Impact of the circuit layout on the charge collection in a monolithic pixel sensor

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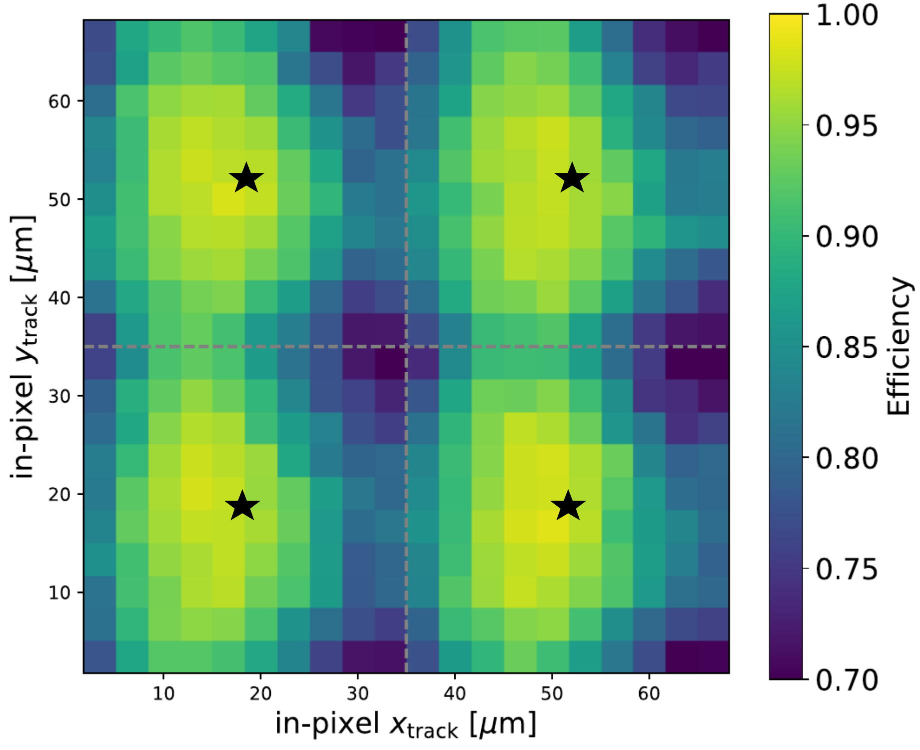
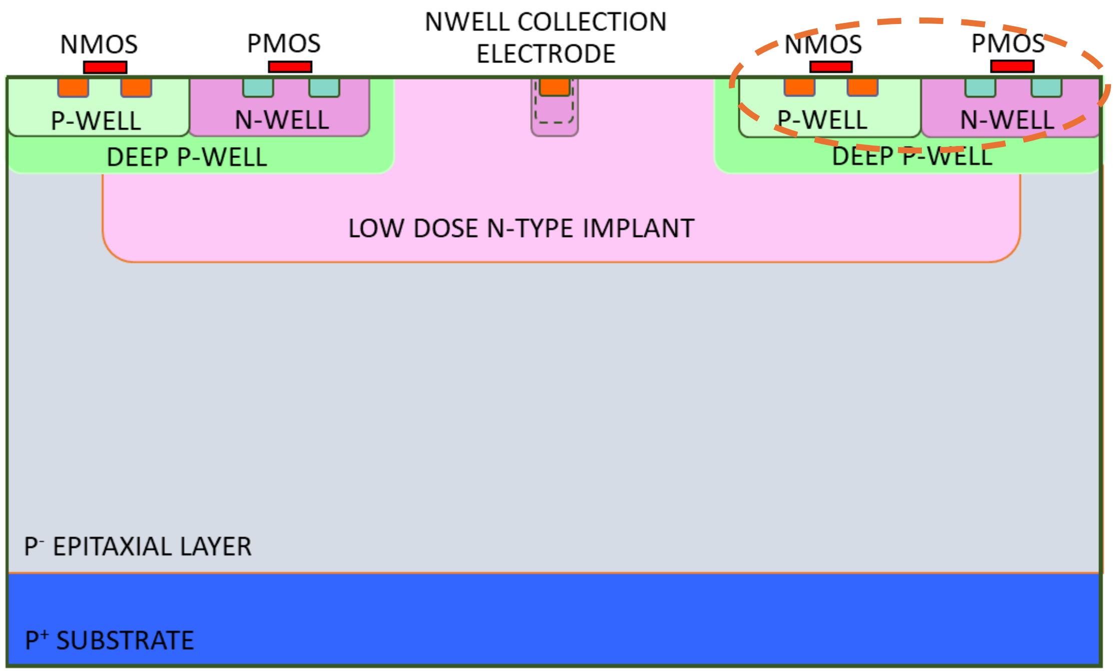
Symmetric sensor with asymmetric efficiency ?

- See Sara's presentation on H2M chip, 65nm monolithic CMOS
- Explain efficiency asymmetry pattern with simulation



★ Collection electrode

Full CMOS in the matrix available thanks to deep p-well shielding



Simulation procedure

Sensor structure

TCAD
Sentaurus

3D simulation of semiconductor electrical behaviour

Fully self-consistent
Resource intensive

Electric field

Physics simulation of charge deposition
Geant 4

Monte Carlo
Allpix^2

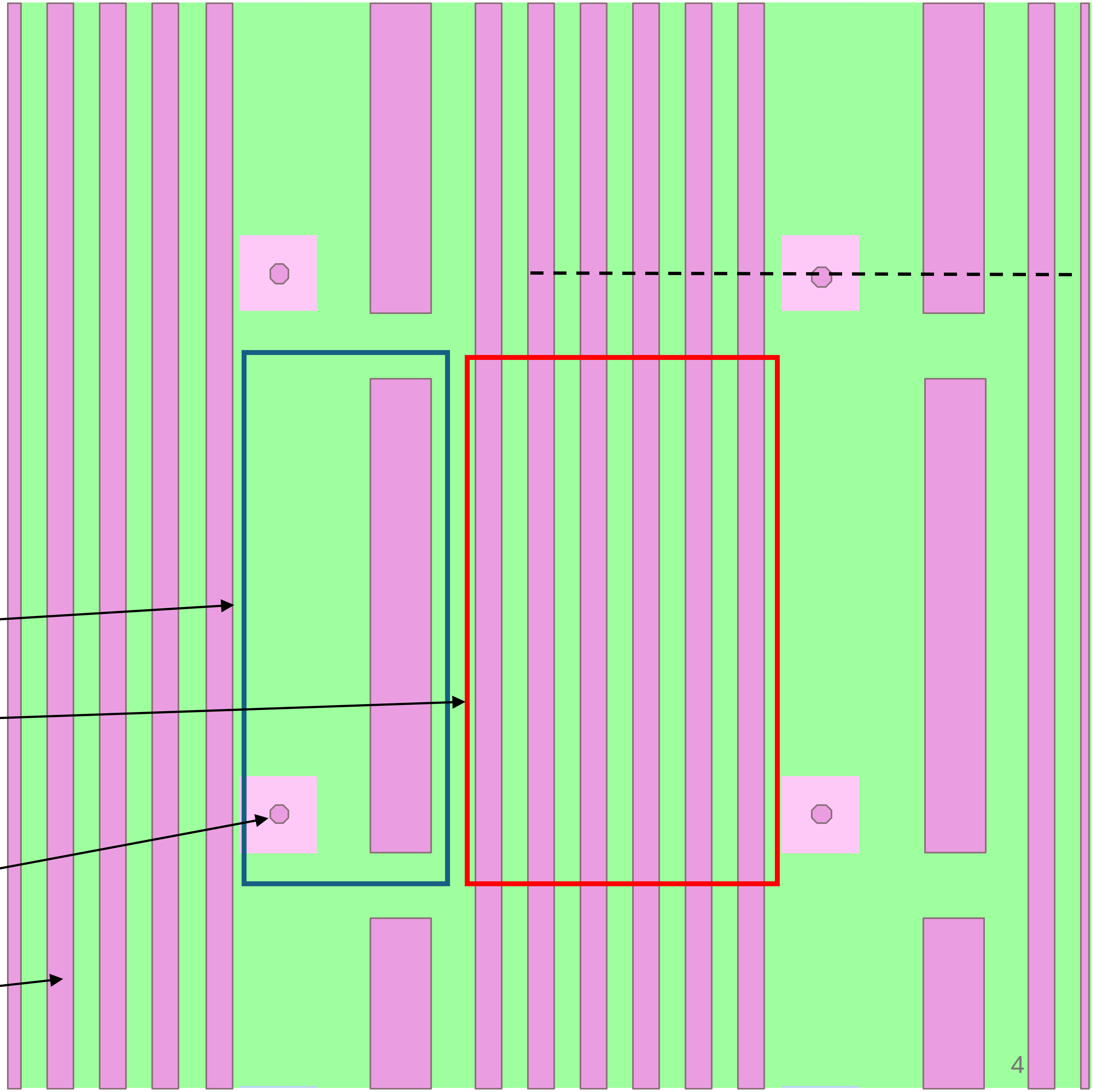
Charge propagation in precomputed static electric field

Fast
Simplified

Charge collected by the sensor

H2M layout

- Digital: several long and thin standard cell columns
- Analog: All pmos grouped in a single large nwell*



Analog circuit

Digital circuit

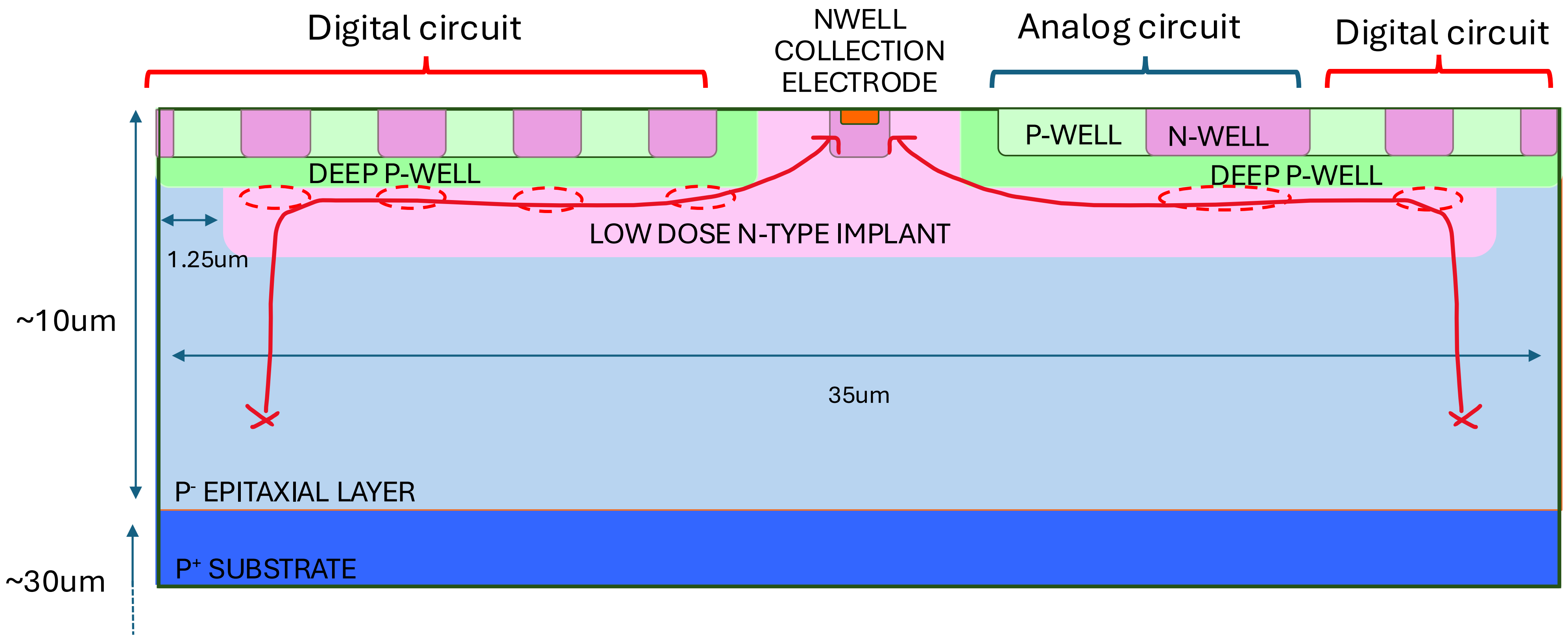
Collection Electrode

N-well

*Layout is slightly simplified compared to the real one

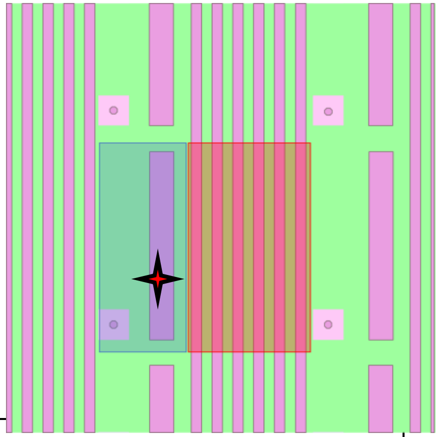
Sensor structure: H2M cross section

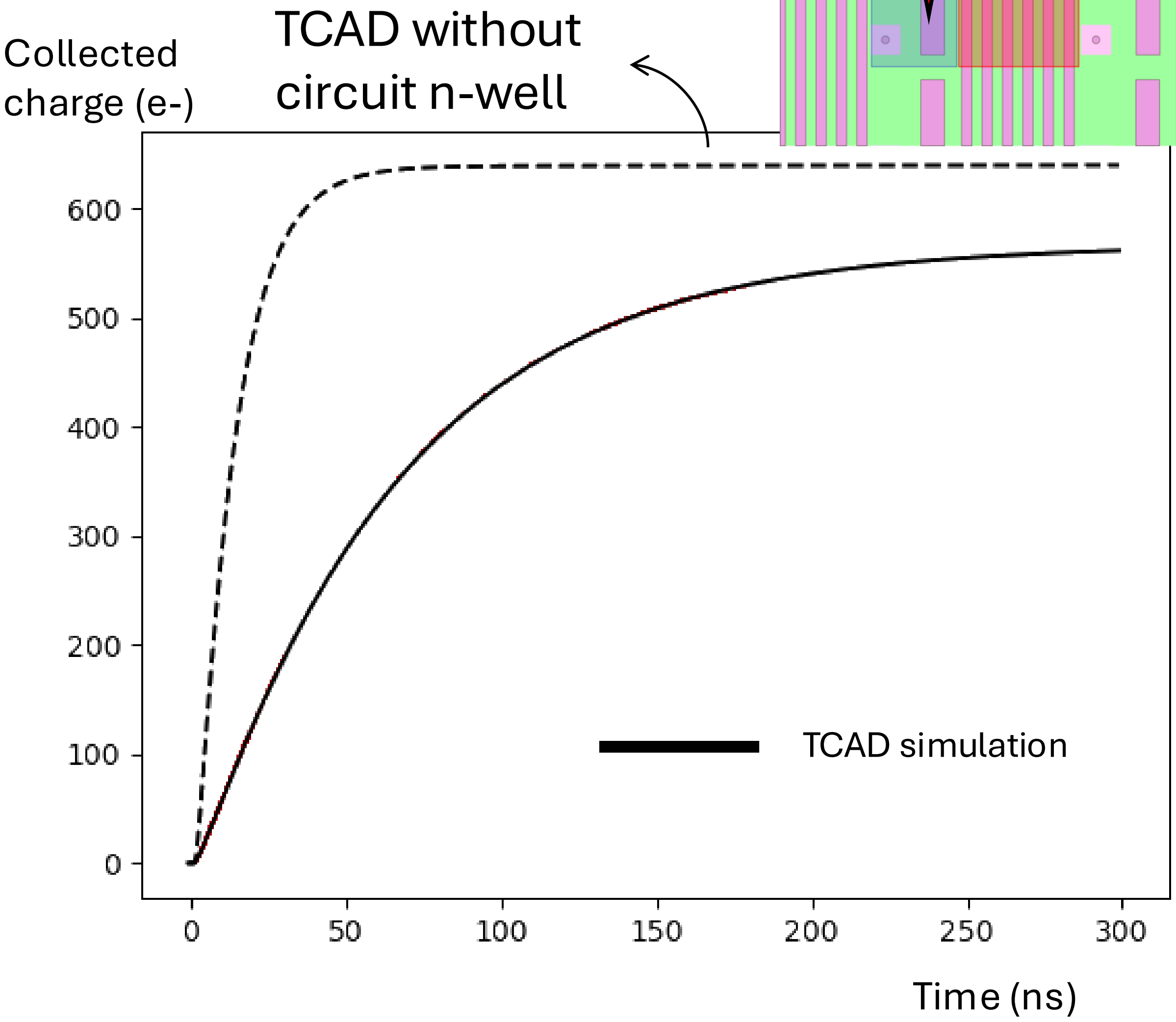
- Local variation of the electric field close to the n-wells of the circuitry compared to simulation without the wells for the circuit



From TCAD simulation to Monte Carlo

- One MIP perpendicularly incident to the sensor
- Single position, in analog n-well
- With n-well: significant slowdown of charge collection
- Similar total collected charge (~10% variation)





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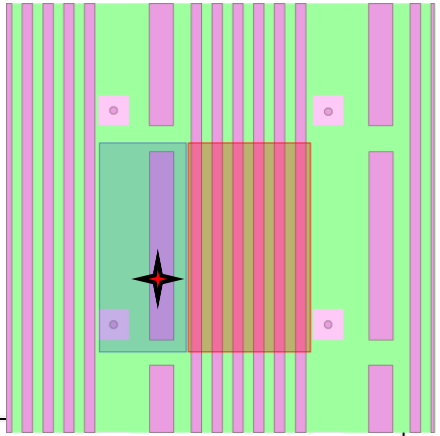

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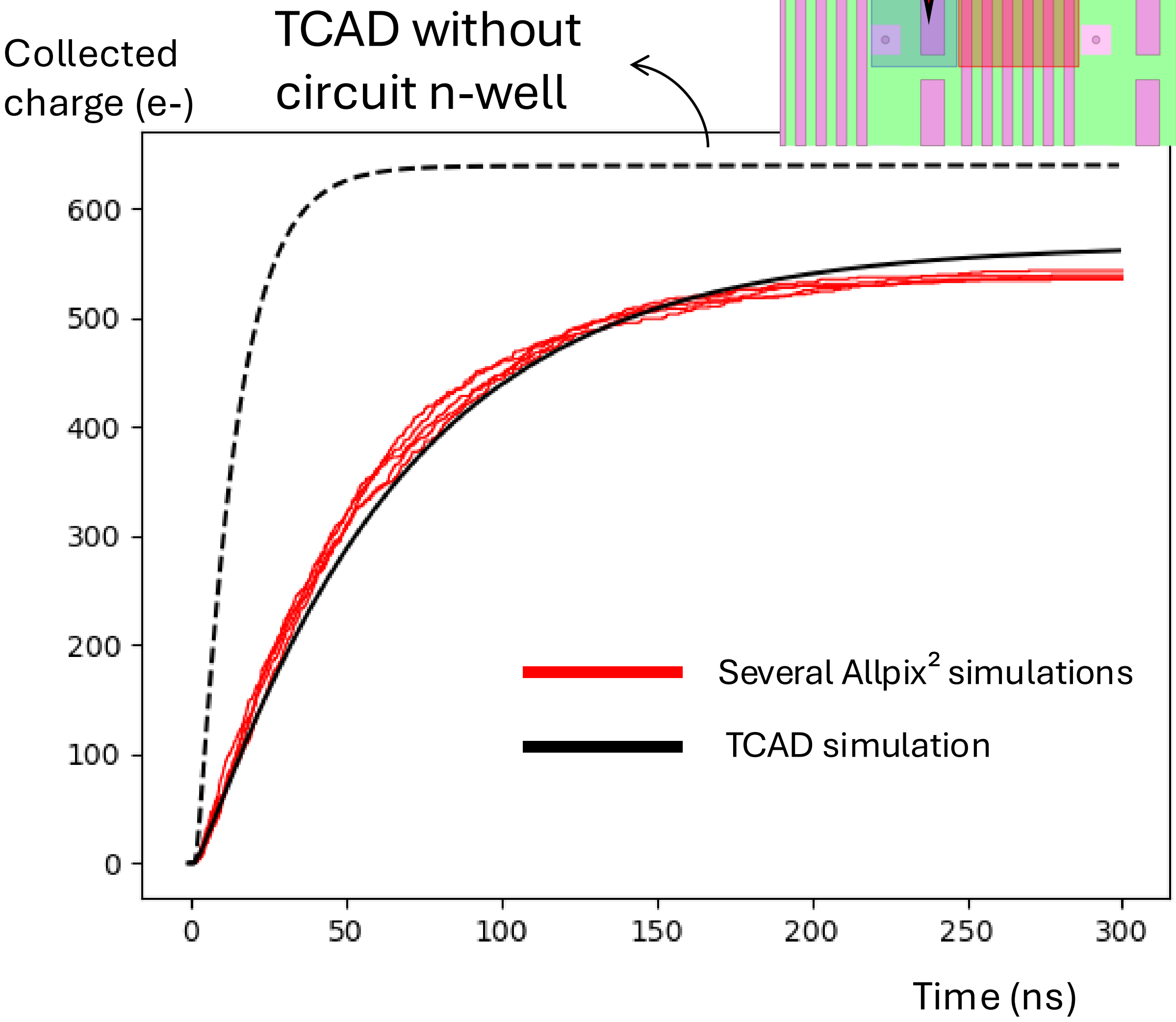
- => Allpix² is a viable solution to study the effect of n-well



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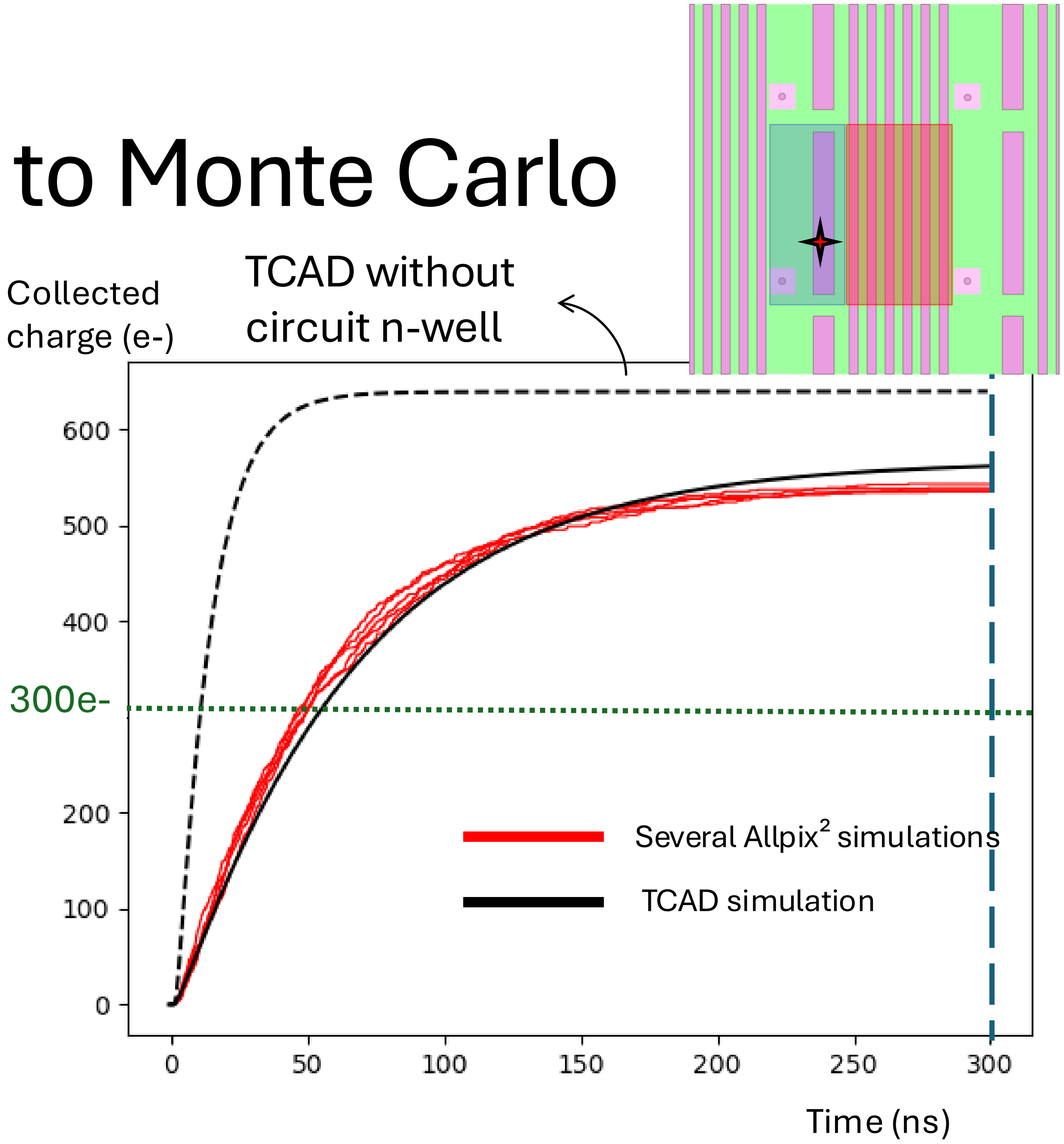


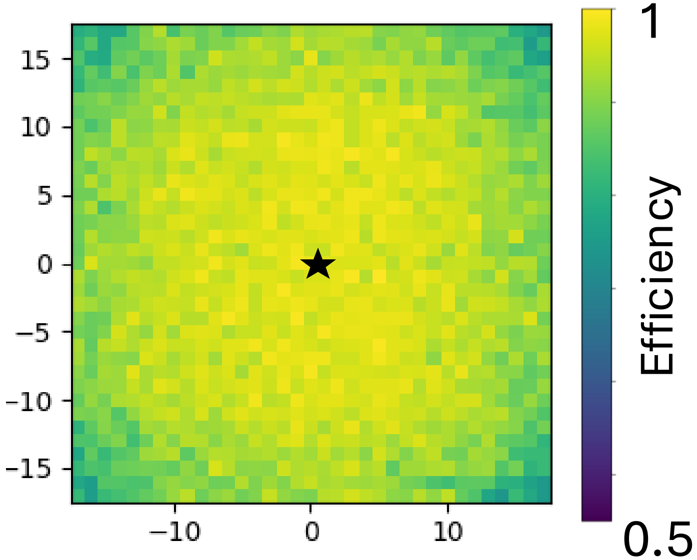
Monte Carlo simulation

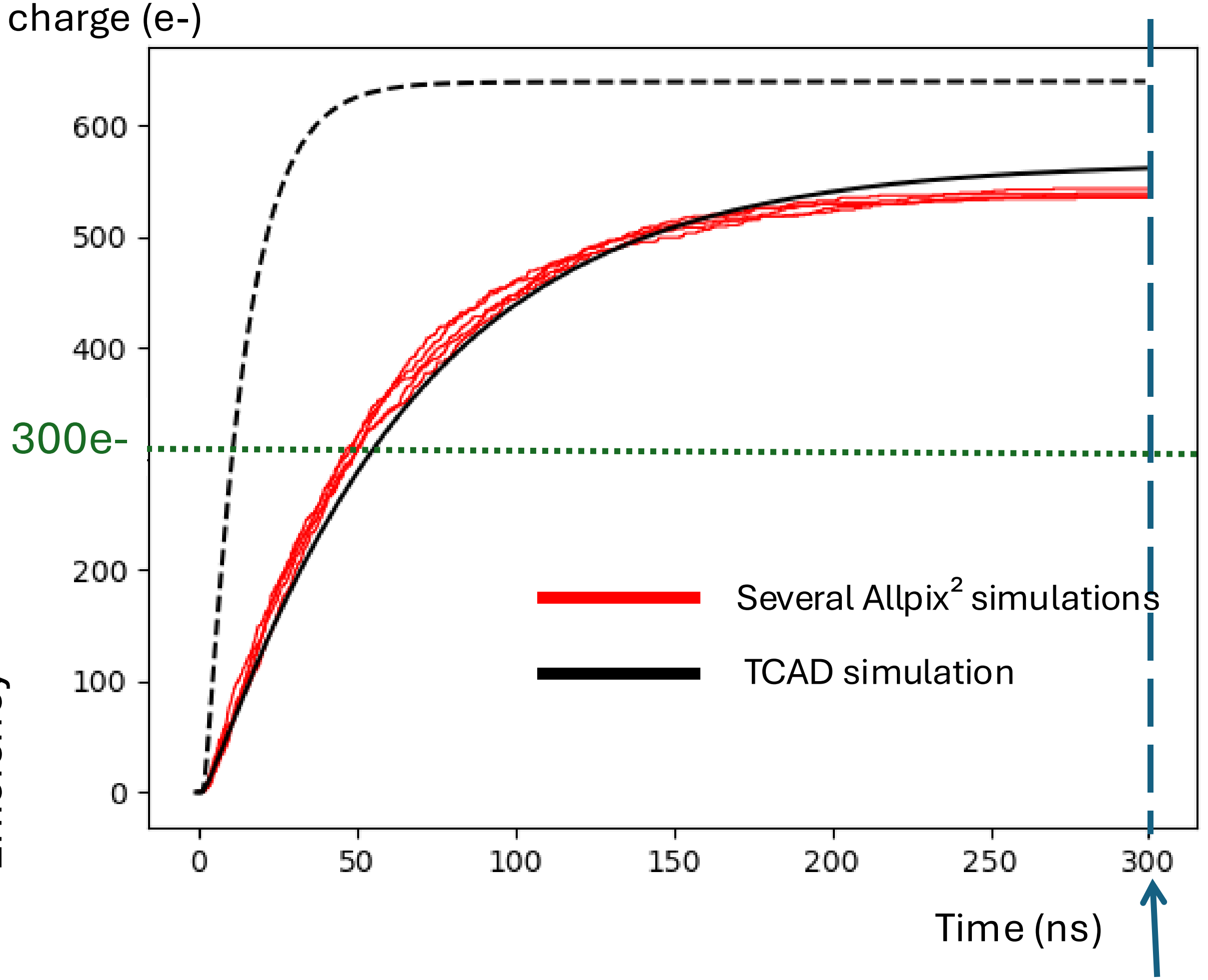
Allpix^2: **test beam simulation**

- Perpendicular 5GeV e- beam
- Lifetime: SRH-Auger model
- Mobility: Masetti-Canali model
- Timestep: ≤2ps

- Compare to 300e- threshold
- High statistics over the full pixel
- No asymmetry pattern

In pixel efficiency map
At 300ns





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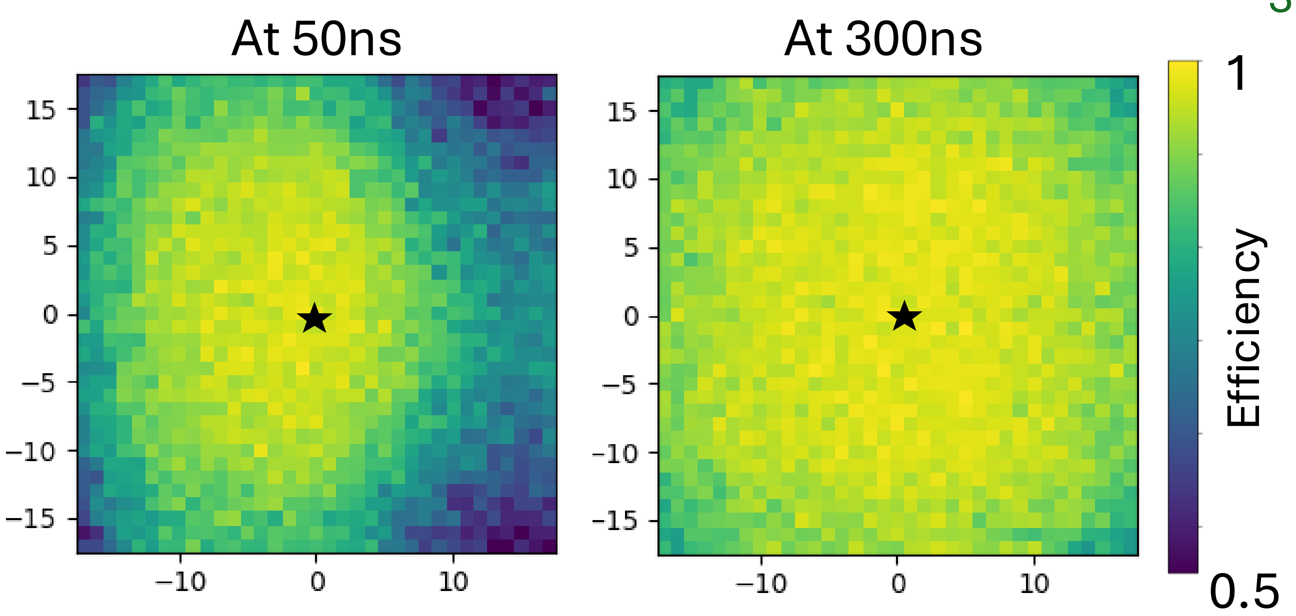
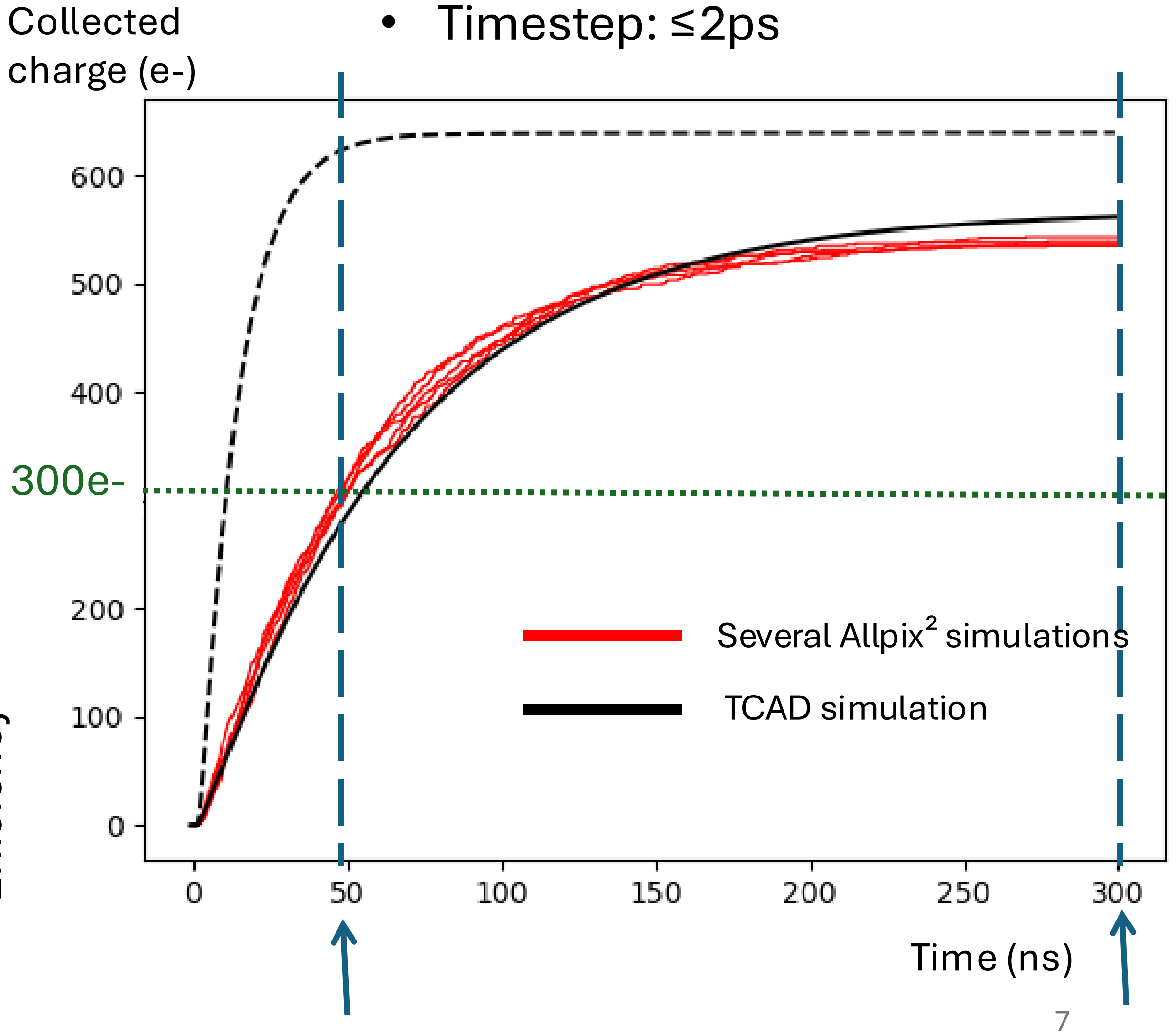
In pixel efficiency map



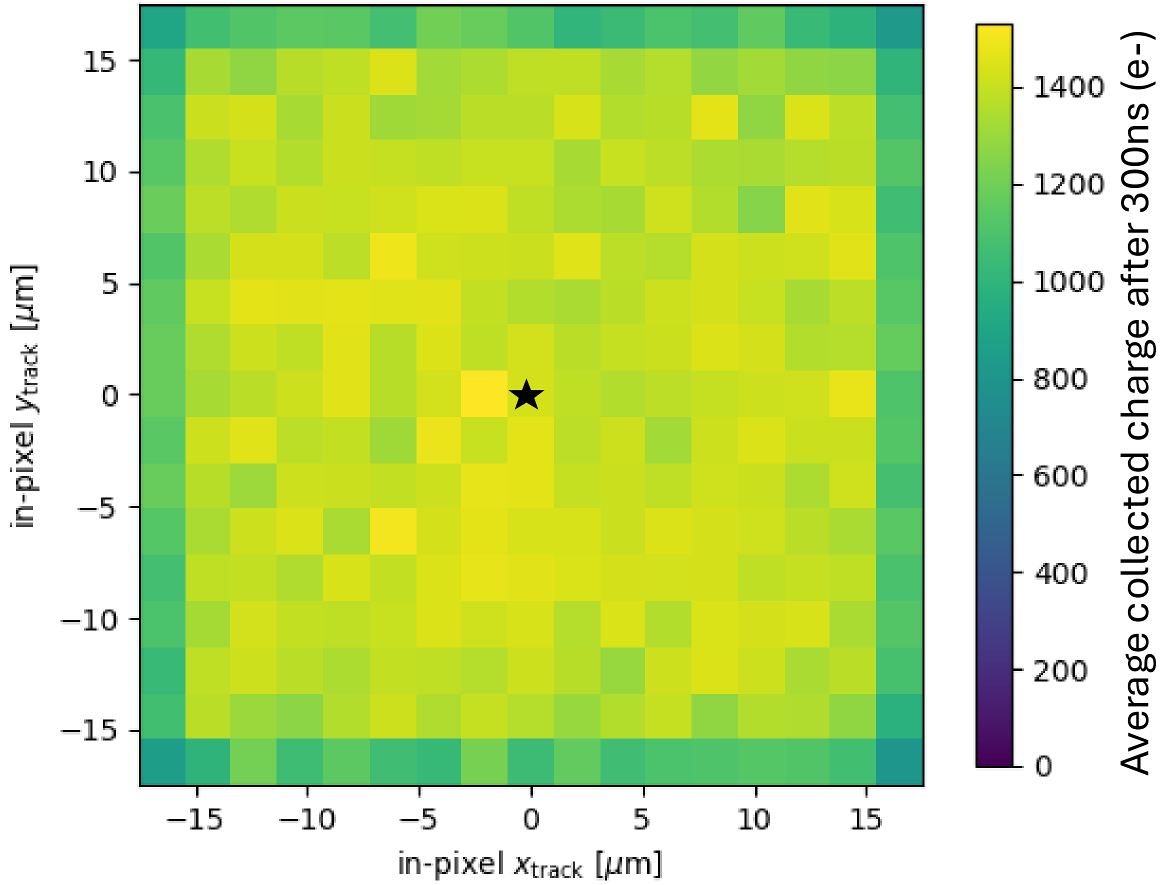


Importance of rise time

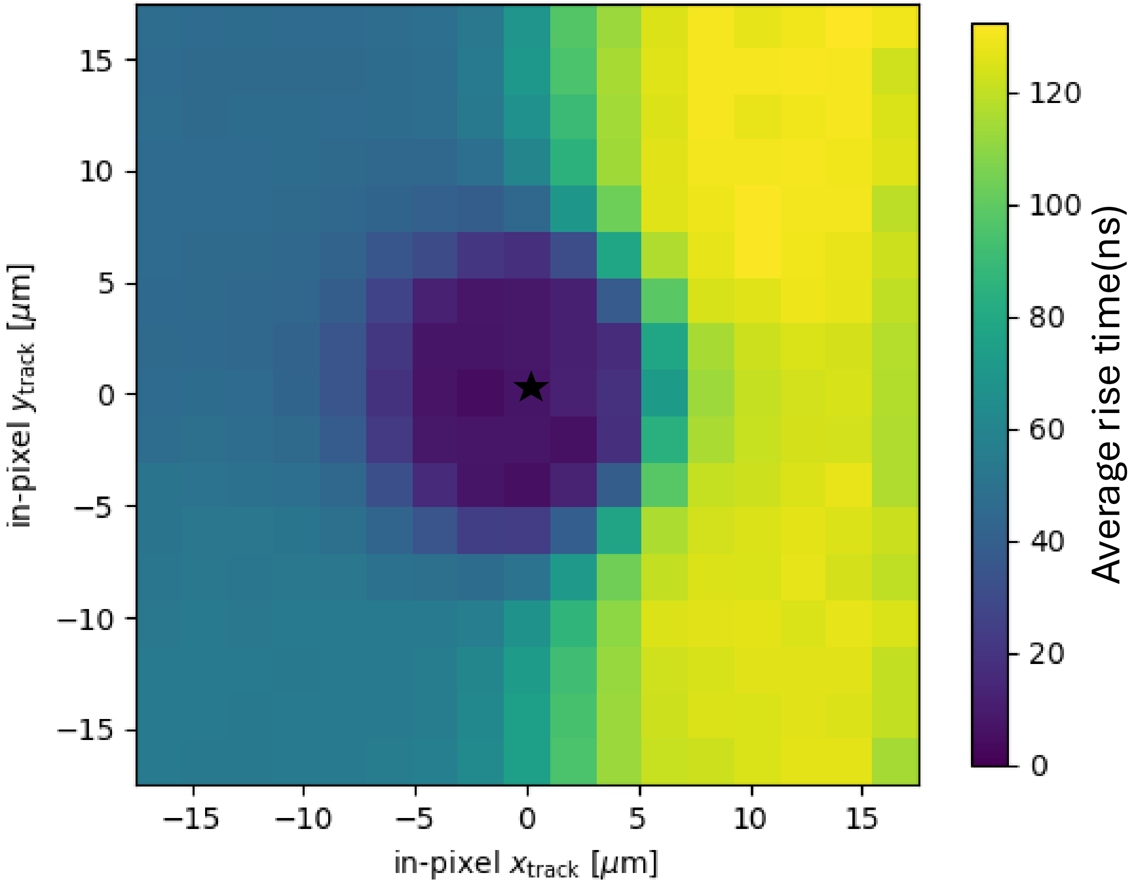
Allpix^2: **Simple iron source**

- Point like deposition of 1.6 or 1.8ke-
- Lifetime: SRH-Auger model
- Mobility: Masetti-Canali model
- Timestep: ≤2ps

★ Collection electrode

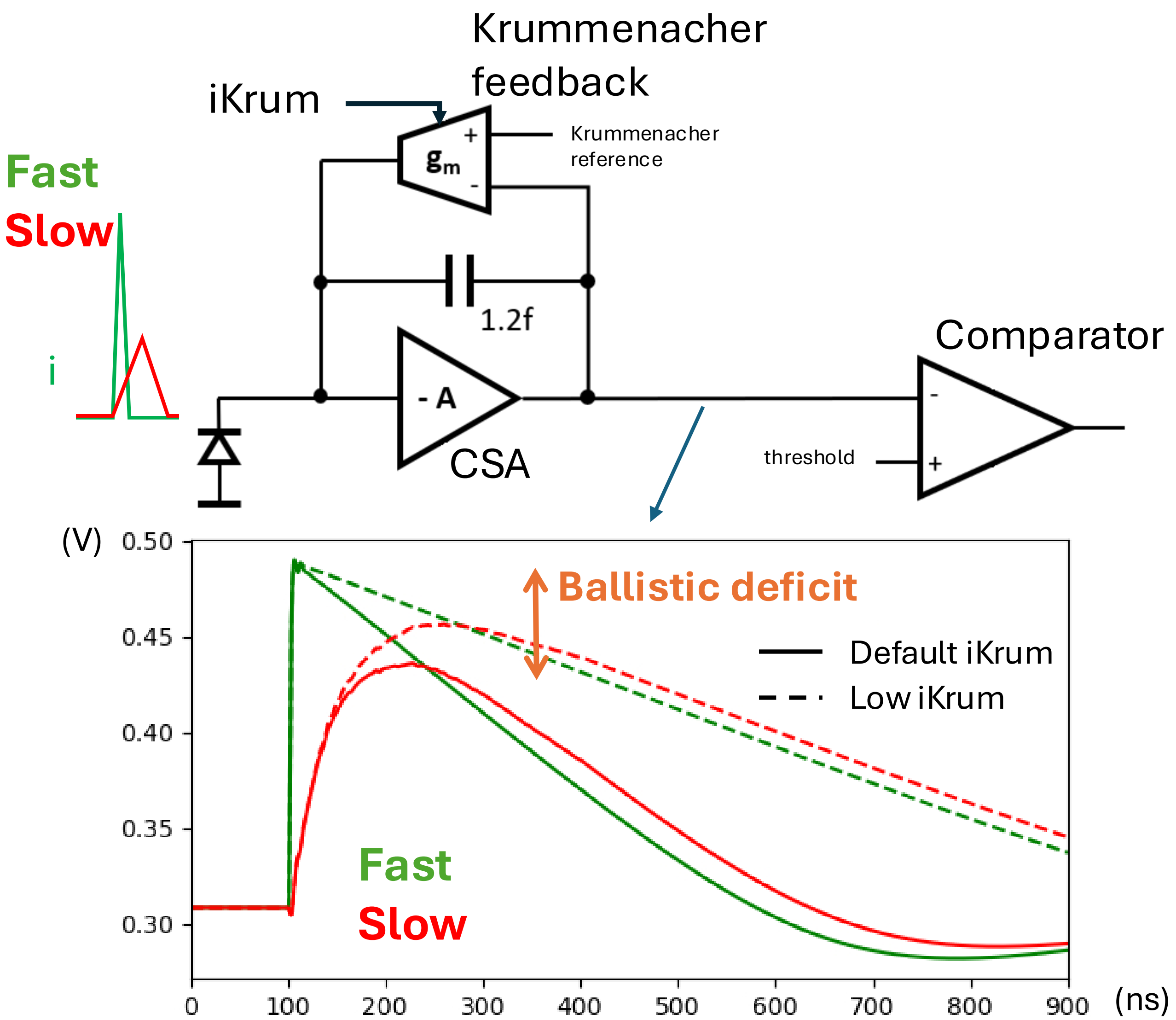


Total charge collected is uniform



Rise time (10% to 90%) is strongly asymmetric

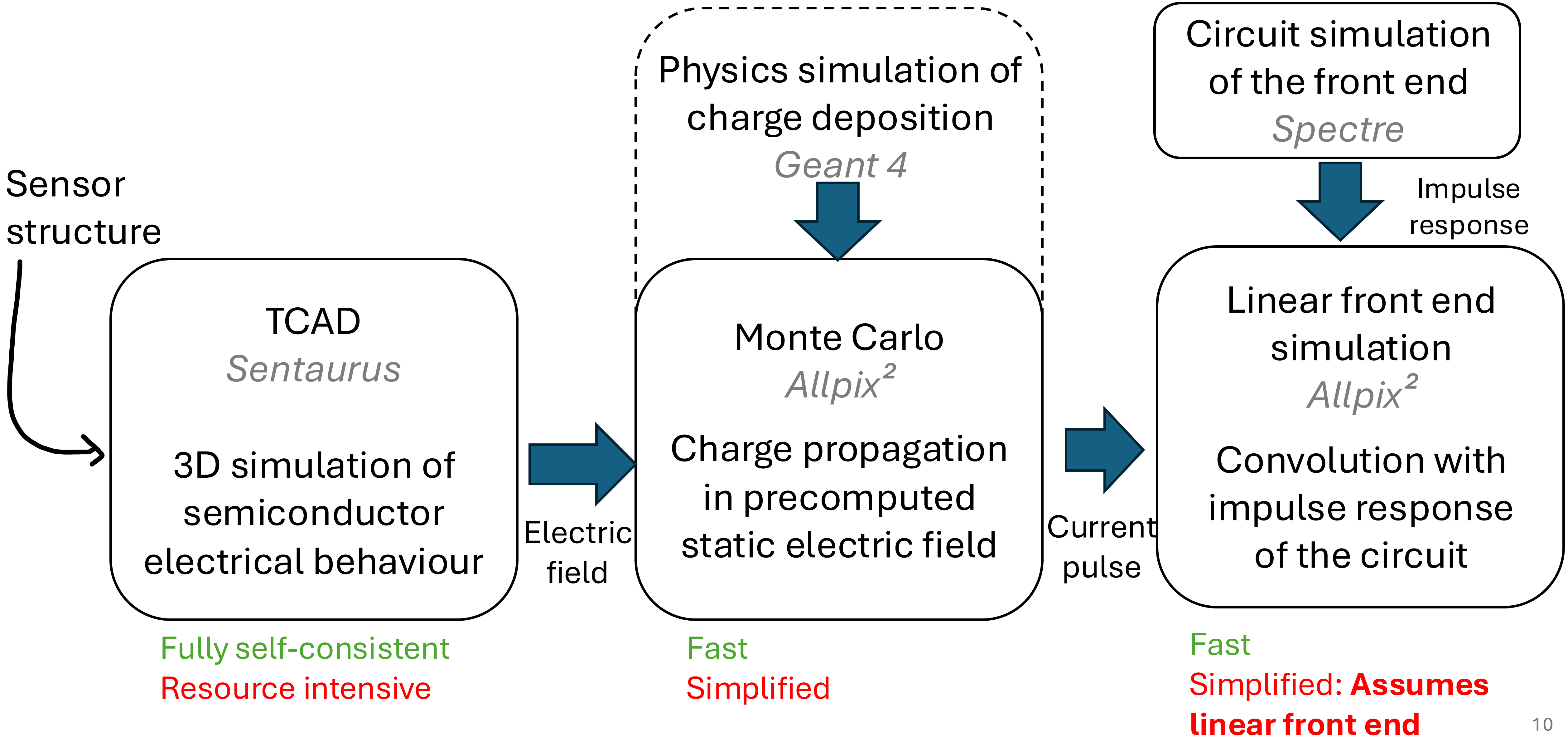
Ballistic deficit



- For TOT, return to baseline at constant slope, set by 1/iKrum
- For the same total charge, collection speed affects amplitude through ballistic deficit
- Faster return to baseline (=higher iKrum) is more affected

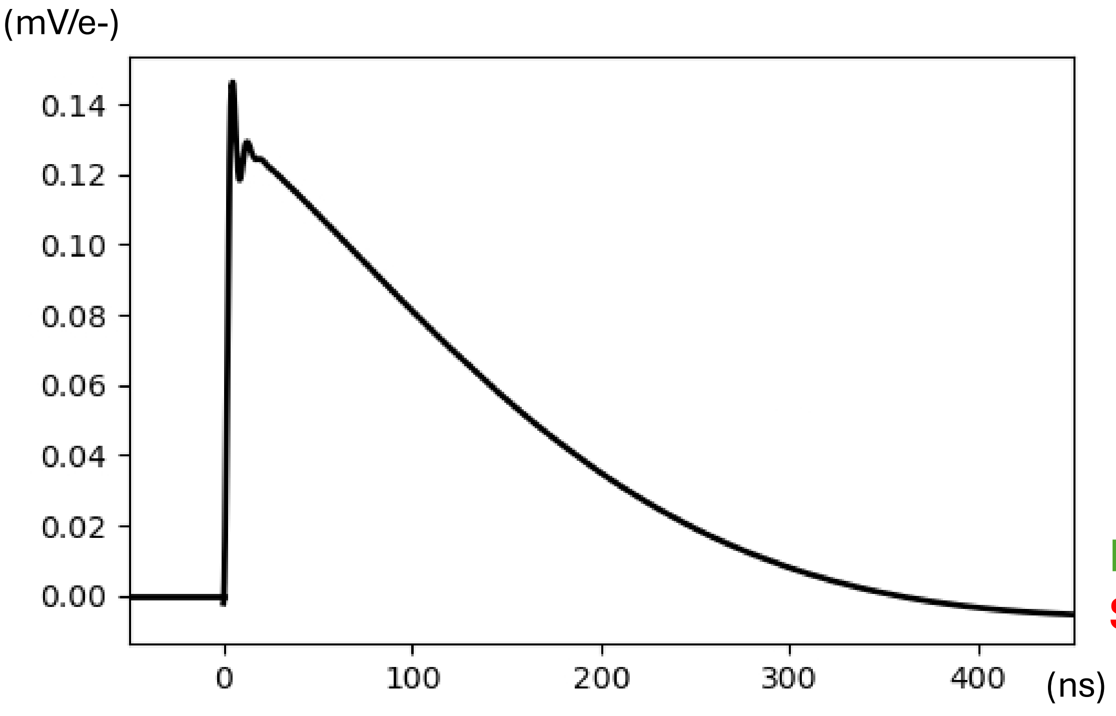
Simulated output of the CSA for the same input charge (1600e-) but different rise time.

Including the front end in the simulation

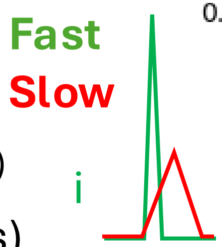


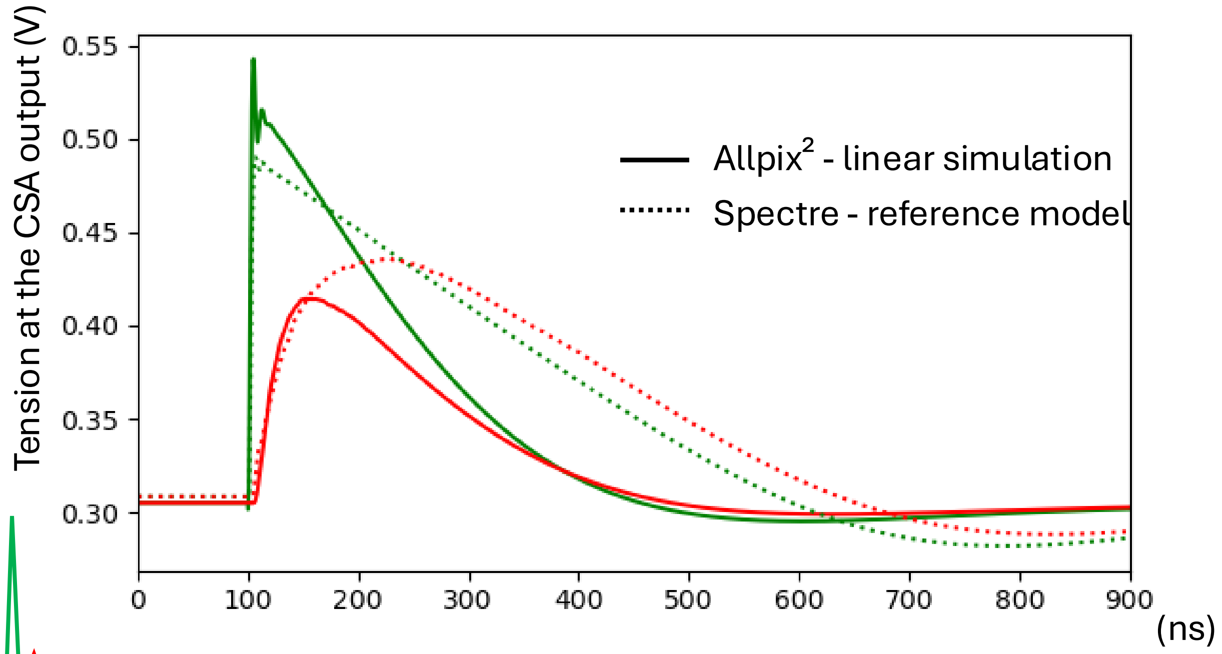
Including the front end in the simulation

- Front end response is **not** linear (e.g. return to baseline)
- Linear approximation overestimates the ballistic deficit
- Return to baseline of simulated waveforms is completely off



Impulse response of the front end (default settings)





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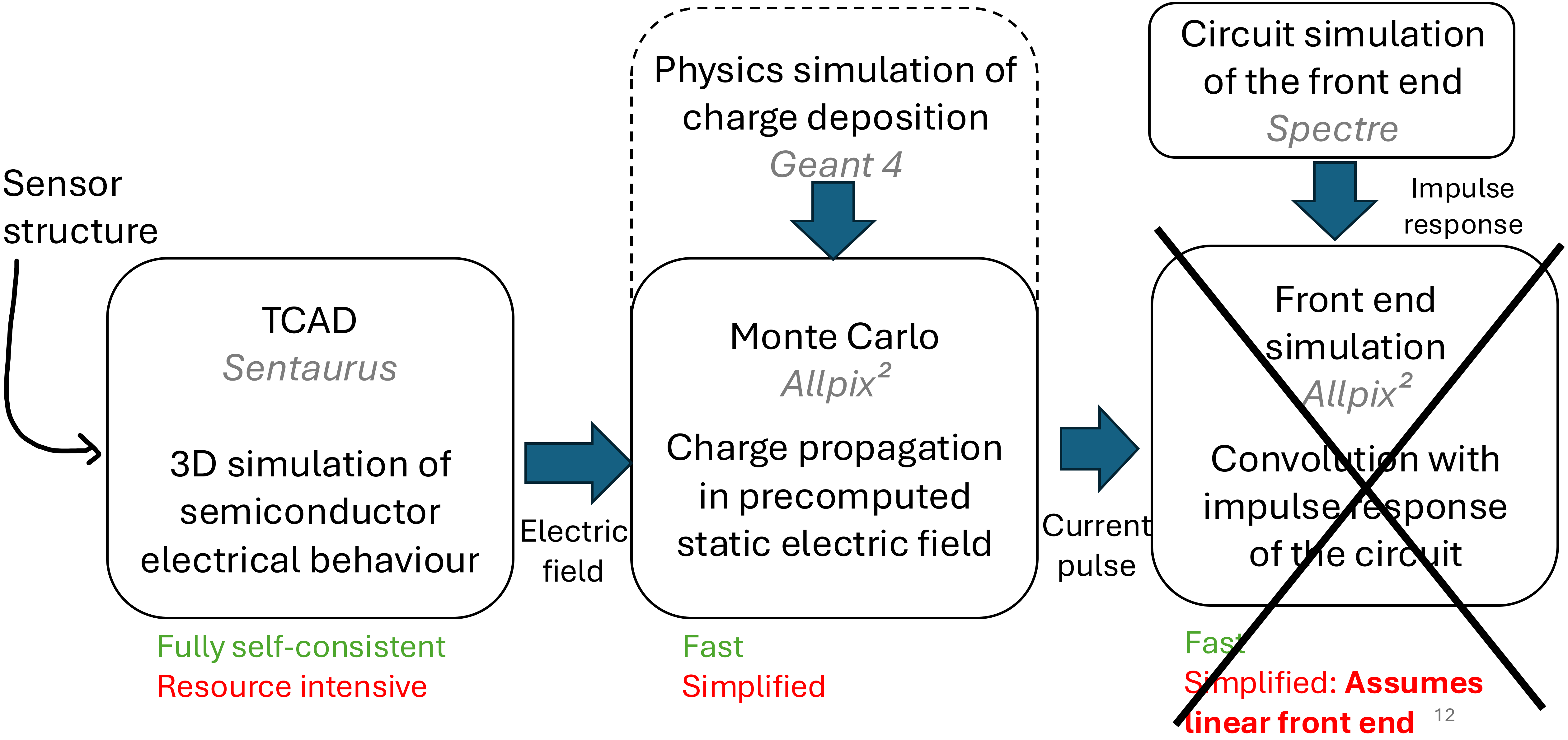

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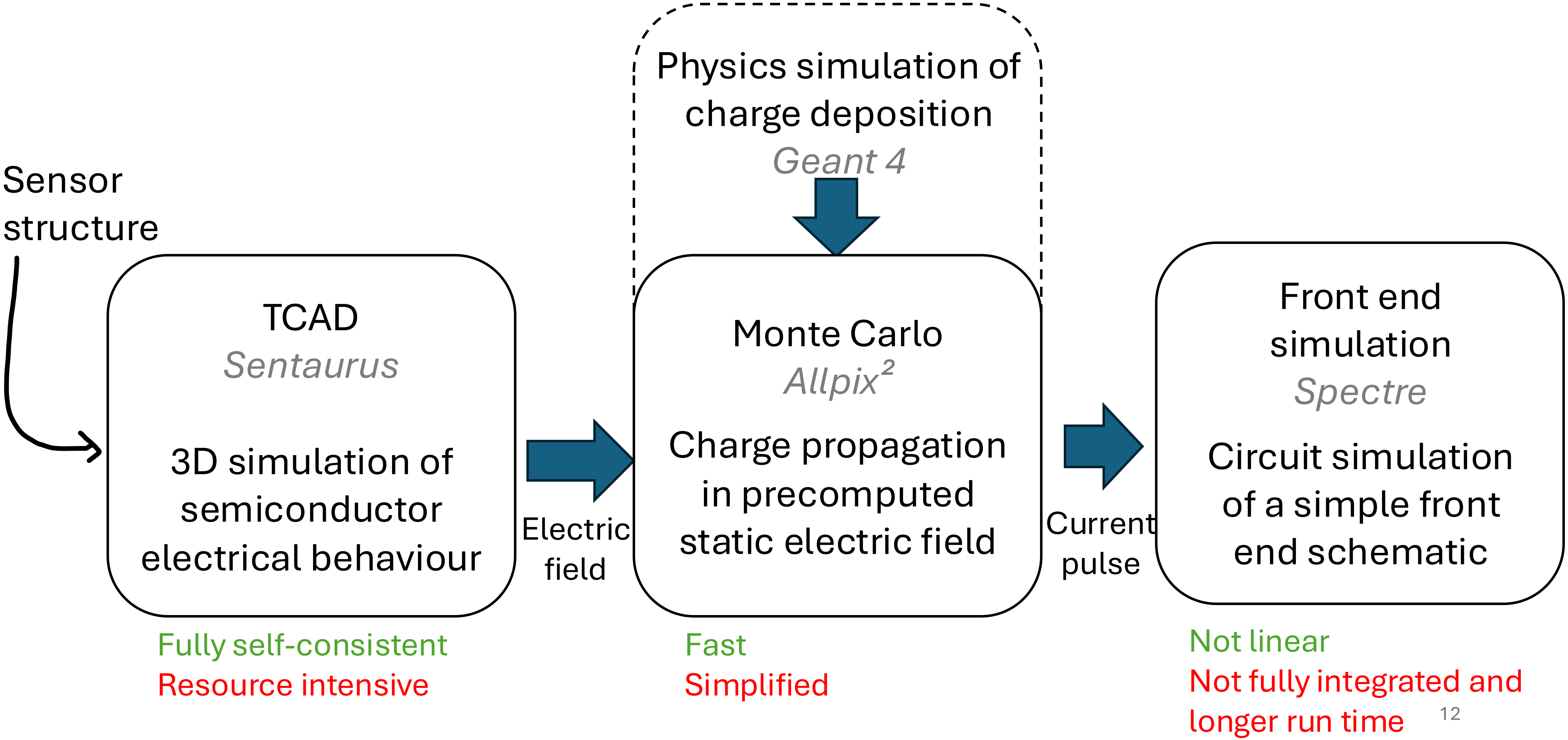


Simulation results

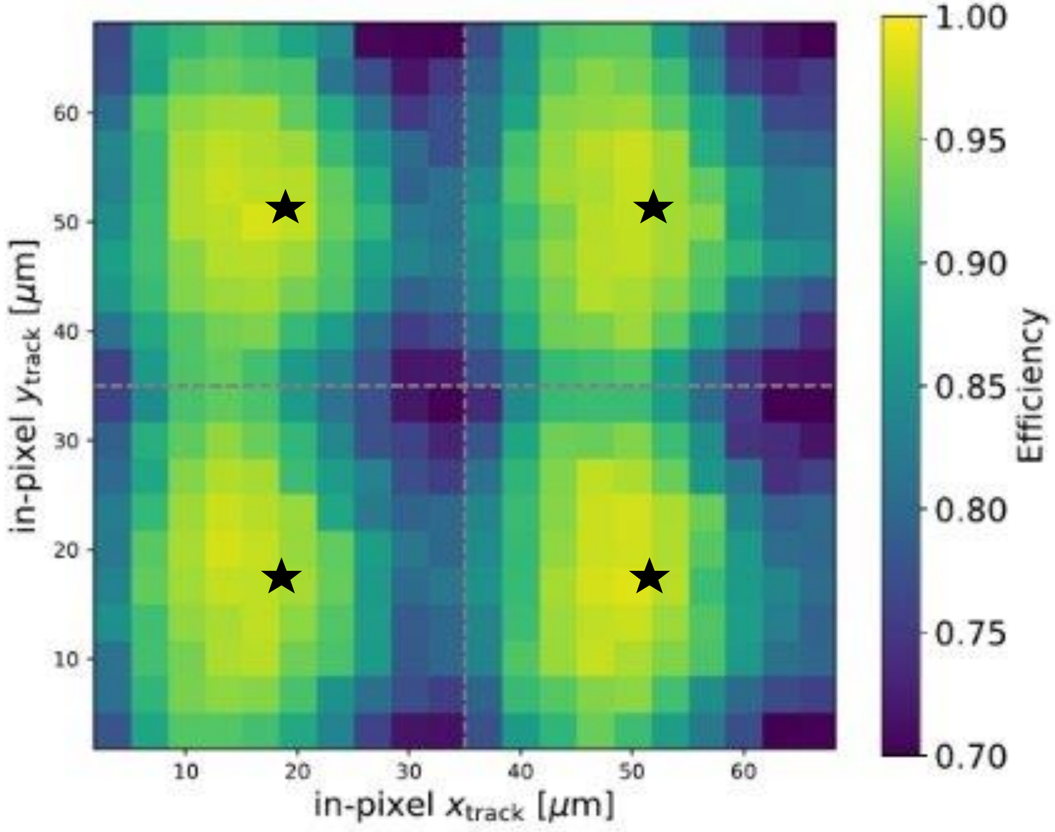
Allpix²: test beam (see parameters slide 8).
Spectre: schematic view, liberal, without noise.
Analysis: adding ~33e- rms noise
3um track smearing (telescope resolution)
Calibration on 1600e- pulse with ~70ns rise time

Measurements

Simulations

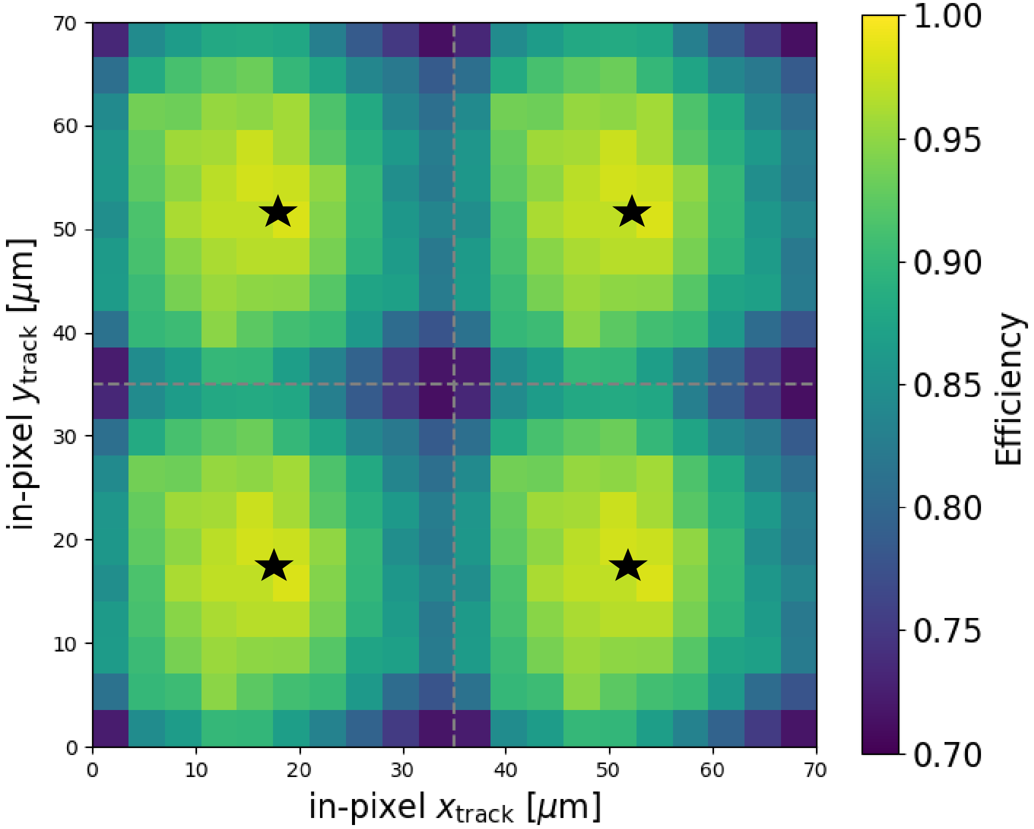
Vbias = - 1.2 V, ikrum = 21, THL = 323 e-

Efficiency = 87.2%



★ Collection electrode

Efficiency = 88.4%



For the simulation, the plotted data are the same for all 4 pixel

Simulation results

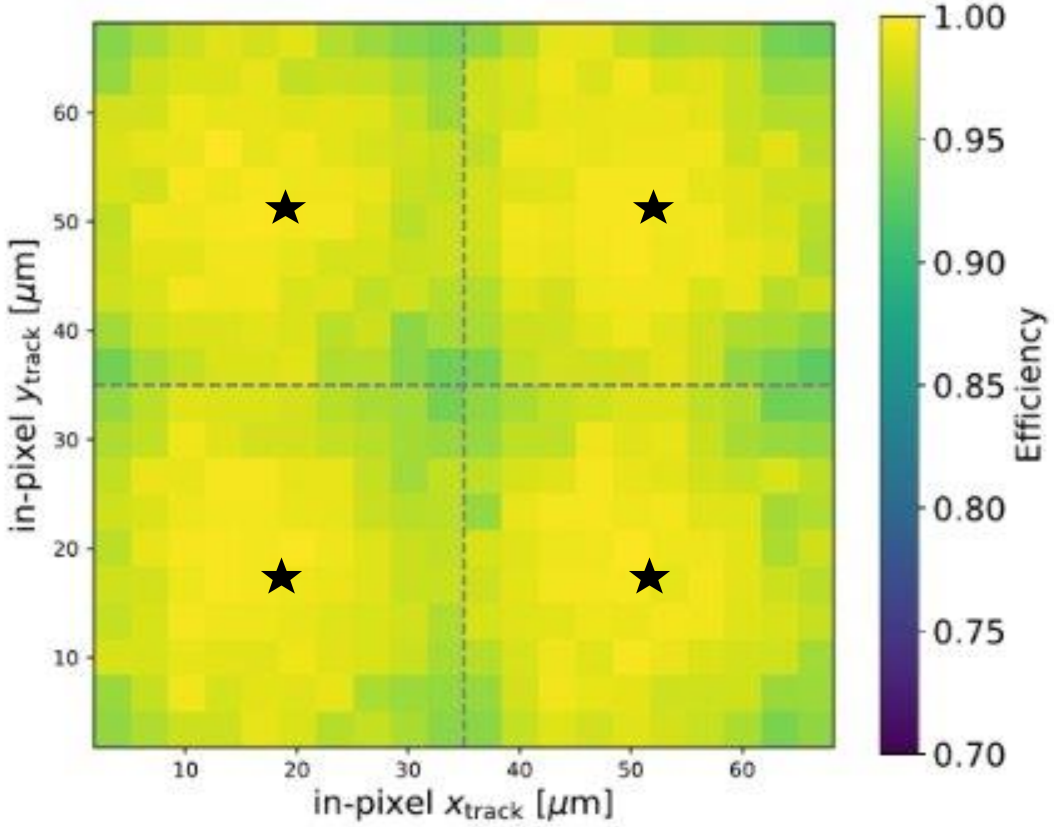
- Asymmetry and trend reproduced

Still not perfect matching with data

Measurements

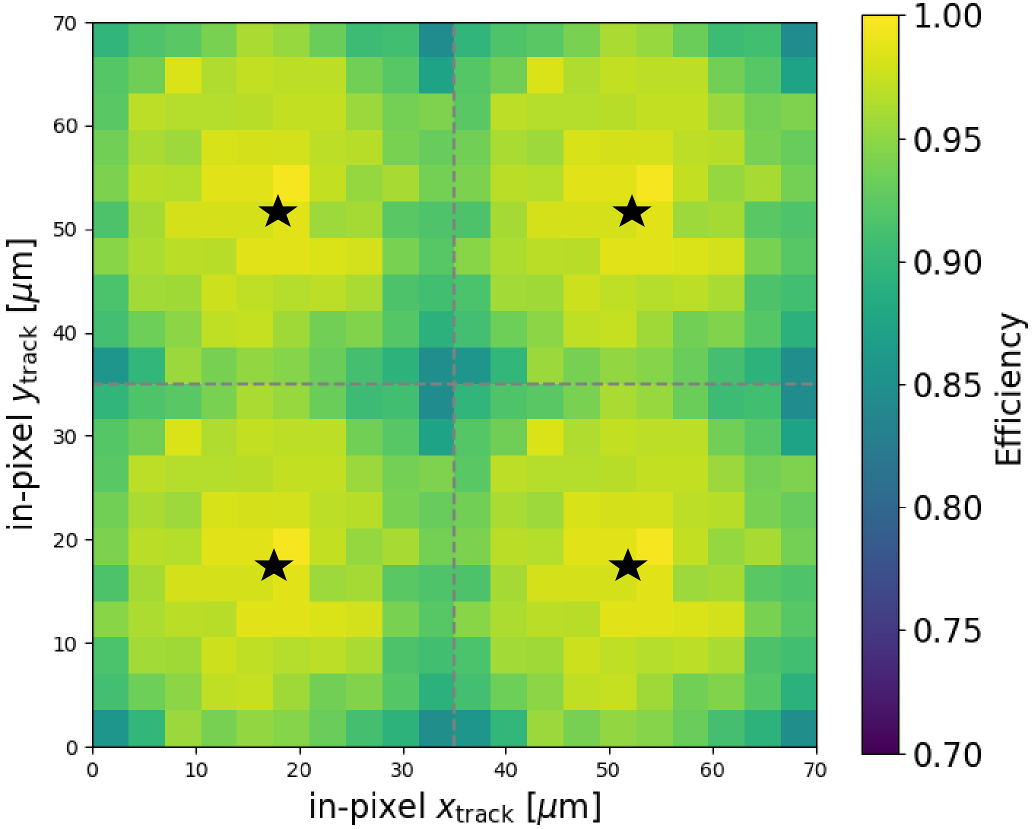
Efficiency = 97.9%

Vbias = - 3.6 V, ikrum = 10, THL = 240 e-



Simulations

Efficiency = 94.5%



★ Collection electrode

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Conclusions

- The asymmetric efficiency pattern of the H2M was reproduced in a simulation combining TCAD, Monte Carlo and circuit simulator.
- The underlying mechanism is that specific circuit layout features can slow down the charge collection for large pixel pitches.
- The fast H2M front end filters out slower signals, therefore impacting the efficiency at high threshold.
- No such effects observed other prototypes in the same technology (APTS, DPTS, MOSS…)
- Now this unexpected effect can be evaluated at the design stage, which is crucial for future large pitch and fast front end sensors.
  - Exercised on the future MOSAIX sensor, no expected issue.