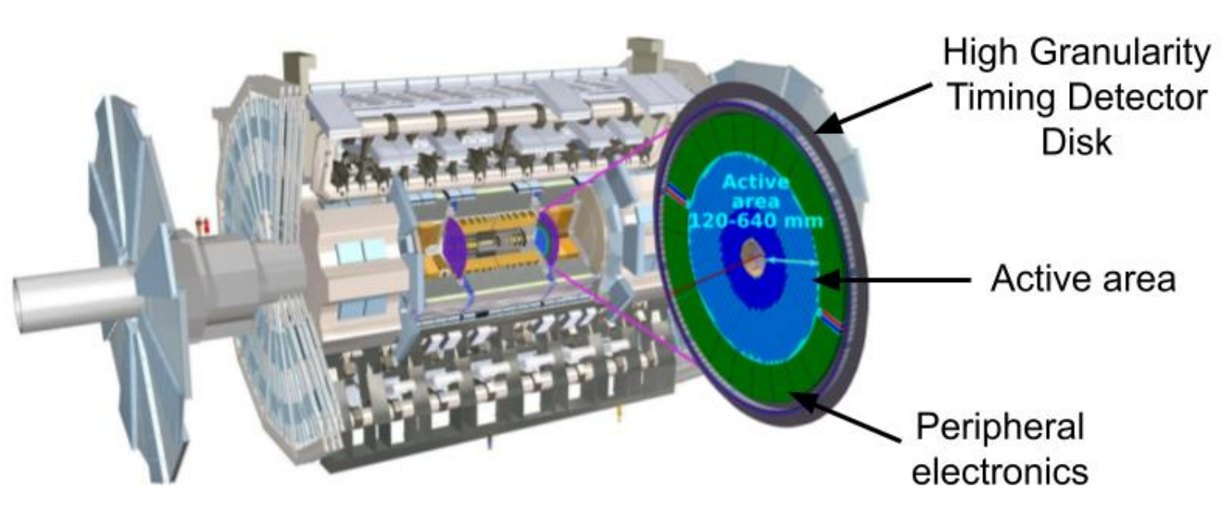
Preliminary Test Results of LGADs from Teledyne e2v for the LHC's High-Luminosity Upgrade

Jonathan Mulvey on behalf of a collaboration between:

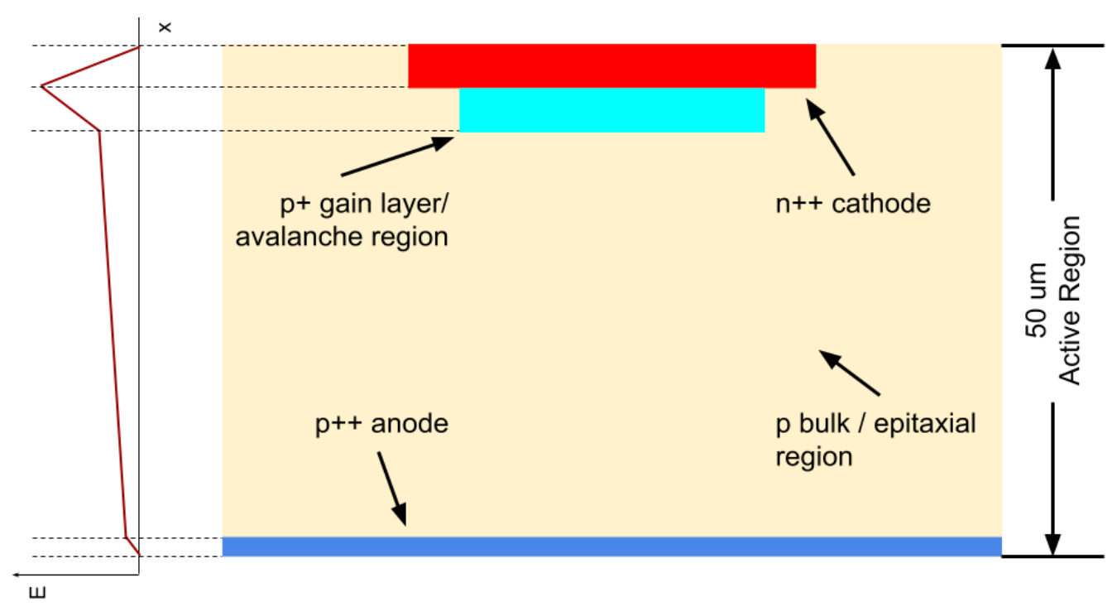
University of Birmingham, Rutherford Appleton Laboratory, University of Oxford, Open University, Teledyne e2V

Introduction



[3]

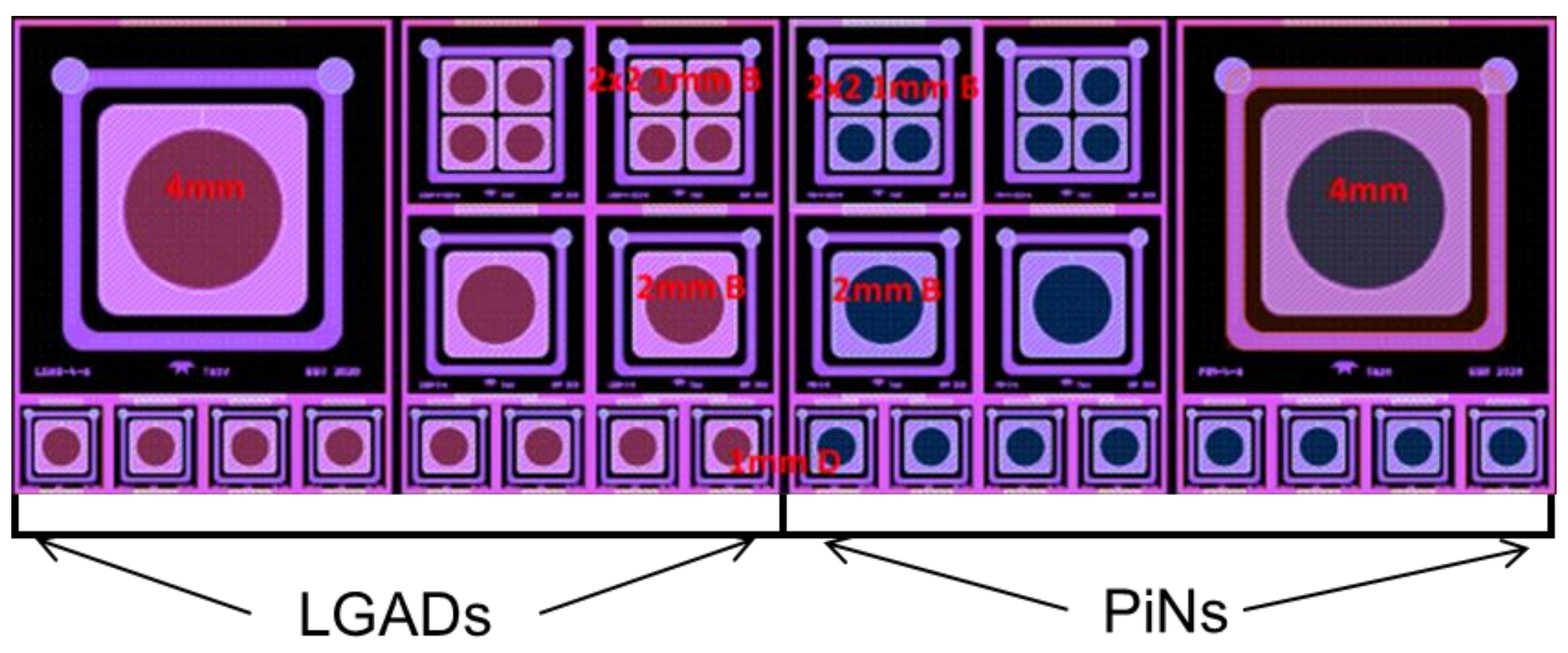
- The LHC's **High-Luminosity** upgrade will see a large increase in collisions and resultant particle tracks. [1]
- At these scales along the beam line, it becomes harder to go from hits to tracks and then tracks to vertices. [1]
- With an initial timing resolution on the track of **~30ps**, **4D tracking** overcomes these issues. Towards the end-of-life, this resolution can increase to **~50ps** [2]
- LGADs are an expansion of PiN diodes where small **p+ gain layer** is driven in to create an **avalanche region** allowing fast timing. [2]



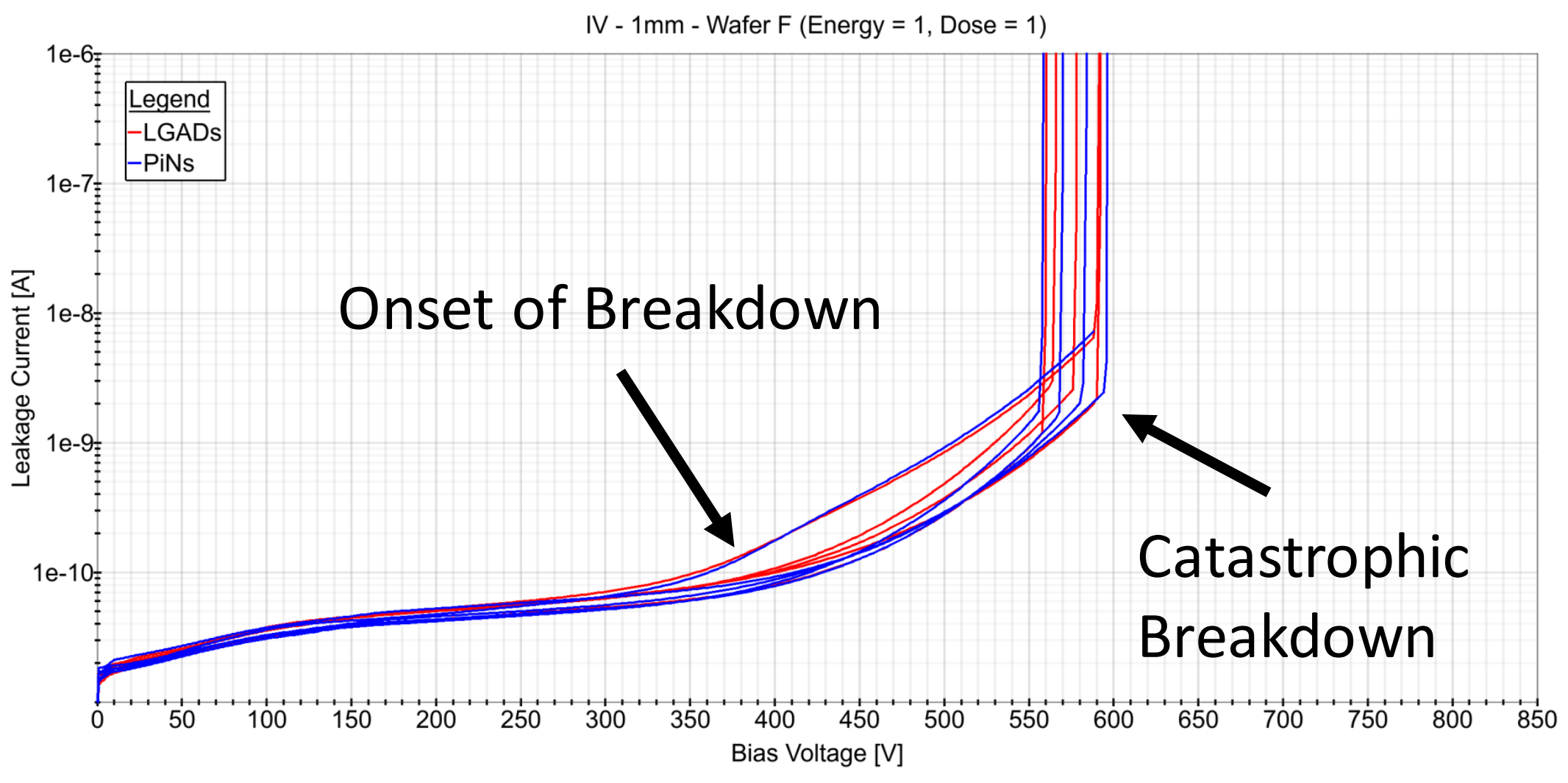
[2]

Teledyne e2v – Batch 1

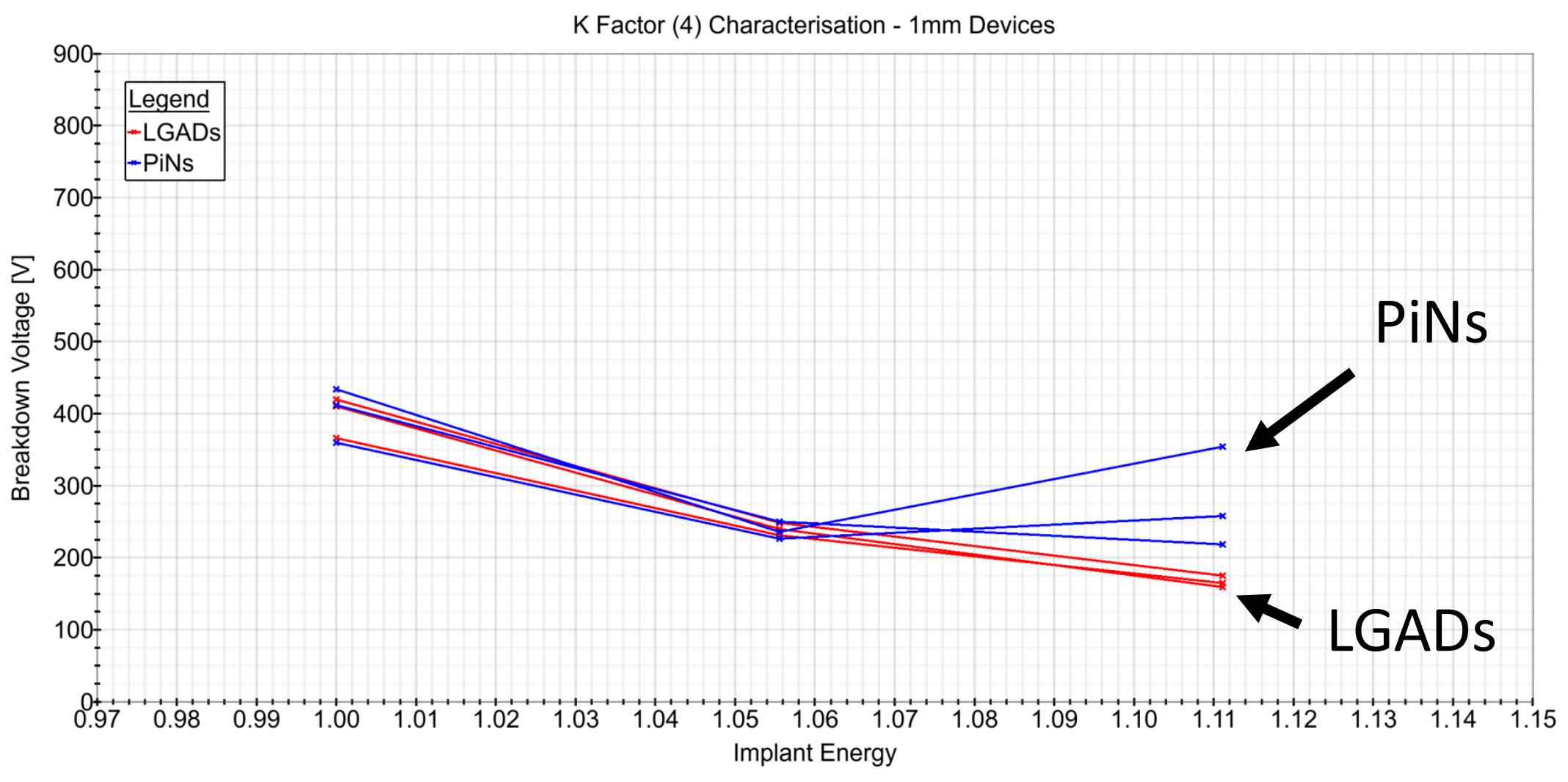
- **Teledyne e2v** is a UK based foundry capable of a **large production volume**, which they already have setup for the production of CCDs.
- We are currently testing our first batch of 22 wafers, which come in triplets of the same implant energy and dose.
- Each wafer contains sets of LGADs and PiNs, differing only by the presence of the gain layer in the LGAD.
- There are 4 different size configurations: **1 mm**, **2 mm**, **4 mm**, and **2x2 arrays of 1 mm**.
- The 1 mm and 2 mm variants also come in different "flavours" where properties such as the distance from the pad to the guard ring is varied.



Breakdown Characterisation



Example IV curves for 1mm devices of a single wafer type. For 1mm devices there is little difference between LGADs and PiNs.

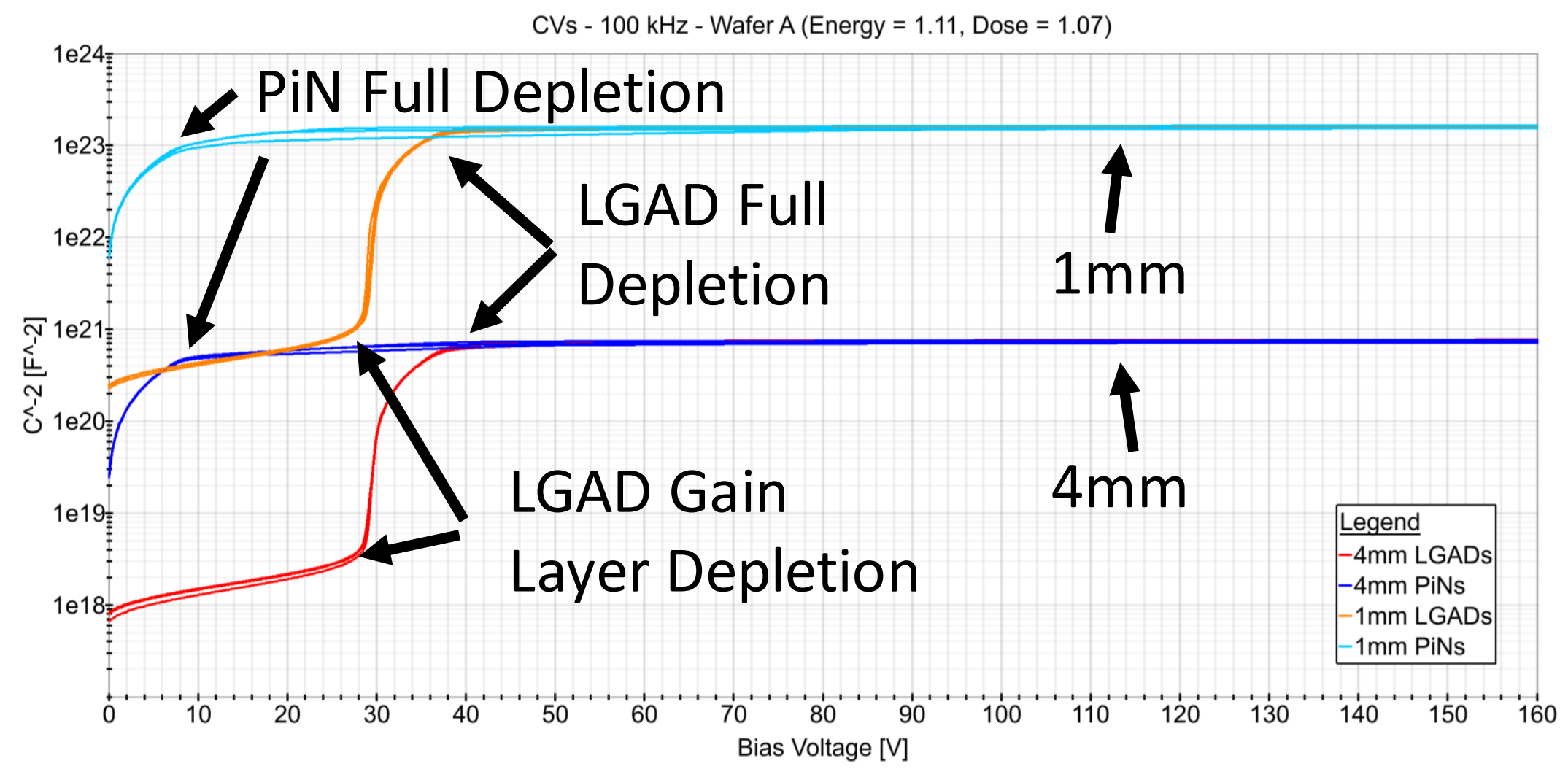


Breakdown is defined as the significant increase in leakage current as a function of bias voltage. Breakdown voltage is calculated via the **K-Factor characterisation** method, where **K = 4** is defined as "**soft breakdown**". This is then plotted against the normalised wafer implant energy.

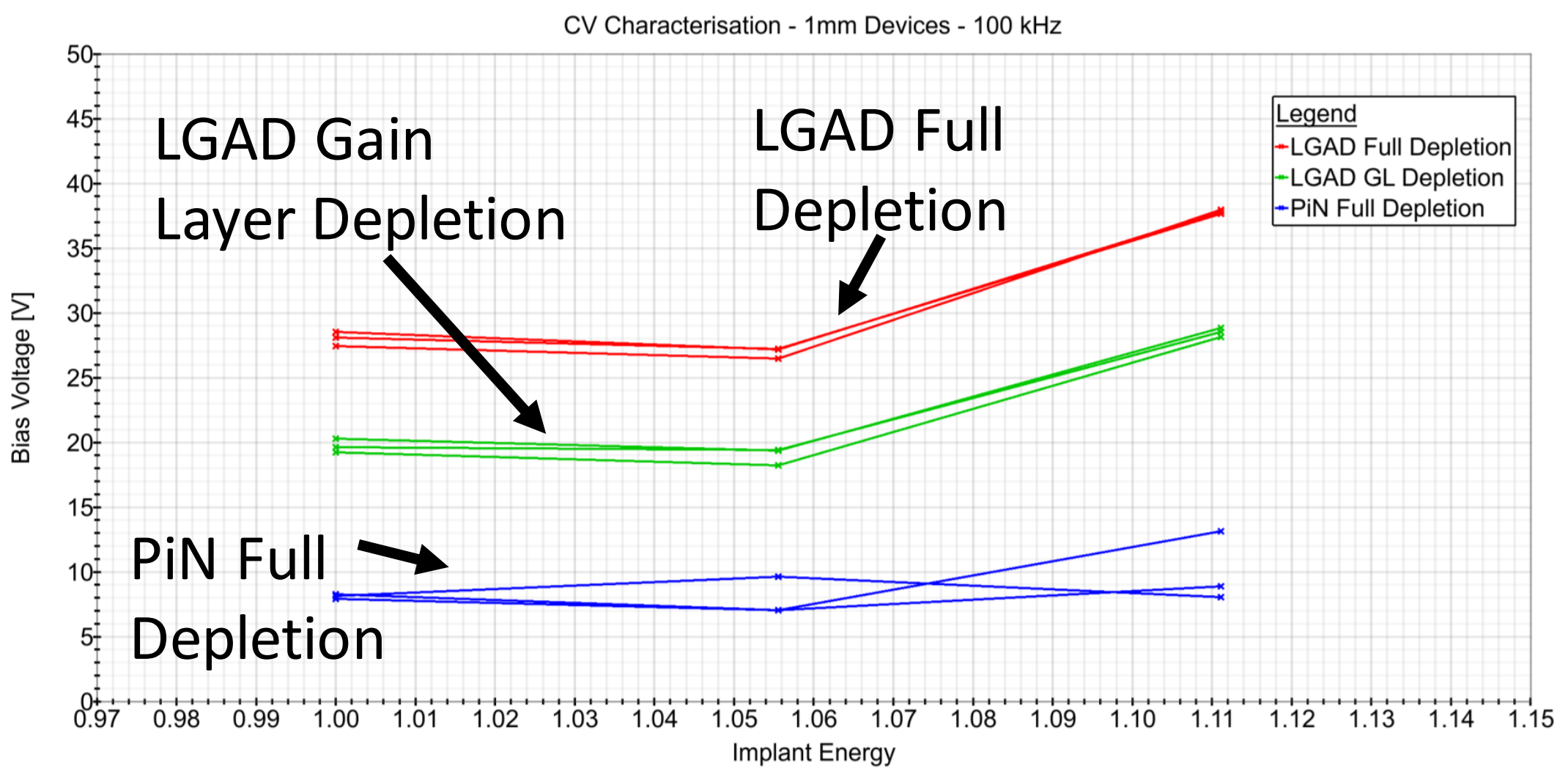
$$K = \frac{I}{V} * \frac{dI}{dV}$$

As the implant energy increases, the breakdown voltage appears to decrease, as one might expect.

Depletion Regions



Capacitance ($1/C^2$) vs Bias Voltage curves for 4mm & 1mm devices of a single wafer type. There is a clear capaticance difference for the difference sizes. We also see the delay in **full depletion** in LGADs due to the **gain layer depletion**.

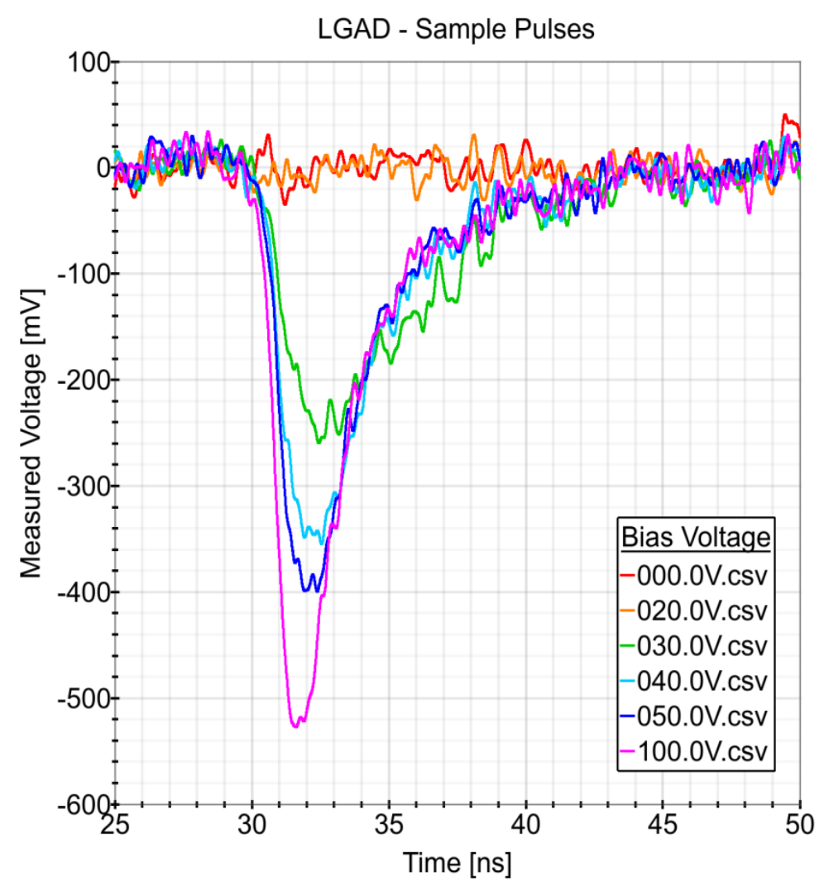


We can extract the two depletion voltages and plot them against the normalised implant energy.

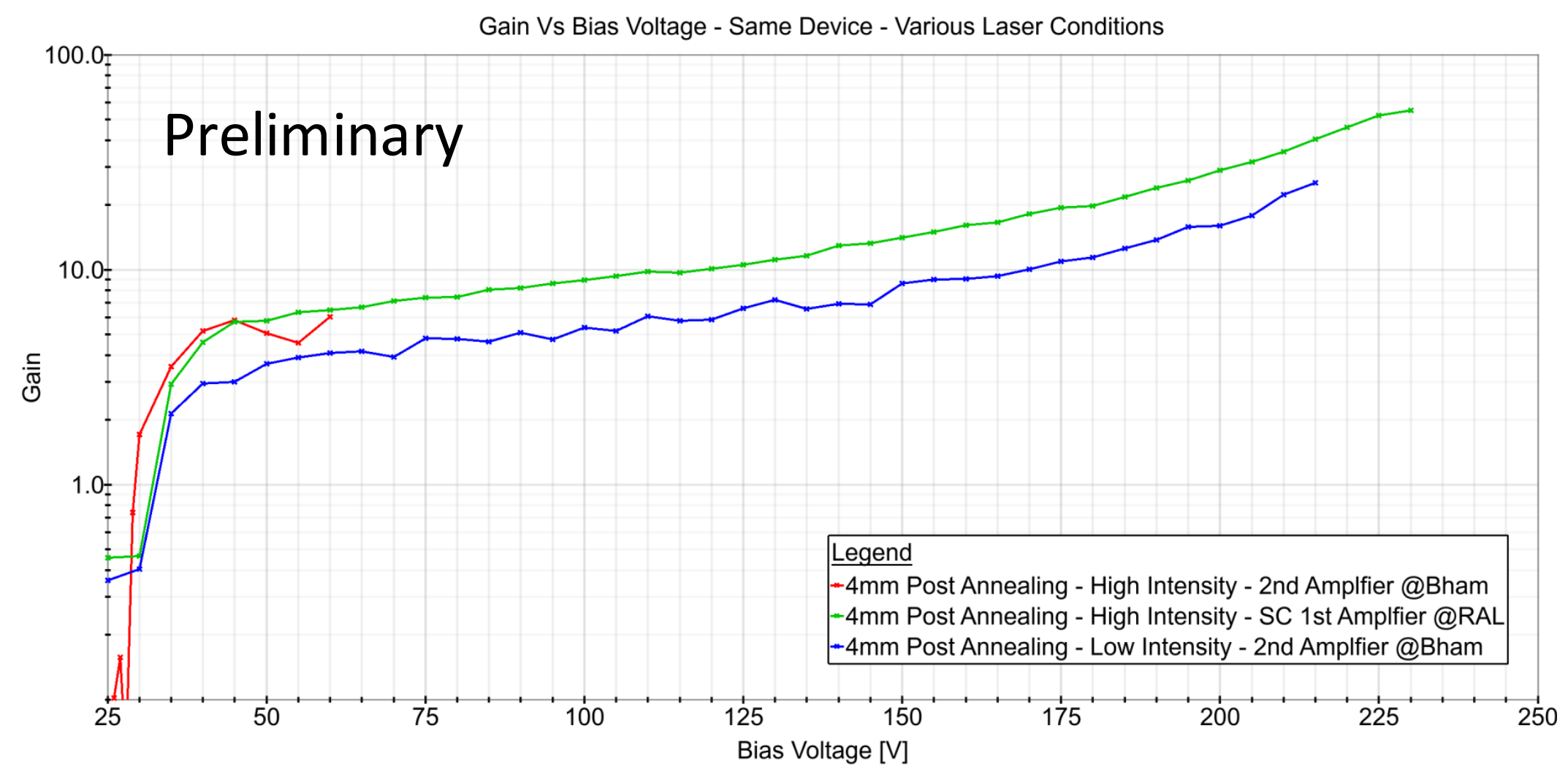
We can see a clear increase in depletion voltages at higher implant energies, which corresponds to an **increased gain layer thickness**, as expected.

The difference between gain layer and full depletion does not seem to change, as expected since the increased implant energy should only affect the gain layer.

Gain Measurements



Charge is injected via a **pulsed 1064 nm laser**. The resultant pulse from the sensor (which is connected to a fast amplifier) is integrated over a specific time window. The result of that **integral**, as a function of bias voltage, can be plotted.



The gain is calculated as the **ratio** of the pulse integral between an LGAD and a PiN.

There is an initial voltage offset caused by the gain layer in the LGAD. This is seen where the gain goes above 1 at around **35V**. At higher voltages, we see the gain increase exponentially.

Discrepancies are seen between higher and lower laser intensities, as well as between the amplifiers used. These are **preliminary** results and require further investigation.

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References

[1] Kuehn, S., *Impact of the HL-LHC detector upgrades on the physics program of the ATLAS and CMS experiments*, 2021
[2] Mazini, R., *A High Granularity Timing Detector for the ATLAS Phase-II Upgrade*, 2021
[3] Francesco, L., Ludovico, P., *Technical Design Report: A High-Granularity Timing Detector for the ATLAS Phase-II Upgrade*, 2020