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Timing properties of the RD50-MPW2 CMOS detector

17th Trento Workshop, 02.03.2022

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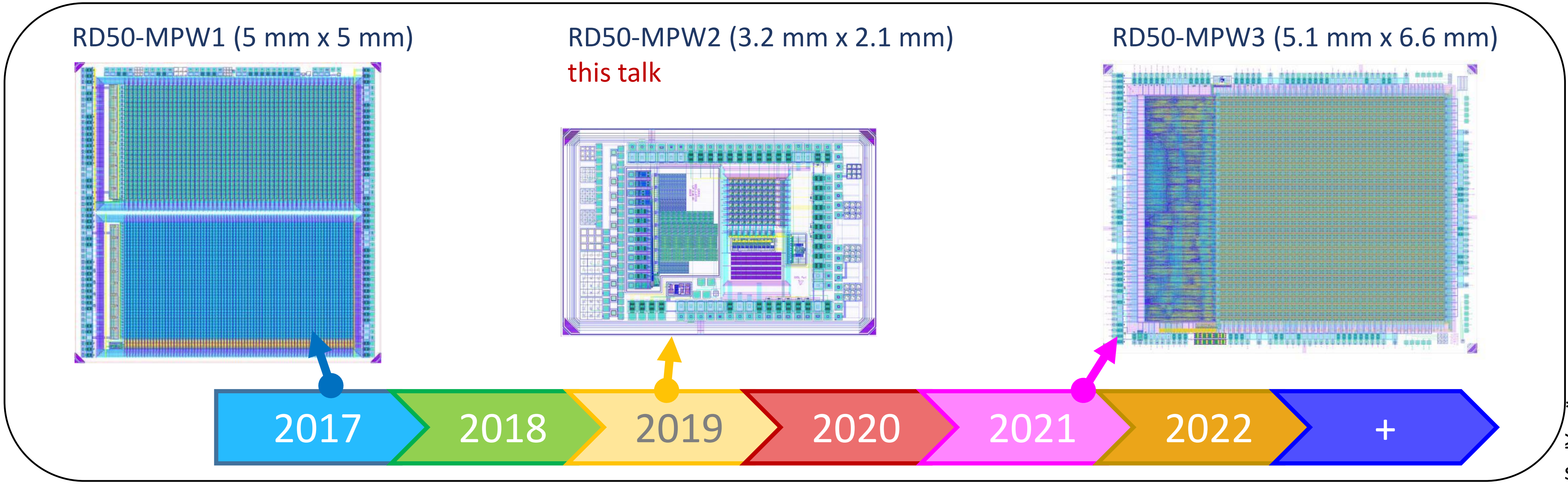
CERN-RD50 CMOS development program

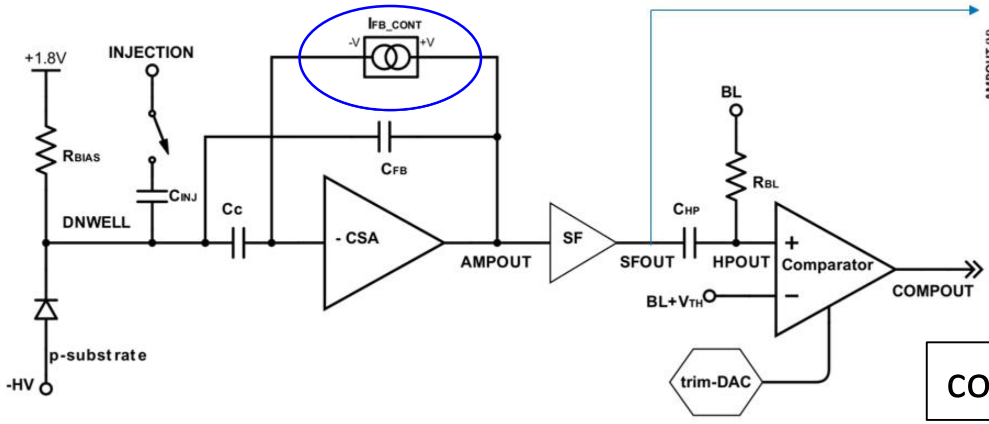
- CERN-RD50 collaboration
  - Radiation hard semiconductor devices
  - > 400 people, 64 institutes
- CERN-RD50 CMOS working group
  - Program to study and develop radiation hard monolithic CMOS sensors
    - ASIC design, TCAD, DAQ development, performance evaluation
    - > 40 people, 14 institutes
  - 3 CMOS prototypes designed so far in LFoundry 150 nm HV-CMOS process

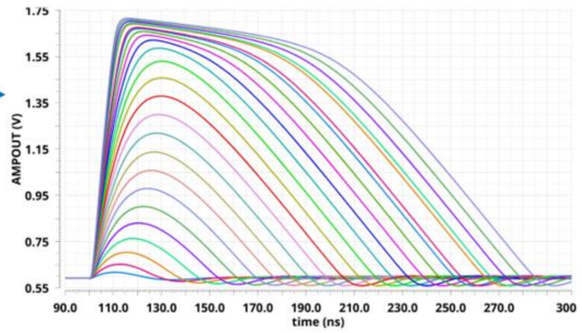


* chips delivered ≥ 5 months after submission

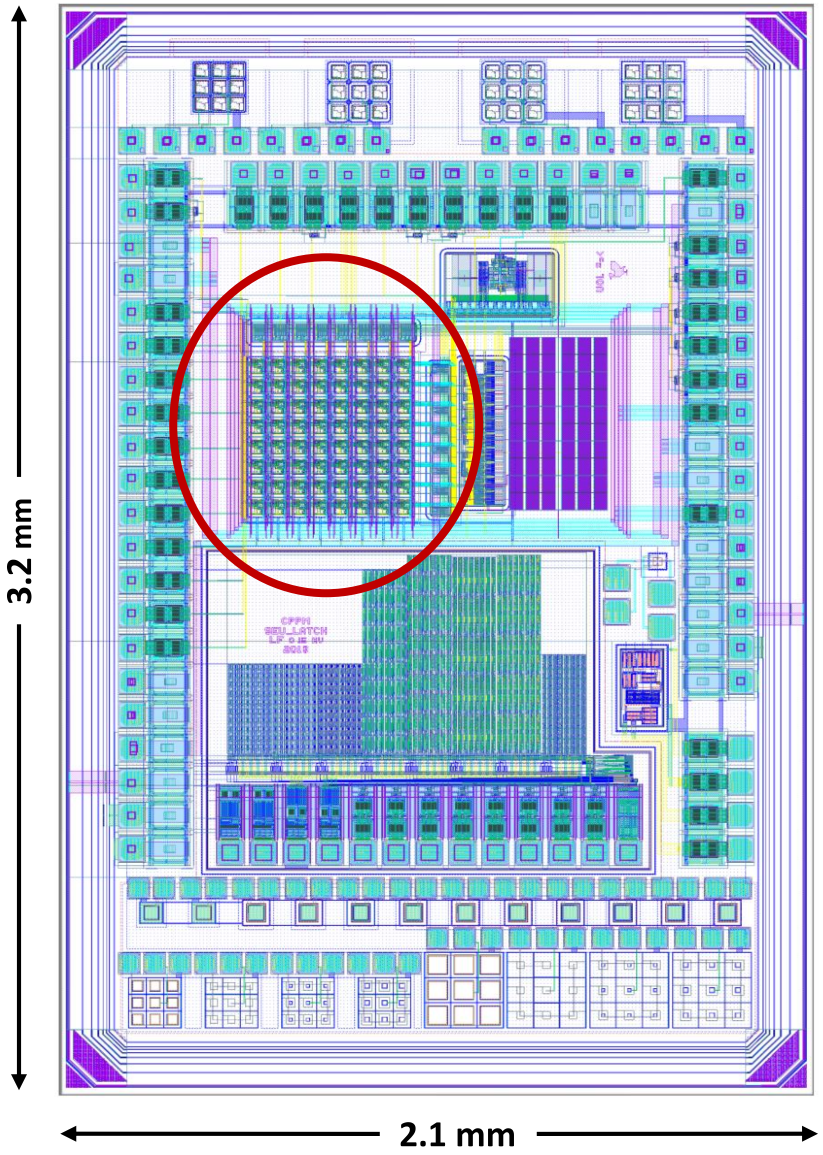
RD50-MPW2

- CMOS chip with dedicated test structures
  - Four p-type substrate resistivities 20 Ω·cm – 3 kΩ·cm, V_{bd} = - 120 V
- Including 8 x 8 active pixel matrix (60 µm x 60 µm) with analog front end
  - Charge sensitive amplifier + discriminator
  - Two pixel flavours with different CSA reset options:
    - Continuous reset – Time over threshold (100s ns)
    - Switched reset – short pulses (10 ns)
- This talk: Investigated a method to measure timing properties with laser
  - Time resolution, Time walk



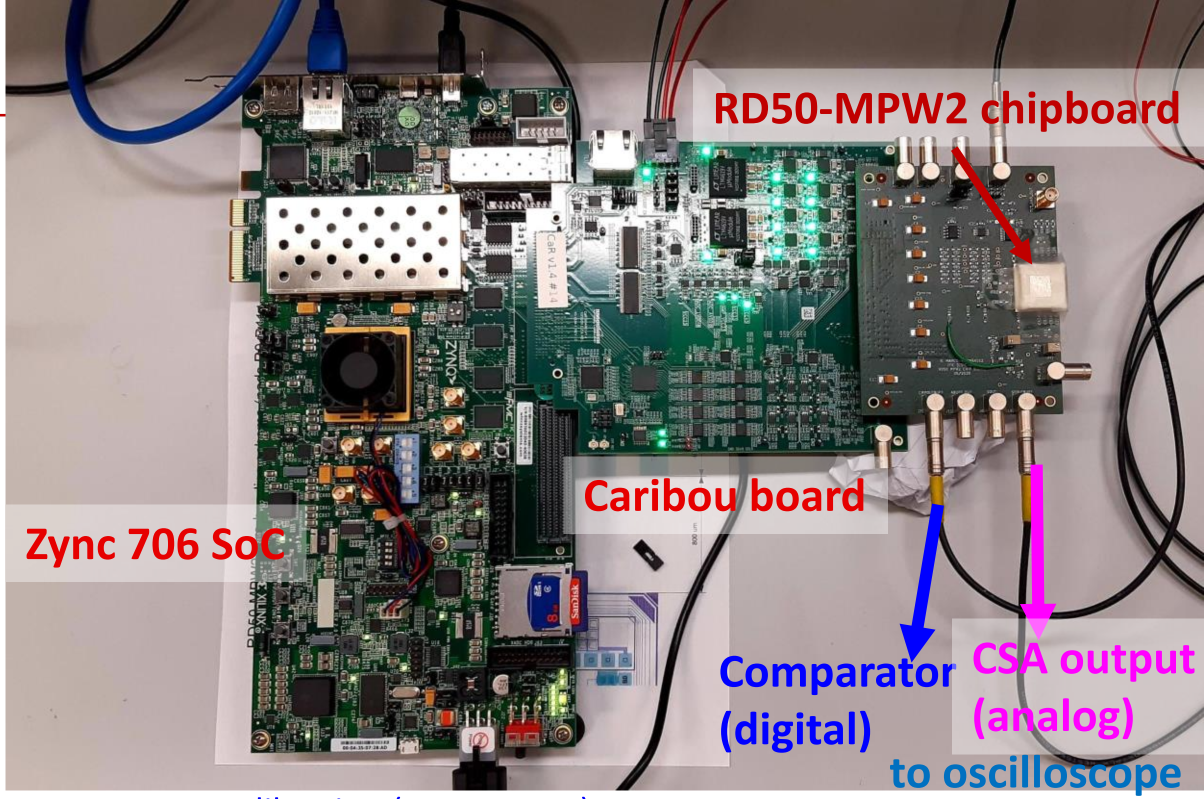


continuous reset pixel

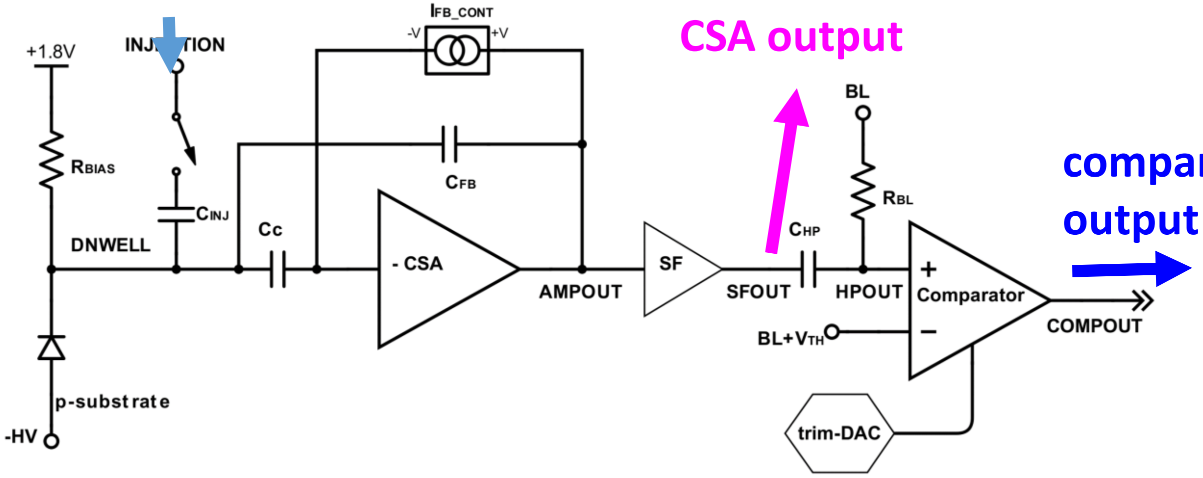


RD50-MPW2 DAQ

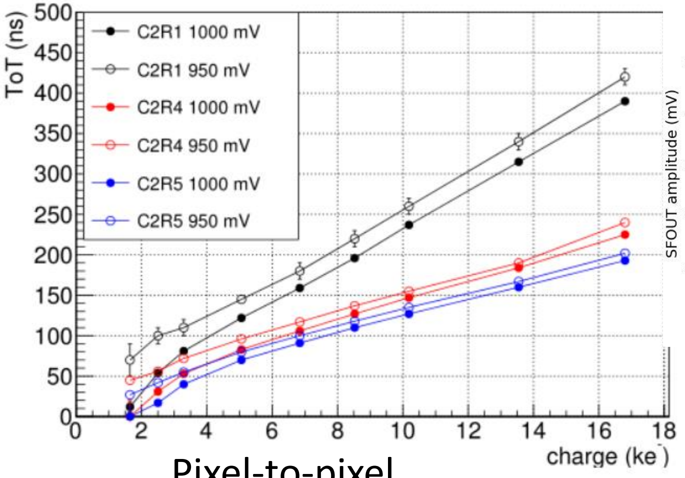
- Chip configuration and DAQ via Zync 706 SoC + Caribou system
- Active pixel outputs also routed out for probing with oscilloscope
  - Analog signal after **charge sensitive amplifier**
  - Digital **comparator output** – used for timing measurements
- Continuous reset pixel: Comparator **ToT ∝ charge**
- Calibration circuit with injection capacitor C_{inj} = 2.8 fF



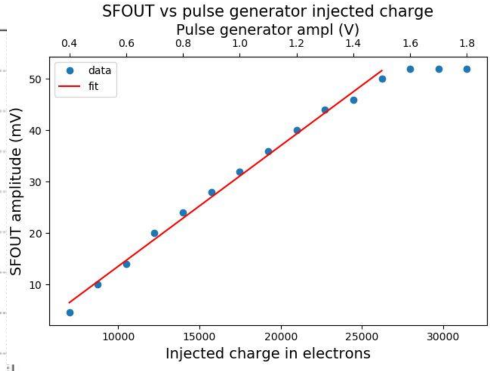
Ext. Injection (Pulser)



ToT calibration (comparator)



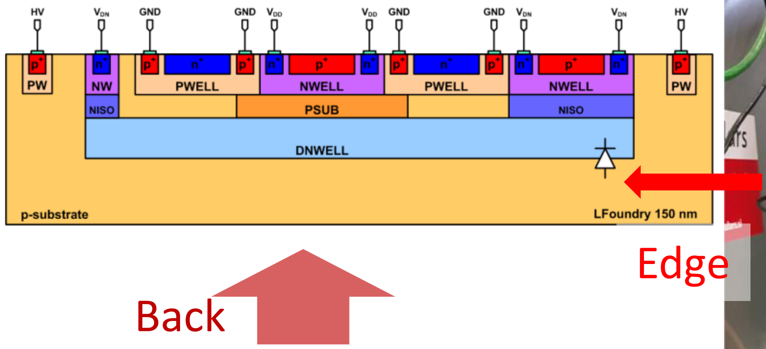
Pixel-to-pixel gain variation

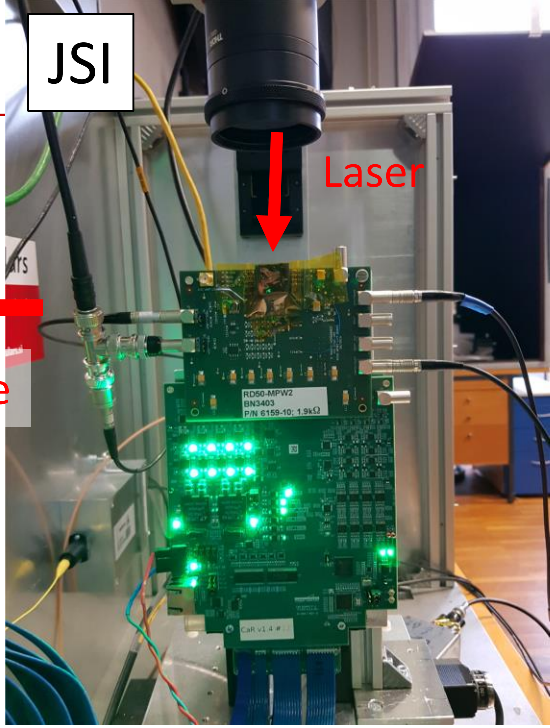


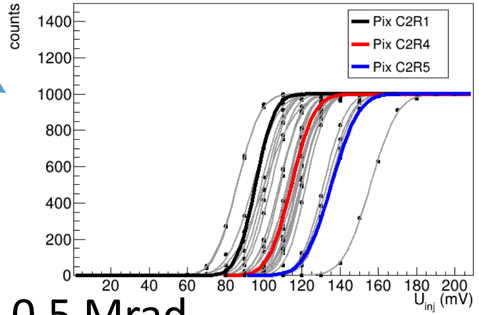
ToT calibration (analogue)

TCT setup

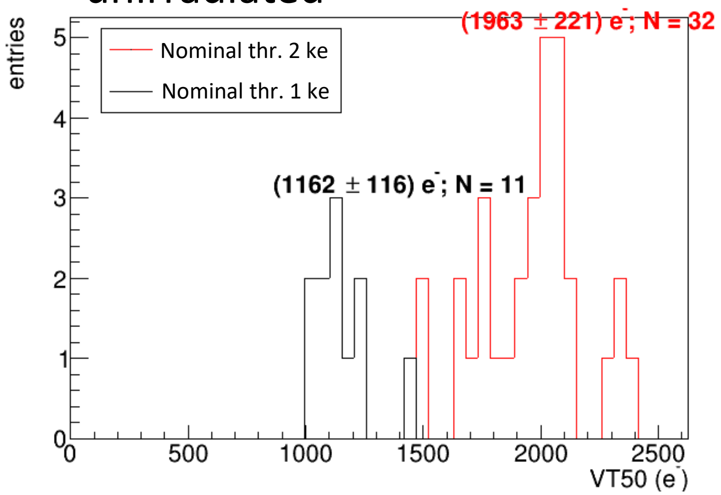
- Two TCT measurement setups (IR 1064 nm)
  - Jožef Stefan Institute, Edge-TCT, position sensitive
  - Nikhef, Back-TCT, full pixel illuminated
- Samples with substrate resistivity > 1.9 kΩ·cm
  - 2x unirradiated, 1x 5e14 (0.5 Mrad) neutron irradiated
  - Depletion depth 180 µm/120 µm before/after irradiation
  - Nominal comp. threshold ≈ 1000 e, 2000 e
    - Not tuned
    - At 1 ke noise problematic



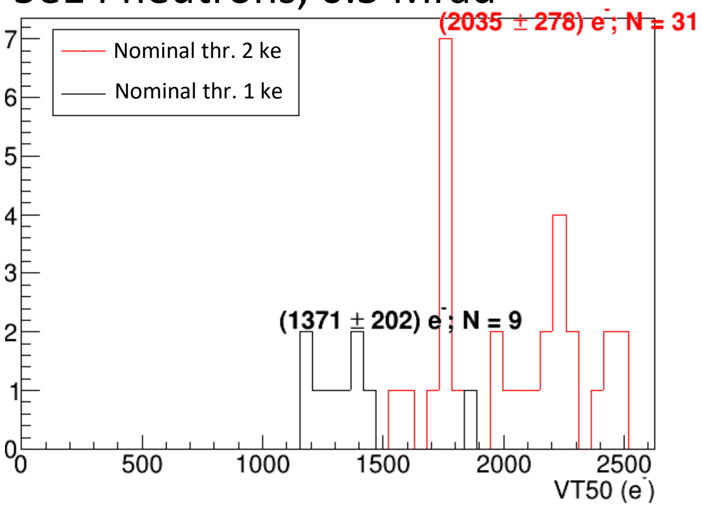


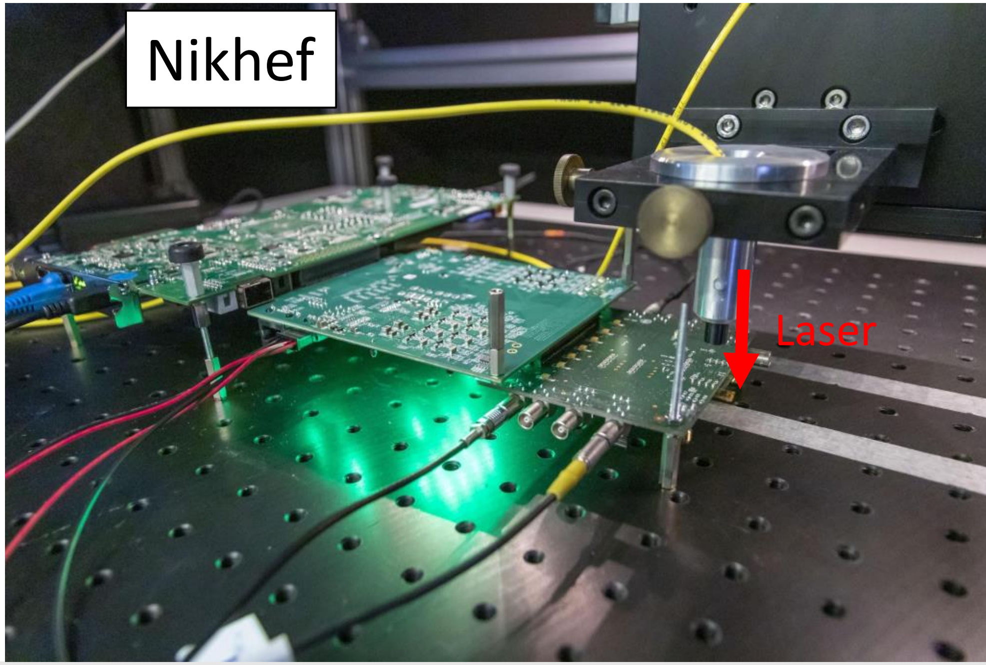


unirradiated



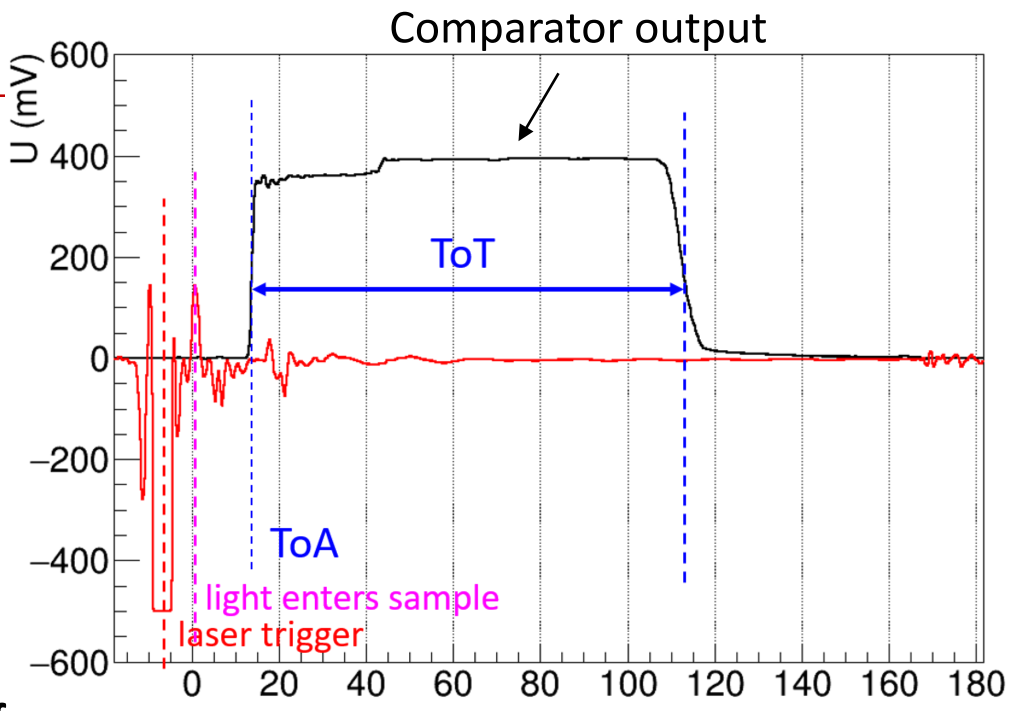
5e14 neutrons, 0.5 Mrad

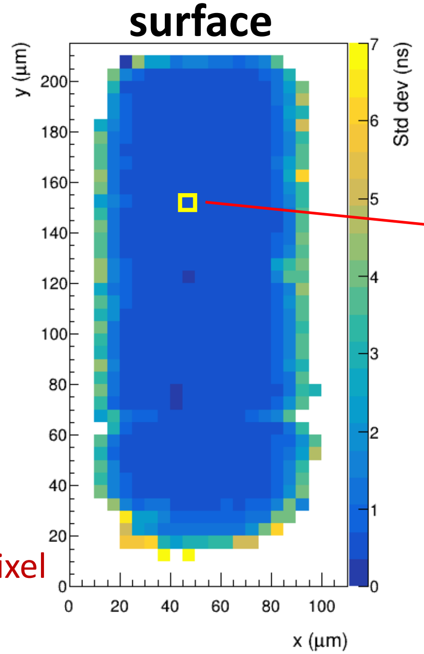




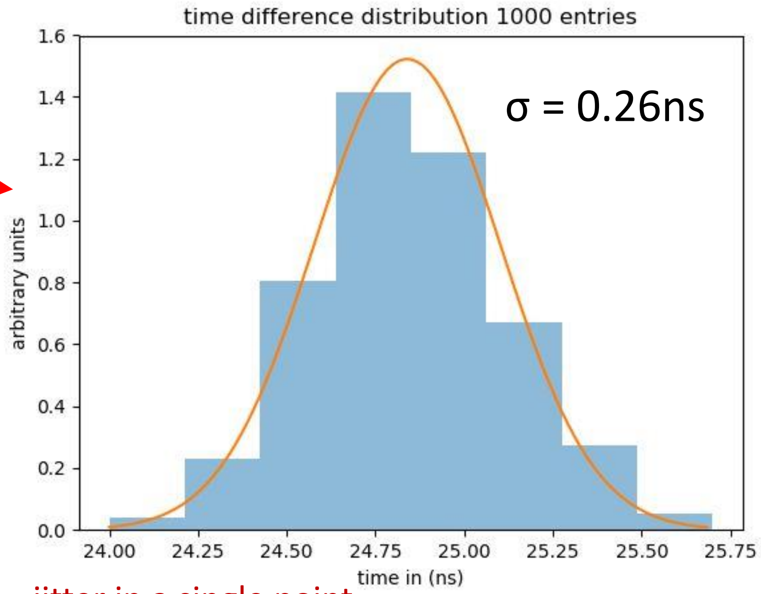
Timing measurements - methodology

- Measuring **Time walk** and **Timing resolution (jitter)** with **comparator** output signal:
  - Reference time (Trigger from laser driver)
  - Time of arrival (ToA) - compensated for cable length
  - Time over threshold (ToT)
- Sampling time at 50 % maximum, linear interpolation
- **Time walk:**
  - Dependence of ToA on ToT
  - Average of 100 pulses
- **Jitter:**
  - Spread of the difference between ToA and Laser Trigger
  - Statistics on 1000 pulses



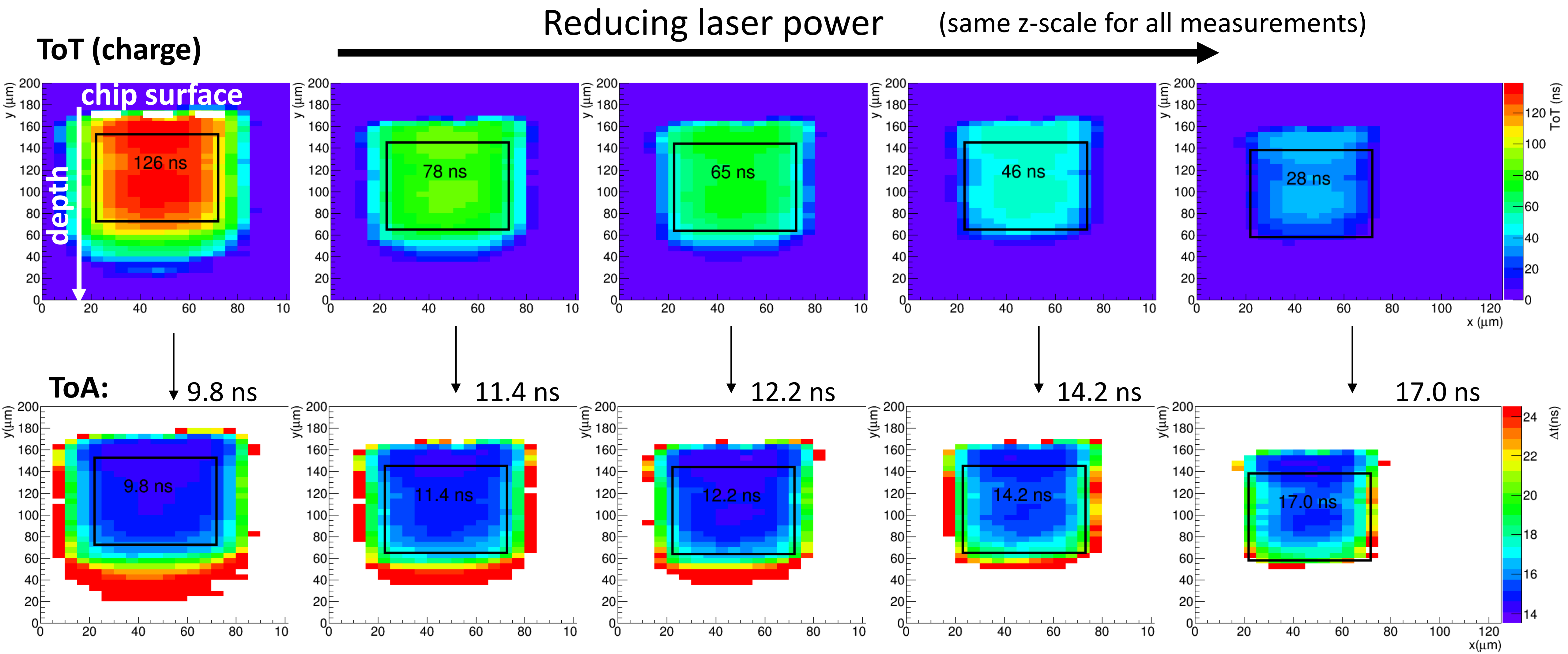


ToA–Ref difference distribution within pixel



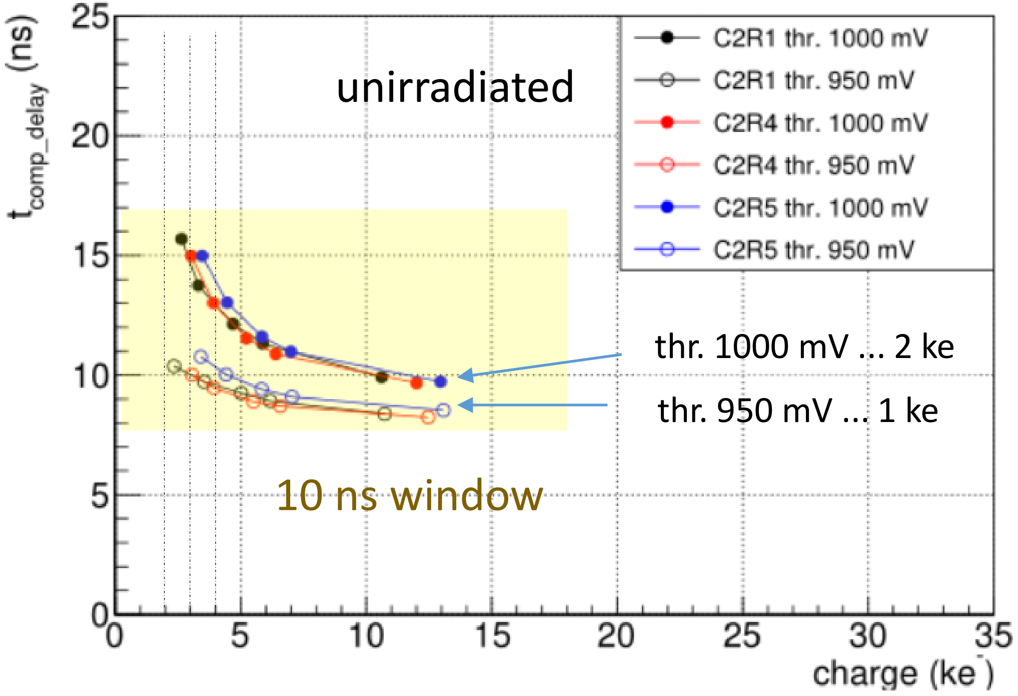
jitter in a single point

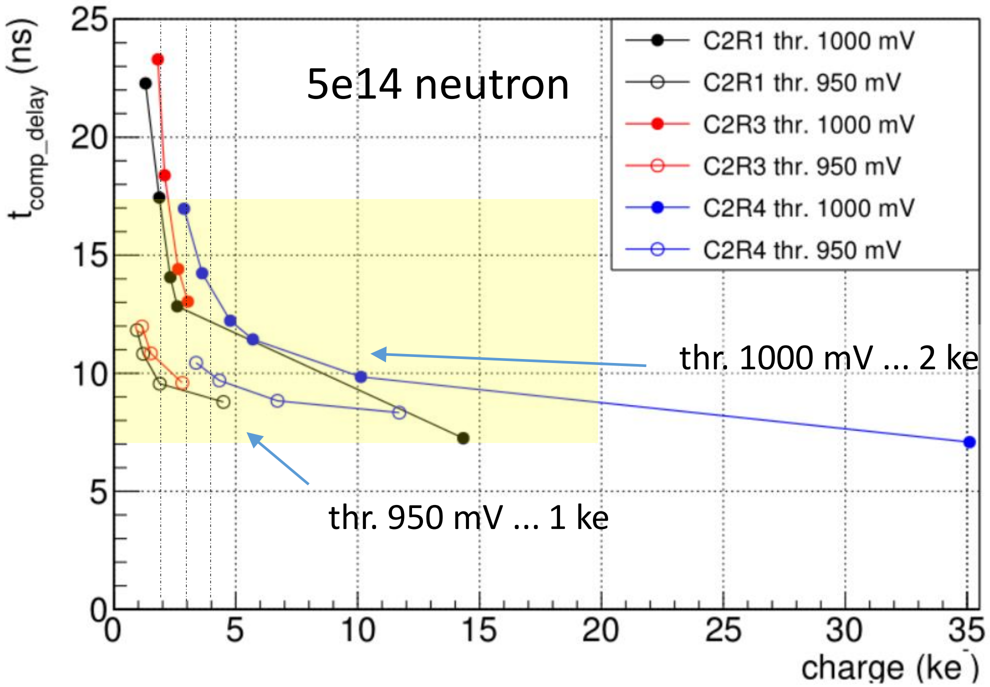
Time walk: In-pixel ToA and ToT



- ToA and ToT averaged over central part of the pixel
- ToA (time walk) – output delay increases at smaller charge

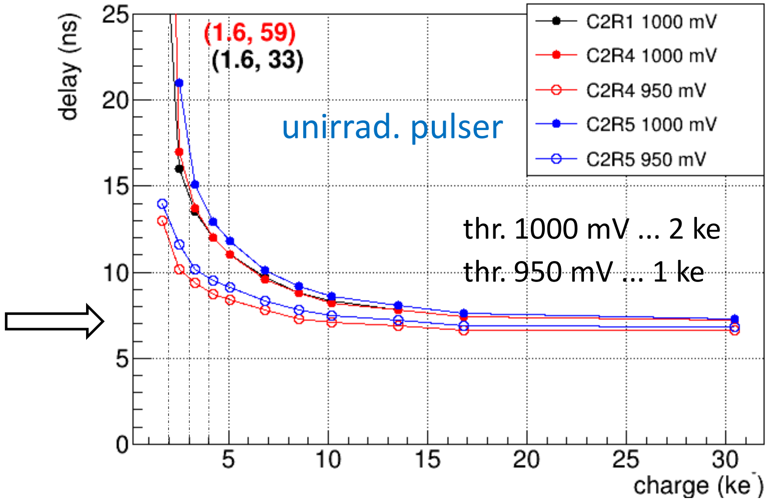
Time walk



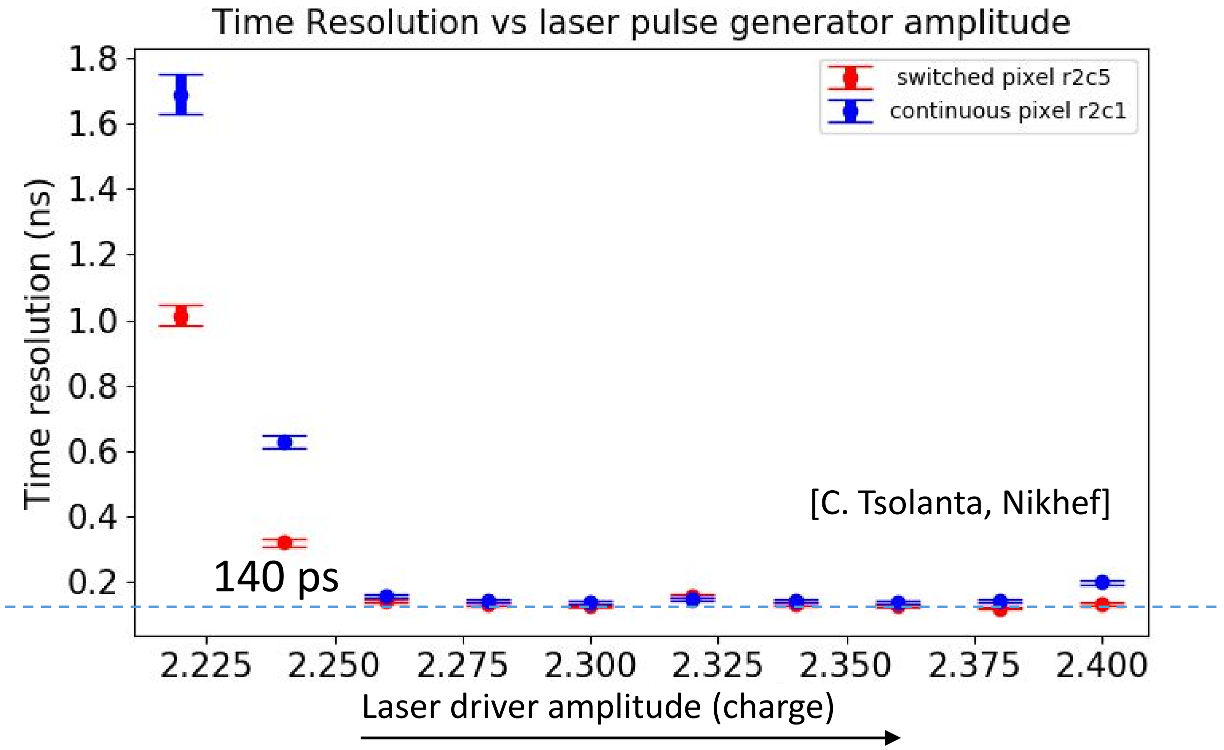


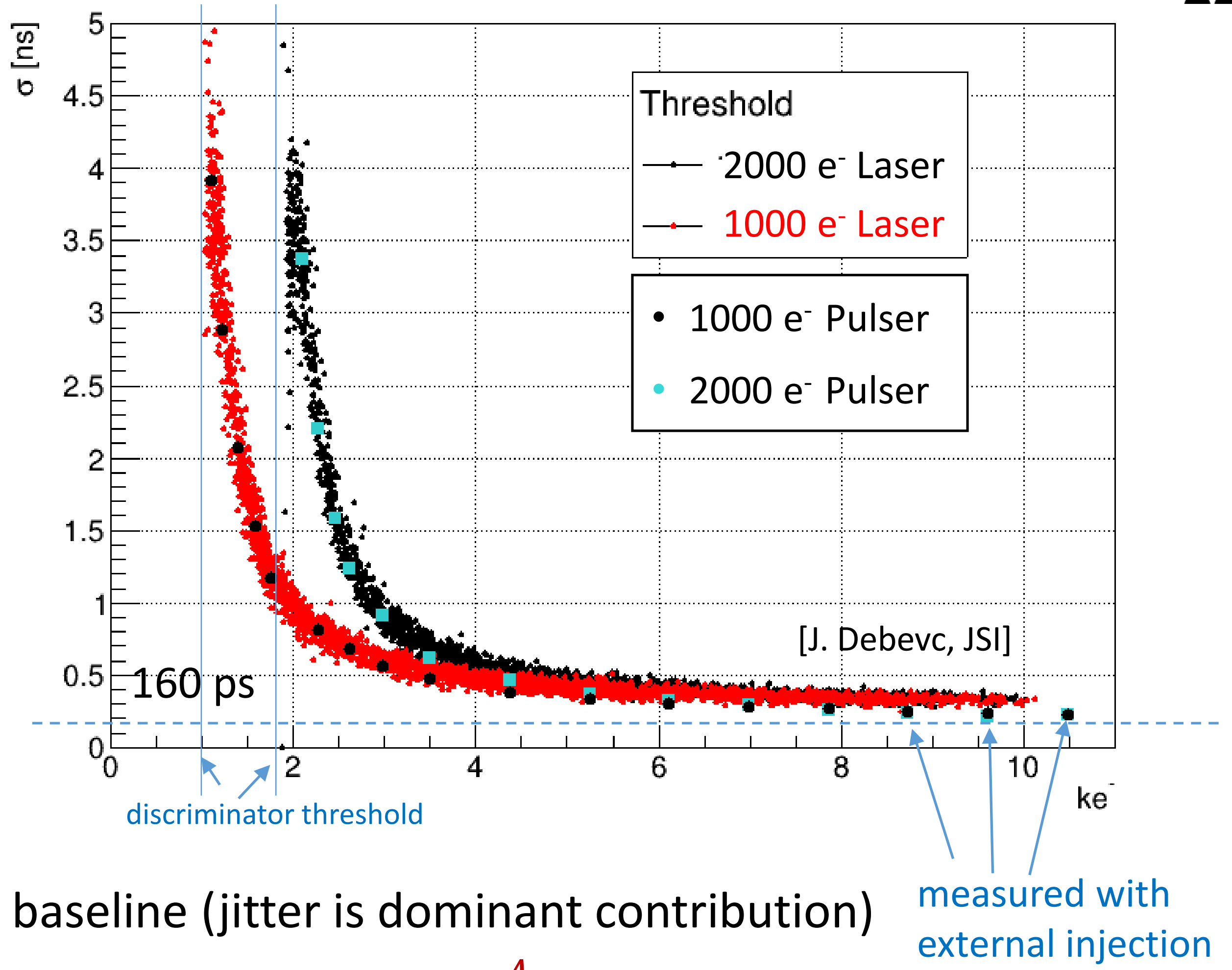
[B. Hiti et al., 2021 JINST 16 P12020]

- Time walk can determine in-time efficiency of the detector
- Minimal output delay ≈ 7 ns
- Signals above 2000 e⁻ are within 10 ns of the fastest signals
- Results are compatible with time walk measured with pulser
    - < 1 ns additional delay due to drift observed



Timing resolution unirradiated





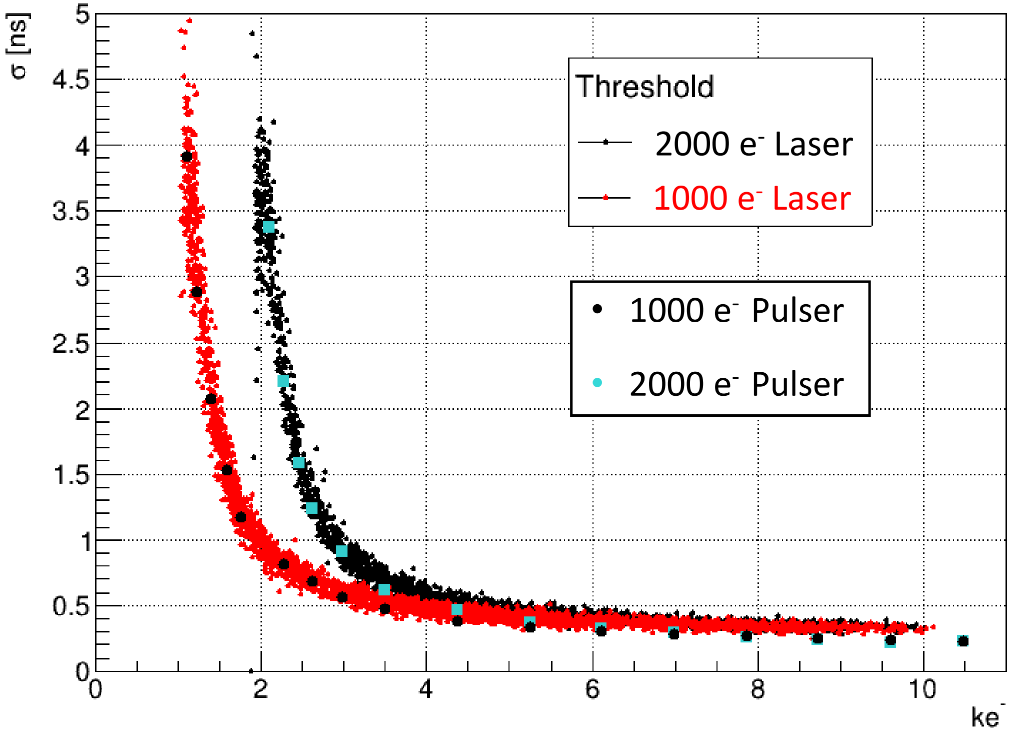
- Timing resolution scales as $(S/N)^{-1}$ with an asymptotic baseline (jitter is dominant contribution)
  - Asymptotic fit value at charge >> 10 ke$^-$: **140 ps/160* ps**
  - Approx. 300 ps at 10 ke$^-$
  - *at JSI using DRS4 oscilloscope, not yet compensating for different bin width

$$f(x) = \frac{A}{(x - x_{\text{thr}})} + \sigma_{\text{asympt.}}$$

- Switched reset pixels have higher gain than continuous reset → better resolution at low signals
- Generally good matching between laser and pulser measurements
  - Asymptotic value smaller with pulser (≈ 100 ps)

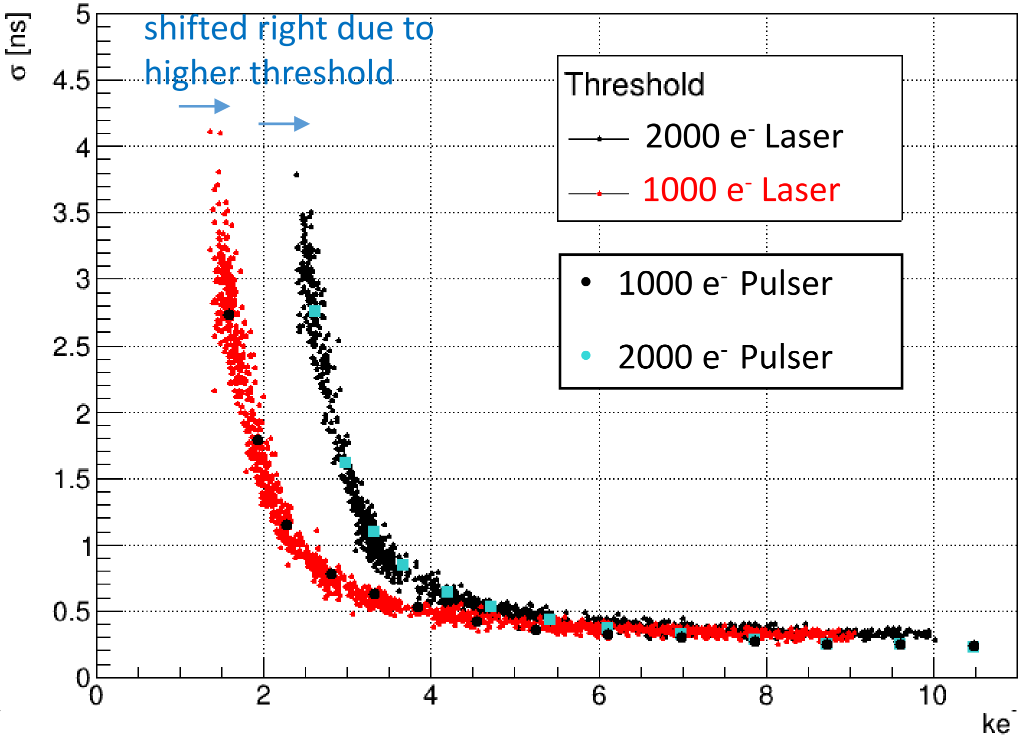
Timing irradiated sample

[J. Debevc, JSI]



before irradiation

5e14 neutrons, 0.5 Mrad
JSI TRIGA



after irradiation

- Measurement repeated with 5e14 neutron / 0.5 Mrad irradiated sample
- Higher pixel threshold in irradiated sample (samples not tuned)
- No difference at high signals, asymptotic resolution 160 ps

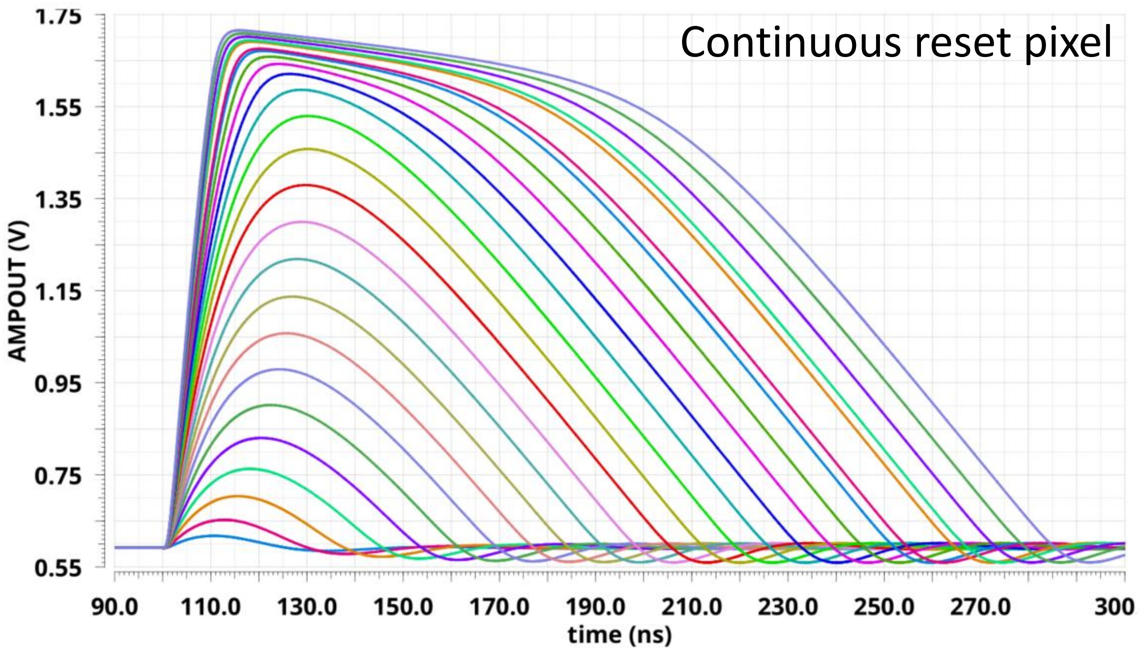
Summary

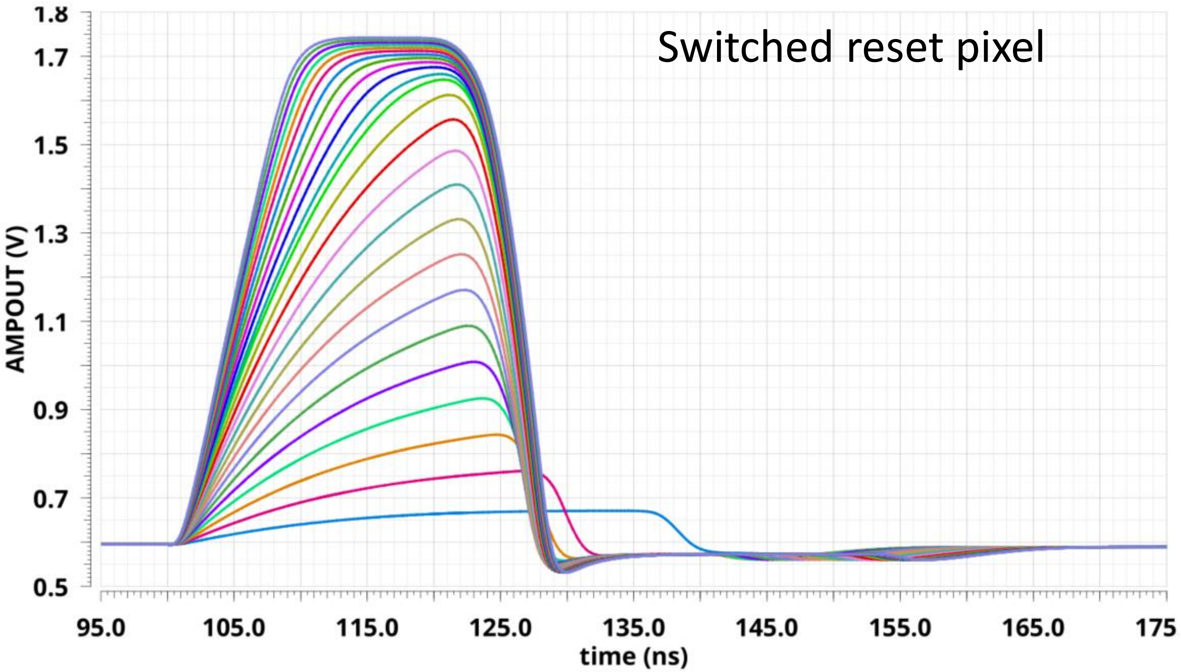
- Analog performance of RD50-MPW2 CMOS chip evaluated
- Investigated a method for timing measurements using laser TCT
  - Time walk < 10 ns for signals above 2 ke^-
  - Time resolution (jitter) scales with $(S/N)^{-1}$ within the investigated range
  - Time resolution of 140 ps measured with laser for high signals > 10 ke^-
- Results compatible with pulser measurements
- Outlook
  - New monolithic chip RD50-MPW3 has been submitted in Dec 2021
  - Preparing Sr90 setup for timing tests with radioactive source

This work has been partly performed in the framework of the CERN RD50 collaboration.
The authors would like to thank the crew at the TRIGA reactor in Ljubljana for help with irradiations of detectors.
The authors acknowledge the financial support from the Slovenian Research Agency (research core funding No. P1-0135 and project ID PR-06802).

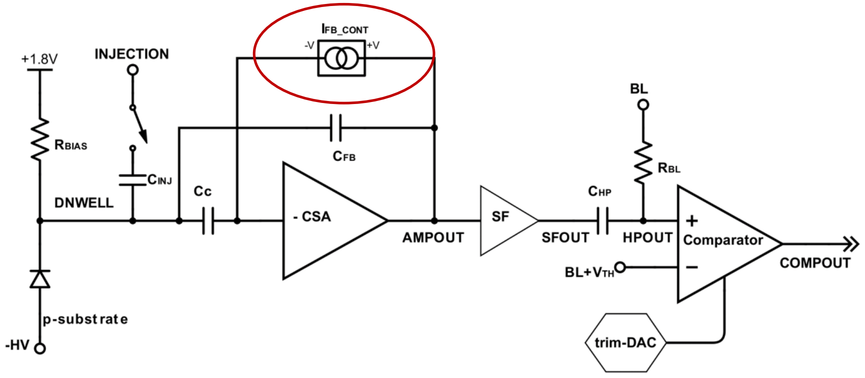
BACKUP

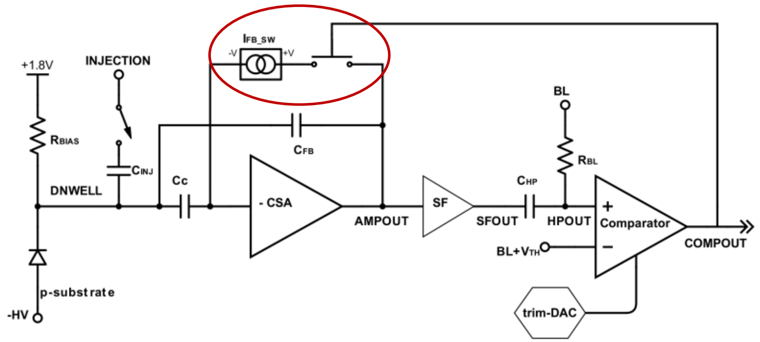
CSA simulation



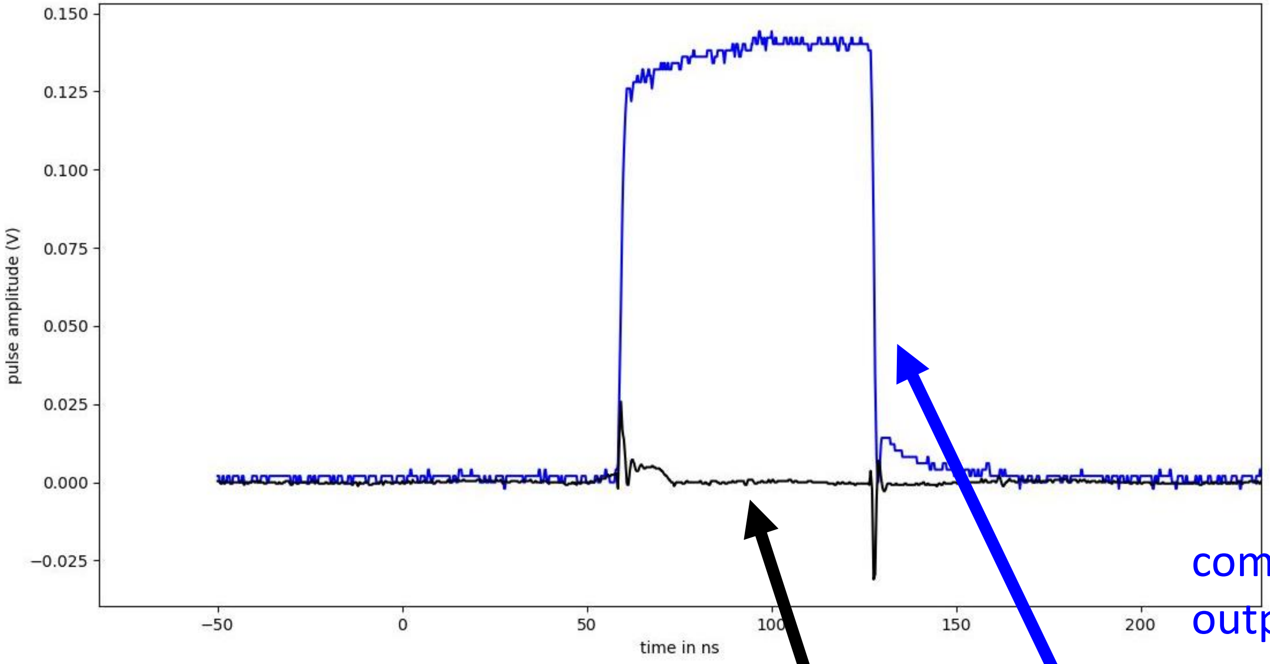


Simulation of charge sensitive amplifier output for injected charge 1 ke – 25 ke





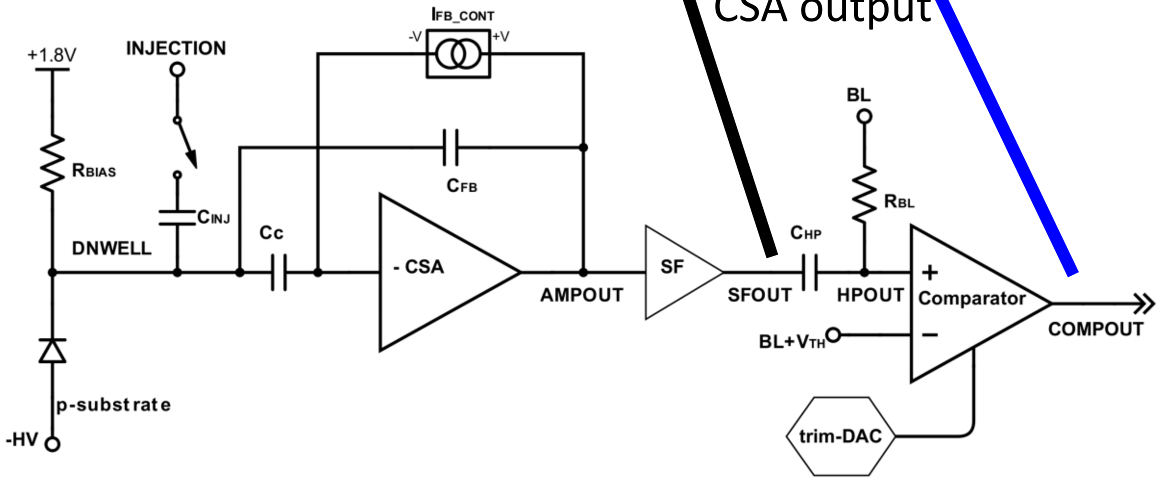
Output signals



1.8 V clipped due to 50 Ohm oscilloscope termination

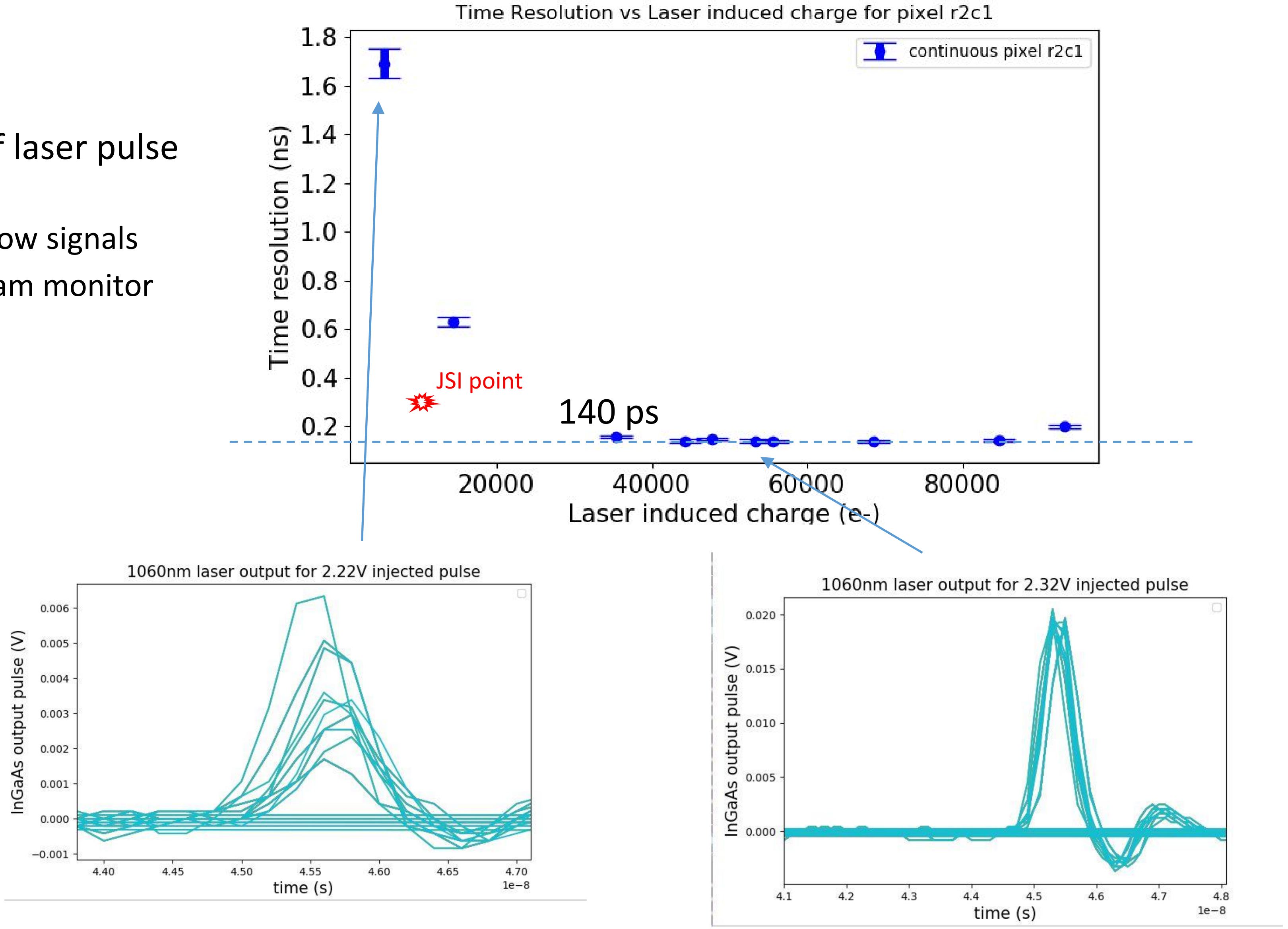
comparator output

CSA output



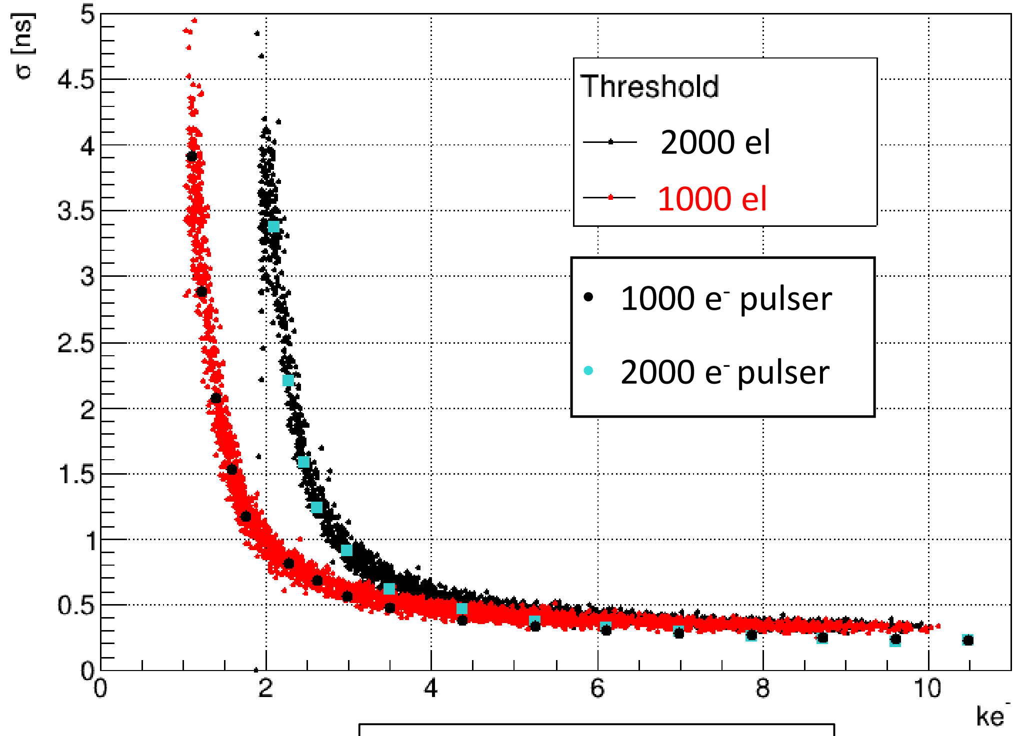
Nikhef jitter measurement

- Large event-to-event variations of laser pulse energy at low power
  - Dominant jitter contribution at low signals
  - Can be compensated using a beam monitor



Timing resolution fit – laser injection

before irradiation

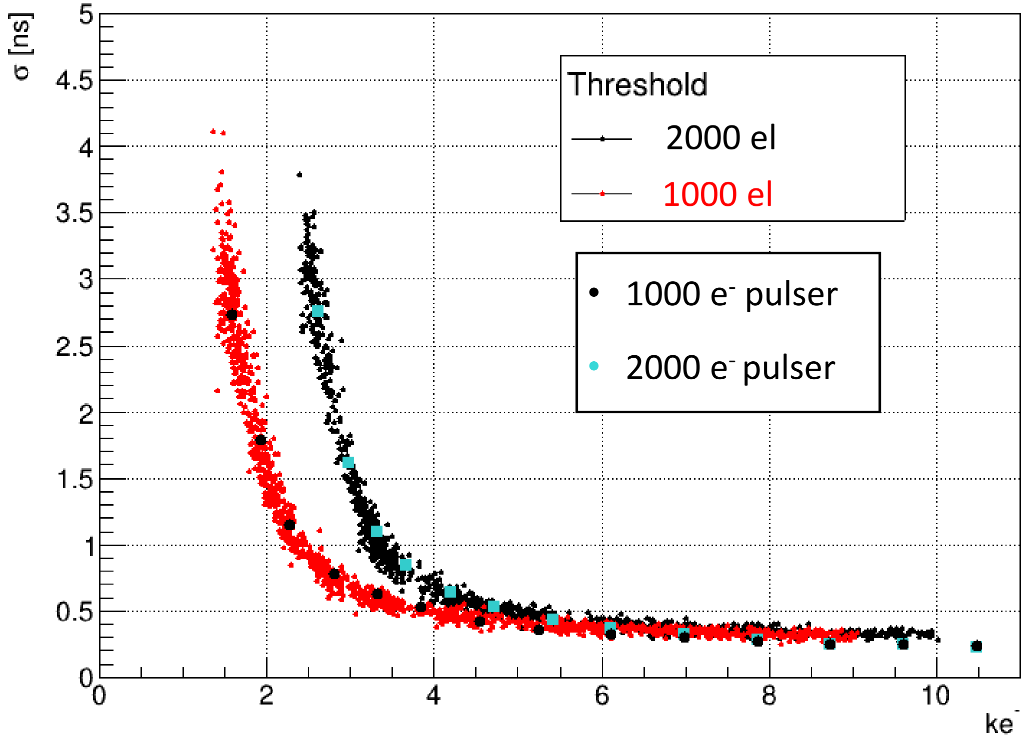


A = (0.89 ± 0.01) ke·ns
B = (199 ± 2) ps
x_0 = (0.866 ± 0.002) ke

A = (0.94 ± 0.01) ke·ns
B = (185 ± 2) ps
x_0 = (1.72 ± 0.003) ke

$$f(x) = \frac{A}{(x - x_0)} + B$$

after irradiation

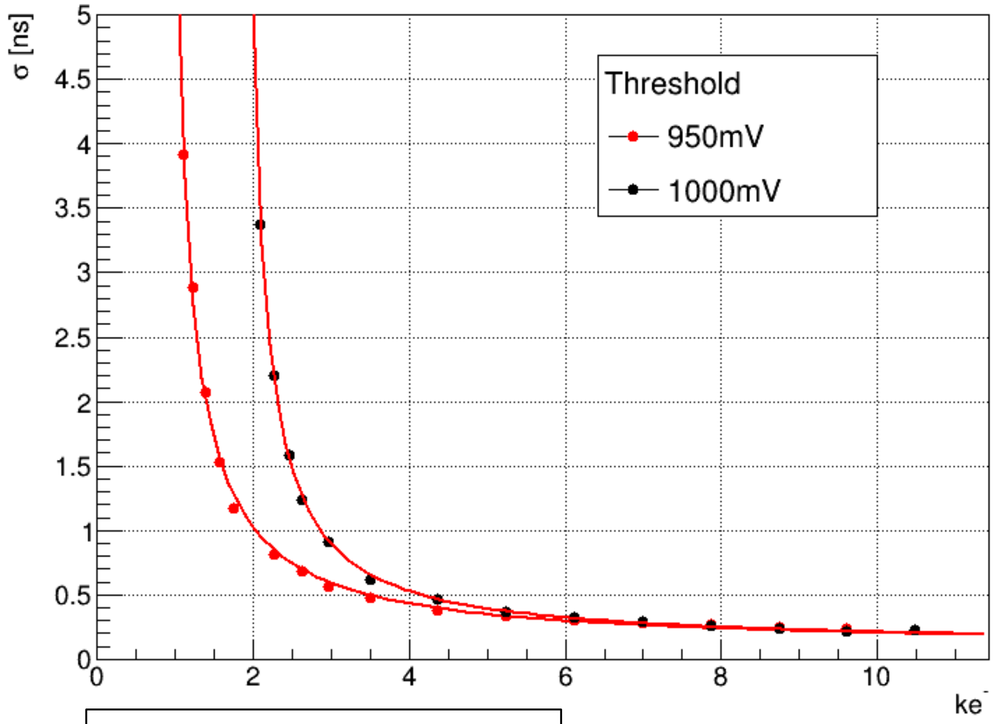


A = (1.07 ± 0.01) ke·ns
B = (144 ± 3) ps
x_0 = (1.13 ± 0.005) ke

A = (0.97 ± 0.01) ke·ns
B = (162 ± 3) ps
x_0 = (2.17 ± 0.004) ke

Timing resolution fit – pulser

unirradiated

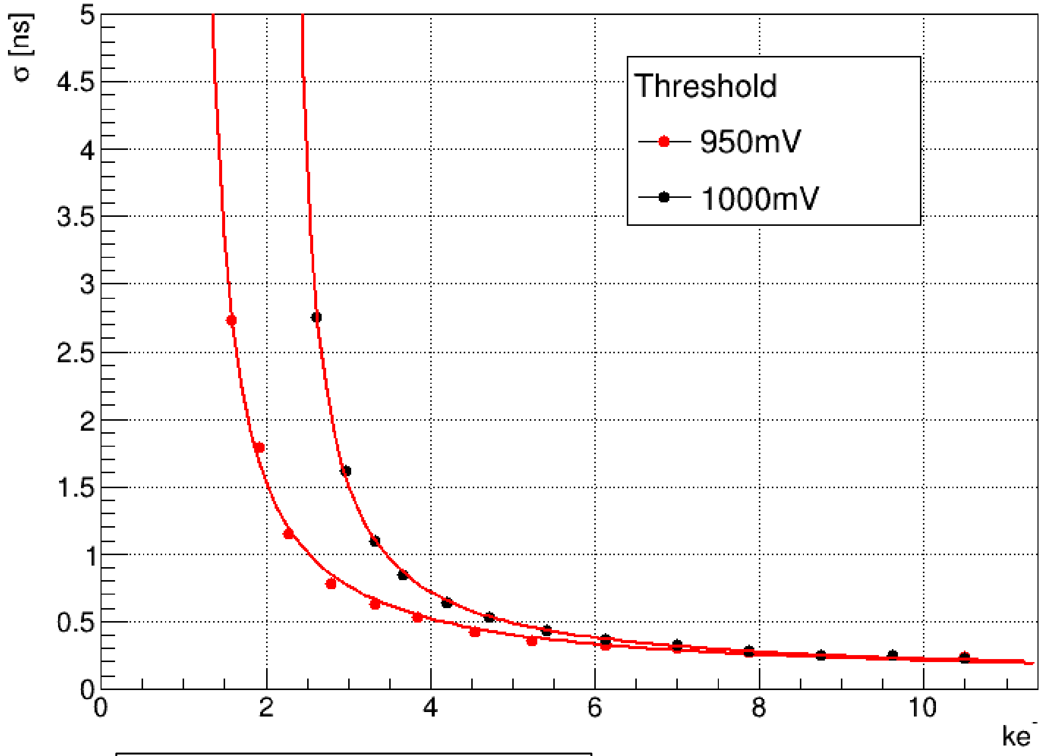


A = (1.12 ± 0.05) ke·ns
B = (84 ± 22) ps
x_0 = (0.81 ± 0.01) ke

A = (0.96 ± 0.02) ke·ns
B = (96 ± 10) ps
x_0 = (1.81 ± 0.01) ke

$$f(x) = \frac{A}{(x - x_0)} + B$$

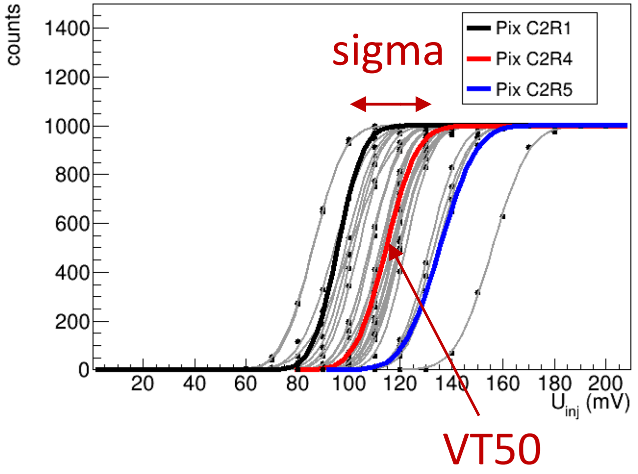
5e14n, 0.5 Mrad



A = (1.37 ± 0.10) ke·ns
B = (55 ± 30) ps
x_0 = (1.07 ± 0.04) ke

A = (1.18 ± 0.03) ke·ns
B = (71 ± 11) ps
x_0 = (2.18 ± 0.01) ke

Threshold and noise distribution in MPW2



$C_{inj}U$ ~ 17.5 e/mV

unirradiated 5e14 neutrons, 0.5 Mrad