“Study of gain homogeneity and radiation effects of Low Gain Avalanche Pad Detectors”

JC79 (paper)， 09/28/2018

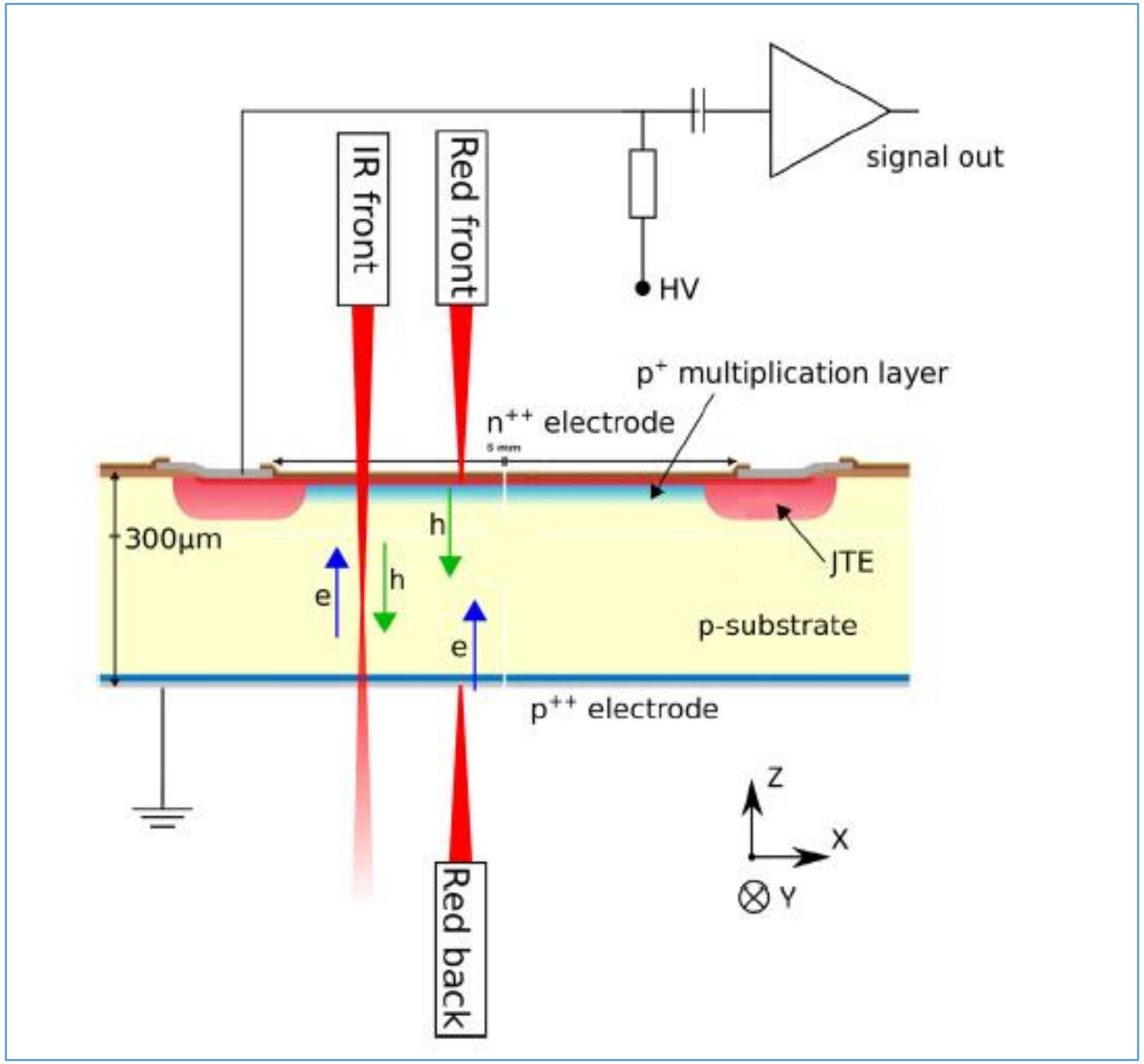


Fig. TCT measurement setup

TCT: Transient Current Tchnique

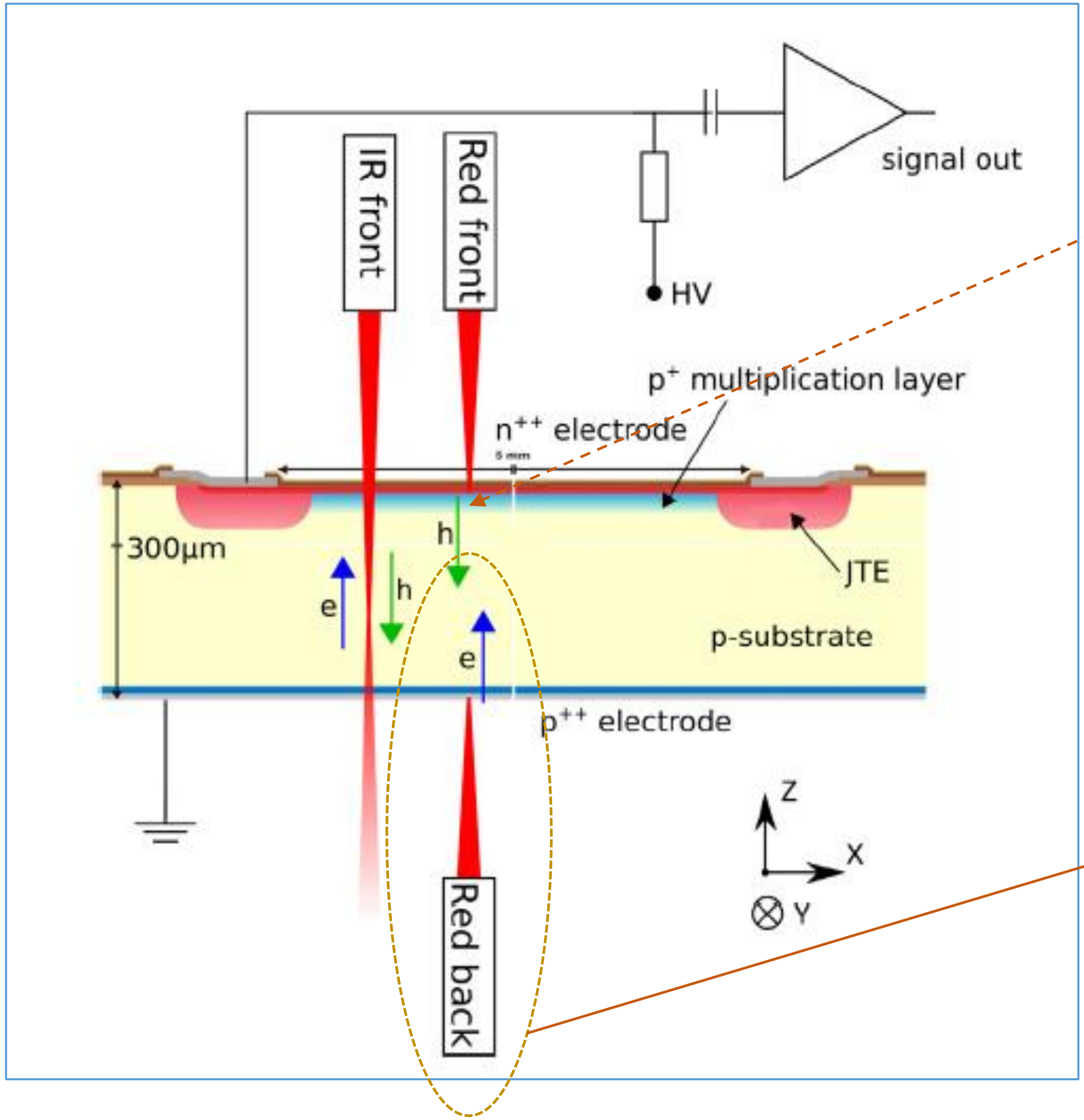
= illuminating the sensor (from front/back/side direction) with Laser etc. to induce the electron/hole pairs inside at desired position

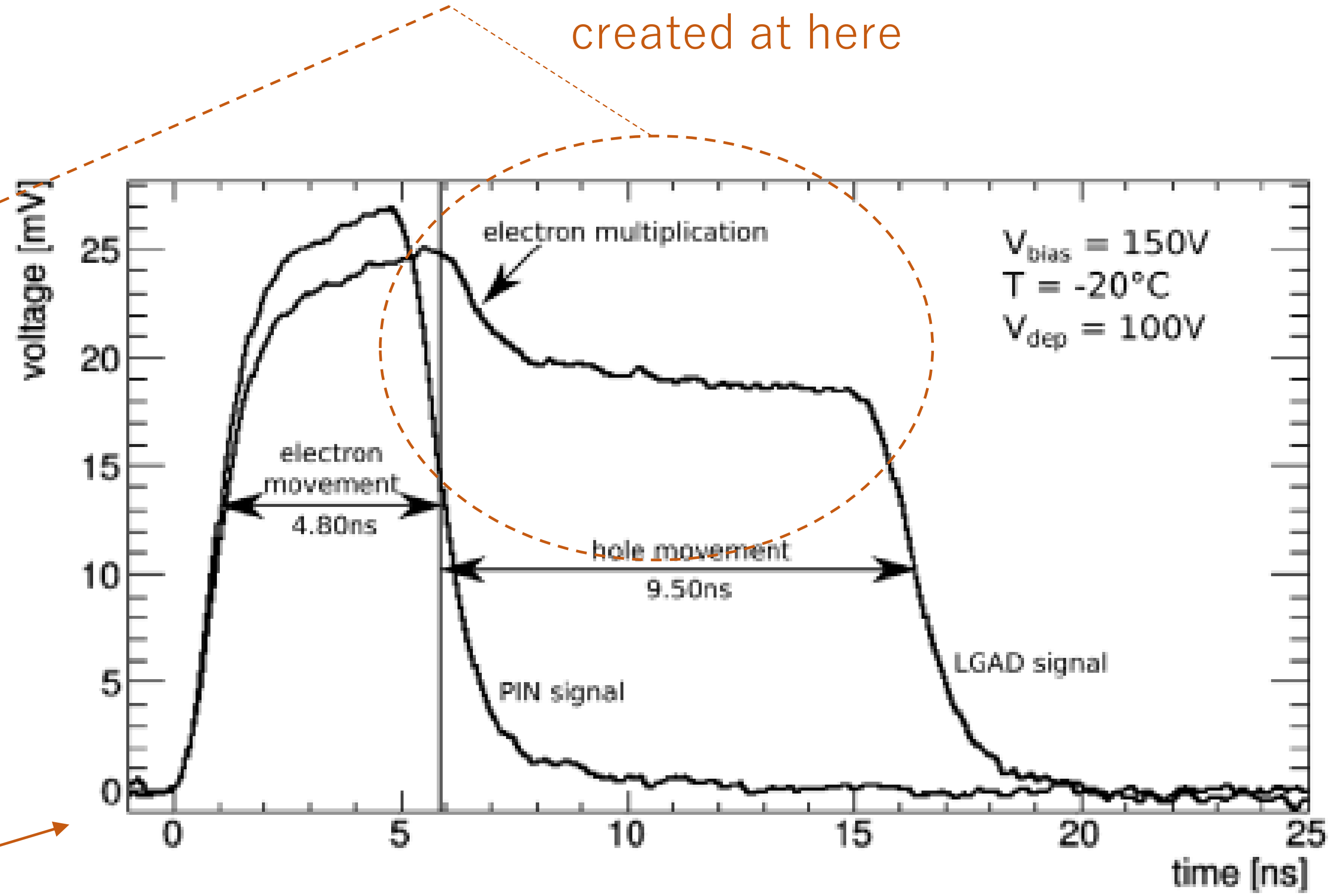
Laser (in this paper) :

"Red" (λ=660 nm) from the front/back side which can absorbed (created pairs) immediately

"Infra-red" (λ=1064 nm) from the front side which can penetrate the whole sensor

“Electron” Injection

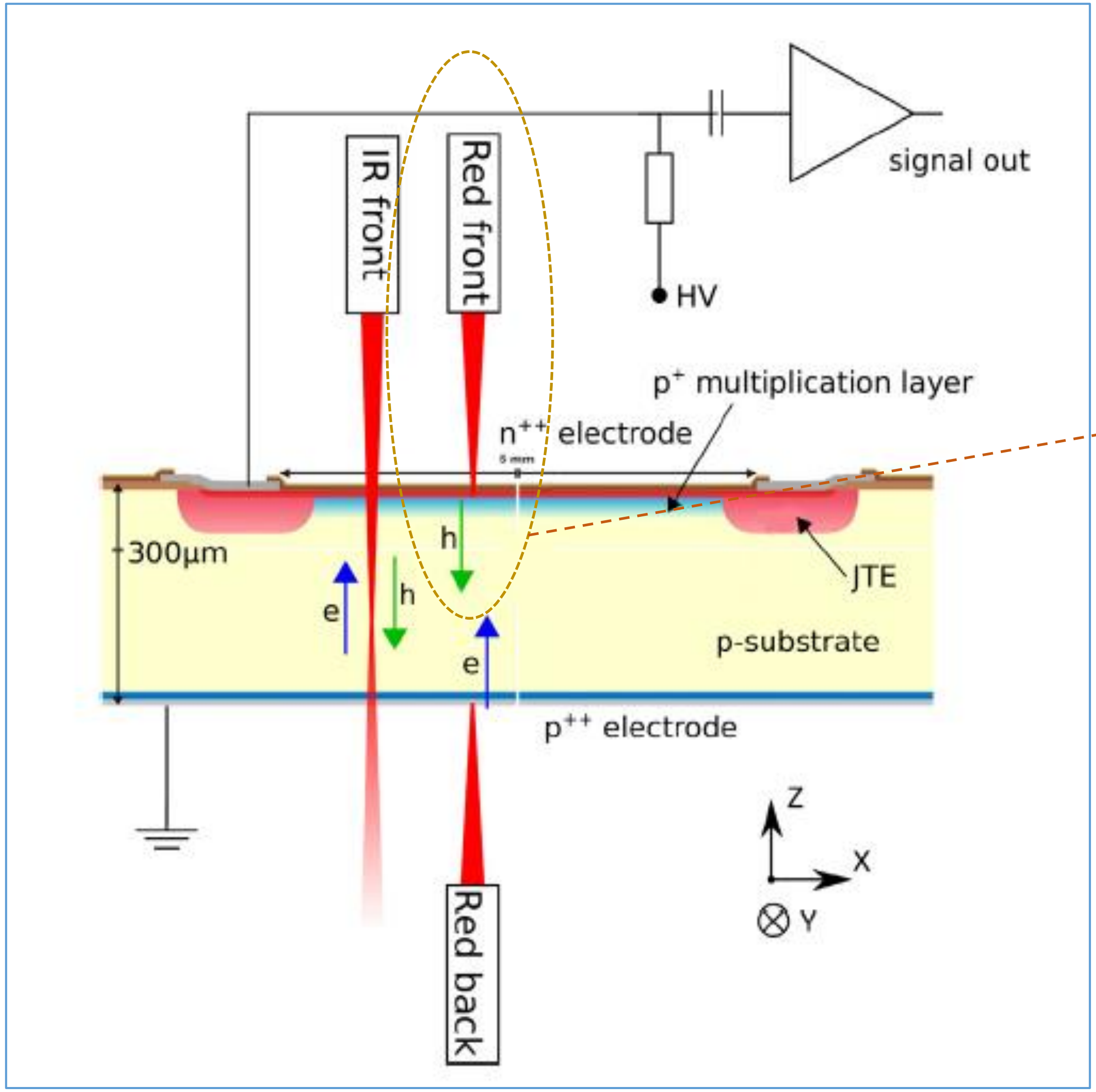


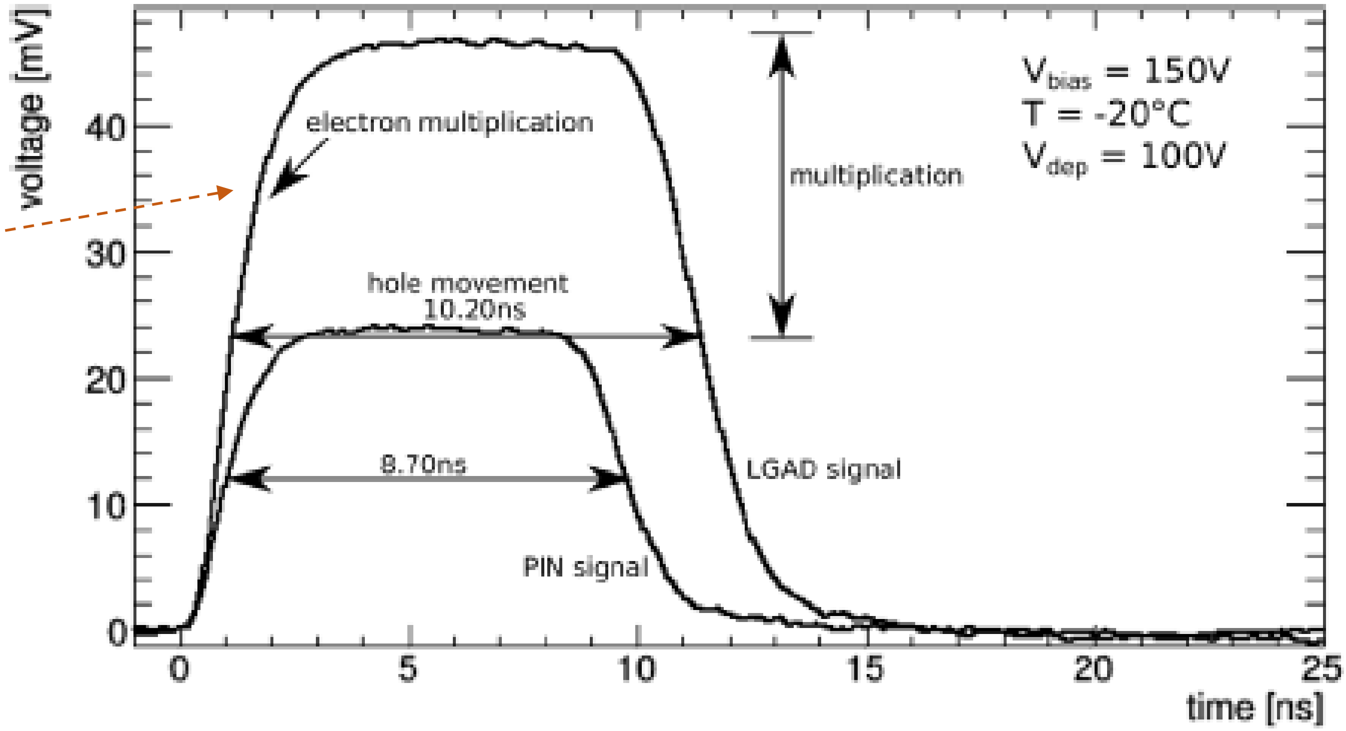


(a) Electron injection [6].

Velocity (mobility) of the hole is generally ~ 3 times slower than the electron.

"Hole" Injection

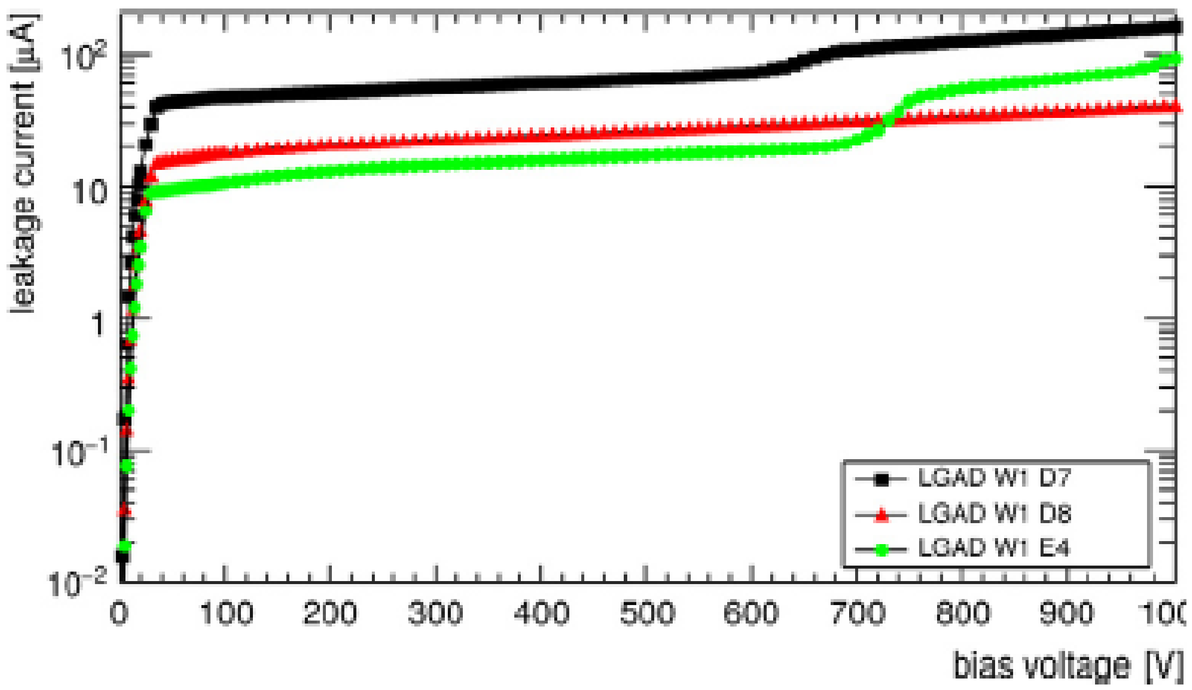




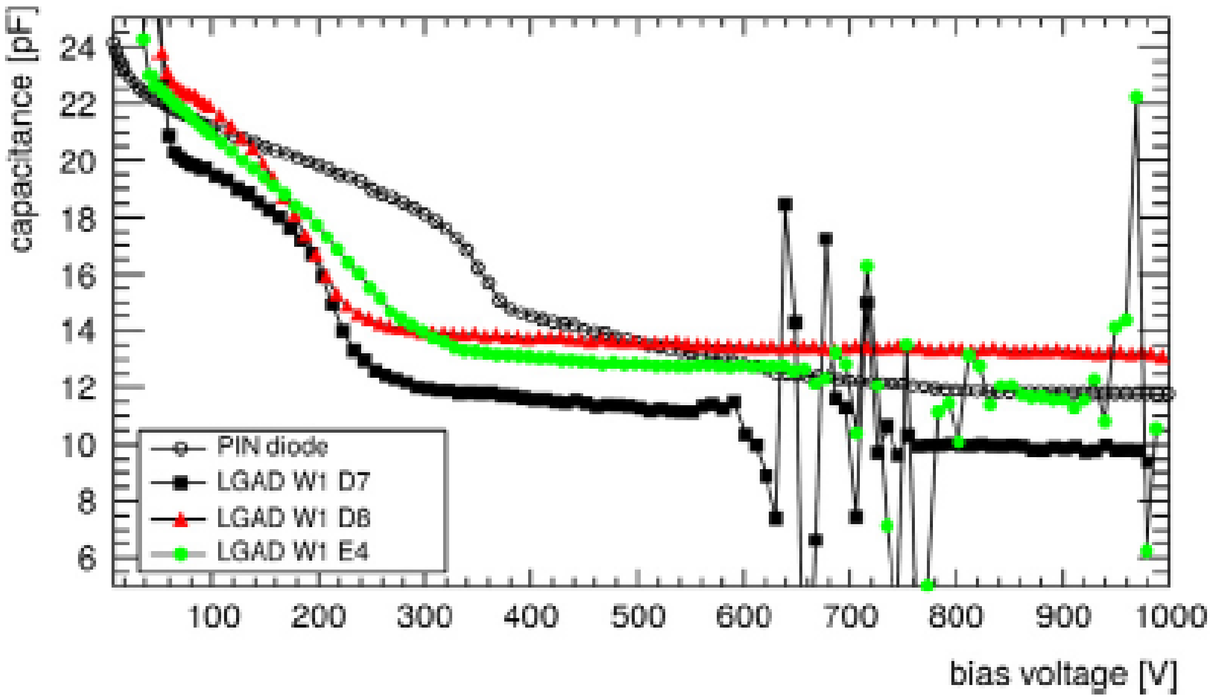
(b) Hole injection.

Arriving time of the holes at p++ electrode between the initial one & created by the multiplication layer is the same order

Measurements for unirradiated LGAD devices I.



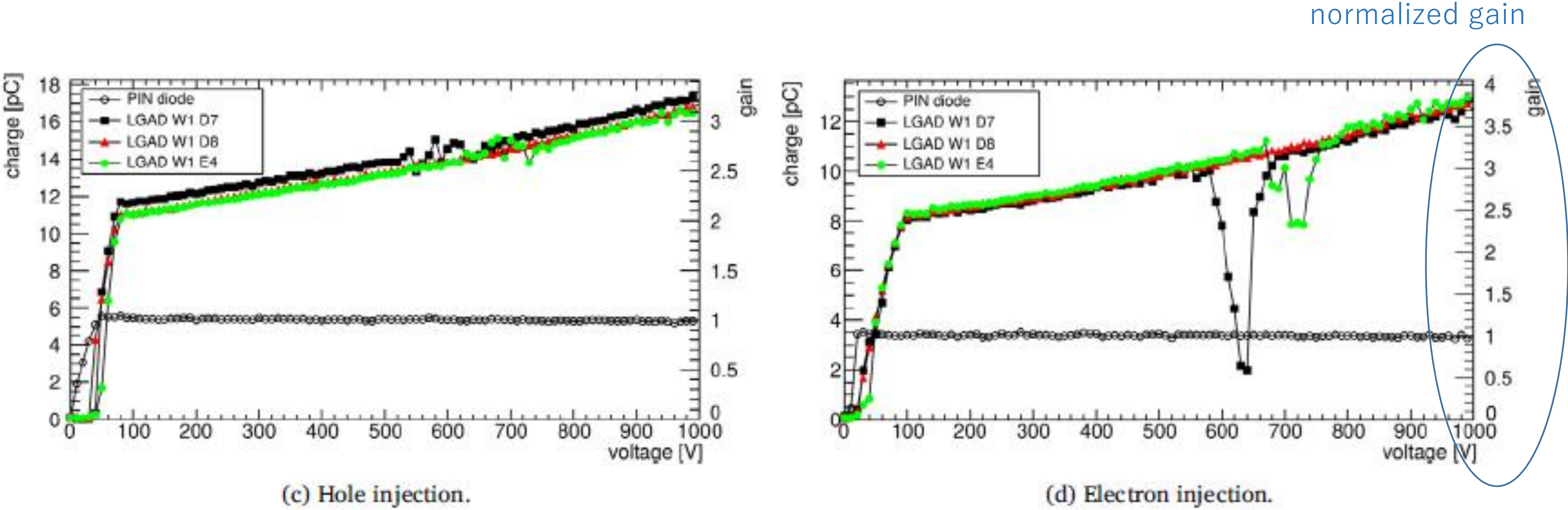
(a) IV measurement.



(b) CV measurement.

IV & CV measurement

Measurements for unirradiated LGAD devices II.



(c) Hole injection.

(d) Electron injection.

Collected charge VS bias voltage

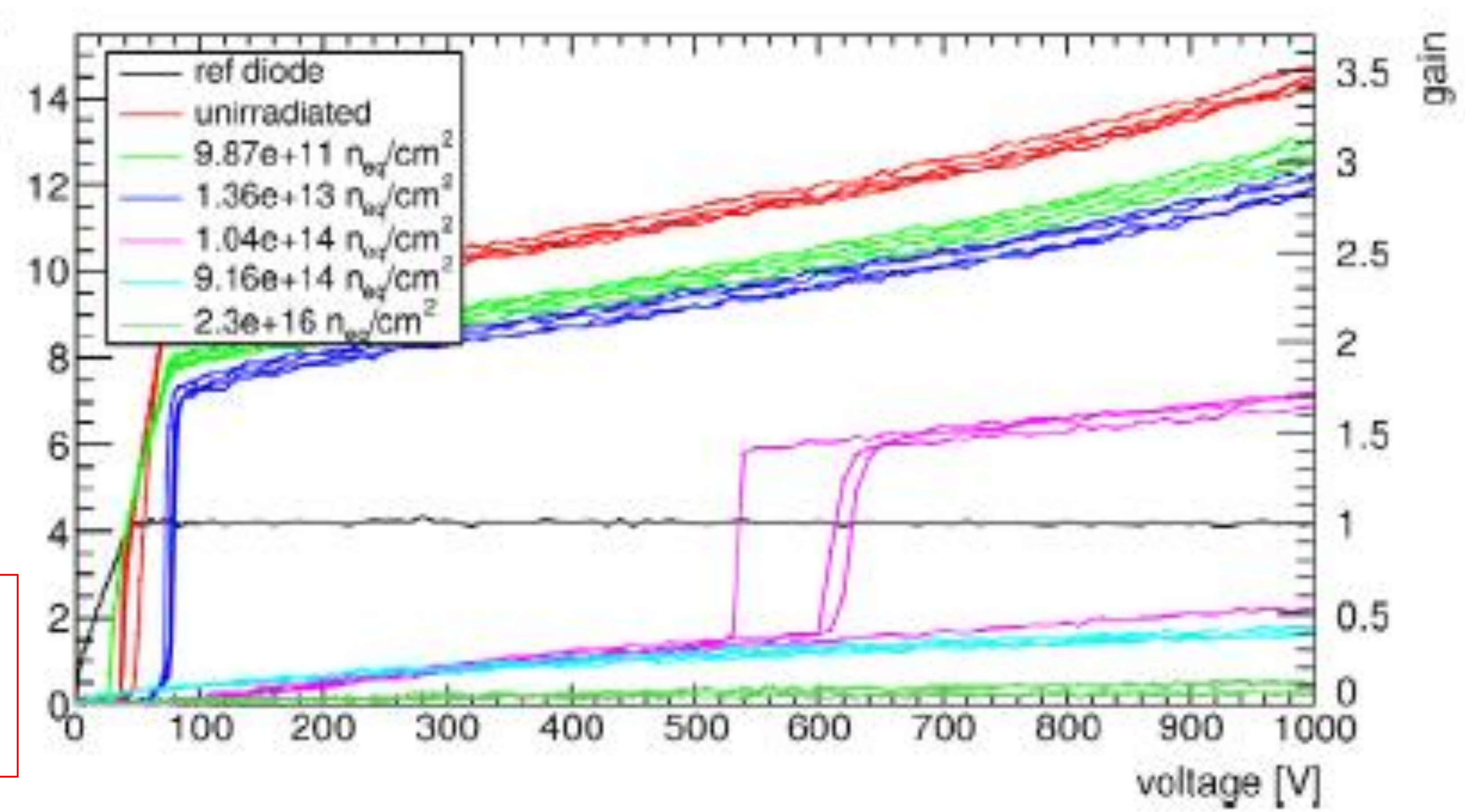
“ .... The mean charge for voltages > 500V was used as the reference to calculate the gain of the LGAD ”

Measurements for irradiated LGAD devices I.

Table 1
Table of irradiated samples tested in this study indicating the collected fluence for each type of irradiation.

800 MeV protons	Reactor neutrons
9.87×10^{11} n_{eq}/cm^2	
1.36×10^{13} n_{eq}/cm^2	1×10^{13} n_{eq}/cm^2
1.04×10^{14} n_{eq}/cm^2	1×10^{14} n_{eq}/cm^2
9.19×10^{14} n_{eq}/cm^2	1×10^{15} n_{eq}/cm^2
2.30×10^{16} n_{eq}/cm^2	1×10^{16} n_{eq}/cm^2

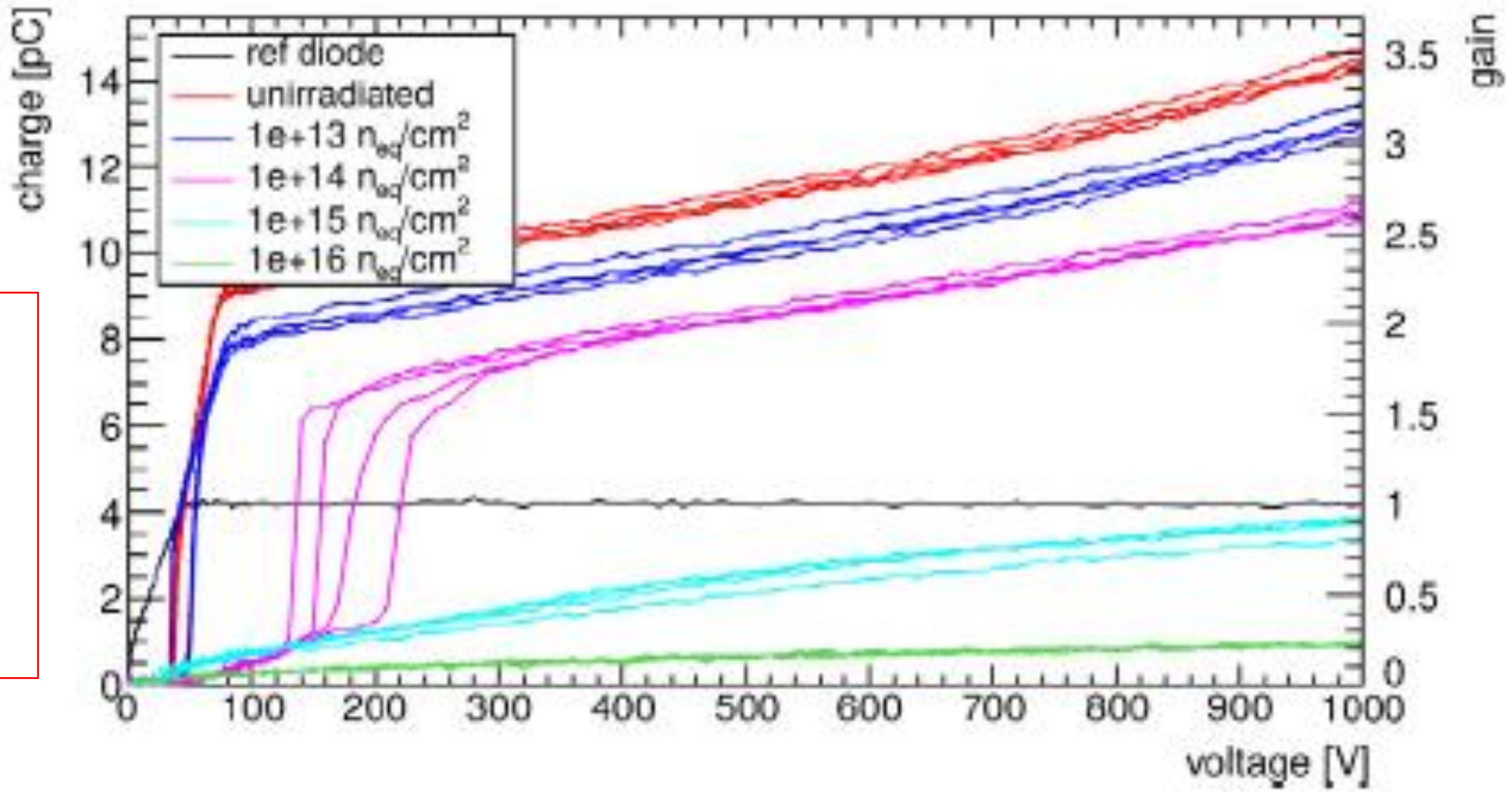
The gain will be lower from 10^{14} n_{eq}/cm^2



(a) Proton irradiation, hole injection.

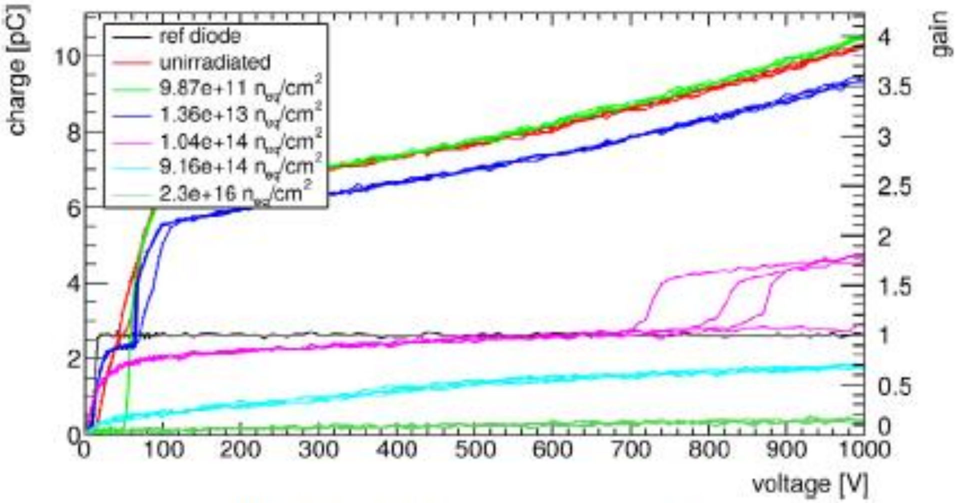
Measurements for irradiated LGAD devices II.

For neutron irradiation, the gain will be lower from 10^{15} n_{eq}/cm^2

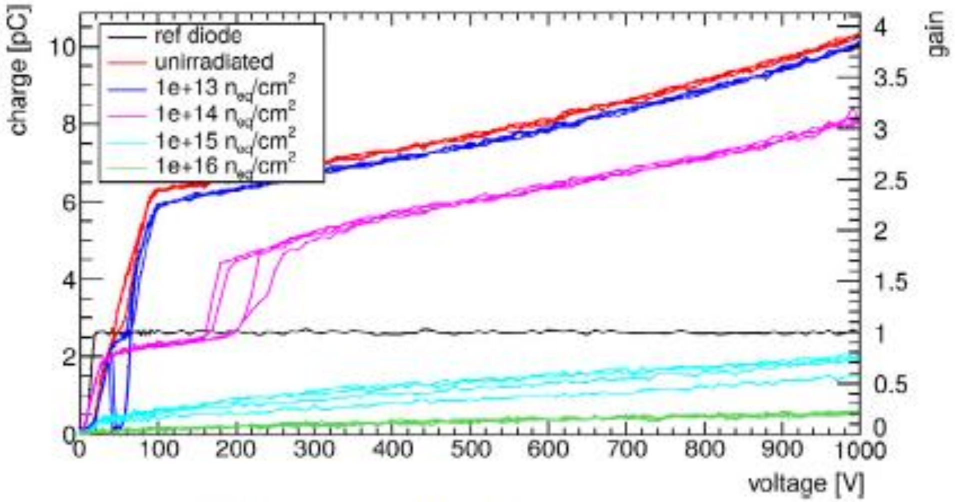


(b) Neutron irradiation, hole injection.

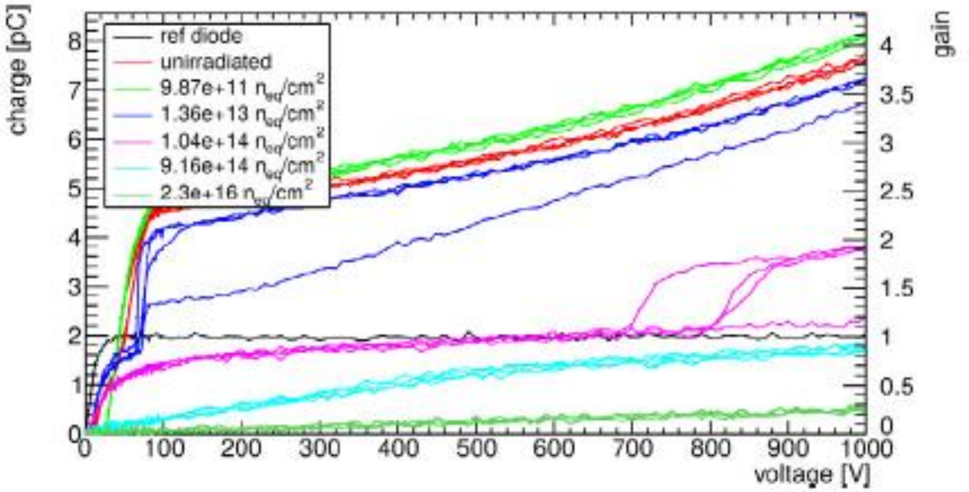
Measurements for irradiated LGAD devices III.



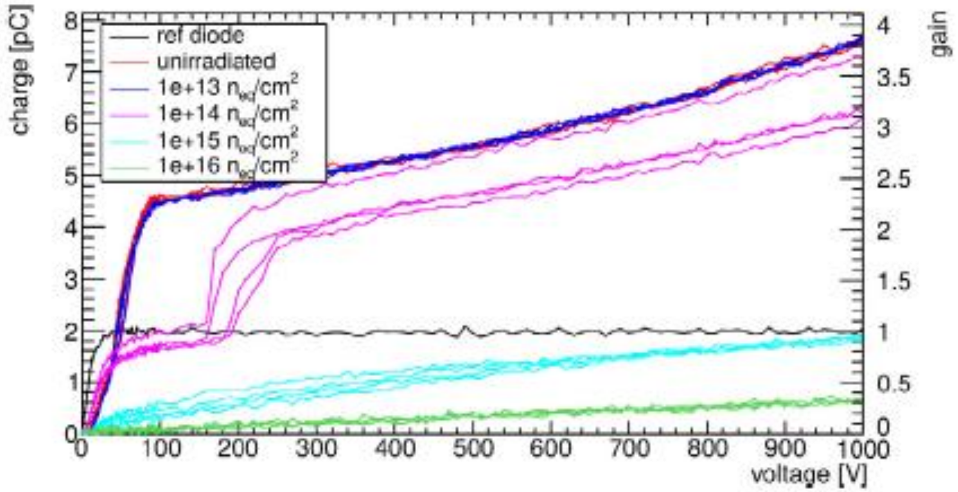
(c) Proton irradiation, electron injection.



(d) Neutron irradiation, electron injection.

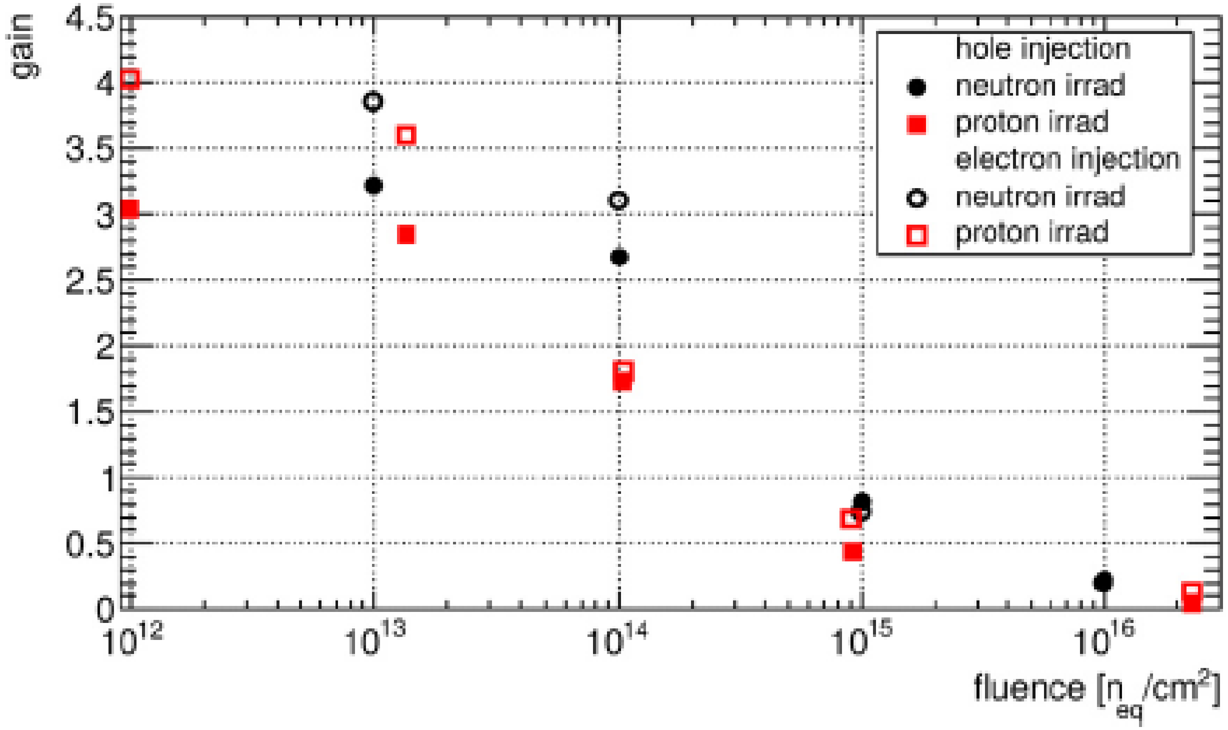


(e) Proton irradiation, infra-red.

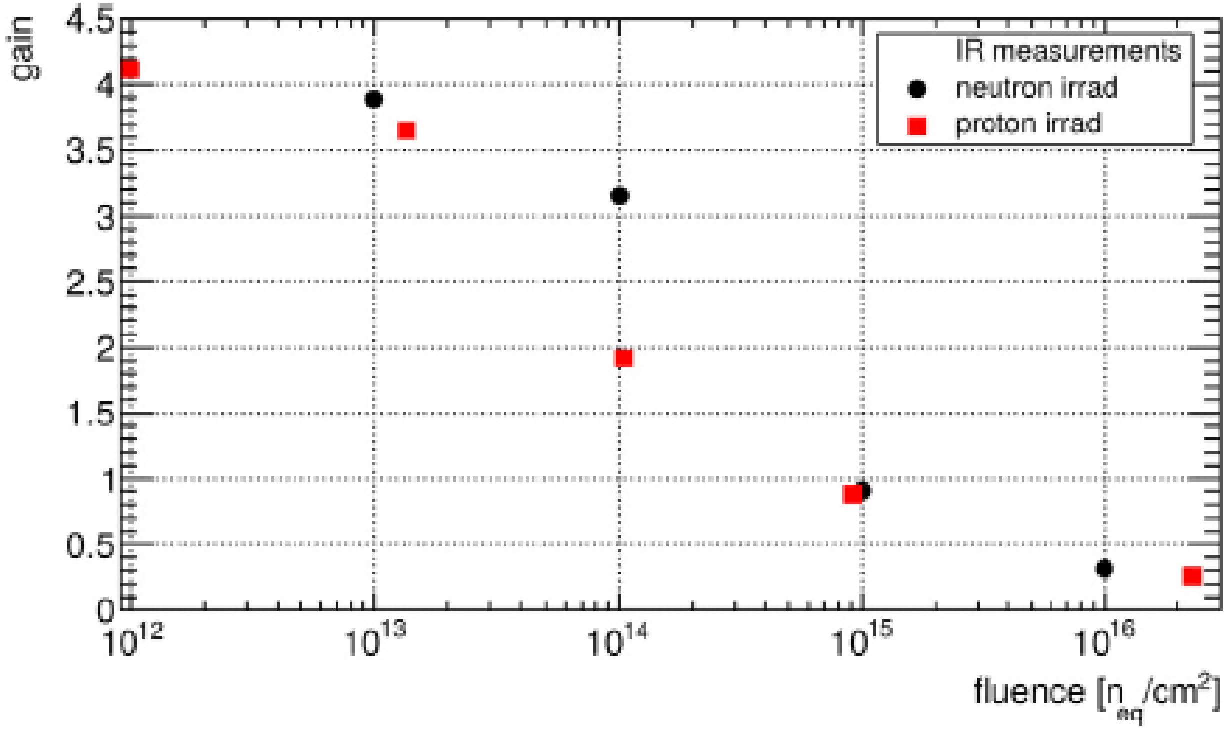


(f) Neutron irradiation, infra-red.

Gain VS fluence



(a) Hole and electron injection.

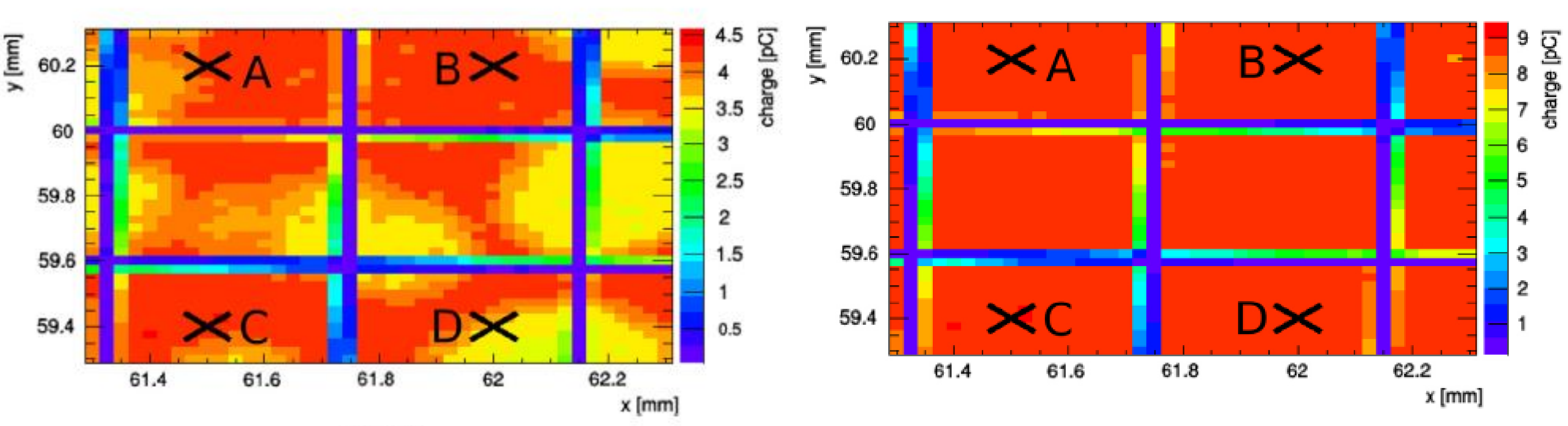


(b) IR pulses.

$10^{14} \sim 10^{15}$ seems to be a boundary

Uniformity of the gain

-- the 2D plots are obtained from the electron injection



(a) 50 V.

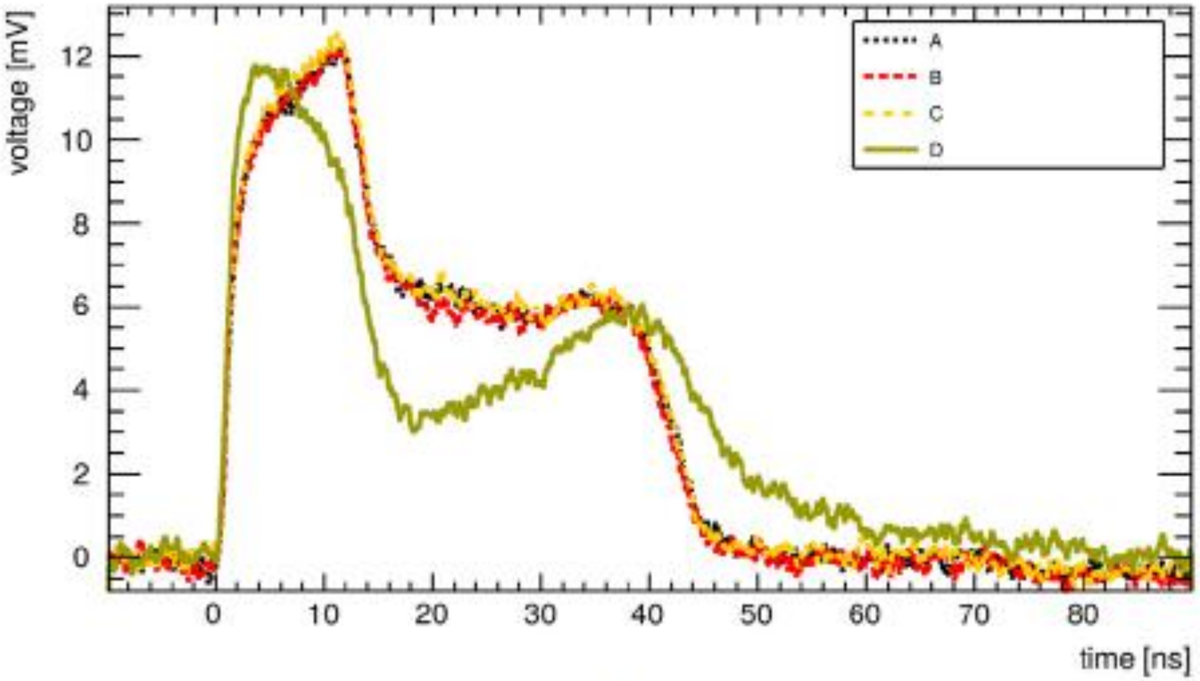
(b) 200 V.

It is explained in the figure caption that the metal grid on the backside for the electrical contact is visible . . .

Markers (“X”) show the 4 points for the additional voltage scan (next slide)

Position dependence

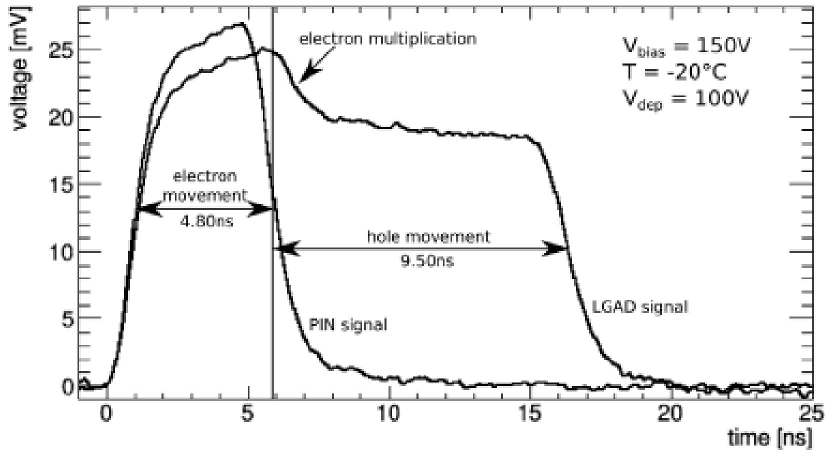
fluctuation between A/B/C & D



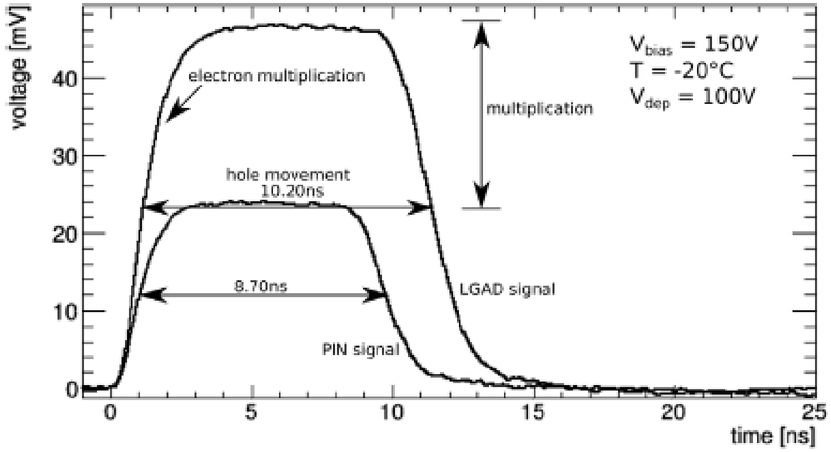
(b) 62V - below full depletion voltage.

Before irradiation

reference



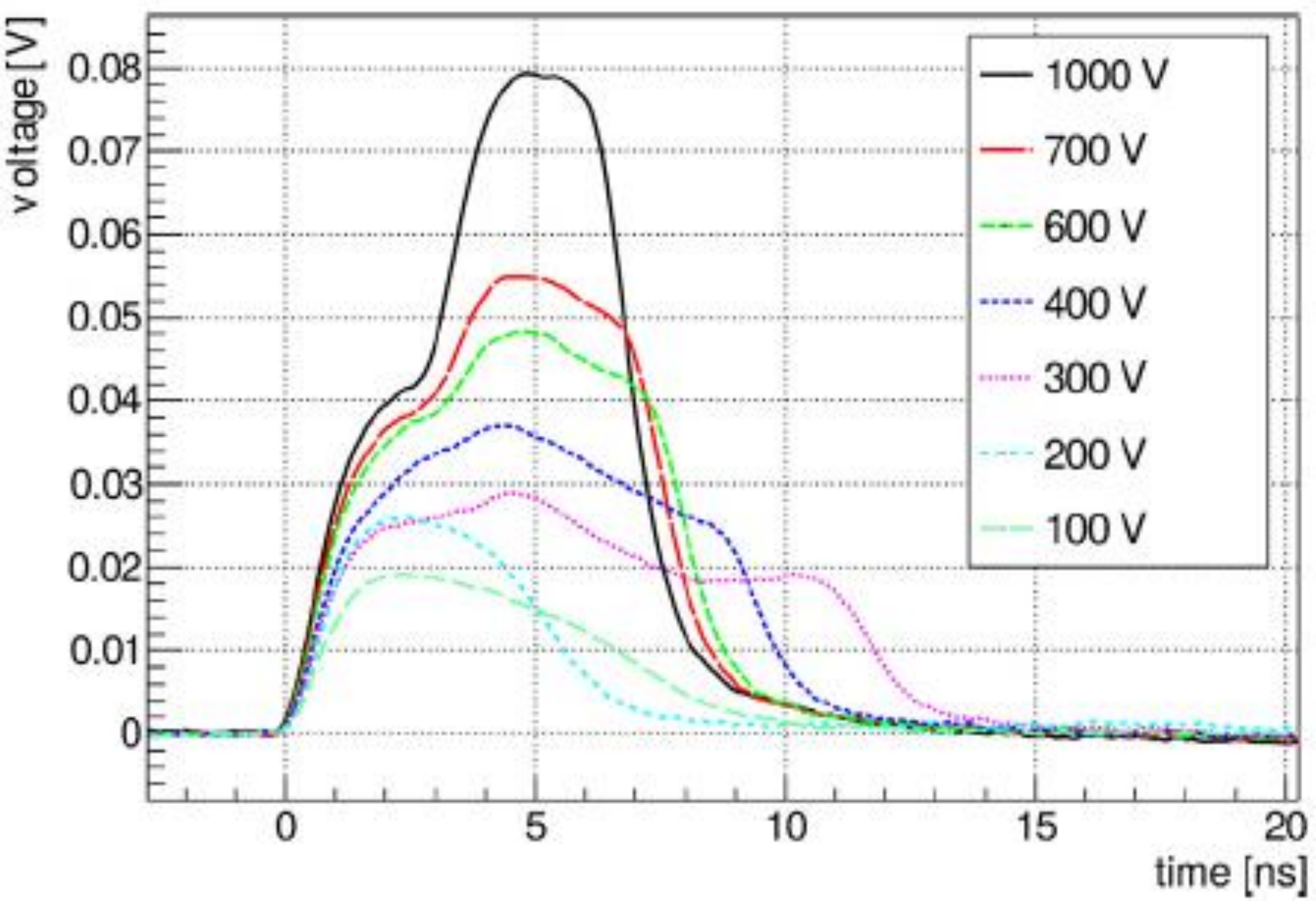
(a) Electron injection [6].



(b) Hole injection.

both are "electron" injection

Waveform after irradiation



They conclude that the form (under 200V <--> above 300V) is similar to that of “D” position

Summary I.

・ LGAD detectors with a gain of ~ 4 have been investigated before and after irradiation.

・ The focus was towards the intrinsic charge multiplication and gain of the devices, based on TCT.

・Up to 10^{15} n_{eq}, the gain is comparable to that of PIN.

・ Acceptor removal effect works faster for charged hadrons than neutron.

Summary II.

・TSC (Thermally Stimulated Current) shows possible explanation of the relationship between the inhomogeneous region and the leakage current.

・ Type inversion might have contribution too.

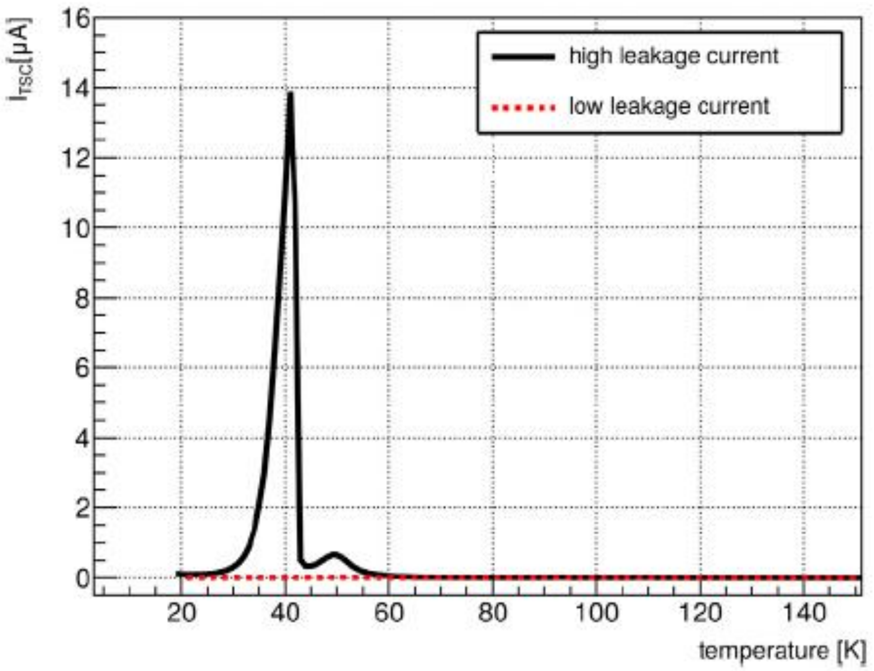


Fig. 10. Thermally stimulated current (TSC) measurement on unirradiated LGAD devices with high and low leakage current. The high leakage current device shows a peak in the TSC signal at 40 K.

"It remains necessary to investigate this behavior on irradiated LGAD structures of future lots" .

Questions

Question from Xin :

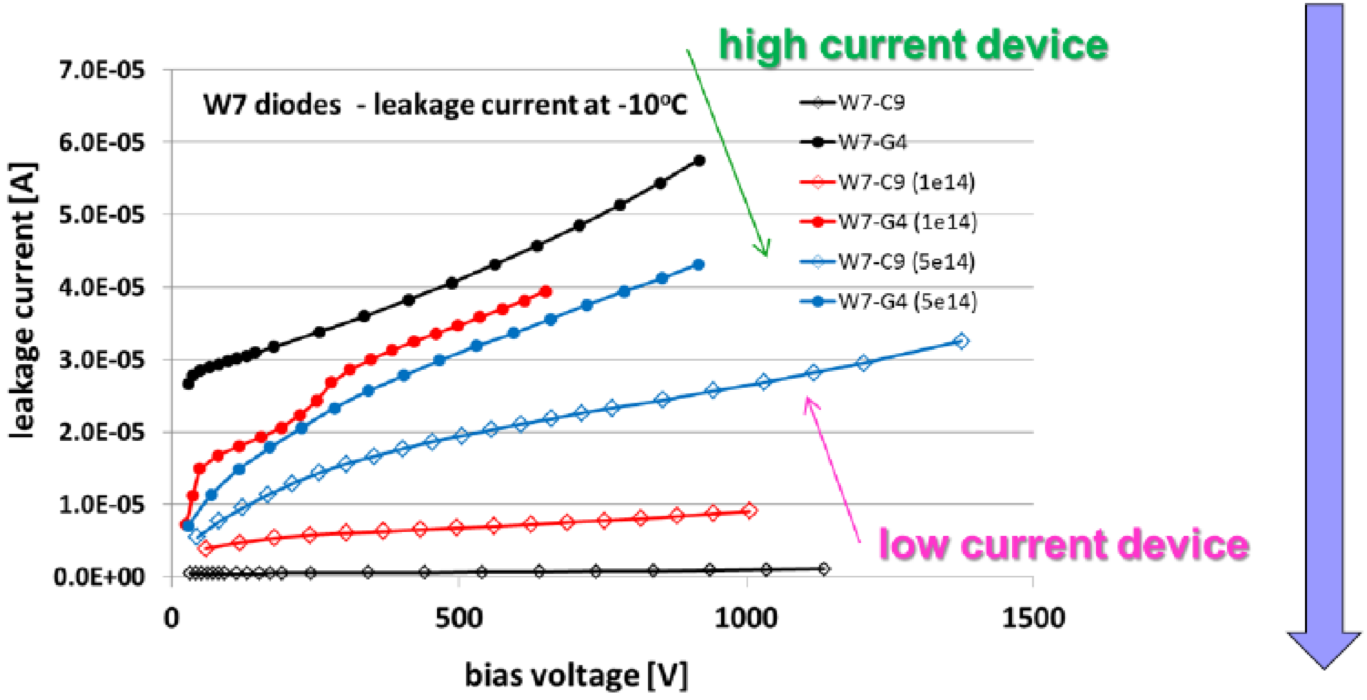
Could you elaborate the two proposed reasons for the gain degradation in LGAD devices?

"Measurements on LGAD samples with leakage current in the range of few μA showed that the voltage needed to deplete the multiplication layer after irradiation decreases. This effect was associated with an acceptor removal due to the removal of boron in the multiplication layer [6,11] which would also explain the observed gain degradation. An alternative explanation for the gain degradation in LGAD devices is based on the simulation of LGAD structures which showed that the effect could be caused by charge trapping in the device [17]."

→ Basically,　the acceptor removal makes the material (Silicon) pure than before, it can explain the decreasing of the current. But it might not so simple, since there would be "defect" in the silicon which can increase the current.

How does it behave with irradiation?

The excess current changes with irradiation – gets smaller with irradiation, but doesn't disappear - the reduction of total leakage with fluence



If it remains substantial it can effect the space charge and this should point to what it is

- hole current
- electron current

But they also discussed that the temperature dependence of the leakage current is not big , , ,
which means the main source of the leakage current might not be that of bulk.

Conclusions

- It seems that the excess current is dominated by hole current
  - the origin is not known, but it is not localized at a hot spot
  - It is not dependent on temperature (not a generation current?)
- Excess current in LGAD influences the space charge after irradiation
  - It can lead to SCSI which requires higher voltage to deplete the multiplication layer.
  - Space charge is heavily influenced by temperature. which can be explained by almost independent hole concentration (constant current) and strongly dependent de-trapping times
- The behavior is independent on irradiation particle type

Reference [17]： R. Dalal et al., NIMA, 836 (2016) 113-121

the E-filed change due to the irradiation is simulated with TCAD !

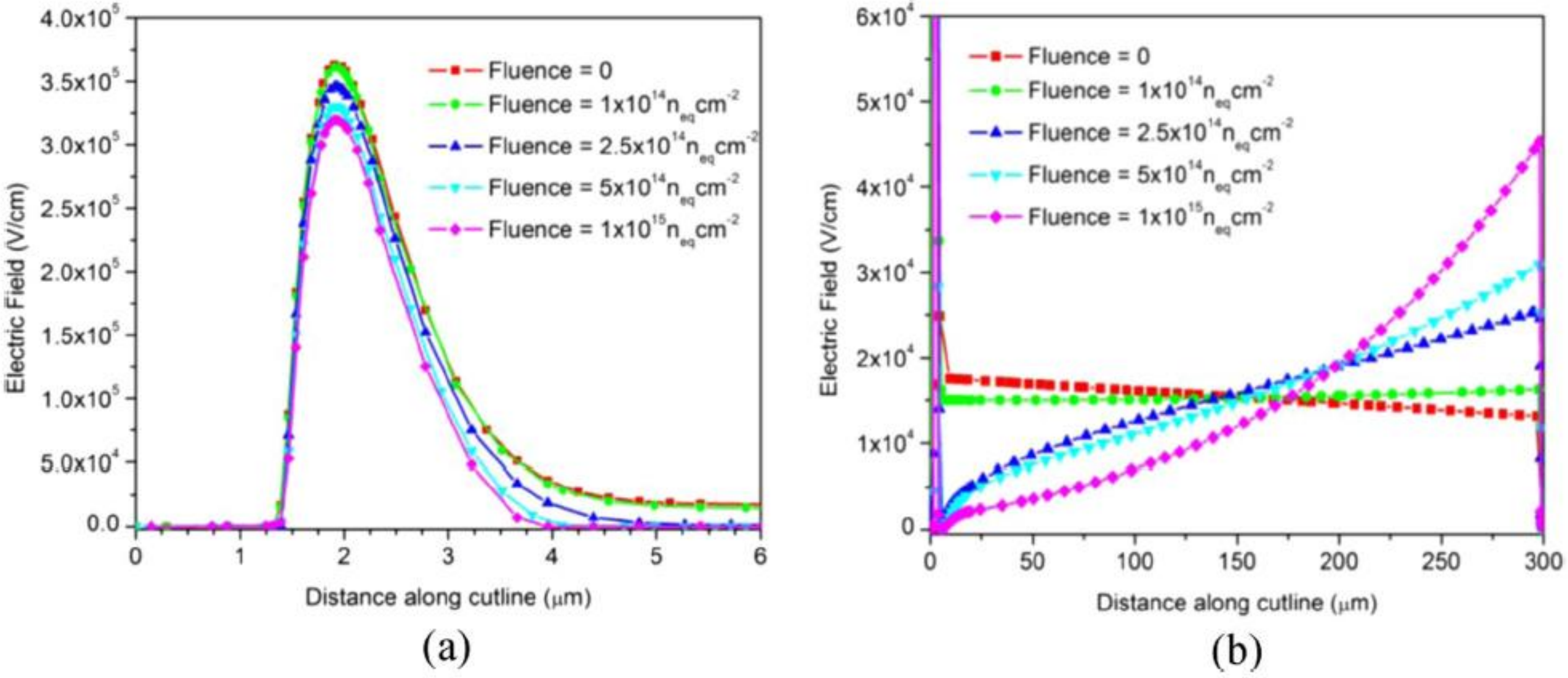


Fig. 11. The electric field for different irradiation fluence (a) for $V_{bias}=500$ V around the multiplication region, and (b) inside the sensor volume for $N_p=9.75\times10^{16}$ cm^{-3} (moderate gain case) at T=253 K.

Question from Yuhang :

My question: The reason about comparing the results for neutron and proton irradiation but also with previous measurements in the fluence range below 10^15 neq/cm^2 showed that the effective acceptor removal works faster for charged hadrons.

This is one of hot topic for the study of radiation damage, and one of summary of this paper.

32nd RD50 Workshop, Hamburg, June 4-6 2018

Effects of protons and neutrons irradiation to the gain layer and bulk of 50-micron thick FBK LGAD sensors doped with Boron, Boron Low diffusion, Gallium, Carbonated Boron and Carbonated Gallium

M. Ferrero[1], R. Arcidiacono[4], M. Boscardin[5], N. Cartiglia[1], G.F. Dalla Betta[3], F.Ficorella[5], M. Mandurrino[1], L. Pancheri[3], G. Paternoster[5], I. Sanna[2], F. Siviero[2], V. Sola[1,2], A. Staiano[1] , M.Tornago[2]

[1]INFN, Torino, Italy
[2]Università di Torino, Torino, Italy
[3]University of Trento and INFN, Department of Industrial Engineering, Trento, Italy
[4]Università del Piemonte Orientale, Novara, Italy
[5]Fondazione Bruno Kessler (FBK), Trento, Italy

From a slide on the RD50 workshop this year

Evolution of active acceptor density with fluence

$$N_A(\phi) = g_{eff}\phi + N_A(\phi = 0)e^{-c\phi}$$

Φ = fluence

N_A = active acceptor density at fluence *Φ*

g_{eff} = empirical constant (~0,02 *cm^{-1}*) → to compare with the measurements on irradiated PiN diode

C = coefficient of the acceptor removal → Dependent upon the irradiation type, the acceptor type and the initial acceptor density

For More detail on the acceptor removal model see the N. Cartiglia talk on thin workshop

Coefficient "*c*" comparison between Neutrons and Protons

Neutron | **Proton (No NIEL)** | **Proton (NIEL)**

Gain Layer	c_n $[10^{16}\ cm^2]$	c_p $[10^{16}\ cm^2]$ (No NIEL)	c_n/c_p (No NIEL)	c_p $[10^{16}\ cm^2]$ (NIEL)	c_n/c_p (NIEL)
Ga	7.1 ± 1.0	$9. \pm 1.5$	0.79 ± 0.22	$15. \pm 1.5$	0.47 ± 0.08
B	5.4 ± 1.0	6.5 ± 1.5	0.83 ± 0.29	10.8 ± 1.5	0.50 ± 0.11
B LD	4.7 ± 1.0				
Ga + C	4.0 ± 1.0	4.2 ± 1.5	0.95 ± 0.43	7.0 ± 1.5	0.57 ± 0.19
B + C	2.1 ± 1.0	3.3 ± 1.5	0.63 ± 0.66	5.5 ± 1.5	0.38 ± 0.54

Considering the **real value of proton fluence** (*p/cm^2*) the c_p coefficients (proton) and the c_n ones (neutron) are **compatible** with each other.

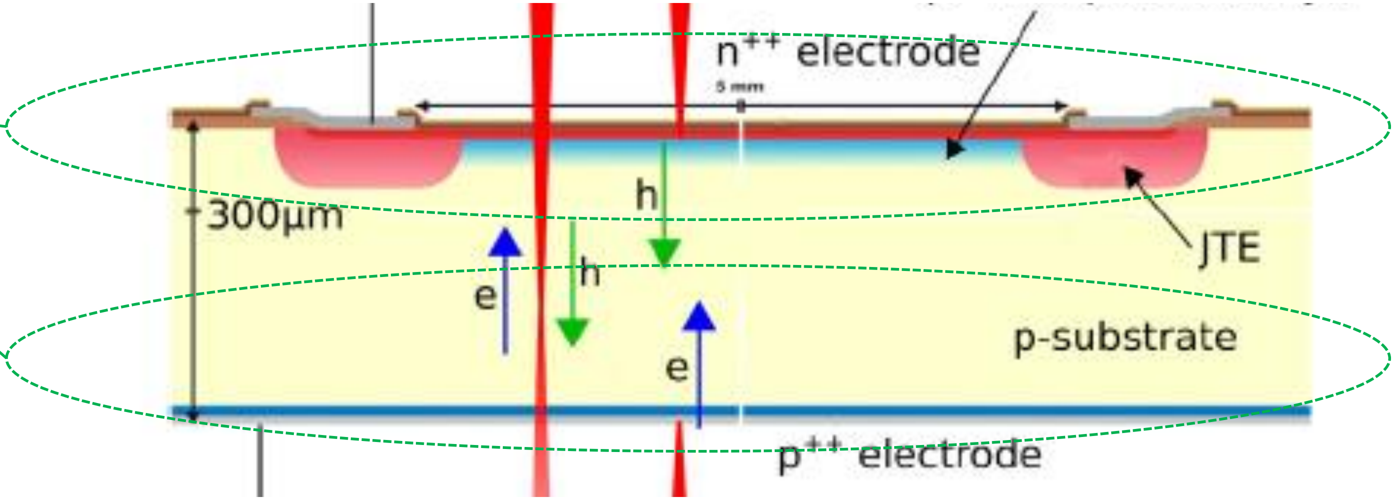
If the **NIEL factor** was applied the c_p coefficients are almost **twice** c_n

Question from Suyu :

We can easily see the influence on the gain of the devices, but what can we learn for intrinsic charge multiplication?

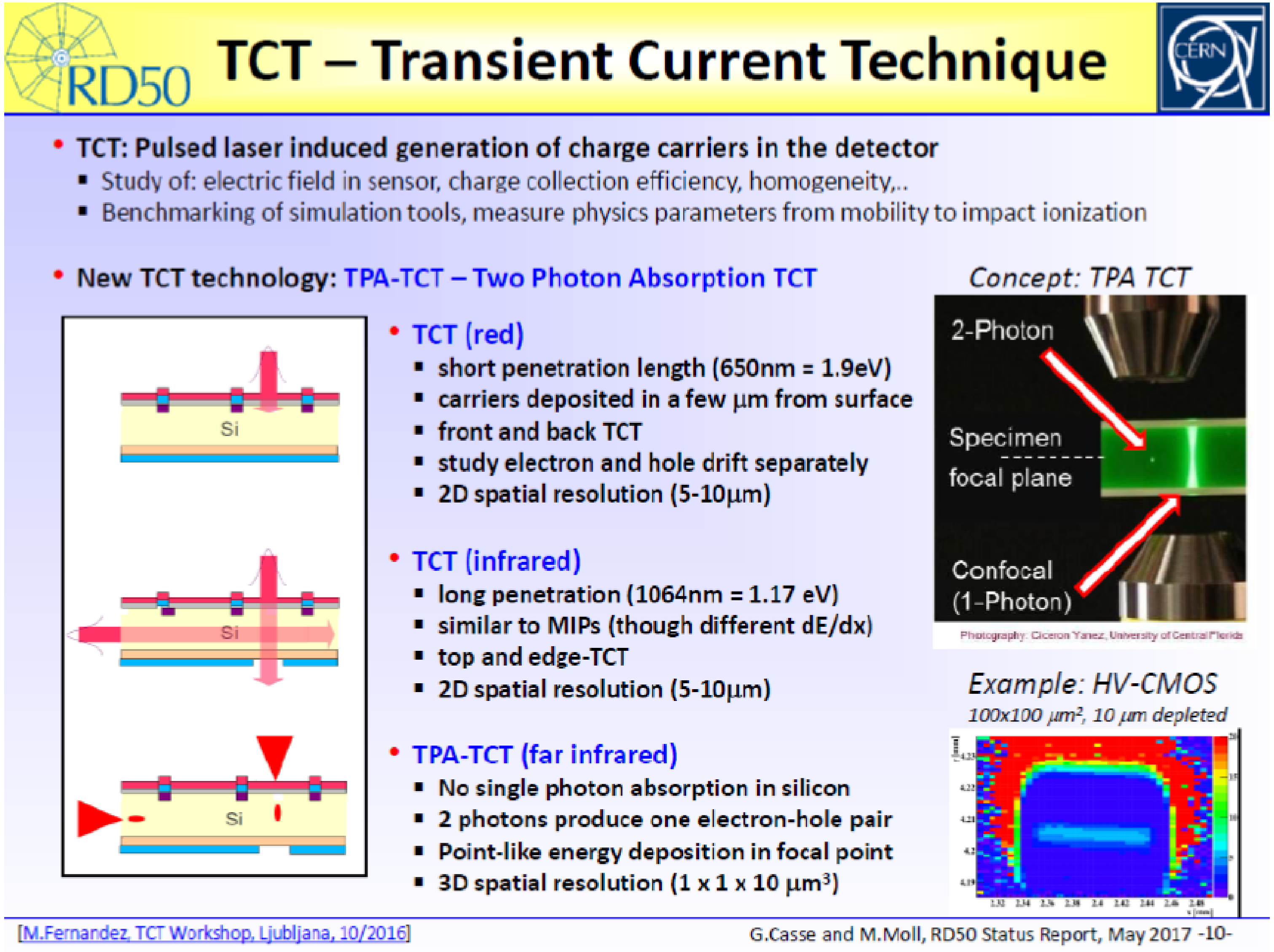
I agree. From the histograms in the paper, the decreasing of the gain by the multiply layer & the other part is not clearly separated.

There are combined.



Two Photon Absorption TCT

Although we can get information from “hole/electron” injections,,, the Two Photon Absorption TCT might give us further clue (or not)



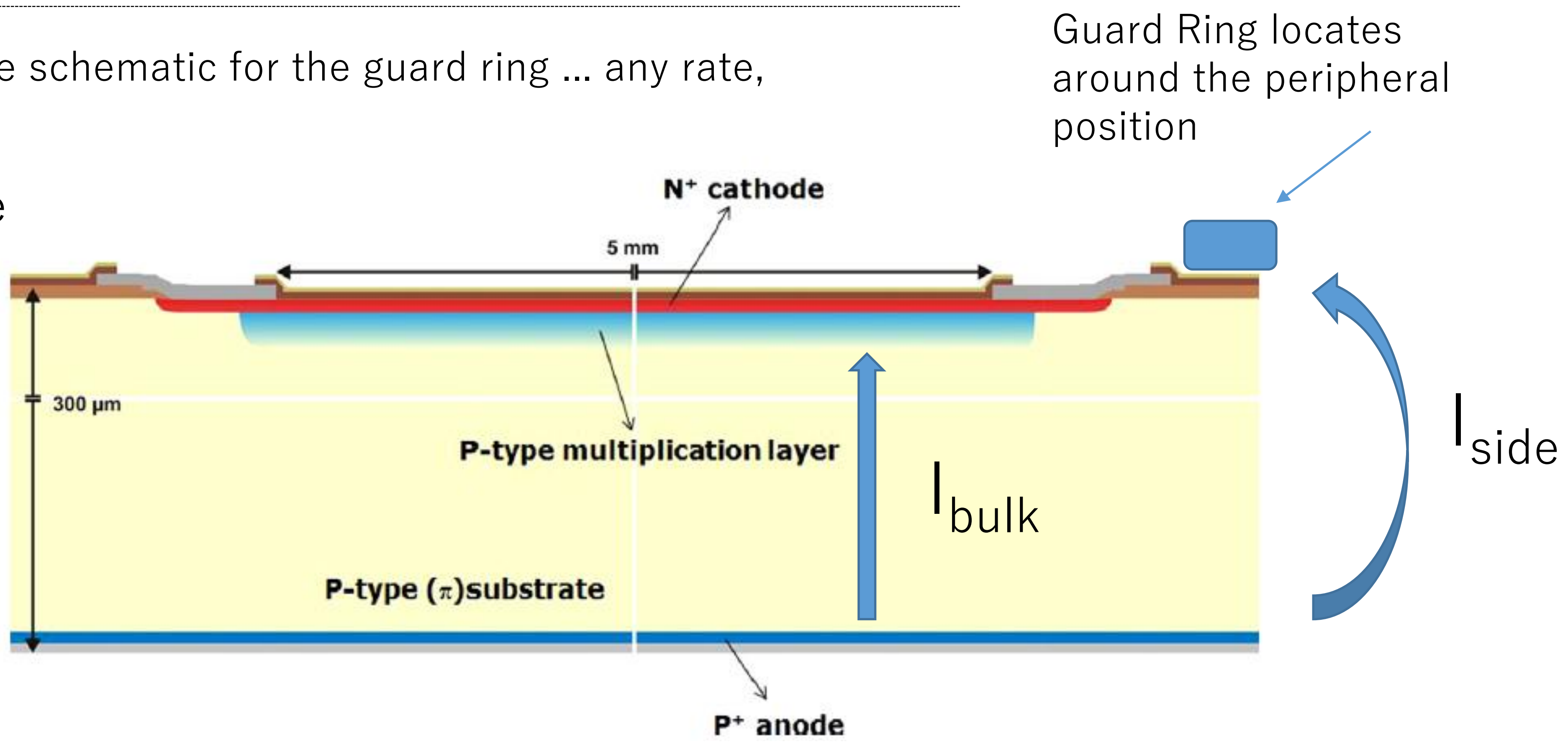
From my past special topic on March 2018.

Question from Amit :

Question: What is the guard ring structure in the design and why due to the absence of a guard ring structure in the design it is impossible to distinguish surface from bulk current contribution?

I was trying to find out the schematic for the guard ring ... any rate,

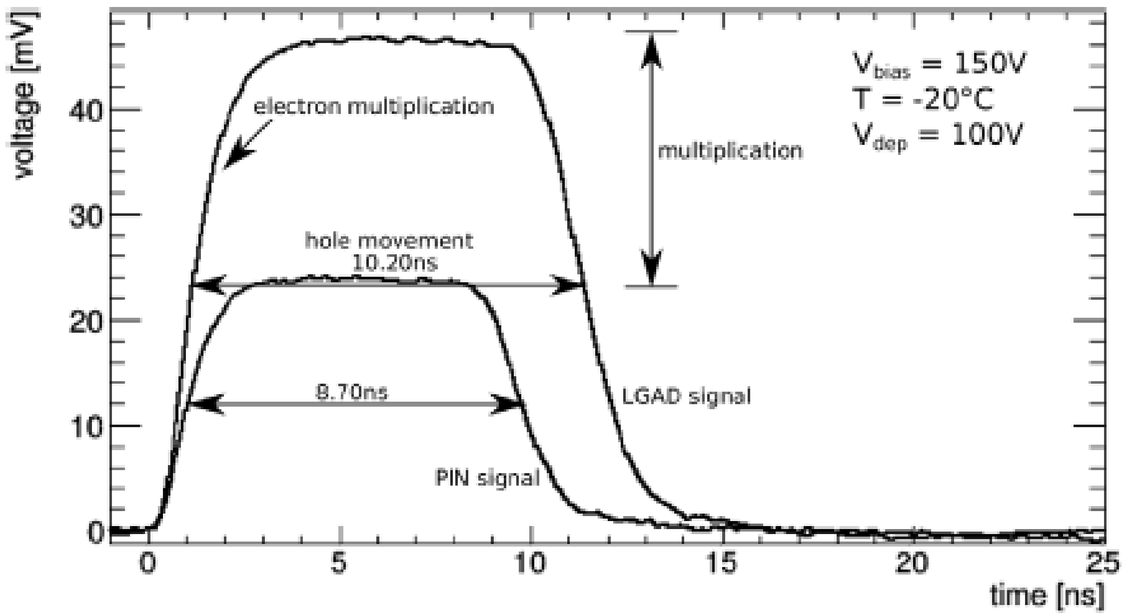
$$I = I_{bulk} + I_{side}$$



Question from Kai :

My question is:
In Fig2., what caused the left side of the signal increased more sharply compared with the righthand side? it seems more clear on plot (b), and there's a small tail on the right side.

Maybe , the total amplitude (by the multiply layer) as well as the enhanced E-field.



(b) Hole injection.