Evaluation of 3D diamond detectors for application in medical radiation dosimetry

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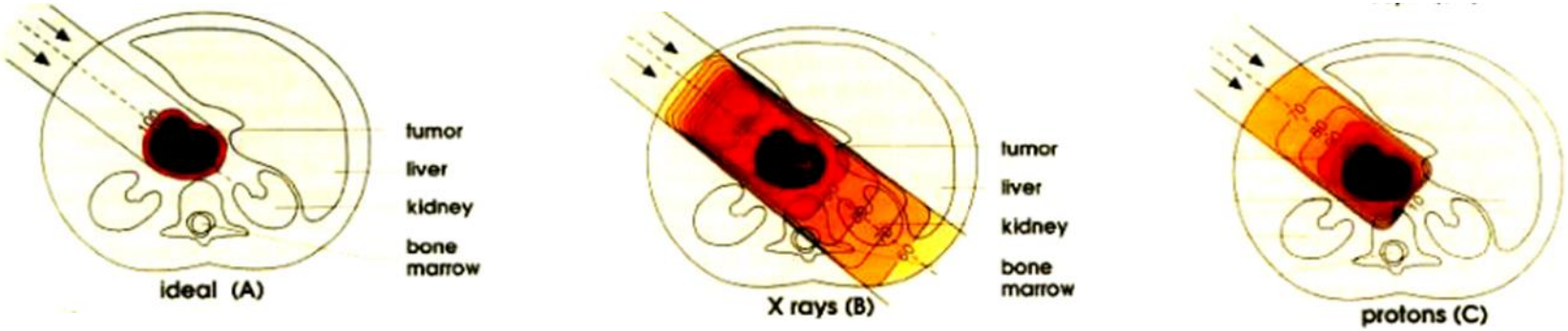
Outline

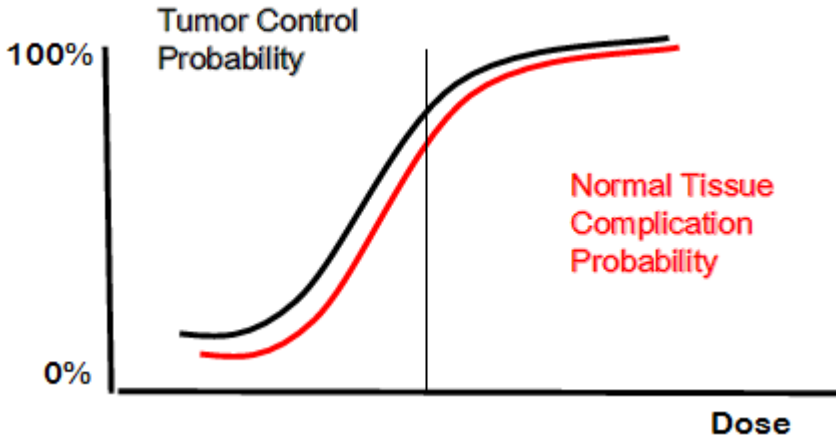
- ✓ Radiotherapy basics.
- ✓ Diamond detectors for medical dosimetry.
- ✓ 3D diamond detector as a dosimeter
- ✓ Experimental setup and measurements
- ✓ Conclusions.

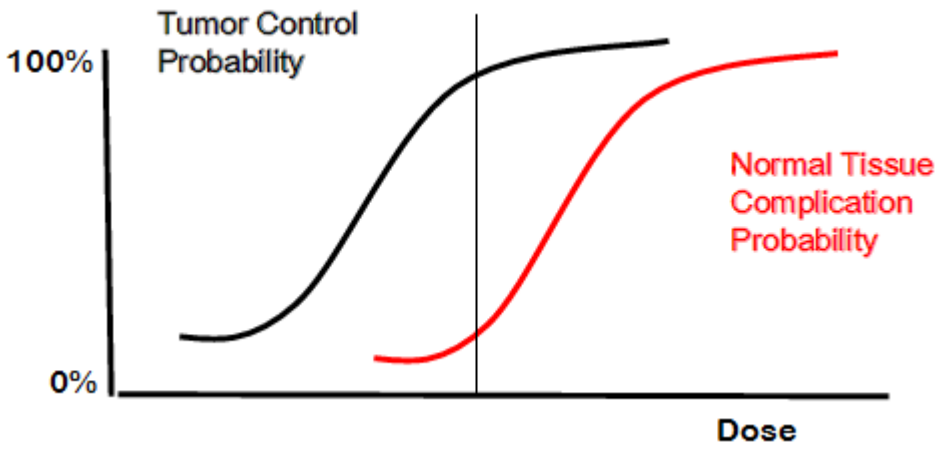
Radiotherapy Basics

radiation in medicine



Tumour cells are not isolated, healthy tissue will also receive a high dose





Diamond detectors for dosimetry

An ideal dosimeter

- Stable
- Linear with dose
- Linear with dose rate
- Energy independent
- Direction independent
- Fast response
- Good S/N ratio
- Minimal correction
- High spatial resolution

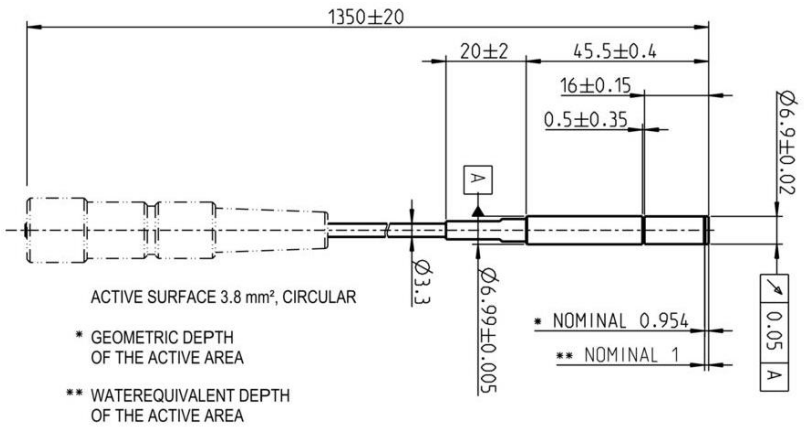
CVD Diamond detectors

- Near Tissue equivalent (Z=6)
- High sensitivity
- Low leakage current
- High collection efficiency
- Very high carrier drift velocity, faster response
- High resistance to radiation damage
- Small volume

→ **Use CVD diamond detectors for dosimetry**

Diamond Dosimetry – State of Art

PTW 60019
synthetic single crystal diamond

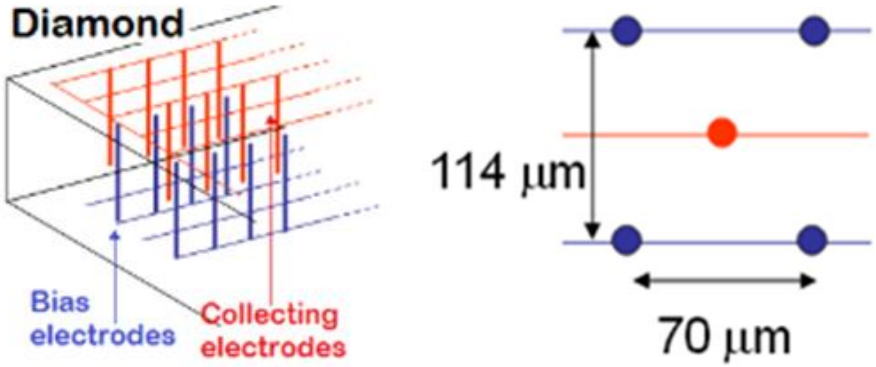


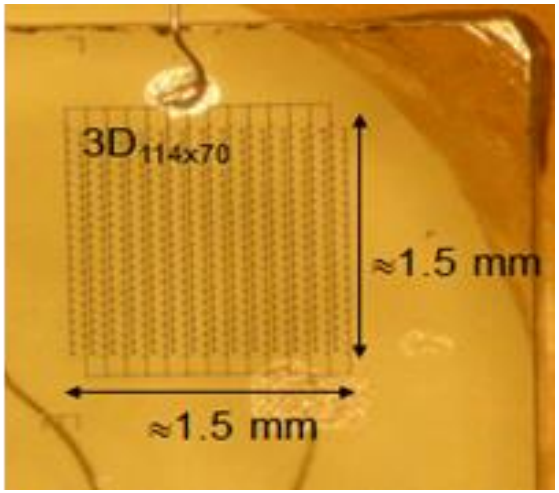
Specifications

Type No.	60019
Design:	waterproof, disk-shaped, sensitive volume perpendicular to detector axis
Measuring quantity:	absorbed dose to water
Nominal sensitive volume:	0.004 mm³, radius 1.1 mm, thickness 1 µm
Reference point:	on detector axis, 1 mm from detector tip, marked by ring
Nominal response:	1 nC/Gy
Detector bias:	0 V
Radiation quality:	100 keV ... 25 MV photons (6 ... 25) MeV electrons (70 ... 230) MeV protons
Field size:	(1 x 1) cm² ... (40 x 40) cm²
Connectors:	BNT, TNC or M

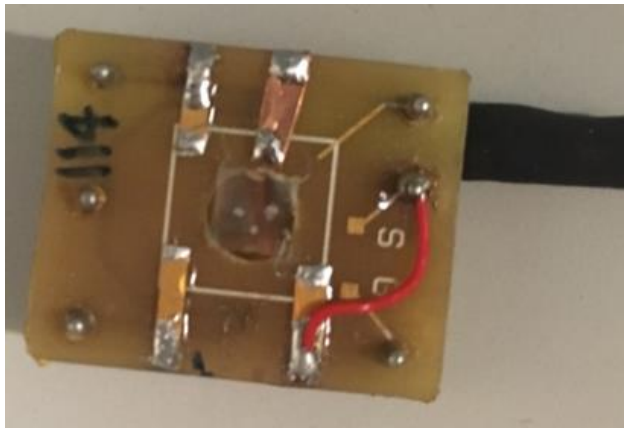
3D diamond detector as a dosimeter

3D pCVD diamond detector was produced in collaboration with the National Institute of Nuclear Physics (INFN) and the European Laboratory for Nonlinear Spectroscopy (LENS) of Florence.





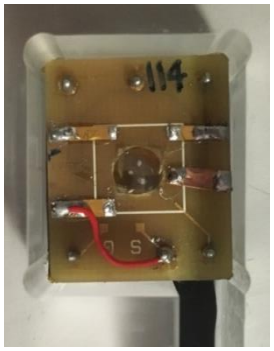
The resulting structure has arrays of graphitic columns of about 10 μm in diameter forming cells of 114 x 70 μm with a thickness of 0.5 mm for a total of 275 cells with a single cell sensitive volume of 0.004 mm^3 and a total diamond sensitive volume of about 1.1 mm^3.



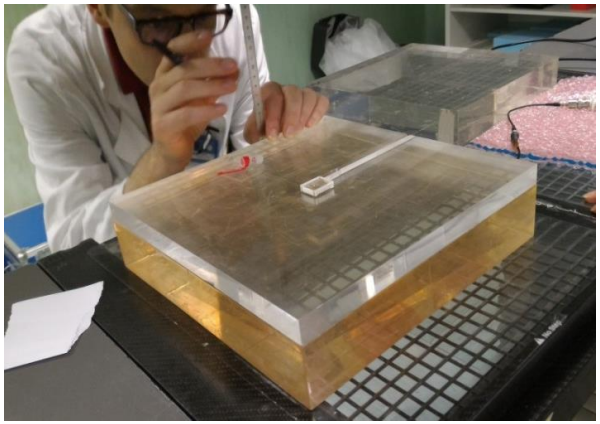
Experimental Setup

The response of the diamond detector was studied irradiating it with 6 MV photons produced by a medical linear accelerator (Clinac DBX 600 Varian) with 10 × 10 cm^2 field at the 'Santa Maria della Misericordia' Hospital of Perugia.

1. Measurements in air



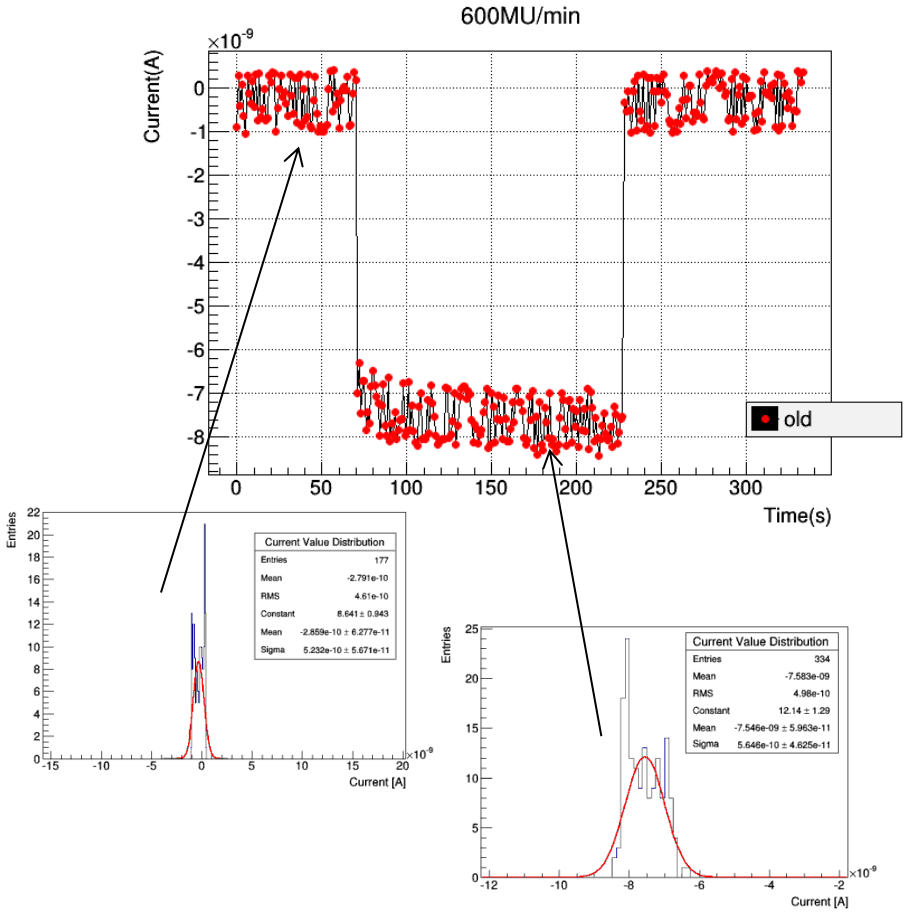
2. PMMA Encapsulated 3D diamond Detector



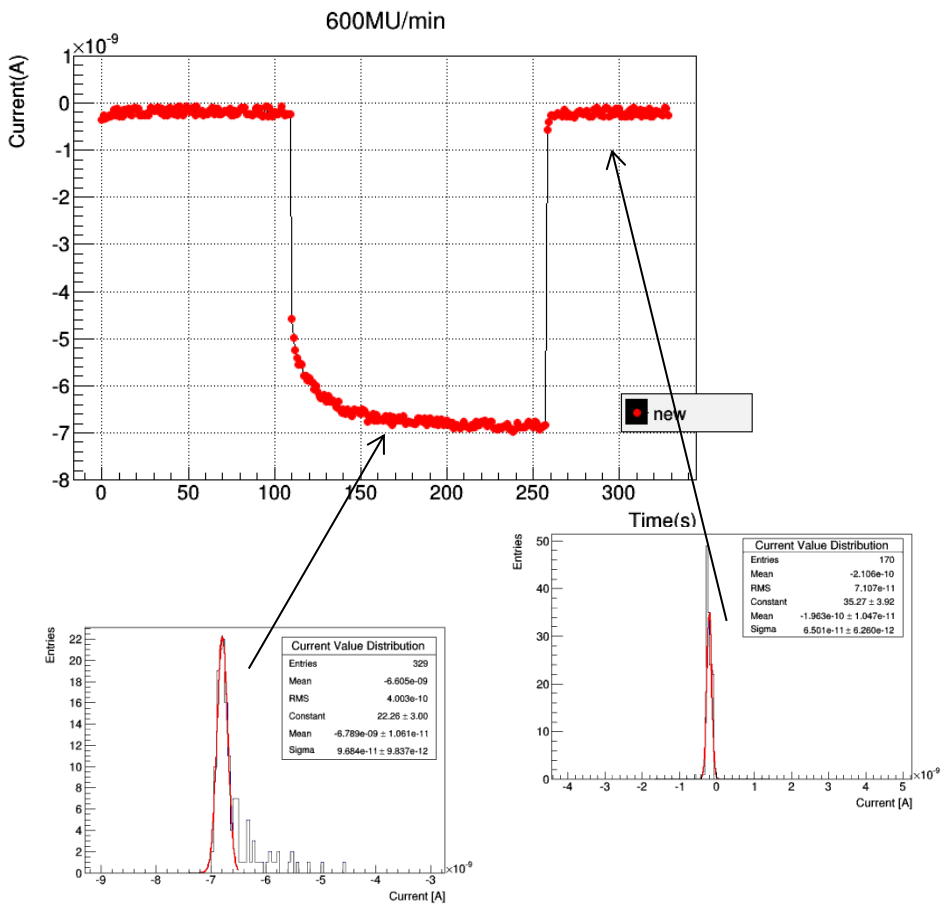
The detector was biased with a Keithley source meter 2410 and the output current is obtained by reading in parallel all the collecting graphitic columns.

Measurements in air - improvement in the readout system

Before



After

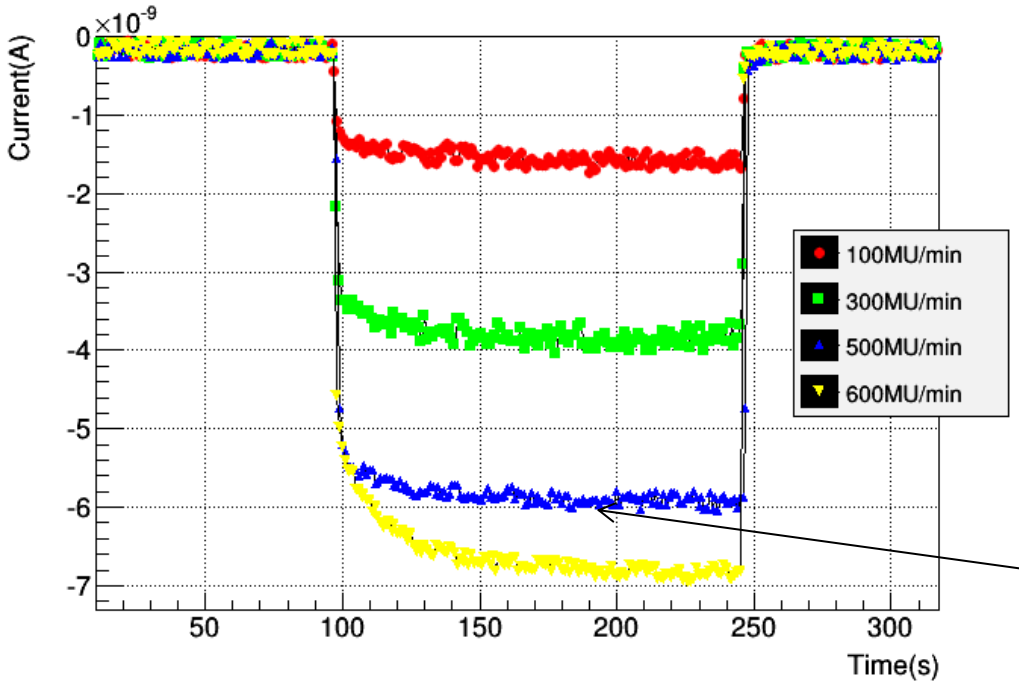


Current value fluctuations ≈ ±500pA

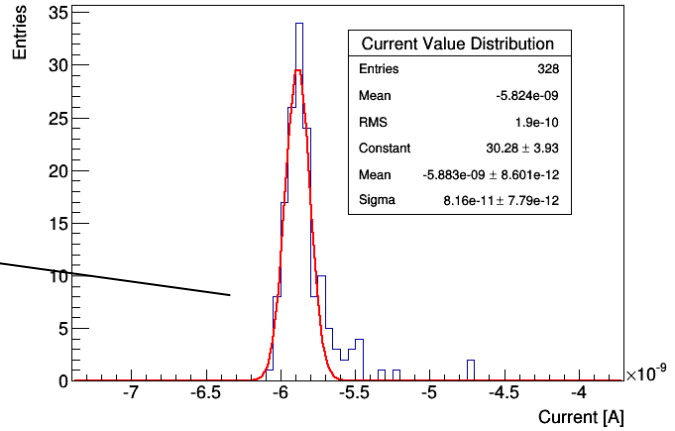
Current value fluctuations ≈ ±90pA

Dose Rate Dependance in Air

The detector was biased with -80V



Current value distribution when the detector is irradiated with 6MV photon and a dose rate of 500MU/min:



The output signal of the detector is an electric current so in principle it measures dose rates.

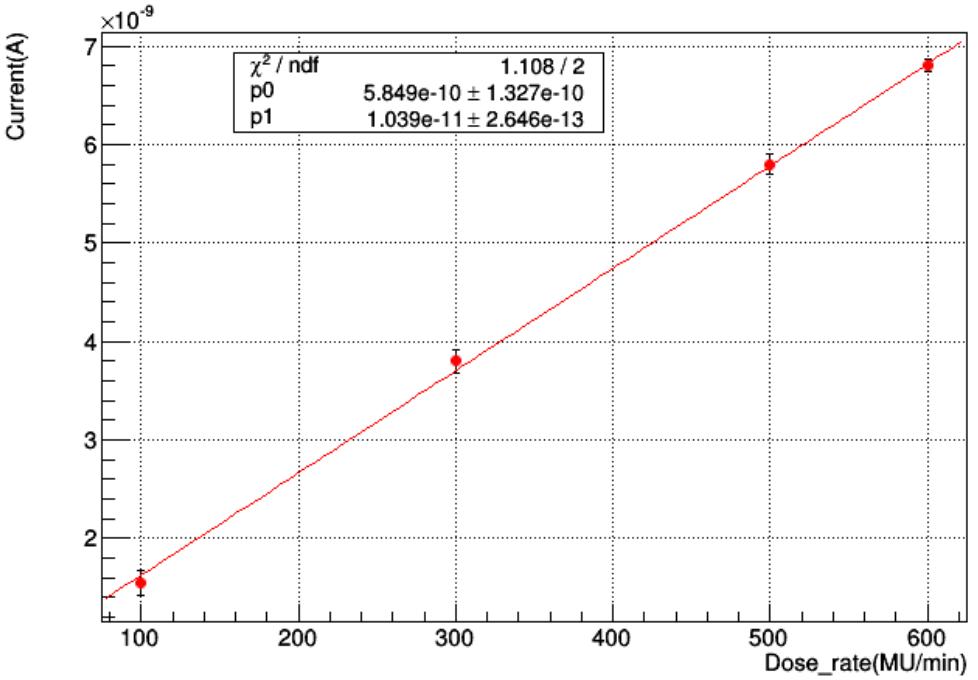
Dose Rate Dependance in Air

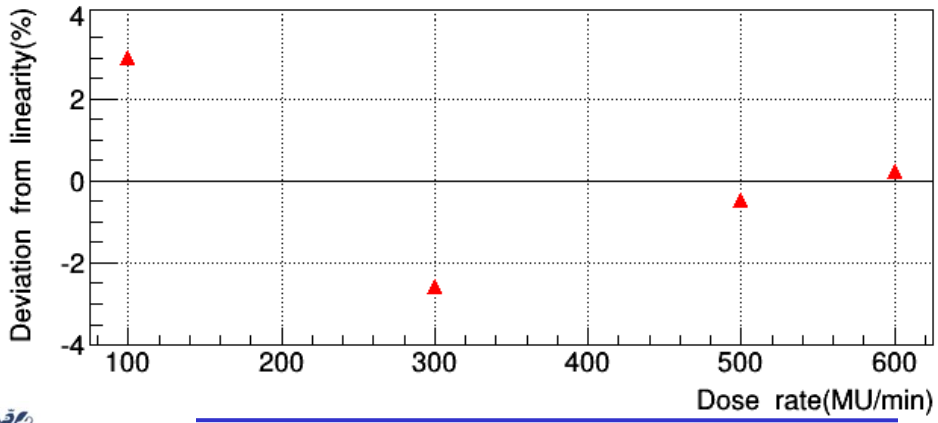
The detector was biased with -80V.

Each point of the first graph rappresents the mean value of the current distribution in correspondence of different dose rates when the 3D detector is beeing irradiated with 6MV photons.

The deviation from linearity is within 4%.

For low dose rates (100MU/min) the photon beam becomes partially instable.

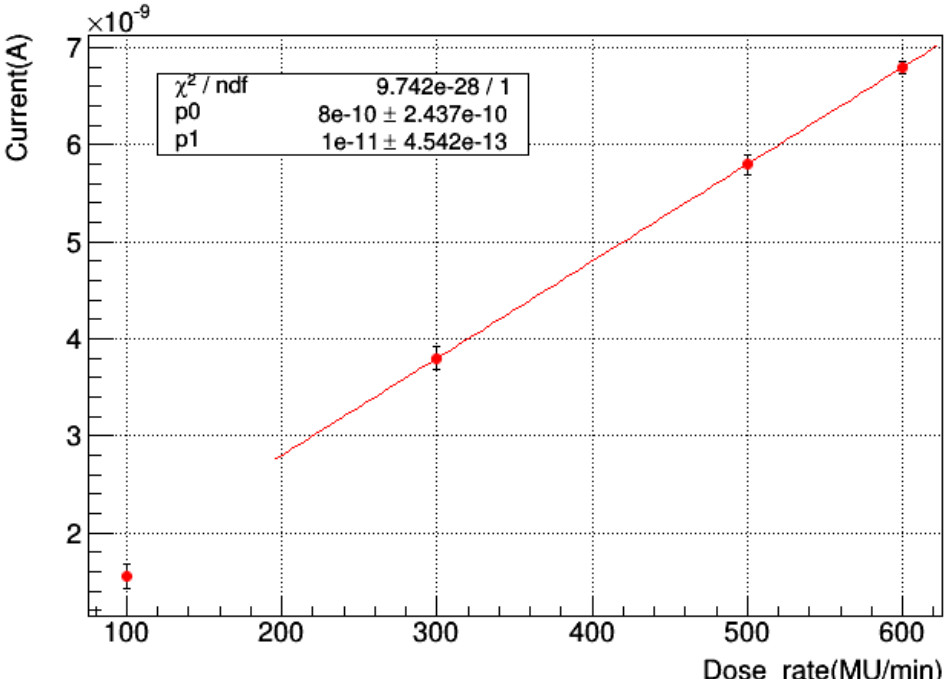




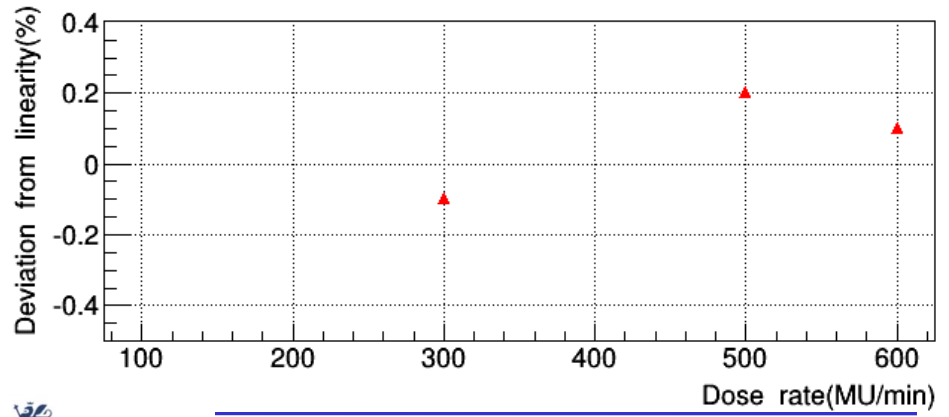
Dose Rate Dependance in Air

The detector was biased with -80V.

The fit was obtained excluding the point at 100 MU/min from the fit.

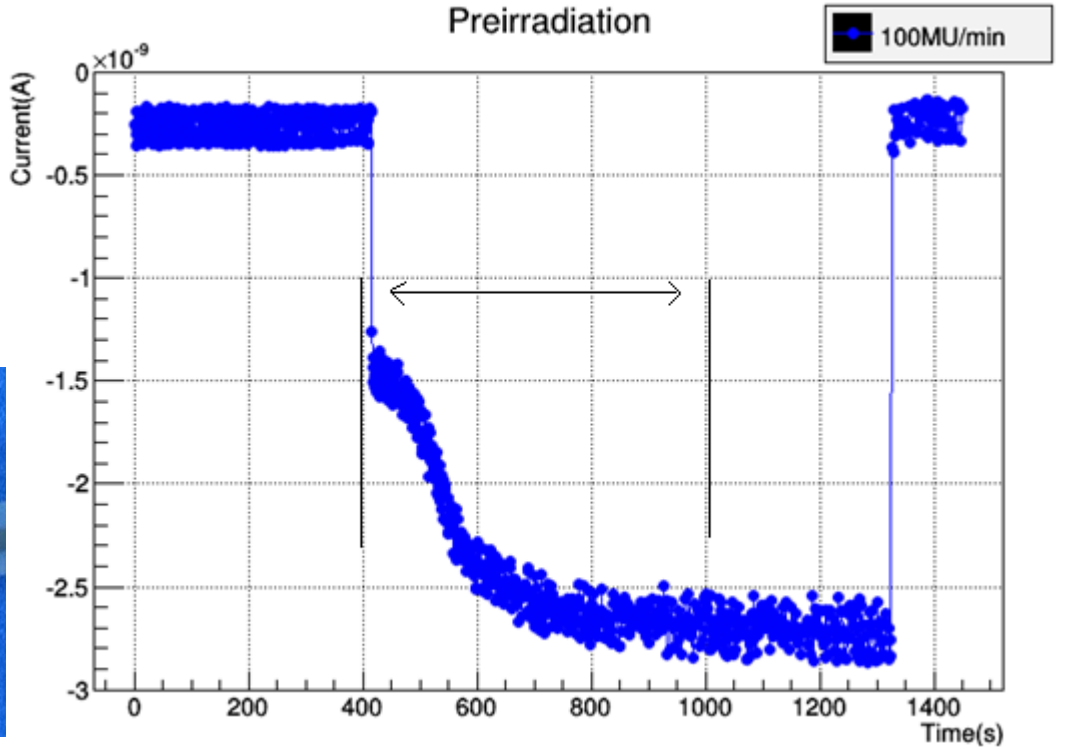


The deviation from linearity is within 0.4% indicating negligible dose rate dependence.



Measurements with PMMA incapsulated detector

In order to reach the response stability of most synthetic diamond detectors is often required a pre-irradiation time, which can vary with the characteristics of the diamond material.

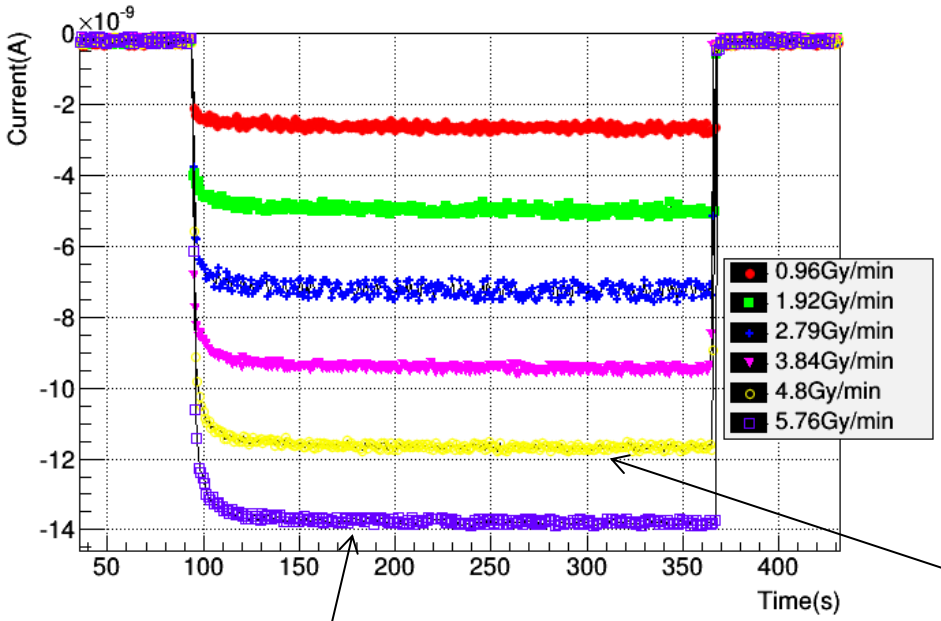


The dose necessary for pumping the diamond was about 820 MU.

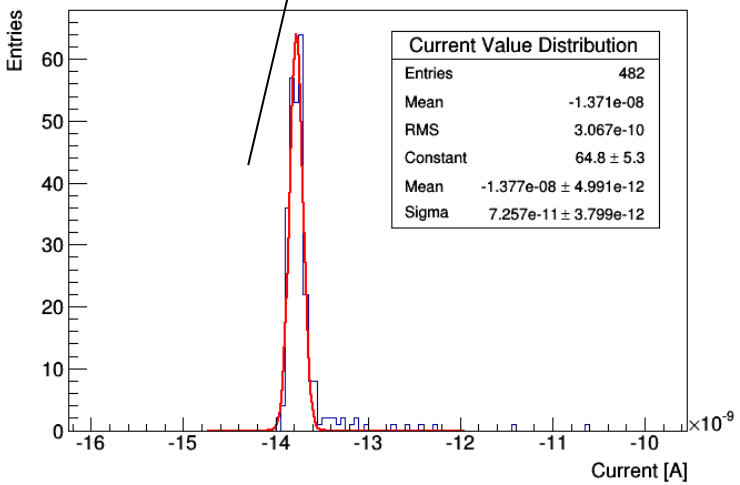
Using an ionization chamber Farmer FC65G which was placed in the same positions as the diamond sensor, the dose necessary for pumping was equal to 7.8 Gy

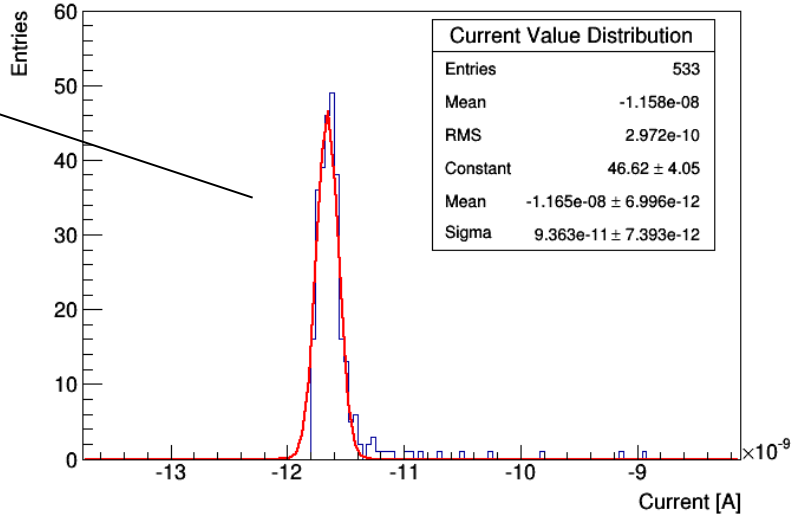
Conversion factor: 1 MU = 0.96 cGy

Linearity with dose rate - PMMA

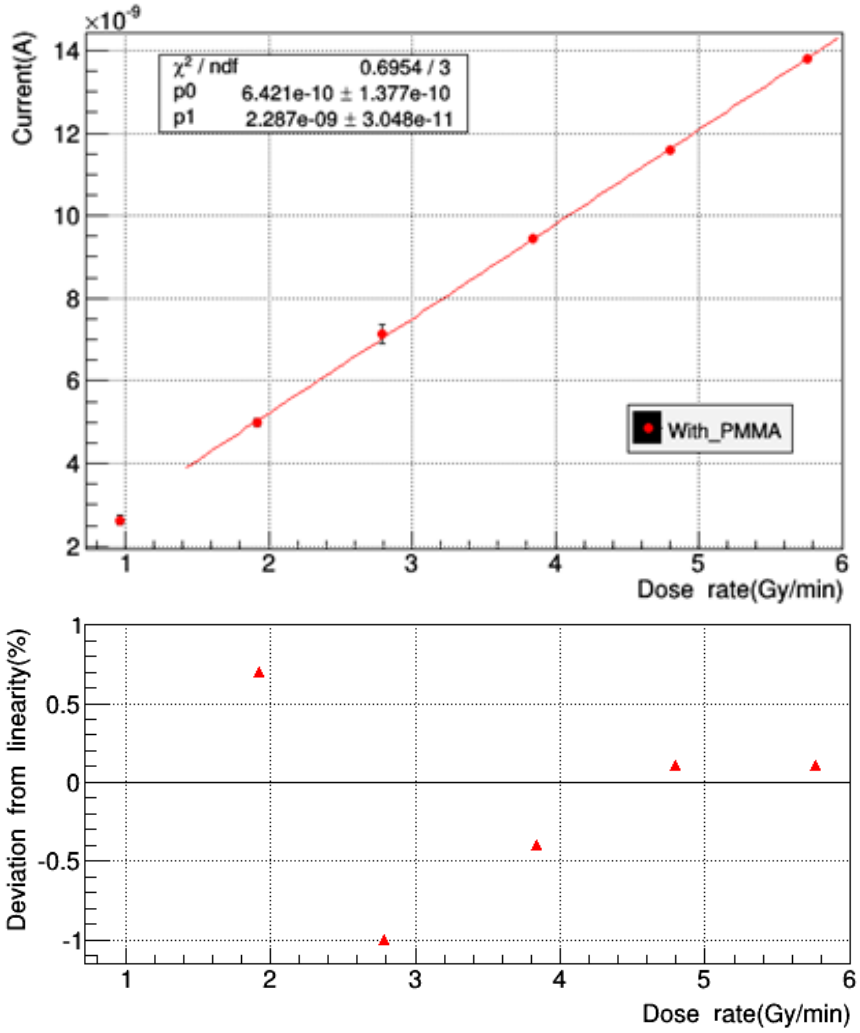


The sensor was irradiated with 6 MV photon beam for 4.5 min with 6 different dose rates





Linearity with dose rate - PMMA

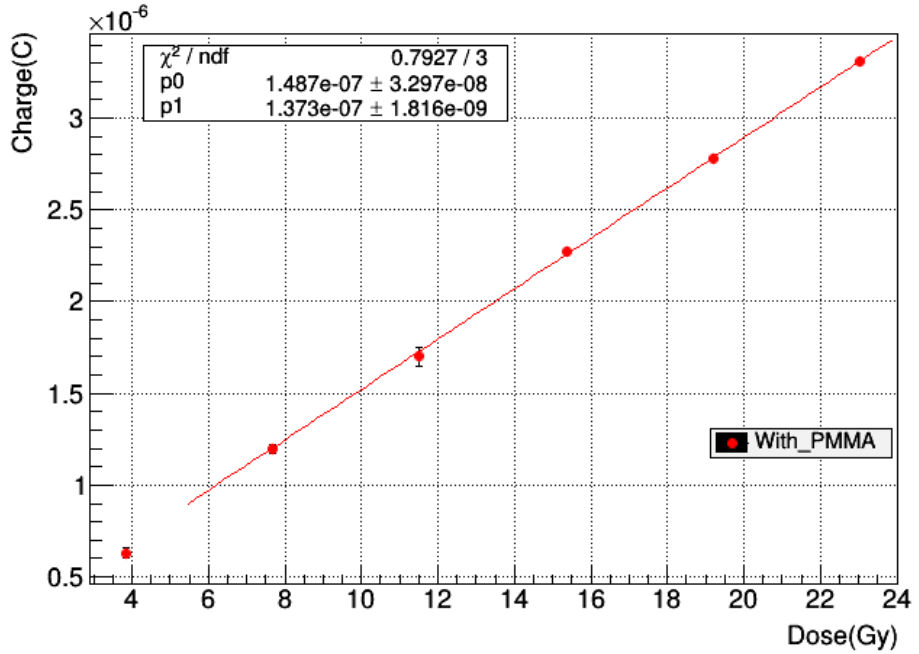


The fit was obtained excluding the point at 0.96 Gy/min from the fit.

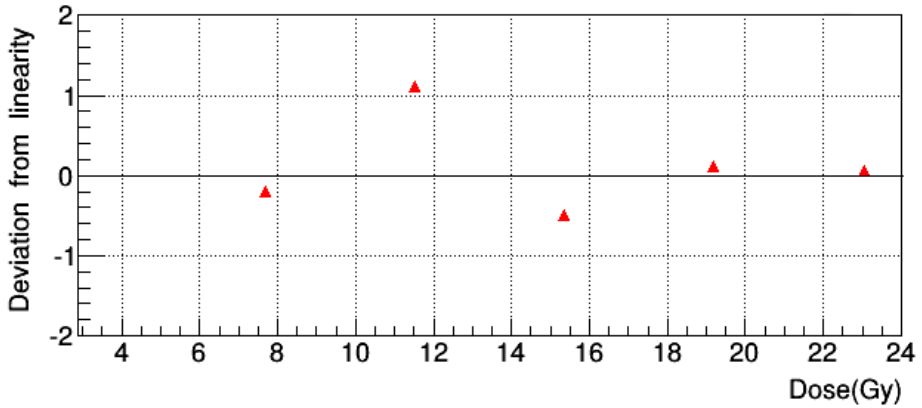
The deviation from linearity is within 1%.

Linearity with dose – PMMA

The 3D detector measures currents so the amount of charge that corresponds to each dose value has been calculated by integrating in time the current reading for a given time interval.



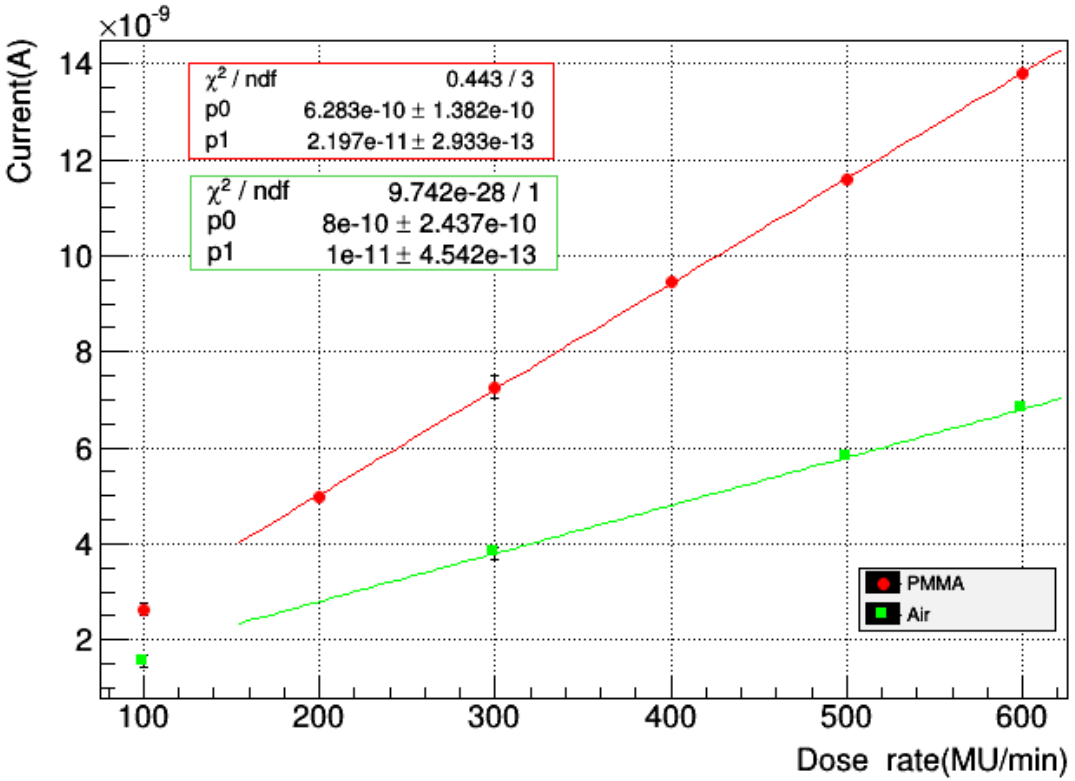
The deviation from linearity within 1.1% is an indicator of the good time stability of the detector response.



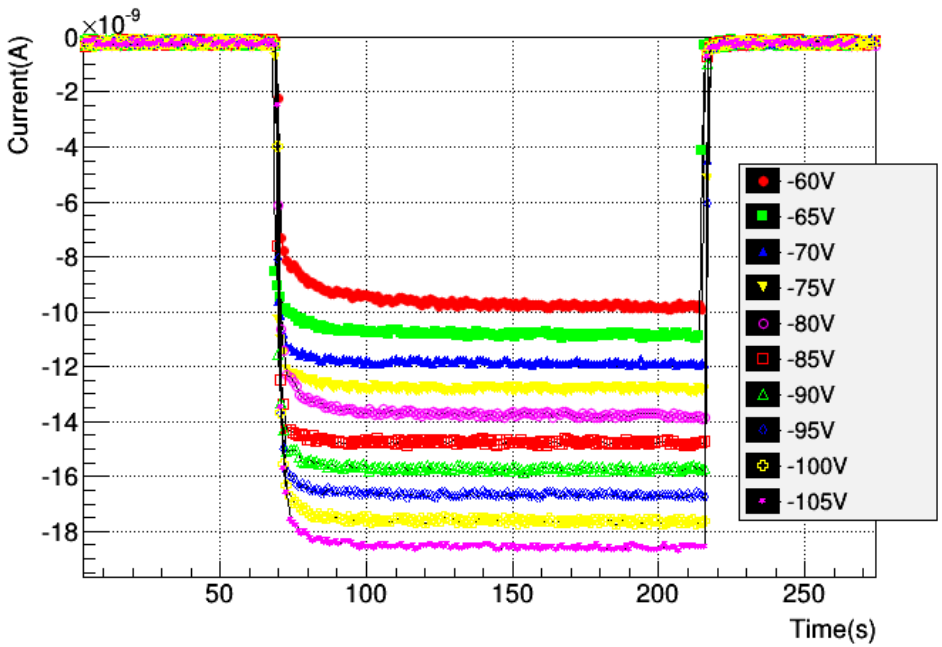
Linearity with dose rate – AIR vs PMMA

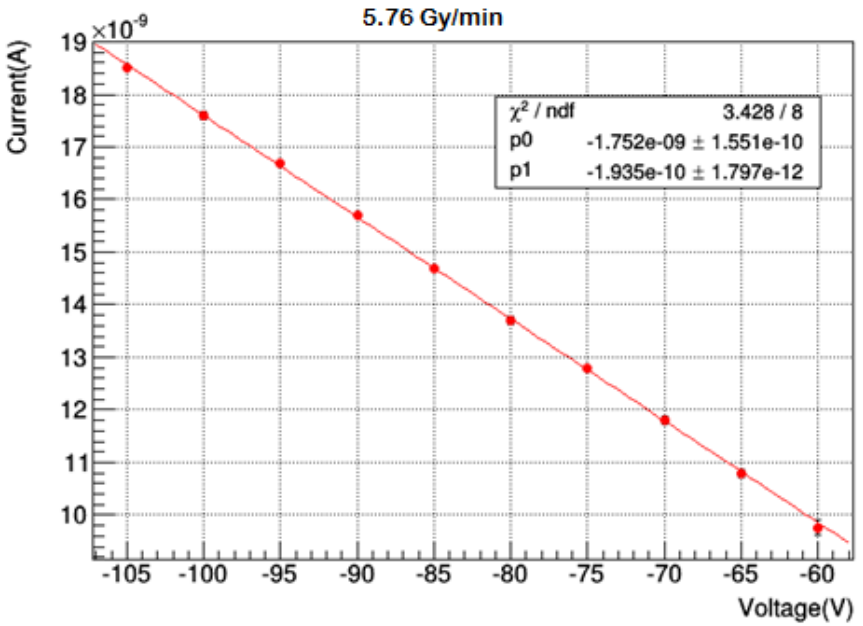
Comparison of current readings in correspondence of some dose rate values with and without PMMA:

The detector response encapsulated in the PMMA block is higher compared to the detector response in air, as it includes the backscatter radiation.

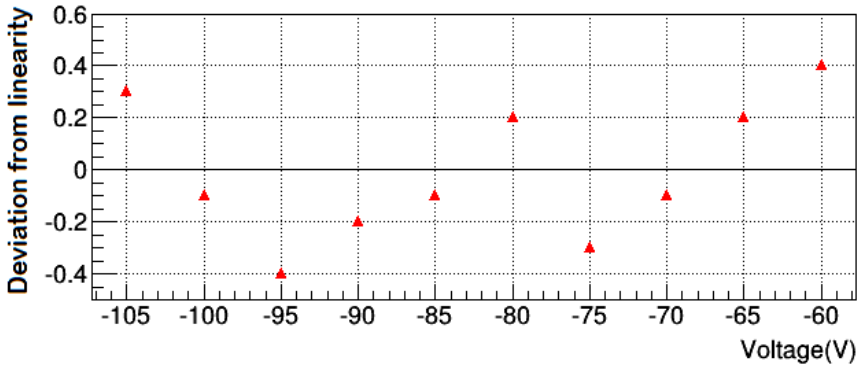


Voltage scan - PMMA





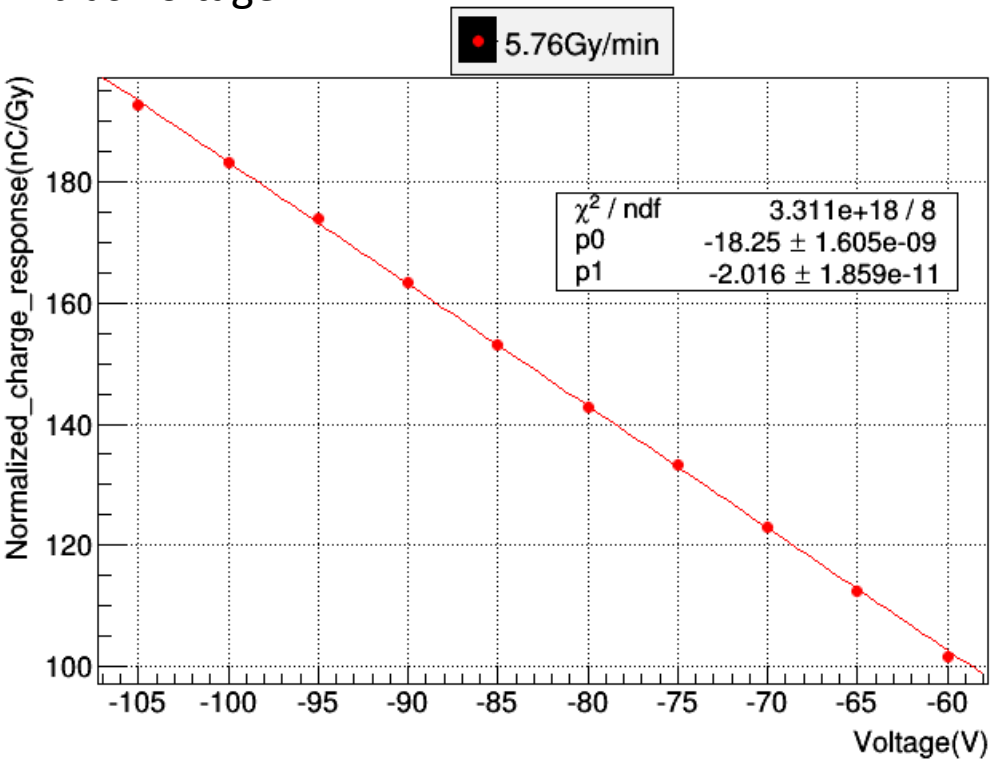
For each point measurements were done with costant dose rate = 5.76 Gy/min
costant dose = 11.52 Gy



The deviation from linearity is within 0.5%.

Normalized charge response – PMMA

The 3D detector charge response normalized to the dose rate was found calculating average current after the beam and detector stabilized at 5.76 Gy min^{-1} and represented as a function of the bias voltage.



There are 275 3D single cells, each one with a 0.004 mm^3 sensitive volume and a spatial resolution of 0.008 mm^2.
At -80V the sensitivity of each cell is about 0.52 nC/Gy.

The commercial PTW-60019 has a sensitive volume of 0.004 mm^3 and a spatial resolution of 4 mm^2 with a nominal sensitivity of 1 nC/Gy.

Conclusions

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

- ✓ An additional work on selecting the best bias voltage in order to ensure the highest sensitivity without losing the stability of the detector is in progress.

- ✓ Once the present fabrication technology has been optimized, we can expect that large sensitive area polycrystalline CVD diamond segmented dosimeters will be obtainable.

- ✓ 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.