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

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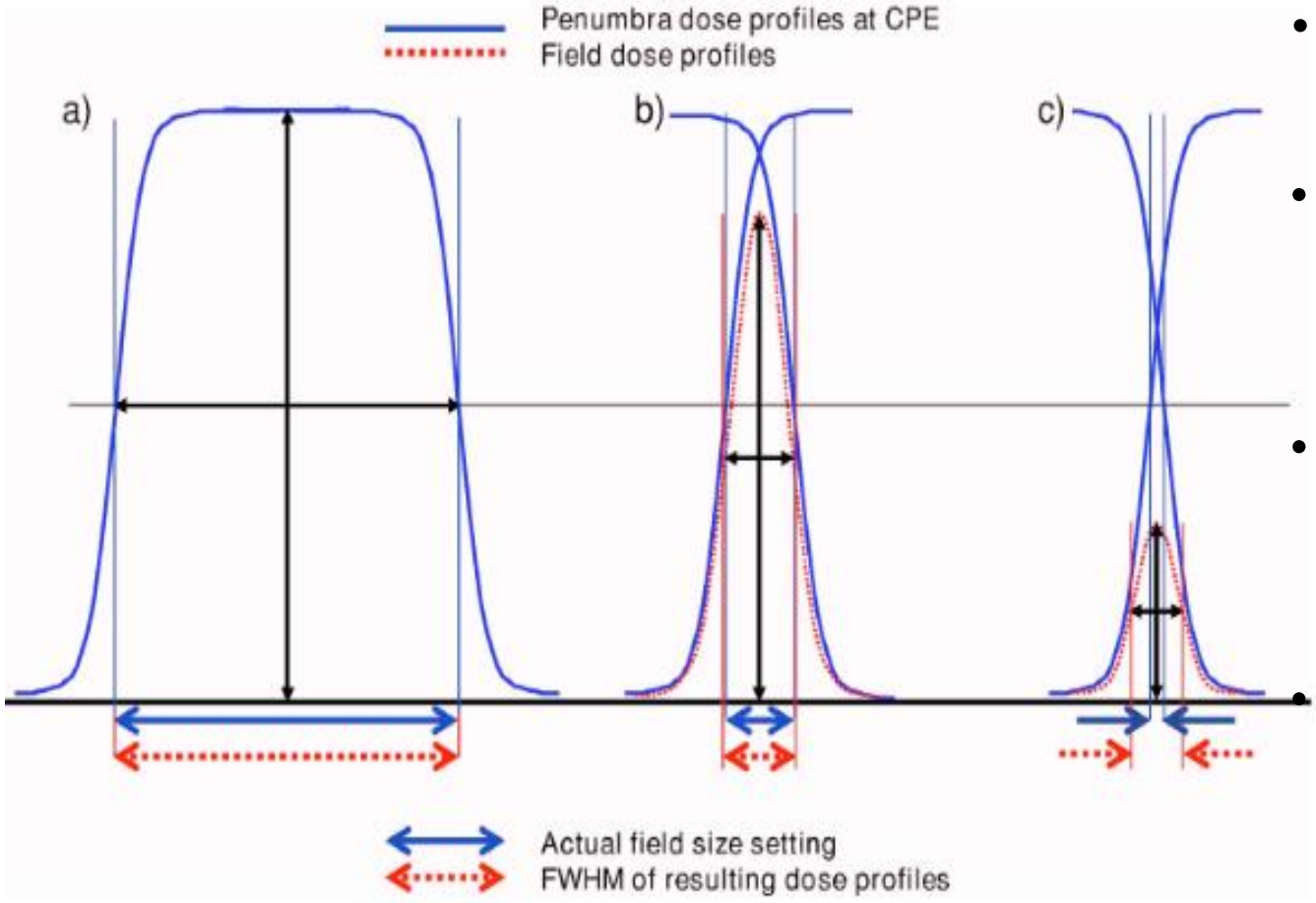
Outline

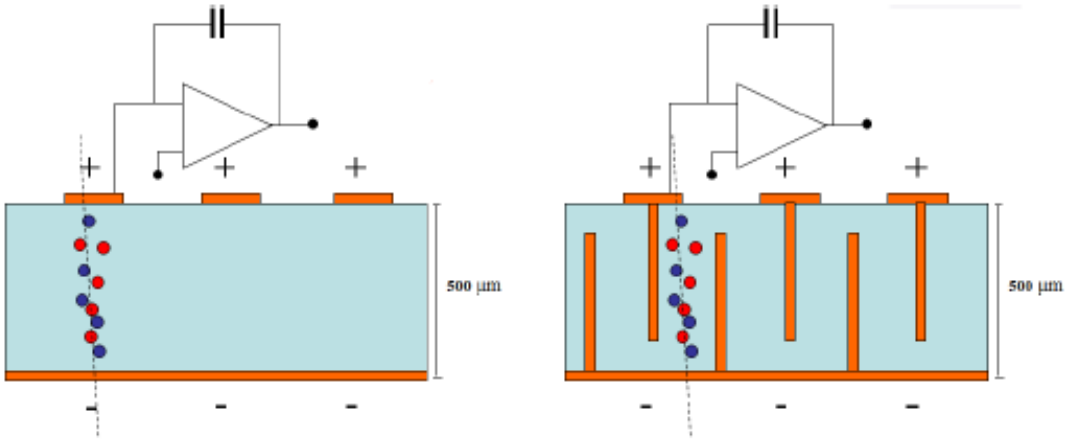
- ✓ Small field dosimetry issues
- ✓ 3D diamond detectors
- ✓ Characterization of two 3D detectors made off different substrates (polycrystalline diamond and diamond on iridium) using an x-ray tube
- ✓3D polycrystalline diamond detector dosimetric measurements with a medical linear accelerator
- ✓Conclusions

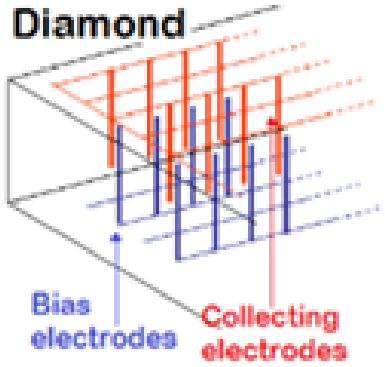
Small field dosimetry issues



- **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

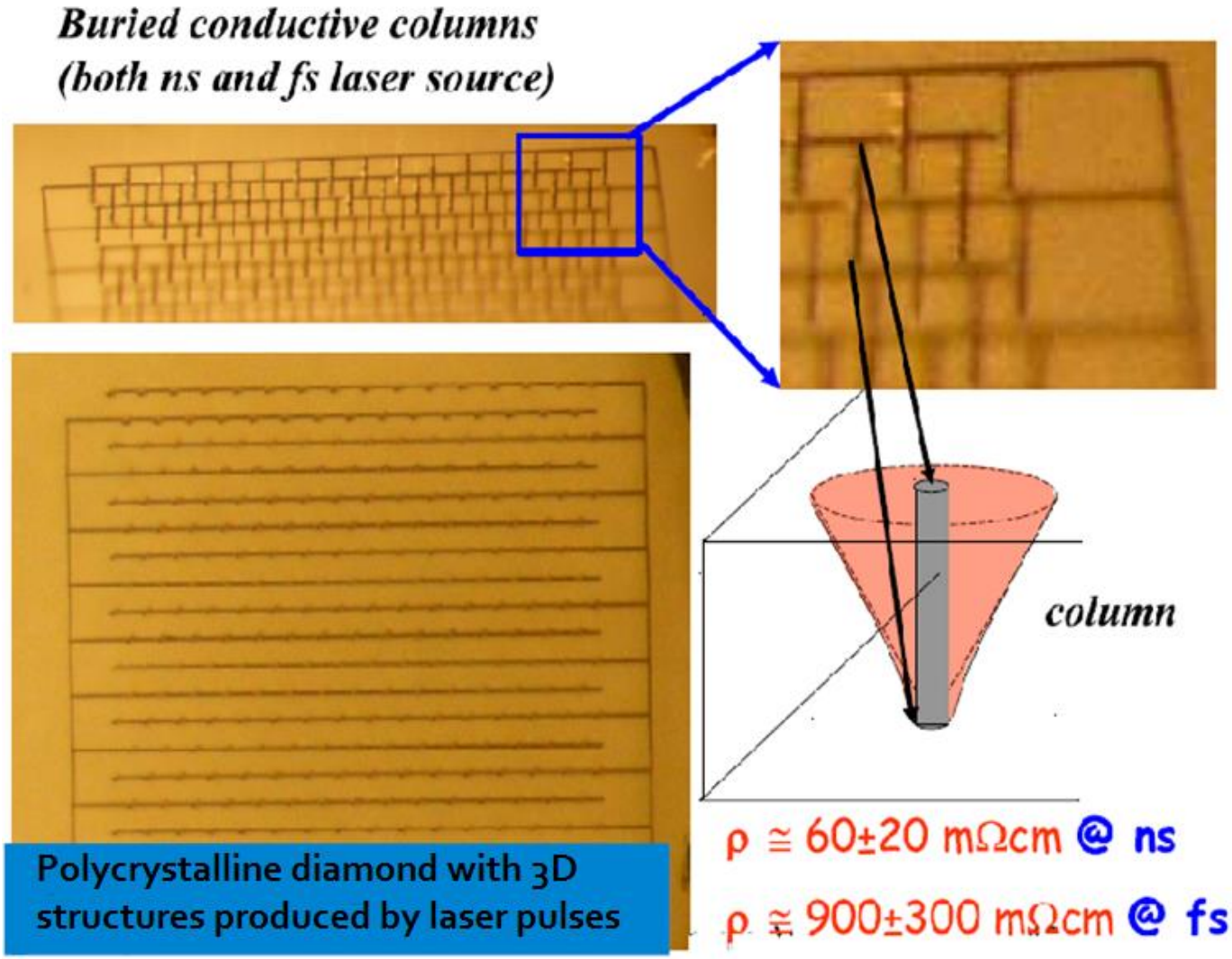




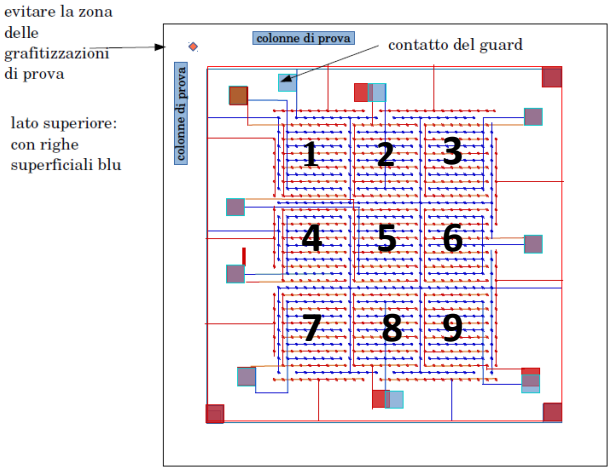
Why 3D Diamond for dosimetry:

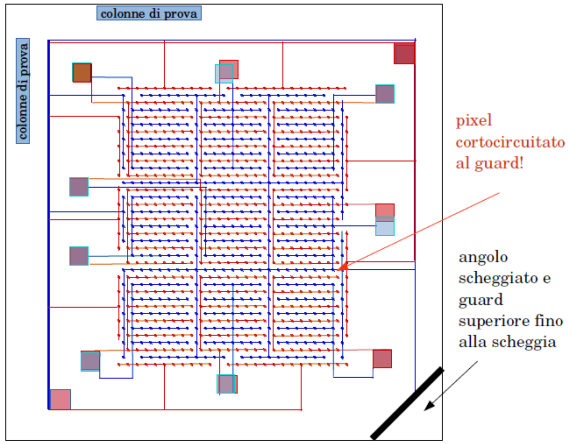
- **Low bias voltage (few V) with high active volume;**
- **Reproducibility of the elementary 3D cell**
- **An 'all-carbon' detector exposed to the beam (tissue equivalence)**
- **High spatial segmentation, even 0.1 x 0.1 mm^2**
- **High resistance to radiation damage**

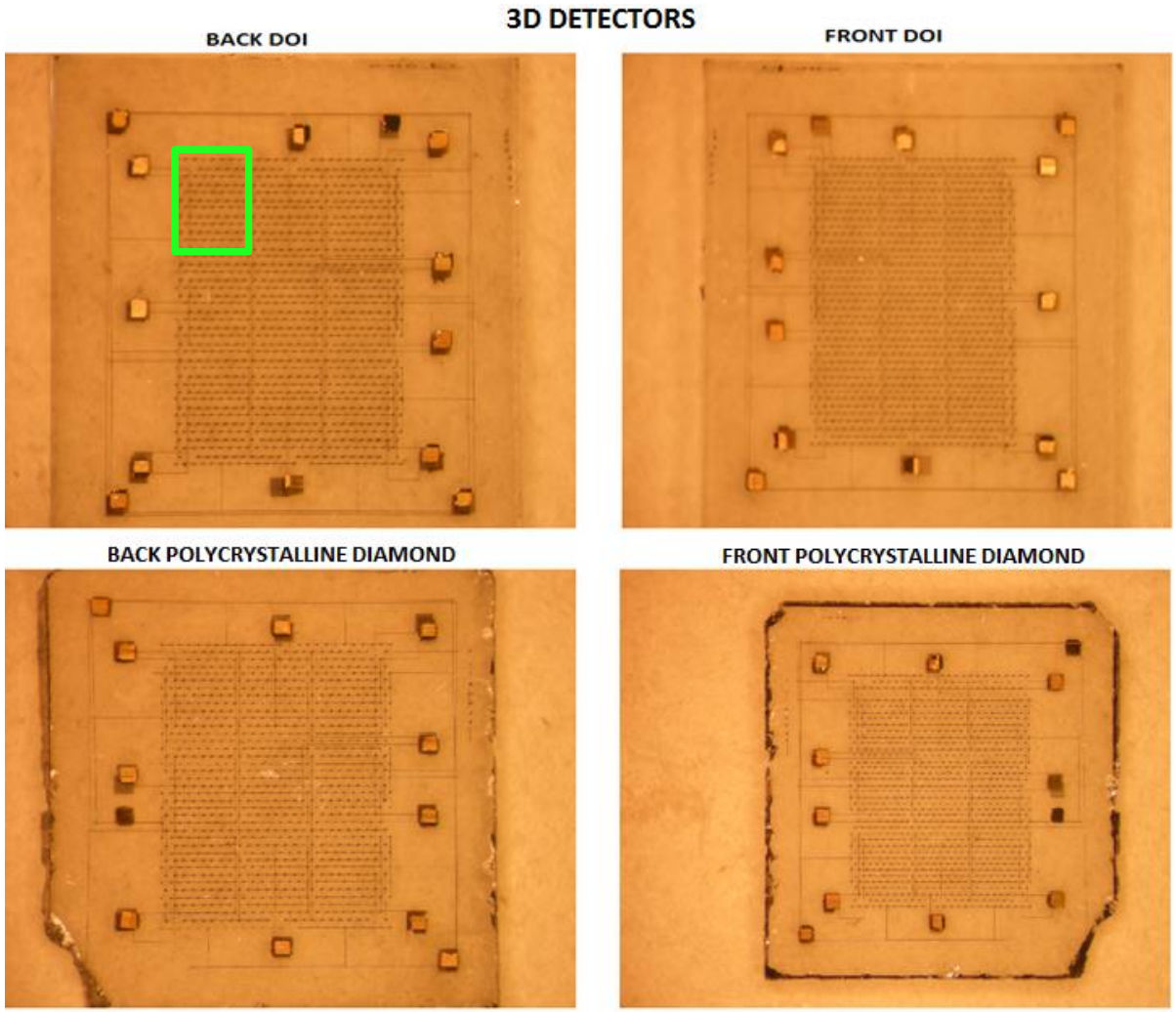
3D Diamond detectors for dosimetry



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

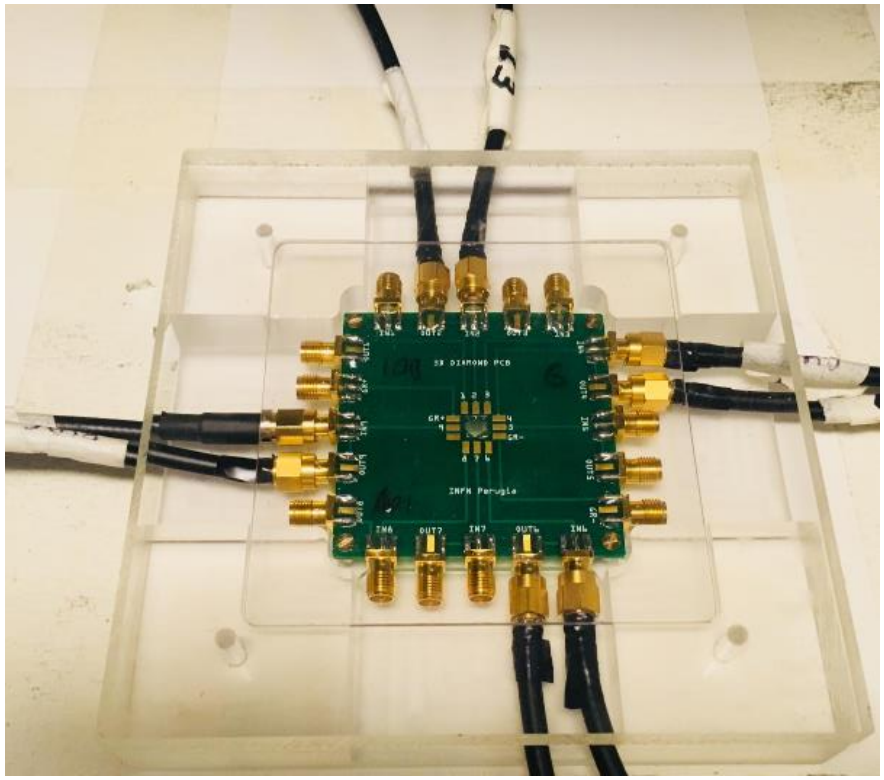




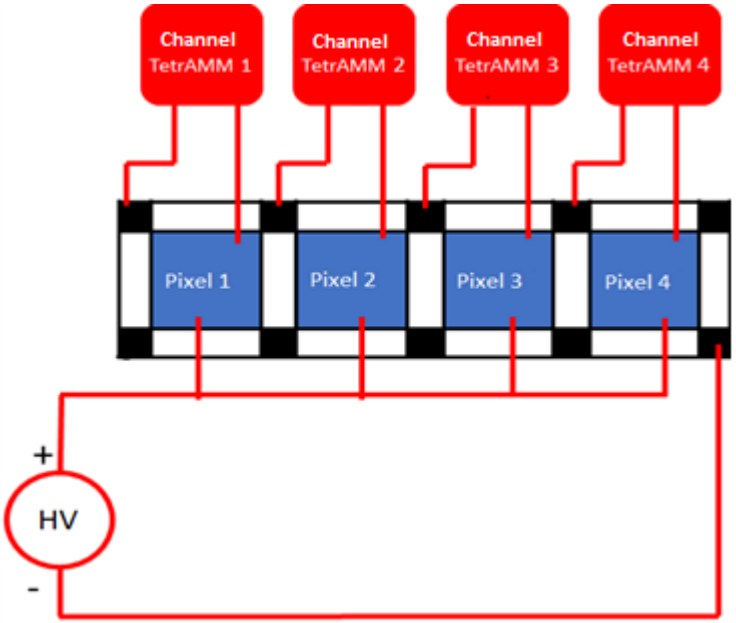


New 3D detectors with multiple indipendent cells readout

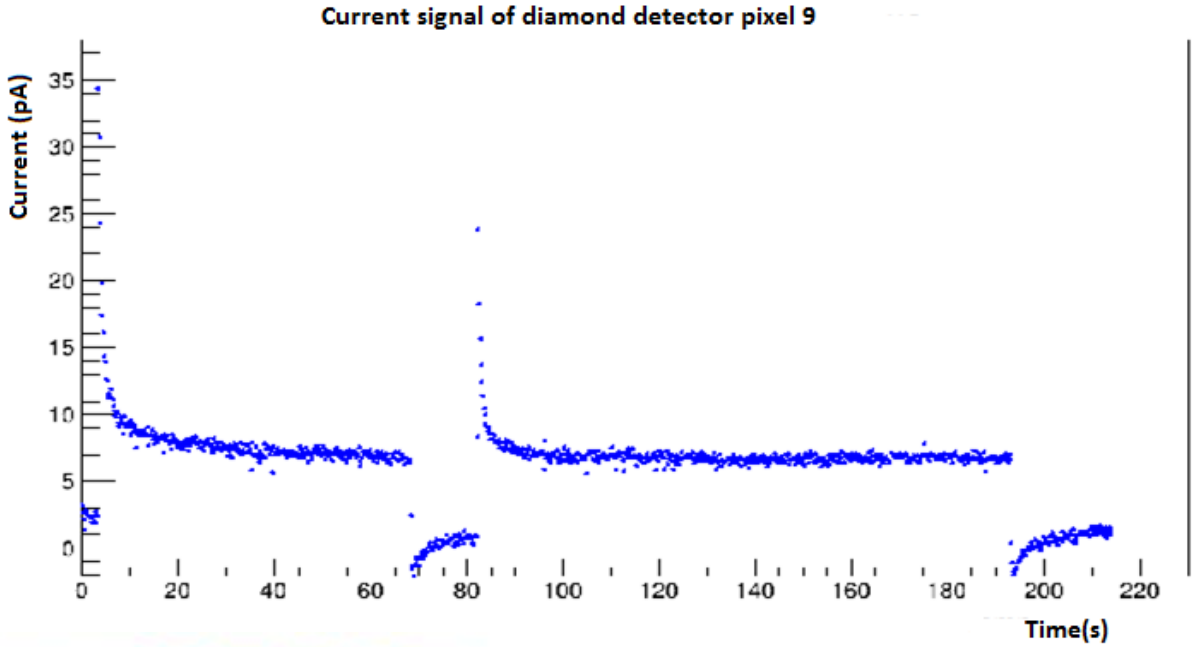
4 / 8 cells readout in parallel

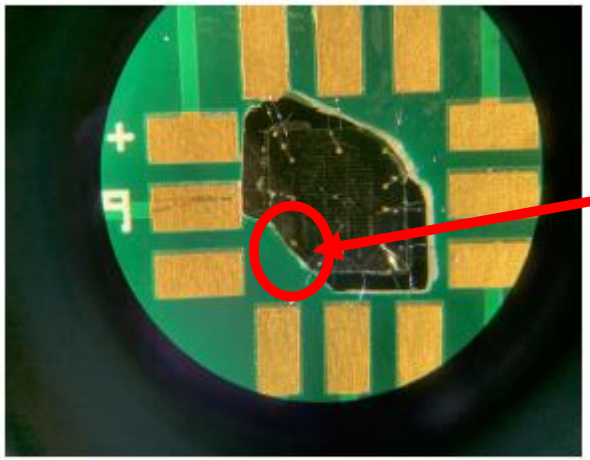


TETRAMM Picoamperometer : 4 readout channels + 1 integrated high voltage source



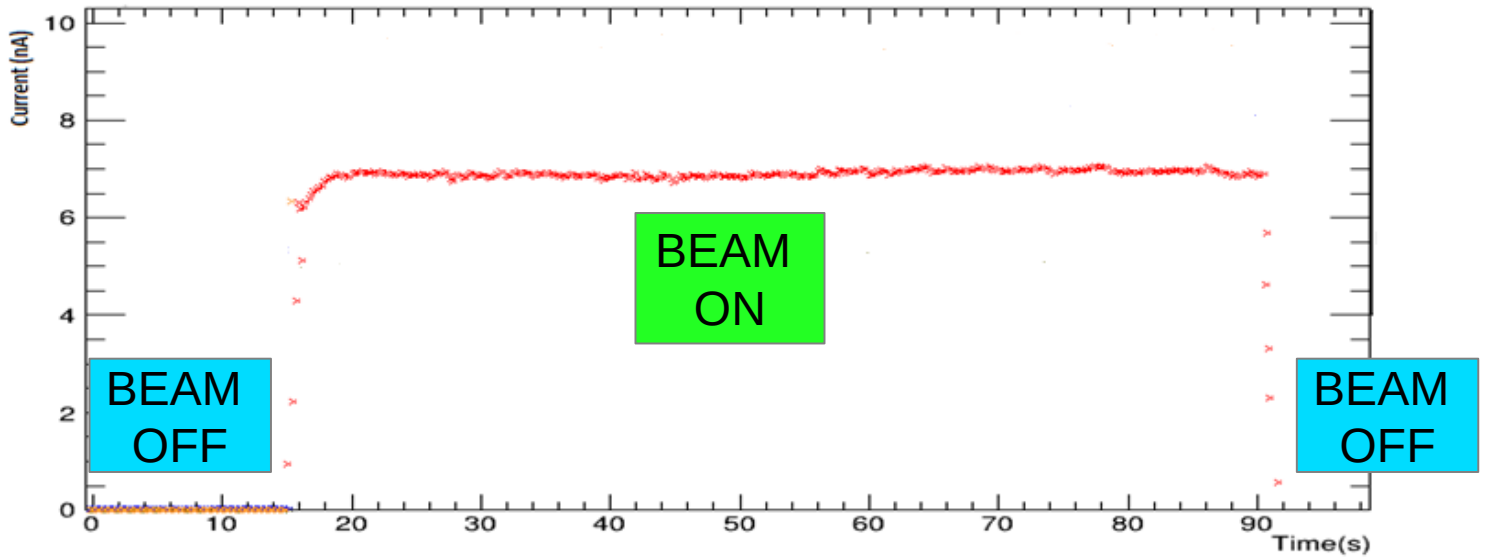
BAD PIXELS

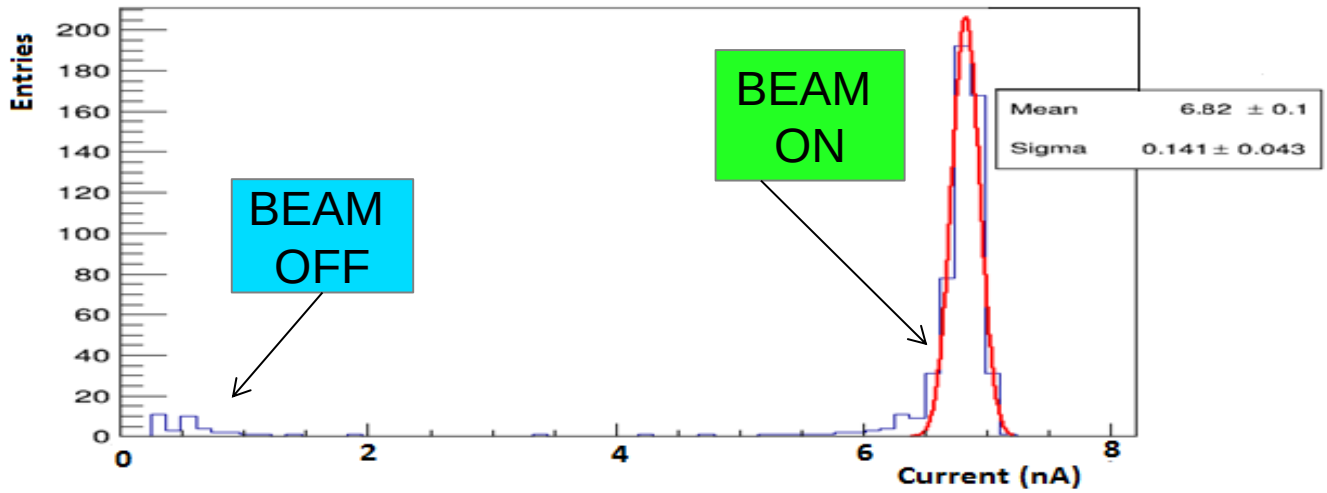




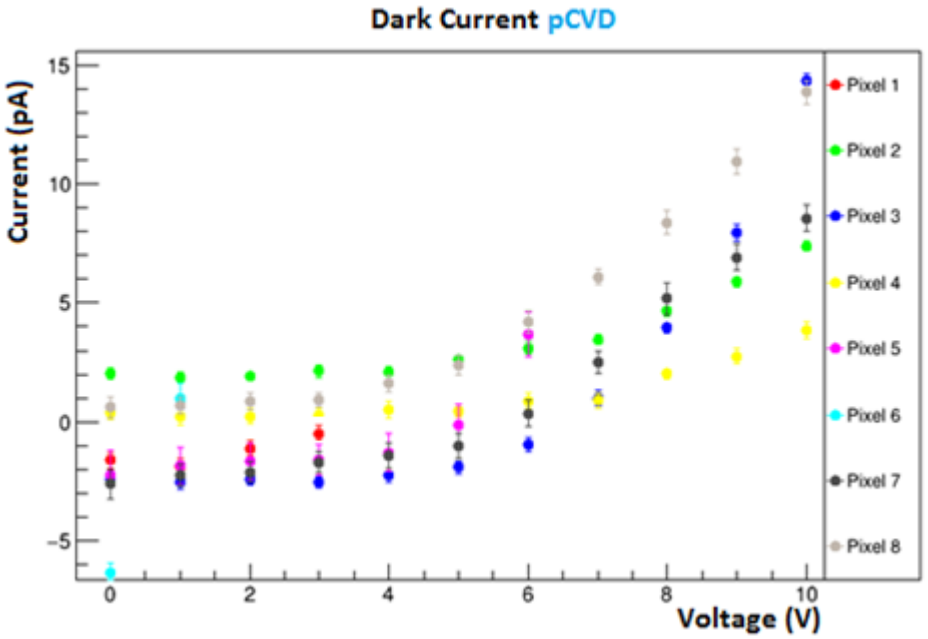
For each detector there is a pixel with abnormal current response due to the incorrect bonding.

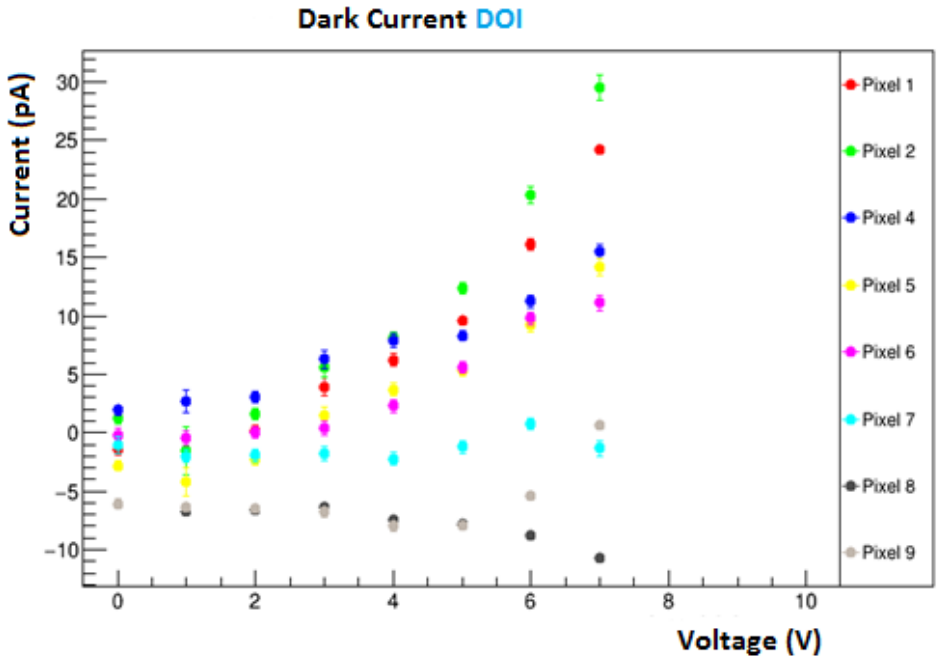
3D Detector Current Response





3D pCVD Diamond & Diamond on Iridium detectors dark current





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.

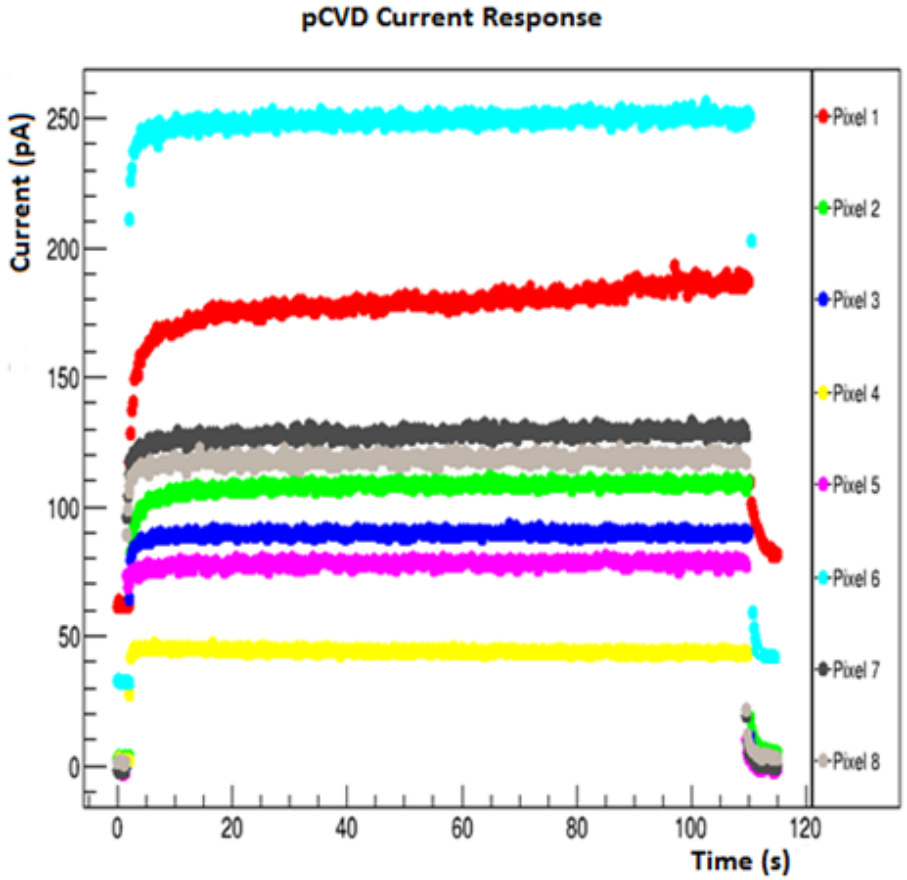
Measurement setup – Xray tube

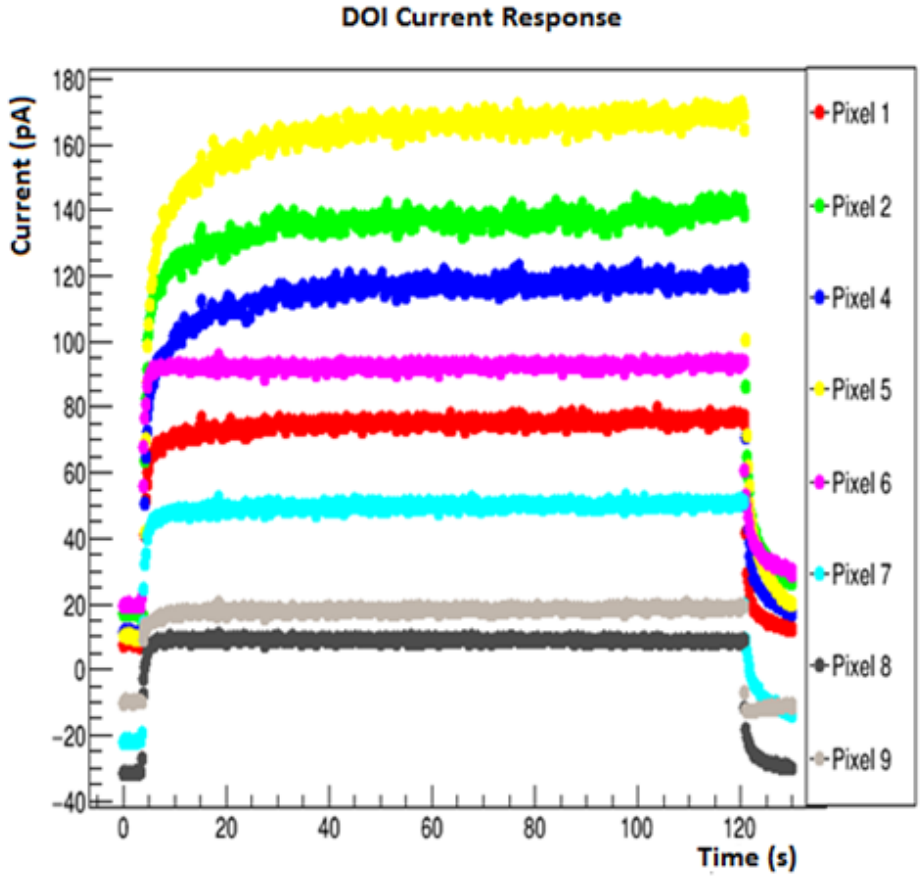
Newton scientific X-ray tube

- ✓ **Max voltage 50 kV**
- ✓ **Max current 200 uA**
- ✓ **Opening angle of the emitted cone 100°**
- ✓ **The detector encapsulated inside a 14 x 14 x 14 cm^3 PMMA block at 1 cm depth**

3D pCVD Diamond & Diamond on Iridium detectors current response to the photon beam

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





Current response rise and fall time

X-ray 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

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

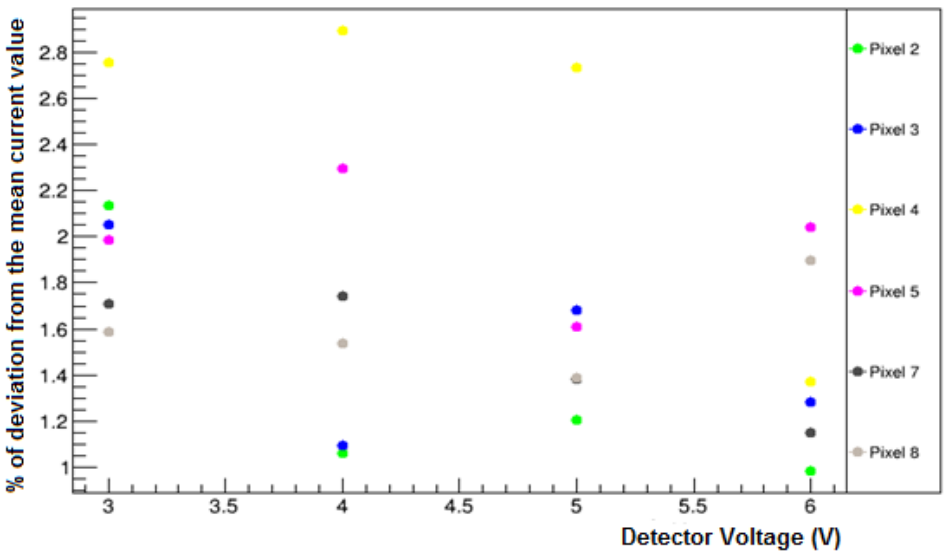
Except pixel 1, rise and fall time of the pCVD pixels response are below 1s

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

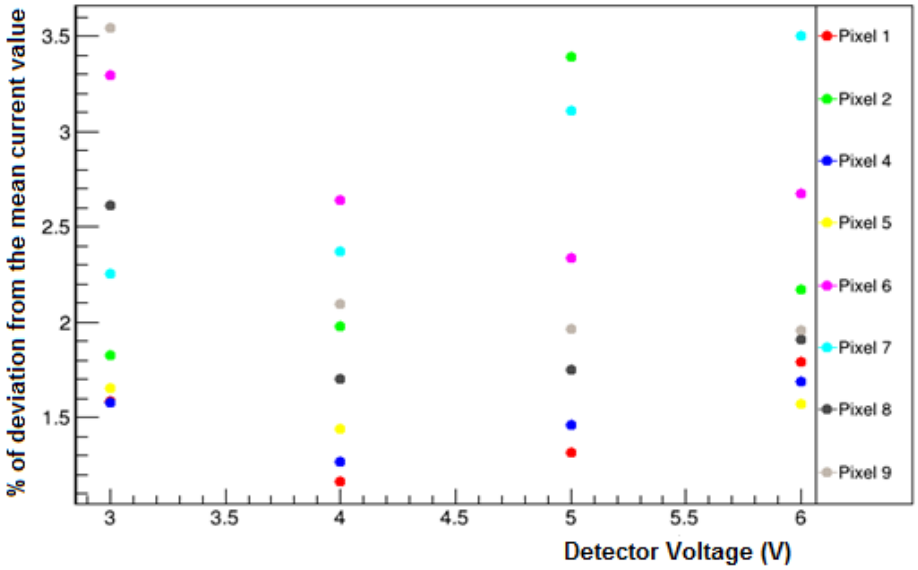
Stability

x Ray tube voltage 30 kV, current 140 uA

pCVD



DOI



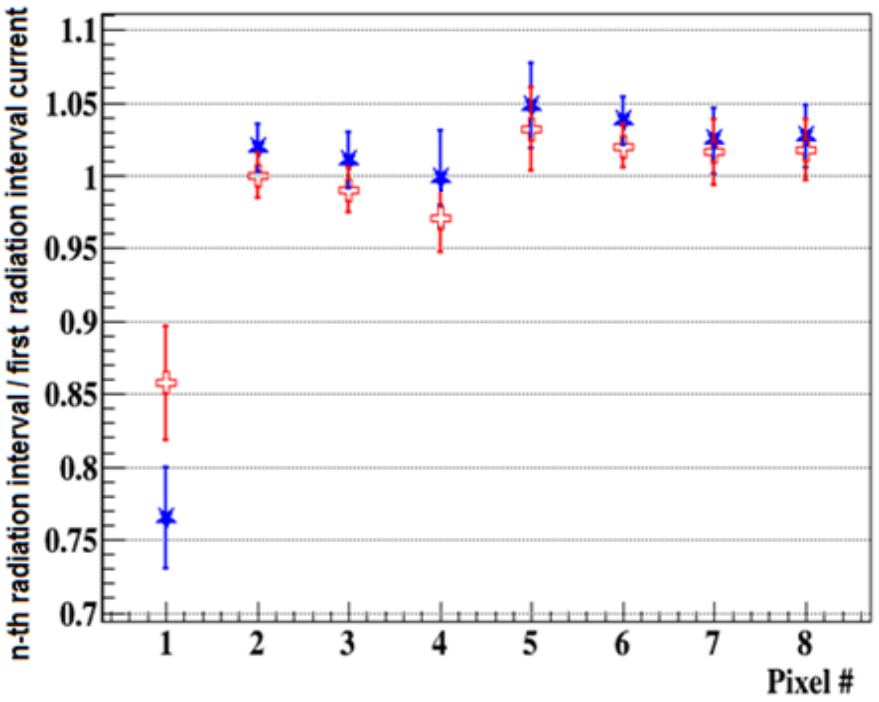
Max deviation from stability <3%

Max deviation from stability <4%

Repeatability

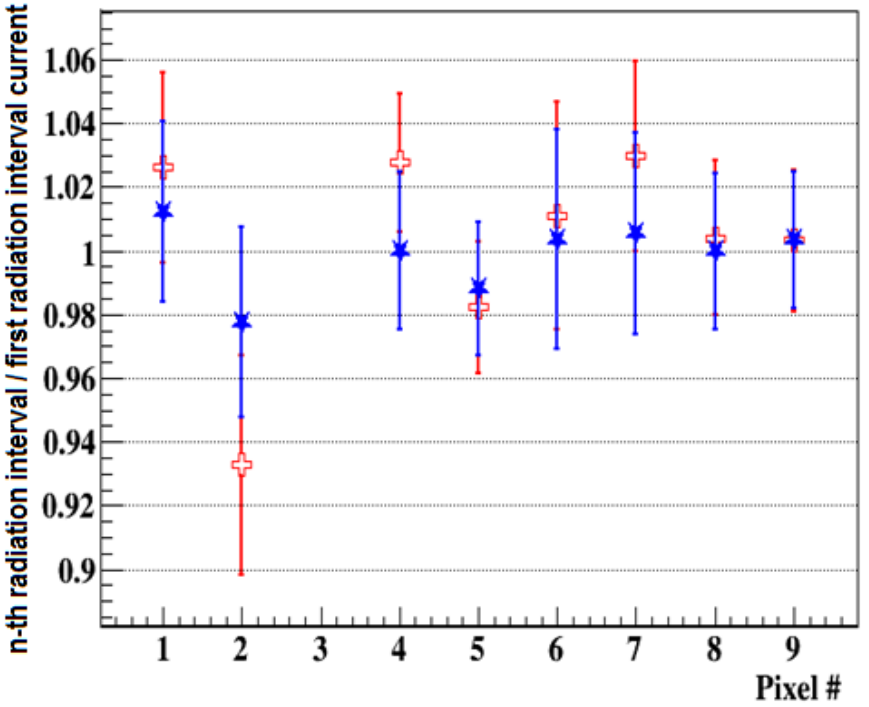
x Ray tube voltage 30 kV, current 140 uA. Detector bias voltage 4V.

pCVD



Max deviation from repeatability:
<3% for pixels 2,3,7 e 8
>3% for pixels 1,4,5 e 6

DOI

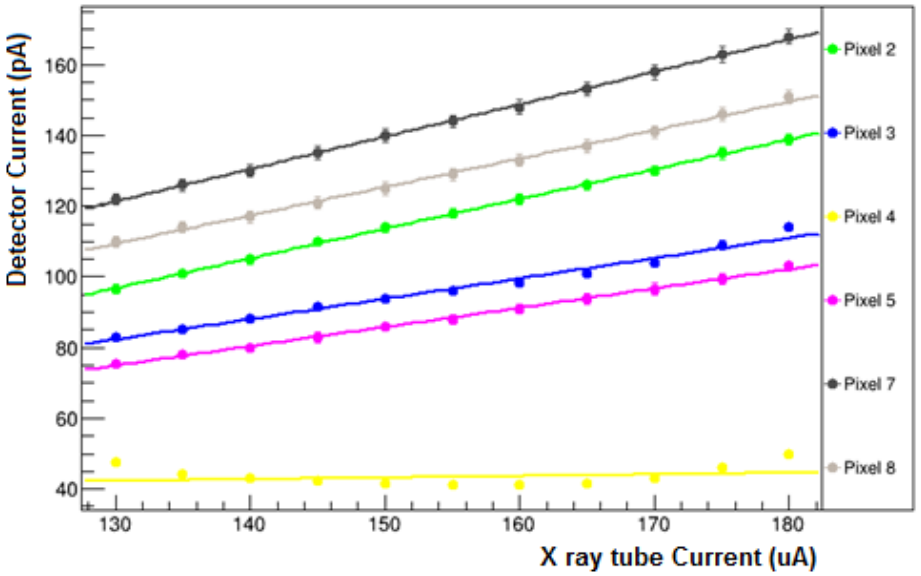


Max deviation from repeatability:
<3% for all pixels except the #2, but with higher uncertainty bars

Linearity with the X-ray tube current

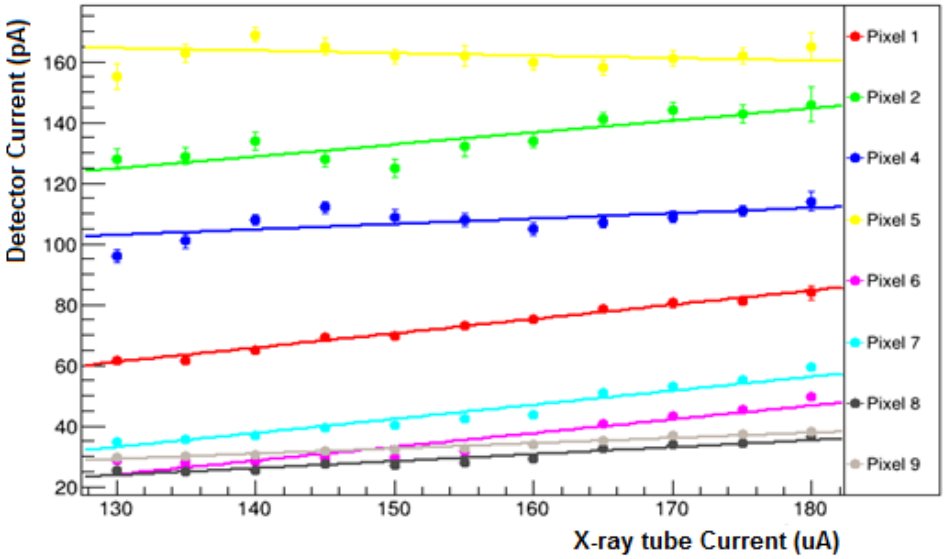
X-ray tube voltage 30 kV, detector bias voltage 4V

pCVD



Max deviation from linearity:
pixel 2,3,5,7,8: <3%
pixel 4: bad pixel

DOI

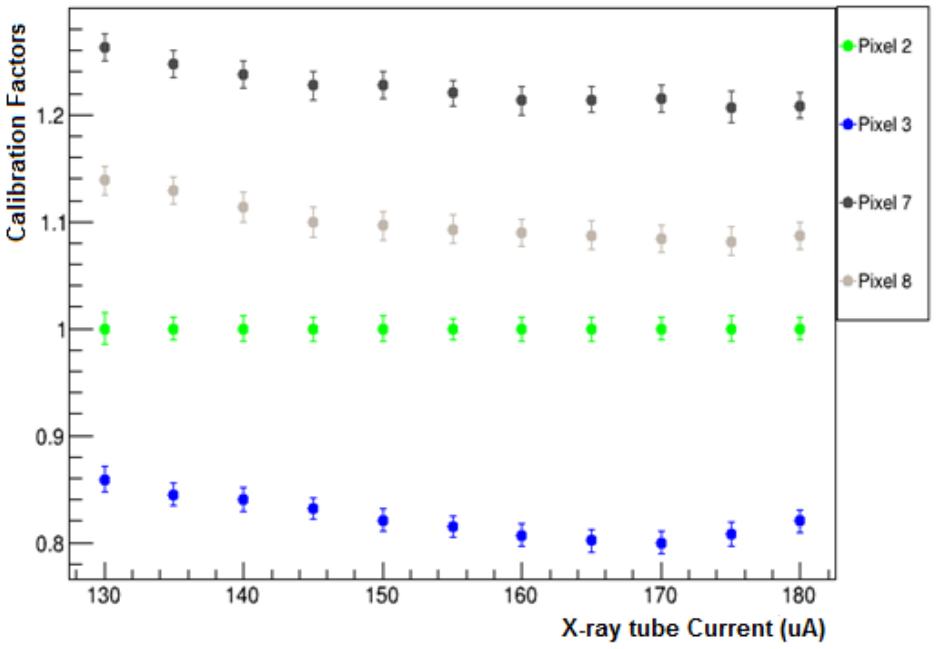


Max deviation from linearity: >3%
Pixel 4,5: bad pixels

InterCalibration factors

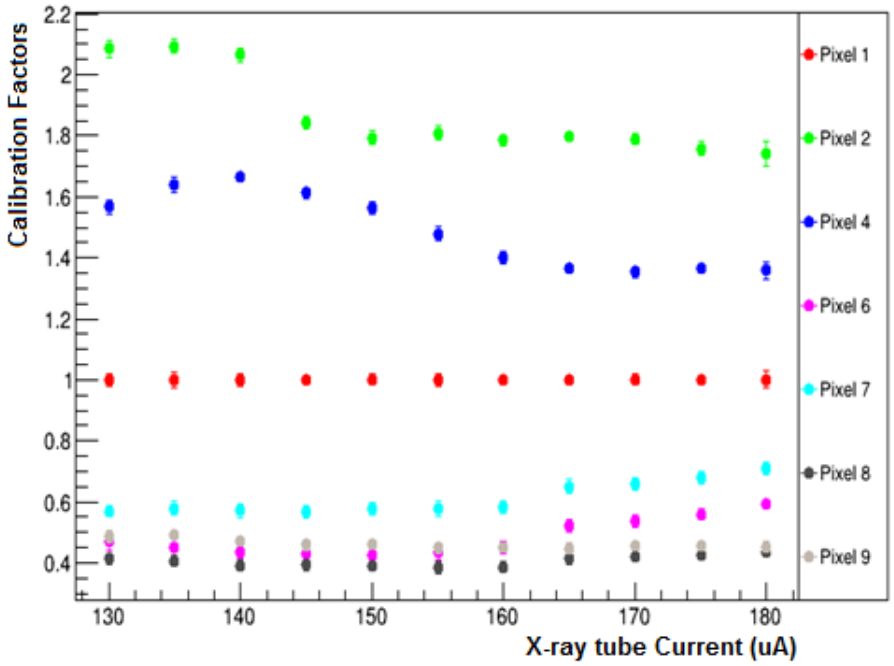
X-ray tube voltage 30 kV, detector bias voltage 4V

pCVD



Max deviation <4%

DOI



Max deviation >8%

Pixel 2,4 abnormal response

Summary

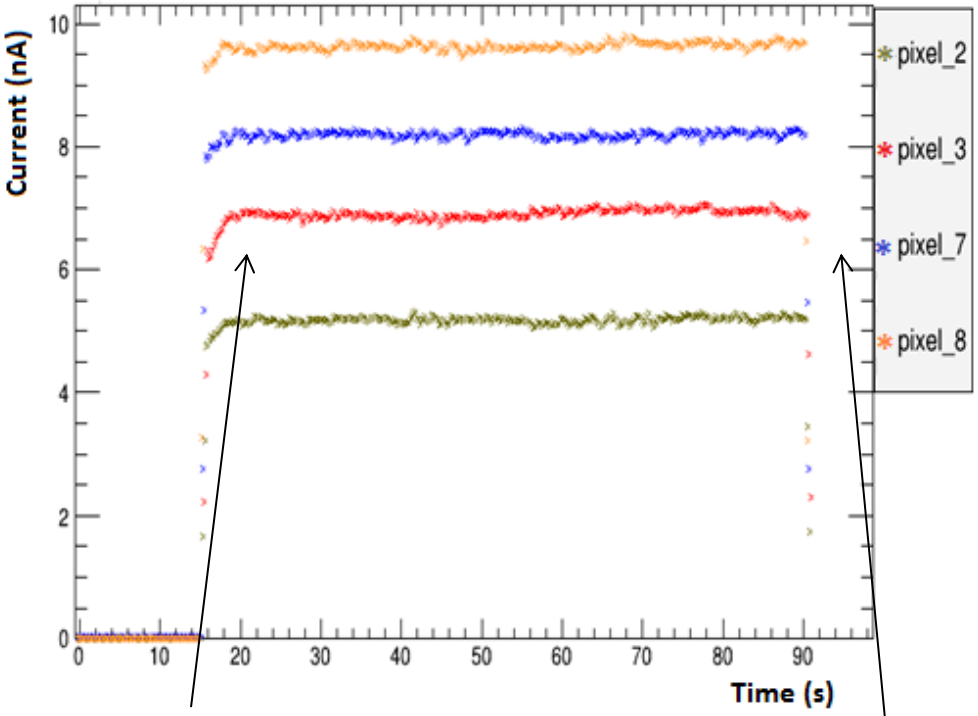
	pCVD	DOI
Dark Current	< 15 pA	< 30 pA
Operating Voltage	≥4 V	4 V
Repeatability	< 3%	< 3 %
Stability	< 3 %	< 4 %
Linearity	< 2.7 %	> 3%
Max signal to noise ratio	1845	412
Intercalibration factors	< 4 %	> 8 %
Mean rise time	(0.73± 0.39) s	(3.25 ± 2.13) s
Mean fall time	(0.35 ± 0.19) s	(5.18 ± 3.14) s

Test beam at the Perugia Hospital

- ✓ Medical linear accelerator (Elekta Synergy Sband)
- ✓ 6 MV photons
- ✓ 10 × 10 cm^2 field
- ✓ 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 - medical photon beam

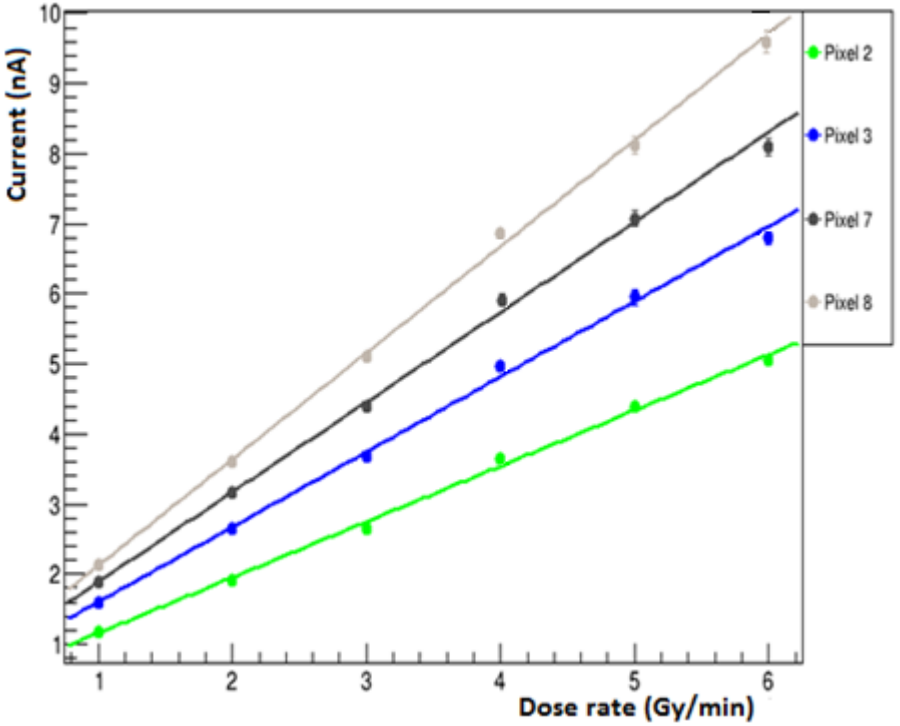
Detector response at 6 Gy/min



Rise time <0.5 s at 6Gy/min

Fall time <0.3 s at 6Gy/min

Dose rate linearity



Max deviation from linearity 2%

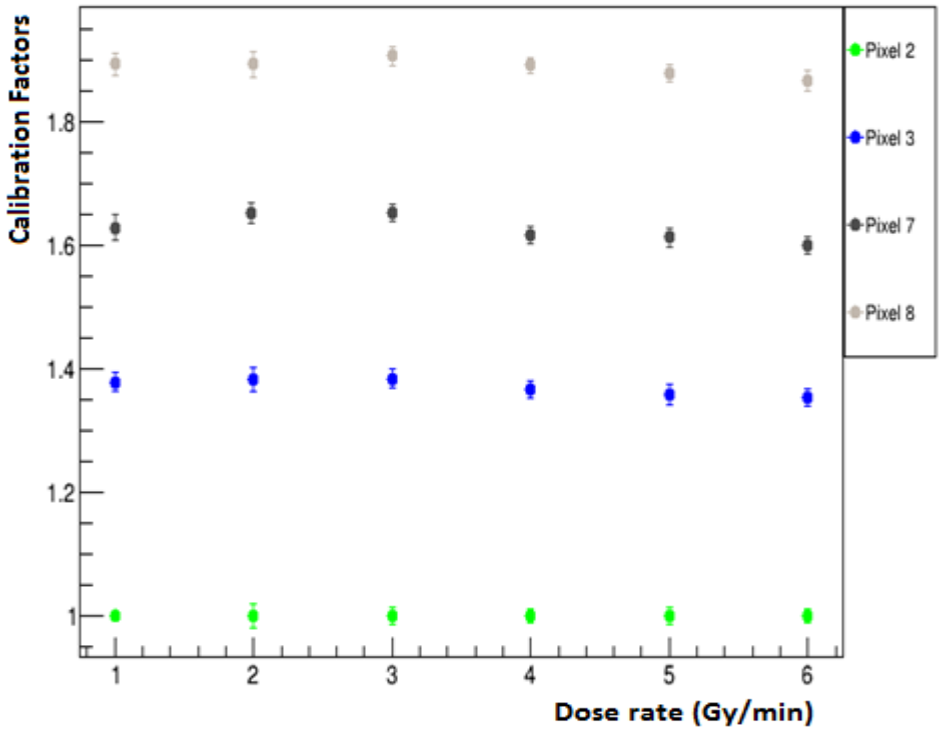
3D pCVD - medical photon beam

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%

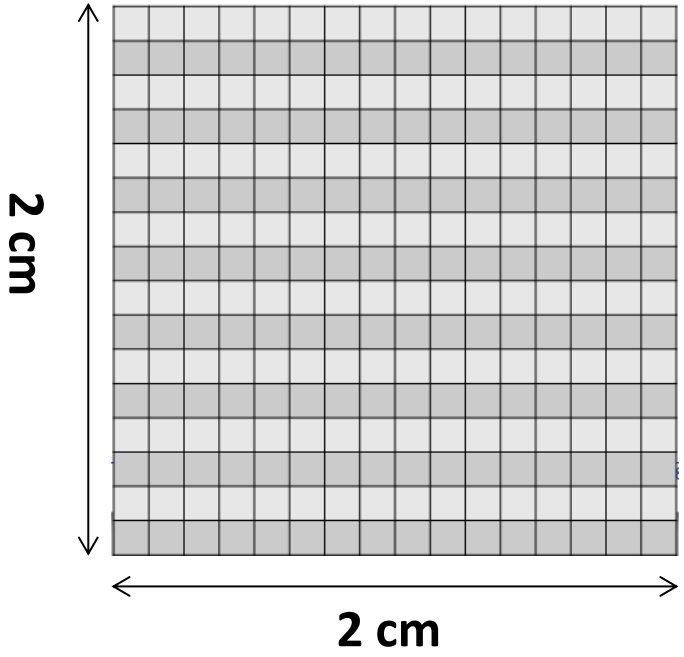
Calibration factors normalized to pixel 2

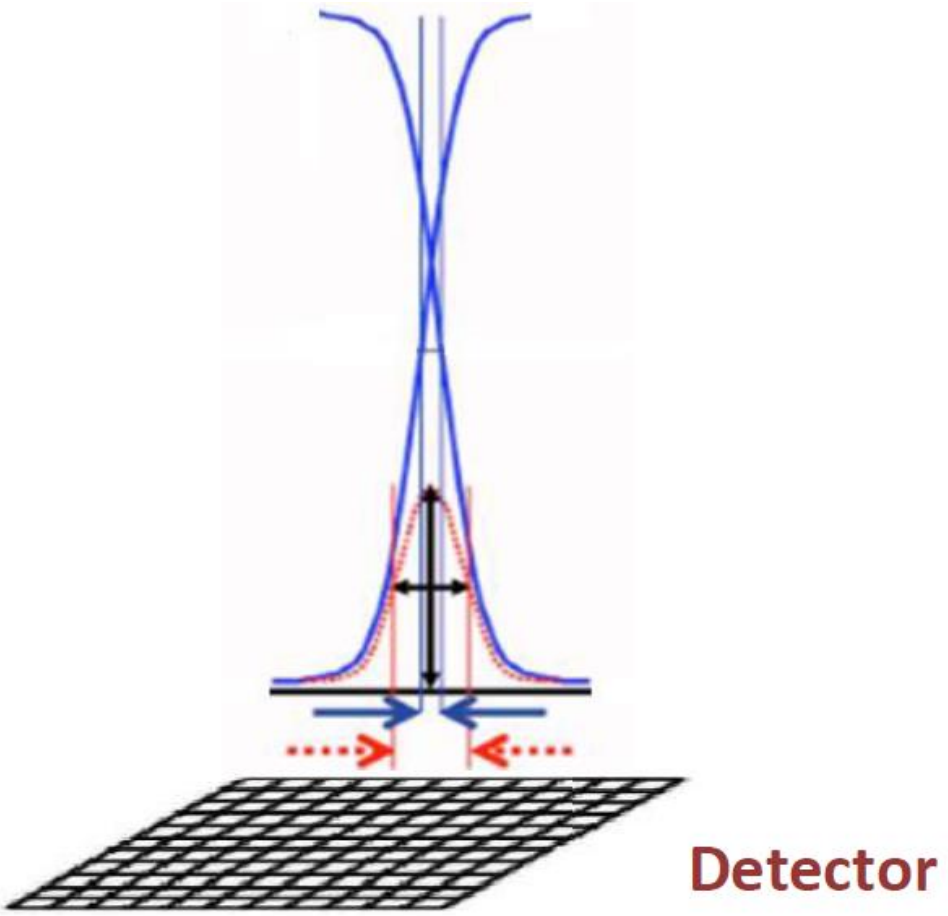


Max deviation of calibration factors 2%

Next? New highly segmented polycrystalline diamond dosimeter

256 pixels 3D diamond matrix





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!