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Time Resolution Studies of Low Gain Avalanche Detectors Fabricated at Micron Semiconductor Ltd.

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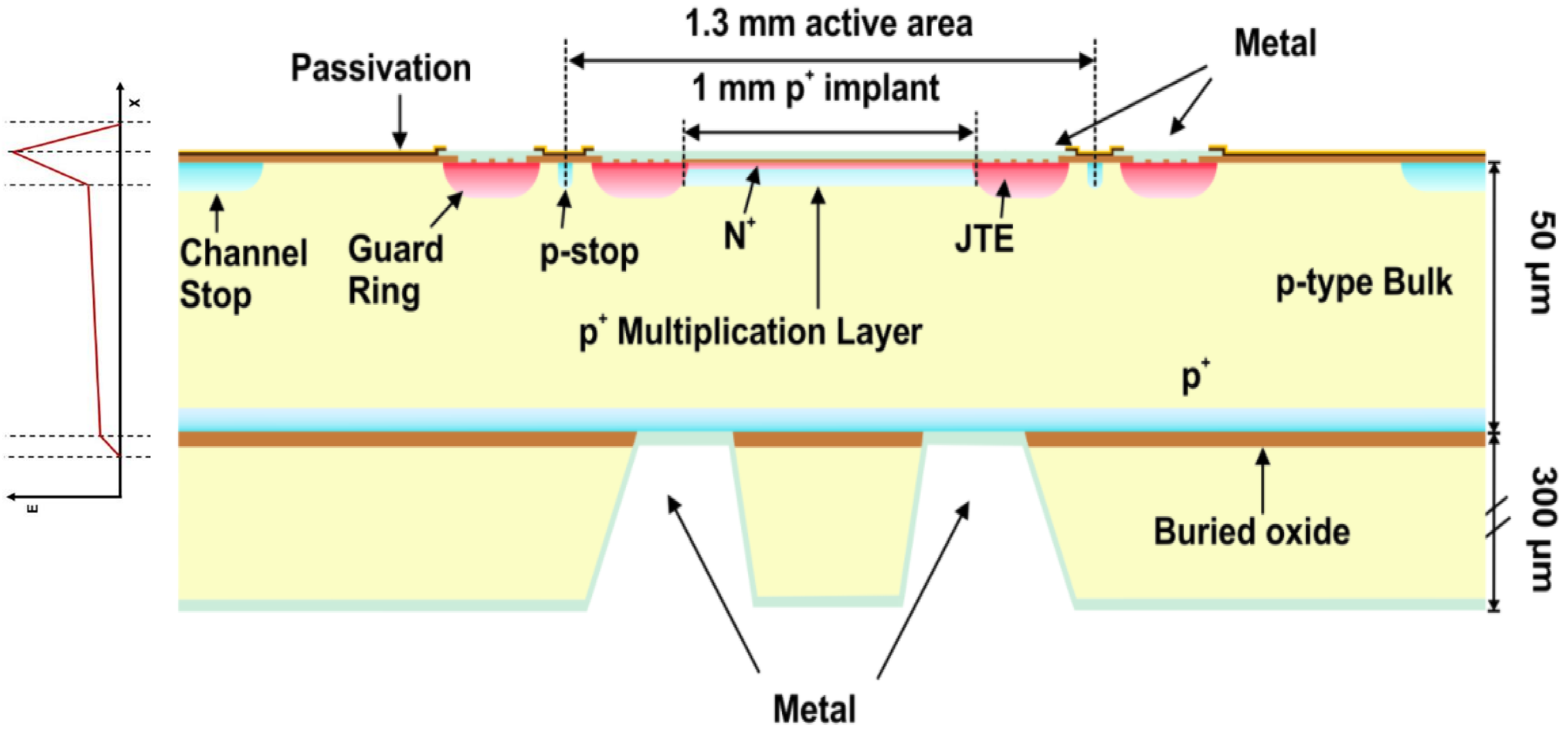
Low Gain Avalanche Detectors Design (Briefly)

- LGADs have a p^+ multiplication layer near cathode
- Allows high E-field in region

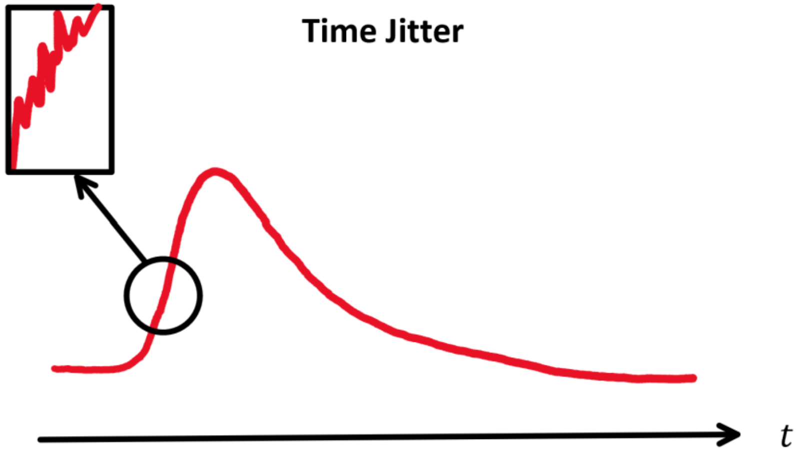


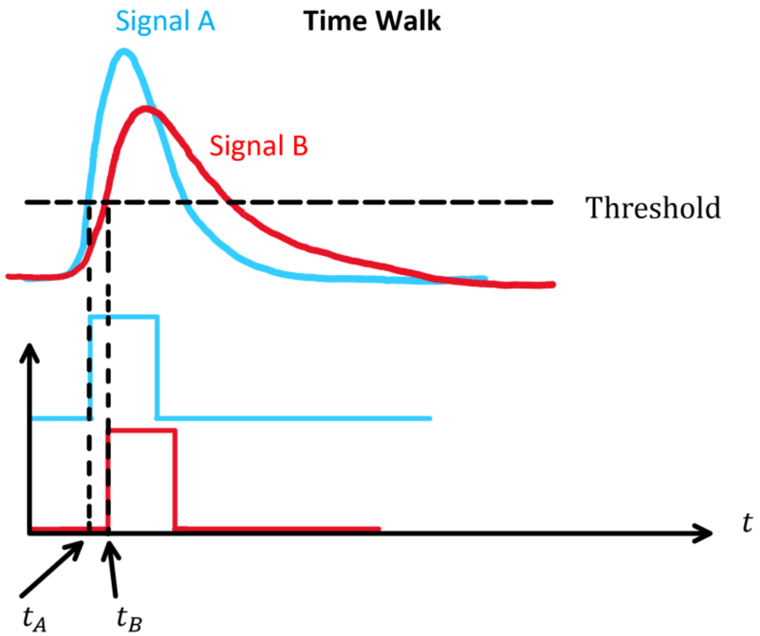
Timing Resolution Dependence

- Time resolution of LGADs dependent on different parameters:

$$\sigma^2_{Total} = \sigma^2_{Jitter} + \sigma^2_{Time\,Walk} + \sigma^2_{TDC} + \sigma^2_{Landau\,Noise} + \sigma^2_{Distortion}$$

  - Jitter
  - Time Walk
  - Time to Digital Converter (TDC)
  - Landau Noise
  - Distortion





Requirements for Timing Detectors

- LGADs must be optimised to get excellent time resolution

$$\sigma^2_{Total} = \sigma^2_{Jitter} + \sigma^2_{Time\,Walk} + \sigma^2_{TDC} + \sigma^2_{Landau\,Noise} + \sigma^2_{Distortion}$$

$\sigma_{jitter} \approx \frac{t_{rise}}{\left(\frac{S}{N}\right)} \Rightarrow$ maximise $\frac{S}{t_{rise}} \Rightarrow$ go thin

$\sigma_{Time\,Walk} = \left[\frac{V_{th}}{S/t_{rise}}\right]_{RMS} \Rightarrow$ maximise $\frac{S}{t_{rise}} \Rightarrow$ go thin

TDC: Negligible; not from sensor

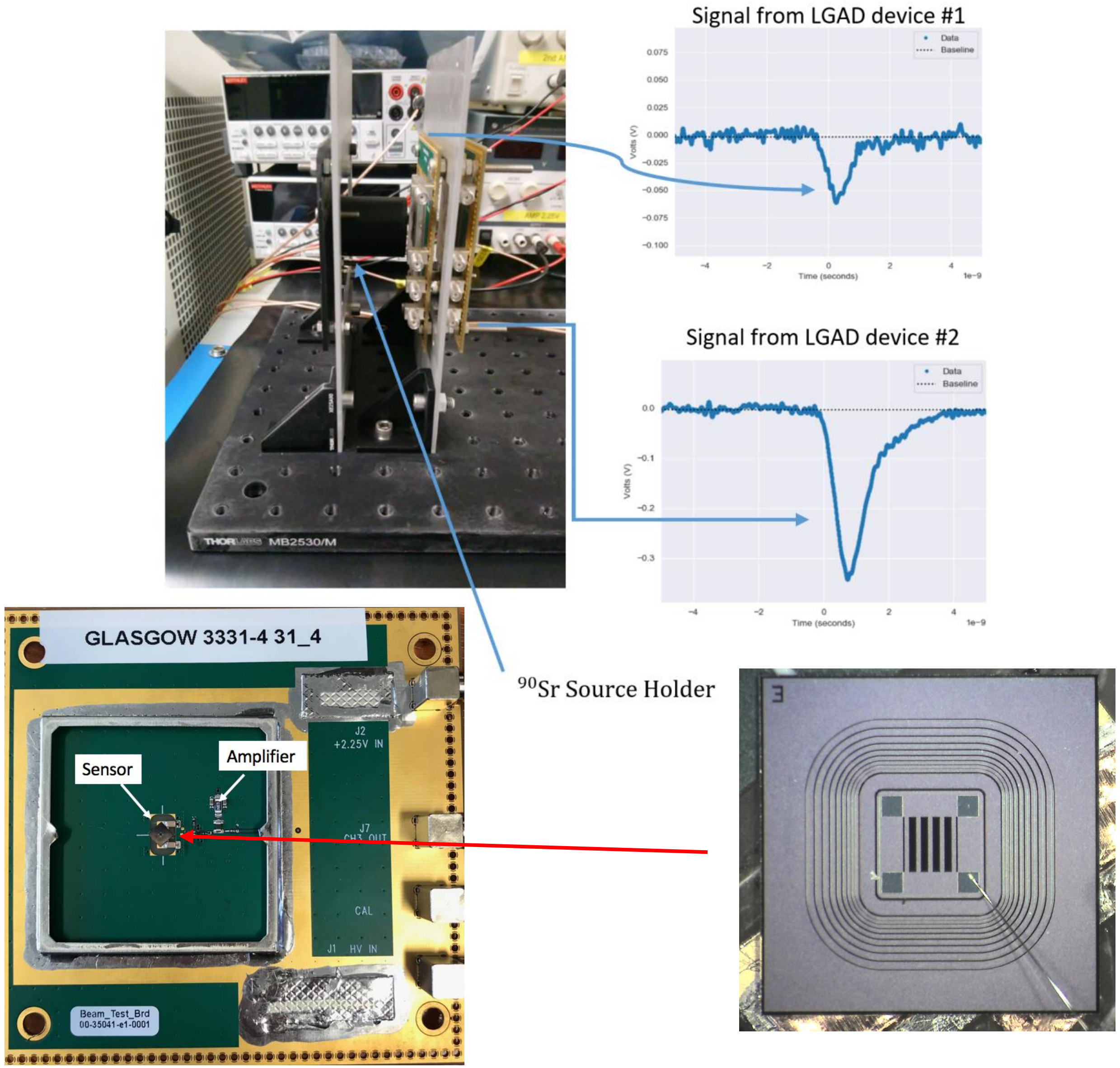
Landau Noise: Simulations indicate thin detectors reduce Landau Noise

Distortion: Uniform weighting field and operate at saturated drift velocities

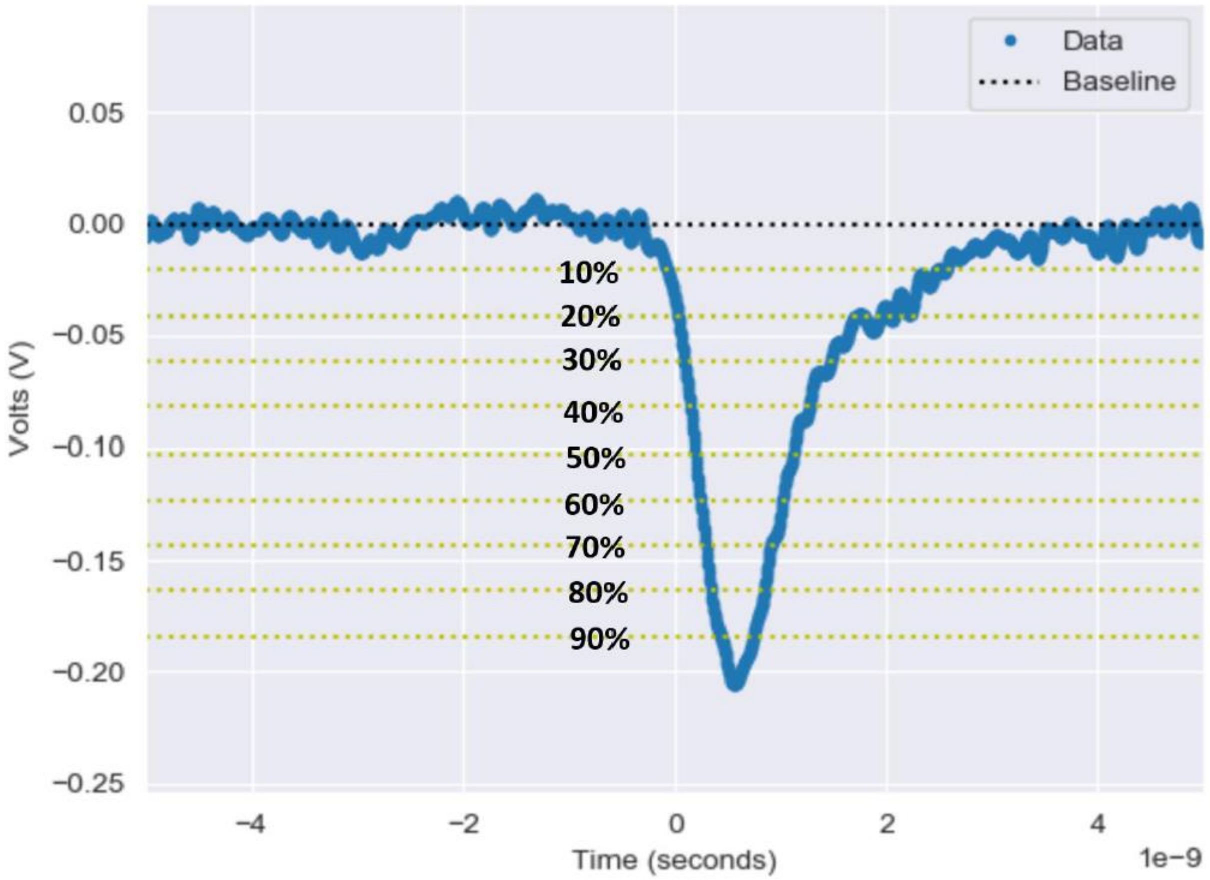
- Best timing resolution obtained by $\sim 50 \mu m$ sensor thickness and higher gain of ~ 20

Experiment for Timing Studies

- Components:
  - ^{90}Sr source holder
  - Timing printed circuit board (PCB)
- DAQ: Fast Oscilloscope
  - effective resolution: 3.13 ps
  - Two channels used
  - Event selection: AND qualifier, trigger over threshold
- Alignment ensured through four screws at each corner
- Entire setup placed in climate chamber for temperature control
  - Dry air constantly pumped to avoid humidity issues



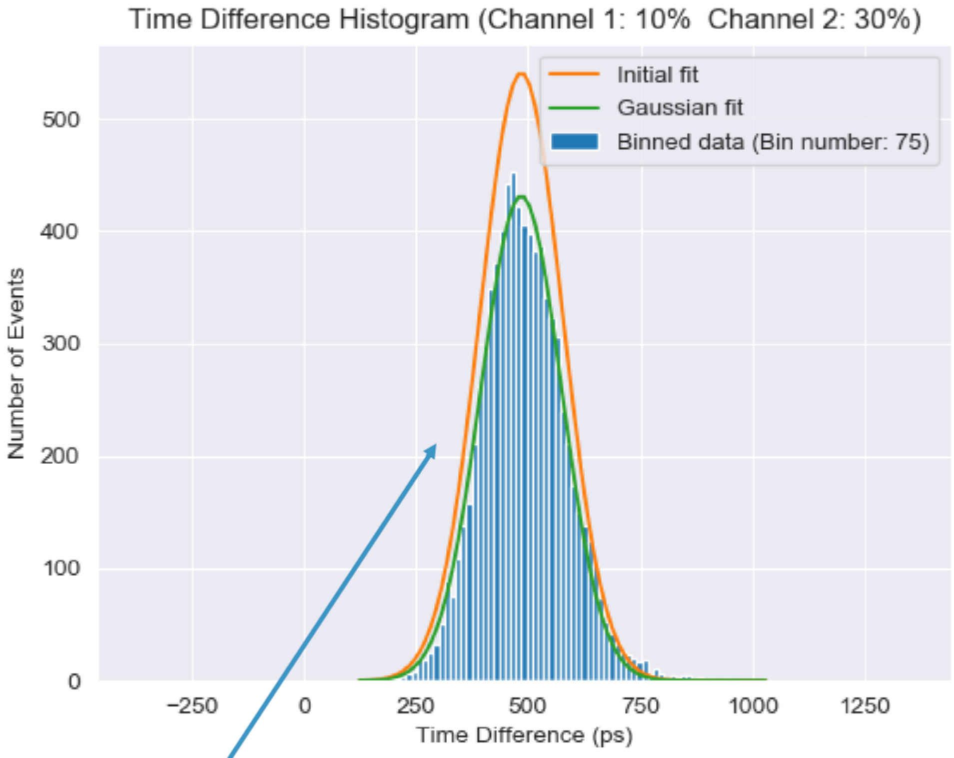
Analysis Procedure, Part 1



- Constant Fraction Discrimination Method was used
  - Entire analysis procedure done by dedicated python script
- Define time of arrival (ToA) at thresholds in signal's rising edge that is certain percentage of signal amplitude
- Two fits are used:
  - Quadratic fit: 20 points ($\sim 60\ ps$) to approximate peak position
  - Linear fit: 12 points ($\sim 36\ ps$) centered at closest data point to threshold to approximate time of arrival

Analysis Procedure, Part 2

- Subtract CH2's ToA to CH1's ToA to get time difference
  - Done for all possible combinations of thresholds (81 total)
- Binning yield Gaussian distribution
  - Optimal Bin size selection through Shimazaki-Shinomoto method (mean integrated squared error minimisation)
- Sigma of Gaussian is the time resolution



Time difference histogram of ~8000 events comparing signal from forward device's 10% threshold to rear device's 30% threshold

Analysis Procedure, Part 3

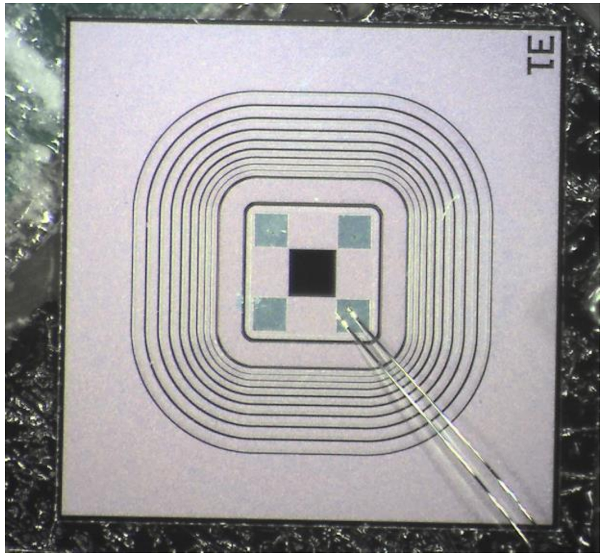
- Error Analysis procedure:
  - Rerun same experiment multiple times while switching off power in-between (done 5 times)
  - Uncertainty is the standard deviation of the time resolutions
  - Done for only one voltage value to save time
- Assumed devices have similar timing resolution to get the device's timing resolution

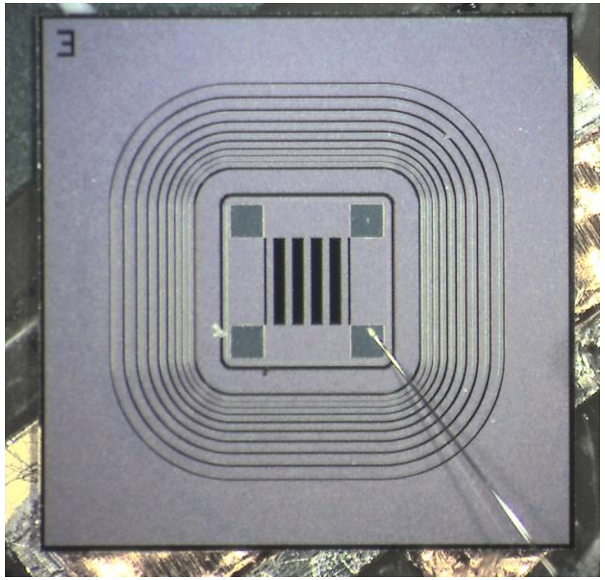
$$\sigma_{average}^2 = \sigma_{DUT\_1}^2 + \sigma_{DUT\_2}^2$$

$$\Rightarrow \sigma_{DUT} = \frac{\sigma_{average}}{\sqrt{2}}$$

Devices Tested

- Multiple LGAD Wafers produced ($200\mu m$ wafer for gain studies, etc.) by Micron Semiconductor Ltd.
  - $50\mu m$ wafer for timing studies
  - Top right: 1 x 1 pad with pixel size of 1mm
  - Bottom right: 1 x 1 pad with pixel size of 1.3mm
- CNM devices: Run 9088 W7 LGB31 and LGB52
  - Thickness: $45\mu m$
- Gain and IVs measurements of devices are work in progress

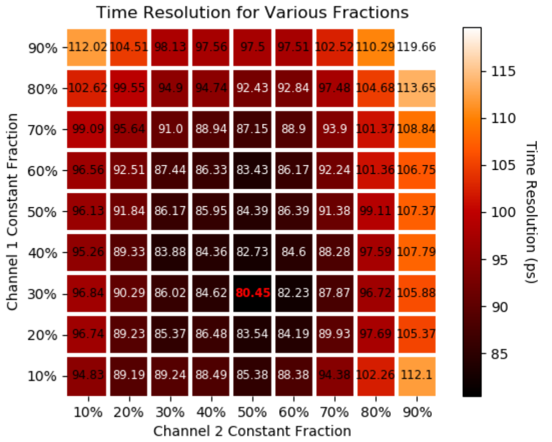




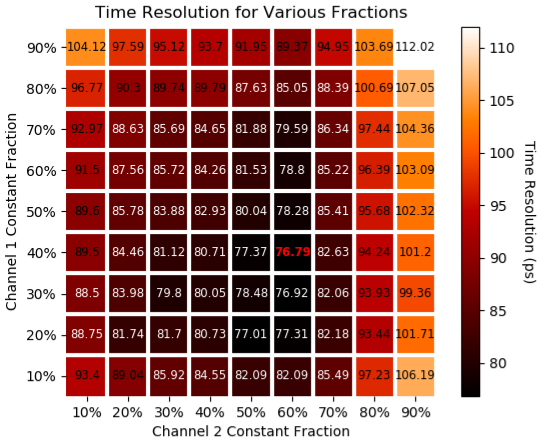
Results: CNM Devices

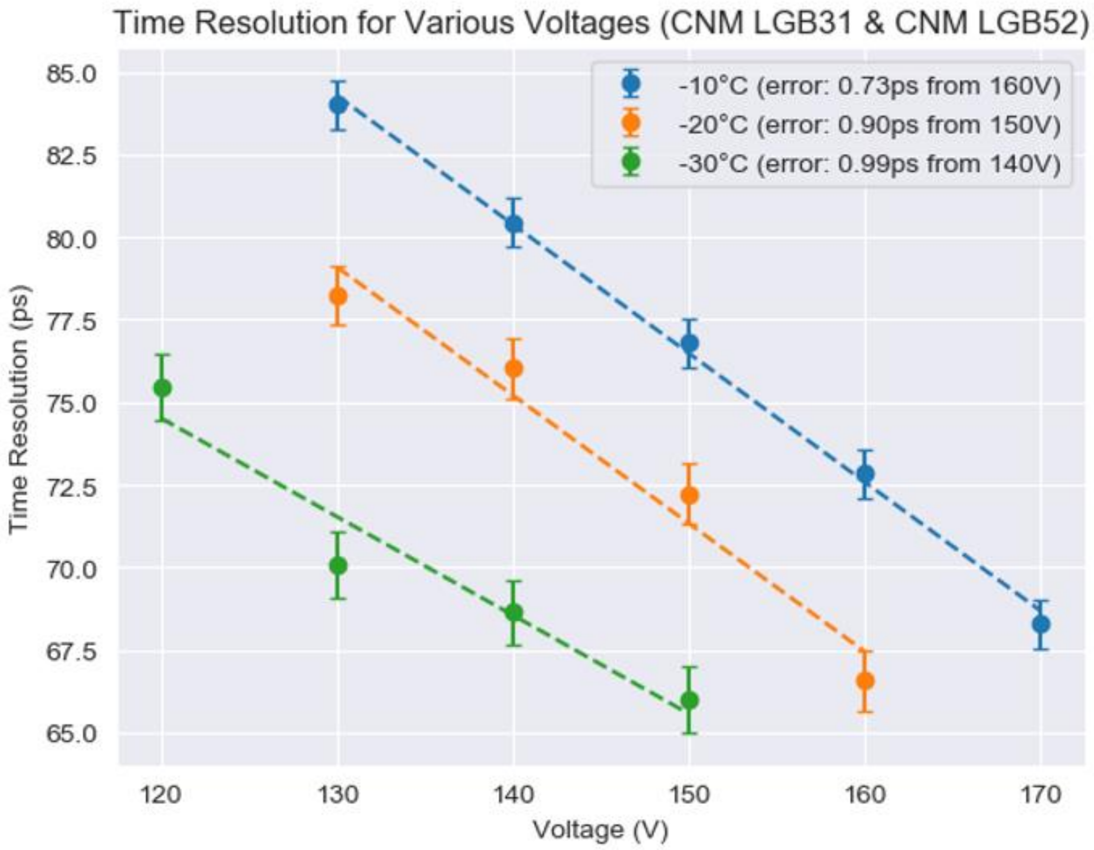
- ~2000 events per measurement run
- Taken February 2020
- Same bias voltage applied to both devices
- Show clear dependence with voltage and temperature

CNM Devices (140V, -10°C)



CNM Devices(150V, -10°C)

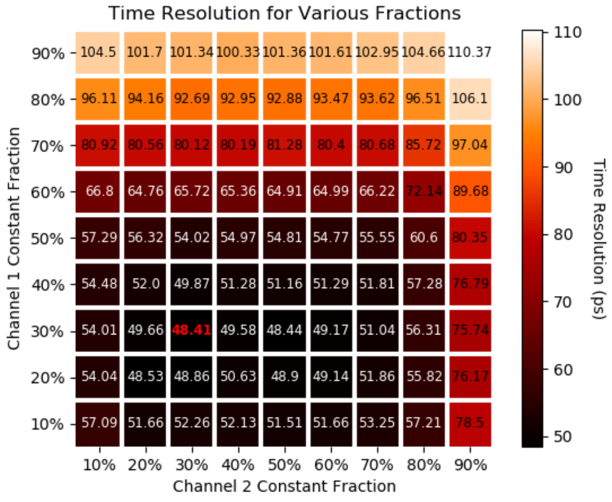




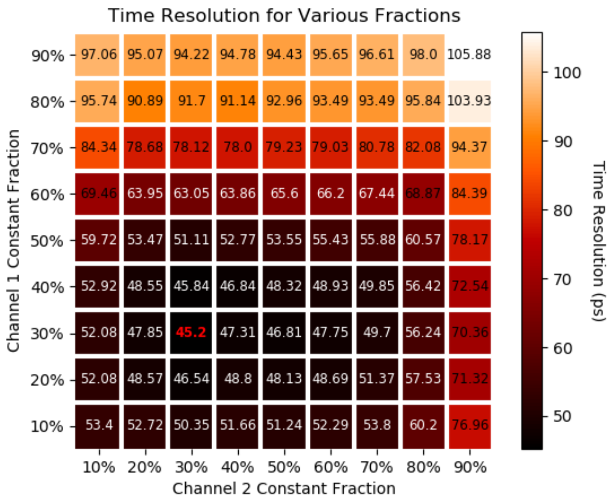
Results: Micron and CNM Devices

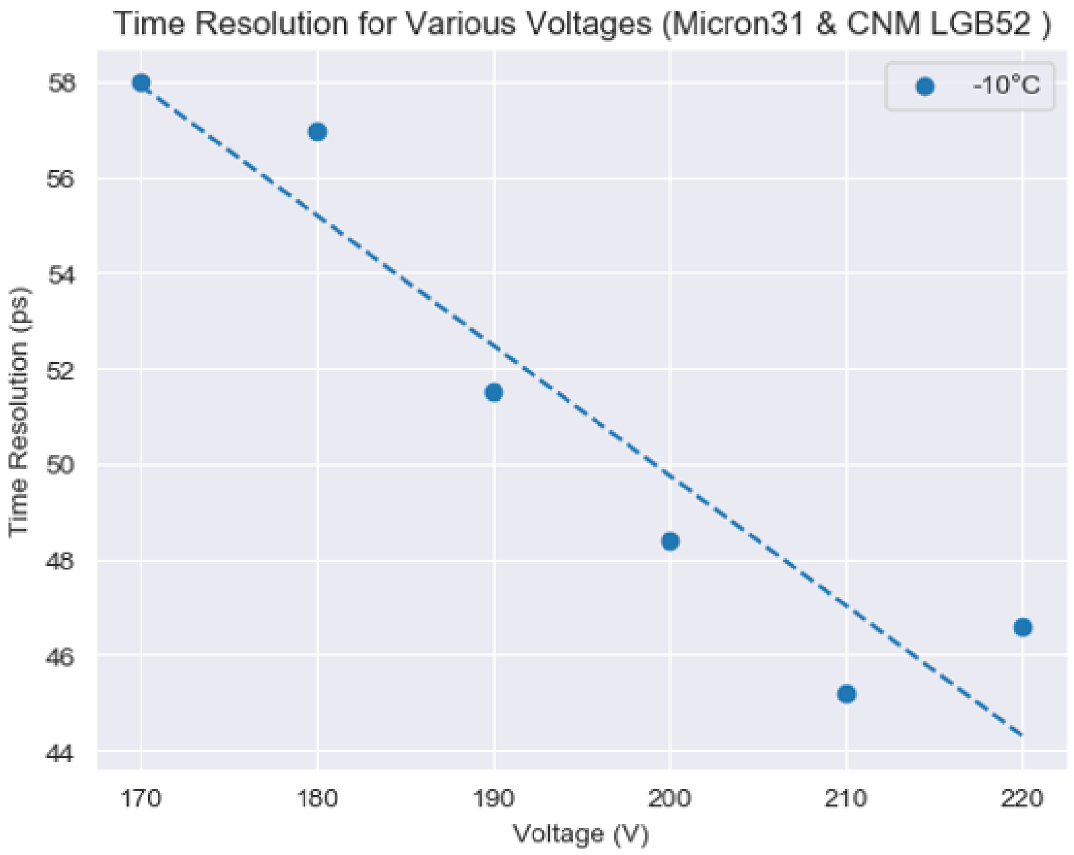
- ~2000 events per measurement run
- Same bias voltage applied for both devices
- Again see clear temperature and voltage dependence

CNM & Micron Devices (200V, -10°C)



CNM & Micron Devices (210V, -10°C)

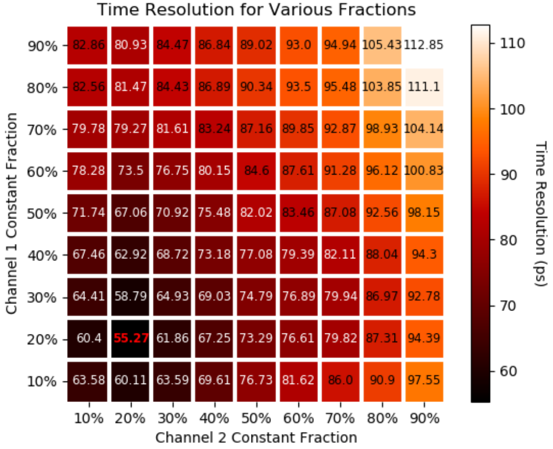




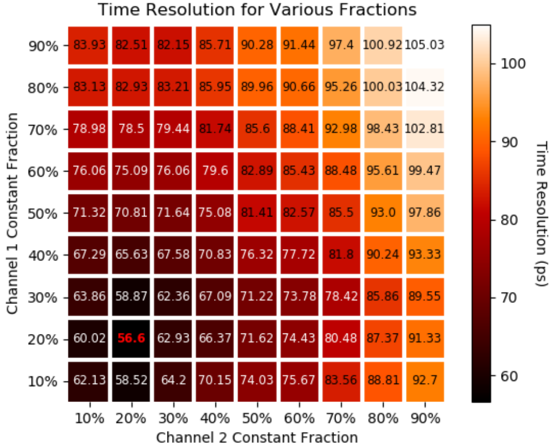
Results: Micron Devices

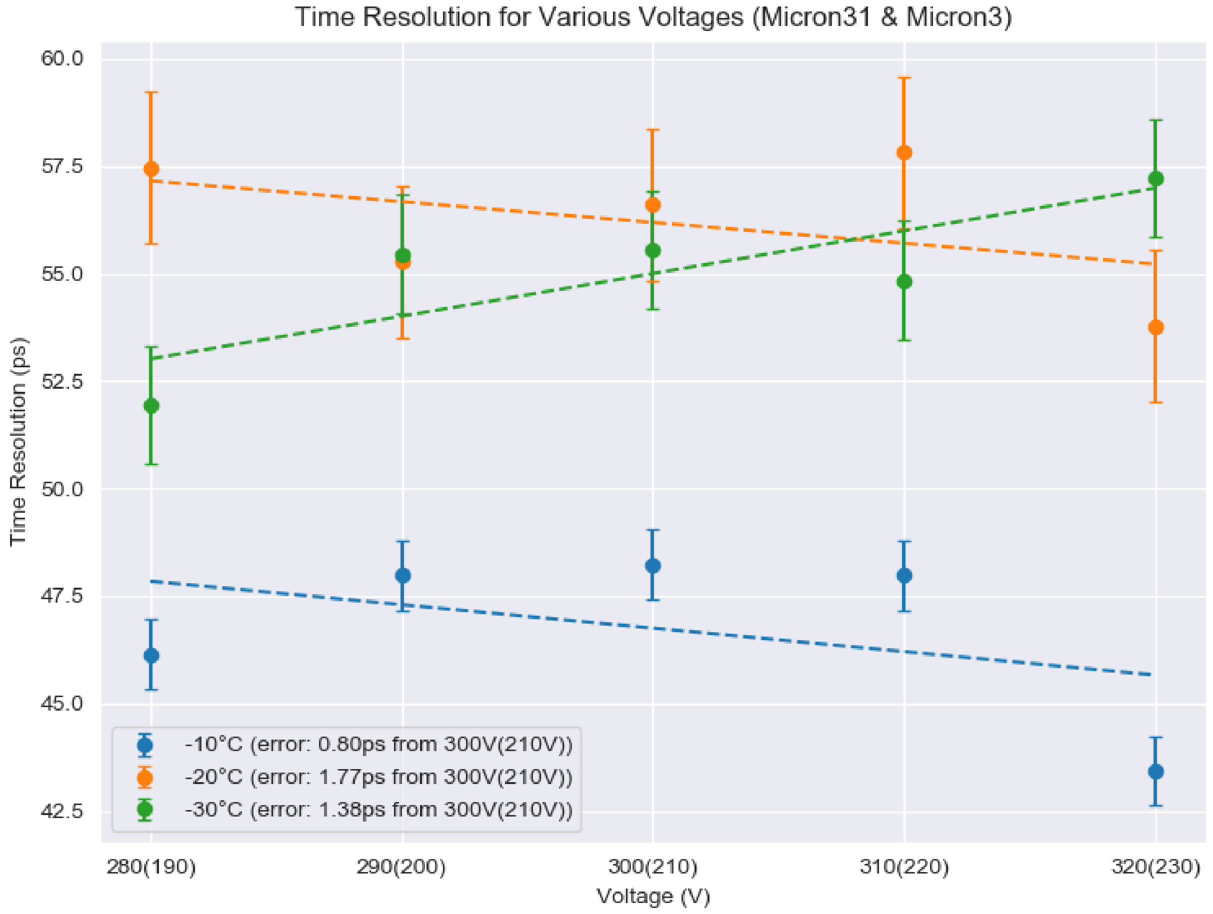
- ~2000 events per measurement run
- Different voltages applied for different devices
- Less obvious dependence with temperature and voltage
- Likely due to saturated gain in tested range.

Micron Devices (290V (200V), -20°C)



Micron Devices (300V (210V), -20°C)





Micron 31 goes from 280V – 320V

Micron 3 goes from 190V – 230V

Future Work and Summary

- Future Work:
  - Further measurements of devices
  - Timing studies after irradiation
- Summary:
  - Timing Requirements of LGADs
  - Experimental Setup for coincidence measurements
  - Analysis procedure
  - Timing results of LGADs produced by Micron Semiconductor Ltd.
    - $\sim 55ps$, with the lowest being $\sim 43ps$

Thank you for your Attention!

Questions?