Performance of CVD Diamond Detectors Irradiated by Carbon Beams

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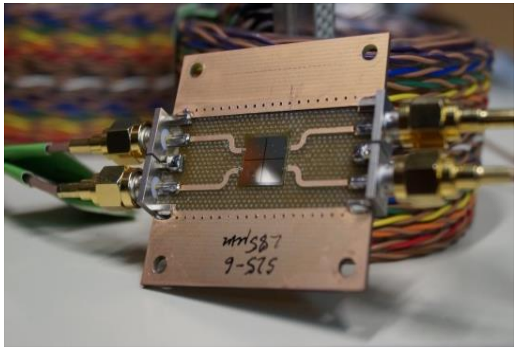
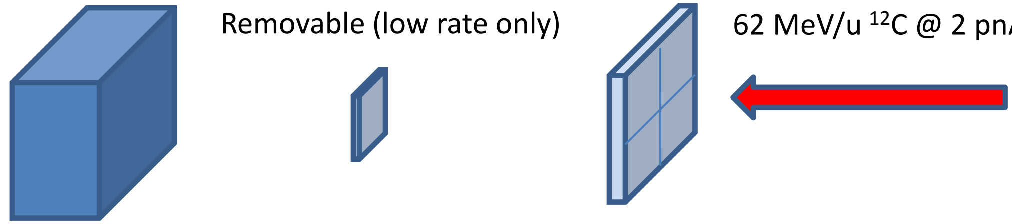
LNS 2015: Radiation Hardness Tests





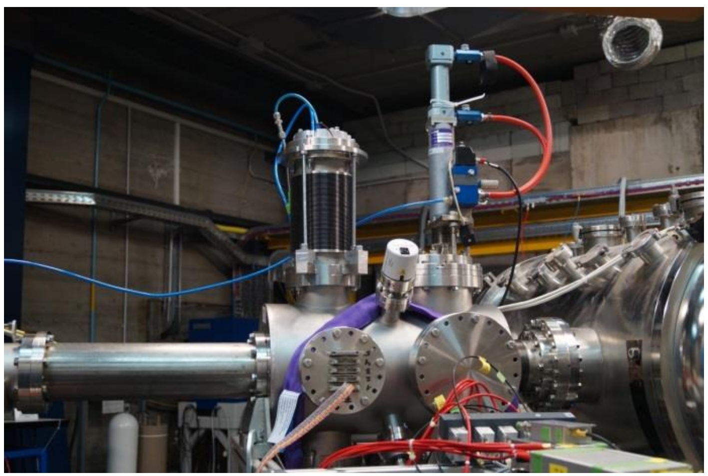
IC

Removable (low rate only)

62 MeV/u ^{12}C @ 2 pnA

1 x SC CVD
Area: 2x2 mm^2
Bias: +100 V
Electrodes: Au 100 nm

1 x 4 Quad PC CVD
Area: 10x10 mm^2
Bias: +300 V
Electrodes: Cr/Au, 50/150 nm



Schlemme et al. 2017 under preparation.

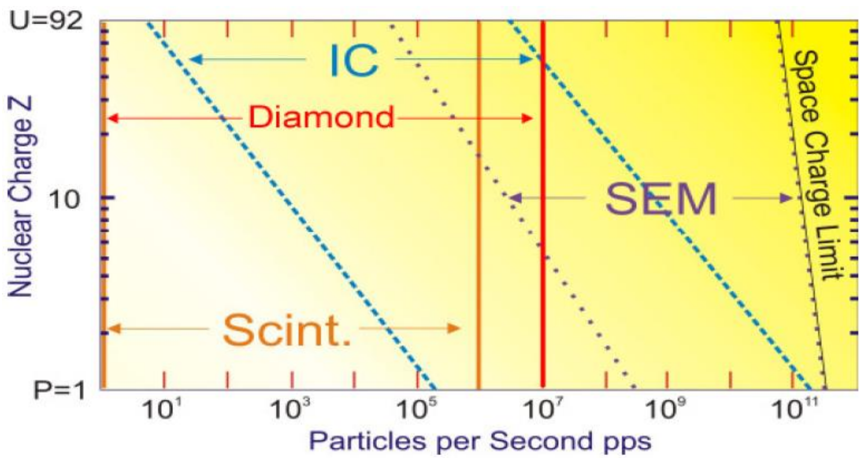
Summary:

- ❑ Unchanged signal properties of the pcCVD DD after 40 hours of irradiation;
- ❑ Variation in the signal properties of the scCVD DD after 12 hours of irradiation;
- ❑ Deposited Dose = 1.8x10^6 Gy (^{12}C@62 MeV/u) equivalent to ~ 400 days of operation at Super-FRS;
- ❑ Other characteristics: σ < 45 ps; *rate* > 500 Hz/mm^2 [F. Schirru et al., J. Phys. D: Appl. Phys. **49** (2016)].

Super-FRS requirements fully met.

LNS 2017: Motivation

A new particle detector combination (PDC) is under development at GSI. The system will be used to measure the expected high primary beam intensities at FAIR (up to a factor of 10-100 over present) and the consequently increasing intensities of radioactive beams produced at the Super-FRS.



In its present design, the PDC is made up of three different detectors able to cover the wide range of particle rates.

- ❑ DDs [Lower Rates]
- ❑ IC [Medium Rates]
- ❑ SEETRAM [Higher Rates]

Why diamond detectors?

- ❑ In principle, ability to work at higher particle rates (up to 10^7 particles/s);
- ❑ Radiation Hardness (pcCVD DD);
- ❑ Material available in larger sizes (pcCVD DD).

LNS 2017: The Goals

- ❑ Study of the response and calibration of the DDs, IC, SEETRAM by means of 62 MeV/u ^{12}C beams at different rates between 10^3-10^{10} Hz.

In addition…

- ❑ Verify the correct functioning of the DDs for E > |1| V/µm;
- ❑ Verify any evidences of radiation damages on the scCVD device;
- ❑ Calculate the efficiency ratio of the pcCVD/scCVD DDs;
- ❑ Compare the DDs performance by using two different preamplifiers;
- ❑ Compare the DDs performance by using two different cable lengths.

Extra Task…

- ❑ Evaluate the x-rays response of the DDs before and after performing the PDC test.

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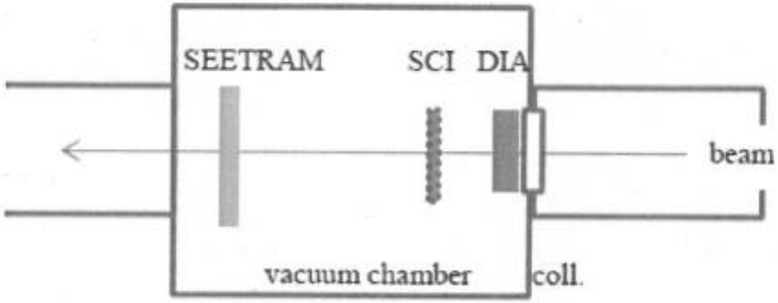
Experimental Setup @LNS



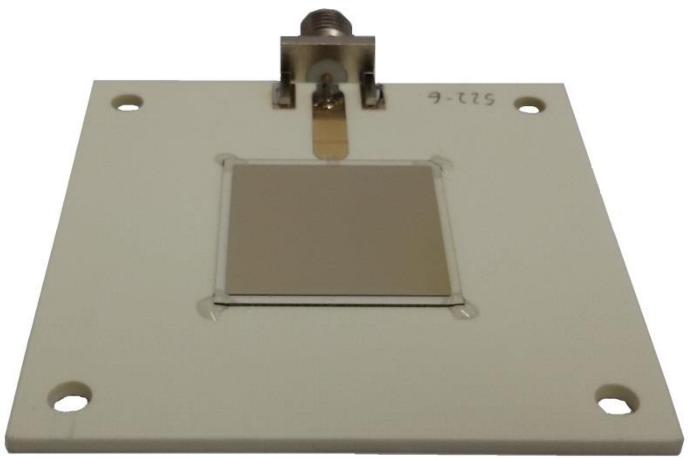
- ^{12}C @62 MeV/u, 2 pnA
- Collimator, ∅ 2.5 mm

Detectors:

- scCVD DD, 3.23x3.23x0.16 mm
- pcCVD DD, 18x18x0.3 mm
- SCI, 100x100x0.25 mm
- SEETRAM, 3 foils each 24 µm

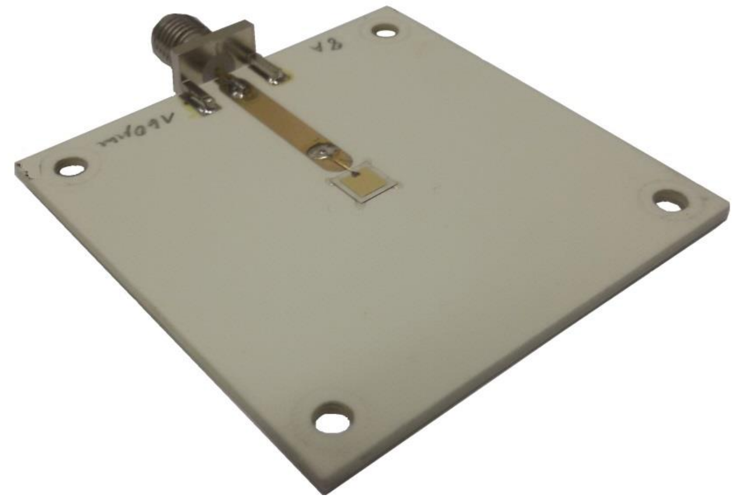
The DDs signals were amplified with the DBA III and then sent either to the oscilloscope (100 ps/bin) or to the discriminator and scaler (VULOM/CAEN) for data acquisition.

Diamond Detectors



pcCVD diamond detector E6_622-5

Thickness	300 µm
Surface Treatment	Oxygen Termination
Electrode Type	Au, 100 nm
Area	20.0x20.0 mm^2
Active Area	18.5x18.0 mm^2



scCVD diamond detector E6_534-8A

Thickness	160 µm
Surface Treatment	Oxygen Termination
Electrode Type	Au, 100 nm
Area	4.2x4.2 mm^2
Active Area	3.23x3.23 mm^2

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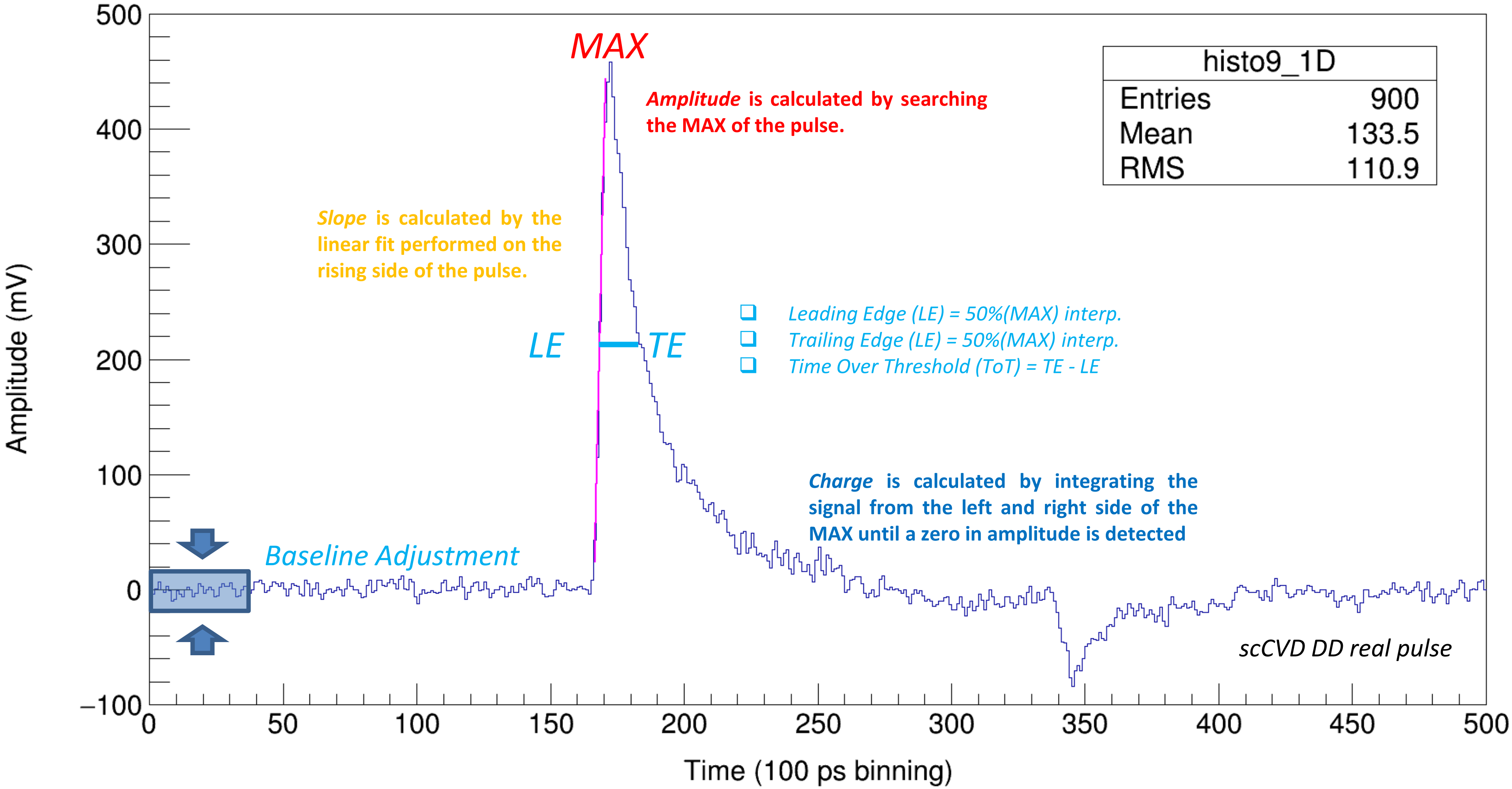
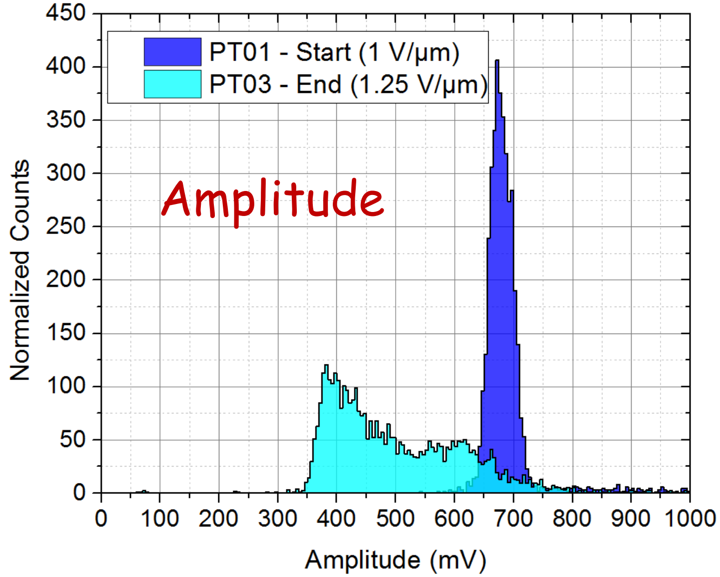
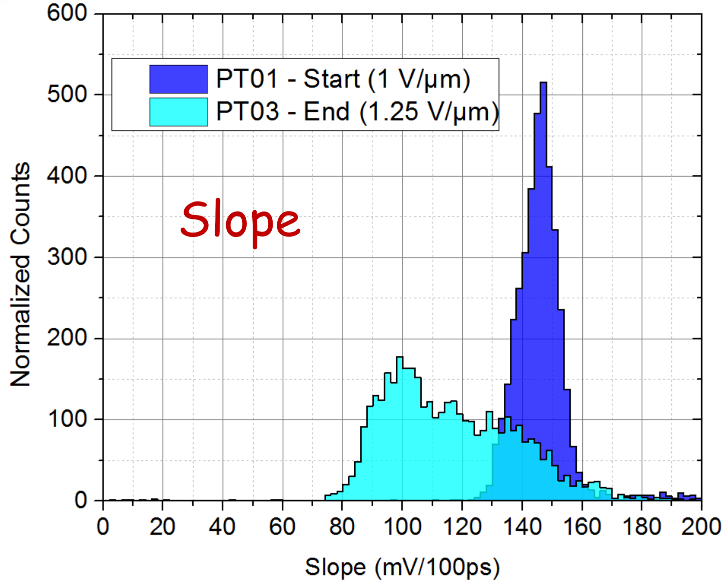
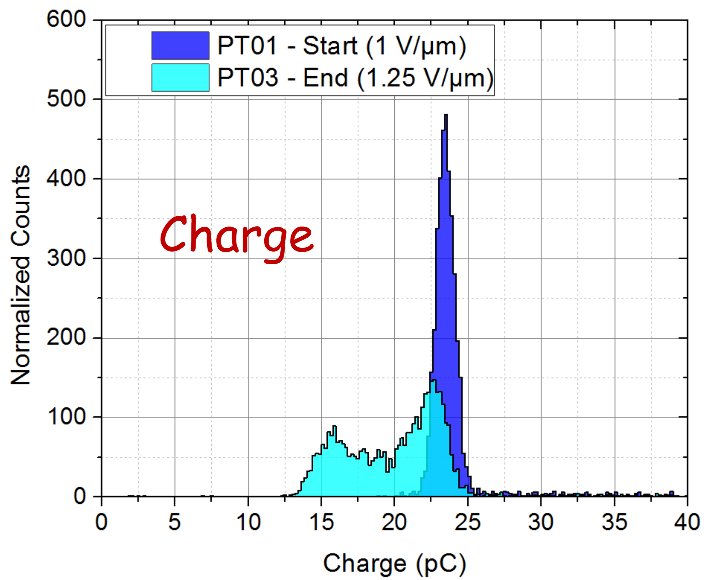
Waveforms Processing



Signal Distributions (scCVD DD)



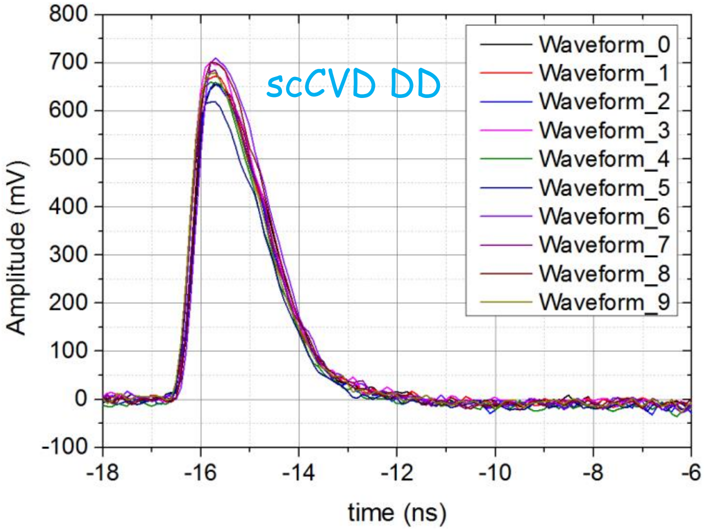


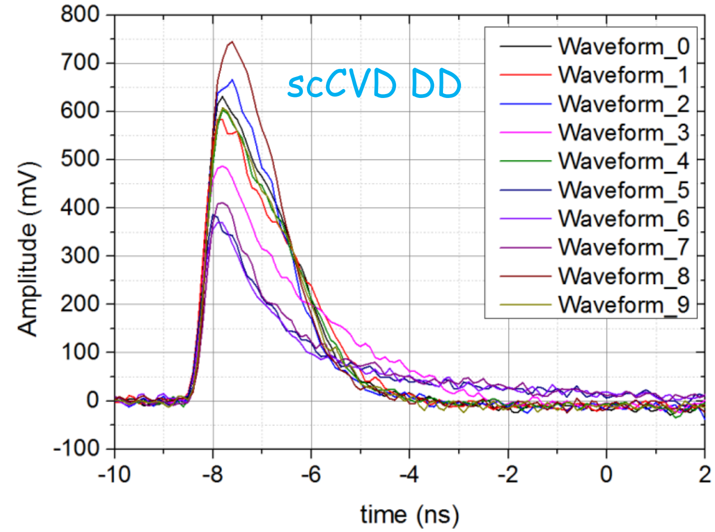


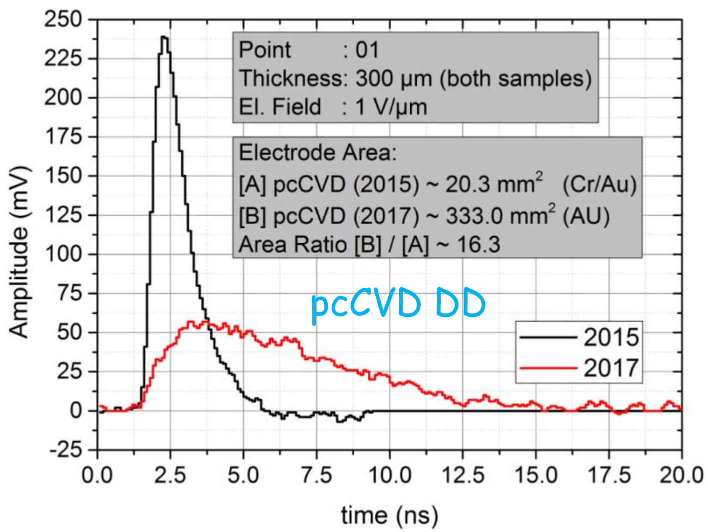
Remarks:

- ❑ Broadening of the distributions with double peaks;
- ❑ Scintillator distributions still good;
- ❑ Unknown accumulated dose;
- ❑ The minimum dose at which the device was still operating correctly is ~20 kGy.

Diamond Detectors Waveforms







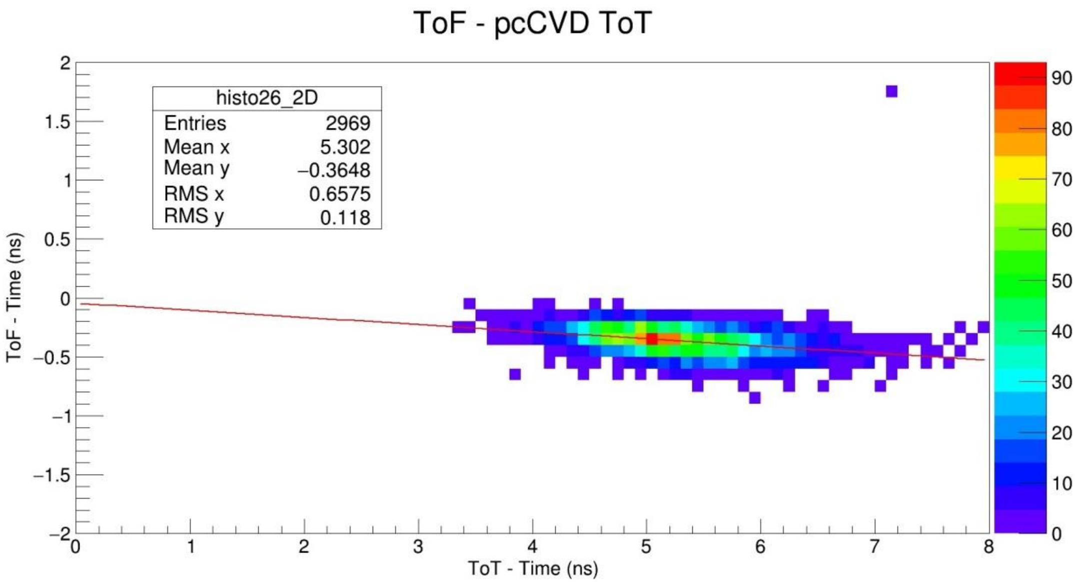
Remarks (scCVD DD):

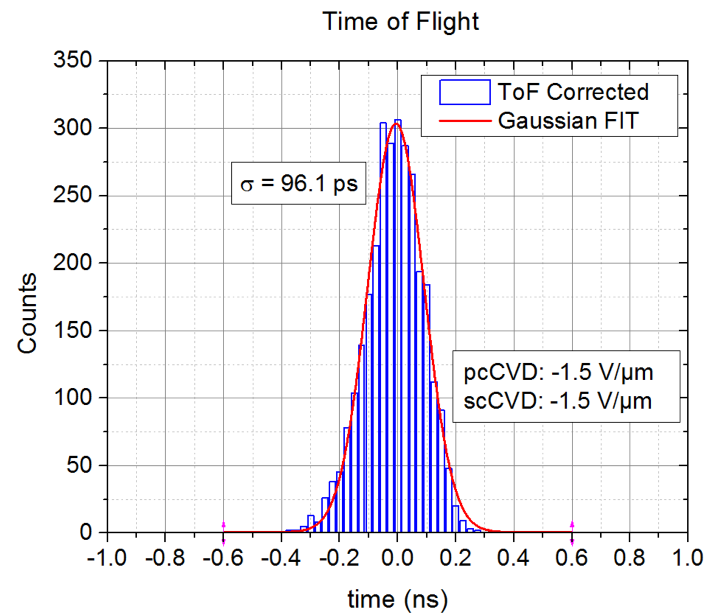
- broad range of signal amplitudes after beam exposure;
- different decay times;

Remarks (pcCVD DD):

- larger area electrodes compatible with signals having smaller slope and longer decay times.

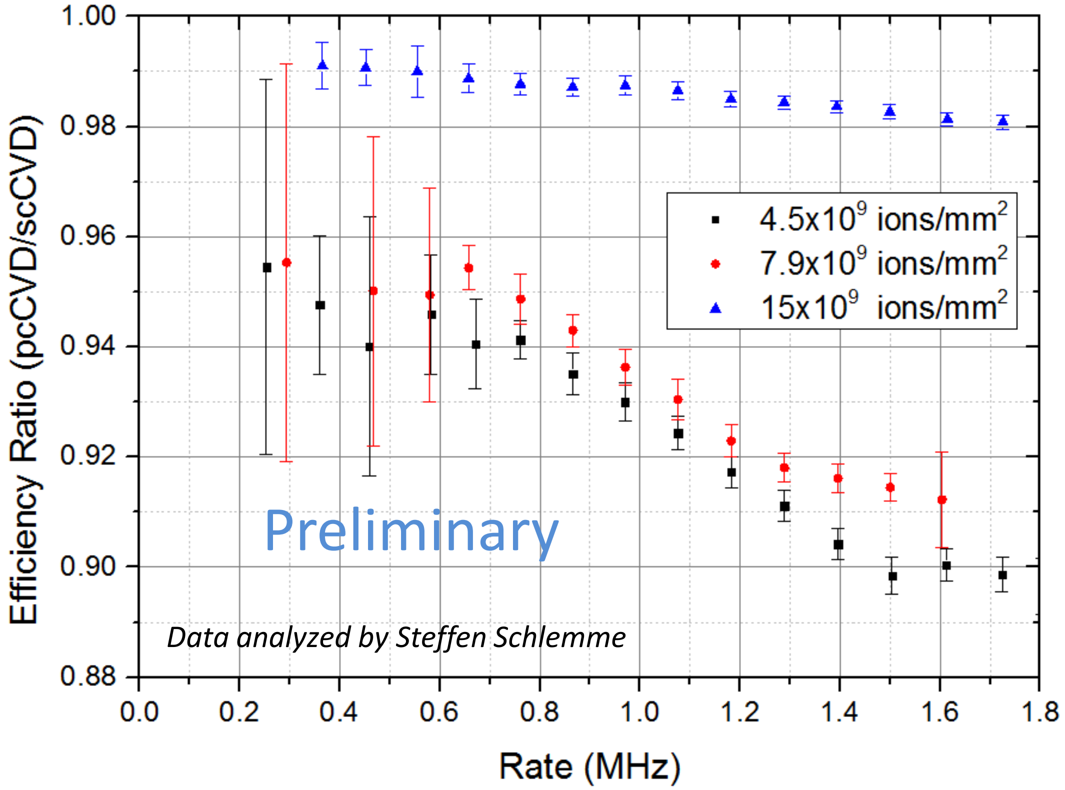
ToF Assessment





- ToF measurements performed for E = 1 V/µm and E = 1.5 V/µm on both DIA devices;
- σ correction obtained by linear fit between ToF and pcCVD DIA ToT distributions;
- For E = 1.5 V/µm, correction leads to σ ~96 ps;
- Only slight improvement (few percent) of σ for E = 1.5 V/µm.

Efficiency Assessment



- pcCVD DD @ -350V;
- scCVD DD @ -200V;
- Rate given by SEETRAM.

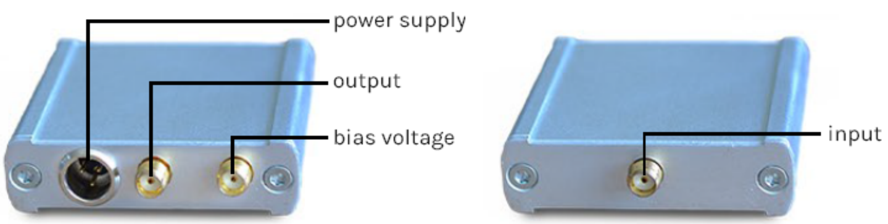
E_{pcCVD} = [94.9 ± 1.8]%

Efficiency Ratio vs Rate ⇩

Efficiency Ratio vs Dose ⇧

PA-20 vs DBA III (Specifications)

Type	current preamplifier
Gain	20 dB
Energy range	100 MeV
Bandwidth	1 MHz - 1.5 GHz
Noise RMS	190 µV (19 µV input referred)
Input impedance	50 Ω
Output impedance	50 Ω
Input/output coupling	AC coupled
Input polarity	bipolar
Output polarity	bipolar (inverting)
Linear output voltage range	+/- 1 V
Max. bias voltage	+/- 500 V
Power supply	+12 V, 45 mA

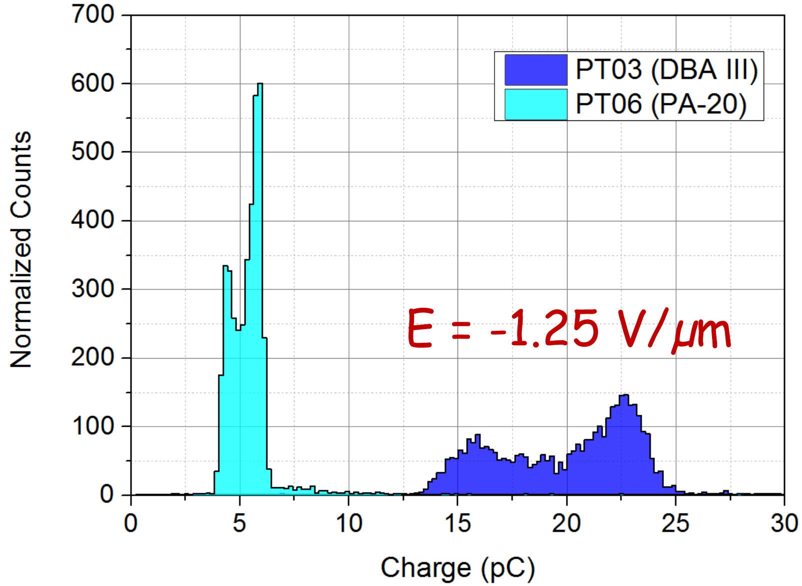


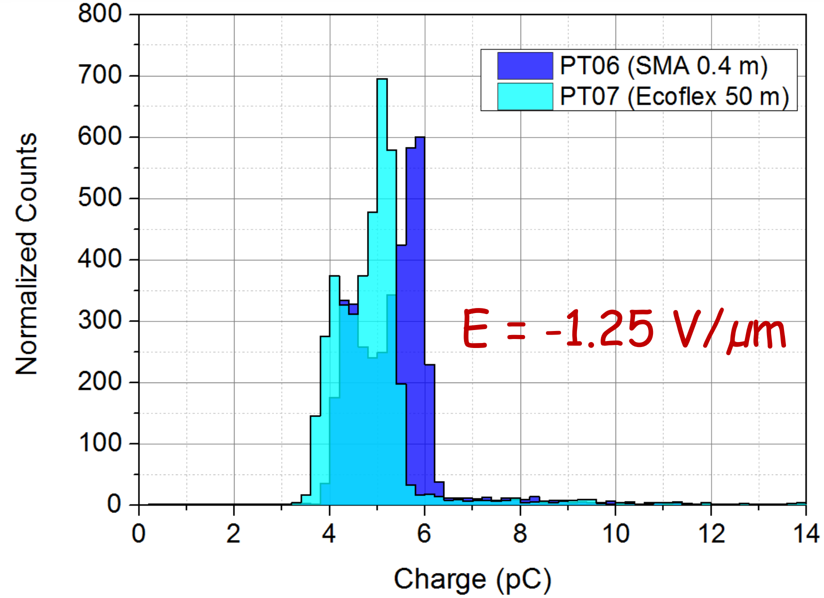
Size	65 mm x 55 mm x 15 mm
Box material	aluminium with RF shielding
Signal connectors	SMA female
HV connector (detector bias)	SMA female
Power connector	mini XLR (power supply cable included)

http://widebandamplifiers.com for more info

Type	DBA-III/R
Description	GaAs 2-stage MMIC Inverting Broadband Amplifier
Bandwidth (-3 dB)	0.003 - 2.3 GHz
Gain	+42 dB
Input Impedance	50 Ohms, SWR <1.5
Output Impedance	50 Ohms, SWR <1.5
Noise Figure (Input terminated)	3 dB
Max. Output Power Level	+18dBm / $2V_{peak}$
Max. Bias Voltage for the Detector	+/- 2000V, no input protection, the biased input must not be shorted to ground or disconnected !
Power Supply	+12 V, 100mA
Dimensions	Length: 95mm, Width: 47mm, Height 25 mm
Connectors	RF in/out, Bias: SMA; Power: LEMO 4pole

PA-20 Tests (scCVD DD)





File Set	Amp Type	Amplitude (mV)	Slope (mV/100 ps)	Charge (pC)	LE (ns)	Cable (m)
3	DBA III	391.05	97.95	15.65	16.92±0.04	0.4
3	DBA III	600.76	137.19	22.84	"	0.4
6	PA-20	83.16	16.59	4.41	16.87±0.04	0.4
6	PA-20	127.73	22.96	5.53	"	0.4
7	PA-20	52.48	7.84	3.83	16.82±0.07	50
7	PA-20	84.20	10.73	4.88	"	50

Preamp Comparison (File Sets 3 and 6)

Cable Comparison (File Sets 6 and 7)

Data obtained by Gaussian fit of the distributions generated with over 4000 recorded waveforms per set with the scCVD diamond detector.

RG214 cable leads to:

- ❑ decrease of the signal amplitude by ~35%;
- ❑ decrease of the signal slope by factor ~2;
- ❑ LE noisier

Mini X-rays Setup

Target thickness	1 μm (Au)
Tube Voltage	10 to 50kV
Tube Current	5 μA min. / 200 μA max.
Approximate Dose Rate	Dose Rate ~1.3 Sv/h @ 30 cm
Collimator	2 mm

Settings

- ❑ Detector distance : ~10 mm;
- ❑ Tube voltage : 40 kV;
- ❑ Tube current : 90 μA;
- ❑ Collimator : 2 mm ∅ (x-rays flux within a cone of 5º).

The metallic box itself, without detector being connected, has an intrinsic leakage current in the order of 10^{-13} A for ±500 V voltage applied.

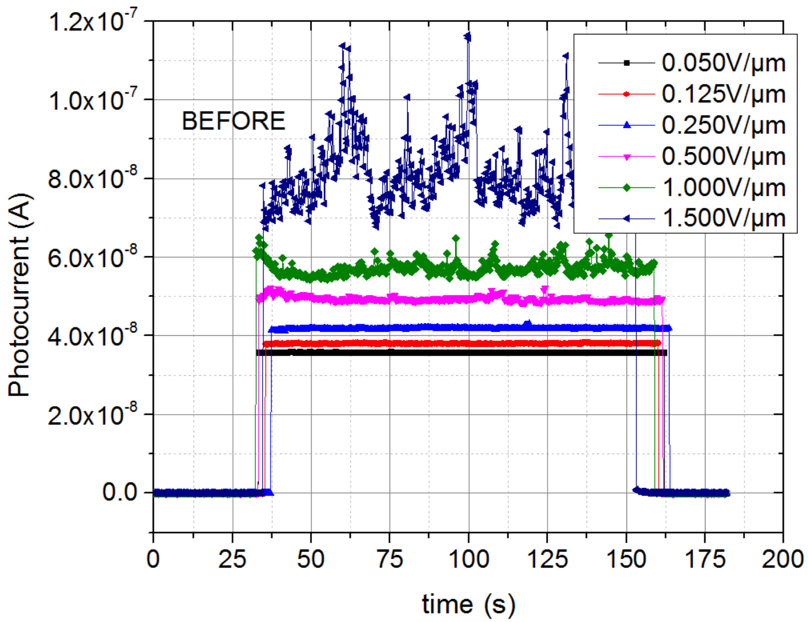
Measurement Program (scCVD DD)

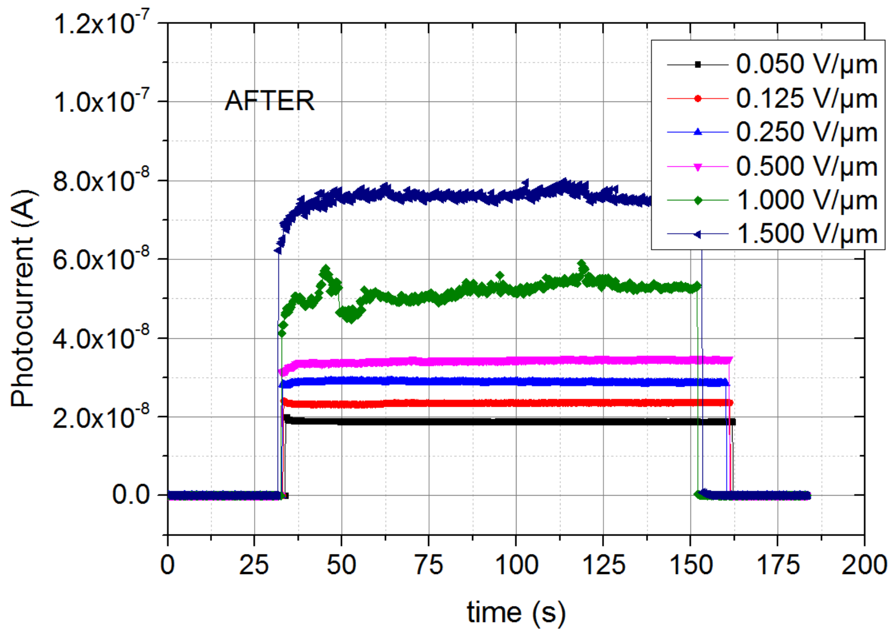
Chronological Order

- ❑ Evaluation of the photocurrent characteristics (dynamic response and fluctuation of the signal) for different voltages applied;
- ❑ Measurement of the *I-V* characteristics of the leakage current;
- ❑ Long term measurement (over 160 minutes) to check the stability of the detector signal at different stages.

Bias (V)	El. Field (V/µm)
-240	-1.5
-160	-1
-80	-0.5
-40	-0.25
-20	-0.125
-8	-0.05
0	0
8	0.05
20	0.125
40	0.25
80	0.5
160	1
240	1.5

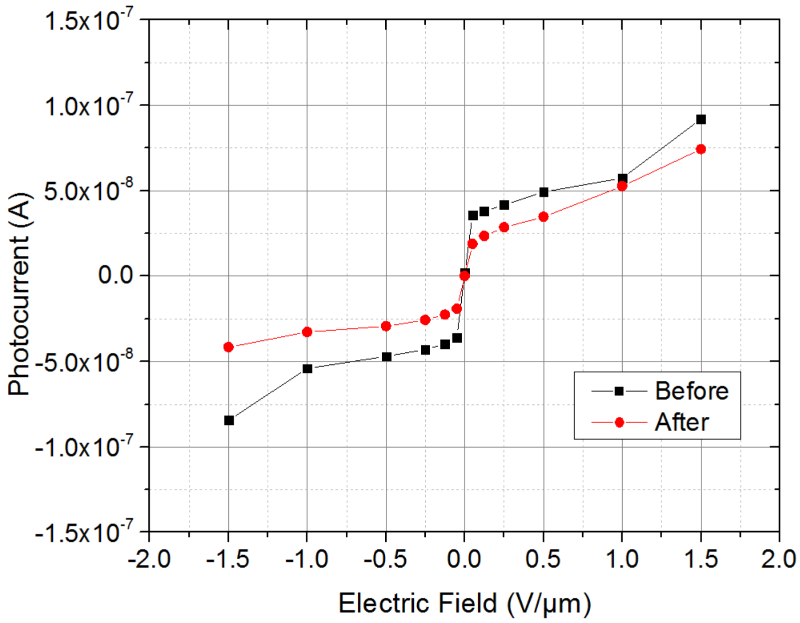
Dynamic Response & Signal Fluctuations

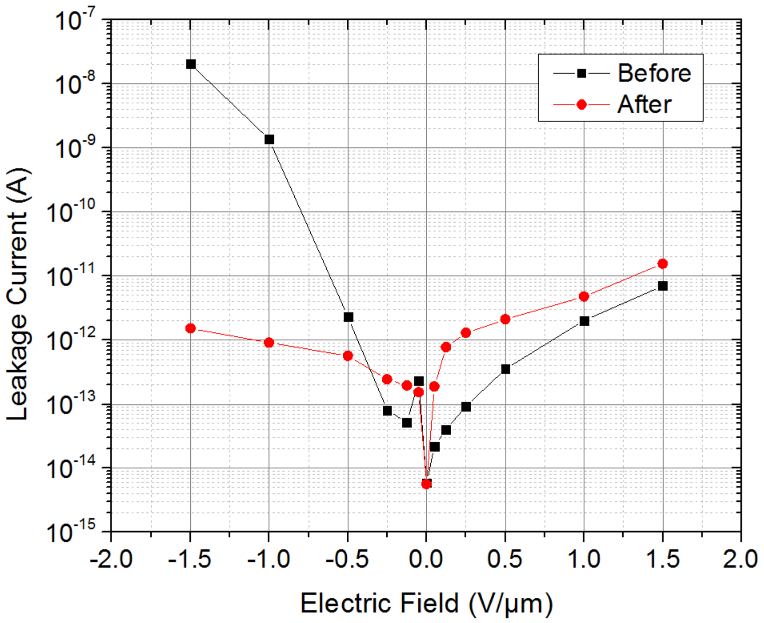




- ❑ Generally, similar behaviour;
- ❑ Slightly lower value of the photocurrent (AFTER) especially at lower voltages;
- ❑ The detector exhibits faster saturation (x-rays ON) of the signal for $E < 1$ V/µm;
- ❑ Instability of the signal for $E > 0.5$ V/µm;
- ❑ Instability decreases for $E > 0.5$ V/µm (AFTER)

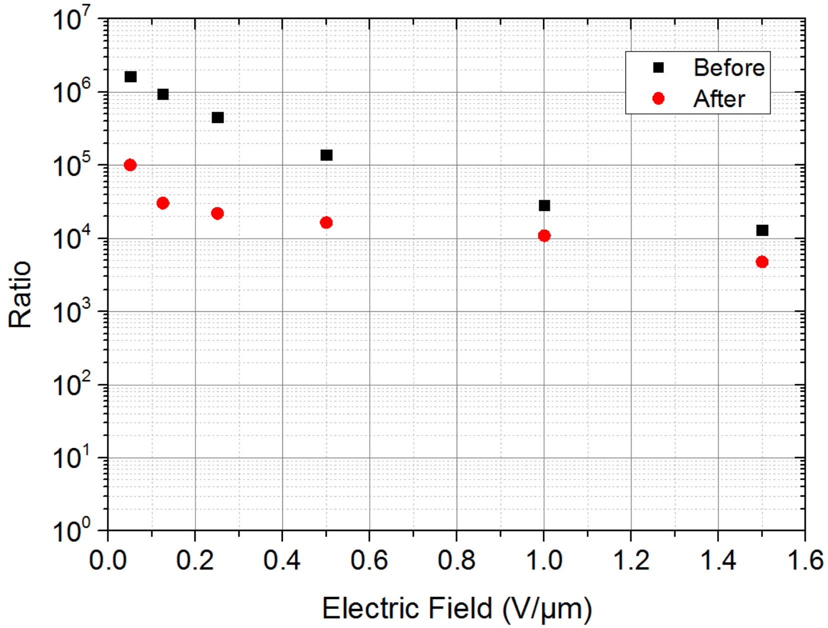
Photocurrent and Leakage Current

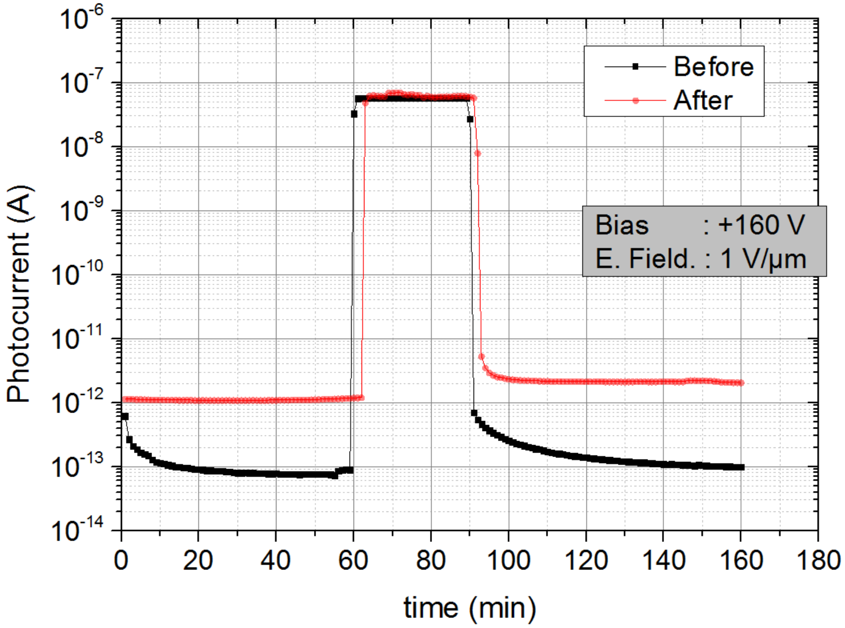




- ❑ Leakage current calculated as average over ten data points recorded just before switching on the x-rays source;
- ❑ Photocurrent calculated as average over ten data points recorded just before switching off the x-rays;
- ❑ Leakage current slightly increases for E > 0 while decreases a few order of magnitudes for high values of E.

SNR & Long Term Measurements





- The SNR differs by one order of magnitude and becomes smaller for E > 1 V/µm;
- The SNR decreases while increasing E since the leakage current increases more compared to the photocurrent;
- Long term measurement at E = 1 V/µm, {60 minutes [leakage current]; 30 minutes [x-rays tube ON]; 70 minutes [photocurrent decay]};}
- 160 points whose value corresponds to an averaged electric current over one minute of measurement;
- Strong instability of the signal.

Contents

Conclusions

- As already observed in the 2015, the scCVD diamond detector shows deterioration of the signal properties after exposure to irradiation;
- The large electrode area of the pcCVD device influenced its performance;
- For beam rate < 1 MHz, the efficiency of the pcCVD diamond detector is > 94%;
- The new preamplifier PA-20 was successfully tested;
- The 50 m cable influences the ToF and the signal properties of the scCVD device. Detector counting can be compensated by adjustments of the electronics settings;
- The x-rays tests confirms the worsening of the scCVD diamond detector signal properties;
- Signal instability due to high electric field applied is still an issue to be solved.

Acknowledgements

The research leading to these results has received funding from the European Union HORIZON2020 research and innovation programme under Grant Agreement n. 654002 - ENSAR2

Collaborators:

J. Enders[2], P. Figuera[3], J. Frühauf[1], M. Jastrzab[4], M. Kiš[1], A. Kratz[1], N. Kurz[1], C. Nociforo[1], S. Salamone[3], S. Schlemme[1,2], B. Szczepanczyk[1], M. Träger[1], R. Visinka[1]

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Thank you!

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