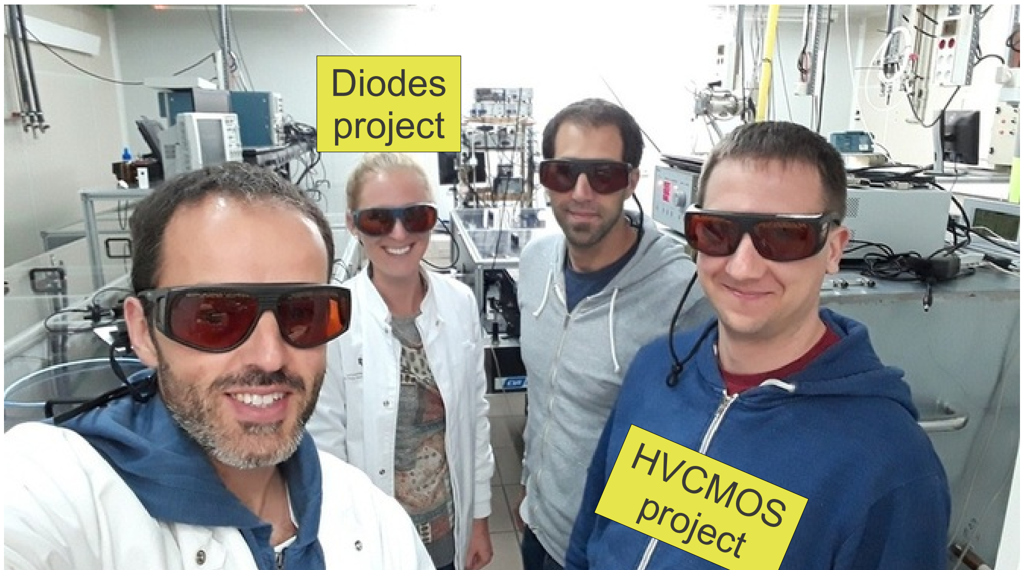
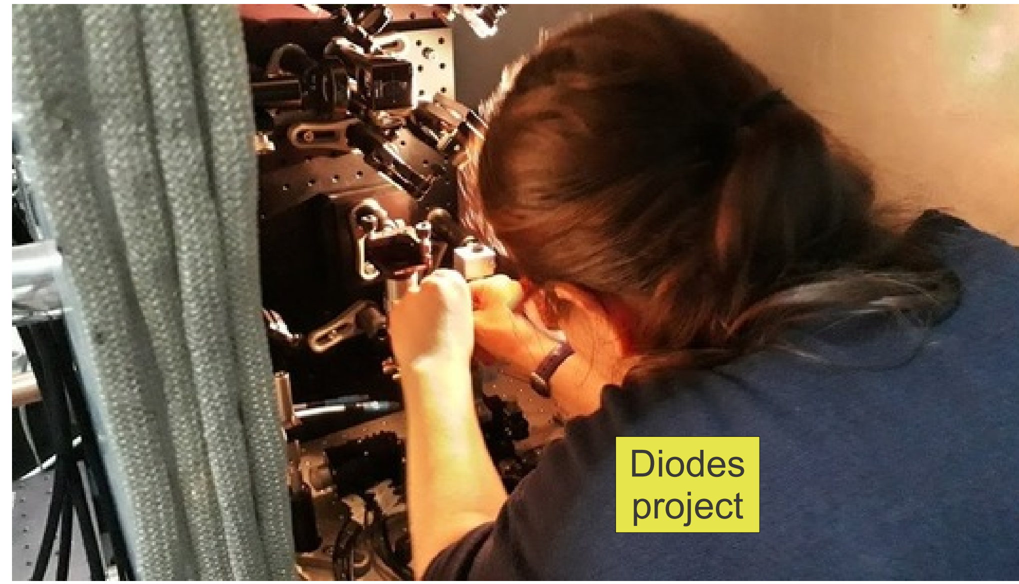
RD50 Two Photon Absorption-TCT projects: status and plans





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Universidad de Sevilla

Rogelio Palomo

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31st RD50 workshop – 20 - 22 Nov 2017, CERN

Outline

Two Photon Absorption (TPA) **introduction**

Edge-TPA on irradiated **HVCMOS**

Edge-TPA on **diodes**
    TPA on **LGADs**

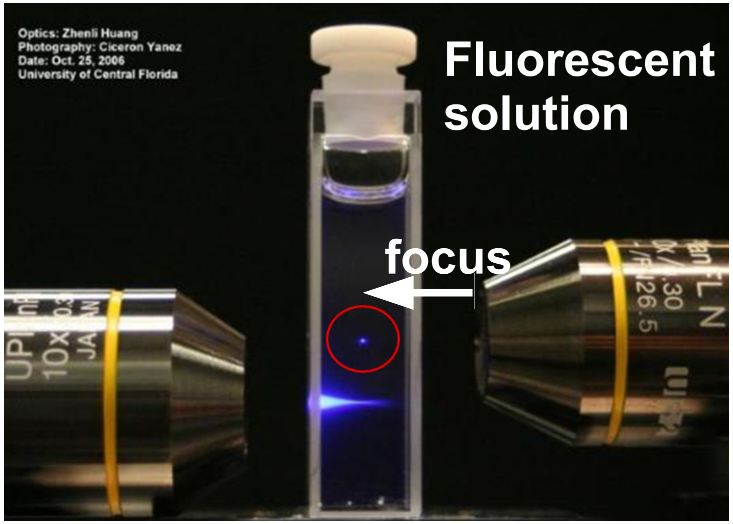
Summary

Reminder I: TPA basics

SPA

Single Photon Absorption

Continuous energy deposition

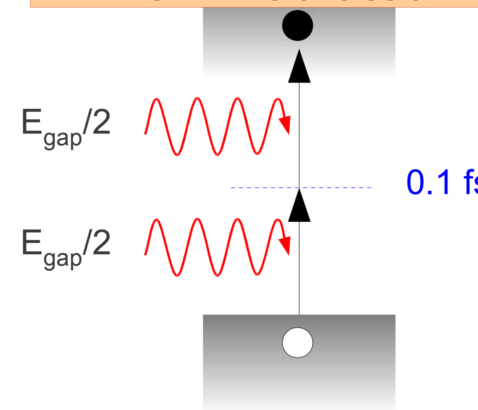


TPA

Two Photon Absorption

Energy confinement

Non irradiated

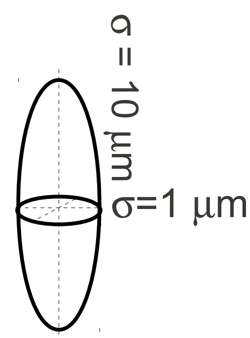


$$\frac{dN(r,z)}{dt} \propto \frac{\beta_2 I^2(r,z)}{2\hbar\omega}$$

Two **P**hoton **A**bsorption

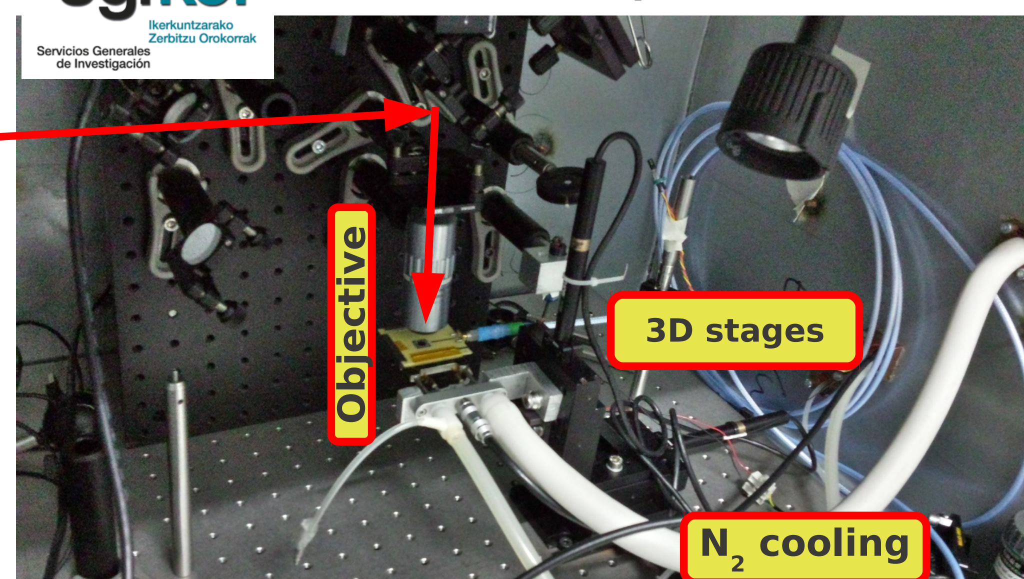
Spot size

Two Photons must be **coincident in time** (pulsed **mode-locked** lasers) and in **space** (**microfocusing**)



×**100** objective

Setup



Running RD50-TPA projects

Two RD50-TPA projects **running** during this year:

- **RD50-2016-04**

  “*Determination of the Electric Field across the electrodes of **planar pad-like diodes** using an **Edge TCT** technique based on a Two-Photon-Absorption (TPA) process*”

  6 RD50 institutes: IFCA, CERN, IJS, MPI, IMB-CNM, INFN-To
  Contact person: Iván Vila

- **RD50-2017-02**

  *"3D imaging of irradiated and non-irradiated **HVCMOS** using Two Photon Absorption **edge** illumination"*

  5 RD50 institutes: CERN, IFCA, IJS, IFAE, Liverpool
  Contact person: Marcos Fernández

Status of these 2 projects reported in this talk

Running RD50-TPA projects

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  Pending for measurements

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  5 RD50 institutes: CERN, IFCA, IJS, IFAE, Liverpool
  Contact person: Marcos Fernández

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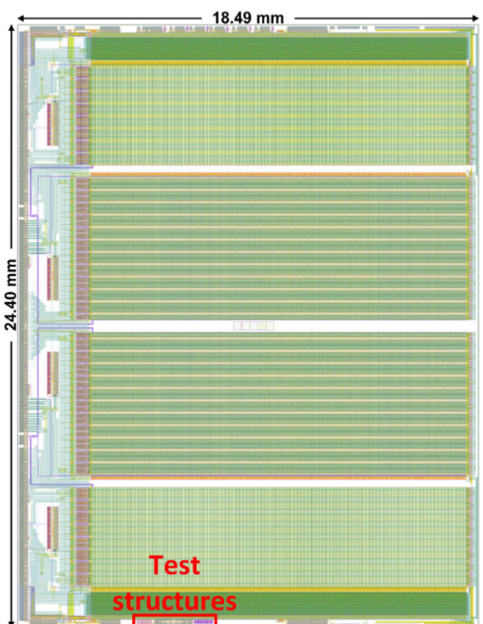
Status of these 2 projects reported in this talk

Liverpool's HV35demo

User: Liverpool
Dates: 29th-30th June 2017 **Percentage of project completion: 70 %**
Device: H35demo, 1 kΩ.cm, thinned down to 100 µm, back bias.
TPA @ (1300 nm,60fs)



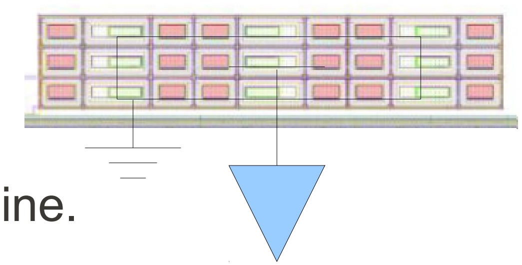
A **large area** demonstrator chip (ATLAS) in the AMS 350 vm HV-CMOS technology produced on wafers of different resistivity.
Here: 1 kΩcm *[Designers: I. Peric, E. Vilella,R. Casanova]*

For TCT purposes:

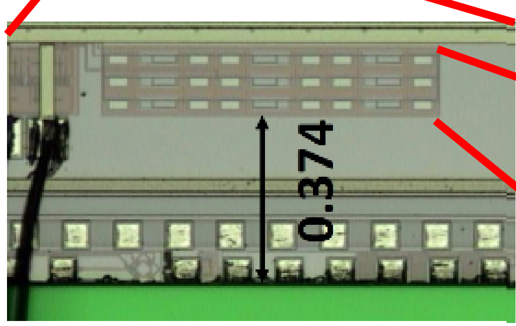
1 test structure with 3×3 passive pixels $250_y \times 50_z\ \mu m^2$

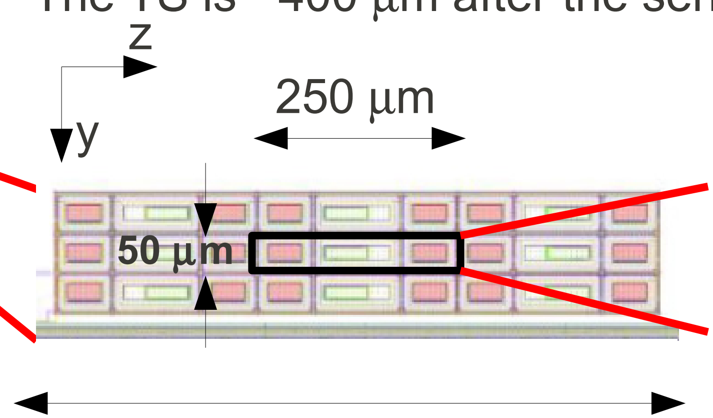
1 pixel contains 3 Deep N wells $(70+110+70)_y \times 50_z\ \mu m^2$

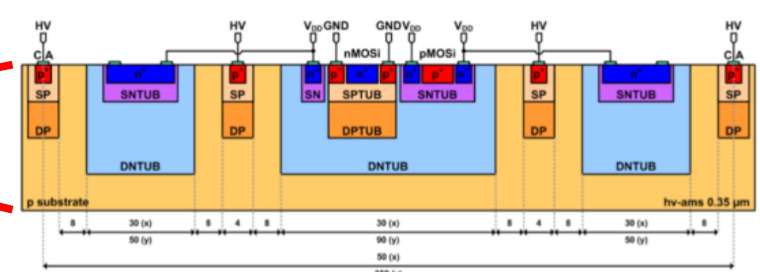
Central pixel connected to the amplifier.
Its 8 neighbors are grounded together



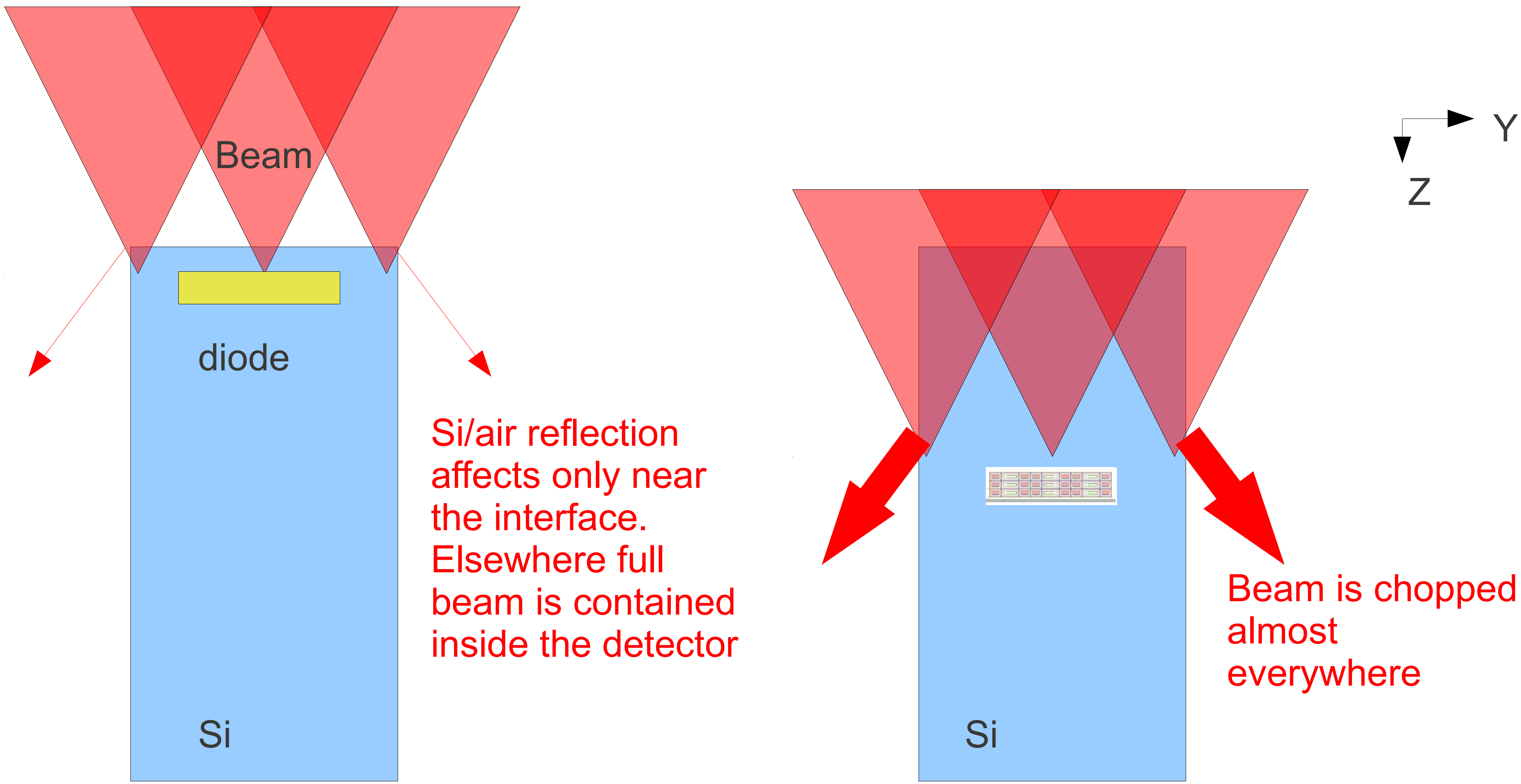
The TS is ~400 µm after the sensor cut-line.







Beam coupling to deep motifs

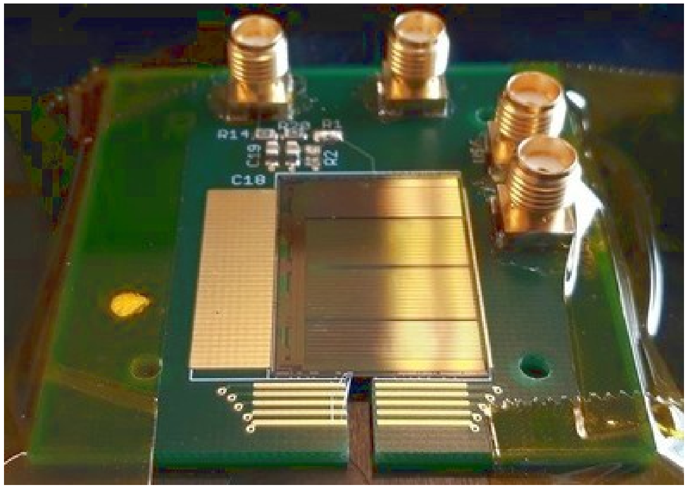


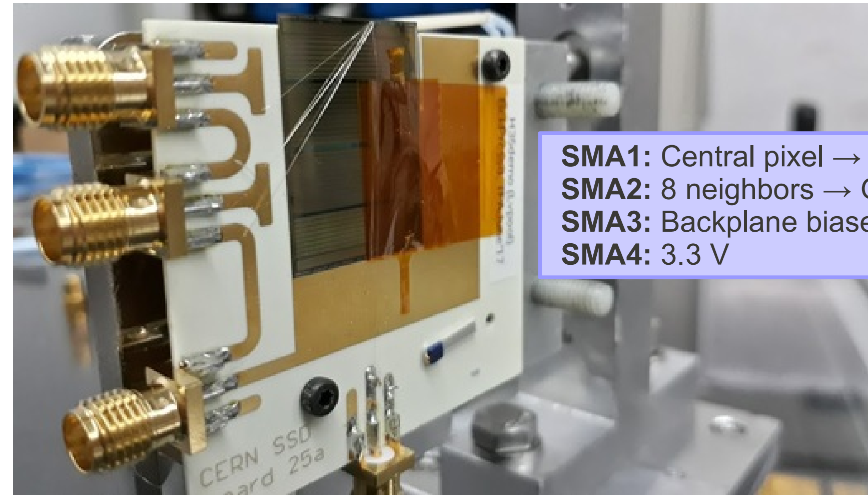
Shallow motif to scan
Small loss due to reflection at the borders
Approximately constant coupling of energy to focus.
Good layout for TPA measurement

Deep motif to scan
Very asymmetric coupling to the focus
Bad layout for TPA measurement

edge-TPA on HV35demo

beam

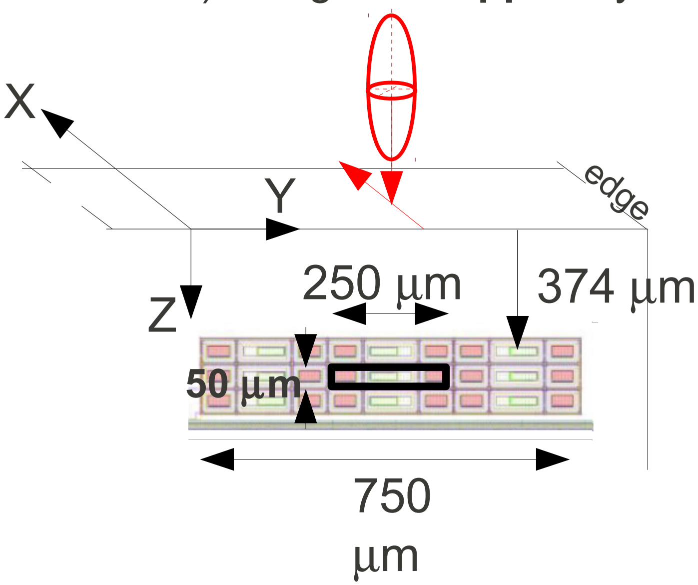




SMA1: Central pixel → ampli
SMA2: 8 neighbors → GND
SMA3: Backplane biased
SMA4: 3.3 V

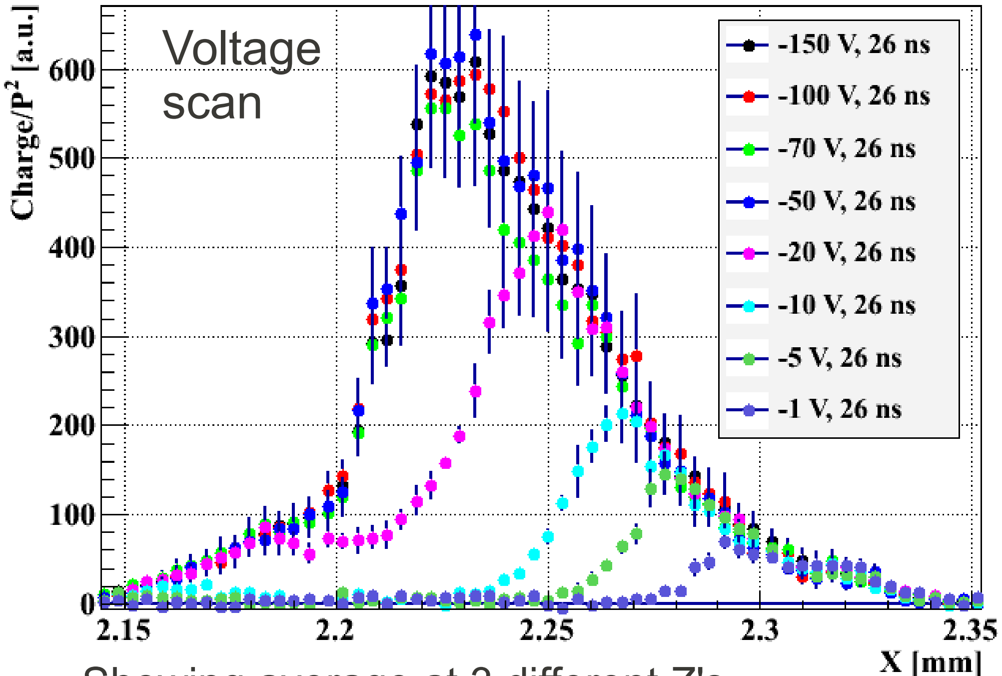
Liverpool **PCB** was **not compatible** with **TPA** setup
Light has to channeled by **narrow slit** before reaching the detector. TPA uses a very **divergent beam** (microfocus) that gets **chopped** by this channel

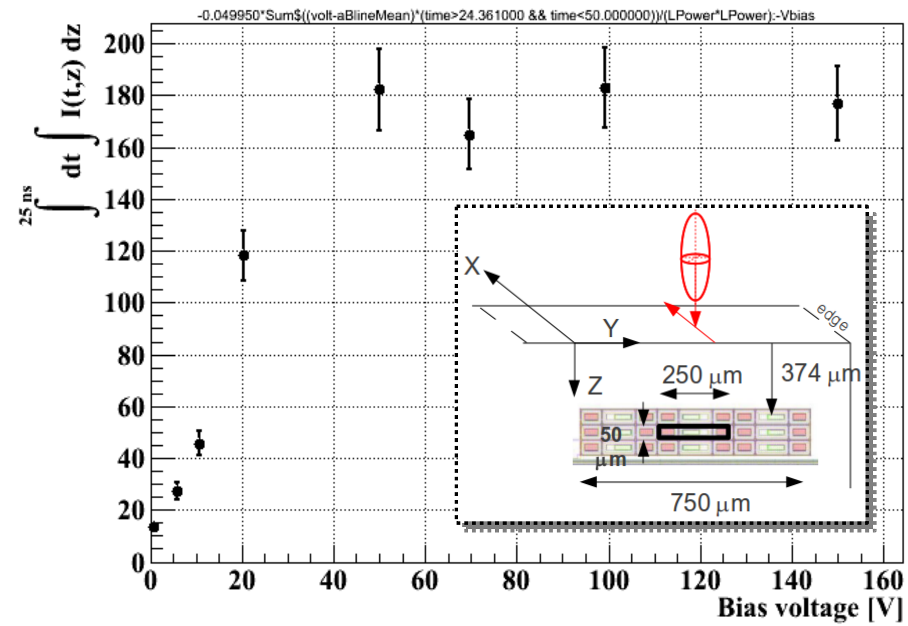
New detector glued to **standard** CERN edge-TCT **PCB**. One of the bonds is 4.5 cm long (new bondlab record). The kapton tape ensures this long bond not touching the detector.

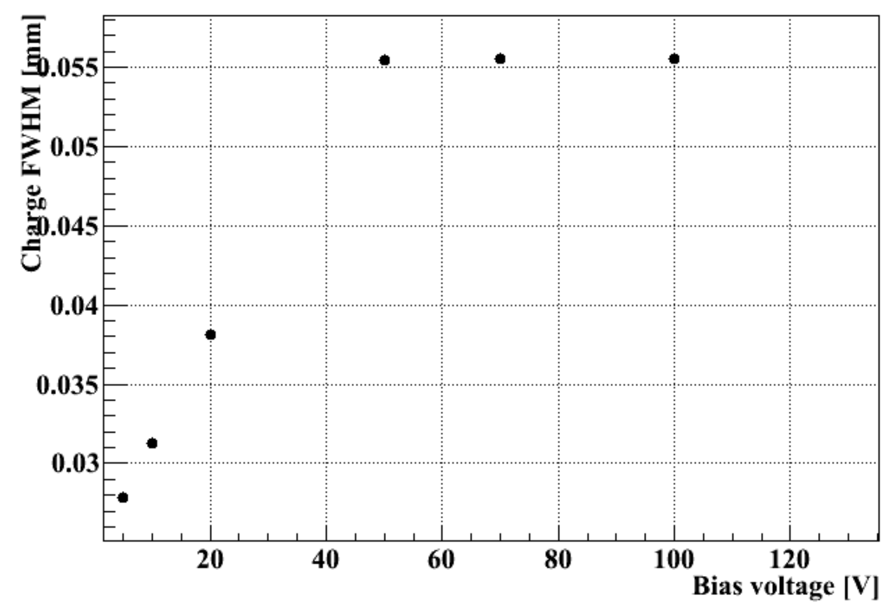


- TPA uses a highly focused beam (NA~0.5)
- The H35 TS is “deep” below the surface. The beam has to travel Δz~400 µm before arriving to the central pixel.
- Light coupling to focus will depend on X and Z (see next slide)

TPA on HV35demo

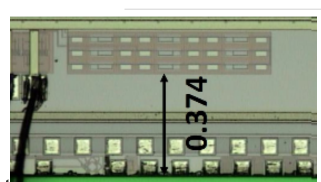




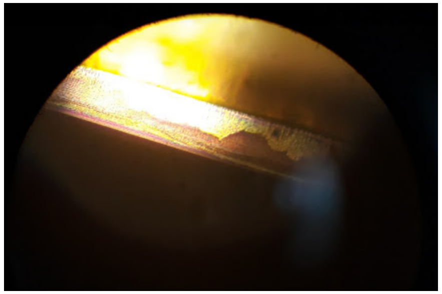


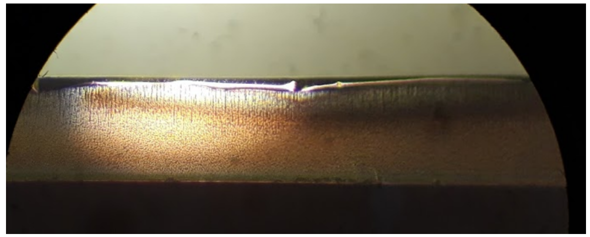
- Showing average at 3 different Z's.
- The detector starts depleting from the front.
- Very **slow raise** of Q(x) observed. The width of charge distributions at FWHM saturates at 50 µm. Probably affected by the **vignetting** of the beam during the X scan.
- At -20 V the whole bulk seems to contribute to charge collection
- From -50 V on, the full device seems to be depleted.

Next: thin-down the dead space between the edge and the test structure

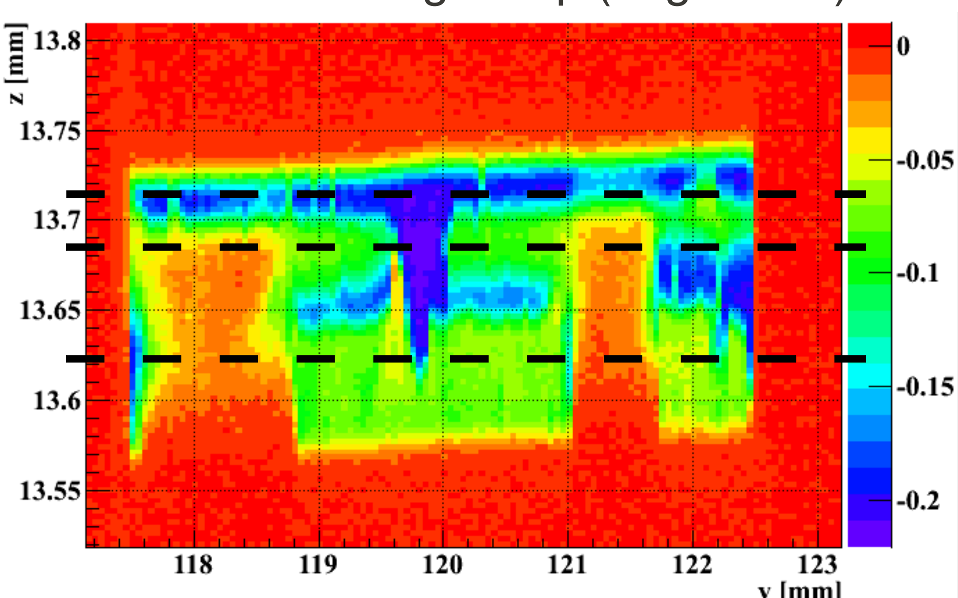


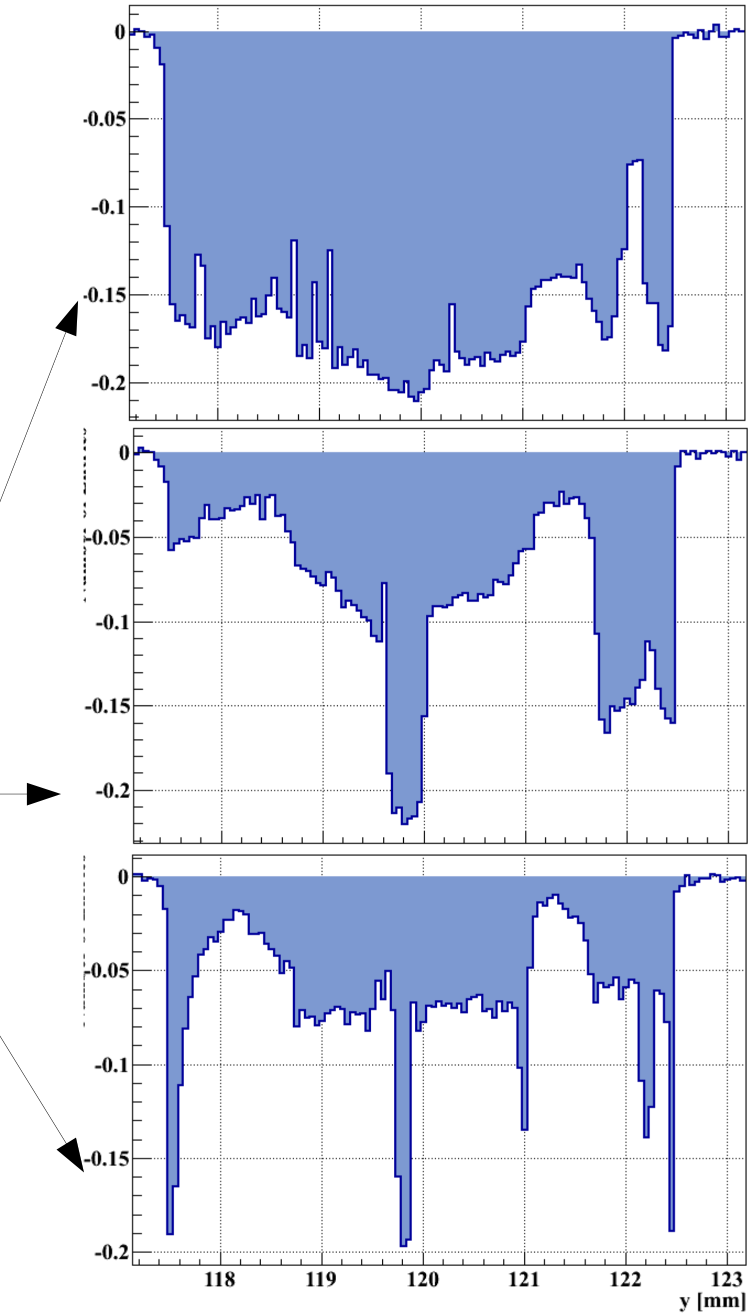
TPA on Advacam diodes





Collected charge map (edge scan)



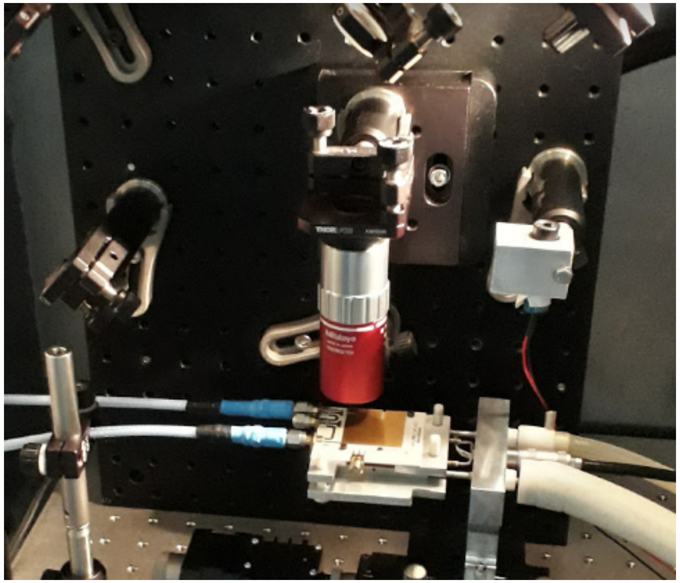


CERN SSD TCT+ edge-TCT

[See some results in backup slides]

Irradiated LGADs

- 285 µm x 3x3 mm^2 LGAD diodes CNM Run 7859
  Wafers 1 and 2:
    multiplication layer dose: **1.8**x10^{13}cm-2, **low** gain.
  Wafers 3 and 4:
    multiplication layer dose: **2.0**x10^{13}cm-2, **high** gain.
- Irradiated @ CERN IRRAD facility with 24-GeV/c protons.
- Four fluences: 10^{12}, 10^{13}, 10^{14}, 10^{15} n_{eq}/cm^2
- Annealing after irradiation: 80 min at 60ºC



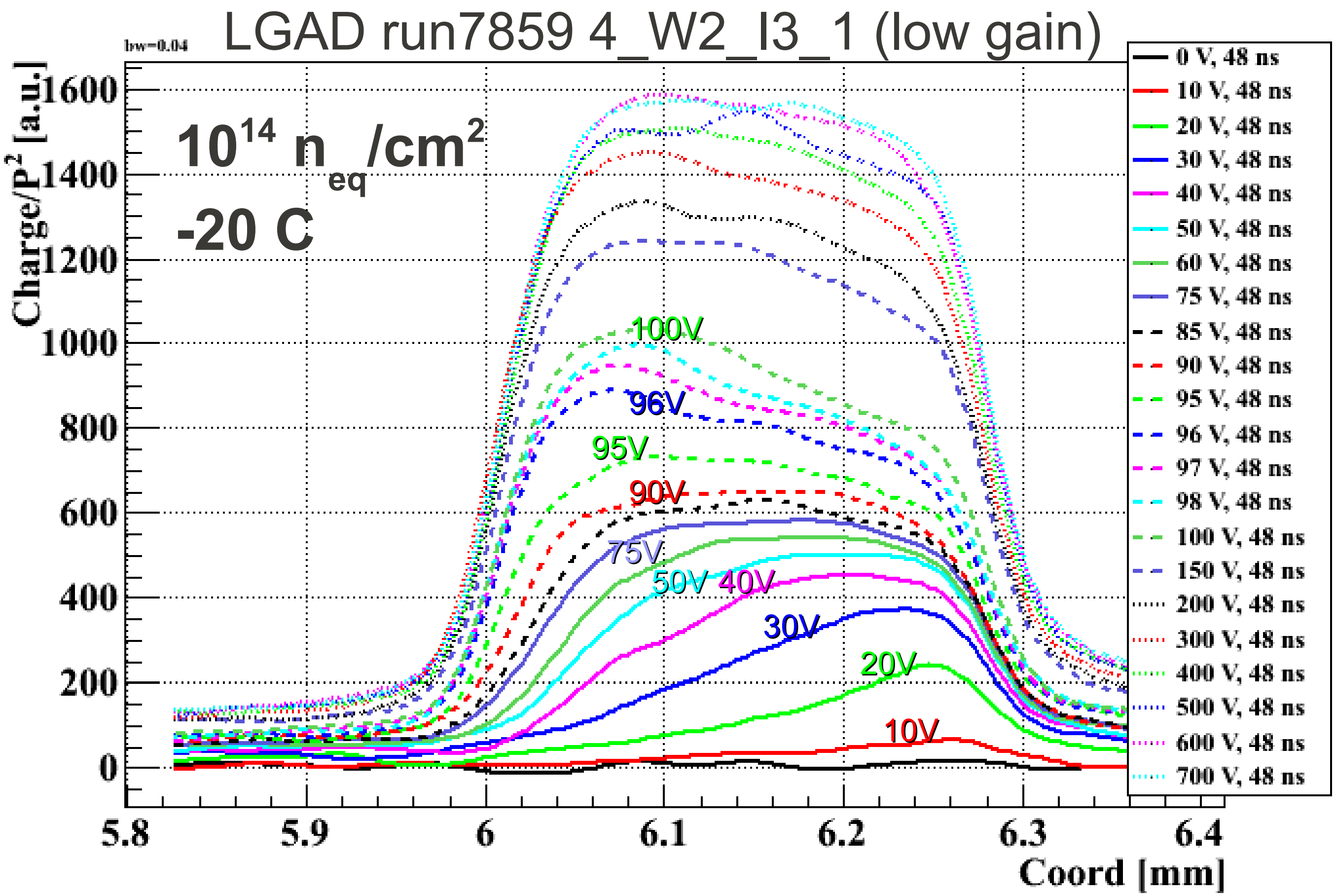
Top-TPA configuration

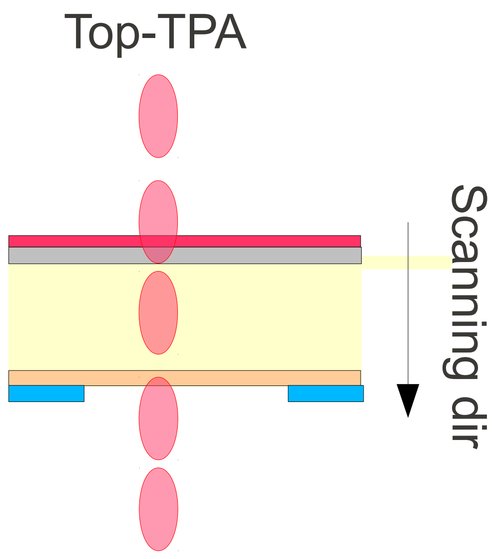
These devices are interesting because they show:

1) an increase of multiplication onset voltage with fluence
2) Early signal collected from red back TCT
3) A reduction of the multiplication onset with time → **Beneficial gain annealing**

Futher details:
*See **S. Otero**, Vertex 2017 , Asturias (Spain)*
__I. Vila__ - ETL sensor group, Oct. 2nd 2017, CERN

Top-TPA on LGADs: collected charge

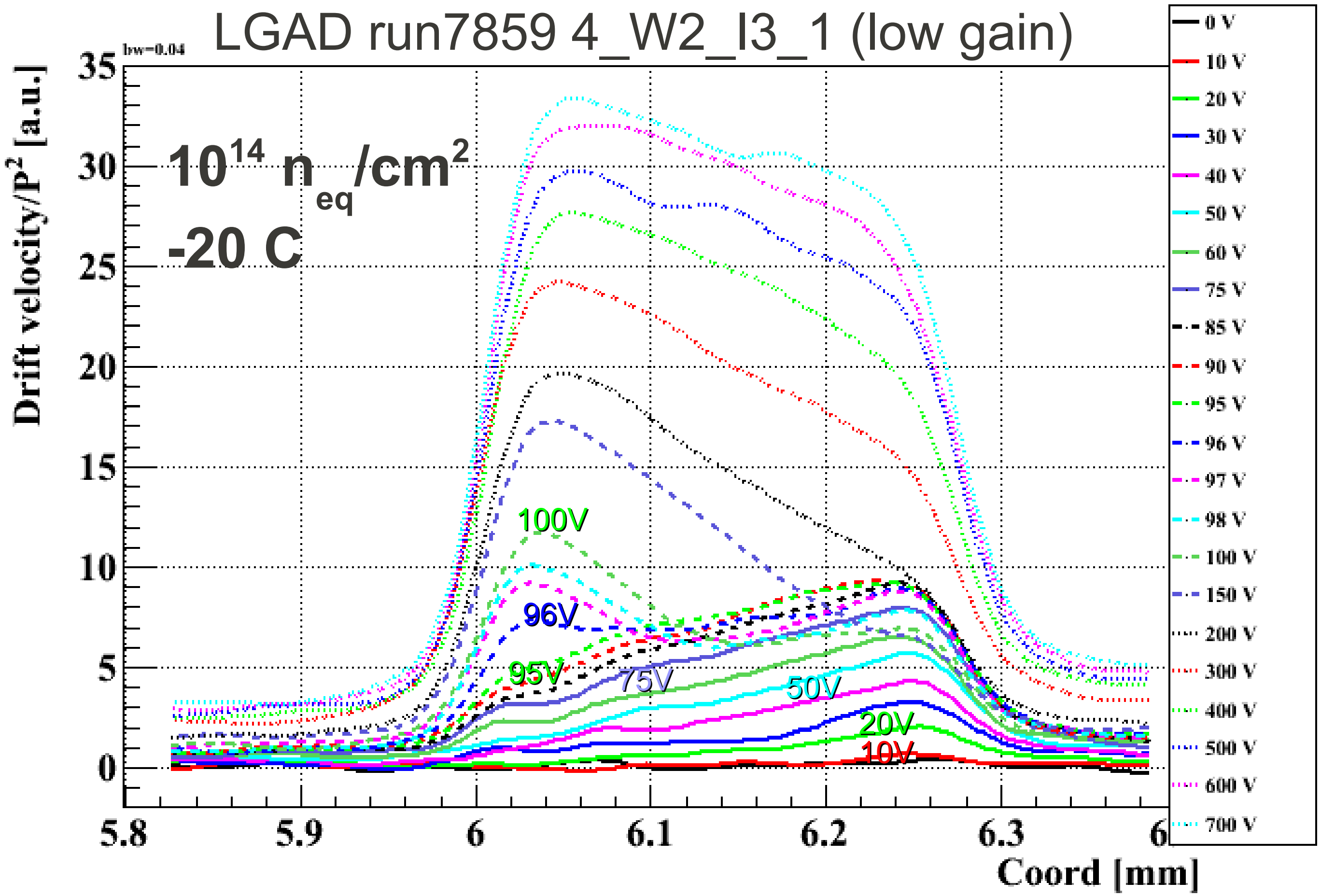


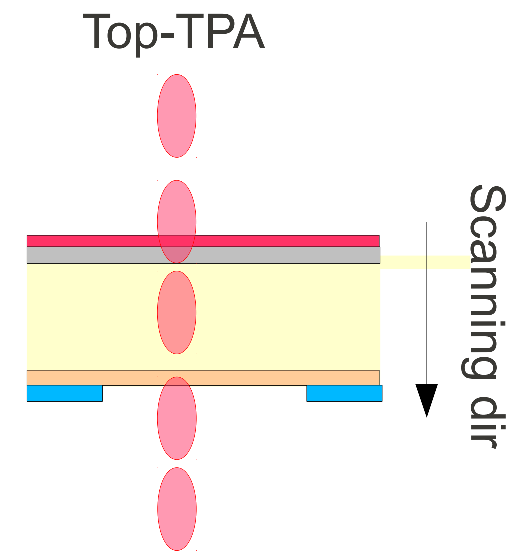


Low dose, low gain LGAD
PS protons: 10^{14} n_{eq}/cm^2

- ▶ Collected charge profile:
  - Focus is "pushed" from the top. Induced charge recorded as a function of focal point position. Time integration of the pulse yields induced charge
  - Charge **collection** starts from **behind**
  - **Depleted** width **increases** with **bias** voltage
  - Between **95V** and **96 V** there is a **change of trend:** collected charge is higher at the front.

Top-TPA on LGADs: drift velocity





Low dose, low gain LGAD
PS protons: 10^{14} n_{eq}/cm^2

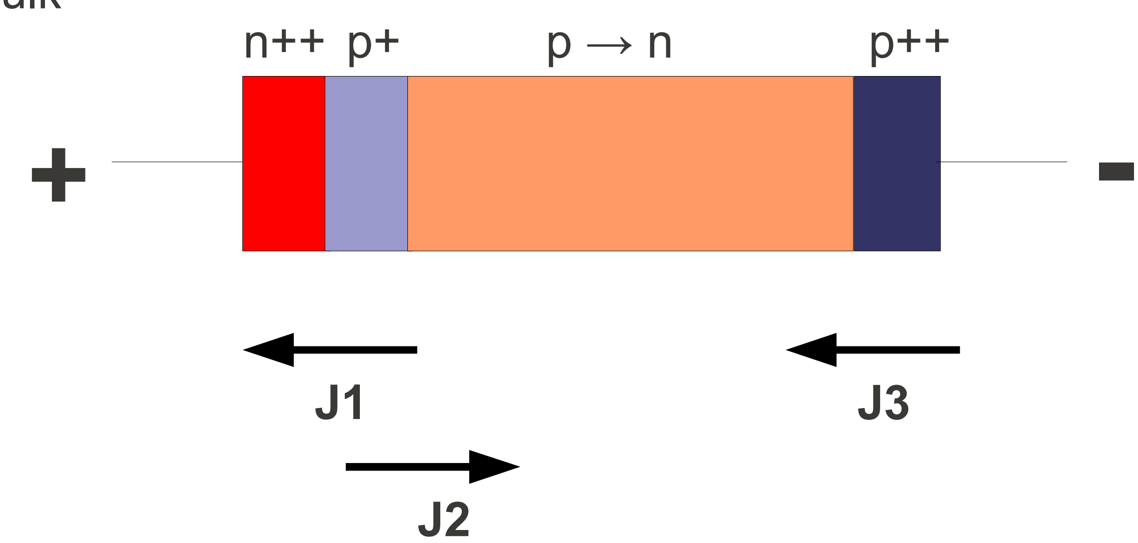
- Note of caution:
  - Drift velocity shown here is calculated using “prompt's method”:

$$v_{drfit}(e+h) \propto I(\ t \leq 400\ ps)$$

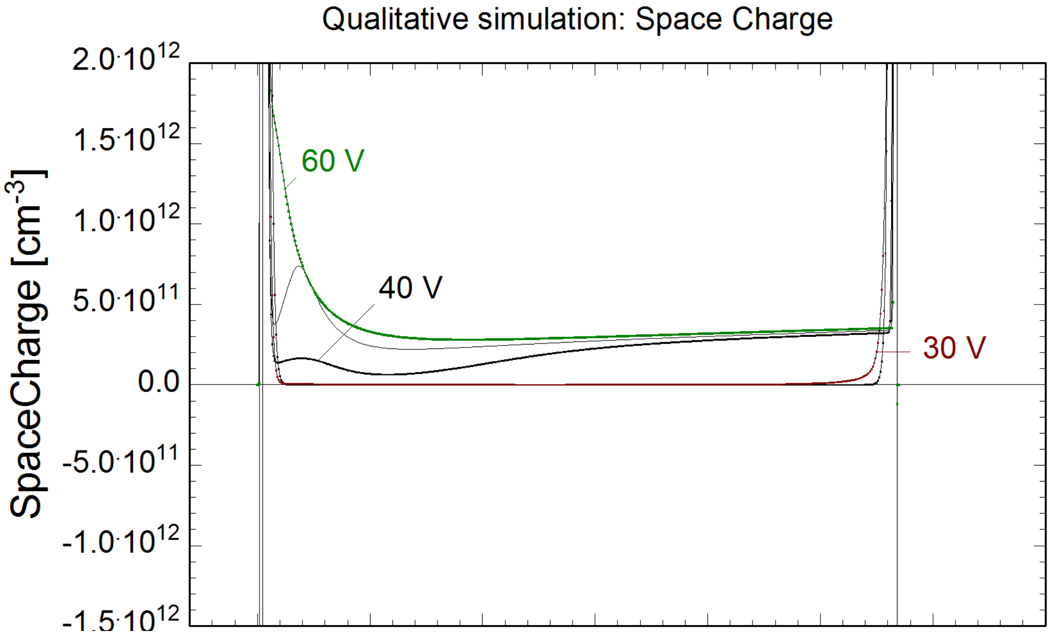
  - For LGADs, once there is CM, this method will overestimate the drift velocity due to the extra generated charge.
  - Showing vdrift here (for illustration purposes) because devices are low gain.

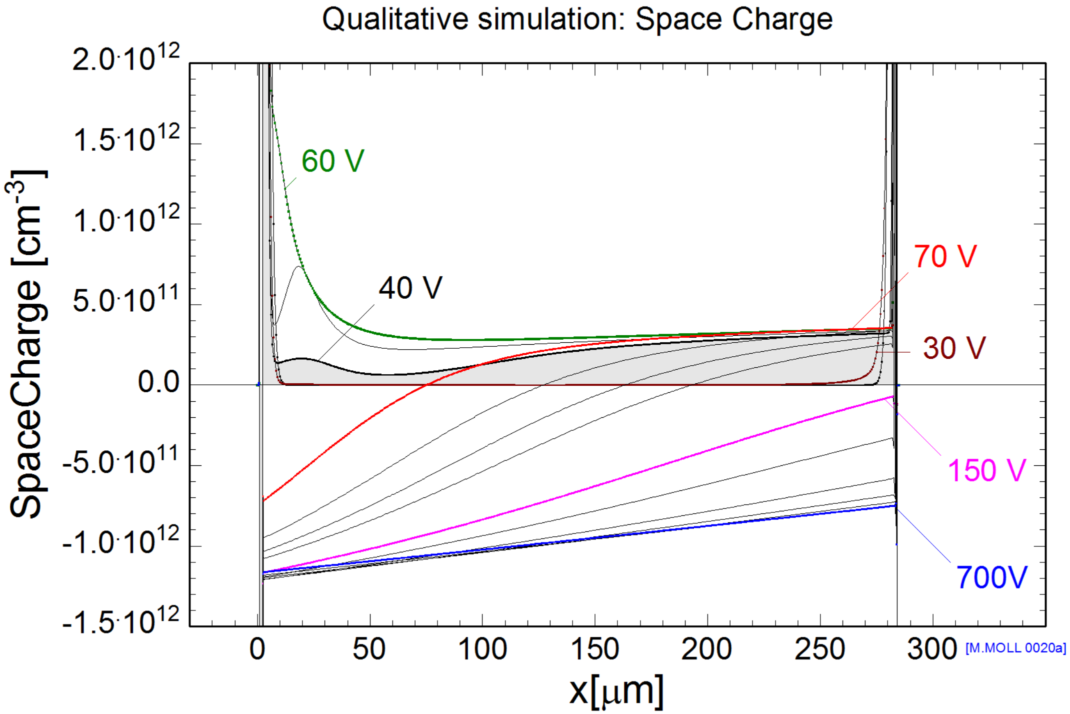
DJ effect in SCSI LGAD

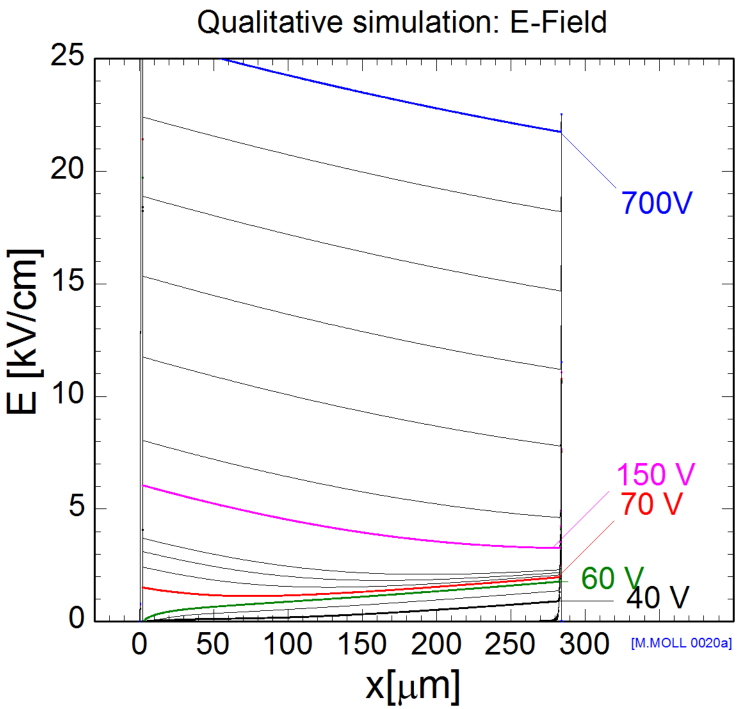
- What kind of space charge profile can give such a flipping E-field characteristic?
- What follows is an explanation based on a qualitative simulation (M. Moll)
- **Space charge sign inversion** of the bulk in LGADs (**p to n**) creates a **n++/p+/n/p++** structure
  - We get 3 junctions J1/J2/J3:
  - The ones in **front**(**J1** n++/p+) and **back**(**J3** n/p++) are **reverse biased**
  - The one **between the gain layer and the bulk (J2)** is "forward biased" leading to a **strong accumulation of holes**, that **suppresses** the **DJ** effect at the front
  - The **field** grows **from the back** (positive space charge in the bulk)
  - Only when the field at the front is **high enough** to **overcome J2** we see the "**standard**" double junction effect and the space charge starts to flip from positive to negative in the bulk



DJ effect in SCSI LGAD: qualitative simulation







By Michael Moll

Summary & continuation...

RD50 funded projects on TPA measurements of Diodes and HVCMOS are ongoing

Diodes measured: Advacam and LGADs
HVCMOS devices: H35demo

TPA-TCT is best operated under edge incidence when the test structure is “shallow”. We need to grind down some material to do a proper measurement of the H35a.

Extra measurements on the 2 projects still need to be accomplished. We can profit from this RD50 to organize the new measurement rounds

Top-TCT measurements of irradiated LGADs ($1x10^{13}$,$2x10^{14}$ at 0, -20C) were accomplished.

Clear Double Junction effect measured.
Interpreted as p-bulk SCSI (positive SC!) followed by hole accumulation at the gain layer. After sufficient E-field intensity the layer can be overcomed and the junction grows from the front.

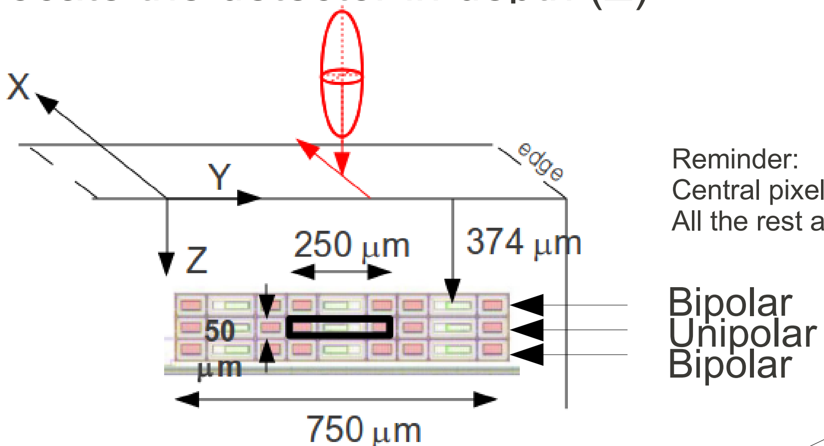
Thanks to CERN bonding lab (F. Manolescu, I. McGill) for various, and always urgent, bonding requests

Backup

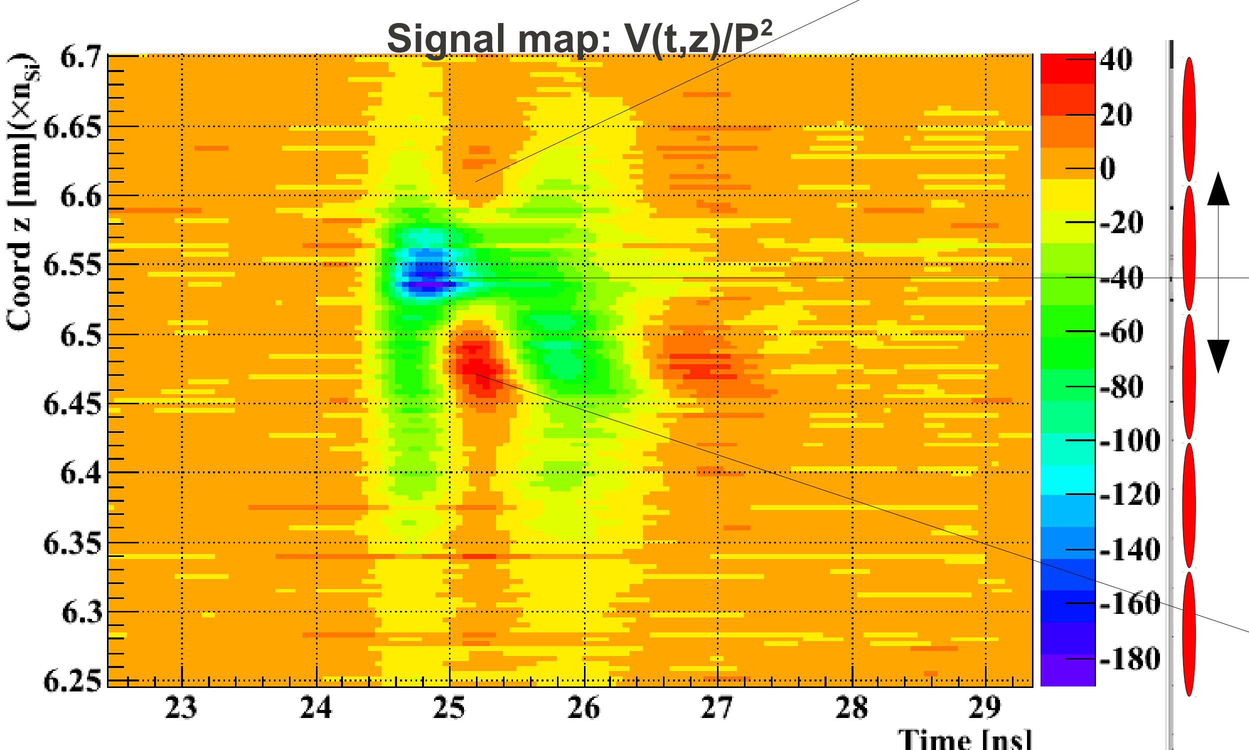
Extra info on H35demo TPA characterization

edge-TPA on HV35demo

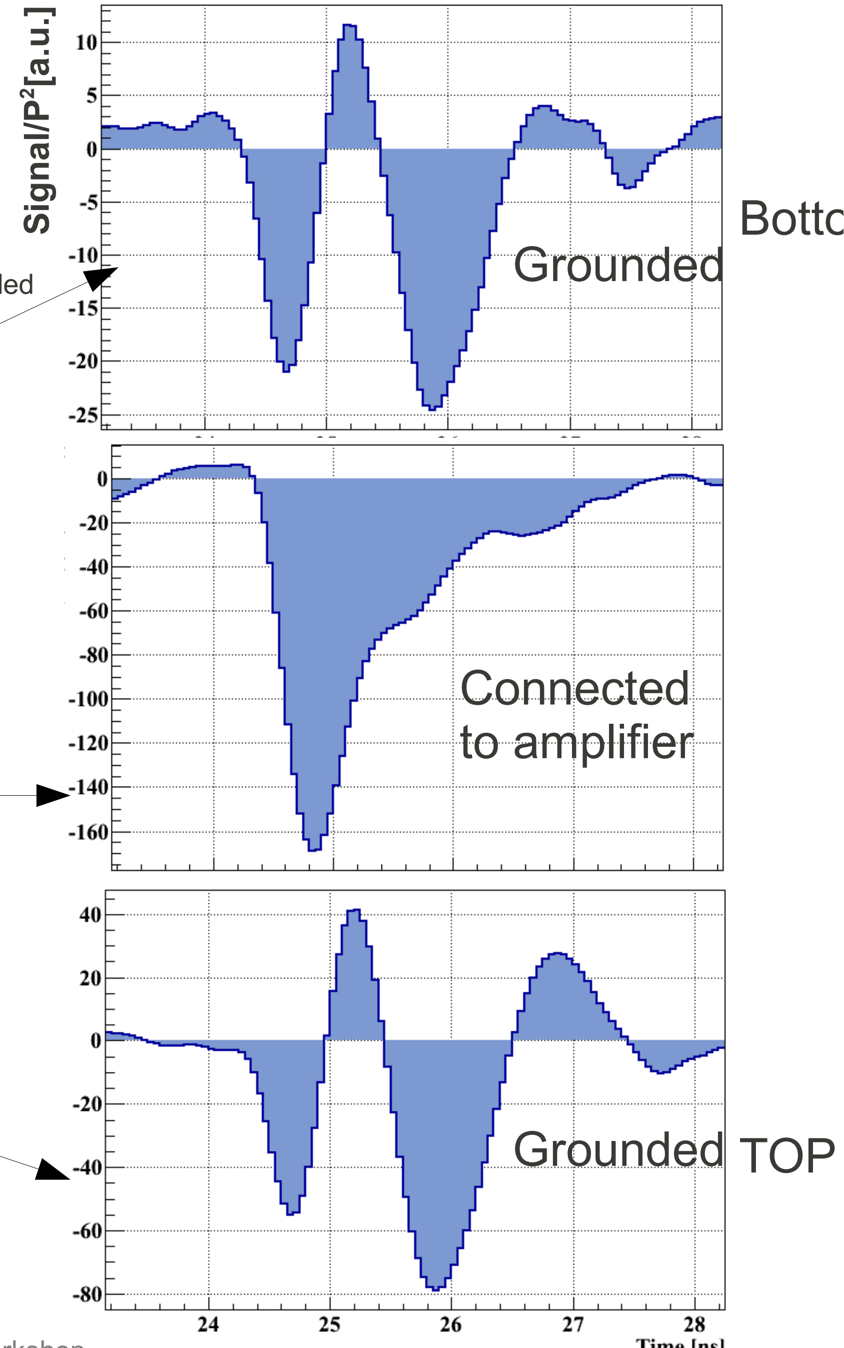
Non collecting electrodes give bipolar signal → handle to locate the detector in depth (Z)



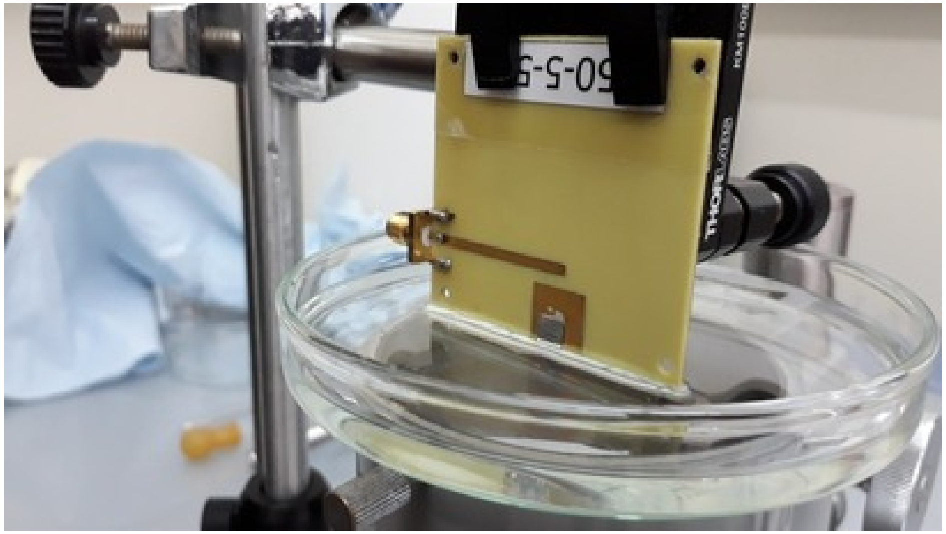
Reminder:
Central pixel connected to amplifier
All the rest are shorted together and grounded

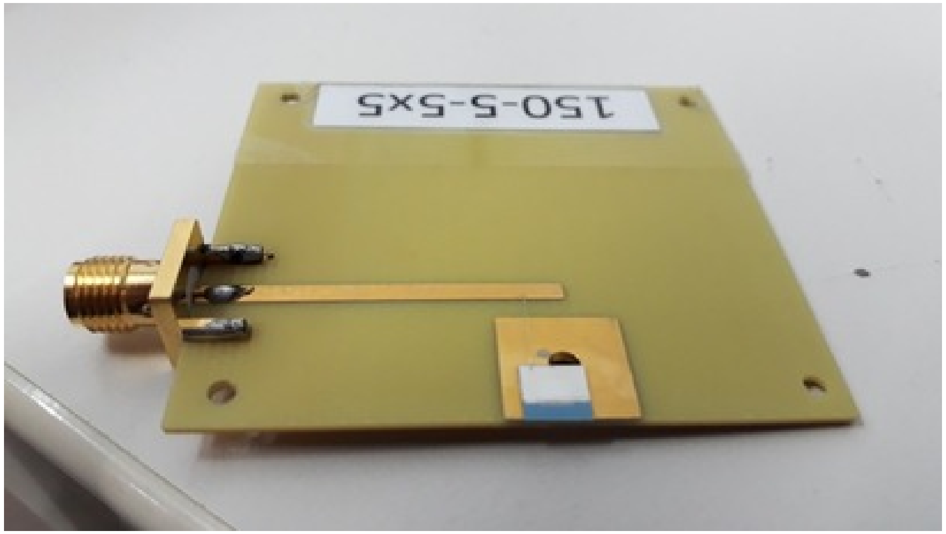


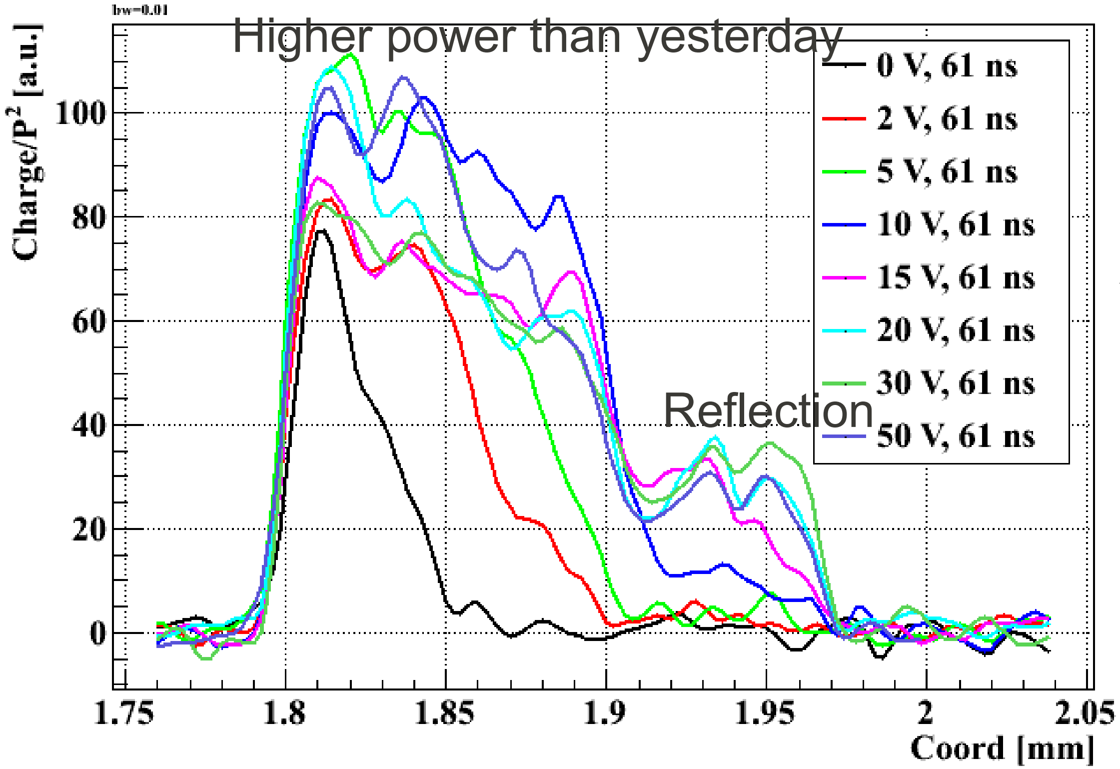
20170630_1059_H35_DEMO_A25_1300nm_60fs_baseline_subtracted.Zscan.root

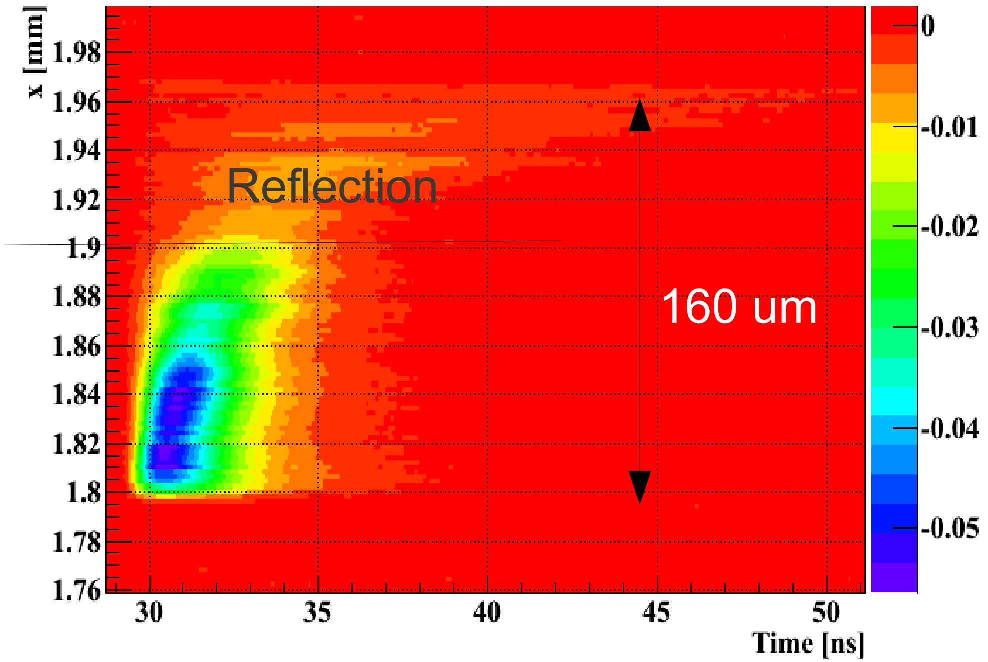


Extra info on ADV TPA characterization

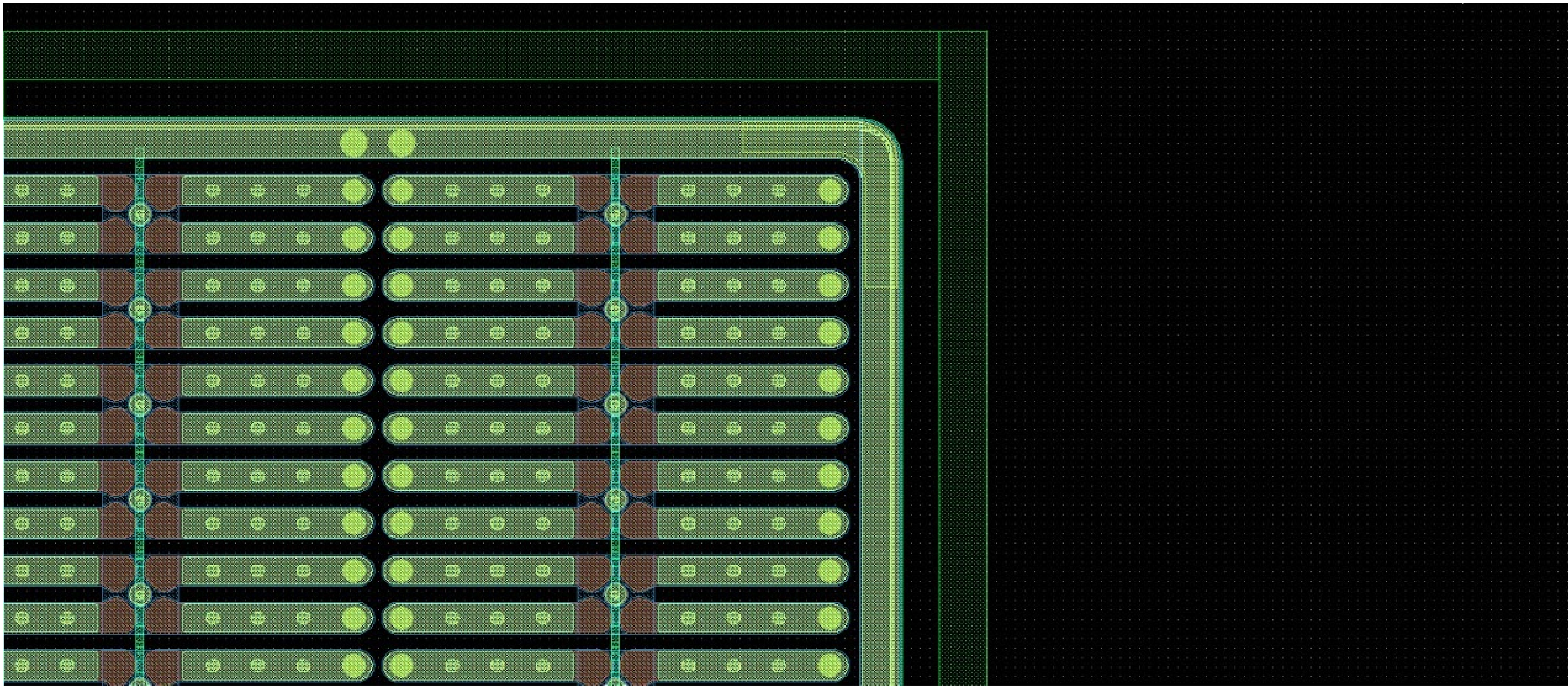



150-5-5x5

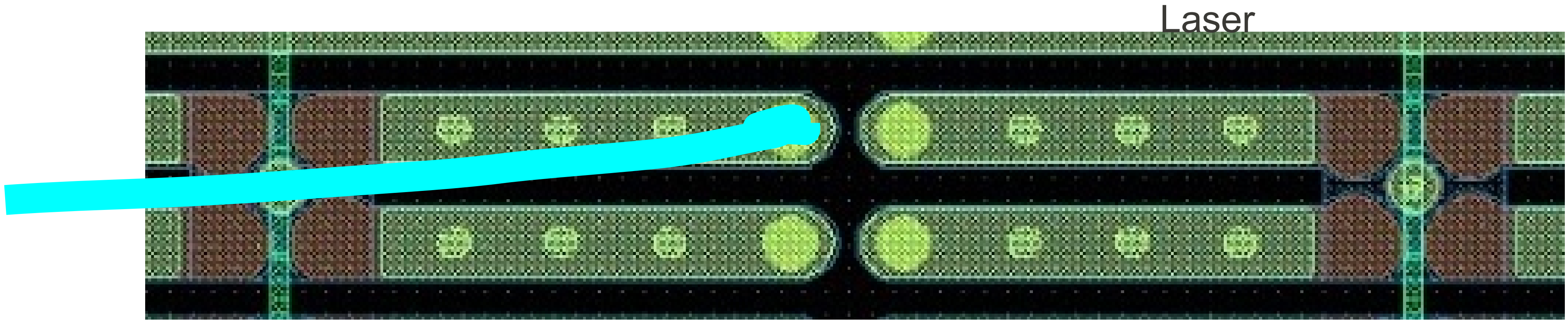

bw=0.01
Higher power than yesterday
Charge/P^2 [a.u.]
0 V, 61 ns
2 V, 61 ns
5 V, 61 ns
10 V, 61 ns
15 V, 61 ns
20 V, 61 ns
30 V, 61 ns
50 V, 61 ns
Reflection
1.75
1.8
1.85
1.9
1.95
2
2.05
Coord [mm]
0
20
40
60
80
100

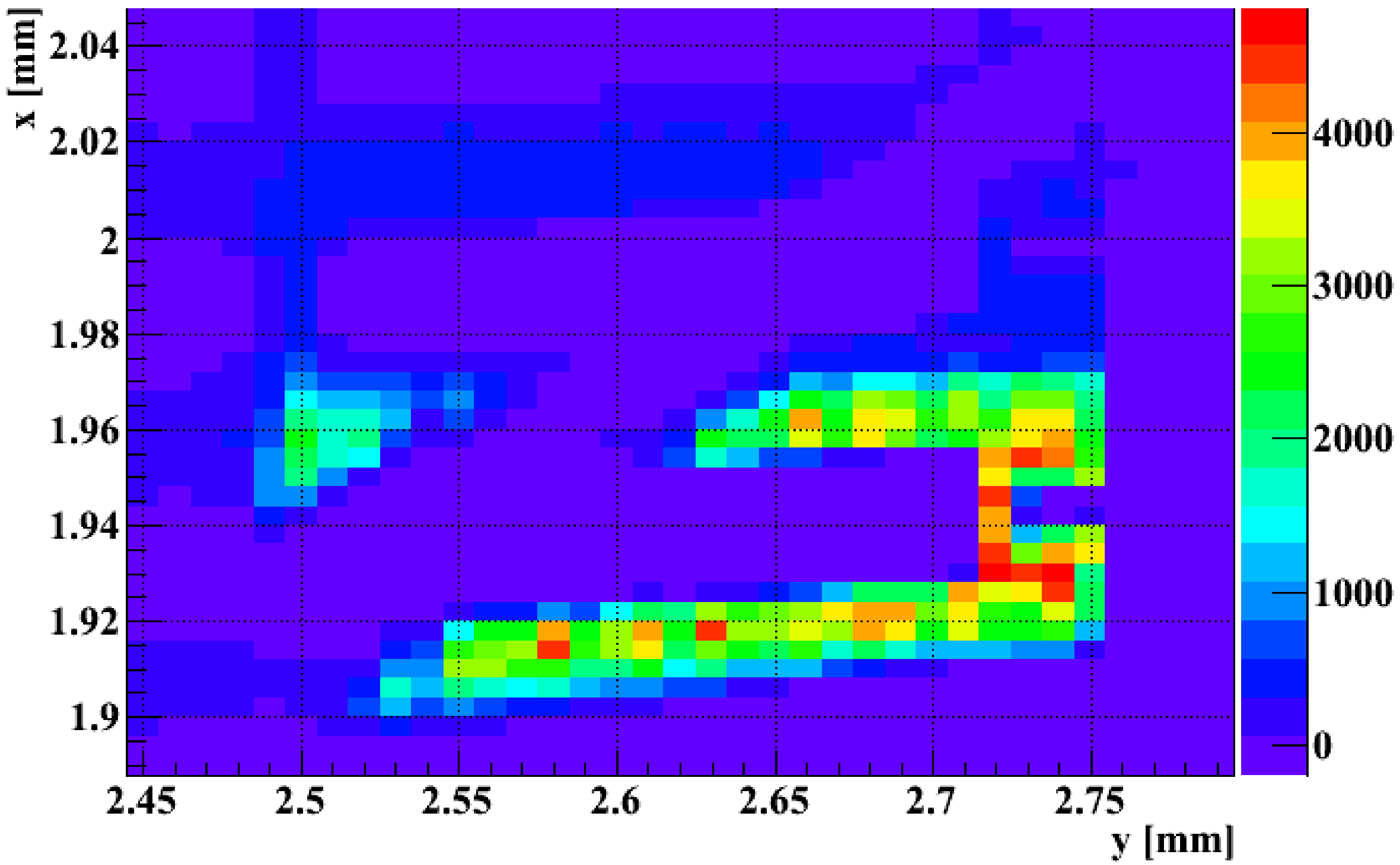

x [mm]
Reflection
160 um
Time [ns]
30
35
40
45
50
1.76
1.78
1.8
1.82
1.84
1.86
1.88
1.9
1.92
1.94
1.96
1.98
0
-0.01
-0.02
-0.03
-0.04
-0.05

Top-TPA TCT
150-2-4B

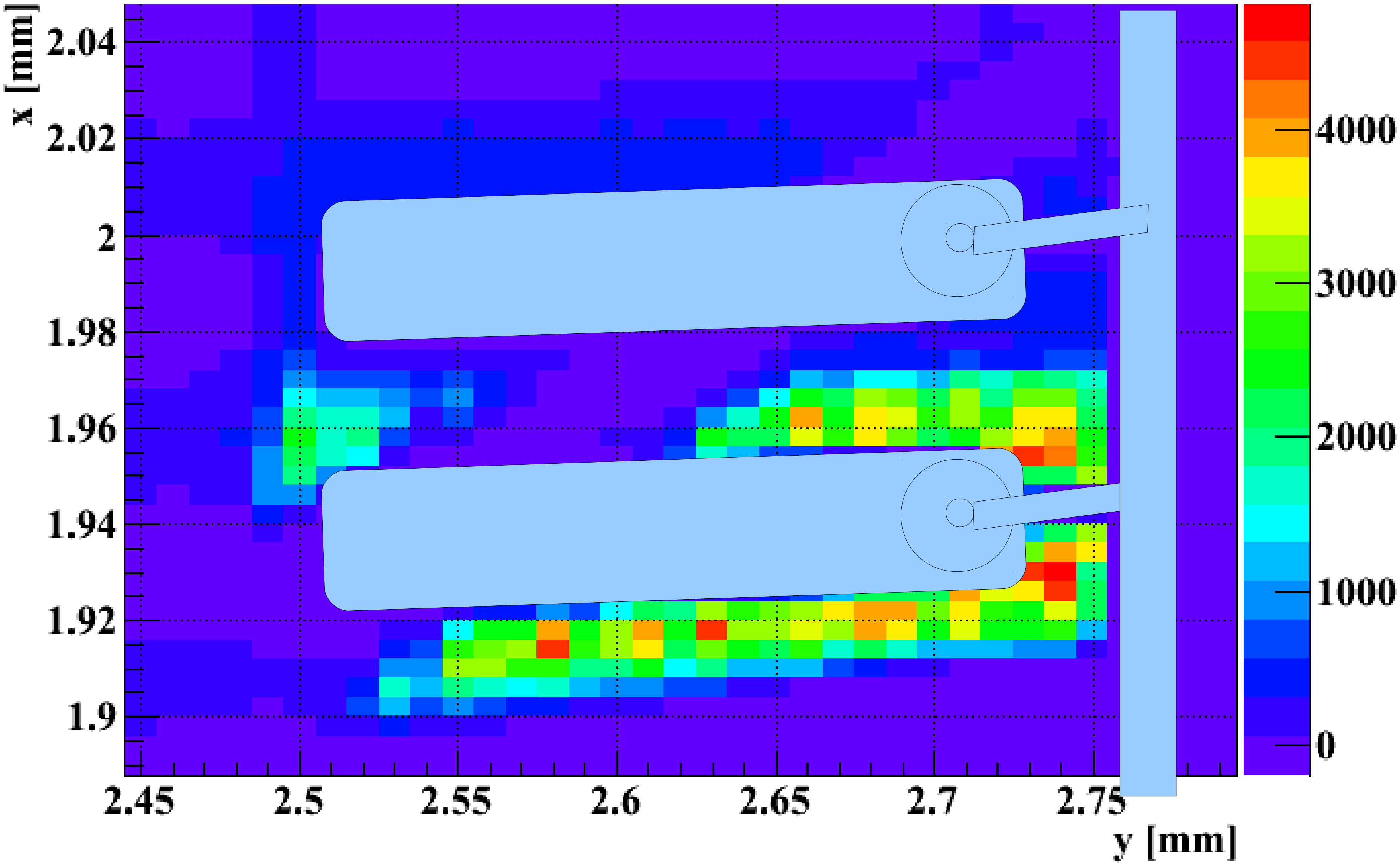


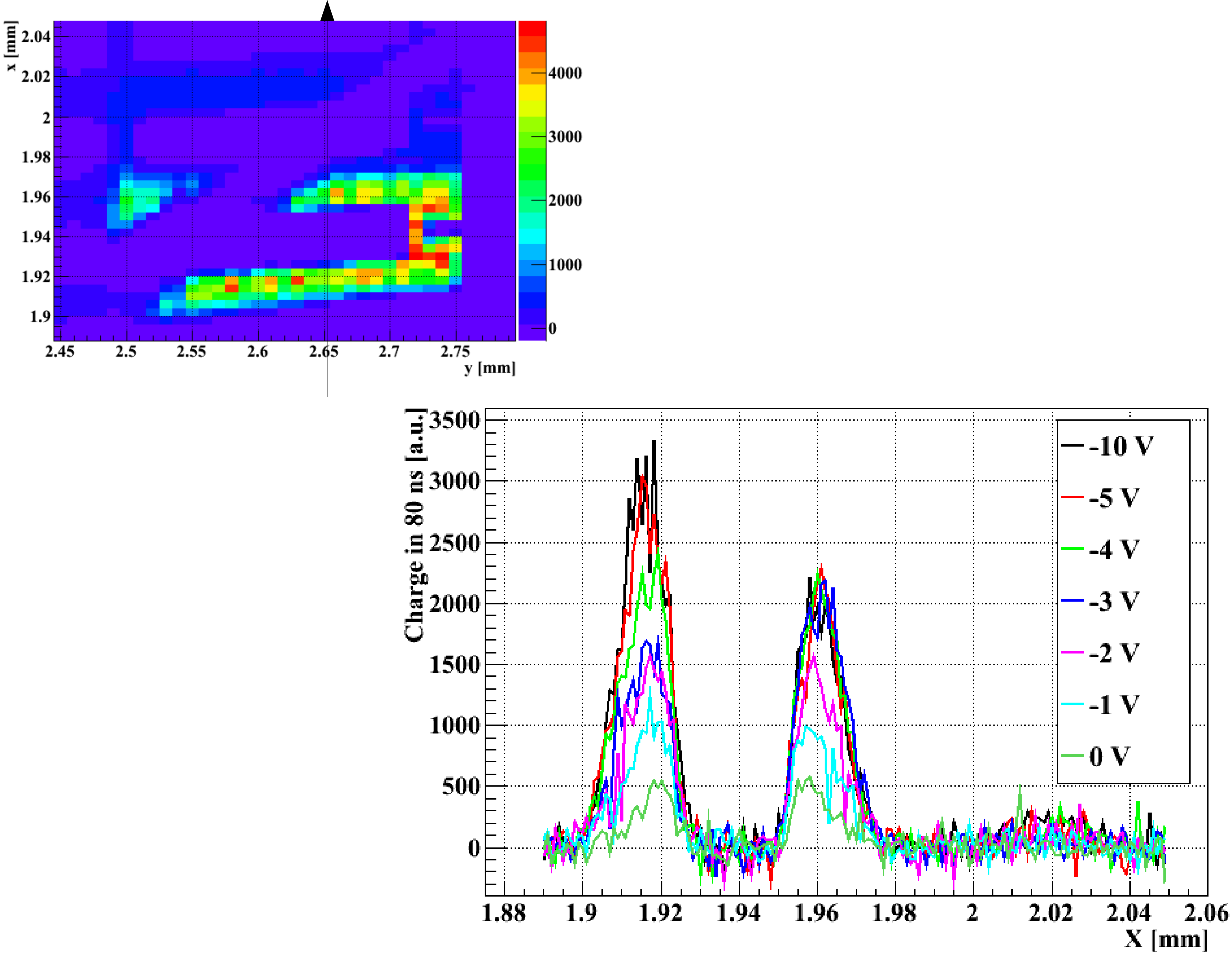
Backbiasing, IFCA board
1stSMA: Pixel ->attenuation->C2->Scope
2ndSMA;GND
3rd SMA: HV





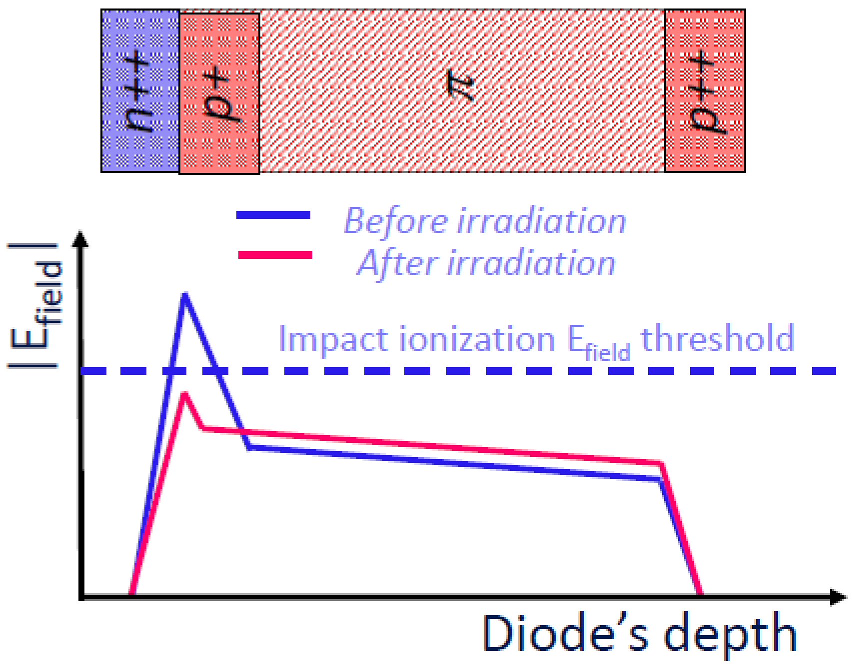
Bipolar pulses in boundaries between neighbor and RO pixel

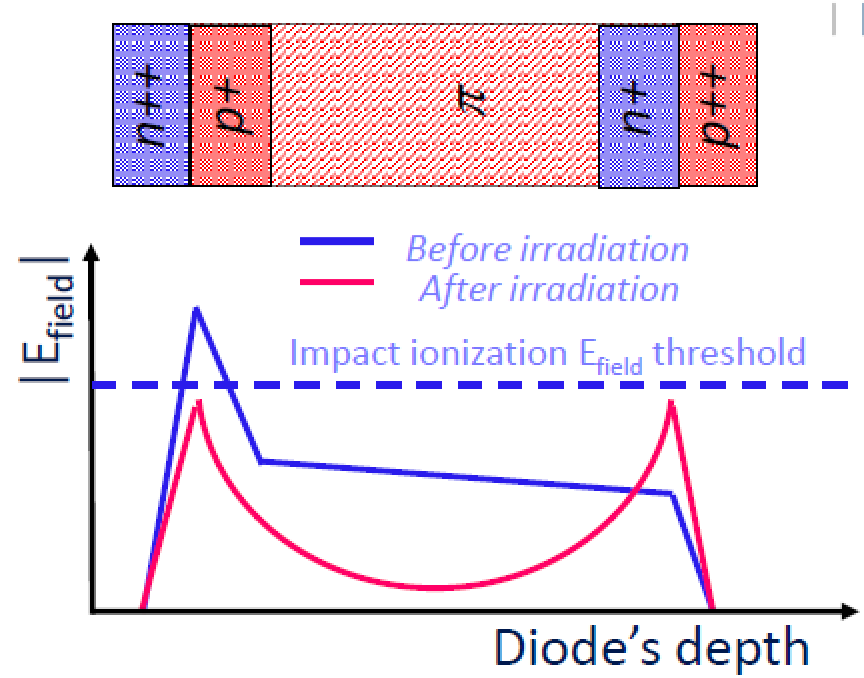

x [mm]
2.04
2.02
2
1.98
1.96
1.94
1.92
1.9
2.45
2.5
2.55
2.6
2.65
2.7
2.75
y [mm]
4000
3000
2000
1000
0


x [mm]
y [mm]
4000
3000
2000
1000
0
Charge in 80 ns [a.u.]
X [mm]
-10 V
-5 V
-4 V
-3 V
-2 V
-1 V
0 V

Extra info on LGAD TPA characterization

Signatures of radiation damage mechanisms





Acceptor Removal gain suppression:

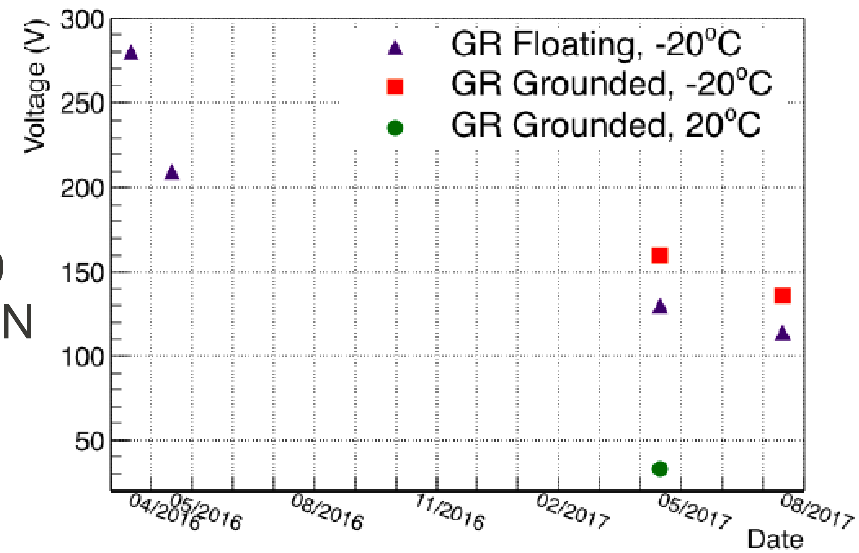
- Radiation-induced reduction of multiplication layer doping (B deactivation).
- Depletion from the front-side to the back-side.
- Amplification on-set voltage decreases with fluence

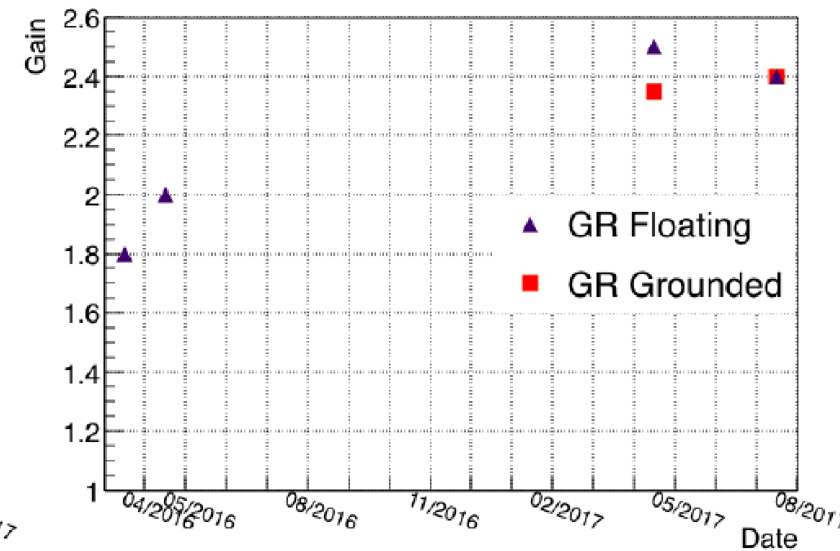
Double-Junction gain supression:

- Radiation-induced back-side junction drives diode depletion & reduces the electric field at the multiplication layer
- Depletion from back-side to front-side.
- Amplification on-set voltage increase with with fluence (Temp. dependence)

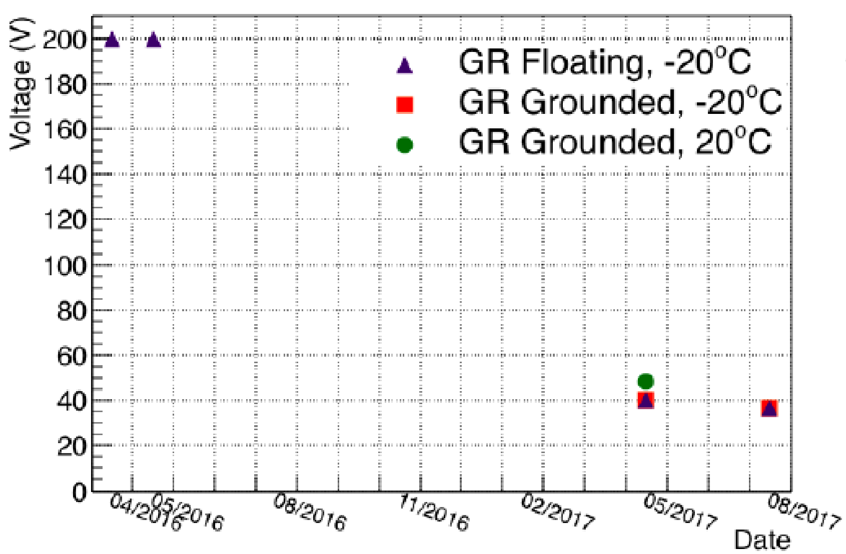
Multiplication onset & gain evolution (low gain samples)

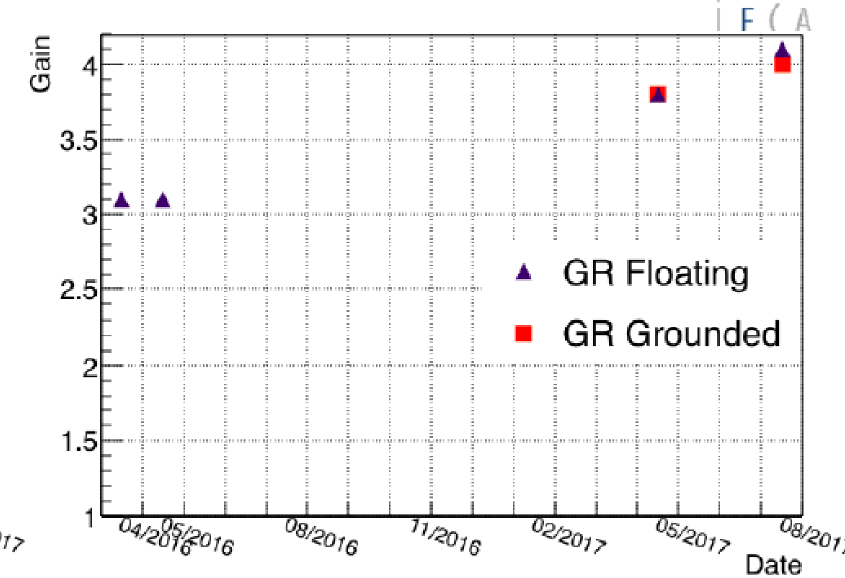
LGADs
CNM run 7859
S. Otero, CERN





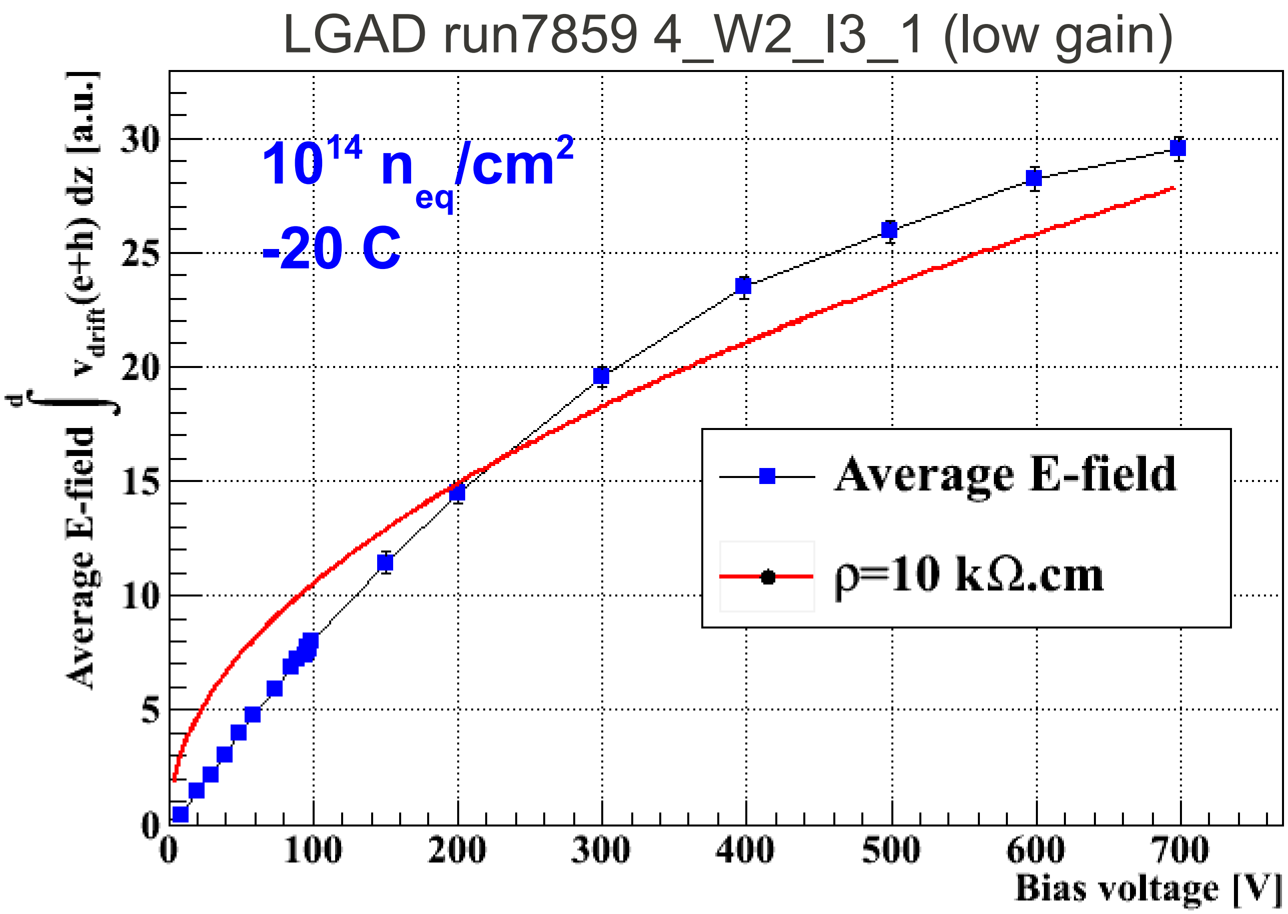
Multiplication onset & gain evolution (high gain samples)



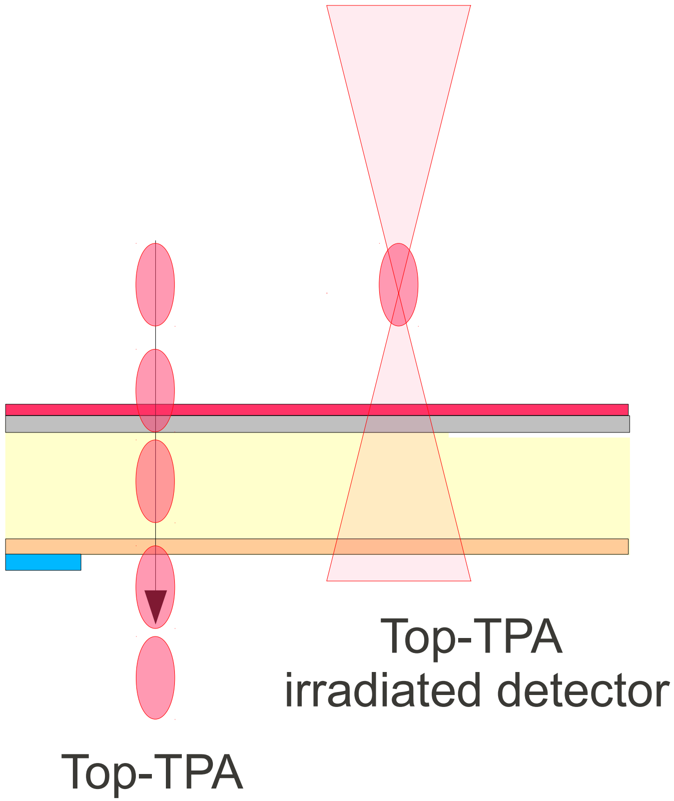


Onset voltage before irradiation: ~32 V
Gain before irradiation at 400V and -20ºC: ~6.83

Gain at 400 V, -20ºC. Calculated w.r.t a PiN. Normalised by laser power.



Average E field (evaluated as vdrift integral over thickness) compared with the nominal E-field (V/d), where d depends on voltage


Top-TPA
irradiated detector
Top-TPA