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Effects of charge screening in LGADs

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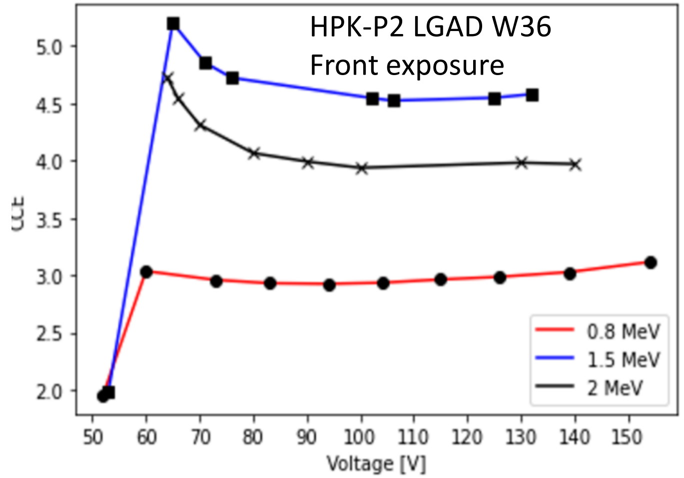
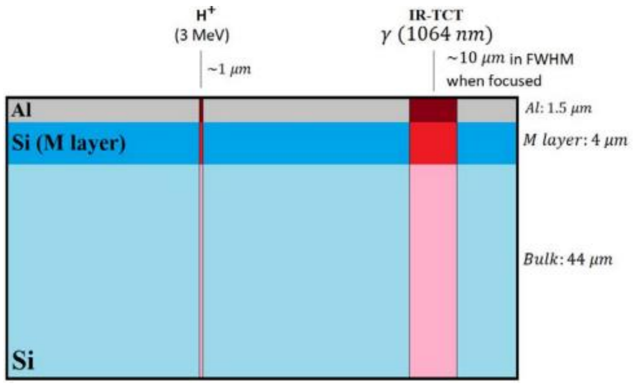
Motivation

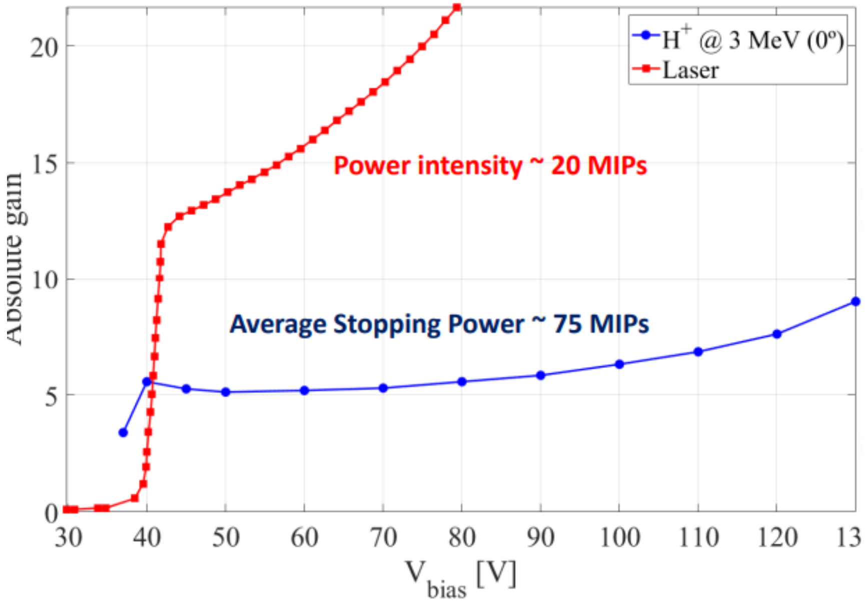
- Collected charge (gain) in LGADs often depend on many parameters among them is also the impinging particle's energy and type or laser intensity
- It is important to understand this limitations in particular for heavily ionizing particles (e.g. for use in ion-beam experiments, beam monitors for cancer therapies)
- It is important to know the benefits for mip tracks crossing the detectors under certain angle

M. Manojlović et a.l, A feasibility study on the utilization of the Ion Beam Induced Charge (IBIC) Nuclear Microprobe Technique at the RBI for the LGAD's Characterization including Interpad-Gap Measurements, 38th RD50 Workshop



M.C. Jiménez-Ramos et al, Gain supression by IBIC-MCJR 38th RD50 Workshop





Motivation continued …

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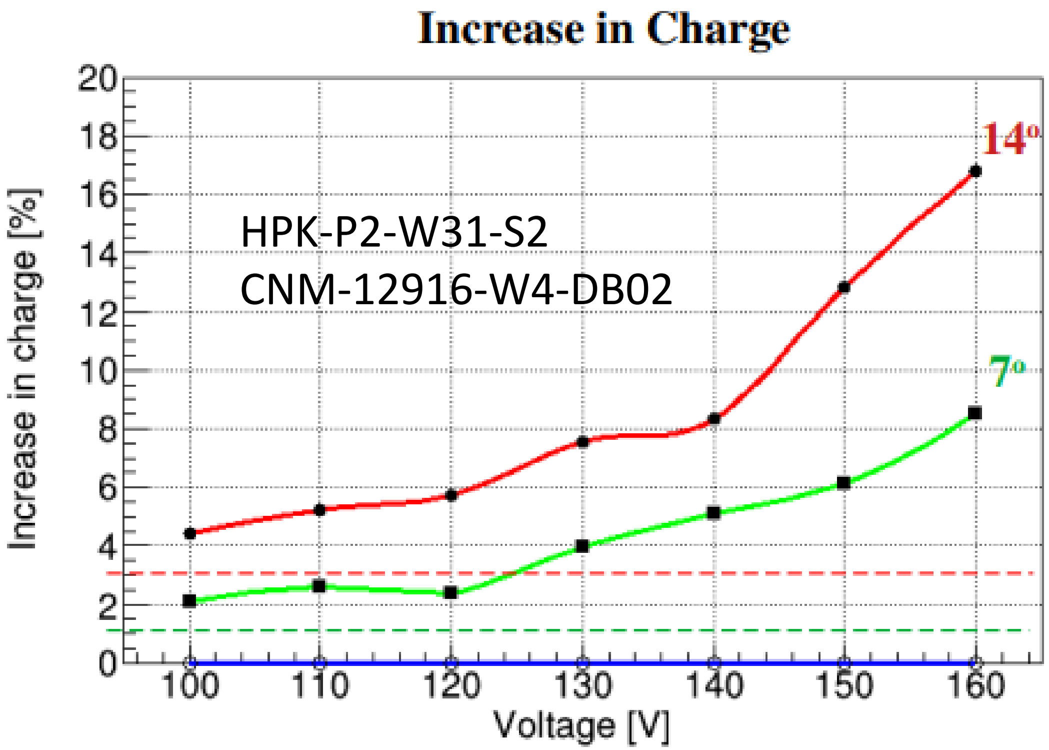
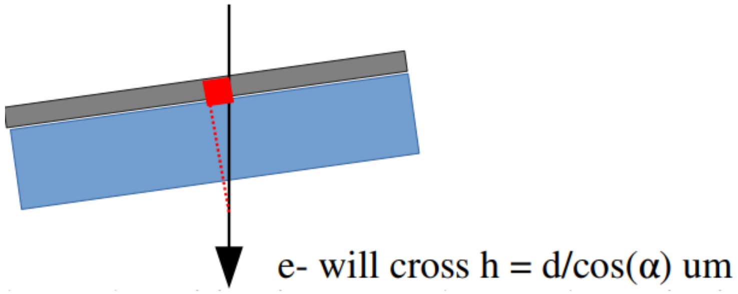
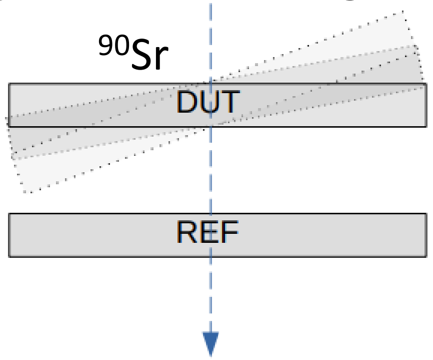
E. Curras et al,
GainSuppressionMechanismLGADs_RD50_CERN_JUN_2021.pdf



3.0 %
1.0 %
geometry effect

DUTs positioned at different angles: 0, ~7, ~14 deg





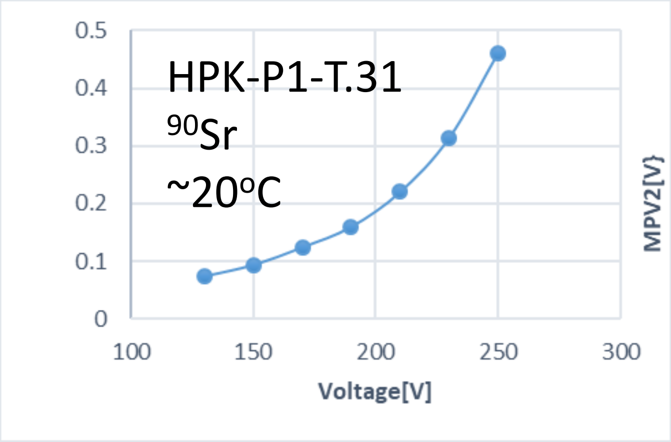
ATLAS tracks: 2-10°
CMS tracks: 6-22°

a beneficial effect for charge collection at HL-LHC (more for CMS with substantial increase of charge)

Samples and Setup

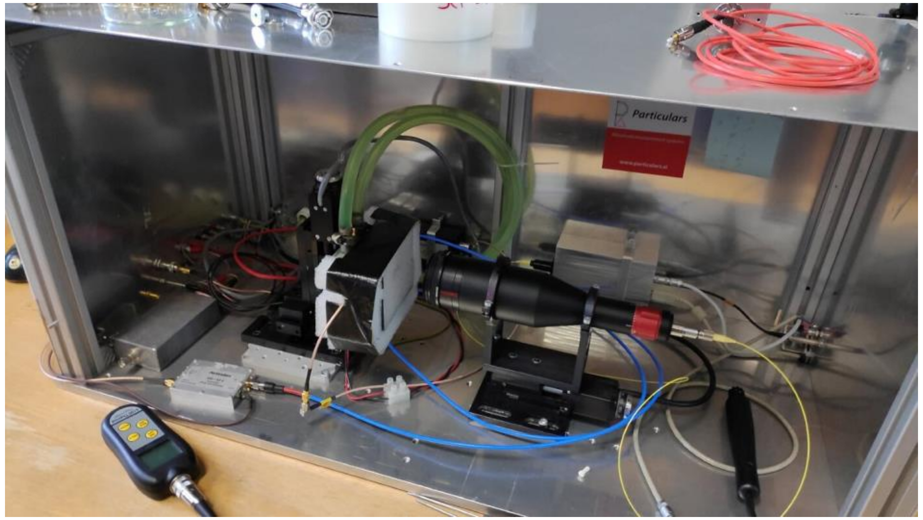
Samples used were HPK-P1 from ATLAS/CMS production

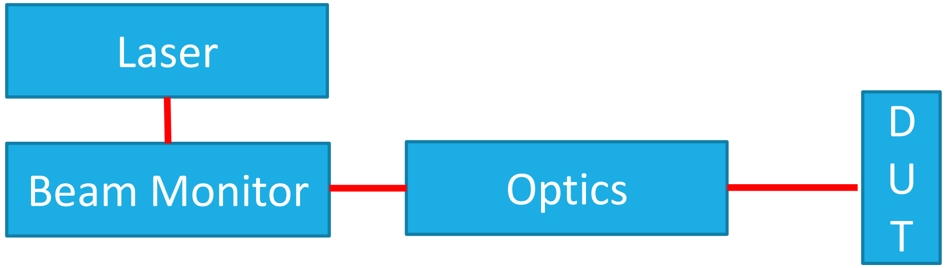
- T3.1 sensor, V_{gl} ~ 41 V, x_{gl}~1.6 μm, V_{bd}~250 V
- T3.2 sensor, V_{gl} ~ 55.5 V, x_{gl}~2.4 μm, V_{bd}~140V
- Both 50 μm active zone
- 200 μm thick sensor
- 1.3x1.3 mm^2
- Non-metalized sensor for TCT



Particulars Scanning-TCT
beams spot FWHM~10 μm
pulse duration <350 ps
1064 nm light used (660 nm, 520 nm to be used)

Measurements done at 20°C on non-irradiated samples

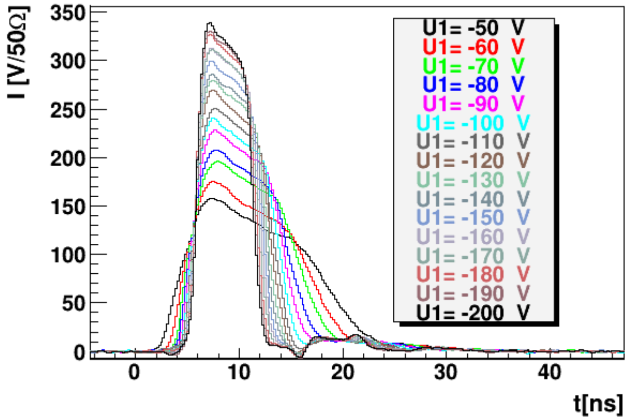


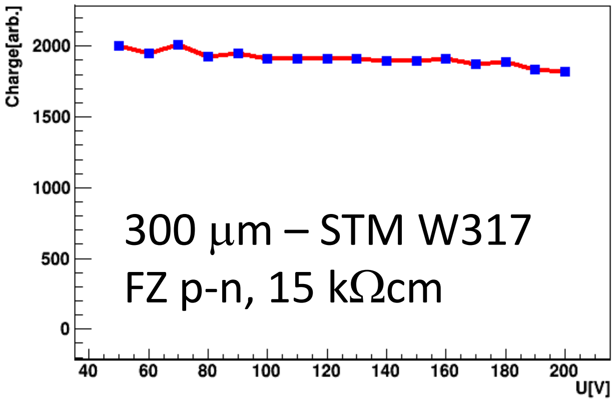


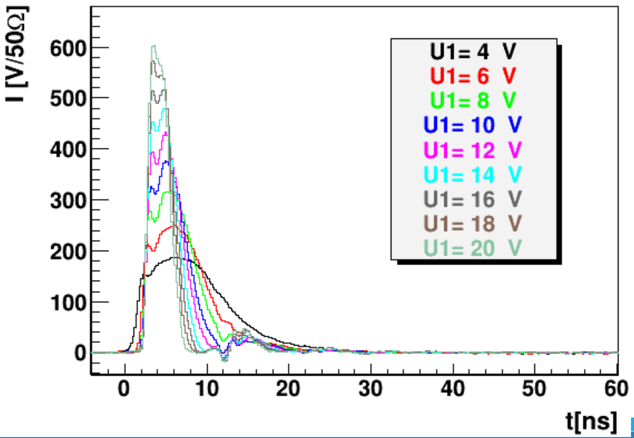
Calibration of the system – ^{241}Am

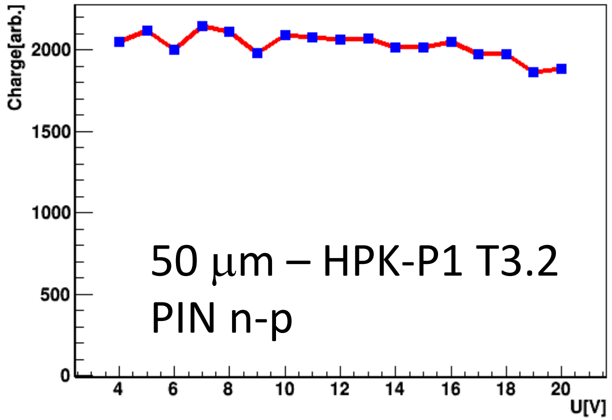
We used ^{241}Am (E=5.8 MeV) placed on top of the source for estimation of the concentration of e-h pairs created by alpha particle.

Estimated amount of charge penetrating the 7 mm of air and passivation ~3.5-4 MeV .







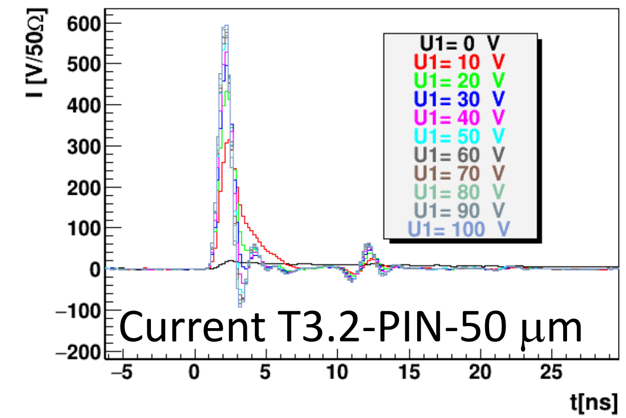


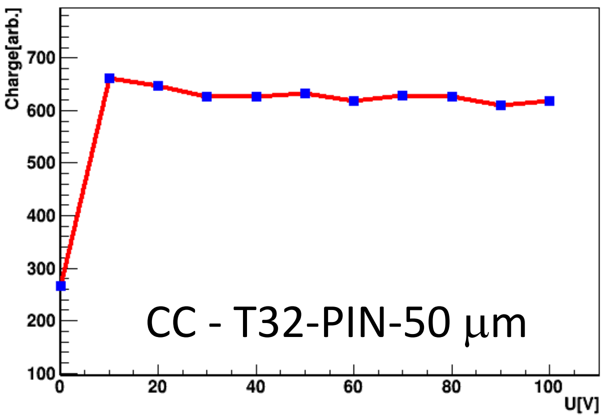
Same charge measured on both p-n standard 300 μm thick detector and 50 μm thick n-p sensor.

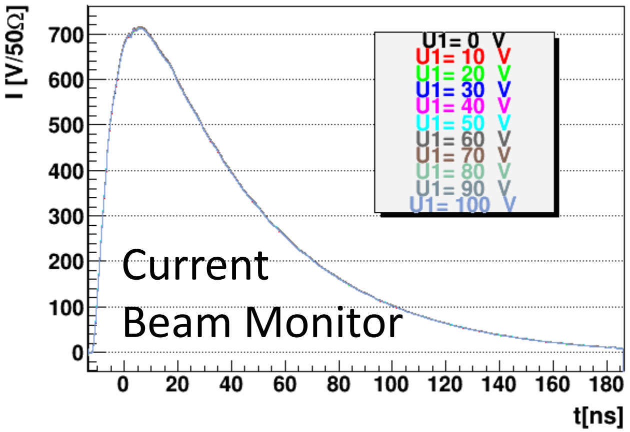
2000 mW ns ~ 1 M e-h pairs

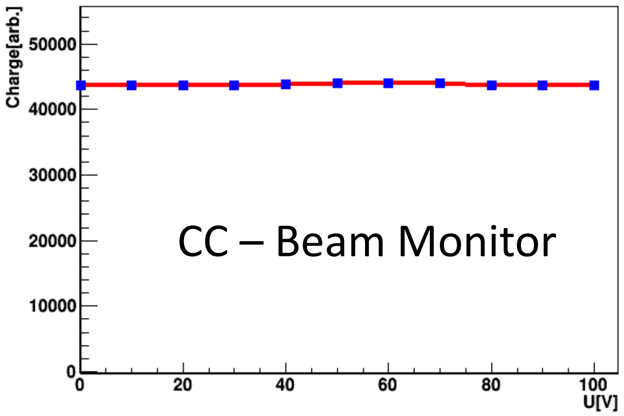
Calibration of the system

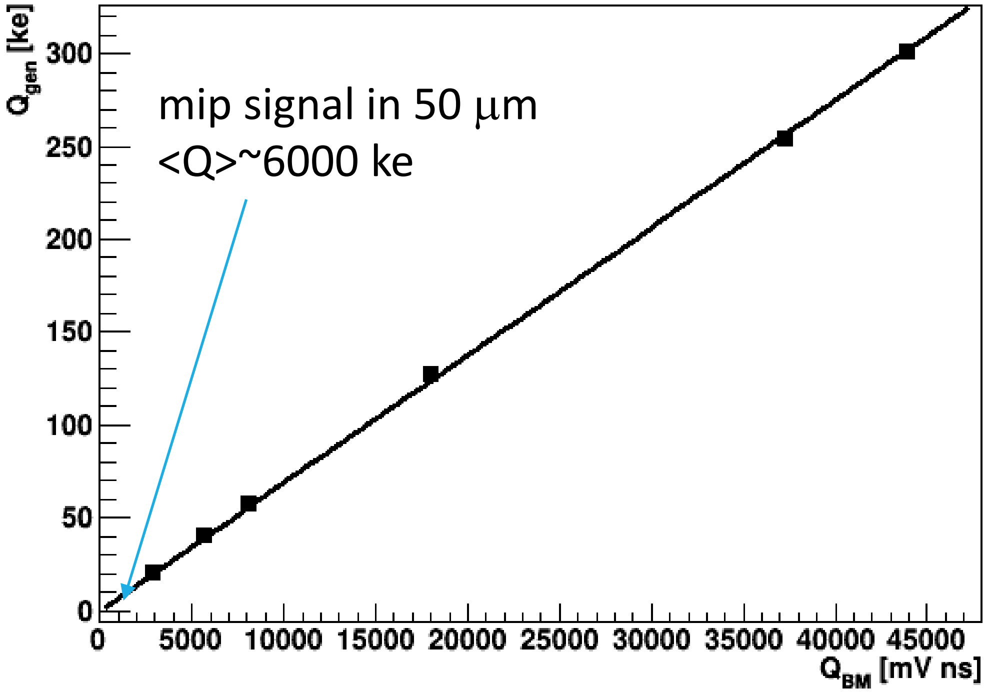
Beam monitor was used to calibrate the $N_{e\text{-}h}$ pairs created in the sensor. With calibrated PIN diode the BM can be calibrated. Calibrated BM is used to determine the absolute amount of charge in LGAD.











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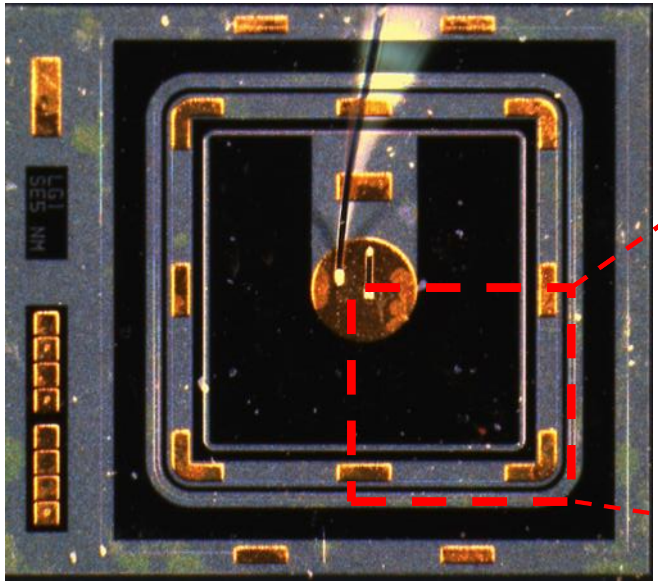
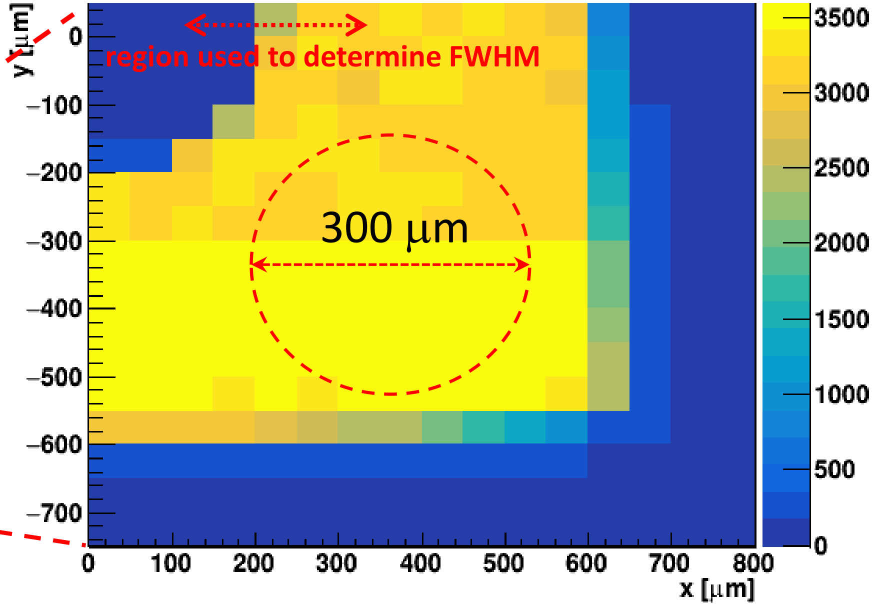
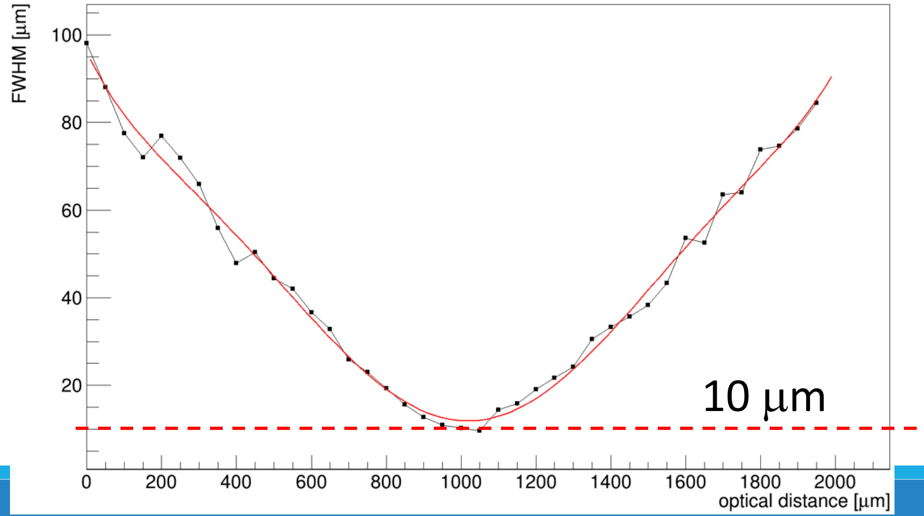


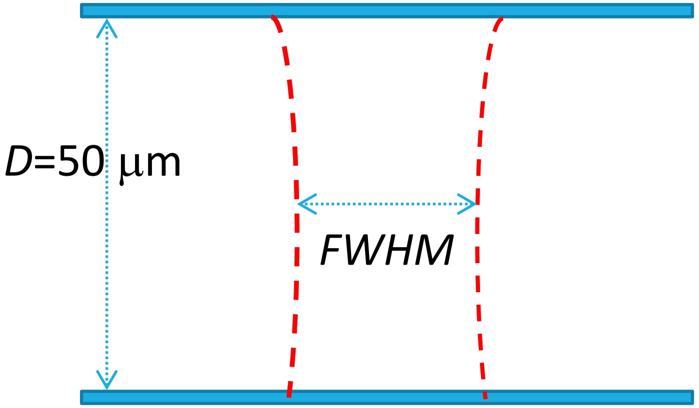




Assumptions:

- FWHM stays constant over the active layer thickness
- Inside the profile the density of charge is homogenous
- Uniform deposition along the beam:

D<<penetration depth 1 mm



$$\boxed{n_{e-h} \sim \frac{Q_{gen}}{S\ D} = \frac{4\ Q_{gen}}{\pi\ D\ FWHM^2}}$$

Changing the intensity

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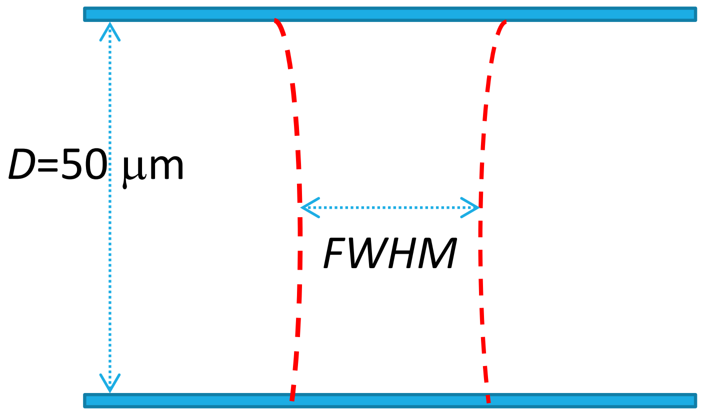
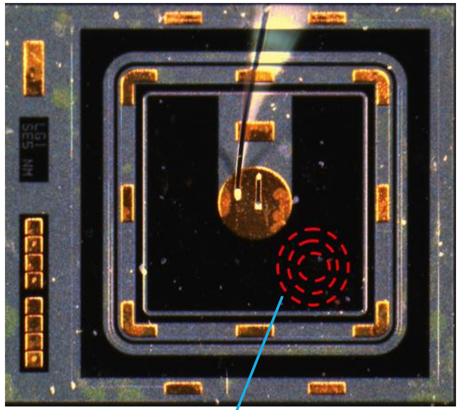


$$n_{e-h} \sim \frac{Q_{gen}}{S\,D} = \frac{4\,Q_{gen}}{\pi\,D\,FWHM^2}$$

Density of carriers (e-h) can be modified by:

- changing the intensity of laser - Q_{gen}
- changing the focusing of the beam - FWHM

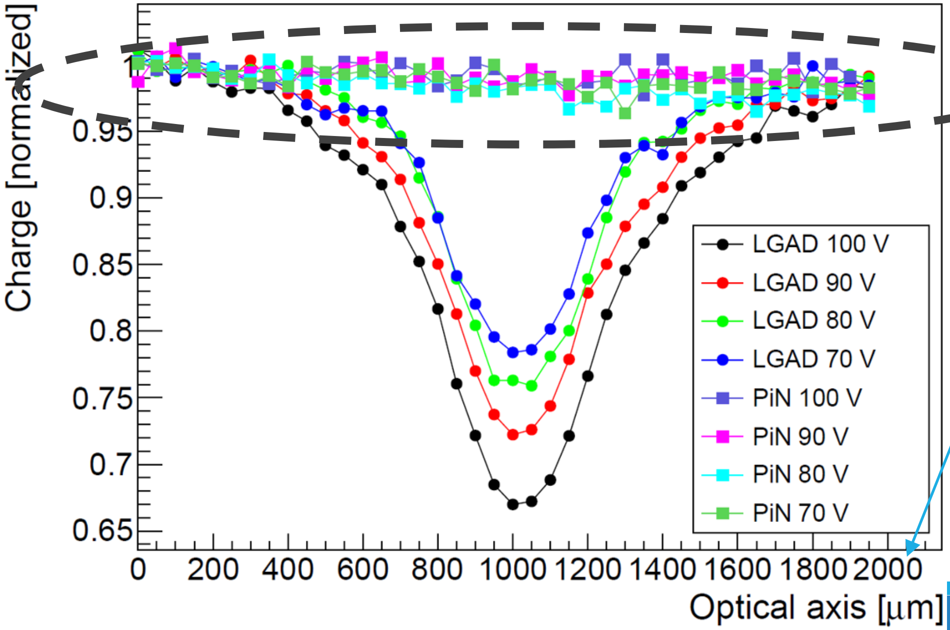
ⓧ optical axis



Goal is to determine ***G(V*** $\boldsymbol{G(V_{bias}, n_{e-h})}$ for both sensor types T3.2 and T3.1

There is no recombination in the PIN devices (in silicon bulk):

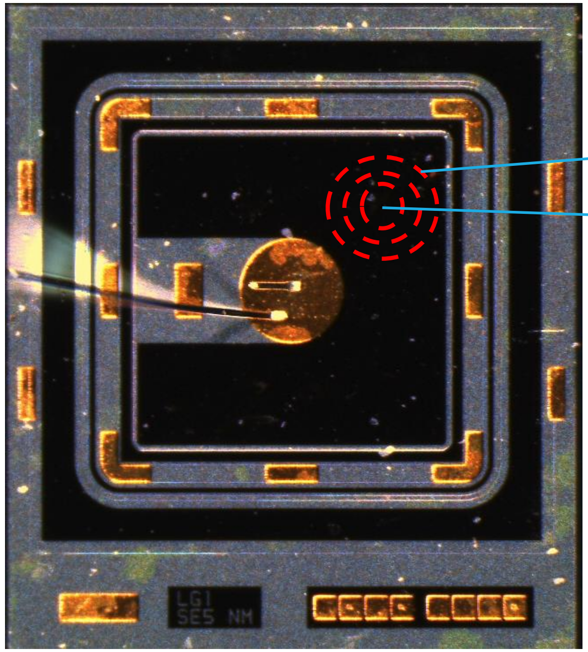
$Q_{coll} \neq Q_{coll}(n_{e-h})$

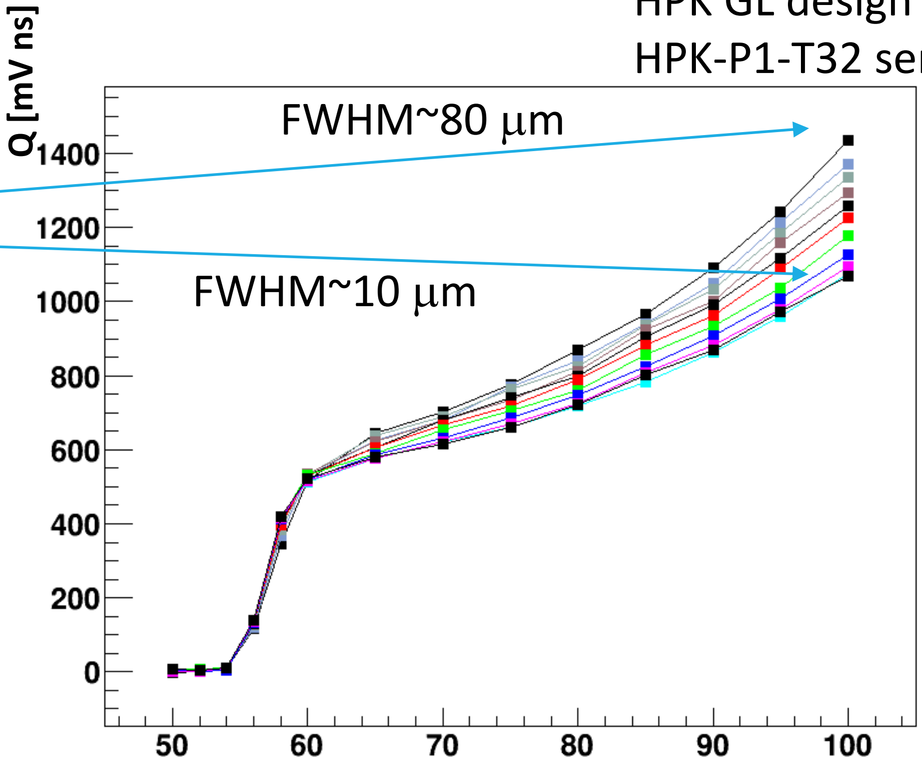


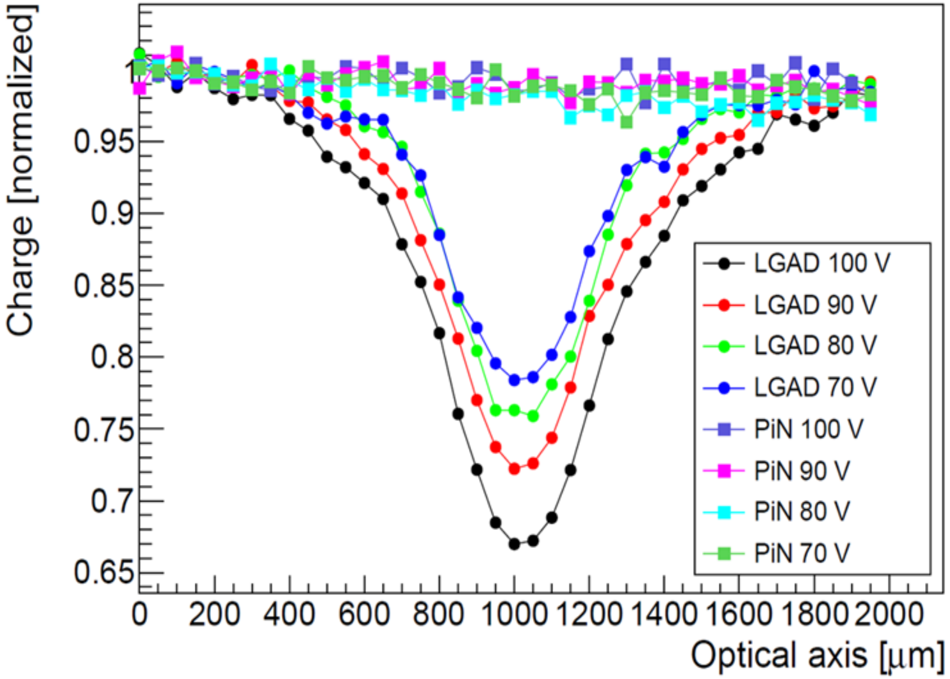
optical axis changes the spot size

Gain and density of ionization

HPK GL design
HPK-P1-T32 sensor



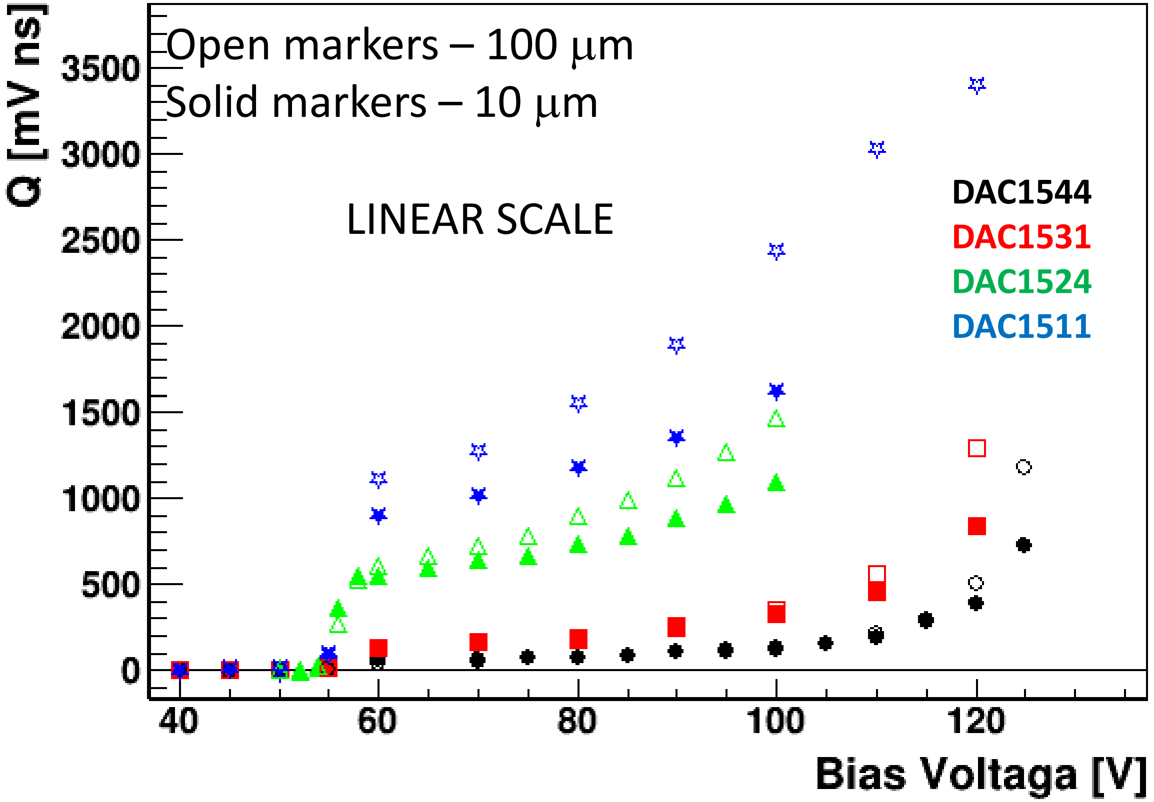


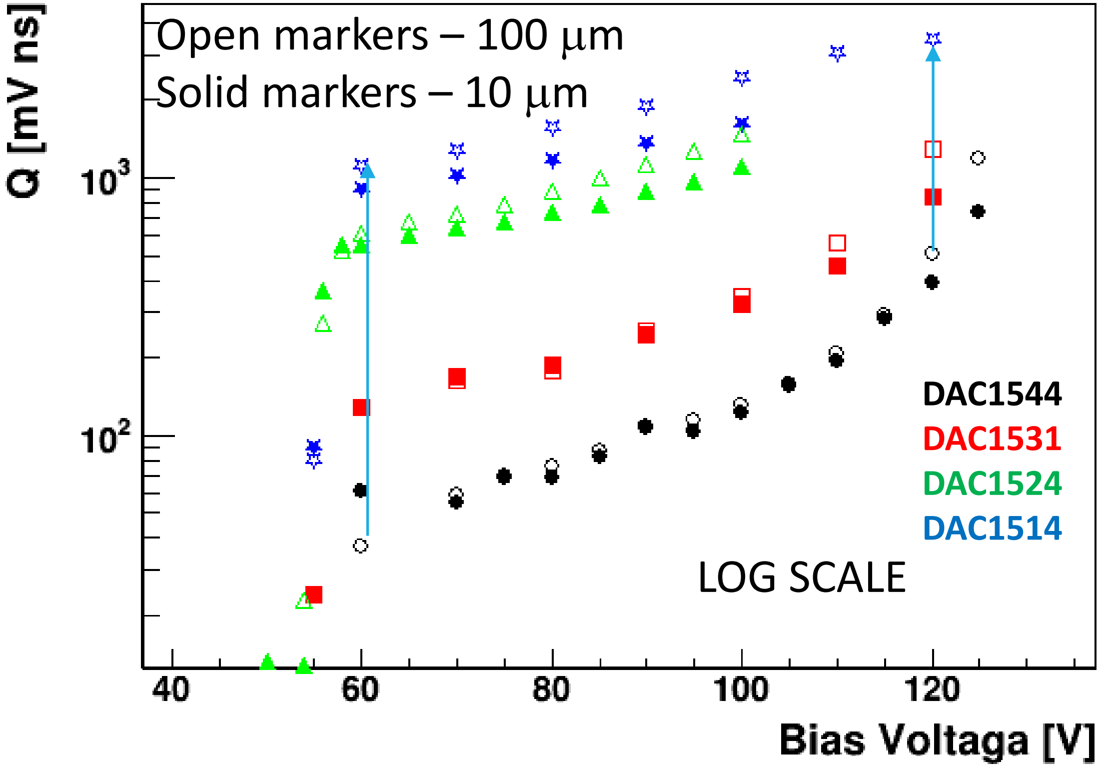


The most likely hypothesis: **multiplied carriers are present during the gain process screen the external field**

- How valid are the simulations using impact ionization models where the conditions/density is different?
- Taking about the gain makes sense only for given particle type (and angle?)

Changing laser intensity (HPK-P1-T3.2)





What can be seen:

- The difference is getting smaller with larger bias – large ionization density reduces gain increase with bias voltage
- Large ionization density leads to differences already at moderate gain while for low ionization density the gain remains the same and only differs at the highest bias voltages

Gain vs e-h pair density (HPK-P1-T3.2)

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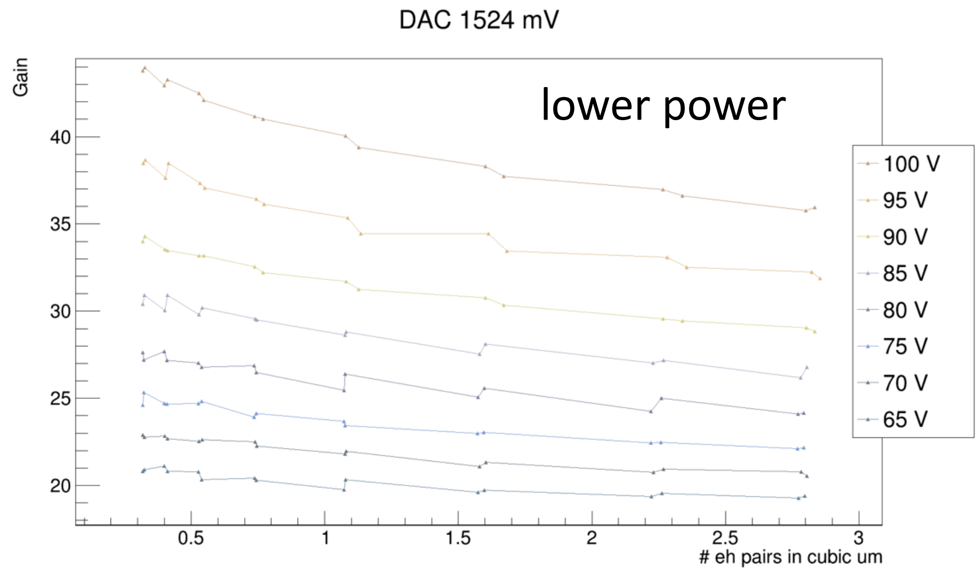
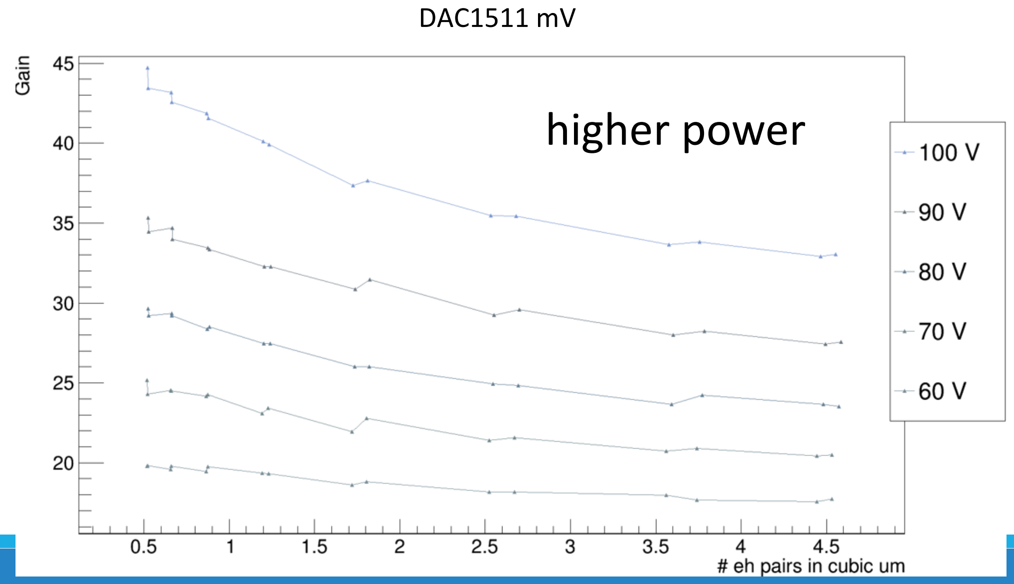


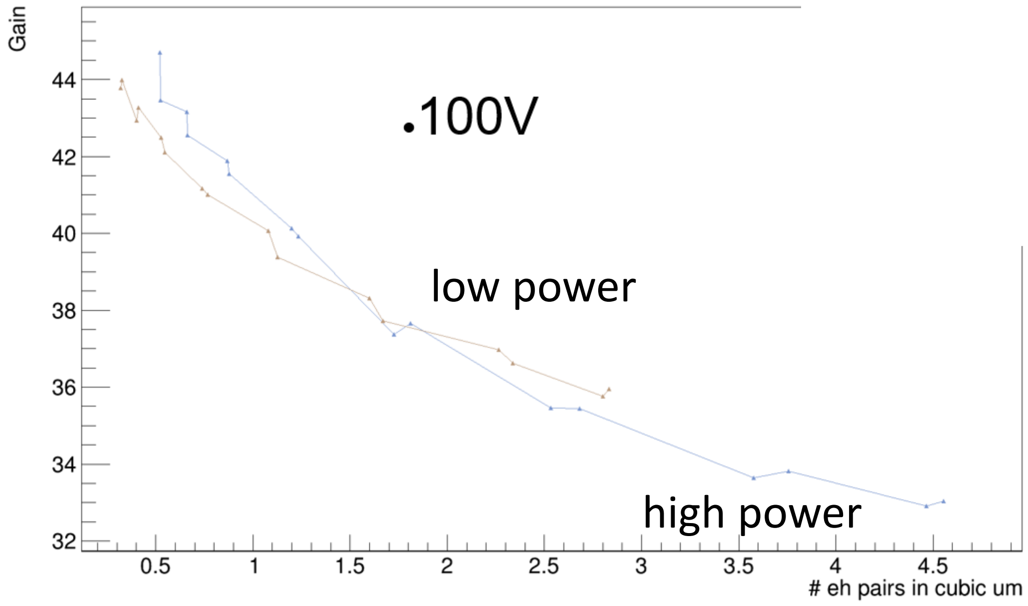


Similar gain is obtained at given voltage for changing the density of carriers with:

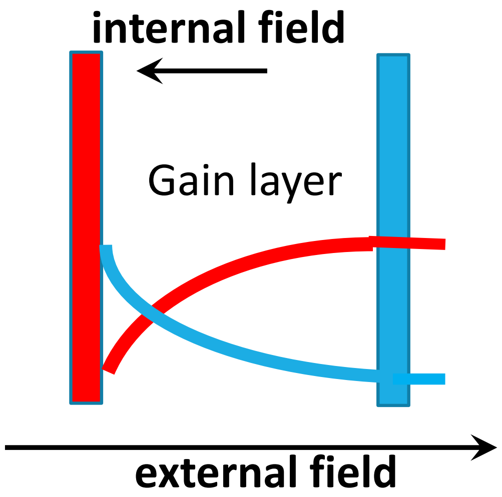
- laser power
- focusing of the beam

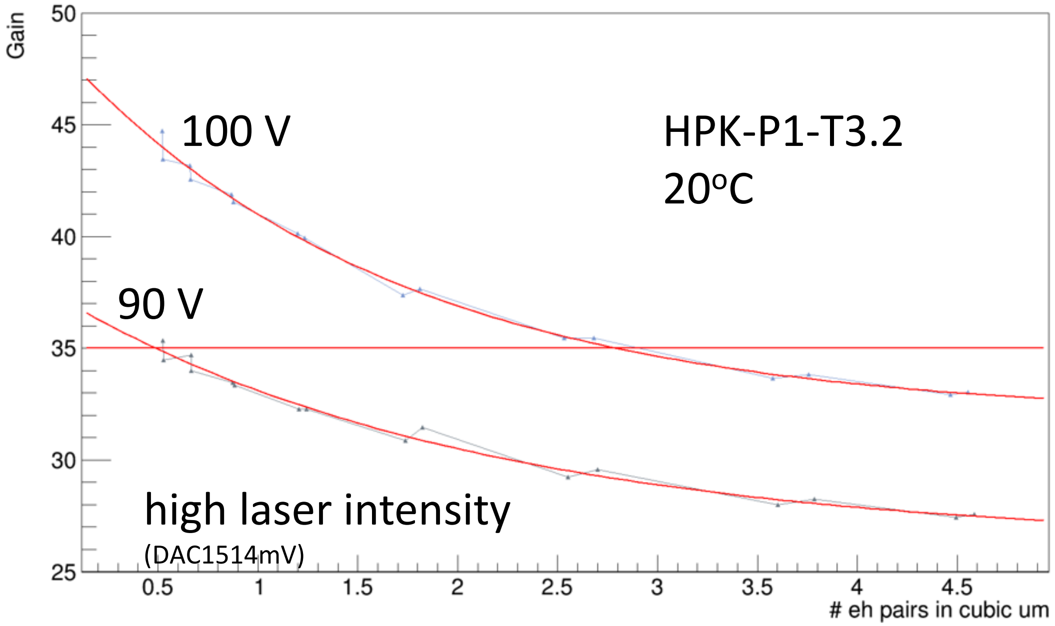
density of carries for mips: ~tens e-h/μm^3

~100 e-h/μm deposited – lateral dimension of ionization of 1-2 μm



Modelling





Very simplistic model (steady state):

- all the electrons are concentrated at the n^{++} implant
- all the holes are the end of the gain layer x_{gl}
- the polarization opposes to the external field

That is equivalent to a capacitor with electric field equal:

$$E_{int} = \frac{U}{x_{gl}} = \frac{Q}{x_{gl}\,\varepsilon\varepsilon_0 \frac{S}{x_{gl}}}$$

$$E_{int} = \frac{S x_{gl}\, n_{e-h} G(V_{bias})}{S\,\varepsilon\varepsilon_0}$$

$$\boxed{E_{int} = \frac{n_{e-h} G(V_{bias}) x_{gl}}{\varepsilon\varepsilon_0}}$$

G(90 V, 0.5 e-h/μm³)=G(100 V, 2.7 e-h/μm³)

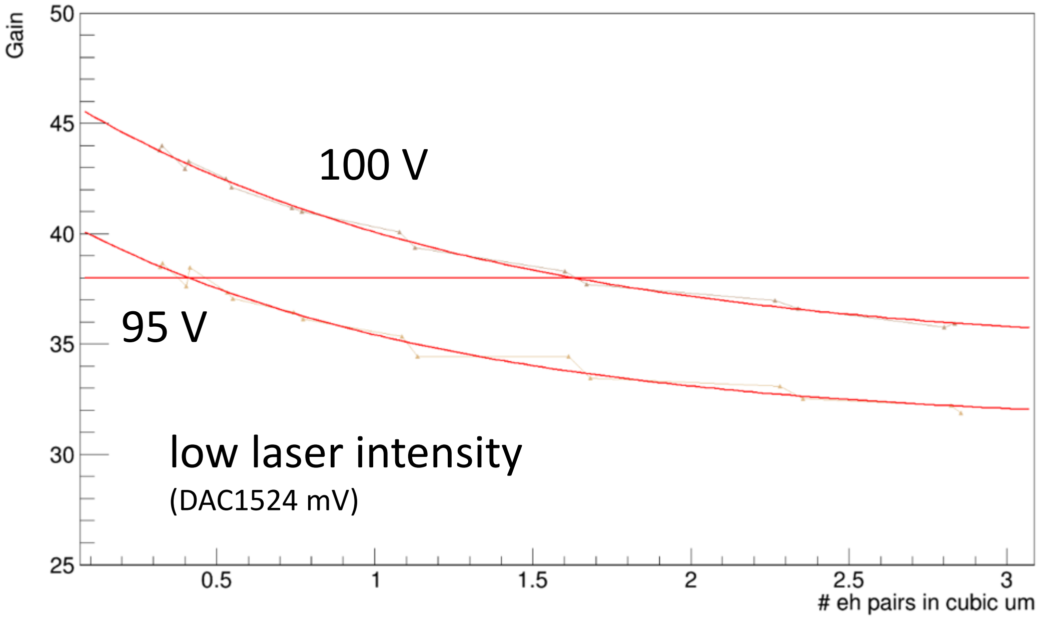
Higher n_{e-h} has to compensate for the difference in "external" electric field:

$\Delta E = \Delta V_{bias}/D = 10\ V/50\ \mu m$ = 0.2 V/μm

$\Delta E_{int} = \frac{\Delta n_{e-h} G(V_{bias}) x_{gl}}{\varepsilon\varepsilon_0}$ = 0.24 V/μm

Similar values confirm approximate validity of the assumptions

Modelling



G(95 V, 0.4 e-h/um3)=G(100 V, 1.5 e-h/um3)

Higher $n_{e\text{-}h}$ has to compensate for the difference in "external" electric field:

$\Delta E = \Delta V_{bias}/D = 0.1$ V/µm

$$\Delta E_{int} = \frac{\Delta n_{e-h} G(V_{bias}) x_{gl}}{\varepsilon \varepsilon_0} = 0.13 \text{ V/µm}$$

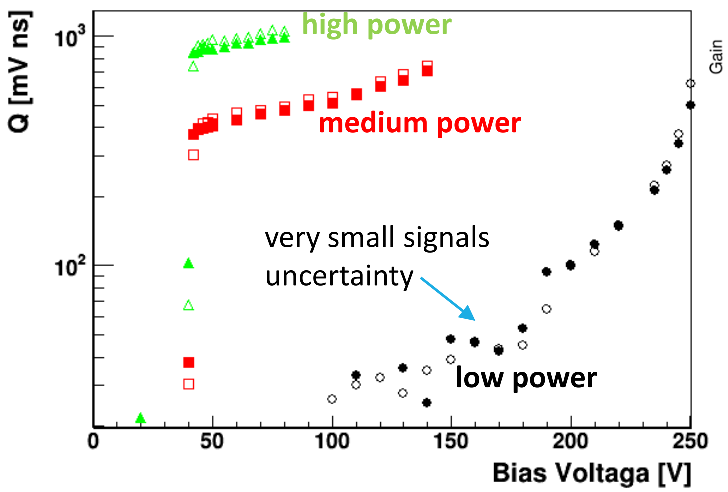
Similar values confirm approximate validity of the assumptions

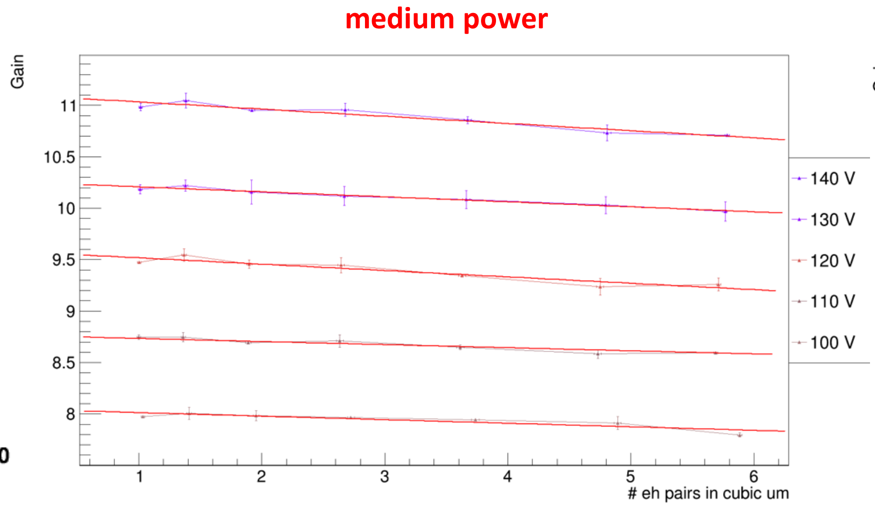
for heavily ionizing particles (ions) the field is completely screened already at very low gains (see G. Medin's talk)

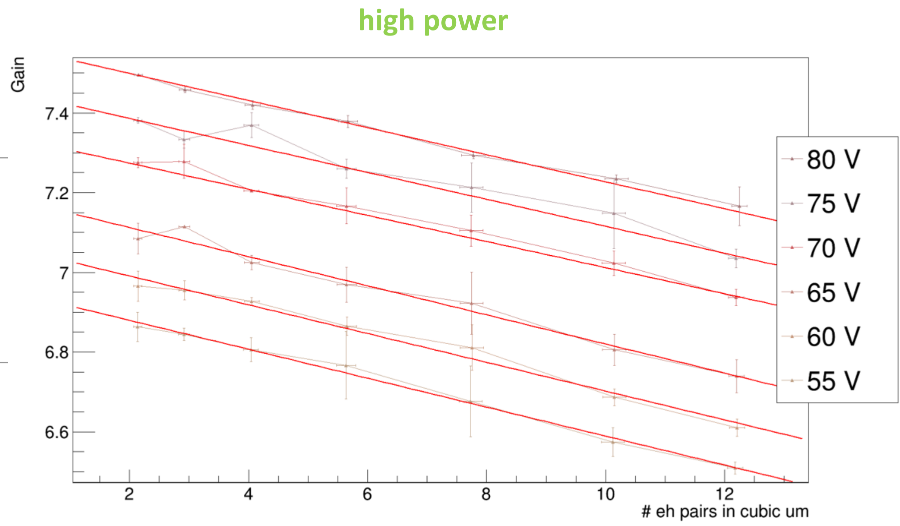
ANGLED TRACKS

The density of ionization is the same, but the projection to the gain layer surface is larger. The setting up of the screening field takes longer, hence the gain is larger.

Gain vs e-h pair density (HPK-P1-T3.1)







- Similar observation as for T3.2 sensor, with even more pronounced gain increase at low density. Problem is large signal for large density and saturation of the amplifier.
- $G(V_{bias}, n_{e\text{-}h})$ is compatible for both laser intensities
- The difference in $n_{e\text{-}h}$ and required difference in external field is compatible with the model.

Conclusions

- TCT on special LGADs from HPK was used determine the influence of ionization density on gain
- A simple model was proposed (polarization of gain layer) to understand and calculate the field screening and it was verified with the measurements
- The measurements on differently doped samples (smaller/larger initial gain) agreed with the model.
- Next steps:
  - use of short wavelengths where the ionization of concentration is larger, but significant ionization is created outside gain layer
  - perform similar study on irradiated samples