Development of **Enhanced Lateral Drift (ELAD)** sensors

TCAD Simulations

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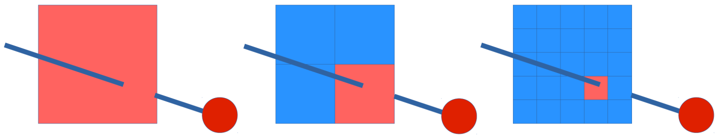
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES
PIER
DESY-Strategy-Fund
DESY.

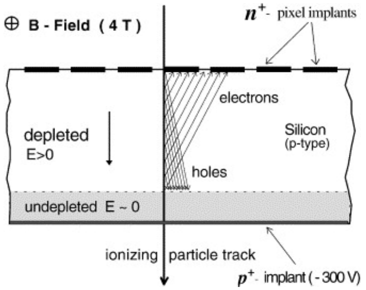
Position resolution

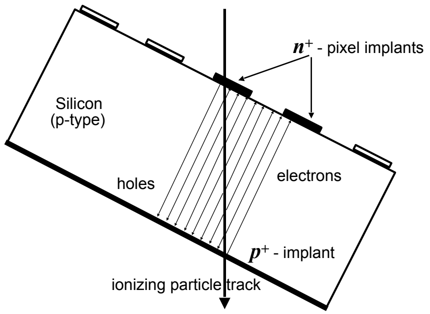
Improving position resolution:

- **Down-sizing the pitch**



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





Position resolution

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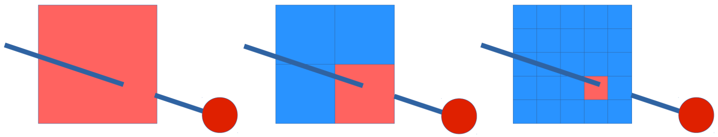
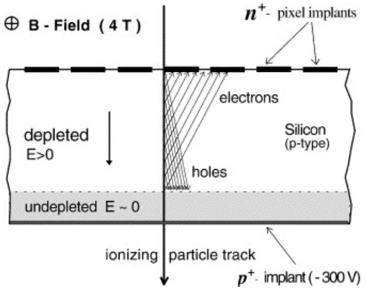
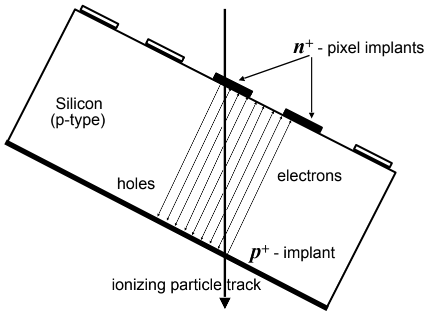


- **Down-sizing the pitch**
  - Disadvantages:
    - Increases number of readout channels
    - Potentially higher band width from detectors
    - Less area/logic on-chip per channel
    - Higher power dissipation



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



Position resolution

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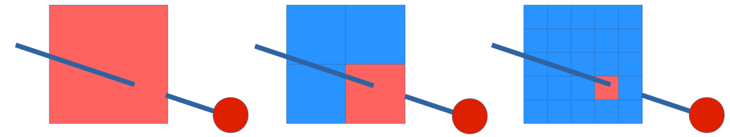

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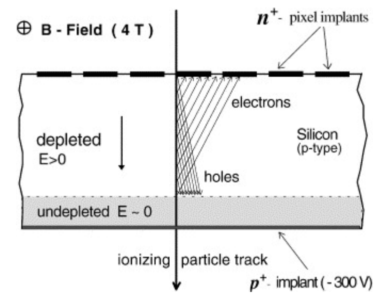
- **Charge sharing**



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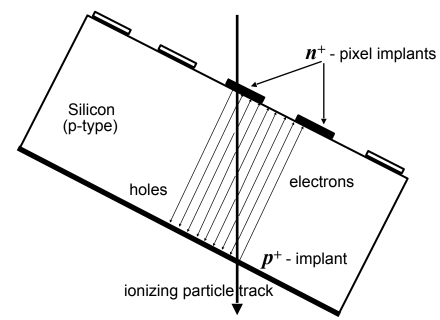
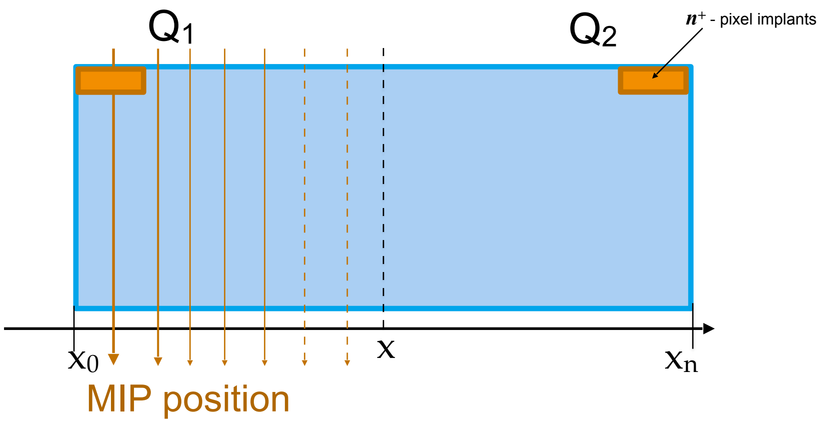


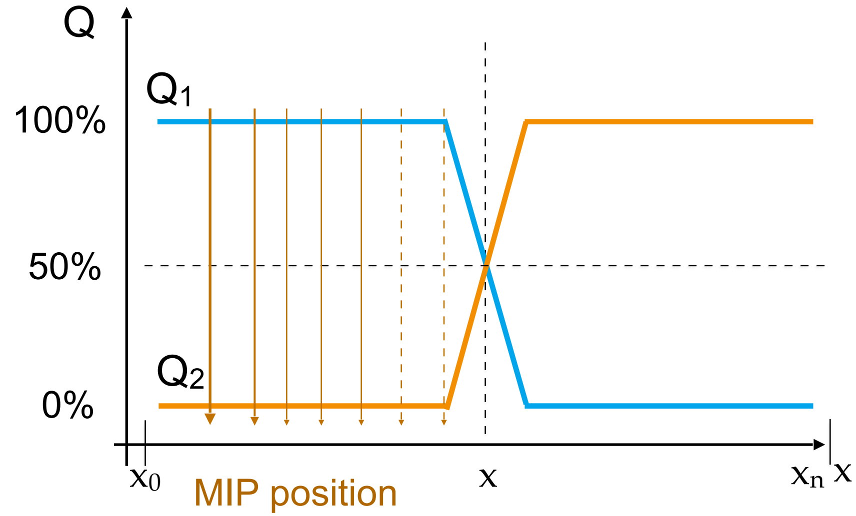
- **What else can be done?**

Charge sharing

Towards the theoretical optimum of position resolution

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





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

Charge sharing

Towards the theoretical optimum of position resolution

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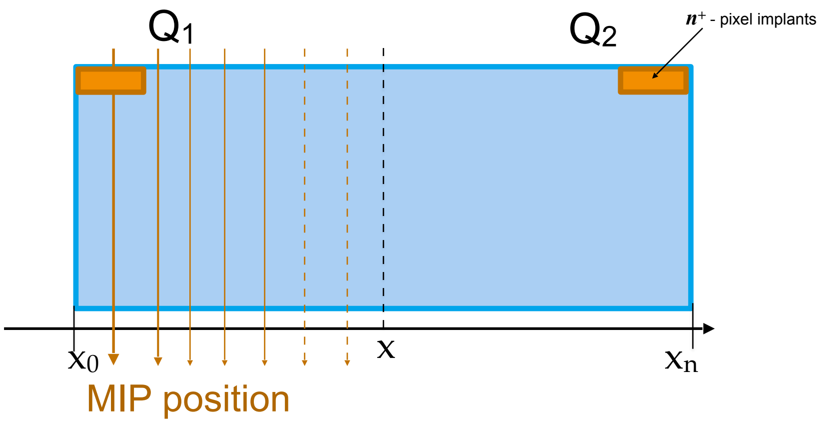
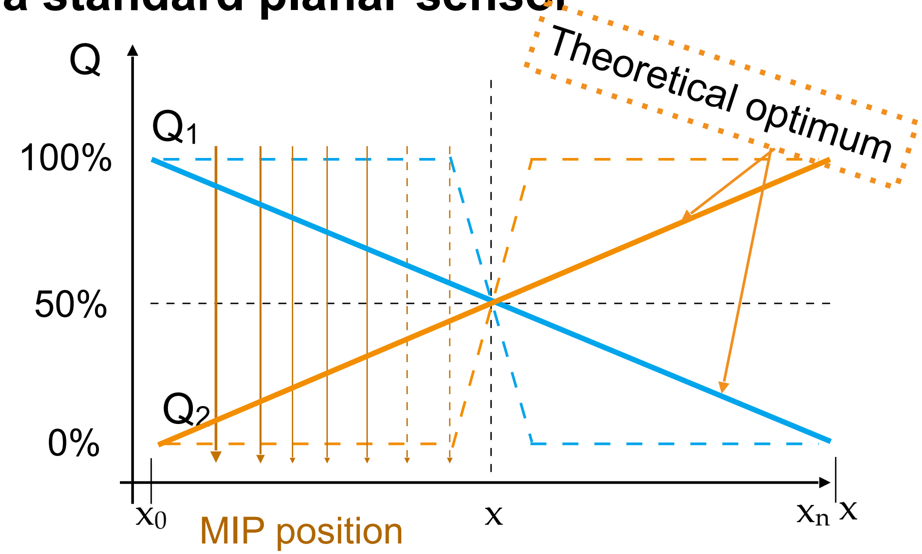




- Standard sensor design:
  - charge in the left part of pitch collected by 1st strip,
  - charge in the right part of pitch collected by 2nd strip.

- In an ideal case:
  - charge distribution between 1st and 2nd strip is **linear** → best charge sharing.

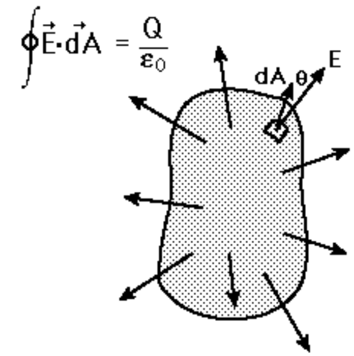
Enhanced Lateral Drift Sensor

Manipulating the electric field

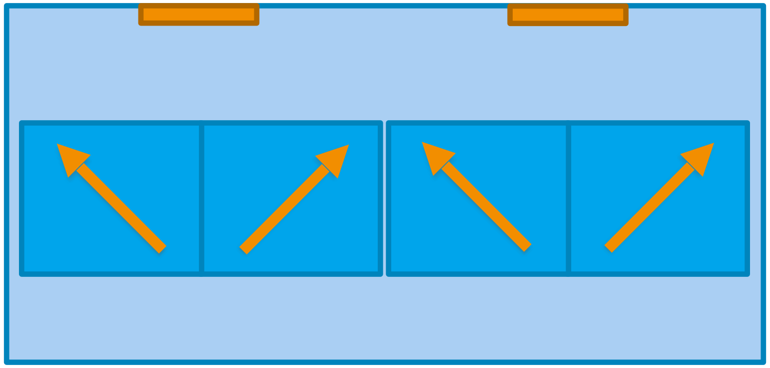
- **Achieve improved position resolution of charged particle sensors**
  - Induce lateral drift by locally engineering the electric field

- Charge carriers follow the electric field lines.

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



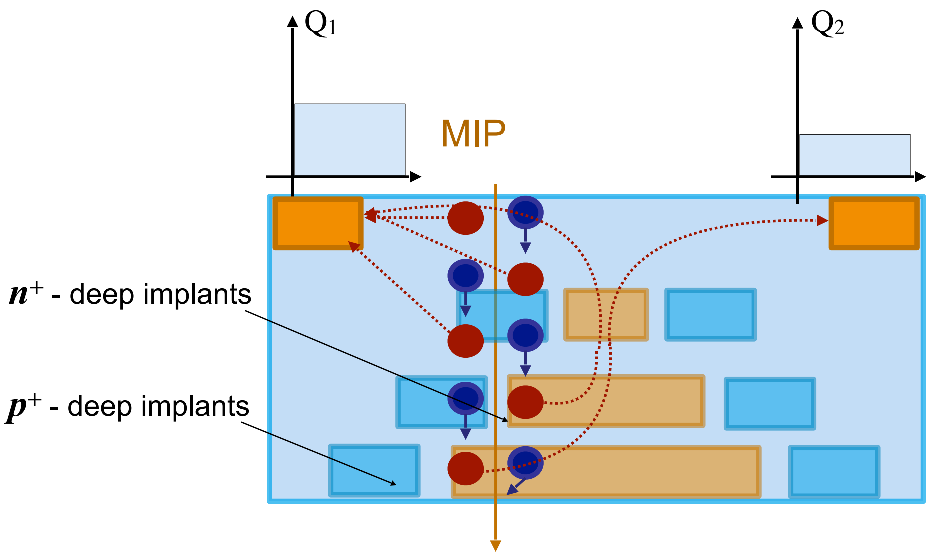
- Needed a lateral electric field inside the bulk.



Enhanced Lateral Drift Sensor

Manipulating the electric field

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

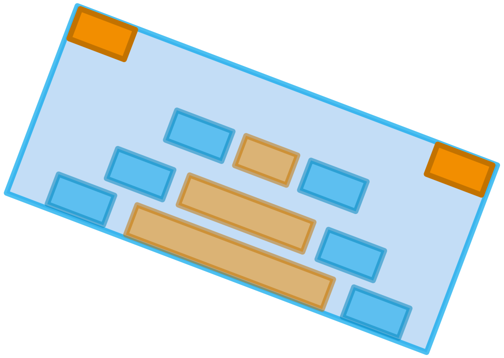


p-ELAD sensor

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

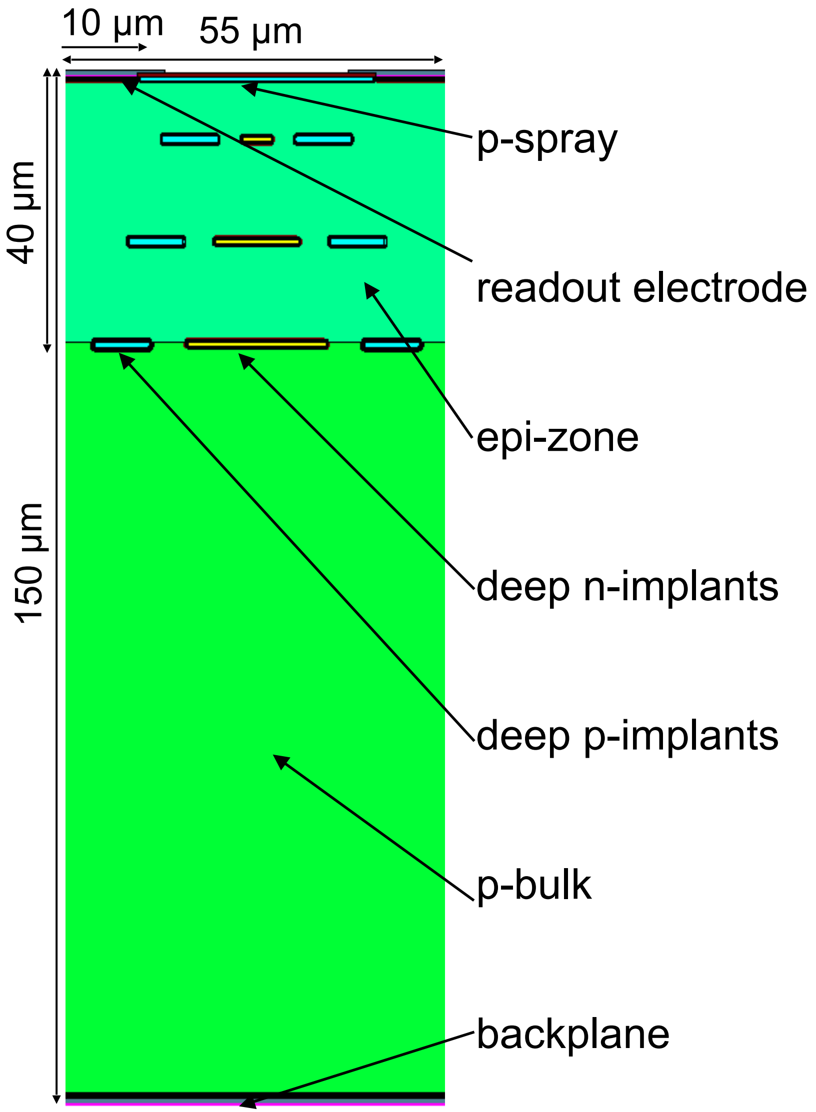


- **Parameters for simulation:**
  - Width, depth of implants
  - Distance within/to next layer
  - Position/shift to neighbouring layer
  - Number of layers
  - Optimal doping concentrations for deep implants
- **Quasi stationary:**
  - Solve electric field
  - Ramp voltage to the set value
- **Transient:**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

TCAD simulations

ELAD geometry

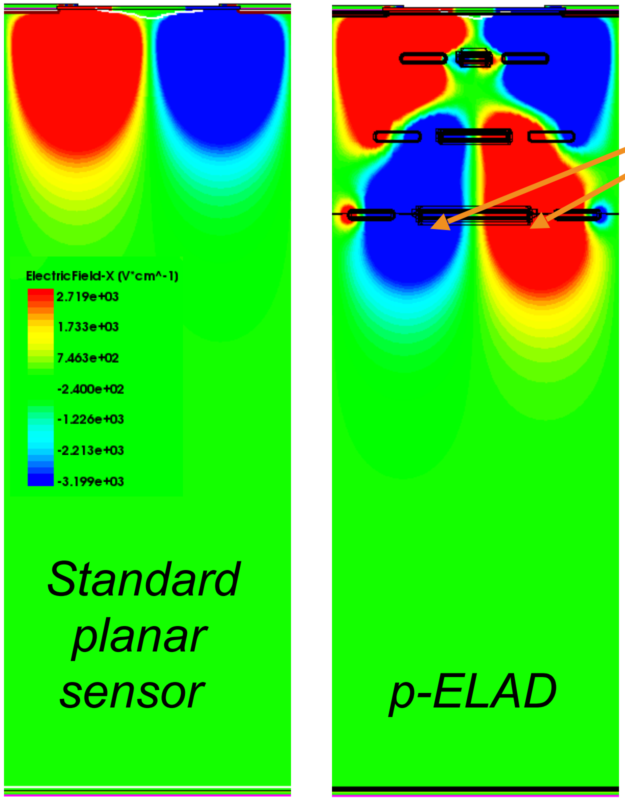
- low concentrated deep p and n implants are located in the sensor bulk
- with changing the type of deep implants the n-ELAD (p-in-n) can be created.
- first and second layer are located in the epitaxial part of the sensor with a thickness 40 µm
- TimePix3 geometry
  - pitch 55×55 µm
  - pixel implant size 20 µm



TCAD simulations

Electric field simulations

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



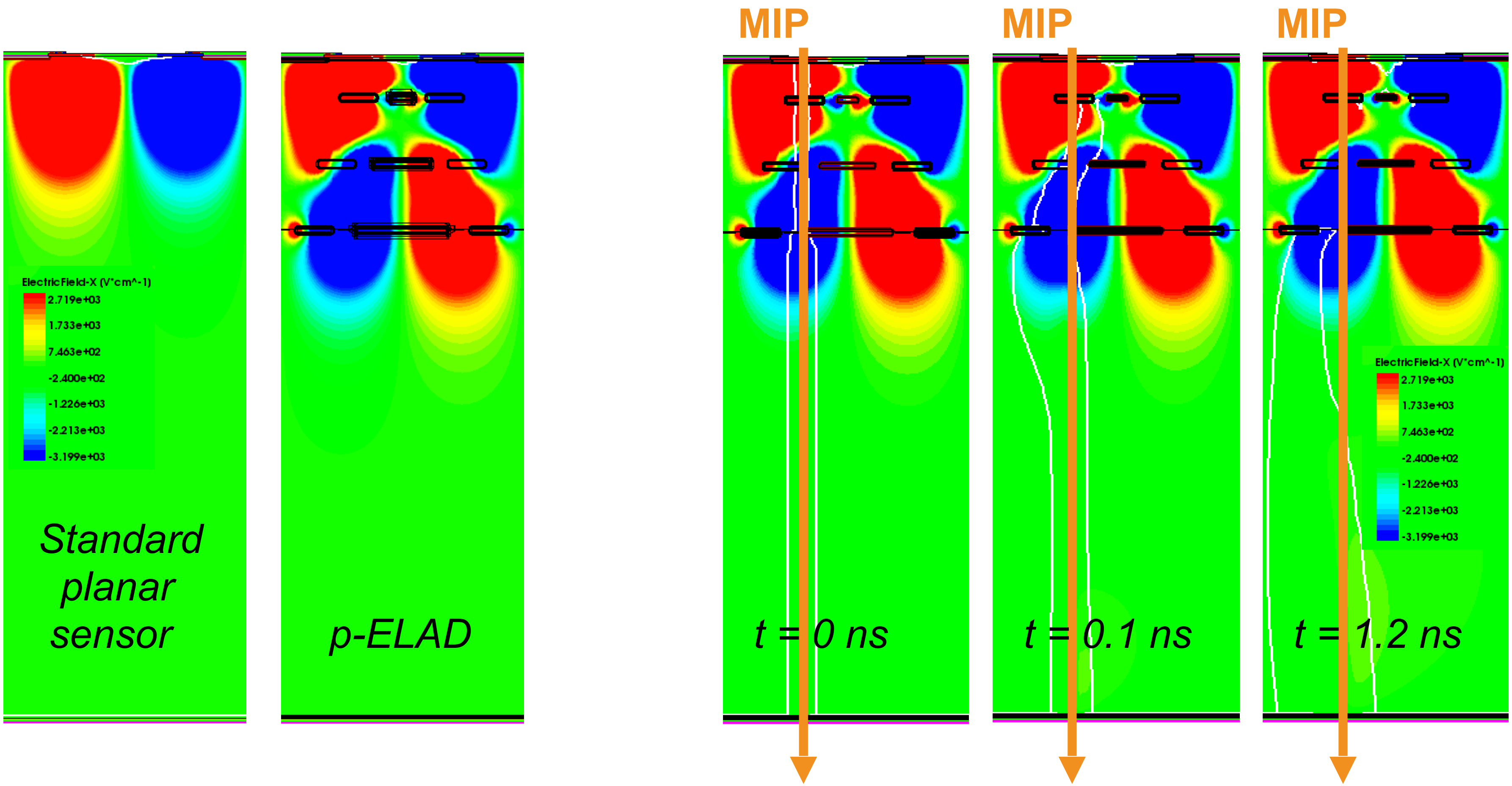
Repulsive areas for charge carriers.
In the blue sones electrons move in the right direction, in the red - left.

V = 400 V

TCAD simulations

Electric field simulations

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



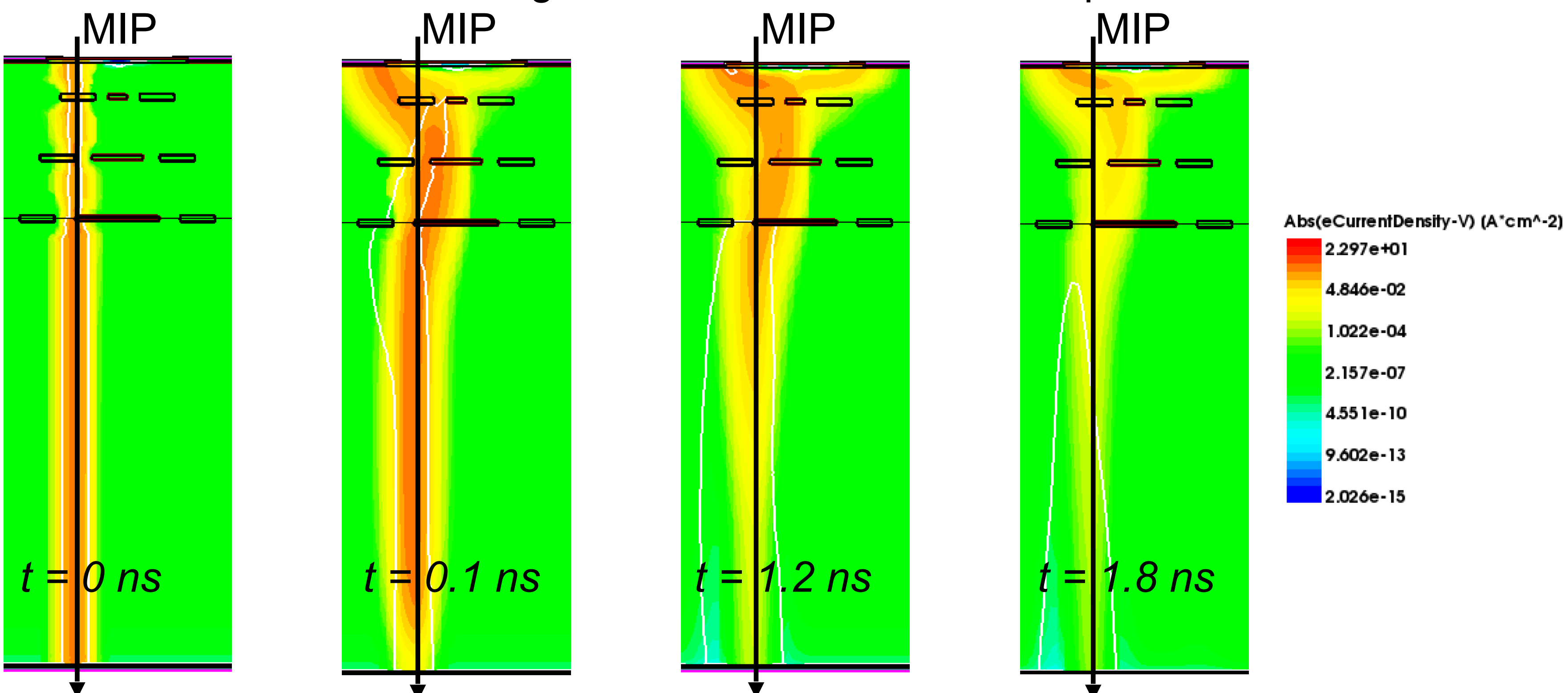
- **The non-homogeneous electric field in the ELAD sensor is stable in time.**

V = 400 V

TCAD simulations

Drift with MIP

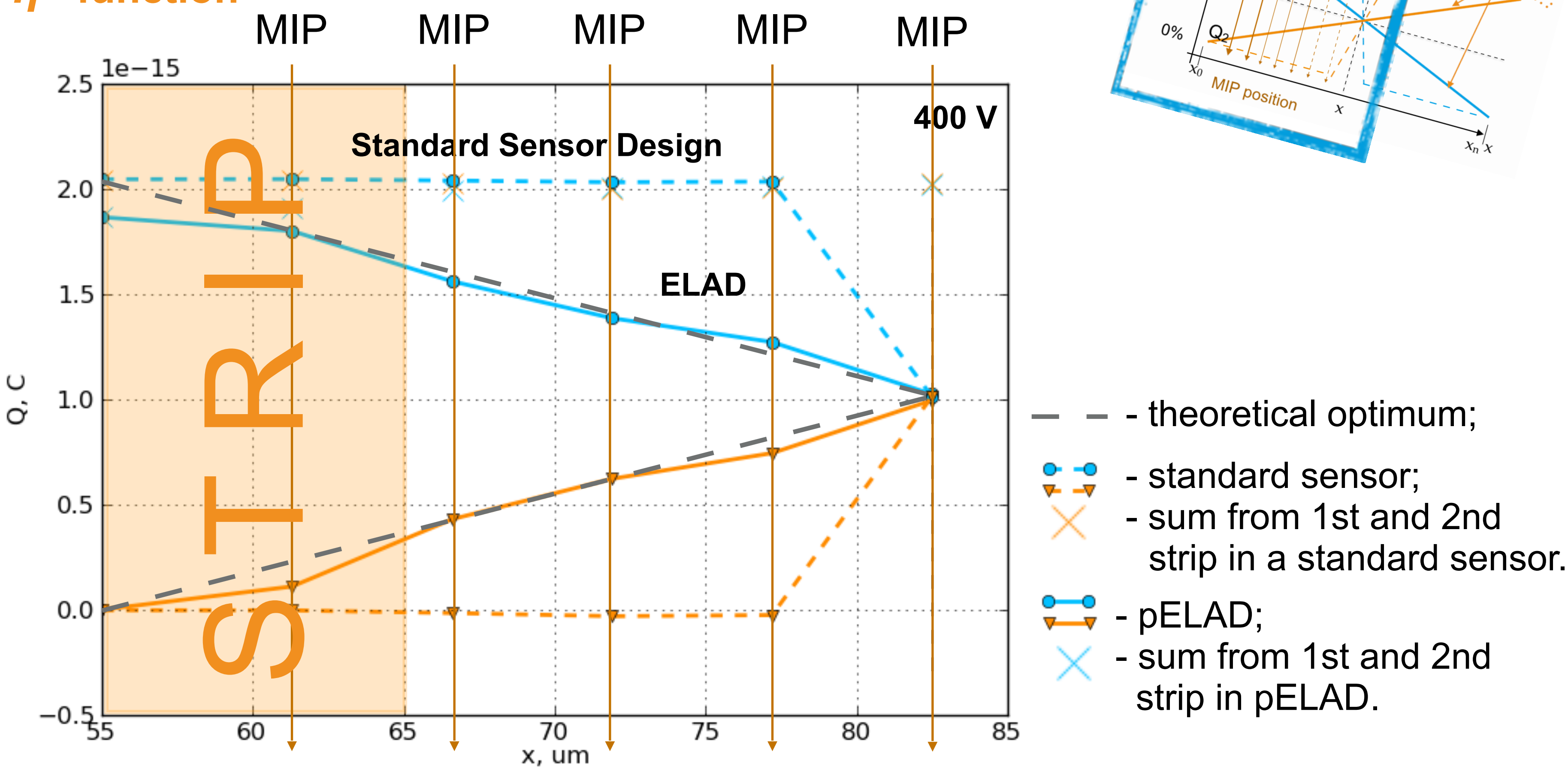
- In comparison to the usual design, with the same MIP position and applied voltage, in the ELAD sensor the charge is shared between two strips.

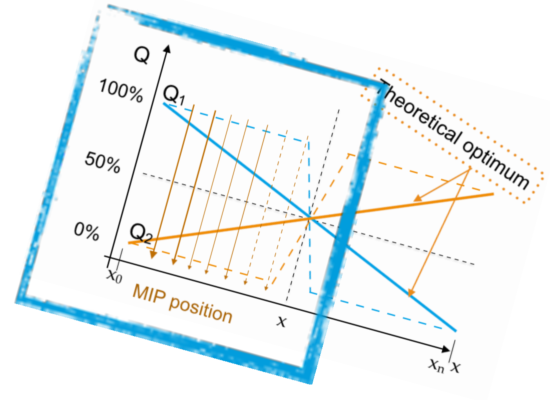


- The part of the charge created beneath the deep implants area changes the drift path
  - It is collected by two electrodes

TCAD simulations

η - function

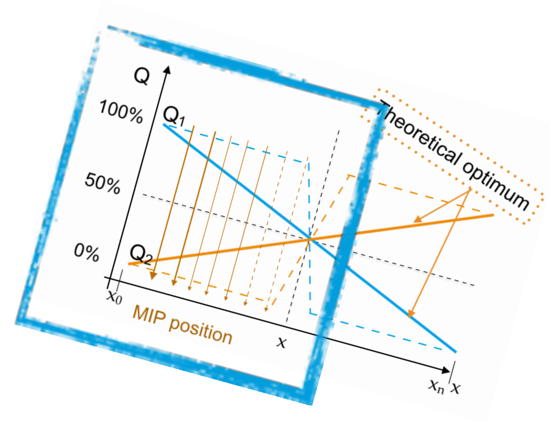


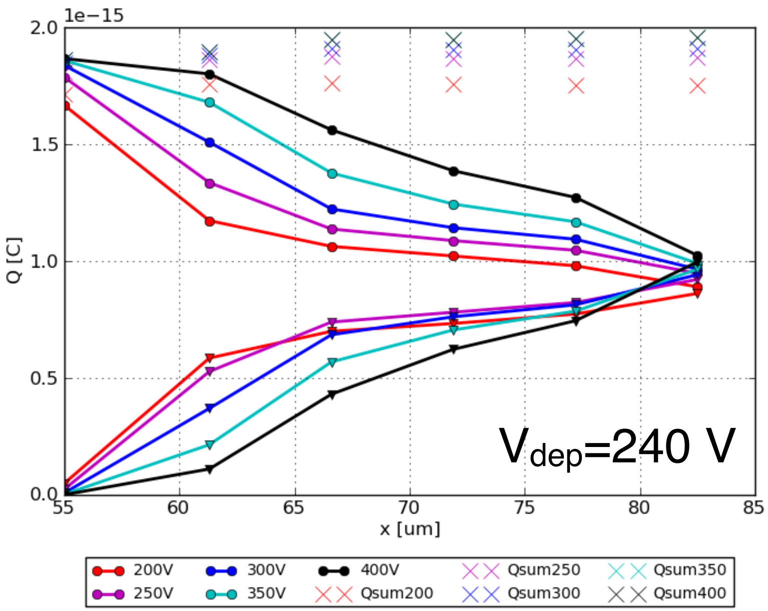


- The collected charge as a function of the MIP incident position.
- **ELAD design** gives an opportunity to tune the ***η* - function** close to the **theoretical optimum.**

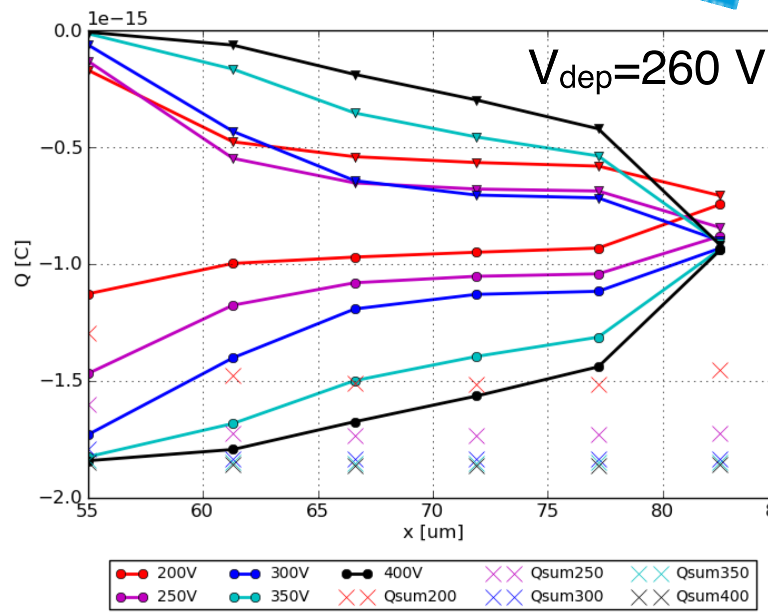
TCAD simulations

η - function, Voltage scan





p-ELAD

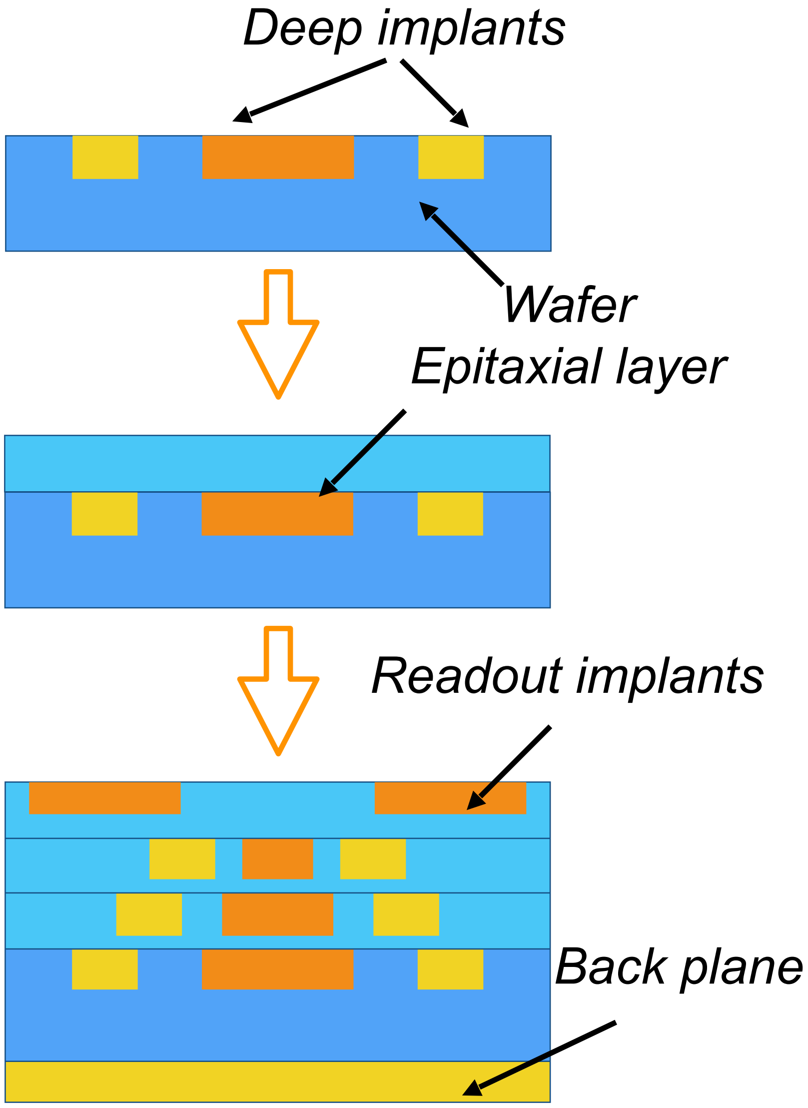


n-ELAD

- The optimal voltage for the p-ELAD is in a range between 350V and 400V.
- The optimal voltage for the n-ELAD is in a range between 300V and 350V.

Production

New method

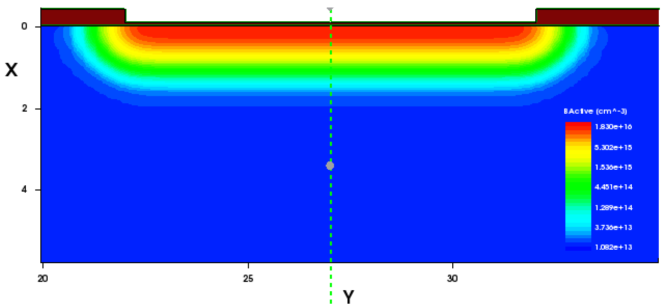


- **Ion beam implantation** on to the wafer surface (ISE, Freiburg).
- **Epitaxial growth process**, a thin silicon layer is grown on the wafer surface. Process temperature is approximately 1150°C (ISE, Freiburg).
- **Combination of implantation and epitaxial growth** is repeated three times. After the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

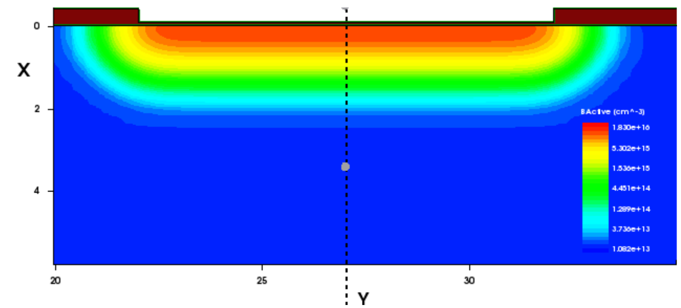
Production

Process simulations in TCAD

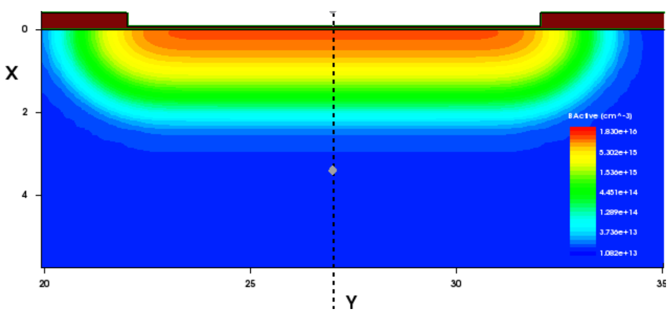
- Simulation of the effect from the epitaxial growth process.



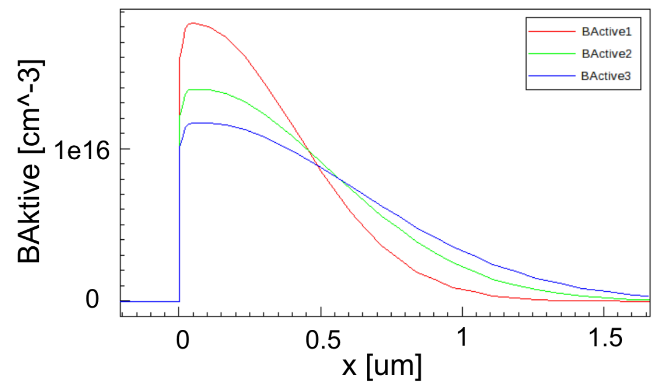
Boron implant, 1st temperature cycle



Boron implant, 2nd temperature cycle



Boron implant, 3rd temperature cycle



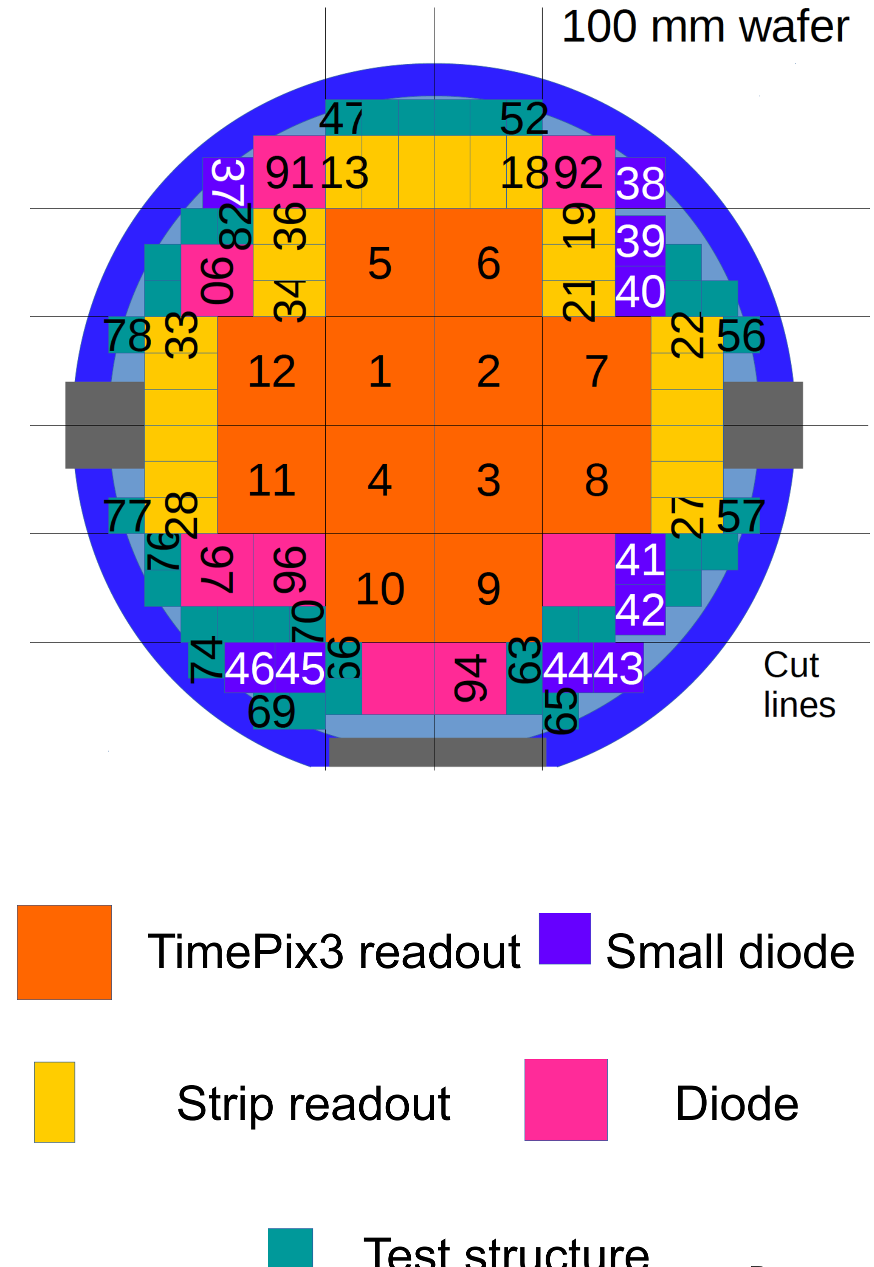
Active Boron concentration after 1st, 2nd and 3rd temperature cycle as a function of depth

- The difference in sizes (less than 1 μm) of deep implants has a negligible effect on a charge sharing between strips.

Production

Wafer layout

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



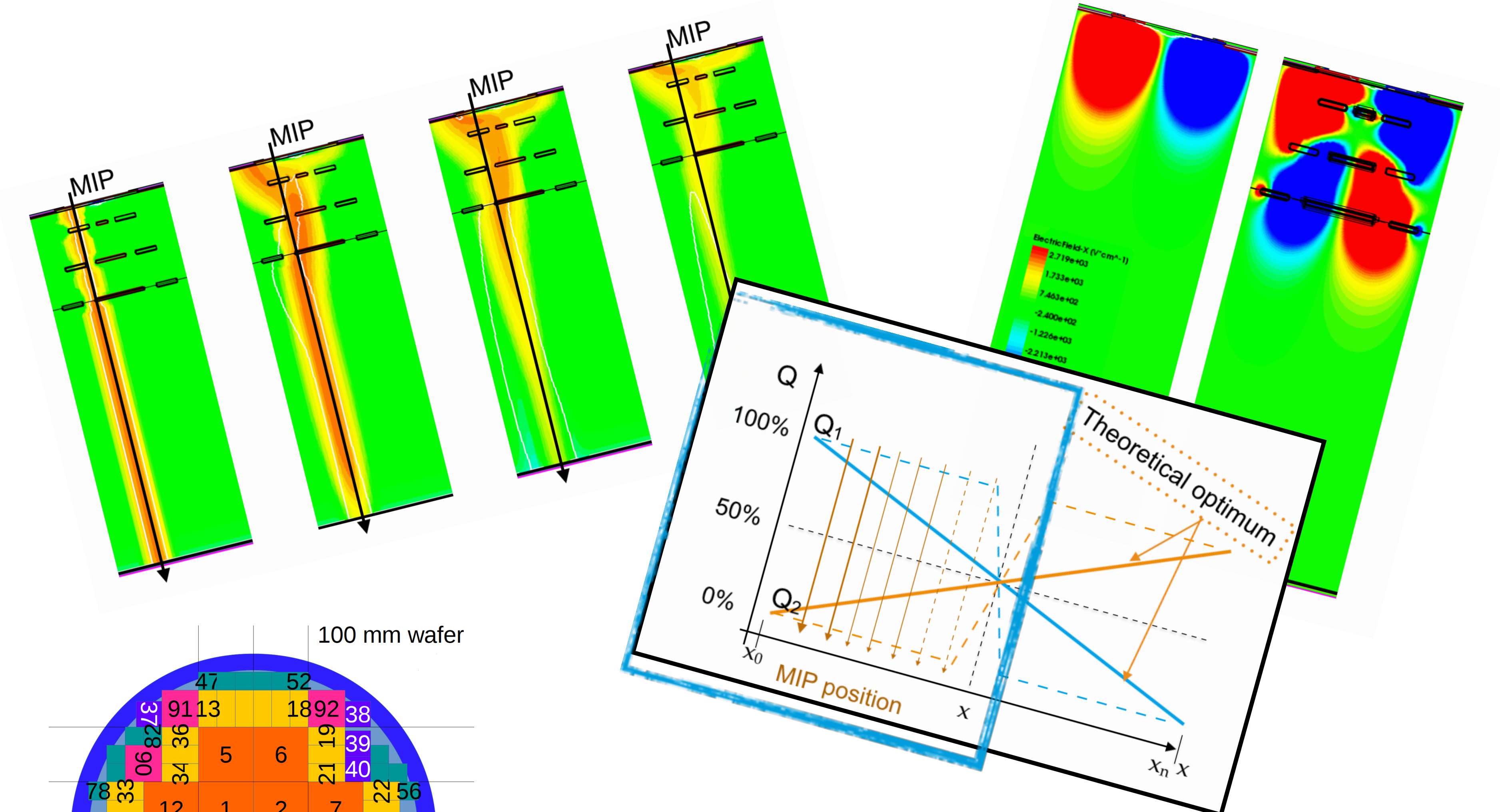
Summary & Outlook

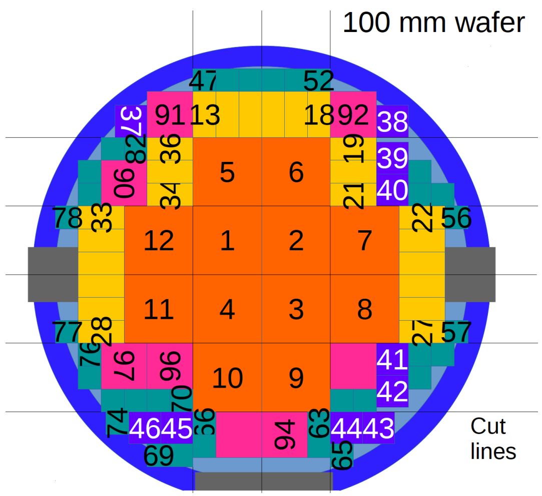
Summary

- 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

- Creation of wafer layout files for production (DESY + CiS)
- Production of the prototypes
- Flip chipping with TimePix3 sensor
- Tests at DESY/CERN
    - Lab: IV, CV, TCT
    - Test beam





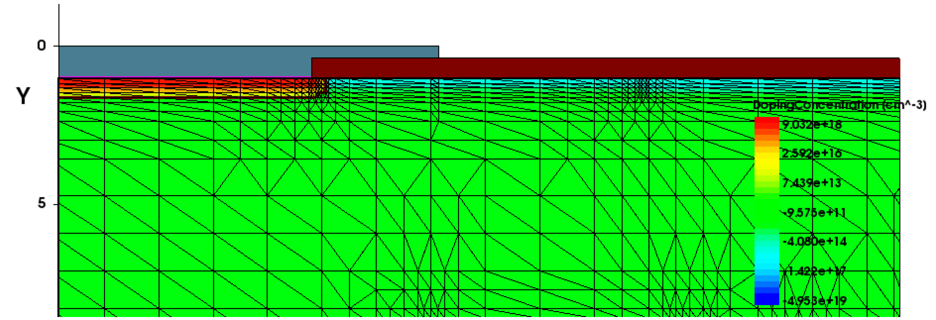
Thank you for attention!

Backup!

TCAD simulations

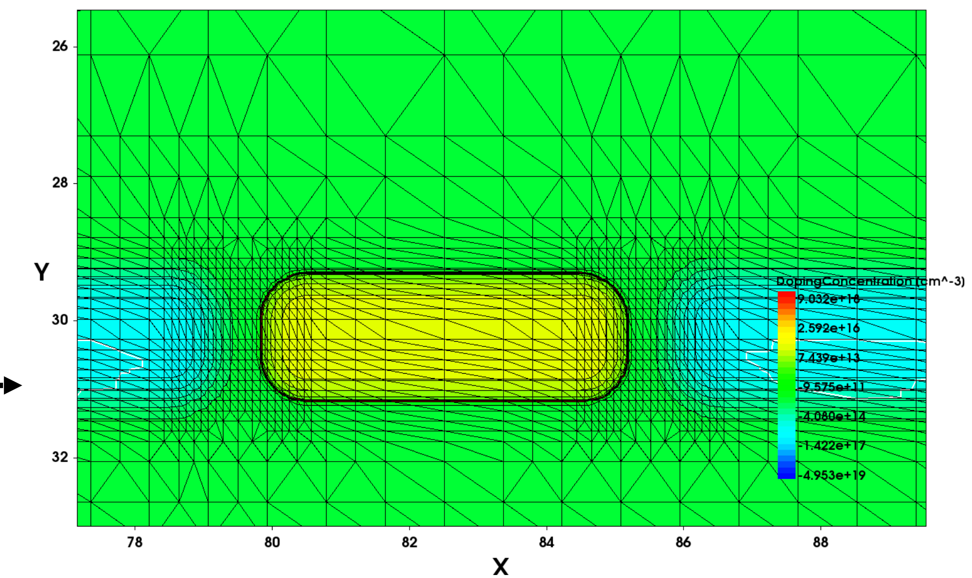
Meshing

- *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

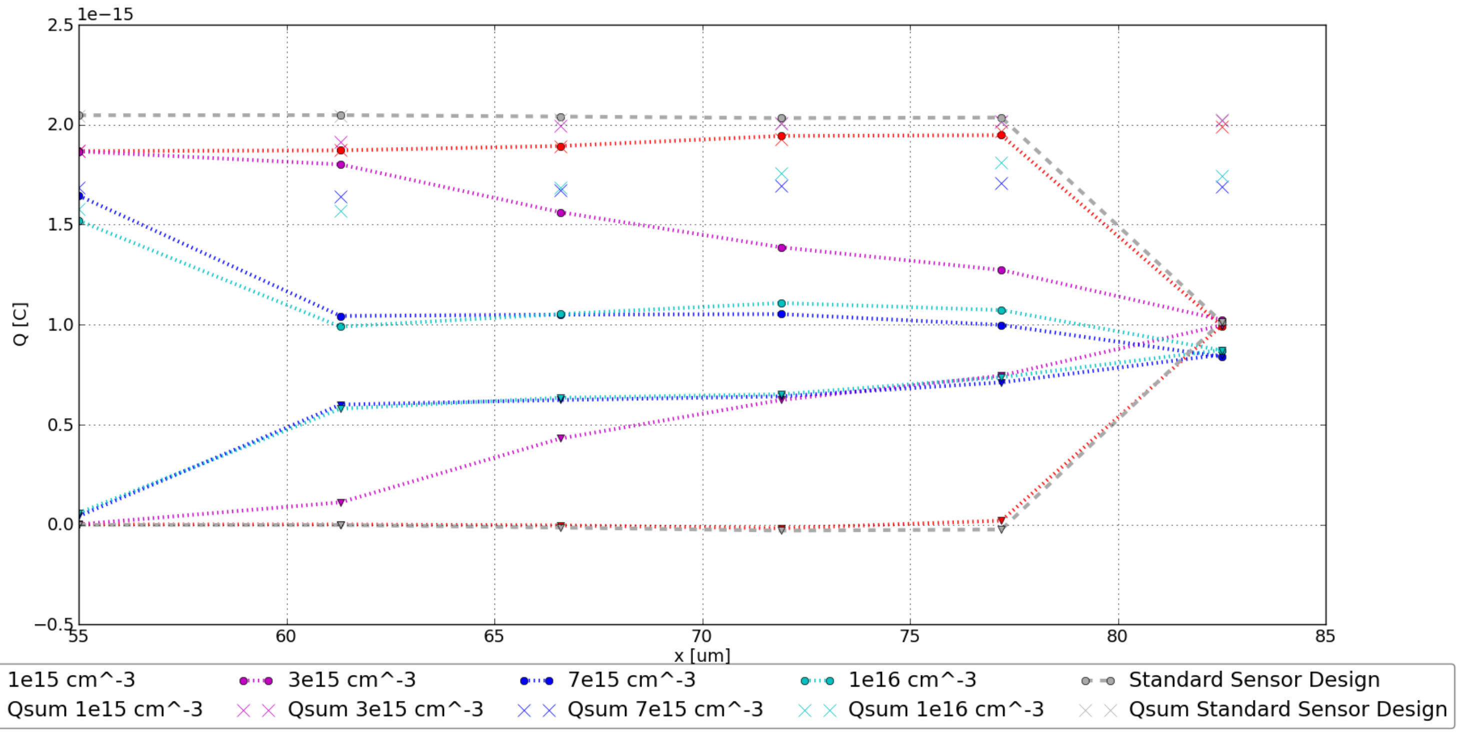
- *Deep p+ and n+ implants*



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}.

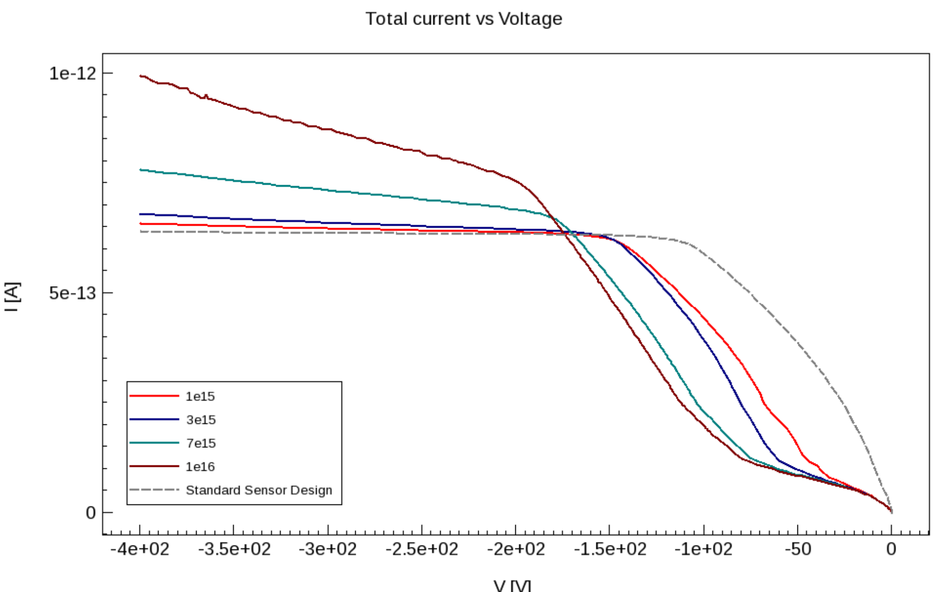


- The deep implant concentration 1e15 cm^-3 gives no effect on a charge sharing.

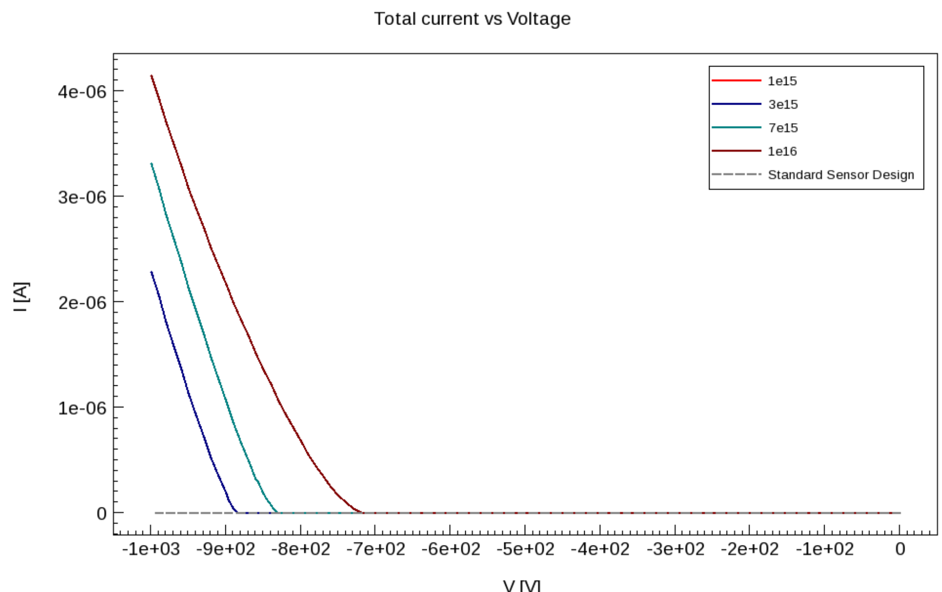
TCAD simulations

Deep implant's concentration

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



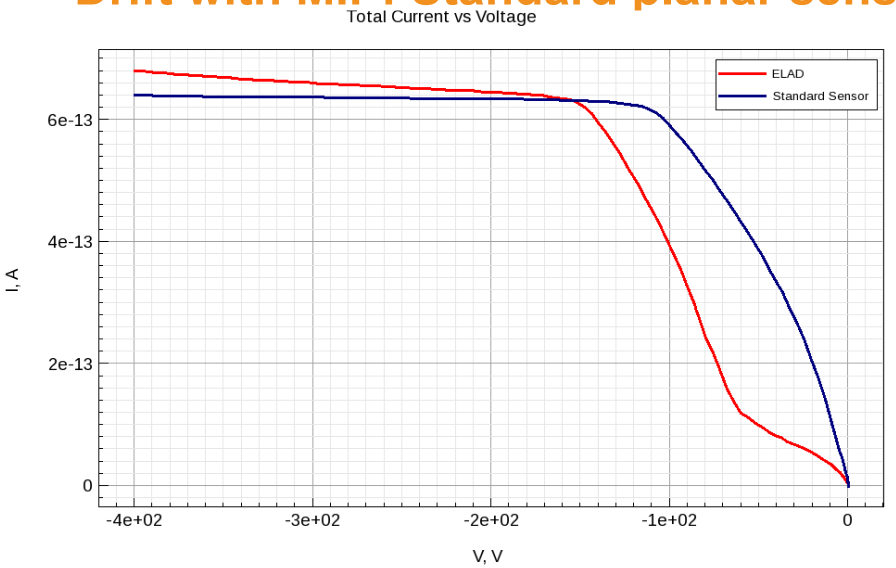
I vs V (up to 400V) for ELAD sensors with deep implant concentrations 1e15 cm^{-3}, 5e15 cm^{-3}, 7.5e15 cm^{-3} and 1e16 cm^{-3}

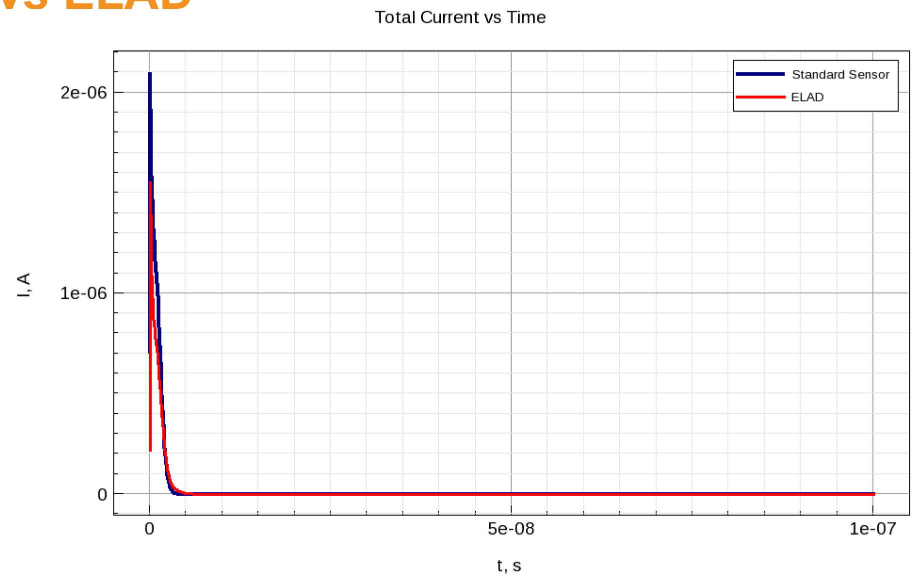


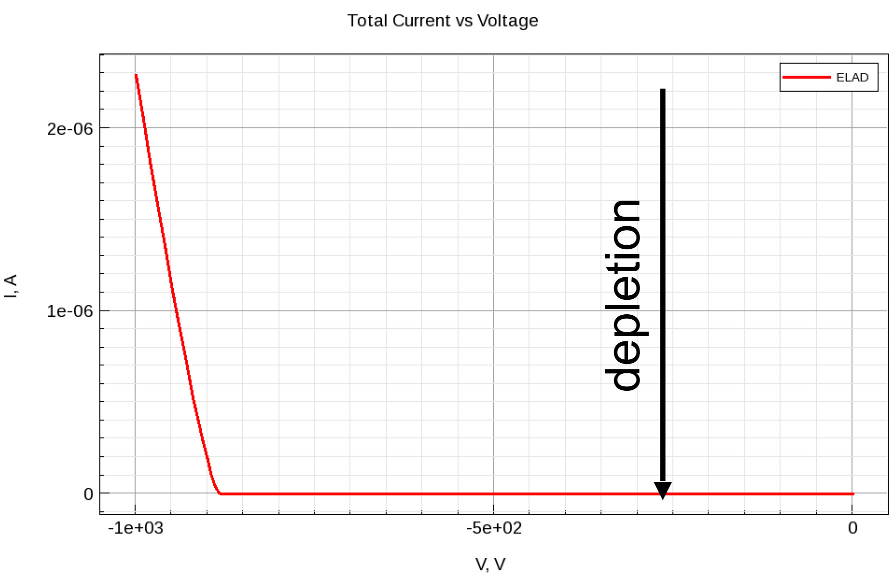
Breakdown voltage for ELAD sensors with deep implant concentrations 1e15 cm^{-3}, 5e15 cm^{-3}, 7.5e15 cm^{-3} and 1e16 cm^{-3}

TCAD simulations

Drift with MIP: Standard planar sensor vs ELAD



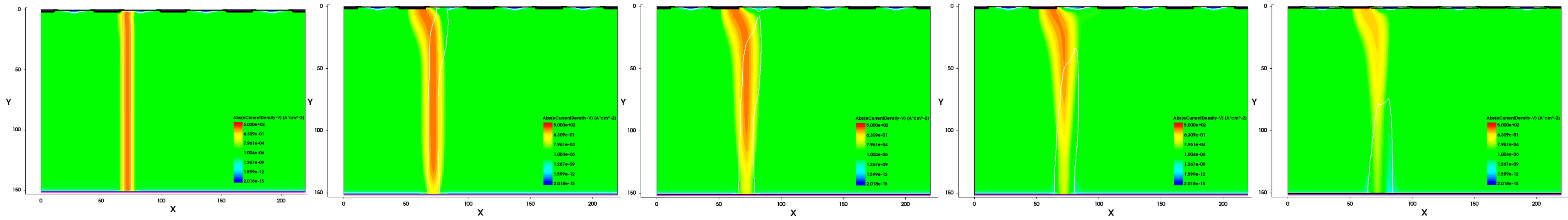




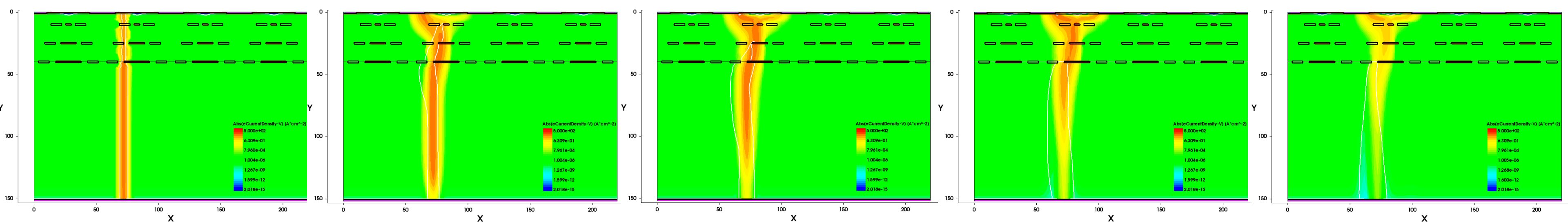
- Total current in ELAD sensor during the voltage ramping is higher due to high deep implants concentration
- Signal from the standard sensor and ELAD looks the same
- Breakdown voltage is 880 V

TCAD simulations

Drift with MIP: Standard planar sensor vs ELAD



Standard planar sensor



ELAD sensor

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