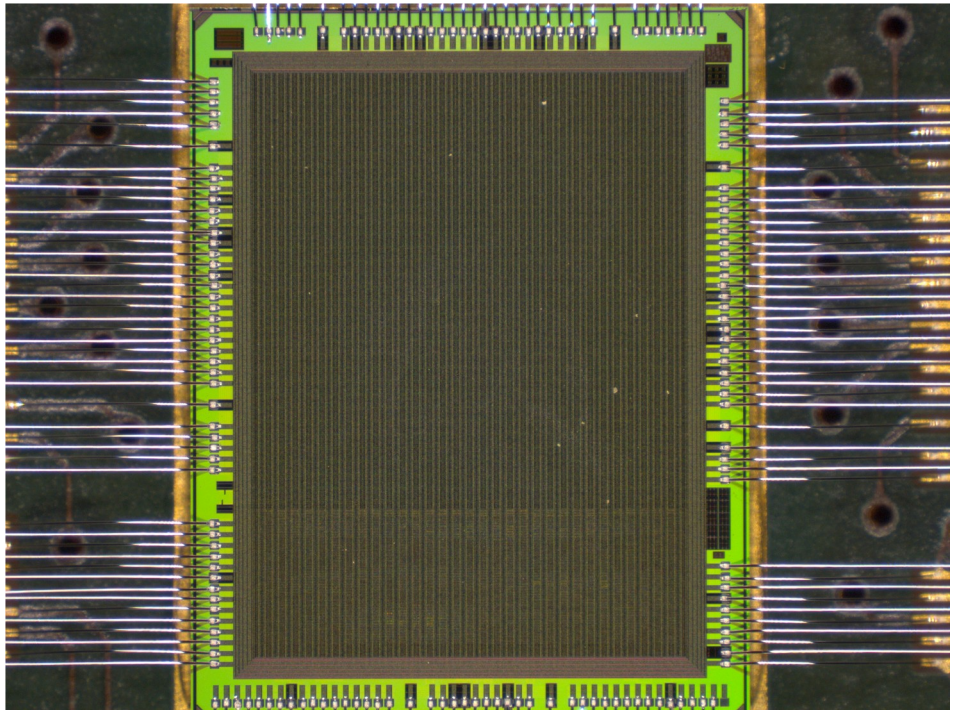
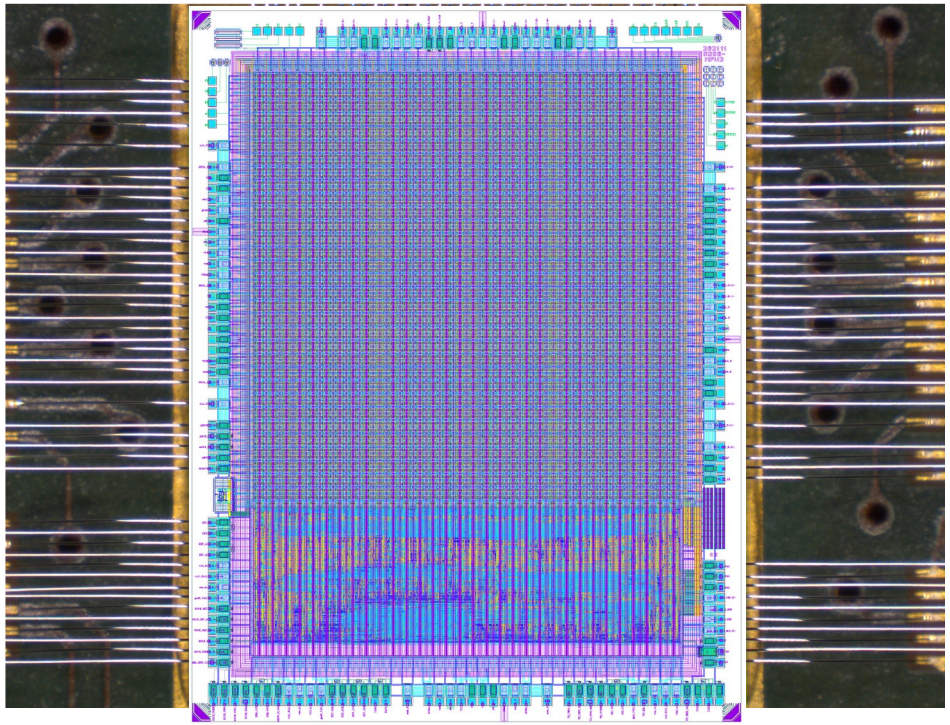
Timing performance of the RD50 HV-CMOS



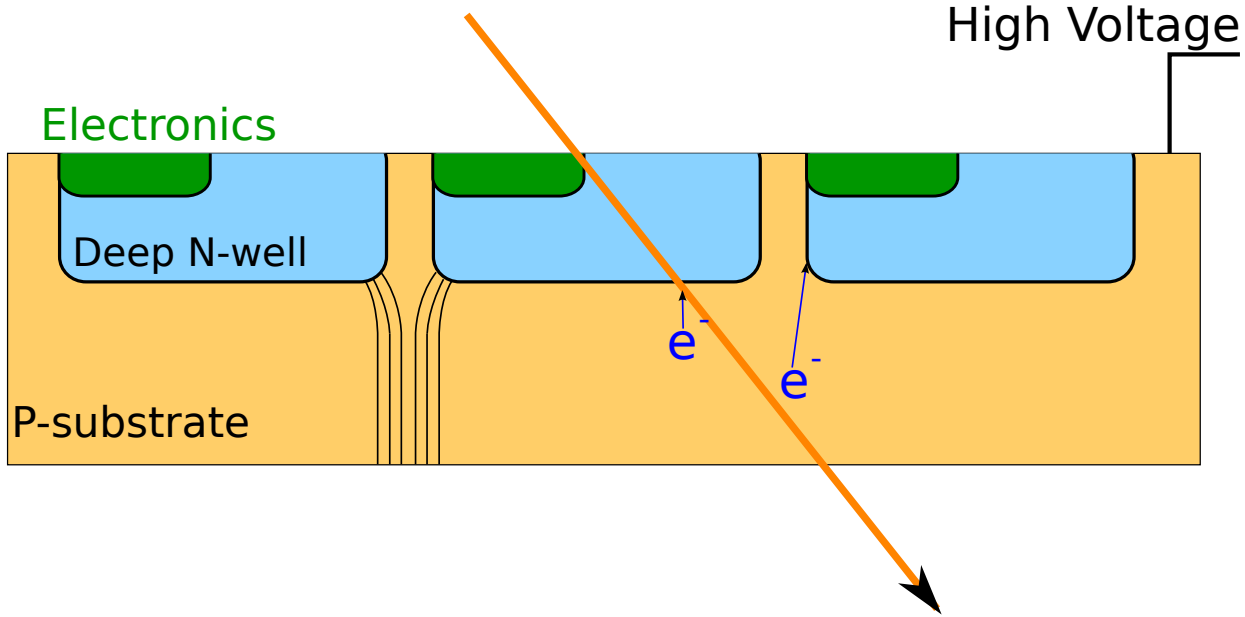


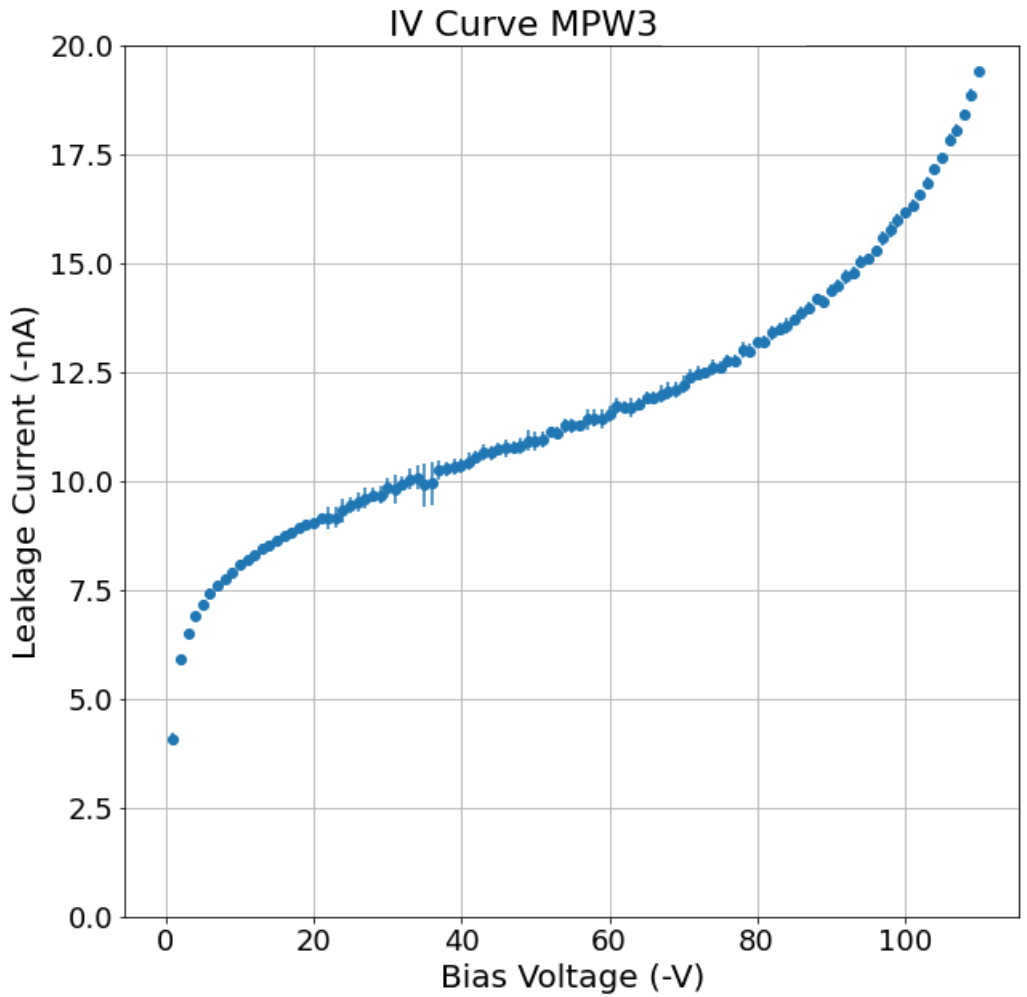
HV-CMOS for radiation hard depleted MAPS

- Electronics embedded in a large deep N-doped well to shield from high voltage
  - Allows for application of ~O(100 V) reverse bias
    - Large depletion zone
    - Fast and more stable charge collection

      → Less sensitive to trapping

      → Improved time resolution



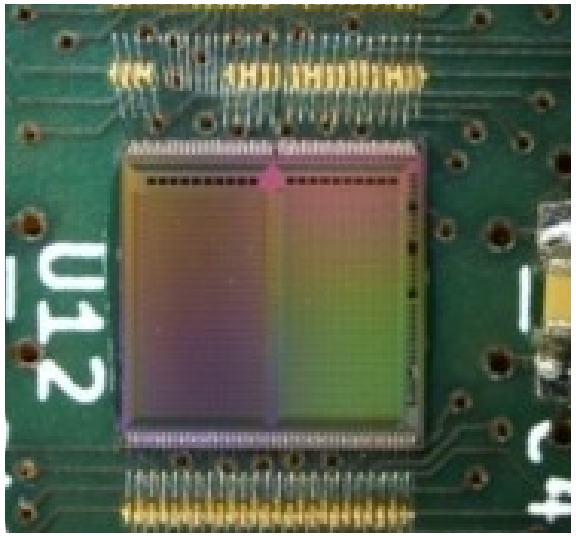


The RD50 DMAPS sensors

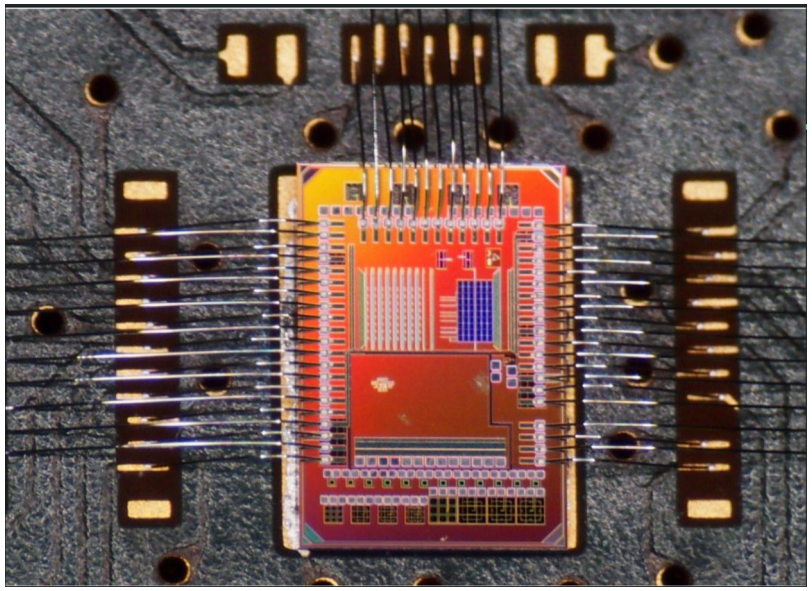
- Currently three iterations of Depleted Monolithic Active Pixel Sensors (DMAPS) as part of RD50 project
  - All manufactured by LFoundry in 150 nm HV-CMOS process
  - Recent prototype RD50-MPW3 was delivered in July 2022

2017 — 2019 — 2022

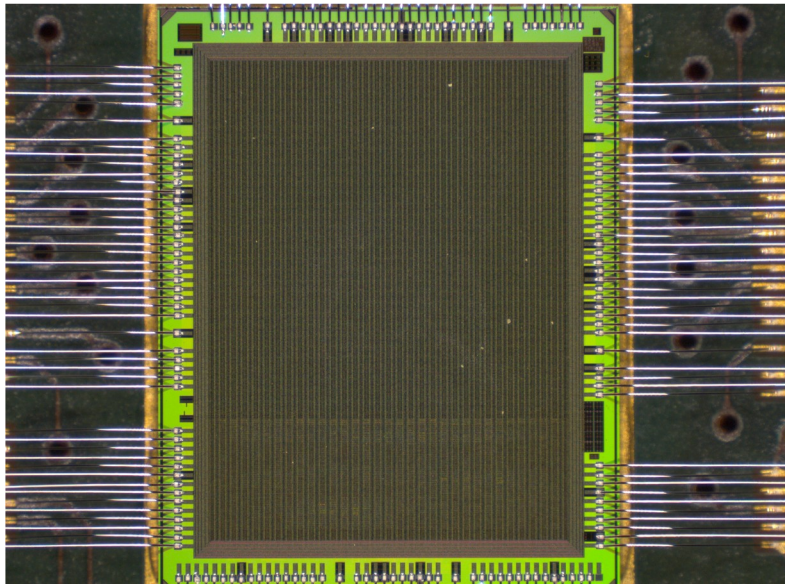
RD50-MPW1



RD50-MPW2

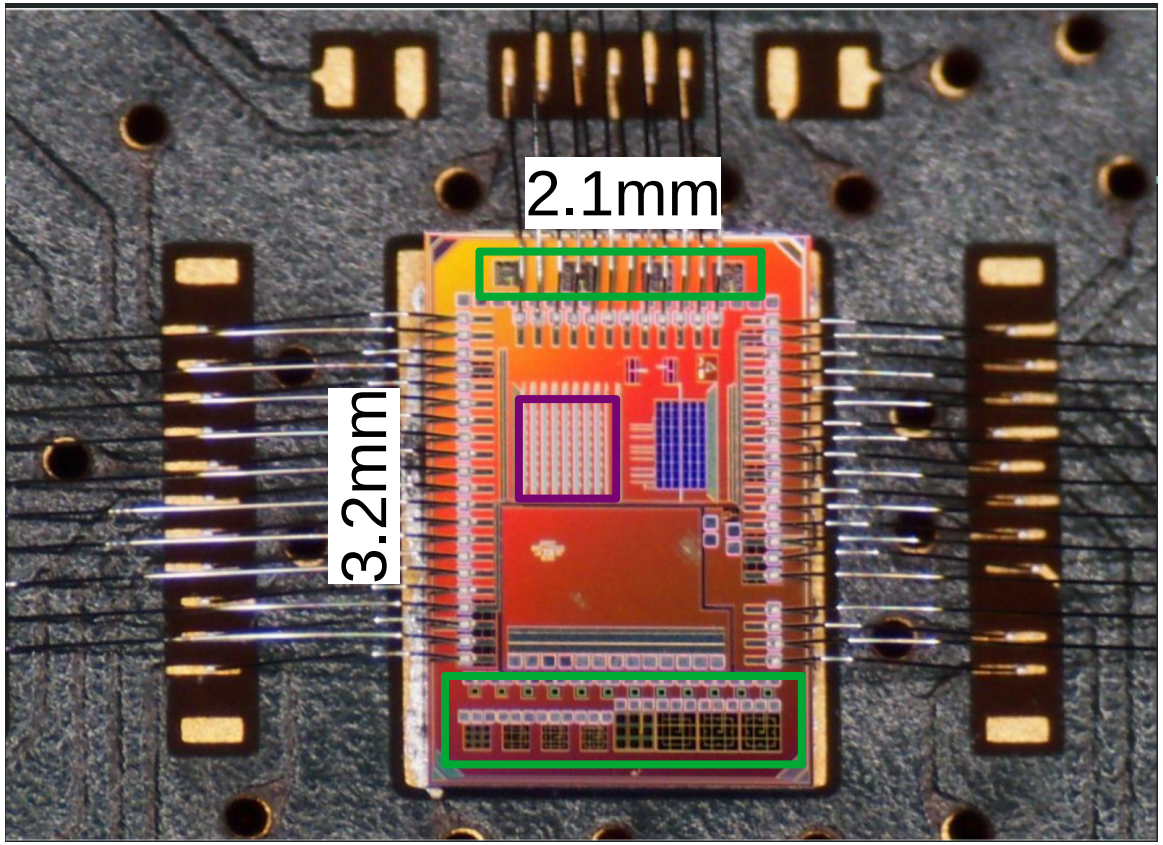


RD50-MPW3



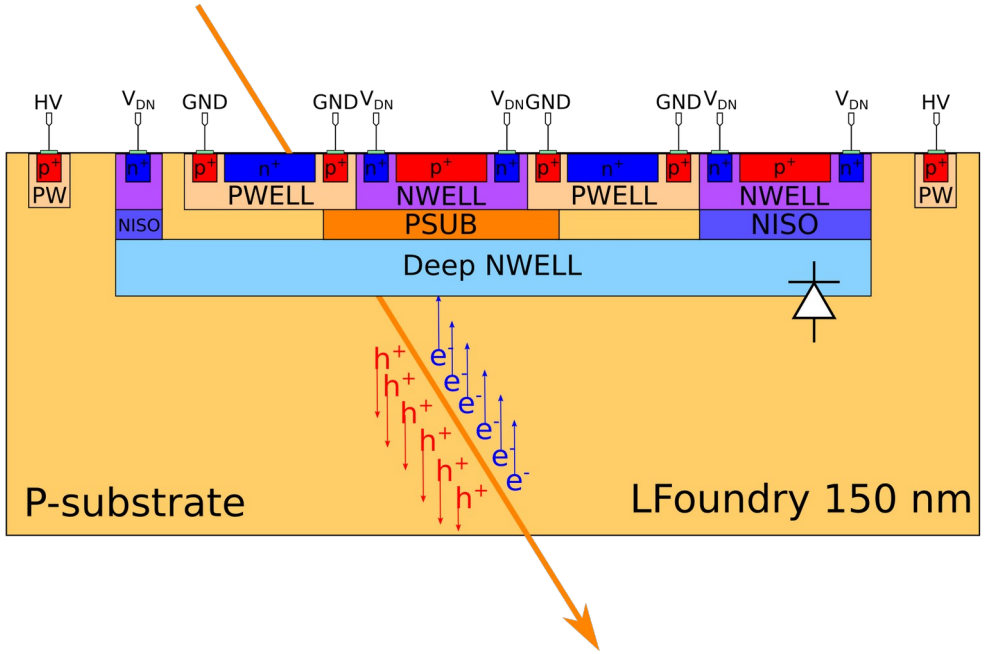
MPW2, the previous generation

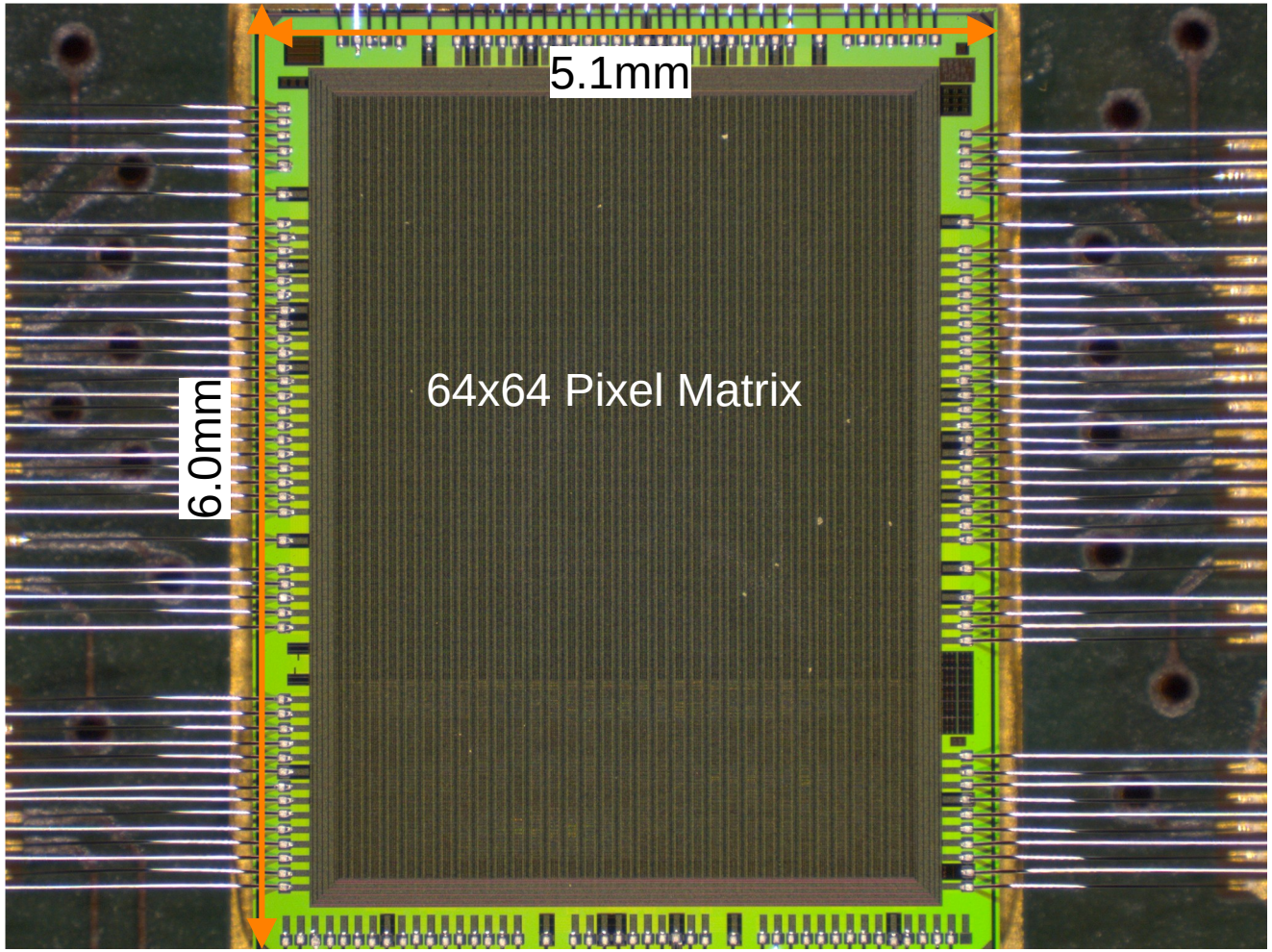
- 8x8 pixel matrix
- Two pixel flavors
- Large variety of test structures
- Purely analog readout
- Depletion depths of ~190 µm
- Produced in 1.9 kΩ·cm and 3.0 kΩ·cm resistivities



The RD50-MPW3

- CMOS chip with full analog and digital electronics
- 1.9 kΩ·cm and 3.0 kΩ·cm resistivities
- 320 MHz input clock





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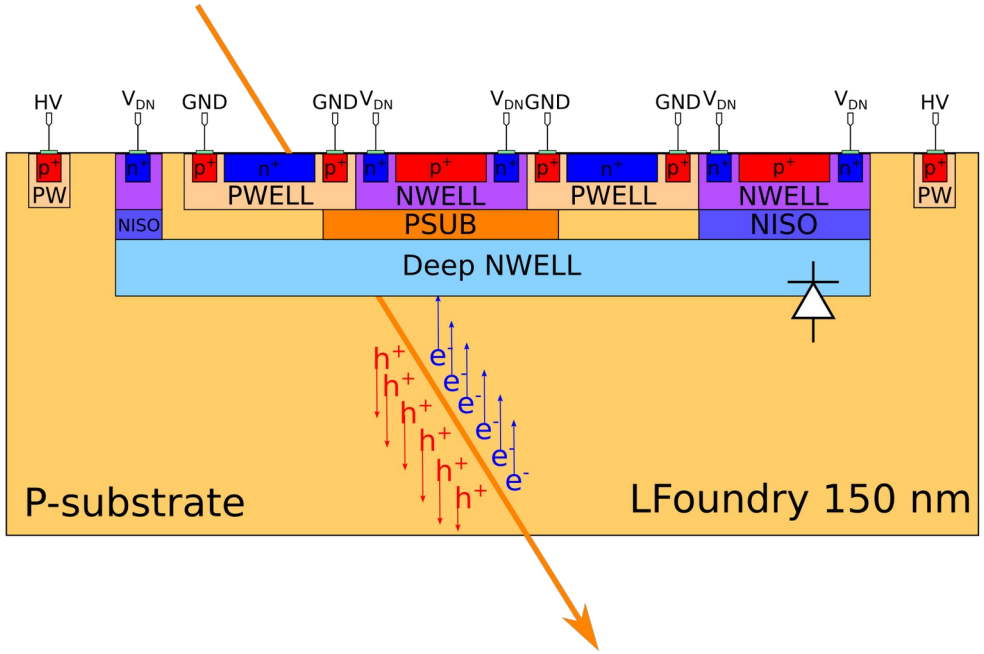
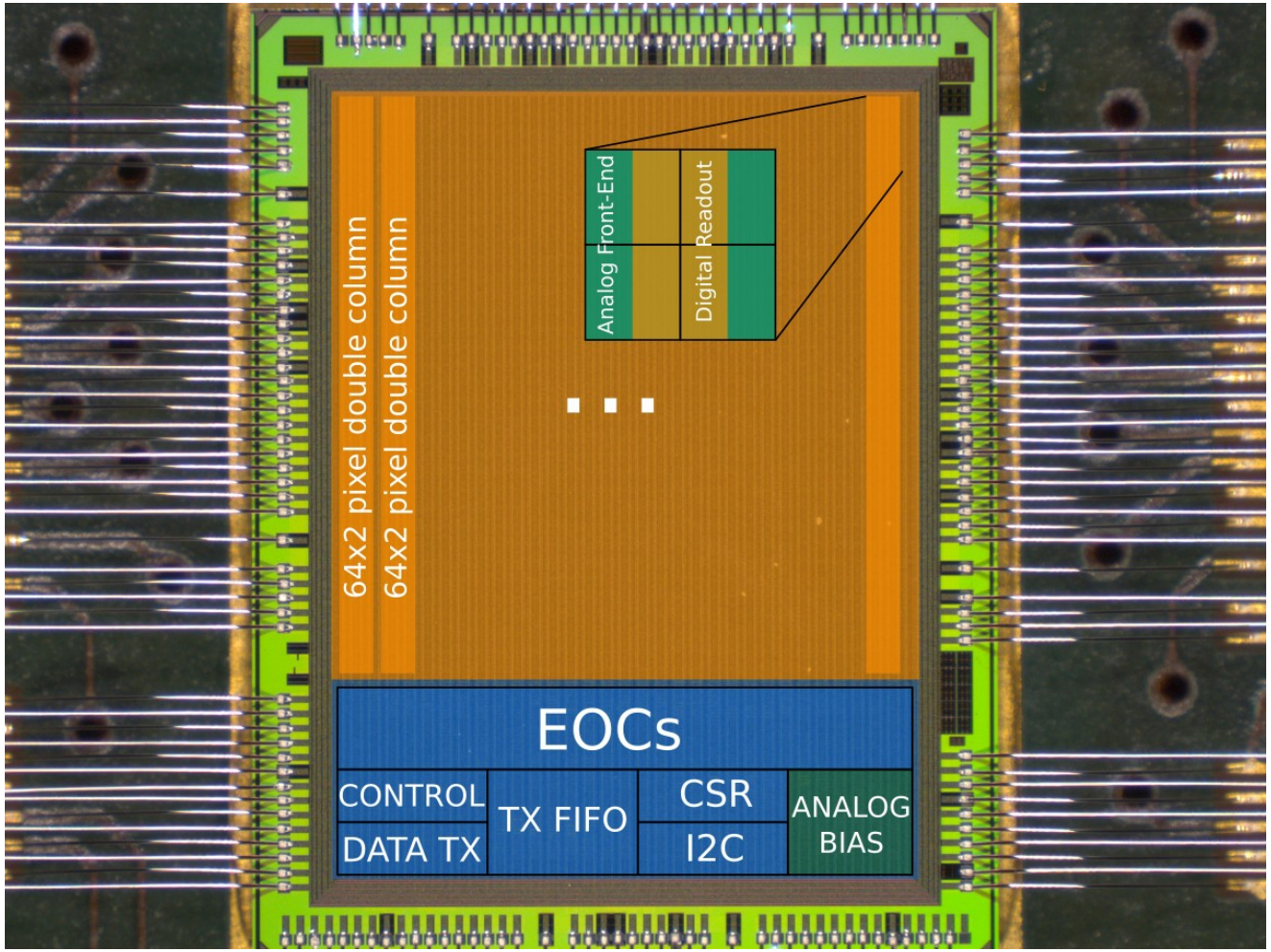
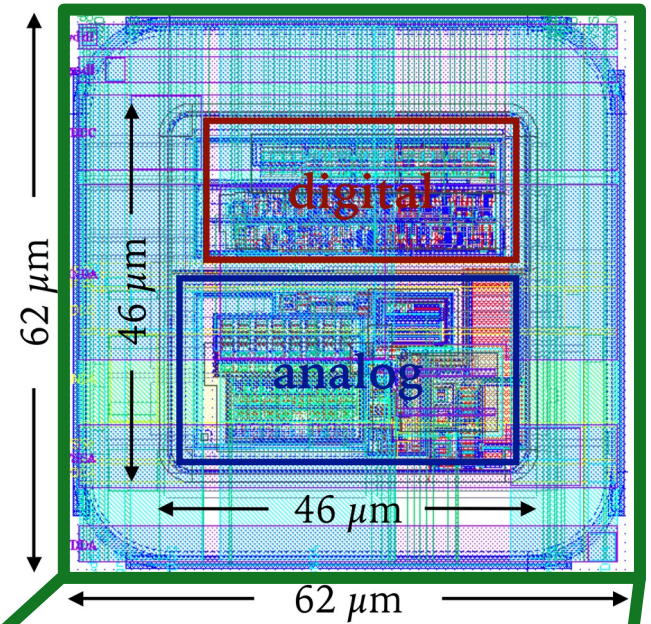
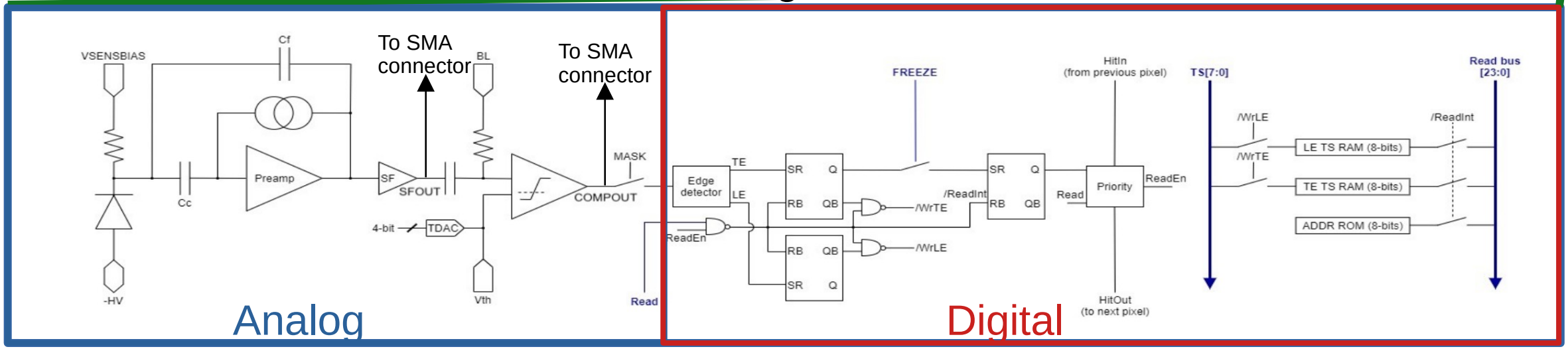




The pixel logic

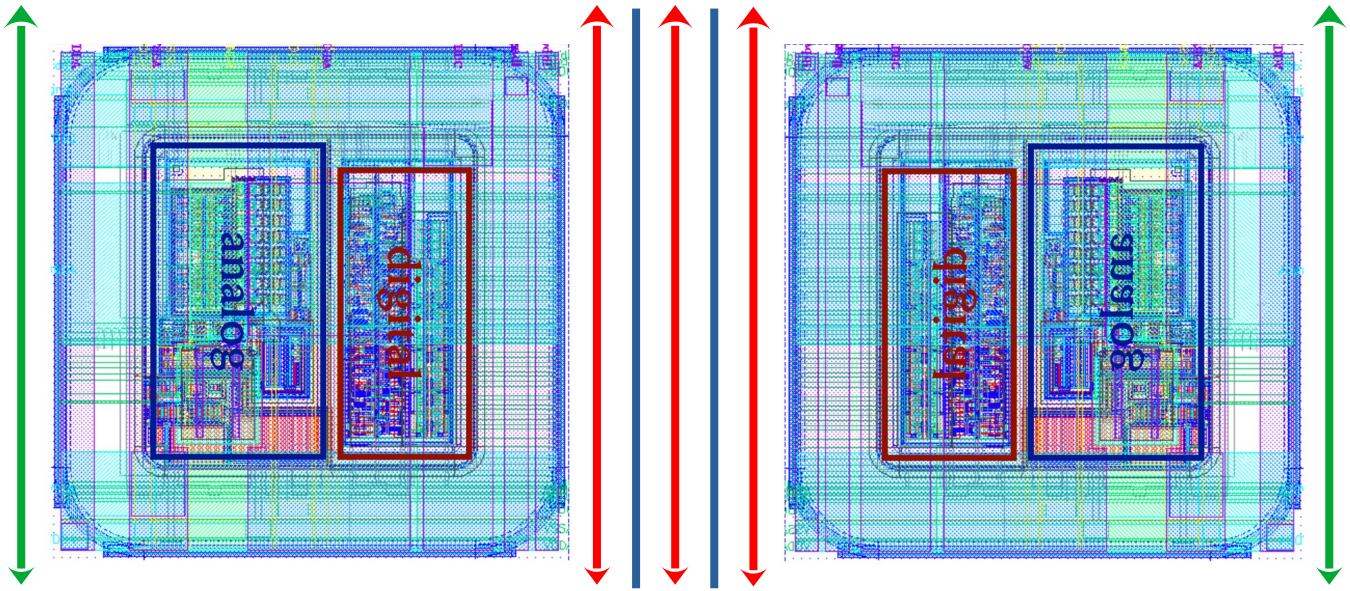
- Inherited analog pixel design from MPW2
  - 4-bit trim DAC for threshold adjustment
  - Continuous reset current readout
  - Injection circuit for calibration
  - Routing of analog pixels to SMA
- Digital logic newly integrated
  - 8-bit timestamp of leading and trailing edge
  - Double column drain readout and rolling shutter





Double column readout

- Pixels within double column are mirrored
- Double columns with digital signal line in between pixels
- Columns are separated by analog signal lines
- Voltage via mesh from all sides



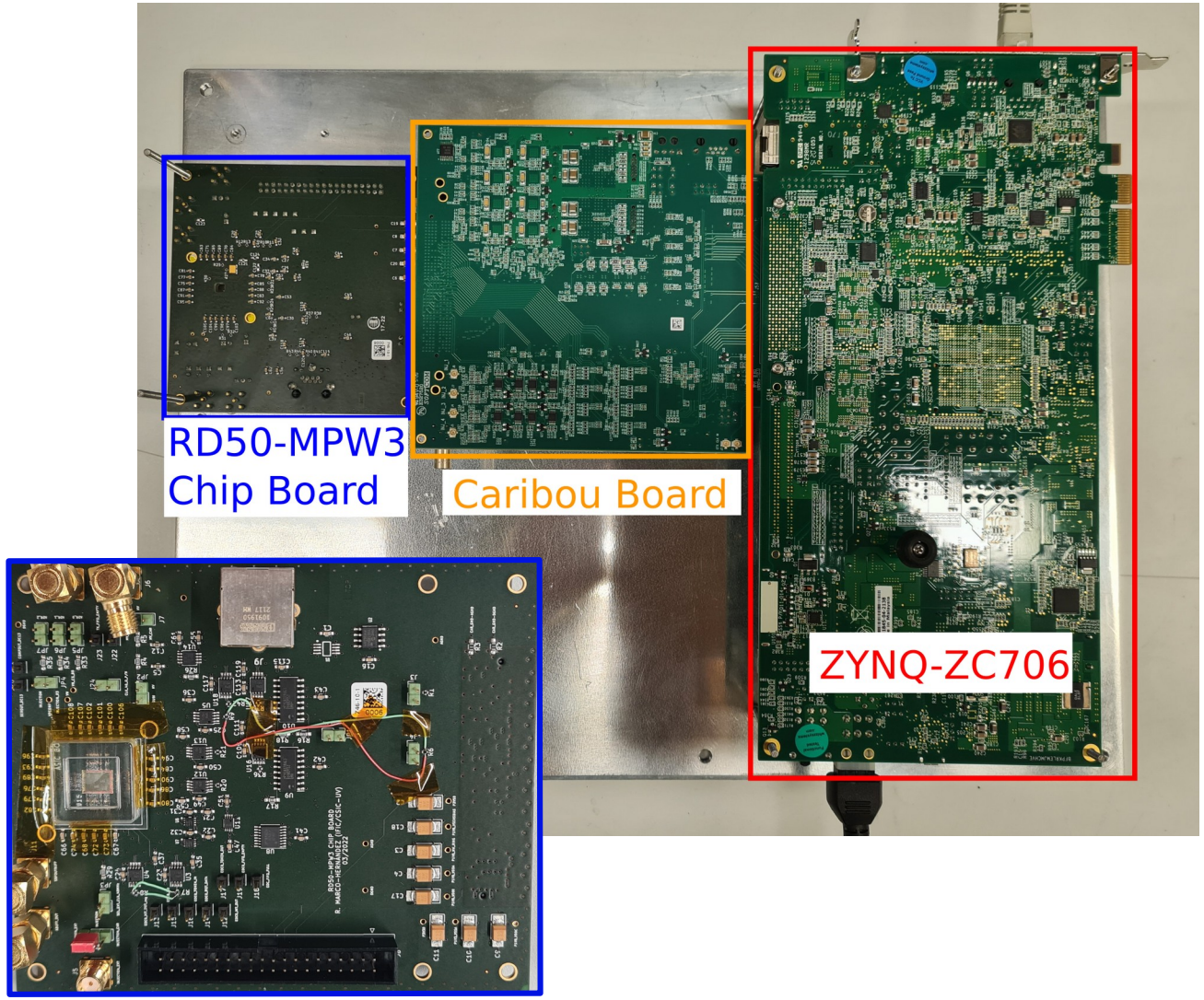
Analog signal line

Digital signal line

Shielding line

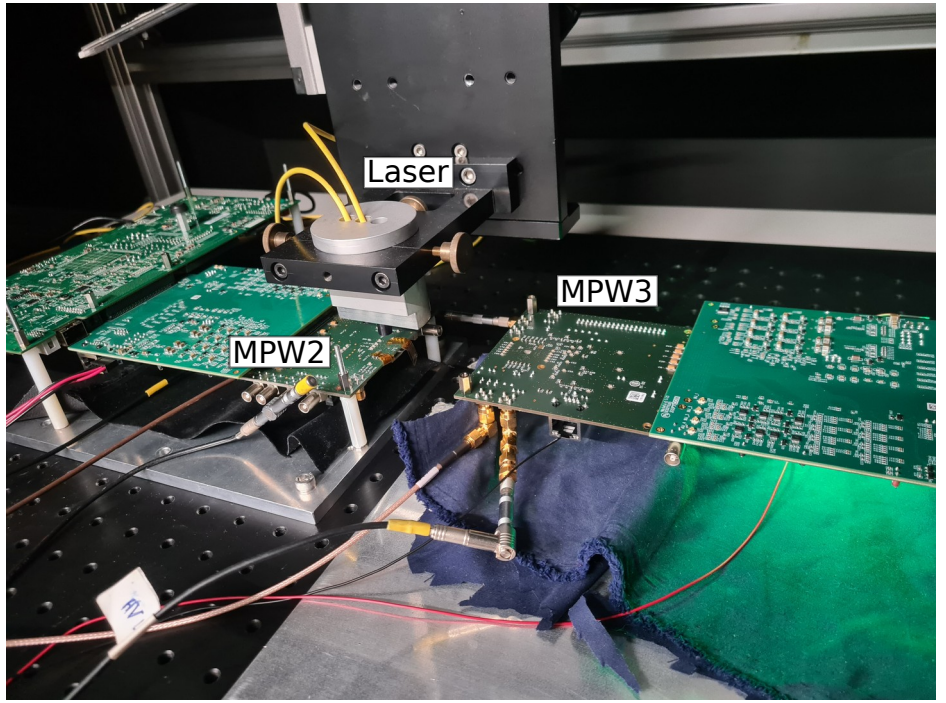
DAQ system

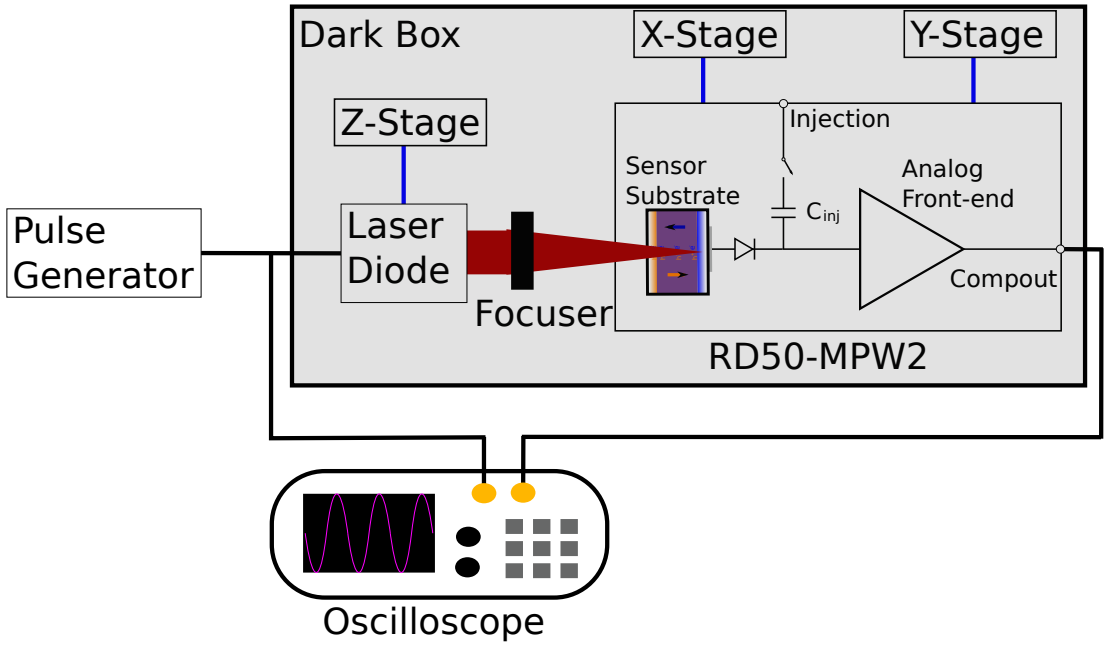
- Chip readout based on Caribou readout system
  - ZYNQ-ZC706 with Yocto based linux
  - Caribou for power distribution
  - Custom chip carrier board
    - Allows chaining of second chip board
    - SMA connectors to probe analog outputs from circuitry



Measuring the time resolution

- Measurements performed in a dark-box
- Setups installed on movable stage
- Signals generated via:
  - Test pulses using injection circuit
  - 980nm laser using bottom-TCT
- Comparator/Hitbus output measured via oscilloscope





Measuring the time resolution

- 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

    $\Delta t = t_{rise\_hit\_50\%} - t_{rise\_pulse\_50\%}$
  - Test pulse measurements

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

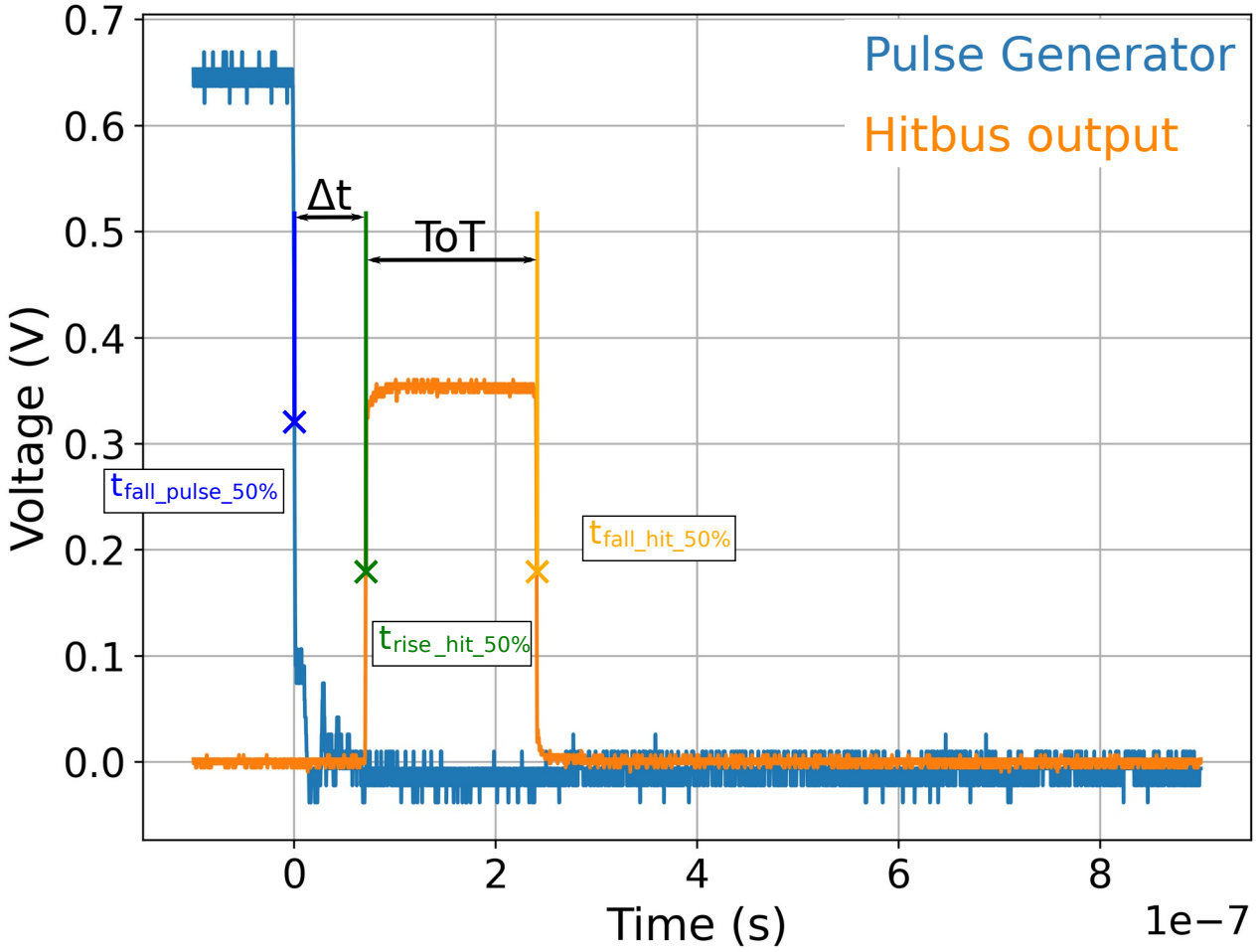
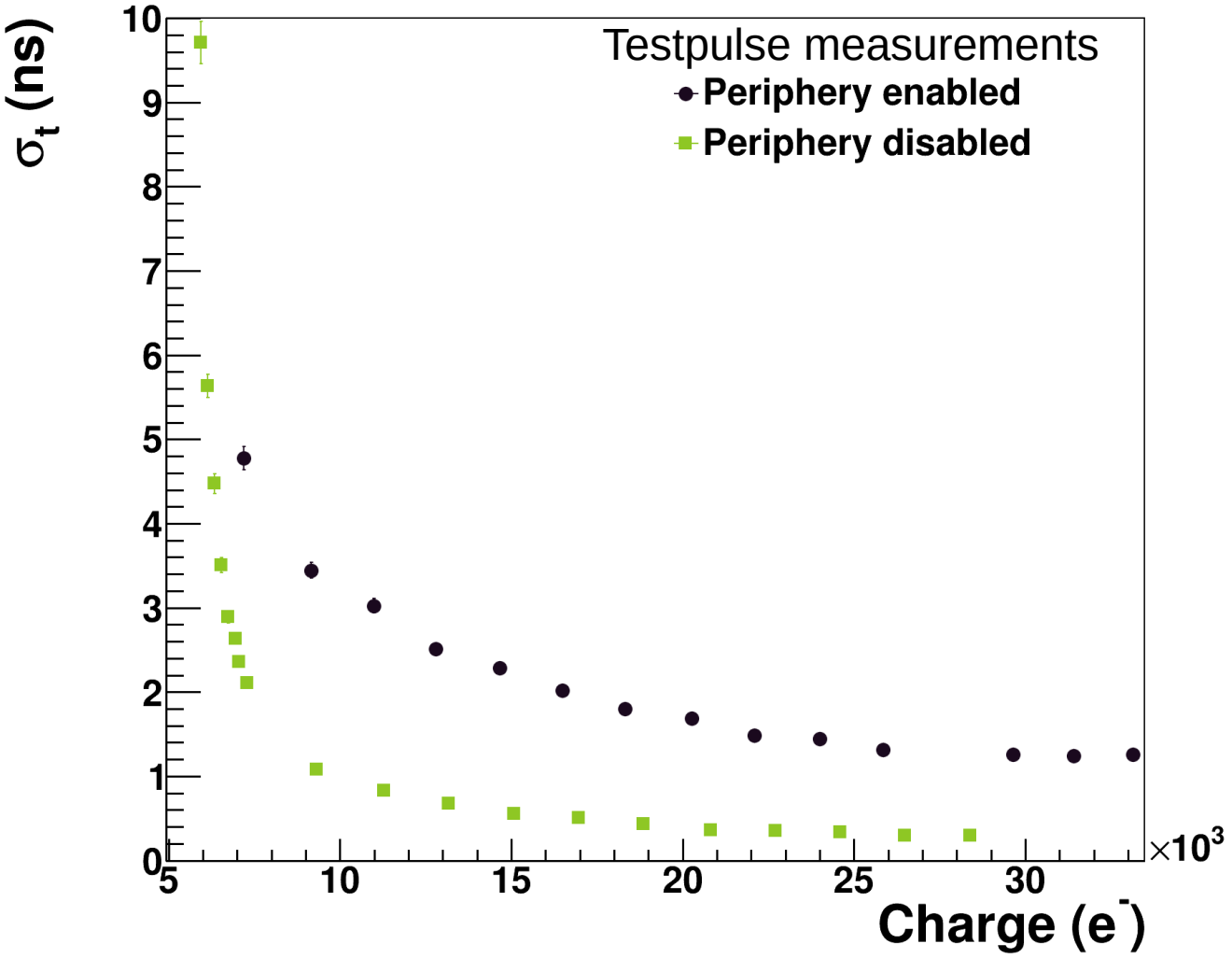


Fig.: Waveform from test pulse measurement

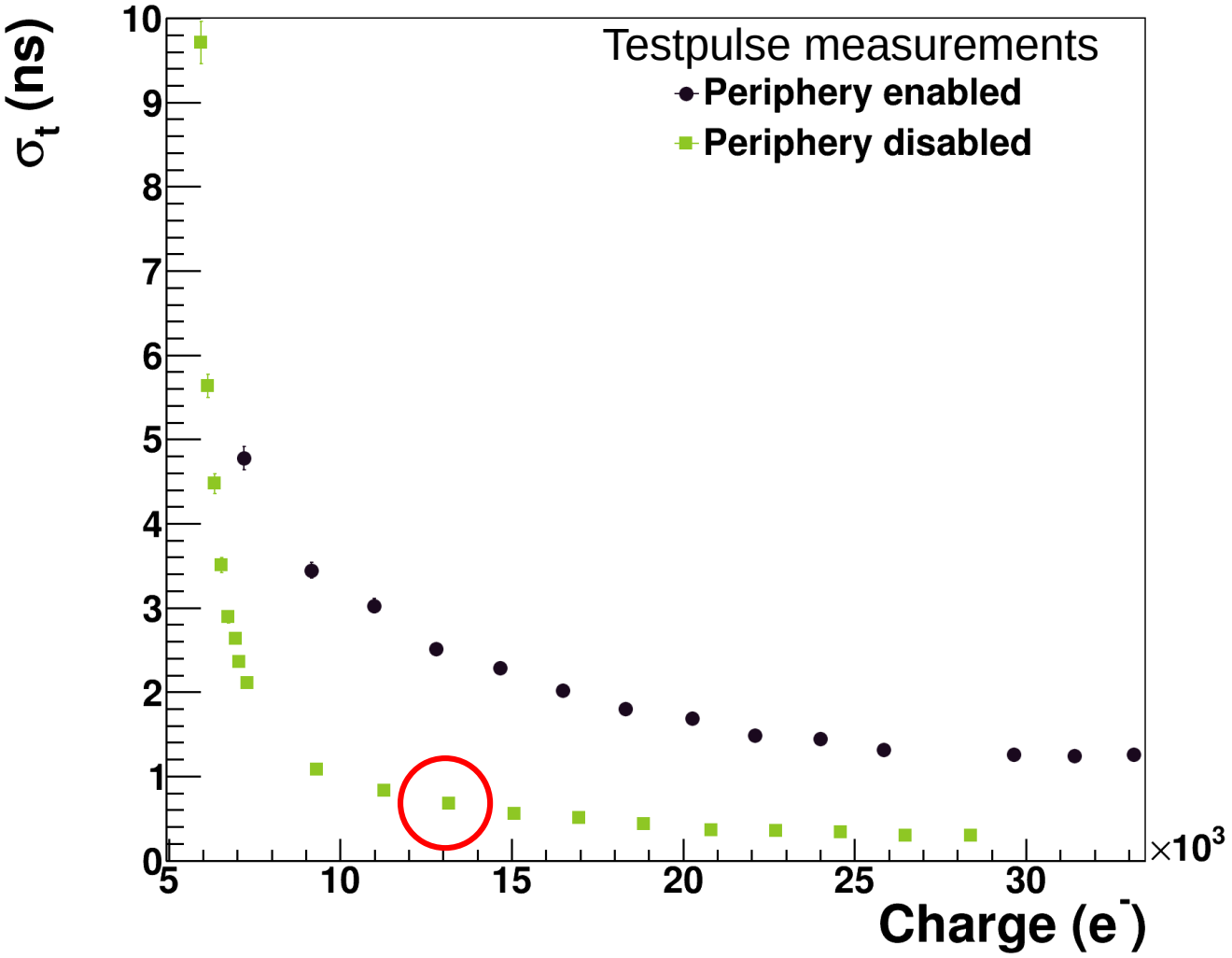
A small caveat

- Behavior of system is as expected
- Overall time resolution from testpules far worse than expected
- Digital periphery injects a lot of noise into the system
- All measurements operated with periphery disabled



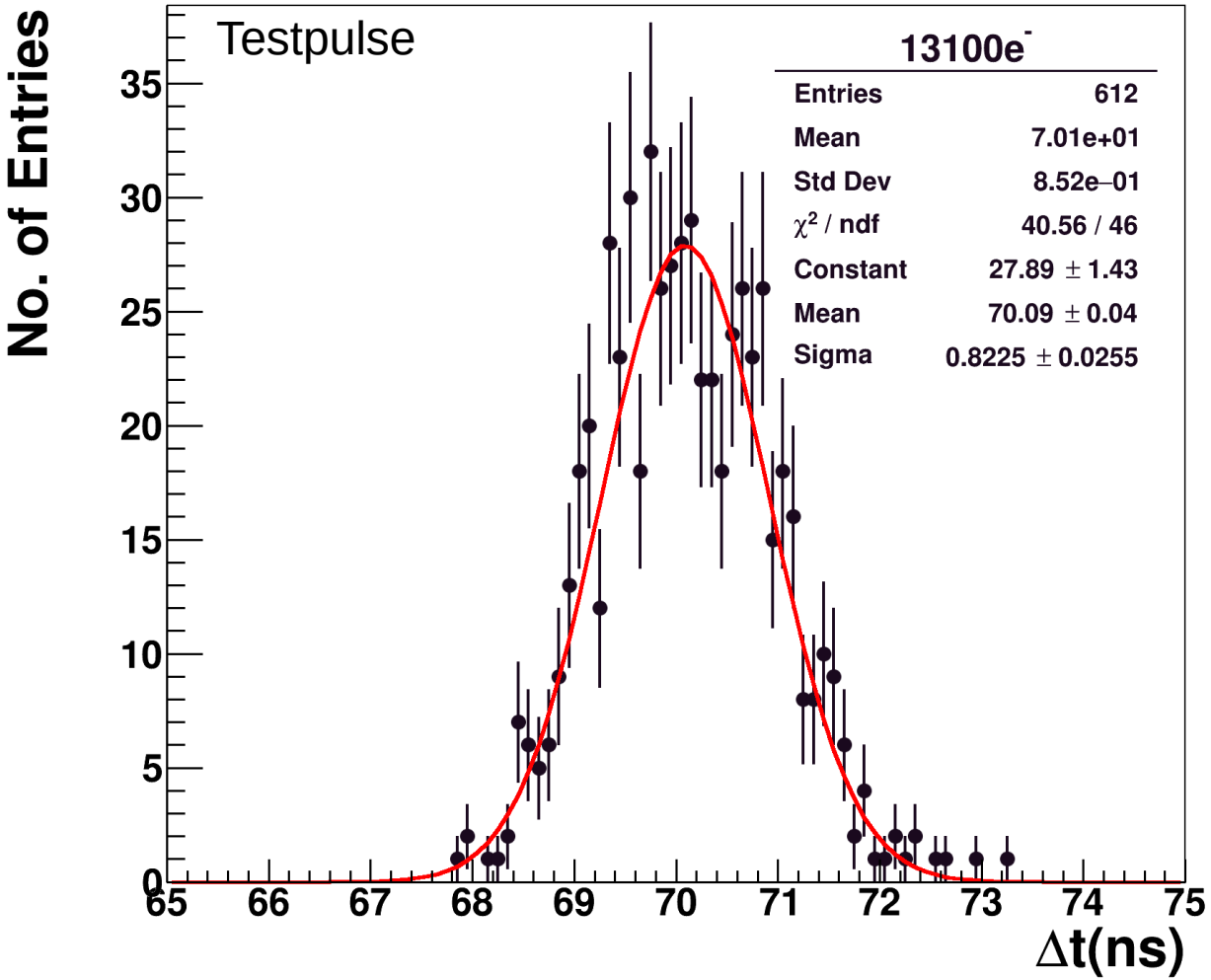
A small caveat

- Behavior of system is as expected
- Overall time resolution from testpules far worse than expected
- Digital periphery injects a lot of noise into the system
- All measurements operated with periphery disabled
- Measurements chosen close to MIP ~ O(13700e-)



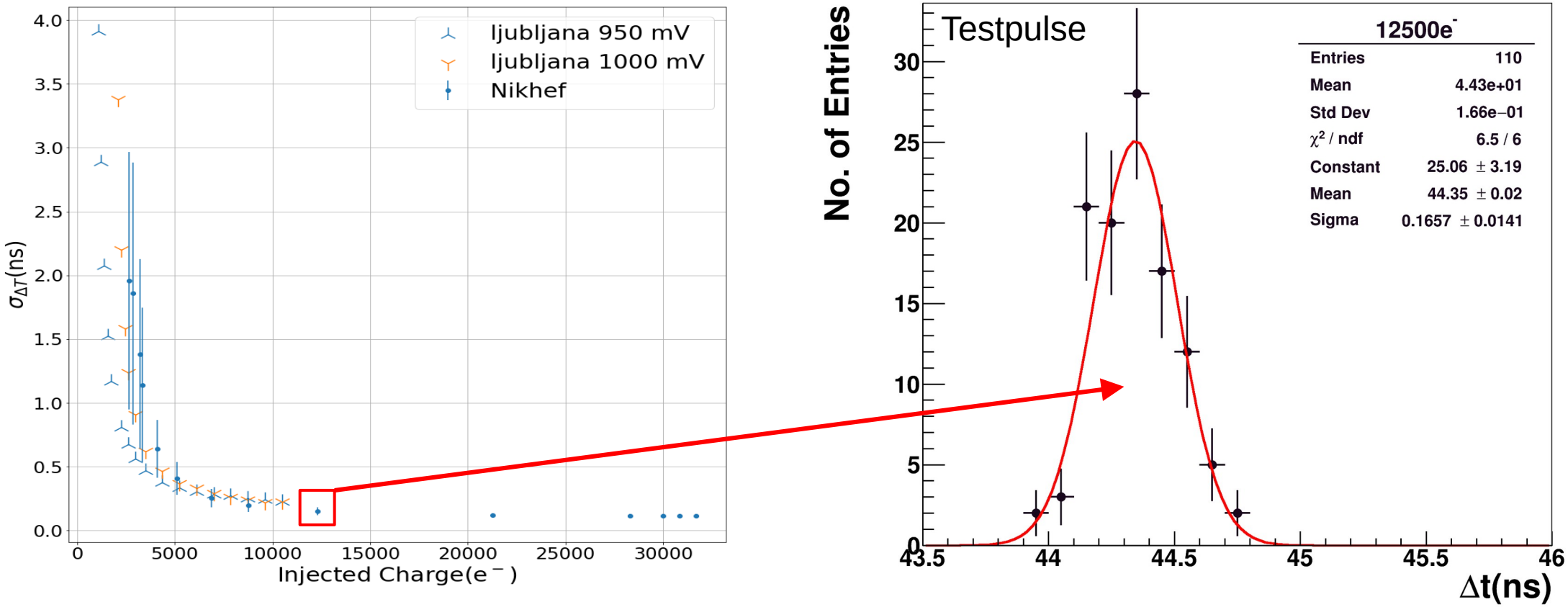
Testpulse measured time resolution of the MPW3

- MIP like charge injections
- Significant variation in spread
- Achieved time resolution for MPW3
  - $\sigma_{front\_end} \approx 800$ ps @ 13100e$^-$



MPW2 by comparison

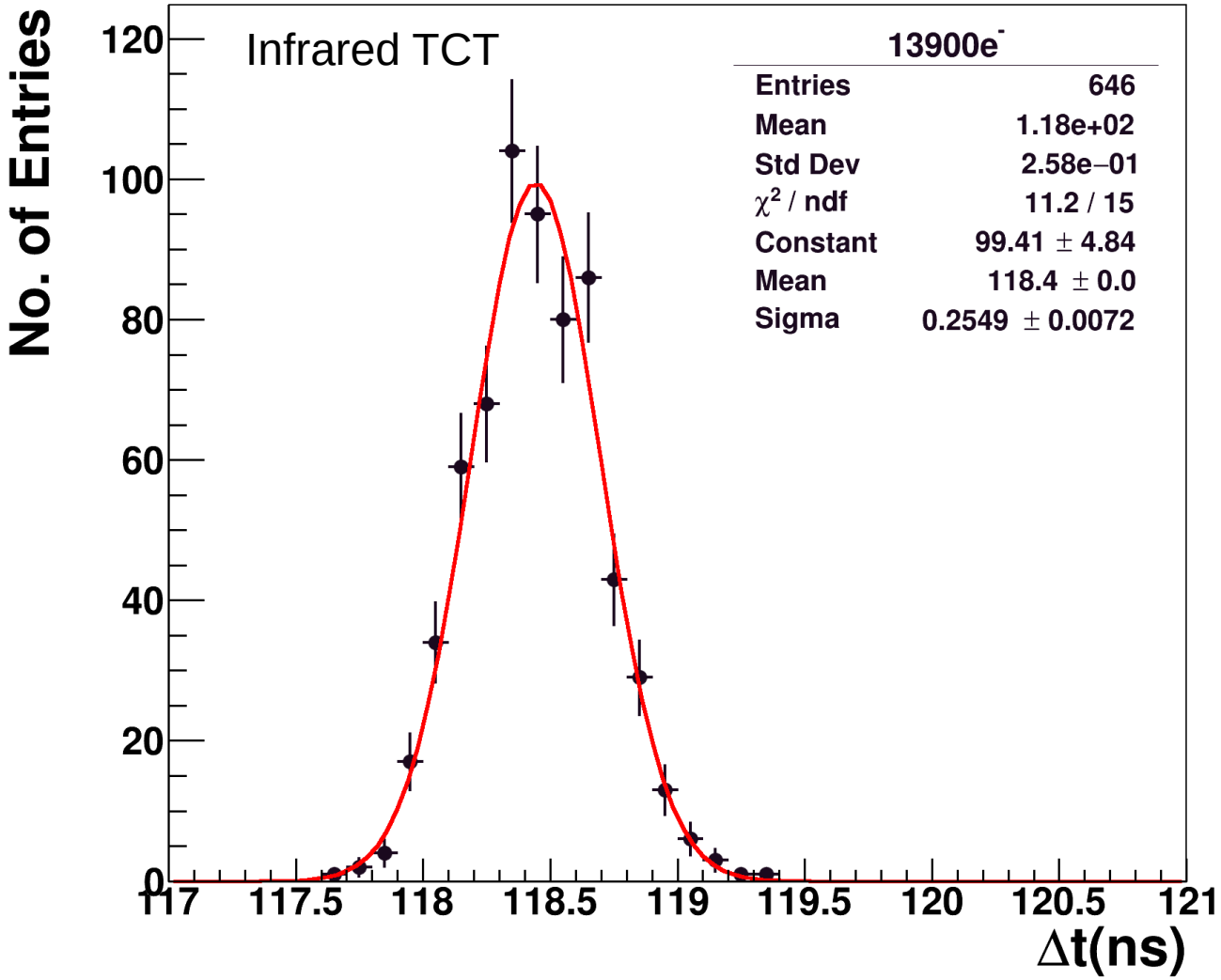
- Far better time resolution using test pulses with MPW2
  - **$\sigma_{front\_end} \approx 170$ ps @ 12500e$^-$**



TCT measured time resolution of the MPW3

- Charge injection via laser performed to verify test pulse results.
- Measured time resolution far better
  - **$\sigma_{front\_end} \approx 250$ ps @ 13900e$^-$**

- At this point unclear where the difference in result comes from
- TCT result is more comparable to TCT result by MPW2.



Summary

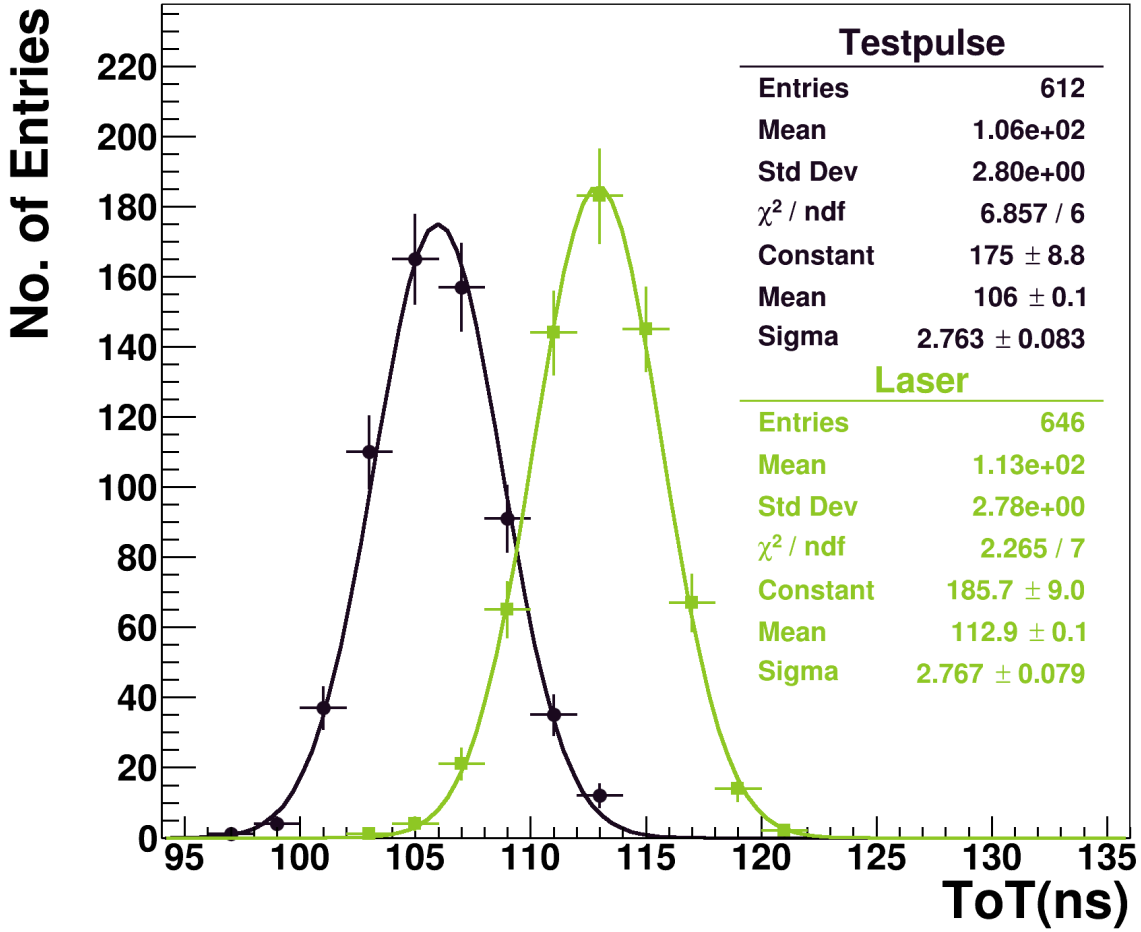
- New RD50-MPW3 chip produced by LFoundry
  - Far Larger matrix
  - Full digital and analog readout

- MPW3 in general more complicated system with some noise issues (see talk from Patrick Sieberer)
- Overall behavior similar to MPW2 though test pulses perform far worse
- Large discrepancy between achievable time resolution between test pulses O(800ps) and bottom TCT O(250ps)
- Plan to measure analog time resolution at the next test beam.

Backup slides

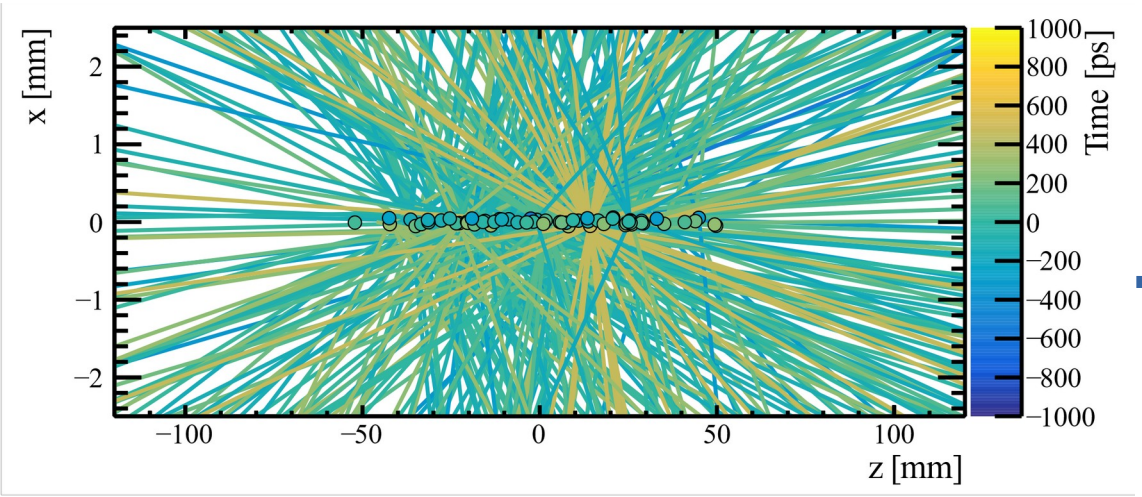
Laser ToT vs Testpulse ToT

- For now injected charge in electrons was simply estimated based on ToT comparison



Time resolution

- Next future accelerator is the High-Luminosity upgrade of the LHC
  - More collisions per interaction window
  - Higher track densities
  - Higher amounts of radiation
- Track time resolution ~30 ps can resolve many of these issues → 4D Tracking



Timing