Test Beam characterization of irradiated 3D pixel sensors

iWoRiD

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On behalf of the CMS Collaboration

Instituto de Física de Cantabria

Outline

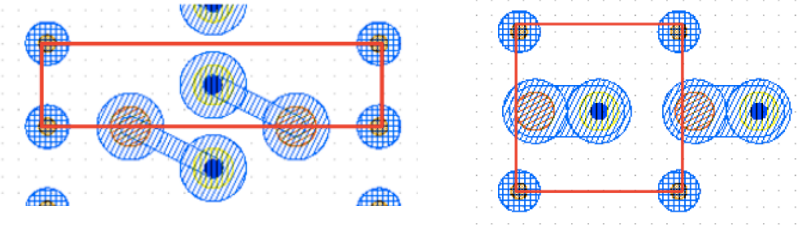
- Motivation
- Sensor description
- Setup
- Non homogeneous fluence
- Study of non homogeneous radiation damage over the sensor: Irradiated sensors working at low bias voltage:
  - Efficiency and collected charge in differently irradiated zones
- Test sensor radiation tolerance: Irradiated sensors at operation bias voltage:
  - Efficiency and collected charge in differently irradiated zones
- Conclusions

Motivation

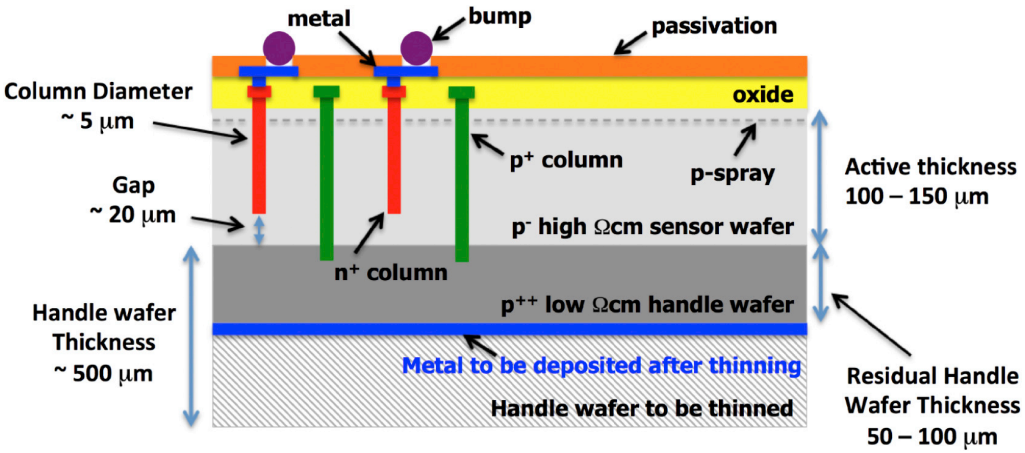
- Phase-2 Upgrade of the CMS detector: define which pixel sensors are the best for the Inner Tracker.
- 3D is one of the technologies considered for the innermost layer of the CMS pixel detector.
- Objective: characterization of 3D pixel sensors at different fluences, voltages and temperatures, when read by the RD53A readout chip, at several Test Beam campaigns.
- Summary of the results made with irradiated 3D pixel sensors in 25x100 and 50x50 μm^2 geometries is shown.
- These sensors were not homogeneously irradiated. Studies of same fluence sensor regions.

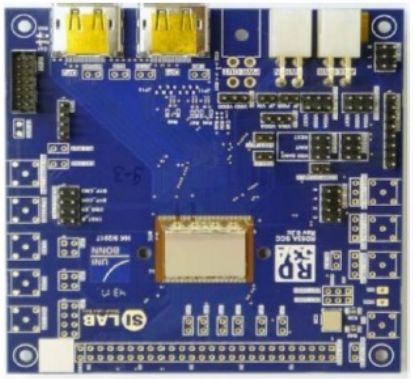
Sensor description

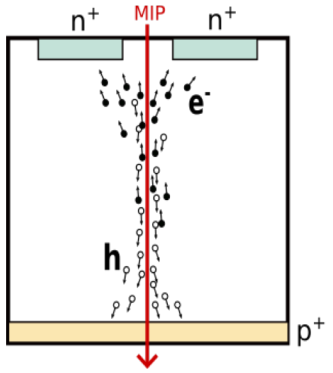
- Pixelated FBK 3D sensors with single side technology (Si-Si).
- Pitch types:
  - 25x100 µm^2 (1E)
  - 50x50 µm^2

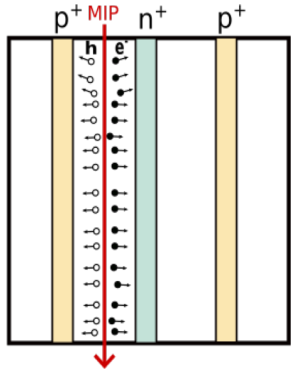


- Active thickness: 130 µm
- Physical thickness: 200 µm
- No biasing structure
- Bump bonded to RD53A ROC
- Modules on SCC RICE and Bonn cards
- LIN FE results (measured also SYNC)



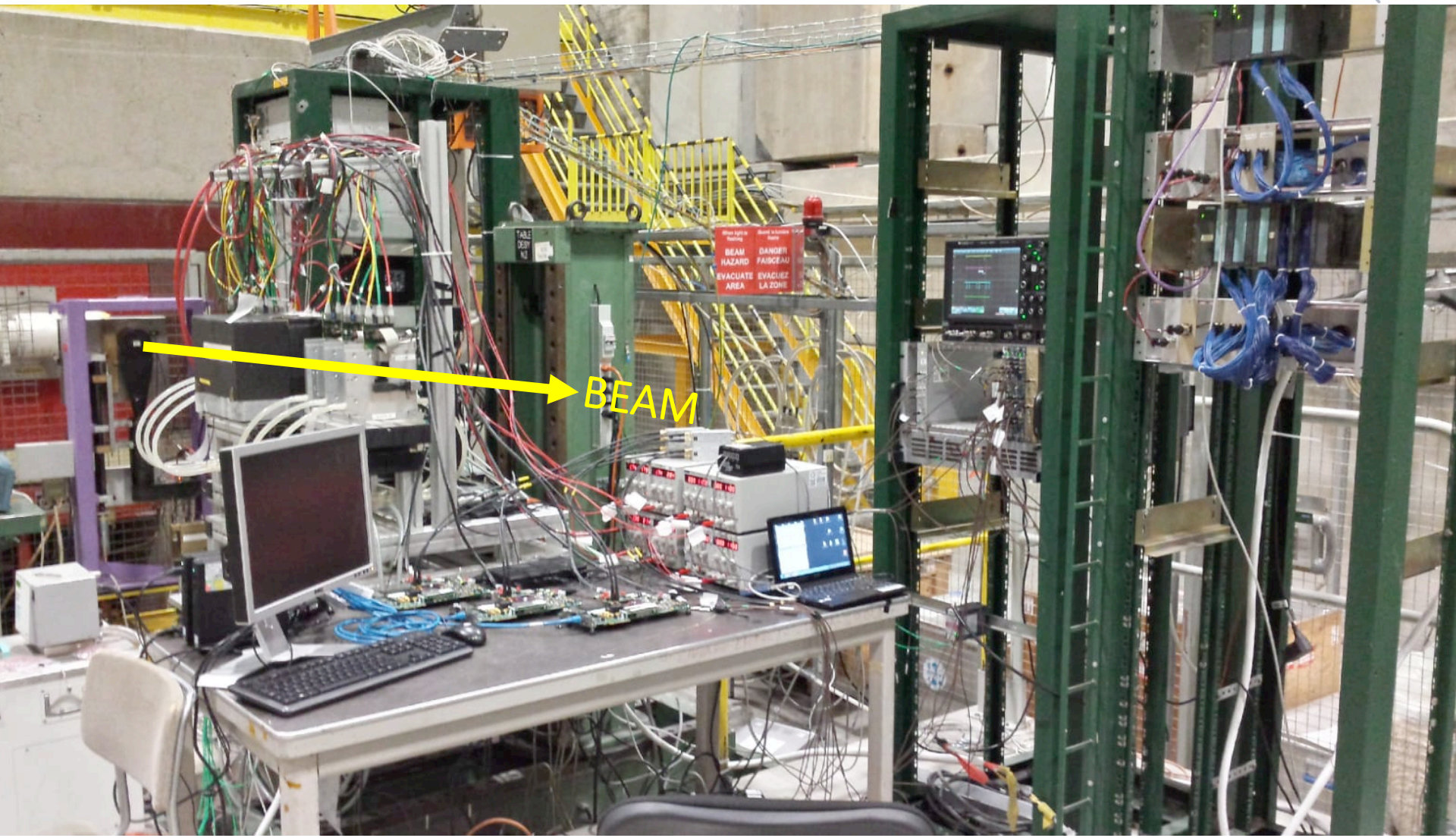






Setup

– H6B SPS. Beam energy: 120 & 60 GeV. AIDA telescope. NTC on SCC and Pt1000.



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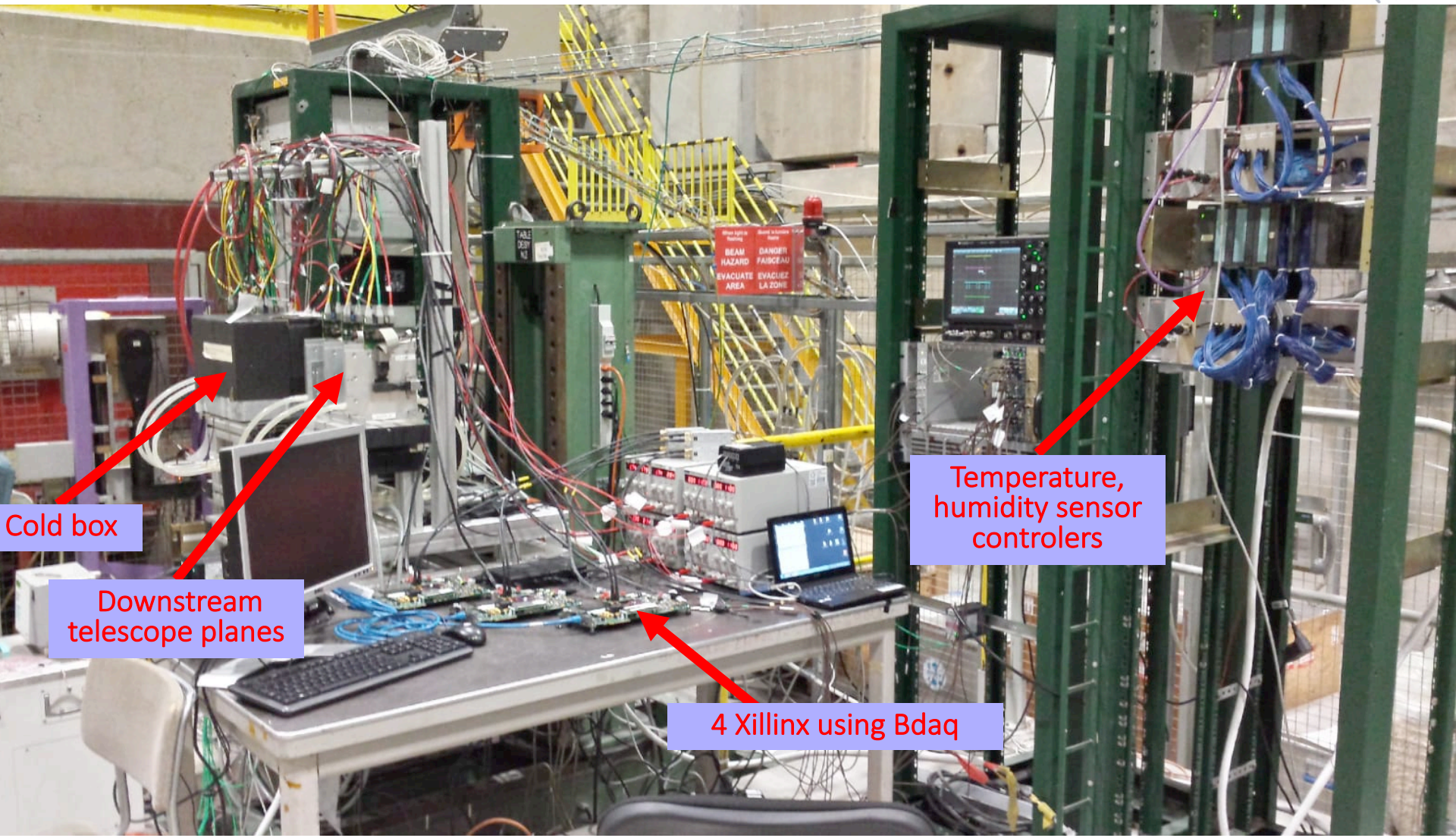
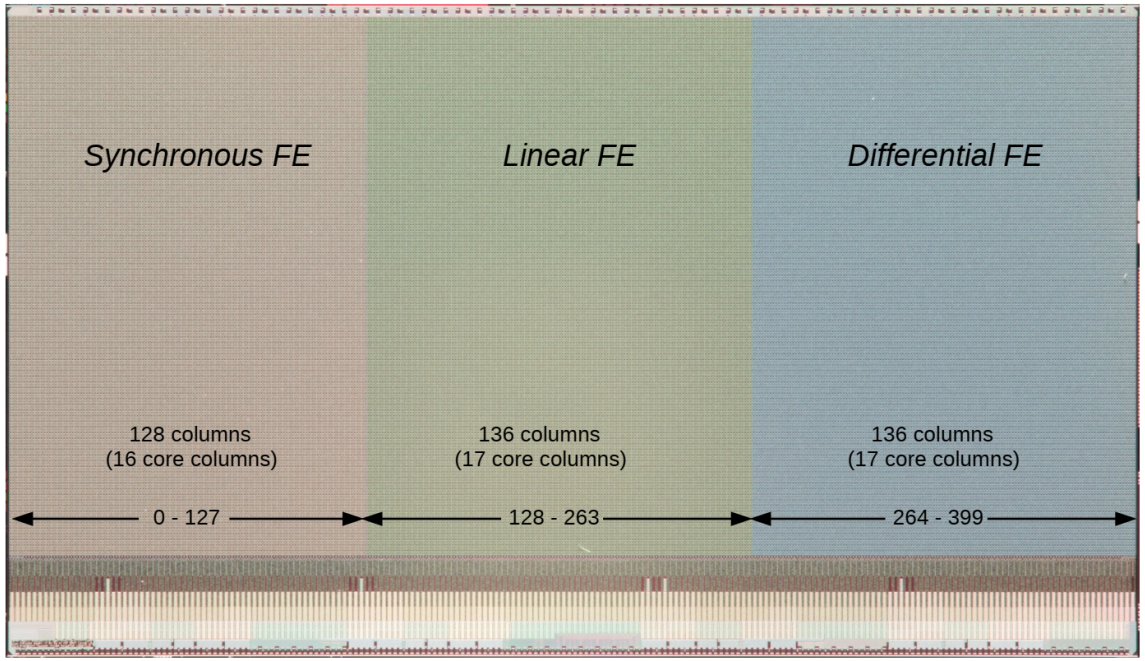


Read out chip

The RD53 collaboration focused on pixel chips for ATLAS/CMS phase 2 upgrades and produced a prototype RD53A chip, a new generation Pixel Readout ASIC for the HL-LHC



Three different FE flavours

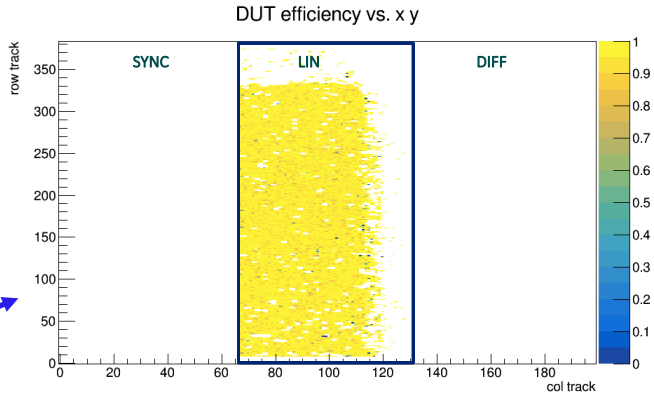
Two different readout architectures

IP's are silicon proven (with minor changes)

Common calibration circuitry:

- Calibration pulses generated via commands starting from 2 voltages.
- Different operation modes (step/pulse, single pixel and neighbours).
- Pulses can be phase shifted with a global fine delay (640 MHz clk).

Our results in this talk: with the Linear Front End

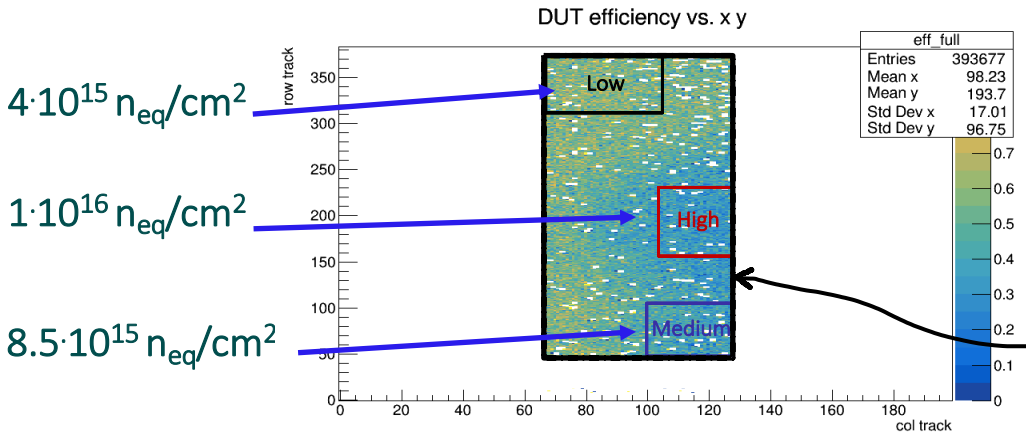


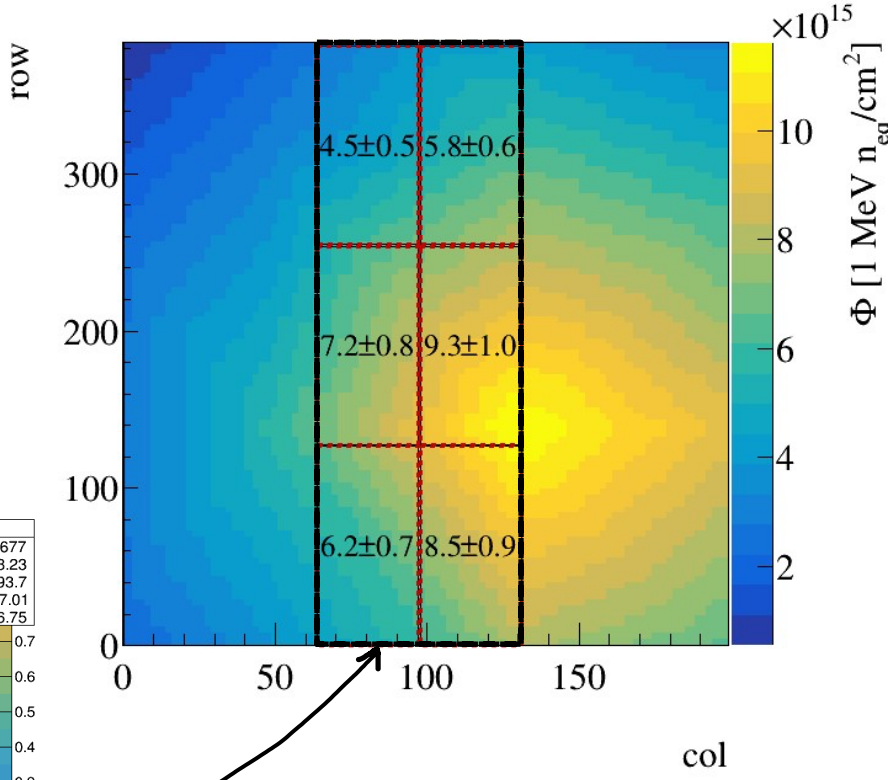
Very preliminary: Non homogeneous fluence

- Target fluence for the 3D sensors: 10^{16} n_{eq}/cm^2, but irradiation was not homogeneous.

- Beam profile was not uniform.
- The whole surface of the sensor was not inside the beam.

Study is done by zones with different irradiation:





Study non homogeneous radiation damage over the sensor:

Irradiated sensors working at low bias voltage

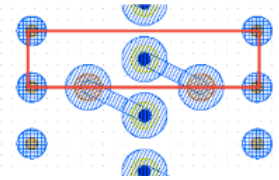
(worst conditions)

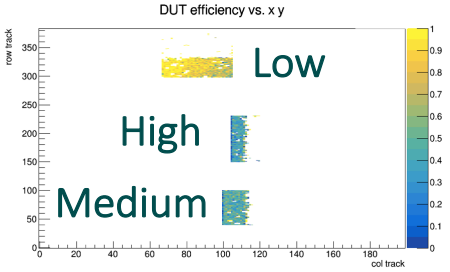
After irradiation: 25x100 µm²

Normal incidence

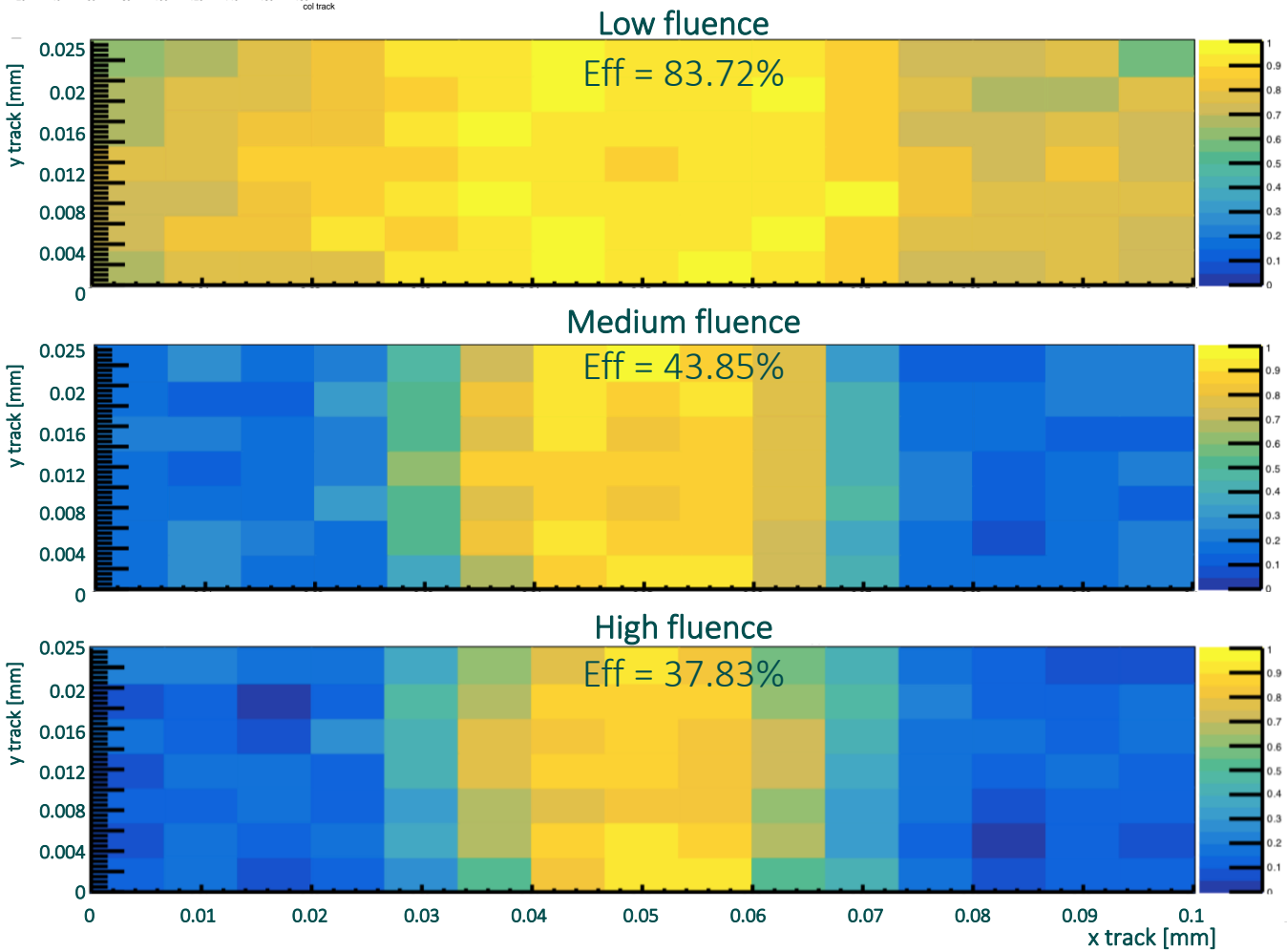
V=44V. T=-30ºC

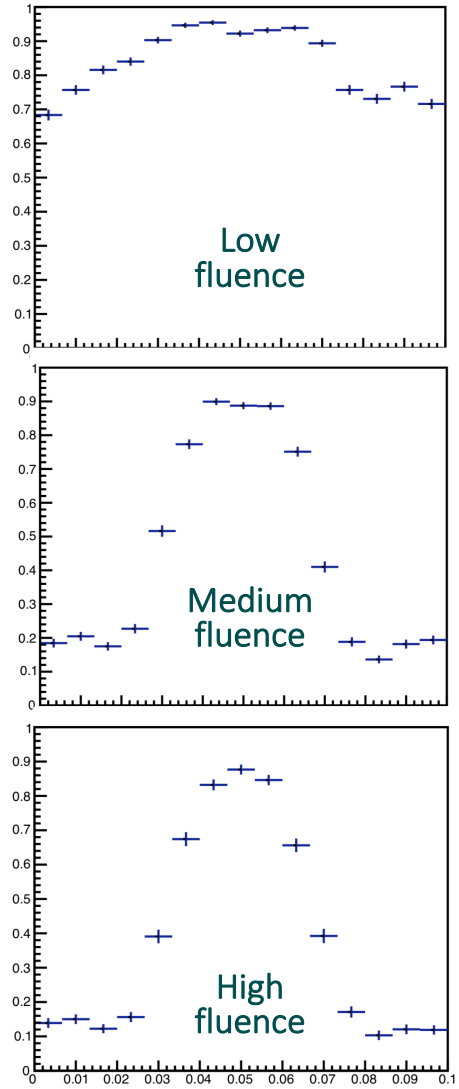
Efficiency: 58%





Efficiency pixel cell map and profiles over X direction





After irradiation: 25x100 µm²

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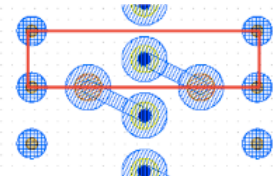
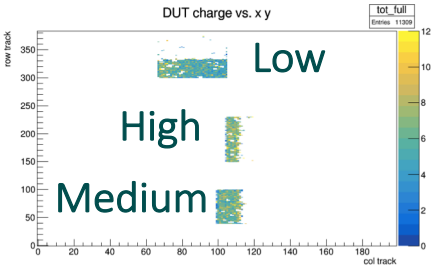
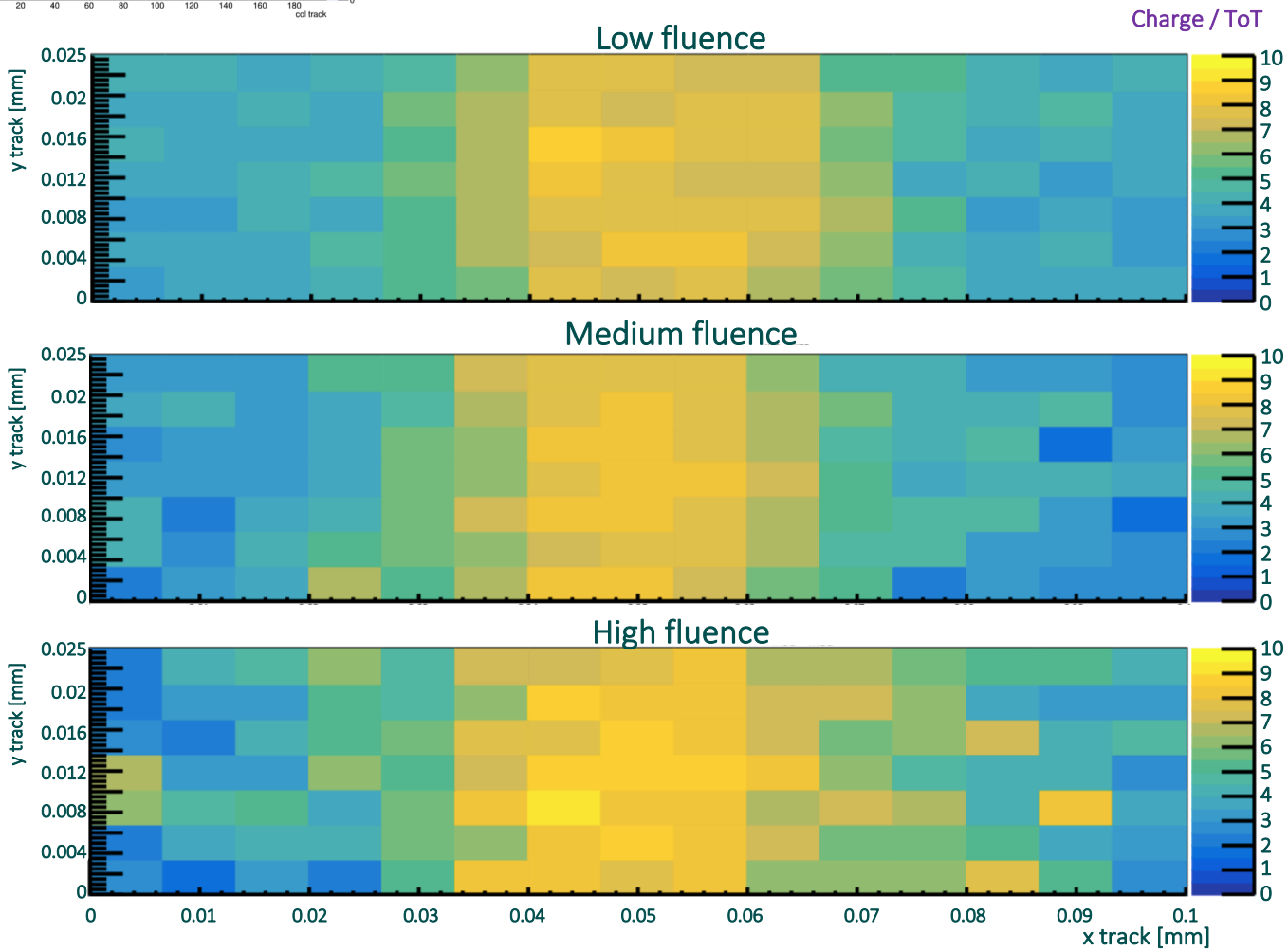
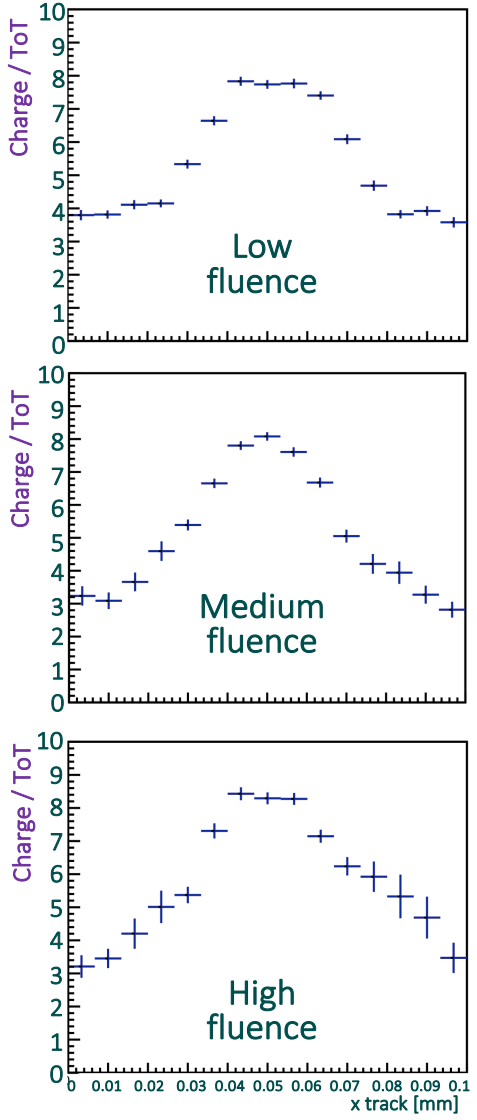




Collected charge pixel cell map and profiles over X direction





Test sensor radiation tolerance:

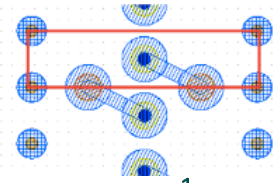
Irradiated sensors at operation bias voltage

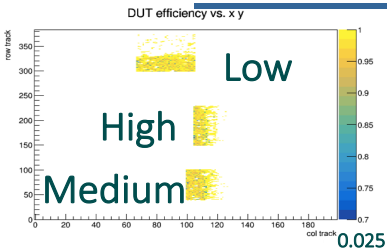
After irradiation: 25x100 µm^2

Normal incidence.

V=125V. T = -36ºC

Efficiency: 96.6%





Efficiency 1x1 pixel cell maps and profiles over X direction

Before irradiation

Low fluence

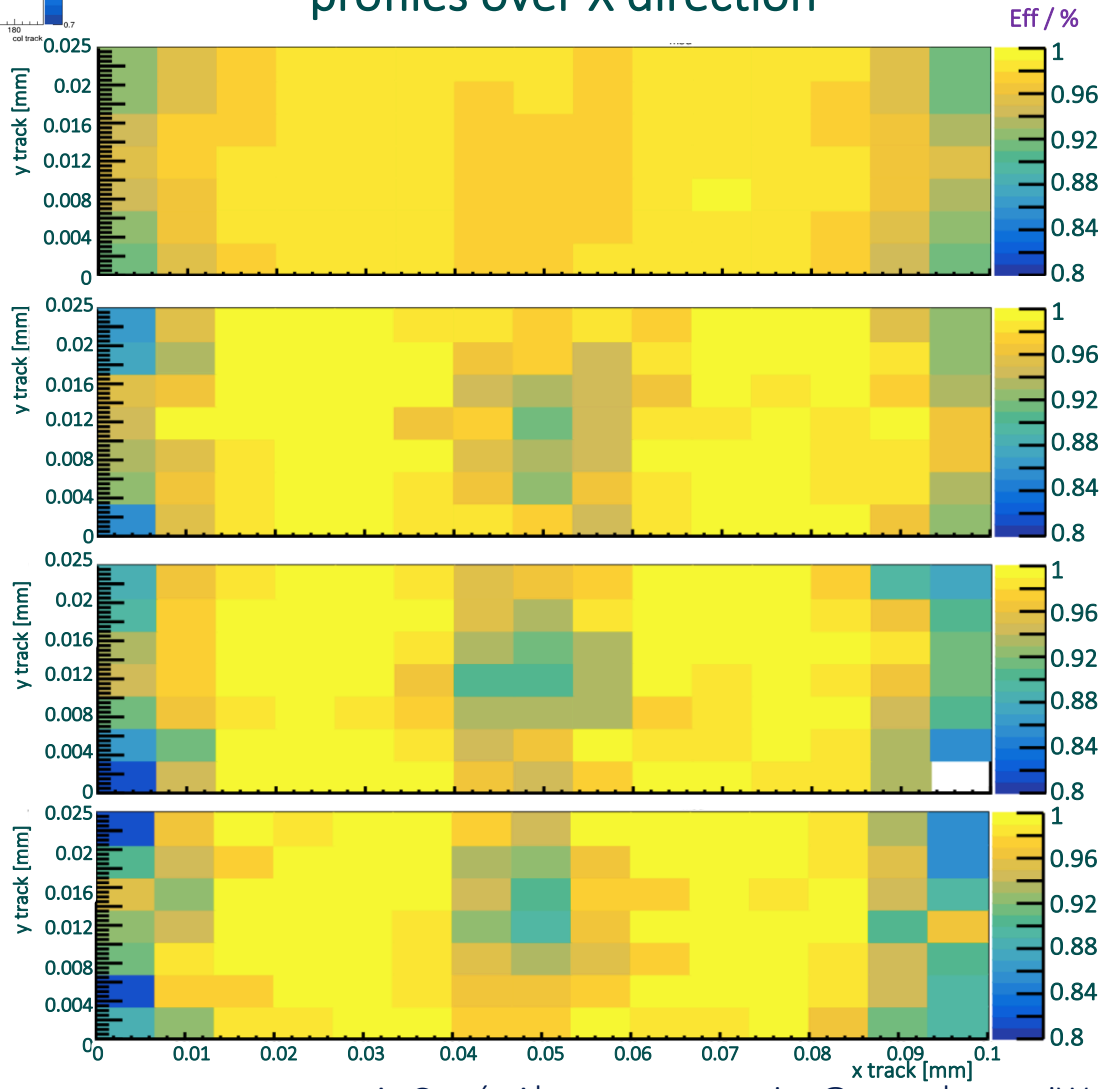
Eff = 97.35%

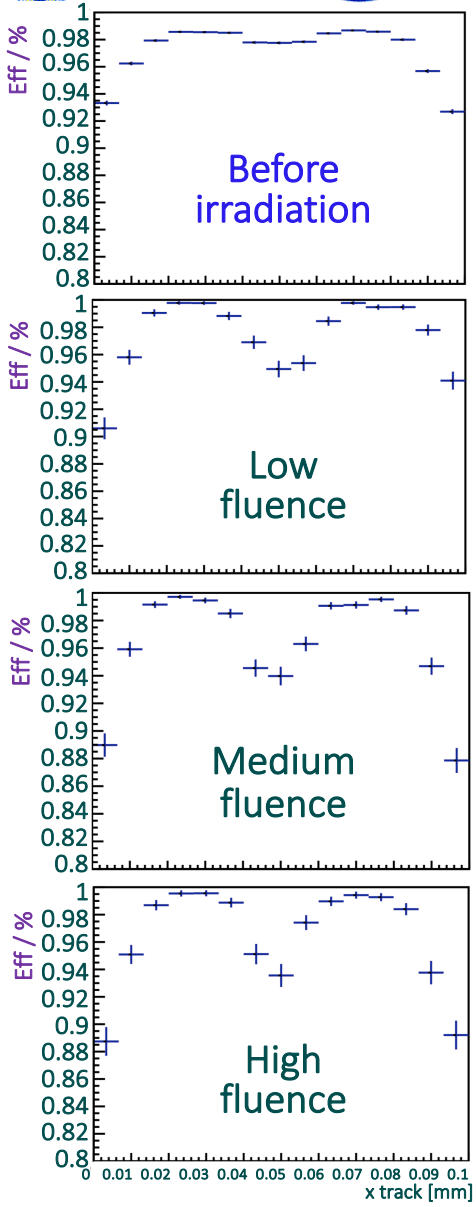
Medium fluence

Eff = 96.35%

High fluence

Eff = 96.36%



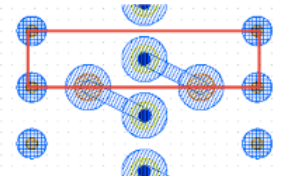


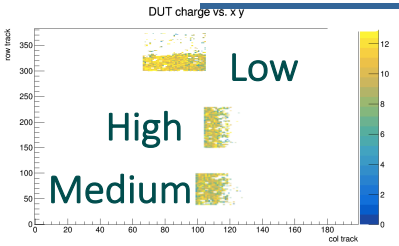
After irradiation: 25x100 µm^2

Normal incidence.

V=125V. T = -36ºC

Efficiency: 96.6%





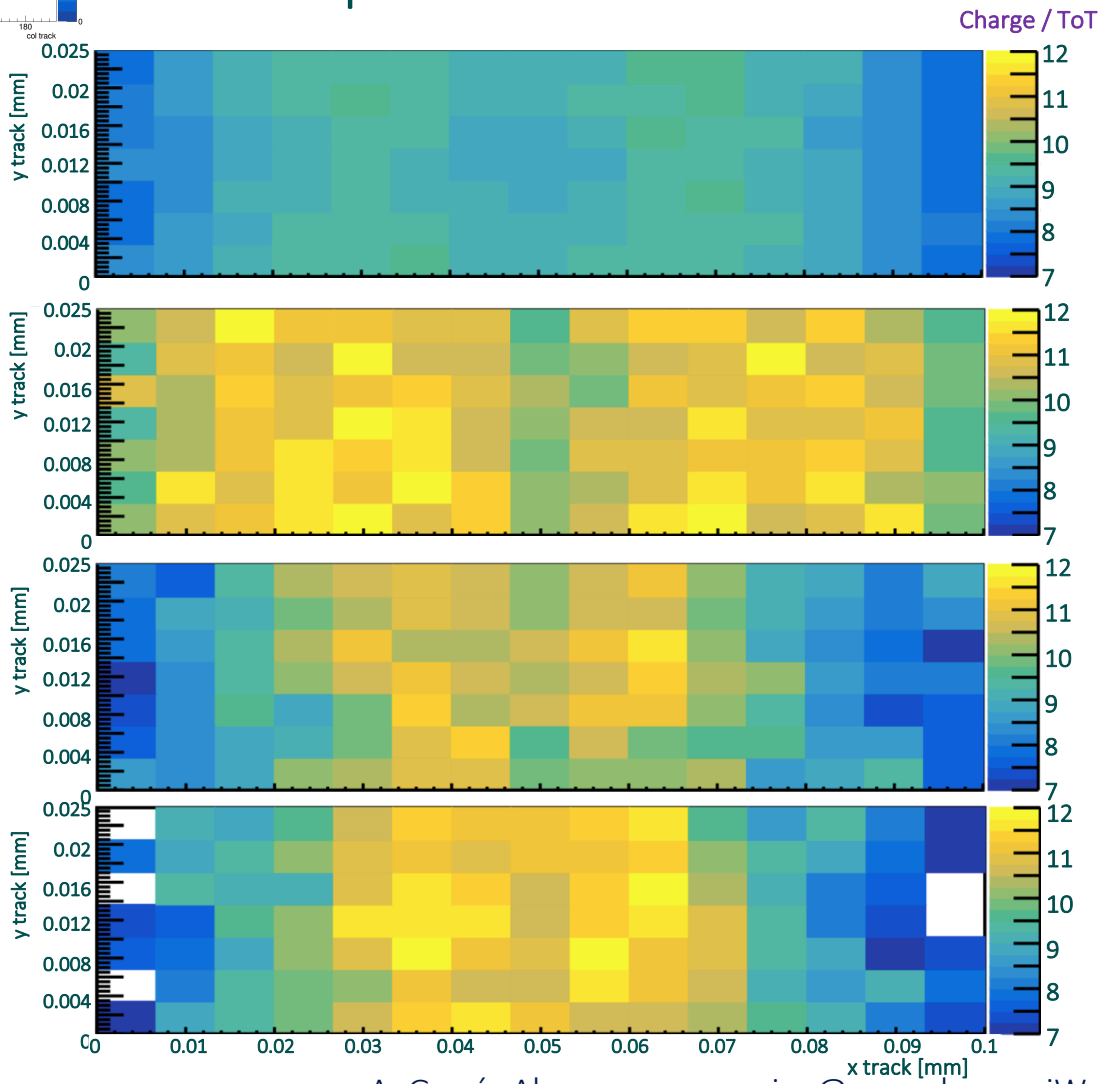
Collected charge 1x1 pixel cell maps and profiles over X direction

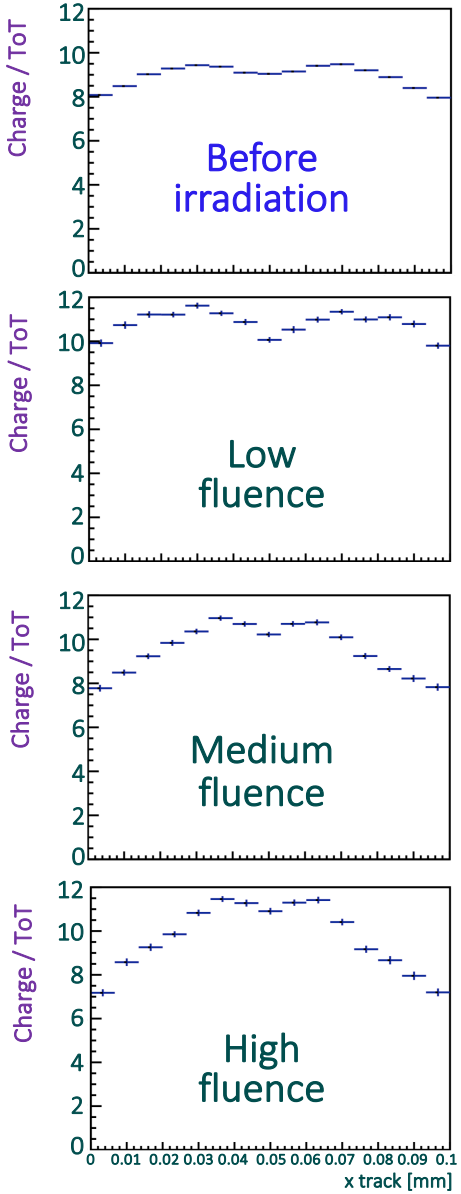
Before irradiation

Low fluence

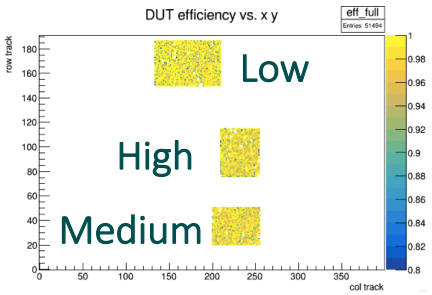
Medium fluence

High fluence





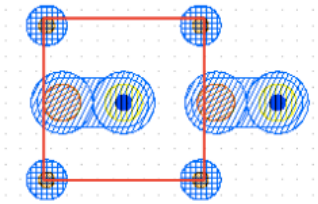
After irradiation: 50x50 µm^2



Normal incidence.

V=141V. T=-36ºC

Efficiency: 97.5%



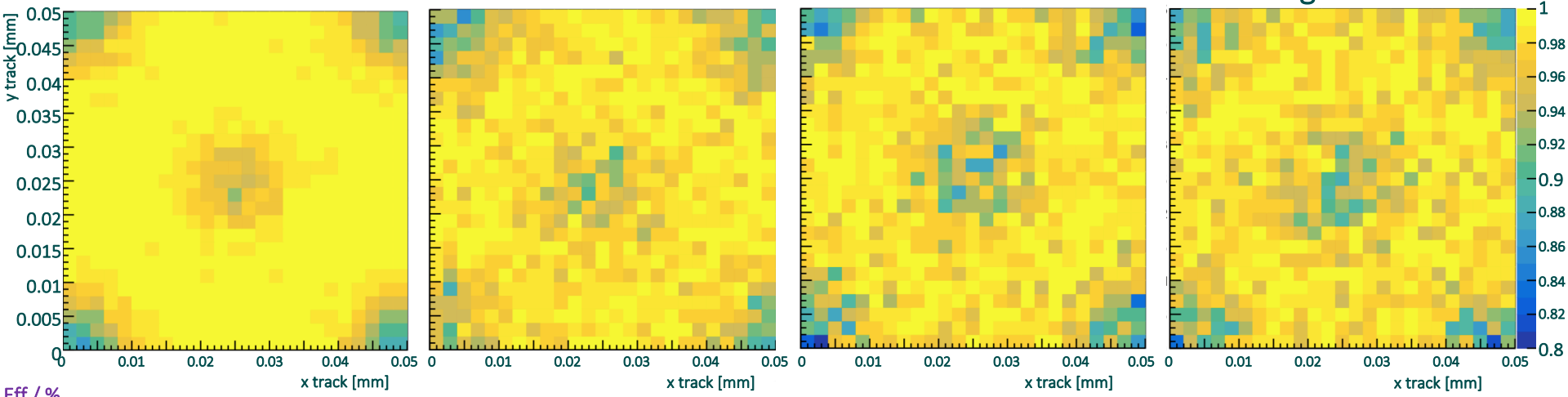
Efficiency 1x1 pixel cell maps and profiles over X direction

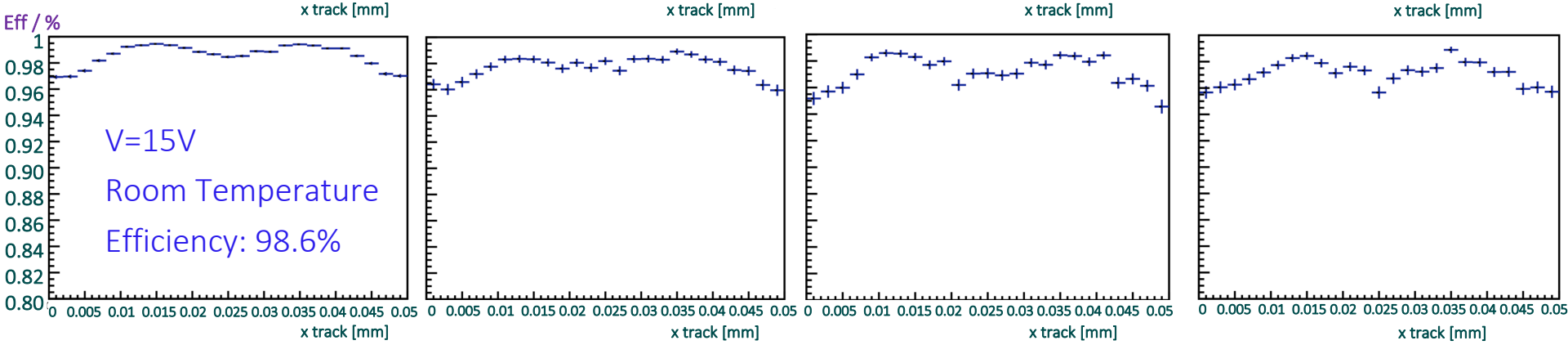
Before irradiation

Eff = 97.68%
Low fluence

Eff = 97.20%
Medium fluence

Eff = 97.11%
High fluence



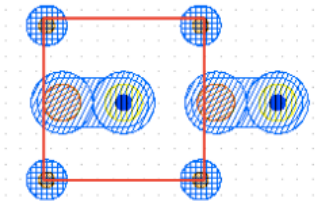


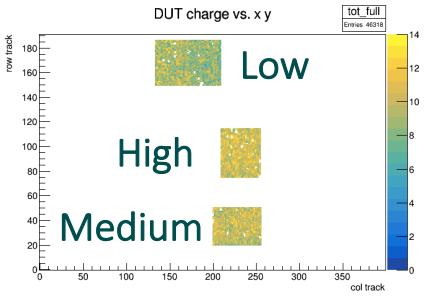
After irradiation: 50x50 μm²

Normal incidence.

V=141V. T=-36ºC

Efficiency: 97.5%

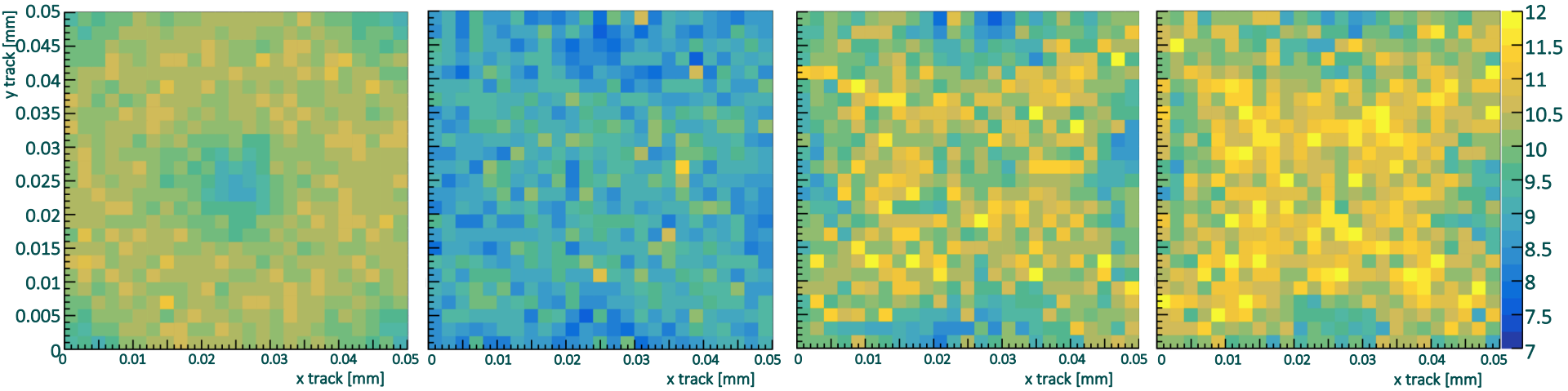


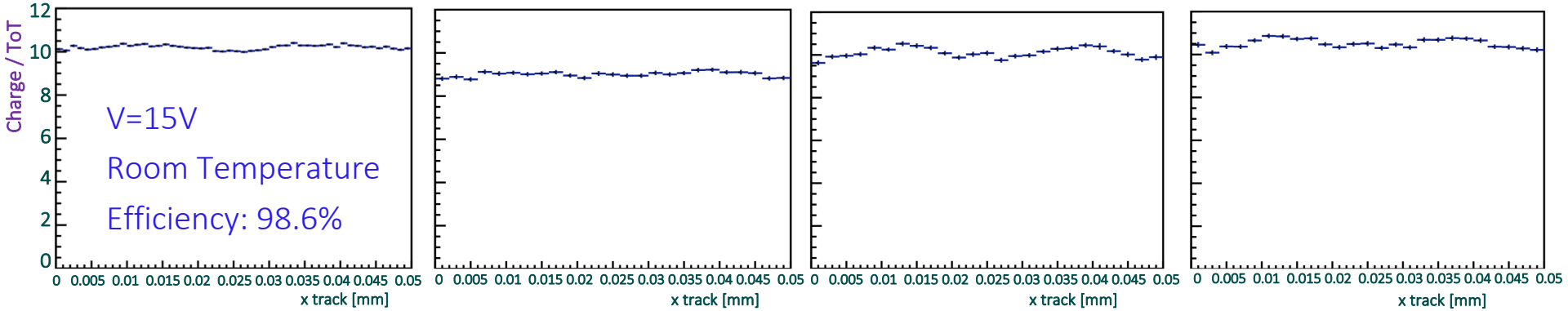


Collected charge 1x1 pixel cell maps and profiles over X direction

Before irradiation | Low fluence | Medium fluence | High fluence

Charge / ToT





Conclusions

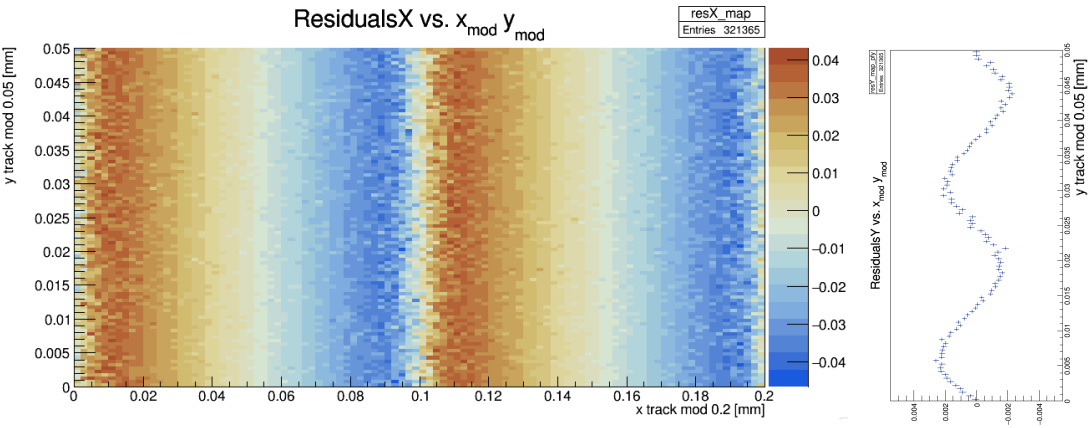
- When depleted, high charge collection and efficiency almost 100%. 3D sensors are a good option for the CMS Inner Tracker Upgrade.
- Non homogenously irradiated sensors make possible the fluence study and comparison in identical conditions.
- At low bias voltage operation, study damage effect in each of the differently irradiated areas has been carried out.

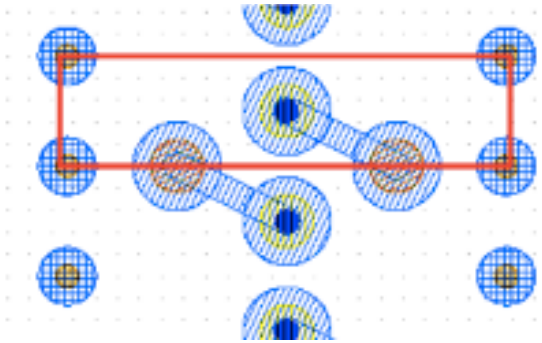
BACKUP

Crosstalk in irradiated 3D 25x100 um^2 *125V*

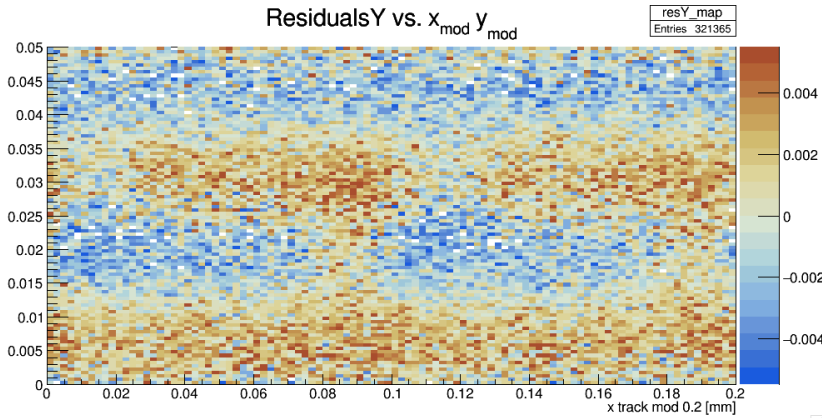
– Normal incidence. Run 2950. V=157V I=334uA. T=-36ºC. Efficiency: 96.6%

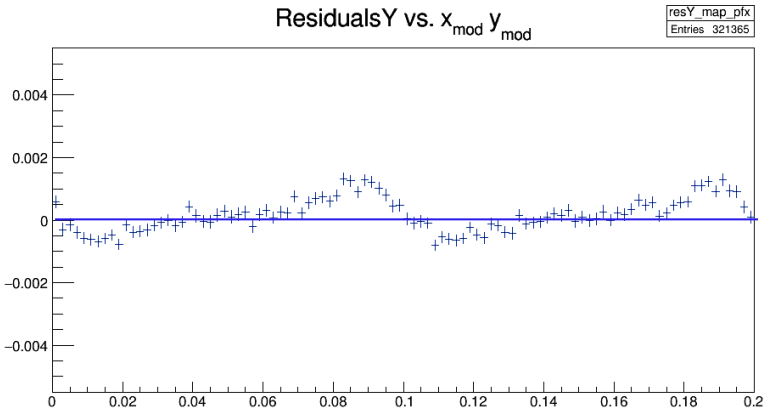
Residual map in X





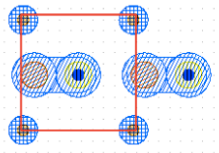
Residual map in Y





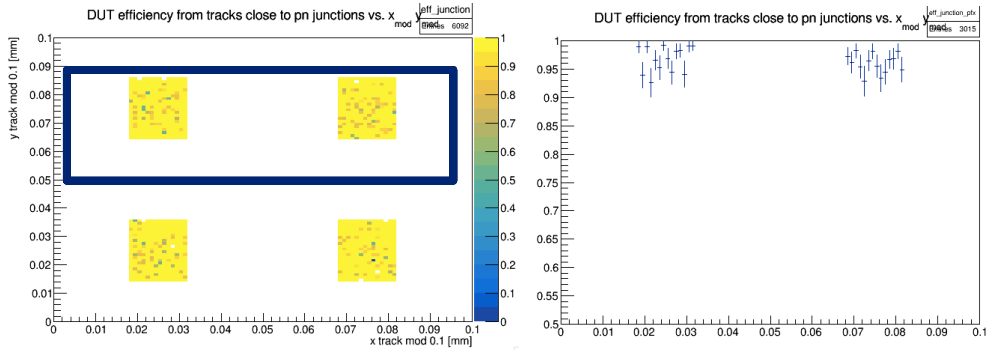
Residual increases around 2-3 µm in very limited regions

Results after irradiation: 50x50 um^2. 141V

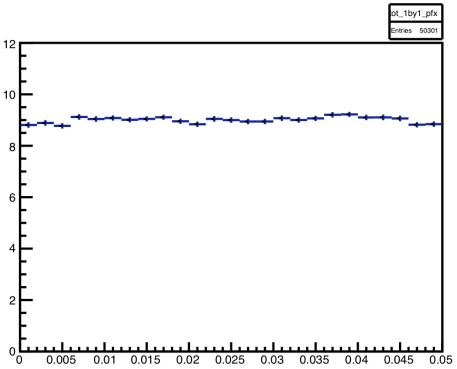


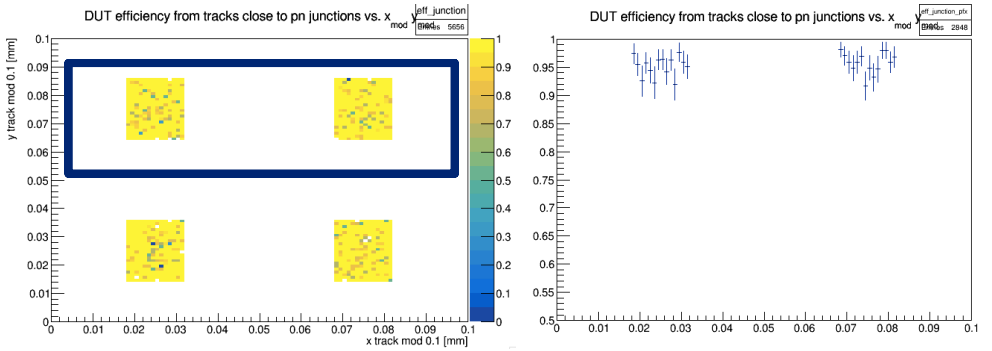
Bin 50 to 90

At the junctions, 100% efficiency is reached

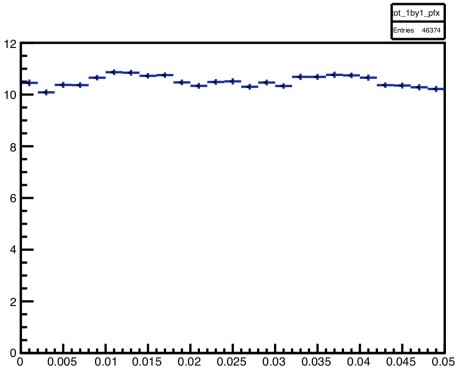


Zone 1
Low fluence

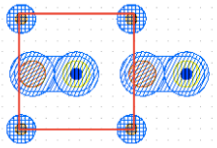




Zone 2
High fluence

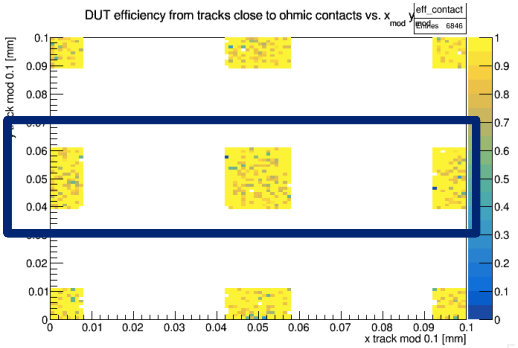


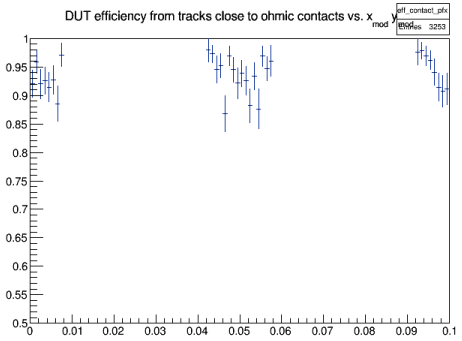
Results after irradiation: 50x50 um^2. 141V



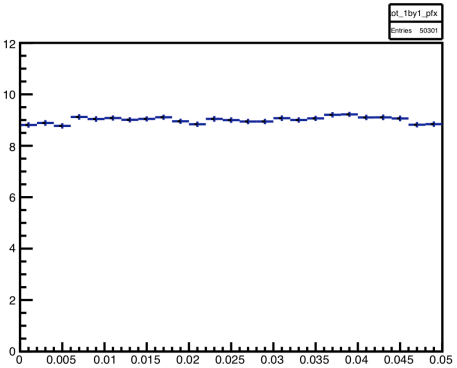
Bin 30 to 70

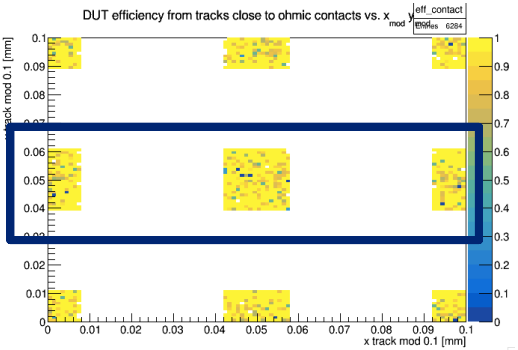
Ohmic contacts

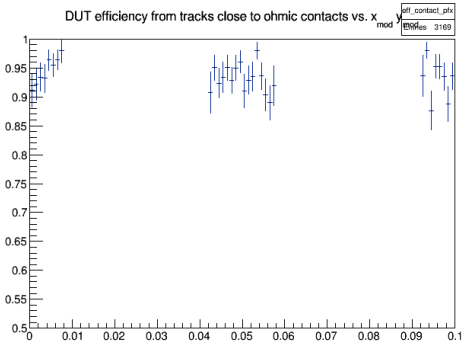




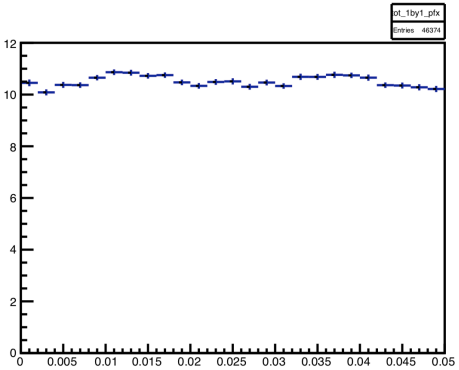
Zone 1
Low fluence



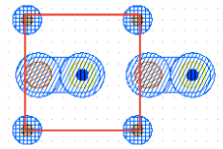




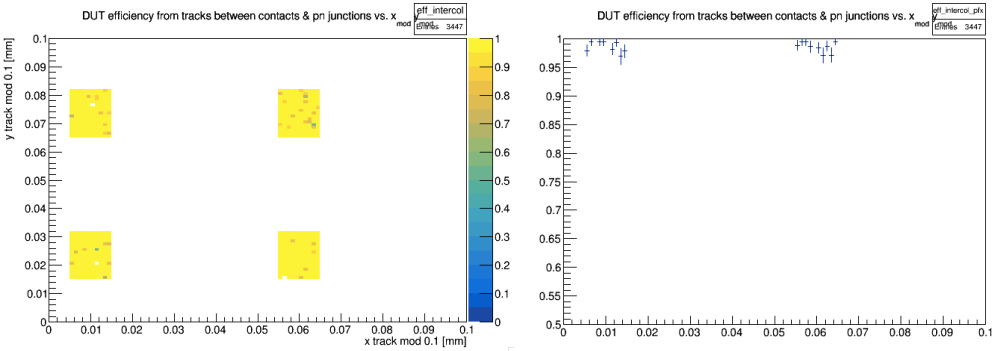
Zone 2
High fluence



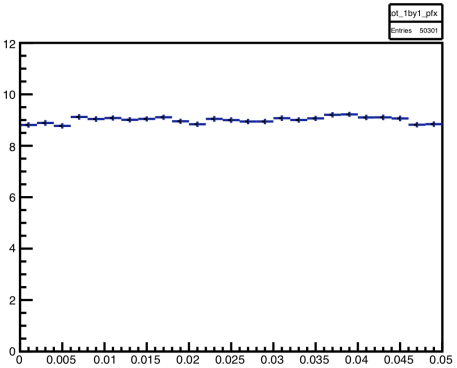
Results after irradiation: 50x50 um^2. 141V

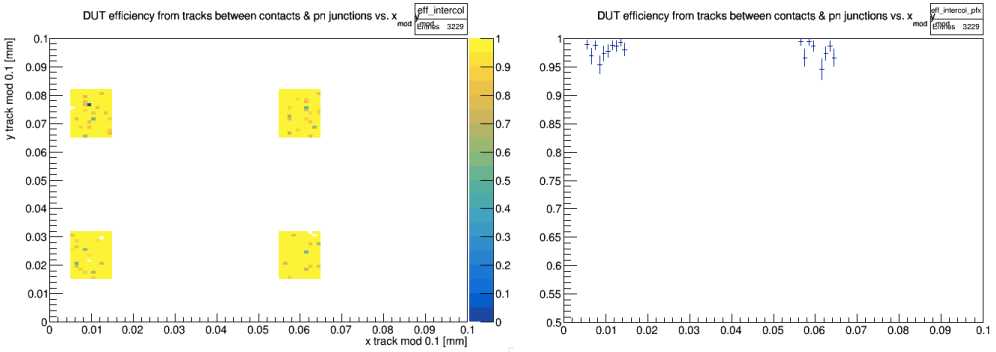


Space between columns: 100% efficiency clearly reached

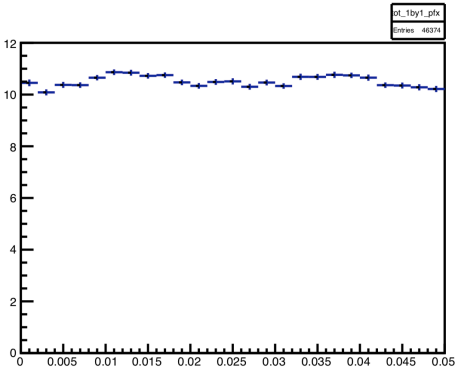


Zone 1
Low fluence

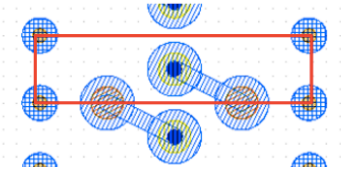




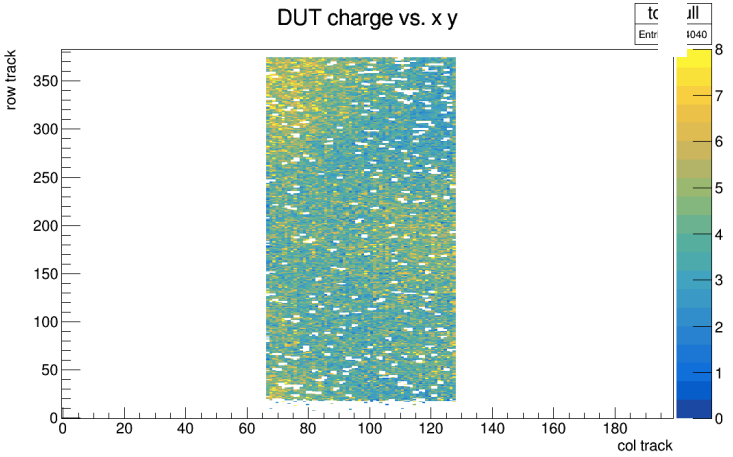
Zone 2
High fluence

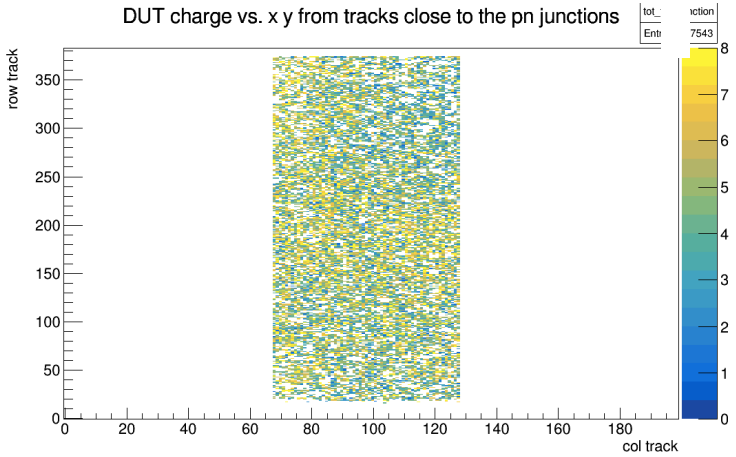


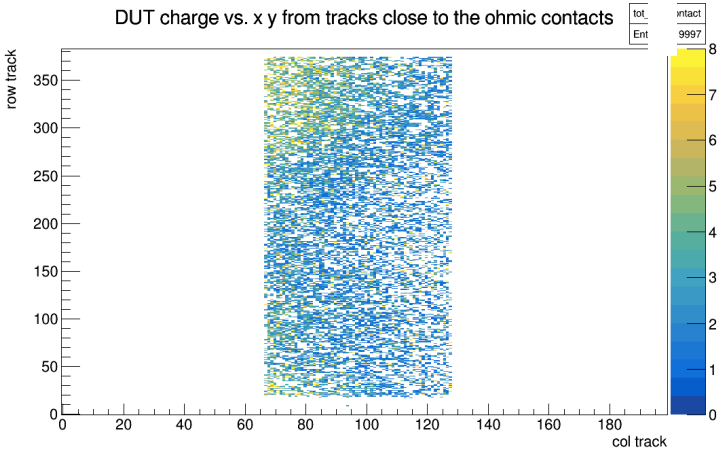
Charge 2D maps distinguishing PN junctions / ohmic contacts



3D 25x100 (1E)





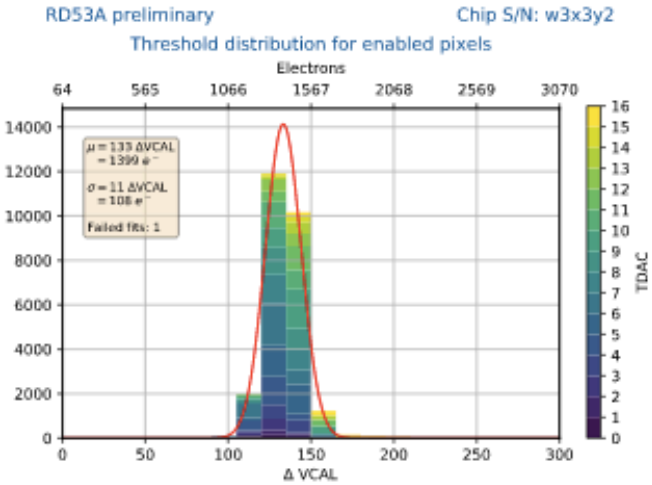


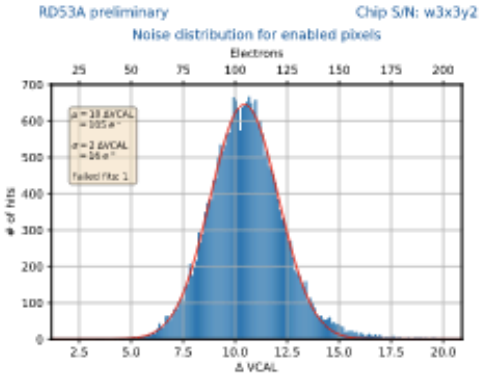
From: Andrea García Alonso - IT sensors meeting 26th March 2019

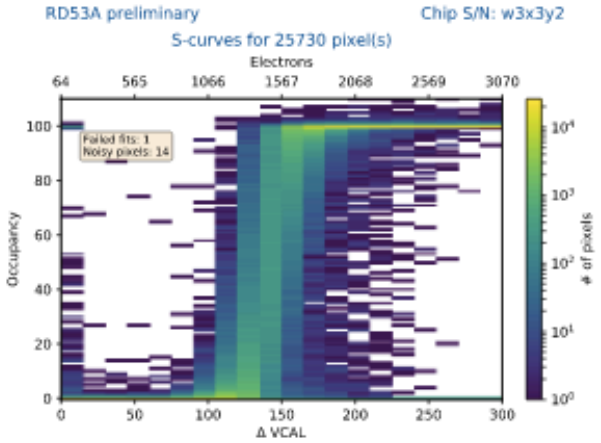
Test Beam campaigns

Threshold and Noise for irradiated samples

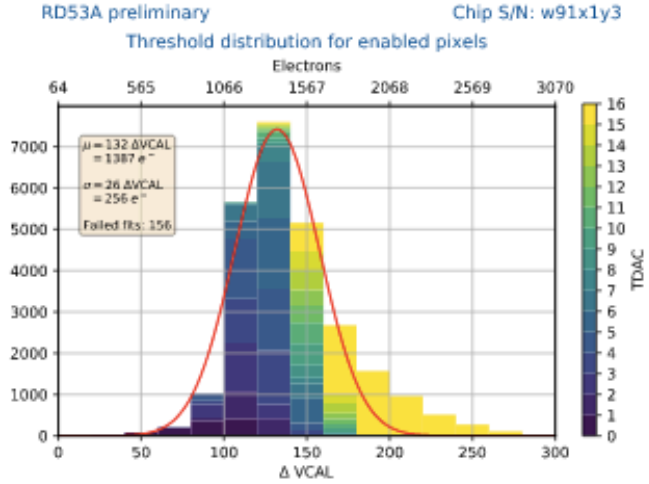
25x100: Threshold ~1400 e⁻, noise = 105 e⁻

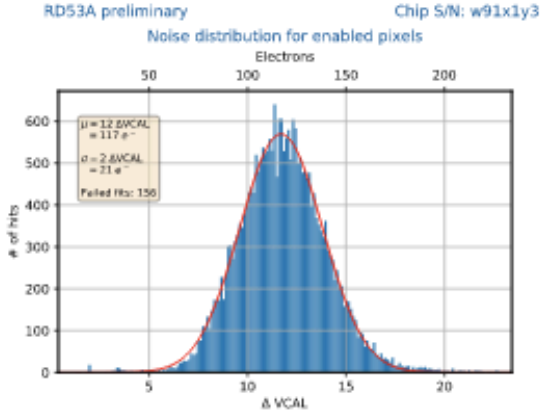


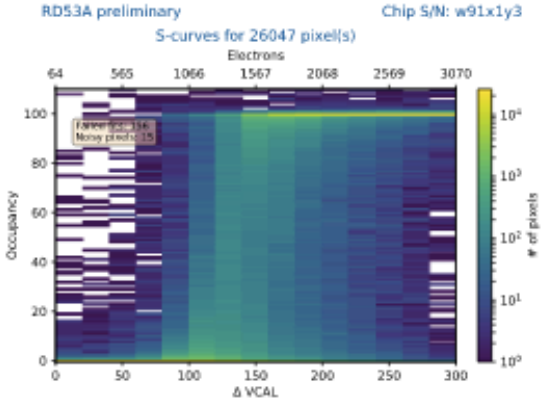




50x50: Threshold ~1400 e⁻, noise = 120 e⁻ Tuning difficult, too many pixels stuck @ Tdac 15





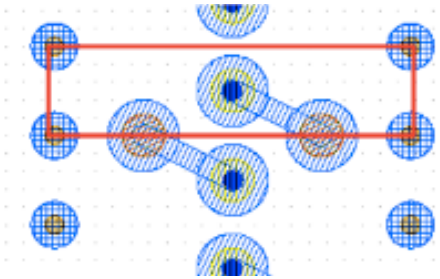


Results before irradiation: 25x100 um^2

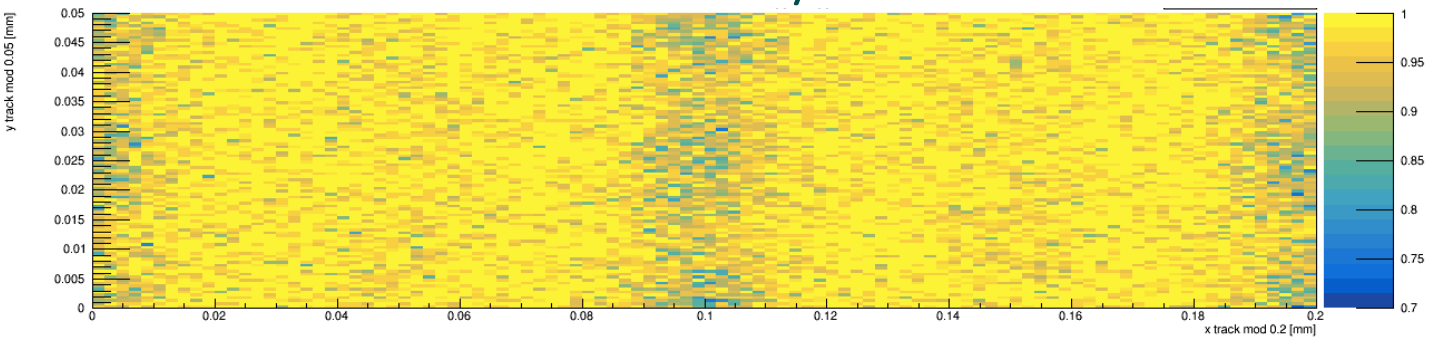
Normal incidence.

V = 5V. Room Temperature.

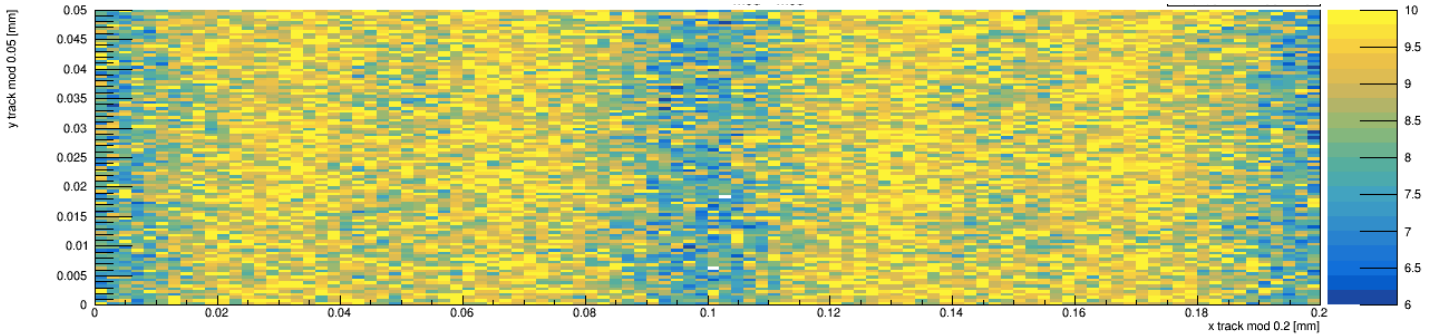
Efficiency: 97.3%



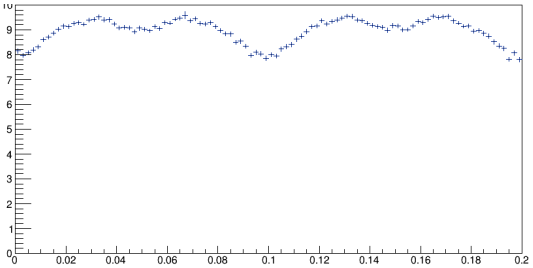
Efficiency



Charge



Charge profile over X direction



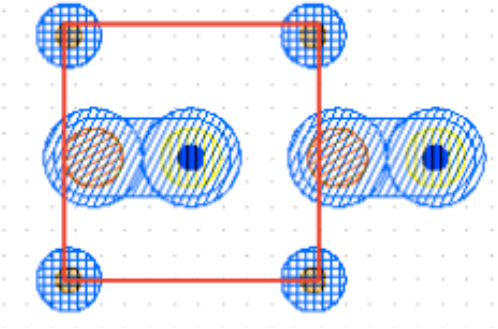
Results before irradiation: 50x50 um^2

Normal incidence.

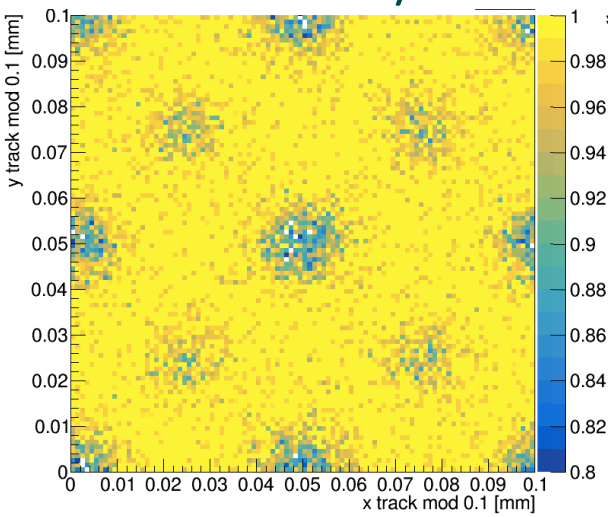
V=15V.

Room Temperature

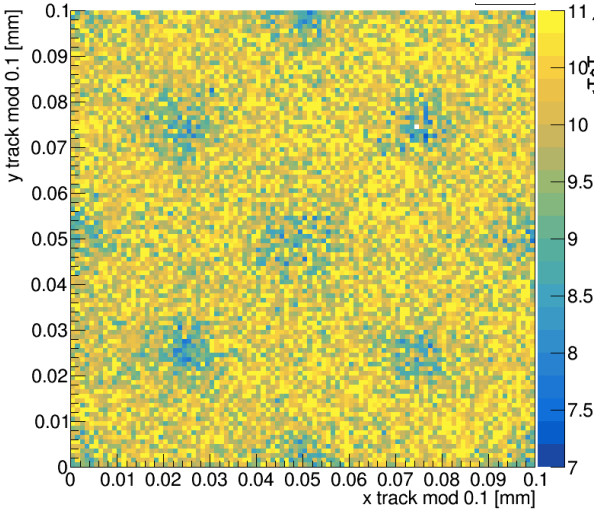
Efficiency: 98.6%



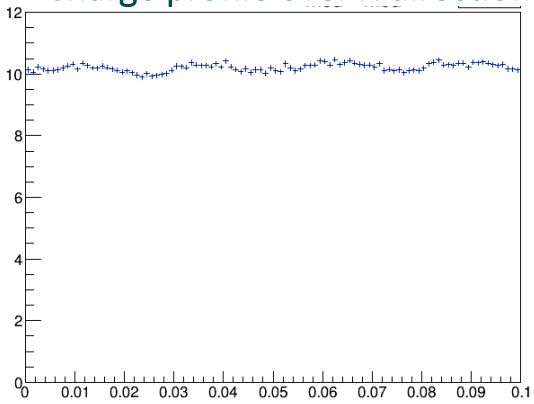
Efficiency



Charge



Charge profile over X direction

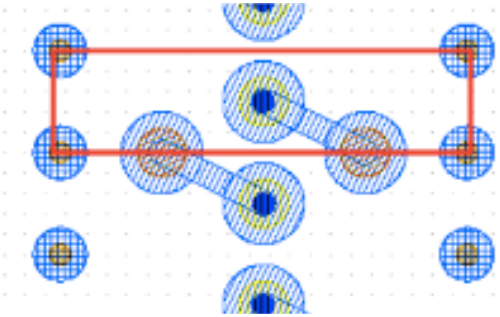


Results after irradiation: 25x100 um^2. 44V

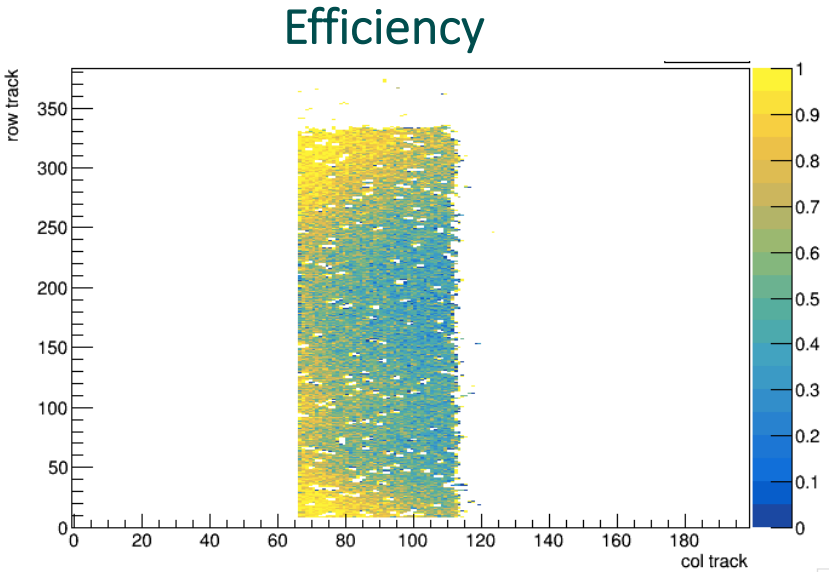
Normal incidence.

V=44V. T=-30ºC

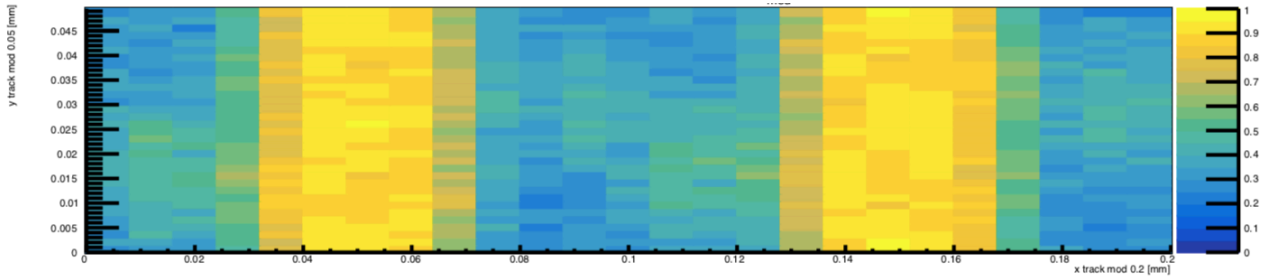
Efficiency: 58%



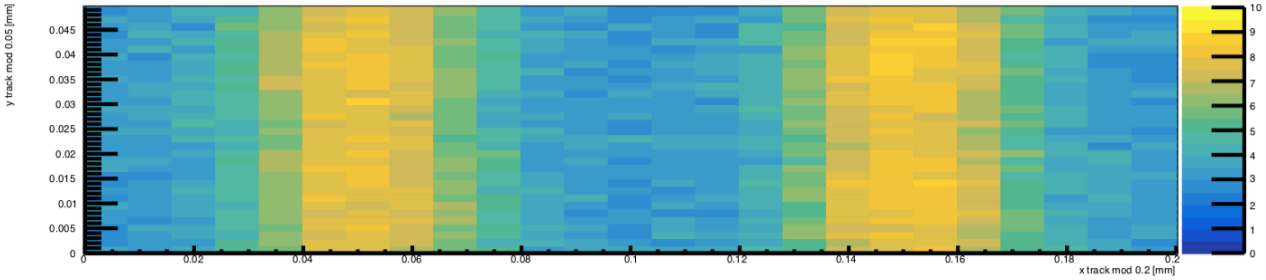
Efficiency



Efficiency



Charge

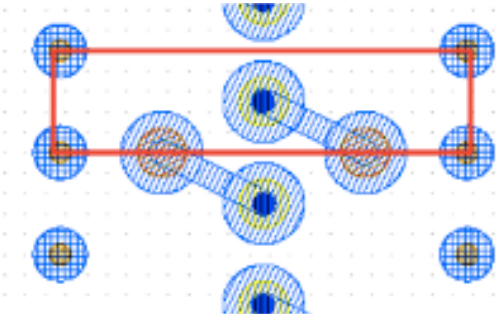


Results after irradiation: 25x100 um^2. 125V

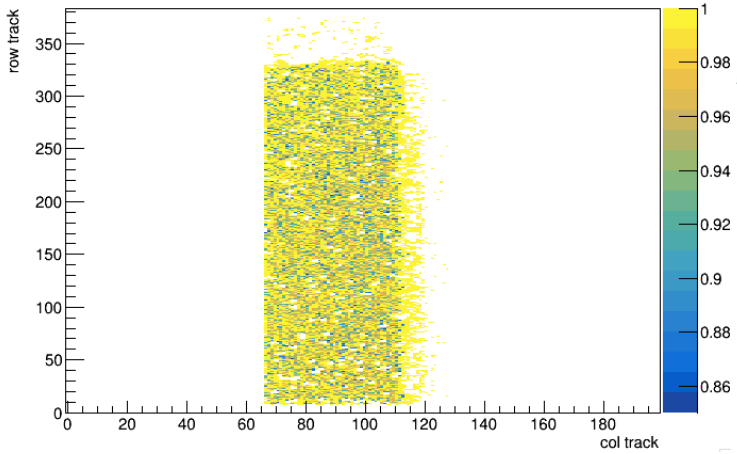
Normal incidence.

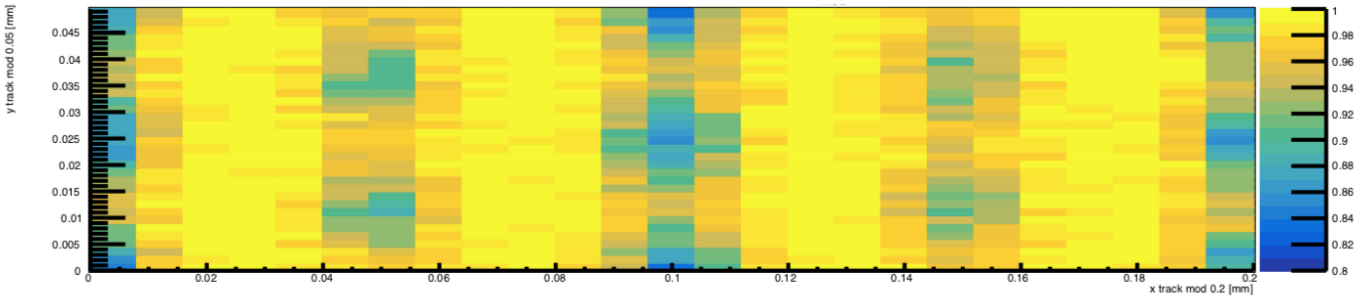
V=125V. T = -36ºC

Efficiency: 96.6%

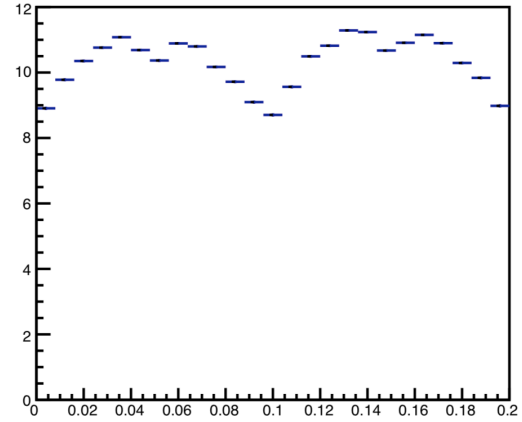


Efficiency

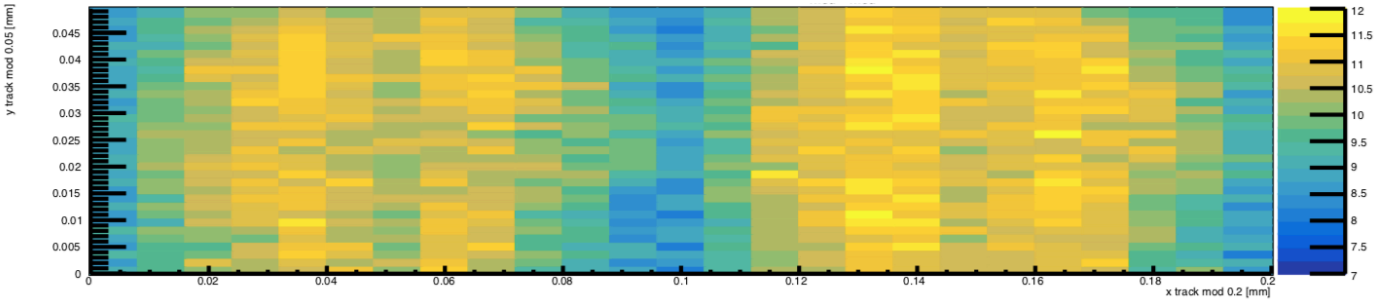




Charge profile over X direction



Charge

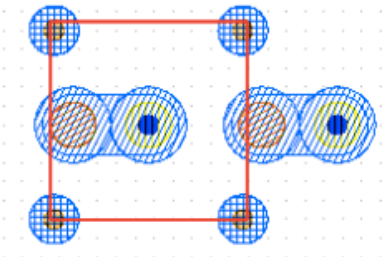


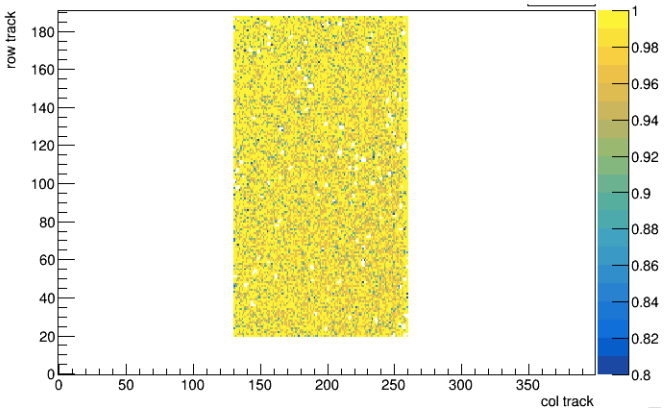
Results after irradiation: 50x50 um^2. 141V

Normal incidence.

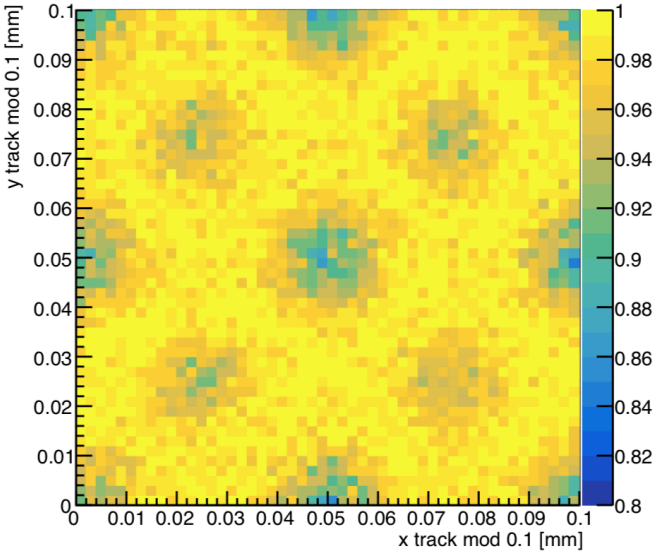
V=141V. T=-36ºC

Efficiency: 97.5%

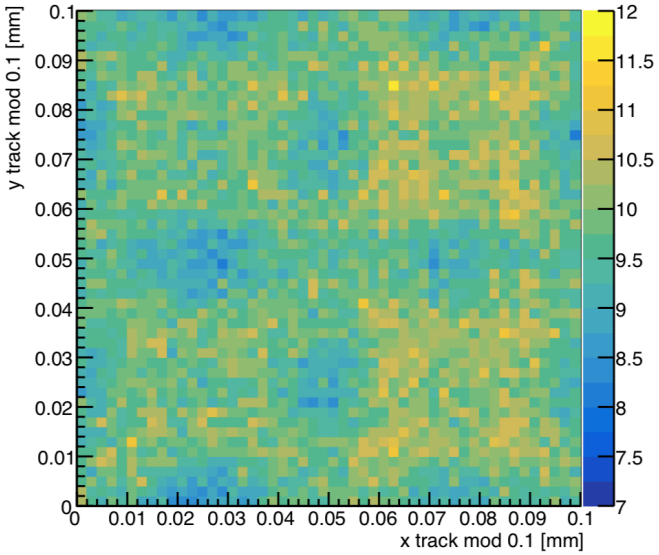
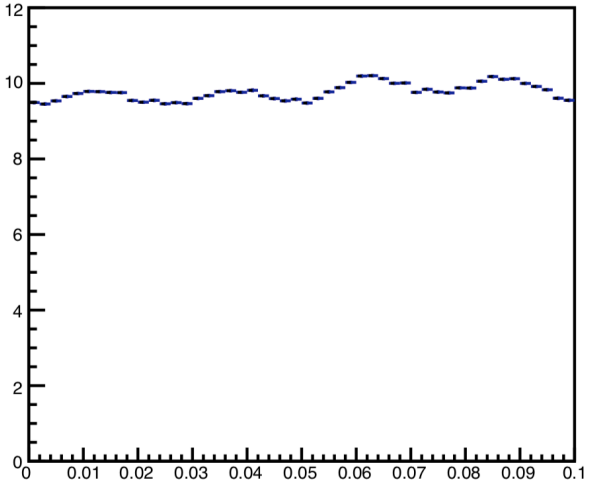




Efficiency



Charge



Charge profile over X direction