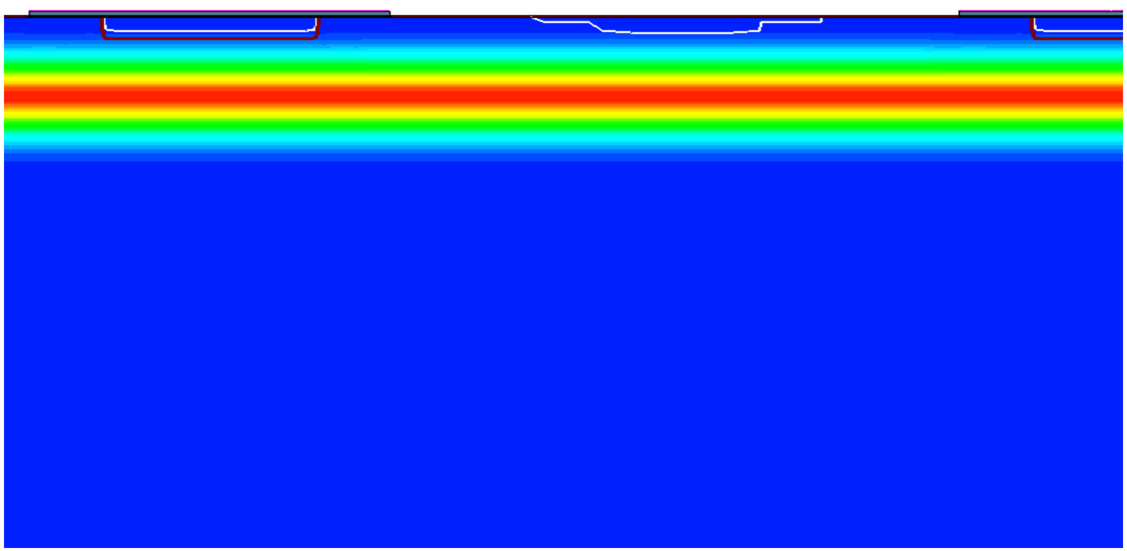
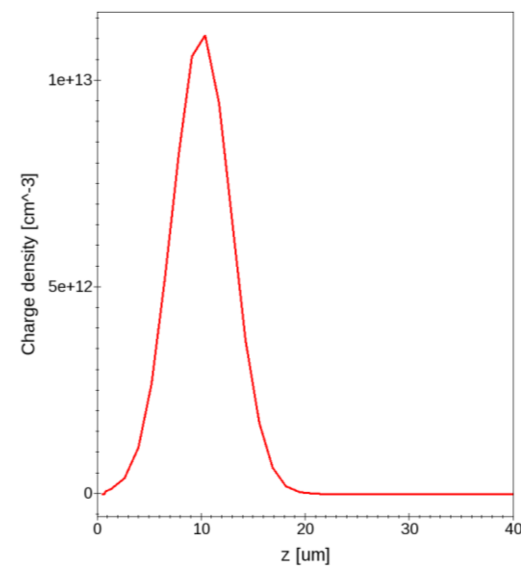
Simulations of edge-TCT, interstrip resistance and 2-defect model CCE

22nd RD50 Workshop
June 3rd - 5th 2013

T. Peltola[1), J. Härkönen[1)

[1)Helsinki Institute of Physics, CMS Tracker Project.





Outline

- ❑ Edge-TCT simulations of nonirradiated Si detector with Synopsys TCAD
  - $Q(z)$, $t_c(z)$, $v_{drift}(z)$, $E(z)$
  - Comparison with measured edge-TCT
- ❑ Interstrip resistance simulations of a device using p-stop isolation
  - Dependence on pitch, p-stop width, spacing and doping
  - Synopsys vs Silvaco
- ❑ Charge collection efficiency simulations
  - 2-level defect model for protons and neutrons
  - Comparison with SiBT measured CCE of 320P and 200P

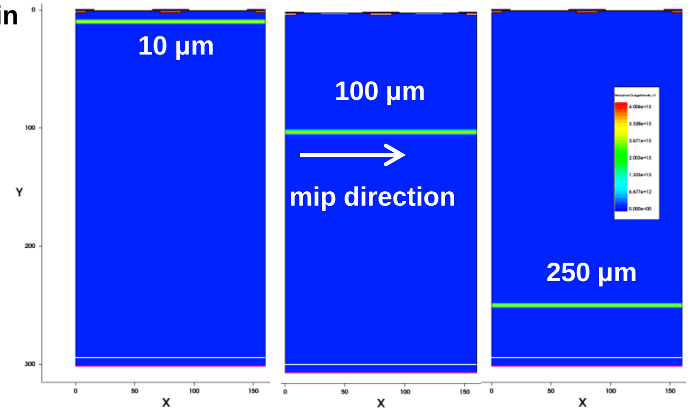
Edge-TCT simulations

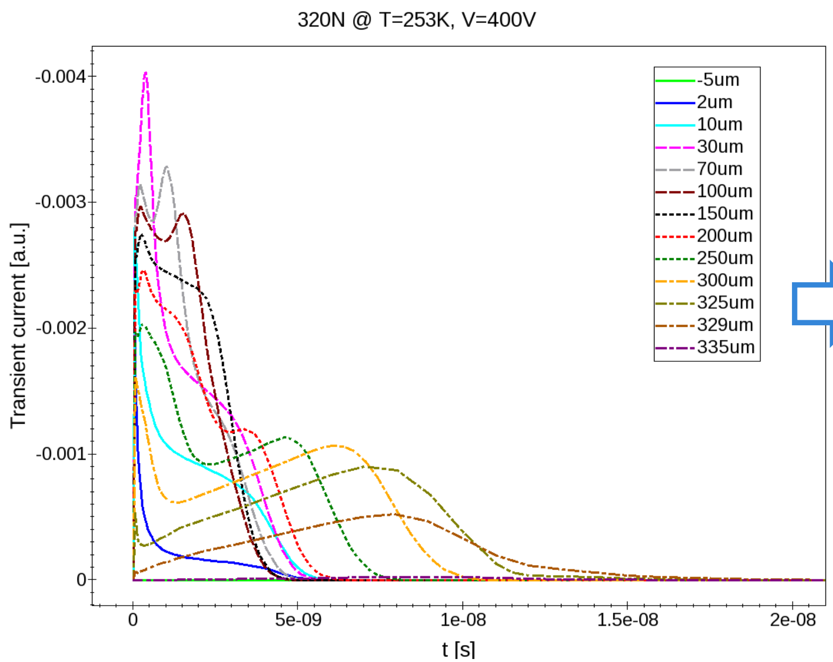
edge-TCT: method

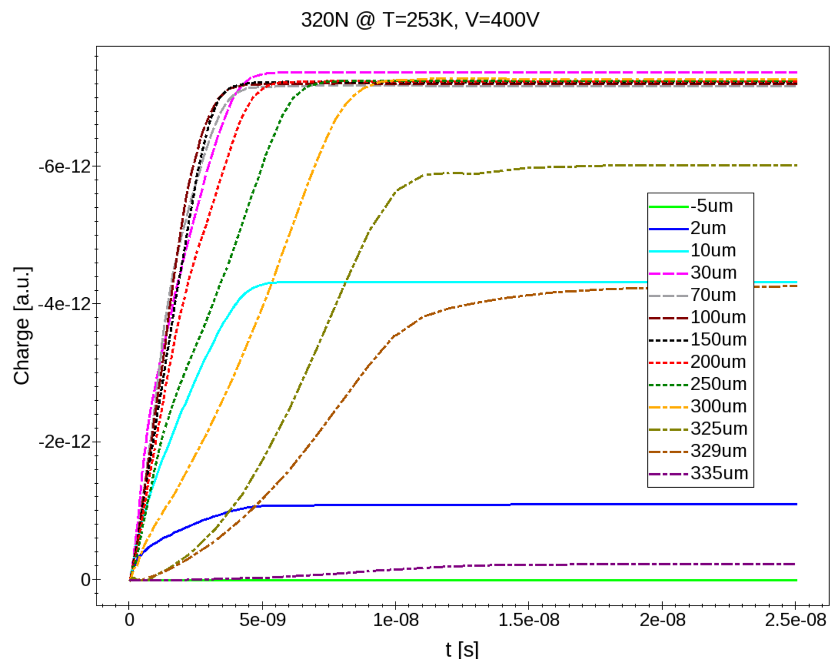
- ❑ **Goal:** extract electric field E from drift velocity v_{drift} using eTCT
- ❑ eTCT provides measurement of collection time t_c that is proportional to the v_{drift}
- ❑ v_{drift} is related to the E → possible to determine E out of drift velocity?

- ❑ Collected eTCT generated transient signals and charges as a function of injection distance:

MIP trajectories in 300N device:





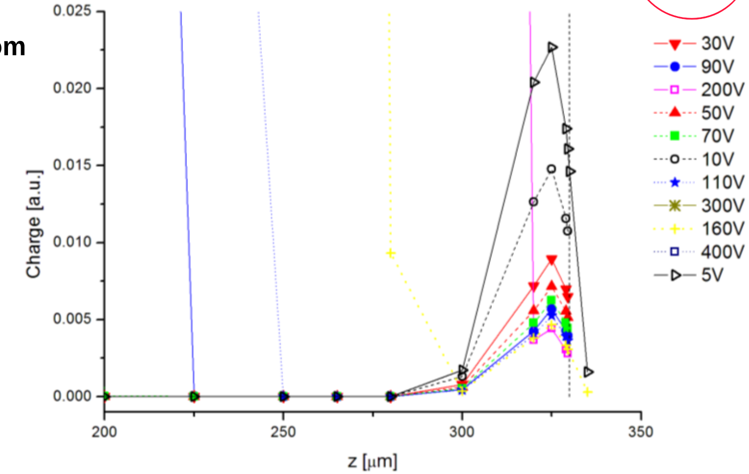


edge-TCT: nonirradiated MSSDs

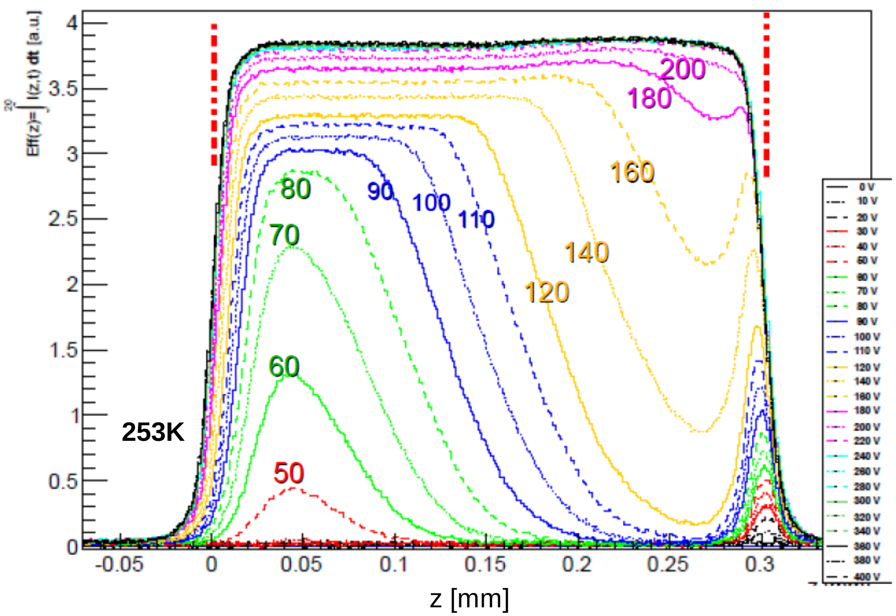
- ❑ Simulated structure and parameters correspond to the measured HPK detector (320N, V_{fd} ~ 210 V, region 7-80)

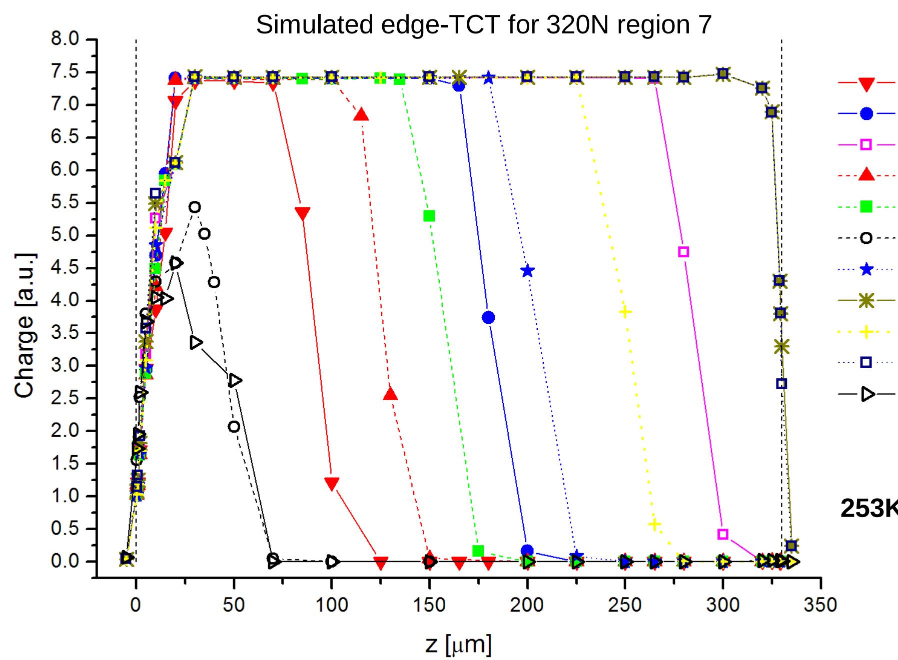
- ❑ Simulated max. value of Q(z) for the region 7 reached already at ~50V
- ❑ Simulated backplane bump ratio to max. value of Q(z) ~two orders of magnitude lower than measured

Backplane zoom from the simulation:

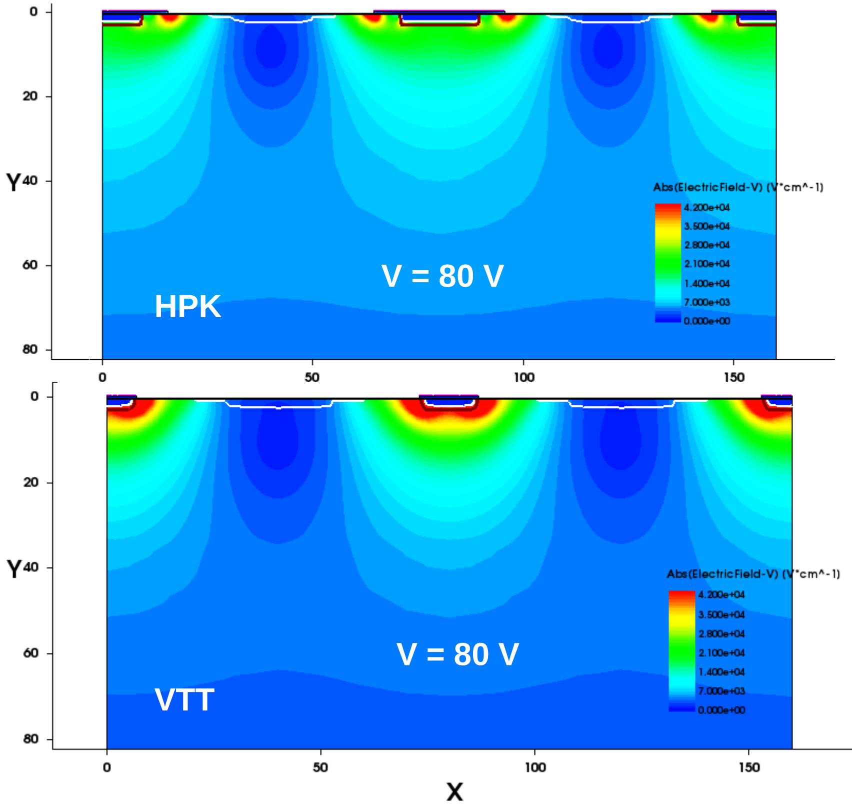


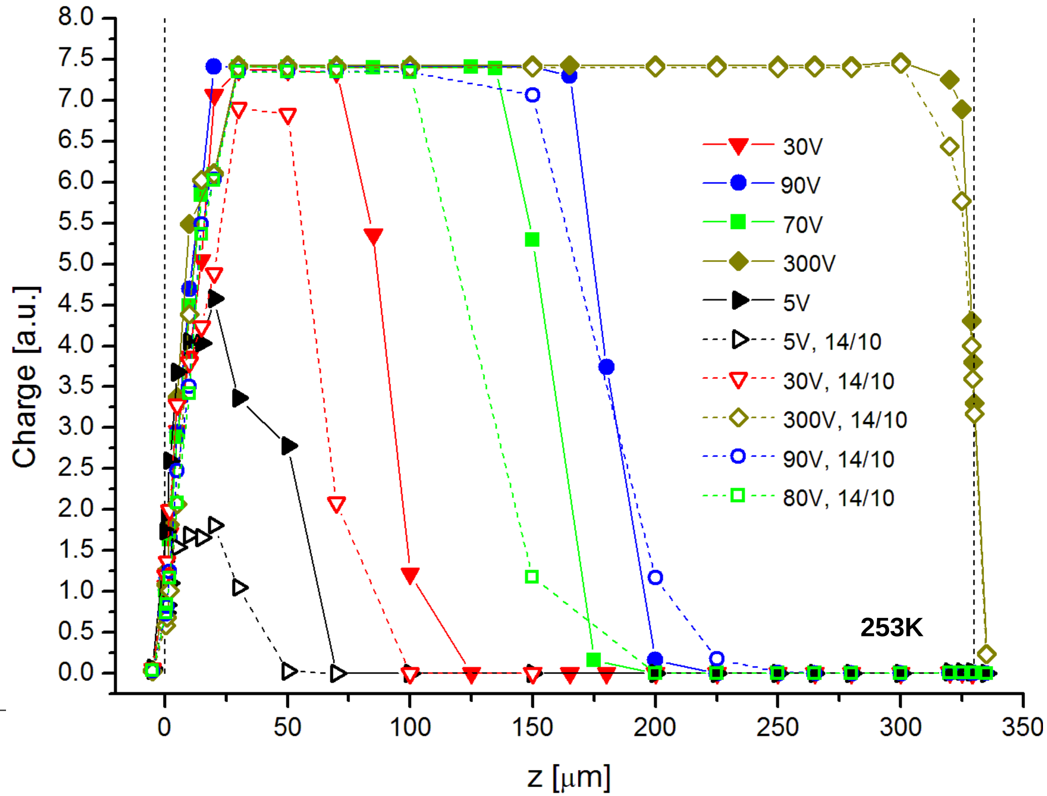
FZ320N region 7 eTCT-measurement (M. Fernandez 2013). V_{fd} ~ 210 V





edge-TCT: strip widths 31 and 14 μm

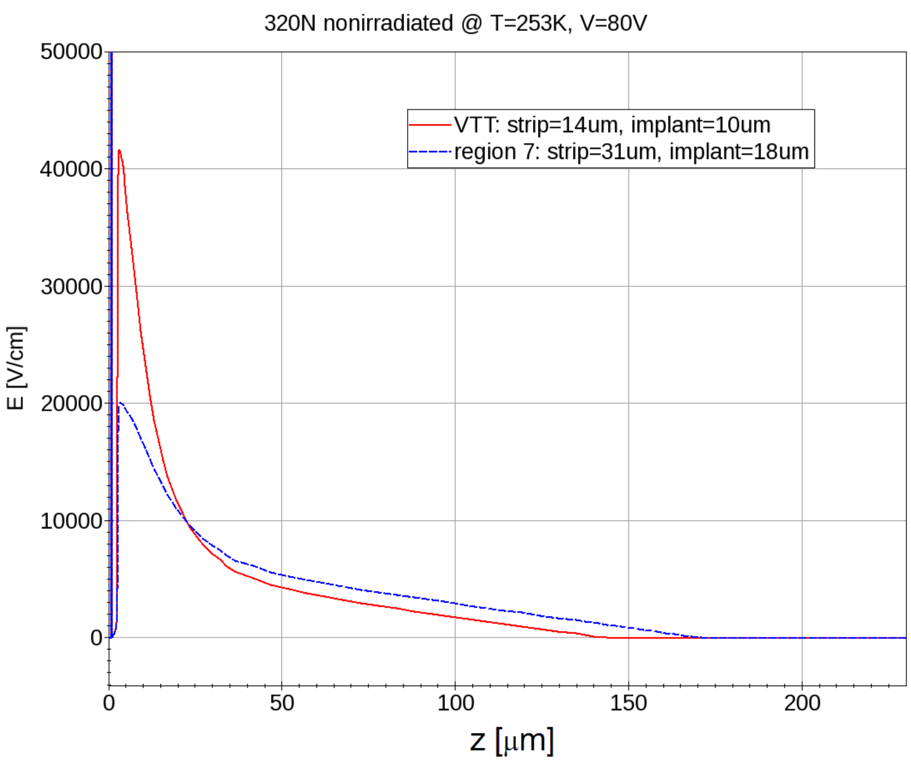


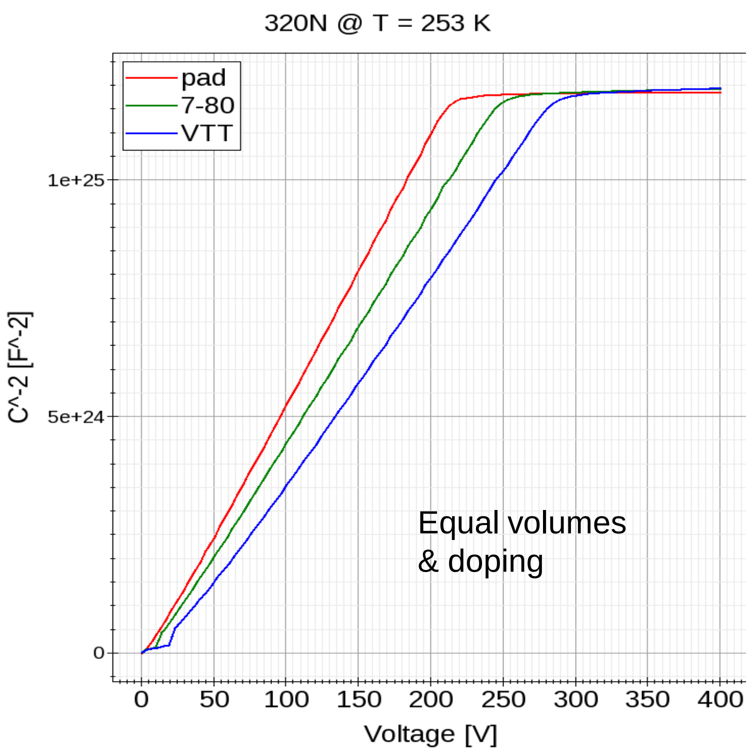


- ❑ VTT detector 14/10: strip w=14 μm, implant w=10 μm
- ❑ HPK 7-80: strip w=31 μm, implant w=18 μm

- ❑ Simulation with VTT parameters is closer to the measured behaviour, but still not matching at $V < V_{fd}$
- ❑ Because of smaller strip width both amplitude of Q(z) and depletion region increase slower with voltage compared to HPK region 7

edge-TCT: strip widths 31 and 14 µm





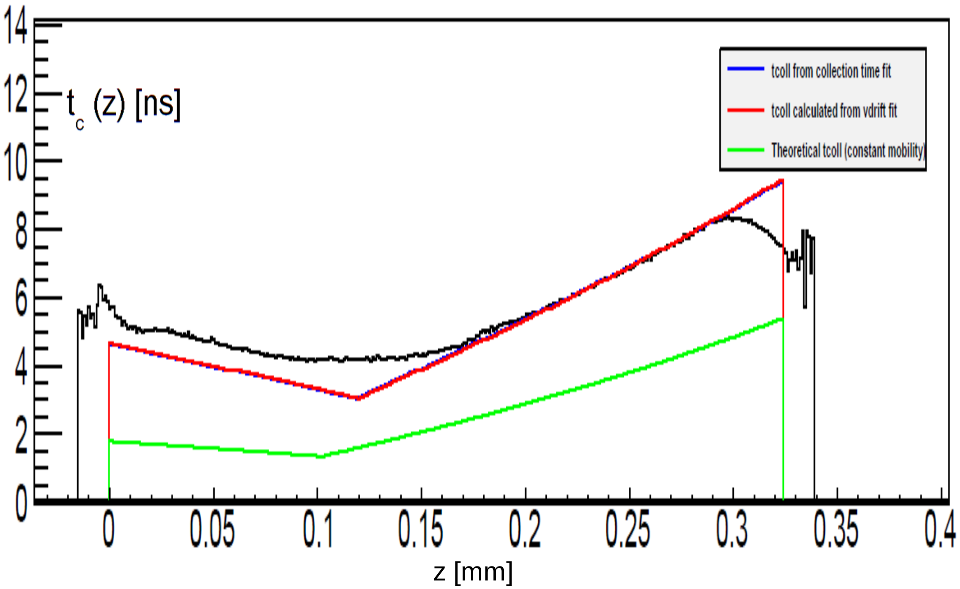
❑ Larger strip width results in deeper extension of electric field for each voltage → higher and wider Q(z), lower V_{fd}

❑ Compared to measurement, simulation produces too large increase of E(z) depth for each voltage → larger structure in lateral direction needed?

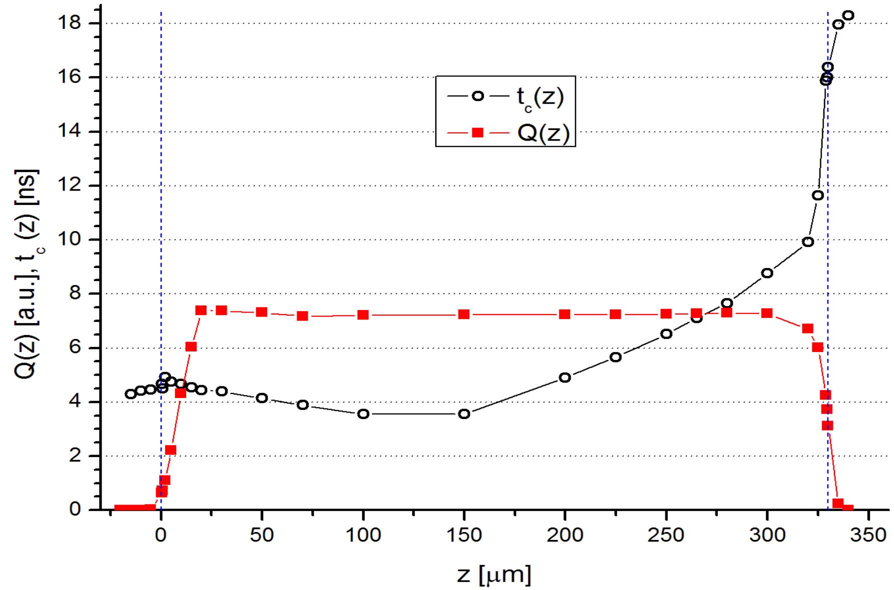
edge-TCT: VTT detector collection time

HELSINKI INSTITUTE OF PHYSICS

Measured & fitted collection time @ V=400 V (M. Fernandez 2013)



Simulated collection time & collected charge @ V=400 V



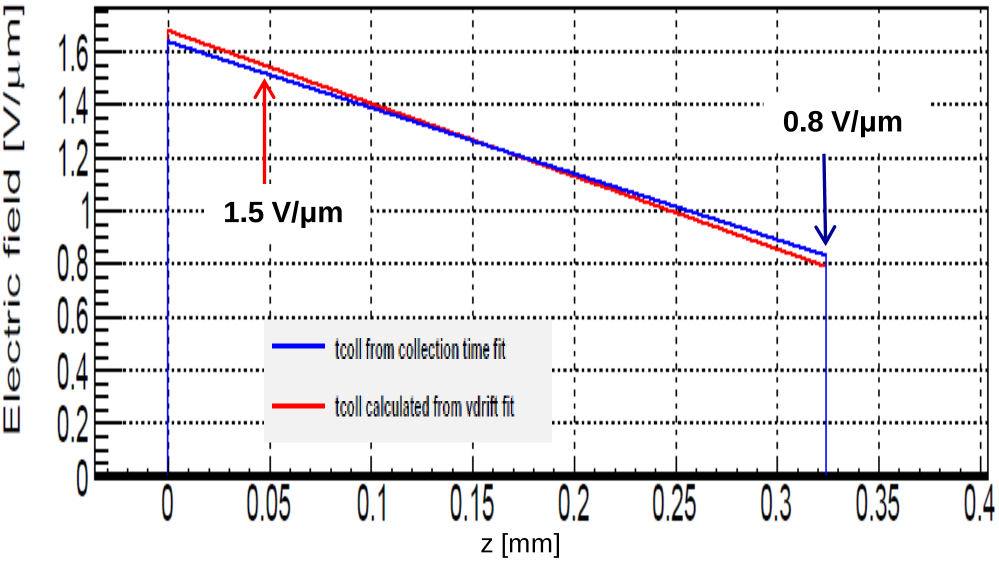
- ❑ V > V_{fd}
- ❑ Signal collection time t_c: time that takes to collect 0.98*Q_{max}
- ❑ Measurement: t_c was set to zero when thickness < laser z-position < 0

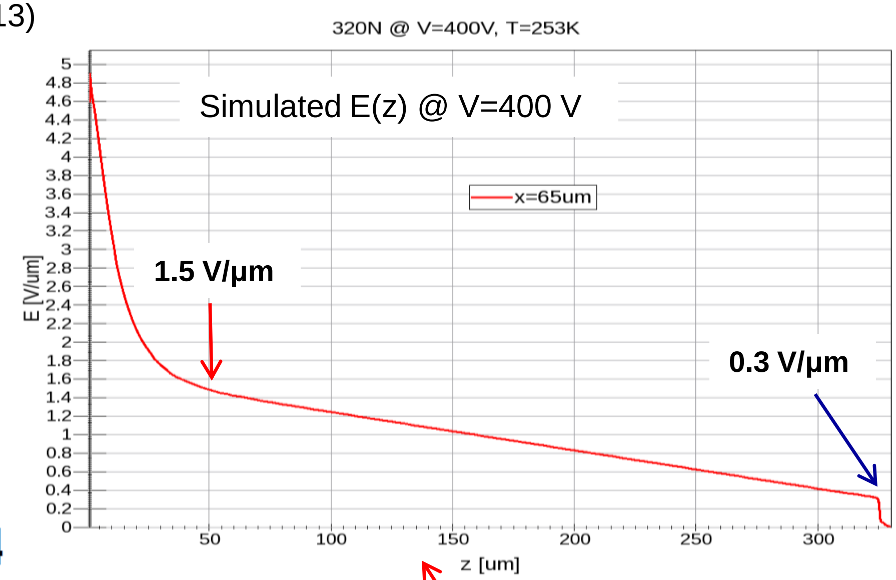
- ❑ Simulated t_c values/evolution very close to measurement at $0 \leq z \leq 320$
- ❑ Enables further comparison of parameters calculated from fits

edge-TCT: VTT detector E(z)

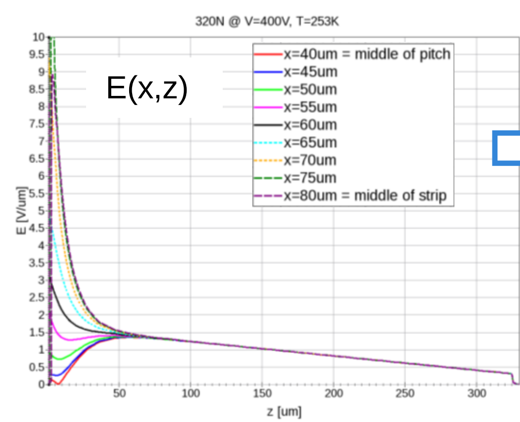
HELSINKI INSTITUTE OF PHYSICS

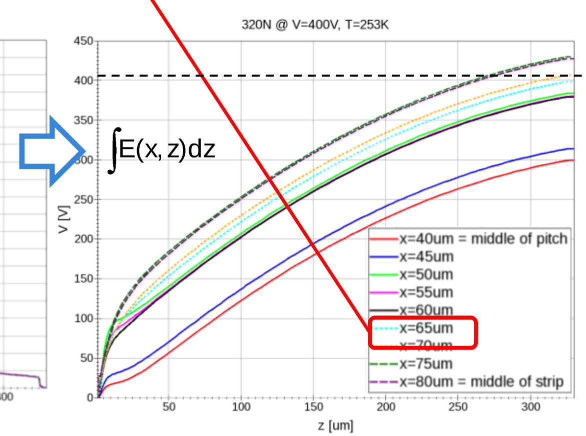
Calculated E(z) from $v_{drift}(z)$, $t_c(z)$ fits@ V=400 V (M. Fernandez 2013)





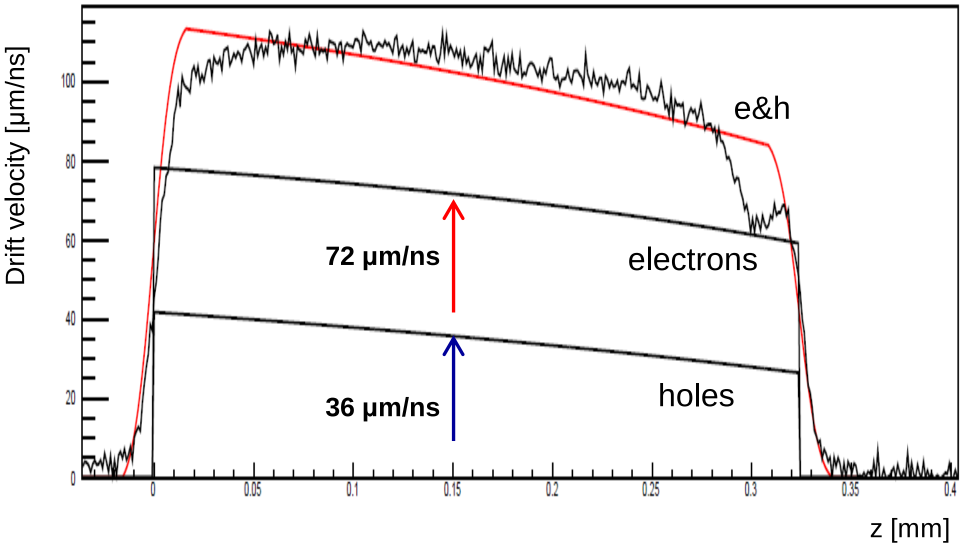
- ❑ E(z) is calculated from fits with linear approx.
- ❑ Calculated E(z) is compared with simulated E(z,x=65 µm) since it reproduces the applied voltage most accurately
- ❑ Simulation matches the calculated value at z = 50 µm, but has a steeper slope

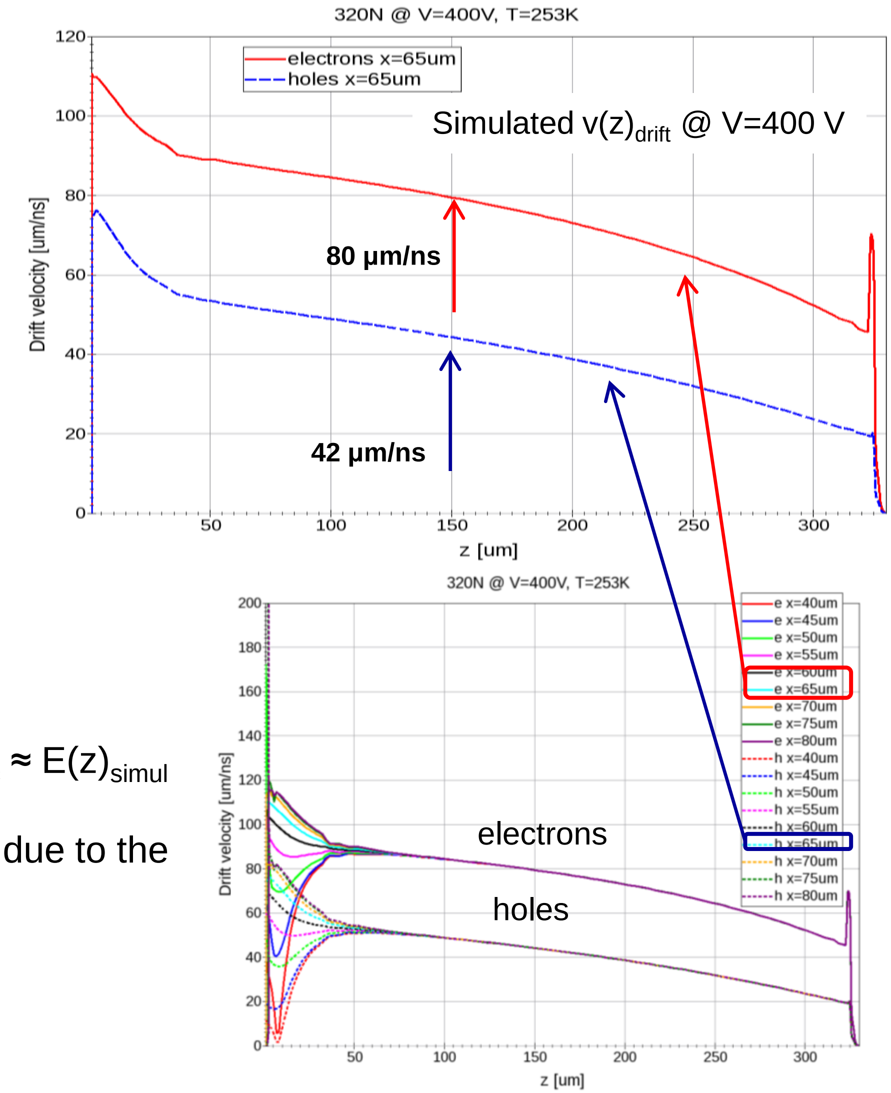




edge-TCT: VTT detector $v_{drift}(z,x)$

Measured & fitted $v(z)_{drift}$ @ V=400 V (M. Fernandez 2013)





- ❑ Simulated $v(z)_{drift} = \mu_{e,h}(z,x=65\ \mu m)E(z,x=65\ \mu m)$
- ❑ Large differences in values at z=50 µm, where $E(z)_{calc} \approx E(z)_{simul}$
- ❑ To be investigated: are the differences in $v(z)_{drift}$ more due to the simulated charge carrier mobility or the fit?

Interstrip resistance simulations

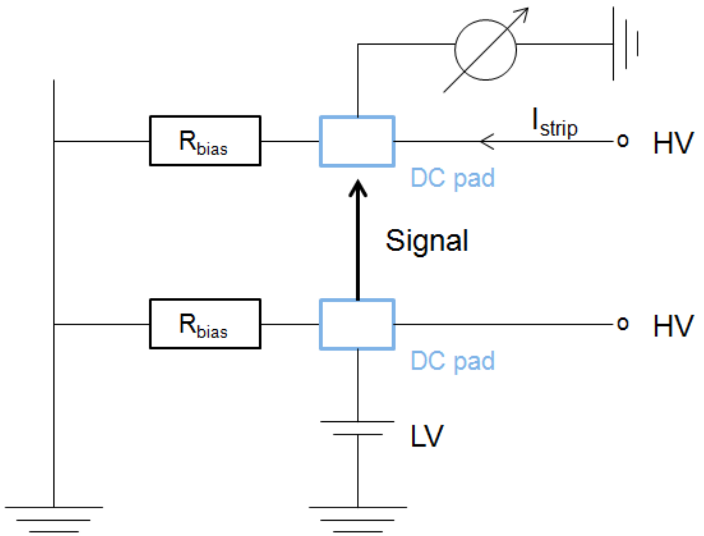
MSSD interstrip resistance simulations

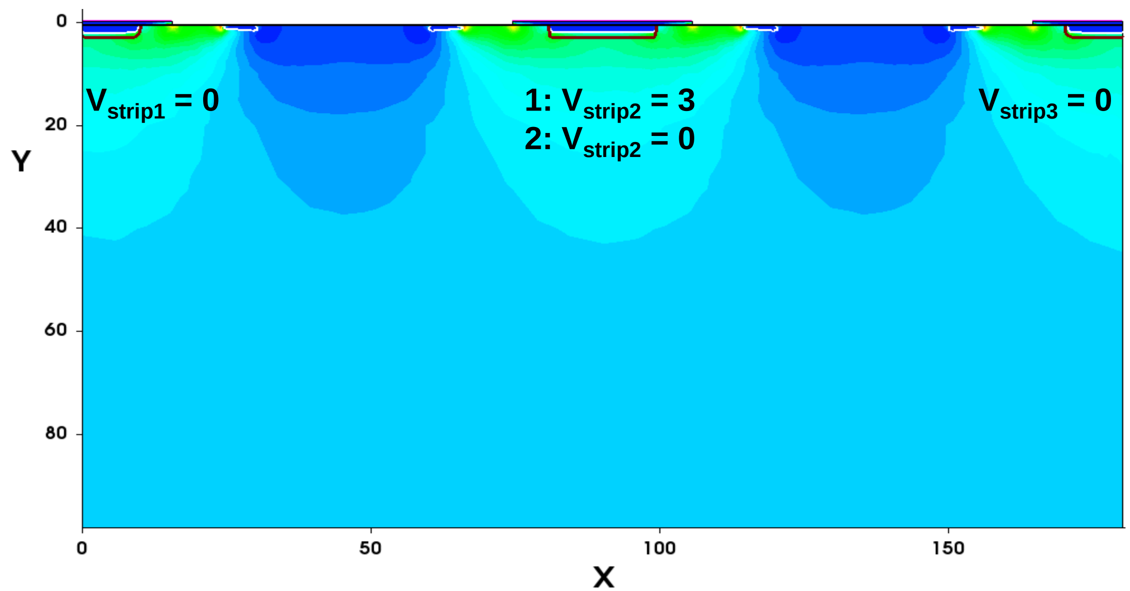
- 3 strip structure, $V_{strip1} = V_{strip3} = 0$, $V_{strip2} \sim 3$ V and 0 V
- V = -HV at the backplane
- Interstip resistance (R_{int}) is defined as (Induced Current Method):

$$R_{int} = \frac{V_2(3V)}{\frac{I_1(3V)+I_3(3V)}{2} - \frac{I_1(0)+I_3(0)}{2}}$$

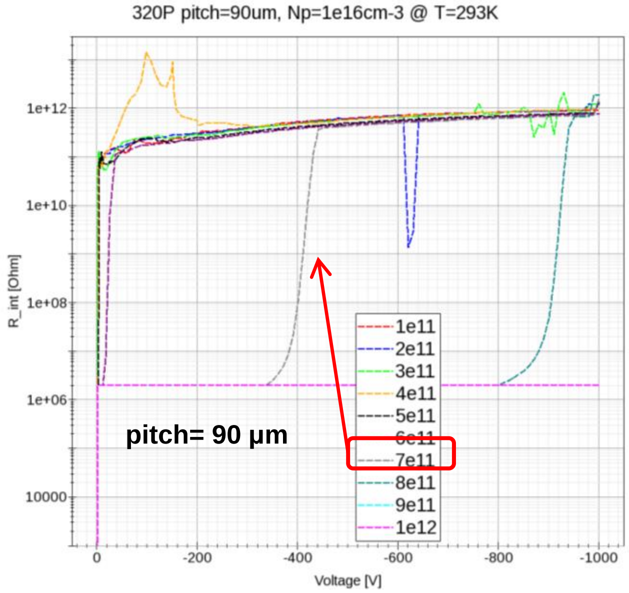
- R_{int} is plotted as a function of applied voltage V

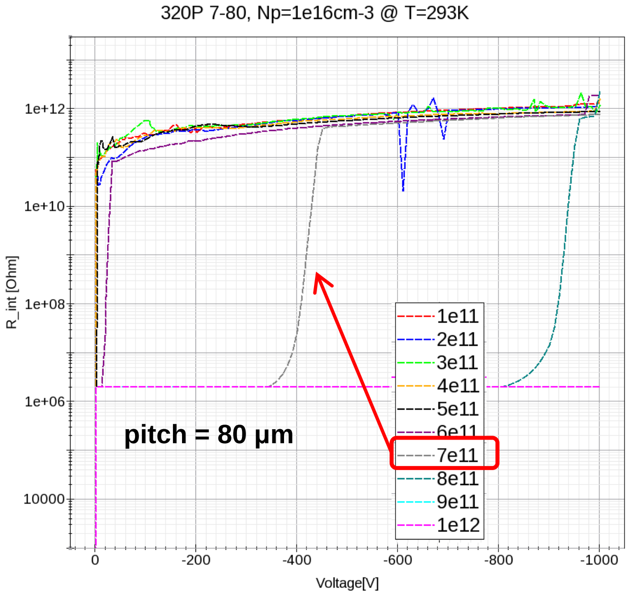
- **Device parameters:**
  - 320P
  - Bulk doping = 3.4e12 cm^{-3}
  - p-stop depth = 1.6 µm
  - p-stop width = 6 µm
  - p-stop spacing = 6 µm
  - implant depth = 2.2 µm
  - R_{bias} = 1 MΩ

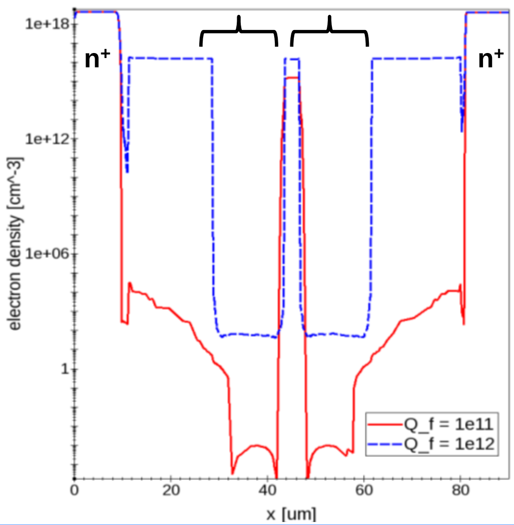




MSSD interstrip resistance: pitch



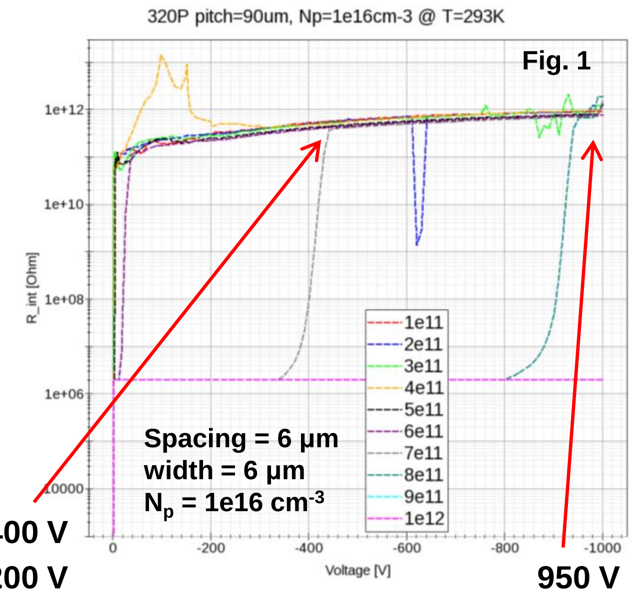


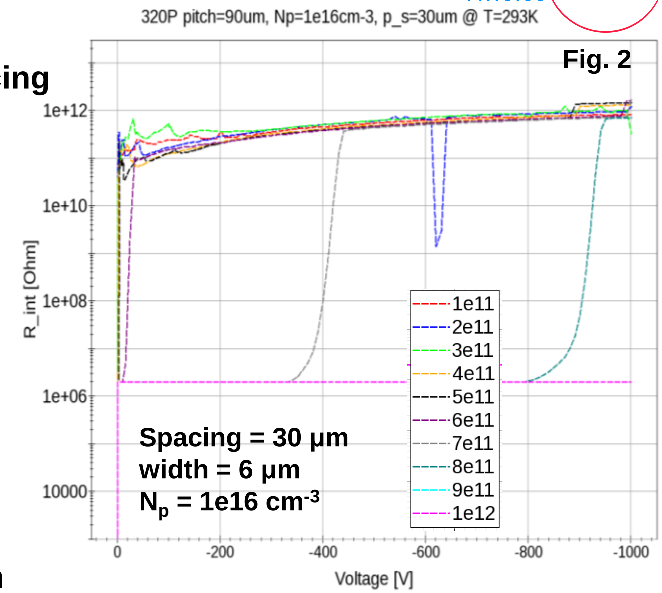


- ❑ Oxide charges Q_f of the Si/SiO_2 interface are varied
- ❑ Isolation fails for practical voltages at Q_f > 7e11 cm^{-2}
- ❑ 7-80: Smaller fluctuations, R_{int} otherwise pitch independent
- ❑ Minimum R_{int} determined by R_{bias} values of the two strips

- **Electron densities between implants and p-stops: isolated and short-circuited cases**

MSSD interstrip resistance: p-stop spacing, width & doping





400 V

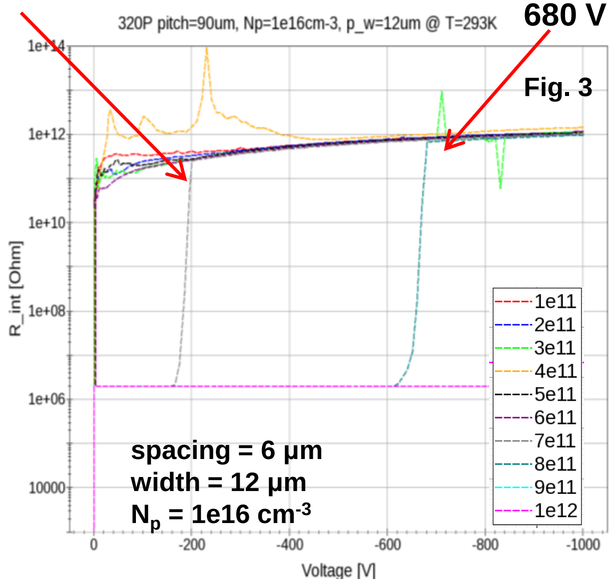
200 V

950 V

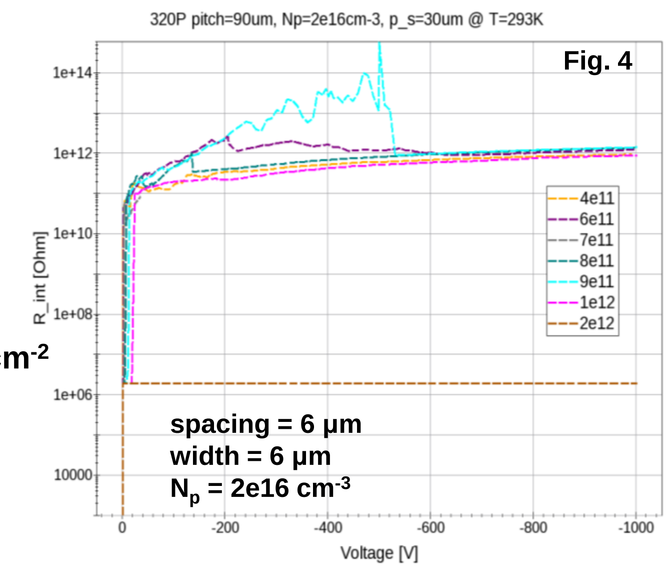
680 V

- ❑ No dependence on p-stop spacing observed (fig. 2)

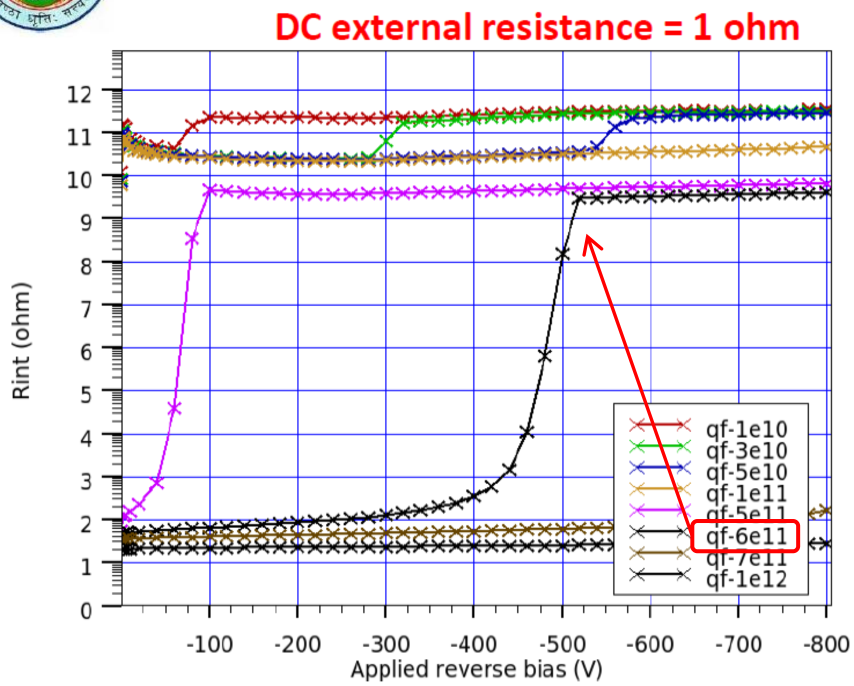
- ❑ Double p-stop width (fig. 3) :
  - ▪ Q_f = 7e11 cm^{-2} isolation reached ~200 V lower voltage
  - → R_{int} has strong dependence on p-stop width

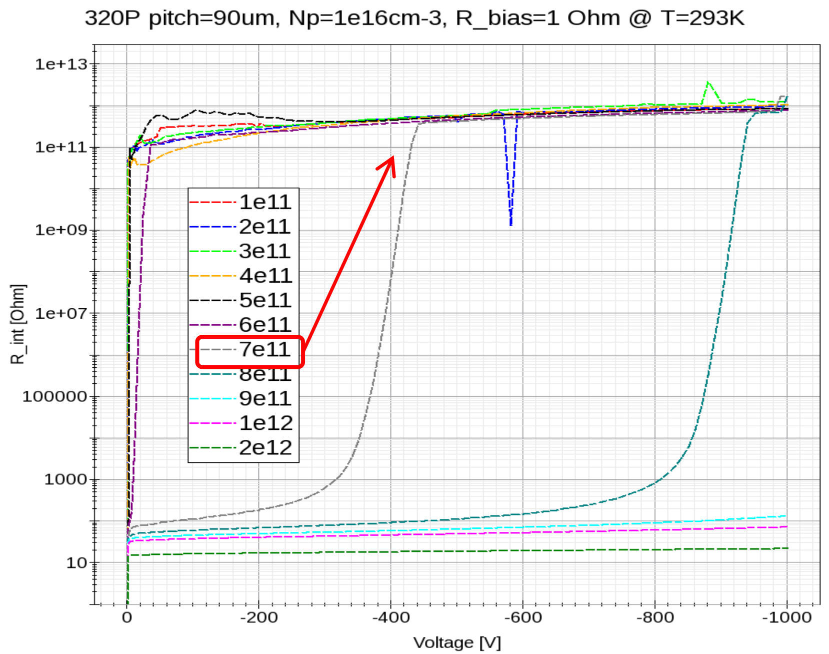


- ❑ Double p-stop doping (fig. 4) :
  - ▪ Strips are isolated at $Q_f \leq$ 1e12 cm^{-2}
  - ▪ Higher electric fields at p-stop edges (~40% increase)



MSSD interstrip resistance : Synopsys vs Silvaco





- Identical structures & simulation parameters (R_{bias} = 1 Ω)
- Matching qualitative behaviour between packages
- Slight difference in intermediate values of Q_f and voltages needed for isolation
  - Synopsys: Q_f = 7e11 cm^{-2} transition at V ~ 400 V
  - Silvaco: Q_f = 6e11 cm^{-2} transition at V ~ 500 V

CCE simulations

CCE simulations: defect models & SiBT data

EVL defect model tuned to T = 253 K by Robert Eber, KIT

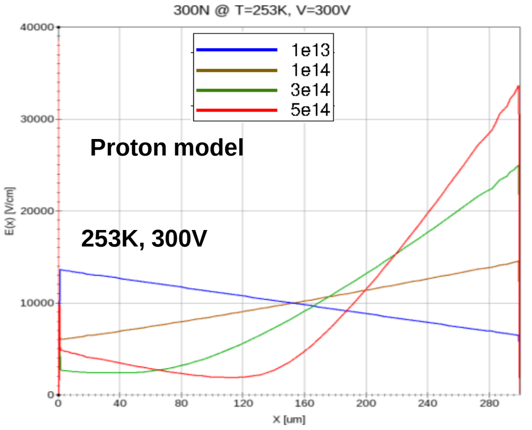
Proton model

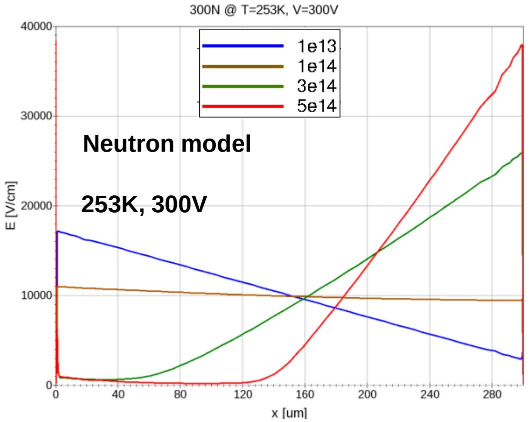
Type of defect	Level [eV]	σ_e [cm^2]	σ_h [cm^2]	Concentration [cm^{-3}]
Deep acceptor	E_C - 0.525	1e-14	1e-14	1.189*F + 6.454e13
Deep donor	E_V + 0.48	1e-14	1e-14	5.598*F - 3.959e14

Neutron model

Type of defect	Level [eV]	σ_e [cm^2]	σ_h [cm^2]	Concentration [cm^{-3}]
Deep acceptor	E_C - 0.525	1.2e-14	1.2e-14	1.55*F
Deep donor	E_V + 0.48	1.2e-14	1.2e-14	1.395*F

❑ **Both models produce correct leakage current & DP behaviour:**





SiBT data fluencies

Device	Φ (1 MeV n_{eqv} p) [cm^{-2}]	Φ (1 MeV n) [cm^{-2}]	$\Sigma\Phi$ (1 MeV n_{eqv}) [cm^{-2}]
FZ320P	0.0	4.0e14	4.0e14
FZ320P	8.0e14	5.0e14	1.3e15
FZ200P	3.0e14	0.0	3.0e14
MCz200P	9.0e14	5.0e14	1.4e15

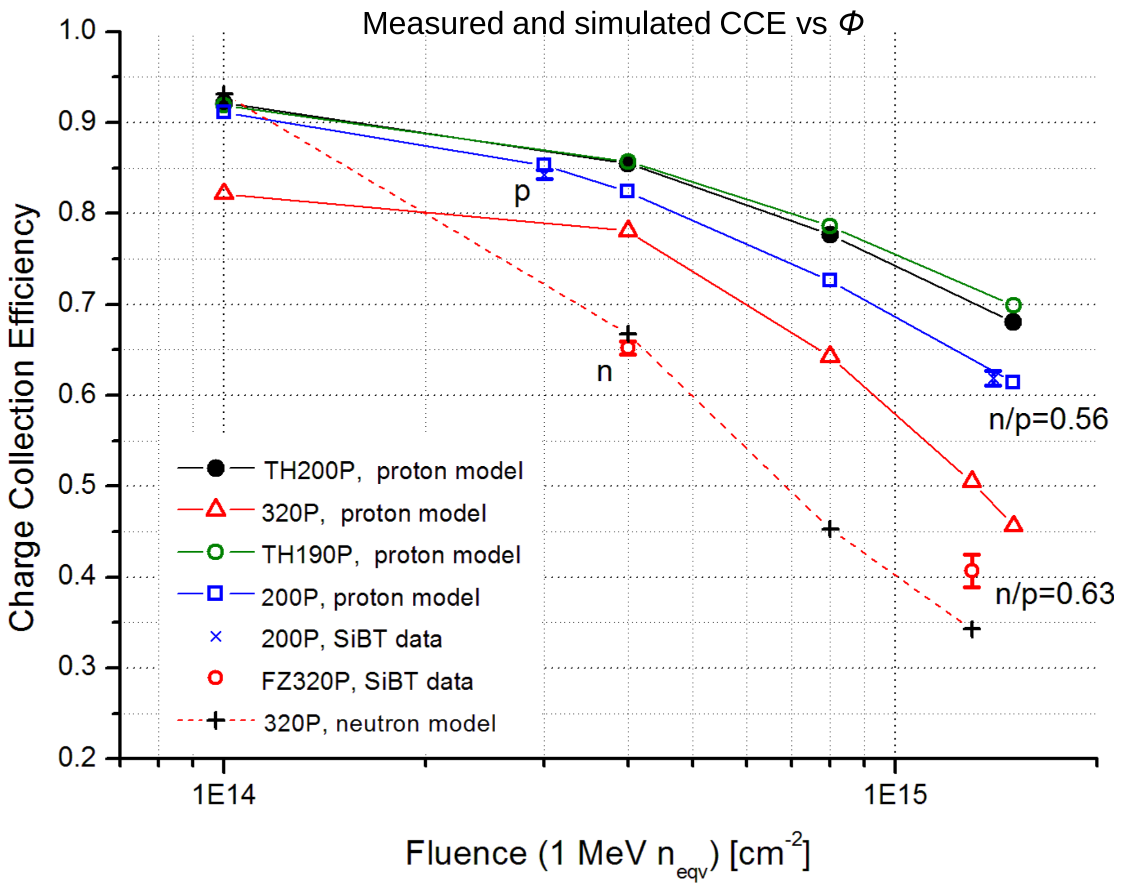
❑ **Since irradiations included both protons and neutrons, both defect models are needed**

❑ **Thicknesses of the reference detectors and DUTs are not equal, so measured CCE is determined by:**

$$CCE_{data} = \frac{Q_{DUT}}{Q_{ref}} \frac{d_{ref}}{d_{DUT}}$$

Q = collected signal
d = detector thickness

CCE simulations: SiBT data vs simulation



- ❑ 5-120 region, T = 273 K , V ≈ 600 V
- ❑ Tuning to match I_{leak} @ T = 273 K for both models: $\sigma_{e,h}(273K) = 0.75^{*}\ \sigma_{e,h}(253K)$
- ❑ Proton model matches the SiBT data for 200P, no match for 320P
- ❑ Neutron model is within 0.8% of the neutron irradiated measurement
- ❑ Problems: proton model for 320P and mixed doses

Summary

- Simulated edge-TCT can succesfully model measurement. Next steps:
  - Structure tuning needed at $V < V_{fd}$
  - Investigation of simulated mobility

- Induced Current Method was applied to simulate interstrip resistance
  - Strong dependence on p-stop width was observed for R_{int}
  - Synopsys and Silvaco produce results that match qualitatively

- 2-level defect models for both protons and neutrons were applied for the CCE simulations
  - Simulated CCE(200P) matches the experimental SiBT results
  - Simulated CCE(320P) models the neutron irradiated SiBT measurement
  - Further defect model required for mixed doses?