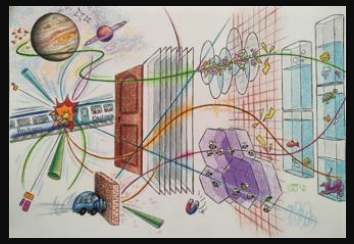
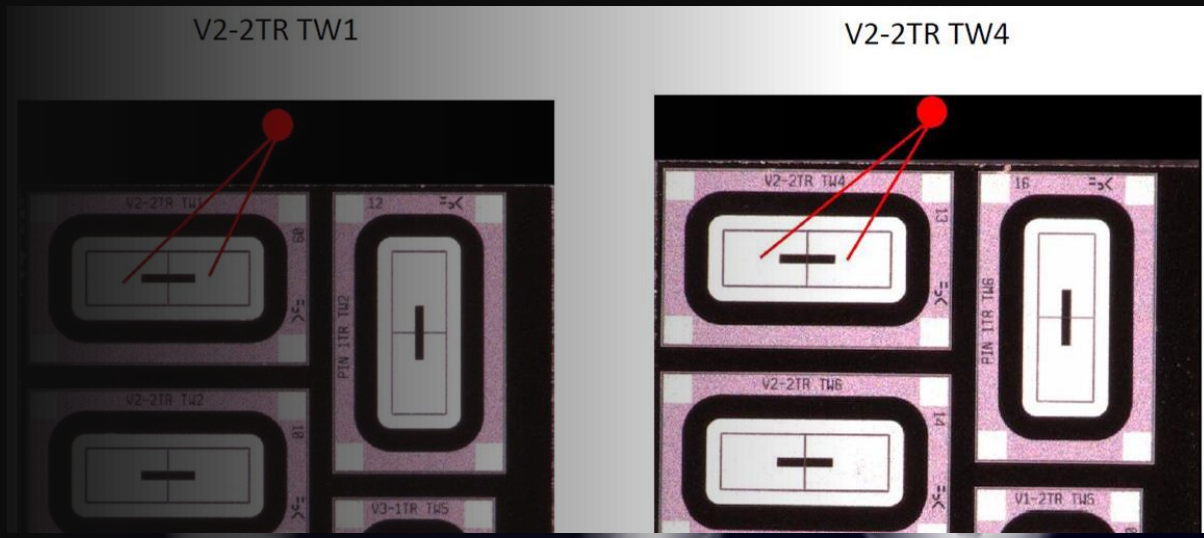


DRD3

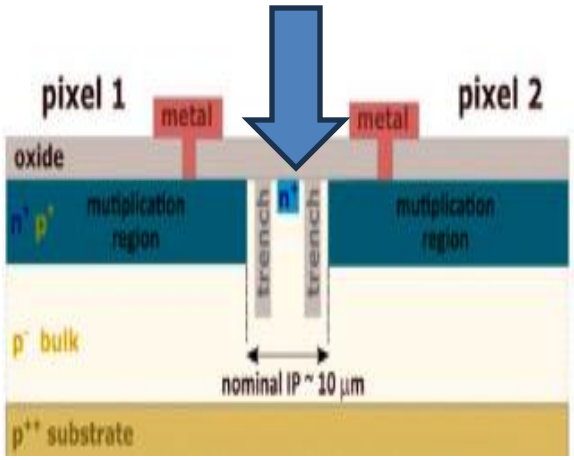
2nd DRD3 week on Solid State Detectors
2 - 6 December, 2024, CERN, Geneve R&D

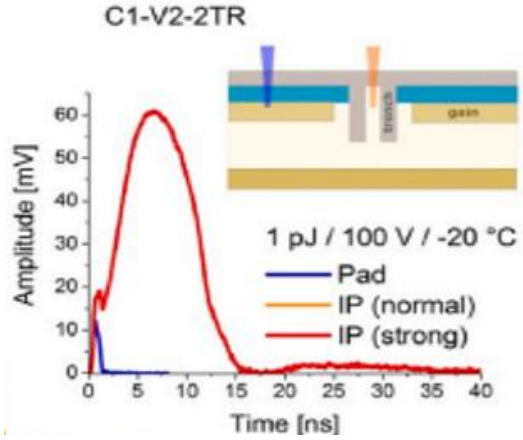


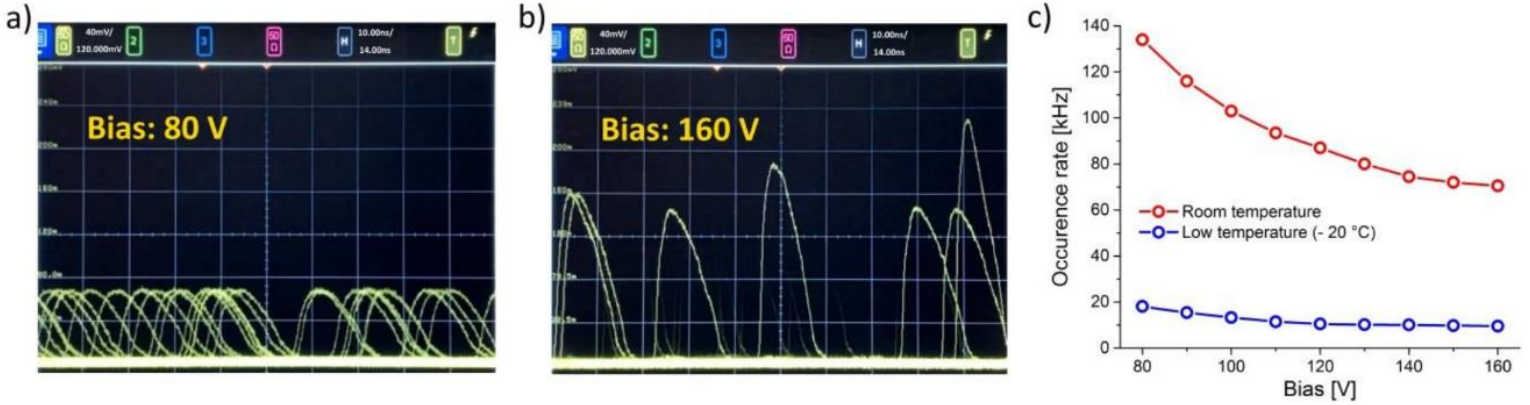
GHOSTY TI-LGAD

Gordana Lastovicka-Medin[1], Danijela Mrkic[1], Vuk Baletic[1], Gregor Kramberger[2], Jiri Kroll[3] Mateusz Rebarz[4]

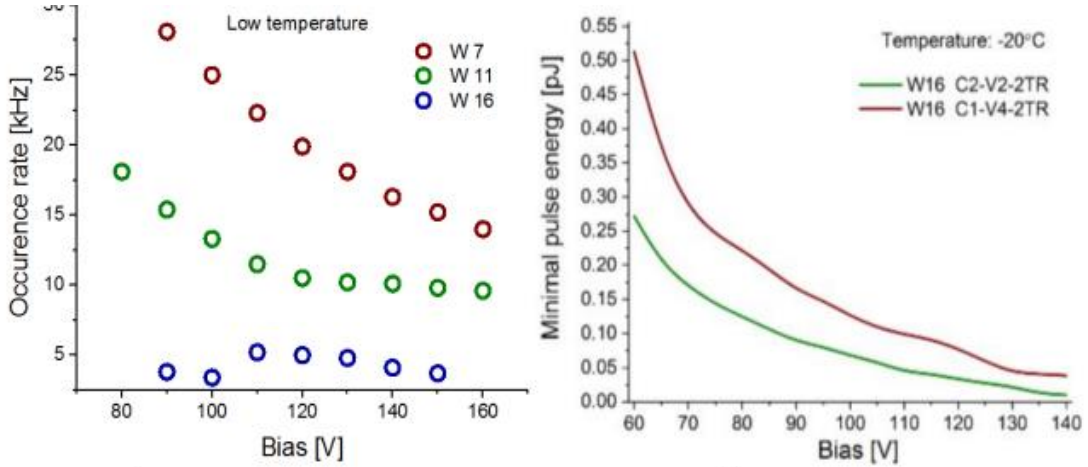
Faculty of Natural Sciences and Mathematics, University of Montenegro
[2] Jozef Stefan Institute, Ljubljana, Slovenia
[3] Institute for Physics at the Czech Academy of Science, Prague, Czech Republic
[4] ELI ERIC, ELI Beamlines, Prague, Czech Republic


pixel 1
pixel 2
metal
metal
oxide
n+ p+
multiplication region
trench
n+
trench
multiplication region
p- bulk
nominal IP ~ 10 µm
p++ substrate


C1-V2-2TR
Amplitude [mV]
Time [ns]
1 pJ / 100 V / -20 °C
Pad
IP (normal)
IP (strong)



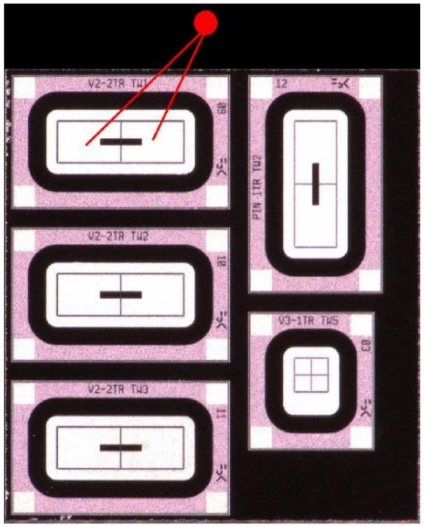
Examples of randomly generated "ghost signal" waveforms (oscilloscope screenshots) in 2TR TI-LGAD at a) 80 V and b) 160 V at room temperature ; c) occurrence rate of the "ghost signal" vs. bias voltage at room temperature and -20 ^{0}C.



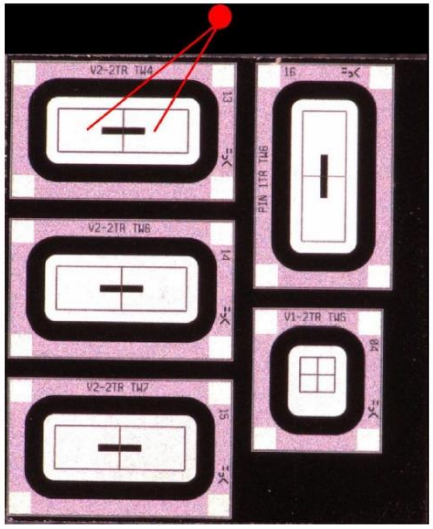
Occurrence rate vs bias for the ghsts from the 2Tr Ti-LGADs, fabricated from three different wafers with the different trench depths: W7 (V2), W11 (V2), W16 (V3). b) The laser pulse energy threshold vs bias for the laser-stimulated signals from the inter-pixel region; the inter-pixel region was illuminated by fs-laser.

AIDA INNOVA
IRRADIATED TI-LGAD

Sensor 1
V2-2TR TW1



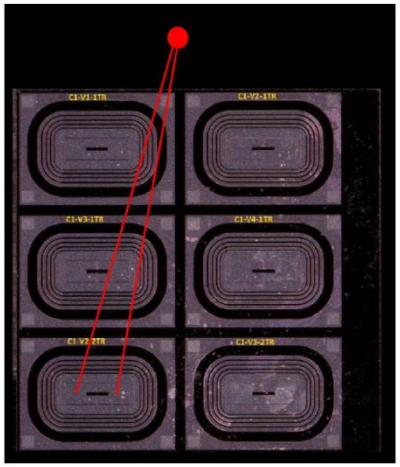
Sensor 2
V2-2TR TW4



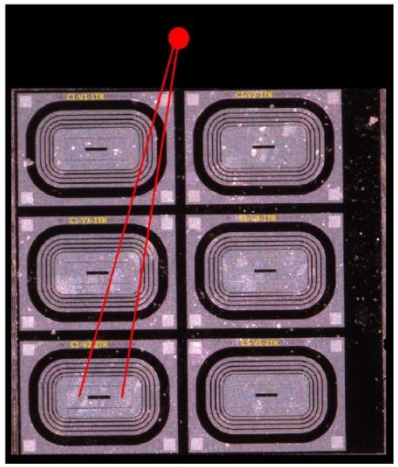
Investigated 2TR LGADs and PINs

1. AIDA C-TS3 LGAD: V2-2TR TW1 **(8e14)**
2. AIDA C-TS4 LGAD: V2-2TR TW4 **(1.5e15)**
3. RD50 LGAD: C1-V2-2TR **(4e14)** W3-A1 1,4
4. RD50 LGAD: C1-V2-2TR **(4e14)** W3-A1 5,2
5. RD50 LGAD: C1-V2-2TR **(8e14)** 1,3 (5)
6. RD50 PIN: C1-V2-2TR **(8e14)** W3-A1 6,3

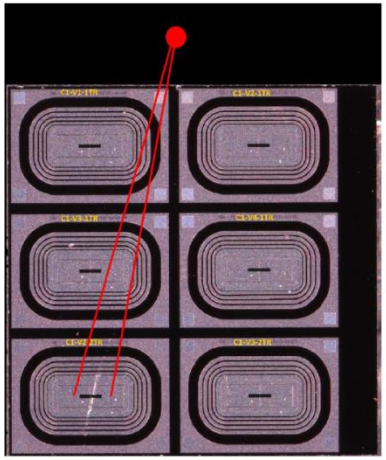
Sensor 3
C1-V2-2TR



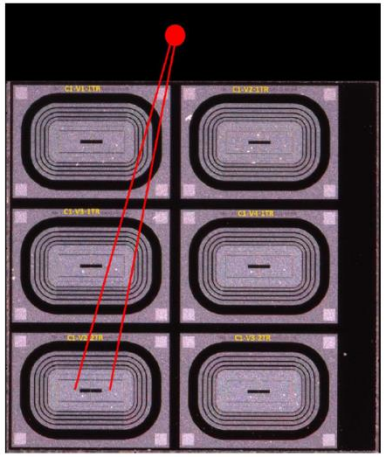
Sensor 4
C1-V2-2TR



Sensor 5
C1-V2-2TR



Sensor 6
C1-V2-2TR

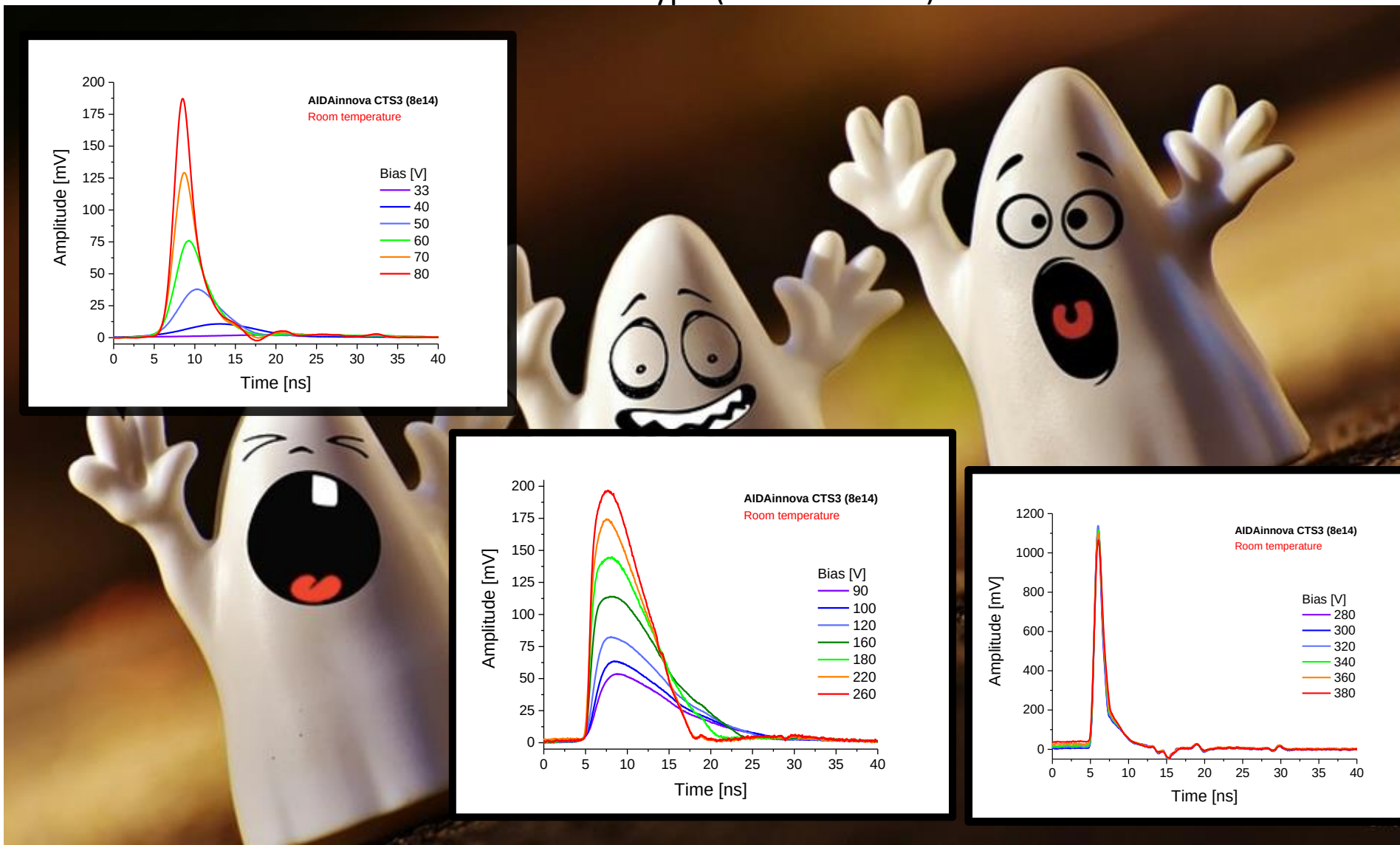


AIDA 2 Tr LGAD C-TS3 8e14

Room Temperature

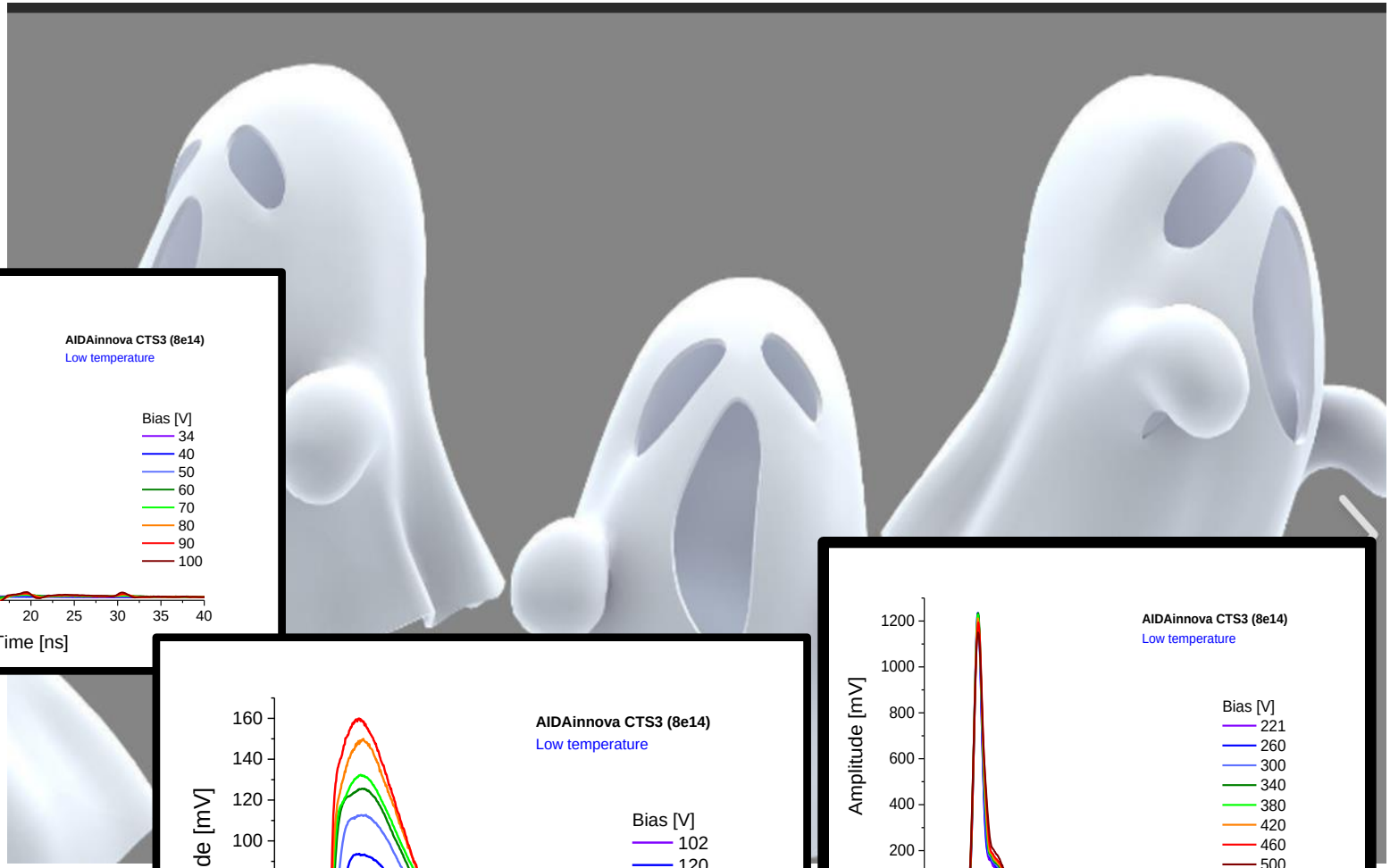
Recorded waveforms

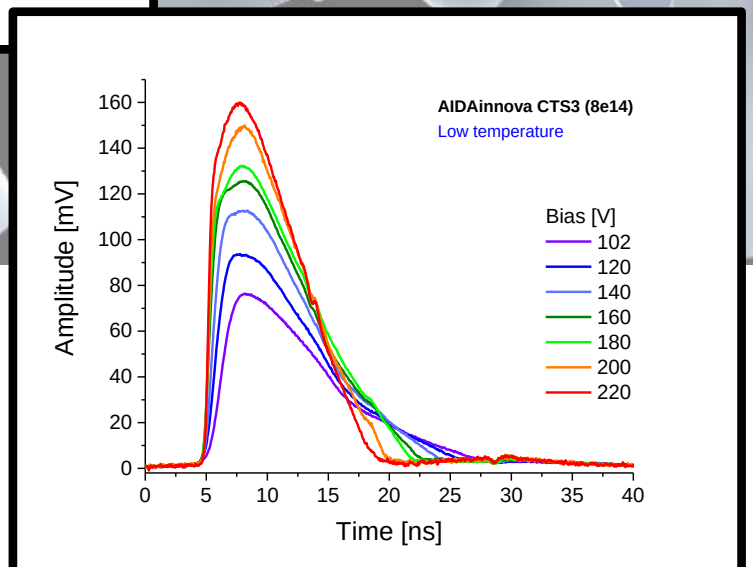
Thre types of ghosts in 3 different bias ranges. They don't coexist. There are sharp thresholds to switch from one to another type (90V and 280V)



AIDA 2 Tr LGAD C-TS3 8e14

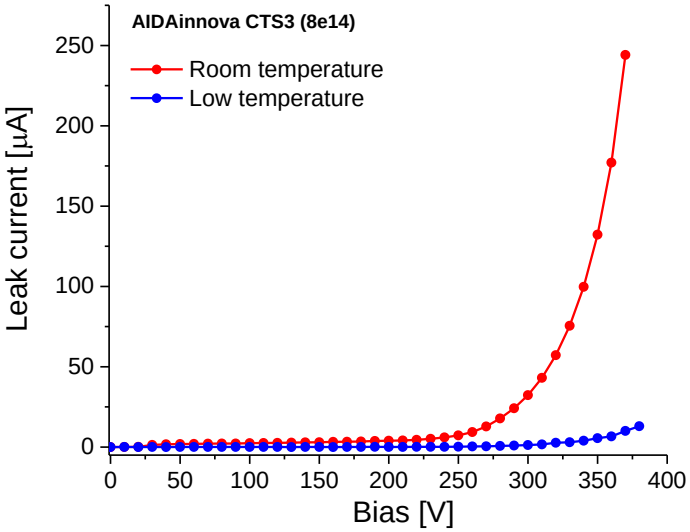
Low Temperature





AIDA 2 Tr LGAD C-TS3 8e14

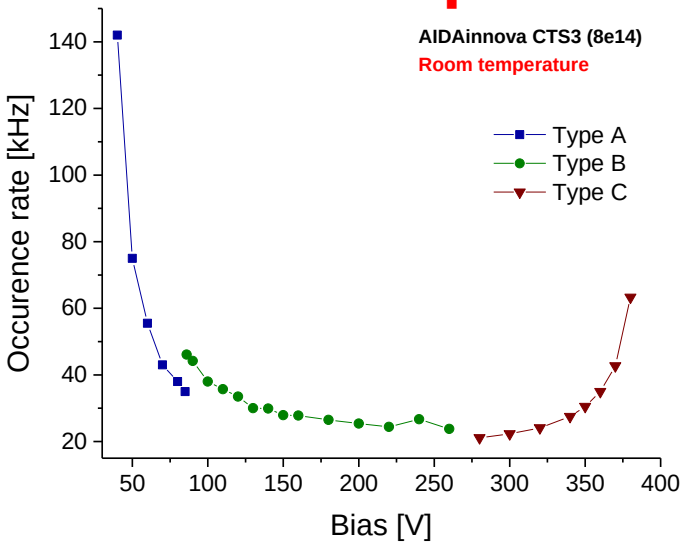
Leakage current



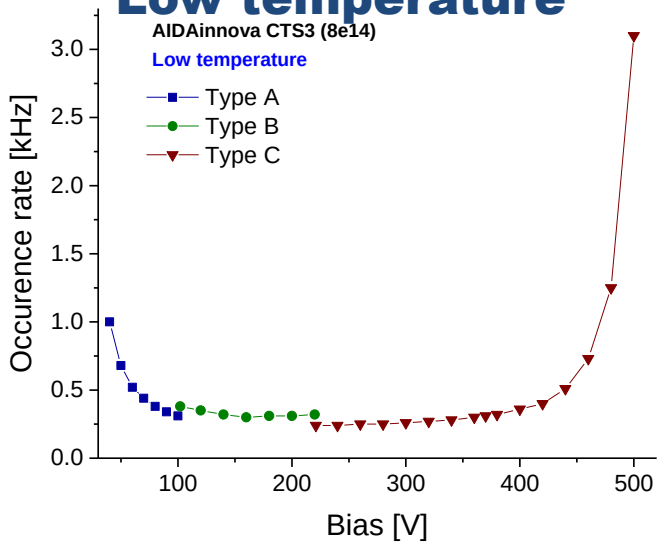
Occurrence rate strongly depends on temperature, much lower frequency at low temperature.
3 types of ghosts have different behavior vs bias.

Occurrence rate

Room temperature



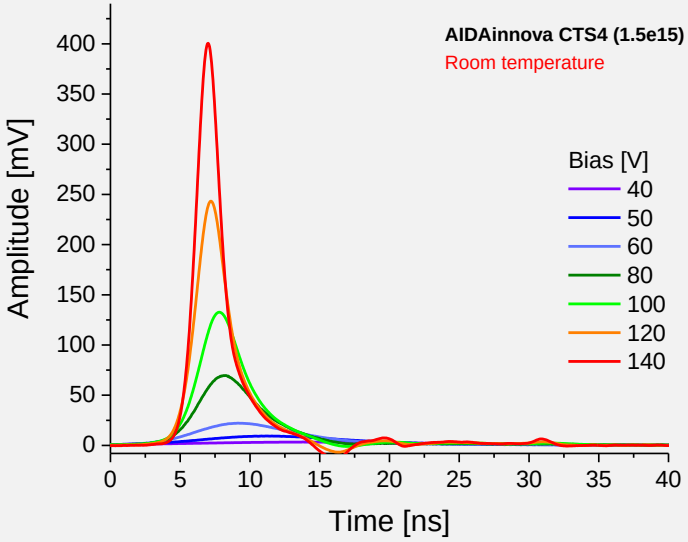
Low temperature



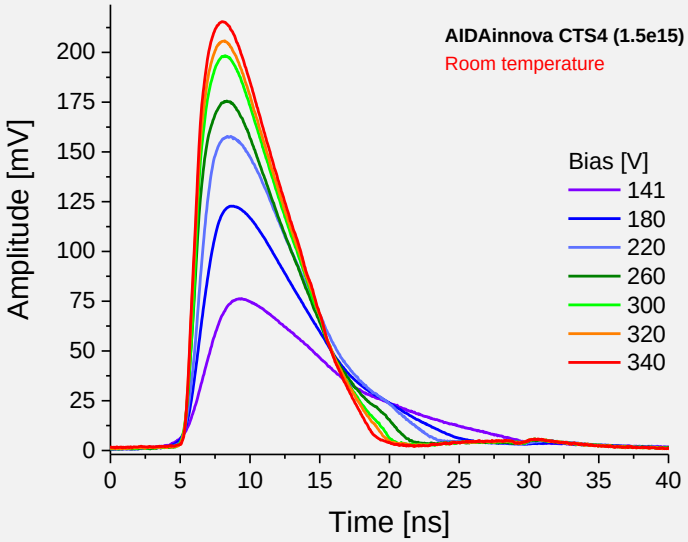
AIDA 2 Tr LGAD C-TS4 1.5e15

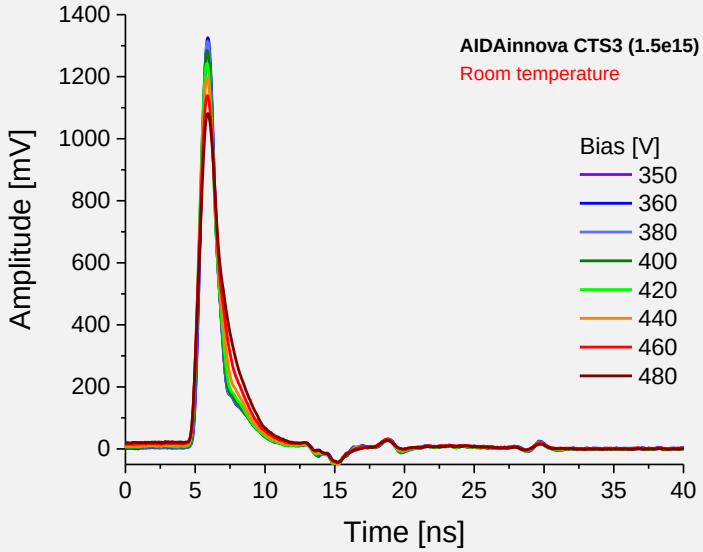
Room Temperature

Recorded waveforms



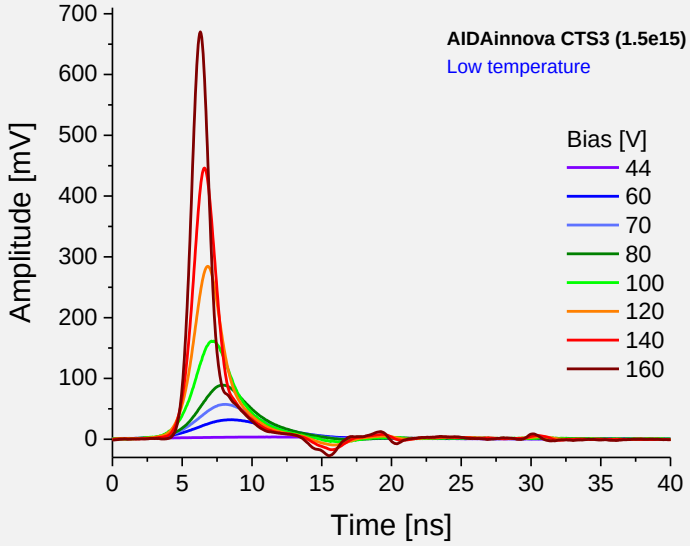
Similar situation to C-TS3 sensor. We have 3 types of ghosts in 3 different bias ranges.

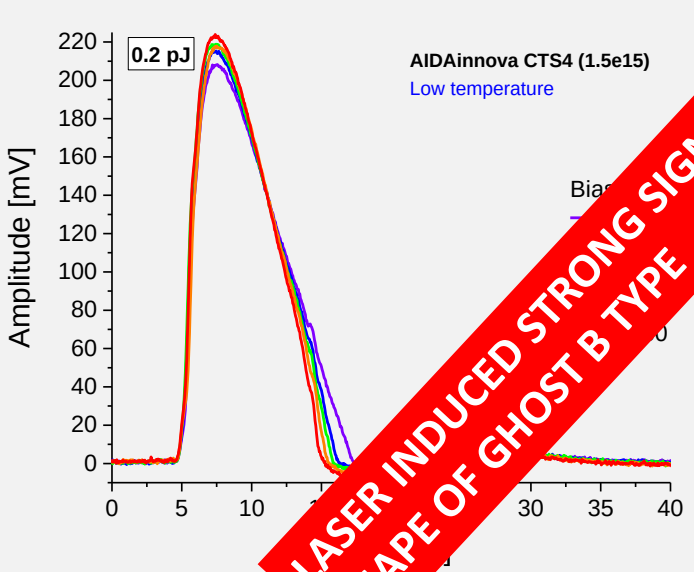


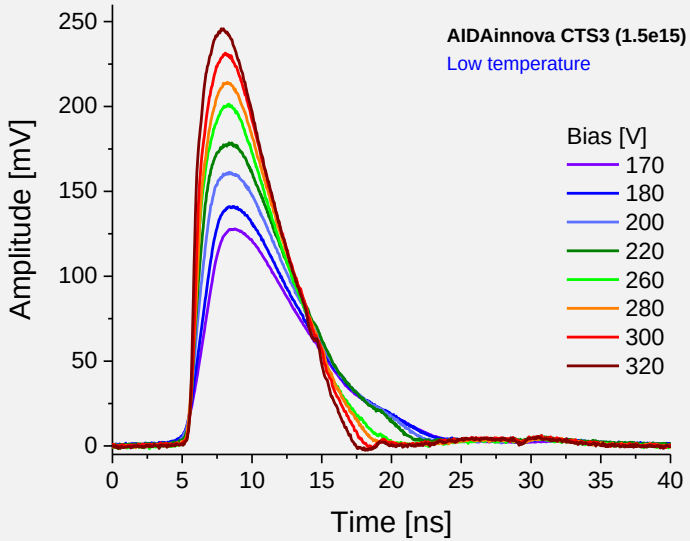


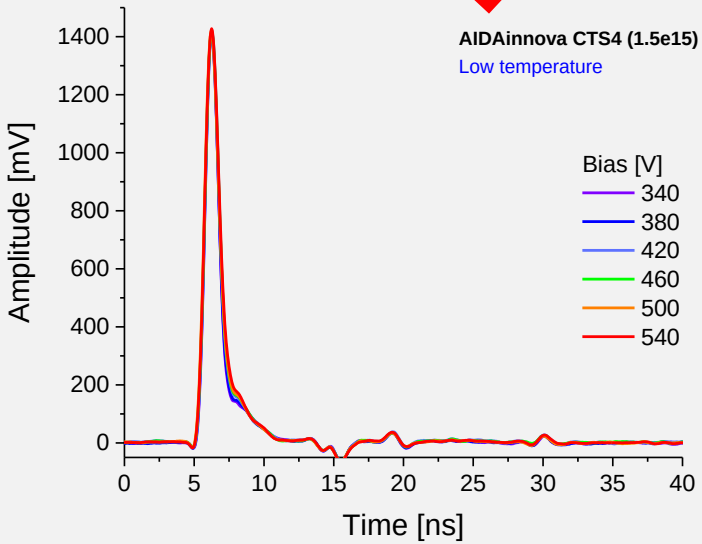
AIDA 2 Tr LGAD C-TS4 1.5e15 Low Temperature

Recorded waveforms



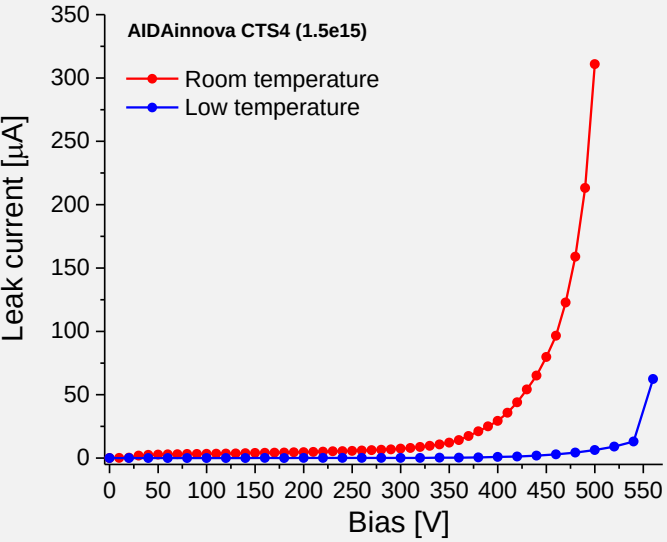




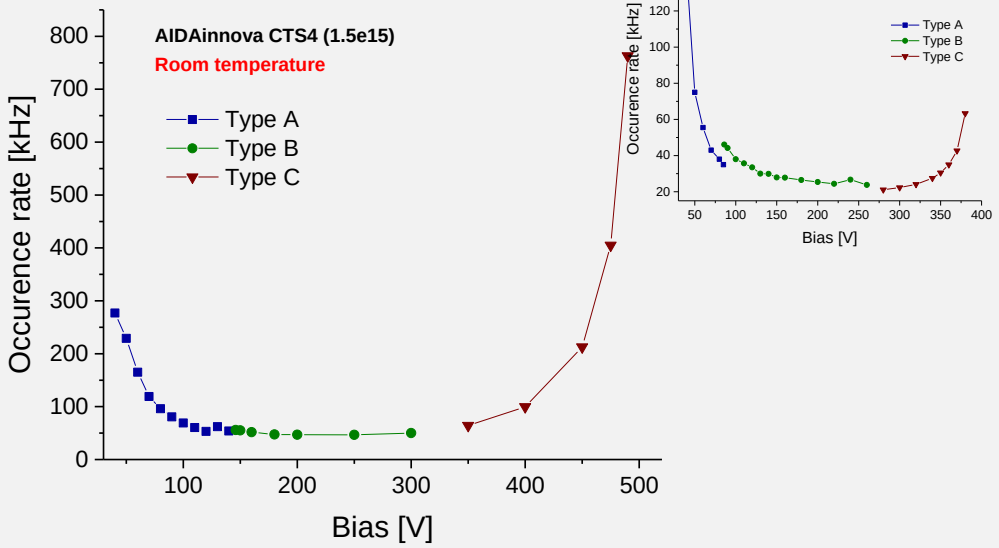


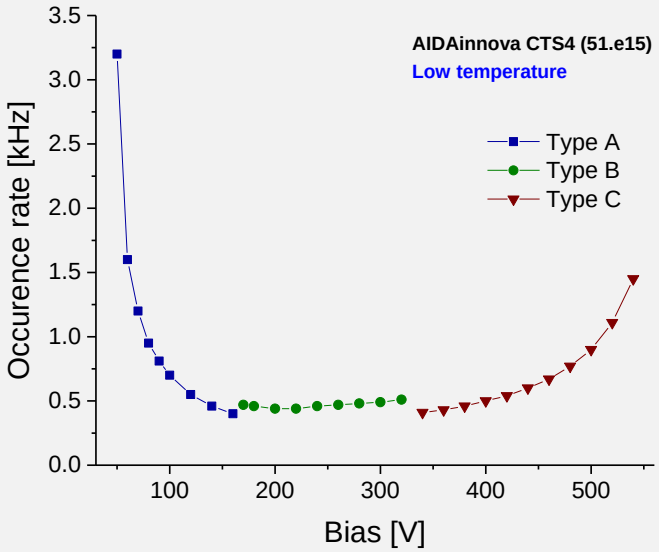
AIDA 2 Tr LGAD C-TS4 1.5e15

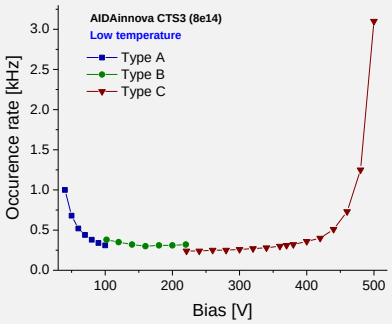
Leakage current



Occurrence rate

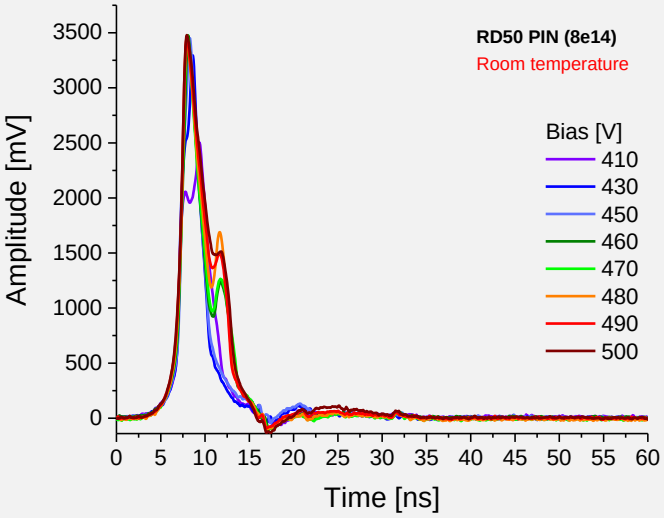


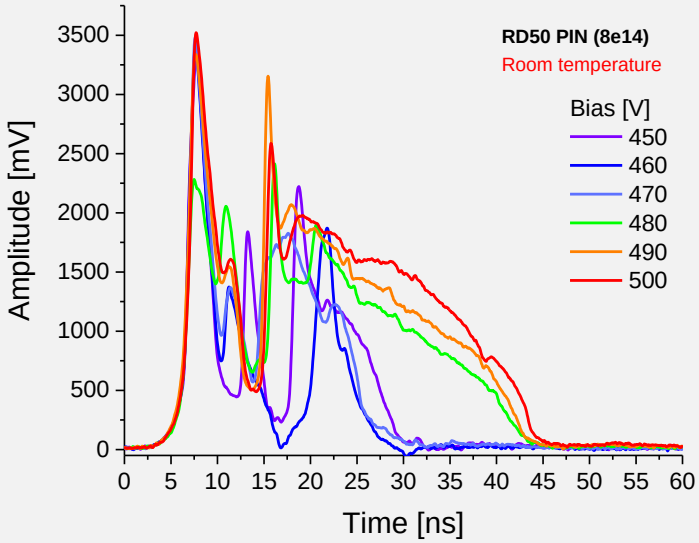




RD50 2 Tr PIN 8e14

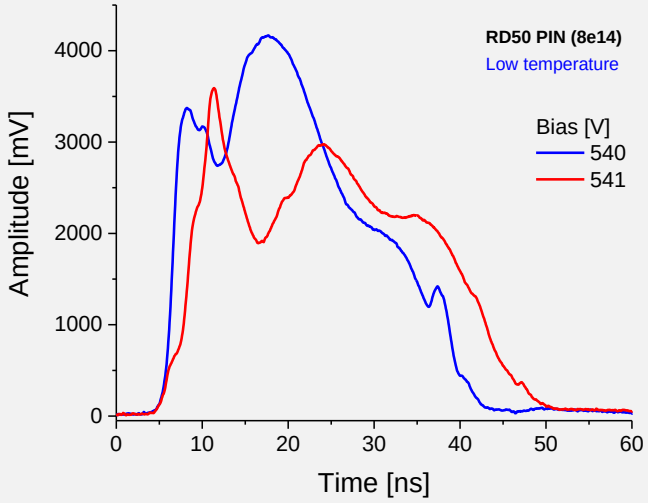
Room Temperature





Hide and seek play + ping-pong game ☺ - TEAM WORK!

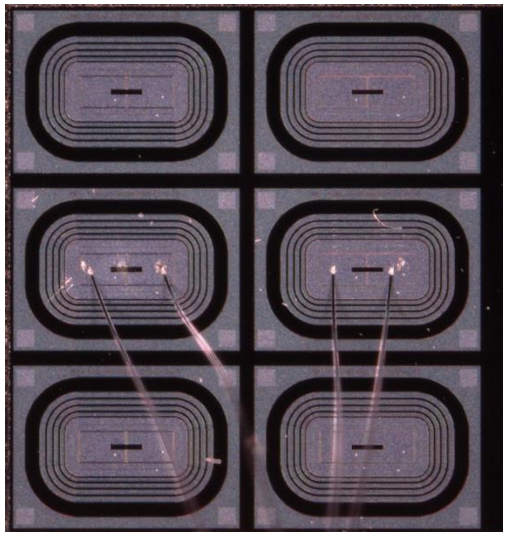
Low Temperature



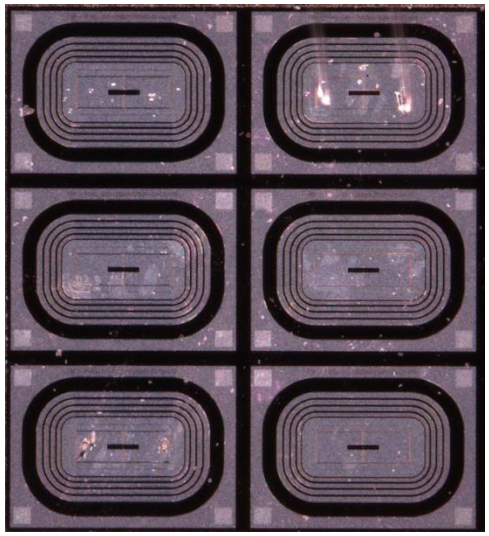
At 542V the sensor broke down.
Fortunately we managed to register the ghosts for 540 and 541 V.

Occurrence rate is about 6 kHz at RT (a bit jumpy)
and a few Hz (very unstable) at low temperature

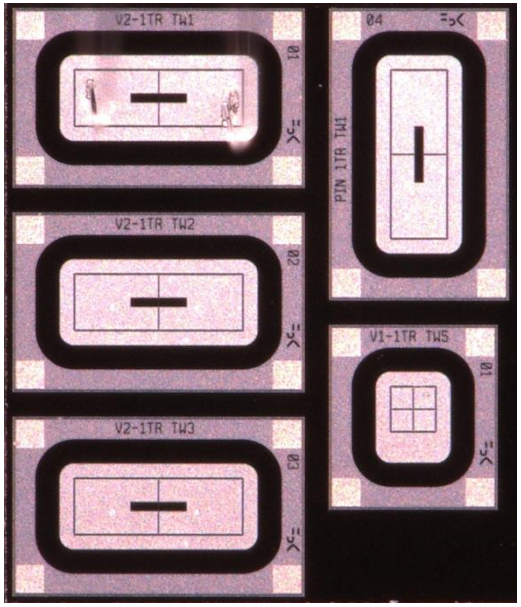
RD50 LGAD: C1-V3-1TR and C1-V4-1TR (non-irr)



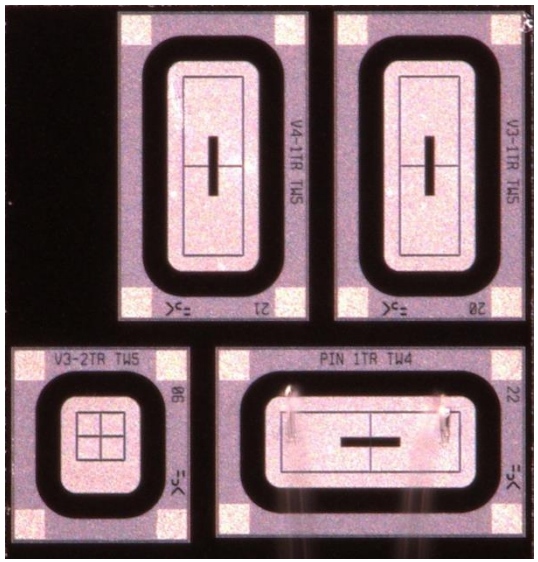
RD50 LGAD: C1-V2-1TR (4e14)



AIDA TS1: V2-1TR TW1 (8e14)



AIDA TS8: PIN 1TR TW4 (1.5e15)



Investigated 1TR LGAD and 1Tr PINs

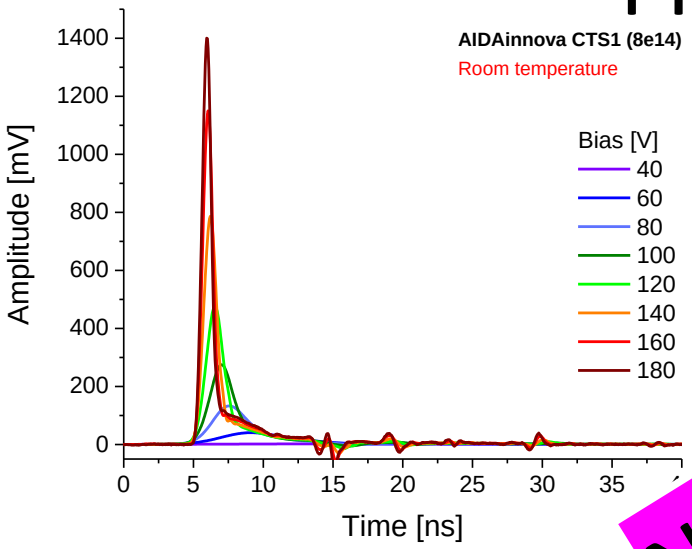
1. RD50 LGAD: C1-V3-1TR and C1-V4-1TR **(non-irr)** W11-A1 5,4 (old sensor revisited)
2. RD50 LGAD: C1-V2-1TR **(4e14)** W3-A1 5,2
3. AIDAinnova CTS1: V2-1TR TW1 **(8e14)** 10,8 (Cell-C)
4. 4. AIDAinnova CTS8: PIN 1TR TW4 **(1.5e15)** 10,8 (Cell-C)

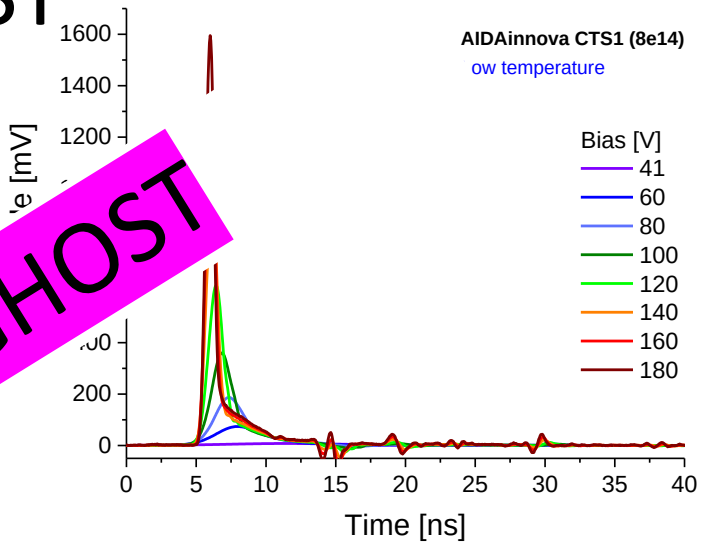
AIDA 1 Tr LGAD C-TS1 8e14

Room Temperature

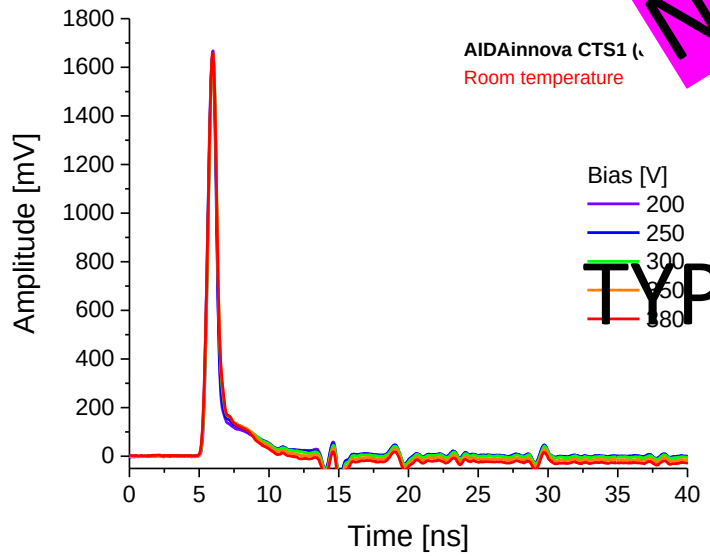
Low Temperature

TYPE A GHOST

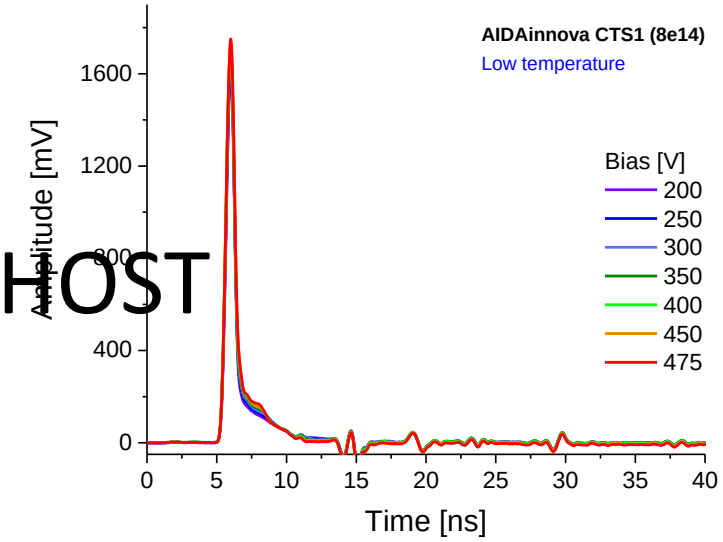




No TYPE B GHOST

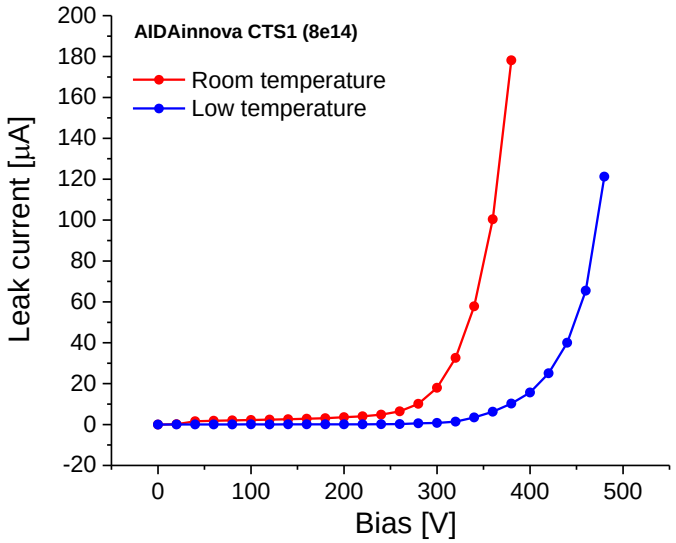


TYPE C GHOST

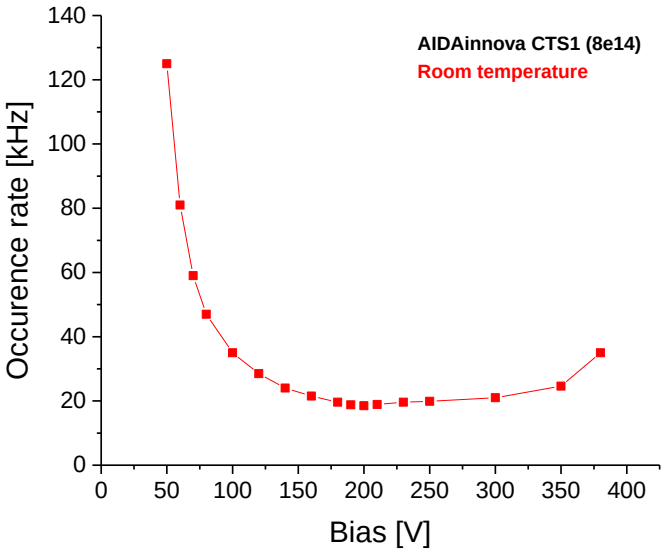


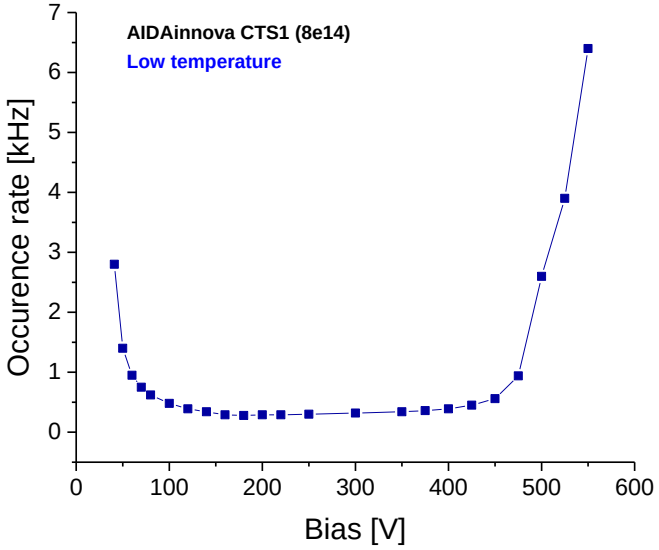
AIDA 1 Tr LGAD C-TS1 8e14

Leakage current



Occurrence rate





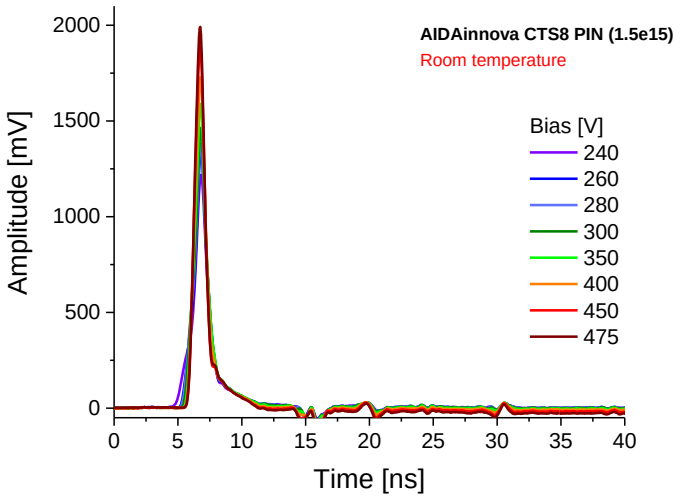
Occurrence rate similar to what was measured for 2TR i LGADs (even though we don't have Type B ghosts here).

First quick drop vs bias, then slower, and increase at high bias.

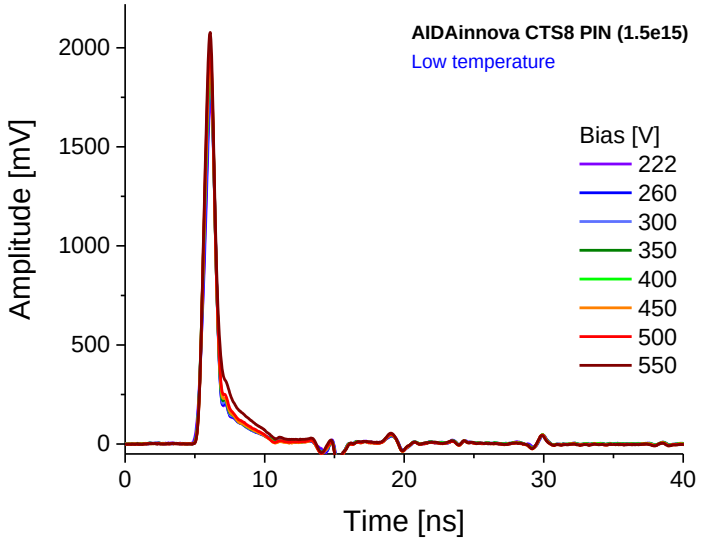
General frequency at low temperature decreases drastically (about 100 times)

AIDA 1 Tr PIN C-TS8 1.5e15

Room Temperature

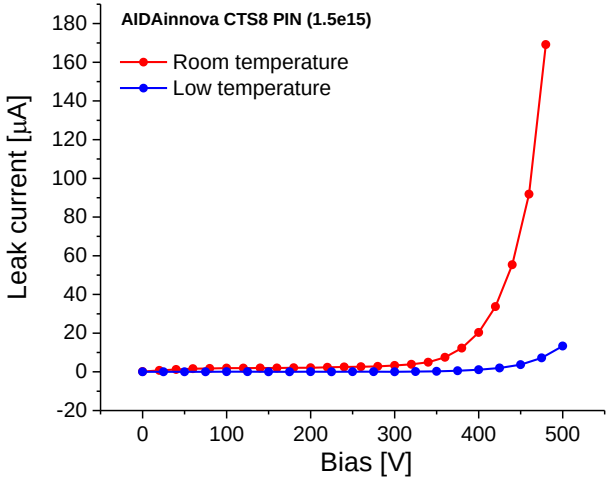


Low Temperature

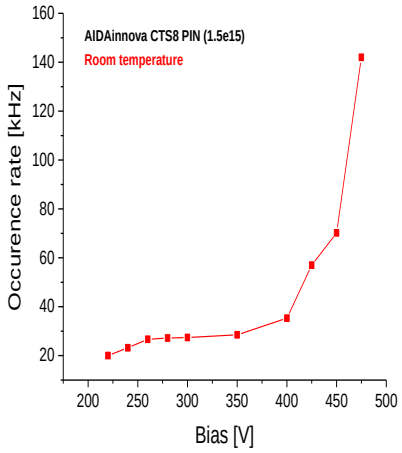


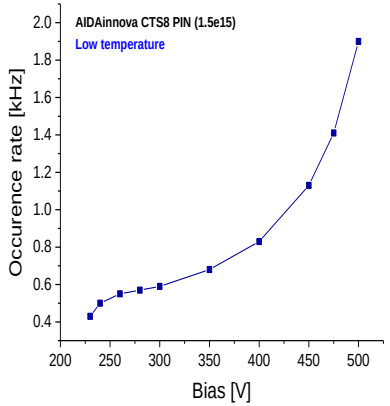
In PIN we see ghost but only the very strong ones (similar to Type C in LGADs) that appear above 220 V

Leakage current



Occurrence rate

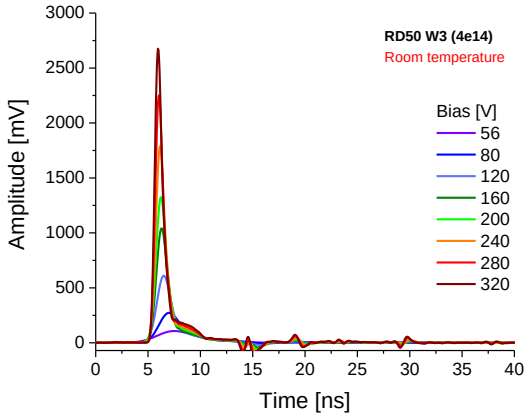




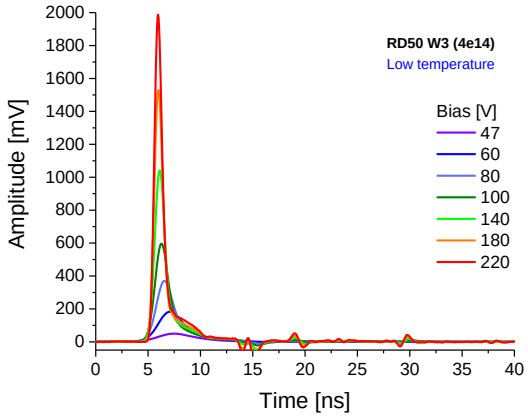
RD50 1 Tr W3 PIN 4e14

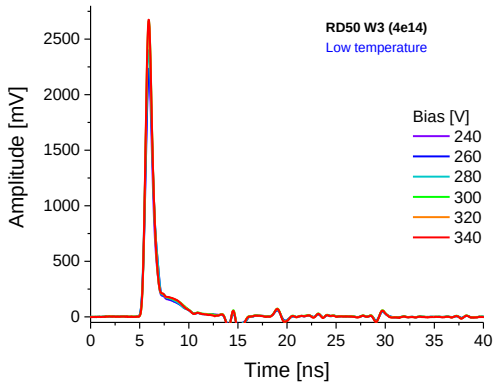
In RD50 1TR PIN we have also Type A and Type C (at least at low temperature).No Type B.

Room Temperature

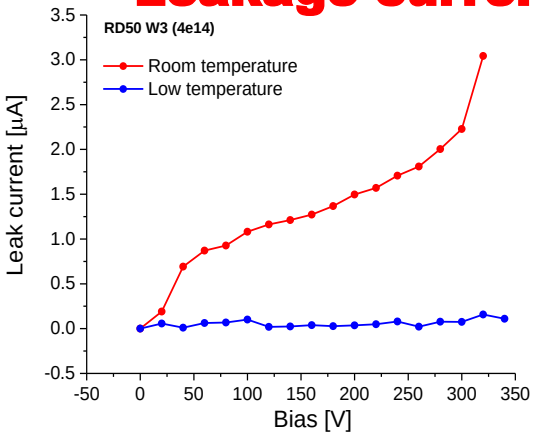


Low Temperature

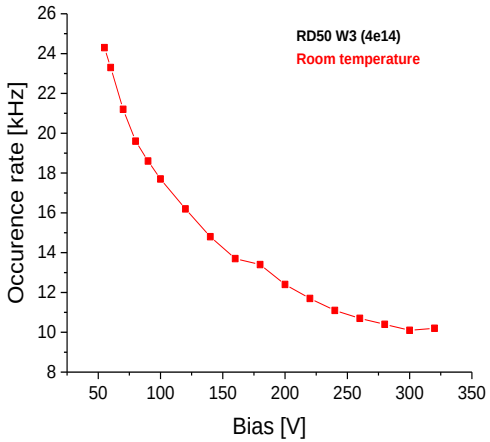


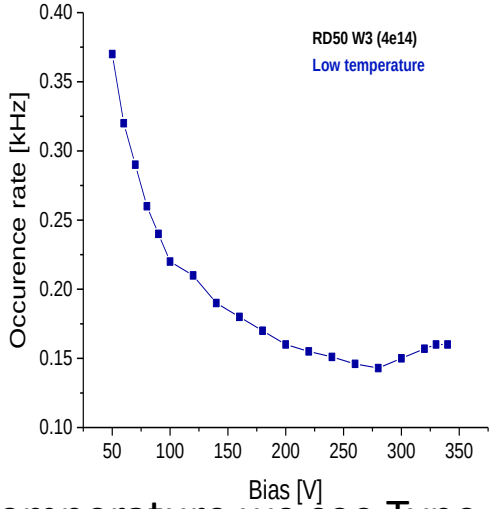


Leakage current



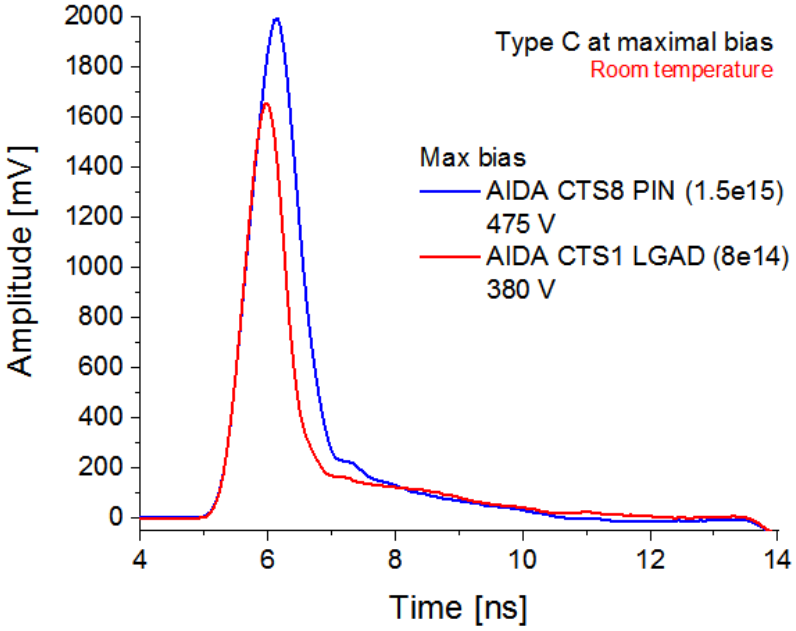
Occurrence rate

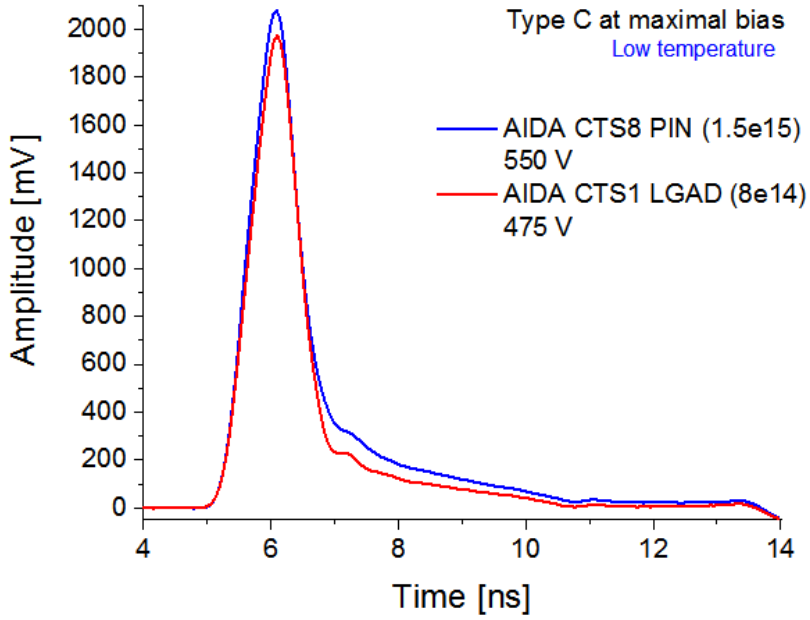




Occurrence rate is consistent with type of ghosts we see. At room temperature we see Type A only so frequency decreases with bias. At low temperature we see also Type C at high bias and occurrence rate start increasing in that region

Type C Ghosts: PIN vs LGAD

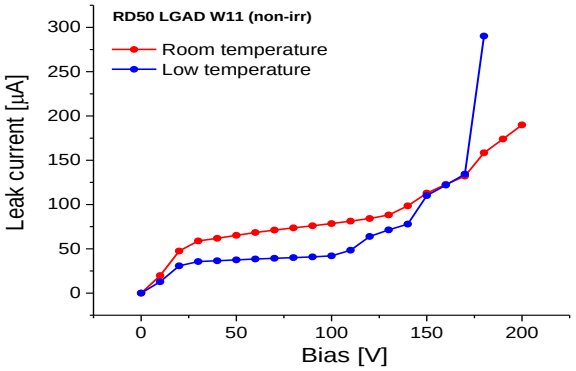




Revisited:

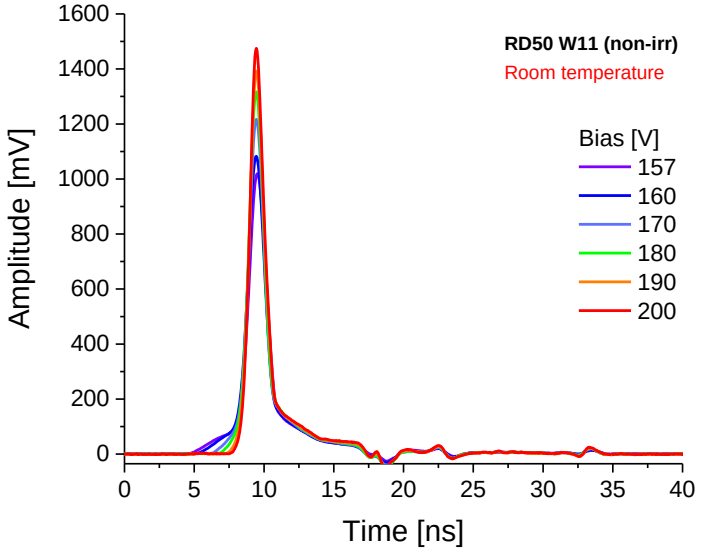
RD50 1Tr LGAD non-irradiated (W11)

Leakage current

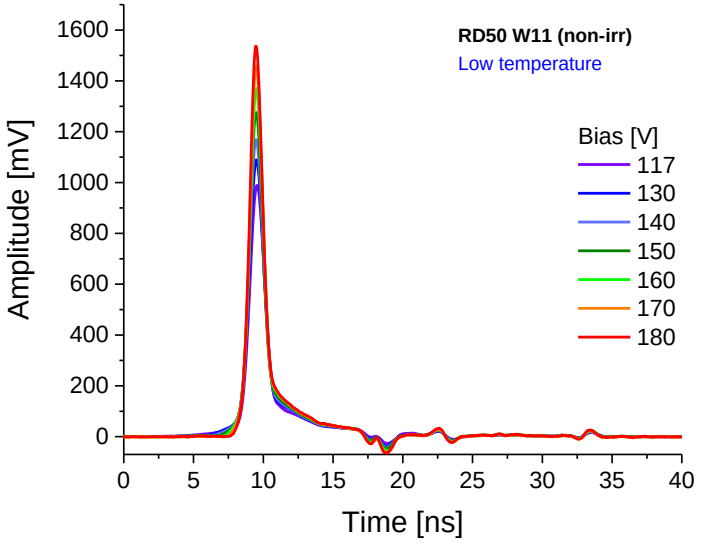


We revisited non-irradiated 1TR LGAD
Previously, we assumed that there is no ghosts in 1TR LGADs. However now we clearly see ghosts.
It seems that they are only Type C ones.

Room Temperature



Low Temperature



CONCLUSION: MESSAGE TO BE TAKEN HOME

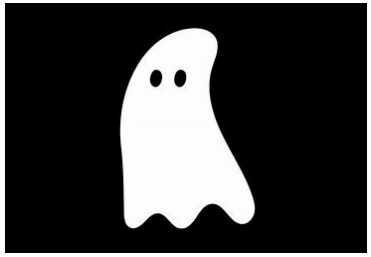
Non-irradiated 2 Tr LGAD

Irradiated 2 Tr LGAD

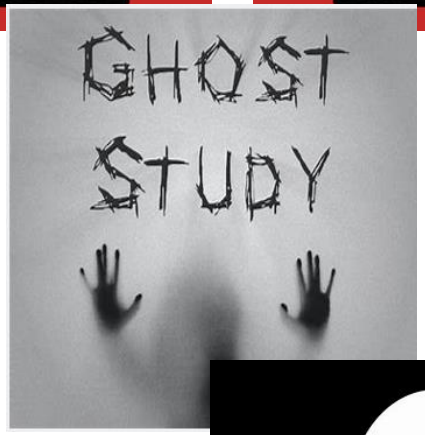
Non-irradiated 2 Tr PIN

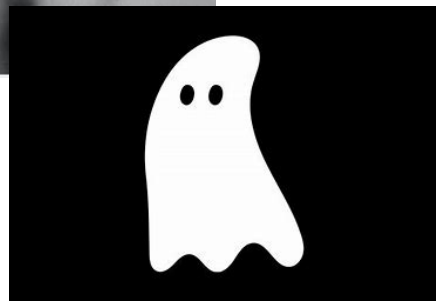
Irradiated 2 Tr PIN

Non-irradiated 1 Tr LGAD



Irradiated 1 Tr LGAD





Non-irradiated 1 Tr PIN

Irradiated 1 Tr PIN

When cooled

Tench isolation vs others

What was observed

1. In all trench sensors we have measured ghosts in all types trench-isolated LGADs (1TR, 2TR, irradiated or non-irradiated, LGAD or PIN)

2. **There is no ghosts in non-trench sensors (we tested (re-investigated again) Type10 and Type9 interpad layout and even close to maximal bias there is nothing) so it looks that ghost effect is related to trench presence.**

2TR LGADs

1. In 2TR LGADs we have measured three types of ghosts
   - Type A: initially low and broad but quickly increasing in amplitude and becoming narrower (occurrence rate decreases quickly with bias)
   - Type B: clearly broader than Type A (very similar to “strong” IP signal), amplitude increases with bias, occurrence rate decreases slowly with bias
   - Type C: similar in shape to Type A but much stronger (observed for high bias), amplitude not much dependent on bias (or independent), occurrence increasing with bias

2. In 2TR LGADs we see laser induced “strong” IP signal very similar to Type B ghosts

3. Ghosts and “strong” IP signal are observed for irradiated (4e14, 8e14, 1.5e15) and non-irradiated 2TR LGADs

4. Ghost occurrence rate is strongly dependent on temperature, it decreases drastically if we go from +20C to -20C.

1TR LGADs

1. Ghosts are also present in 1TR sensors (both irradiated or non-irradiated)

2. Only Type A and Type C ghosts exists in 1TR LGADs (very similar to those observed in 2TR LGADs). They evolve smoothly so it's even difficult to say if there are two type of ghosts (no sharp threshold).

3. By increasing bias ghosts become stronger and narrower (like Type A) and at high bias amplitude stops growing (like Type C).

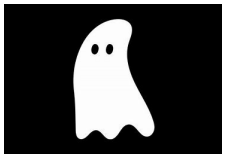
4. Occurrence rate first decreasing quickly vs bias, then decreasing slowly and finally at high bias starts increasing (similar evolution to ghosts in 2TR LGADs)

5. Ghost occurrence rate is strongly dependent on temperature, it decreases drastically if we go from +20C to -20C.

5. There is no Type B ghosts in 1TR LGADs

6. There is no laser induced "strong" IP signal in 1TR LGADs

Strong signal (induced by laser) is definitely synhronized with Type B ghost and linked to presence of 2 trenches.



Trenched PINs

1. In 2TR PINs we also see ghosts but they appear only at high bias (AIDAinnova, similar to Type C) or very high bias (RD50) close to damage threshold

2. PIN ghosts in RD50 are very strong and have much broader shape than LGADs ghosts

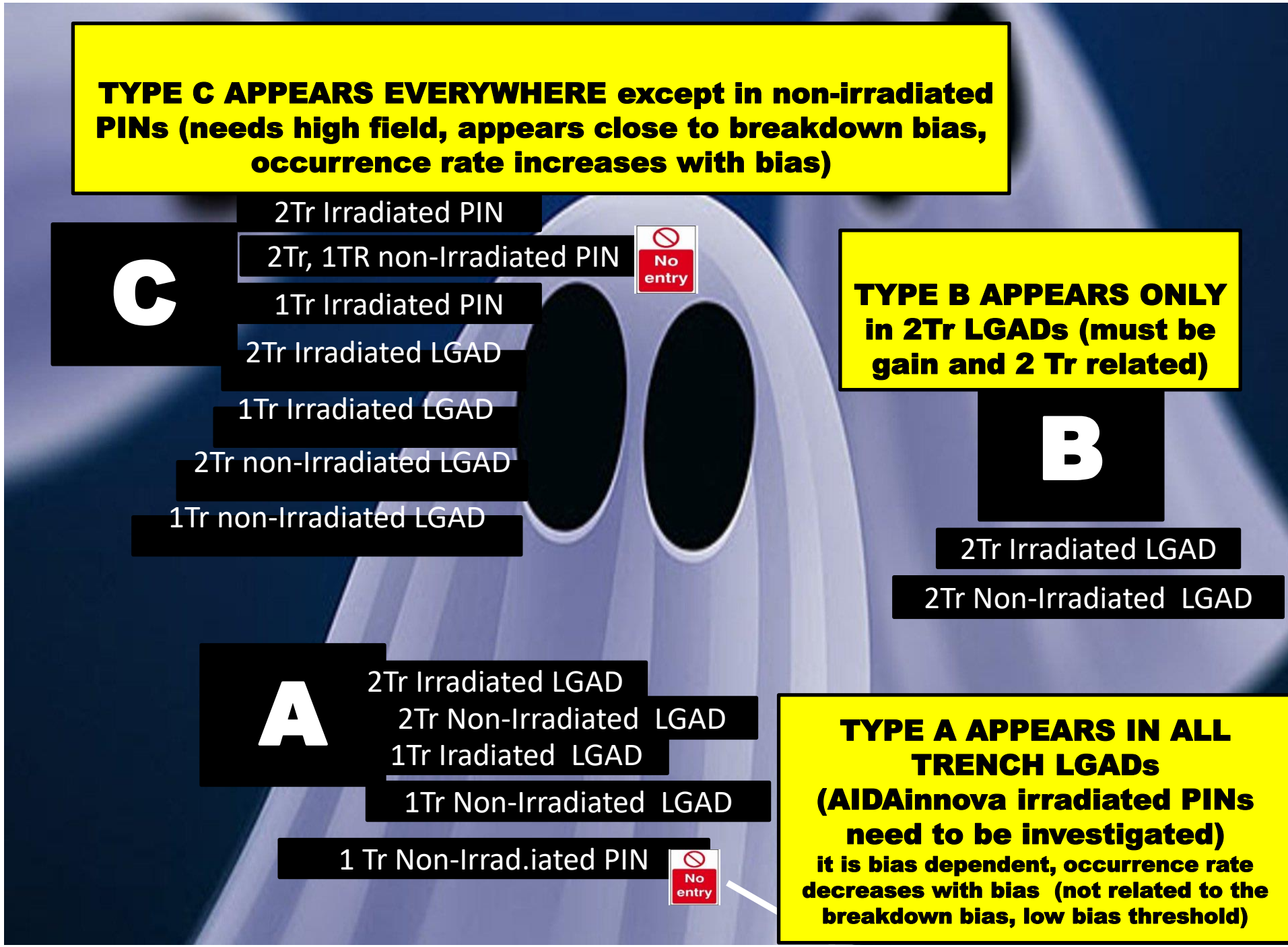
3. “strong” IP signal was also observed in non-irradiated RD50 2TR PINs at high bias (close to maximal bias)

Irradiation

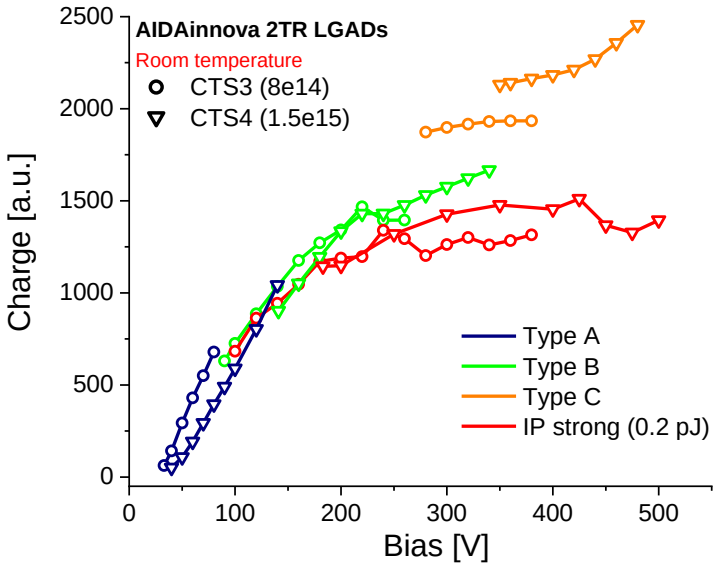
1. It seems that irradiation does not decide if ghosts are present or not (we see them for every fluence)

2. Previous conclusion that radiation can kill the ghosts was wrong. It was based on one sensor only and that was most probably PIN (wrongly considered LGAD)

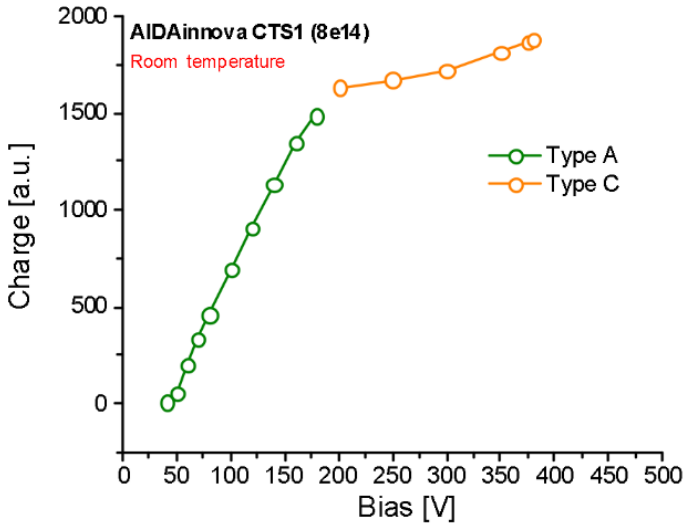
3. Irradiation enables application of much higher bias so probably thanks to this we can identify these very strong ghosts close to damage threshold (not manifested in non-irradiated sensors limited to 200 V)


TYPE C APPEARS EVERYWHERE except in non-irradiated PINs (needs high field, appears close to breakdown bias, occurrence rate increases with bias)
C
2Tr Irradiated PIN
2Tr, 1TR non-Irradiated PIN
No entry
1Tr Irradiated PIN
2Tr Irradiated LGAD
1Tr Irradiated LGAD
2Tr non-Irradiated LGAD
1Tr non-Irradiated LGAD
TYPE B APPEARS ONLY in 2Tr LGADs (must be gain and 2 Tr related)
B
2Tr Irradiated LGAD
2Tr Non-Irradiated LGAD
A
2Tr Irradiated LGAD
2Tr Non-Irradiated LGAD
1Tr Iradiated LGAD
1Tr Non-Irradiated LGAD
1 Tr Non-Irrad.iated PIN
No entry
TYPE A APPEARS IN ALL TRENCH LGADs (AIDAinnova irradiated PINs need to be investigated)
it is bias dependent, occurrence rate decreases with bias (not related to the breakdown bias, low bias threshold)

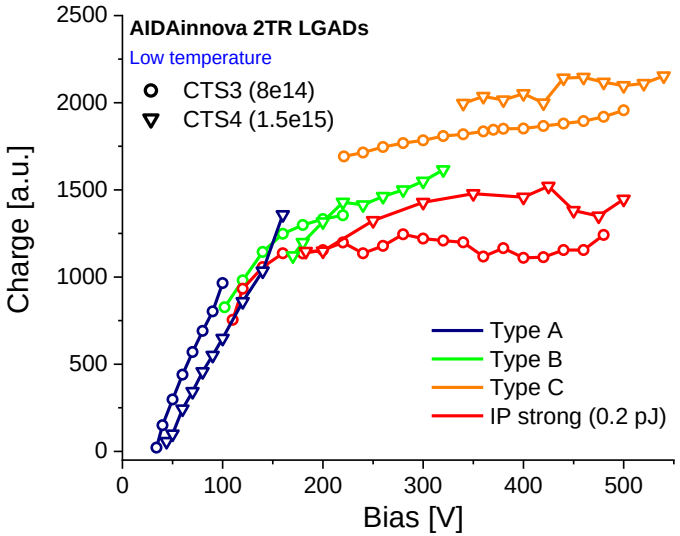
2 Tr LGAD

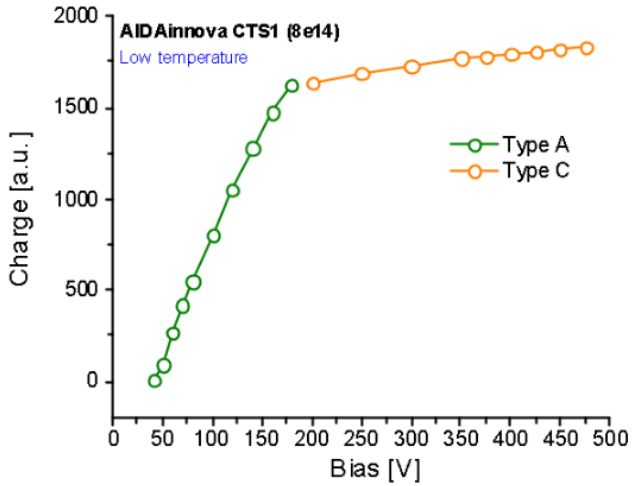


1 Tr LGAD



What we can learn from charge vs bias pattern

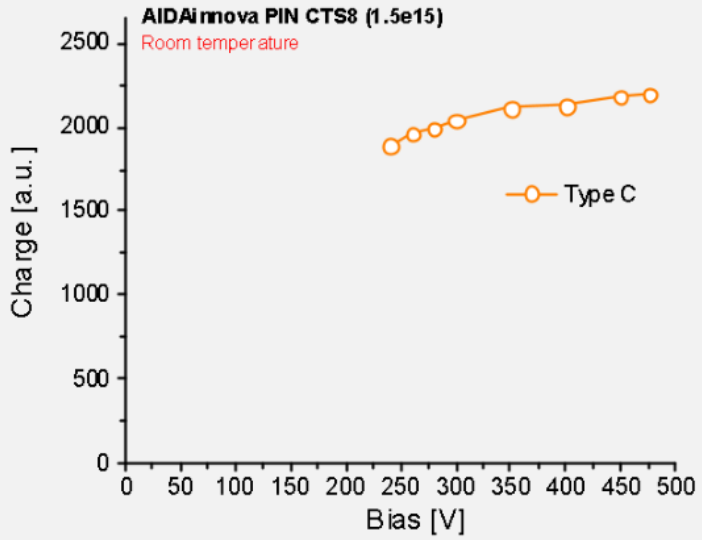


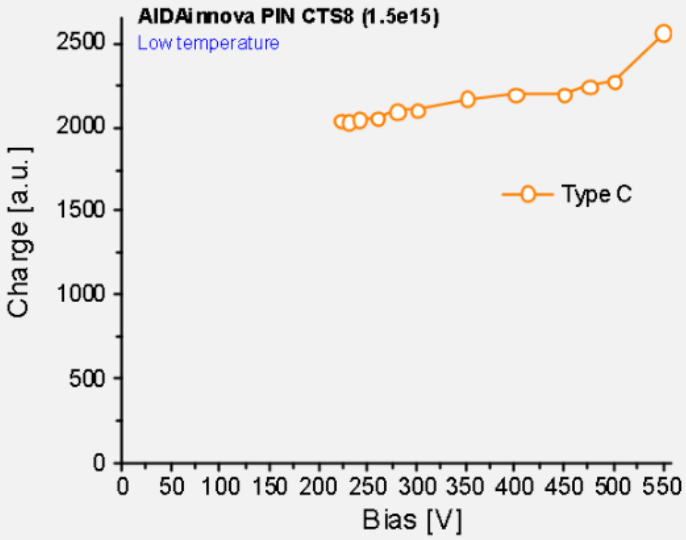


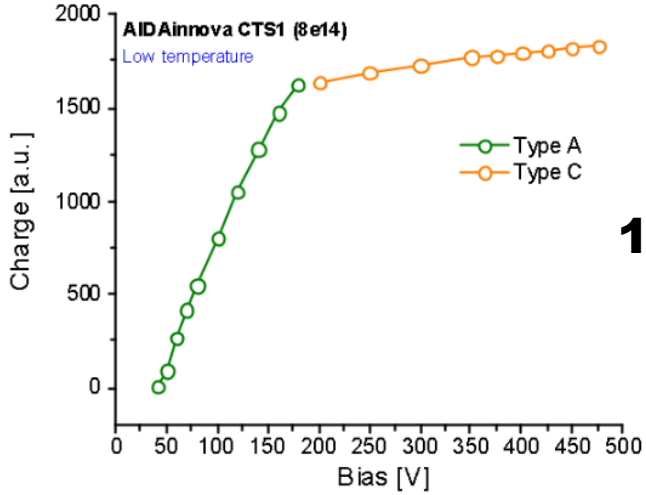
1 Tr PIN

AIDA C-TS8 PIN **1.5e15**

Charge vs bias for ghosts

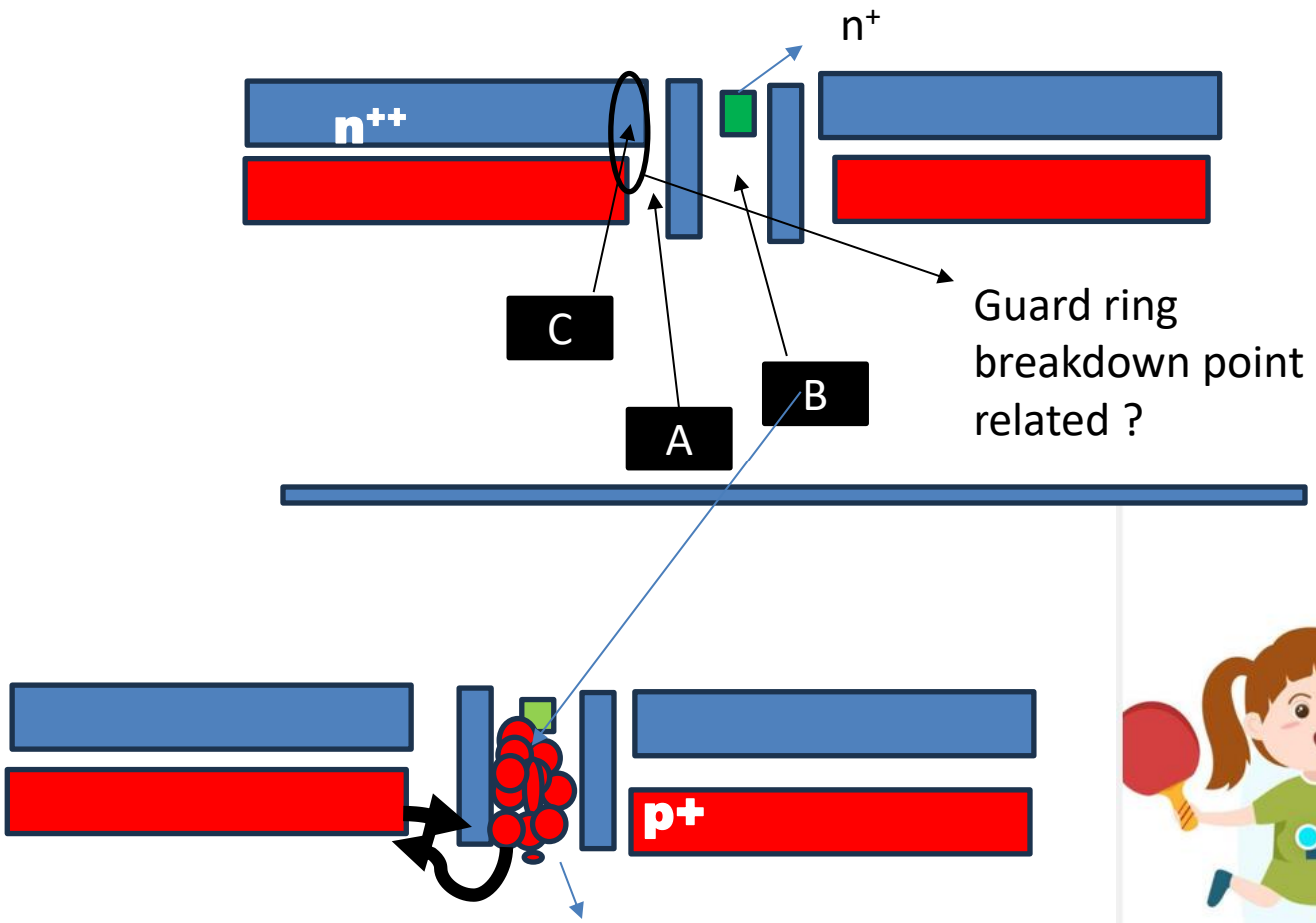






1 Tr LGAD

ORIGIN of GHOSTS?



Discharge + ping-pong game between electron and hole impact ionization in gain layer and at the bottom of trenches, respectively

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Thank you.