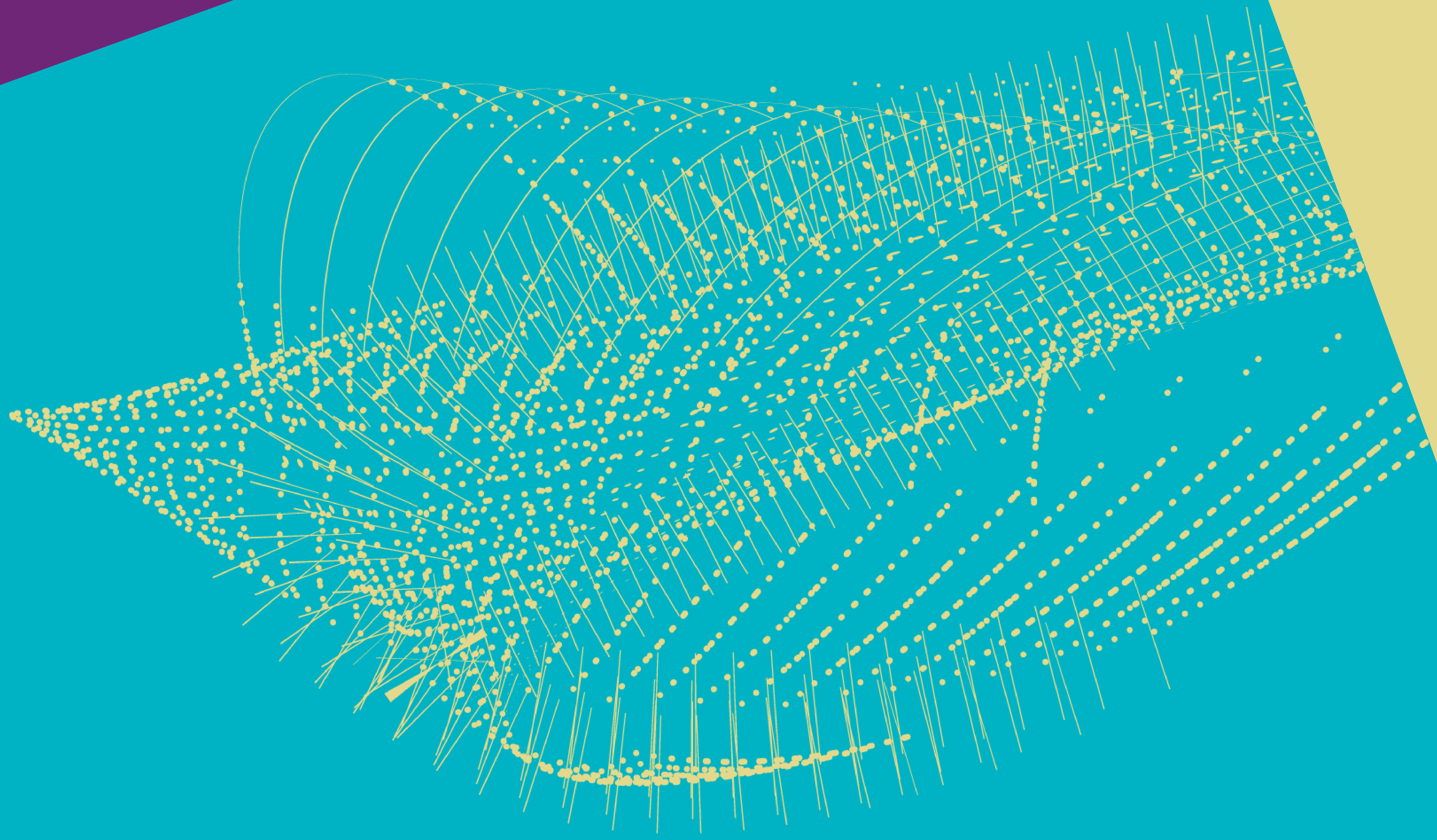


Robbert Geertsema

The characterisation of the timing aspects of Timepix3

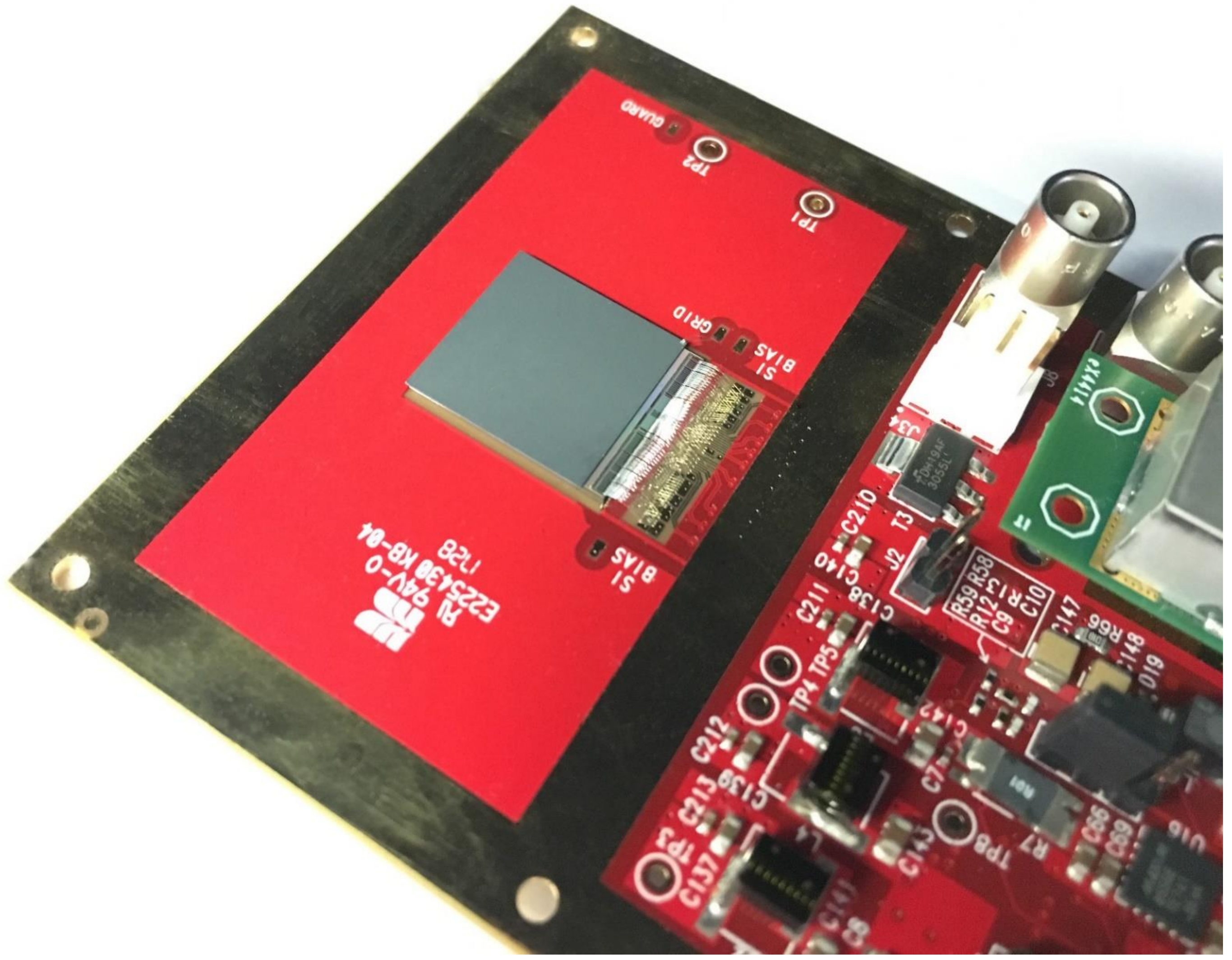
Lunteren
01-11-2019

Layout

- Short introduction into hybrid pixel detectors

- Explain two methods to measure timing systematics in Timepix3:
  - Charged particle beam from CERN SPS (testbeam)
  - Lab based laser system

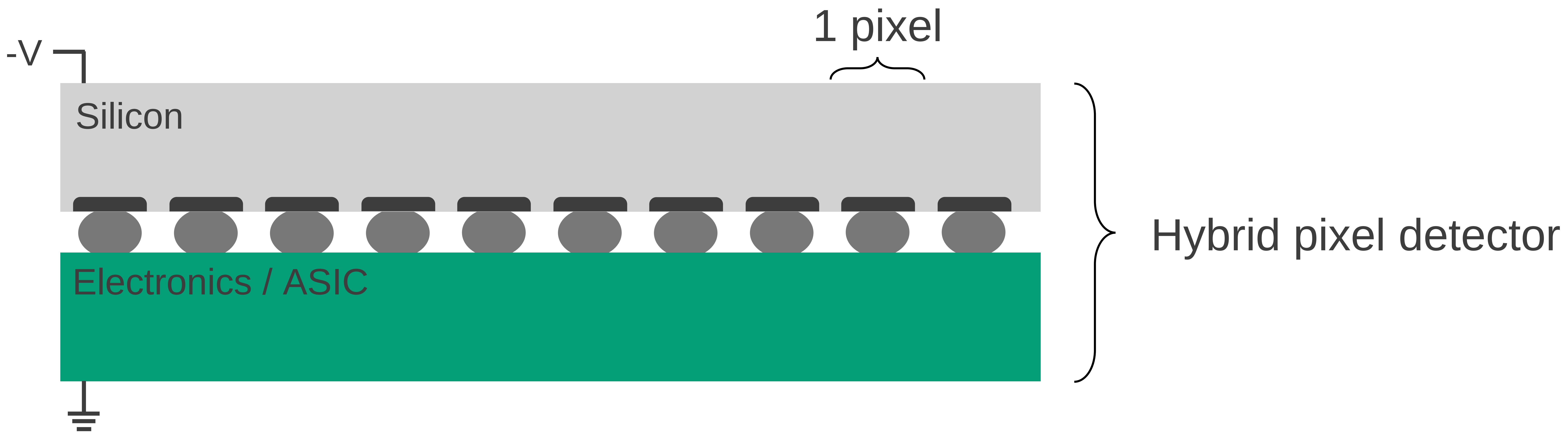
- Show timing aspects of Timepix3 → what do we gain from this?



(Hybrid) pixel detectors

- Rely on detecting material in which charge carriers are liberated by the particles

- Generated charge particles are measured as current → can be detected!



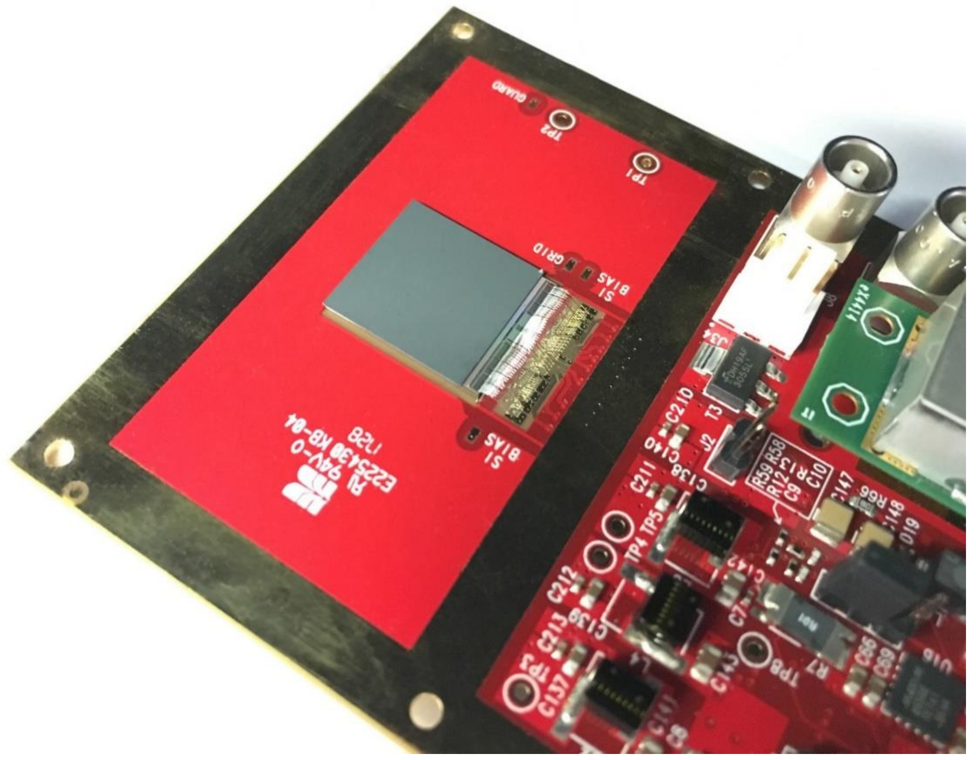
Medipix and Timepix collaboration

- Collaboration of multiple institutes (Nikhef, CERN, …)
- Currently two detectors produced which can measure time of arrival

Timepix

- Released 2006
- 25 ns time bins
- Time <u>or</u> charge measurement

Timepix3



- Released 2014
- 1.56 ns time bins
- Time <u>and</u> charge measurement

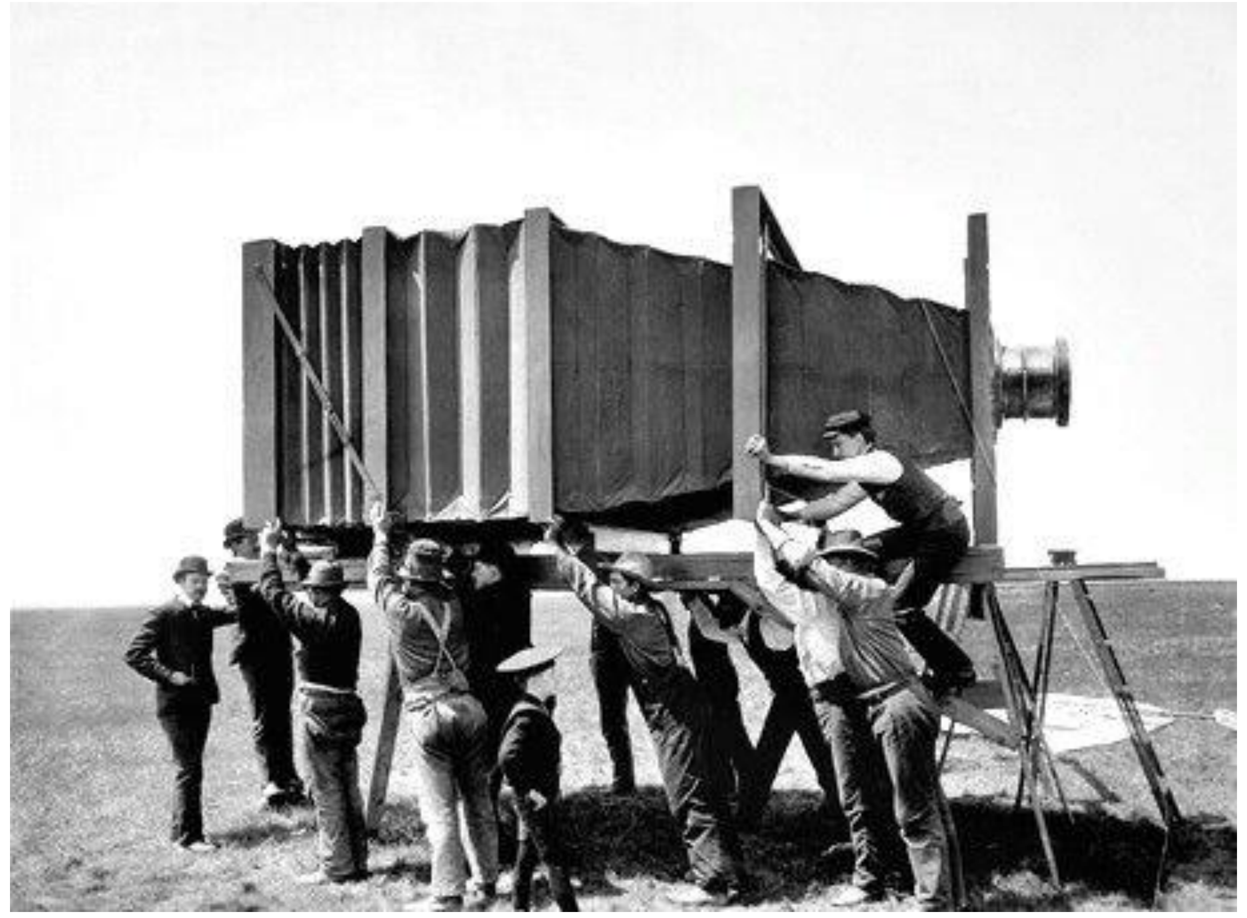
Timepix4

- Released 2020?
- 200 ps time bins
- Time <u>and</u> charge measurement

Medipix and Timepix collaboration

- Collaboration of multiple institutes (Nikhef, CERN, …)
- Currently two detectors produced which can measure time of arrival

Timepix



Timepix3

Timepix4

- Released 2006
- 25 ns time bins
- Time <u>or</u> charge measurement

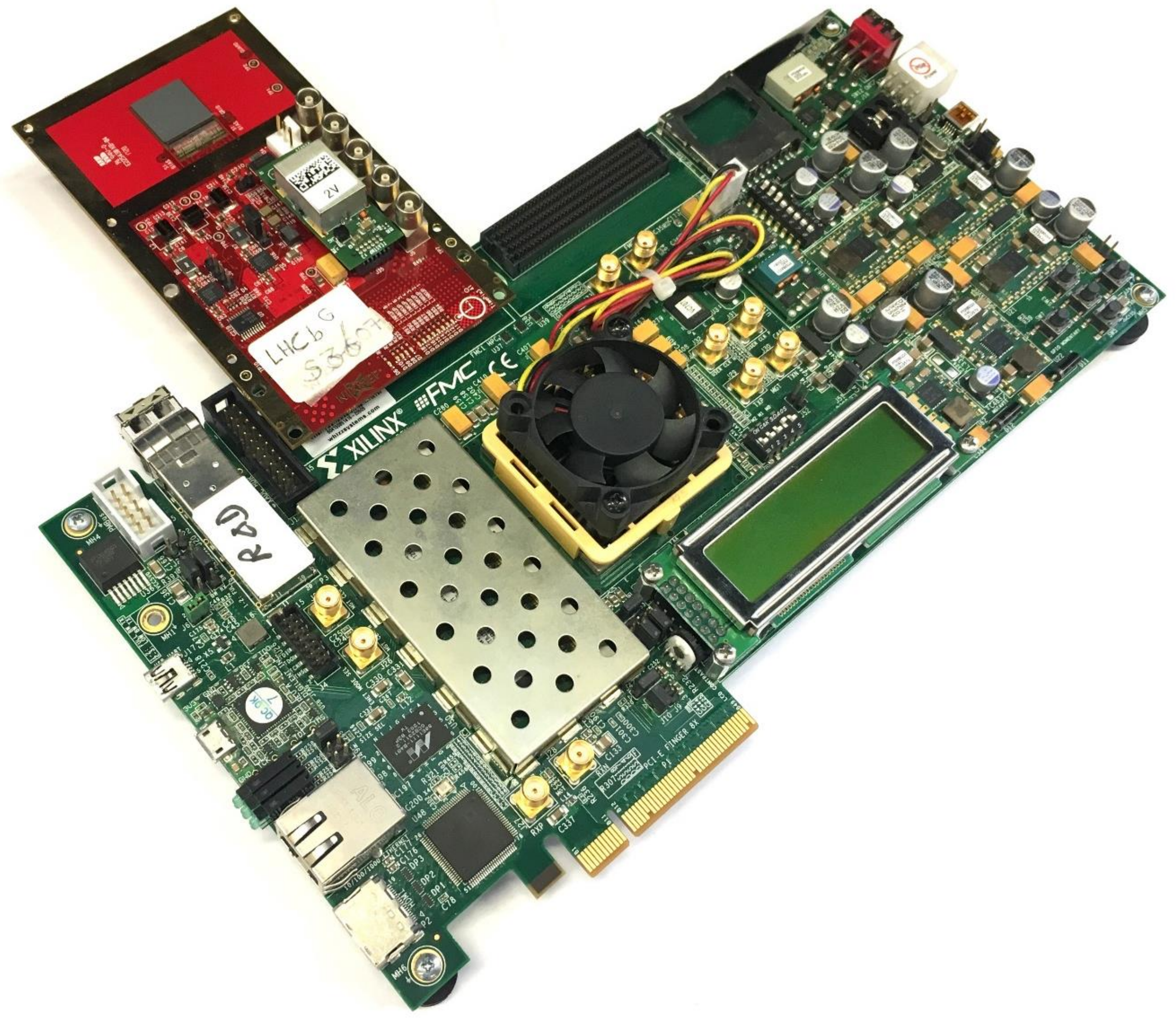
- Released 2014
- 1.56 ns time bins
- Time <u>and</u> charge measurement

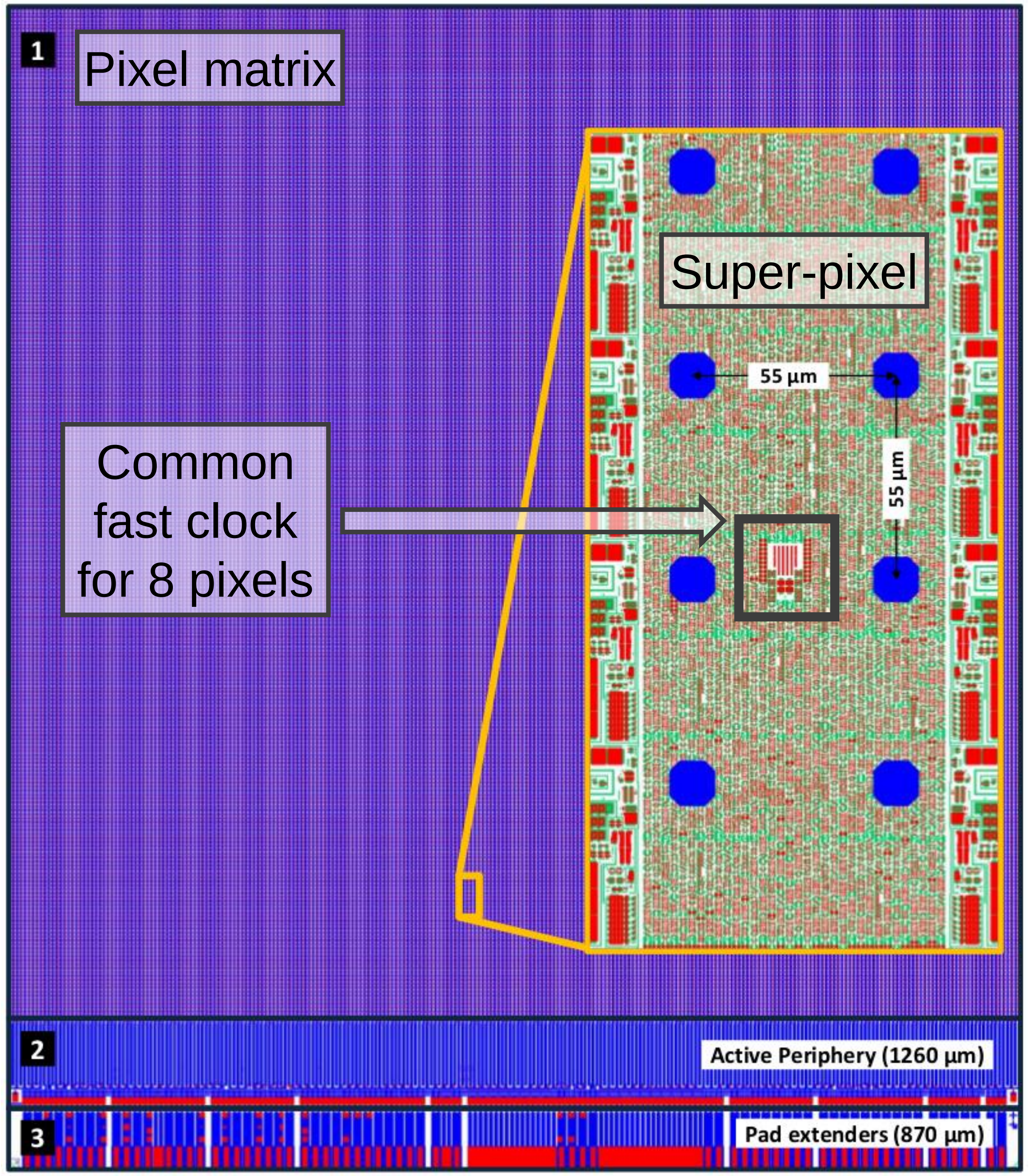
- Released 2020?
- 200 ps time bins
- Time <u>and</u> charge measurement

Timepix3 ASIC

Timepix3 [1]:

- 256 x 256 pixels
  - Pitch of 55 μm (high granulairity)
- Measures arrival time and charge of the hits
- Time bins of 1.56 ns
- Triggerless readout
- Maximum of 80 Mhits/s/ASIC





[1] Poikela, T *et al*. Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout. *Journal of instrumentation* 9, C05013 (2014).

Measurement with Timepix3

How to investigate the systematics

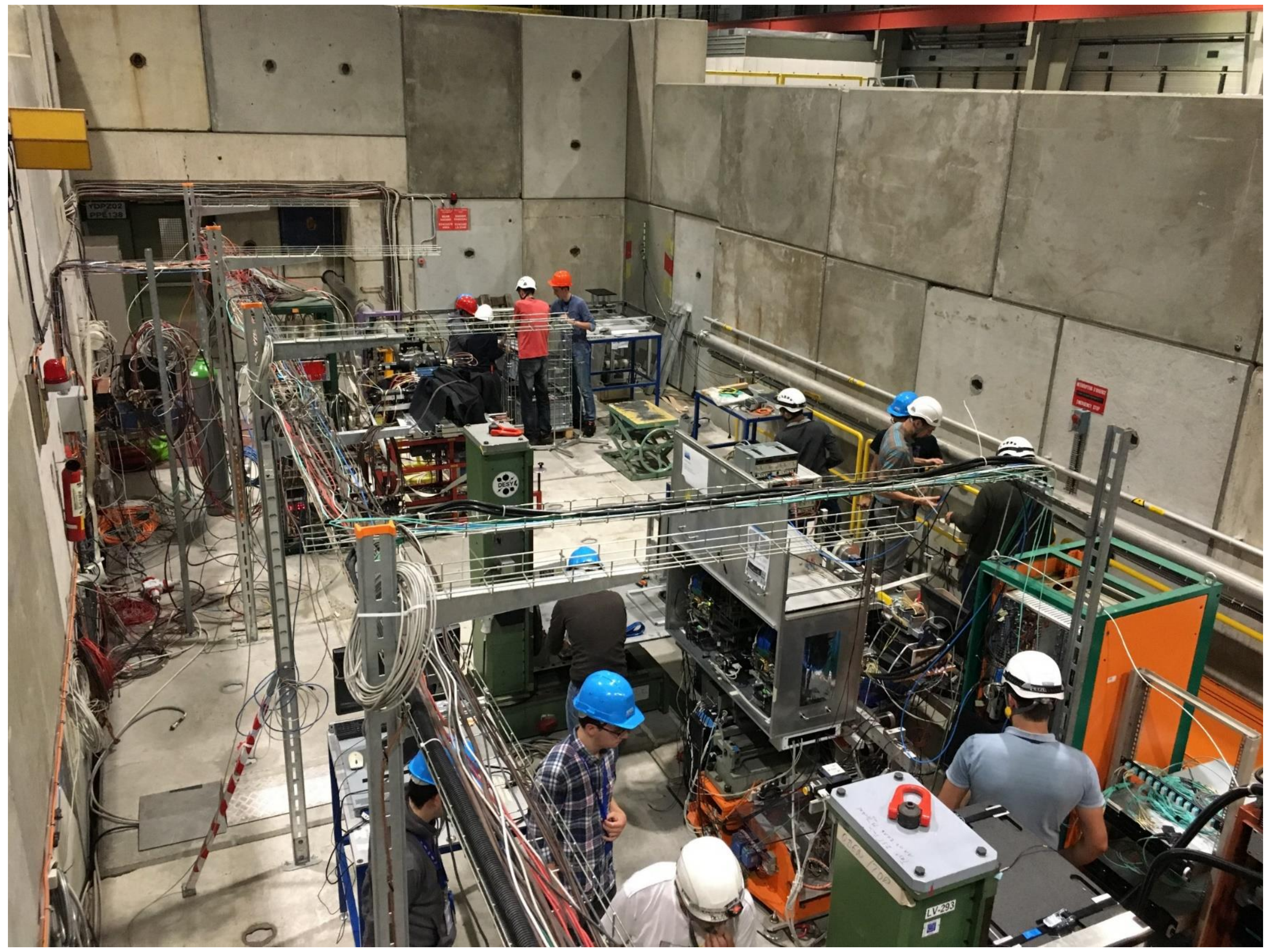
We want to investigate and correct the timing systematics of Timepix3 in order to increase the time resolution

Two requirements:

- Known position of liberated charge
- Known time of liberation of charge

Two methods we used:

- Testbeam at CERN



Testbeam location at the North Area testbeam facilities

How to investigate the systematics

We want to investigate and correct the timing systematics of Timepix3 in order to increase the time resolution

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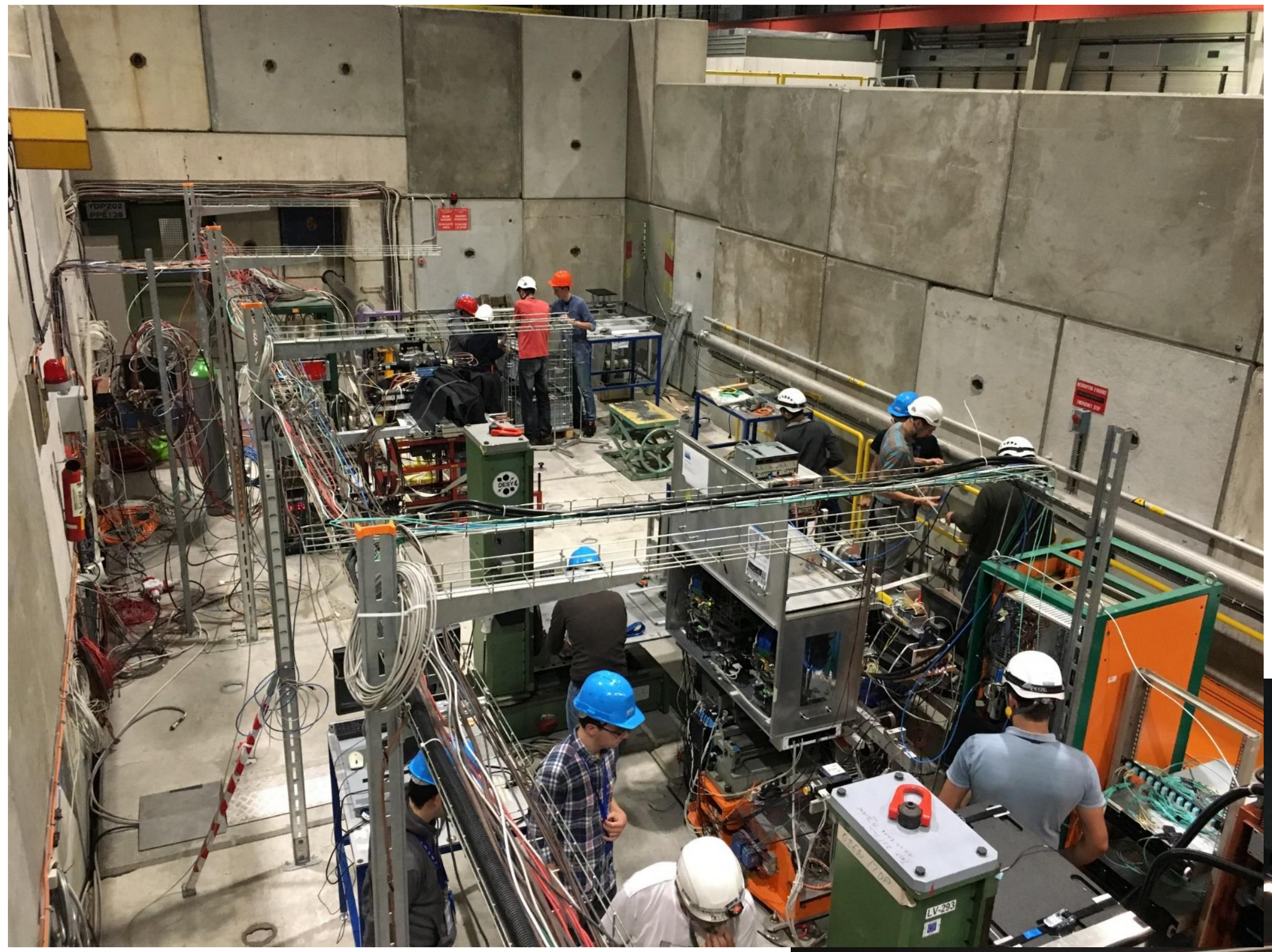
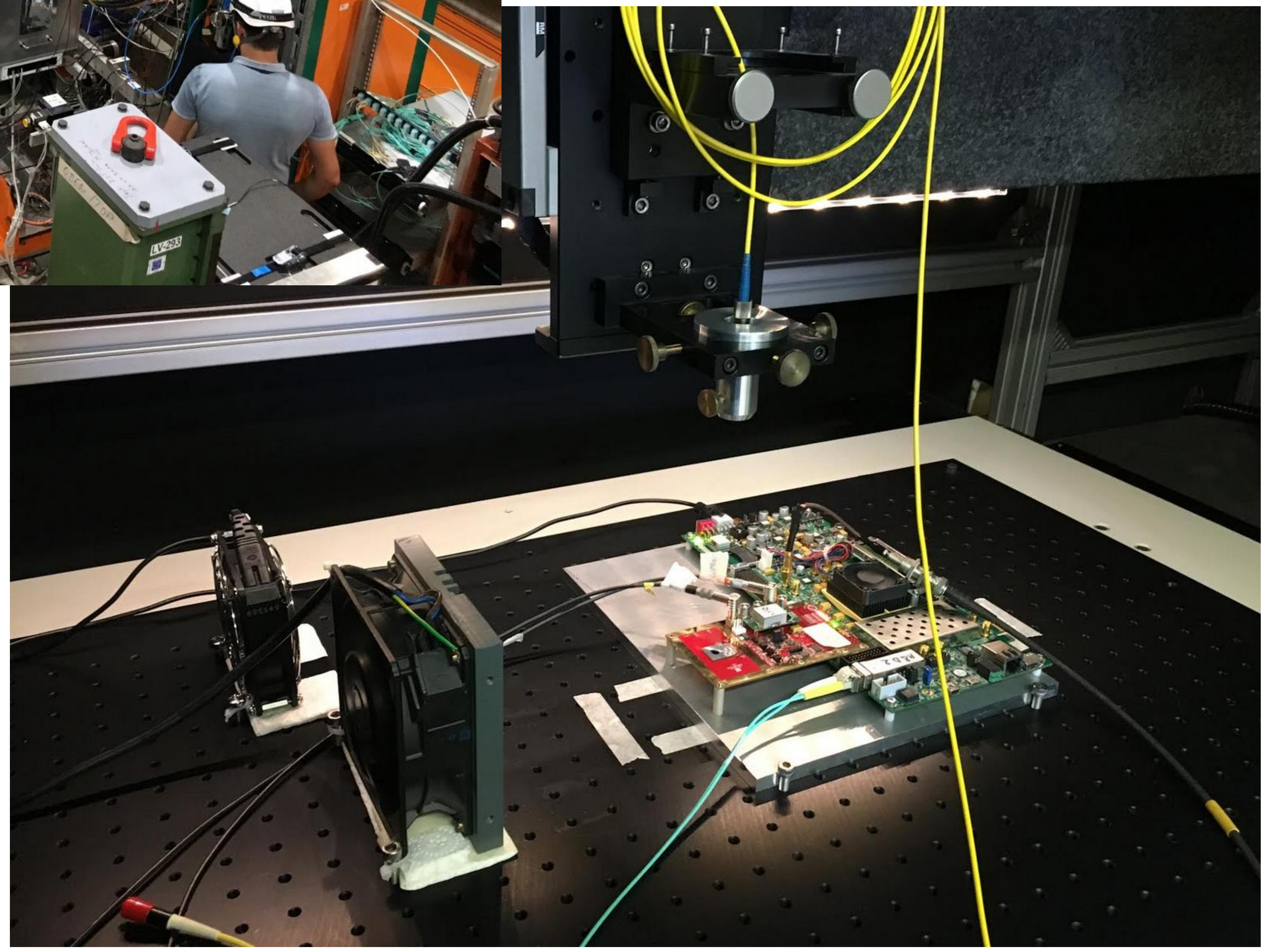
- Laser setup at Nikhef



Testbeam location at the North Area testbeam facilities



Laser setup at Nikhef

How to investigate the systematics

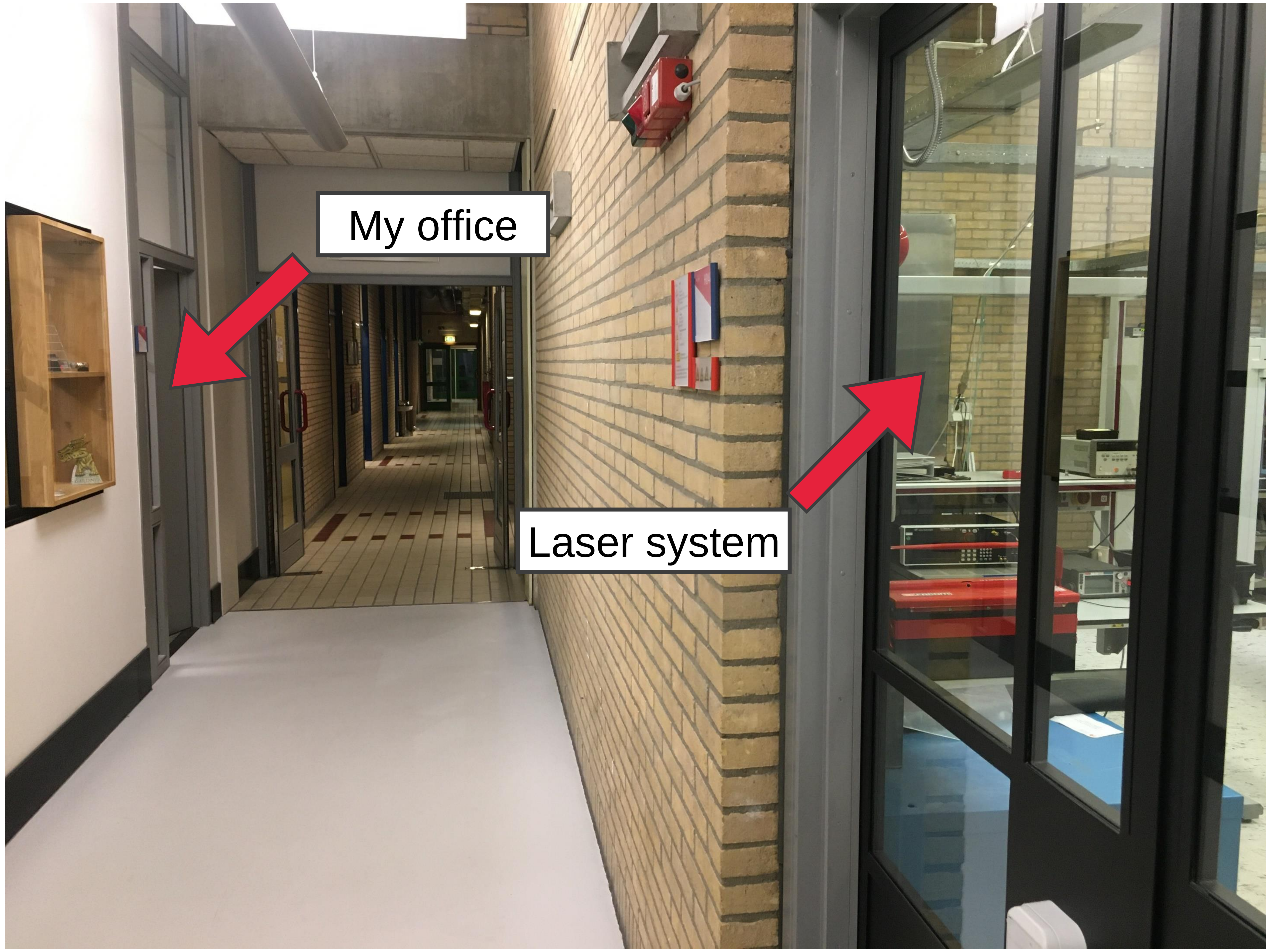
We want to investigate and correct the timing systematics of Timepix3 in order to increase the time resolution

Two requirements:

- Known position of liberated charge
- Known time of liberation of charge

Two methods we used:

- Testbeam at CERN ~ 10 hour drive
- Laser setup at Nikhef ~ 10 second walk



Laser Setup

Technique

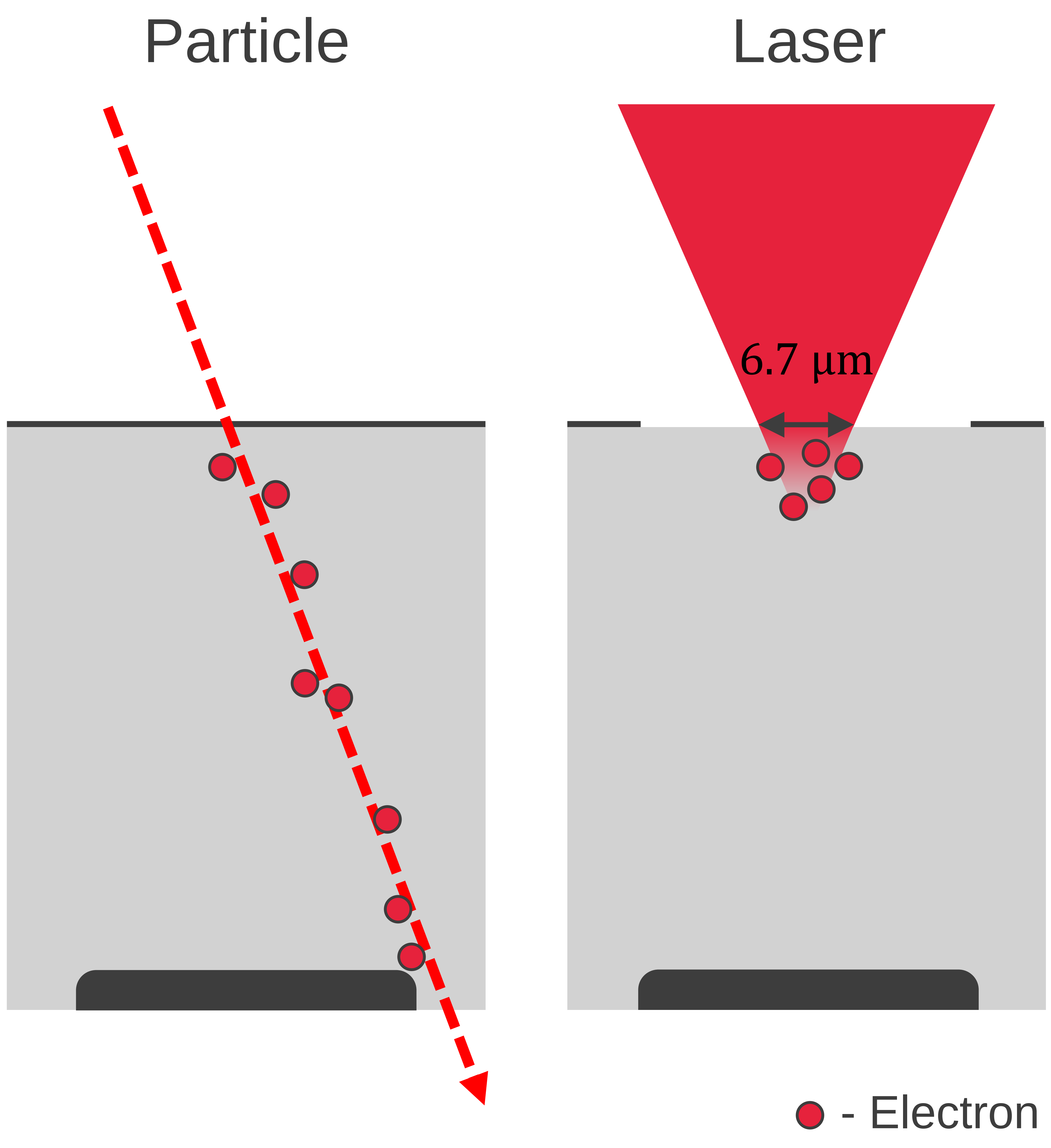
- Use photons instead of charged particles
- 660 nm with a pulse length of 4.6 ns

Advantage

- Precise timing of photons is known
- Deposited charge can be controlled
- Timewalk effects cancel in pixel-to-pixel comparison
- Not limited to testbeam facilities making it possible to take data at Nikhef

Drawback

- Deposition in top of sensor (not mimicking charged particle)



Testbeam: Method

Specialised setup is needed to provide position and timing information on the particles: Timepix3 telescope

How it works:

Akiba, K. *et al*. LHCb VELO Timepix3 telescope. *Journal of Instrumentation* 14, P05026–P05026 (2019).

Testbeam: Method

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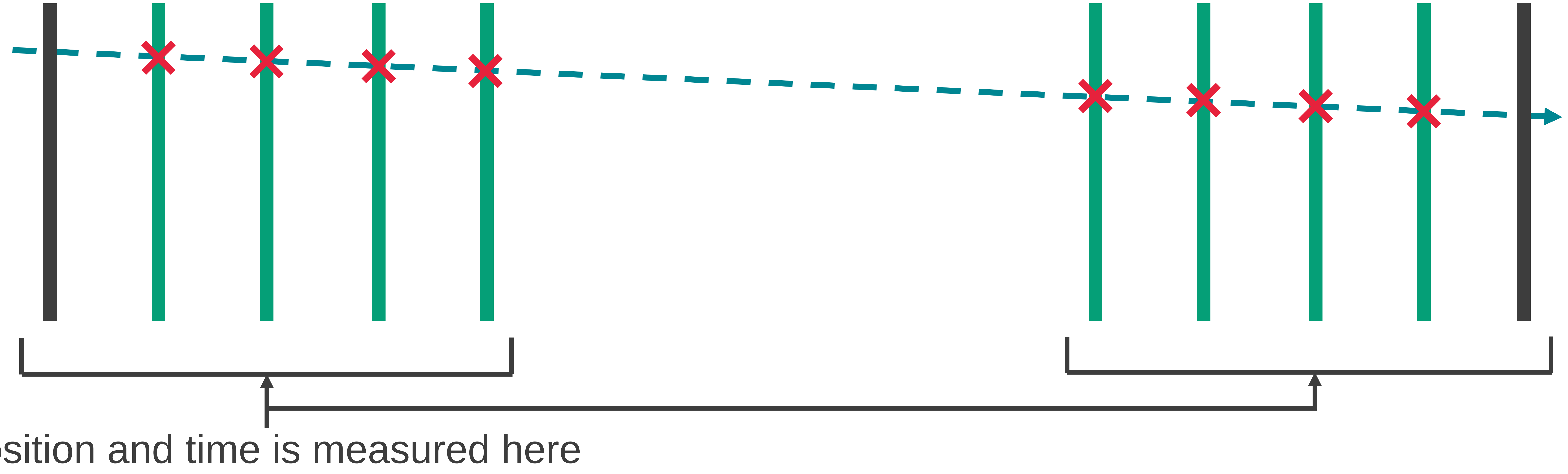

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Testbeam: Method

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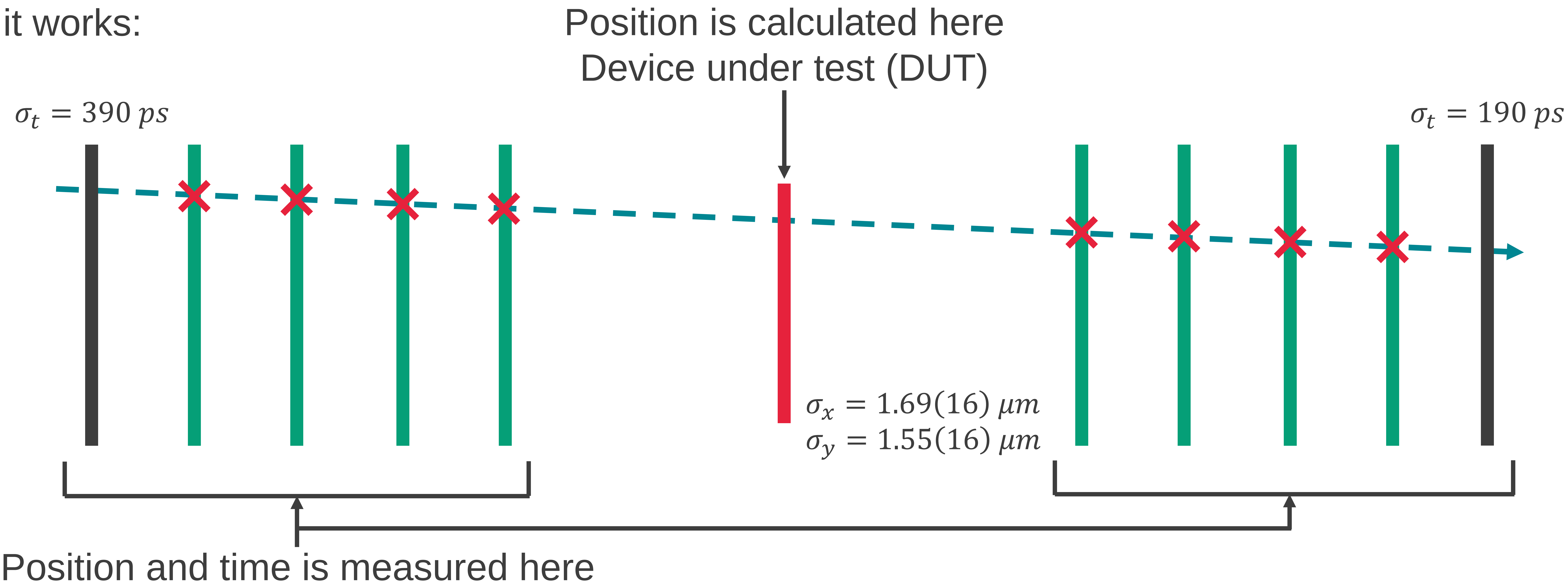

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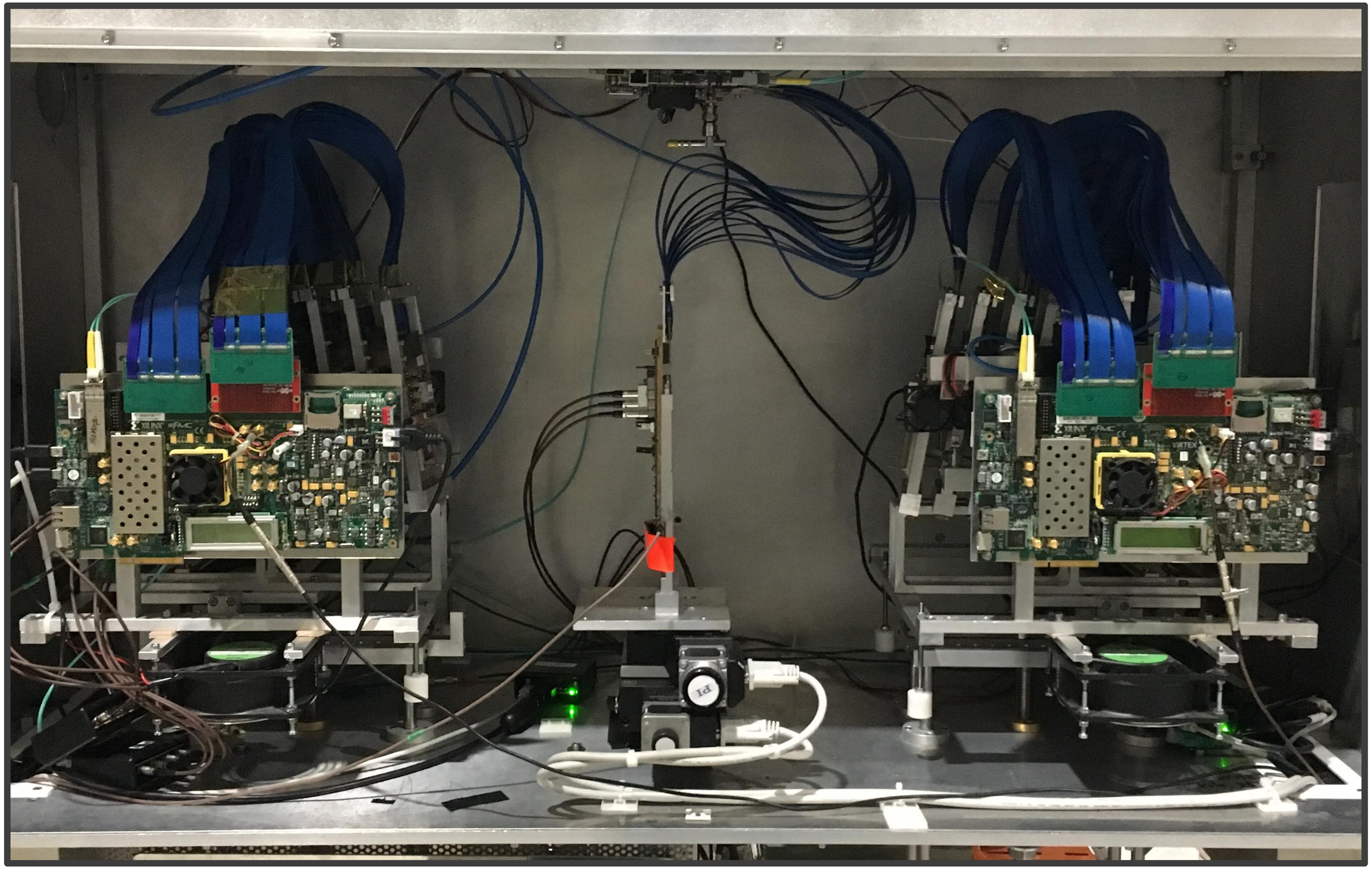
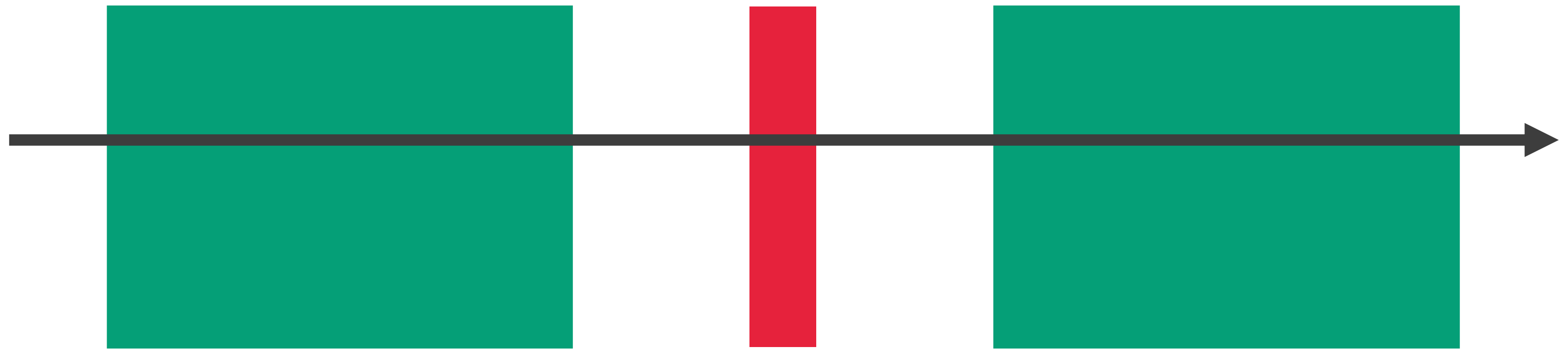
Testbeam: Method



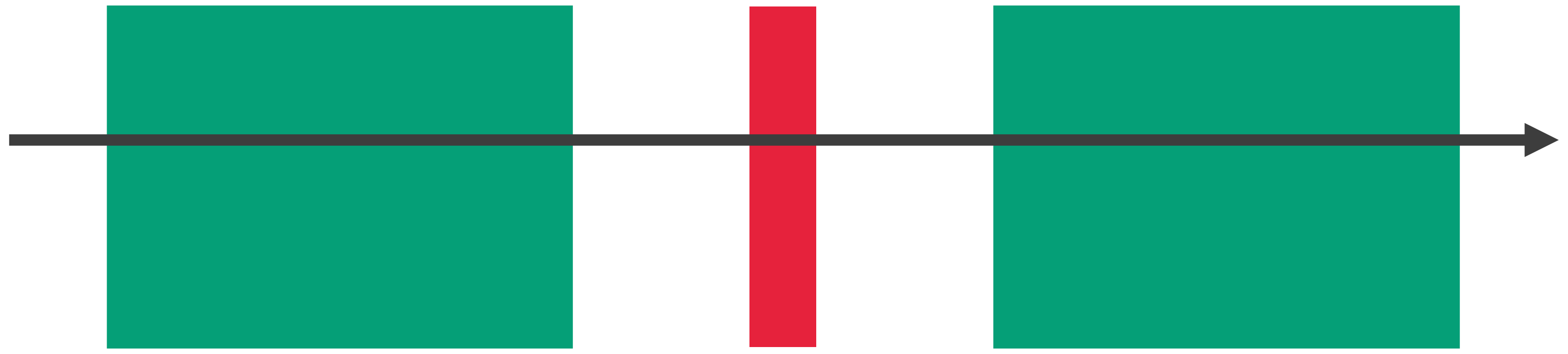
Testbeam: Analysis



Per particle the telescope provides a time reference

Compare this reference to measured time by DUT

Testbeam: Analysis



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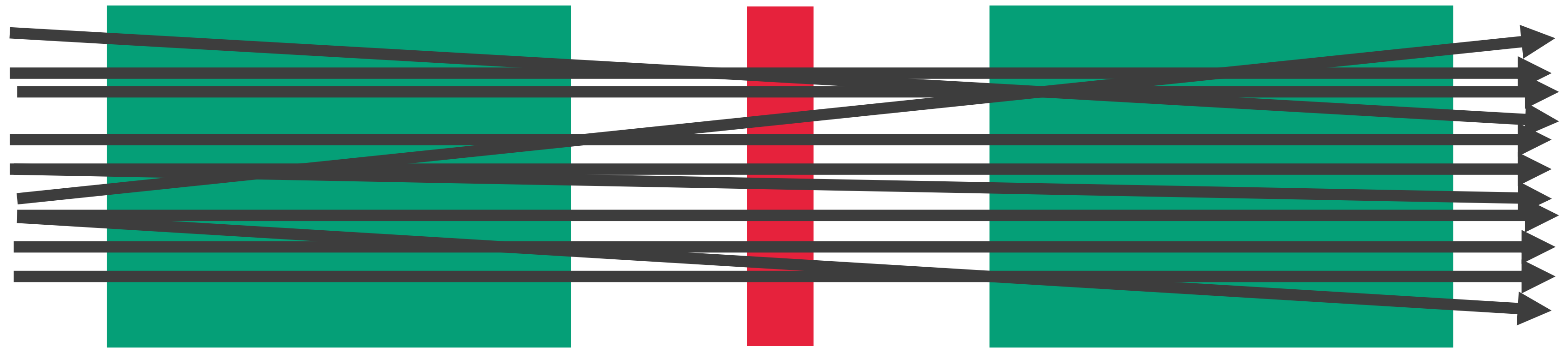
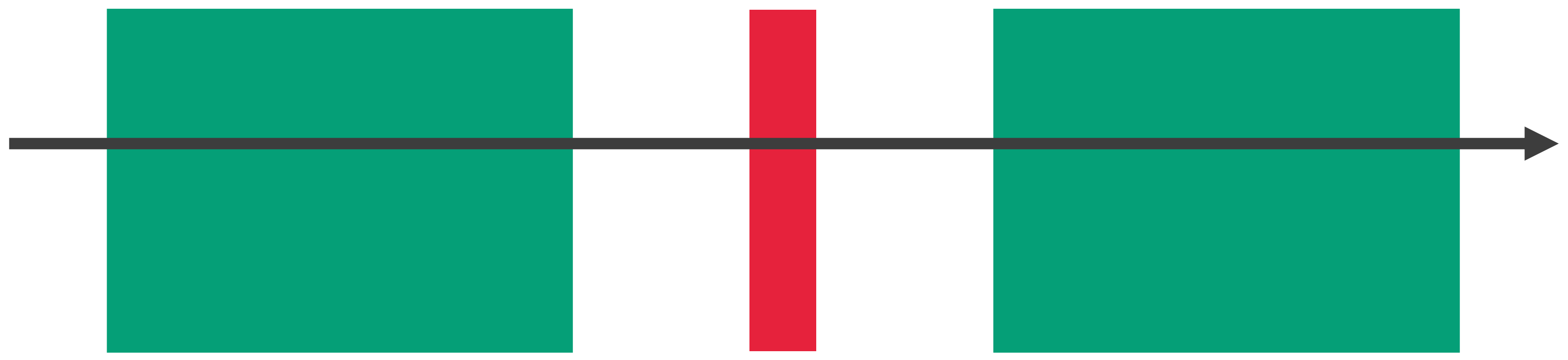


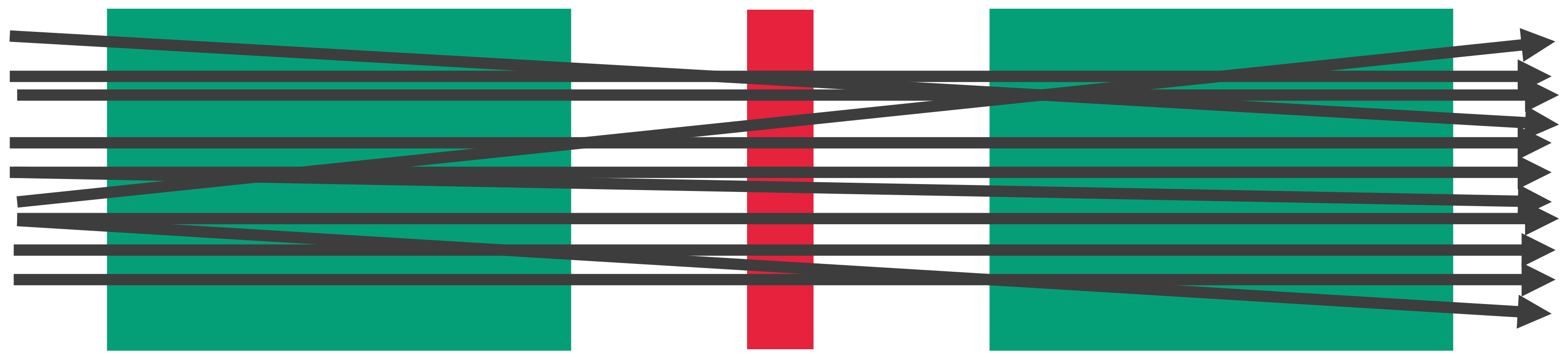
Collect enough statistics

Testbeam: Analysis

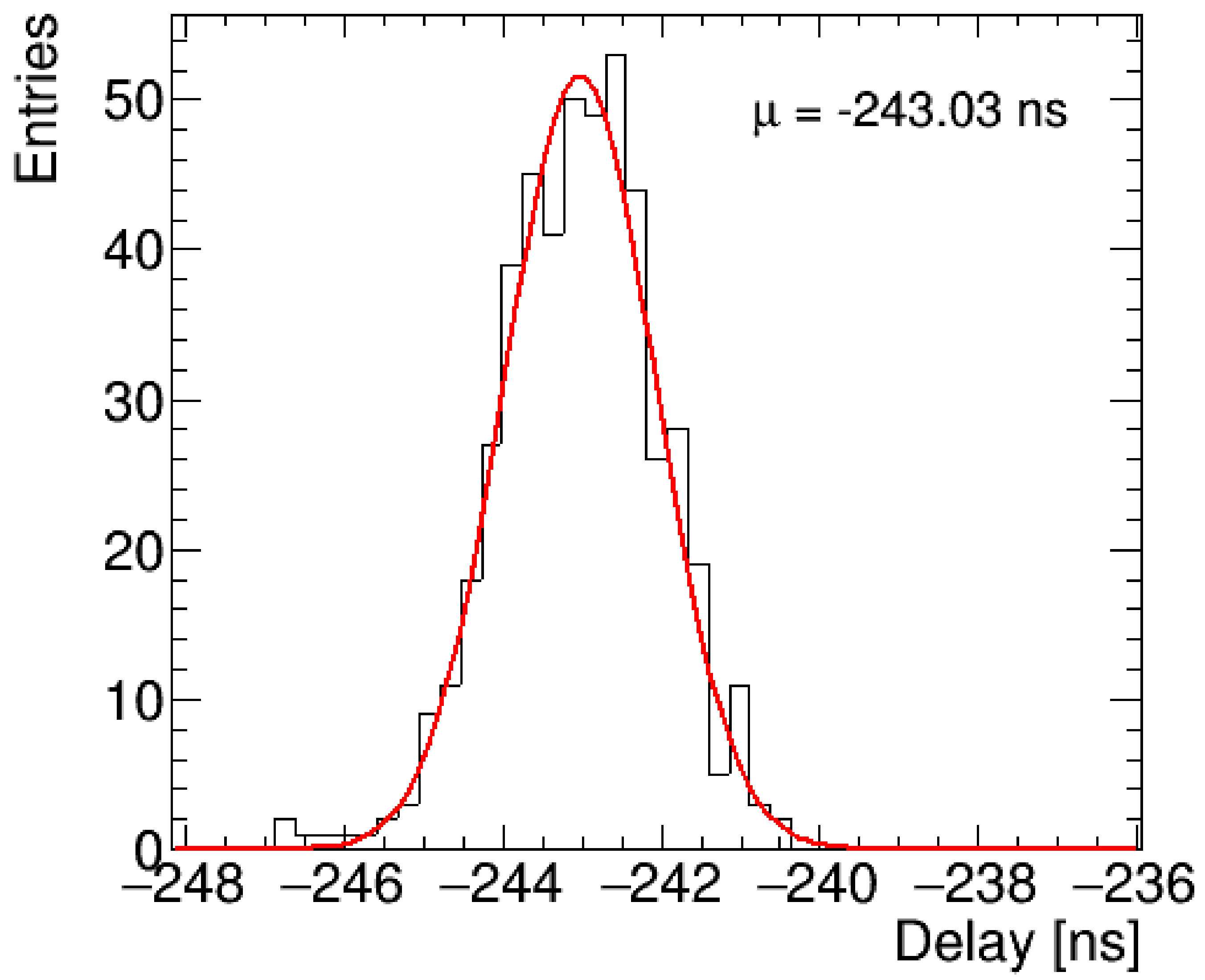


Per particle the telescope provides a time reference

Compare this reference to measured time by DUT



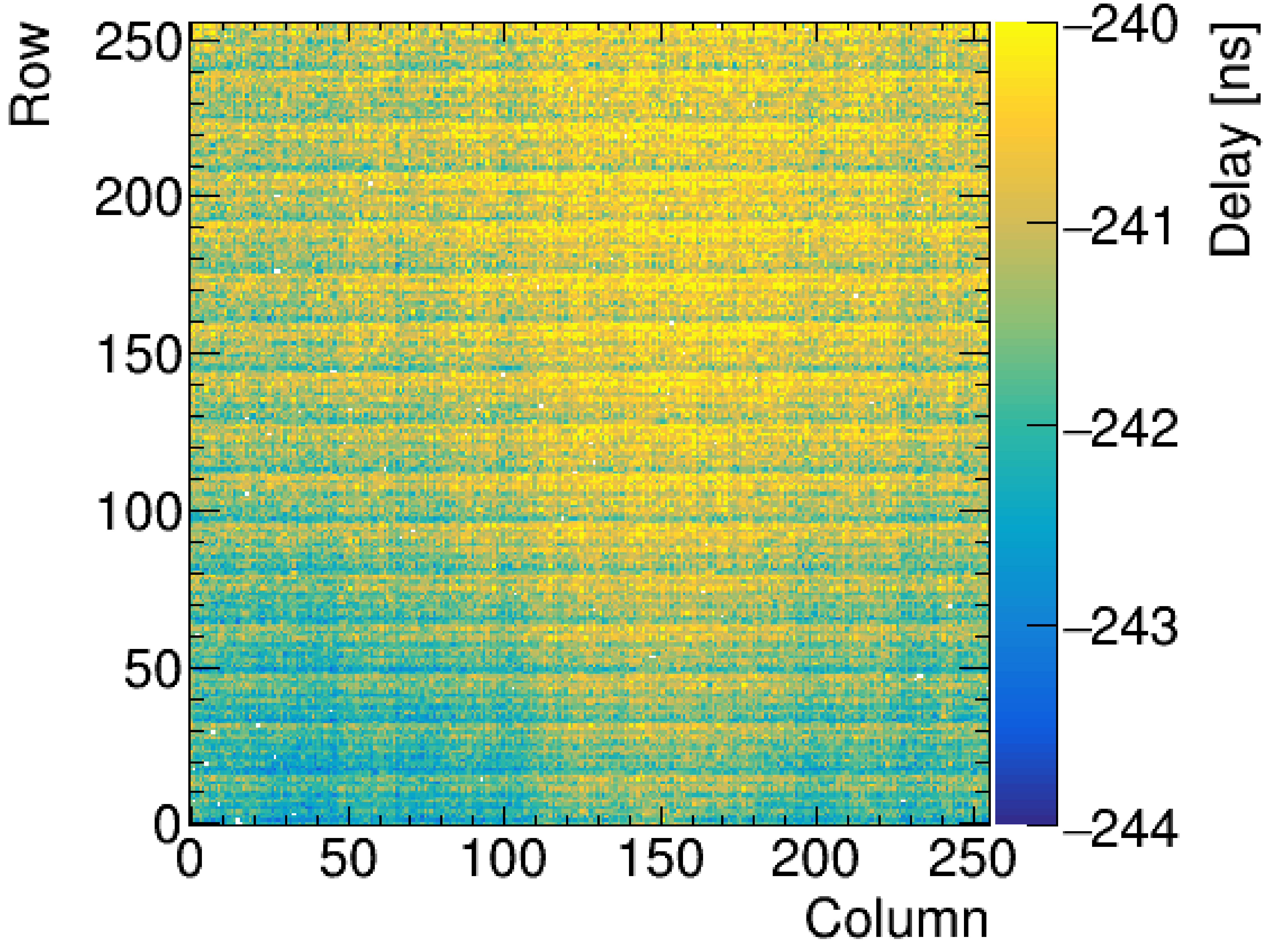
Collect enough statistics



Determine average delay for each pixel by fitting a normal distribution

Testbeam: Results

50 µm Si sensor
90 V bias
25 V full depletion



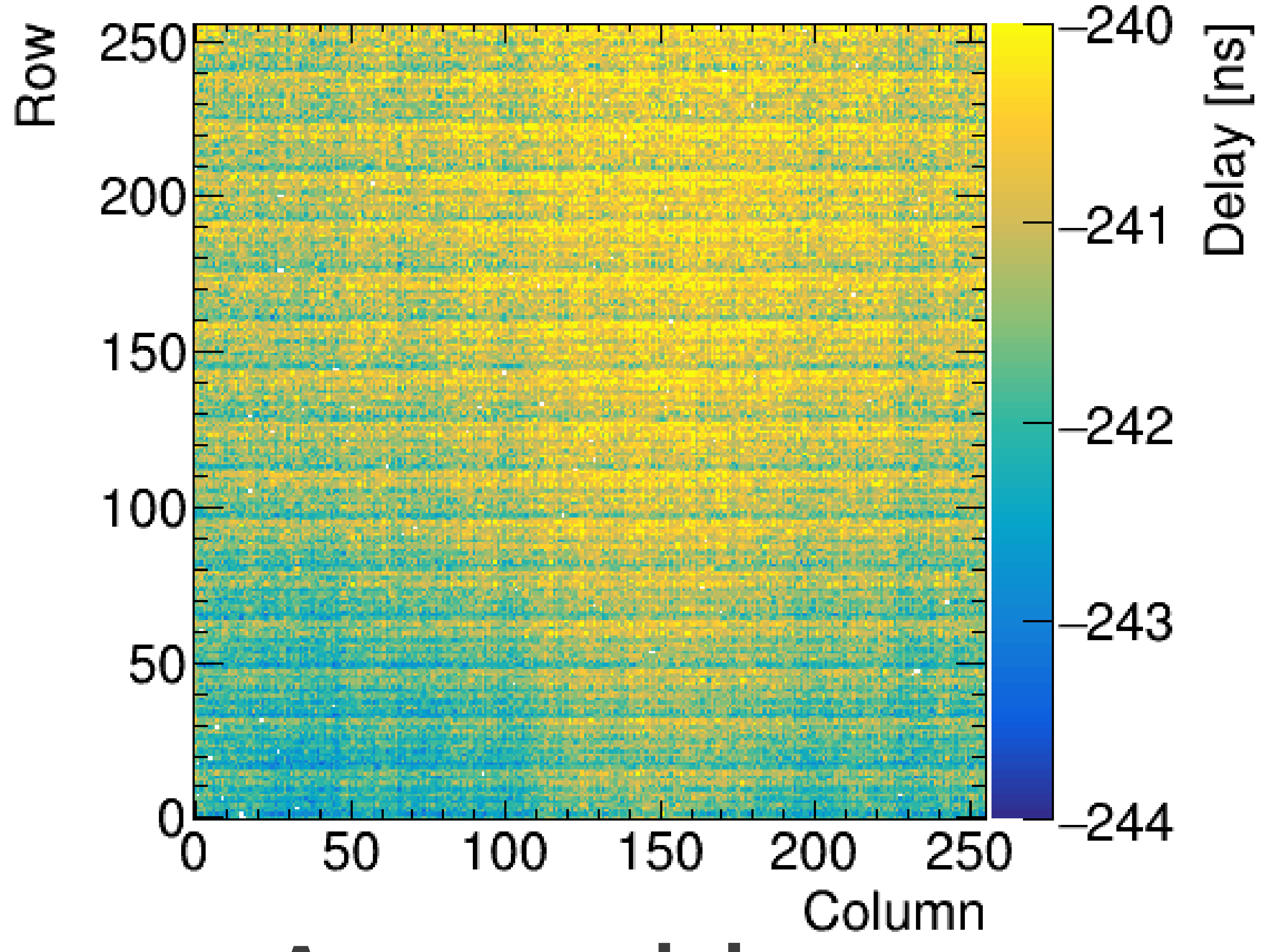
Periodic structure visible:

- Due to building blocks of pixel matrix (e.g. clock buffer), routing
- Maximum difference of ~4 ns → large effect compared to time bins of 1.56 ns

Testbeam: Results

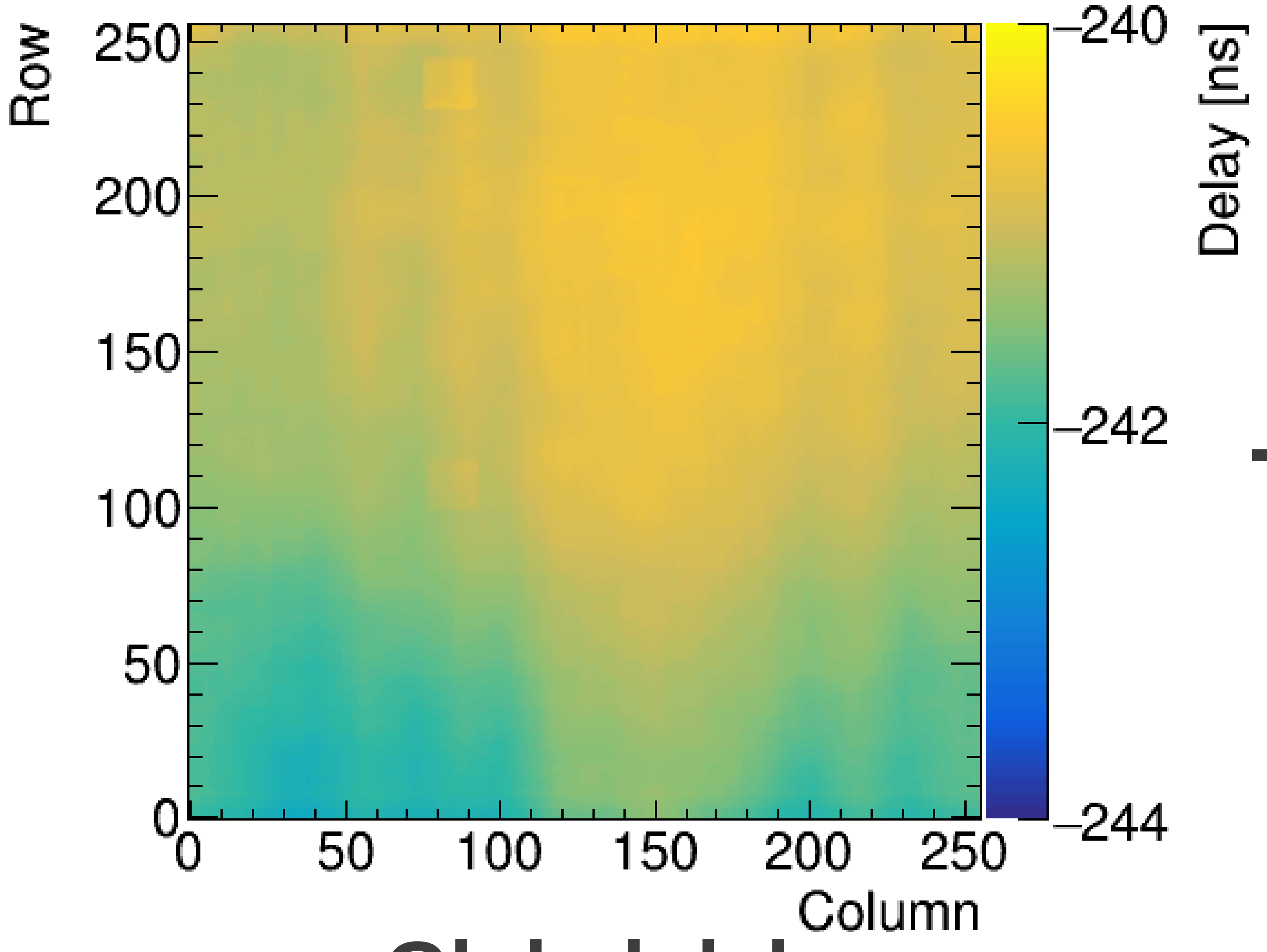
50 µm Si sensor
90 V bias
25 V full depletion

Measured **average delay** consists of two main contributions: **global** and **local**



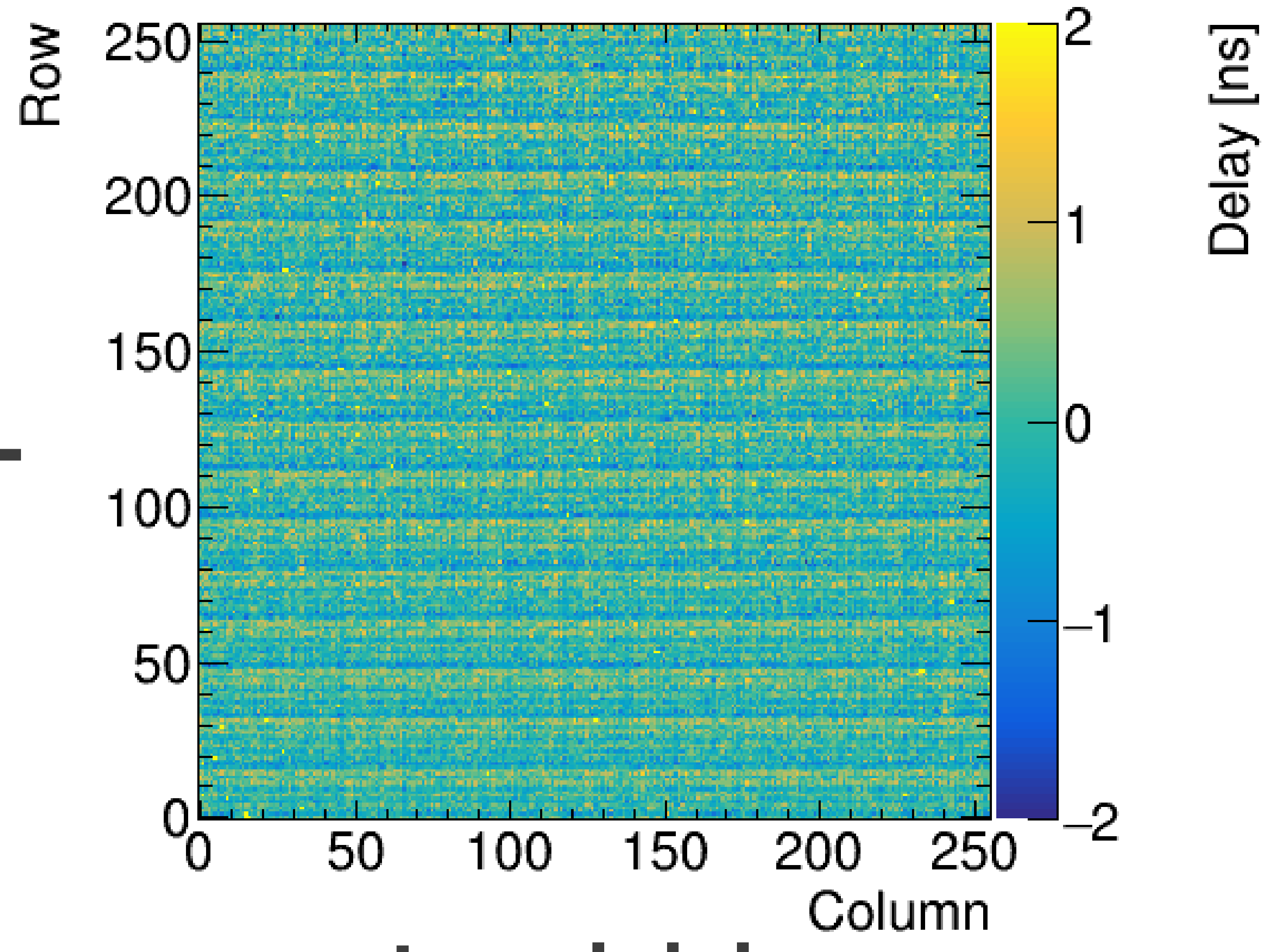
Average delay

=



Global delay
Due to power distribution

+

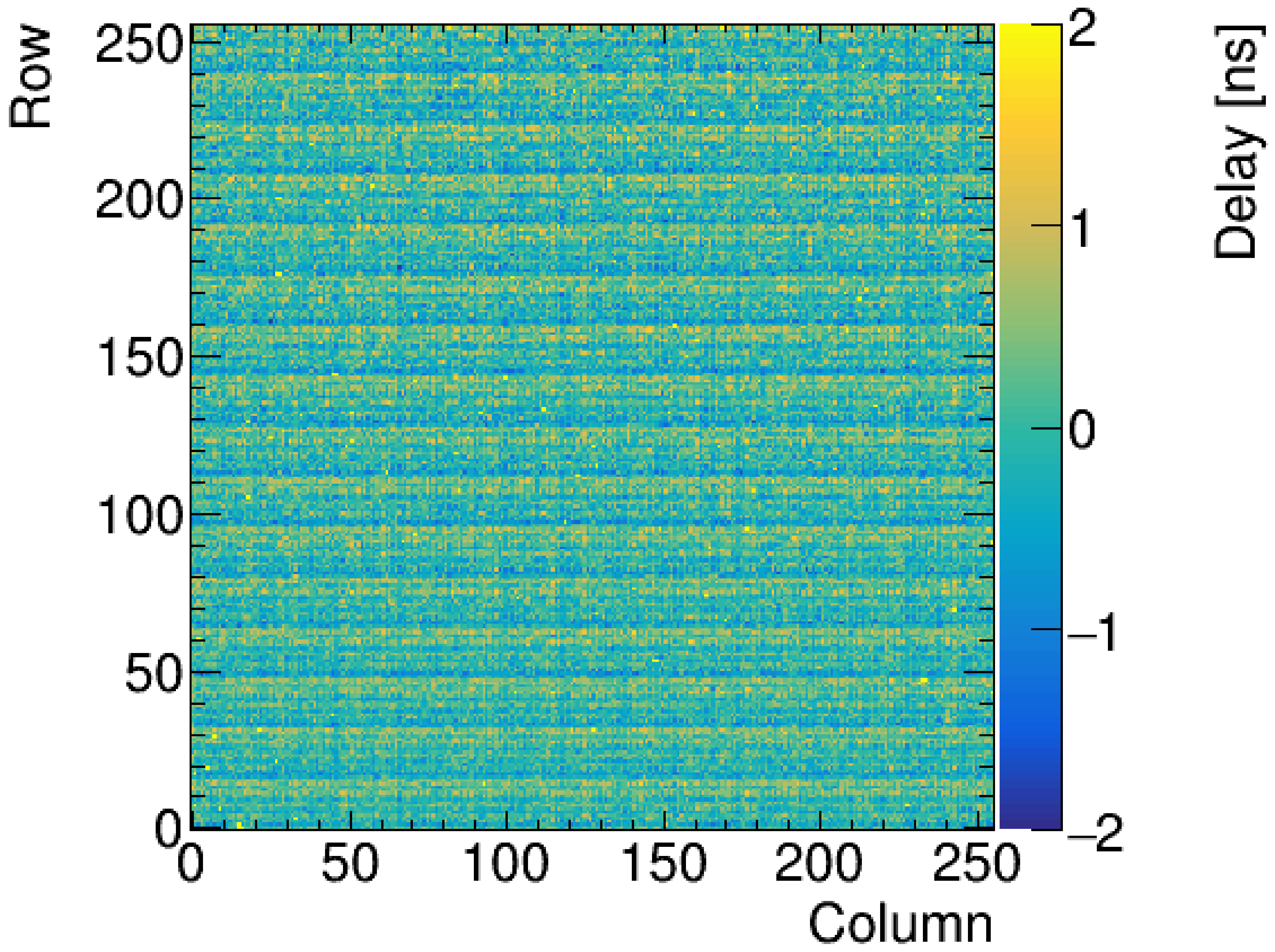


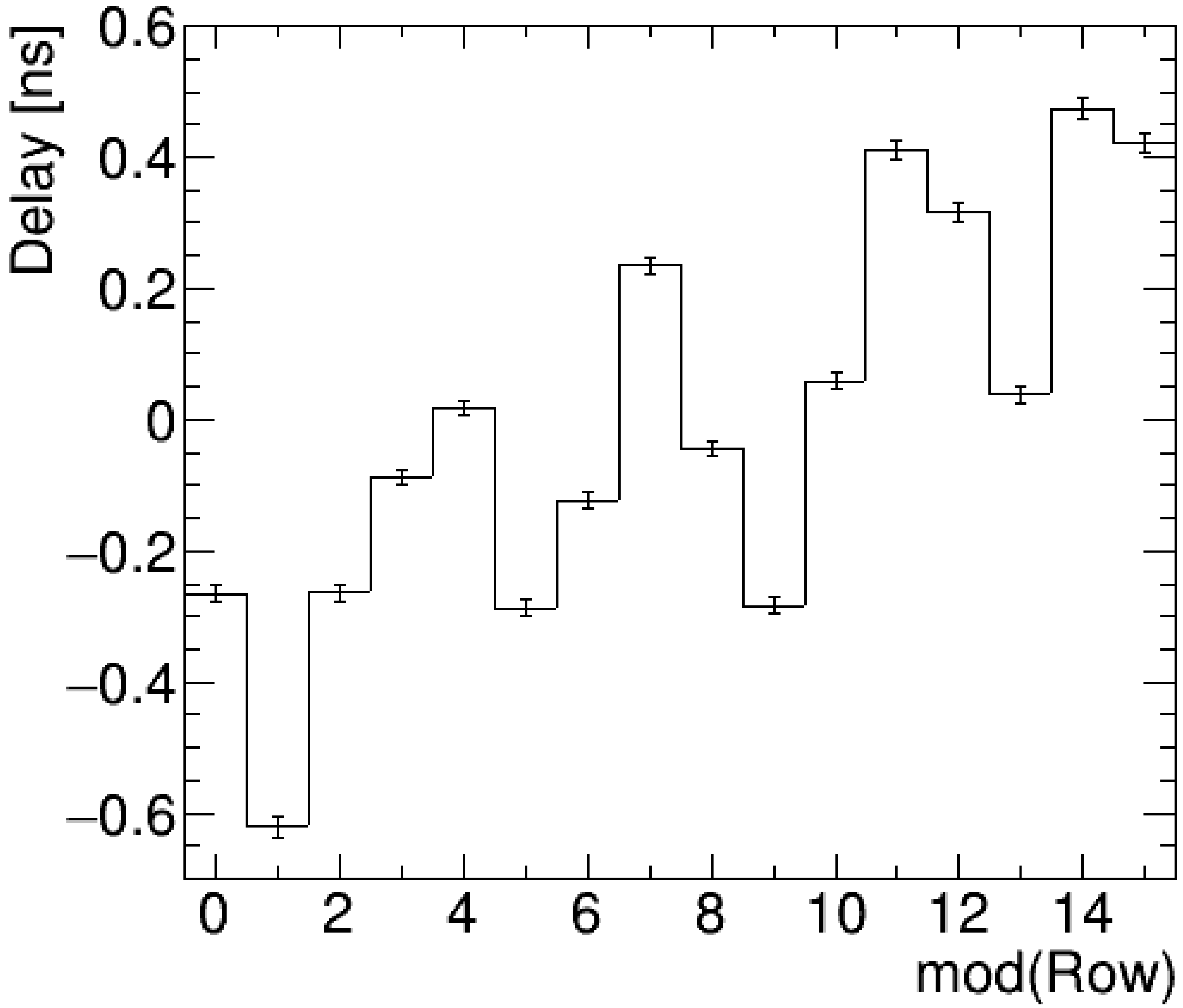
Local delay
Due to clock routing within substructure of pixel matrix

1. Calculate **global delay** from **average delay**
2. Subtract **global delay** from **average delay** to find the **local delay**

Testbeam: Local Delay

50 μm Si sensor
90 V bias
25 V full depletion

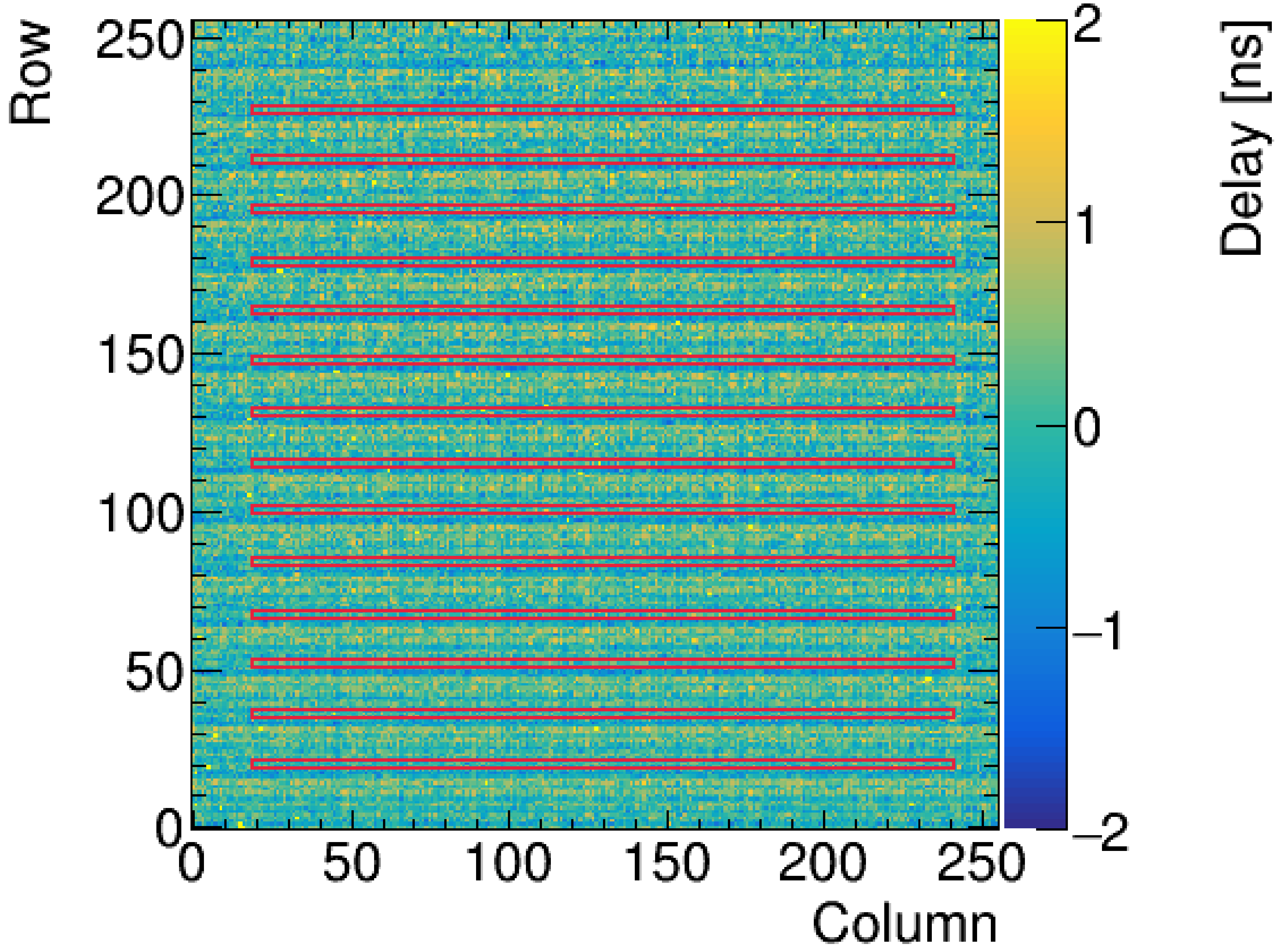


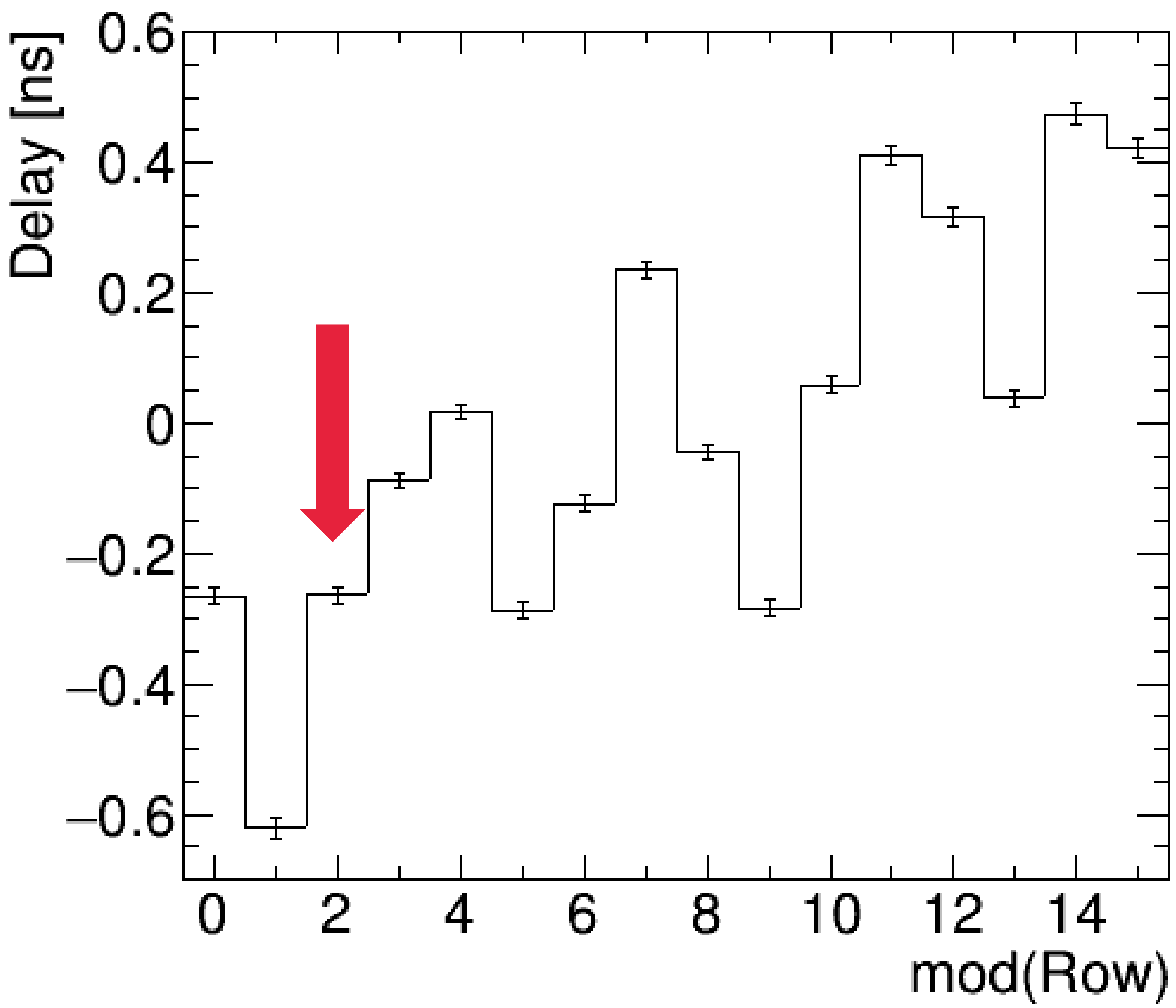


Due to the bin size of 1.56 ns there is a relatively large error on the delay value of a single pixel (451 ps)
→ Calculate the average of a row of the building block to decrease the error (for visualisation and comparison)

50 μm Si sensor
90 V bias
25 V full depletion

Testbeam: Local Delay

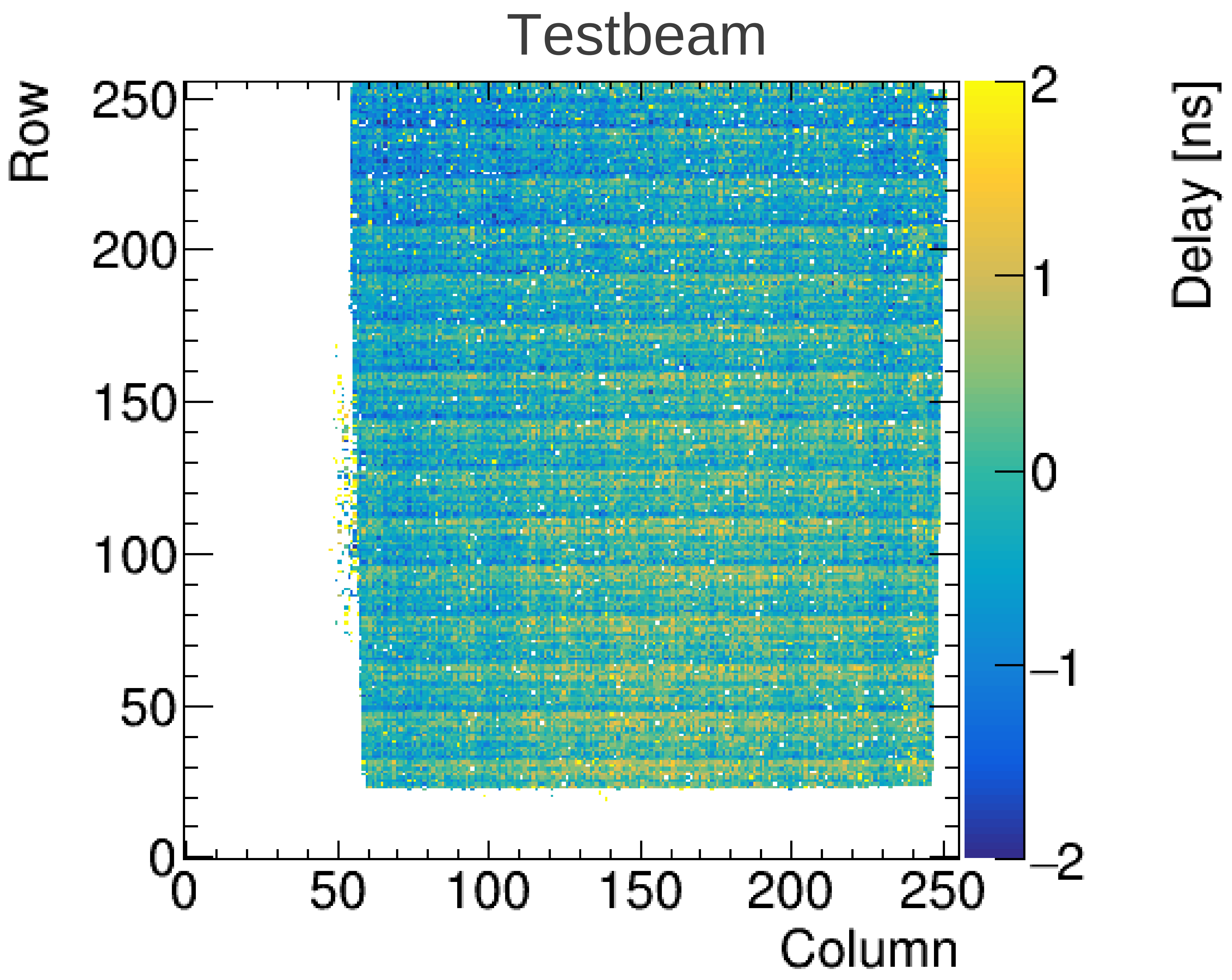




Due to the bin size of 1.56 ns there is a relatively large error on the delay value of a single pixel (451 ps)
→ Calculate the average of a row of the building block to decrease the error (for visualisation and comparison)

Laser: Comparison of time delay

200 μm Si sensor
200 V bias
115 V full depletion

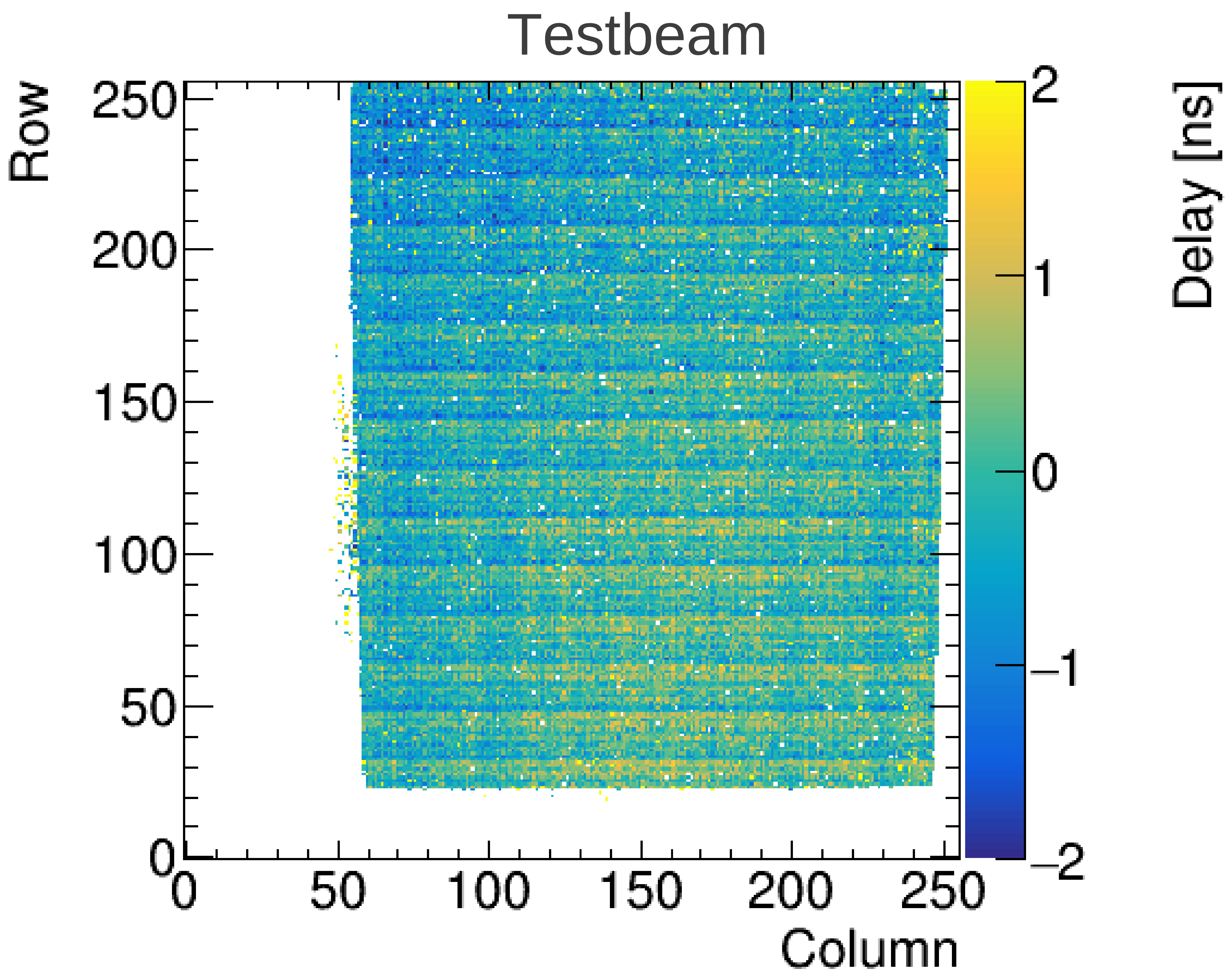


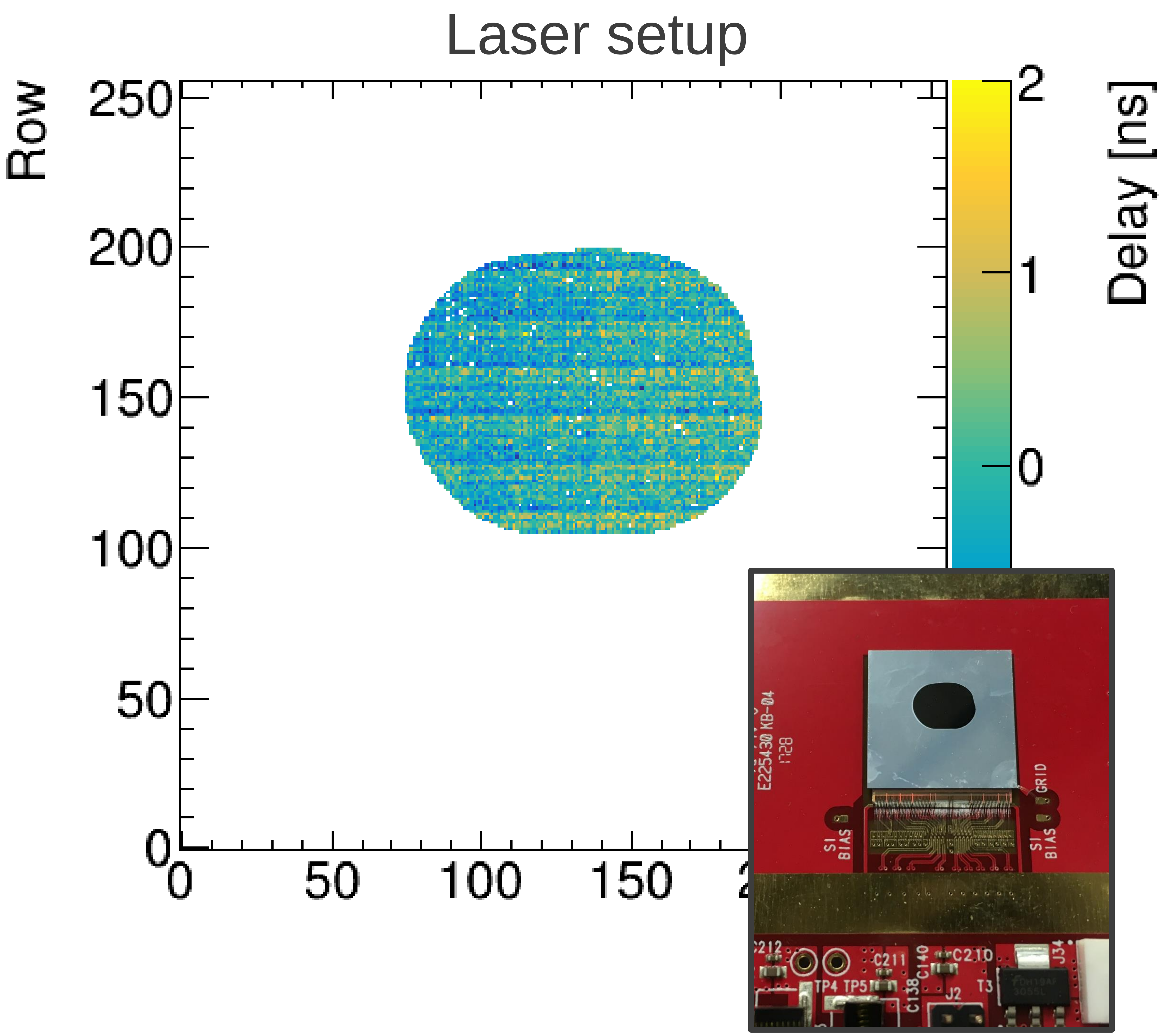
The average delay is determined in the same way as with the testbeam

Note that this is a different sensor from the previous slides

Laser: Comparison of time delay

200 µm Si sensor
200 V bias
115 V full depletion

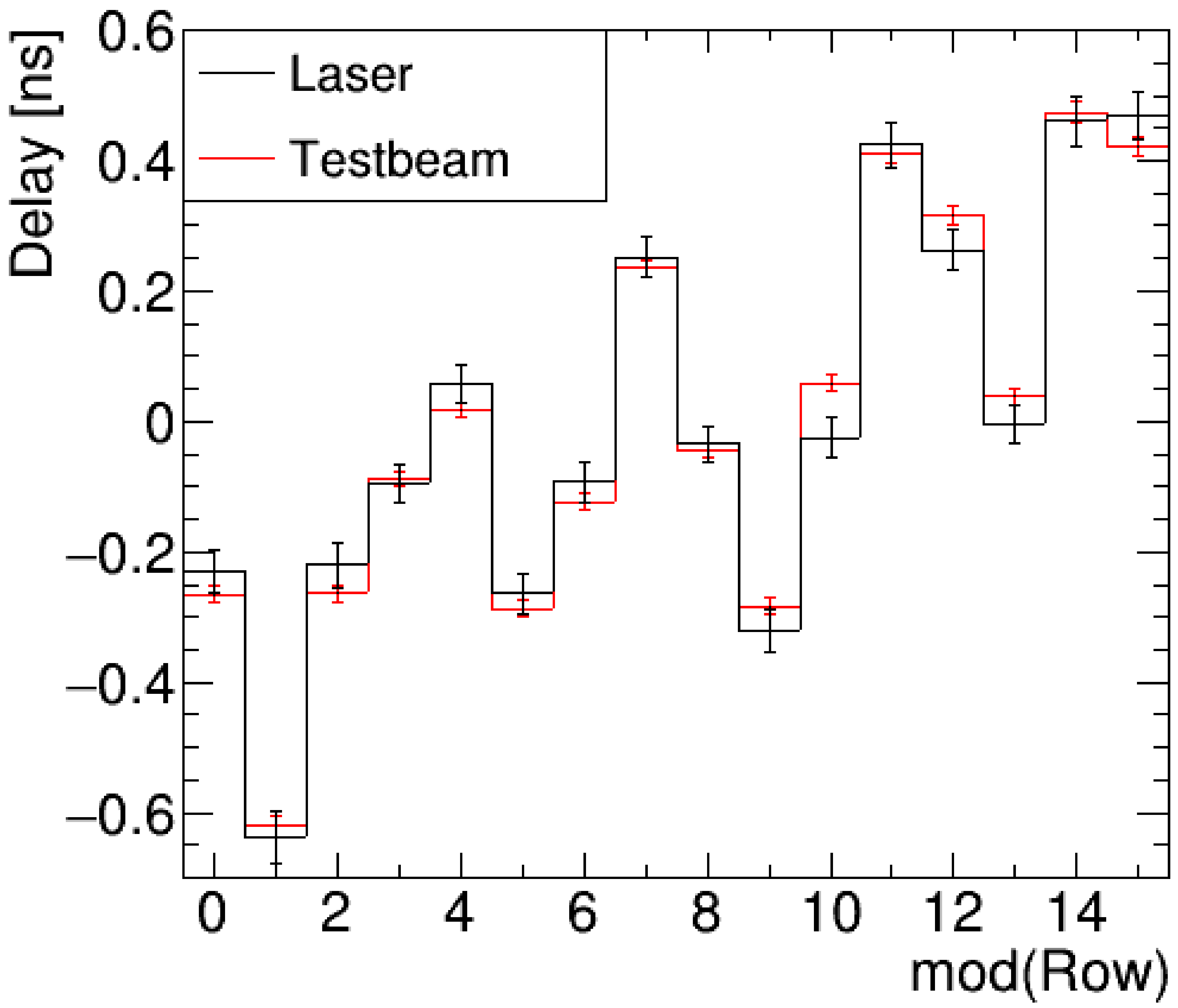




- Overall structure is similar
- To make qualitative comparison, compare the row projection to reduce the systematic error

Laser: Comparison of time delay

200 μm Si sensor
200 V bias
115 V full depletion



Row projection for the periodic structure:

- Both methods give similar results!

Time resolution improvements

Correcting for timing structure:

- Time resolution consists of two components:
  - ASIC resolution: $\sigma_{t,ASIC}$
  - Sensor resolution: $\sigma_{t,sensor}$

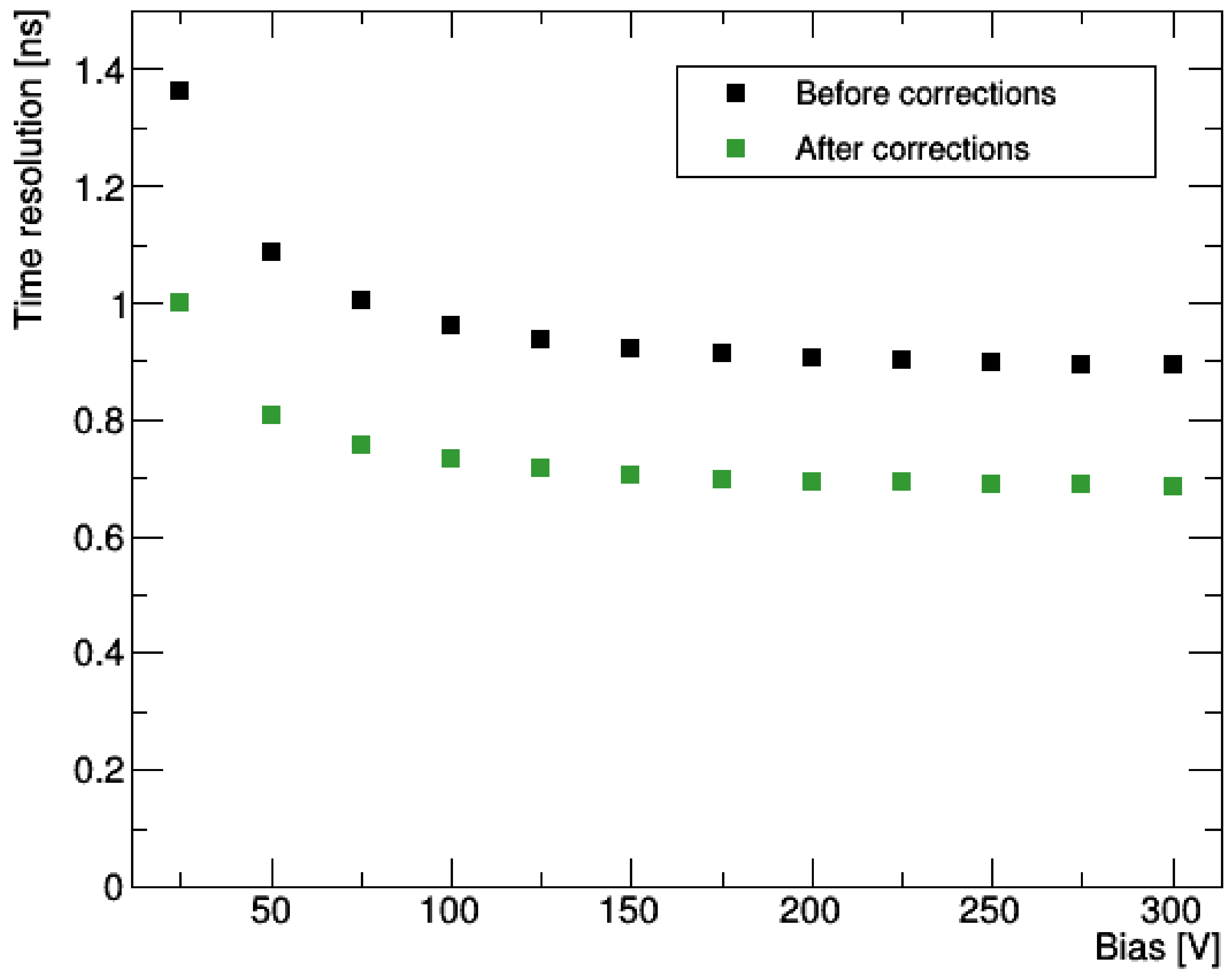
- $\sigma_{t,ASIC}$ consists of size of time bin and further non-uniformities → can be decreased now that pixel systematics is known!

- The error due to different systematics is:

  σ_t(pixel systematics, 300 V) $=$ 560 ps

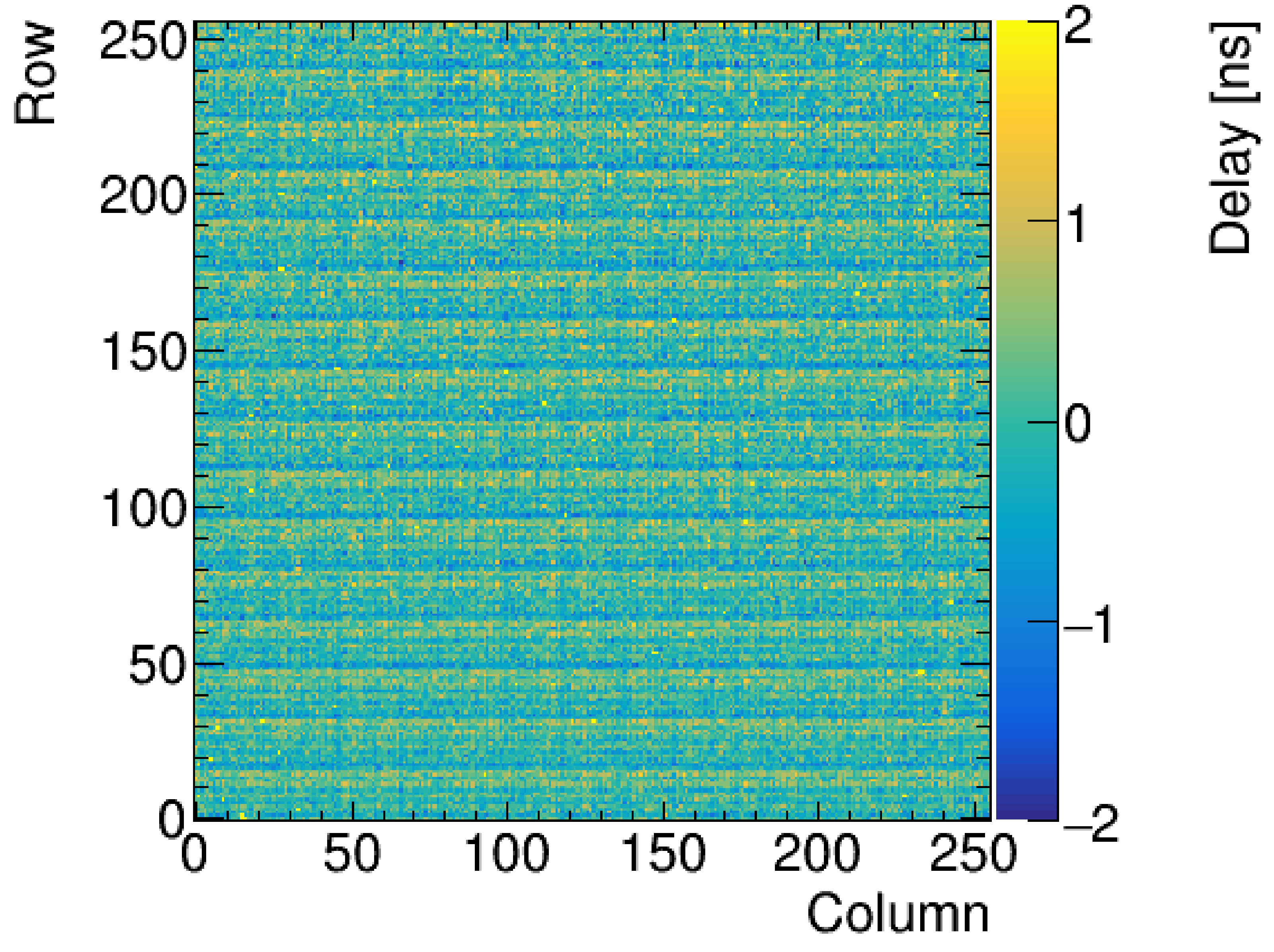
- $\sigma_{t,sensor}$ estimated at 510 ps

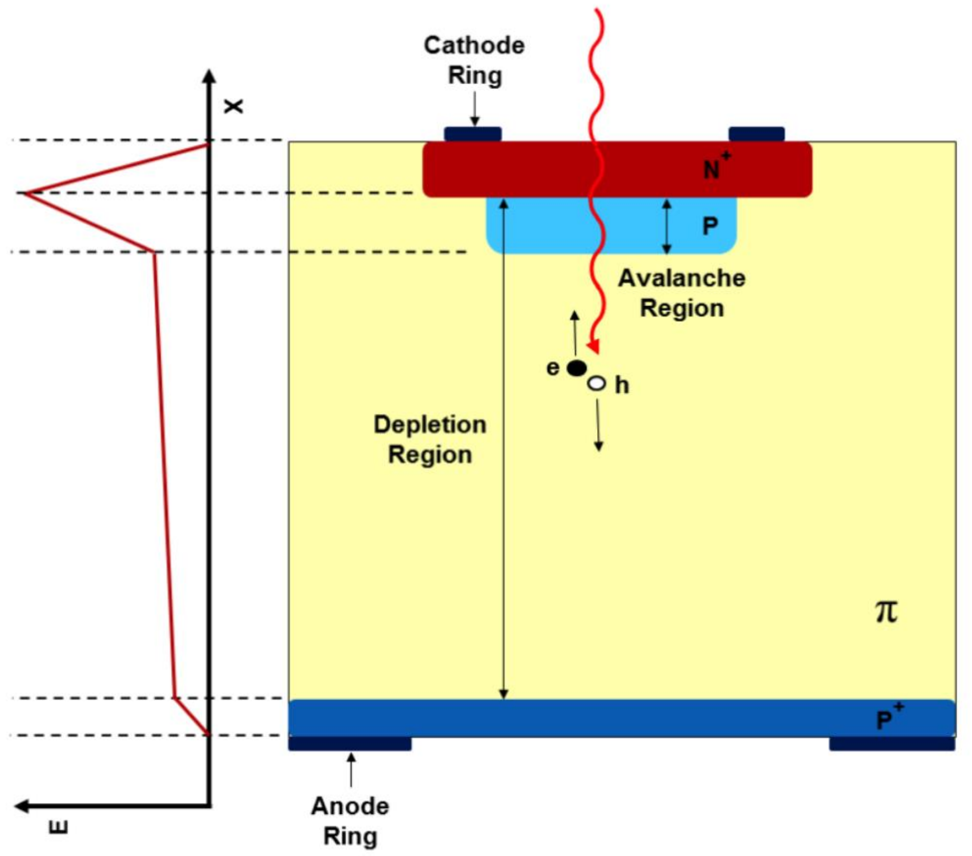
200 µm planar Si



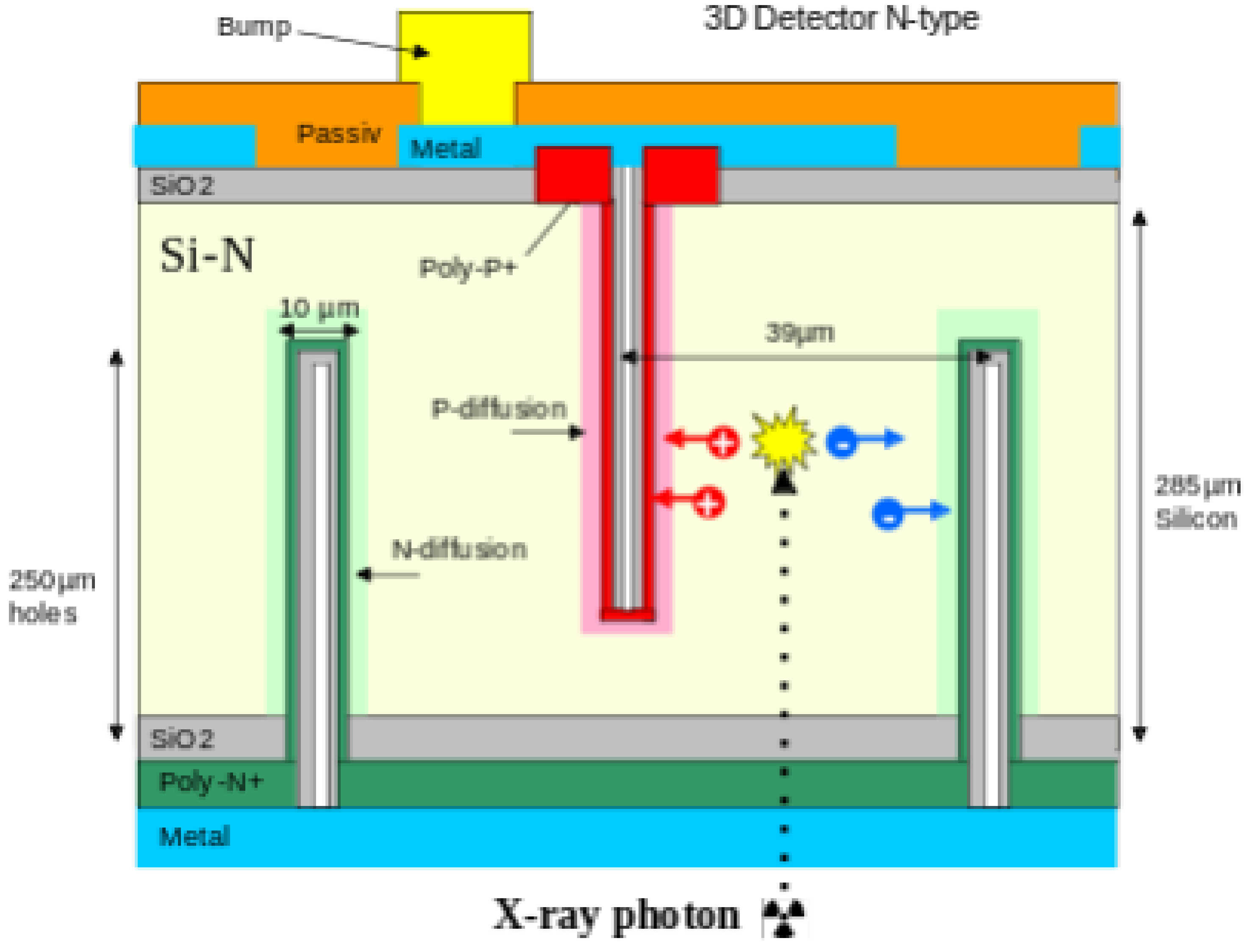
Outlook

- Timepix4! Better time measurement: 200 ps
- Upgrade laser system to two-photon absorption
- Search for faster sensors: 3D sensors, thinner planar sensors, LGAD, ELAD
- New sensor designs? Who knows what the future holds!





Kramberger, G. *et al*. Radiation Hardness of Thin Low Gain Avalanche Detectors (2018).



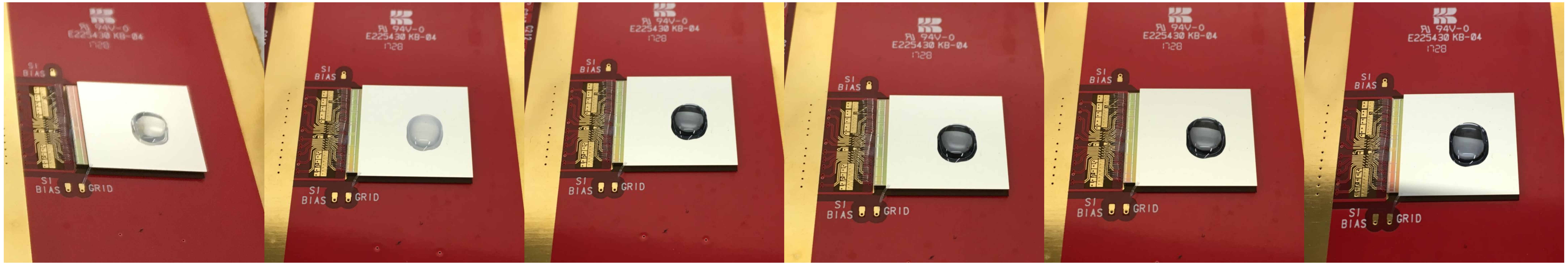
Backup: Etching of metallization

Normally a metal layer is on top of silicon to shield from stray light

Removed using a mixture of:

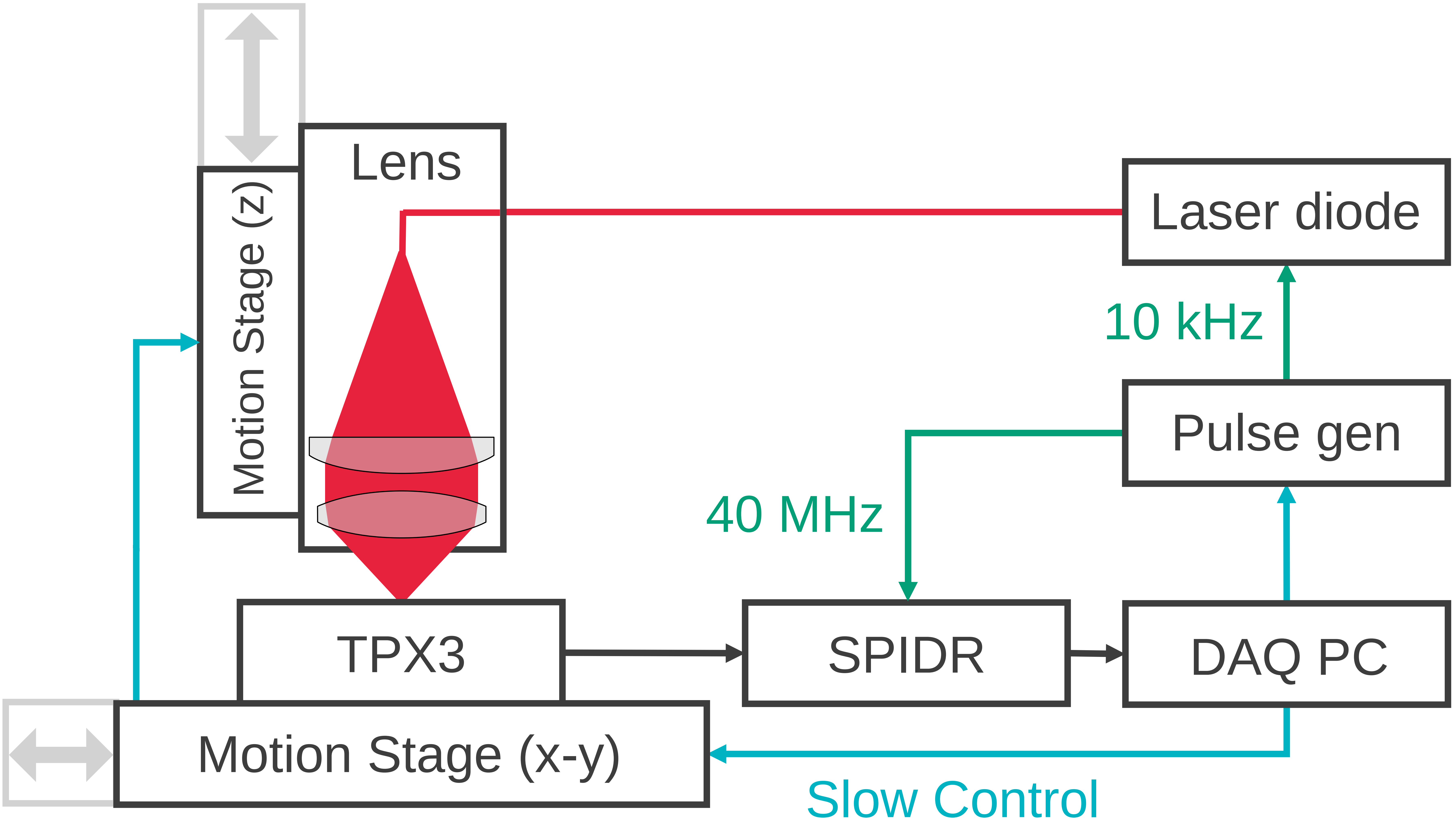
- Nitric acid
- Phosphoric acid
- Water

Etching took ~2 hours



0 min → 100 min

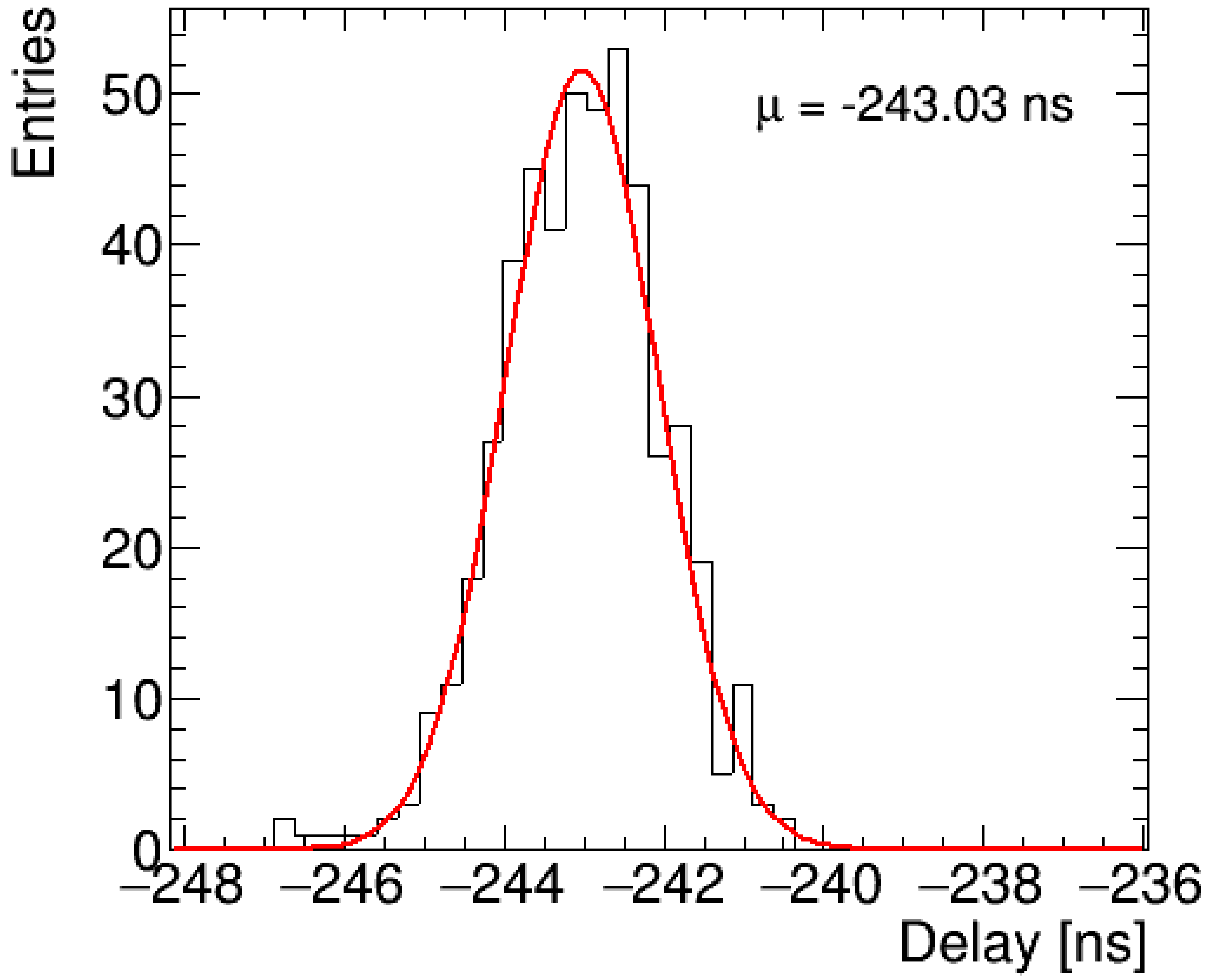
Backup: Laser Setup



FBG stabilized laser diode

- Wavelength: 683 nm (absorbed within 15 µm)
- Max output: 2 mW
- FWHM (max): 1 nm
- Minimum spot size: 6.7 µm
- Working distance: ~12 mm

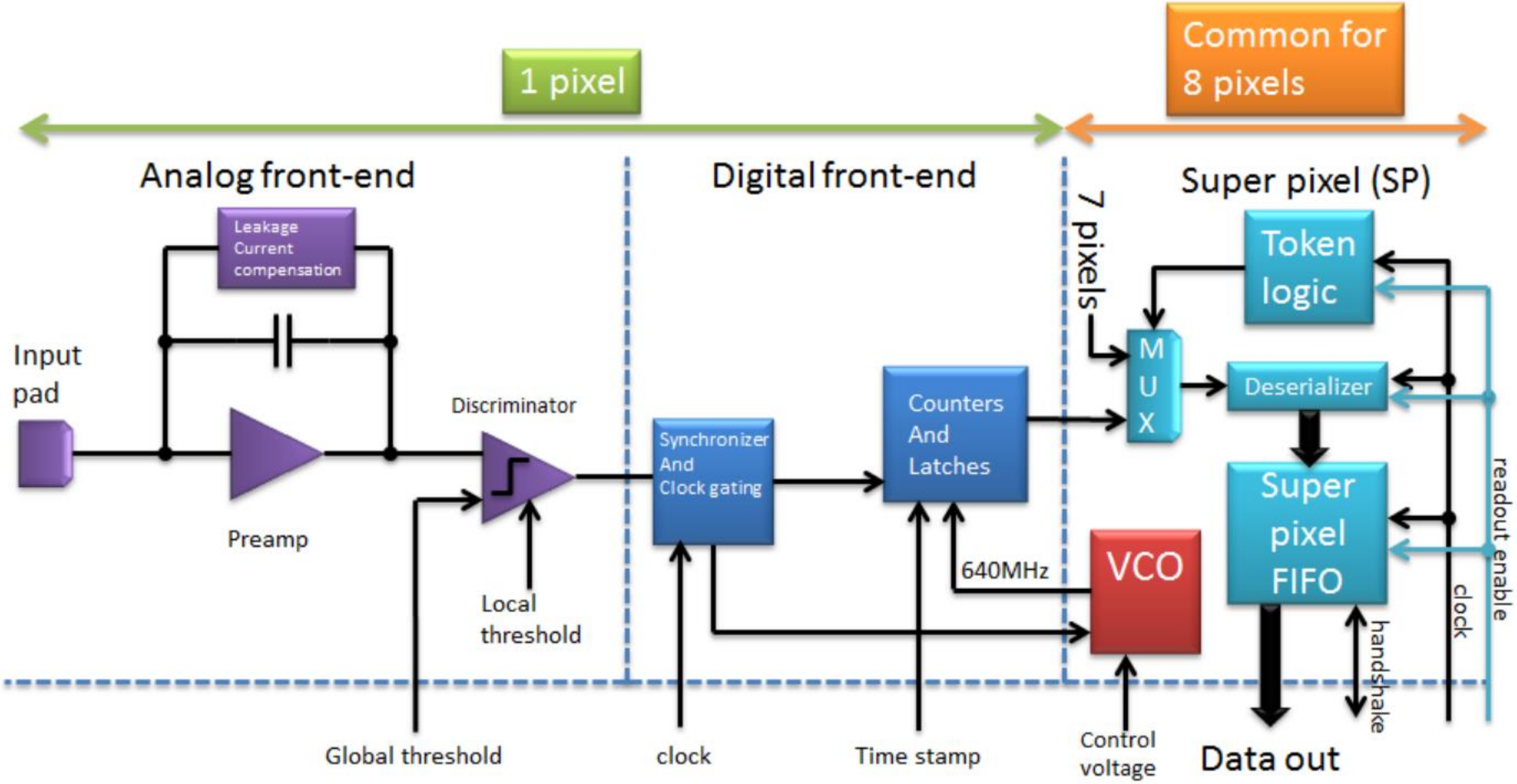
Backup: Calculation of Delay



Error on average delay μ:

$$\sigma_\mu = \sqrt{\sigma_{fit}^2 - \left(\frac{1.56}{\sqrt{12}}\right)^2 - \left(\frac{0.26}{\sqrt{12}}\right)^2}$$

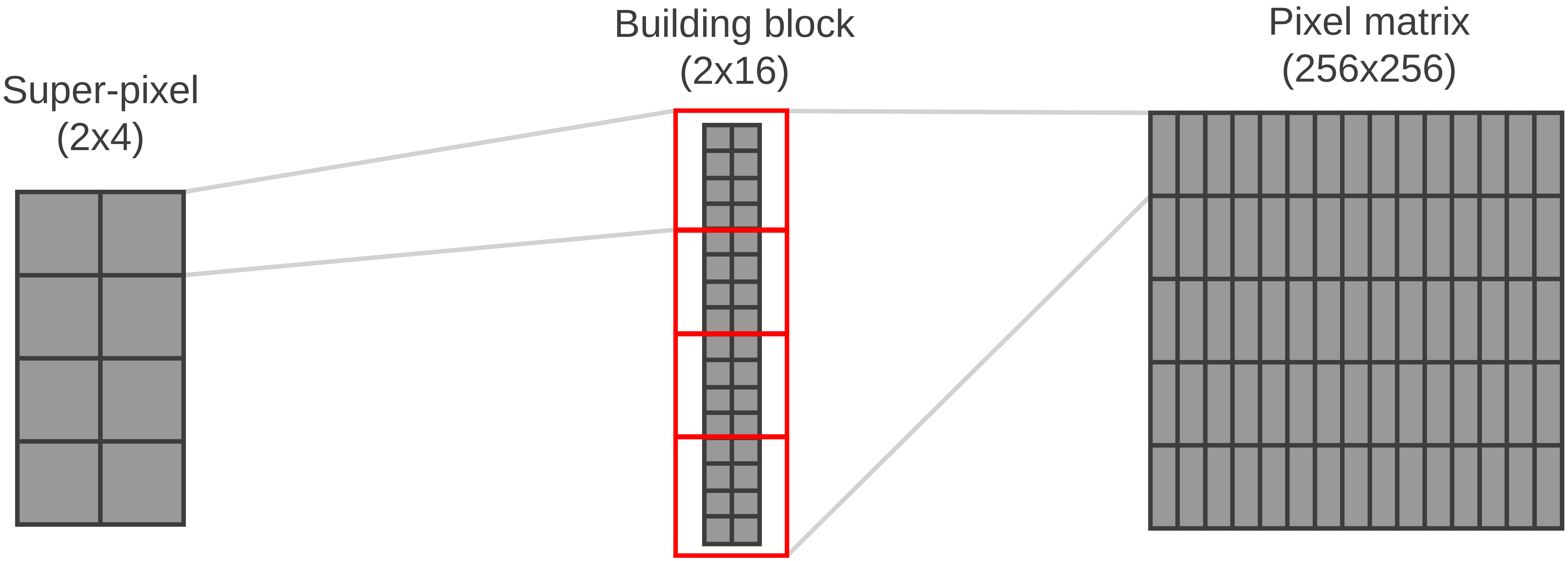
Backup: Pixel Design



Poikela, T et al. Timepix3: a 65K channel hybrid pixel readout chip with simultaneous ToA/ToT and sparse readout. *Journal of instrumentation* 9, C05013 (2014).

Backup: Pixel matrix

Not each pixel of the pixel matrix of Timepix3 are the same
Difference between routing and components within the building block

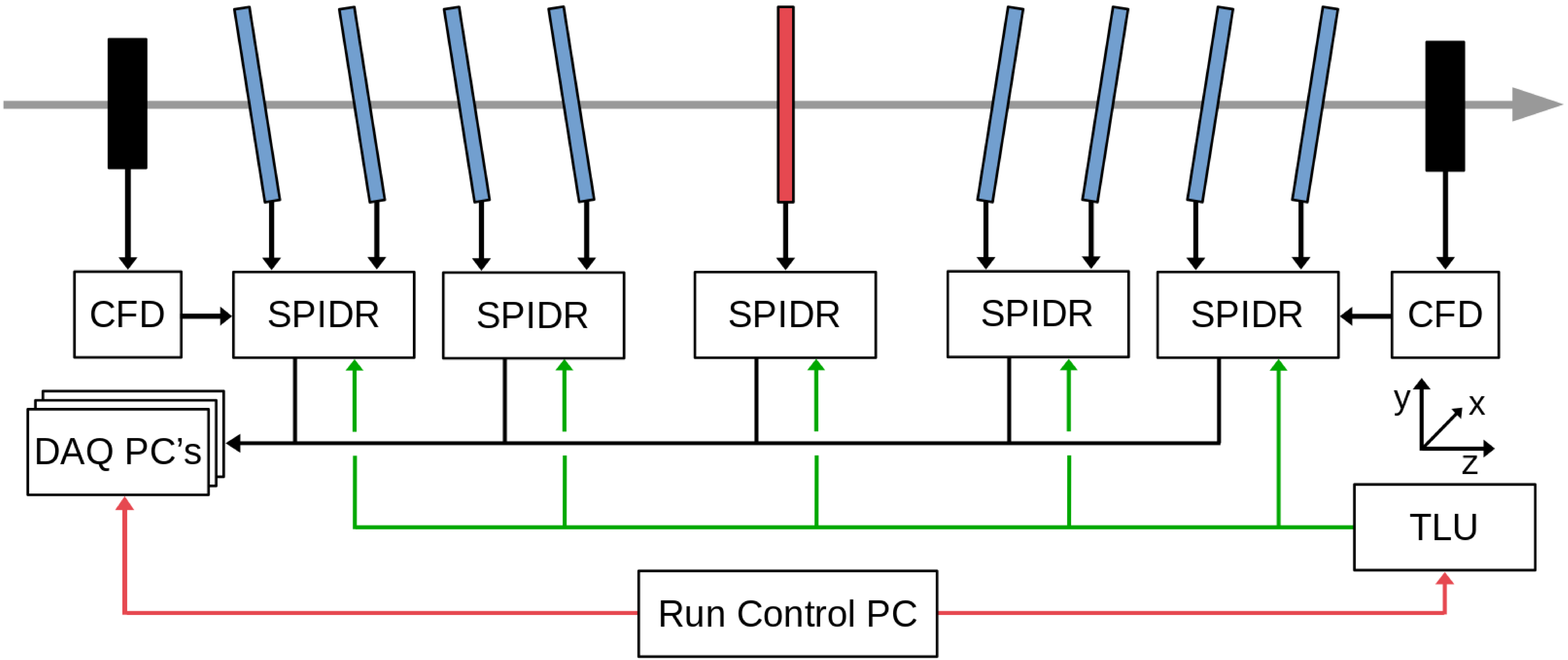


Shares common logic
Such as 640 MHz clock

Shares clock buffer
Consists of 4 super-pixels

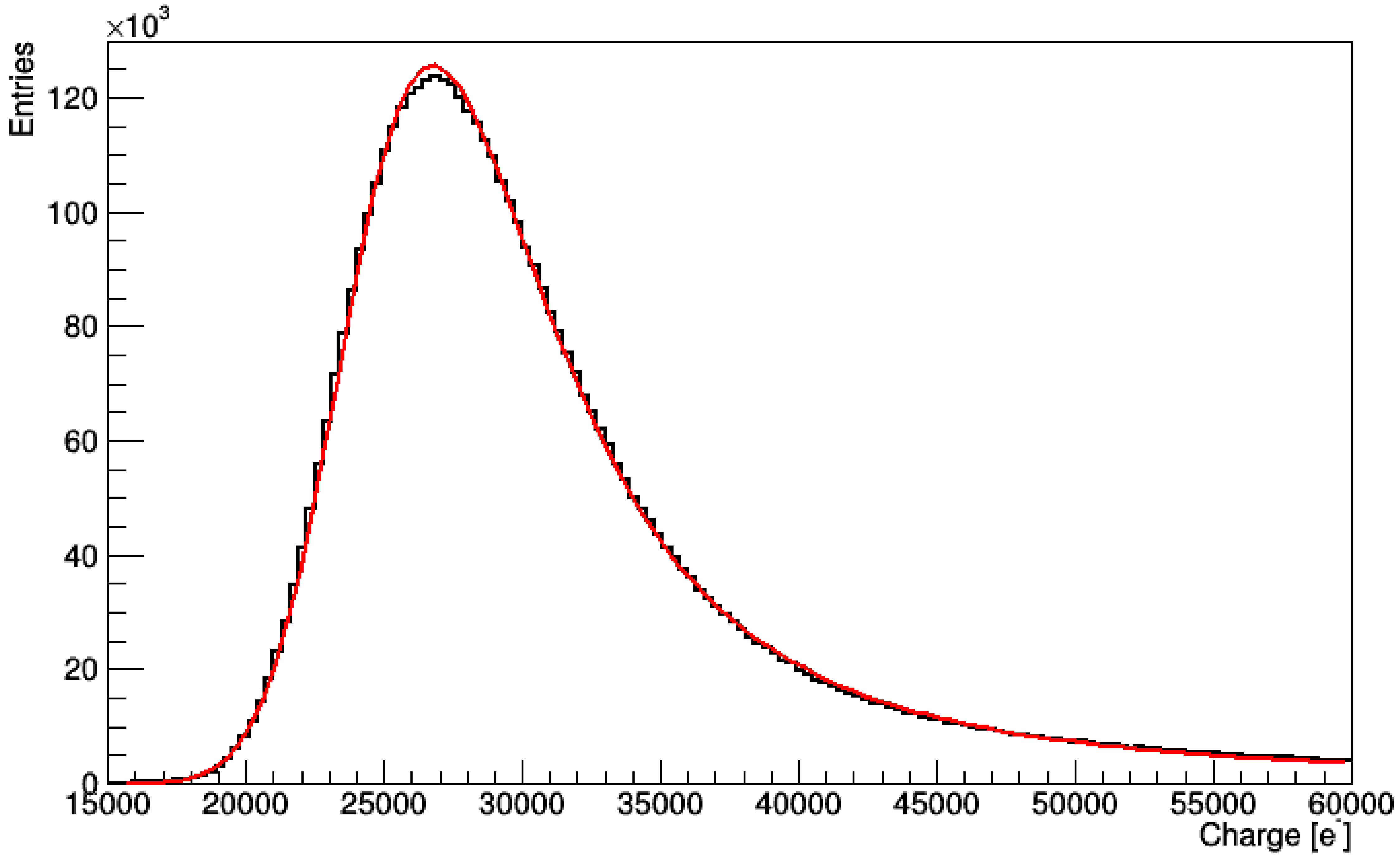
Consists of 128x16
building blocks

Backup: Timepix3 telescope

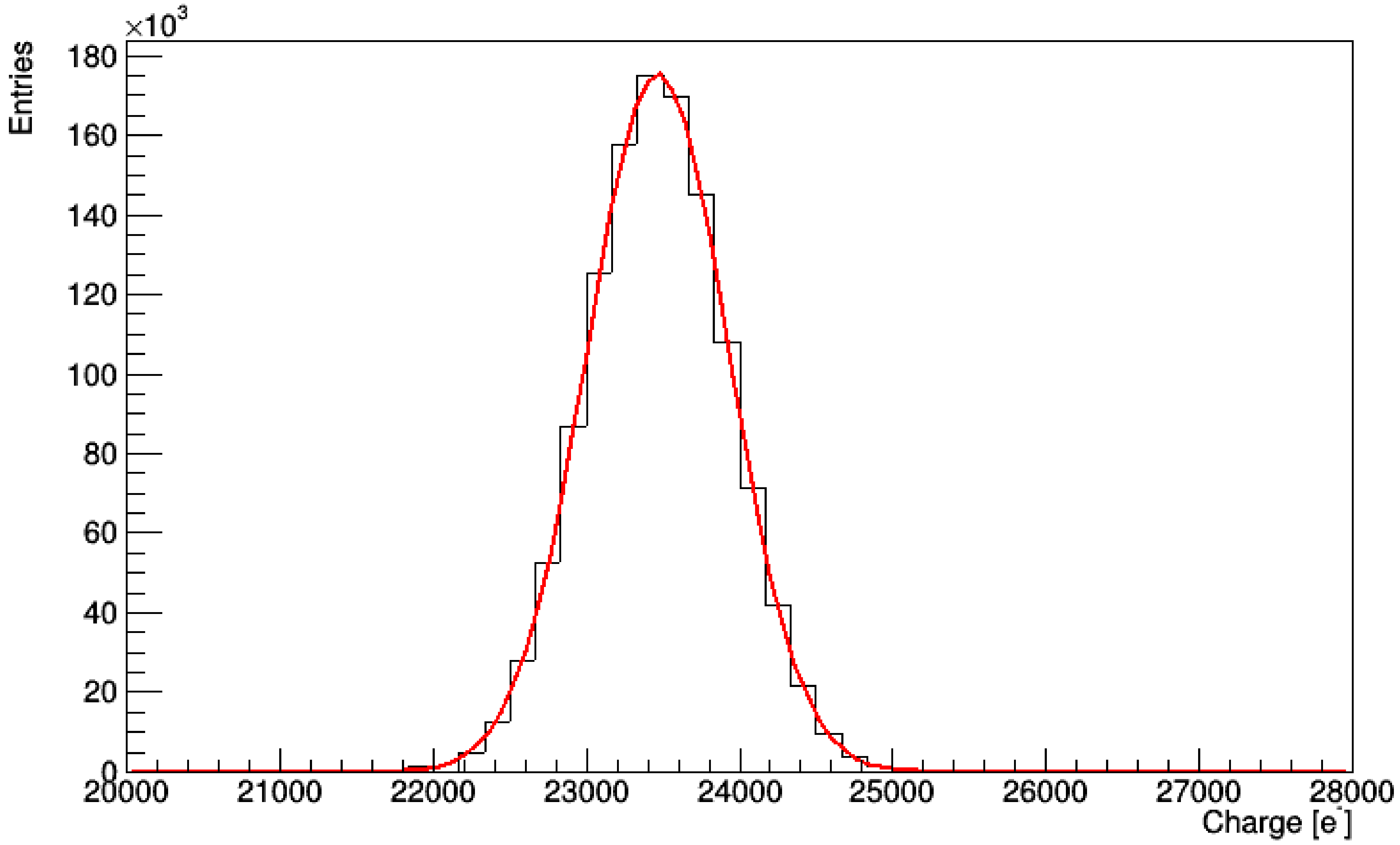


Backup: Charge Deposition

Particle



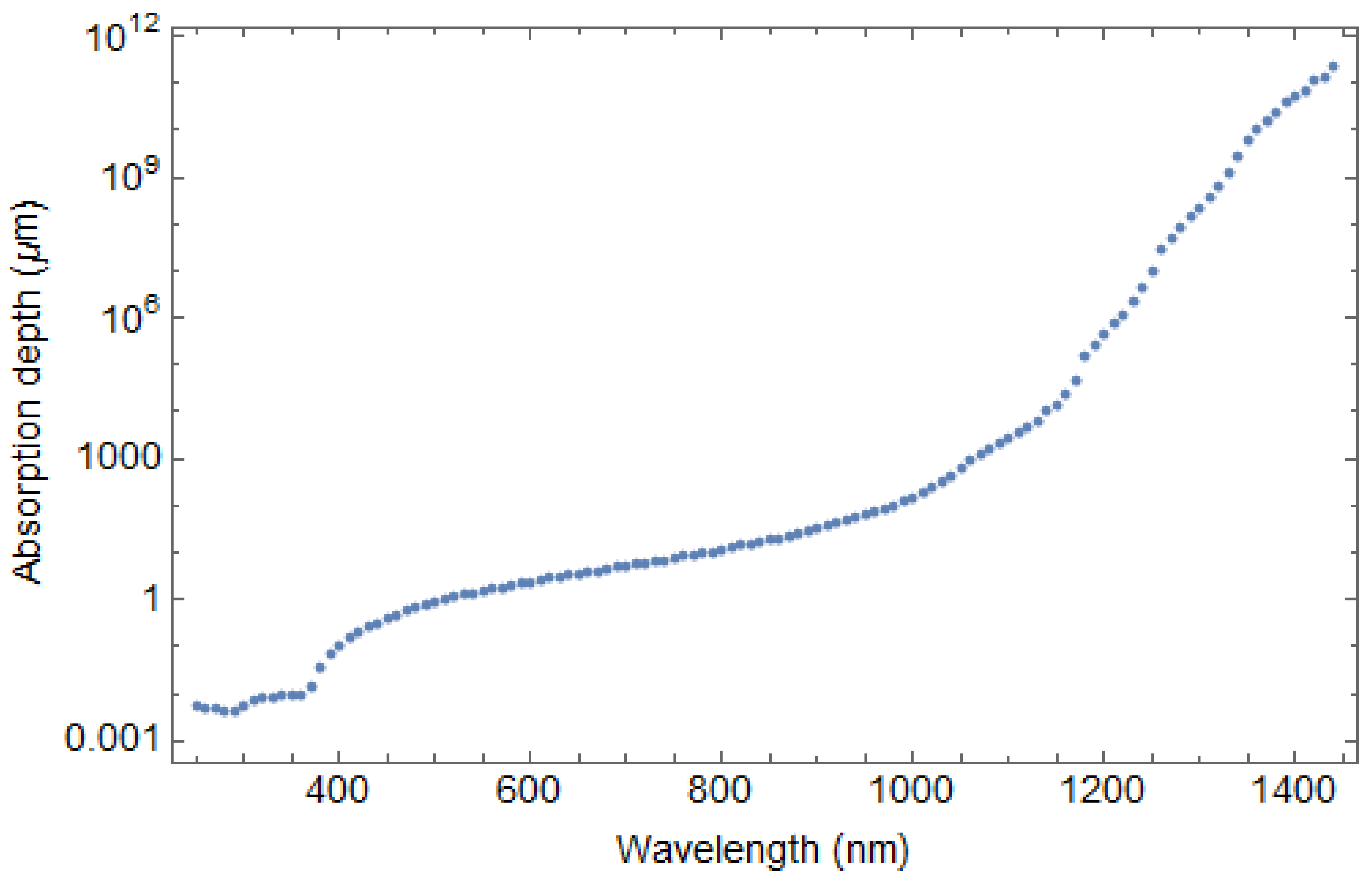
Laser

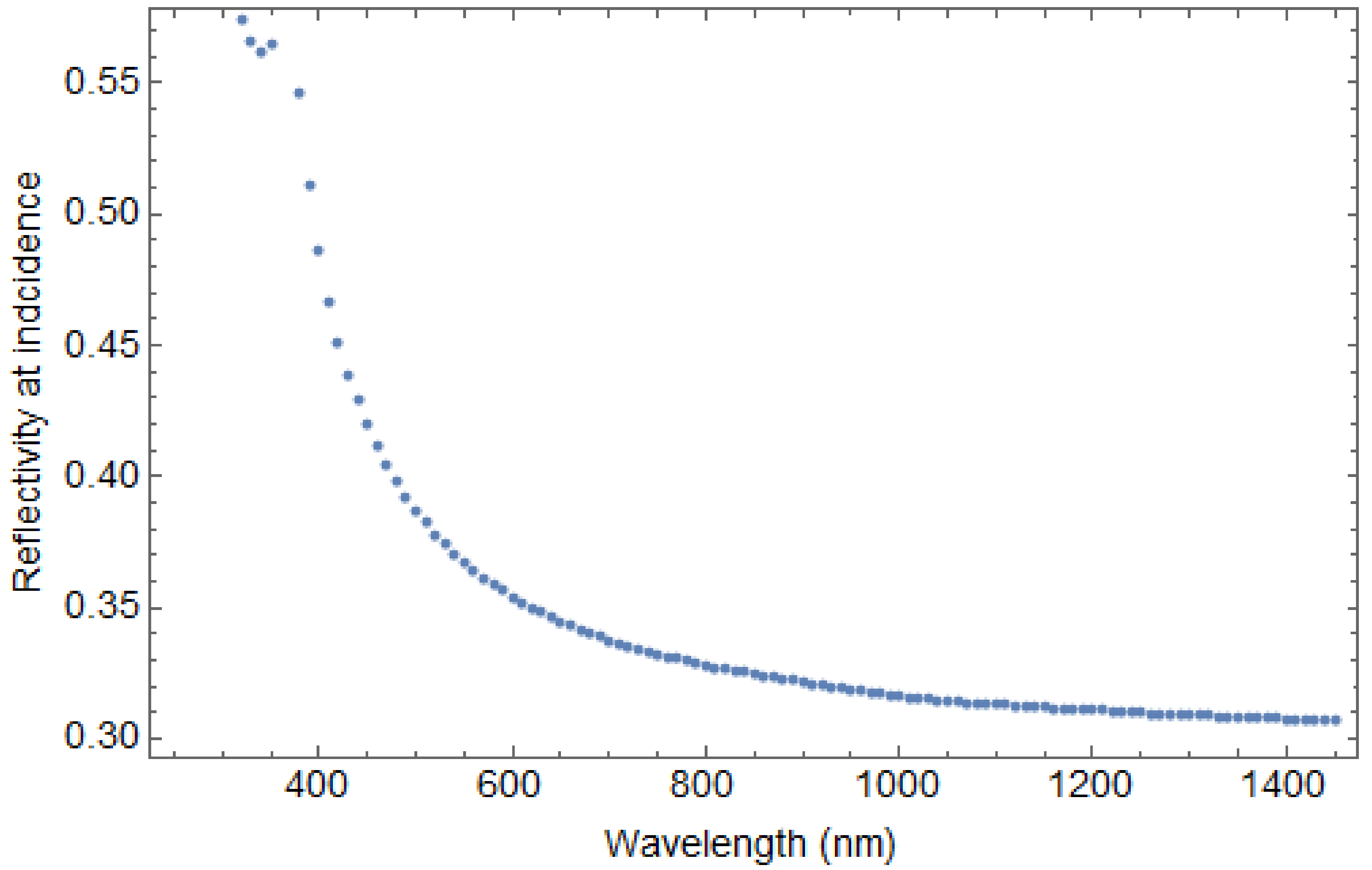


Backup: Laser Properties

FBG stabilized laser diode @ 683 nm

- Max output: 2 mW
- FWHM (max): 1 nm
- Minimum spot size: 6.7 µm
- Focal length: ~12 mm
- Absorption depth: <15 µm





Green, M.A. and Keevers, M. "Optical properties of intrinsic silicon at 300 K ", Progress in Photovoltaics, p.189-92, vol.3, no.3; (1995)

Backup: Timing information

Number of combinations to search for next pixel on tracks is decreased by looking at time information besides spatial information