UNIVERSITY OF BIRMINGHAM | SCHOOL OF PHYSICS AND ASTRONOMY

Timing Results of LGADs from Teledyne e2v using an Sr-90 Beta Source

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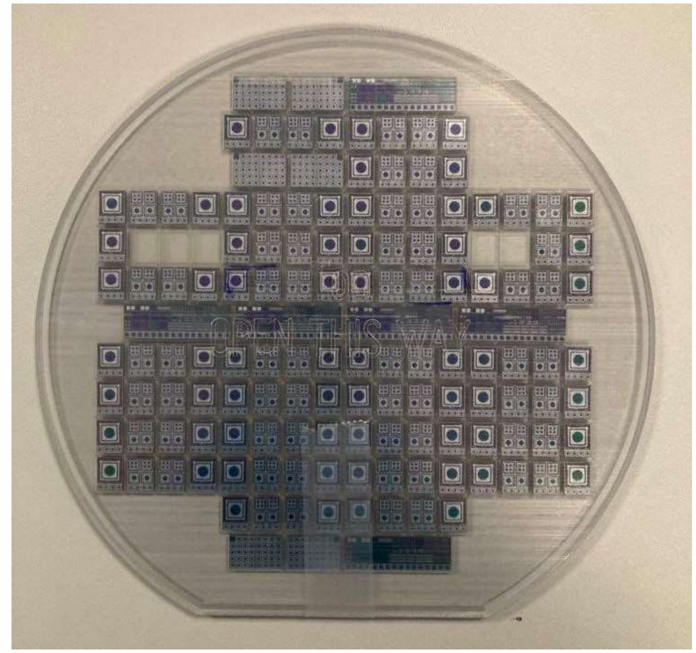
Outline

- **Teledyne e2v and Sensor Design**
- Gain Measurements
- Timing Measurements
- Future Plans / Summary

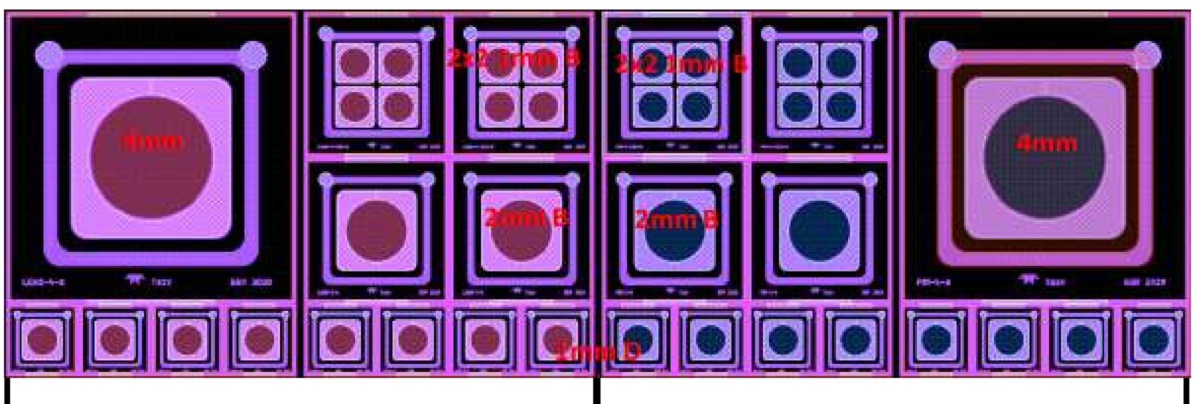
- In the previous RD50 meeting, we presented IV, CV and preliminary gain measurements for our first batch of 22 wafers.
- This time we would like to present some additional gain measurement results and then our initial timing measurements

- Collaboration between the University of Birmingham, University of Oxford, RAL and the Open University
- We are working closely with the UK foundry at Teledyne e2v whom already have a large production volume capability as a major producer of CCDs for space, astronomy and other scientific projects

- The results in this talk focus on 1mm LGADs and PiNs of Wafer A



Wafer code	Normalised Dose (D)	Normalised Energy (E)
A	1.07	1.11
B	1.07	1.05
C	1.07	1.00
D	0.92	1.05
E	1.15	1.05
F	1.00	1.00
G	1.00	1.05
H	1.00	1.11



LGADs PiNs

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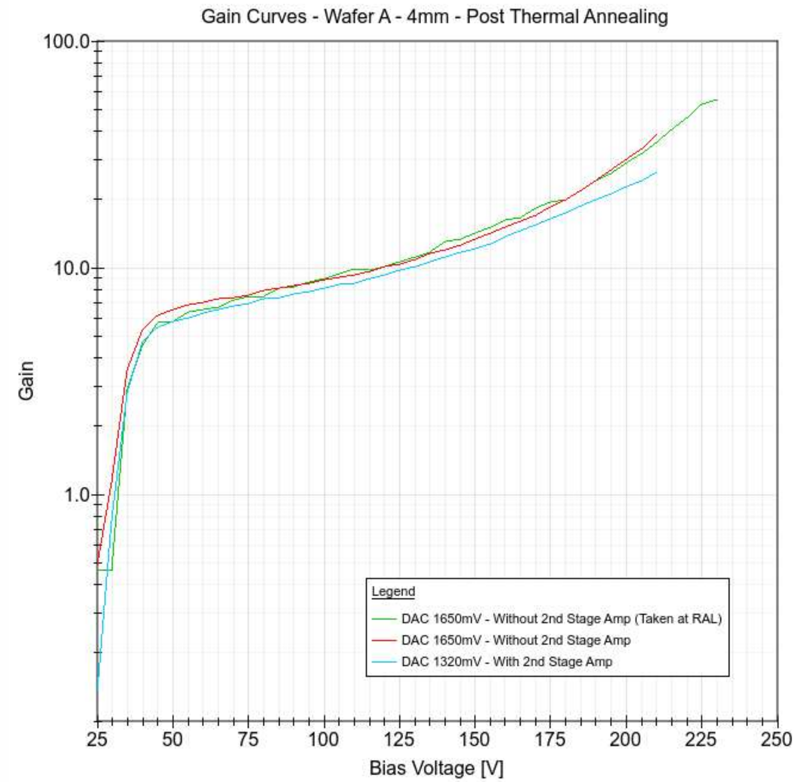

- The gain of our devices can be calculated by injecting charge via a 1064nm IR laser

- We do this for a range of bias voltages, and the output signal is then amplified by a Particulars AM-02 A RF amplifier and the signal is recorded. We integrate these signals and then take a ratio between the LGAD and PiN to calculate the gain (assuming the PiN has a gain of ~1)

- The plot on the right shows the gain for a 4mm LGAD from Wafer A. There is good agreement with our colleagues at RAL (green solid line) where an identical LGAD was tested under the same conditions

- Note that this LGAD is 4mm in size and has undergone thermal annealing after dicing. The LGAD's discussed in the rest of this talk are 1mm and have not undergone thermal annealing after dicing

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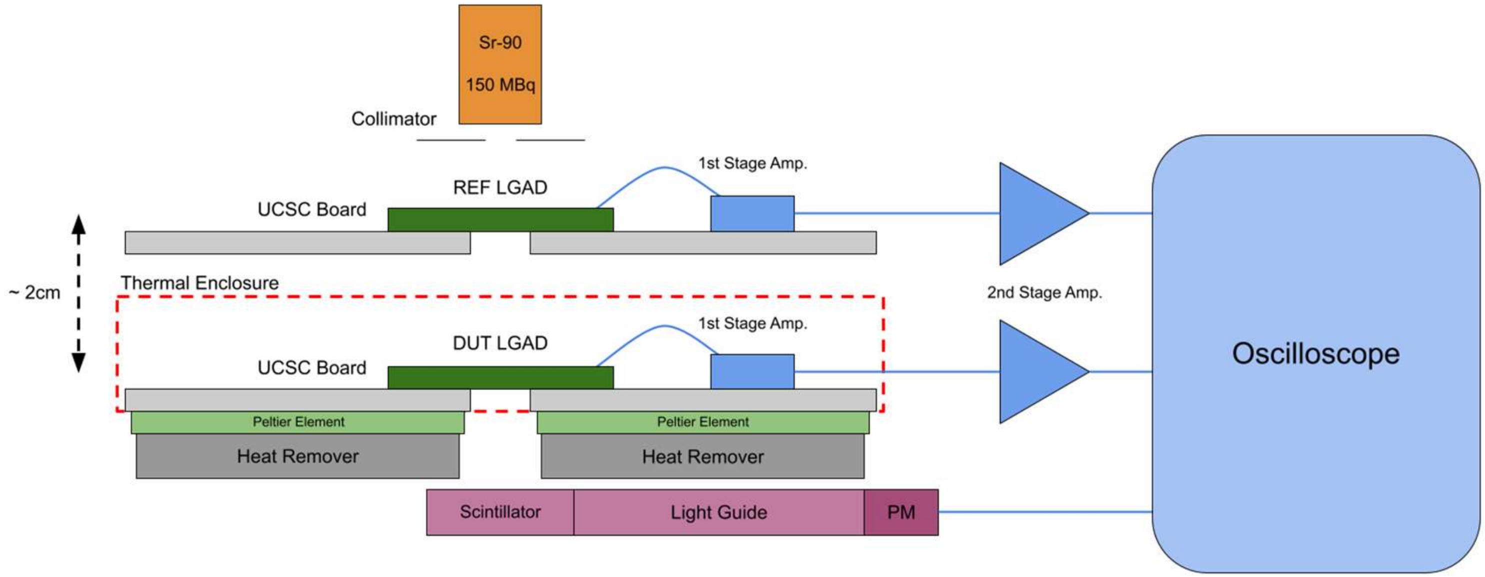
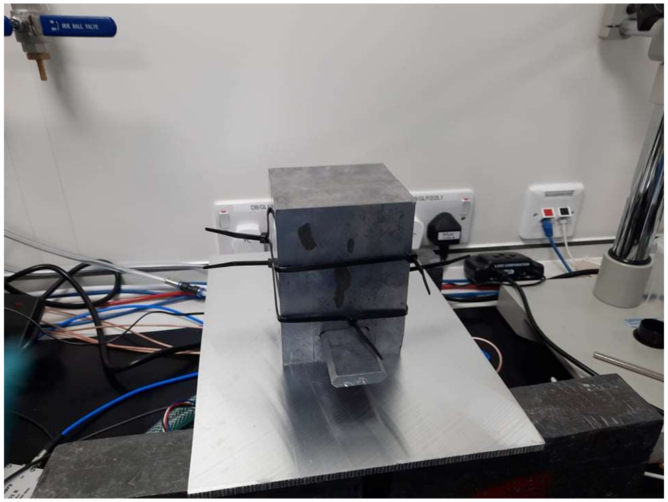


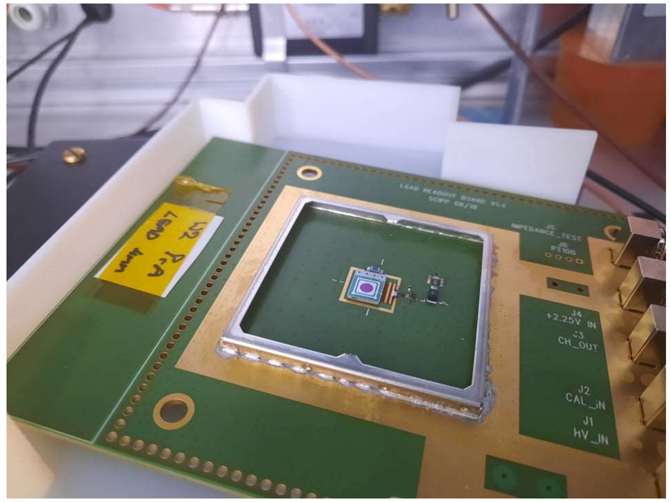
Timing setup from Ljubljana

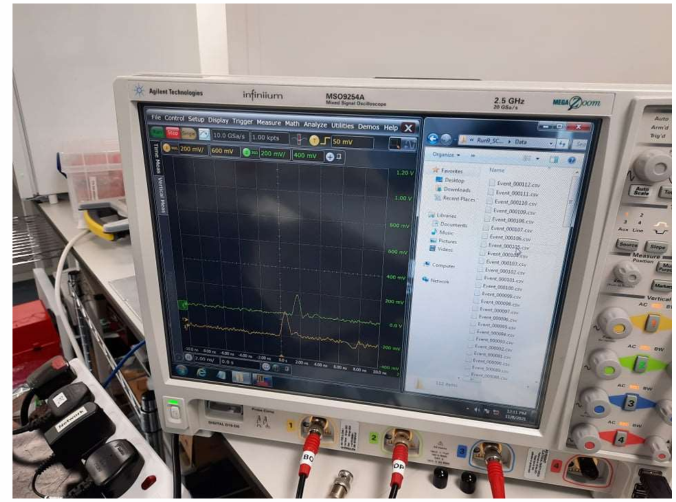
- The timing resolution of an LGAD is a combination of errors and jitters ranging from Landau fluctuations of how a particle deposits energy, to the noise from the readout electronics. To study the time resolution we need some measurable quantity related to timing that we can test multiple times to produce a histogram.

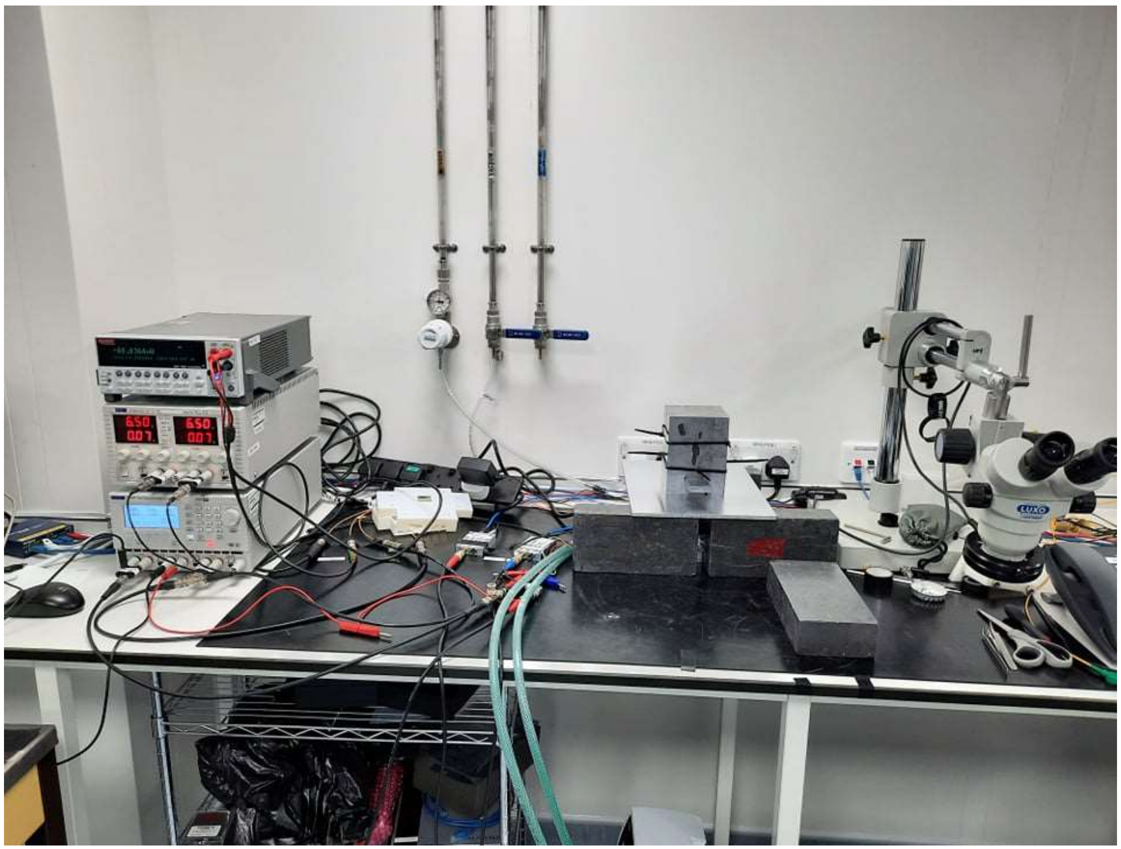
- With help from our colleagues at Ljubljana, we have commissioned a new setup for this purpose from the diagram above. Two LGADs are aligned directly below a Strontium-90 beta source such that a single emitted electron can strike both LGADs. Triggering is done by the DUT LGAD and not the PM

- Differences due to the electron's time of flight, as well as the length of any cables creates a delay between the two LGADs. This delay is arbitrary and constant but will exhibit error in the form of a standard deviation which can be measured.

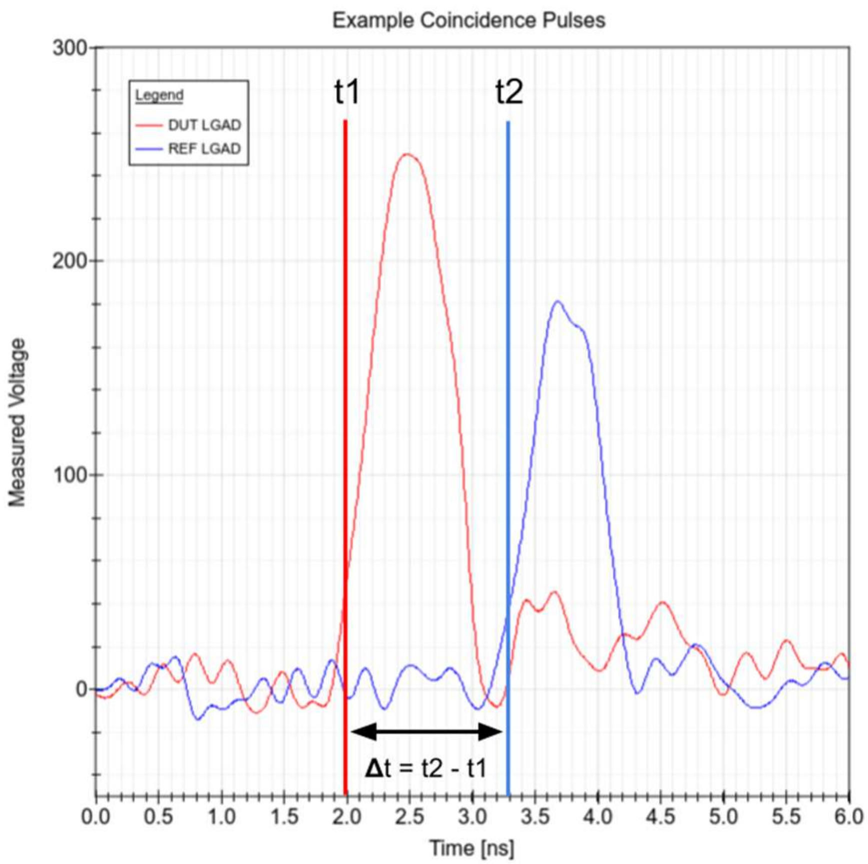


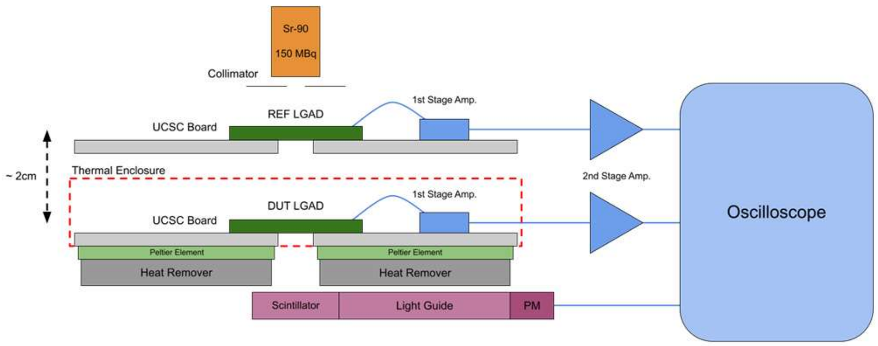






- Preliminary timing setup until the final support structure is built.
- The LGADs are placed on the PCB from Santa Cruz which provides the first stage of amplification. The output goes to the second stage amplifier (Particulars AM-01B 35dB 2GHz) which is then read by an oscilloscope.
- The oscilloscope is controlled by a Python script which is setup to continuously trigger on the bottom LGAD and save the waveforms each time





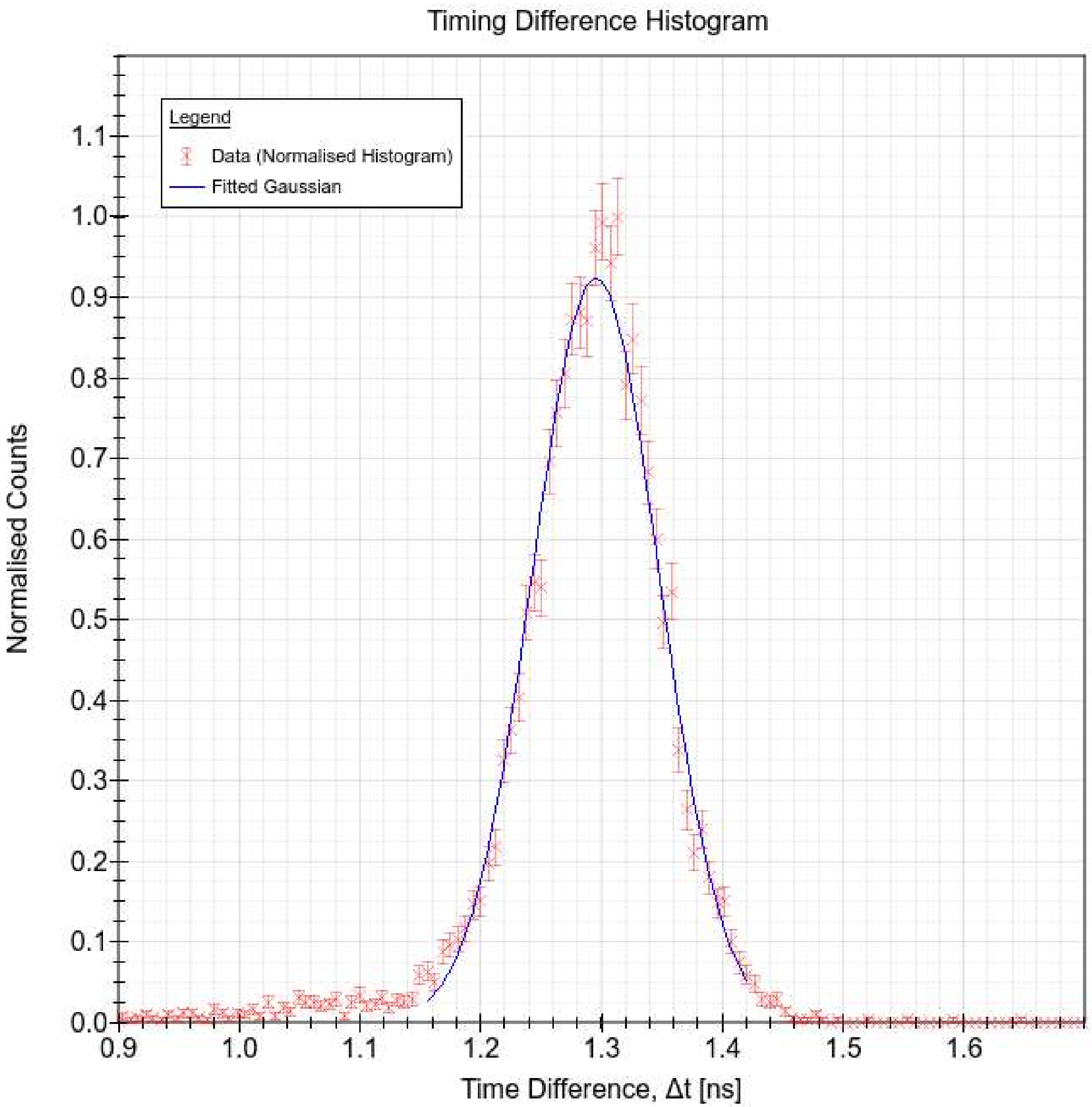
Timing setup from Ljubljana

- Once the setup has been left running for a number of hours, the saved waveforms can be analyzed offline. Since the oscilloscope only triggers on the bottom LGAD, it often triggers on an electron which did not hit the other LGAD on top. Therefore the first part of the offline analysis is to apply a 75mV threshold and check for each event that both waveforms exceed this threshold, indicating a coincidence event has occurred.

- For each coincidence event, we then use a constant fraction discriminator (CFD) to identify the time of arrival (relative to the oscilloscopes trigger). The value we choose as CFD can greatly affect the jitter and typically values of 25% are chosen. We have used a CFD of 20% as that appeared to give us the best results initially.

- The time difference is then simply the difference between the time of arrival of the pulse from each LGAD

Timing Difference Histogram



- The plot is a normalised histogram of the time differences with a fitted Gaussian on top
- The fitted Gaussian is truncated as shown
- Both LGADs were biased at 245V (roughly 10V below breakdown)
- Counts = 8573
- Bin width: 6.3 ps
- Temp.: ~23 °C (Not controlled)
- RH: ~50% (Not controlled)
- All measurements performed under the above conditions
- Fitted mean: 1.30 ns
- Fitted Standard Deviation: 52.1 ps
- Reduced Chi-Sqr: 2.3

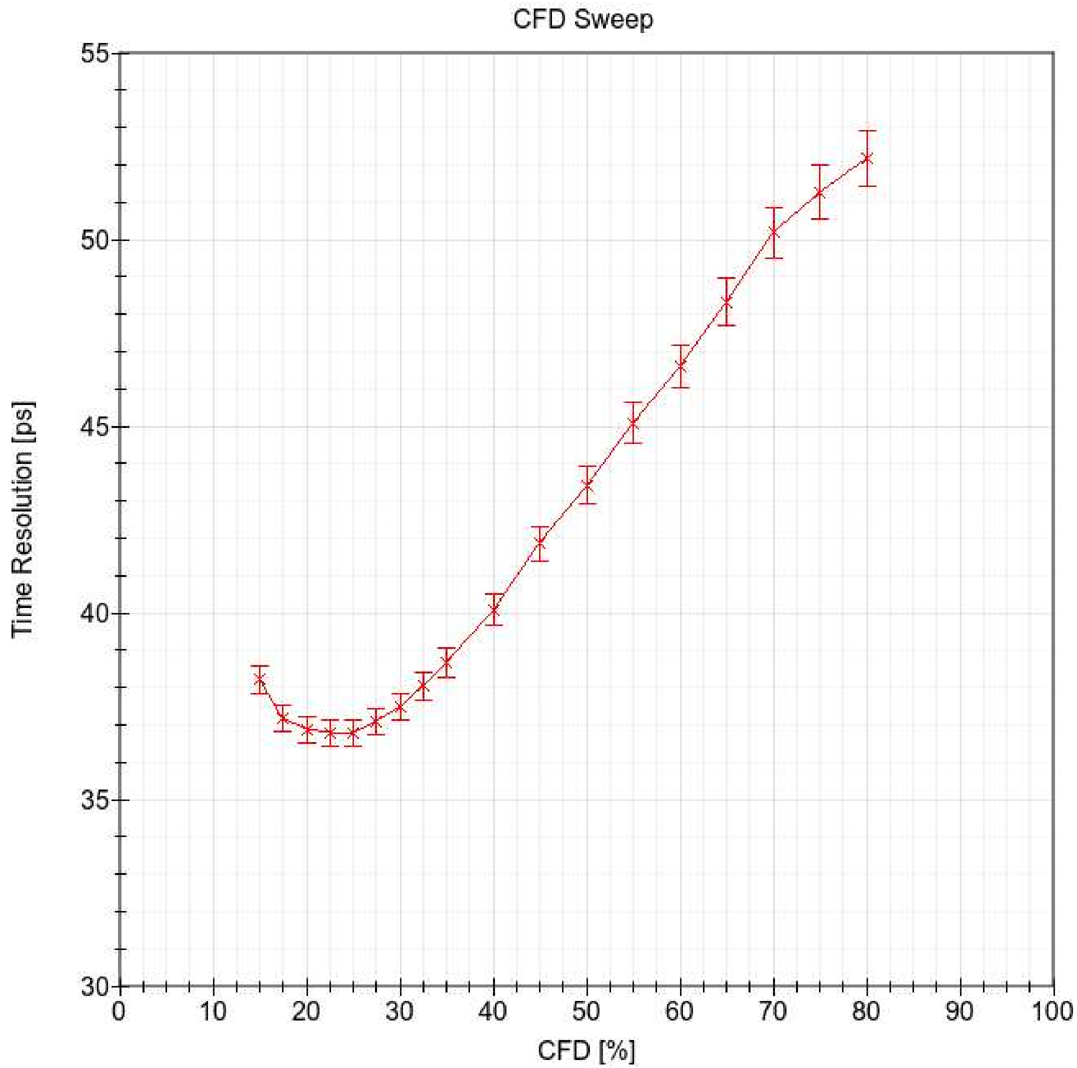
- The standard deviation (sigma) of fitted Gaussian is *not* the time resolution of the LGAD's under test. This is because the calculation of the time difference is the addition of two Gaussians (one from each LGAD)

- The sigma of the fitted Gaussian can be written as,

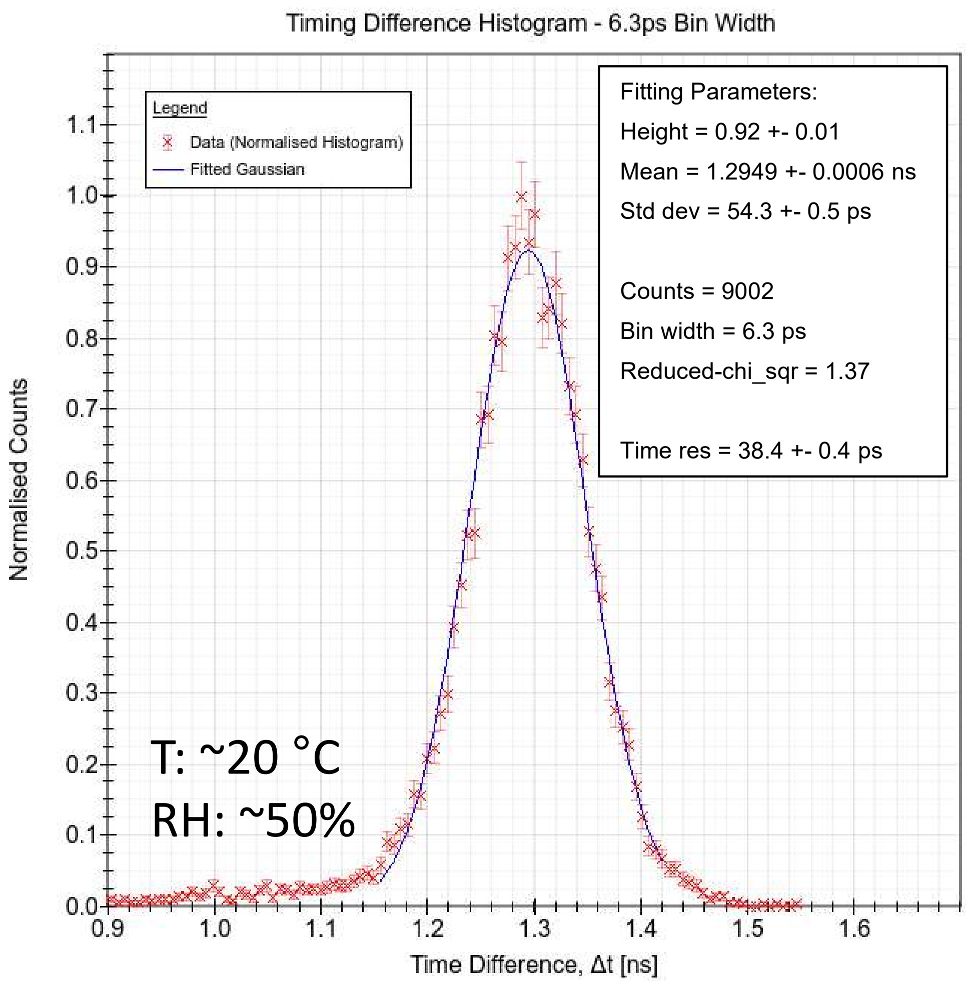
$$\sigma_{MEAS}{}^2 = \sigma_{DUT}{}^2 + \sigma_{REF}{}^2$$

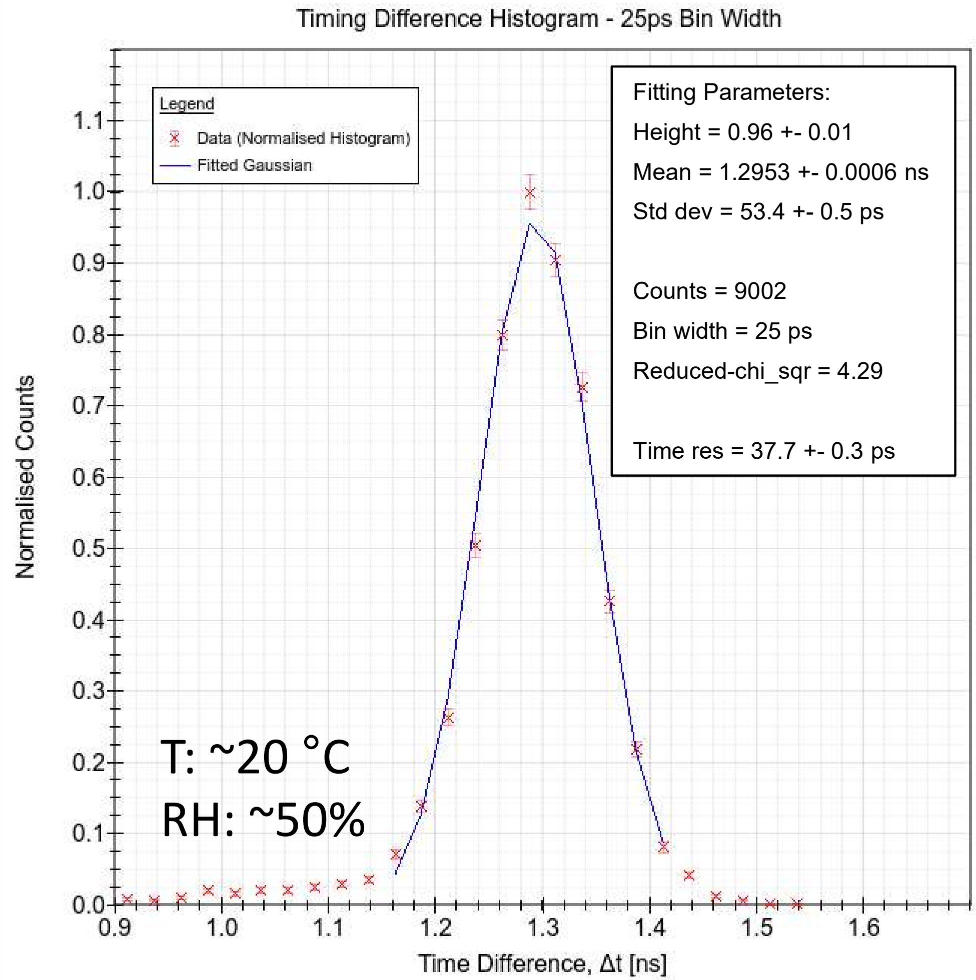
- If the DUT and REF LGAD are assumed to be identical (which they should be in this case), then this formula simplifies to,

$$\sigma_{MEAS}{}^2 = {\sigma_{DUT}{}^2}\Big/{\sqrt{2}}$$



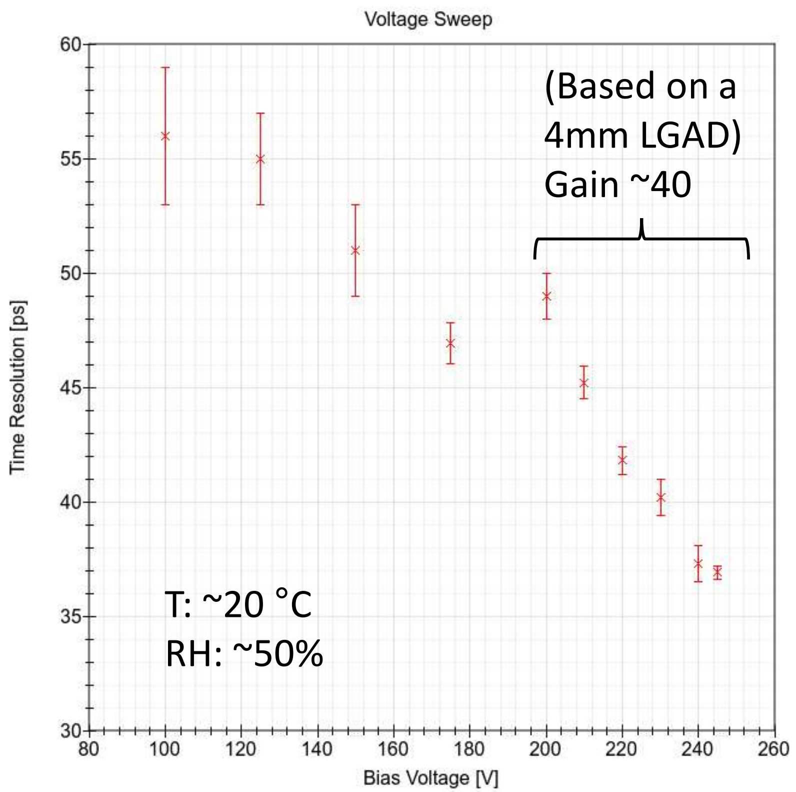
- As mentioned previously, the CFD makes a large impact on the timing resolution (calculated using the factor of root 2). We use a value of 20% (although a value of 25% is often used by others)
- The plot above shows a sweep of different CFDs for the 245V biased LGADs. As expected, the best time resolution is found between 20% and 25%

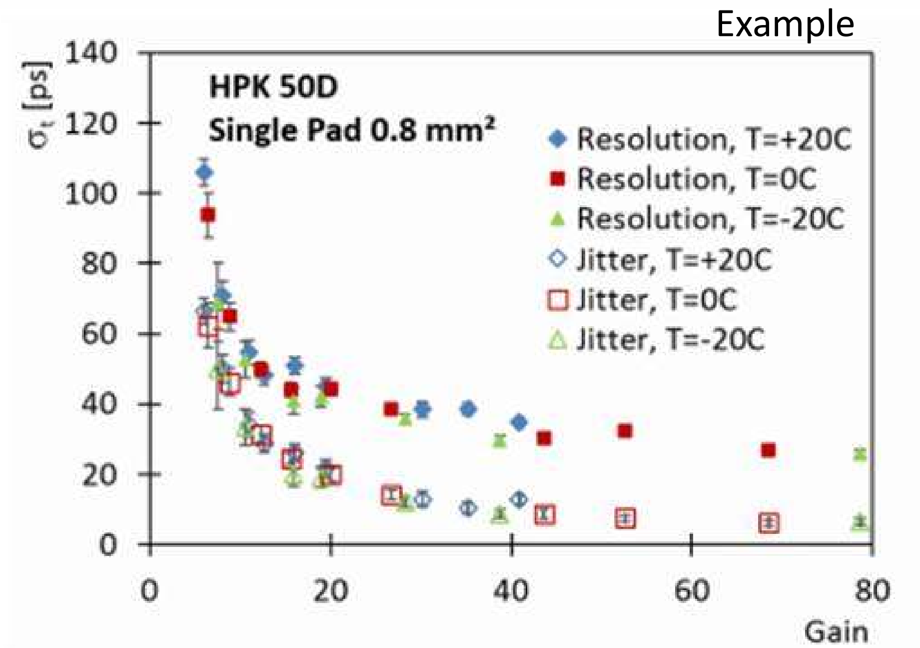




- The fastest that our oscilloscope can record data points is in steps of approximately 6.3 ps. This presents a problem when binning as you want your bins to be much smaller than sigma, whilst being much larger than the oscilloscope's resolution.
- Having investigated numerous bin widths, choosing 6.3ps itself seems to produce the best histogram, however the chosen binning did not seem to affect the fitted standard deviation which is reassuring.

- The two plots show a binning of 6.3 ps (left) and 25 ps (right) when the LGAD's were biased at 240V





Sadrozinski, H., Ultra-fast Silicon Detectors, 2017

- The time resolution of LGADs is also expected to change with bias voltage (or more specifically, the gain of the LGAD at that bias voltage)

- The plot on the left is a voltage sweep (for both LGADs) and shows clearly that an increase in bias voltage leads to an improved timing resolution. Our best timing resolution is at 36.9 +- 0.3 ps

- The plot on the right is a similar sweep but for some HPK devices with voltages converted to gain. Note the difference between the resolution and jitter which we see when comparing timing results with our colleagues at Oxford/RAL

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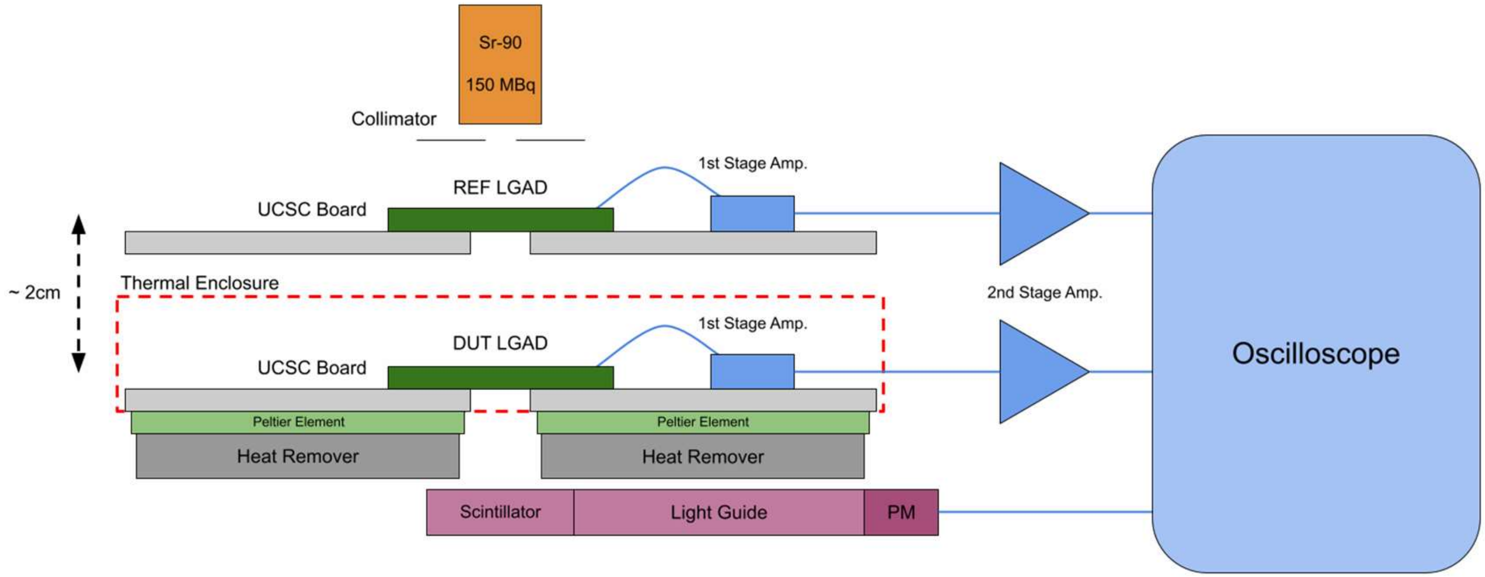

Timing setup from Ljubljana

- The plan going forward is to continue improving the timing setup and introduce cooling to the device under test. This will allow us to perform measurements on irradiated structures.

- We also plan to trigger using a scintillator placed below both LGADs. This should improve the efficiency (percentage of events which are actually coincidence) of our setup. A collimator placed directly below the Sr-90 source would also help to improve the efficiency.

- Naturally we plan to test more of our wafers to identify which gives the best timing performance, informing us for our design of Batch 2 which we hope will arrive by the end of Q1 2022.

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Summary

- We have our first timing results from our LGAD's designed and fabricated by Teledyne e2v!
- Our best timing resolution so far is 36.9 +- 0.3 ps
- These are still preliminary measurements. There are many splits in terms of wafer implants and LGAD flavours, so a systematic study of the time resolution over LGAD design is required.