Timepix4 timing layers

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Introduction and deliverables

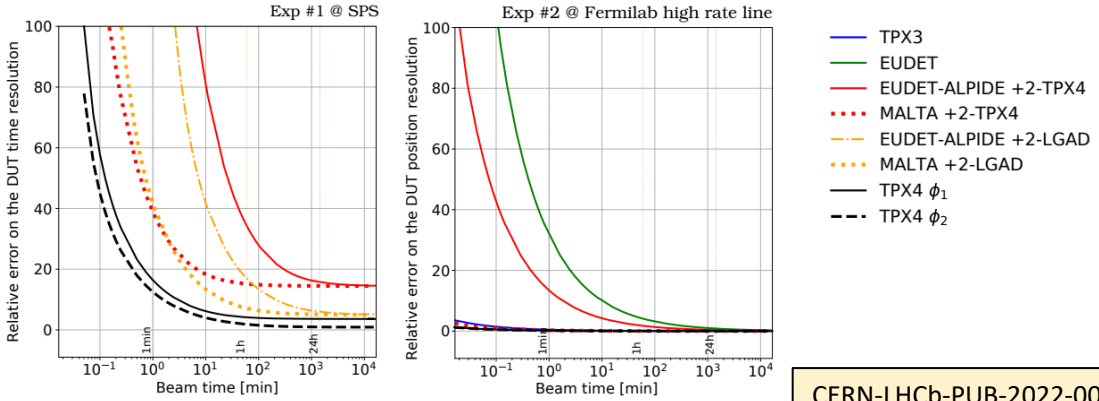
Main objectives:

- Sub-nanosecond timing capabilities for EUDET style telescopes
- (3.3.1) Integration of Timepix4 planes into EUDAQ2

- Ambition is to deliver track timestamp with O(100) ps resolution
  - Requires fast sensors that provide large (e.g. 10 ke-) signals
  - Sensors not yet available, at least not in full size
- Currently testing with full size ‘standard’ planar sensors
  - This will limit the resolution to several 100 ps
  - But still allows us to find (and correct) for systematic effects of Timepix4
- So far the developments focused on the Timepix4 characterization
  - ASIC itself, and system level timing aspects, and not yet on DAQ integration

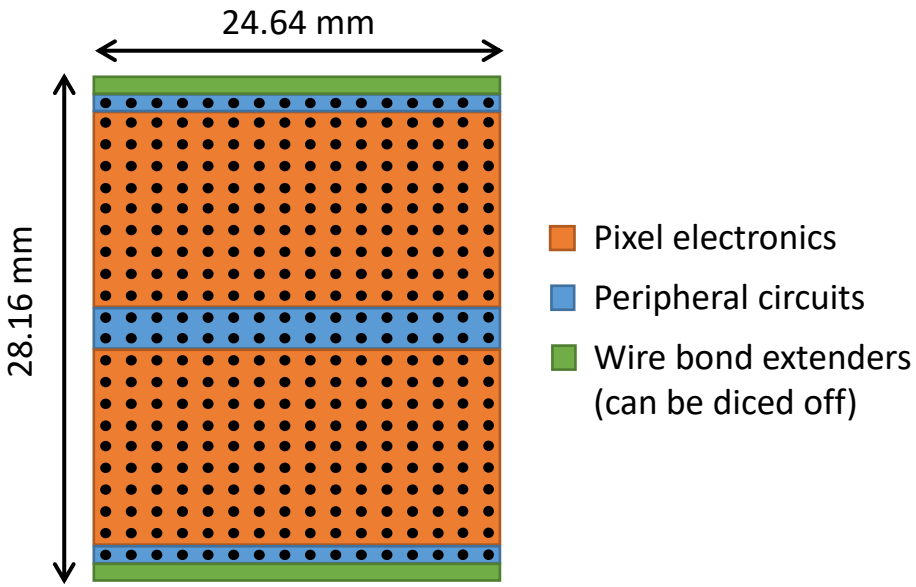
Why Timepix4?

- Readout ASIC + readout is available
  - Profit from (large) Medipix4 collaboration
- Large area, 7 cm^2
- Good time resolution, theoretical limit of TPX4: 80 ps @ 10 ke-
  - Not including sensor contributions
  - And after all corrections such as per-pixel time-walk, offsets, etc.
- High rate, tens of millions tracks/cm^2/s
  - Many studies are statistics limited



CERN-LHCb-PUB-2022-001

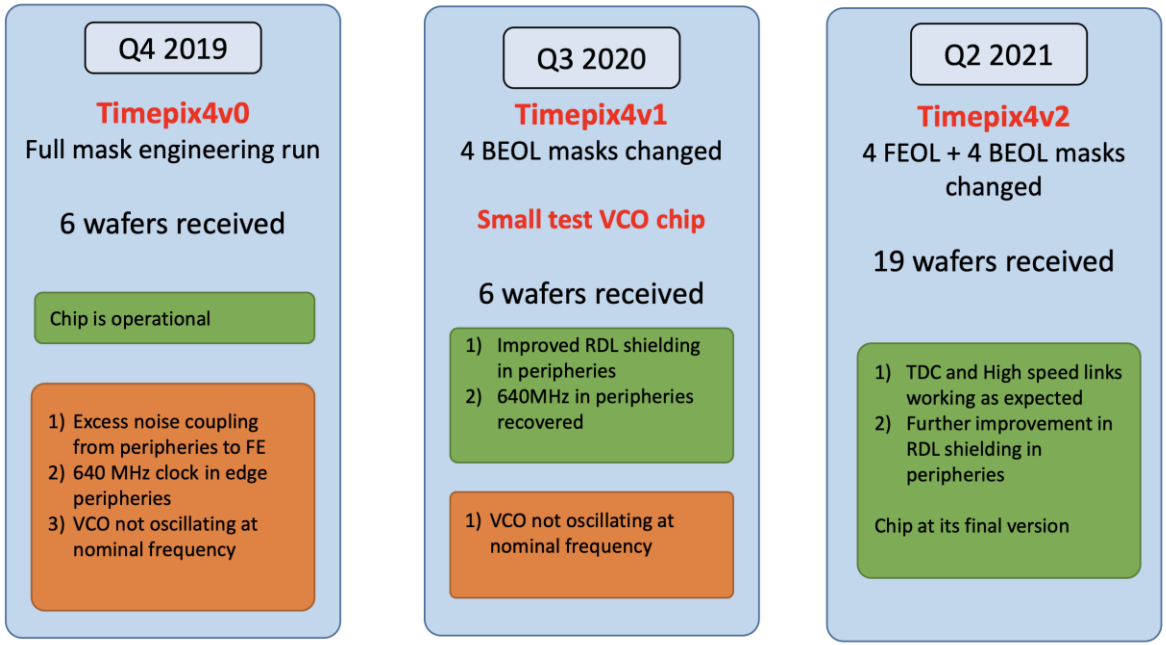
Timepix4 main specifications



X. Llopart et al. 2022 JINST 17 C01044

- 65 nm CMOS
- Designed by CERN, Nikhef, IFAE
- Matrix of 512 x 448 pixels
- 55 x 55 um^2 pixels
  - Electronics in 55 x 51.4 um^2
- Active area 6.94 cm^2
- 4-side buttable, using redistribution layer
- Many modes, for telescope: simultaneous Time-Of-Arrival and Time-Over-Threshold
- 195 ps TDC bins
- Data driven readout: 16 x 10.24 Gbps
- Min. threshold: ~500 e-

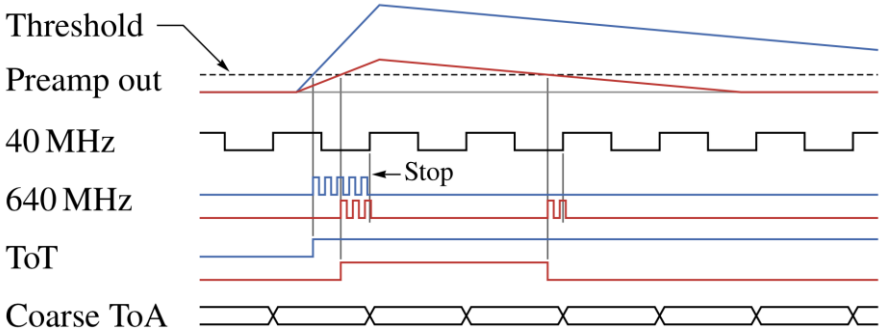
Timepix4 versions

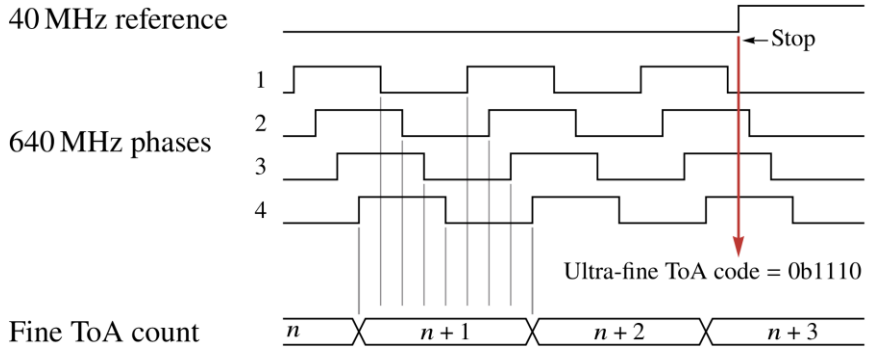


- Version1 with sensor used in first testbeams
  - Voltage Controlled Oscillator running 25% too fast
  - And not properly locked to its reference oscillator
- Version2 with corrected VCO used in latest testbeams
- n.b. there exists a version3; only difference w.r.t. v2 is aspect ratio of bondpads

More Timepix4 info in Xavi Llopart's seminar: https://indico.cern.ch/event/1121147/

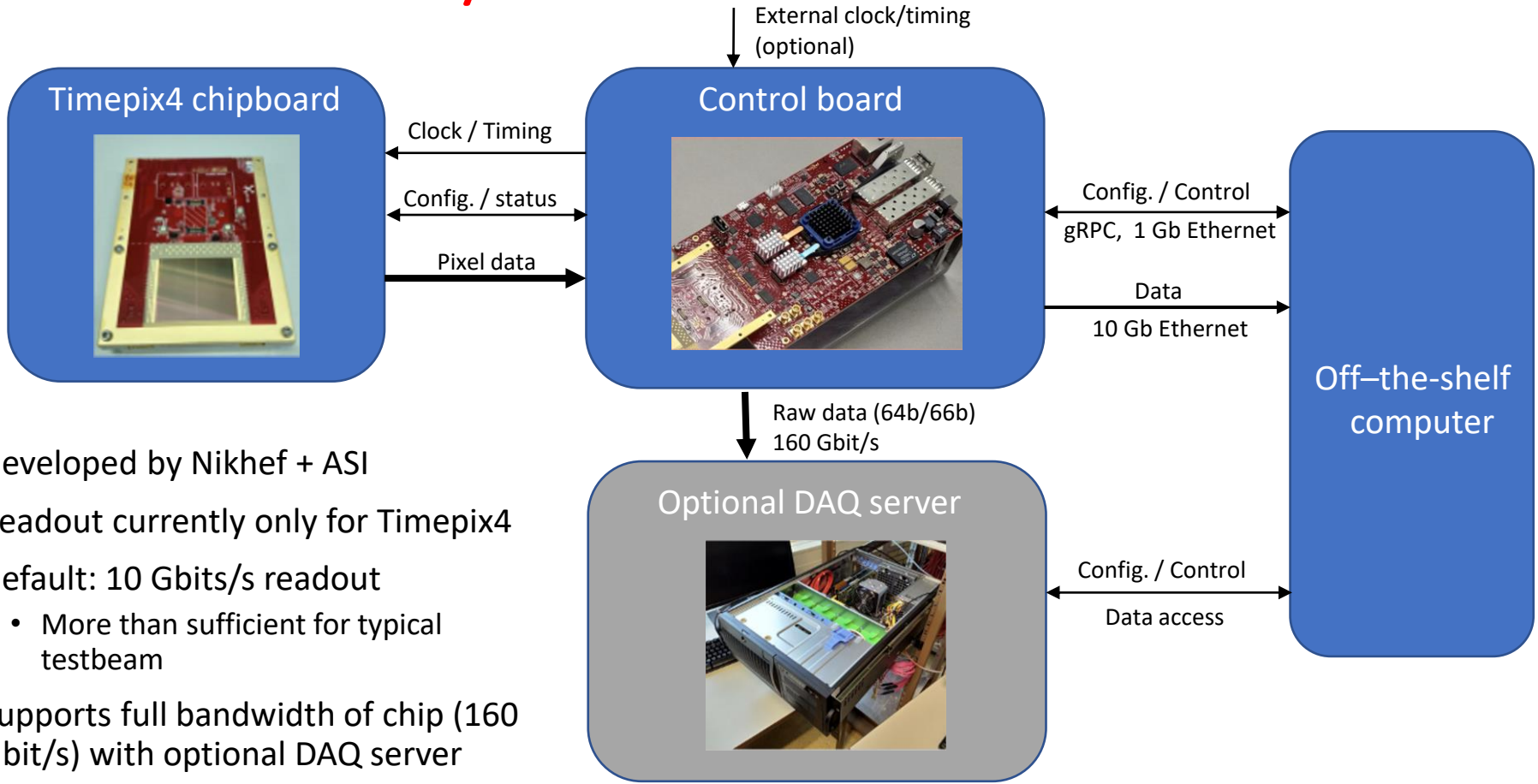
Timepix4 time measurement



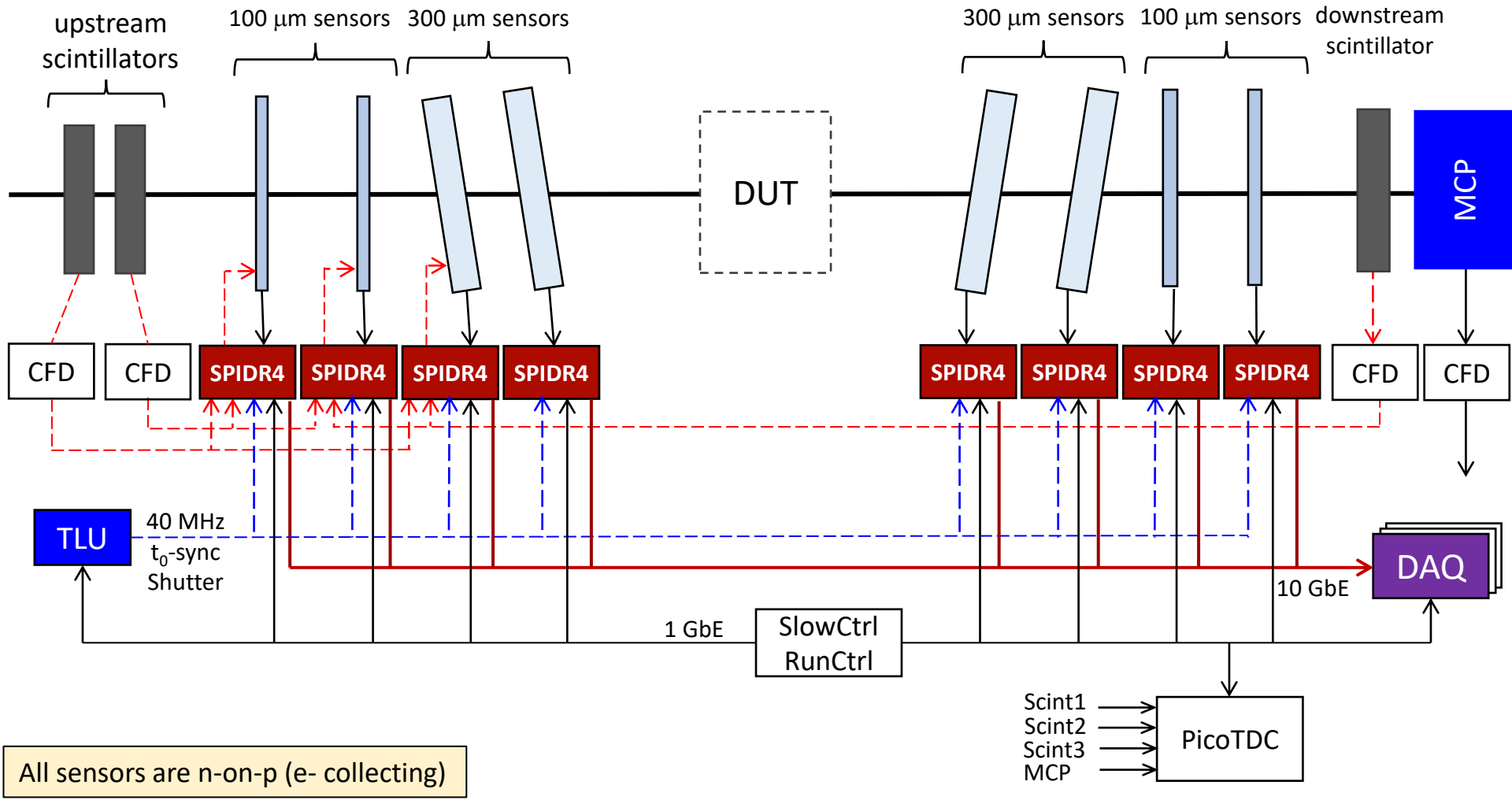


- Base clock of 40 MHz
- Hit starts 640 MHz oscillator
  - 1.56 ns bins
  - Count #clock cycles (like in Tpx3)
  - Oscillator shared by 8 pixels in superpixel
- Oscillator is stopped by first rising edge of 40 MHz clock
- In addition the internal state of ring oscillator (VCO) is captured –> 195 ps bins (56 ps rms)
- Back edge of Time-over-Threshold signal is measured with a high time resolution
  - Improved ToT measurement

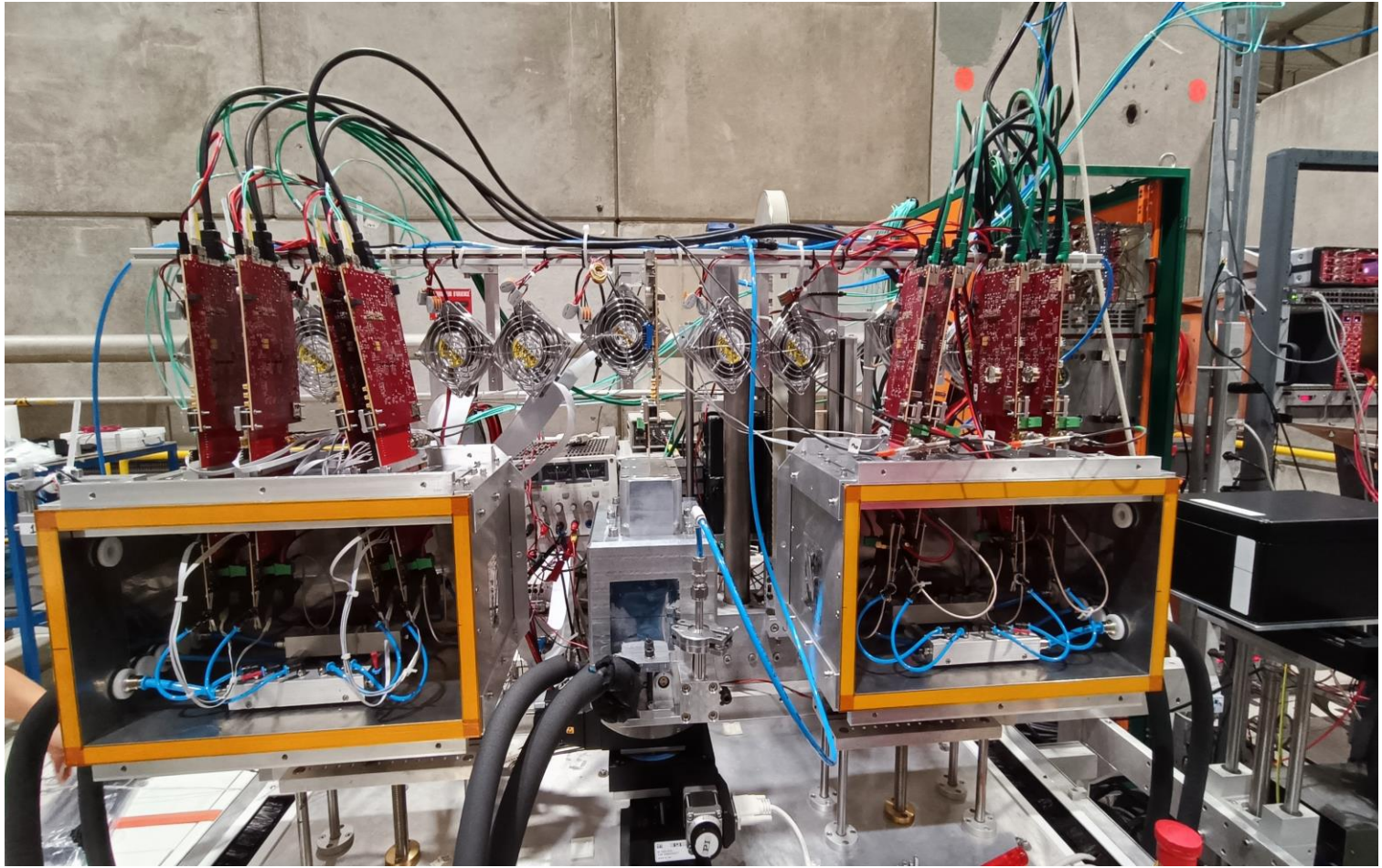
SPIDR4 readout system

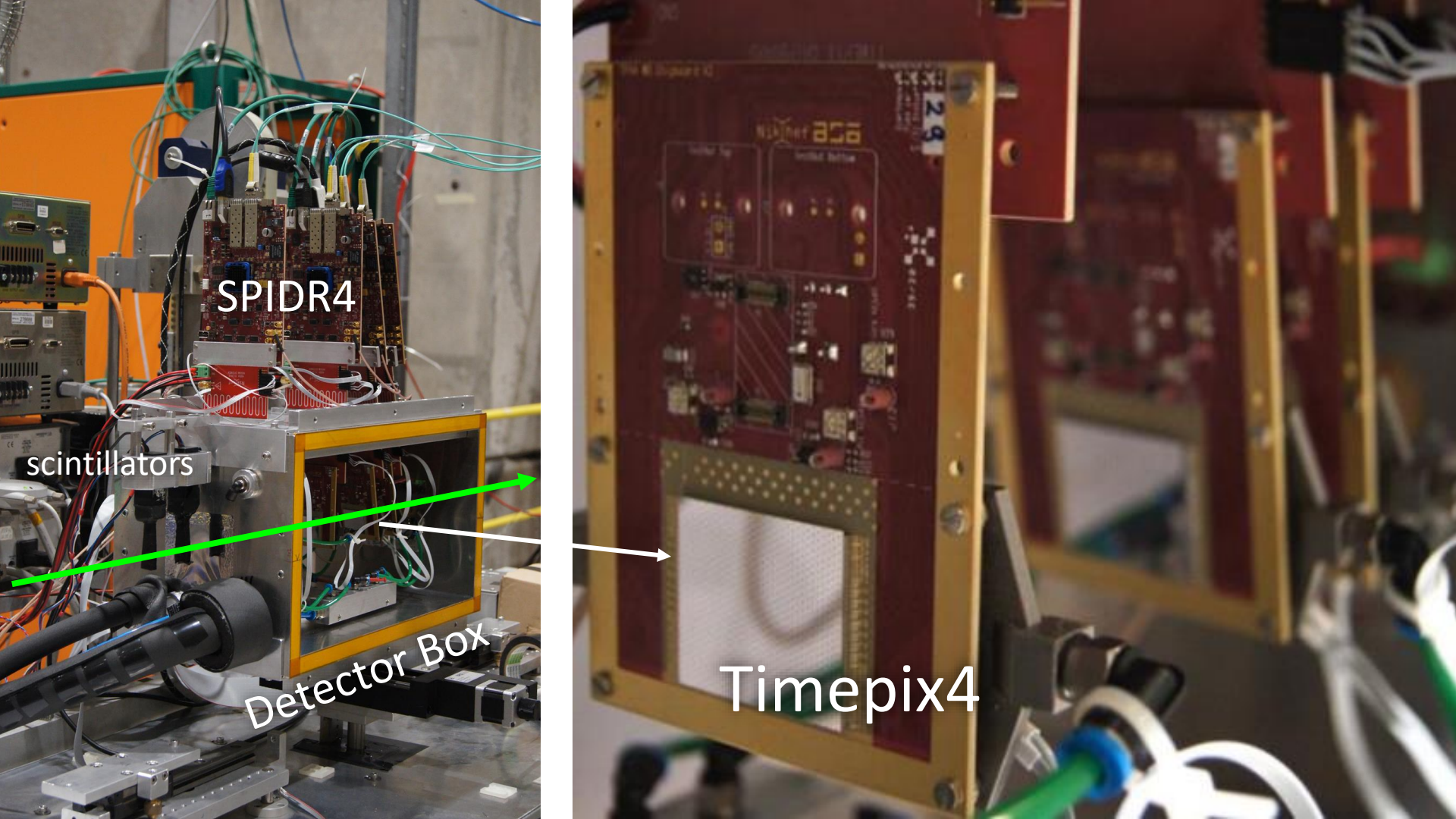


- Developed by Nikhef + ASI
- Readout currently only for Timepix4
- Default: 10 Gbits/s readout
  - More than sufficient for typical testbeam
- Supports full bandwidth of chip (160 Gbit/s) with optional DAQ server



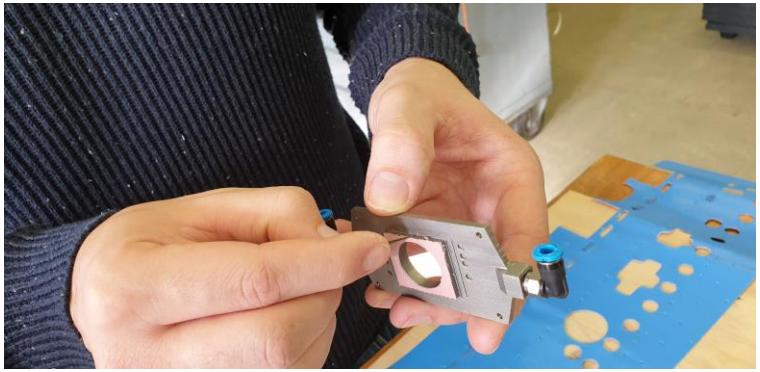
All sensors are n-on-p (e- collecting)

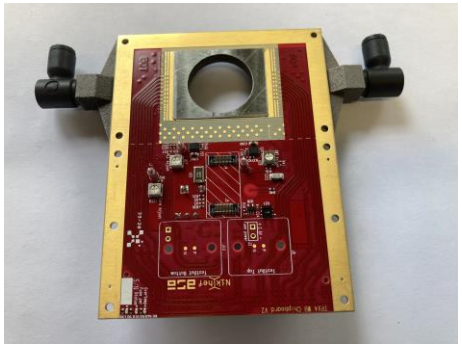



SPIDR4
scintillators
Detector Box
Timepix4

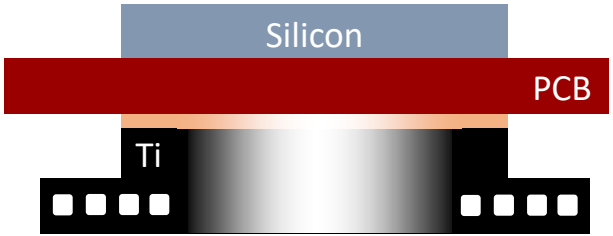
Cooling

- Power consumption of few Watts per Timepix4
  - Air cooling is insufficient
- All chips/PCBs attached to 3D printed titanium cooling block
- Glycol used to cool chips to room temperature
  - ready to go cold(er)

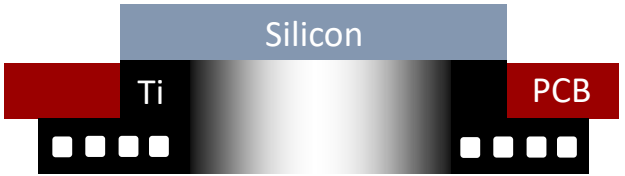




Current cooling

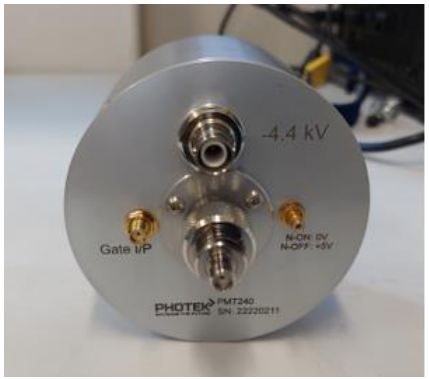


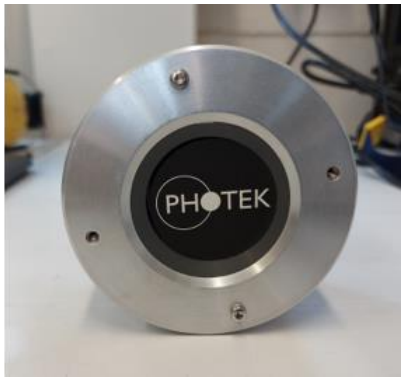
Envisioned cooling



Reference timing

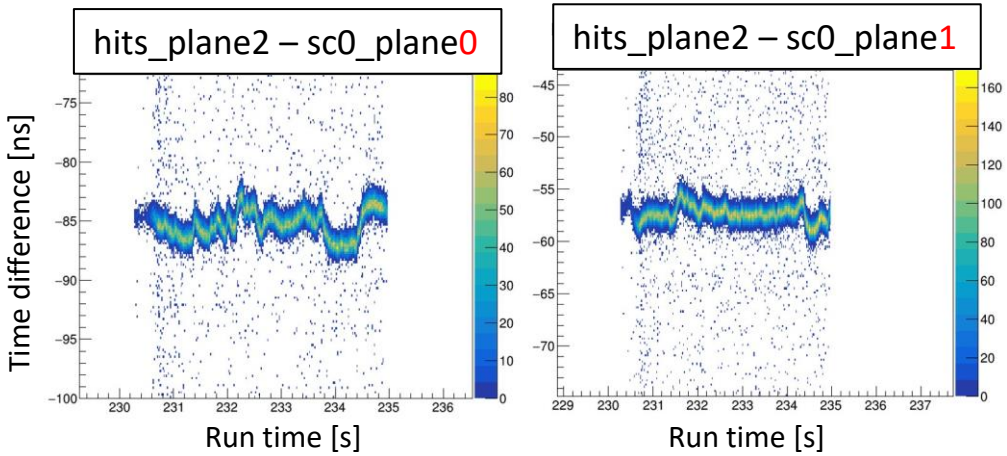
- Reference timing system consists of 3 scintillators and 1 MCP, all equipped with CFDs
- Scintillator combined time resolution is order 70 ps
  - Time measured via multiple signal copies sent to SPIDR4 and picoTDC
  - Allows cross checking of SPIDR4 clock stability, see later slide
- MCP provides time resolution of order 15 ps
  - Only read out by picoTDC, experimental configuration

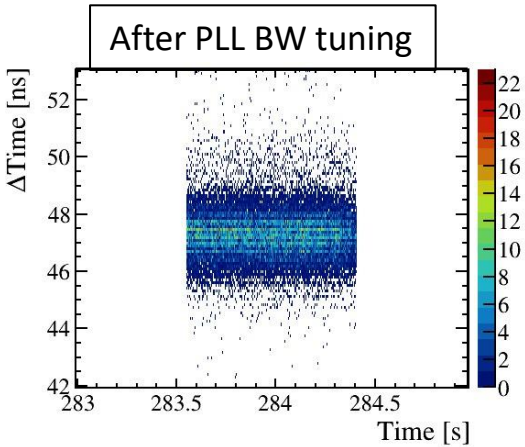




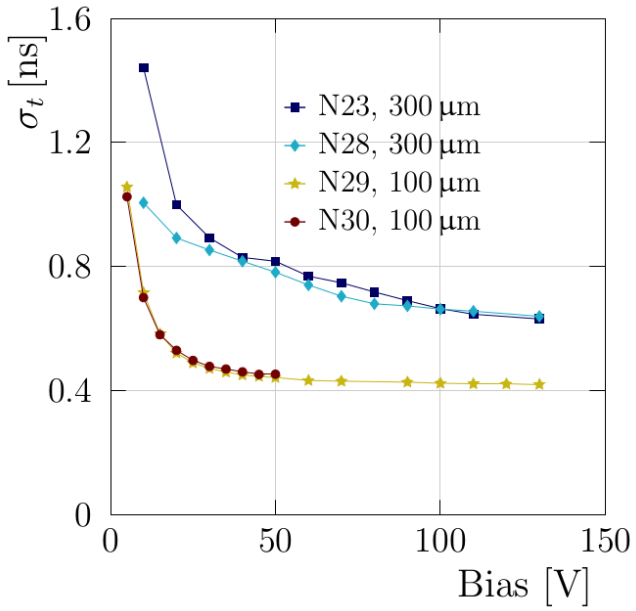
Clock cleaning, lesson learnt

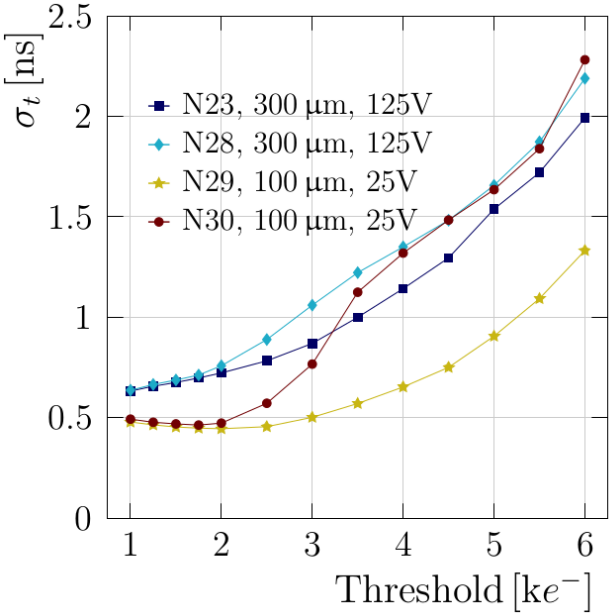
- Observed a nanosecond time drift between planes in early testbeam data
- Due to combination of poor common input clock and clock cleaning PLL on SPIDR4
  - PLL relies on reference crystal, which wasn't great either
- Slow drift corrected offline for old testbeam data (possible thanks to high rate)
- Tuned PLL bandwidth, and improved ref. crystal of PLL for new batch of SPIDR4 boards
- Clock manager circuits are great devices, but need a clear master/slave configuration





Temporal resolution of individual planes



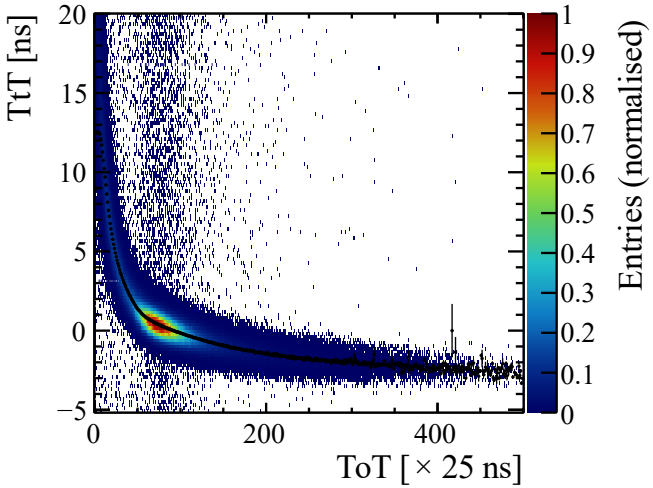


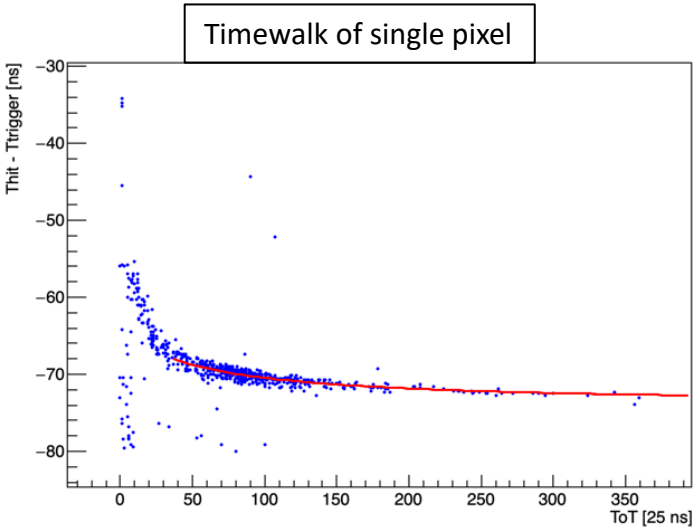
- Timepix4v1, 2021 data
- Same timewalk correction parameters for all pixels
- Resolution of thick sensors limited by bias voltage
- Timepix4v2 shows a slightly better time resolution

K. Akiba *et al.*, 'Reconstruction of charged tracks with Timepix4 ASICs', *Journal of Instrumentation*, vol. 18, no. 02, p. P02011, Feb. 2023.

Time resolution of 100 um sensors is higher than expected

- We used the same time-walk correction parameters for all pixels
- Pixel to pixel time offsets broaden the resolution
- Is the shape of the timewalk curve the same for all pixels?



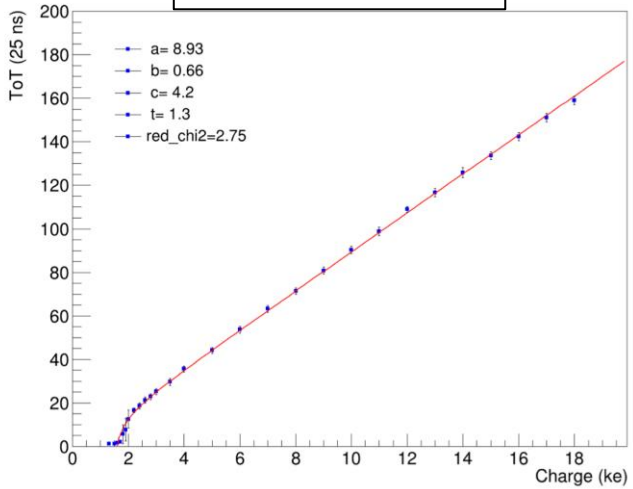


- Need per-pixel timewalk correction parameters
- Requires substantial statistics per pixel
- Testbeam next week to take high-statistics runs

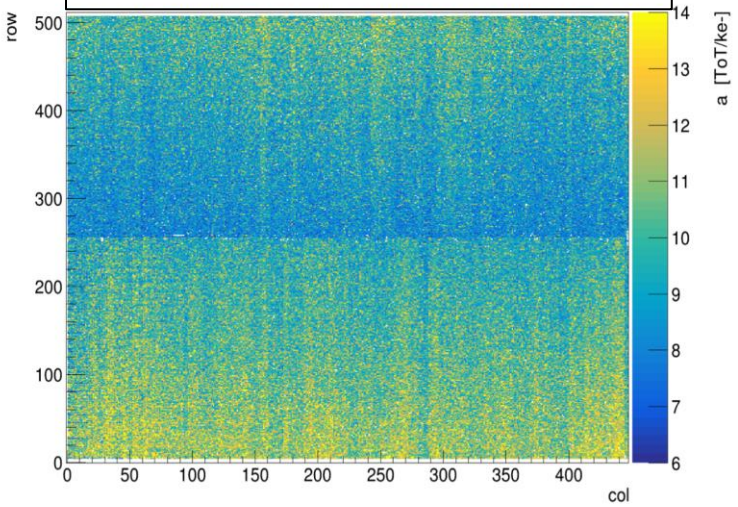
Charge calibration

- First step for timewalk correction is per-pixel charge calibration (equalization)
- Can use internally generated testpulses
  - Method has been cross-checked with pulsed laser and radioactive sources
- Large (random) pixel-to-pixel ToT spread, and a systematic effect along columns

Charge-ToT calibration

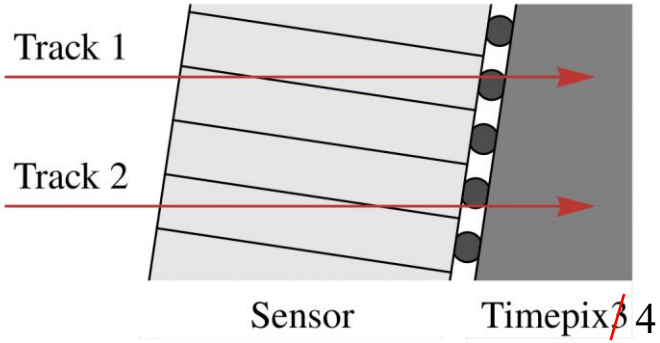


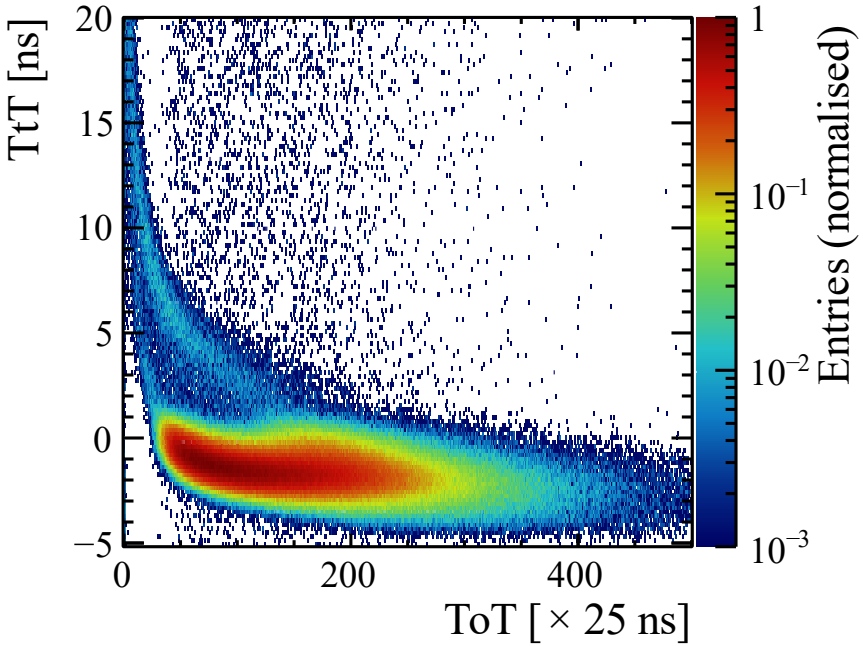
Slope-parameter (a) variation across matrix



“Timewalk” correction for thick tilted planes

- Tilting sensors is beneficial for spatial resolution, but affects time resolution
- Timewalk plot for tilted thick sensor shows multi-band structure
- Requires correction based on track topology, currently limited by statistics

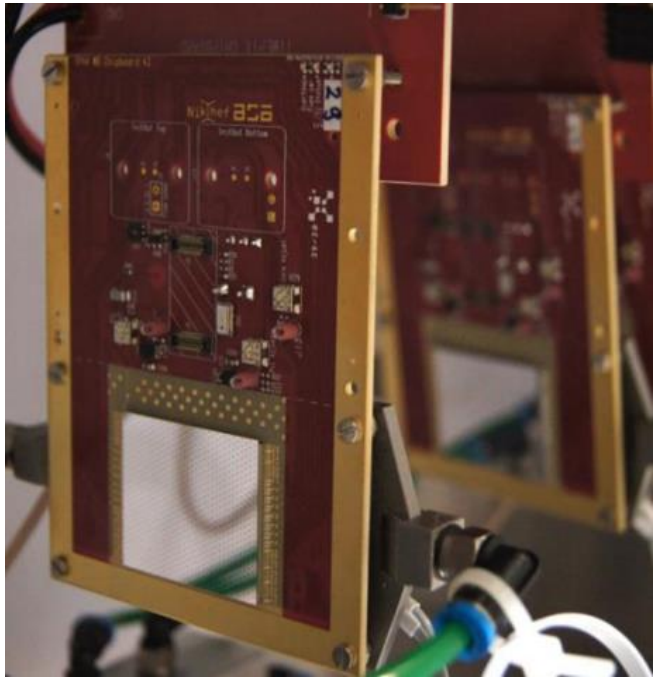




More details: K. Heijhoff https://doi.org/10.1088/1748-0221/15/09/P09035

Summary and outlook

- Successfully reconstructed tracks with Timepix4 telescope and SPIDR4 readout
- Achieved sub-ns time resolution
  - “Out of the box” time resolution of ~400 ps
- Significant improvement expected from per-pixel timewalk correction parameters
  - Lacking the required large statistics
- Need faster sensors (WP6) for O(100) ps time resolution



Next steps, also in view of M36 milestone

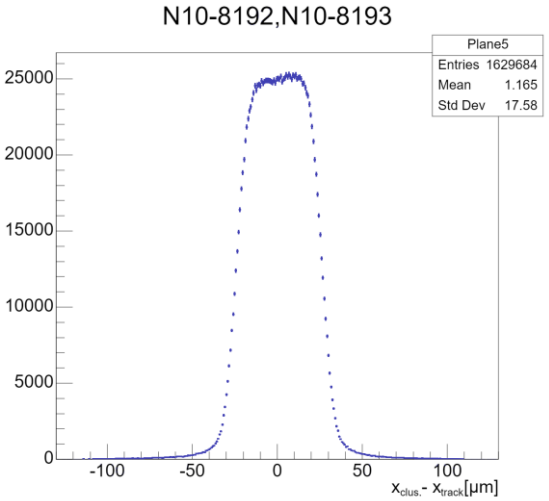
- Determination of per-pixel (correction) parameters
- Integration with EUDAQ2 and AIDA-style TLU
- Mechanical/cooling integration in AIDA-style telescopes

Thank you

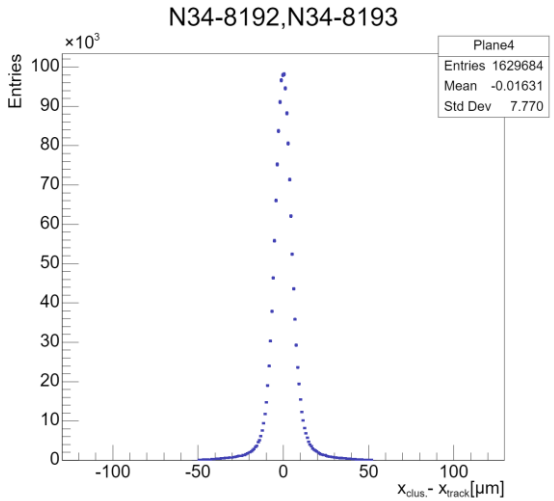
Spatial resolution

- Unbiased residuals, measured extrapolating tracks made with the rest of the detectors for each run
- 6 planes working for these examples:

  3 x 300 µm & 3 x 100 µm
- The pointing resolution is not subtracted from these values, hence the huge differences



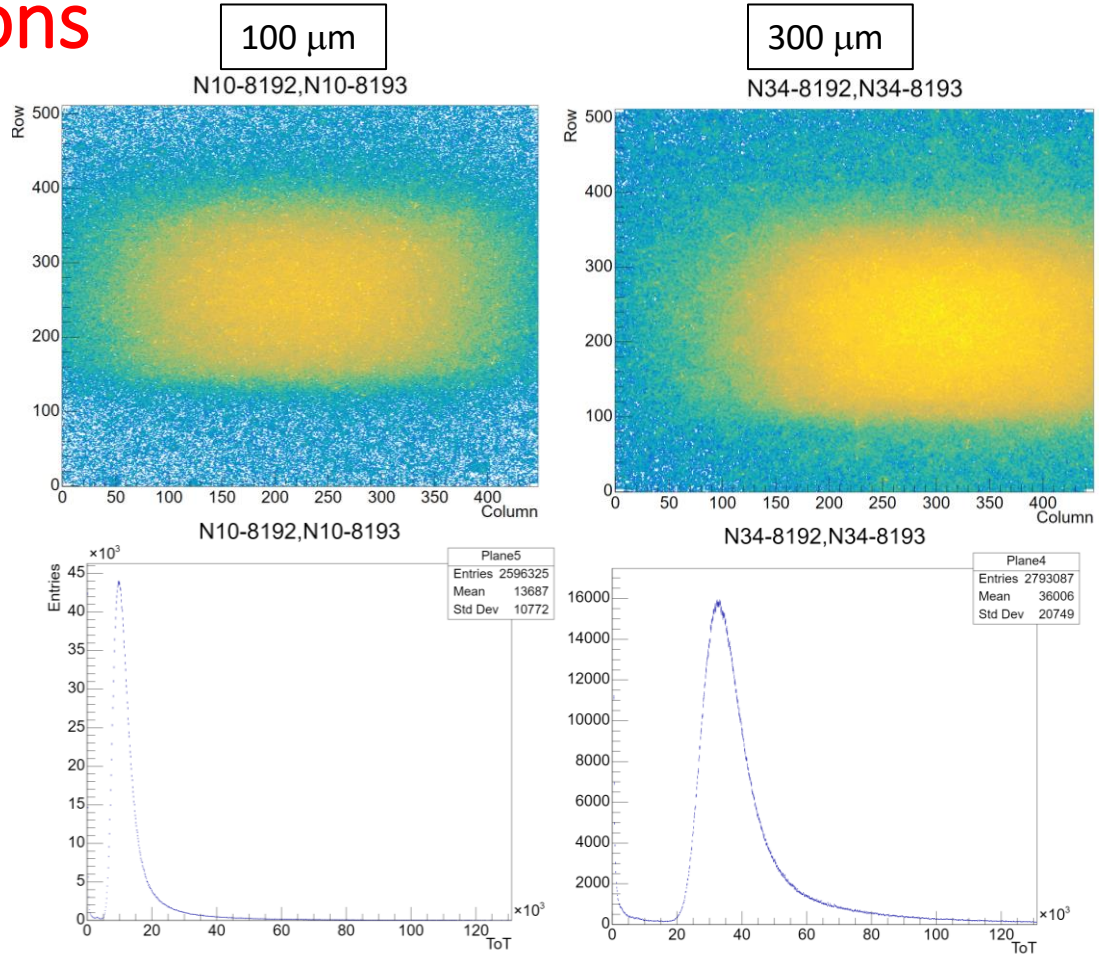
100 µm sensor
Residual dominated by sensor pitch of 0º
(not by telescope: 3 thick sensors used in track reconstruction)



300 µm sensor
Residual is mix of sensor and Telescope (only the remaining 2 thick sensors used in track reconstruction)

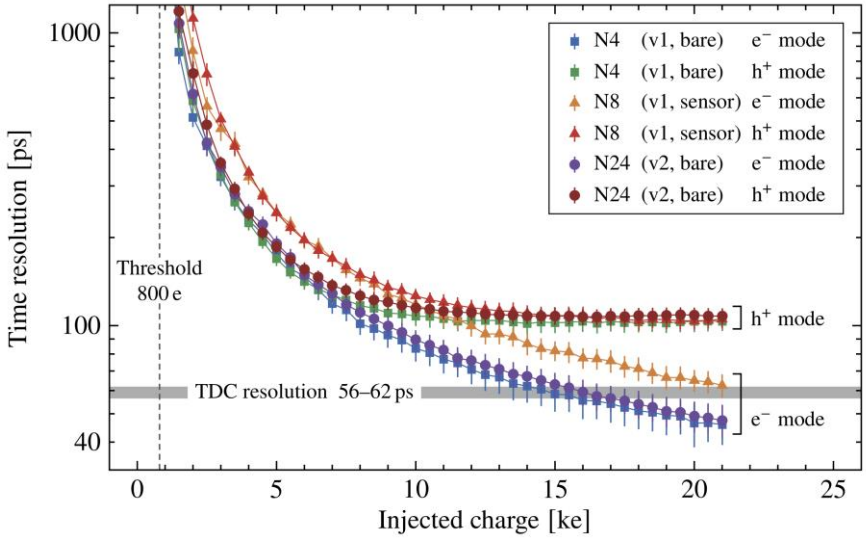
Landau distributions

- Online monitoring to check performance
- ToT and hitmap look “as expected”
- Offline and online analysis using the LHCb’s Kepler framework.

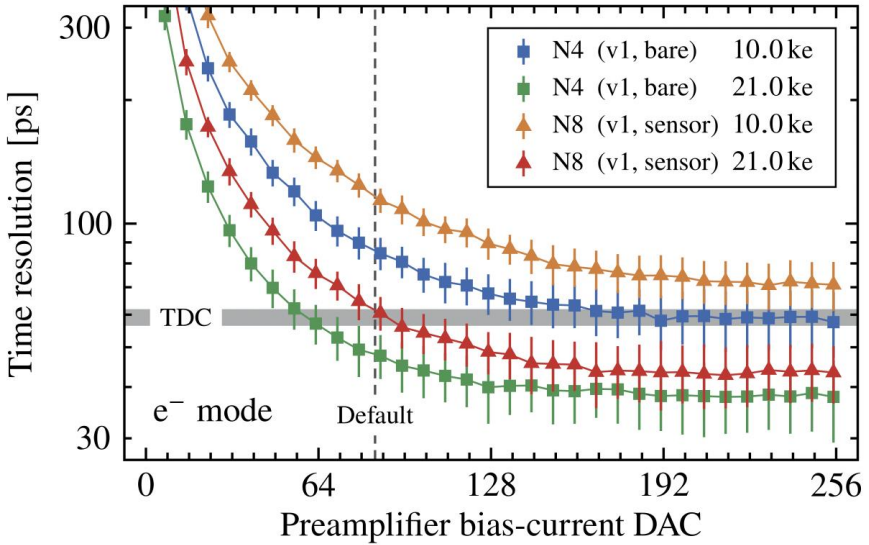


Timepix4 analog front-end (with testpulse)

Time resolution as function of charge



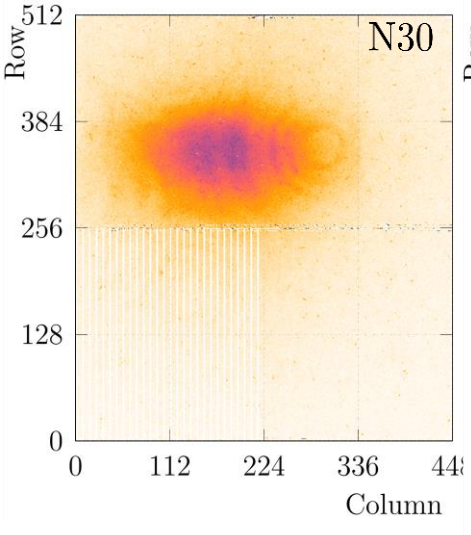
Time resolution of function of preamp current



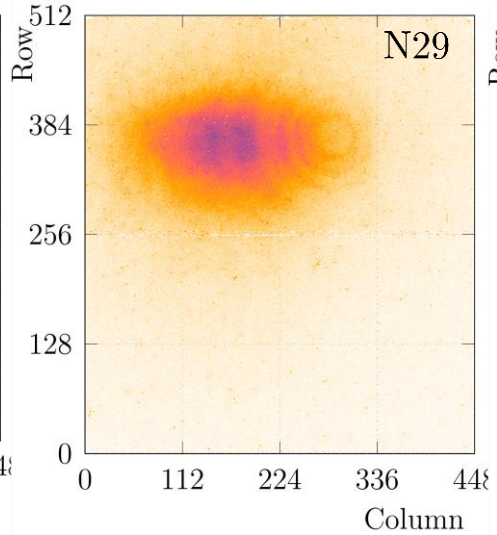
K. Heijhoff: arXiv:2203.15912 (accepted by JINST)

Efficiencies

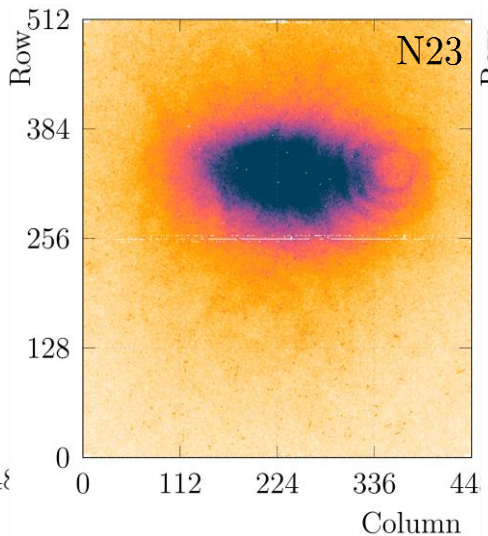
$\varepsilon = (92.0 \pm 5.0)\%$



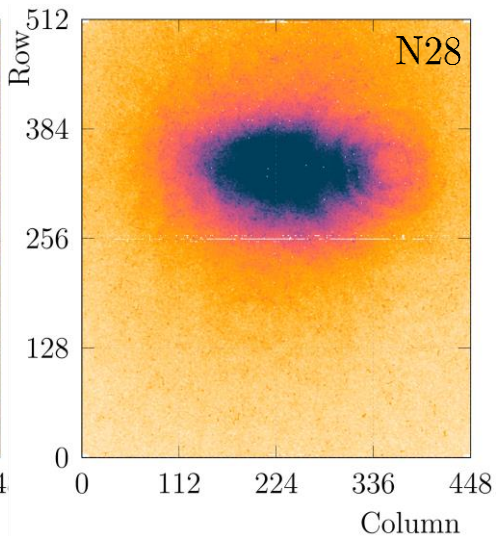
$\varepsilon = (99.4 \pm 0.2)\%$



$\varepsilon = (99.1 \pm 0.4)\%$



$\varepsilon = (98.2 \pm 0.3)\%$



- ”Out of the box” efficiencies
- Not yet optimized (but anyhow, >> 90% sufficient for telescope)