Large Area Continuous Position Sensitive Diamond Detectors

Part I

Simulations and Test Results of Large Area Continuous Position Sensitive Diamond Detectors

M. Ciobanu, M. Pomorski, E.Berdermann, C. Bunescu, H. Comisel, V. Constantinescu, M. Kiš,
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Diamond & Related Materials, 65 (2016) 115-124

1. The four-corner LACPSDD structure
2. 2D Simulations of charge diffusion in the DLC layer
3. The signal to noise limitation
4. Tests of the tetra-lateral LACPSDD structure

Part II

The U304 experiment, GSI, June 14-16 2016

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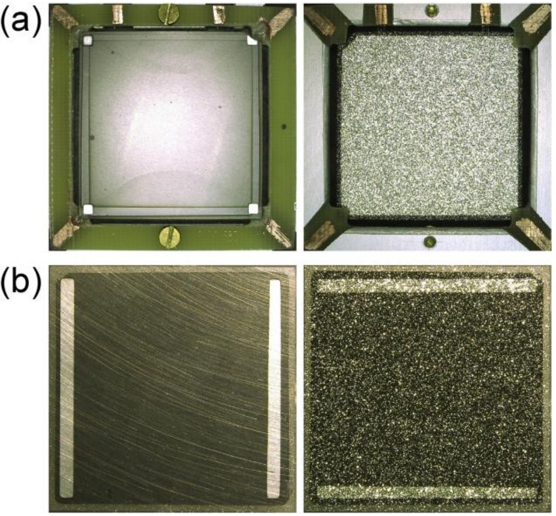
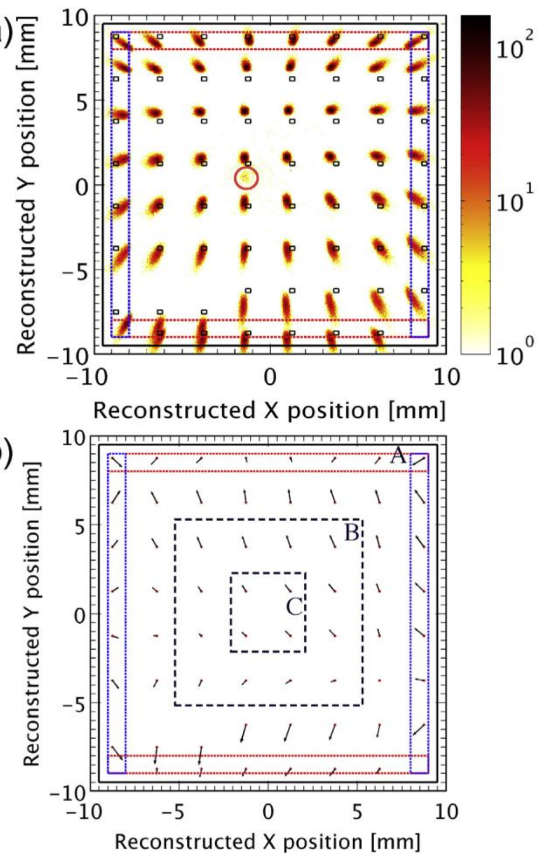
The tetra-lateral structure on Diamond on Iridium: 1. plate 3.4 x 3.4 x 0.25 mm^3.

2. plate 10 x 10 x 0.25 mm^3.

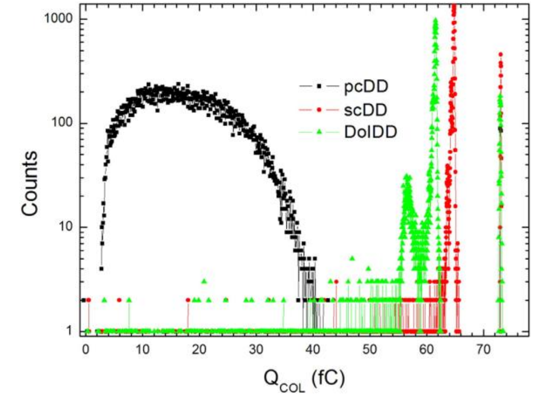
3. 1D Simulations for front-end electronics optimization.

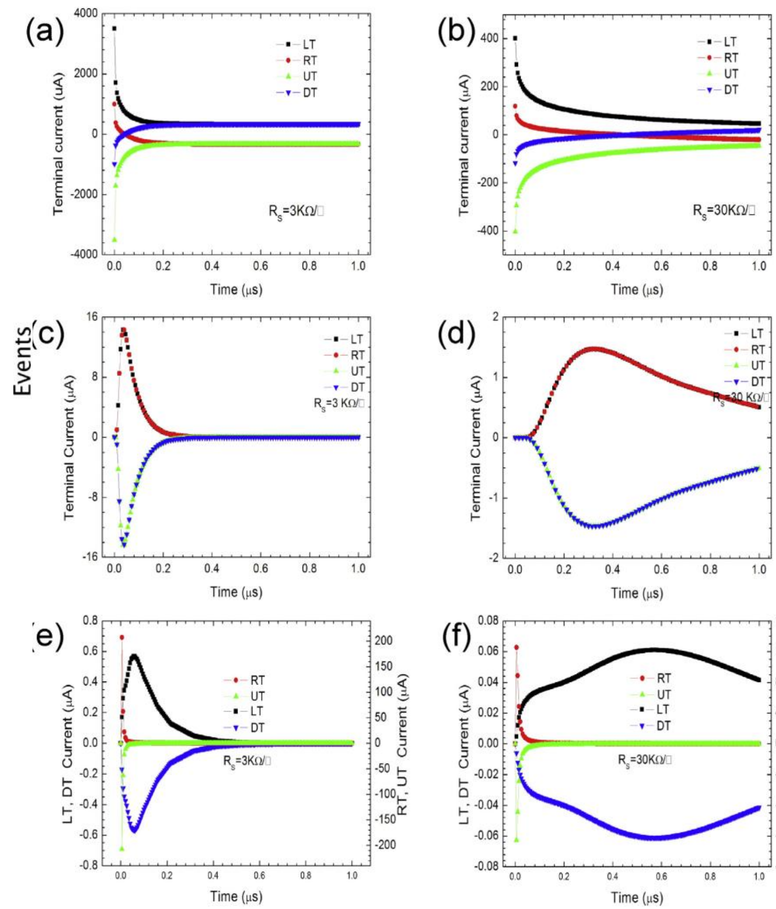
4. Tests for „polarization“ understanding.



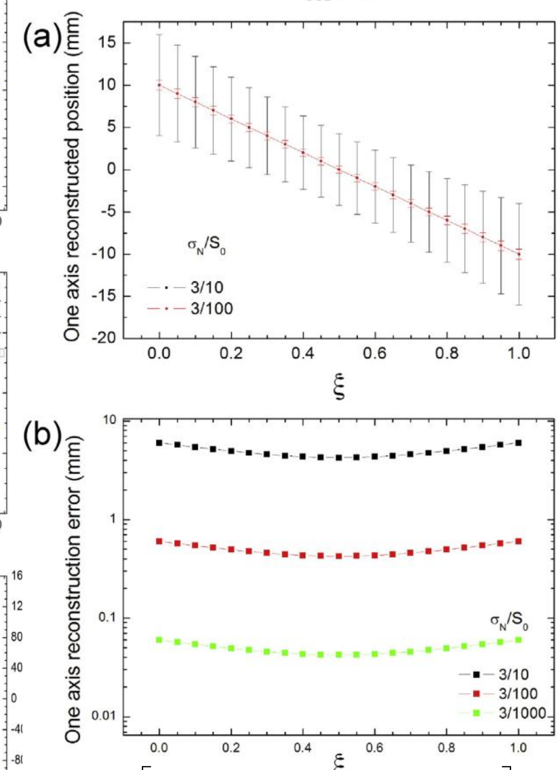


PART I: Main results





a-b) the DLC resistivity calibration
c-d) charge injection at x=0, y=0
e-f) charge injection at x=9 mm, y=9 mm



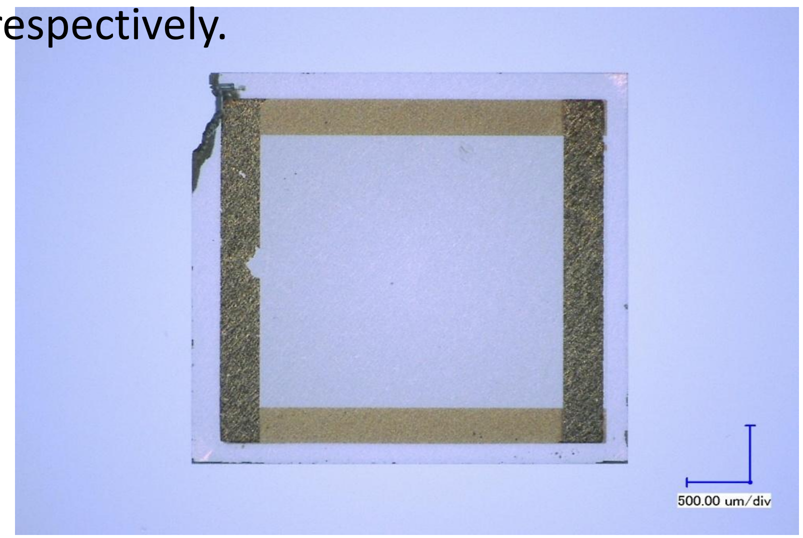
$$X_R = \left[1-2k \pm 2\cdot\sqrt{2\cdot k^2-2\cdot k+1}\cdot\left(\frac{S_{DN}}{\bar{S}}\right)\right]\cdot\frac{L}{2}$$

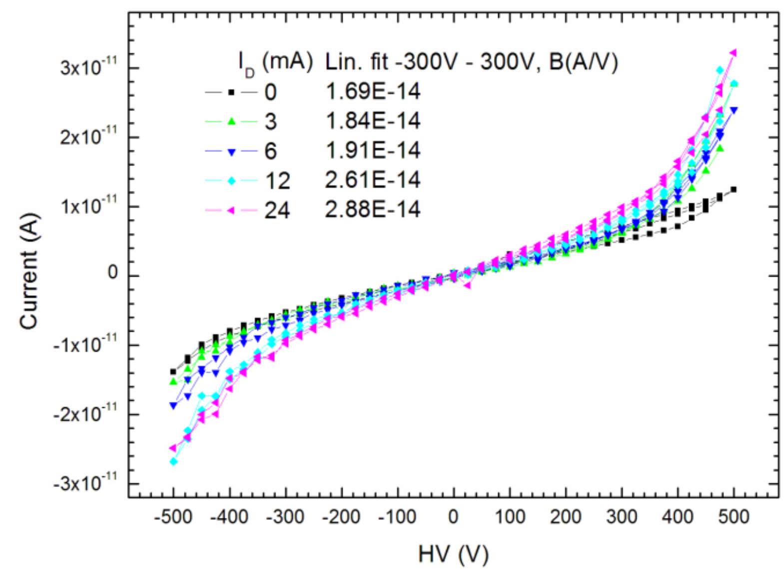
$$Y_R = \left[1-2l \pm 2\cdot\sqrt{2\cdot l^2-2\cdot l+1}\cdot\left(\frac{S_{DN}}{\bar{S}}\right)\right]\cdot\frac{L}{2}$$

$\bar{S} \approx S_0 * \lambda_P$: for scDD, λ_P =1;
for pcDD, λ_P =0.1 – 0.4.

Part II 1. The tetra-lateral structure on Diamond on Iridium: plate 3.5 x 3.5 x 0.25 mm^3.

PSD2 detector uses the Diamond on Iridium (DoI) material sensor of $3.5 \times 3.5 \times 0.25$ mm^3. The sensor is designed with semitransparent resistive layers obtained by implantation of O and Ar microwave plasma at a potential difference of 1-2kV. The measured surface resistances on the front and back side are R_S=73.2 KΩ/□ and R_S =92.5 KΩ /□, respectively. Four metallic electrodes are deposited in the tetra-lateral configuration for the charge collection.
The detector capacitance and the average time constant are C_D=1.75 pF and τ_D=145 ns, respectively.



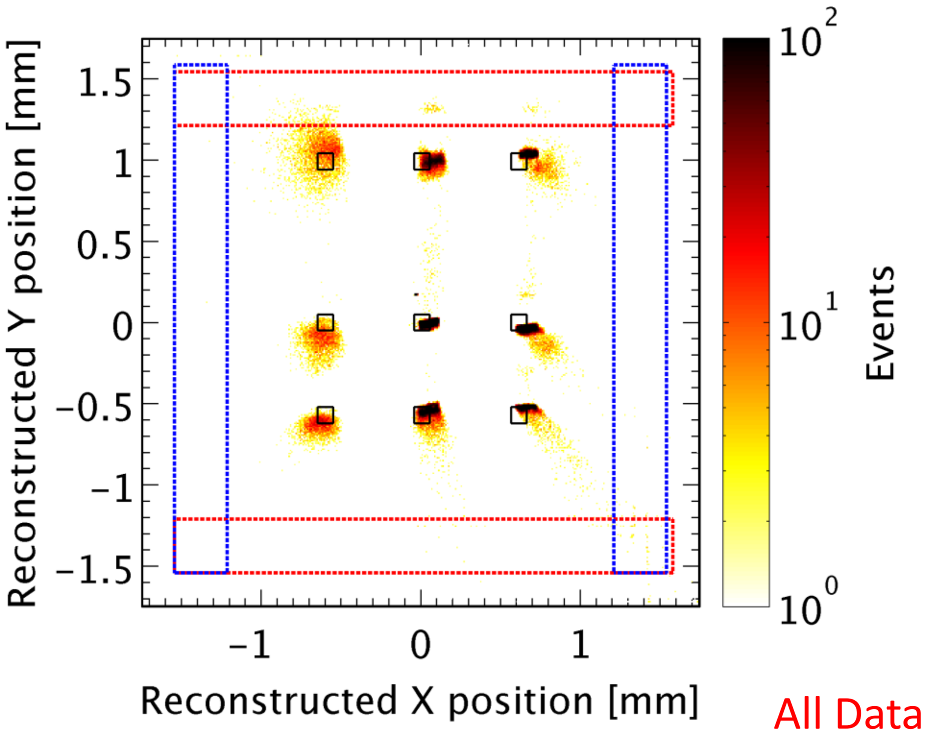


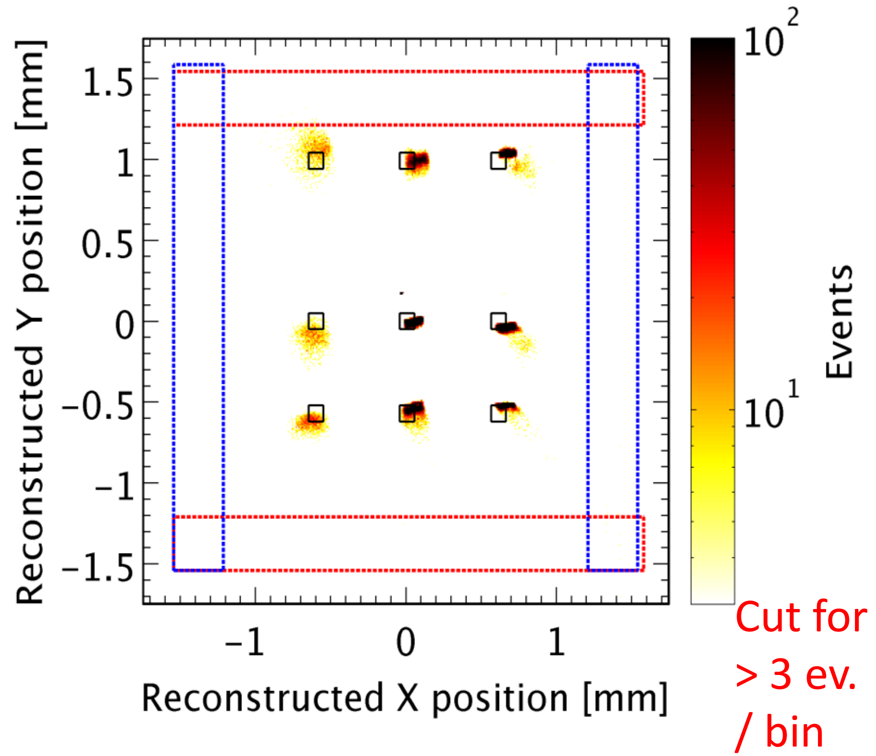
U-I characteristic measured at ISS – Bucharest. The model tested in beam contains a red LED (~ 3 mm diameter) mounted on the back of the diamond detector ; the right picture shows the influence of the LED light on the U – I characteristic, with the LED current I_D as a parameter. In beam, I_D ~ 10 mA.

The PSD2 detector was irradiated by ^{12}C ion beam (4.8MeV/um) at the Microprobe beam facility at GSI-Darmstadt. The reconstruction and correction are based on the following equations:

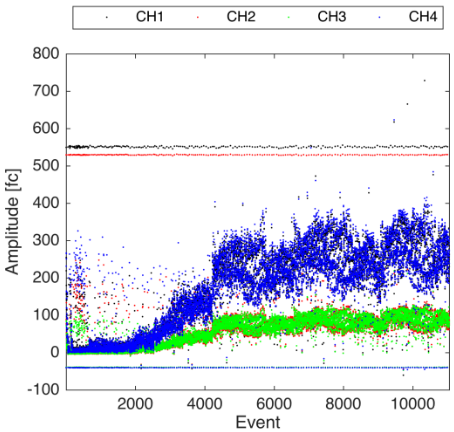
$$X_R = \frac{Q_4 - Q_3}{Q_4 + Q_3} \times \frac{L}{2}; \qquad Y_R = \frac{Q_2 - Q_1}{Q_2 + Q_1} \times \frac{L}{2} \quad ; \quad X_{COR} = S \times X_R + T_x; \qquad Y_{COR} = S \times Y_R + T_y \tag{1}$$

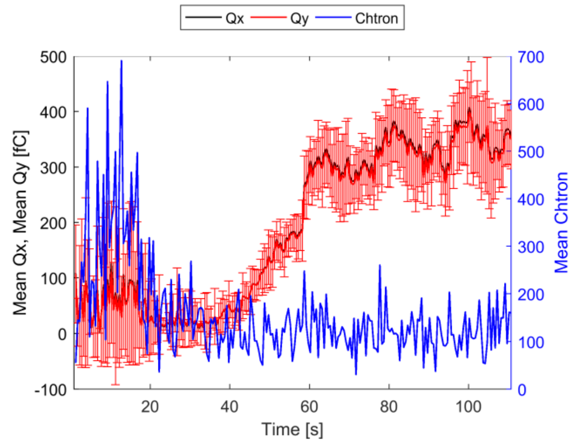
where L=2.4 mm represents the side length of the active region, defined by the central area bordered by the collection electrodes. The secondary correction of the reconstructed position implies a scaling of the primary reconstructed position by a factor S=1.2 and a translation factor T_x= - 0.05 mm and T_y= + 0.2 mm on the X and Y axes, respectively.

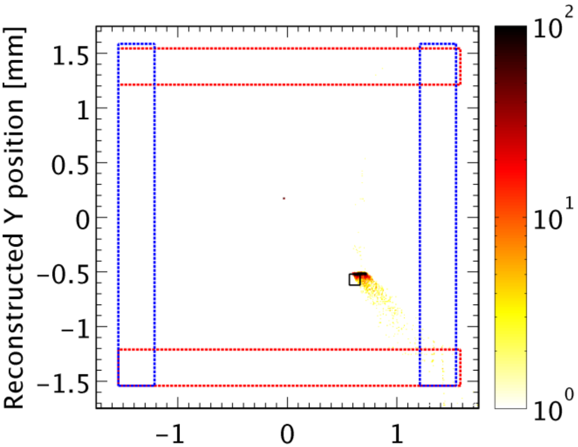


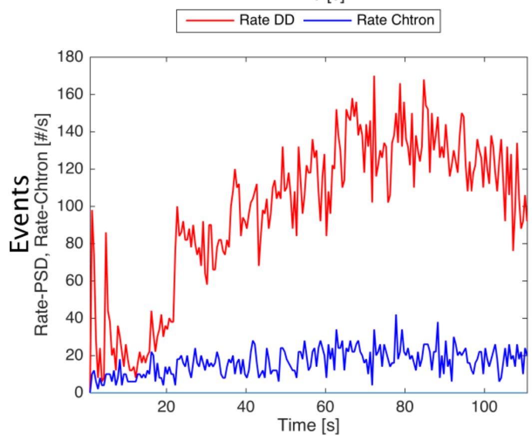


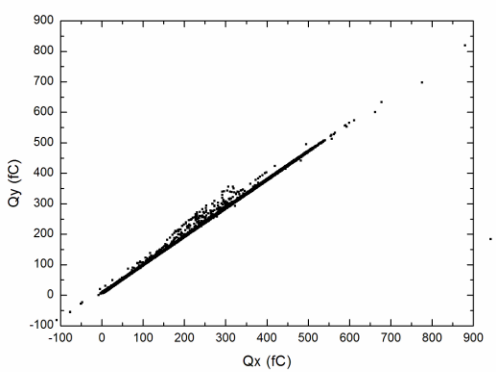
File: PSD2_35.dat, X_M =61000, Y_M =4350, HV=-600V, 1.1us, thr -12.8mV, 20+6 dB, sweep, LED

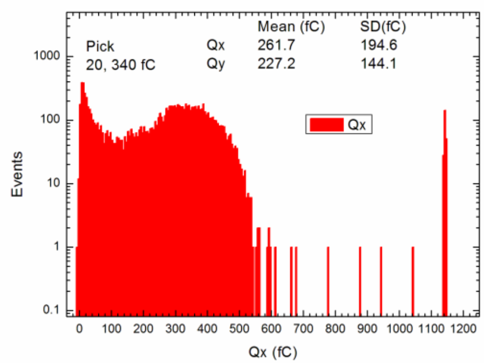






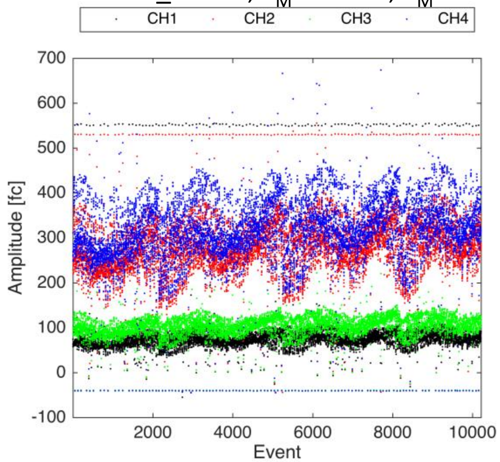


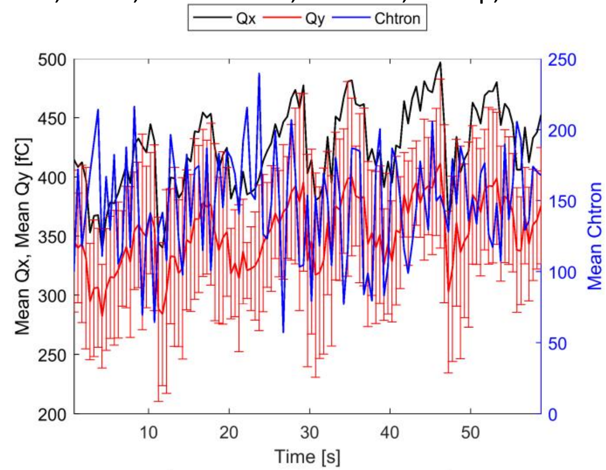


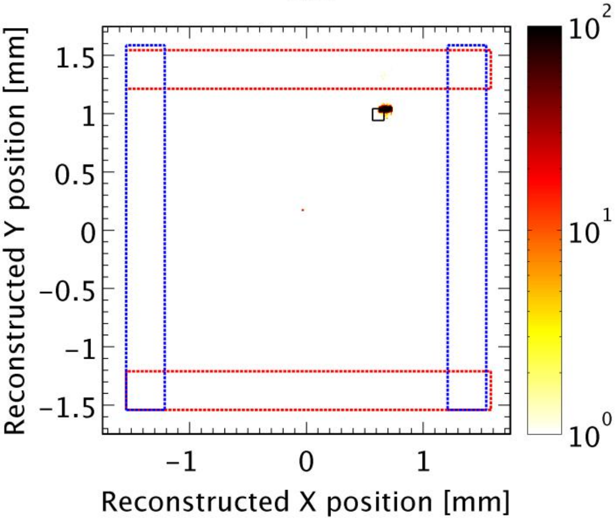


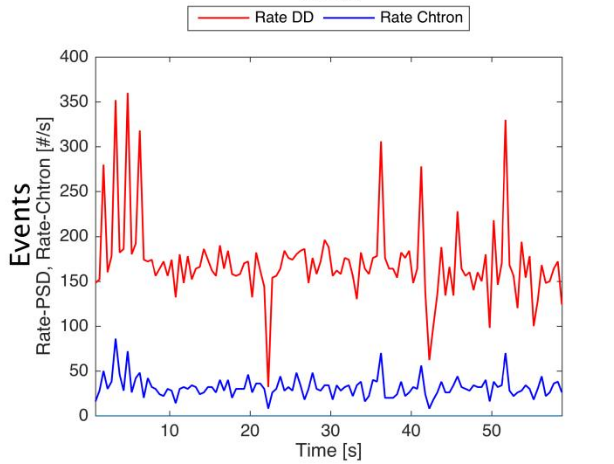
Qmin=0fC; Qpick=20, 340fC;
Qmax=600fC; Qmed=261.7fC
If Qbeam=711fC, we can evaluate:
Q=[0 – 0.84]*Qbeam, with
Qmed=0.368*Qbeam and
SDQ=0.274*Qbeam.

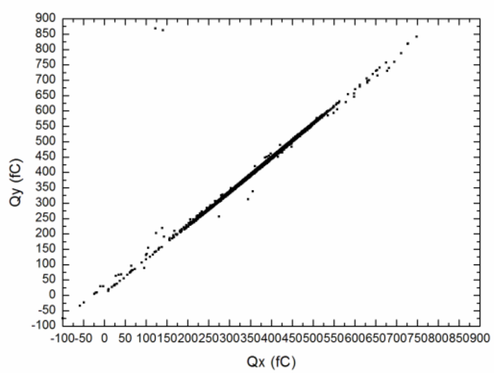
File: PSD2_45.dat, X_M =61000, Y_M =11200, HV=-600V, 1.1us, thr -12.8mV, 20+6 dB, sweep, LED

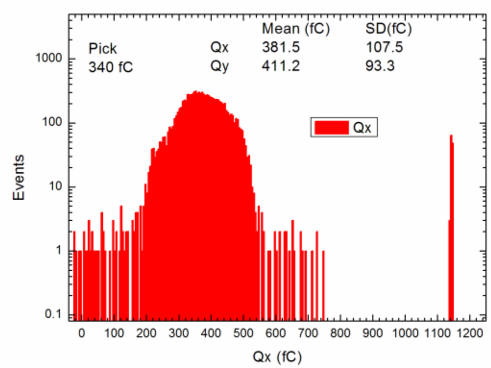






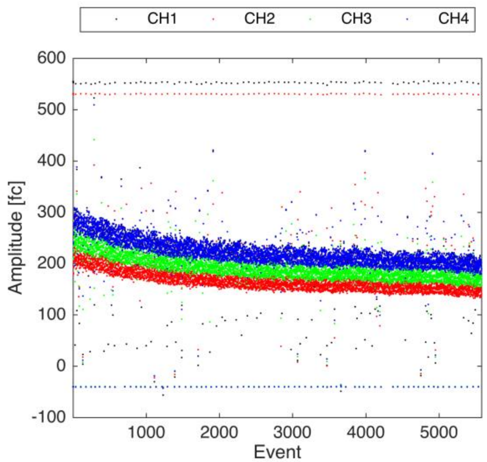


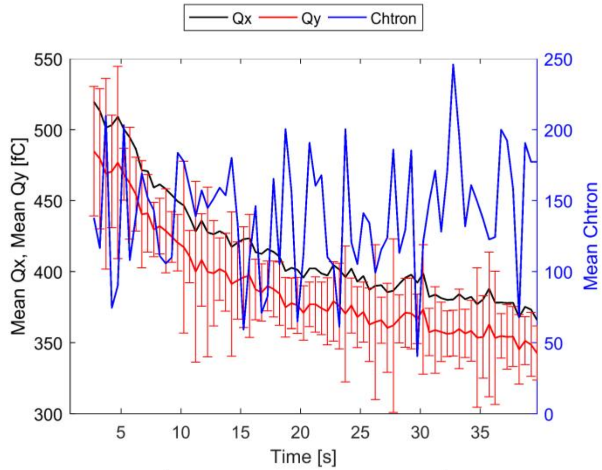


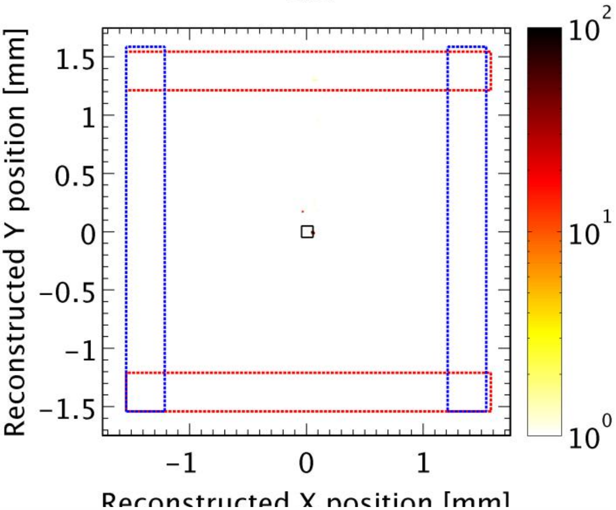


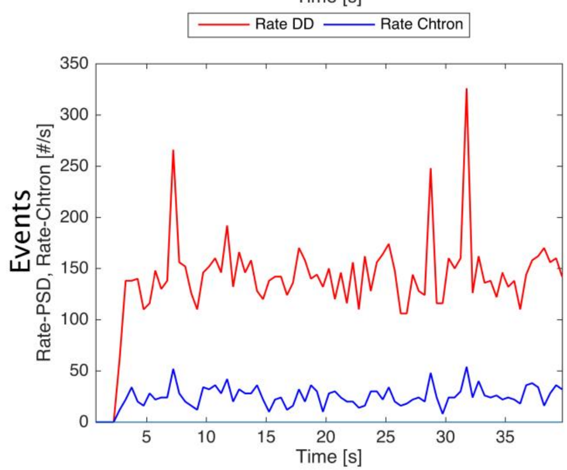
Qmin=0fC; Qpick=340fC; Qmax=750fC;
Qmed=381.5fC
If Qbeam=711fC, we can evaluate:
Q=[0 – 1.06]*Qbeam,
with Qmed=0.536*Qbeam
and SDQ=0.15*Qbeam.

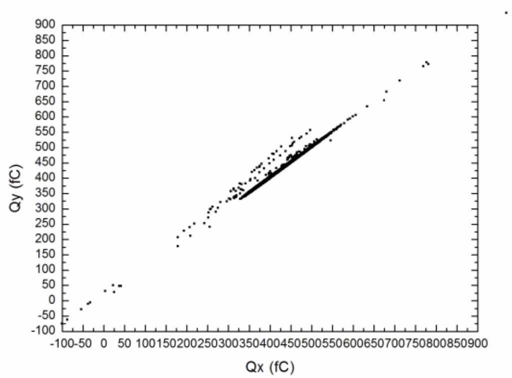
File: PSD2_46.dat, X_M =44000, Y_M =6850, HV=-600V, 1.1us, thr -12.8mV, 20+6 dB, point, LEDON?

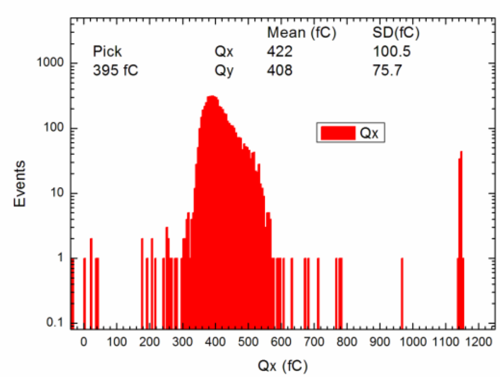








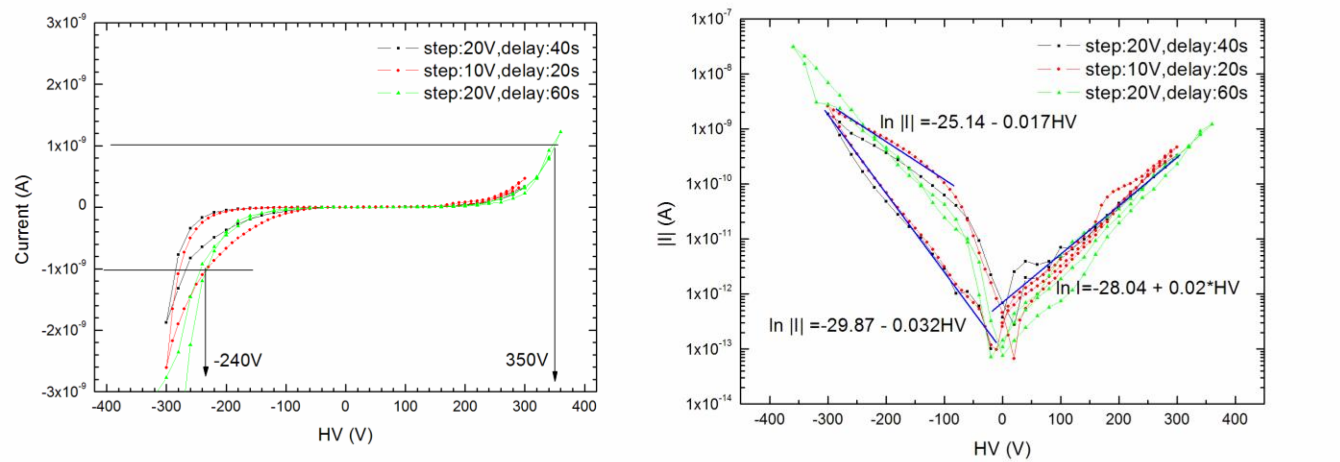




Qmin=5fC; Qpick=395fC; Qmax=760fC;
Qmed=422fC
If Qbeam=711fC, we can evaluate:
Q=[0.007– 1.07]*Qbeam,
with Qmed=0.594*Qbeam
and SDQ=0.14*Qbeam.

2. The tetra-lateral structure on Diamond on Iridium: plate 10 x 10 x 0.25 mm³.

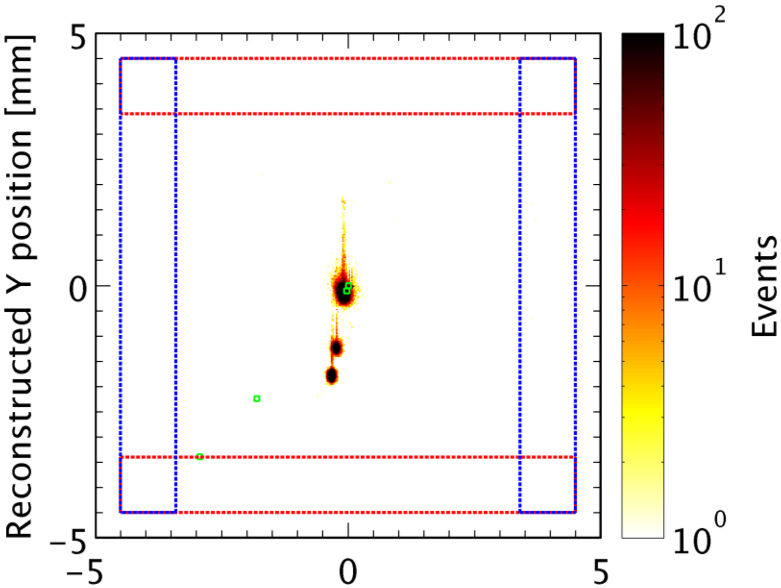
PSD3 detector uses the Diamond on Iridium (DoI) material sensor of $10 \times 10 \times 0.25$ mm³. The sensor has two DLC layers. The measured surface resistances on the front and back side are R_S=16.3 KΩ/□ and R_S =2.76KΩ /□, respectively. Four metallic electrodes are deposited in the tetra-lateral configuration for the charge collection. The detector capacity and the time constant are C_D=17 pF and τ_D=282 ns and 47ns, respectively.



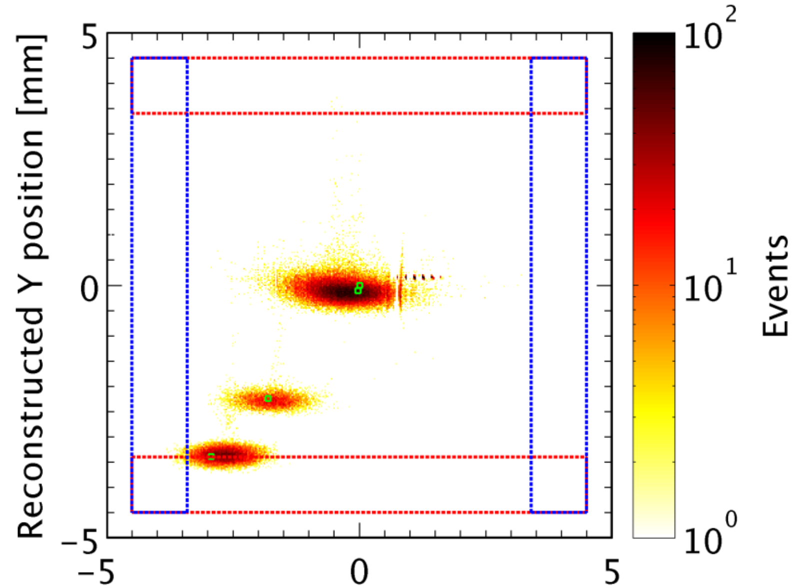
The U – I characteristic

The main problem of this detector is the big difference between DLC surface resistances. Simulations confirm that the charge responsivity depends on the layers' surface resistances and can be different compared to pulser charge responsivity.

For the reconstruction of impact position, we use the set of formulas (1) , where L=7.26 mm represents the side length of the active region, defined by the central area bordered by the collection electrodes. The secondary correction of the reconstructed position implies a scaling of the primary reconstructed position by S_X=10, S_Y=2 and a translation factor T_x= 0.6 mm and T_y= 0.2 mm.



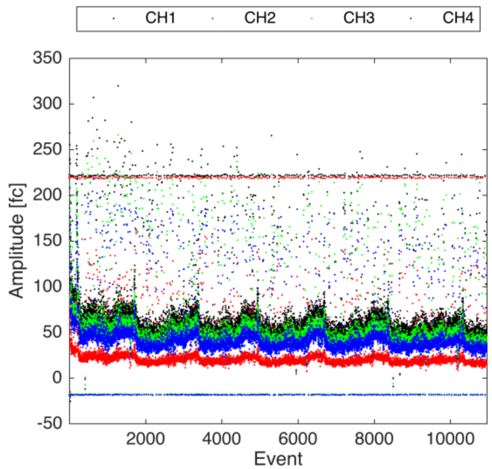
a)

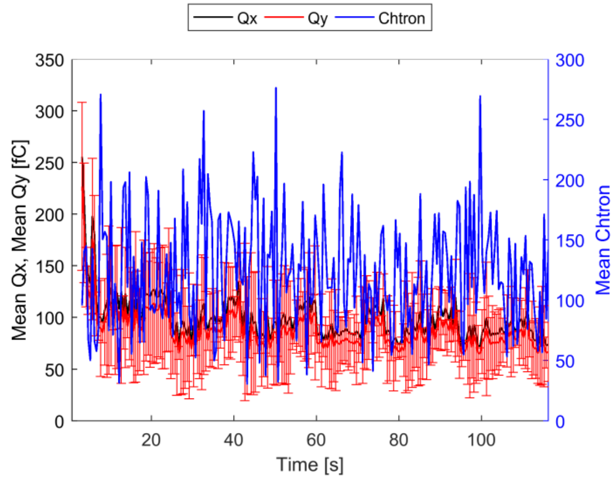


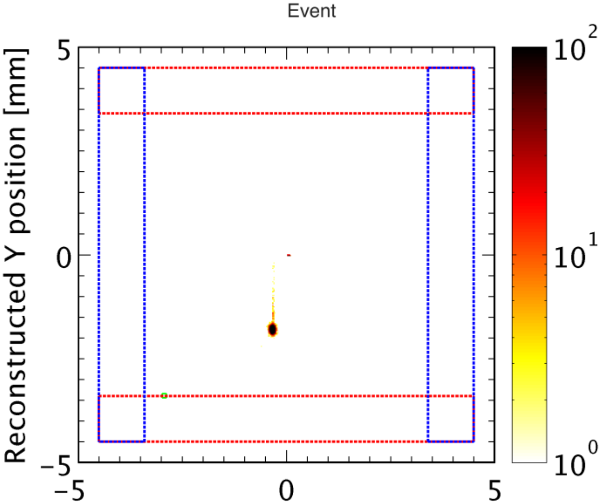
b)

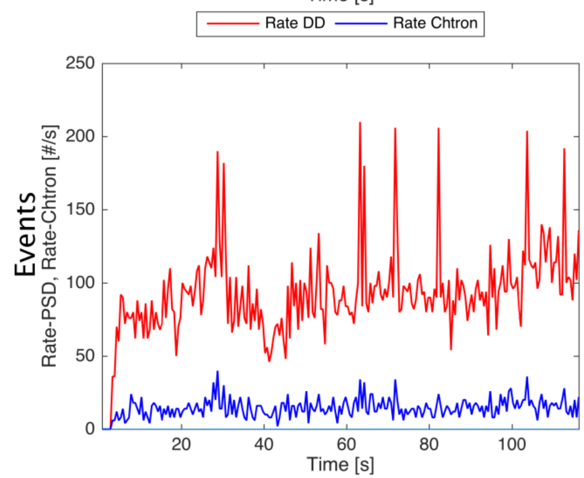
Reconstructed and corrected position histograms by binning the events on a 400x400 grid.
a) Uncut data showing all the measured events; axes are X_R and Y_R .
b) Corrected data with X_{COR} and Y_{COR} axes.

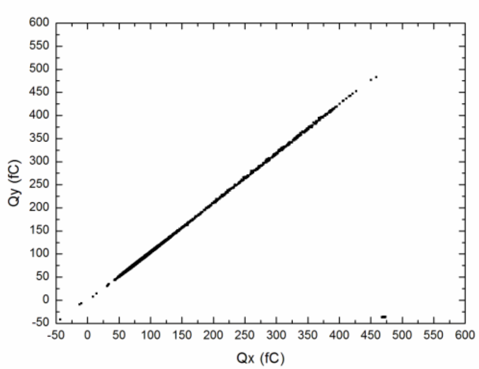
File: PSD3_18, X_M/Y_M=20000/5000, X_D/Y_D=2.93mm/3.38mm, 20dB, -375V, sweep, LED

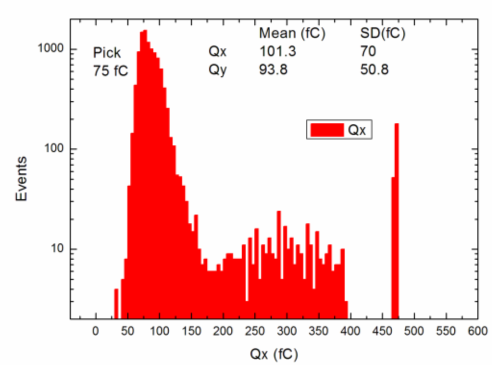






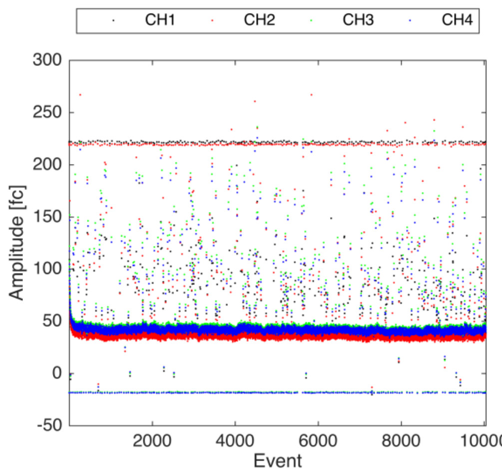


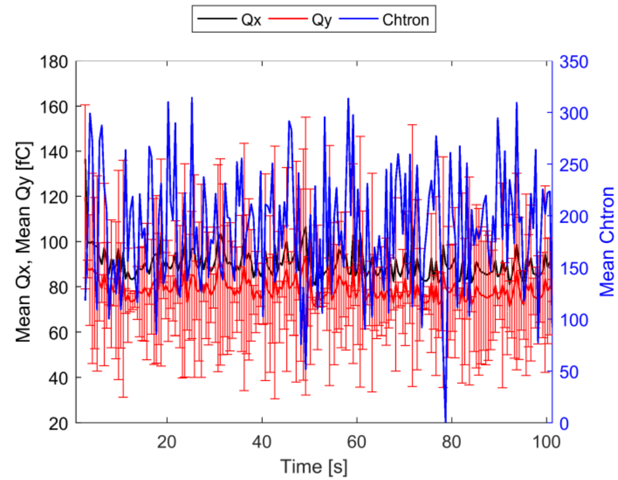


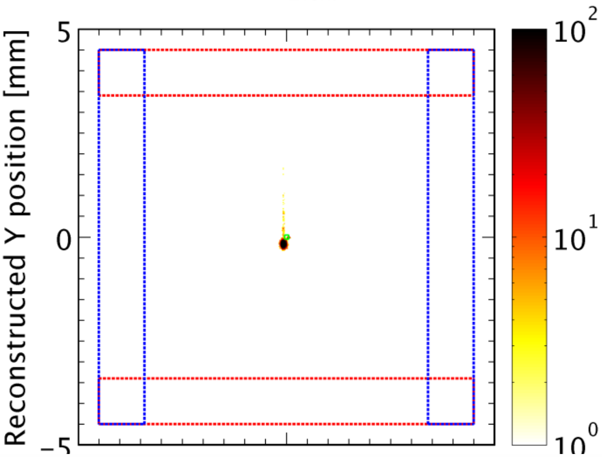


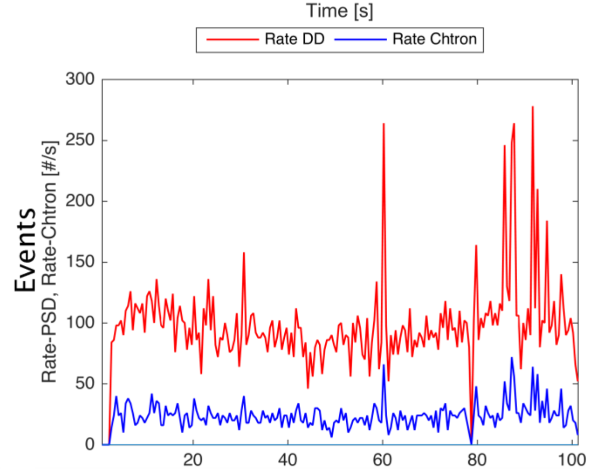
Qmin=30fC; Qpick=75fC; Qmax=315fC;
Qmed=101.3fC
If Qbeam=711fC, we can evaluate:
Q=[0.04 – 0.44]*Qbeam,
with Qmed=0.142*Qbeam
and SDQ=0.098*Qbeam.

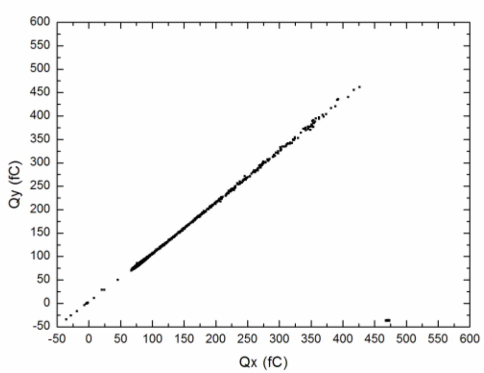
File: PSD3_19, X_M/Y_M=104000/20500, X_D/Y_D=-0.0087mm/0mm, 20dB, -375V, point, LED

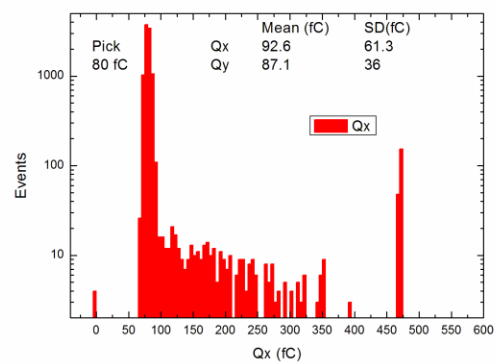






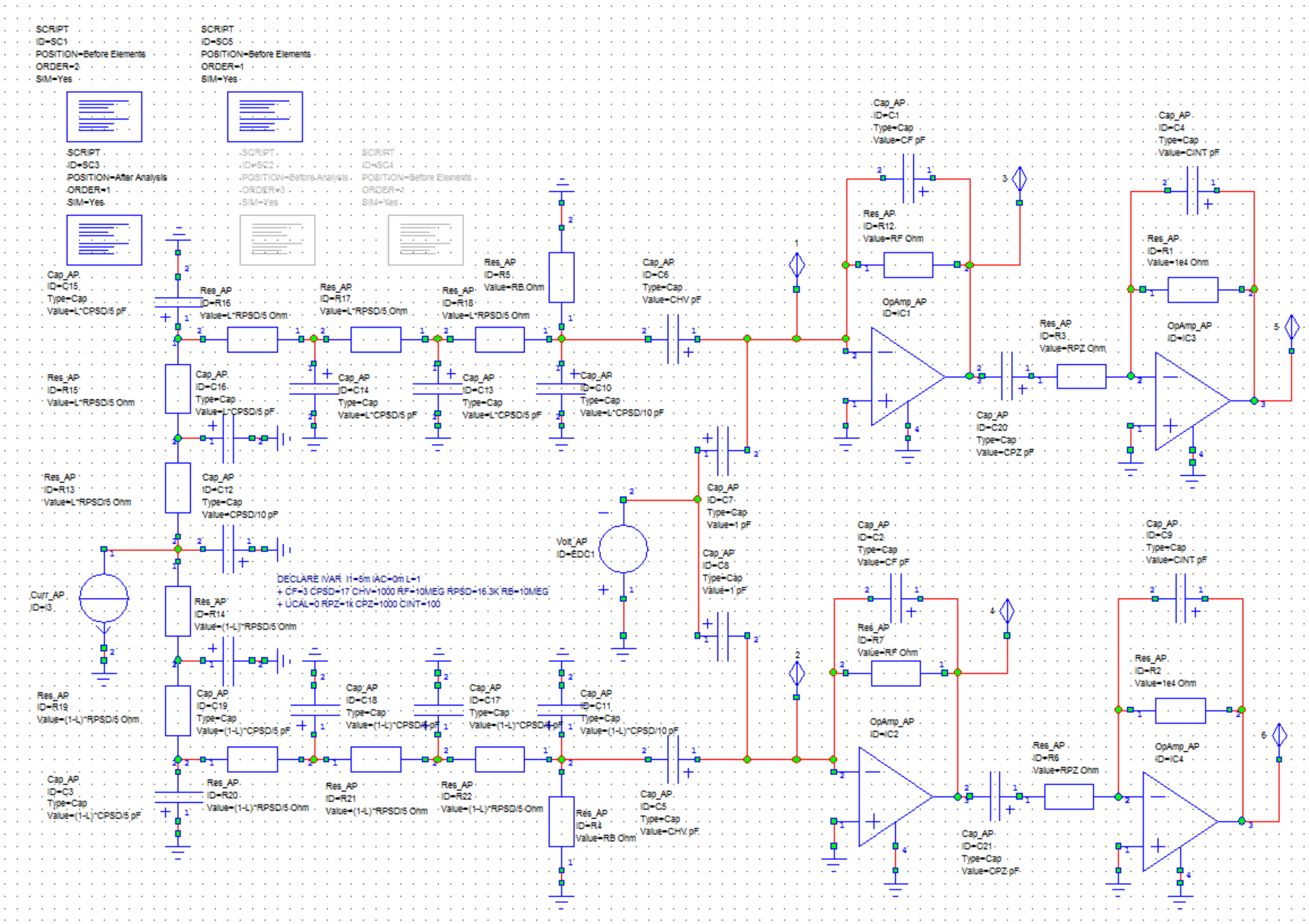






Qmin=65fC; Qpick=80fC; Qmax=380fC;
Qmed=92.6fC
If Qbeam=711fC, we can evaluate:
Q=[0.09 – 0.53]*Qbeam,
with Qmed=0.13*Qbeam
and SDQ=0.086*Qbeam.

3. 1D Simulations for front-end electronics optimization.

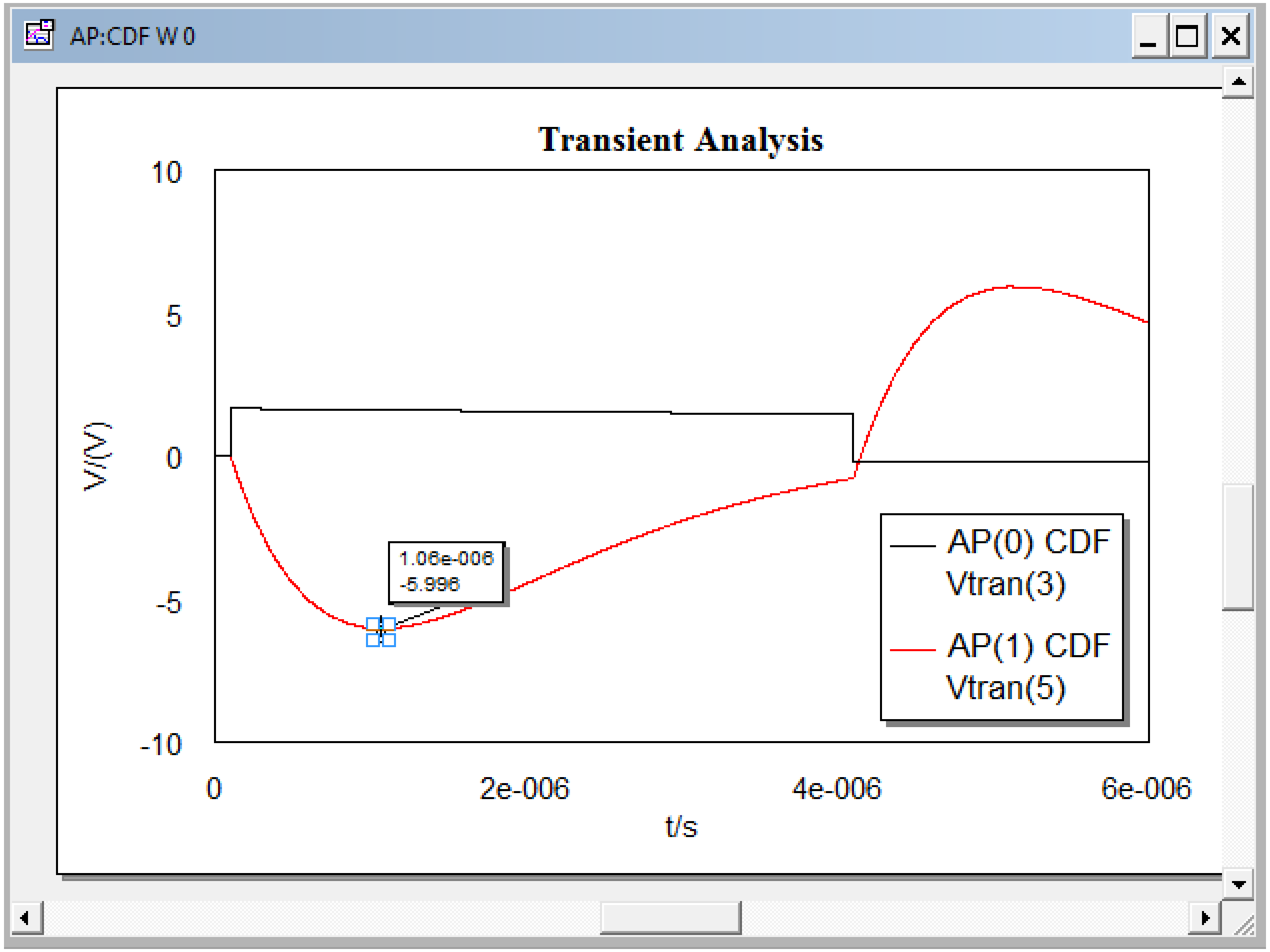


By using concentrated elements we simulate the distributed resistance and capacitance of one axis DLC layer. The layer resistance (RPSD) and capacitance (CPSD) is divided in 10 resistors and 11 capacitors. The charge signal generator I3 (5pC) is connected in the middle point of the of the chain structure. By introducing a parameter L (having values= [0,....,1]) for values of resistors and capacitors we can simulate the injection of charge along the chain axis.

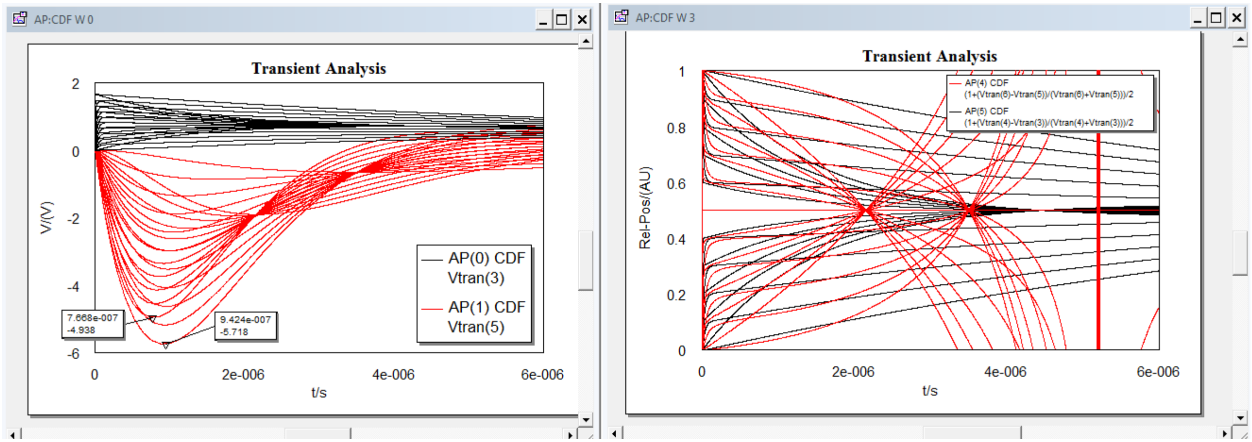
RB represents the connection resistors to HV (or GND for the second DLC layer). CHV are the connection capacitors to the Charge Sensitive Amplifiers (IC1 and IC2). The Shaper – Amplifier (IC3 and IC4) is of CR –RC type. All Operational Amplifiers used are ideal amplifiers.

The electrical calibration implies a pulse generator EDC1 and two 1pF capacitors which generate the same charge (5pC).

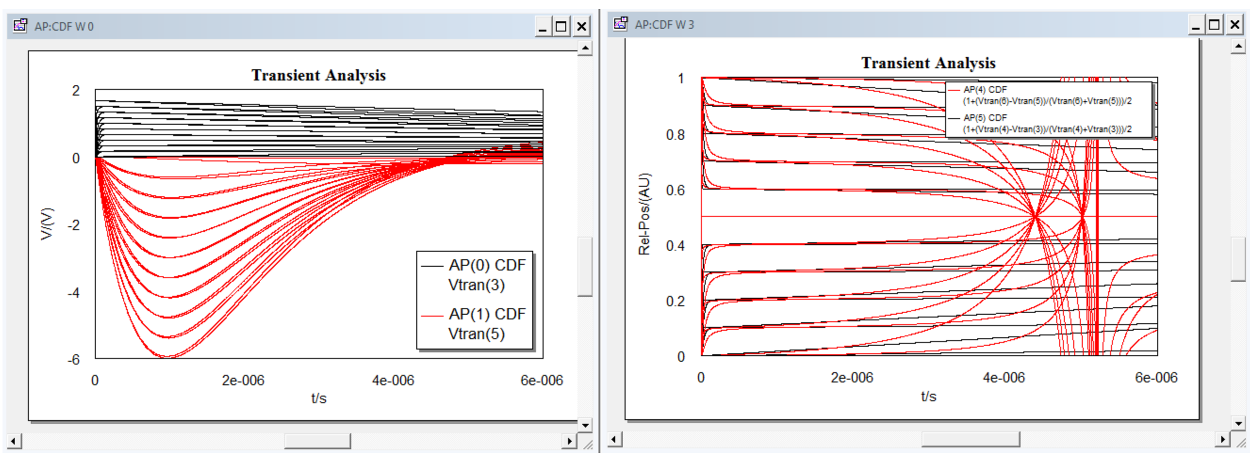
The simulation program sweeps the L parameter in 11 steps (0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1) and the RPSD for two values: 16.3k and 2.36k.



The electrical calibration: the pick value (Vtran(5)) is ~6V for 5pC. We can see the independence of the output signal to swept parameters.



The coupling capacitor CHV is like in beam tests, 1nF: the pick value (Vtran(5)) is dependent on position (L parameter) and the maximum value depends also 0n RPSD value (~4.8v and ~5.9V for 5pC).



The coupling capacitor CHV is modified to 22nF. The dependence on RPSD is decreased.

4. Tests for „polarization" understanding.

Remember some basics:

$\boldsymbol{D} = \varepsilon_0\boldsymbol{E} + \boldsymbol{P} = \varepsilon_0\boldsymbol{E} + \boldsymbol{P_t} + \boldsymbol{P_p} = \varepsilon_0(1+X_e)\boldsymbol{E} + \boldsymbol{P_p}$

$\boldsymbol{D}$ = the electric induction

$\boldsymbol{P}$ = the electric polarization

$\boldsymbol{P_t}$ = temporary electric polarization

$\boldsymbol{P_p}$ = permanent electric polarization

X_e = the electric susceptibility

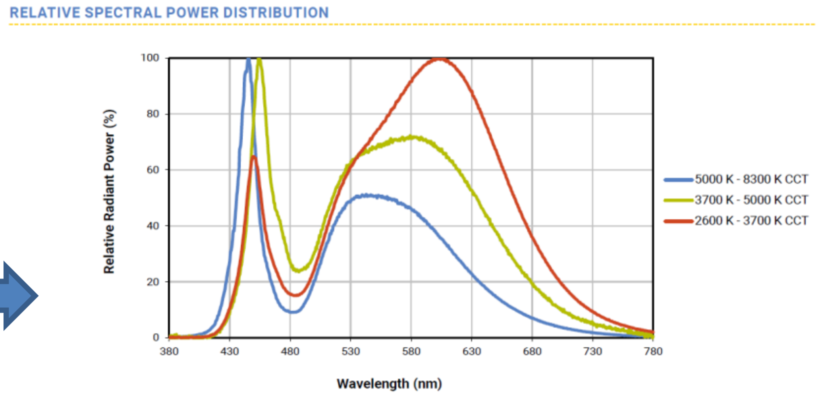
ε_0 = vacuum permittivity = 8.85418781761E-12 F/m

$\varepsilon_r = 1+X_e$ relative permittivity; for diamond ~ 5.5

ψ = the electric flux

$$\Psi = \iint_{\Sigma} D \cdot dA = q_{\Sigma} = q_t + q_p$$ the electric flux law

For intense UV-visible light excitation
we used XLAMP XM-L LED



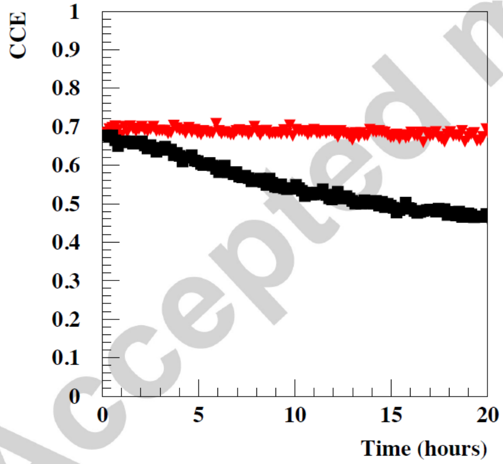


Figure 10: Comparison of M4 detector operation with (red triangles) or without (black squares) red light illumination. Weak source data is at left and hot source is at right. In both cases the red light improves and stabilizes CCE, though a slight rate dependence persists.

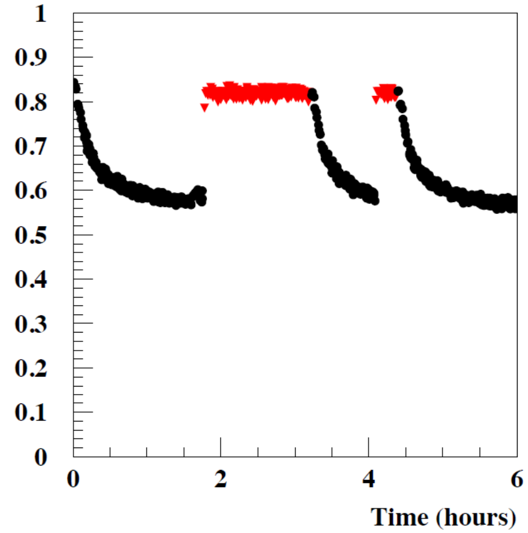
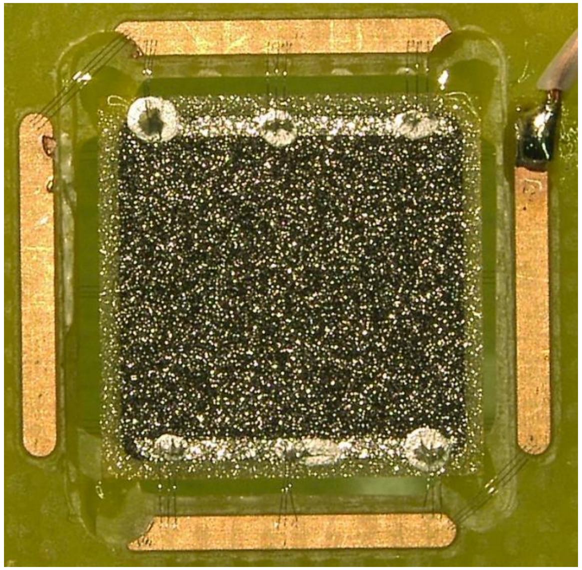
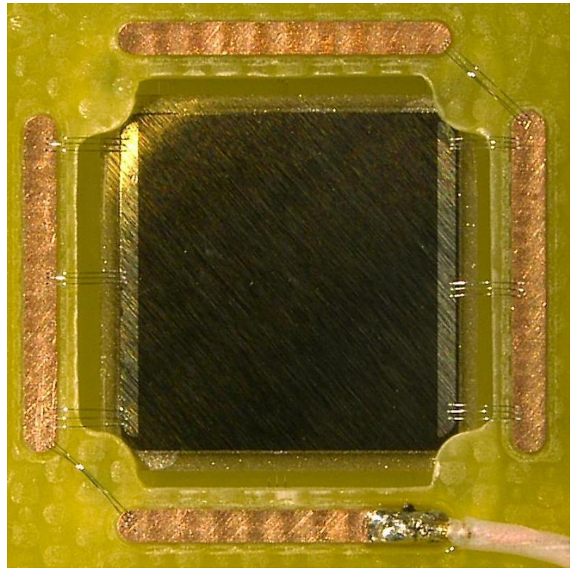
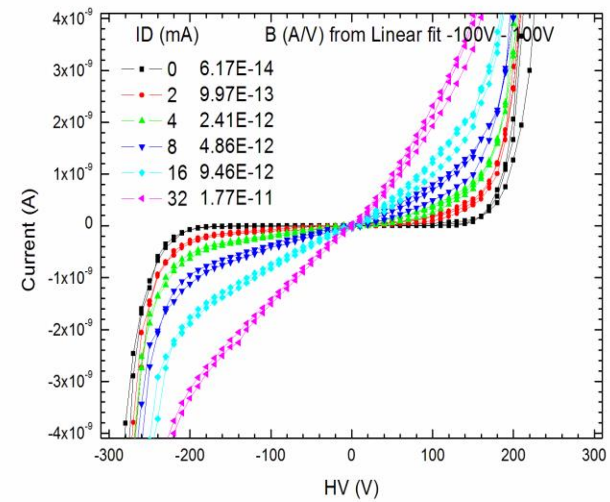


Figure 11: The CCE of the 5×10^{13} n/cm^2 irradiated sensor (S132) under the hot source, exposed to 645 nm, 4 mW/cm^2 red light (red triangles) and in the dark (black circles). The sensor's CCE drops from the pumped state under the hot source, until the red light is turned on, effecting an increase of CCE back to the pumped level. As soon as the light is removed, the sensor depumps again.

B. Bentele, J.P. Cumalat, D. Schaeffer, S.R. Wagner, G. Riley, S. Spanier,
Rate Dependence, Polarization, and Light Sensitivity of Neutron-Irradiated scCVD Diamond Sensors,
Accepted date: 22 June 2016, *Nuclear Inst. and Methods in Physics Research, A*

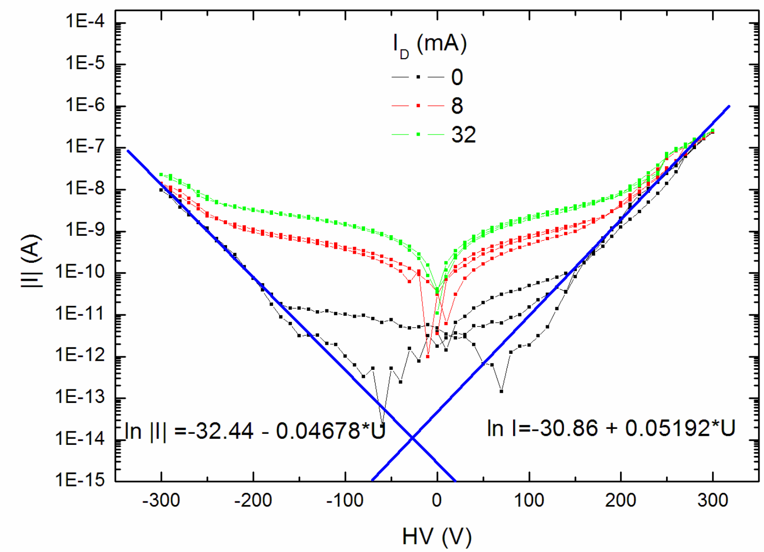






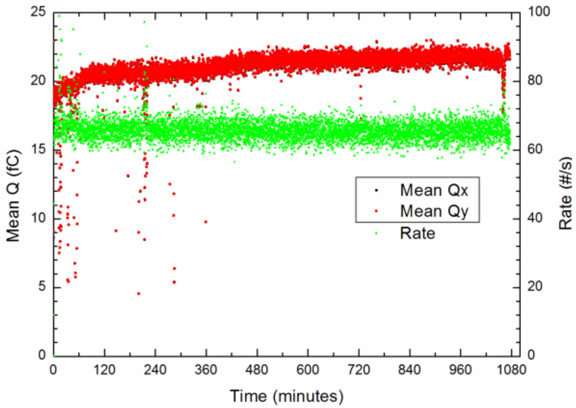
PSD1, 10 mm x 10 mm x 0.11 mm, polycrystalline DD, uses an old DLC technology for two resistive layers, R_S=37.9KΩ/□ on growth side (UP, Ch3-4), R_S=7.04 KΩ/□ on substrate side (DOWN, Ch1-2), C=49.5 pF.

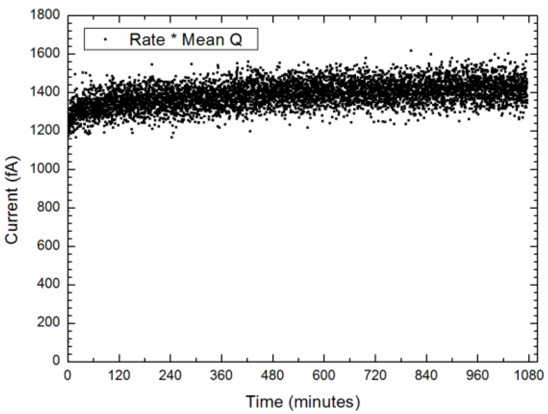
After two years, the surface resistivity of the growth layer has increased to ~ 51 KΩ/□.



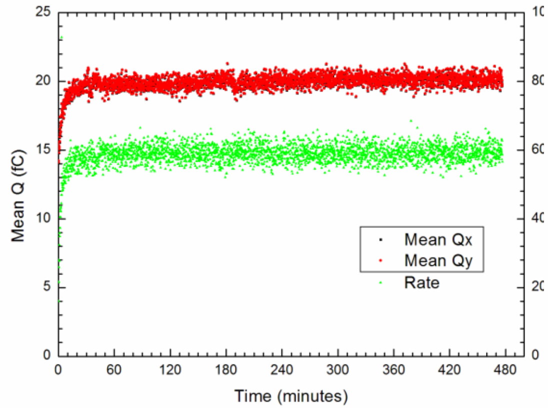
Alpha tests using PSD1 detector.

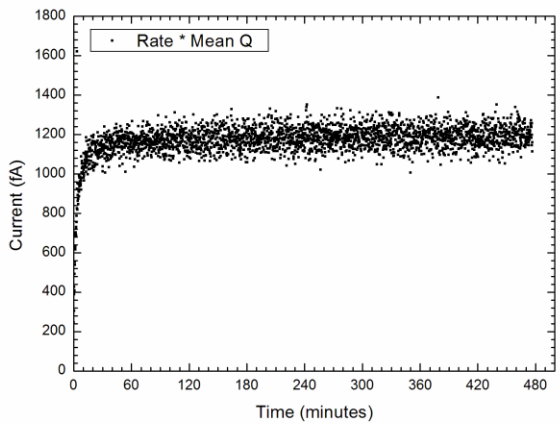
HV=+250V



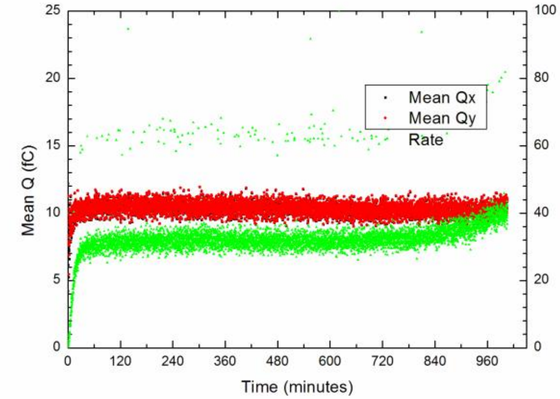


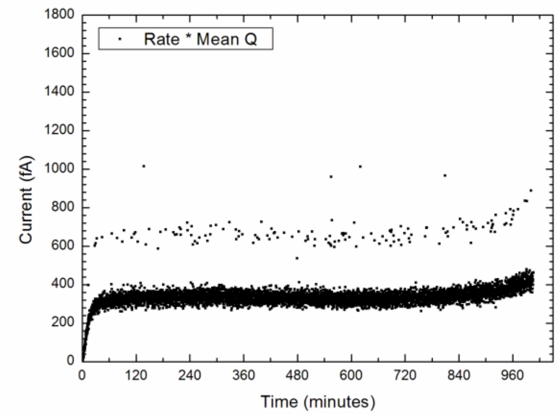
HV=+150V

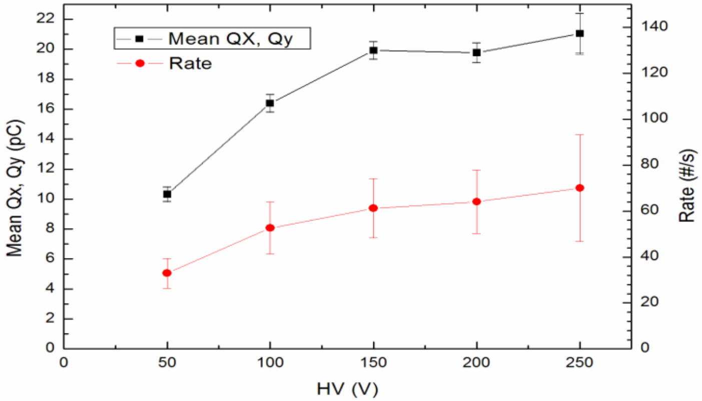


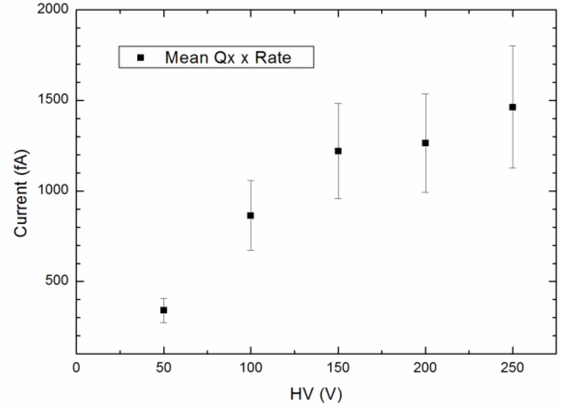


HV=+50V







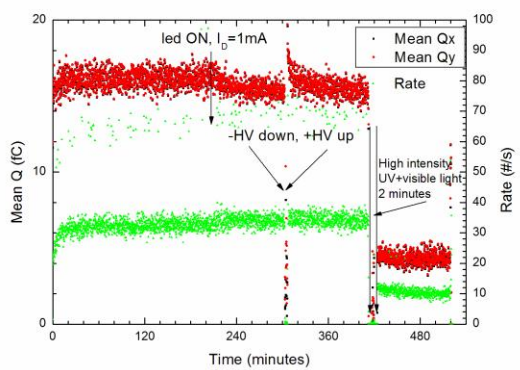


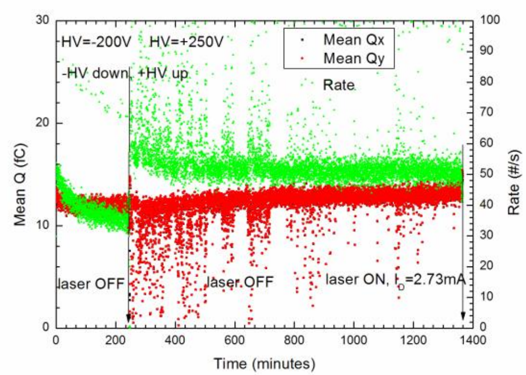
dependence to HV

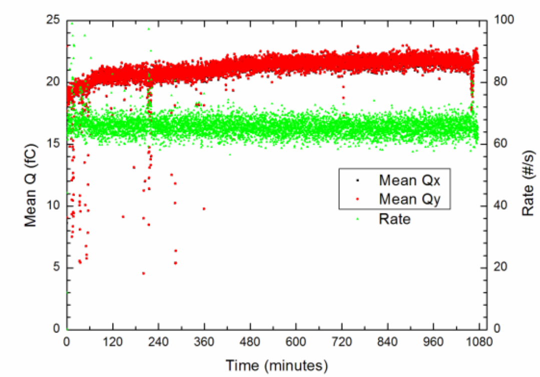
2 minutes UV+visible light

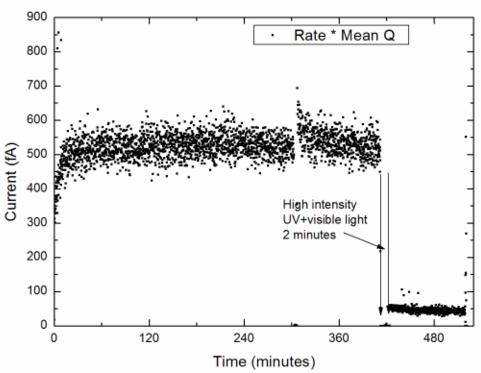
-HV or +HV

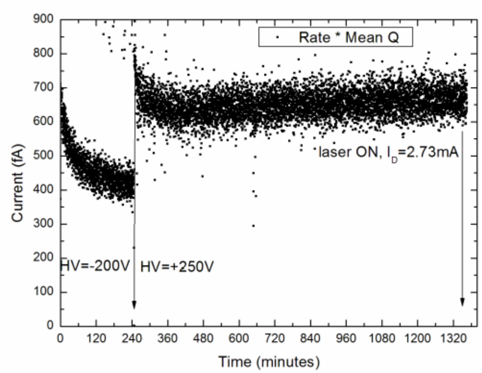
After ~150 h β + γ

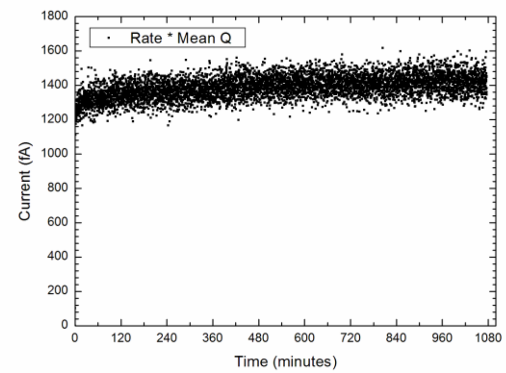






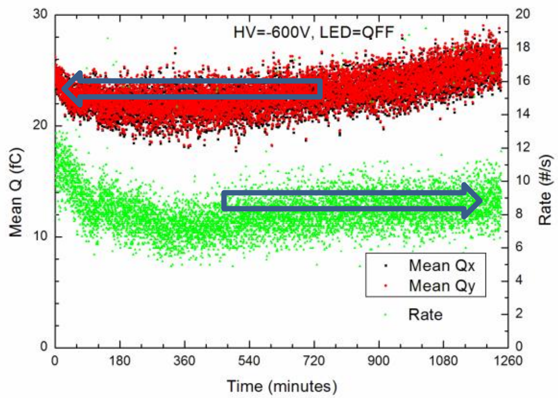


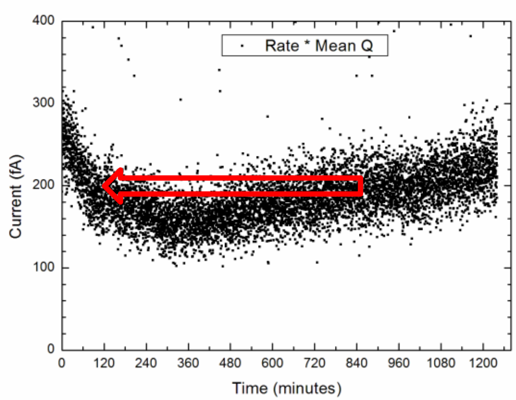




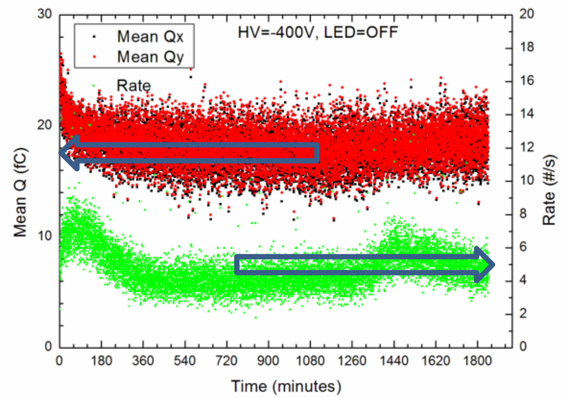
Alpha tests using PSD2 detector.

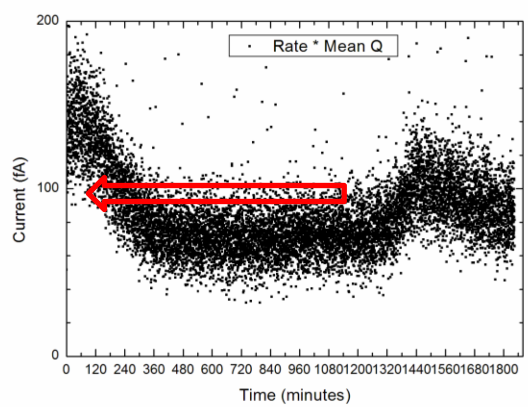
HV=-600V



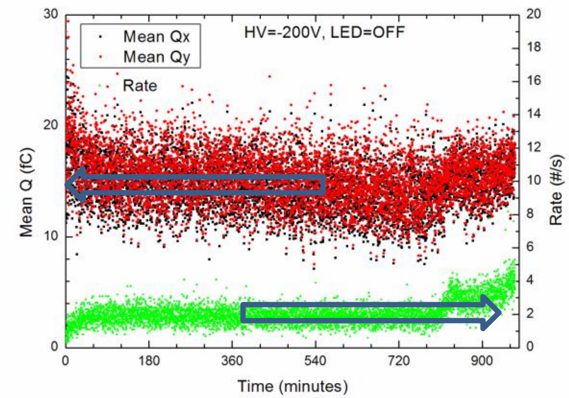


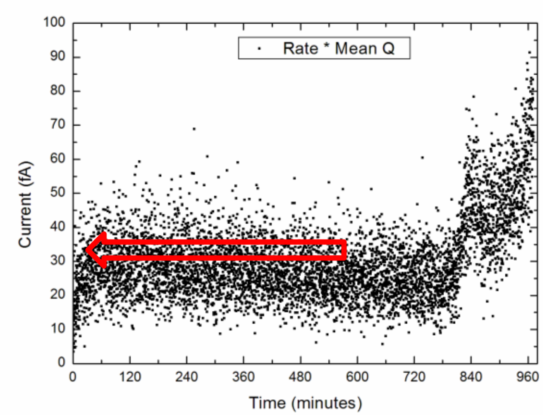
HV=-400V





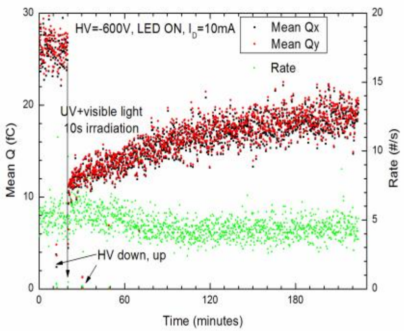
HV=-200V

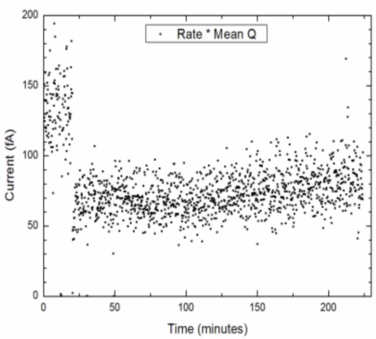




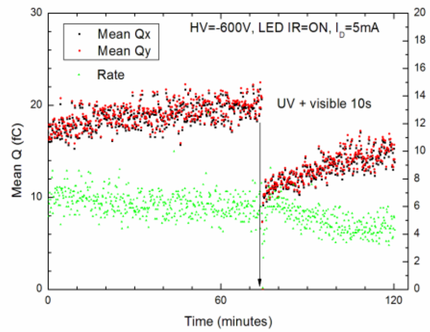
The response to 10s irradiation with UV + visible

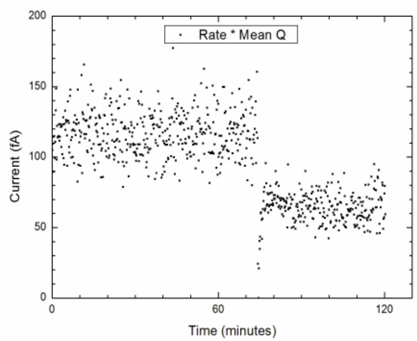
Red LED



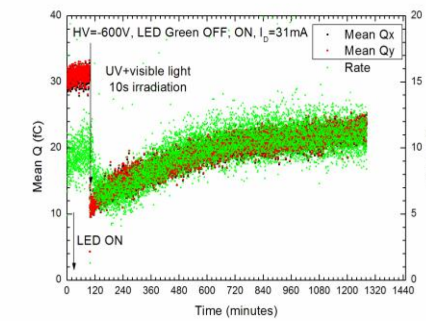


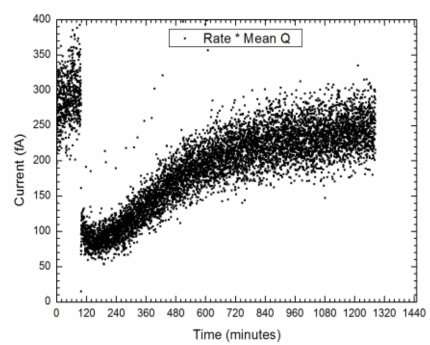
IR LED



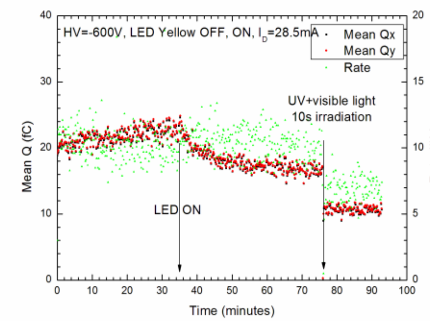


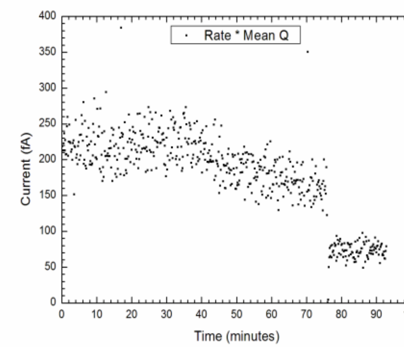
Green LED





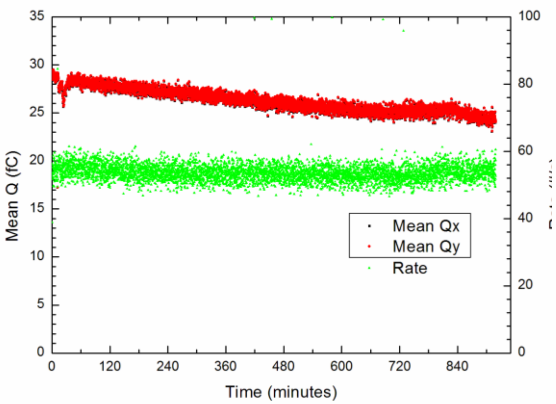
Yellow LED

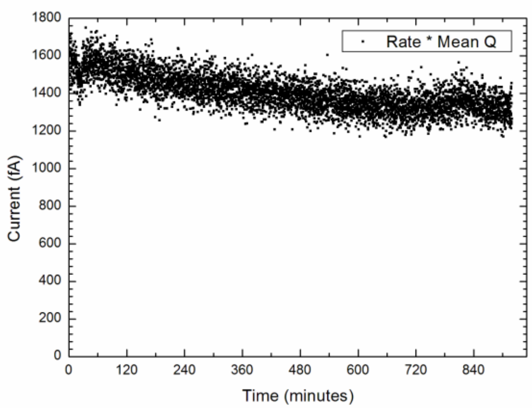




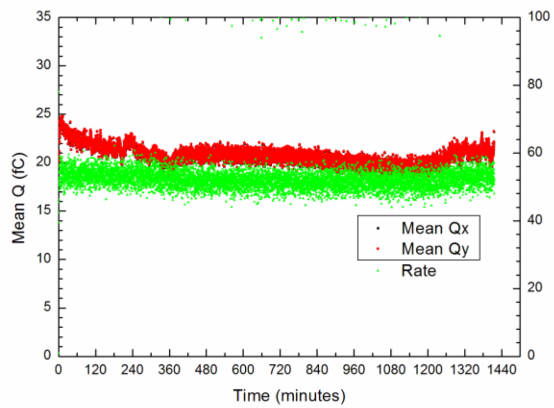
Alpha tests using PSD3 detector.

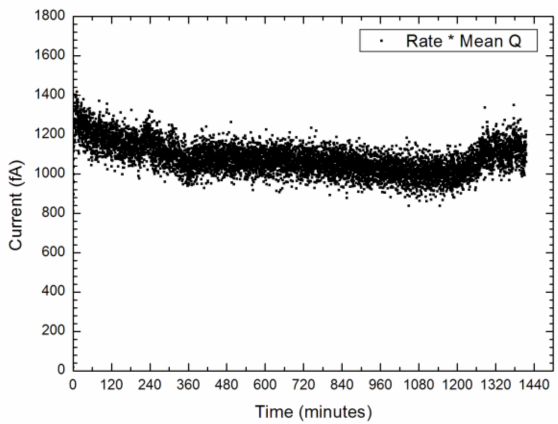
HV=-300V



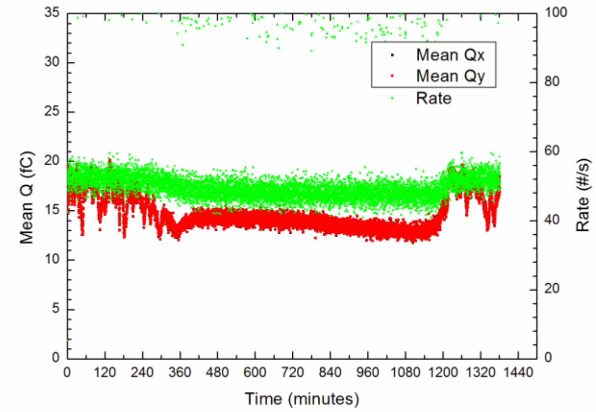


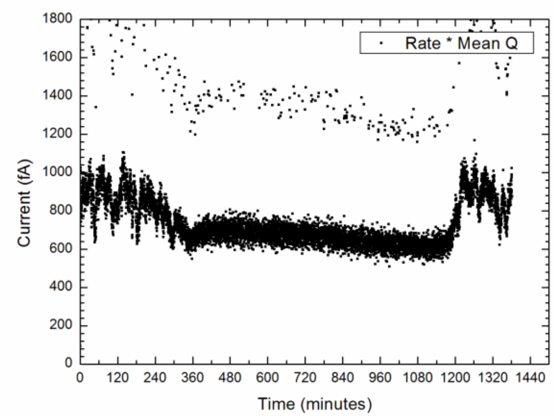
HV=-200V



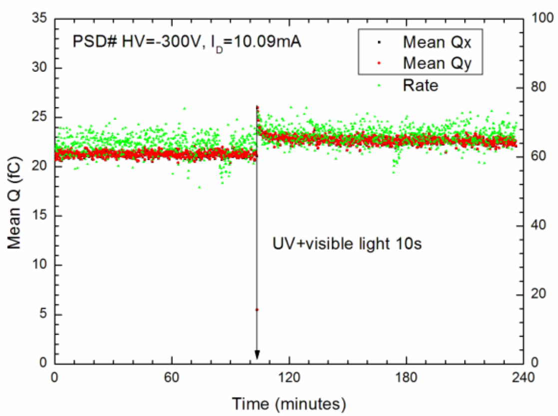


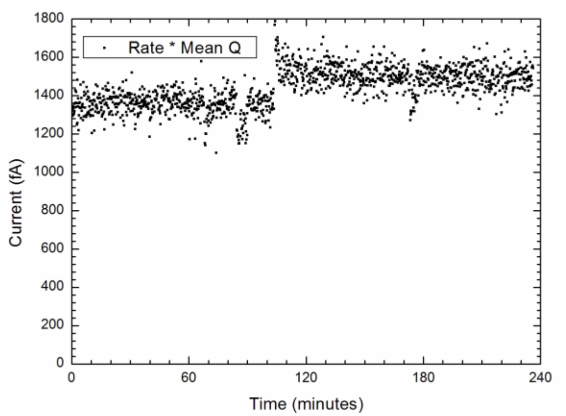
HV=-100V



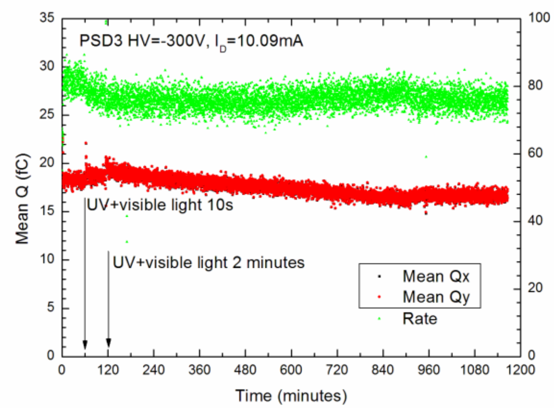


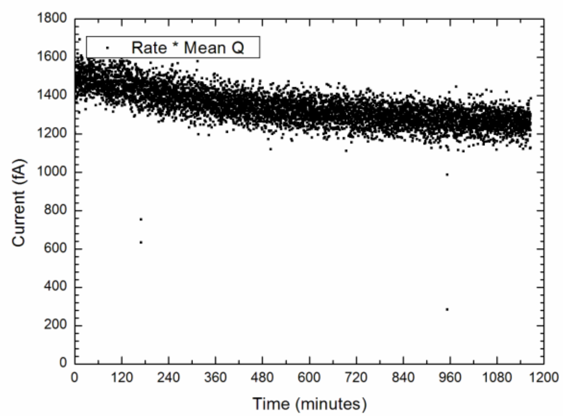
$\alpha + \beta + \gamma$ + Red LED



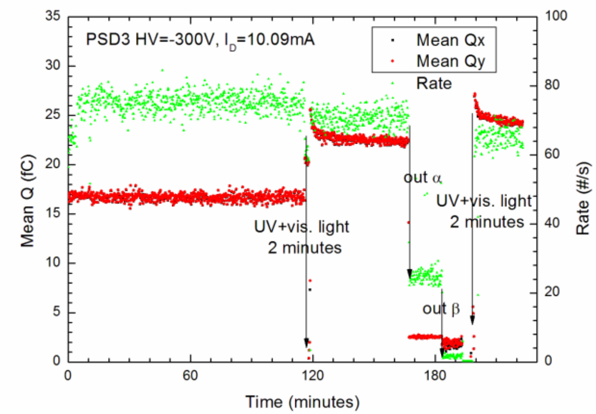


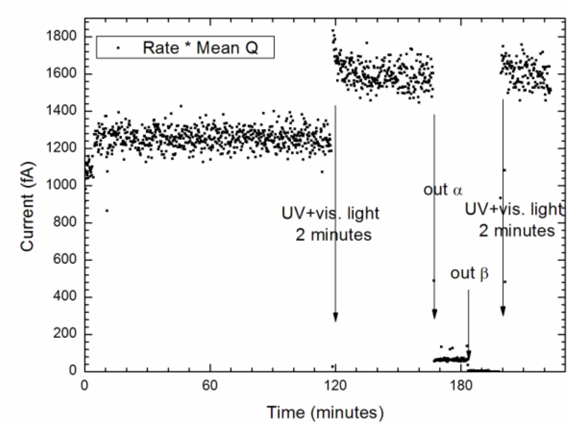
$\alpha + \beta + \gamma$ + Red LED



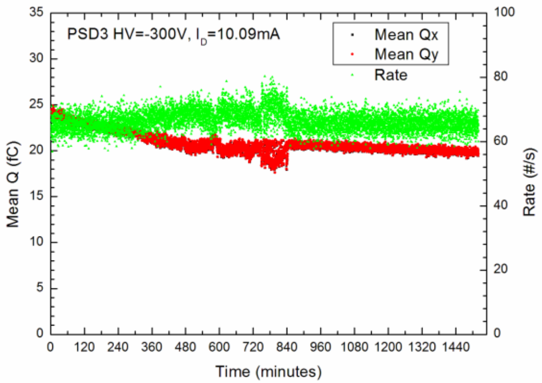


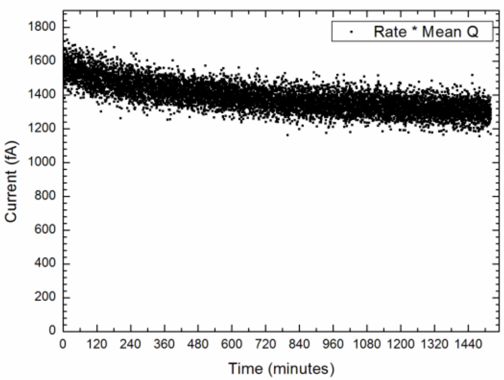
α +($\beta + \gamma$)+ Red LED



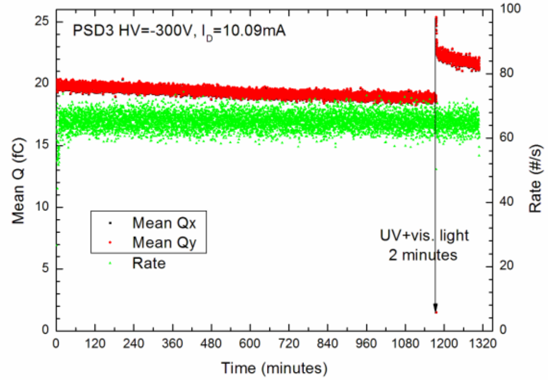


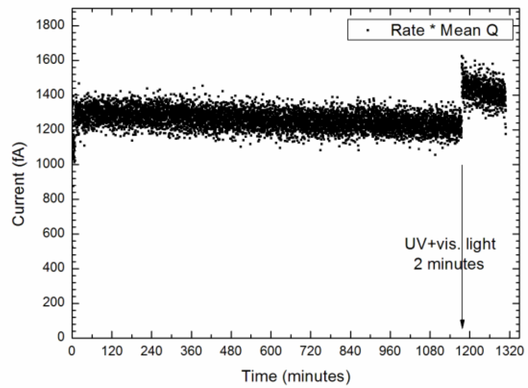
α + Red LED



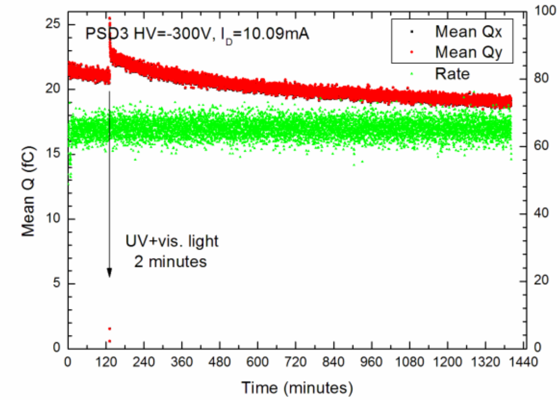


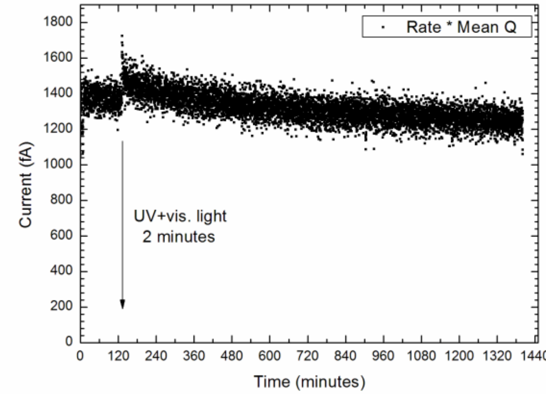
α + Red LED



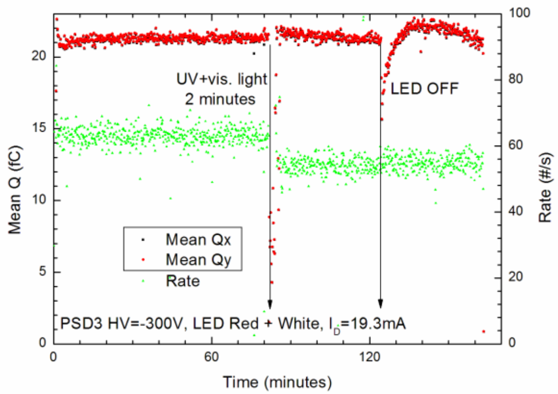


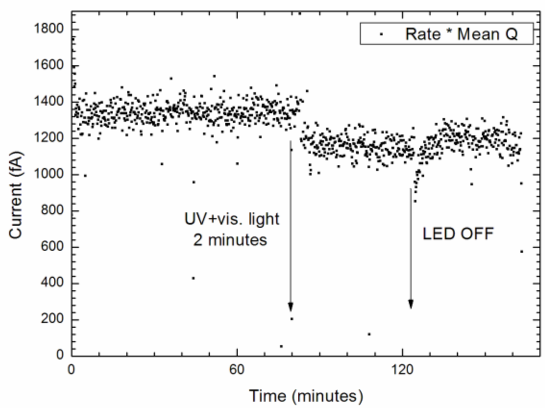
α + Red LED



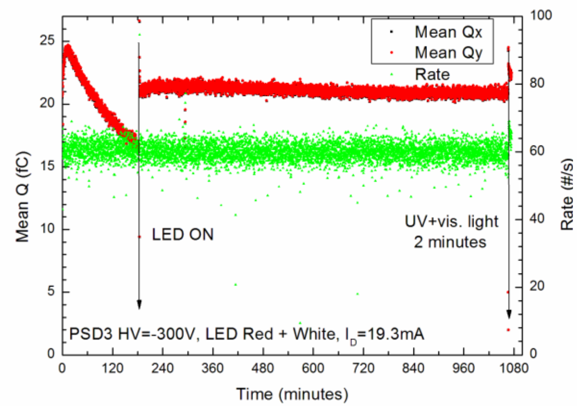


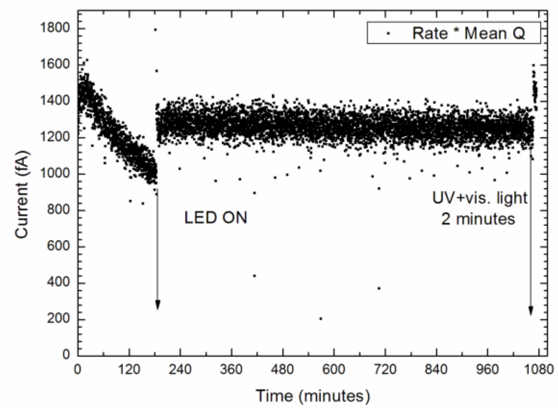
α + (Red + White LED's)



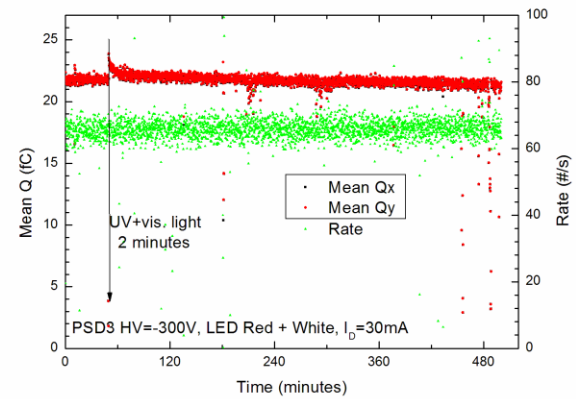


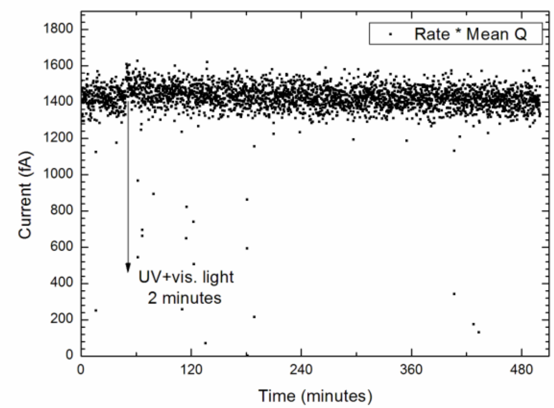
α + (Red + White LED's)





α + (Red + White LED's)

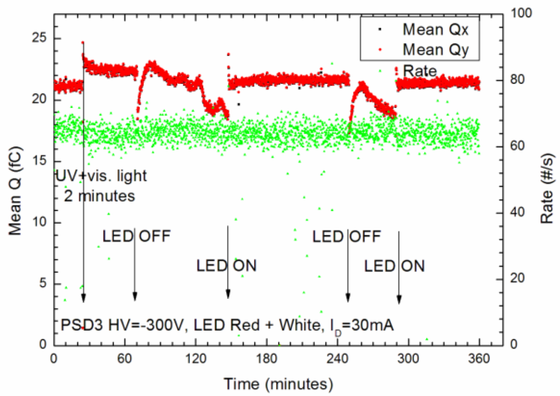


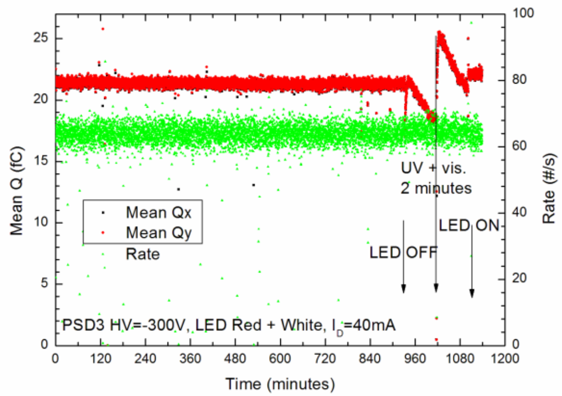


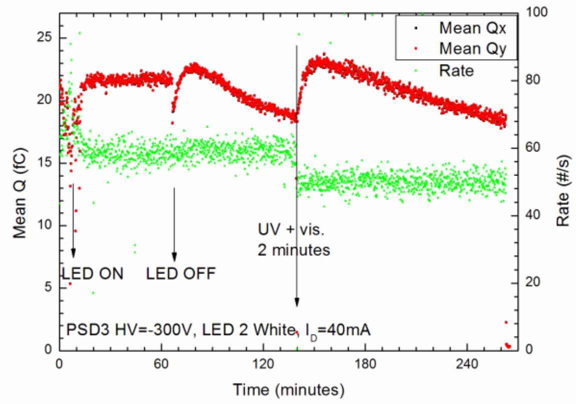
α + (Red + White LED's)

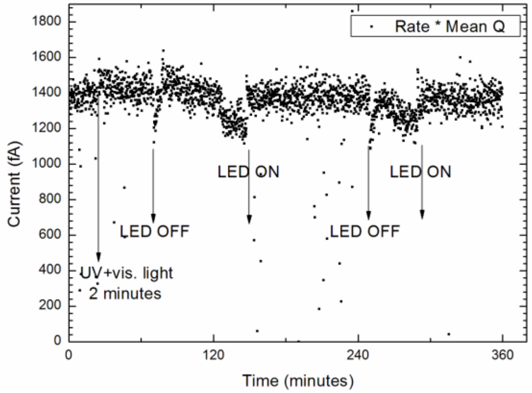
α + (Red + White LED's)

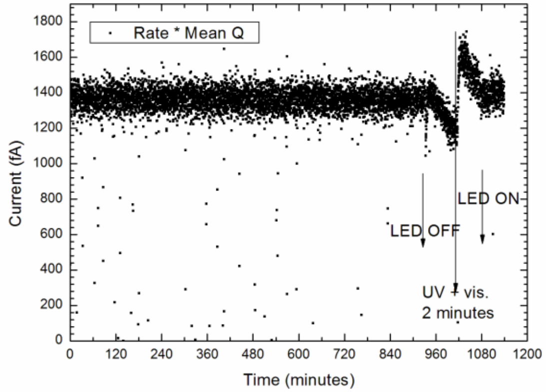
α + 2 White LED's

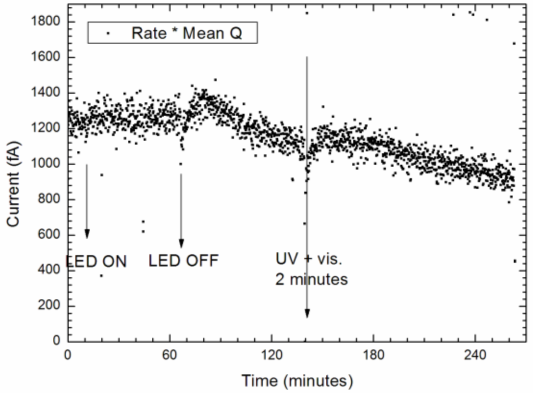








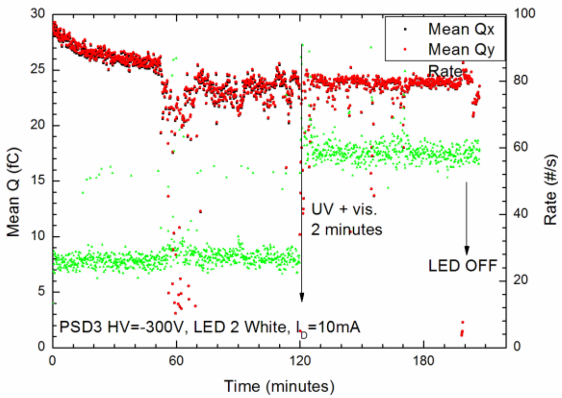


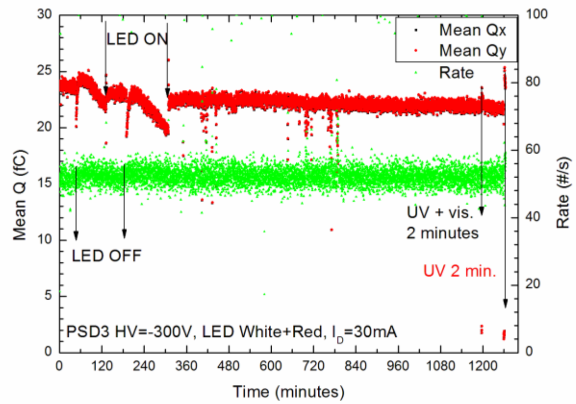


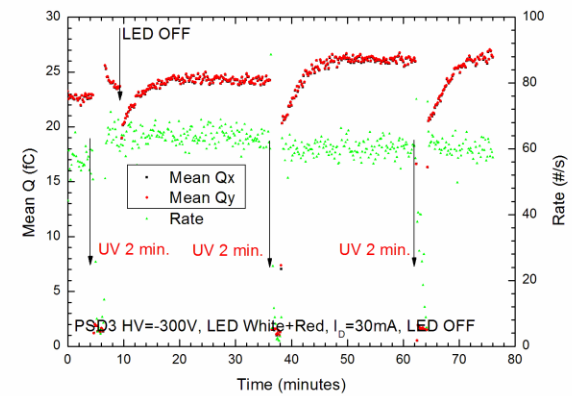
α + 2 White LED's after ~70 hours of β + γ pumping

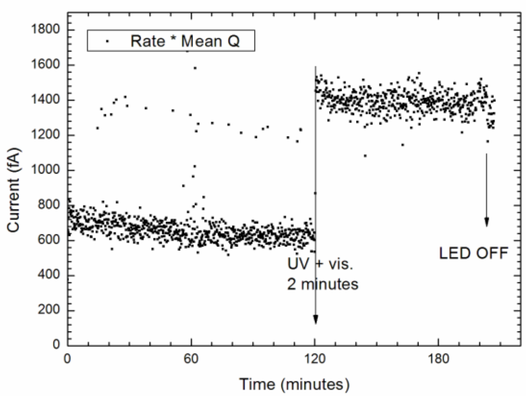
α + (Red + White LED's)

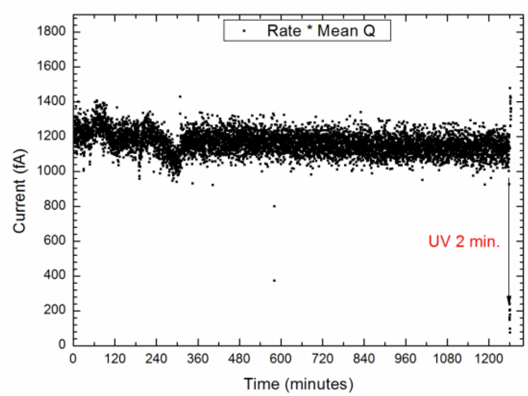
α + (Red + White LED's)

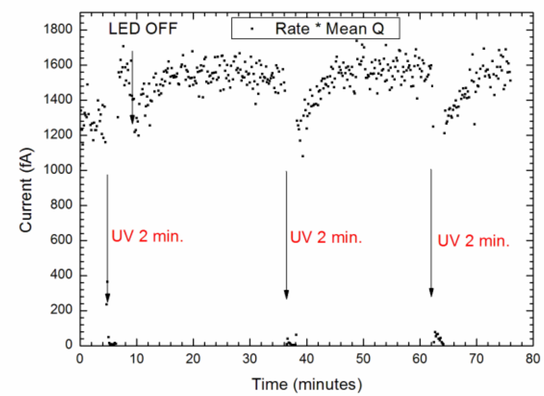












Summary and outlook

- We understood and corrected the hardware errors made in the U304 experiment:
  - The detector – CSA coupling capacitor 1nF modified to 22 nF;
  - the FEE peaking time not matched with the detector time constant;
- The test in ^{12}C micro-beam confirmed that the LACPSDD concept works!
  - The correction of the 2D nonlinearity can be done if the detection system is very stable.
  - The detector polarization must be minimized!
- The Alpha tests of three types of detectors (one pc and two DoI) have shown that the long term irradiation (tens of hours) with β and γ decrease the detector polarization.
- For one detector (DoI) we find that white + red light irradiation stabilize the detection.
- The U – I characteristic of three detectors (all having the old DLC technology) is unsymmetrical; one detector made with the new DLC technology has a symmetrical behavior.
- We must: 1) repair two detectors with the new DLC technology, 2) continue the polarization tests and 3) repeat the ^{12}C micro-beam tests.
- We consider very promising for the future the DoI material.
- By using multiple parallel mounted LACPSDD detectors it will be possible to verify the correct execution of an irradiation prescription In Carbon-ions Cancer Therapy.

Acknowledgment

- The work in Romania was supported by the Romanian Space Agency under the STAR program, contract 61/2013 DIADEMS.

- The support of the ADAMAS collaboration is gratefully acknowledged as well.