Simulation of small pixel LGAD's, PixeLGADs

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Outline

- **Motivation for LGADS**
- **Production of LGAD’s**
- **Gain and Timing Performance**
- **Small Pixel Effect**
- **Timepix3 LGAD’s**
- **Future Work**
- **Summary**

Motivation

- Our aim is to be able to detect low energy x-rays in the region of 1 keV, sub-threshold detection
- Timepix3 has a noise level of roughly 2 keV
- In order to detect such a photon an internal gain of around 5-10 is needed.
- LGAD's have also been shown to have a timing resolution of the order of 20ps.
- Segmenting LGAD's provides high spatial and timing resolution required for the ATLAS experiment.
- The LHCb experiment is also interested in using highly segmented LGAD sensors for the VELOpix chip, based on the Timepix3 chip.
- Hence the study and fabrication of LGAD's is very interesting to us.

Recent Production of LGAD's

Pixel Size:

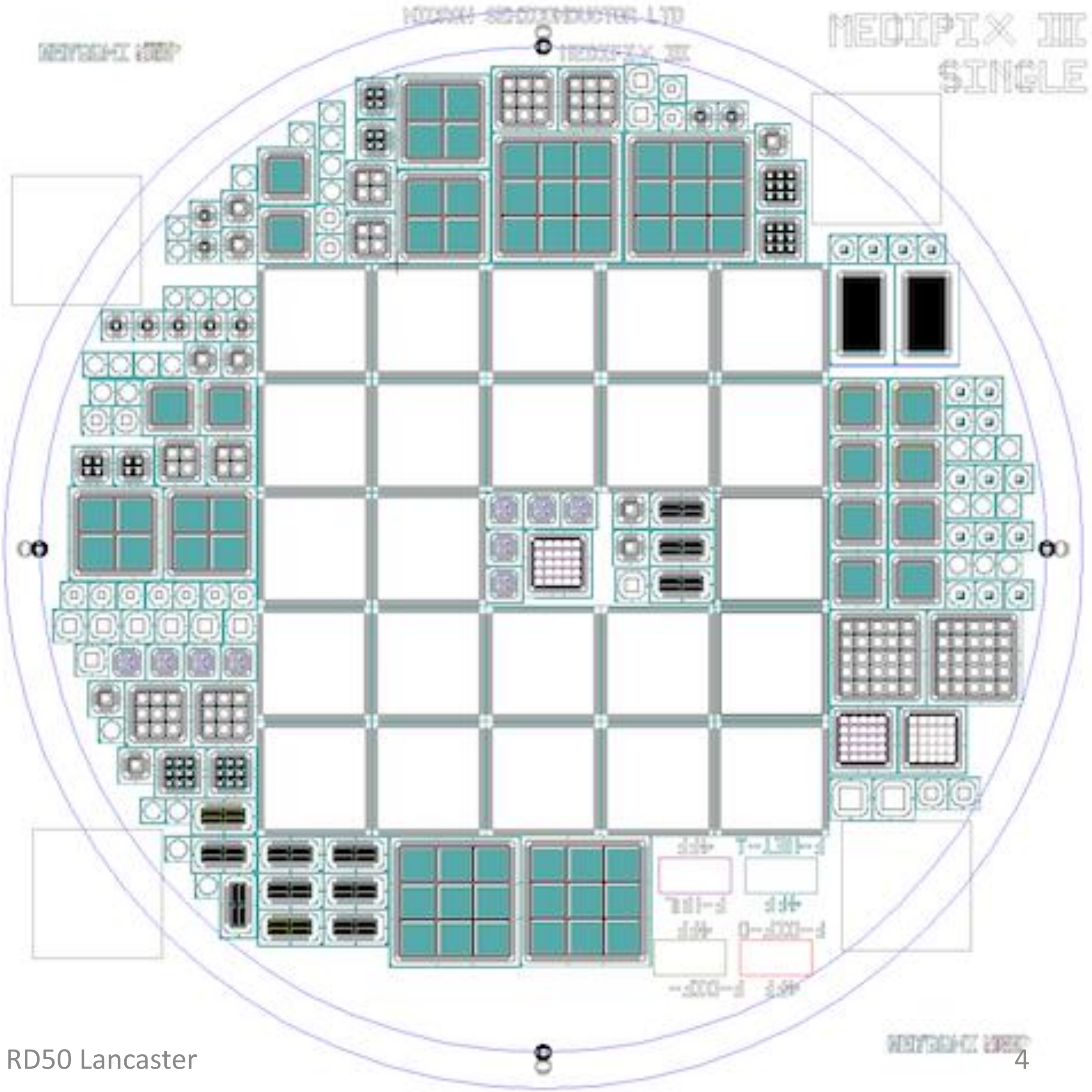
- 0.22mm
- 0.5mm
- 1mm
- 1.3mm
- 2mm
- 5mm

Arrays:

- 1x1
- 2x2
- 3x3
- 5x5

Medipix Arrays:

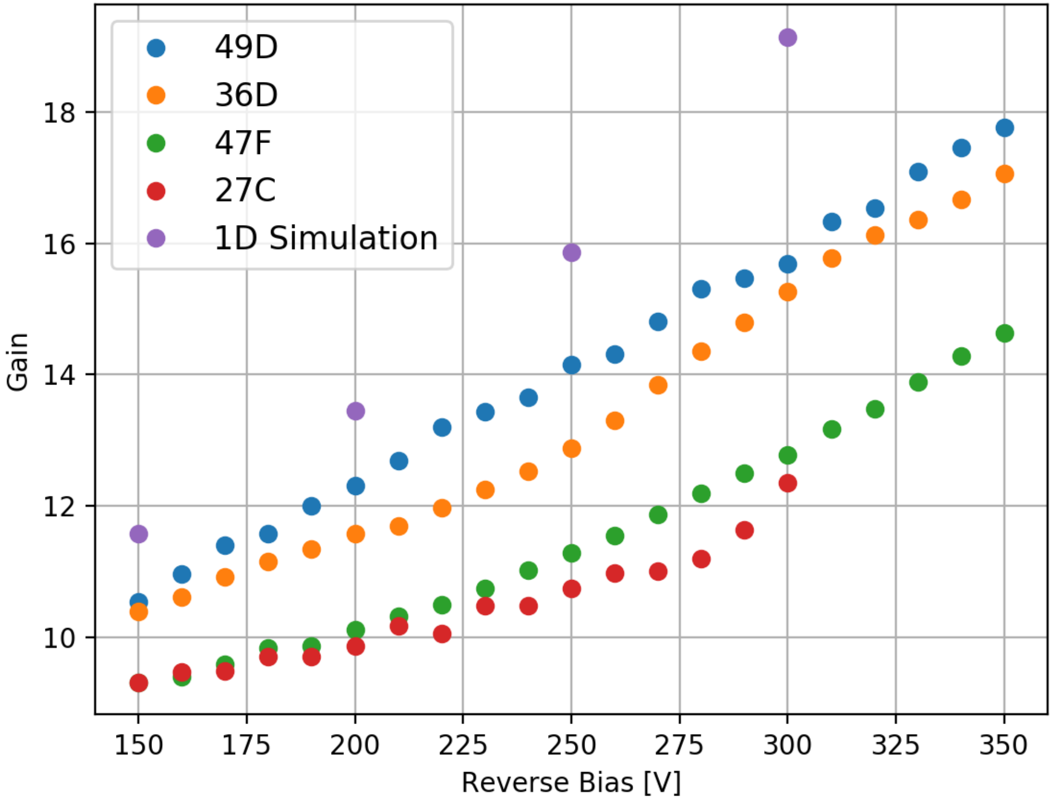
- Pixel pitch 55um
- Pixel pitch 110um
- Pixel pitch 220um.



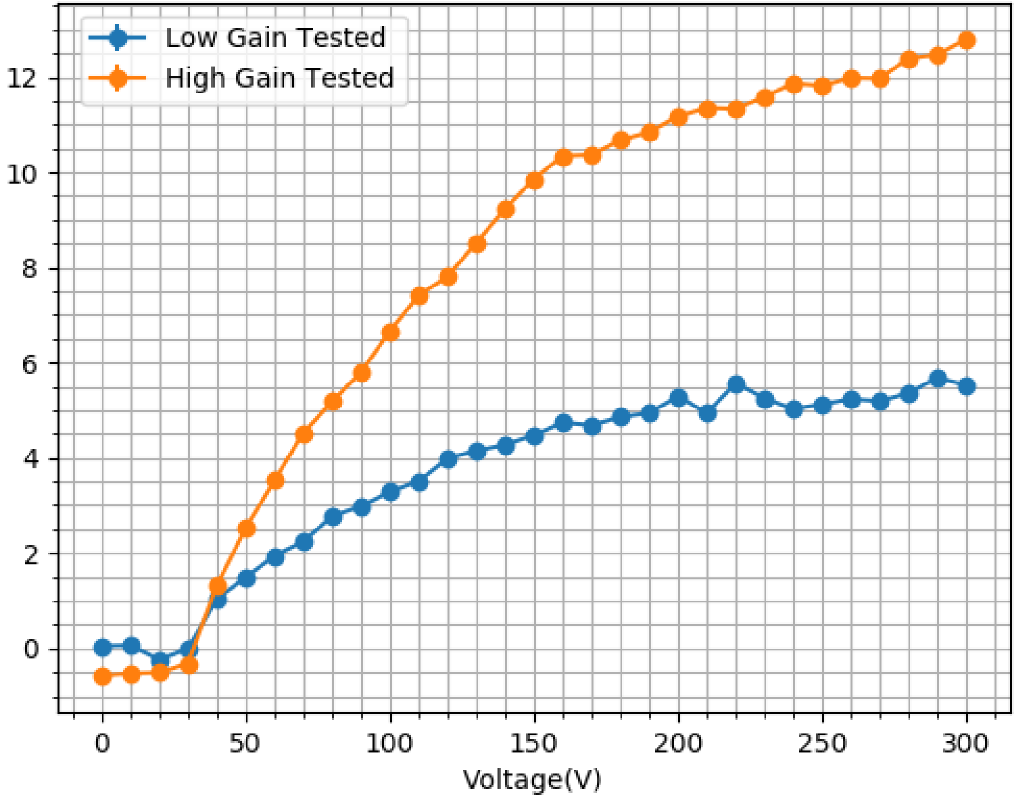
Wafers Fabricated:

- Low, Medium and High Multiplication implant doses
- 12 ,250um wafers.
- 3 have been thinned to 50um

Gain Measurements

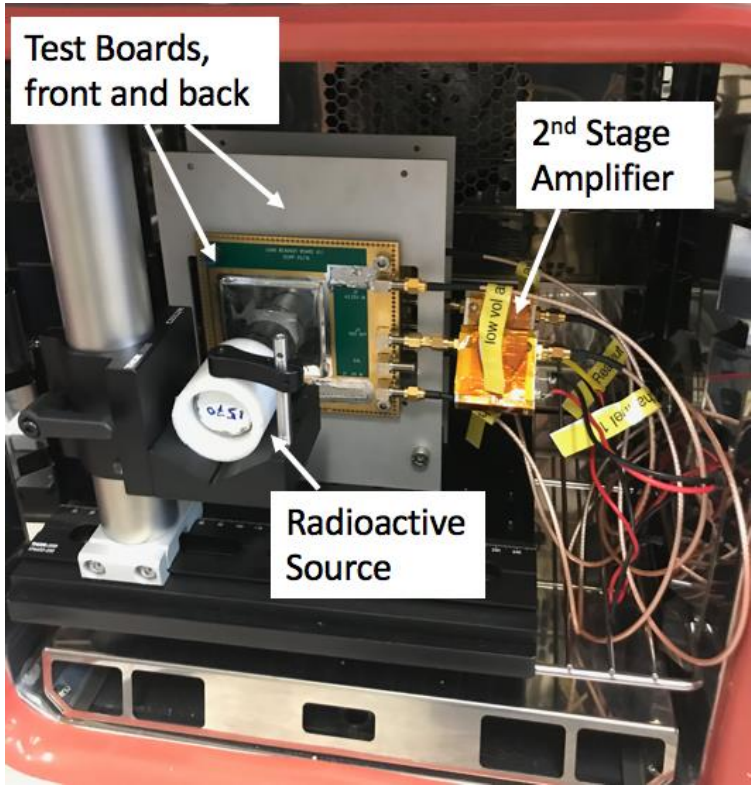


- Low and high dose have significant impact on gain of 5mm pads.
- Process control to vary gain where necessary



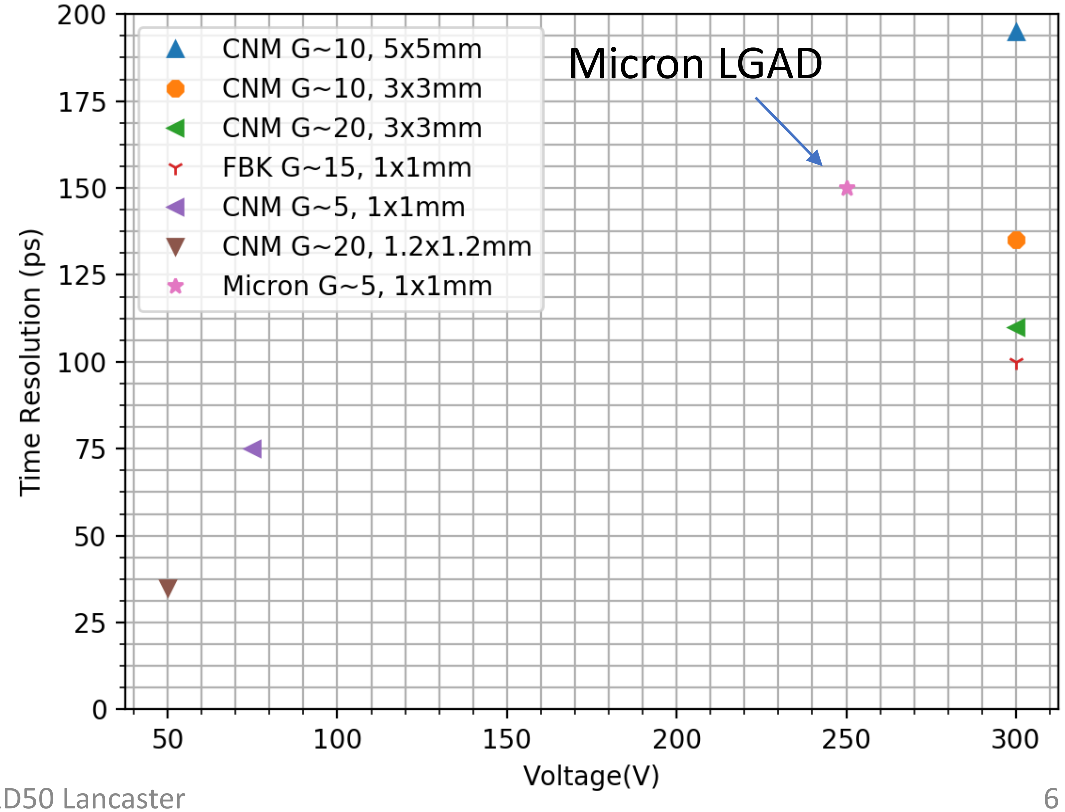
- 5mm Pads with high multiplication dose
- Similar performance across the wafer
- Good agreement with the Simulation

Timing Performance



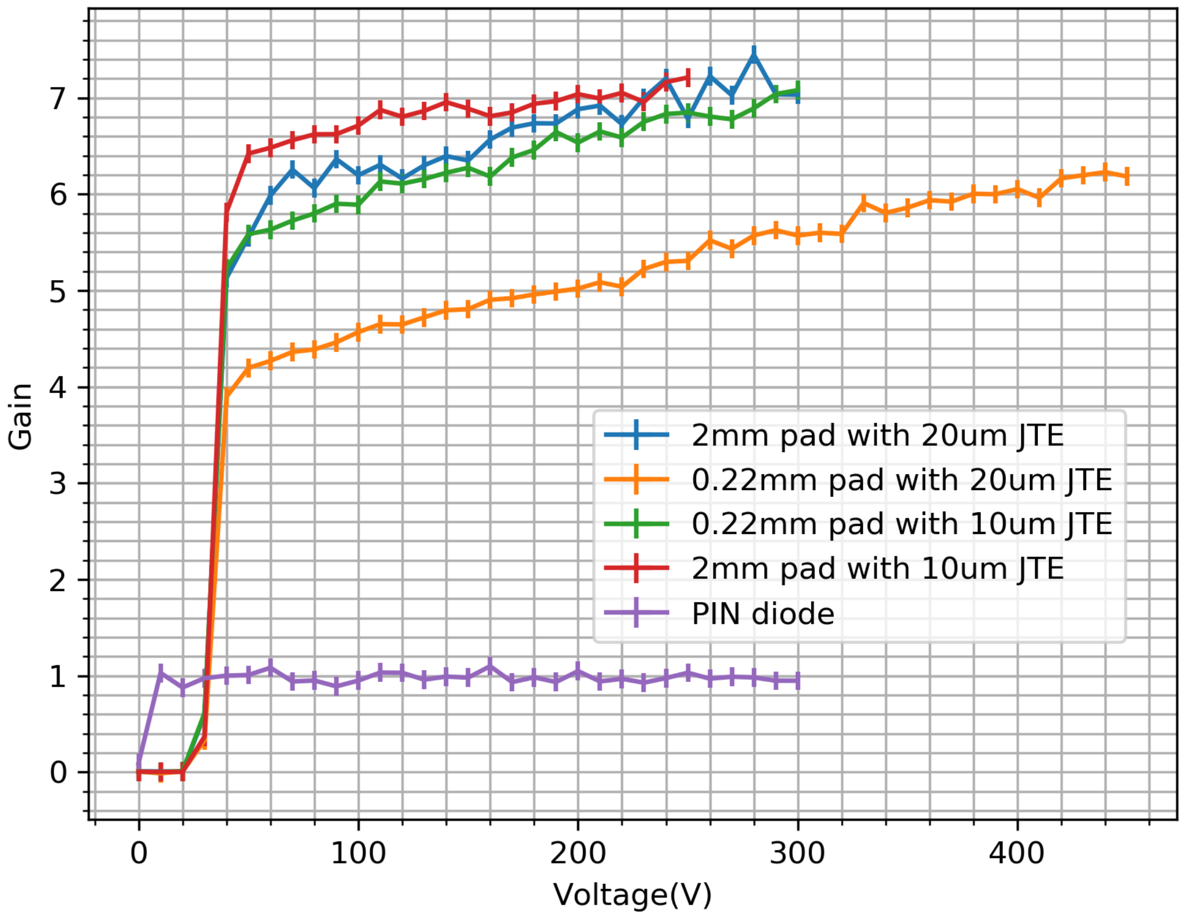
- Timing set-up of two LGAD's in series.
- Coincident measurements from Sr90 source
- Timing resolution given as the sigma of the spread of the time difference between detector hits.

- Micron sensor has a timing resolution of 150ps.
- This fits in the results obtain for similar devices from FBK and CNM.
- Time resolution limited by jitter contribution.
- No variation seen with change in voltage/gain.



Small Pixel Effect

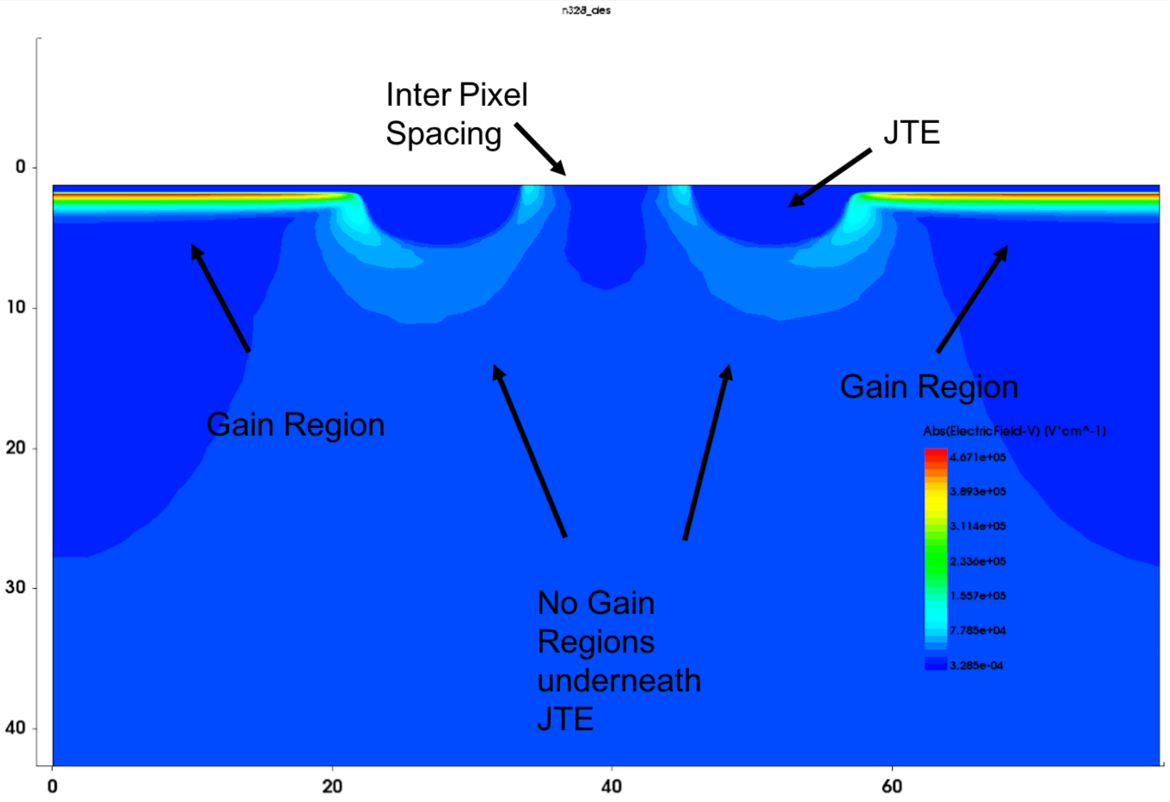
- First seen in fabricated devices.
- As the pixel size reduced below 2mm, the gain was effected.
- All measurements performed using TCT with the laser focused in the centre of the sensor.
- Gain was more greatly effect as the JTE size increased.
- Gain recovers at larger voltages for the 2mm pads.
- The 220um pads show significant loss of gain of the order of 20% reduction going from a 10um JTE to a 20um JTE.
- TCAD simulation was then performed to investigate gain loss mechanism.



Small Pixel Effect Studies

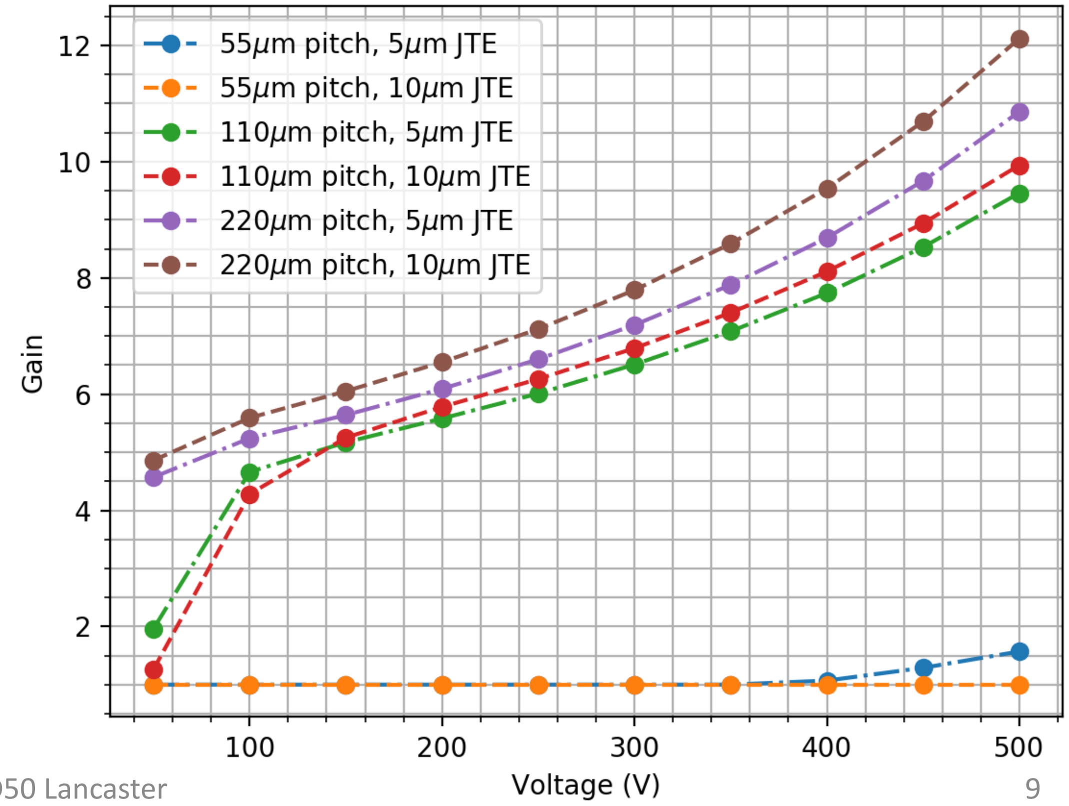
- What causes gain loss?
- How much does this effect gain for various pixel sizes?
- Can we recover the gain with increasing voltage?
- How does this play a role in effective fill factor?

Small Pixel Effect, Simulation

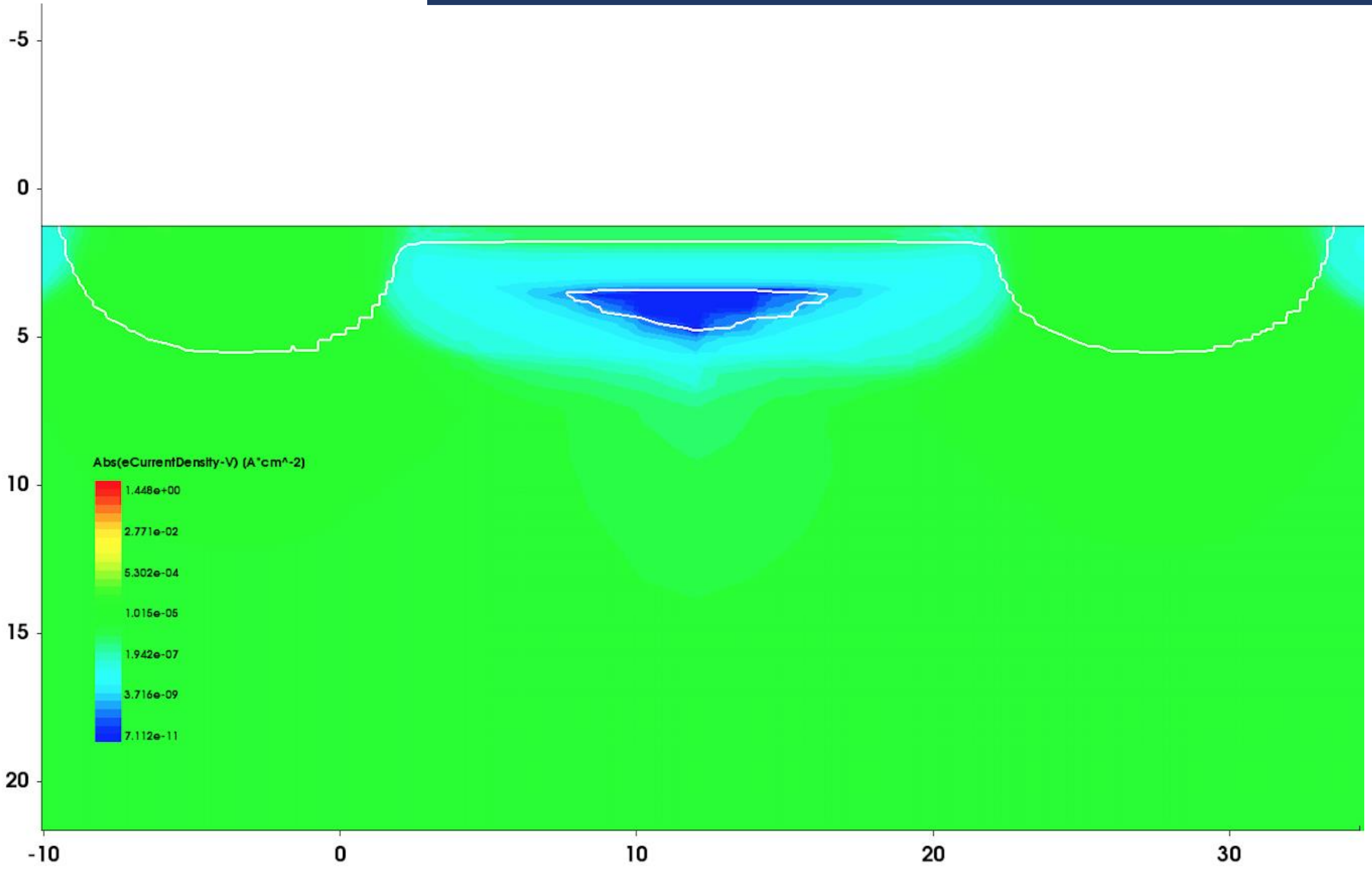


- JTE effects the size of the border region between pixels.
- Geometrically the gap between the multiplication region of one pixel and the adjacent pixel is 29um
- A sufficient gap between JTE's required for isolation as implants diffuse laterally throughout fabrication of 19um

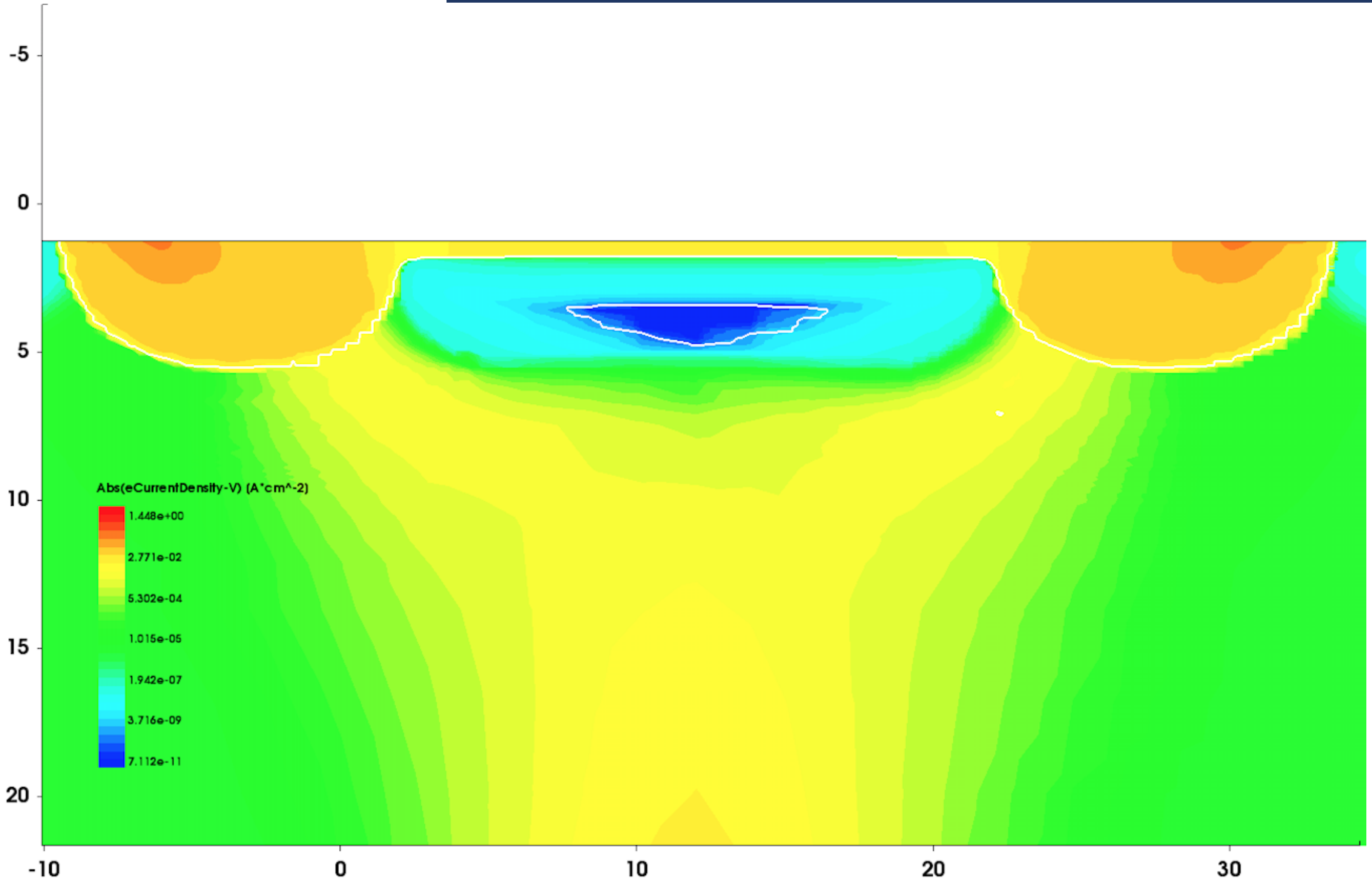
- Alpha type charge injection at backside of sensor in centre of pixel.
- At low voltages gain of 110um pixel is slightly reduced, but recovers at higher voltages.
- Only small gain seen for 55um pitch at 500V



Charge Collection, 0ps,55um



Charge Collection, 500ps



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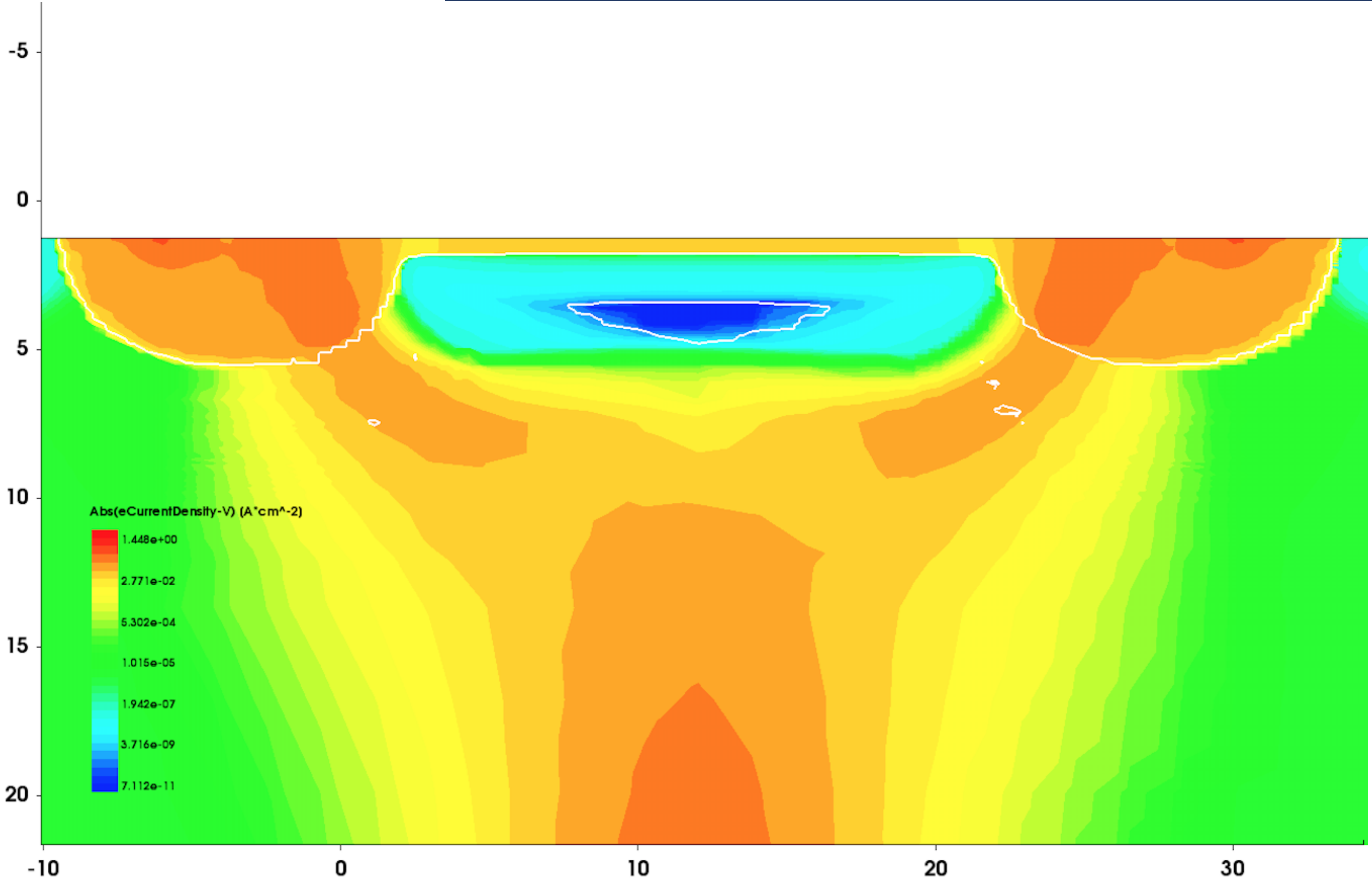
Charge Collection, 1000ps



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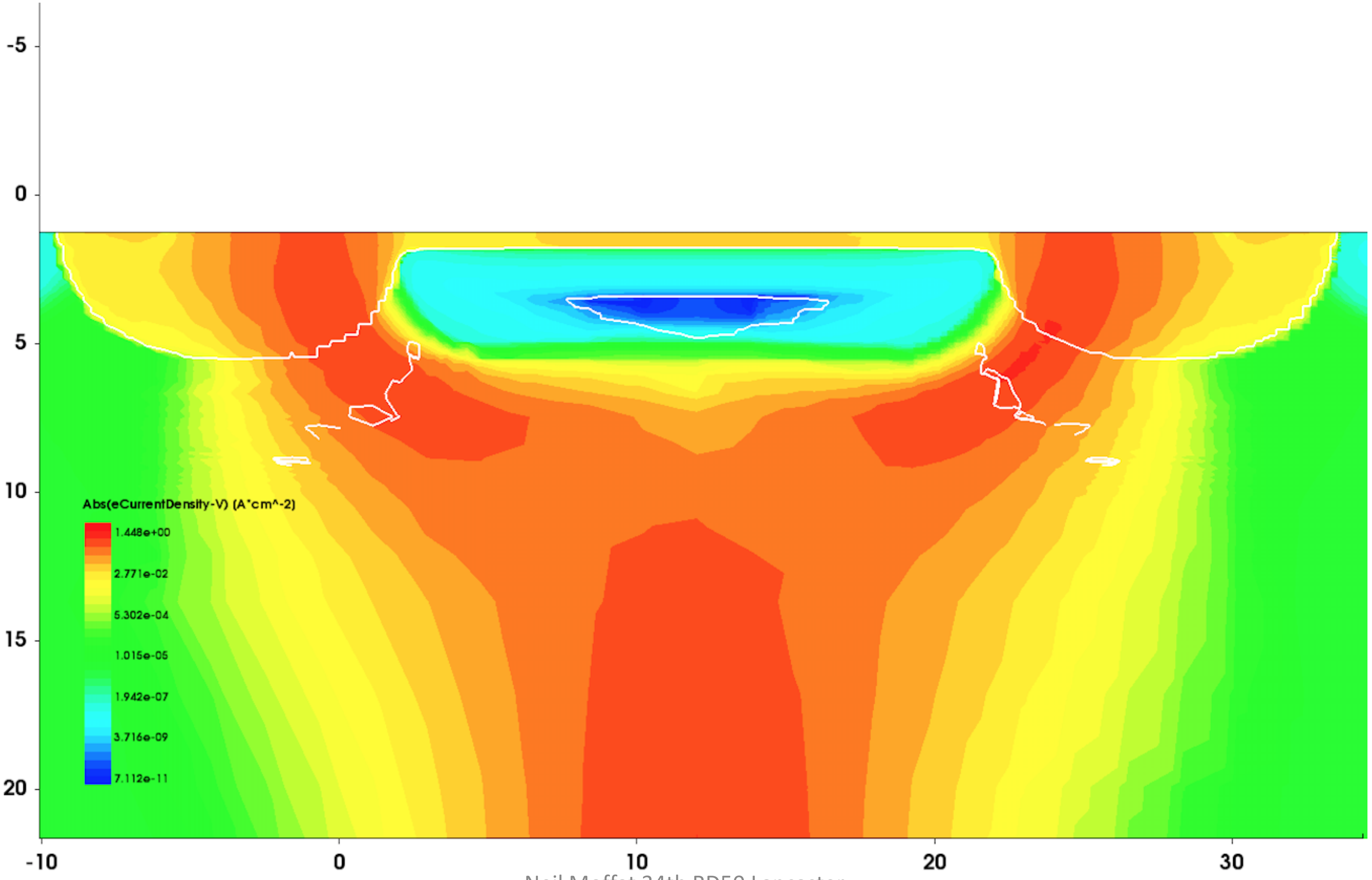
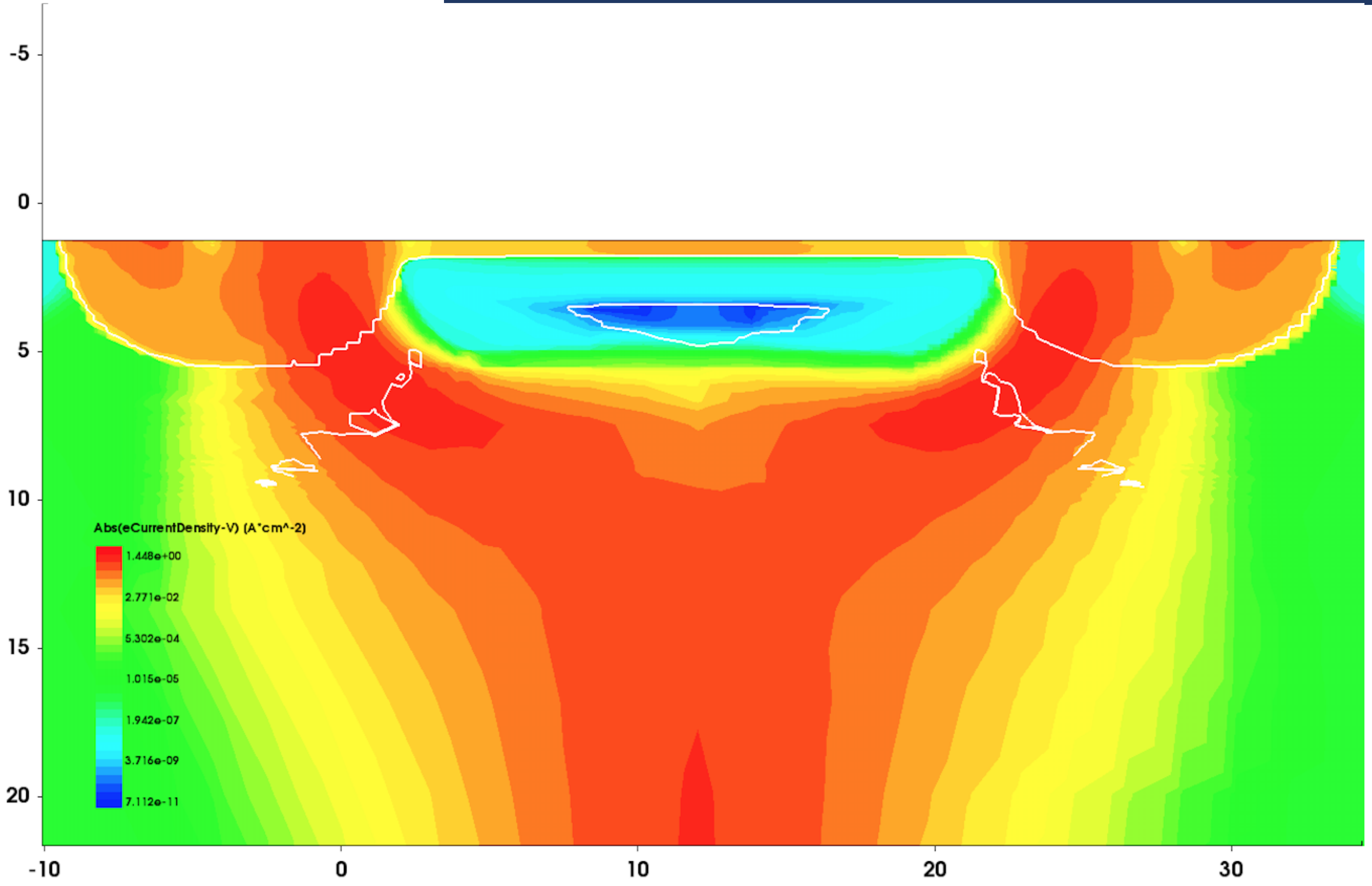
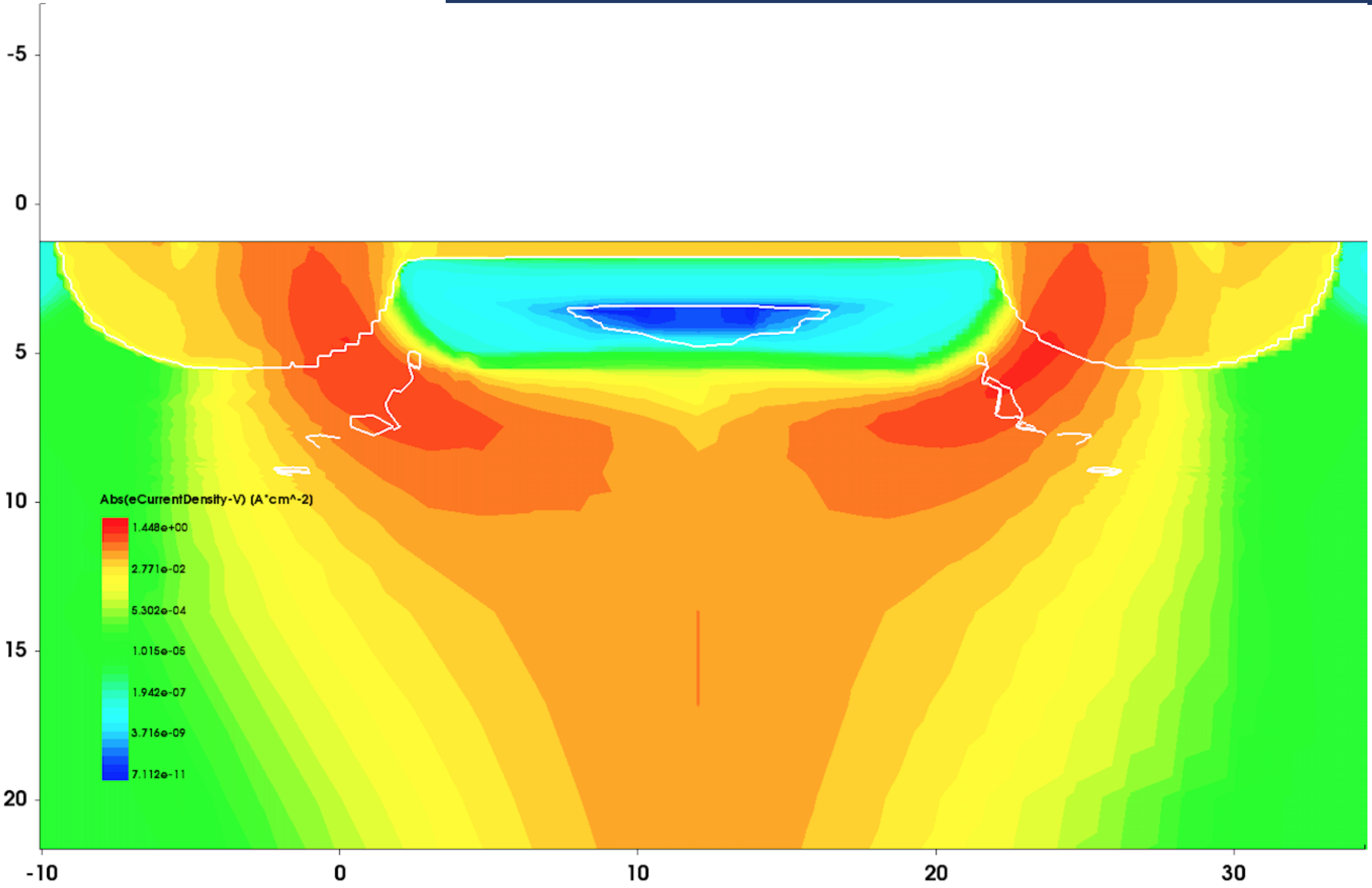
Charge Collection, 1500ps



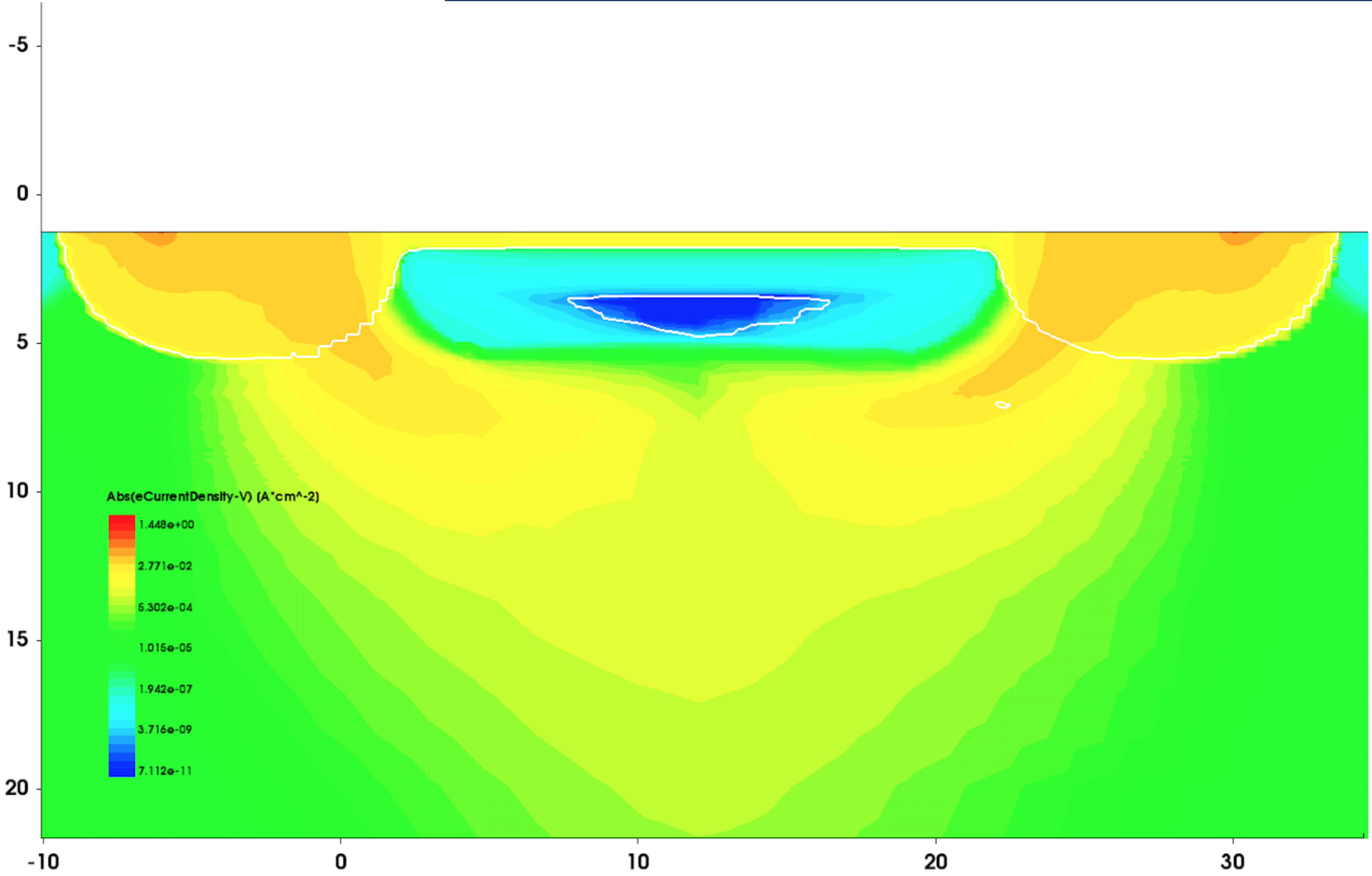
Charge Collection, 2000ps



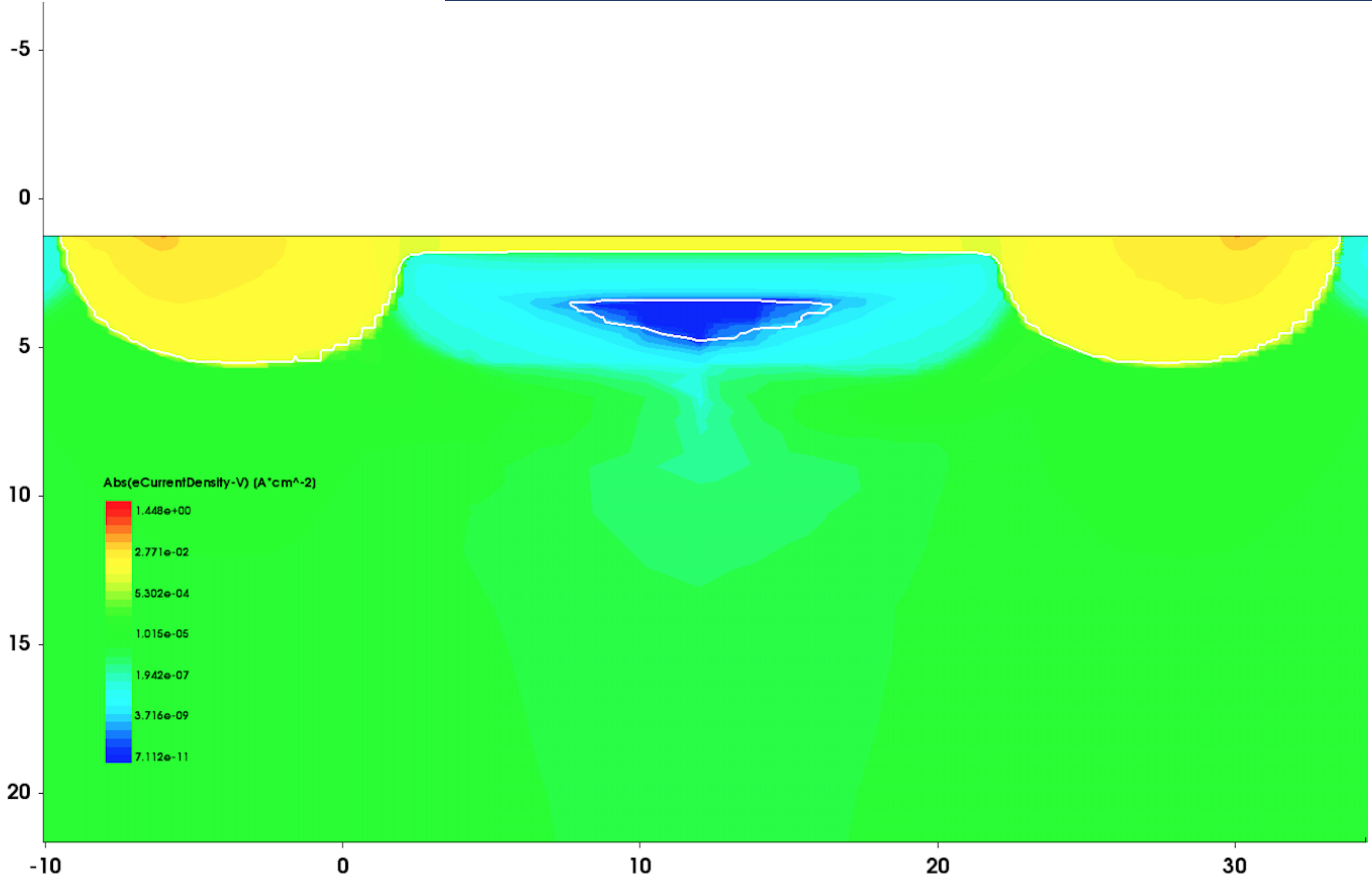
Charge Collection, 2500ps



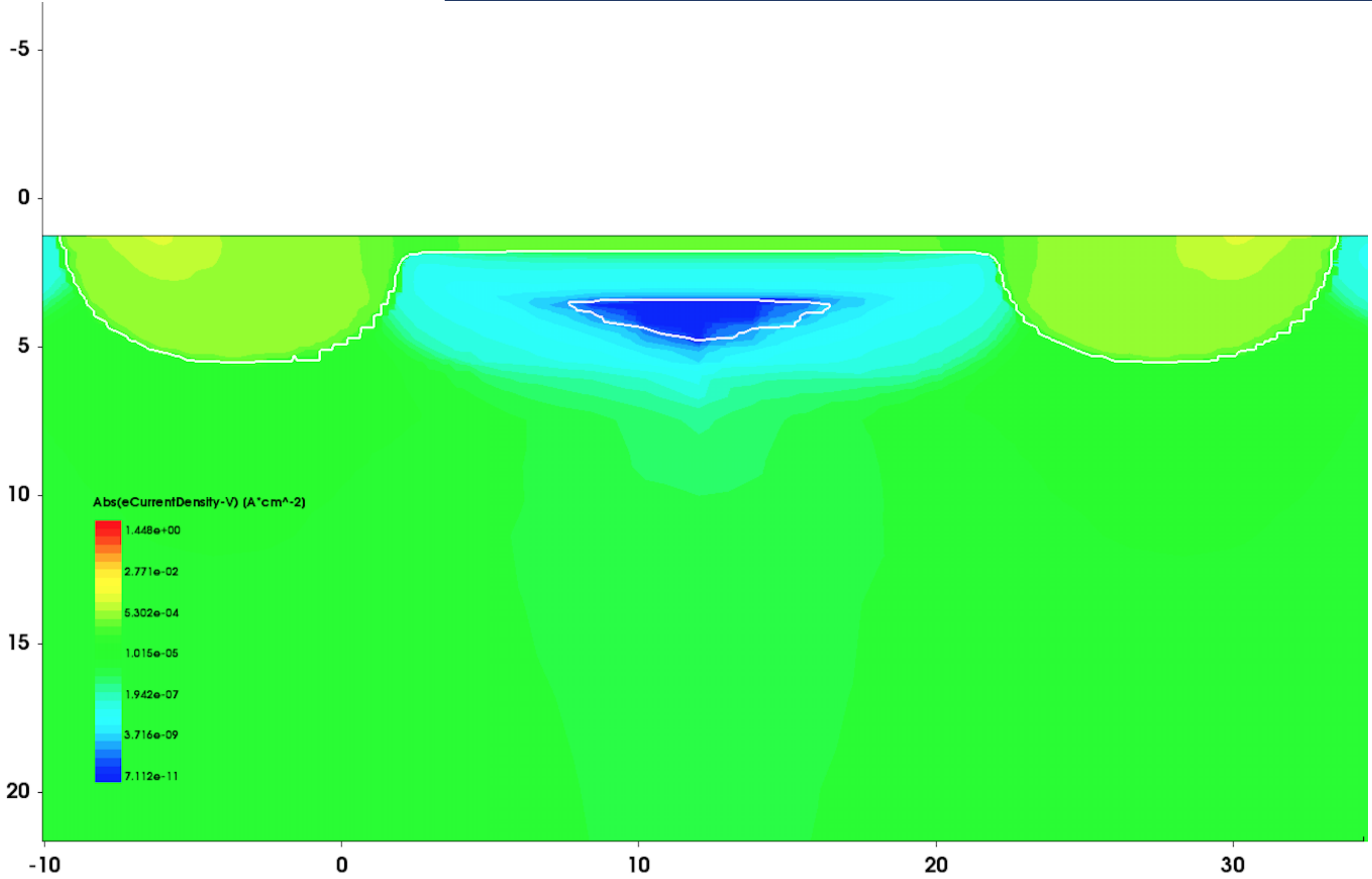
Charge Collection, 3000ps



Charge Collection, 3500ps



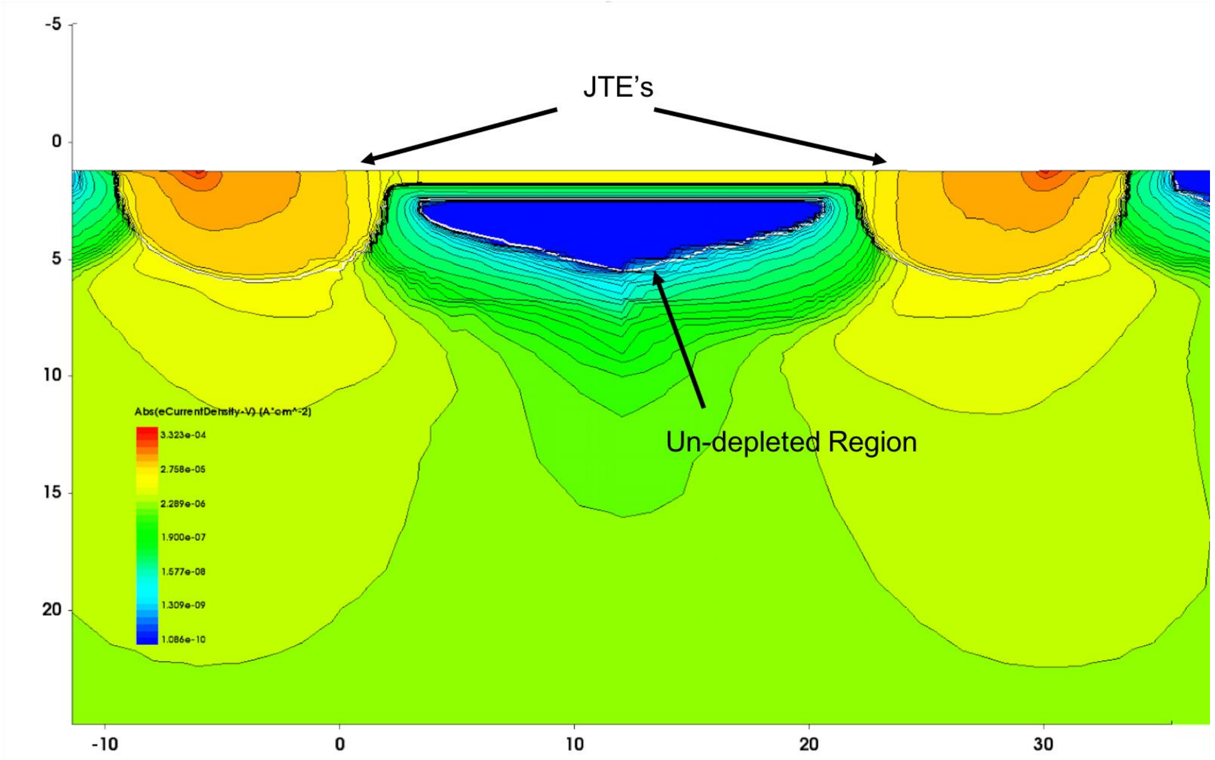
Charge Collection, 4000ps



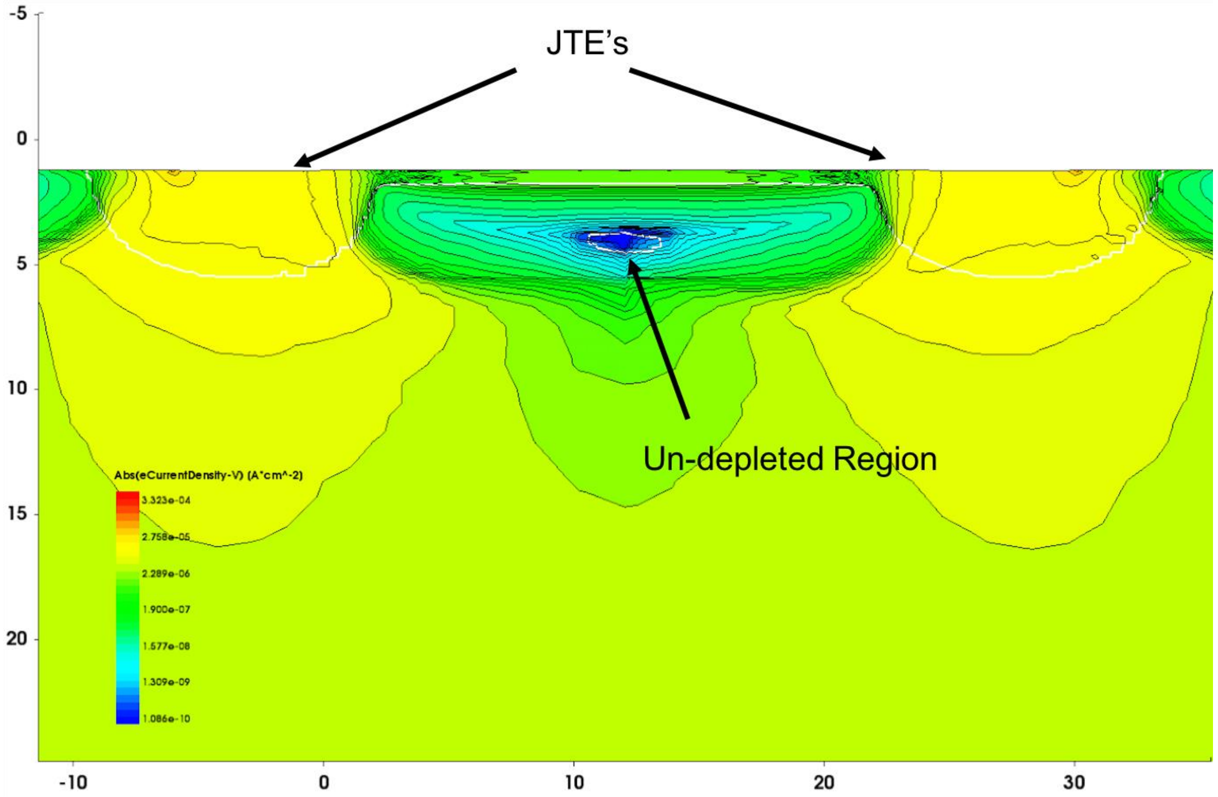
Charge Collection Mechanism

- Charge collected via the Junction Termination Extensions
- Electrons drift towards collecting electrode.
- There is a shielding effect on the high field region by undepleted region.

- This is caused by the close proximity of the JTE's to one another.
- Electrons never travel through high field region.
- Undepleted region shrinks with increasing voltage.



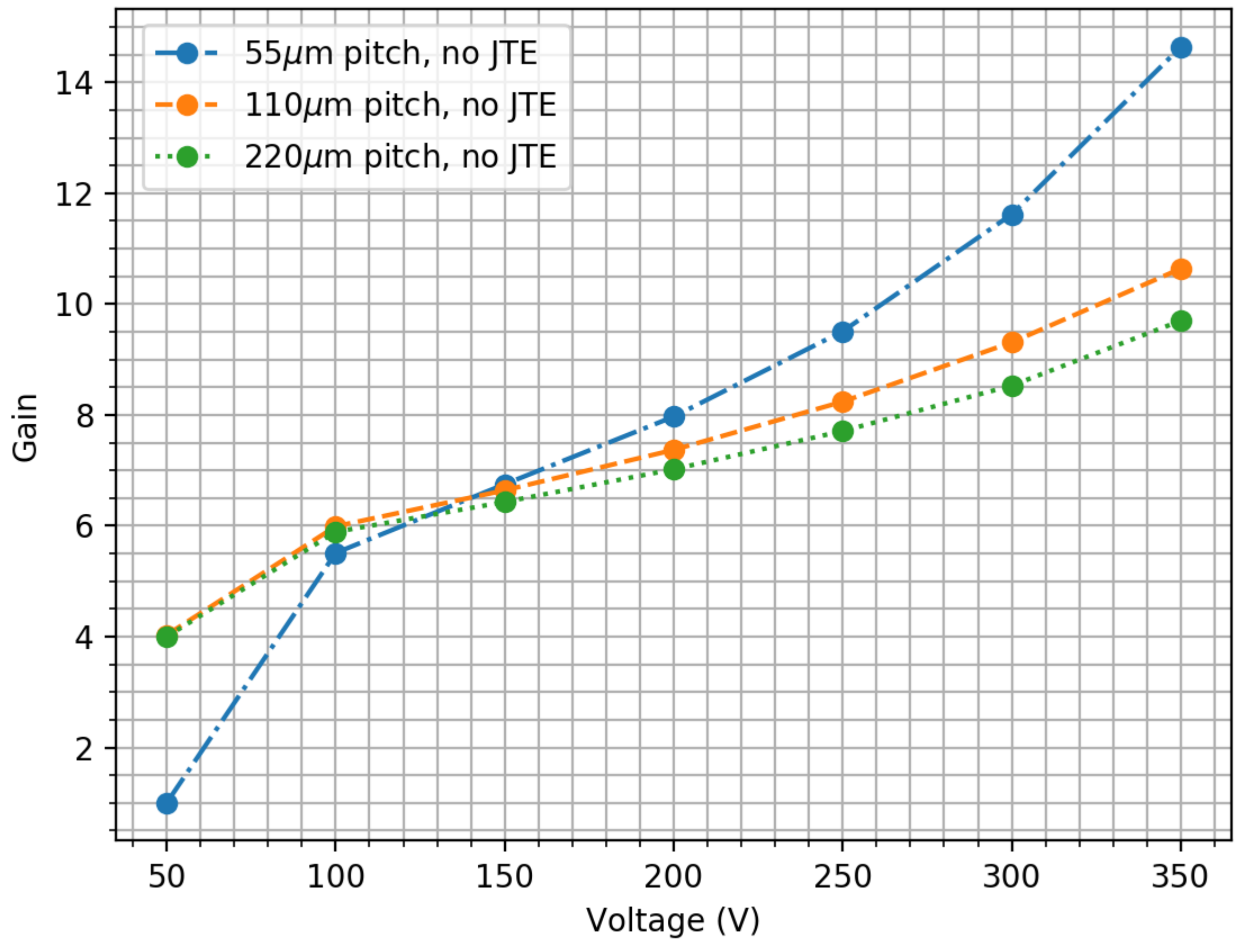
50V Bias Applied.



350V Bias Applied.

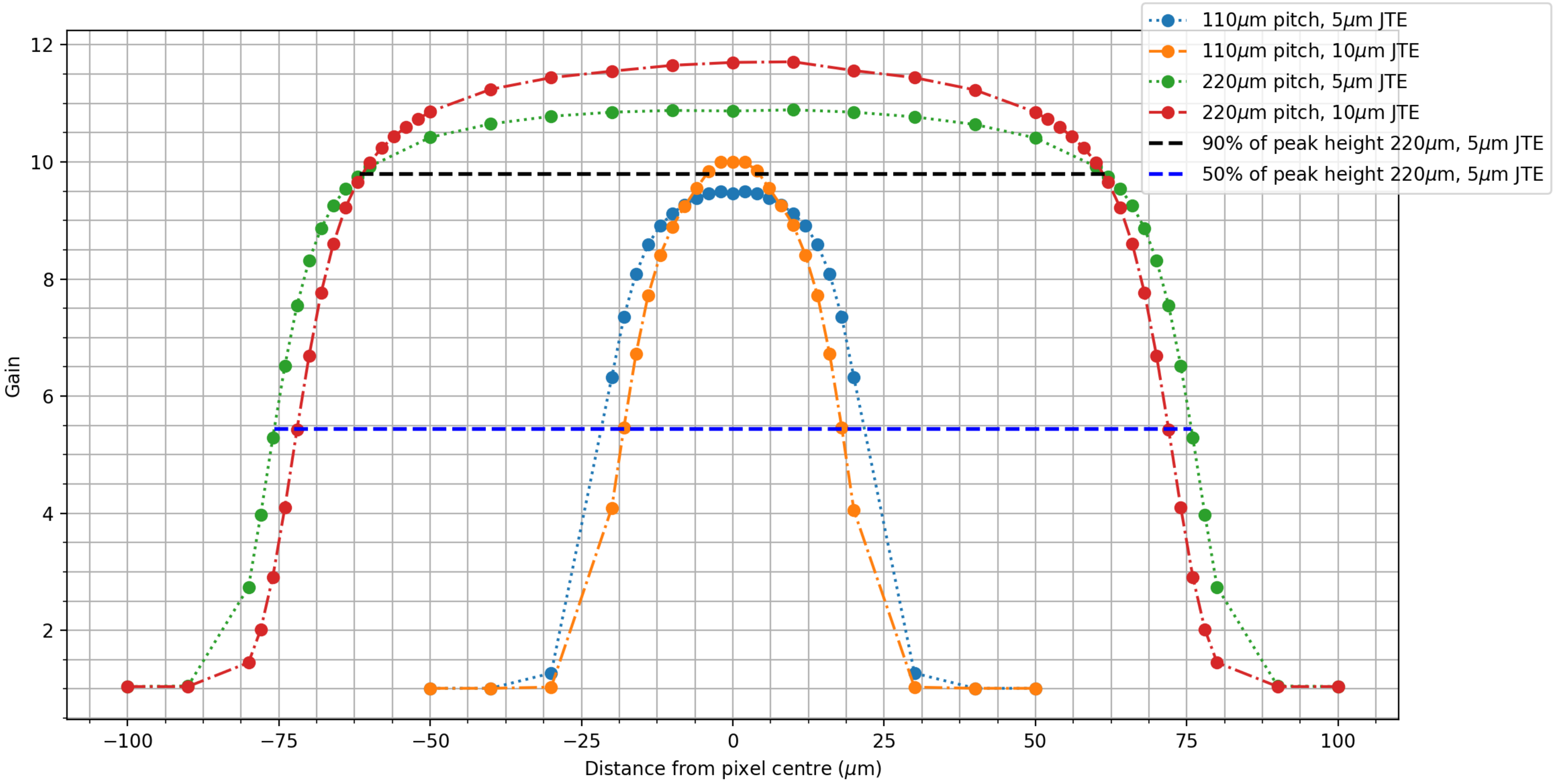
Removal of JTE

- Removing JTE shows dramatic increase in Gain shown for 55um pixels.
- All pixels show gain of expected values above 100V.
- Smaller pixels show reasonable breakdown voltage but still reduced compared with devices with JTE.
- These simulations were an ideal case of the particle interaction underneath the centre of the pixel.



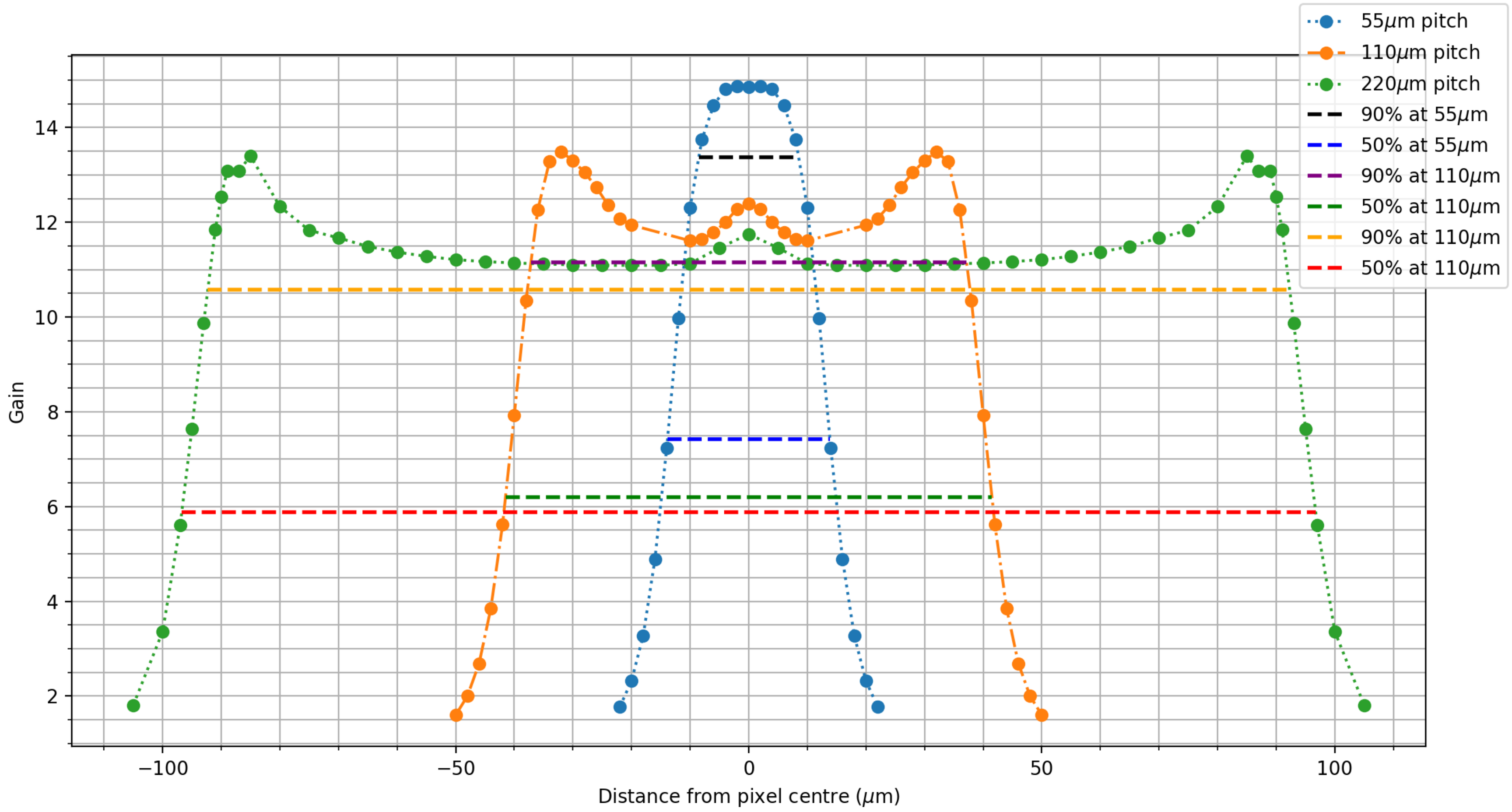
Effective Fill Factor with JTE

- 55um pixels show a fill factor of 0% with JTE's of all widths.
- 110um, Fill factor of 6.8% and 2.9% at 90% of peak height for JTE widths of 5um and 10um..
- 220um, Fill Factor of 31.3% and 24.8% at 90% peak height for JTE widths of 5um and 10um



Effective Fill Factor no JTE

- 55um, Fill factor of 9.5% and 28.2% at 90% and 50% peak height
- 110um, Fill Factor of 60.6% and 75.1% at 90% and 50% peak height.
- 220um, Fill Factor of 78.4% and 88.7% at 90% and 50% peak height.



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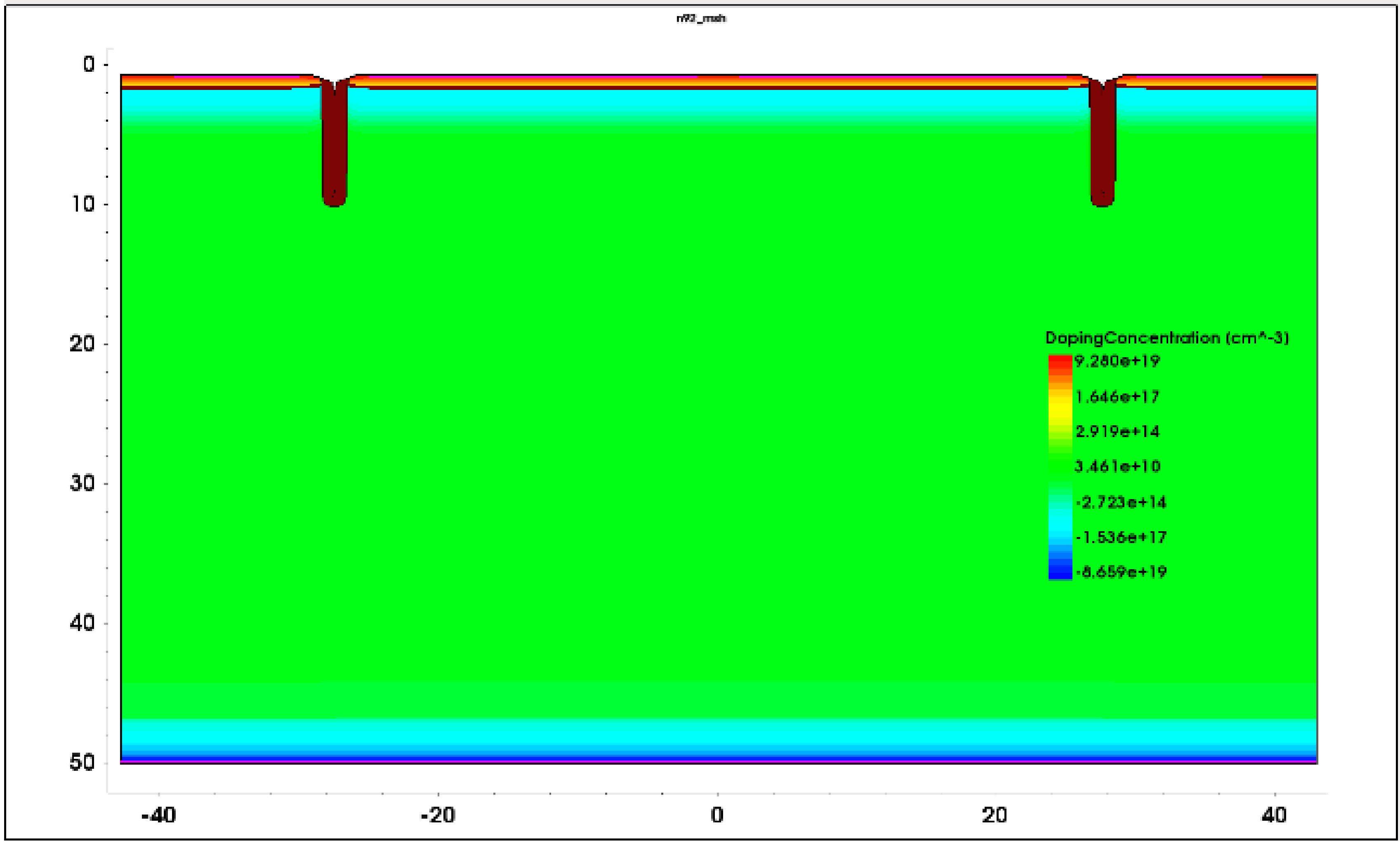
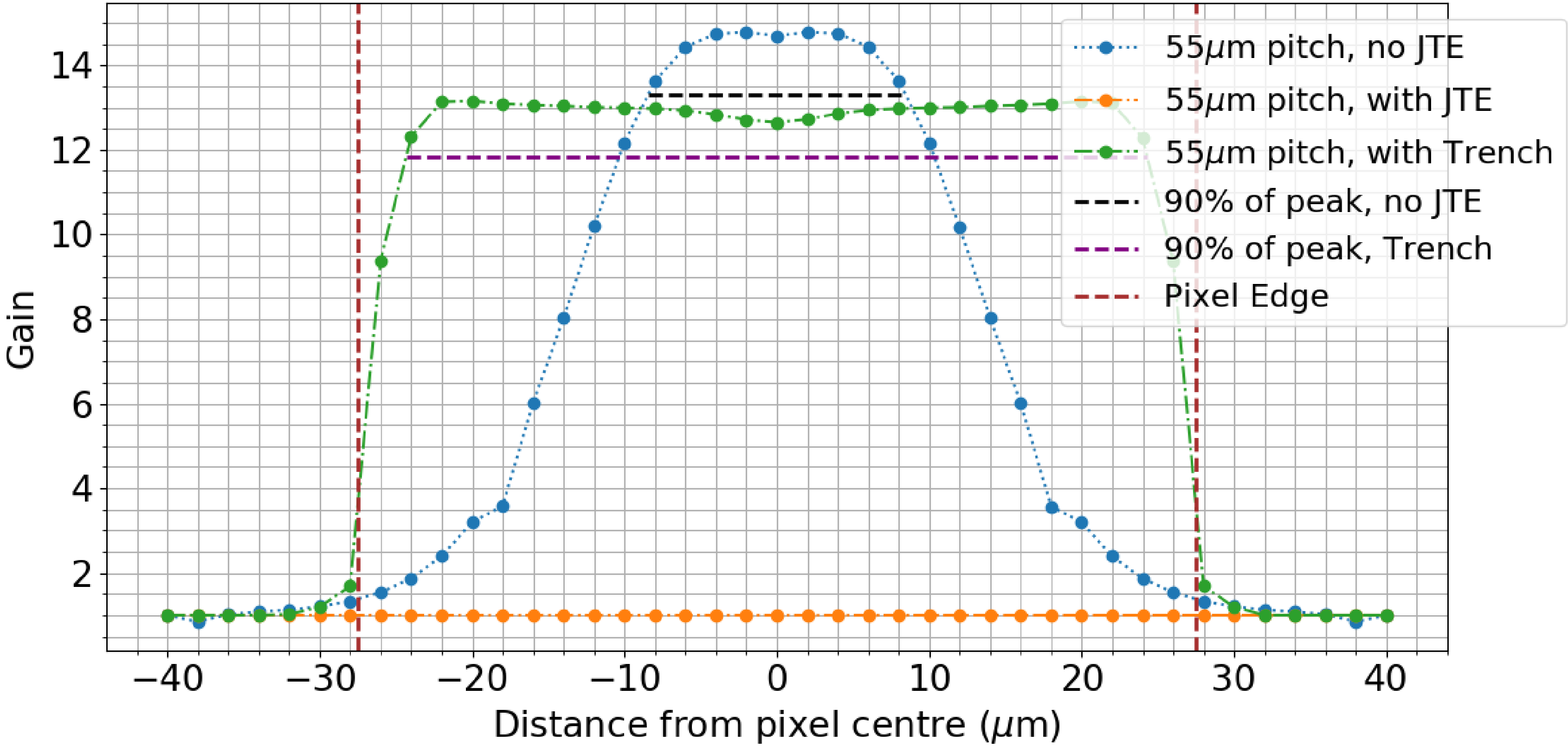
Trench Isolation

- Trench Isolation introduced by CMM at the last RD50 meeting.
- This involves etching a trench between pixels to isolate pixels.
- Can produce very narrow trenchs ,approx. 1um wide and 10um depth.
- Simulations performed to evaluate possibility of introducing trench etch step into our original process flow.
- Initial simulations are very promising.



Trench Isolation, Effective Fill Factor

- Trench Isolation of 55um pixels:
- Fill Factor at 90% Peak height is 79%
- A factor of 8x greater than a device with a gap between the pixels.
- IV characteristics show breakdown voltage > 500V



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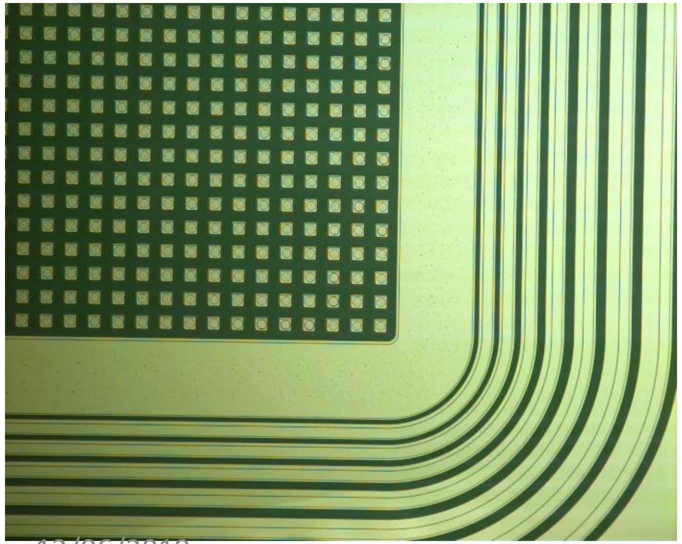
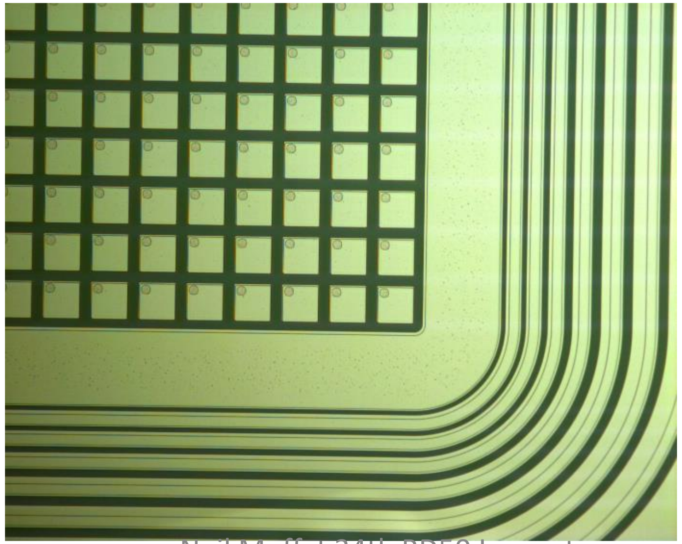
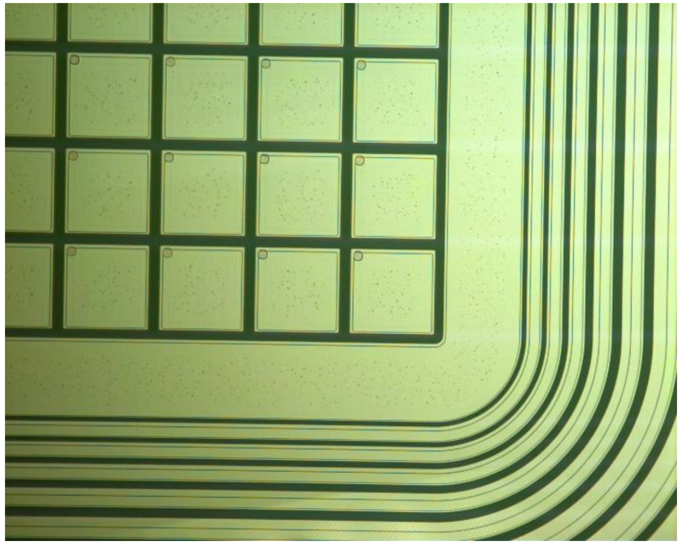
Timepix3 LGAD's

- Timepix3 Part of a family of hybrid pixel detectors with readout channels segmented at a pitch of 55um.
- They can be used for event counting and energy resolution measurements simultaneously.
- They have a time resolution of the order 1.56ns
- 5 Devices bump bonded with low multiplication dose.
- A 220um, 110um and 3x55um pitch sensors.
- The 220um bonds failed, this is to be investigated.
- 3 of the fives sensors work with varying results.
- The 110um and one the 55um breakdown at approx 130V
- The final device has breakdown voltage > 300V.







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Future Work

- Continued Simulation of Trench Isolation Technology.
- Implementation of trenches in our current process flow.
- This will performed at a closely connected research facility.
- Collaboration between the University of Glasgow, University of Manchester and AGH Krakow has been ongoing in pursuit of PixeLGADS for the LHCb upgrade with the VELOPix chip.
- Work is ongoing to improve LGAD fill factor by trench isolation as well as the possibility of using the iLGAD.
- Simulation work for this is performed at the University of Manchester.
- Thin LGAD's for timing applications have been fabricated at Micron with a variety of Multiplication implant doses. These will be tested in Glasgow this summer.
- Following results an irradiation campaign will be undertaken.
- A beam test at Diamond Light source is expected before the end of the year to fully characterize the Timepix3 chips bonded to LGAD sensors.

Summary

- Small pixels shown to have decrease in Gain.
- Effect of JTE implant is huge on pixels smaller than 220um.
- New device periphery's are being studied to produce a higher fill factor device.
- Trench isolation using Micron’s process flow has been shown to increase effective fill factor up to 79% for a 55um pitch pixel.
- Collaboration with the University of Manchester and AGH Krakow has provided necessary links to the LHCb experiment for possible use of LGAD’s in the timing layer of the VELOpix.