In-depth study of Inverse-Low Gain Avalanche Detectors (ILGAD) for 4-dimensional tracking and radiation tolerance assessment of thin LGADs

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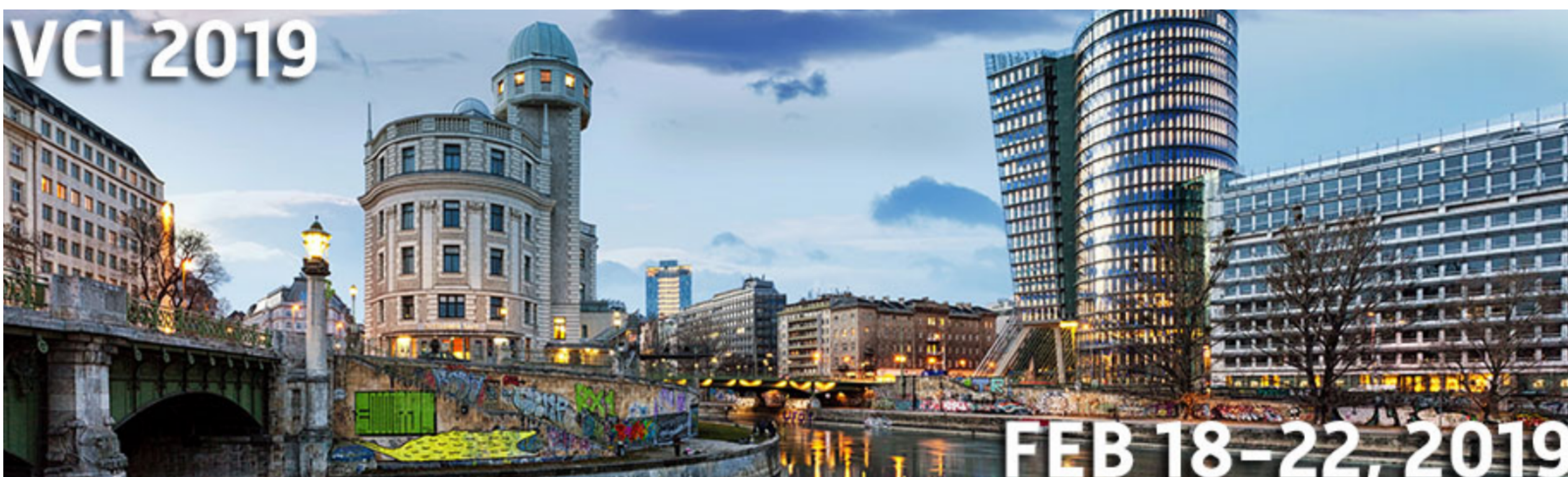

The Team

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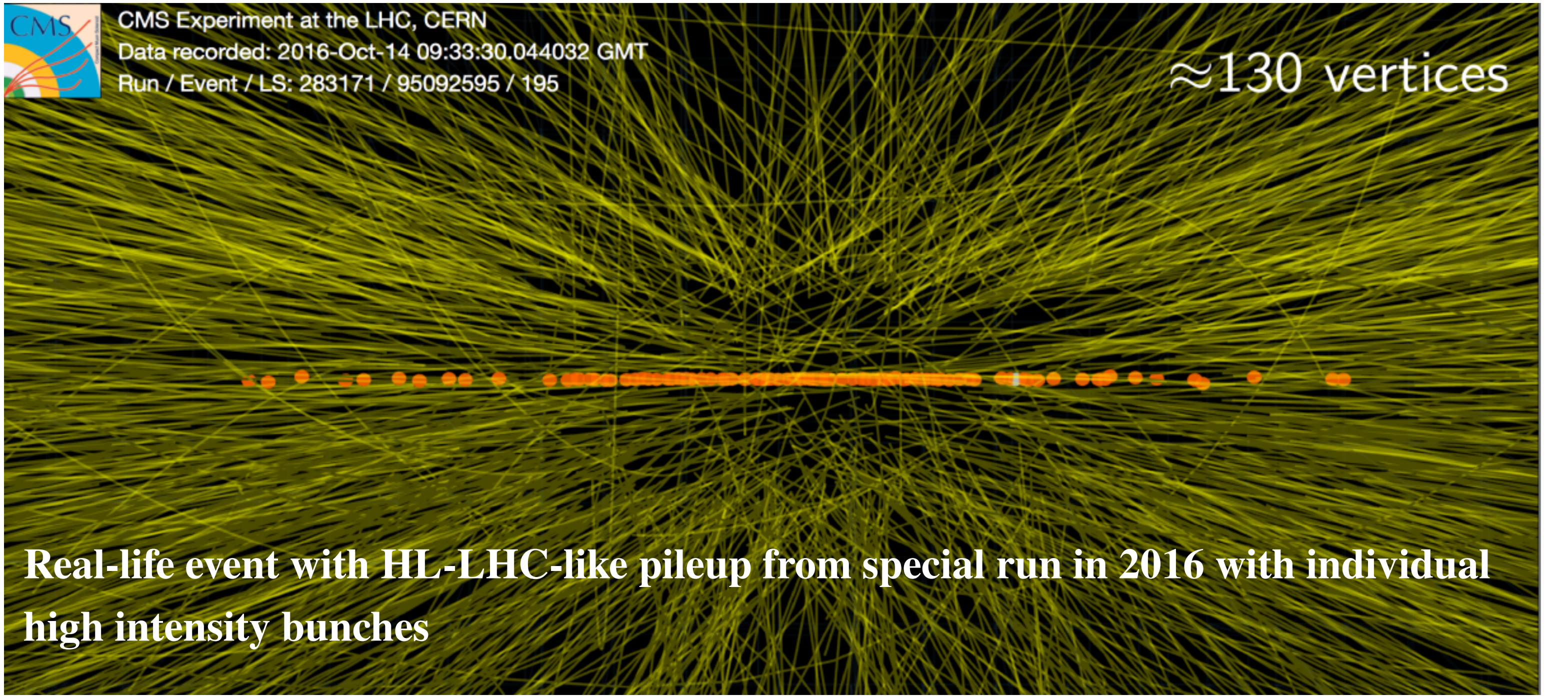
Motivation

High-luminosity LHC upgrade: ATLAS and CMS experiment are planning to include dedicated detector systems to measure the arrival time of Minimum Ionizing Particles (**MIPs**).



Pile-up mitigation (up to 200) → time resolution needed of ~30 ps per MIP.

Increase of the detector radiation tolerance → up to ~ 3E15 n_{eq}/cm^2.

Radiation tolerance assessment of thin LGADs

Devices description

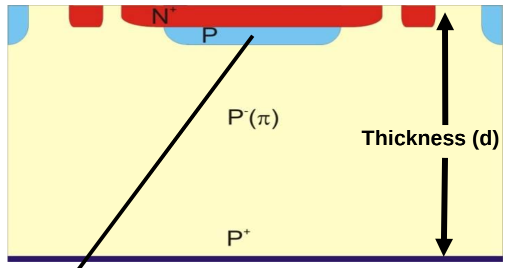
LGADs produced by CNM (run 11748).

Devices under study coming from two different wafers with different active thicknesses (d):

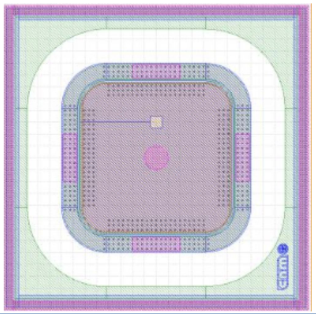
- **d = 50 µm**
- **d = 35 µm**

Also PIN diodes for reference.

A pad-like LGAD



Highly doped gain layer
Signal amplification
Better SNR !!



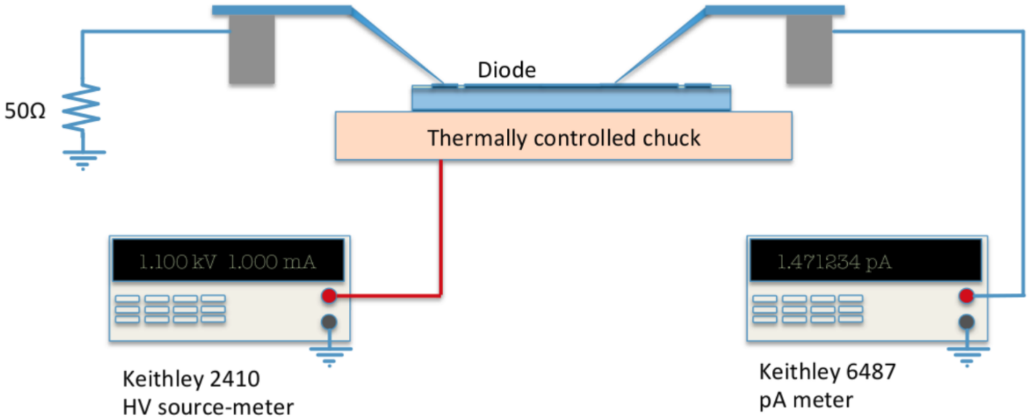
Total area of 2.6x2.6 mm^2
Active area of 1.3x1.3 mm^2
Intermediate gain (1.8E13)

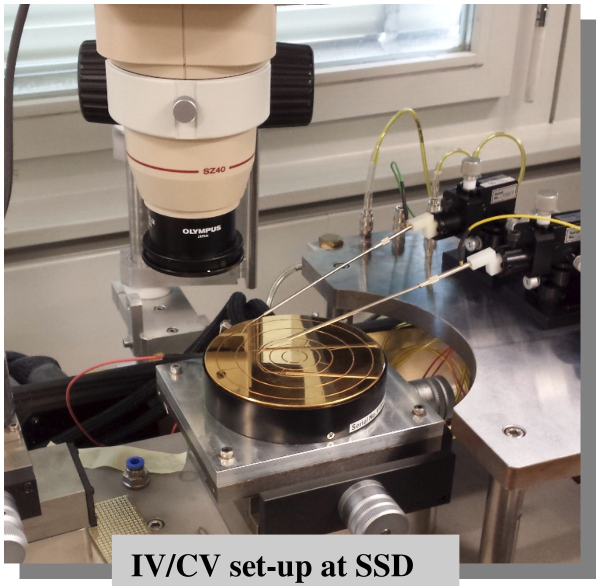
Study plan

1. Electrical characterization. ✔
2. Irradiated at CERN PS with 24 GeV protons at 5 different fluences. ✔
   - 6E13 n_{eq}/cm^2
   - 1E14 n_{eq}/cm^2
   - 3E14 n_{eq}/cm^2
   - 1E15 n_{eq}/cm^2
   - 3E15 n_{eq}/cm^2
3. Annealing right after irradiation of 10 minutes at 60 ºC. ✔
4. Electrical characterization after irradiation. ✔
5. Laser measurement: Gain studies. ✔ … ongoing.
6. Laser measurement: timing studies. ✘ … to be done.

Electrical characterization

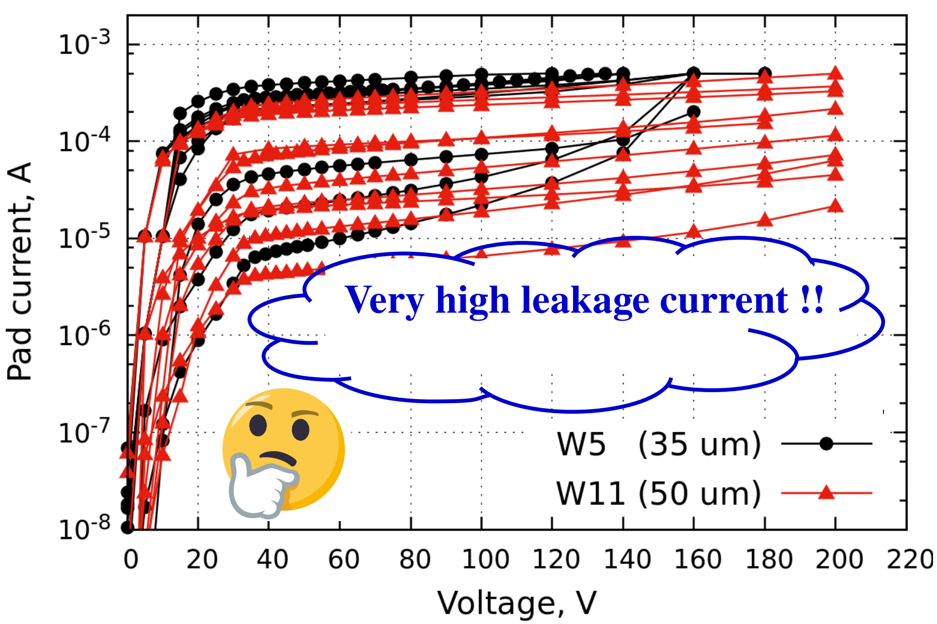
IV → Measure of the leakage current as a function of the bias voltage.



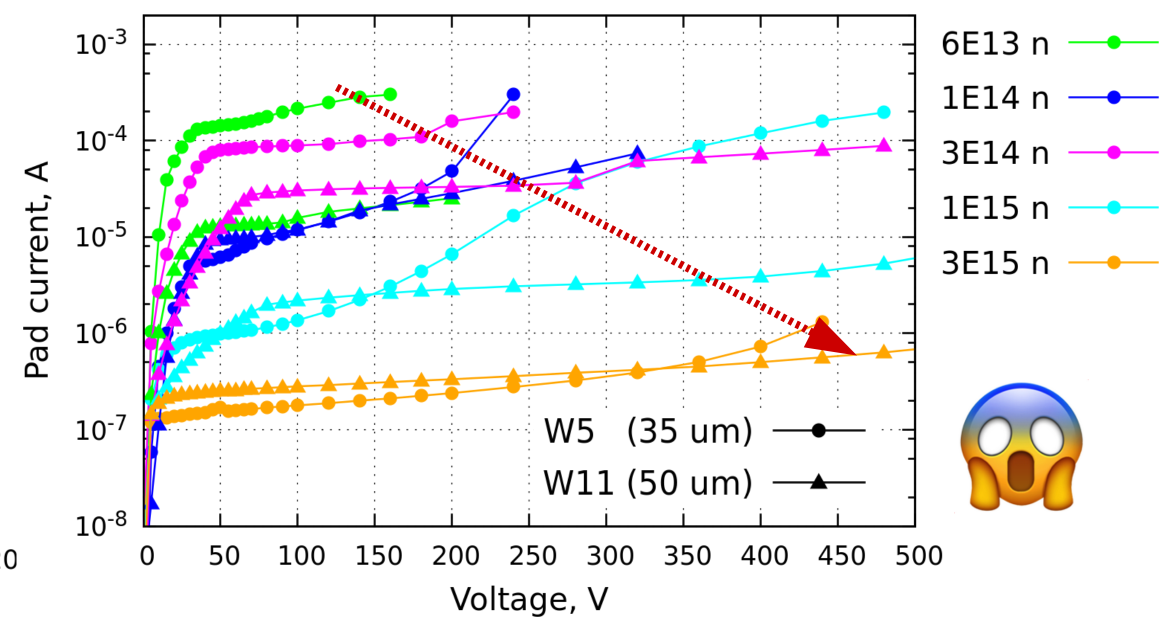


IV/CV set-up at SSD department at CERN

IV (35 um vs 50 um) T: 20C unirradiated



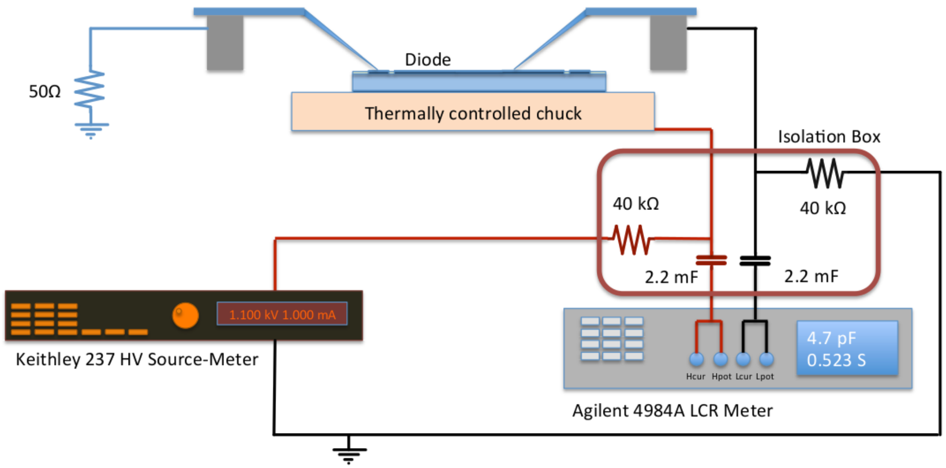
IV (35 um vs 50 um), T: -20C, irradiated

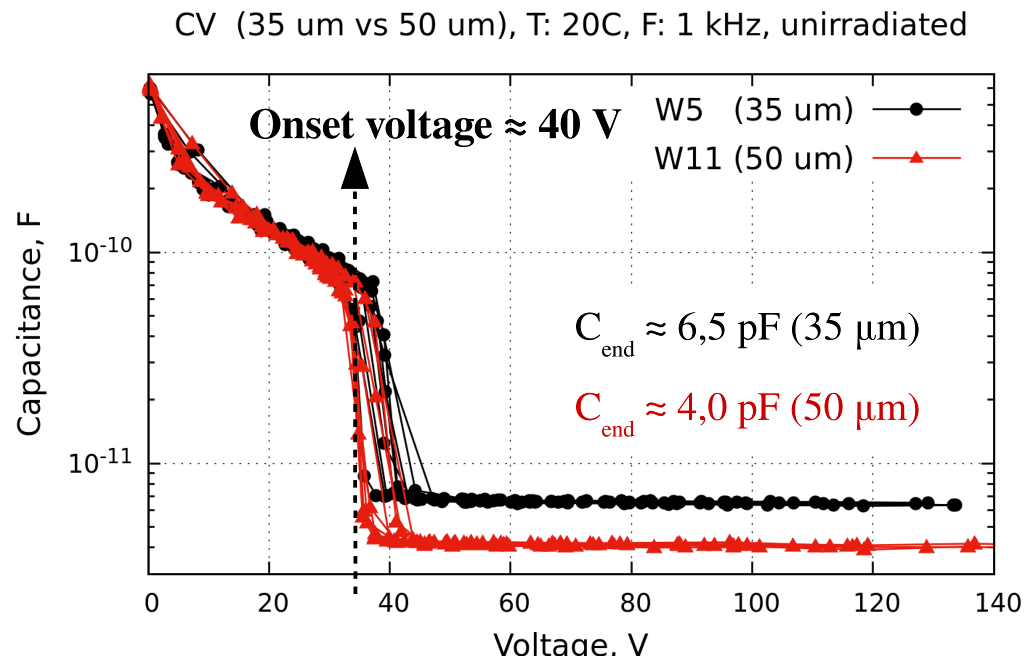


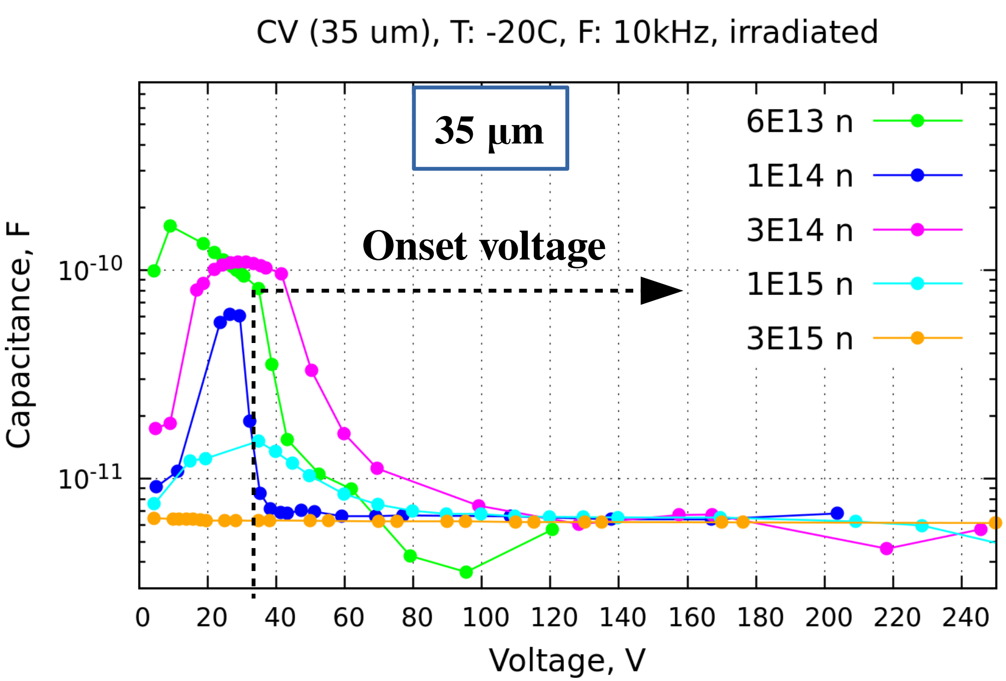
The higher the fluence the lower the leakage current !!

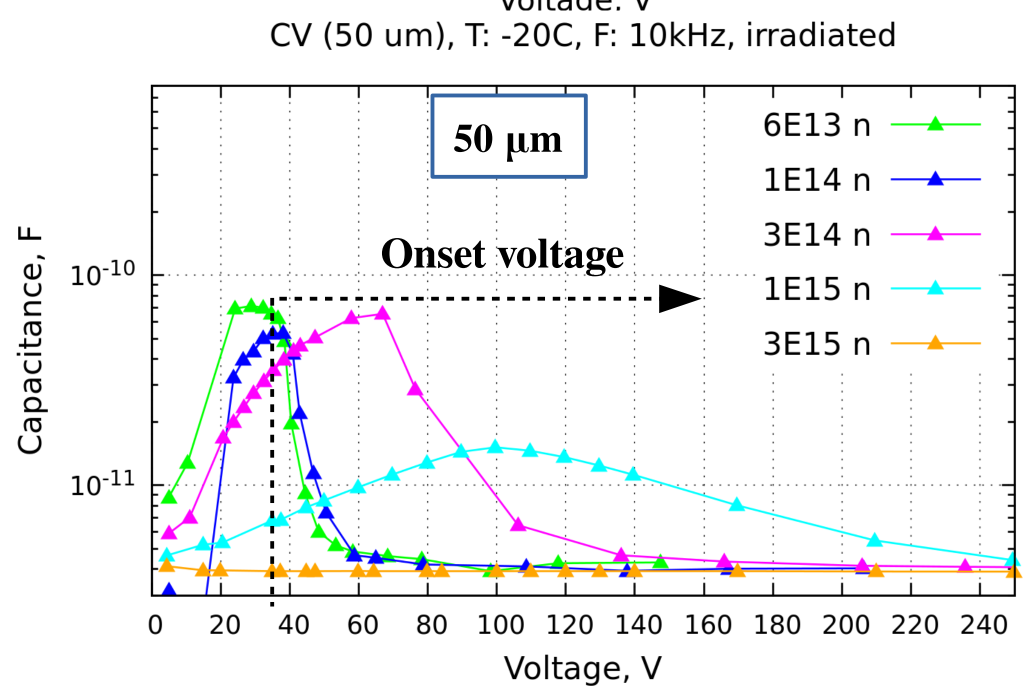
Electrical characterization

CV → Measure of the capacitance as a function of the bias voltage.



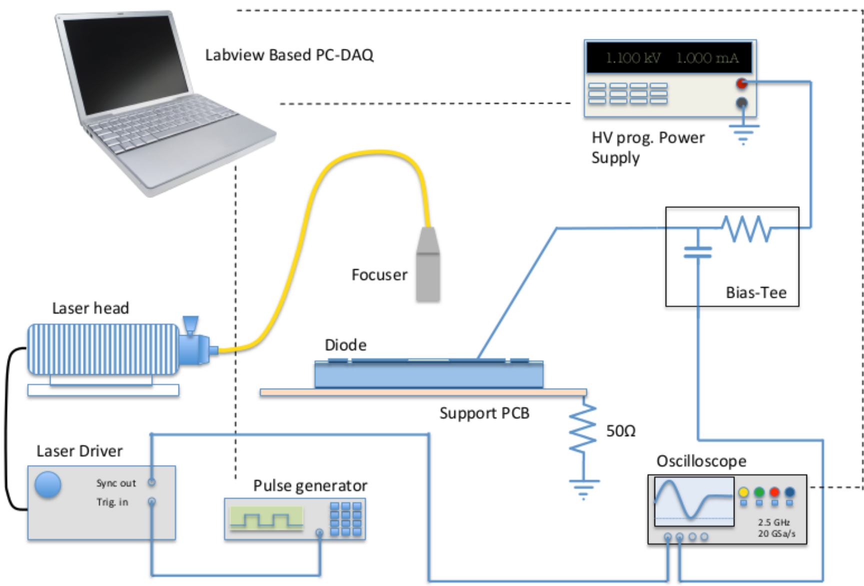


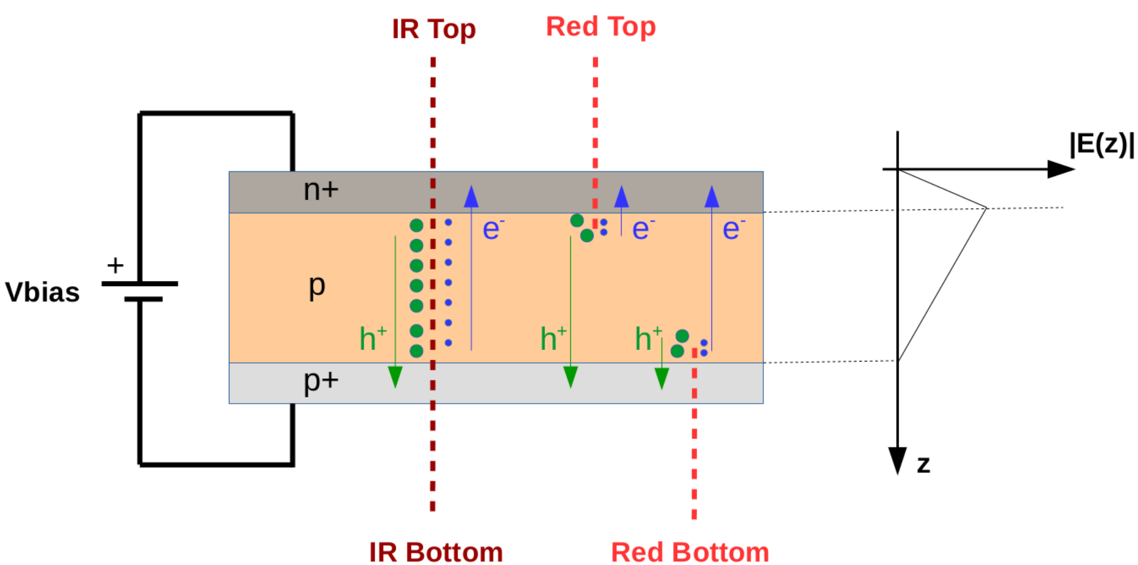


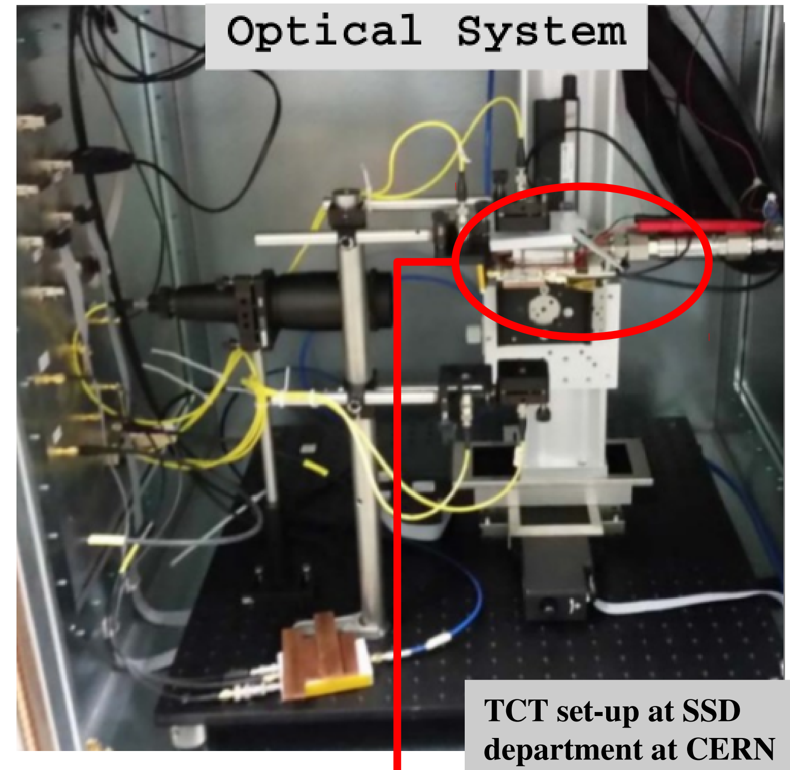


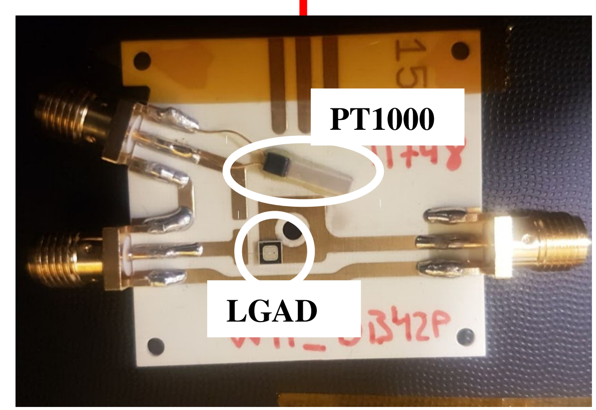
Laser measurements: Gain studies

Transient Current Technique (TCT) working principle





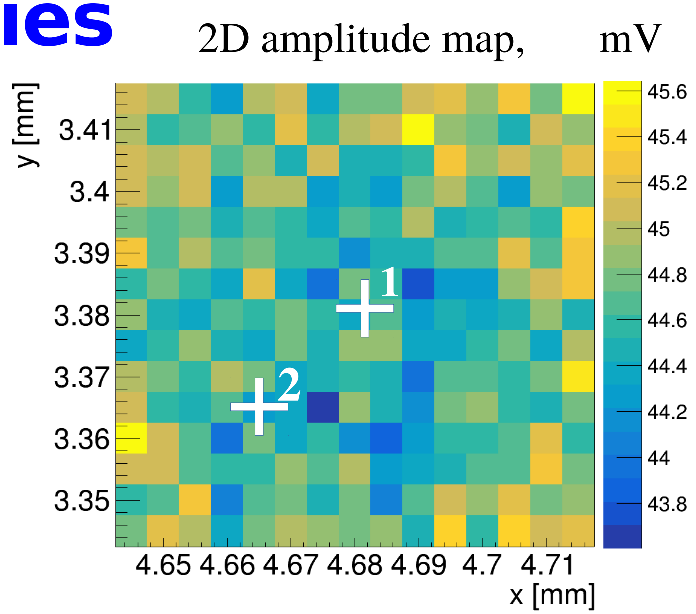




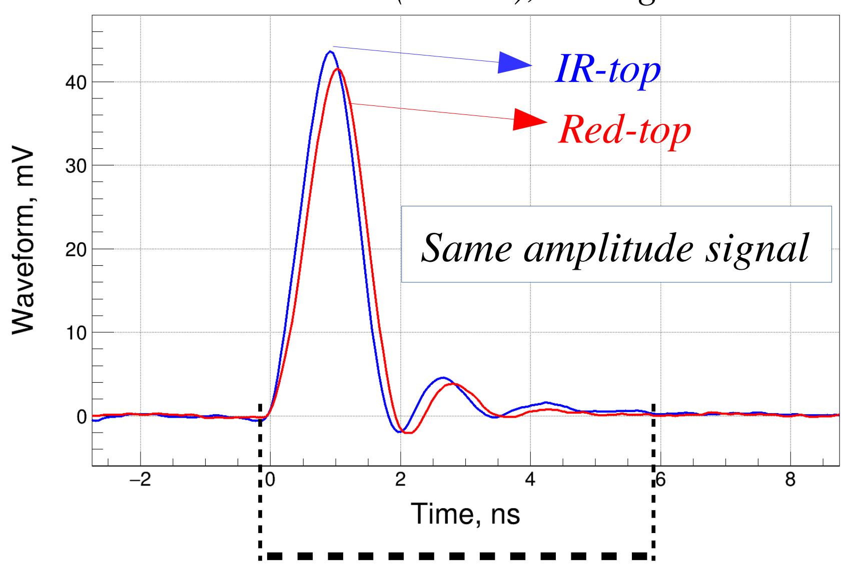
Laser measurements: Gain studies

Measurements set-up and waveforms

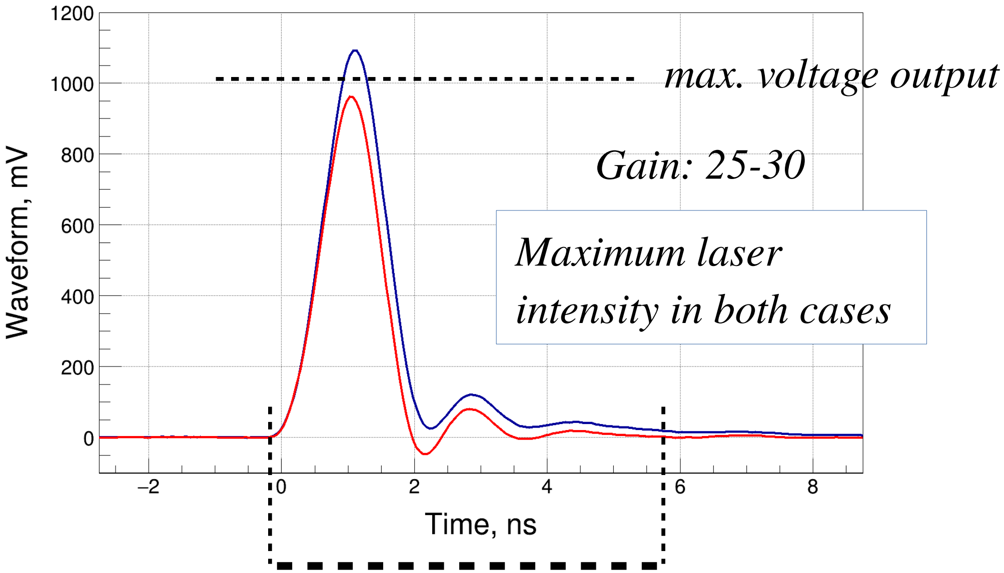
- IR laser and red laser
- Top illumination
- Same laser intensity in both cases
- Temperature: -20 C
- Amplifier: CIVIDEC C2, 2 GHz, 40 dB
- Osciloscope: Agilent DSO 9254, 2.5 GHz, 20 GSa/s
  - Averaging of 256 to improve SNR



PIN diode W11 (50 um), Voltage: 100 V



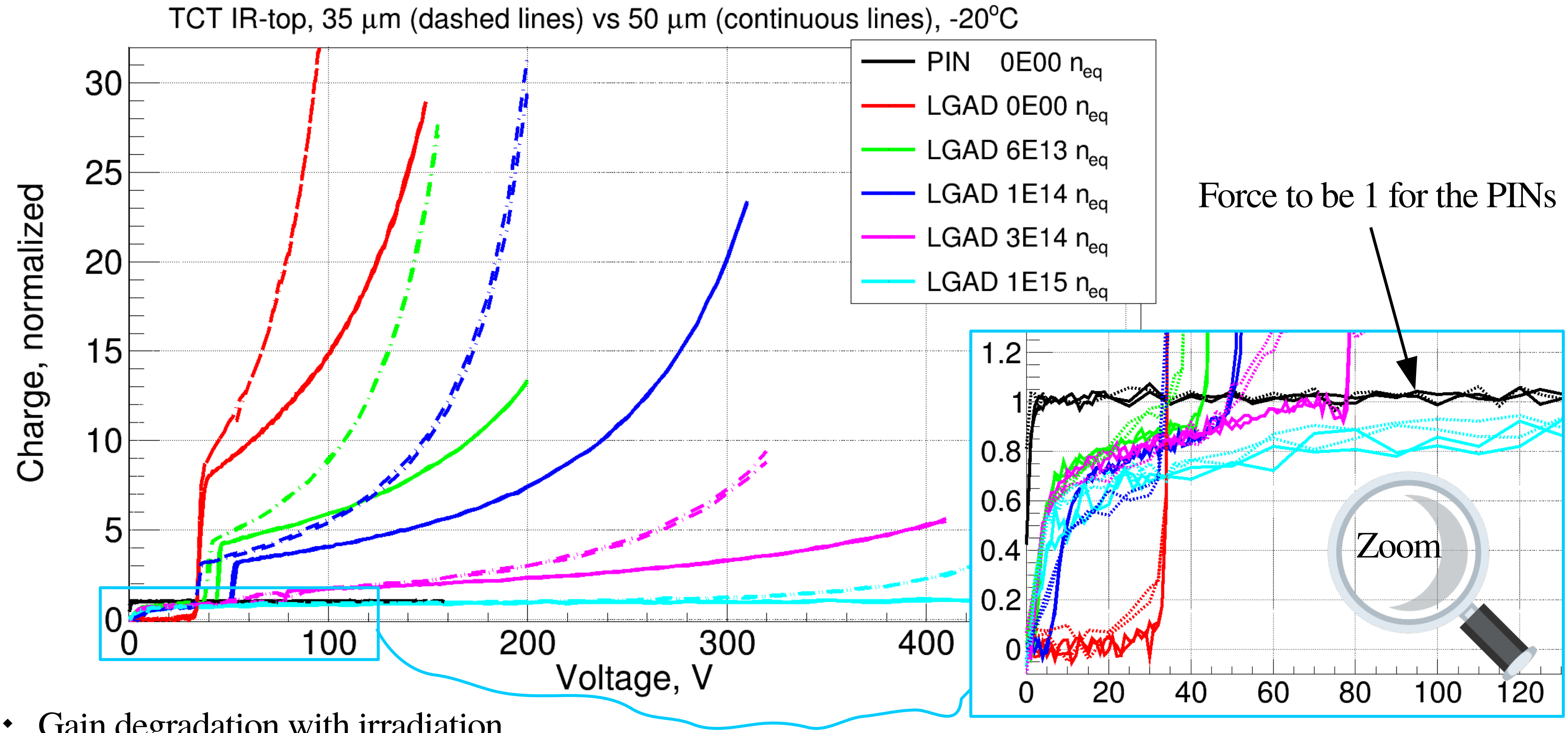
Unirradiated LGAD W11 (50 um), Voltage: 150 V



→ **Charge collection measured by the pulse integral within the first 6 ns.**

Laser measurements: Gain studies

IR laser measurements 35 um (dashed lines) vs 50 um (continuous lines)

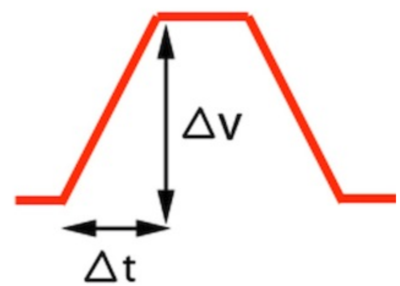


- Gain degradation with irradiation
- Increase of the amplification onset with irradiation: hint of double-junction mechanism (consistent with the capacitance measurements)
- Acceptor removal effect can not be extracted from the onset voltage
- Better behavior of thin sensors

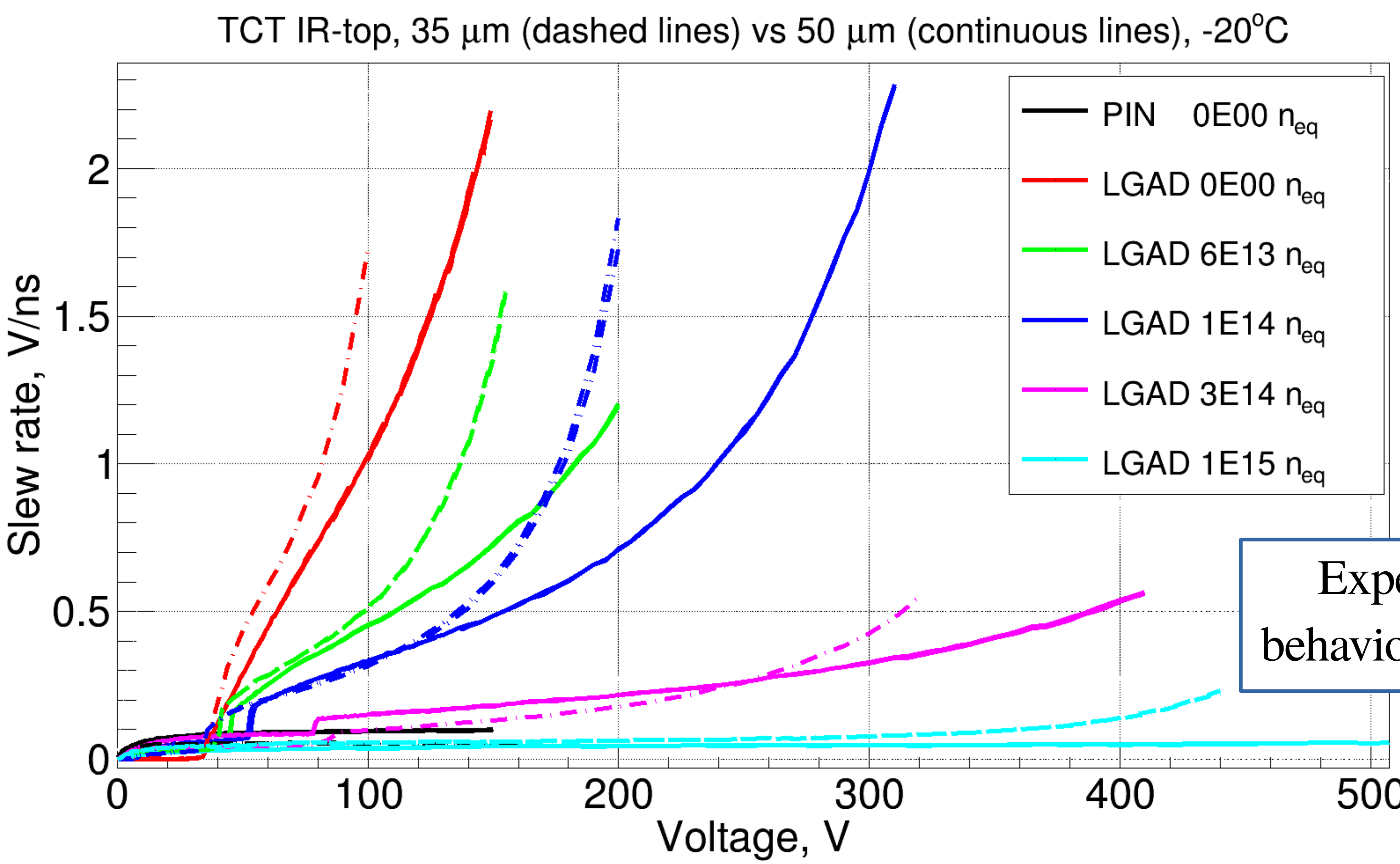
Laser measurements: Slew rate (SR)

IR laser measurements 35 um vs 50 um

$$\delta_{time} \propto \frac{\delta_{noise}}{\left|\frac{dV}{dt}\right|} \propto \frac{\Delta t}{\Delta V} * \delta_{noise} = \frac{\delta_{noise}}{SR}$$



$$SR = \frac{\Delta V}{\Delta t}$$



Expected good timing behavior up to 3E14 n_{eq}/cm^2

Radiation tolerance assessment of thin LGADs:

Conclusions and outlook

- Very high leakage current observed: problem under investigation.
- We still observe amplification up to a fluence of 3E14 n_{eq}/cm^2.
- Better behavior observed for the thinner devices.

Bias voltage needed for a SR value of 0.5:

Fluence (neq)	0.00E+00	6.00E+13	1.00E+14	3.00E+14	1.00E+15
35 um	54 V	98 V	132 V	312 V	x
50 um	64 V	110 V	152 V	390 V	x

➔ Need to complete laser measurements, including noise studies.

➔ Perform timing measurements:

  ➔ Infrared laser.

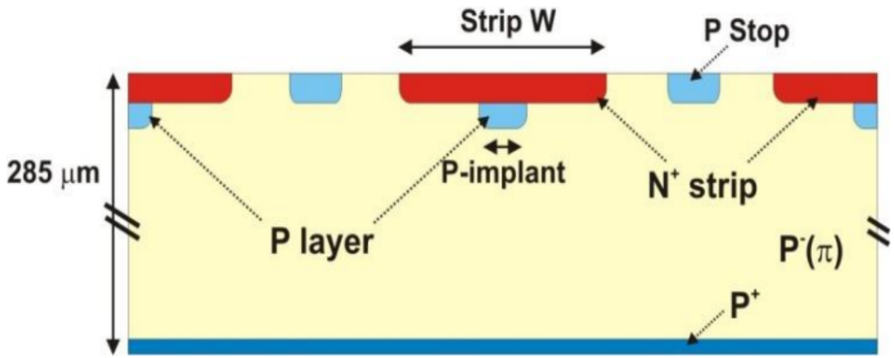
  ➔ Sr-90 source.

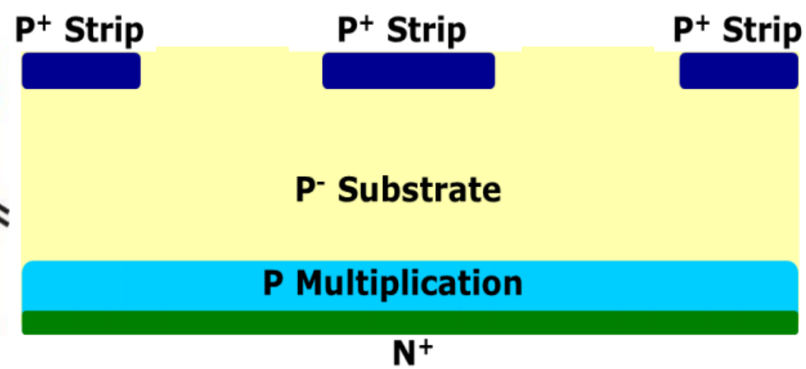
In-depth study of Inverse-Low Gain Avalanche Detectors (ILGAD) for 4-dimensional tracking

I-LGAD basics: a 4th dimensional tracking sensor

Multiplication layer divided into strip
Collects negative carriers (e)
Simple single side process

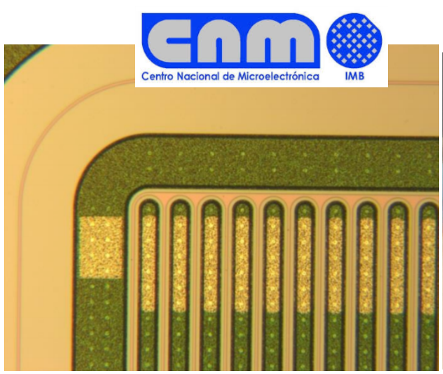
Multiplication layer extended over the electrode
Collects positive carriers (h)
Complex double side process

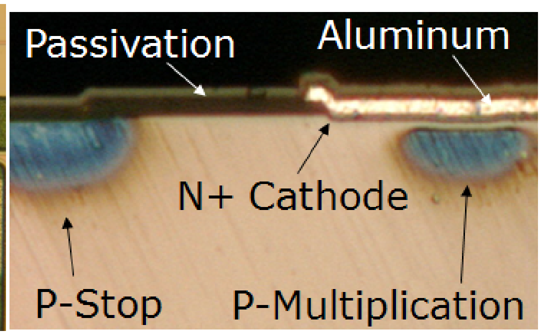




LGAD | N on P microStrip

P on P microStrip | iLGAD





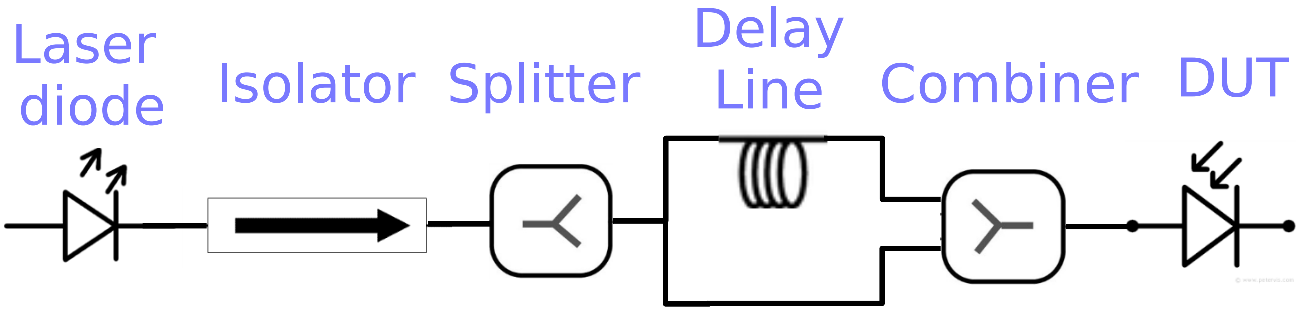
***The fill factor issue**: gain spatial uniformity

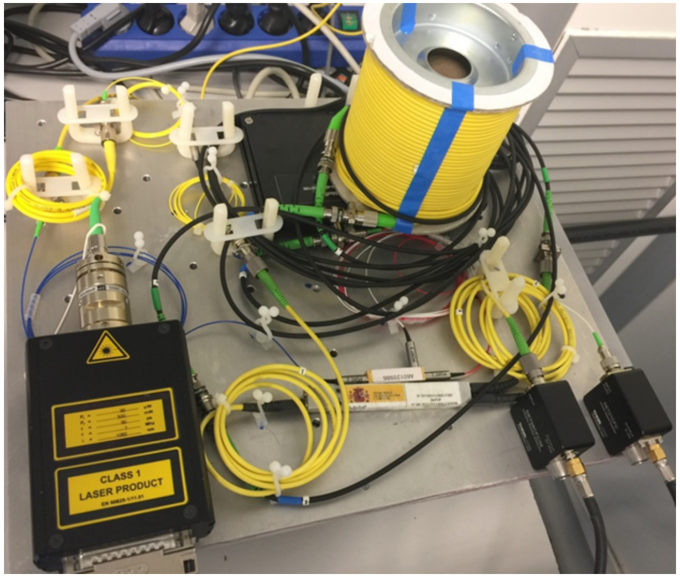
- LGAD: multiplication layer inter-space presents reduced/suppressed gain.
- I-LGAD: non-segmented multiplication layer should present uniform gain.

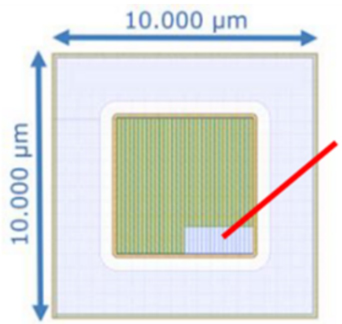
** Fill factor studies were presented at Trento workshop 2017→ Link to the talk*

https://indico.cern.ch/event/666427/contributions/2881813/attachments/1603622/2544525/20180219_I-LGAD_IvanVila.pdf

Set-up for timing characterization and DUTs





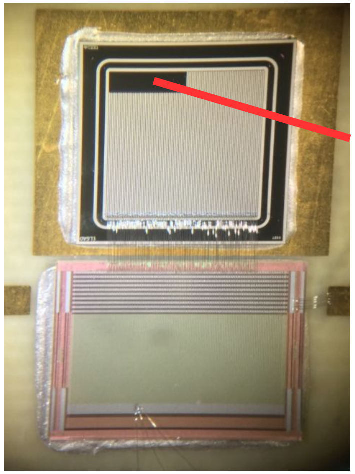


I-LGAD strip

45 strips

Thickness 285 um

Pitch 160 um



PIN strip

90 strips

Thickness 285 um

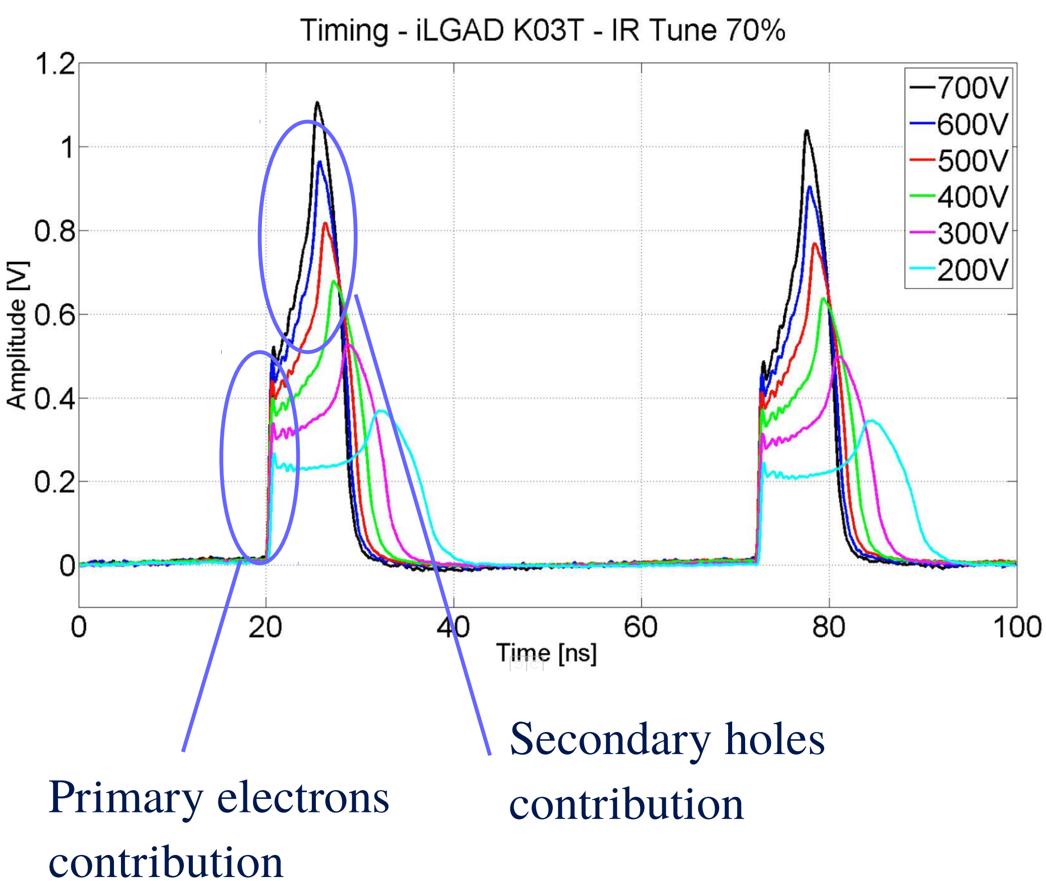
Pitch 80 um

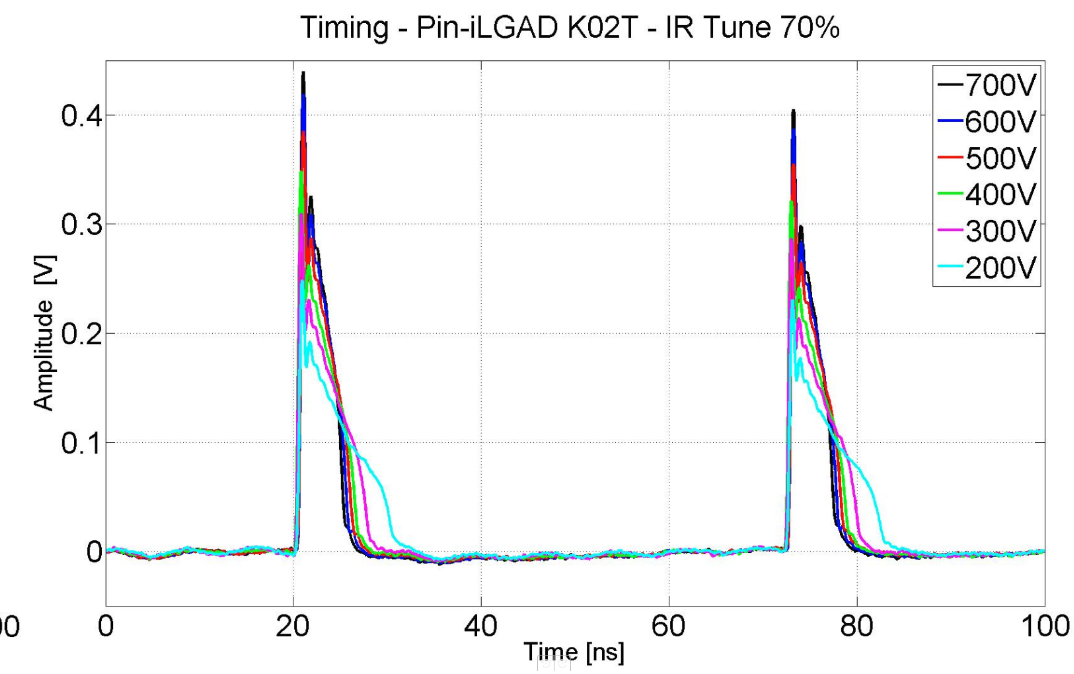
- **Time standard:** constant time interval between two picosecond IR laser pulses (1060 nm)
- Fixed time interval between laser pulses generated by optical splitting and delayed recombination of a single laser pulse.
- **External time reference is not needed.**

** Strips → small electrode capacitance → good for timing studies*

Set-up for timing characterization and DUT (2)

- Signal amplified (60db, miteq 1660) & digitized (25GSa/s)
- Acquired averaged waveform from I-LGAD and PIN sensors with a time interval of 52.23 ns between pulses



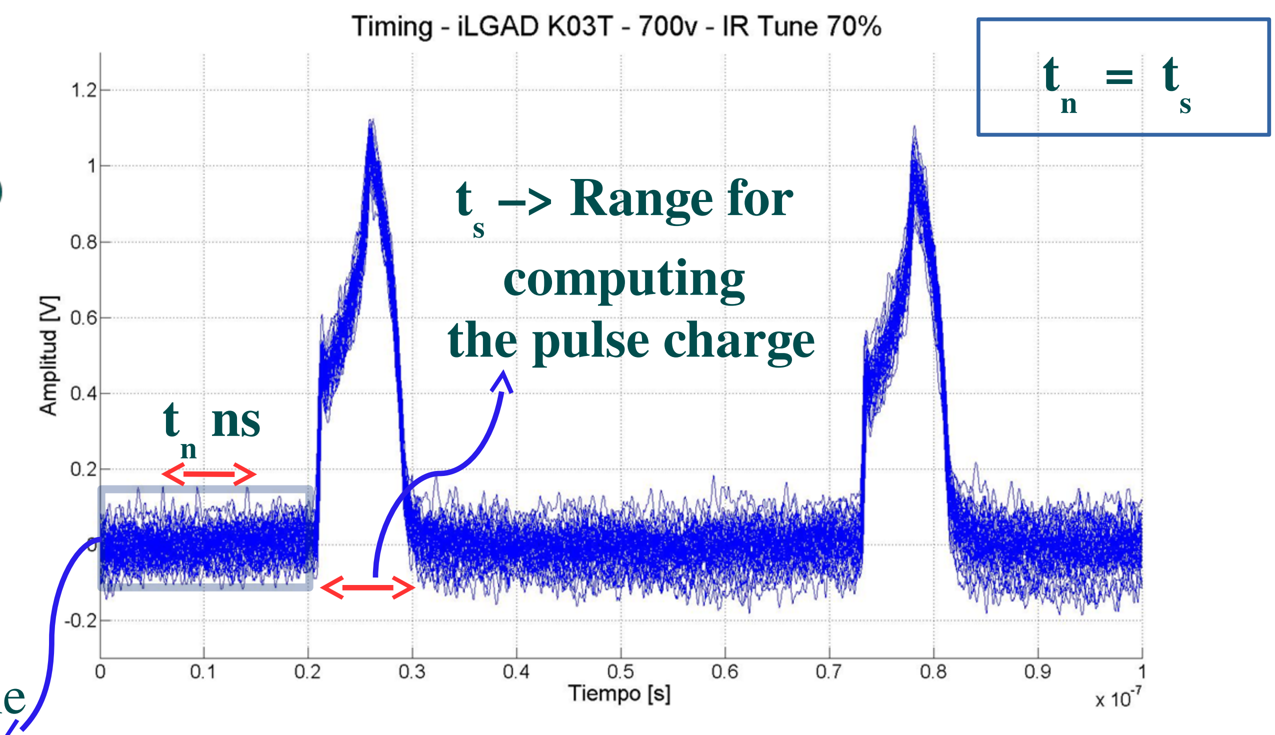


Parameter extraction of the waveform.

- Single-shot (non-averaged) superposition of signals.
- For each shot measured: Rise time, Signal amplitude and noise.
- **Signal estimation** as the charge under the transient waveform.
- **Noise estimation** as the RMS of charge (from the first nanoseconds of the waveform).

$$\sigma \equiv RMS\ (Charge\ baseline)$$

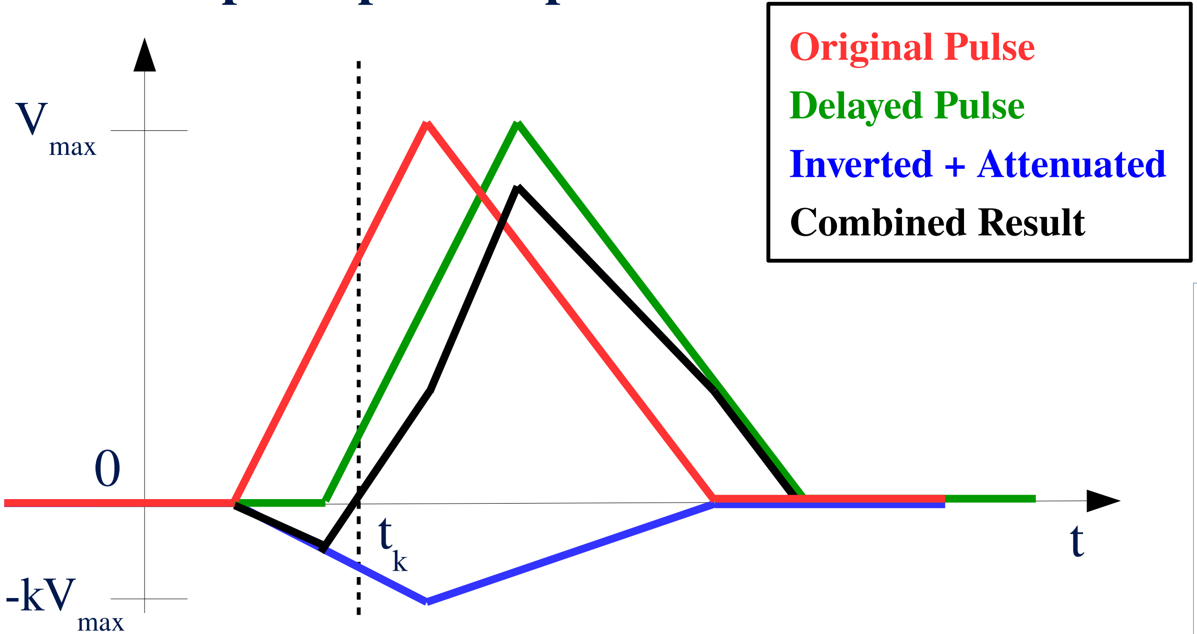
$$SNR \equiv \frac{Signal\ Charge}{\sigma}$$



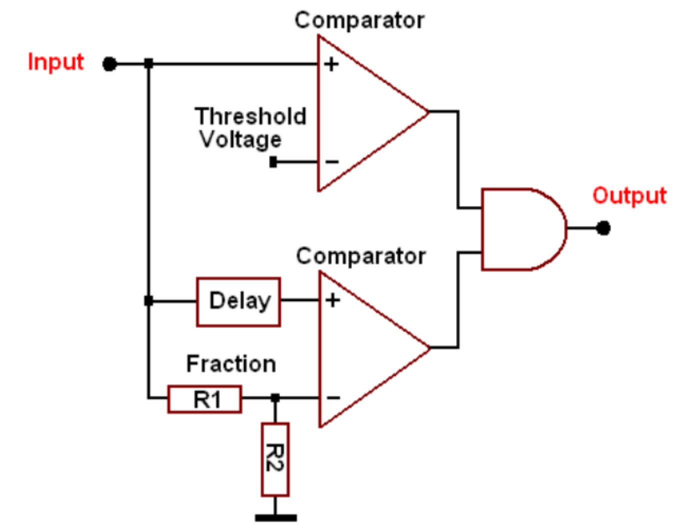
Waveform section from where the baseline noise is estimated

Timing computation:
Constant Fraction Discrimination method (CFD)

CFD principles of operation

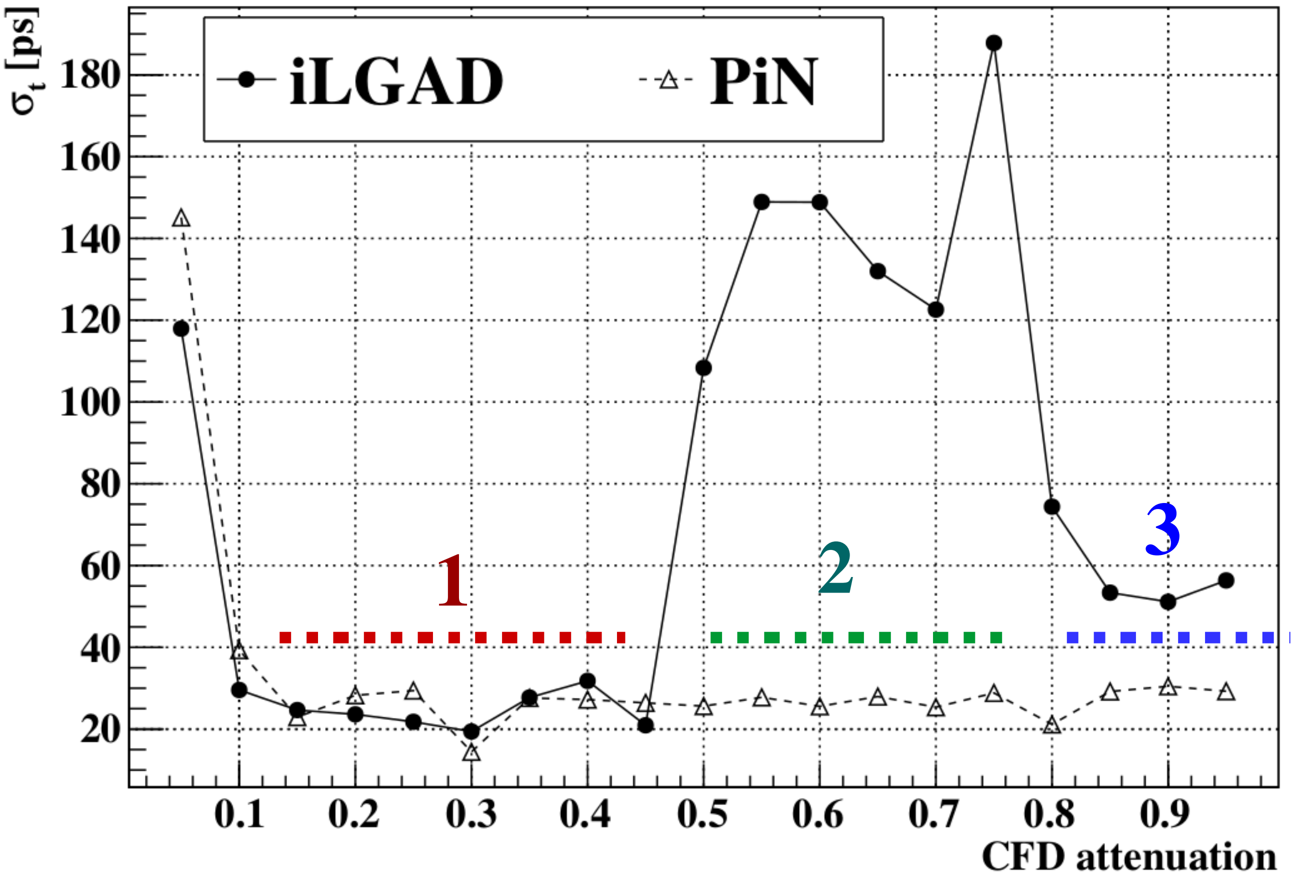


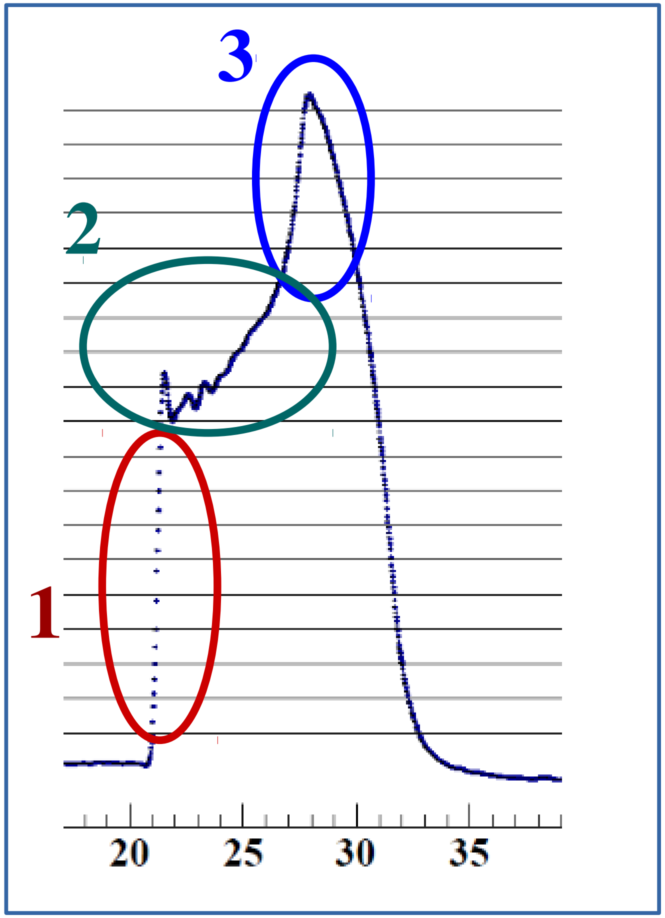
Emulate by software a real CFD electronic circuit



- Split the input signal in two parts
- Delay on part
- Attenuate ($-kV_{max}$) and invert the other
- Add the two signals together
- The zero crossing point of the bipolar signal (t_k) will always be constant

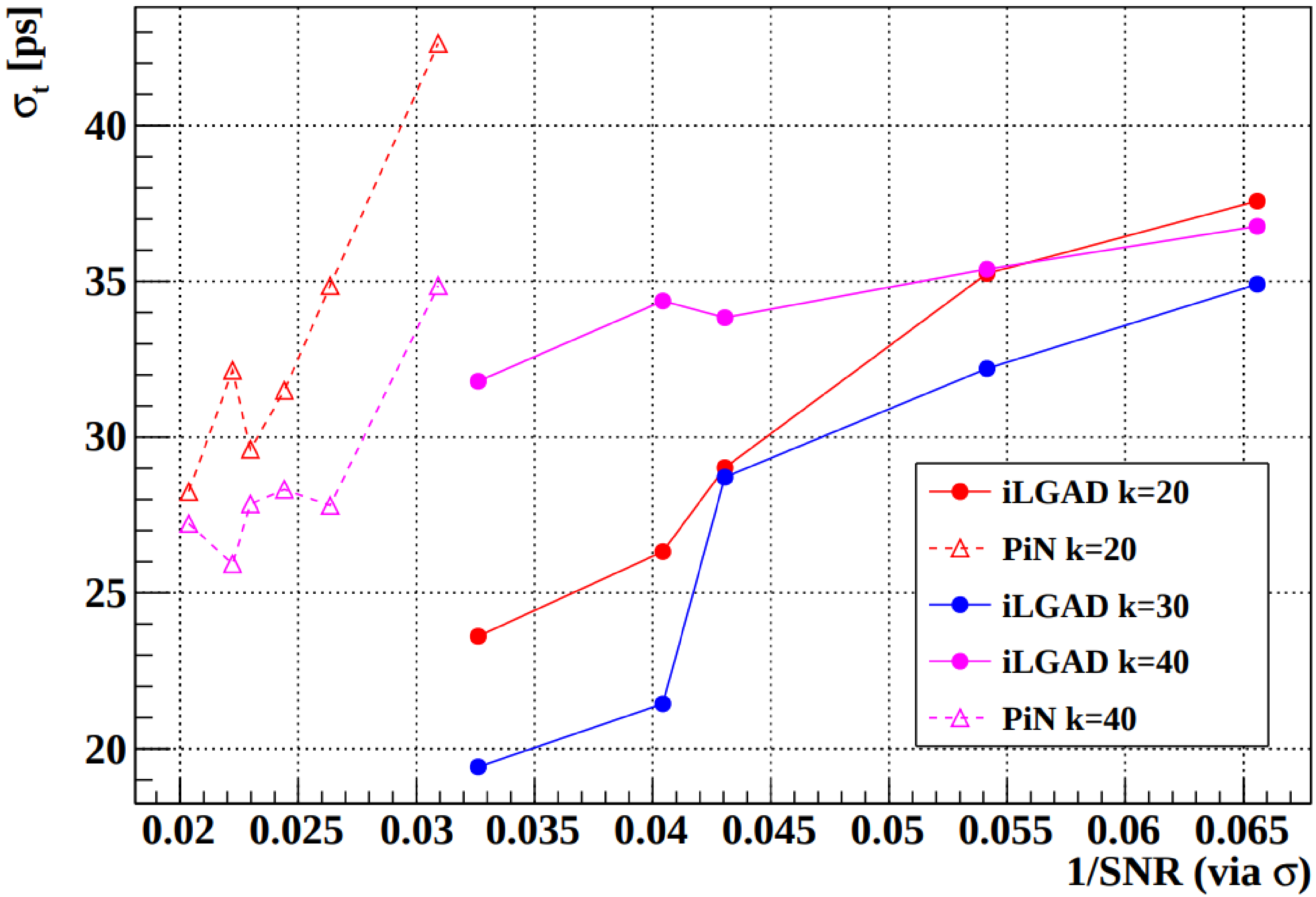
Constant Fraction Discrimination method (CFD):





- Optimum value of the k parameter for the I-LGAD in zone 1.
- For the PIN k parameter is optimum in almost the full range.

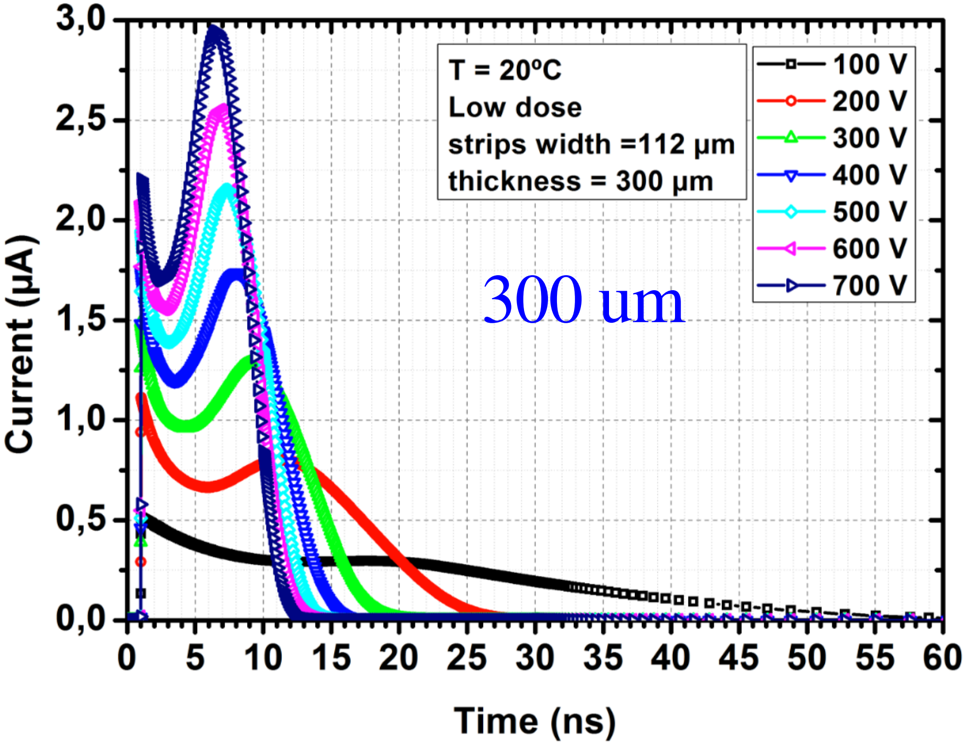
Constant Fraction Discrimination method (CFD):

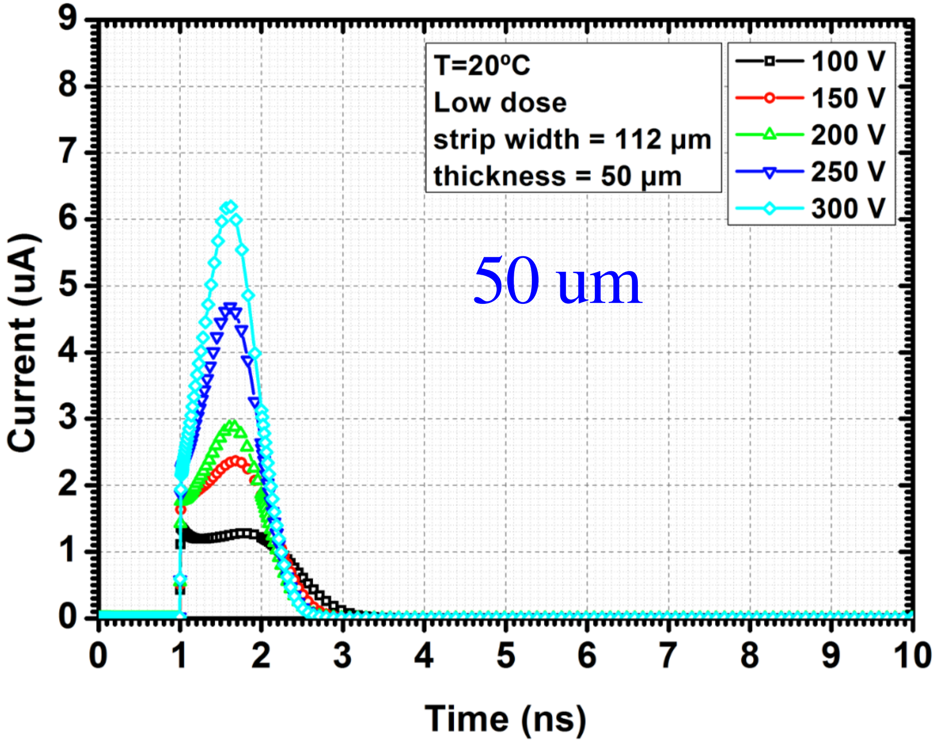


- Better time resolution for the I-LGAD even with lower SNR.

Constant Fraction Discrimination method (CFD):

Simulation 300 um vs 50 um.





- First part of the signal very fast and good for timing but not as good in SNR terms.
- Second part still good with better SNR but worse rise time.
- If we go to 50 um we can have both benefits: Good SNR and low rise time.

In-depth study of Inverse-Low Gain Avalanche Detectors (ILGAD) for 4-dimensional tracking:

Conclusions and outlook

- We compared the timing performance of one I-LGAD strip sensor with a similar PIN strip sensor.
- Time resolution was estimated using a more realistic CFD method.
- Better time resolution with the I-LGAD sensor for a lower SNR.

→ Simulations show a promising time performance of 50 um I-LGADs strip devices.

Thank you for your attention !!