Thermal characterization of Low Gain Avalanche Diodes

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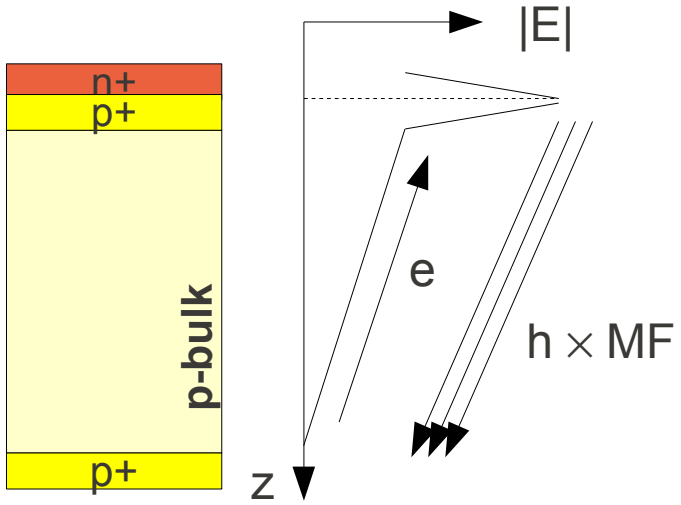
Nov 13 2013, 23rd RD50 Workshop, CERN

Contents

LGAD = pad diodes with internal gain

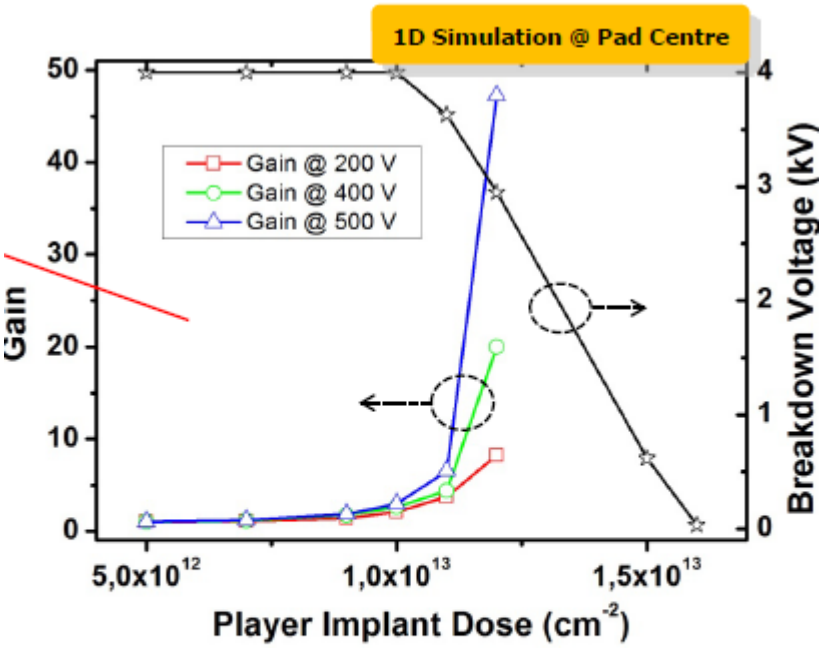


Highly resistive p-wafer

P-well = multiplication layer below n-implant

High E-field, secondary ionizations

Main **technological challenge**: tune doping to achieve gain while keeping breakdown voltage at a reasonable high value.



Small modifications in the Boron implant dose (~ 2×10^{12} cm^{-2}) induce great changes in Gain and V_{BD}

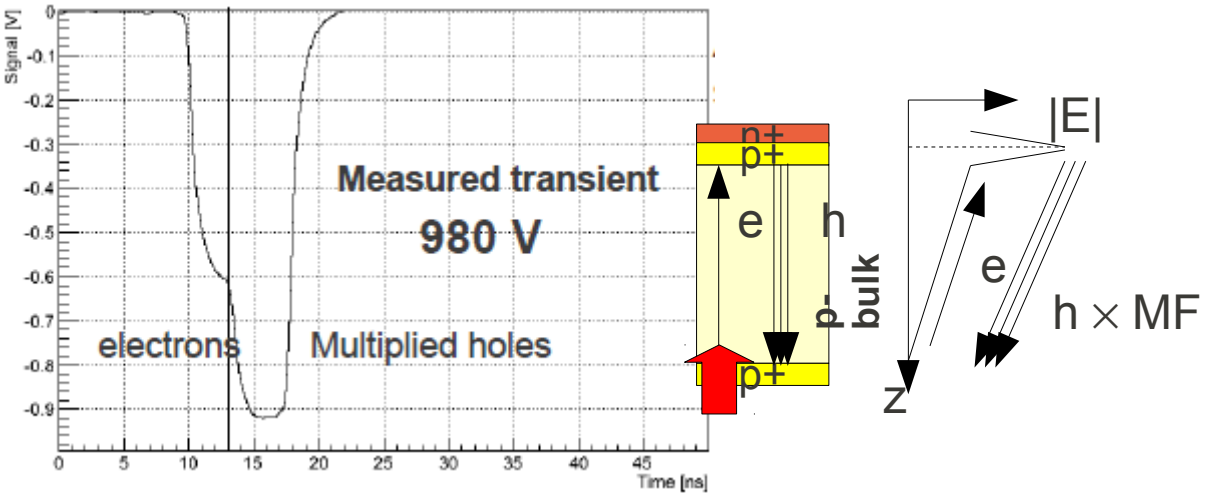
More info:

[1] S. Hidalgo, 22nd RD50 Meeting Albuquerque 2013
[2] G. Pellegrini, Hiroshima symposium, Sept. 2013

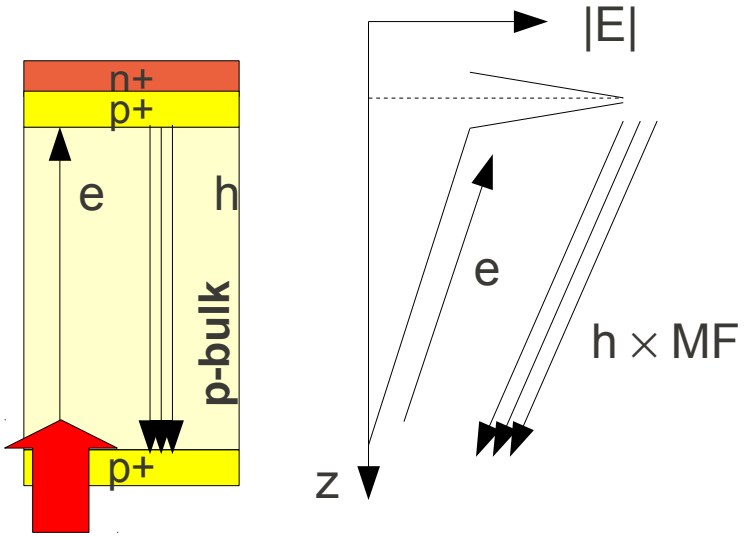
Calculation of gain

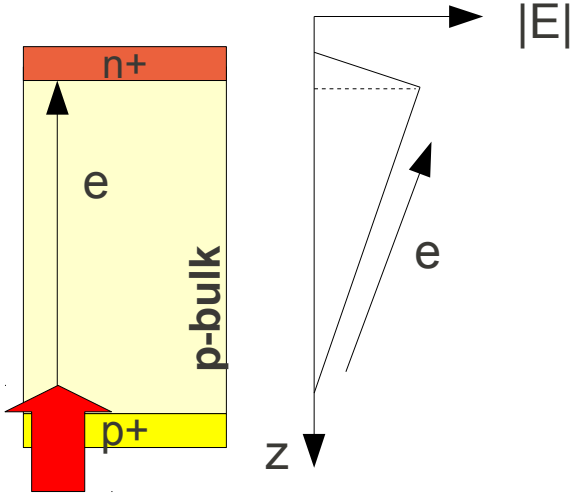
Several methods available:

1) If the gain is high, we can easily separate e drift from hole drift and integrate the pulse directly



2) Comparing collected charge of a **LGAD** (left) with one **reference** detector (right) without amplification (wafer 9)





$Q_{LGAD} = Qe + MF \times Qh$

$$\text{Gain} = \frac{Q_{LGAD}}{Q_{ref}} = 1 + MF$$

$Q_{ref} = Qe$

MF=Multiplication Factor

Available samples

LG Avalanche Diodes available at CERN & IFCA-Santander:

SR	2	W7F3, **W7J9**
DR	6	W7D2, W7B4, W7H8, W7D8, W7H10, W8D2
SC	7	W7C3, W7C5, W7G7, W7E9, W8C3, W8C5, W8K9
DC	8	W7I10, W7E2, W7E4, W7E6, W7I8, W8C4, W7C4, W7E10

Reference diodes W9 (same run, different wafer), no multiplication

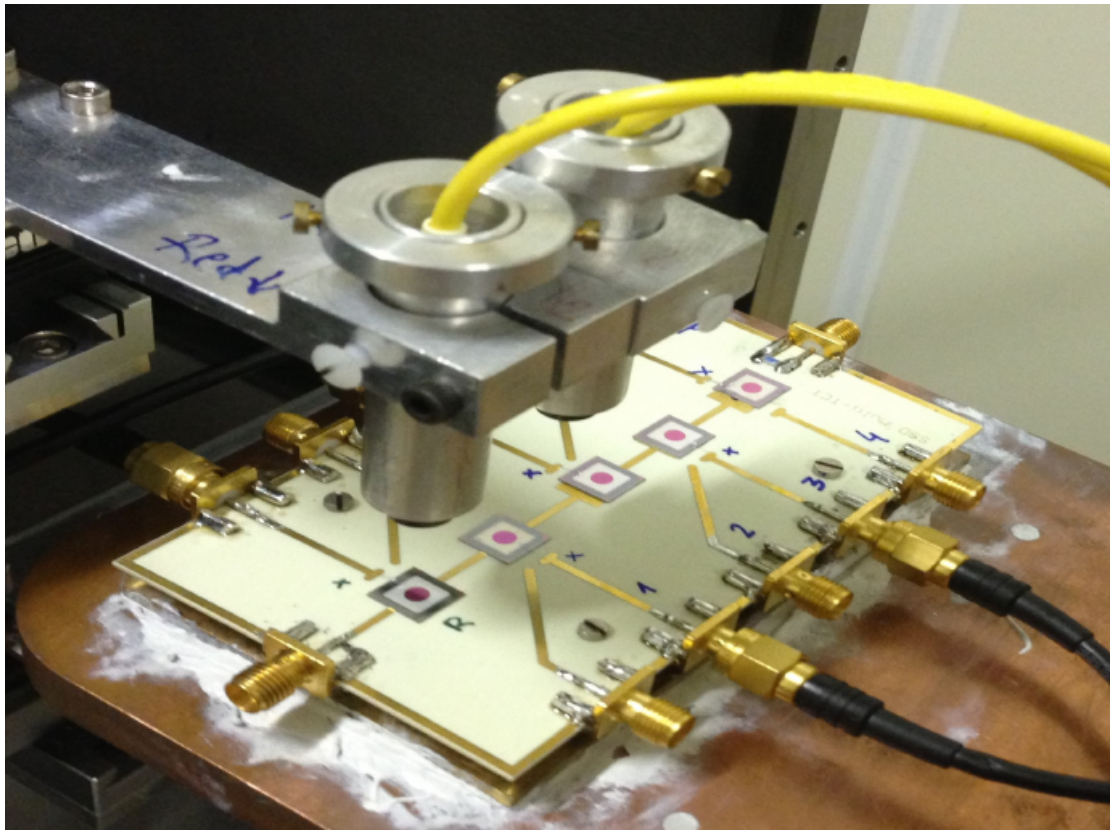
SR	2	W9F11, W9H11
DR	6	W9D10, W9H10
SC	7	W9E9, W9E11
DC	8	W9E8, W9G8

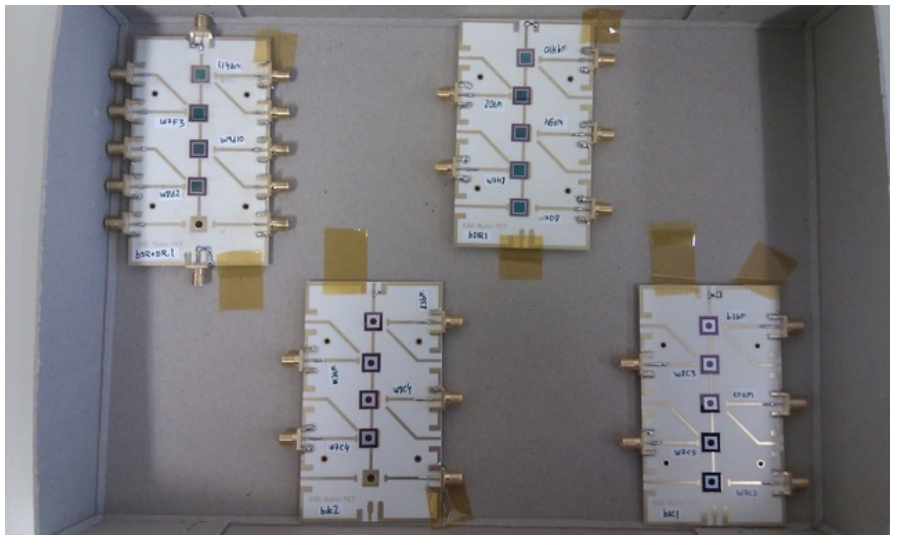
Color legend:
Temp measurement ↔ Mounted in mTCT board
Mounted in single boards (for Santander) ↔ XY scan

Nomenclature of the diodes"RingWindow":

Sx=Single N diffusion (JTE) Dx=Double N Diffusion (JTE+Ring)
xR= Rectangular window, xC=Circular window

TEMPERATURE SCANS





SSD facility at **CERN**

Up to 5 diodes (4+1 reference) mounted in a mTCT board

2 laser heads (red/IR), fiber splitted into 4 ends: top red/IR, bottom red/IR.

Laser fixed, diode selected using **1D stage motor**

Board on Cu support, cooled using a Huber Unichiller CC3. Temp read out on-board extreme using PT1000.

Temp sequence T=20C..-15C in steps of ~5C.

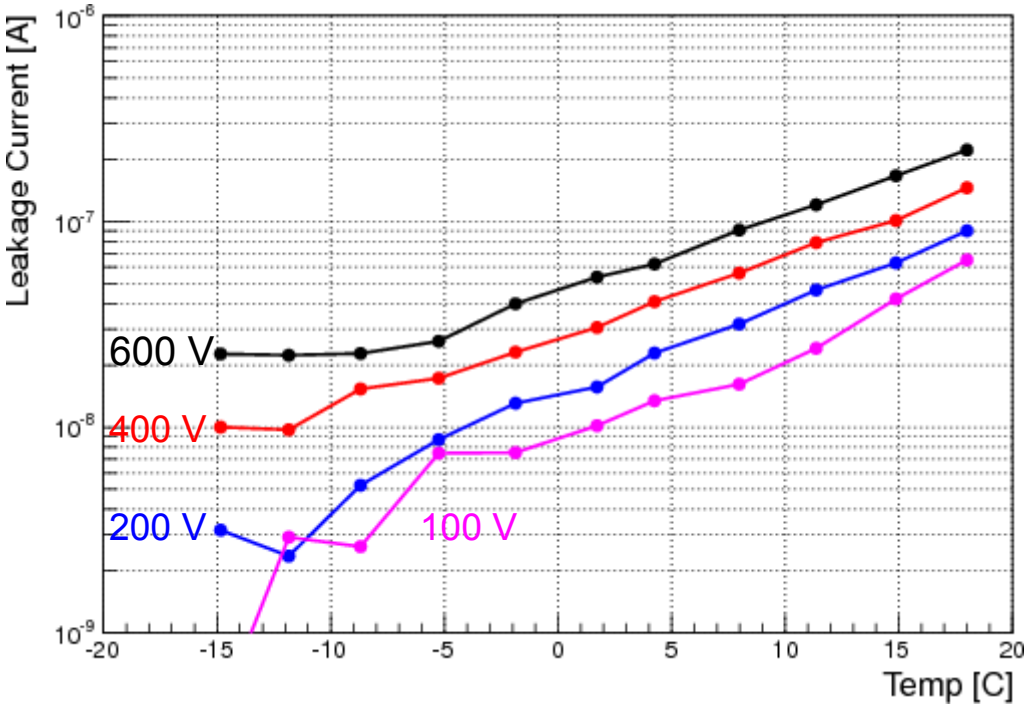
Top side is biased, backplane grounded.

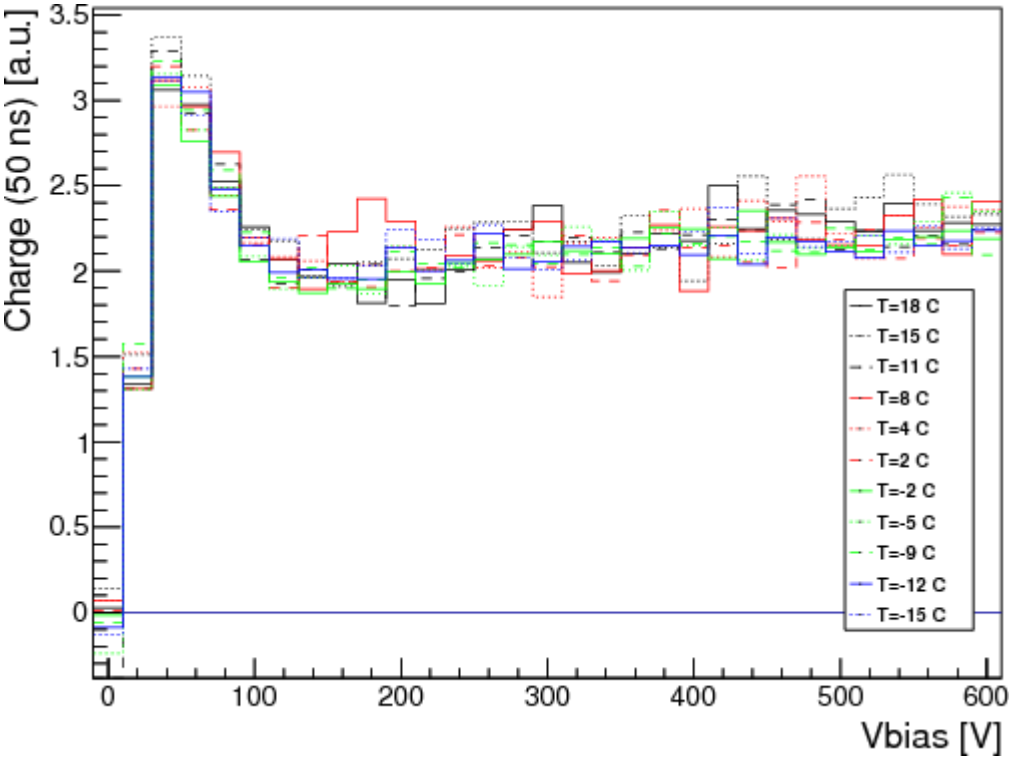
Red bottom injection.

LGAD: temperature effects

All measurements are red TCT, rear illumination

Standard diode, behavior with temperature (DC type, w9g8)



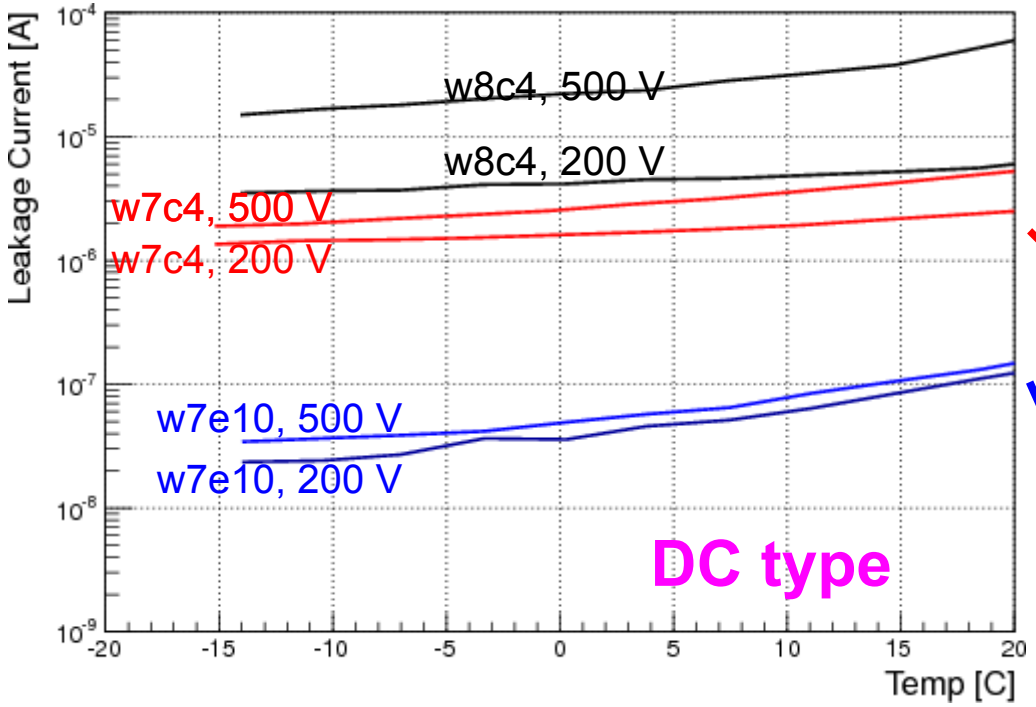


Leakage current decreases with T, as expected

Collected charge does **not** depend on temperature

Gap does not change with T, within T⊂[-20,20] C → absorption in Si for red light does not change in this T-range.

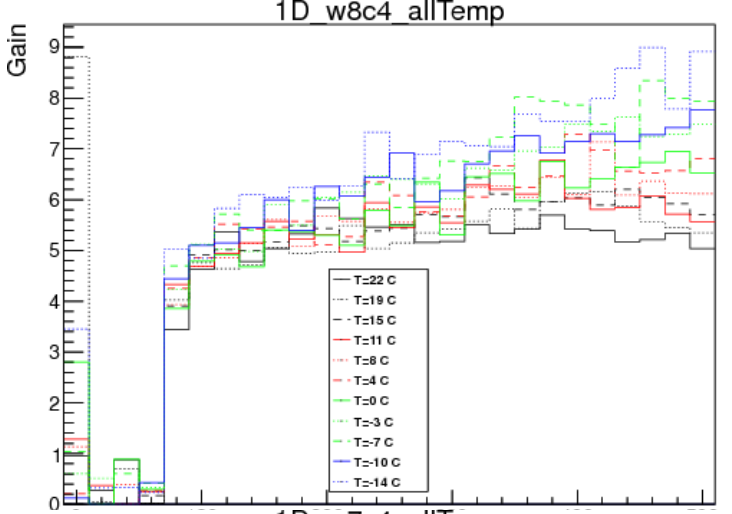
LGAD behavior with temperature

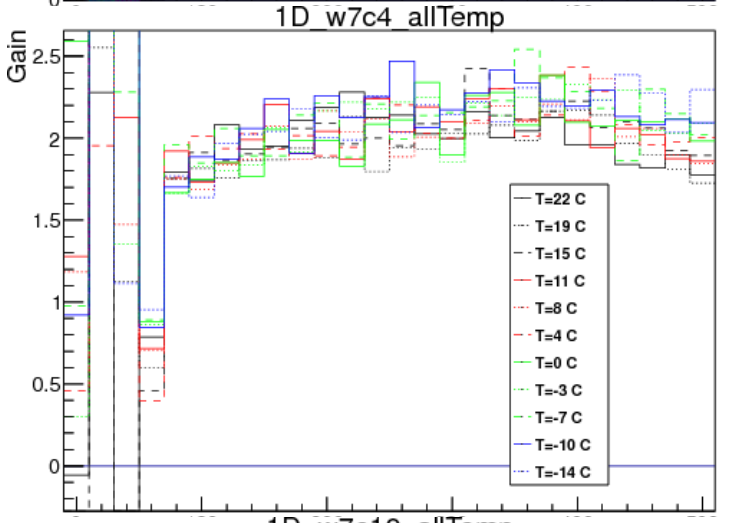


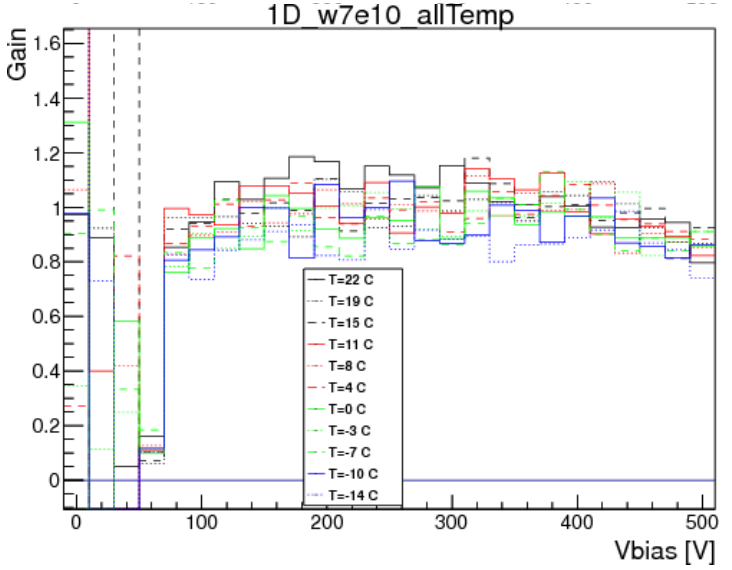
Gain~7

Gain~2

Gain~1







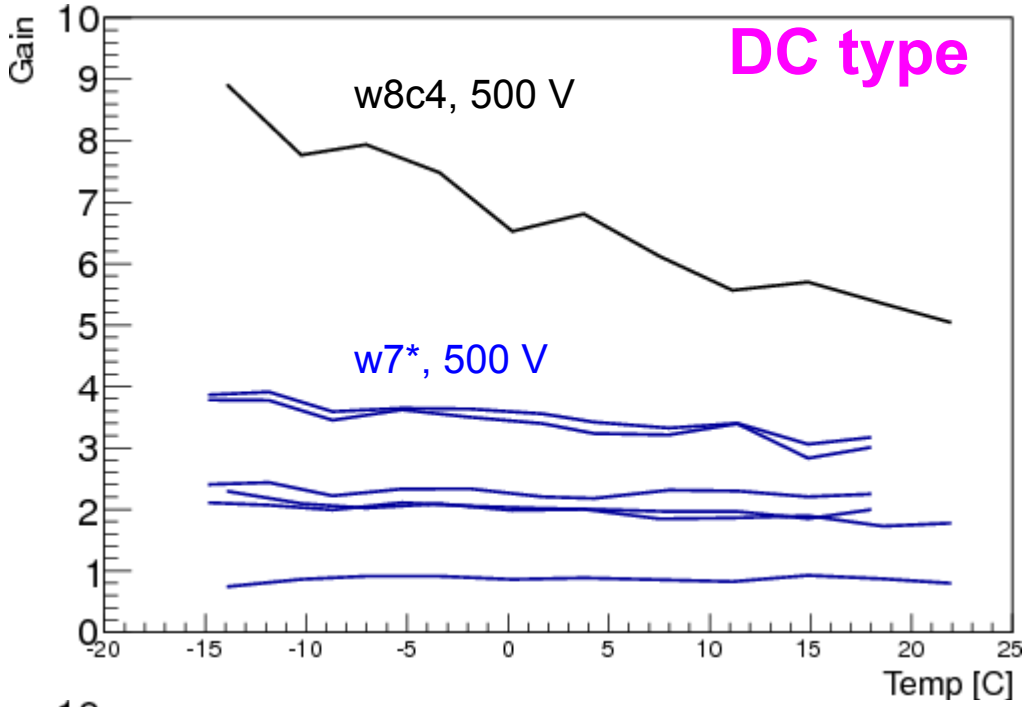
Leakage current:

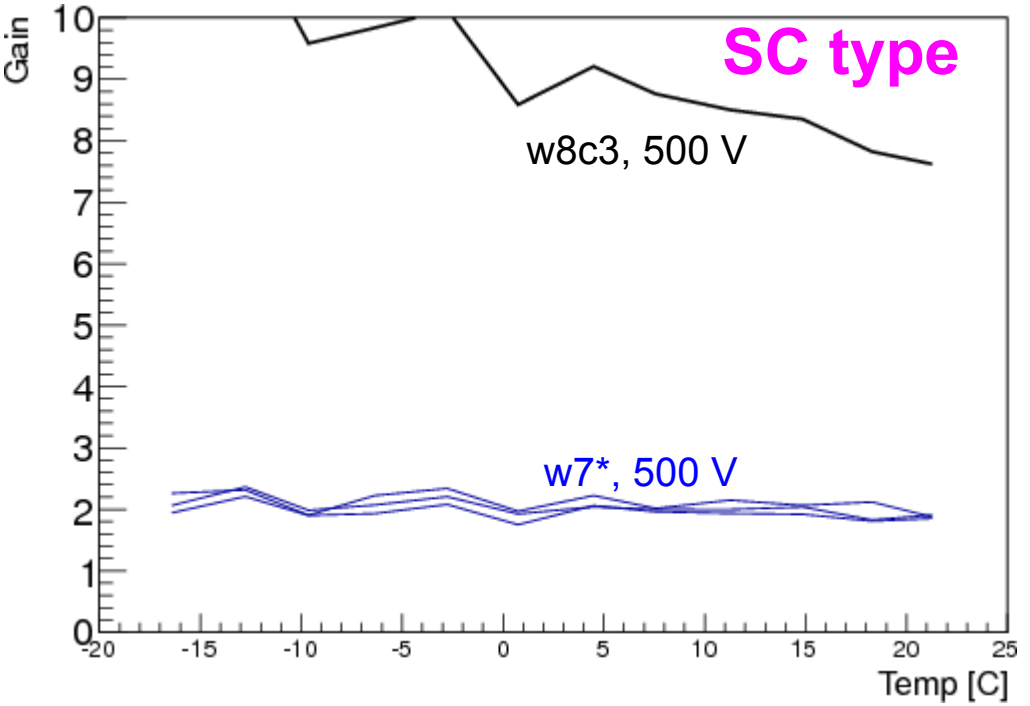
W7e10 → No gain observed

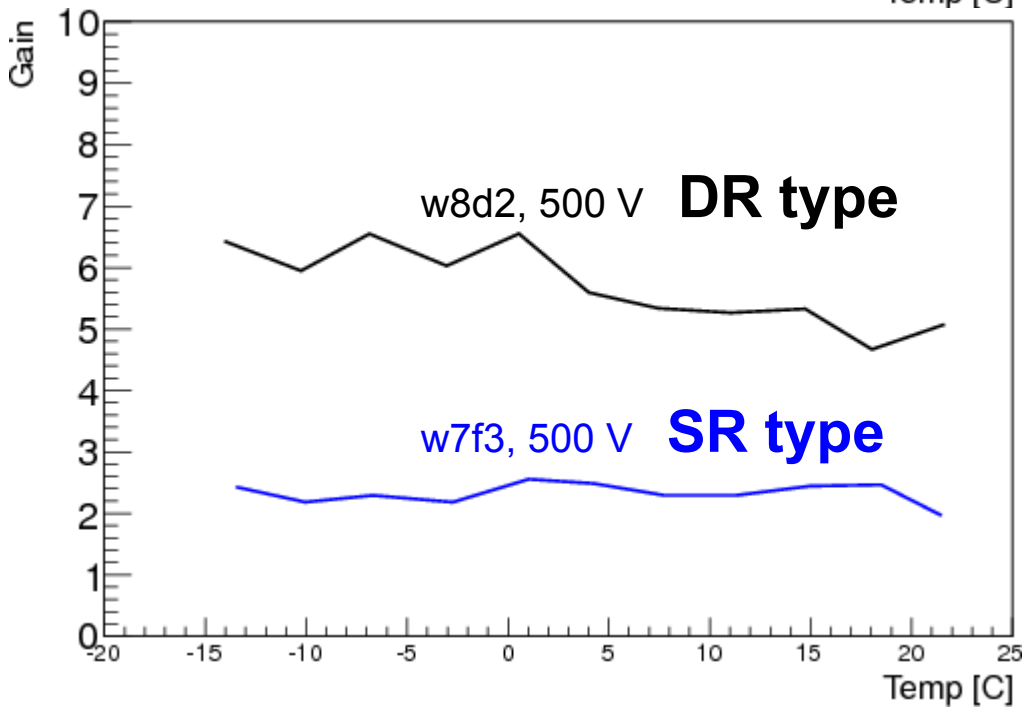
w7c4 and **w8c4** have ×10 and ×100 higher leakage current, respectively.

Calculating gain from IV characteristics (see I. Tapan et al, NIM) ratio not applicable in these devices (surface currents?)

LGAD behavior with temperature







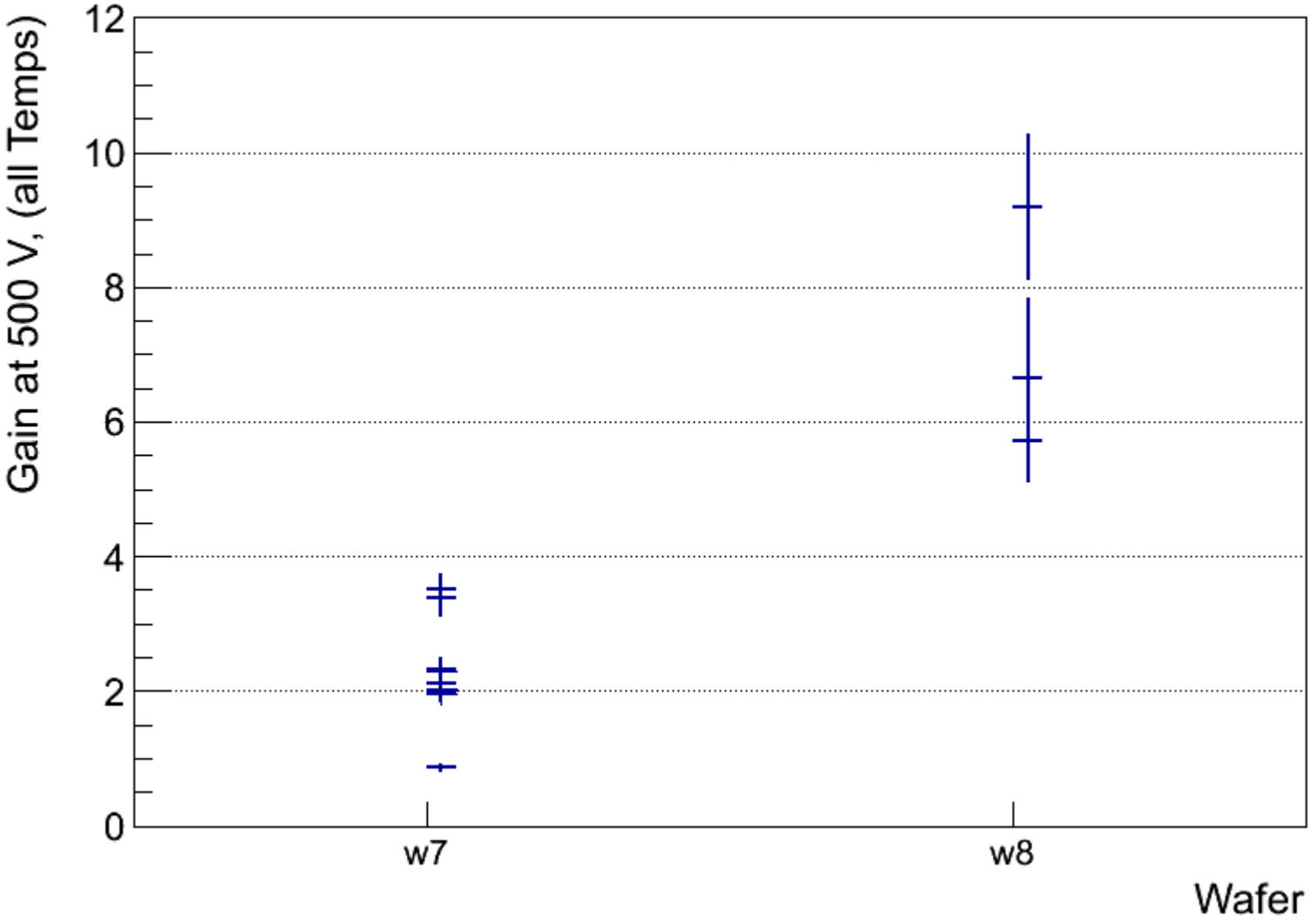
Gain increases at lower T

No differences observed *wrt* Ring type and Window shape

Higher variation of gain with T for sensors with higher gain (w8)

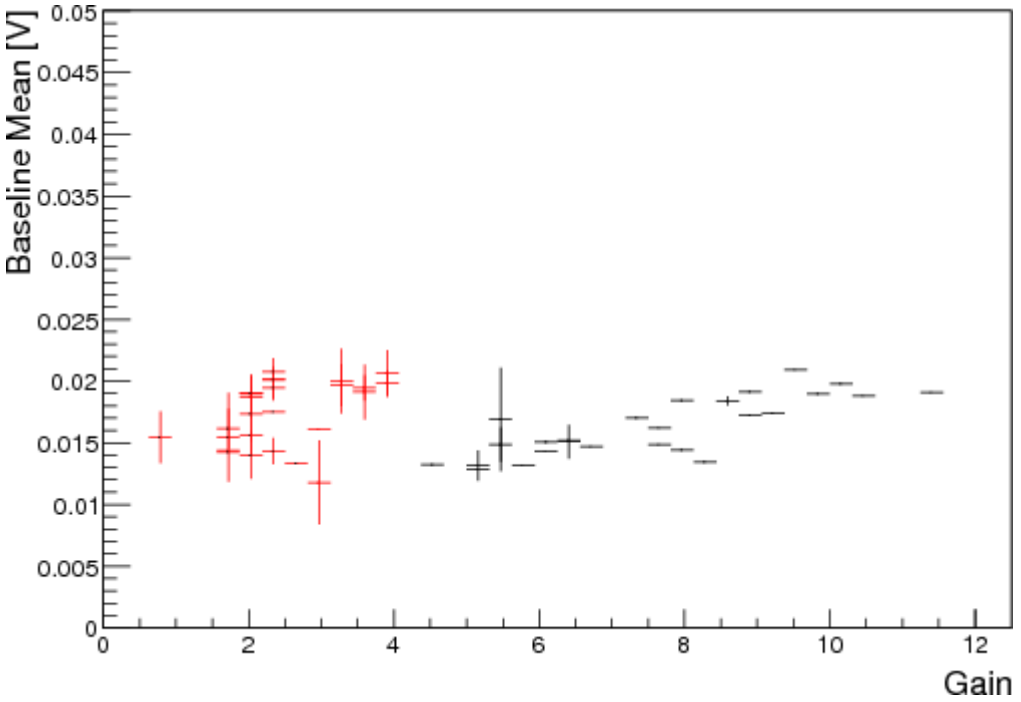
Wafer 7 has a gain 2-4
Wafer 8 has a gain > 5-10

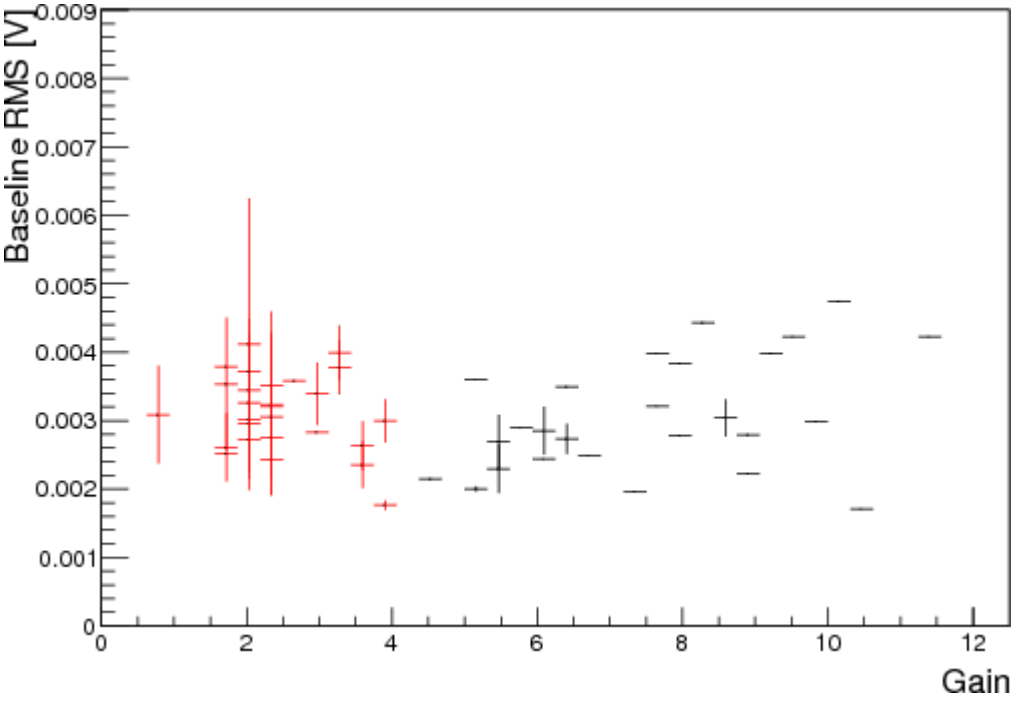
Gain vs wafer



Error bar is spread due to variation of gain with temperature (RMS)

Noise vs Gain,irrespectively of T



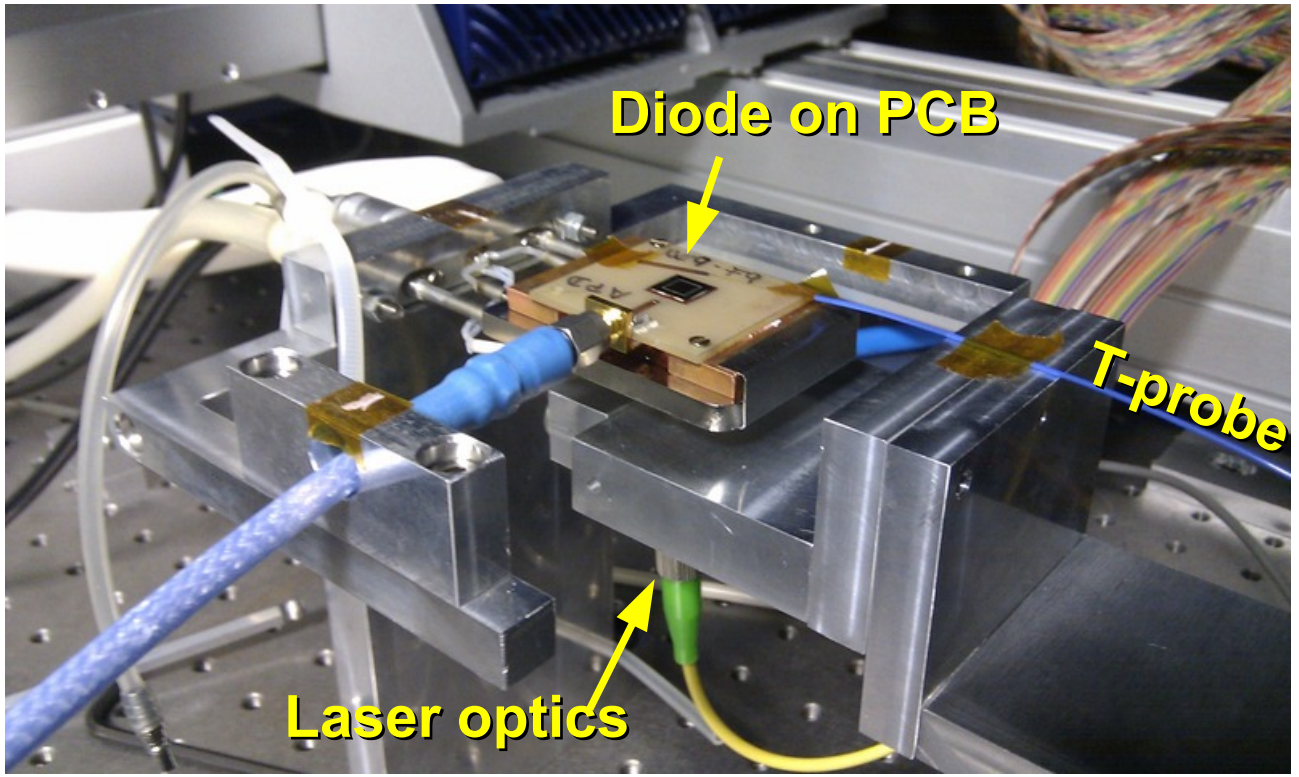


Neither the baseline mean, nor the RMS of the baseline depend on the gain. Measurements at different temperatures are shown here.

Note:
The baseline is defined as the signal before the actual current transient. For these measurements we have integrated the baseline over 15 ns before the transient. The scope does 256 averages before acquisition.

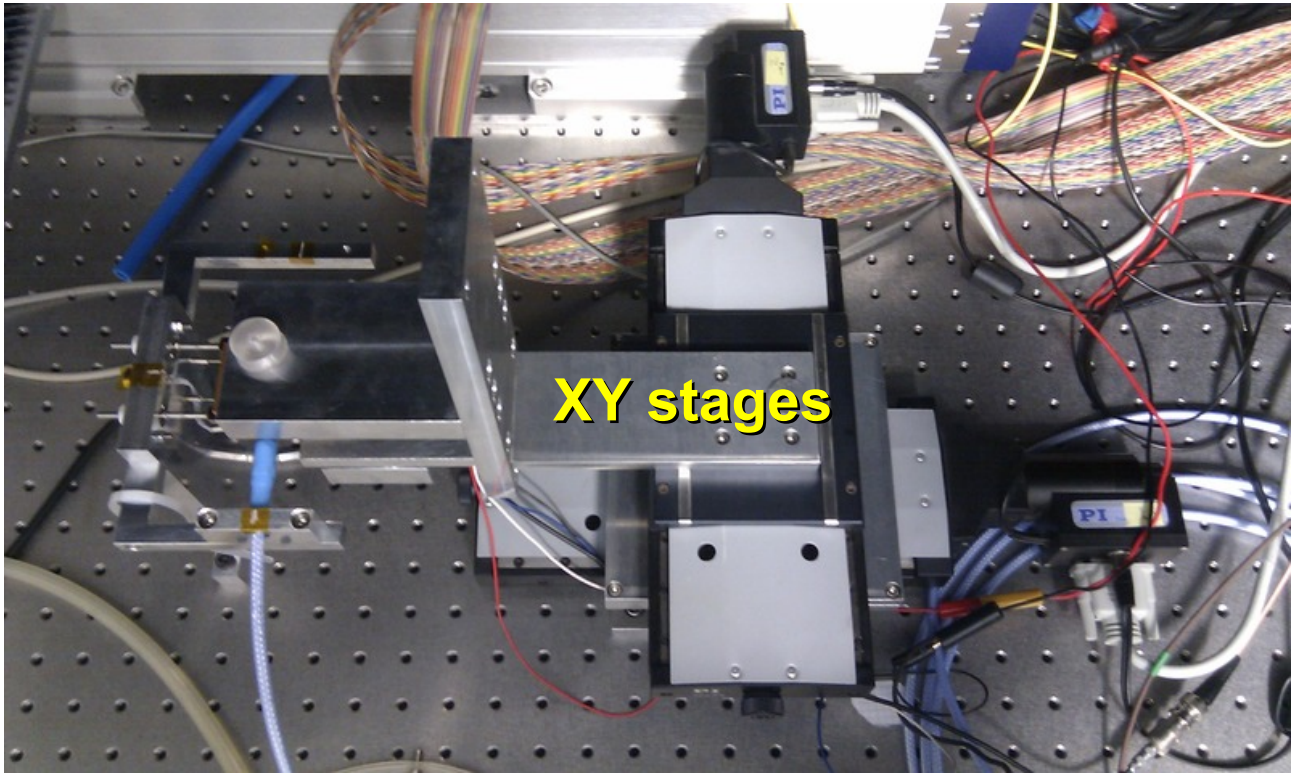
LGAD: gain uniformity

All measurements are red TCT, rear illumination

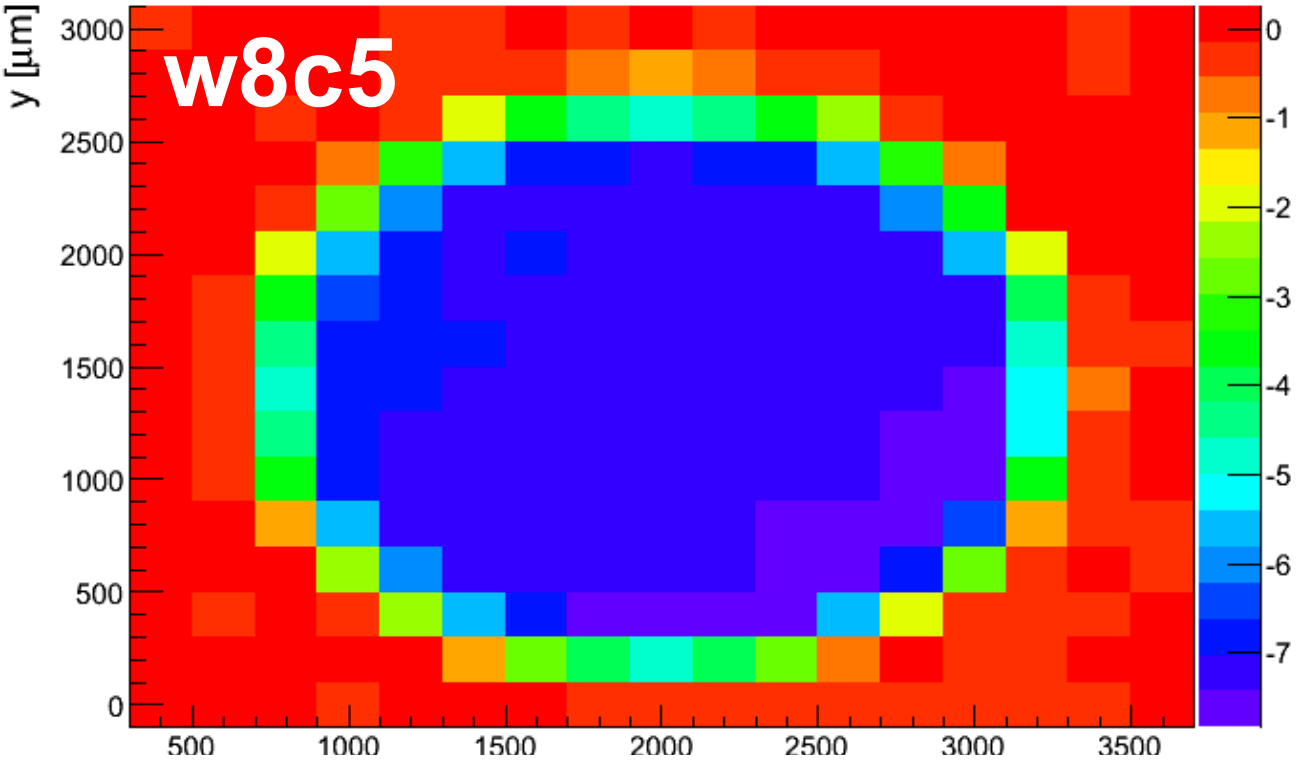


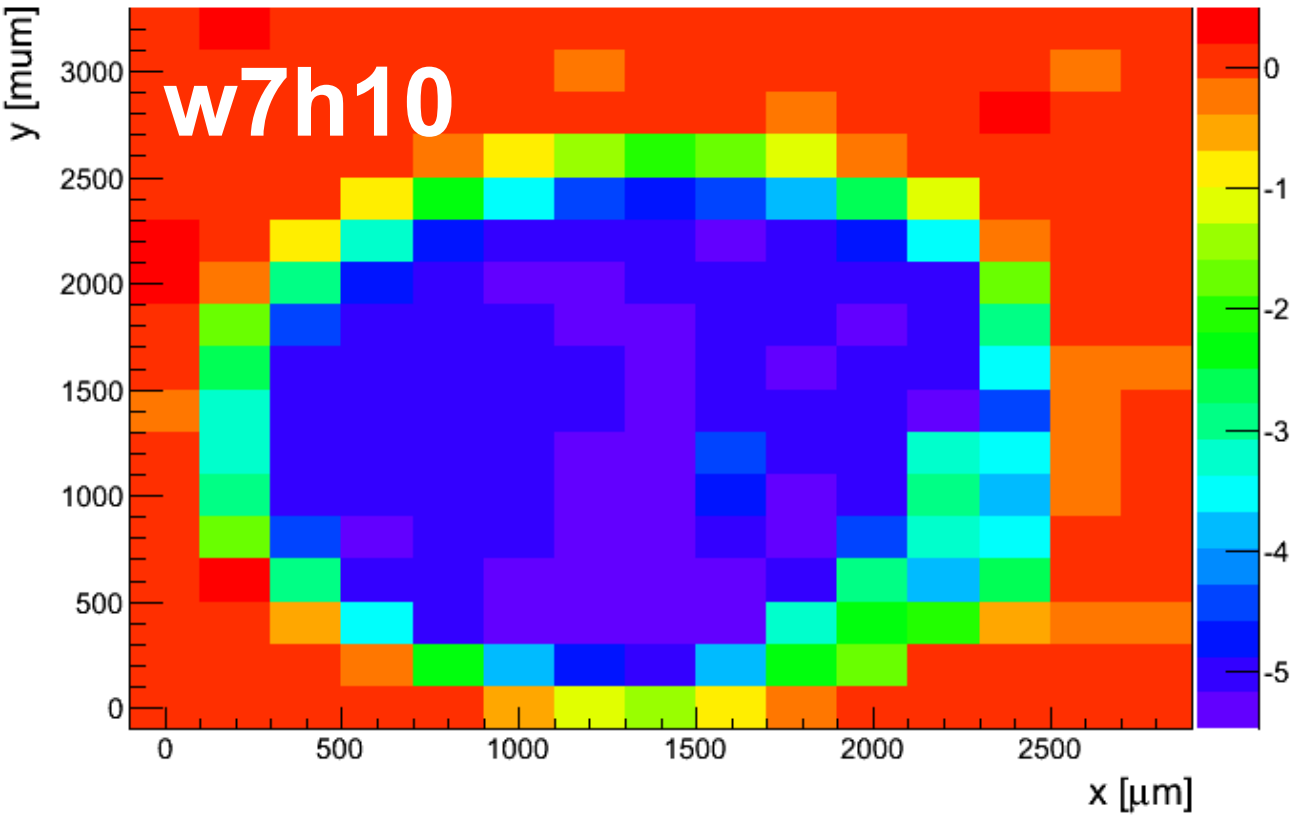
Diode mounted on Peltier element (Linkam)

Red TCT, rear incidence



XY stages





Showing Charge mappings:

$$Q=Q(x,y)$$

Very good uniformity

Circular motif seen is actually the window in the cooling support (to allow rear illumination).

Conclusions

- 13 LGAD (+5 references) have been measured at different temperatures

- By measuring the reference diodes (no amplification) we observed that absorption of red light in Si does not change with T in the range [-20,20] C.

  Charge collected vs bias voltage has a flat response in ref.diodes

- Higher gain detectors, also have higher leakage current

- Gain increases as temperature decreases

  Gain for wafer 7: 2-4
  Gain for wafer 8: 5-10

- The electronics noise (calculated from the baseline) does not depend on the gain.

- Even if each sensor is different, the uniformity of gain within each device is very good.

- Next steps? Proton irradiation in “fine” steps. I would take devices with highest amplification when unirradiated. tbd