# Preliminary Results of Measurements on Proton Irradiated LGAD-PAD Detectors

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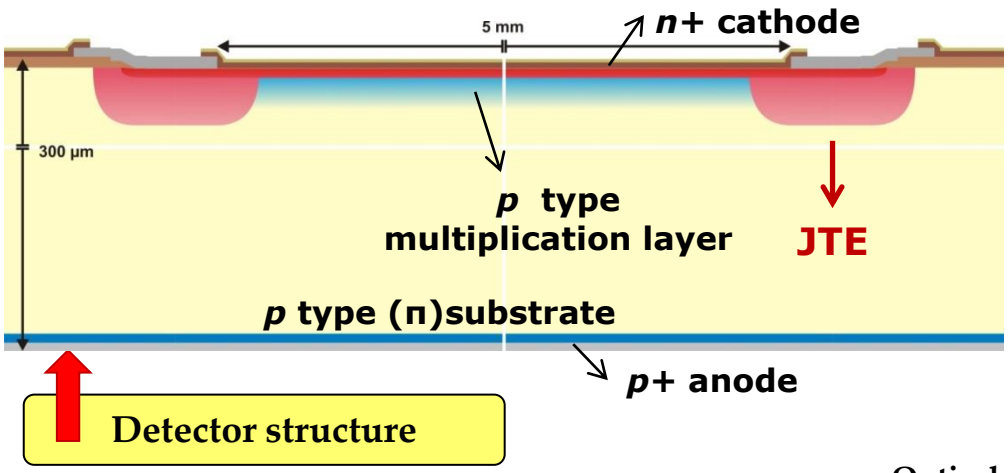
CSIC
Consejo Superior de Investigaciones Científicas

# Talk Outline

- **LGAD devices** (Run7062_LGAD_PAD)
- **Laser TCT** measurements of non-irradiated LGAD diodes
- Preliminary measurements of **proton irradiated** LGAD diodes

# LGAD Detectors

**LGAD = Low Gain Avalanche Diode**

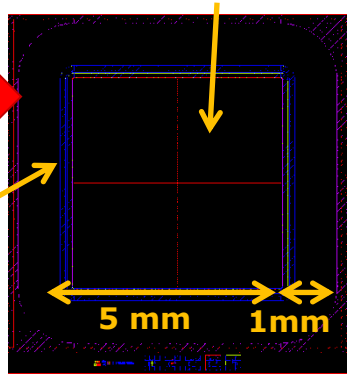


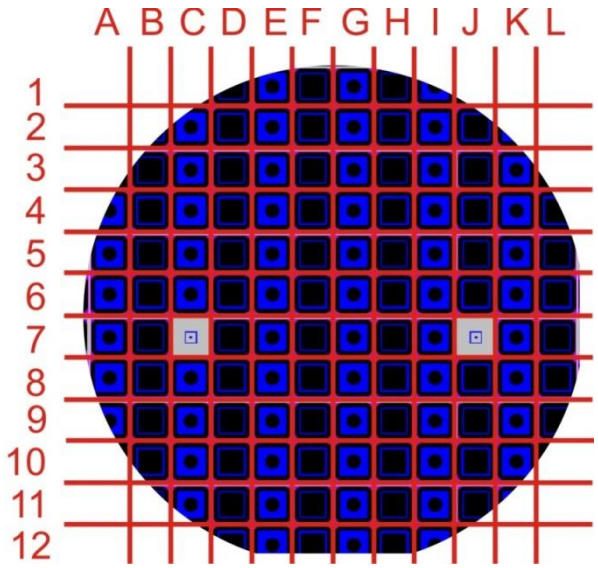

Detector structure

- p-type diode
- p-type multiplication layer
- Low doping n-well JTE (junction termination extensions)

- 5mm x 5mm large active area
- Window in the cathode metallization for laser characterization

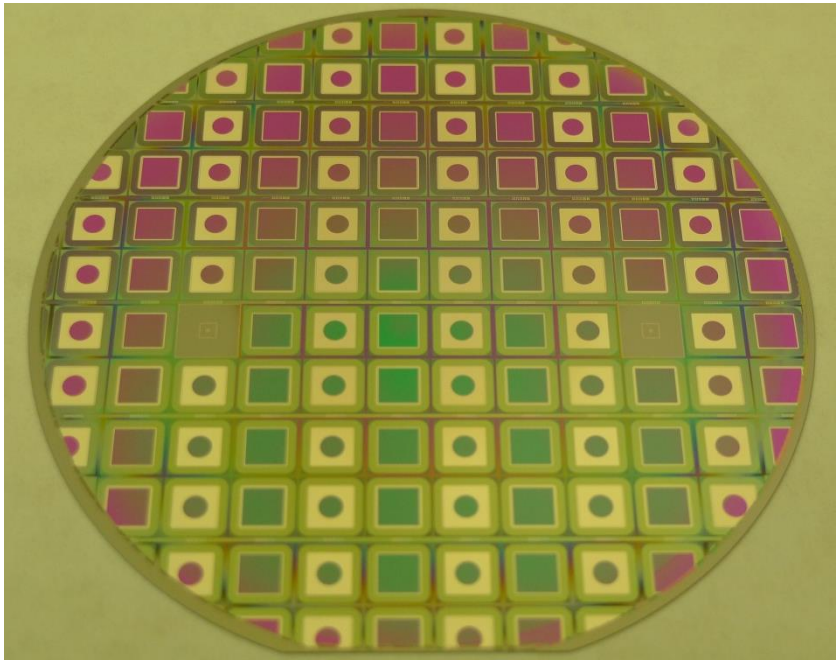
Single LGAD layout



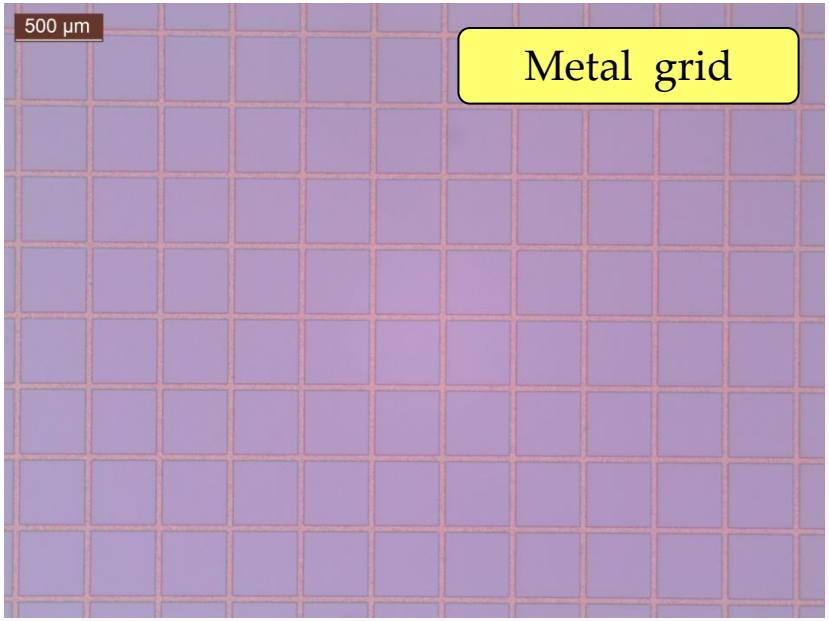

Mask layout

# LGAD Detectors



**Front** view of the wafer

**Back** view
of **one LGAD detector**



# LGAD Fabrication Runs

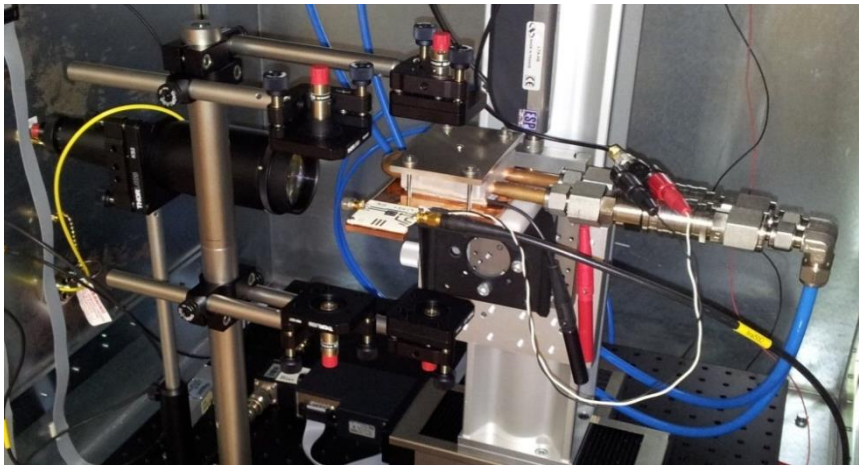
- Various fabrication runs to improve the characteristics of the LGAD devices.
  - Latest run → **Run7062**
    - High resistivity p-type substrate; 300µm thick;
    - 3 couples of wafers with increasing p-layer doping
    - A PiN wafer for reference

| Wafer Number | P-layer Implant (E = 100 keV) | Substrate features | Expected Gain |
|---|---|---|---|
| 1-2 | 1.6 × $10^{13}$ $cm^{-2}$ | HRP 300 (FZ; ρ>10 KΩ·cm; <100>; T = 300±10 µm) | 2 – 3 |
| 3-4 | 2.0 × $10^{13}$ $cm^{-2}$ | HRP 300 (FZ; ρ>10 KΩ·cm; <100>; T = 300±10 µm) | 8 – 10 |
| 5-6 | 2.2 × $10^{13}$ $cm^{-2}$ | HRP 300 (FZ; ρ>10 KΩ·cm; <100>; T = 300±10 µm) | 15 |
| 7 | (---) PiN Wafer | HRP 300 (FZ; ρ>10 KΩ·cm; <100>; T = 300±10 µm) | No Gain |

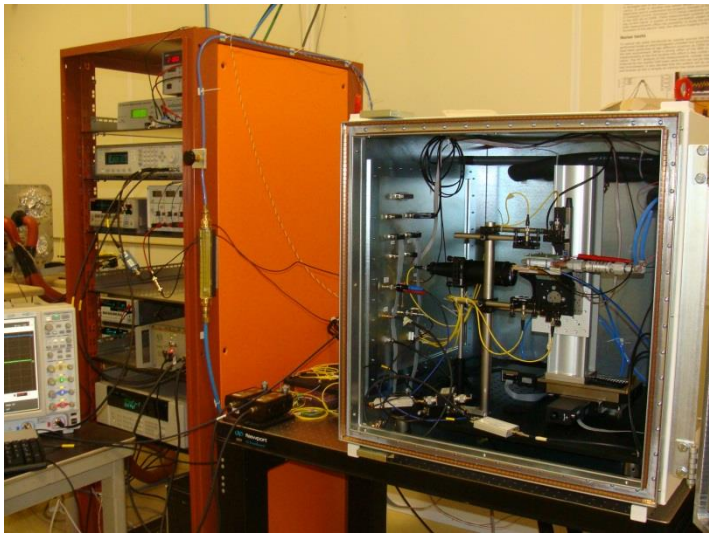
# Laser TCT Measurements of Non-Irradiated LGAD diodes

# Laser TCT Measurements - Setup

Laser TCT measurements performed at **CERN**
Setup described in:
Christian Gallrapp et al., *TCT, eTCT and I-DLTS measurement setups at the CERN SSD Lab*

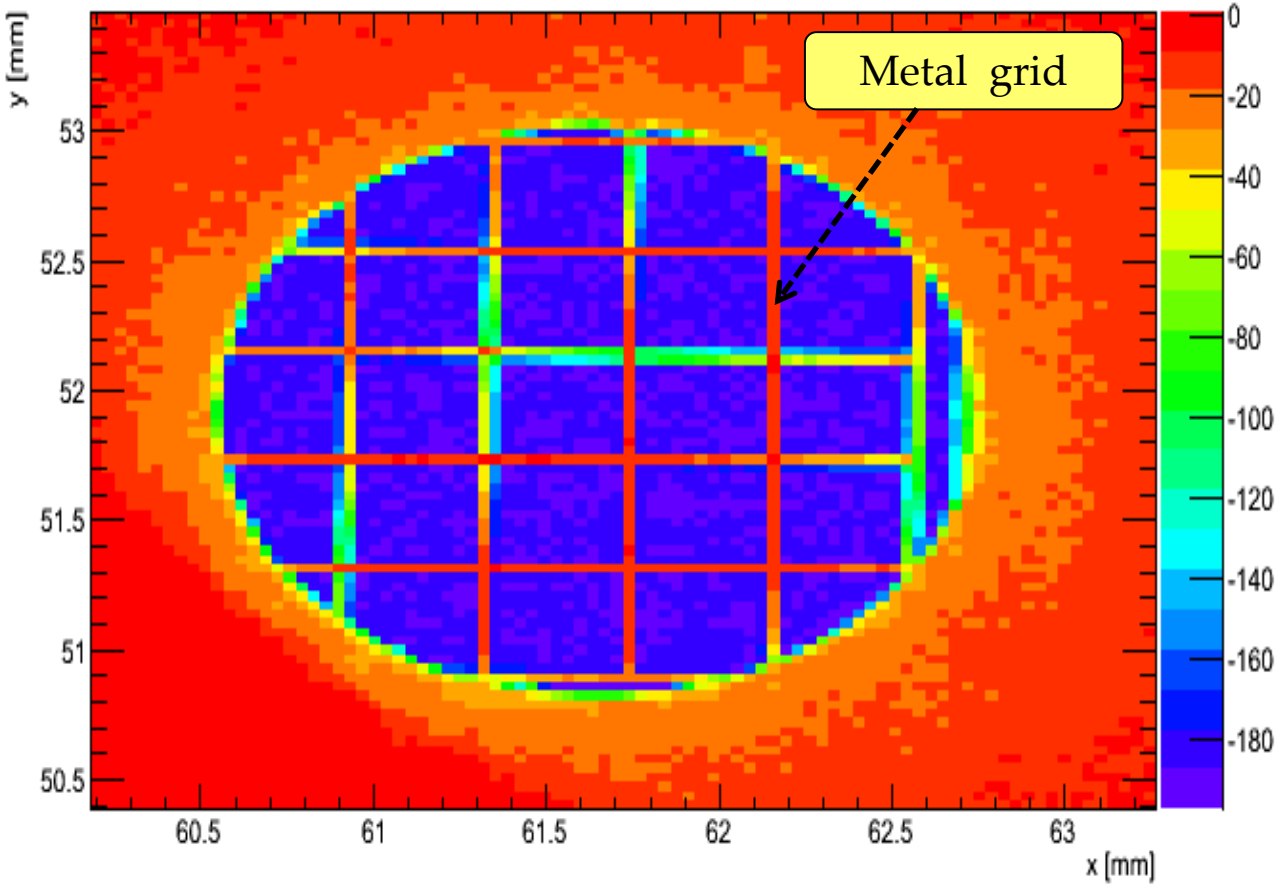


- Equipment
  - Picosecond-pulsed LASER
    - **Red** (660nm)
    - **IR** (1064nm)
  - Optics for illumination
    - **Top** red and IR
    - **Bottom** red and IR
  - Bias voltage up to 1000V
  - XYZ stages with µm step width
- LabView based software to loop parameters
  - temperature, bias voltage, position and repetition



# Laser TCT Measurements

## Laser TCT surface scan → Red Laser – Back Side



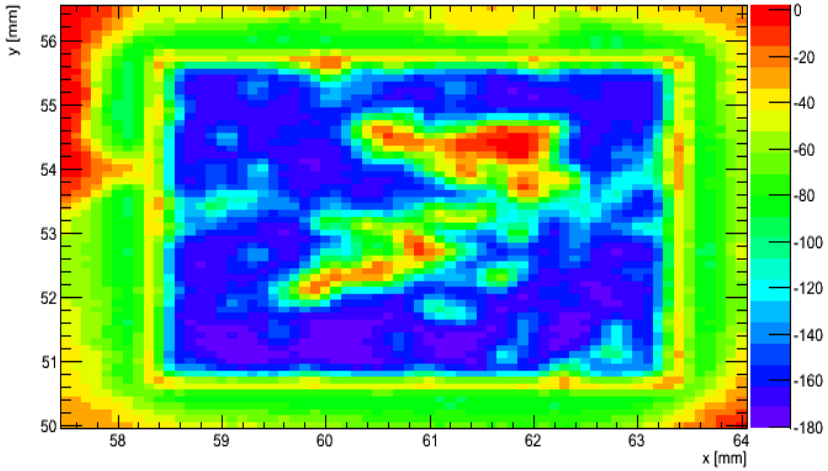

Illumination from the **back side** through a circular hole in the PCB

**75µm steps**

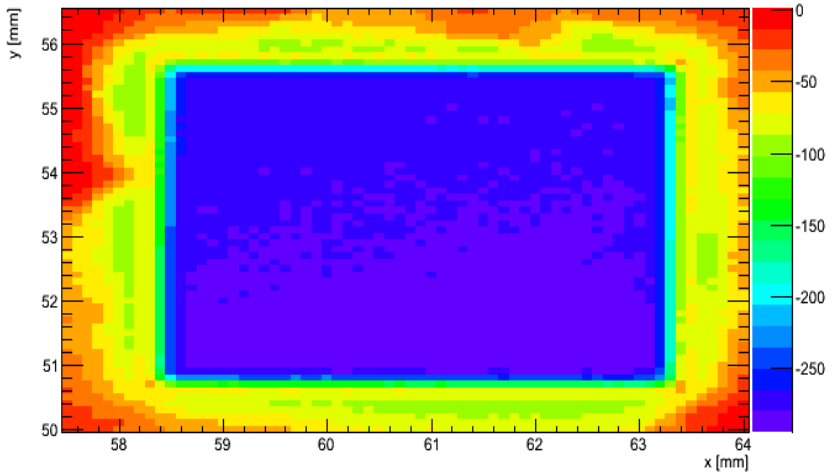
**150V**
**-20ºC**

# Laser TCT Measurements

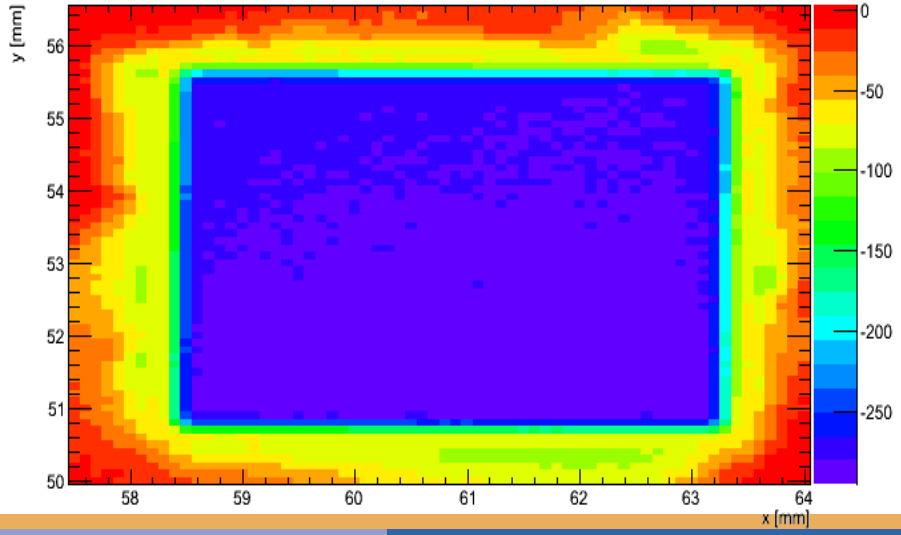
## Laser TCT surface scan → Red Laser – Front Side




50V




100V

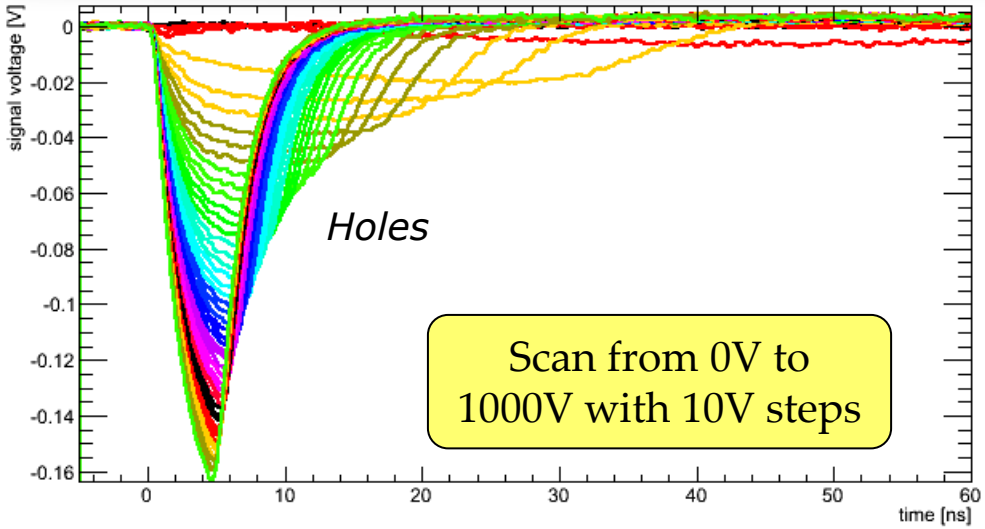


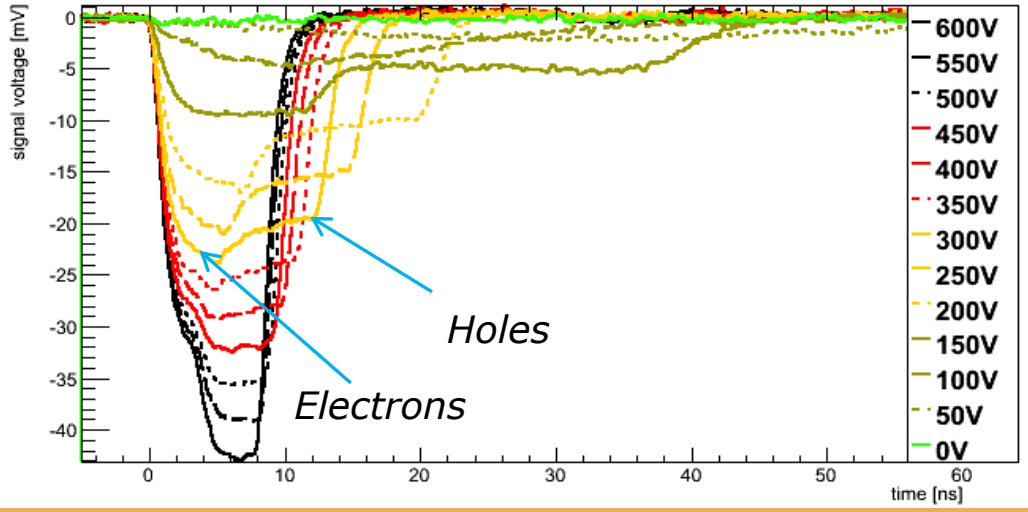

150V

Illumination from the **front side**

T = -20ºC

# Laser TCT Measurements




**Laser TCT Voltage Scan**
**→ Red Laser**

Illumination from the
**front side**
almost in the centre

Illumination from the
**back side**
almost in the centre

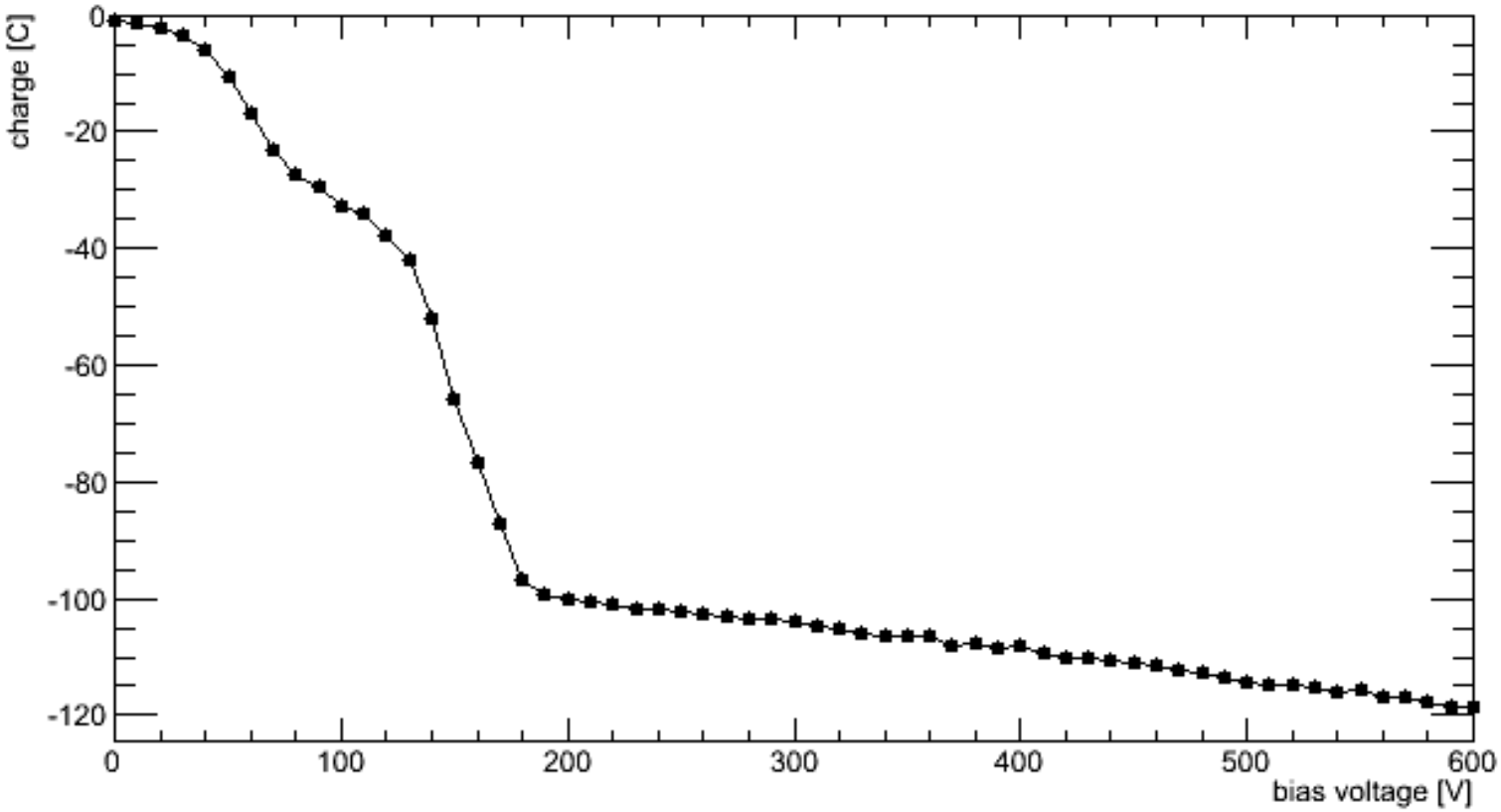
Scan from 0V to 600V
with 50V steps

# Laser TCT Measurements

**Collected Charge** as a function of reverse bias voltage

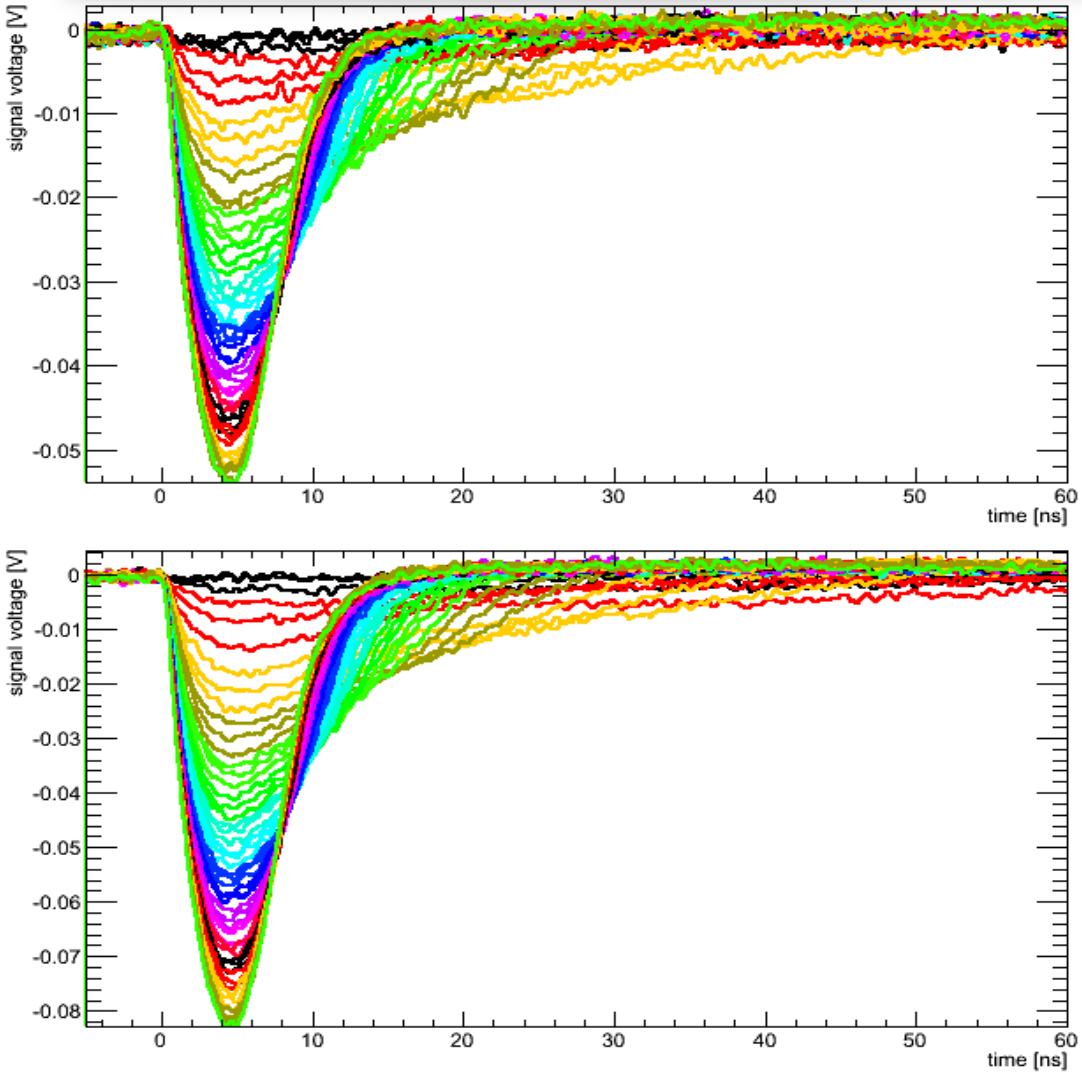
**Red Laser**

Illumination from the **back side**




Charge integrated over **25ns**

# Laser TCT Measurements




**Laser TCT Voltage Scan**

→ **Infra-Red Laser**

Illumination from the **front side** almost in the centre

Scan from 0V to 1000V with 10V steps

Illumination from the **back side** almost in the centre

# Preliminary Measurements of Proton Irradiated LGAD diodes

# Proton Irradiation

- Irradiation with **protons** in Los Alamos

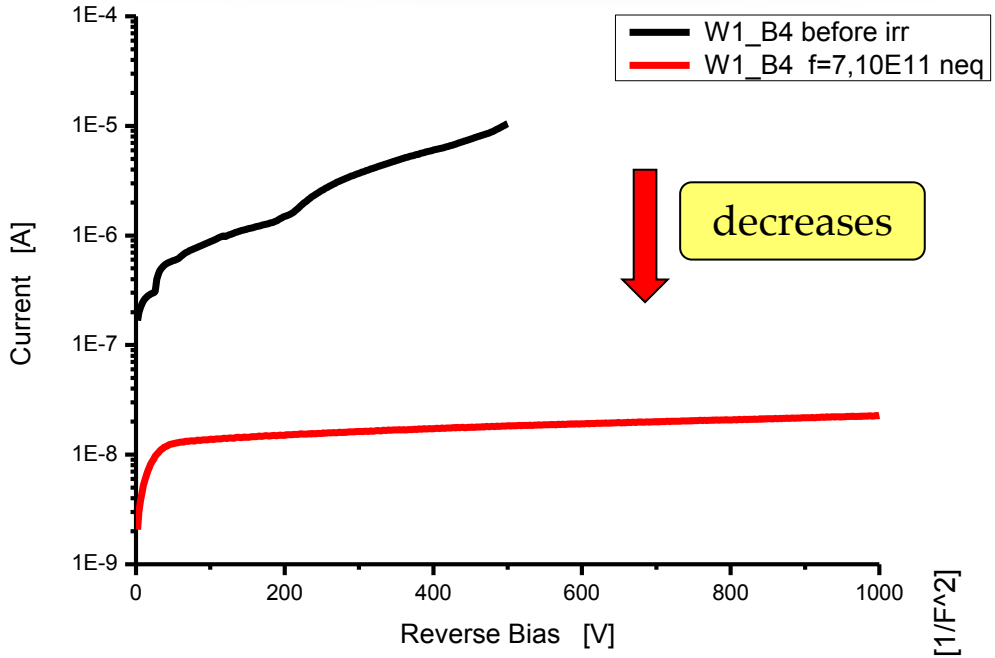
| Device | Run | Type | Features | Requested Dose [p/cm^2] | Requested Dose [neq/cm^2] |
|---|---|---|---|---|---|
| W1_A7 | 7062 | LGAD | SC | 1,00E+12 | 7,10E+11 |
| W1_B4 | 7062 | LGAD | DR | 1,00E+12 | 7,10E+11 |
| W9_C3 | 6474 | PIN | SC | 1,00E+12 | 7,10E+11 |
| W1_B6 | 7062 | LGAD | DR | 1,20E+13 | 8,52E+12 |
| W1_B7 | 7062 | LGAD | SR | 1,20E+13 | 8,52E+12 |
| W9_C5 | 6474 | PIN | SC | 1,20E+13 | 8,52E+12 |
| W1_B9 | 7062 | LGAD | SR | 1,50E+14 | 1,07E+14 |
| W1_C4 | 7062 | LGAD | DC | 1,50E+14 | 1,07E+14 |
| W9_D3 | 6474 | PIN | SR | 1,50E+14 | 1,07E+14 |
| W1_C6 | 7062 | LGAD | DC | 1,80E+15 | 1,28E+15 |
| W1_C8 | 7062 | LGAD | DC | 1,80E+15 | 1,28E+15 |
| W9_C8 | 6474 | PIN | DC | 1,80E+15 | 1,28E+15 |
| W1_A6 | 7062 | LGAD | DC | 3,00E+16 | 2,13E+16 |
| W1_D2 | 7062 | LGAD | DR | 3,00E+16 | 2,13E+16 |
| W9_D4 | 6474 | PIN | DR | 3,00E+16 | 2,13E+16 |

Conversion factor (NIEL hypothesis) = **0,71**

**Run7062** LGAD

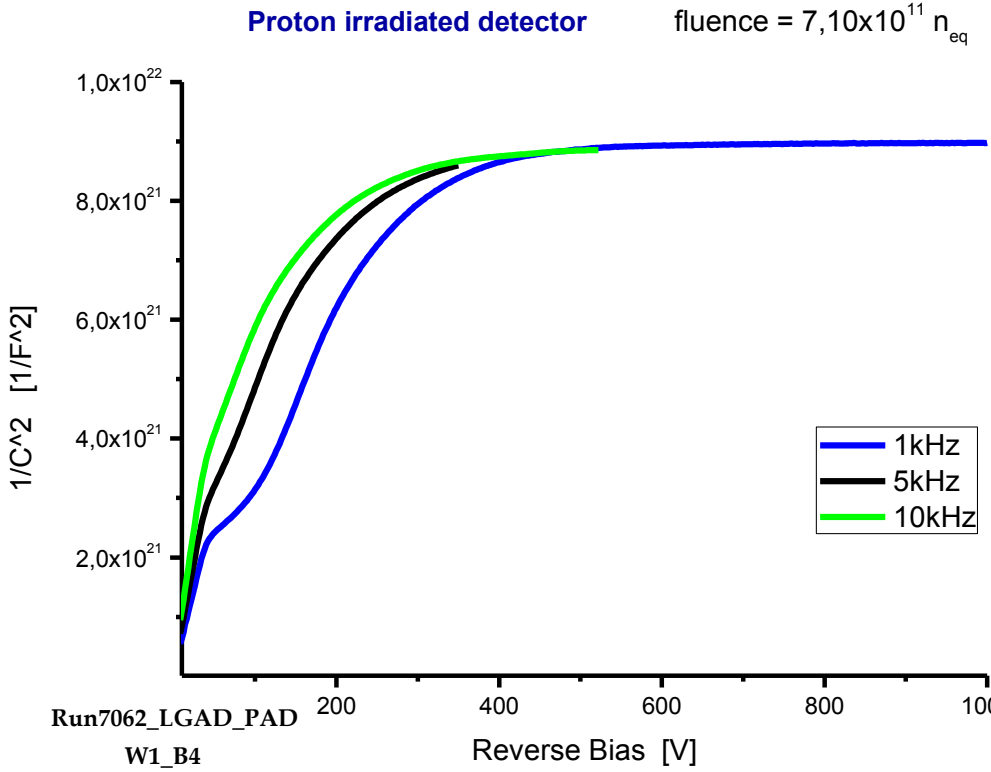
Reference diodes from **Run6474** LGAD

# Electrical Characterization After Irradiation

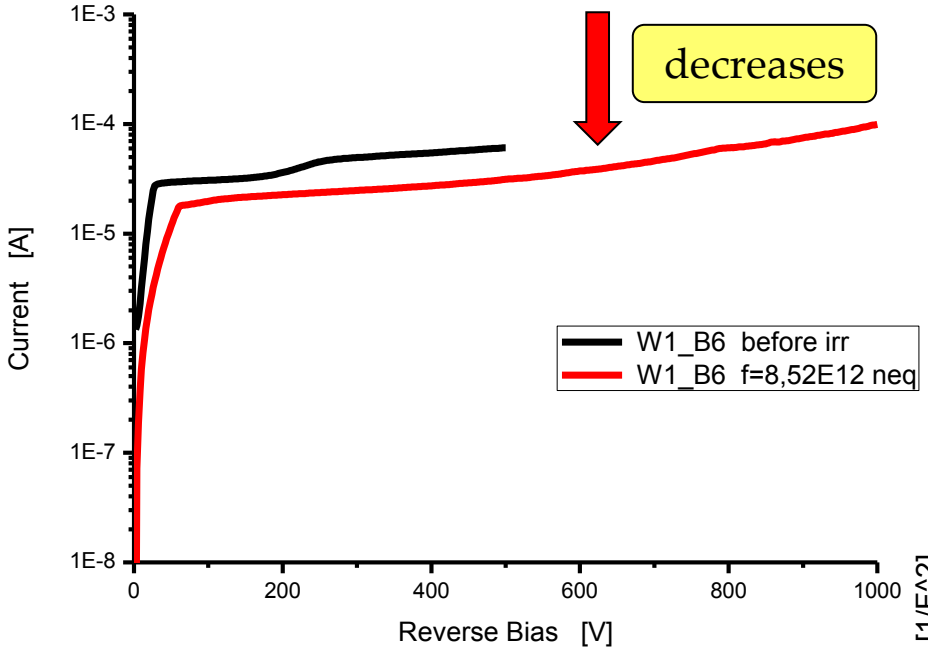



**fluence = 7,10E+11 neq/cm^2**

**LGAD diode**

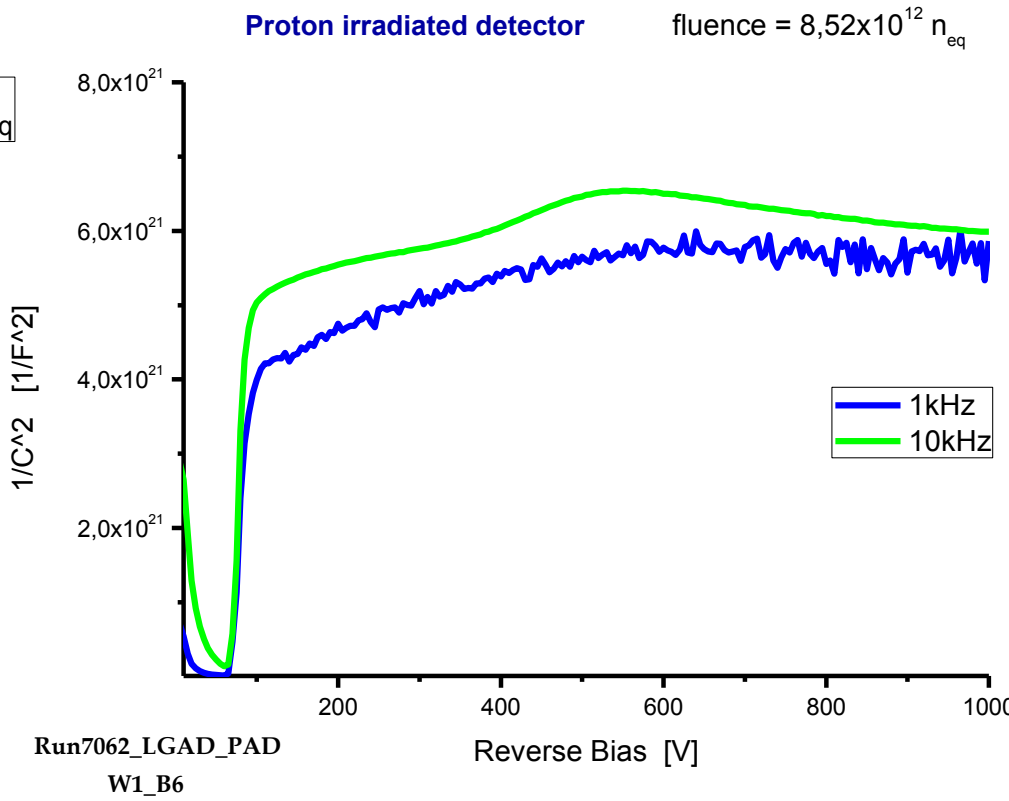


# Electrical Characterization After Irradiation

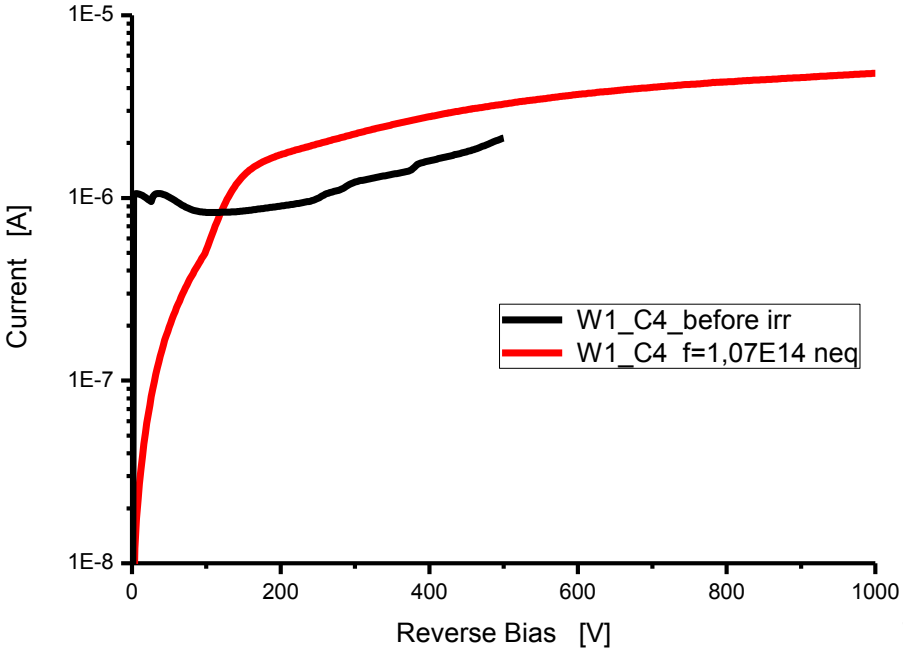



**fluence = 8,52E+12 neq/cm^2**

**LGAD diode**

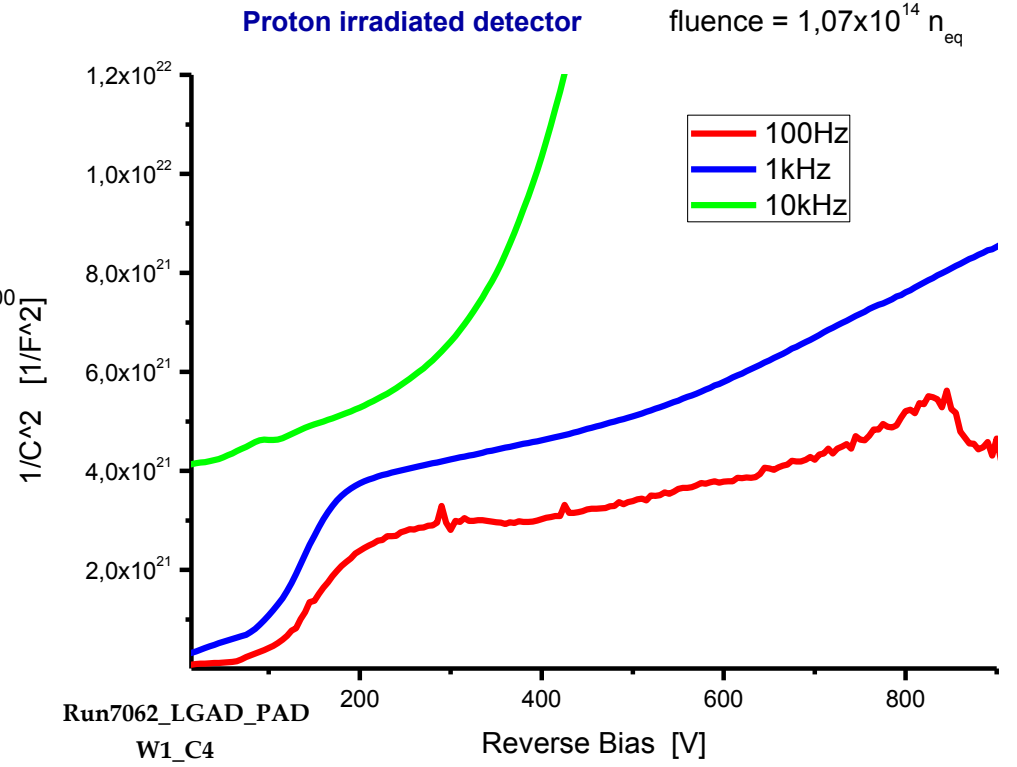


# Electrical Characterization After Irradiation

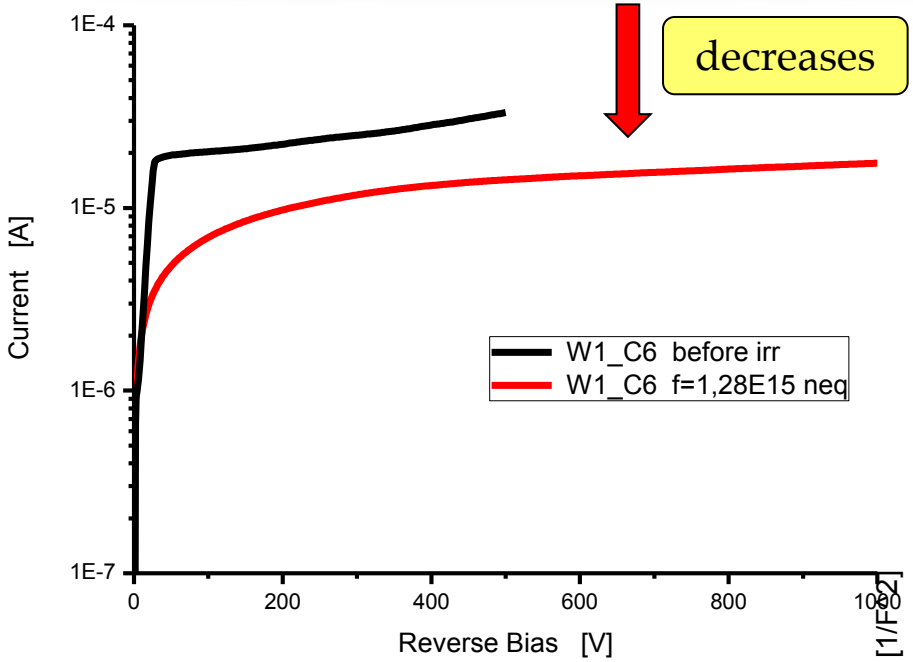



**fluence = 1,07E+14 neq/cm^2**

**LGAD diode**

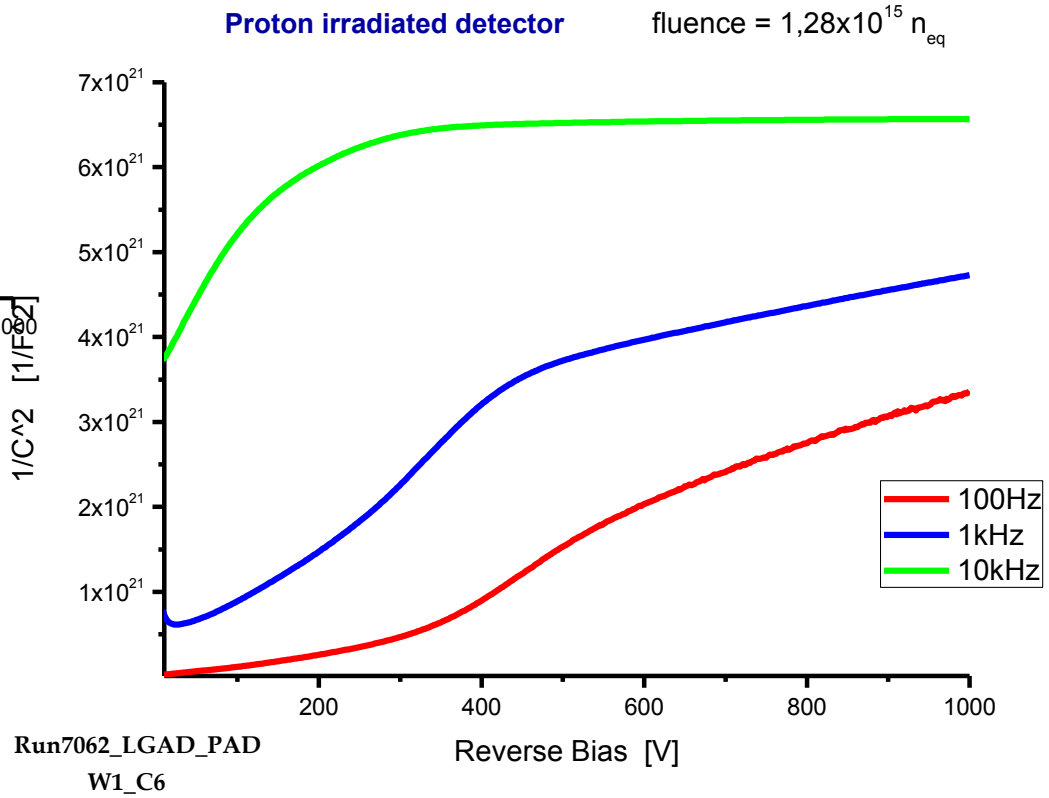


# Electrical Characterization After Irradiation

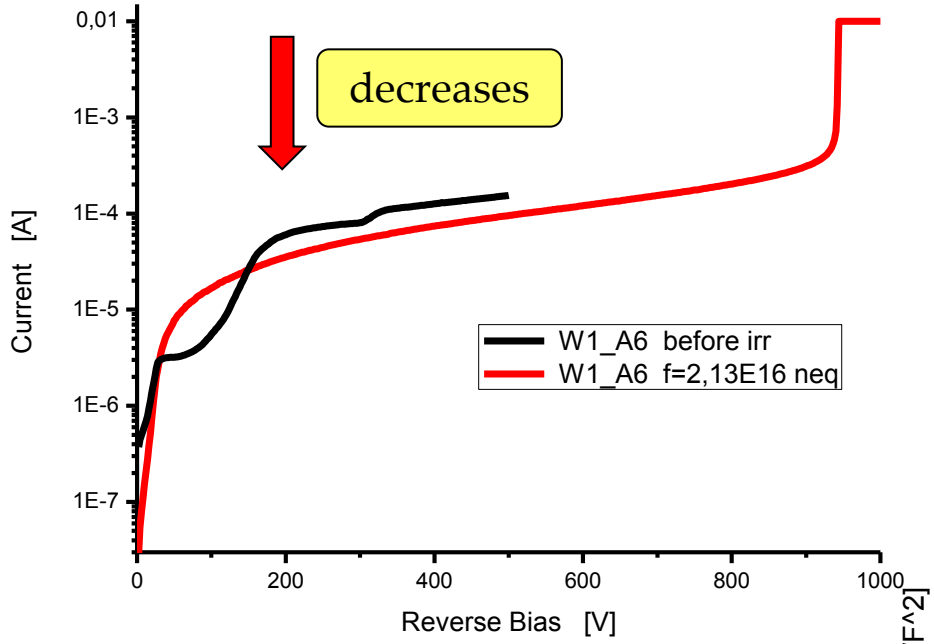



**fluence = 1,28E+15 neq/cm^2**

**LGAD diode**

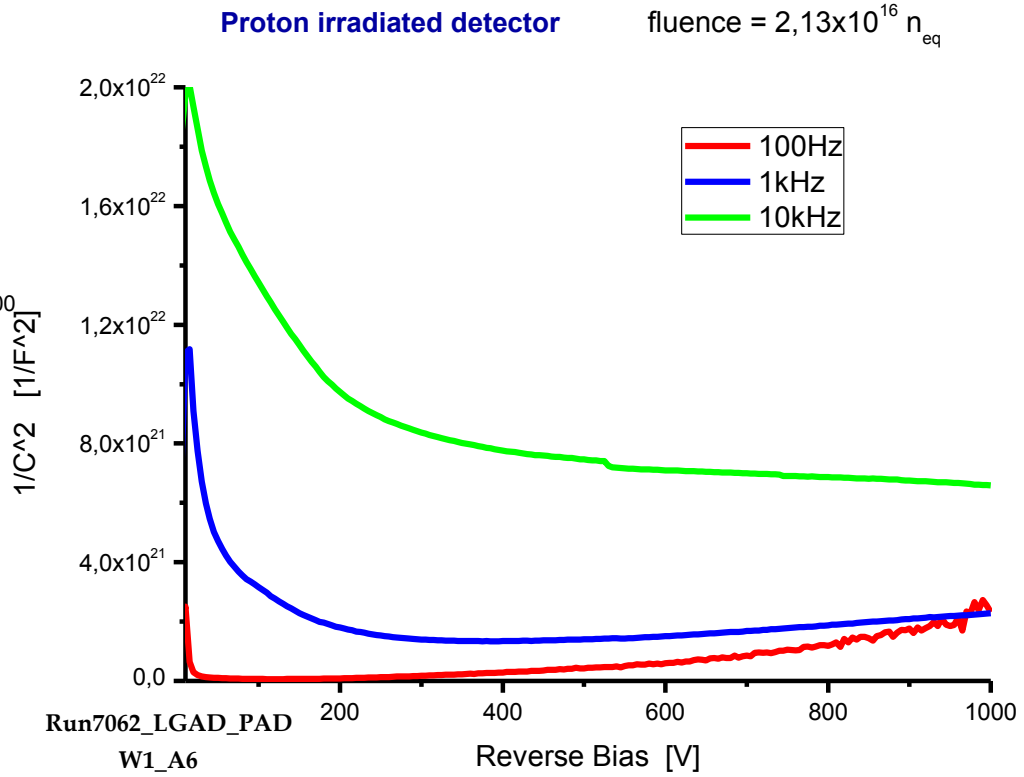


# Electrical Characterization After Irradiation




**fluence = 2,13E+16 neq/cm^2**

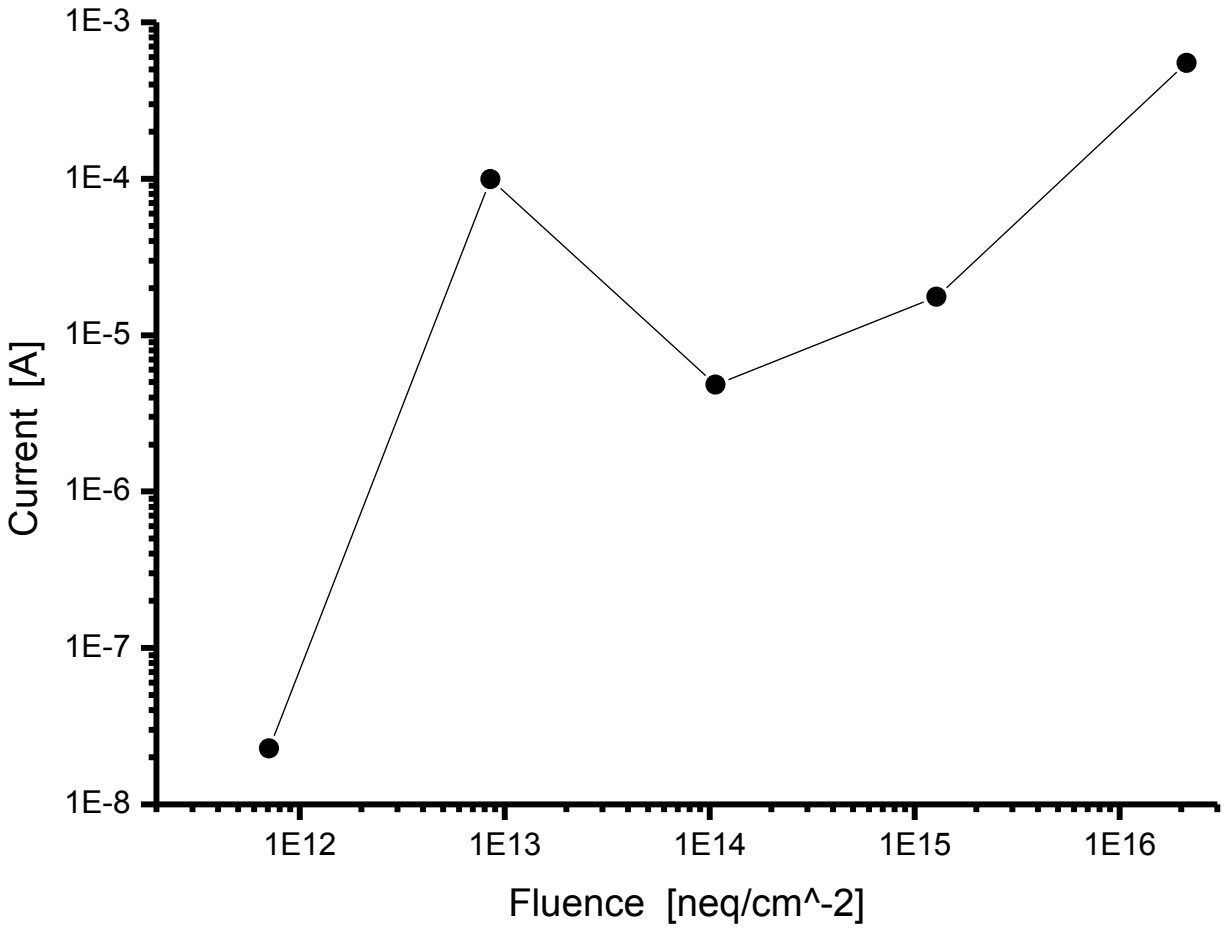
**LGAD diode**




- In general, the current after irradiation is lower then before
- It confirms the hypothesis that before irradiation surface current is dominant

# Electrical Characterization After Irradiation

## Leakage Current as a function of fluence

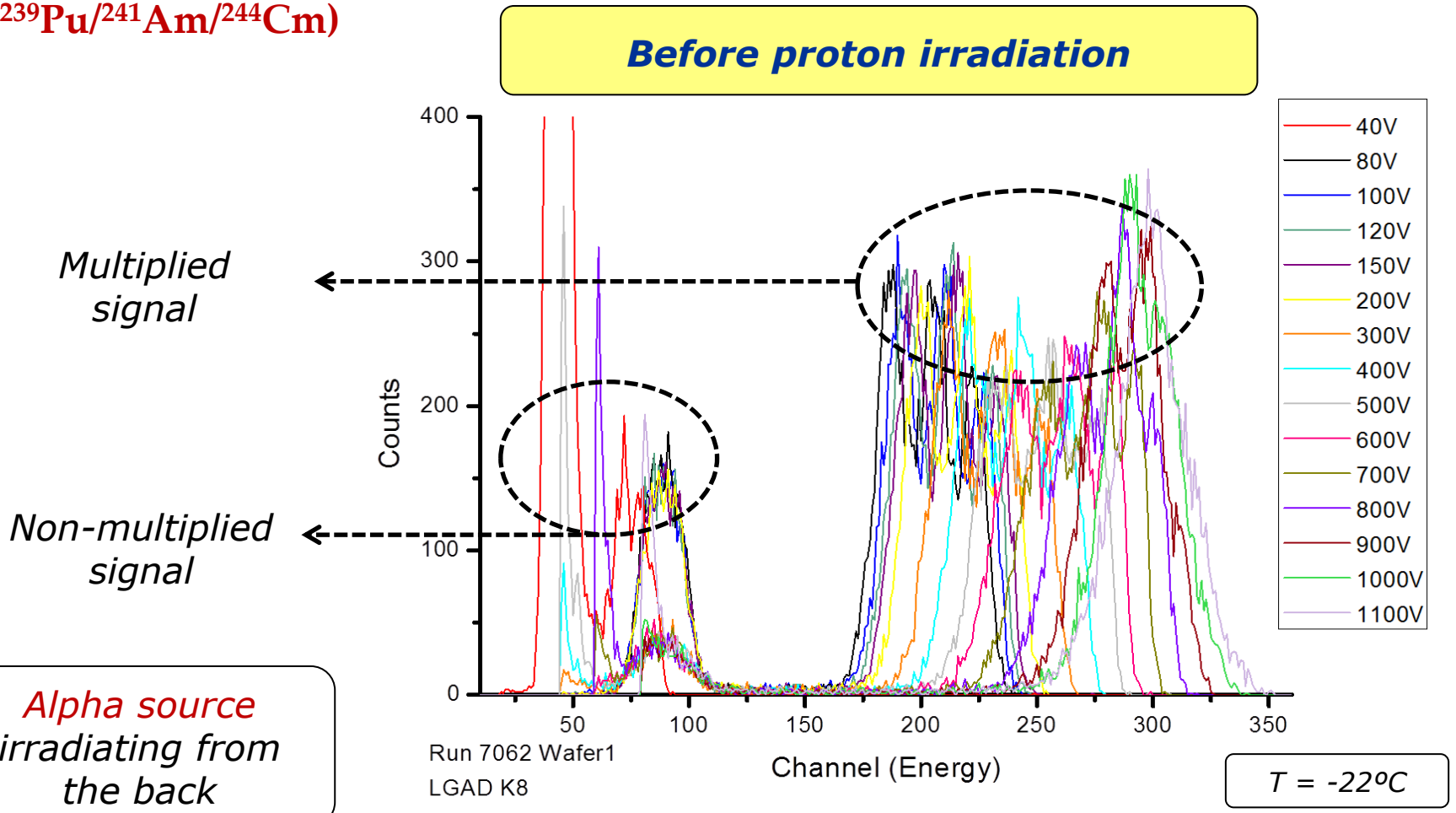



- @V=1000V
- Leakage current increases with fluence

# Charge Collection → Alpha Particles

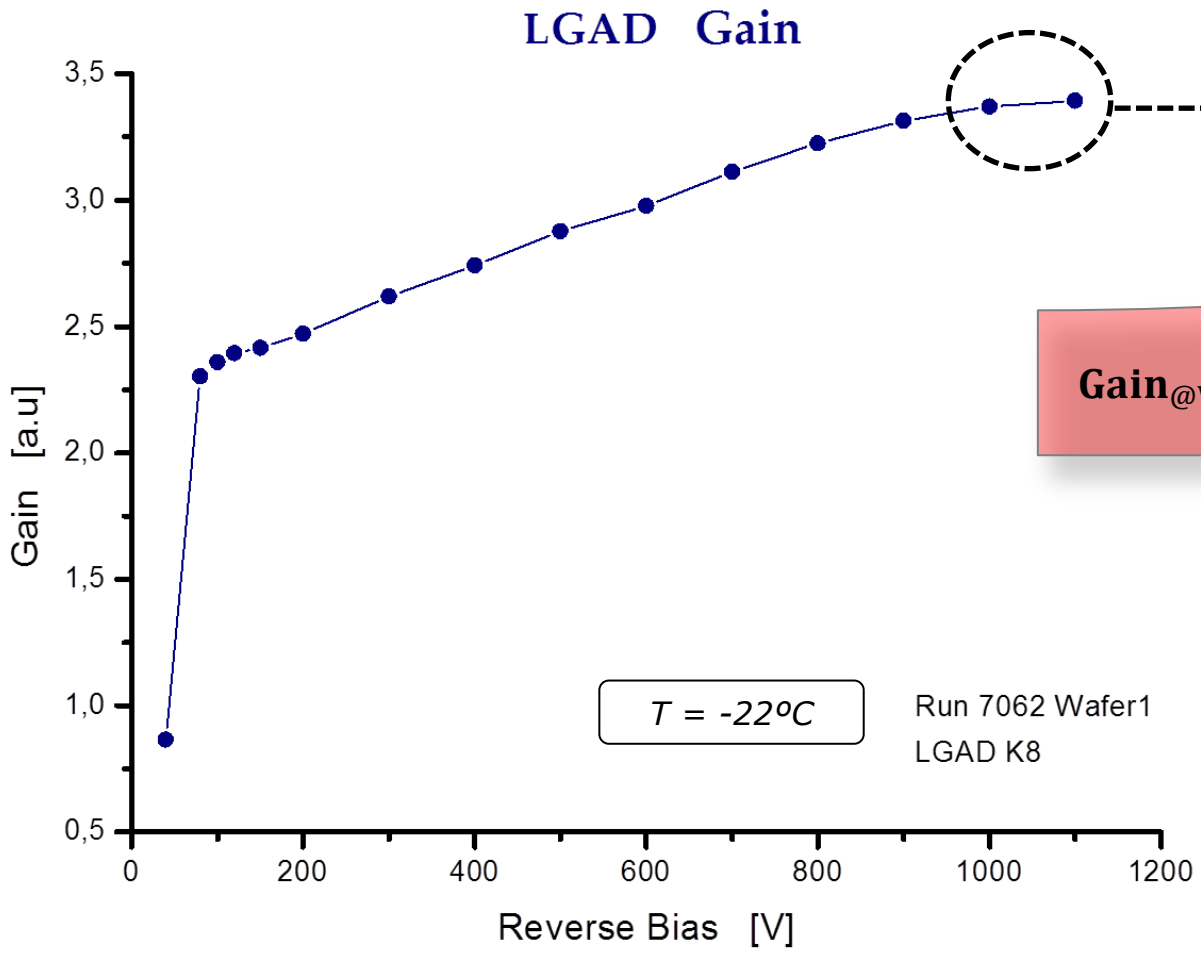
- Multiplication factor measured with **tri-alpha radiation source →**

($^{239}$Pu/$^{241}$Am/$^{244}$Cm)



# Alpha Particles → Gain

**Before proton irradiation**




*Gain ~ 2,3 ÷ 3,5*

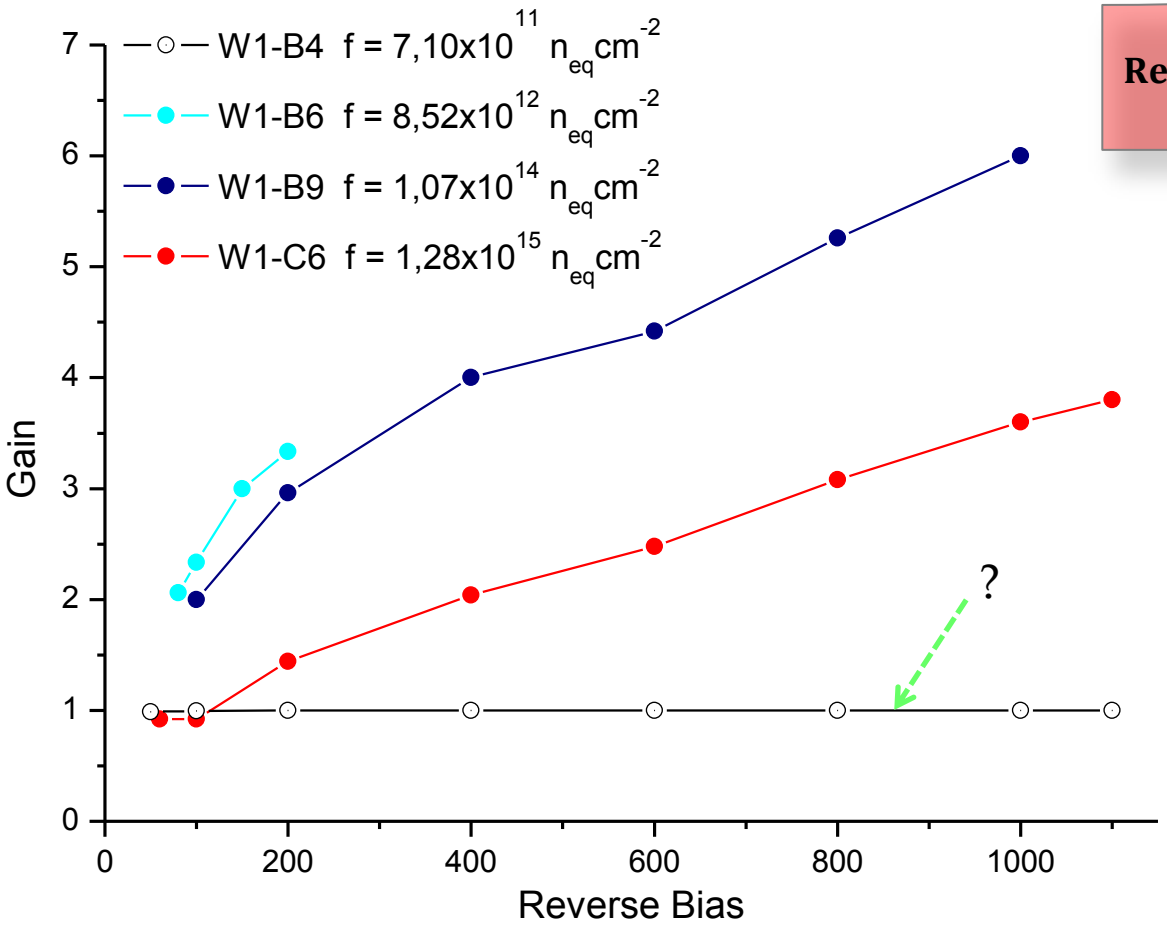
$$\text{Gain}_{@V} = \frac{\text{Central Peak Channel}_{@V}}{\text{Central Peak Channel}_{\text{No mult}}}$$

# Gain After Proton Irradiation

**After proton irradiation**

$$\text{Rel Gain}_{@V} = \frac{\text{C. Peak Channel Irr Det}_{@V}}{\text{C. Peak Channel Irr Det}_{\text{No mult}}}$$

## Relative Gain after proton irradiation

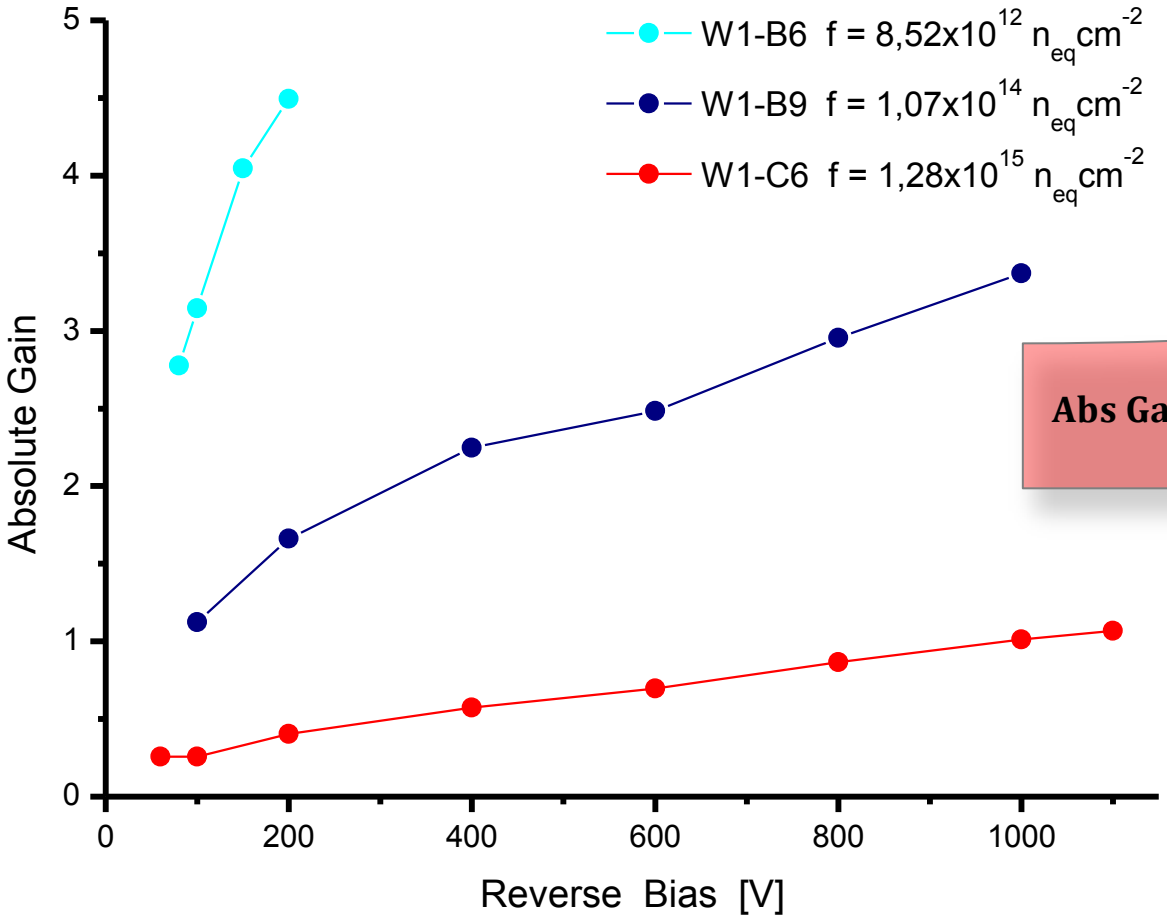



- W1_D2 (2,13E16 neq/cm^2) → we don't see signal
- The gain decreases with increasing fluence
- Relative Gain after proton irradiation higher than before.

# Gain After Proton Irradiation

## Absolute Gain after proton irradiation

**After proton irradiation**




$$\text{Abs Gain}_{@V} = \frac{\text{C. Peak Channel Irr Det}_{@V}}{\text{C. Peak Channel NonIrr Det}_{\text{No mult}}}$$

# Conclusions

- **Laser TCT measurements** on LGAD diode (Run7062 W1)
  - surface scan shows that the diode is very homogeneous
  - voltage scan → the signal keeps increasing with voltage; with red laser we can distinguish electrons and holes

- **Electrical characterization** of **proton irradiated** LGAD diodes
  - current after irradiation is lower than before
    → high current before irradiation due to surface current
- **Charge collection measurements** with alpha particles
  - Relative gain → higher after irradiation
  - Absolute gain →lower (?)

# Future Work

- Further **characterization with alpha particles** of proton irradiated LGAD with low doped multiplication layer → more statistic
- **Laser TCT measurements** of proton irradiated LGAD diodes.

  → to be performed at CERN
- Irradiation with protons of LGAD diodes with **higher doped multiplication layer**.

- **New fabrication run**, with a new geometry that includes **isolation structures** (p-stop, collector ring, channel stop).

  → Mask already defined.

Thank you for your attention!