Time resolution of the RD50-MPW2 HV CMOS

Uwe Krämer, Jory Sonneveld

Nikhef

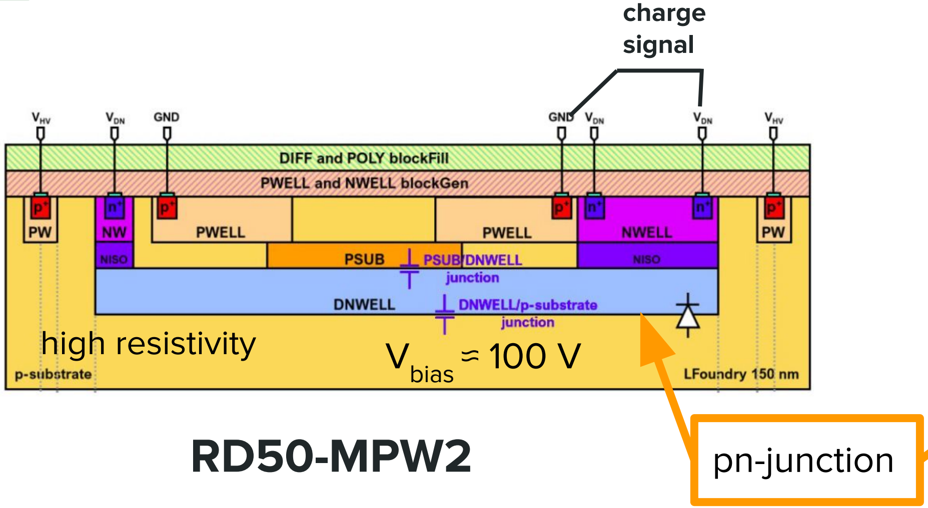
jory.sonneveld@nikhef.nl

43rd RD50 Workshop 2023

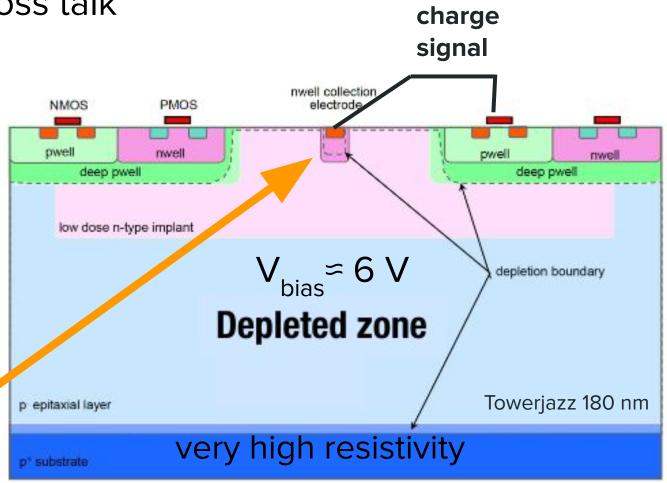
Depleted MAPS: small and large collection electrodes

✅ High field almost everywhere
✅ Short drift distances
✅ Higher radiation tolerance

✅ Very small sensor capacitance ~5 fF
✅ Reduced noise & power
✅ Readout outside charge collection well: less cross talk



RD50-MPW2



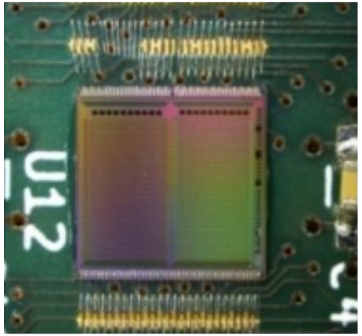
ALICE MAPS prototypes

- Stronger electric field results in less trapping and higher radiation tolerance
- Larger electric field comes at a cost: more capacitance, power and more noise

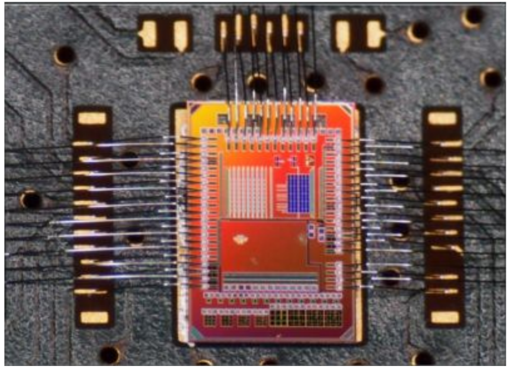
From E. Vilella, Vertex2018

RD50 CMOS development

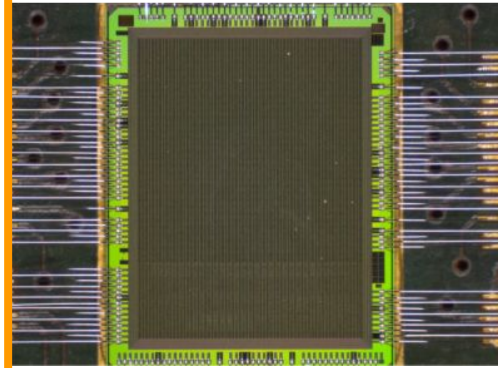
2017
RD50-MPW1



2019
RD50-MPW2



2021
RD50-MPW3



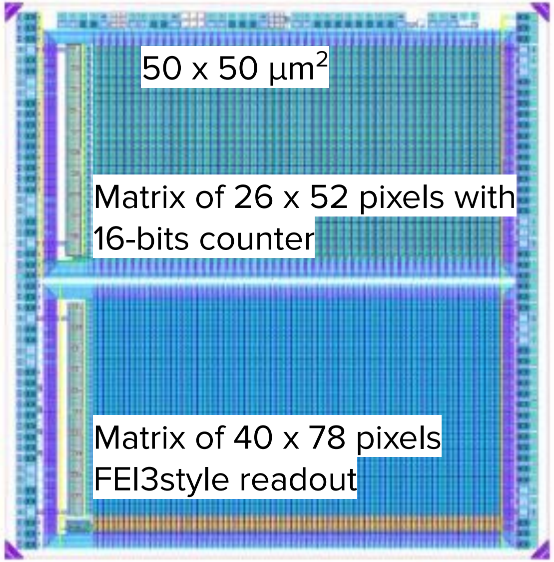
2023
RD50-MPW4

Coming soon!

Three submissions of RD50 HV CMOS monolithic sensors

RD50-MPW1

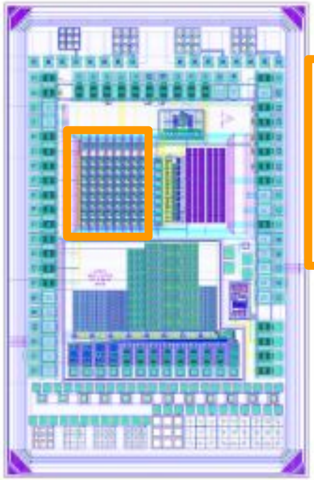
5×5 mm^2



Low breakdown $V_{bd} \approx 60$ V
High leakage current I_{leak}~µA

RD50-MPW2

3.2×2.1 mm^2

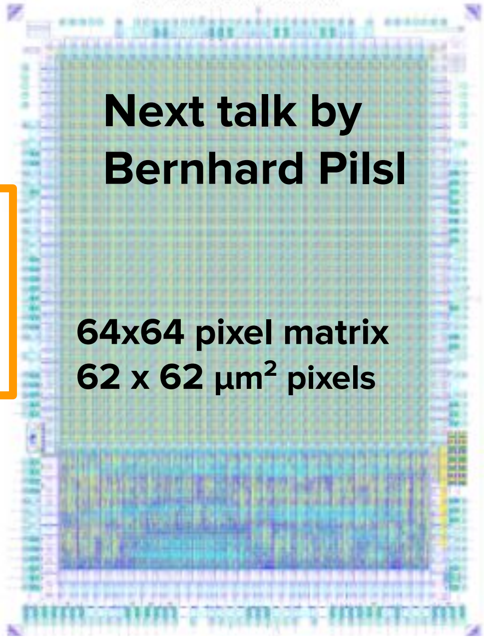


Small 8x8 matrix 60 x 60 µm^2 pixels

High breakdown $V_{bd} \approx 120$V
Low leakage current I_{leak}~nA
Analog readout only

RD50-MPW3

6.6×5.1 mm^2



In-pixel digital readout
Advanced peripheral readout

Image from [40th RD50 workshop](https://indico.cern.ch/event/1157463) https://indico.cern.ch/event/1157463

RD50-MPW2

- Two pixel flavors
- 4-bit trim DAC
- Large variety of test structures
- Depletion depths of ~190 µm
- Produced in 1.9 kΩ·cm and 3.0 kΩ·cm resistivities

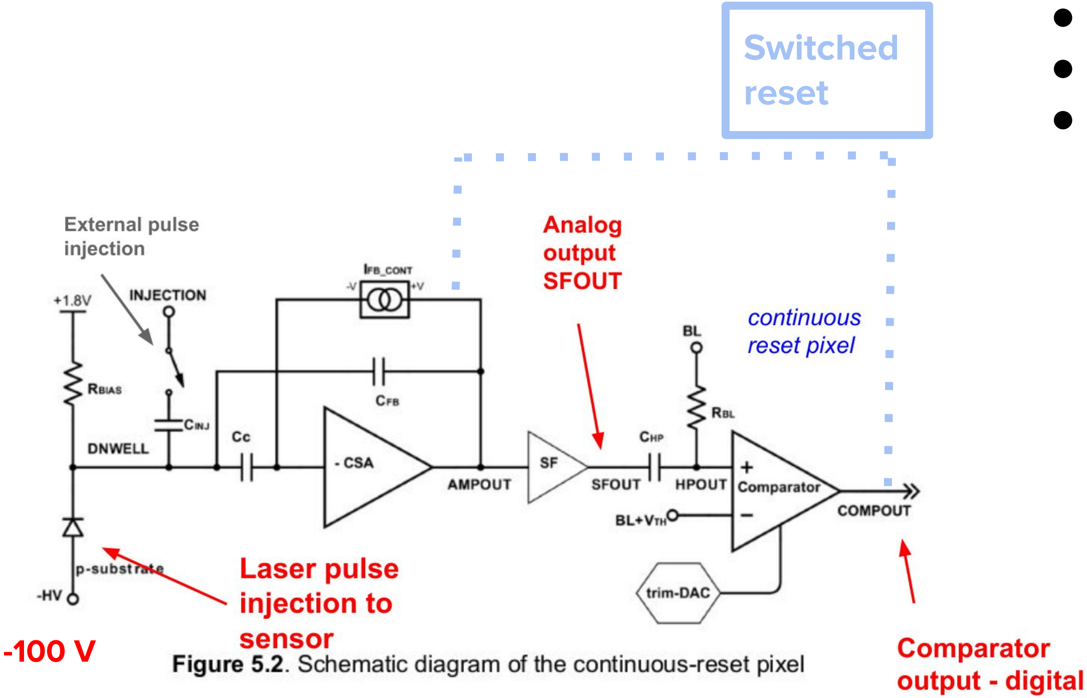
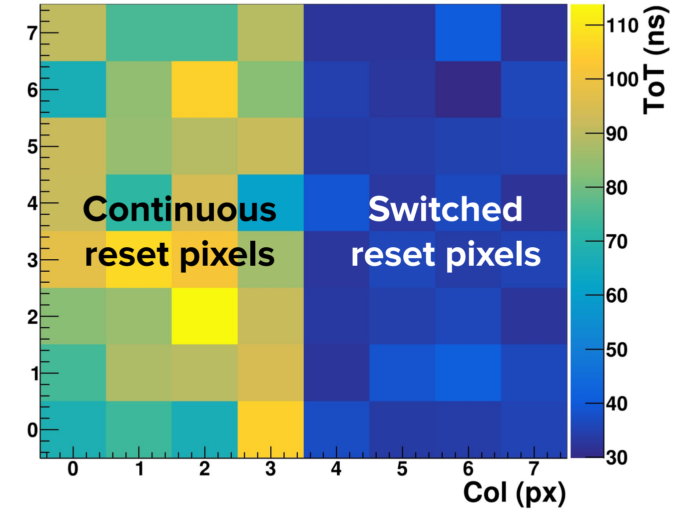
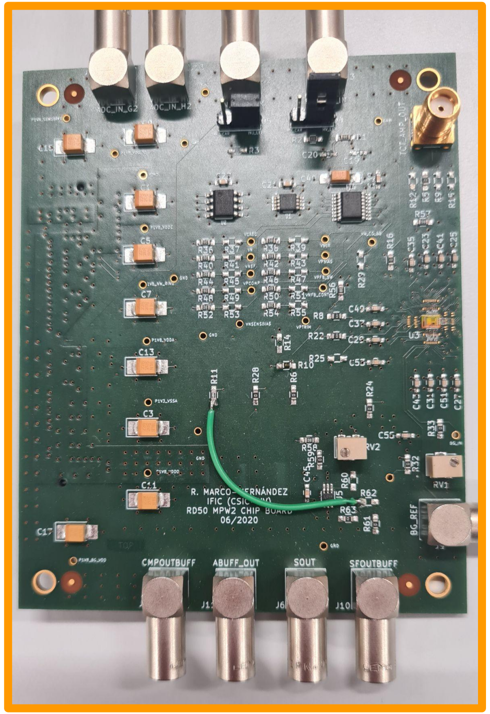


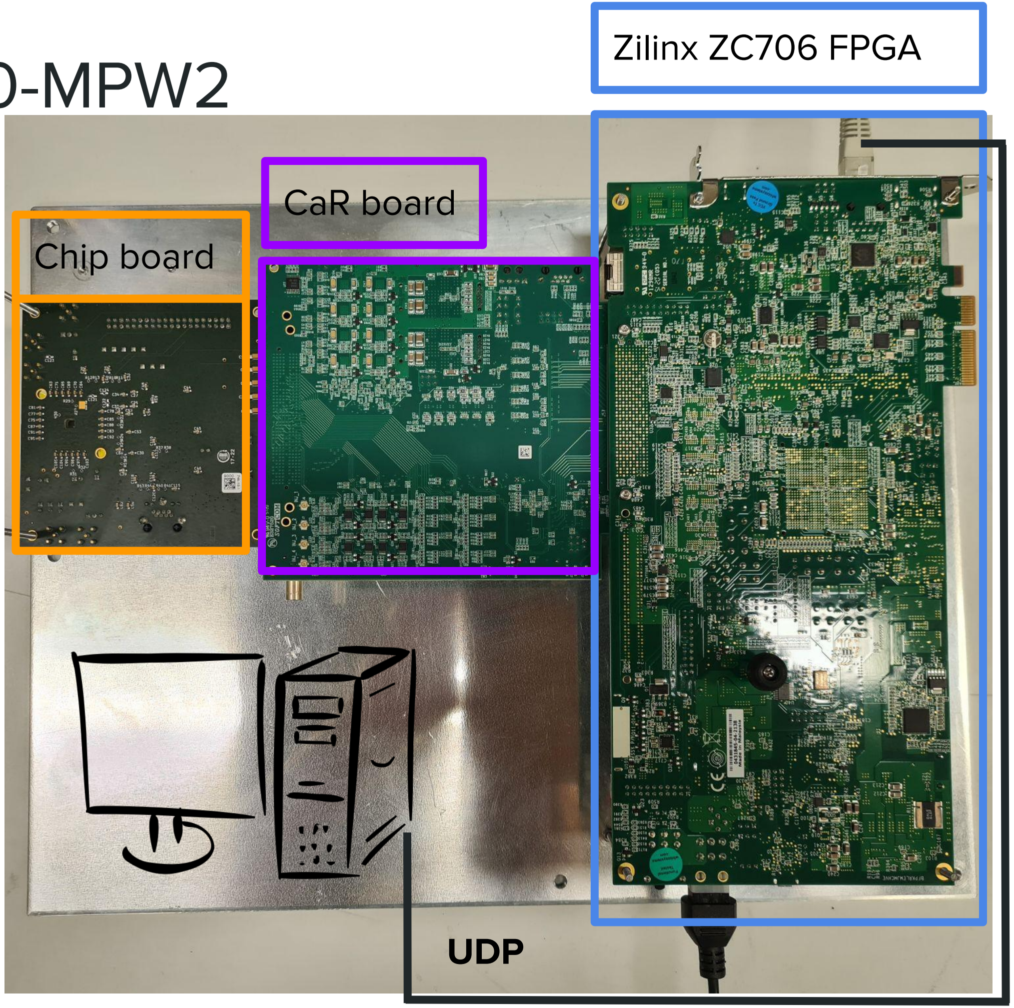
Figure 5.2. Schematic diagram of the continuous-reset pixel



- Continuous reset ToT scales with signal size
- Switched reset much faster reset

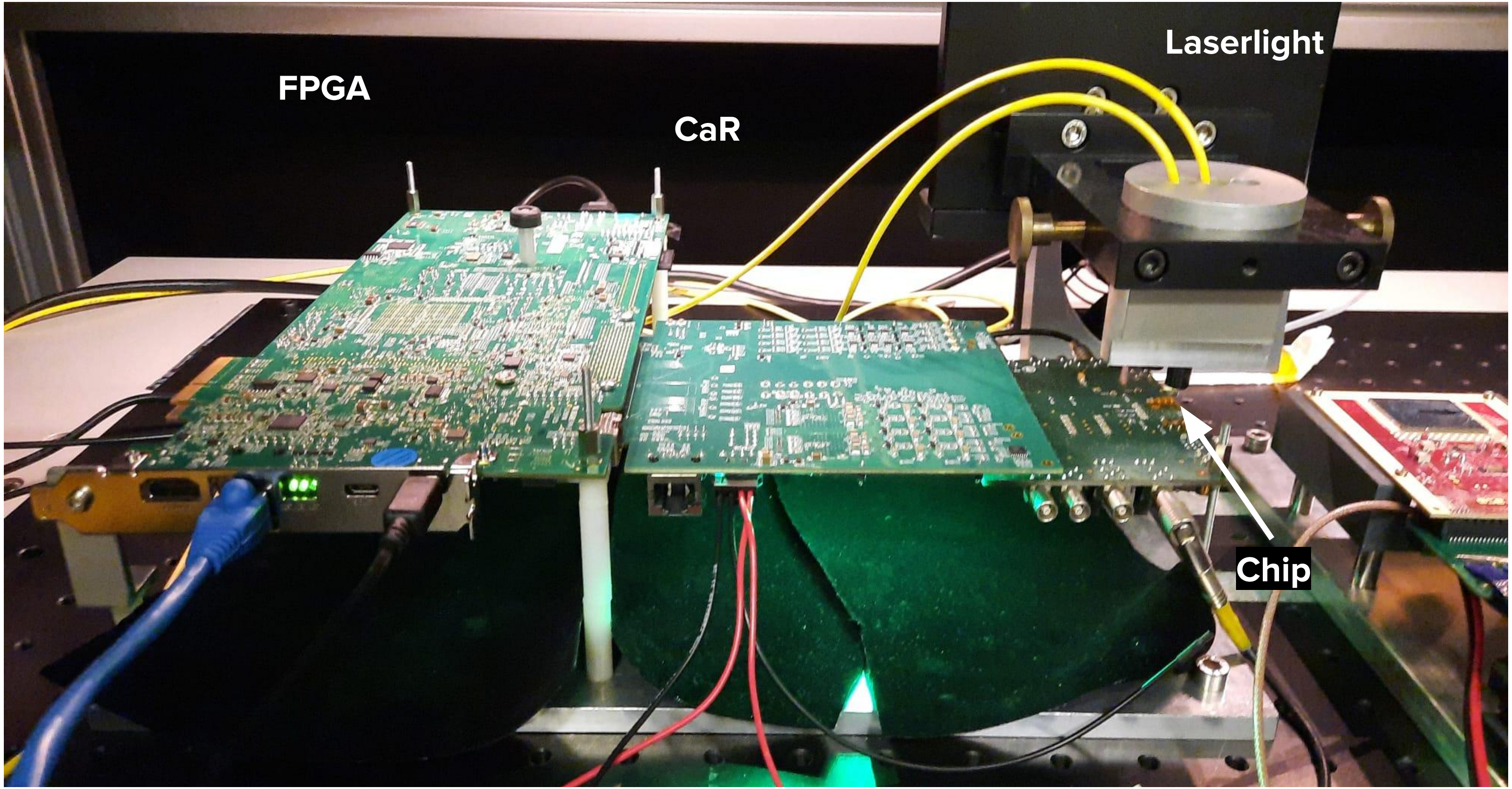
Data acquisition of RD50-MPW2





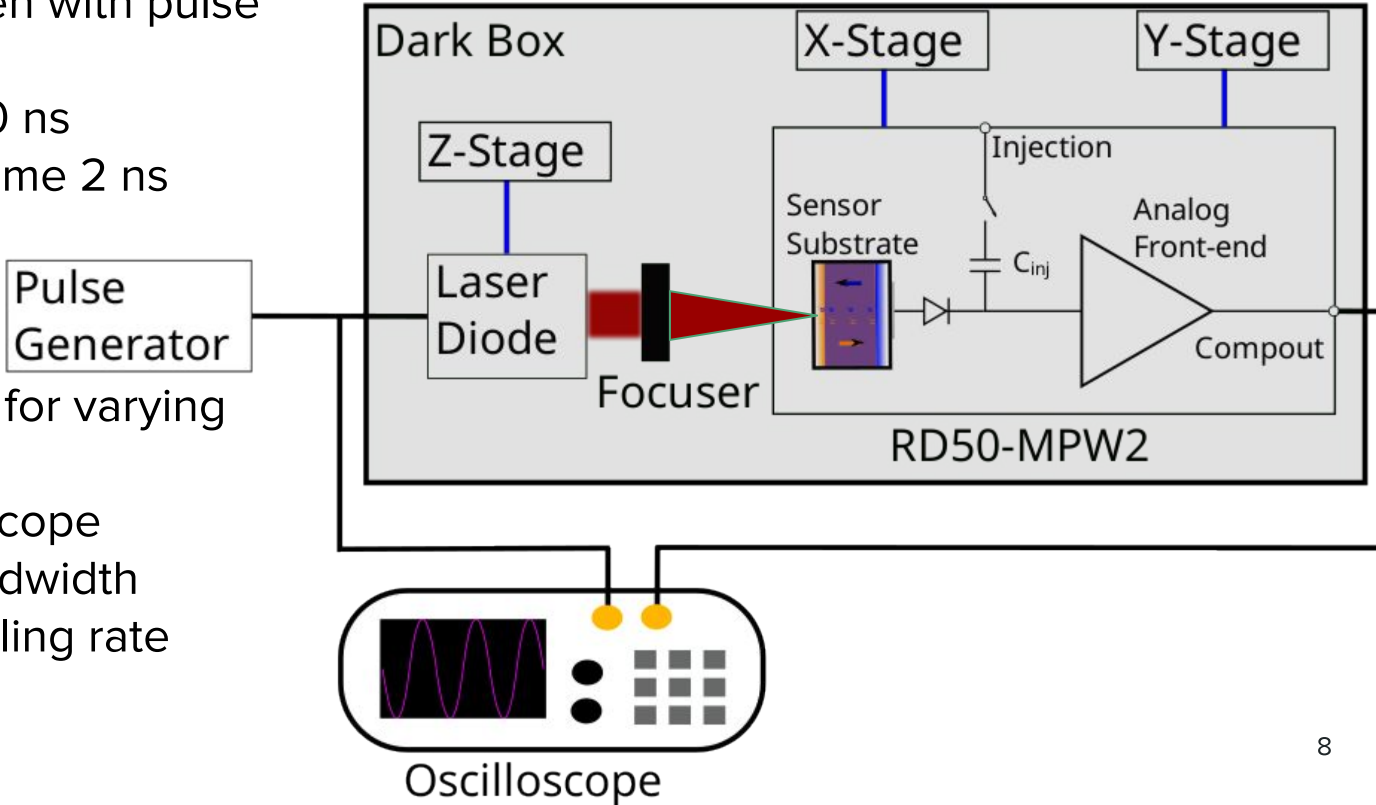
- Caribou used for powering
- ZYNQ-ZC706 with Yocto based linux

Back-TCT measurements at Nikhef



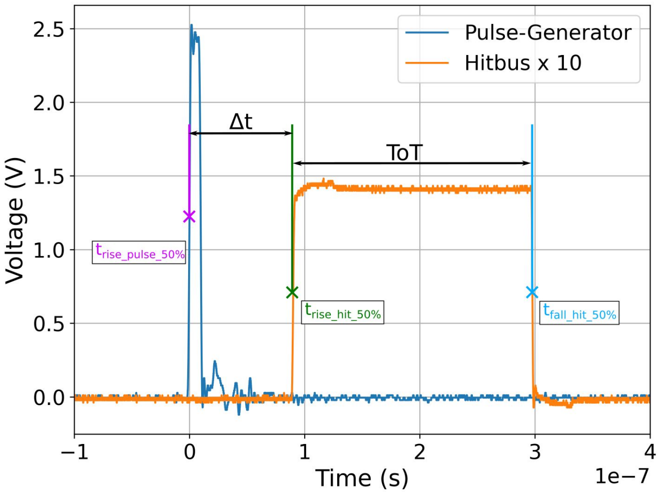
Back-TCT measurements at Nikhef

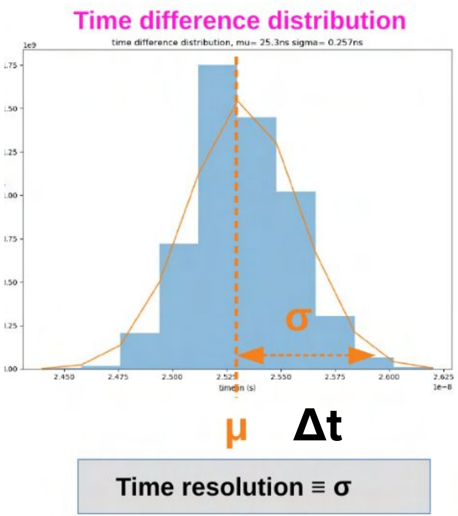
- 980 nm laser driven with pulse generator
  - Pulse width 10 ns
  - Rise and fall time 2 ns
- Amplitude 2.4 V
- Optical attenuator for varying laser intensity
- DSO3000 oscilloscope
  - 500 MHz bandwidth
  - 4 GSa/s sampling rate

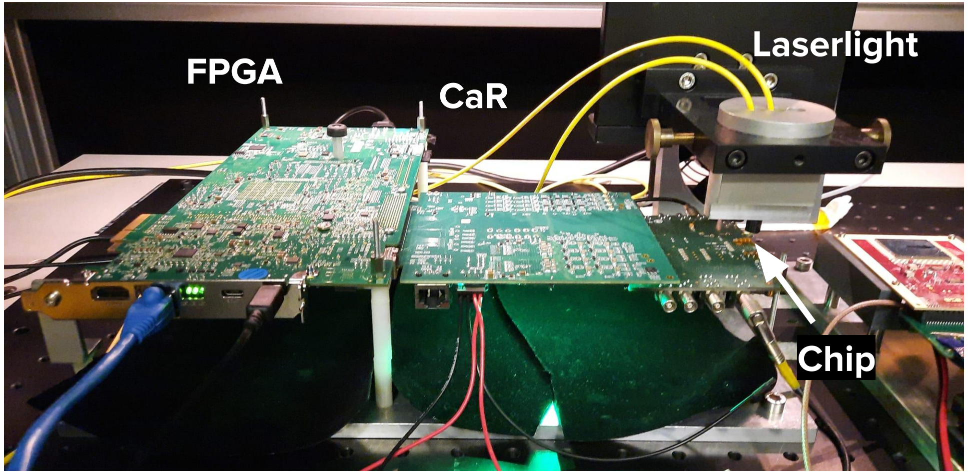


Time resolution

Laser pulse injected with various intensities







The spread in the time difference between the pulse sent to the laser and the comparator output from the chip gives the time resolution

Time resolution measurement

- All measurement points are at 50% constant fraction
- ToT = $t_{fall\_hit\_50\%}$ - $t_{rise\_hit\_50\%}$

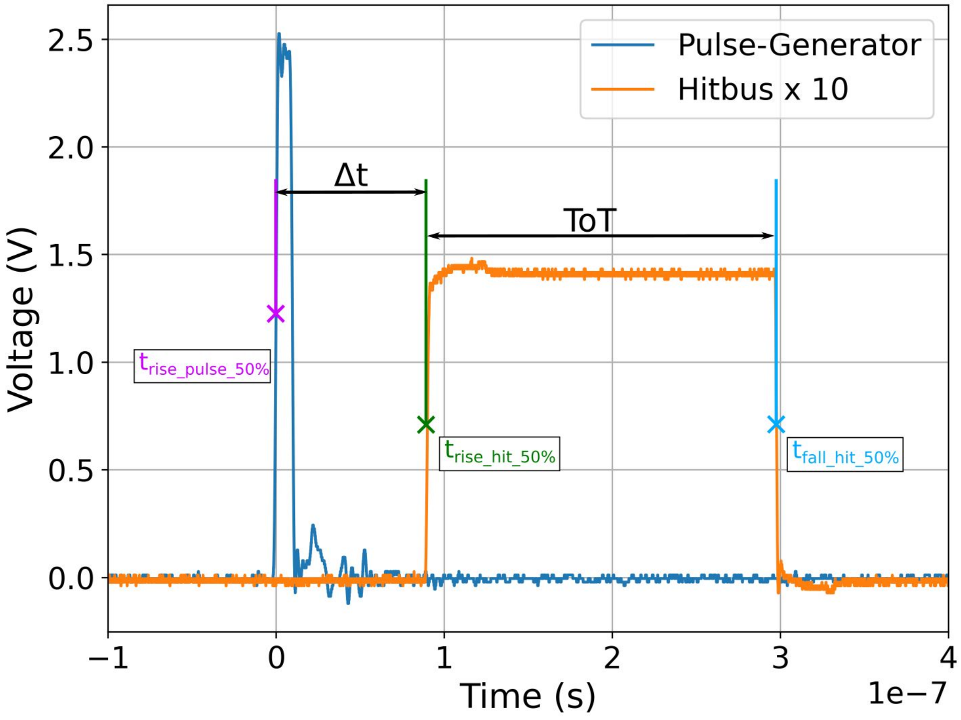
First point of signal is relevant value for time measurement:

Laser measurements

- Δt = $t_{rise\_hit\_50\%}$ - $t_{rise\_pulse\_50\%}$

Test pulse measurements

- Δt = $t_{rise\_hit\_50\%}$ - $t_{fall\_pulse\_50\%}$



Threshold and calibration

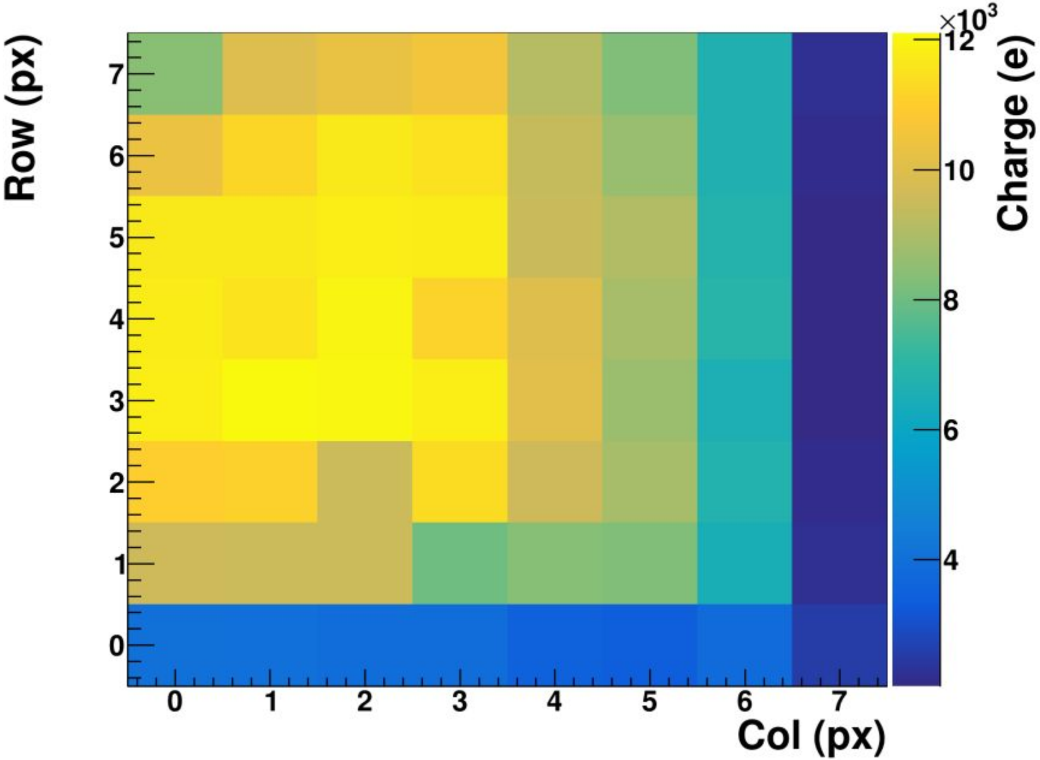
Threshold:

- Threshold 1000 mV with a baseline of 900 mV
- Performed threshold equalization (trimming)
- Switched reset pixels: 1460 e^-
- Continuous reset pixels: 2980 e^-

Charge calibration:

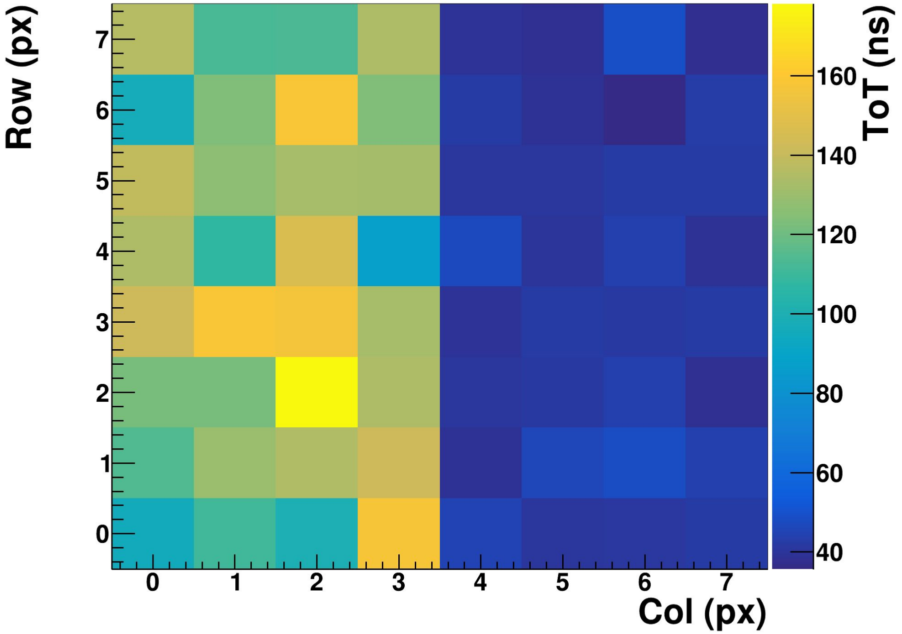
- For continuous pixels time over threshold ∝ charge
- Charge calibrated with time over threshold from charge injection at different voltages

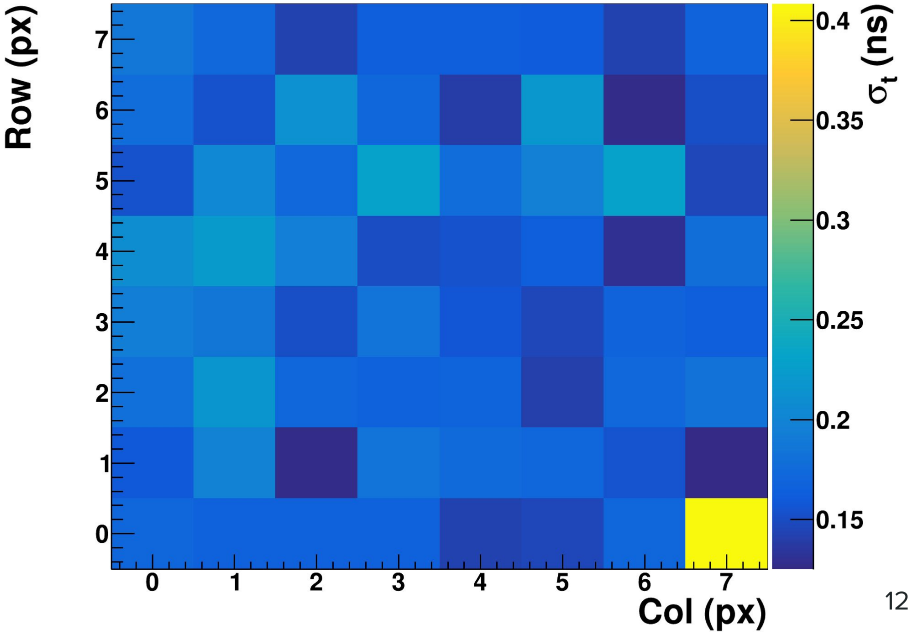
V_{bias} = 100 V



Electronics circuit contribution to time resolution

- Charge of 12100 e^- injected through injection capacitance bypassing the pixel sensor
- Time resolution from electronics only is 200 ps



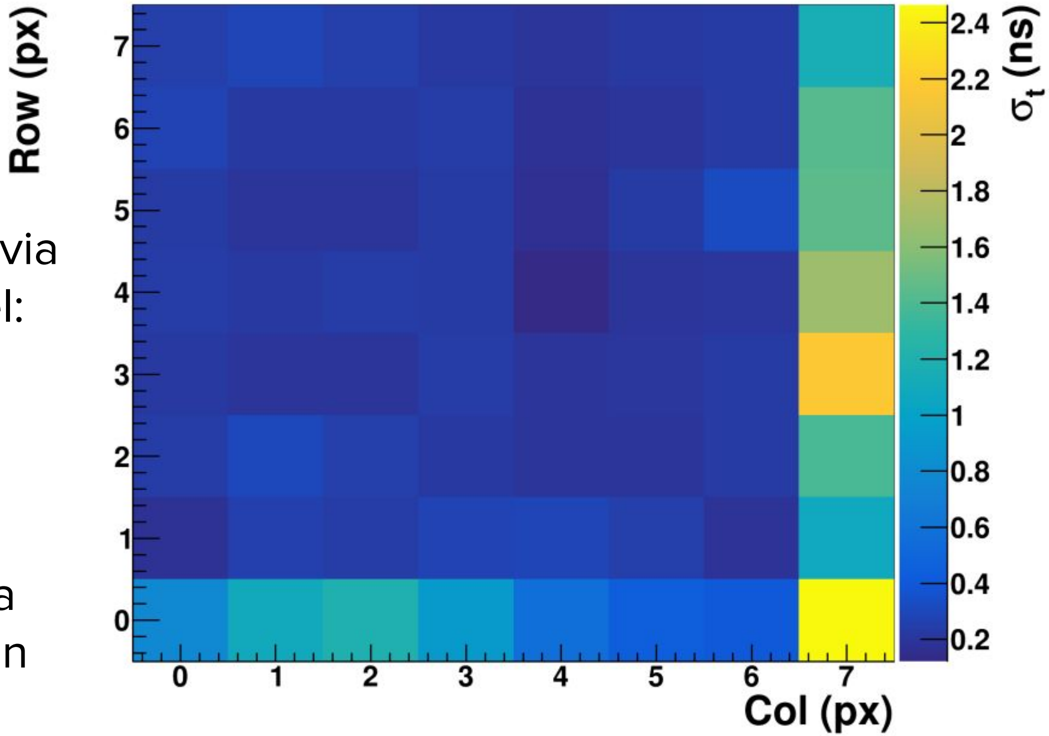


Time resolution for RD50-MPW2 pixel matrix

- V_{bias} = 100 V
- MIP-like charge of 12100 e^- equivalent charge injection via laser centered on each pixel:

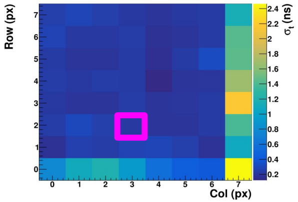
$\sigma_{t,\text{ switched}}$ = 211 ± 45 ps
$\sigma_{t,\text{ continuous}}$ = 227 ± 27 ps

- Switched reset pixels have a slightly better time resolution



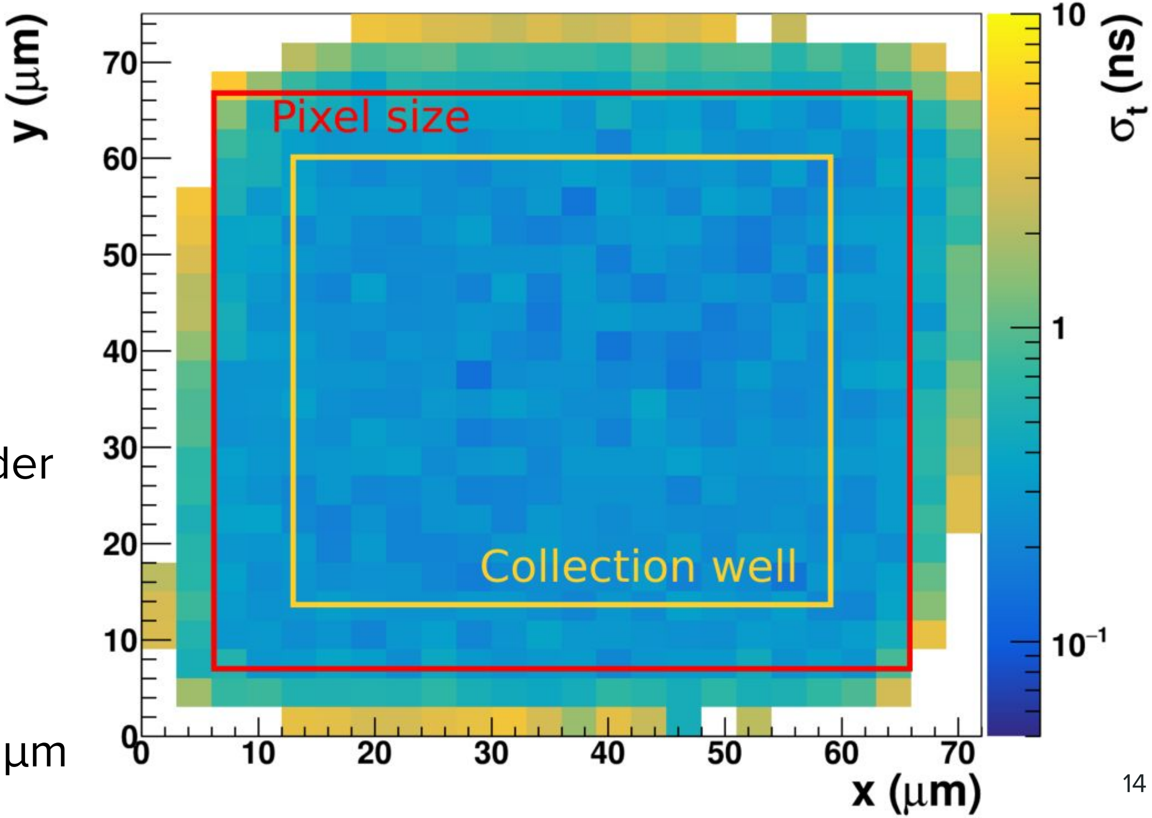
In-pixel time resolution

- Scan in 3 µm steps
- Continuous pixel (3,2)



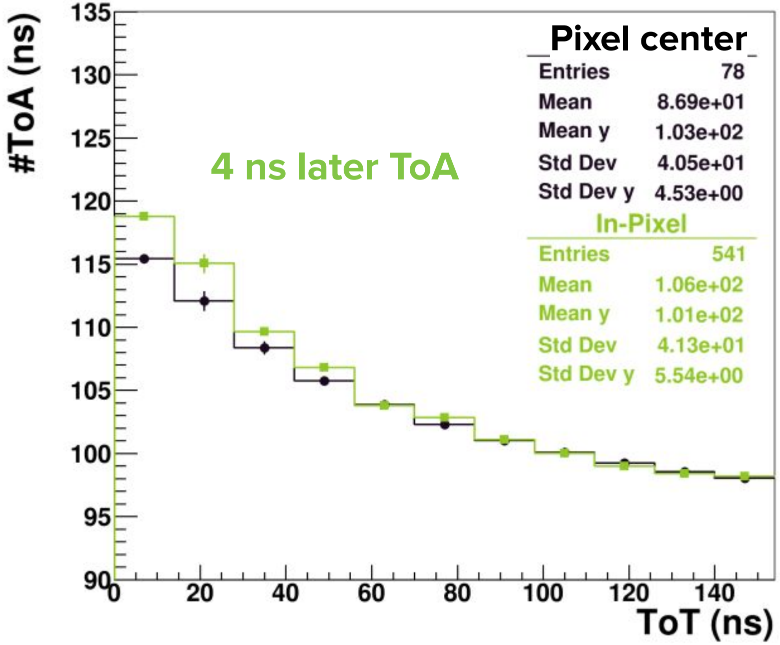
- Better time resolution under collection well:
  $\sigma_{t,\ \mathrm{well}}$ = 250 ± 42 ps
  $\sigma_{t,\ \mathrm{pixel}}$ = 267 ± 56 ps

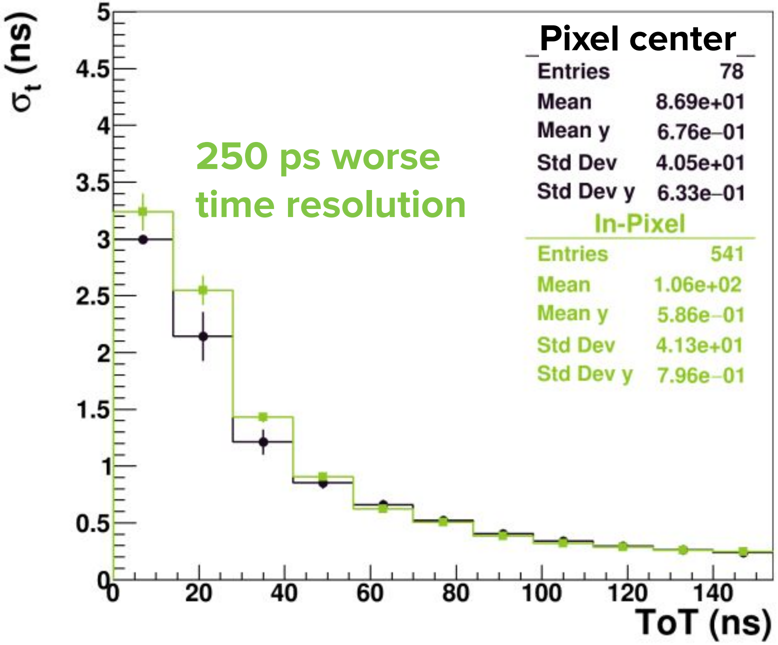
- Charge sharing up to ~10 µm beyond pixel boundary



In-pixel vs pixel center ToA and time resolution

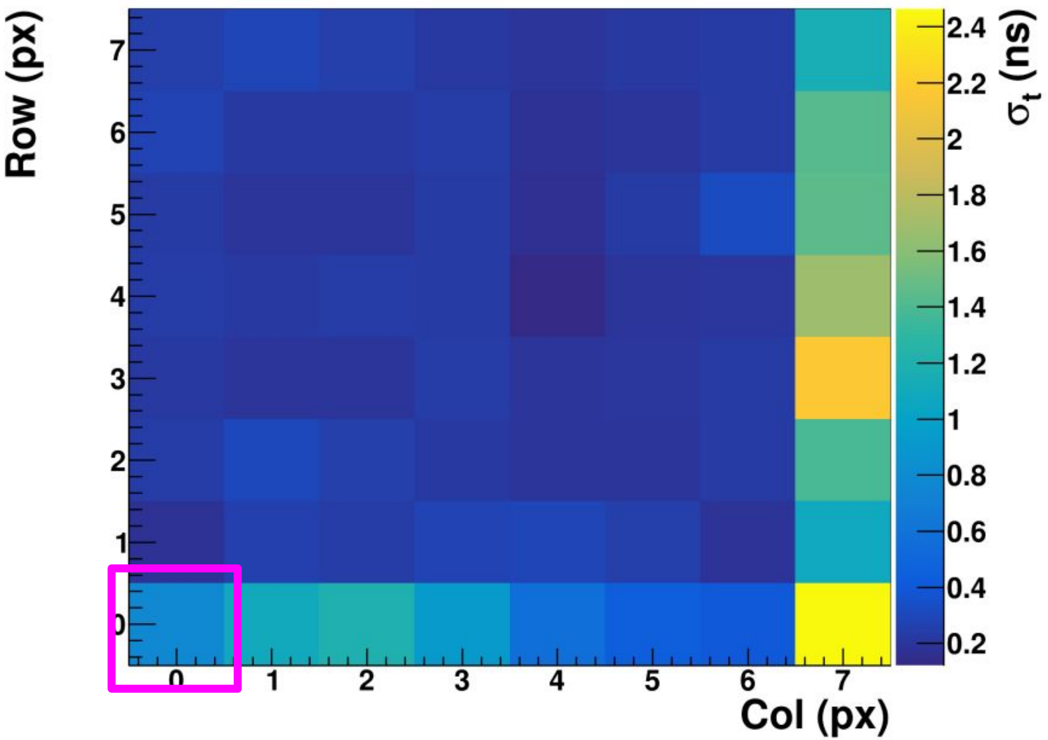
- **In-pixel scan over entire pixel**
- **Scan at center of pixel varying charge by attenuating laser signal**
- Overlap at high ToT values: in-pixel scan over center
- Below ToT = 150 ns: fluctuations from inhomogeneous charge collection times





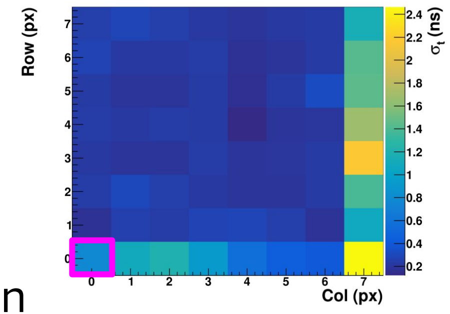
Time resolution for RD50-MPW2 pixel matrix

- Effect in row 0 and column 7 was also seen in other chips
- In-pixel scan of continuous pixel at border to investigate worse time resolution
- This effect is no longer seen in RD50-MPW3 and is not expected in RD50-MPW4.

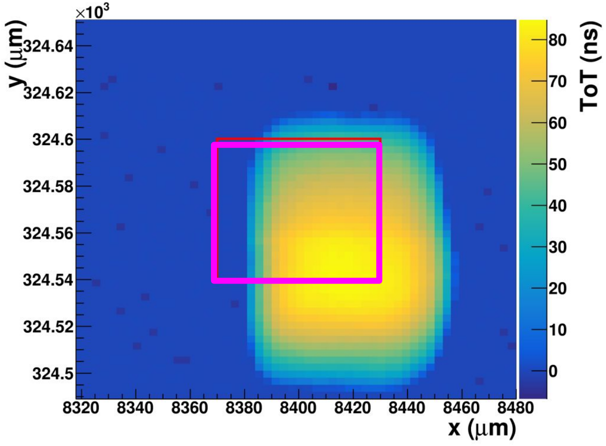


In-pixel measurement (0,0)

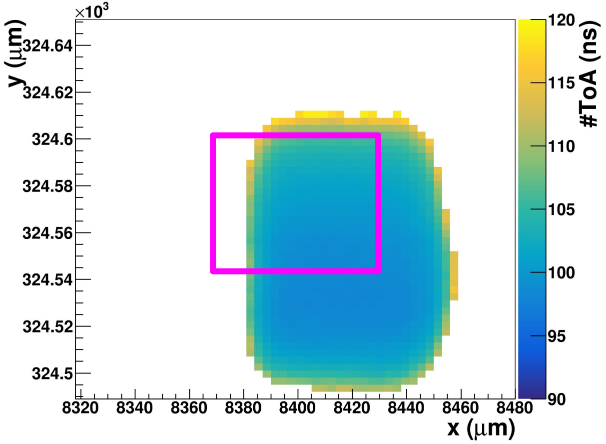
- Pixel shape is skewed
- Electric field not symmetric: uncontained only in one direction



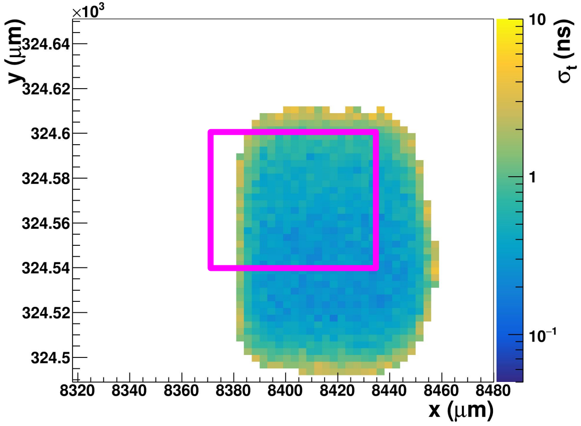
Time over threshold



Time delay

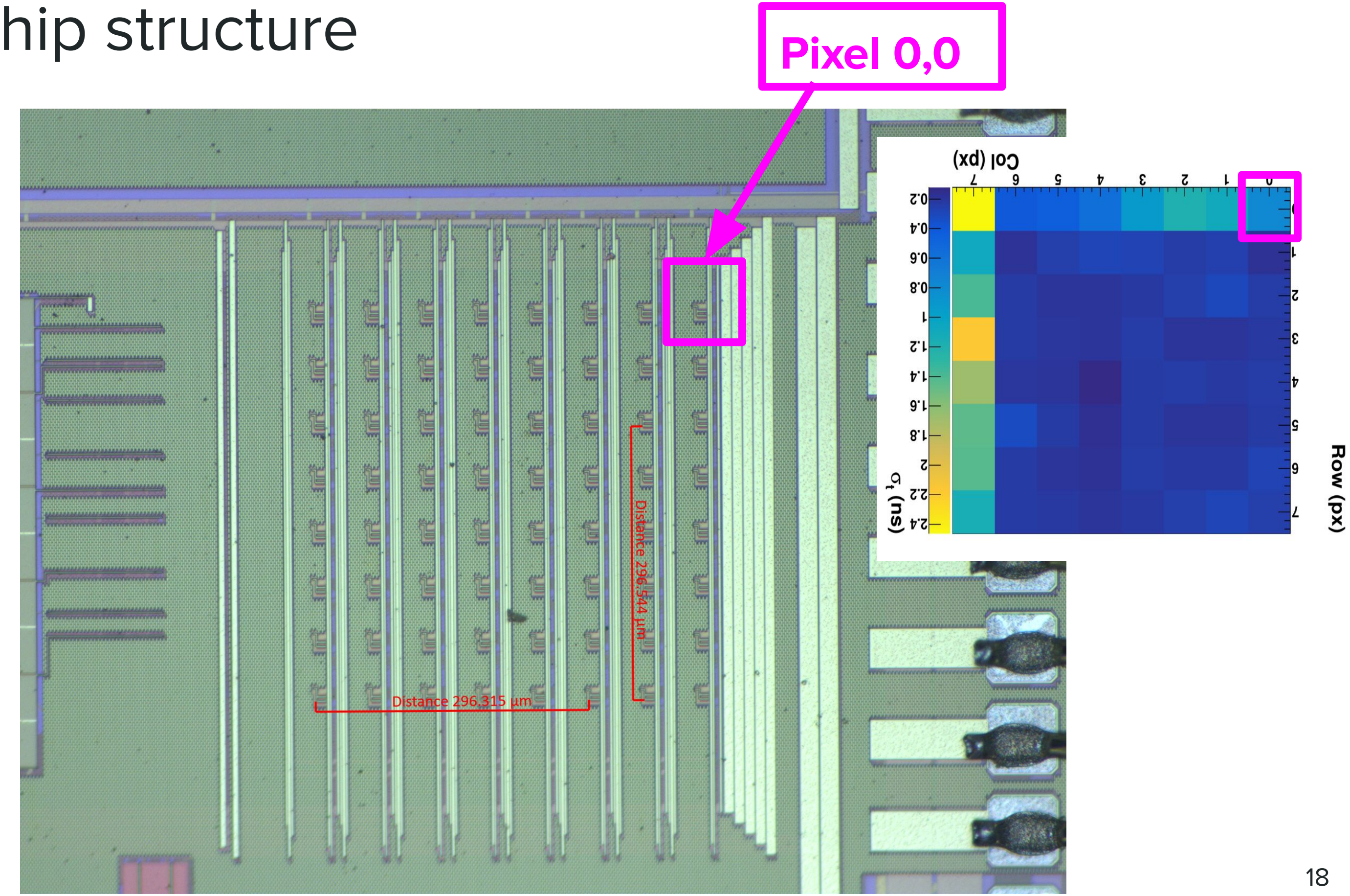


Time resolution



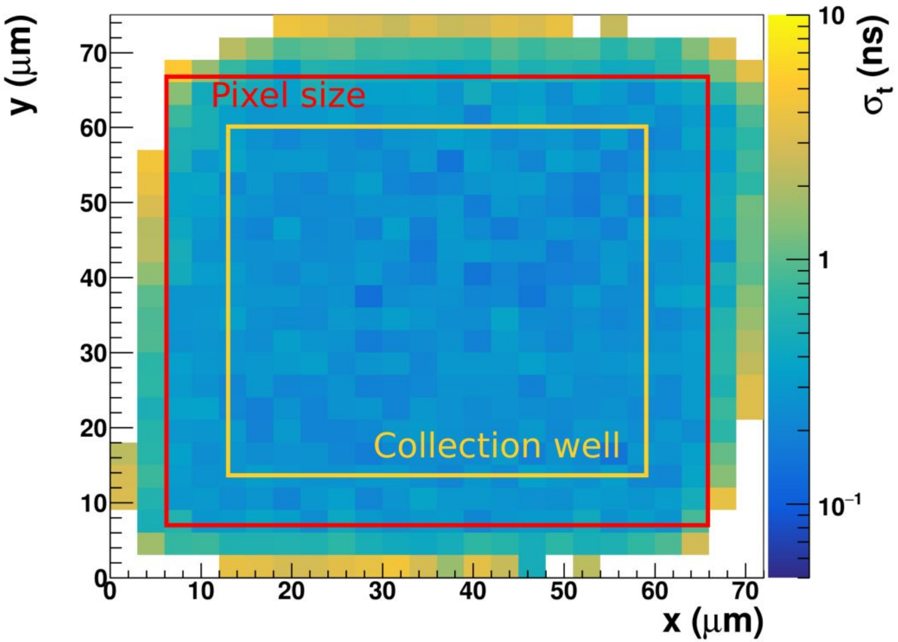
RD50-MPW2 chip structure

- Lines are top level metal lines
- Structure not symmetric for each edge of the pixel matrix



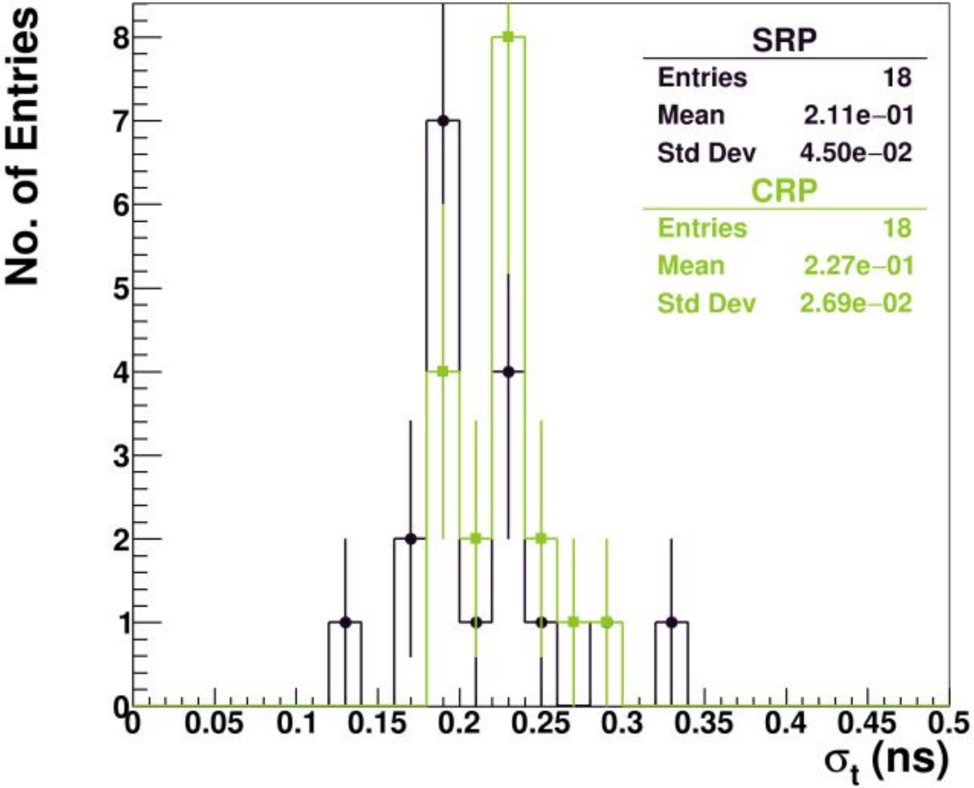
Summary and outlook

- RD50 HV CMOS not optimized for fast timing can achieve 227 ps time resolution for a MIP-like charge
- The electronics contribution to the time resolution is 220 ps
- A first in-pixel scan of RD50-MPW2 shows quite homogeneous time resolution over entire pixel
- MPW3 results shown last meeting
- Expect improved results in RD50-MPW4 that will arrive soon.



Additional material

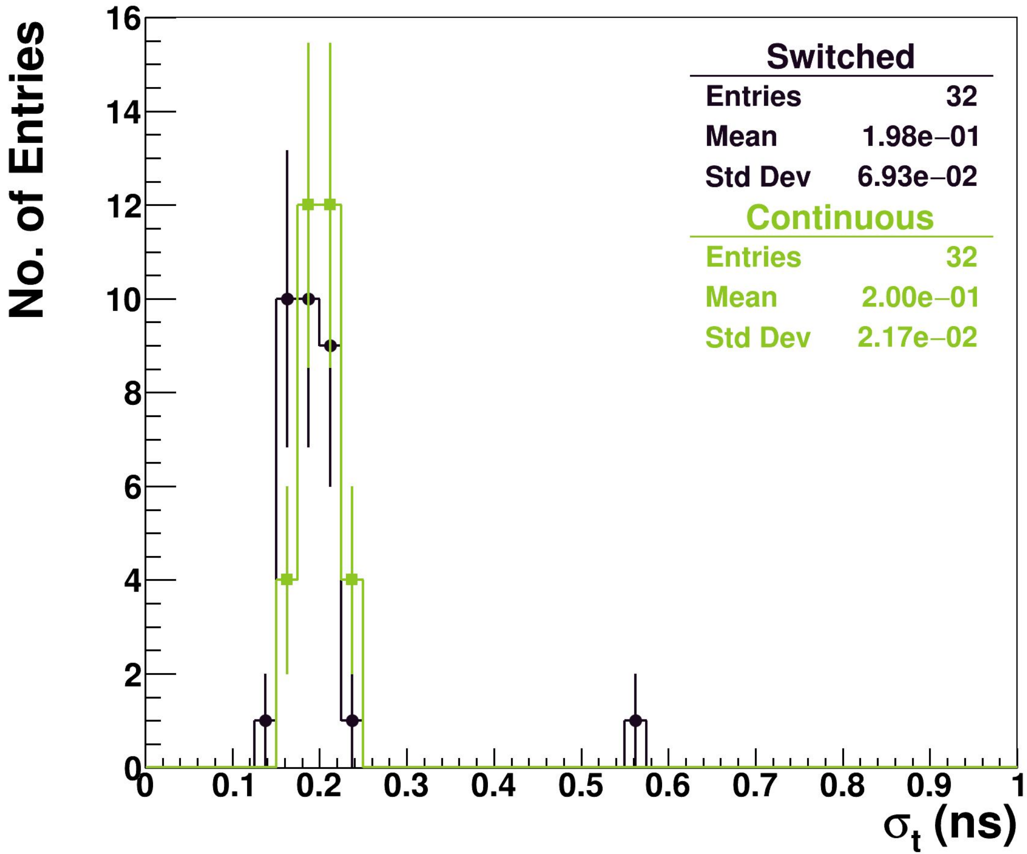
Time resolution for switched vs continuous reset pixels



- 12100 e^- equivalent charge injection via laser centered on each pixel
- Charge calibrated with time over threshold from charge injection at different voltages

Time resolution for electronics only

- Charge of 12100 e^- injected through injection capacitance bypassing the pixel sensor
- Time resolution from electronics only is 200 ps



Time resolution measurement

- All measurement points are at 50% constant fraction
- ToT = $t_{fall\_hit\_50\%}$ - $t_{rise\_hit\_50\%}$

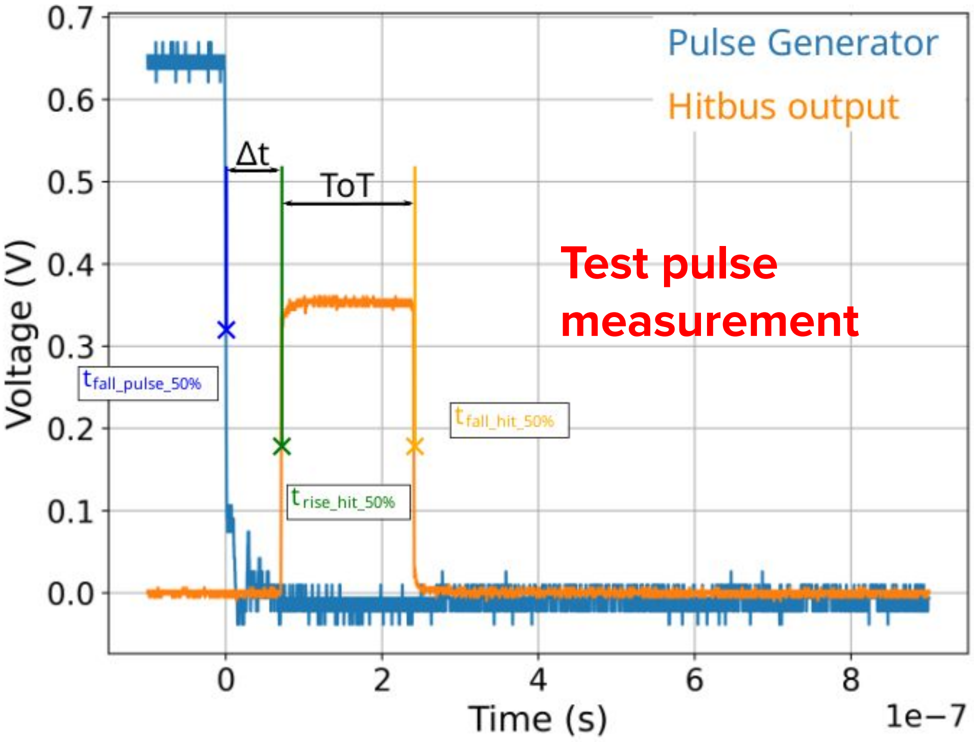
First point of signal is relevant value for time measurement:

Laser measurements

- Δt = $t_{rise\_hit\_50\%}$ - $t_{rise\_pulse\_50\%}$

Test pulse measurements

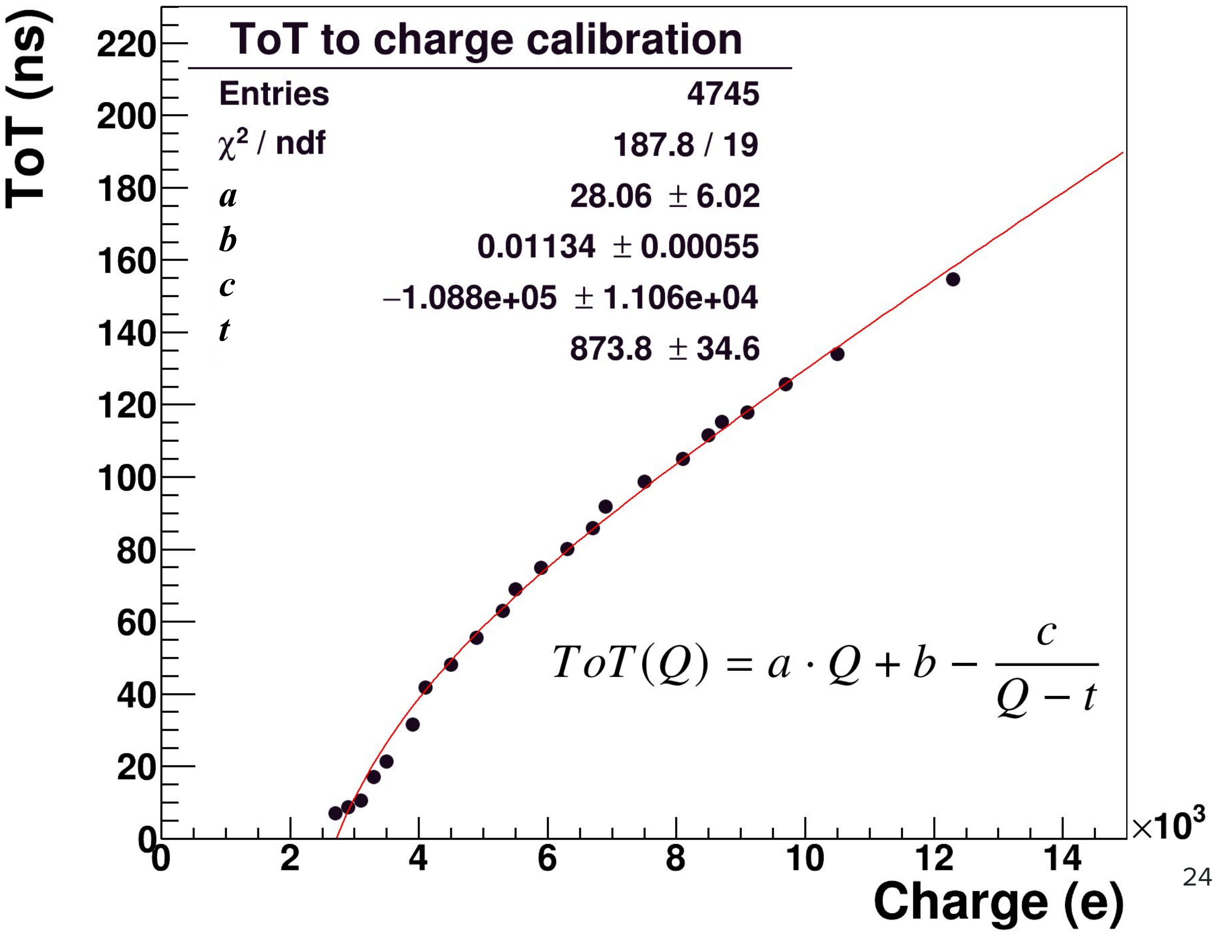
- Δt = $t_{rise\_hit\_50\%}$ - $t_{fall\_pulse\_50\%}$



Charge calibration

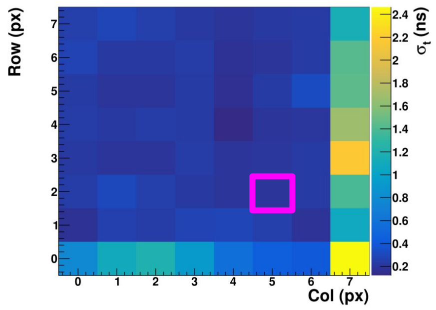
- Voltage step function with amplitude U_{inj}
- Connected to injection capacitance C_{inj} = 2.8 fF
- Injected charge: $Q_{\text{inj}} = C_{\text{inj}} U_{\text{inj}}$

Time over threshold to charge conversion from fit to measured ToT by varying U_{inj}

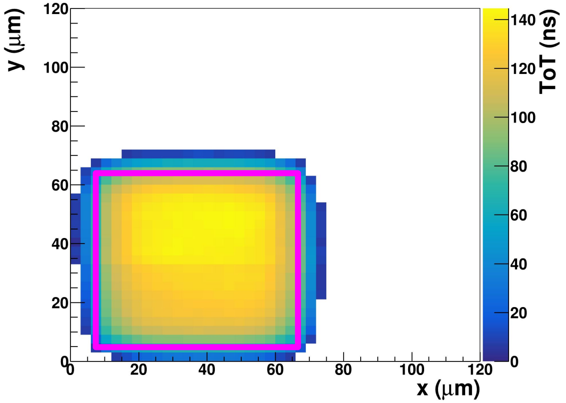


In-pixel measurement: (5,2)

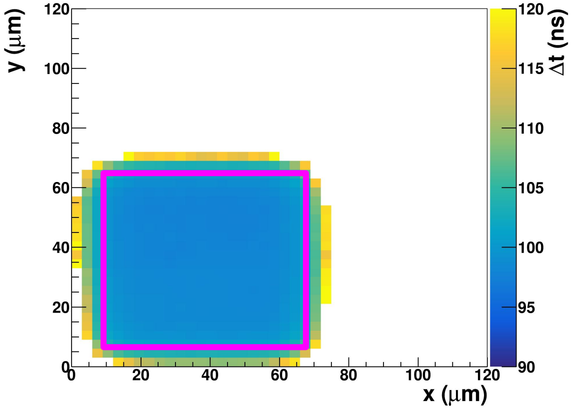
- Charge sharing appears to be reduced relative to continuous pixel
- ToT appears to increase halfway through the pixel, possibly resulting from laser fluctuations



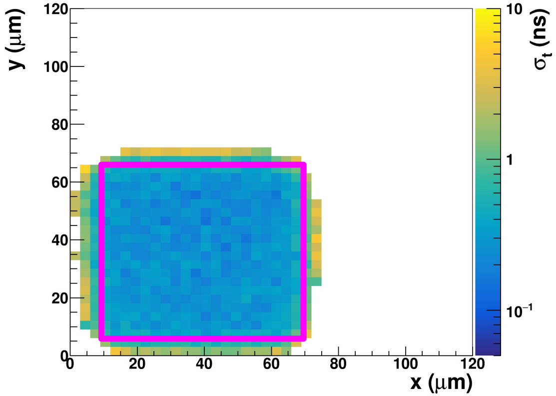
Time over threshold



Time delay

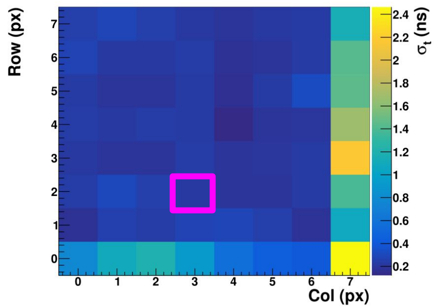


Time resolution

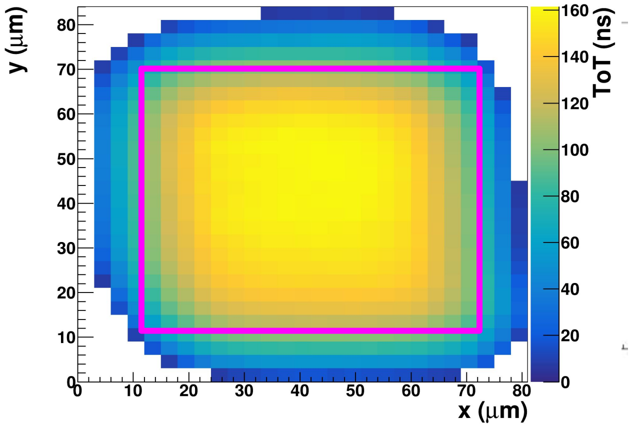


In-pixel measurement: (3,2)

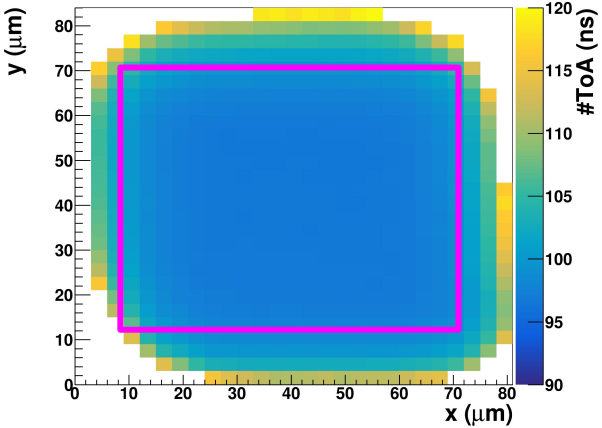
- Continuous pixel gathers charge ~10 µm beyond pixel "boundary"



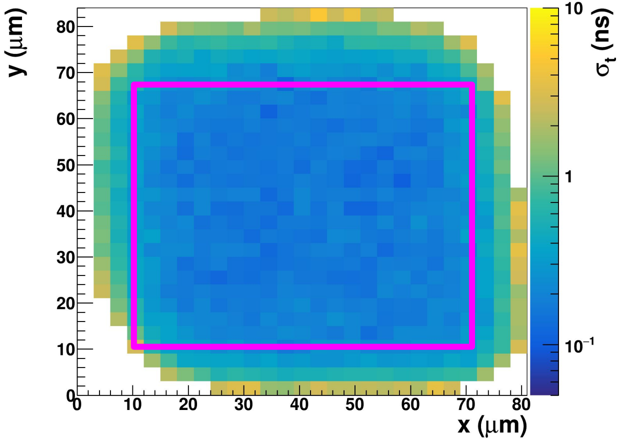
Time over threshold



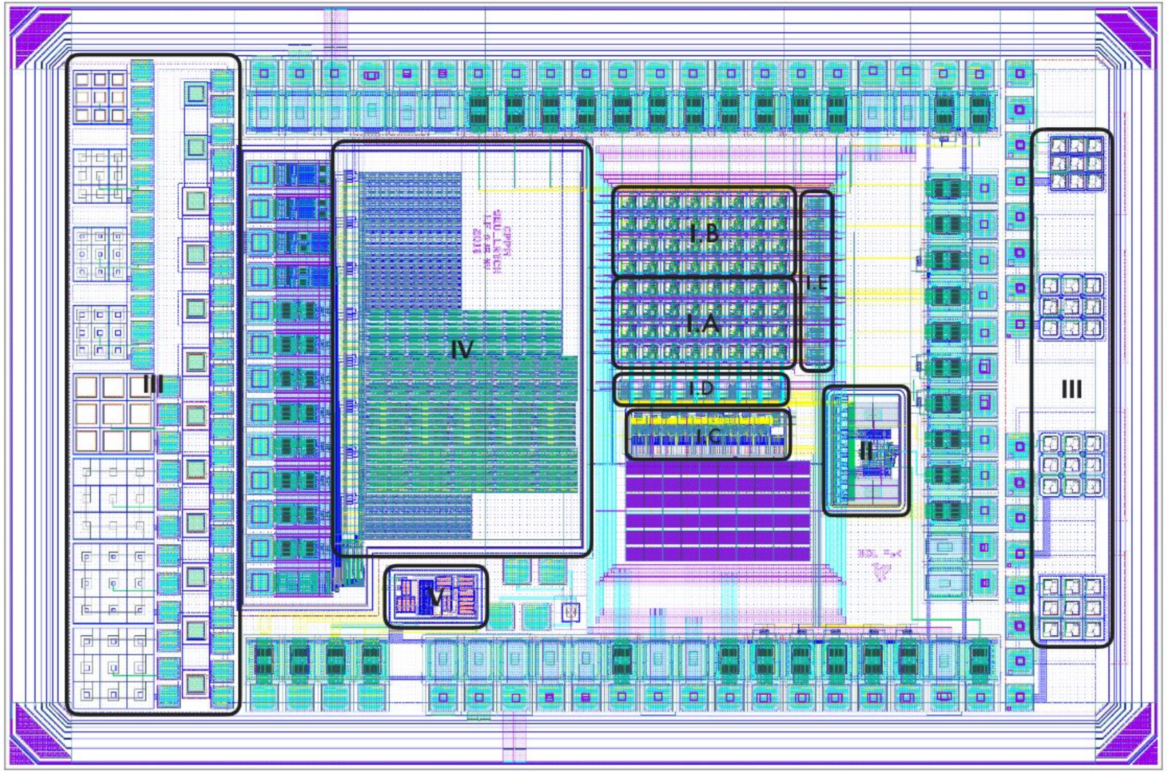
Time delay



Time resolution

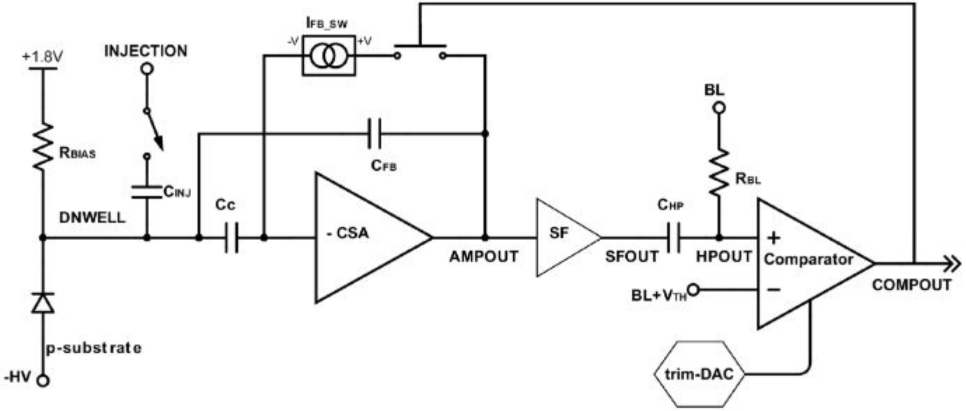


RD50-MPW2 layout

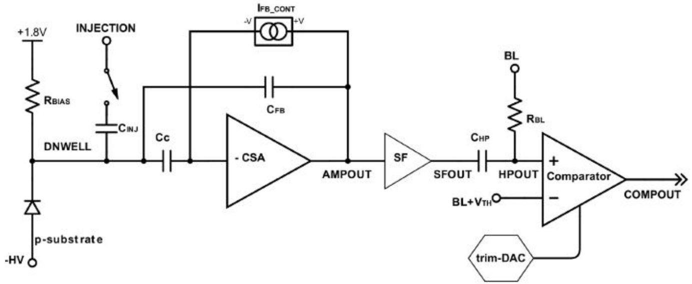


I. 8 × 8 Analog pixel matrix with pixel size
of 60 µm × 60 µm, two flavors:
I.A.Continuous-reset pixels (column 0 to 3)
I.B. Switched-reset pixels (column 4 to 7)
I.C. Bias block
I.D. Row configuration registers
I.E. Column configuration registers
II. Analog buffer
III. Test structures
IV. SEU tolerant memory
V. Bandgap

RD50-MPW2 frontend



Switched reset



Continuous reset

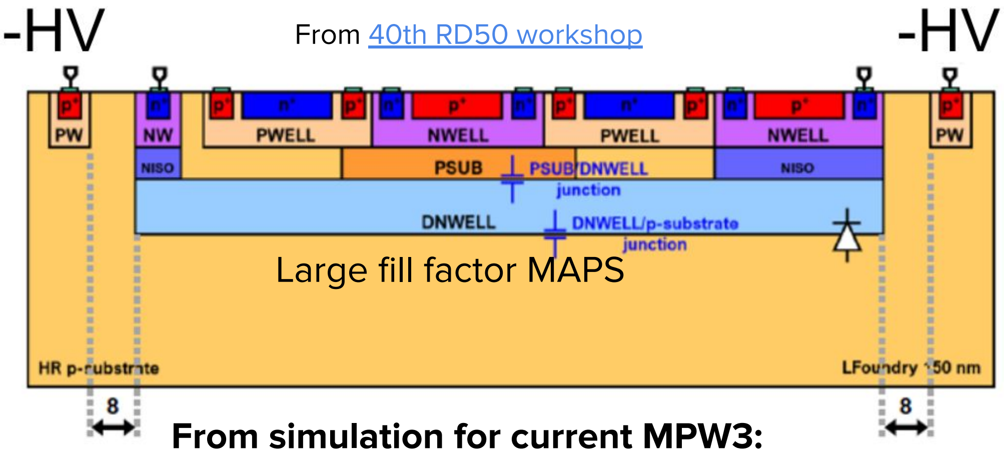
Measured performance of RD50-MPW2

Measured in previous MPW2:

- ENC < 50 e-
- Time-walk < 10 ns
- Leakage 120 pA/pixel
- ToT 30 ns
- Breakdown 120 V

Collection electrode size:
40 µm in MPW2
42 µm in MPW3

From [40th RD50 workshop]



From simulation for current MPW3:

Pixel size	$62\ \mu m \times 62\ \mu m$
Cd	~ 250 fF
Power	$22\ \mu W$/pixel (VDD = 1.8 V)
Gain	230 mV (for 5 ke-)
ToT	55 ns (for 5 ke-)
ENC	120 e-
Time walk	9 ns