5th Allpix Squared User workshop
-
Simulation of the H2M MAPS

Corentin Lemoine, based on measurements of the H2M chip

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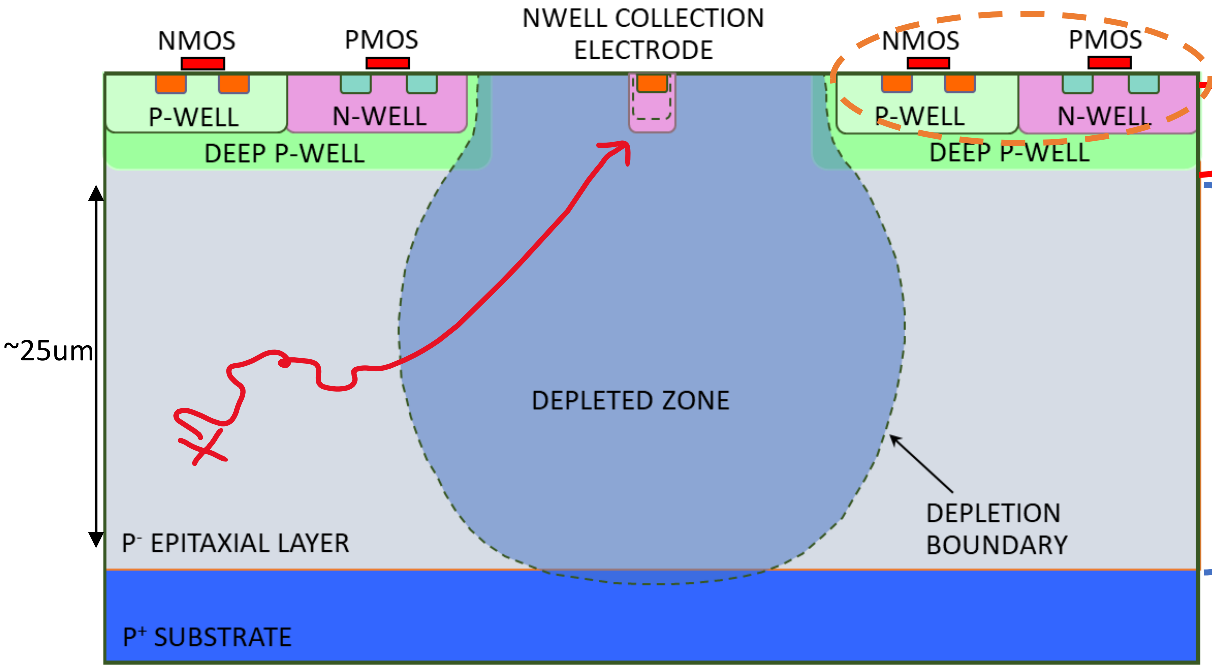
Monolithic pixel sensors in HEP

- ALICE ITS2: 10m^2 installed, ALPIDE sensors in 180nm technology

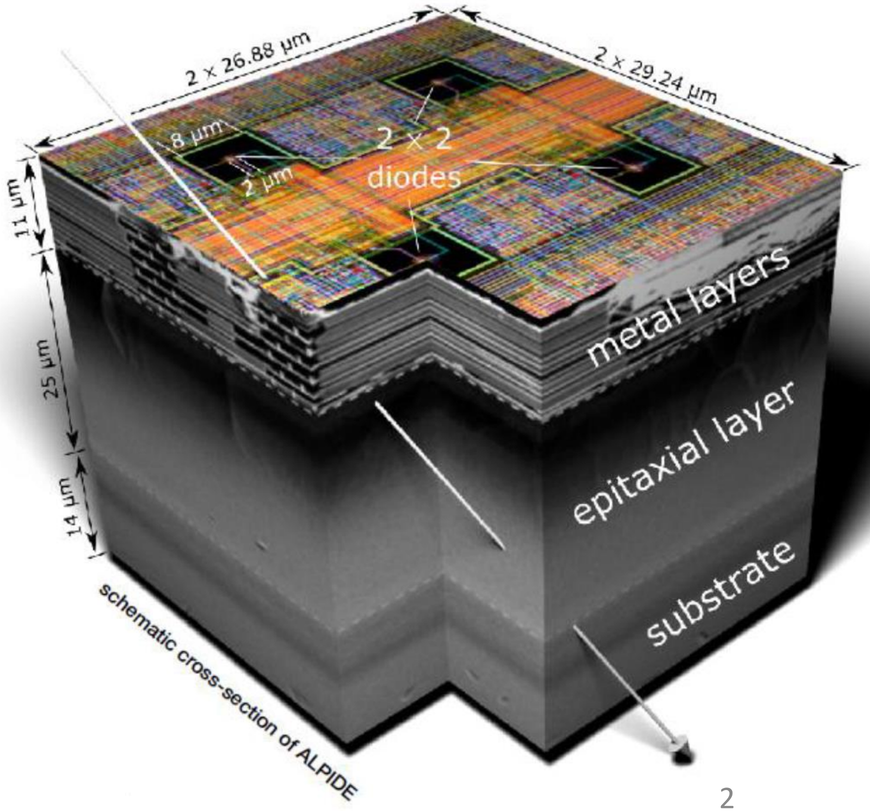
Full CMOS electronic available thanks to deep p-well shielding

Not at scale



Complex and small feature size structure

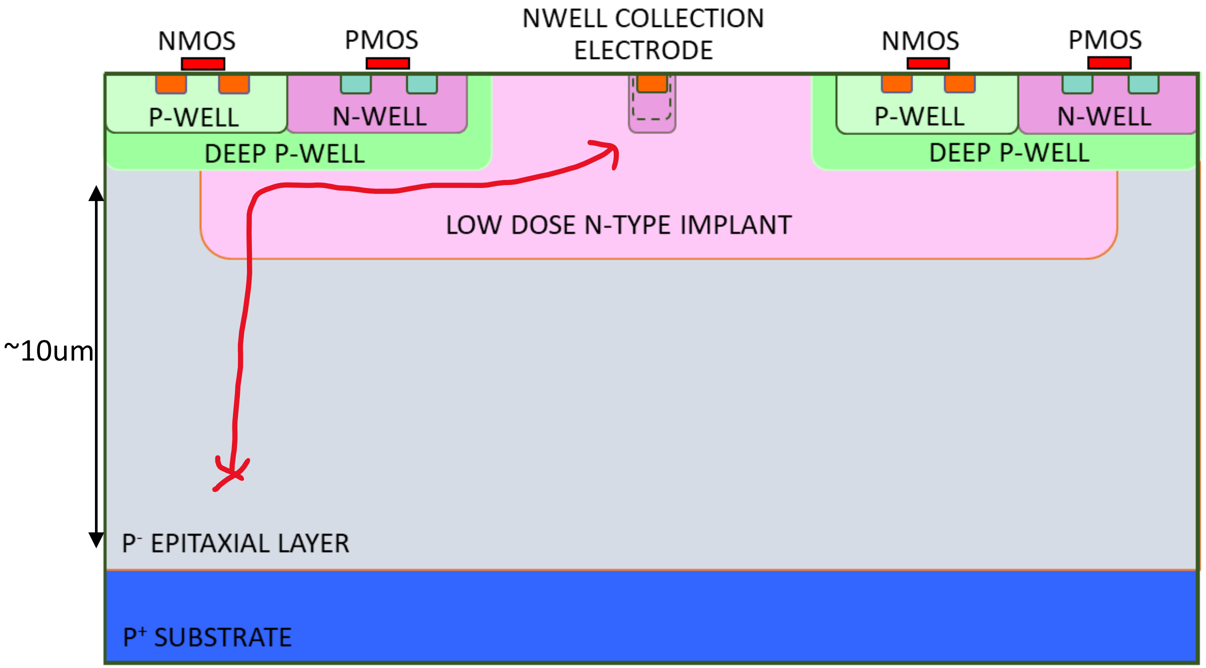
Sensitive volume



Developments in a 65nm technology

Developments for ITS3 and more…

Cross section of the modified with gap process

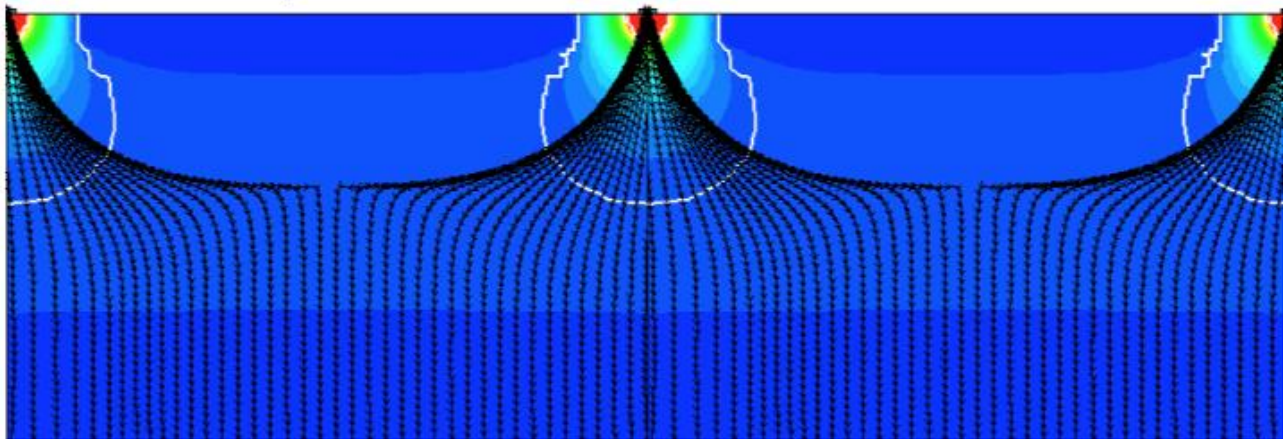


- Process modification by adding a deep n-type implant:
  - Move the junction deeper in the sensor
  - Enable larger depleted volume
  - Charge collection mostly by drift →Reduces charge sharing, leading to more signal in the seed pixel

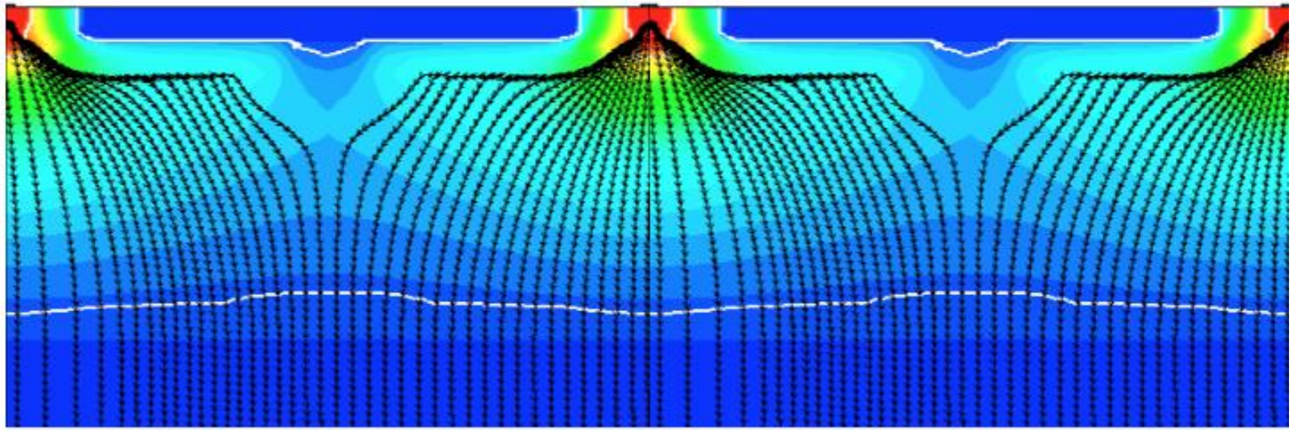
Developments in a 65nm technology

EP R&D

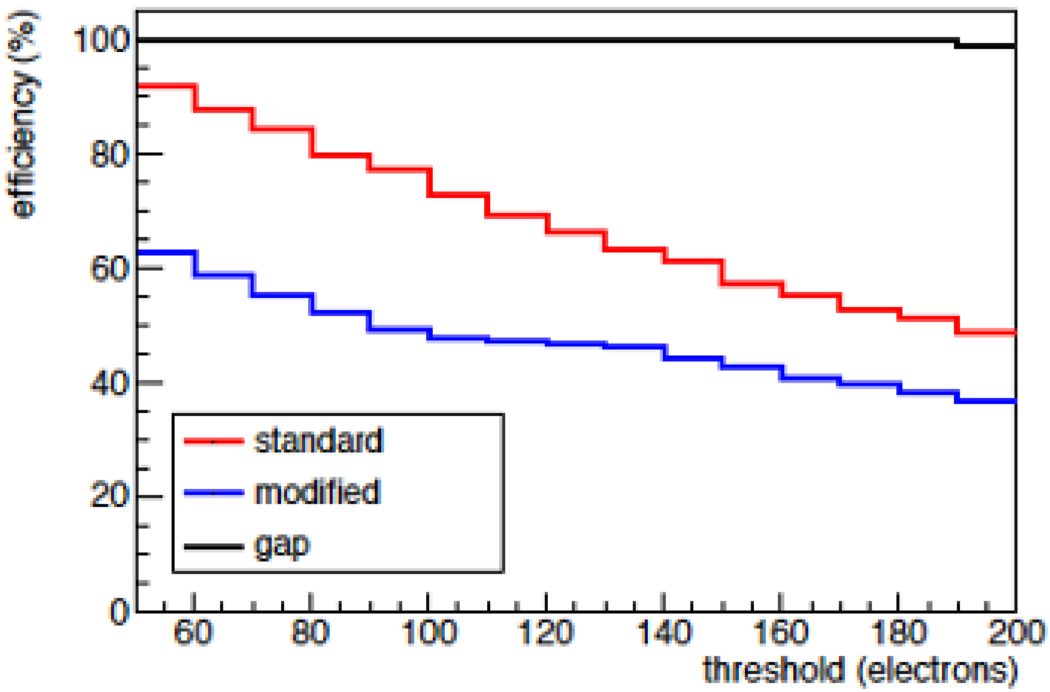
Standard – ALPIDE like sensor



Modified with gap sensor



- Developed with TCAD and Monte Carlo simulations

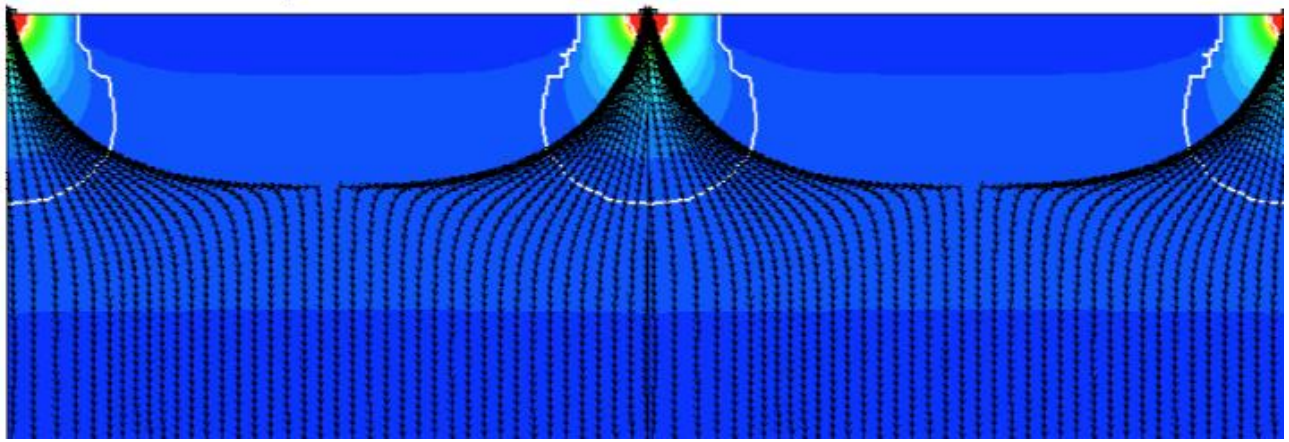


Jan Hasenbichler - https://doi.org/10.22323/1.420.0083

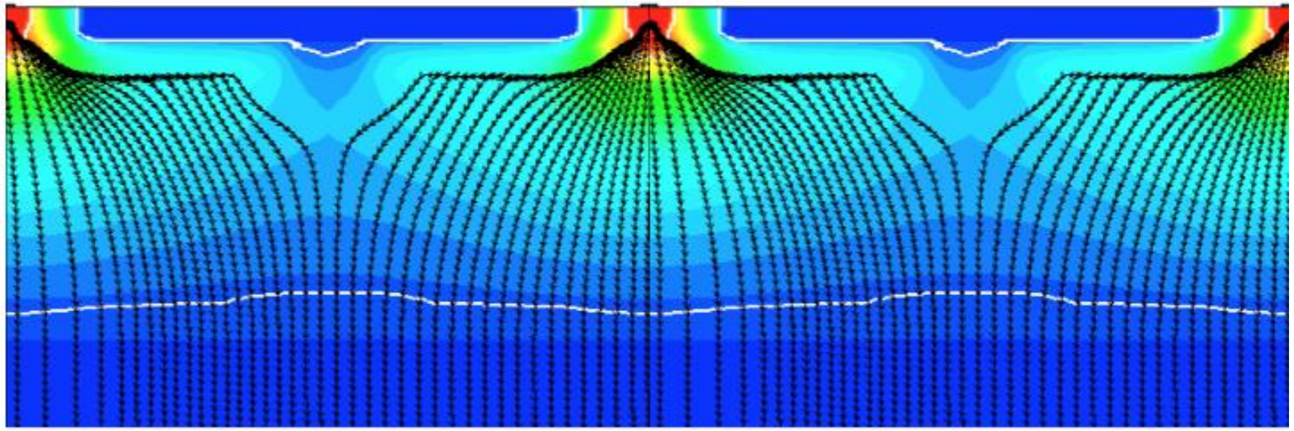
Magdalena Munker, CLIC Workshop, January 2019

Developments in a 65nm technology

Standard – ALPIDE like sensor

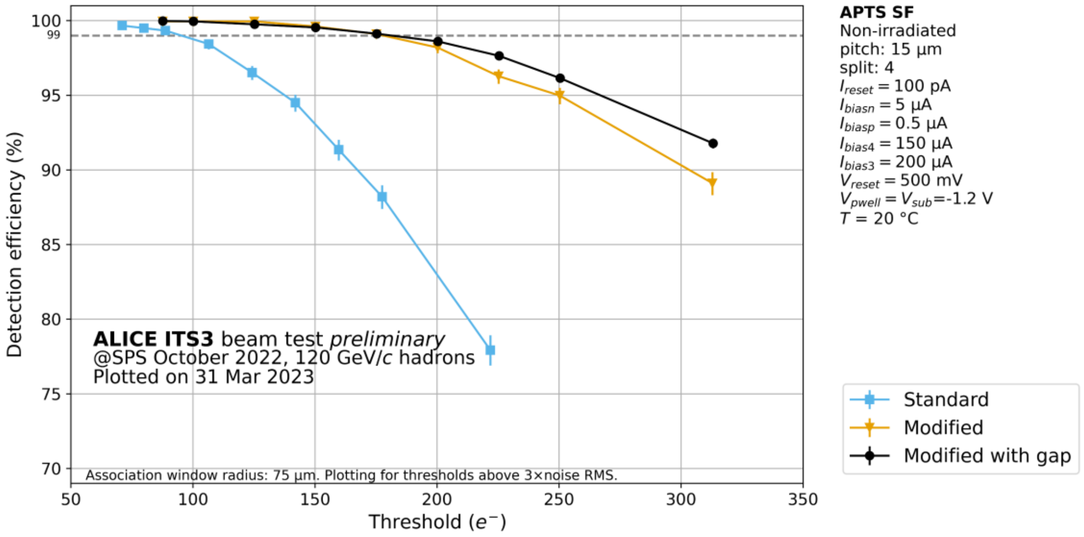


Modified with gap sensor



Magdalena Munker, CLIC Workshop, January 2019

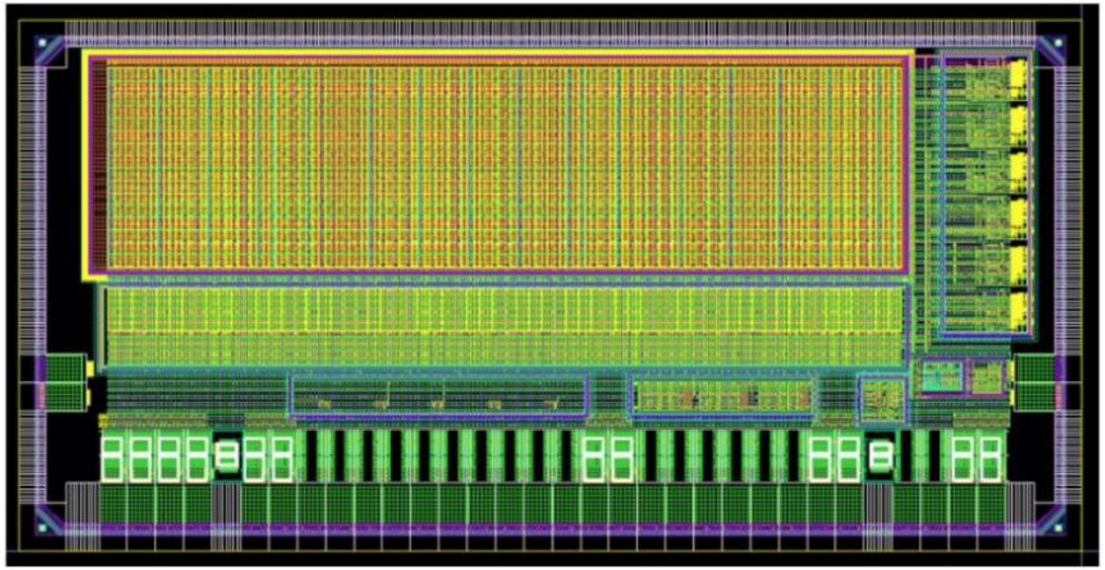
- Developed with TCAD and Monte Carlo simulations
- Confirmed in measurements



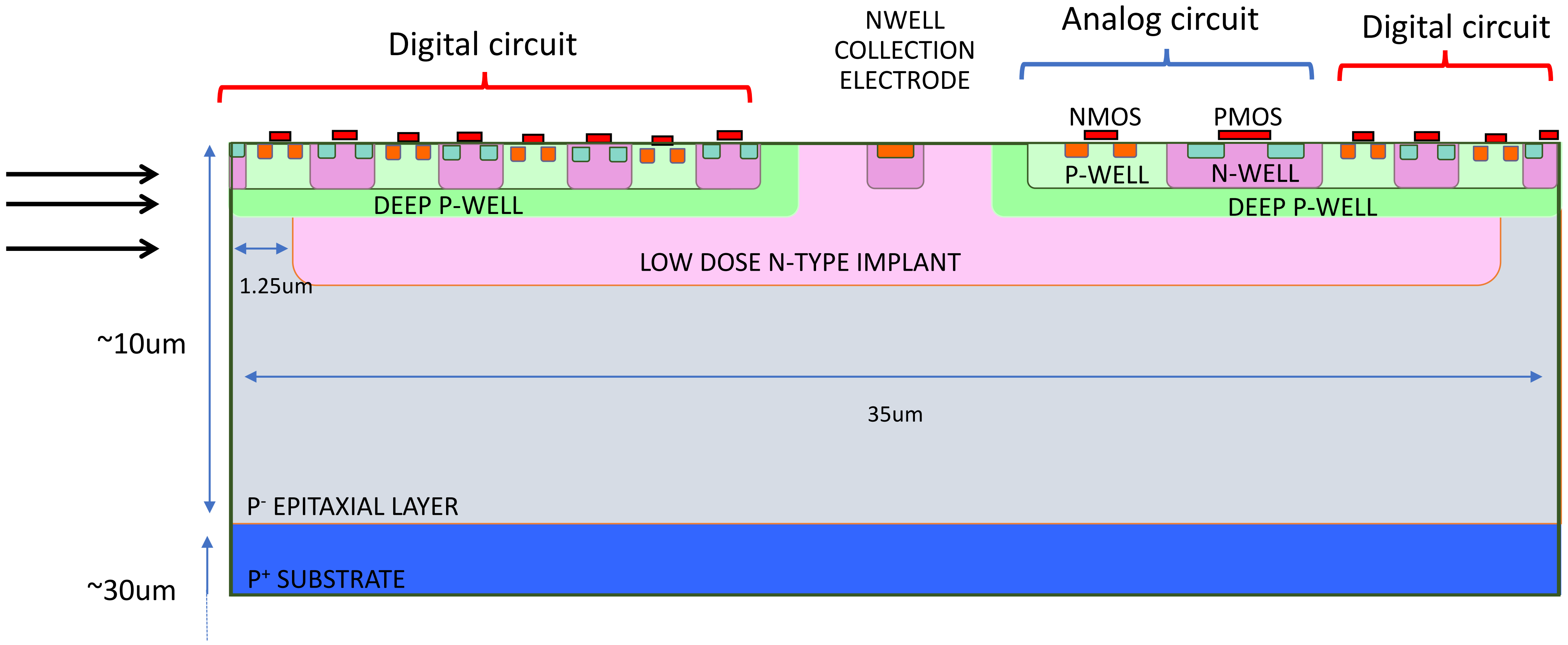
https://cds.cern.ch/record/2890181?ln=en

Hybrid to monolithic: H2M

- Port a hybrid detector architecture to a monolithic chip with digital on top design
- 65nm technology, ‘modified with gap’ type
- Pixel matrix: 64 × 16 pixels
- Pixel pitch: 35 × 35 μm^2
  - -> largest pixel tested in this technology
- TOA, TOT, photon counting…
- Front end shaping time O(ns)
  - Targeting time resolution ~5-10ns

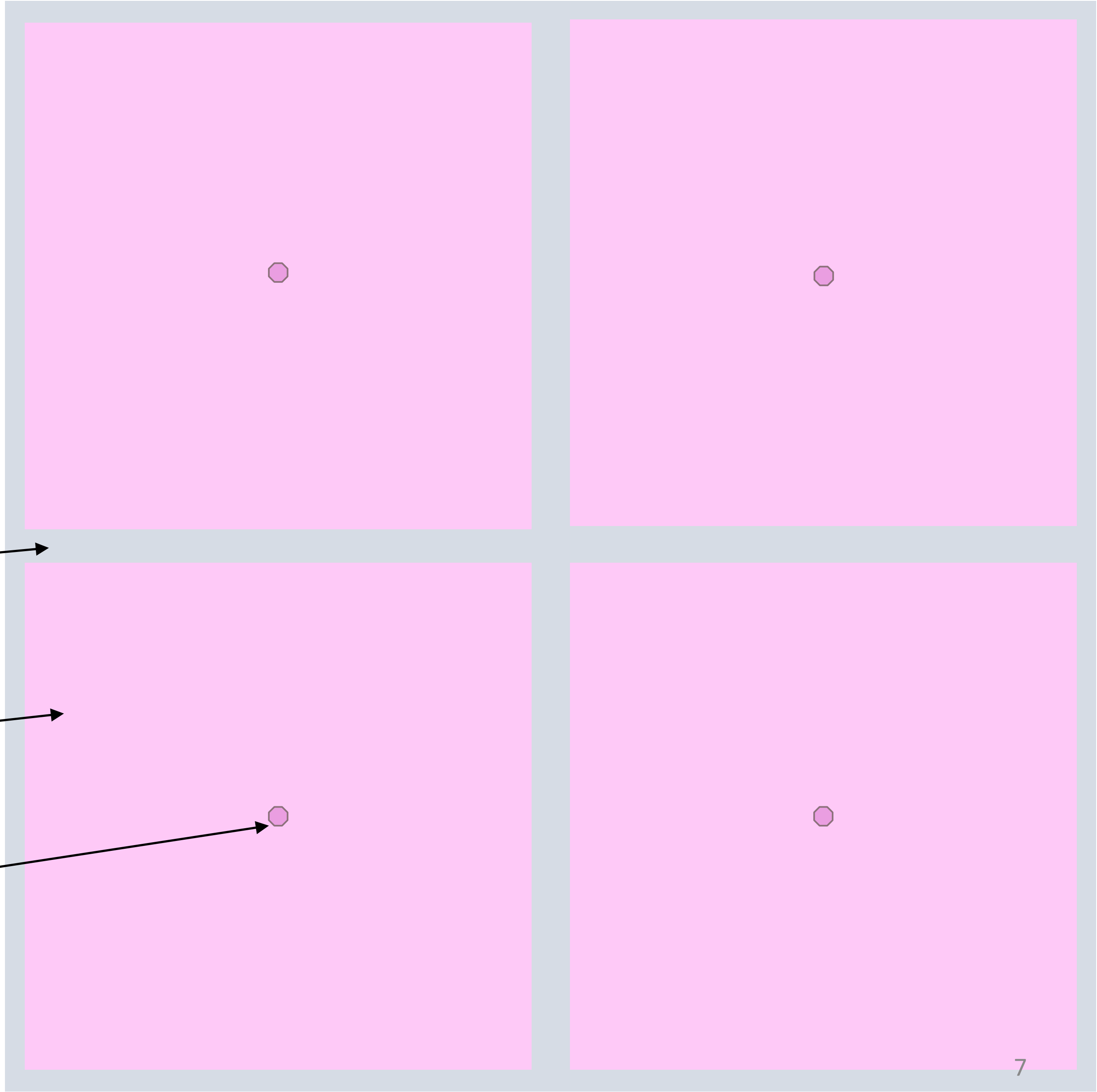


H2M cross section



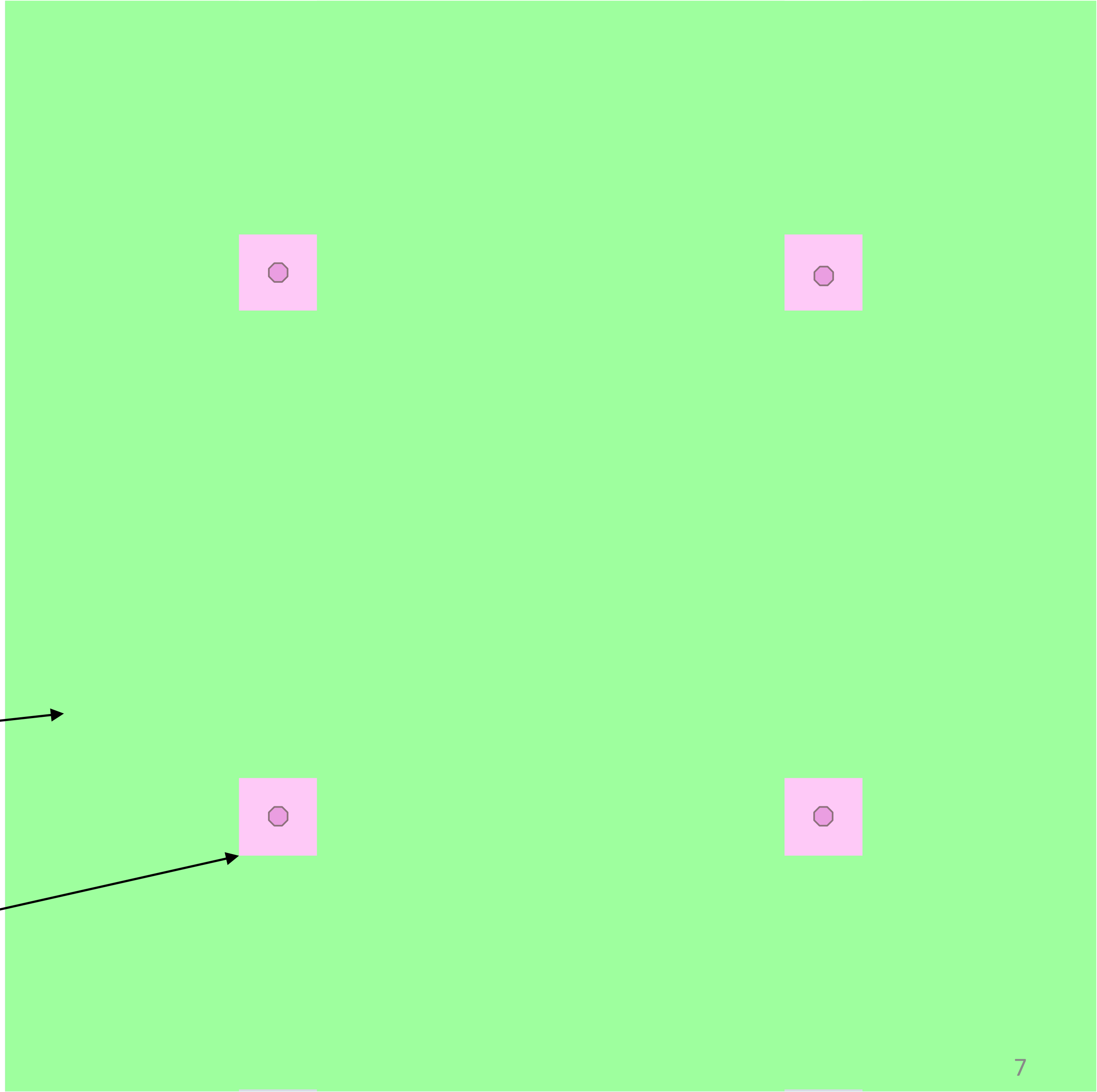
H2M layout

At the depth of the low dose n-type implant



H2M layout

At the depth of the deep p-well



Deep p-well

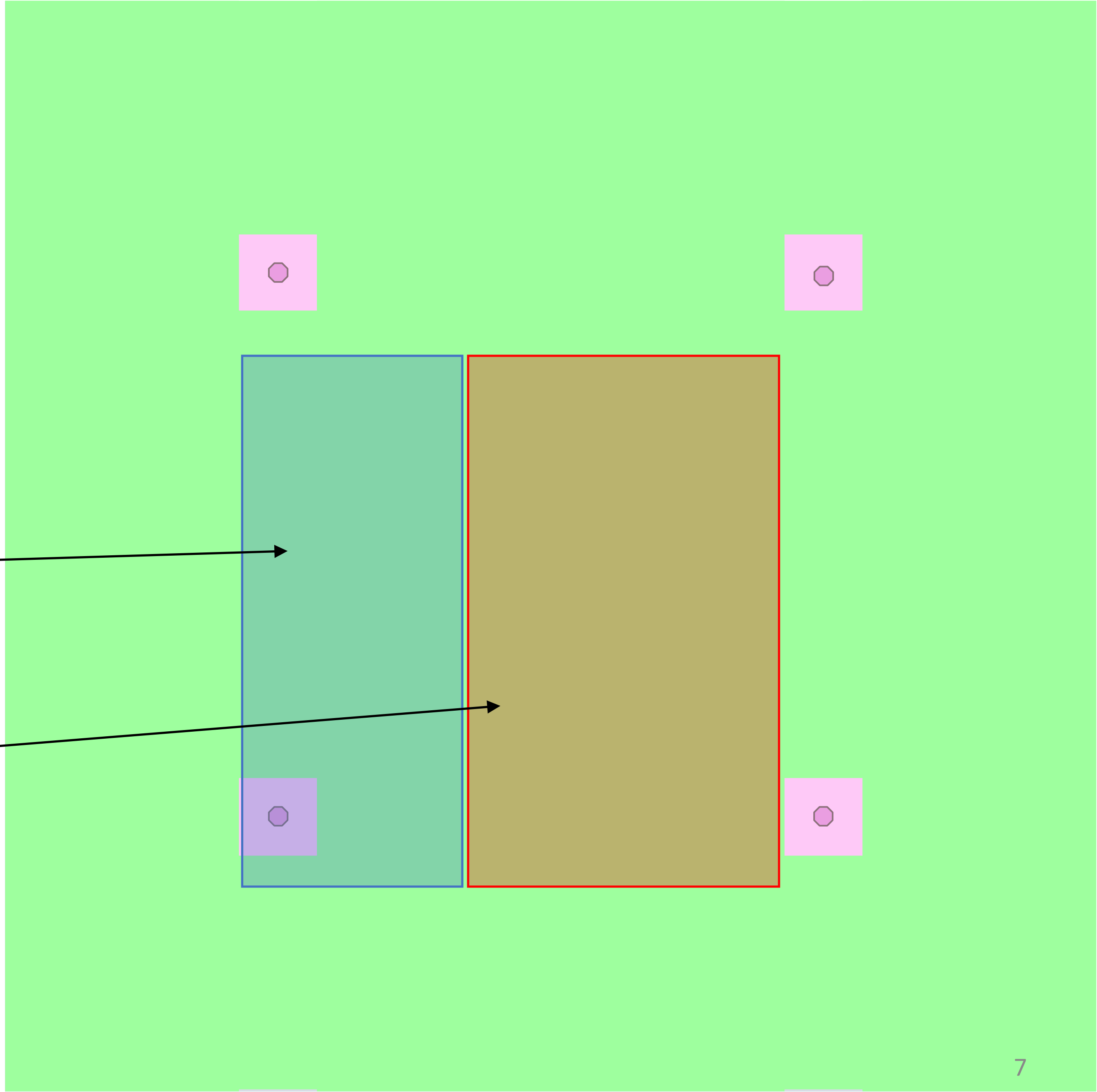
Deep p-well opening
around the electrode

H2M layout

At the depth of the deep p-well

Analog circuit

Digital circuit

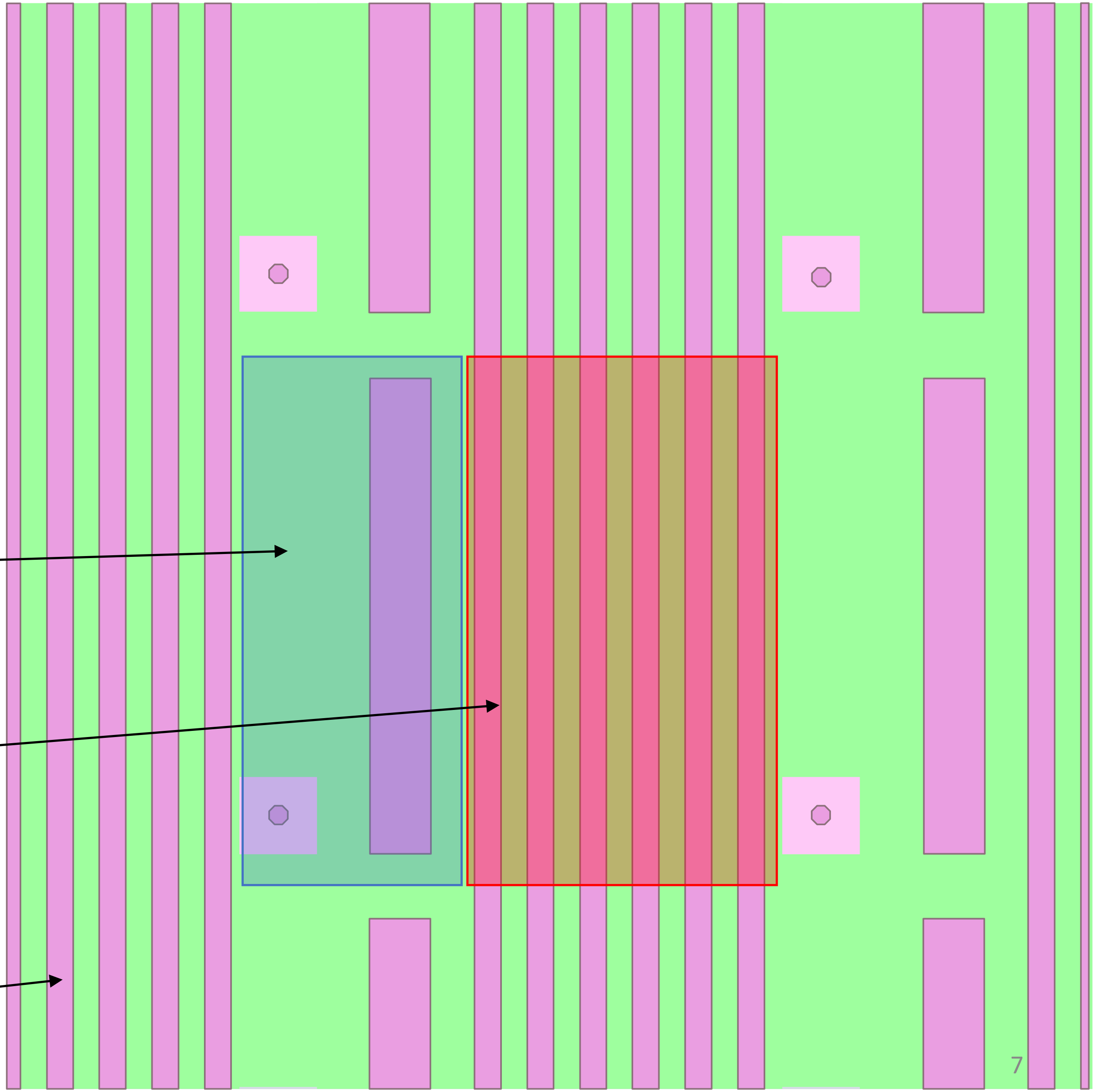


H2M layout

At the depth of the n-wells and p-wells

Analog circuit

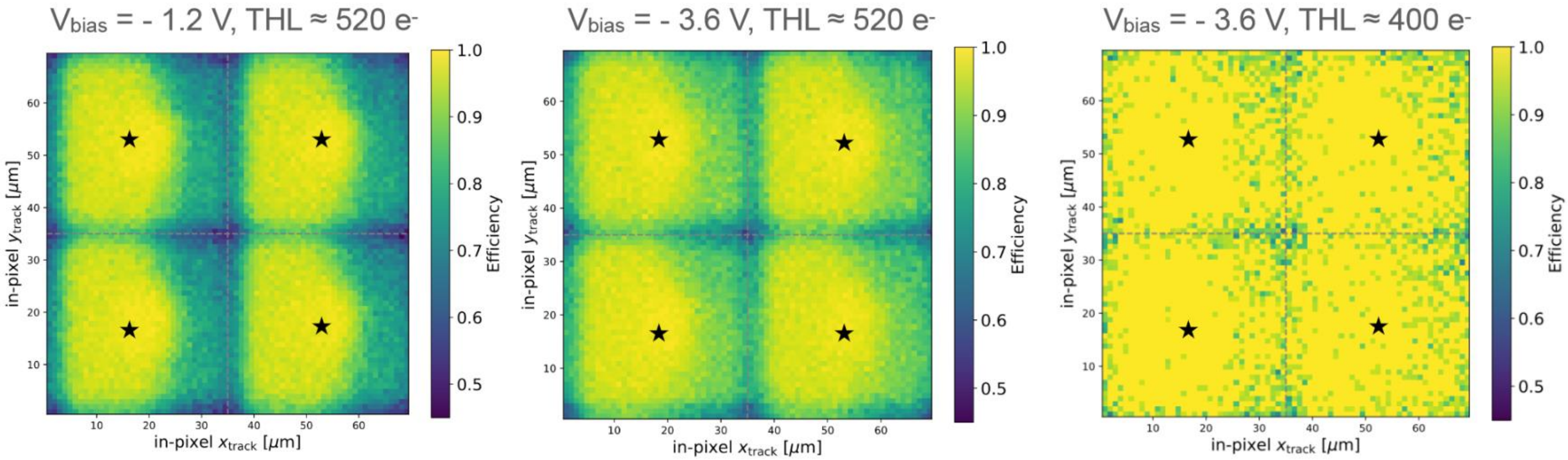
Digital circuit



N-well

*Layout of the n-wells is simplified compared to the real one

H2M measured efficiency map

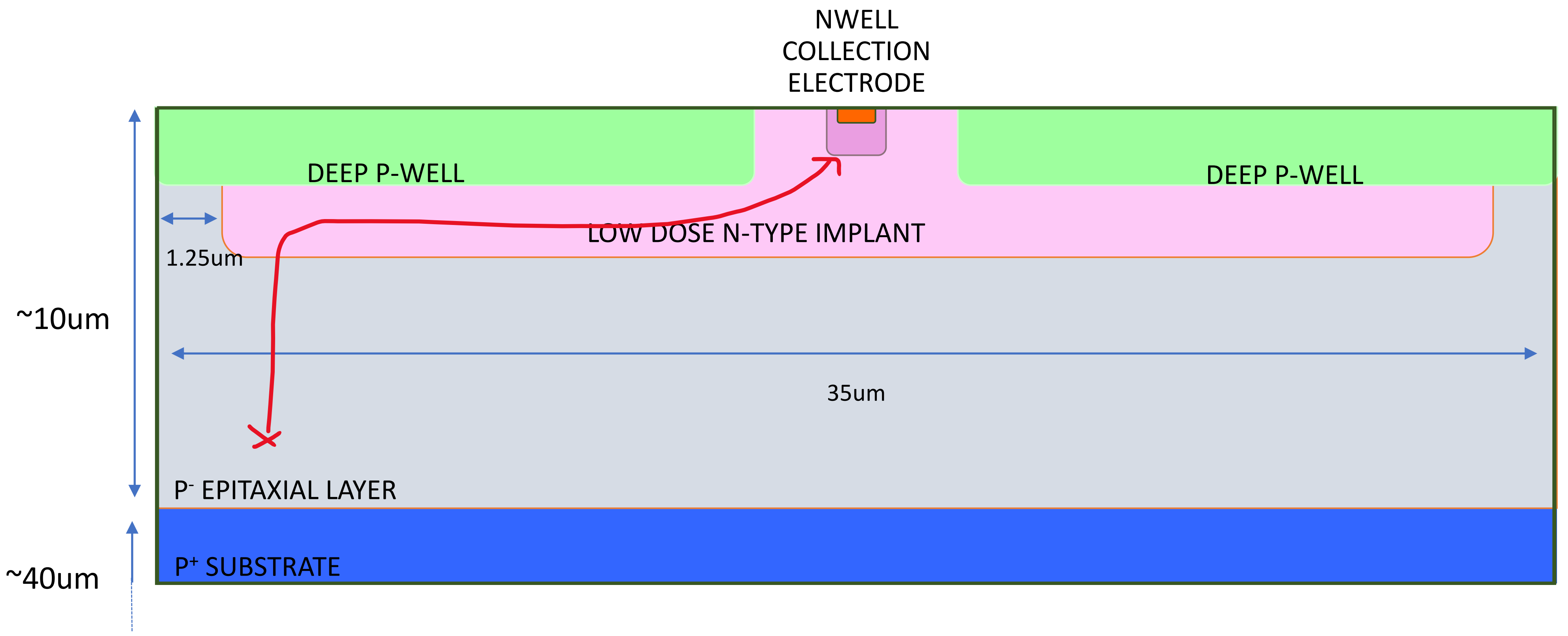


Sara Ruiz Daza for the H2M team: https://indico.desy.de/event/43834/contributions/165308/

- Asymmetric efficiency pattern
- Shape also confirmed with test via laser deposition (see ref)

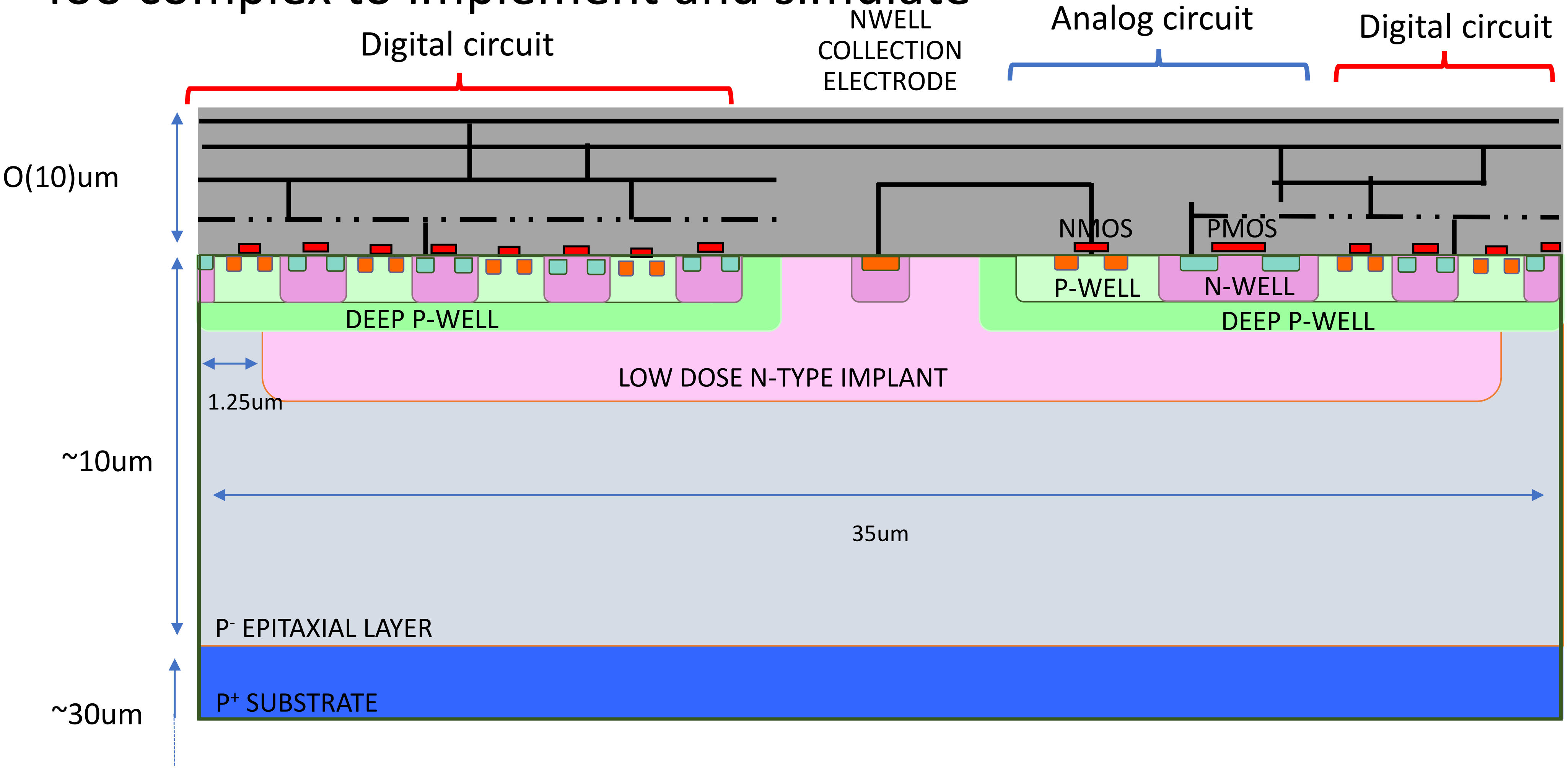
H2M ‘simple’ cross section

- Simulate the sensor only (eventually add behavioral model of the circuit)
- Fully symmetric -> cannot explain asymmetry



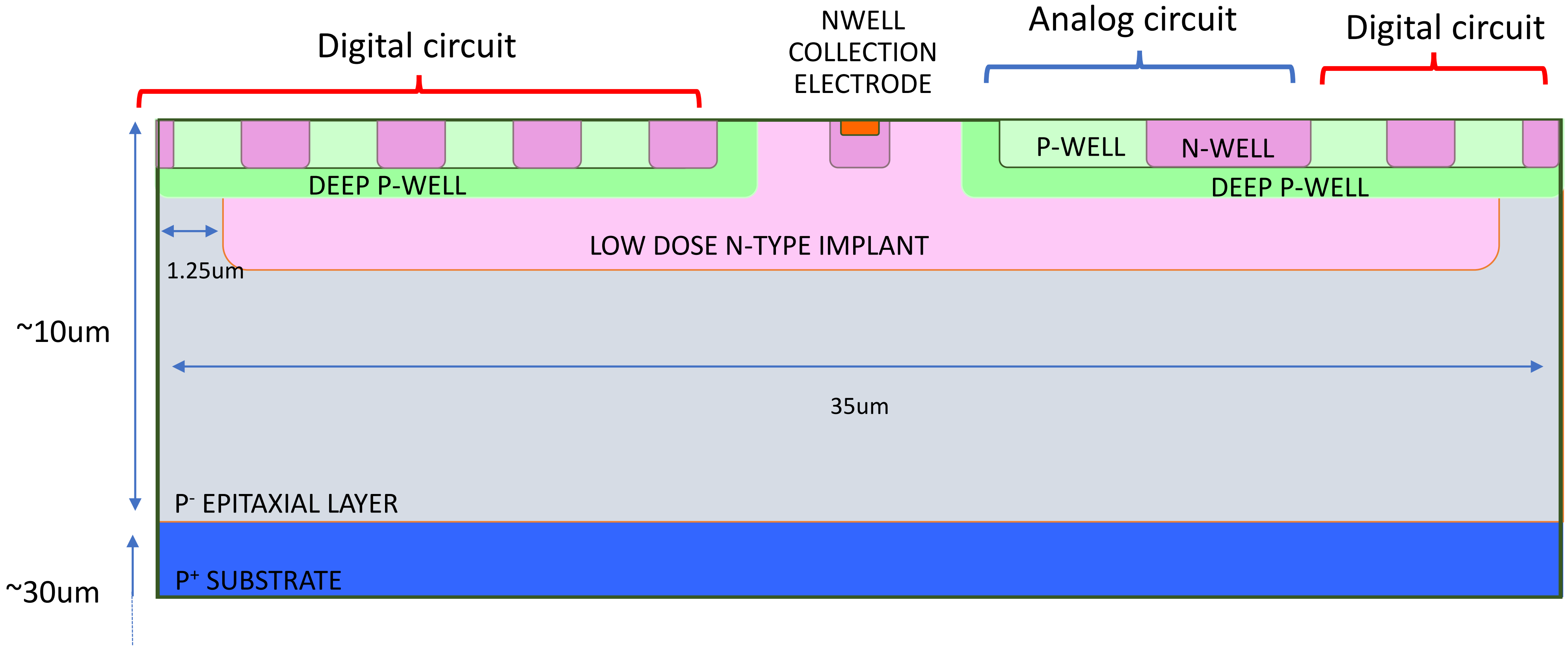
H2M 'realistic' cross section

- Too complex to implement and simulate



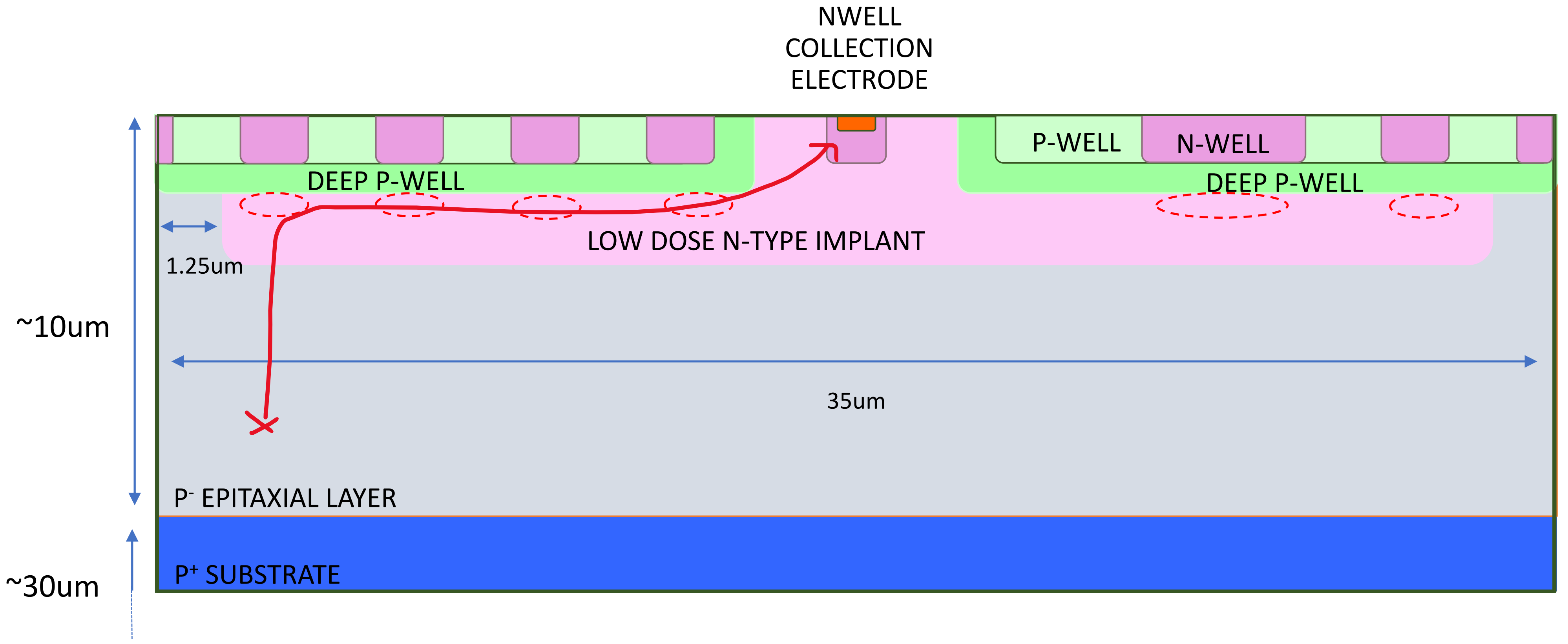
H2M 'good enough' cross section

- Simplified enough to be doable
- Detailed enough to contain asymmetry



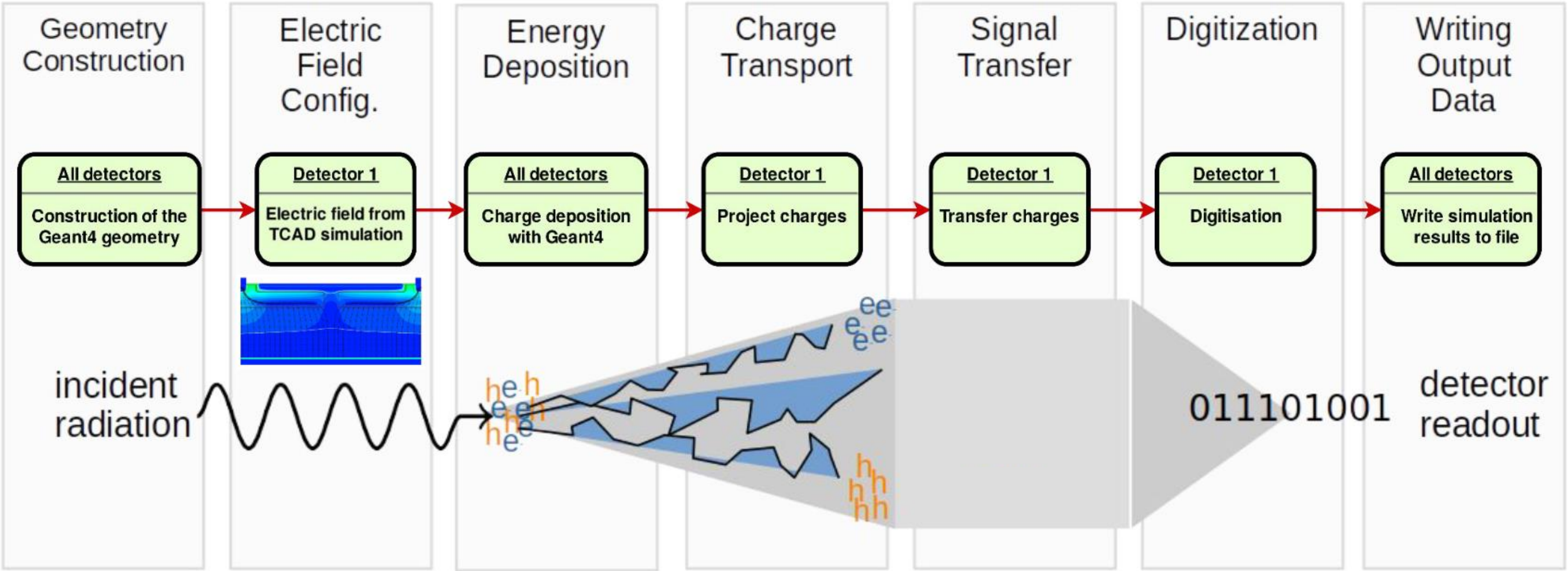
TCAD simulation

- Confidential doping profiles -> No plots ☹
- Local variation of the electric field close to the n-wells of the circuitry compared to simulation without the wells for the circuit



Simulation workflow

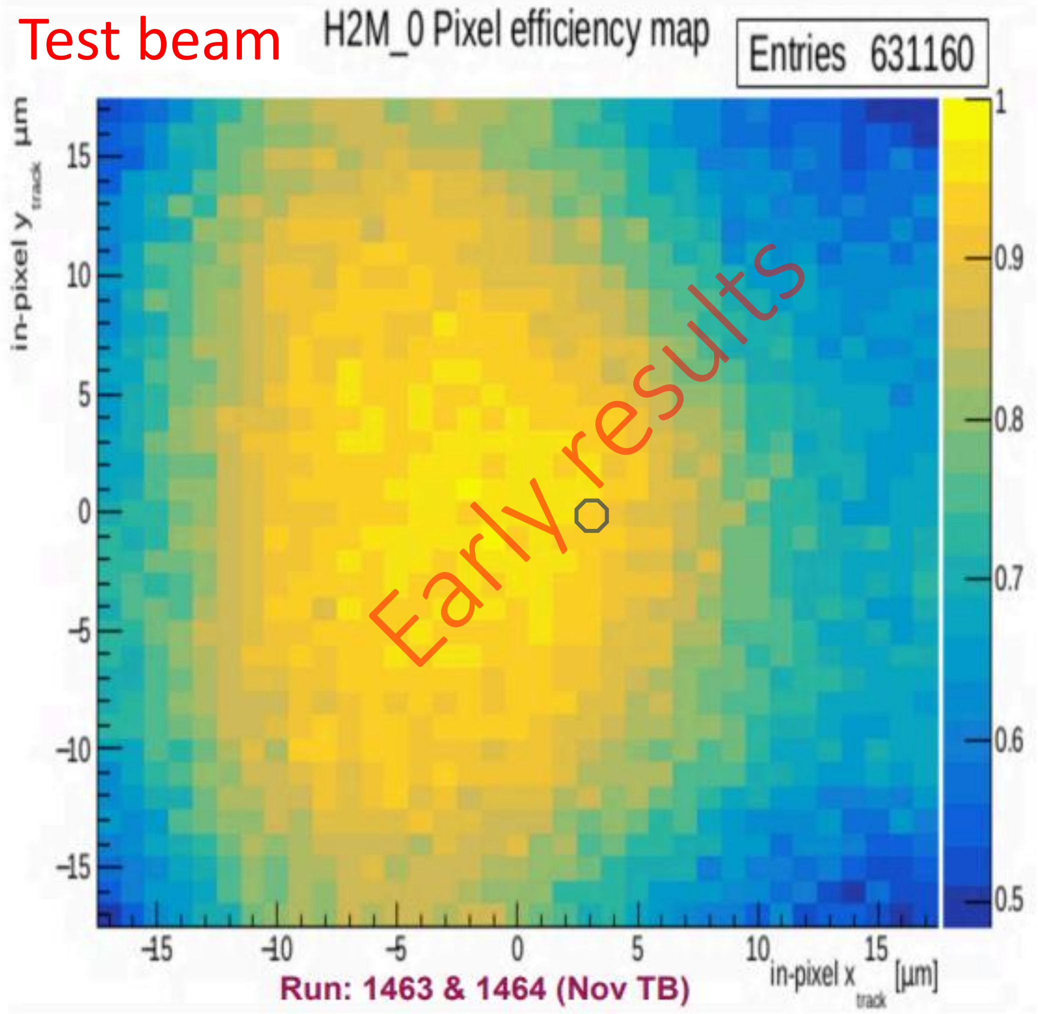
5GeV e- beam
Generic propagation 50ns (max step 50ps)
Set a threshold
Smearing results with the telescope resolution of ~3um



Adriana Simancas, 4th Allpix² workshop

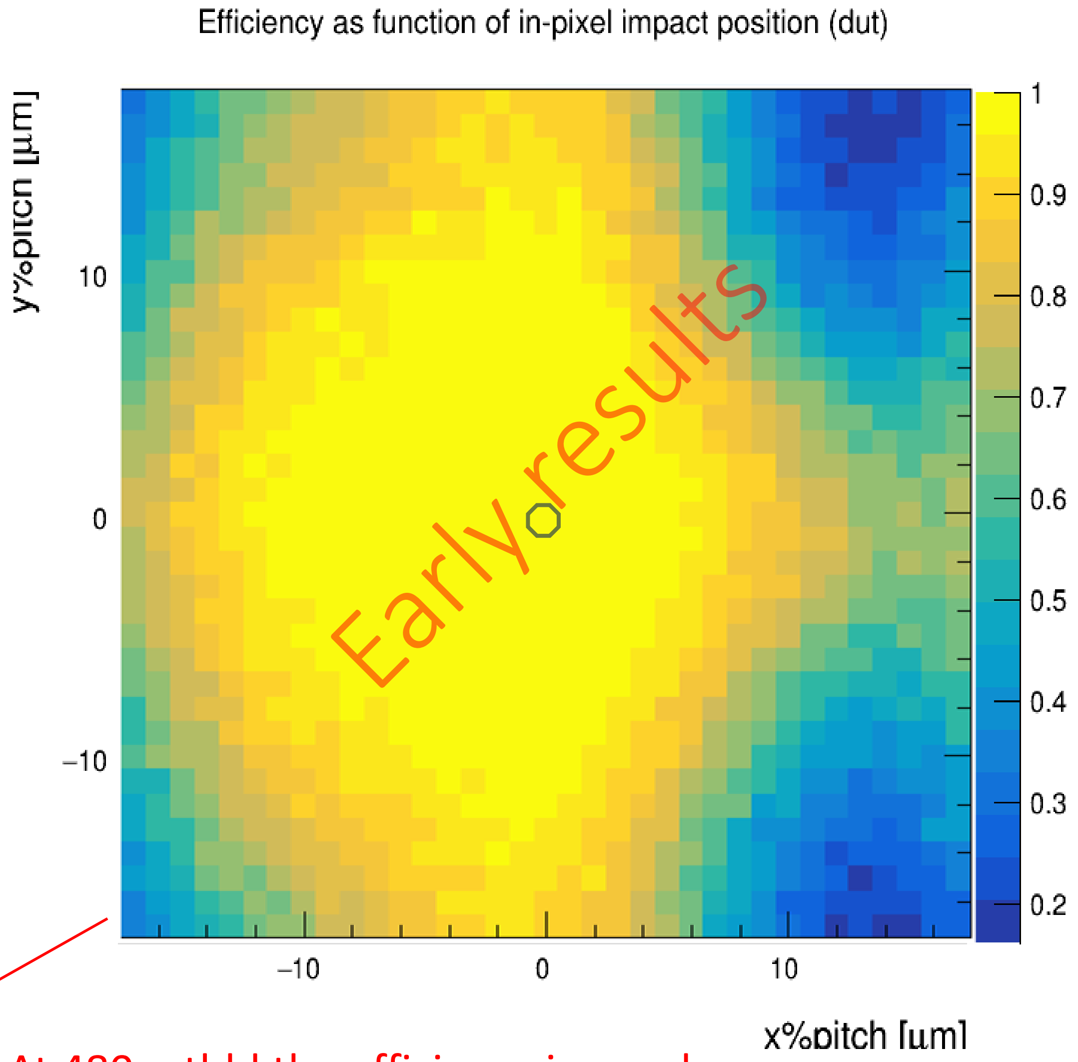
First simulation results

Test beam



Run: 1463 & 1464 (Nov TB)
Mean efficiency ~ 0.79
H2M-2, V_{bias} = -1.2 V
Threshold = 81 DAC, Baseline = 69 DAC

Simulations



~480e- 100e-

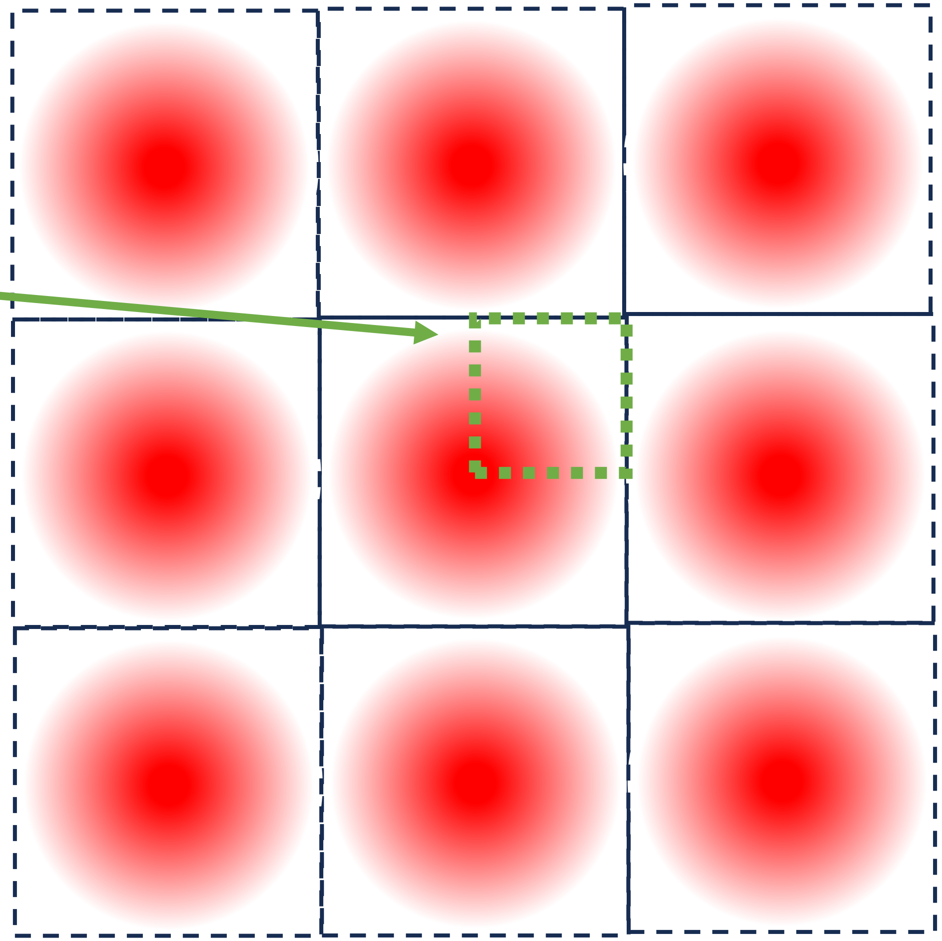
At 480e- thld the efficiency is very low

Pattern is approximately reproduced, but not the efficiency value

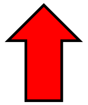
Improving simulation with TCAD

- Usually, pixels are symmetric
- One quadrant only needs to be simulated
- Synopsys TCAD implements by default mirror boundary conditions, perfect for this case

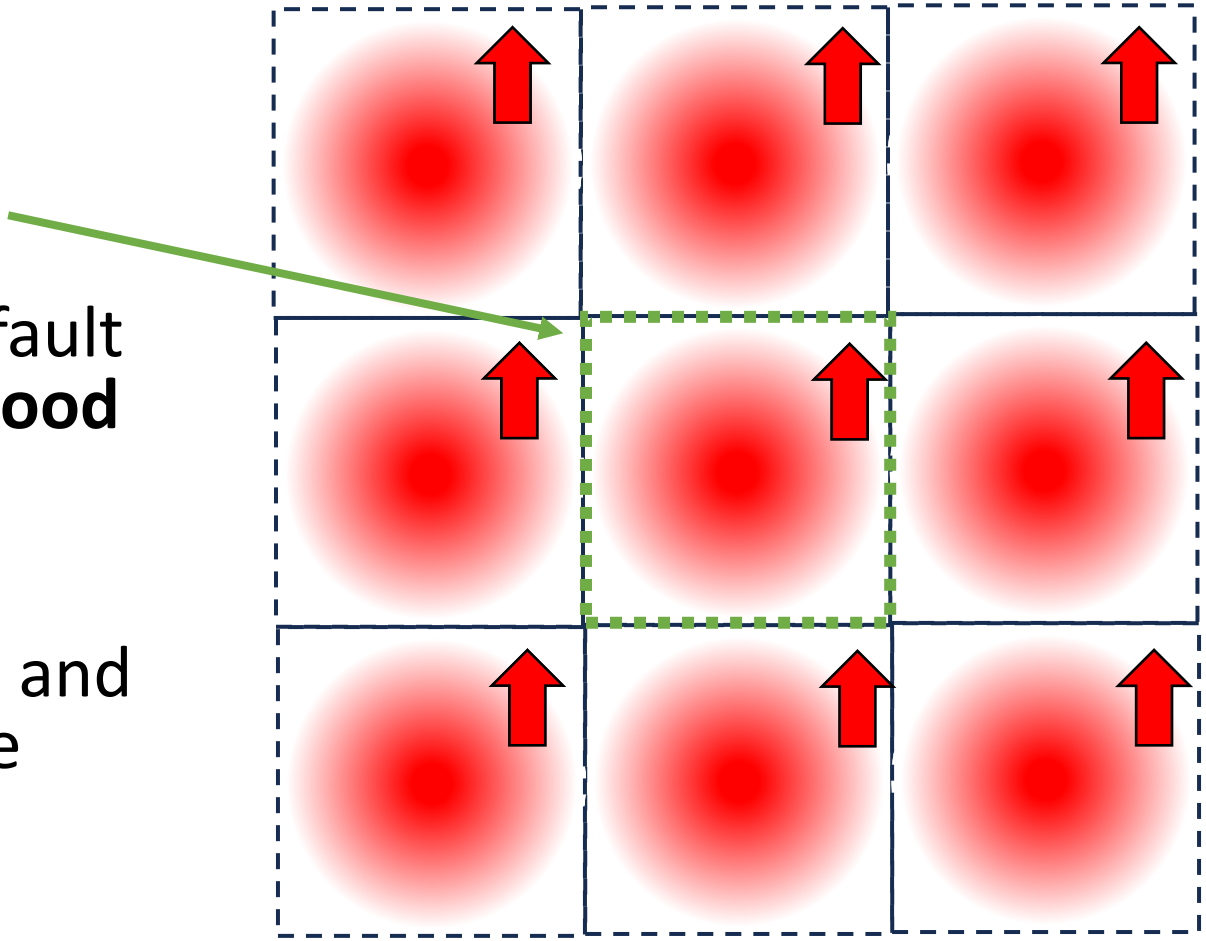
- Can simulate a small structure with a good meshing and get good boundary conditions



Improving simulation with TCAD

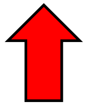

= marker for asymmetry

- Here, pixels are not symmetric
- At least one full pixel needs to be simulated
- Synopsys TCAD implements by default mirror boundary conditions, **not good for this case**



- Need to simulate a large structure and the boundary condition will still be different than reality

Improving simulation with TCAD



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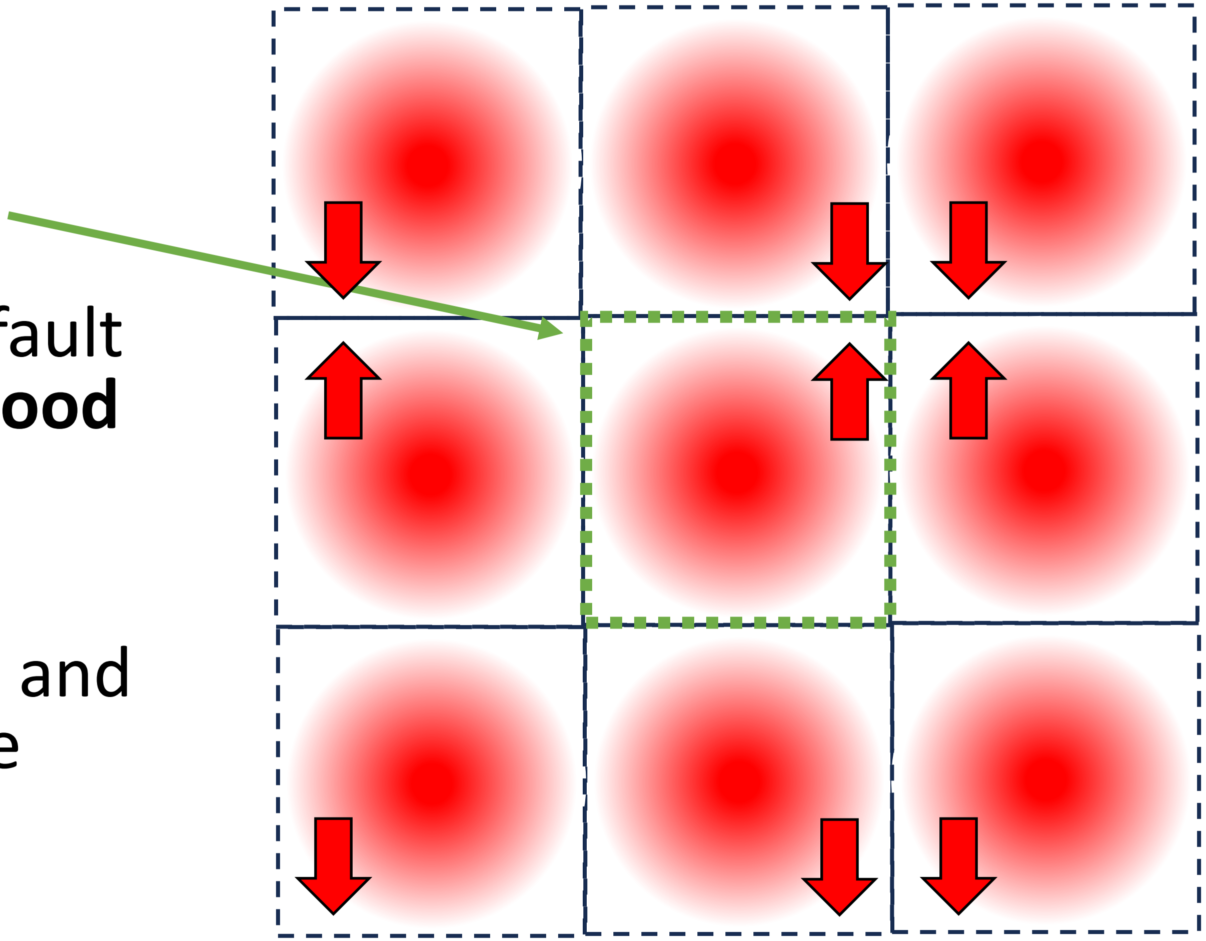


Improving simulation with TCAD

- Electron trajectory in a sensor simulated with “bad” (mirror) boundary condition

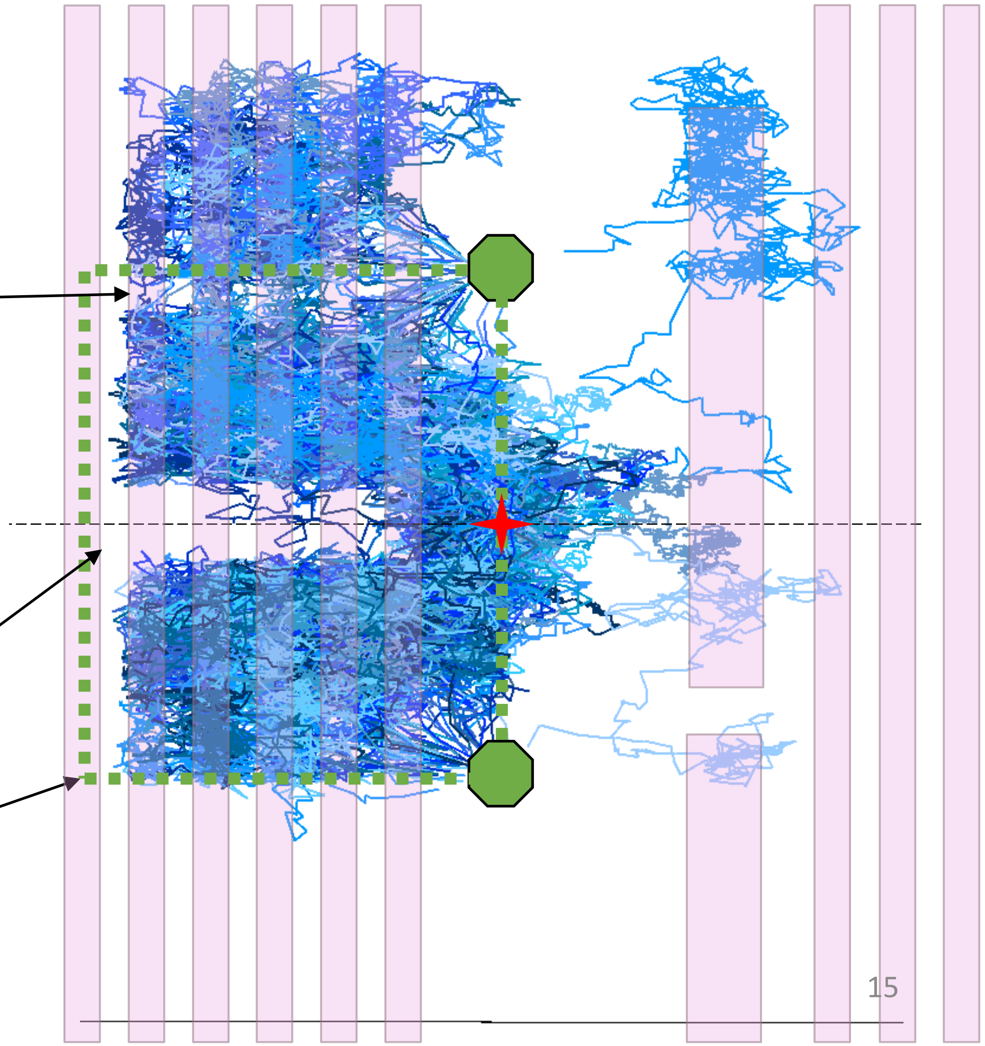
Orthogonal line charge deposition between two pixels

Pattern due to wrong boundary condition

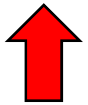
Should be ~symmetric

Gap in the deep n-type implant

Boundary of the simulated TCAD



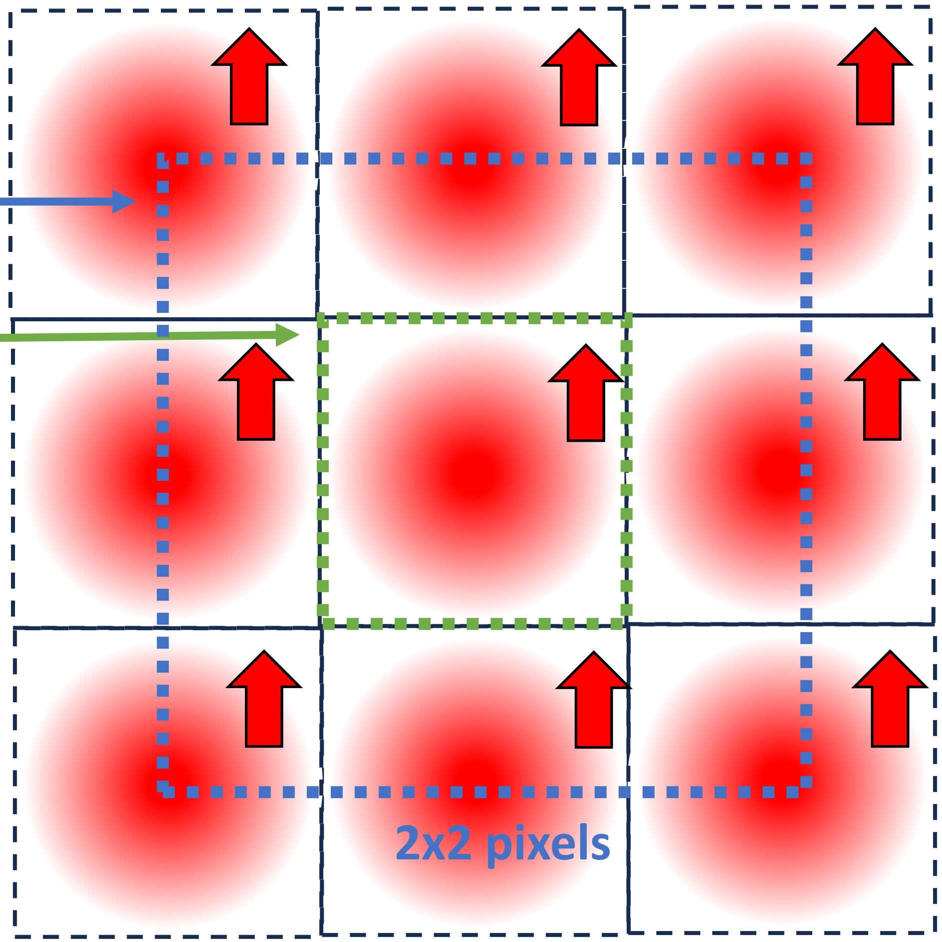
Improving simulation with TCAD



= marker for asymmetry

Improving boundary conditions :

- Simulate a larger structure in TCAD with mirror boundary condition and crop result to a single pixels
  - Most error due to the wrong boundary condition will be in the cropped part
  - Require even larger simulation
- Simulate a single pixel and enforce periodic boundary conditions in the simulation
  - Did not manage, convergence issue ☹



Improving simulation with TCAD

- Electron trajectory in a sensor simulated with “good” boundary condition (cropped 2x2 structure)

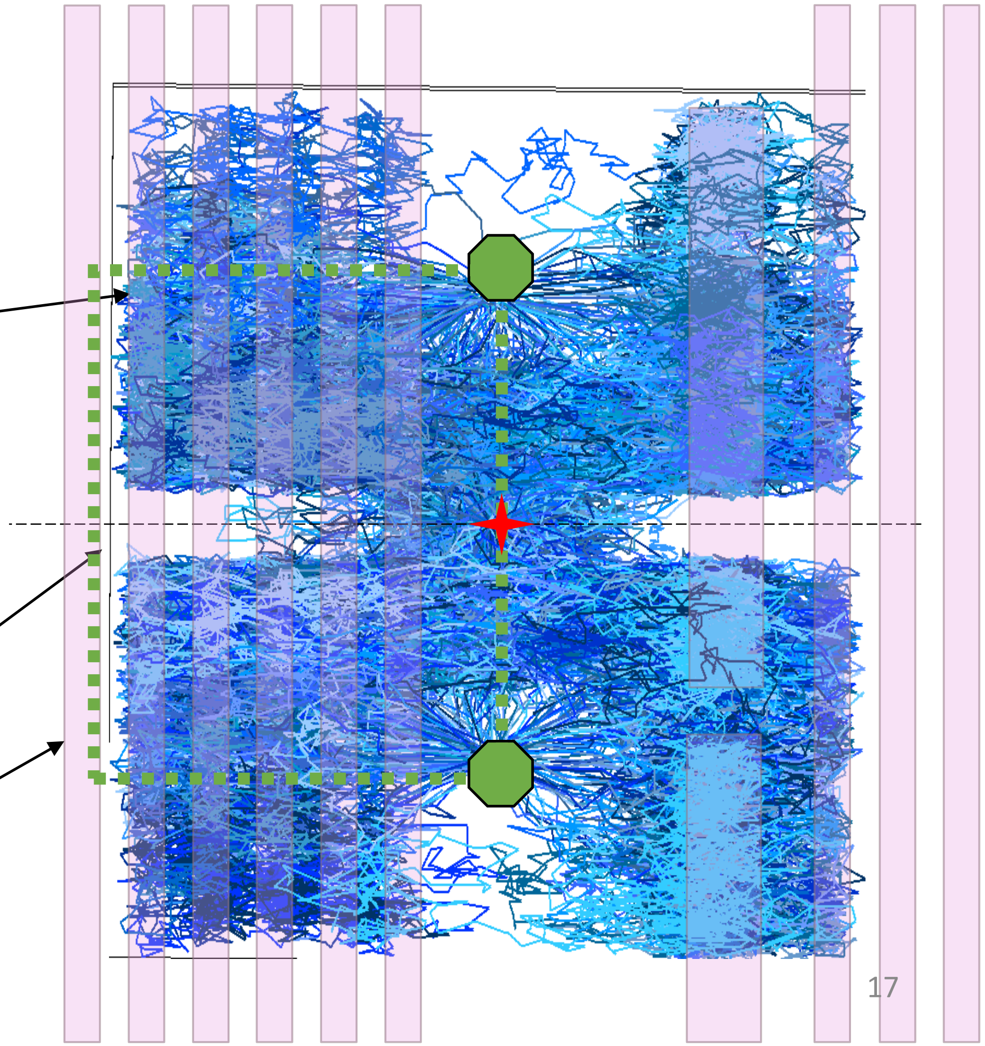
Orthogonal line charge deposition between two pixels

No more pattern due to wrong boundary condition

symmetric

Gap in the deep n-type implant

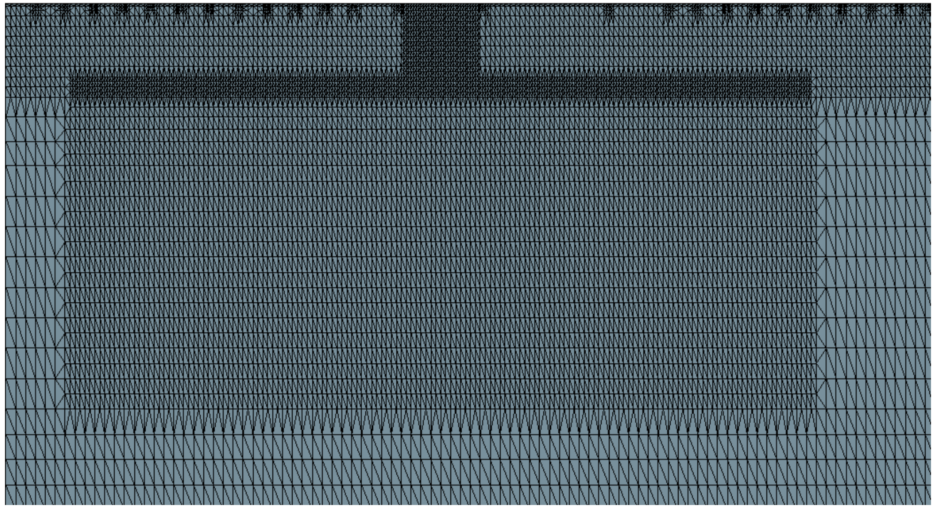
Boundary of the simulated TCAD



Improving simulation with TCAD

Choice of the meshing:

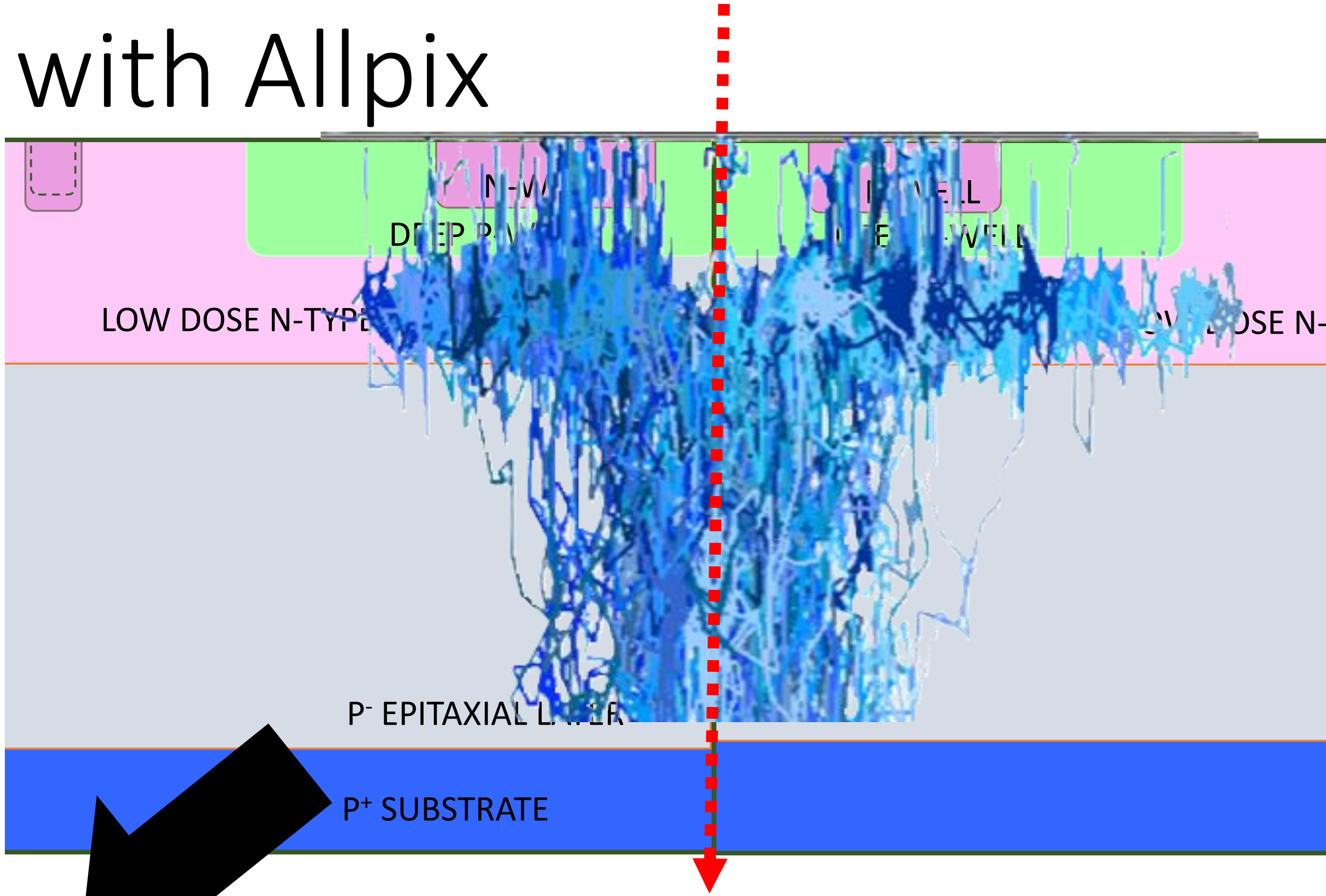
- For the H2M, 2x2 pixels is 70umx70um and at least 10um depth
- Maximum mesh possible is imposed mainly by the memory (and by simulation time), in my case O(2M) points or O(10M) elements for O(100h) CPU simulation time
- Prioritize:
  - Central pixel
  - EPI
  - Electrode
  - Wells and immediately bellow

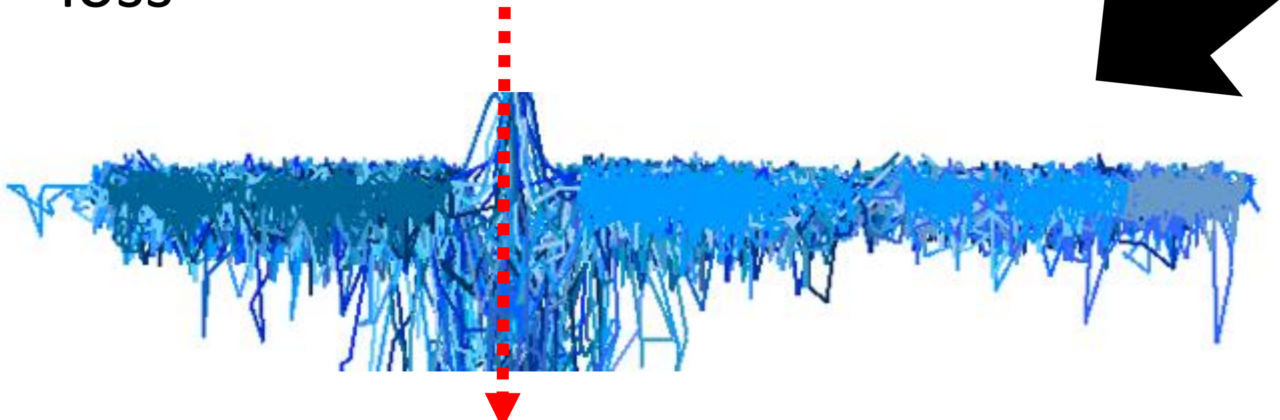


Improving simulation with Allpix

- Weird : charges going in the n-well and lost, never reaching the electrode
  - Not expected from TCAD

- Time step reduced from 50ps to <5ps : no more such loss

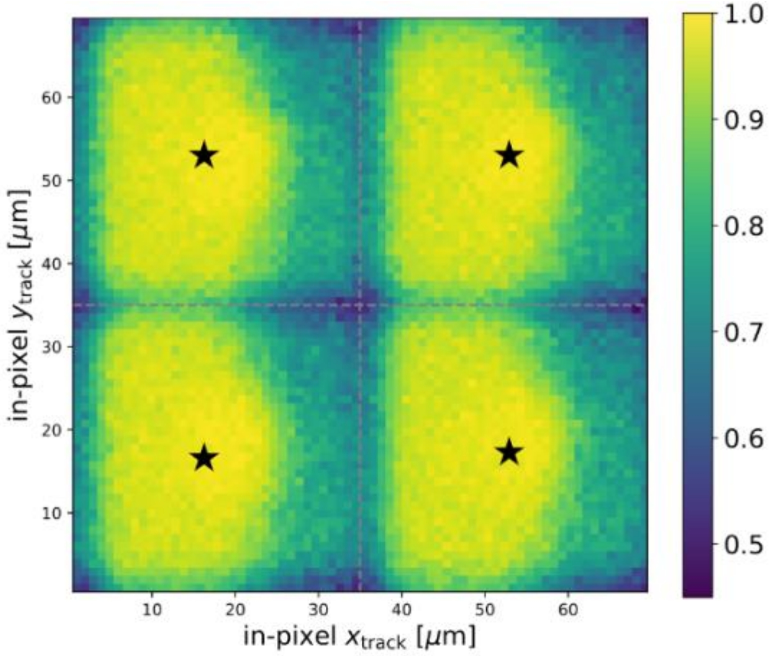




Improved simulation results

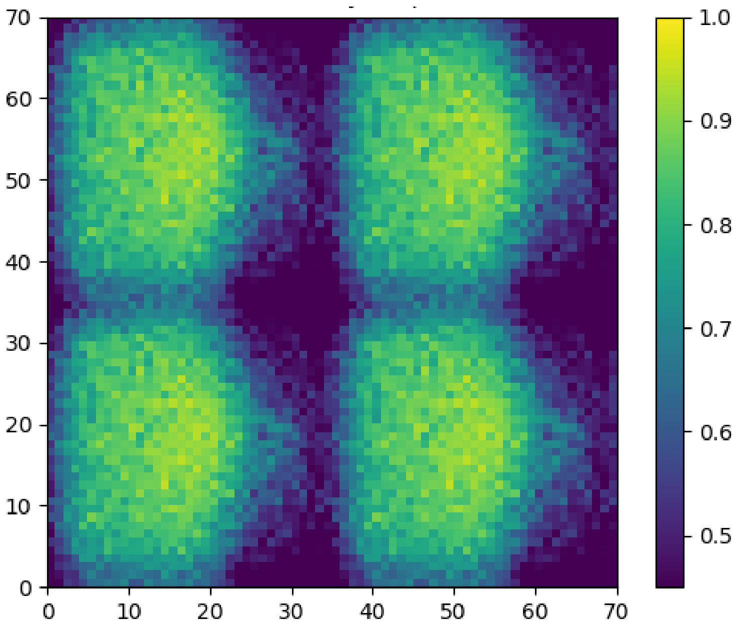
Test beam

Vsub = -1.2V, THLD=520e-

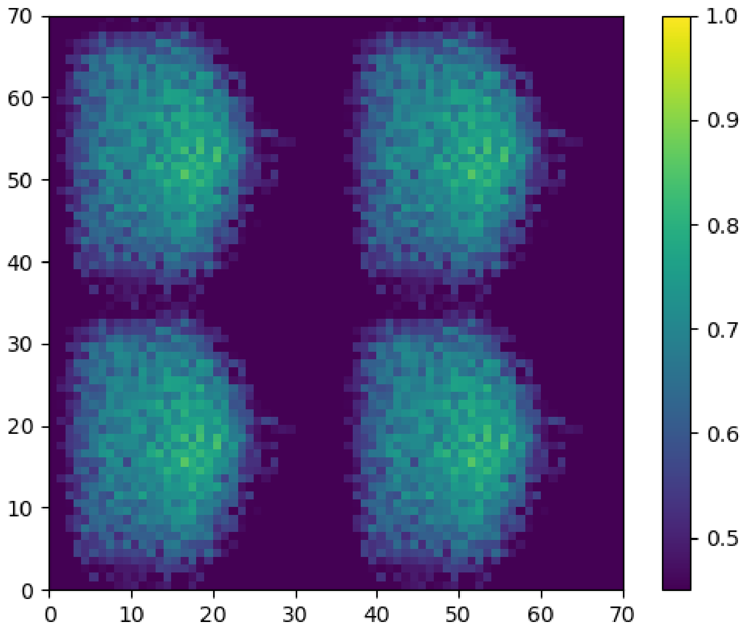


Simulations

Vsub = -1.2V, THLD=400e-

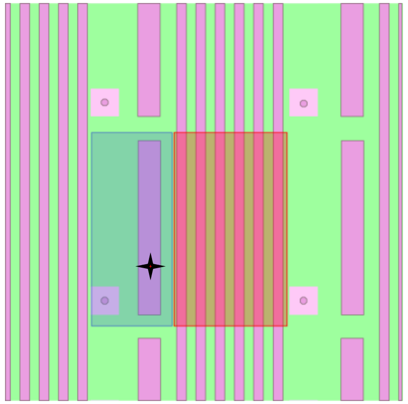


Vsub = -1.2V, THLD=520e-



- Significant improvements, good qualitative matching but still far from being quantitative

Further possible improvements



- Simulation cut at 50ns is too short to collect all charge when the circuit is present
- But the front end has a small shaping time of O(ns)

- Simply extending simulation cut time will not be enough, effects of the front end would need to be simulated