Characterisation of HFS Detectors

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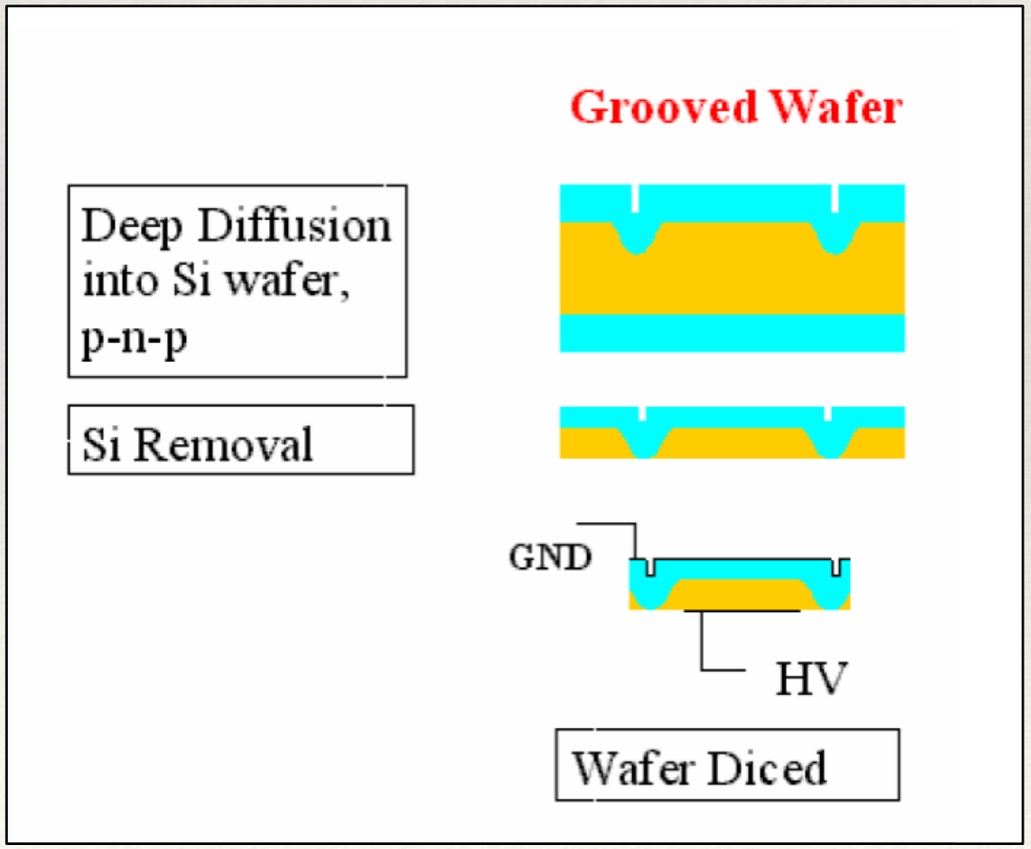
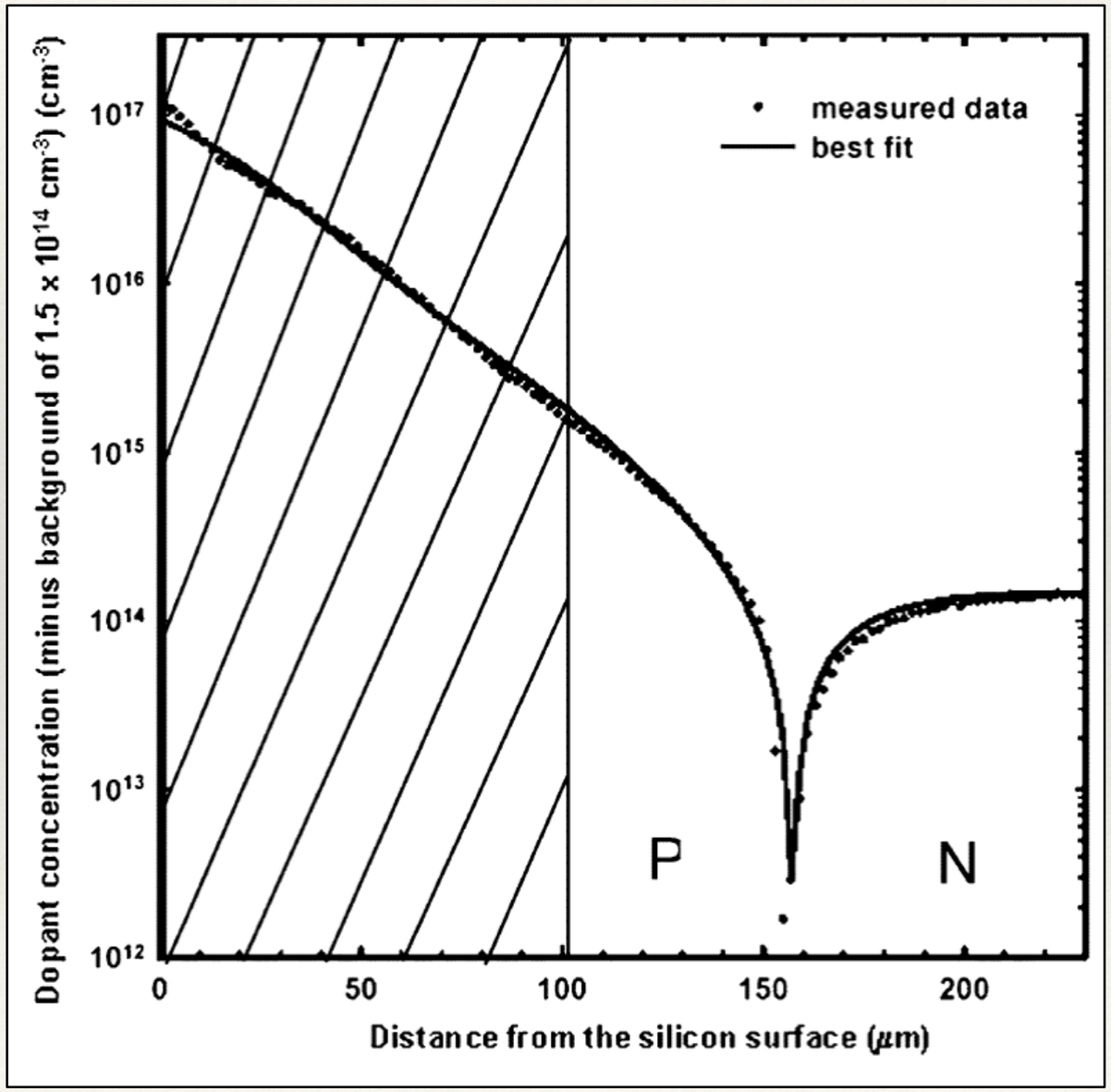
Hyper Fast Silicon Detectors

- Manufactured by RMD (Radiation Monitoring Devices Inc.)
- **Based on Deep Diffused APD**
  - n-type NTD-doped silicon from Topsil
  - Grooving wafer
  - Deep diffusion of p-type dopants
    - Gallium used as dopant
  - Etching of surface layer



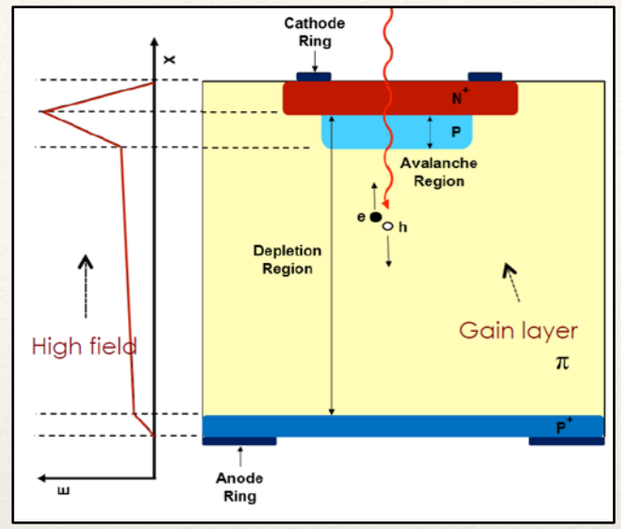
[2004, McClish et al., IEEE TNS]

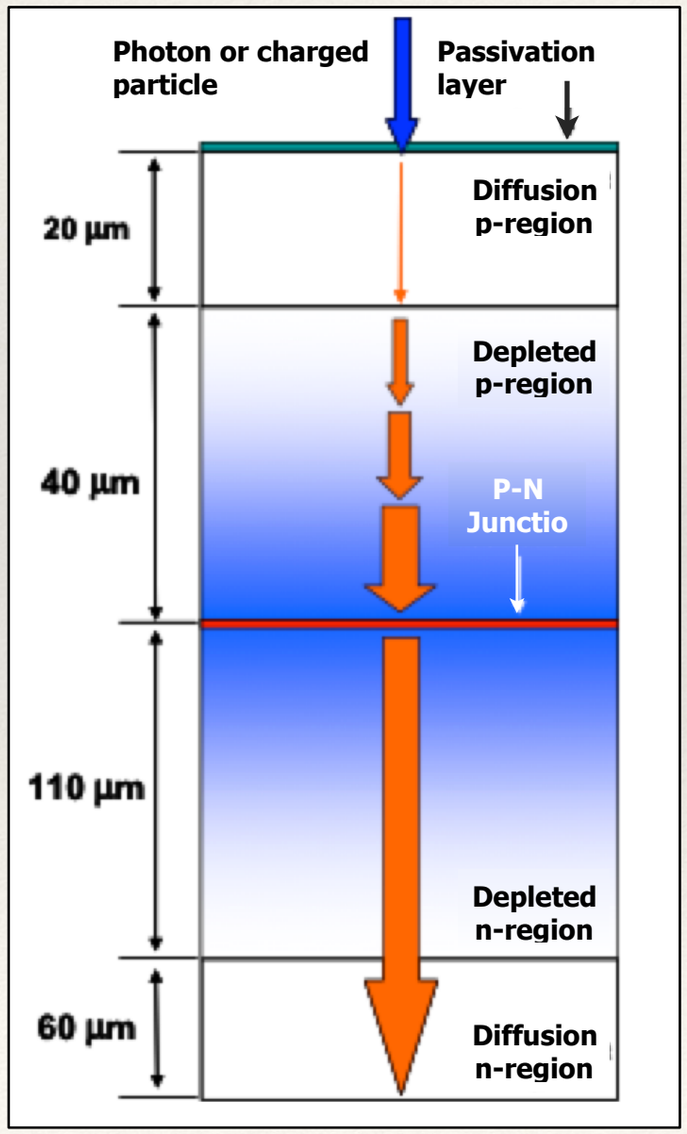
[2006, McClish et al., IEEE TNS, 53, 3049]



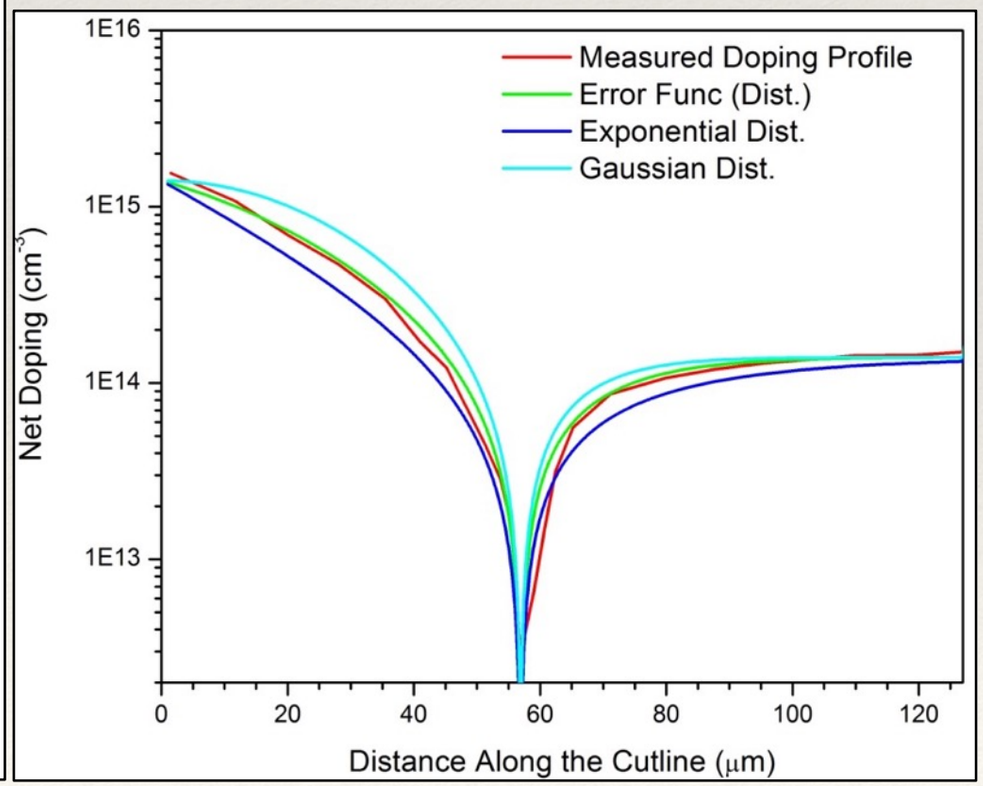
Charge Multiplication and Gain

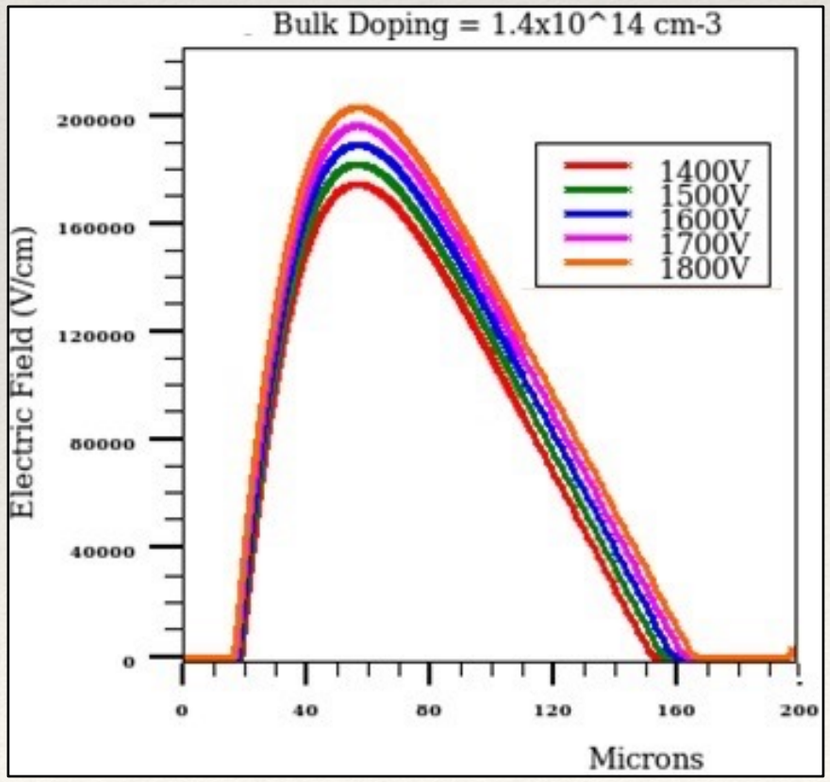
- **Deep Diffused APDs**
  - Amplification deep inside the bulk of the sensor
  - Requires high voltage (1700 V - 1800 V)
  - Delivers high gain and fast response time





- **TCAD Simulations**
  - Doping profile based on measured data (literature) used to simulate the E-field.

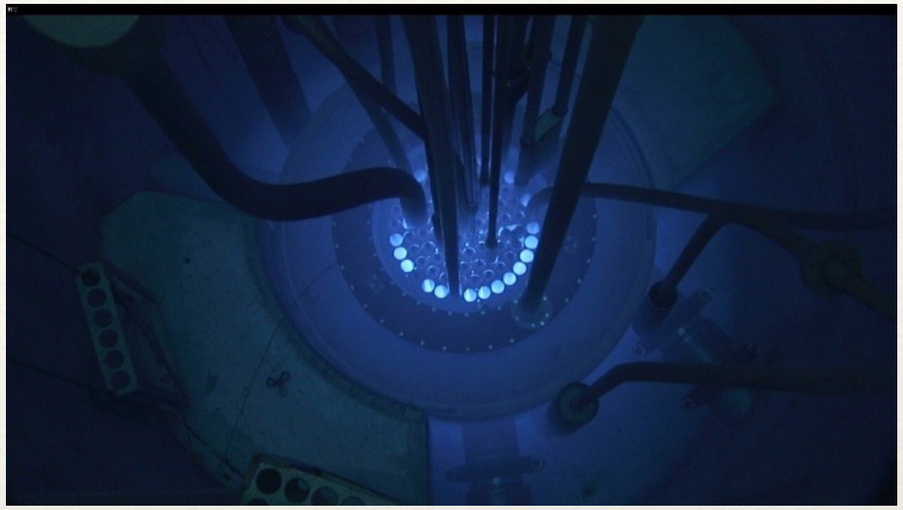


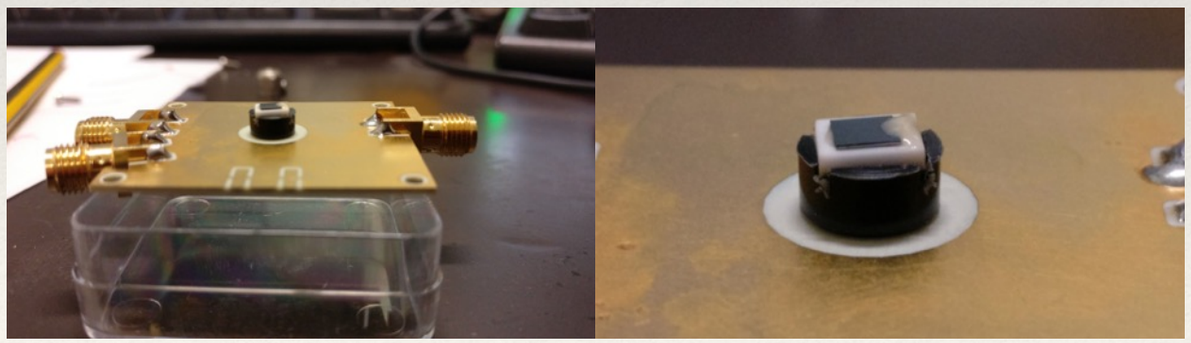


Samples and Measurements

7 HFS detectors

- 2 left for reference (unirradiated)
- 5 sent to Ljubljana for neutron irradiation
  - 3E13 n/cm^2
  - 6E13 n/cm^2
  - 3E14 n/cm^2
    (two samples received this fluence)
  - 1E15 n/cm^2



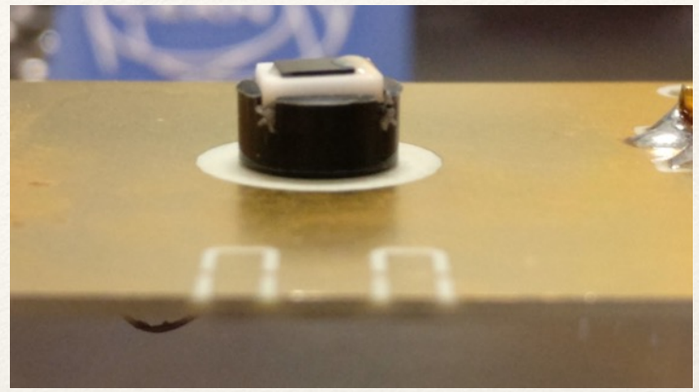


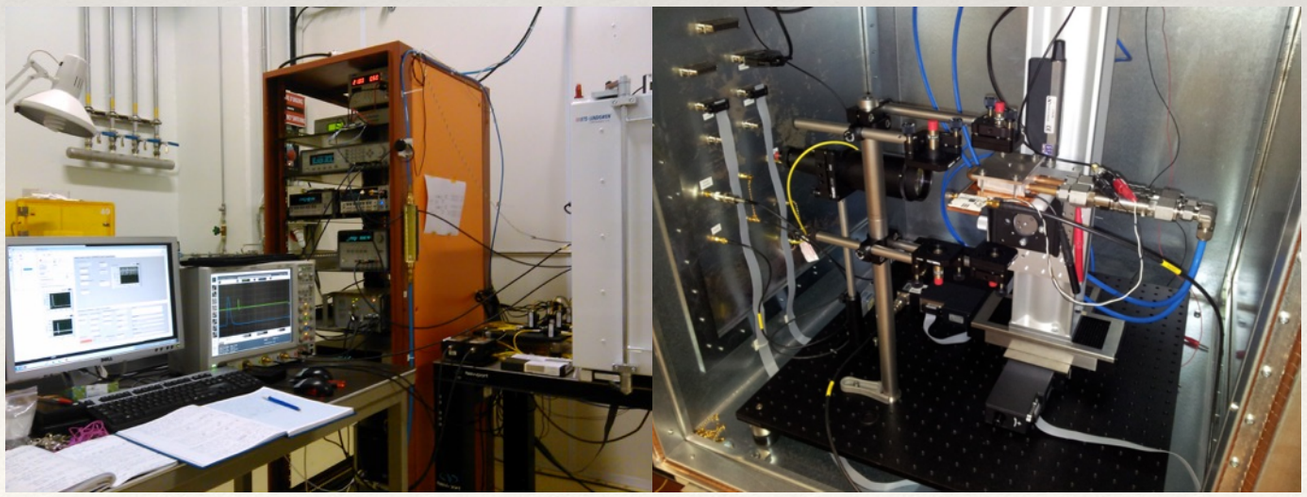
Type of measurements performed

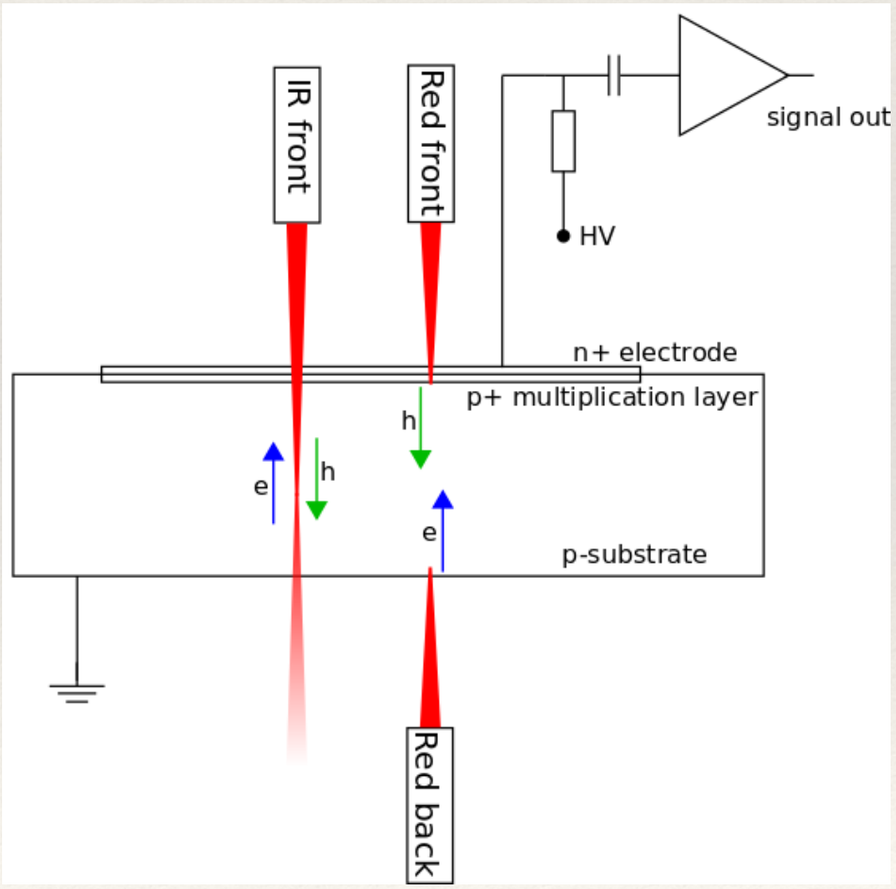
- **TCT**
  - Front XY scans
    - Red and infrared
  - IR front voltage scans
- **CV/IV**

TCT Measurements

- Picosecond-pulse LASER (200 ps)
  - Red front (660 nm, 77 μW avg. peak power)
  - IR front (1064 nm, 137 μW avg. peak power)
- Customised bias T (C = 4.4 nF; R = 1 MΩ) + amplifier (effective amplification: 10 dB)
- Read-out and biasing from the back (cathode).





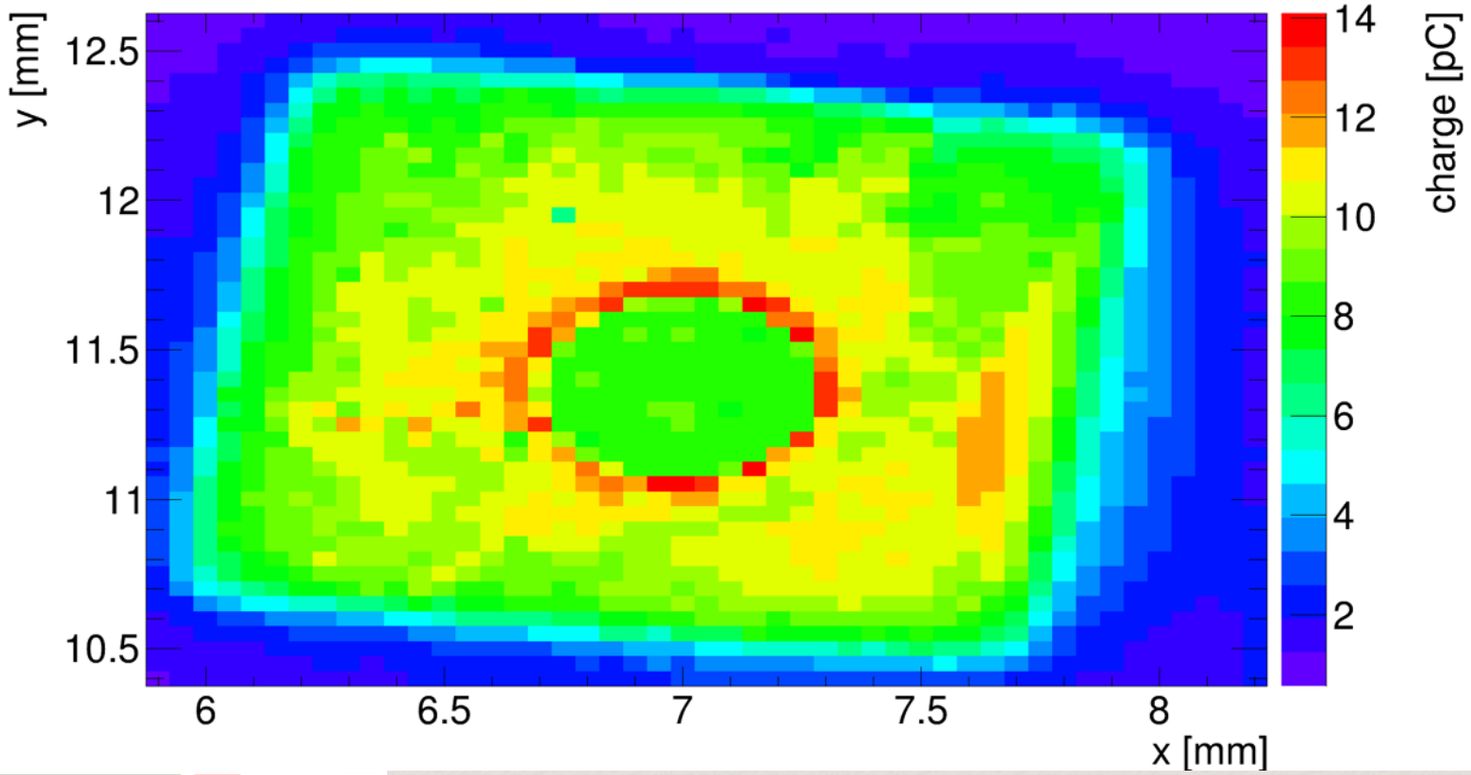


TCT XY SCANS

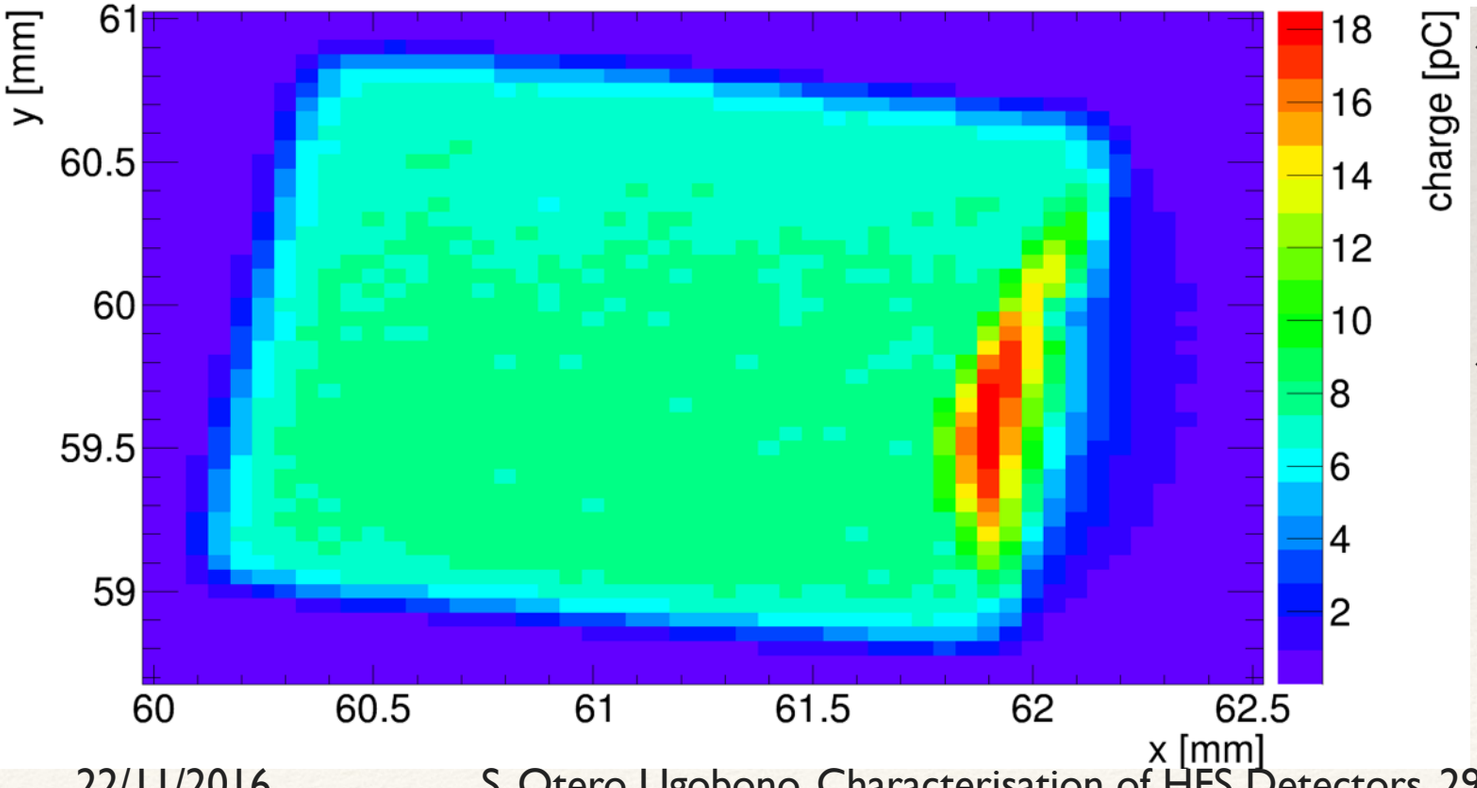
Unirradiated Sample

- Sample name: 394_1_7
- **Red and IR front scans at 1700 V, 20°C**
- Max. leakage current observed ≈ 0.05 μA

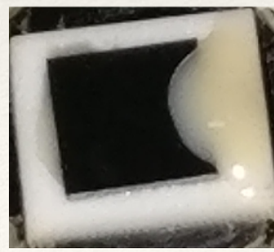
IR front



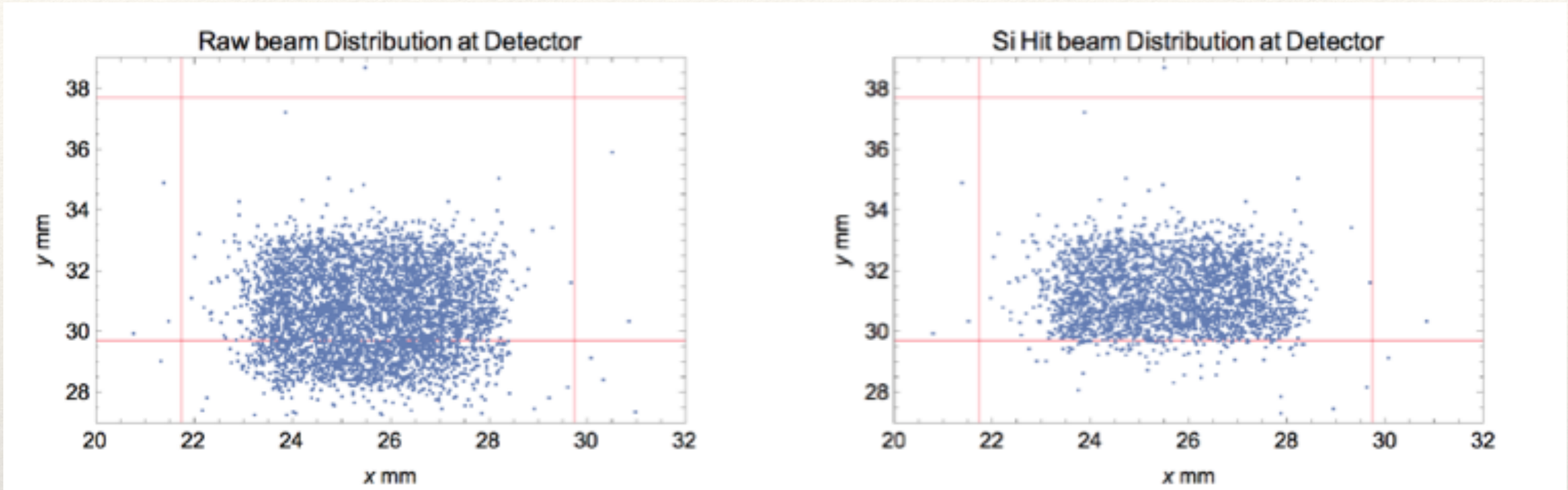
Red front



- Ring observed in IR scan
  - Optical effect cause by LASER reflection on the back connection.
- Right side inhomogeneity in red scan
  - Optical effect caused by reflections on glue blob.



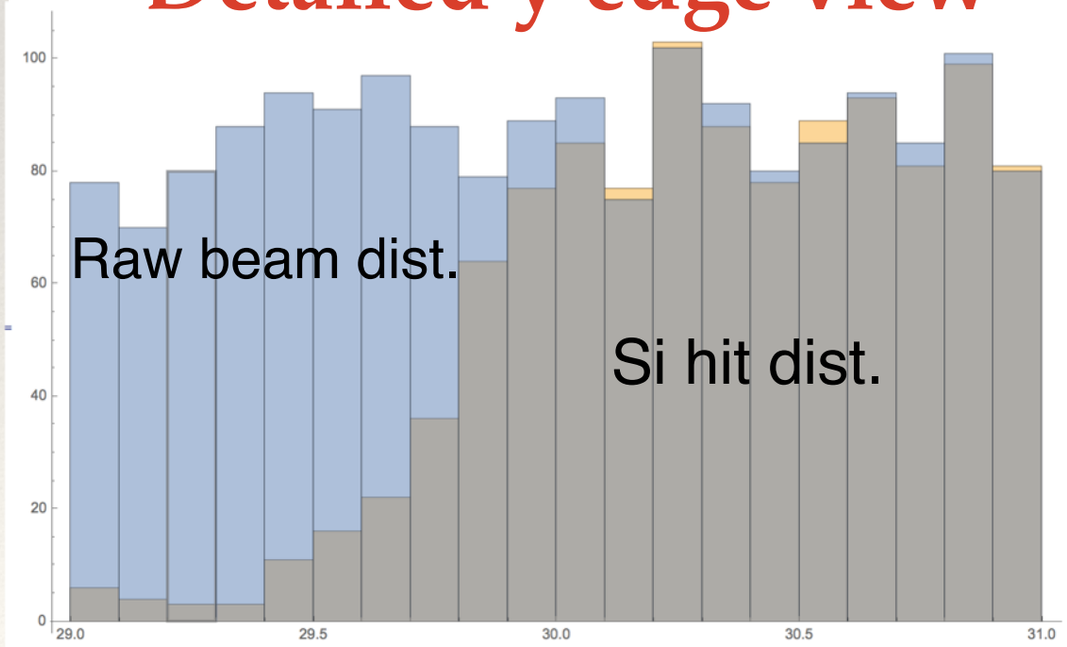
Unirradiated Sample



- Test beam results obtained on a HFS detector of different dimensions (8x8 mm) to that characterised in this presentation.
- Homogeneous particle detection.

(For more information see backup slides)

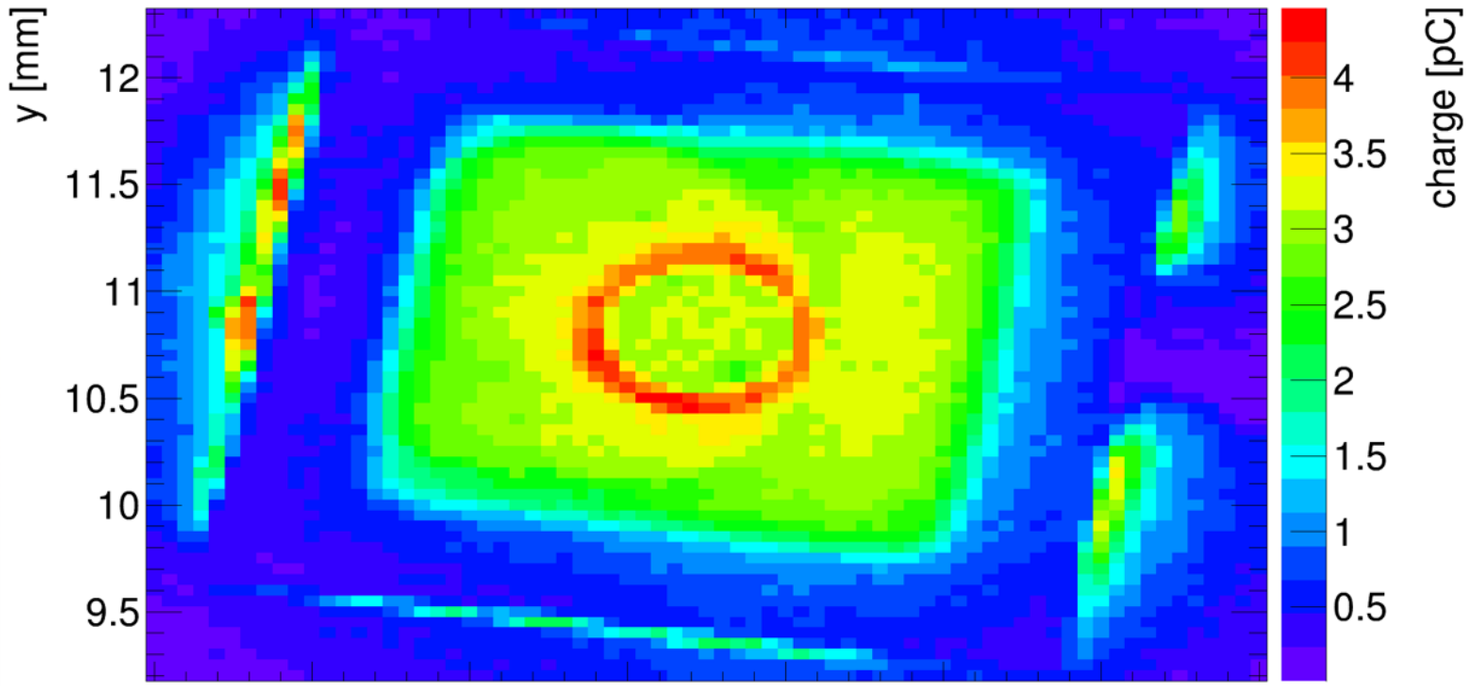
Detailed y edge view



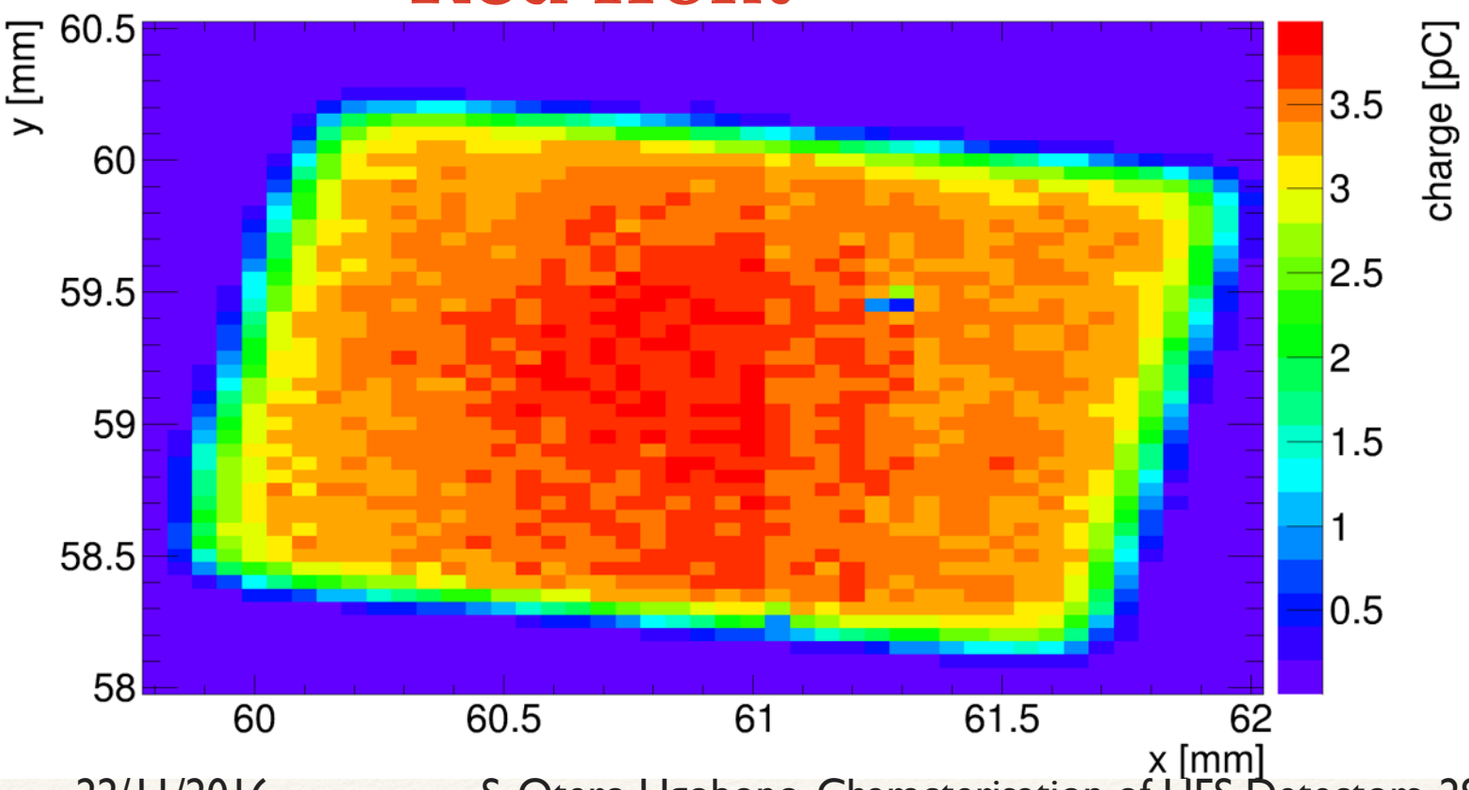
Irradiated 3E13 n/cm^2

- Sample name: 394_1_1
- **Red and IR front scans at 1700 V, -20°C**
- Max. leakage current observed ≈ 2.5 μA

IR front



Red front

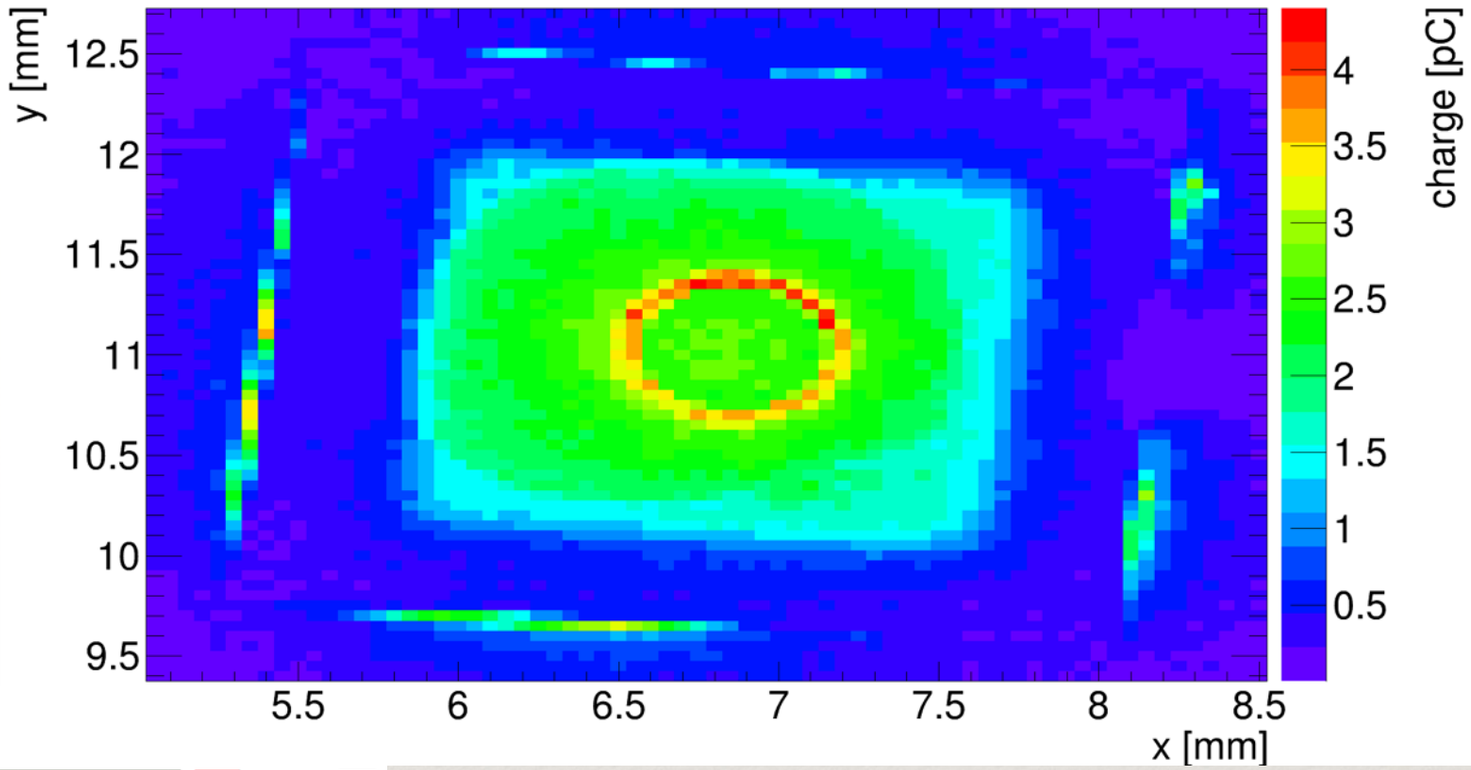


- The charge collection observed outside the sensor's active area on the IR scan is caused by reflections on glue surrounding the sensor (see backup slides).

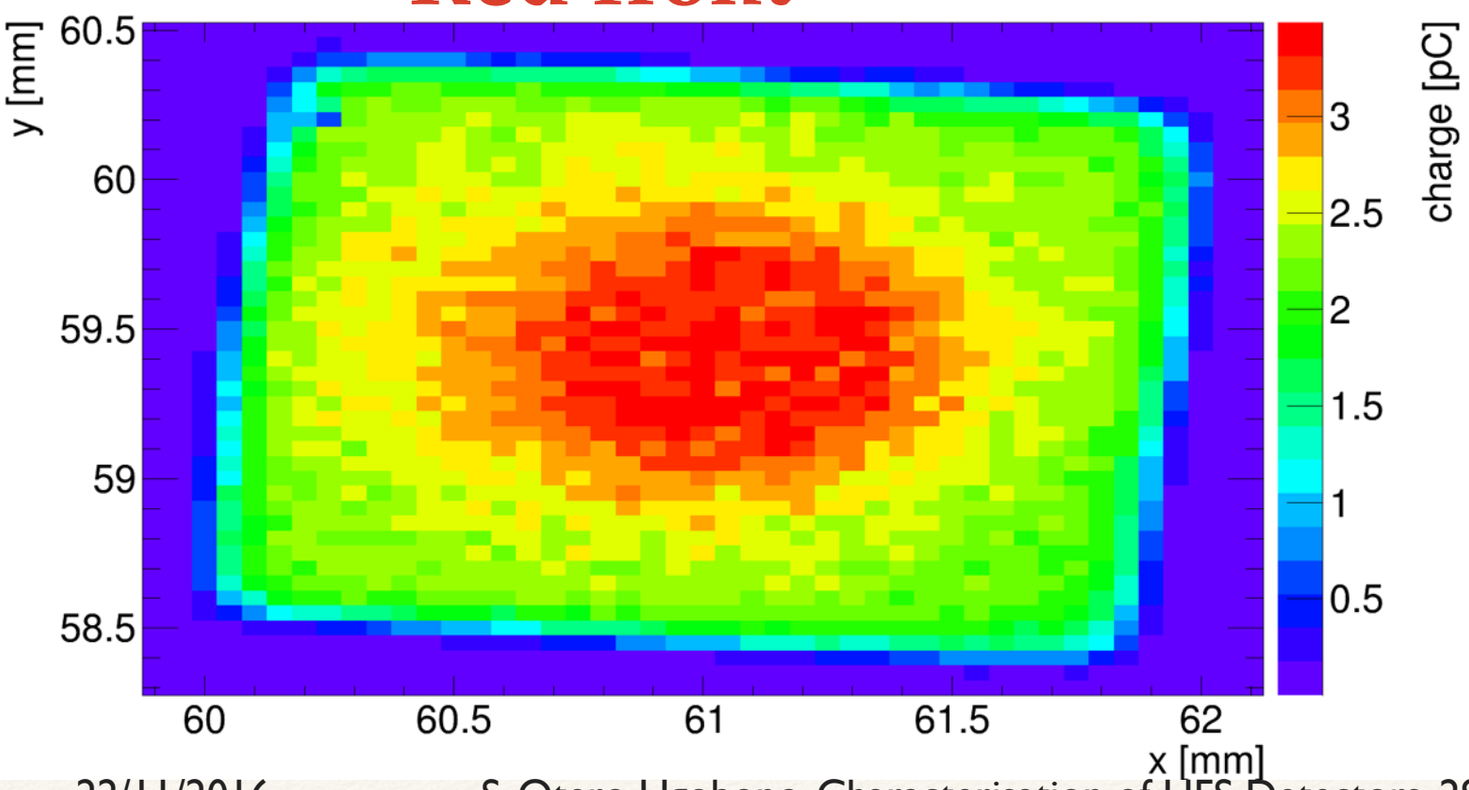
Irradiated 6E13 n/cm^2

- Sample name: 394_1_3
- **Red and IR front scans at 1700 V, -20°C**
- Max. leakage current observed ≈ 2.0 μA

IR front



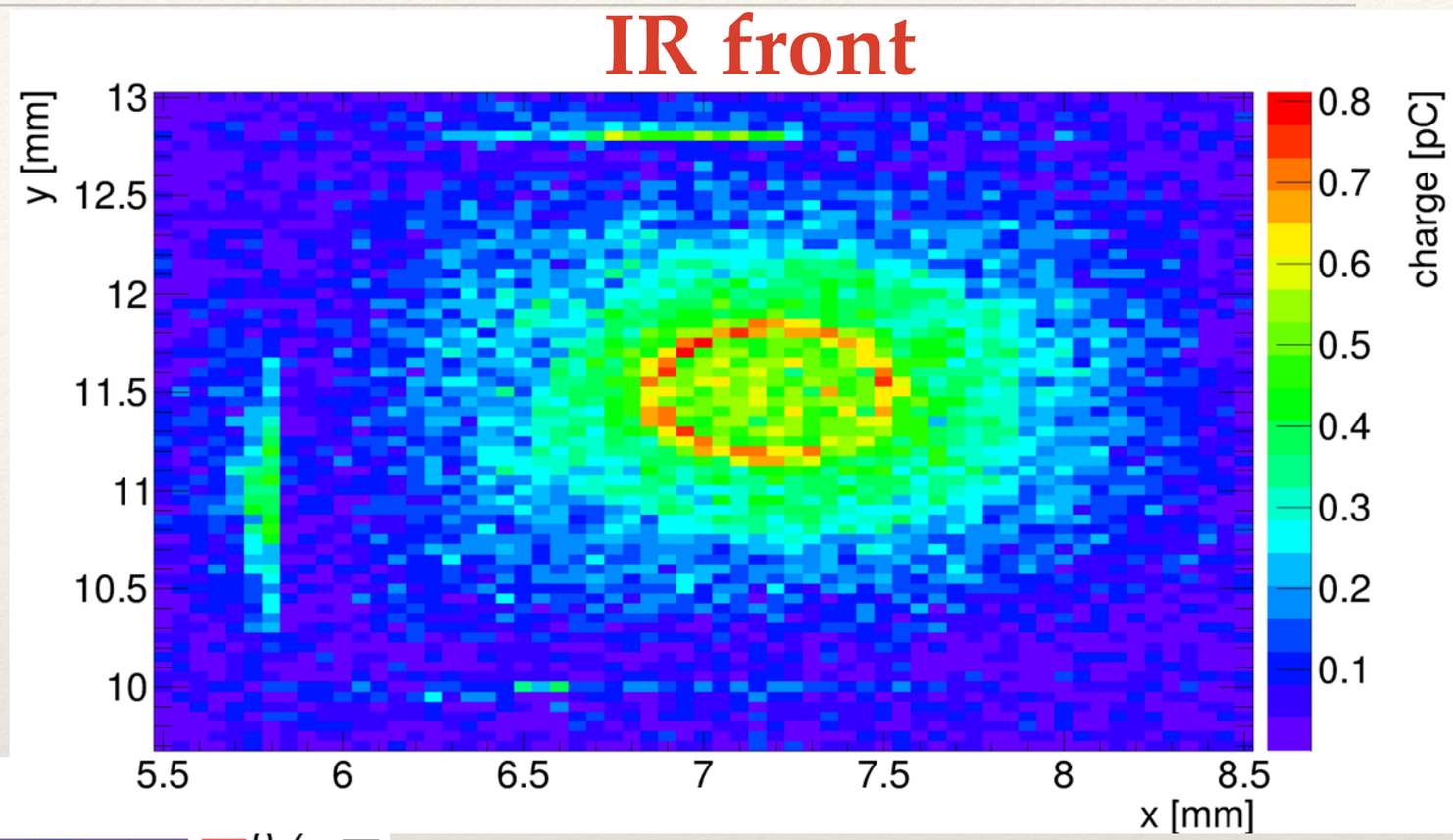
Red front

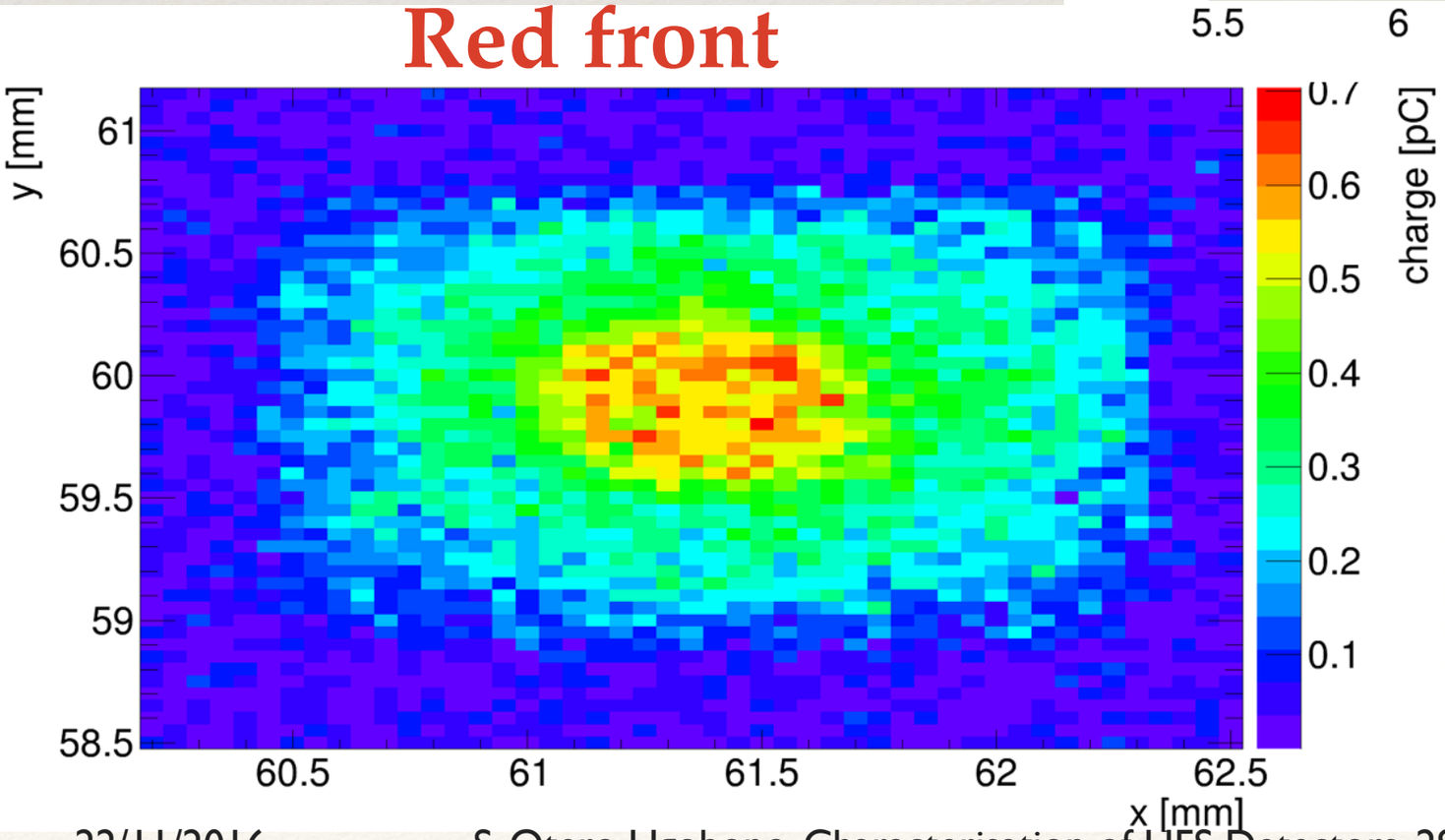


- Unexpected charge collection inhomogeneity in red scan.

Irradiated 3E14 n/cm^2

- Sample name: 394_1_5
- **Red and IR front scans at 1700 V, -20°C**
- Max. leakage current observed ≈ 2.0 μA





- Significant reduction of the active area.
- Unexpected charge collection inhomogeneity in red scan.

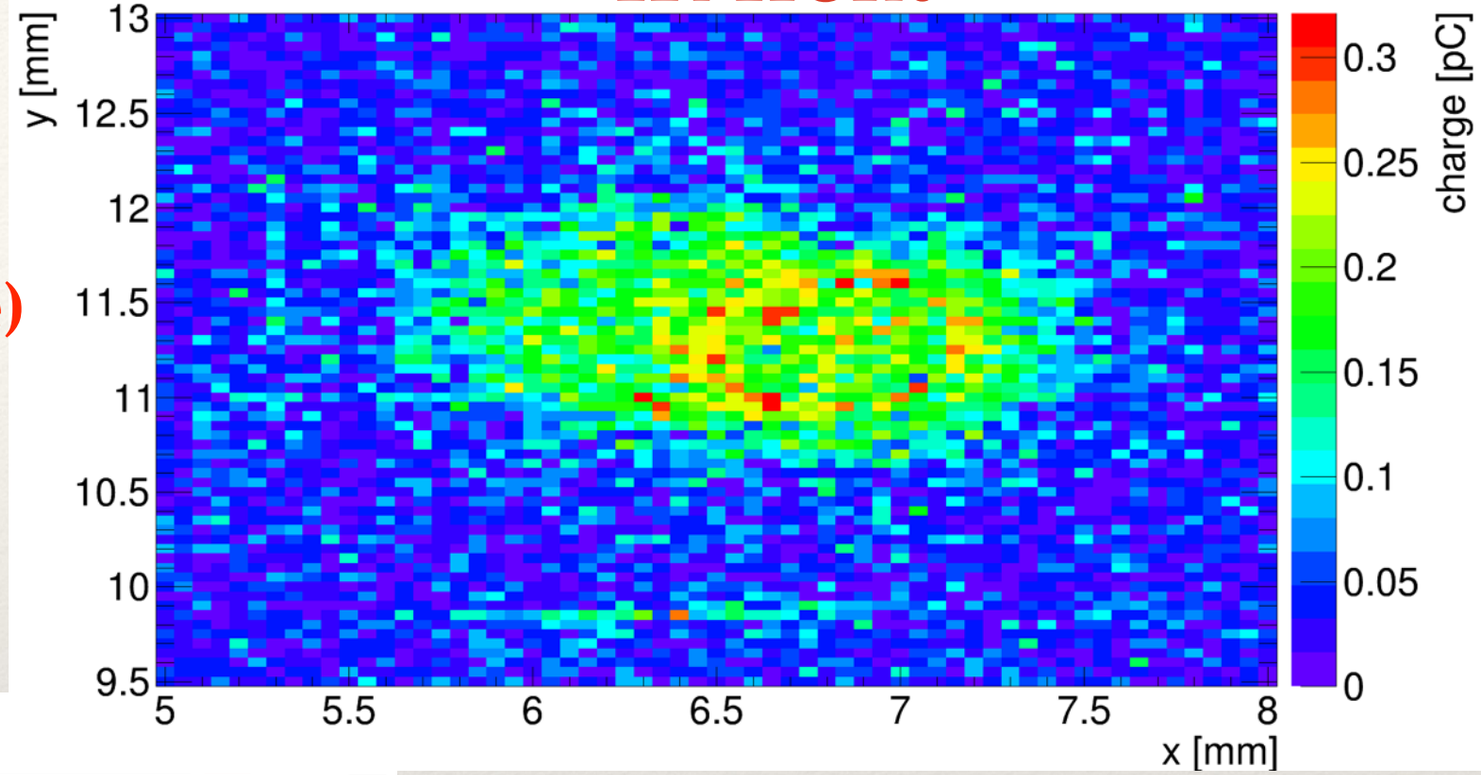
Irradiated 3E14 n/cm^2

- Sample name: 394_1_4

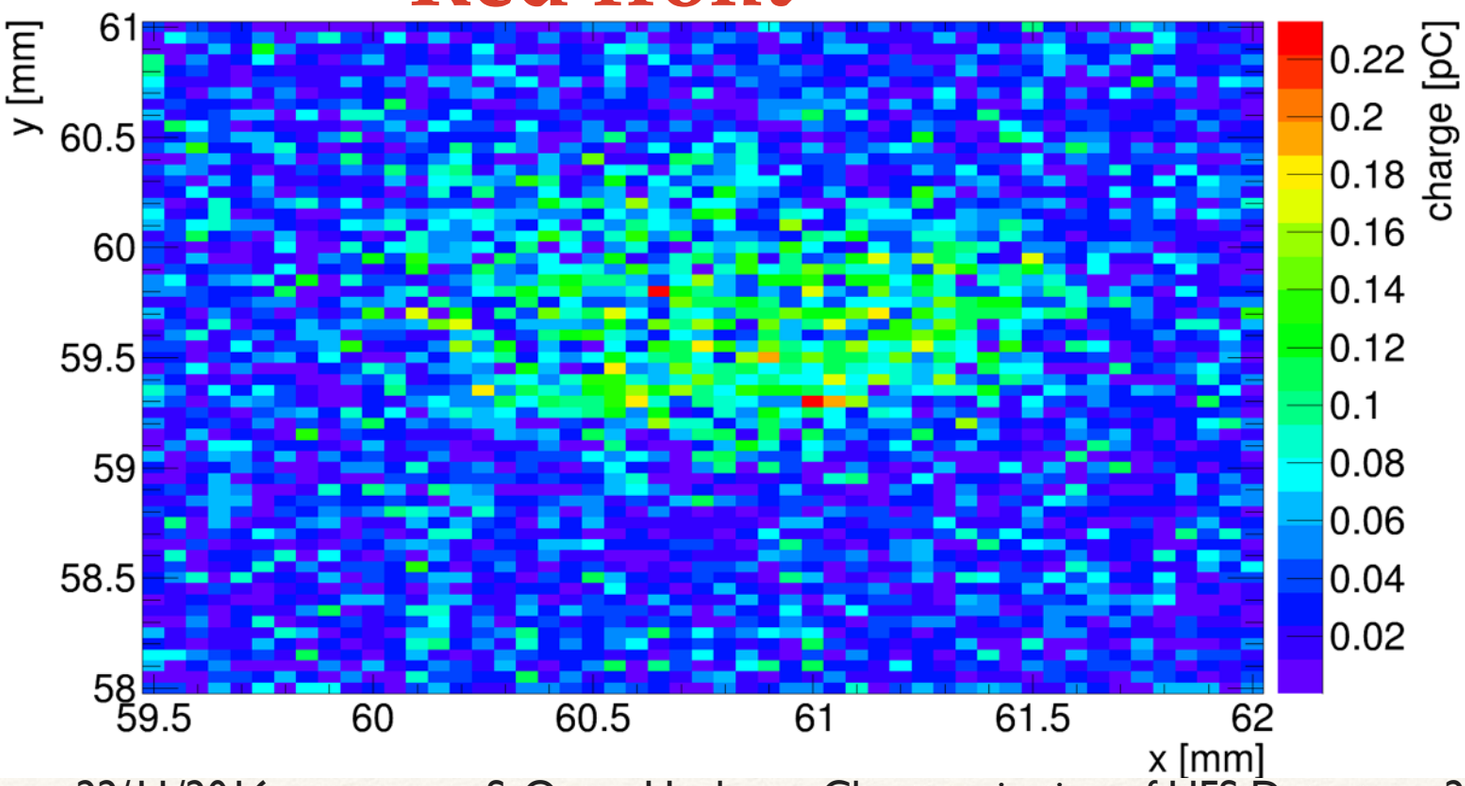
⚠ **At 1530 V leakage current: 10 μA (compliance)**

- **Red and IR front scans at <u>1500 V</u>, -20°C**

IR front



Red front

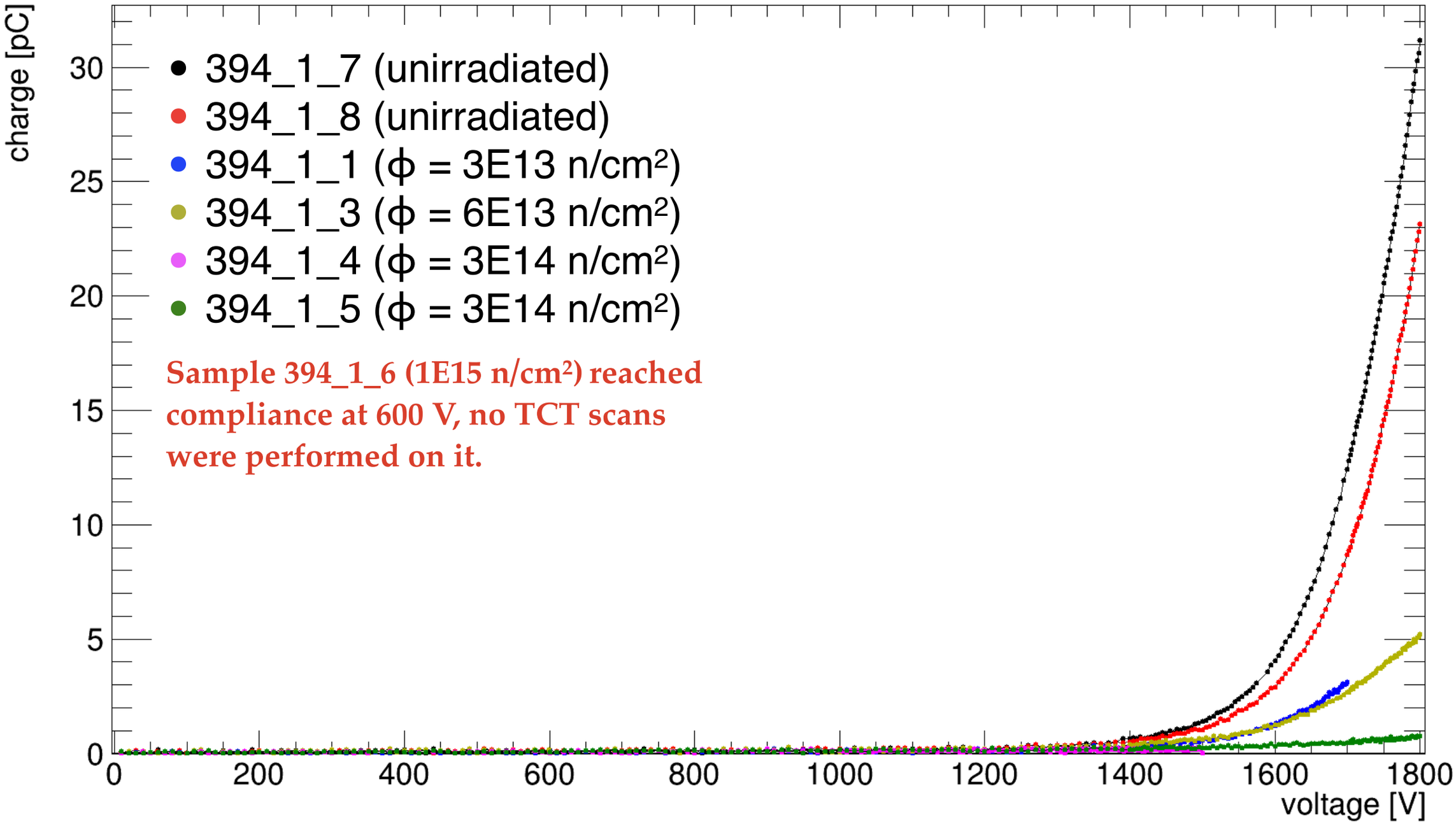


- Extreme reduction of the active area.

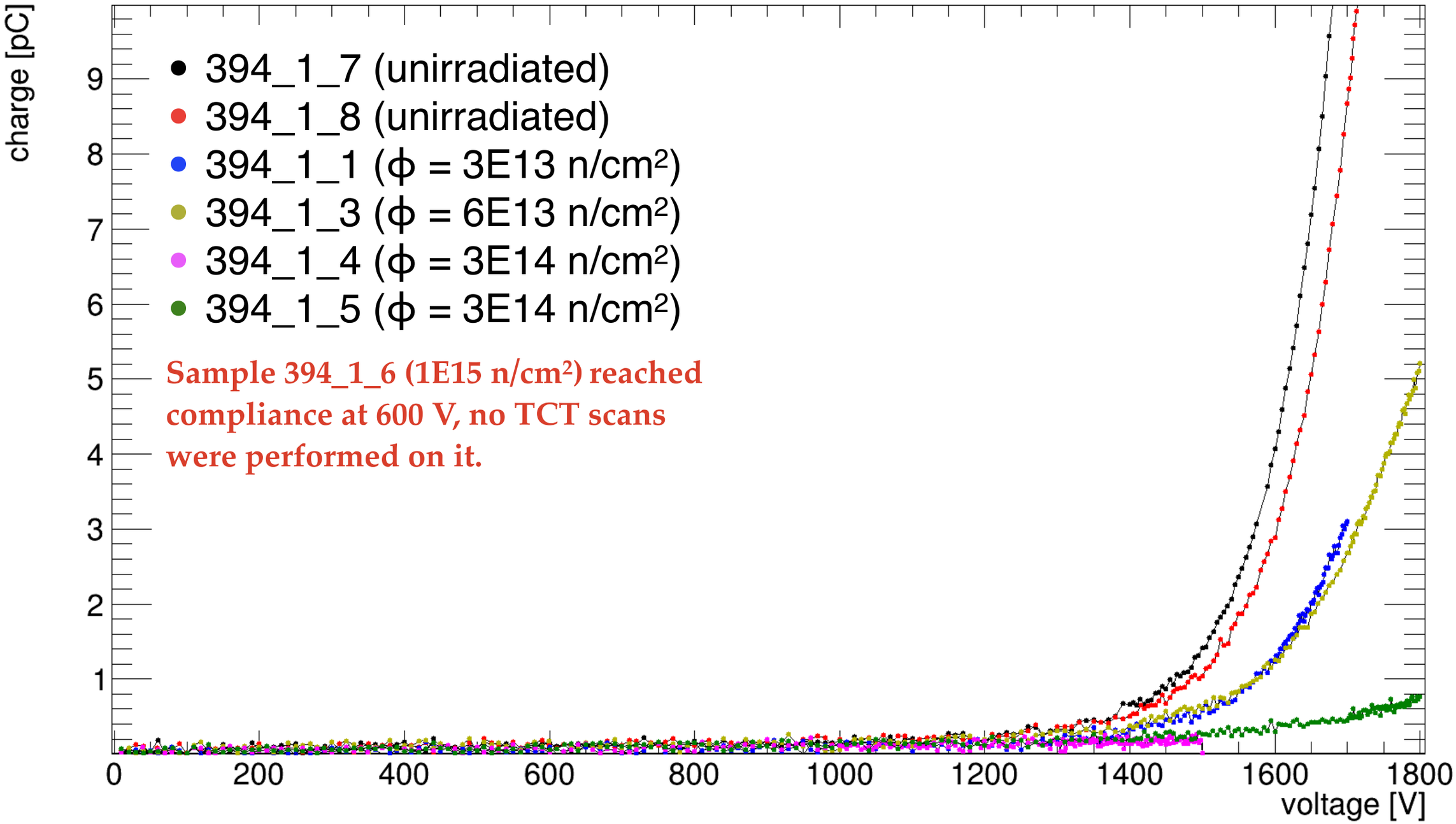
The sample irradiated up to 1E15 n/cm^2 reached compliance at 600 V, thus, no TCT scans were performed on it.

TCT VOLTAGE SCANS

Voltage Scans @ -20°C

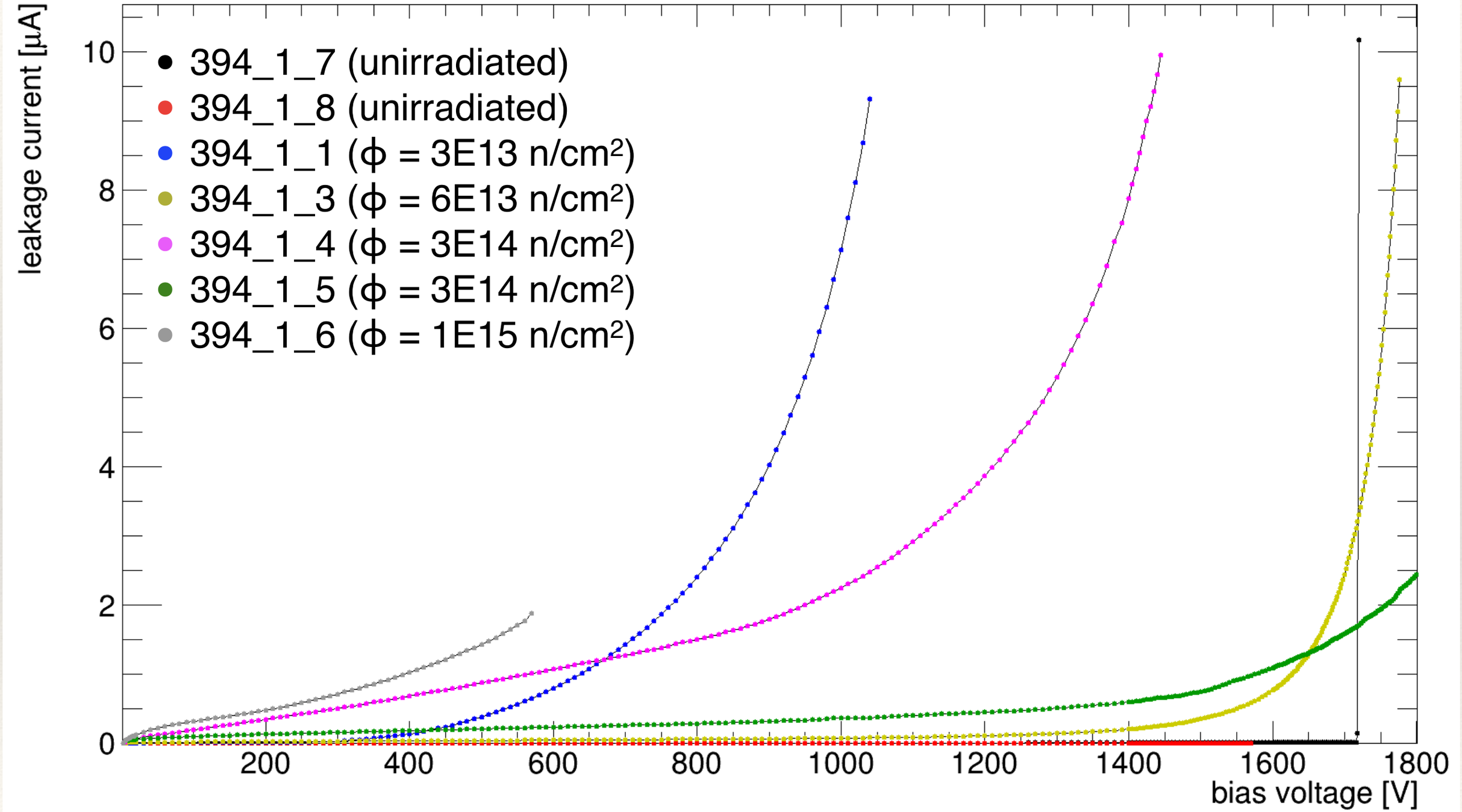


Voltage Scans @ -20°C



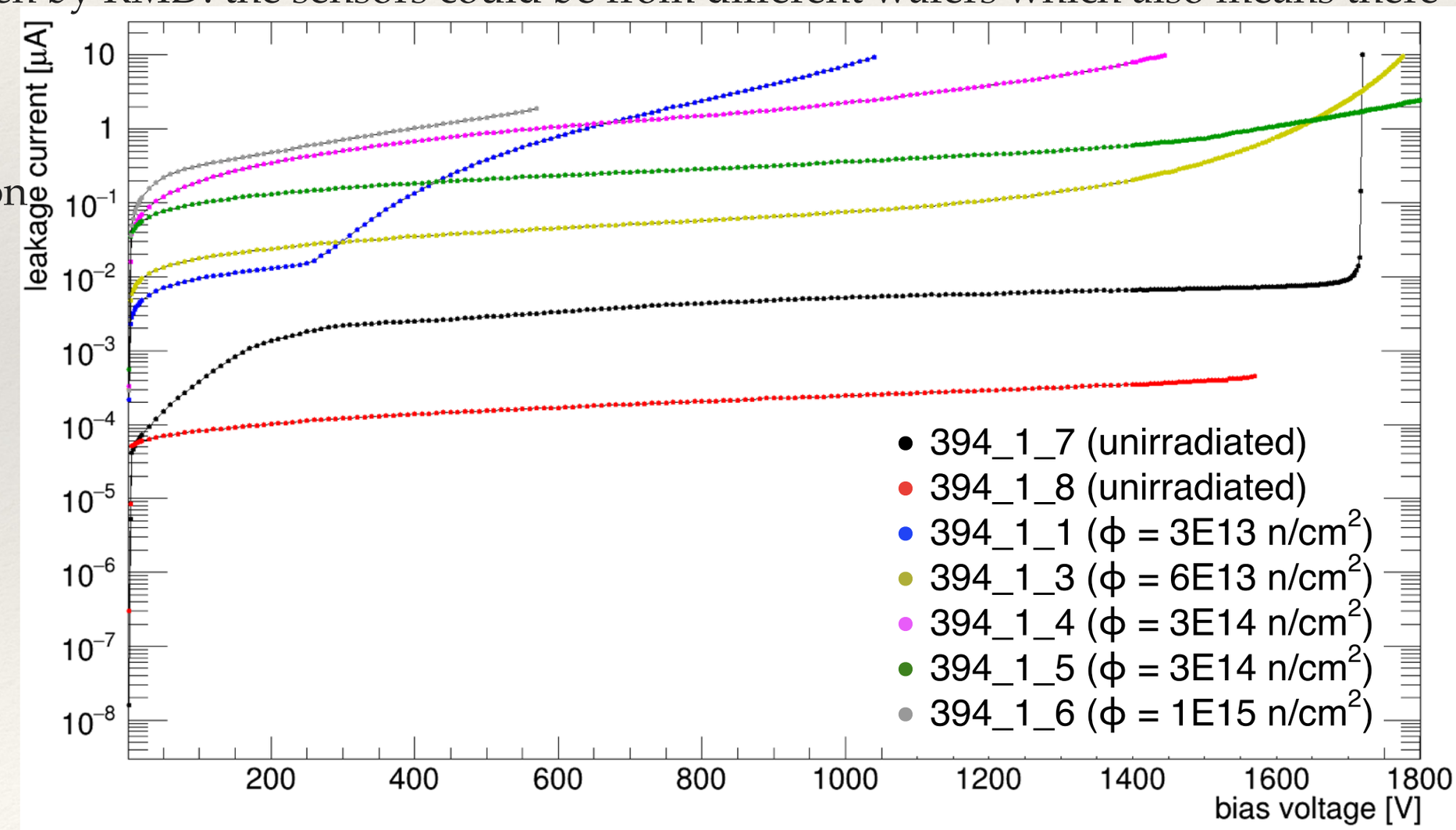
IV CURVES

IV Curves @ -20°C

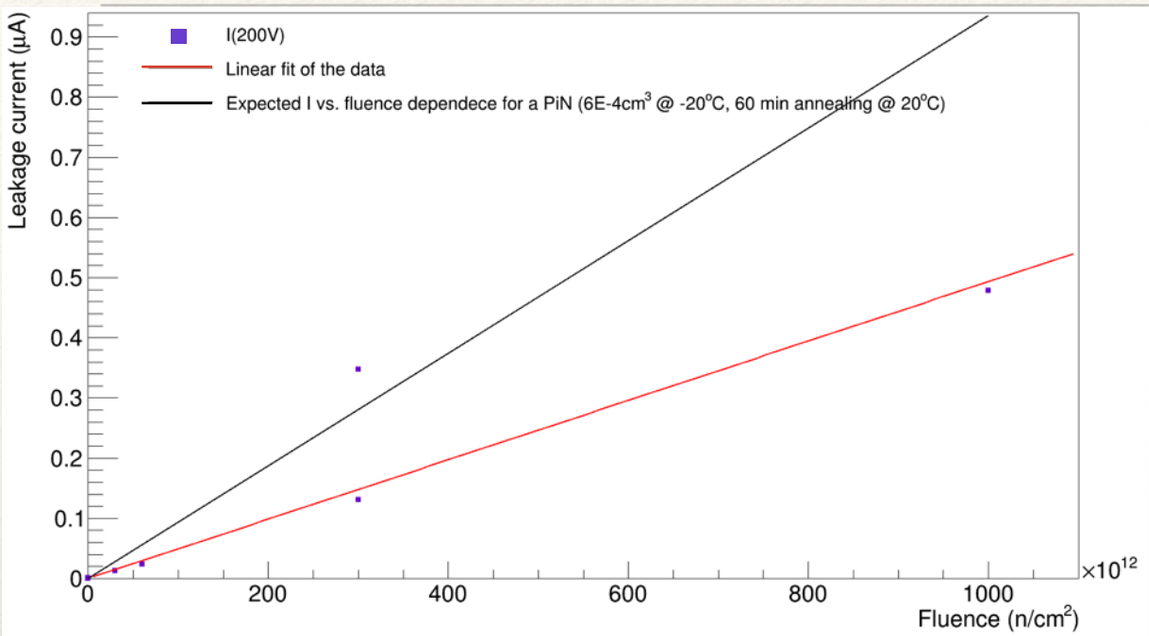


IV Curves @ -20°C

- Sample 394_1_3 suffered a change in breakdown voltage with respect to when TCT measurements were performed.
  - Possible explanation: damage to the cathode and/or anode connections.
- Samples 394_1_4 and 395_1_5 (both irradiated to 3E14 n/cm^2) behave differently.
- Also, the two unirradiated samples behave differently.
  - Possible explanation given by RMD: the sensors could be from different wafers which also means there could be differences in:
    - Doping profile
    - Depth of the PN junction
    - Thickness of the sensor



I(200 V) vs. Fluence @ -20°C



Damage coefficient:

- From fitting HFS data:
  $\alpha_{fit} \approx$ 8.22E-19 A/cm
- For a PiN with equal volume and annealing:
  $\alpha_{PiN} \approx$ 15.6E-19 A/cm

ESTIMATION

Active volume changes are not being considered.

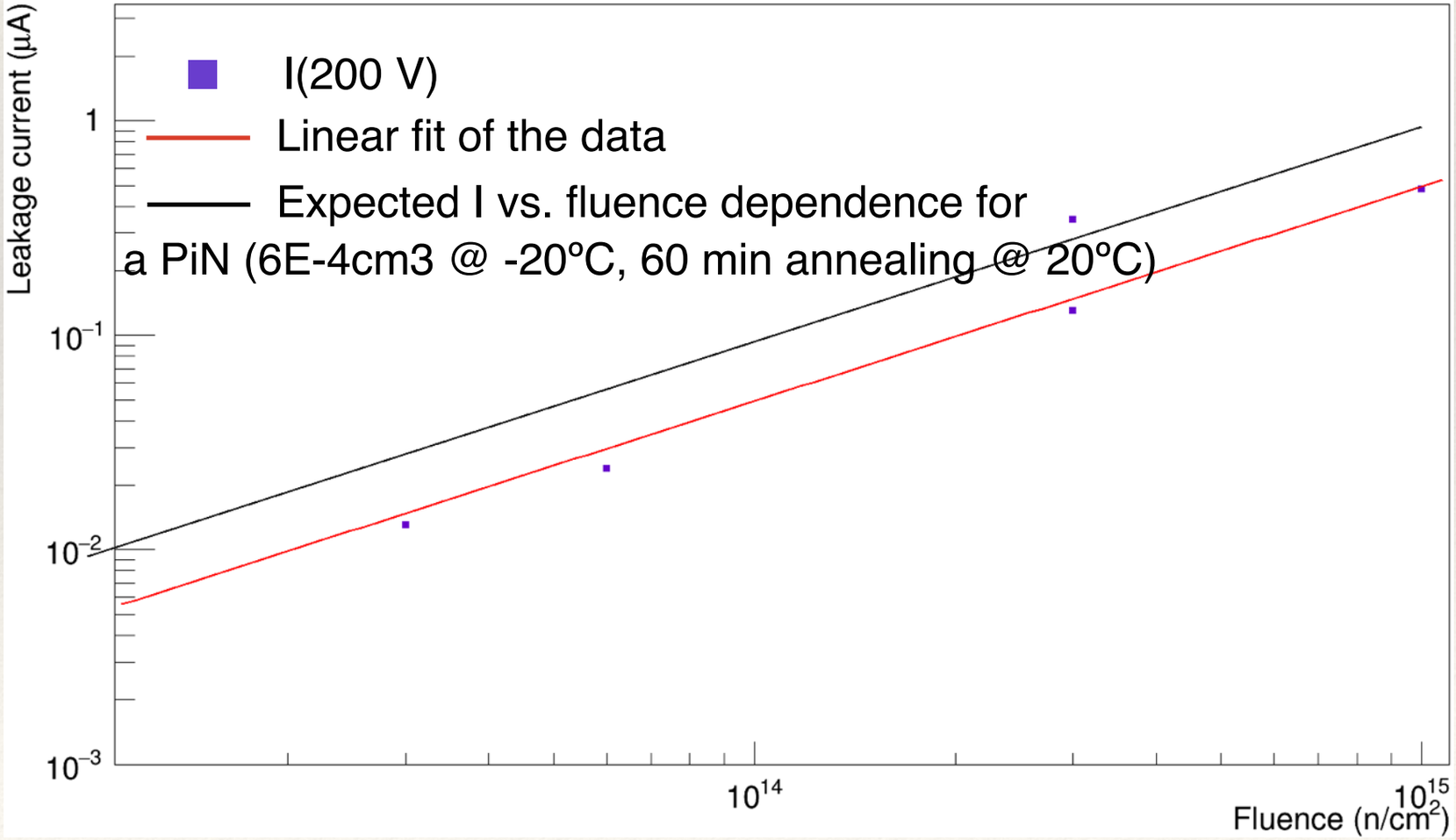
Dimensions assumed:

Active area: 2x2 mm

Thickness: 120 μm

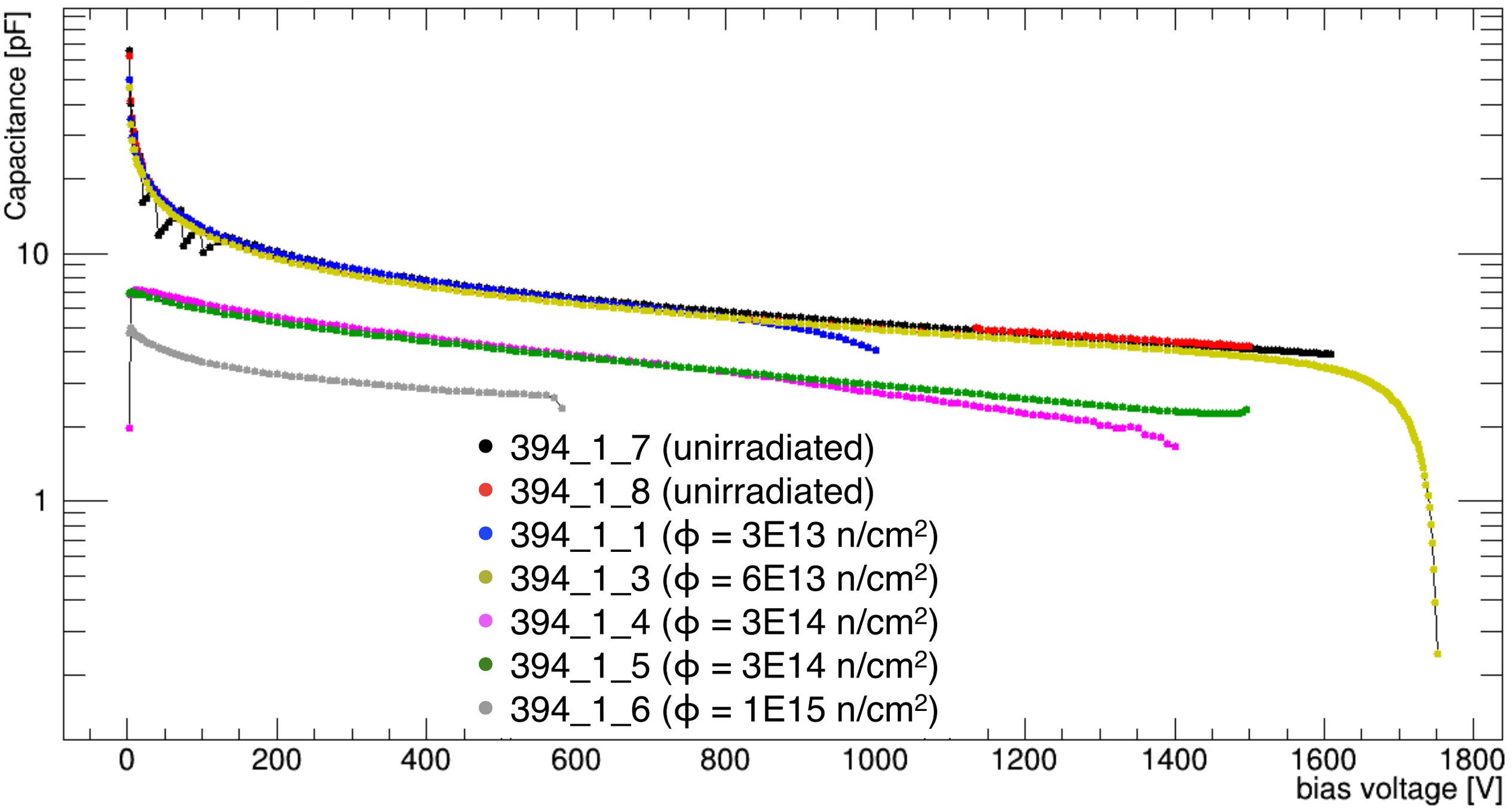
Estimated annealing:

60 min @ 20°C



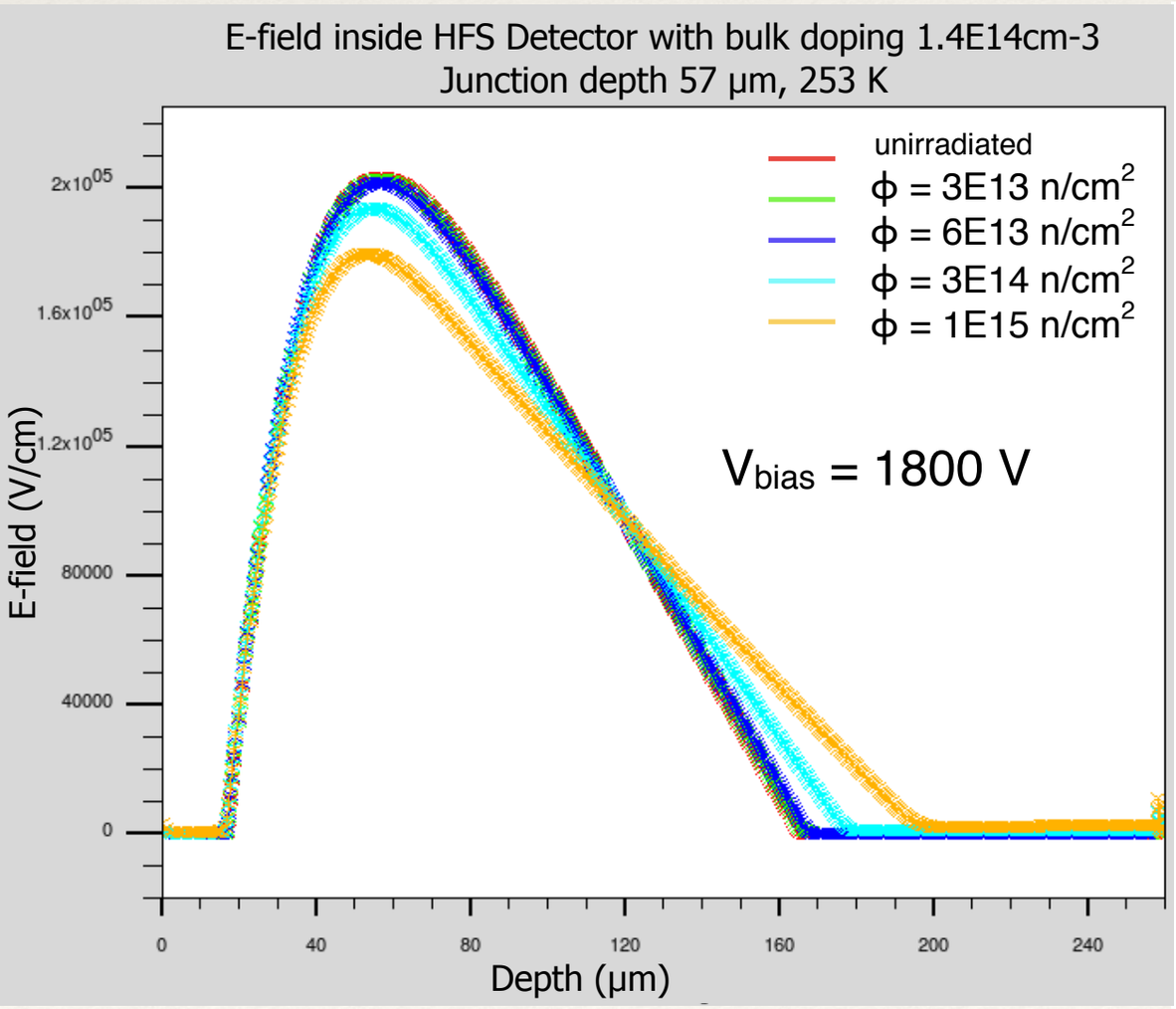
CV CURVES

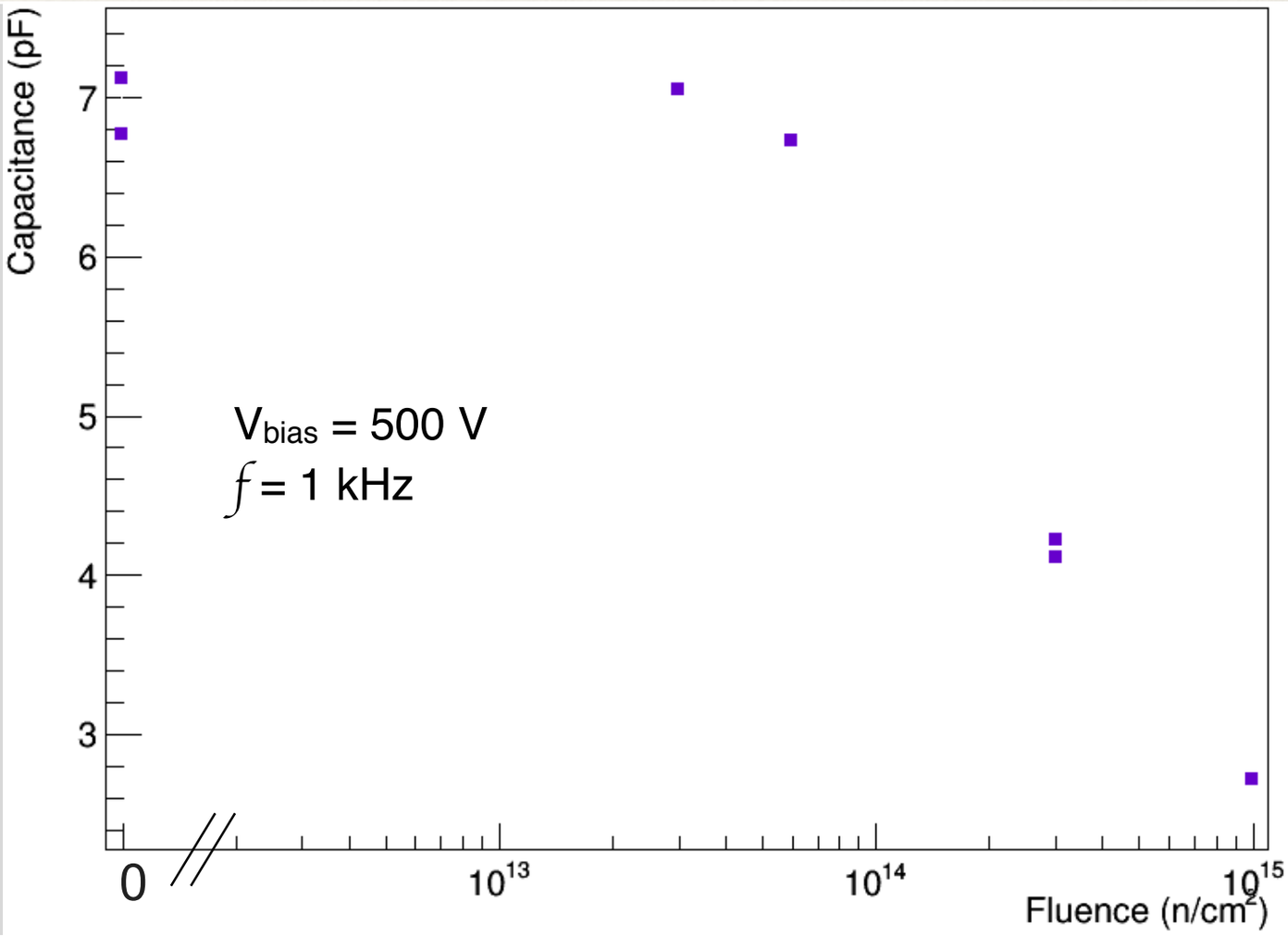
CV Curves @ -20°C



CV Curves @ -20°C

- Capacitance decreases with fluence.
  - Equivalent to an increase in thickness of the depletion region.
  - Same tendency as the simulations done on TCAD by the Delhi group.

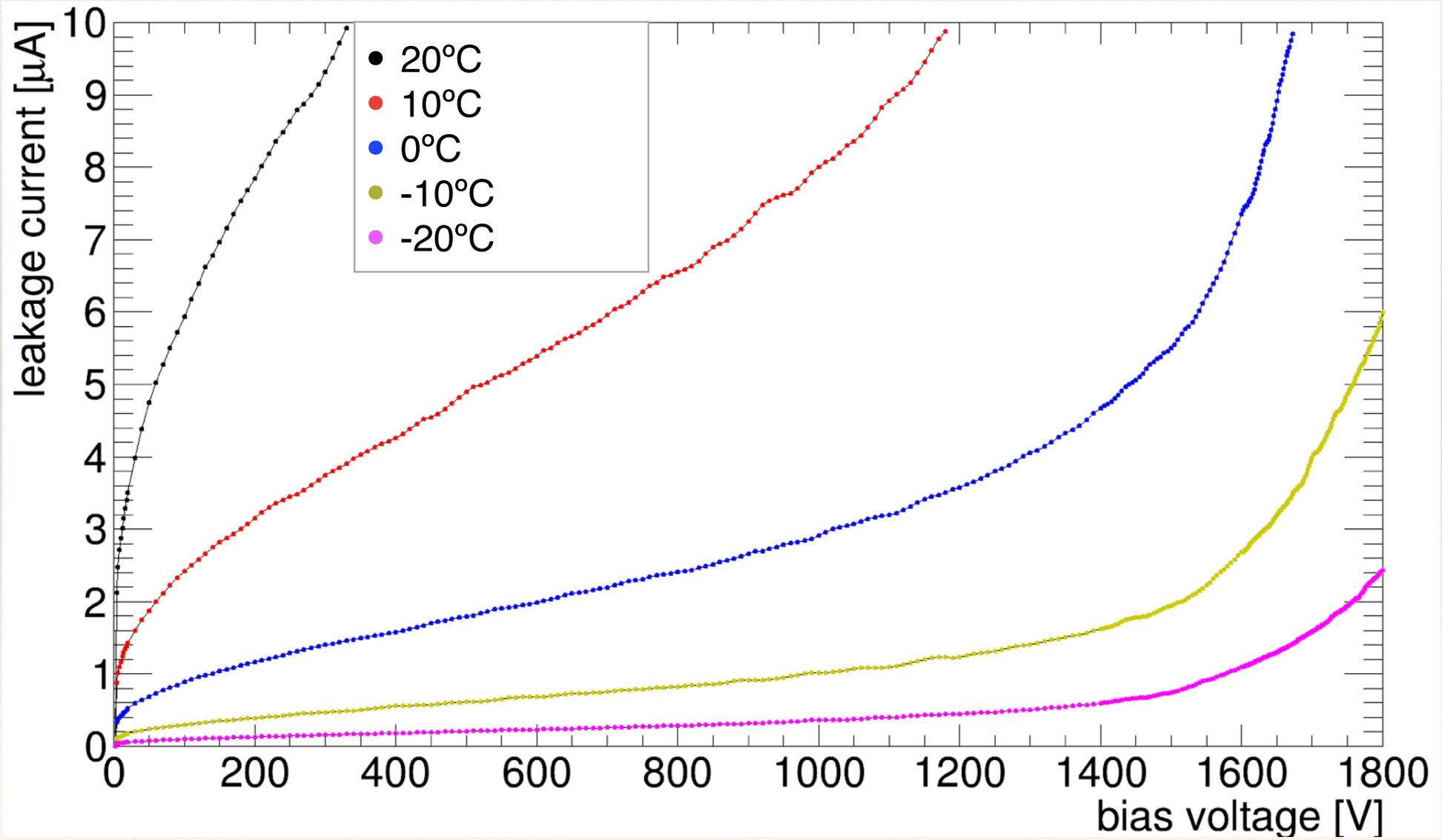




IV vs. T

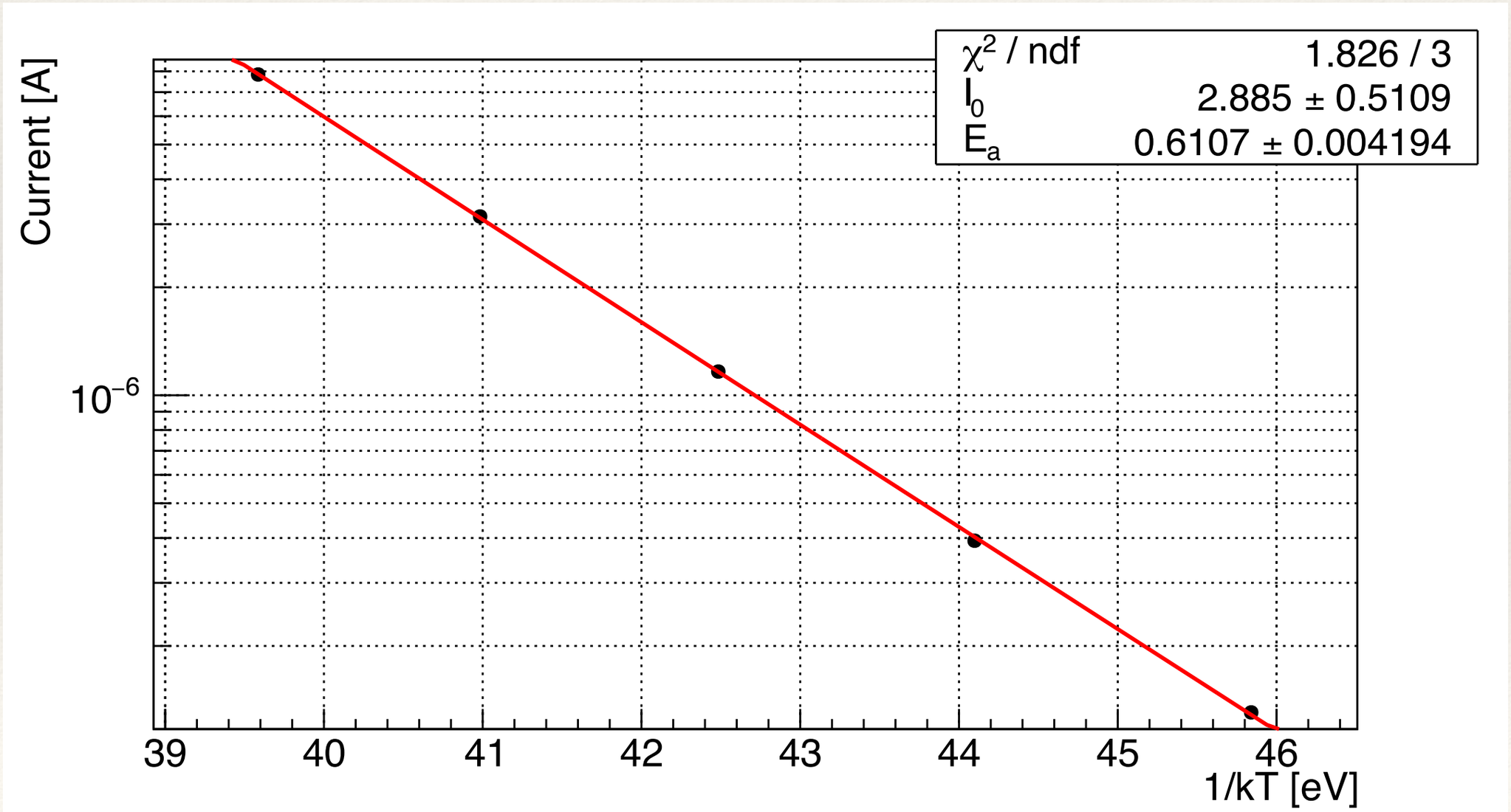
IV Curves @ Different Temperatures

- **Sample 394_1_5, ϕ = 3E14 n/cm^2.**
- IV curves were measured at 5 different temperatures.
- Objective: produce an Arrhenius plot, calculate the activation energy and compare it with the expected value.



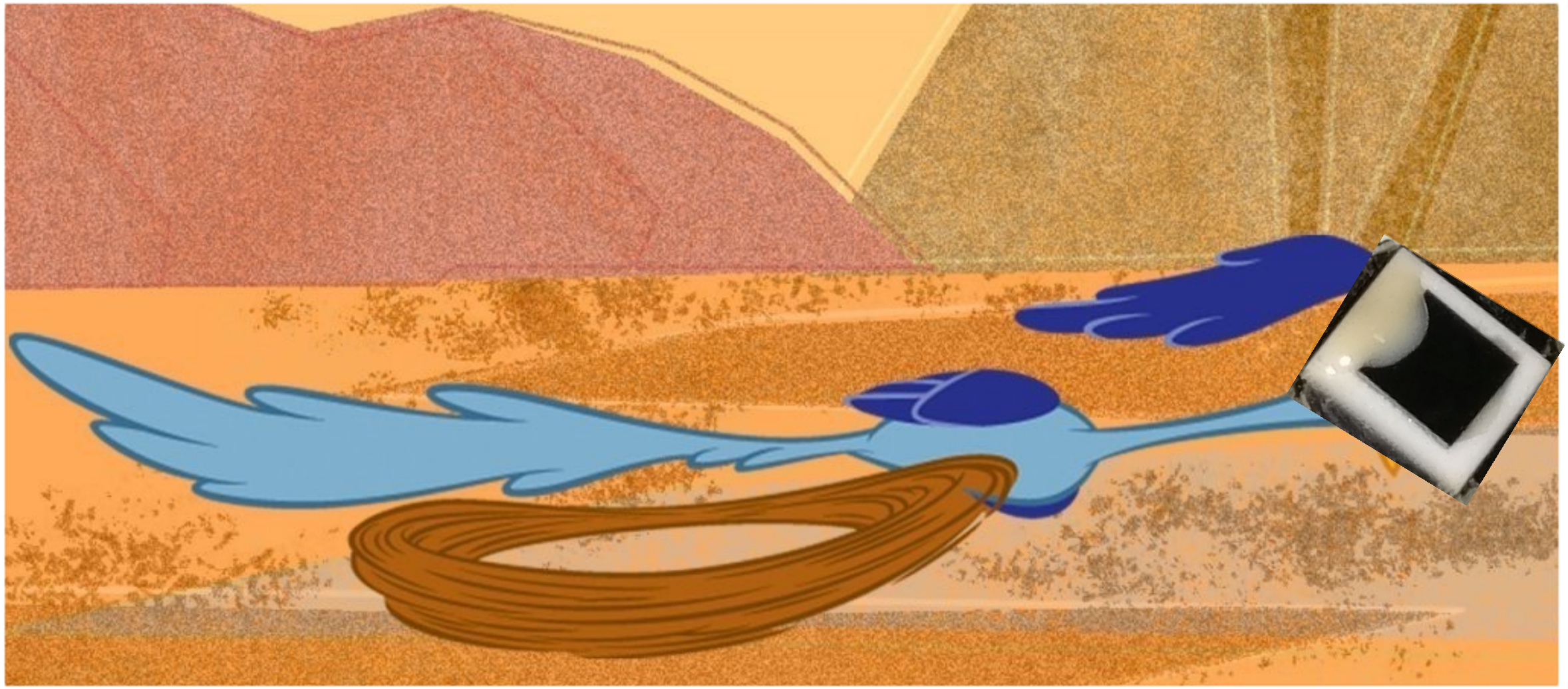
Arrhenius Plot

- **Sample 394_1_5, ϕ = 3E14 n/cm², I(200V).**
- Result from the fit: $E_{ef}^{fit} \approx 1.22$ eV.
- Expected result: $E_{ef} \approx 1.21$ eV. [2013, A. Chilingarov, JINST 8 P10003]



Conclusions

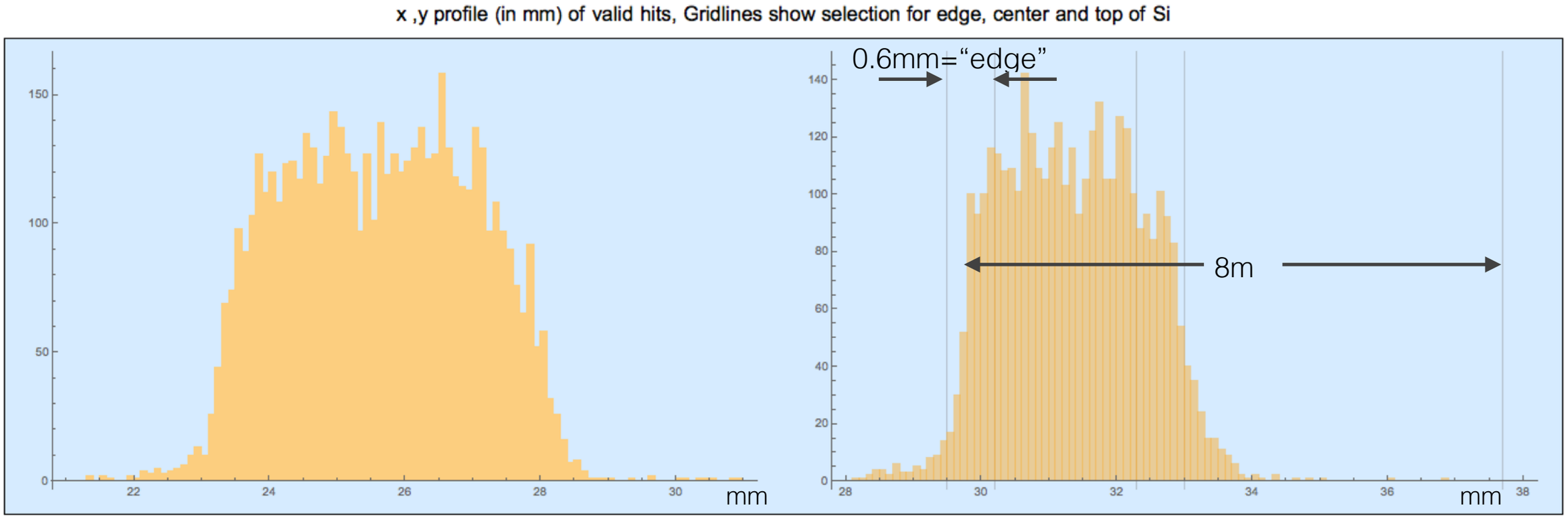
- TCT XY scans on unirradiated samples show inhomogeneities due to purely optical effects
  - This inhomogeneities are not seen with particles (test beam results).
- TCT XY scans show an apparent reduction with fluence of the active area of the sensors.
- A central inhomogeneity appears in the red laser scans of samples irradiated to a $\phi \geq 6E13\ n/cm^2$.
  - This has yet to be understood.
- TCT voltage scans show a decrease in charge collection with fluence.
- From the IV measurements @ 200 V (gain=1) it was possible to estimate α (8.22E-19A/cm), which resulted of the expected order of magnitude.
- CV measurements show an increase in the depletion region thickness with fluence.
  - In agreement with simulations.
- Variation in CV/IV and TCT observed between different samples:
  - For two non irradiated samples
  - For two samples irradiated to the same fluence (3E14 n/cm^2)
    - RMD stated this could be due to the samples coming from different wafers.
    - **It is crucial to measure and test <u>all</u> samples before an irradiation campaign.**
- **We must study a new set of detectors in order to have a better understanding of their behaviour.**
  - We already have the samples and work will begin in the following weeks.

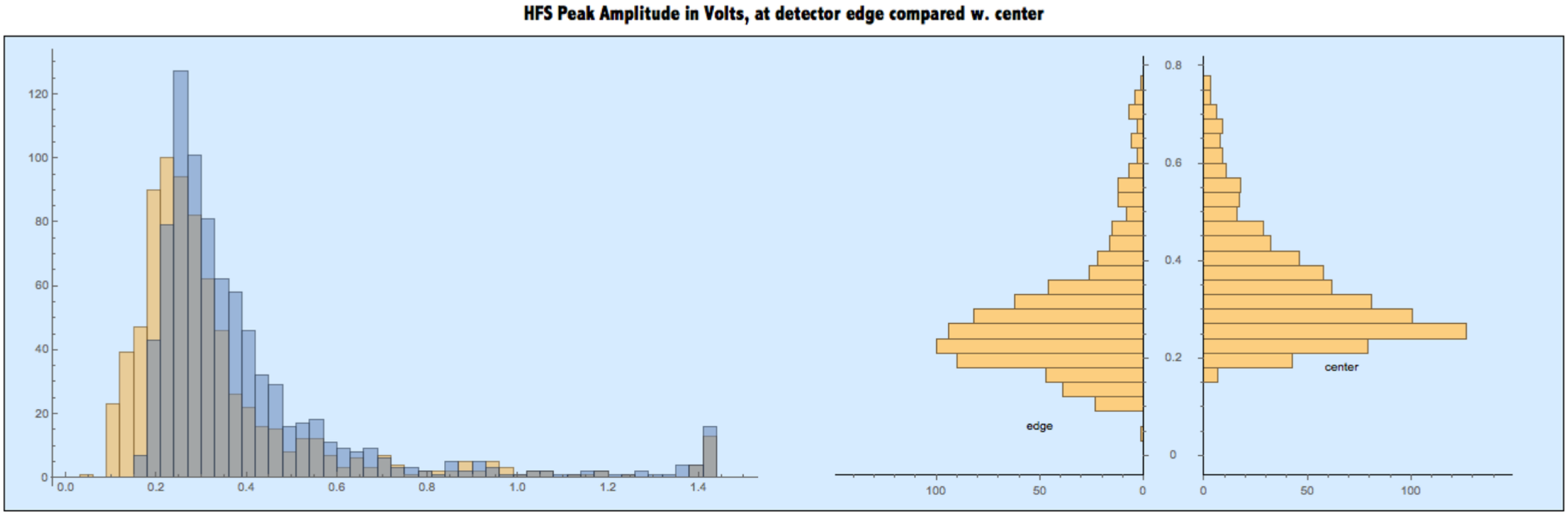


Thank you

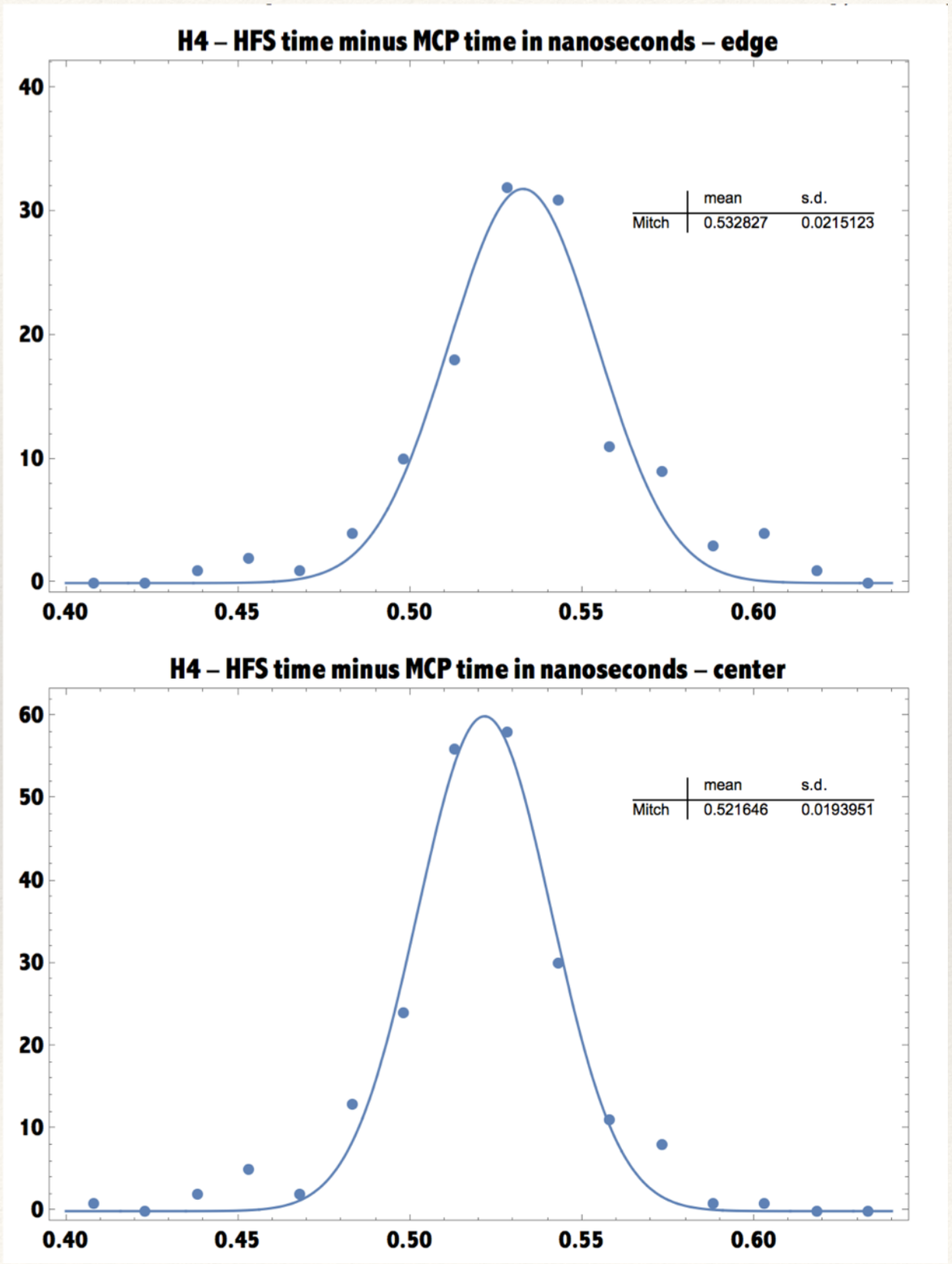
BACKUP SLIDES

8x8 HFS Hit Distribution - Test Beam Results



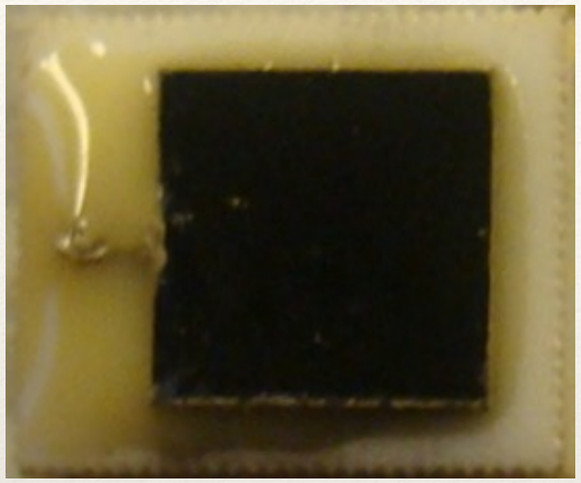


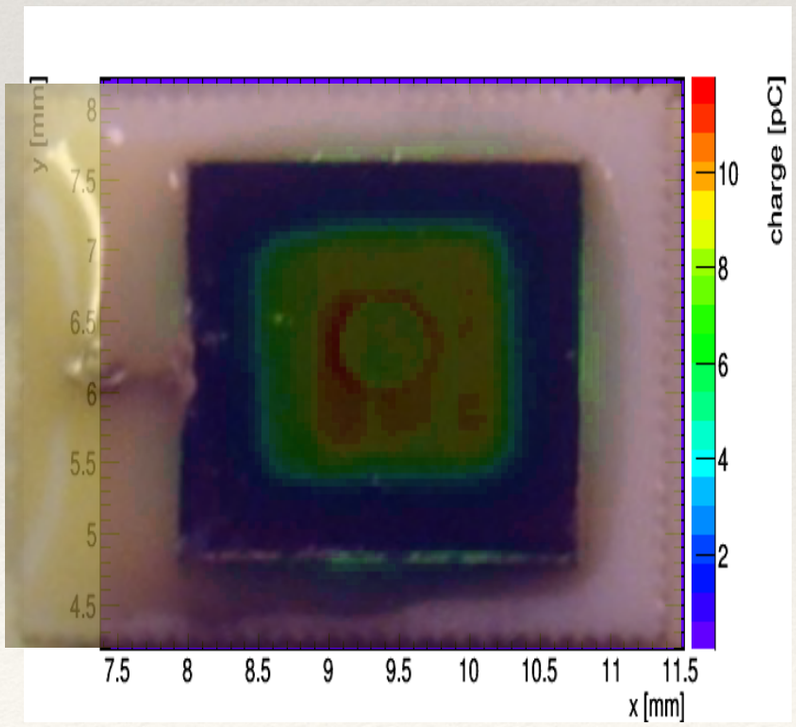
Very Preliminary Look at Timing on Detector Edge



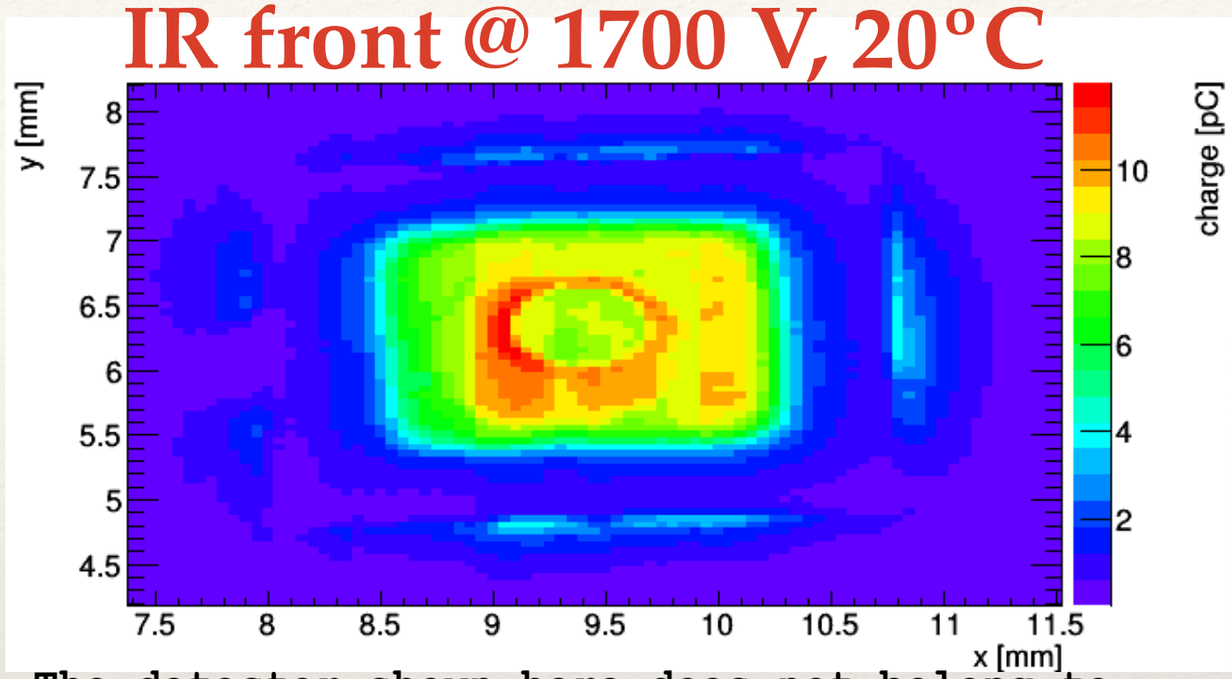
- Due to the complicated edge structure of this high field Si, it was difficult to evaluate w.
- First look at edge behaviour is encouraging.
- The timing algorithm is still preliminary.
  - Small pulse height distortion.

Charge collection outside the active area





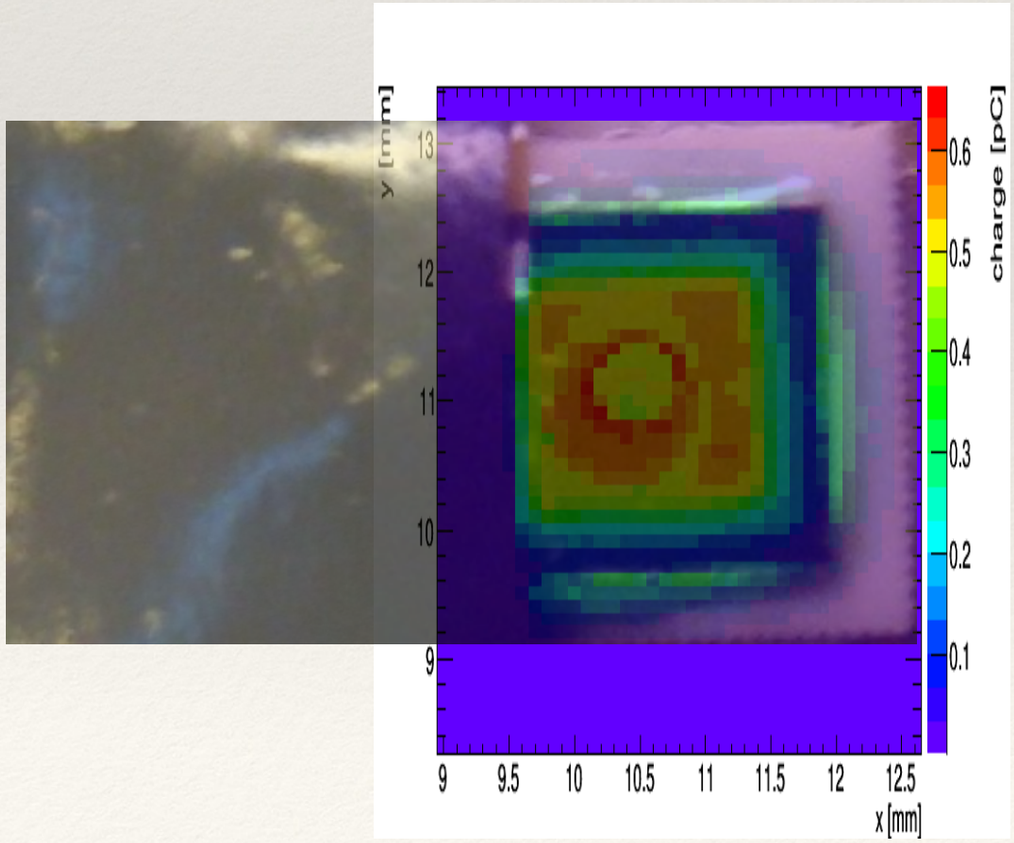
IR front @ 1700 V, 20°C



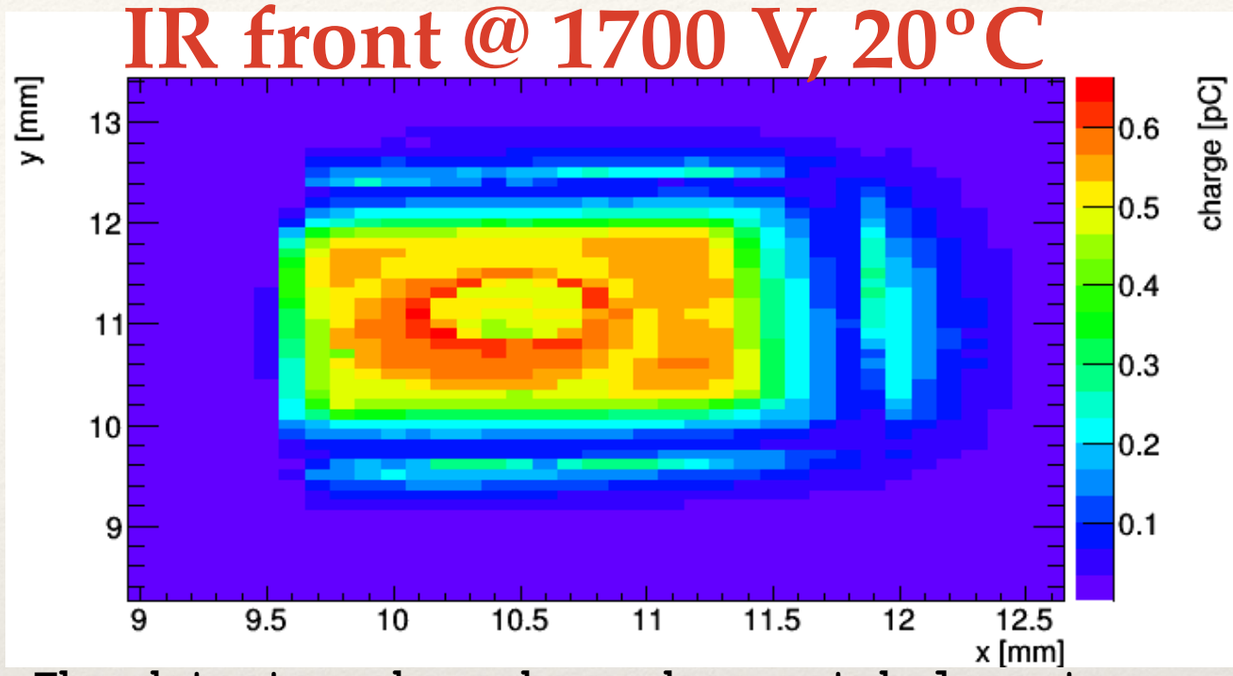
The detector shown here does not belong to the batch characterised in this presentation.

- The glue surrounding the sensor seems to be causing the laser to reflect and enter the Si even though the laser is not pointed towards it.
- This would explain the observed charge collection outside the active area of the sensor.

Charge collection outside the active area



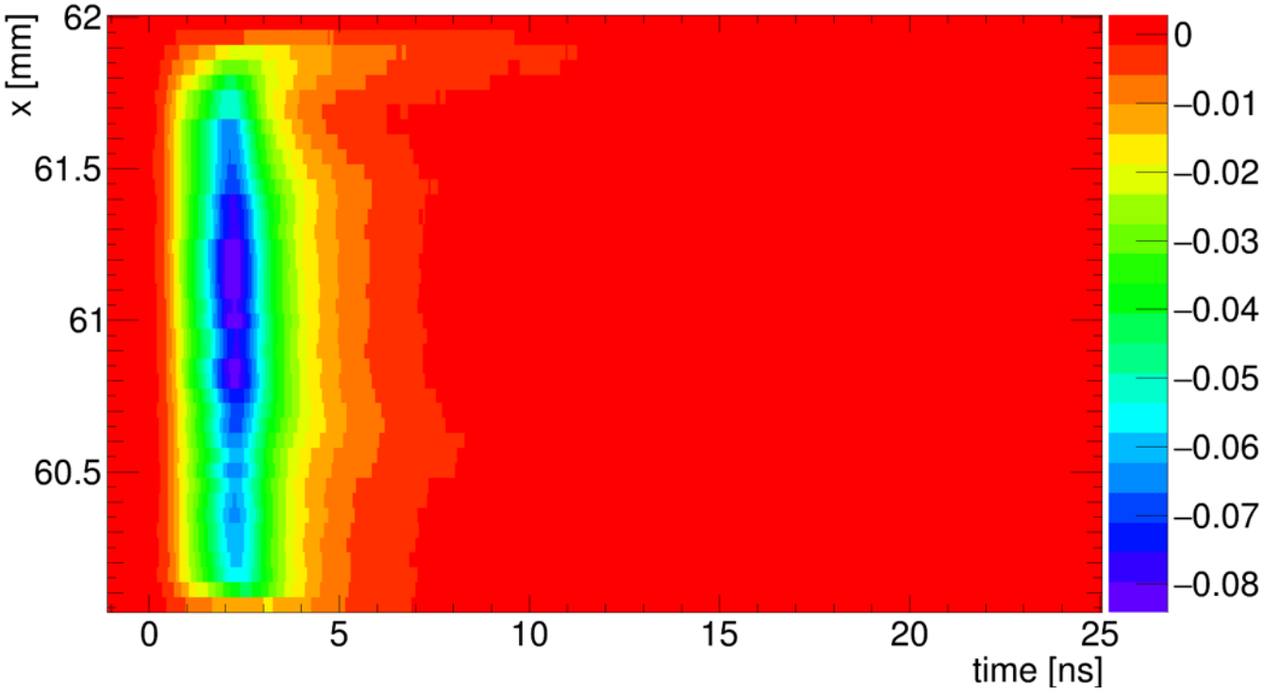
IR front @ 1700 V, 20°C

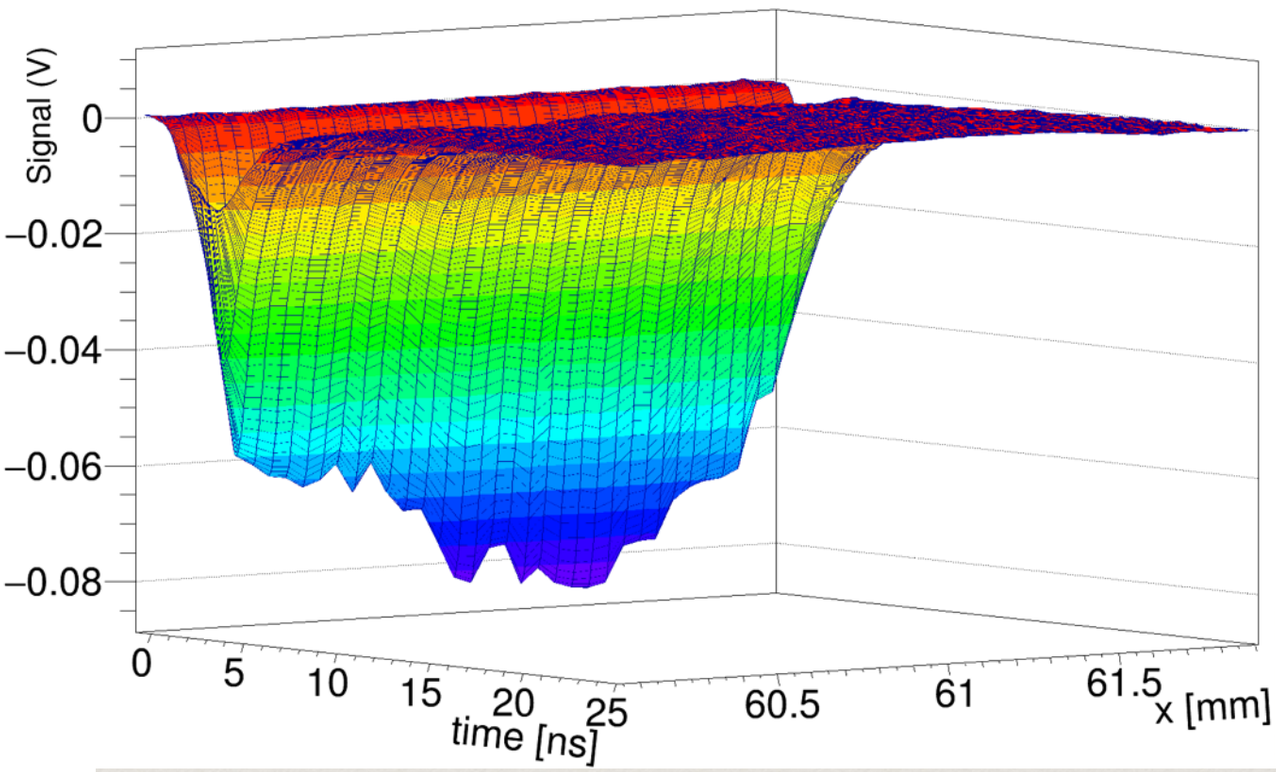


The detector shown here does not belong to the batch characterised in this presentation.

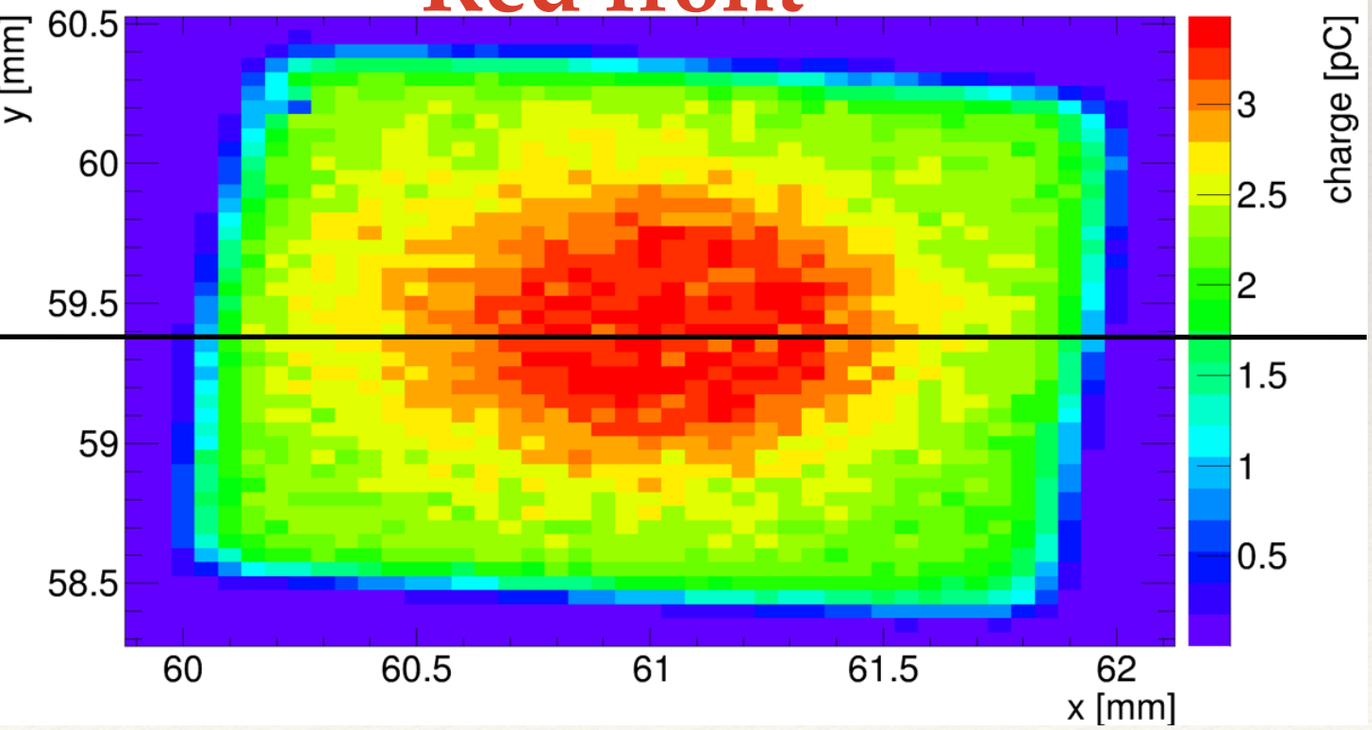
- We covered one of the sides of the sensor so that a portion of the glue would be concealed.
- A TCT scan was done and the corresponding odd charge collection area disappeared.
- We concluded that the abnormal charge collection areas served are due to the reflection the laser on the glue.

Red Scan Inhomogeneity





Red front



- Sample name: 394_1_3
- **Red front scan at 1700 V, -20°C**
- $\phi = 6\text{E}13\ \text{n}/\text{cm}^2$