22nd International Workshop on Radiation Imaging Detectors

Intercalibration and comparative tests of 3D diamond and diamond on iridium detectors for medical dosimetry

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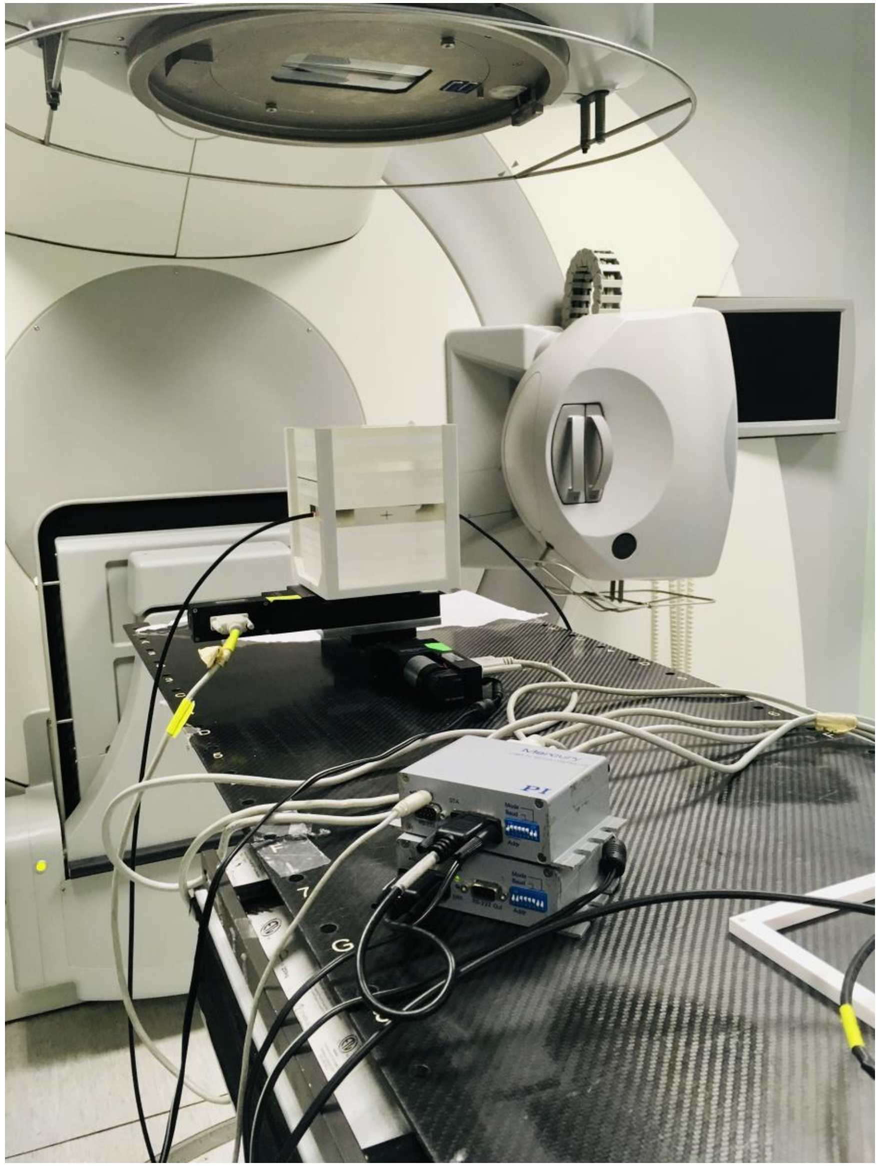
Istituto Nazionale di Fisica Nucleare

3Dose Experiment Research Group



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Collaborations:
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University of Wollongong
“The Christie” Hospital Manchester,
Santa Maria della Misericordia Perugia,
Careggi Firenze,
Santa Maria Terni,
Città di Castello.

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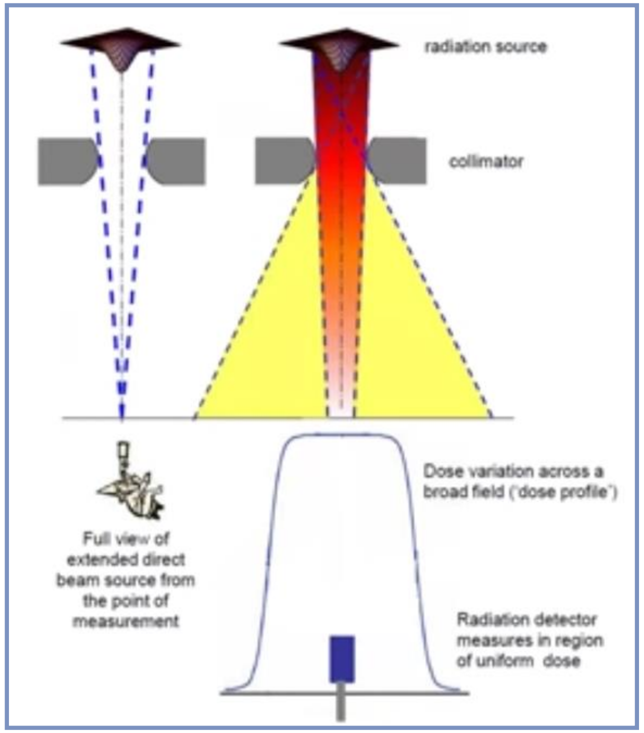
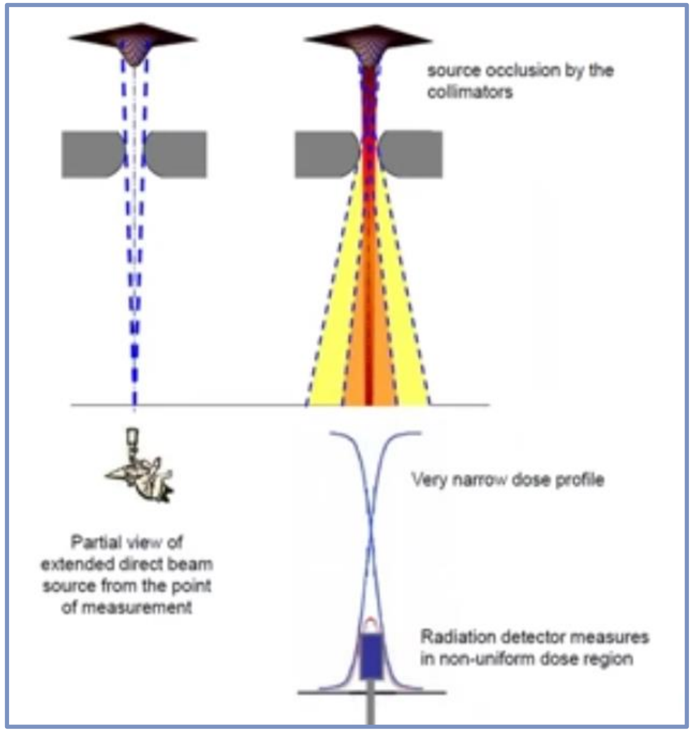
- ✓ Small field dosimetry issues
- ✓ 3D diamond detectors
- ✓ Characterization of two 3D detectors made off different substrates (polycrystalline diamond and diamond on iridium) using an x-ray tube
- ✓ 3D polycrystalline diamond detector dosimetric measurements with a medical linear accelerator
- ✓ Conclusions

Small field dosimetry issues





- Partial occlusion of the primary source + lack of electronic balance
- Strong dose reduction on the central axis of the beam

↓

- Errors due to incorrect use of the detectors in the dosimetry of small fields

Dosimeters, why diamond?

The presence of the dosimeter introduces a perturbation of the fluency of the charged particles because it is different in density and composition from the human body.
The effect depends on:

- **the geometry and physical properties of the detector**
- the medium in which the measurement is made
- the energy of the beam, the size of the field

Properties	Diamond	Silicon
Gap [eV]	5.5	1.12
Hole Mobility [cm2/Vs]	1200	450
Electron Mobility [cm2/Vs]	1800	1450
Effective atomic number Zeff	6	14
Wigner Energy [eV]	43	13-20

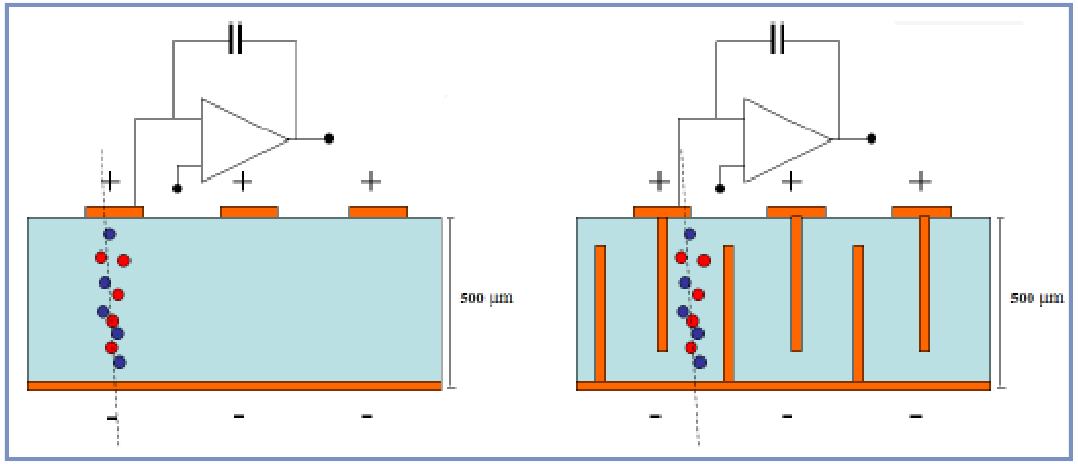
→ Low dark current

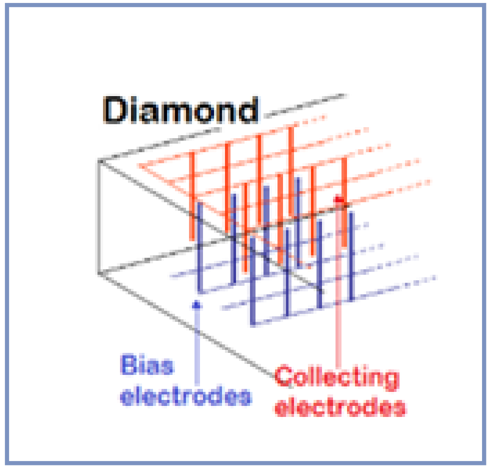
→ Fast Response Time

→ Tissue Equivalence

→ Radiation Hardness

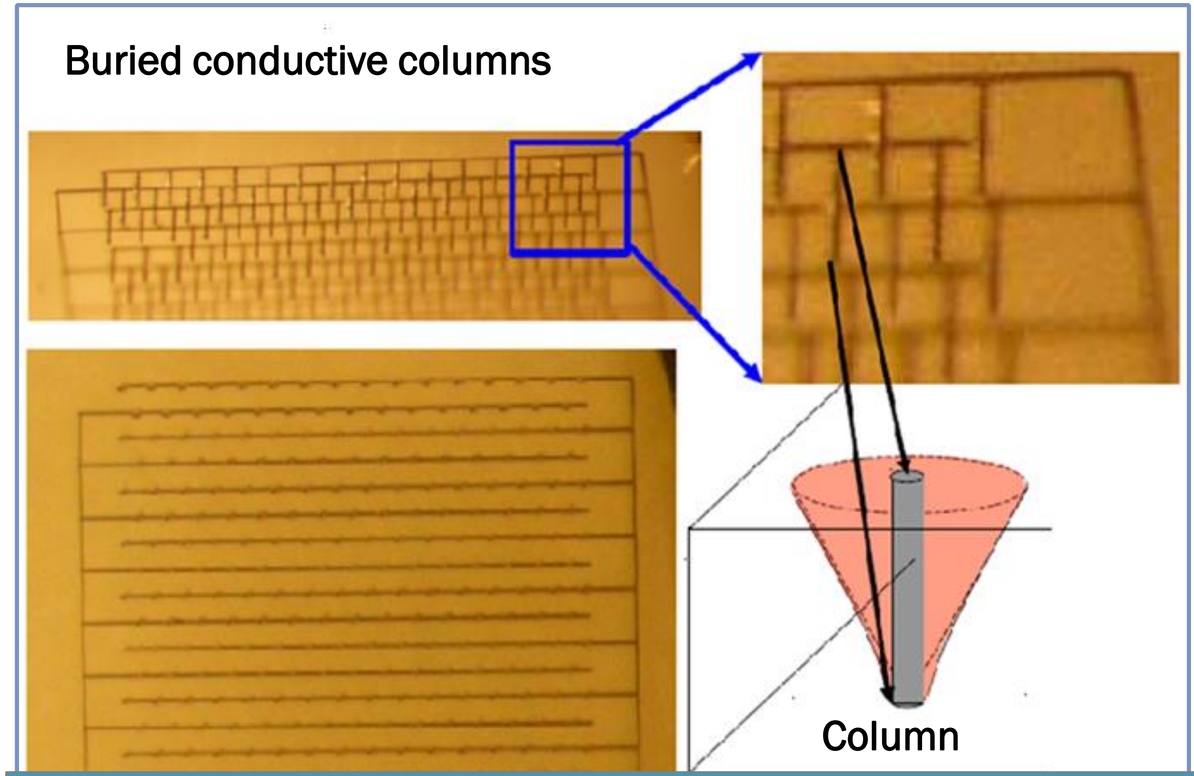
Diamond detectors with 3D electrodes



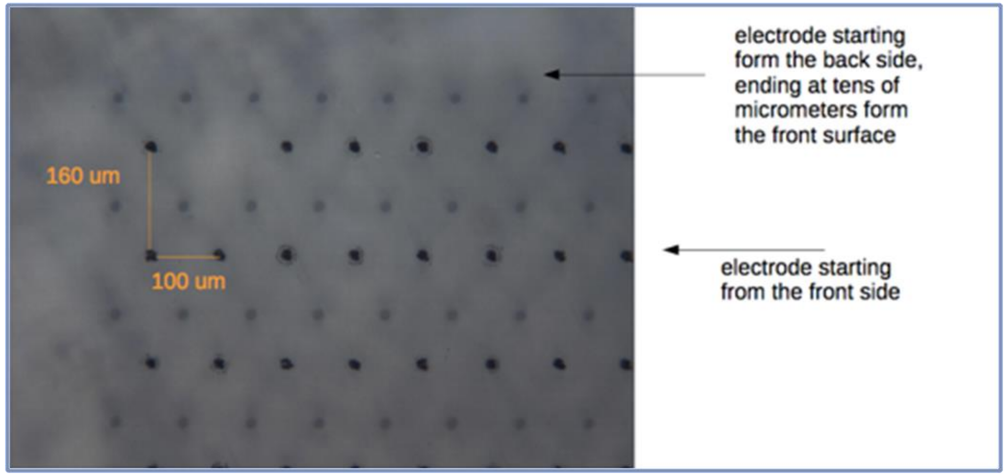


- Low bias voltage (few V) with high active volume;
- Reproducibility of the elementary 3D cell
- An 'all-carbon' detector exposed to the beam (tissue equivalence)
- High spatial segmentation, even 0.1 x 0.1 mm^2
- High resistance to radiation damage

Laser Graphitization



Polycrystalline diamond with 3D structures produced by laser pulses



Graphitic conductive path resistivity:

$\rho \cong 60 \pm 20$ mΩcm @ns
$\rho \cong 900 \pm 300$ mΩcm @fs

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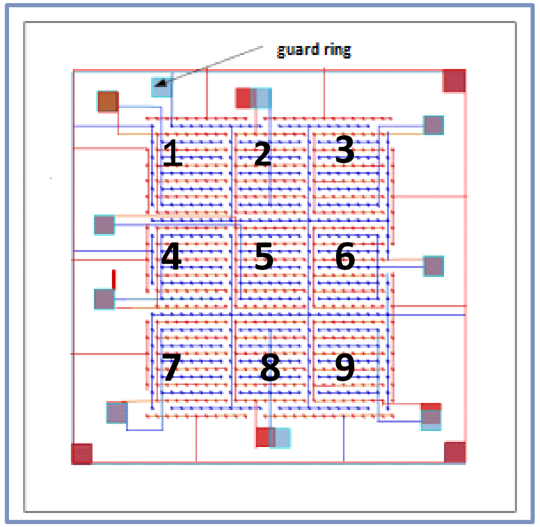
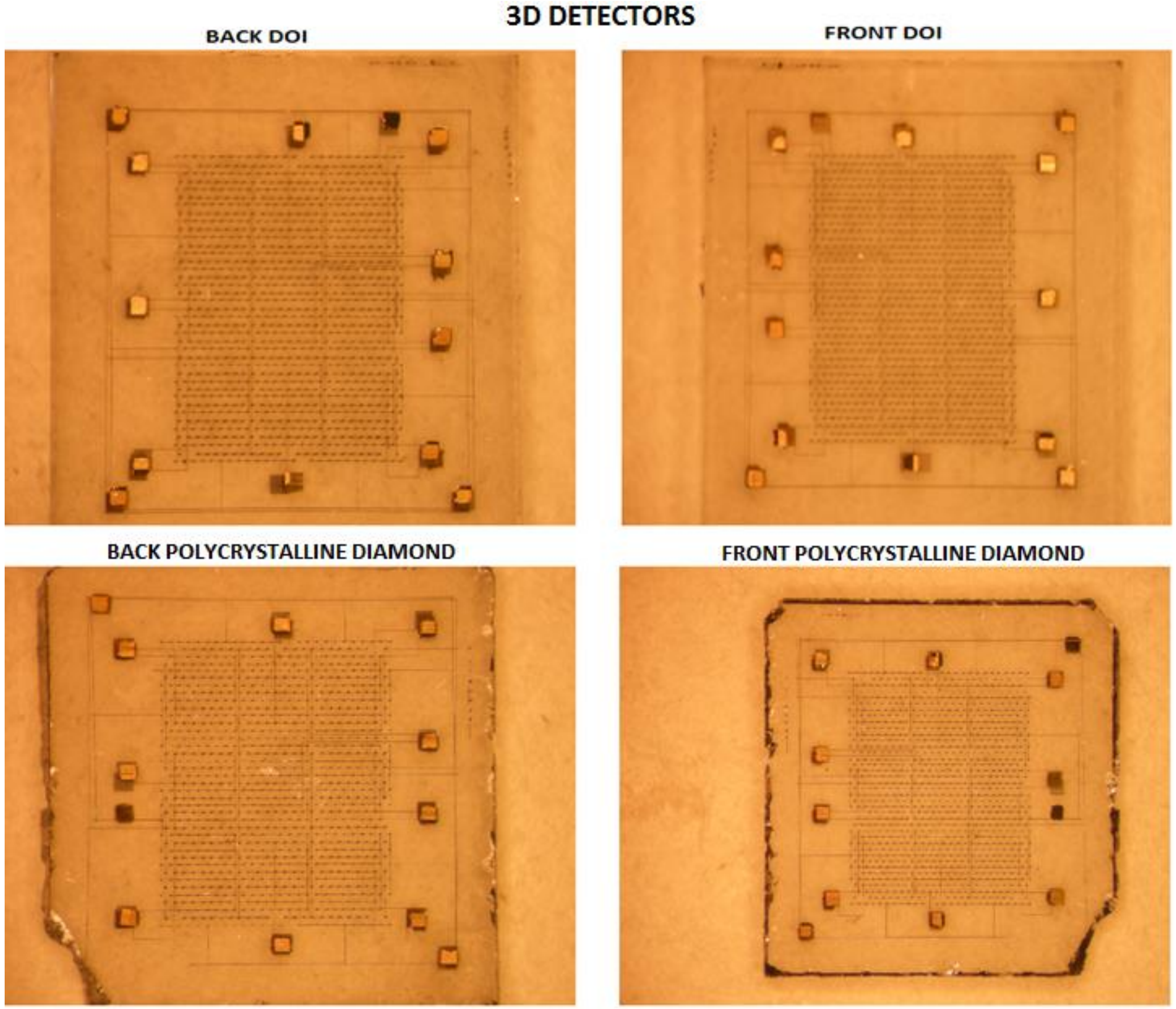
New 3D detectors with indipendent cells readout



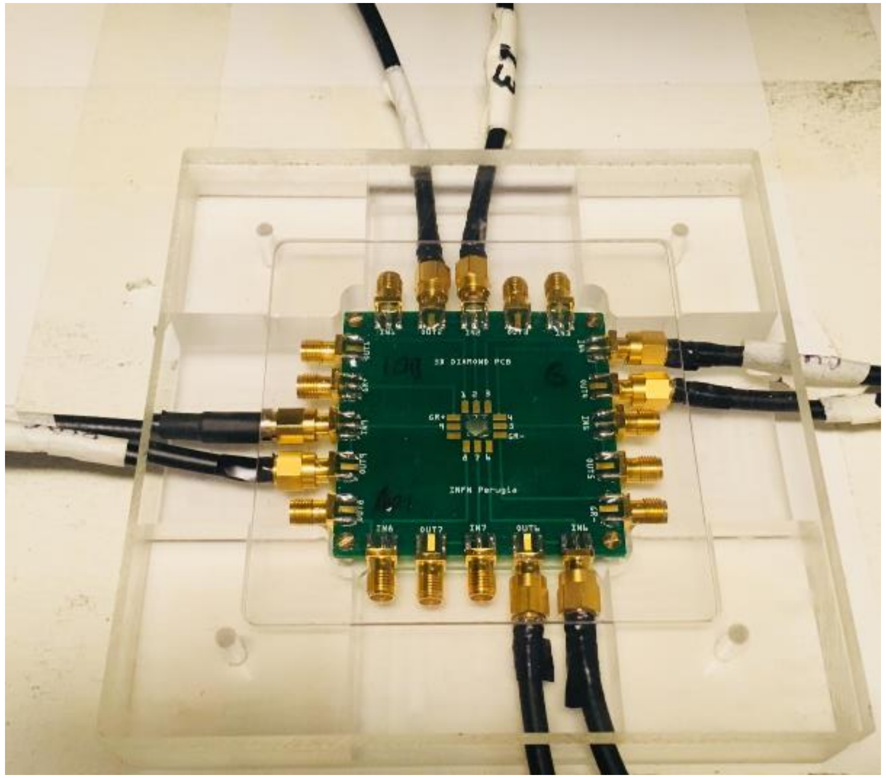


Schematic view of two 3D detectors with the same geometry & different substrates:

Diamond & Diamond on Iridium

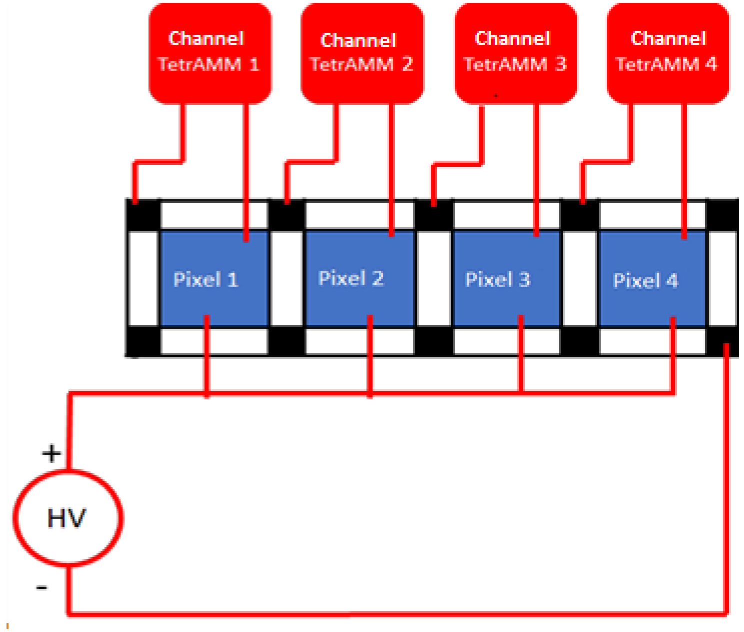
New 3D detectors with independent cells readout

4/8 cells readout in parallel



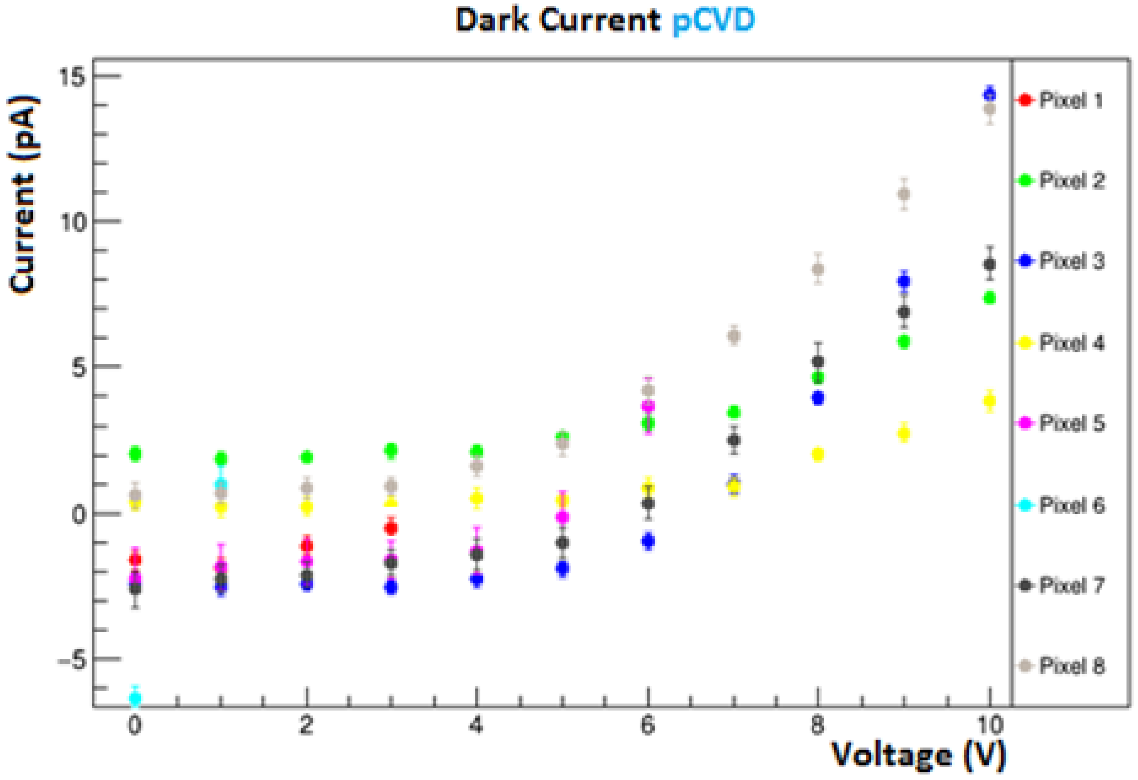
TETRAMM Picoamperometer :

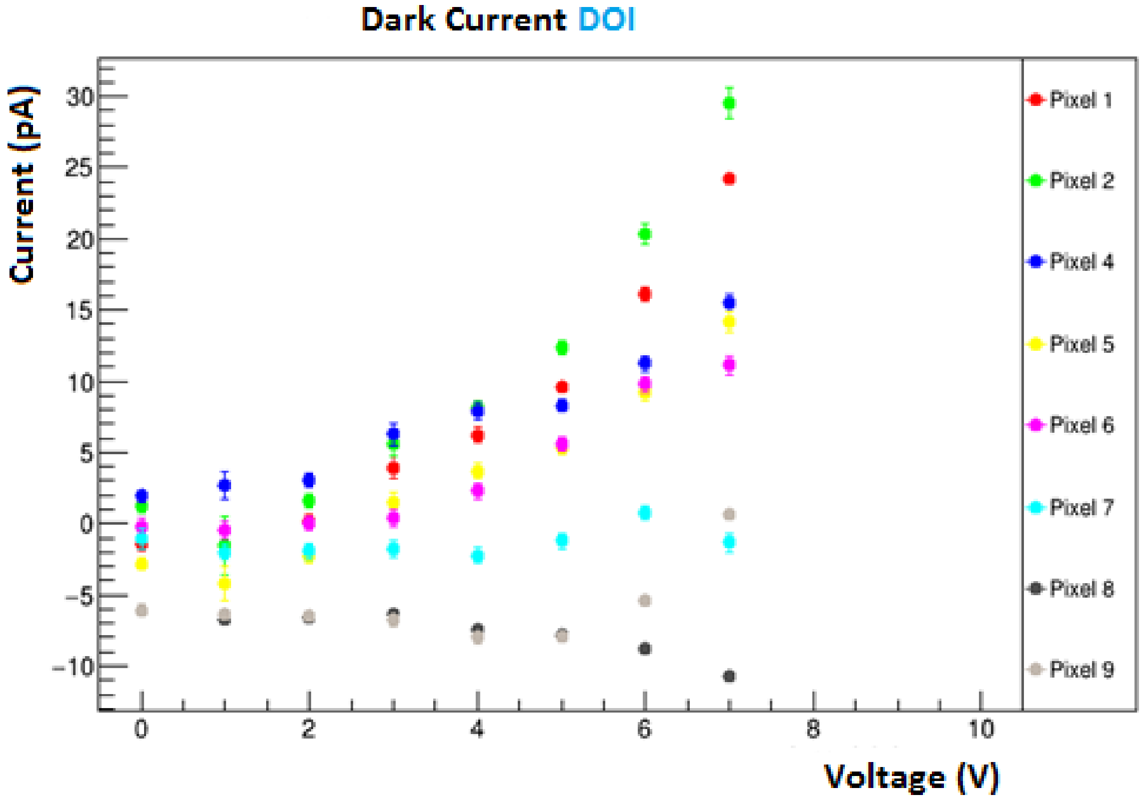
4 readout channels + 1 integrated high voltage source



3D Diamond & Diamond on Iridium dark current

Before irradiating the detectors:





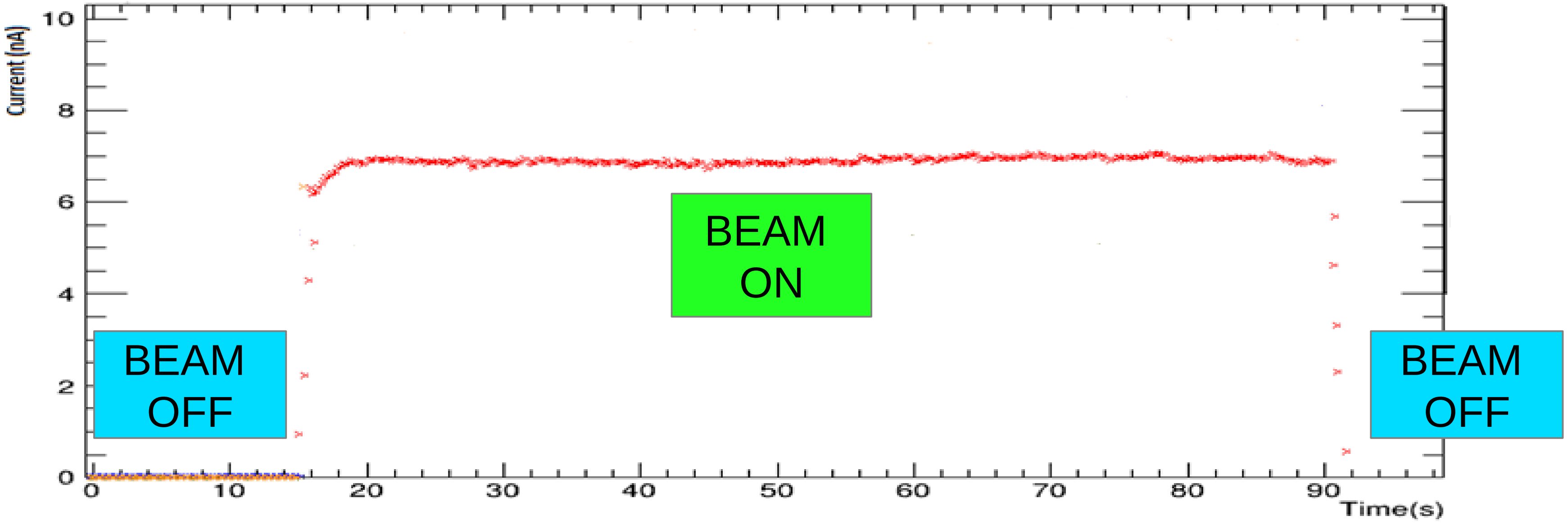
For the diamond on iridium substrate detector, it was not possible to apply voltages over 7V because the dark current became too high and the response unstable.

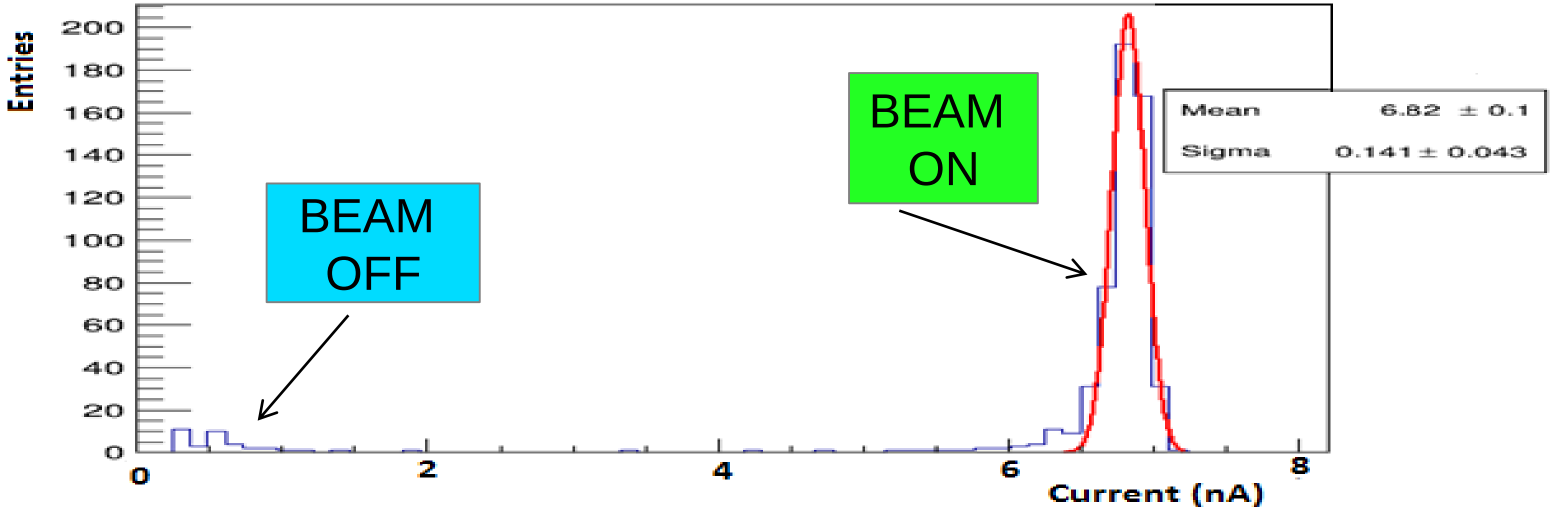
First measurement setup: Xray tube

Newton scientific X-ray tube

- ✓ Max voltage 50 kV
- ✓ Max current 200 uA
- ✓ Opening angle of the emitted cone 100°

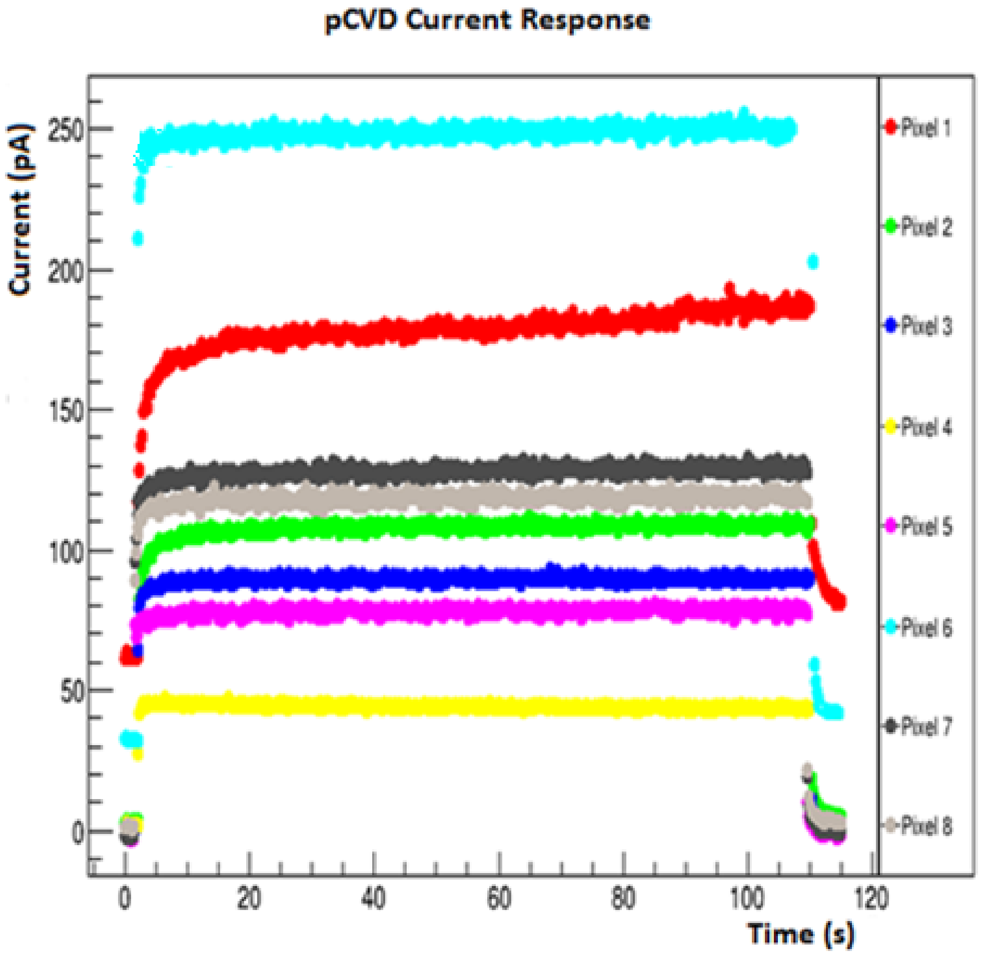
3D detector current response

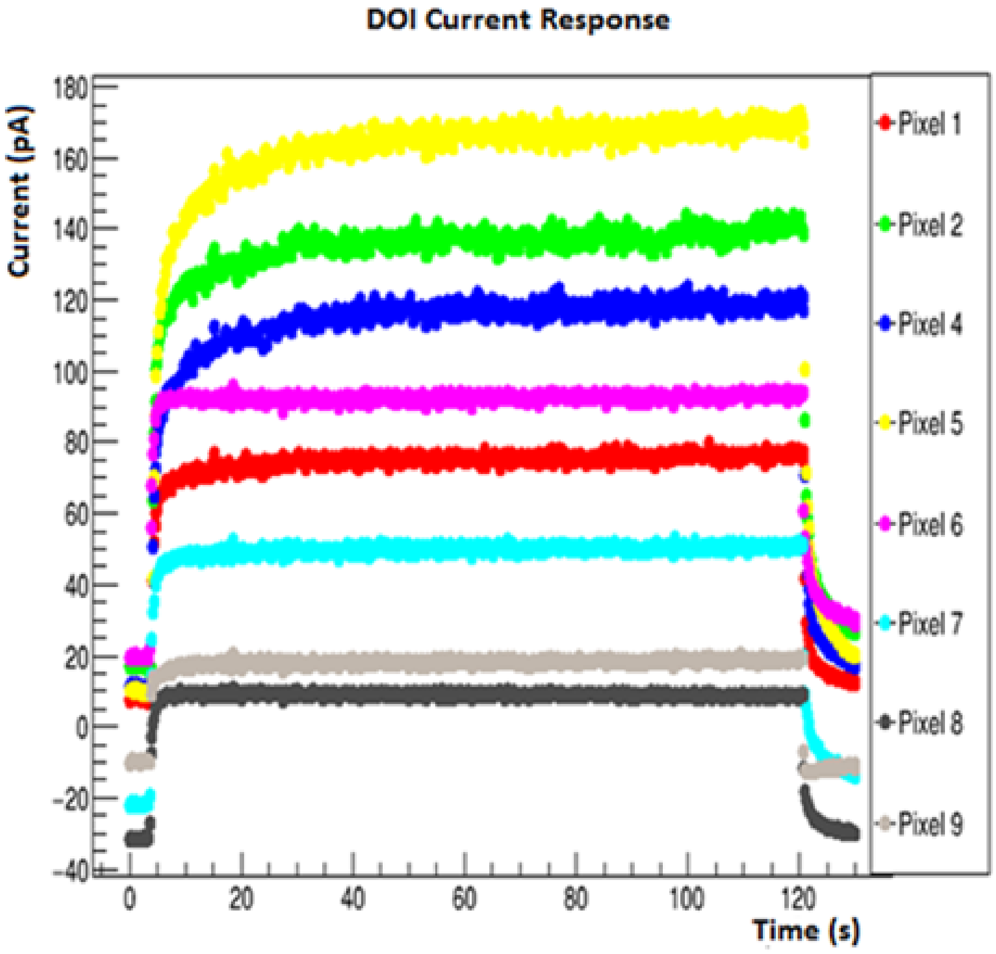




3D detectors current response

XRay tube voltage 30 kV, current 140 uA. Detector bias voltage 4V.





Current response rise and fall time

XRay tube voltage 30 kV, current 140 uA. Detector bias voltage 4V.

pCVD

Pixel	Rise Time (s)	Fall Time (s)
1	2.50	5.00
2	0.30	0.60
3	0.50	0.20
4	0.30	0.30
5	0.10	0.30
6	0.60	0.40
7	0.60	0.20
8	0.50	0.40

Except pixel 1, rise and fall time of the pCVD pixels response are below 1s

DOI

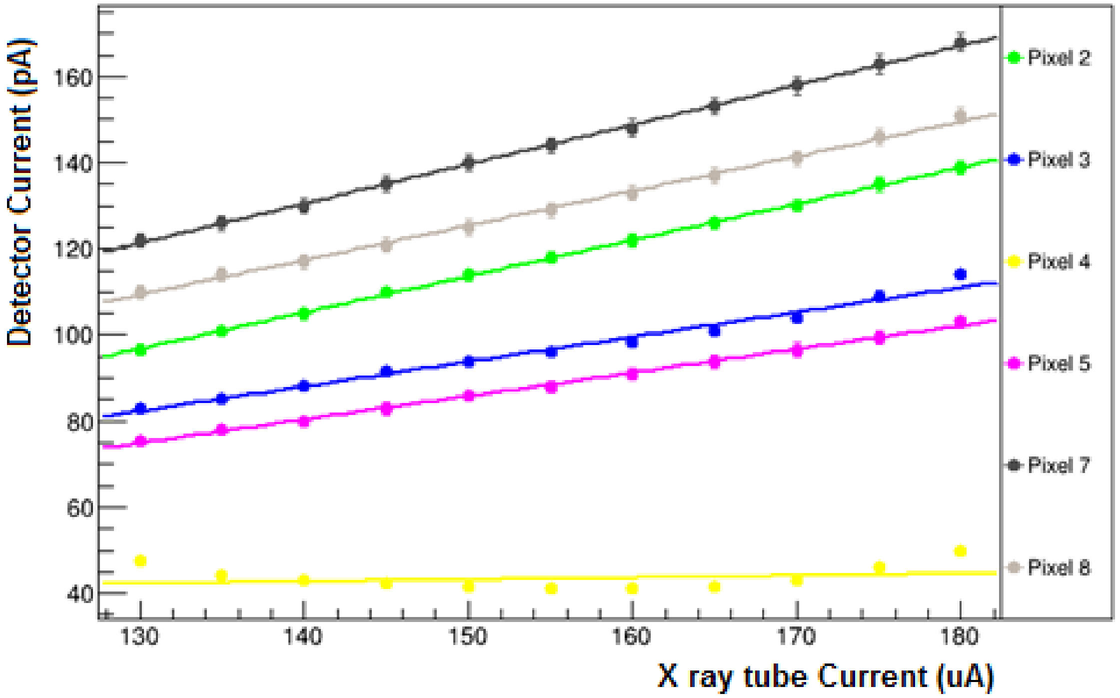
Pixel	Rise Time (s)	Fall Time (s)
1	2.50	3.40
2	4.50	6.60
4	6.10	4.60
5	6.20	5.00
6	1.00	9.40
7	1.40	9.20
8	1.20	3.00
9	3.10	0.20

None of the DOI pixels has both rise and fall time below 1s

Linearity with the Xray tube current

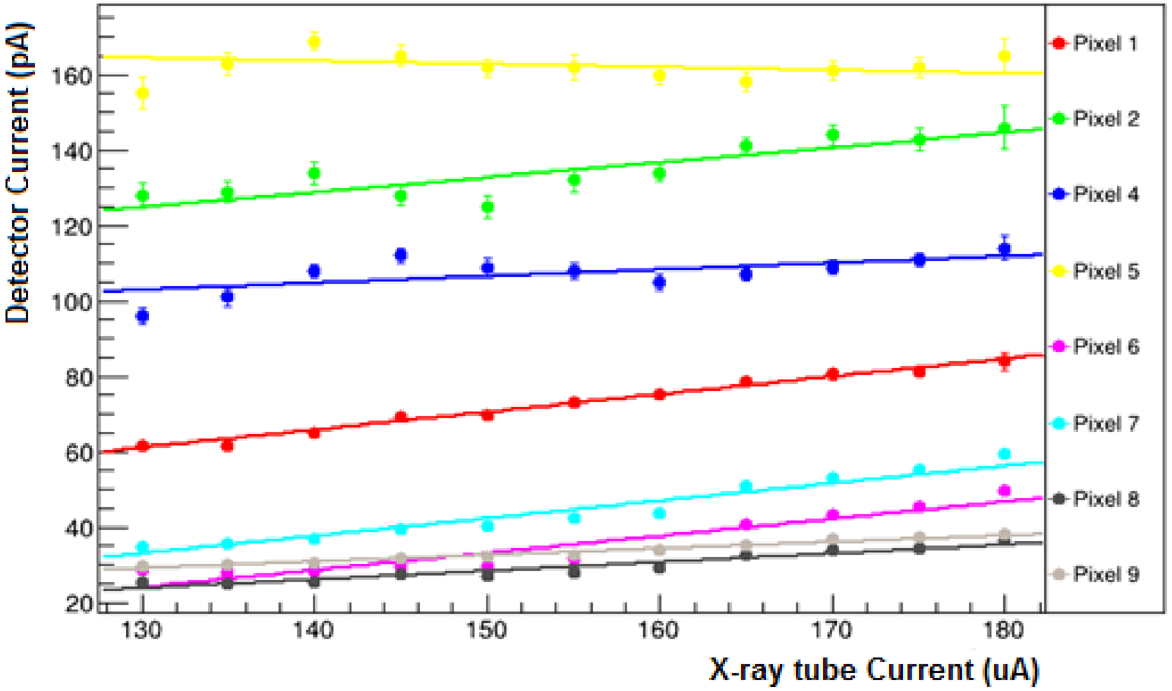
XRay tube voltage 30 kV, current 140 uA. Detector bias voltage 4V.

pCVD



Max deviation from linearity: <3%
pixel 4: bad pixel

DOI

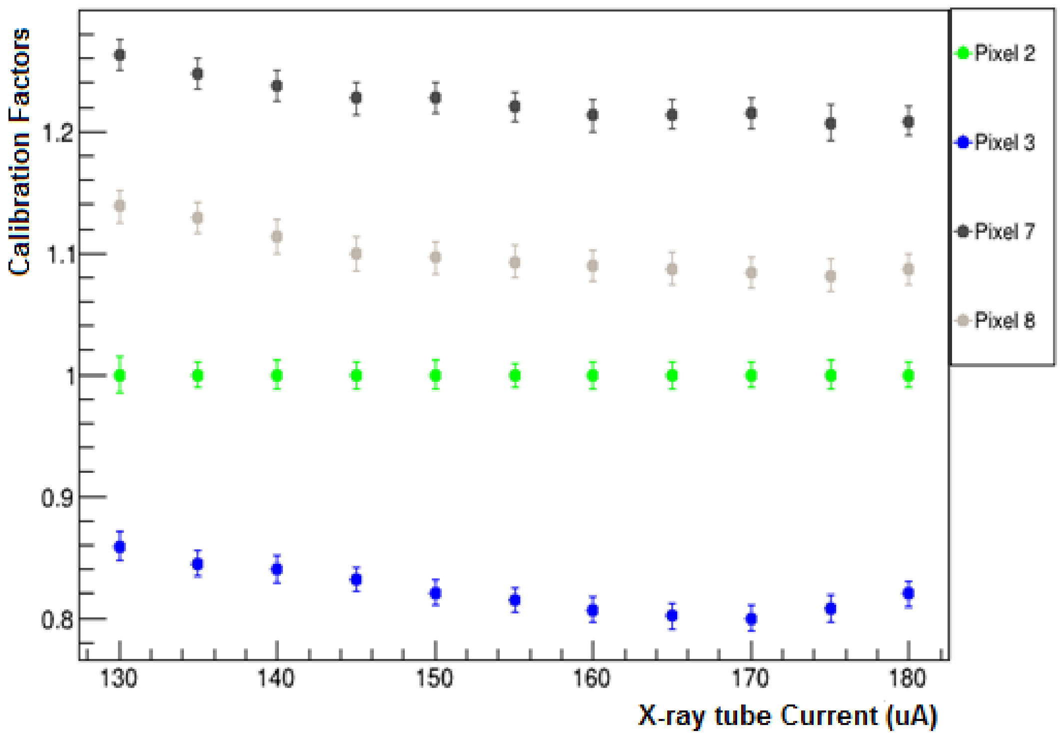


Max deviation from linearity: >3%
Pixel 4,5: bad pixels

Intercalibration Factors

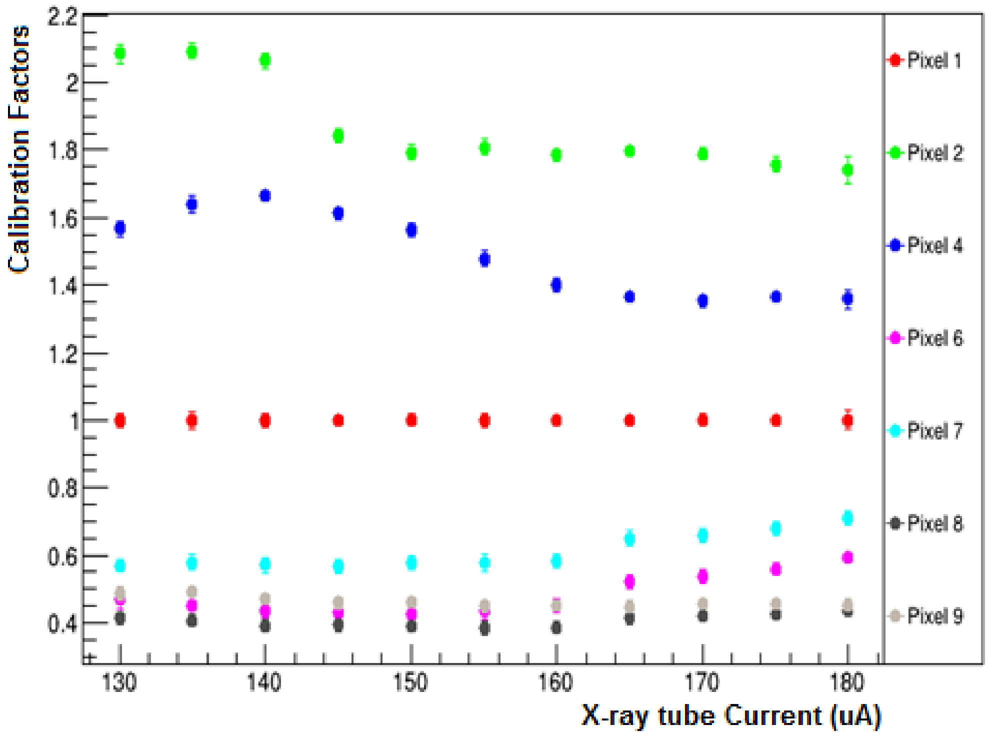
XRay tube voltage 30 kV, current 140 uA. Detector bias voltage 4V.

pCVD



Max deviation <4%

DOI



Max deviation >8%

Pixel 2,4 bad pixels

Summary

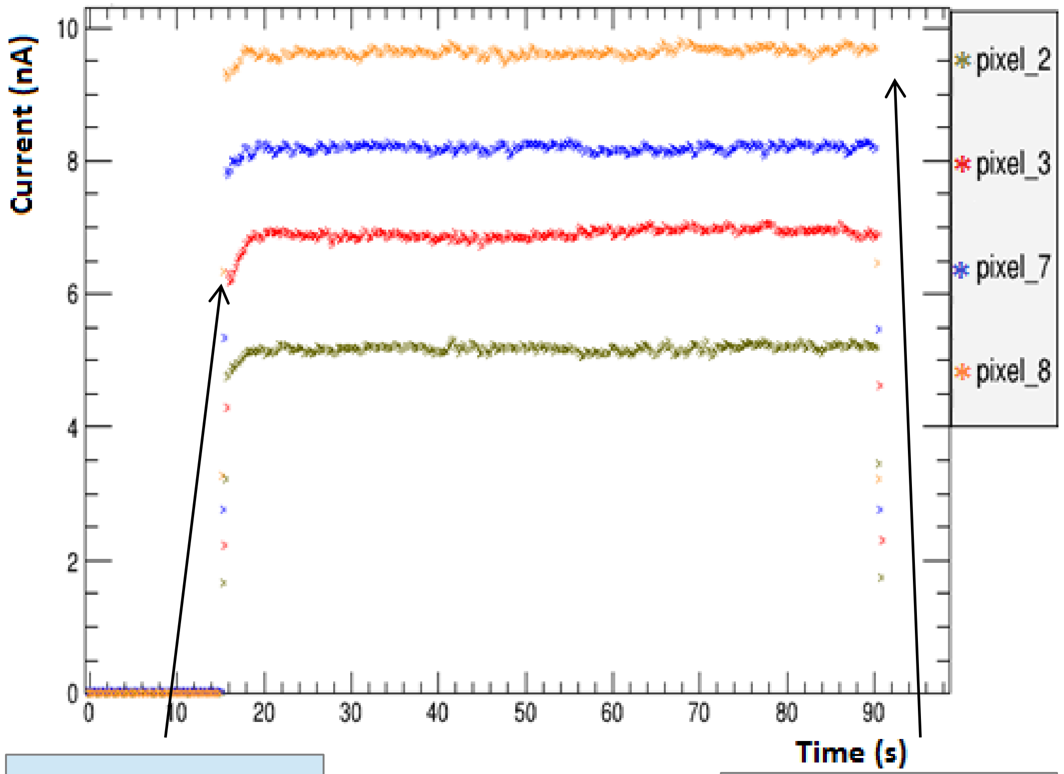
	pCVD	DOI
Dark Current	< 15 pA	< 30 pA
Operating Voltage	≥4 V	4 V
Repeatability	< 3%	< 3 %
Stability	< 3 %	< 5 %
Linearity	< 2.7 %	> 3%
Max signal to noise ratio	1845	412
Intercalibration factors	< 4 %	> 8 %
Mean rise time	(0.73± 0.39) s	(3.25 ± 2.13) s
Mean fall time	(0.35 ± 0.19) s	(5.18 ± 3.14) s

Dosimetric measurements at the Perugia Hospital

- ✓ Medical linear accelerator (Elekta Synergy Sband)
- ✓ 6 MV photons
- ✓ 10 × 10 cm^2 field
- ✓ 1.6 x 1.6 cm^2
- ✓ 0.8 x 0.8 cm^2
- ✓ The detector encapsulated inside a 14 x 14 x 14 cm^3 PMMA block at 10 cm depth
- ✓ placed at 100 cm from the beam source.

3D pCVD current response to photon beam

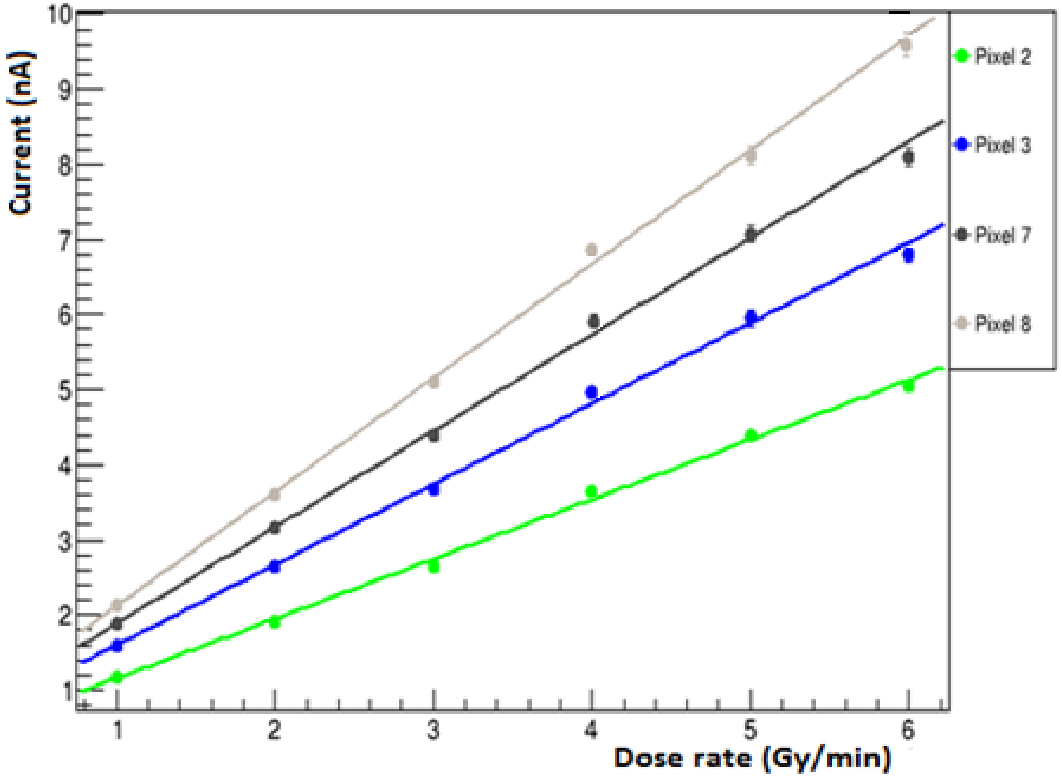
Detector response at 6 Gy/min



Rise time <0.5 s at 6Gy/min

Fall time <0.3 s at 6Gy/min

Dose rate linearity



Max deviation from linearity 2%

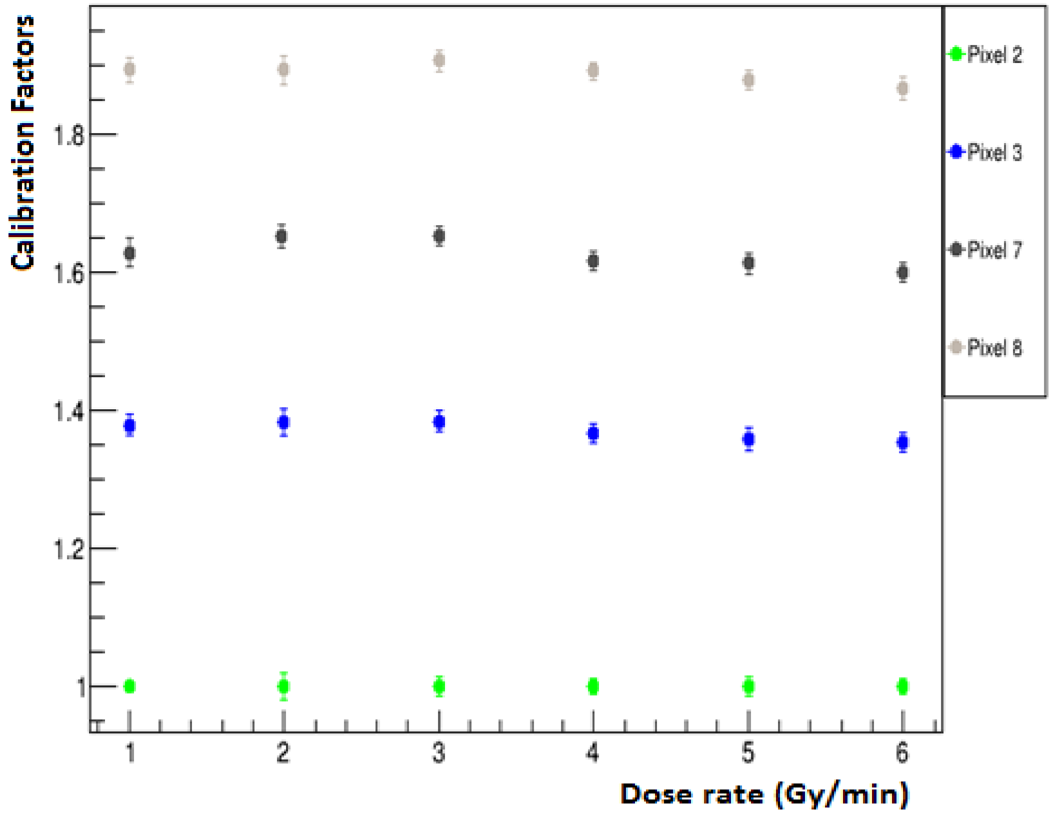
3D pCVD Repeatability & Calibration factors

Repeatability

	Dose-rate	
Pixel	2 Gy/min	6 Gy/min
2	0.87%	0.72%
3	0.10%	0.91%
7	0.18%	0.47%
8	0.26%	0.41%

Max deviation < 1%

Calibration factors normalized to pixel 2

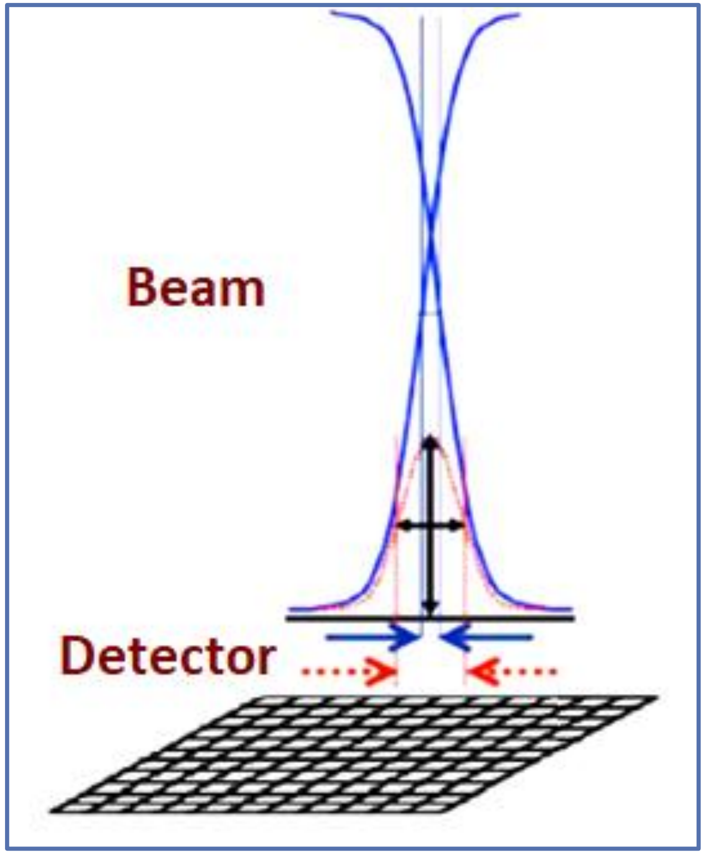


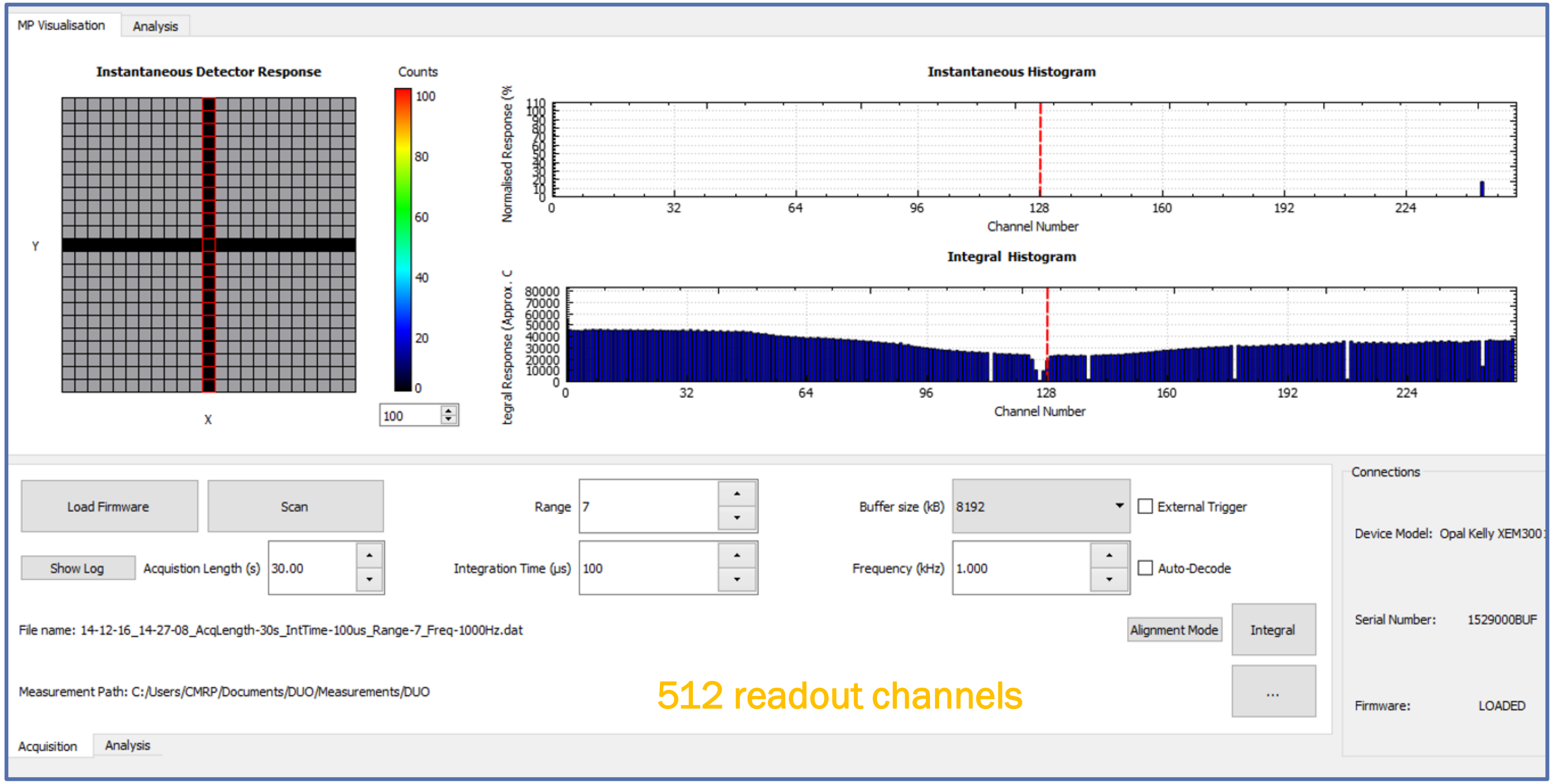
Max deviation of calibration factors 2%

What’s next?

Multi-channel read-out system

Wollongong University





512 readout channels

Conclusions

- ✓ Results demonstrate that the polycrystalline diamond substrate compared to the diamond on iridum is more suitable for dosimetric applications since it shows better linearity, repeatability and time stability and has a faster response to the photon beam.

- ✓ Each single pixel of the detector has a different sensitivity to the radiation beam and is partially influenced by the experimental enviroiment, but the response is linear and stable hence different calibration factors can be applied to obtain an overall detector response and reduce the incertainty of the delivered dose.

- ✓ 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.

Thank You

For Your Attention

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