Enhanced Lateral Drift (ELAD) sensors

Charge sharing and resolution studies

Anastasiia Velyka, Hendrik Jansen
Pixel 2018
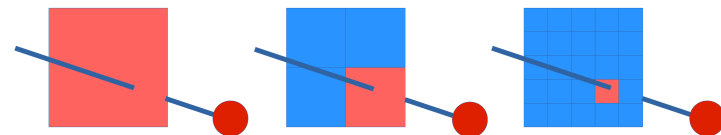Taipei
13.12.2018

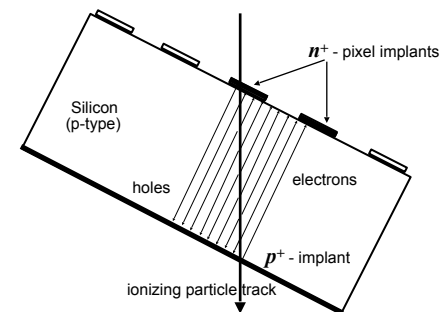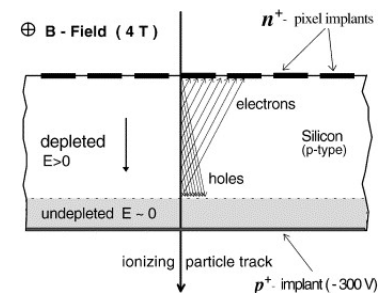# Position resolution

Improving position resolution:

▸ **Down-sizing the pitch**

▸ **Charge sharing**

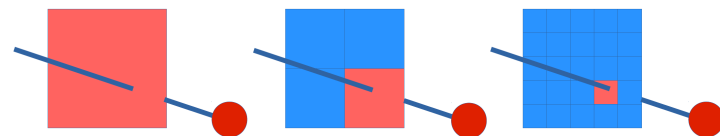   ▸ Lorentz angle or tilted sensor

Position resolution

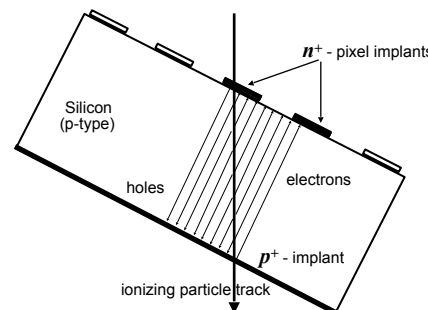**Improving position resolution:**

▸ **Down-sizing the pitch**

   ▸ Disadvantages:
- ‣ Increases number of readout channels
- ‣ Potentially higher band width from detectors
- ‣ Less area/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

Position resolution
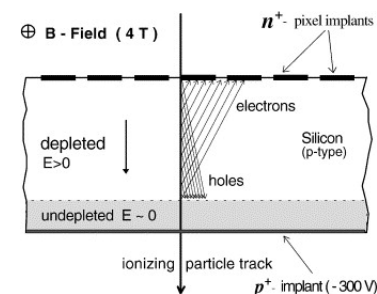## Improving position resolution:

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    ▸ Lorentz angle or tilted sensor

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- ‣ Doesn't work for thin sensors
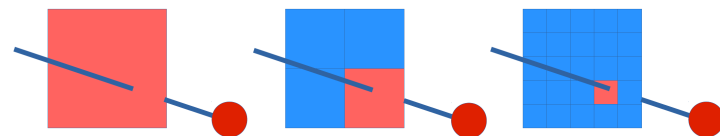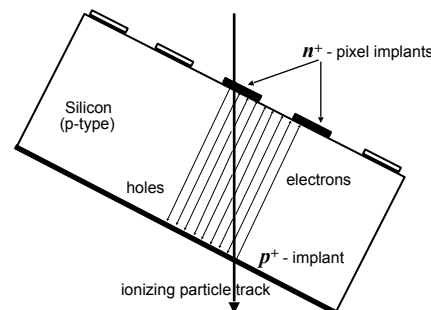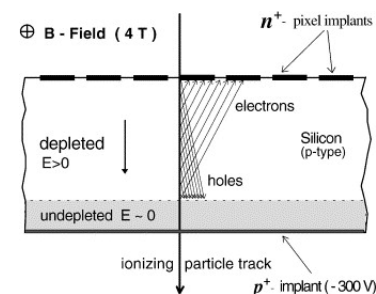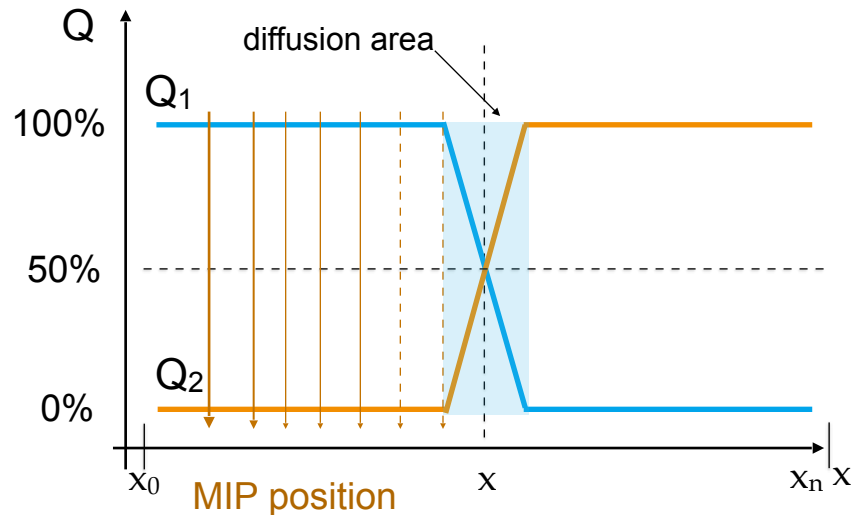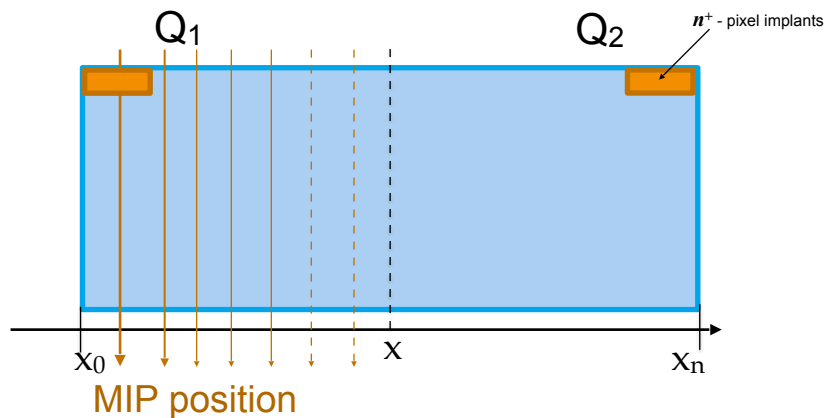- ‣ Tilting increases material budget

▸ **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
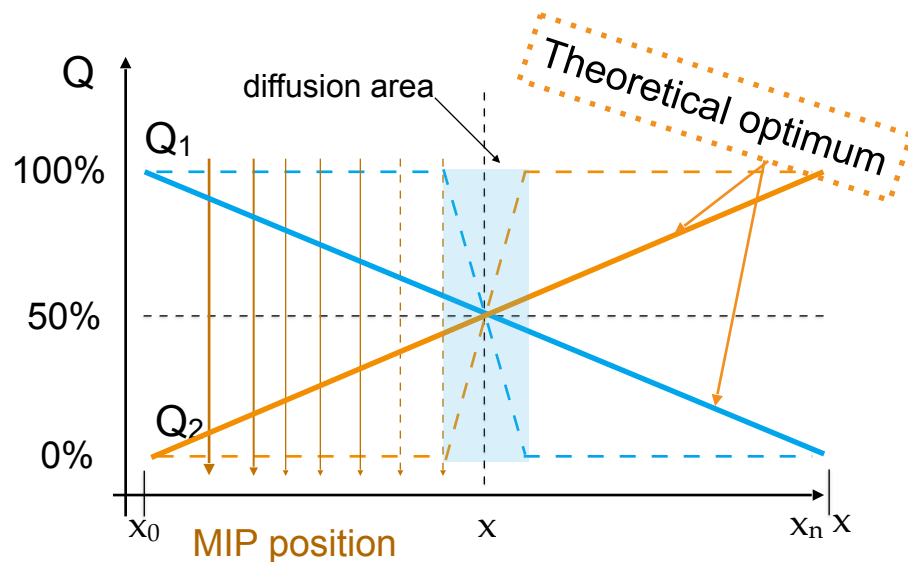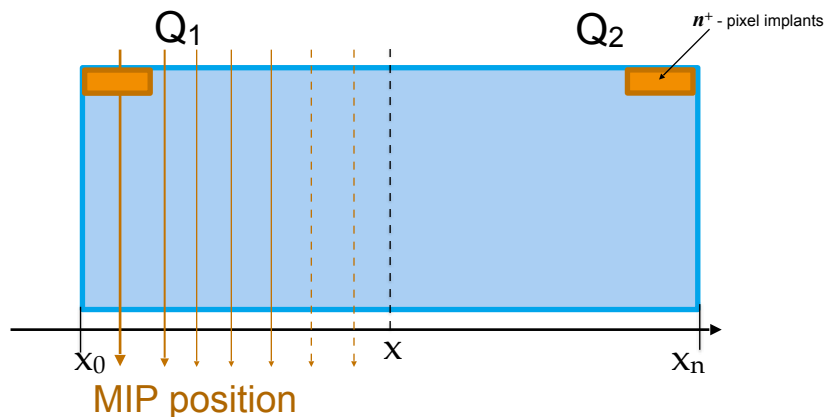
▸ **Charge collection between 2 strips**

▸ Standard sensor design:

   ▸ charge in the left part of pitch collected by 1st strip,

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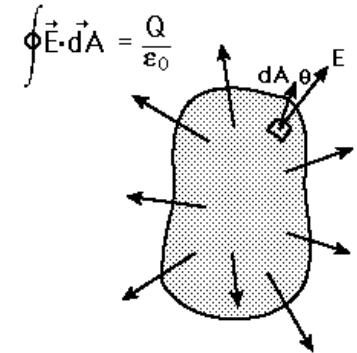
▸ In an ideal case:

   ▸ charge distribution between 1st and 2nd strip is **linear** → best charge sharing.

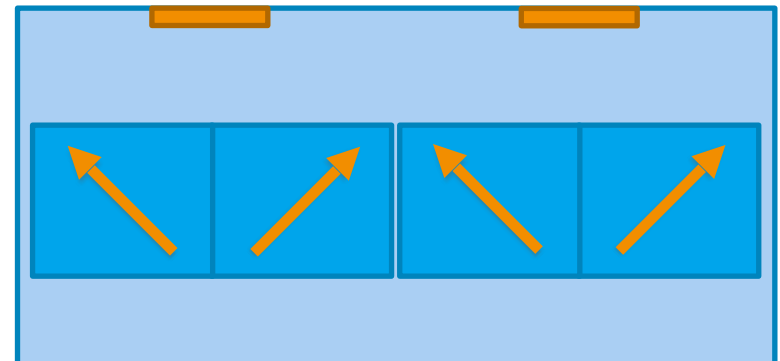# Concept of an Enhanced Lateral Drift Sensor

Manipulating the electric field

▸ Charge carriers follow the electric field lines.

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

$$\oint \vec{E} \cdot \vec{dA} = \frac{Q}{\varepsilon_0}$$

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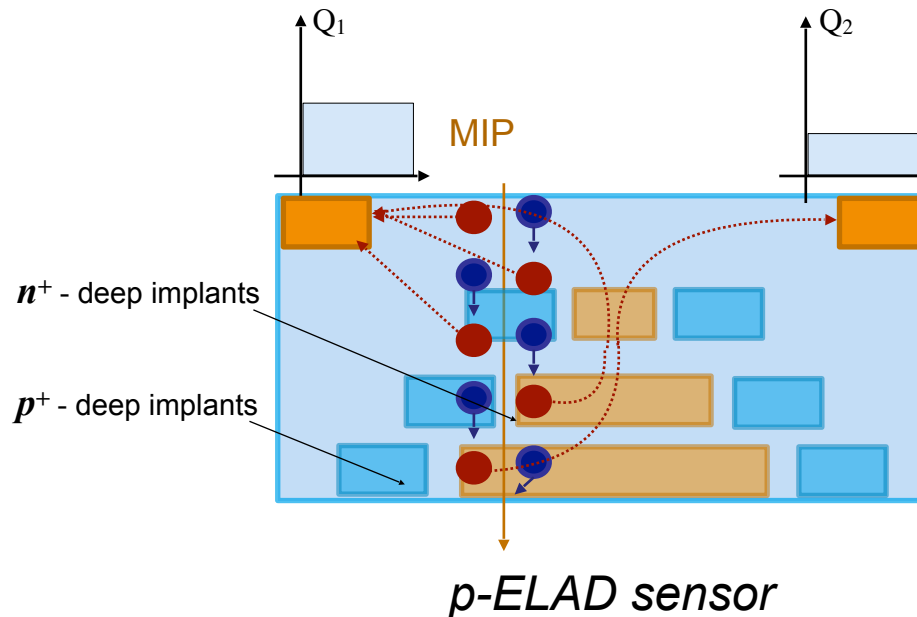 ▸ Induce lateral drift by locally engineering the electric field

▸ Introduce a lateral electric field inside the bulk.

Enhanced Lateral Drift Sensor

Manipulating the electric field

▸ **Charge guiding areas created by adding higher doping concentration.**

n^+ - deep implants

p^+ - deep implants

p-ELAD sensor

▸ Lateral electric field is introduced 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** by adding p-n-p structure.

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:**
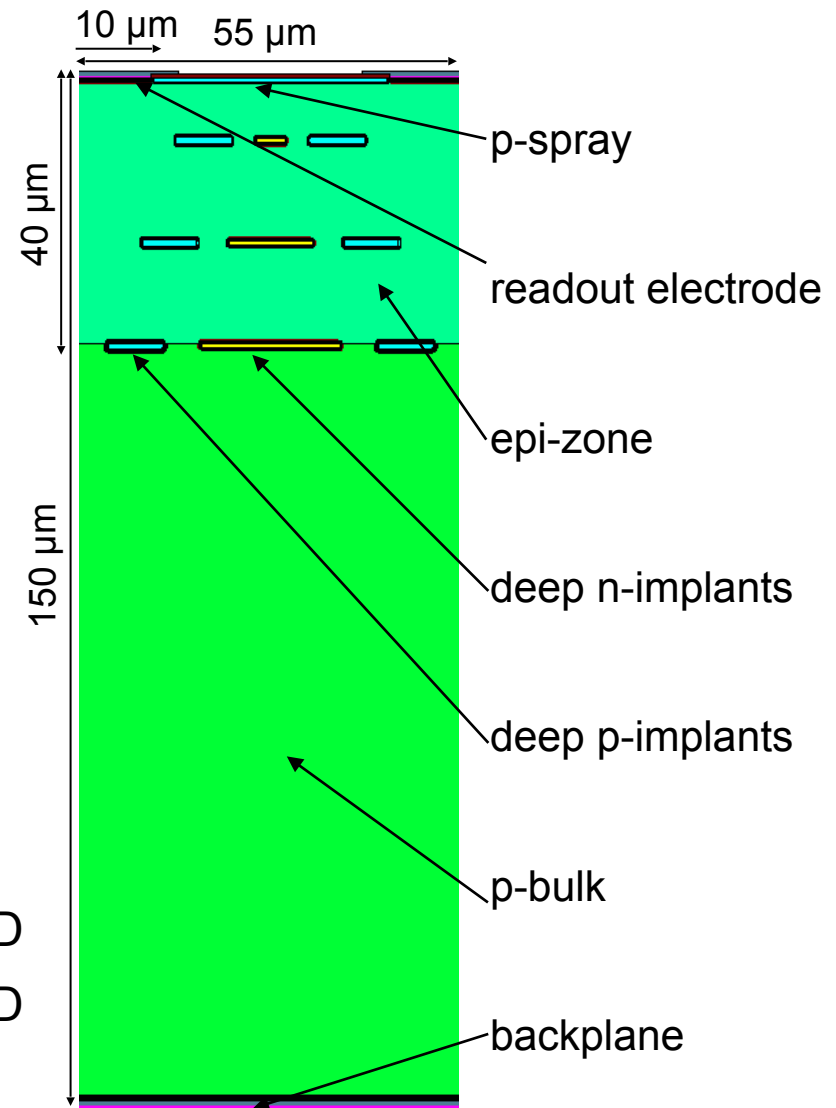 - ▸ Solve electric field
  - ▸ Ramp voltage to the set value

▸ **Transient:**
  - ▸ Poisson's equation
  - ▸ Carrier continuity equations
  - ▸ Traversing particles or arbitrary charge distribution
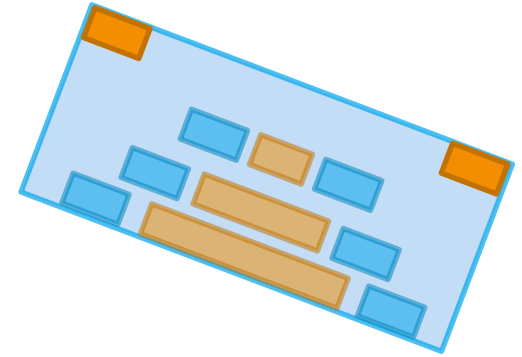
TCAD simulations

ELAD geometry

▸ deep p and n implants are located in the sensor bulk

▸ 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

▸ p-substrate, p-EPI, p-n-p structure→p-ELAD
▸ n-substrate, n-EPI, n-p-n structure→n-ELAD

TCAD simulations

Electric field simulations

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

Electric field lines move to the centre.
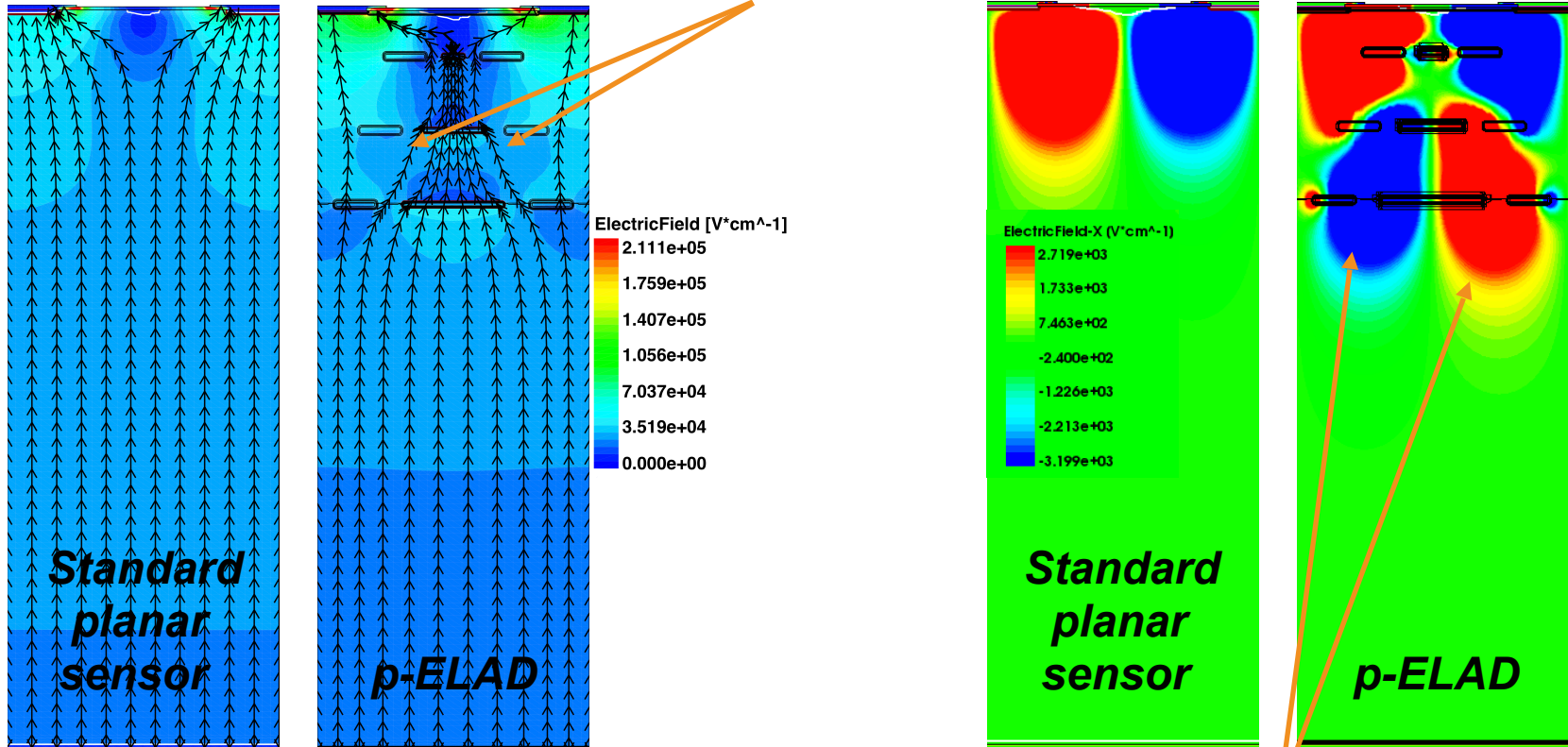
U = 400 V

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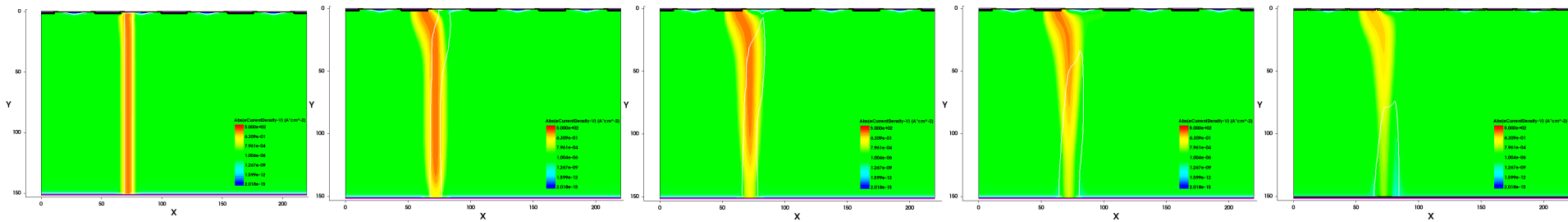
TCAD simulations

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.
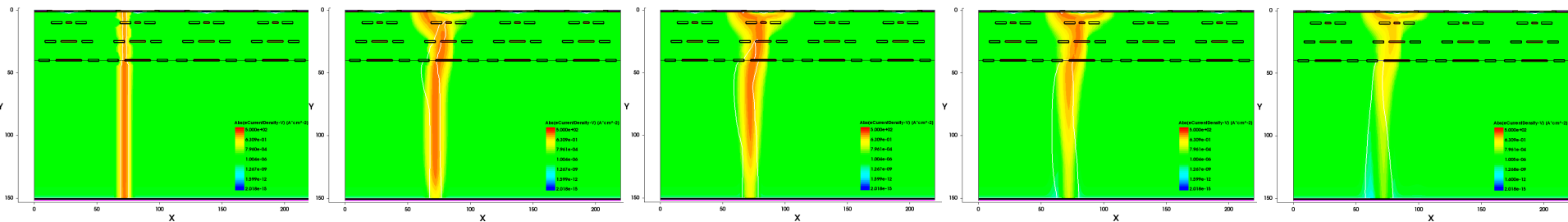

MIP MIP MIP MIP

Abs(eCurrentDensity-V) (A*cm^-2)

2.297e+01
4.846e-02
1.022e-04
2.157e-07
4.551e-10
9.602e-13
2.026e-15

t = 0 ns   t = 0.1 ns   t = 1.2 ns   t = 1.8 ns
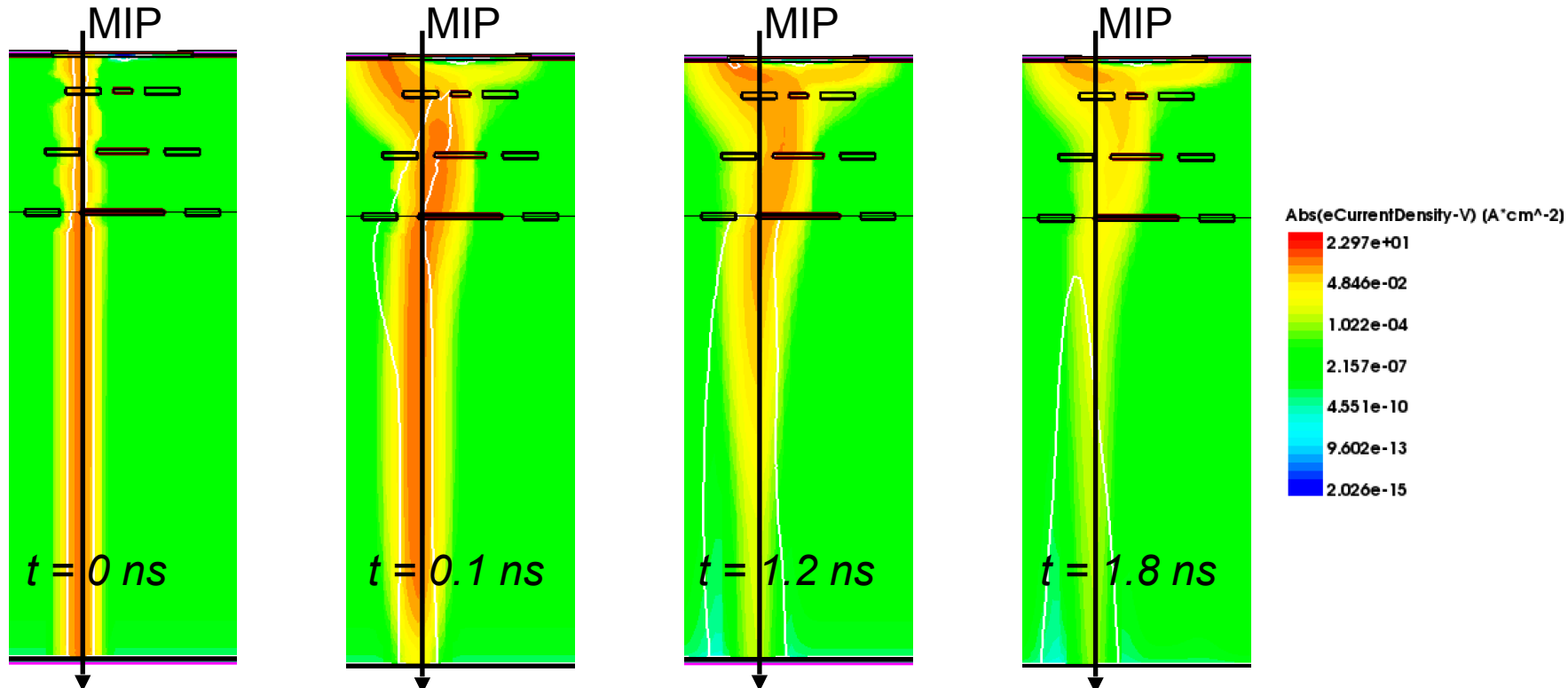
▶ The part of the charge created beneath the deep implants area changes the drift path
  ▶ It is collected by two electrodes

TCAD simulations

Drift with MIP: Standard planar sensor vs ELAD

Standard planar sensor

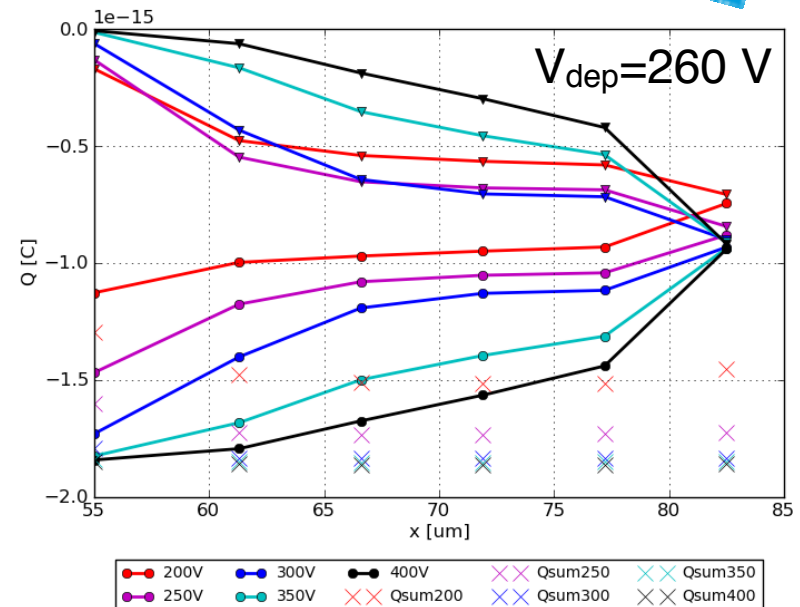ELAD sensor

TCAD simulations
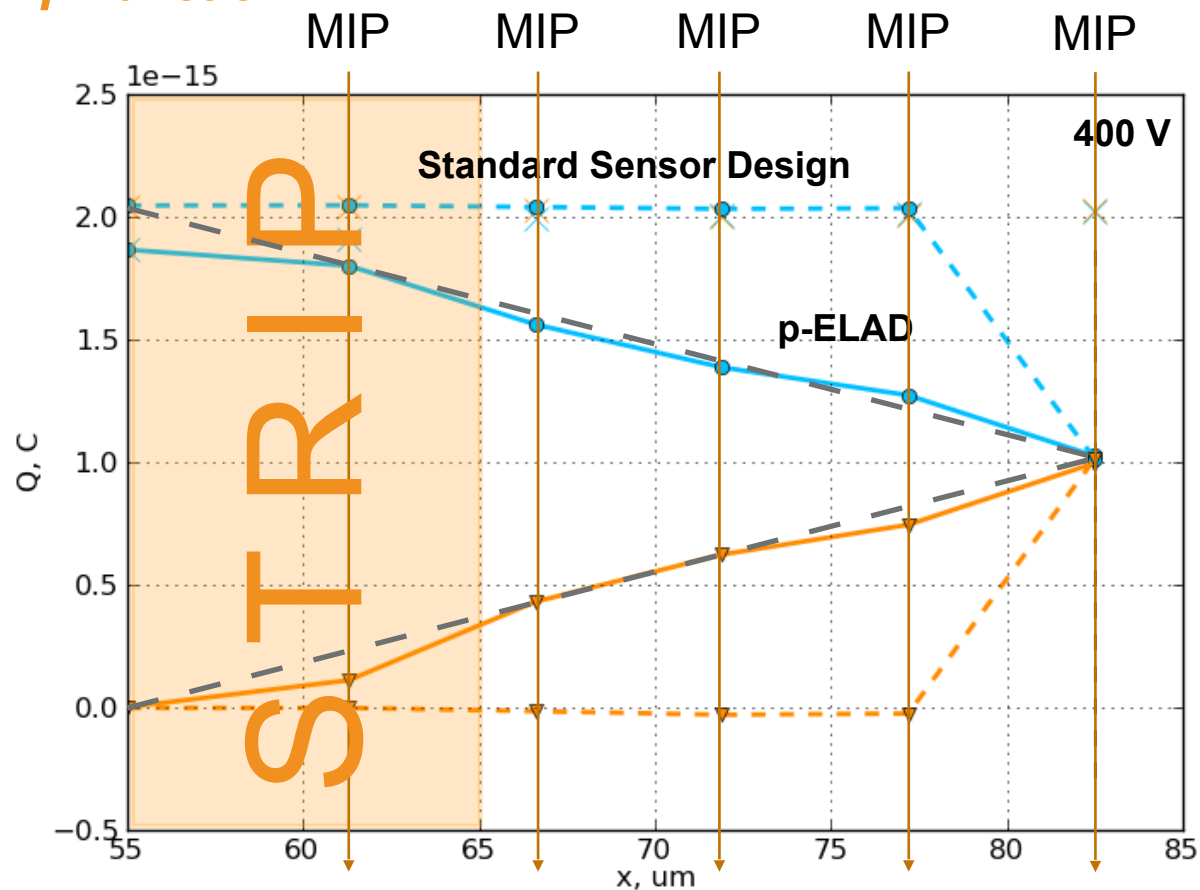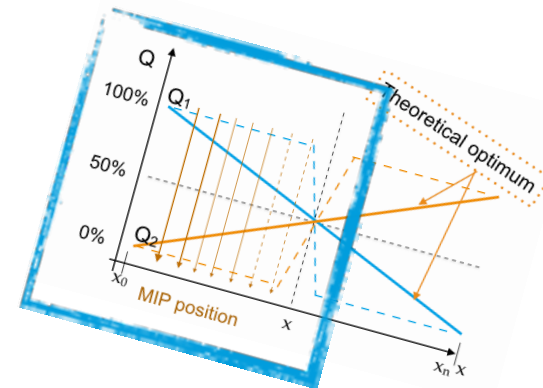
η - function

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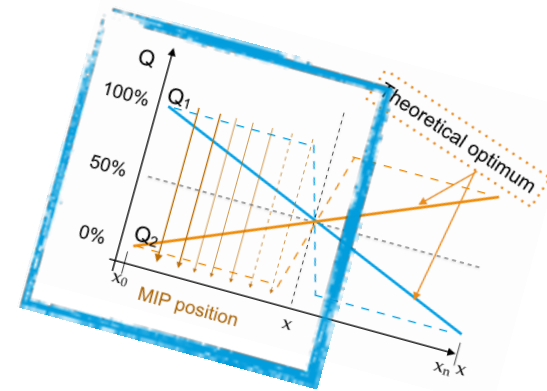
TCAD simulations

η - function, Voltage scan
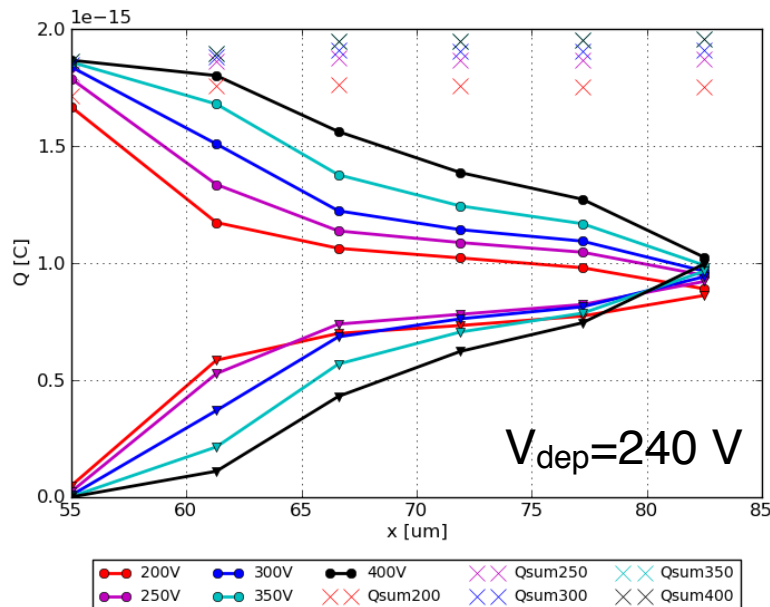
p-ELAD

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.

▸ High depletion voltage is an artefact of available background concentration of EPI.

Allpix² simulations

Resolution studies

▸ To estimate the position resolution → AllPix² simulations.

▸ Allpix2 - generic simulation framework for silicon tracker and vertex detectors

▸ Simulations with MC particles

▸ Based on Geant4 and ROOT

▸ Possibility to use TCAD electric field
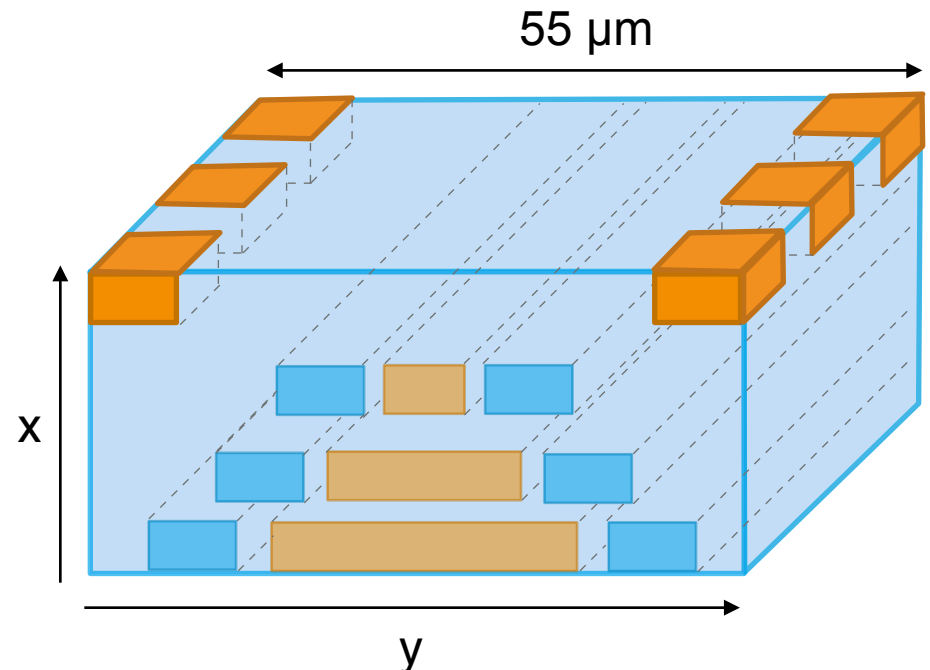
Allpix² simulations

Results for n-ELAD

Deep implant concentration 3e15 cm^-3, U=300V

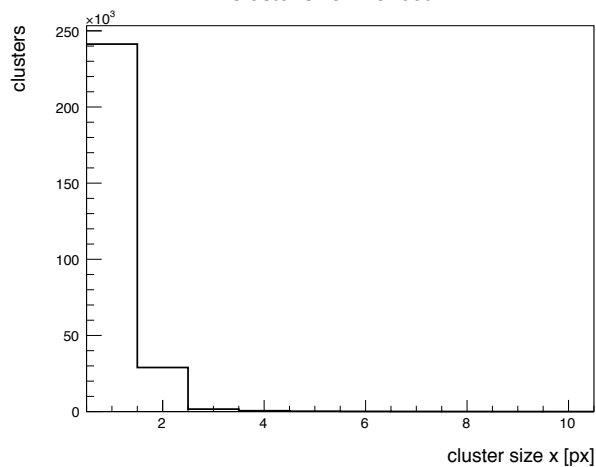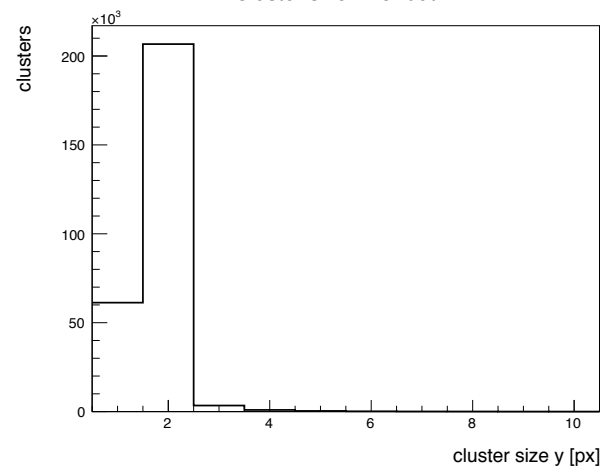Cluster size in X as function of in-pixel impact position for dut
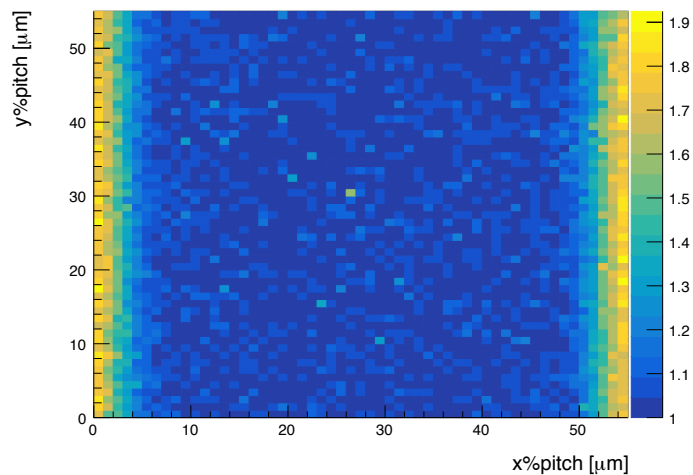
Cluster size in Y as function of in-pixel impact position for dut
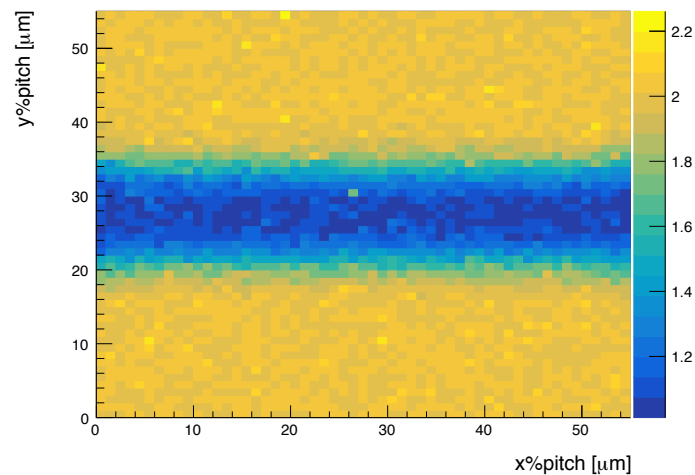
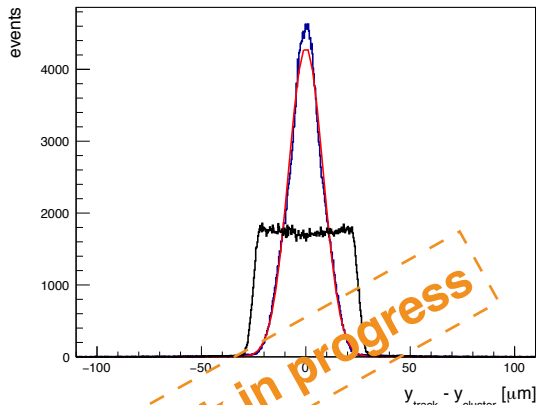Cluster size X for dut

Cluster size Y for dut

Allpix² simulations

Residuals for n-ELAD
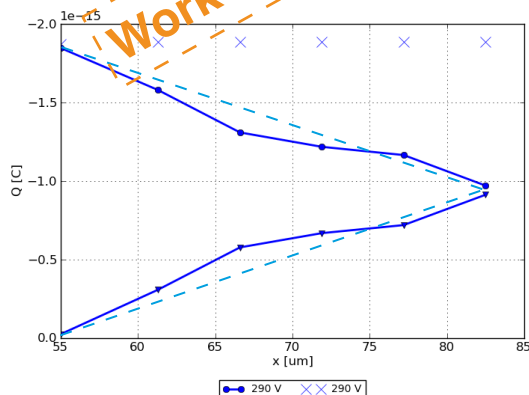
Deep implant concentration 3e15 cm^-3, U=280V, 290V, 300V
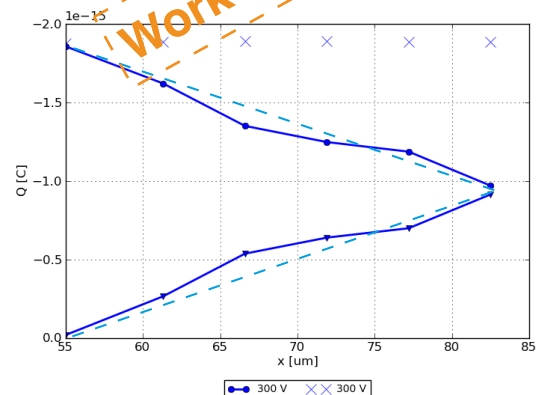
280V

Residual 8.2 um

290V

7.7 um

300V

7.6 um

Production

New method

Deep implants

Wafer

Epitaxial layer

Readout implants

Back plane
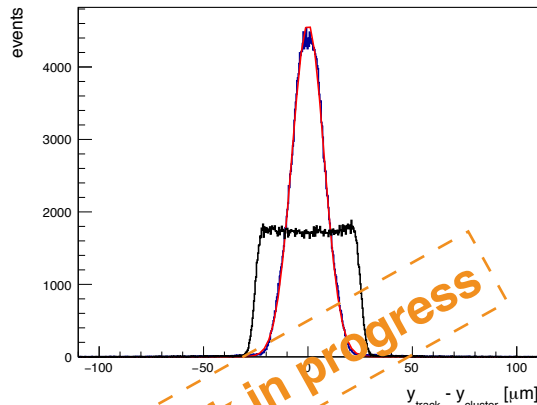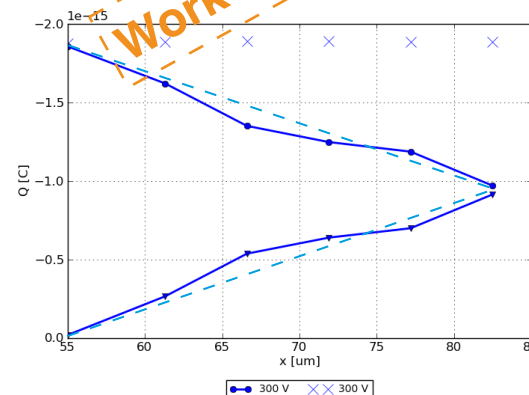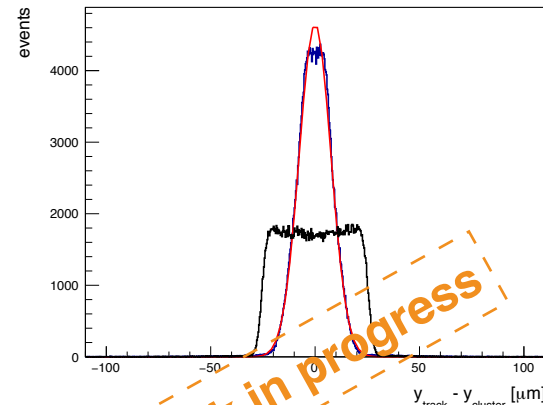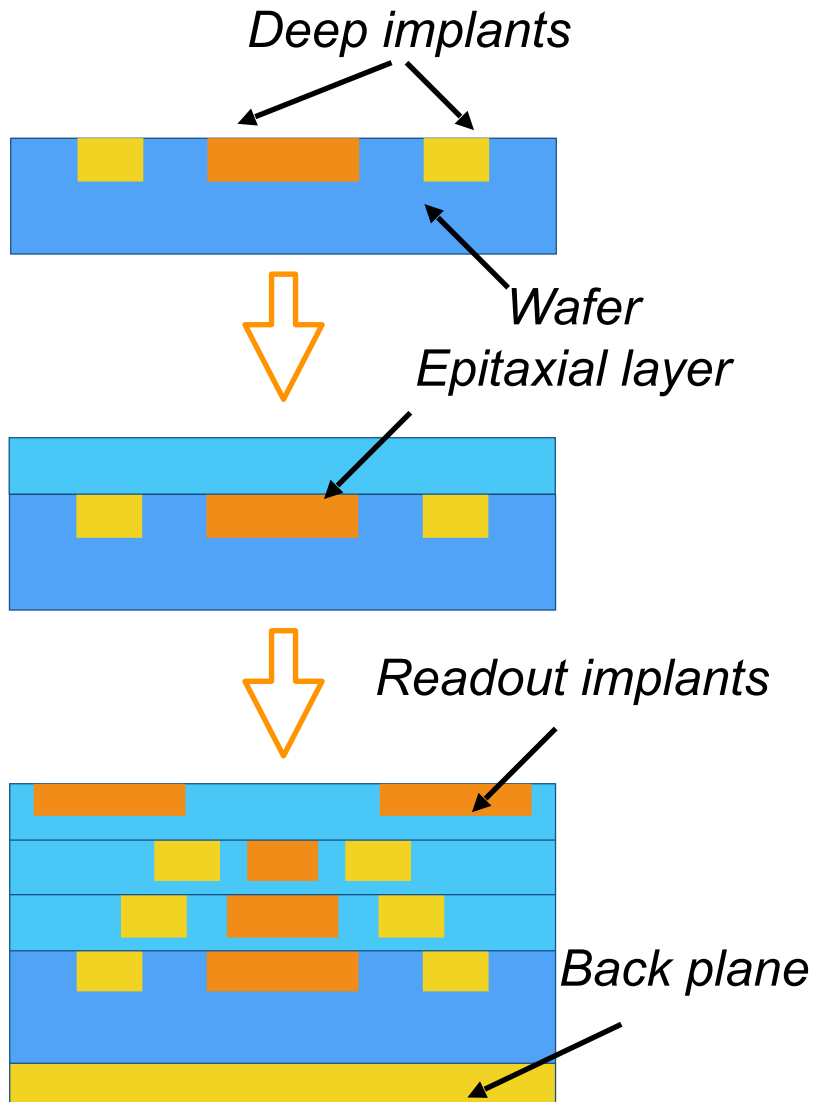
▸ **Ion beam implantation** on to the wafer surface (ISE, Freiburg).

▸ **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).
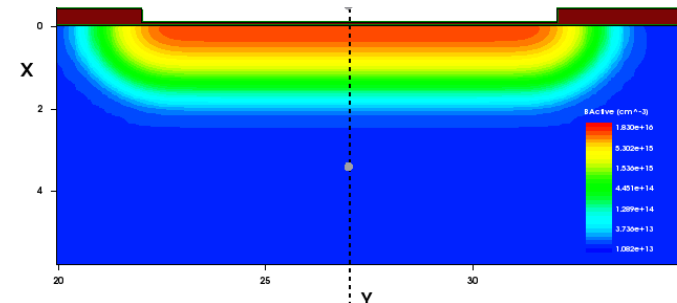
Production

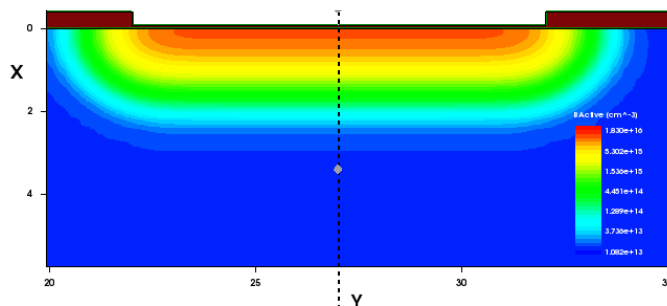## Process simulations in TCAD

▸ Simulation of the effect from the epitaxial growth process.
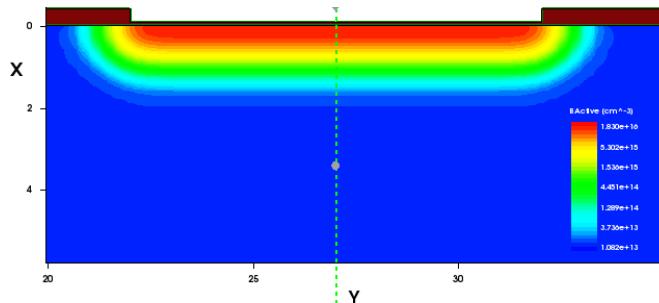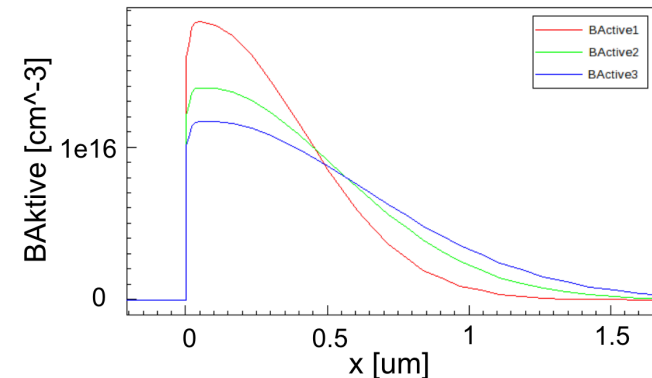

Boron implant, 1st temperature cycle

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.
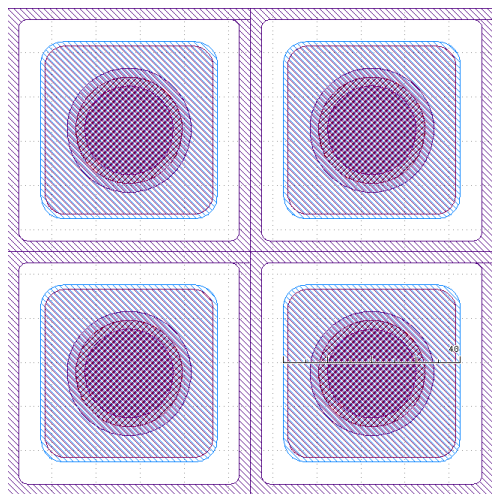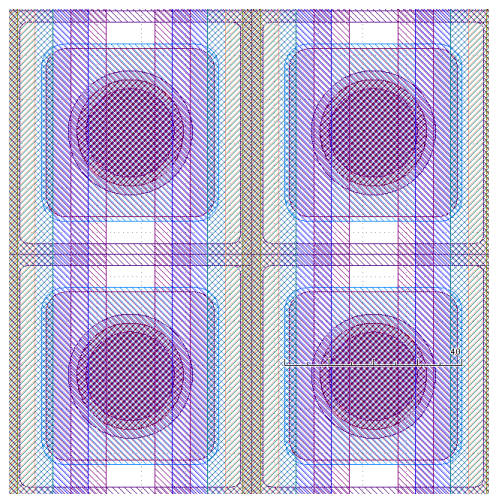
Production

Epi process on implantation

- ▸ Ph implant in n-type silicon
- ▸ n-type epi on the implanted silicon
- ▸ Epitaxial process replaced the annealing process
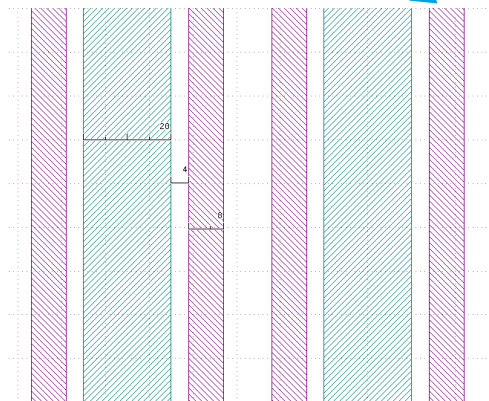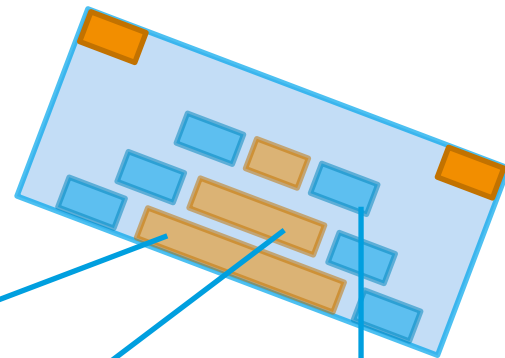- ▸ Possible to reach the necessary deep implant concentration
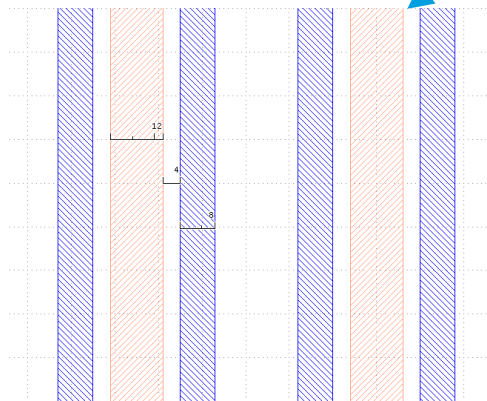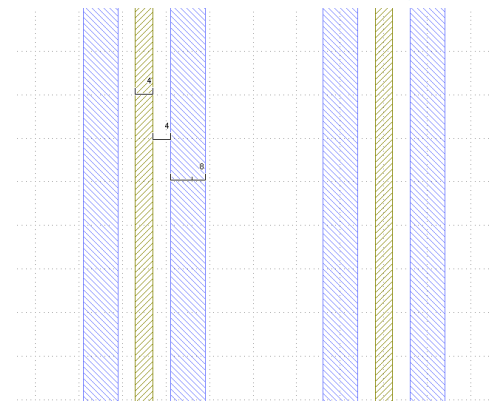
GDS
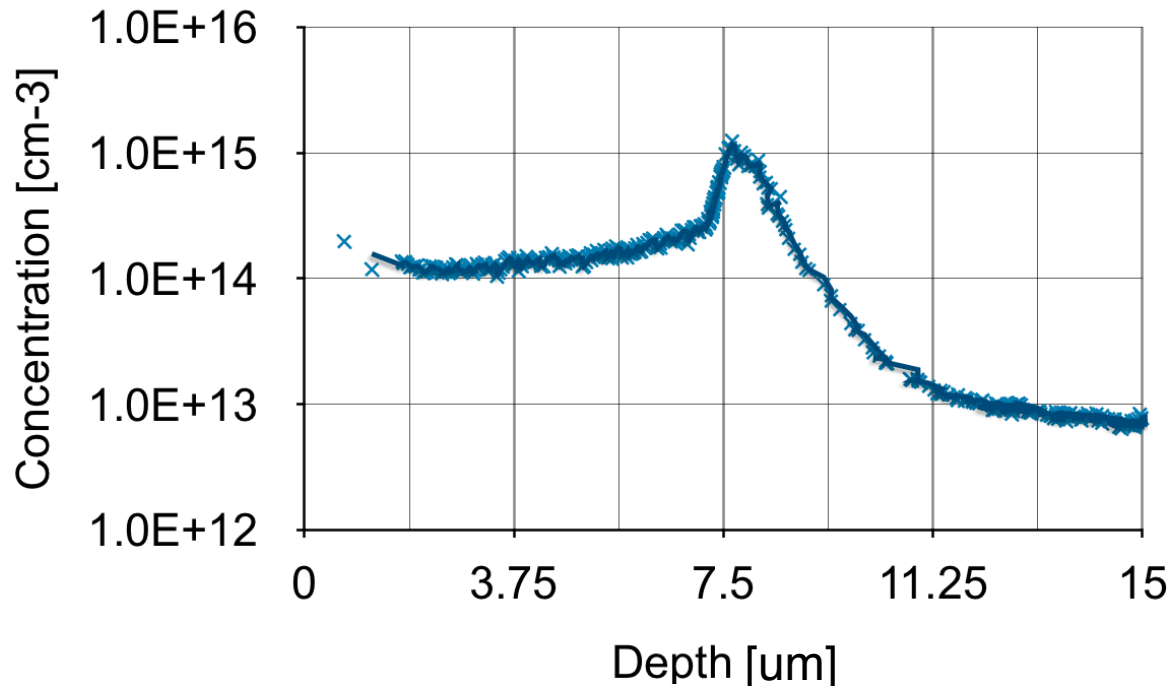
Pixel readout

Pixel readout

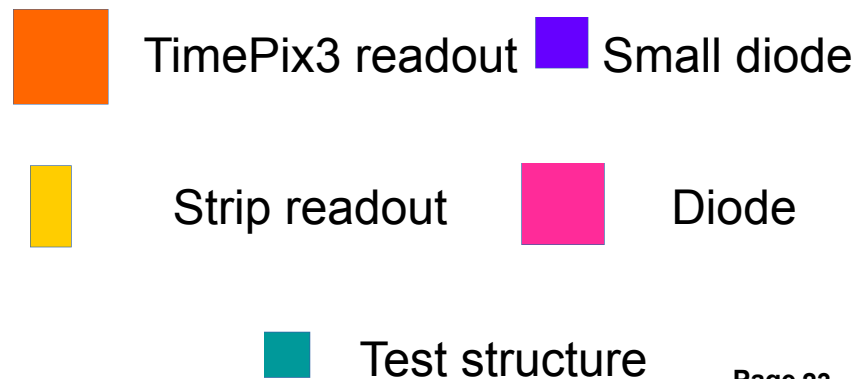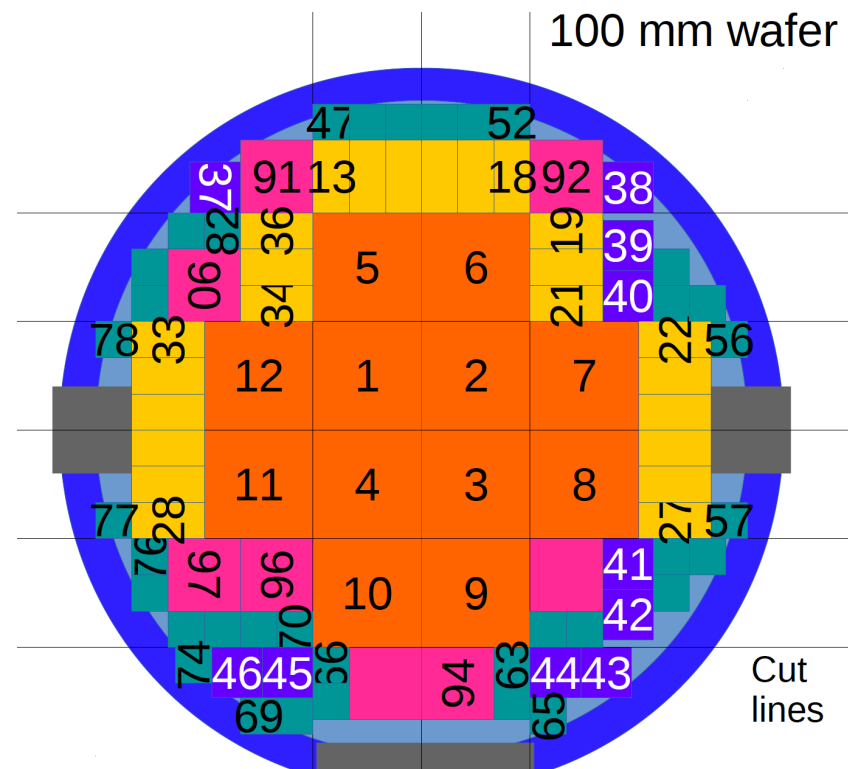ELAD design

1st deep implants layer

2nd deep implants layer

3rd deep implants layer

Production

Wafer layout

▸ Three types of sensors:

  ▸ TimePix3 pixel sensor

  ▸ strip sensor

  ▸ diode

▸ Sensors with different values of deep implant concentrations are foreseen.

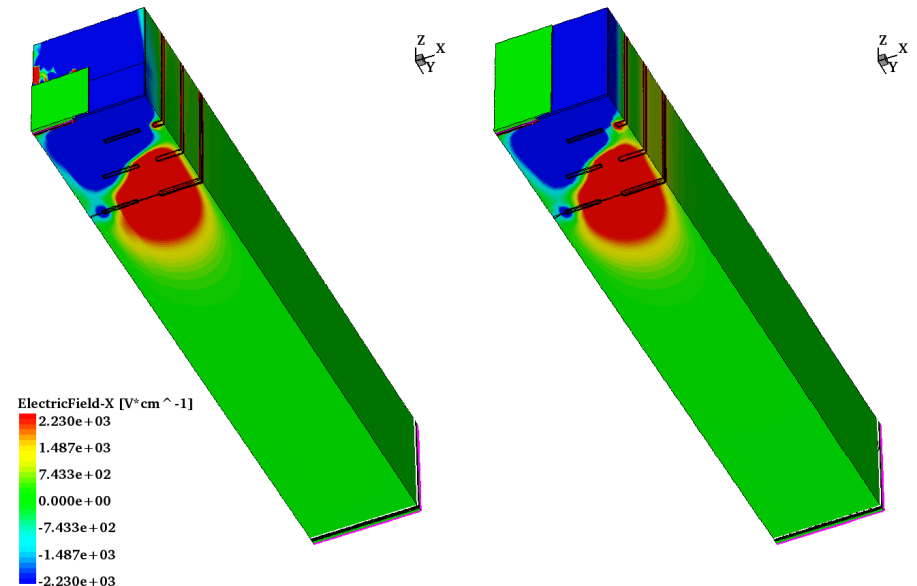▸ Wafers including the epitaxial layers but excluding the deep implants will be produced.
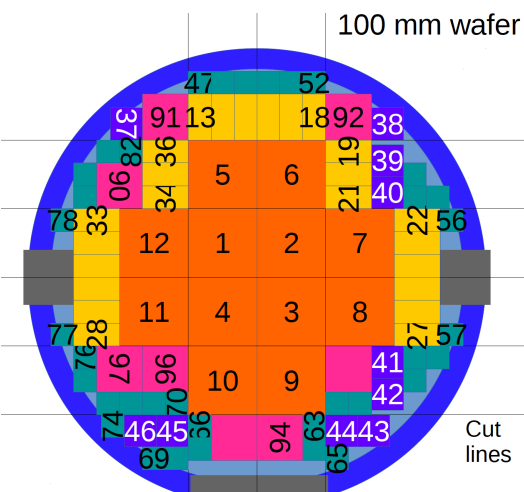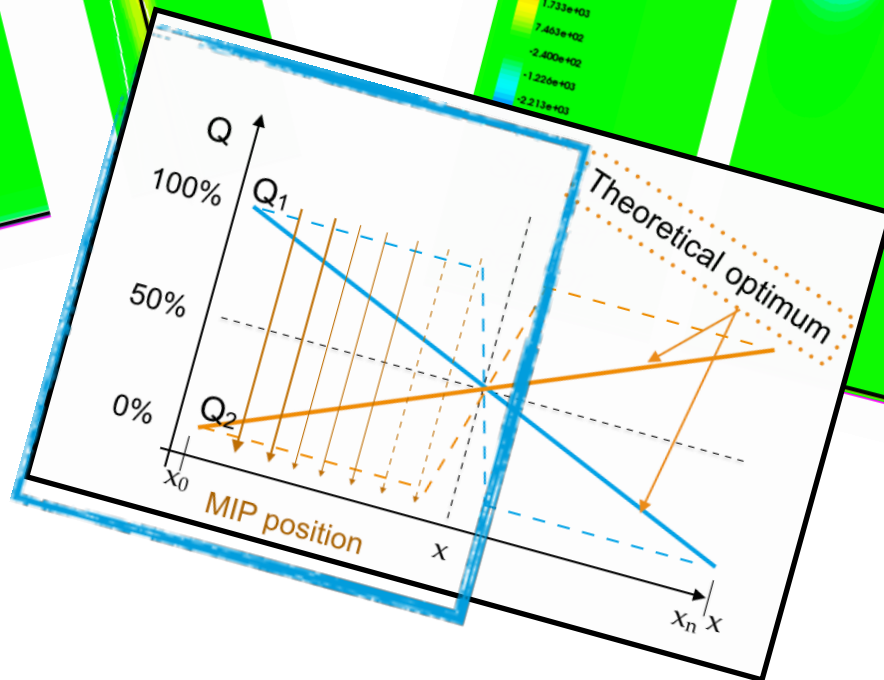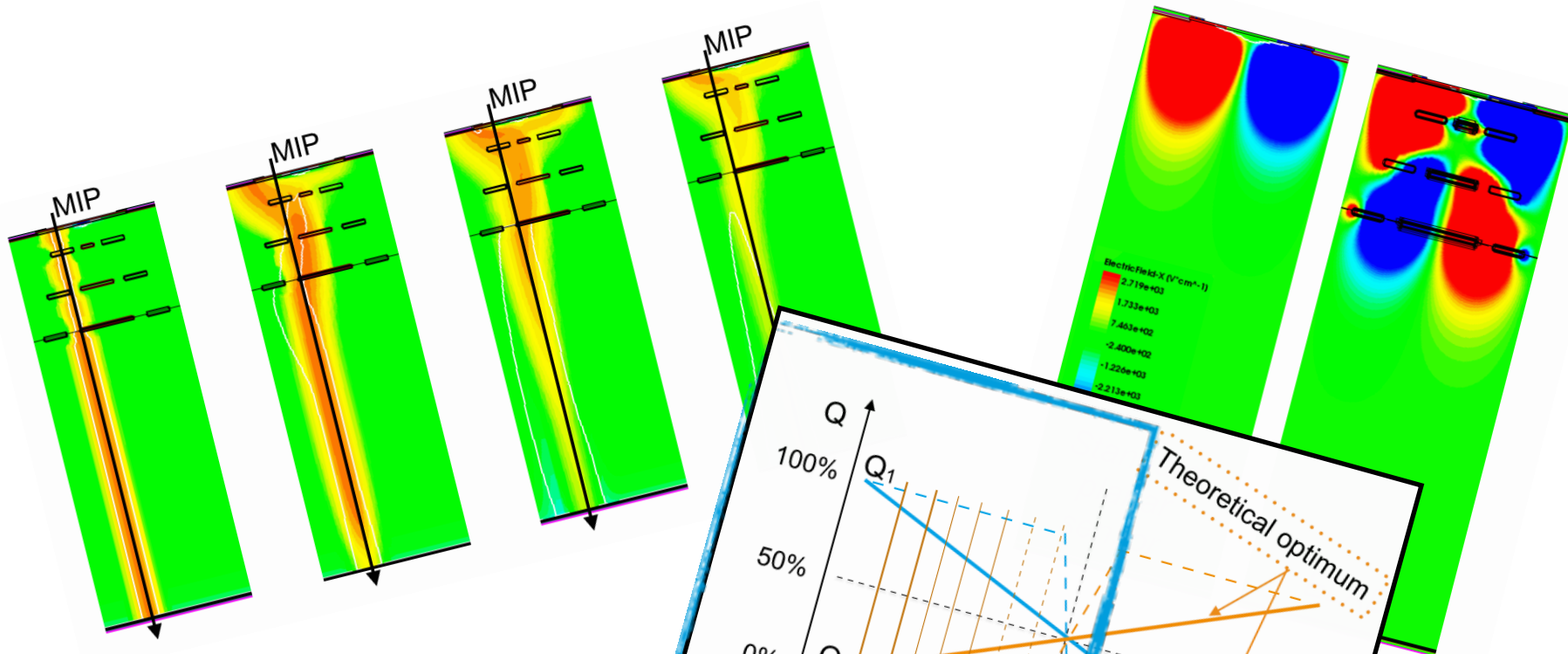
Summary & Outlook

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

▸ Implementation of the 3D TCAD simulation
   to the AllPix2

▸ AllPix2 simulation

▸ 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

ElectricField-X [V*cm^-1]

2.230e+03
1.487e+03
7.433e+02
0.000e+00
-7.433e+02
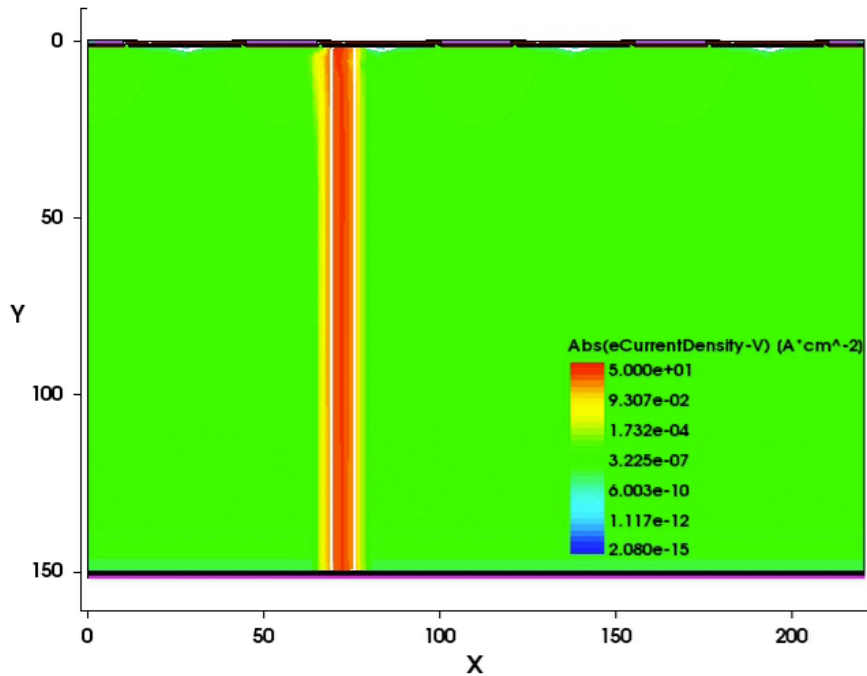-1.487e+03
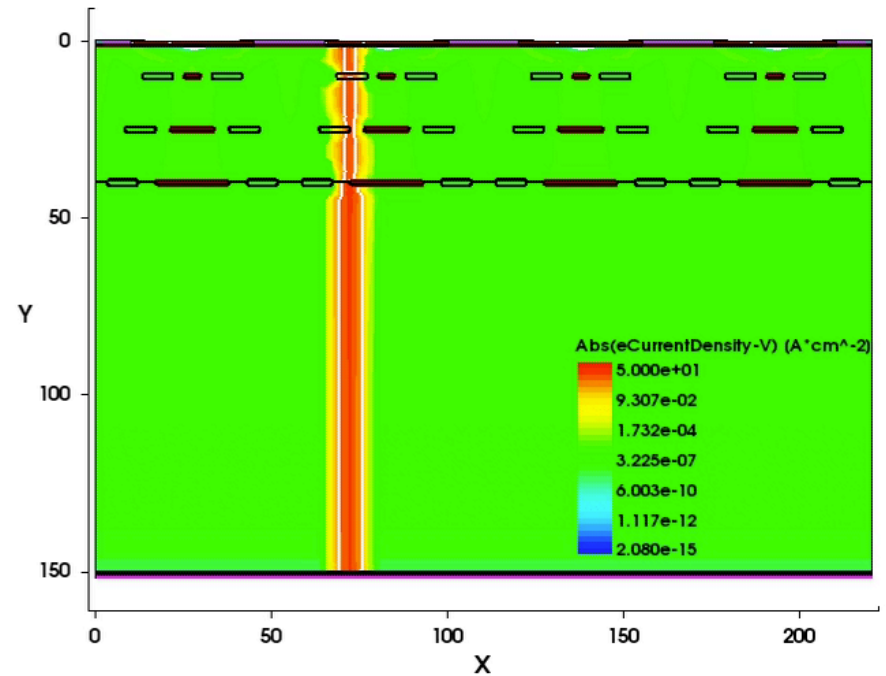-2.230e+03

Thank you for attention!

Backup!

TCAD simulations

Drift with MIP: Standard planar sensor vs p-ELAD

Standard planar sensor

p-ELAD sensor