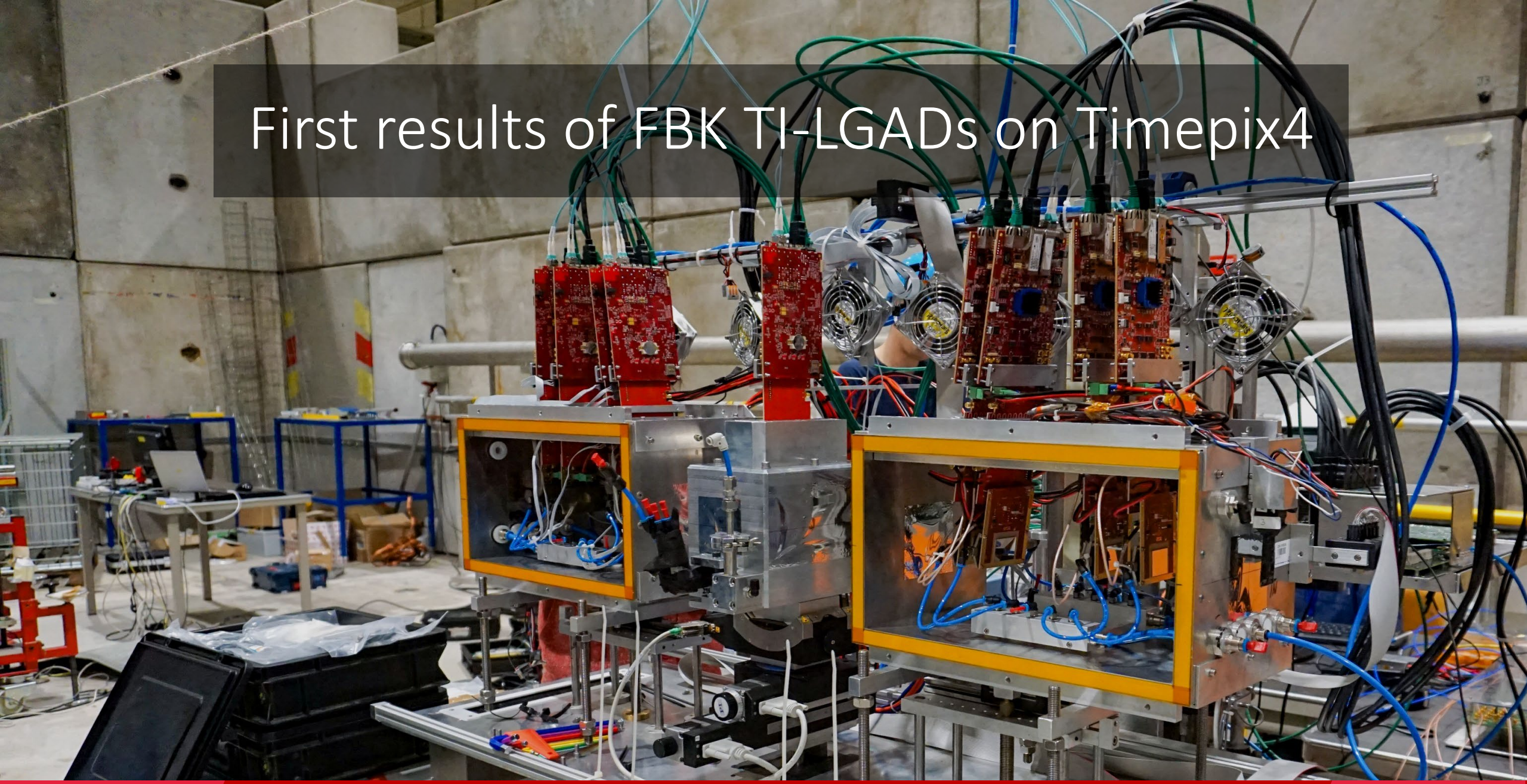
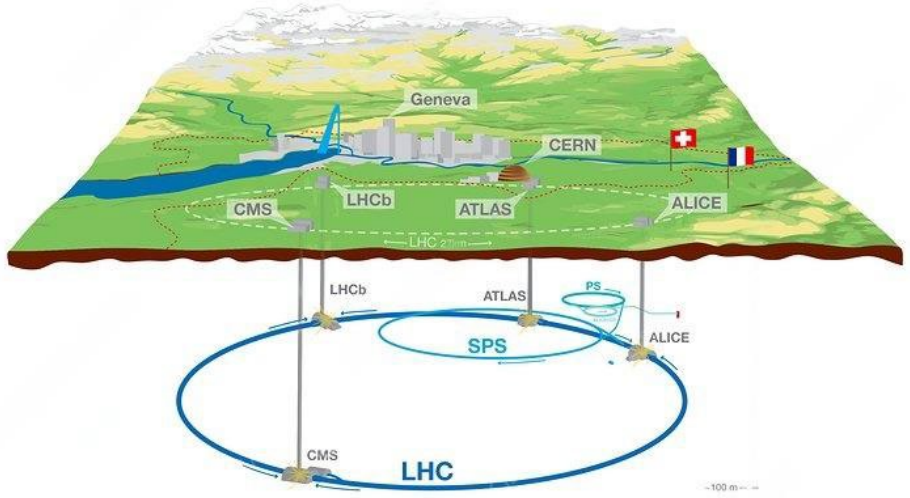
First results of FBK TI-LGADs on Timepix4



LHC -> HL-LHC

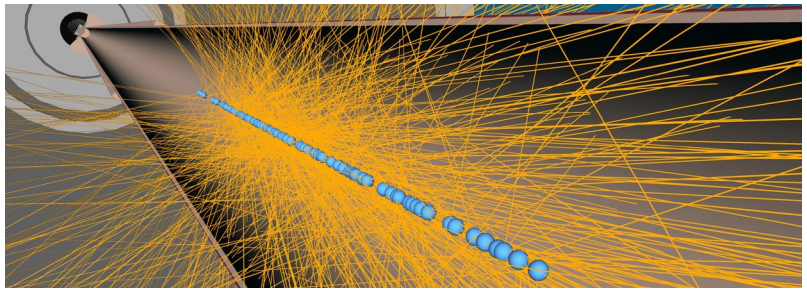
- High luminosity LHC increases the luminosity tenfold.
- This increases the pile-up of events



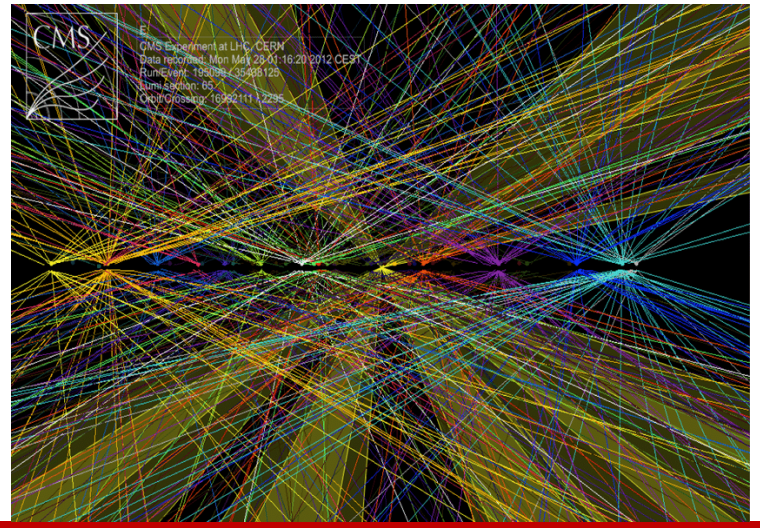
Pile-up of events

- The High-Luminosity upgrade increases the pile-up of events
- Difficult to achieve same tracking performance for pure spatial separation
- High tracks per events -> High computational load on track finding

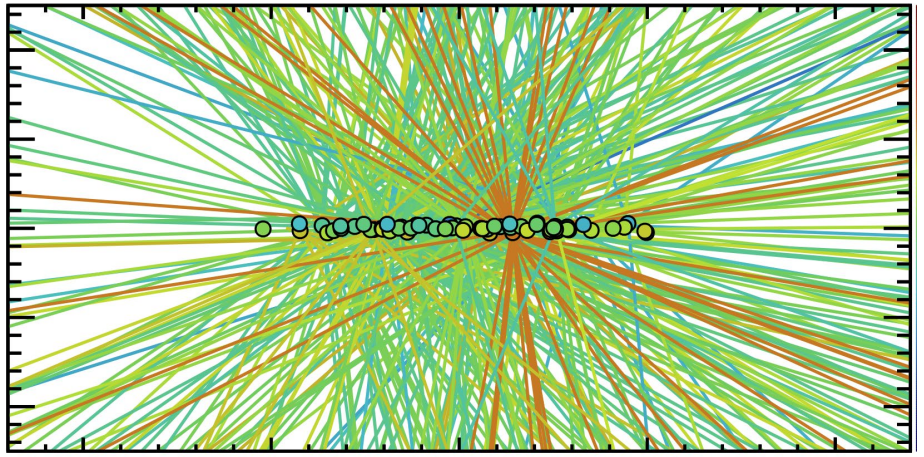
Atlas



CMS



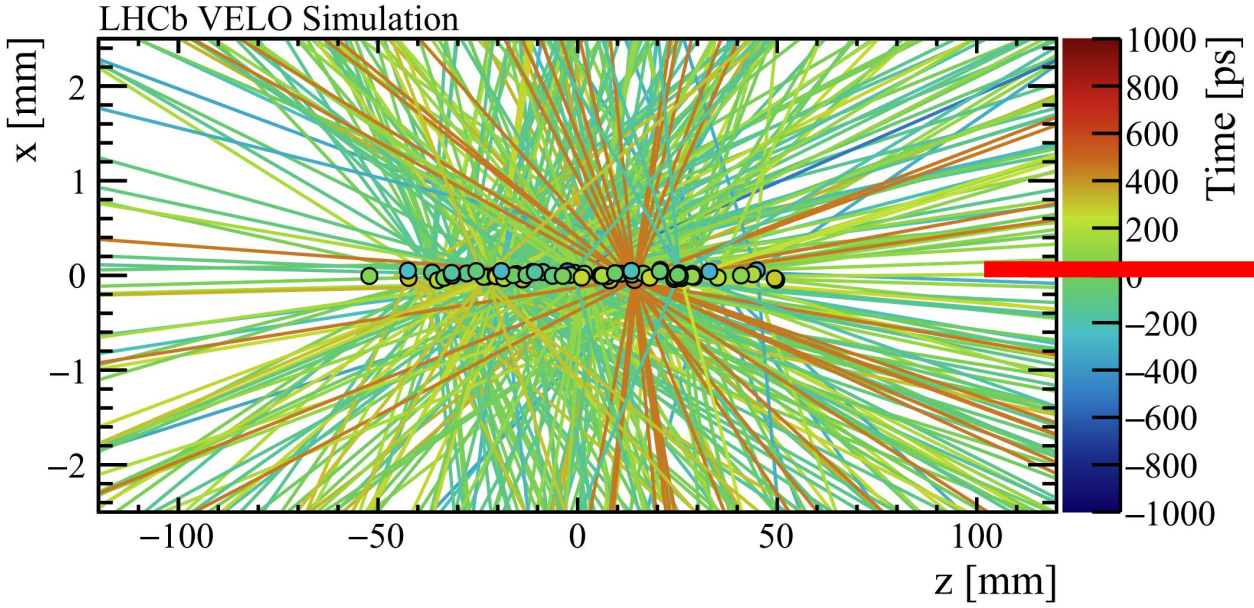
LHCb



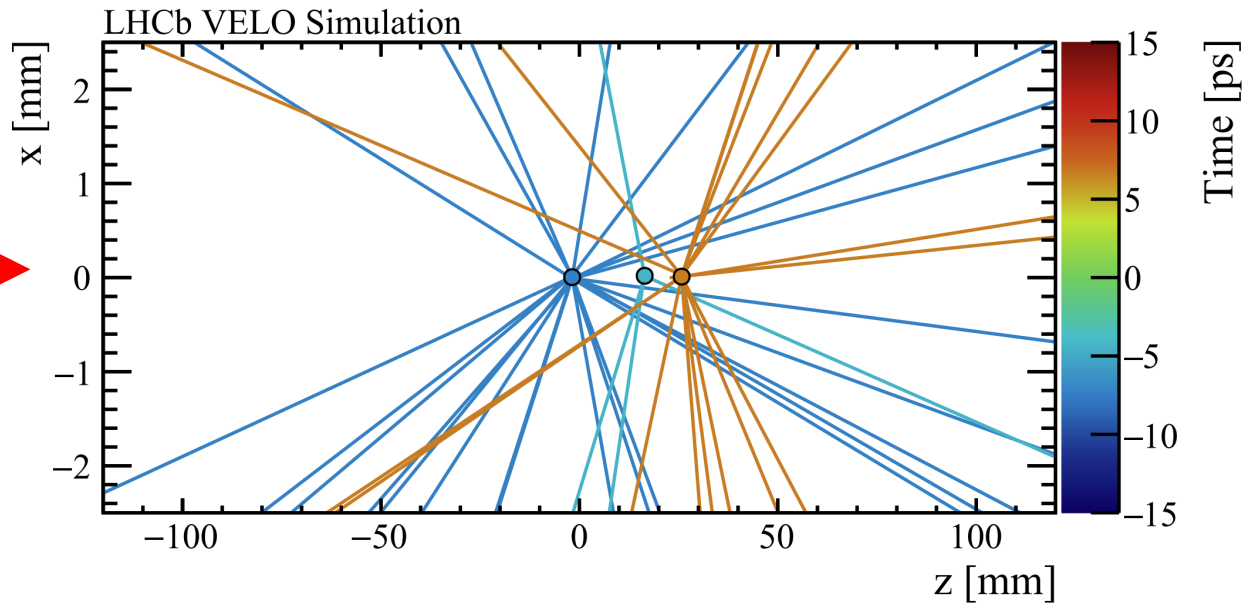
Why fast timing

- 4D tracking can solve the problem
- ~30 ps timing resolution can reduce the pile-up to previous levels

Window: 2000 ps



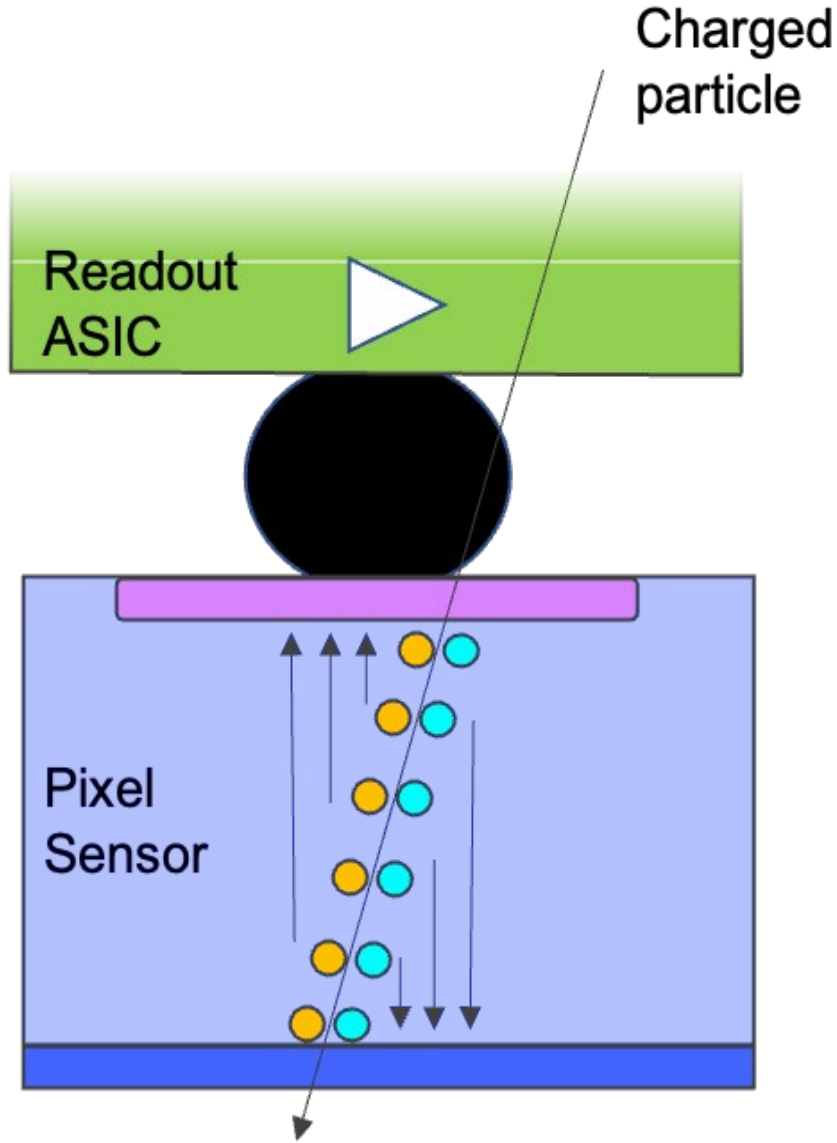
Window: 30 ps



How to get fast timing?

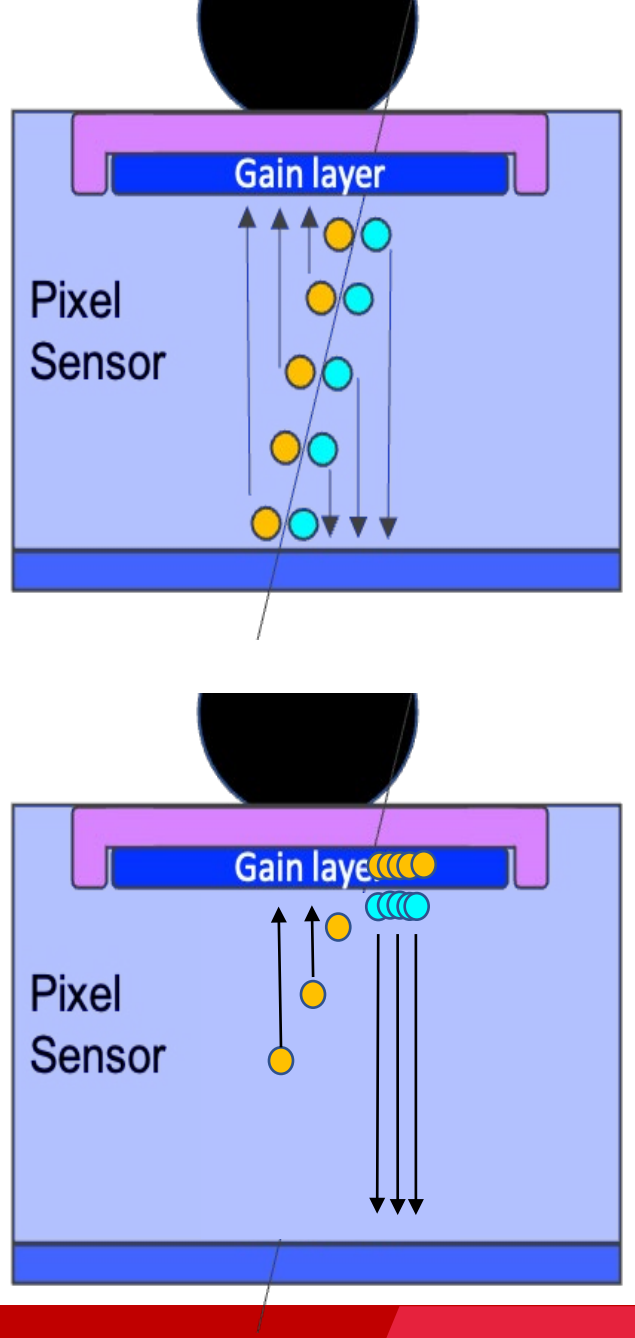
In a hybrid detector : Sensor + ASIC

- Planar sensors too slow to achieve ps timing
- Current ASICs also too slow to achieve O(30ps) timing
- We need new technologies for both



Low Gain Avalanche Diode

- A particle passes through the silicon
- Creates electron hole pairs
- The electrons are multiplied in the Gain layer



TI-LGADs

- Regular LGADs have a no gain region of ~ 100 micron
- Trench Isolation brings this down to ~ 10 micron
- This gives a better fill factor which allows for smaller pixels

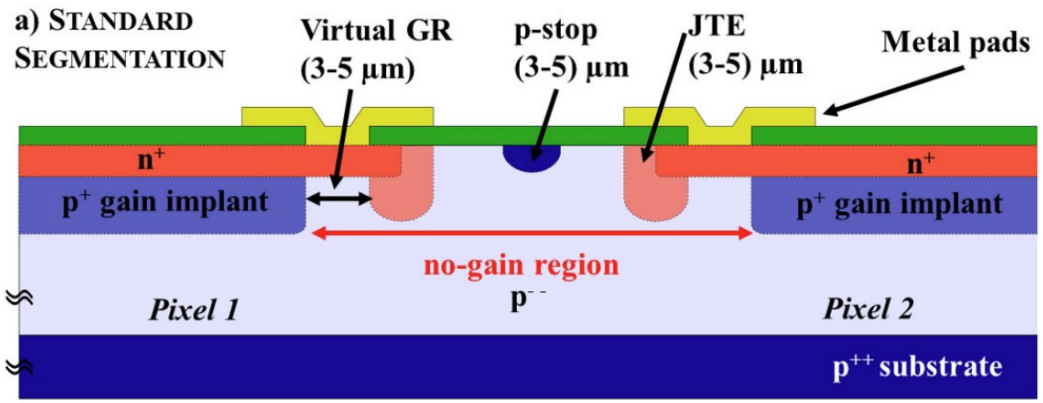
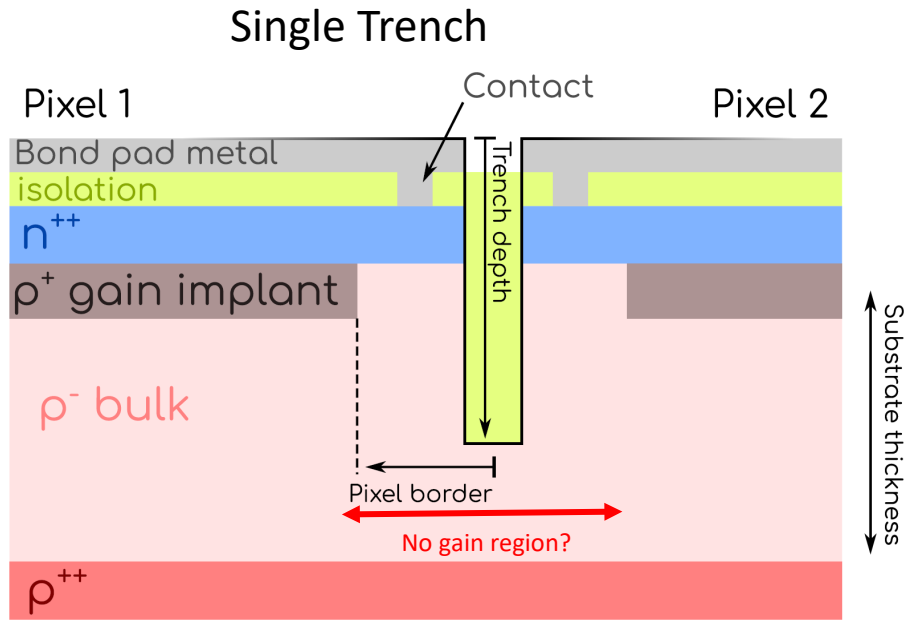
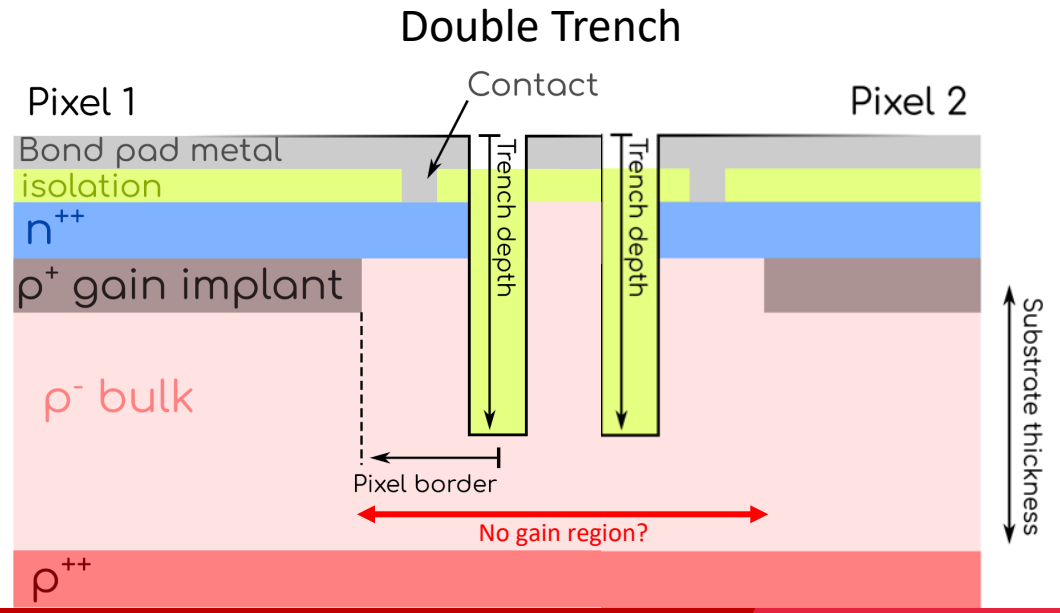


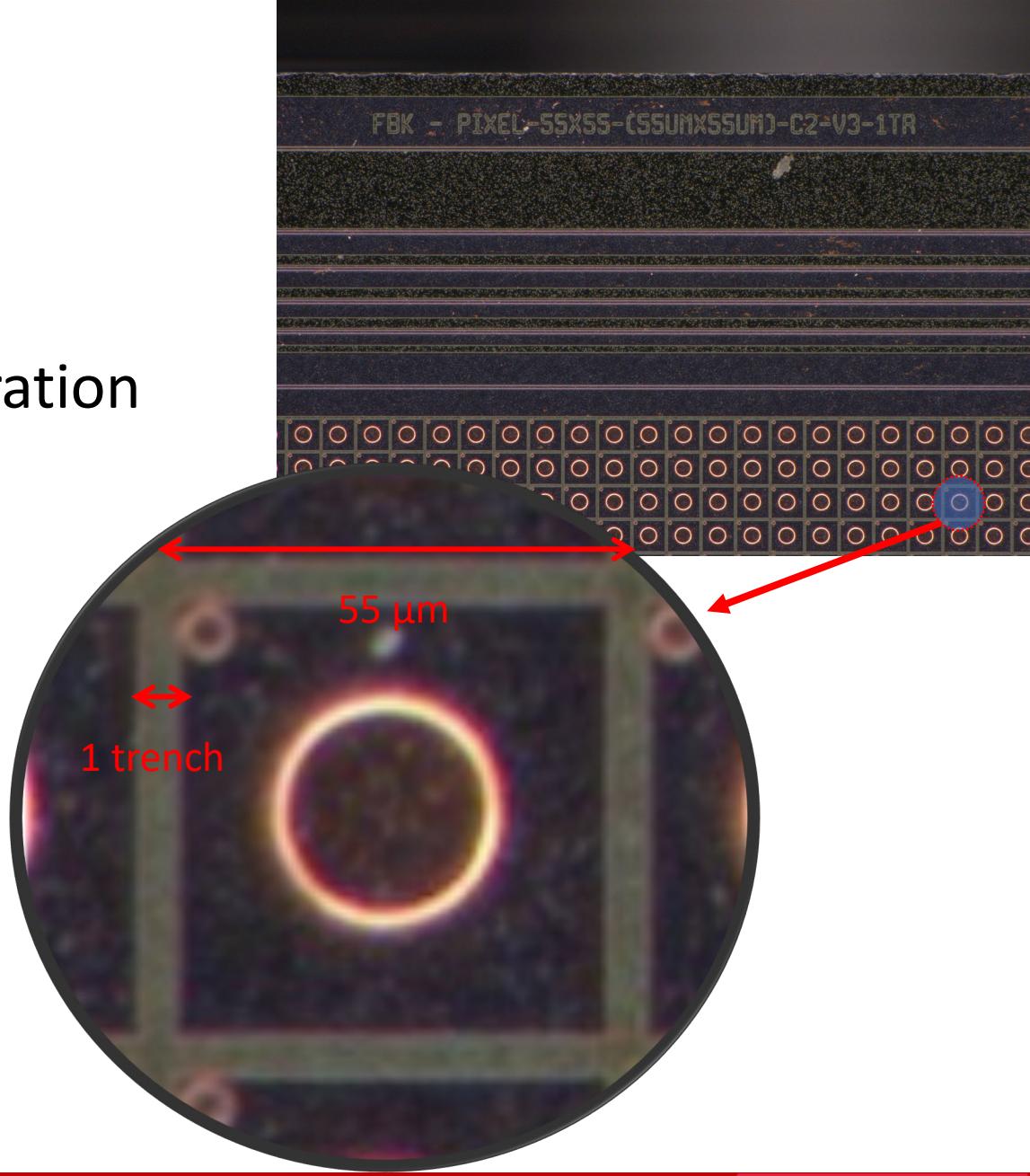
Figure adjusted from
A Comprehensive Characterization of the TI-LGAD Technology
https://doi.org/10.3390/s23136225





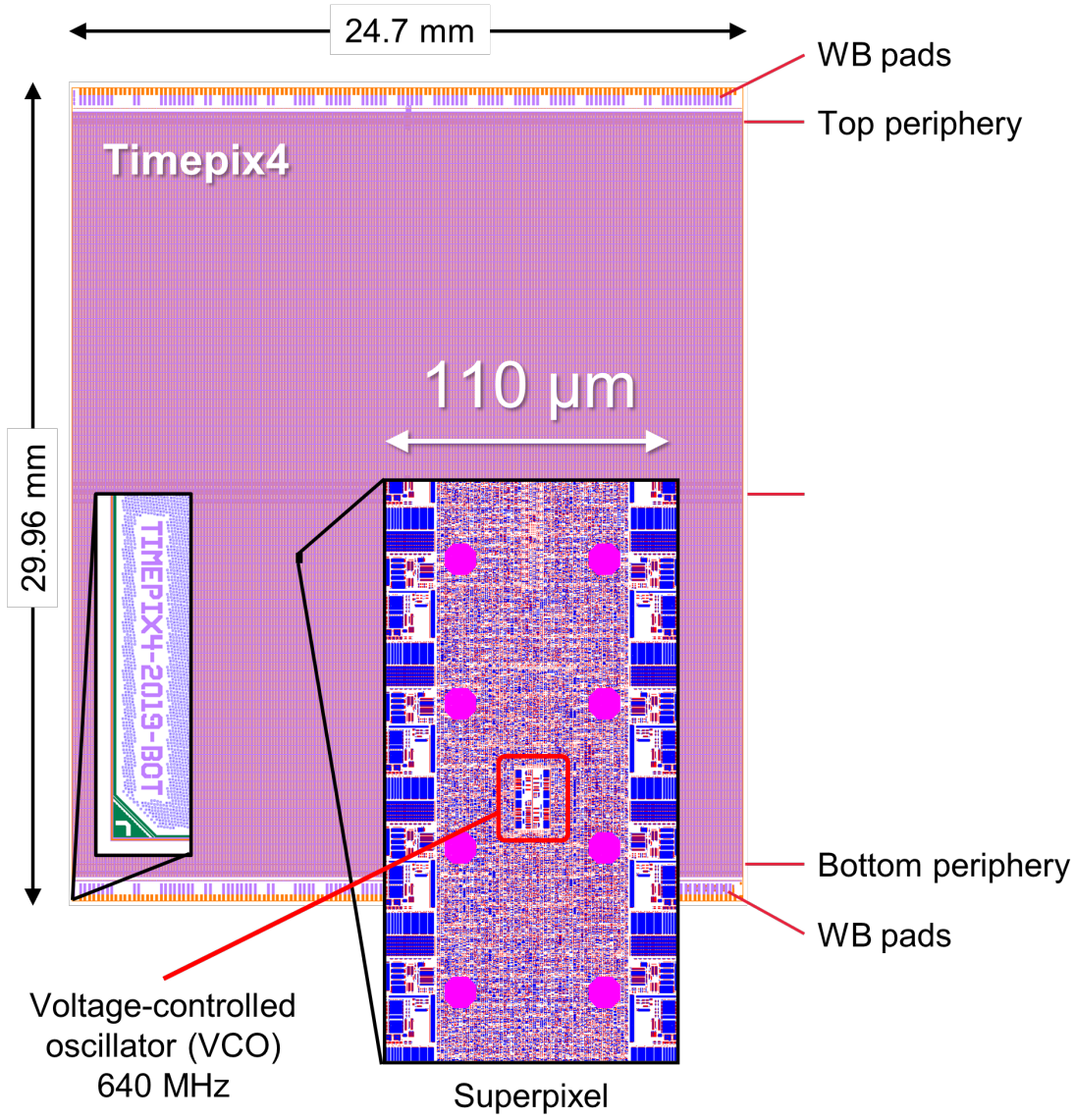
Our sensors

- Produced by FBK for the RD50 collaboration
- 50 micron depletion thickness
- Bump bonded to Timepix4



Timepix 4 ASIC

- Developed by CERN, Nikhef, and IFAE
- 448×512 pixels, 55×55 µm2 pitch
- Simultaneous measurement of Time of Arrival (ToA) and charge deposition (by measuring Time over Threshold (ToT))
- Max rate: 360×10^6 hits/cm^2/s (160 Gb/s for single chip)

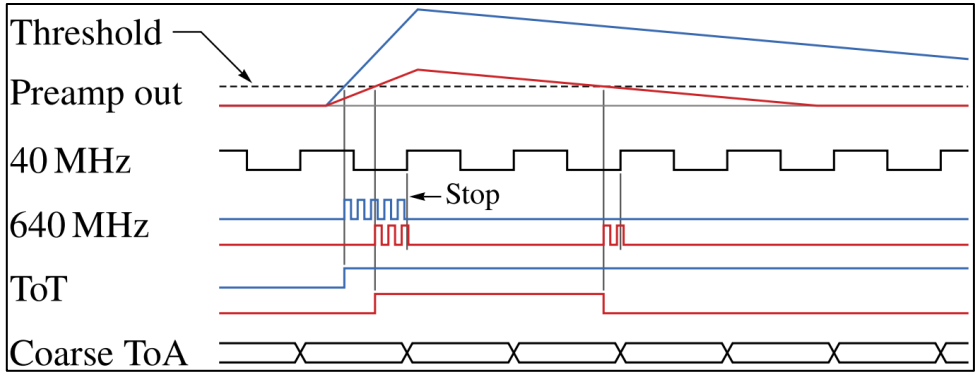


Timing measurements in Timepix4

Time measurement in Timepix4

Two clocks :

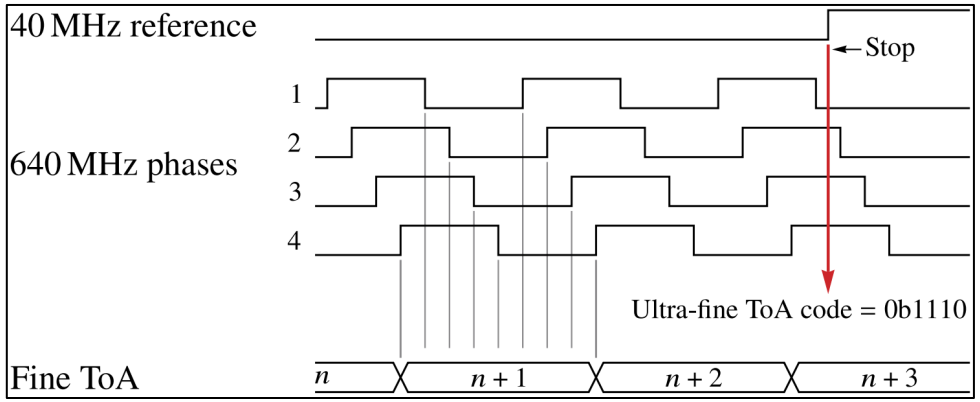
- 40 MHz
- 640 MHz VCO -> FTOA
  - 4 Phases-> 195ps timebins -> uFTOA



Best possible timing resolution ~ 56 ps

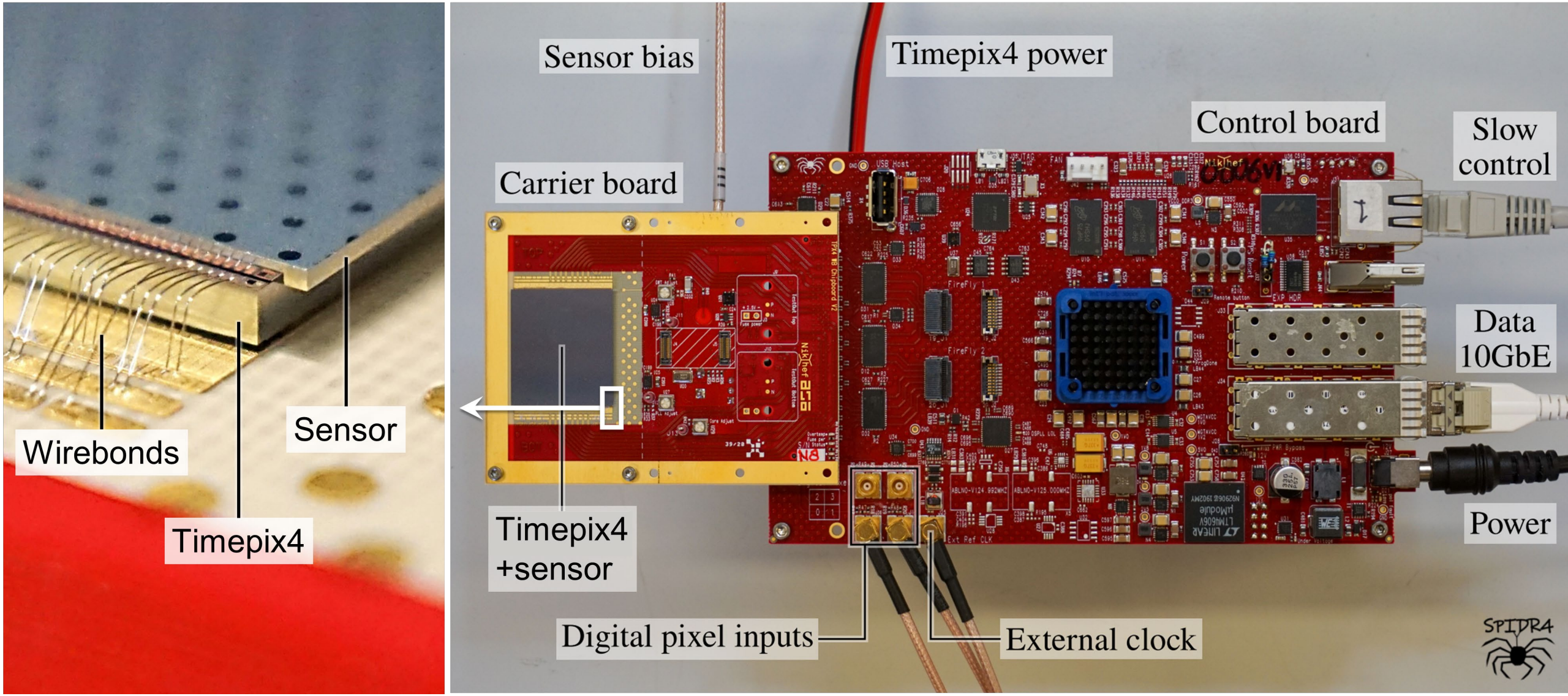
To get anywhere near we need corrections

- Timewalk
- Clock frequencies



Timing performance of the Timepix4 front-end
K. Heijhoff et al 2022 JINST 17 P07006, DOI 10.1088/1748-0221/17/07/P07006

Readout system

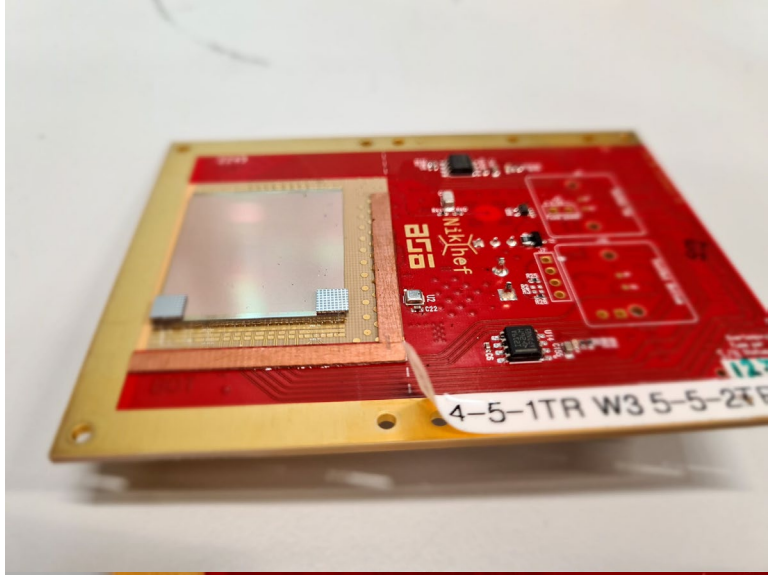


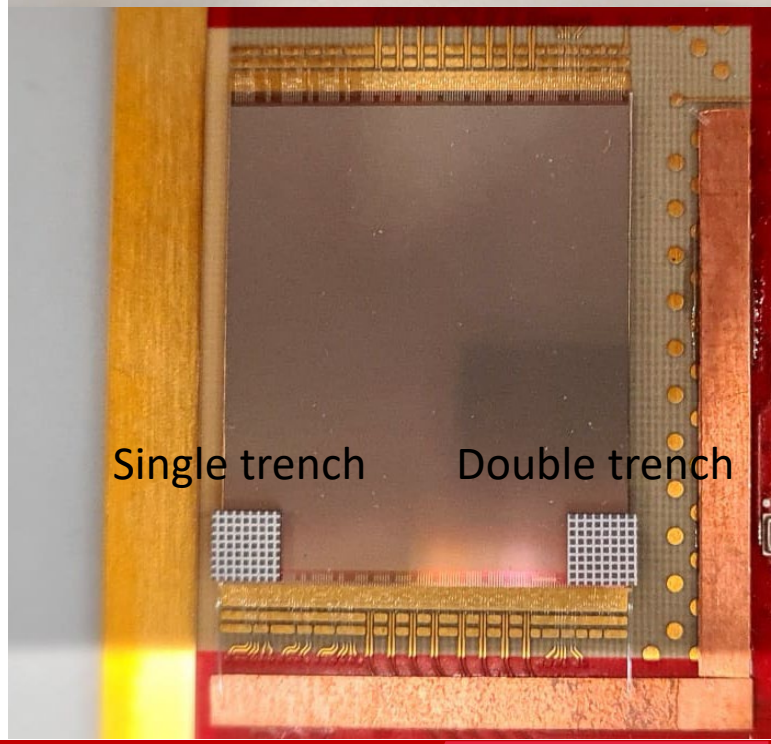
TI-LGAD on TPX4

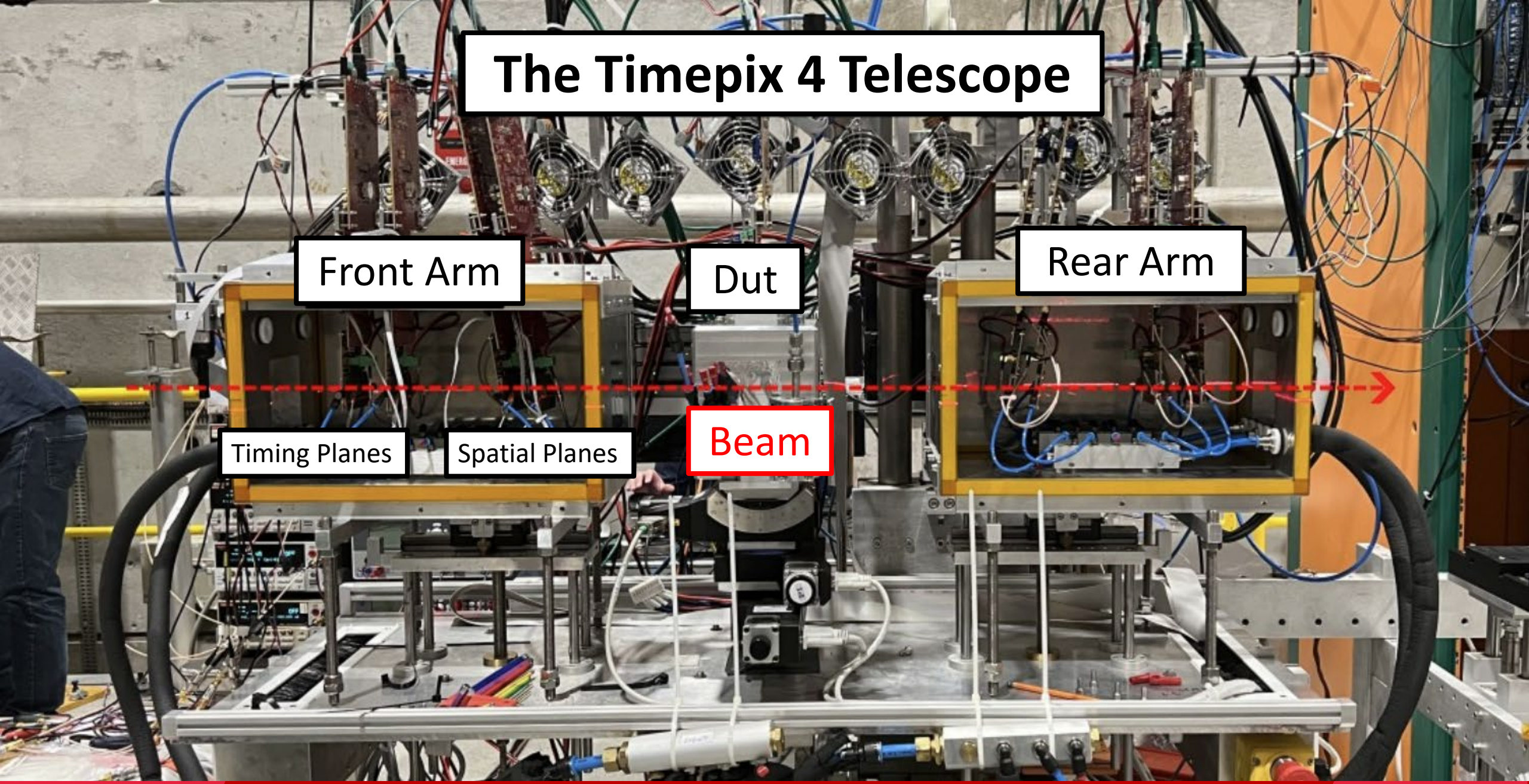
Two assemblies:
Both are full system assemblies -> all pixels read out at the same time

- One functioning single trench assembly
  - Max bias : –100V
  - Single trench and double trench

- Max voltage double trench assembly
  - Max bias : –200V
  - Double trench only
- Per area : 55x55 pixels, 55 micron pixel pitch

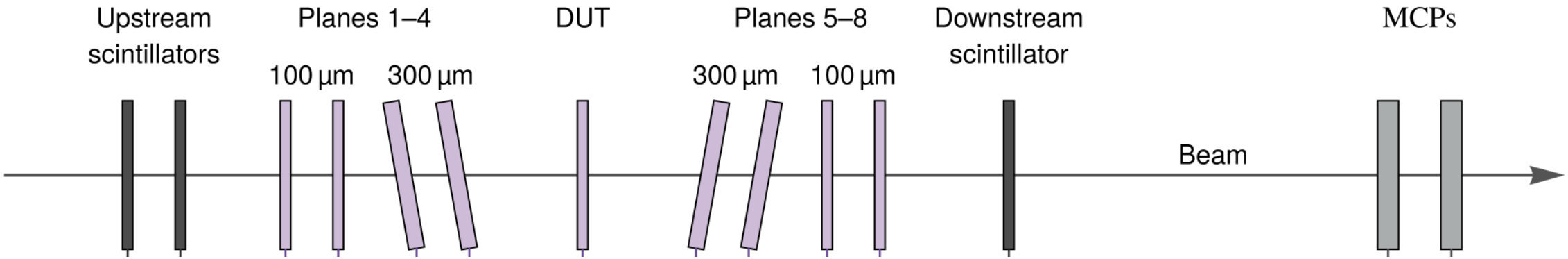





The Timepix 4 Telescope
Front Arm
Dut
Rear Arm
Timing Planes
Spatial Planes
Beam

Timepix4 telescope

- 4 x 300 micron tilted planes for spatial resolution -> **track resolution of ~ 2.5 micron**
- 4 x 100 micron planes for timing information **~ 160-180 ps per plane**
  -> Combined tracktime ~ 90 ps
- MCPs for reference timing **~ 12ps**
- Cooled using glycol at **~ 20 °C**

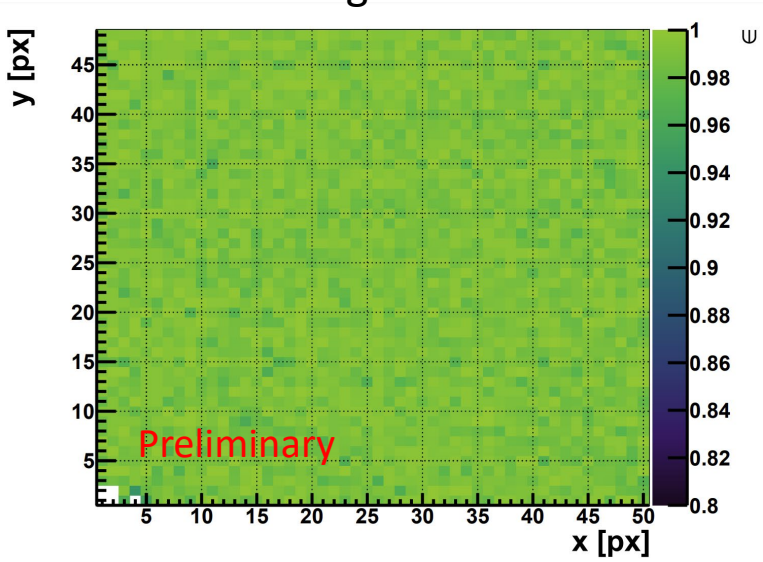


Efficiency – pixel behaviour

- Single trench has higher efficiency, similar to 50 µm planar

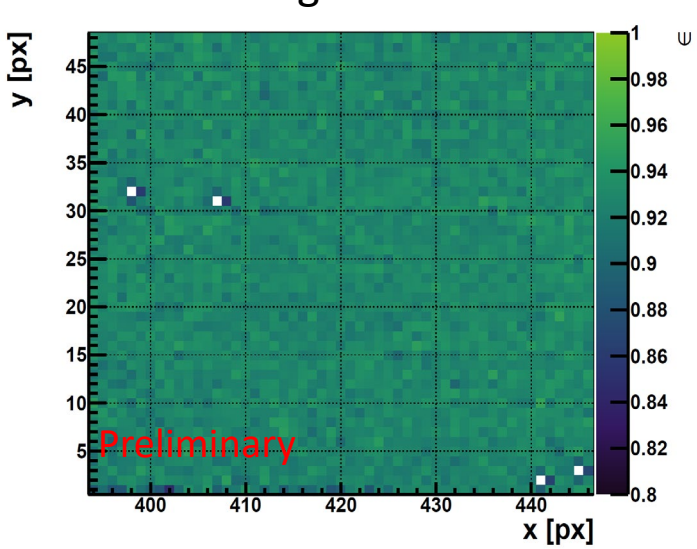
Single trench – 100V

Average ~ 97%



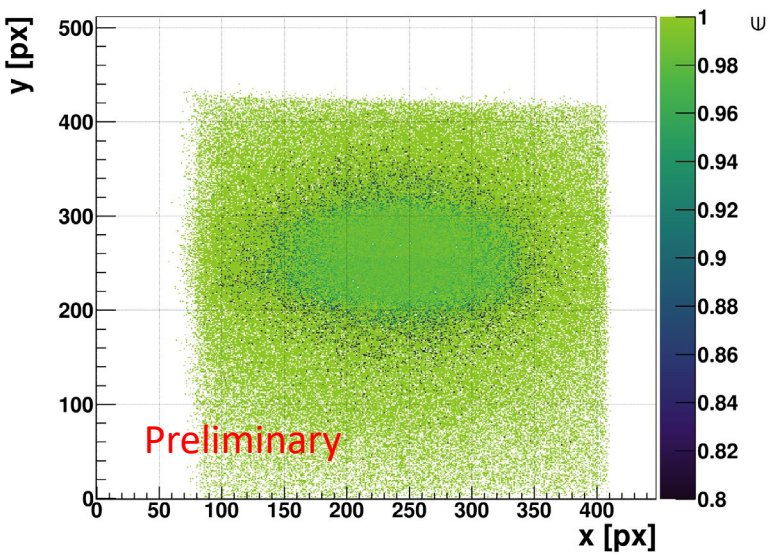
Double trench – 200V

Average ~ 93%



Reference 50 µm planar – 60V

Average ~ 97%



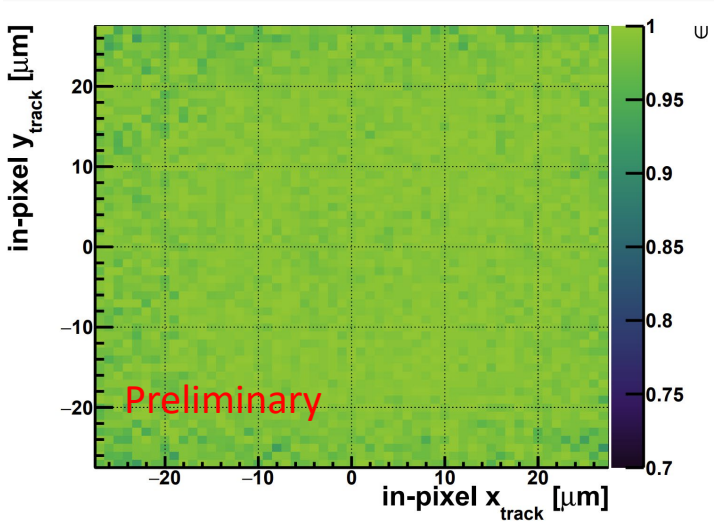
Efficiency - intrapixel

- Loss of efficiency towards the edges and corner in double trench, not found in single trench

Preliminary

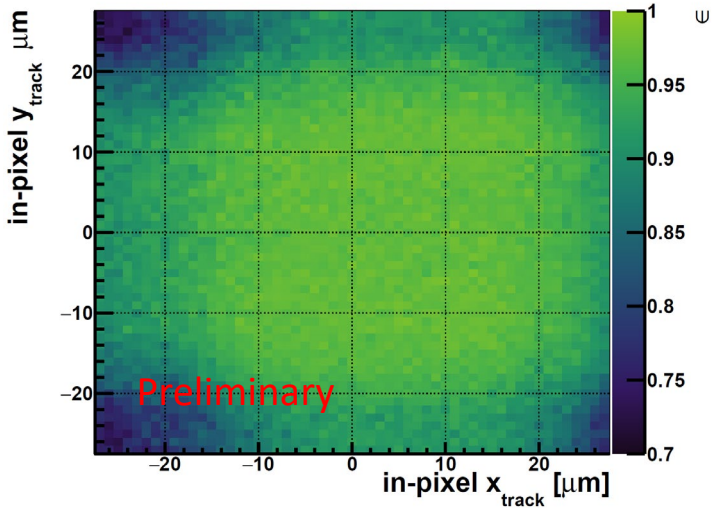
Single trench – 100V

Average ~ 97%



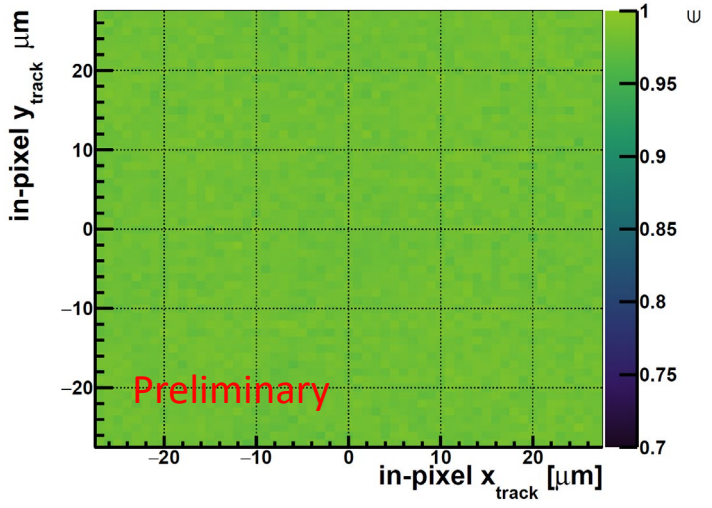
Double trench – 200V

Average ~ 93%



Reference 50 µm planar – 60V

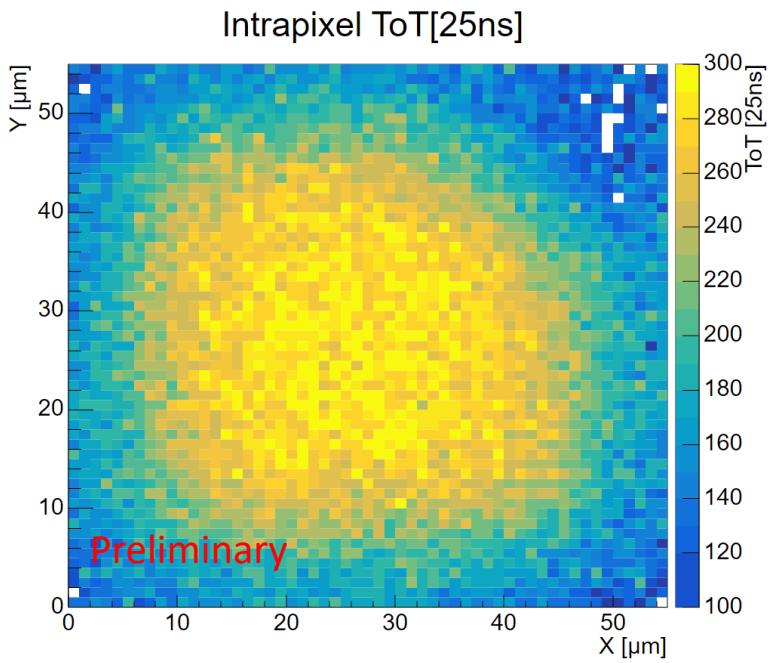
Average ~ 97%



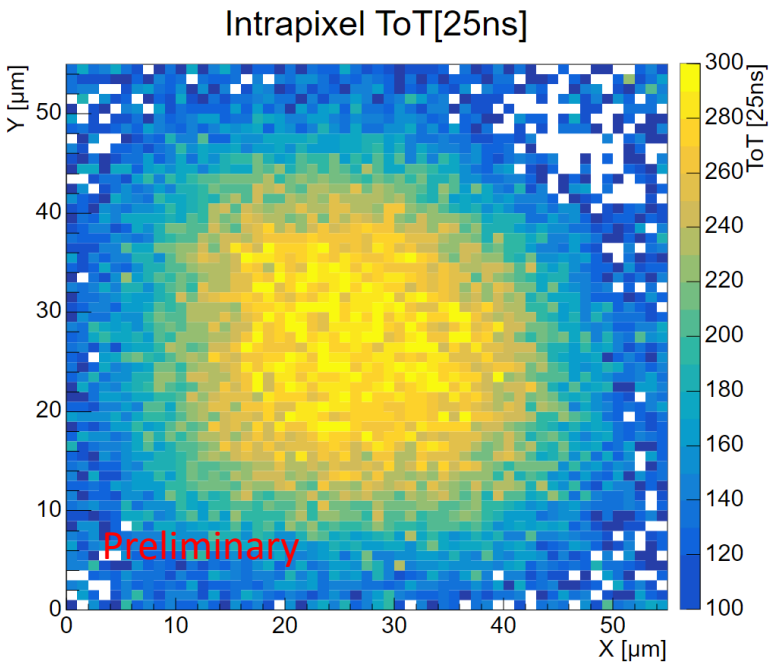
Gain

- Gain differs between single and double trench, same asymetric shape
- Larger area with gain for the single trench device

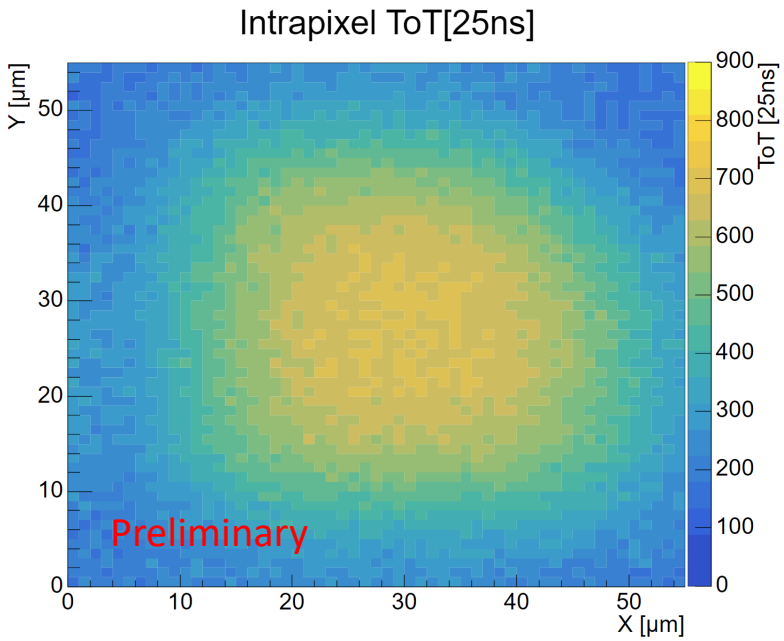
Single trench – 100V



Double trench – 100V



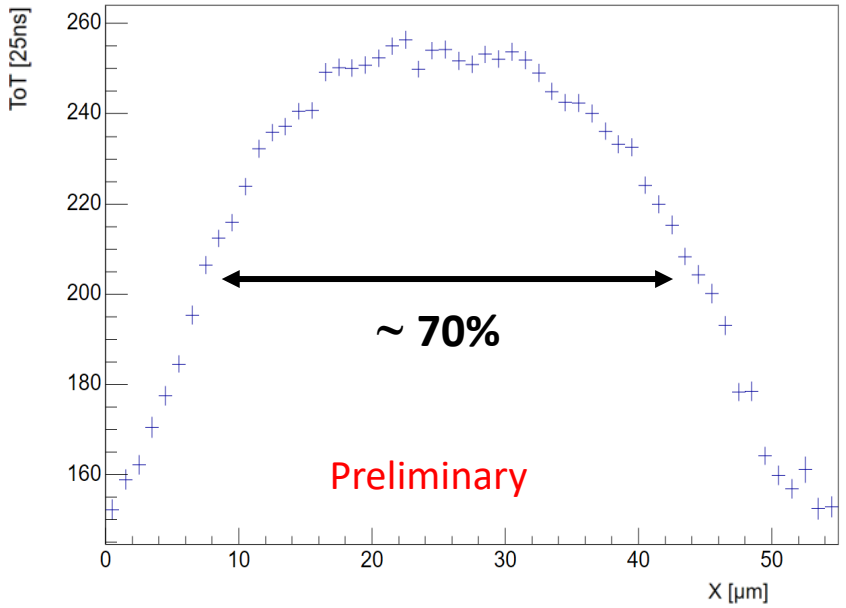
Double trench – 200V



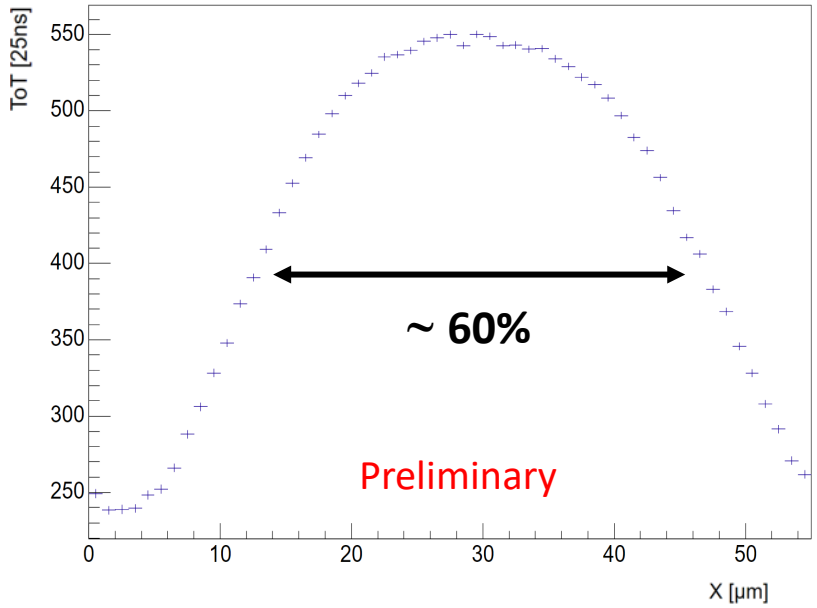
Gain profile - x

- Asymmetry for double trench likely due to misalignment
- Single trench shows gain in ~ 70% of the width -> ~ 49% of the pixel
- Double trench shows gain in ~ 60% of the width -> ~ 36% of the pixel

Single trench – 100V



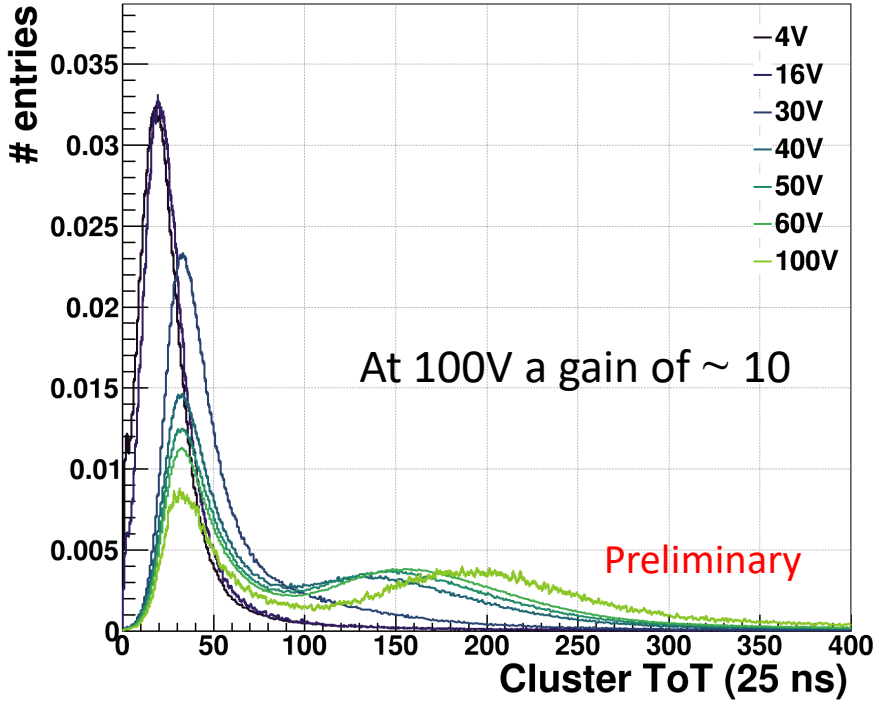
N127 – Double trench – 200V



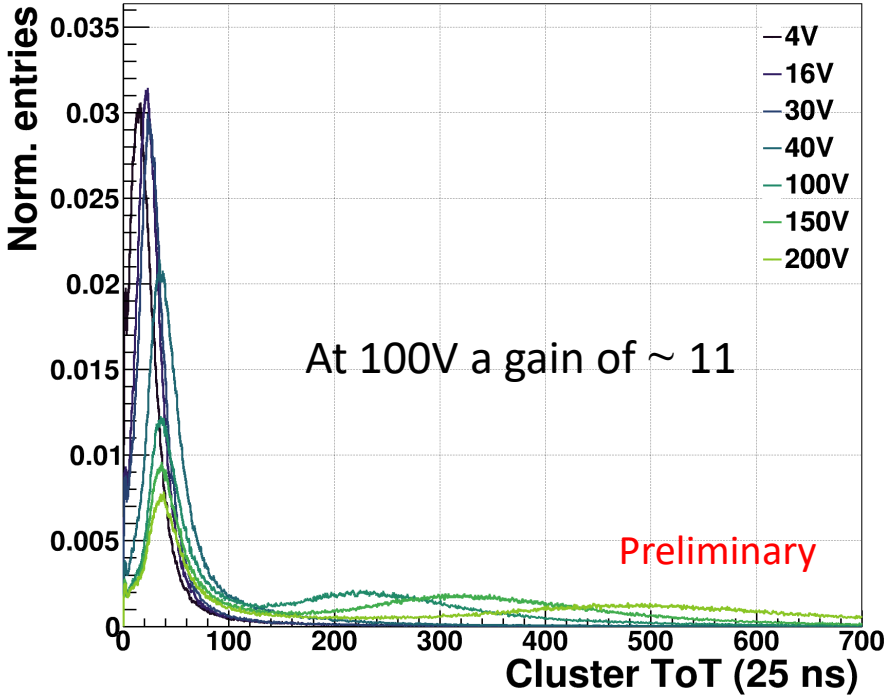
Gain vs Bias

- Single and double trench from different wavers -> explains gain difference
- Gain peak is lower for the double trench -> Smaller area with gain.

Single Trench

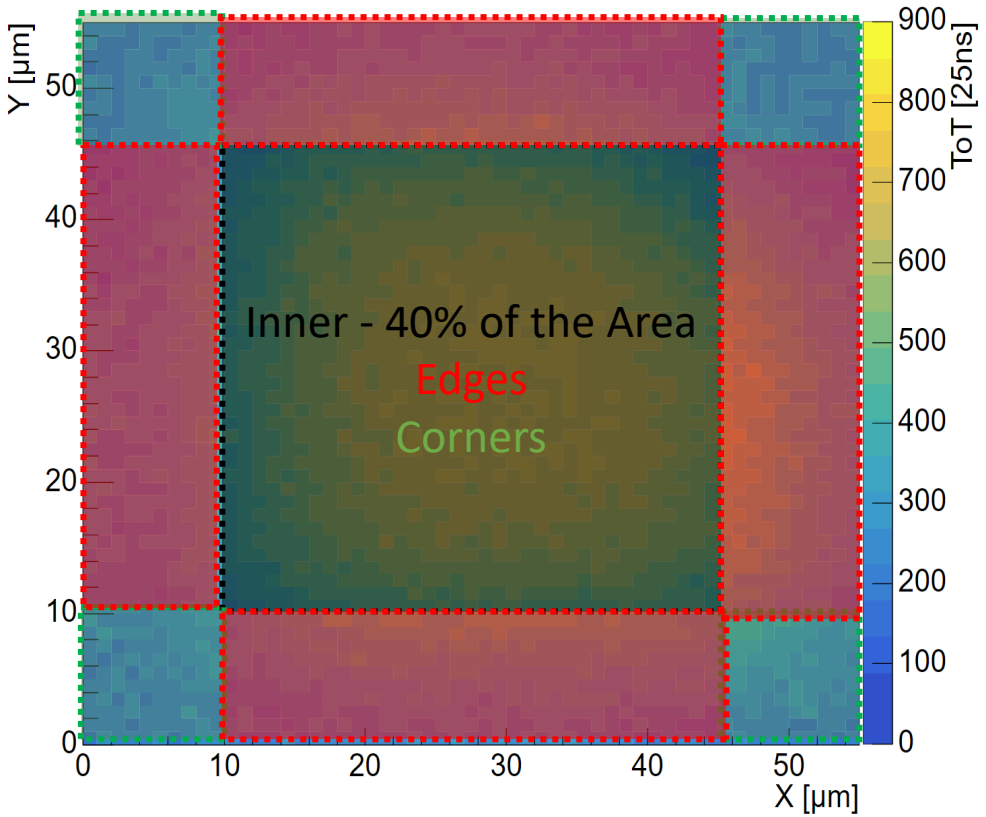


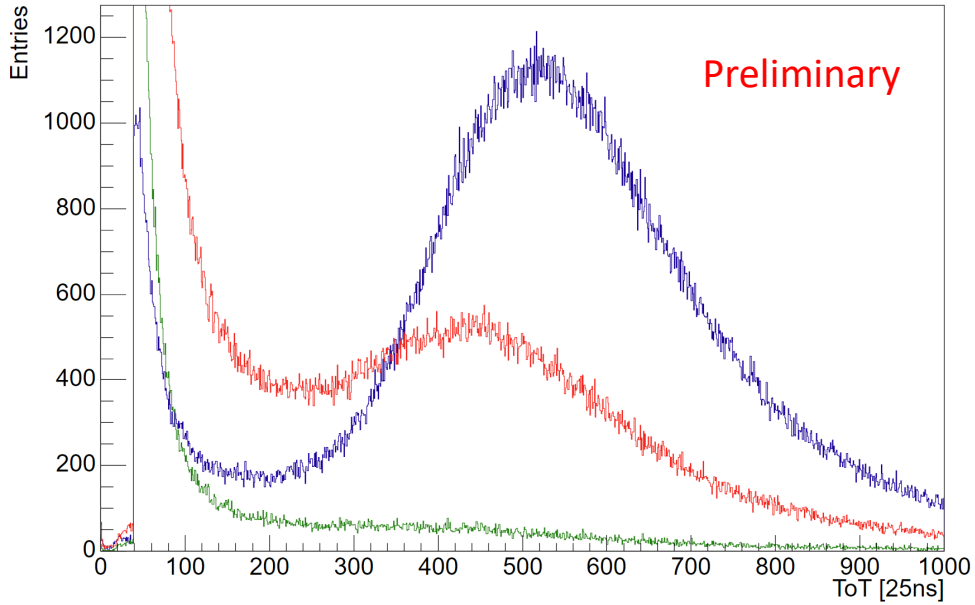
Double Trench

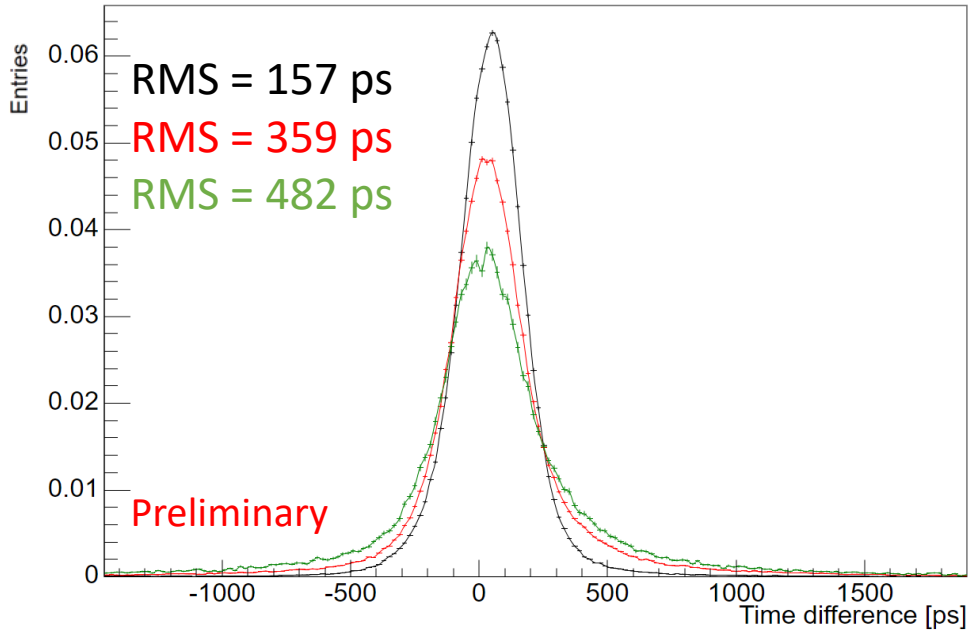


Timing

- Double trench 200v
- Outer area's have lower ToT -> More timewalk
- Only 40% shows good timing performance – 132 ps



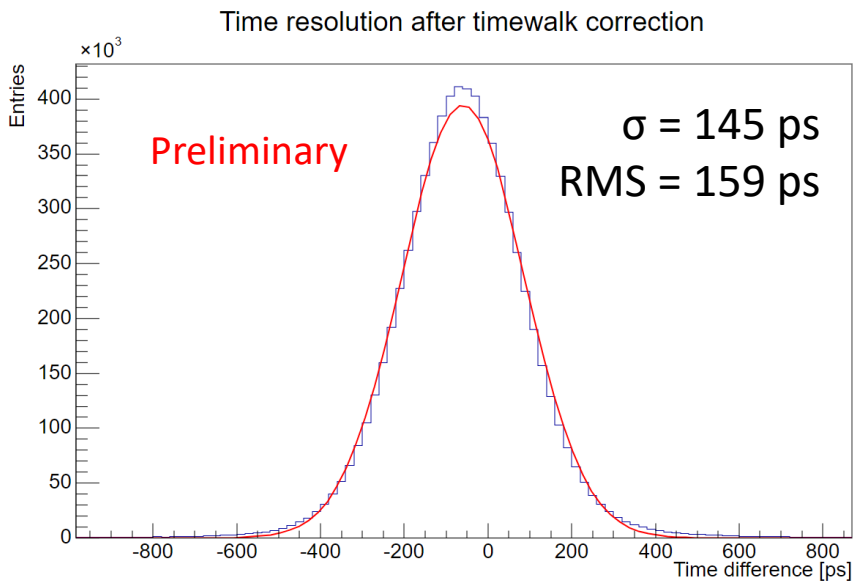




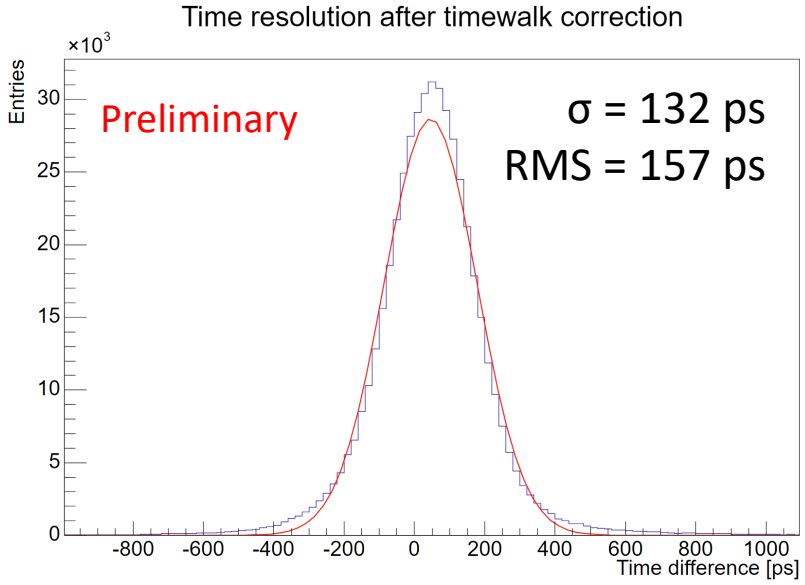
Timing

- Inner 40% timing performance
- No VCO correction

Single trench – 100V



Double trench – 200V



Summary + Outlook

Achieved

- First full system assembly measurements with TI-LGADs on Timepix4
- Found 132 ps time resolution after timewalk corrections
- Good timing performance at 40% of the area due to gain mainly being present in the central area.

Goals

- 100 ps timing resolution with VCO correction and improved Timewalk correction
- Investigate the impact of the no gain region around the trenches -> Use a TPA laser to fully study this in 3D
- New sensors with a larger area and more pixels are coming.
- Compare with a no gain TI-LGAD on Timepix4