Timing properties of the RD50-MPW2 HVCMOS chip

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40th RD50 Workshop – June 24, 2022

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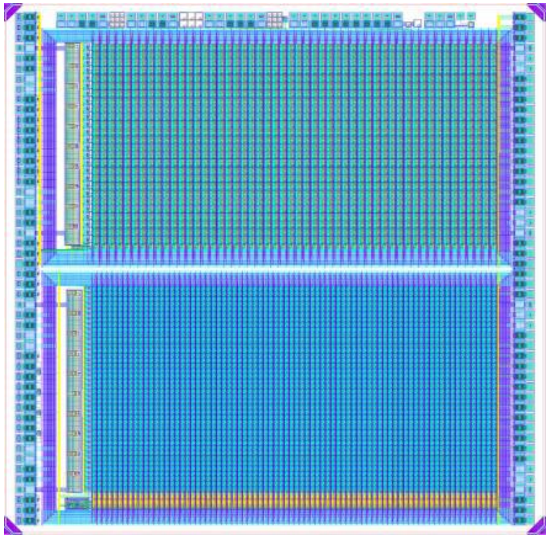
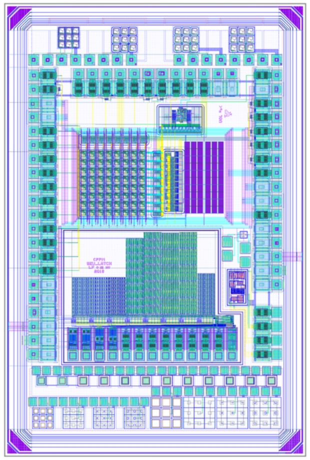
CERN-RD50 CMOS development program

- CERN-RD50 CMOS working group
  - Program to develop and study radiation hard monolithic sensors in CMOS technology
  - 3 CMOS prototypes developed so far
    - LFoundry 150 nm HV-CMOS process
    - Large electrode design

RD50-MPW1
5 x 5 mm²

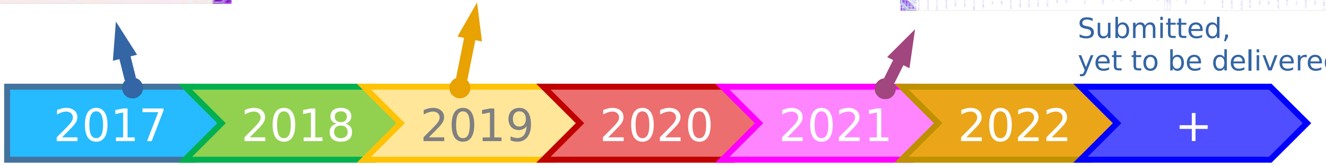


RD50-MPW2
3.2 x 2.1 mm²
Presented here



RD50-MPW3
6.6 x 5.1 mm²

Submitted,
yet to be delivered

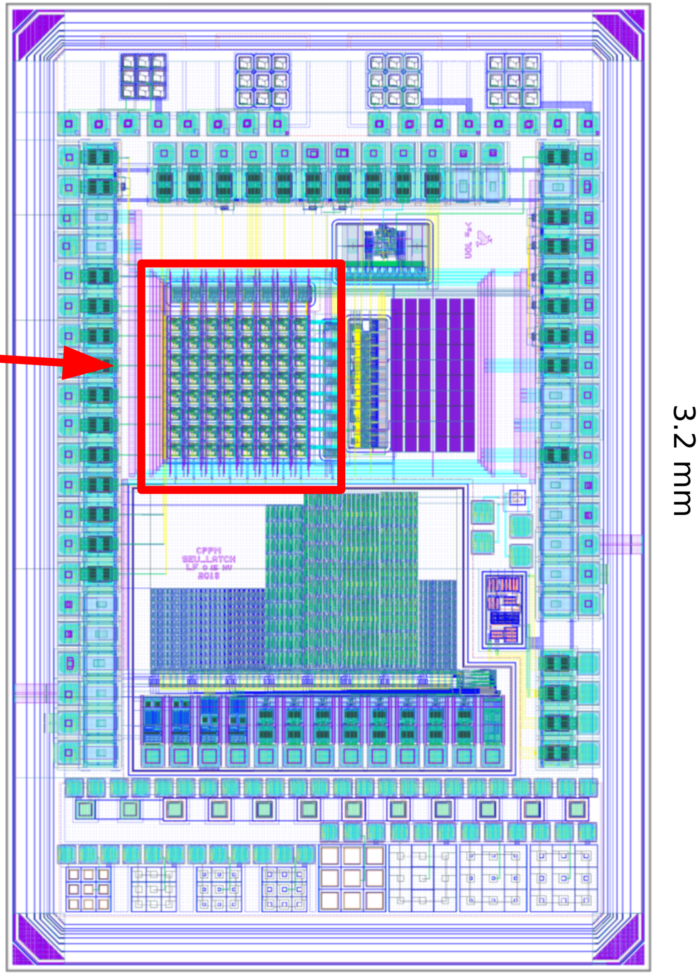


RD50-MPW2

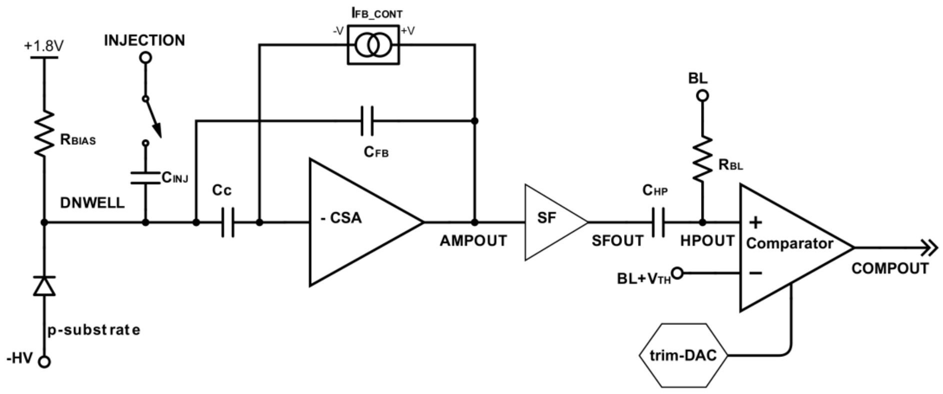
- CMOS prototype with several test structures
- p-type substrate, 4 resistivities: 20 Ωcm – 3 kΩcm
- Breakdown voltage V_{bd}= - 120 V

8 x 8 active pixel matrix

- 60 x 60 µm² pixel size
- Charge sensitive amplifier and discriminator
- Two pixel flavors with different CSA resets:
  - Continuous reset – Time over threshold > 100 ns
  - Switched reset – Time over threshold ~ 10 ns
- Analog front end

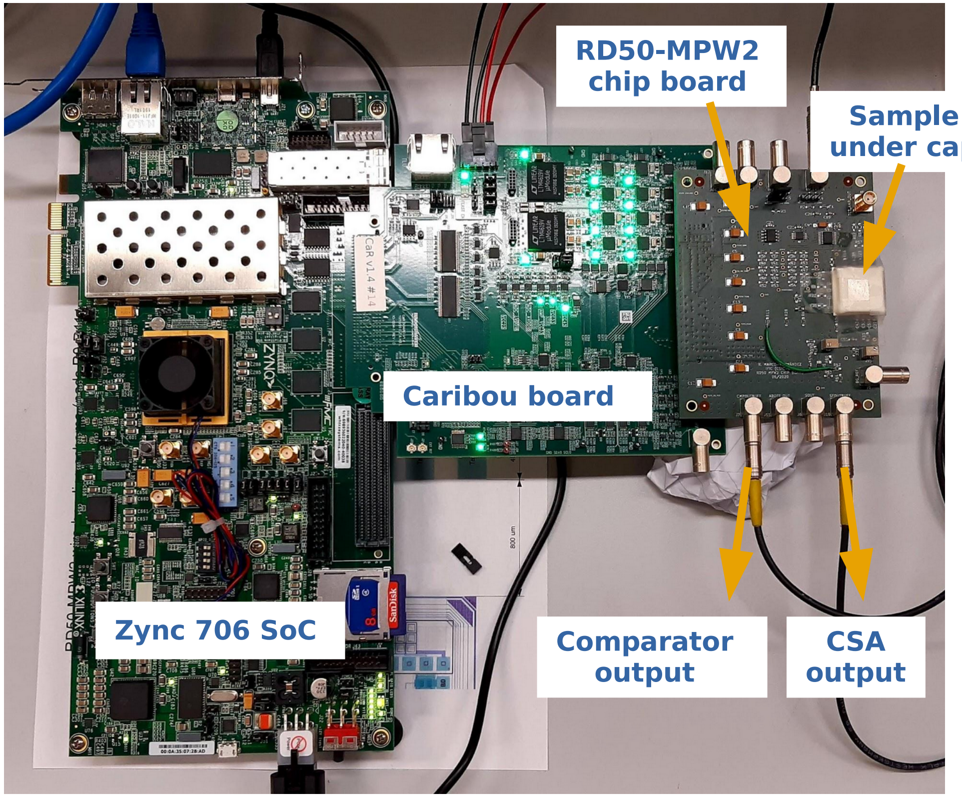


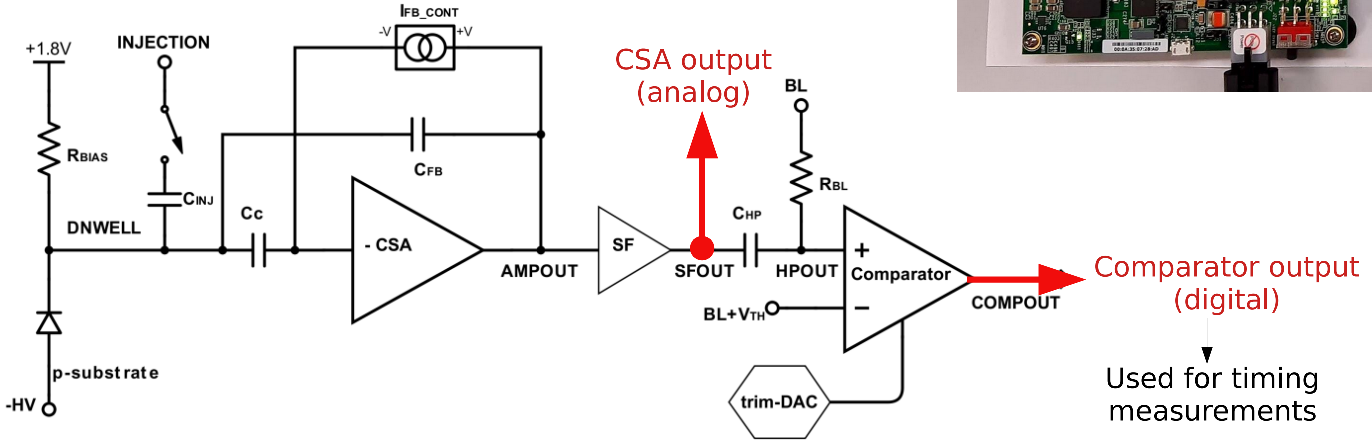
Continuous reset pixel:



RD50-MPW2 DAQ

- Chip configuration and DAQ via Zync 706 SoC and Caribou system (developed by Liverpool and Vienna)
- Pixel analog and digital outputs connected to oscilloscope for measurements
- Single pixel readout only

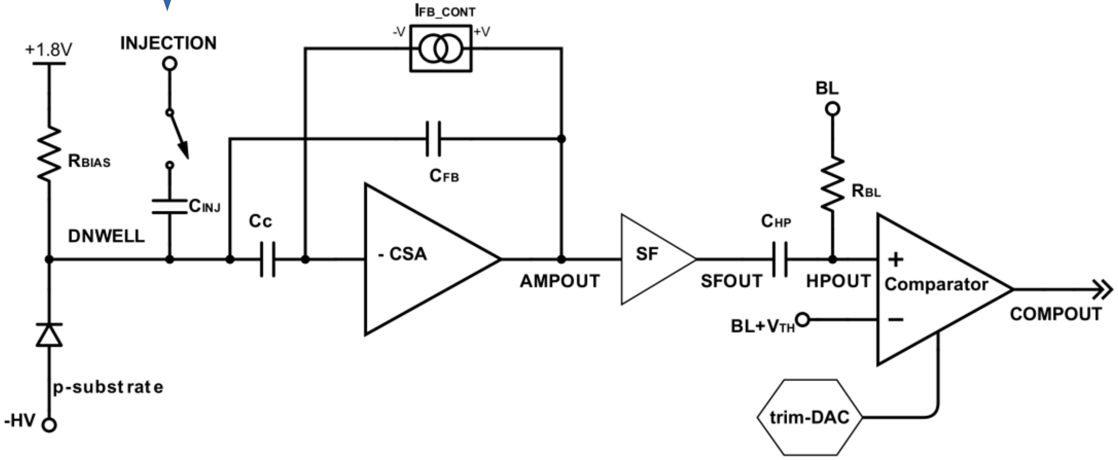




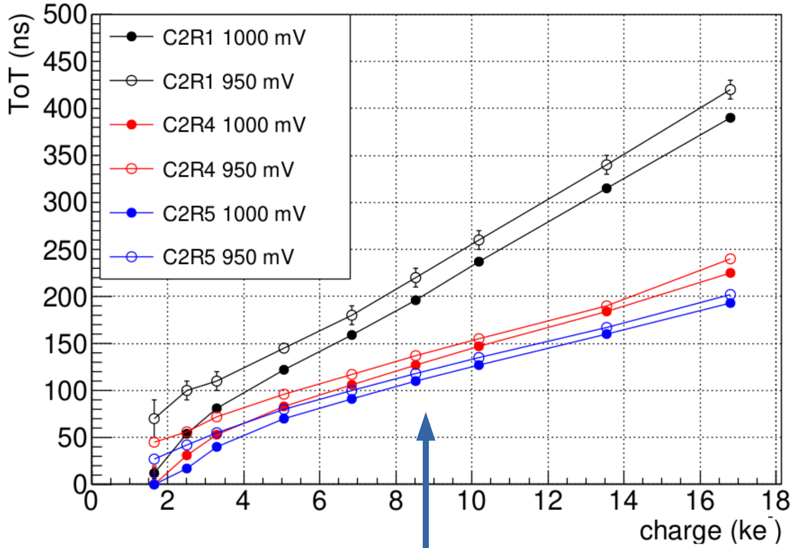
Continuous reset pixel calibration

- Continuous reset pixel calibration:
  ToT ∝ Injected charge,
  CSA amplitude ∝ Injected charge
- Calibration done via calibration circuit with injection capacitor C_{inj} = 2.8 fF

External charge injection via pulser

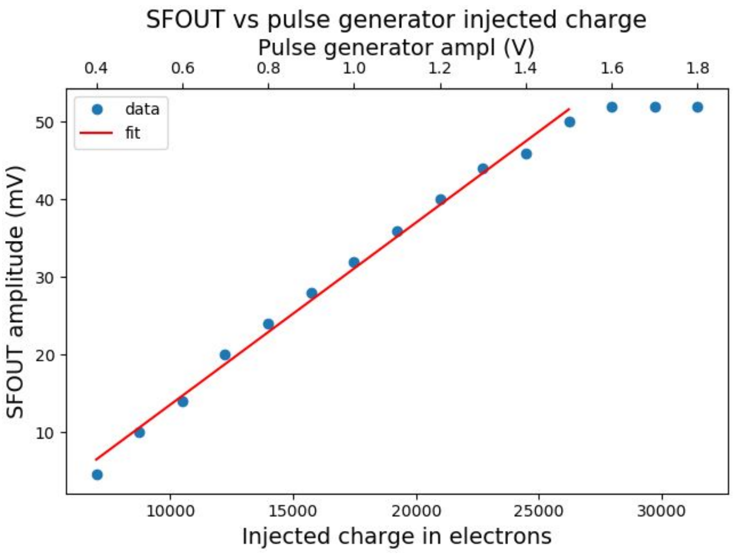


ToT calibration (comparator)



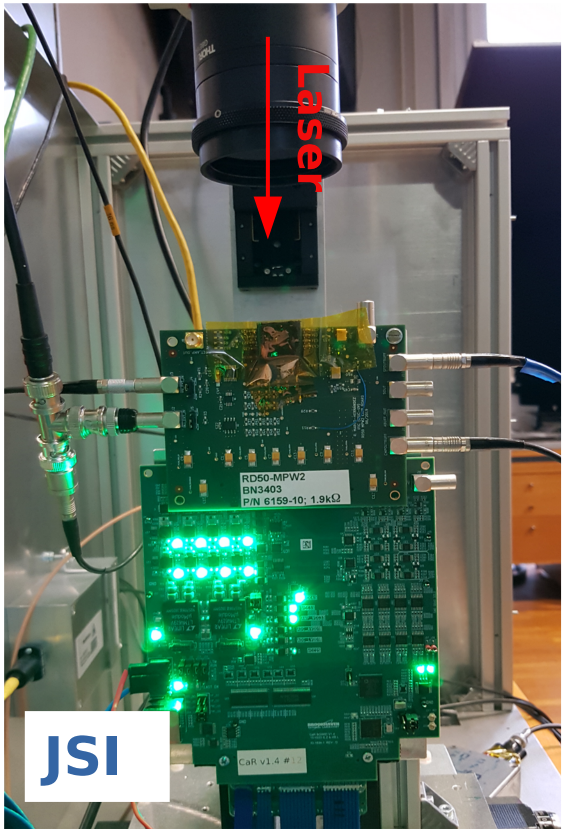
Significant variations in pixel-to-pixel gain

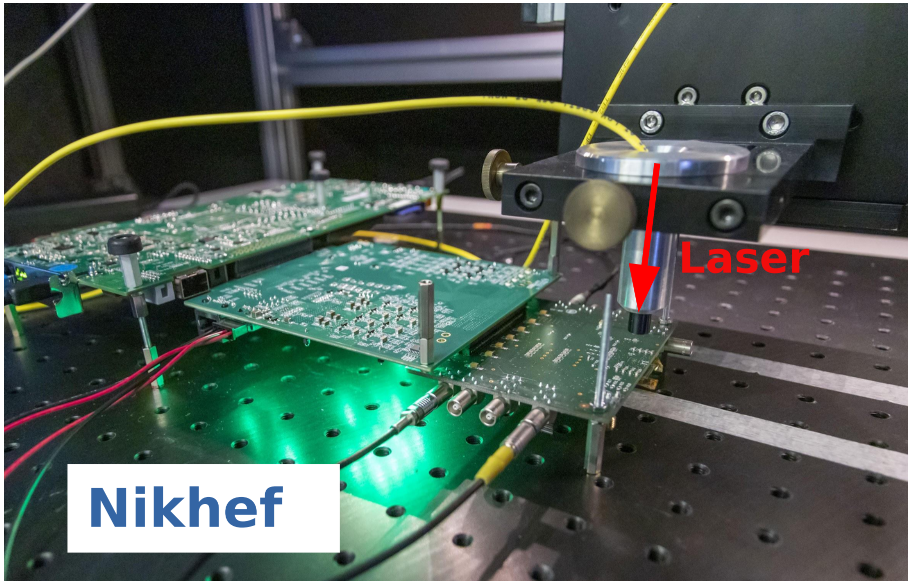
CSA output calibration



TCT setup

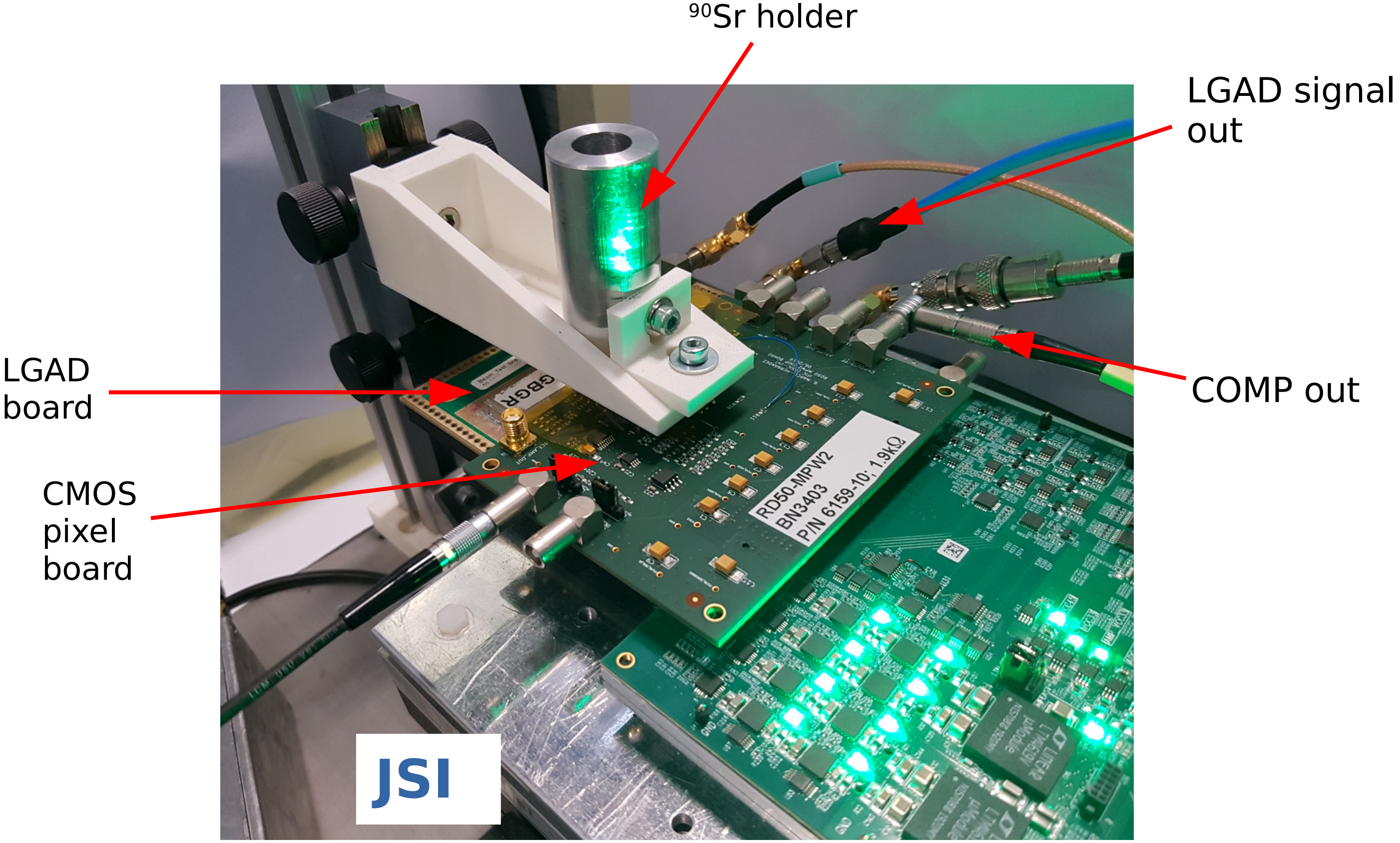
- TCT measurements with 1064 nm IR laser pulses
- Two setups:
  - Jožef Stefan Institute → Edge-TCT, Position sensitive
  - Nikhef → Back-TCT, Illumination of entire pixel





^{90}Sr setup

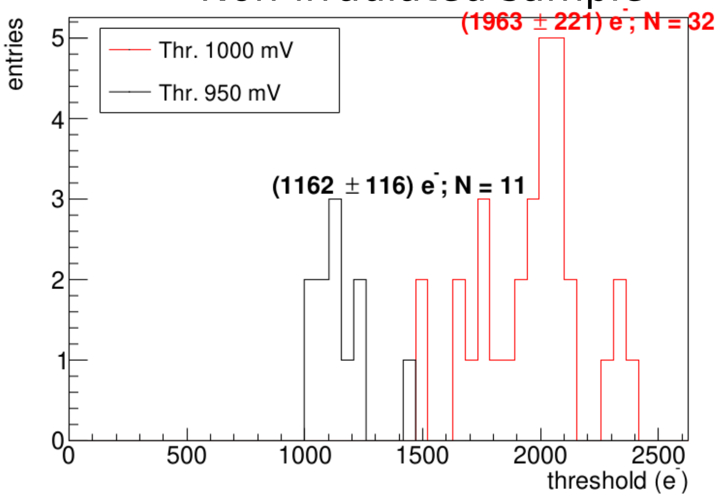
- Timing measurements with ^{90}Sr at Jožef Stefan Institute
- Reference signal from 1 x 1 mm^2 LGAD detector mounted on Santa Cruz timing board behind the CMOS chip
- Trigger: sample + LGAD
- LGAD jitter of ~30 ps is negligible in comparison with jitter of CMOS pixel
- Low rate: ~ 1 event/min with 18 MBq source

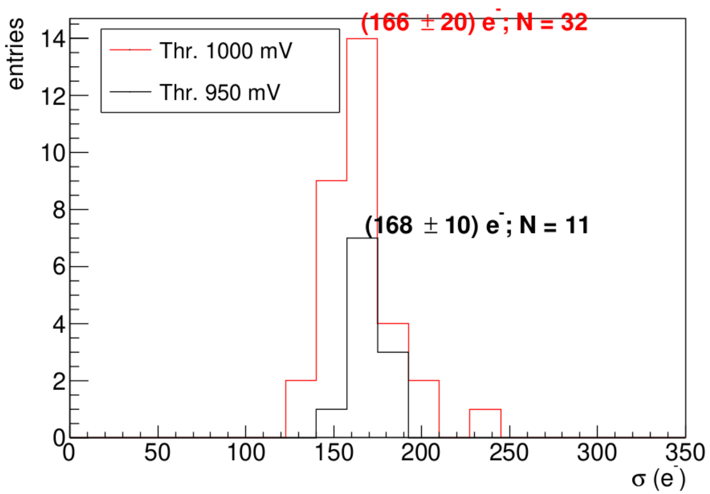


Measured samples

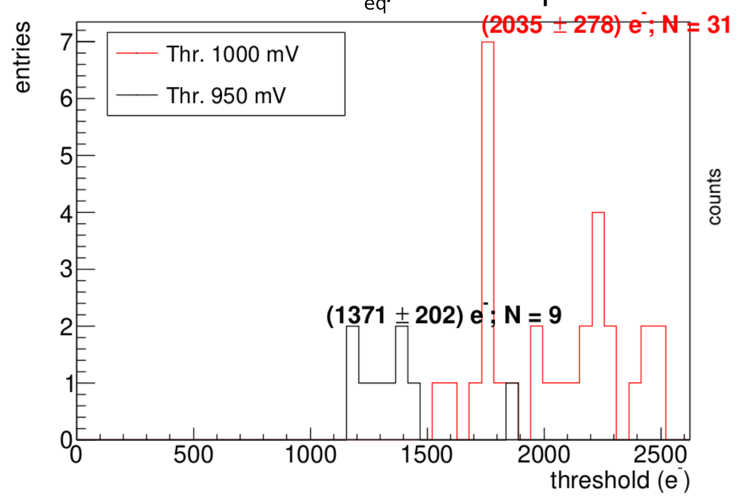
- Resistivity 1.9 kΩcm
- Unirradiated and irradiated to $5 \cdot 10^{14}\ n_{eq}/cm^2$ (irradiation with neutrons at TRIGA reactor in Ljubljana)
- Depletion depth 180 µm (120 µm) before (after) irradiation
- Nominal comparator threshold ≈ 1 ke, 2 ke

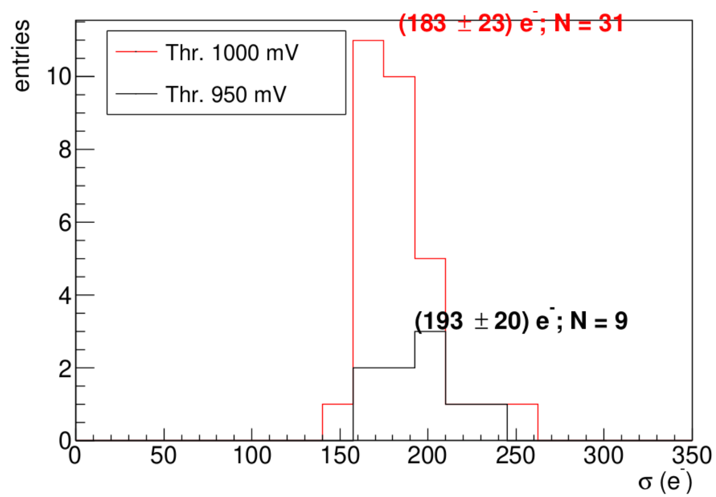
Non-irradiated sample



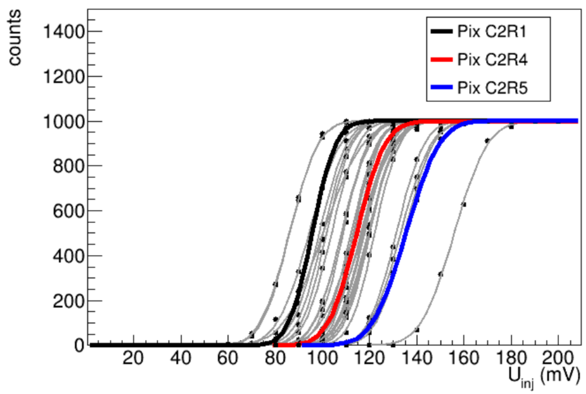


$5 \cdot 10^{14}\ n_{eq}/cm^2$ sample





Unirradiated



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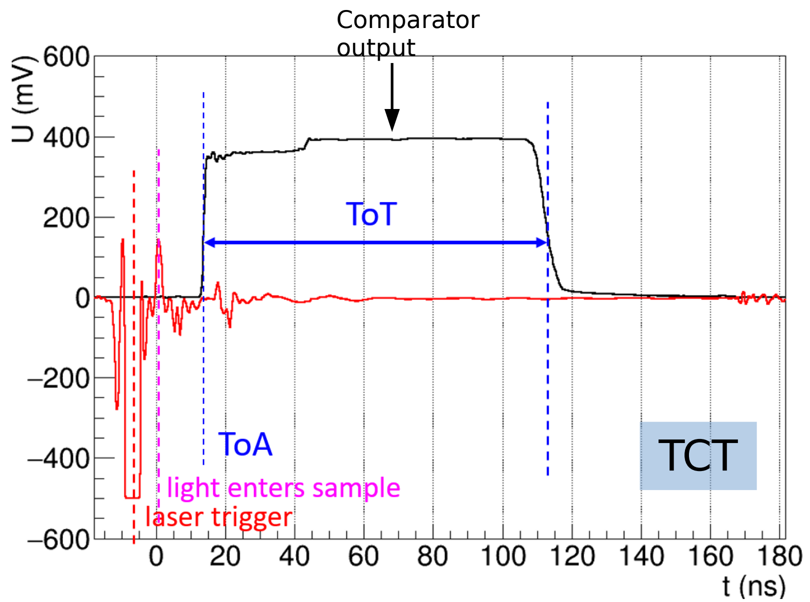
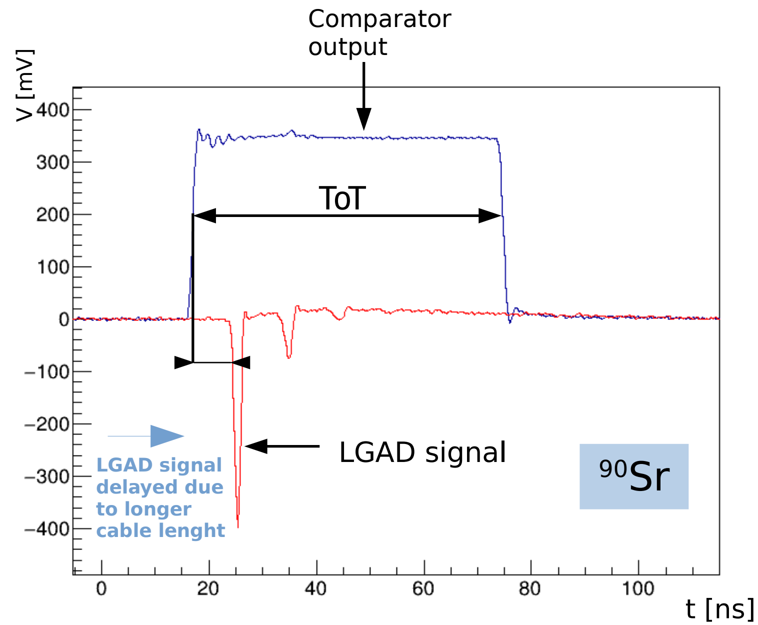
Timing measurements - methodology

- Time walk and timing resolution (jitter) measurements with comparator output signal
  - Reference time (Trigger from laser driver, LGAD signal)
  - Time of arrival (ToA) – compensated for cable length
  - Time over threshold (ToT)
- Sampling time at 50% maximum, CFD on LGAD signal, linear interpolation



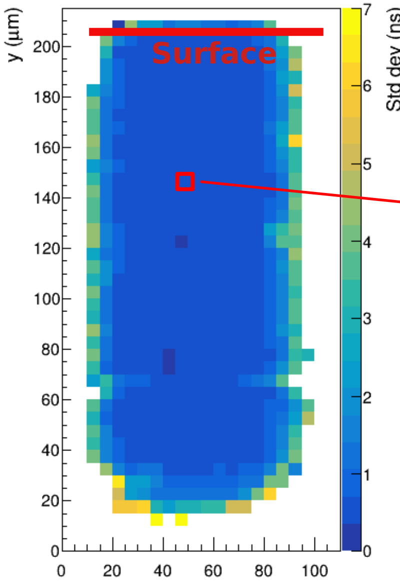
- Time walk measurements
  - Dependence of ToA on ToT
  - Average of 100 pulses



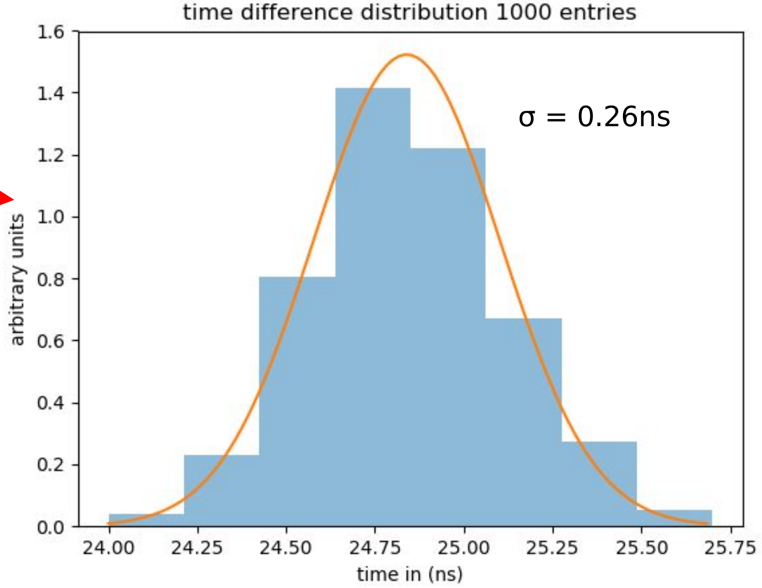
Timing measurements - methodology

- Jitter measurements
  - Spread of difference between ToA and reference signal
  - TCT: Statistics on 1000 samples
  - ^{90}Sr: Events binned in 10 ns bins over ToT

TCT

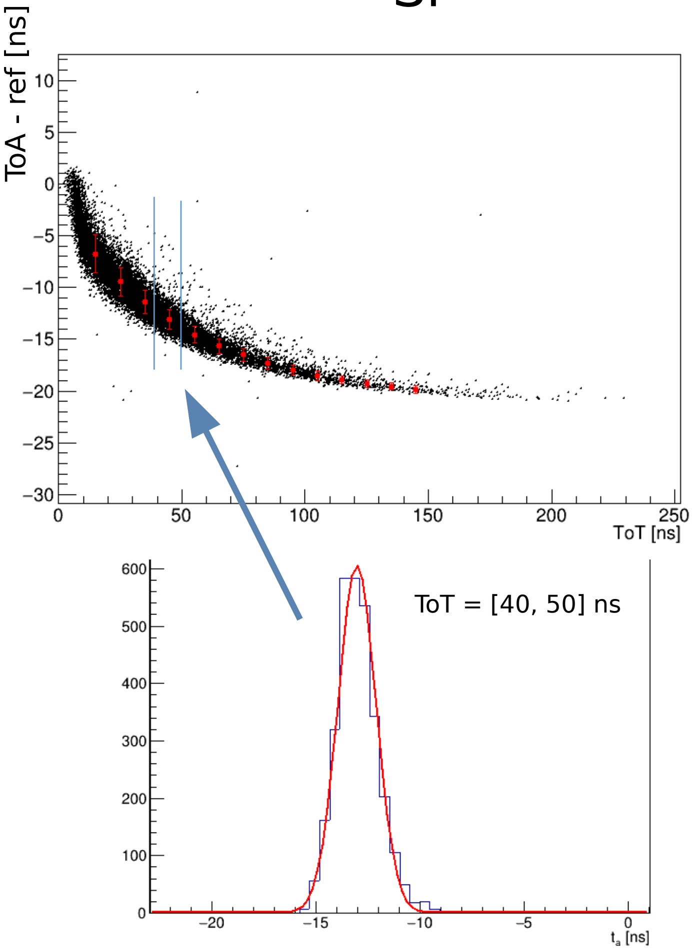


Spread of ToA–Ref difference distribution within pixel



Jitter in a single point

^{90}Sr



ToA–Ref difference distribution for single 10 ns bin

Time walk - Edge-TCT

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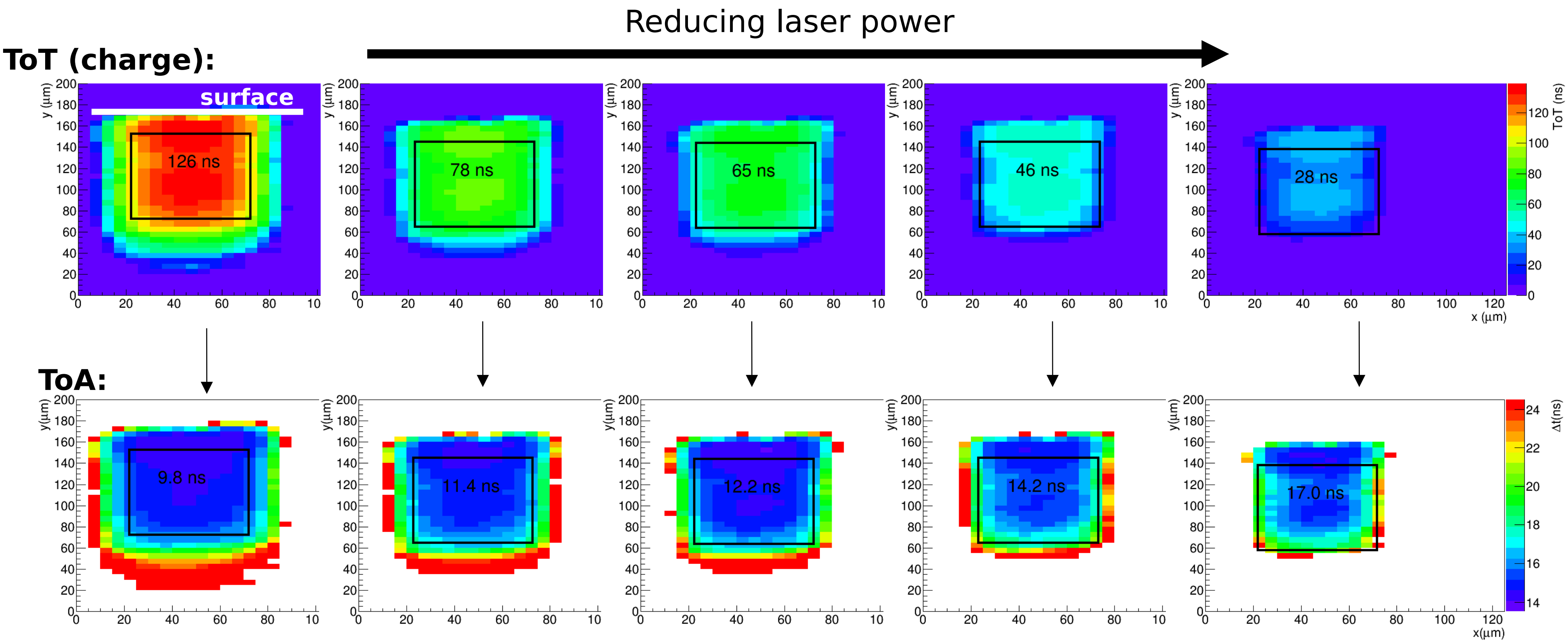
- Average of ToA and ToT over central part of pixel
- Output delay increases for smaller charge



(same z-scale for all measurements)

Time walk

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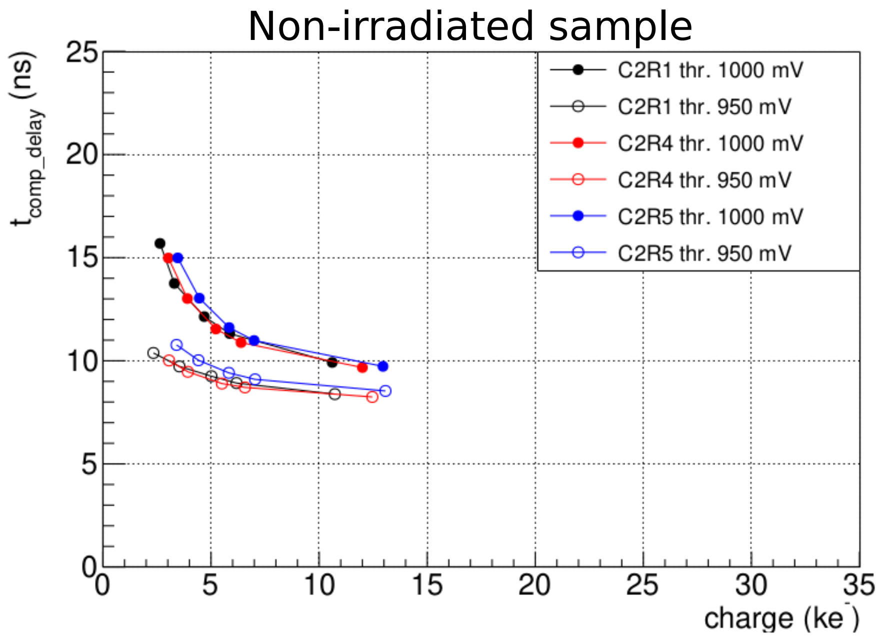
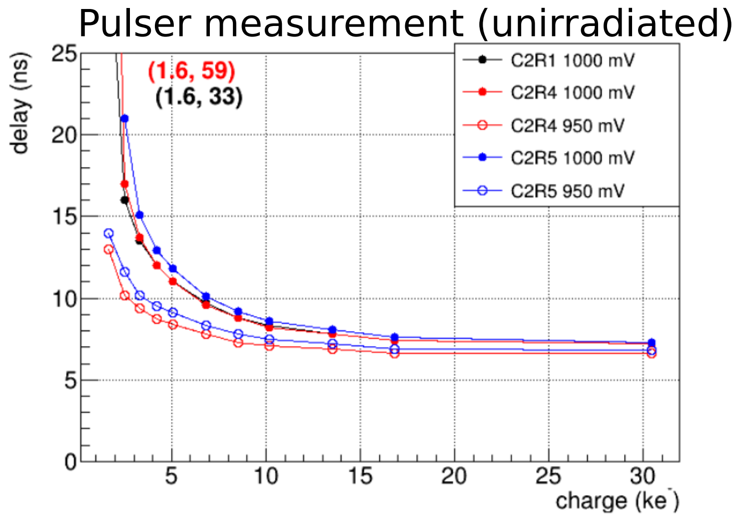
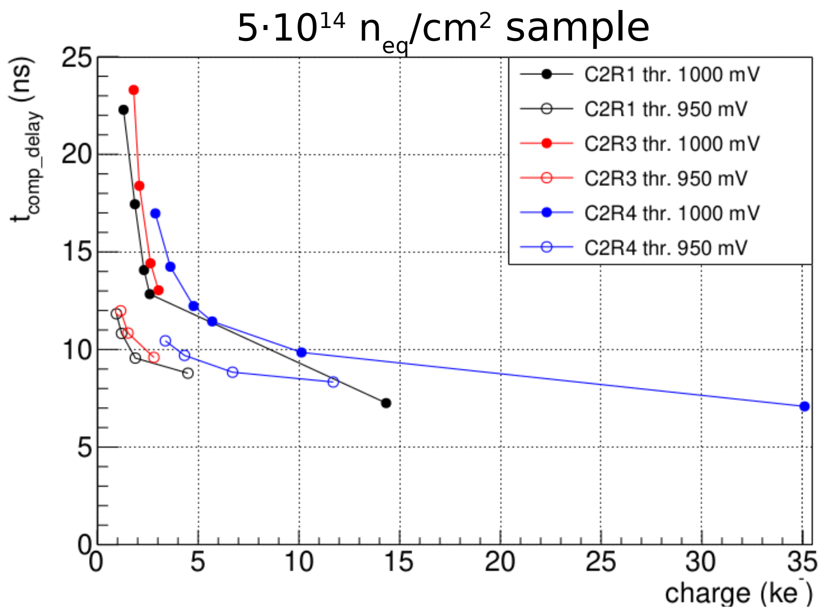


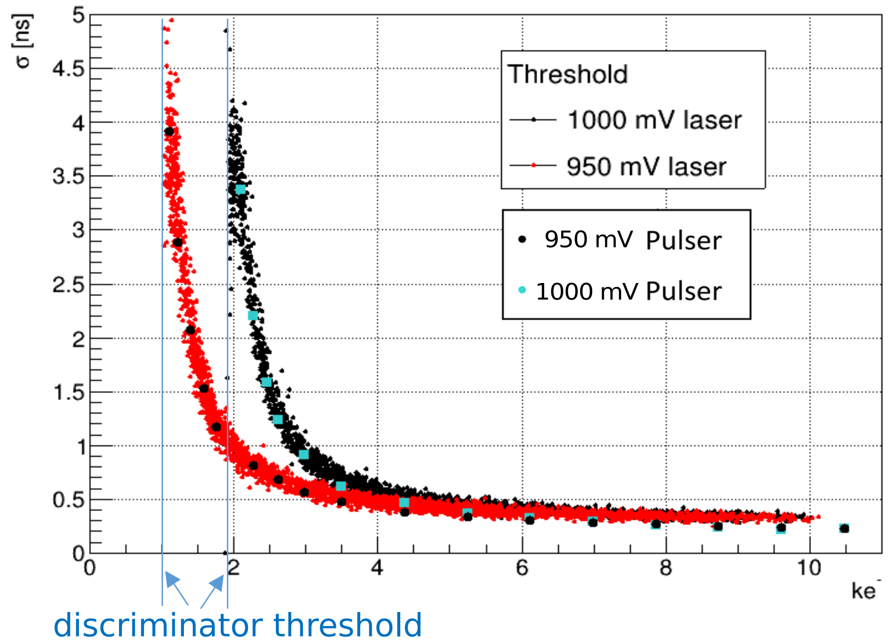




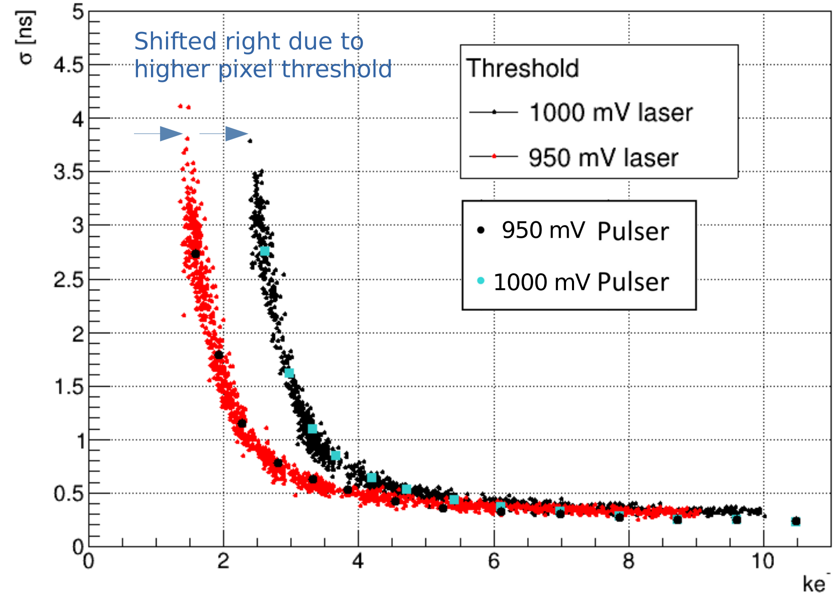
- Above 2 ke, comparator response at most 10 ns slower than the fastest signals
- Good agreement with measurements using direct charge injection (pulser) – 1 ns larger delay with TCT due to charge carrier drift

Timing resolution - TCT

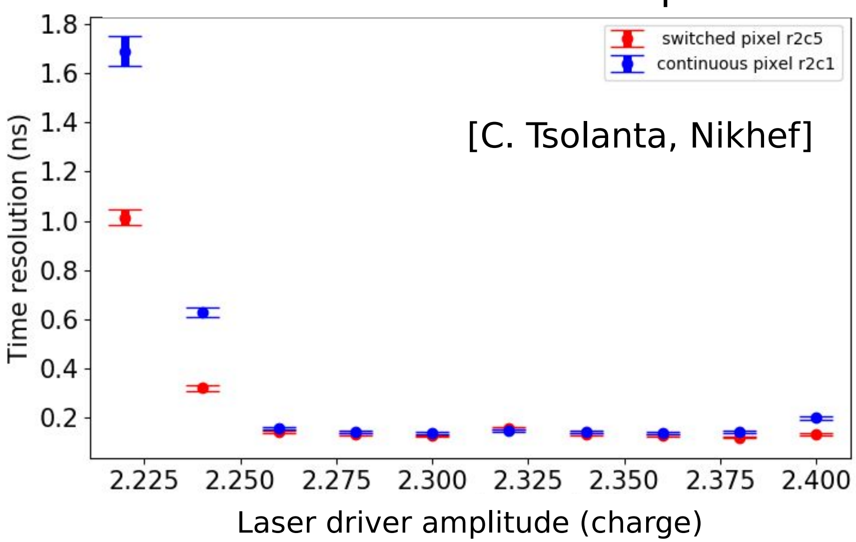
Non-irradiated sample



$5 \cdot 10^{14}\ n_{eq}/cm^2$ sample



Non-irradiated sample



Timing resolution scales as $(S/N)^{-1}$ with baseline:

$$f(x) = \frac{a}{x - x_{\mathrm{thr}}} + \sigma_{\mathrm{asymp}}$$

σ_{asymp} fit values: 140 ps / 160 ps

Timing resolution at 10 ke: ~ 300 ps

Theoretical estimate for $t_{\mathrm{rise}} = 20\,\mathrm{ns}$, $N = 170\,\mathrm{e}^-$

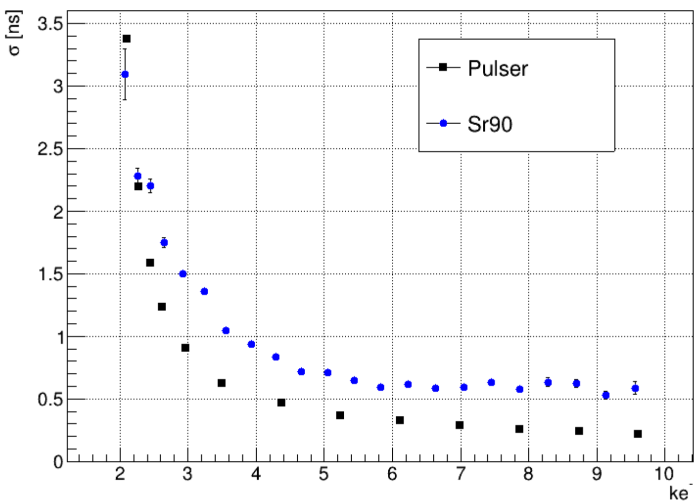
$$\sigma_{\mathrm{t}} = \frac{t_{\mathrm{rise}}}{S/N} = \frac{20\,\mathrm{ns}}{10\,\mathrm{ke}^-/170\,\mathrm{e}^-} = 340\,\mathrm{ps}$$

agrees with measurements

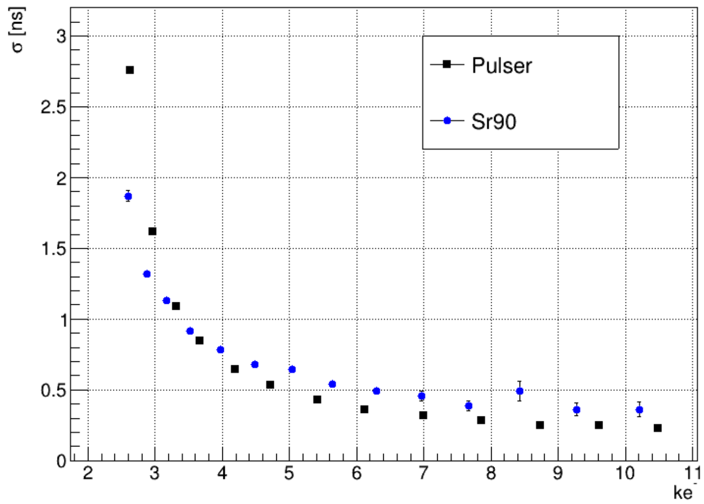
- Good agreement of laser and pulser measurements for both samples (better asymptotic resolution for pulser)
- No significant increase in jitter after irradiation

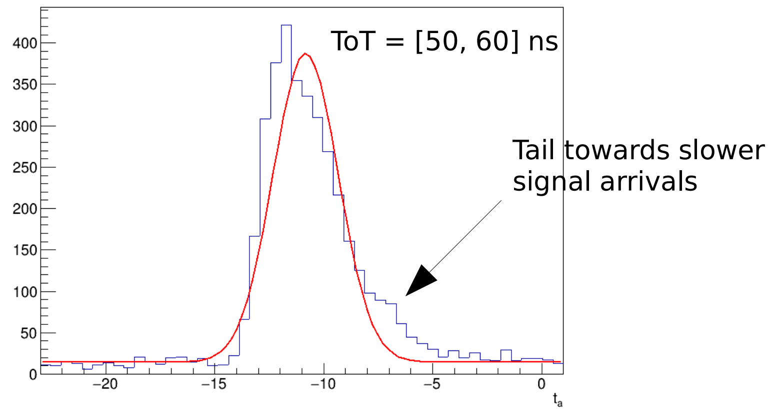
Timing resolution - ^{90}Sr

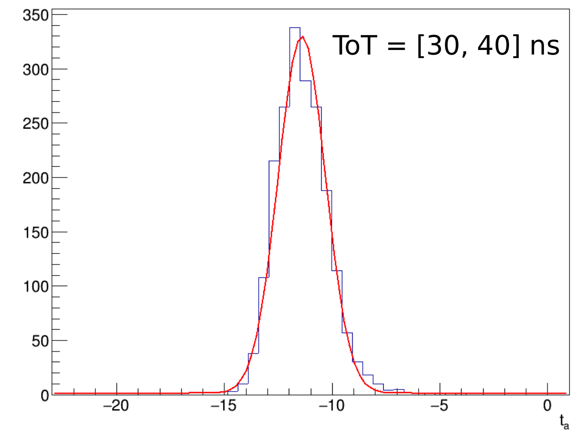
Unirradiated sample



$5\cdot10^{14}$ n_{eq}/cm^2 sample







- Timing resolution with ^{90}Sr larger than from pulser measurements
- Unirradiated sample showing worse resolution at large charge values (~ 600 ps) compared to irradiated sample (~ 350 ps)
- Slow charge collection in low field regions and via diffusion in unirradiated sample → Slower signals, widening of the distribution
- Charge recombination faster in irradiated silicon + trapping of charge → Slower signals not present

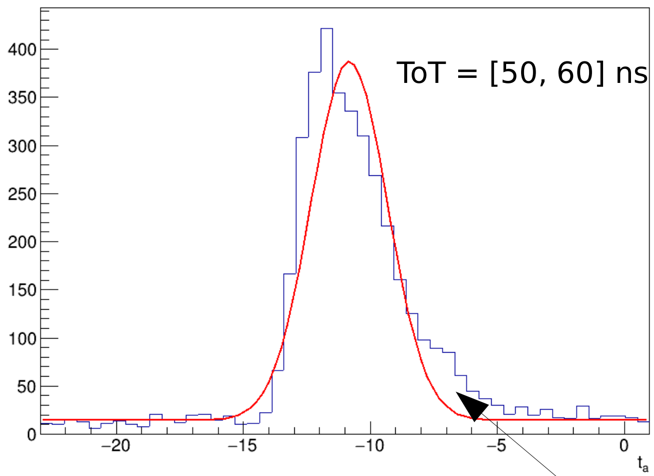
Conclusions

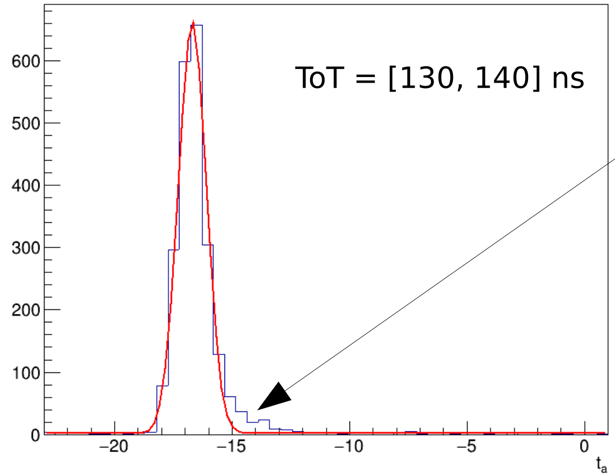
- Timing measurements of RD50-MPW2 prototype using IR laser light in TCT and electrons from ^{90}Sr
- Measurements compared with direct charge injection via pulser
- Time walk within 10 ns for charges > 2 ke
- Timing resolution scales as $(S/N)^{-1}$, ≈ 150 ps asymptotic resolution
- ^{90}Sr measurements show larger timing resolution
  - ~ 600 ps unirradiated sample, ~ 350 ps for $5 \cdot 10^{14}$ n_{eq}/cm^2 sample
  - worse timing resolution in unirradiated sample due to significant charge collection by diffusion (slower)

Backups

^{90}Sr measurements – Tails in distribution of unirradiated sample

Unirradiated sample

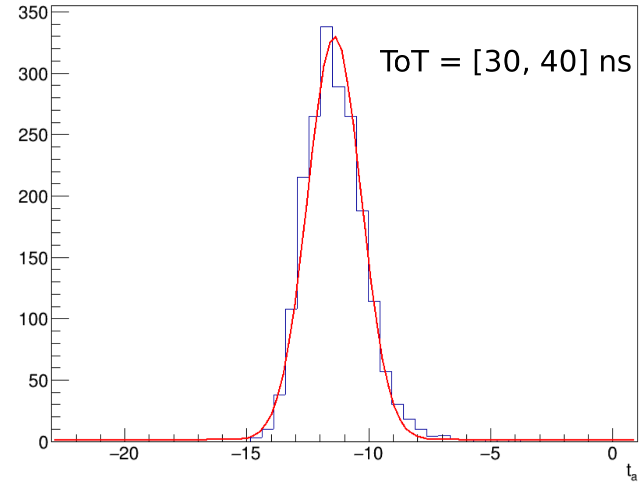


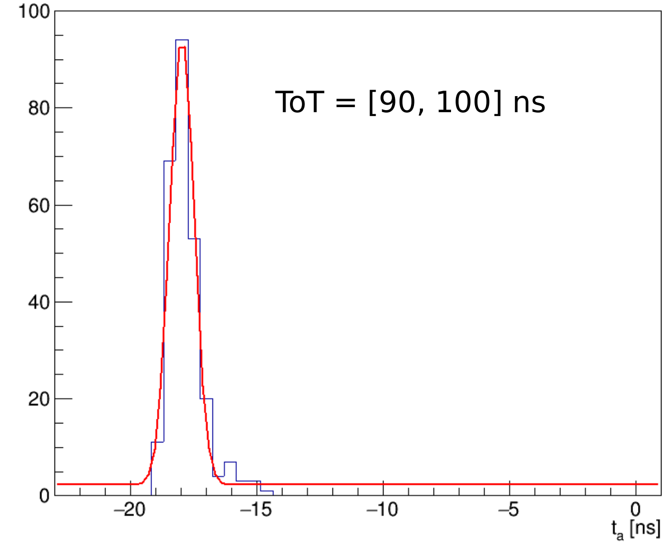


Tail towards slower signal arrivals

Charge collection by diffusion

$5\cdot10^{14}$ n_{eq}/cm^2 sample



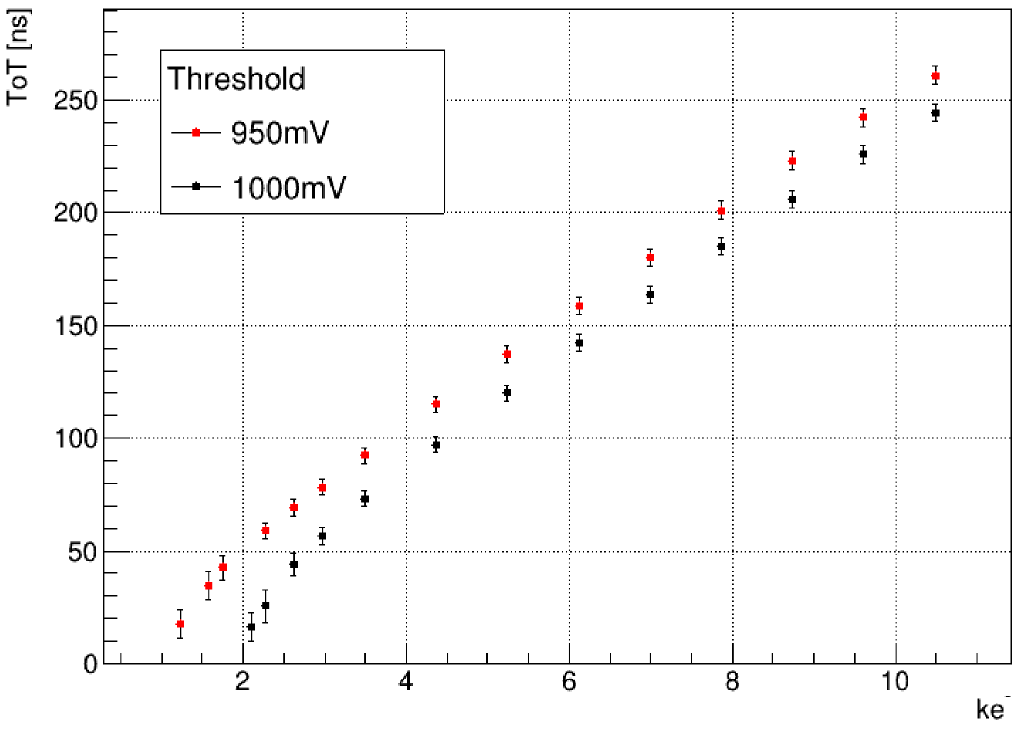


- Tails in distributions not present in irradiated sample
- More charge reaching the depletion layer via diffusion in unirradiated sample due to slower recombination in undepleted region

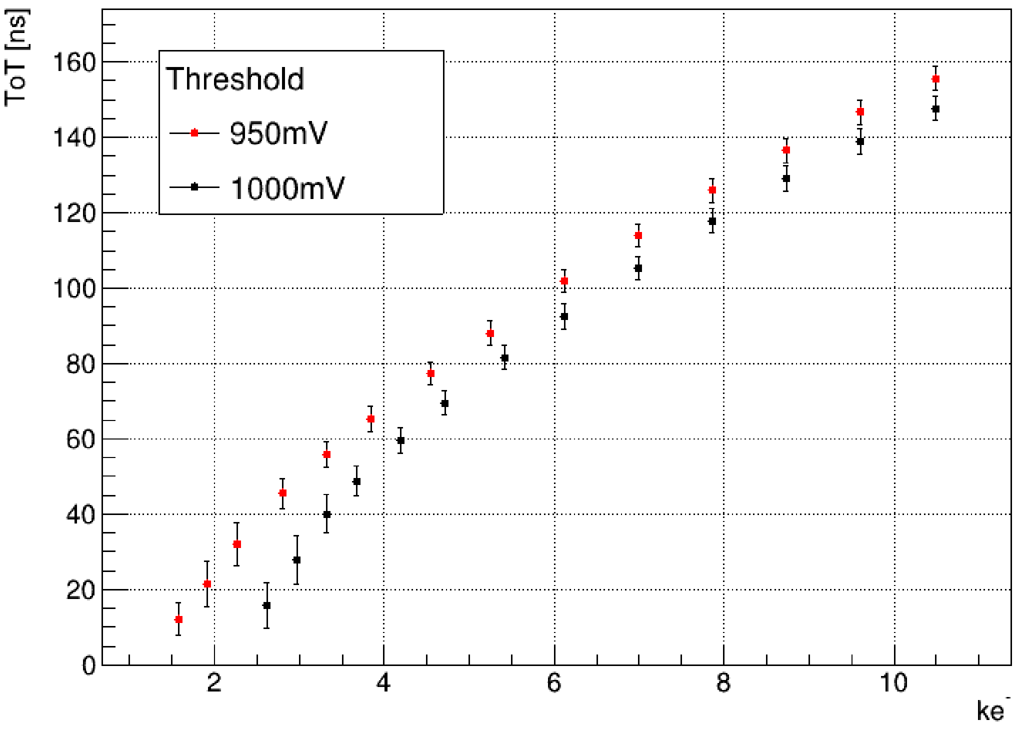
Backups

ToT calibration

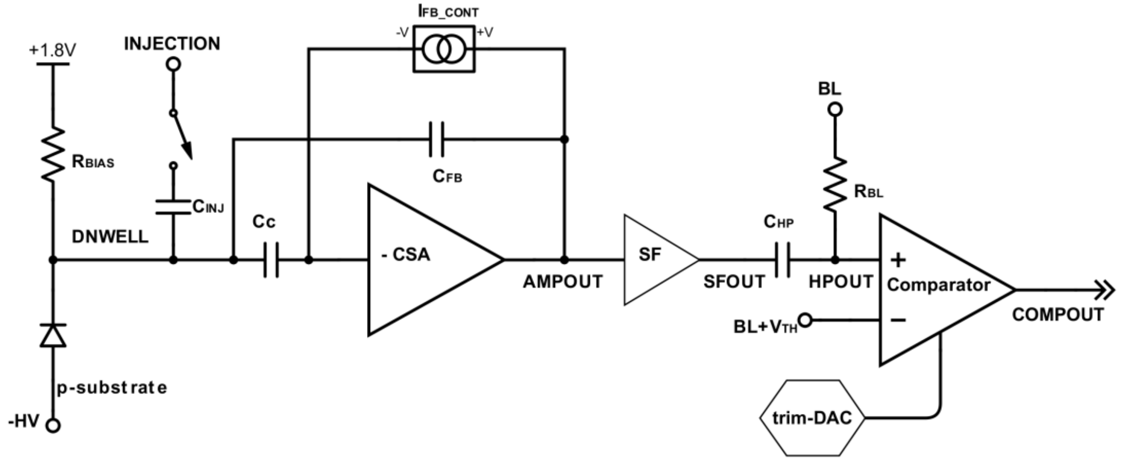
Unirradiated



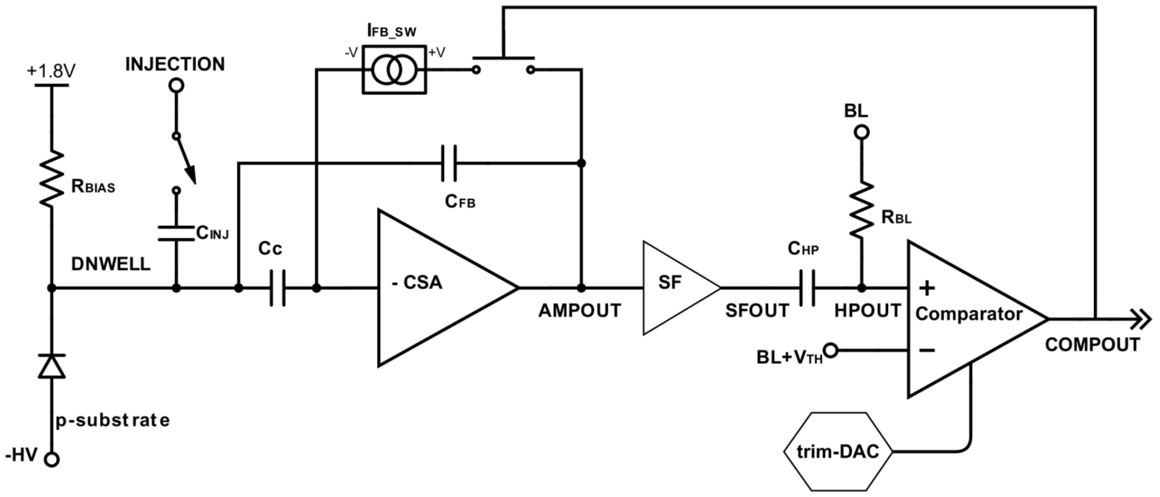
5e14 n/cm²



Pixel circuit diagrams



Continuous reset pixel



Switched reset pixel