Planar sensor studies for CLIC

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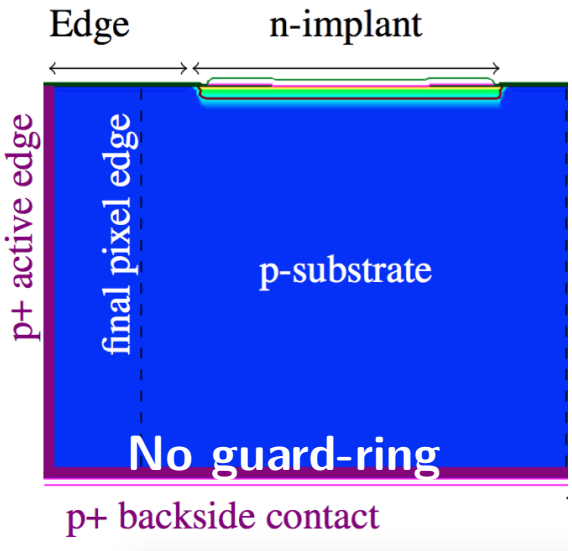
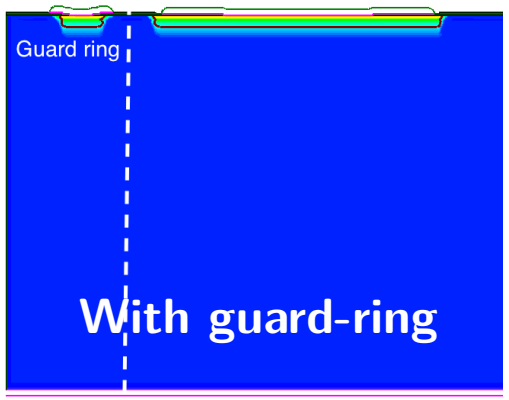
Outline

- Planar active edge sensors on Timepix3
  - Testbeam results
  - Comparison to T-CAD simulation
- CLICpix planar sensor studies
  - First 50 µm thin planar sensor assembly

Active edge sensors on Timepix3 ASICs

- Study feasibility of thin sensors with active edge using Timepix3 ASICs
- 50 µm to 150 µm thick n-in-p sensors, 55 µm pixel pitch
- Deep Reactive-Ion Etching is used to cut the edge of the silicon sensor
- Implantation on the sidewall of the sensor ⇒ extension of the backside electrode on the edge ⇒ Charge created in the edge region can be collected by the first pixel
- Reduction of inactive area, good coverage without overlapping sensor tiles, reduction of material budget

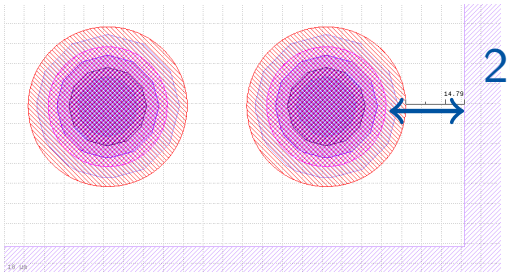




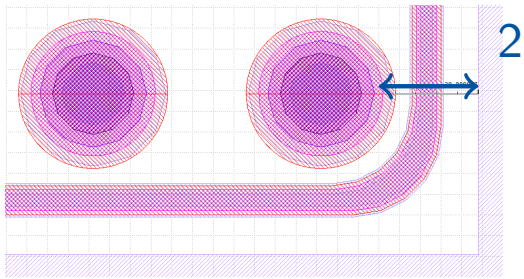
Guard ring layouts

- 4 different guard ring layouts implemented
- Edge distance is defined as the distance between the last n-implant and the cut edge

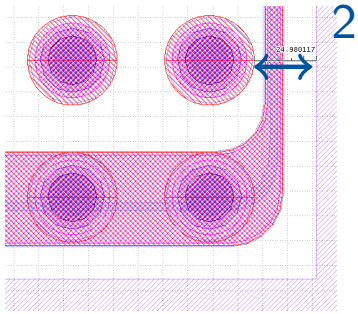
- 20 µm edge, no guard-ring



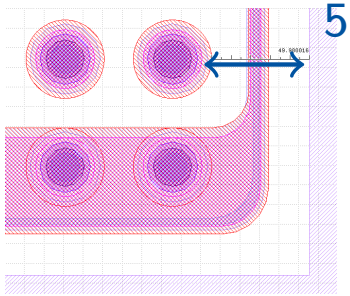
- 23 µm edge, floating guard-ring



- 28 µm edge, GND guard-ring

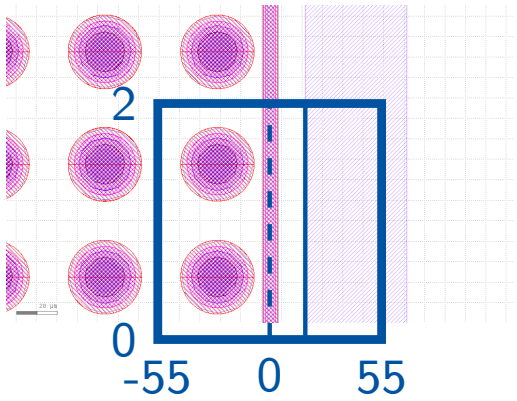


- 55 µm edge, GND guard-ring



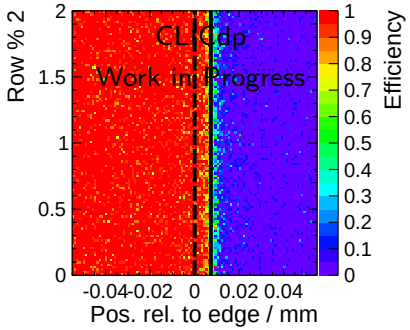
Edge performance

- Performance at the edge:
  - Consider only tracks close to the sensor edge
  - Tracks are periodically mapped into a 2 by 2 pixel cell
  - For illustration, end of the periodic pixel matrix (dashed line) and physical edge of the sensor (solid line) are indicated in the following plots

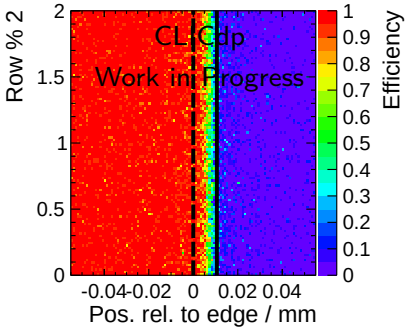


Efficiency and signal in the edge

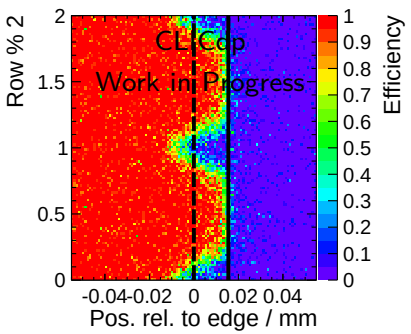
- 50 µm thick, 20-noGR



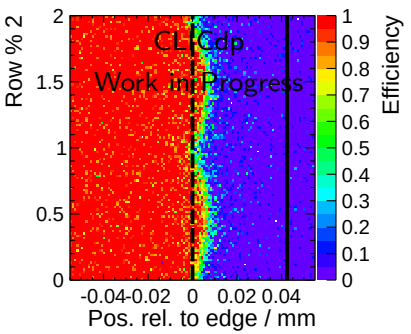
- 50 µm thick, 23-floatGR



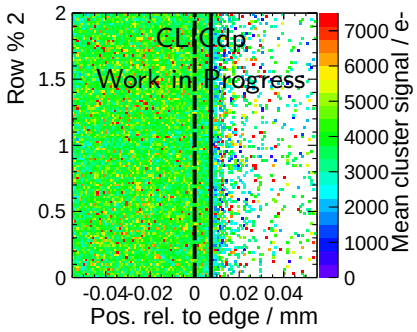
- 50 µm thick, 28-groundGR



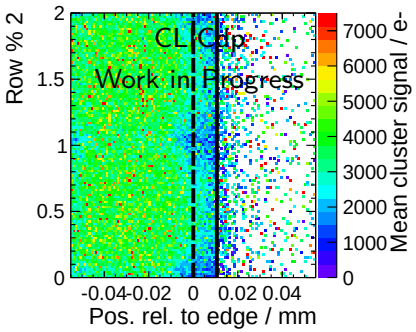
- 50 µm thick, 55-groundGR



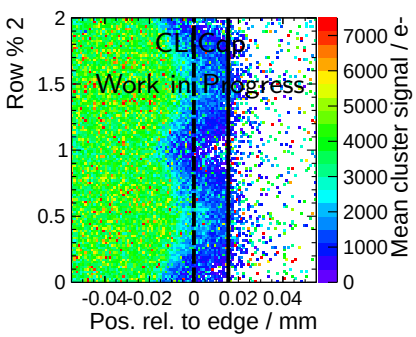
- 50 µm thick, 20-noGR



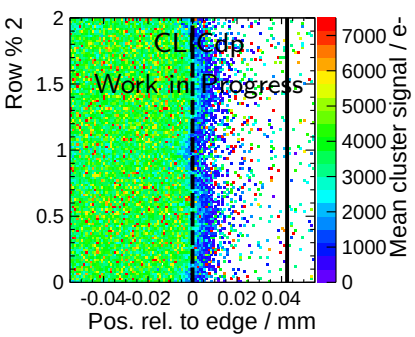
- 50 µm thick, 23-floatGR



- 50 µm thick, 28-groundGR

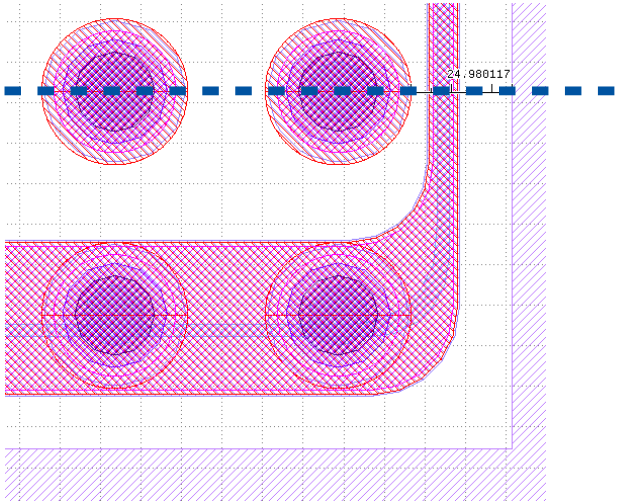


- 50 µm thick, 55-groundGR



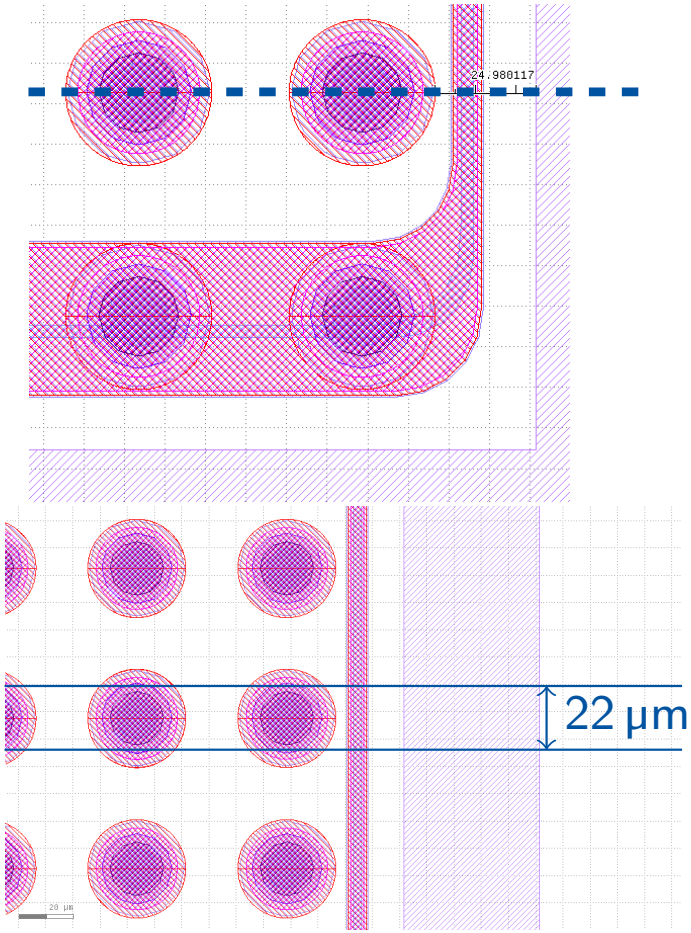
T-CAD

- Implementation of different edge geometries and guard ring layouts in Synopsys Sentaurus
- 2D simulation $\rightarrow$ cut at center of pixel implant
- Static (electric field) and transient simulation (MIP scan)
- Simplified: noise, threshold and landau fluctuations not included



T-CAD

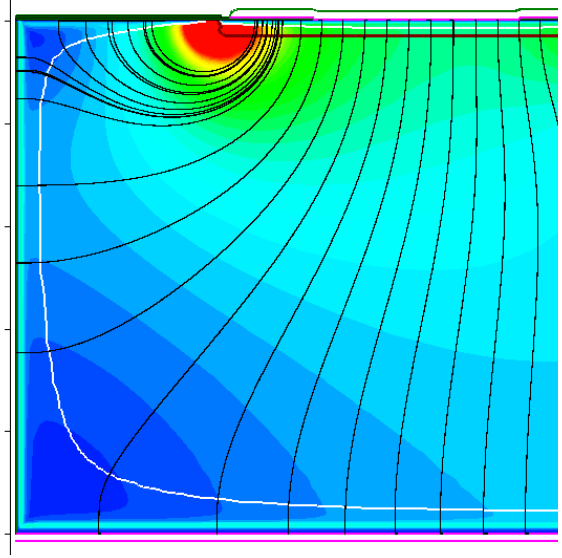
- Implementation of different edge geometries and guard ring layouts in Synopsys Sentaurus
- 2D simulation $\rightarrow$ cut at center of pixel implant
- Static (electric field) and transient simulation (MIP scan)
- Simplified: noise, threshold and landau fluctuations not included
- For better comparability in 2D simulation: restrict data to tracks passing close to pixel center



Electric field for different guard ring designs

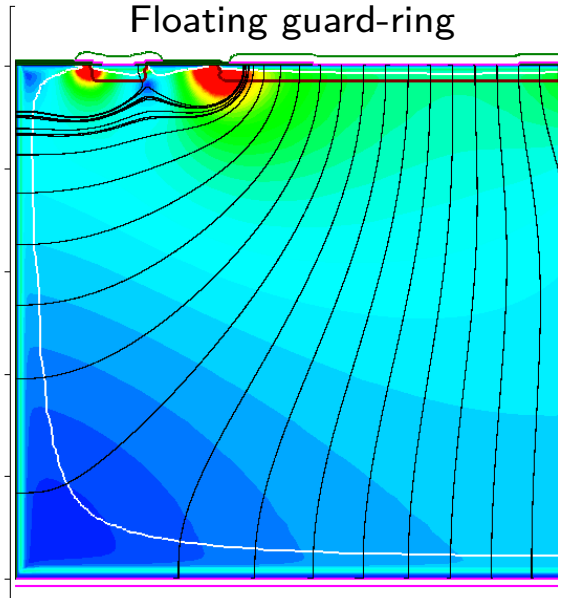
- $\sim 20\,\mu m$ edge, $50\,\mu m$ thick
- Electric field and depleted region extend towards the edge

No guard-ring



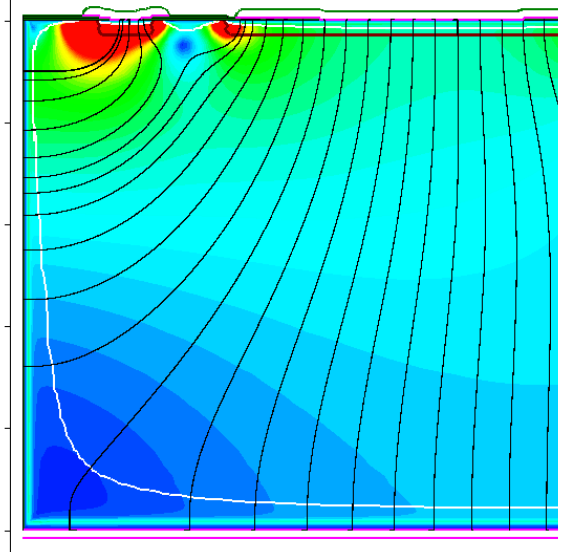
- Field lines end at the last pixel
- Expect no charge loss

Floating guard-ring



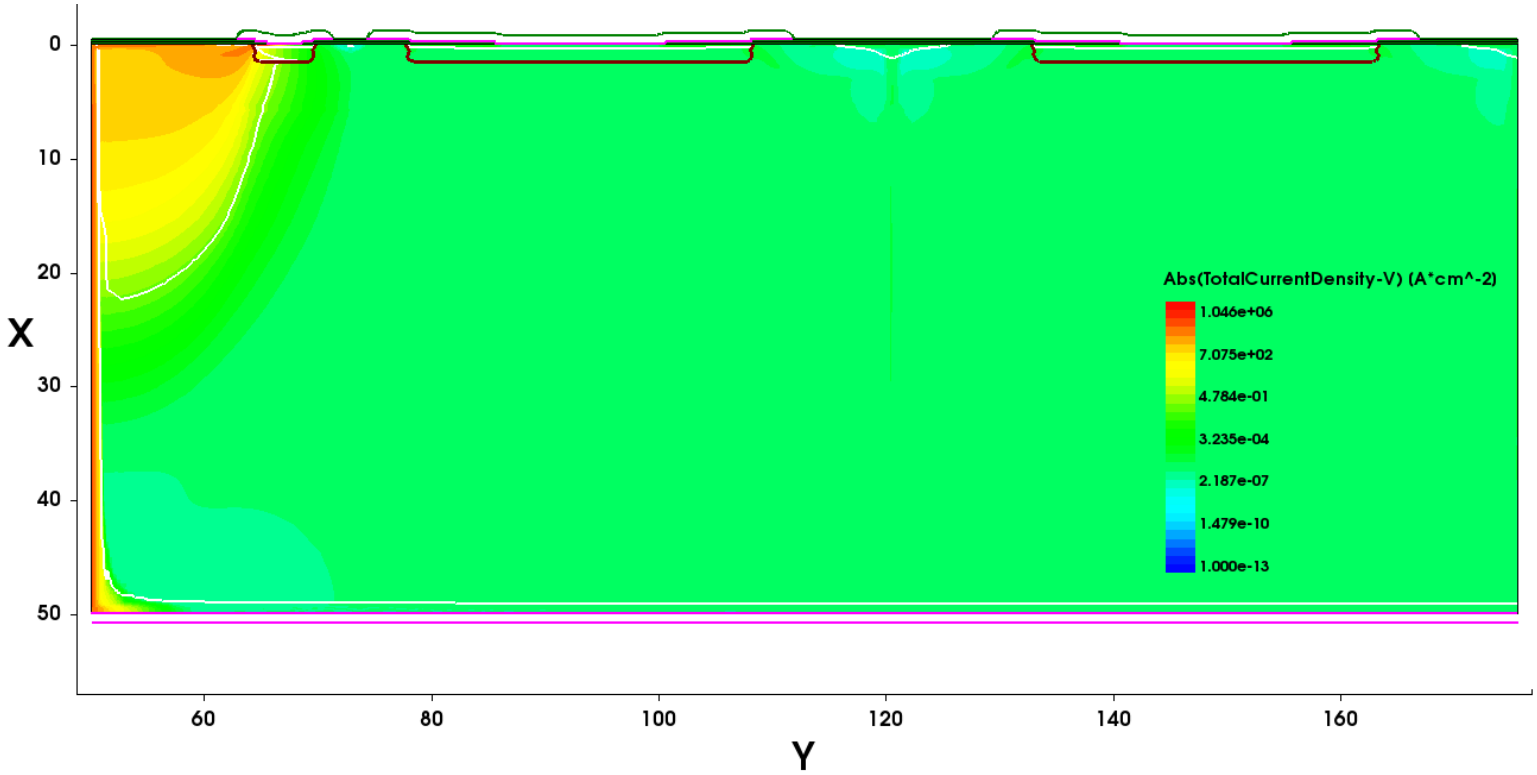
- Most field lines end at the last pixel
- Small charge loss

Grounded guard-ring



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

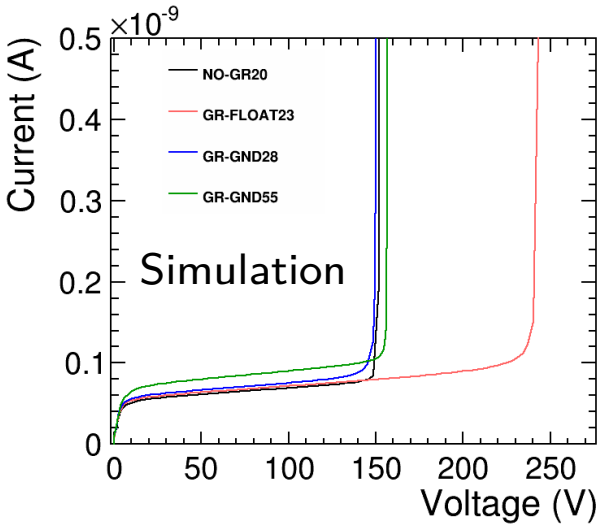
Breakdown - simulation

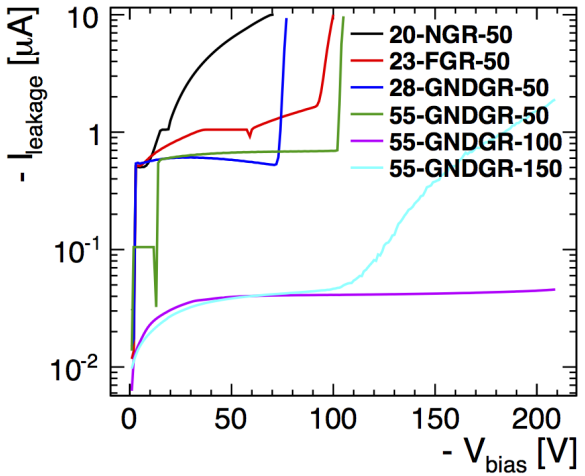


- Total current density
- 50 µm thick, grounded guard ring
- Breakdown occurs between the edge and the first implant

Breakdown - simulation

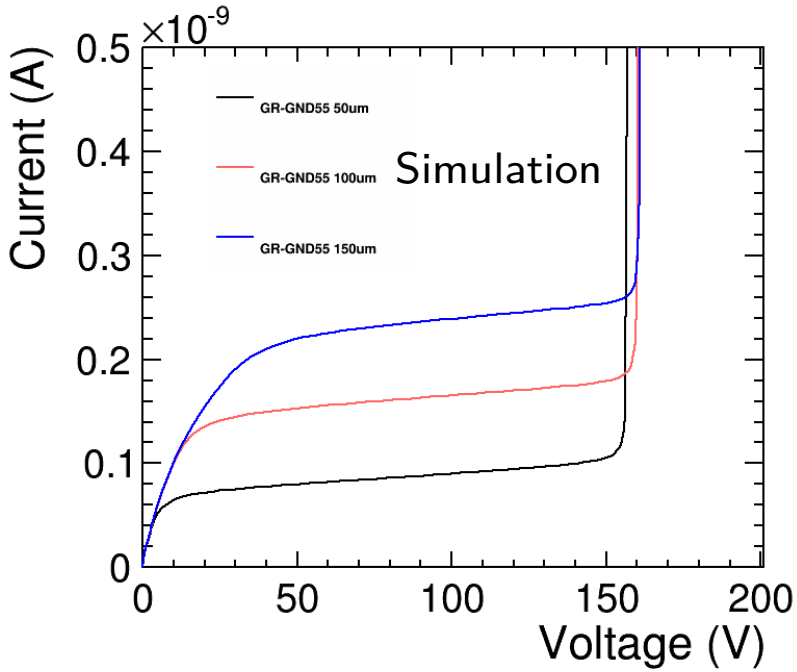
- 50 µm thickness: no guard ring and grounded guard ring break down around 150 V
- Similar distance between edge and first grounded implant
- Floating guard ring smoothens potential drop
- Lower electric field at given bias → higher V_{bd}
- Comparison to measurements not easy, measurement not very reproducible
- Extra row of bumps influencing floating guard ring and/or active edge





Breakdown - simulation

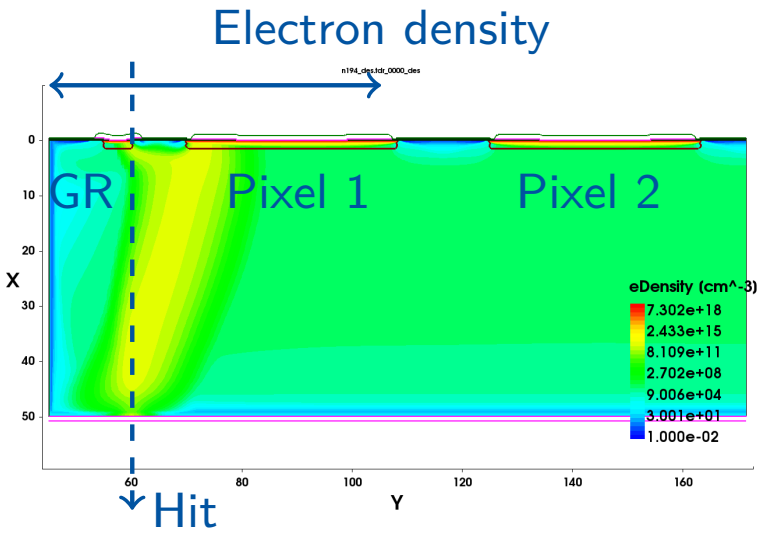
- Thicker devices, grounded guard ring, 55 µm edge
- For given guardring layout, field at the surface not depending on the sensor thickness $\rightarrow$ V_{bd} not depending on the thickness

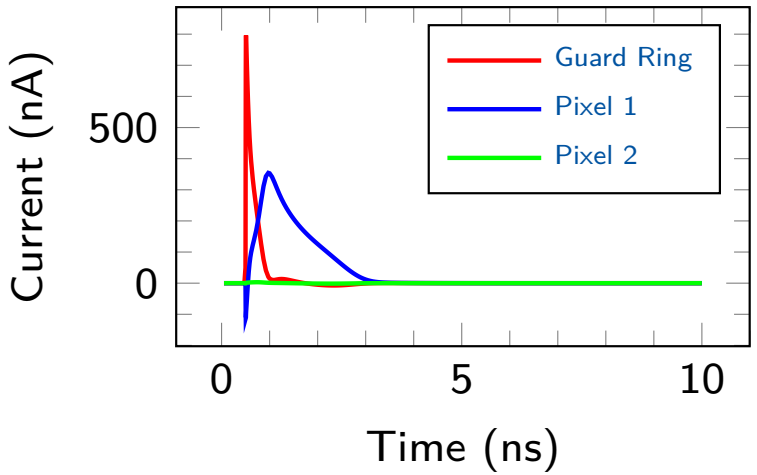


Transient simulation

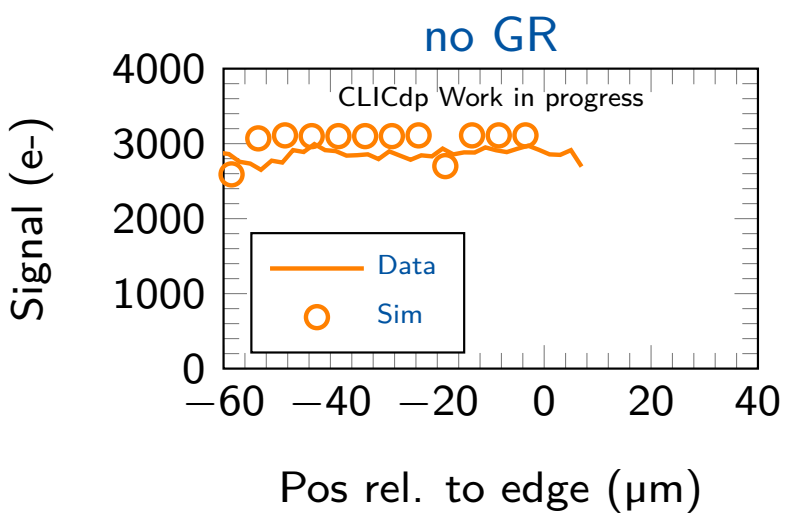
- Create charge along particle path, constant ionization
- Collect charges at the electrodes
- Record transient current in electrodes
- Integrate to obtain charge signal
- Scan particle over the edge region

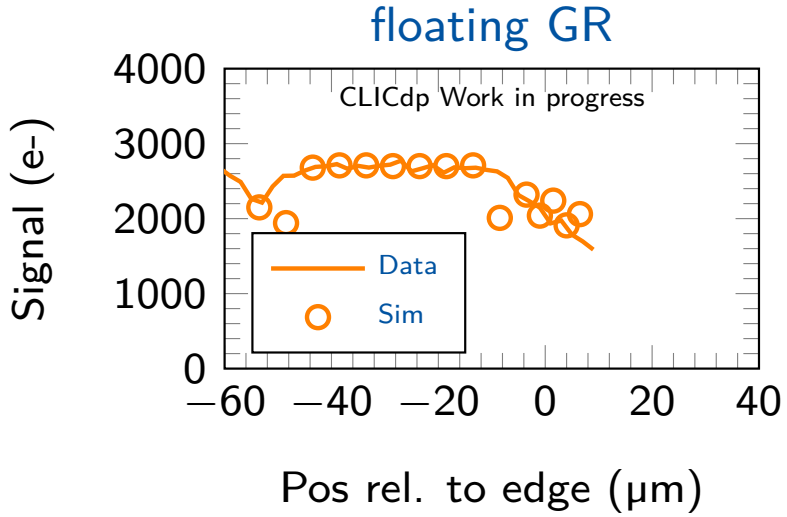
- Example for a 50 µm thick sensor with grounded guard ring:

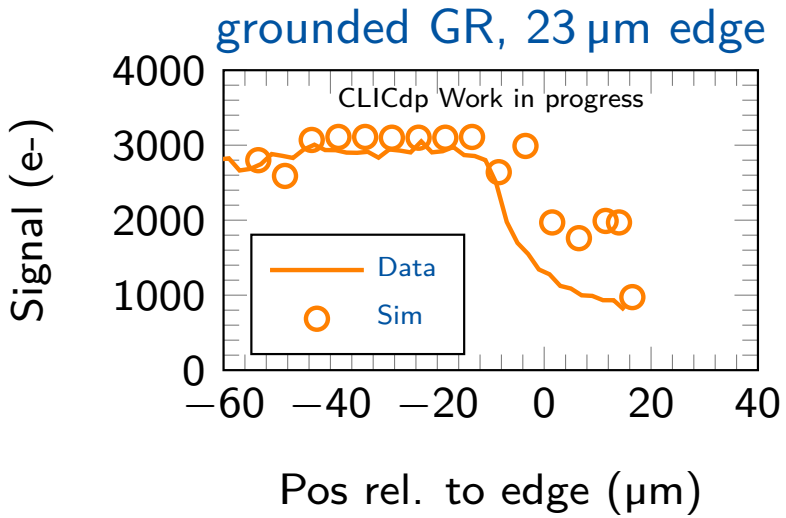


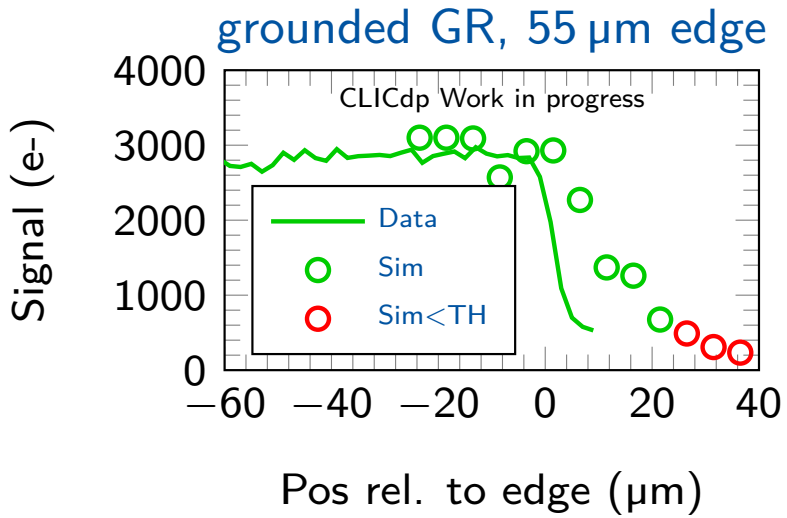


Signal in the edge - T-CAD transient simulation



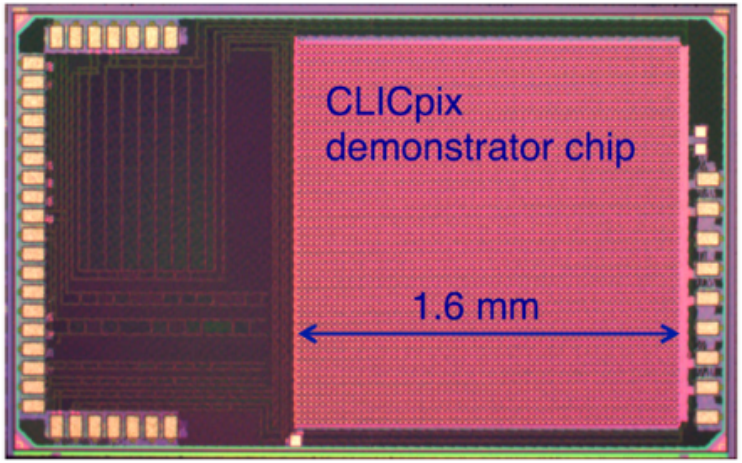


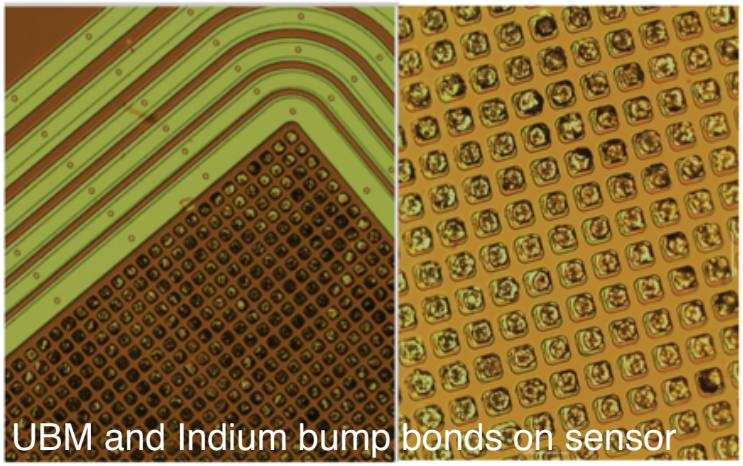


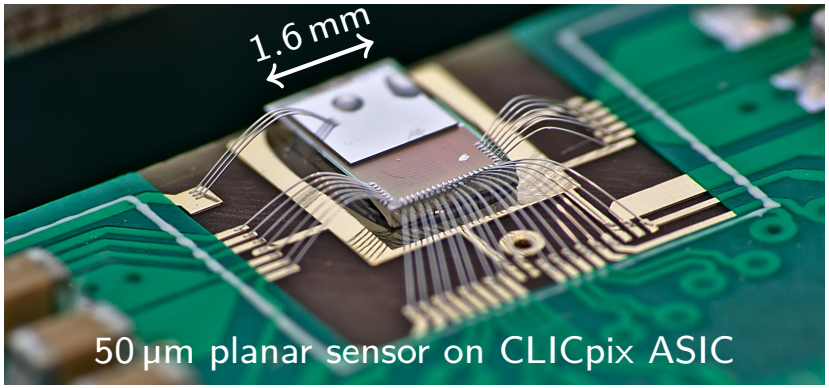


CLICpix planar sensor assemblies

- Single-chip Indium bump-bonding process for 25 µm pitch developed at SLAC
- Assemblies produced with 200 µm, 150 µm and 50 µm n-in-p sensors
- 200 µm assembly tested in AIDA telescope at SPS in 2015
- This talk: 50 µm assembly tested in Timepix3 telescope at SPS in August 2016

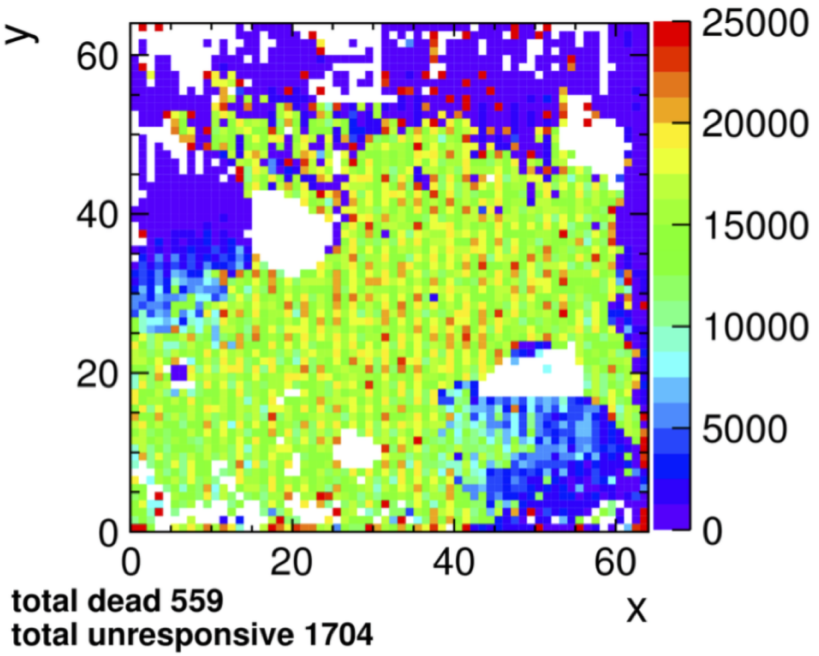






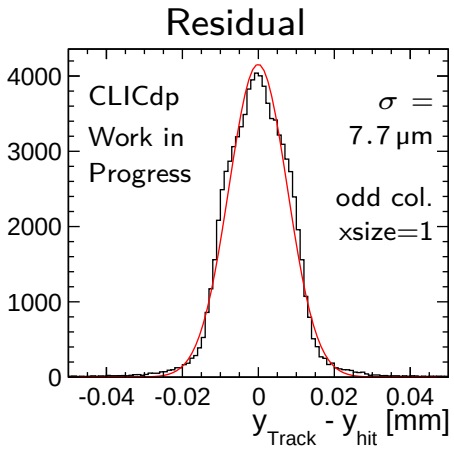
50 µm **thin planar CLICpix assembly**

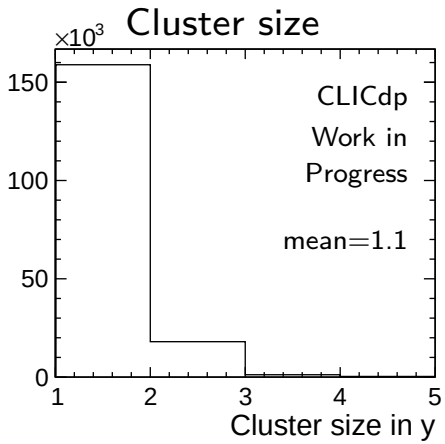
- Advacam 50 µm thin planar n-on-p sensor with active edge
- Assembly shows large dead regions and can only be biased up to 5 V
  → Possible improvements in bump-bonding process identified, more assemblies to come
- Our first 50 µm assembly with 25 µm pixels → Testbeam → focus analysis on good regions
- No edge efficiency results

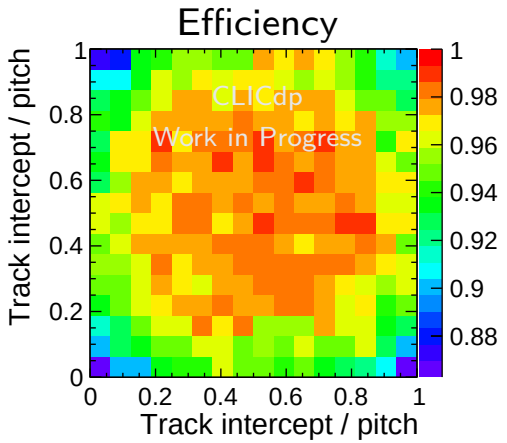


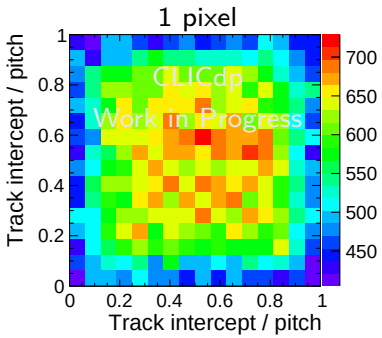
CLICpix with thin planar sensor: Analysis results

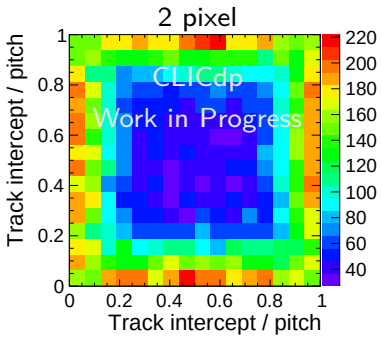
- 5V bias, $\sim 1300\,e^-$ (lowest possible threshold for this assembly)

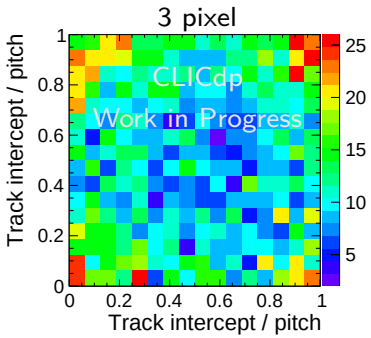


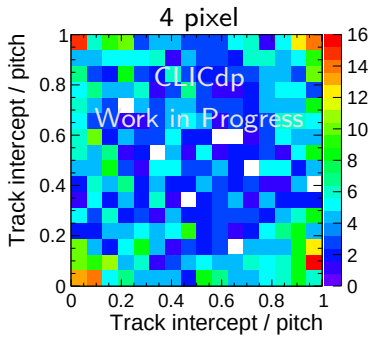








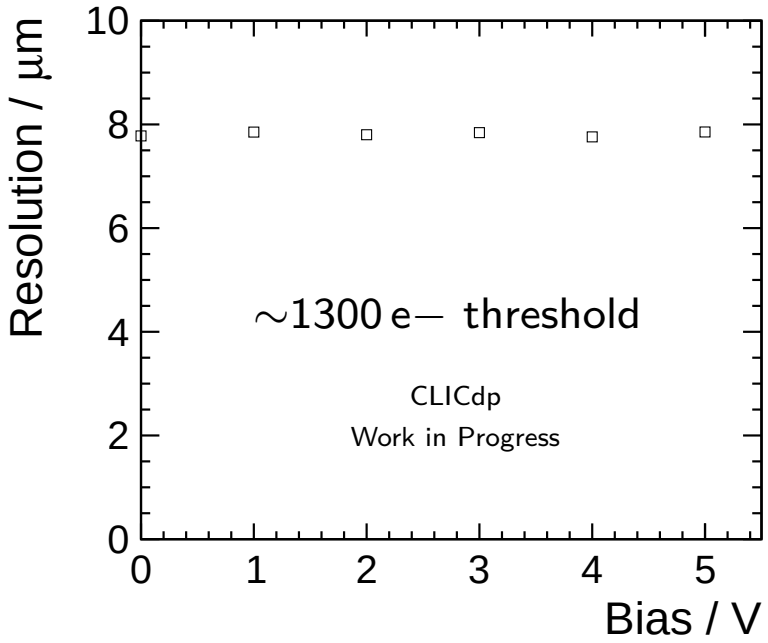


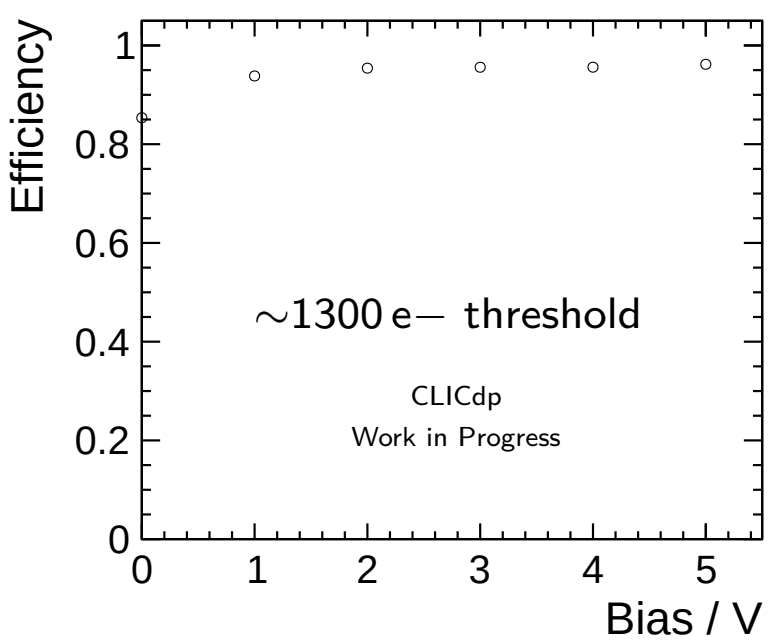


- DUT performance as expected from 50 µm thin sensor at this threshold
- Telescope pointing resolution of $\sim 2\,\mu m$ allows for in-pixel studies even with 25 µm small pixels

Bias scan

- Bias scan from 0 V to 5 V
- Very low depletion voltage around 1 V

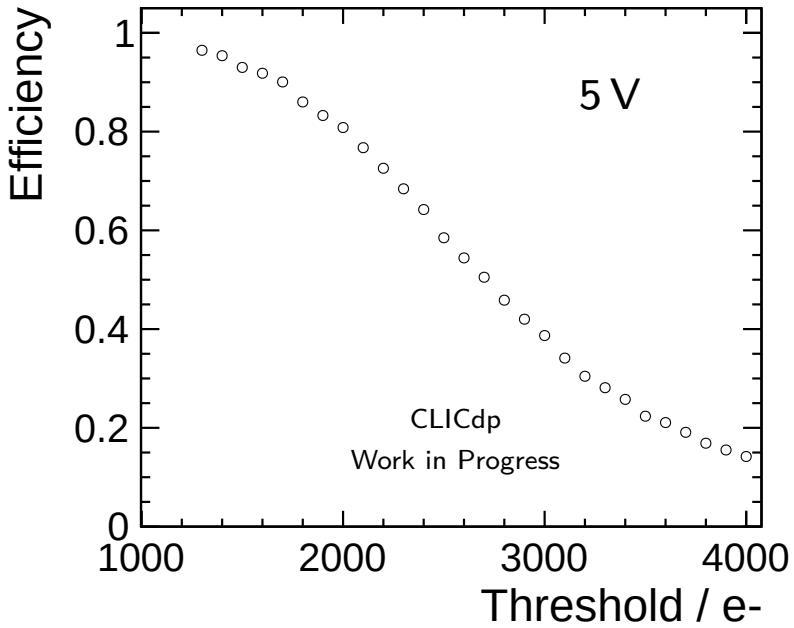


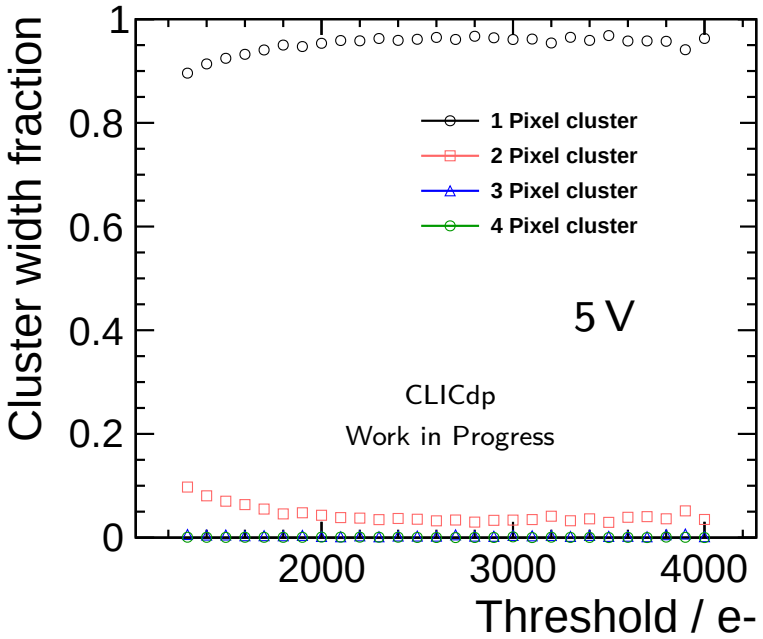


- Cluster size and resolution almost independent from bias voltage
- Efficiency constant above full depletion

Threshold scan

- Threshold scan from 1300 e^- to 4000 e^-





- High efficiency reached at lowest possible threshold, non-responsive regions masked
- Efficiency drops quickly with threshold, as expected for 50 µm thin sensor
- $\Rightarrow$ Threshold has to be set as low as possible for efficient operation

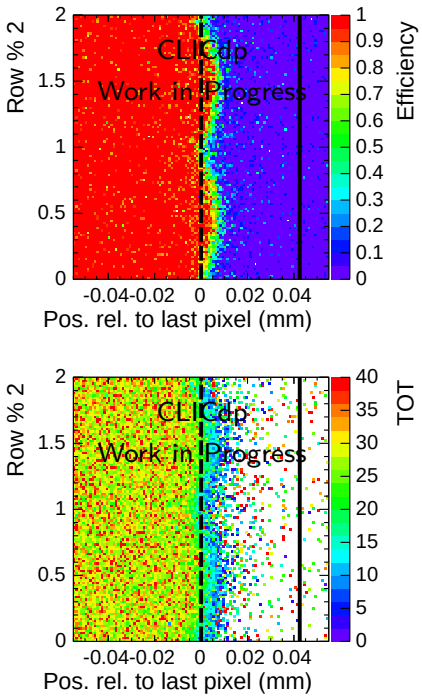
Summary

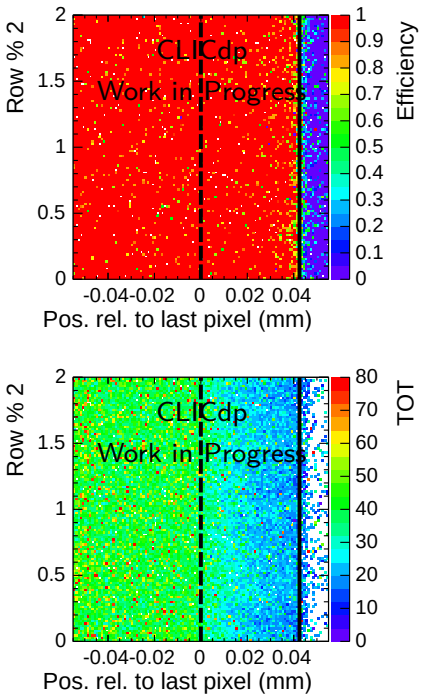
- Investigation of thin planar sensors with active edge using Timepix3 readout
  - Different guard-ring solutions can have significant impact on edge efficiency
  - Study is accompagnied by T-CAD simulations, good agreement to experimental results
  - 50 µm thin sensor, 20 µm edge distance and floating guard ring shows high signal collection and efficiency ($> 99\,\%$) up to the physical edge of the sensor at low threshold (500 electrons)
- 50 µm thin CLICpix planar sensor assembly
  - Assembly successfully tested in Timepix3 beam telescope
  - Little charge sharing in thin sensor limits resolution
  - Significantly higher threshold (1300 electrons) results in slightly degraded detection efficiency ($> 97\,\%$)
  - Sharp drop-off towards higher thresholds $\rightarrow$ low threshold imperative for efficient operation of thin sensors

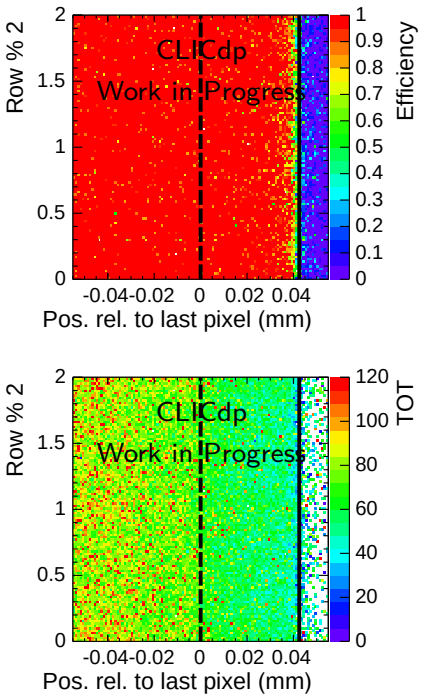
Backup

Edge efficiency vs. thickness

- 50 µm thick, 55-groundGR
- 100 µm thick, 55-groundGR
- 150 µm thick, 55-groundGR

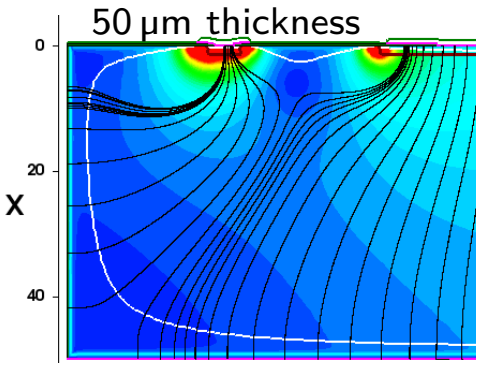


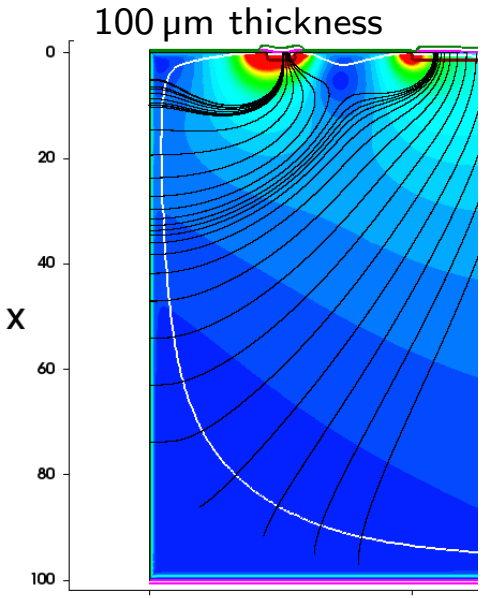


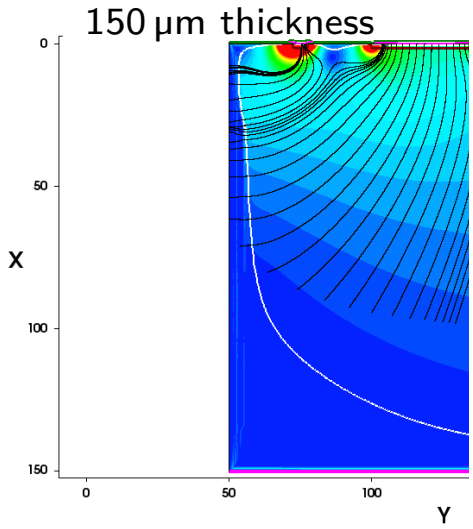


- Higher signal in 100 µm and 150 µm thick sensors
- Thicker sensors efficient up to the edge, even with grounded GR

Electric field in the edge vs. thickness, GND-GR

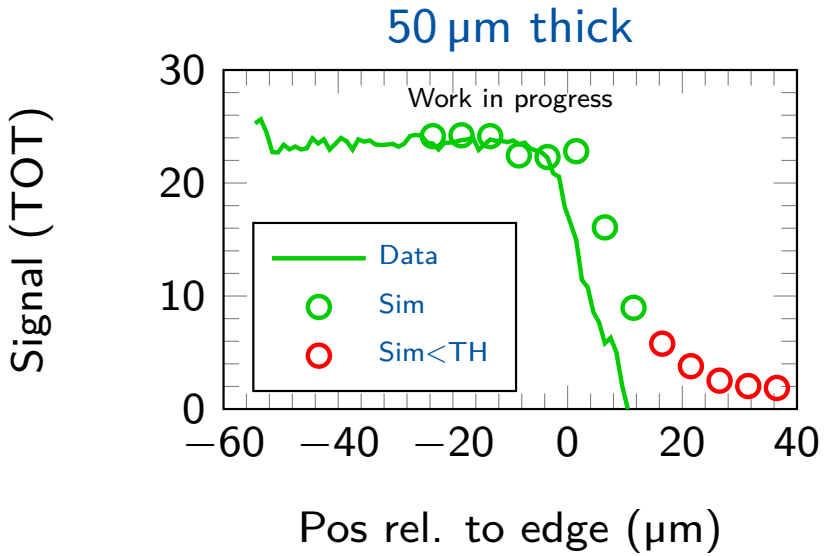


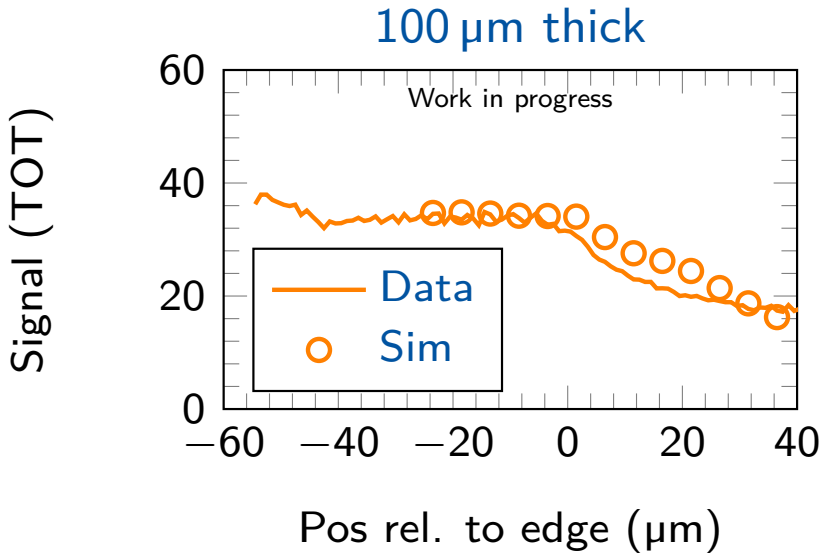


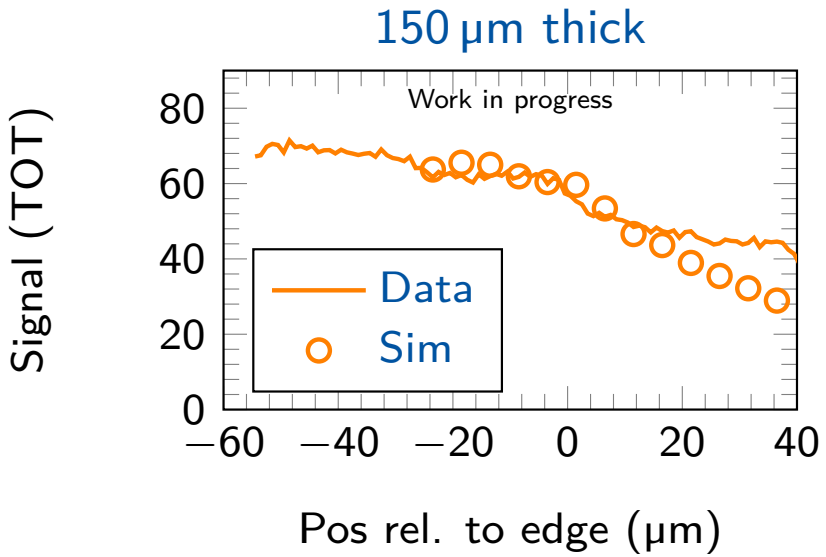


- 55 µm edge, grounded guard ring
- With increasing thickness, sensitiviy of the last pixel extends to the edge region

T-CAD: Signal vs. thickness

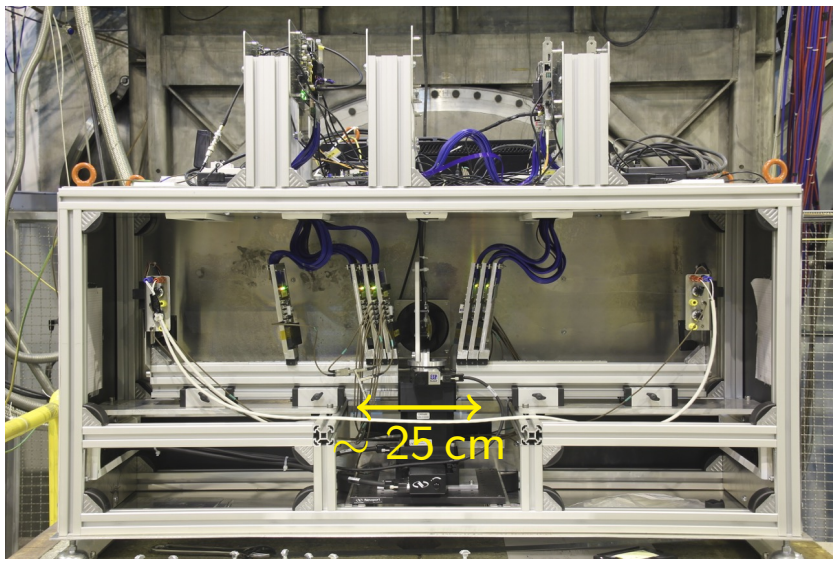


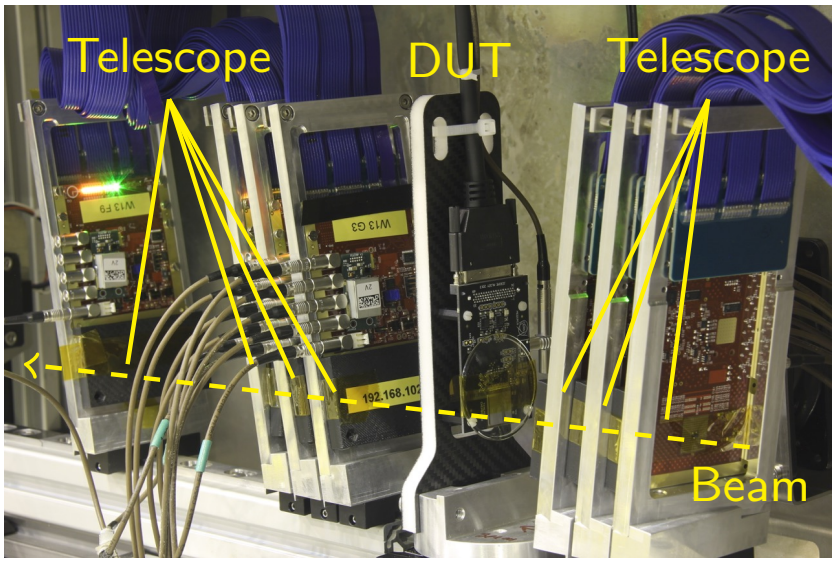




Timepix3 Telescope

- Operated in H6 beamline at CERN SPS, 120 GeV pions
- 7 planes of Timepix3 assemblies (300 µm thick, 55 µm pitch, p-in-n sensors) for reference tracking
- Spatial resolution: $\sim 2\,\mu m$ on DUT
- Timing resolution: $\lesssim 1$ ns on DUT, each pixel hit is time tagged with 1.56 ns clock
- Rate: $\sim 1 \times 10^6$ Tracks/s





CLICpix: Telescope integration

- Frame-based readout
- Count 400 scintillator triggers to define length of the frame, $\sim$ constant occupancy
- CLICpix DAQ records timestamp of shutter open and close
- Analysis builds telescope events, attach the corresponding CLICpix frame
- $\Rightarrow$ Each frame is used in several telescope events