# Silicon Strip Sensor Simulations

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Silicon Strip Sensor Simulations
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# Simulation software

- Synopsys TCAD
  - Comercial package for semiconductor simulations
  - Framework:
    - Create 2D or 3D structure (materials, doping, etc) and generate a mesh
    - Select physical models to be used in simulation: temperature, field generation, carrier recombination, trapping (→ radiation damage), carrier lifetime, etc.
    - Include external effects: electric circuit (SPICE), laser illumination, traversing particle...
    - Specify what kind of simulation: simple I-V, capacitive, or time-dependant
    - Run simulation: at each mesh-point solve poisson's equation $\frac{d^2V(x)}{dx^2} = -\frac{\rho(x)}{\epsilon_r \epsilon_0}$ and carrier continuity equations:
      $$\nabla \cdot \vec{J}_n = q\left(R_{\text{eff}} + \frac{\partial n}{\partial t}\right)$$
      $$-\nabla \cdot \vec{J}_p = q\left(R_{\text{eff}} + \frac{\partial p}{\partial t}\right)$$
    - Derive physical properties: electric field, current flows, charge distributions, etc.

# Simulation group within CMS sensor upgrade WG

- 4 other institutes: Delhi, Helsinki, Karlsruhe, Pisa
- Task list with simulation activities:
  - Device design
    - MSSD, MPix, diodes, p-stop/p-spray, deep diffusion, biasing schemes, etc.
  - Charge collection and read-out
    - Capacitance, 3D-coupling, lorentz angle, etc.
  - Radiation damage
    - Full defect list, trap models, cluster defects, IV/CV/transient simulations, CCE, E-Fields, double junction, etc.
  - General
    - Comparison of simulation tools and packages
- First selected task: device design, MSSD capacities

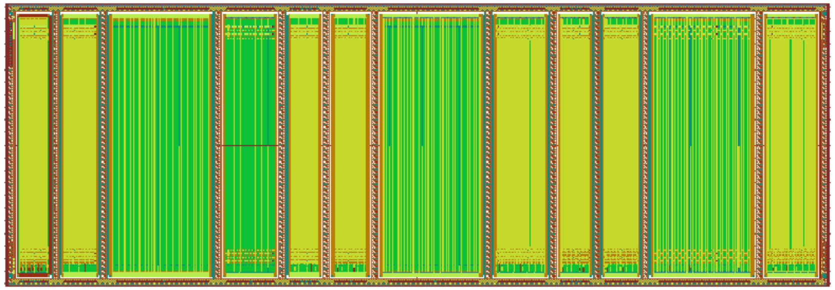
# MSSD capacities

- MSSD properties:
  - 12 strip sensor regions with different pitch and width → interstip capacitance $C_{int}$ should vary
  - Scaling factor X for comparison:

    $X = p / [d + p*f(w/p)]$ with

    $f(w/p) = -0{,}00111(w/p)^{-2} + 0{,}0586(w/p)^{-1} + 0{,}24 - 0{,}651(w/p) + 0{,}355(w/p)^2$

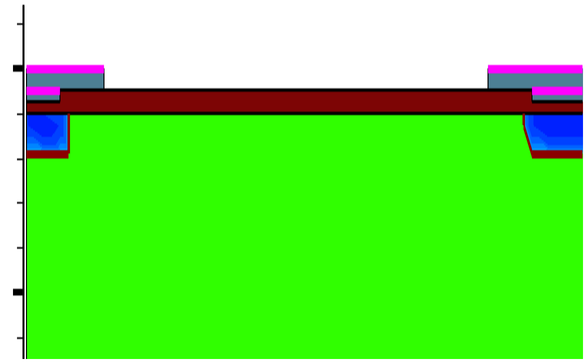
  - Measurements: total sensor capacity $C_{tot} = C_{int} + C_{back}$ is constant for all X → try to reproduce in simulations

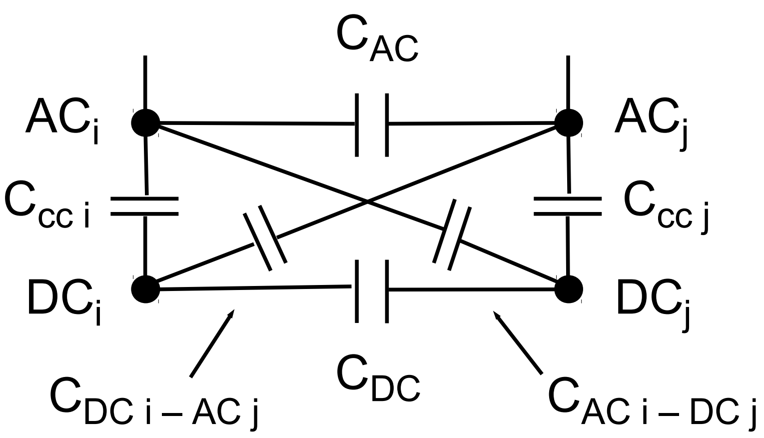


| Sensor | Pitch [µm] | Implant width [µm] | Alu width [µm] | w/p | X |
|---|---|---|---|---|---|
| 1 | 120 | 16 | 29 | 0,133 | 0,31 |
| 2 | 240 | 34 | 47 | 0,142 | 0,54 |
| 3 | 80 | 10 | 23 | 0,125 | 0,22 |
| 4 | 70 | 8,5 | 21,5 | 0,121 | 0,19 |
| 5 | 120 | 28 | 41 | 0,233 | 0,33 |
| 6 | 240 | 58 | 71 | 0,242 | 0,6 |
| 7 | 80 | 18 | 31 | 0,225 | 0,23 |
| 8 | 70 | 15,5 | 28,5 | 0,221 | 0,2 |
| 9 | 120 | 40 | 53 | 0,333 | 0,35 |
| 10 | 240 | 82 | 95 | 0,342 | 0,64 |
| 11 | 80 | 26 | 39 | 0,325 | 0,24 |
| 12 | 70 | 22,5 | 35,5 | 0,321 | 0,21 |

# MSSD capacities II

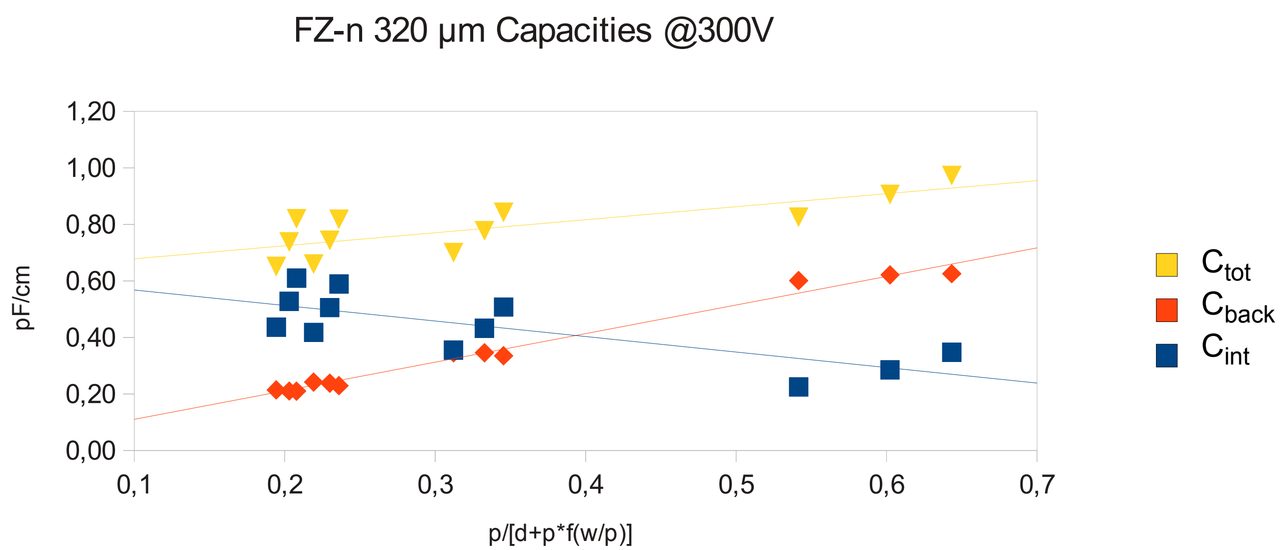
- First capactitance calculation
  - Device schematic: strip sensor with 4 (or more) strips, measure $C_{int}$ between the 2 center strips
  - How should $C_{int}$ be simulated?
  - Direct capacitance between 2 AC contacts is < 0,001 pF/cm → far too low!
  - Consider further capacities: → $C_{int} \sim C_{AC} + C_{DC} + C_{DCi\text{-}ACj} + C_{ACi\text{-}DCj}$
  - See *S. Chatterji et al.* in *Solid-State Electronics 47 (2003) 1491 – 1499*
  - This method gives $C_{int}$ values in the magnitude of measurements, but is it physically correct?





# MSSD capacities III

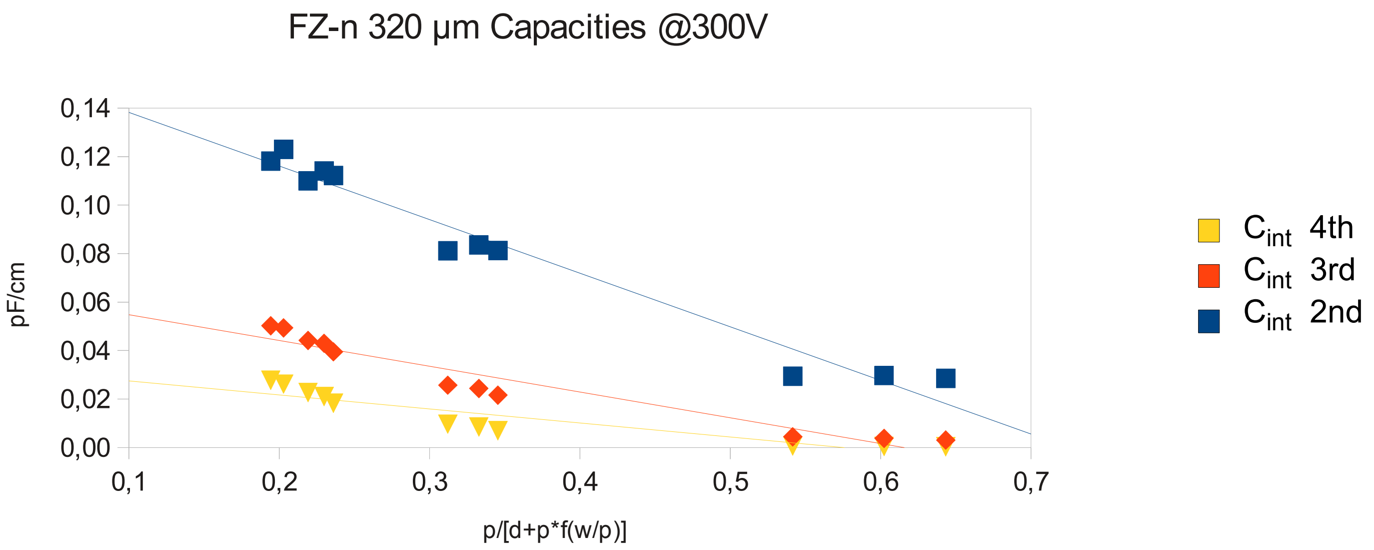
- Results with 'added' capacitance network
  - $C_{int}$ and $C_{back}$ show same behaviour as in measurements (decreasing resp. increasing with X)
  - But: $C_{tot} = C_{int} + C_{back}$ is not constant, as $C_{int}$ is too small (off by a factor of 1,8 compared to measurements)



# MSSD capacities IV

> Interstrip capacitance towards further neighbours:

- $C_{int}$ shows decreasing behaviour in X and in neighbour distance as expected
- But as with $C_{int}$ to direct neighbour, these values are probably too low, although no experimental data for comparison is available

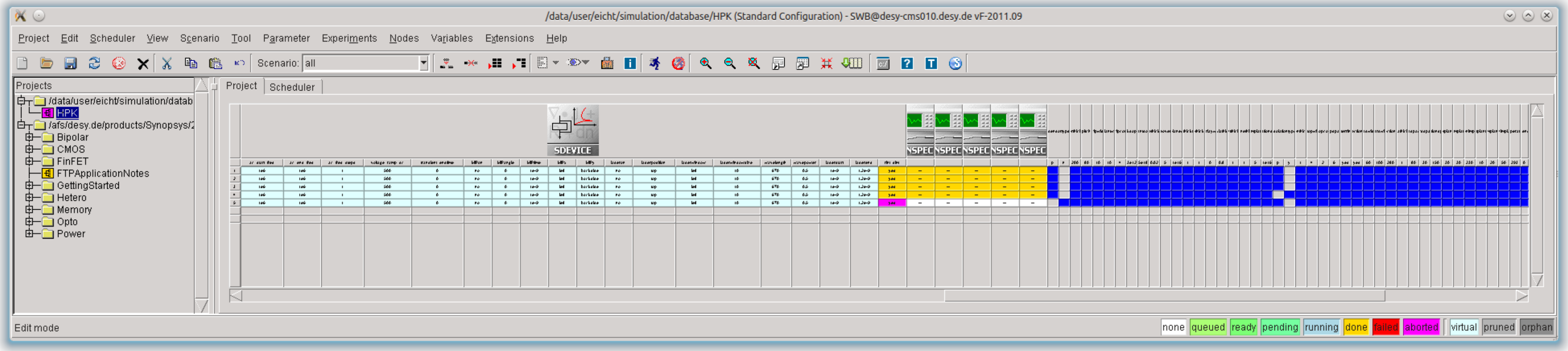


# MSSD capacities V

- Is the capacitance simulation generally flawed?
- Step back: go to simpler structures to see where error occurs
  - Simulation of a simple parallel-plate capacitor
    - Two aluminum strips separated by dielectric (Si or $SiO_2$, vacuum doesn't work)
    - Gives correct capacity, combinations of Si and $SiO_2$ also work (though using only $SiO_2$ makes the simulation crash, at least 1µm of Si is needed)
  - Diode with pn-junction and doping
    - Also gives correct result
  - Segment one Al-side to get 'real' strip sensor
    - Backplane capacity drops, $C_{int}$ is far too low
- Capacitance anomalies could come from 'wrong' structures

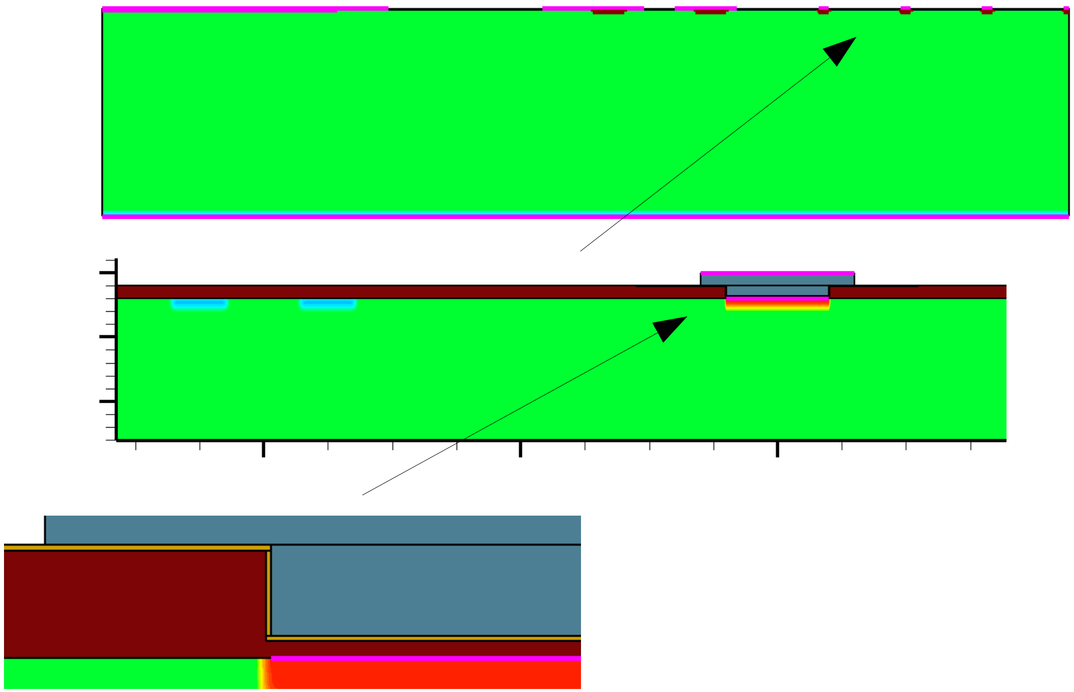
# TCAD Workbench I

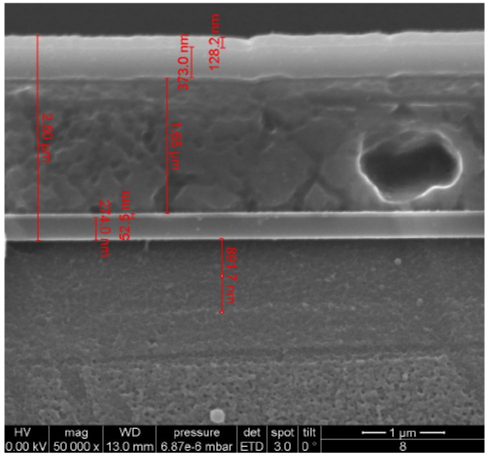
- To recheck geometry and make multiple simulations easier: usage of the workbench package:
  - Script and parameterize the entire simulation process instead of using command files
  - Corrections, new features, models, parameters can be added to all simulations at once
  - Has been shared with the other simulation groups → everyone can use same geometry (future: same simulation steps/models/etc.) → comparability of results
  - No user interaction needed when simulating multiple devices/setups



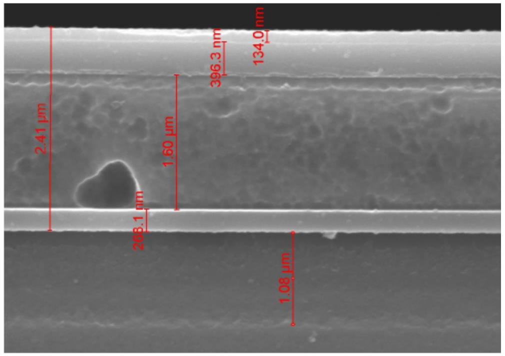
# TCAD Workbench II

- Scripted and parameterized geometrical features:
  - All strip sensor distances: thickness, pitch, implant size, strip count, etc.
  - Sensor type: p- or n-type with correct doping, p-spray or p-stop(s)
  - HPK feature: 50nm $Si_3N_4$ over implants
  - Optional outer ring structure: protection- guard- and bias ring






Strip cross section of FZ-320-Y W6




Strip cross section of FZ-320-P W4

W. Treberspurng, HEPHY Vienna

# TCAD Workbench III

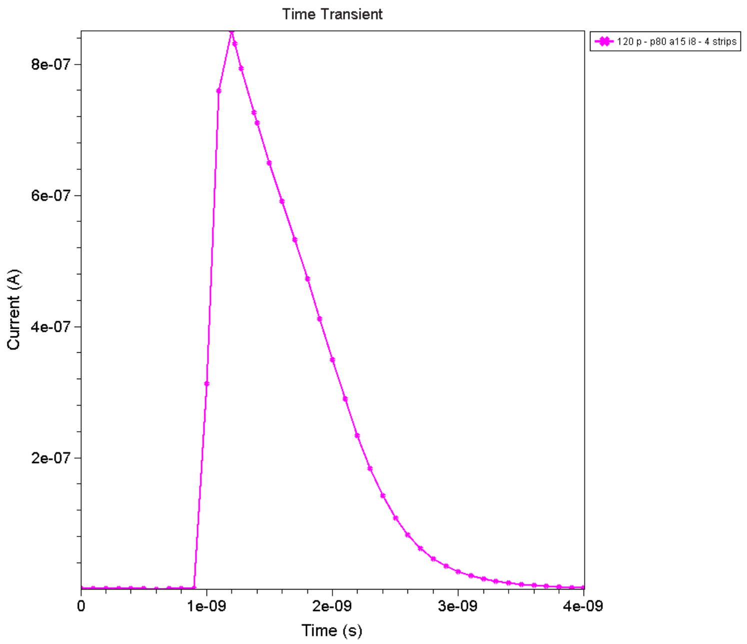
- Scripted and parameterized simulation steps:
  - Biasing/grounding, bias resistors, floating guardring
  - Physical parameters (temperature, fluence, etc.)
  - Voltage ramp → IV curve production and plot
  - Time transient with laser/mip (angle, duration, intensity, etc.)
  - Interstrip resistance measurement
  - Capacitance simulation → CV and $C_{int}$
  - Automatic plot generation under construction
  - Extraction of 'interesting' values planned

- The following results are only based on a few test simulations

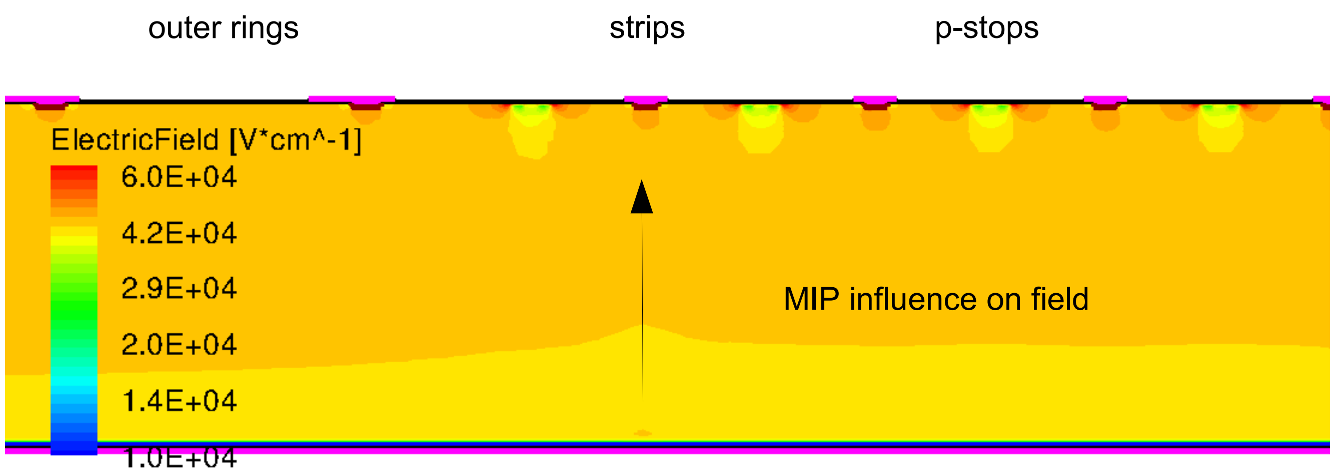
# Crosscheck of scripting - simulation results I

## Time transient of traversing MIP

- 20°C, 500V, p-type, MIP: 0° angle, hits on strip 1
- Current height and shape as expected
- Simulation takes too long: ~ 1h on desy-cms010 → numerical issue?



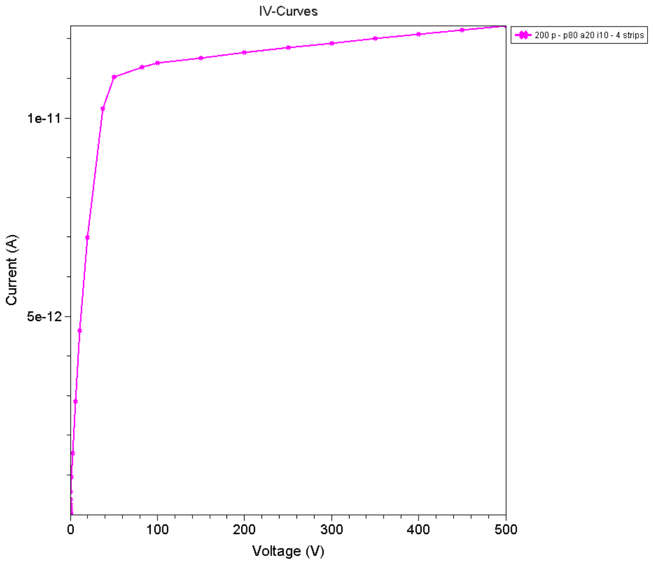

- Electric field: influence of p-stops, MIP and outer rings visible

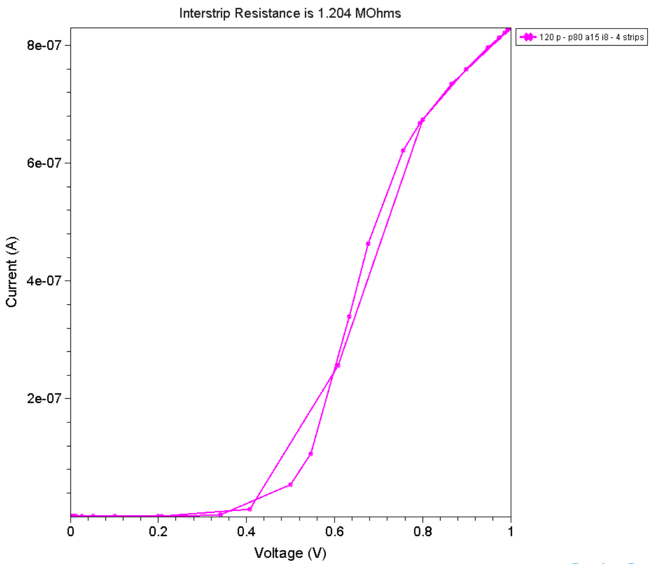


# Crosscheck of scripting - simulation results II

- IV-curves
  - Shape correct, absolute values will be corrected for actual sensor size (3D) to be comparable to data

- $R_{int}$ simulation
  - First problems: expected Rint ~ 100-300 GΩ independent of type/isolation
  - Simulation: n-type has 234 GΩ → good fit, but p-type has an Rint of only 1.2 MΩ → needs to be investigated



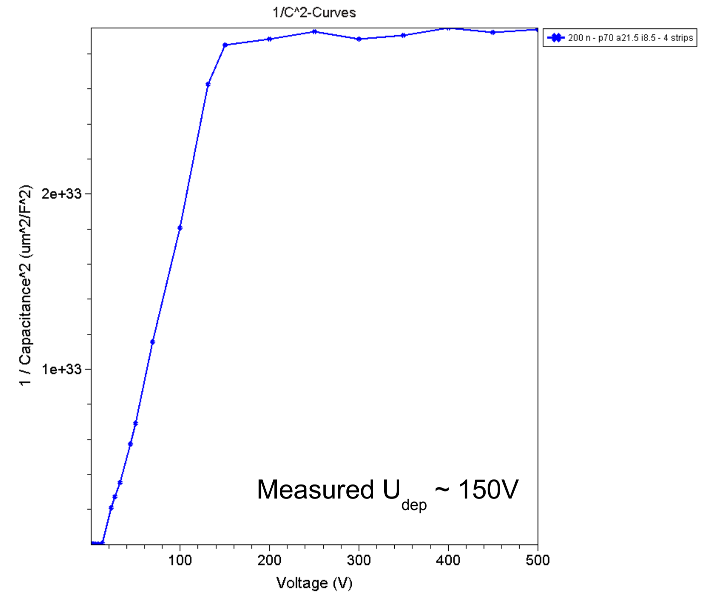
# Crosscheck of scripting - simulation results III

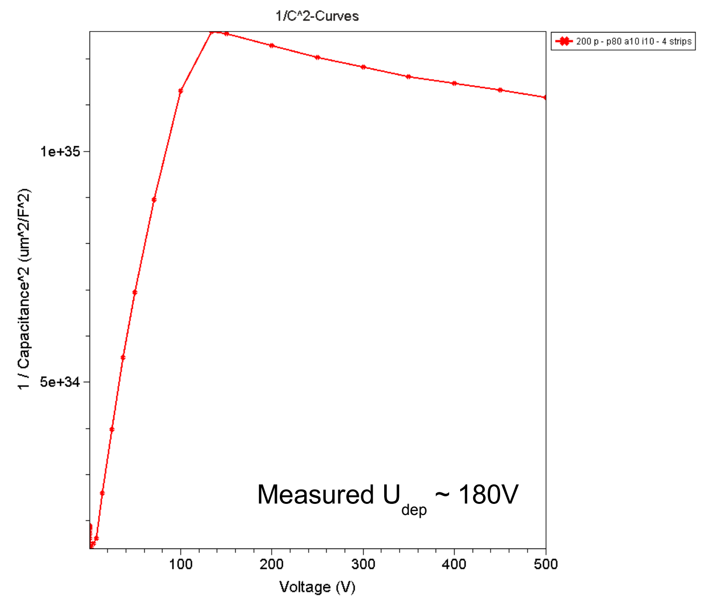
- Capacitance simulations
  - CV: extractable depletion voltage agrees with measurements. Y-axis has to be scaled to actual geometry
  - P-type has strange shape, $U_{dep}$ not as good
  - $C_{int}$: with no additional capacities, $C_{int}$ in n-type is only one magnitude off (0.2pF/cm)
  - In p-type still a factor of ~ 1000 too low

→ n-type shows that direct AC-contact simulation can work

→ 'Tiny' $R_{int}$ in p-type may correspond to low $C_{int}$

→ Recheck isolation, possibly a more exact geometry can improve results



# Summary

- Simulation group
  - Delhi and Karlsruhe are checking radiation damage models – will be implemented into the workbench script when ready
  - Workbench script made public to group → comparability of results

- TCAD workbench
  - 'mass production' of simulations possible, allows more structured approach
  - Now running on workgroup server with local access → speed, disk space
  - Still to be done:
    - Improve plot generation, parameter extraction
    - Possibly transform simulation output into a non-proprietary format

- Simulations
  - Improved geometry to model HPK sensors more accurately → more input needed
  - Oxide and oxide/silicon interface seems to be critical to $R_{int}$ and $C_{int}$

    → recheck mechanism of oxide traps and charges