Timepix3 Telescope Timing

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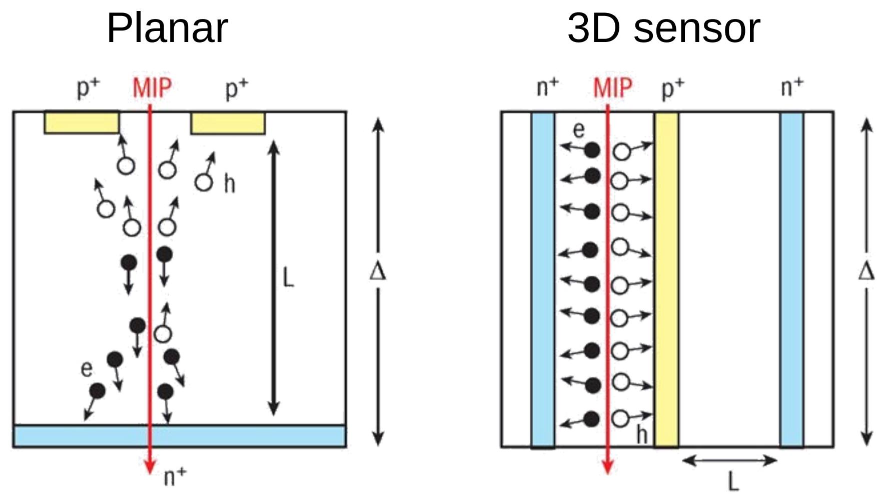
Detector R&D Group Meeting
2019-03-13

Fast timing

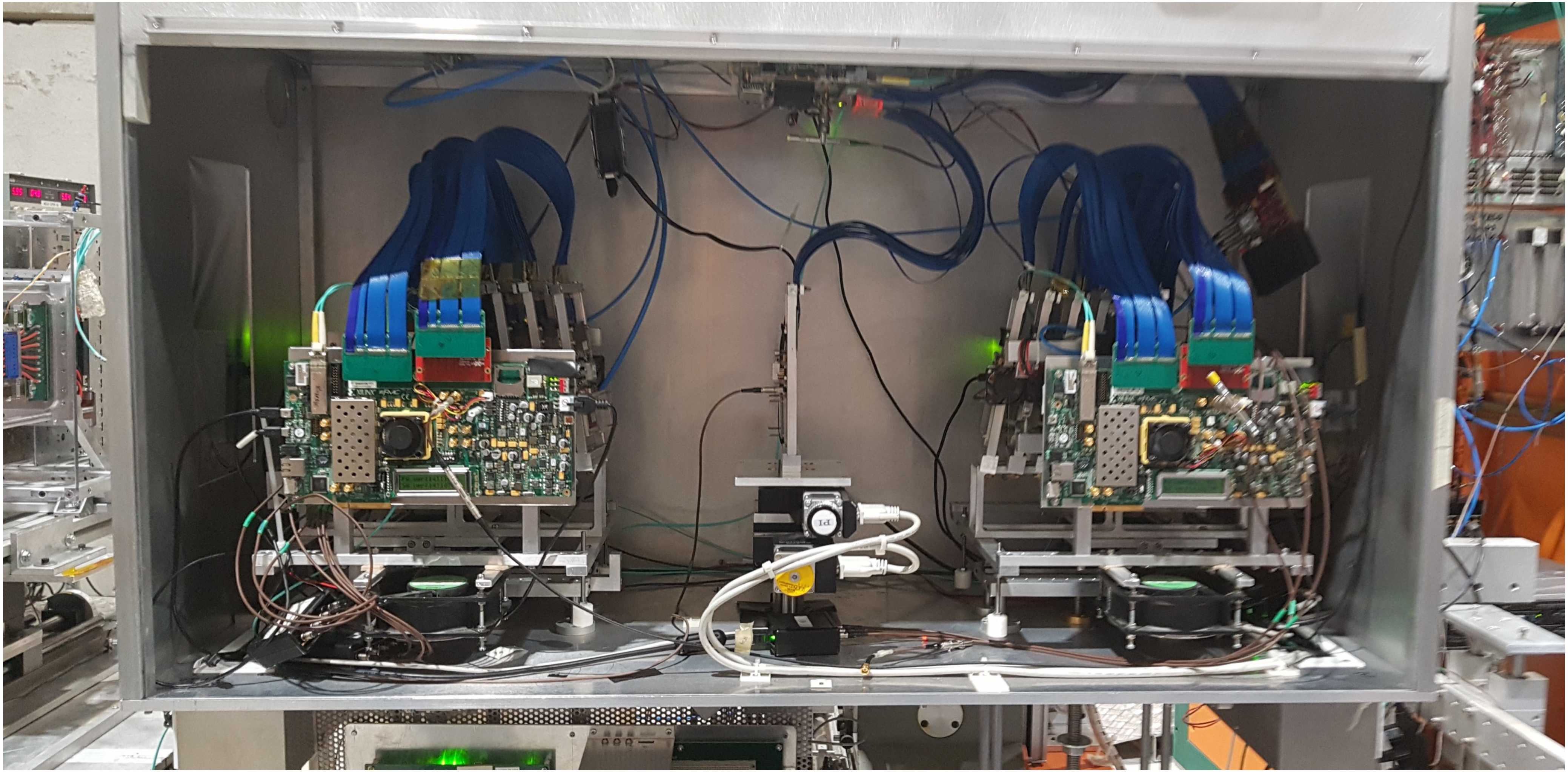
- Studying high time-resolution silicon pixel-detectors in view of future vertex detectors
  - 3D, thin planar, possibly also LGADs

- **High time-resolution can help to mitigate pile-up** by using time information in addition to spatial information.

- Testbeam measurements, TCAD simulations



The Timepix3 telescope



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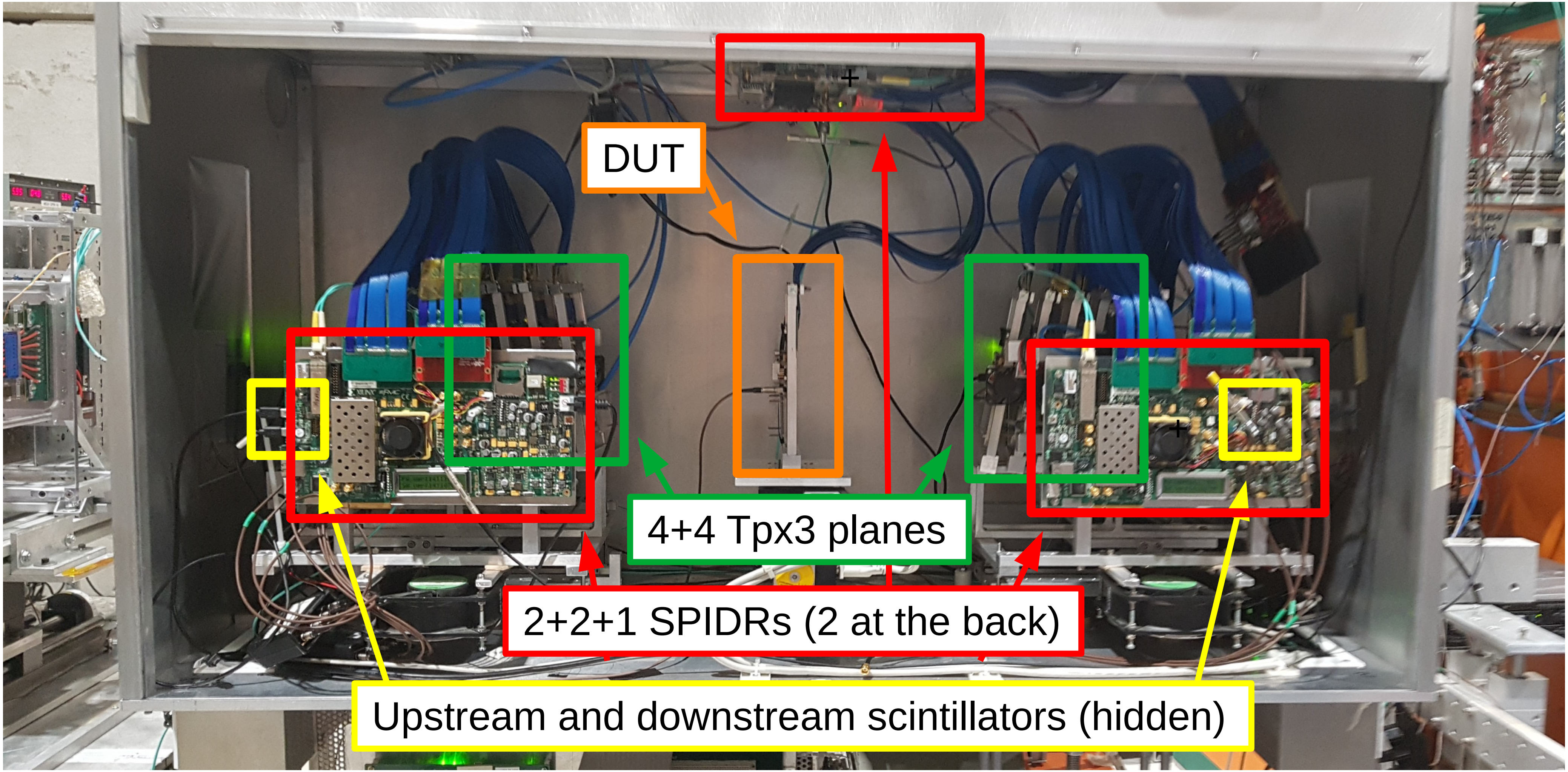
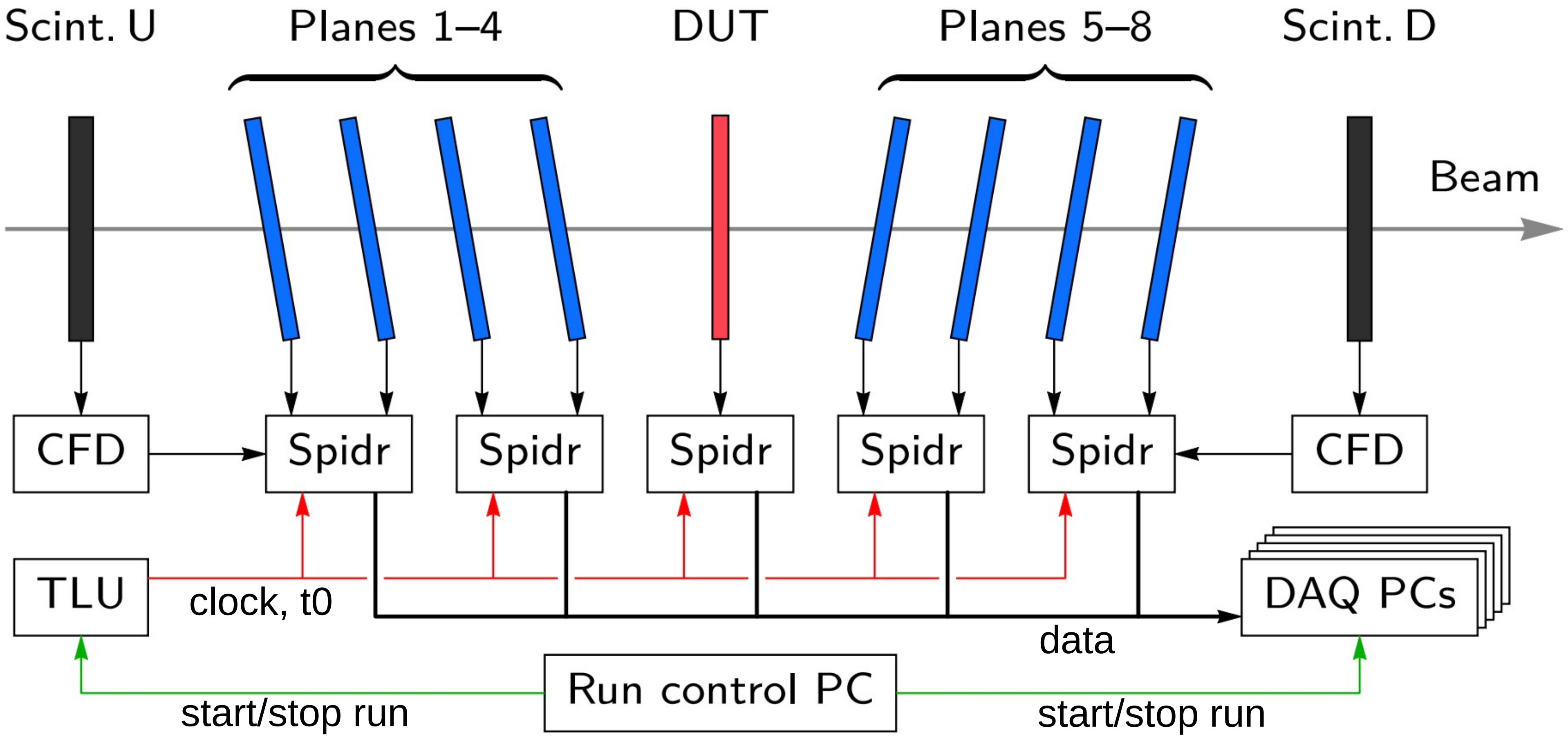


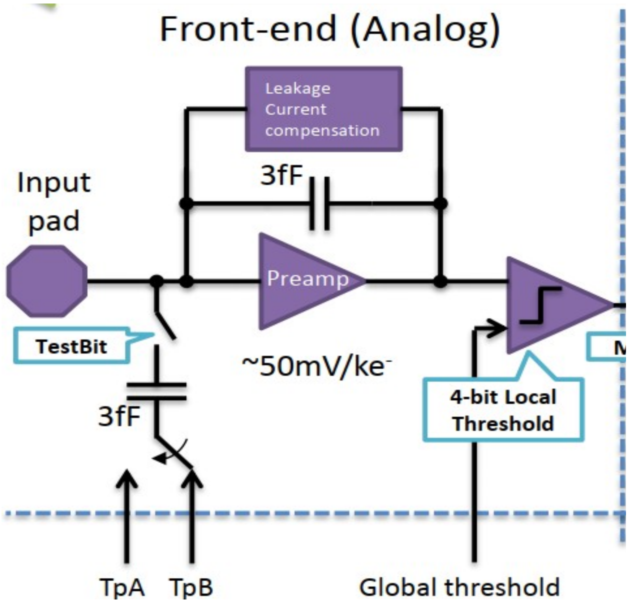
The Timepix3 telescope

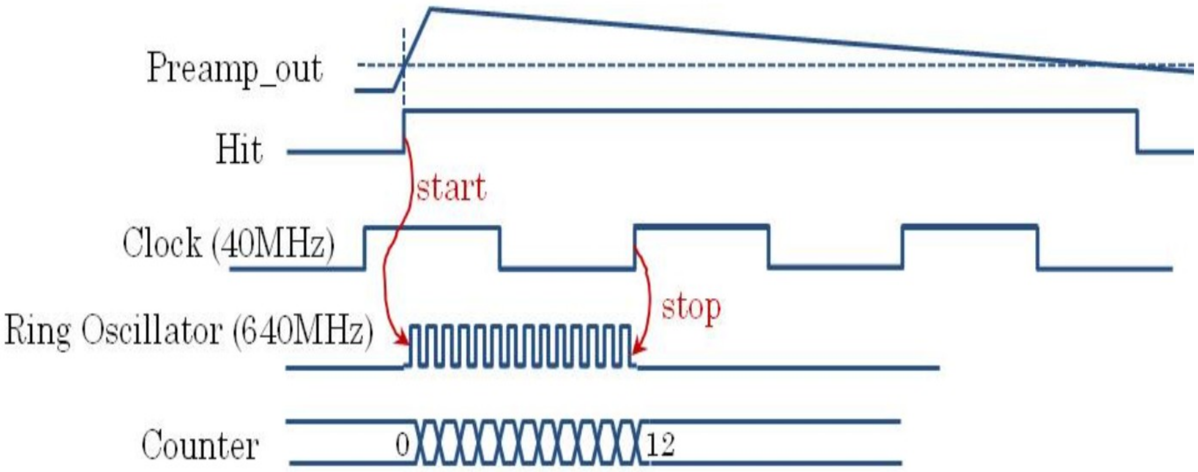


Timepix3 planes

- 300 μm p-on-n silicon sensors (Biased at 200 V)
- 256×256 pixels of 55×55 μm
- Simultaneous measurement of time and charge deposition for each event

- **Time measurement:**
  Bin size of 25 ns / 16 ≈ **1.56 ns**
- **Charge measurement:**
  Count the time-over-threshold (ToT)
  Bin size of 25 ns

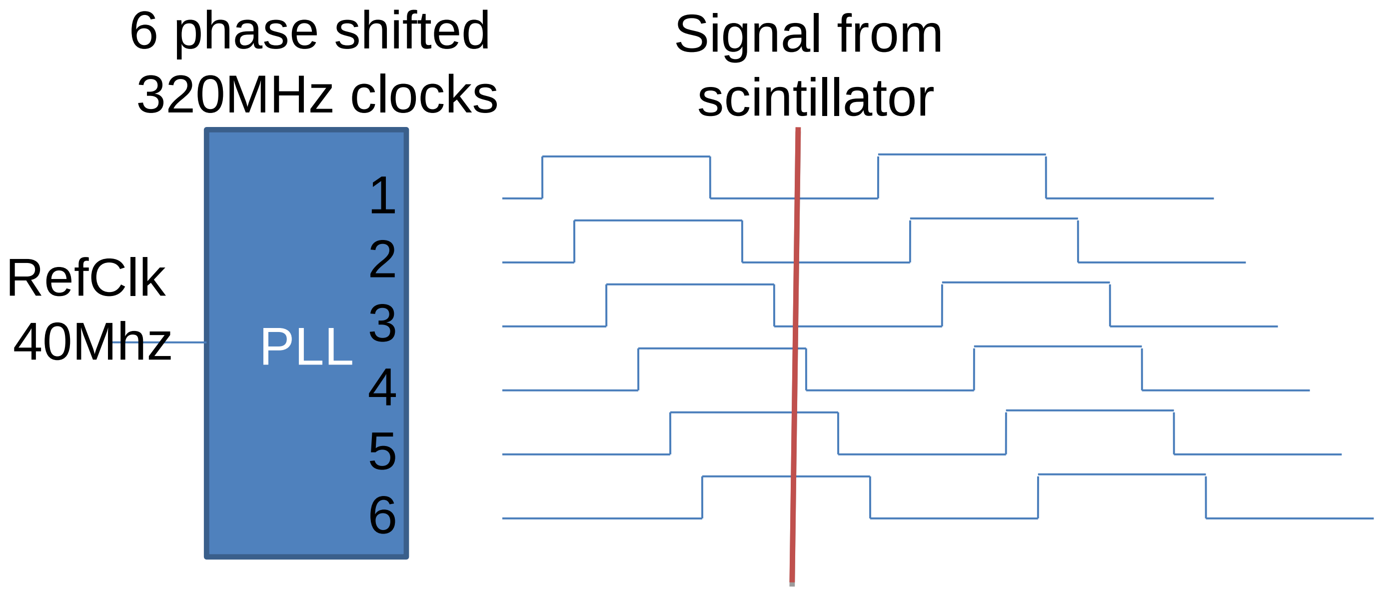




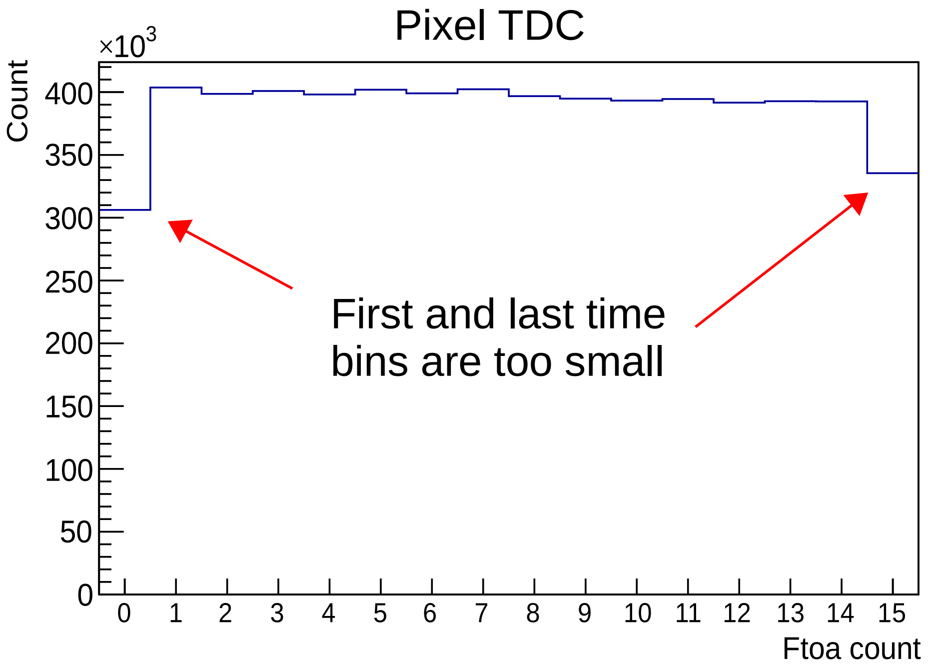
Up- and downstream scintillators

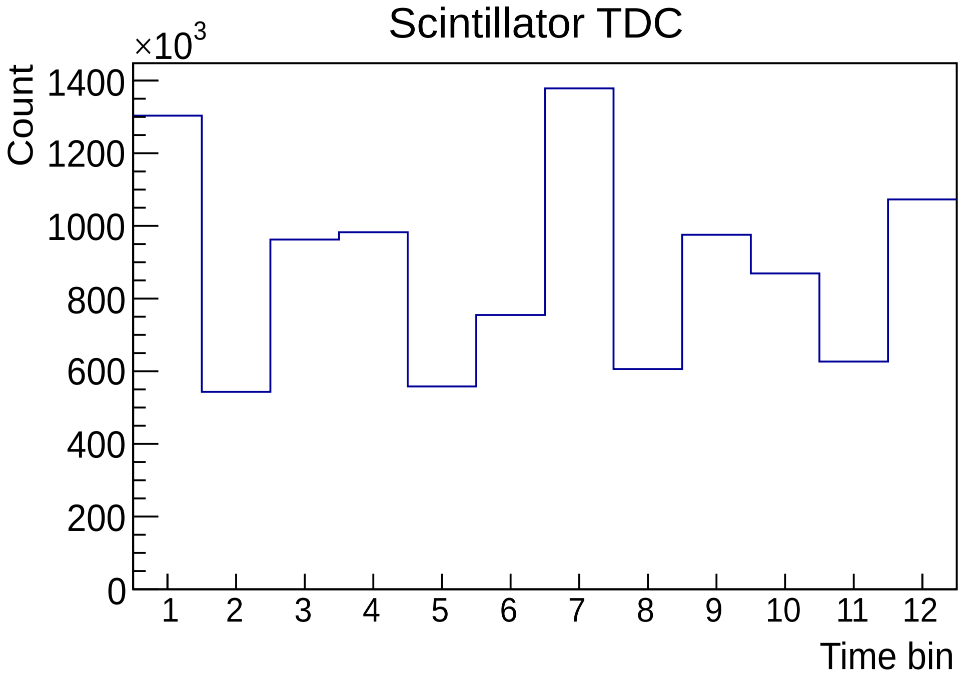
- 1.5×1.5 cm^2 scintillators
- TDC on SPIDR provides the timestamp
- 6 phase shifted clocks provide 12 time bins of 25 ns / 96 = **260 ps**

- **Scintillator resolution:**
  Upstream: ~390 ps
  Downstream: ~190 ps
- Upstream CFD not properly tuned



Nonuniformity of fine time-bins

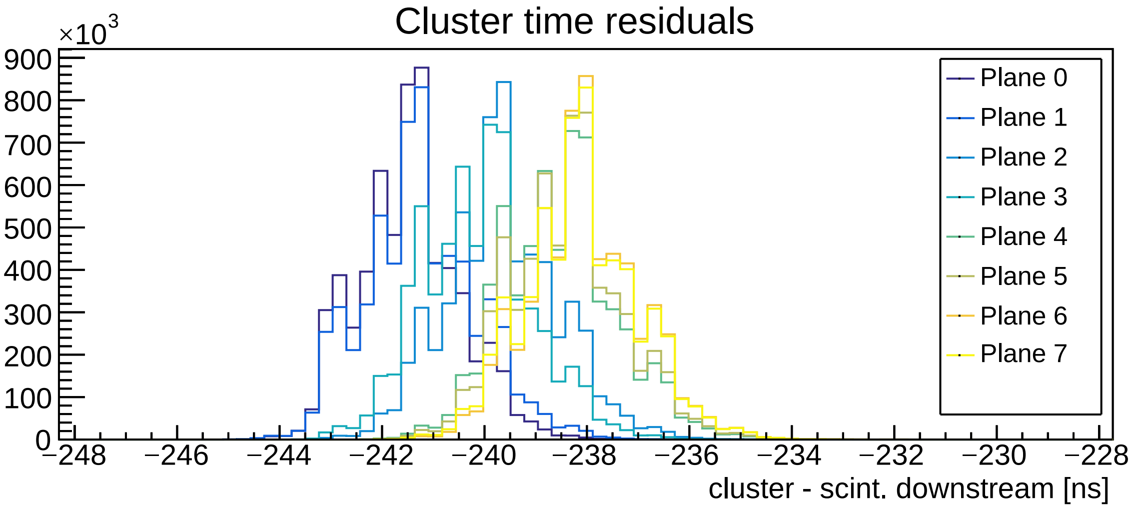


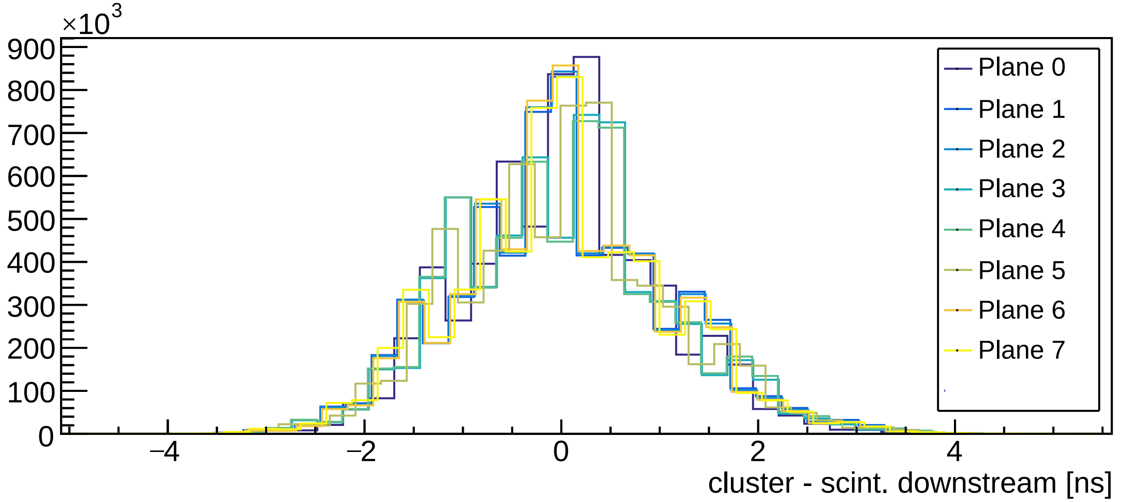


- Time bins have different sizes
- Degrades the time resolution

Track time

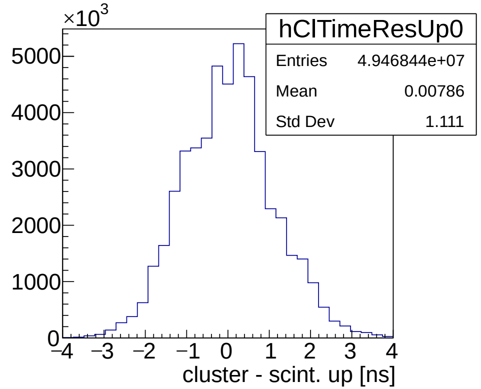
- Each track has **8 clusters**. One on each telescope plane. (We require this.)
- Earliest hit in a cluster defines the **cluster time**
- Track time is mean of cluster times
- First calibrate out all plane offsets. *Doesn't affect time resolution*, but makes the analysis easier.

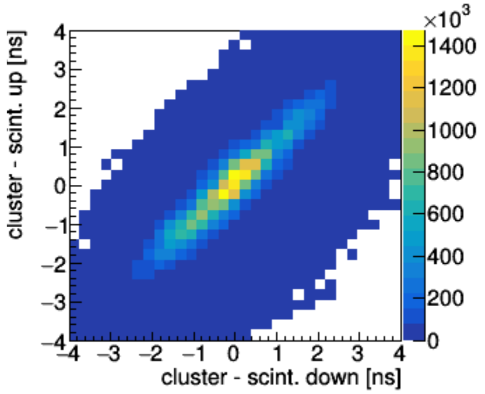




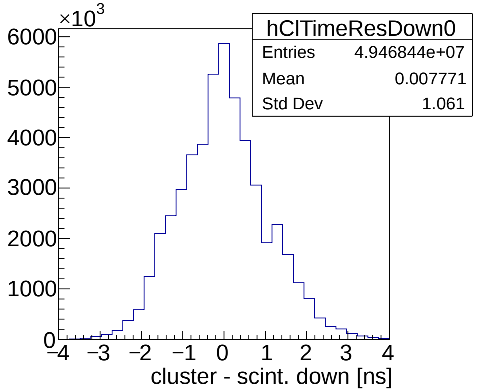
Time resolution

Clusters

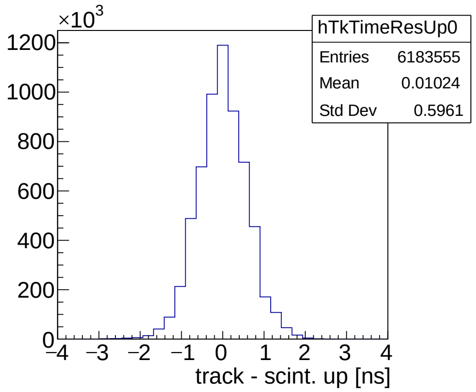


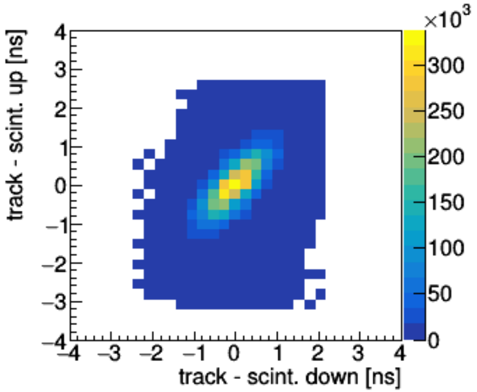


$$\sigma_t(plane) \approx 1\,\mathrm{ns}$$



Tracks

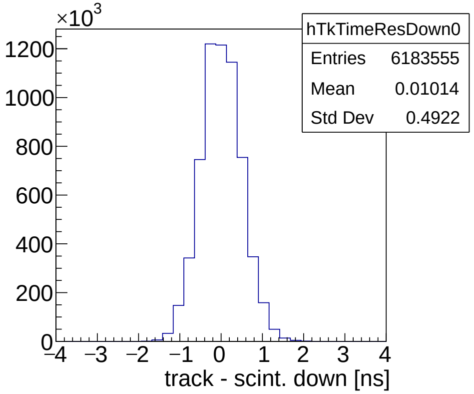




$$\sigma_t(track) \approx 450\,\mathrm{ps}$$

- Would naively expect:

$$\frac{1\,\mathrm{ns}}{\sqrt{8}} \approx 350\,\mathrm{ps}$$



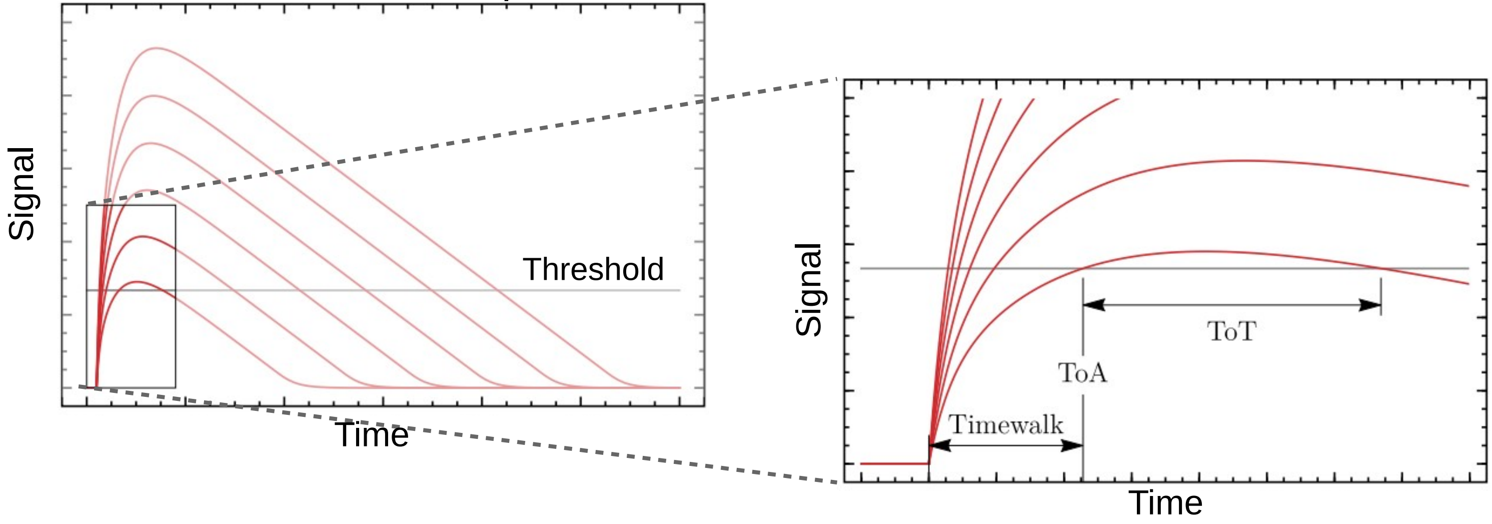
$$\sigma_t(T) = \sqrt{\mathrm{cov}(T - scint.up., T - scint.down.)}$$

Systematics in time measurements

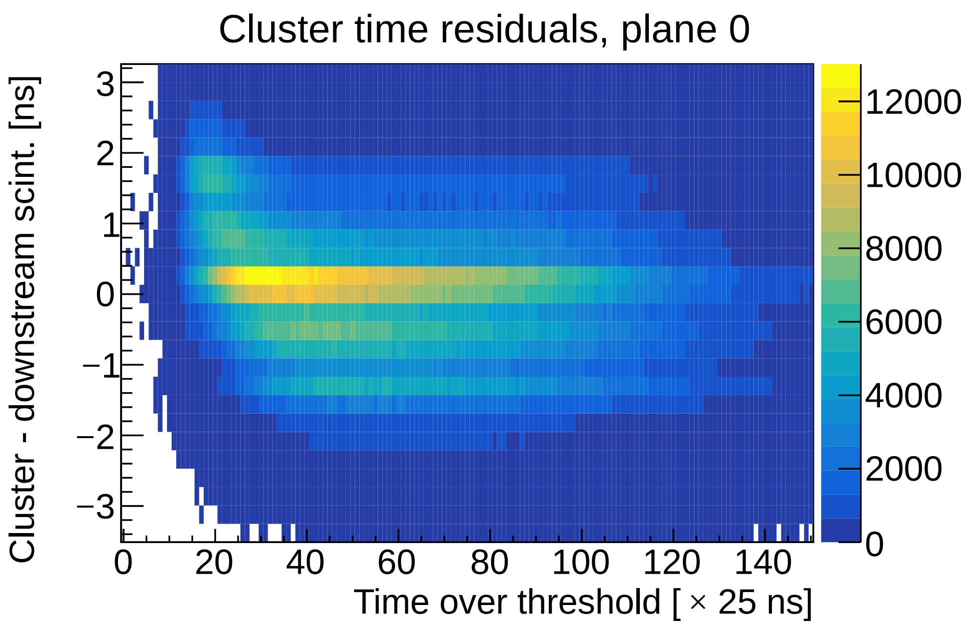
We want to correct (and understand) systematic errors in the time measurement. For example:

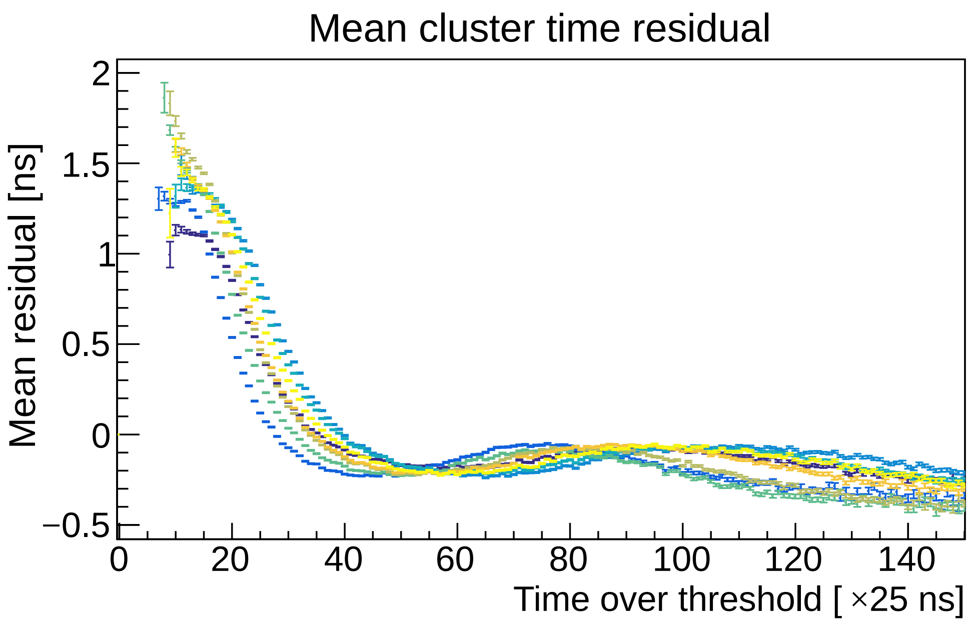
- **Timewalk:** Time measurement depends on the amount of deposited charge in an event.
- **Pixel matrix systematics:** Time measurement depends on clock delay along the columns and is affected by the power distribution

Timewalk example



Timewalk correction

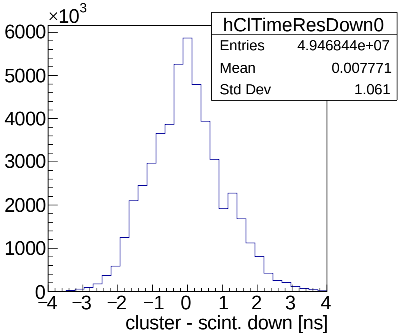


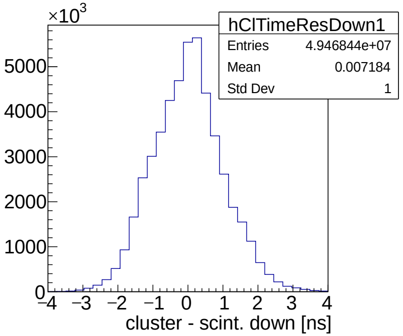


- Looks different from most timewalk distributions because we are using cluster times (= first hit)
- Calculate correction for each plane separately
- Improves the resolution slightly

$\sigma_t(track) \approx$ 450 ps ➔ 440 ps

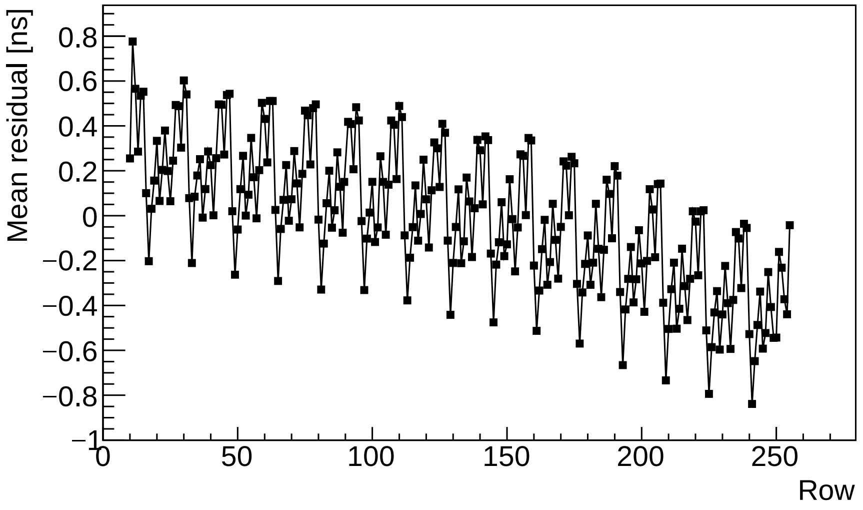
Cluster time residuals



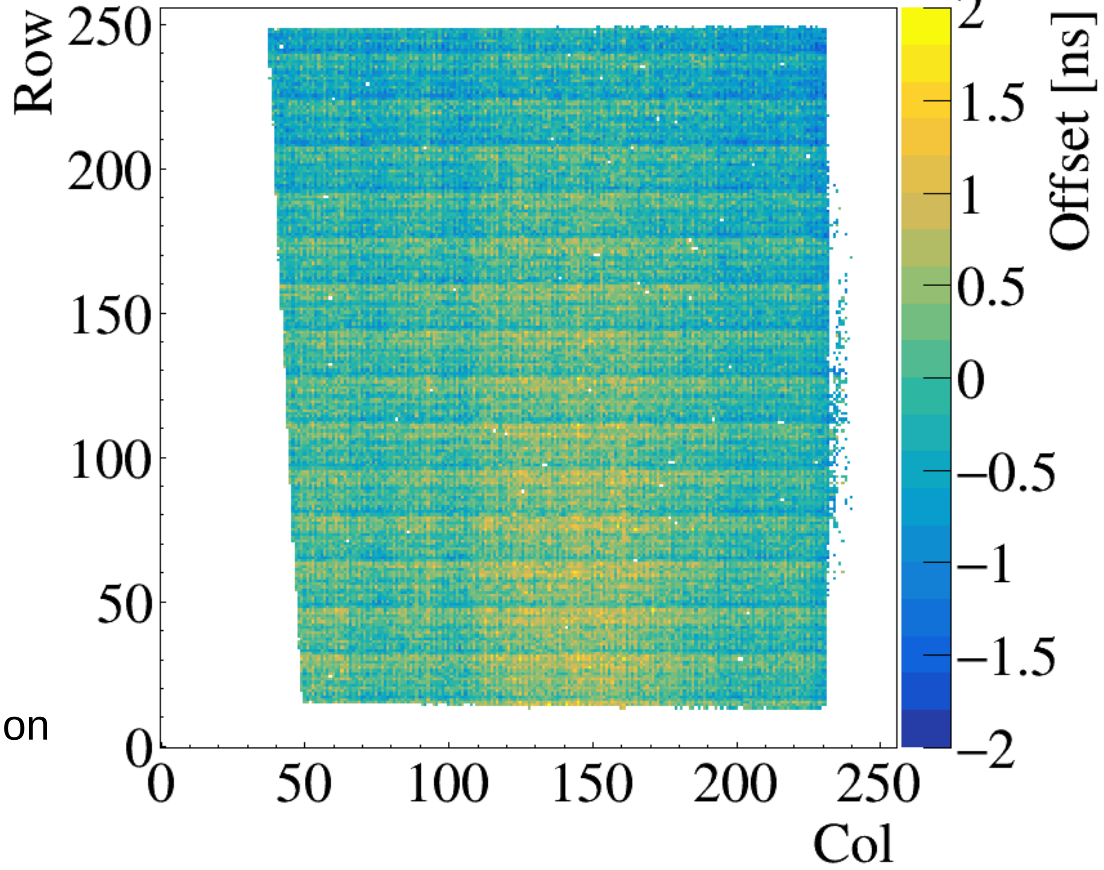


Pixel matrix systematics

Mean residual per row, plane 0

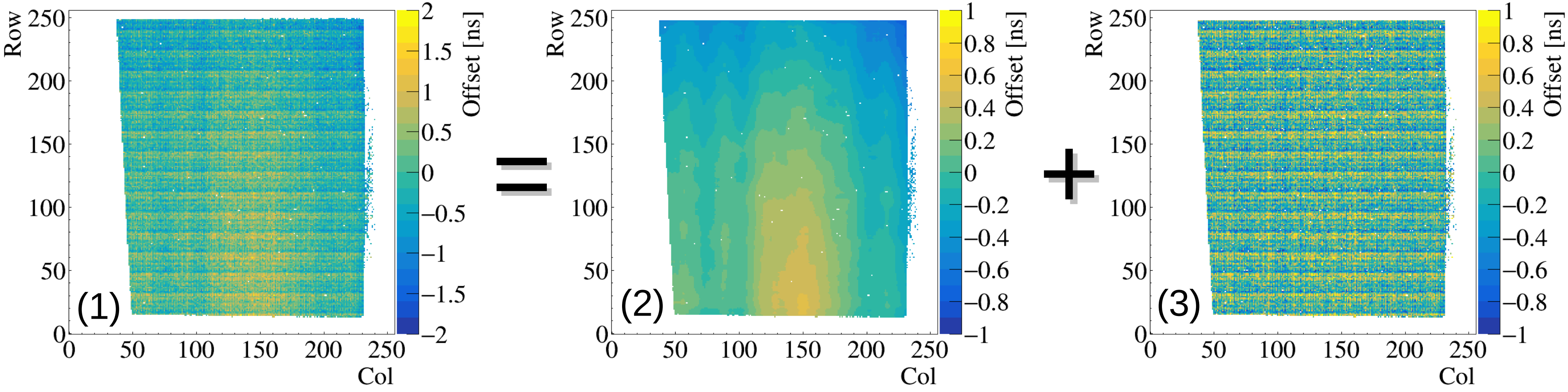


Mean residual per pixel, plane 0



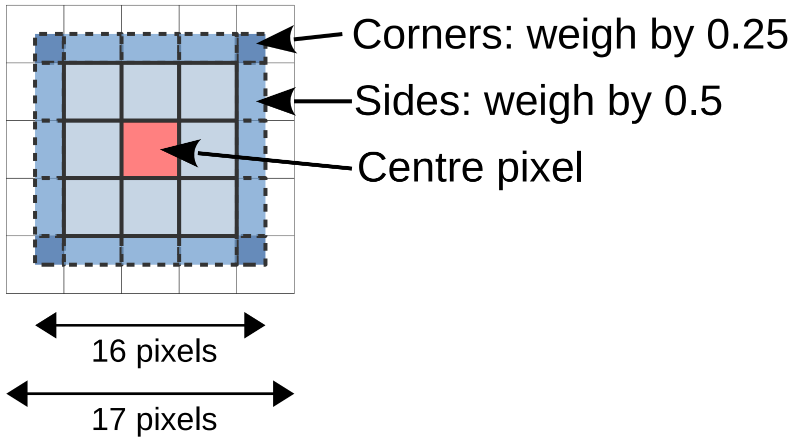
- Regular pattern on top of gradual variation visible
- From clock propagation and power distribution

Pixel matrix systematics separation

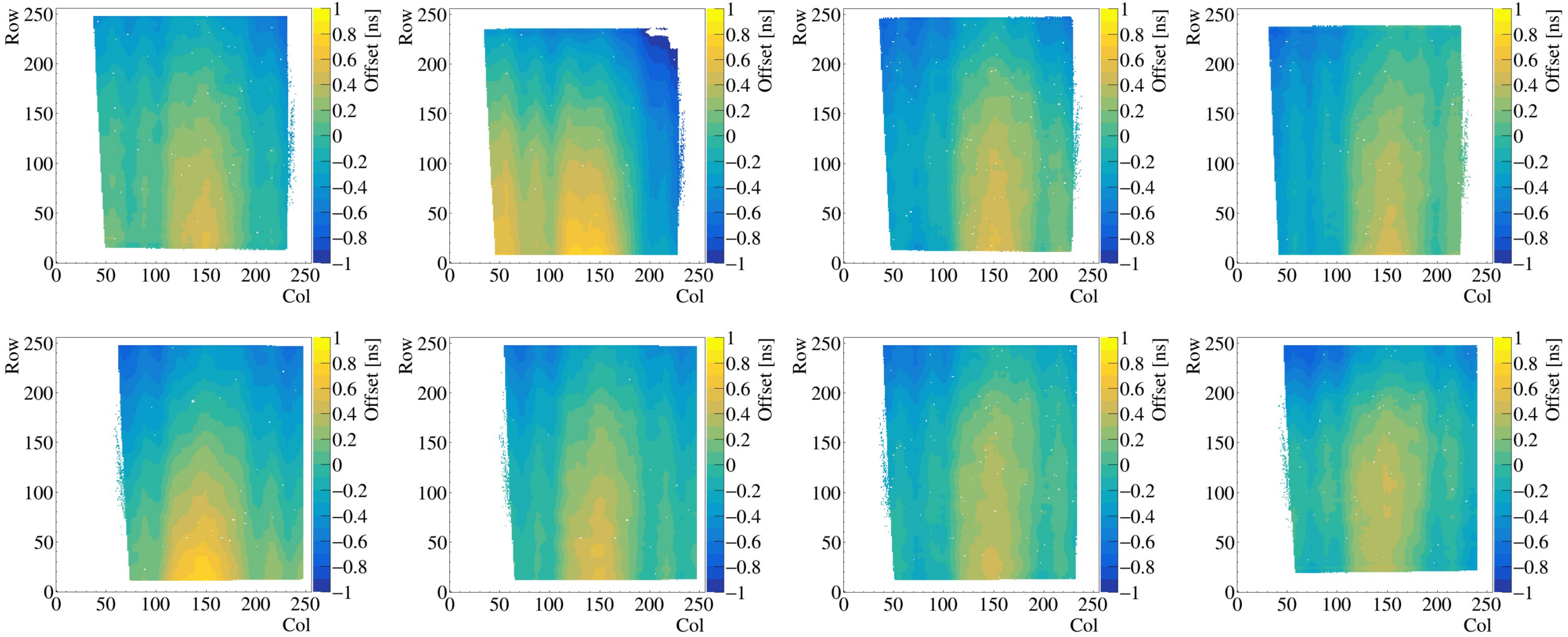


Quick method to separate offsets from power- and clock distributions:

- Calculate mean of 16×16 pixels to get (2)
- Subtract (2) from (1) to get (3)

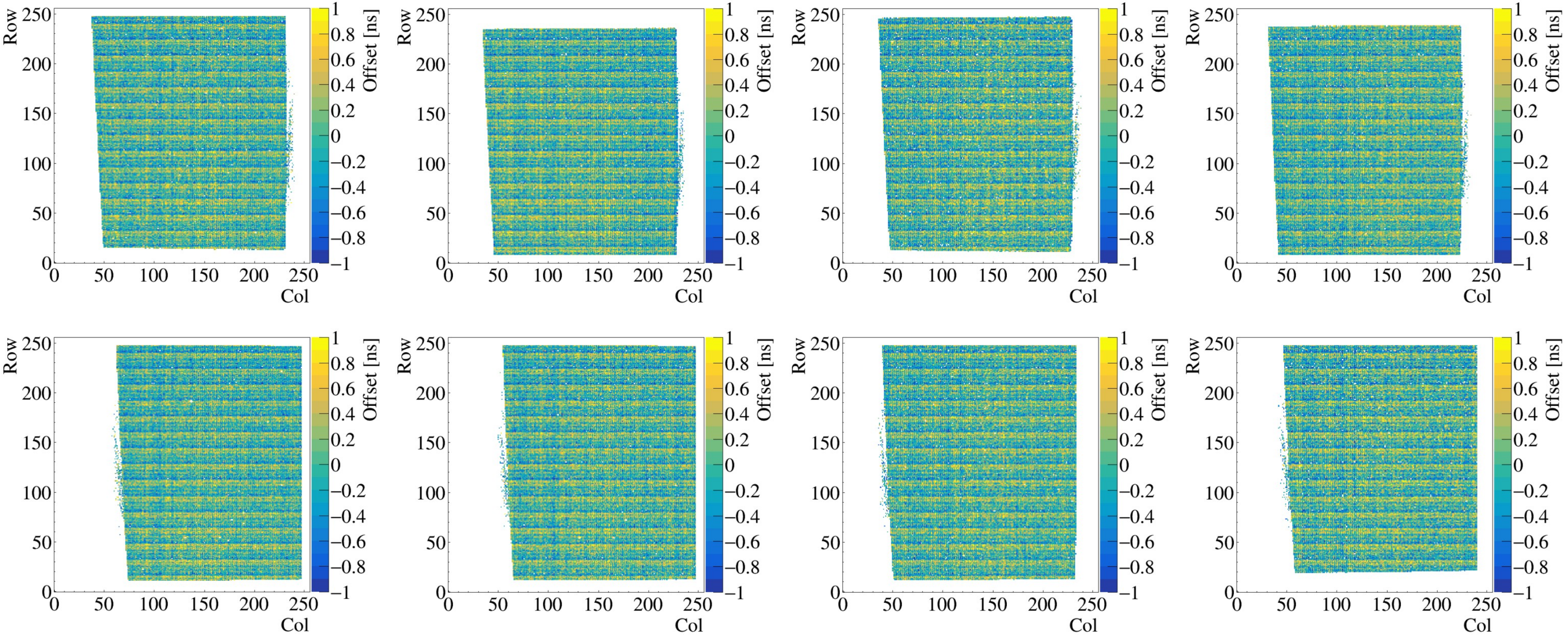


Global pixel time-offsets



- The gradual variation over the pixel matrix doesn’t look the same for all chips
- From power distribution

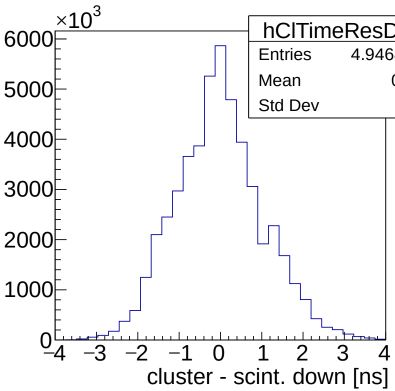
Pixel time-offset pattern

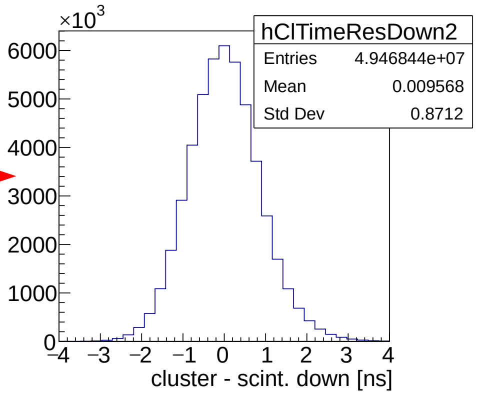


- From clock distribution and other efffects

Time resolution after corrections

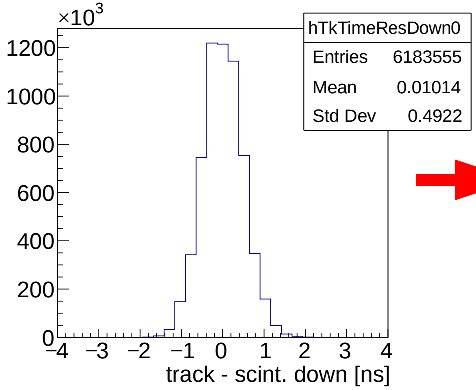
Clusters residuals

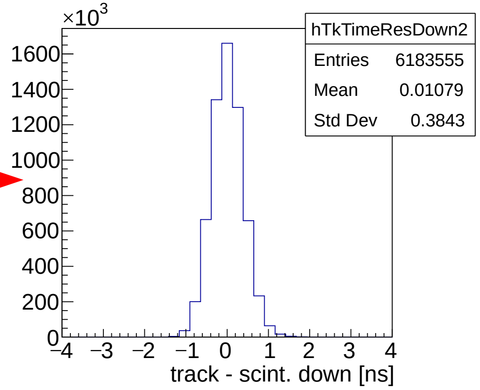




$$\sigma_t(plane) \approx 1\,\text{ns} \rightarrow 850\,\text{ps}$$

Track residuals





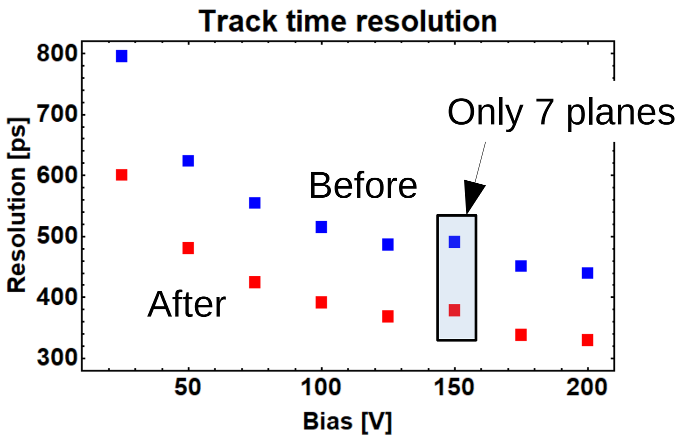
$$\sigma_t(track) \approx 450\,\text{ps} \rightarrow 330\,\text{ps}$$

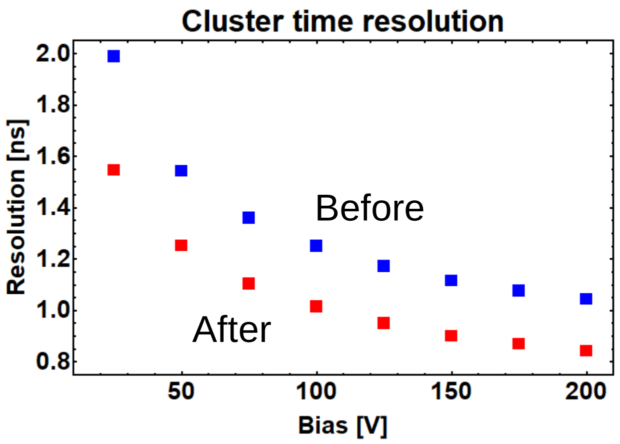
- Dominated by sensor/jitter:

$$850\,\text{ps} \ominus 450\,\text{ps} = 721\,\text{ps}$$

$$\updownarrow$$

$$\frac{1.56\,\text{ns}}{\sqrt{12}}$$

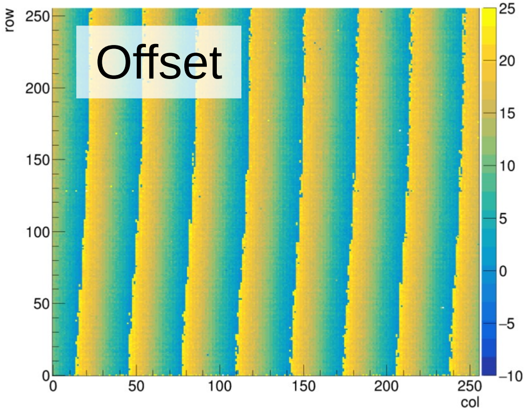


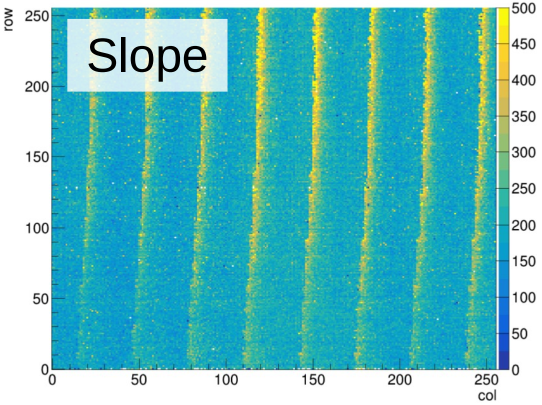


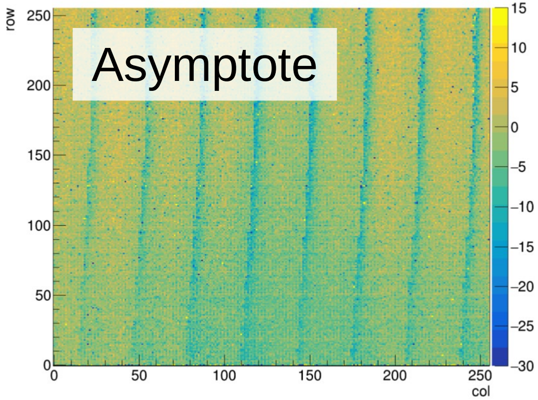
Other work going on

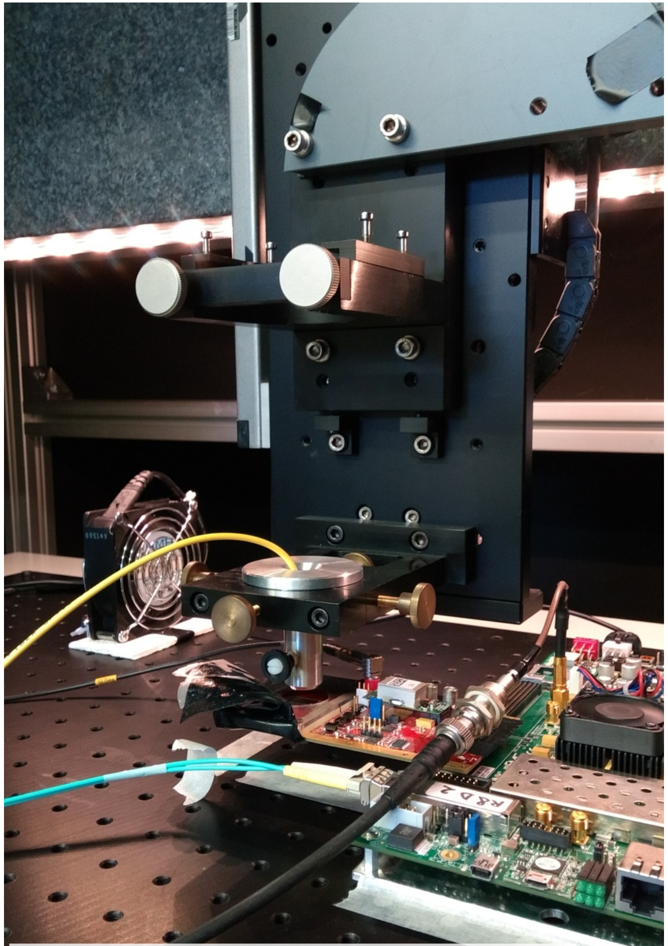
- Robbert Geertsema (master student) is working on per-pixel timewalk measurements using test pulses and **improving our laser setup** to cross check pixel matrix systematics

$$Timewalk = \frac{slope}{ToT - asymptote} + offset$$



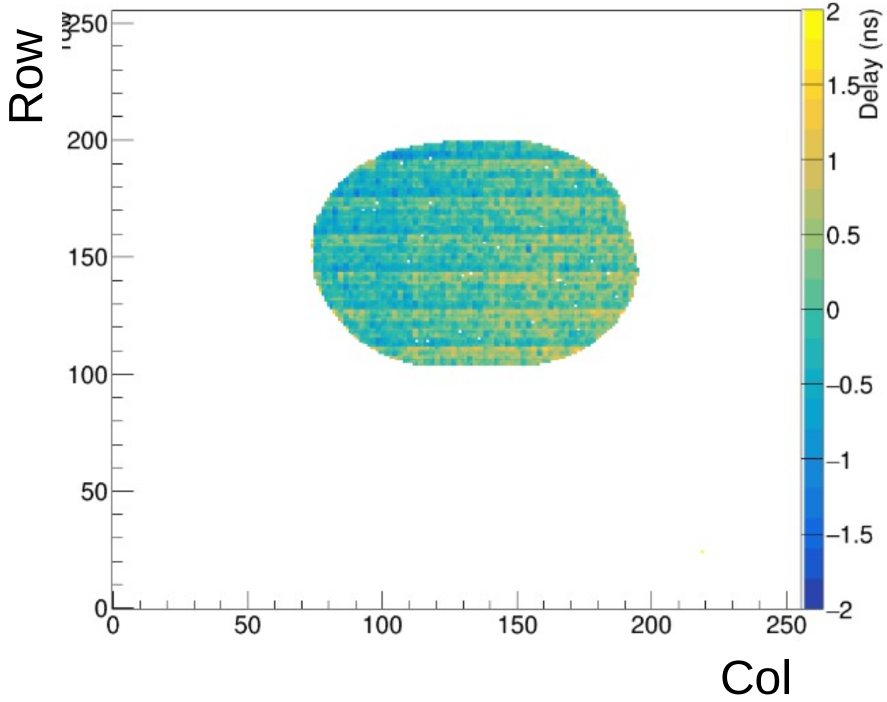


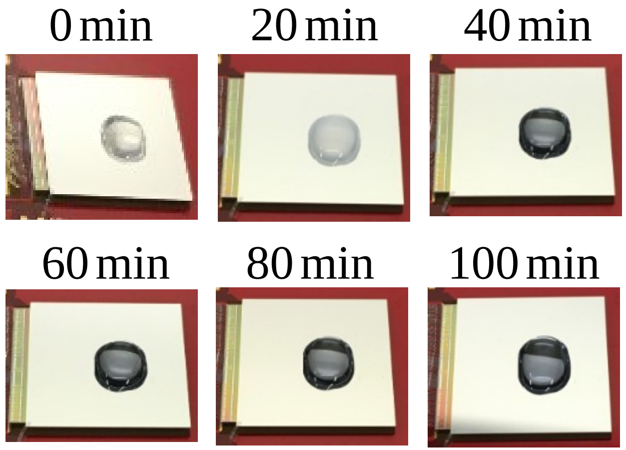


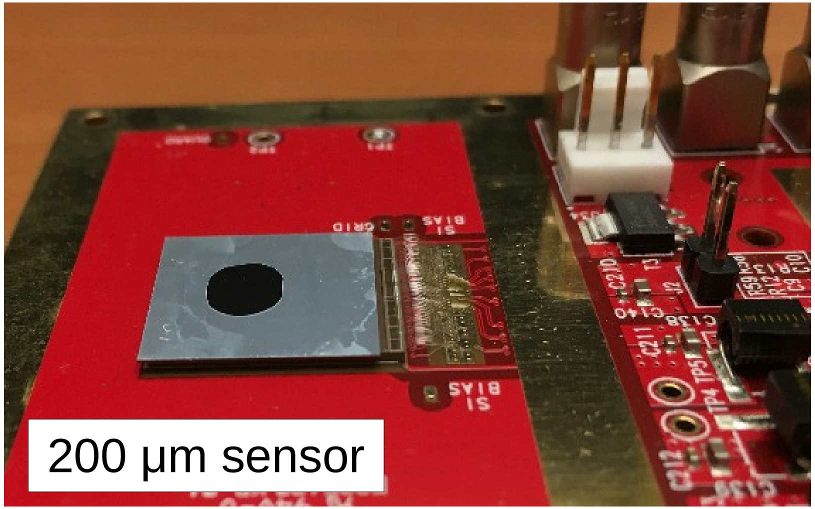

Sensor in the laser setup

Etching DUT's for laser measurements

- We are investigating if we can etch away sensor metallisation for laser measurements to **cross-check DUT testbeam-measurements**
- First attempt successful 👍



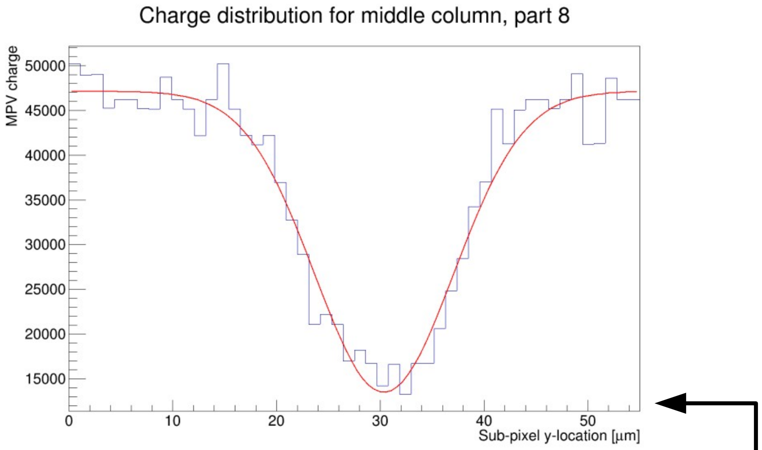


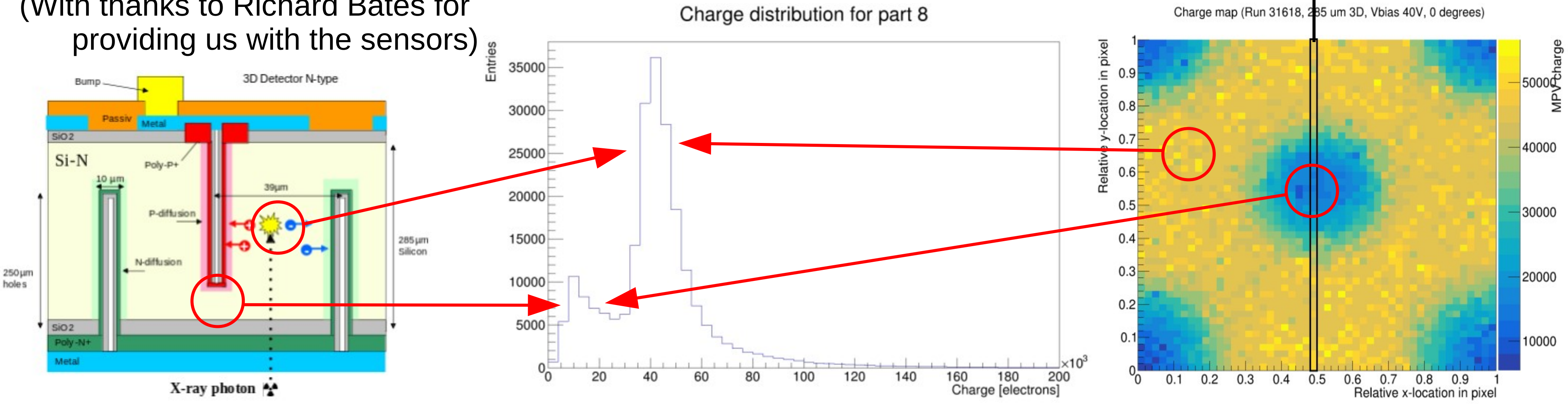


3D sensor testbeam data

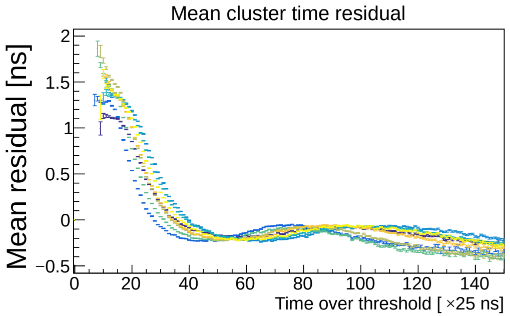
- Peter Bosch (master student) is analysing testbeam data of a 3D silicon sensor and currently investigating charge deposition.
- Goal is to look at **timing performance** of the 3D sensor
- Currently working on some alignment problems

(With thanks to Richard Bates for providing us with the sensors)



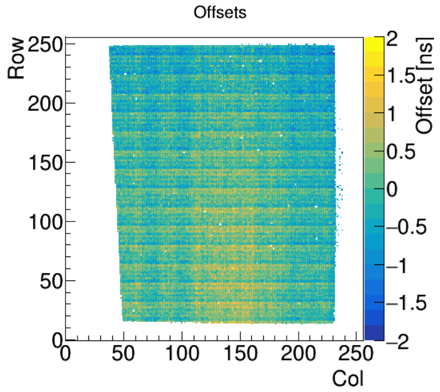


Conclusion and outlook



- We showed that we can improve the time resolution by correcting timewalk and pixel matrix systematics

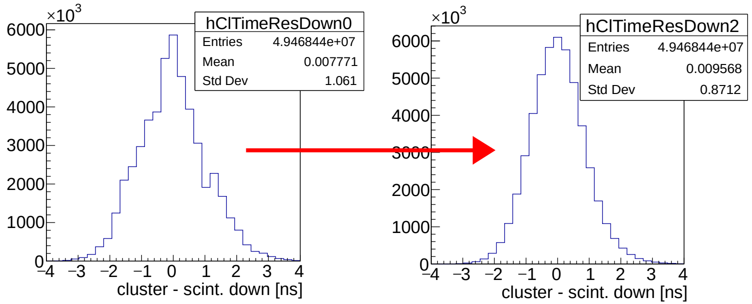
$$\sigma_{\mathrm{t}}(track) \approx 450\,\mathrm{ps} \quad \rightarrow \quad \sigma_{\mathrm{t}}(track) \approx 330\,\mathrm{ps}$$



- Understanding the systematics will become more important for next generation devices

What is next?

- Working on TCAD simulations of DUT's (3D, thin planar)
- Cross check the matrix variations using the laser as an independent measurement
- Investigate timing performance of 3D sensor
- Getting ready for Timepix4



Pixel time-offsets