UNIVERSITY OF BIRMINGHAM

Development of Low Gain Avalanche Detectors at Teledyne e2v

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Teledyne e2v Everywhereyoulook™

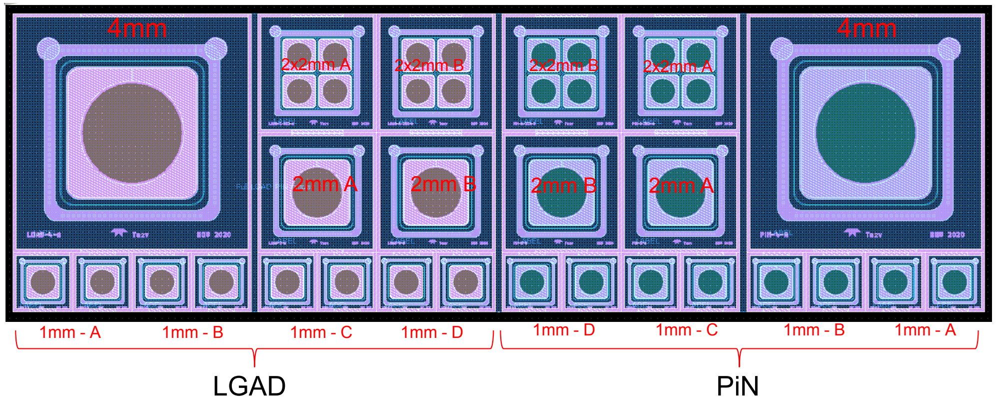
Outline

- Project description
- Wafer probing results
- Measurements on diced devices
  - Gain and timing
  - SIMS vs TCAD
- Preparation of second submission
- Conclusion

Project description

- The project aim is to demonstrate LGAD fabrication capability at Te2v.
  - 1st submission targets LGAD specifications for ATLAS/CMS timing layers at HL-LHC.
- 6” wafers of 50 μm HR p-epi layer.
  - 8 combinations of gain layer implant dose and energy.
- Cathode size of single cells 4, 2 & 1 mm and one 2 x 2 array of 1 mm cells.
  - Up to four cell layout flavours (A, B, C, D), different distances of guard ring to cathode.
  - LGAD and PiN share the same layout, the only difference is the presence or not of the gain layer.

Wafer Number	Normalised Dose (D)	Normalised Energy (E)
19,20,21	1.00	1.00
17,18	1.07	1.00
15,16	0.92	1.05
12,13,14	1.00	1.05
9,10,11	1.07	1.05
7,8	1.15	1.05
4,5,6	1.00	1.11
2,3,24	1.07	1.11



Wafer testing

- IV and CV measurements performed on 6 out of 8 combinations of gain layer implant dose and energy.

- Tested single cell devices (LGAD and PiN) of all sizes in different locations across the wafer.
  - This talk will focus mostly on the results on 1 mm devices.

- Systematic analysis of breakdown voltage and depletion voltage as a function of energy and dose, completed so far using data from 5 different energy/dose combinations.

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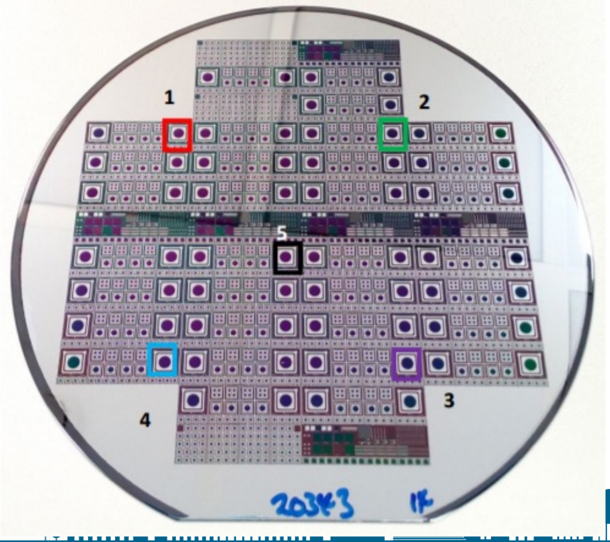
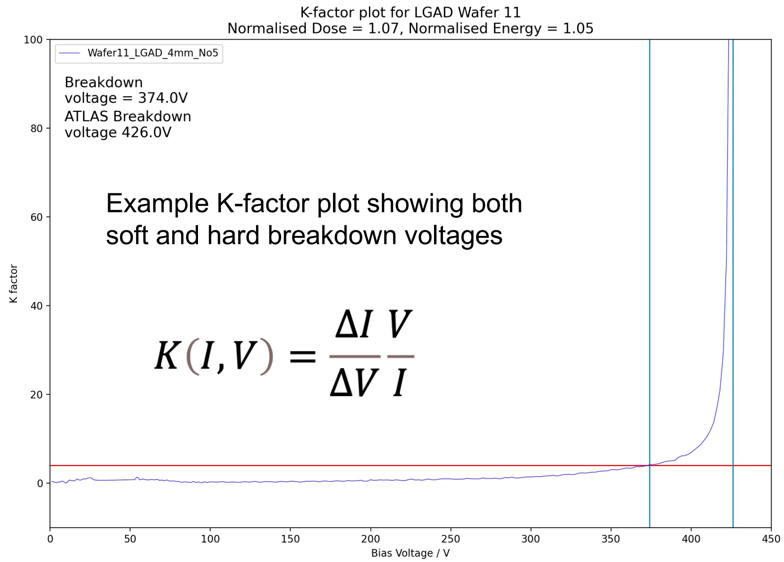
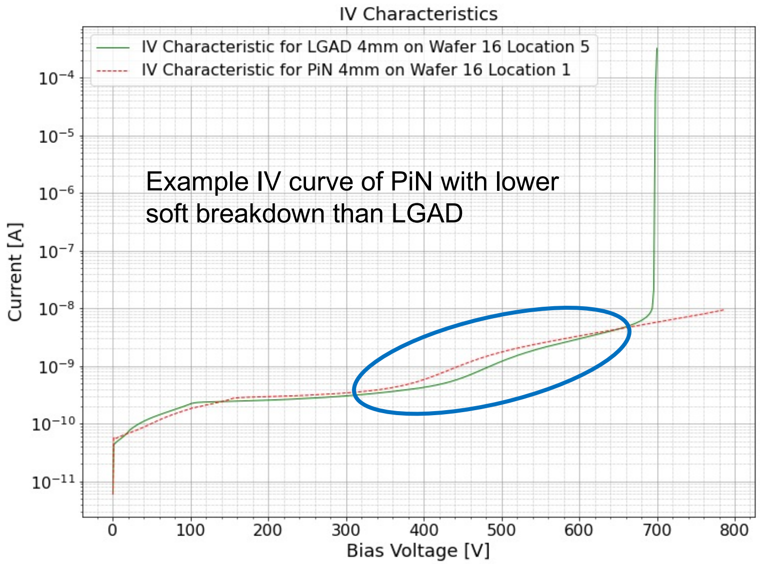


Extraction of breakdown voltage from IV curves

- Soft breakdown has been defined using the K-factor method (K=4).
  - In a few instances, PiN diodes showed a lower soft breakdown voltage than for the corresponding LGADs.

- Hard breakdown voltage has been defined as a factor of 10 increase in current in a 5V step, inspired by the ATLAS market survey requirements for the HGTD.
  - Some devices, especially PiNs, did not reach hard breakdown.
  - In this cases, hard breakdown is defined as the highest voltage measured.

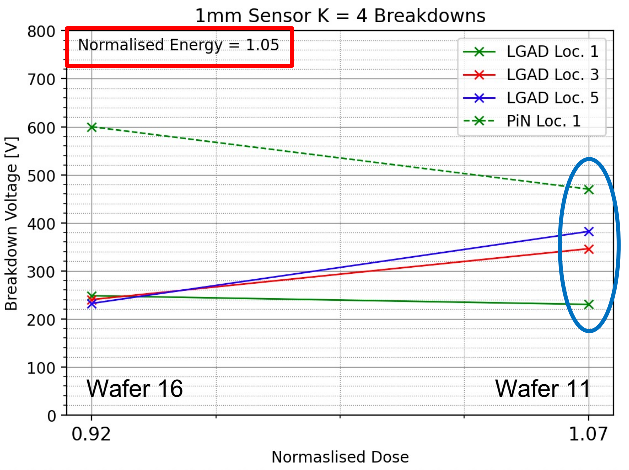


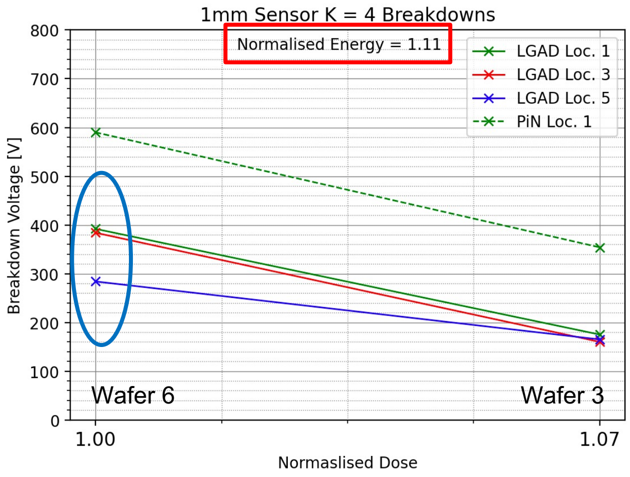


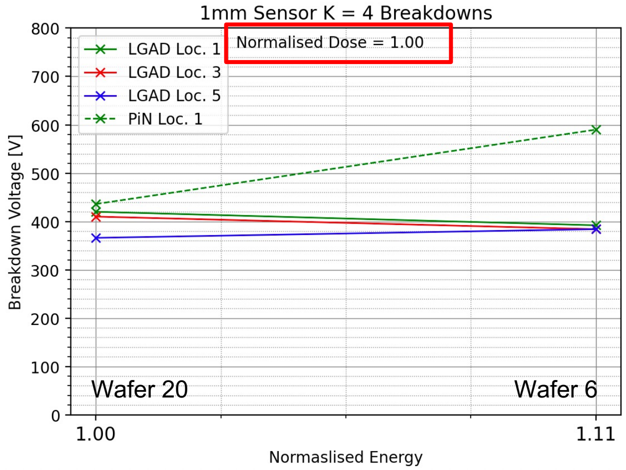
Soft breakdown

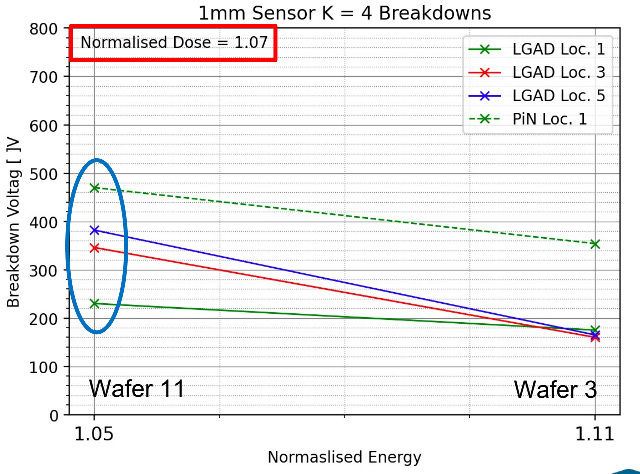
- Large variation in LGAD soft breakdown voltage across different locations on wafers 11 and 3 makes it difficult to discern a clear trend with energy and dose.

- PiN soft breakdown voltage varies across wafers.



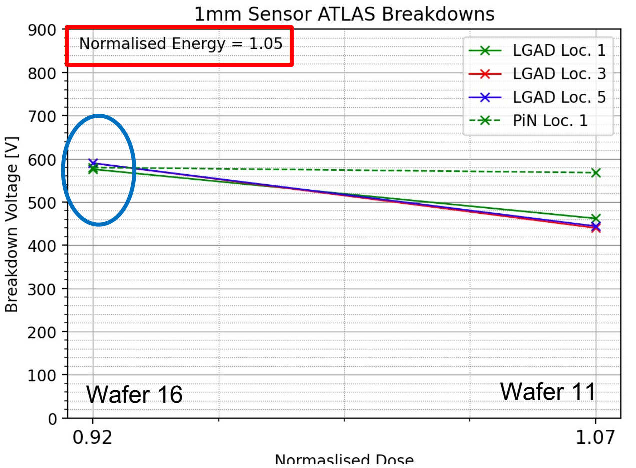


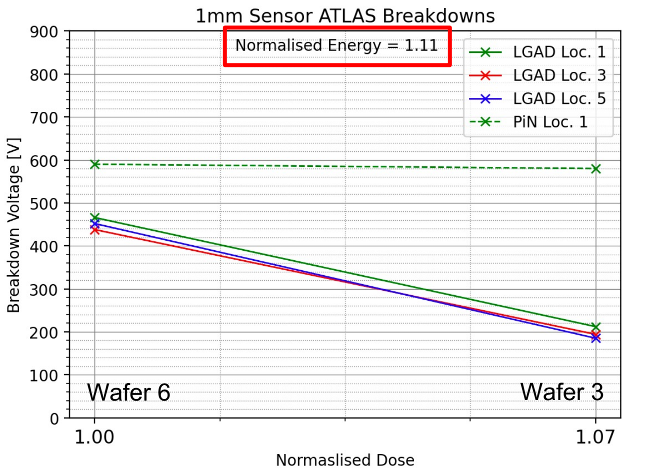


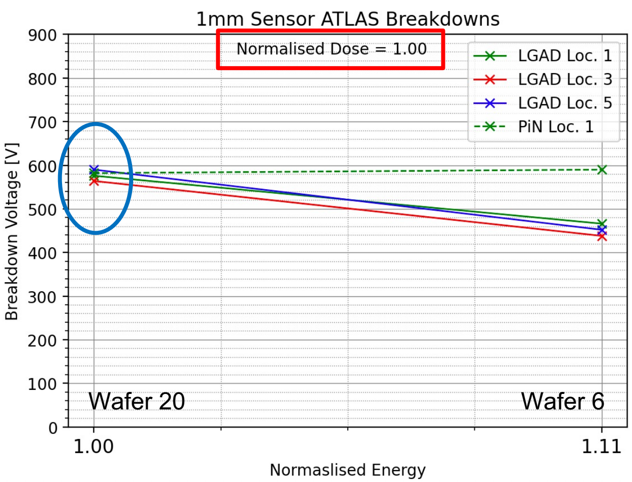


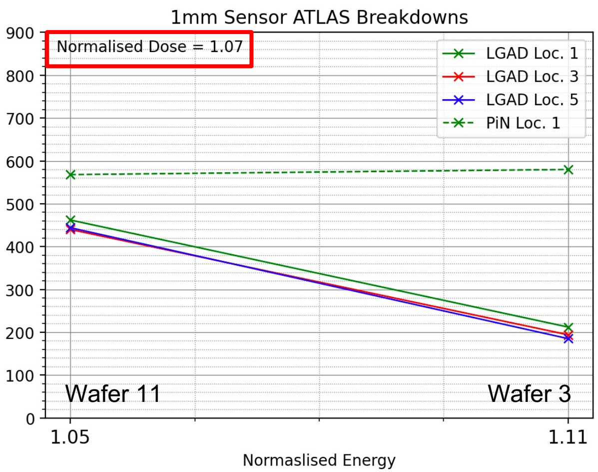
Hard breakdown

- LGAD hard BD voltage decreases with increasing energy and dose, as expected.
  - PiN hard BD voltage consistent across wafers, as expected.
- Highest LGAD hard BD voltage on wafers 20 & 16.
  - LGADs and PiNs reach hard BD at the same voltage on wafer 20.
  - LGAD and PiN in wafer 16 do not reach hard BD over the measured range of voltage.



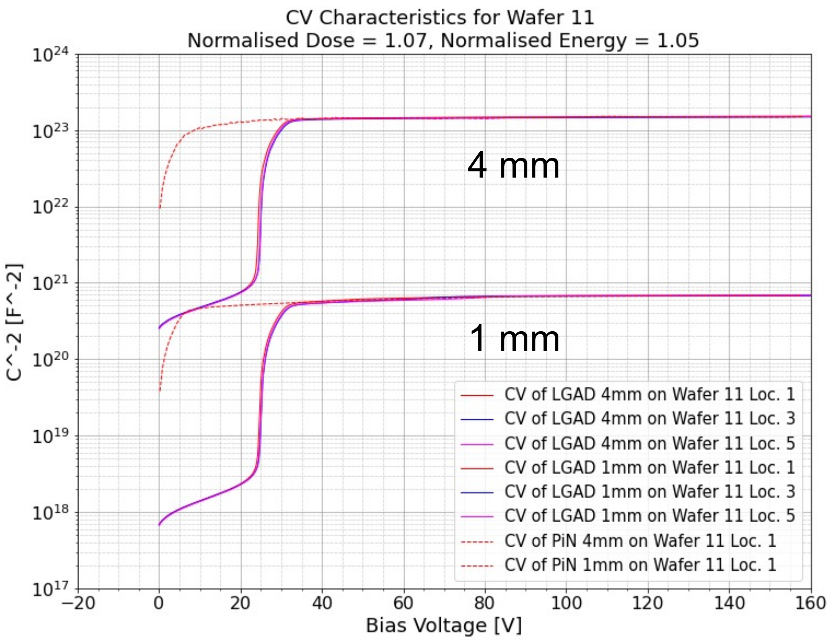


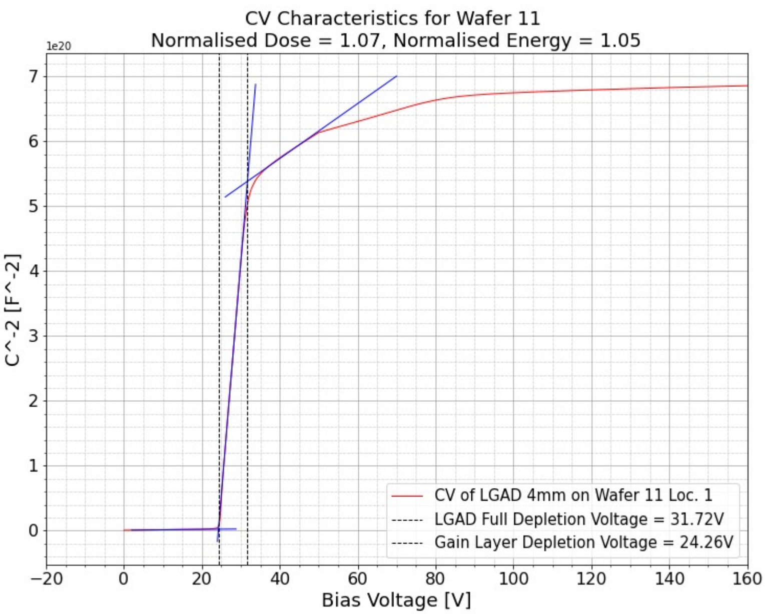




Example of CV measurements

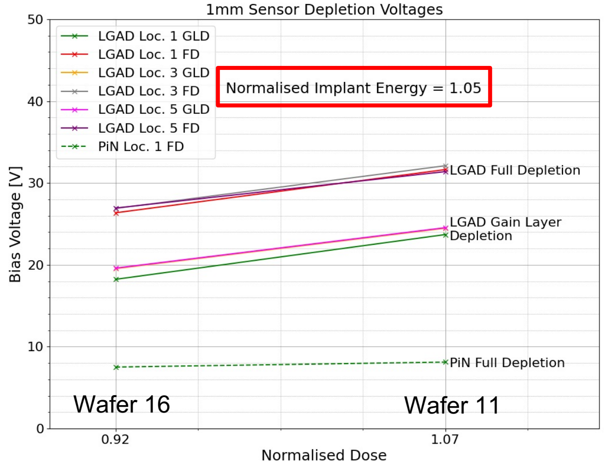
- CV measurements indicate clearly the LGAD gain layer depletion.
- Gain layer depletion voltage (LGAD only) and full depletion voltage (LGAD and PiN) extracted via linear fits, as shown in the plot below.

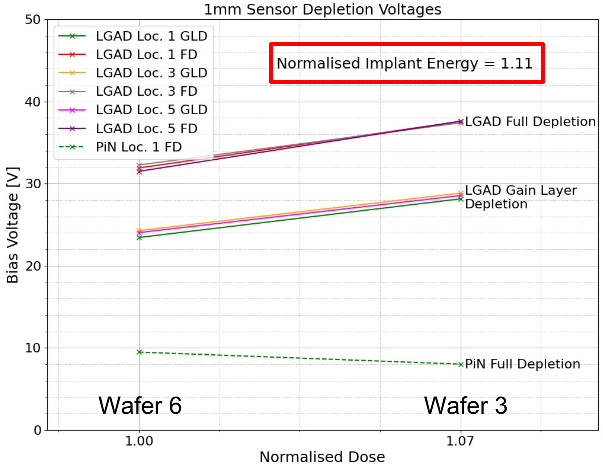


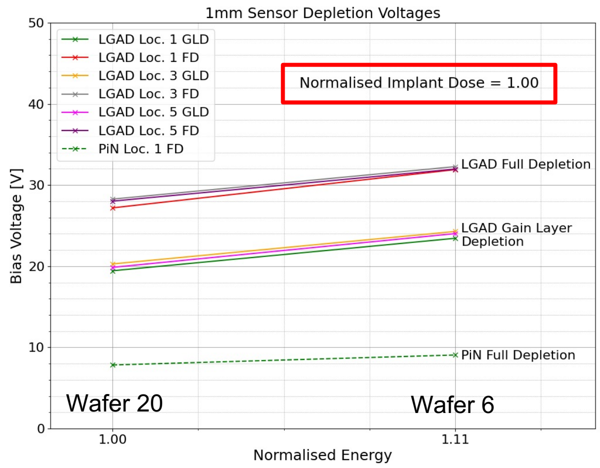


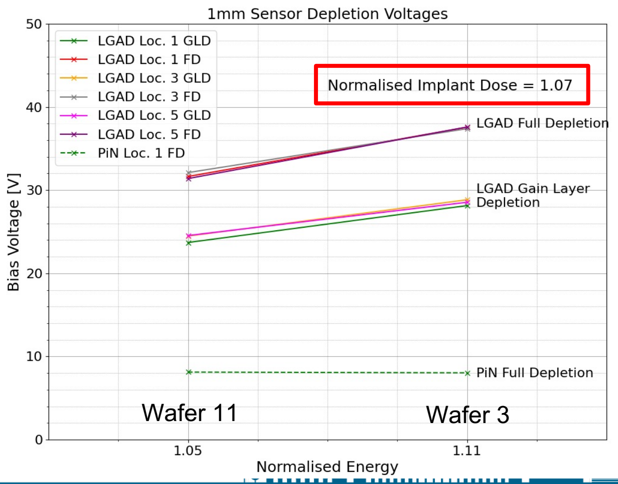
Depletion voltages

- Expected trend of increasing GLD and FD voltages with dose and energy.
  - PiN depletion voltage not affected, as expected.









Wafer dicing

- Wafers 2, 3, 10, 21 laser diced; wafers 9, 24, 11, 6 saw diced.
  - On laser diced devices, effect of dicing on breakdown voltage, esp. for PiNs.
  - λ = 1028 nm, laser power = 10 W, beam size = 25 x 25 μm^2.
  - Suspected surface states formed after wafer dicing → thermal annealing treatment (150C for 2 hours) mitigates the effect.

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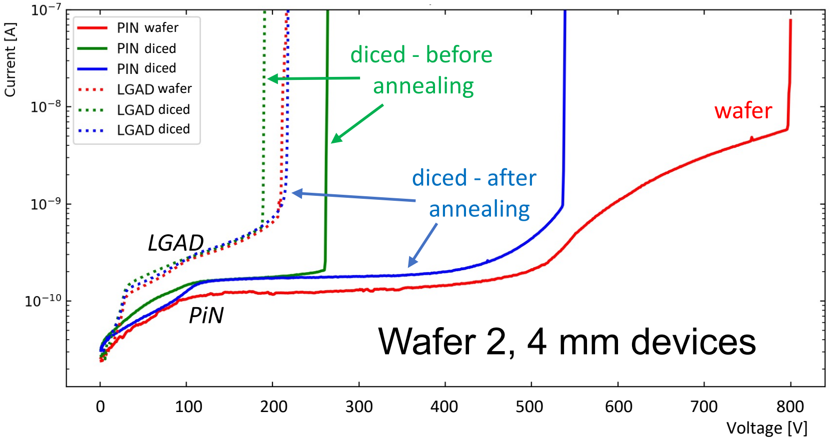


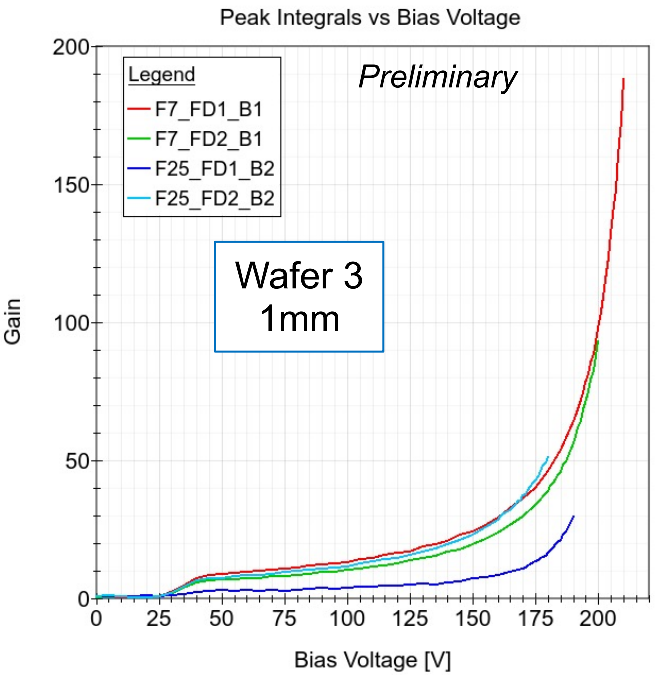
- 1 mm devices from wafers 2 and 3 are being tested for gain and timing.
- 2 x 2 arrays of 1 mm devices from wafers 9 and 24 to be sent to CMS colleagues as part of the market survey exercise.

Gain measurement

- Measurement setup:
  - Charge is injected using a 1064 nm IR laser.
  - Output signal is amplified by a Particulars AM-02 A RF amplifier.

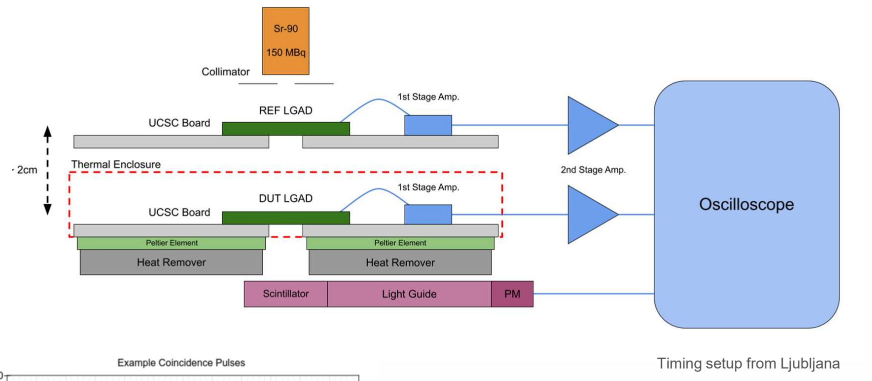
- The gain is calculated as the ratio of the integral under the output signal for LGAD and PiN at different bias voltages.

- Gain on 1 mm LGADs on wafer 3 higher than expected on 3 out of 4 tested LGADs.
  - Previous gain measurements on 1 mm LGAD from wafer 2 showed gain similar to blue curve in the plot.
  - Investigations ongoing to understand the discrepancy.
  - Results here to be considered preliminary.

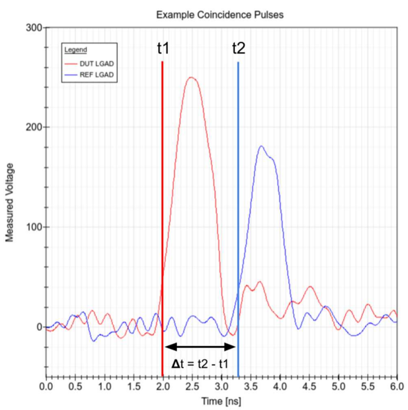


Timing measurement

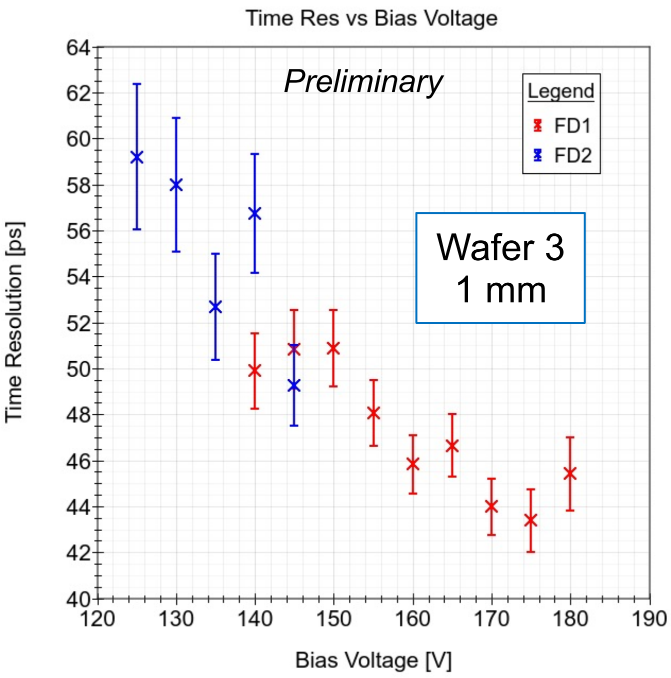
- Measurement setup:
  - Sr-90 coincidence setup, replica of the one used by colleagues at Ljubljana.
  - Trigger is done by the DUT LGAD (scintillator trigger soon to be implemented).
  - LGAD on Santa Cruz board, second-stage amp Particulars AM-01B 35dB 2GHz.
  - CFD is set at 20%.



Timing setup from Ljubljana

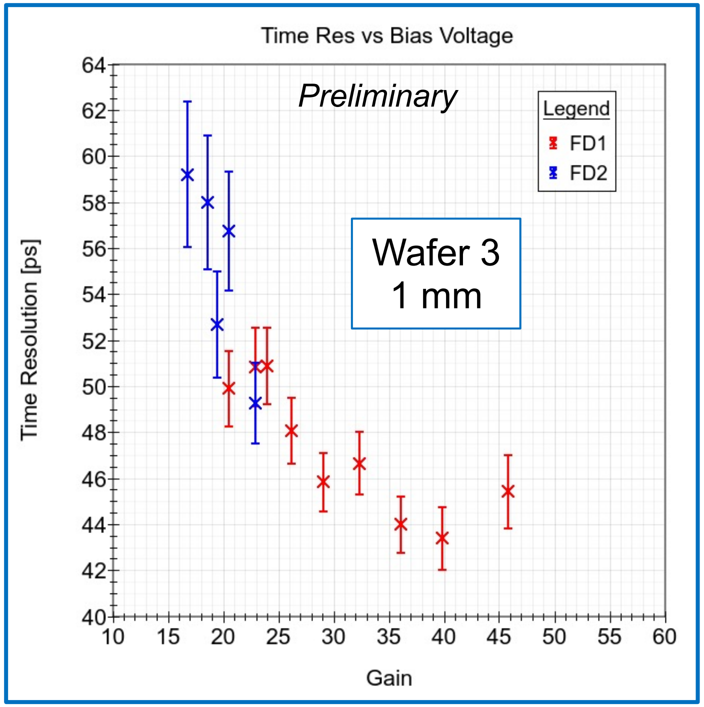


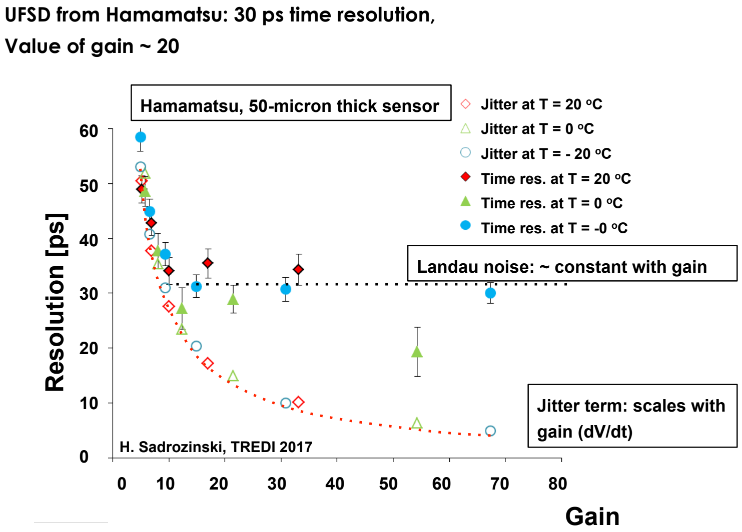
$$\sigma_{meas}^2 = \sigma_{DUT}^2 + \sigma_{REF}^2$$



Timing vs. gain

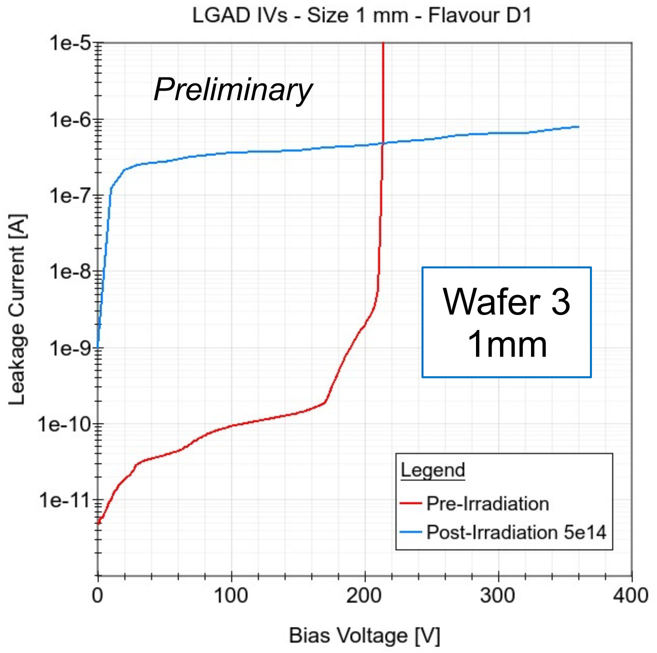
- Time resolution as a function of gain approaches 40 ps at a gain ~ 40.
  - Results on wafer 2 gave a time resolution below 40 ps at a gain of 20 (closer to published results).
  - Further indicates gain results on 1 mm LGADs on wafers 2 and 3 need better understanding.

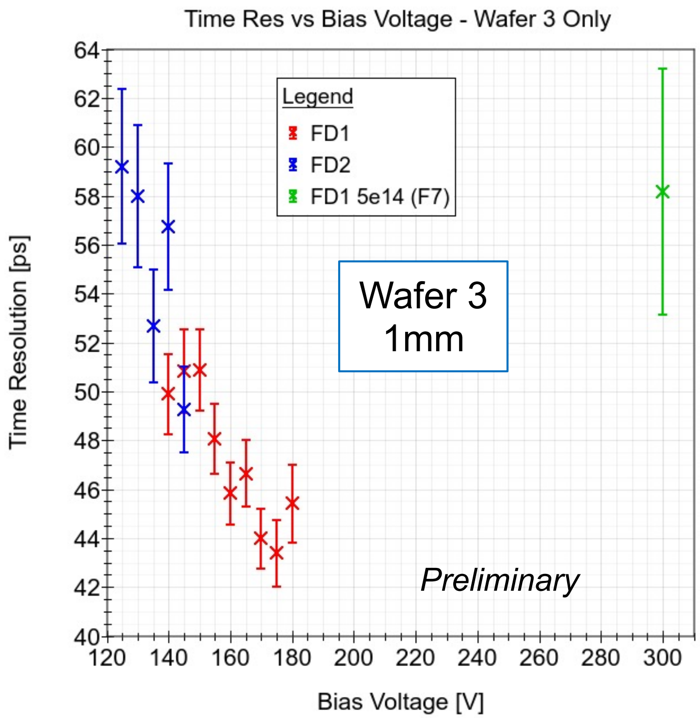




Very preliminary results after irradiation

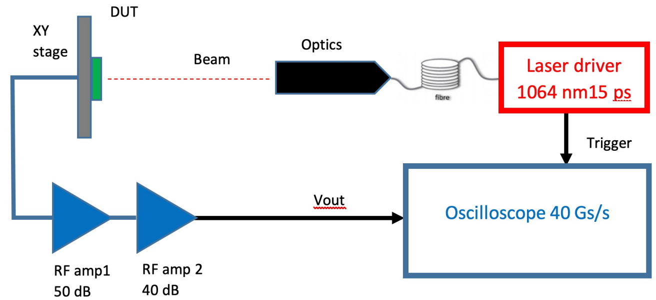
- Two wafer 3 devices have been irradiated to 5e14 and 1e15 1 MeV n_{eq}/cm^2 at the Birmingham MC40 cyclotron with 27 MeV protons.
- For the device irradiated at 5e14 MeV n_{eq}/cm^2.
  - Preliminary IV shows no breakdown until 350 V.
  - First timing measurement gives 58 ± 5 ps at 300V.
- Both devices will undergo complete characterisation (IV, CV, gain, timing).

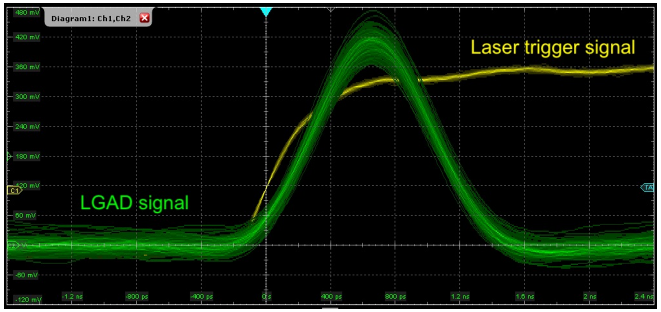


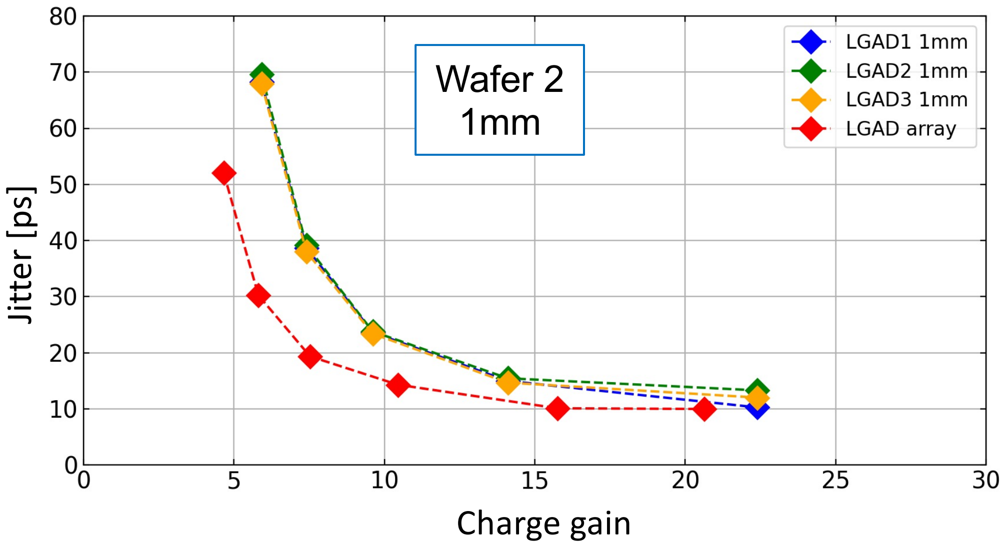


Jitter measurement

- Measurement setup:
  - Charge is injected using a 1064 nm IR laser.
  - LGAD on Santa Cruz board, second-stage amp FEMTO HAS-X-2-40.
- Jitter measurements are performed by measuring the standard deviation of the delay between the 50% of the laser trigger signal and 50% of the LGAD signal.
- Jitter ~10 ps @ gain above 20, in line with published results.

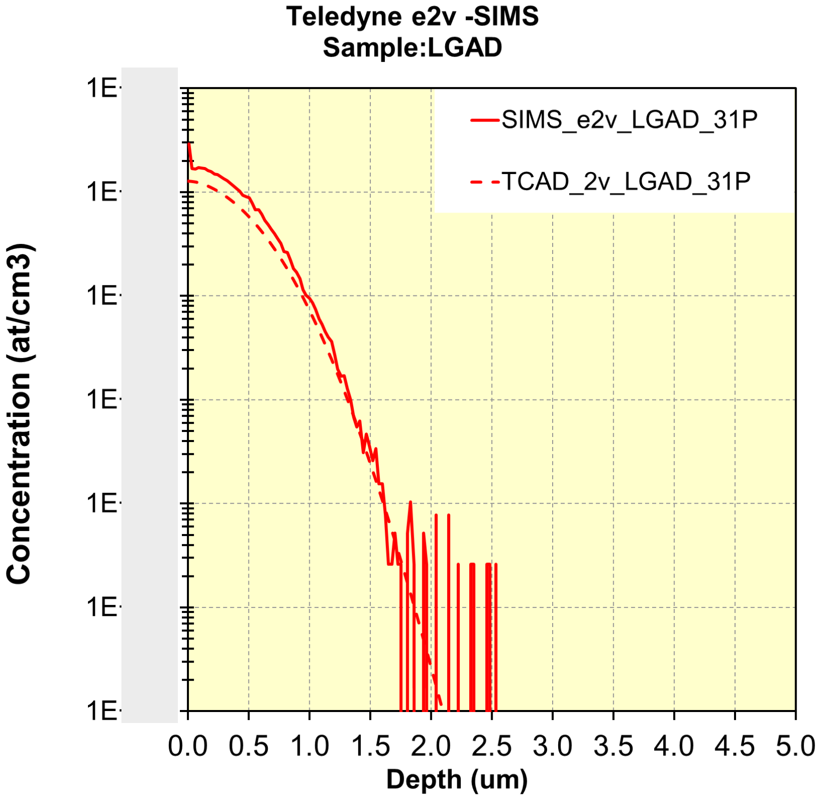


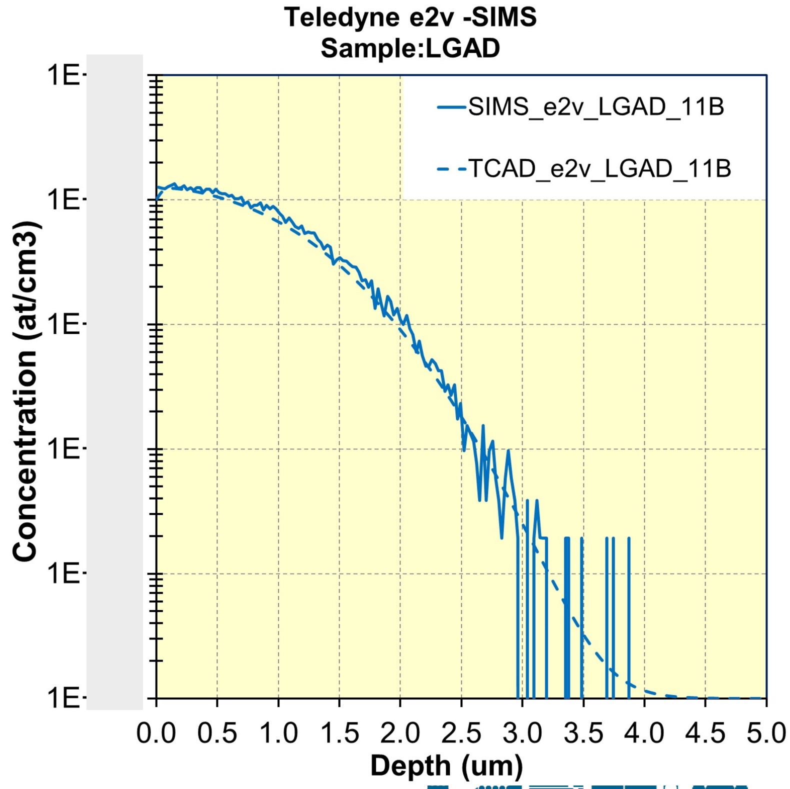




SIMS vs. TCAD

- SIMS performed on wafer 2 LGADs; results compared with TCAD simulations.
- Good agreement between measurements and developed SPROCESS description of Te2v fabrication process.

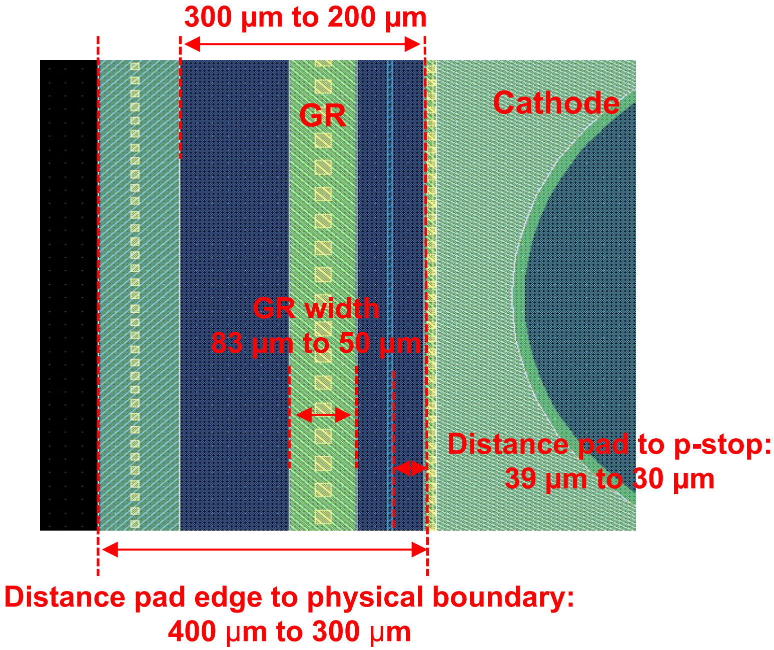


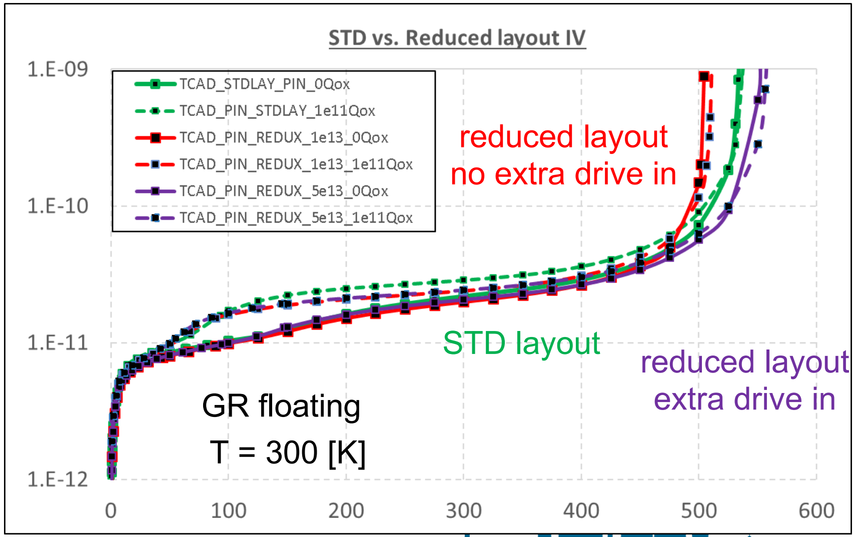


Plans for second submission

- Single cell modified to match requirements of ATLAS and CMS market survey.
  - Increased cell size to 1.3 mm x 1.3 mm.
  - Reduced max distance of pad edge to physical boundary to 300 µm.
  - Reduced distance of pad edge to PS to 30 µm.

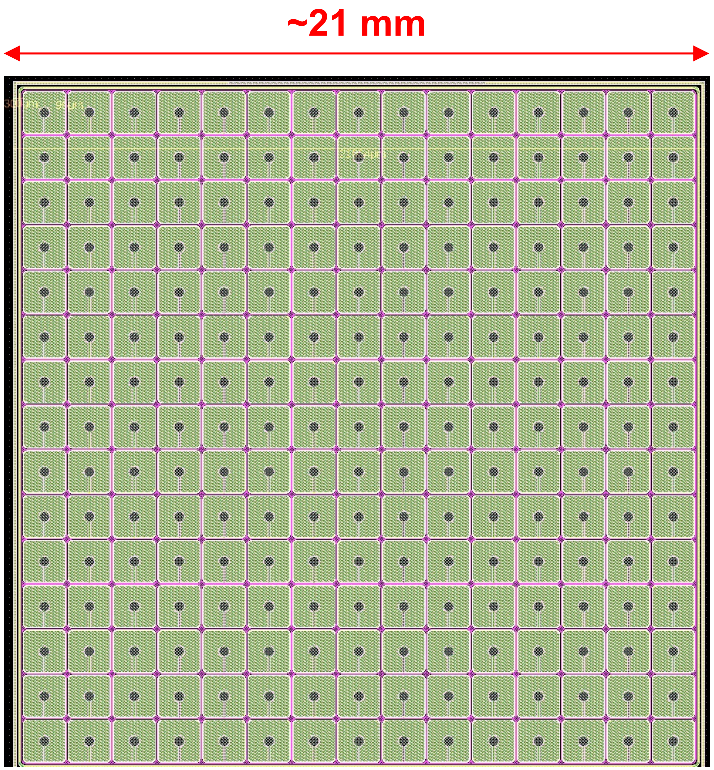
- Reduced p-stop distance decreases the BV → TCAD simulations show that this can be compensated with increased JTE dose and drive in.





Plans for second submission

- Array of 15 x 15 cells built around modified basic cell.
- JTE edge to edge distance reduced from 114 μm to 96 μm.



Conclusion

- Te2v has produced a first batch of LGADs with different size and combination of energy and dose of the gain layer implant targeting ATLAS and CMS HL-LHC timing layers specifications.

- Preliminary gain and timing properties of 1 mm LGADs with the highest energy and dose combination are approaching published results.
  - More studies to understand gain results discrepancy are underway.
  - Initial results after irradiation show devices still working at 5e14 MeV n_{eq}/cm^2.

- Te2v is engaging with the CMS market survey.
  - LGAD 2x2 1 mm arrays about to be shipped to CMS colleagues for testing.
  - Design of second production batch with modification to match MS requirements.

- Next steps:
  - Complete analysis of breakdown and depletion voltages between wafers flavours.
  - Gain and timing measurements, before and after irradiation, on more diced LGADs from different wafers.
  - Comparison of 1 mm LGAD flavours (i.e. influence of guard ring to pad distance).

Previous presentations

- 37th RD50 workshop, Nov 2020
  - https://indico.cern.ch/event/896954/contributions/4106308/
- 38th RD50 workshop, June 2021
  - https://indico.cern.ch/event/1029124/contributions/4411263/
  - https://indico.cern.ch/event/1029124/contributions/4411247/
- PSD12, Sept 2021 (+ proceedings)
  - https://indico.cern.ch/event/797047/contributions/4455947/
- Vertex, Sept 2021 (+ proceedings)
  - https://indico.cern.ch/event/1047531/contributions/4520803/
- 39th RD50 workshop, Nov 2021
  - https://indico.cern.ch/event/1074989/contributions/4601996/
  - https://indico.cern.ch/event/1074989/contributions/4602008/

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