UNIVERSITÄT HEIDELBERG
ZUKUNFT SEIT 1386

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Testbeam Characterization

of the

ATLASpix _Simple Pixel Sensor Prototype

in View of the Requirements for the

CLIC Tracking Detector

Jens Kroeger

(Heidelberg University and CERN)

on Behalf of the CLICdp

CLIC Workshop 2019

Detector Requirements

- **CLIC Tracking Detector:**

  → ~140 m² silicon

  → **triggerless readout**
  in 20 ms gaps between bunch trains

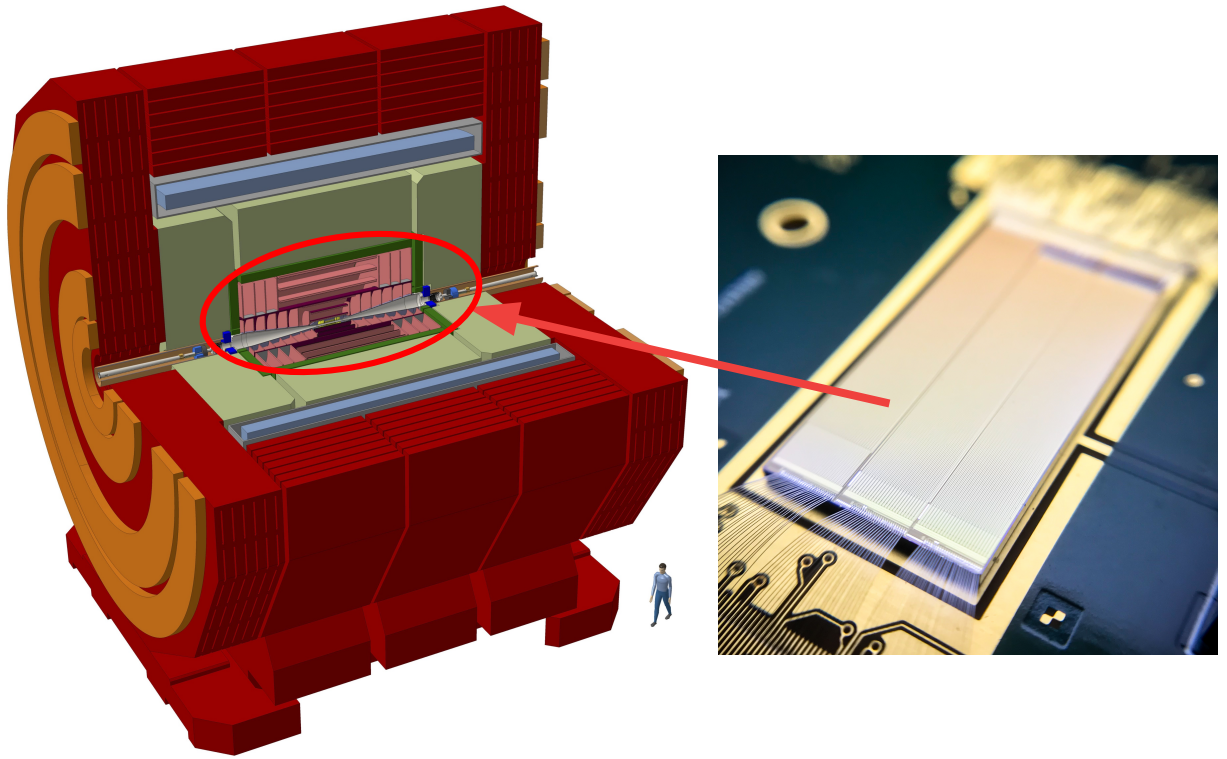
  → spatial resolution: ~ 7 µm (transversal)
  1-10 mm pixel size (long.)

  → timing resolution: ~ 10 ns

  → material budget: ~ 1-1.5 % X_0/layer
  (<200 µm silicon)

  → hit detection efficiency: >99.7-99.9%

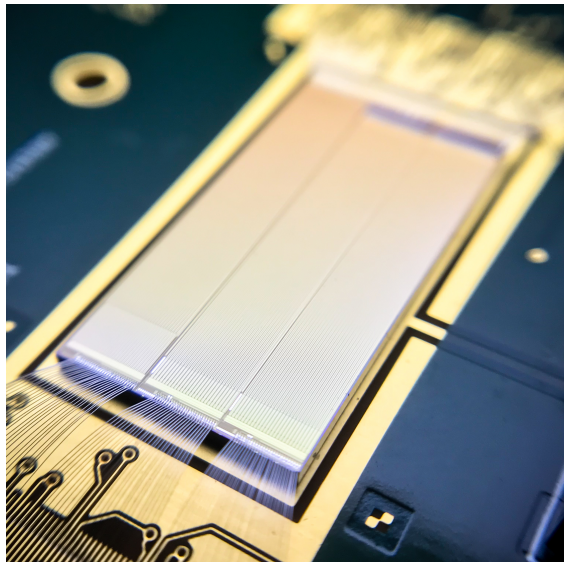
- **Vertex Detector**
  → even more stringent
  → not covered here

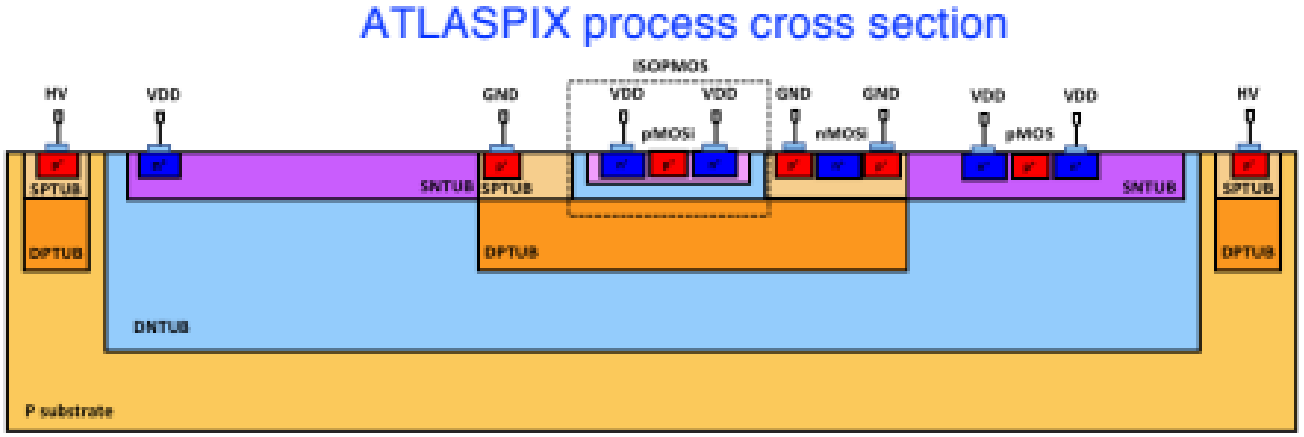


see also *CLICdp-Note-2017-002*

Introduction: ATLASpix

- initially designed for **ATLAS ITK Upgrade**
  → here: test wrt CLIC tracker requirements
- High Voltage Monolithic Active Pixel Sensor (**HV-MAPS**)
  → fully integrated readout
  → fast charge collection
  → low material budget
- **commercial** 180nm HV-CMOS process
  → reduction of cost
- substrate resistivity 20-1000 Ωcm
  → here: **200 Ωcm**
- 100 µm thick
  → can even be thinned to 50 µm

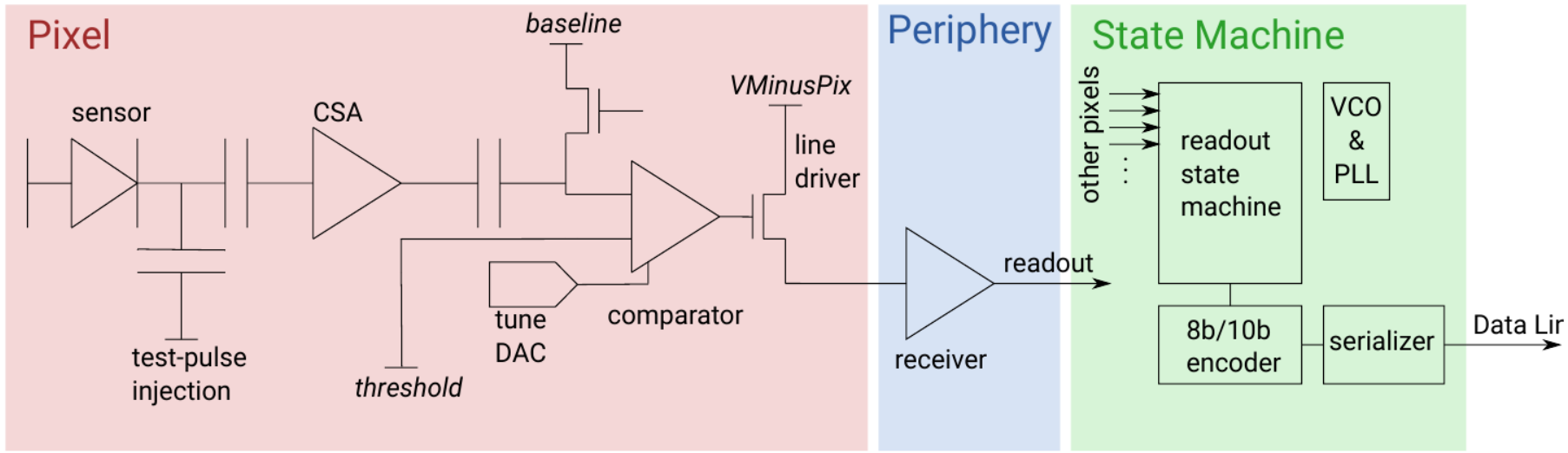


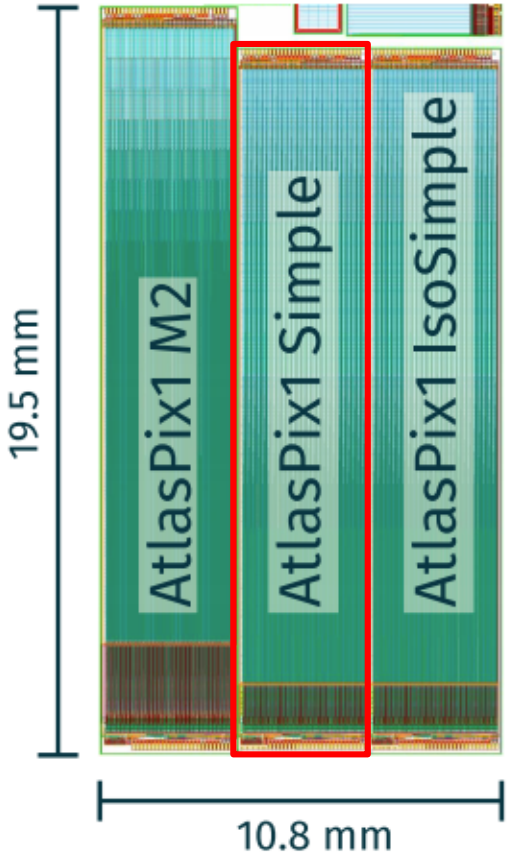


Introduction: ATLASpix

- 3 separate chip flavours:
  - → Simple
  - → Isosimple
  - → M2

- here: **Simple**
  - → triggerless column drain readout
  - → 25 x 400 pixels
  - → 130 µm x 40 µm pitch
  - → 10 bit time-of-arrival
  - → 6 bit time-over-threshold

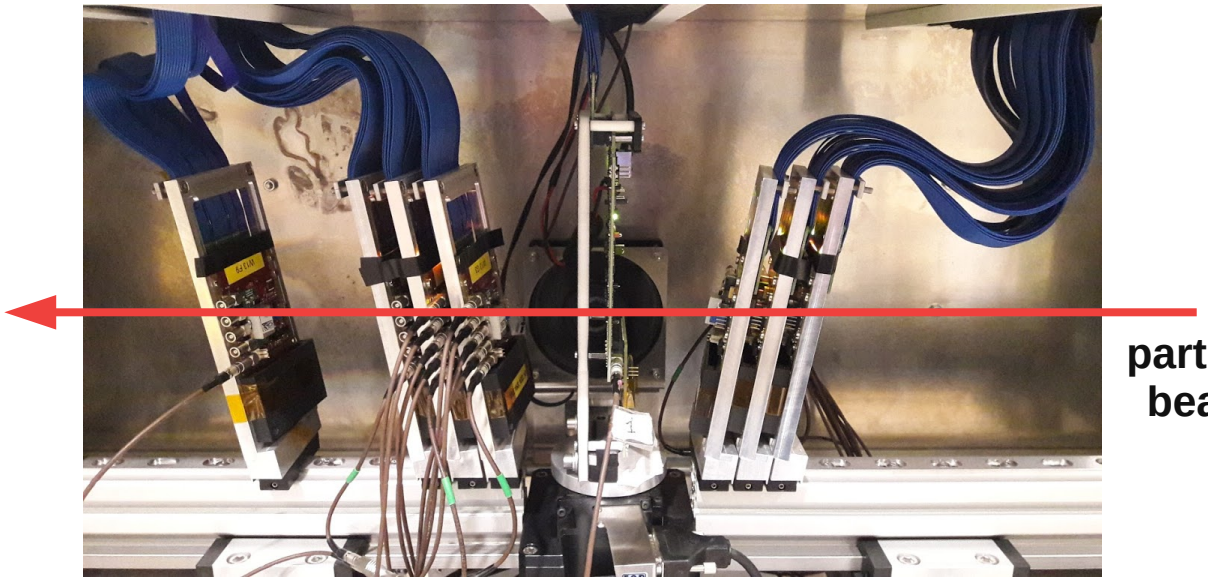


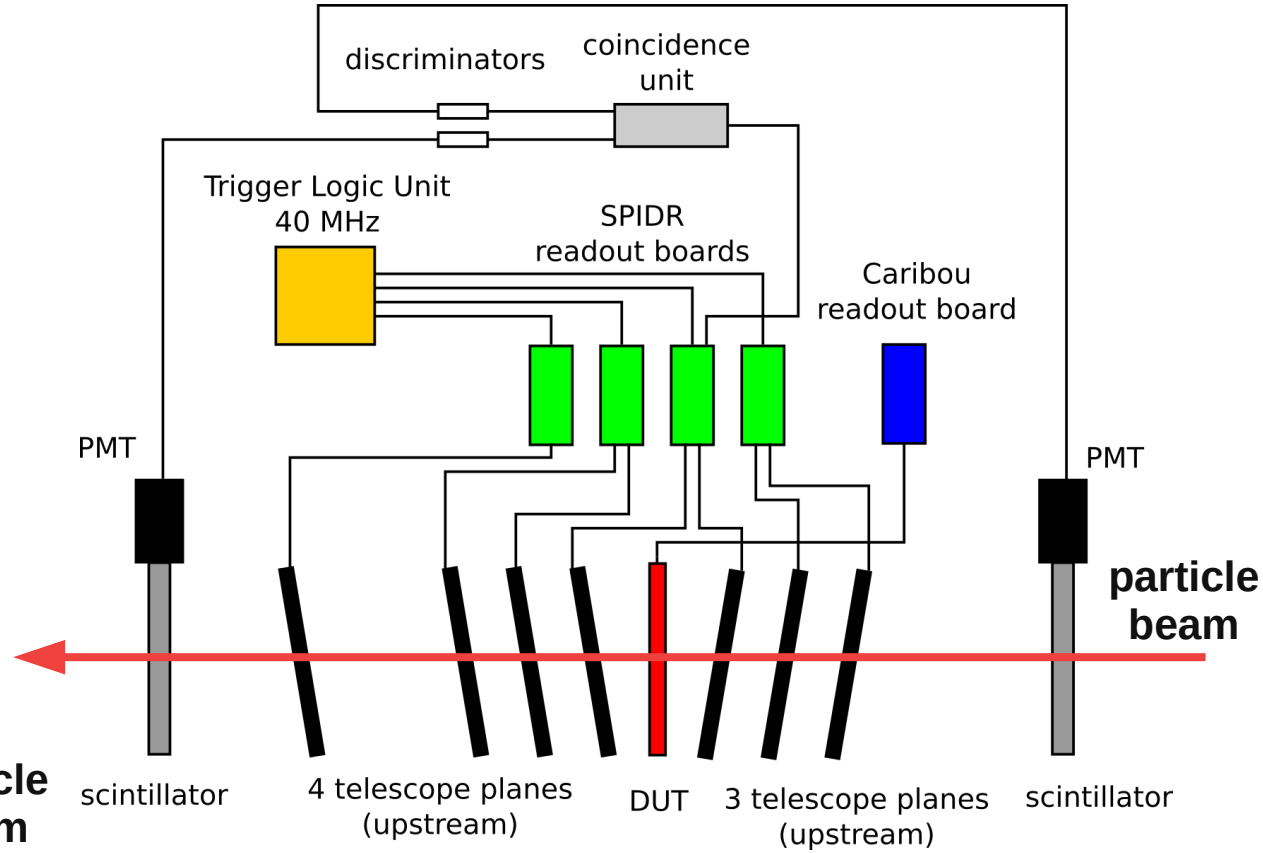


Beam Telescope

- **telescope:** Timepix3
  - → 7 planes (3 upstream, 4 downstream)
  - → pointing resolution ~ 1.8 µm
  - → track time resolution ~ 1 ns

- **device-under-test:** ATLASpix_Simple





Spatial Resolution

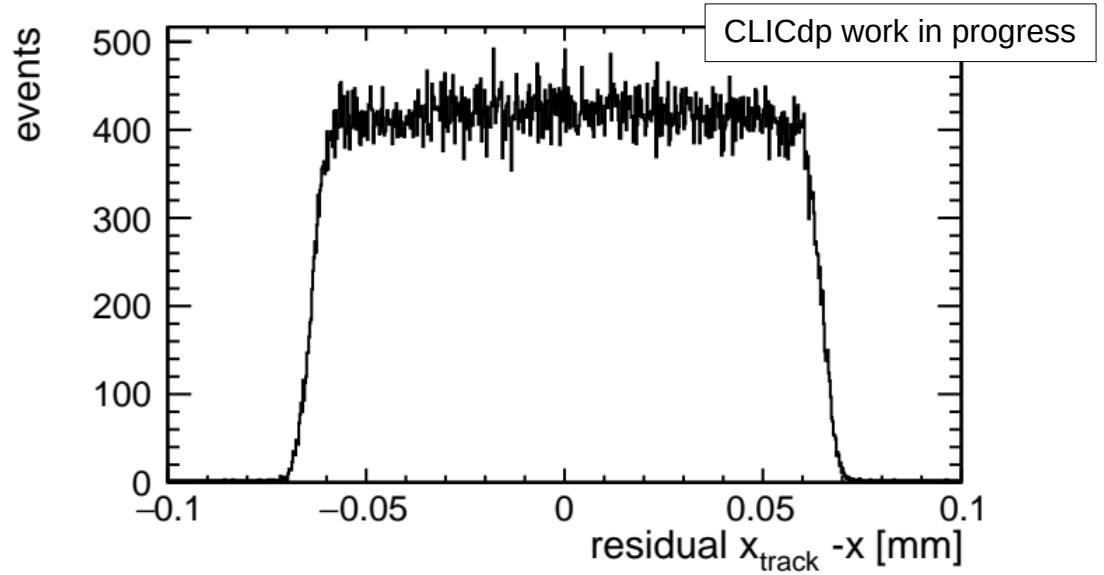
- residual = $x_{track} - x_{hit}$
- spatial resolution:

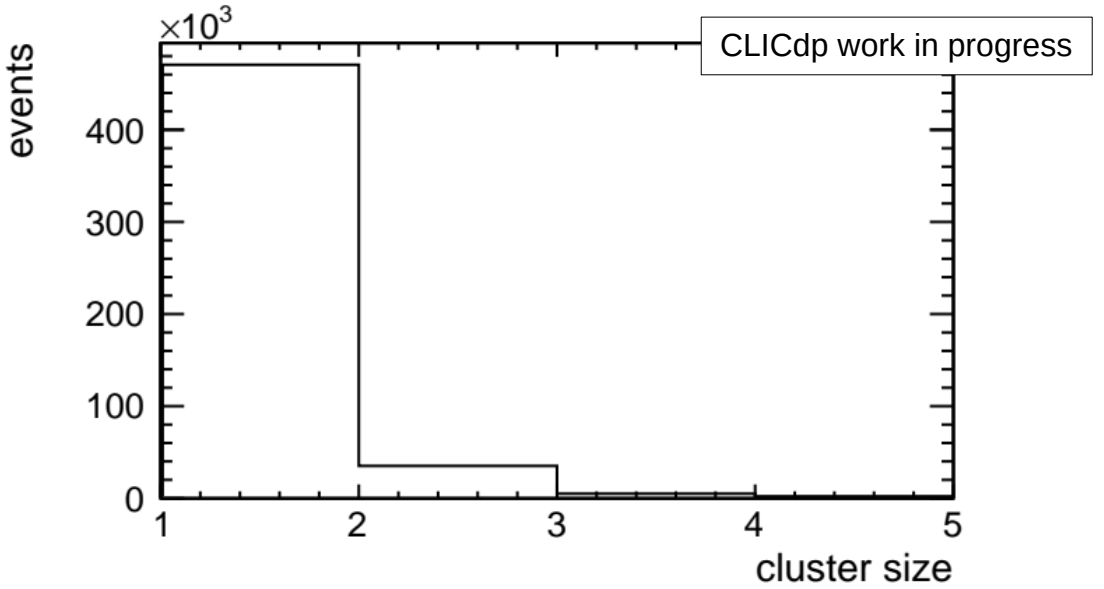
$$RMS_{total} = \sqrt{RMS^2_{telescope} + RMS^2_{DUT}}$$

$$\rightarrow \quad RMS_{total} \approx RMS_{DUT}$$

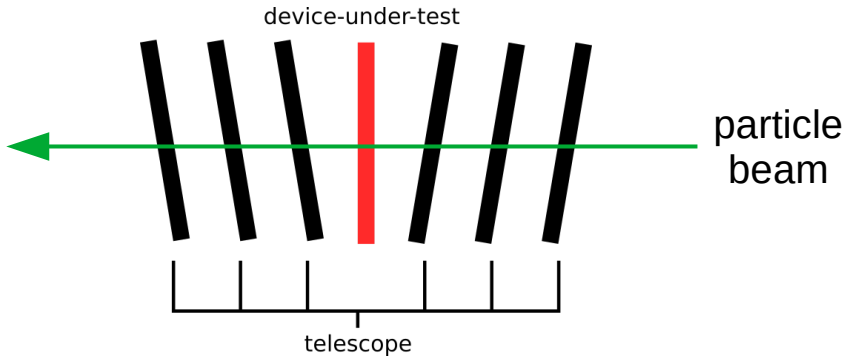
- **RMS in x ~ 37.0 µm**
  → expect 37.5 µm = 130 µm/√12
- **RMS in y ~ 11.3 µm**
  → expect 11.6 µm = 40 µm/√12

- very few multi-pixel cluster
  → not much charge sharing





Timing Resolution



- **time correlation** =  (track) –  (hit on DUT plane)

- timing resolution:

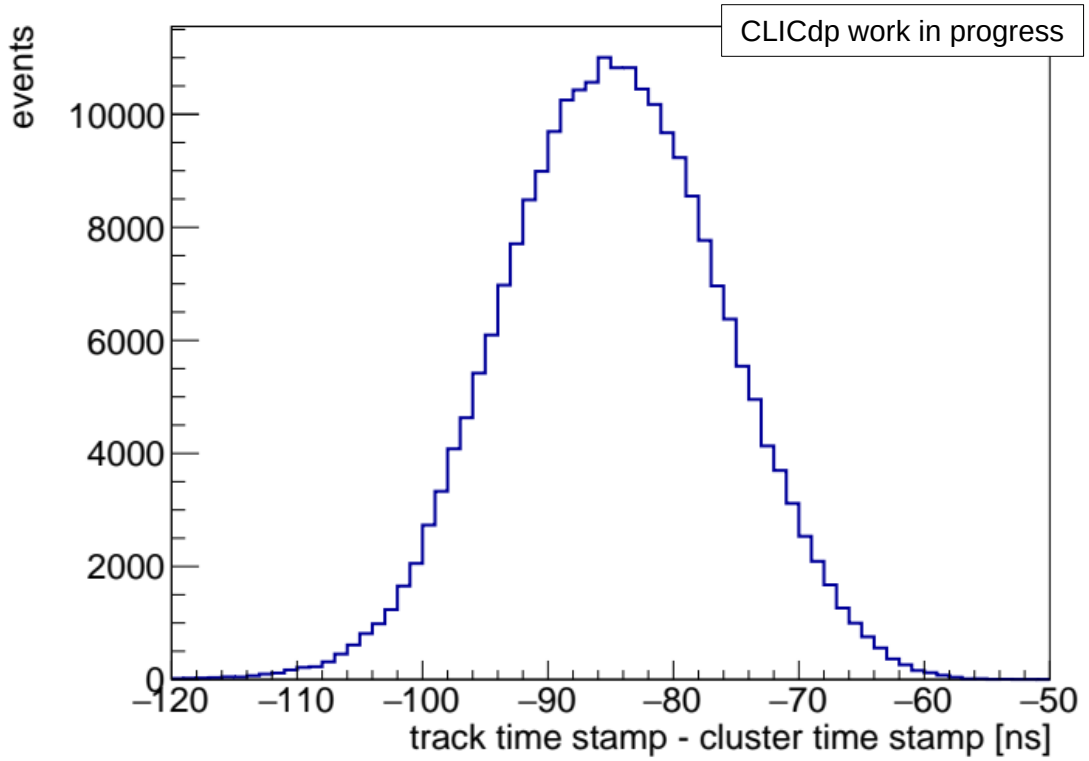
$$RMS_{total} = \sqrt{RMS^2_{telescope} + RMS^2_{DUT}}$$

→ $$RMS_{total} \approx RMS_{DUT}$$

- smeared by **row delay** (next slide)

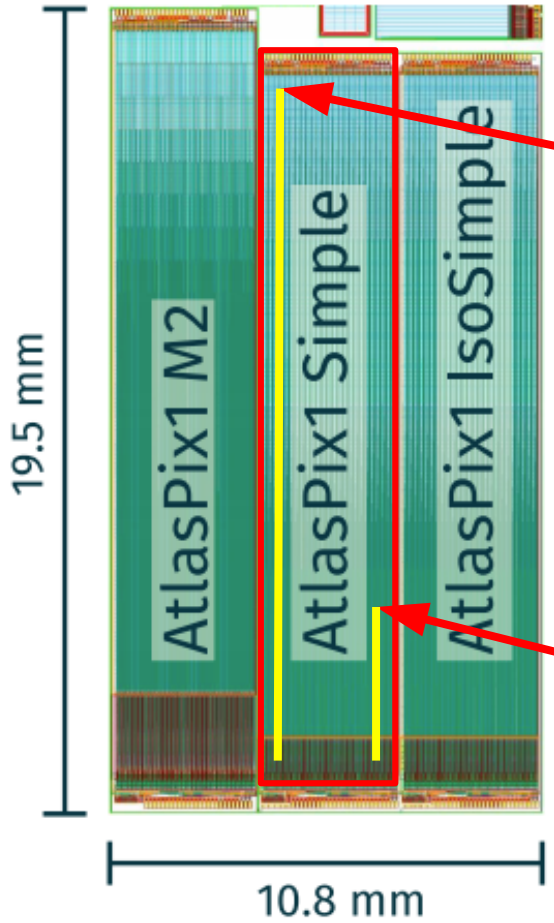
- tail towards late timestamps

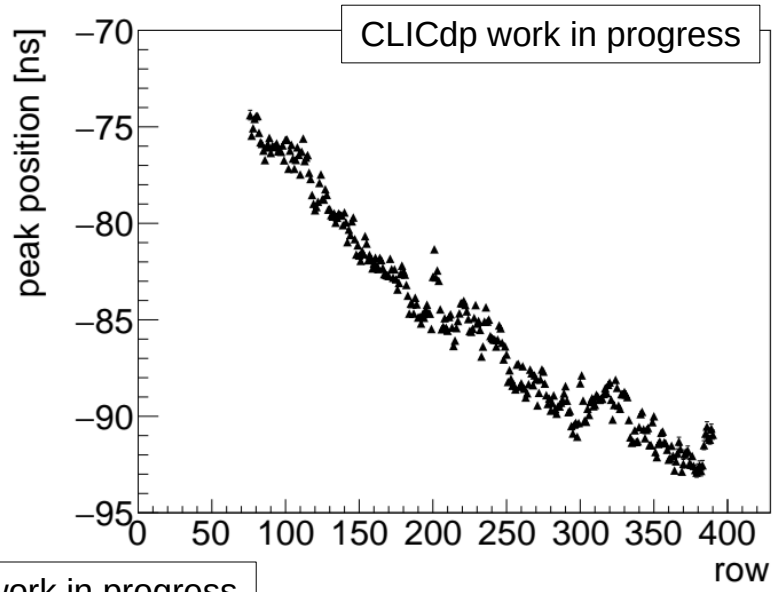
  → **timewalk** (see later)

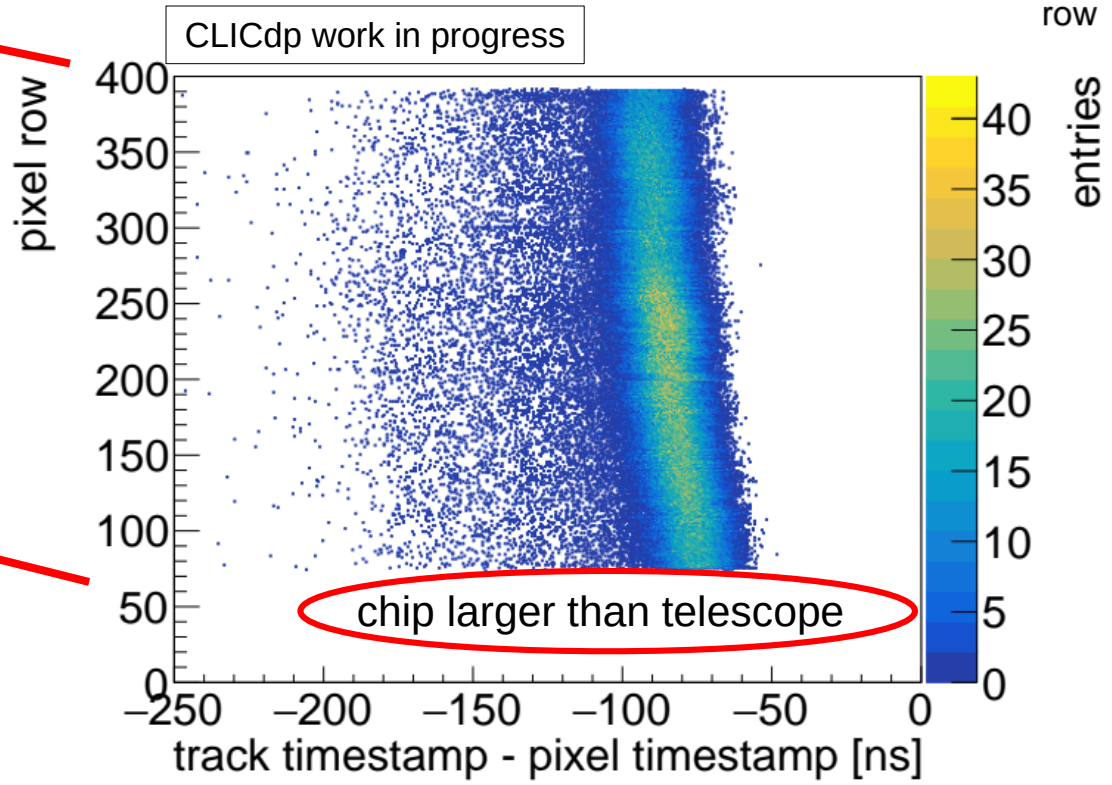


Timing Resolution: Row Correction

- **row delay** due to different wire lengths
  → different RC constant
- deterministic
  → can be corrected for!

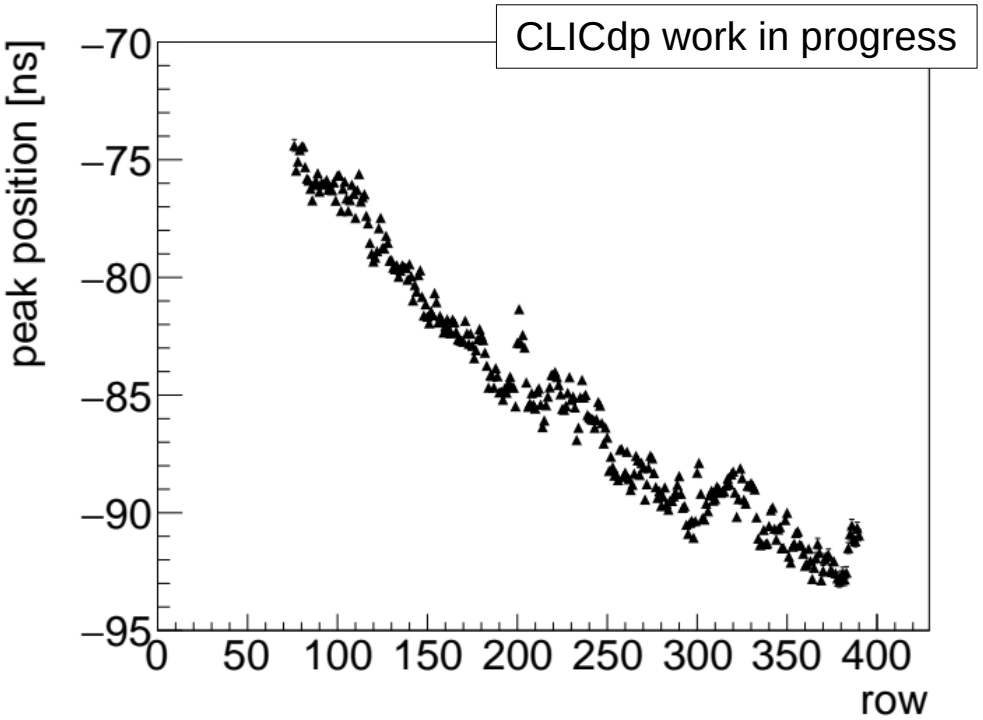


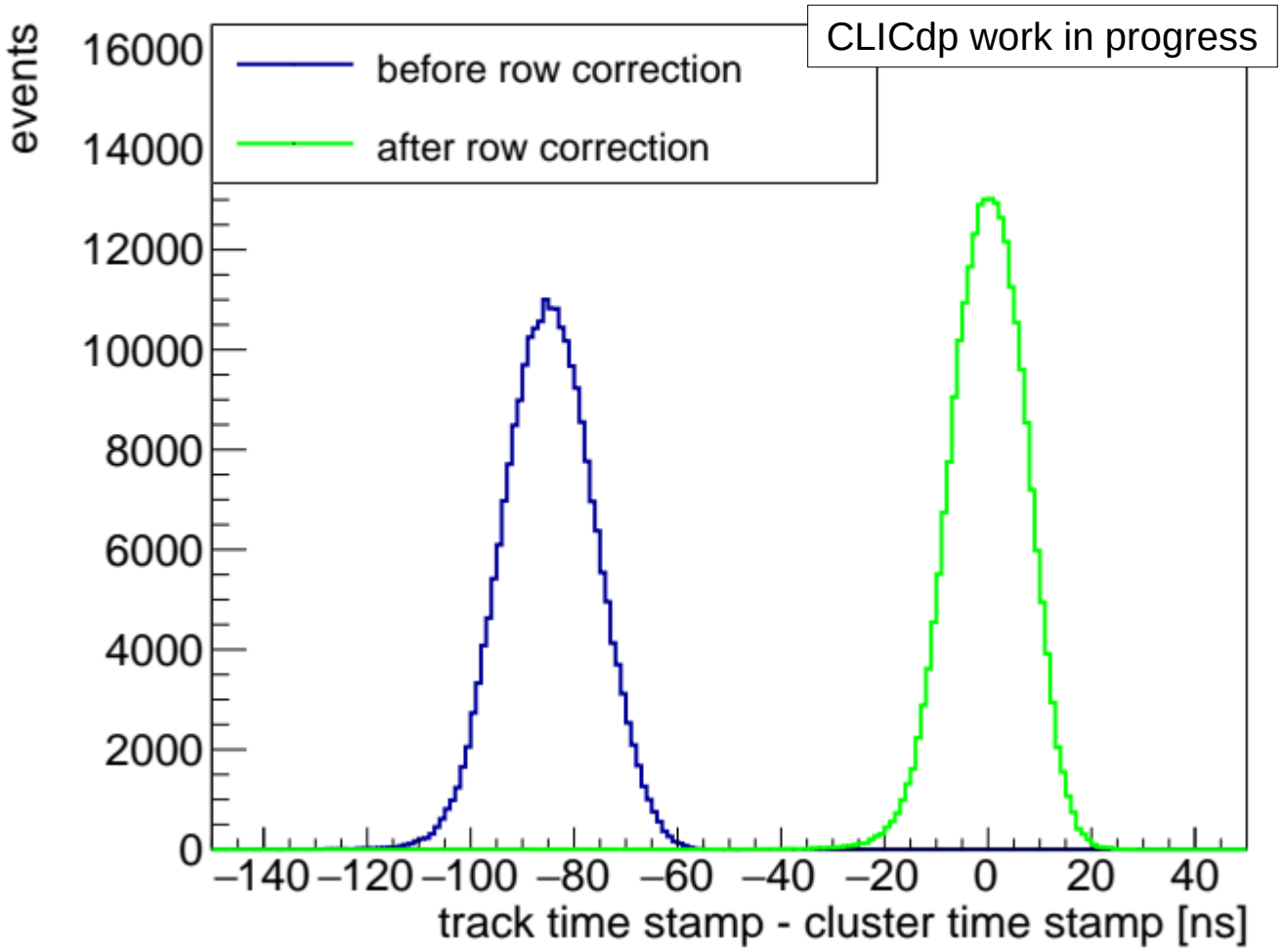




Timing Resolution: Row Correction

- apply correction **row-wise**
- RMS:
  - → before: **8.7 ns**
  - → after: **7.1 ns**





What’s Timewalk?

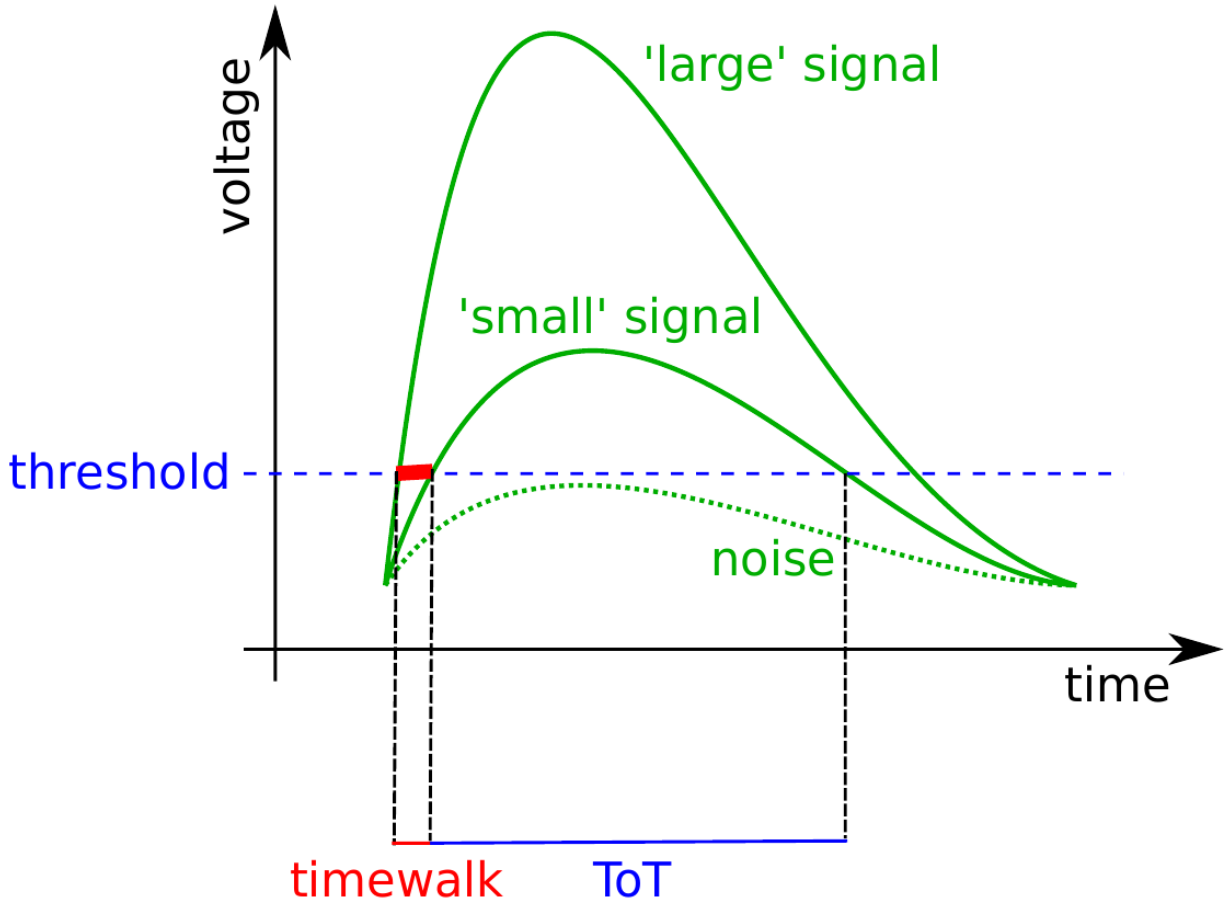
Comparator in pixel:

- hit detected if amplitude > threshold
- threshold set ‘above’ noise level

- different signal amplitude

  → time difference = **timewalk**
  → higher threshold → higher timewalk

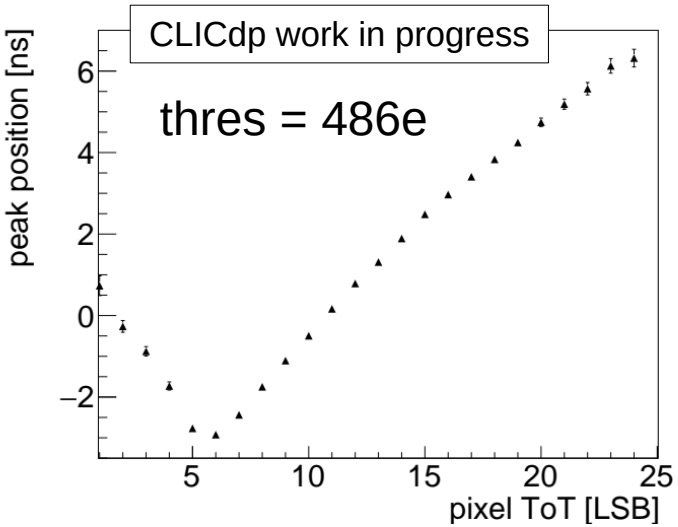
- deterministic → can be corrected for!

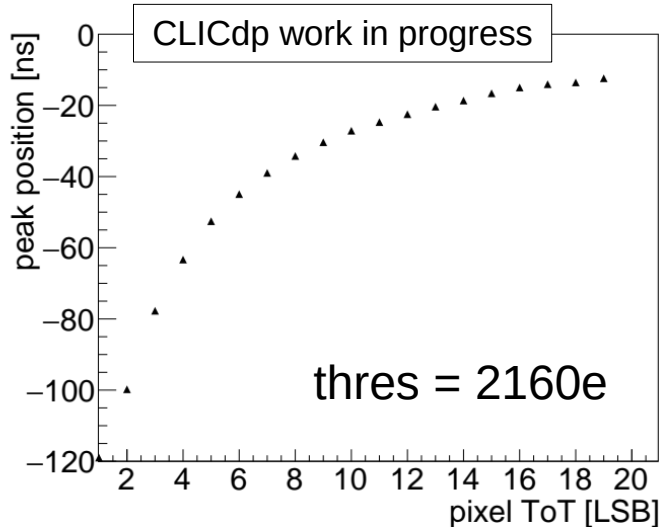


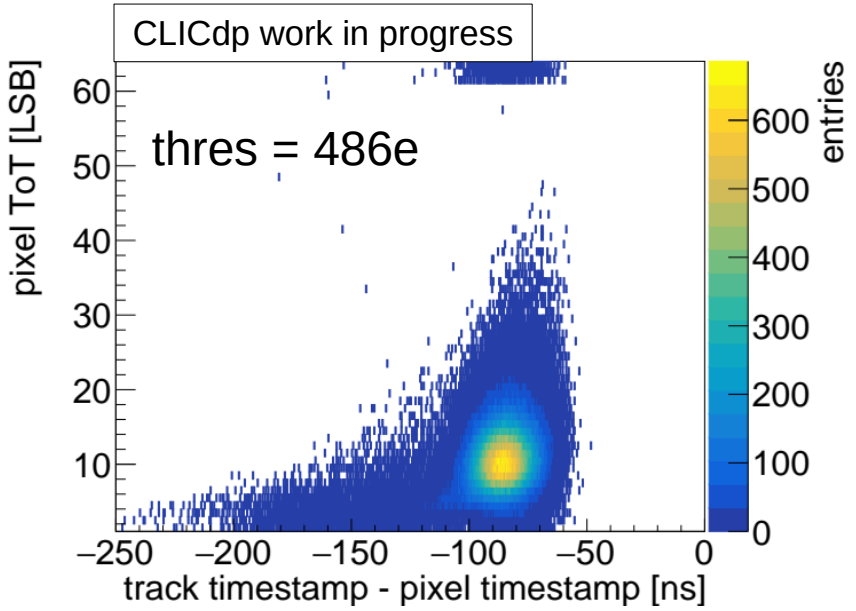
Timing Resolution: Timewalk Correction

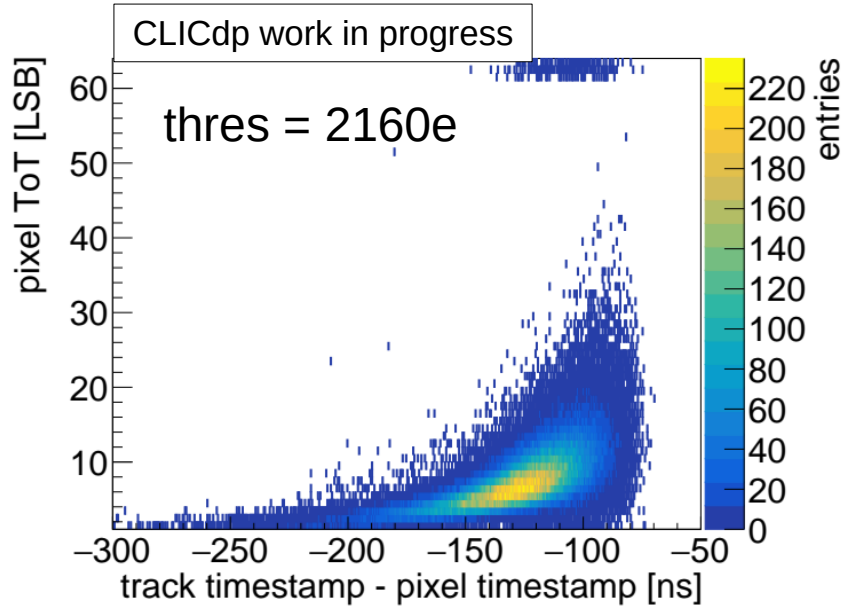
- **thres dependent**:
  higher thres → higher timewalk

- for each ToT ‘slice’
  → find maximum









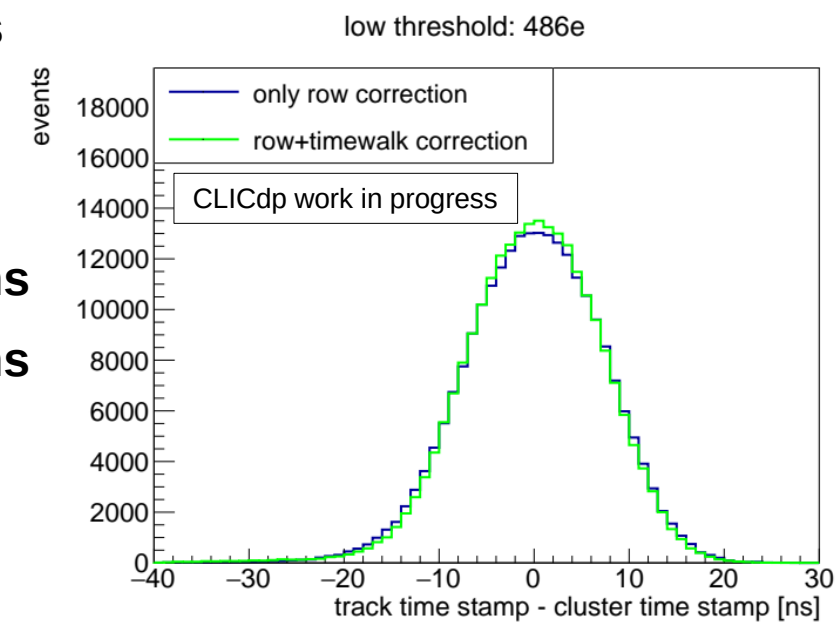
Timing Resolution: Timewalk Correction

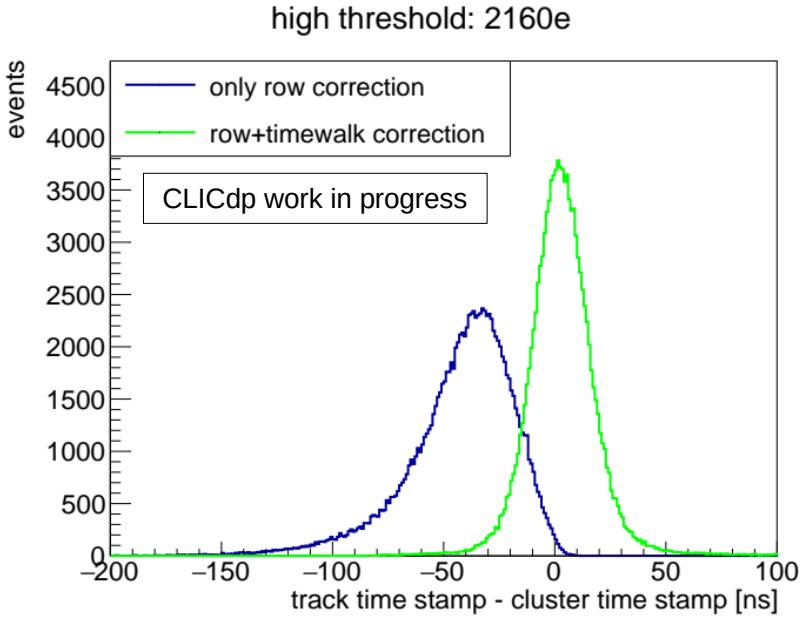
- apply correction **point-wise**

- low threshold
  - → only row: **RMS = 7.1 ns**
  - → row+timewalk: **RMS = 6.9 ns**

- high threshold
  - → only row: **RMS = 24.5 ns**
  - → row+timewalk: **RMS = 16.2 ns**

- strong improvement
  - → especially for high threshold



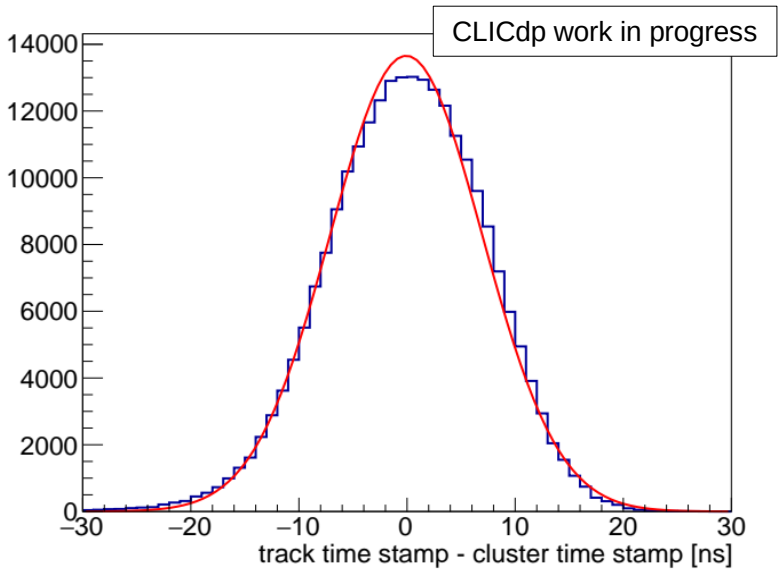


Timing Resolution

- here only row correction (preliminary, work in progress)
- fit convolution of gauss with box function → **binning of clock**

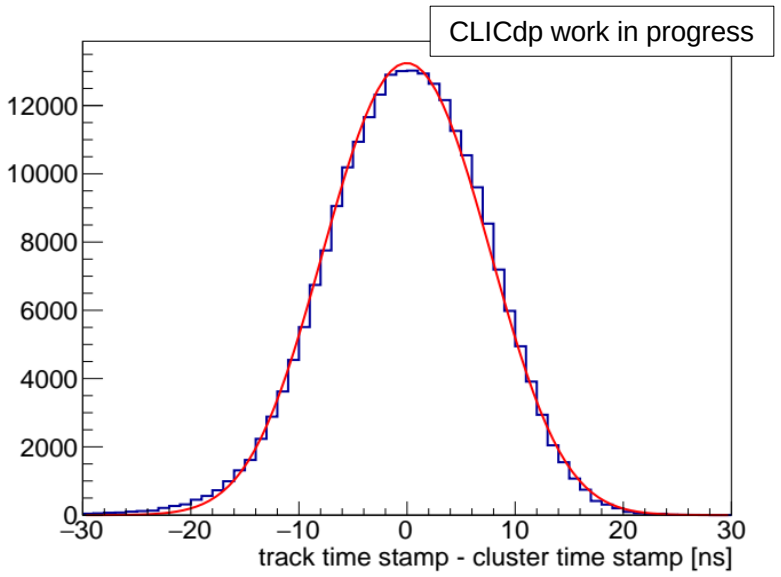
gauss:

- sigma = 7.08 ns
- chi2/ndf = 1826/55



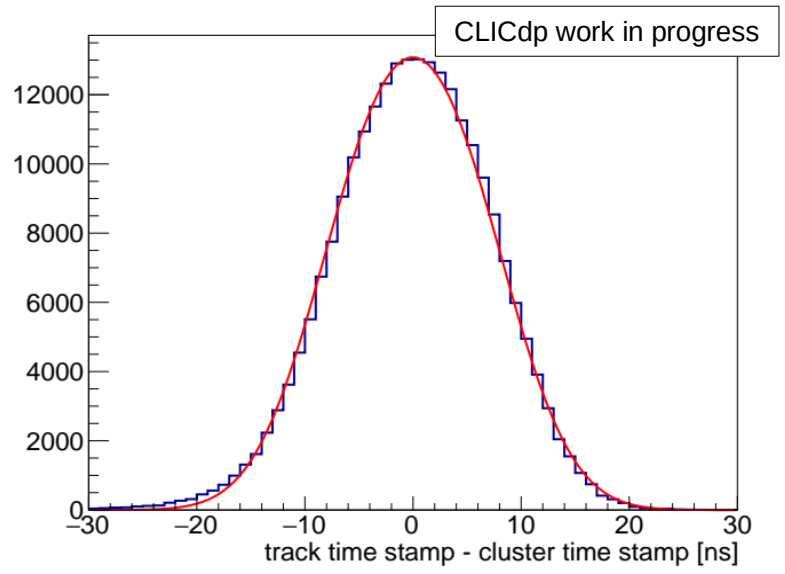
convolution:

- sigma = 5.61 ns
- width = 14.94 ns
- chi2/ndf = 1505/54



convolution:

- sigma = 5.37 ns
- width = 16 ns (fixed)
- chi2/ndf = 1546/54



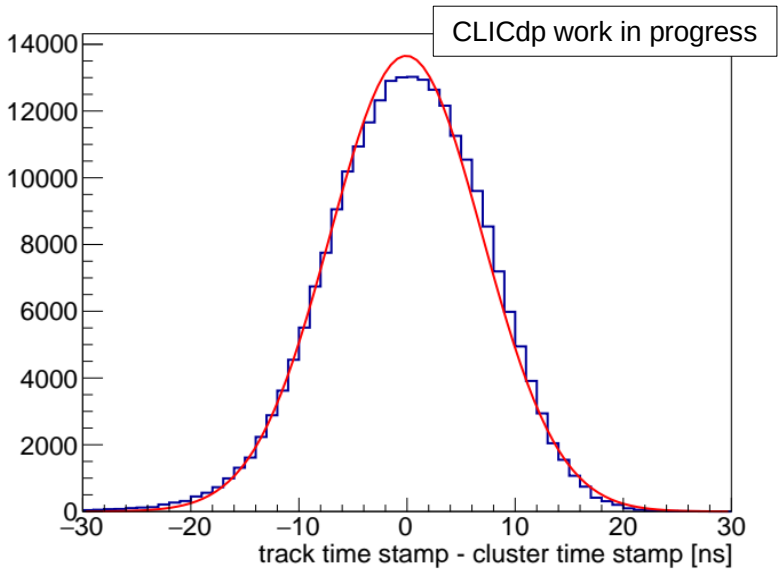
Timing Resolution

upper limit on
intrinsic resolution from
→ charge collection
→ amplification

- here only row correction (preliminary, work in progress)
- fit convolution of gauss with box function → **binning of clock**

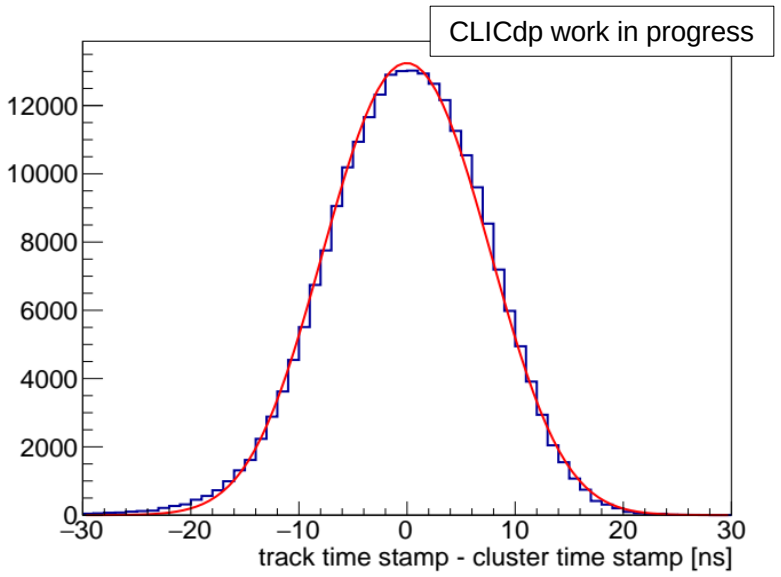
gauss:

- sigma = 7.08 ns
- chi2/ndf = 1826/55



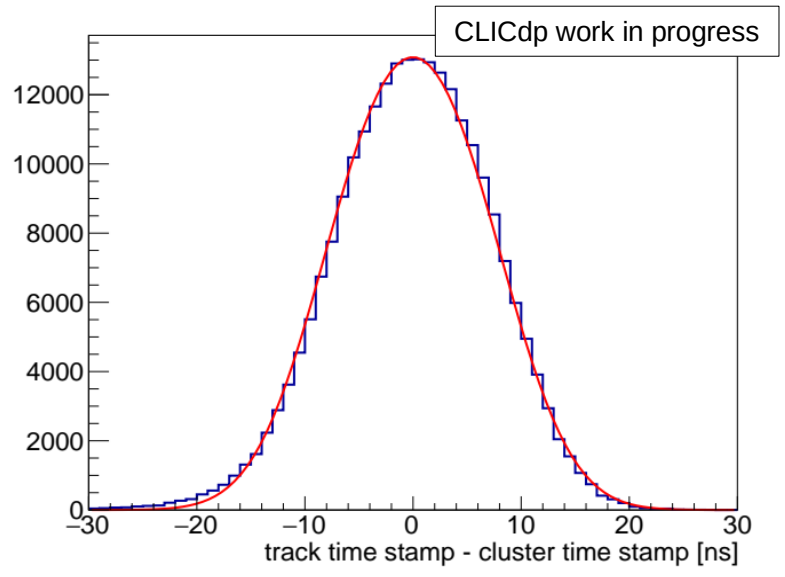
convolution:

- sigma = 5.61 ns
- width = 14.94 ns
- chi2/ndf = 1505/54



convolution:

- sigma = 5.37 ns
- width = 16 ns (fixed)
- chi2/ndf = 1546/54

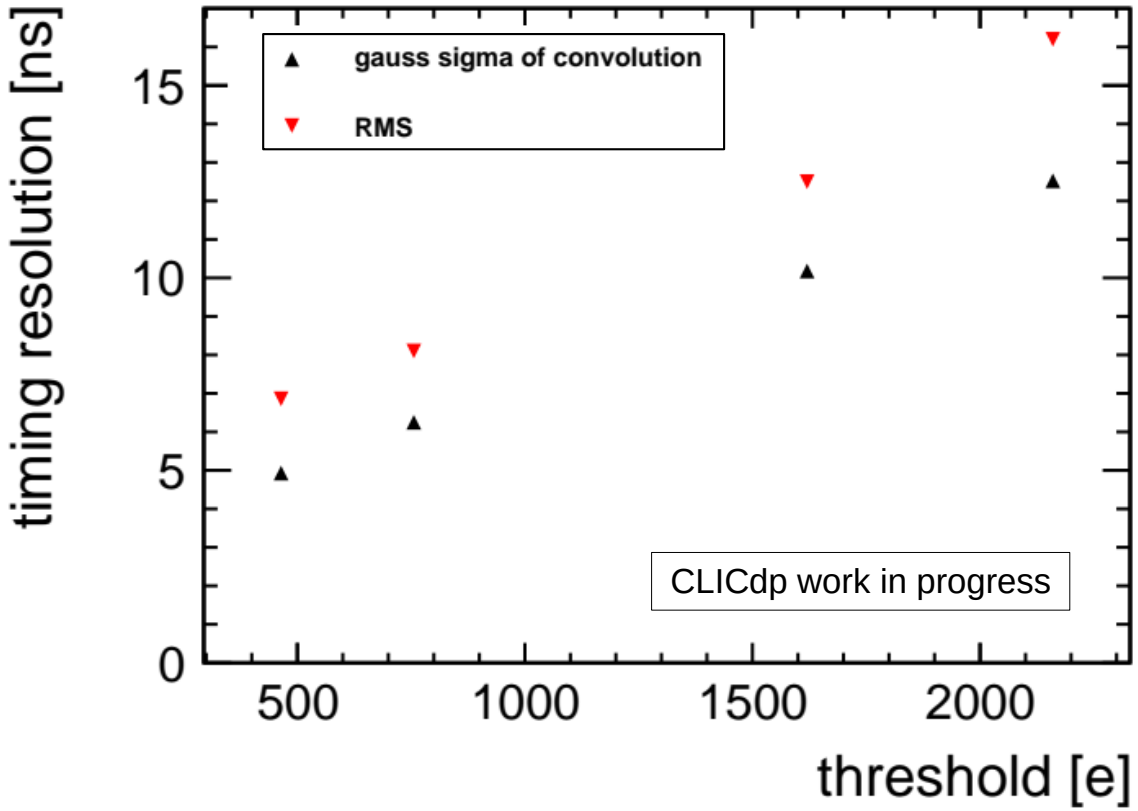


Timing Resolution: Threshold Dependence

- strong threshold dependence:

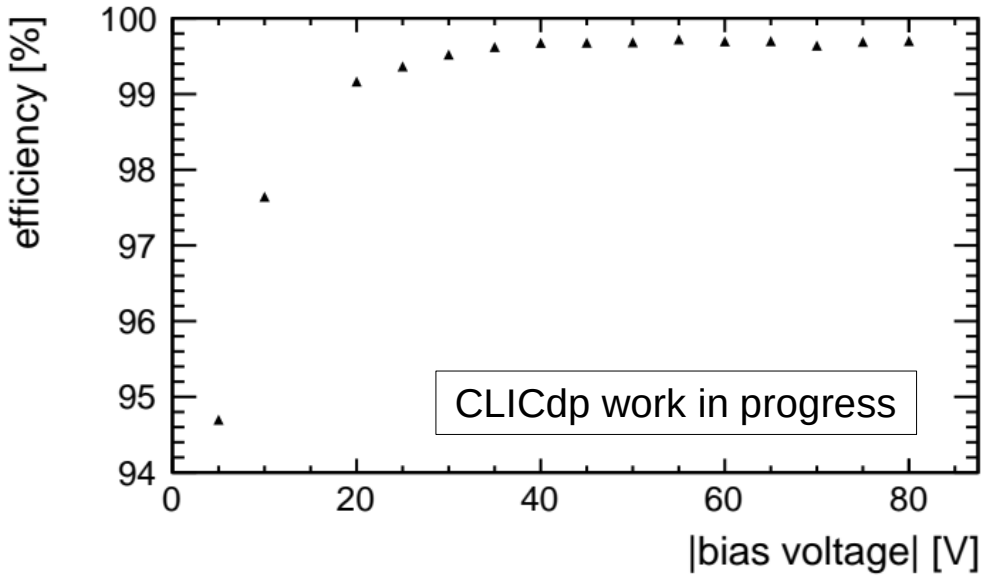
  → **RMS = 6.9 ns** at thres~480e
  → **RMS = 16.2 ns** at thres~4300e

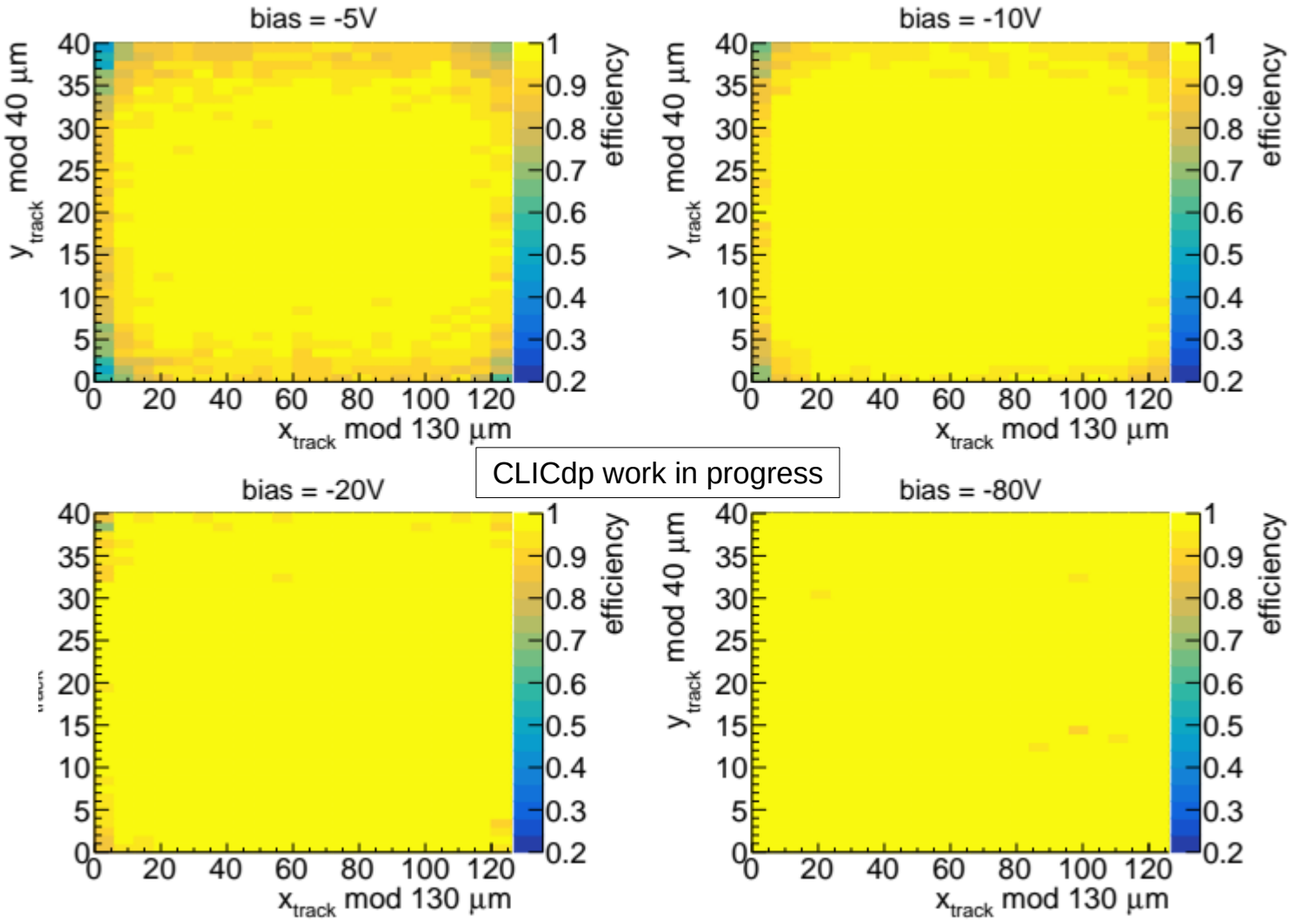
- no problem:
  low noise → threshold can be set very low



Efficiency: Bias Scan

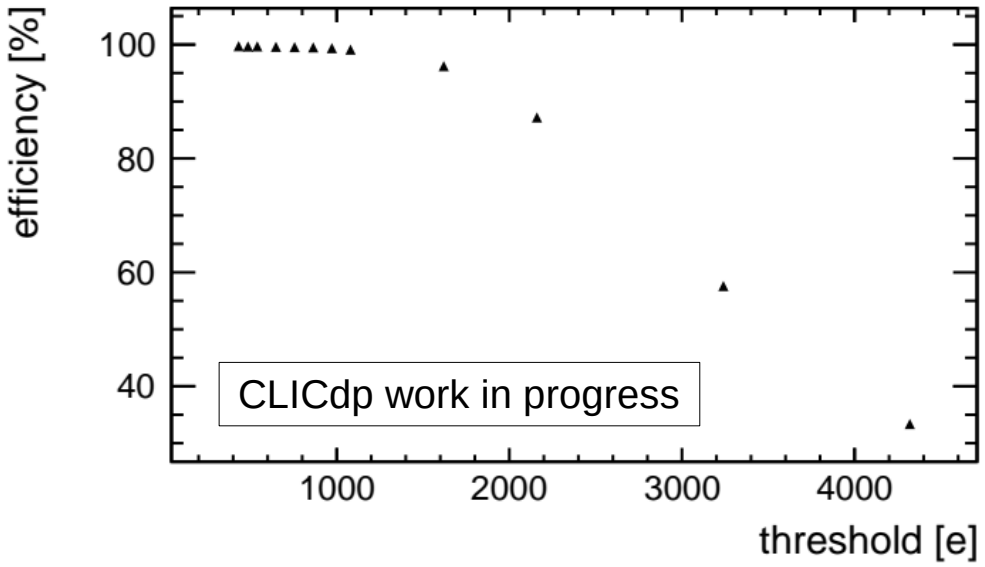
- vary bias
  → from -5V to -80V
- efficiency saturates at **~99.7%**
- in-pixel efficiency:
  → inefficient at low bias in corners
  → as expected

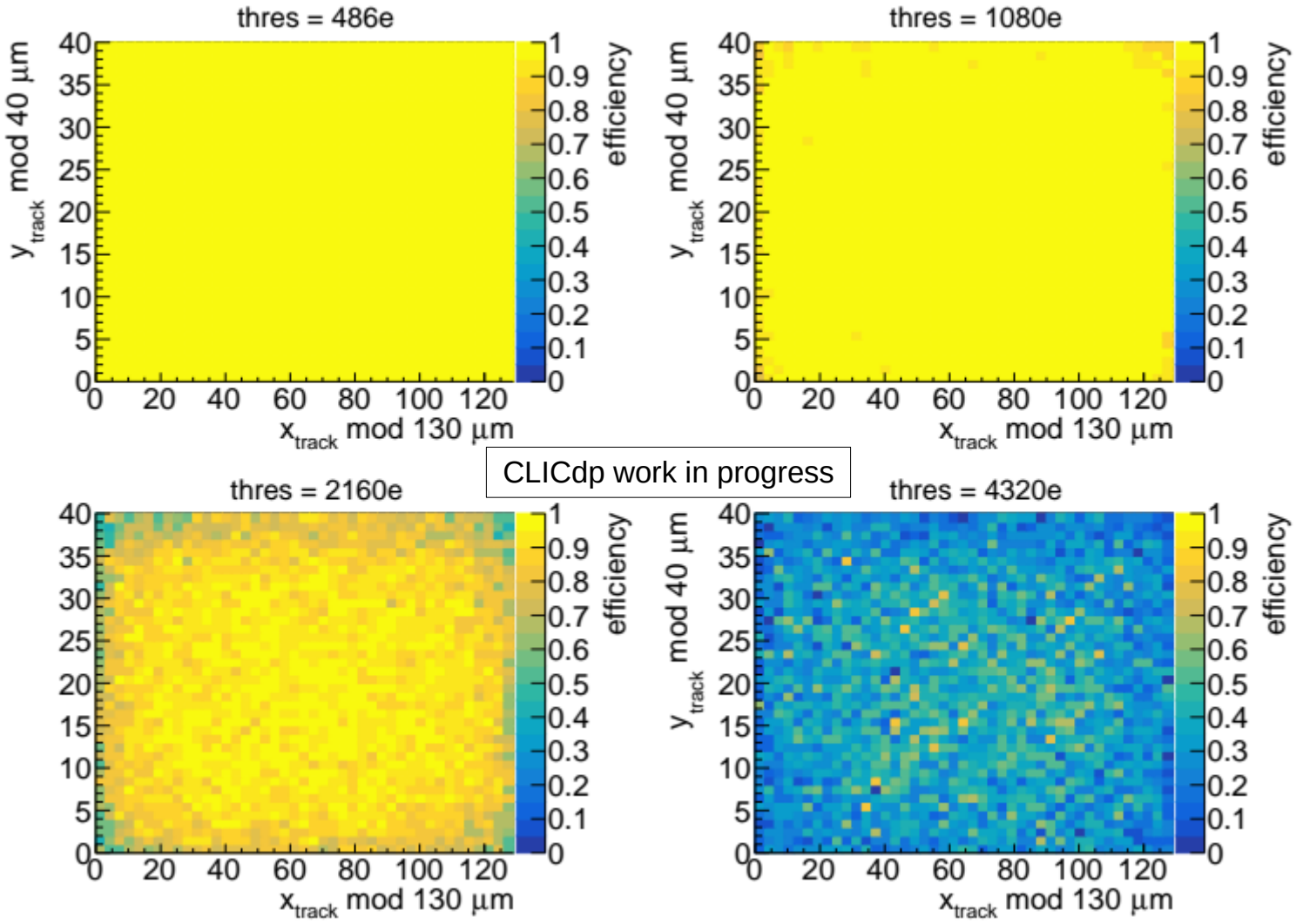




Efficiency: Threshold Scan

- vary threshold
  → from 45mV to 400mV
- efficiency saturates at **~99.7%**
- in-pixel efficiency:
  → inefficiency starts in corners
  → as expected





Summary

Results:

- material budget:
  → 100 µm (50 µm possible)
- spatial resolution:
  → in y: RMS = 11.3 µm
  → in x: pixel size = 130 µm
- timing resolution:
  → 6.8 ns at ~480e thres
- efficiency:
  → above 99.7%
  → no dead/masked pixels

Requirements:

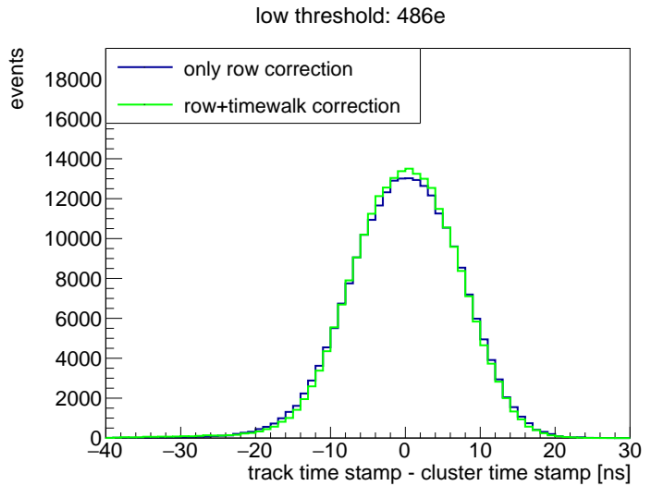
< 200 µm

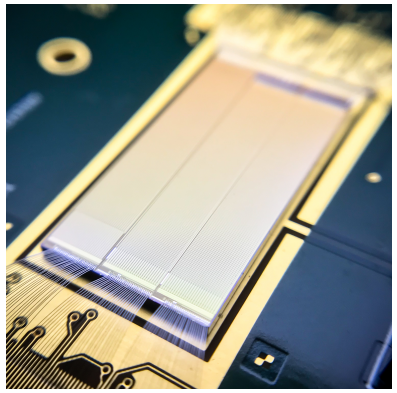
< 7 µm

1-100 mm

< 10 ns

> 99.7-99.9%

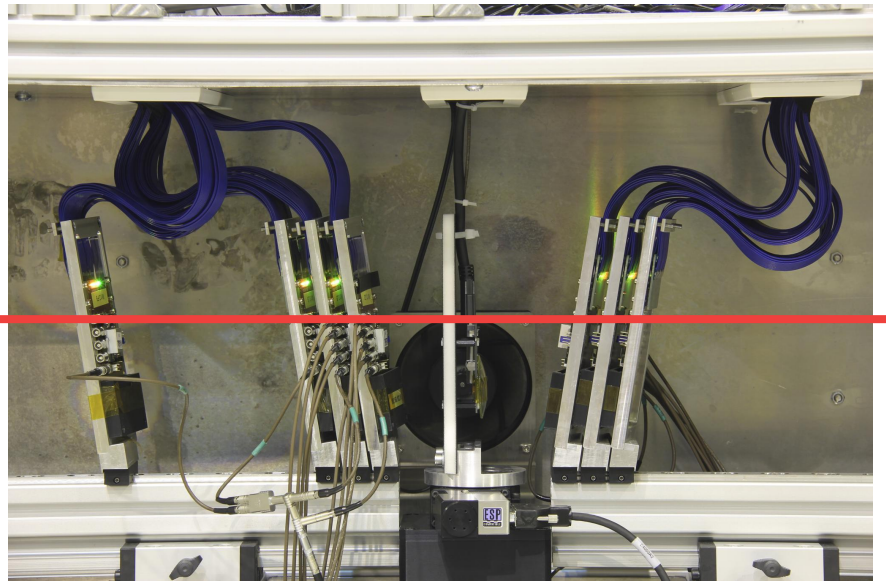




- excellent telescope performance
- very promising results
  → most requirements met
  → suitable technology for CLIC tracking detector
- future:
  → new prototype with smaller pixel size

Backup

Testbeam Facility

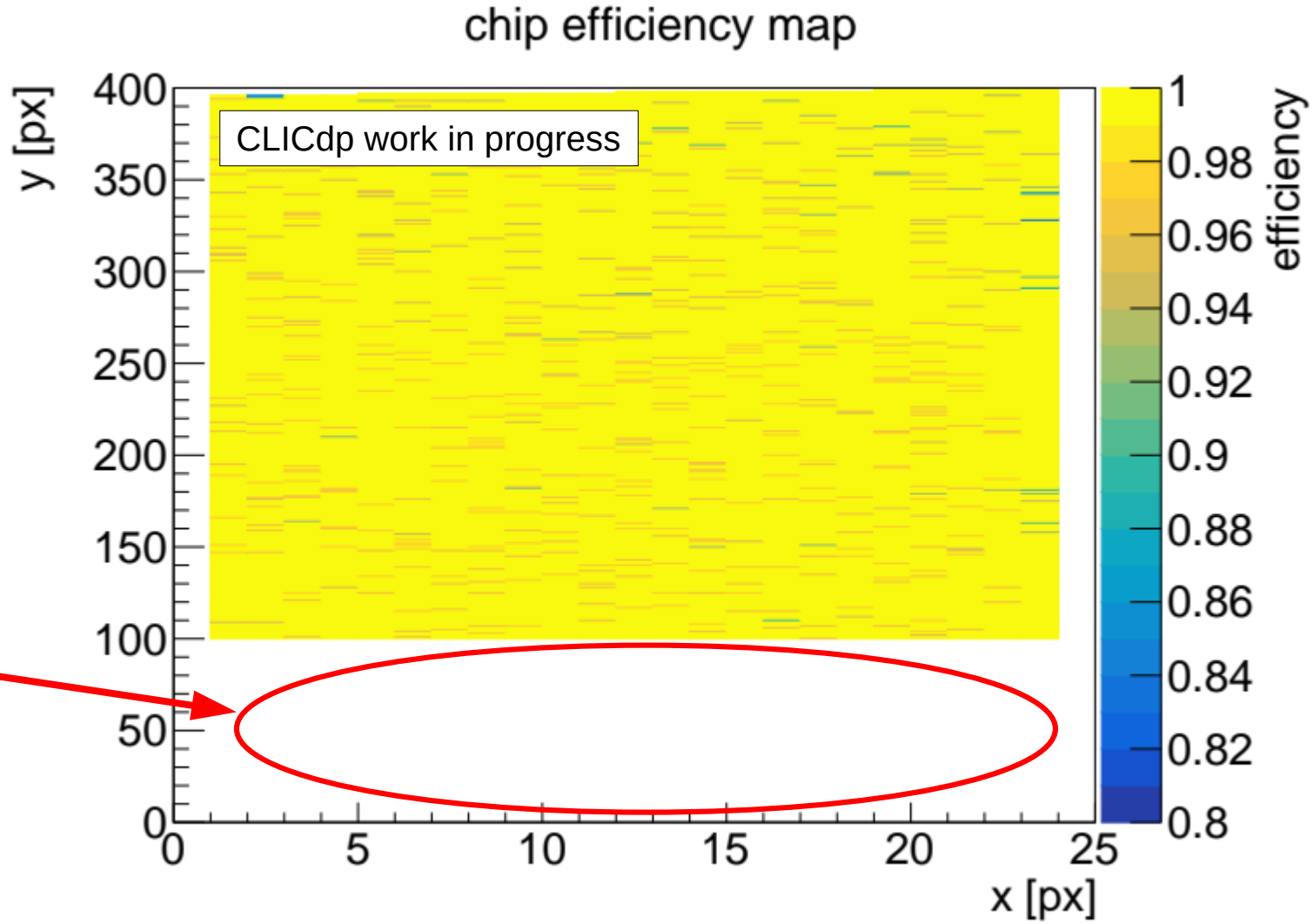


- beamline H6 at SPS
- beam: 120 GeV pions

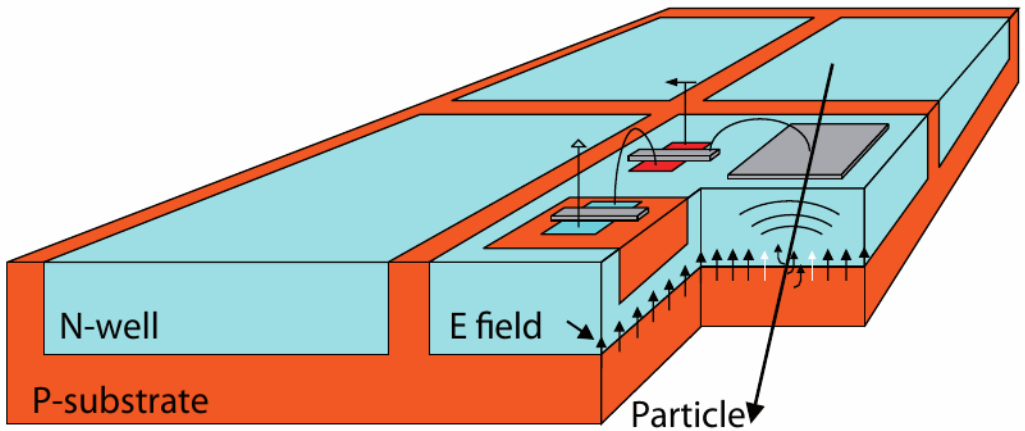
- from 2019: DESY Hamburg

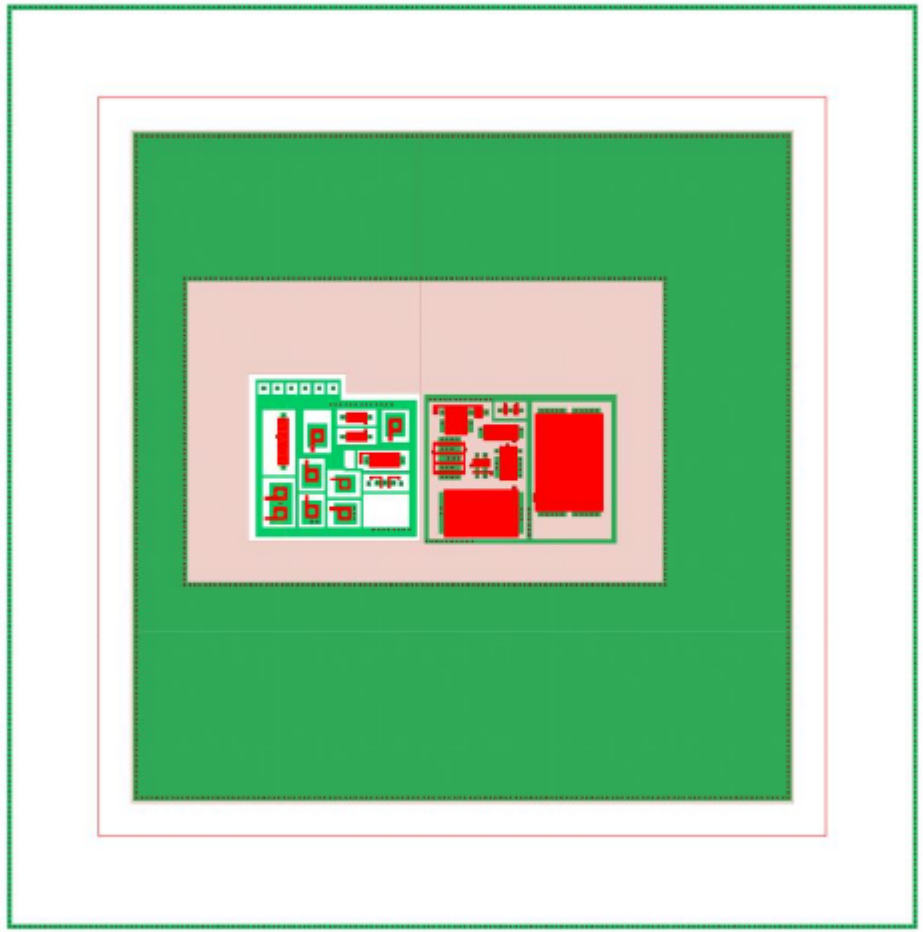
Global Efficiency

- **total efficiency > 99.7%**
- chip fully efficient
  - → no pixel masked
  - → no dead pixels
- DUT larger than telescope
  - → no tracks here
  - → used 2nd run with shifted DUT to cover full chip (not shown here)



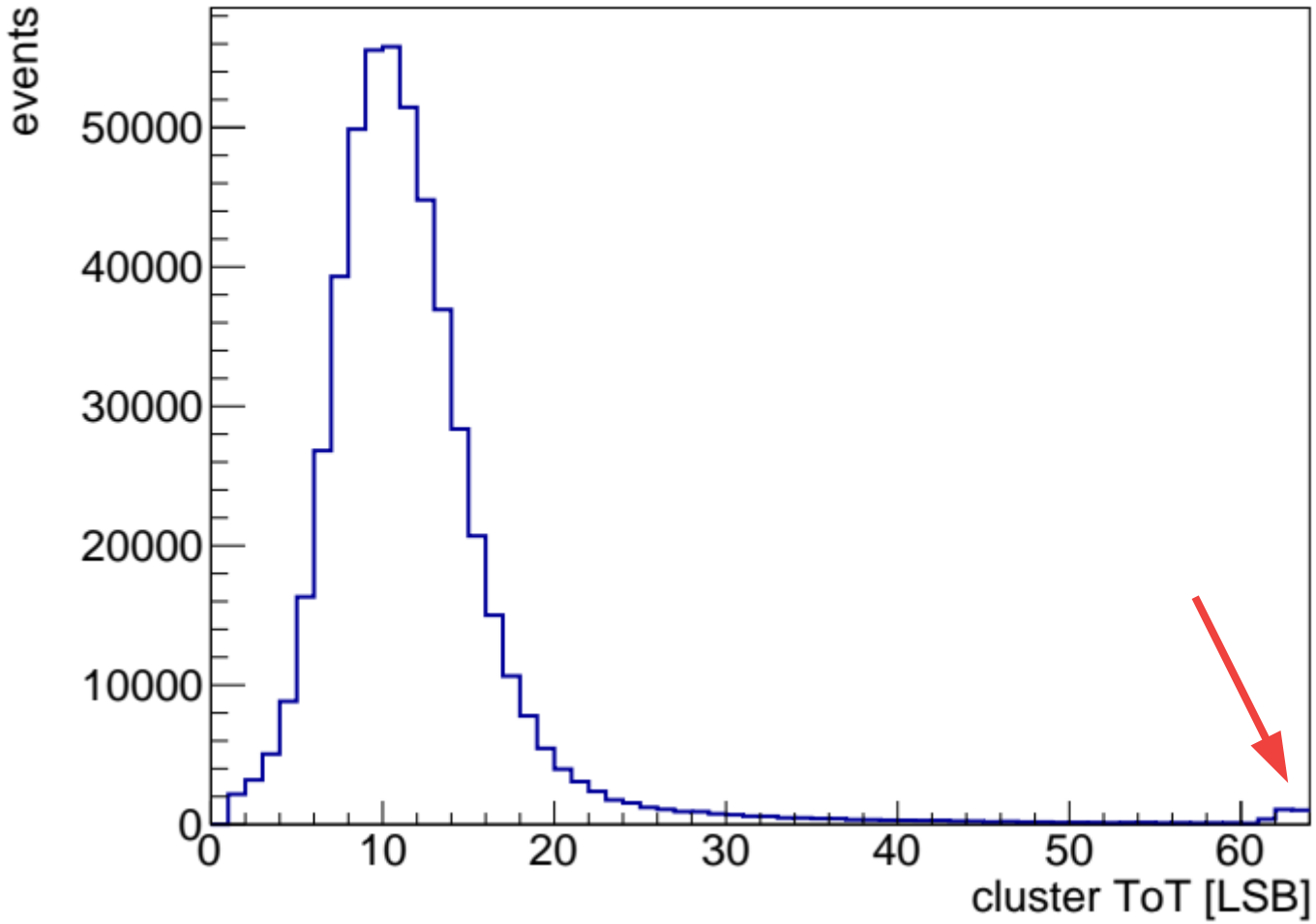
HV-MAPS Schematic & ATLASpix Pixel Layout





Cluster ToT Spectrum

- excess for high ToT (61-63 LSB)
- still under investigation



Thickness Depletion Zone

- different chip: H35DEMO
  → but **same substrate resistivity**
- our sample: 200 Ωcm
- from Mathieu Benoit:
  http://iopscience.iop.org/article/10.1088/1748-0221/13/10/P10004/pdf