Enhanced lateral drift sensors: concept and development.

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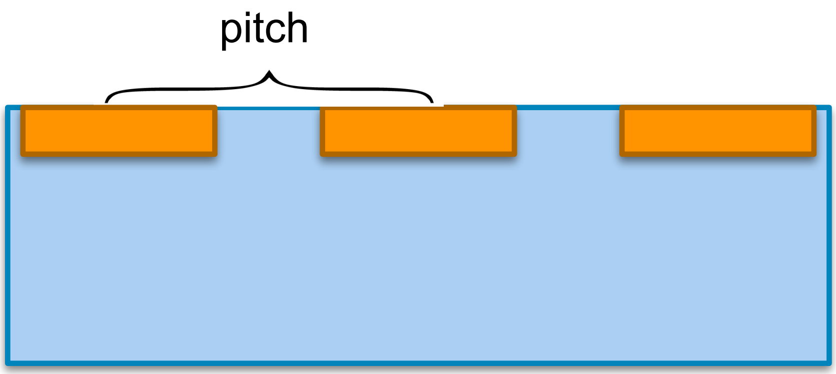
PIER

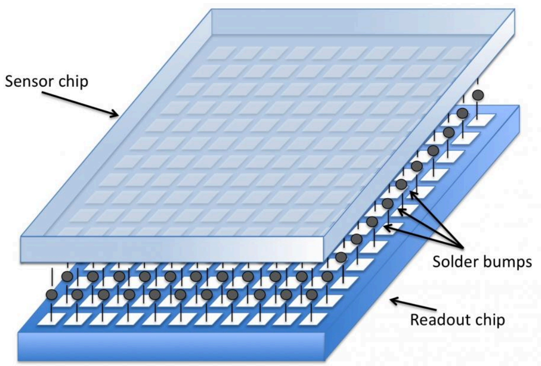
DESY

How to achieve a high resolution?

- **Decrease the size of the read-out cell, i.e. pixel or strip pitch**
  - The number of channels increases
  - Less space on-chip per channel
  - Higher power dissipation

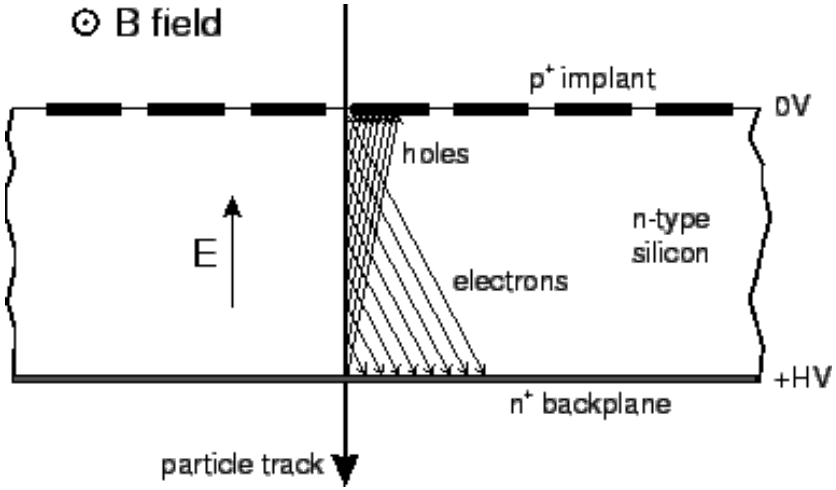


- **Miniaturisation has limits**
  - Size of bump bonds, wire bond pads
  - Minimum of logic/processing on-chip

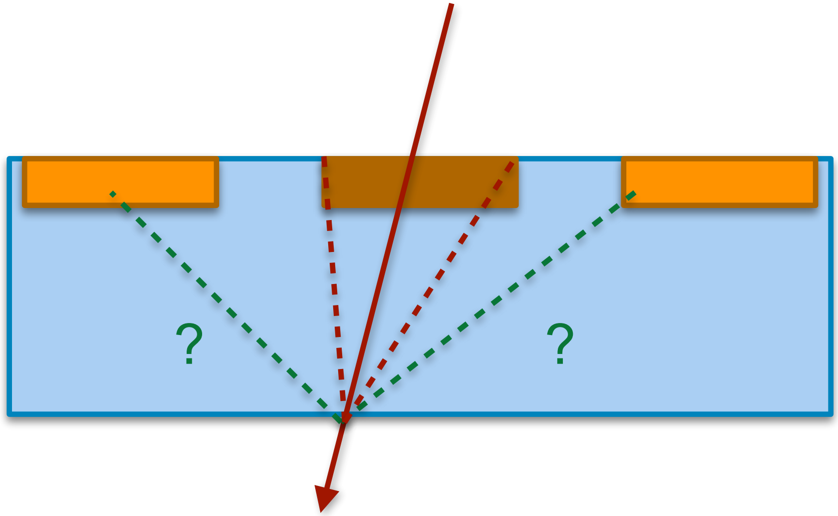


How to achieve a high resolution?

- B-field and/or tilting of sensor
  - increases effective area collecting charge
  - increases material budget
  - doesn't work for thin sensors

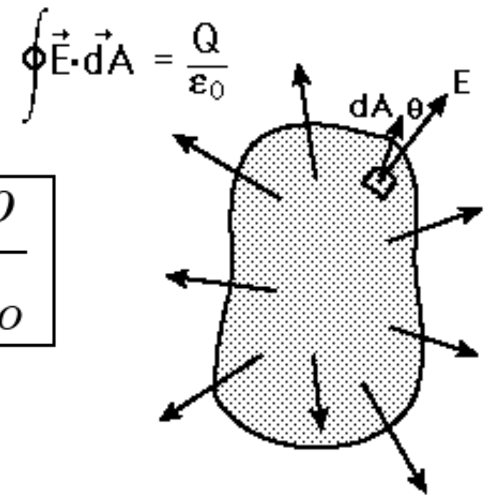


- Increase the lateral size of the charge distribution

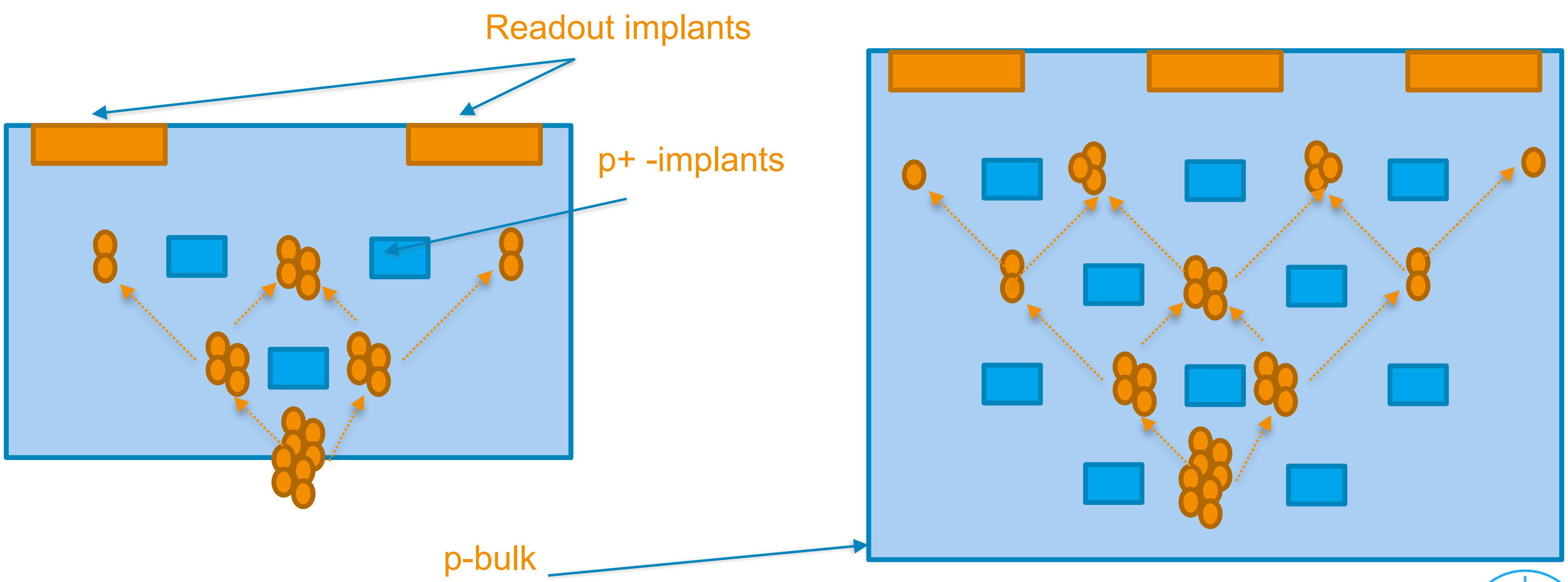


Manipulating the electric field

- Repulsive areas split the charge cloud 50-50
  - Apply this layer-wise
- Achieve lateral enlargement of charge cloud independently of the incident position



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



Manipulating the electric field

Binomial design

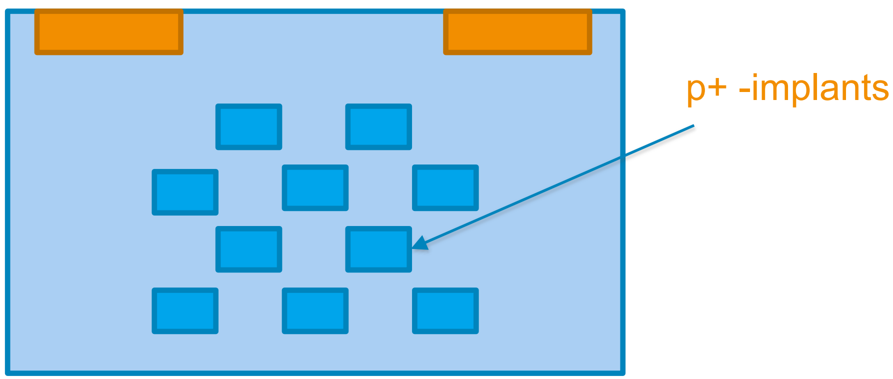
- not enough charge sharing
- high value of N_{eff}
- high number of layers
- cluster size 3

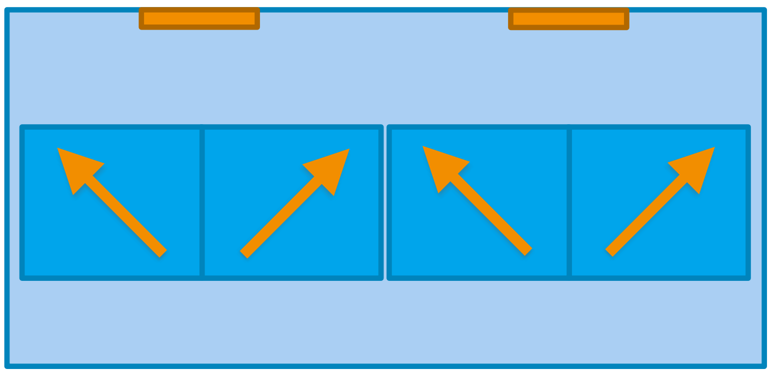
$$N_{eff} = N_D - N_A$$

ELAD design

+ enough charge sharing
+ cluster size 2

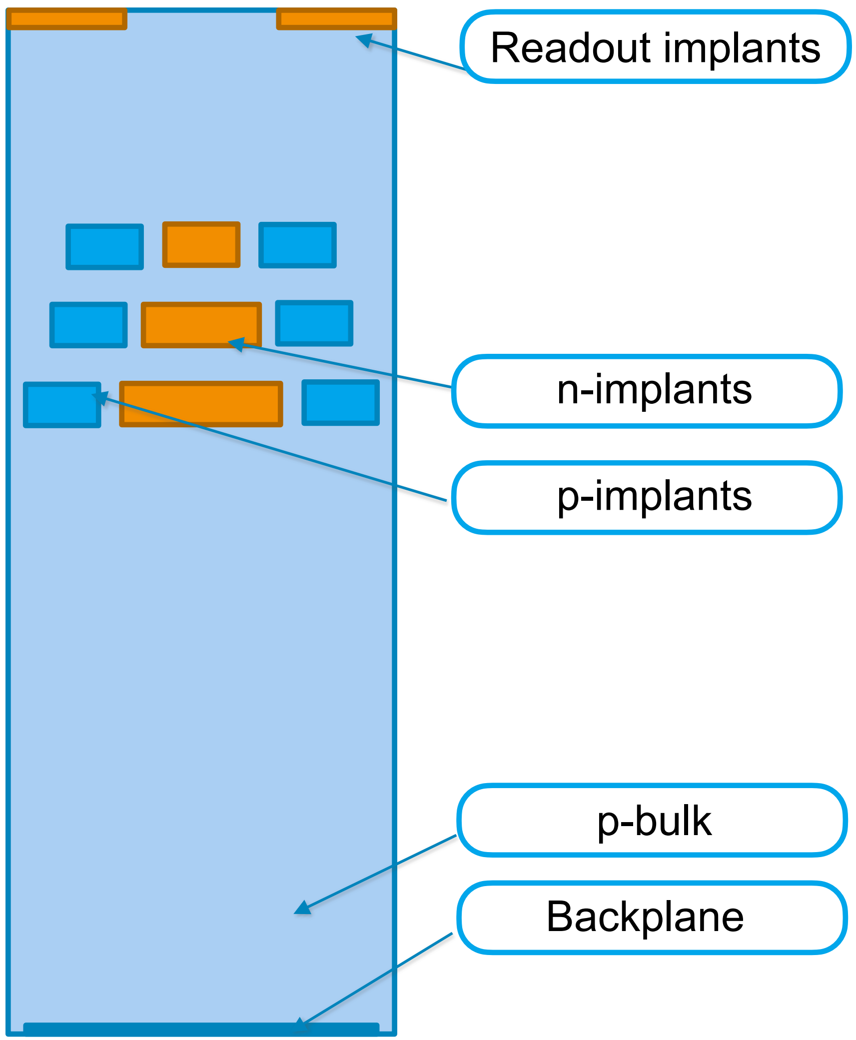
$$V_{depl} = \frac{q_0 D^2 |N_{eff}|}{2\varepsilon_0 \varepsilon_r}$$





Concept of Enhanced Lateral Drift Sensors (ELAD)

- Sharing left AND right is non-optimal
  - threshold would kill the effect
  - aim at cluster size 2
  - controlled value of N_{eff}



TCAD Simulations

- As a tool for simulations, TCAD SYNOPSYS was selected.

- Parameters for simulations:
  - Width, depth of implants
  - Distance within/to next layer
  - Position/shift to neighbouring layer
  - Number of layers
  - Optimal doping concentrations for deep implants

- Electric field profile for best charge sharing

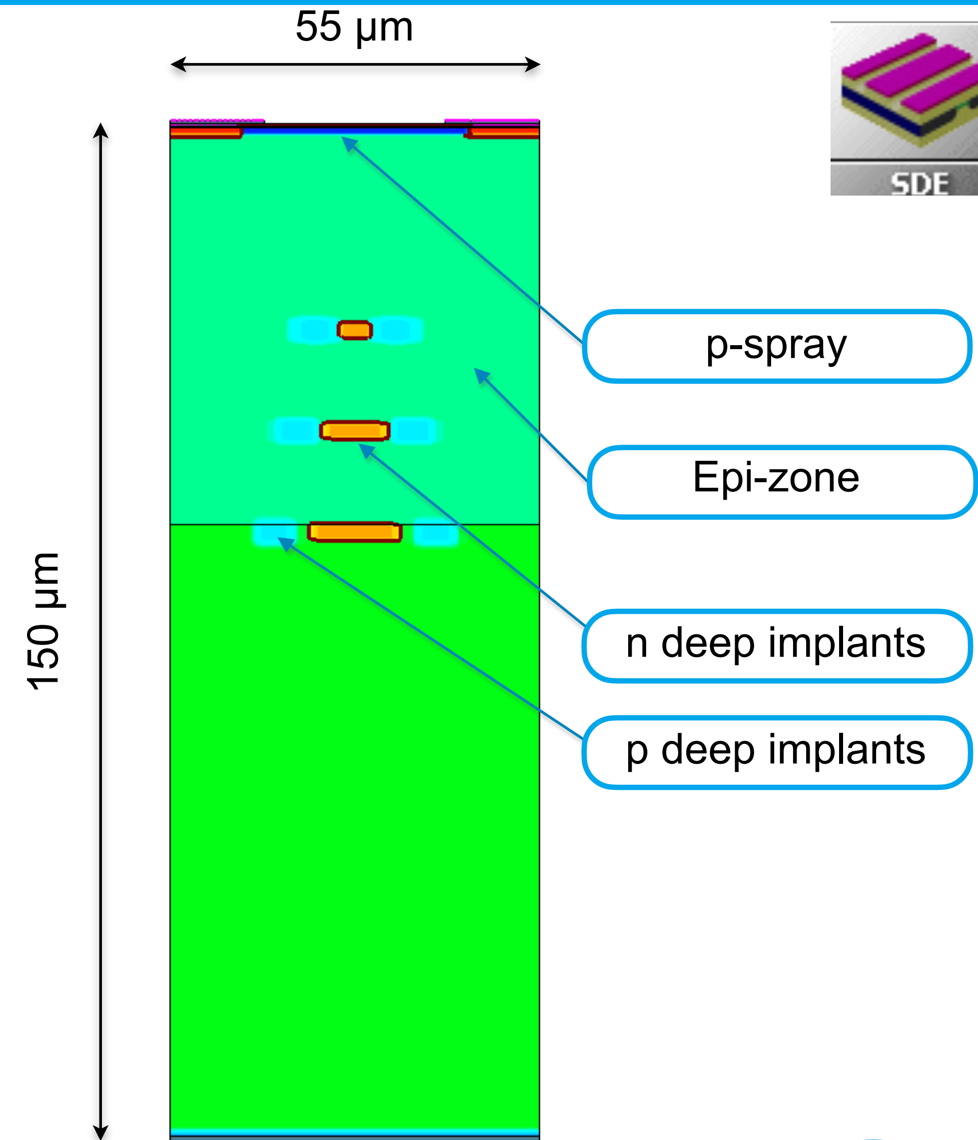
TCAD Geometry

> P-spray isolation is implemented to the sensor geometry

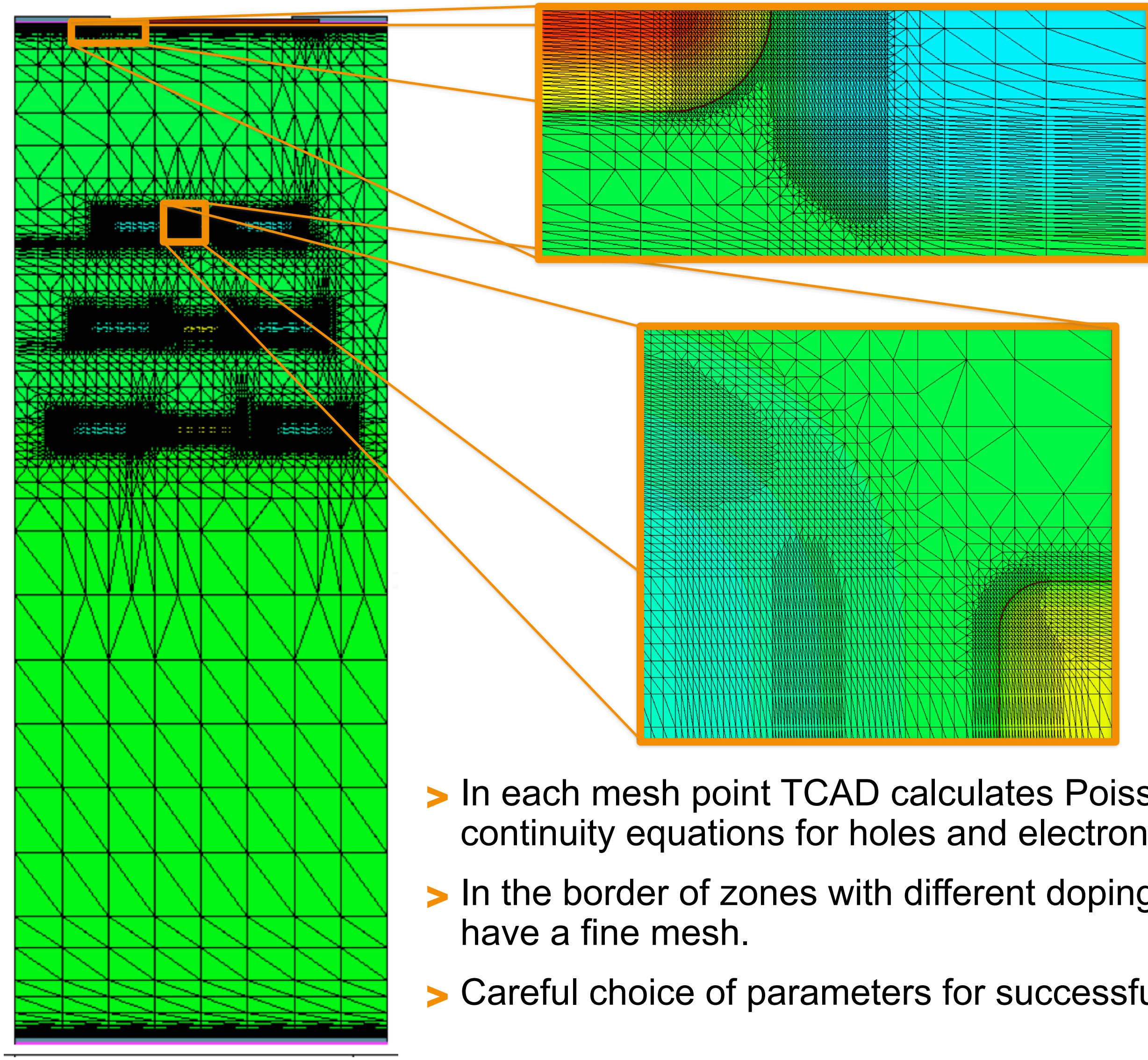
> First and second layer are located in the epitaxial part of the sensor

> 1/2 strip symmetry is chosen according to the boundary condition

> TimePix3 geometry
  > pitch 55×55 μm
  > pixel implant size 20 μm



TCAD Meshing

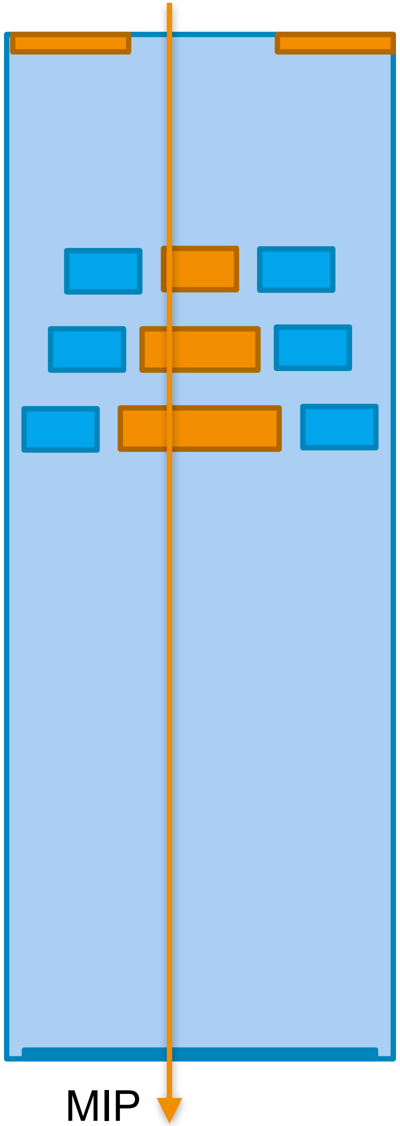


- **Mesh parameters:**
  - x_{min} = 0.01 µm
  - x_{max} = 10 µm
  - y_{min} = 0.01 µm
  - y_{max} = 10 µm
  - Doping dependent

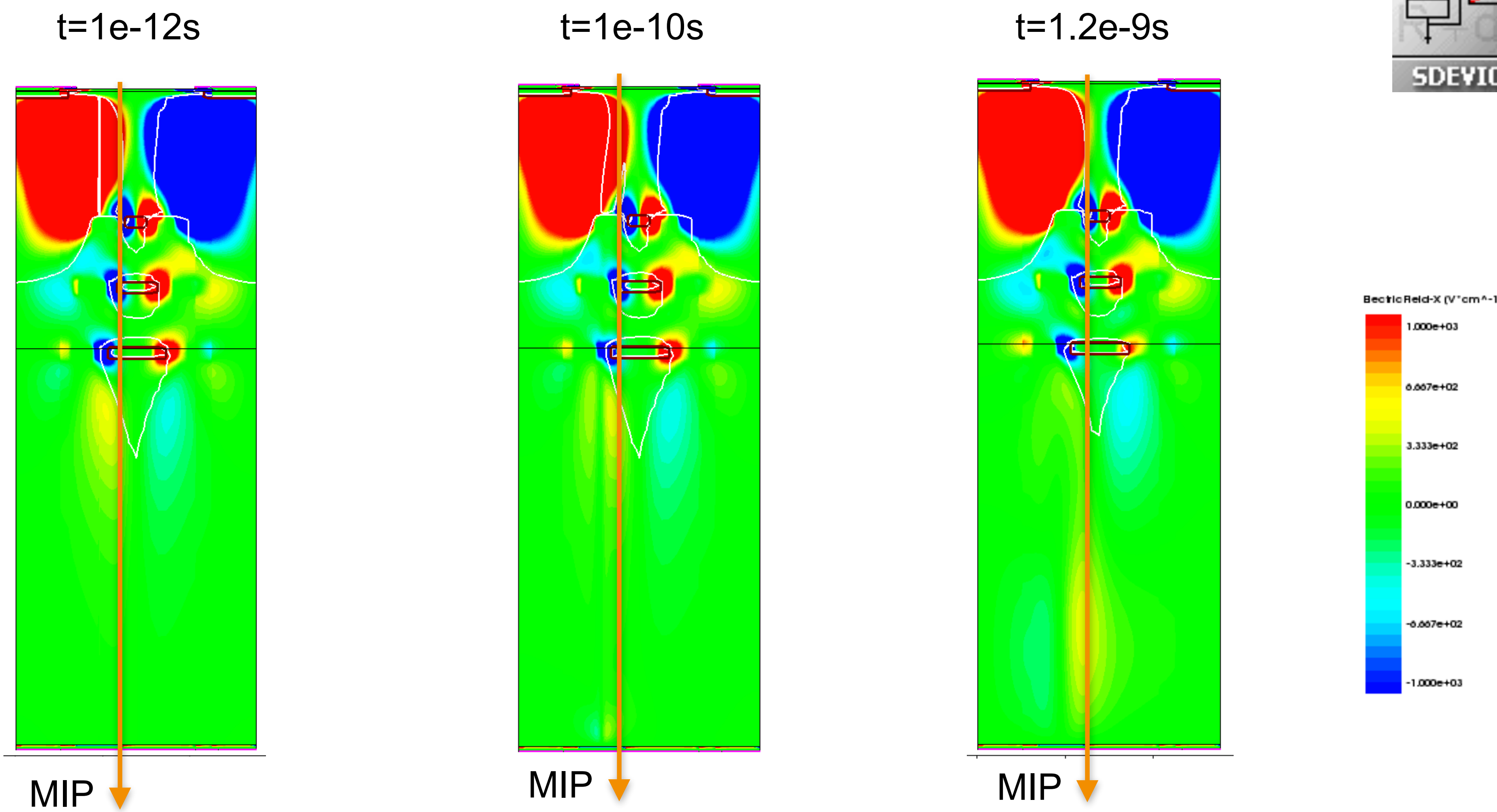
- In each mesh point TCAD calculates Poisson's equation and the carrier continuity equations for holes and electrons.
- In the border of zones with different doping concentrations it is necessary to have a fine mesh.
- Careful choice of parameters for successful simulation.

Device simulation

- Quasi stationary:
  - Solve electric field
  - Ramp voltage to the set value
- Transient:
  - Poisson's equation
  - Carrier continuity equations
  - Traversing particles or arbitrary charge distribution



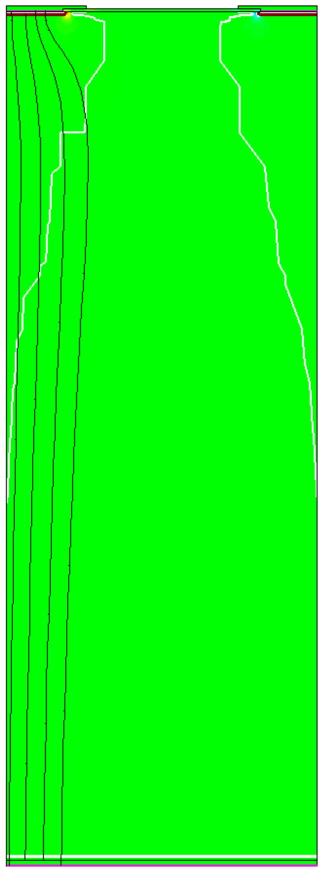
Simulations of the electric field



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

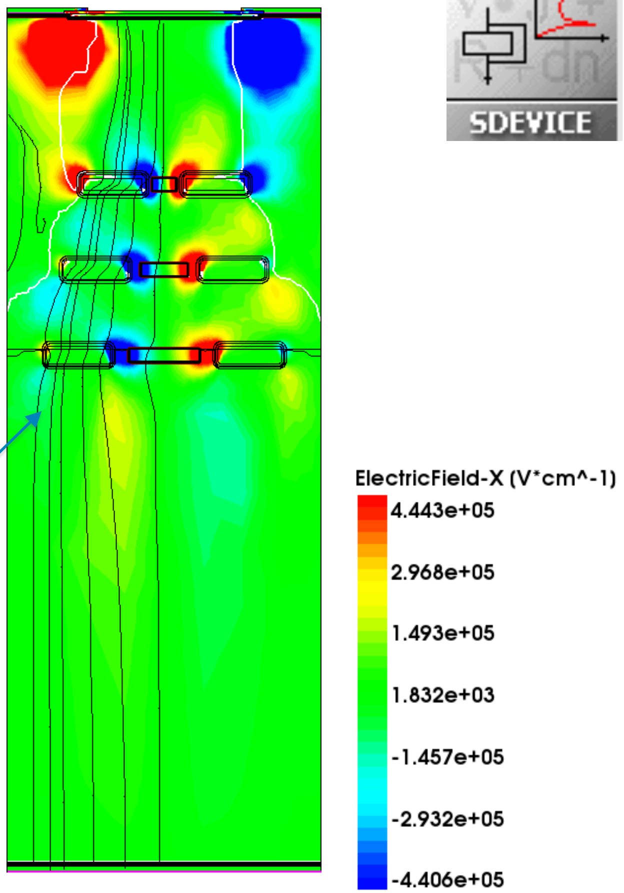
Drift with probe charge

Current streamlines



Without implants

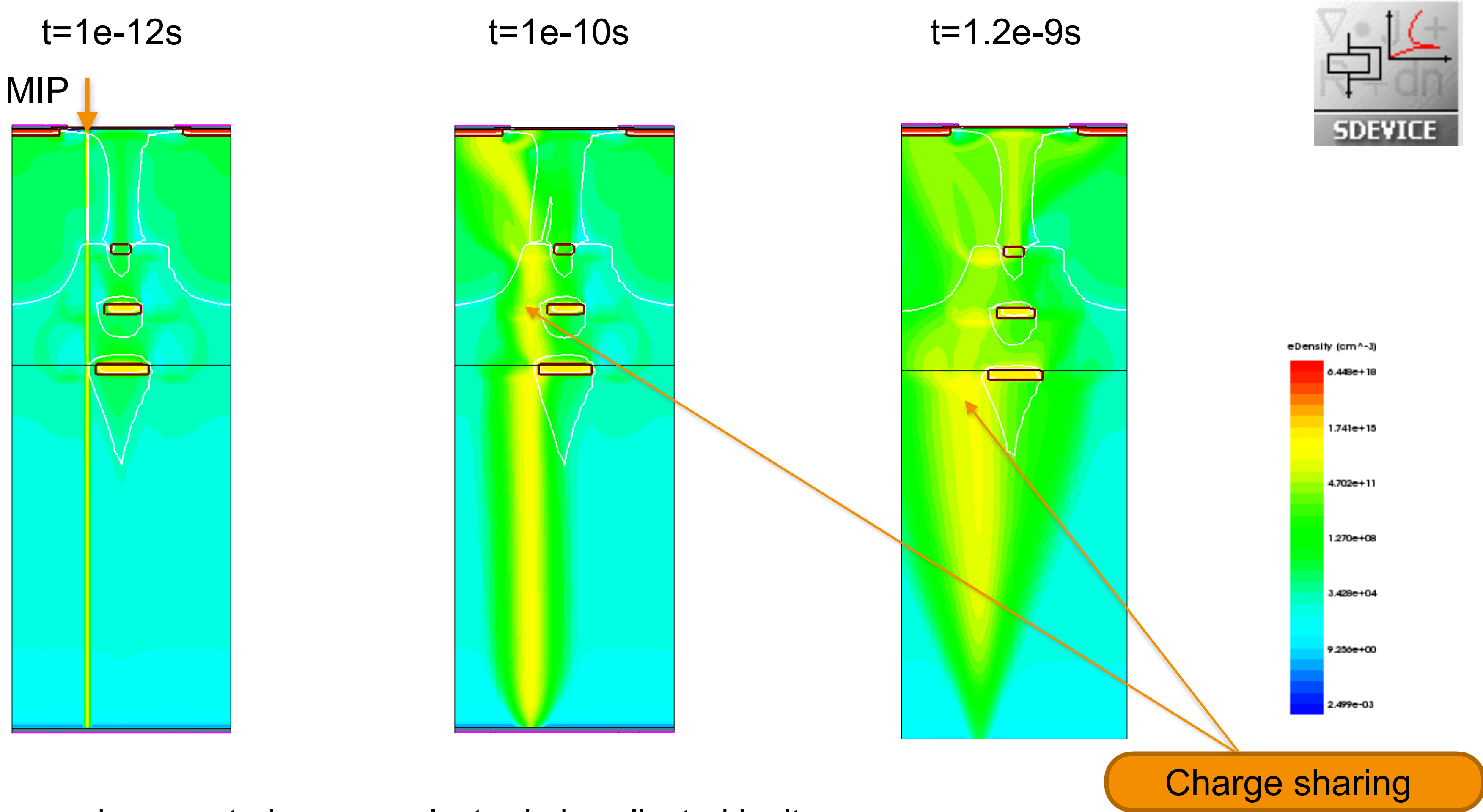
Alteration of drift path



With implants

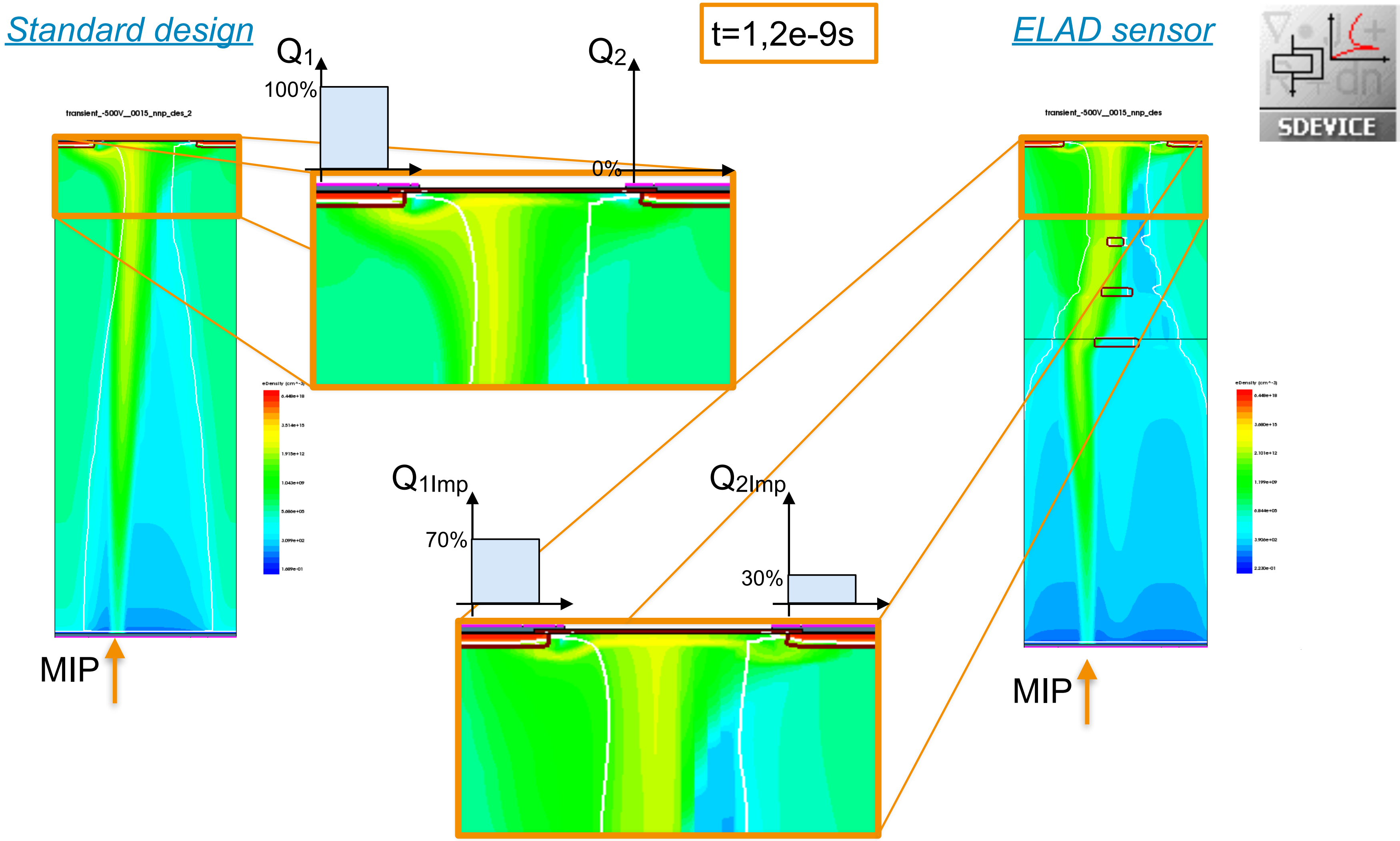
- The drift path is changed by the implants.

Drift with MIP



- Charge carriers created near an electrode is collected by it
- The real part of the charge created beneath the deep implants area changes the drift path
  - It is collected by two electrodes

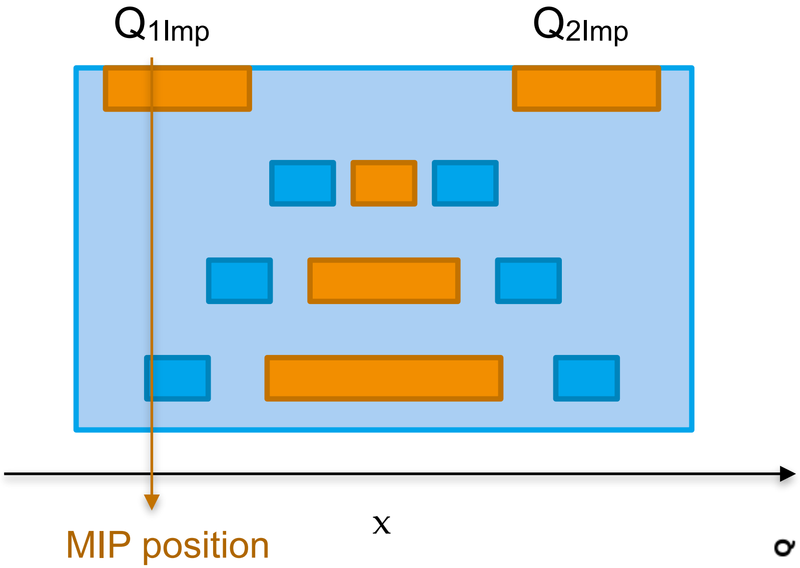
Drift with MIP

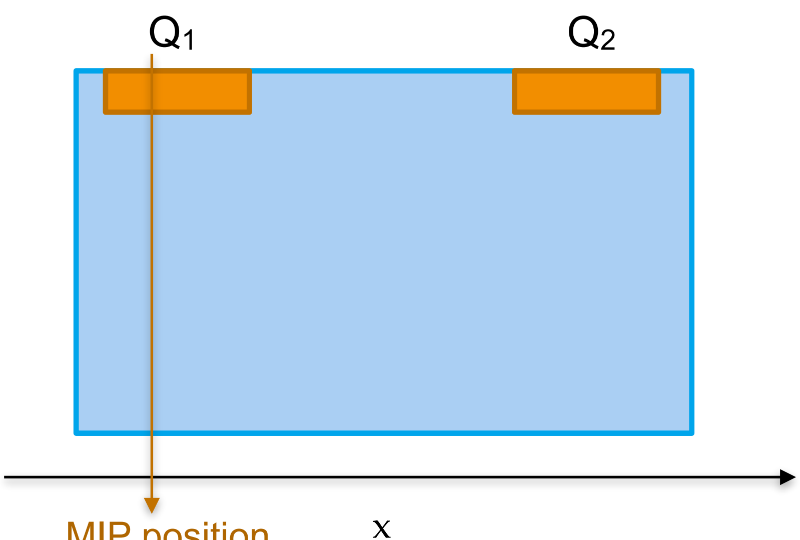


> In comparison to the usual design, with the same MIP position and applied voltage, in the ELAD sensor the charge is shared between two strips

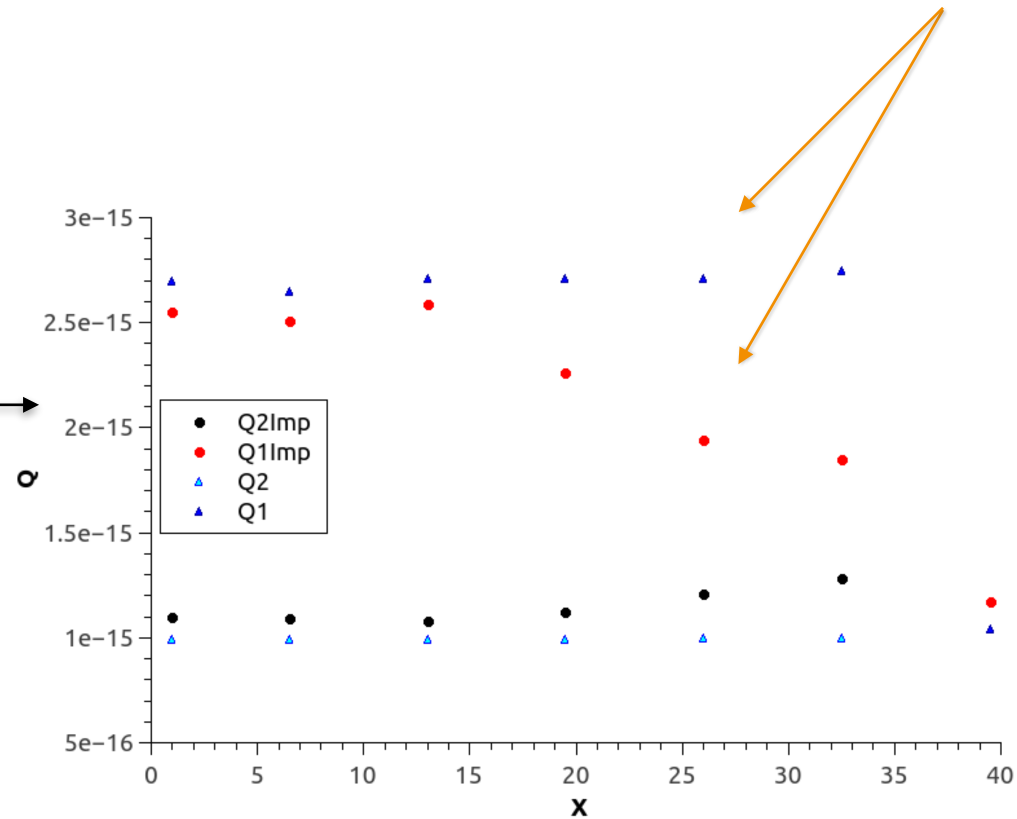
TCAD simulations

- Number of collected charge for each strip

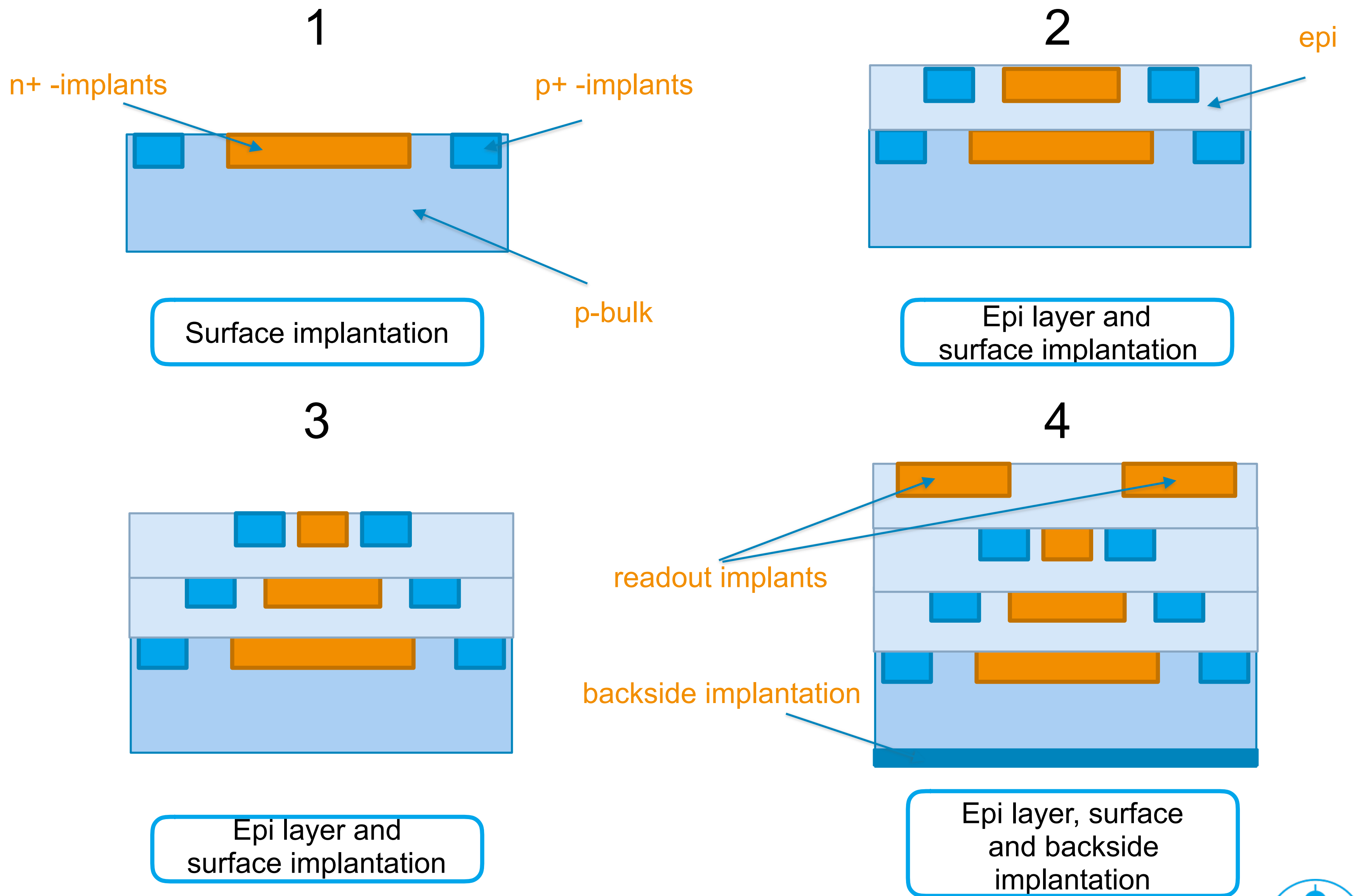




Charge sharing

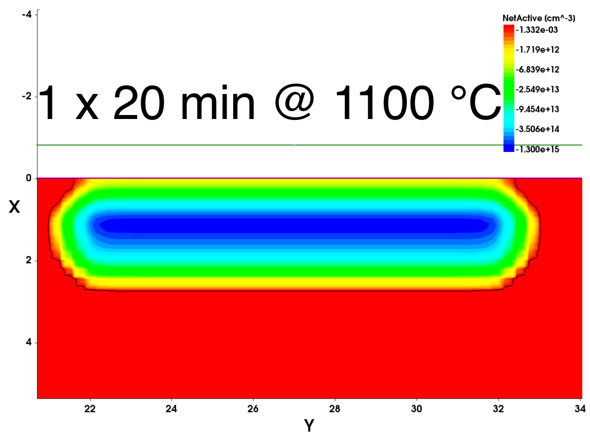


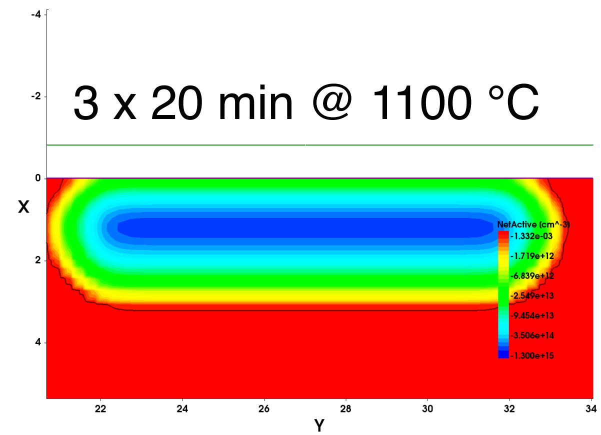
Production


1
n+ -implants
p+ -implants
p-bulk
Surface implantation
2
epi
Epi layer and surface implantation
3
Epi layer and surface implantation
4
readout implants
backside implantation
Epi layer, surface and backside implantation

Process simulation

- In the epitaxial silicon growth process, a thin layer is grown on a single-crystal substrate.
  - One of the grows method is CVD process.
- The temperature in the CVD process is 1100°C.





- Process simulation for deep implants at a temperature of 1100°C.
  - The difference in size less than 1 μm

Pros and Cons

Pros

- Higher resolution for same pitch size w/o B-field (sufficient Lorentz drift) nor tilted sensors (higher material budget)
- Maintain a fast signal (no coupling of readout entities)

Cons

- No one tried this type of production before
- Costly due to multilayer processes, but save on cooling and readout bandwidth/computing power

Conclusions and outlook

Conclusions:

- Trying to achieve high position resolution without using smaller pitches.
- Simulations show that the charge sharing in the ELAD sensor is possible.
- Contacts with companies concerning the production.

Outlook

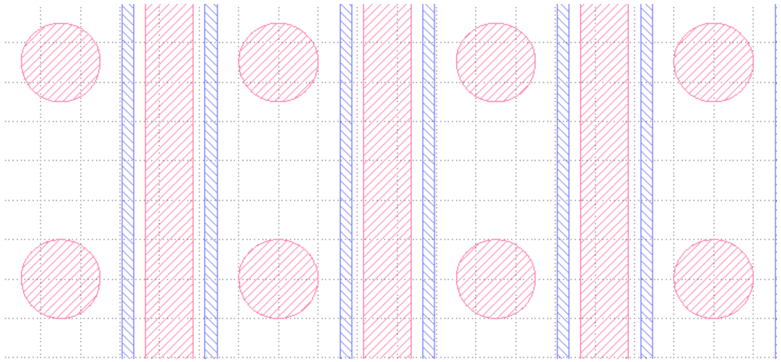
- Perform simulations using different voltages and different MIP positions in TCAD
- Production

Backup

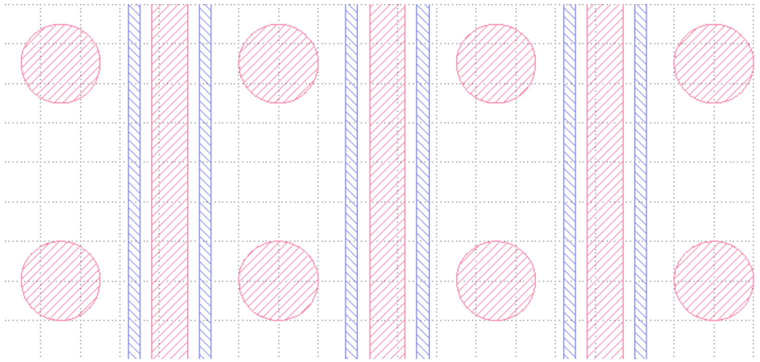
GDS

> pitch 55×55 μm
> pixel implant size 20 μm

1st layer of implants



2nd layer of implants



3d layer of implants