Comparison of Timepix3 active-edge assembly test-beam data with simulation

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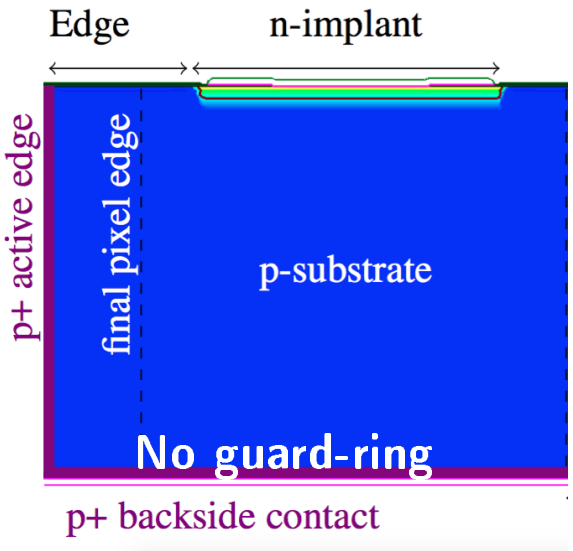
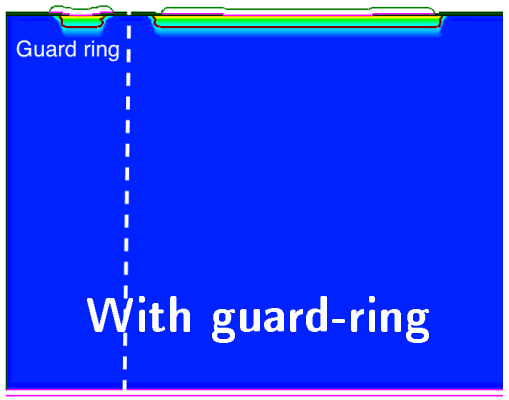
Active edge sensors on Timepix3 ASICs

- Study feasability of thin sensors with active edge using Timepix3 readout ASICs
- Advacam MPW with 50 µm to 150 µm thick n-in-p sensors
- The DRIE (Deep Reactive-Ion Etching) process is used to cut an active edge silicon sensor
- Implantation on the sidewall of the sensor ⇒ control the potential at the edge by creating an extension of the backside electrode on the edge

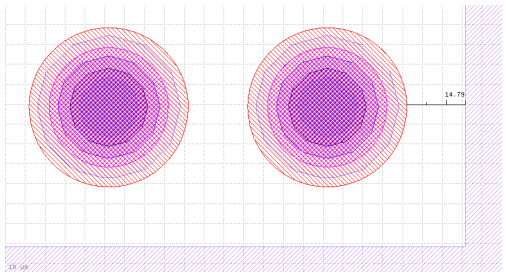




Test-assemblies: Guard ring layouts

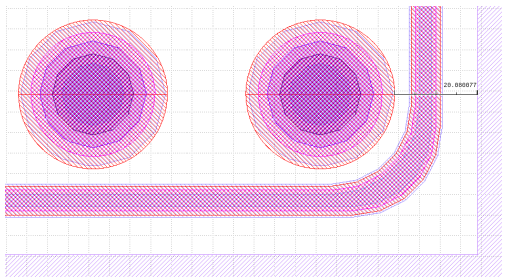
- 4 different guard ring layouts implemented, 6 assemblies tested in beam

- 15 µm edge, no guard-ring



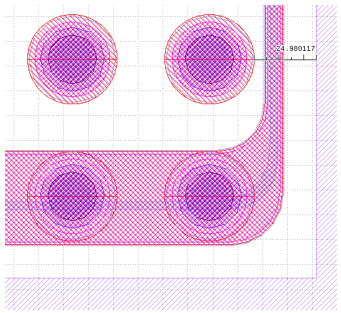
15 µm

- 20 µm edge, floating guard-ring



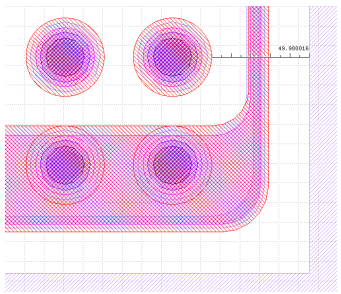
20 µm

- 25 µm edge, GND guard-ring



25 µm

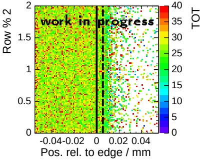
- 50 µm edge, GND guard-ring

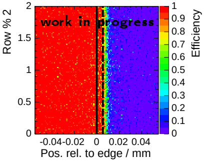


50 µm

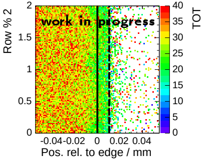
Test beam: Signal and efficiency at the edge

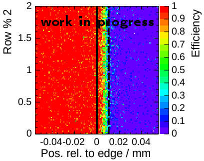
- 50 µm, 15-noGR



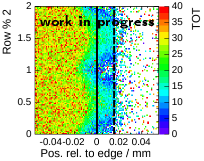


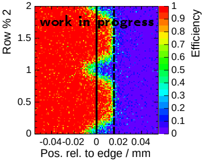
- 50 µm, 20-floatGR



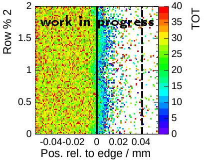


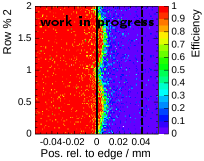
- 50 µm, 25-groundGR





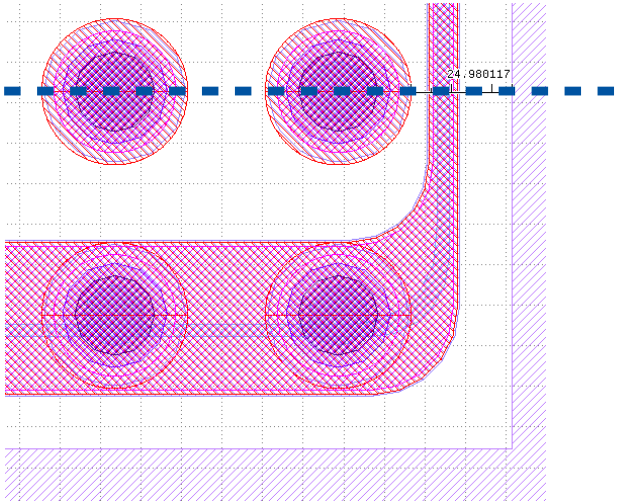
- 50 µm, 50-groundGR





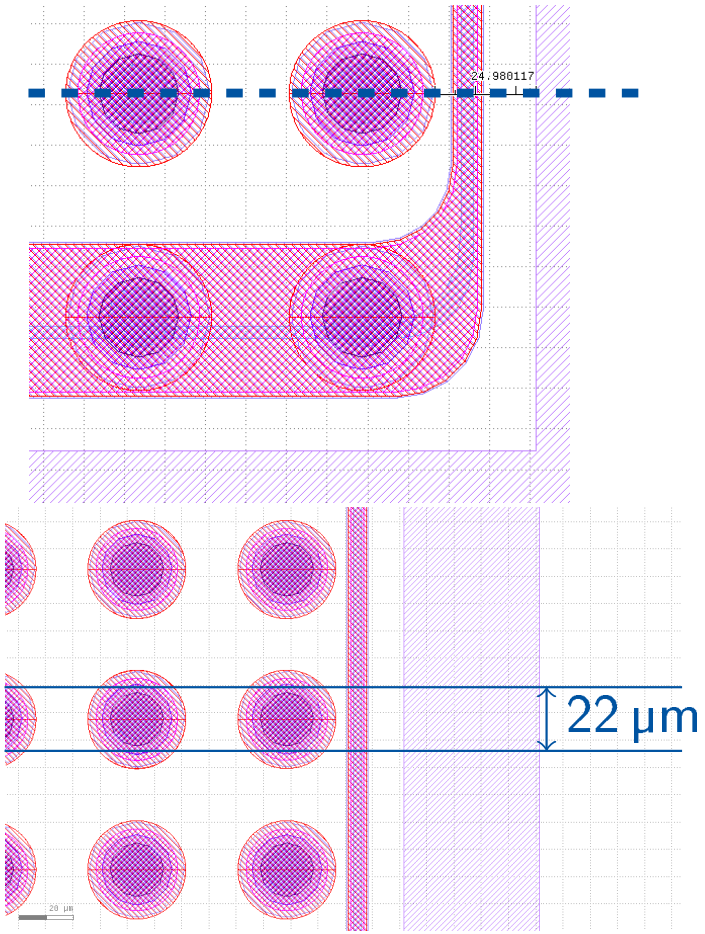
T-CAD

- Implementation of different edge geometries and guard ring layouts in Synopsys Sentaurus
- 2D simulation $\rightarrow$ cut at center of pixel implant
- Guard ring not yet at the correct position
- Static and transient simulation (MIP scan)



T-CAD

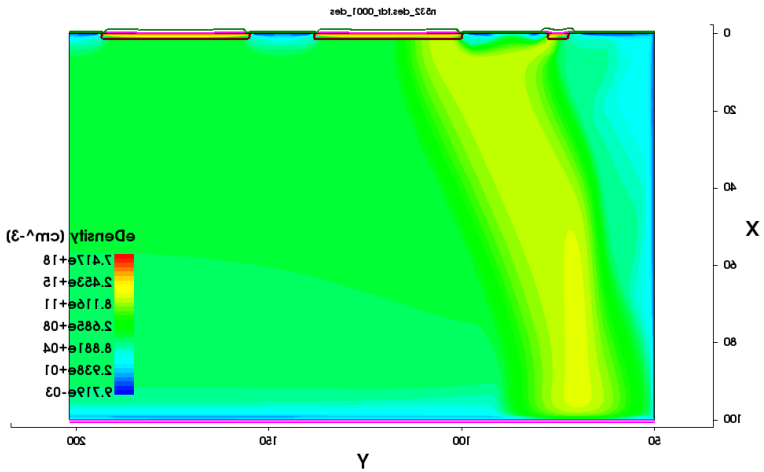
- Implementation of different edge geometries and guard ring layouts in Synopsys Sentaurus
- 2D simulation $\rightarrow$ cut at center of pixel implant
- Guard ring not yet at the correct position
- Static and transient simulation (MIP scan)
- For better comparability: restrict data to tracks passing close to pixel center



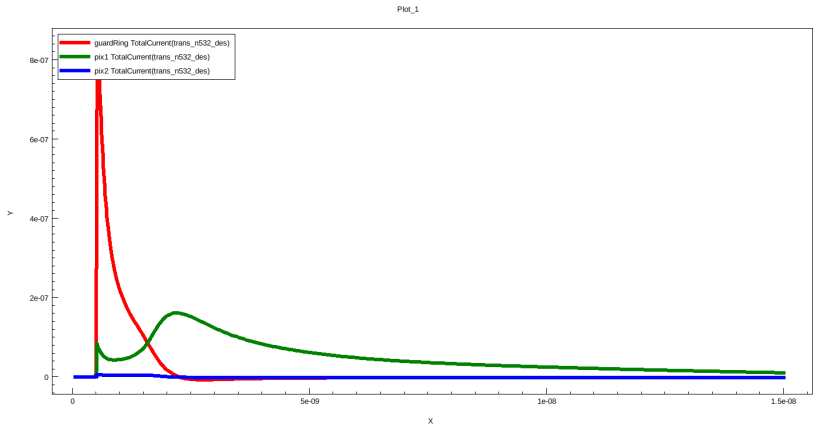
Transient simulation

- Create charge along particle path, constant ionization
- Collect charges at the electrodes
- Record transient current in electrodes
- Integrate (here: 15 ns) to obtain charge signal
- Comparison between measurement (uncalibrated TOT) and simlation (electron signal) not perfectly valid

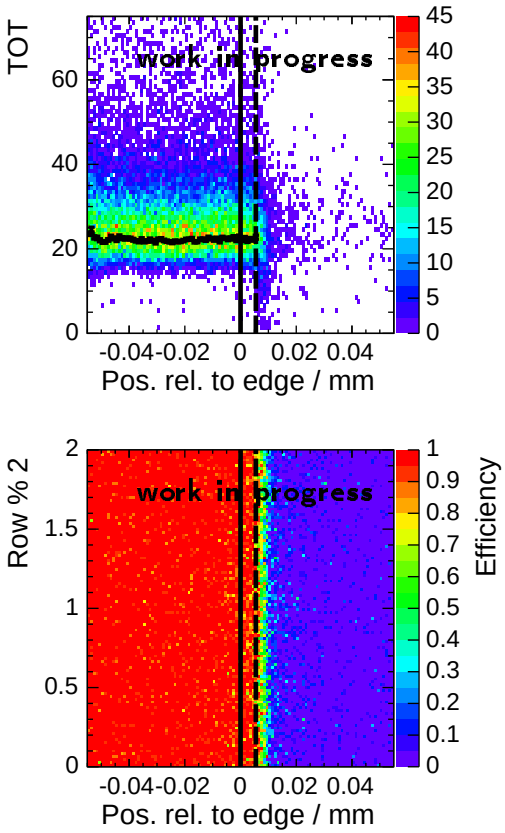
Electron density 1.5 ns after particle hit:

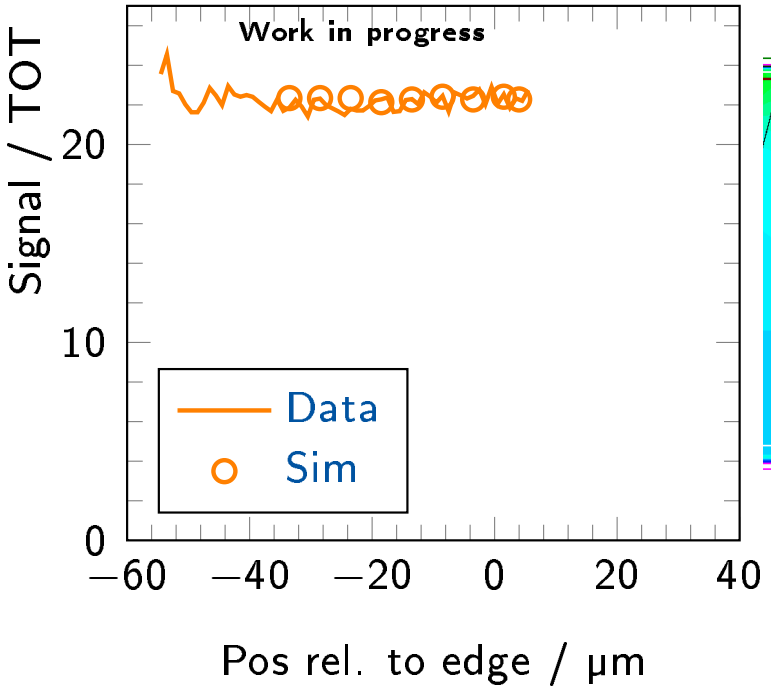


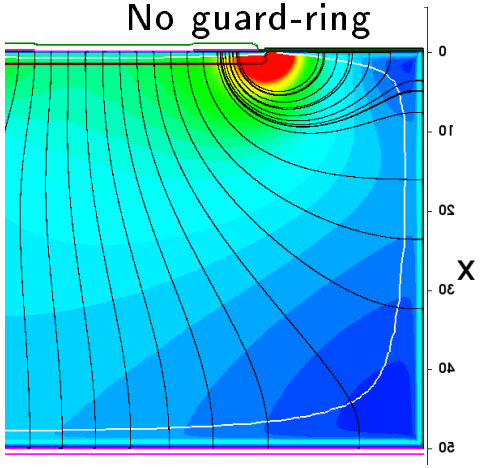
Transient current in pixels and guard ring:



No guard ring - 15 µm edge - 50 µm thick

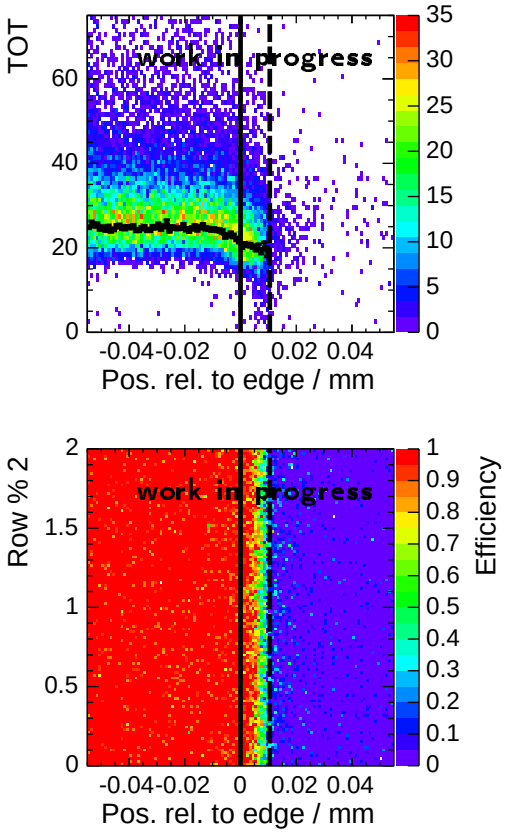


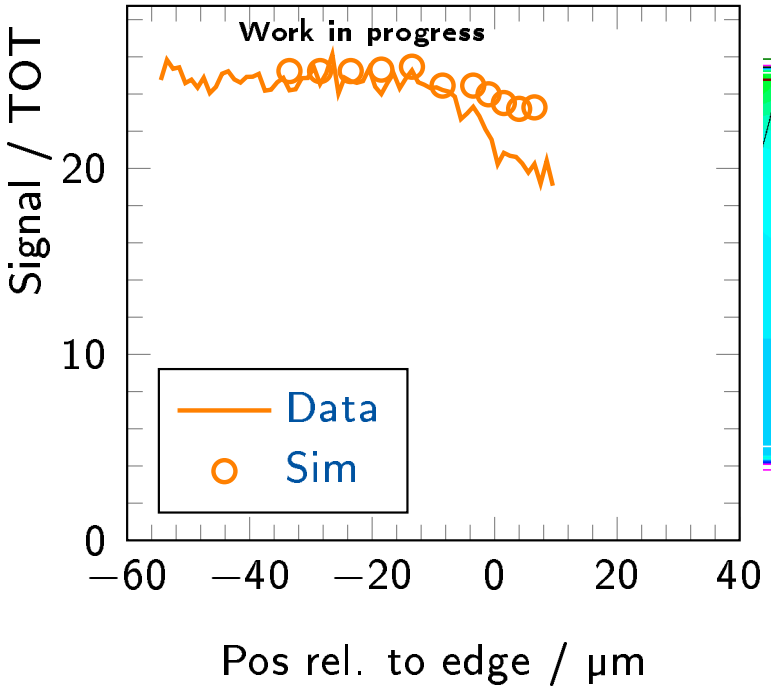


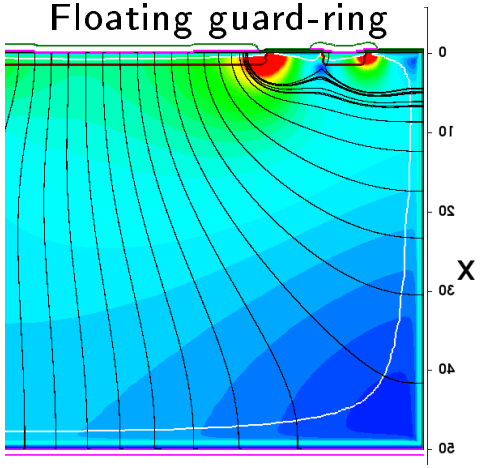


- Full signal collection up to the edge

Floating guard ring - 20 µm edge - 50 µm thick

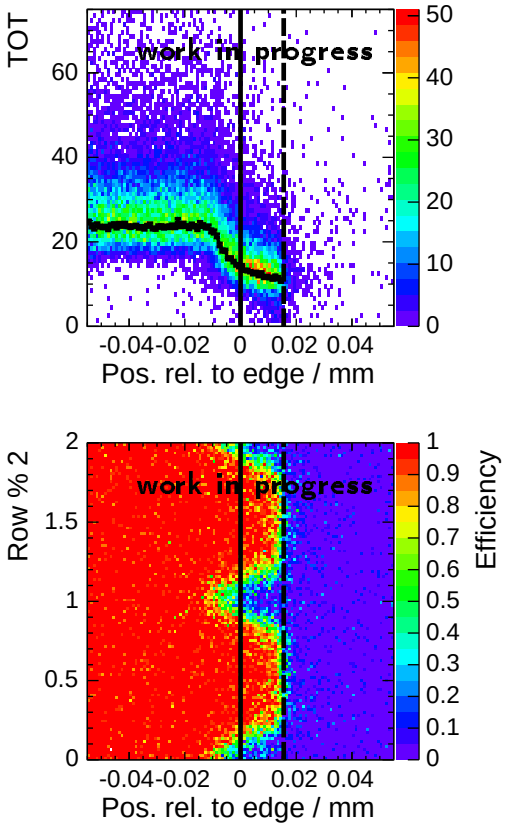


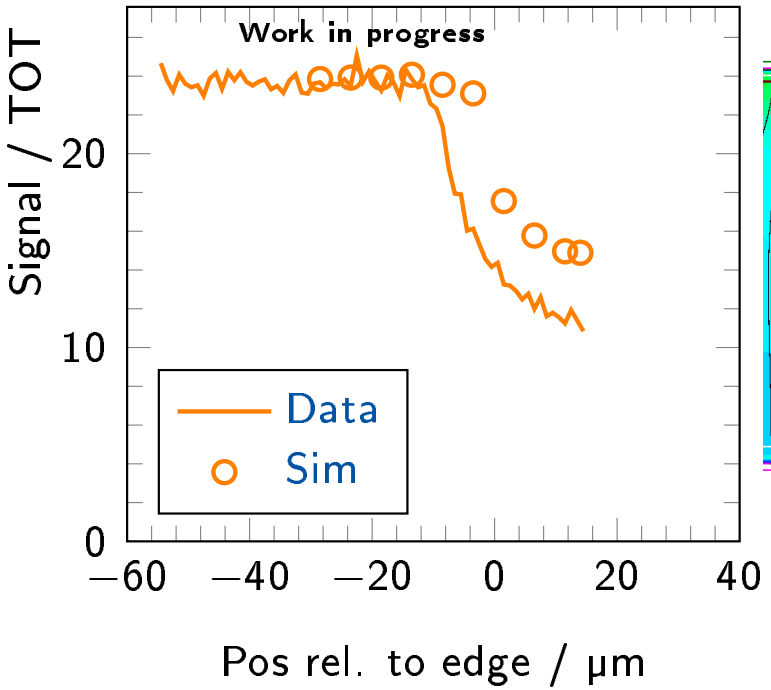


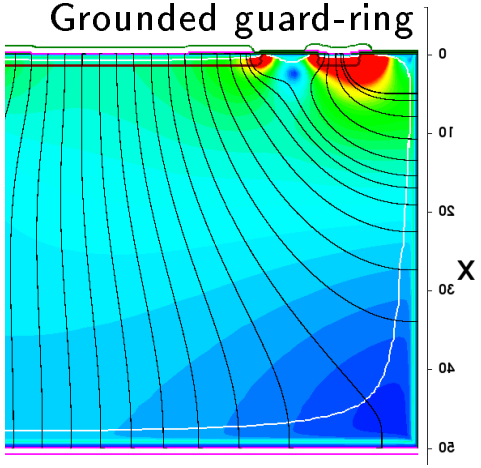


- Slight signal loss in data and simulation

Grounded guard ring - 25 µm edge - 50 µm thick

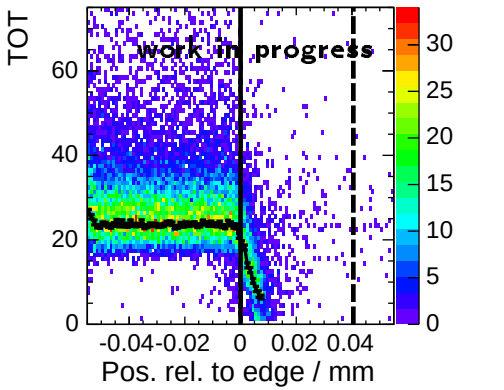


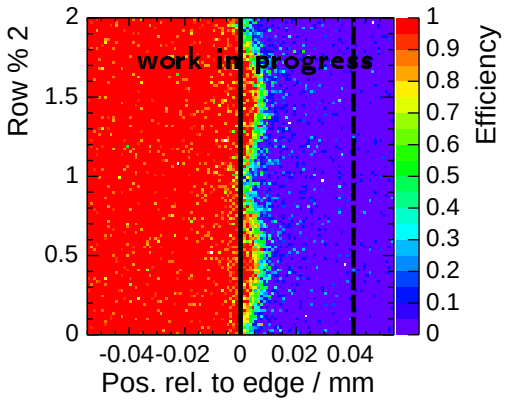


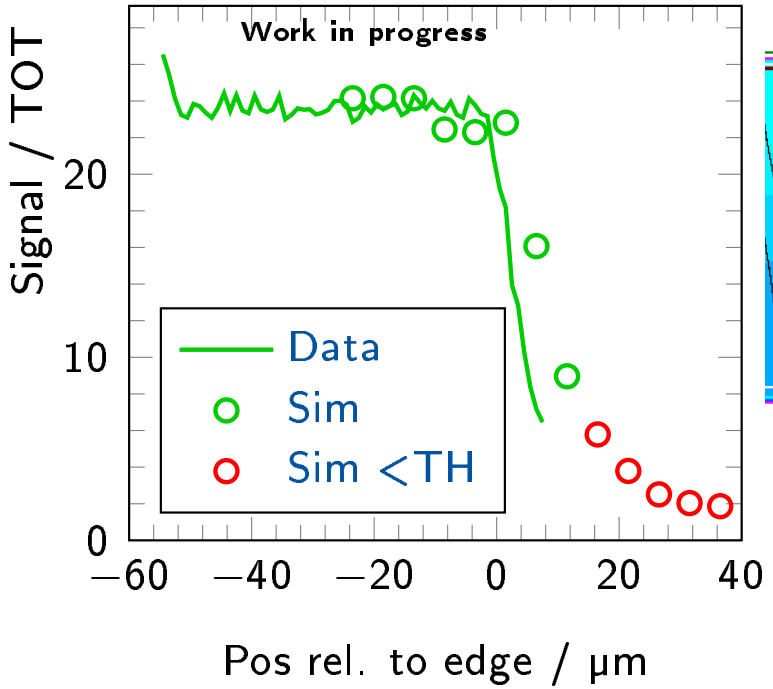


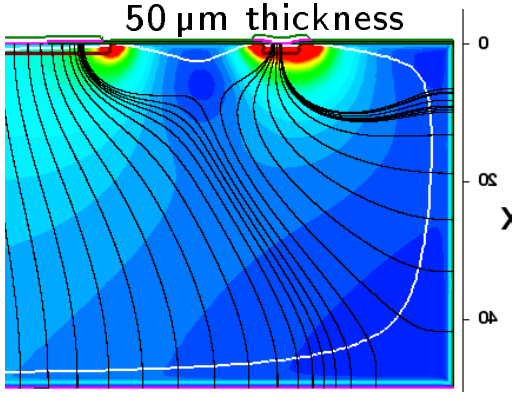
- Strong signal loss in data and simulation

Grounded guard ring - 50 µm edge - 50 µm thick



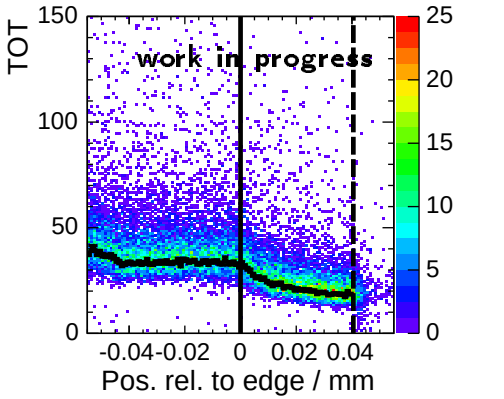


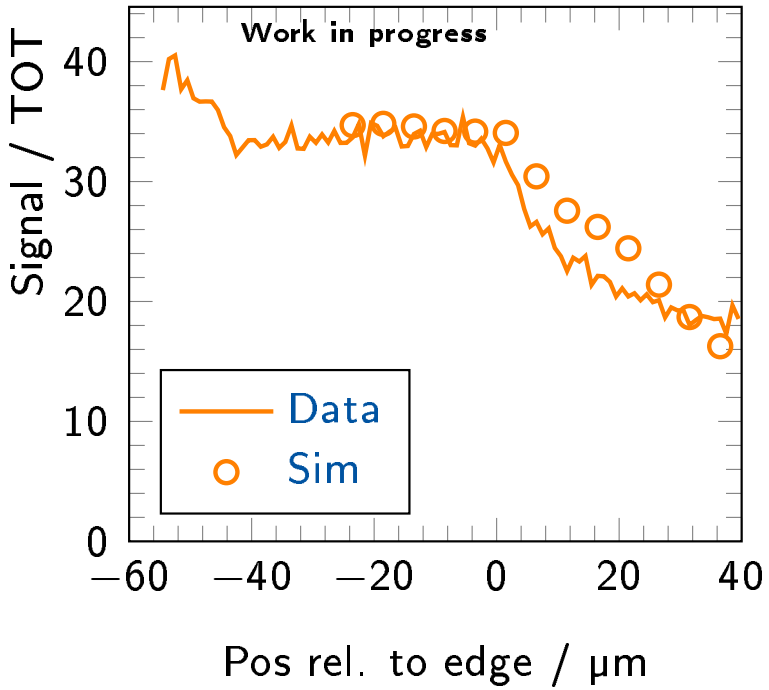


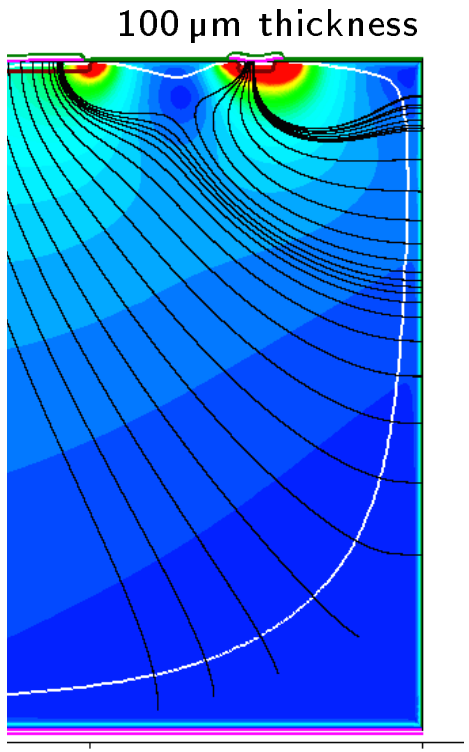


- Strong signal loss in data and simulation, signal partly below threshold → efficiency drops

Grounded guard ring - 50 µm edge - 100 µm thick

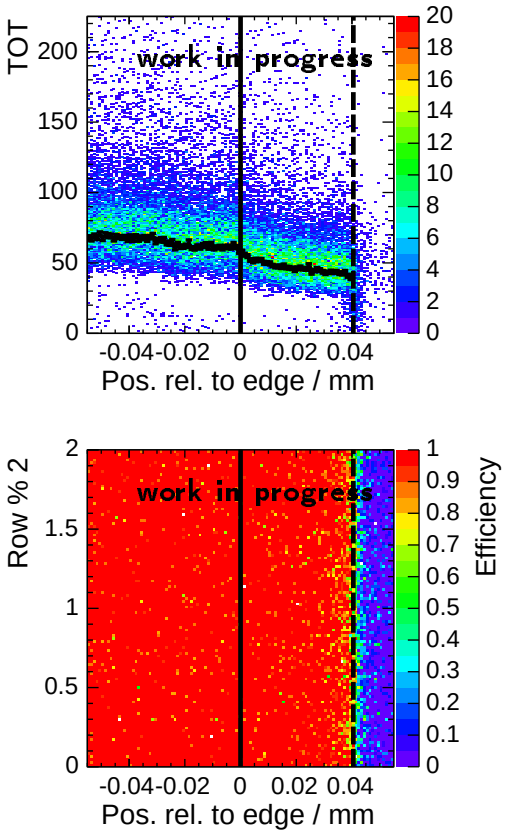


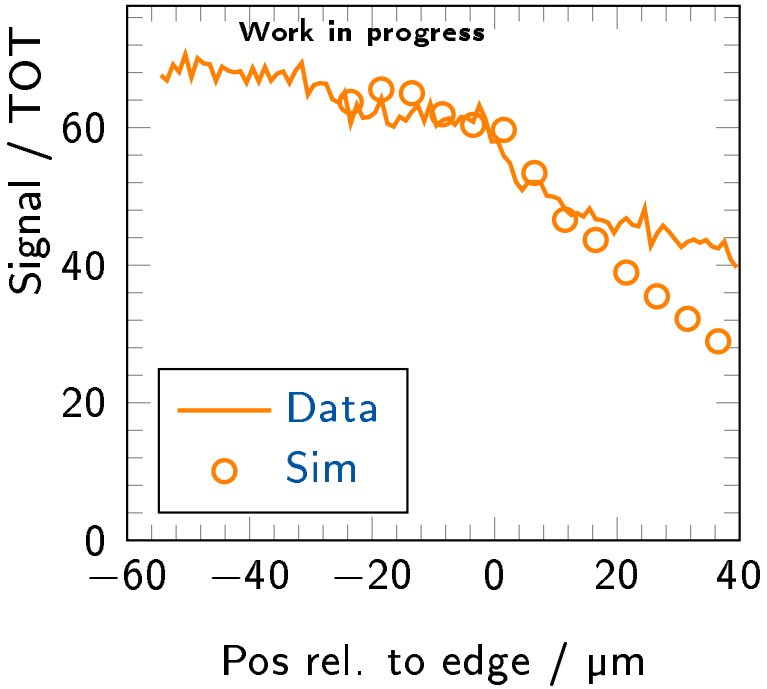


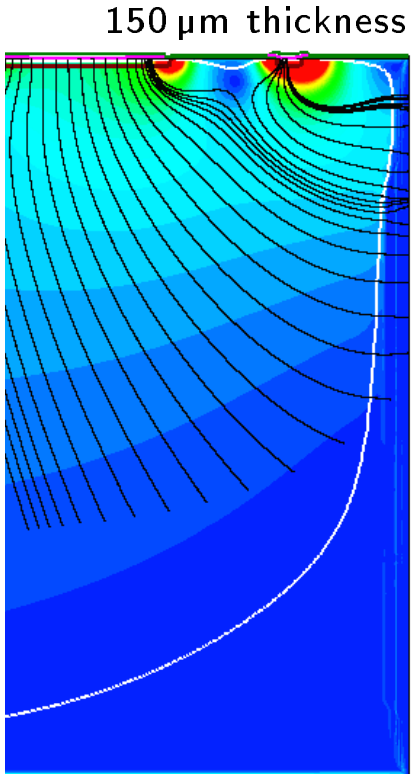


- Last pixel collects charge from edge region, as expected from field map

Grounded guard ring - 50 µm edge - 150 µm thick

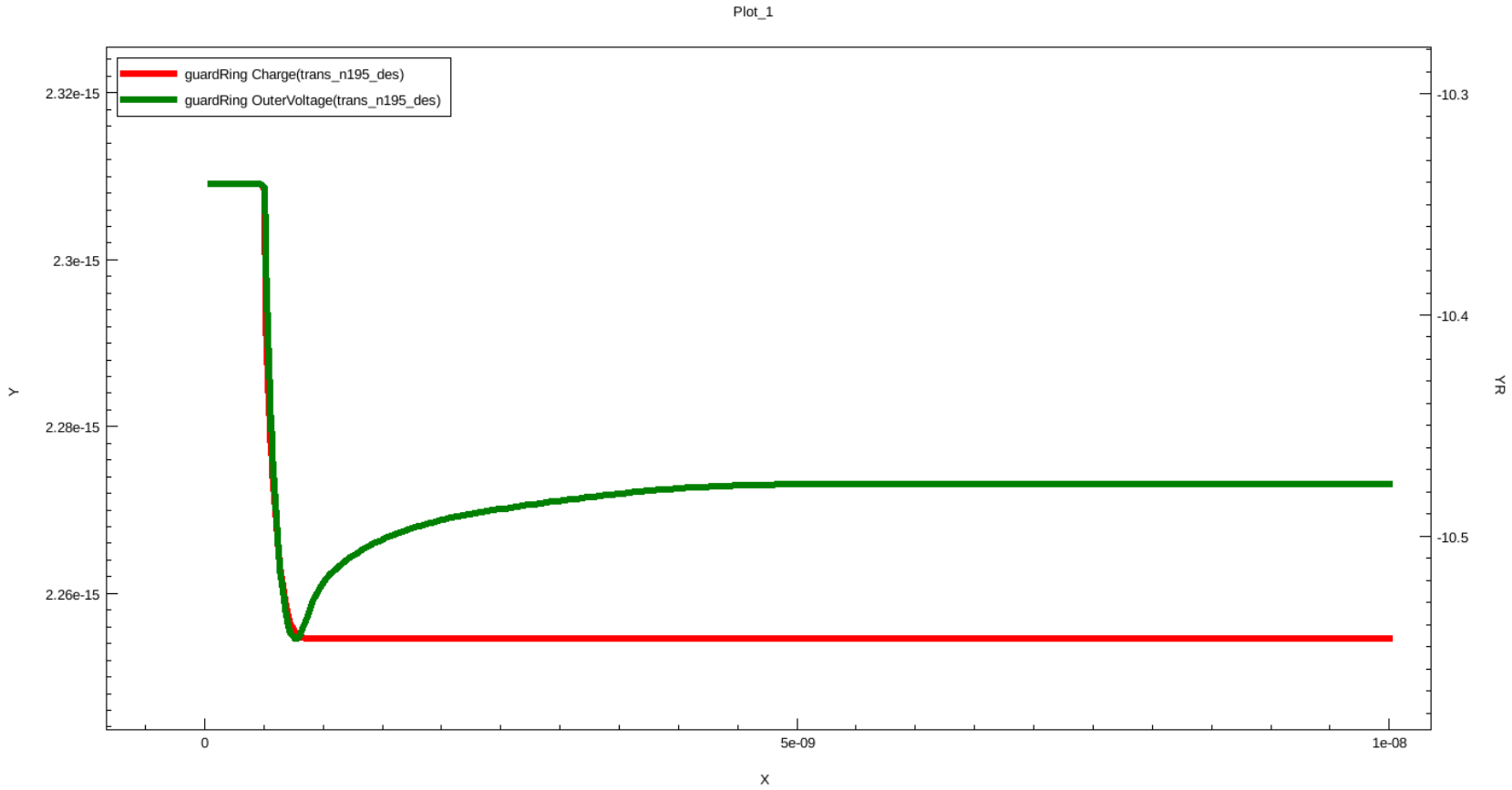






- Last pixel collects charge from edge region, as expected from field map

Floating guard ring - hit close to the edge



- Guard ring collects about $5.4 \times 10^{-17}\,\mathrm{C}$ ($\sim 330\,\mathrm{e}^-$)
- Results in a potential shift of 100 mV
- Charge not released after 10 ns $\rightarrow$ longer transient simulation needed

Summary & outlook

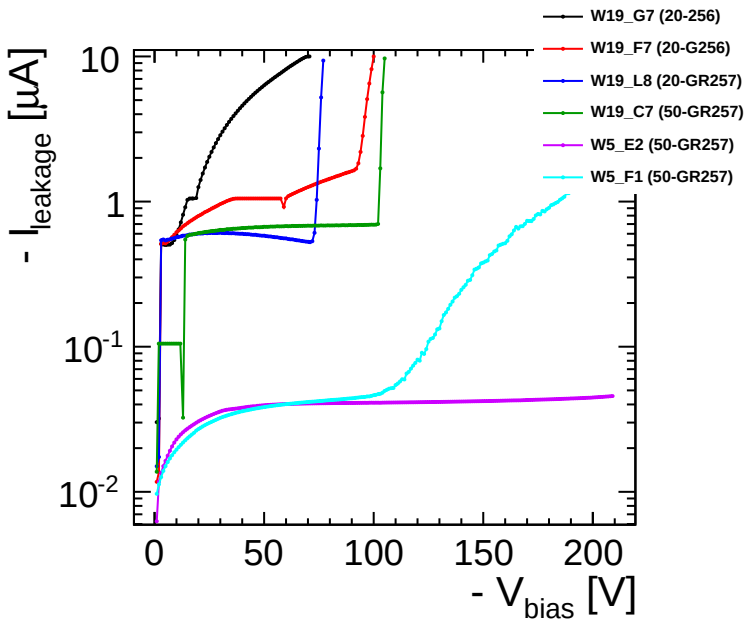
- 2D T-CAD model of active edge pixel sensors, comparison to test beam results
  - 4 edge designs
  - 3 thicknesses from 50 µm to 150 µm
- Static simulation & transient behaviour
- Qualitatively good agreement to measured signal and efficiency distributions
- Future plans:
  - Fix guard ring positioning issue
  - Apply calibration to test beam data for better comparability
  - Investigate feasability of 3D simulation of pixel cell, in order to understand efficiency loss between pixels seen for the grounded guard ring layout

Backup

Advacam active-edge devices

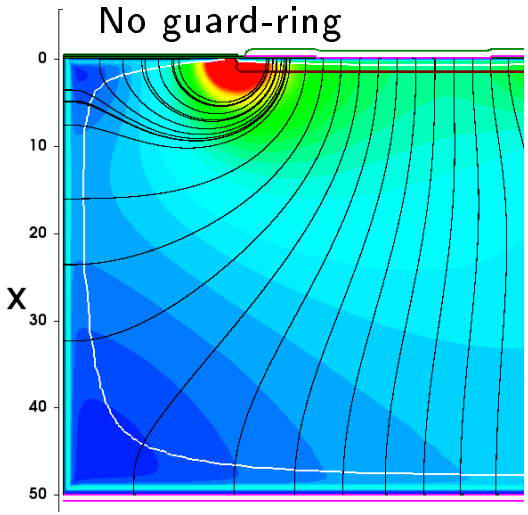
Assembly	Thickness [µm]	Edge width [µm]	Edge type
W19_G7	50	15	No guard-ring (15-noGR)
W19_F7	50	20	Floating guard-ring (20-floatGR)
W19_L8	50	25	Grounded guard-ring (25-groundGR)
W19_C7	50	50	Grounded guard-ring (50-groundGR)
W5_E2	100	50	Grounded guard-ring (50-groundGR)
W5_F1	150	50	Grounded guard-ring (50-groundGR)

- Sensor type: n-in-p
- The IV-curve measurement for all the tested assemblies:
  - The sensor without any guard-ring has a higher leakage current and the break-down occurs earlier (W19_G7)
- All assemblies can be operated above depletion

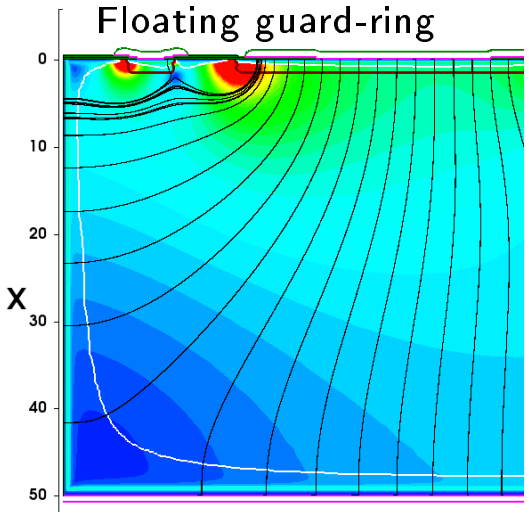


Electric field for different guard ring designs

- 20 µm edge
- Electric field and depleted region extends towards the edge



- Field lines end at the last pixel
- Expect no charge loss



- Field lines end at the last pixel
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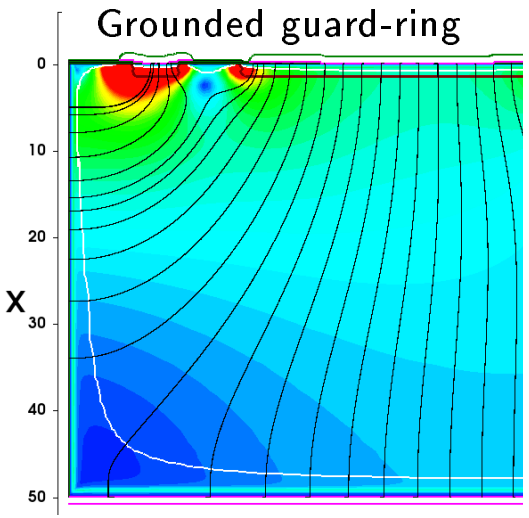
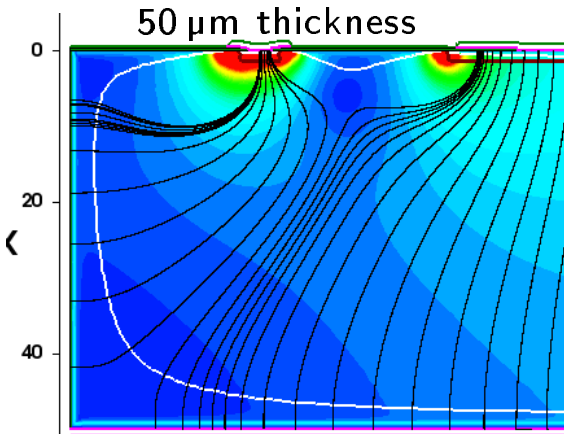
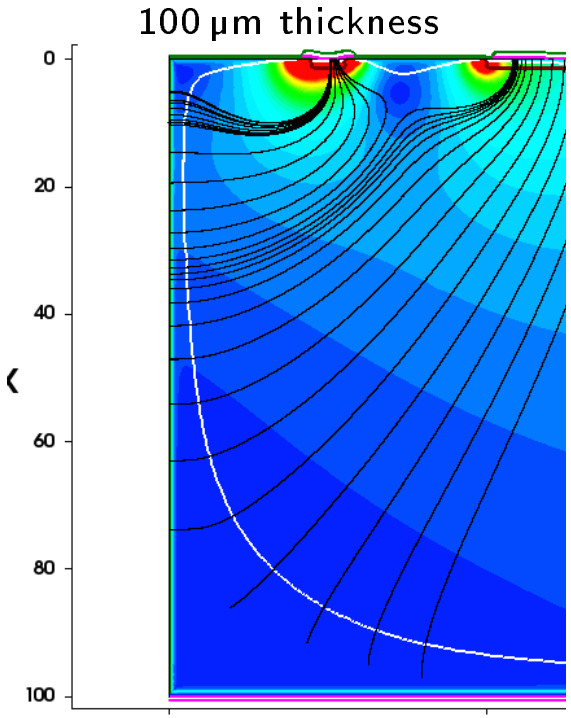
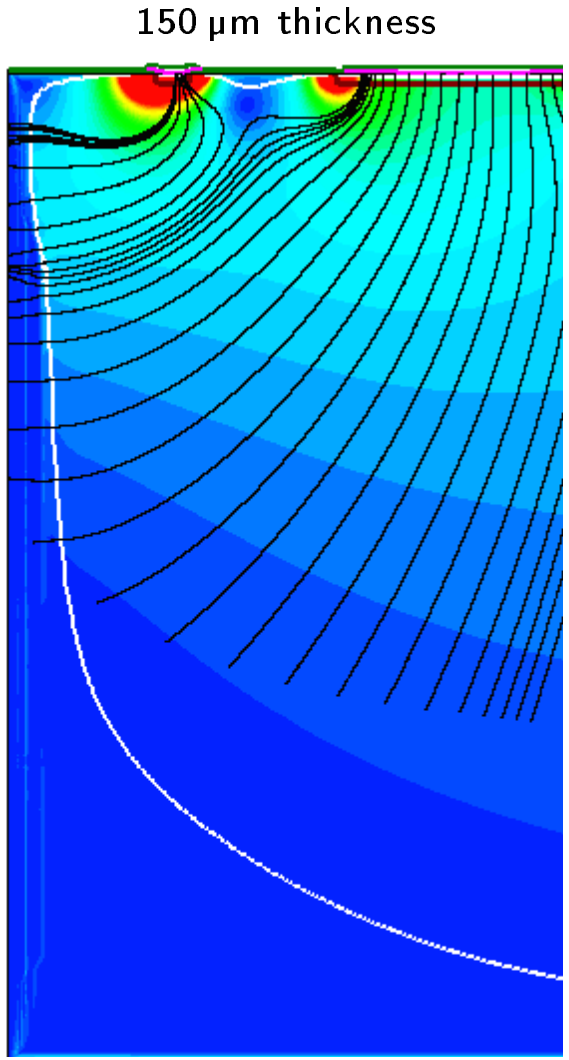


- Some of the lines end at the GR
- Expect charge loss to GR

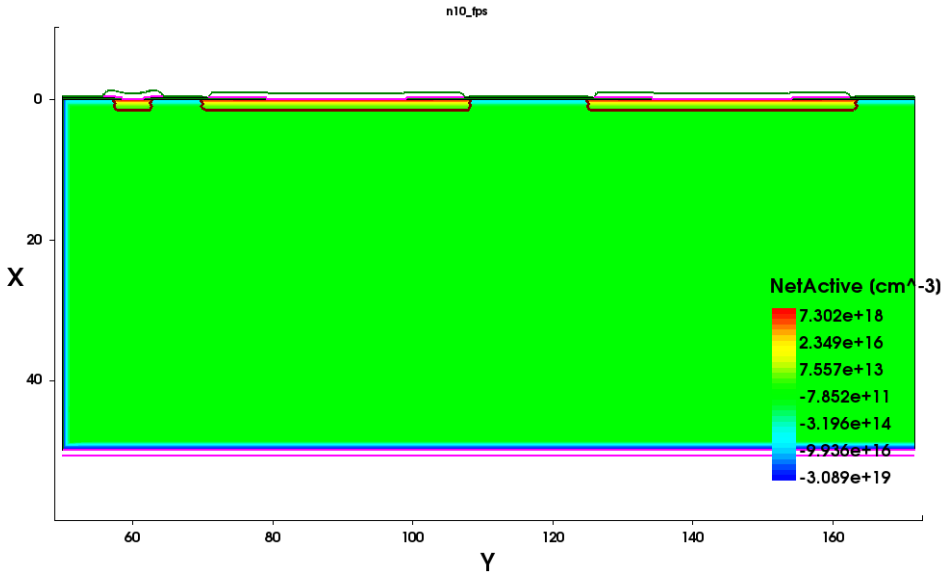
Electric field in the edge vs. thickness

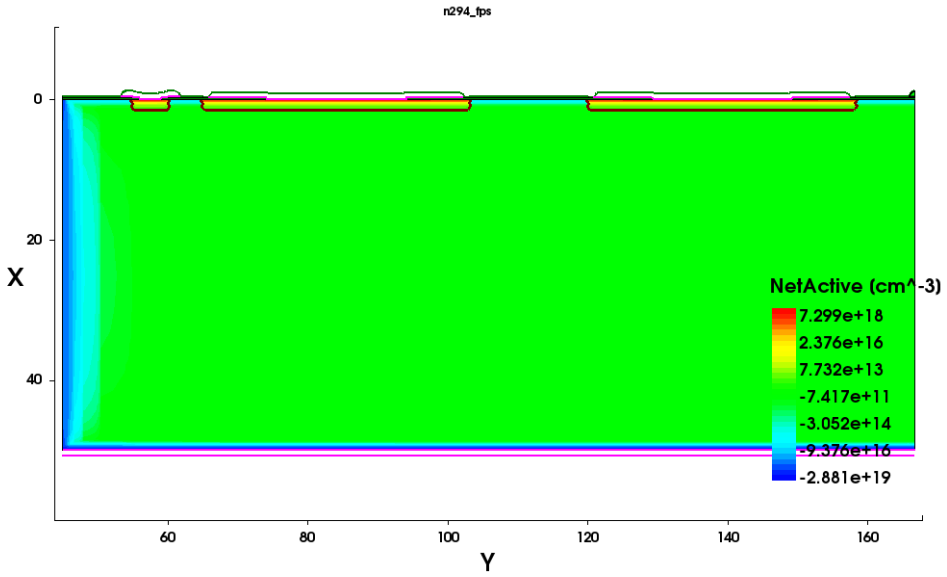






- 50 µm edge
- With increasing thickness, sensitiviy of the last pixel extends to the edge region


n10_fps
0
20
40
X
60
80
100
120
140
160
Y
NetActive (cm^-3)
7.302e+18
2.349e+16
7.557e+13
-7.852e+11
-3.196e+14
-9.936e+16
-3.089e+19


n294_fps
0
20
40
X
60
80
100
120
140
160
Y
NetActive (cm^-3)
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2.376e+16
7.732e+13
-7.417e+11
-3.052e+14
-9.376e+16
-2.881e+19