INTERNATIONAL WORKSHOP ON RADIATION IMAGING DETECTORS 25-29 JUNE 2023

ON SENSITIVITY OF DETECTORS BASED ON HYDROGENATED AMORPHOUS SILICON (A–SI:H) FOR MEASURING RADIATION BEAMS

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HASPIDE PROJECT

The **HASPIDE** project wants to explore the possibility to use **a:Si-H** as a detection material for ionizing radiation of different types.

The demand for radiation-resistant detectors is increasing due to clinical procedures that require high fluxes of particles, new detectors for dosimetry and flux measurement is highly desirable .

The project aims to reach different applications:

⬤ **Clinical Dosimetry** and **Beam monitoring** of clinical and non-clinical accelerators;

⬤ Detection of **cosmic radiation** in space;

⬤ **Neutron** detection;

The project's foundation is the capability already demonstrated to use this material to build devices, such as a detector of ion beam at CNAO.
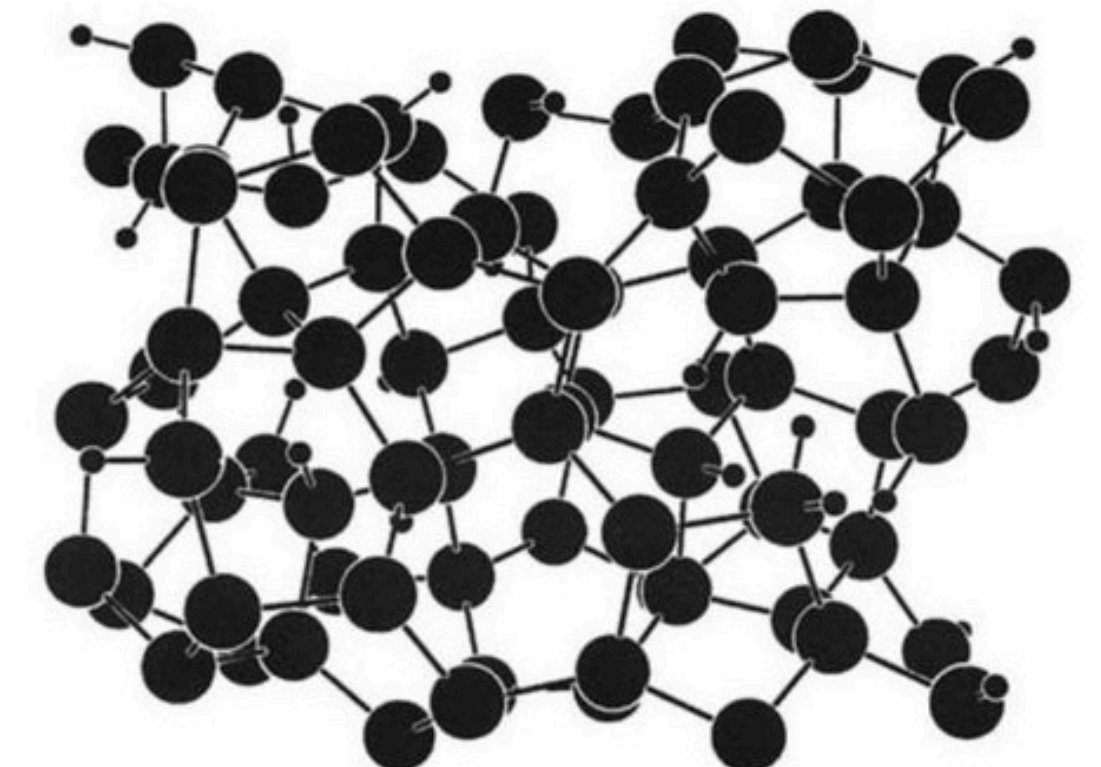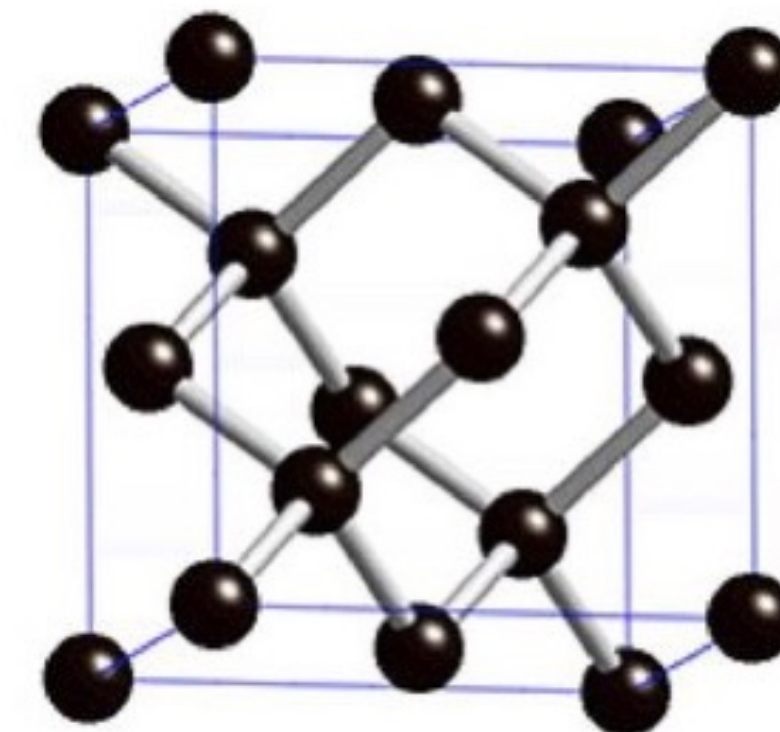
WHY A–SI:H?

We need a **sensitive** material which should have a **high dynamic range** being at the same time very thin, high **radiation resistance**, adjustable geometry and capability of working both in air and vacuum.

a-Si:H is an ideal candidate

The defining property of **amorphous silicon** in contrast to its well-known crystalline form is the absence of long-range order in the atomic positions.
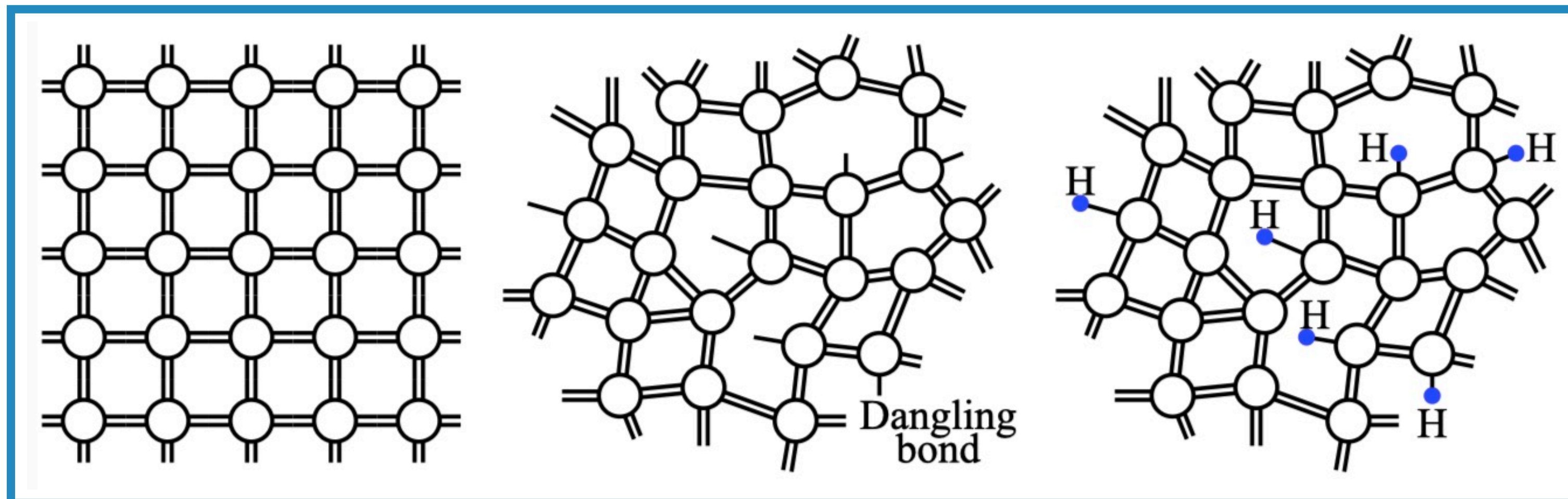
Dangling bond

Hydrogen is introduced to help to lift the over-coordination by the formation of Si-H bonds and to saturate the defects arising from Si dangling bonds

Defects limit the efficiency through the additional electronic states that they generate in the band gap of a-Si

FIRST PROTOTYPE UNDER STUDY

The project will imply the fabrication of several different detector prototypes to assess the performances (basic physical, electrical and charge collection performances).

- Small arrays of **p-i-n diodes** with different areas and diode spacings deposited both on **c-Si** or **Kapton**;
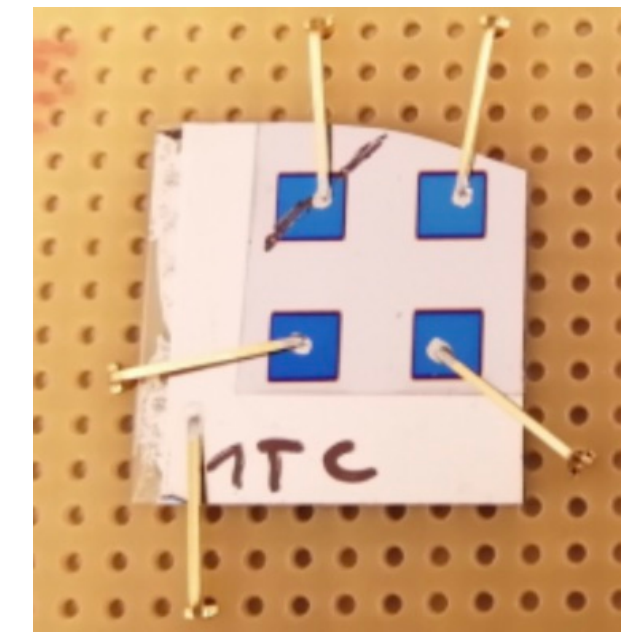
  → tissue-equivalent

- Charge selective contacts (**CSC**);

Different detector configurations differing in **thickness** and **area** of the sensitive volume, **junction type** and deposition **substrate**, have been tested, to study their behavior both in absence and in presence of a radiation source.
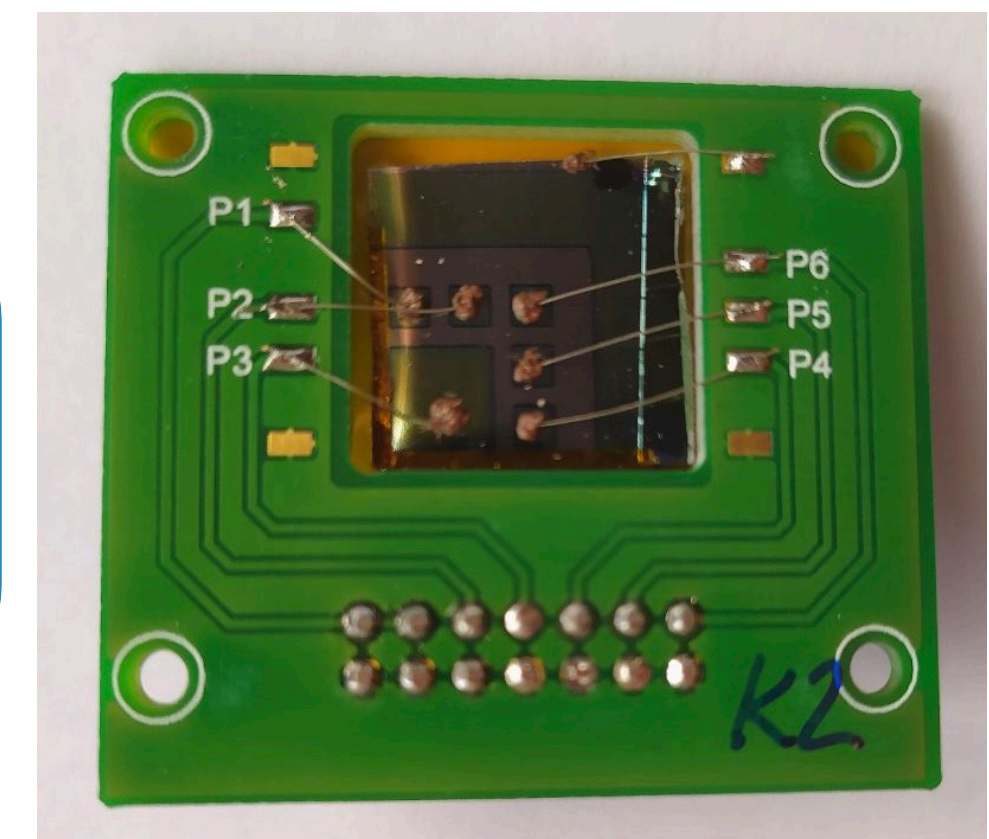
a-Si:H p-i-n
d=10 μm
V=0.0025mm³
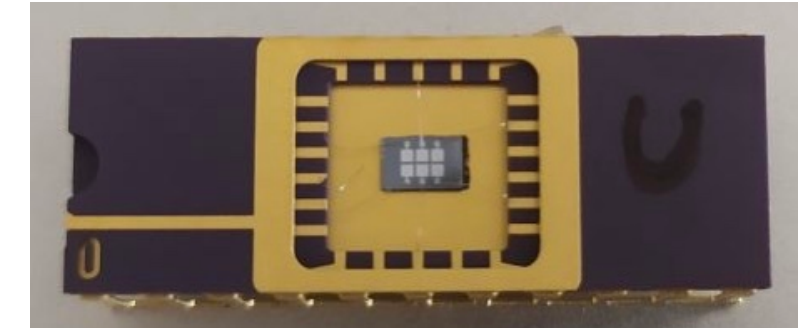
a-Si:H CSC
d=8.2 μm
V=0.13 mm³

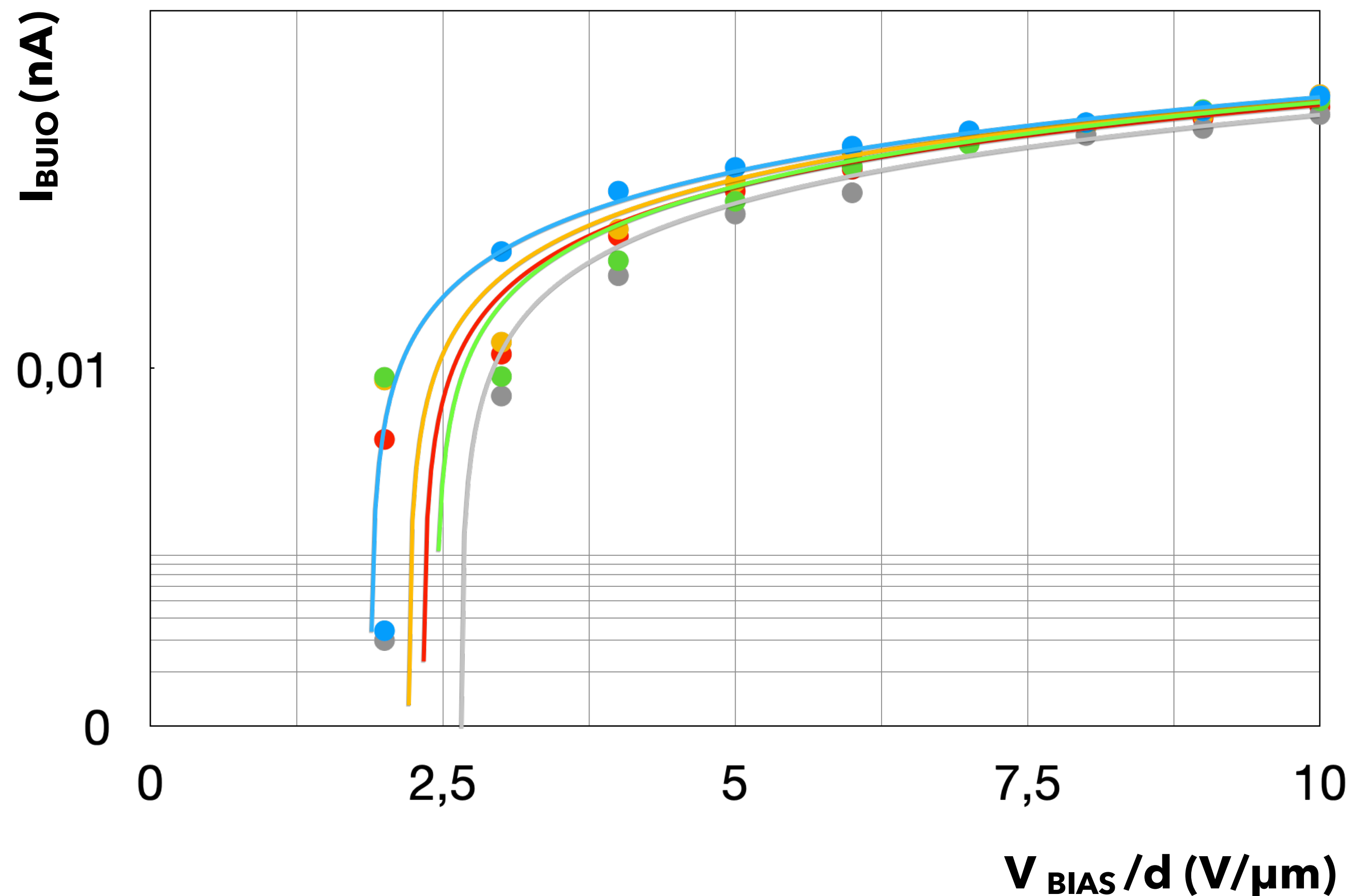**a-Si:H p-i-n**
d=2.5 μm
V=0.06 mm³

PROTOTYPE CHARACTERIZATION

We can state that we are currently able to produce detector that show a **uniform electronic behavior**, with the same geometric characteristic and deposition substrate.

The **noise level** is uniform for all type of prototypes and is in the order of ten **pA**, this implies detection capability around tens of pA with a reasonable signal to noise ratio.

Noise is almost always below 10 pA

~10 pA
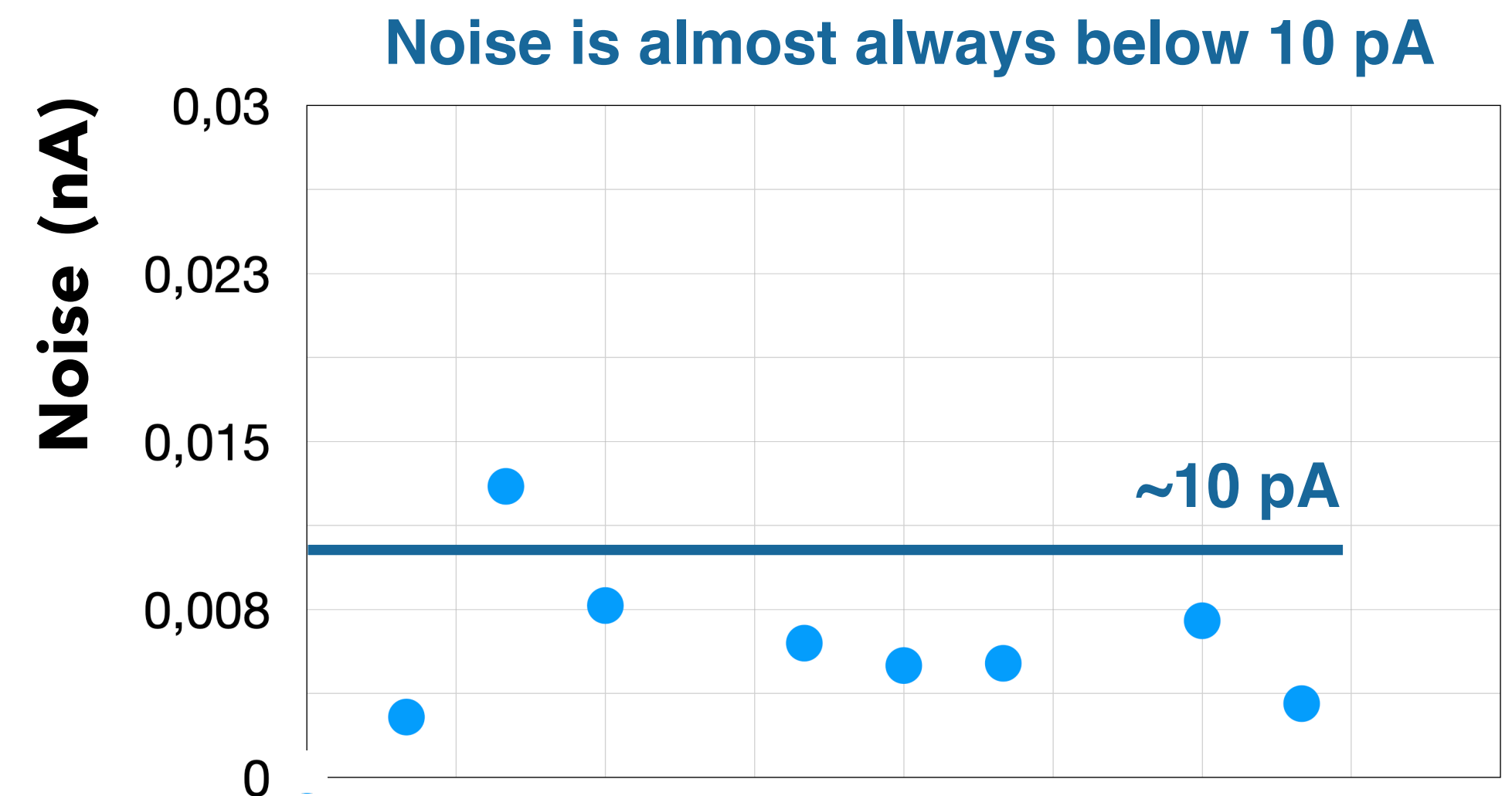
PROTOTYPE CHARACTERIZATION

The second phase of device characterization focuses on the comparison between the different sensors, the aim is to understand if some types are more advantageous than others.

Variables: **contact type**, **substrate** and **thickness**.
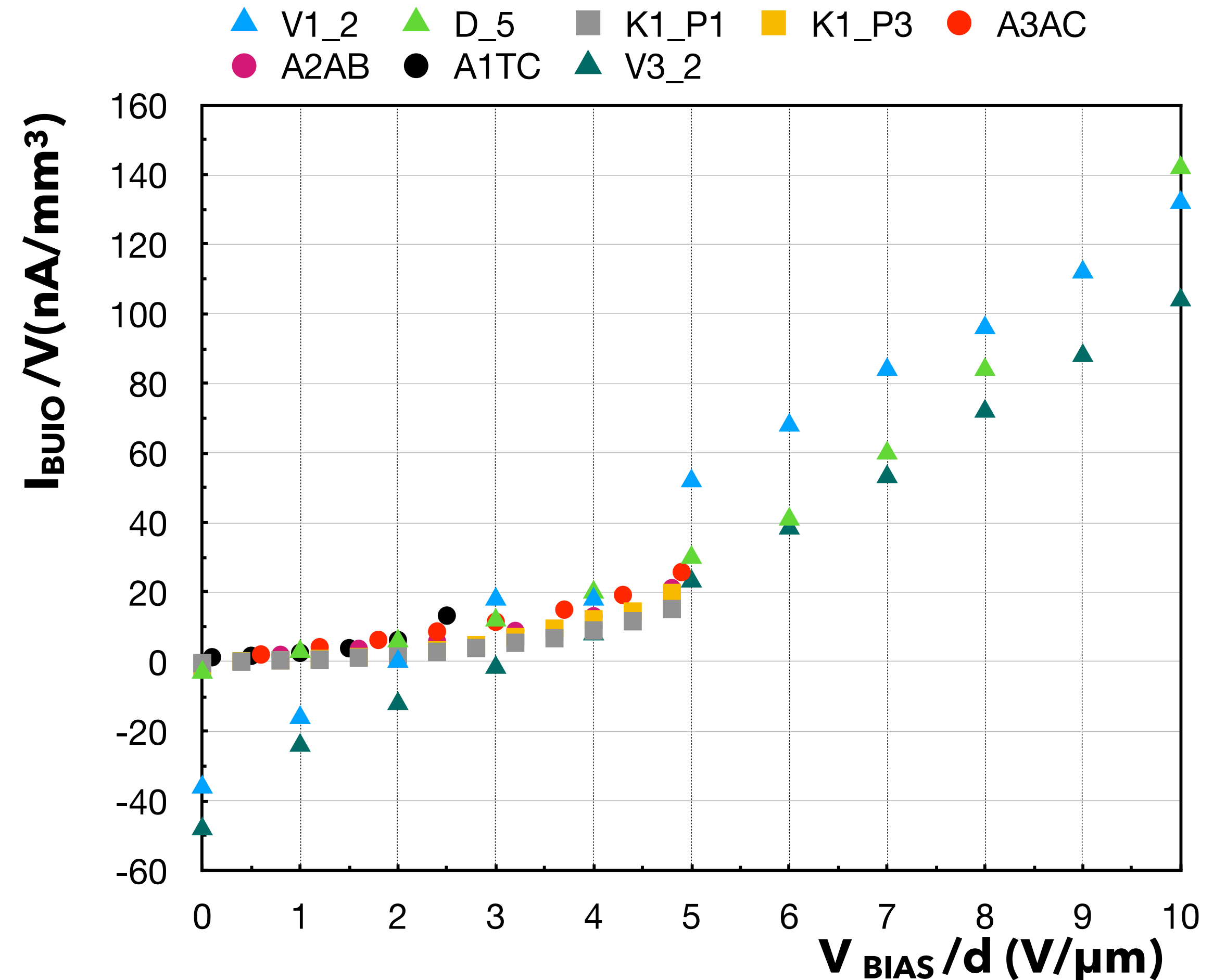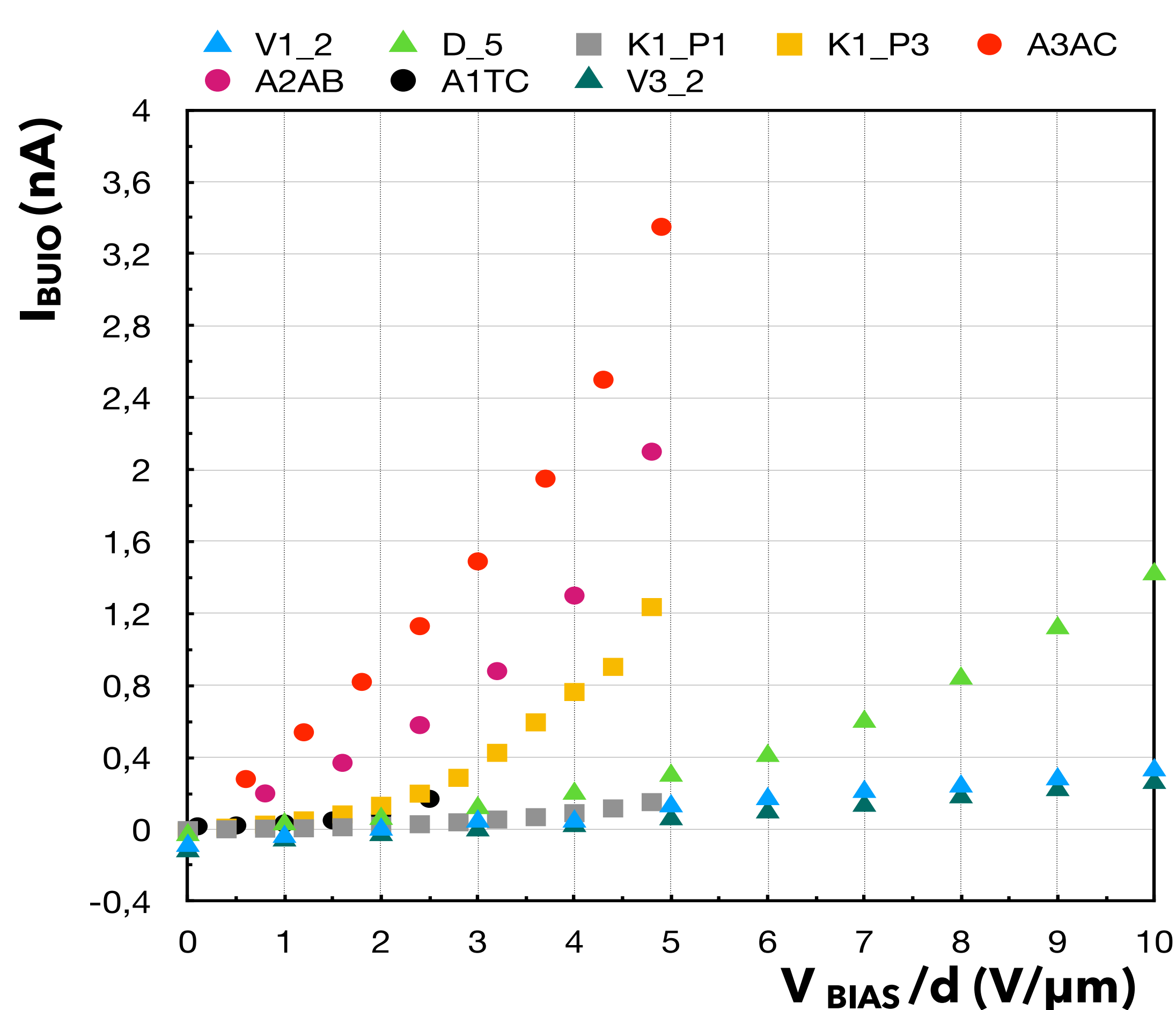
PROTOTYPE CHARACTERIZATION

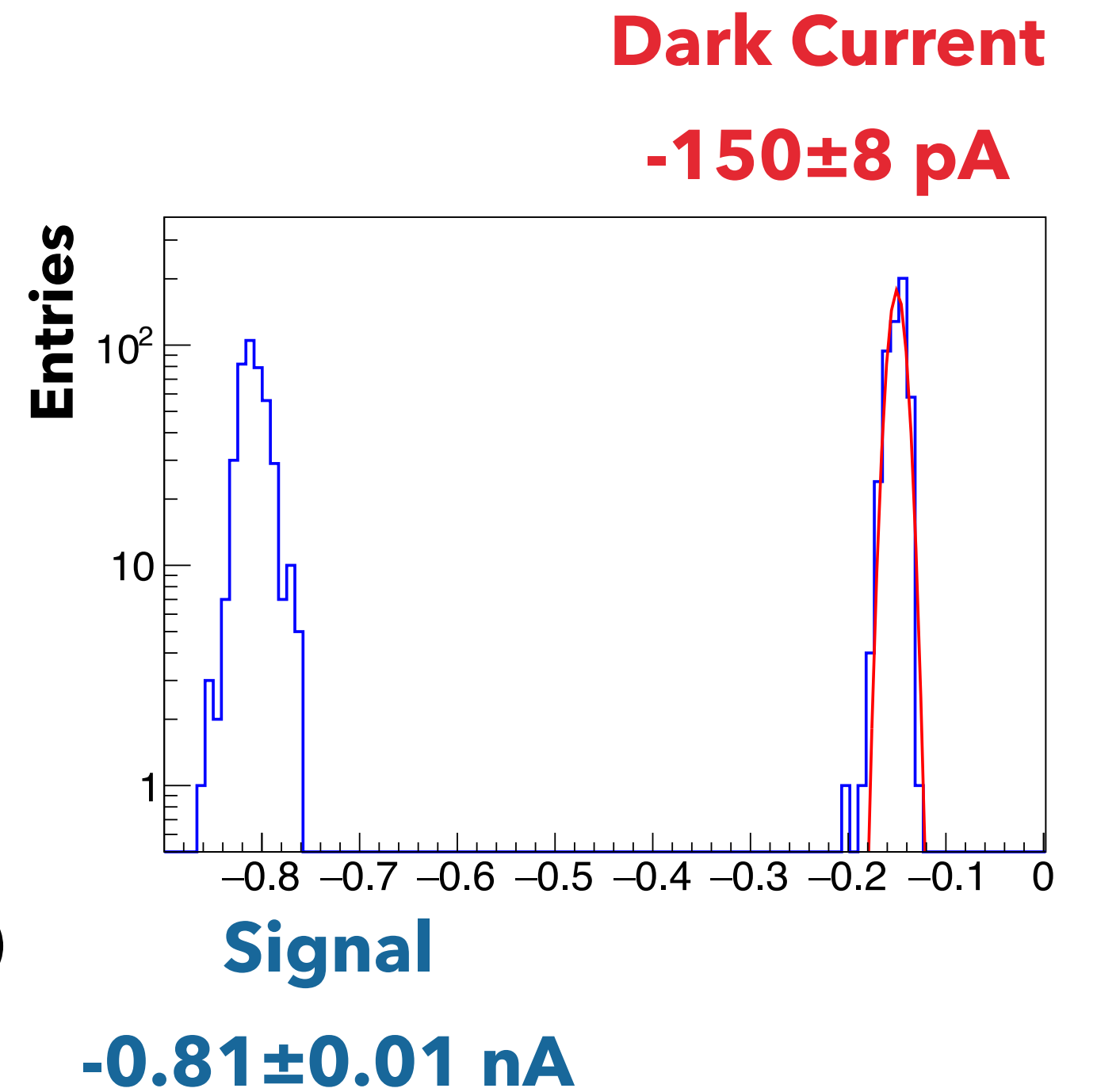All these prototypes were initially characterized in Perugia with an **X-Ray** source.

Dark Current

-150±8 pA

Bias = -8V

Beam on

Signal

-0.81±0.01 nA
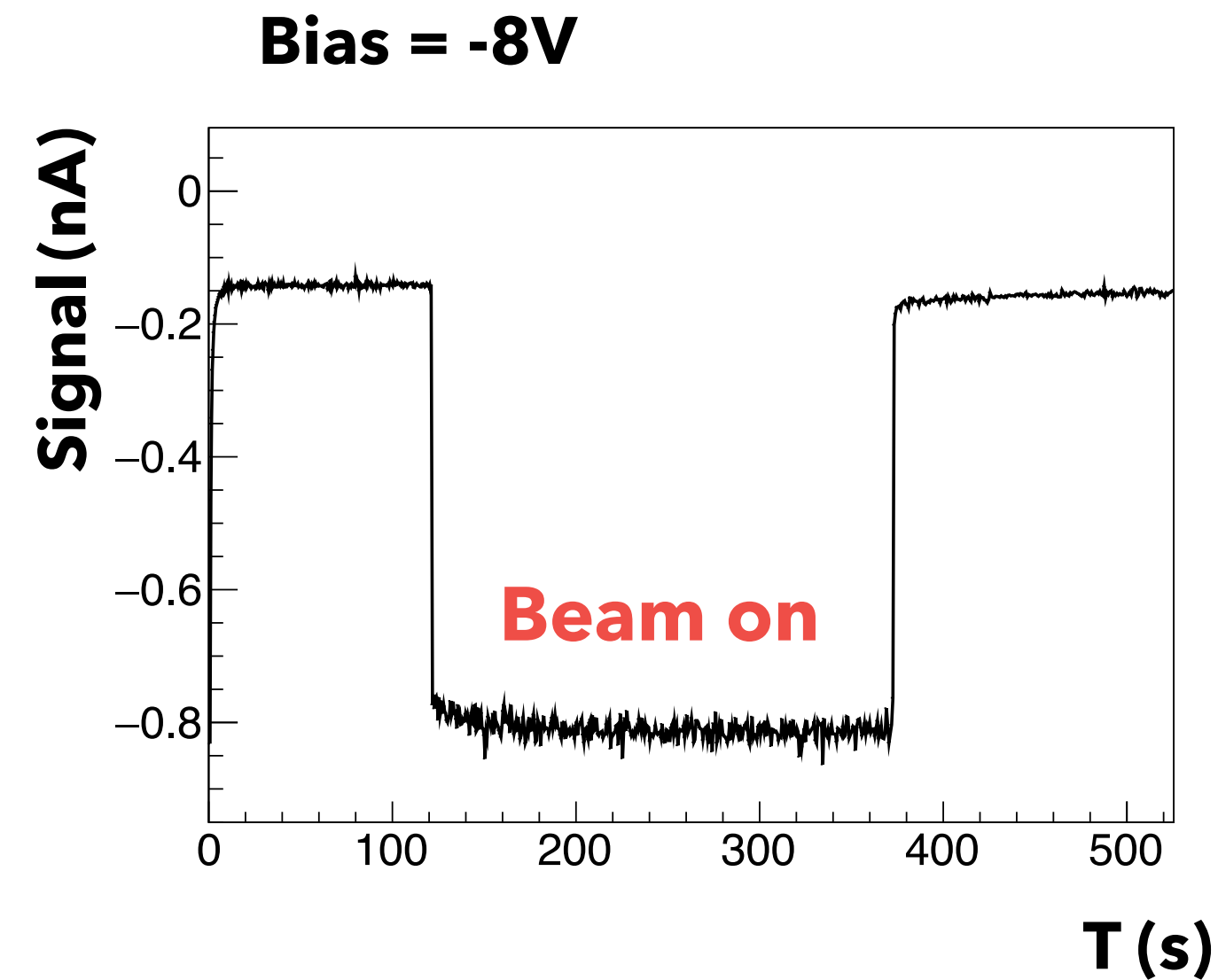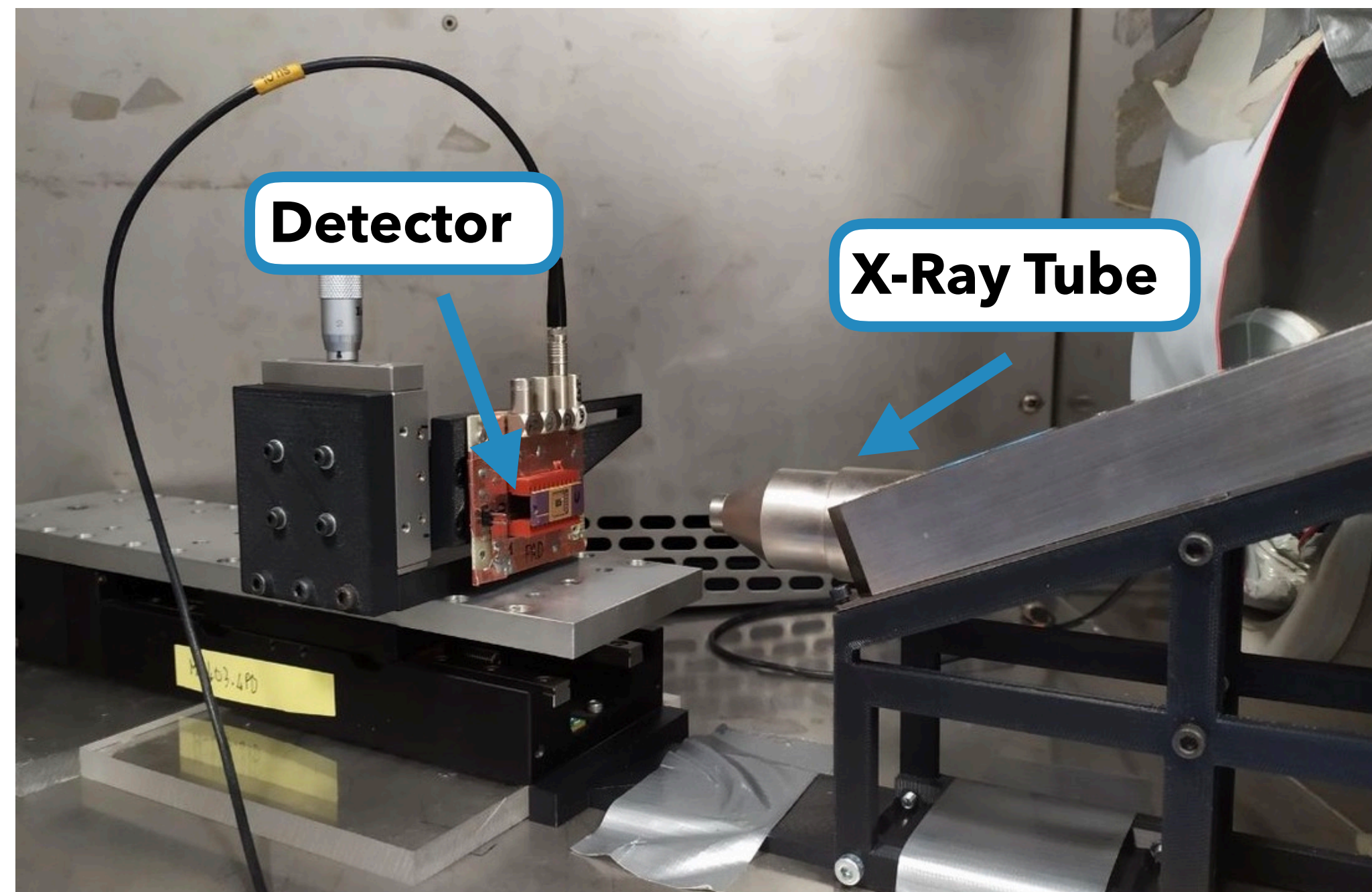
$$S = I_{Signal} - I_{Dark} \qquad \delta S = \delta I_{Signal} - \delta I_{Dark}$$

The values for the signal and noise are extrapolated from the Gaussian fits, the mean value represent the measured current and the sigma value identifies the oscillation.

PROTOTYPE CHARACTERIZATION

The first important result that we obtained is the **linear correlation** between **dose rate** and signal, which is an essential feature for all detectors.

$R^2 = 0,9985$

$R^2 = 0,9994$

$R^2 = 0,9995$

$R^2 = 0,9998$

$R^2 = 1$

pin on Kapton with different bias voltage
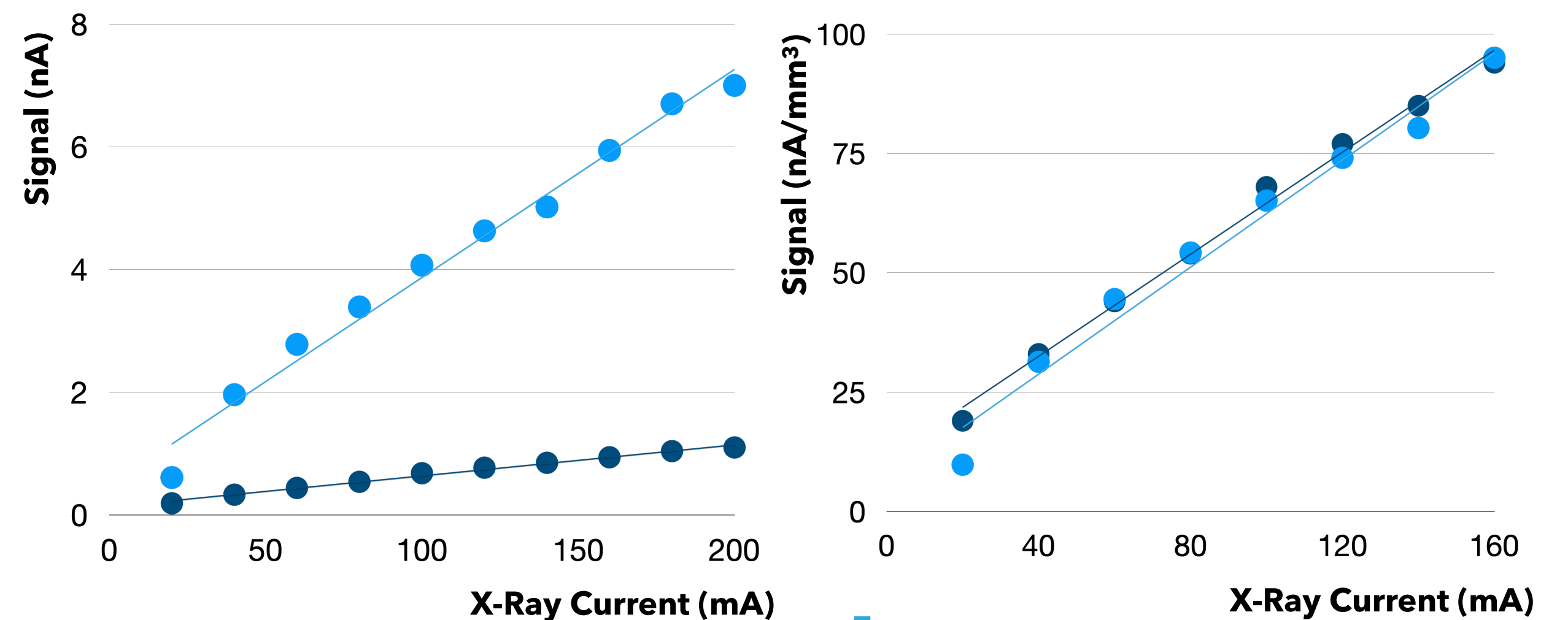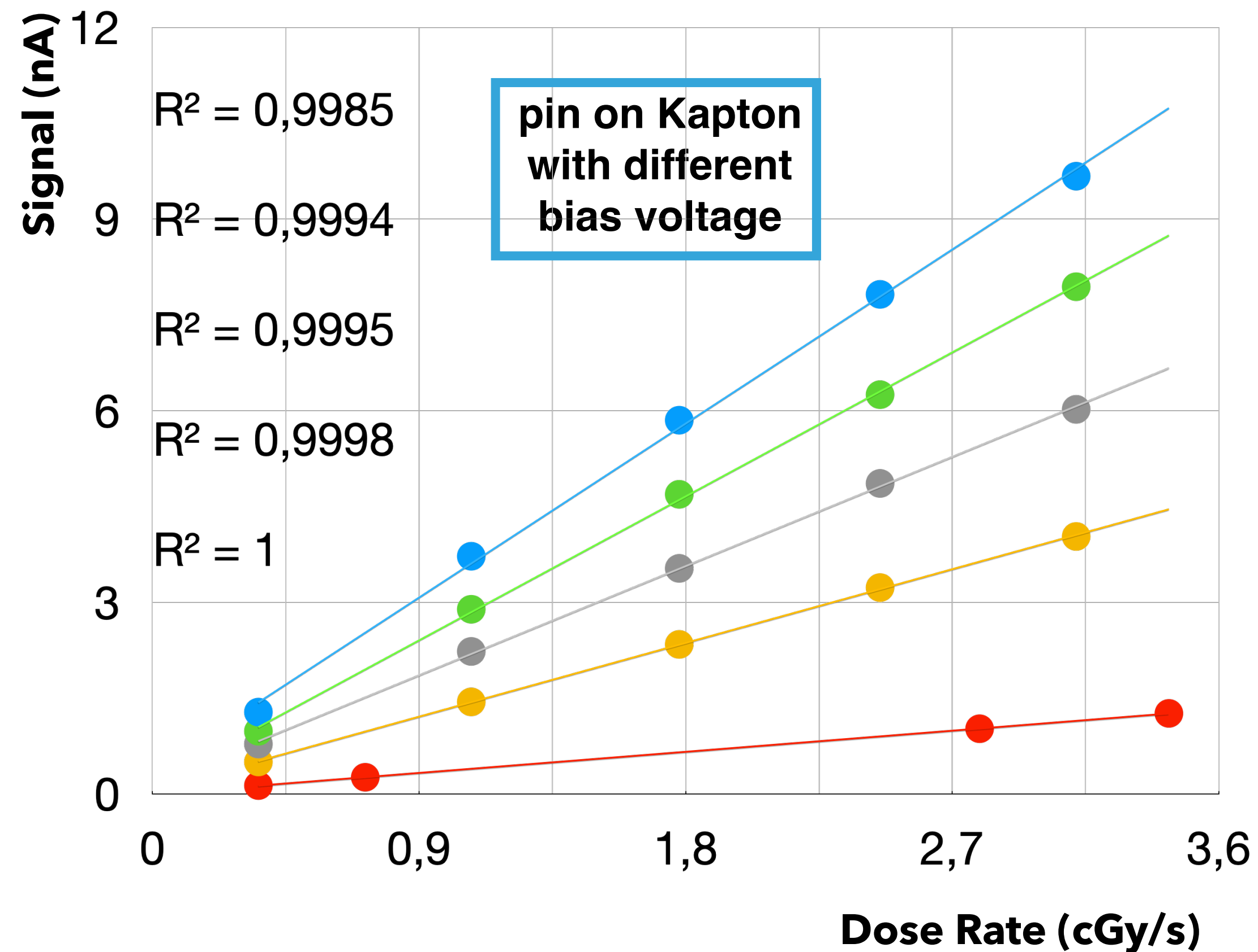
The acquired data at the suggests that, for devices with the same construction characteristics, the sensitivity scales with the sensitive volume.

SENSITIVITY MEASUREMENTS

p-i-n on **Kapton** V = 0.01 mm^3 • **p-i-n** on **c-Si** V = 0.0025 mm^3 • **p-i-n** on **c-Si** V = 0.01 mm^3

p-i-n on **Kapton** V = 0.06 mm^3 • •

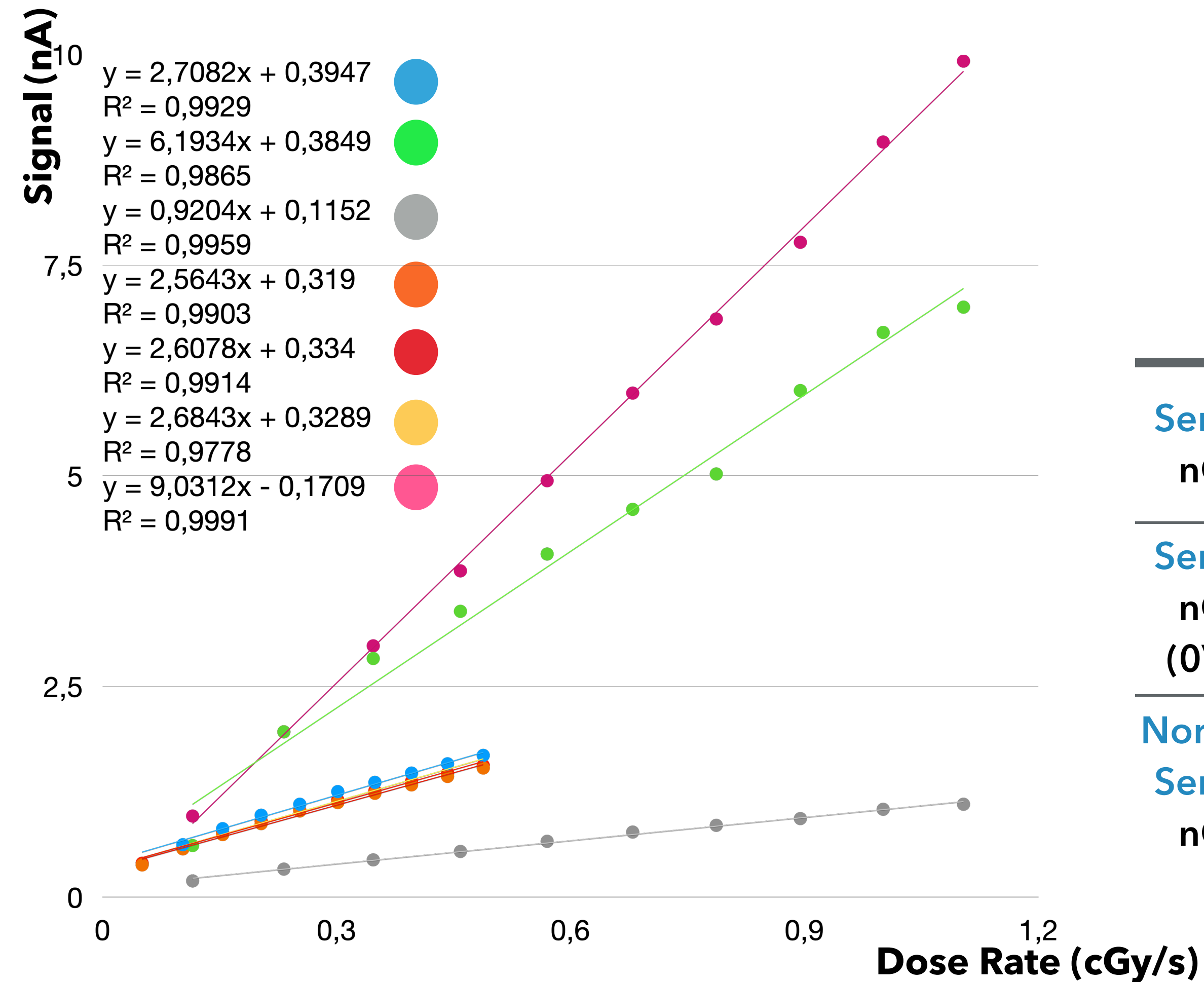$y = 2,7082x + 0,3947$
$R^2 = 0,9929$ •

$y = 6,1934x + 0,3849$
$R^2 = 0,9865$ •

$y = 0,9204x + 0,1152$
$R^2 = 0,9959$ •

$y = 2,5643x + 0,319$
$R^2 = 0,9903$ •

$y = 2,6078x + 0,334$
$R^2 = 0,9914$ •

$y = 2,6843x + 0,3289$
$R^2 = 0,9778$ •

$y = 9,0312x - 0,1709$
$R^2 = 0,9991$ •

Signal (nA) vs Dose Rate (cGy/s)

	p-i-n on **c-Si** V = 0.01 mm^3	**p-i-n** on **c-Si** V = 0.0025 mm^3	**CSC** on **c-Si** V = 0.13 mm^3	**CSC** on **c-Si** V = 0.099mm^3	**p-i-n** on **Kapton** V = 0.06 mm^3	**p-i-n** on **Kapton** V = 0.01 mm^3
Sensitivity nC/cGy	9.0±0.4	2.6±0.4	16.71±0.06	8.78±0.03	6.3±0.8	0.92±0.02
Sensitivity nC/cGy (0V Bias)	/	/	1.37±0.01	0.84±0.01	0.8±0.02	0.07±0.01
Normalized Sensitivity nC/cGy mm^3	903±40	1040±40	128±1 10.5±0.1	89±0.3 8.5±0.1	105±13 13.0±0.3	92±2 7±1

SENSITIVITY MEASUREMENTS

For the sensors deposited on kapton an acquisition test with bias equal to **0V** was also carried out.

p-i-n su **Kapton** V = 0.06 mm^3

Sensitivity: **0.8 nC/cGy** - 0V
Sensitivity: **6.3 nC/cGy** - 8V
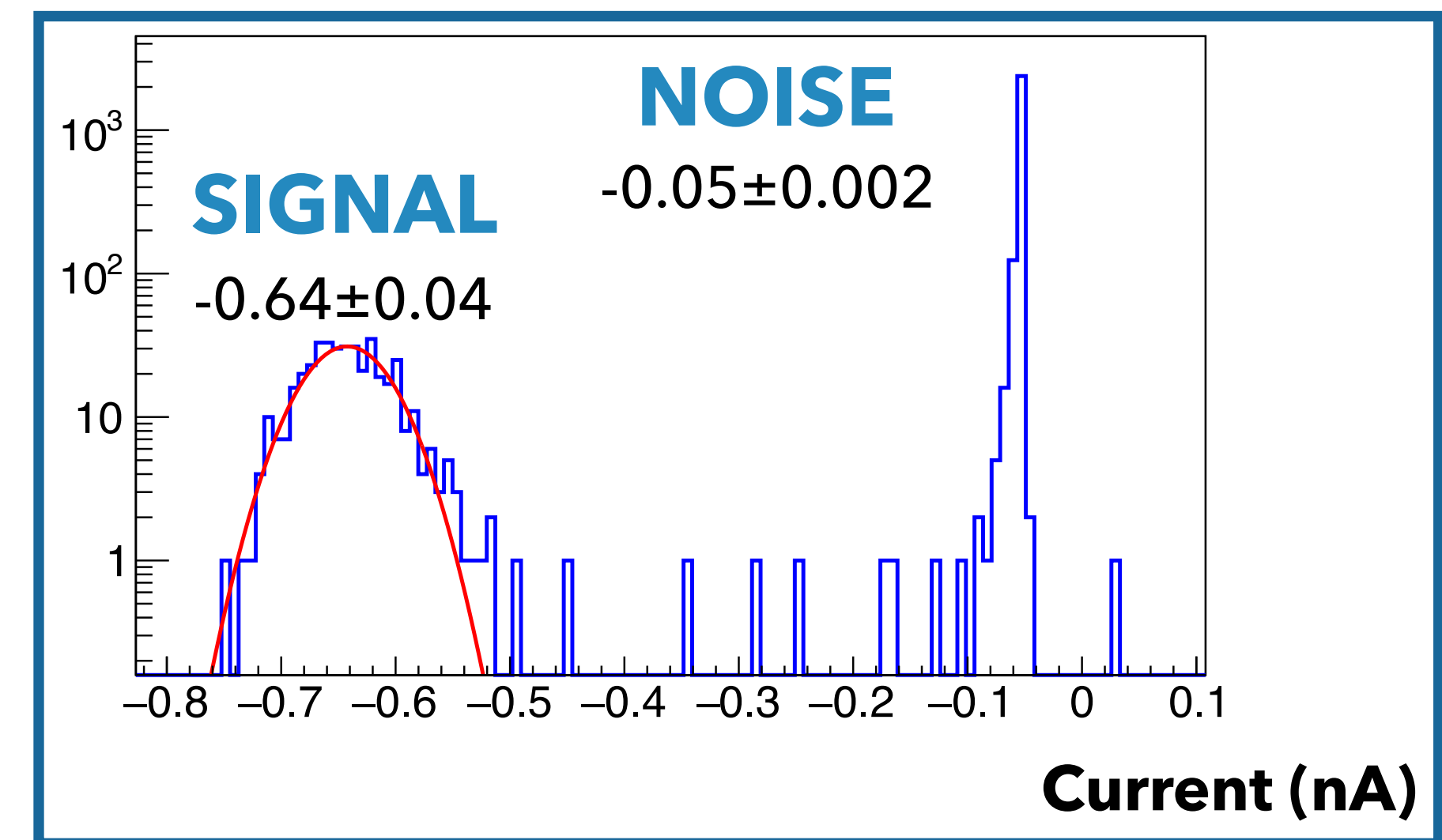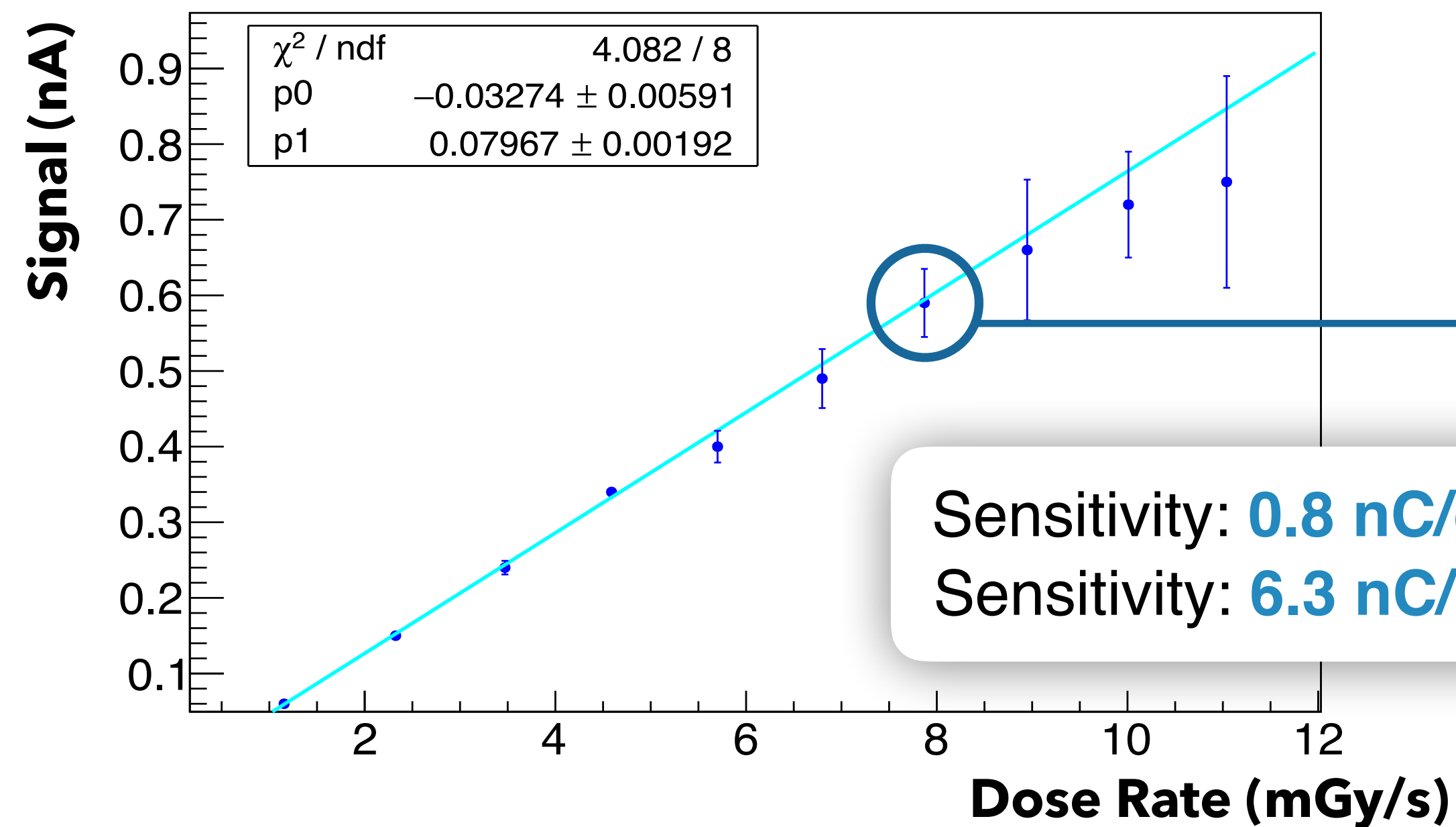
Using **zero voltage bias** detectors in medical applications offers advantages in terms of patient safety, ease of operation, compatibility, cost efficiency, and measurement accuracy.
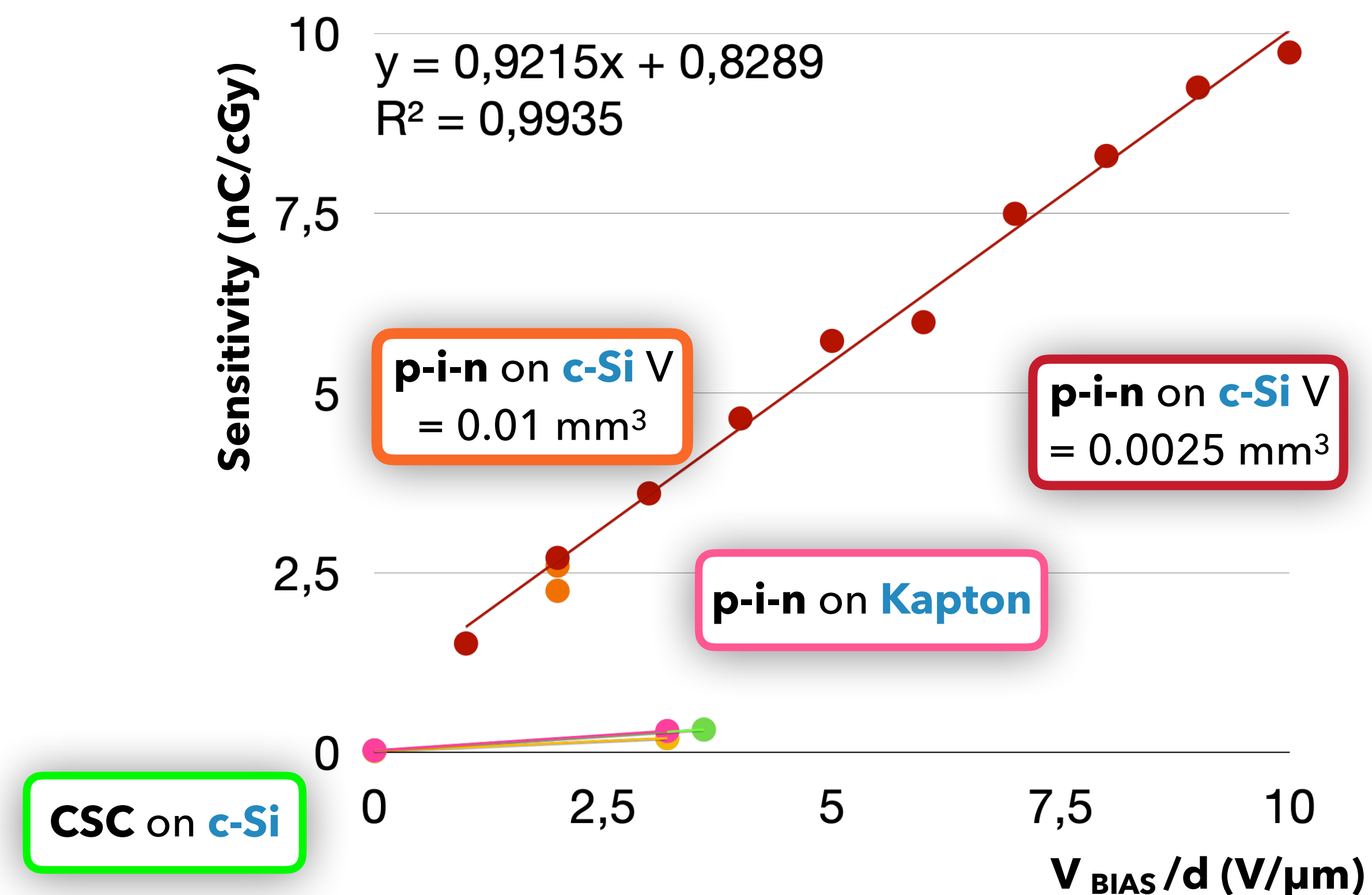
These factors make them a preferred choice.

SIGNAL CHARACTERIZATION

Here we can see the sensitivities normalized to the volume of the pins (0.0025 mm^3) measured for the various types of detectors.

Signal (nA)

$y = 1{,}5174x + 0{,}207$

$y = 3{,}6053x + 0{,}4495$

$y = 4{,}6478x + 0{,}5321$

$y = 5{,}7267x + 0{,}6409$

$y = 5{,}9862x + 0{,}9828$

$y = 7{,}4942x + 0{,}8143$

$y = 8{,}2991x + 0{,}9357$

$y = 9{,}2505x + 1{,}0528$

$y = 9{,}7387x + 1{,}266$

Dose Rate (cGy/s)

Sensitivity (nC/cGy)

$y = 0{,}9215x + 0{,}8289$
$R^2 = 0{,}9935$

p-i-n on **c-Si** V = 0.01 mm^3

p-i-n on **c-Si** V = 0.0025 mm^3

p-i-n on **Kapton**

CSC on **c-Si**

V_{BIAS}/d (V/µm)

For the p-i-n type sensors (on c-Si) the sensitivity trend in relation to the applied bias was studied. Sensitivity increases linearly with the applied bias.

MEDICAL APPLICATION

The beam profile measurement allows for the determination of the beam's size, shape, and symmetry, which are crucial parameters in various scientific and medical applications.
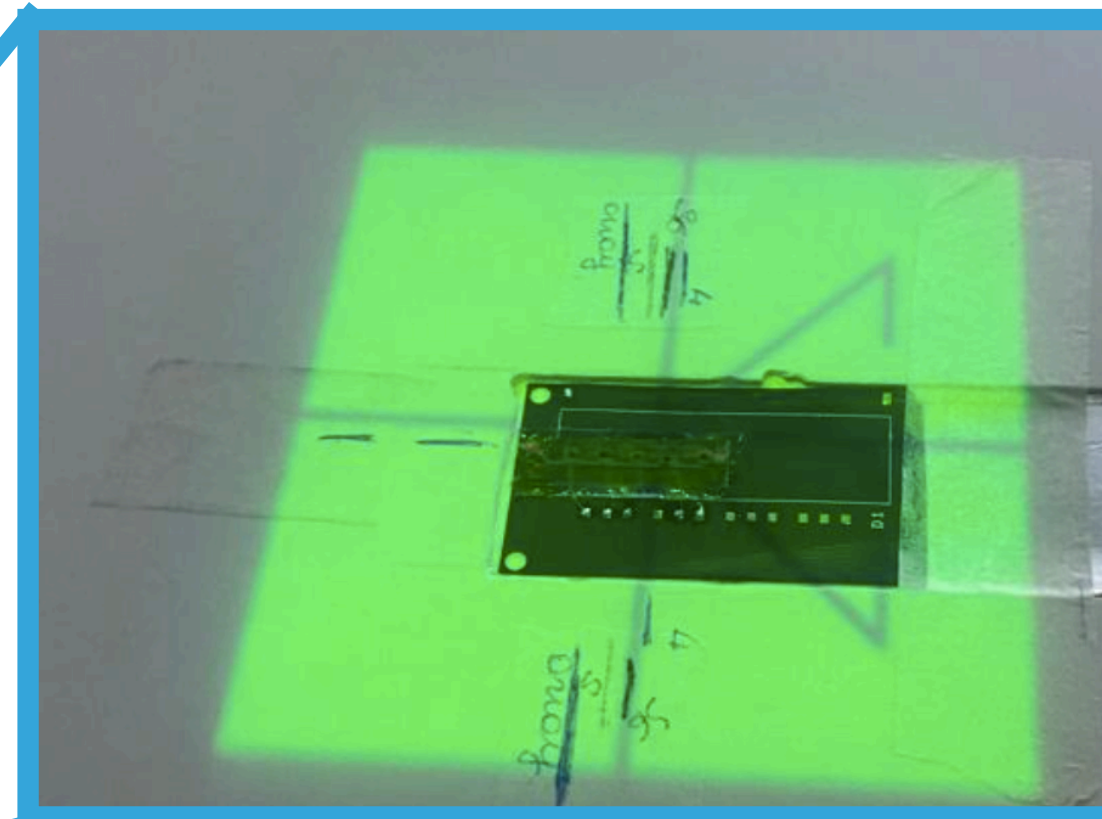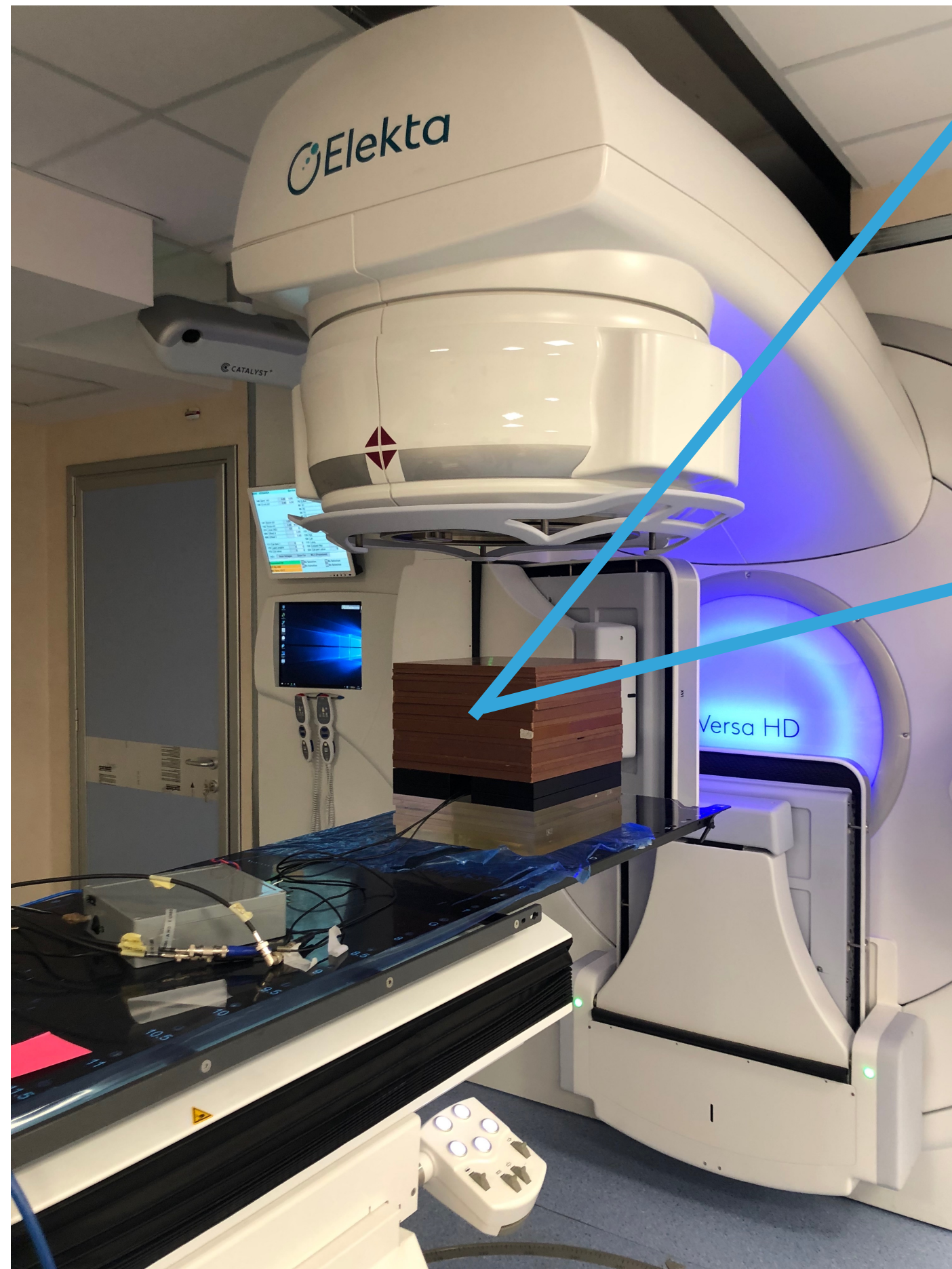
Four **a-Si:H p-i-n diode** structure of **2.5μm** thickness are fabricated on Kapton substrate.
The pad diode area is 2.5x2.5 mm².

70 μm thick **Kapton tape** placed over the sample for protection of the electrical contact as well as to create a consistent and reproducible build-up layer for dosimetry.

Linac: VERSAHD ELEKTA

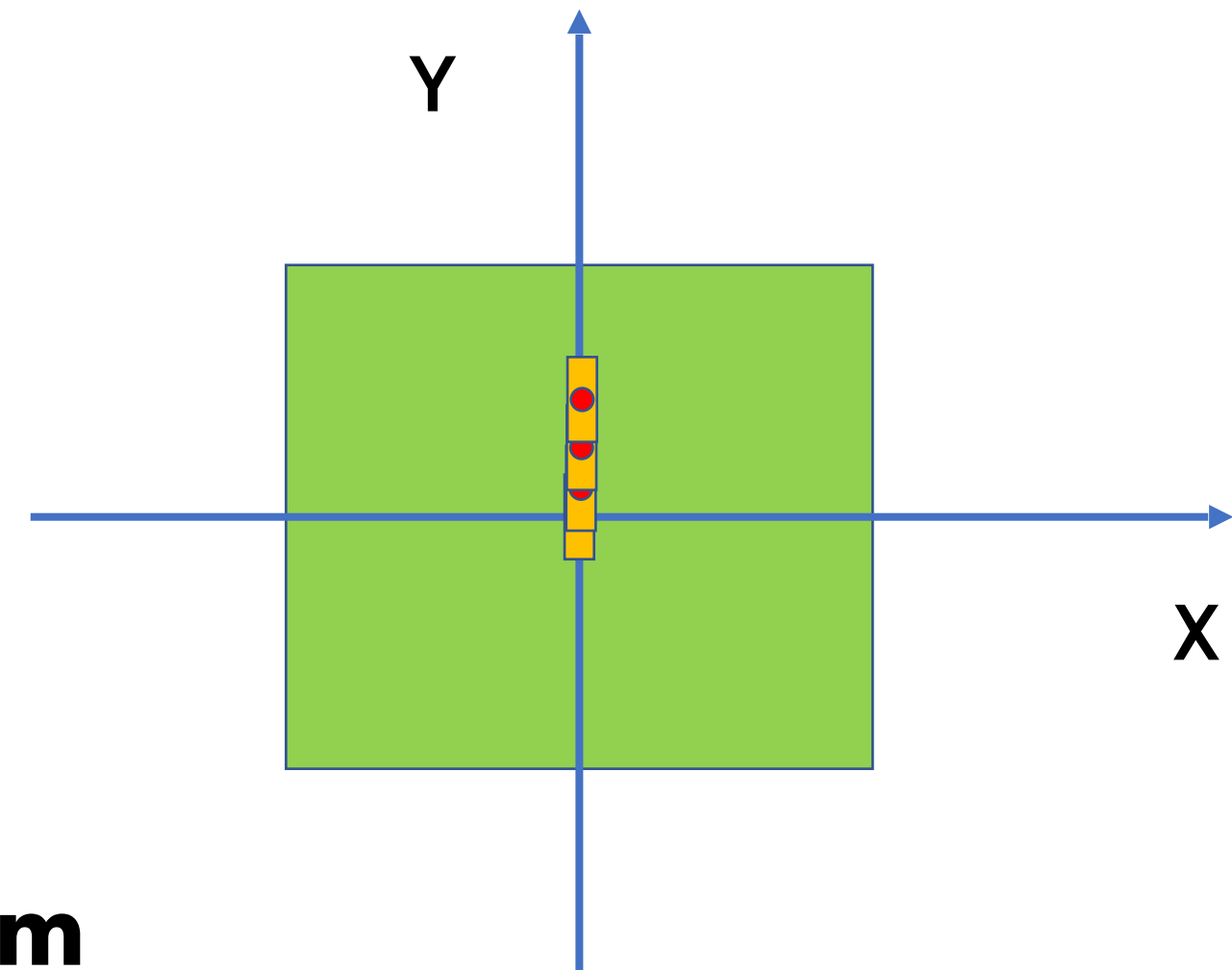**6-10MV Xray beams** with and without Flattening filter

MEDICAL APPLICATION
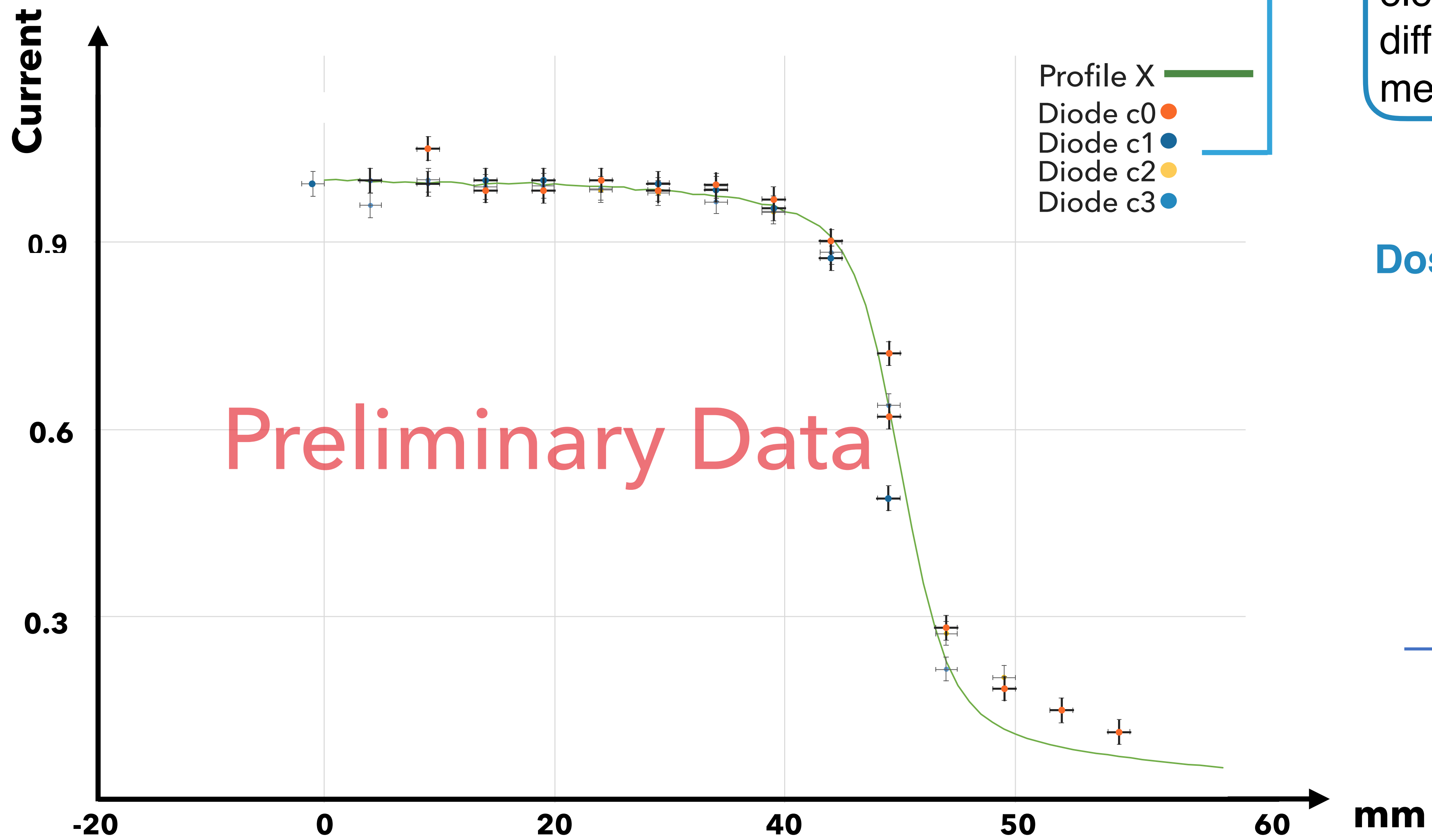
We can see the uniform electronic behavior of the different diodes used for the measurement

Profile X
Diode c0
Diode c1
Diode c2
Diode c3

Current

0.9

0.6

0.3

Preliminary Data

-20   0   20   40   50   60   mm

Dose profile measurement

Field size 10 x 10
6MV Photon Beam
DR=500 cGy/min

Y

X

CONCLUSION

- Different detector configurations differing in thickness and area of the sensitive volume, junction type and deposition substrate, have been tested, to study their behavior

- We are currently able to produce detector with uniform electronic behavior with noise level order of ten pA

- We obtained linear correlation between dose rate and signal, we extract the sensitivity for photons

FUTURE WORK

- As we can see from this preliminary results some configuration seem to work better than others

  - We are carrying out spectroscopic measurements in order to model the way in which the detector's performance is linked to the internal amorphous structure.

- The next step is to test that the sensitivity does not depend on the type of ionizing radiation.

HASPIDE PROJECT