4H-SiC LGADs: fabrication-stability optimization using TCAD simulations

02.09.2026

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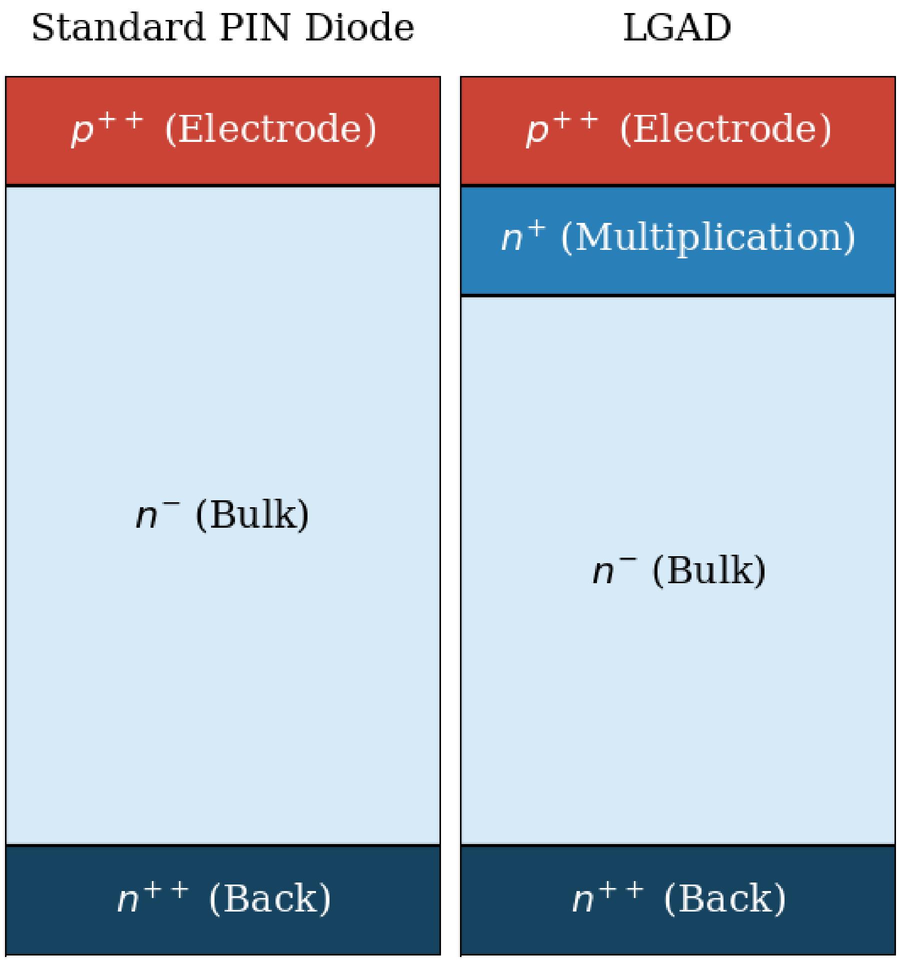
Low-Gain Avalanche Diode (LGAD)



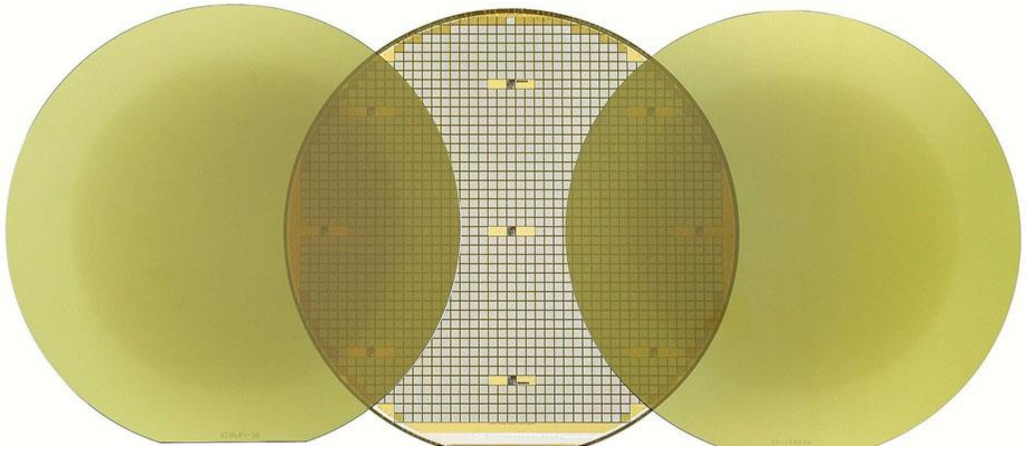
~ PiN diode + internal charge multiplication

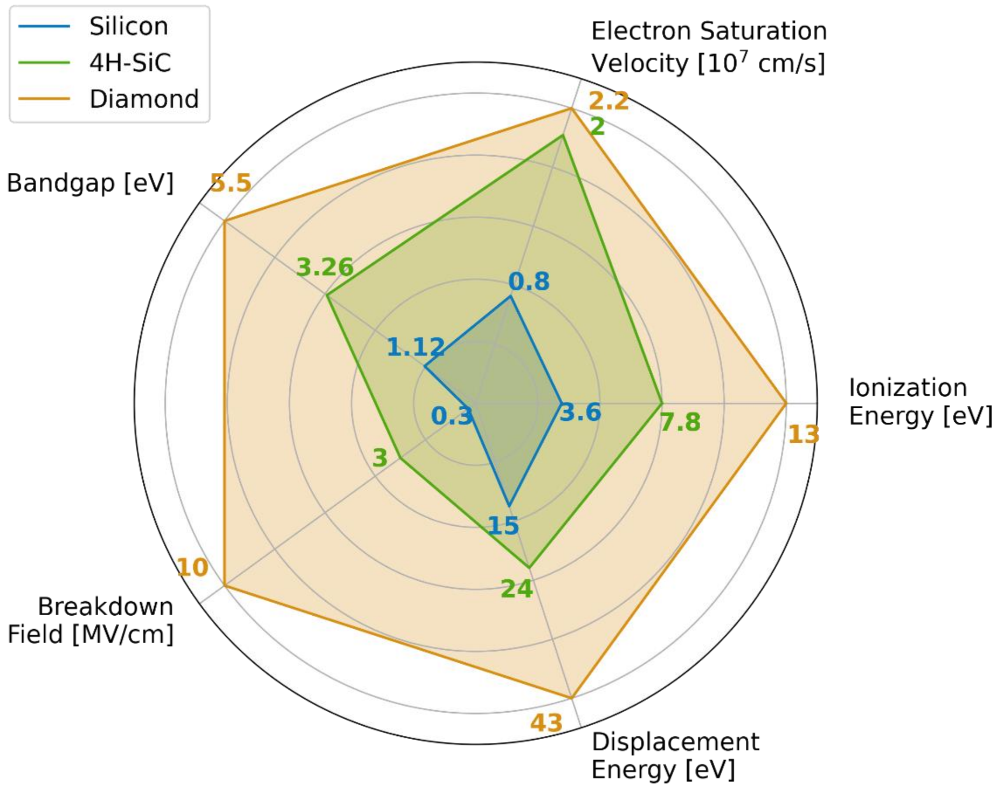
already in use on Silicon in the LHC

+ Superior timing resolution, SNR, low energy detection
- Performance degradation with radiation damage, needs cooling

Applications in HEP, Medical devices, Space

Why wide-bandgap (SiC)



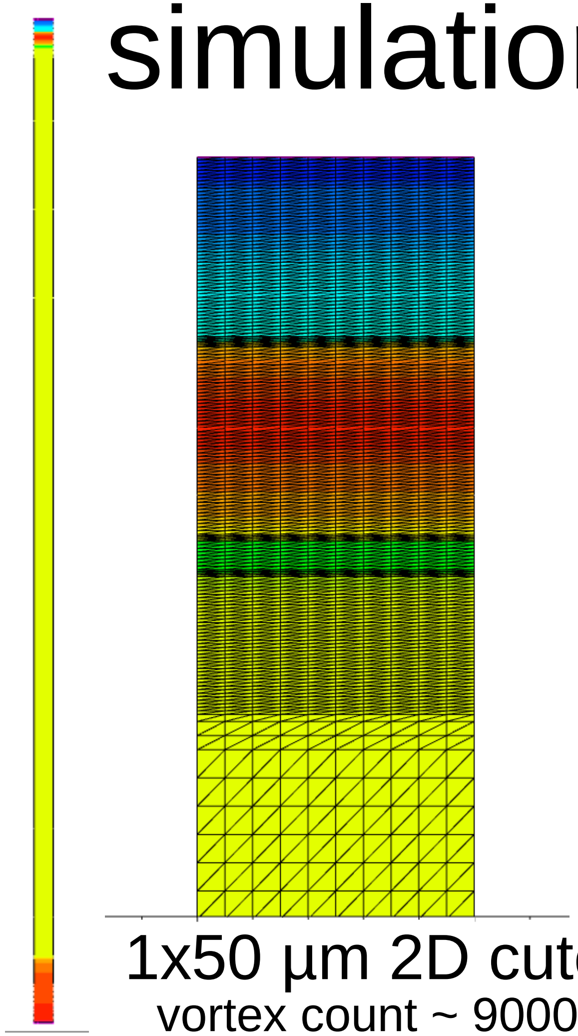


Higher electric field before breakdown (10x),
faster charge collection (2x), higher thermal conductivity (3x),
very low intrinsic carrier concentration (~0), high radiation hardness,
temperature stability

Difficult fabrication without defects, difficult simulation in TCAD

Arbitrary units used (a.u.)

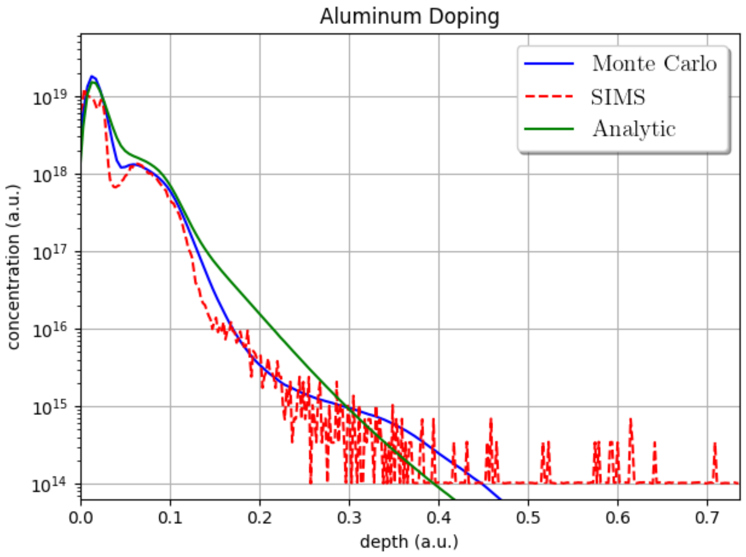
Simulation Model – fabrication process simulation

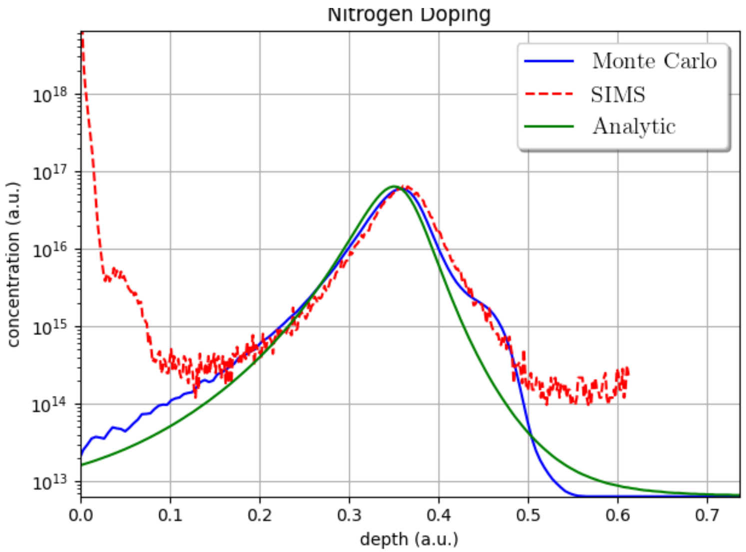


1x50 µm 2D cutout

vortex count ~ 9000

electrical simulation time ~ 1-6 h





(Synopsys Sentaurus TCAD)

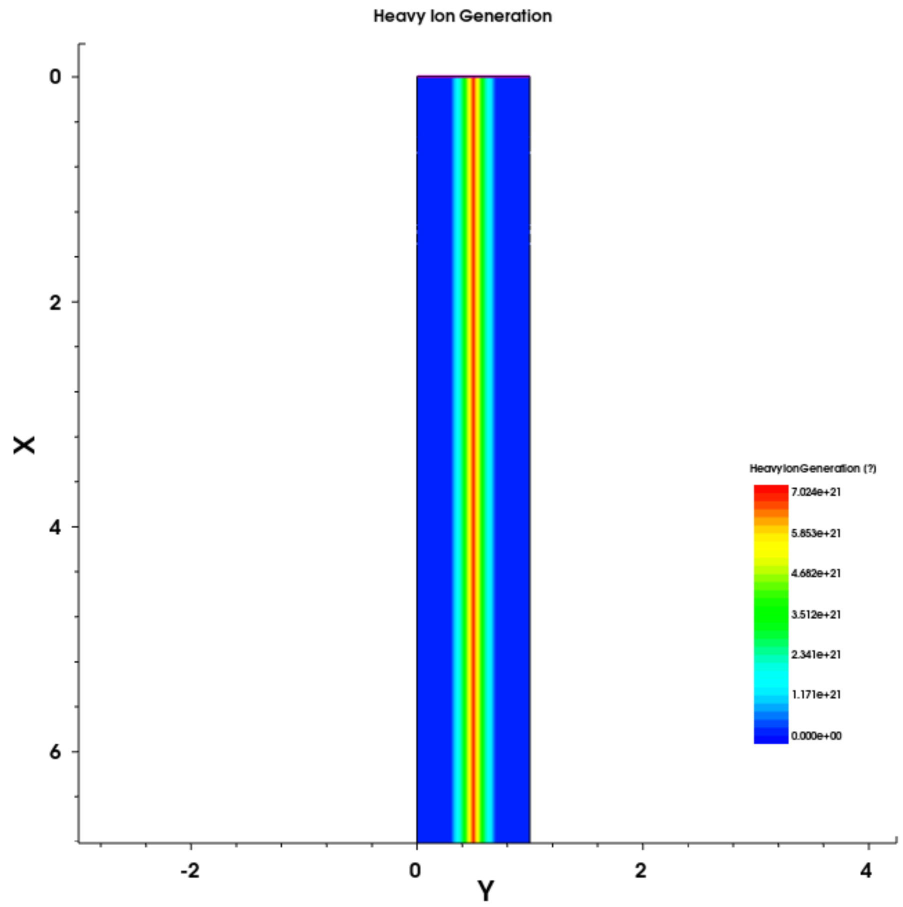
SIMS measurements of doping inaccurate in low concentrations

Doping structure was simulated with Monte Carlo simulations and from analytic tables

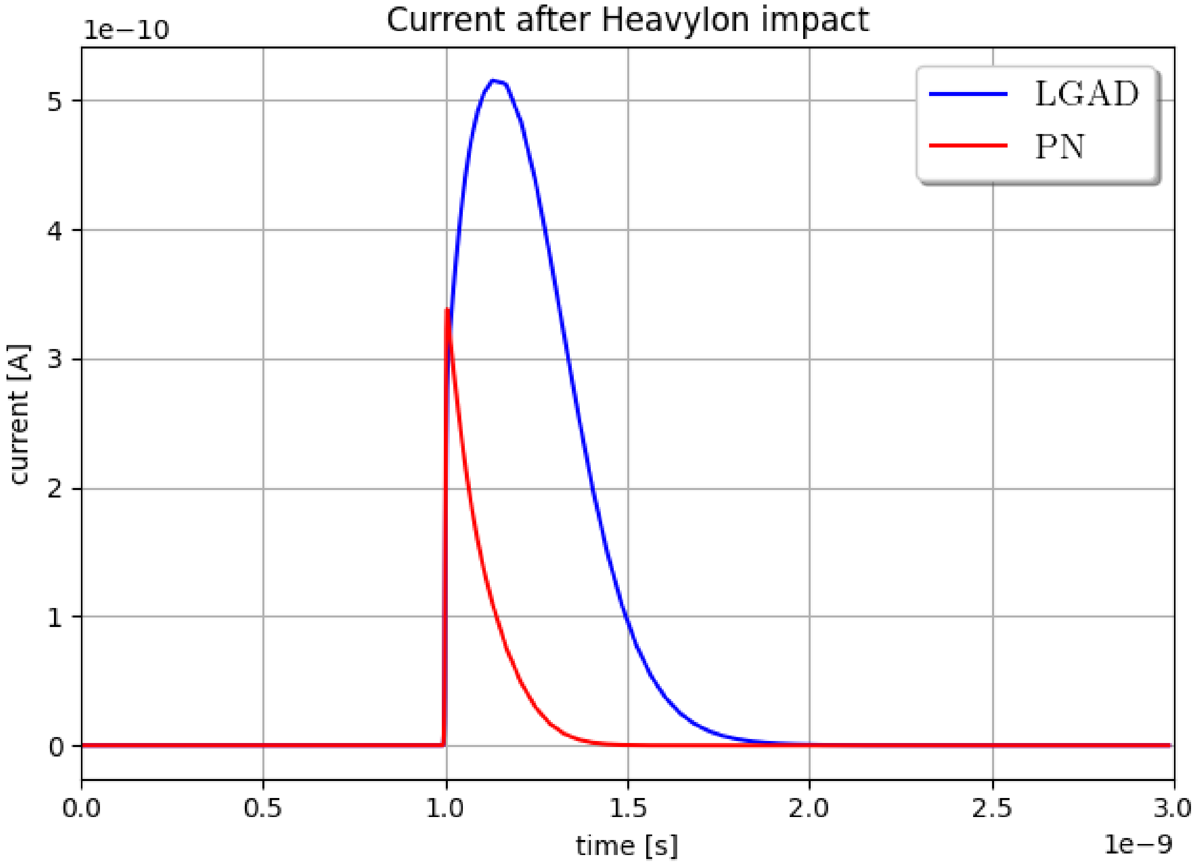
Monte Carlo model was determined to be the most accurate, especially in lower concentrations

Arbitrary units used (a.u.)

Simulation Model – particle strike



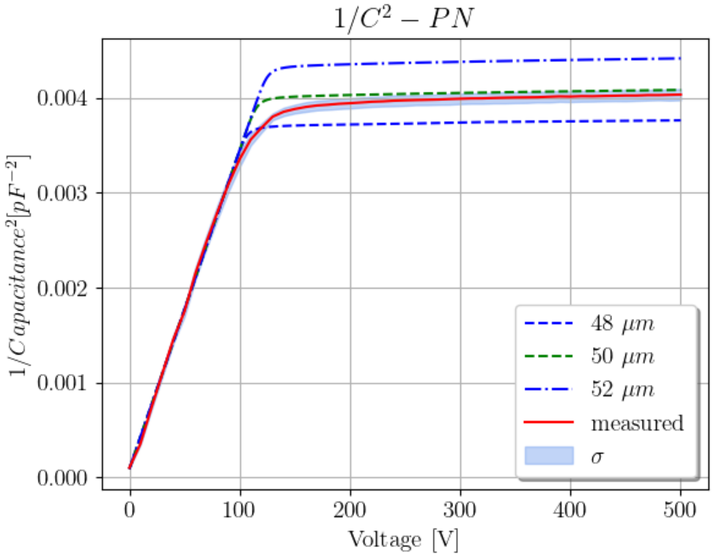
Minimum ionizing particle flown through the whole length
~55 e-h pairs/µm



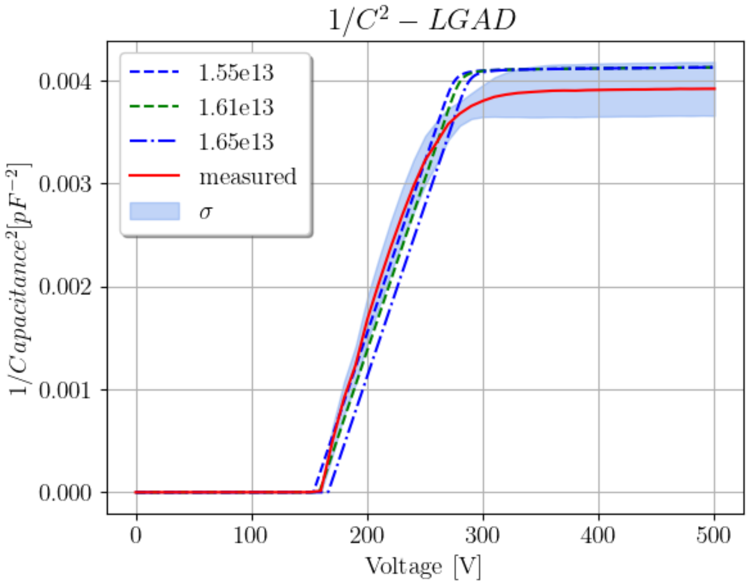
(Both operating at 300 V reverse bias, same geometry)

Arbitrary units used (a.u.)

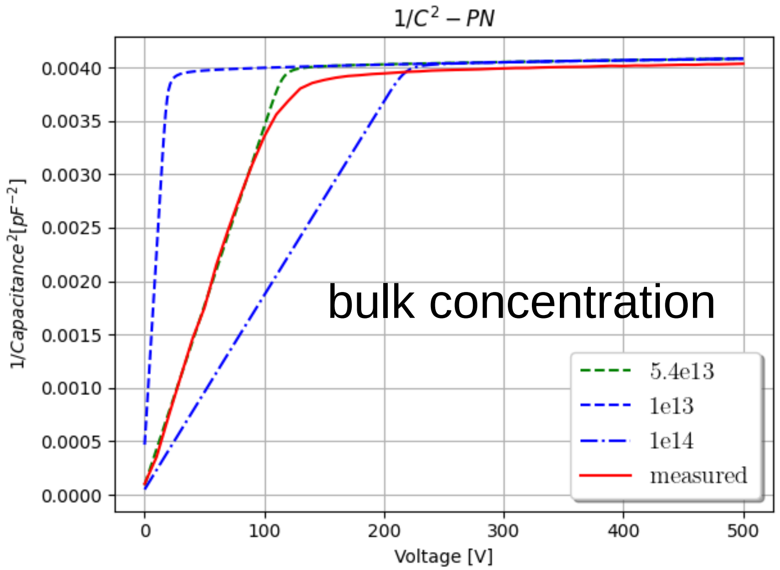
Model Calibration With Matching CV Curves



epitaxy layer length

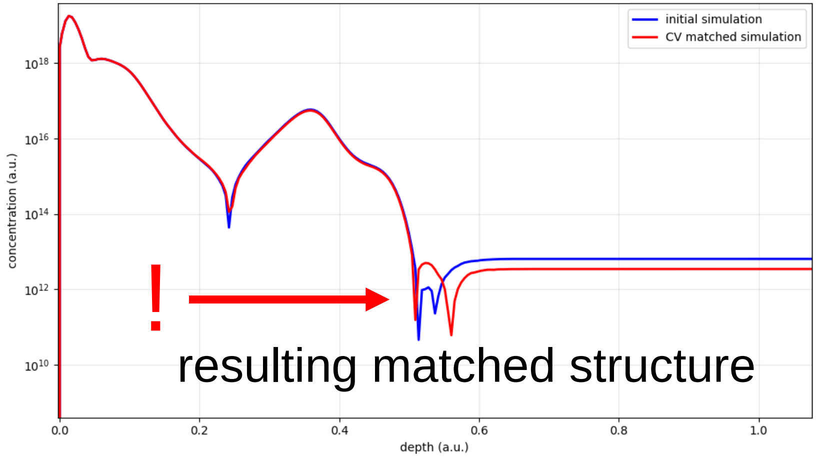


Nitrogen gain layer dose

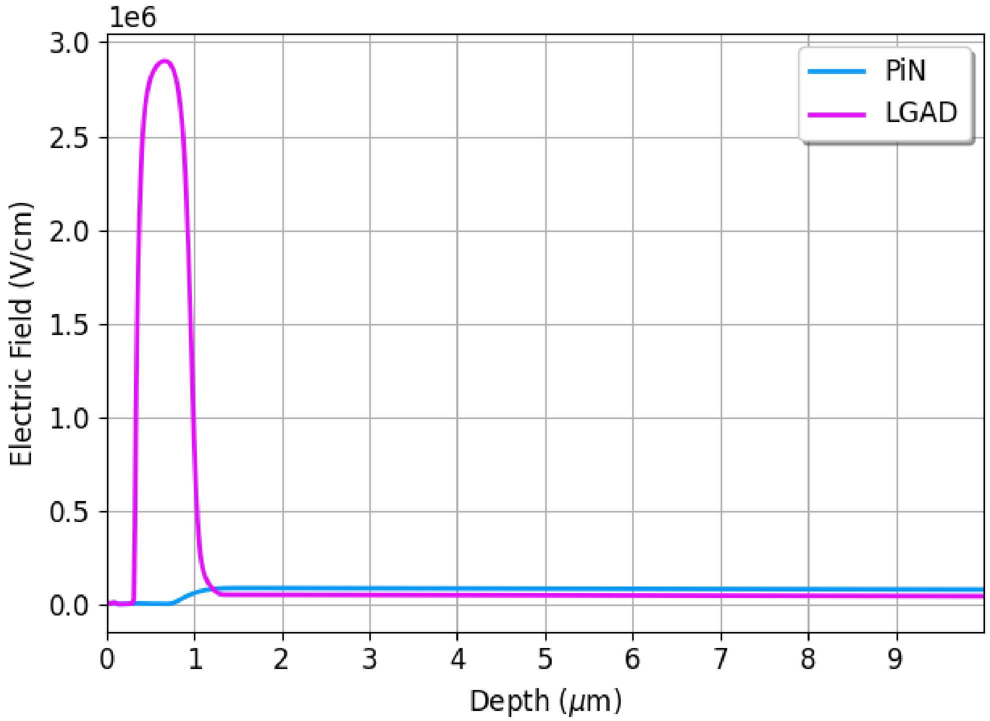


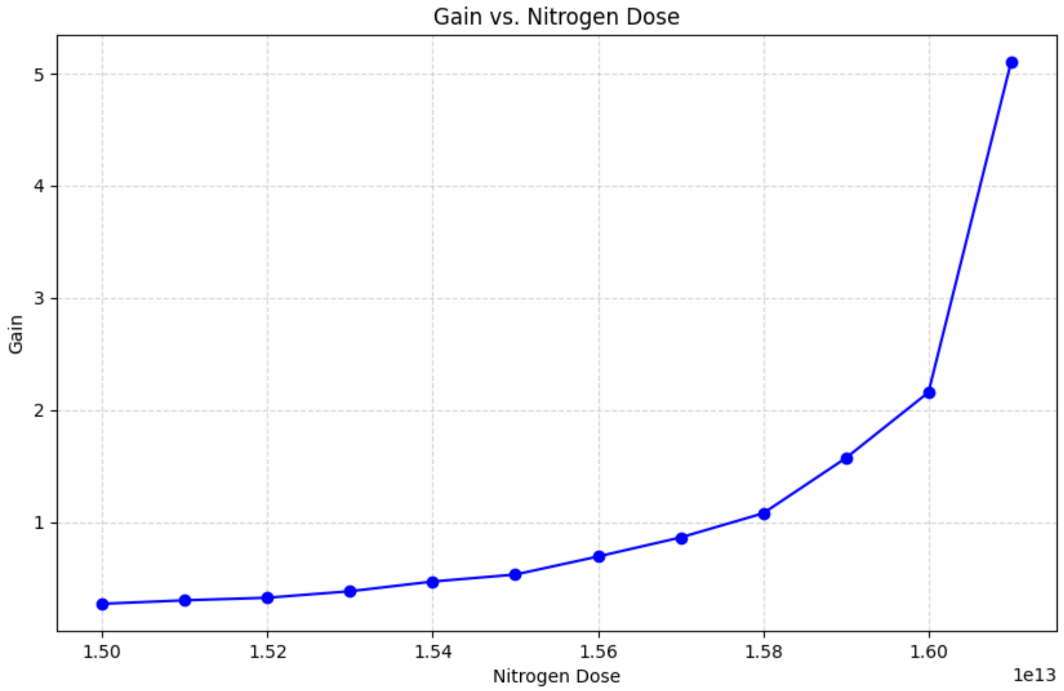
using nominal values from production results
in an inaccurate simulation model

“large” discrepancy in Nitrogen dose (5%)



Sensitivity to Nitrogen Dose (Gain layer size/shape)



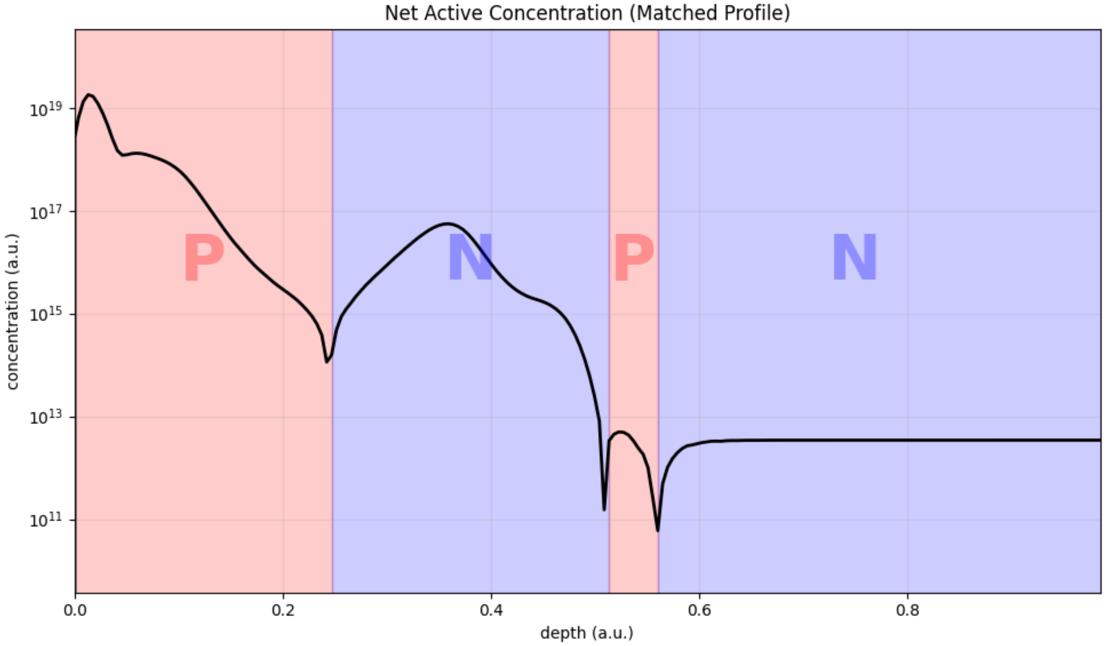


$$\alpha(E) = A\exp\left(-\frac{B}{E}\right)$$

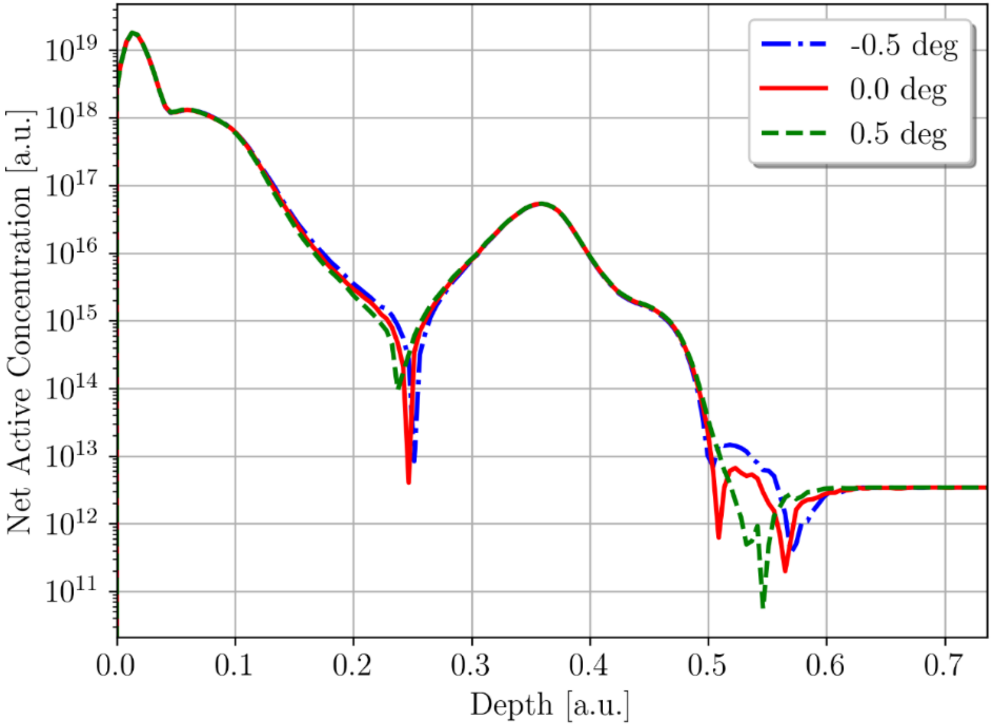
TCAD Avalanche multiplication models may not be accurate

Arbitrary units used (a.u.)

Sensitivity to Angle of Ion Implantation



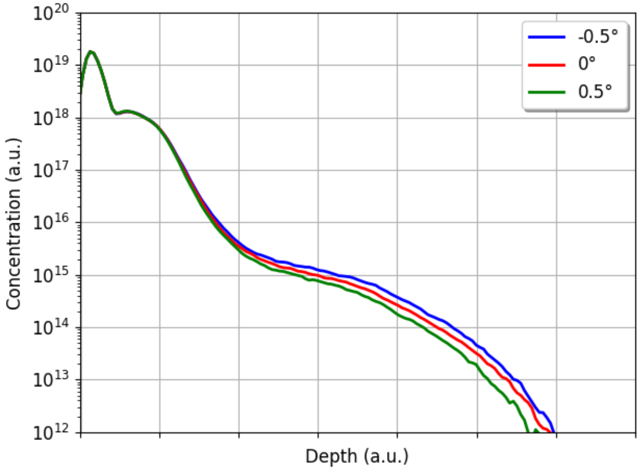
matched model shows a secondary “parasitic” junction



Tilt [deg]	Gain @300 V
-0.5	3.6
0	5.0
0.5	6.4

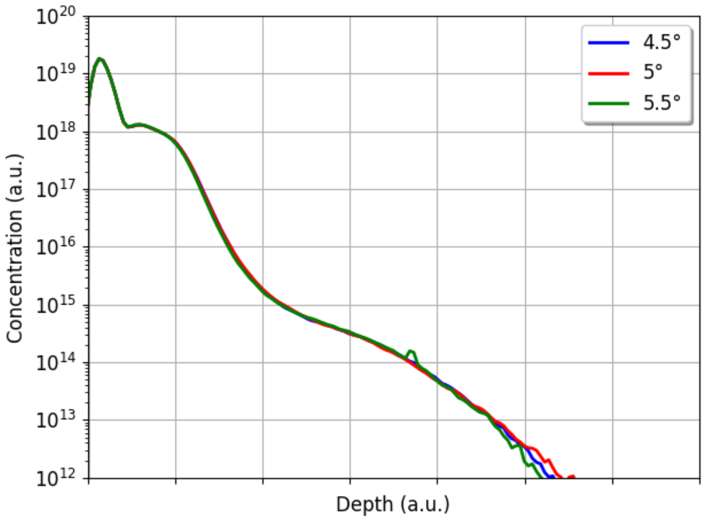
Arbitrary units used (a.u.)

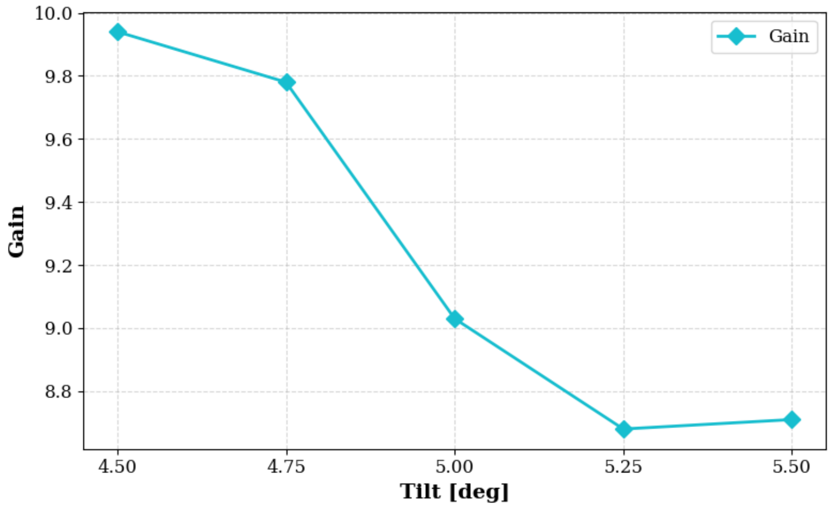
Channelling mitigation

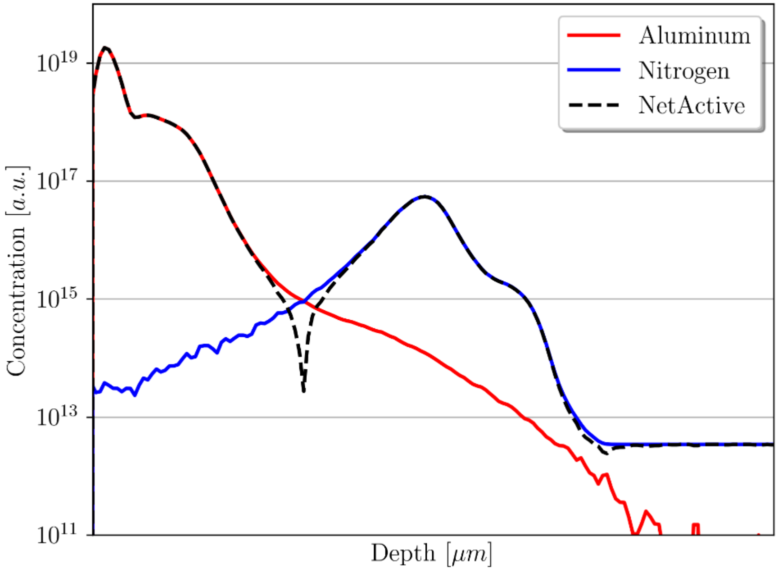


varying low concentration values due to channelling at 0 deg implant

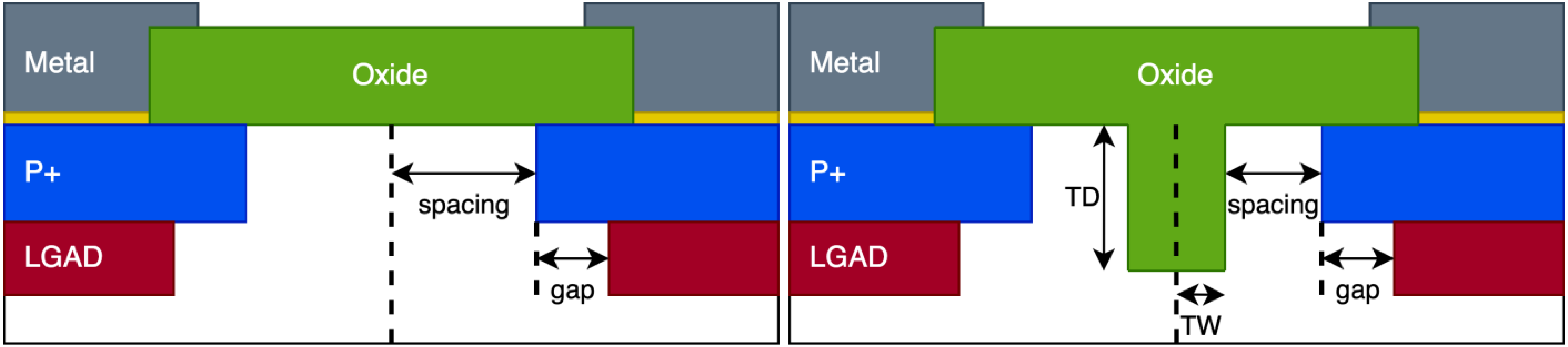
Ion implantation angle set to 5 deg





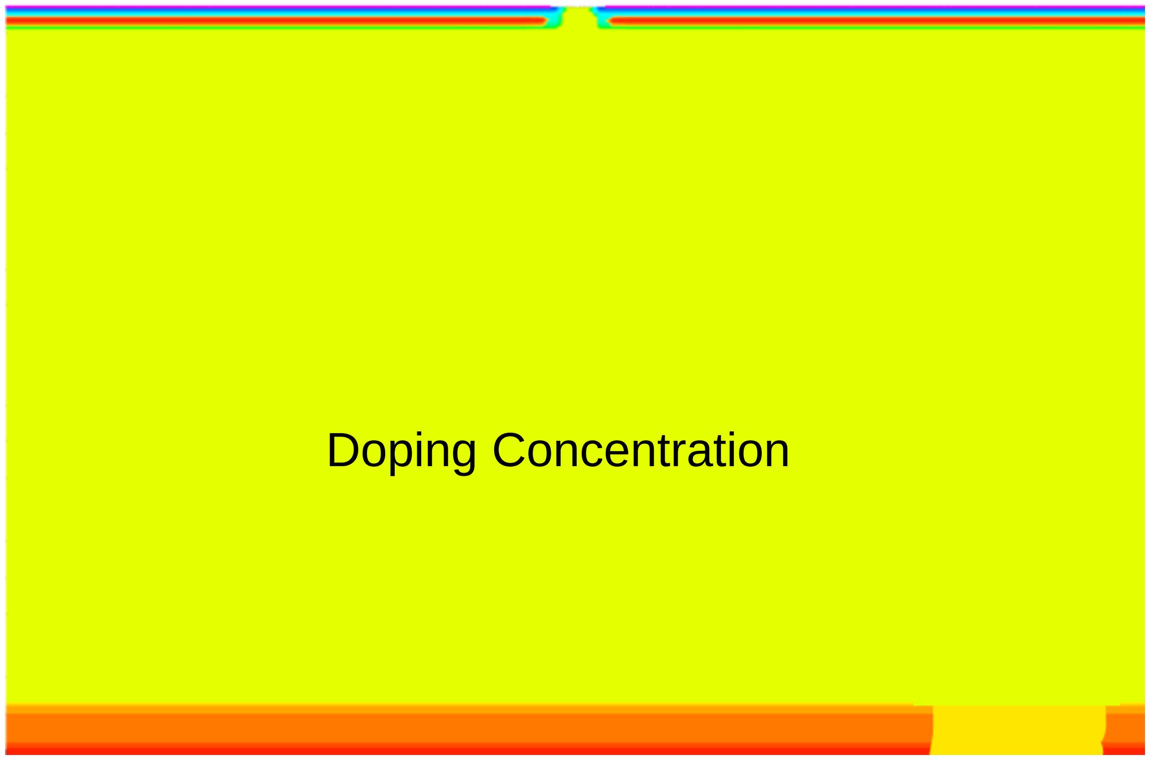


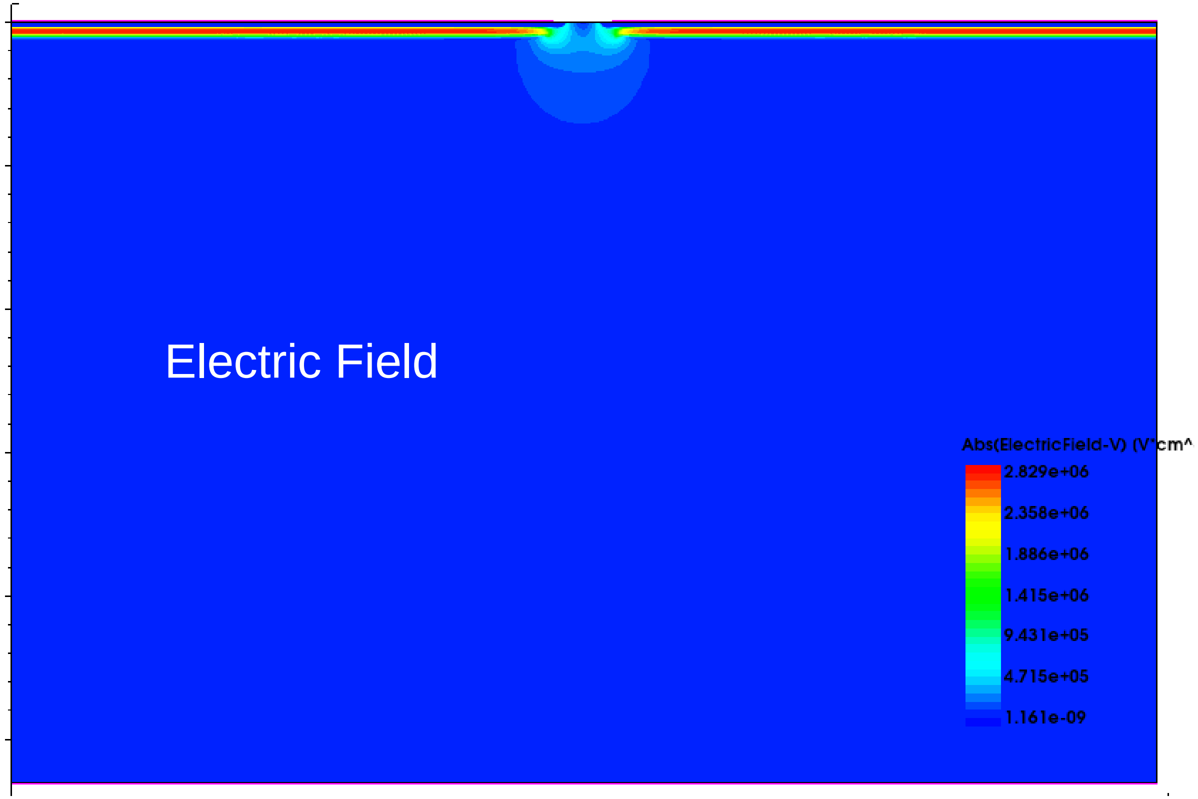
Segmentation strategies



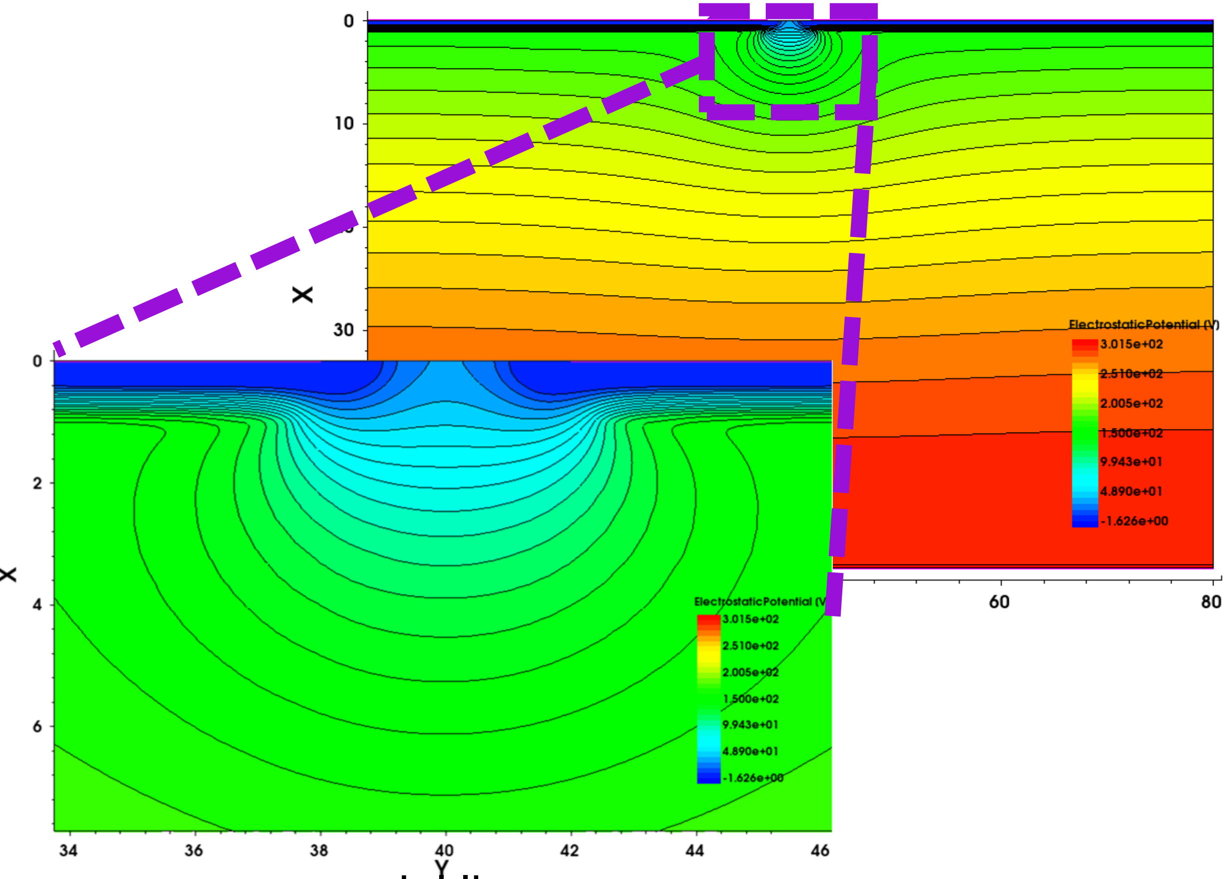
Larger 2D simulations - segmentation

24 simulations per design – point charge generation
vortex count ~ 120 000
simulation time ~ 15 – 60 hours (for 1 point generation)

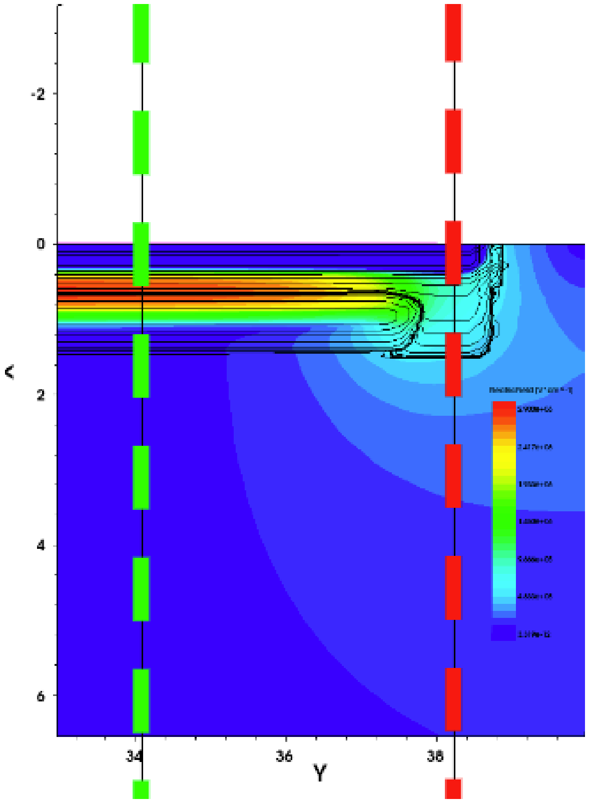


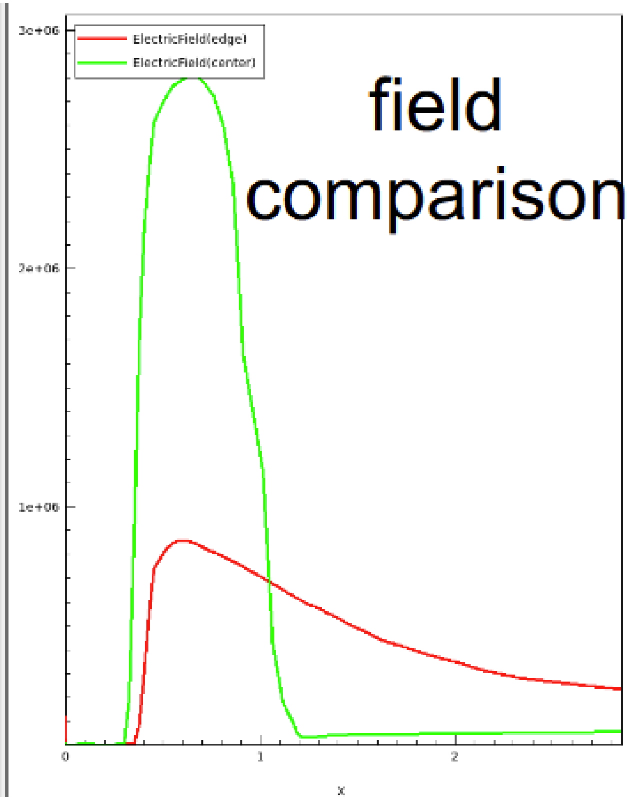


Generated charge is pulled through a low field region, doesn't get multiplied

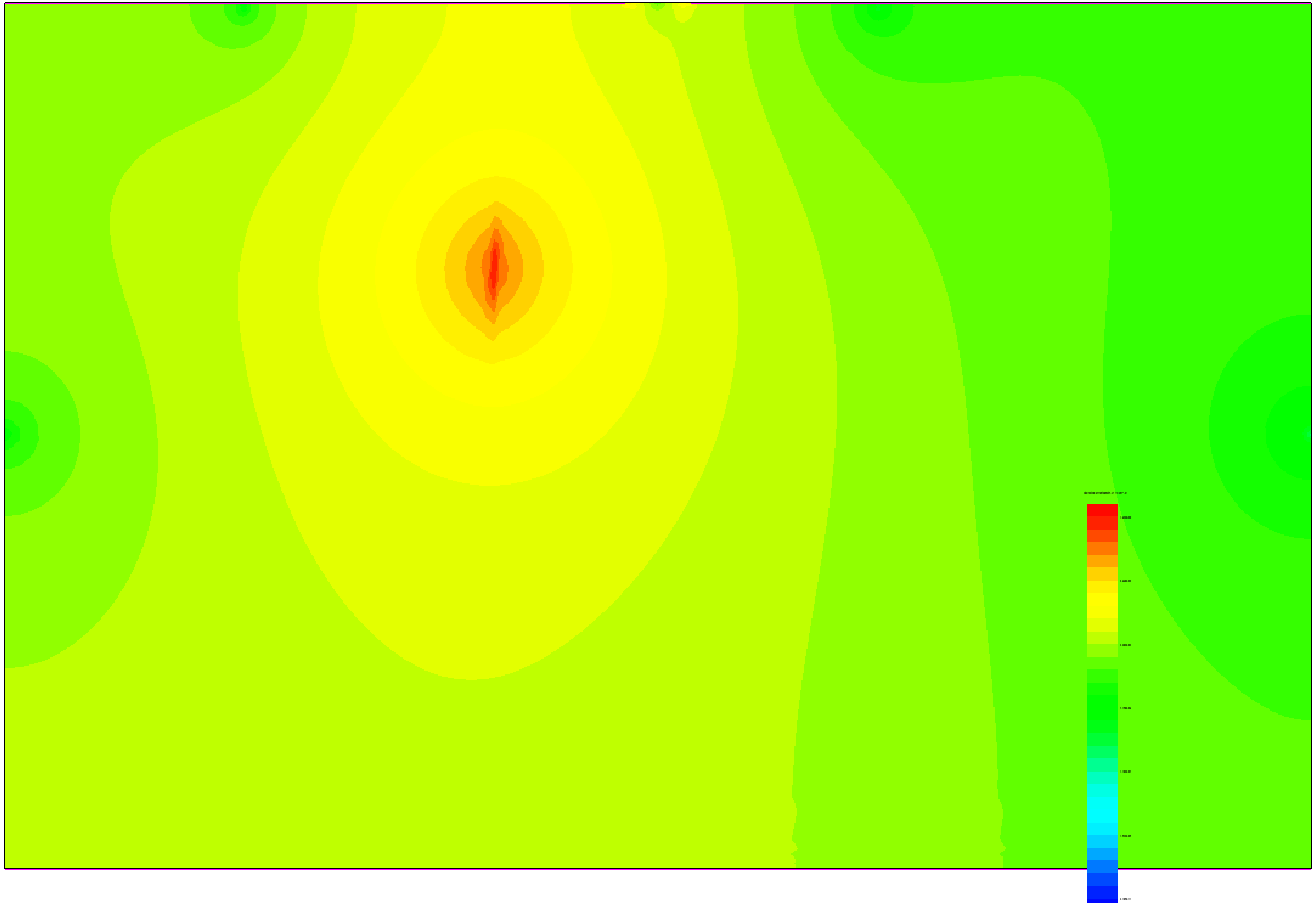


potential lines

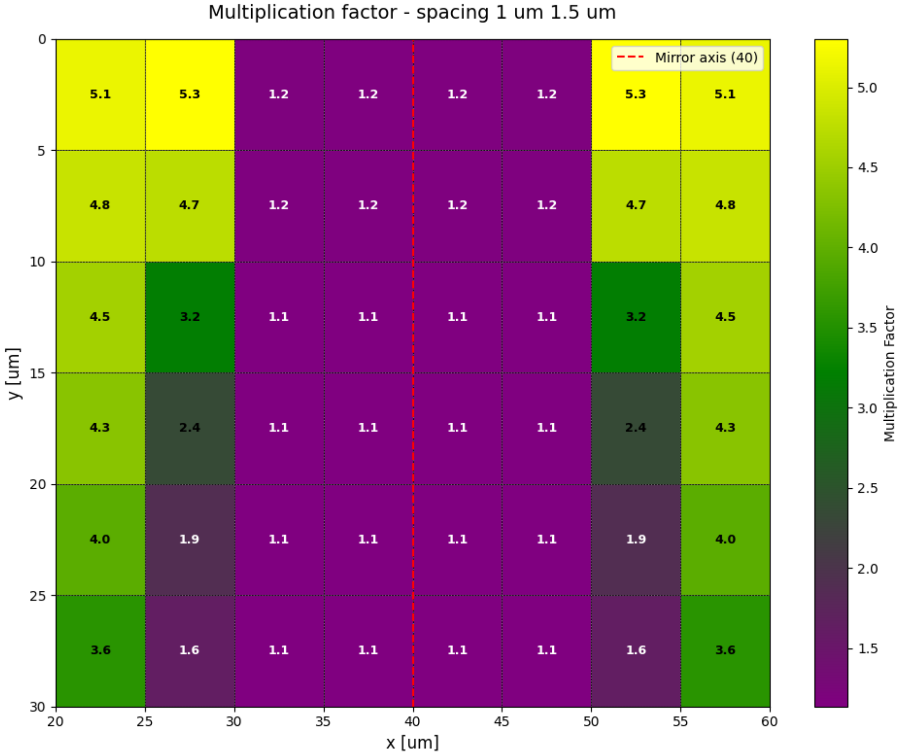


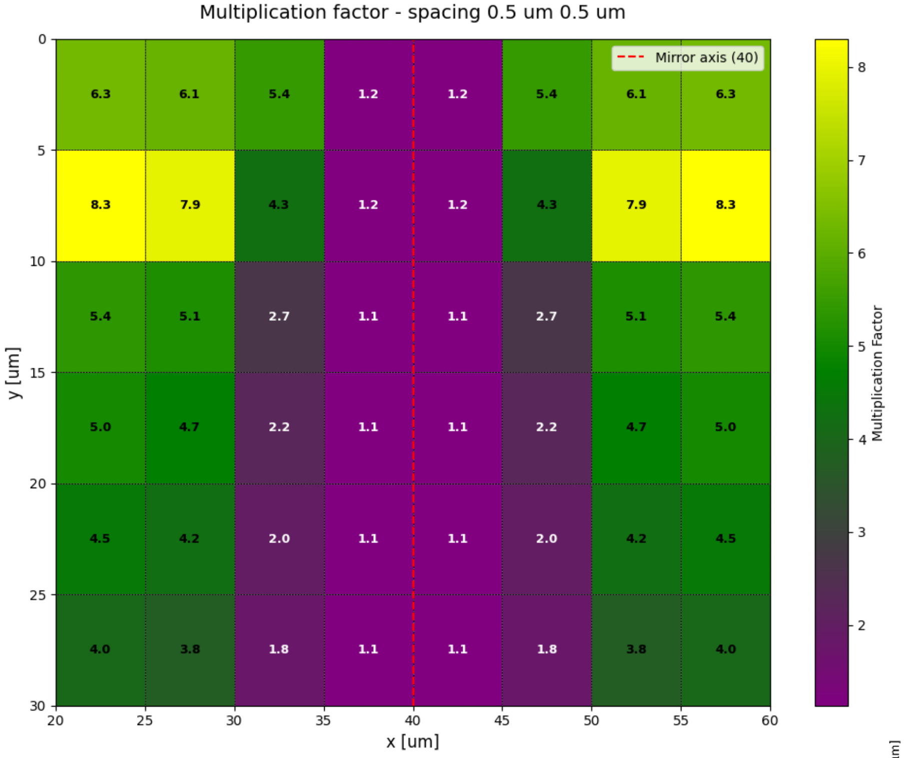


field comparison

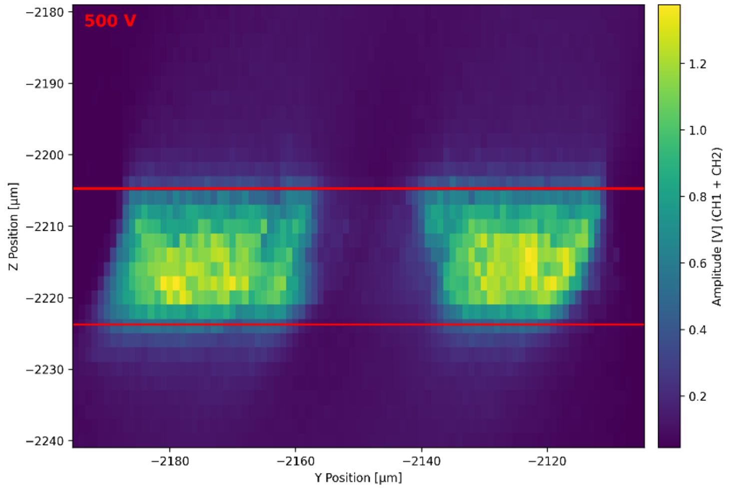


Zero gain region between pixels/strips

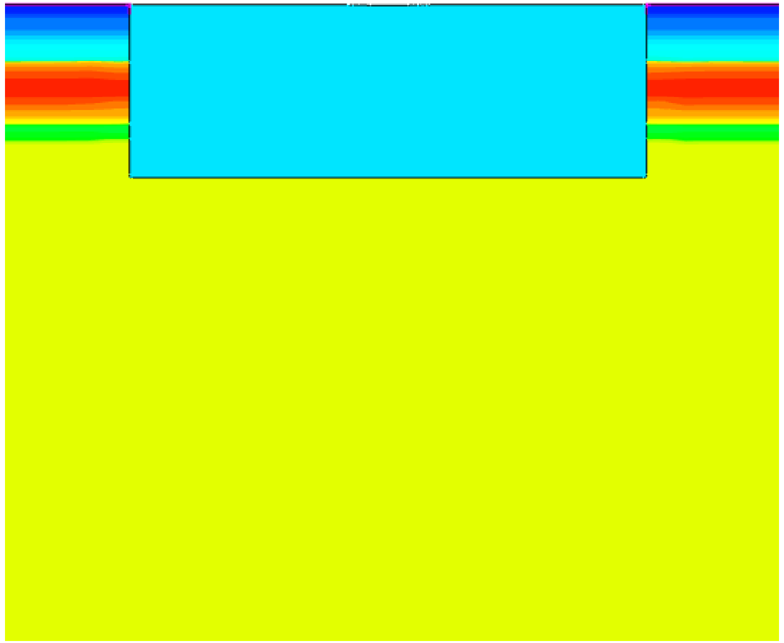


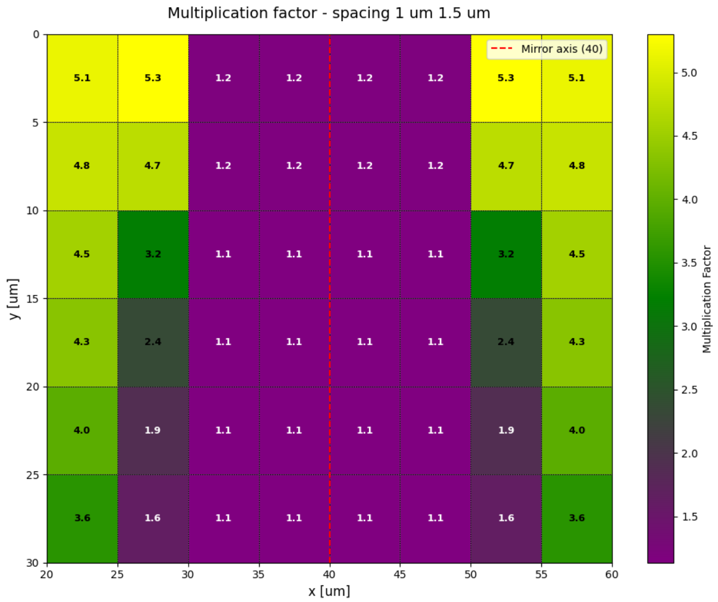


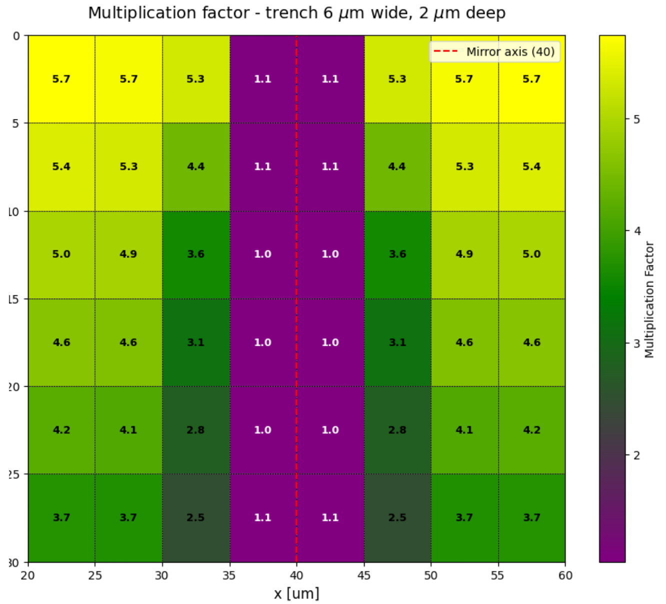
TPA-TCT measurements

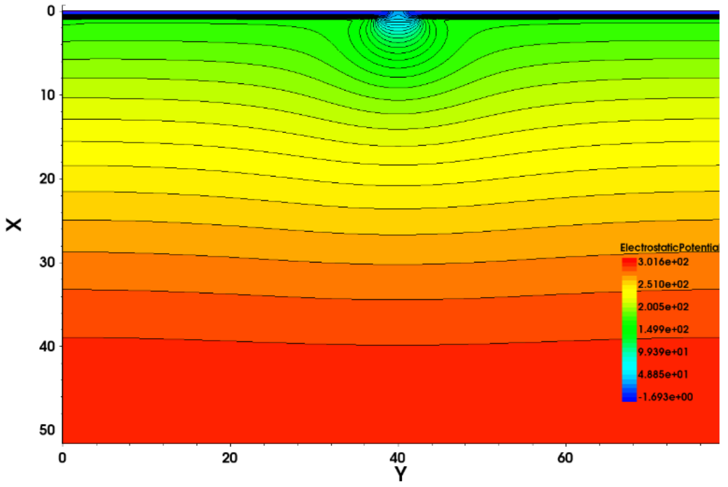


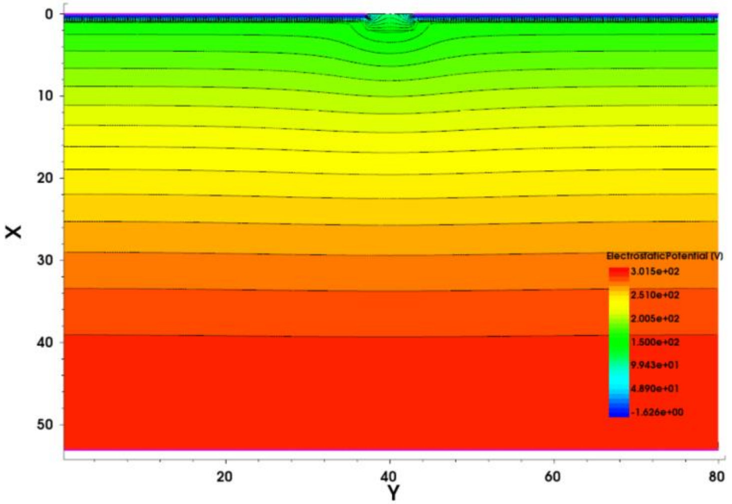
Trench isolation



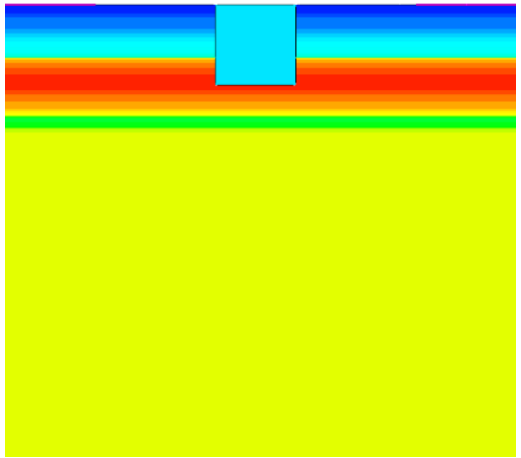


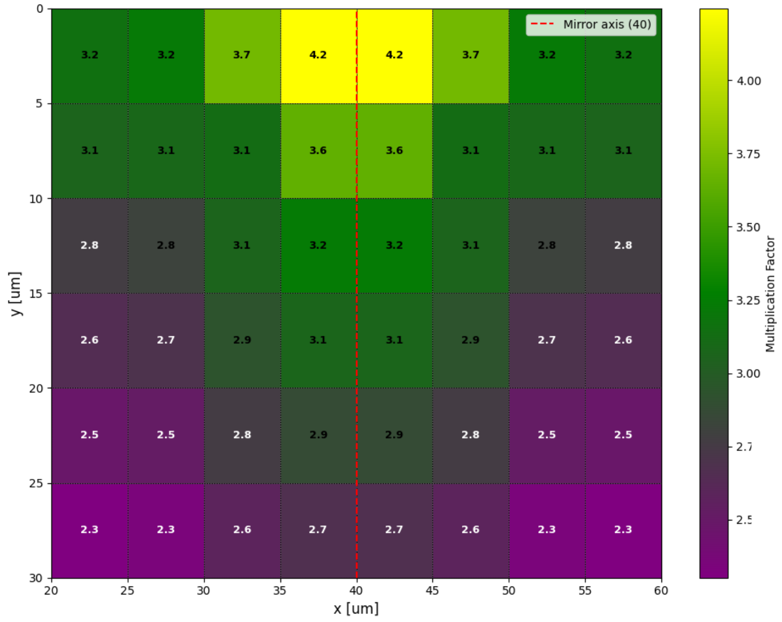


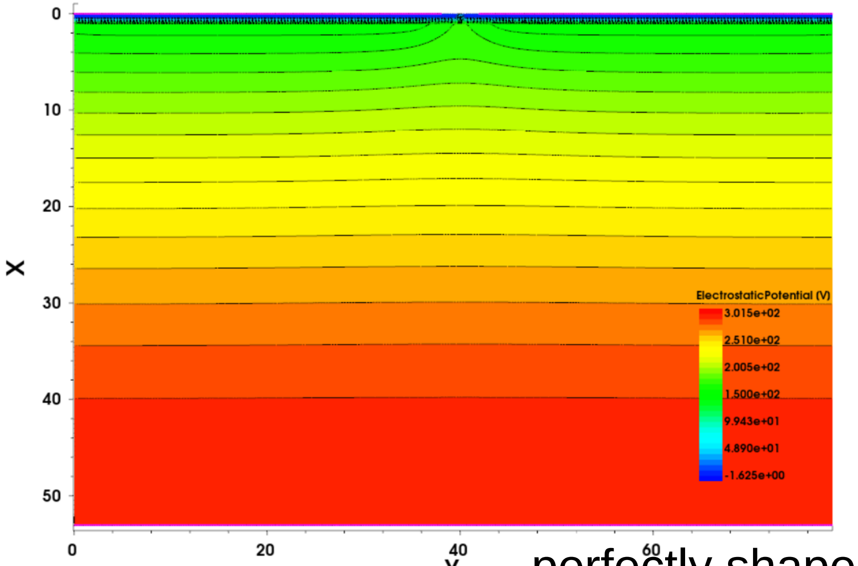




Trench isolation – no zero-gain region

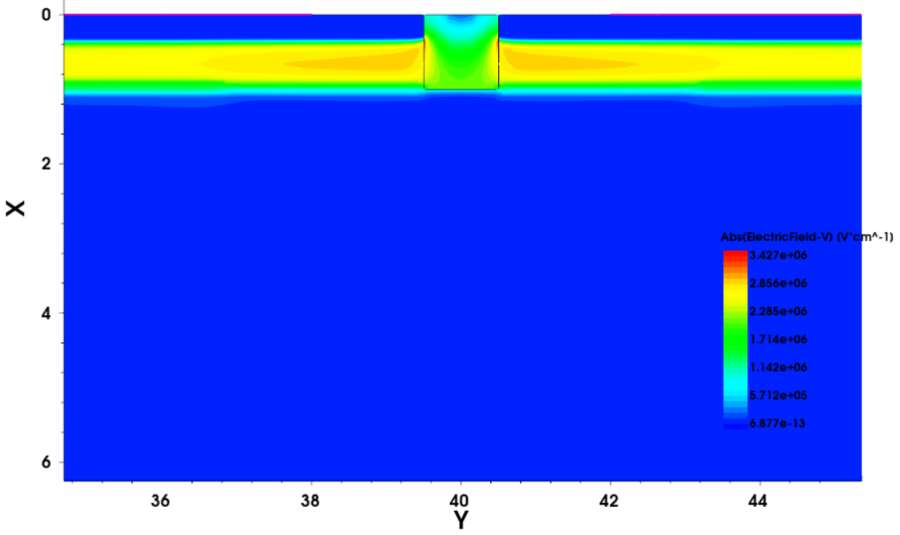






perfectly shaped potential lines

Electric field gets concentrated around the trench, affecting the detector performance



Summary

We established a 4H-SiC LGAD simulation model and used it to improve the reproducibility our first-generations prototypes

We extended the simulation model to study different segmentation strategies

Future work:

- Further optimize the doping structure for maximum reproducibility and lifespan
- Simulate more segmentation strategies, compare with measurements
- Investigate the zero-gain region further

Thank you for your attention!

https://capads.fjfi.cvut.cz

IV characteristics