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First tracks and initial timing results with Timepix4 ASIC from beamtests

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on behalf of the Timepix4 Telescope group

LHCb

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Timepix4 Telescope

- After success of the Timepix3 based **beam telescope**, decided for an **upgrade** using Timepix4
- Main improvement (and challenge) is a **better track time resolution**
  - Timepix3 telescope achieved 236 ps after long and careful tuning
- Timepix4 based beam telescope will be used for characterization of novel sensors (in view of LHC upgrade programmes)

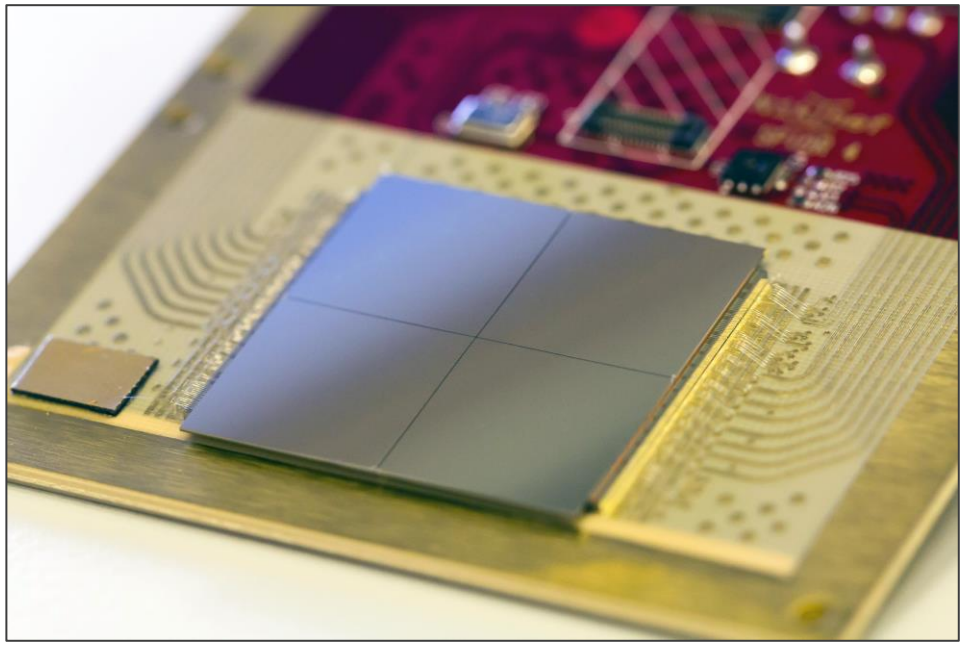
- A 4-layer Timepix4 based telescope was constructed for a testbeam period last October
- This telescope was a **good dress rehearsal** for testbeams this year, and the main aim was to see first tracks in Timepix4 (**not a complete telescope!**)

Tpx3 telescope:
K. Akiba *et al* 2019 *JINST* **14** P05026

Timepix4 ASIC

- 65 nm technology
- Simultaneous Time-over-threshold and Time-of-Arrival measurement

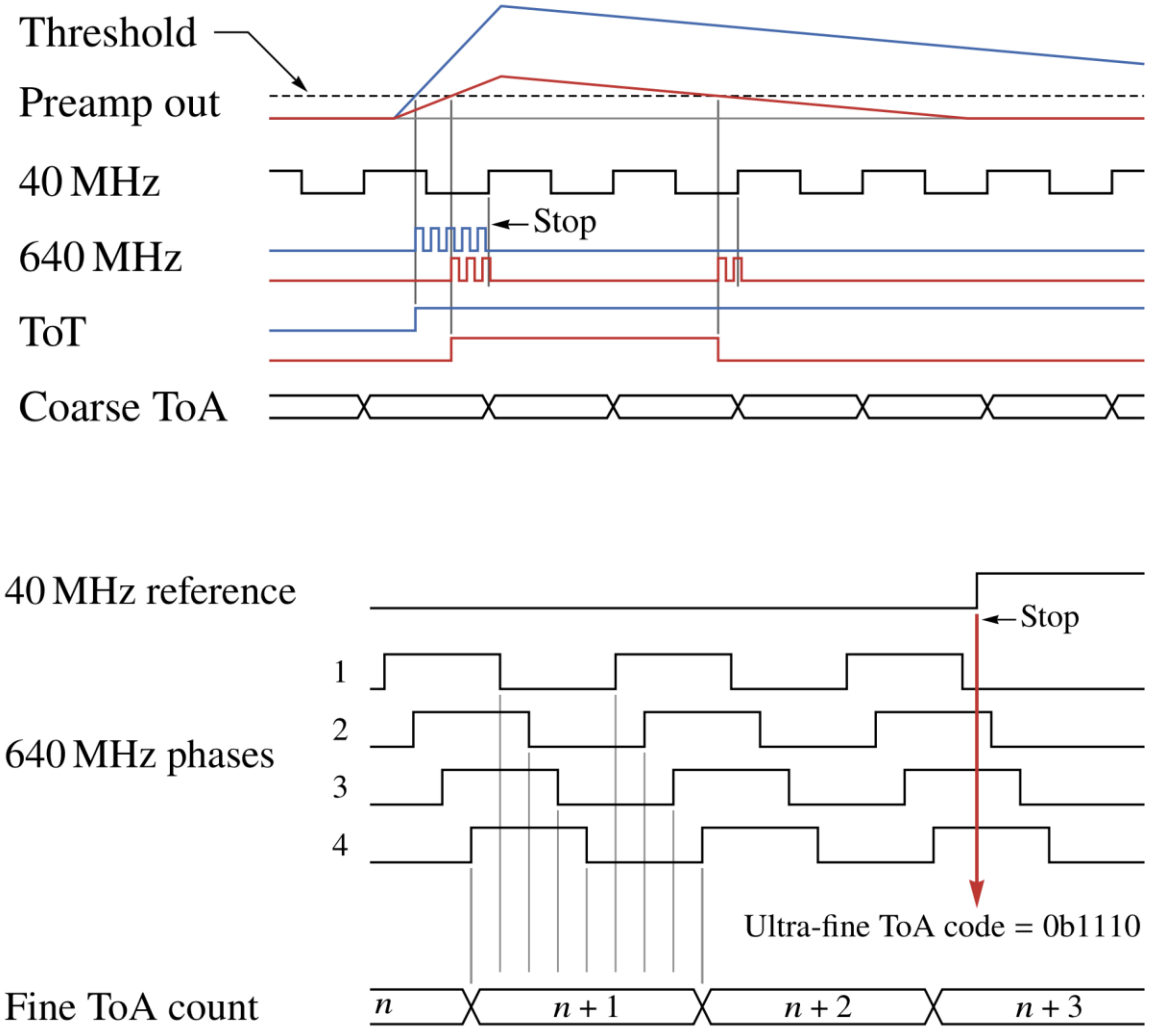
- Pixel size: 55 µm x 55 µm
- Matrix: 512 x 448 pixels
- TDC bins: 195 ps
- Target minimum thl: < 500 e^-
  - For this testbeam 1000 e^- was used



X. Llopart *et al* 2022 *JINST* **17** C01044

Temporal measurement

- Base clock of **40 MHz**
- **Hit starts 640 MHz ring oscillator**
  - 1.56 ns bins
  - Count # clock cycles (like in Tpx3)
  - Oscillator shared by 8 pixels in superpixel
- Oscillator is stopped by first rising edge of 40 MHz clock
- In addition the internal state of ring oscillator is captured → **195 ps bins**

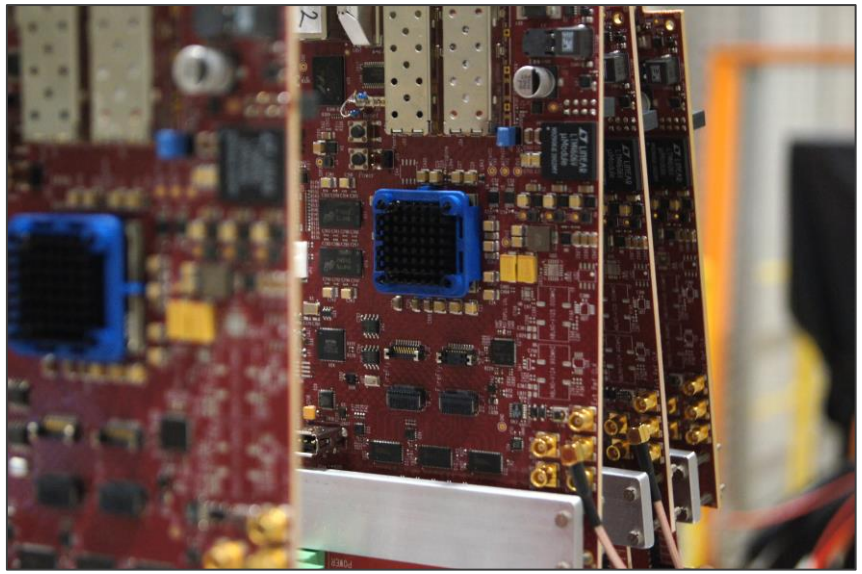


Limitations Timepix4v1 and readout

- Due to a **problem** with the **VCO**, the frequency is too high
  - Leads to **stability problems** in the chip
  - After fine-tuning operation is possible, be it that parameter variations over the chip remain
  - Issue has been fixed in **Timepix4v2**, tests without sensor currently ongoing

- Due to **global chip shortage**, only 10 readout boards (SPIDR4) exist…
  - Limits the current testbeam activities to just 4 planes

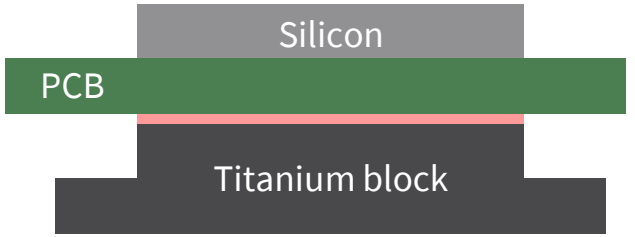
~1/2 of the world's supply of SPIDR4



Preparation for testbeam

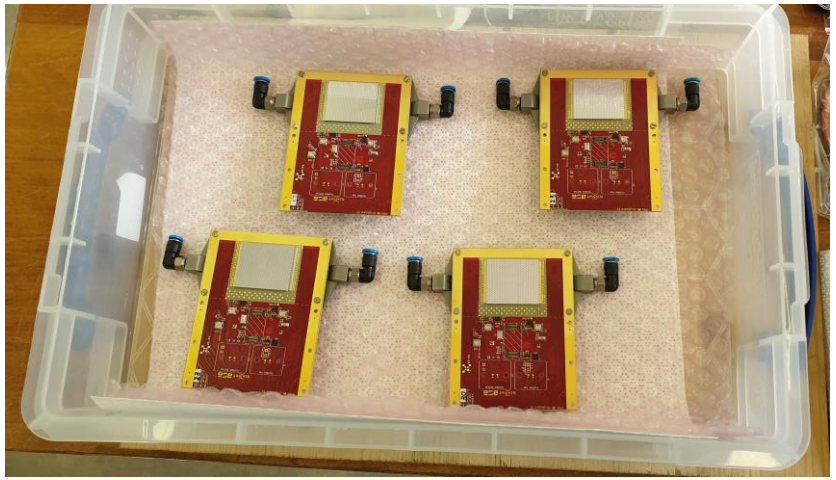
- 4 sensors: 2 x 100 µm (**timing**) and 2 x 300 µm (**spatial**)
  - All sensors are n-on-p (e^- collecting)
- All chips attached to 3D printed **titanium cooling block**
  - Envisioned to directly connected to chip
  - Due to uneven PCB, **thermal conductive pad** needed to be used
  - **Glycol** used to cool chips to room temperature (envisioned to go colder in the final telescope)

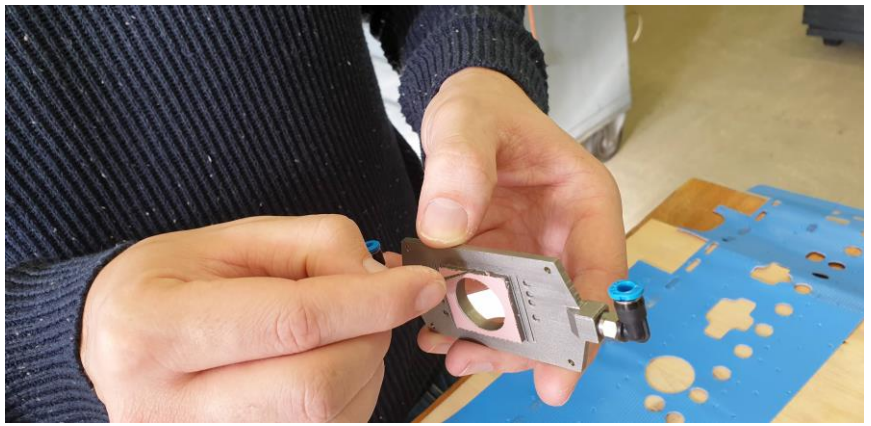
Current cooling:



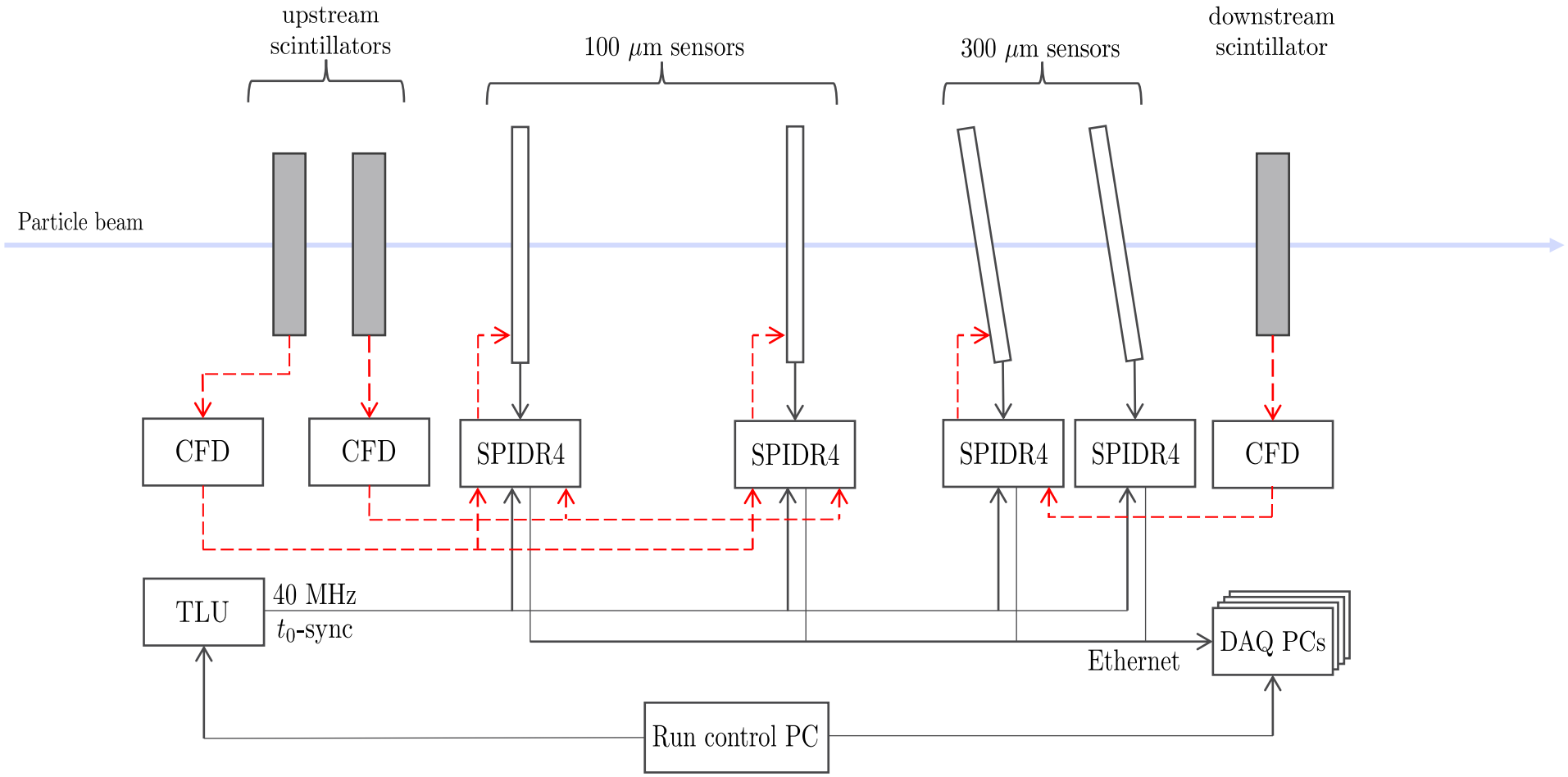
Envisioned cooling:

Four sensors ready for mounting

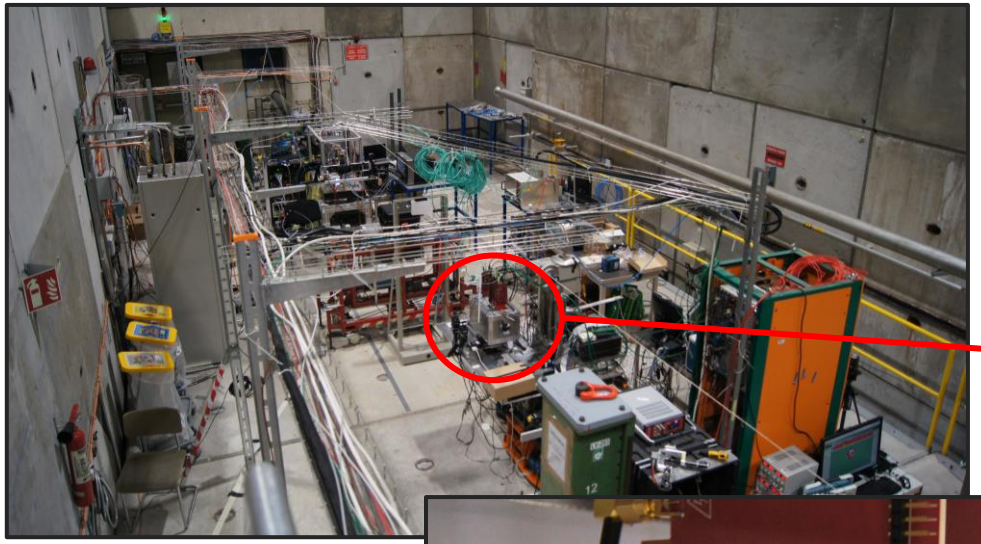


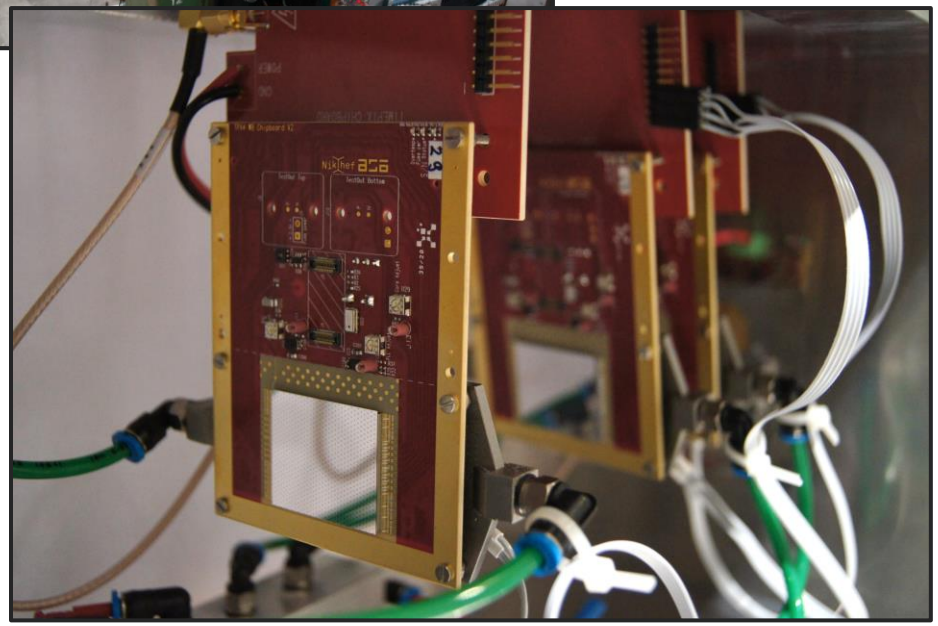


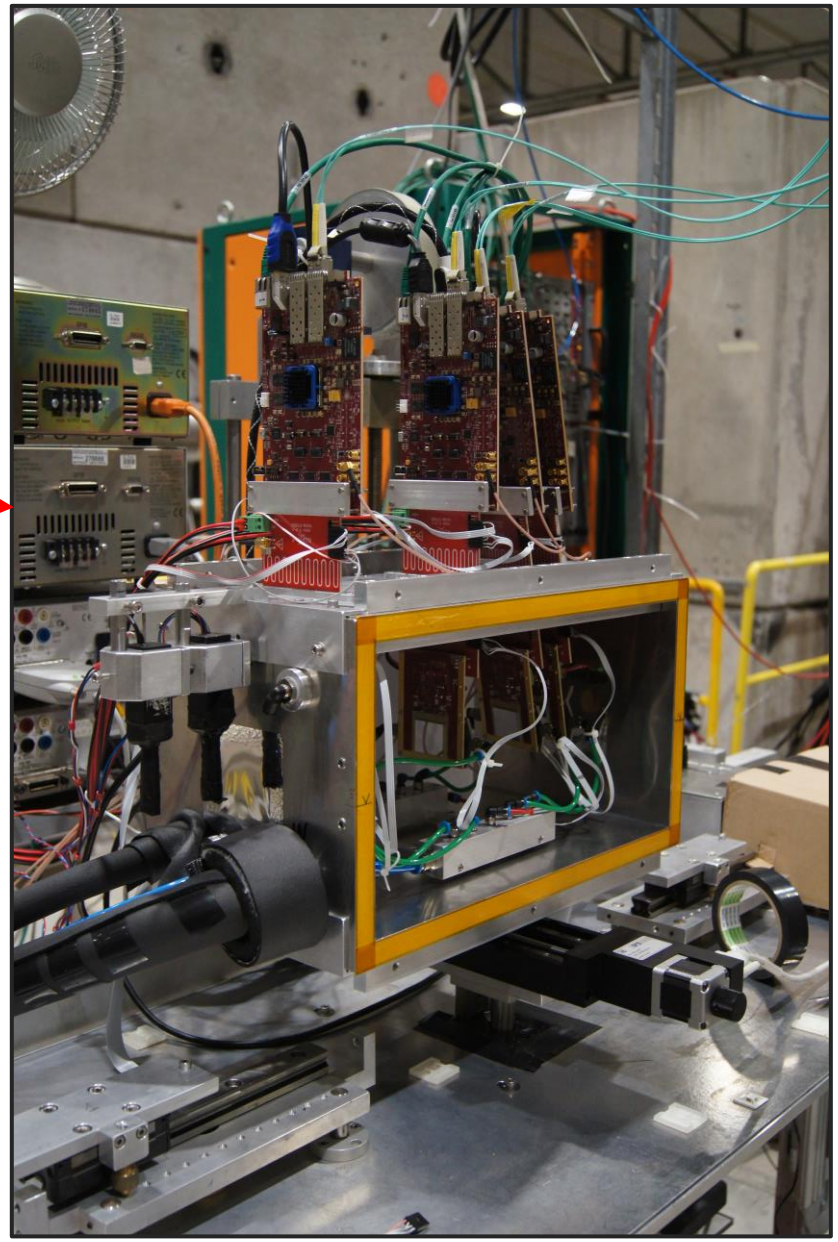
Schematic overview telescope



Timepix4 telescope





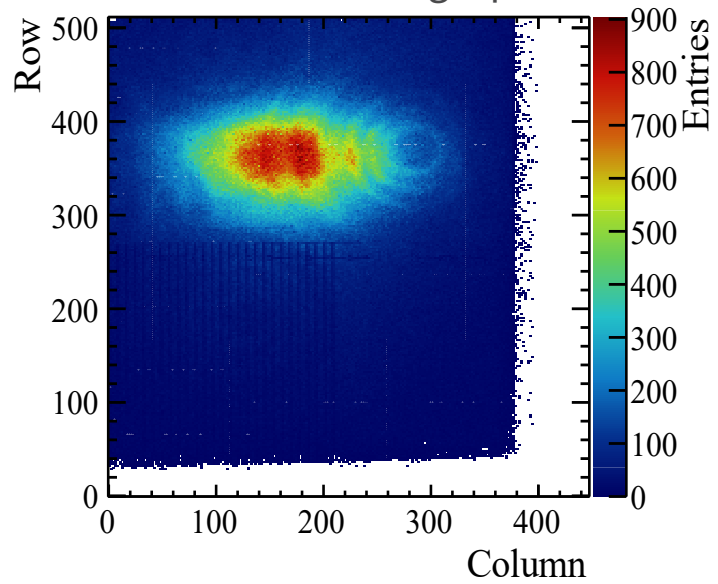


H8 beamline at CERN
180 GeV/c mixed beam
Mostly pions

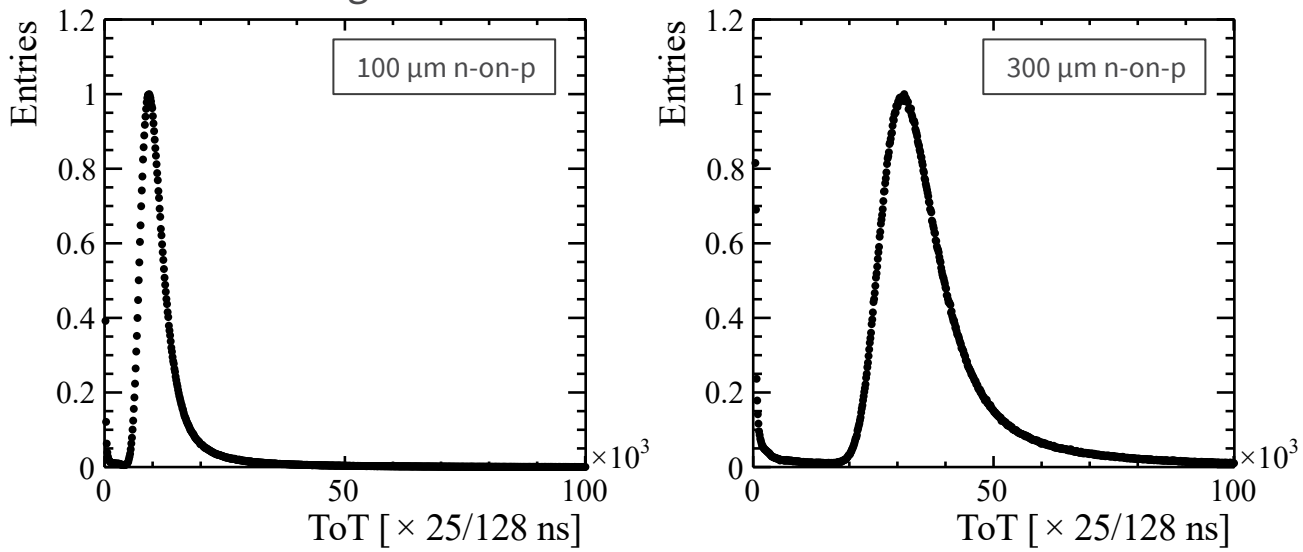
Initial results

- **Online monitoring** to check for performance
- **ToT** and **hitmap** look as expected
  - Some dead columns in the first plane
  - Connector in the beam (upstream) visible
- **Stable operation achieved**
  - Some problems occur in communication during long (~1 hour) runs

Hitmap of associated clusters to a track on a single plane



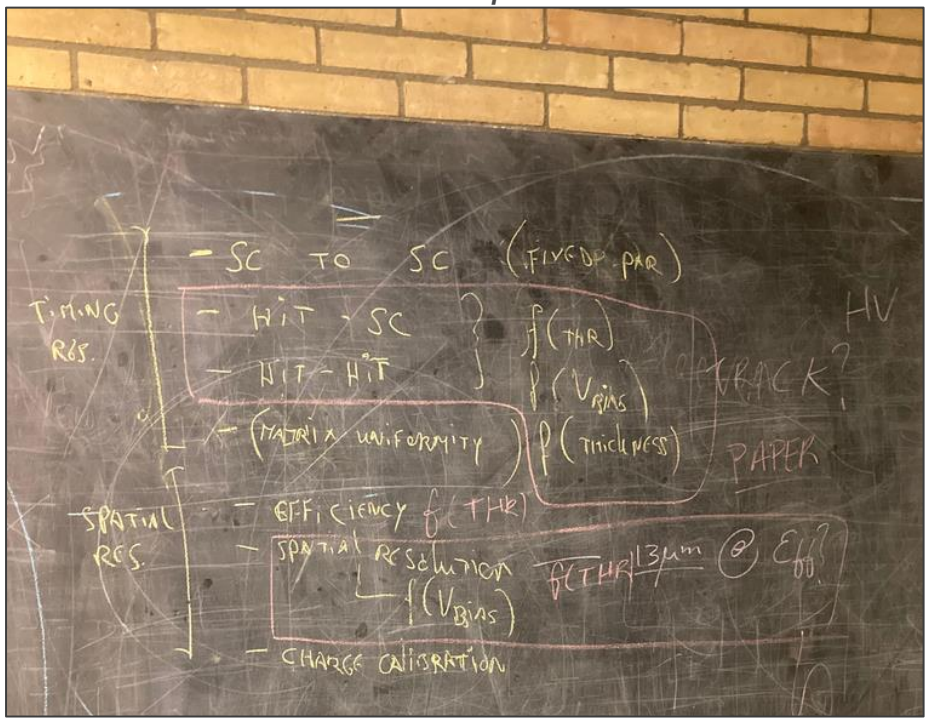
Charge distribution for the two sensor variants



Overview of studies performed

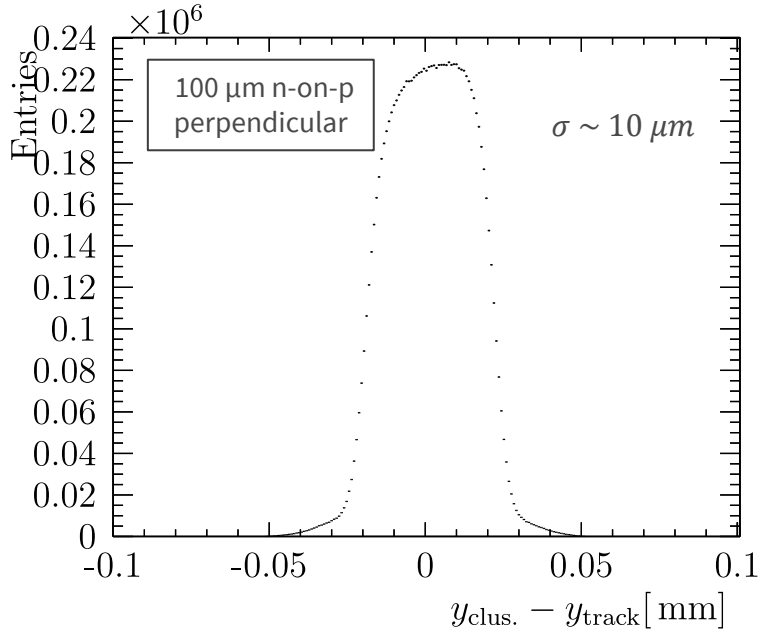
- Spatial studies:
  - **Resolution** of the track/planes
  - Efficiency per plane (work in progress)
- Temporal studies:
  - **Time resolution per plane**
  - **Track time** (resolution)
  - Trigger resolution (~100 ps including digitisation)

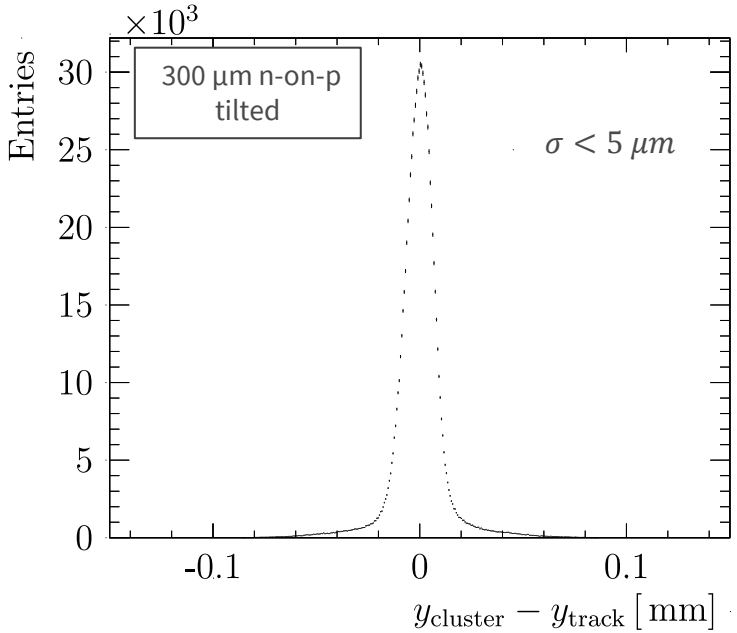
“Master plan”



Track resolutions

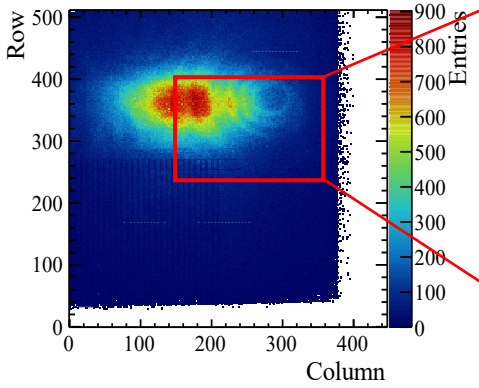
- **Track reconstruction achieved**
  - Resolution is good enough to study unbiased residuals
- Track resolution is (mostly) achieved through the **two tilted sensors** (9°)
  - Room for slight optimalisations
  - Expected to improve for the final telescope

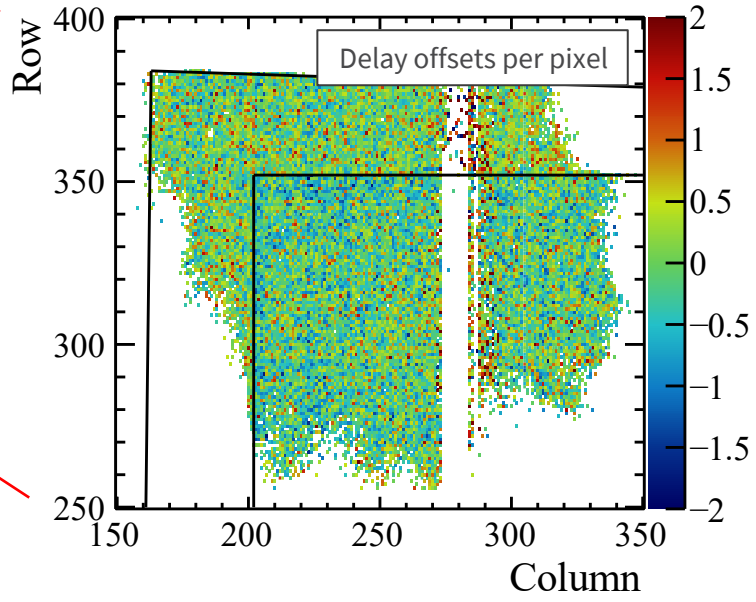


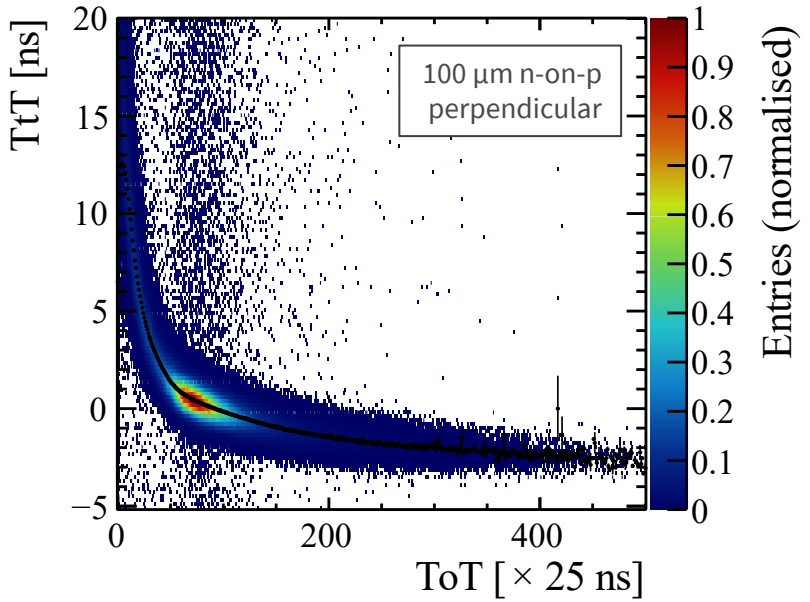


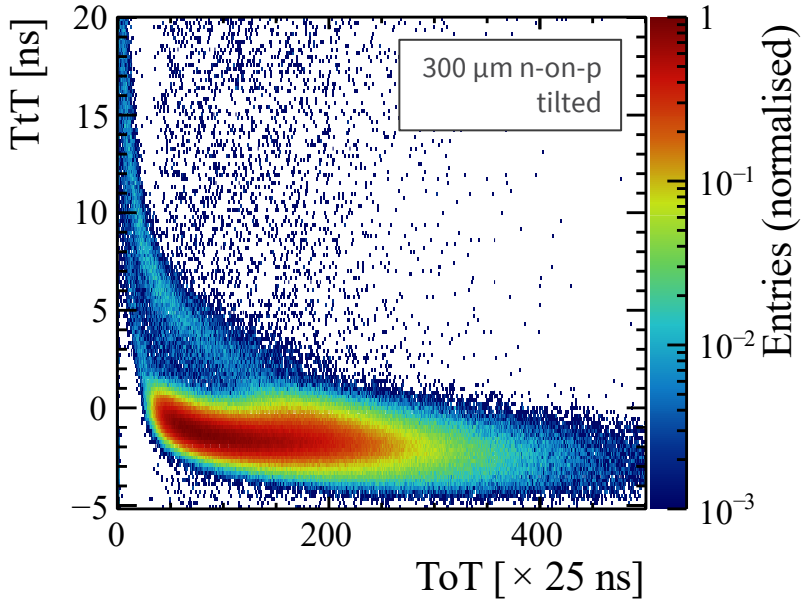
Temporal corrections

- Timewalk correction applied using Time-to-Threshold (TtT) measurements
  - **Track based timewalk** correction for tilted sensors
- Delay **offsets** per-pixel corrected
- Planned for final telescope: **per-VCO bin** delay correction
  - Needs substantial statistics









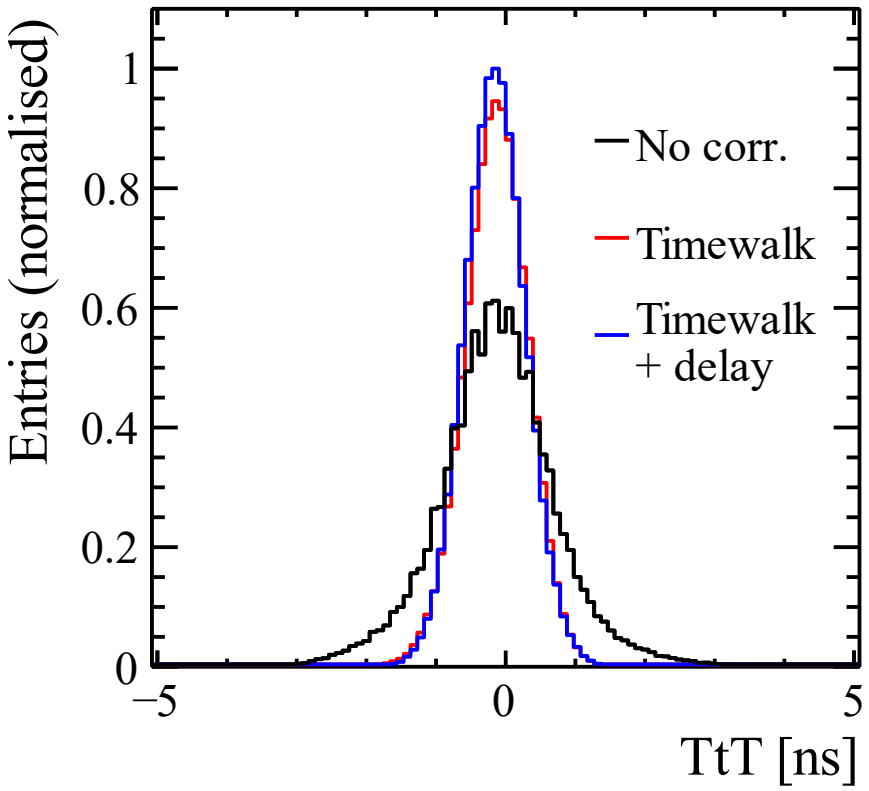
See K. Heijhoff et al., 2020 JINST 15 P09035 for detailed information on track based timewalk and pixel-to-pixel variation corrections

Corrected time resolution (single plane)

- An example of the corrections:
  - 100 µm n-on-p @ 50 V

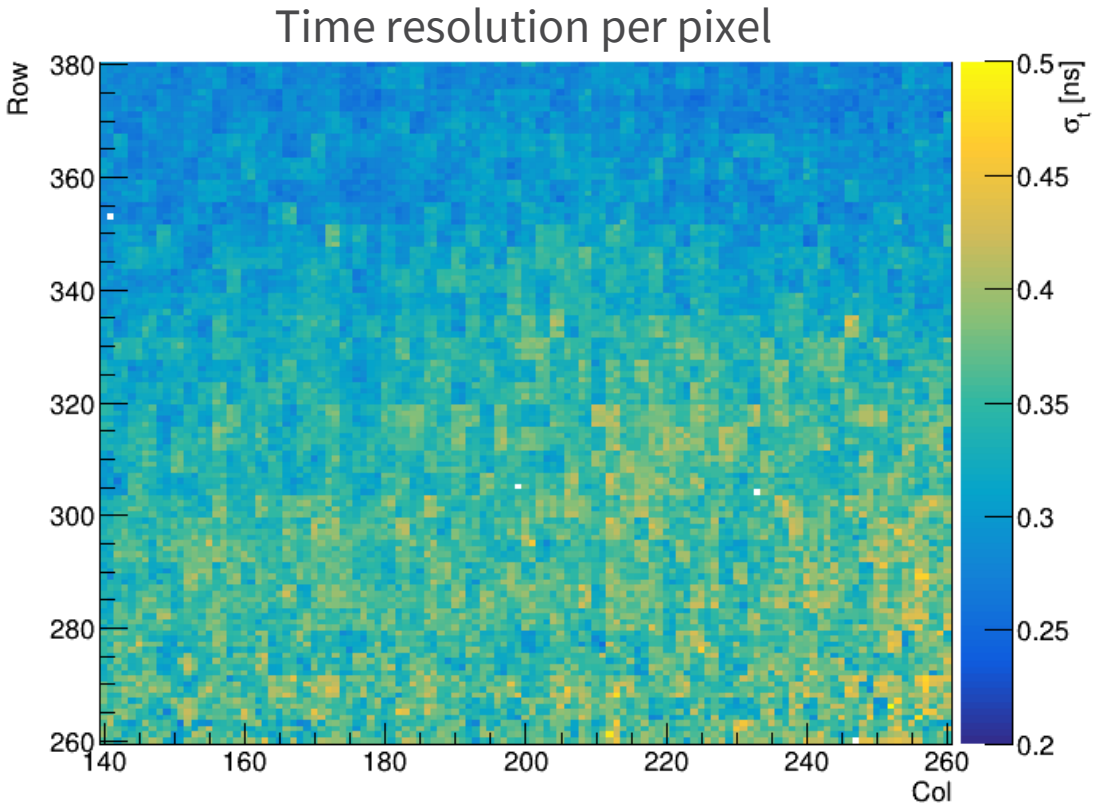
Corrections:	σ_t [ps]
None	789
Timewalk	450
Timewalk + delay offset	439

- **Final goal**: find the best operating condition for **all planes** individually
- Due to lack of time not done for this testbeam
- **Best track resolution** so far, for nominal threshold and highest bias voltage: **360 ps**



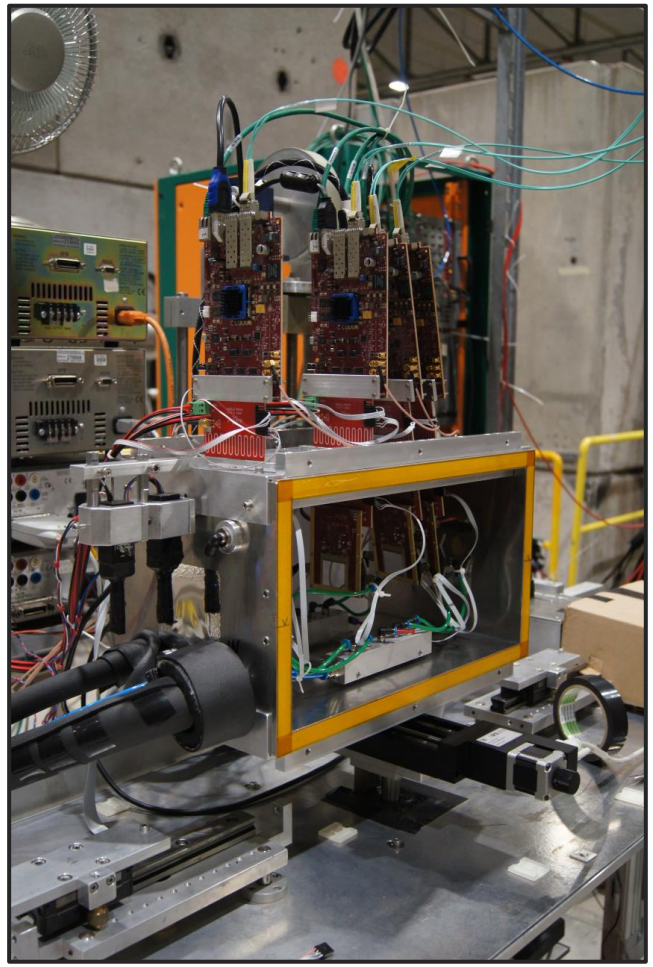
Time resolution variations

- **Variation** of **time resolution** observed over the matrix
  - From 250 ps to 450 ps over half the chip
- Most likely related to **VCO issue** from Timepix4v1
  - Investigation started, and planned to look at the response of Timepix4v2 when available
- Good hope that **Timepix4v2** will **not have** (or drastically reduced) this variation



Conclusion and outlook

- A small, **4-layer**, telescope is constructed with **Timepix4 planes**
  - Stable operation throughout the testbeam
- **First tracks** successfully **reconstructed**
  - Suffering from **issues** with **Timepix4v1**
  - Valuable lessons learned
  - **Initial analysis** provides **track** and **time** resolution indications
- Planning runs with full, **8-layer**, telescope during summer
  - Provided we can produce additional SPIDR4 systems
  - First attempt to run with Timepix4v2
  - **Improve** the time resolution of **reference signal**
    - MCPs + PicoTDC



Thank you for the attention!