3D diamond detectors for small field dosimetry in photon beam radiotherapy

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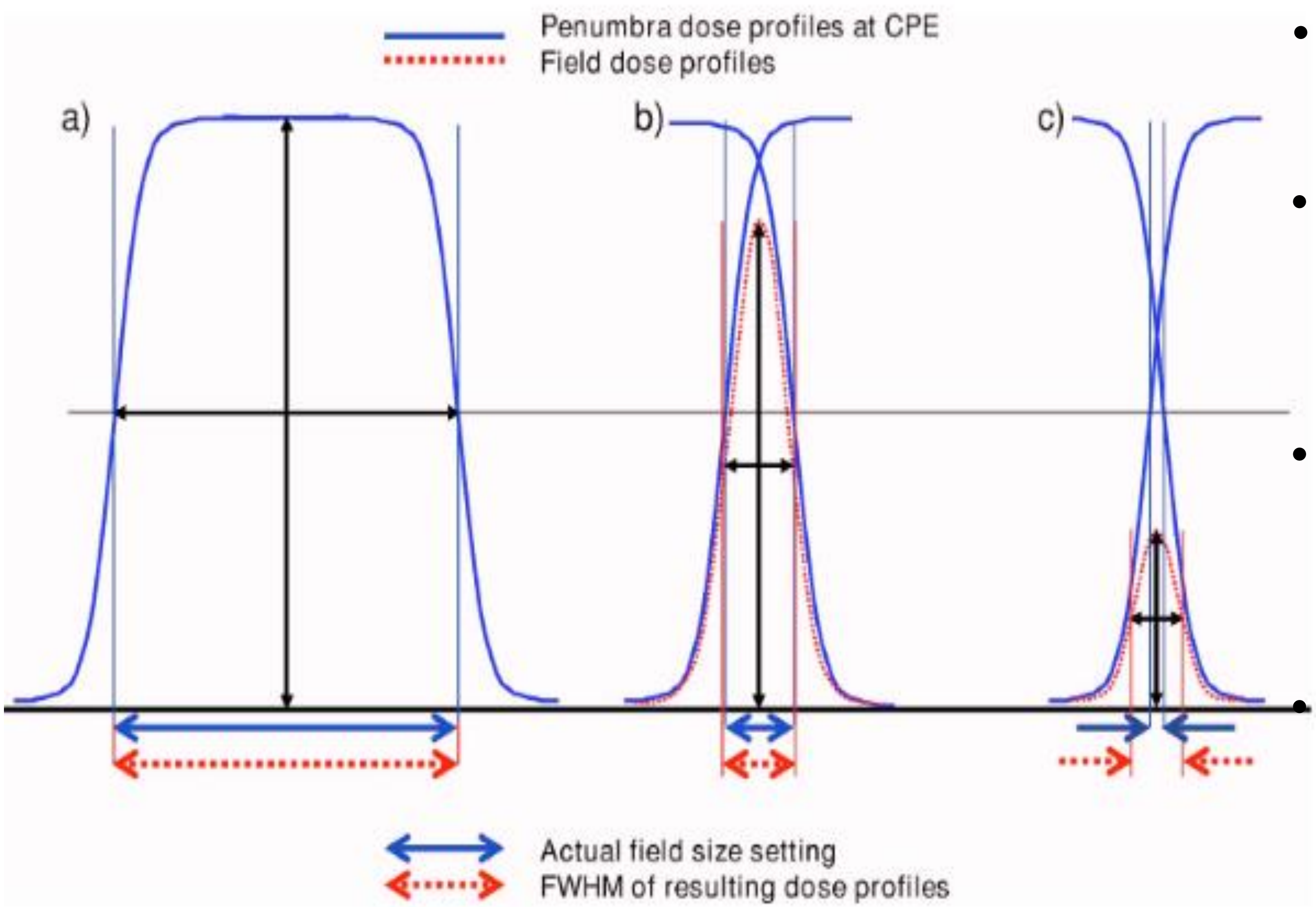
Outline

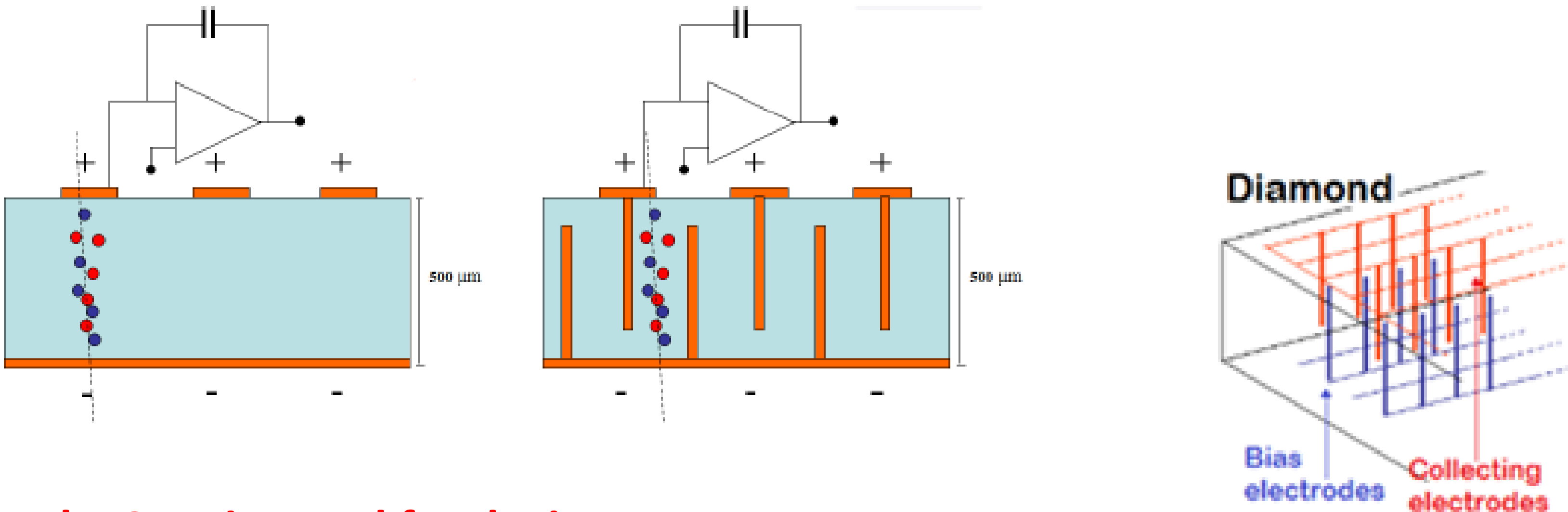
- ✓ Small field dosimetry issues
- ✓ 3D diamond detectors
- ✓ Standard photon beam dosimetry
- ✓ Small photon beam dosimetry
- ✓ Optimization of fabrication process, geometry and readout of 3D dosimeters
- ✓ Conclusions

Small field dosimetry issues



- Small fields < 3x3 cm^2
- Lateral charged particle equilibrium is lost
- Volume averaging due to the detector dimension
- Complexity of dose calculation (Alfonso formalism)

3D Diamond detectors for dosimetry

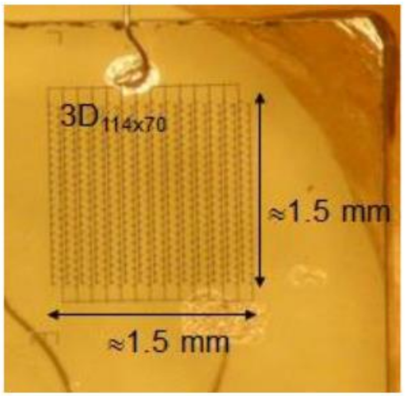


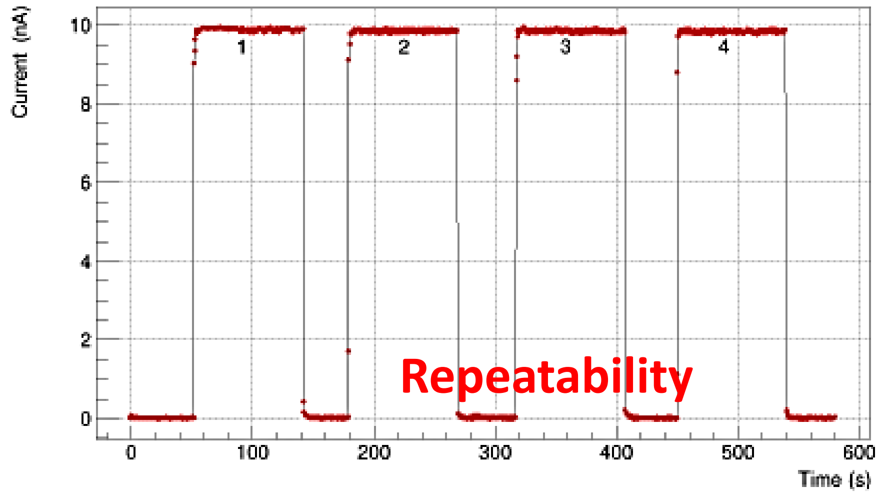
Why 3D Diamond for dosimetry:

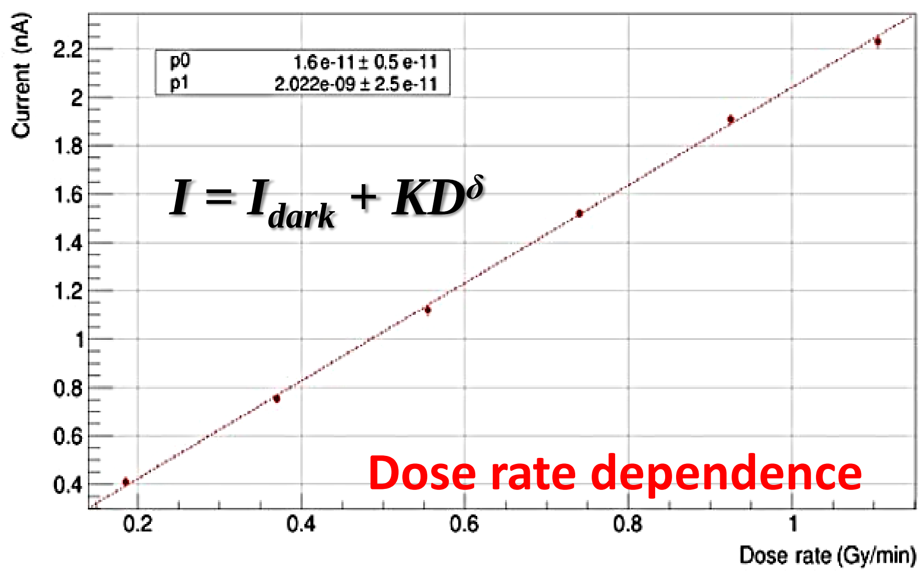
- **Low bias voltage (few V) with high active volume;**
- **Reproducibility of the elementary 3D cell**
- **An 'all-carbon' detector exposed to the beam (tissue equivalence)**
- **High spatial segmentation, even 0.1 x 0.1 mm^2**
- **High resistance to radiation damage**

Standard photon beam dosimetry–Perugia Hospital

5x5 cm^2
6MV photon beam





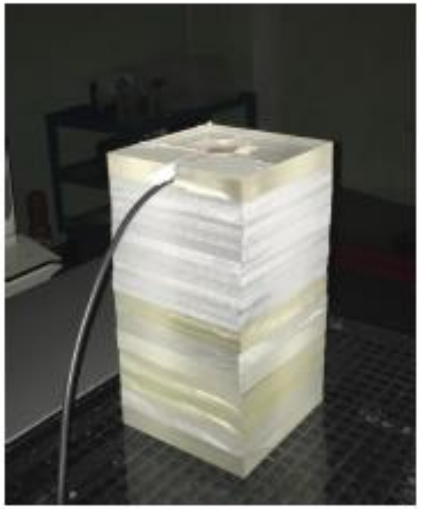


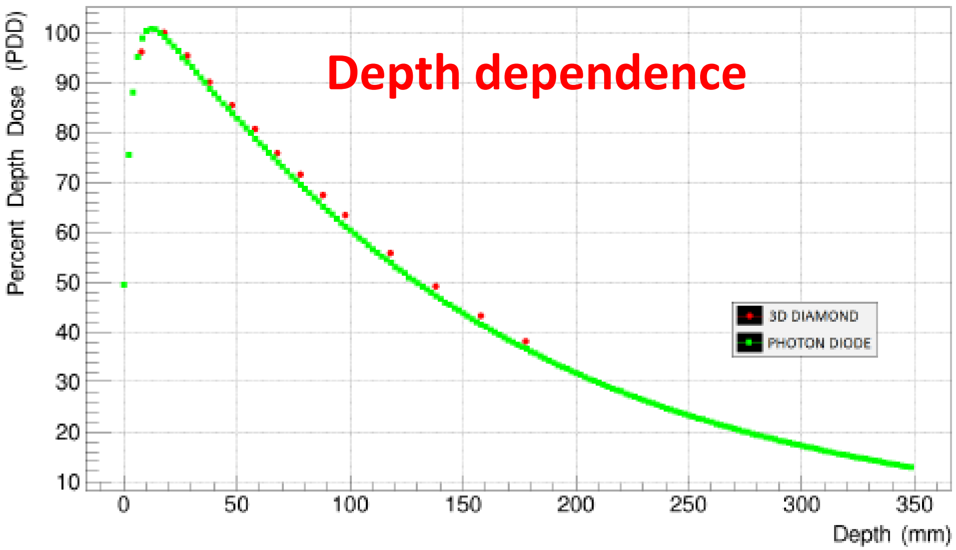
Repeatability within 1%

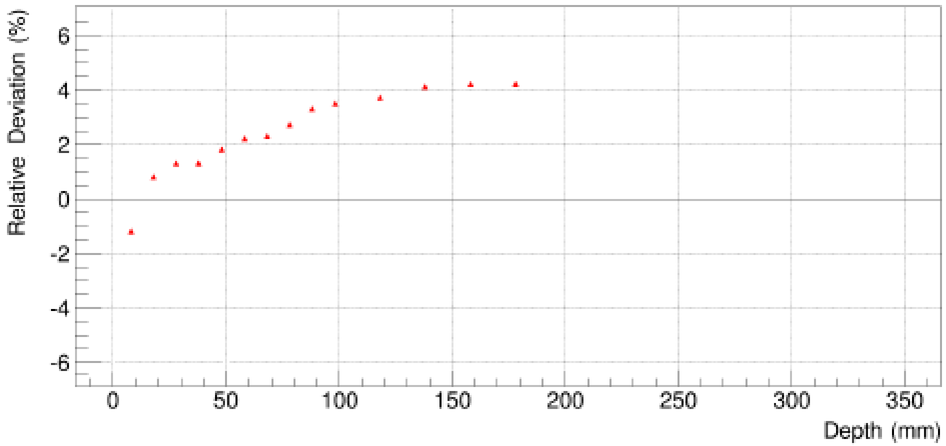
δ = 0.998 indicates linear dependence

Residuals between the predicted values and the measured ones are less than 2%.

Standard photon beam dosimetry–Perugia Hospital





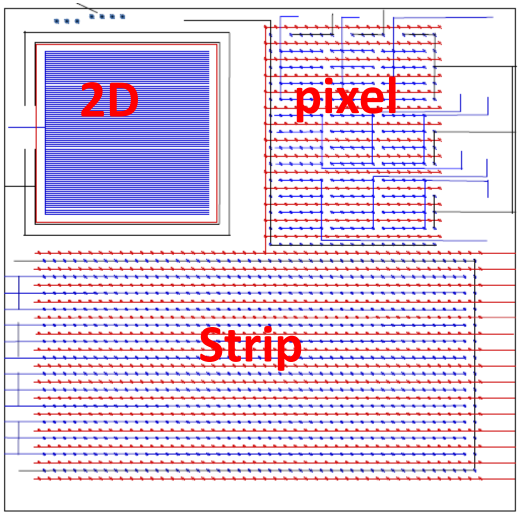


Offset due to the uncertainty on the detector position inside the PMMA.

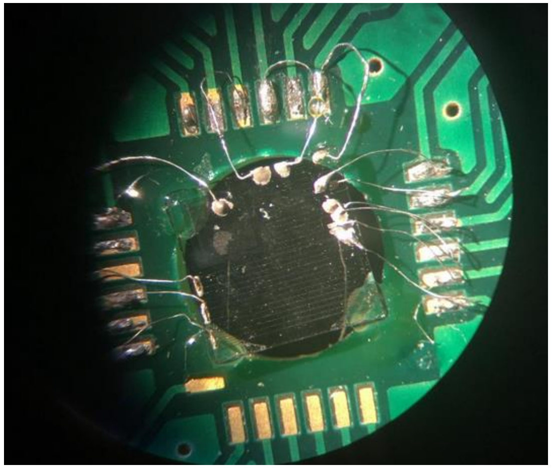
For a 2mm shift on the detector position, a maximum relative deviation of 2.7% and a mean relative deviation of 1.7% are obtained.

Small photon beam dosimetry

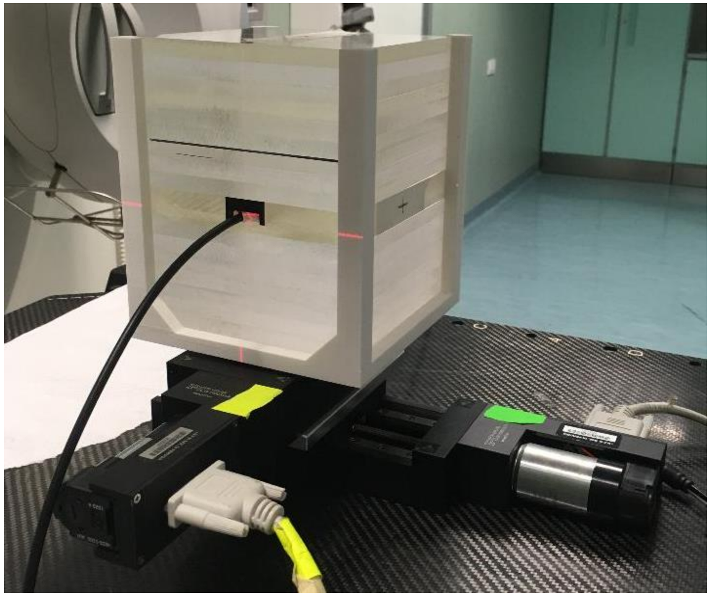
Schematic



Detector



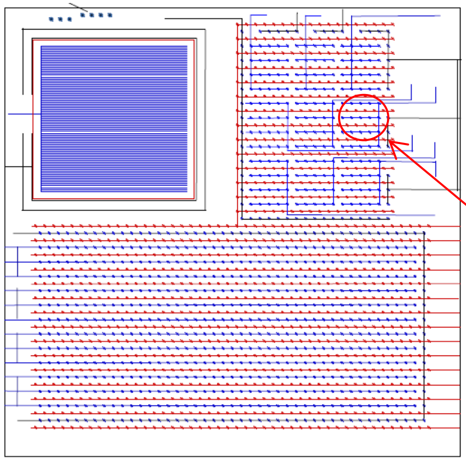
New 3D diamond detector



A meccanical system for linear motion in x, y axes in remote control with 210 nm minimal step used for beam profile measurement

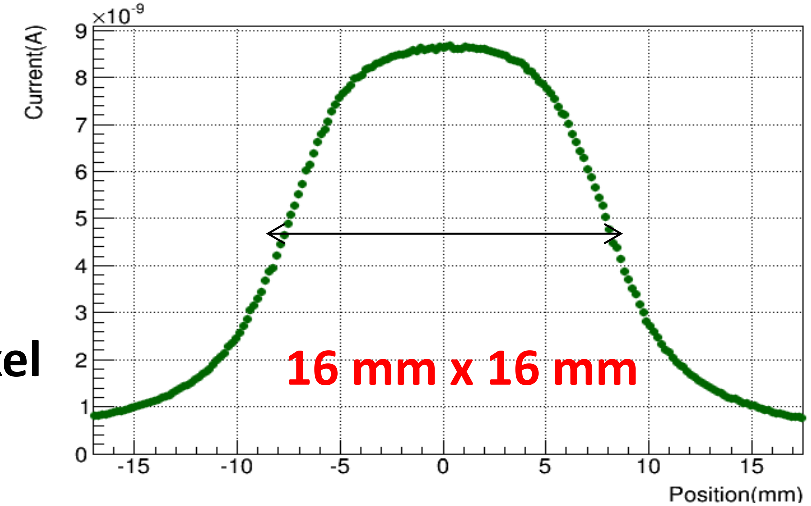
Small photon beam dosimetry–Firenze Hospital

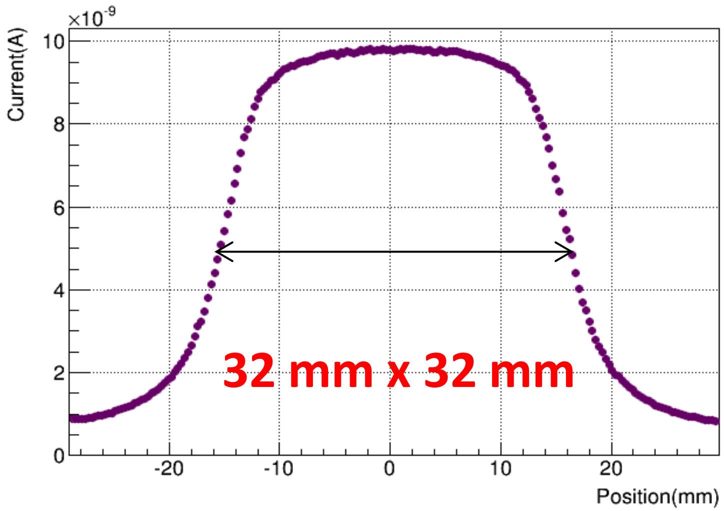
Reconstruction of small beam profiles (200 steps)

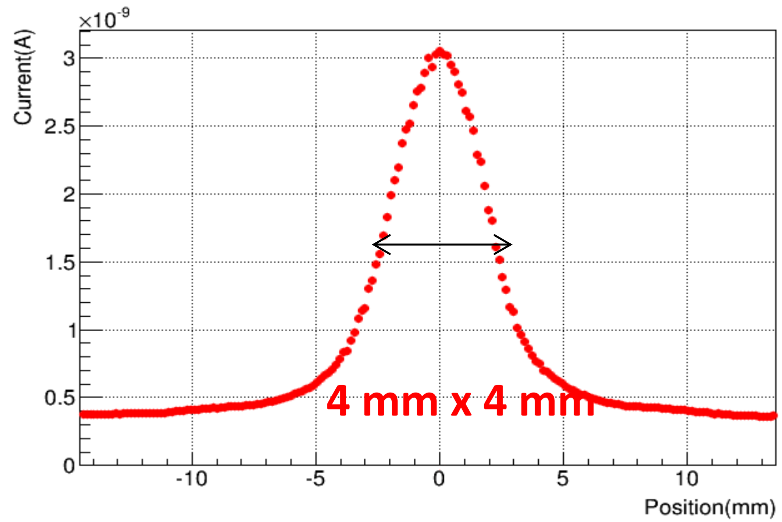


Readout pixel

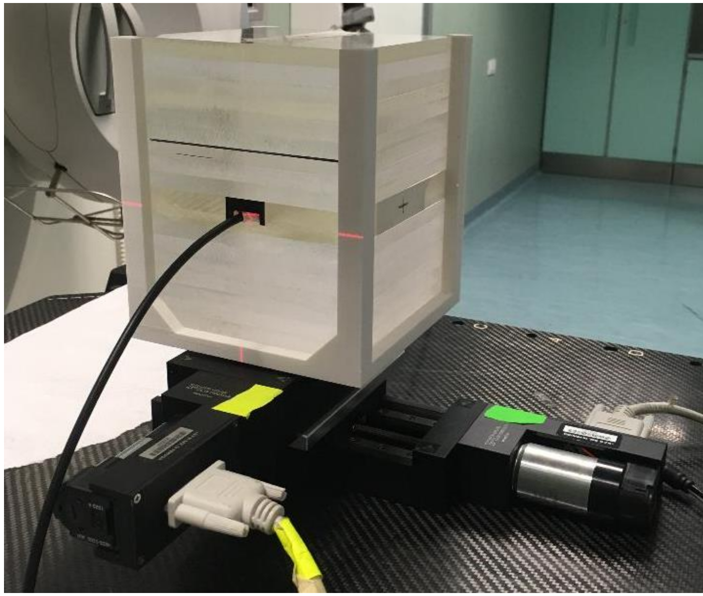
(0.5mm³)



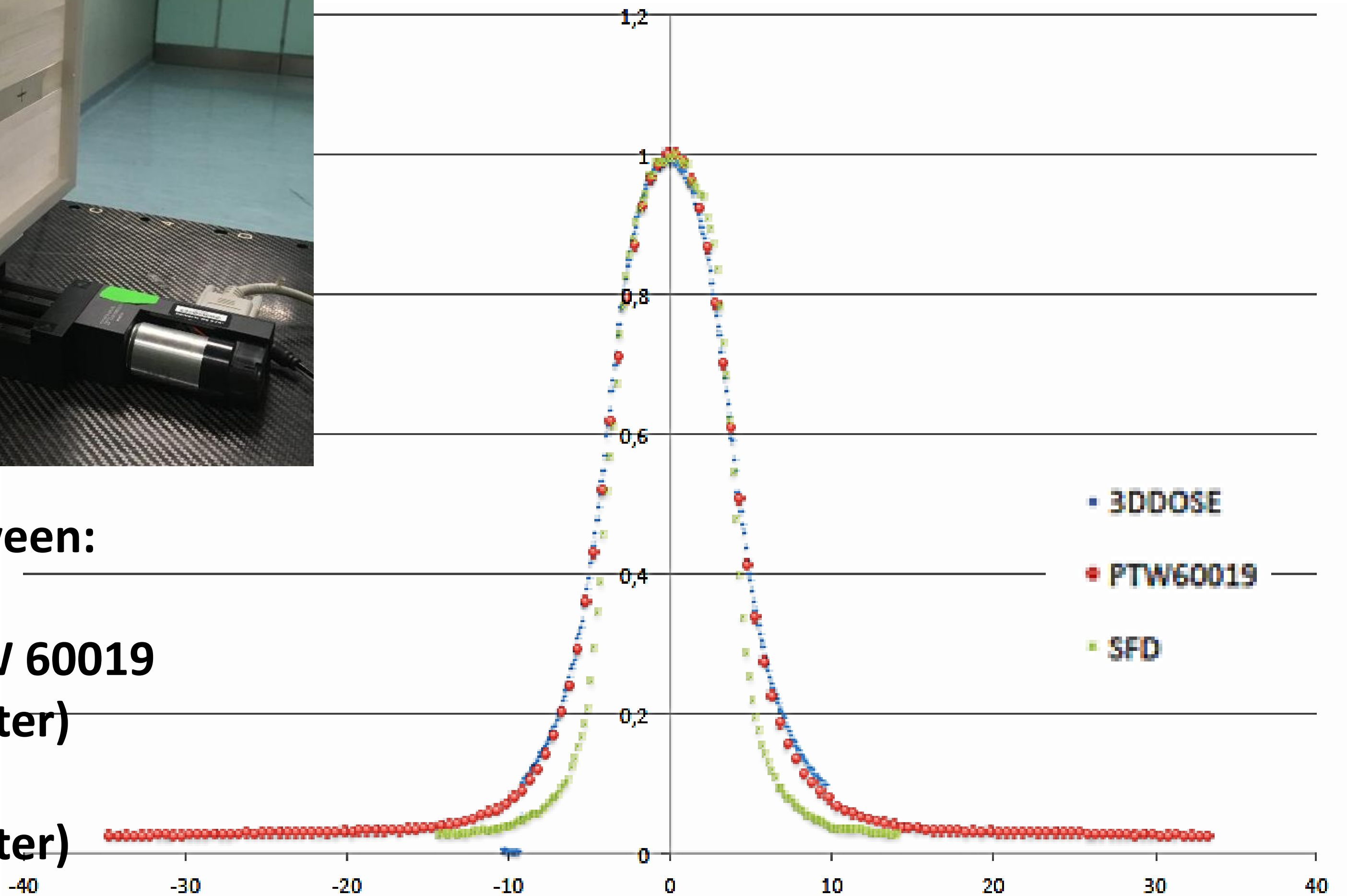




Small photon beam dosimetry–Firenze Hospital



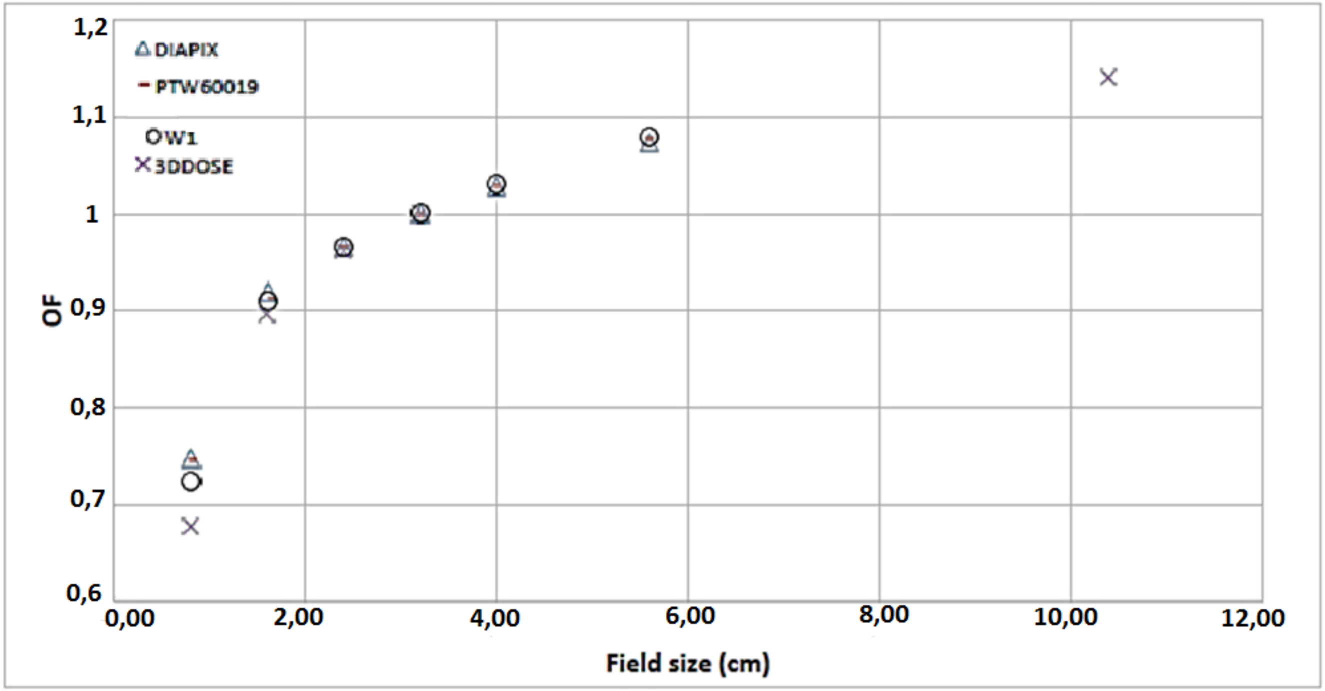
Field size 8 mm x 8 mm



Comparison between:

- diamante 3D
- Diamante PTW 60019 (2.2 mm diameter)
- SFD Diode (0.6 mm diameter)

Photon beam-output factor-Firenze Hospital



Comparison between:

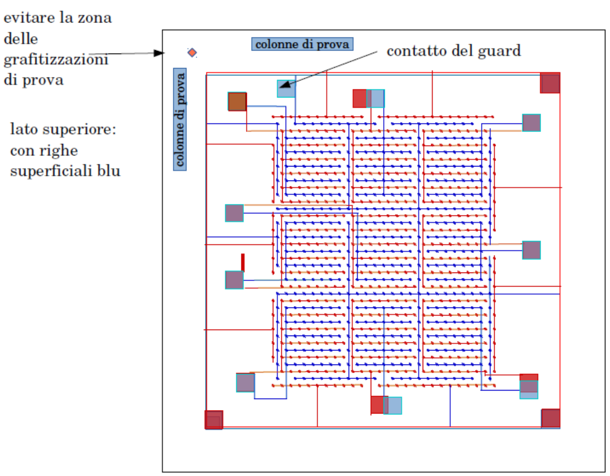
- 3D diamond
- PTW 60019 diamond
- Exradin W1 scintillator
- DIAPIX

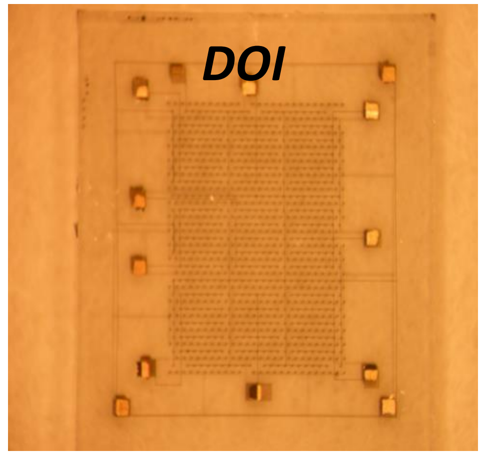
Underestimation of the absorbed dose for the smaller fields due to the uncertainty on the position of the detector inside the PMMA phantom

- Design of mechanical structures for high precision positioning of the detector inside the PMMA

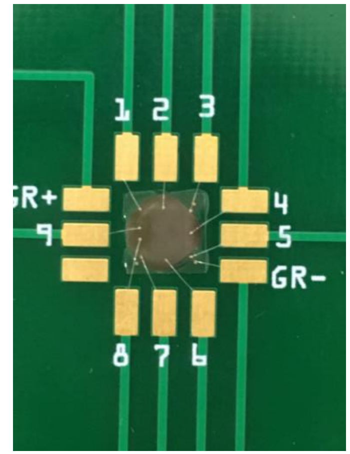
New 3D detectors with multiple indipendent cells readout (Diamond & Diamond on Iridium)

Work in progress

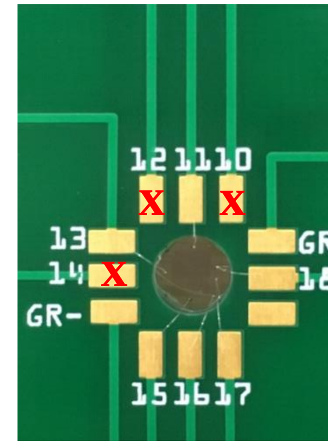


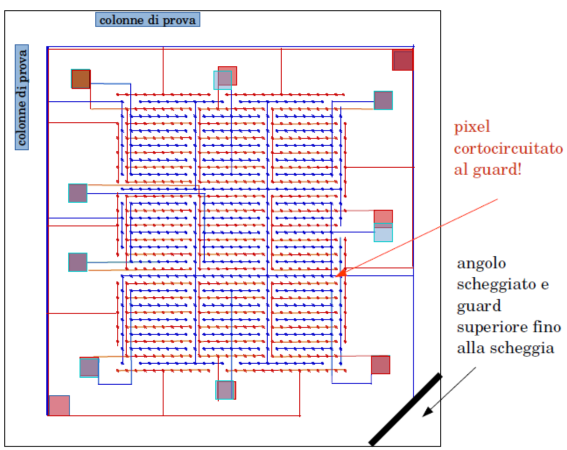


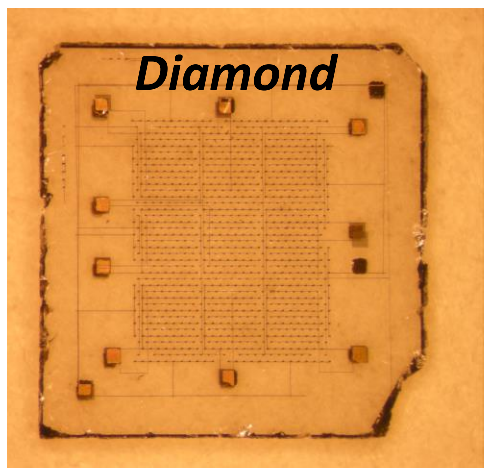
Front

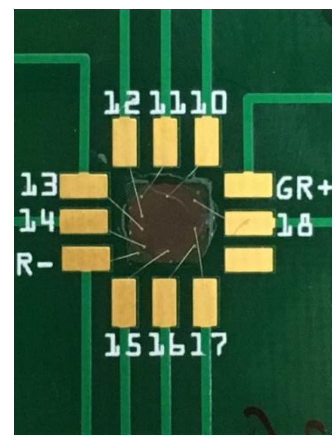


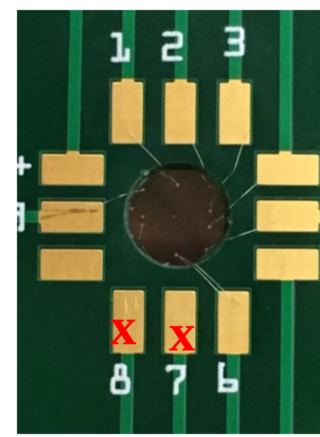
Back





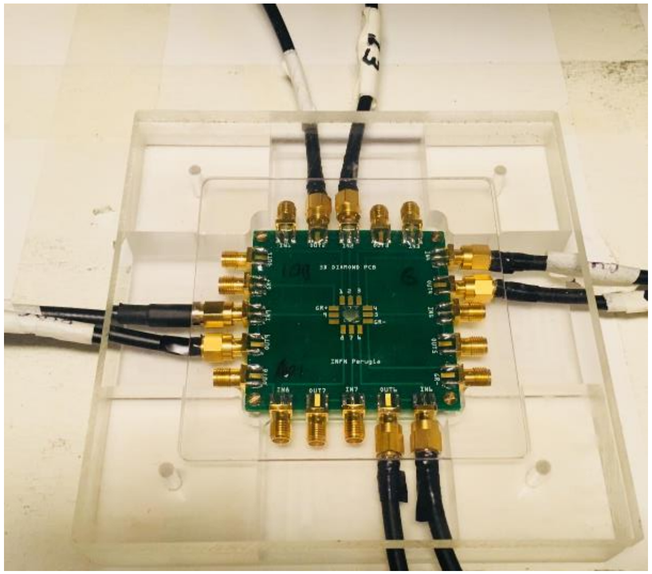






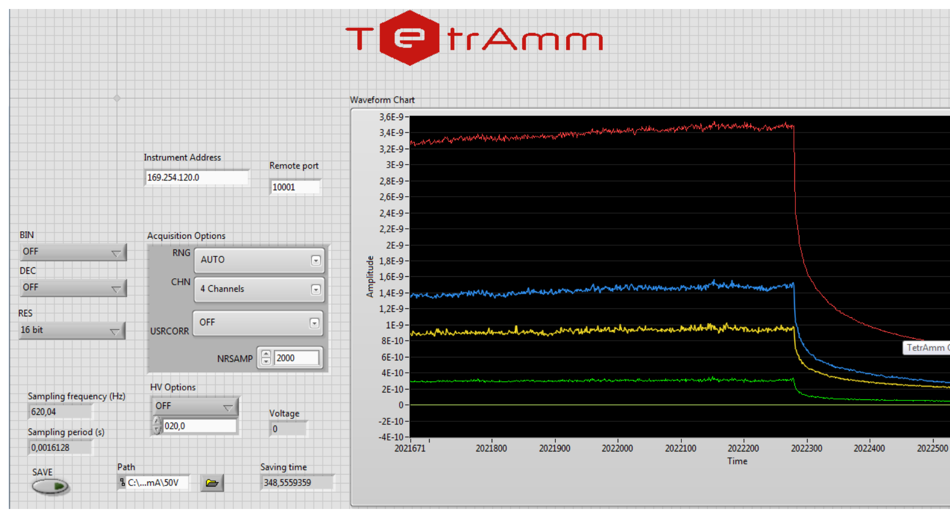
New 3D detectors with multiple indipendent cells readout

4 / 8 cells readout in parallel

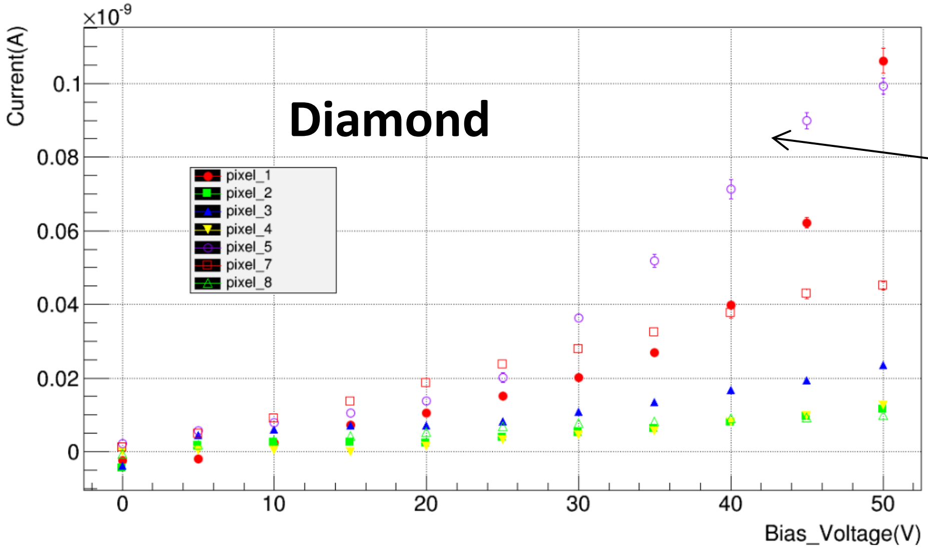


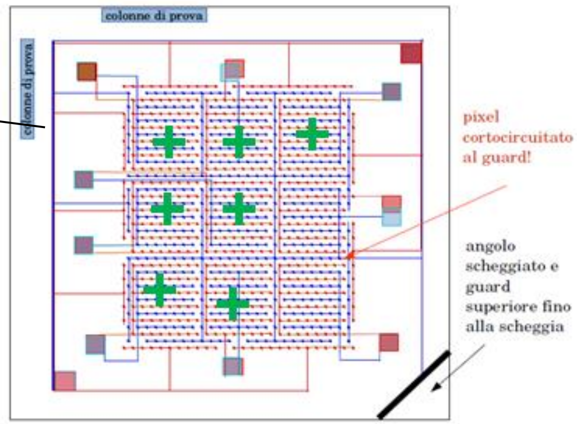
TETRAMM Picoamperometer with 4 readout channels and an integrated high voltage source

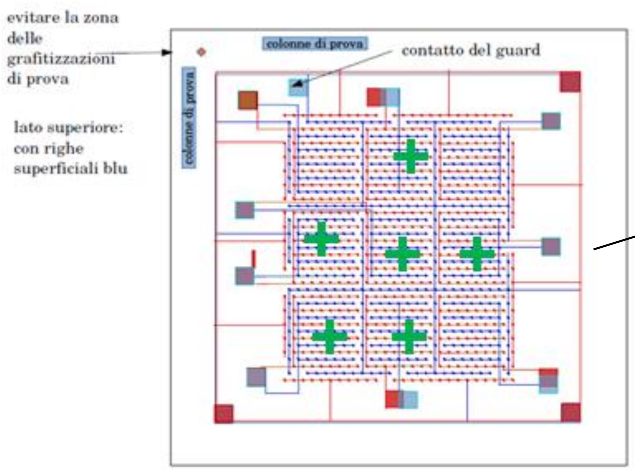
Control software developed

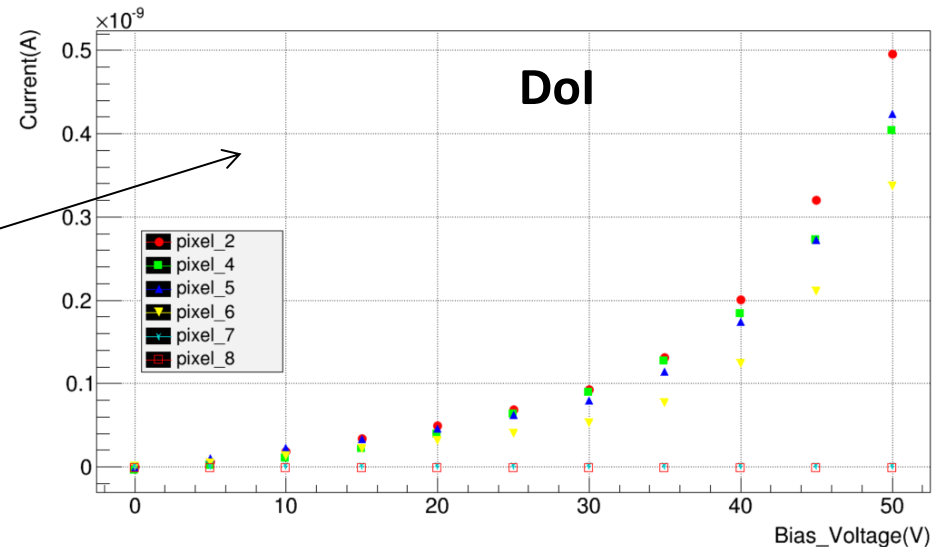


3D Diamond & Diamond on Iridium detectors dark current



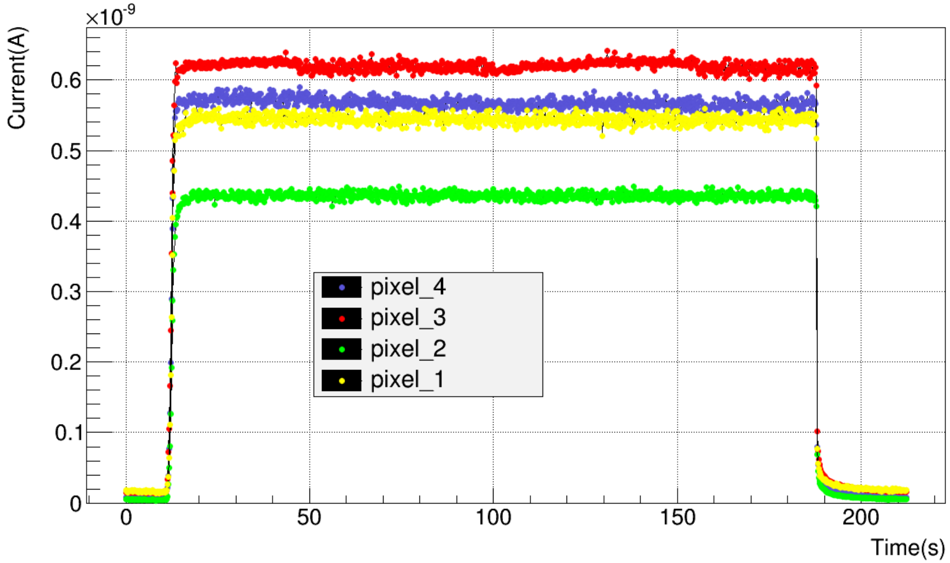


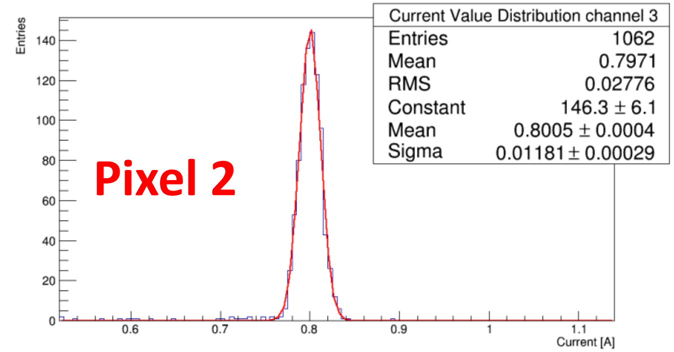


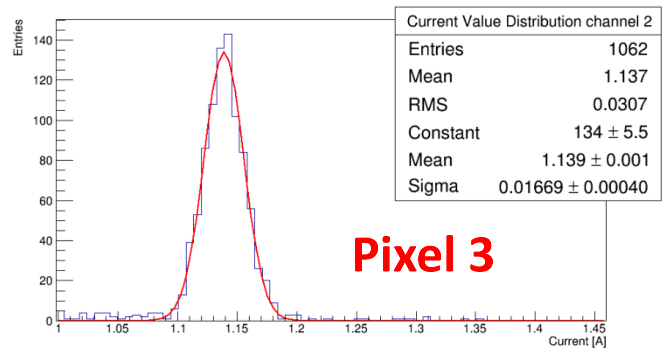


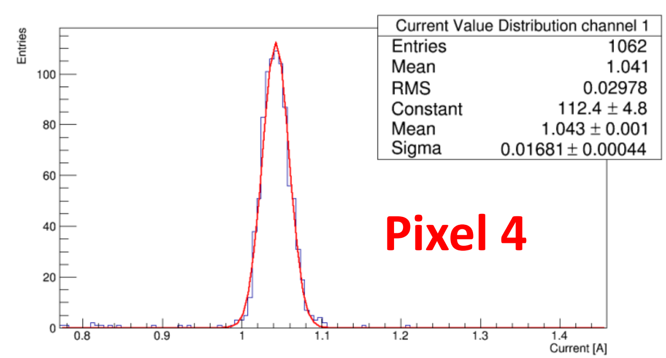
3D Diamond single cells response

Diamond @ 20V, 4 mA 160 kV Xray tube





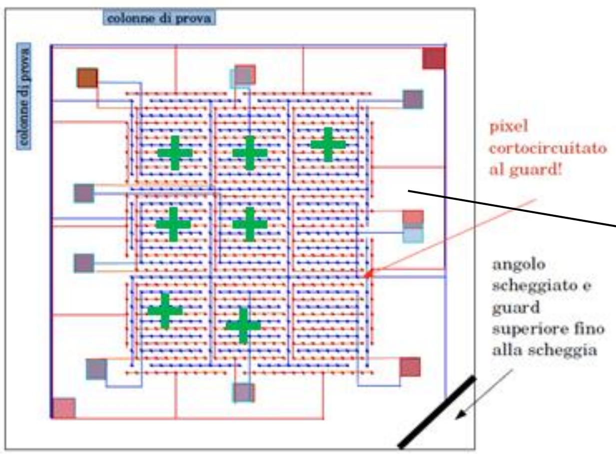




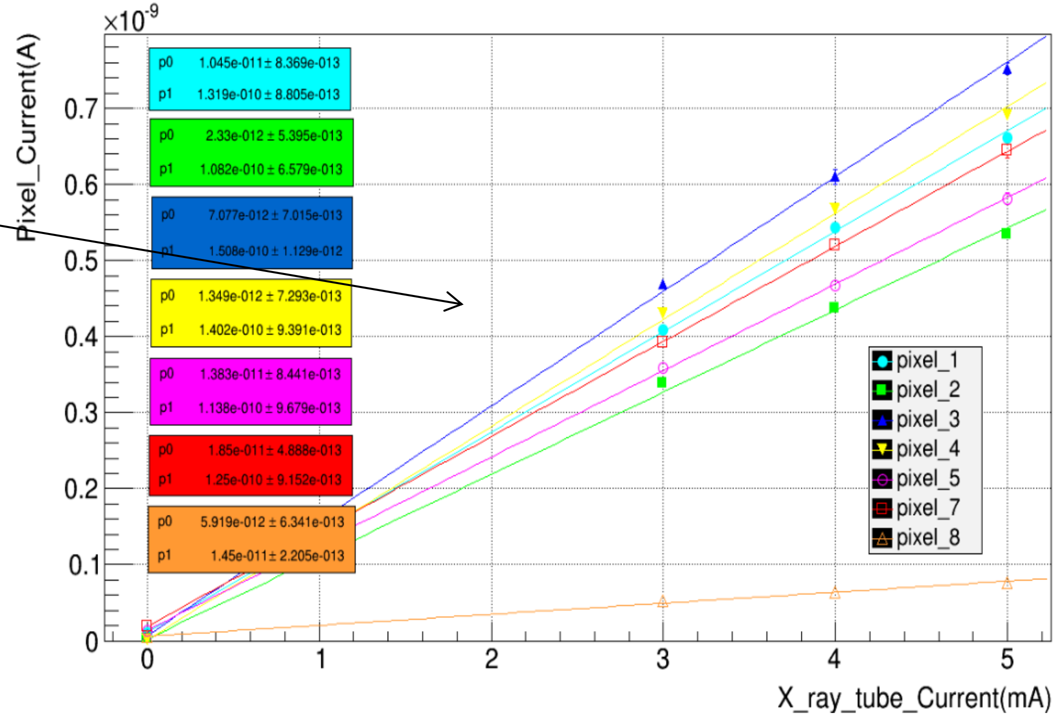
Rise time of about 2-3 sec (dominated by the time that the x-ray tube employs to reach the preset current value)

3D Diamond single cells response

3D Diamond @ 20V

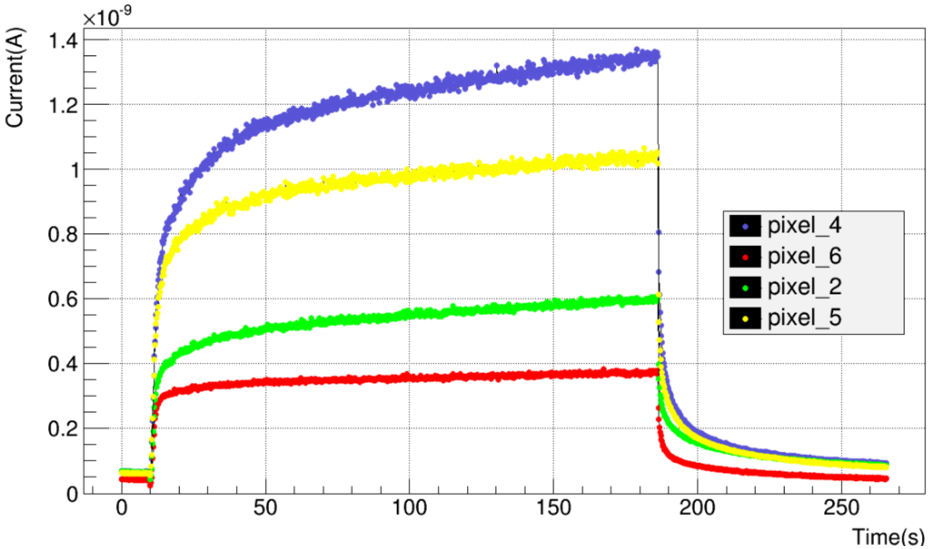


Linearity of response with the x-ray tube current for all 3D cells



The single cells current increases linearly with the tube current (Seifert) (3% of deviation)

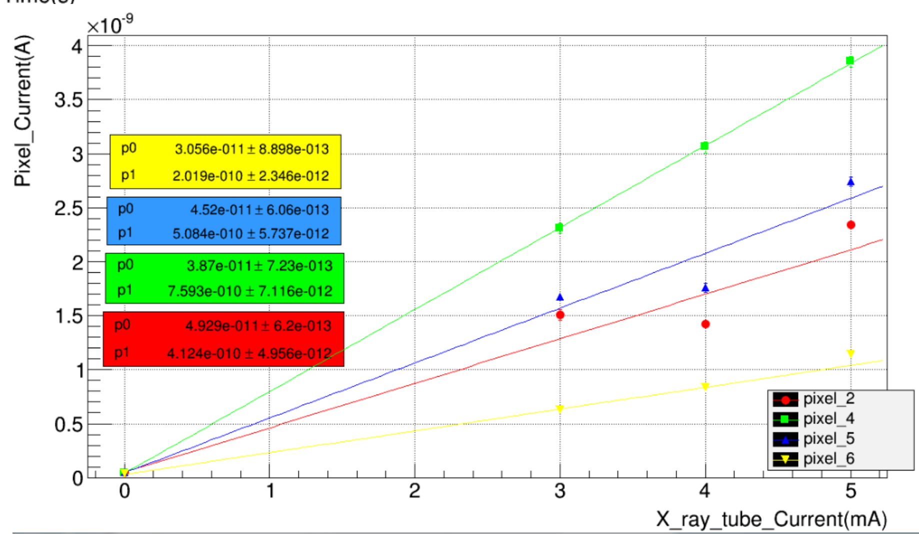
3D Diamond on Iridium single cells response



DOI currently not favored in the choice of the substrate.
Comparative tests on hospital beam – **work in progress**

Very long rise and fall times (does not depend on the time the x-ray tube takes to reach the preset current value)

The single pixel current is not always linear with the tube current (Seifert)

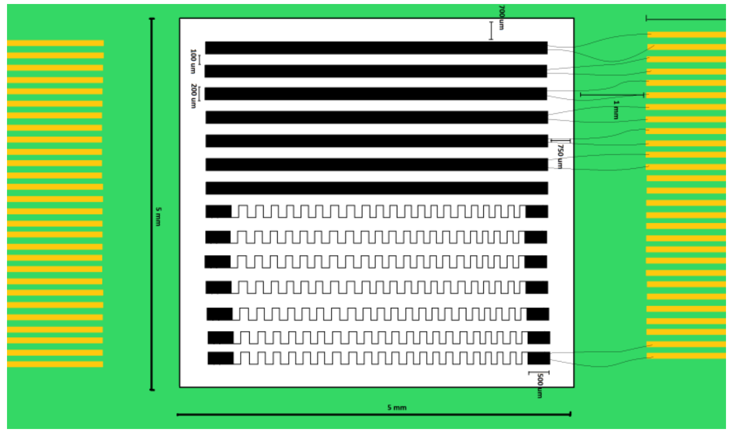


3D Diamond detector optimization

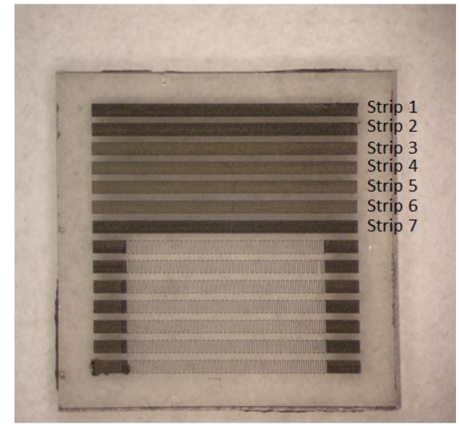
Work in progress

- **Direct bonding on graphite -> all carbon dosimeter**

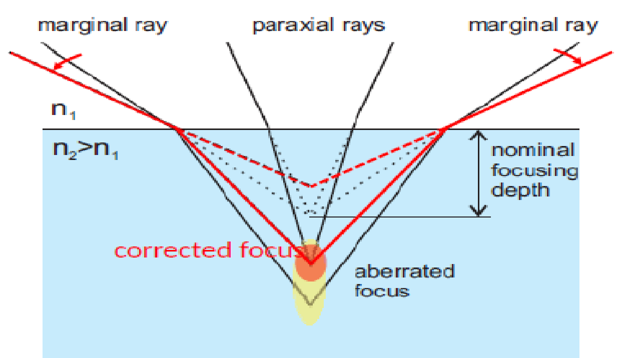
Schematic

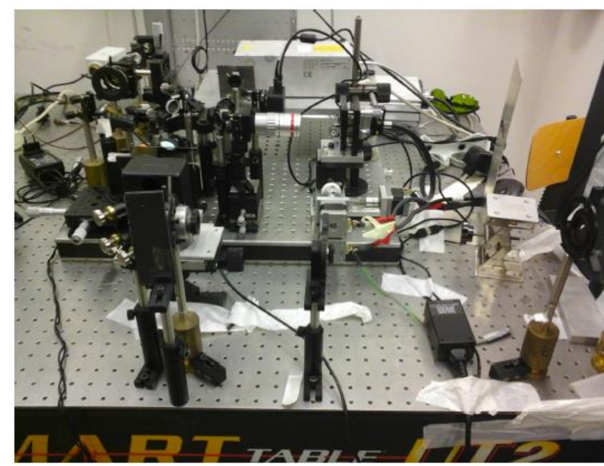


Detector



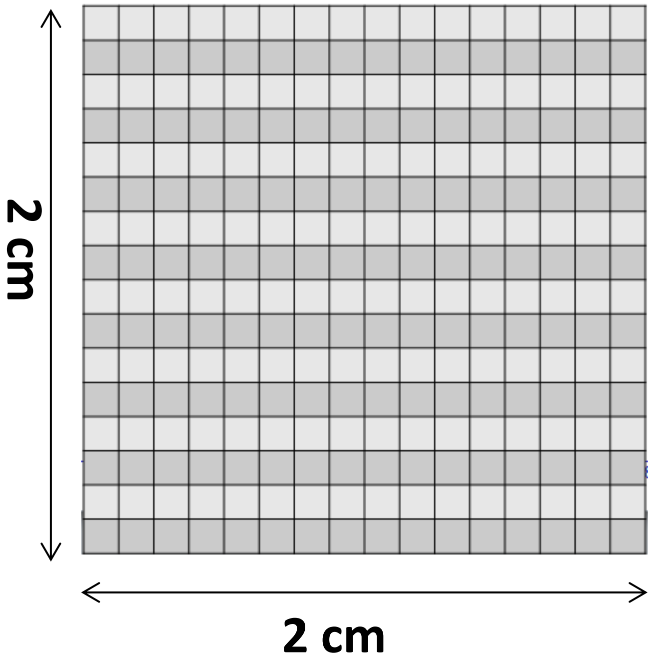
- **focus optimization -> Decrease resistivity and increase column uniformity**





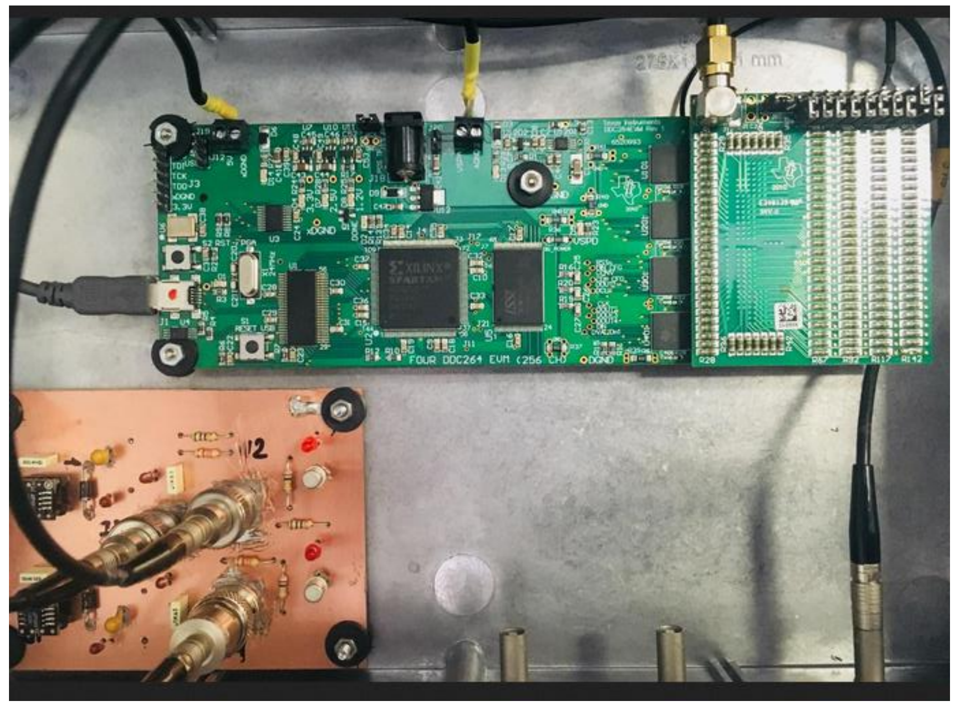
Next? New highly segmented polycrystalline diamond dosimeter

256 pixels 3D diamond matrix



…

256 low noise readout channels



Conclusions

- ✓ Results demonstrate the feasibility of 3D diamond devices for dosimetry of standard clinical megavoltage photon beams, showing a linear dose response, repeatability and time stability.

- ✓ Small field beam profile have been measured with a 3D diamond single cell of 0.5 mm x 0.5 mm x 0.5 mm active volume showing good compatibility with other clinical dosimeters.

- ✓ The development of a new sensor connection technique (direct bonding on graphite) and the optimization of the laser focus are ongoing.

- ✓ A new highly segmented polycrystalline diamond dosimeter will be produced. Due to the simultaneous measurement of many points, a higher accuracy in measurements of very small size field profiles would be possible and the need of using many not standard correction factors will be greatly reduced.