TCAD Simulation of HV-CMOS Pixel Structures

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CLICdp collaboration meeting

Outline

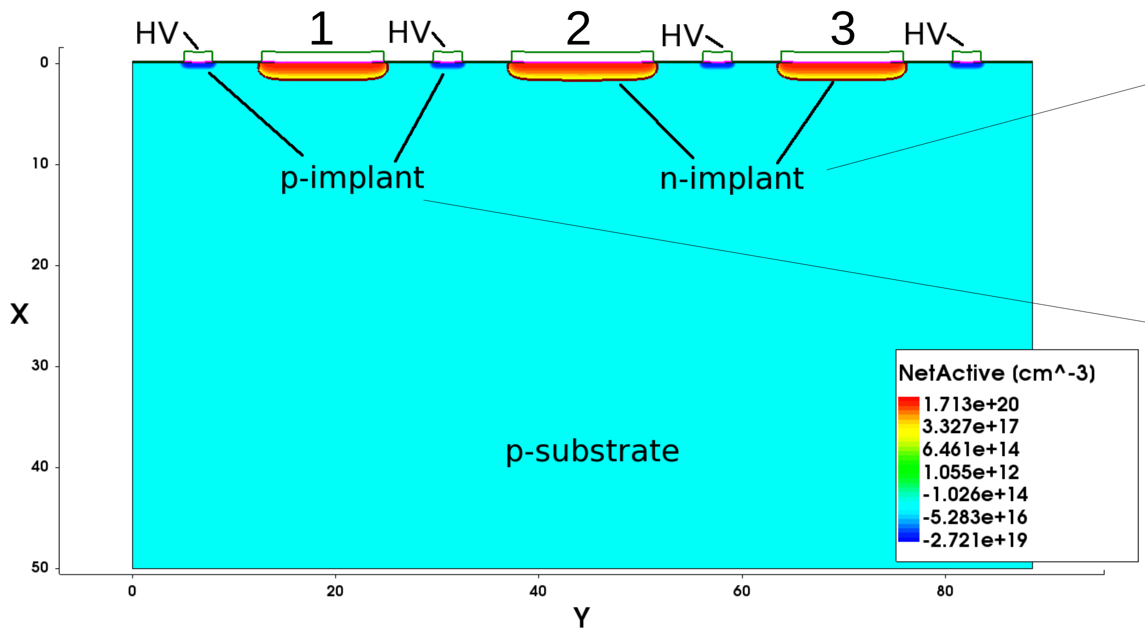
- Motivation
- Simulation layout
- Mip TCAD
- Electric field Comparison
- Depletion Depth
- Compare pulse shape, charge collection and collection time for various mip positions
- Summary

Motivation

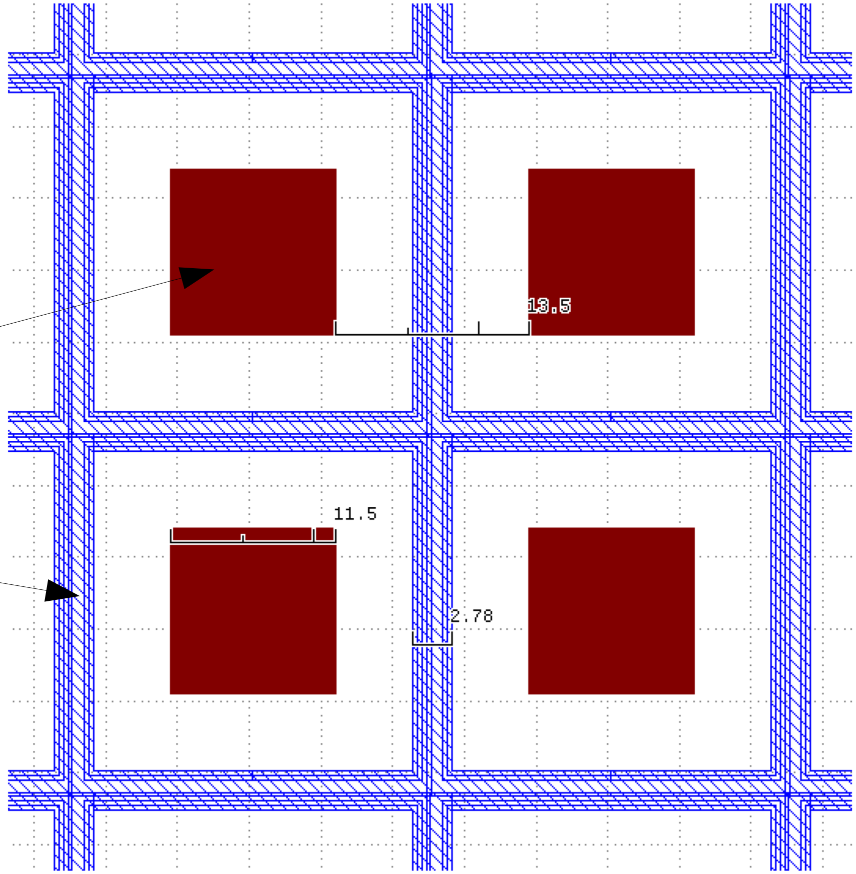
- Perform TCAD simulations to get a better understanding of the CCPDv3 performance
- Helps with optimisation of future sensors
- Done by looking at the pulse height, timing, charge collection for different sensor properties
- Then comparing simulations to test beam and lab measurements
- Two sensors under study: 50μm thick (future goal) and 280μm thick (current sensor)

Simulation Implant Layout

- n-in-p sensor, 3 pixels
- Generic pixel layout, based on CCPDv3 layout, 2D model
- High voltage is applied to the p-implants
- Three n-implants, depth of ≈ 2μm, are the readout channels: pixels 1, 2 and 3



TCAD model

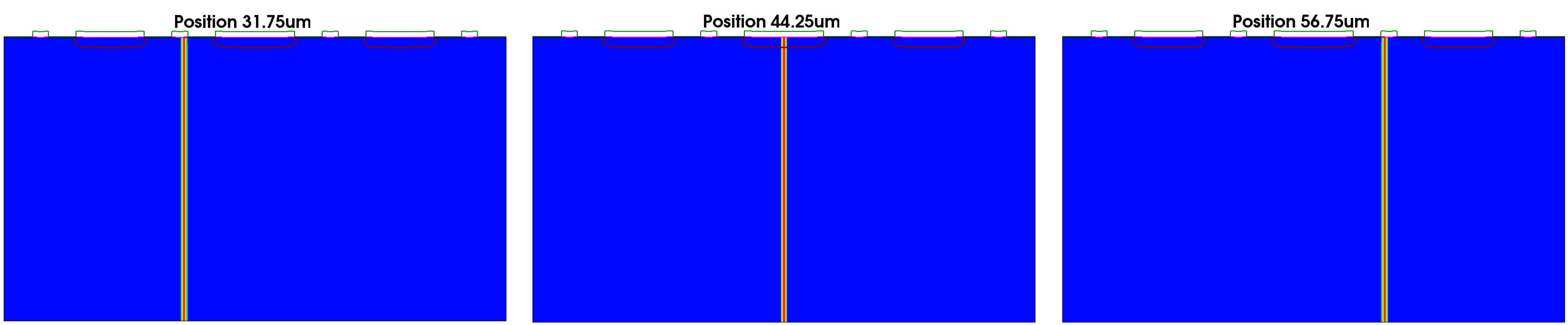


CCPDv3 implant layout

D.Hynds

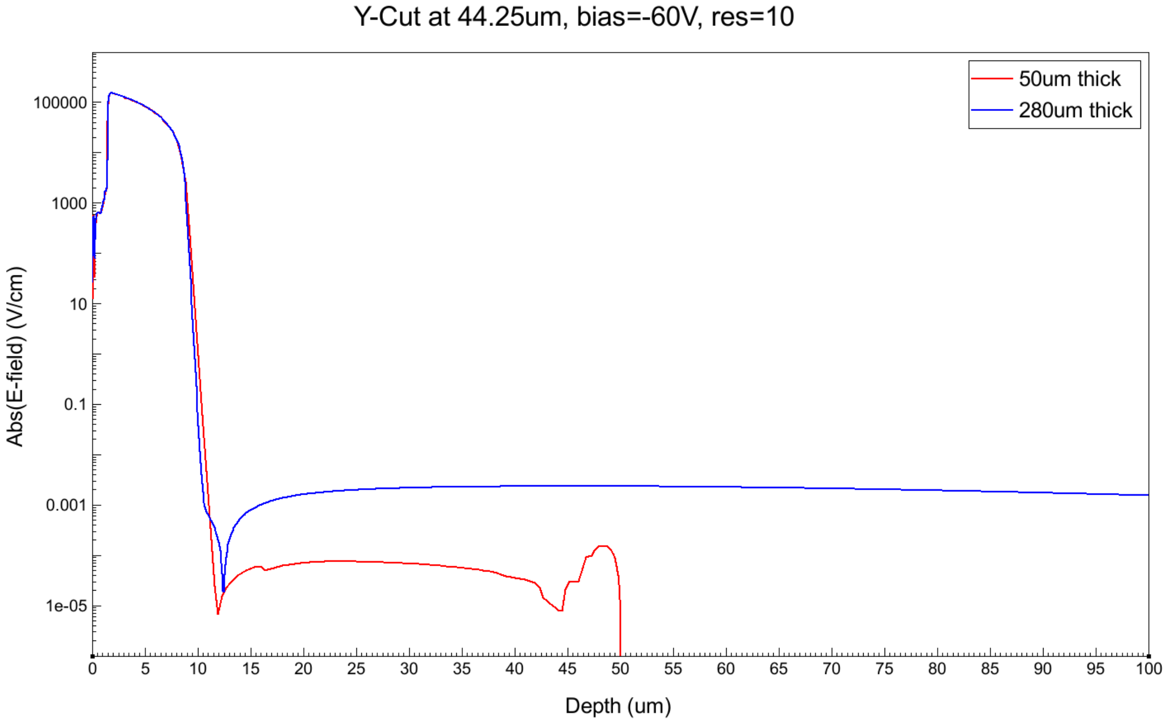
Mip Simulation in TCAD

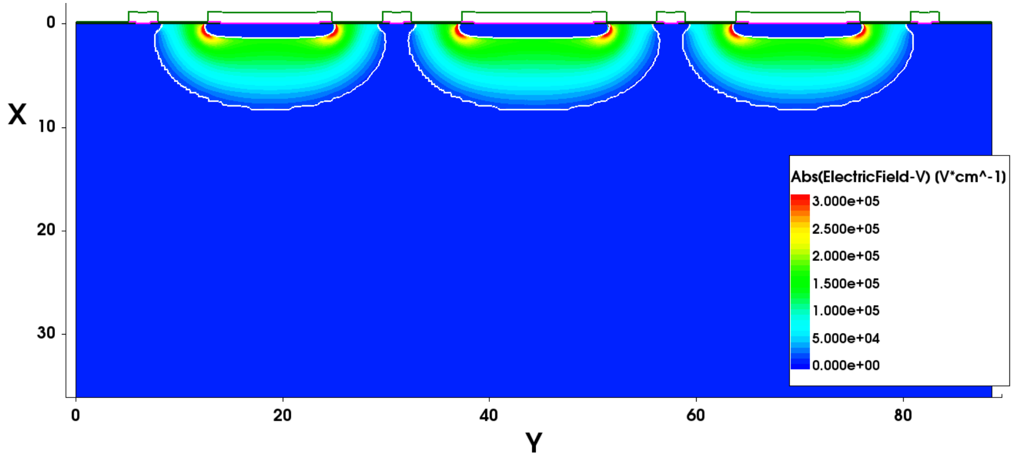
- Set the time at which the mip enters, 0s
- It deposits the charge instantaneously along a user defined track
- Deposits 80eh pairs per micron, LET=1.28×10^{-17}C/µm
- Three mip positons: left (31.75µm), center (44.25µm), right (56.75µm)
- Perform a transient simulation from 0s to 1µs

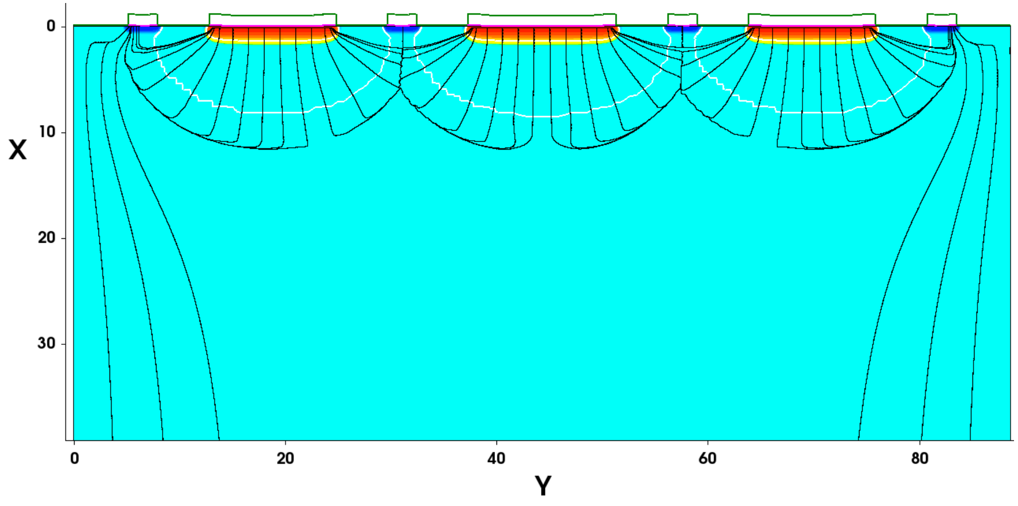


Electric Field, Resistivity 10Ωcm

- Comparing 50µm to 280µm
- Y-cut though middle of sensor
- Very similar up to ≈ 10µm
- E-field in thicker sensor has a larger value outside the depletion region but still very small, ~0.001 V/cm

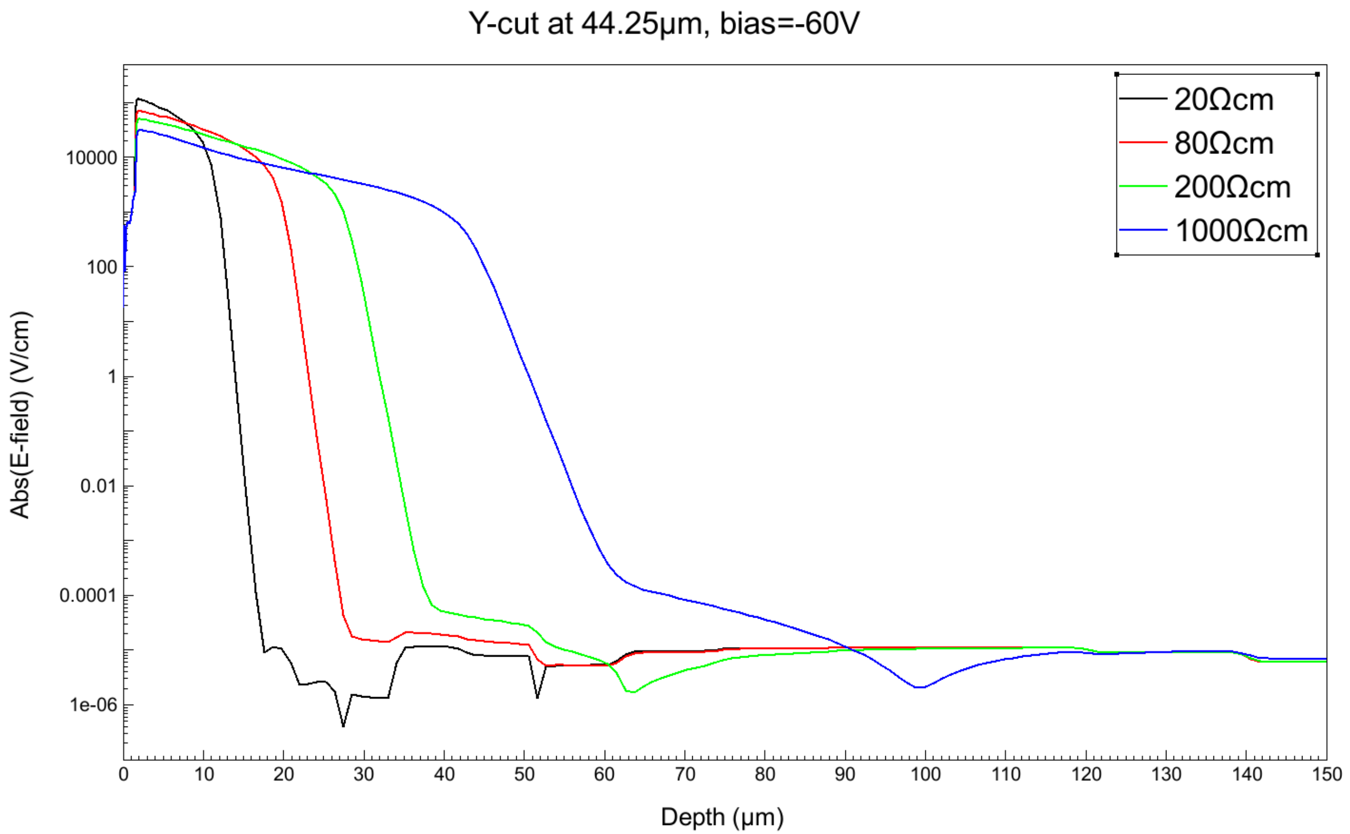






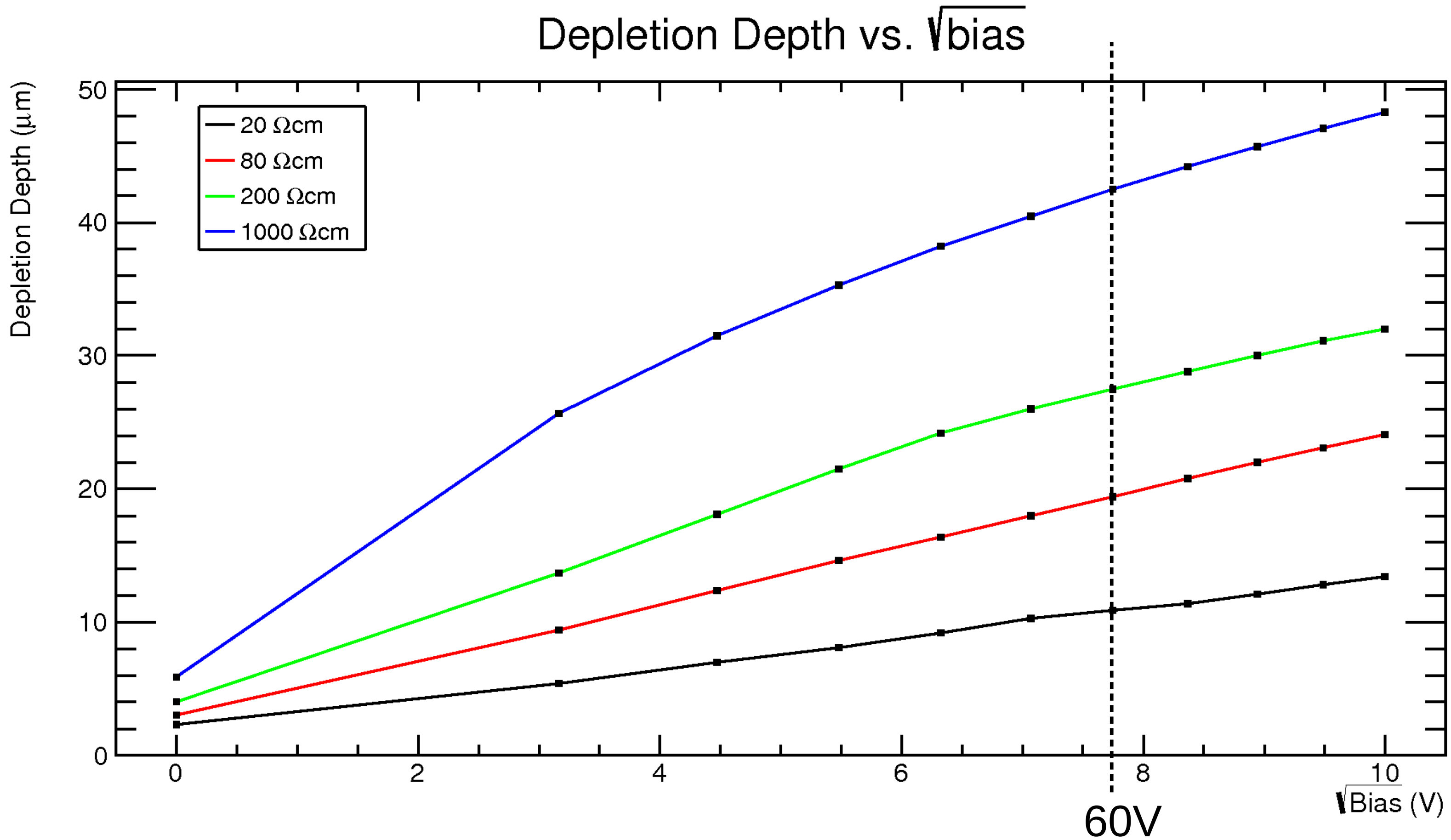
Electric field Depth, -60V, 280µm Thick

- Lower resistivities have a higher electric field in the depletion region
- E-field penetrates deeper for higher resistivities, although at a smaller value
- All have the same value outside depletion after ≈ 120µm



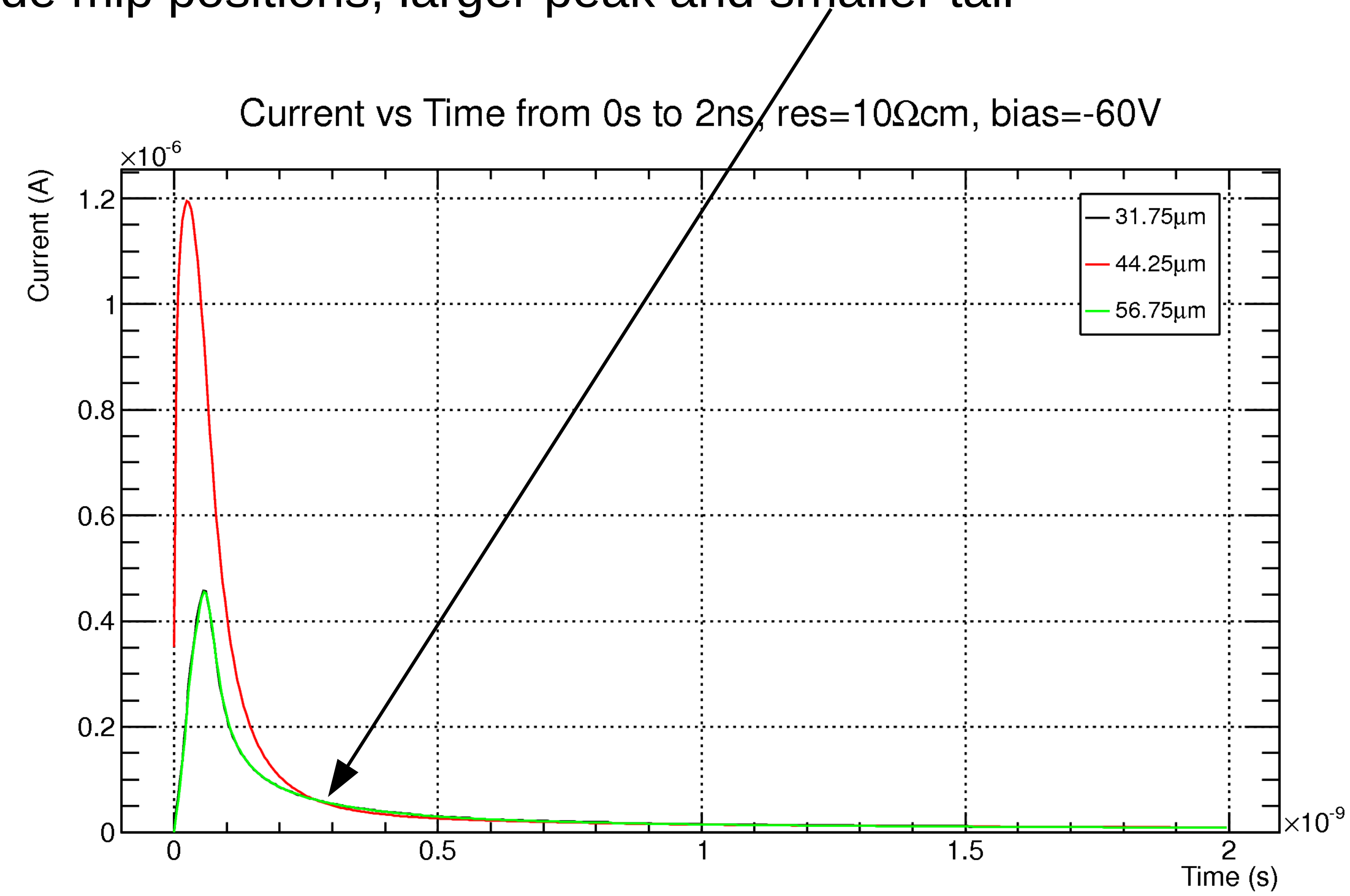
Depletion Depth

- Higher bias and resistivity means larger depletion region
- Largest difference is between 200Ωcm and 1000Ωcm, which was also seen in the E-field depth
- -60V is the max voltage for which this technology is rated



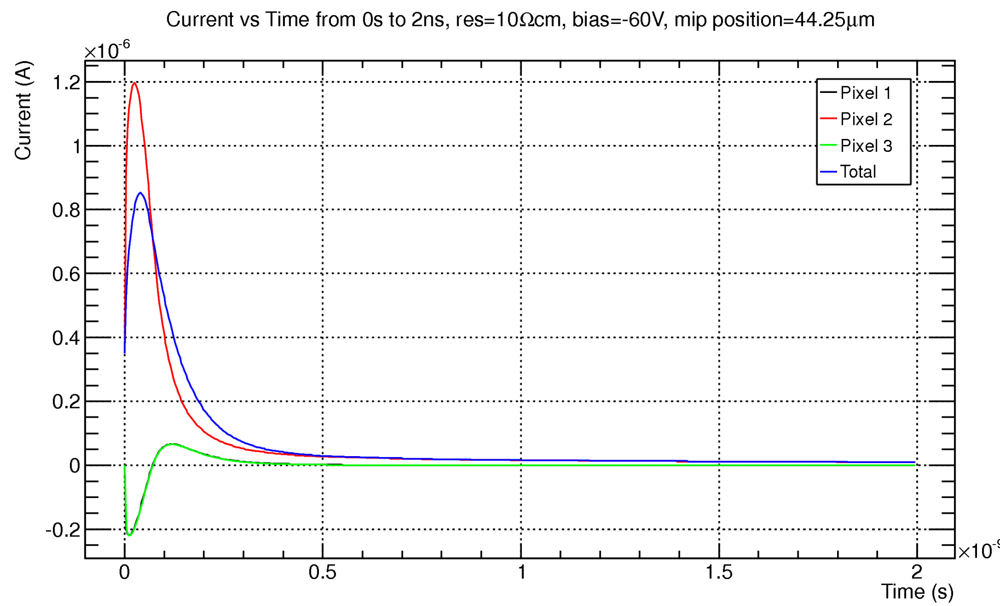
Pulse Shape Comparison of mip Positions

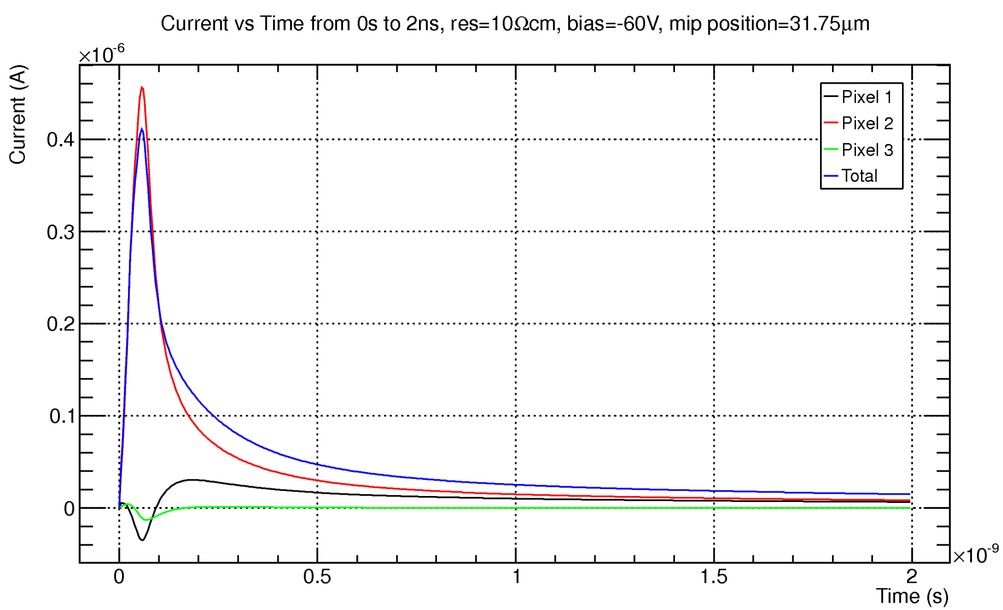
- Readout from pixel 2, thickness: 280µm
- Centre mip position collects more charge due to drift compared to side mip positions, larger peak and smaller tail

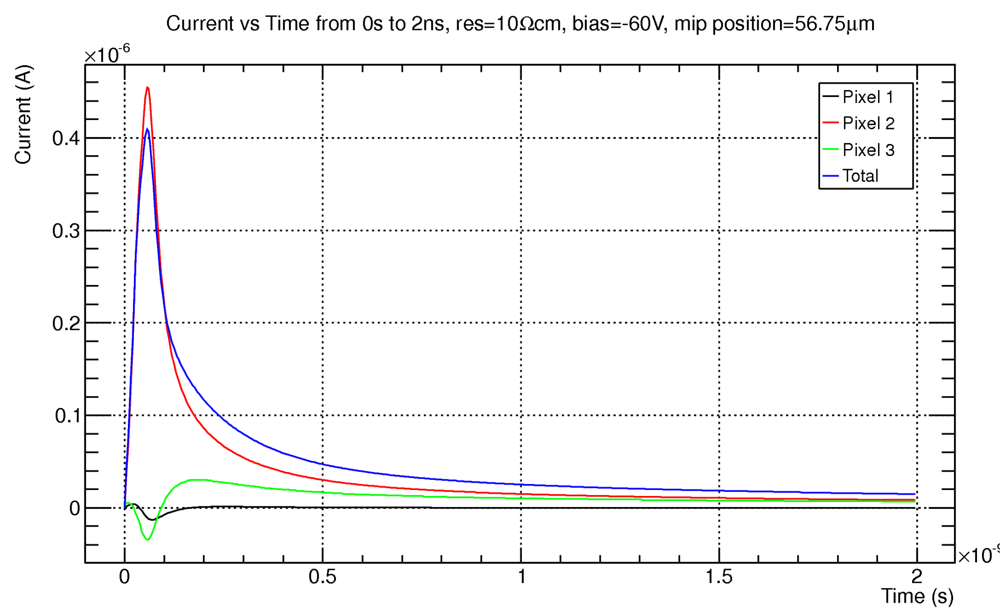


Pulse Shape Comparison, Pixel 1, 2, 3

- Centre mip has a larger total pulse height than the two side positions
- Symmetric for the two side positions

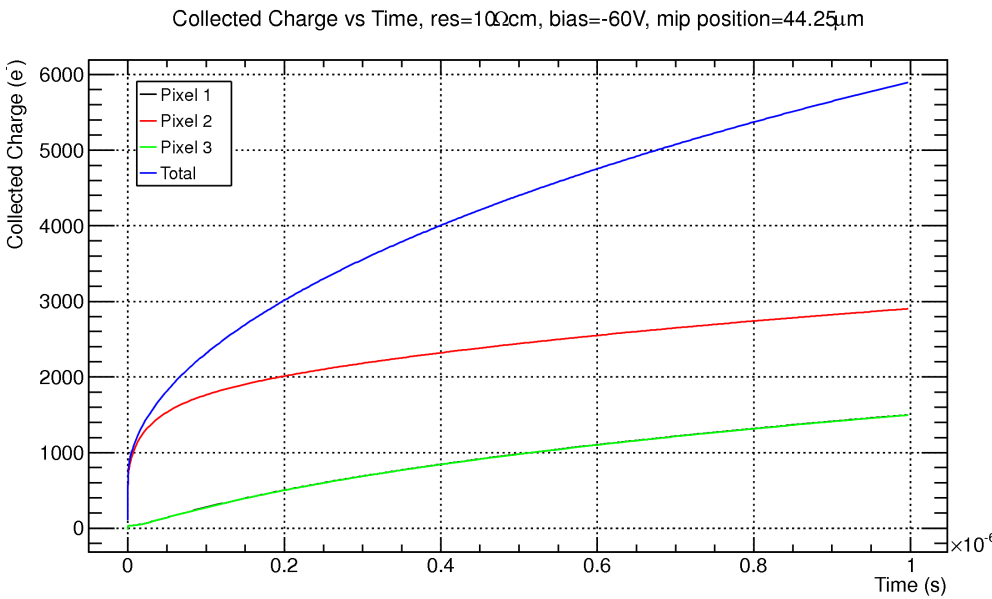


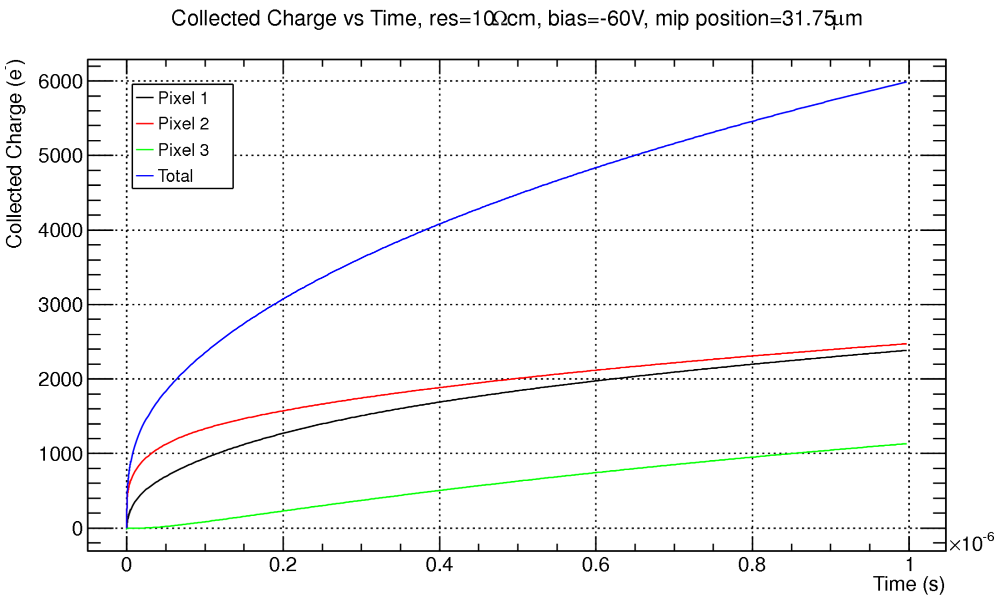


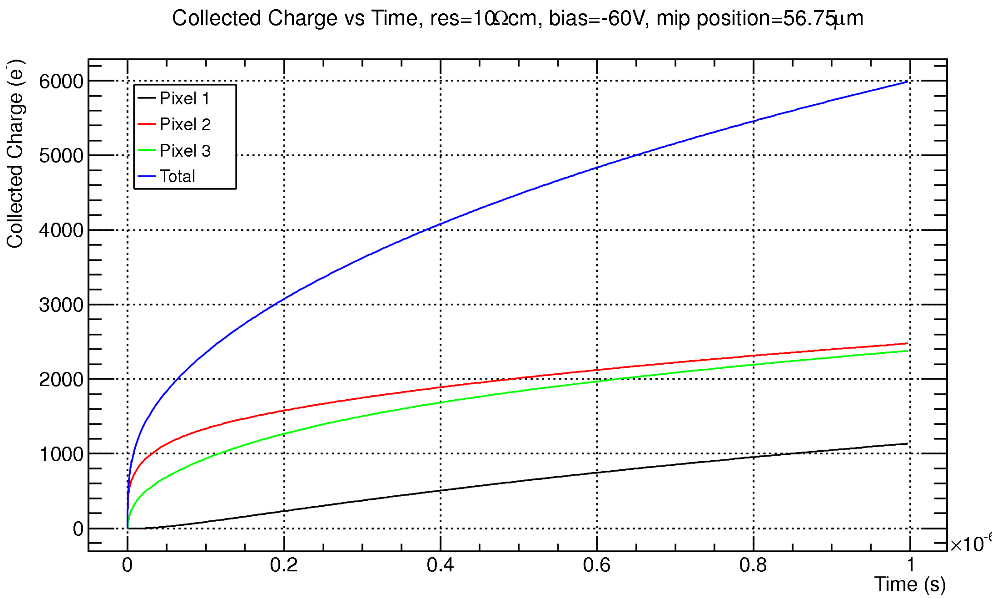


CC vs Time Comparison, Pixel 1, 2, 3

- For centre mip position pixel 2 collects ≈ 400e$^-$ more than 1 and 3
- For side mips the pixel closest to the mip collects the most charge, pixel 2
- The total for all mip positions are the same, ≈ 6000e$^-$

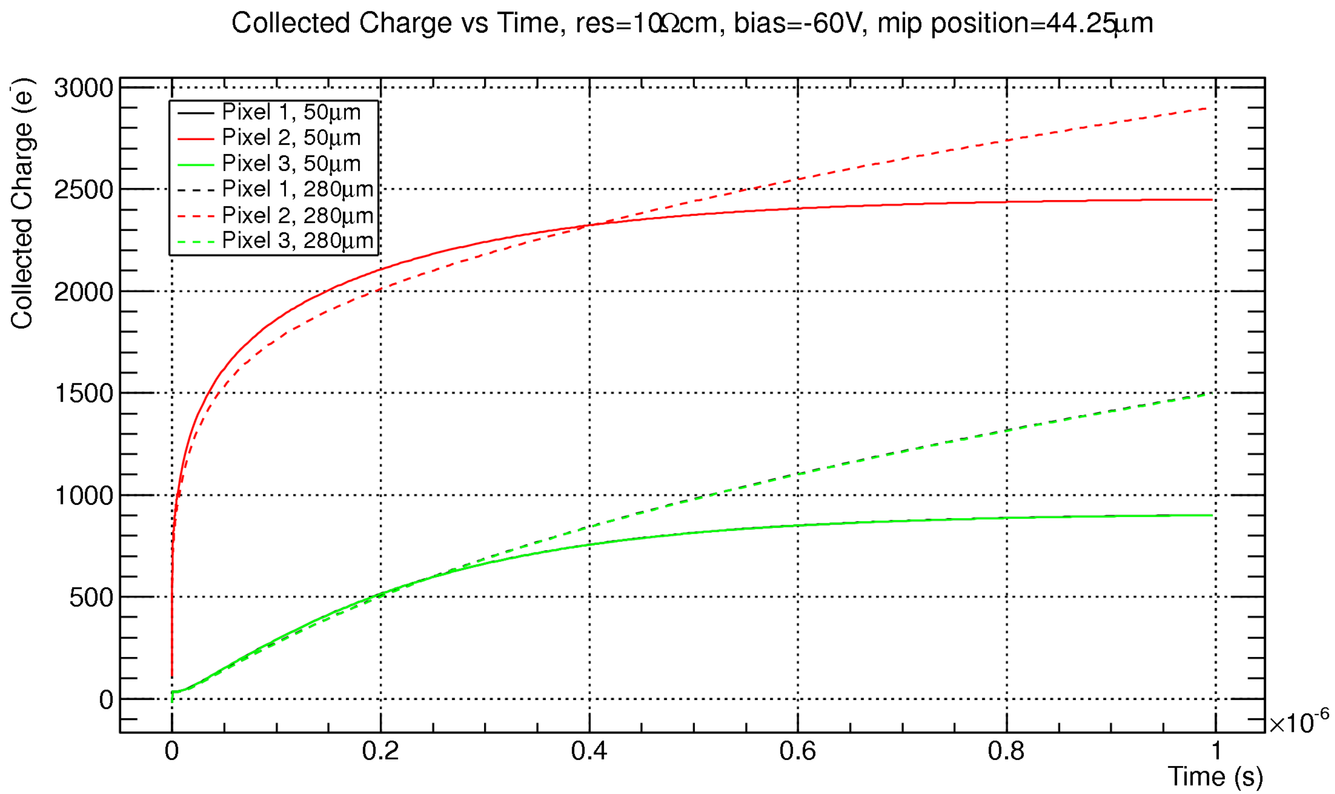






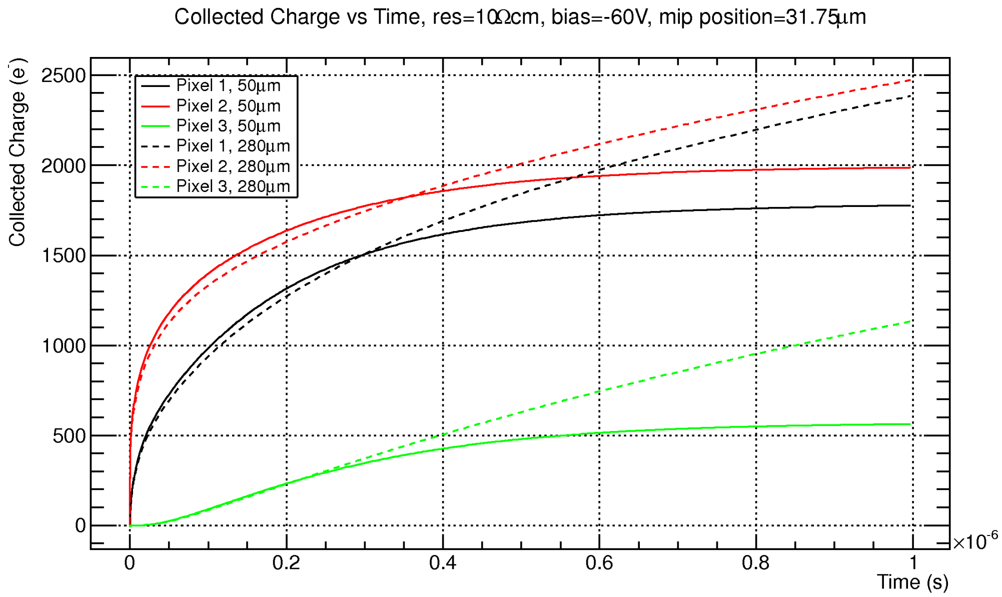
CC vs Time Comparison, Centre mip

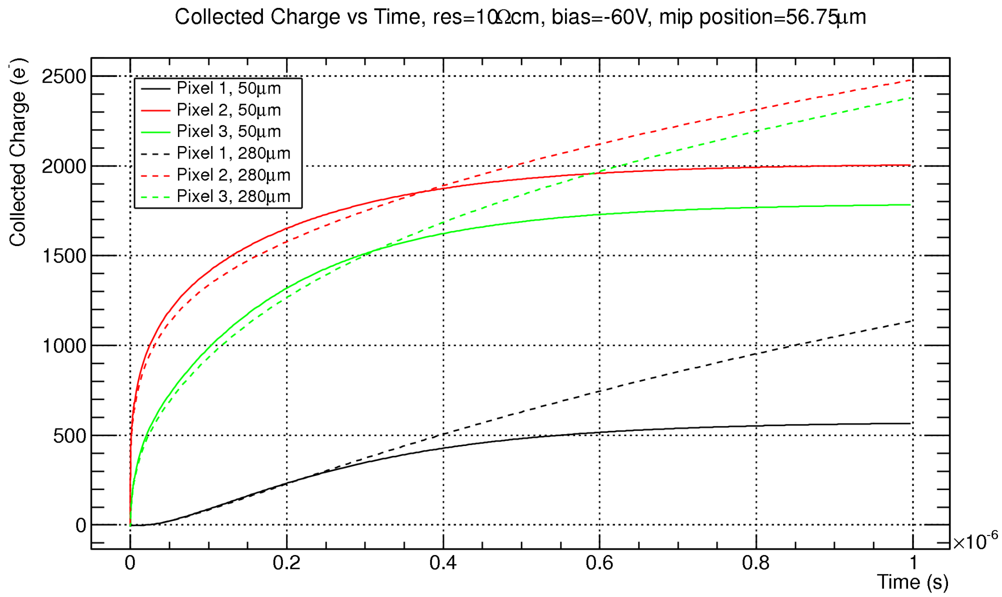
- Pixels 1 and 3 collect same charge at each thickness
- 280μm (dashed line) collects ≈ 500e$^-$ more than the 50μm (bold line) sensor, after 1μs
- The 50μm plateaus as all the charge has been collected
- While 280μm still has diffusion



CC vs Time Comparison, Side mips

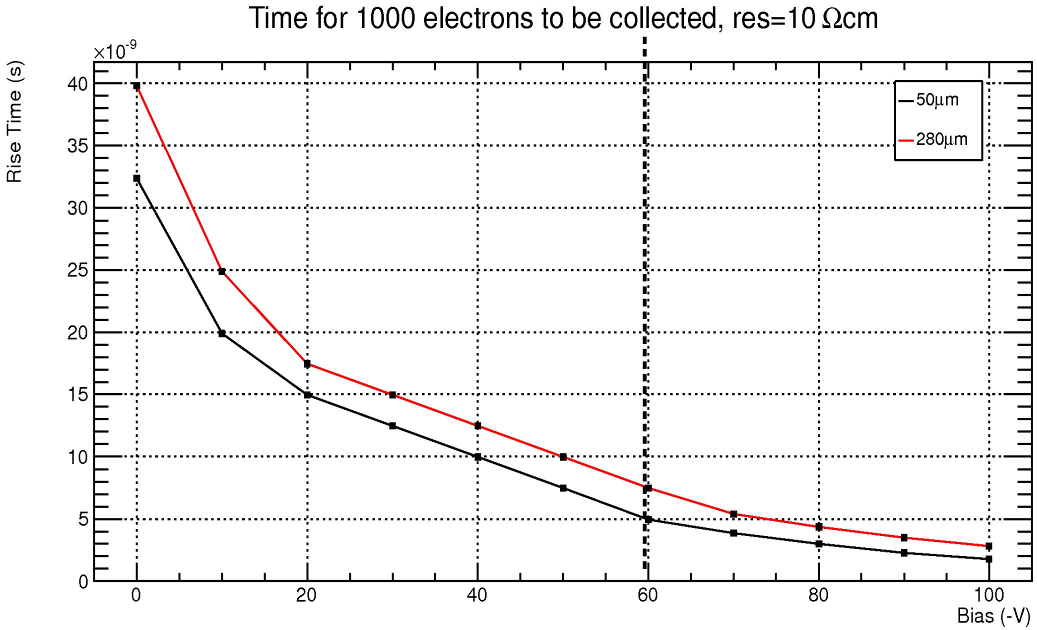
- For two side positions the two adjacent pixels collect the most charge, significant charge sharing
- Furthest pixel away from the mip collects all its charge due to diffusion, very slow rise
- In all cases 280µm sensor curve is still rising

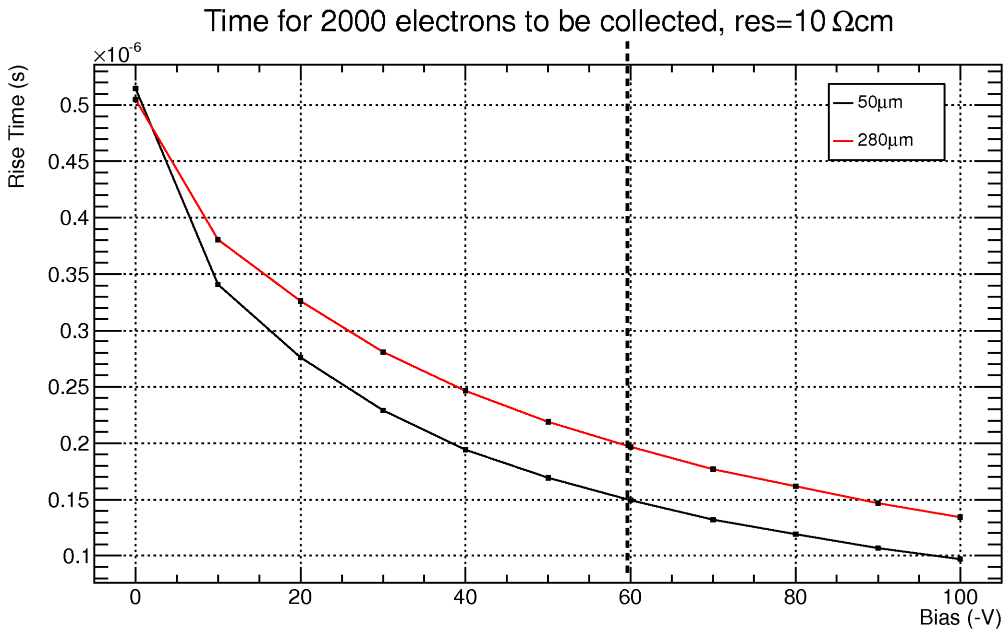




Collection Time, Centre mip, Pixel 2

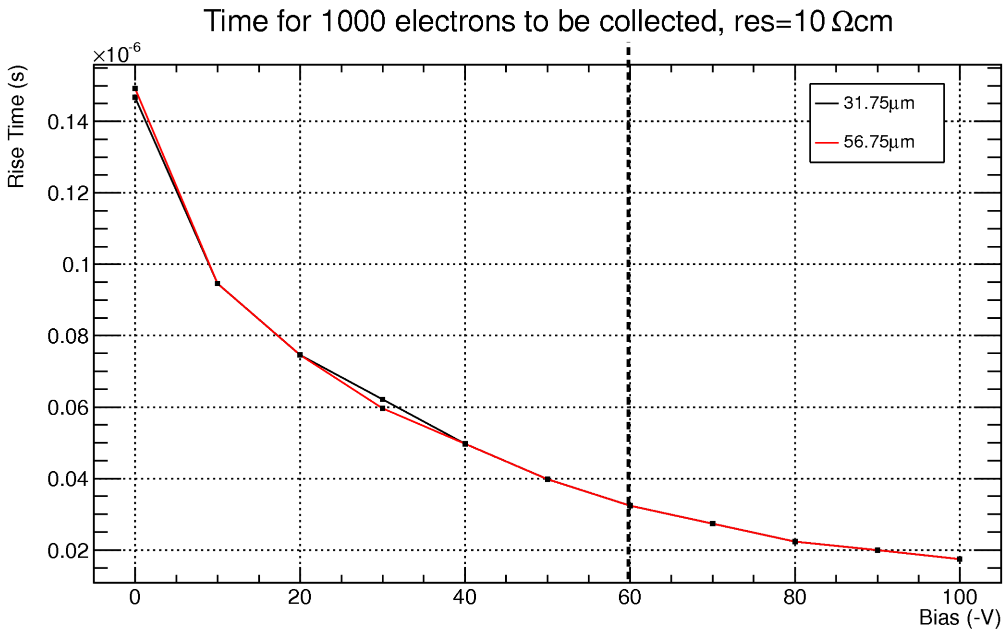
- Higher the bias the faster the CC
- Takes more than 10 times longer to collect double the charge
- 50μm thick sensor collects charge faster, encouraging for the future sensor
- Only a small difference of around 1.2 times in both cases
- Difference decrease slightly with bias in both cases, except for 0V and -10V in the 2000e$^-$ case



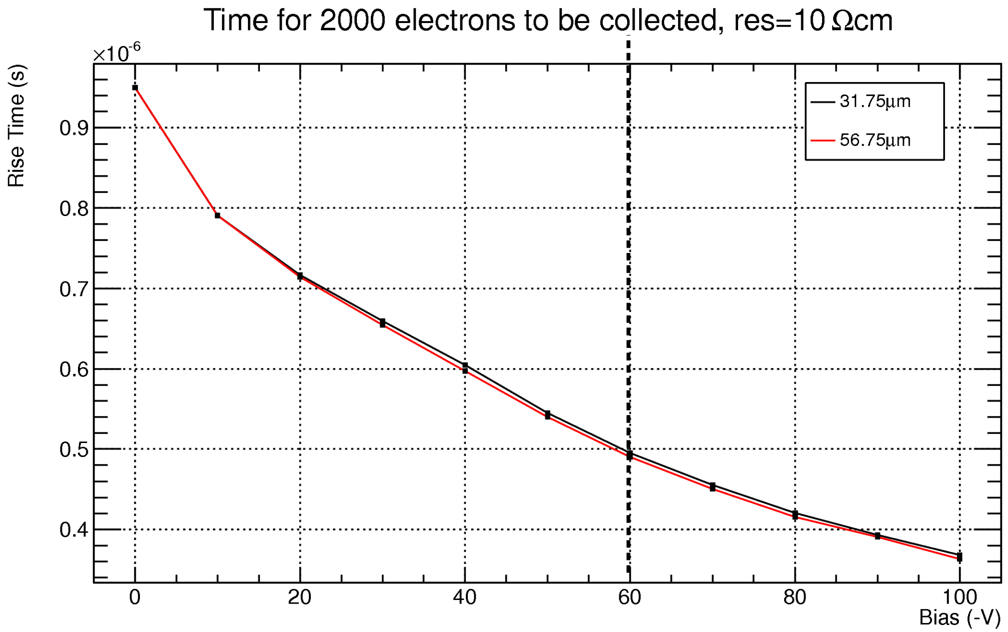


Collection Time, Side mip, Pixel 2

- Thickness 280μm
- Very symmetric
- Around 4 times slower than centre mip collection time



- Very slow for 2000e-



Summary

- Electric fields differ slightly between two thicknesses outside the depletion region but is at a low value
- Electric field depth and depletion depth increase with resistivity, as expected
- 280μm collects more charge after 1μs
- 50μm collects charge faster, although only a small difference
- Slow charge collection under p-implant could be solved by higher resistivity material without higher bias
- Overall there is little difference between the two thicknesses

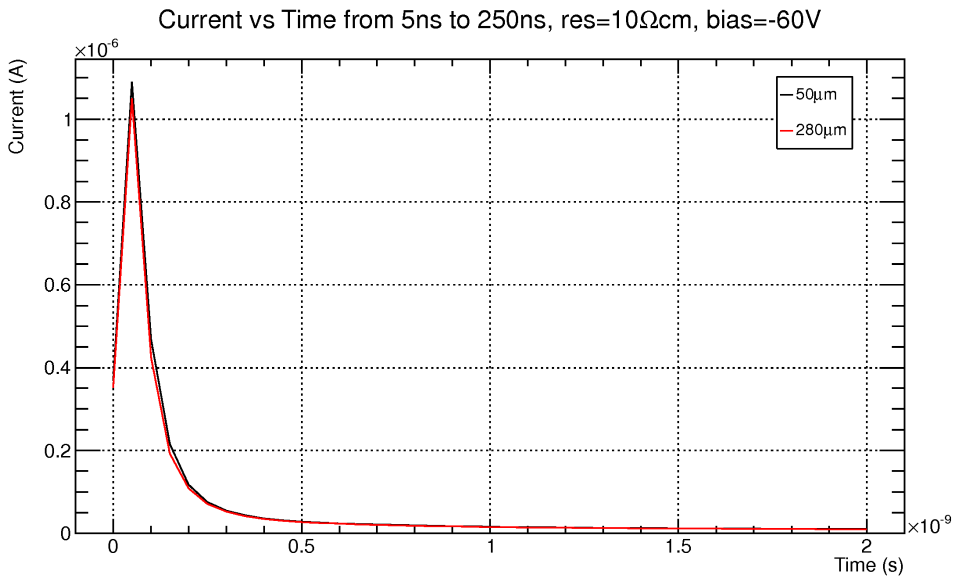
Future Plans

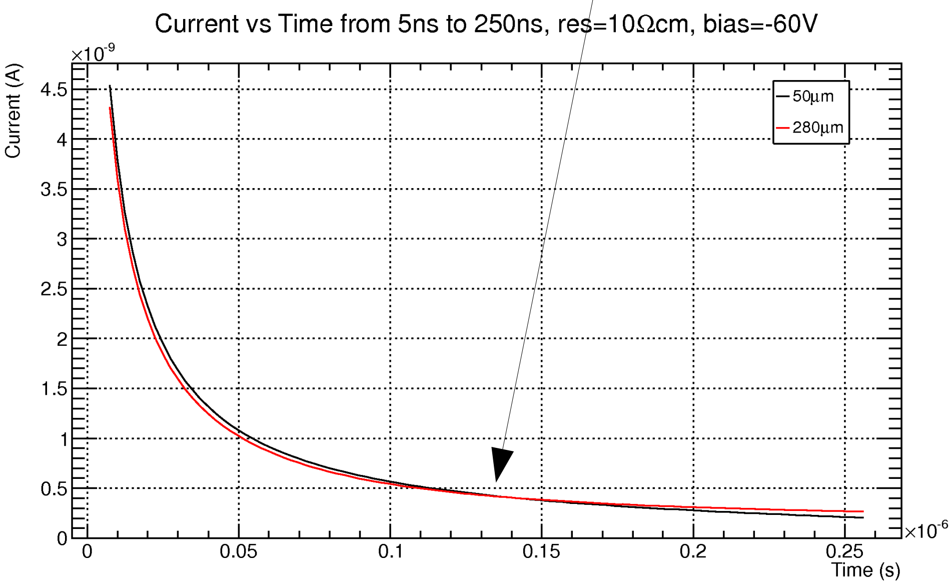
- Produce a more detailed simulation of the CCPDv3
  - Include PMOS and NMOS structure
  - Replicate the AMS 0.18μm design
- Compare to test beam and lab results by interfacing transient charge output with:
  - Simulation of CCPDv3 amplifier response
  - Coupling capacitance
  - CLICPix response

Backup

Pulse Shape, Thickness Comparison

- Readout from pixel 2
- 50μm has a slightly higher peak and remains larger until ≈ 0.13μs
- Suggest 50μm collects more to drift and the 280μm collects more to diffusion
- Could be due to small difference in E-field around 10μm





CC vs Bias, Pixel 2

- Mip enters at 0s and the CC is extracted after 1μs
- 280μm is very symmetric results, unlike 50μm thickness
- 280μm collects more charge