Testbeam characterization of the H2M chip designed in a 65 nm CMOS imaging process

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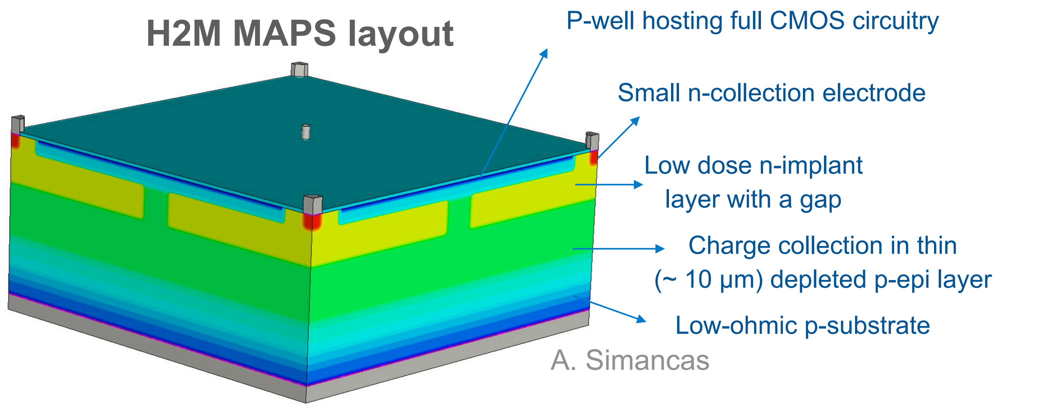
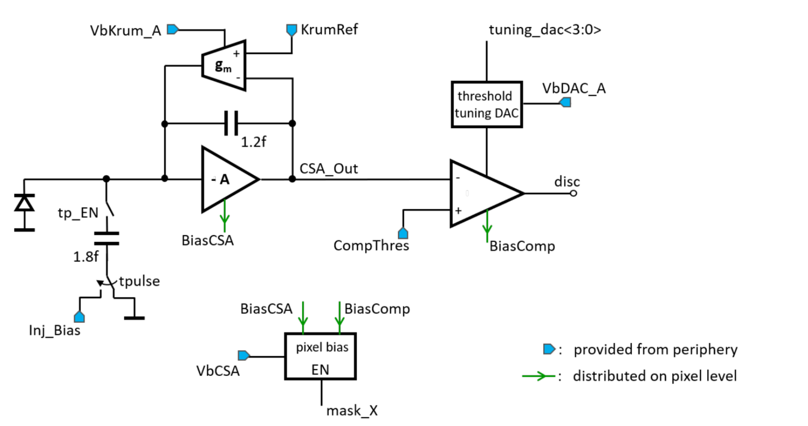
MAPS in a 65 nm CMOS imaging technology

- **MAPS** integrates the sensor and the readout electronics in the same wafer. Compared to hybrid detectors:
  - ✔ Reduces complexity and production cost
  - ✔ Smaller pixel sizes are achievable
  - ✔ Reduces material budget
- **MAPS with a small collection** electrode results in small sensor capacitance and a large S/N.
  - ✔ Good tracking resolution (~ 3μm) ✔ Small power consumption (~ 50 mW/cm²)
  - ✔✔ Good candidates for lepton, electron-ion colliders, and test beam telescopes
- **Simulation-based process modifications** and **layout optimization** enhance charge collection.
- From 180 nm to **65 nm CMOS Imaging Technology**
  - ✔ Higher density of in-pixel logic
  - ✔ Smaller pixels or more complex in-pixel logic

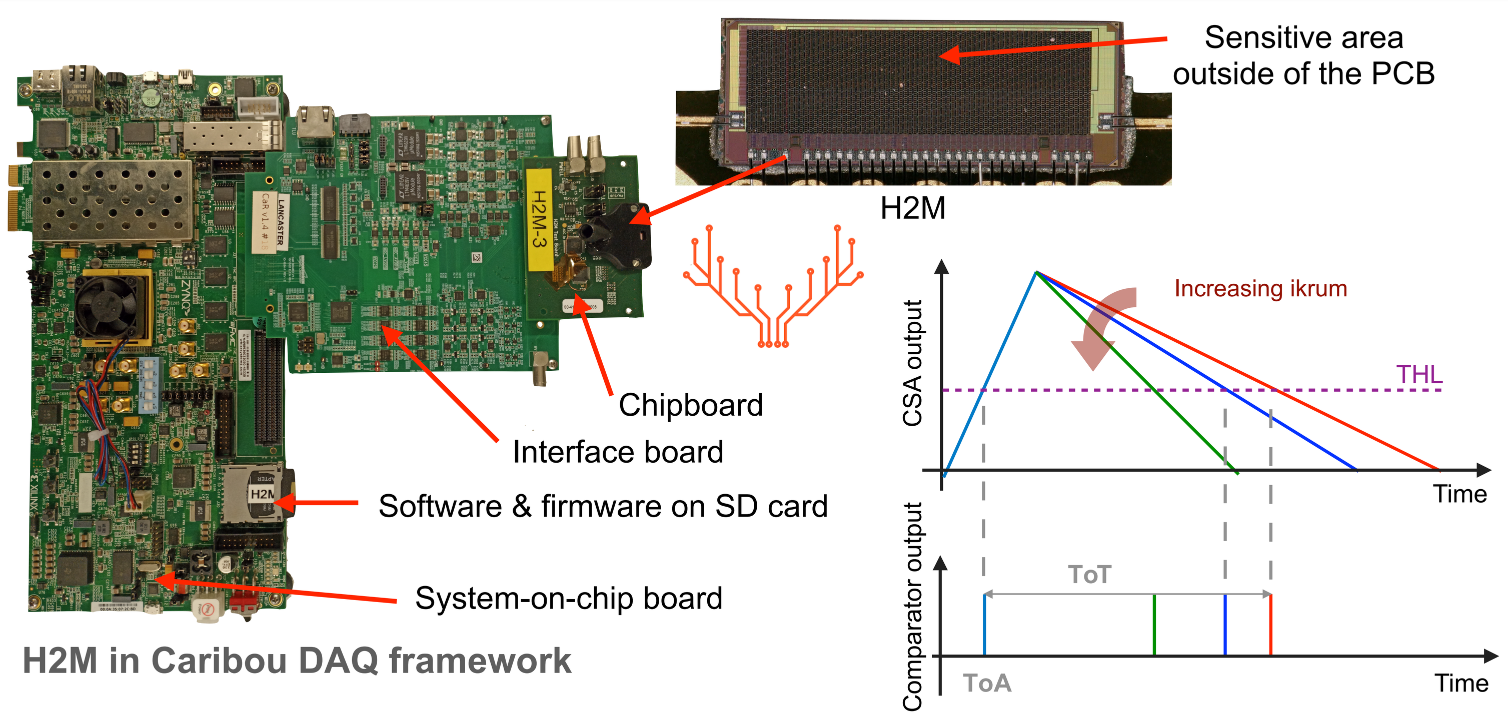
H2M (Hybrid-to-Monolithic)

- Ports a **hybrid pixel detector architecture into a monolithic chip**.
- **Digital-on-top** design workflow.
- Manufactured in a TPSCo **65 nm CMOS imaging process**.

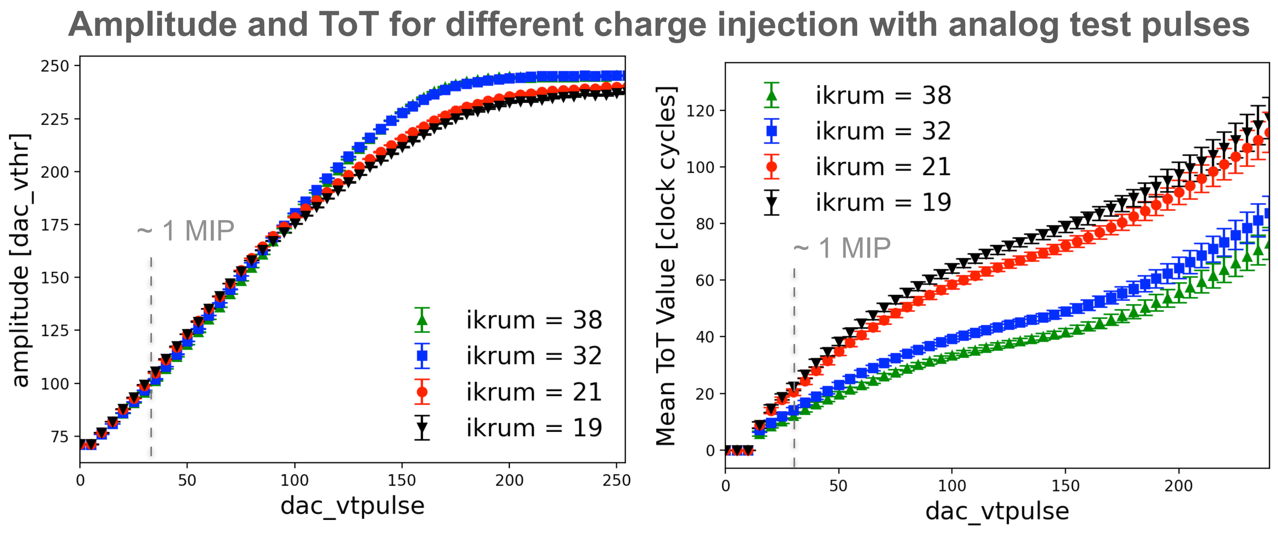




- **35 μm pixel pitch in 64x16 pixel matrix** (total sensitive area: 2.24 × 0.56 mm²).
- Non-simultaneous **acquisition modes**, per pixel: 8 bit ToT resolution, 8 bit ToA resolution (100 MHz clock - 10 ns timing), photon counting, and triggered.
- **Readout**: 40 MHz clock, frame-based without zero-suppression.

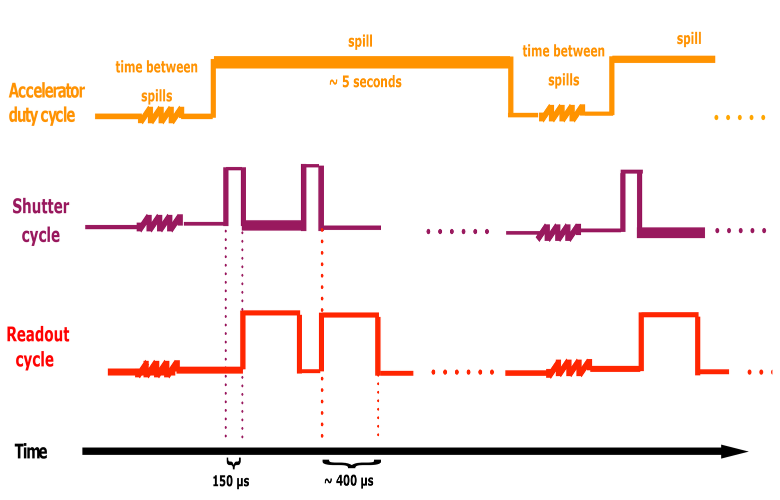


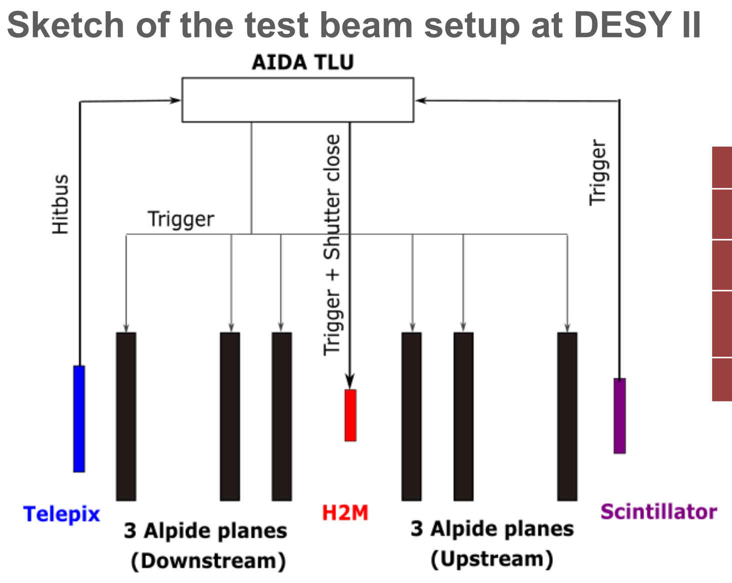
Lab measurements



- Threshold tuning to reduce threshold dispersion between pixels.
- Optimization of the chip operational parameters.
- Single-pixel noise of ~ 70 electrons r.m.s.
- Calibration of test-pulse DACs.
- IV measurements. Increase in leakage current at higher reverse bias (V_{bias}). Safe operation range between 0 and - 4 V_{bias}.

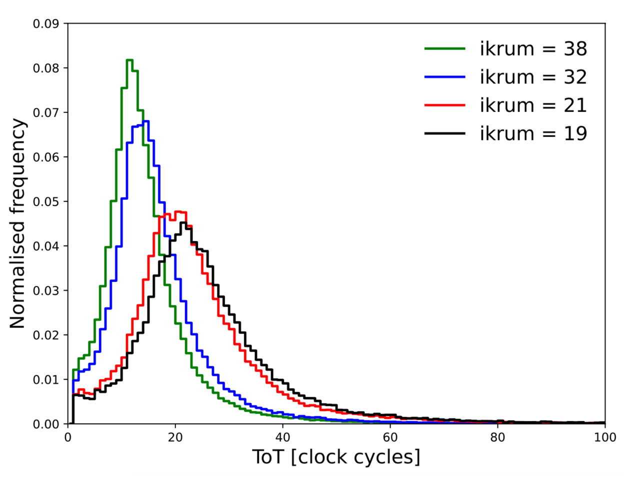
Testbeam measurements

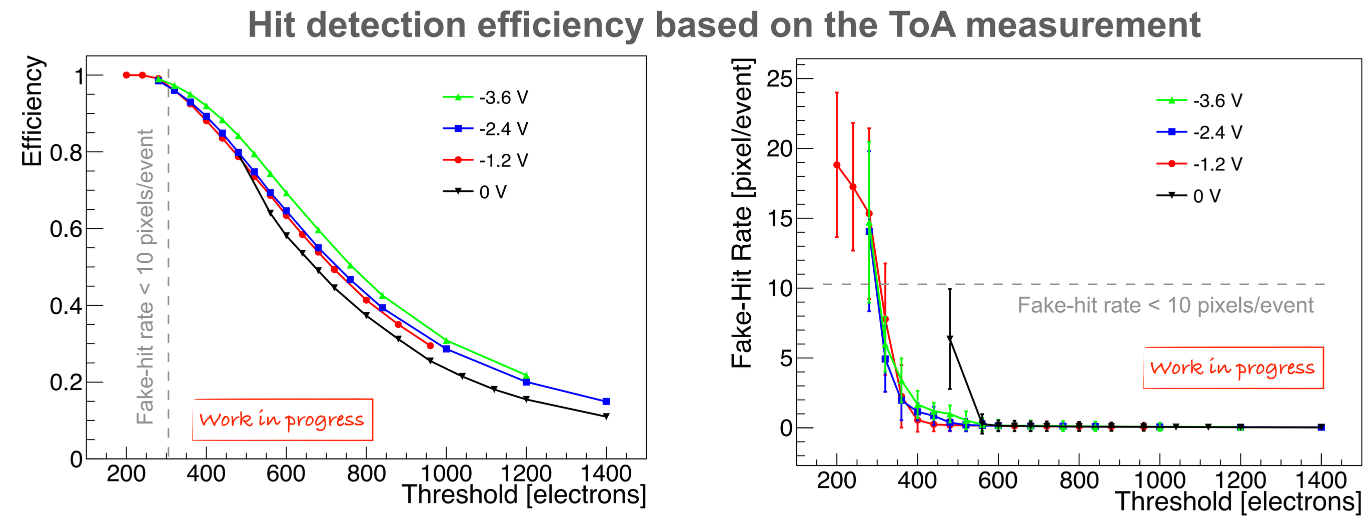




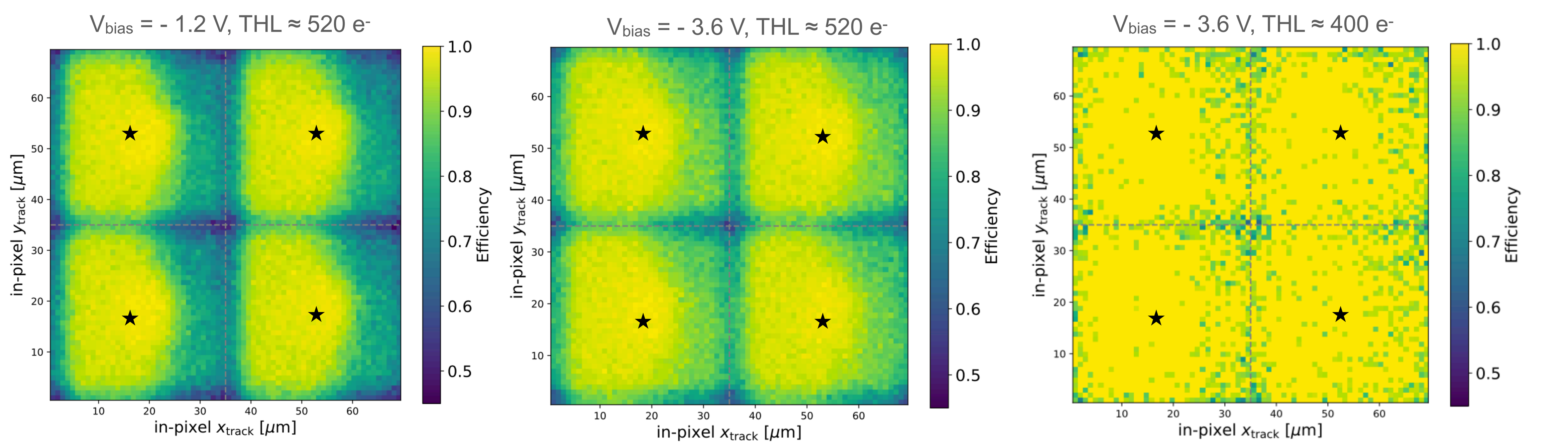
	SPS	DESY II
Beam momentum	120 GeV	5.4 GeV
Testbeam telescope	Timepix3	ALPIDE
H2M acq. mode	ToT	ToA
Acquisition time of H2M	150 μs (*)	~ 1 ms (**)
Trigger	-	Telepix & Scintillator

* Shutter opens after the previous readout; the shutter closes after 150 μs.
** Shutter opens after the previous readout; shutter closes with the trigger signal.





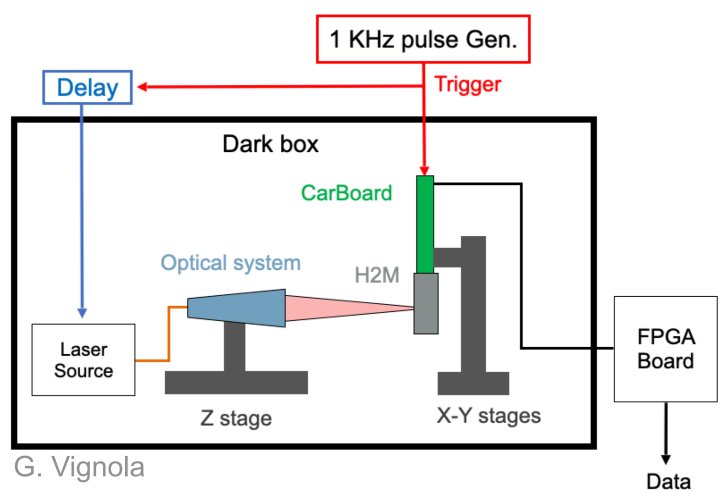
- Observed **expected efficiency and fake-hit rate dependence on threshold** (THL), but :
  - Significant **noise** contribution below ~ 320 electrons, combination of noise level and long acquisition time.
  - **In-pixel efficiency indicates charge loss**, not predicted by simulations using generic doping profiles.

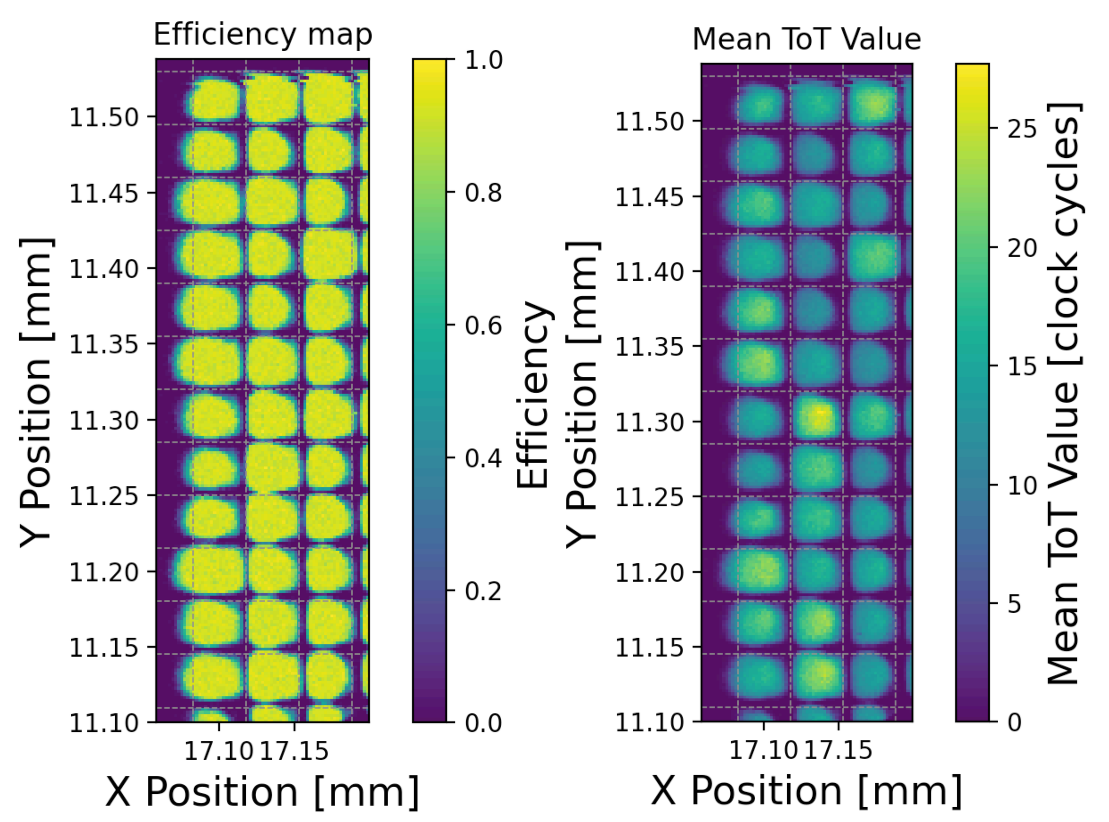


- Pattern qualitatively reproduced in simulations using proprietary doping profiles, related to the size and location of the n-wells of the analog circuitry.
- Mitigated at larger V_{bias} and lower thresholds.

Laser measurements

- Backside incidence with an **infrared pulsed laser.**
- Confirmation of **in-pixel efficiency pattern** observed in test beam measurements.
- **Pixel-to-pixel differences** attributed to differences in the circuit's Krummenacher current and feedback capacitance.





Summary

- **Fully functional advanced digital-on-top sensor in a 65 nm CIS.**
- Successfully integrated into the **Caribou DAQ**.
- **Non-uniform in-pixel efficiency** observed in testbeam.
  - Qualitatively confirmed by simulations and laser measurements.
  - Combined effect of fast front-end, low V_{bias}, large pixel size, and threshold.

Outlook

- Investigating reducing the noise and lowest threshold achievable using the **triggered acquisition mode**.
- Studying **new chip operational parameters** for a more stable operation of the CSA with Krummenacher feedback and smaller pixel-to-pixel differences.
- Threshold and ToT **calibration** per pixel to physical units for direct comparison to simulations.

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