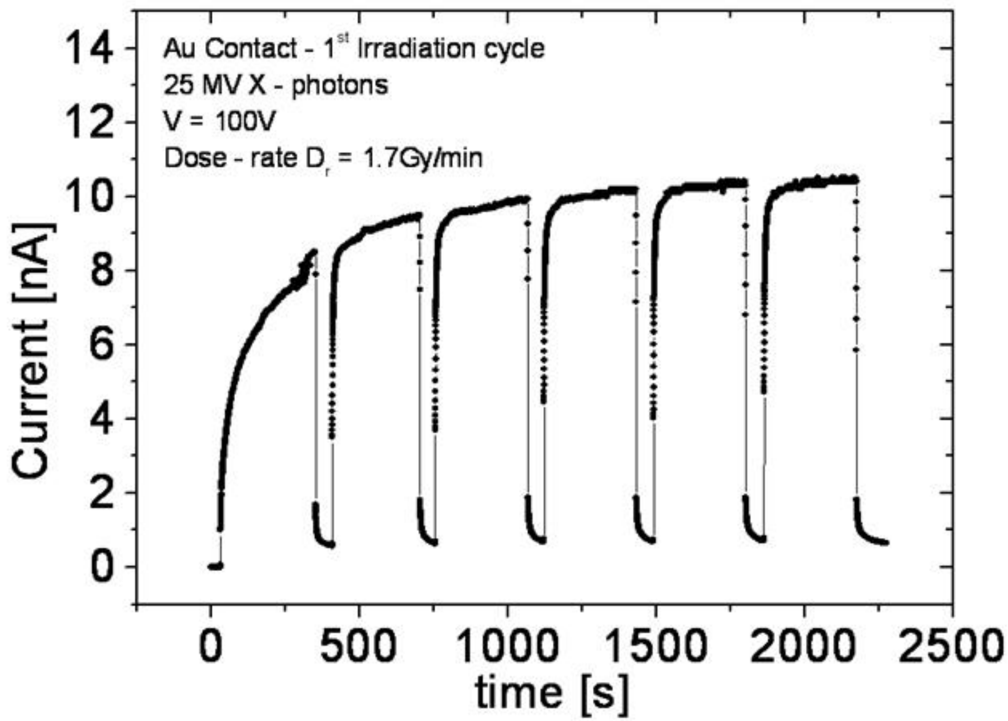

After polishing and Material removal




- Columnar growth – increased quality at growth side

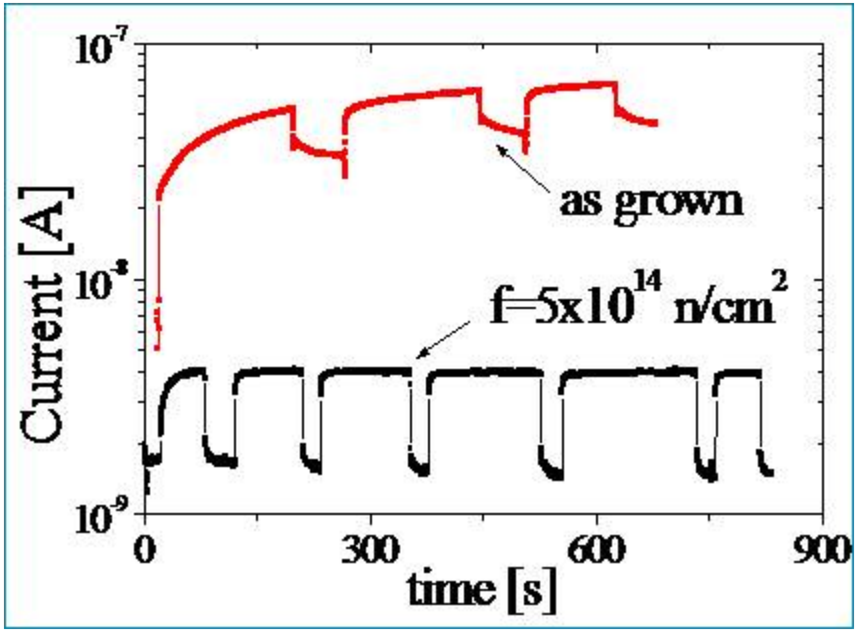


# Problem: priming and instability effects due to defects in pCVD




Current response of the unirradiated sample (Au contact) showing the priming effect during the first 6 successive irradiations.

## The dosimetric characteristics of a diamond film can be significantly enhanced by pre-irradiating it with fast neutrons.

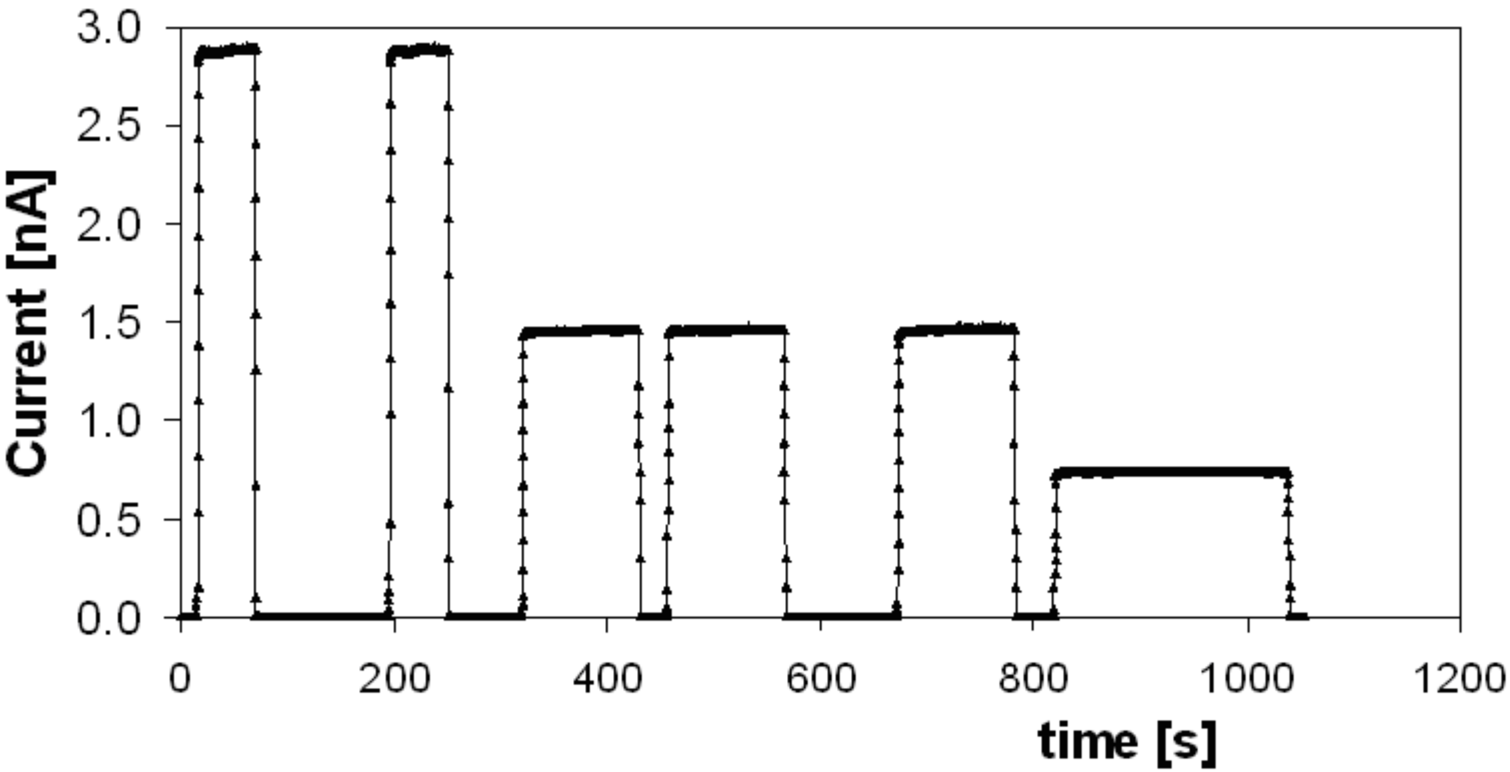



On line response of a sample non "detector grade" before and after irradiation with neutrons

M. Bruzzi et al., Appl. Phys. Lett, (2002)

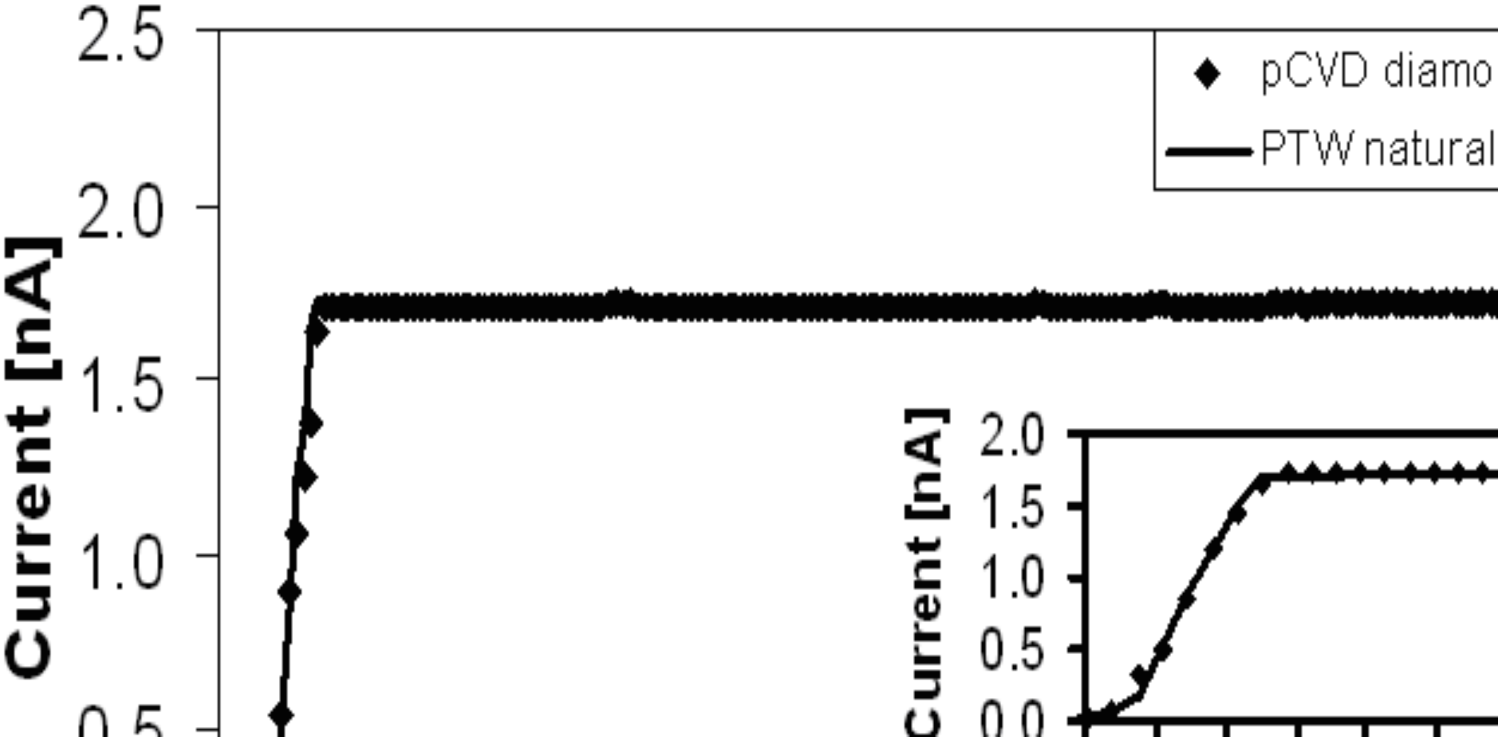
Further stability in dynamic response can be obtained with low / zero bias application

M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: Diamond and Related Materials, 2011.




Deviation from linearity with dose-rate : Δ ~ 0.92-0.96 against Δ ~0.88-0.90 with applied voltage

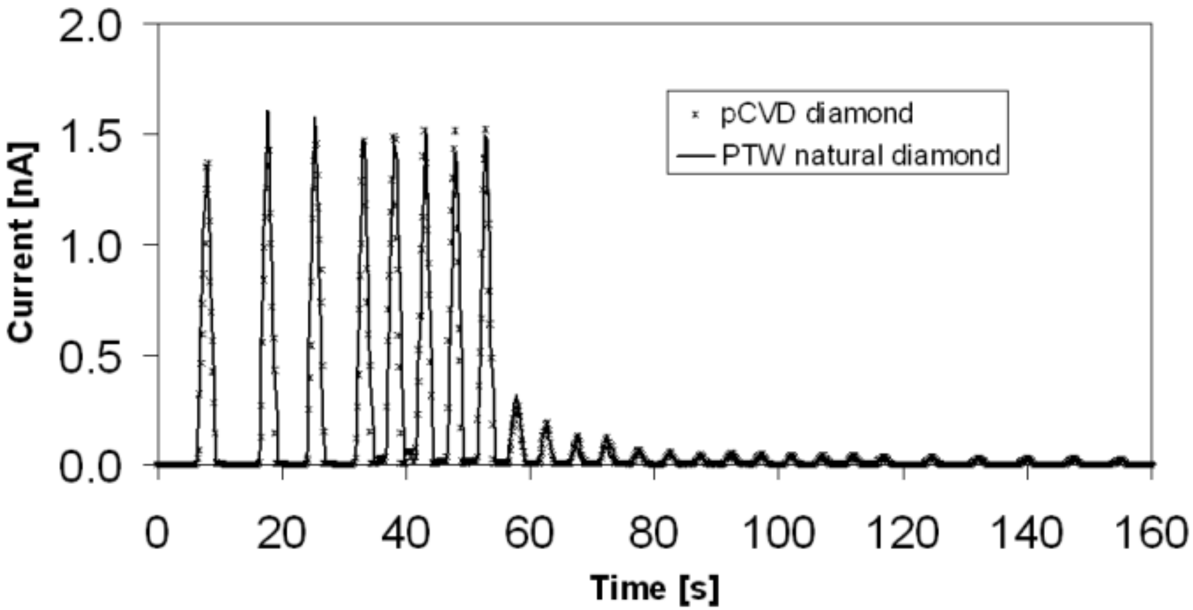
M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: "Zero-bias Operation of polycrystalline Chemically Vapour Deposited Diamond films for Intensity Modulated RadioTherapy", Diamond and Related Materials, 2011.

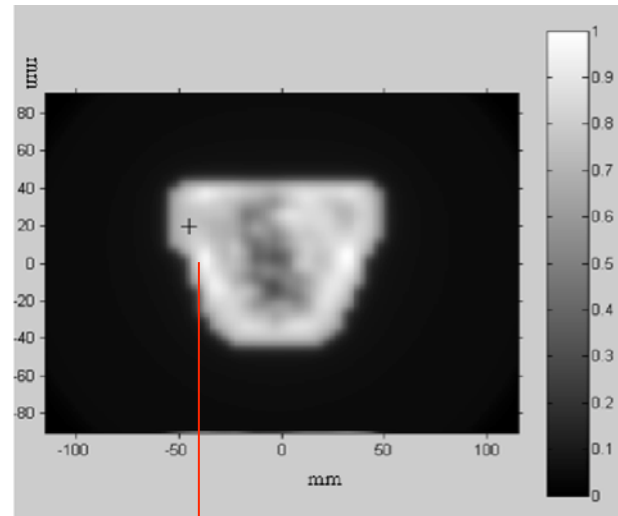



Rising times comparable with those of natural diamond

M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: "Zero-bias Operation of polycrystalline Chemically Vapour Deposited Diamond films for Intensity Modulated RadioTherapy", submitted to Diamond and Related Materials, May-2010.

# First results with pCVD in IMRT fields most promising

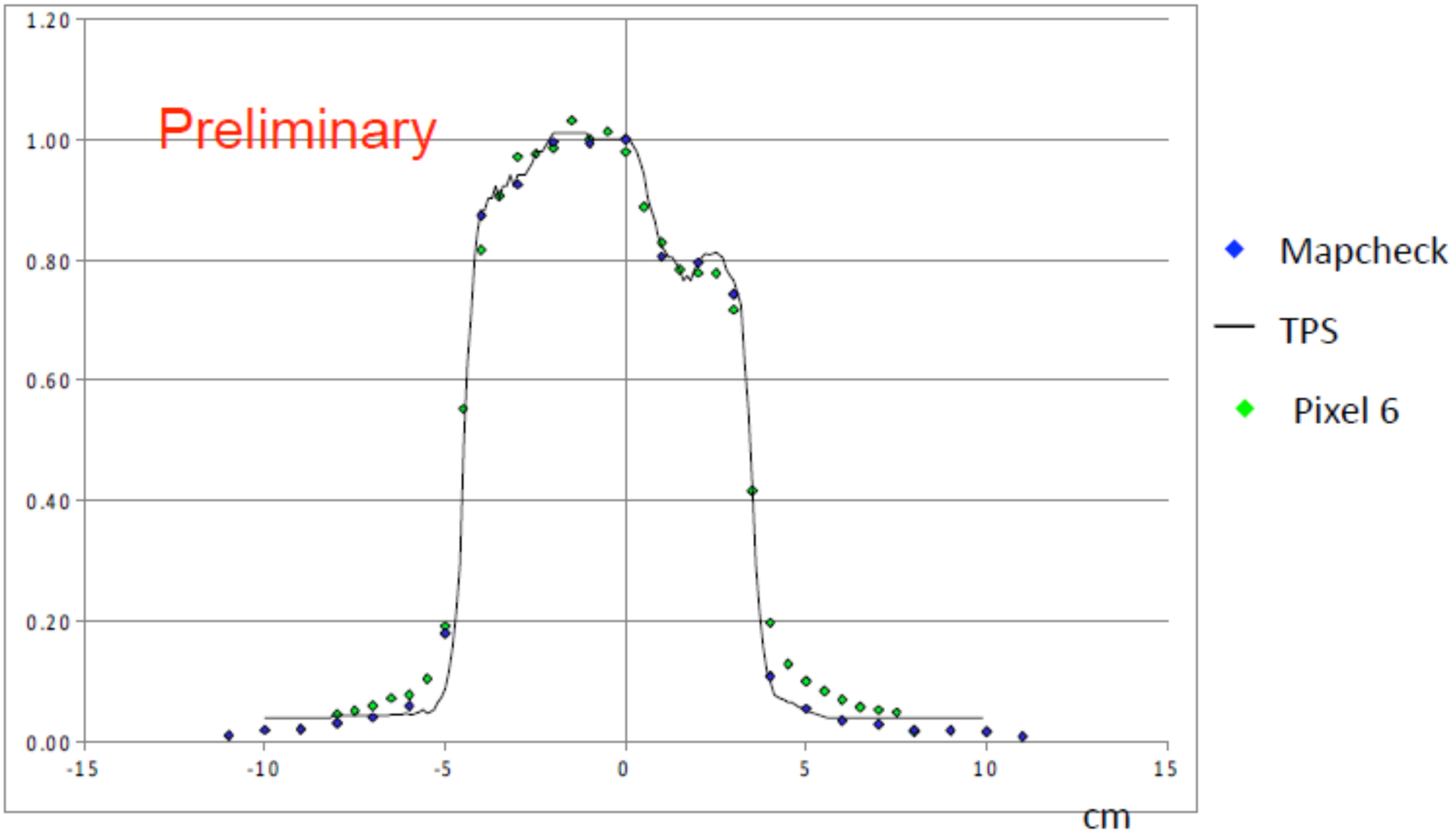



pCVD and PTW diamonds in 10 MV IMRT field
(26 segments in 160 s)

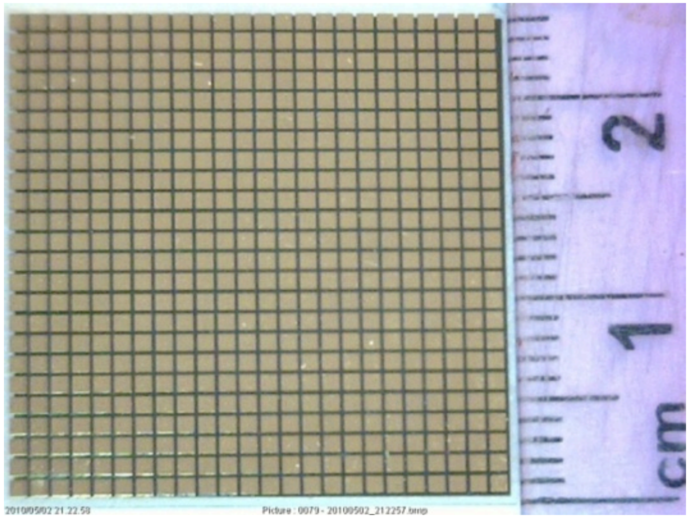
M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: "Zero-bias Operation of polycrystalline Chemically Vapour Deposited Diamond films for Intensity Modulated RadioTherapy", submitted to Diamond and Related Materials, May-2010.

# IMRT Profile




pCVD diamond in IMRT field: DIAPIX INFN

# DIAPIX INFN : First large area IMRT 2D dosimeter with synthetic Diamond

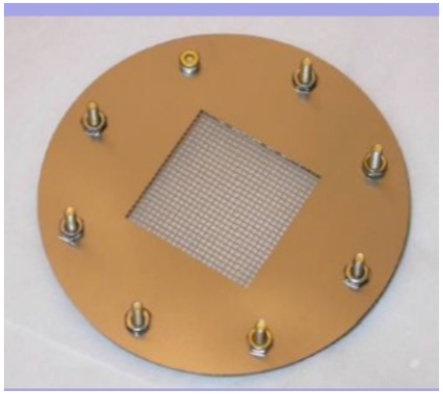



Premium Detector Grade (Diamond Detectors Ltd) polycrystalline diamond, area 2.5cmx2.5cm, thickness = 300μm, 24x24 matrix, pixel area 0.8x0.8mm$^2$ produced in Florence

Chromium evaporation

- 3.5 kW Electron beam
- 10 kV Acceleration field
- 2.5 cc Graphitic liner
- 99.9 % pure Cr Material

24x24 pixels
2D array



Gold Evaporation

- 2 kW Joule source
- Tungsten resistive boat
- 9.99 % pure Au Material

# Development and Test of a prototype system for proton imaging

M. Bruzzi[d,e], V. Sipala[a,b], M. Bucciolini[c,d], G. A. P. Cirrone[g], C. Civinini[d], G. Cuttone[g], D. Lo Presti[a,b], L. Marrazzo[c,d], E. Mazzaglia[g], N. Randazzo[b], S. Pallotta[c,d], M. Scaringella[d,e], C. Talamonti[c,d,] M. Brianzi[d],M. Tesi[e]

a) Dipartimento di Fisica, Università degli Studi di Catania, via S. Sofia 64, I-95123, Catania.
b) INFN, sezione di Catania, via S. Sofia 64, I-95123, Catania.
c) Dipartimento di Fisiopatologia Clinica, Università degli Studi di Firenze, v.le Morgagni 85, I-50134 Firenze
d) INFN, sezione di Firenze, via G. Sansone 1, I-50019 Sesto Fiorentino (FI).
e) Dipartimento di Energetica, Università degli Studi di Firenze, via S. Marta 3, I-50139 Firenze
g) Laboratori Nazionali del Sud-INFN, via S. Sofia 62, I-95123, Catania.

# 1. Proton Computed Tomography

**Advantages of hadron-therapy with respect to conventional gamma - X ray therapy:**

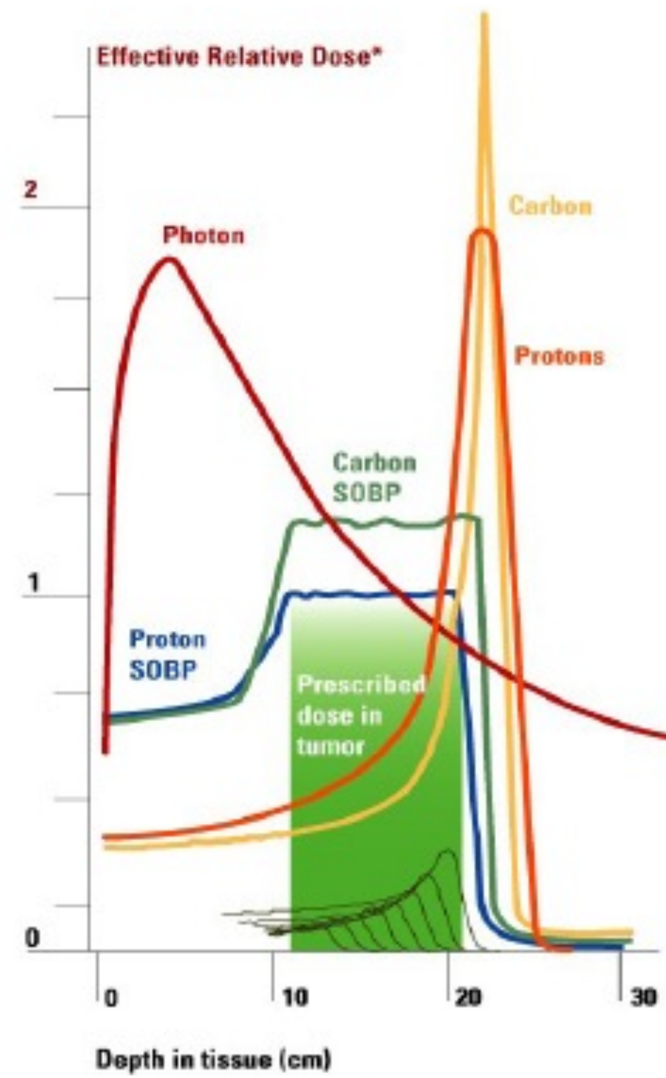
**i) lower dose to healthy tissues in front of the tumor;**

**ii) healthy tissues beyond the tumor are not damaged;**

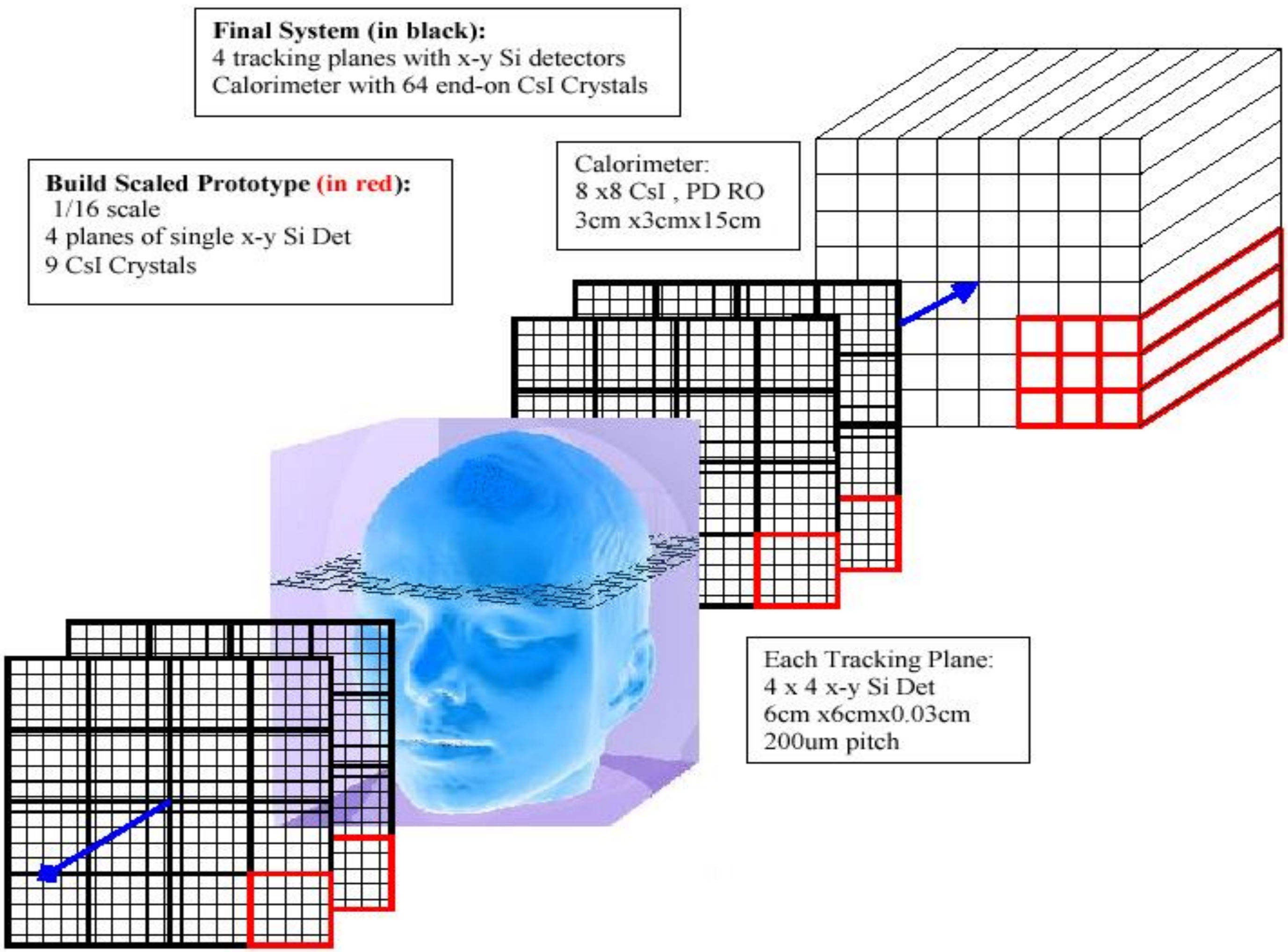
**iii) Multiple scattering for protons is small enough that a very sharp dose profile can be maintained. Lateral healthy tissues are not damaged.**

**The stopping power distributions are the main parameters for dose calculation in hadron therapy. They are derived from measured attenuation coefficients μ of conventional XCT But protons and photons interact differently with matters...**

***"The error intrinsic in this conversion (due to m(he,Z) dependency on atomic number and electron density) is the principal cause of proton range indetermination (3%, up to 10 mm in the head)." Schneider U. (1994), Med Phys. 22, 353.***



# Proton Computer Tomography Set-Up



# THE "PRoton IMAging PROJECT"
# INFN V$^{th}$ Commission

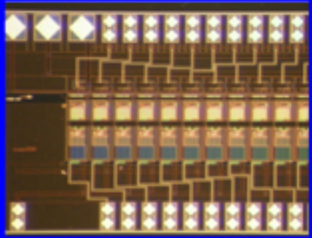
proton Computed Tomography (pCT) is a medical imaging method based on the use of proton beams with kinetic energy of the order of 250 MeV. **This method would permit a direct measurement of the tissues' stopping power distribution (presently calculated from X-rays attenuation coefficients), thus improving the accuracy of treatment planning in hadron therapy**.

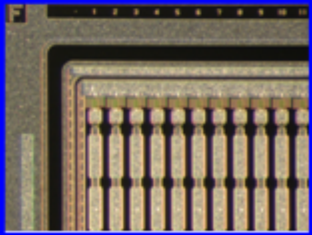
**PROGRAM**

Manufacture a high-performance prototype for proton

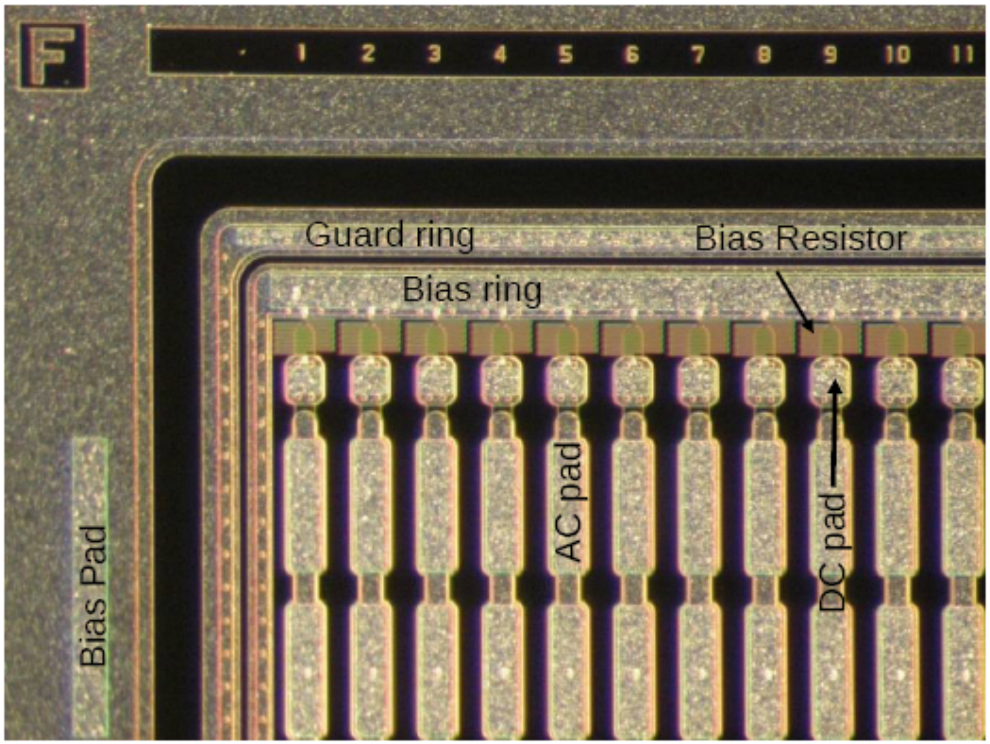
- radiography.
- Develop suitable imaging algorithms:
  - analysis of data;
  - MC simulations.
- Validate the pCR system with pre-clinical studies
- Conceive a configuration for a pCT system:
  - Hardware and data acquisition;
  - Reconstruction algorithms (ART, SART...).

M. Bruzzi, III Seminario Nazionale Rivelatori Innovativi,
4-8 June 2012 INFN Firenze





# Si SENSOR




Manufactured by Hamamatsu Photonics

53x53 $mm^2$

p+-on-n strips

256 ch, 200 μm pitch

200 μm thickness
(To reduce the multiple scattering in the detector planes while keeping a good sensitivity to protons)

Vdep lesser than 75V.

| Proton Energy (MeV) | Energy Loss (keV/μm) | Released Energy (MeV) |
|---|---|---|
| 10 | 9 | 1.8 |
| 30 | 3.5 | 0.7 |
| 50 | 2.5 | 0.5 |
| 100 | 1.4 | 0.28 |
| 200 | 0.8 | 0.16 |

# Segmented calorimeter

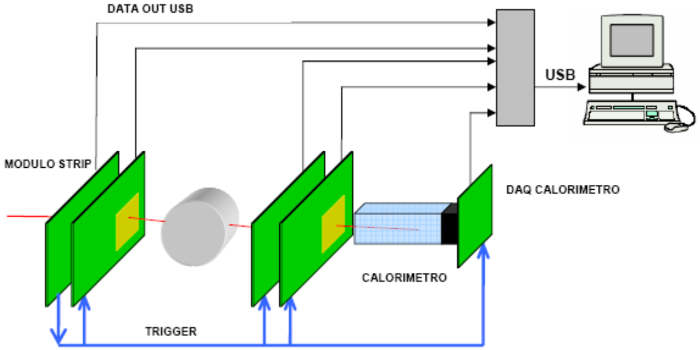
| YAG:Ce properties | |
|---|---|
| Physical properties | |
| Density [g/cm$^3$] | 4.57 |
| Hygroscopic0 | 0No |
| Chemical formula | $Y_3Al_5O_{12}$ |
| Luminescence properties | |
| Wavelength of max. emission [nm] | 550 |
| Decay constant [ns] | 70 |
| Photon yield at 300k [$10^3$ Ph/MeV] | 40-50 |

Scintillator:

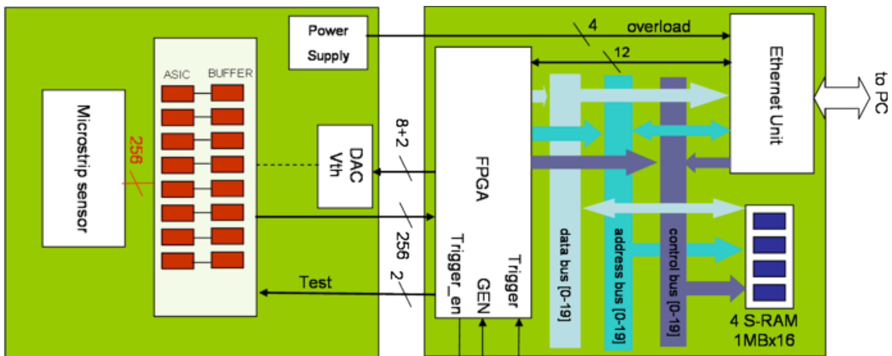
4 YAG:Ce optically separated crystals (Crytur),

30x30x100 mm$^3$ each

Readout: 4 photodiodes (18x18 mm$^2$, Hamamatsu)

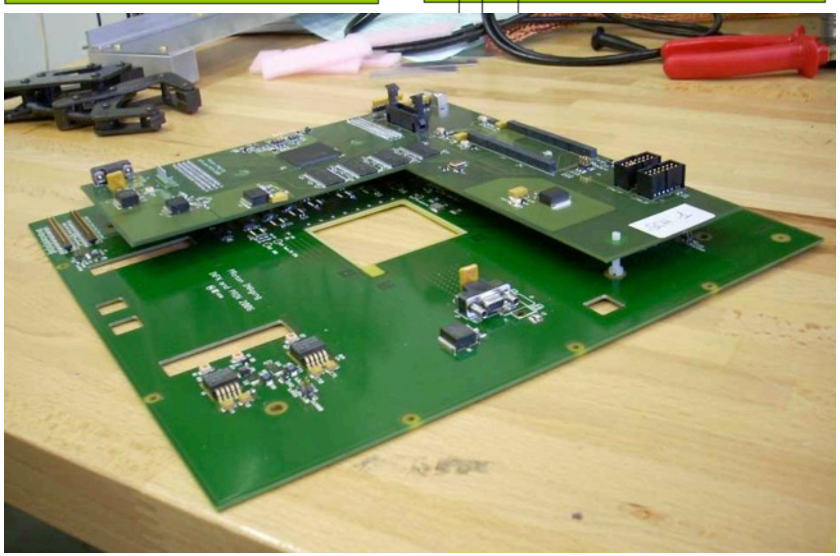


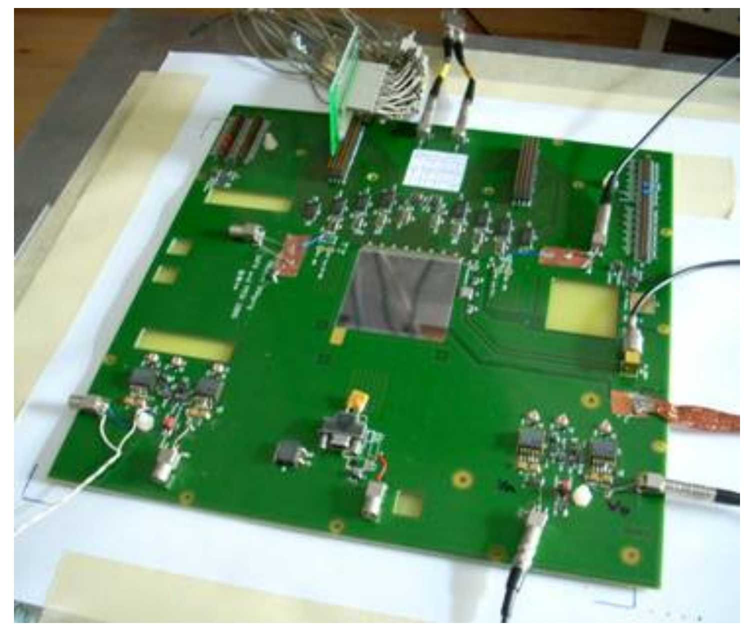

# Development of the pCR -TRACKER MODULE




Local data storage during measurement.

Ethernet data download at measurement completion.



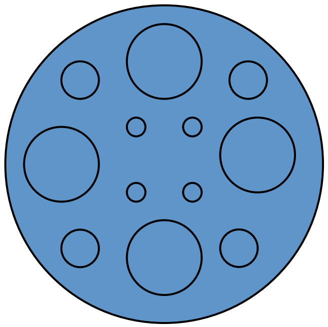


# Proton Computed Radiography Device manufactured by the PRIMA (PRoton IMAging) collaboration

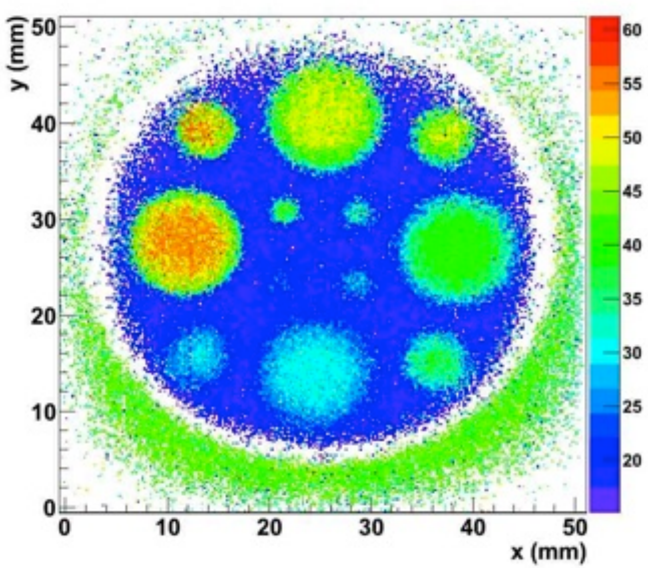

**4 x-y TRACKER MODULES** → **Entry and Exit position and direction**

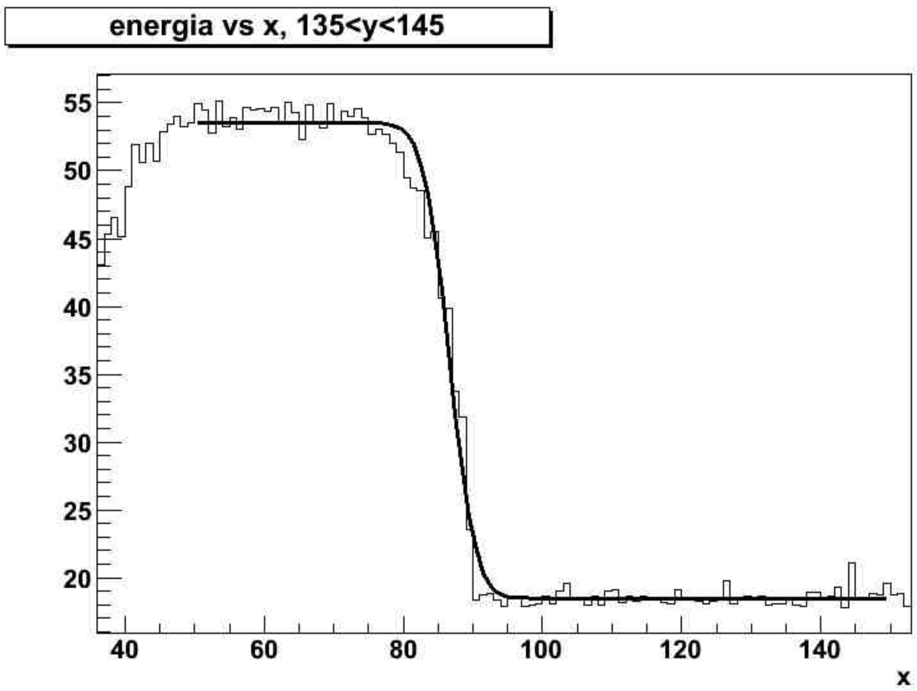
**1 CALORIMETER** → **Residual Energy**

# Complete pCR apparatus
## *Test at LNS (13May 2010)*



**Phantom with different density zones**



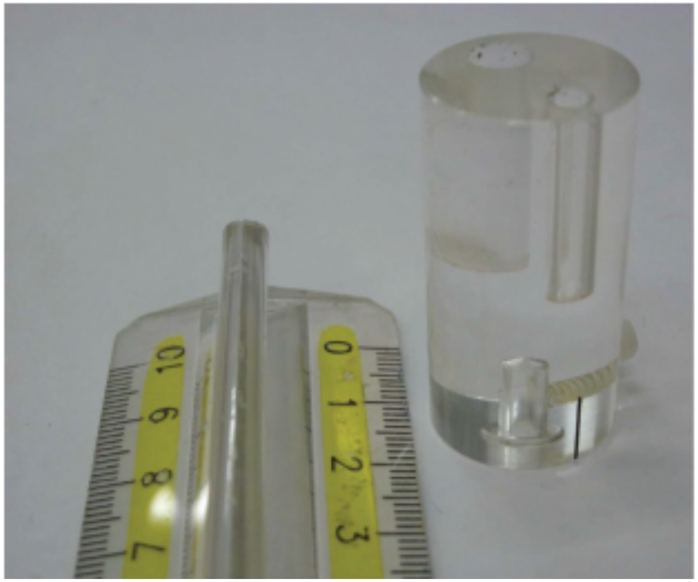



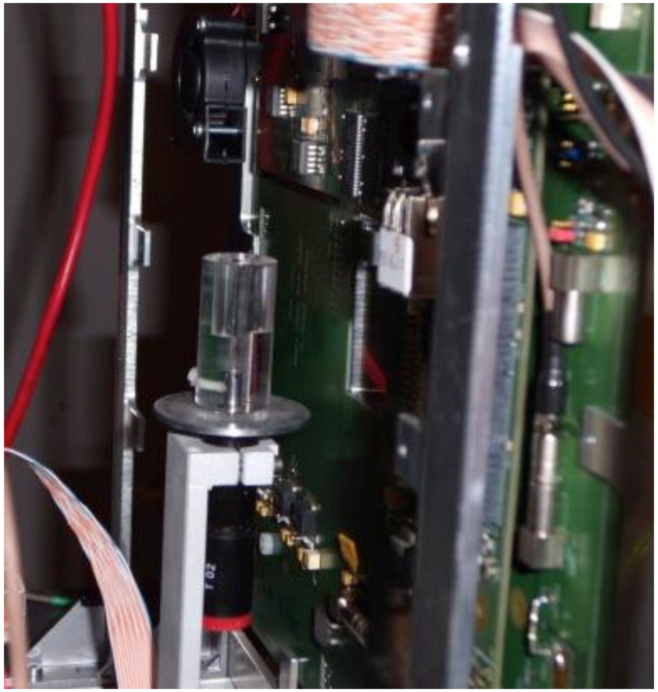

**Between 55MeV and 22MeV → σ = 3strips (600µm)**

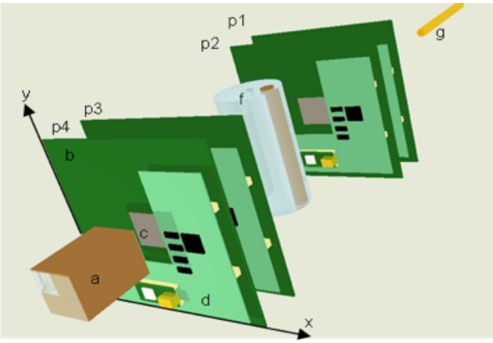
# First Tomography Studies with the PRIMA apparatus

*Test at LNS (May - February 2011)*

Cylindrical PMMA phantom, diam = 20mm, h = 40mm, with two cylindrical holes of diameter 6mm and 4mm. Experimental data acquired irradiating the phantom at angles from 0 to 360° with 10° steps using $10^5$ particles per projection.

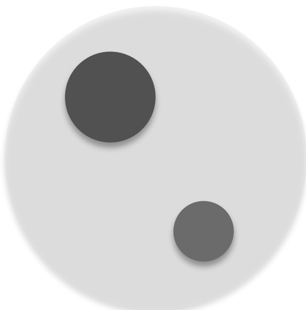


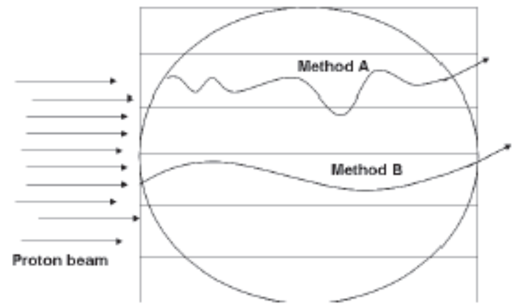




# First Tomographyc reconstructions

FBP (Filtered Back Projection)→ rectilinear and parallel beams, condition satisfied by photons, not by protons. Phantom was ideally subdidived into channels (1mm-thick) perpendicular to the phantom axis. Exclusion criteria: protons entering and exiting same channel A) without checking path inside phantom; B) with proton trajectory always in channel







- New data acquired for better statistics in May 2011 – analysis is in progress
- New reconstruction algorithms under development using an iterative method, allowing to overcome the rectilinear and parallel trajectories → SART (Simultaneus Algebraic Reconstruction Technique).

# Conclusions

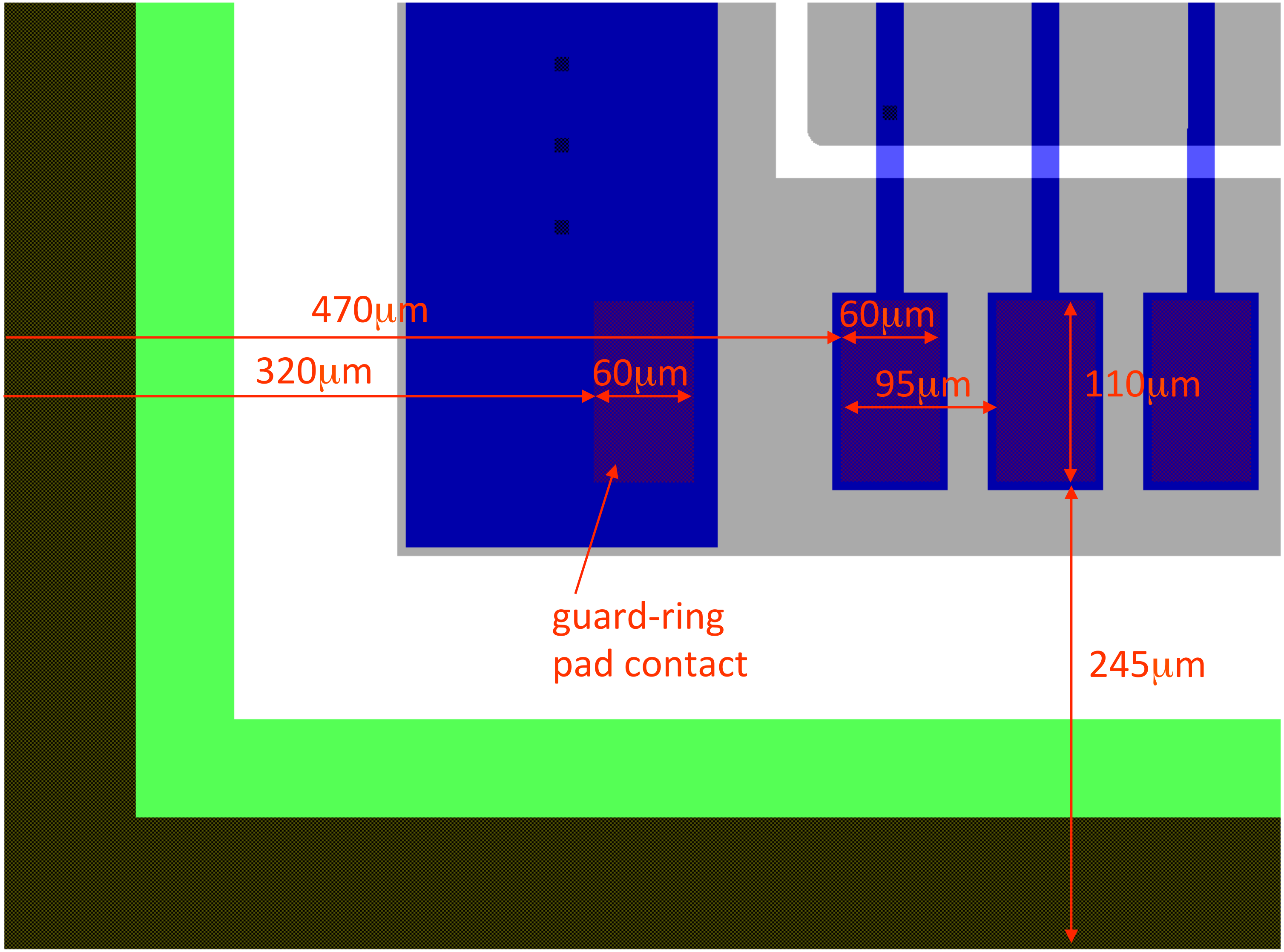
**Silicon and diamond pixel detectors for imaging and dosimetry are needed in advanced radiotherapy systems**

**-A large area 2D bidimensional Si dosimeter system based on p-type epitaxial Si grown on Cz substrates has been developed and tested. Applications under $^{60}$Co gammas, photon, electron and proton beams as well as IMRT field for clinical applications have been investigated. Dosimeter works comparable or better than commercial devices, in particular showing higher sensitivity, and finer temporal and spatial resolutions, radiation hardness;**

**-Extension of the system to large area CVD diamond to get an almost tissue equivalent device is under way. Polycrystalline vs Single crystal diamond are under investigation;**

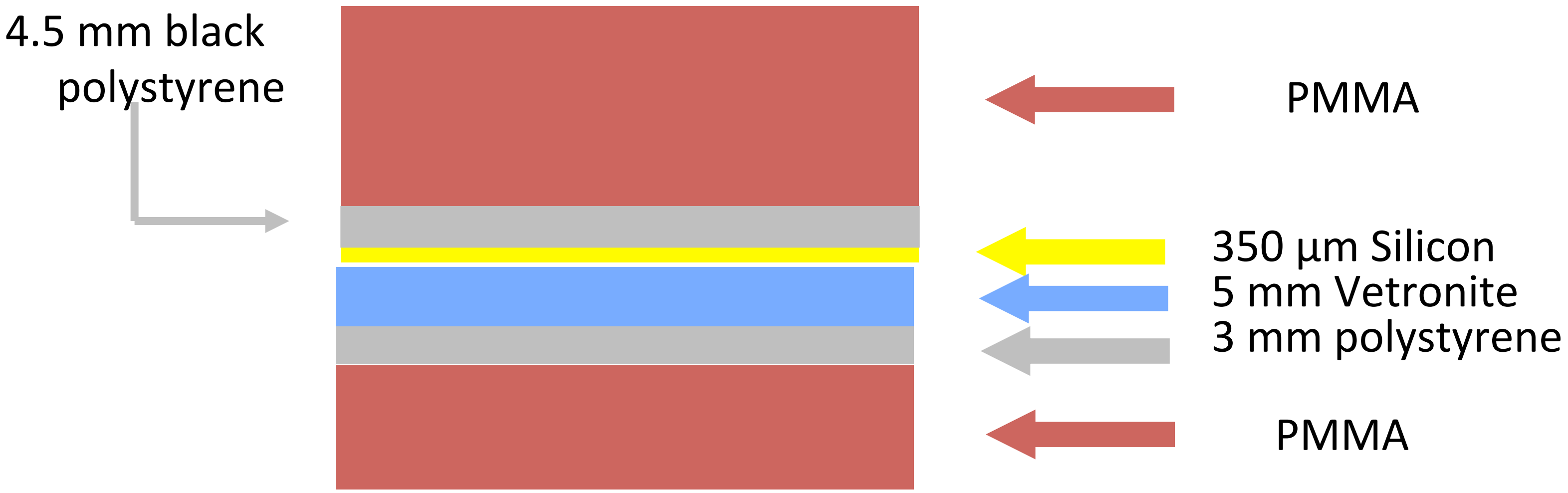
**- A system based on silicon telescope made with microstrip detectors plus a calorimeter has been developed proton for Computer Tomography in collaboration with Catania INFN LNS: first tests carried out with proton show promising results. Scale up of the system under development.**

# Spares


470µm
60µm
320µm
60µm
95µm
110µm
guard-ring
pad contact
245µm

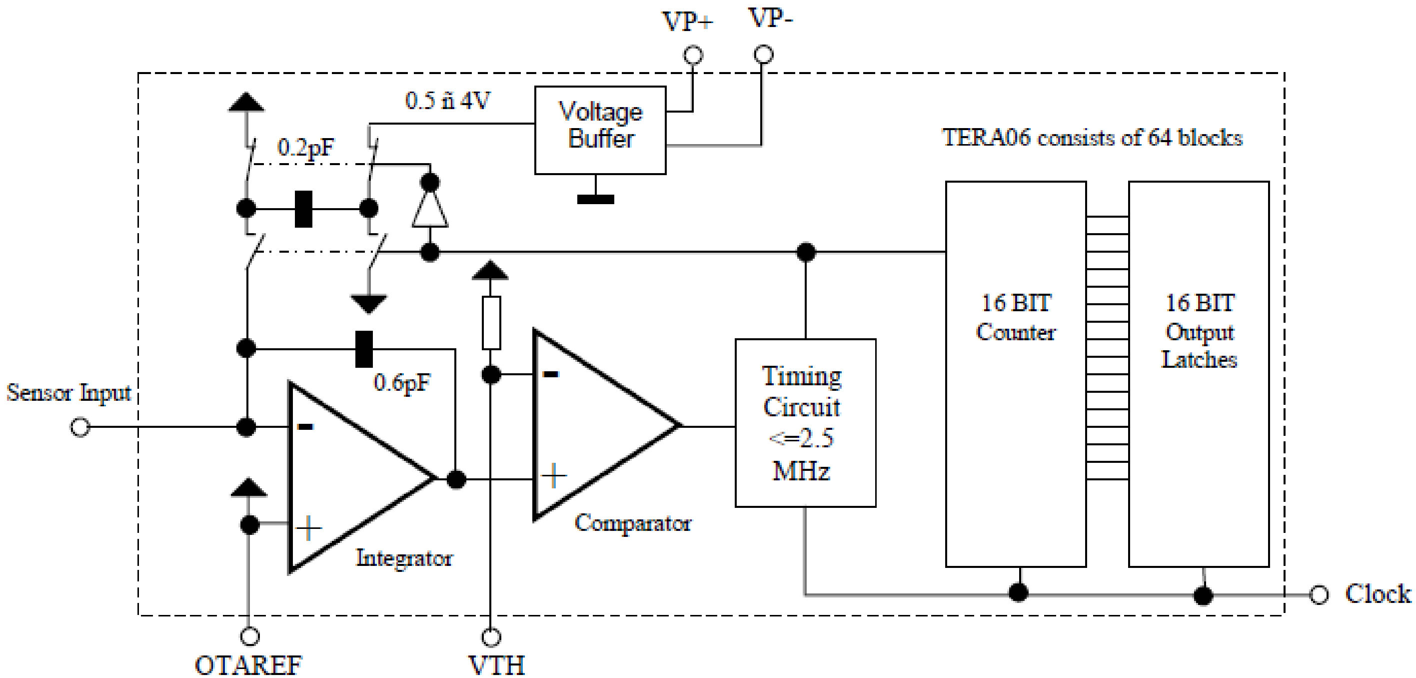
# Sensor arrangement and packaging

Apart the 350 µm Si, all the other materials are almost water equivalent



# TERA06 ASICs : 64 channel current to frequency converter

## PRINCIPLE OF OPERATION




• the integrator circuit charges the feedback capacitor (0.6 pF) with the sensor's input current while the compensation capacitor (0.2 pF) is charged through a reference voltage

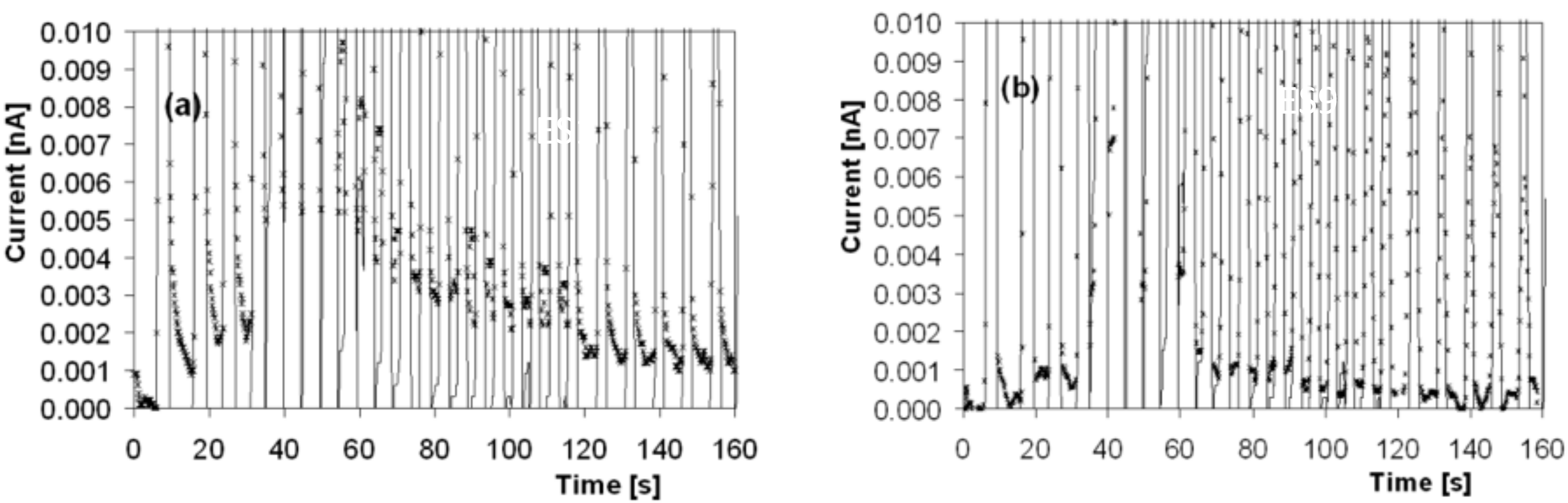
• when the output voltage of the integrator equals the threshold voltage the counter is increased and a compensation sequence starts: the compensation charge is subtracted from the charge integrated on the feedback capacitor

• after the compensation sequence the feedback capacitor is switched back to be recharged

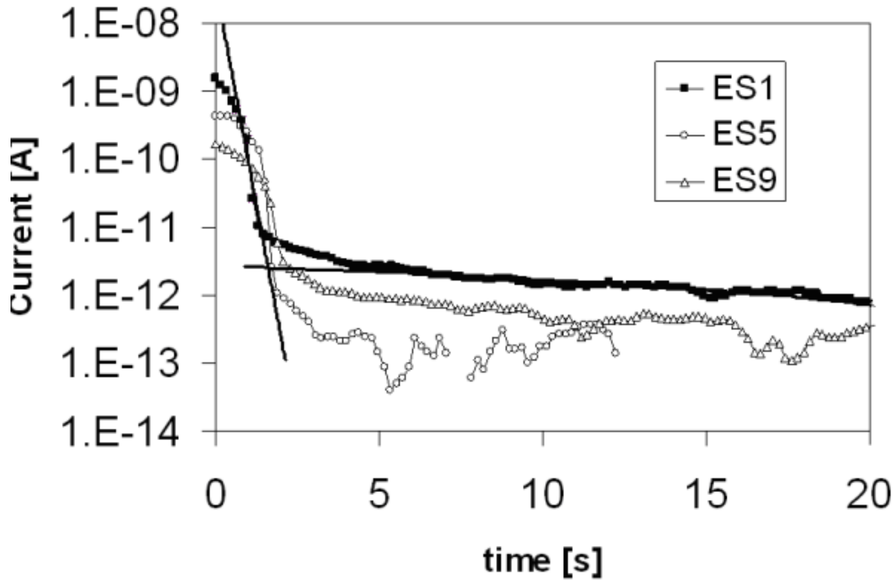
•The charge quantum is given by the compensation capacitance and the reference voltages: $Q=C_{comp}\cdot(V_{p+}-V_{p-})$

# Diamante pCVD paragonabile a PTW se il segnale decade in tempi dell’ordine di 1-3 secondi

M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: “Zero-bias Operation of polycrystalline Chemically Vapour Deposited Diamond films for Intensity Modulated RadioTherapy”, submitted to Diamond and Related Materials, May-2010.



Tempi di discesa dipendenti dalla qualità della giunzione Schottky, da 1-3s a 10-20s.




M. Bruzzi, C. De Angelis, M. Scaringella, C. Talamonti, D. Viscomi and M. Bucciolini: "Zero-bias Operation of polycrystalline Chemically Vapour Deposited Diamond films for Intensity Modulated RadioTherapy", submitted to Diamond and Related Materials, May-2010.