TCT measurements on neutron and proton irradiated LGAD pad sensors

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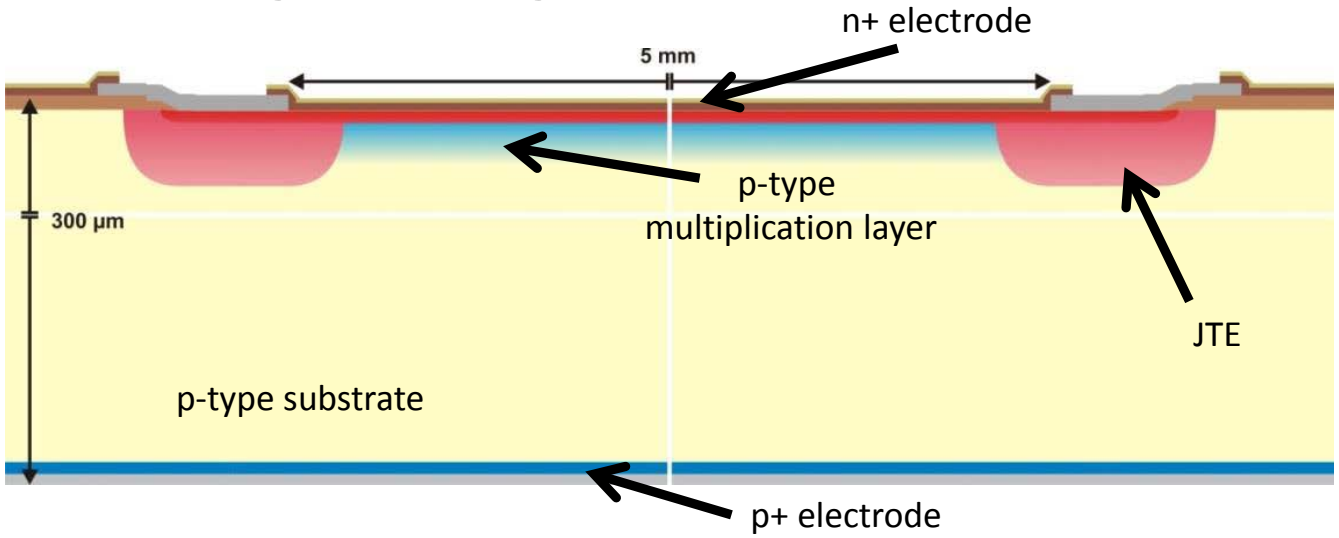
Outline

- LGAD Run 7062 “Virginia” 2014
- Homogeneity study with Red and IR TCT after proton and neutron irradiation from Run 7062
  - Integration time
  - Gain study
  - Radiation damage
- Preliminary measurements on Run 7859

- V. Greco – 24th RD50 meeting Bucharest
  Preliminary results on proton irradiated LGAD PAD detectors
- G. Kramberger – 25th RD50 meeting CERN
  Effects of irradiation on LGAD devices with high excess current

LGAD Run 7062 layout

- p-type pad sensor
  - p-type multiplication layer
  - Low doping n-well JTE (junction termination extensions)
  - 5mm x 5mm large active area
    - Window in the front and grid in the back for TCT characterization with red and IR LASER
  - No guard-ring structure



Run 7062 – 2014 “Virginia”

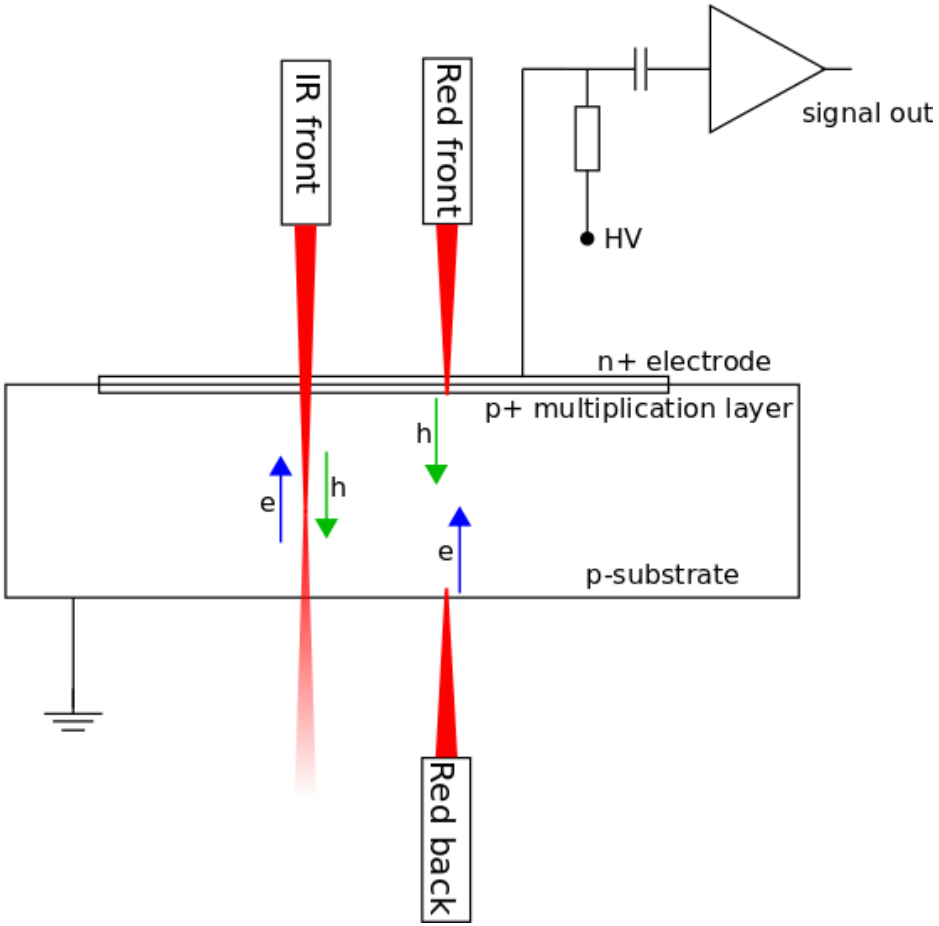
- High Resistivity p-type substrate
  - FZ; ρ>10kΩ·cm; <100>; thickness = 300±10µm

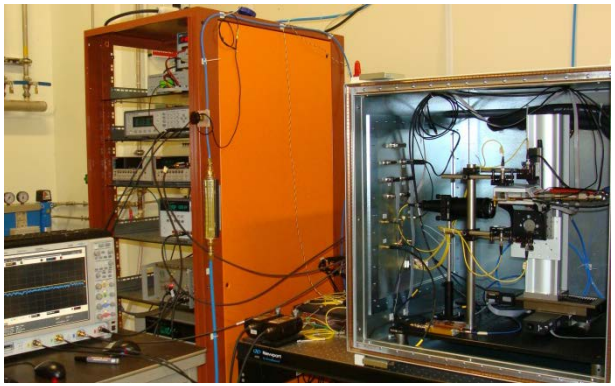
Wafer Number	P-Layer Implant E = 100keV	Expected Gain	Max. bias voltage
1 –2	$1.6\times10^{13}cm^{-2}$	2 – 3	> 1000V
3 – 4	$2.0\times10^{13}cm^{-2}$	8 – 10	~ 500V
5 – 6	$2.2\times10^{13}cm^{-2}$	15	---
7	PiN Wafer	no gain	> 1000V

- Proton irradiation – Los Alamos (800MeV)
  - 9.87E11n_{eq}/cm^2, 1.36E13n_{eq}/cm^2, 1.04E14n_{eq}/cm^2, 9.16E14n_{eq}/cm^2, 2.30E16n_{eq}/cm^2
- Neutron irradiation – Ljubljana (reactor neutrons)
  - 1E13n_{eq}/cm^2, 1E14n_{eq}/cm^2, 1E15n_{eq}/cm^2, 1E16n_{eq}/cm^2

TCT measurements setup

- Picosecond-pulsed LASER
  - Red (660nm)
  - IR (1064nm)
- Illumination
  - Front red and IR
  - Back red
- Bias voltage up to 1000V
- XYZ stages with 1µm step width
- Peltier-cooling down to -20C

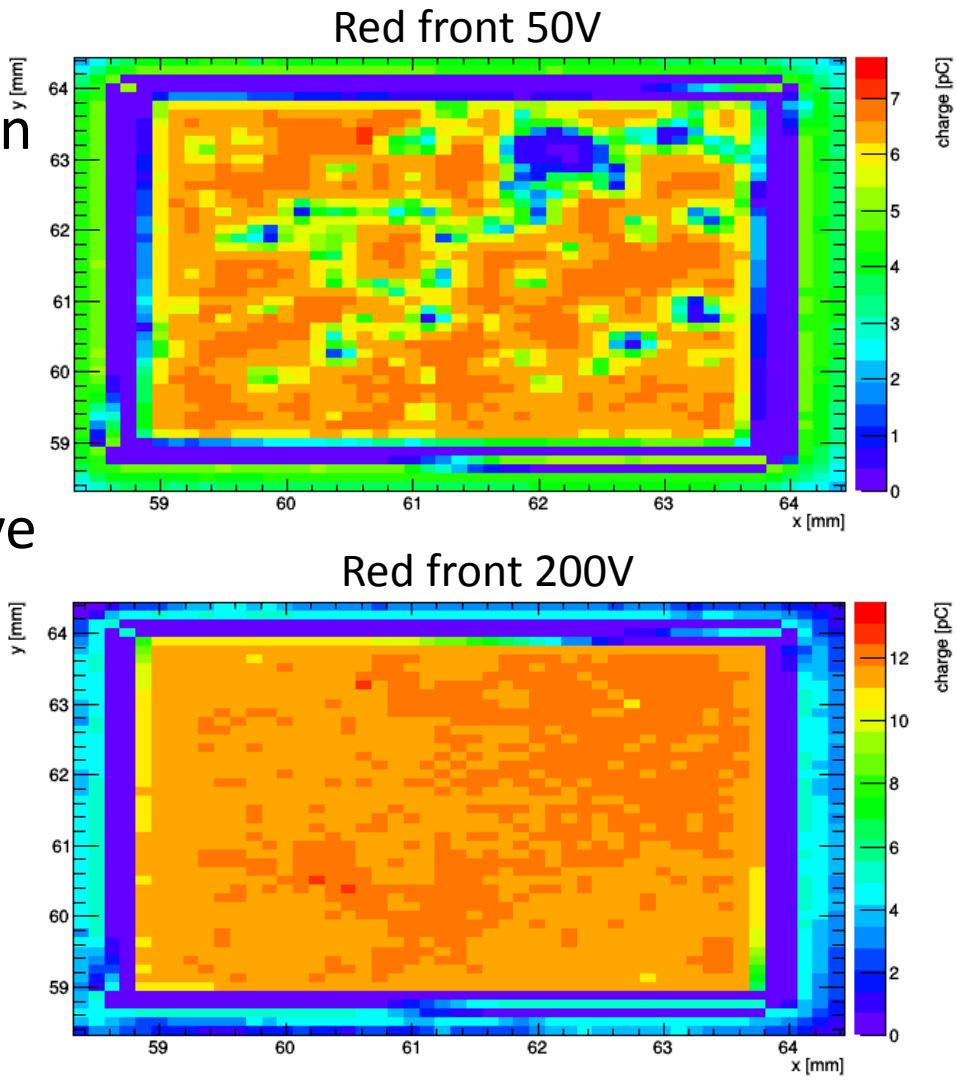




Homogeneity study before irradiation

Why perform a homogeneity study?

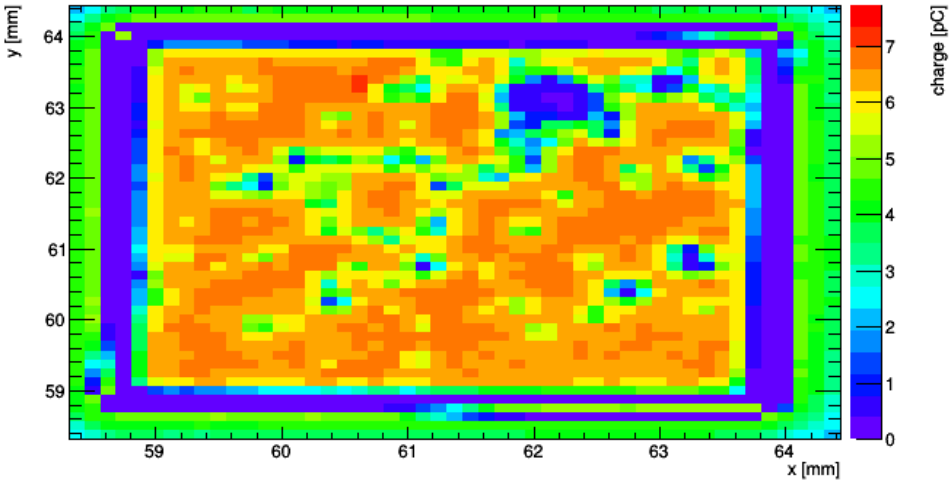
- Surface scans shows inhomogeneous charge collection below full depletion
  - Residues on the surface?
  - Fluctuations in the laser intensity?
  - Inhomogene multiplication layer?
- Inhomogeneities disappear above full depletion
- Solution
  - Select a higher operation voltage!



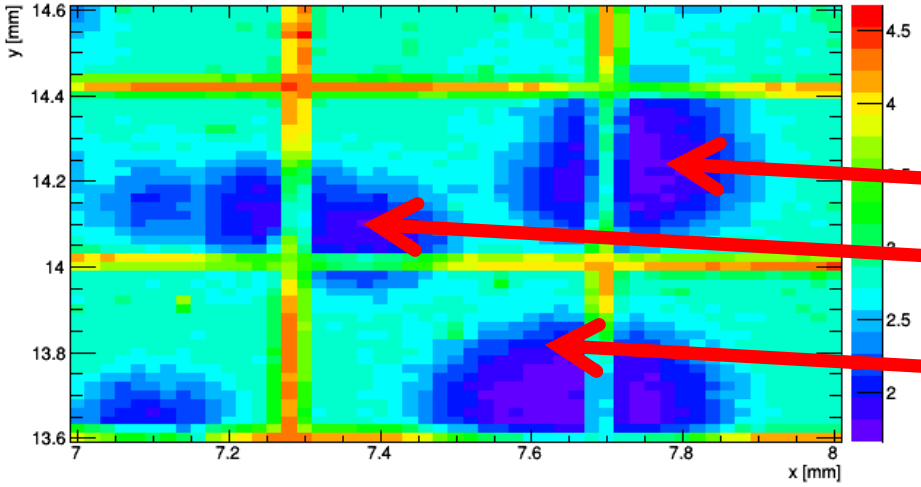
What is going on before irradiation?

- Inhomogeneous charge collection appears for Red front and back as well as IR front
  - Not only a surface effect
  - Same pattern for IR and Red back
- How does this happen?
  - Let's have a look at the signals!

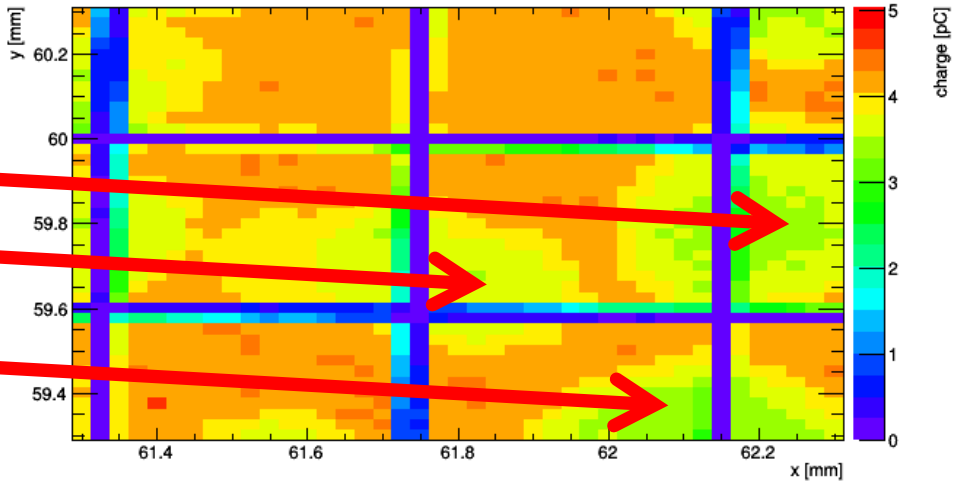
Red front 50V



IR front 50V



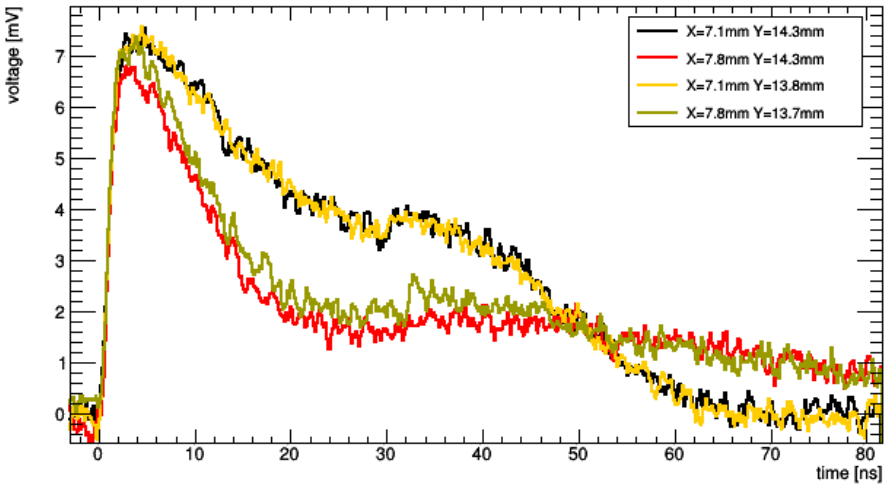
Red back 50V



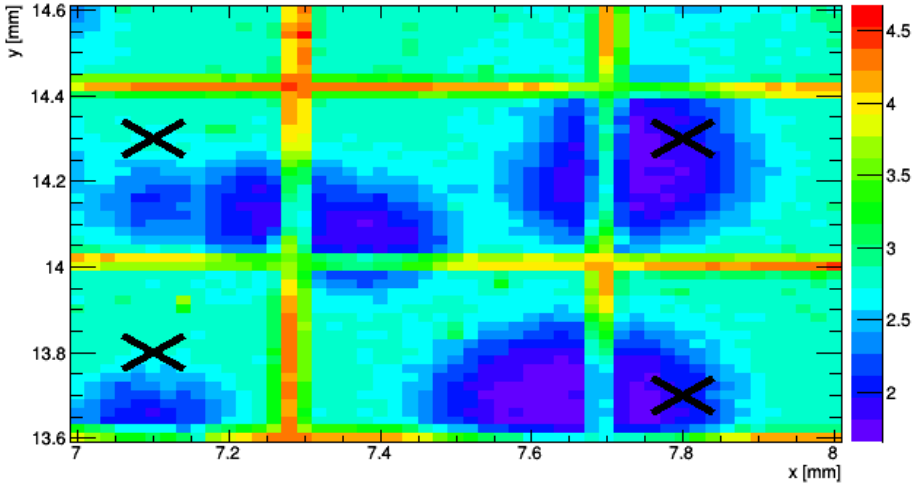
Signal shape before irradiation

- Waveform below full depletion extends more than three times the typical integration time of 25ns
- Inhomogeneities disappear above full depletion at about 100V
  - Waveform length about 25ns
- All that because it is not fully depleted?

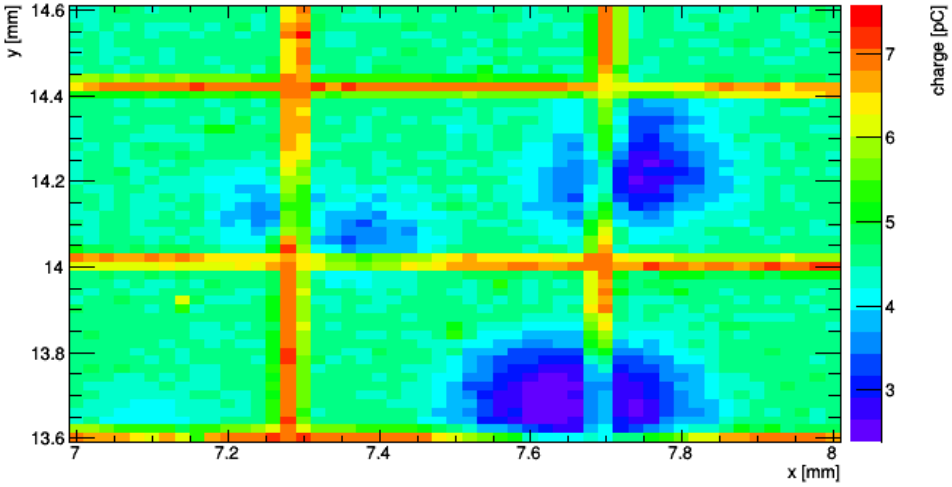
IR front 50V



IR front 50V 25ns integration time



IR front 50V 75ns integration time

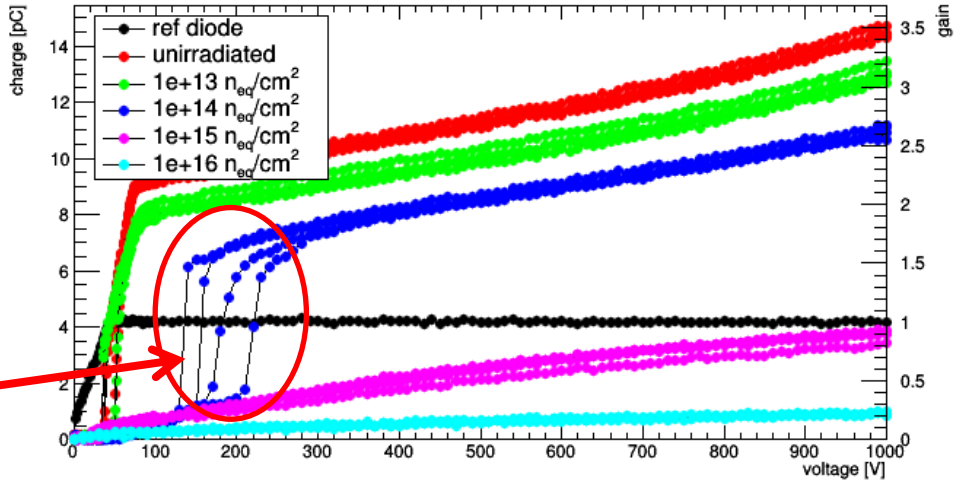


Charge Collection and Gain

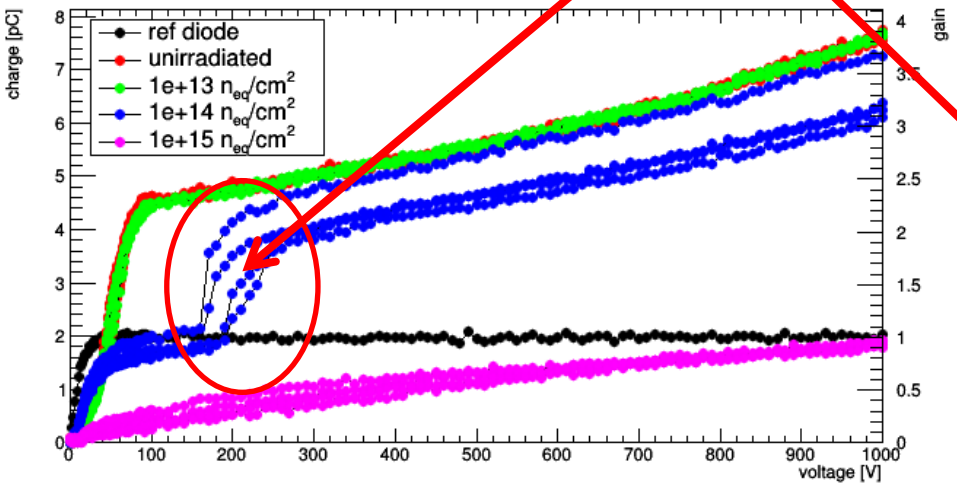
Neutron Irradiation

- Injected charge corresponds to about 10MIPs
- Gain decreases with fluence
  - 1E15: gain is about 1
- What is happening at 1E14?
  - Avalanche variation
  - Charge/Gain offset

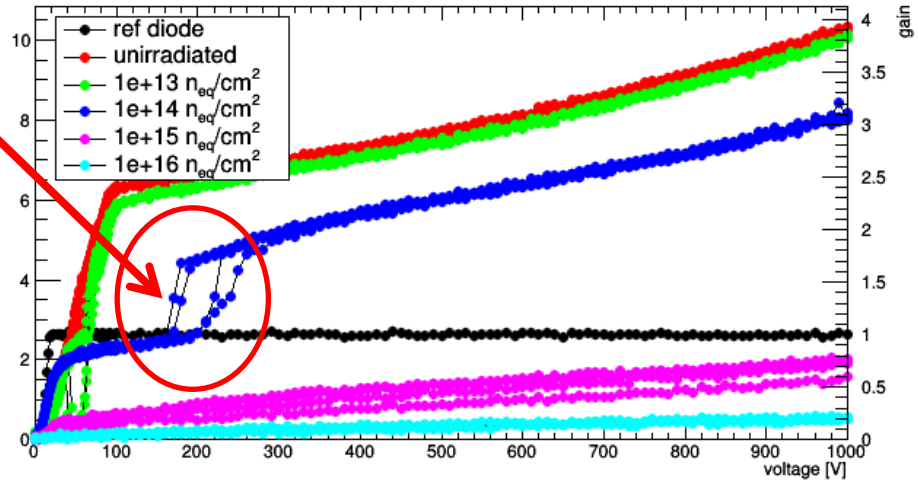
Red front



IR front



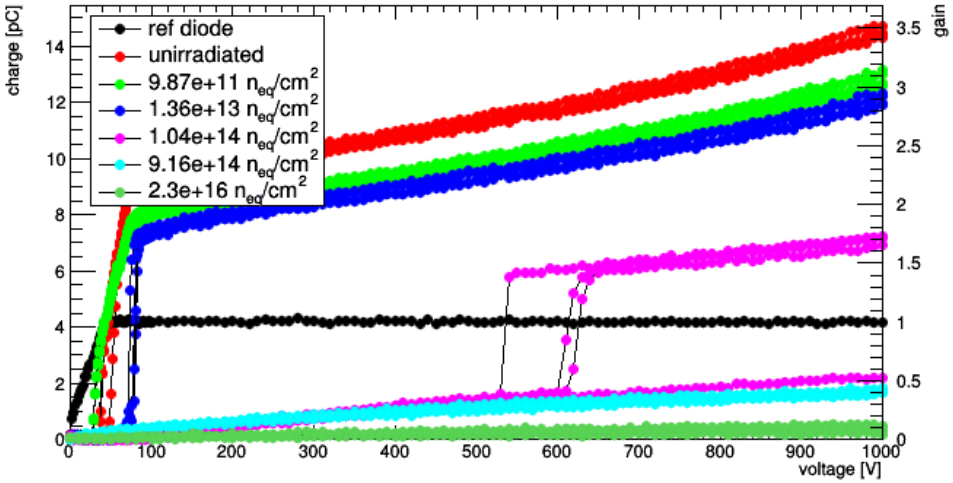
Red back



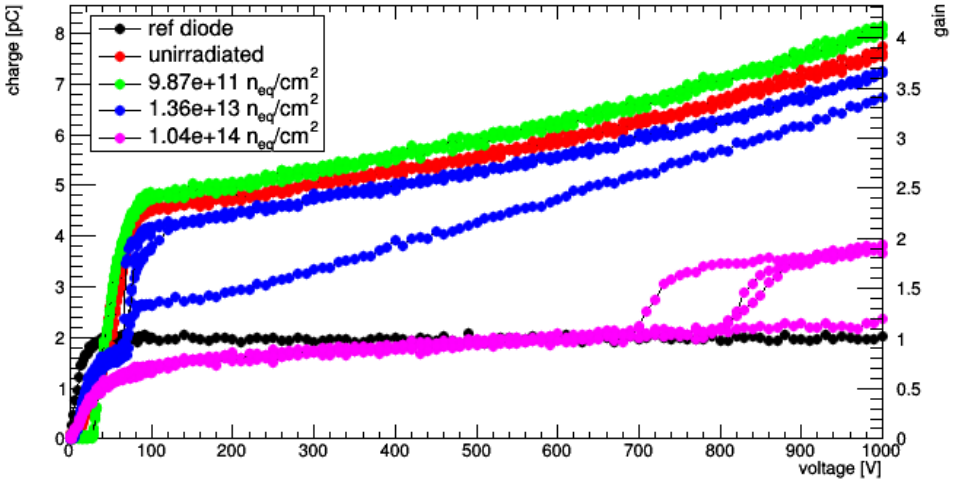
Proton Irradiation

- 1.36E13
  - Low amplification in one measurement point
  - Does not recover till 1000V
- 1.04E14
  - Avalanche variation
  - No avalanche in one measurement point

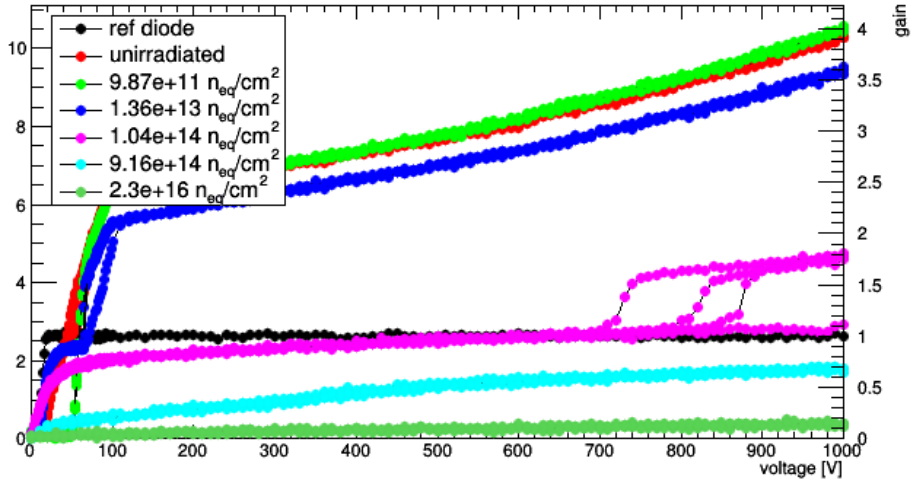
Red front



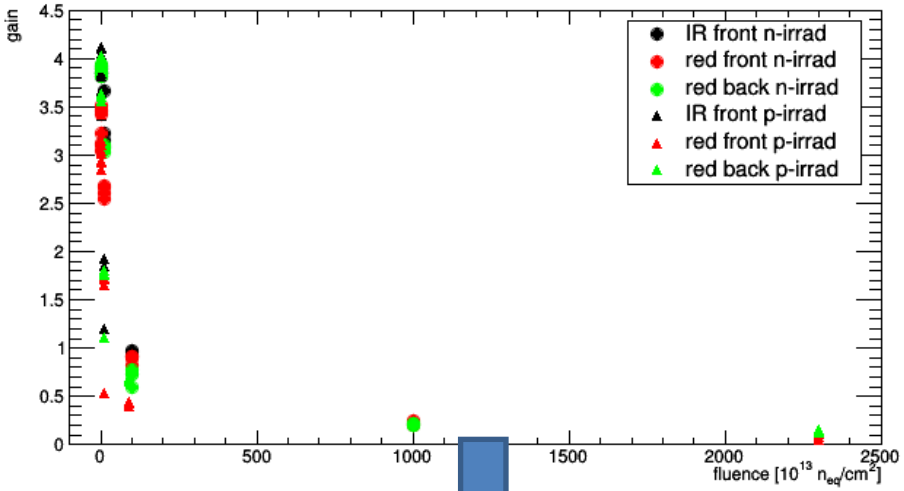
IR front



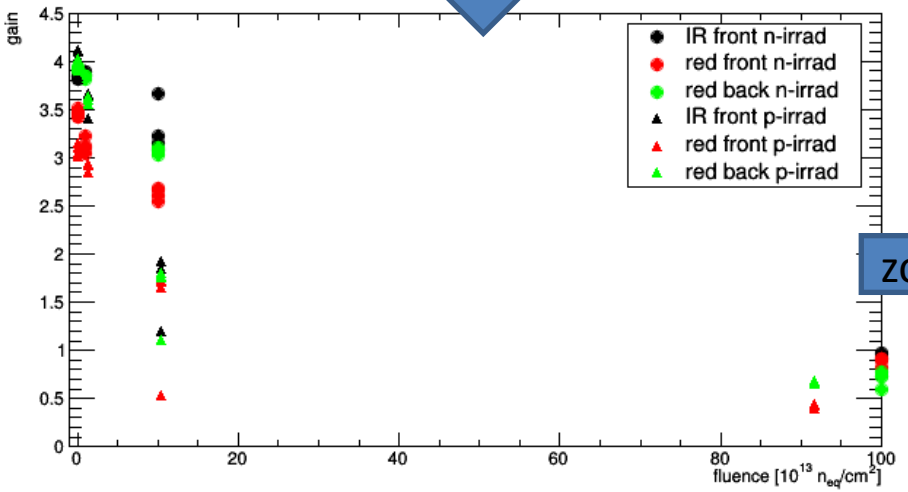
Red back



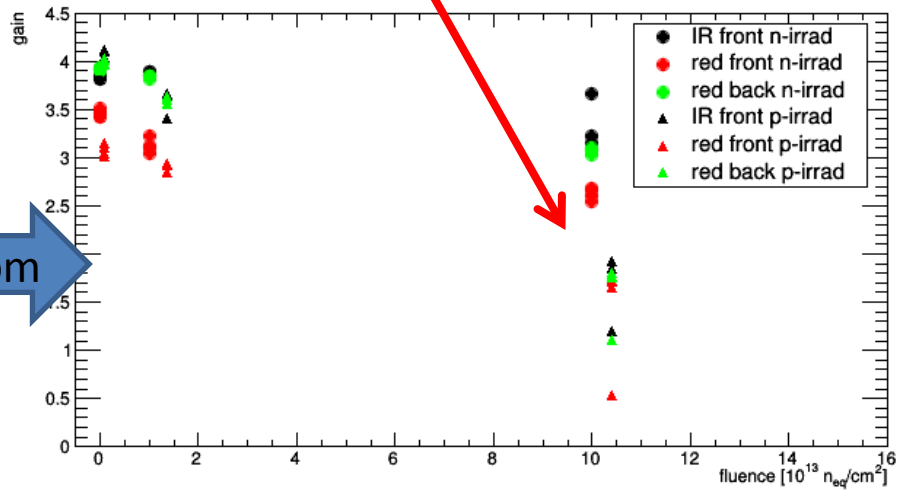
Gain vs. Fluence



zoom



zoom



- Gain at 1000V used for comparison
- Gain about 4 before irradiation
- Gain = 1 between 1E14 and 1E15
- Gain variation in the range of 1E14

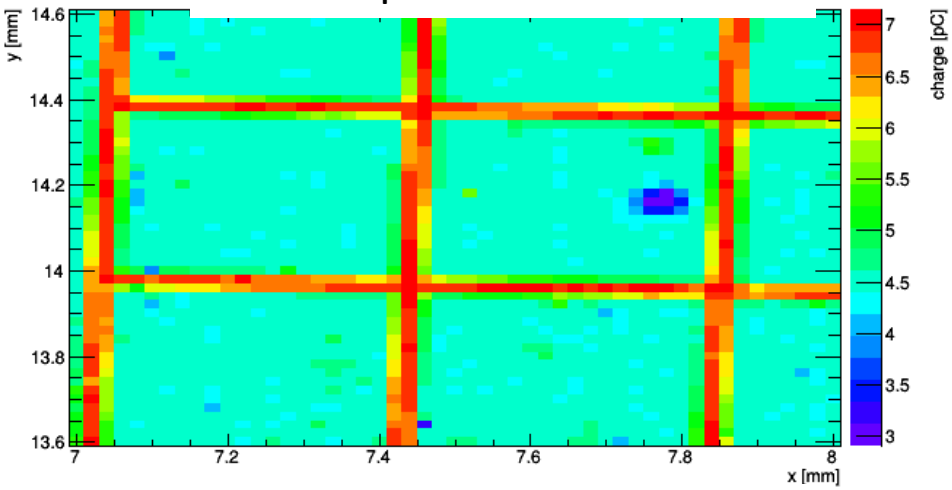
“special” Samples

Fluence of about 1E14n_{eq}

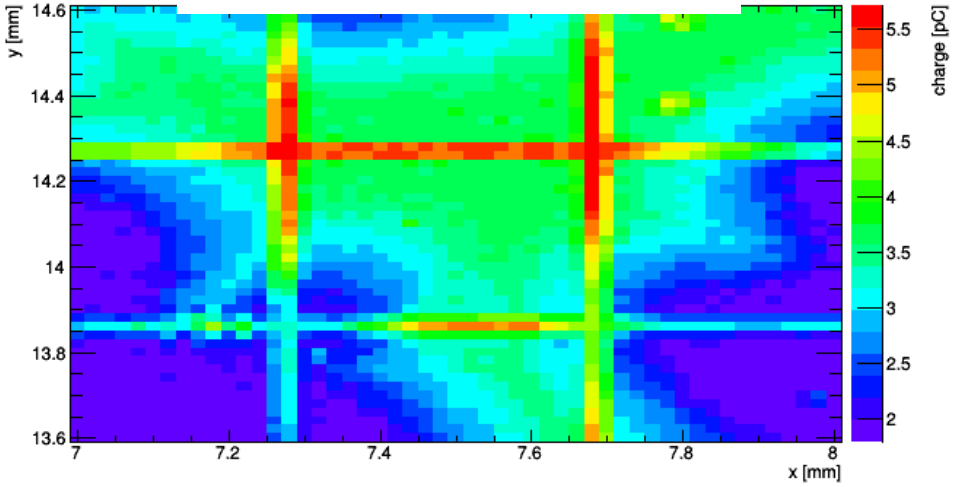
What is happening at 1E14?

- inhomogeneous charge collection up to 1000V
- What about the signals?

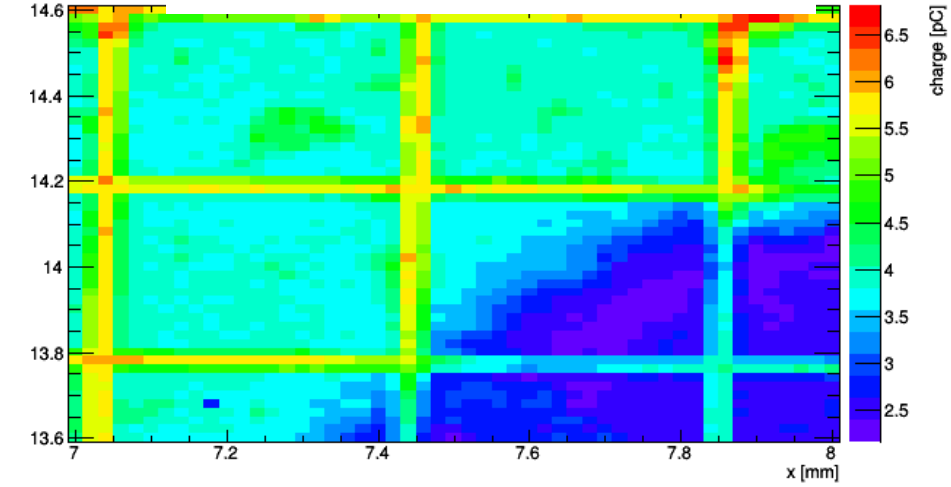
IR front: p-irrad 1.36E13 200V



IR front: n-irrad 1E14 200V



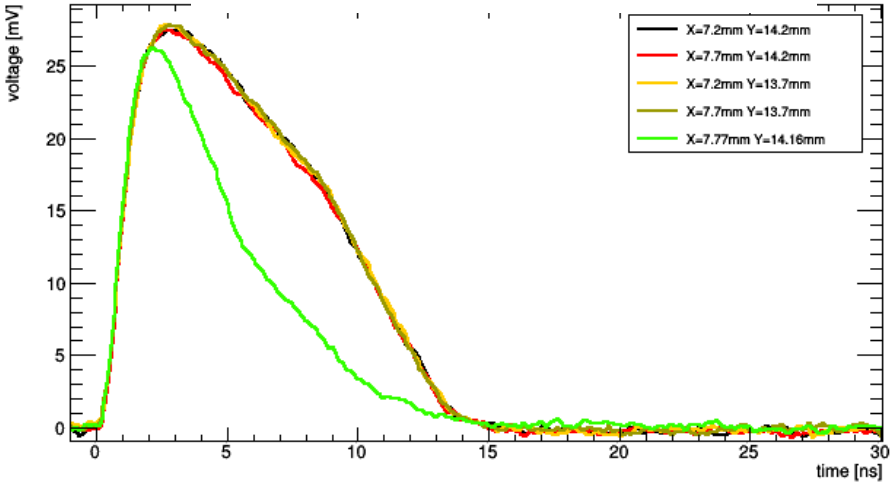
IR front: p-irrad 1.04E14 1000V



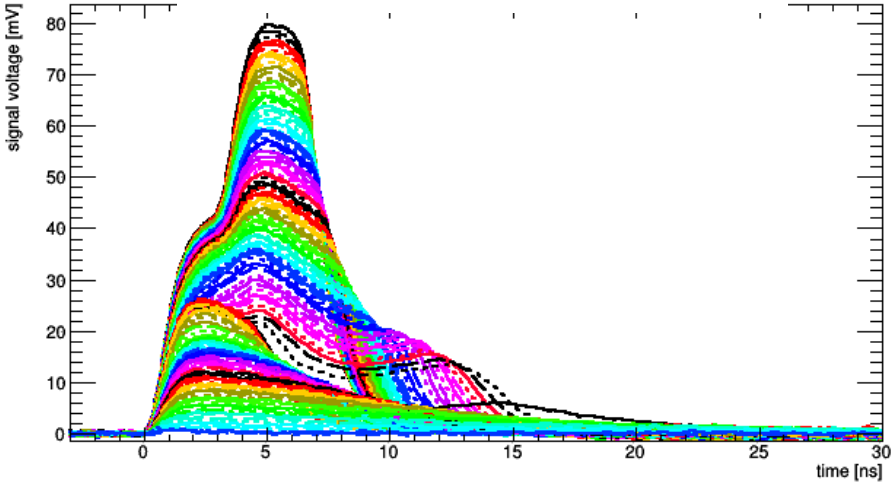
Signals at 1E14

- Signal shape varies depending on the sample position for IR
- Field variation for samples with high leakage current proposed by G. Kramberger (25th RD50 meeting) becomes visible for Red front and back illumination

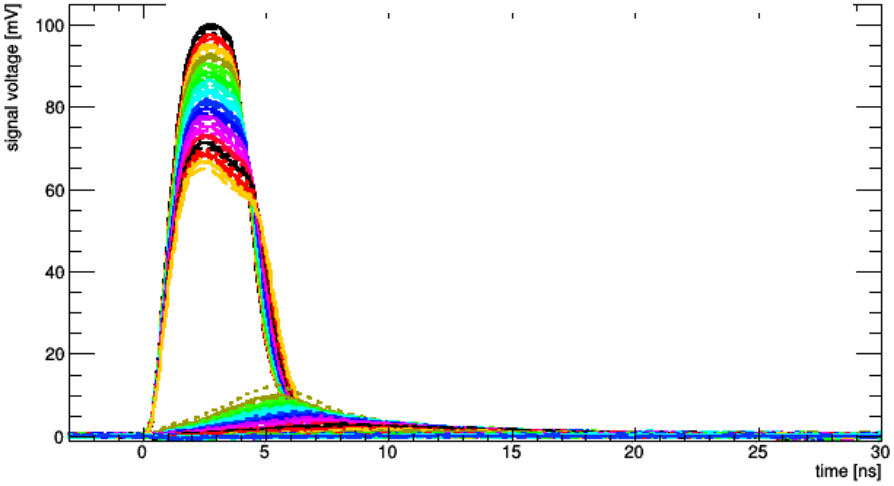
IR front: p-irrad 1.36E13 200V



Red back: n-irrad 1E14 200V



Red front: p-irrad 1.04E14 1000V

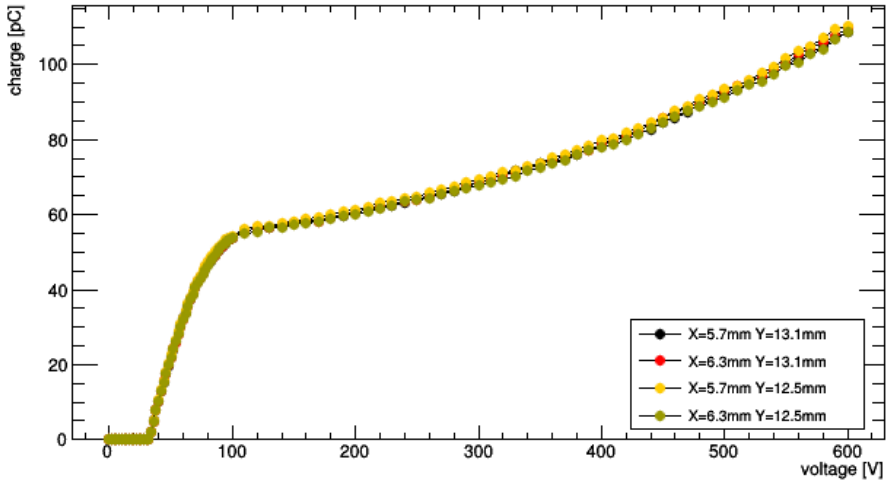


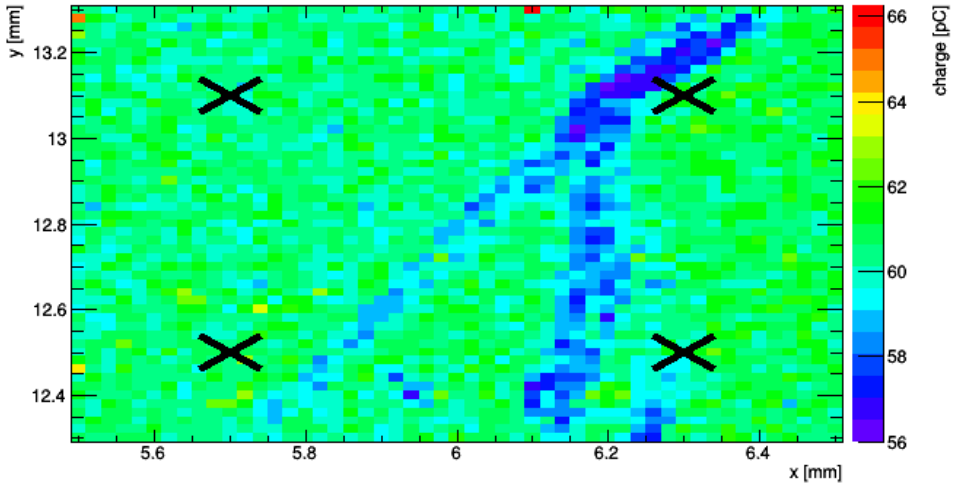
Homogeneity in other LGAD runs

Run 7859

Run 7859: IR front W3-F7

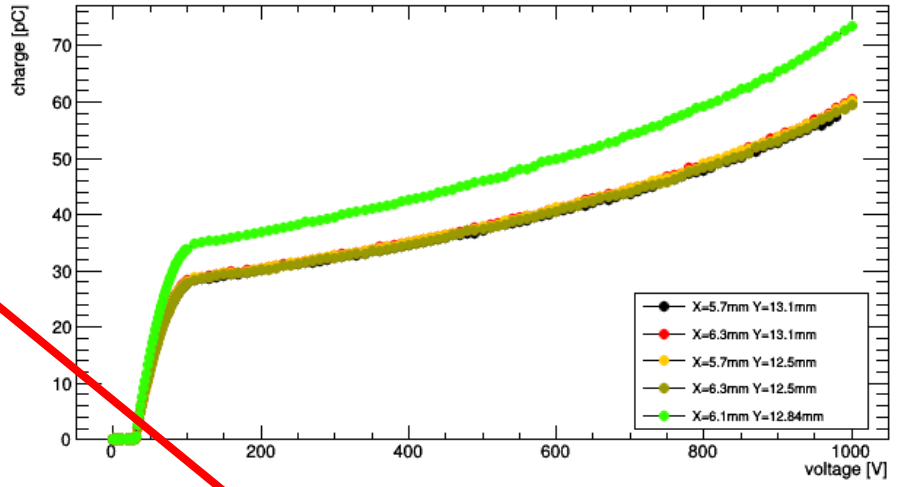
- Yes, there is a structure!
  - Finally a real scratch



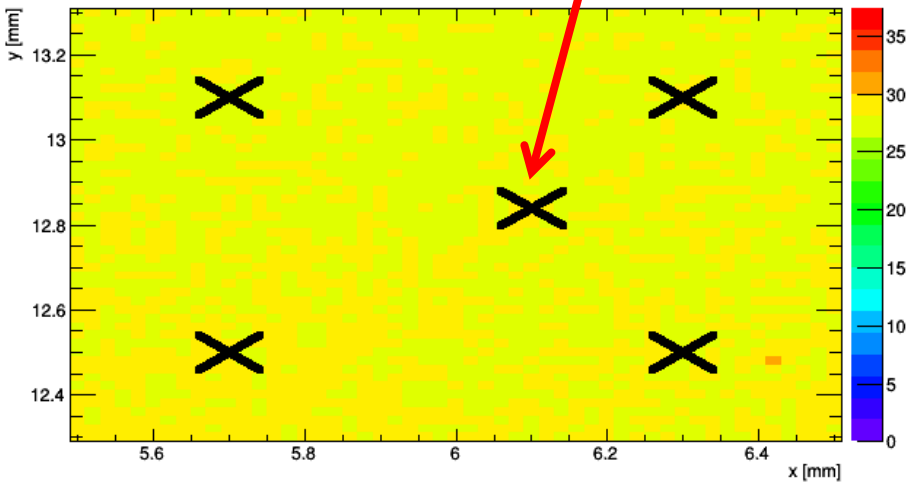


Run 7859: IR front W2-I5

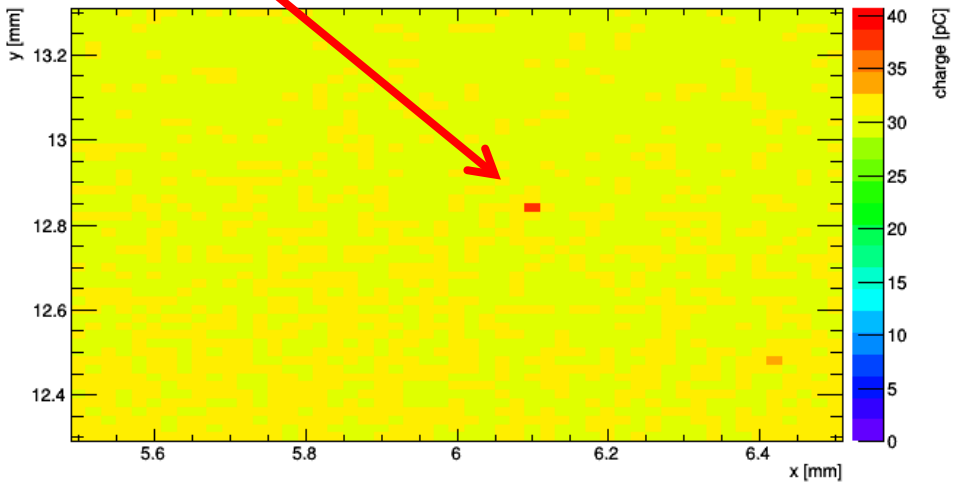
- 20µm x 20µm region with about 20% higher charge
  - This can't be noise
- Red back shows similar results
  - More detailed measurements are needed



IR front 100V



IR front 200V



Conclusion

- Homogeneity study on LGAD pad sensors from run 7062 with Red and IR TCT
  - Measurements after proton and neutron irradiation
  - Charge/Gain development
    - Late avalanche
    - Charge offset
  - Gain vs. Fluence
    - Gain decrease from about 4 before irradiation to 1 between 1E14 and 1E15
  - Inhomogeneous regions with different patterns
    - Signal development expected for samples with high leakage current
- Preliminary measurements on unirradiated pad sensors from Run 7859

Thank you for your attention!