TCAD simulations of HV-CMOS pixel structures

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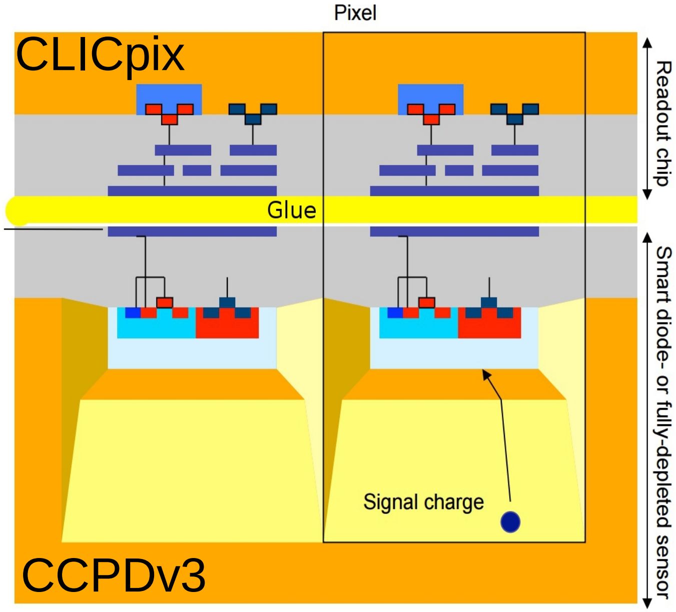
Outline

- Overview of CCPDv3 and TCAD
- Goals of the TCAD simulations
- CCPDv3 simulated structure
- Comparison between 2D and 3D results
- 3 pixel structure
- Summary

CCPDv3 and TCAD



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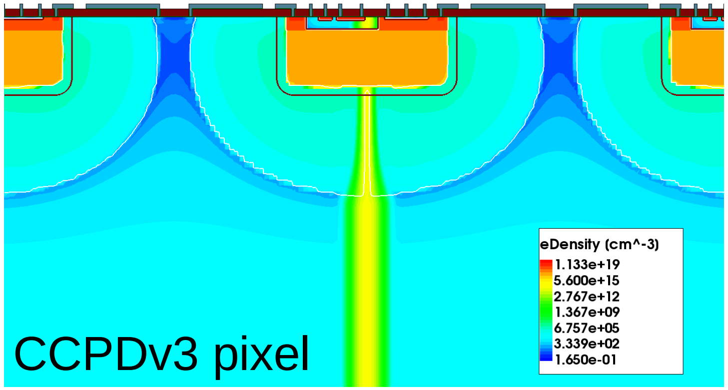
- CCPDv3:
  - HV-CMOS sensor, contains amplifier, peaking time ~120ns
  - Operated at high voltage to maximise the depletion region
  - Improves performance due to decreased detector capacitance and lager signal amplitude
  - Sensor is capacitively coupled to readout chip via glue
  - Hence low cost and low mass, compared to bump bonding
- TCAD:
  - Is a finite element simulation used for semiconductor fabrication and device operation
  - A powerful tool for studying the behaviour of complex structures
  - e.g. doping profile,electrical behaviour and mip simulations



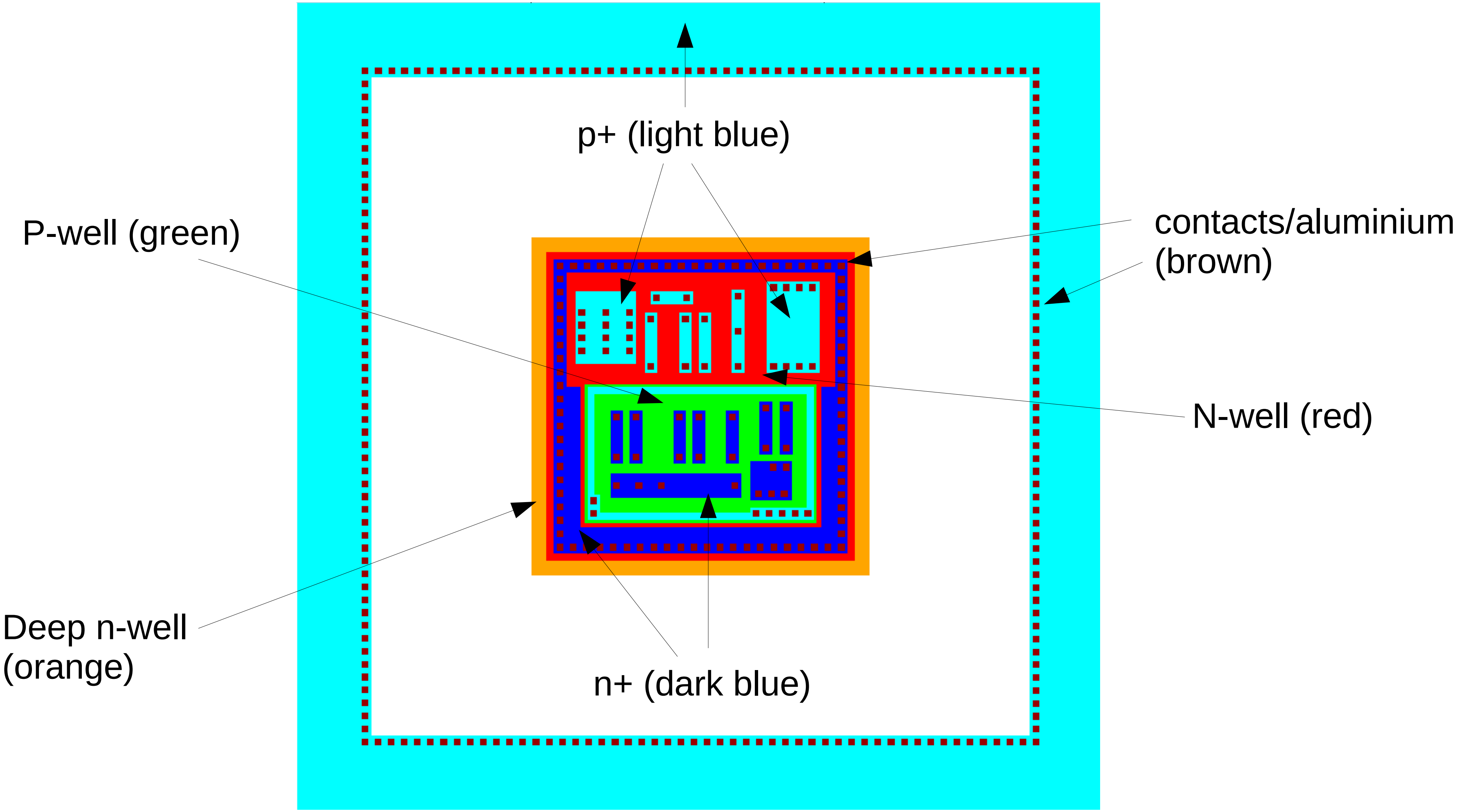
Goals of HV-CMOS TCAD studies

- Understand features of the measurements better e.g. transient signal development
- Improve the comparison between simulation and measurements
- Use as input for simulation chain of sensor and readout chip
- Want to check the validity of the 2D simulations by comparing to 3D ones

- Limitations of 3D simulations:
  - Very memory intensive, using large amount of RAM, long run times
  - Has a trade off between mesh size (convergence) and memory
  - Reduced the model with less implants to reduce memory
- Hence 2D is much quicker but is it realistic?

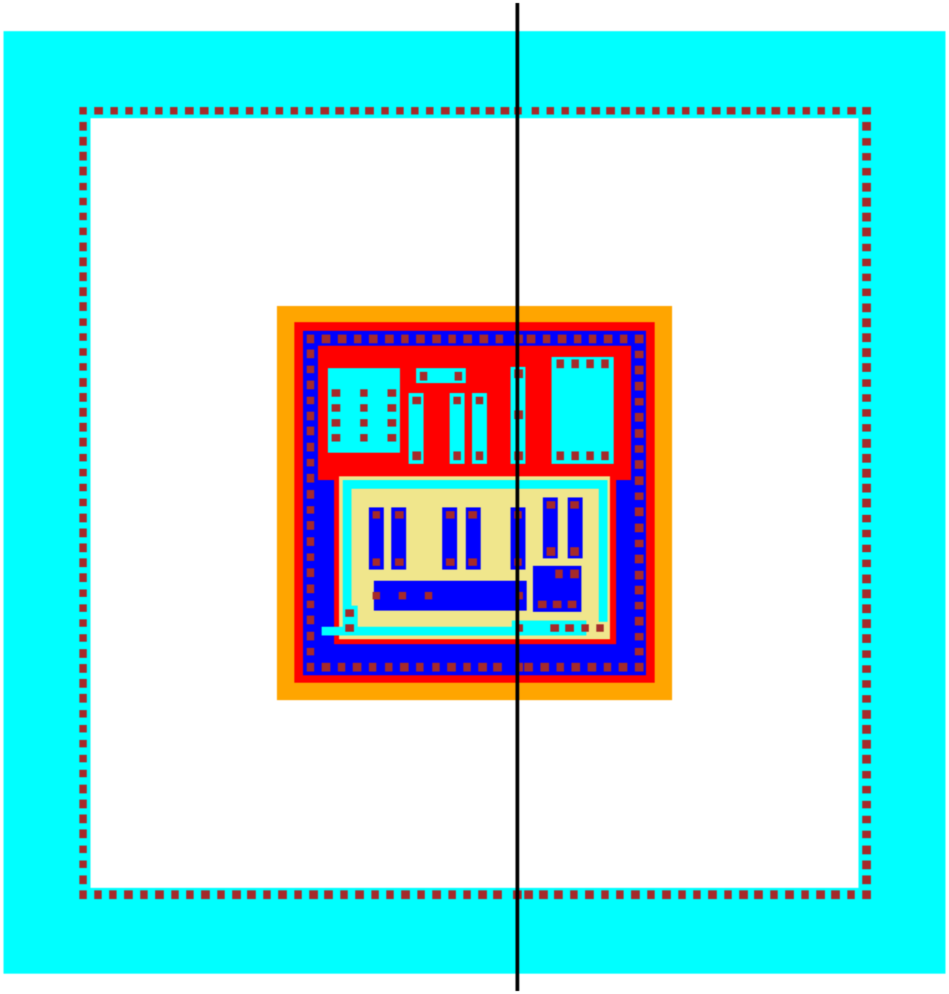
CCPDv3 layers to be simulated

- Layers obtained from the design file (gds layout file)
- Full implant structure, no metal lines shown



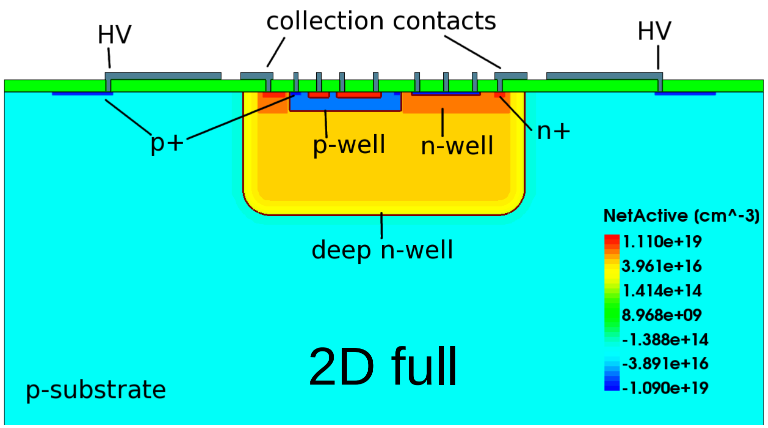
2D Cut

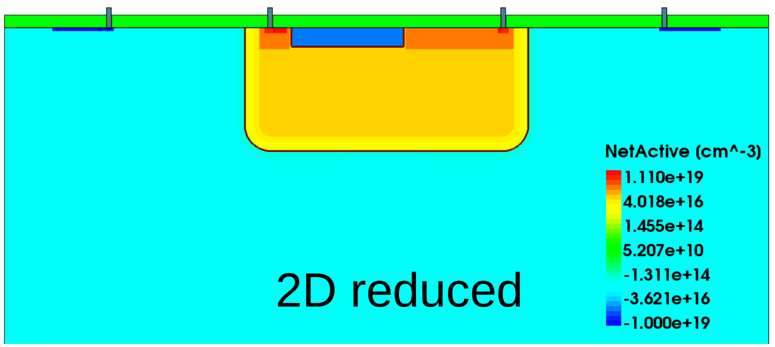
- Not an exact cut of CCPDv3
- There is no ideal cut as it is not symmetric
- Adjusted some layers so that contacts could be made



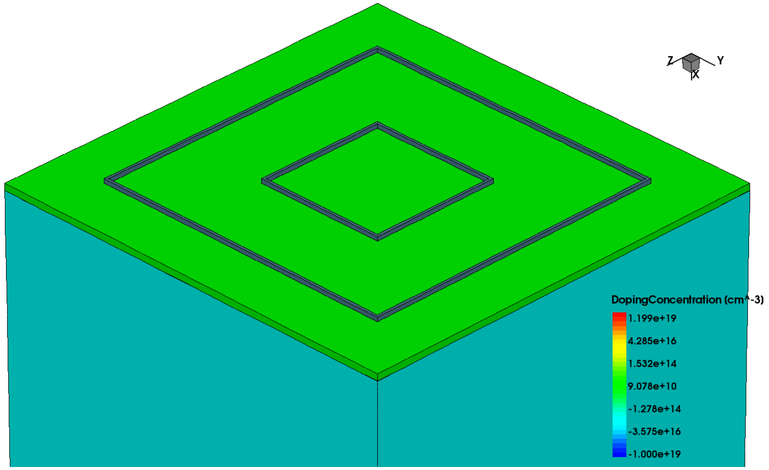
Simulated TCAD structures

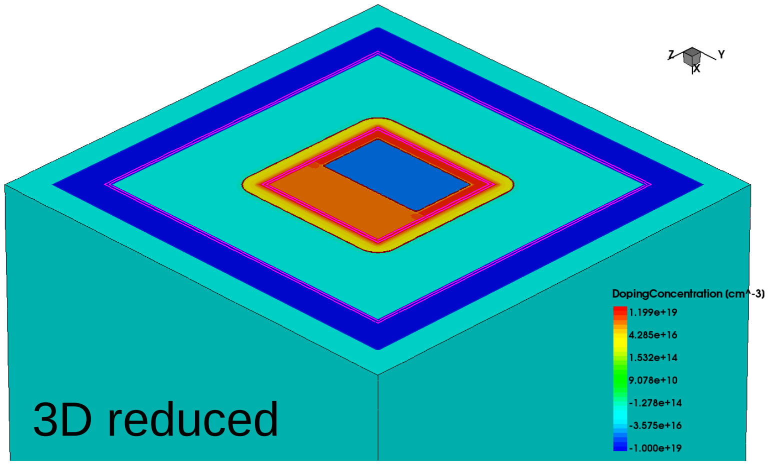
- 3 structures simulated: 2D full, 2D reduced and 3D reduced
- 2D full has all the implants and contacts
- The 2D reduced and 3D reduced structures both have the same implant structure
- 100 µm thick 31.5 µm wide
- “Net active” is the doping concentration





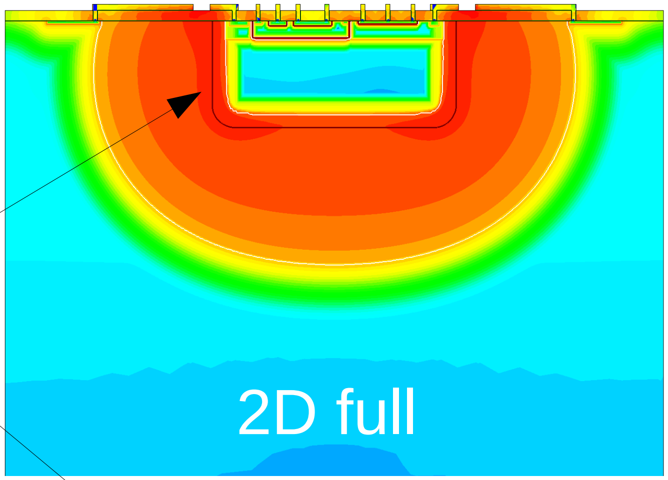
3D reduced with oxide and aluminium

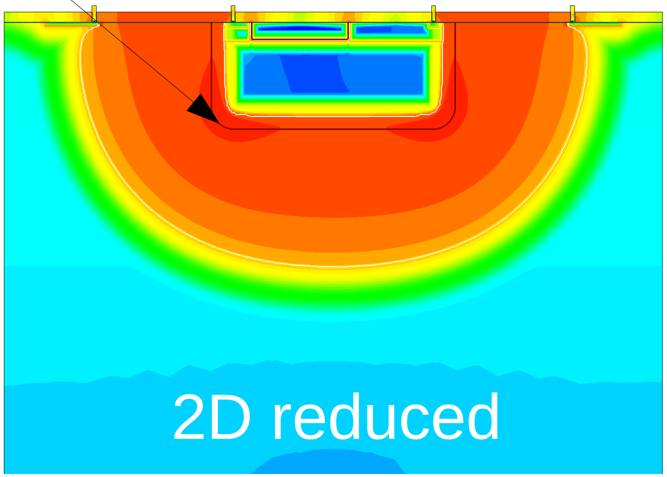


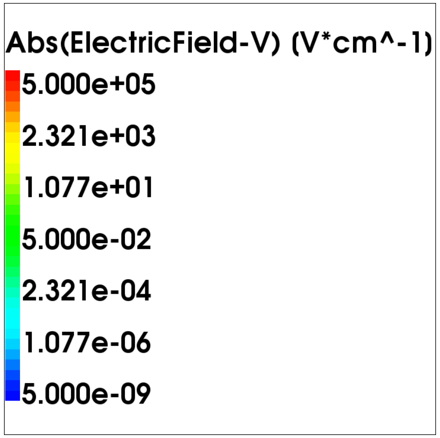


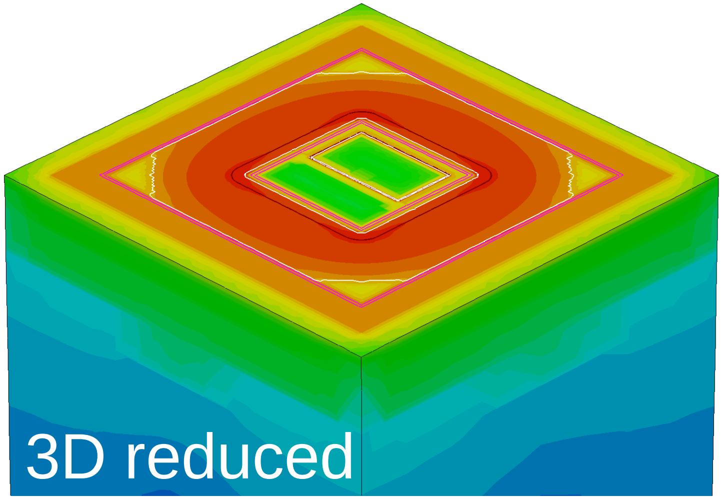
E-field comparison

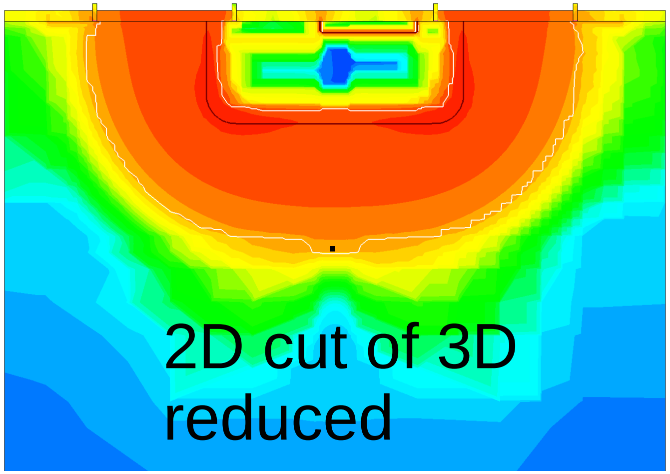
- Biased to -60V, operating voltage of device
- All electric fields are roughly the same, higher value at edges of the deep n-well
- One difference in the 2D full model is a higher electric field value in the oxide and in the substrate because of the metal layer





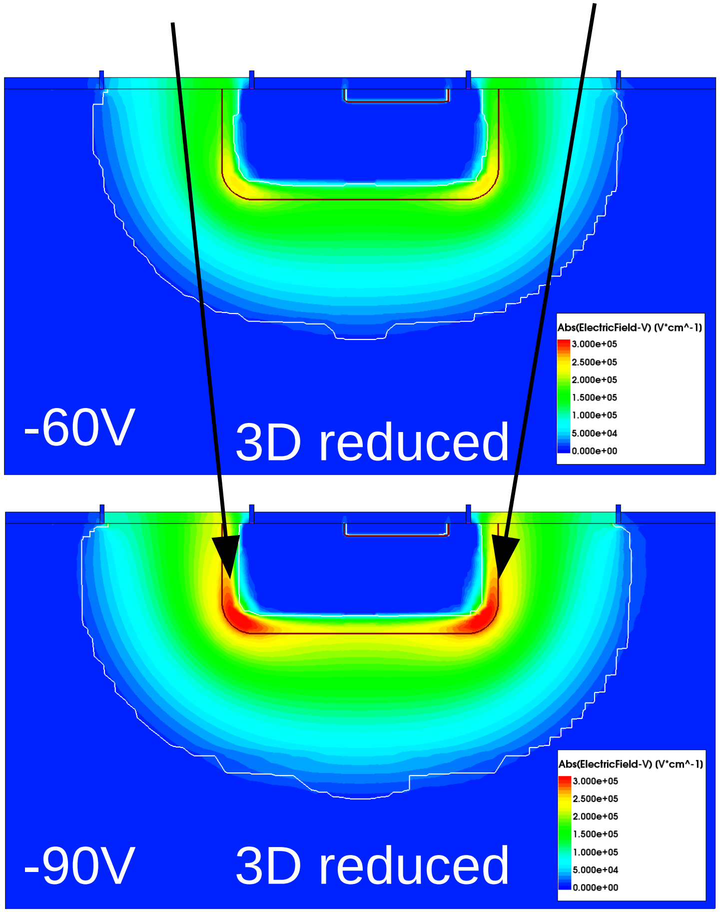


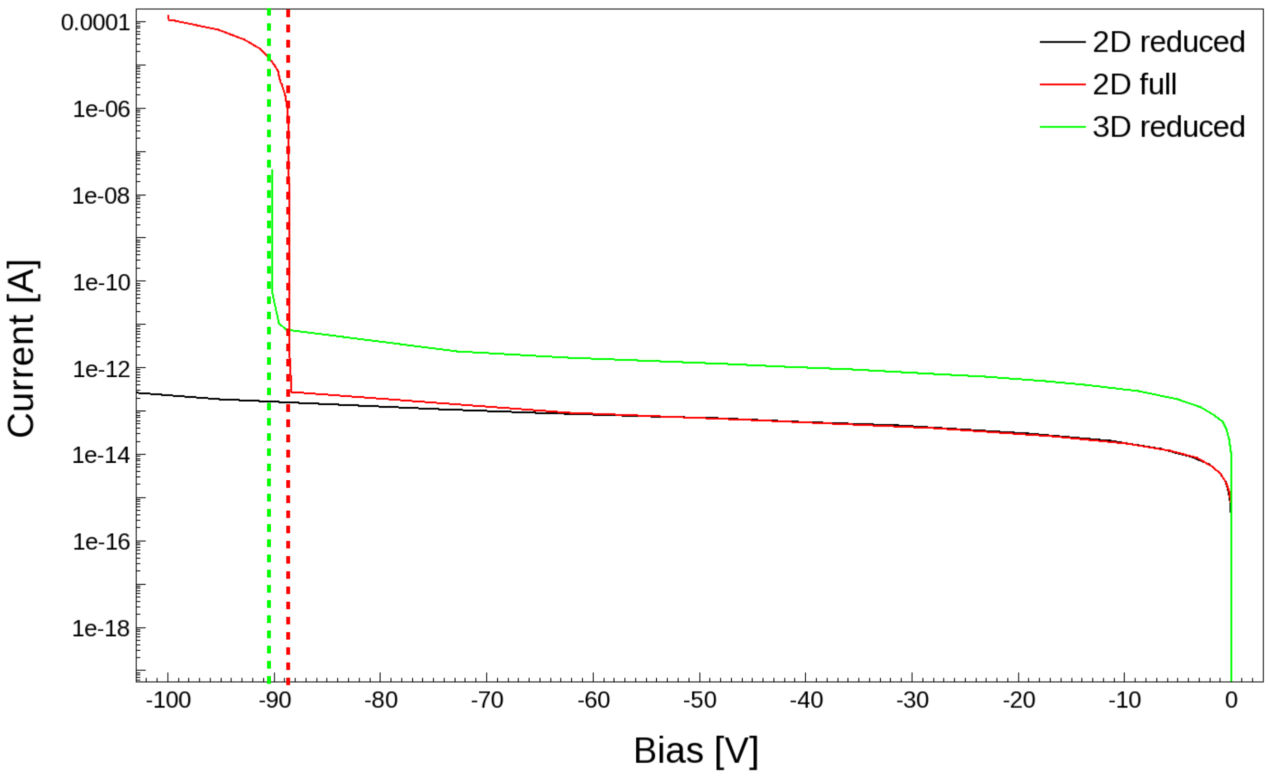




Leakage current comparison

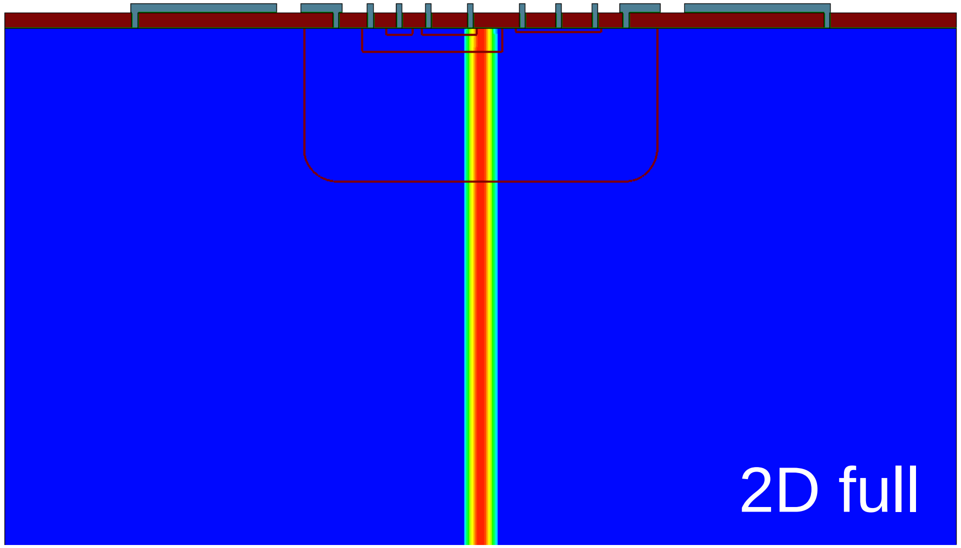
- Breakdown of real device was measured to be -93V
- See breakdown in 2D full at ≈ -88V and for 3D reduced ≈ -90V
- Breakdown in 2D reduced greater than -100V due to no metal layer
- Breakdown field of silicon ≈ $3x10^5$ V/cm





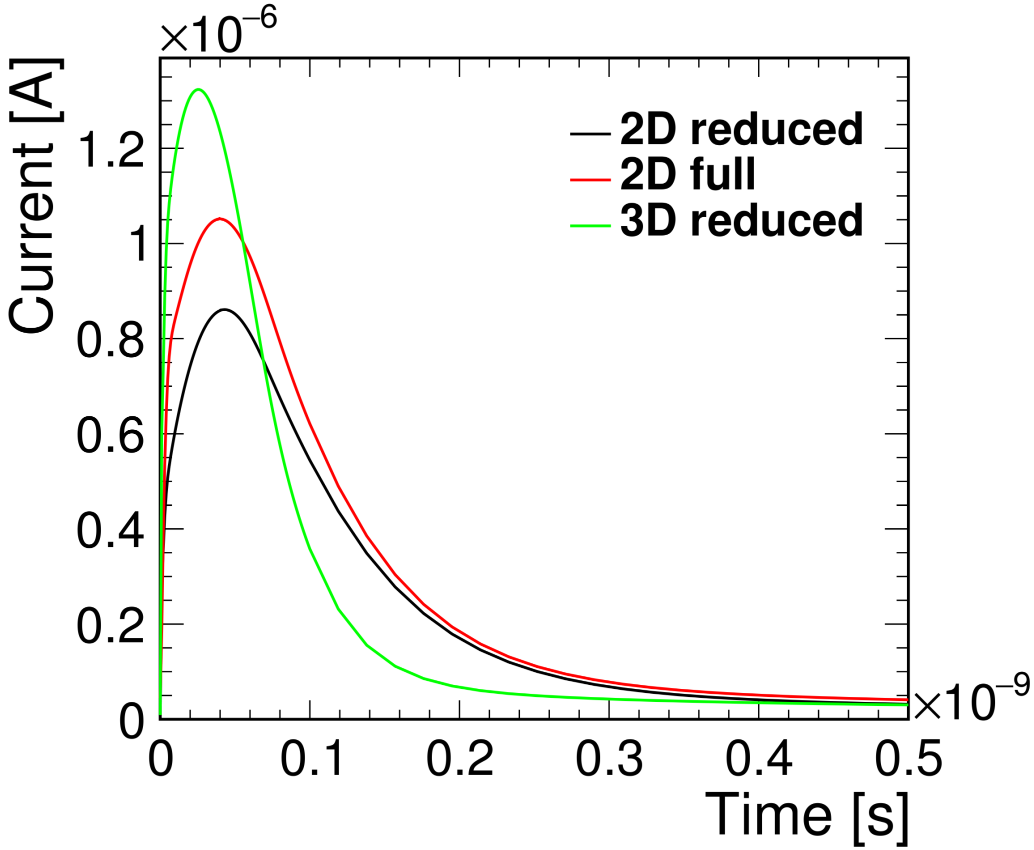
Mip simulation

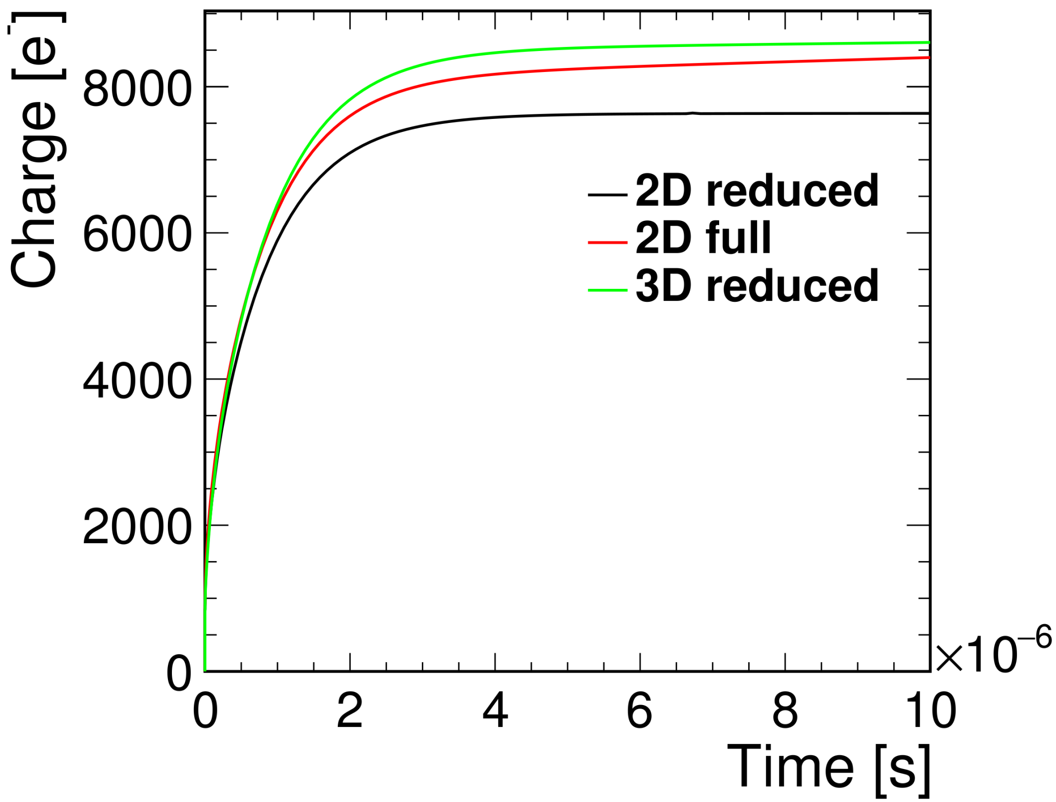
- In TCAD specify time, position and charge deposition of the particle
- Charge is then instantaneously placed
- The mip passes the centre of all three structures
- Deposits ≈ 80 eh pairs per micron
- Transient simulation from 0-10μs is performed at bias -60V
- Real sensor is 250μm thick but found only 100μm contribute to signal hence simulation is quicker



Mip signal

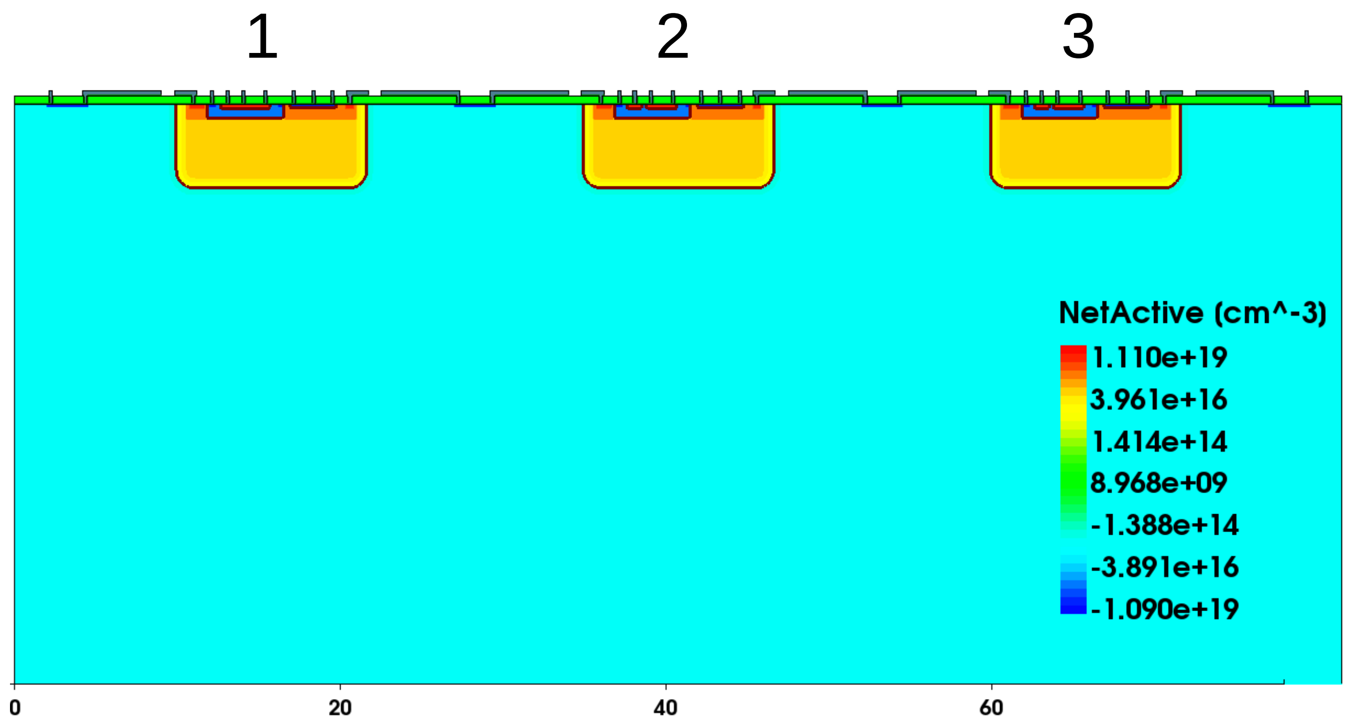
- 3D reduced model has the largest peak but quickly drops to the lowest value
- The 2D full model has larger current value than the 2D reduced model
- After 10μs 3D reduced collects the most charge: around 200e⁻ more than 2D full and 900e⁻ more than 2D reduced
- May be due to coarser mesh





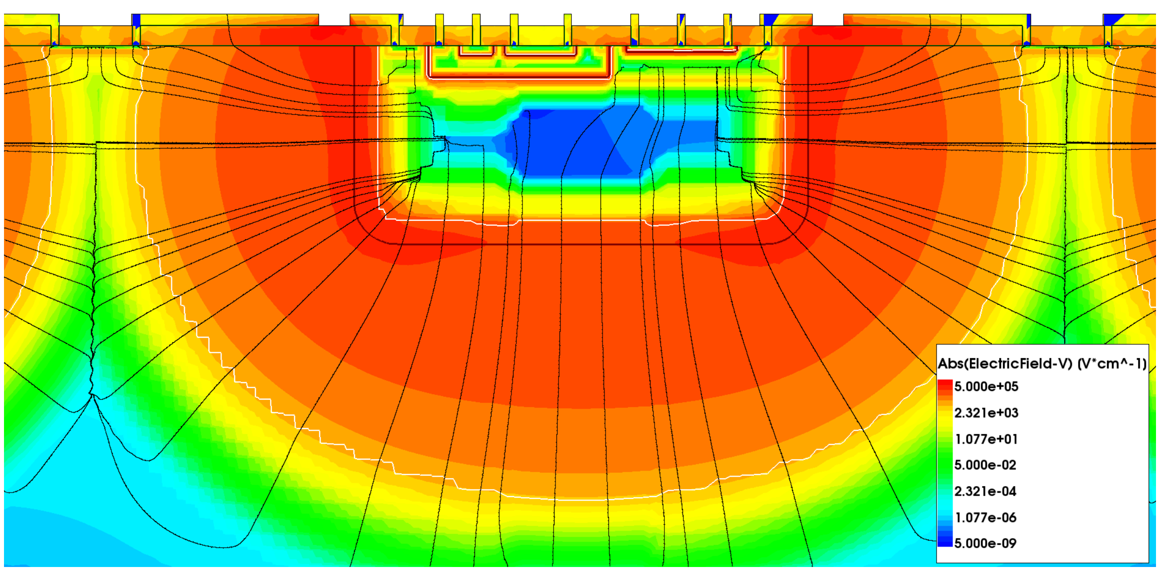
2D full 3 pixel structure

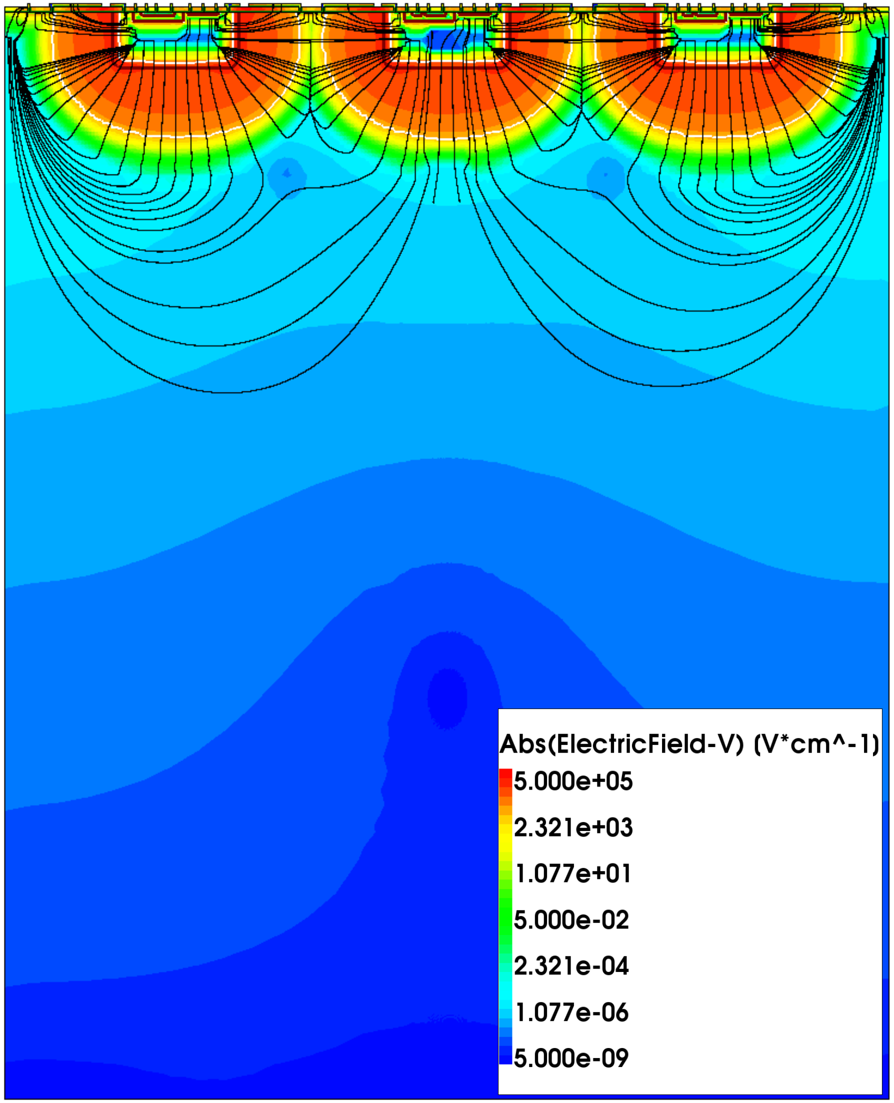
- 3 pixel structure with a pixel pitch of 25µm
- Width 81.5µm, thickness 100µm
- Labelled pixel 1, 2 and 3 from left to right
- Look at different resistivities 10 Ωcm, 80 Ωcm, 200 Ωcm and 1000 Ωcm



Electric field, -60V, 10 Ωcm

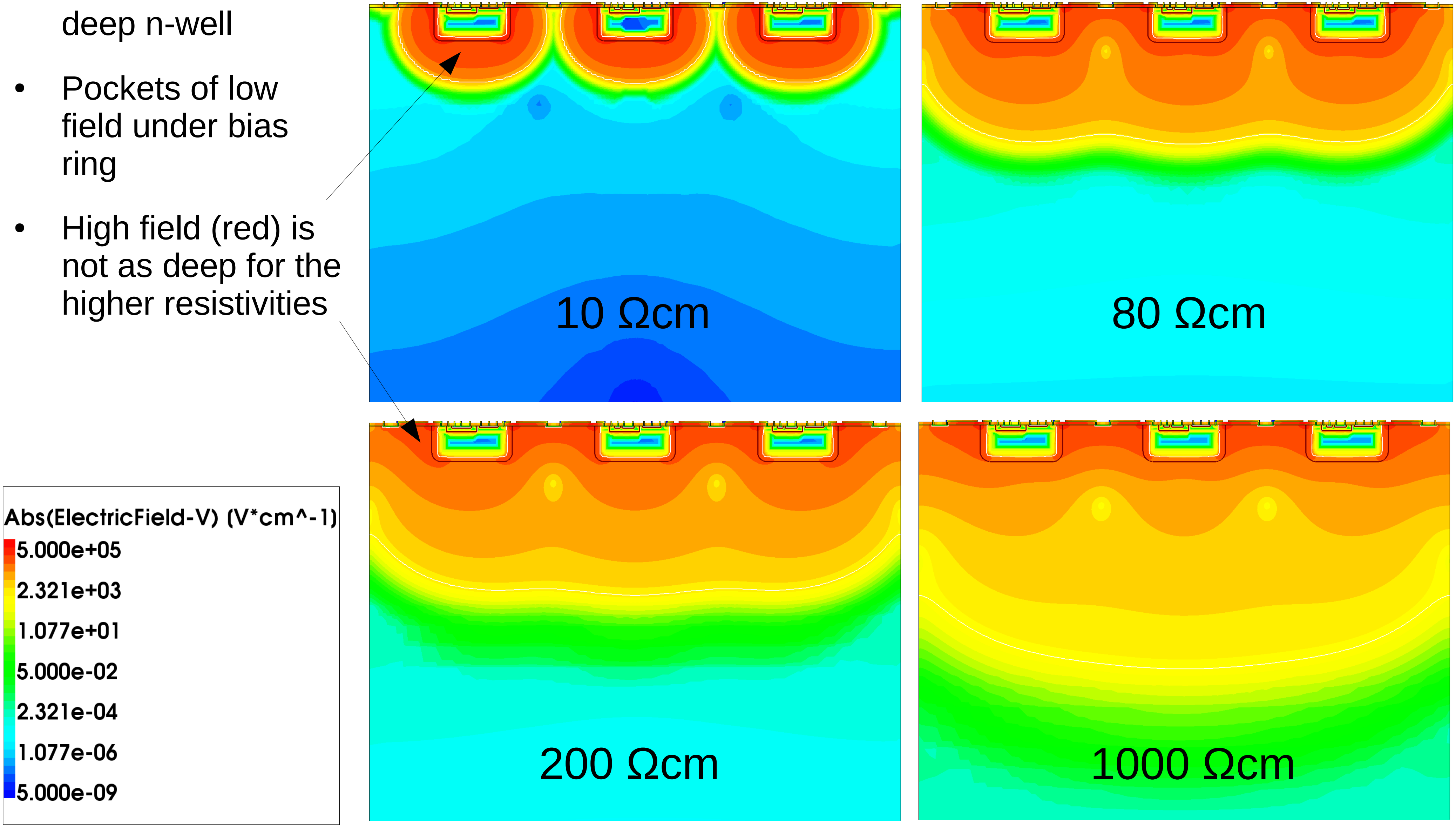
- Very low outside depletion
- Highest around edges of deep n-well
- See low field inside deep n-well
- Field curves round to edges due to geometry of the structure
- Not true field lines, streamlines





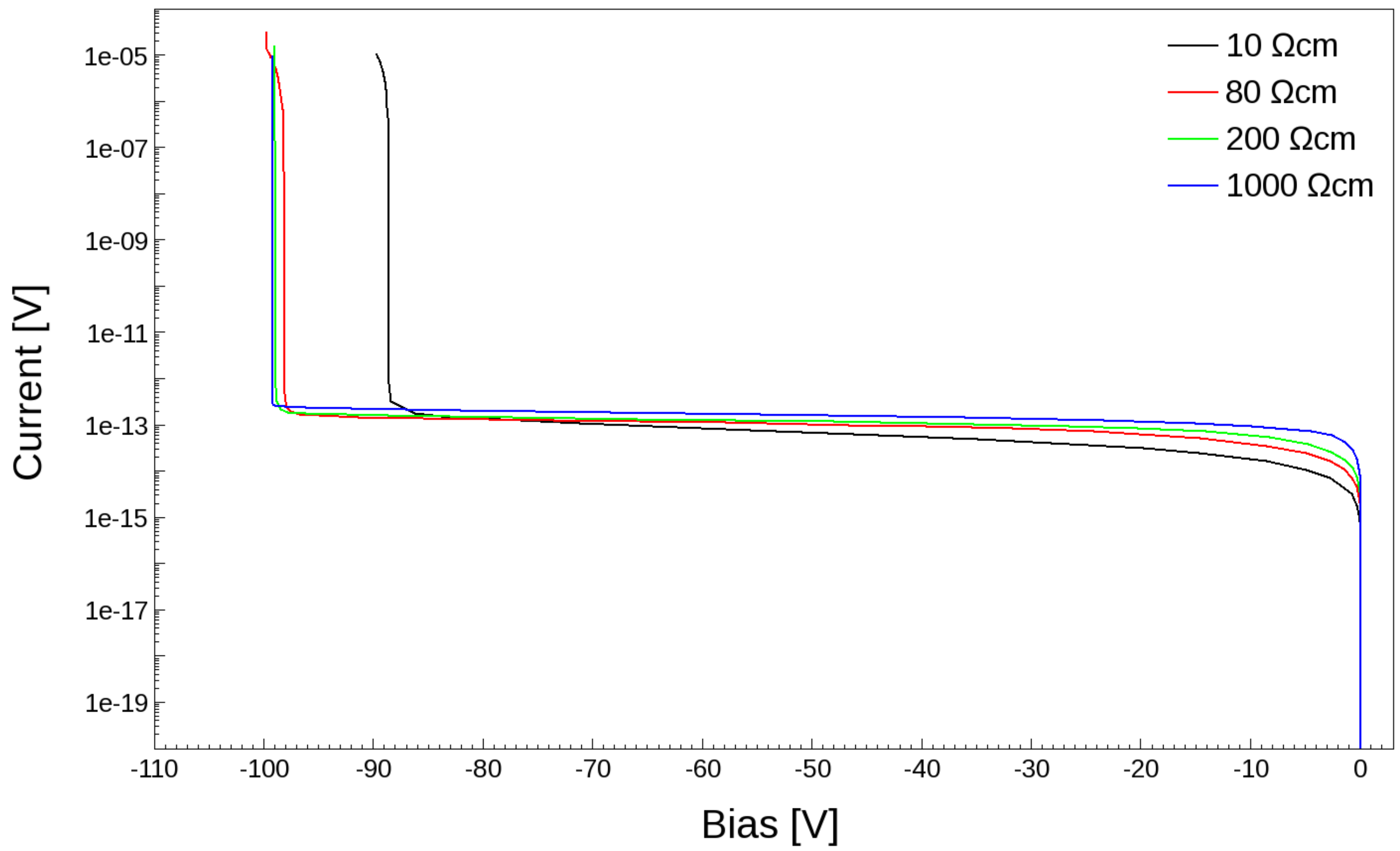
Electric field for different resistivities, -60V

- Field extends the most under the deep n-well
- Pockets of low field under bias ring
- High field (red) is not as deep for the higher resistivities



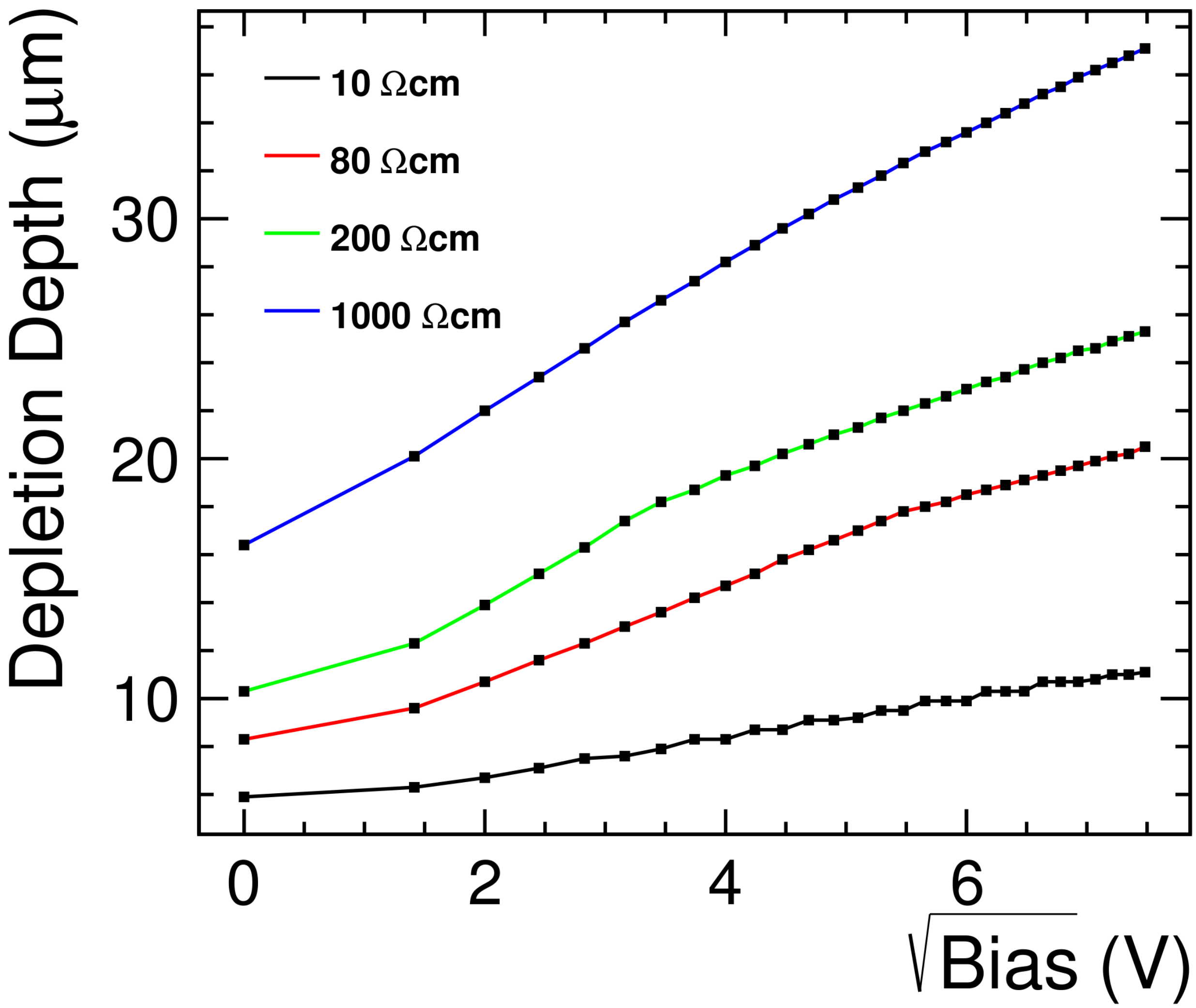
Breakdown for different resistivities

- The breakdown increases with resistivity
- The higher resistivities all breakdown ≈ -100V suggesting the implant structure is the limiting factor



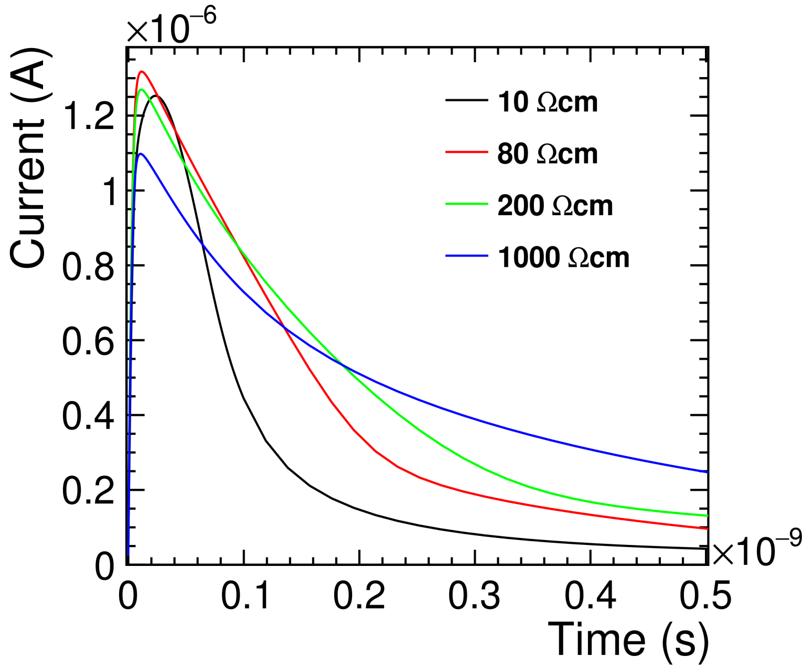
Depletion depth for different resistivities

- As expected the larger the bias and resistivity the larger the depletion depth

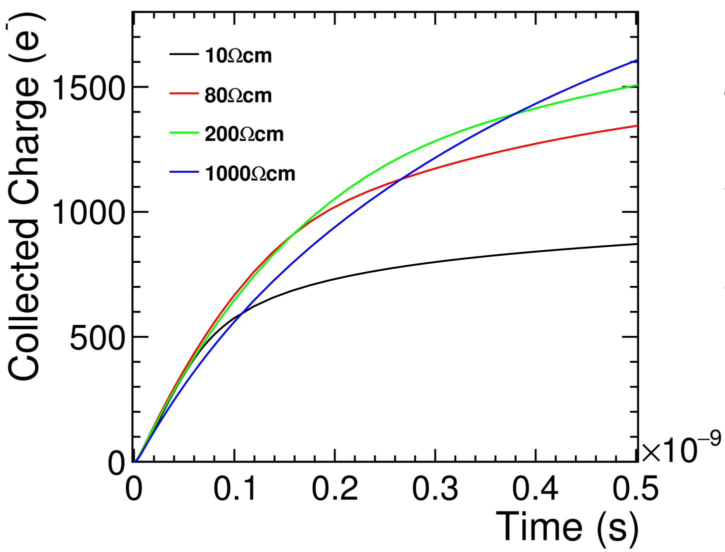


Mip signal for different resistivities, -60V

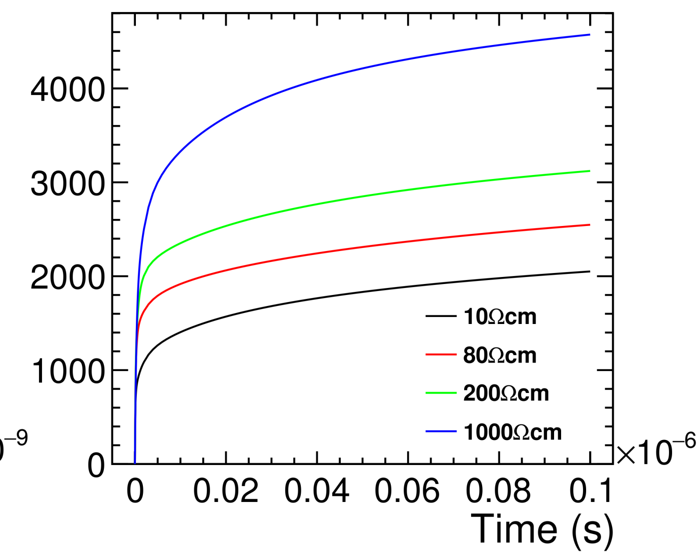
- Send a mip through the centre
- Similar current peak height and time for all resistivities
- After 0.5 ns 10 Ωcm is slower
- The other resistivities collect similar charge
- However after 10 µs 1000 Ωcm collects the most charge by ≈ 1000 e^-



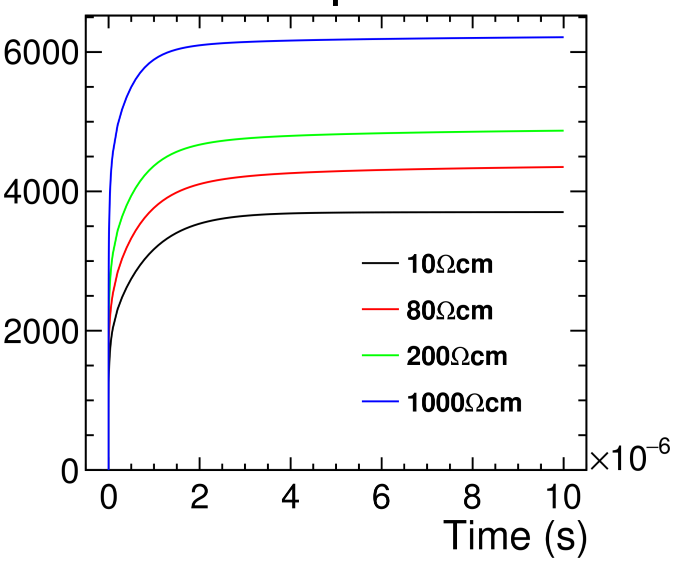
0.5ns



100ns

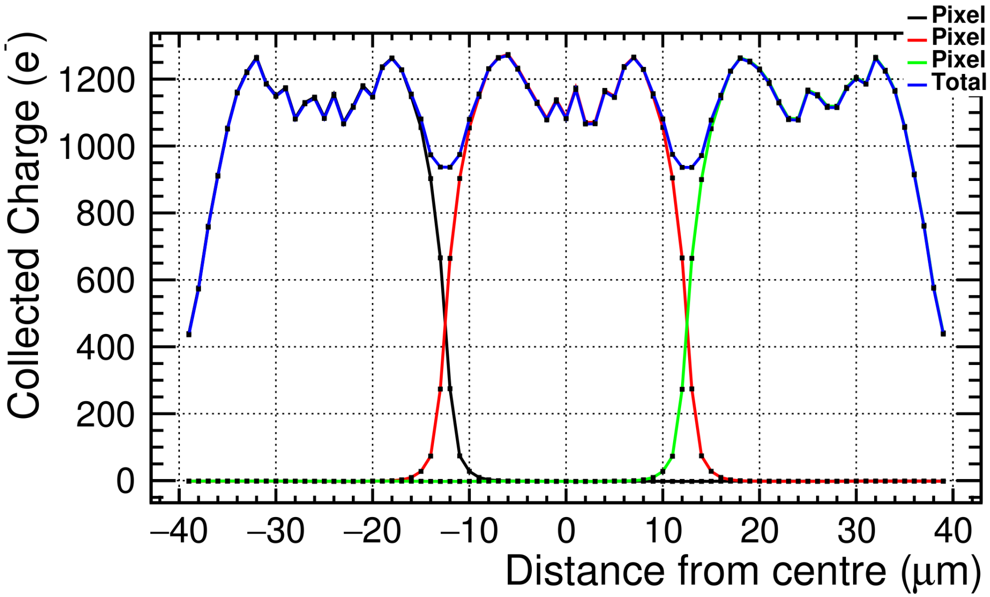


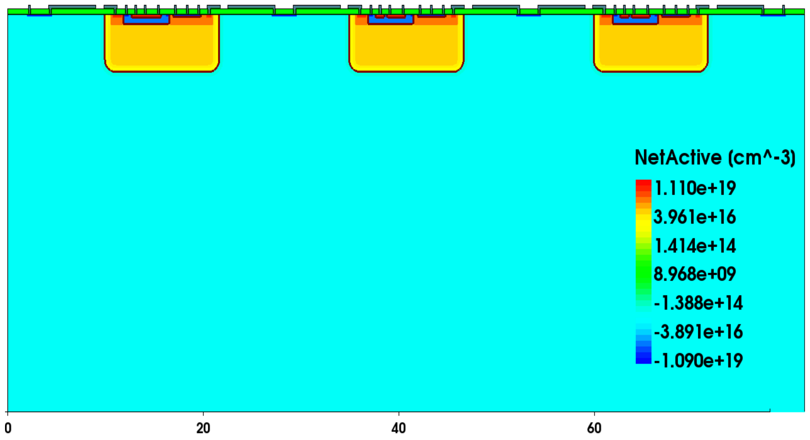
10µs

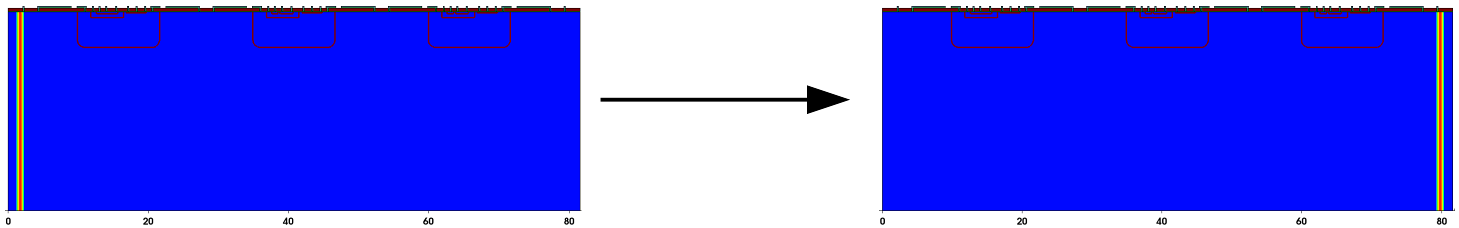


Mip scan collected charge 2ns

- Look at 10 Ωcm, -60V
- Mip scan across the structure, perpendicular to surface
- From 1.75µm (-39µm) to 79.75µm (+39µm) in 1µm steps
- Centre of device is 40.75µm
- After 2ns not as much charge is collected when mip passes through deep n-well
- Also pixels collect 0 charge when the mip is far enough away,
- No diffusion from these regions yet
- Lowest collected charge at edges

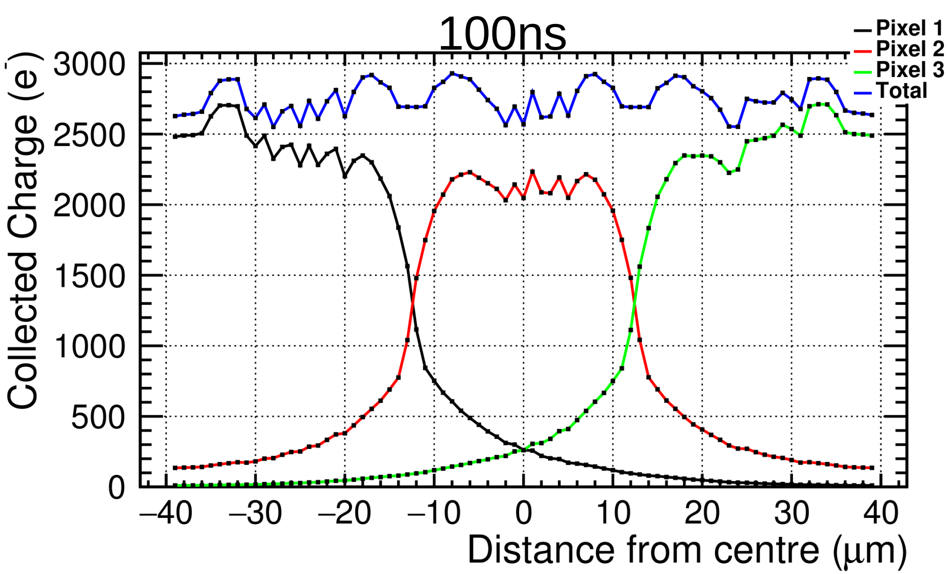


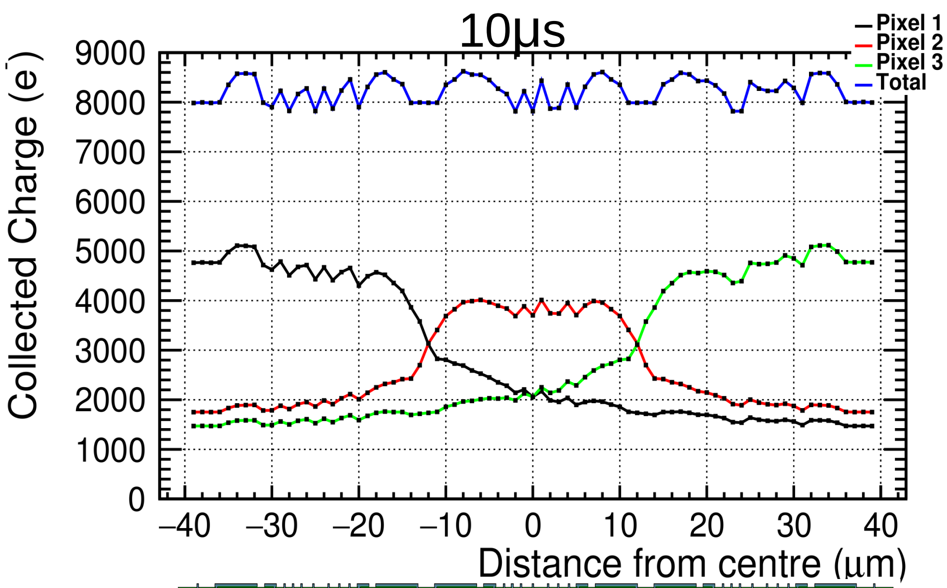


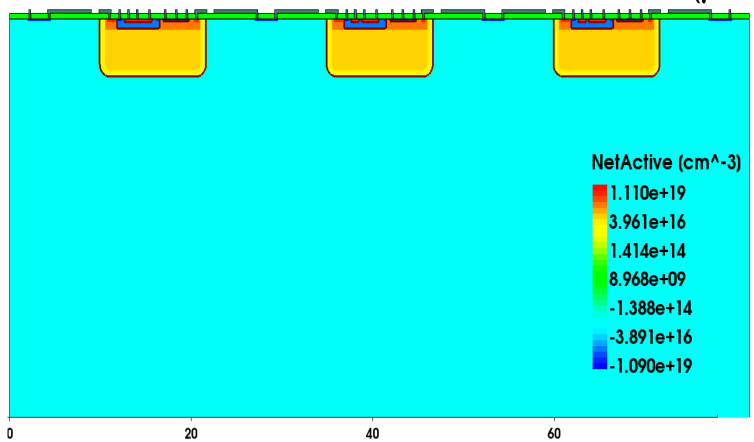


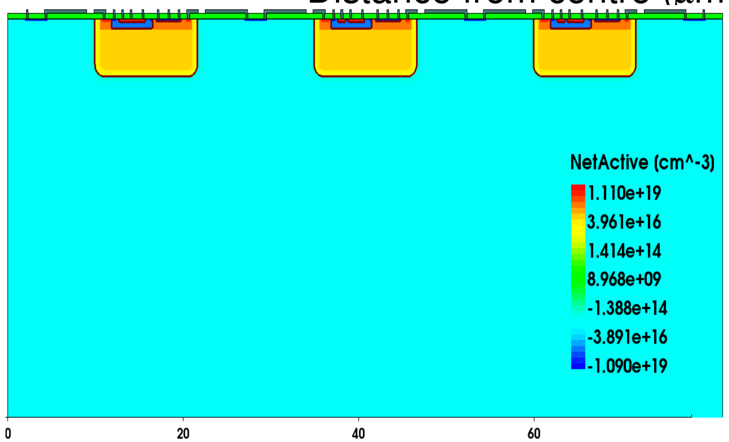
Mip scan collected charge 100ns and 10µs

- Look at 10 Ωcm, -60V
- After 100ns two side pixels collect more charge (edge effect),
- Start to see diffusion to neighbouring pixels
- Edges now collect more compared to 2ns, hence this is due to diffusion









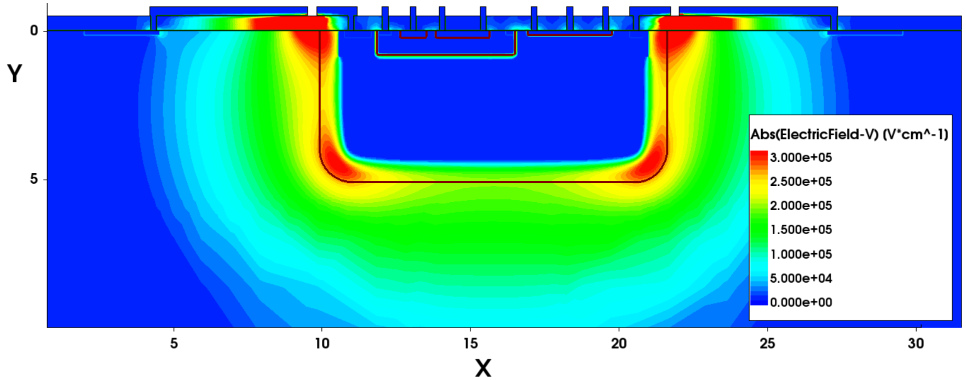
Summary

- 2D 3D comparison:
  - Agreement between the models in electric field
  - IV curves are similar for 2D full and 3D reduced
  - Difference is less than 10% for charge collection after 10μs
  - Reasonable to use the 2D full model

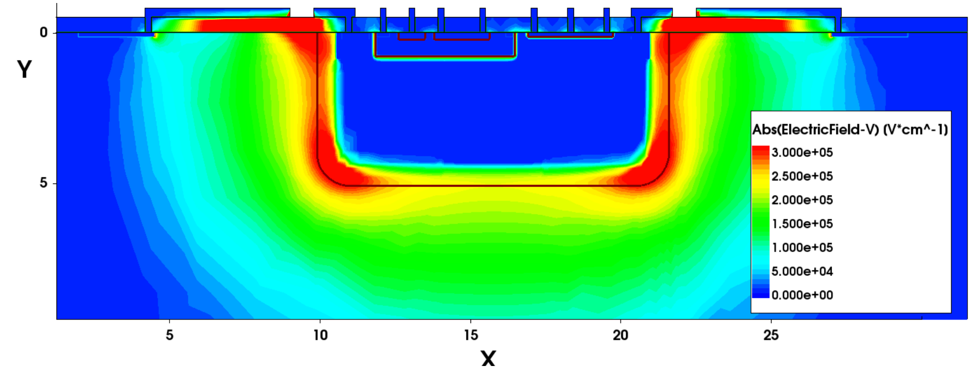
- 3 pixel structure
  - Breakdown and depletion depth increase resistivity
  - Larger resistivities collect more charge, 1k Ωcm significantly more after 100ns, 50% larger than 200 Ωcm
  - After 100ns charge collection is approximately uniform
  - Signal used for input of the simulation of CCPDv3 ASIC part

Backup

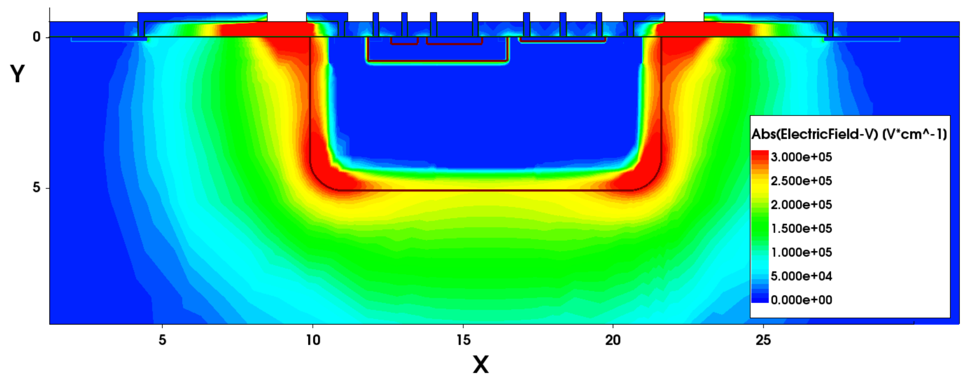
E-field for different metal widths, -100V, 2D full



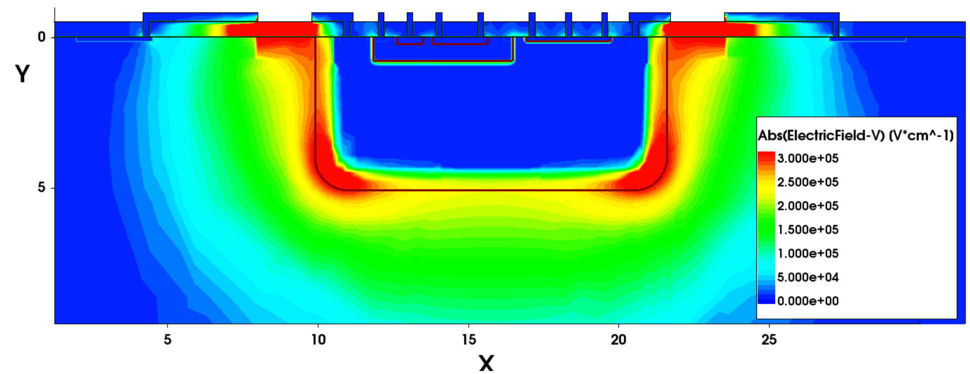
M1+0.5 (-79V)



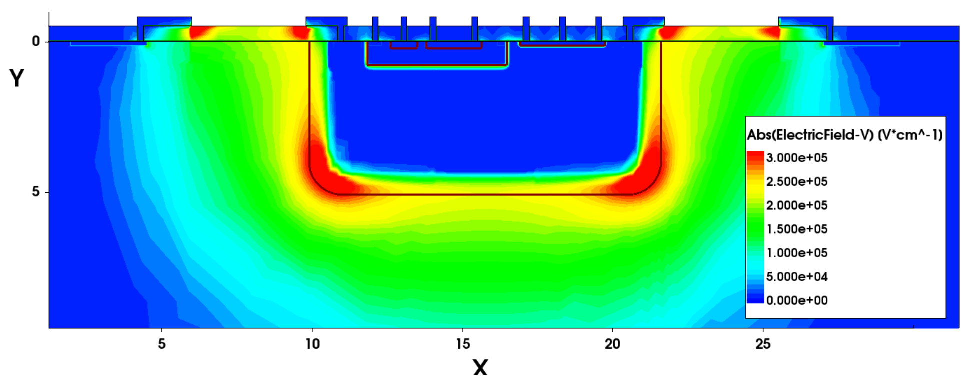
M1



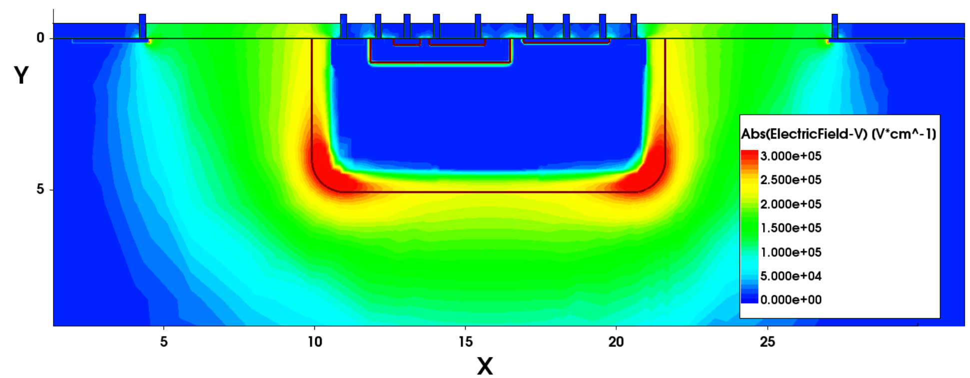
M1-0.5



M1-1



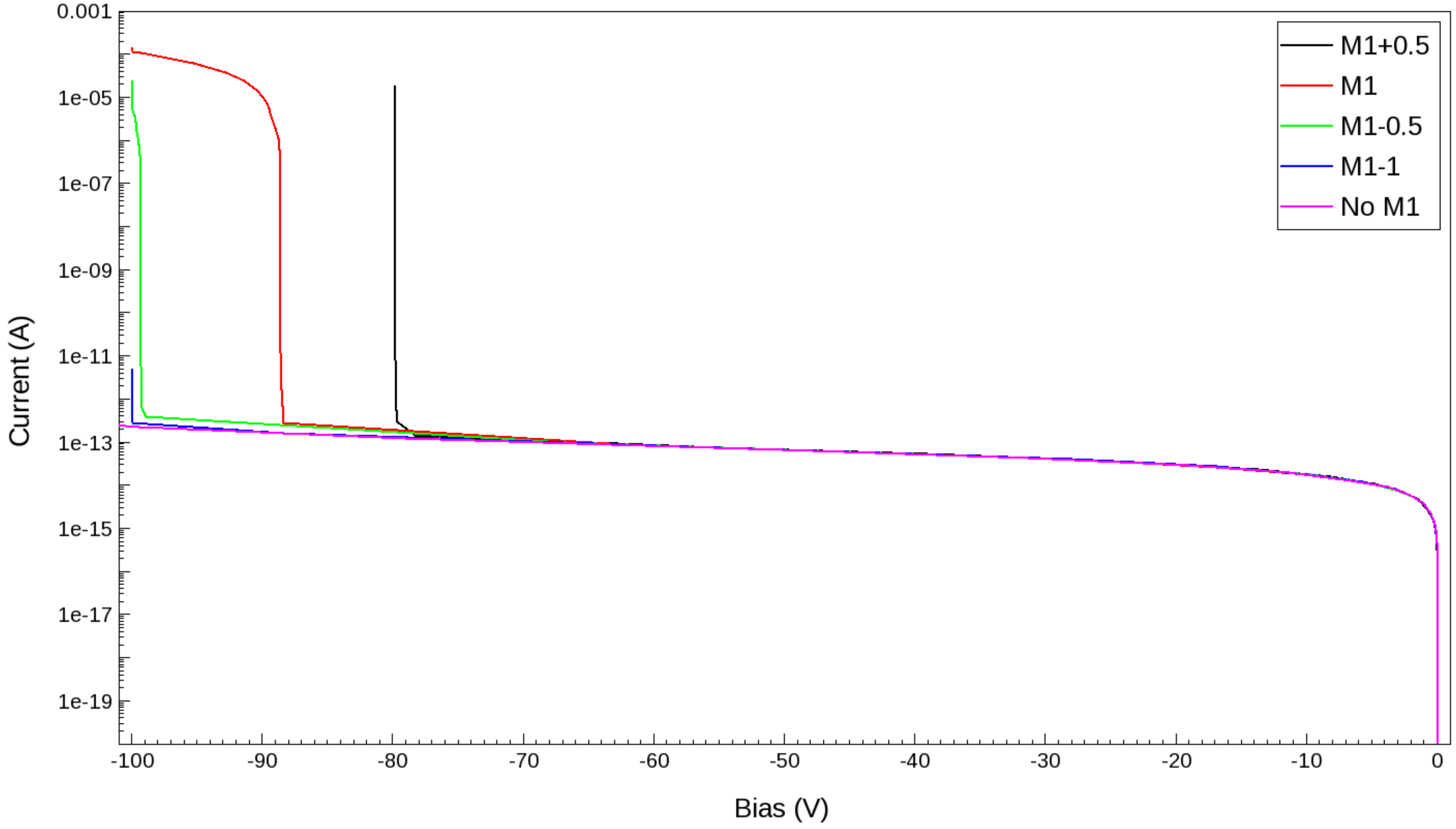
M1-3



No M1

IV Curve M1 comp, 2D full

- The closer the M1 lines are the lower voltage at which breakdown will occur
- Around -88V for the correct M1 lines



E-field depth, 3 pixel structure