A method to model the accumulation of oxide charge with fluence in an irradiated MSSD

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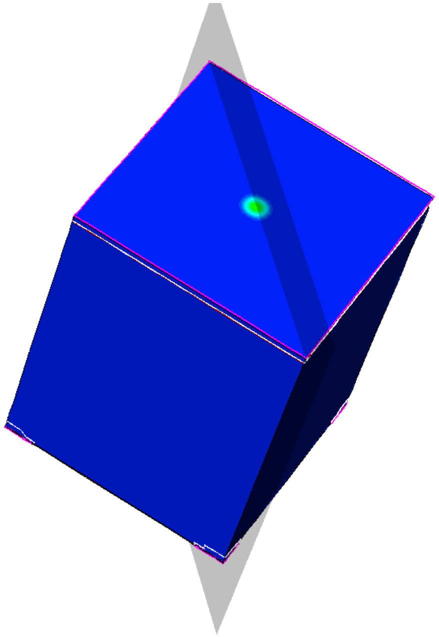
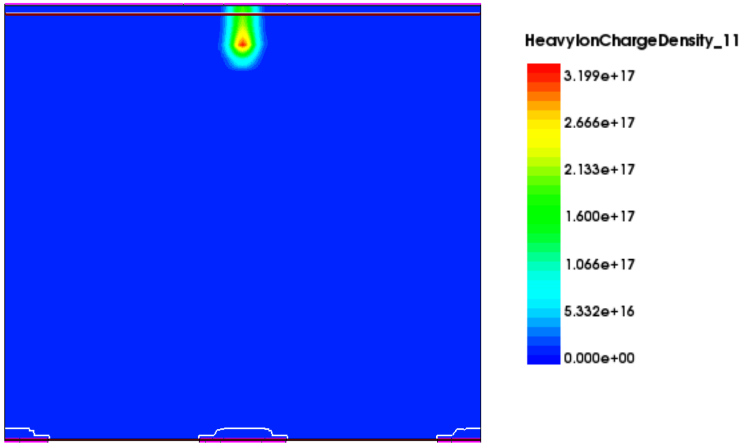




Outline

- ☐ **Motivation & method to determine CCE(x)**
  - Motivation: why non-uniform 3-level defect model?
  - CCE(x): Iteration method
  - CCE(x): proton model vs non-unif. 3-l model

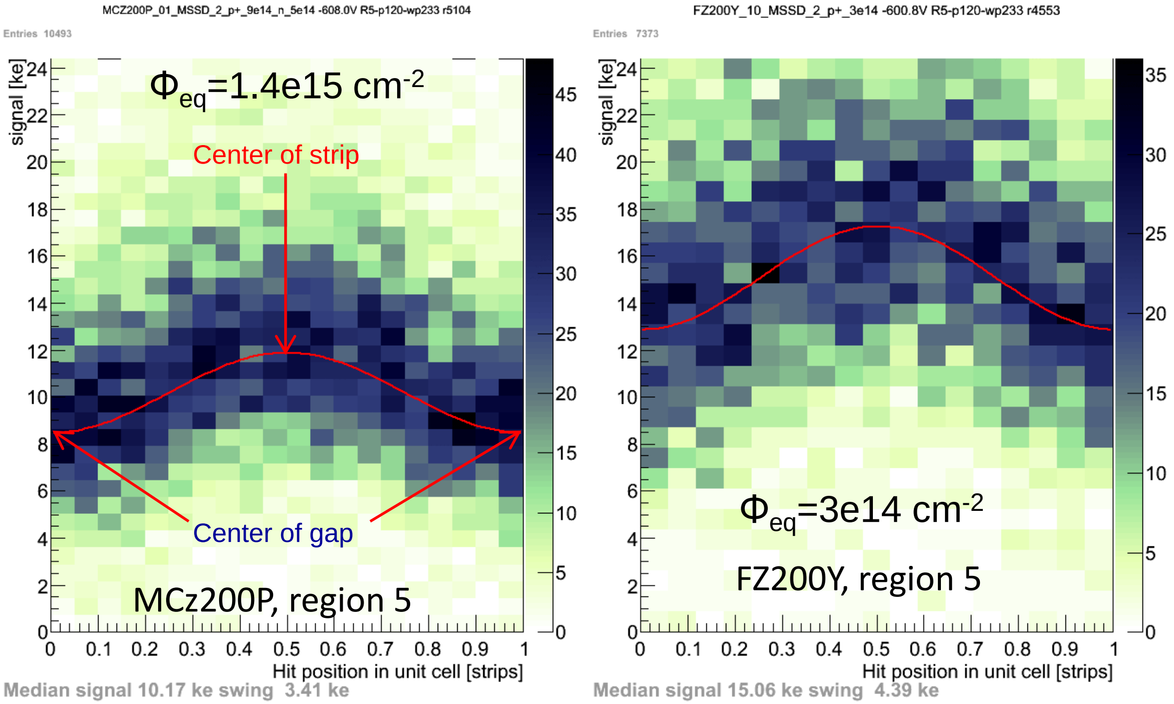
- ☐ **$Q_f(\Phi)$ & $c(\Phi)$ modelling**
  - Measured CCE(x) vs simulation:
    - d & η varied
    - d = constant
  - $Q_f(\Phi)$ & $c(\Phi)$ of region 5 200P MSSD

Motivation & method to determine CCE(x)

Non-unif. 3-level defect model: Motivation

- ❑ 3-level model within 2 µm of device surface + proton model in the bulk: R_{int} (fig. 1) & C_{int} (fig. 2) in line with measurement also at high fluence & Q_f
- ❑ Non-unif. 3-l model can be tuned to equal bulk properties (TCT, V_{fd} & I_{leak}) with proton model → suitable tool to investigate CCE(x)

SiBT measured CCE(x) for proton & mixed fluences (T. Mäenpää):



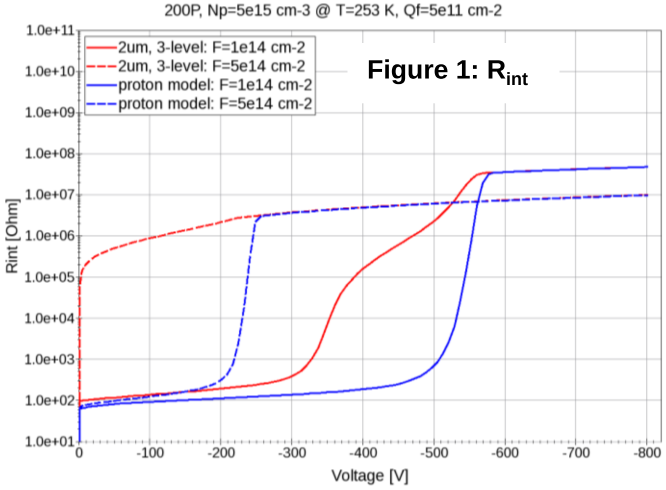


Figure 1: R_{int}

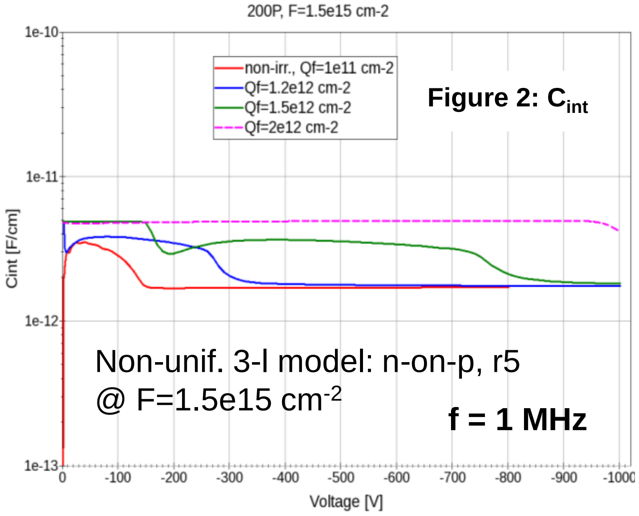
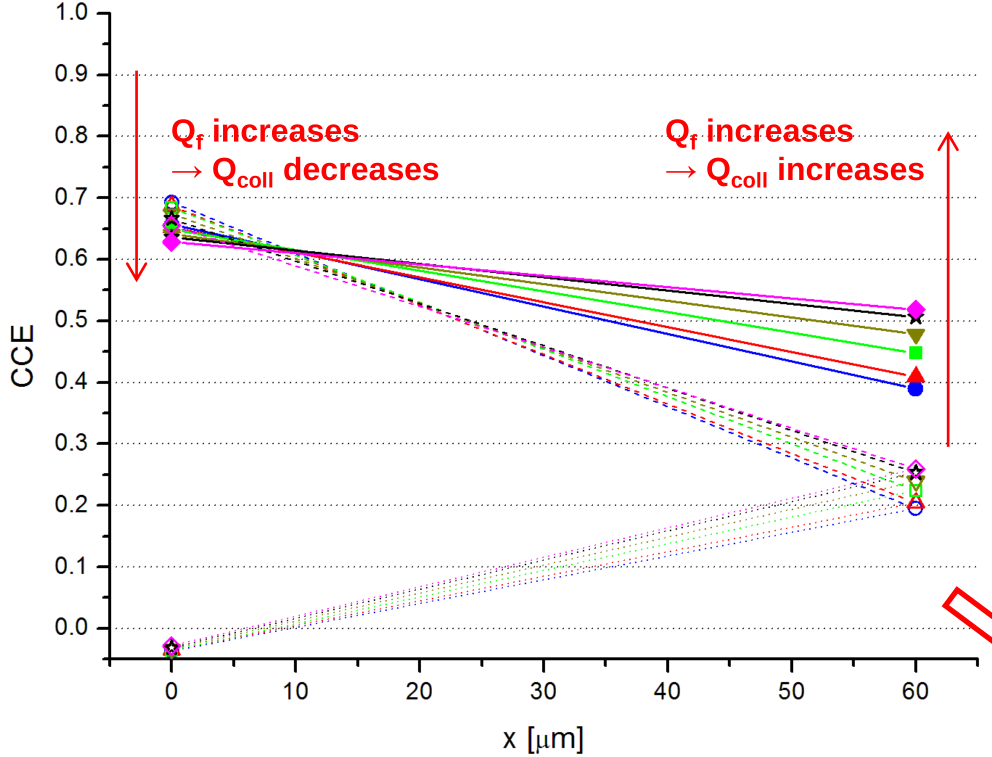


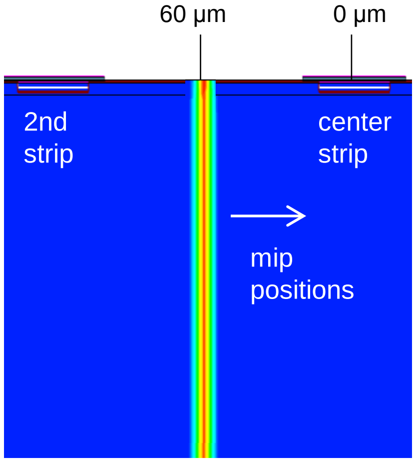
Figure 2: C_{int}

CCE(x) @ Φ_{eq} = 1.5e15 cm^{-2}: Iteration method



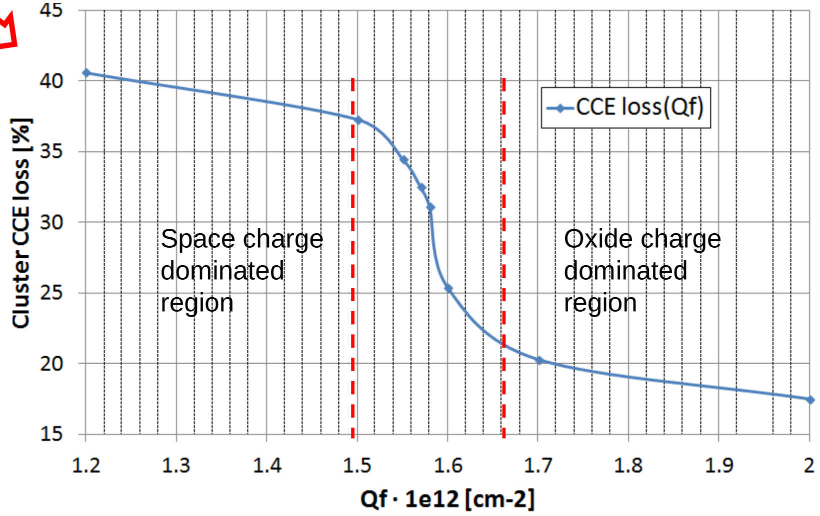
CCE loss:

40.6%
37.3%
31.1%
25.4%
20.3%
17.5%



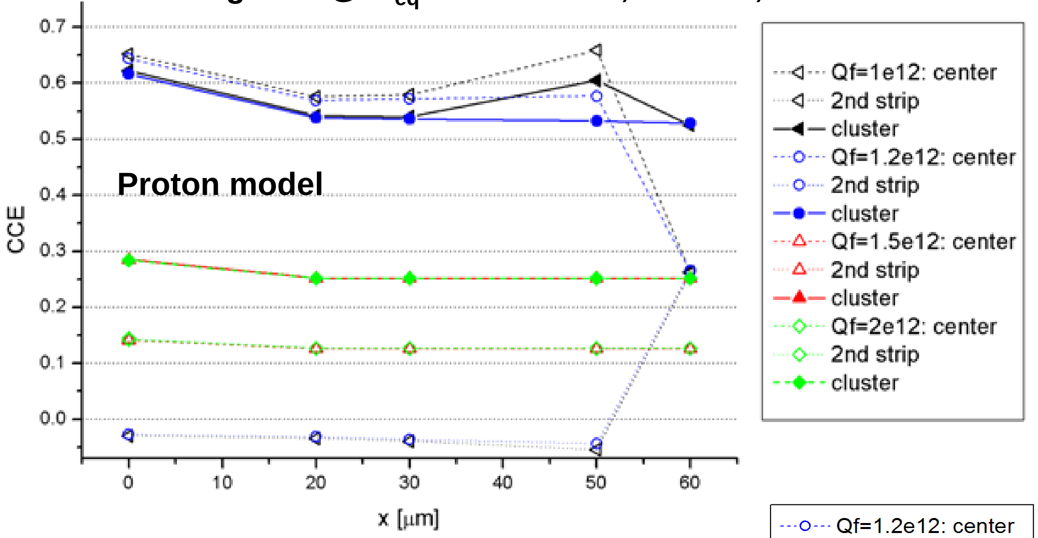
- Principle of CCE(x) simulation for given c(shallow acc.) & voltage
- 5 strip 200P, region 5 @ Φ_{eq} =1.5e15 cm^{-2}, V=-1 kV, T=253 K

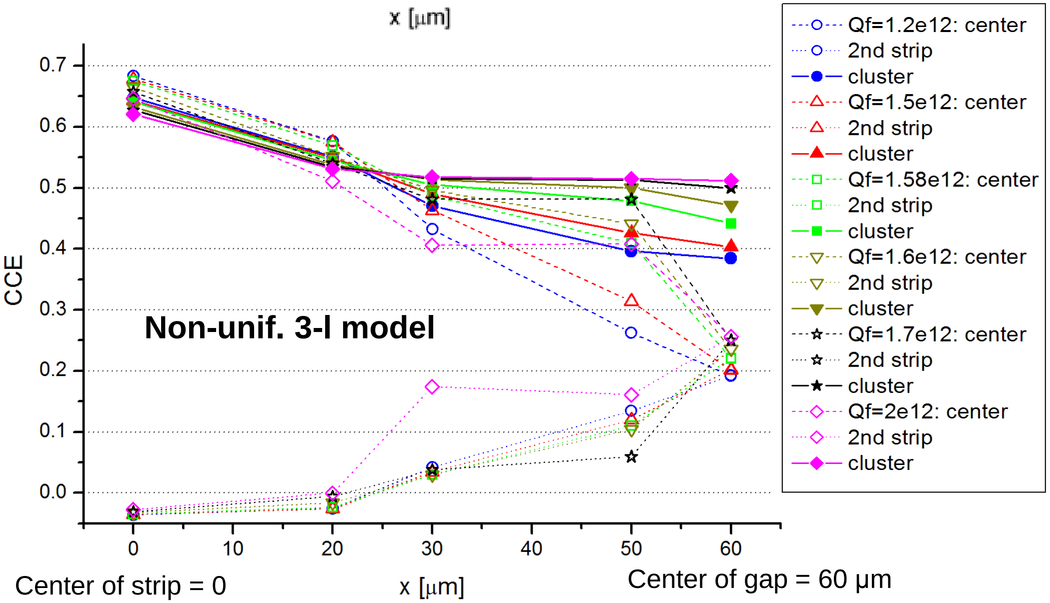
- Acceptor traps remove both inversion layer & signal electrons: better radiation damage induced strip isolation → larger CCE loss between the strips
- Increased Q_f fills more traps → CCE loss decreases, undepleted region between strips grows



CCE(x): proton model vs non-unif. 3-l model

200P region 5 @ Φ_{eq} =1.5e15 cm^{-2}, V=-1 kV, T=253 K





Proton model (tuned by R. Eber)

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

☐ Q_f = 1.2e12 cm^{-2}: CCE loss ≈ 15 %

☐ Q_f ~ 1.5e12 cm^{-2}: no strip isolation & cluster CCE ~0.5 of expected due to undepleted region produced by high Q_f

3-level model within 2 µm of device surface

Type of defect	Level [eV]	σ_e [cm^2]	σ_h [cm^2]	Concentration [cm^{-3}]
Deep acc.	E_C - 0.525	1e-14	1e-14	1.189*Φ + 6.454e13
Deep donor	E_V + 0.48	1e-14	1e-14	5.598*Φ - 3.959e14
Shallow acc.	E_C - 0.40	8e-15	2e-14	40*Φ

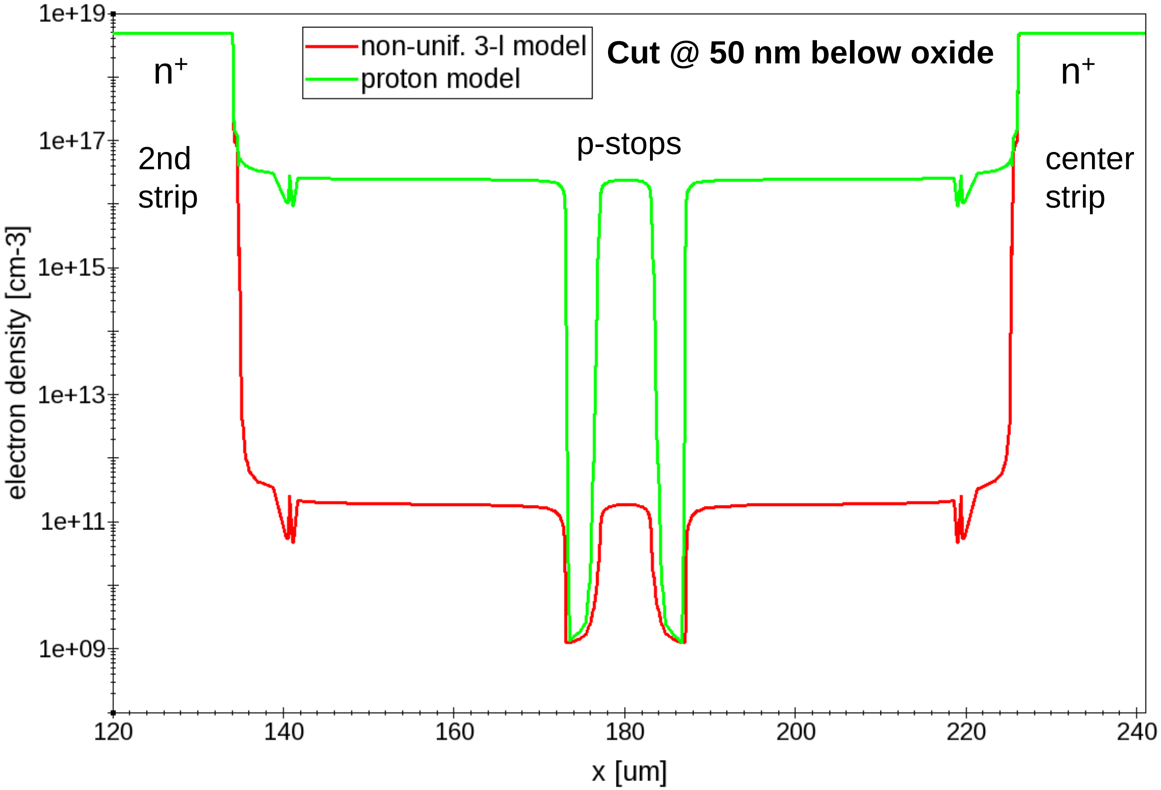
☐ Q_f = 1.2e12 cm^{-2}: CCE loss ≈ 41 %

☐ Q_f = 2e12 cm^{-2}: increased charge sharing when mip position ≥ 30 µm from center strip, but still producing position information

☐ When strips are isolated both models produce same cluster CCE at the center of the strip

proton model vs non-unif. 3-l model: electron density

- ☐ Electron density @ Q_f = 1.2e12 cm^{-2}, V=-1 kV from previous slide
- ☐ Effect of acceptor traps in non-unif. 3-l model is clearly visible:
~5 orders of magnitude difference between models (from n$^+$ to p-stop)



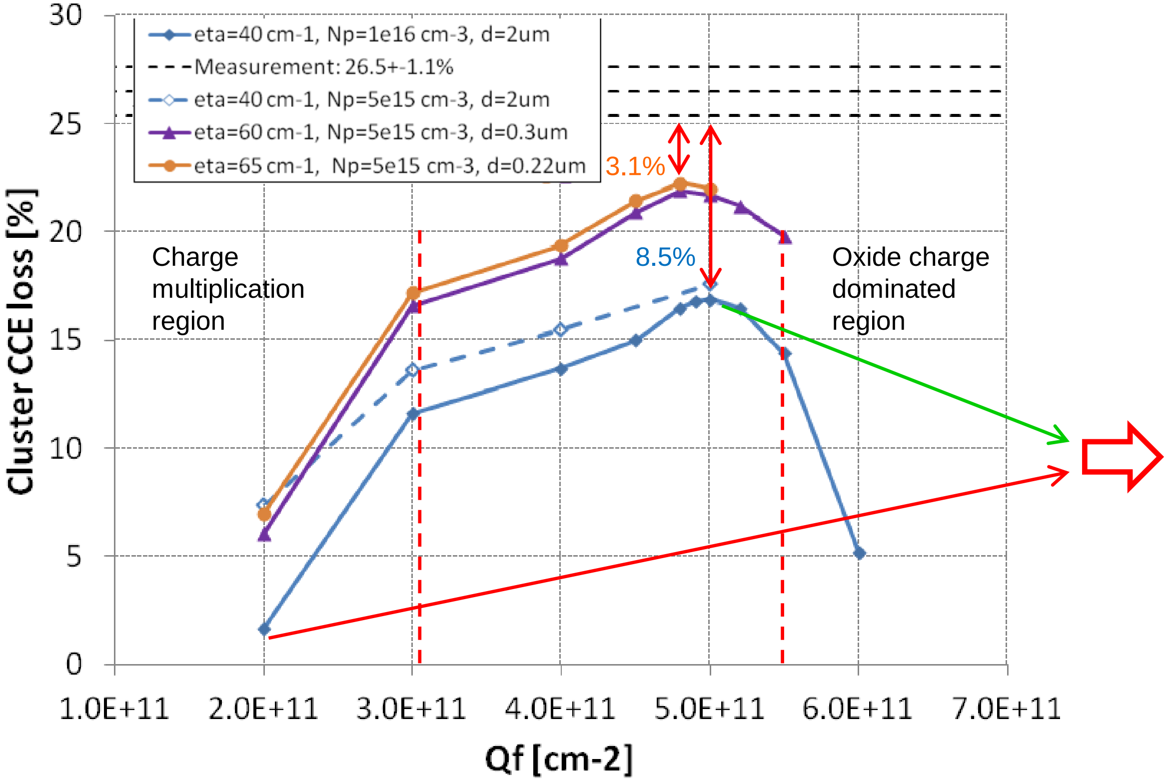
$Q_f(\Phi)$ & $c(\Phi)$ modelling

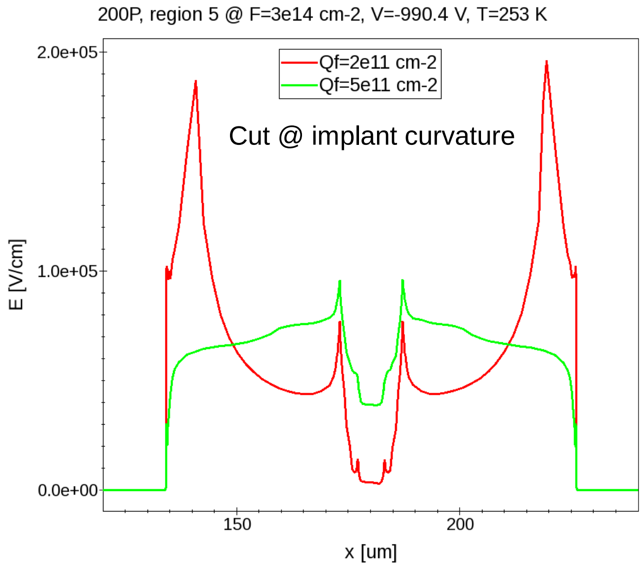
Measured CCE(x) vs simulation: d & η varied

☐ **200P Region 5:** p+ Φ_{eq}=3e14 cm^{-2}, V=-990 V, T=253 K
☐ SiBT measured CCE loss(FZ200P/Y, MCz200P) @ V=600 – 990 V: 26.5±1.1%
☐ Double p-stop: d_p=1.5 μm=$d_{implant}$, w_p=4 μm, spacing=6 μm

☐ **Approach:**

- Iterate η to find CCE loss within measured error margins @ Q_f ~5e11 cm^{-2}
- Change 3-level model thickness to preserve transient signal shape





E(x) between 2nd & center strip for η=40 cm^{-1}, N_p=1e16 cm^{-3}

☐ Two low CCE loss regions observed in Q_f scan
☐ Not seen in Φ_{eq}=1.5e15 cm^{-2} CCE loss simulations, because of higher Q_f values (1.2e12…2e12 cm^{-2})
☐ Interpretation: At very low Q_f high E produces charge multiplication → additional charge carriers fill traps → CCE loss decreases significantly

→ **New approach**: keep 3-level region thickness constant & add constant factor to shallow level c

Measured CCE(x) vs simulation: d = constant

- 3-level region: d=2 µm, strip length = 3.049 cm
- Φ_{eq}≈1.5e15 cm^{-2} has largest statistics at ~600 V → simulation V adjusted

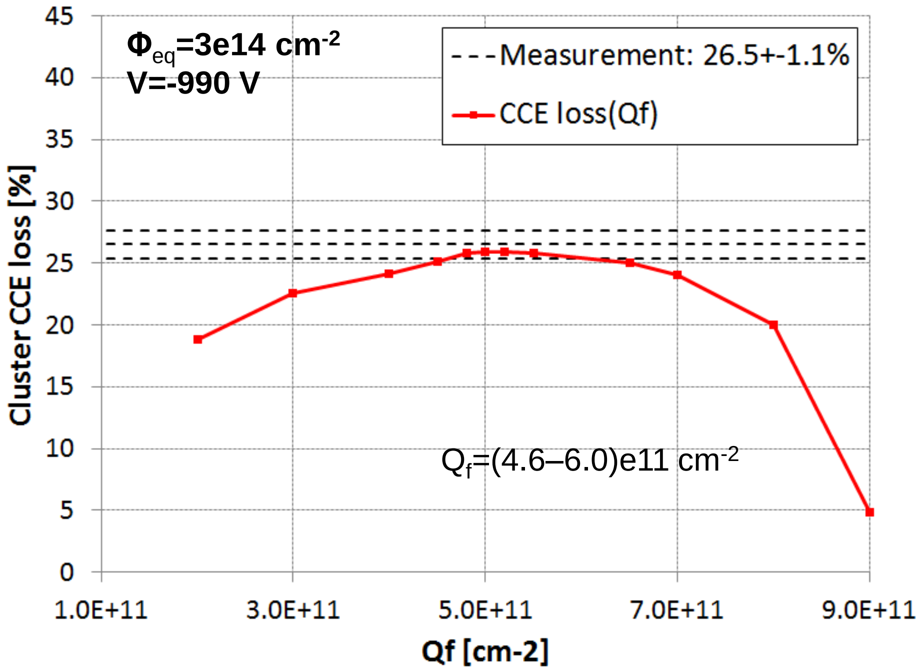
Type of defect	Level [eV]	σ_e [cm^2]	σ_h [cm^2]	Concentration [cm^{-3}]
Deep acceptor	E_C - 0.525	1e-14	1e-14	1.189*Φ + 6.454e13
Deep donor	E_V + 0.48	1e-14	1e-14	5.598*Φ - 3.959e14
Shallow acceptor	E_C - 0.40	8e-15	2e-14	40*Φ

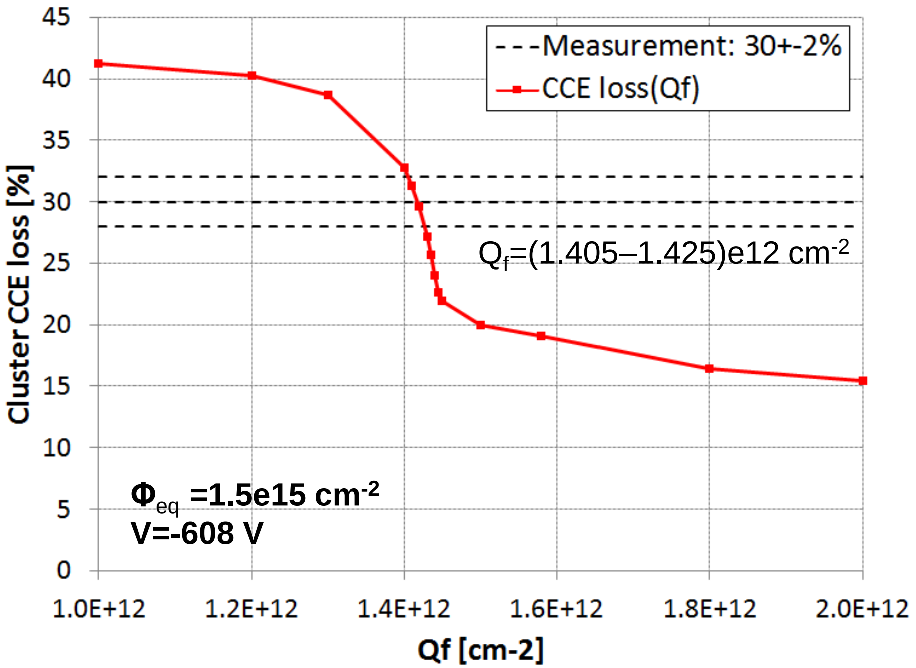
- Target Q_f ~5e11 and ~1.5e12 cm^{-2} for given fluences
- Measurement: 6 µm resolution

Shallow acc.	E_C - 0.40	8e-15	2e-14	14.417*Φ + 3.1675e16

- Measured CCE loss(FZ200P/Y, MCz200P) @ Φ_{eq} (p+) = 3e14 cm^{-2}, V = 600 – 990 V: 26.5 ± 1.1 %

- Measured CCE loss(FZ200P/Y, MCz200P/Y) @ Φ_{eq} (mixed) = (1.4 ± 0.1)e15 cm^{-2}, V = 606 ± 2 V: 30 ± 2 %



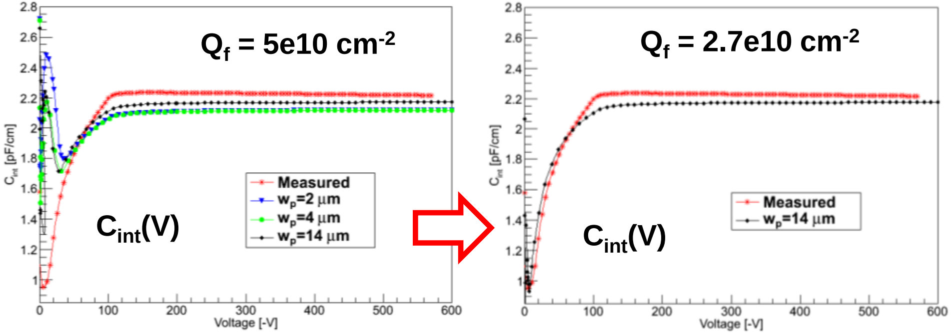


$Q_f(\Phi)$ & $c(\Phi)$ in p+ irradiated region 5 200P

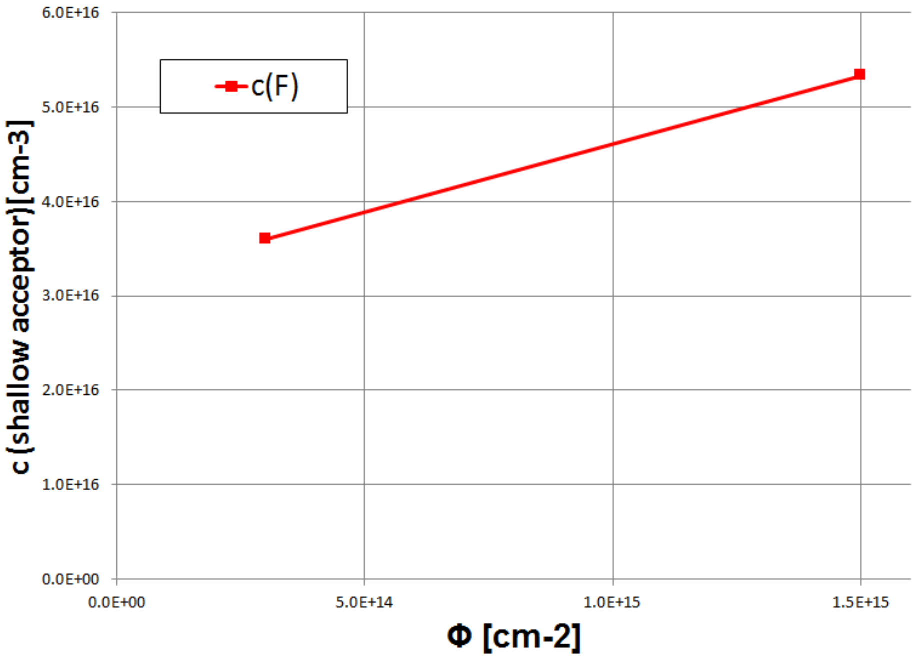
❑ Q_f of non-irradiated 200P from measured initial dip of C_{int}, that is reproduced by decreasing Q_f=2.7e10 cm^{-2}

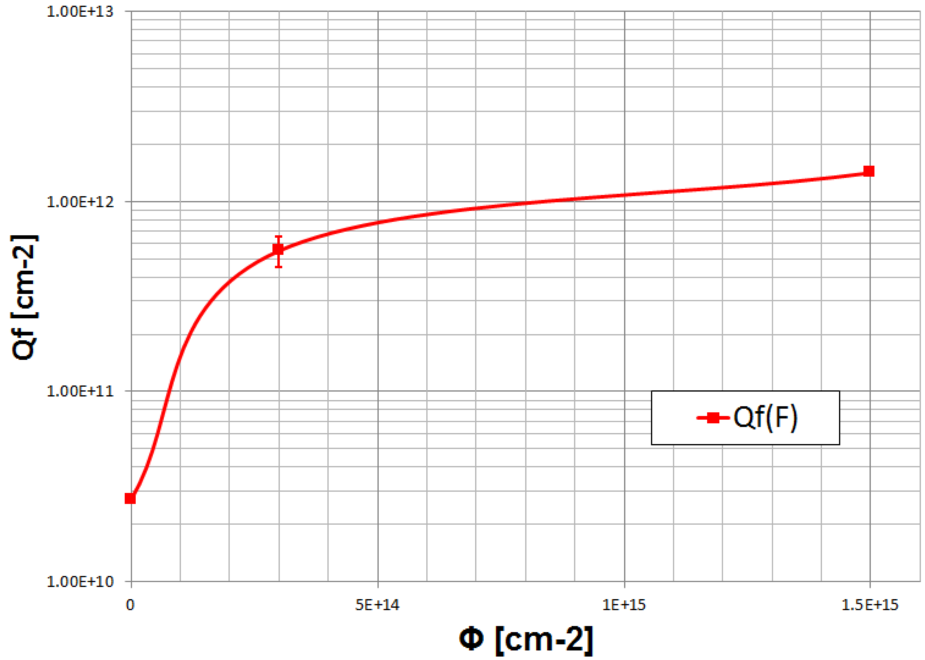
❑ c(shallow acc.) parametrized by using ‘fixed’ values of Q_f → fixed c, parametrized Q_f

❑ Increase of the shallow acceptor concentration is found to be ~0.5 of constant factor at the given fluence range



Fluence [cm^{-2}]	Q_f [cm^{-2}]	c(shallow acceptor) [cm^{-3}]
3e14	(5.3±0.7)e11	3.6e16
(1.4±0.1)e15	(1.415±0.010)e12	5.33e16





Summary

- ❑ When position dependency of CCE is modeled by non-unif. 3-l defect model, it is governed by Q_f and shallow acceptor concentration

- ❑ By tuning these two parameters it is possible to reproduce measured CCE loss between strips for given fluence

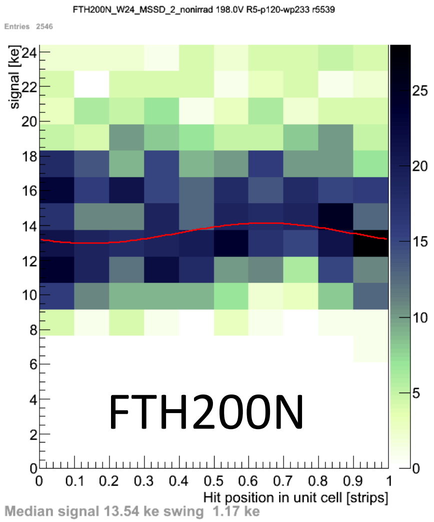
- ❑ If one of the parameters is fixed, the other can be solved reliably → potential for $Q_f(\Phi)$ parametrization

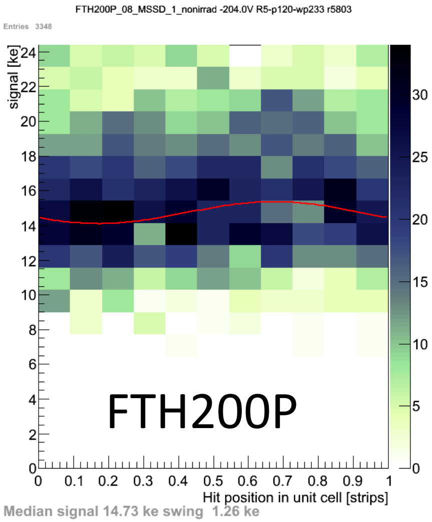
- ❑ With test values of Q_f the shallow acceptor concentration does not have strong dependence on fluence in the range 3e14 → 1.5e15 cm^{-2}

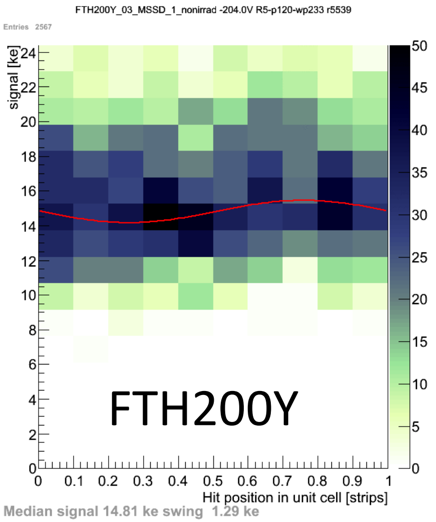
Backup: SiBT measured CCE loss between strips

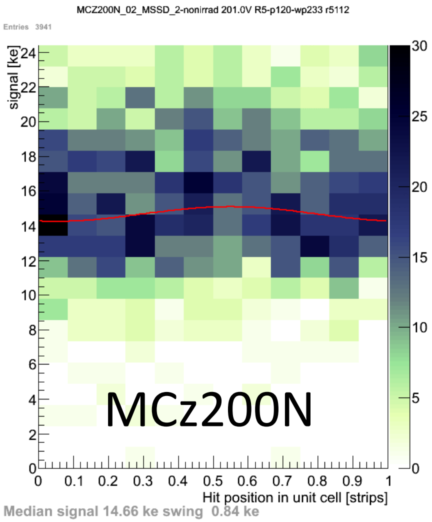
Signal loss in-between strips (p=120µm, w/p~0.23)

non-irradiated



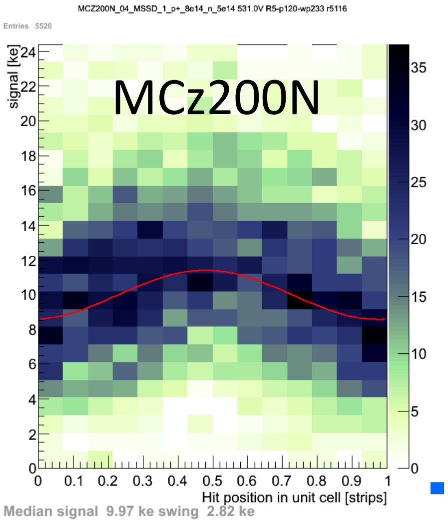


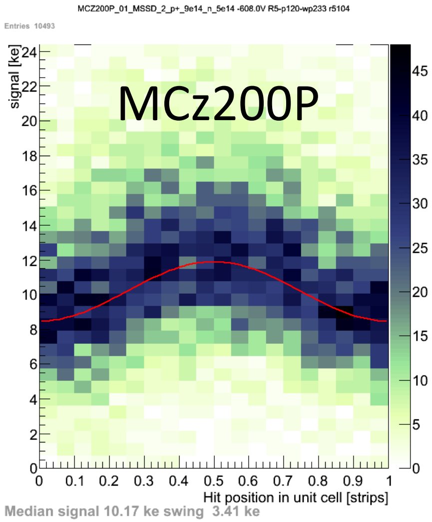


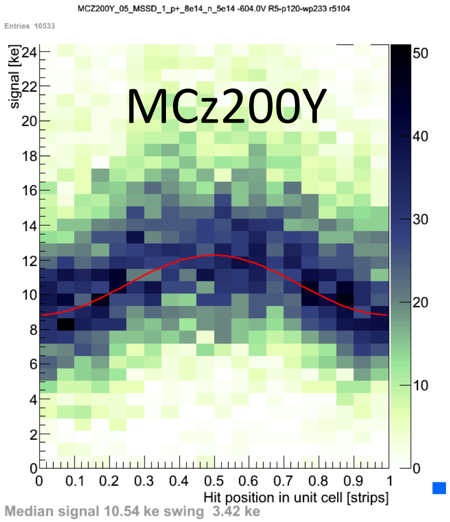


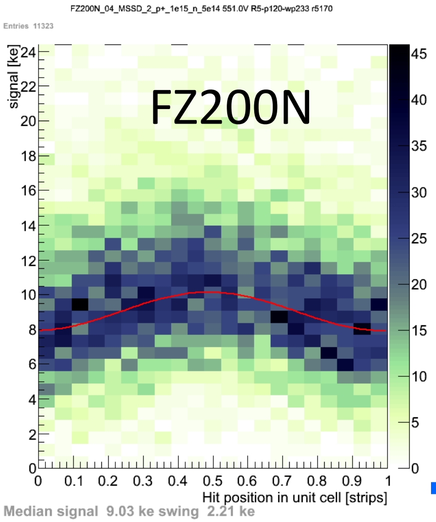
No loss before irrad.; after irrad. ~30% loss; all technologies similar [Phase-2 Outer TK Sensors Review]

mixed irradiated 1.5e15n$_{eq}$/cm^2

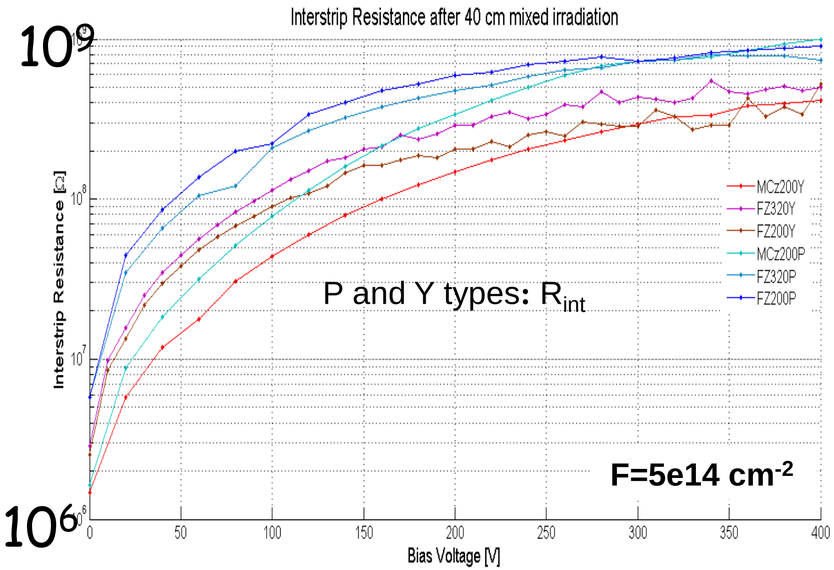








Backup: Measured R_{int}

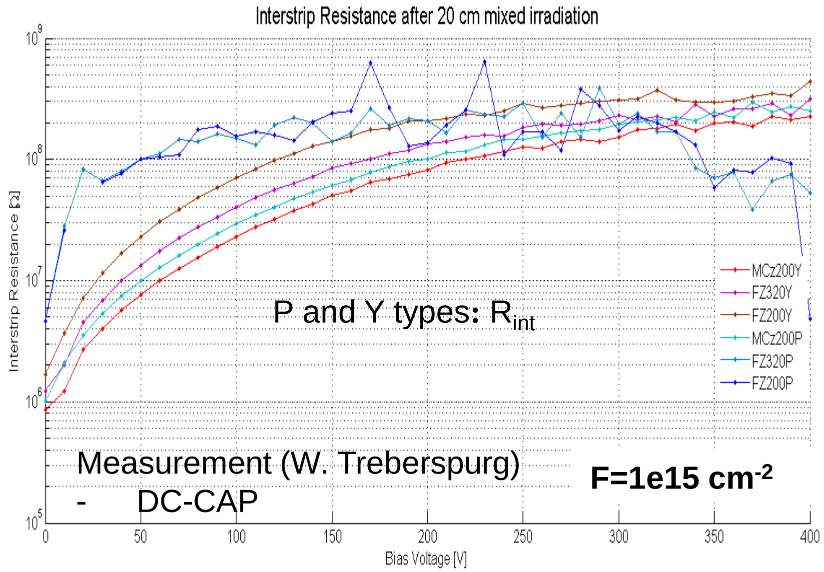


10^9

10^6

P and Y types: R_{int}

F=5e14 cm^{-2}



P and Y types: R_{int}

Measurement (W. Treberspurg)
- DC-CAP

F=1e15 cm^{-2}

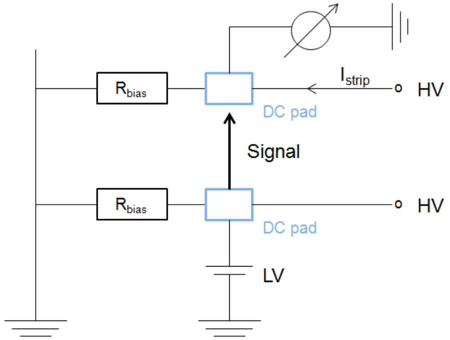
Backup: simulated R_{int} & C_{int}

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

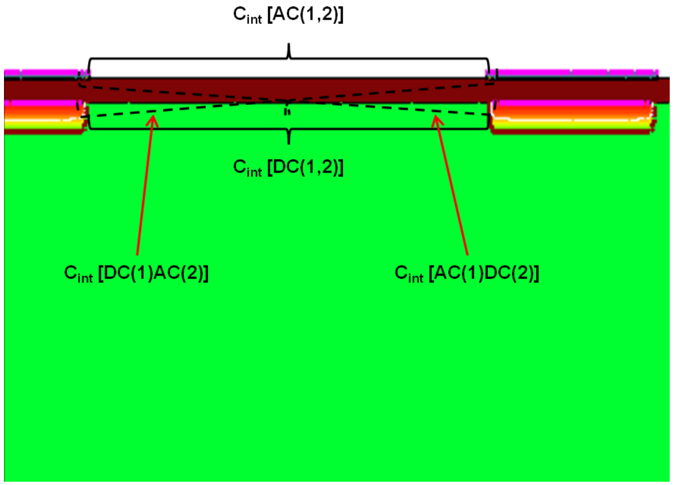
$$R_{int} = \frac{V_2(LV)}{\frac{I_1(LV)+I_3(LV)}{2} - \frac{I_1(0)+I_3(0)}{2}}$$

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

- **Electrical circuit diagram of R_{int} measurement :**



C_{int} simulation principle



C_{int} = 2*[AC(1,2)+DC(1,2)+AC(1)DC(2)+DC(1)AC(2)]

R_{int} simulation principle