Influence of the ionization density on LGAD gain as measured with TCT, TPA-TCT and a Sr-90

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17th (Virtual) "Trento" Workshop on Advanced Silicon Radiation Detectors

Outlook

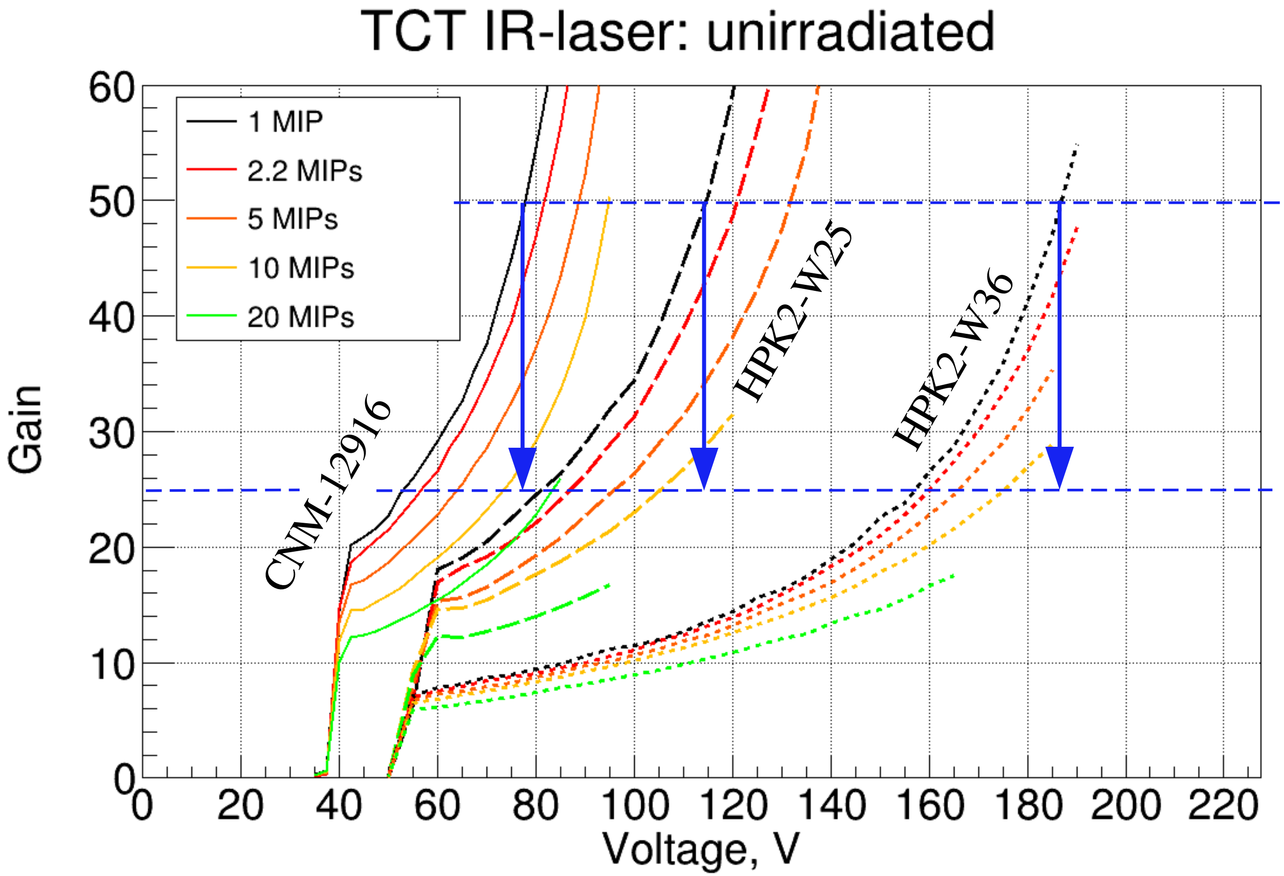
- Introduction: gain reduction mechanism.

- Influence of the ionizing density on 300 um thick LGAD gain:
  - TCT measurements with IR and red laser.
  - SR-90 measurements.
  - TCT-TPA measurements.

- Revisiting the existing impact ionization models.

- Summary.

Gain reduction mechanism observed in different kind of LGADs



Measurements done at +20C

Gain reduction effect observed for all the **50 um LGADs** that we studied.

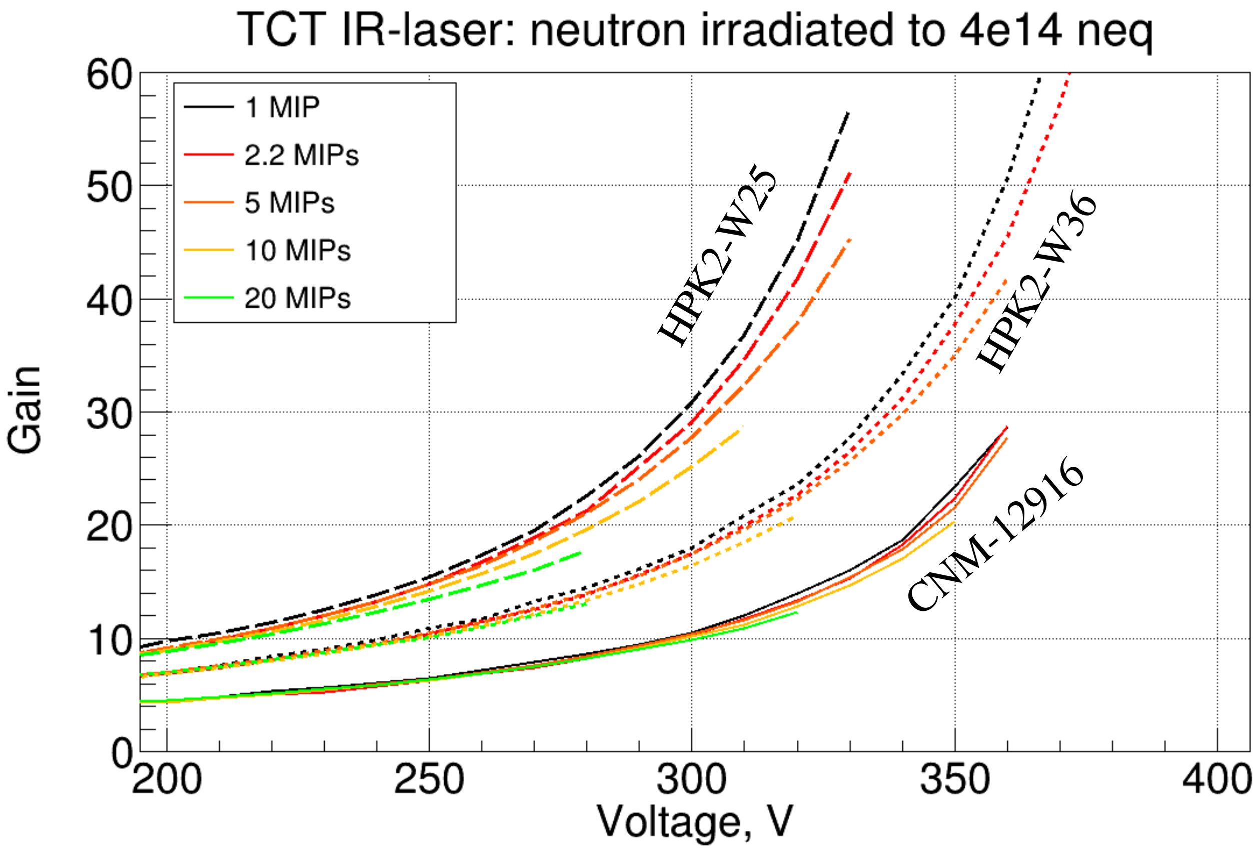
We observe a higher reduction for the LGADs with a higher nominal gain.

For all the samples: the higher the gain the higher the reduction, e.g:

- For a gain of 50 at 1 MIP the gain drops more than 50% for 20 MIPs.

First reported at: "E.Curras et al, 16th (Virtual) "Trento" Workshop on Advanced Silicon Radiation Detectors"

Gain reduction is present after irradiation: $4x10^{14}\ n_{eq}/cm^2$



Measurements done at -20C

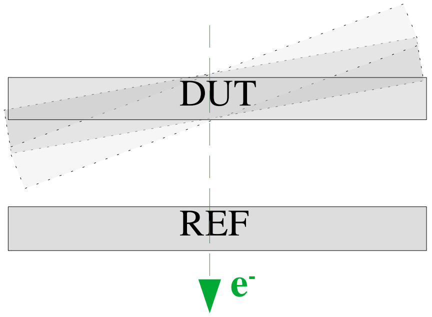
Gain reduction effect observed for all the 50 um irradiated LGADs to 4e14 n_{eq}.

The gain reduction is reduced with irradiation for all these devices.

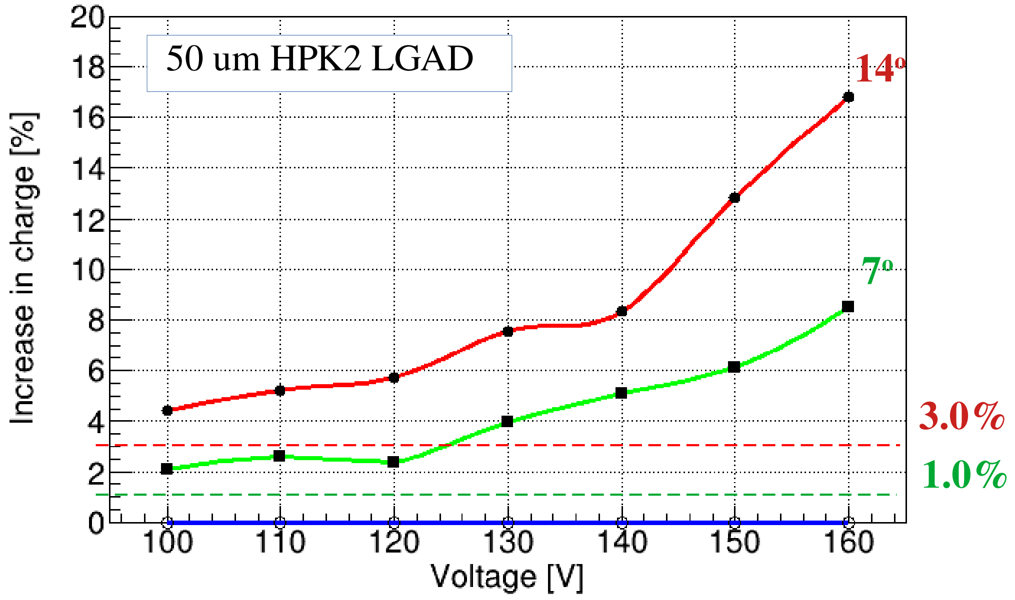
For all the samples: the higher the gain the higher the reduction. But the effect is reduced w.r.t the non-irradiated ones.

Timing performance and collected charge measured with Sr-90 is also affected

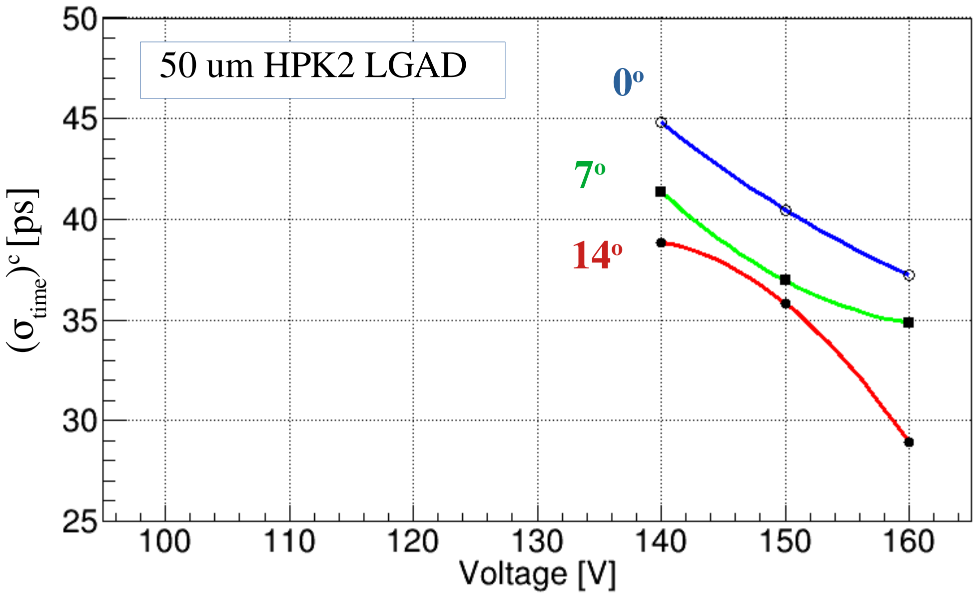
- Charge density arriving to the GL reduced by tilting the DUT.
- Clear increase in the **charge collected** by tilting the sample.
- Clear improve in the **time resolution** by tilting the sample.



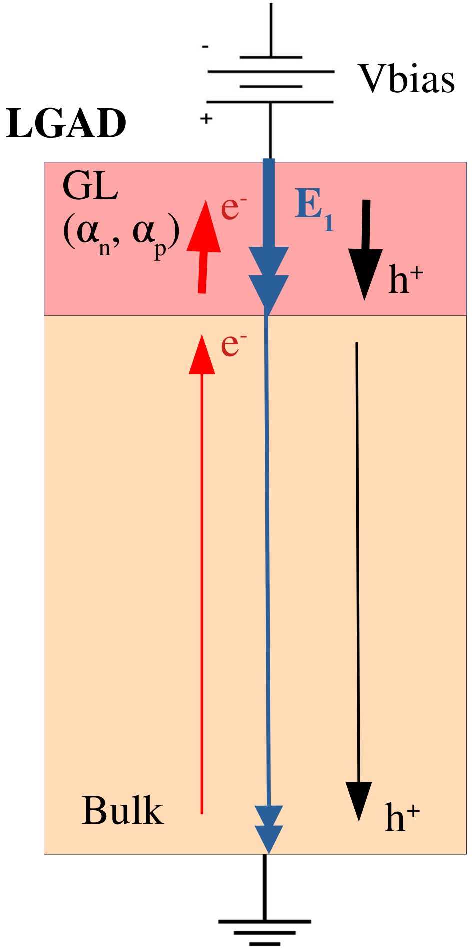
Increase in Charge

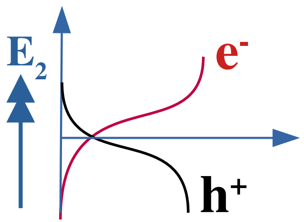


Decrease in Time Resolution



Gain reduction mechanism: electrostatics





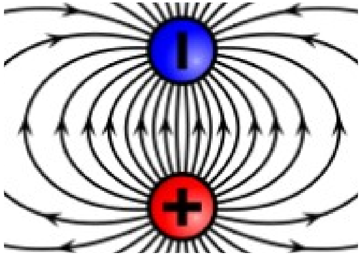
Due to the impact ionization process, the generated density of electrons will be higher at the front side of the GL, while for the h^+, their density increases at the back side of the GL. This generates a couter E_2 that reduces the impact ionization and lowers the gain.

$$E_{GL} = E_1(V) - E_2(E_1, T, t, d_{GL}, \delta)$$

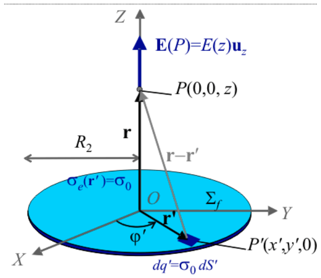
Charge density

Aditional term when we have signal

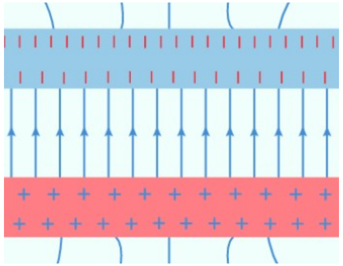
Sr-90 >> **TCT IR-laser** >> **Leakage current**



$$E_2 = \frac{Q}{4\pi\epsilon_0 r^2}\mathbf{u}_r = K\frac{Q}{r^2}\mathbf{u}_r$$



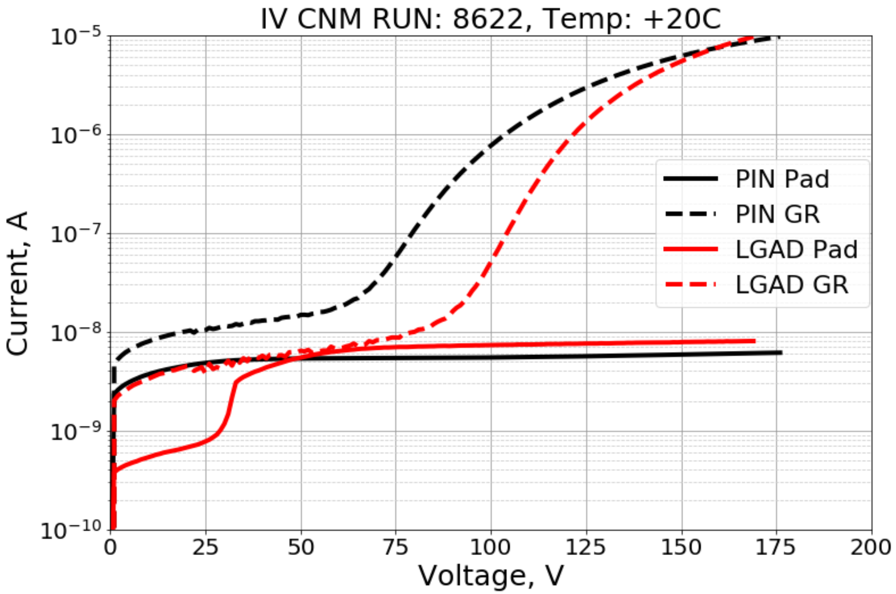
$$E_2 \sim \frac{\sigma_0 R_2^2}{4\varepsilon_0 z^2}\mathbf{u}_z = \frac{1}{4\pi\varepsilon_0}\frac{Q}{z^2}\mathbf{u}_z$$

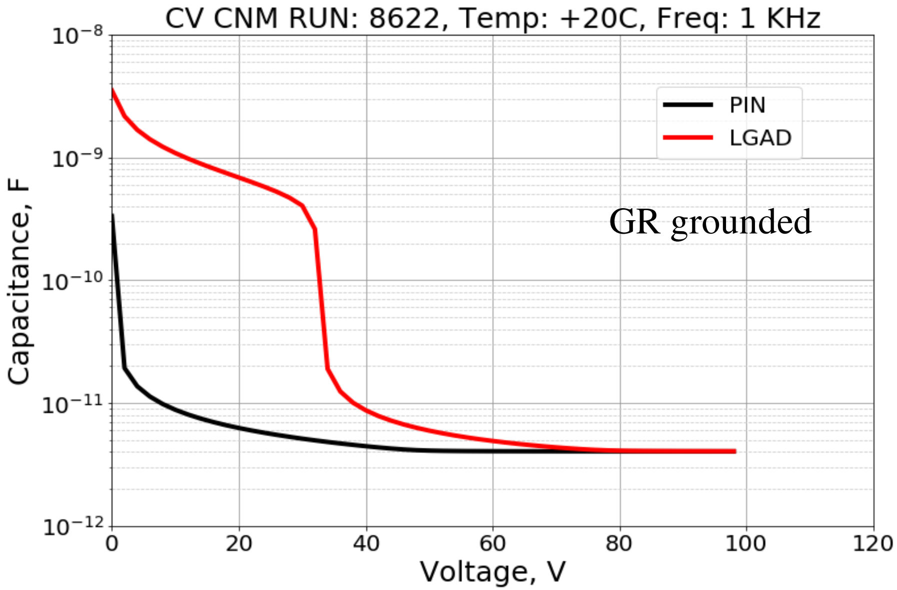


$$E_2 = \frac{\sigma}{\varepsilon_0}$$

See also: "G.KRAMBERGER, EFFECTS OF CHARGE SCREENING IN LGADS, 39TH RD50 WORKSHOP, VALENCIA"

Influence of the ionizing density in low gain 300 um CNM LGAD:



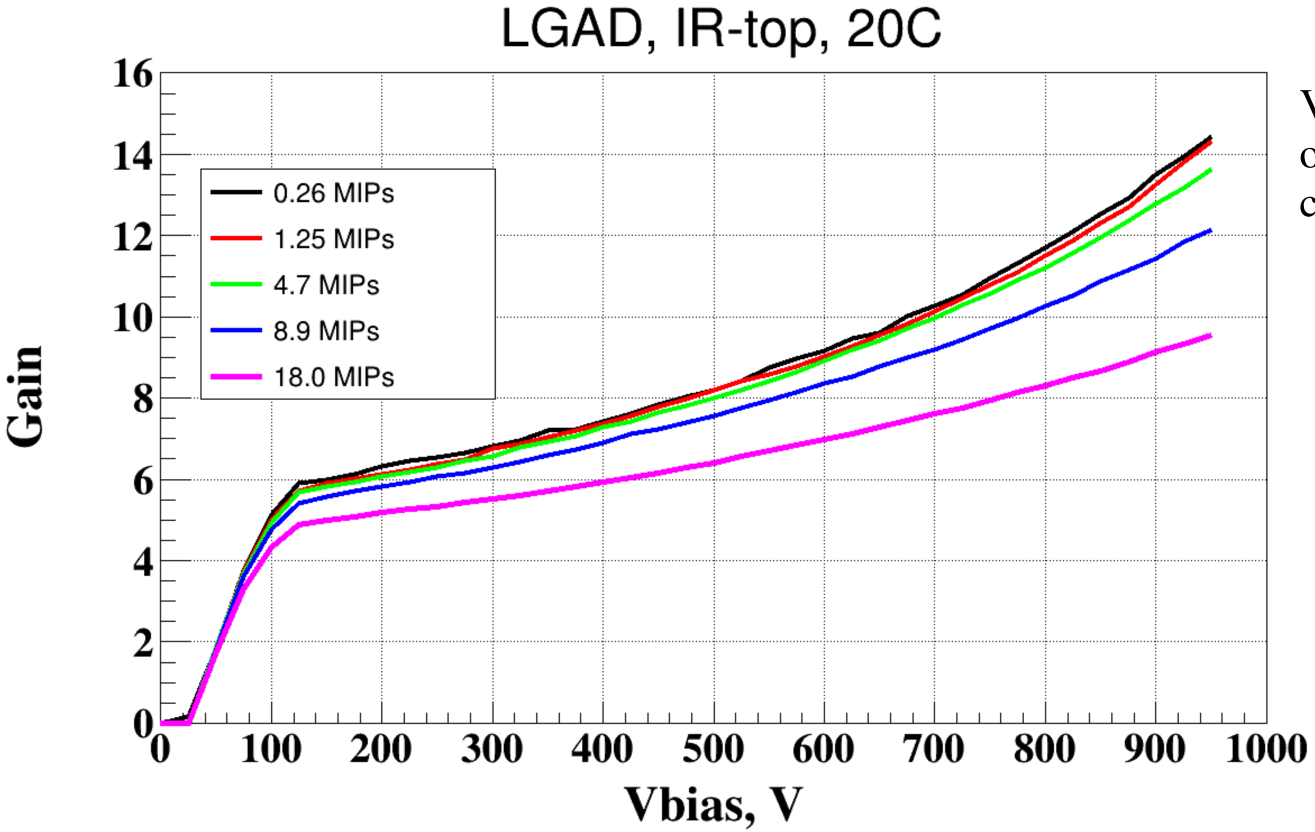


- Electrical properties of the devices under test:
  - $V_{GL} = 32$ V
  - $V_{bulk} = 64$ V
  - $C_{end} = 4$ pF
- Area : 3.3x3.3 mm
- Active thickness : 285 um

Unirradiated sensors !

AC gain at different charges densities:

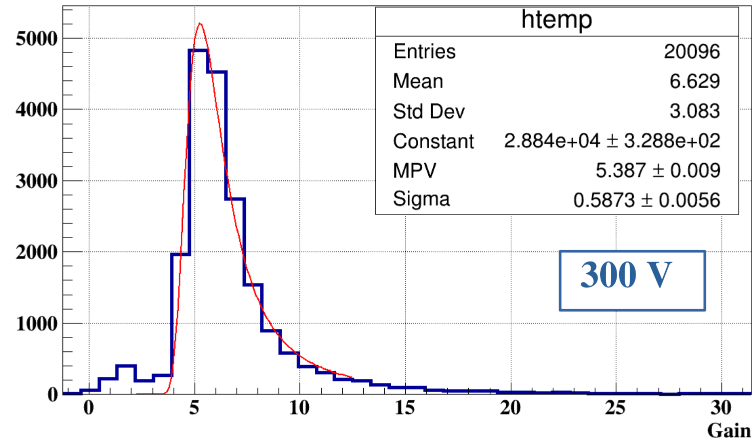
- Gain reference curves at different IR-laser intensities and a temperature of 20C.

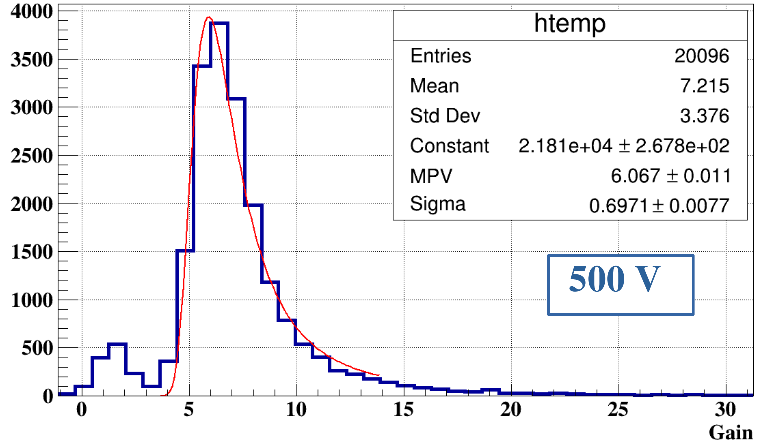


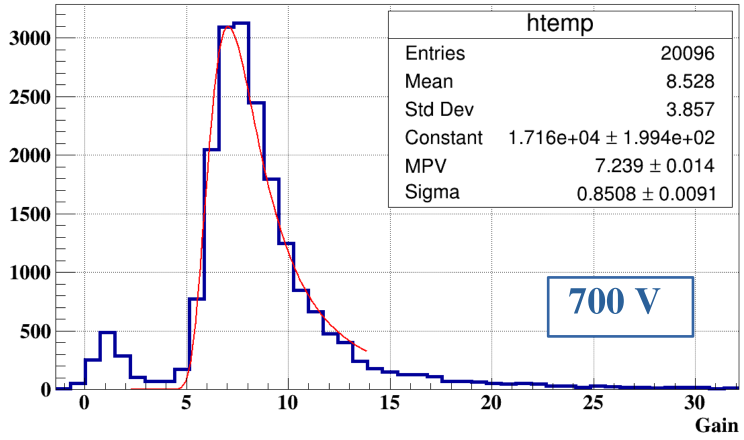
Very important gain reduction effect observed for a relatively low gain, if we compare with the 50 um LGADs.

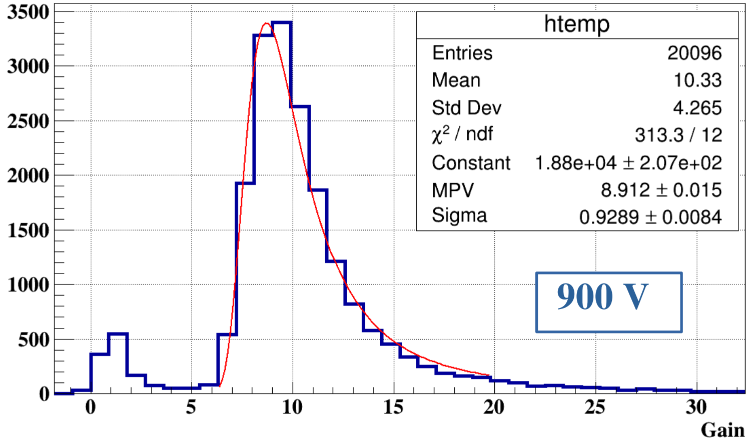
- For a gain of 14 at 1 MIP the gain drops more than 30% for 18 MIPs.

^{90}Sr GAIN measurements: 300 um-LGAD – Temp: 20^{o}C



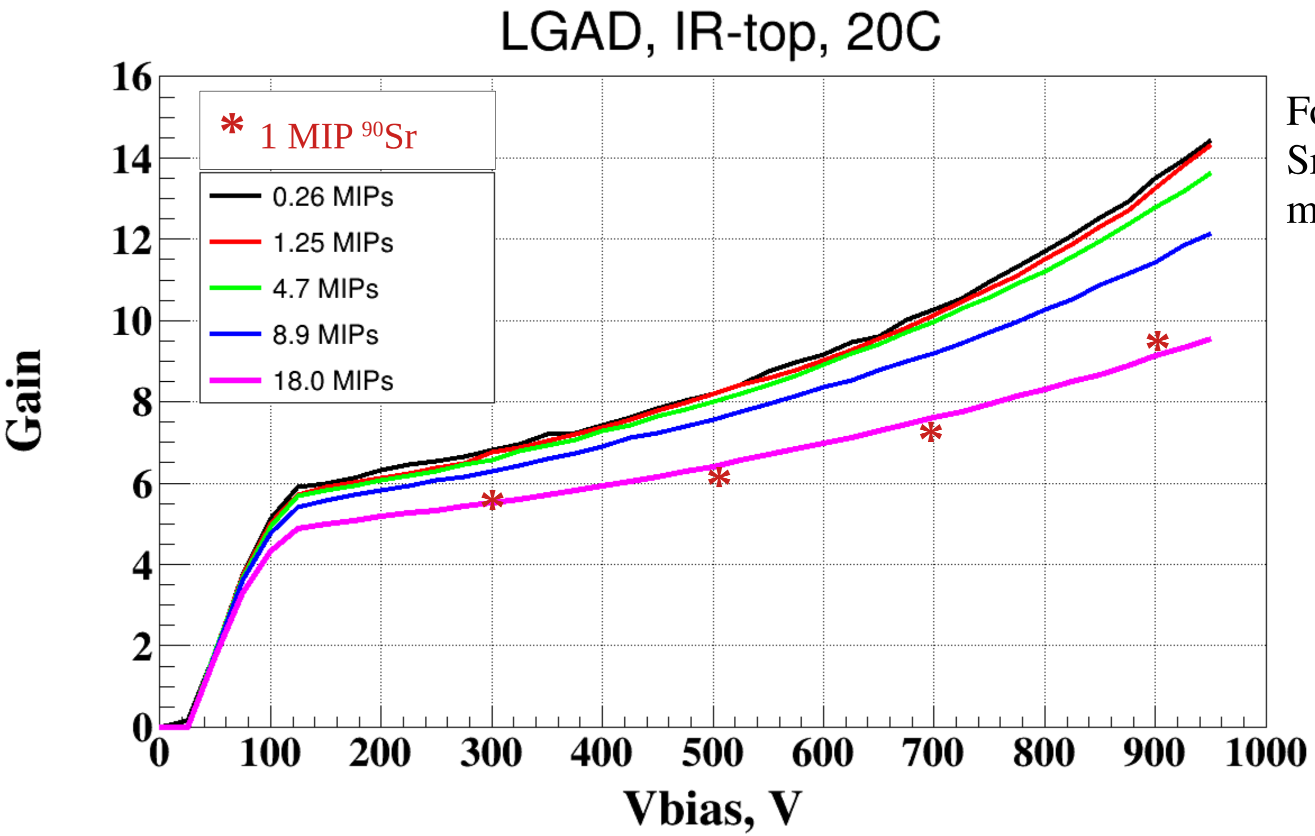






^{90}Sr GAIN measurements: LGAD - 20ºC

- Gain comparison TCT vs ^{90}Sr

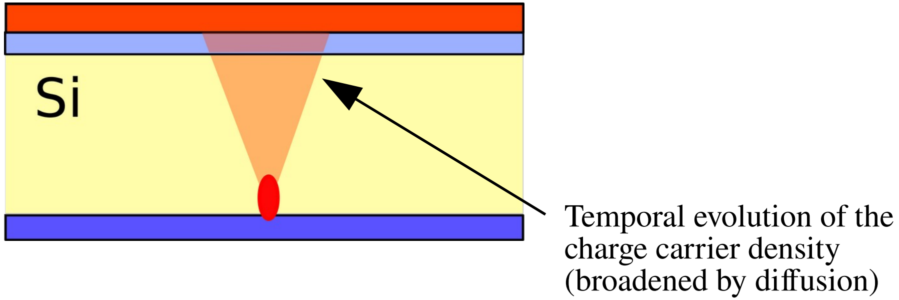


For this samples, the gain measured with the Sr-90 source is equivalent to the gain measure with the IR-laser tuned to 18 MIPs.

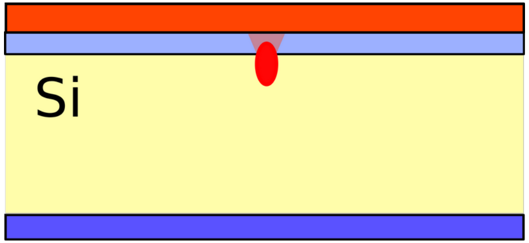
With TPA-TCT we can do the study as a function of the depth

Gain reduction by charge carrier density can be measured in a **single *z*-scan** using TPA-TCT:

Lower charge carrier density inside GL (higher gain):



Higher charge carrier density inside GL (lower gain):

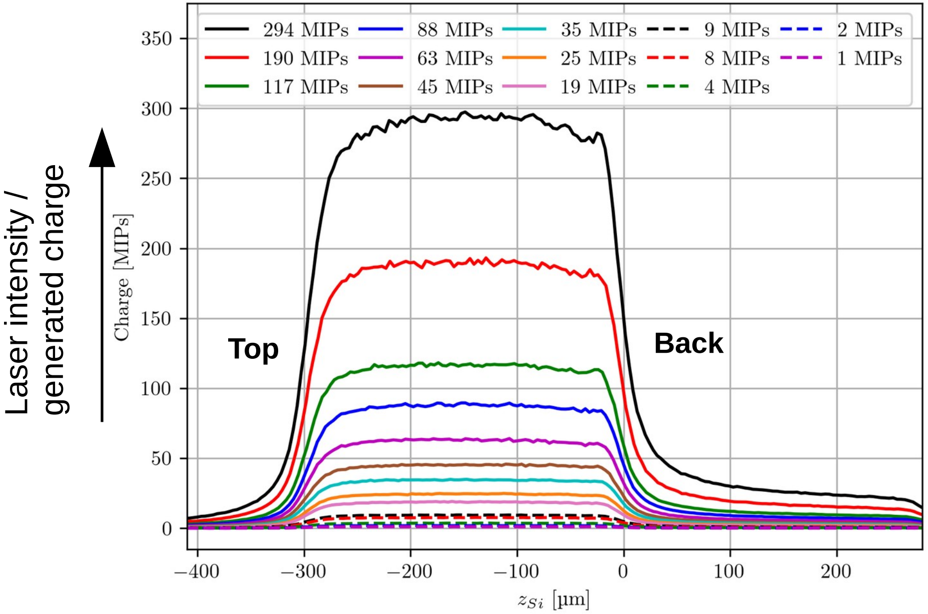


Measurement details:

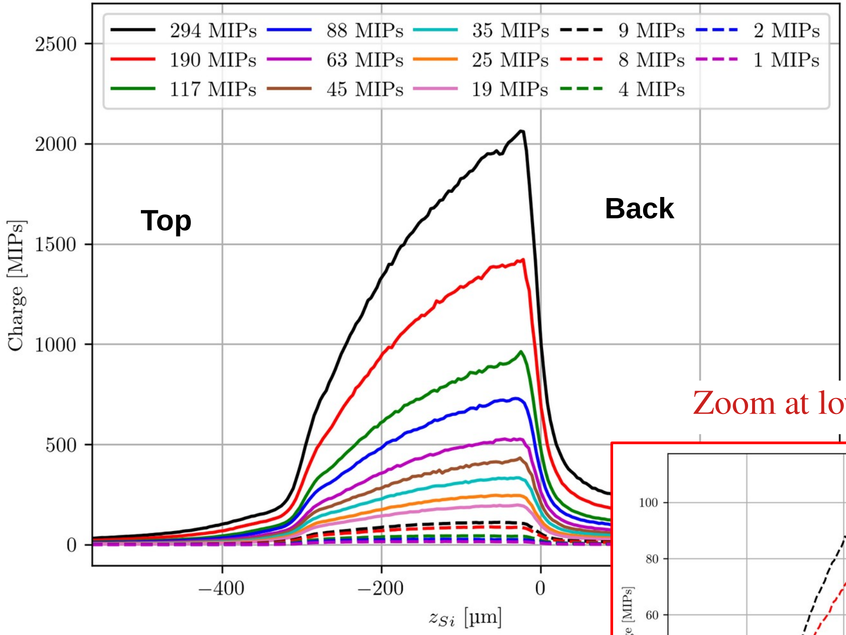
- Temperature controlled at 20°C
- 0% humidity (dry air)
- Tilt corrected (Details: 38th RD50 talk of M. Wiehe)
- Objective with NA = 0.5
- Light injection from the topside
- Back side biased

With TPA-TCT we can do the study as a function of the depth

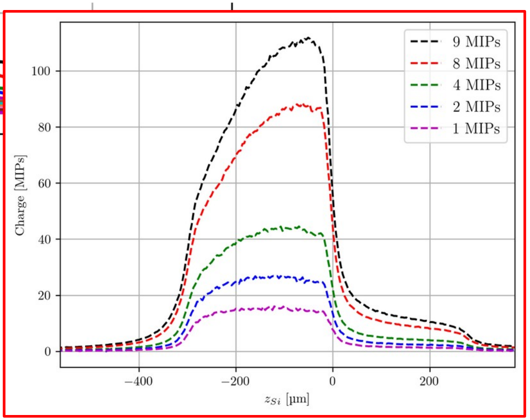
Charge collection in a <u>PIN</u> at different laser intensities :



Charge collection in a <u>LGAD</u> at different laser intensities (V_{bias} = 900 V):

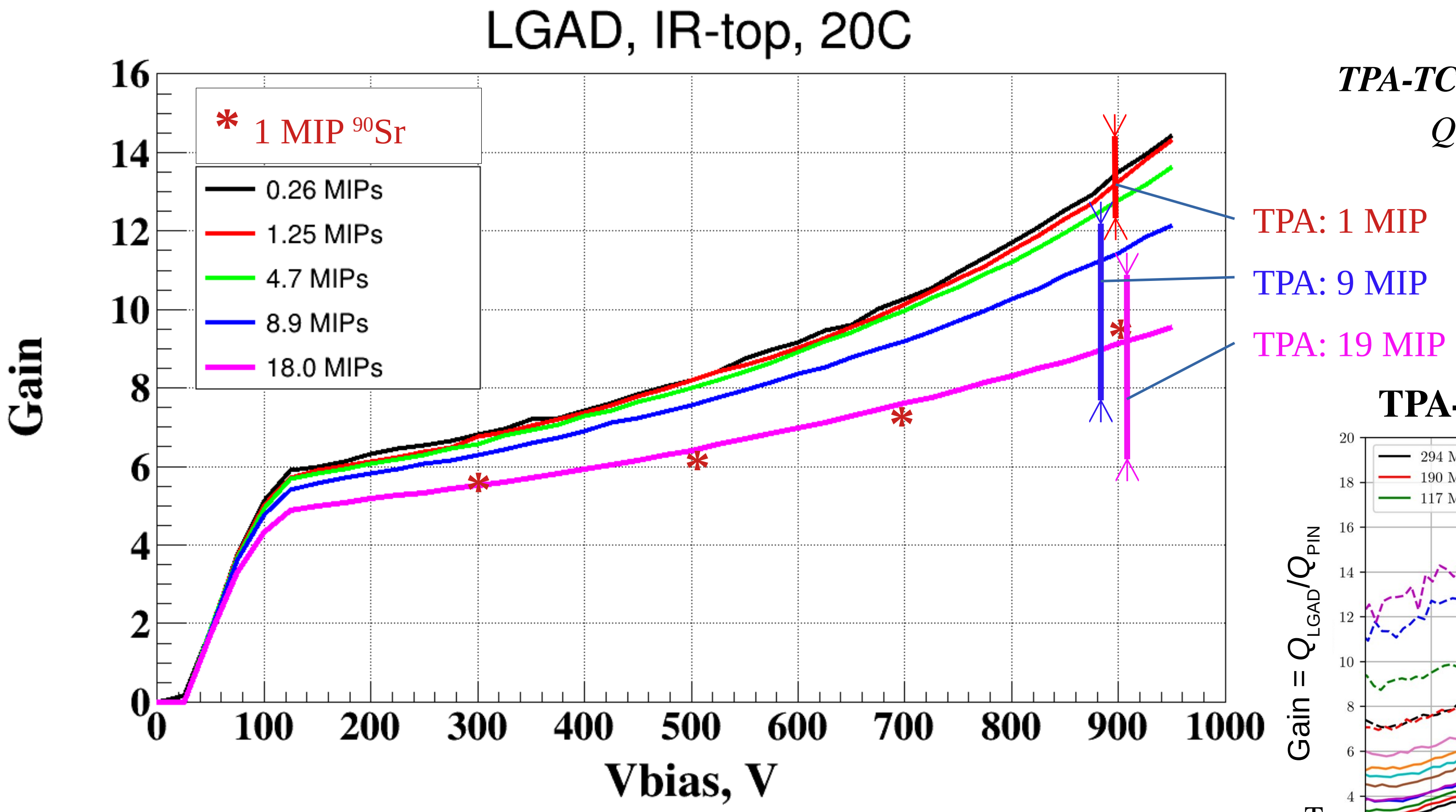


Zoom at lower intensities:



$Q_{\mathrm{LGAD}}(z)/Q_{\mathrm{PIN}}(z)$ yields gain curves

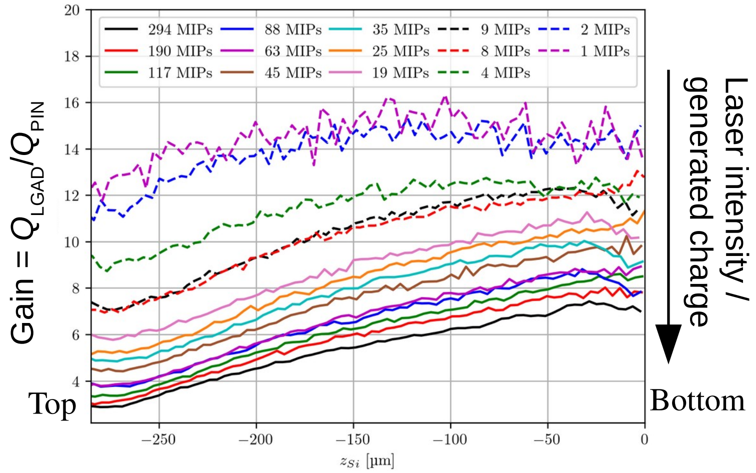
^{90}Sr vs TCT-IR vs TPA-TCT GAIN measurements (300 um LGAD)



TPA-TCT:

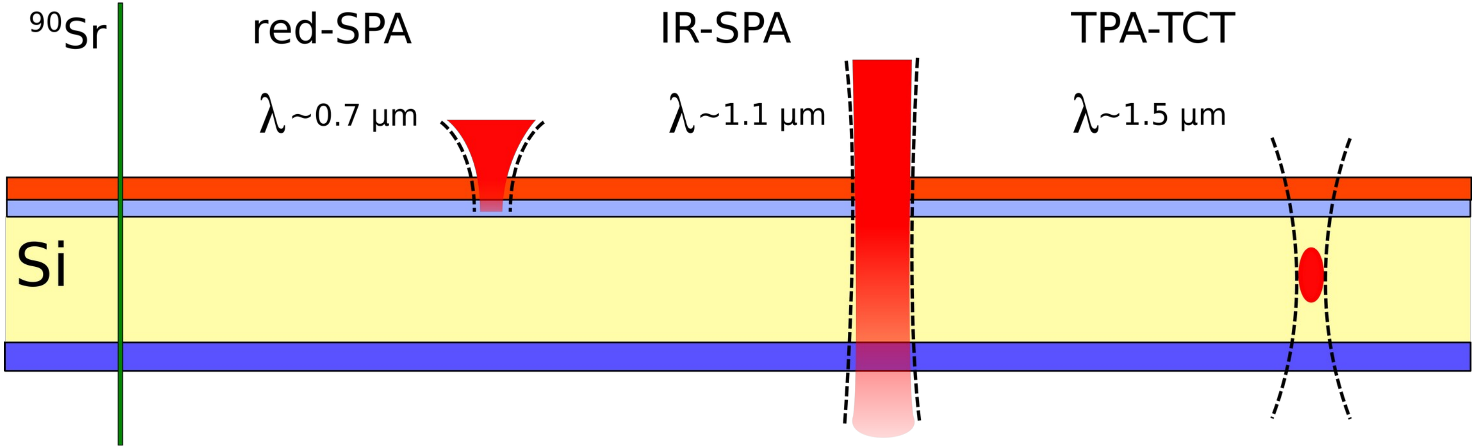
$Q_{LGAD}(z)/Q_{PIN}(z)$ yields gain curves

TPA-TCT Gain curves (900 V):



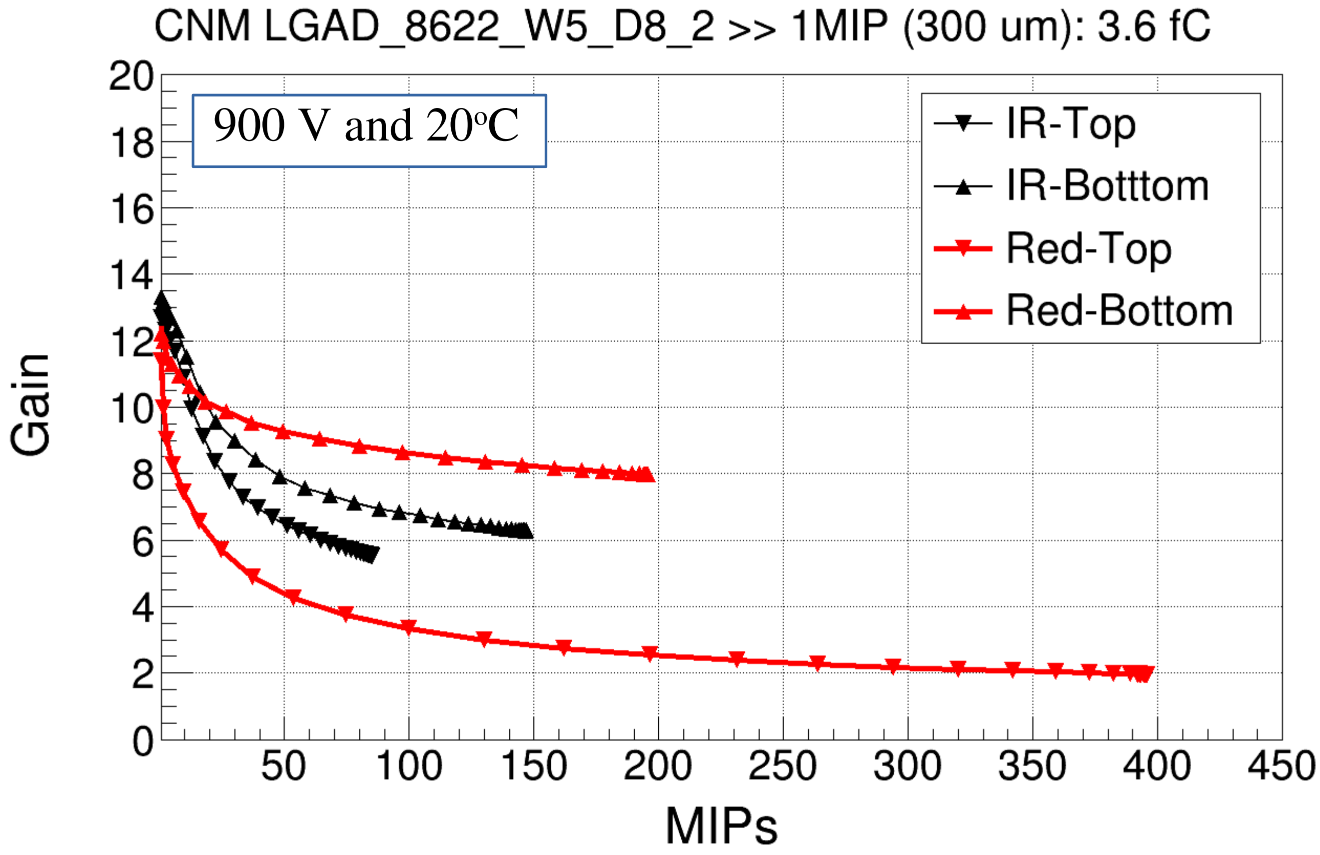
^{90}Sr vs TCT vs TPA-TCT GAIN measurements (300 um LGAD)

The here discussed gain reduction mechanism is driven by the excess electron density inside the gain layer.
The excess carrier volumes and carrier distribution provided by the different methods are very different:



- Difficult to extract the charge carrier density that corresponds to the gain reduction mechanism (Analysis is ongoing)
- For the comparison between the methods the data against the generated charge in equivalents of MIPs

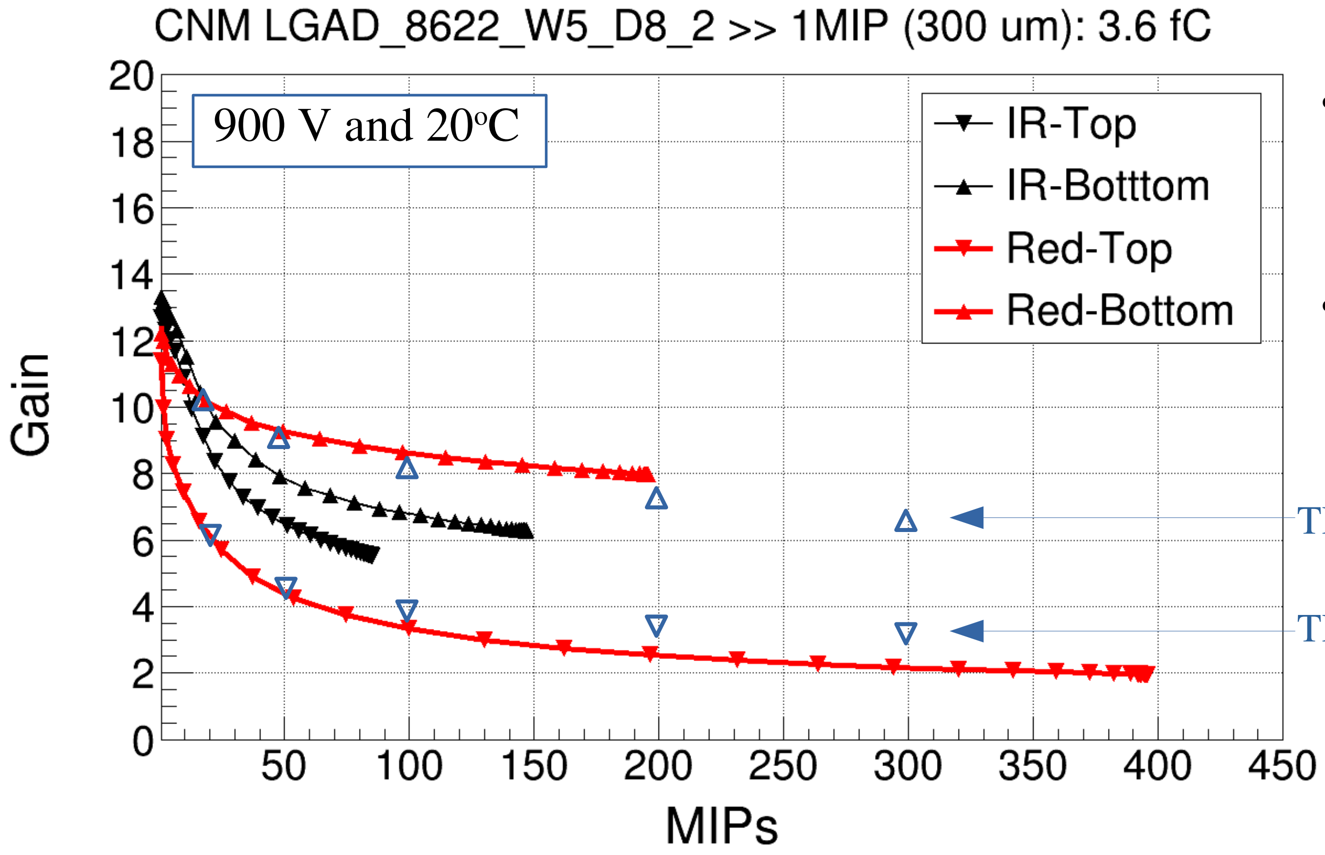
Do we see saturation if we keep increasing the charge density?



- We see more gain reduction when we illuminate from the top.
- The difference top-bottom is much more accentuated with the red laser: same effect as in TPA-TCT top vs bottom.
- We do not see a clear saturation and it seems that the gain is slowly decreasing when the laser intensity is increasing …

  We still can double the laser intensity in all the configurations

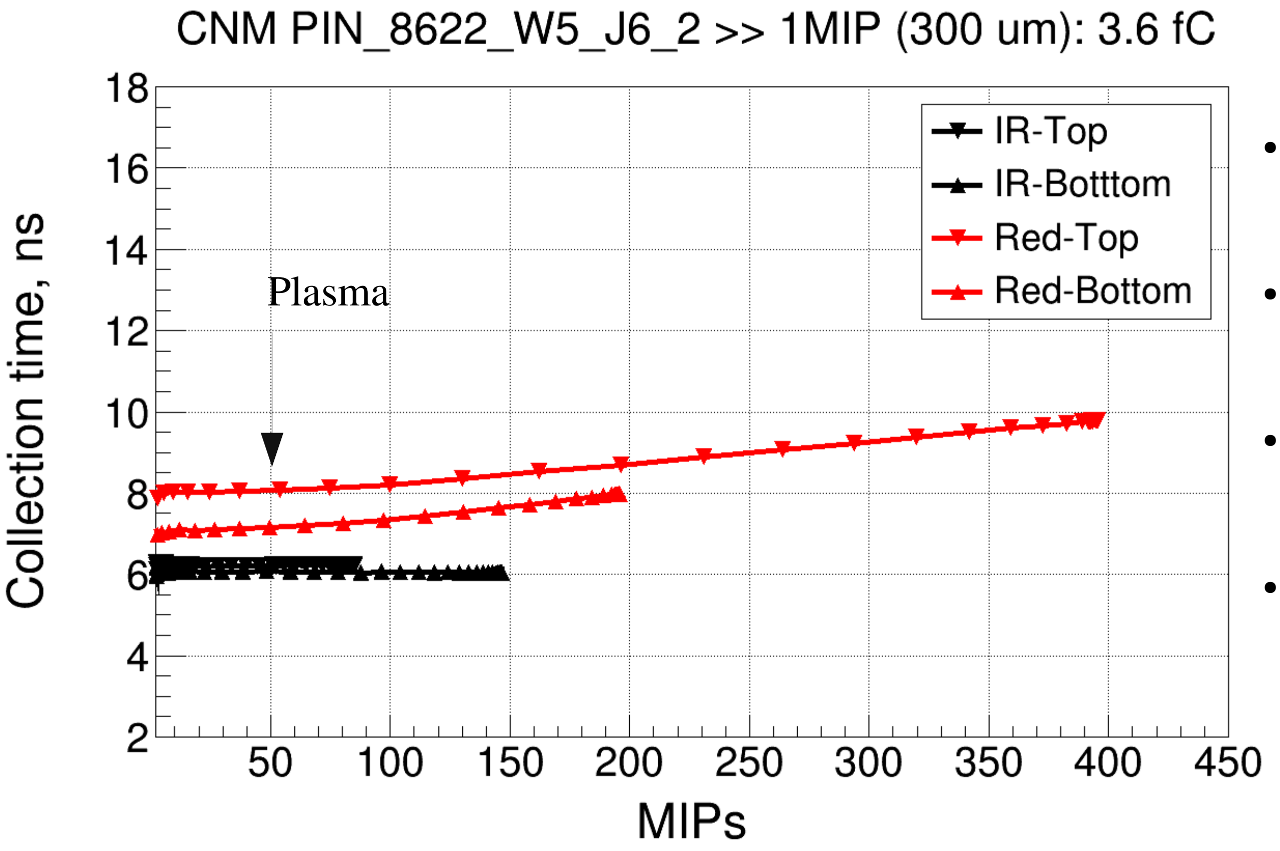
Do we see saturation if we keep increasing the charge density?



- If we add some of the TPA-TCT measurements, these agree very well with the TCT red-laser measurements
- Still we want to compare this results in terms of charge density (e^-/cm^3), but it is not straightforward …

Work in progress

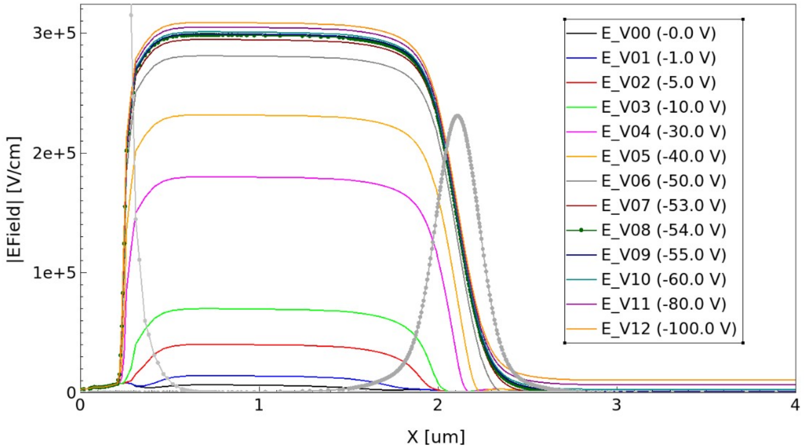
Do we see saturation if we keep increasing the charge density?



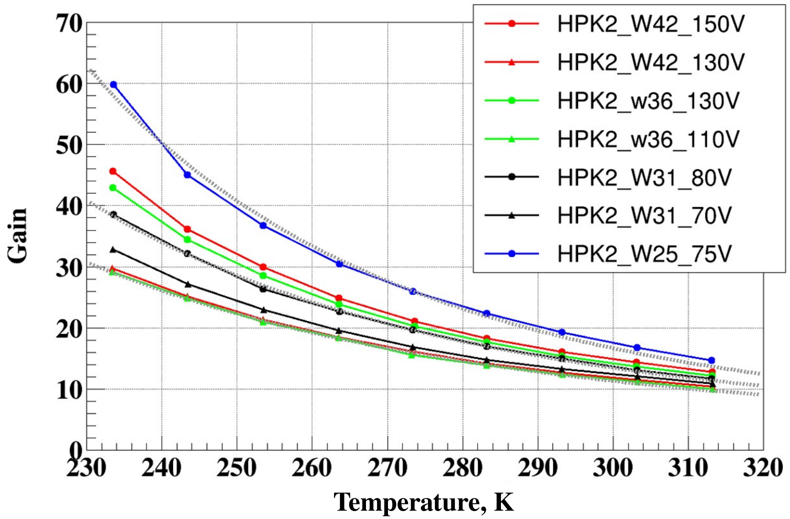
- In the case of the TCT red-laser we start to see plasma around 30-40 MIPs.
- Same observation for the TPA-TCT measurements.
- In the case of the TCT IR-laser we do not see any plasma up to 150 MIPs
- We are studying if the presence of plasma affects further the gain.

Working in a new impact ionization parameter ($\alpha_n(E,T)$, $\alpha_p(E,T)$) model: complicated picture !

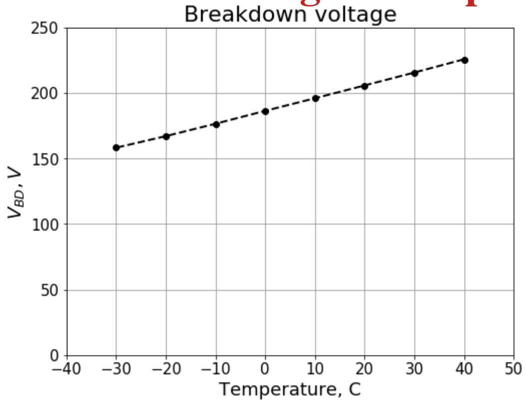
Simulations



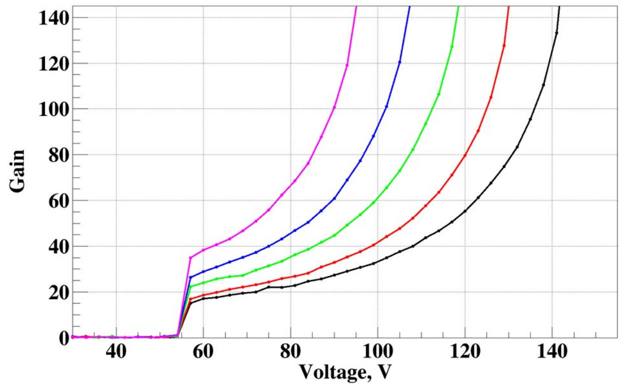
Gain measurements vs Temperature



Breakdown voltage vs temperature



Gain vs Vbias



$$M_n = exp(d_1 \alpha_n) = exp(d_1 exp(\frac{k_n T}{E_{field}})))$$

DC gain from IV measurements

Gain reduction effect

Measurements of α_n, α_p

… work in progress

Summary

- Gain reduction mechanism study extended to 300 um thick LGADs .

- TPA-TCT is a very useful tool for this study:
  - Gain vs charge deposition in depth.
  - Charge carriers diffusion reduced the charge density at the GL. Higher gain when we illuminate at the back side of the detector.
  - Possible to study the effects of the plasma formation in the gain.

- The gain reduction effect does not seem to saturate at very high charge densities, gain keeps decreasing.
  - We reached already the plasma regime with TPA-TCT and TCT Red-laser.

- Working on a new impact ionization parameter (α_n(E,T), α_p(E,T)) model.

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Thank you for your attention