Enhanced Lateral Drift Sensor

Simulations and development

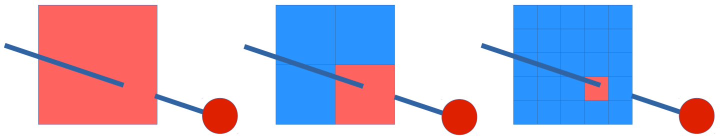
Anastasiia Velyka, Hendrik Jansen
4th MT student retreat
HZB, Berlin
11.06.2018

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
PIER
DESY-Strategy-Fund
DESY.

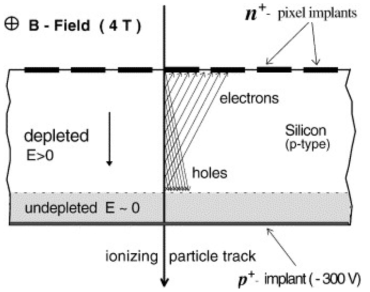
Position resolution

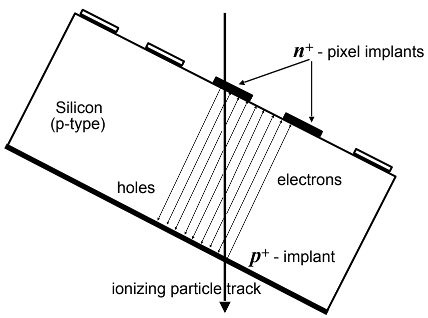
Improving position resolution:

- **Down-sizing the pitch**



- **Charge sharing**
  - Lorentz angle or tilted sensor

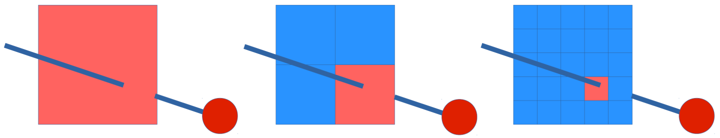




Position resolution

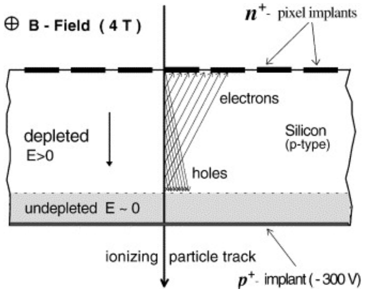
Improving position resolution:

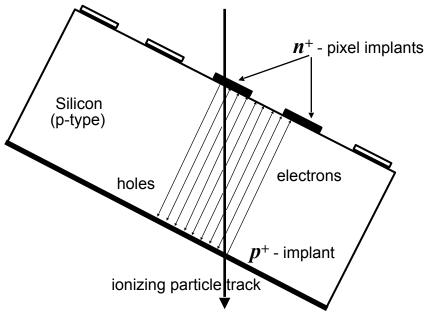
- **Down-sizing the pitch**



  - Disadvantages:
    - Increases number of readout channels
    - Potentially higher band width from detectors
    - Less area on-chip per channel
    - Higher power dissipation

- **Charge sharing**



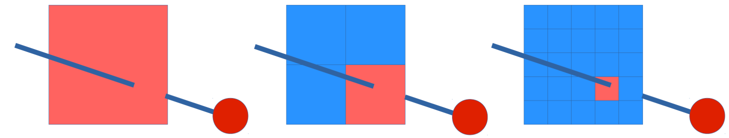


  - Lorentz angle or tilted sensor
    - Disadvantages:
      - Doesn’t work for thin sensors
      - Tilting increases material budget in beam
      - Needs extra studies on a sensor design with considering a magnetic field

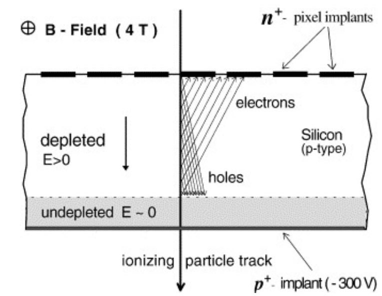
Position resolution

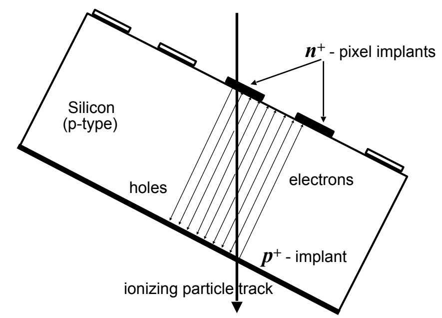
Improving position resolution:

- **Down-sizing the pitch**
  - Disadvantages:
    - Increases number of readout channels
    - Potentially higher band width from detectors
    - Less area on-chip per channel
    - Higher power dissipation



- **Charge sharing**
  - Lorentz angle or tilted sensor
    - Disadvantages:
      - Doesn't work for thin sensors
      - Tilting increases material budget in beam
      - Needs extra studies on a sensor design with considering a magnetic field



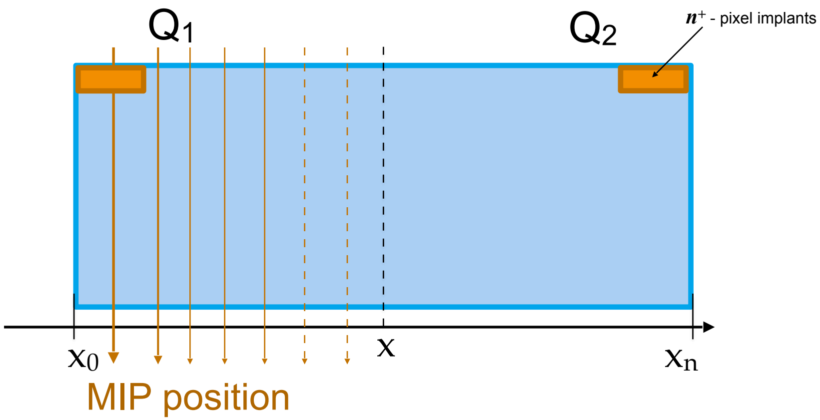


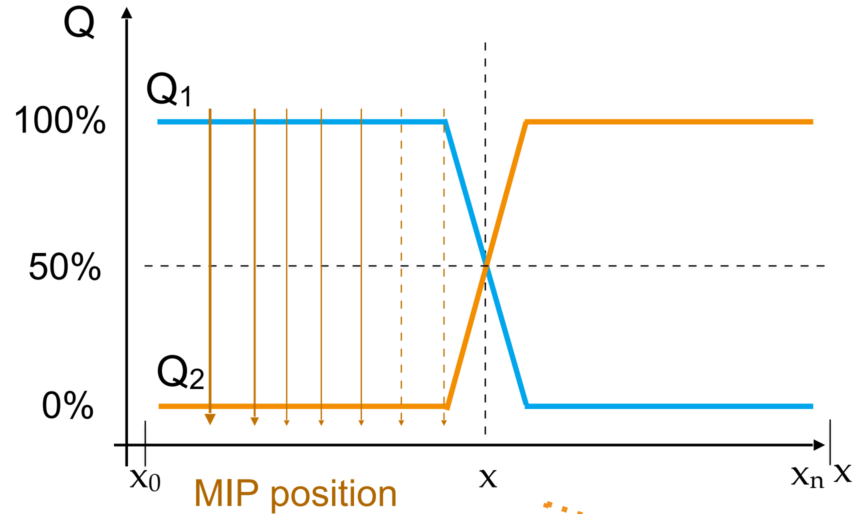
- **What else can be done?**

Charge sharing

Towards the theoretical optimum of position resolution

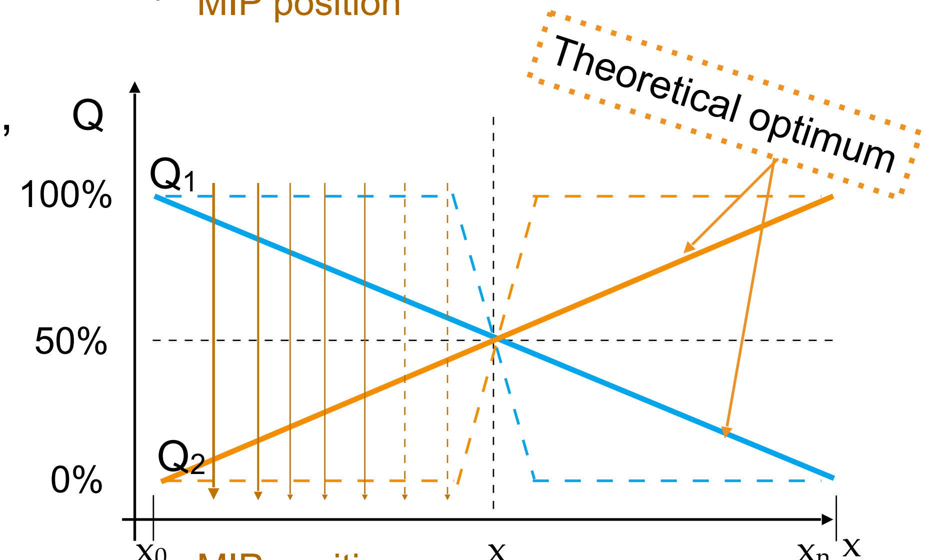
- **Charge collection between 2 strips in a standard planar sensor**





- For a standard sensor design charge in the left part of pitch collected by 1st strip, in the right - by 2nd.

- In an ideal case, the charge distribution between 1st and 2nd strip is linear.
It gives best charge sharing.

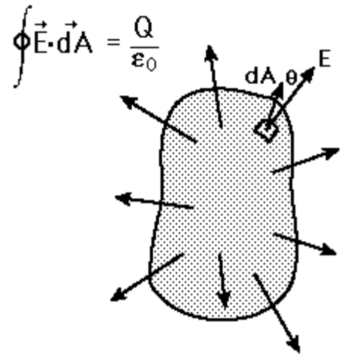


Enhanced Lateral Drift Sensor

Manipulating the electric field

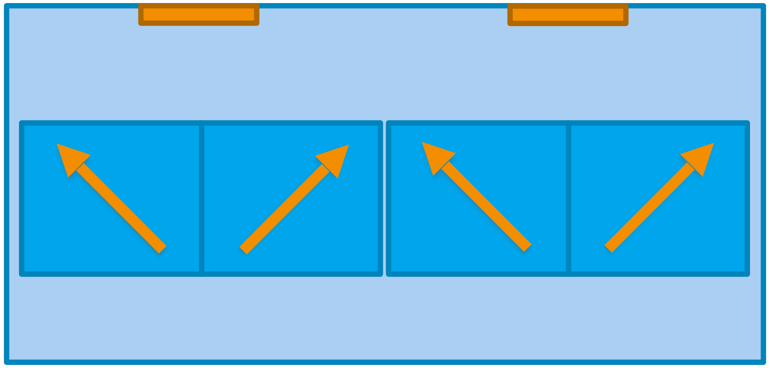
- **Achieve improved position resolution of charged particle sensors**
  - Induce lateral drift by locally engineering the electric field

$$\vec{\nabla} \cdot \vec{E} = \frac{\rho}{\epsilon_o}$$



- Charge carriers follow the electric field lines.

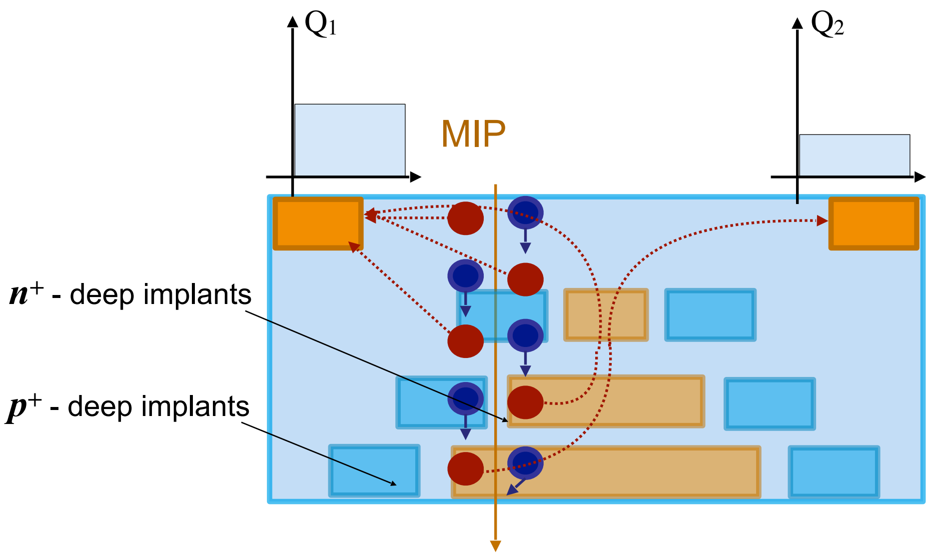
- Lateral electric field has been created by adding repulsive areas inside the bulk.



Enhanced Lateral Drift Sensor

Manipulating the electric field

- **Repulsive areas created by adding higher doping concentration.**

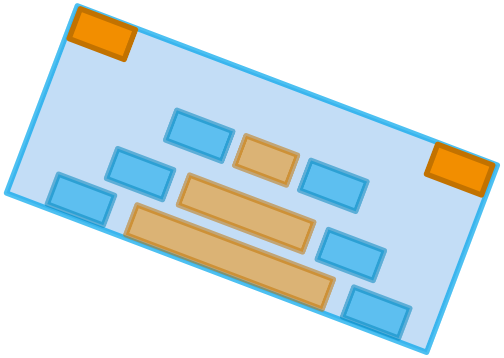


ELAD sensor

- The new concept uses implants deep inside of the bulk.
- Implants constitute volumes with different values of doping concentration.
- This allows for a **modification of the drift path of the charge carriers.**

TCAD simulations

Static and transient simulations in TCAD SYNOPSYS

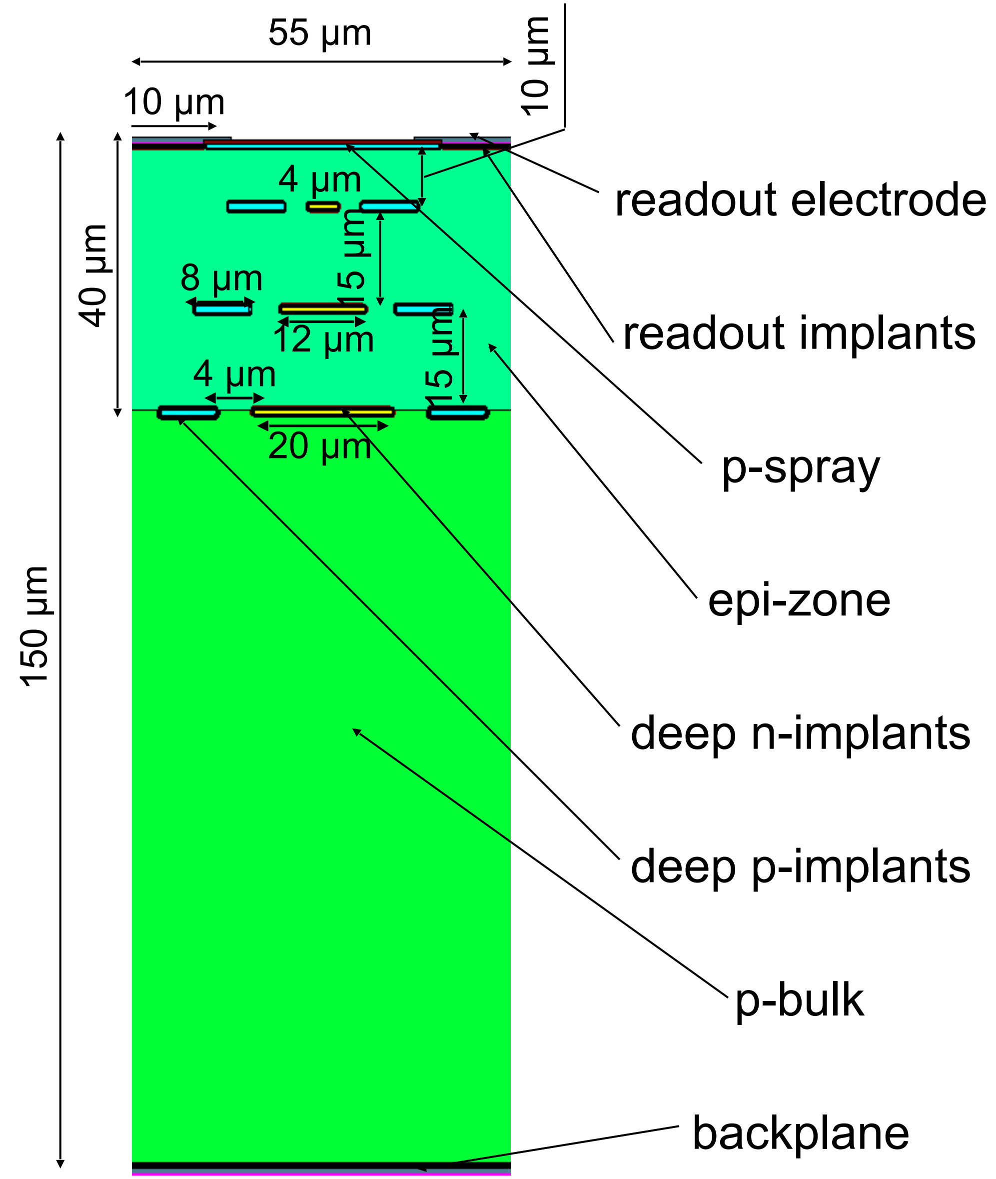


- **Parameters for simulation:**
    - Width, depth of implants
    - Distance within/to next layer
    - Position/shift to neighbouring layer
    - Number of layers
    - Optimal doping concentrations for deep implants
- **Quasi stationary:**
    - Solve electric field
    - Ramp voltage to the set value
- **Transient:**
    - Poisson’s equation
    - Carrier continuity equations
    - Traversing particles or arbitrary charge distribution

TCAD simulations

ELAD geometry

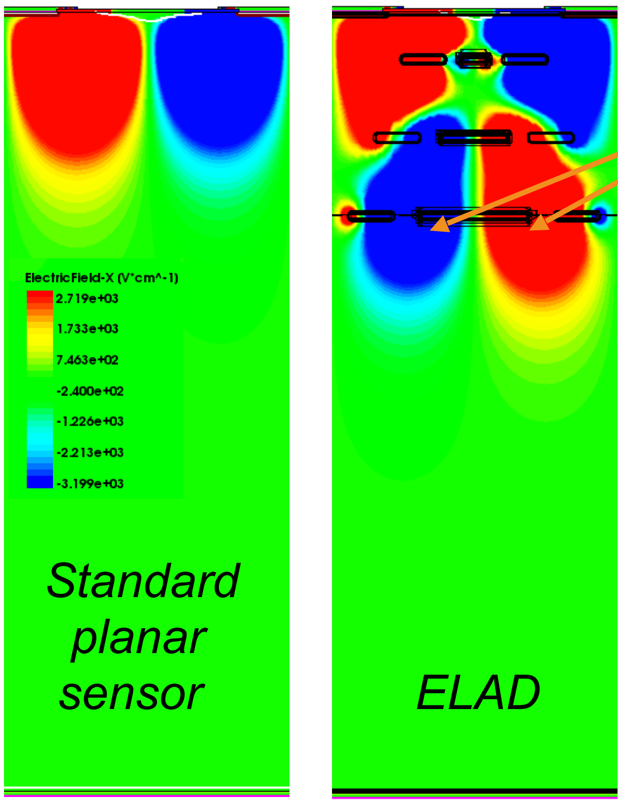
- p-spray isolation is implemented to the sensor geometry
- first and second layer are located in the epitaxial part of the sensor
- 1/2 +3 strip symmetry is chosen according to the boundary condition
- TimePix3 geometry
  - pitch 55×55 µm
  - pixel implant size 20 µm



TCAD simulations

Electric field simulations

- **Deep p^{+}- and n^{+}-implants create the lateral electric field in the bulk.**



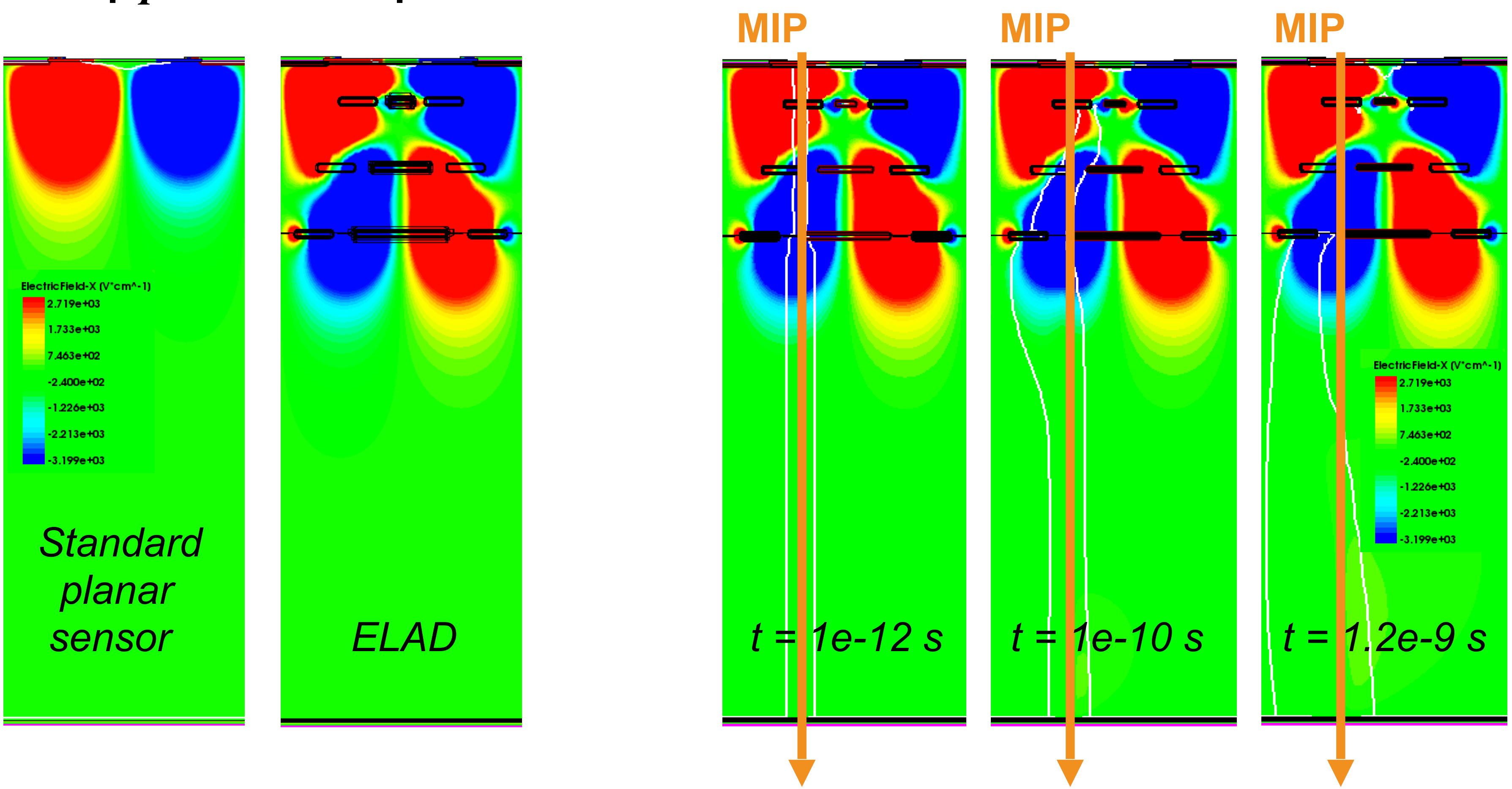
Repulsive areas for charge carriers.
In the blue sones electrons move in the right direction, in the red - left.

V = 400 V

TCAD simulations

Electric field simulations

- **Deep p^{+}- and n^{+}-implants create the lateral electric field in the bulk.**



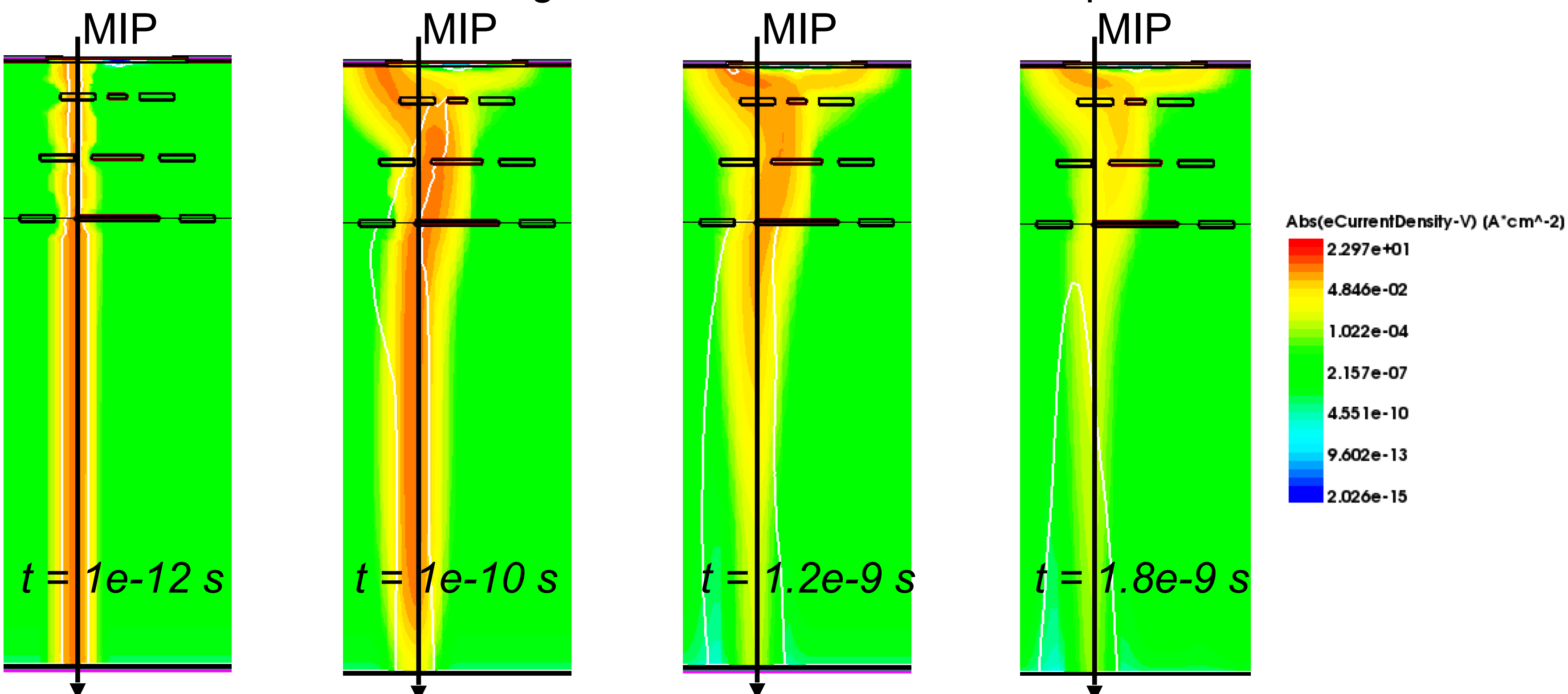
- **The non-homogeneous electric field in the ELAD sensor is stable in time.**

V = 400 V

TCAD simulations

Drift with MIP

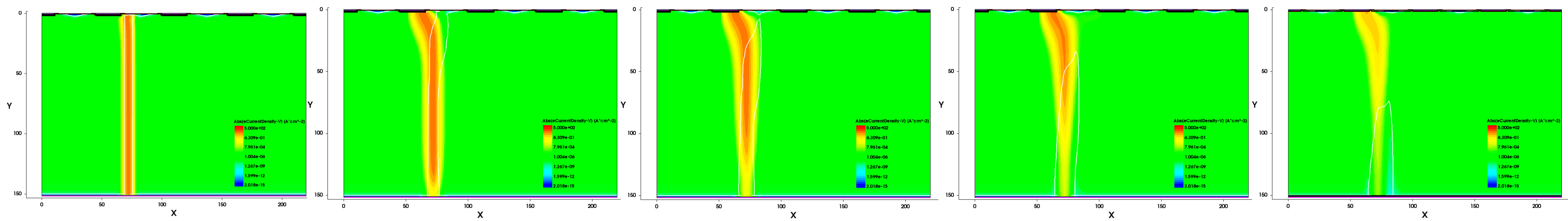
- In comparison to the usual design, with the same MIP position and applied voltage, in the ELAD sensor the charge is shared between two strips.



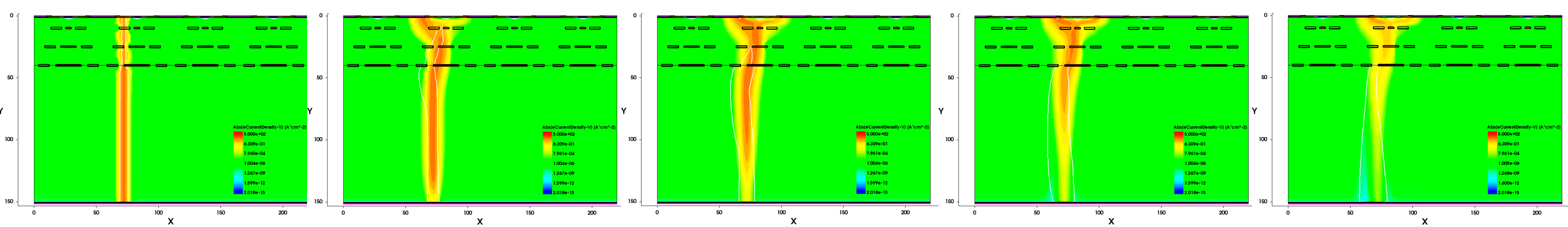
- The part of the charge created beneath the deep implants area changes the drift path
  - It is collected by two electrodes

TCAD simulations

Drift with MIP: Standard planar sensor vs ELAD



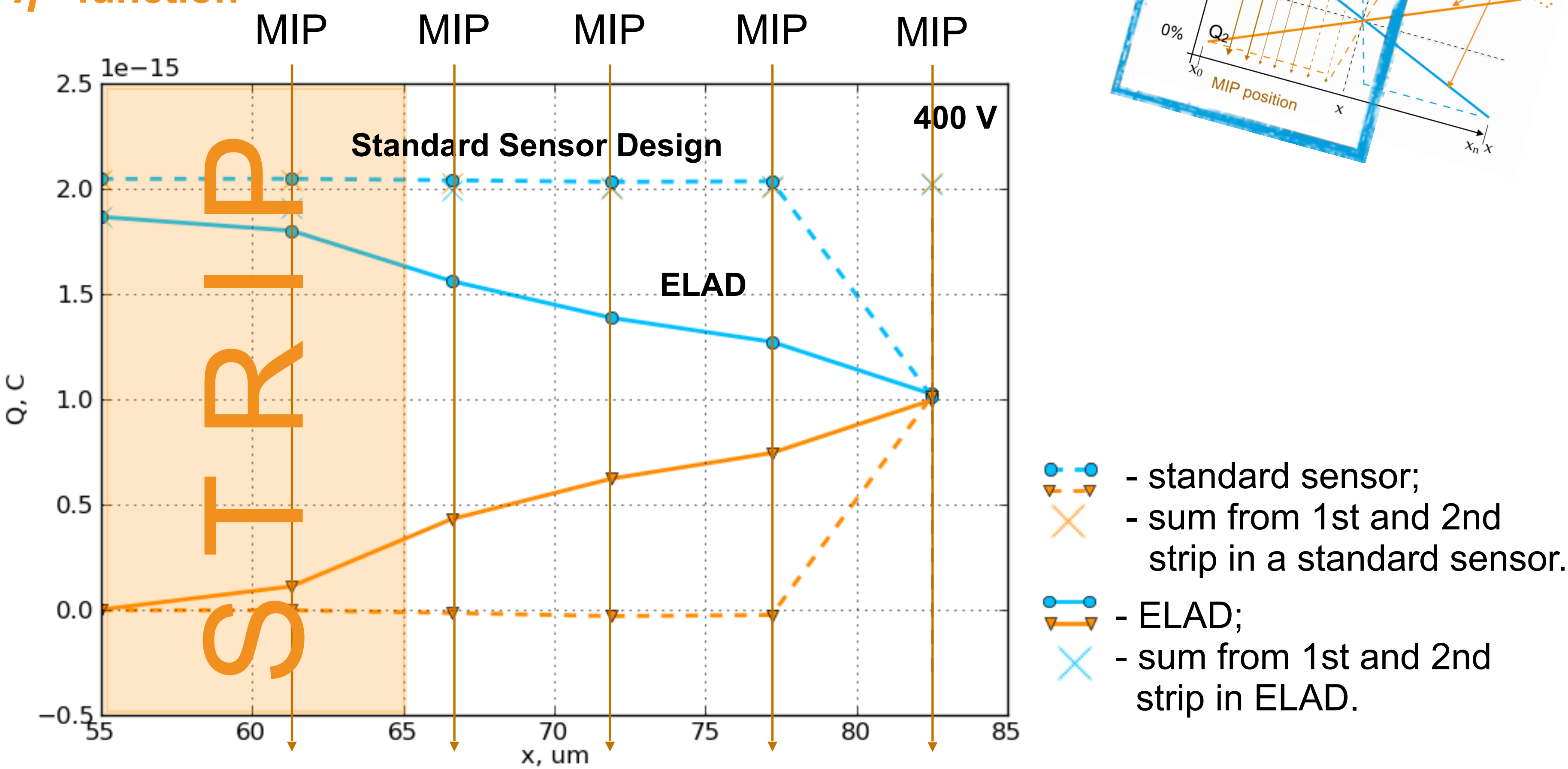
Standard planar sensor

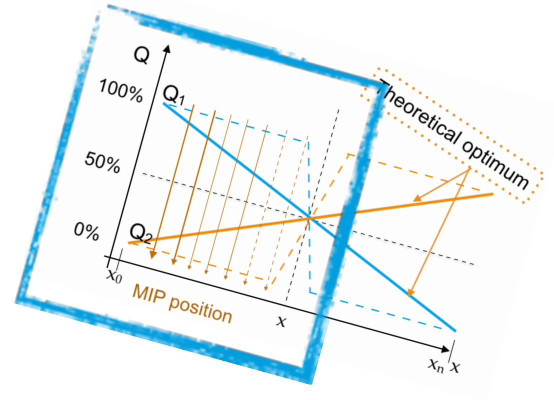


ELAD sensor

TCAD simulations

η - function

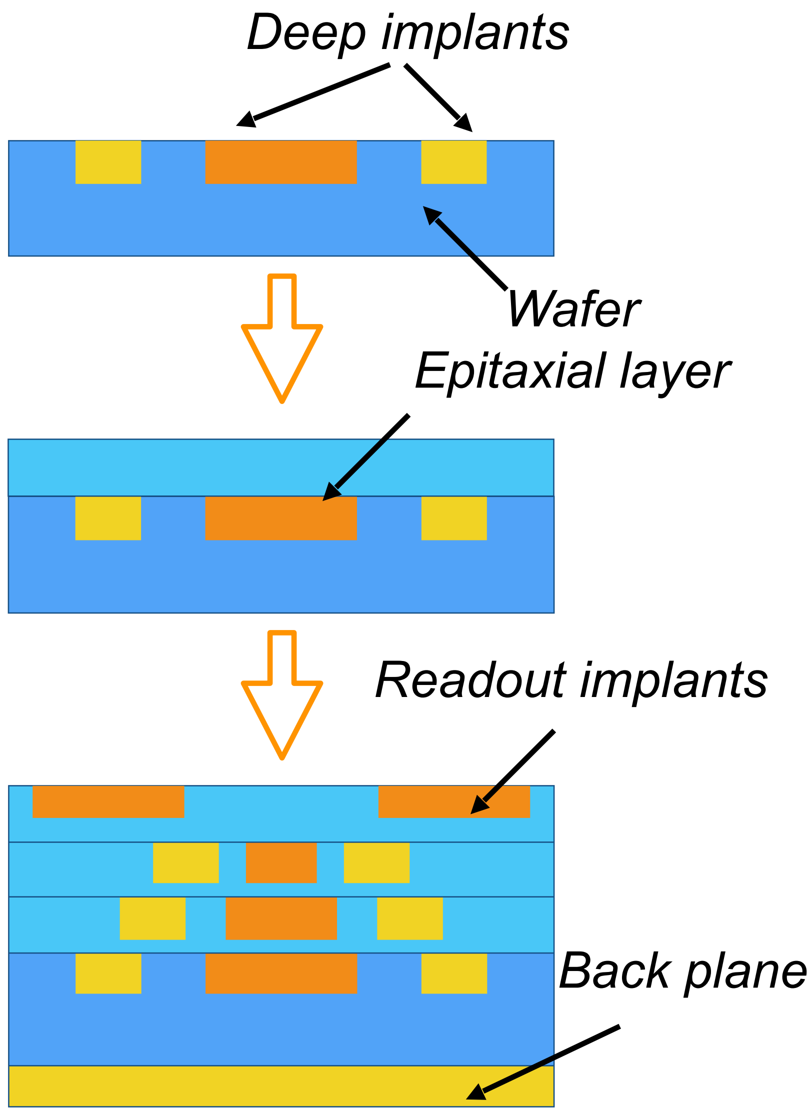




- **The collected charge as a function of the MIP incident position**.
- The x-axis is the incident position of the MIP[µm], the y-axis is the collected charge [C].

Production

New method

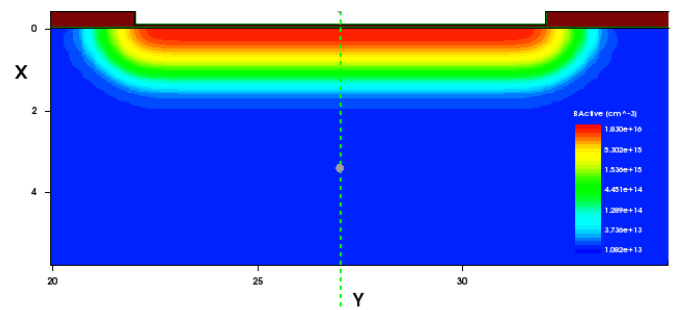


- **Ion beam implantation** on to the wafer surface (ISE, Freiburg).
- **Epitaxial growth process**, a thin silicon layer is grown on the wafer surface. Process temperature is approximately 1150°C (ISE, Freiburg).
- **Combination of implantation and epitaxial growth** is repeated three times. After the last epitaxial growth, the implantation for the readout electrodes is performed (CiS, Erfurt).

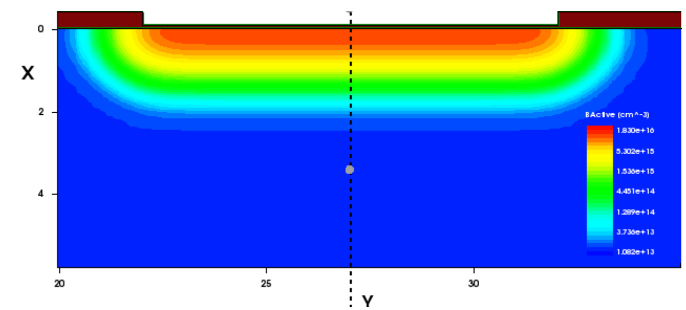
Production

Process simulations in TCAD

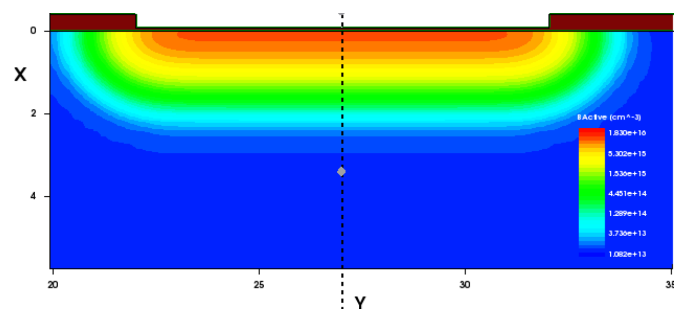
- The difference in an implant size caused by the epitaxial growth is less than 1 µm. The difference in sizes of deep implants from layer to layer has a negligible effect on a charge sharing between strips.



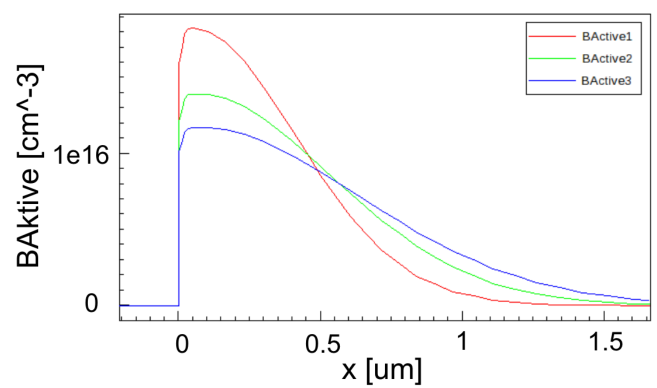
Boron implant, 1st temperature cycle



Boron implant, 2nd temperature cycle



Boron implant, 3rd temperature cycle

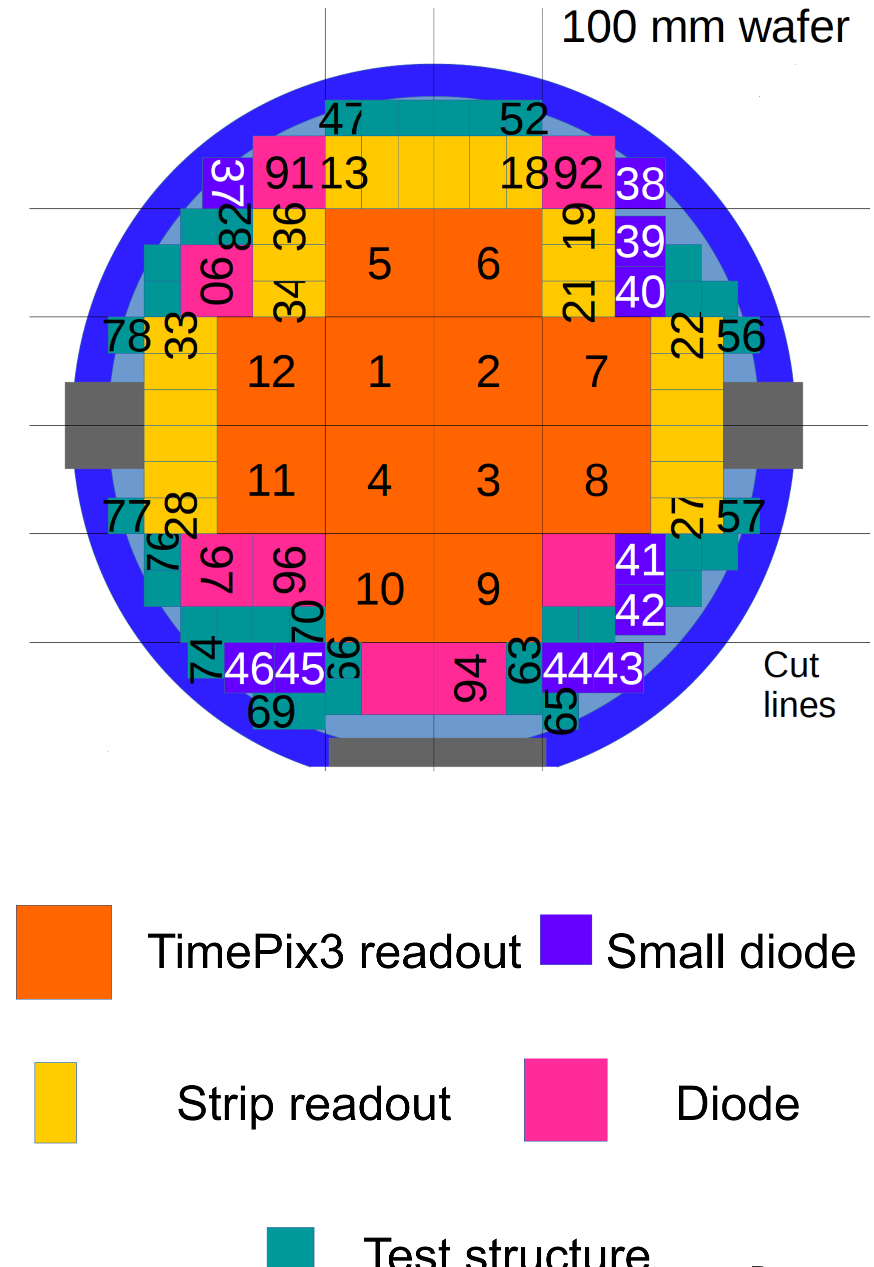


Active Boron concentration after 1st, 2nd and 3rd temperature cycle as a function of depth

Production

Wafer layout

- Three types of sensors:
    - TimePix3 pixel sensor (pitch 55 µm)
    - strip sensor (pitch 55 µm)
    - diode.
- Sensors with different values of deep implant concentrations and p-spray concentrations have been designed.
- Wafers including the epitaxial layers but excluding the deep implants will be produced.



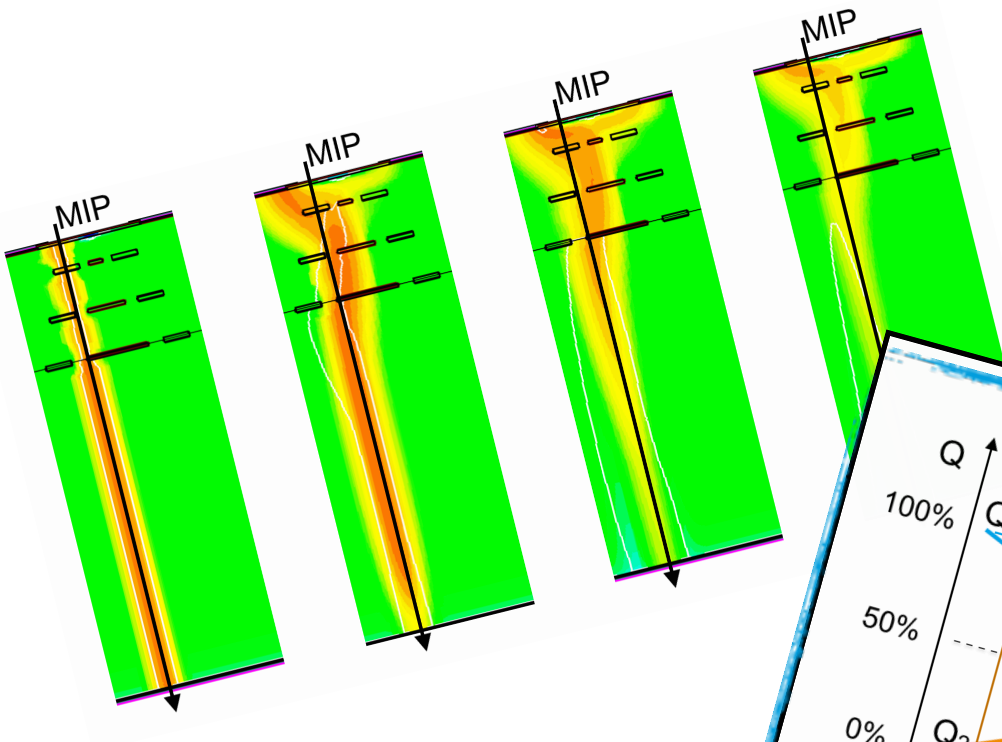
Summary & Outlook

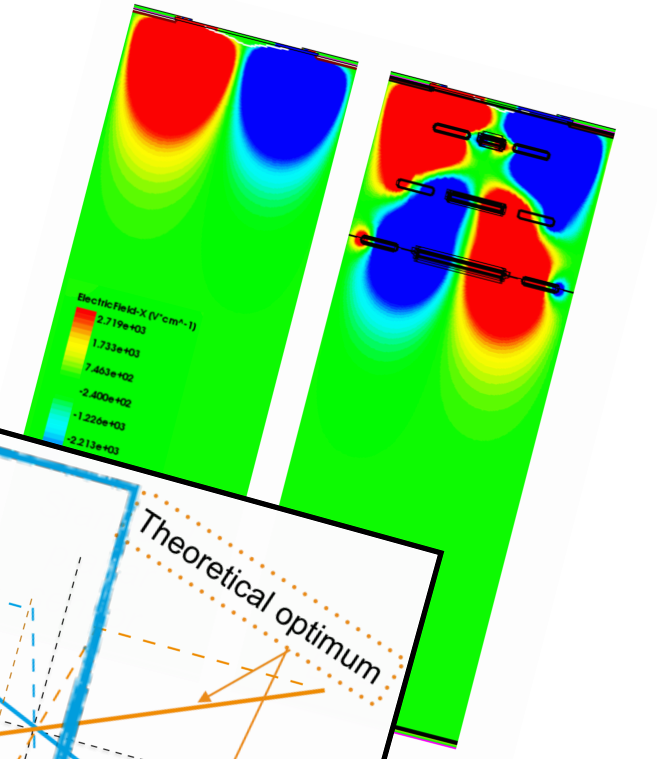
Summary

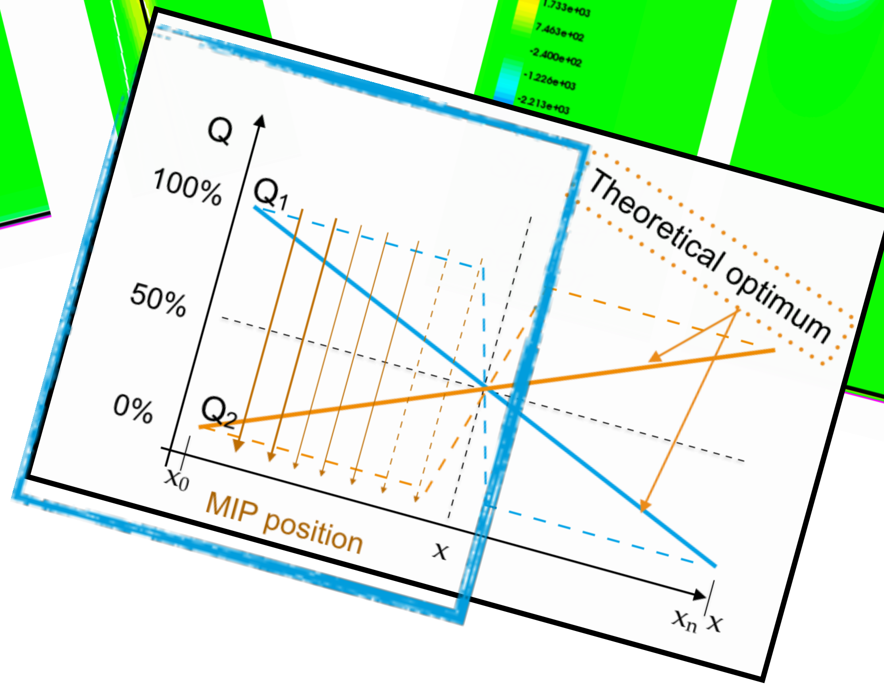
- Technologically challenging project (no one tried this before in HEP)
- Try to reach theoretical optimum of position resolution
- Interesting technology for future HEP detectors

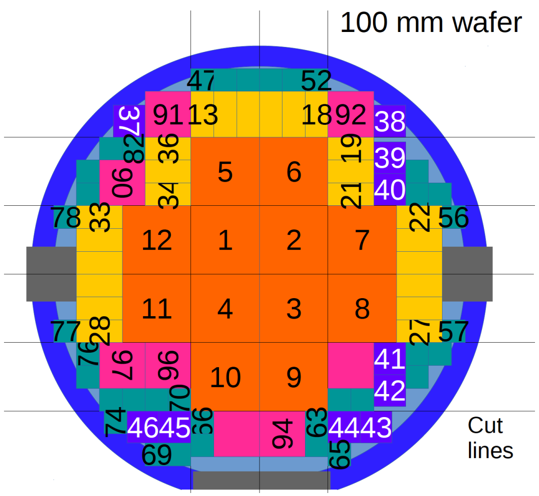
Outlook

- Results on test structures from ISE, Freiburg
- Creation of wafer layout files for production (DESY + CiS)
- Getting prototypes
- Flip chipping with TimePix3 sensor
- Tests at DESY/CERN
    - Lab: IV, CV, TCT
    - Test beam









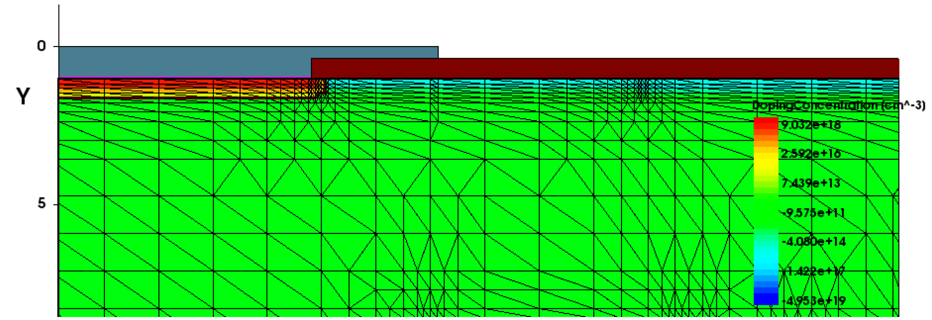
Thank you for attention!

Backup!

TCAD simulations

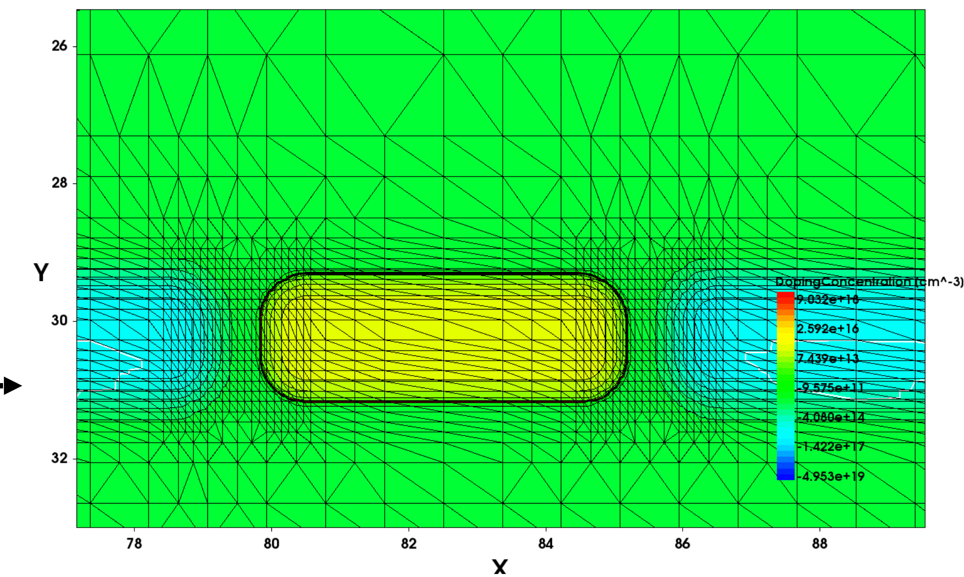
Meshing

- *Readout implant and p-spray*



- **Mesh parameters:**
  - x_{min} = 0.1 µm
  - x_{max} = 2 µm
  - y_{min} = 0.1 µm
  - y_{max} = 2 µm
  - Doping dependent

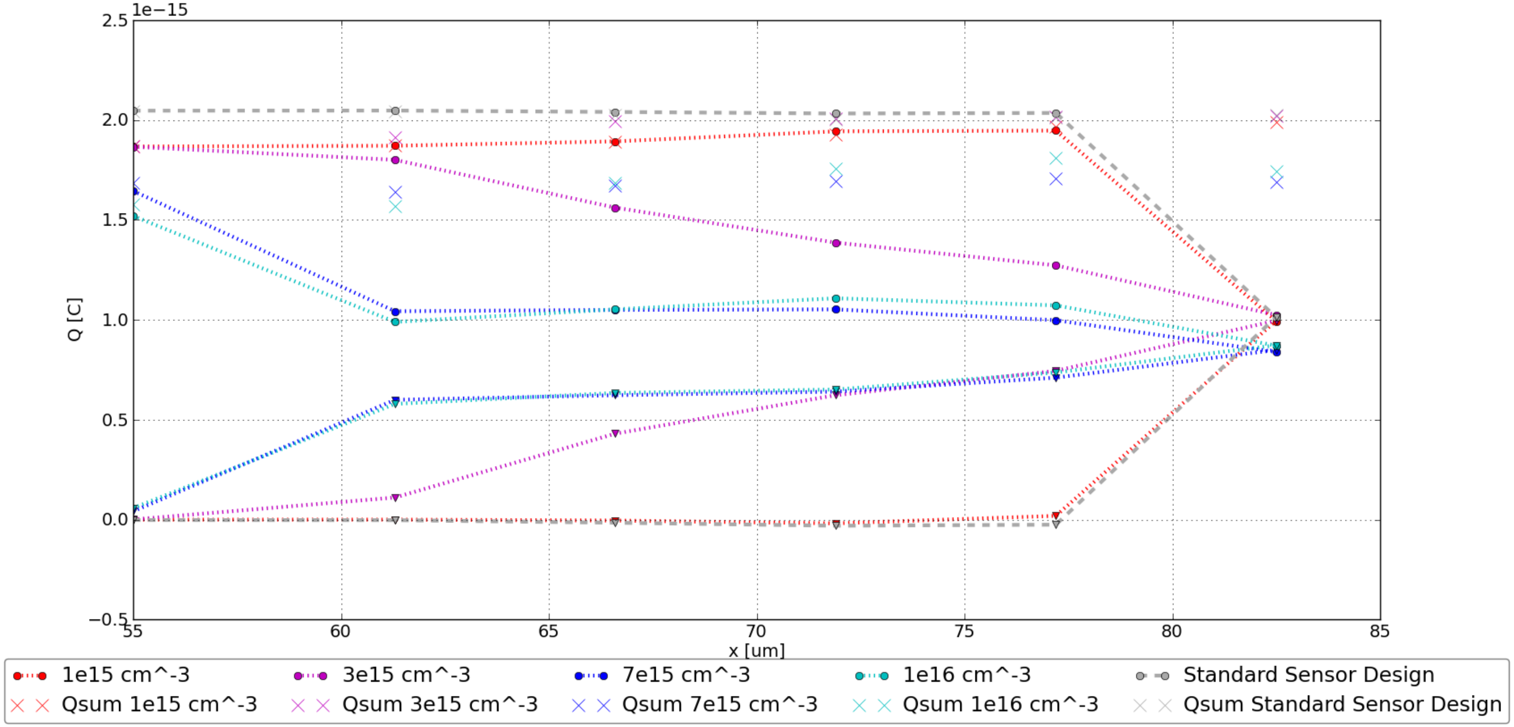
- *Deep p+ and n+ implants*



TCAD simulations

Deep implant's concentration

- Four values of deep implant concentration have been simulated: $1*10^{15}$ cm^{-3}, $3*10^{15}$ cm^{-3}, $7*10^{15}$ cm^{-3}, $1*10^{16}$ cm^{-3}.

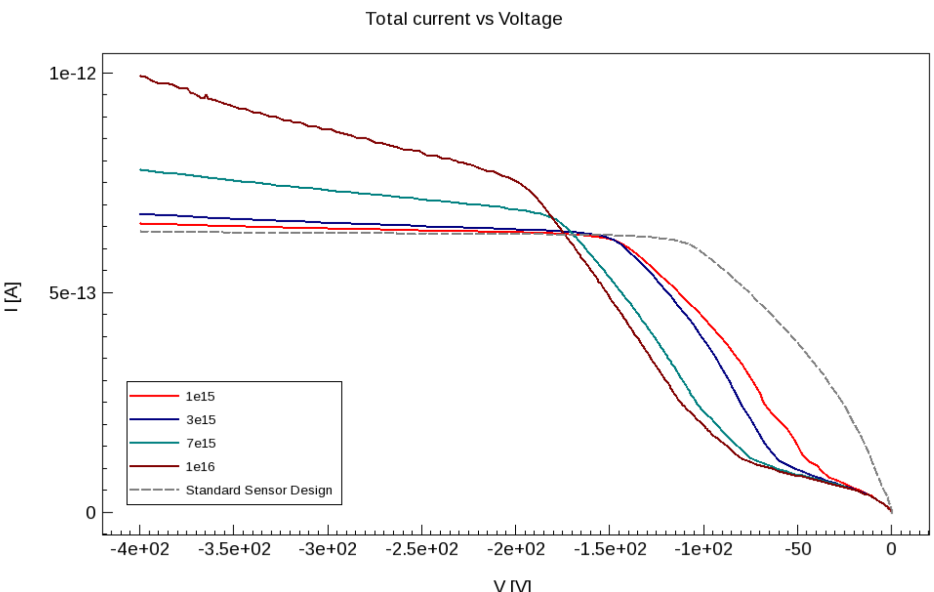


- The deep implant concentration 1e15 cm^-3 gives no effect on a charge sharing.

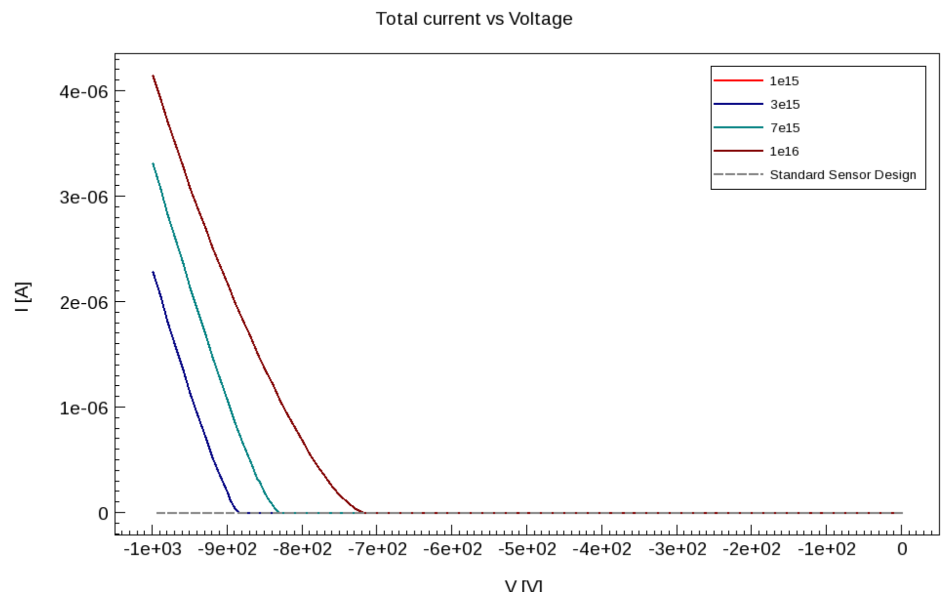
TCAD simulations

Deep implant's concentration

- With increasing the deep implant concentration the breakdown voltage decreases.
- With increasing the deep implant concentration the depletion voltage increases.



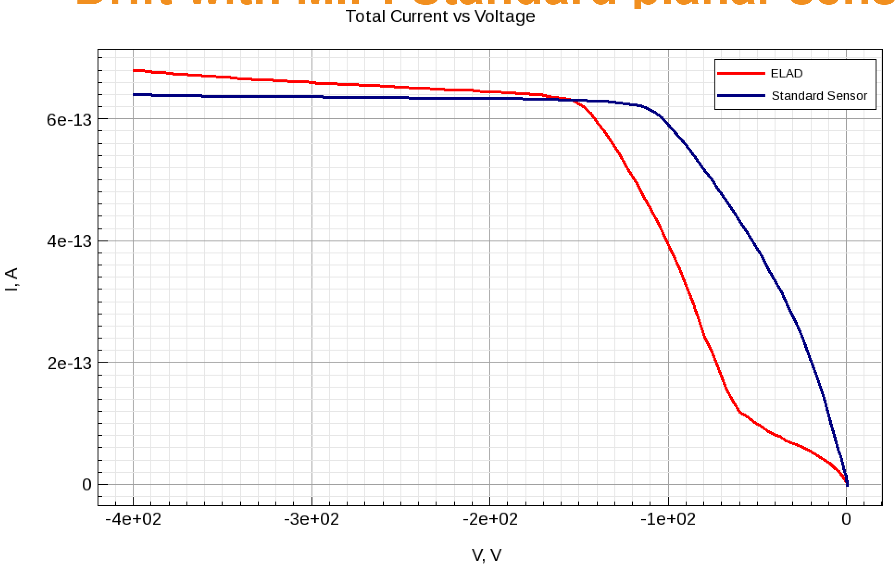
I vs V (up to 400V) for ELAD sensors with deep implant concentrations 1e15 cm^{-3}, 5e15 cm^{-3}, 7.5e15 cm^{-3} and 1e16 cm^{-3}

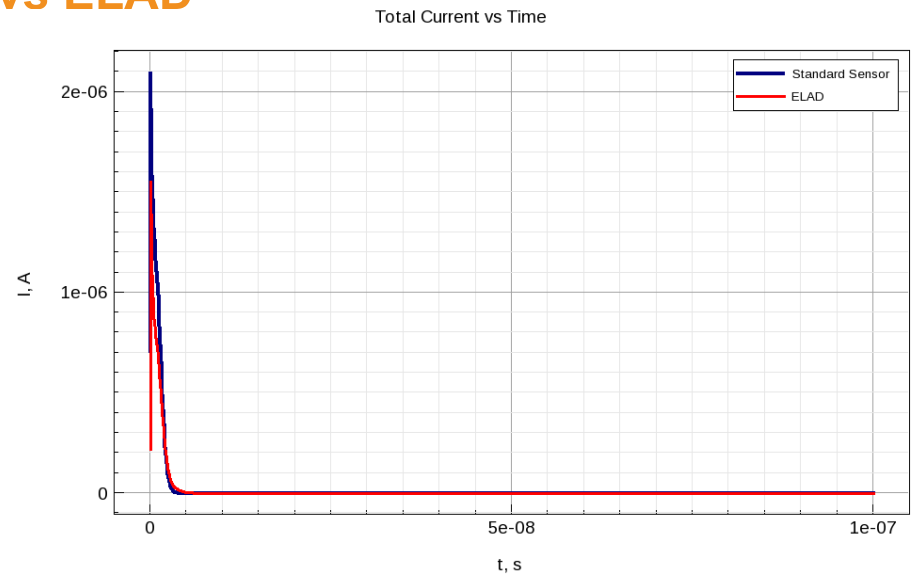


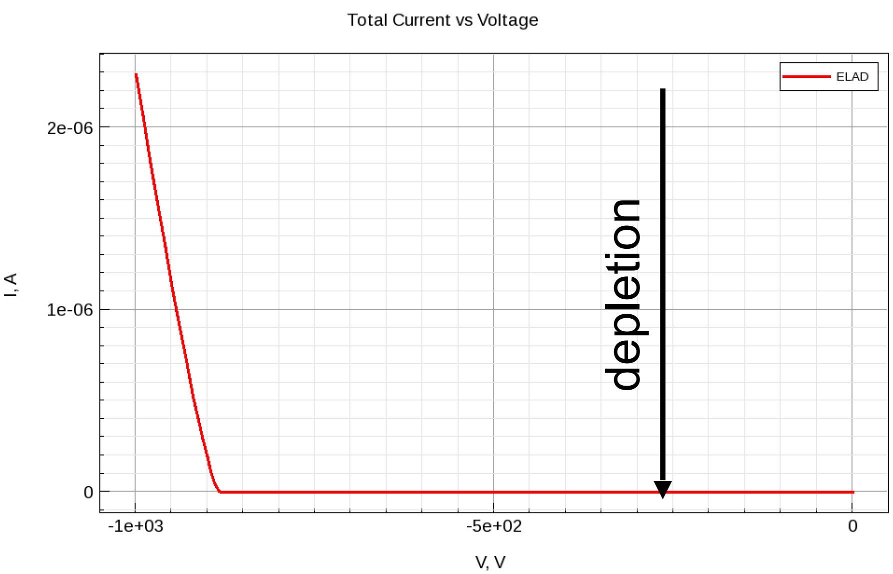
Breakdown voltage for ELAD sensors with deep implant concentrations 1e15 cm^{-3}, 5e15 cm^{-3}, 7.5e15 cm^{-3} and 1e16 cm^{-3}

TCAD simulations

Drift with MIP: Standard planar sensor vs ELAD







- Total current in ELAD sensor during the voltage ramping is higher due to high deep implants concentration
- Signal from the standard sensor and ELAD looks the same
- Breakdown voltage is 880 V