Test-beam studies on the ALICE investigator chip

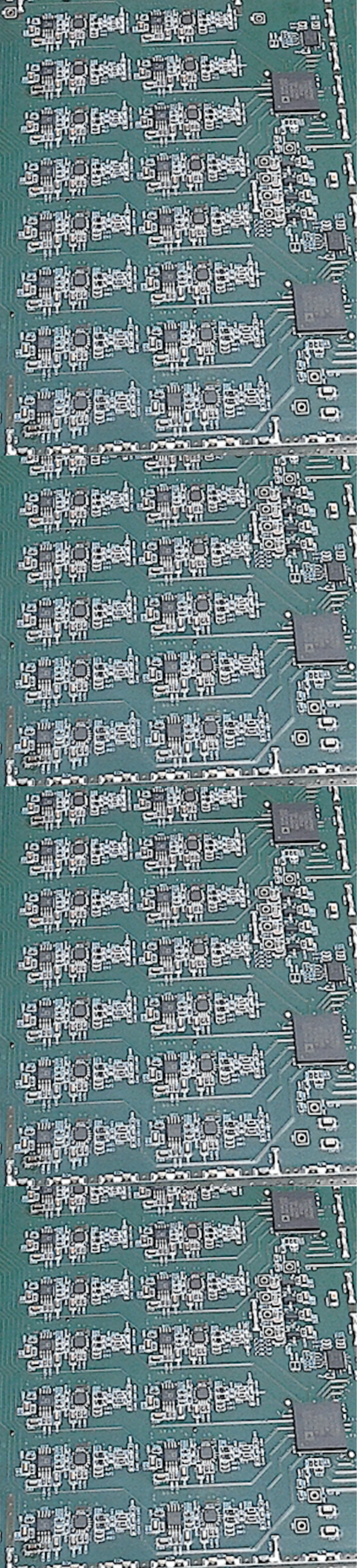
Magdalena Munker (CERN, University of Bonn)

CLICdp collaboration meeting

31 August 2016

SPONSORED BY THE
Federal Ministry of Education and Research

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under Grant Agreement no. 654168.



Outline

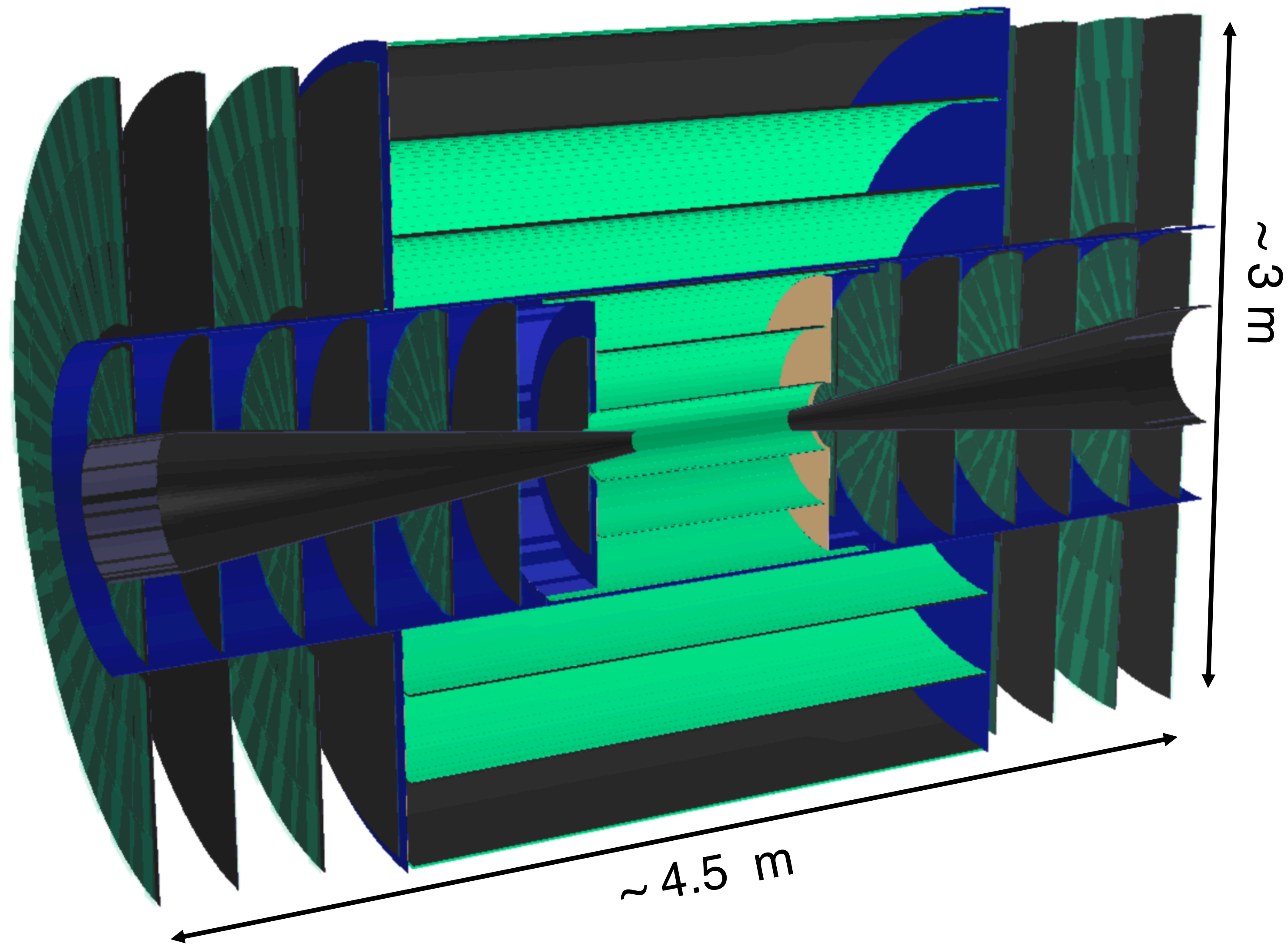
- Motivation of study on ALICE investigator chip
- Introduction of the ALICE investigator chip
- Test-beam data taking & analysed data
- Results
- Summary & outlook

Motivation of studies on ALICE investigator chip

Large surface silicon tracker planned for CLIC (~ 90m²):

→ Need of large scale production

CLIC tracker layout:



Benefit from integrated technologies:

→ Monolithic technologies
→ No need of bump bonding
→ Reduced material budget

Benefit from synergies with ALICE collaboration:

→ Test-chip developed within ALICE collaboration to investigate full analogue performance of monolithic technology chosen by ALICE

→ Interesting to study feasibility of monolithic technology with respect to CLIC tracker requirements (time slicing of 10 ns, single point resolution of ~ 7 µm)

The ALICE investigator chip

ALICE INVESTIGATOR, monolithic HR-CMOS test-chip *(W. Snoeys, J. W. Van Hoorne et. al.)*:

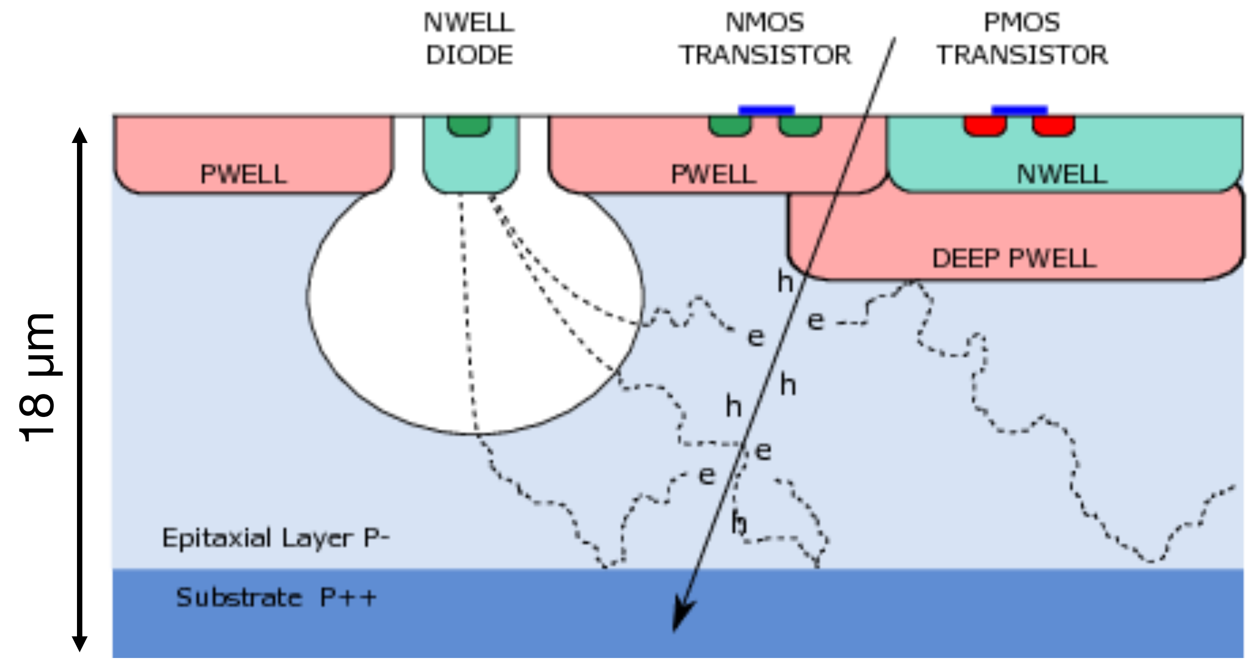
- Developed by the ALICE collaboration to test analogue performance

- 180 nm High Resistivity (HR) CMOS process
- 15-40 μm thick epitaxial layer (1-8 kΩcm)

- 134 mini-matrices with different pixel layouts
- 8x8 pixel matrix per mini-matrix

- Optimisation of collection-diode geometry

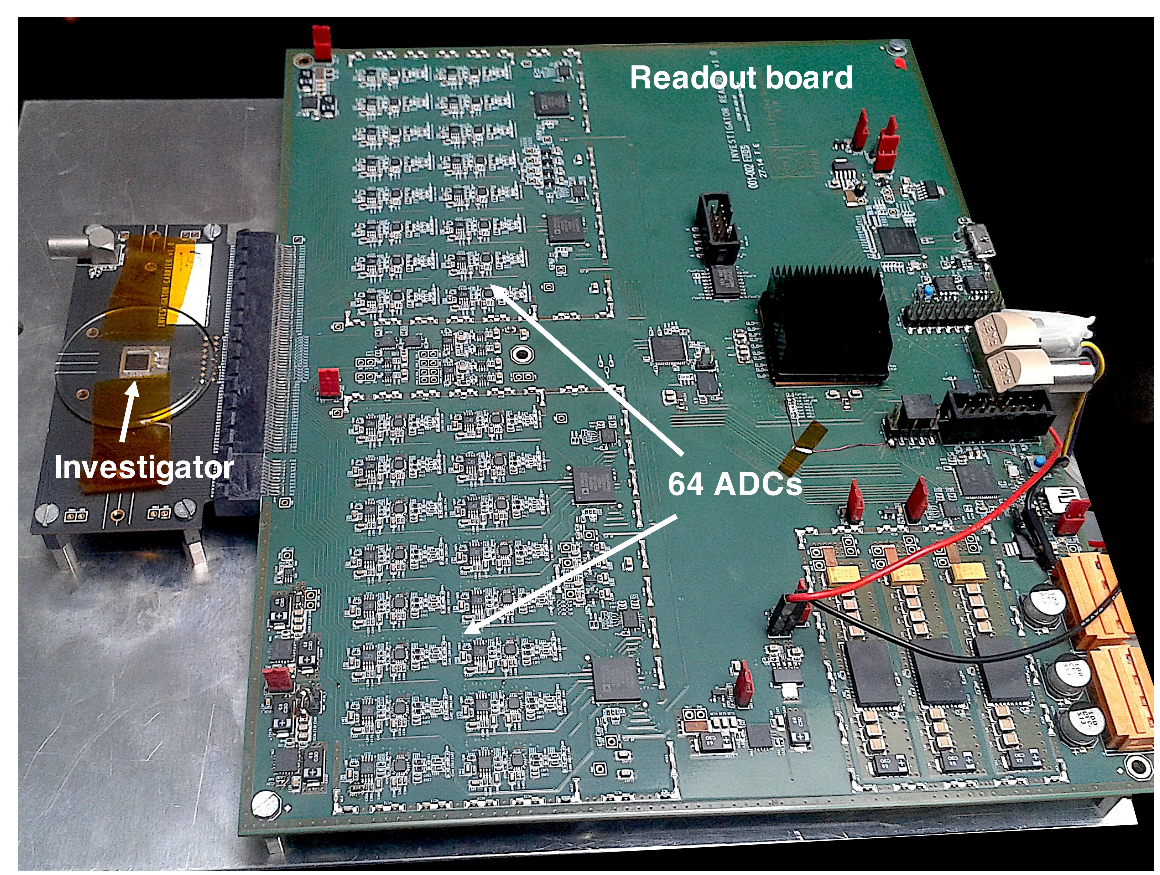
→ Minimise capacitance (~ 2 fF) → fast timing (~ ns)



***External readout** (designed by K. M. Sielewicz):*

- Selectable mini-matrix
  → Connected to readout
  → 64 ADCs to read out full waveform of each pixel

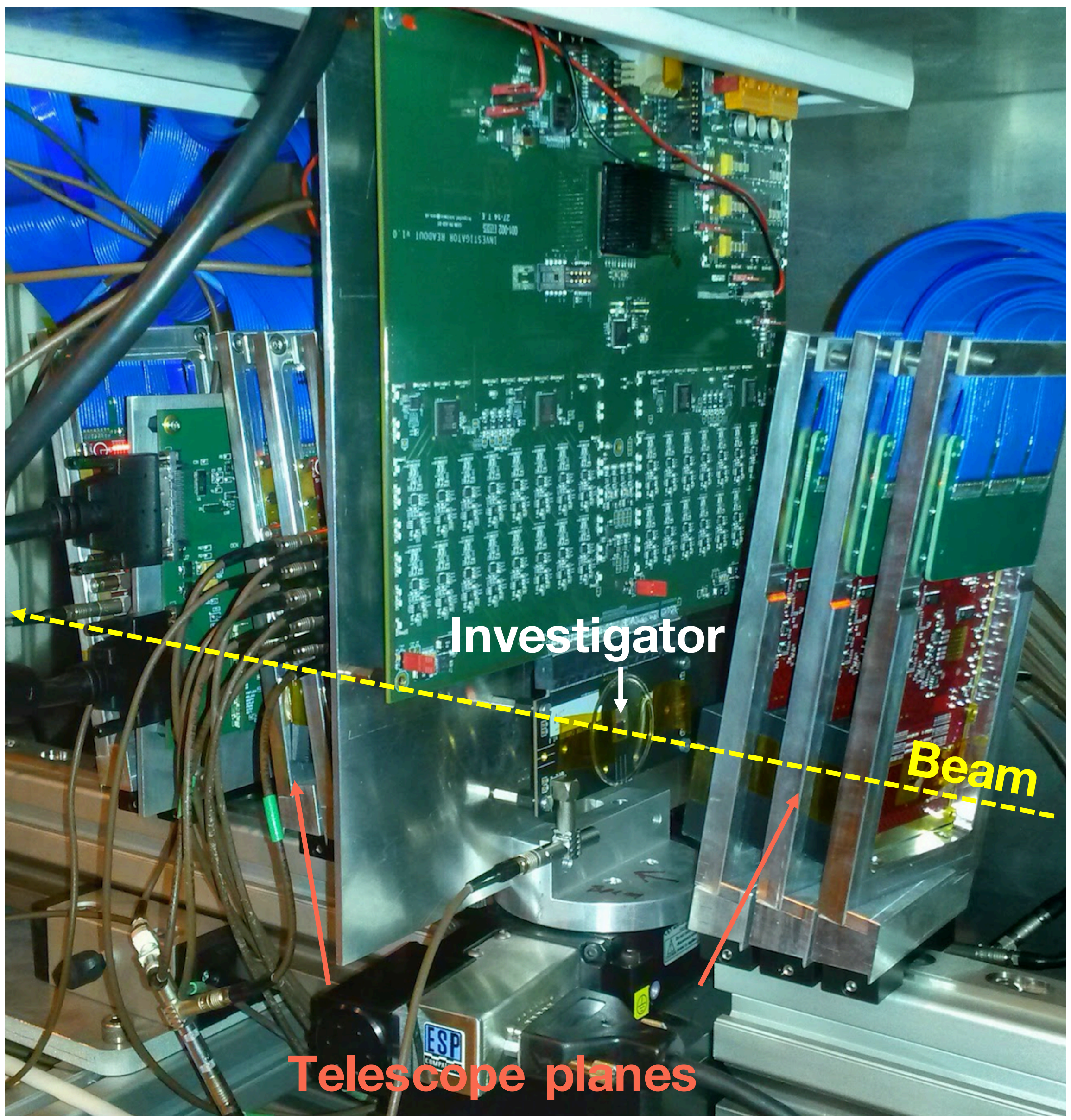
- 65 MHz sampling clock
  → Limits achievable accuracy of timing resolution



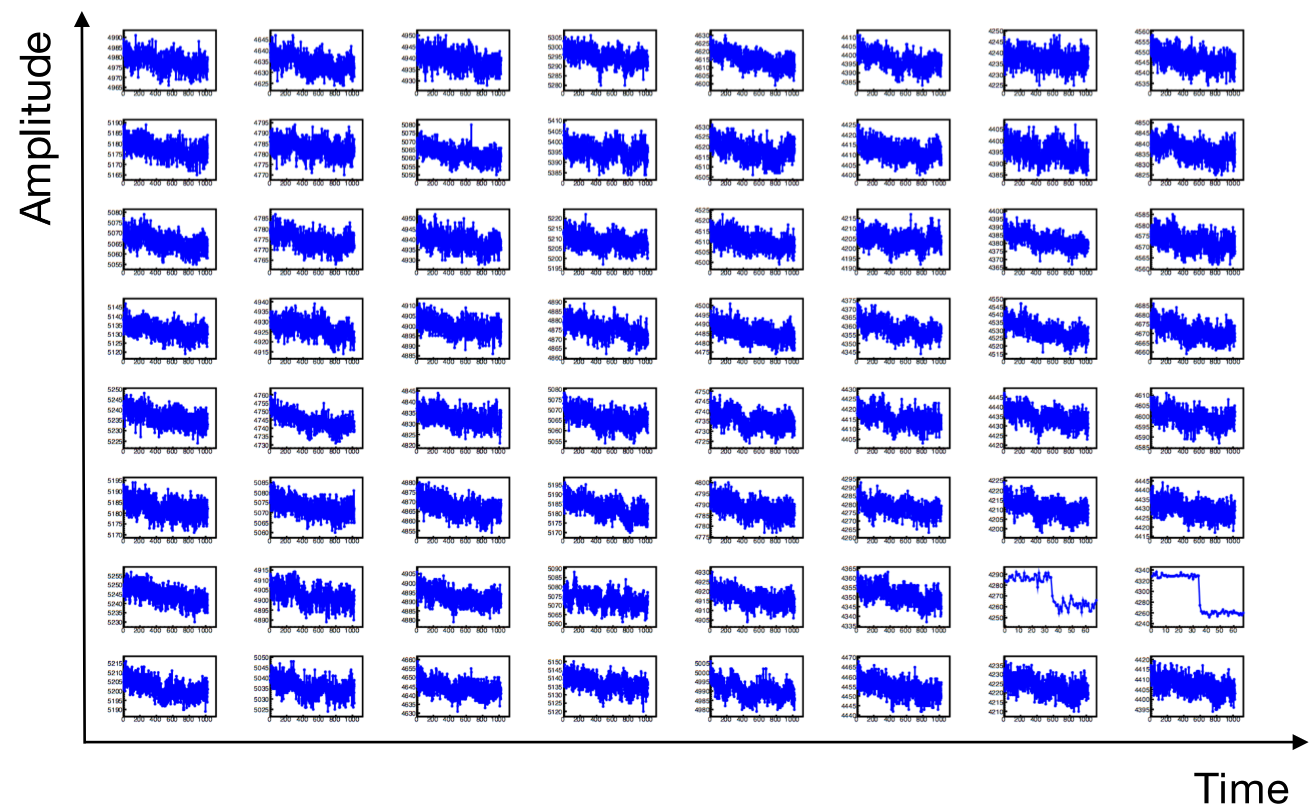
Test-beam data taking

ALICE INVESTIGATOR integrated in CLICdp Timepix3 telescope at SPS beam-line:

Mechanical integration of investigator in Timepix3 telescope setup:



Integration of investigator data in telescope software:



- If a hit gets recorded in the investigator:
  - ➞ Read out of waveform of all pixels
  - ➞ Sent trigger package to telescope planes
  - ➞ Used for offline synchronisation

➞ Benefit from good single point (~ 2 µm) and timing (~ ns) resolution of Timepixe3 telescope

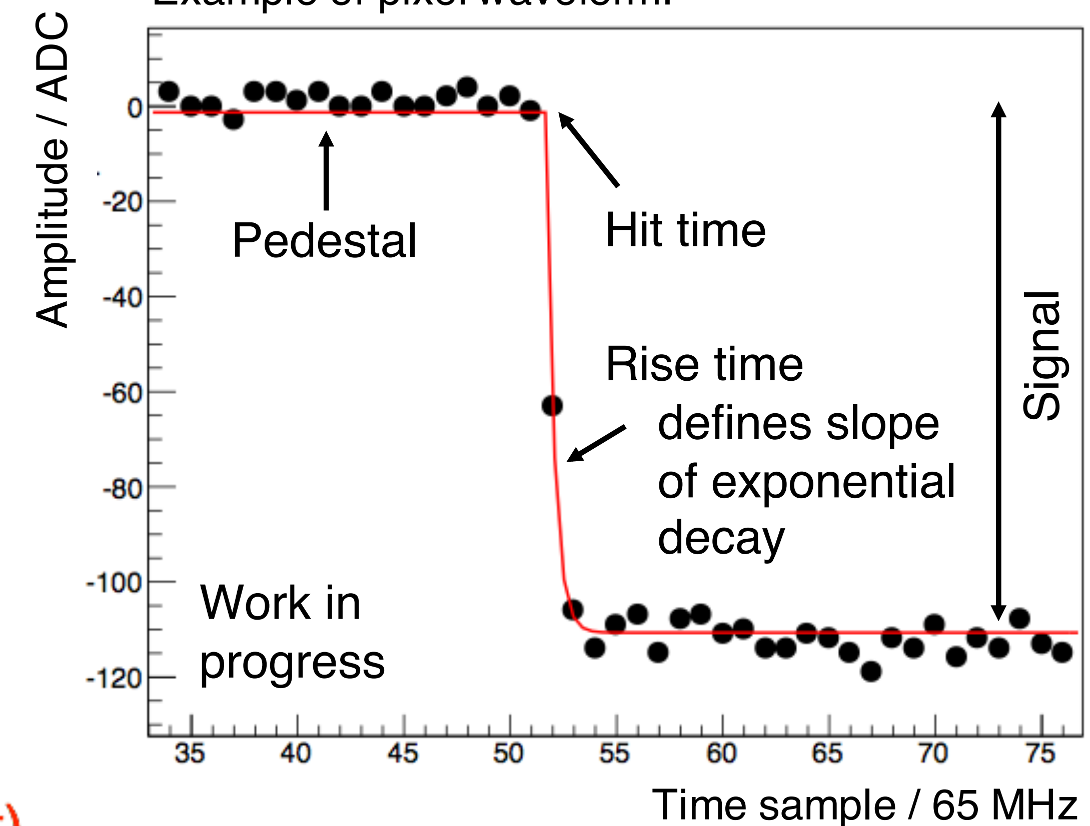
Event reconstruction

Basic reconstruction and definition of observables:

- Signal defined as magnitude of amplitude drop
- Noise defined as RMS of fluctuation around baseline
- Cut on S/N > 8
- Fit exponential function f(t) to waveform of each pixel to extract timing:

$$f(t) = \begin{cases} \text{Pedestal} & t \leq t(\text{hit}) \\ \text{Pedestal} + \text{Signal} * (e^{[t-t(\text{hit})]/t(\text{rise})} - 1) & t > t(\text{hit}) \end{cases}$$

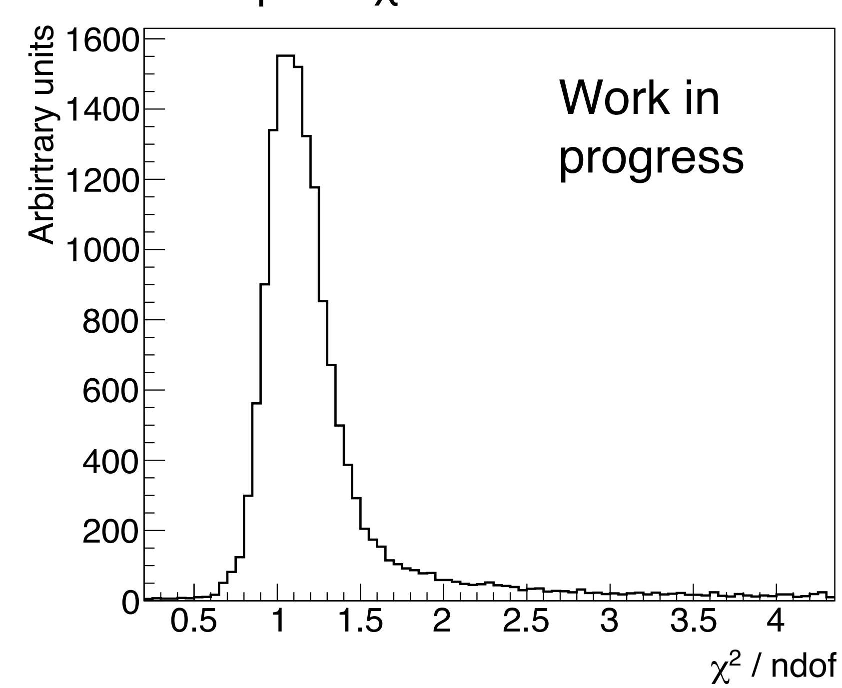
Example of pixel waveform:



Further quality cuts:

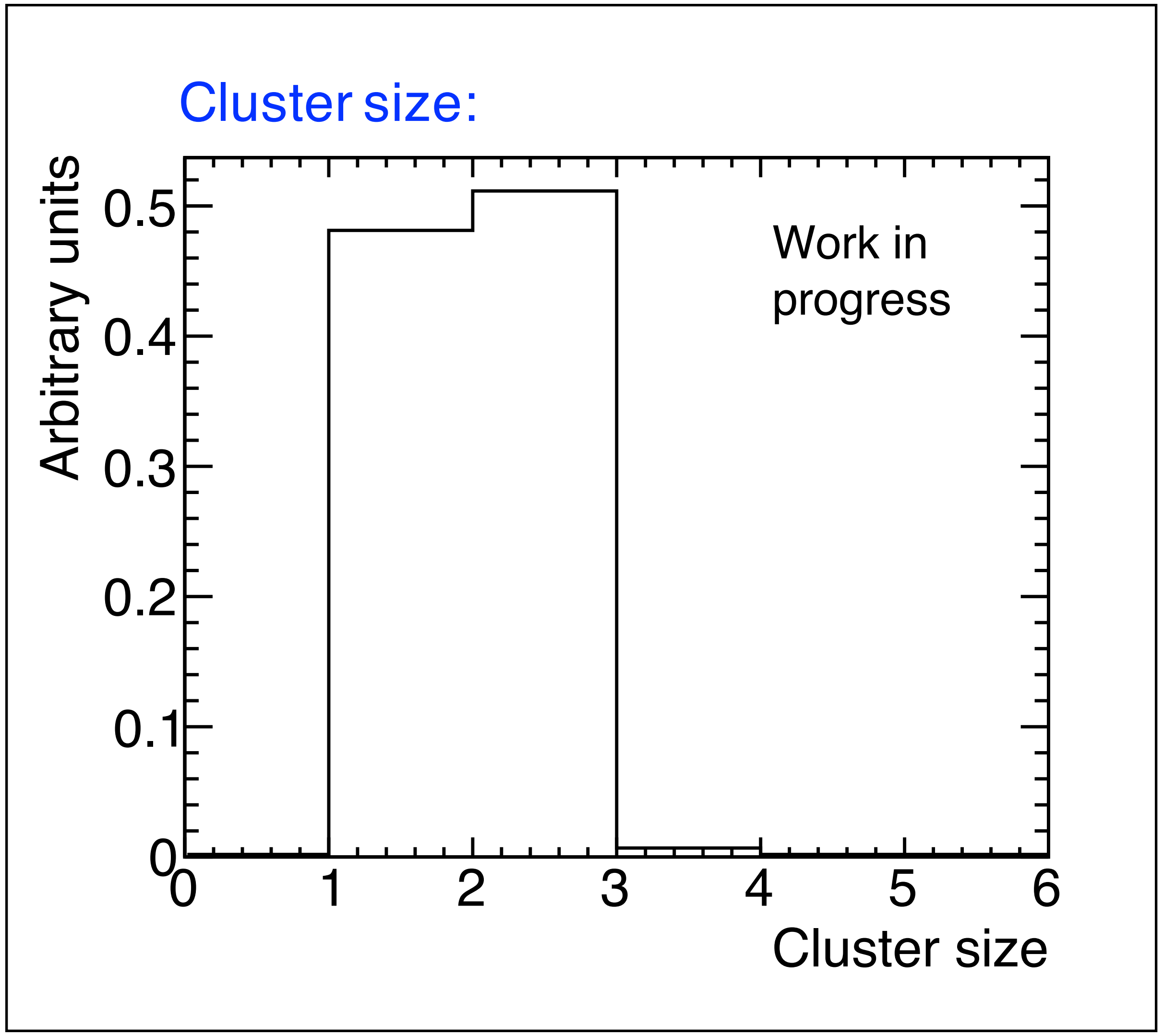
- Cut on $\chi 2$ / ndof of waveform fit → only for timing observables
- Track-cluster distance < 100 µm
- Masking of edge pixels

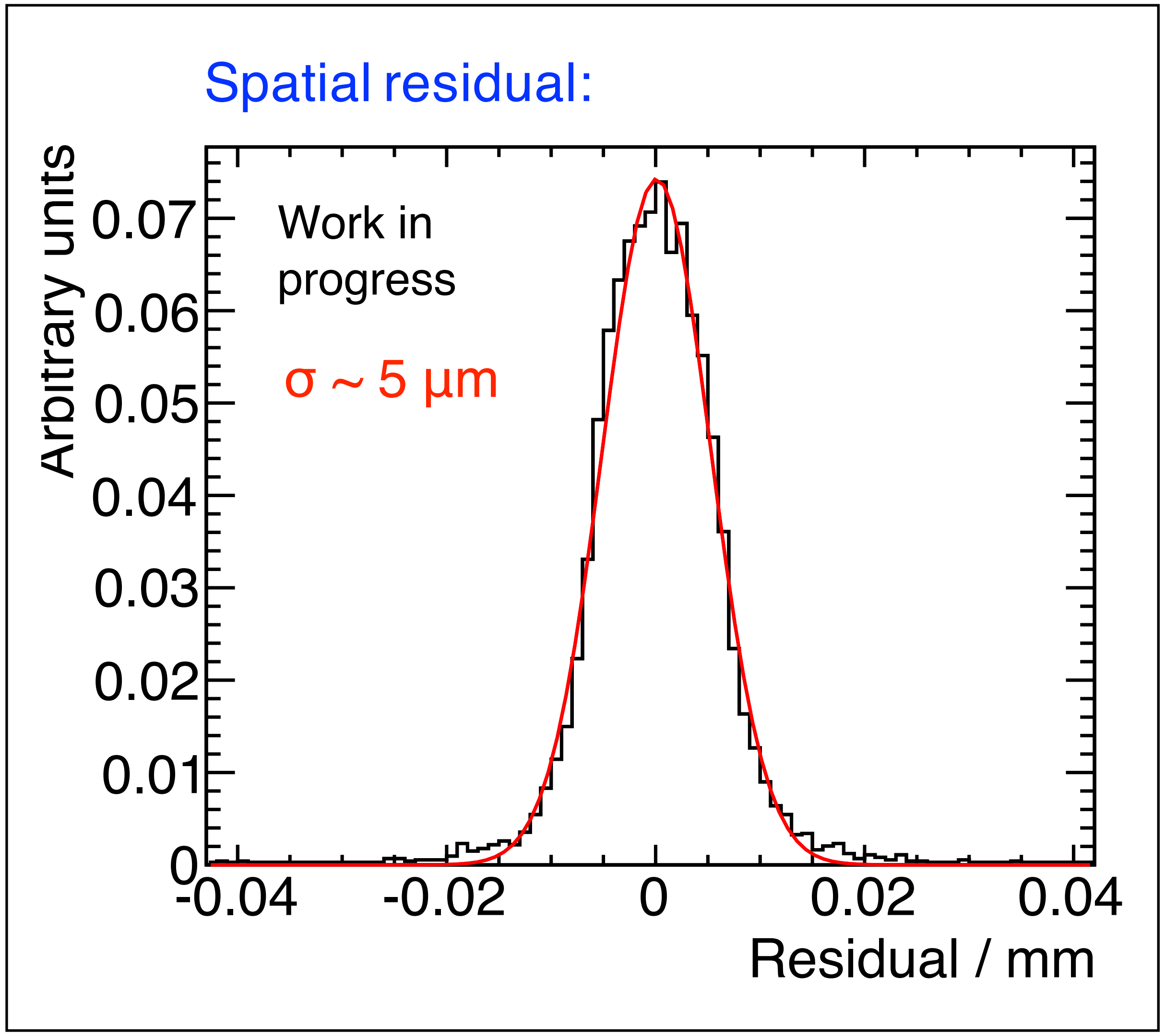
Example of $\chi 2$ / ndof distribution:



Cluster size and spatial resolution for V_{bias} = 6 V

Results for pitch of 28 µm and bias voltage of 6 V:





- Significant charge sharing for small pitch:

→ Cluster size of ~ 1.5

→ Position reconstruction improves with respect to binary expectation of ~ 8 µm (η-correction applied):

→ Single point resolution ~ 4.6 µm (telescope track resolution of ~ 2 µm unfolded)

Hit time resolution and rise time for V_{bias} = 6 V

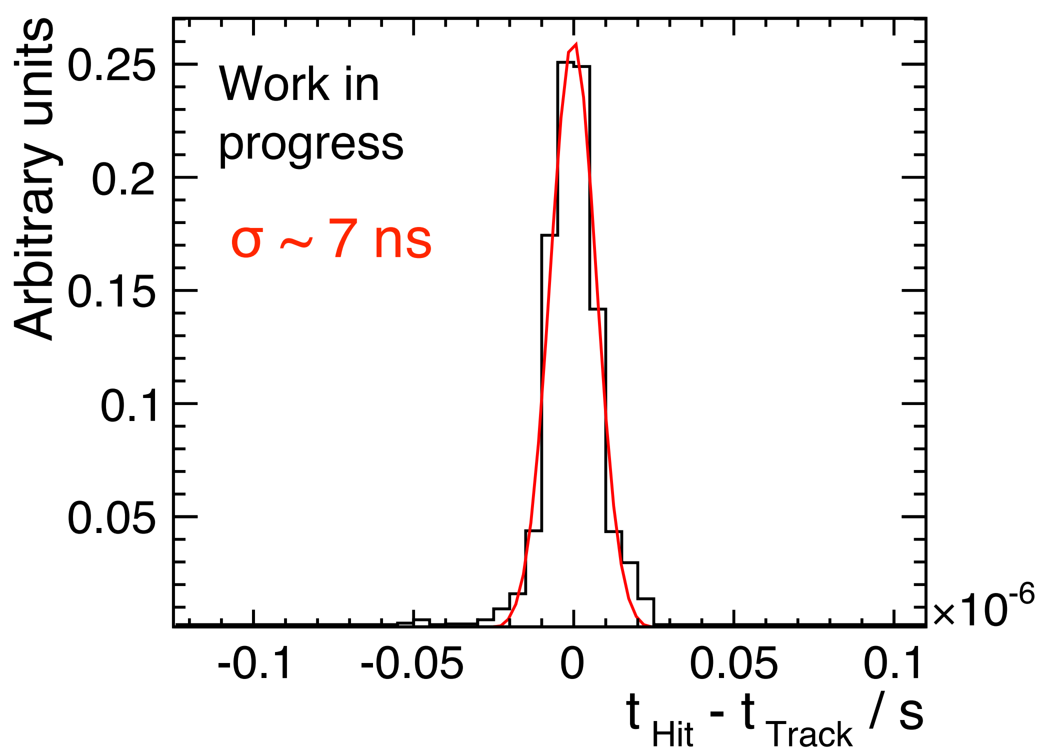
Definition of timing observables:

- Use first pixel in cluster associated to telescope track to extract timing

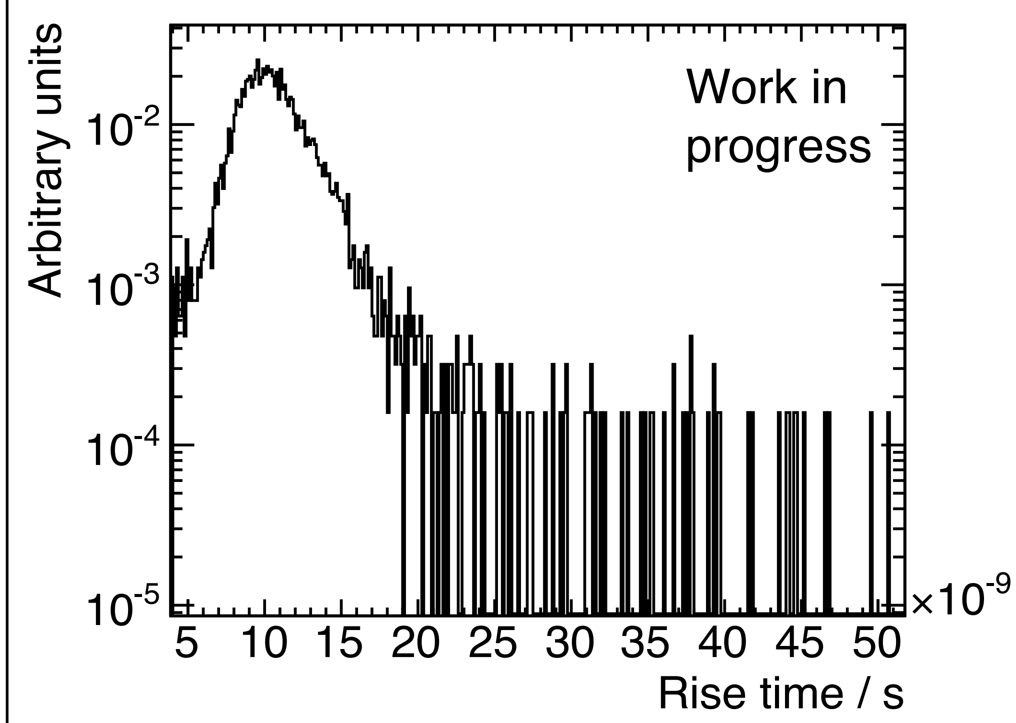
→ Minimise impact from charge sharing

Results for pitch of 28 μm and bias voltage of 6 V:

Hit time with respect to time of telescope track:



Rise time:



- Hit time relevant for CLIC to achieve time slicing of 10 ns:

→ Hit time resolution of ~ 7 ns

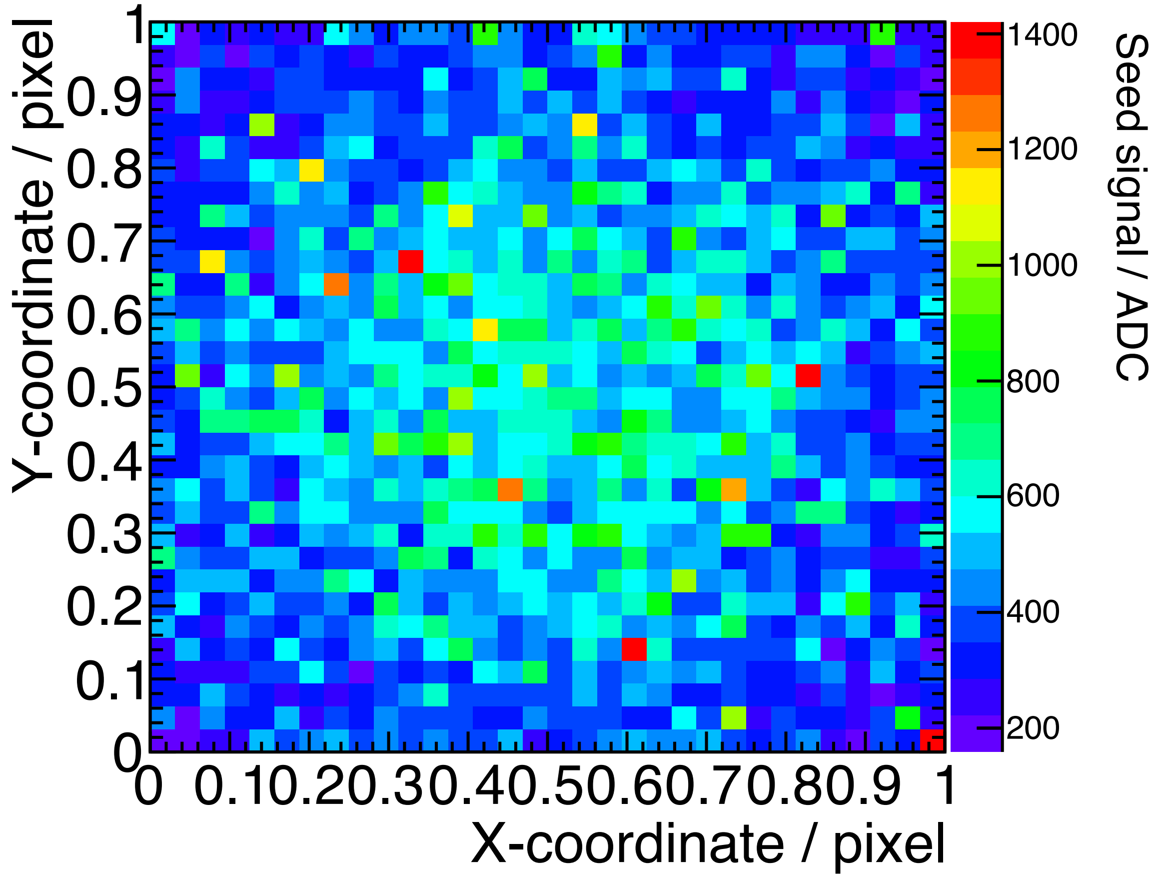
- Rise time interesting to study technology:

→ Expect slower contributions from charge sharing and / or non depleted regions

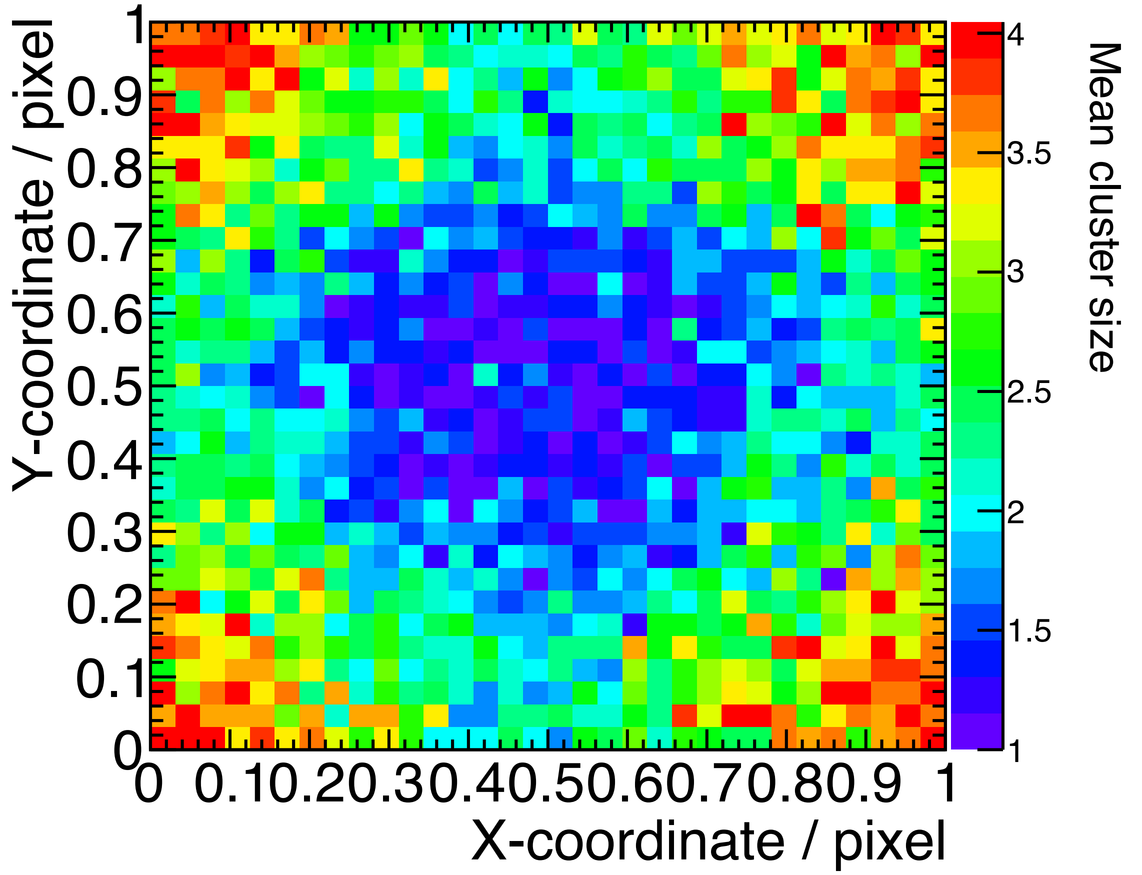
In-pixel studies at V_{bias} = 6 V

Results for pitch of 28 µm and bias voltage of 6 V:

Seed signal, highest pixel signal in cluster:



Mean cluster size:



Work in progress

- Seed signal drops at pixel edges and pixel corners due to charge sharing:

→ Lowest cluster sizes in pixel center

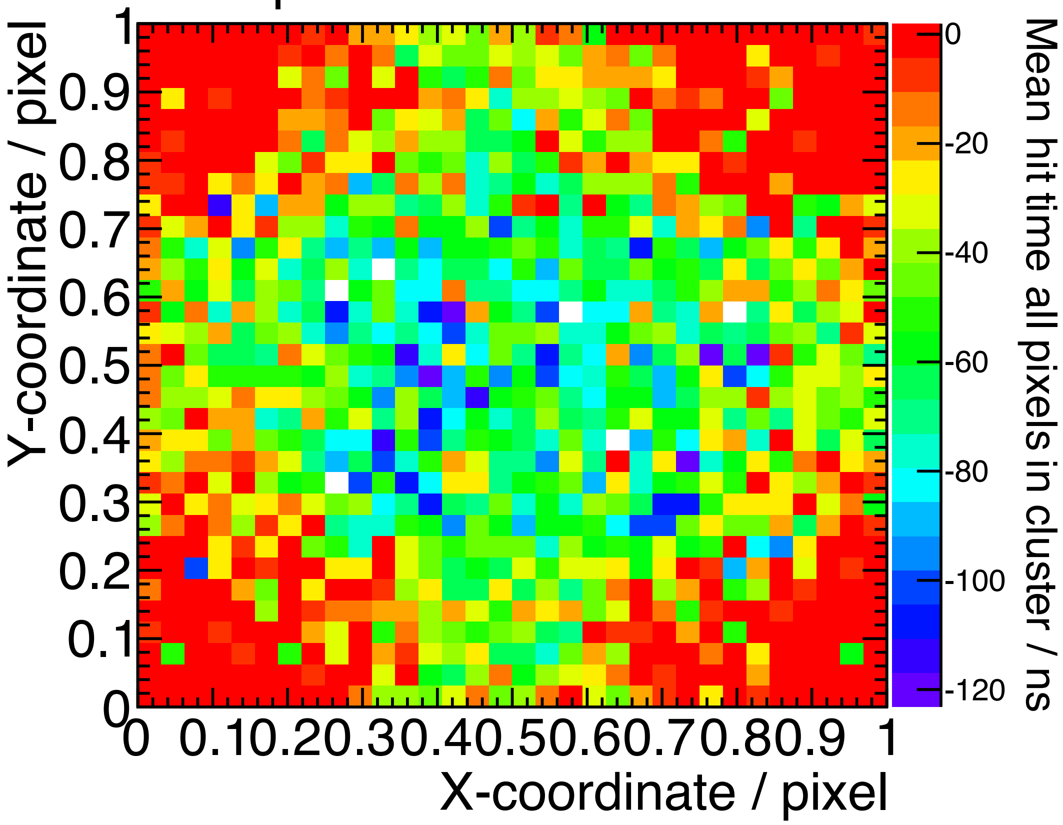
→ Intermediate cluster sizes at pixel edges

→ Highest cluster size in pixel corners

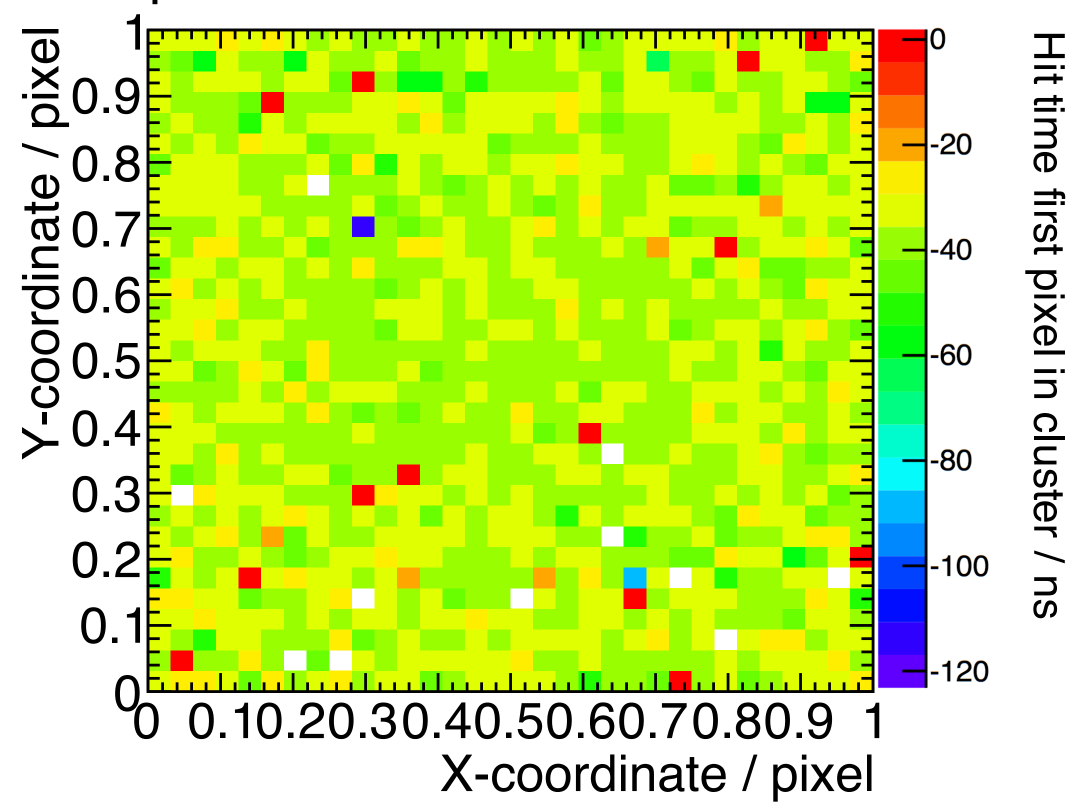
In-pixel studies at V_{bias} = 6 V

Results for pitch of 28 µm and bias voltage of 6 V:

Mean hit time of all pixels in cluster:



Hit time of first pixel pixel in cluster:



Blue = early hits

Red = late hits

Work in progress

- Mean hit time of all pixels in cluster interesting to study dependency of timing in pixel cell on charge sharing:

→ Large variations according to charge sharing at pixel edges and pixel corners

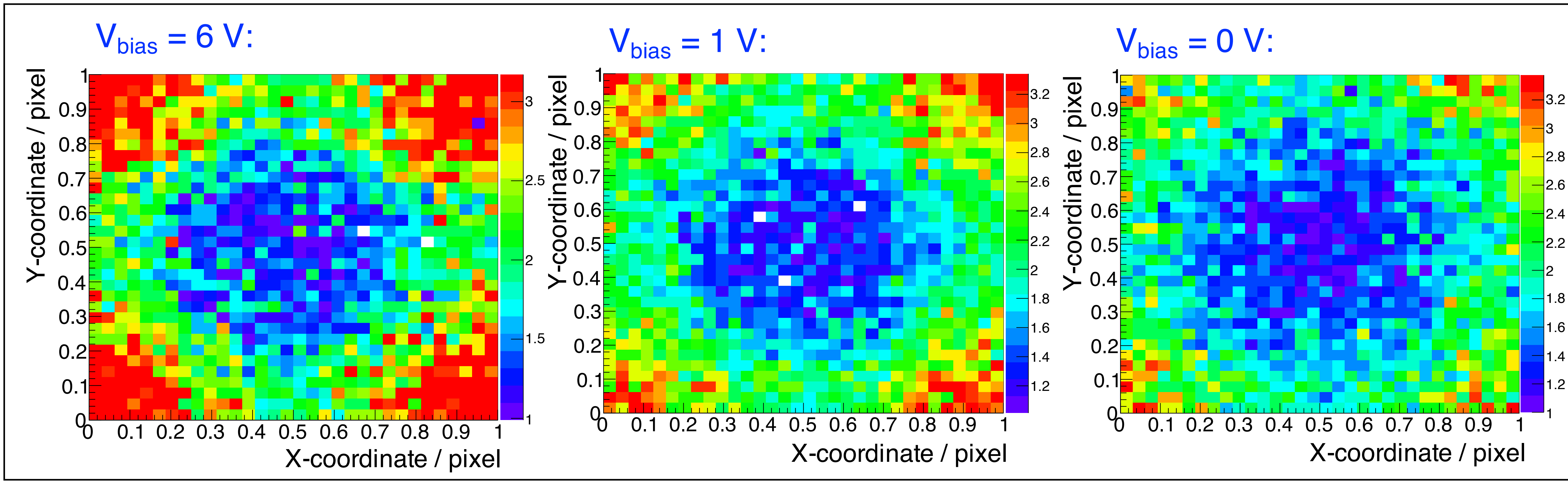
- Hit time of first pixel in cluster interesting to study in pixel performance of time slicing:

→ Small variations in pixel cell → no significant dependency on charge sharing

→ Good timing resolution

In-pixel studies for different bias voltage

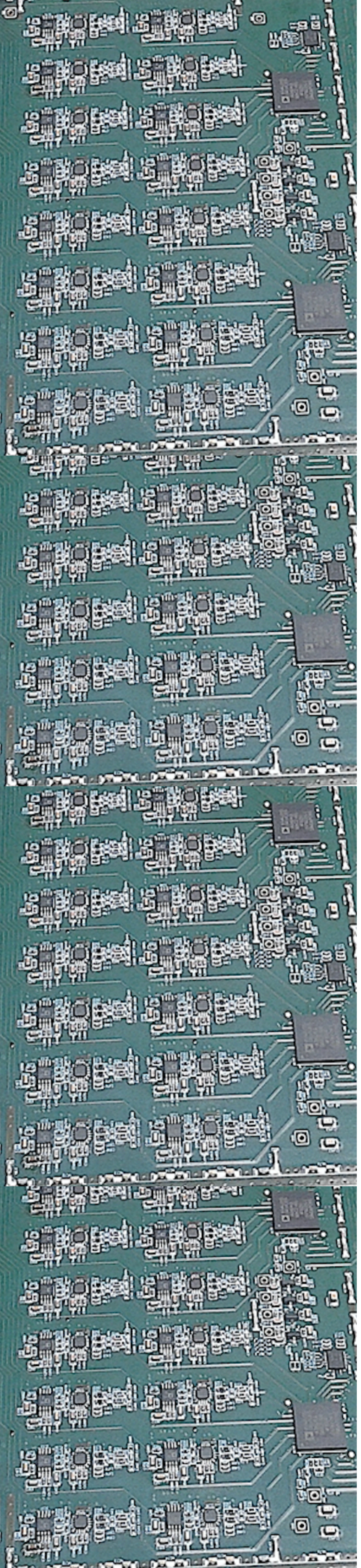
Mean cluster size in pixel cell for a pitch of 28 µm and different bias voltages:



Work in progress

- More charge sharing for higher bias voltages due to:
  - → Larger depleted region for higher bias voltages
  - → Larger signal for higher bias voltages

→ Higher cluster size in pixel corners for higher bias voltage



Summary & outlook

- ALICE investigator chip interesting to study full analogue performance of monolithic technology chosen by ALICE with respect to CLIC requirements

- Integration of ALICE investigator chip in CLICdp Timepix3 telescope

- Single point resolution of ~ 5 µm
- Hit time resolution of ~ 7 ns

  (*Test-chip with external readout)*

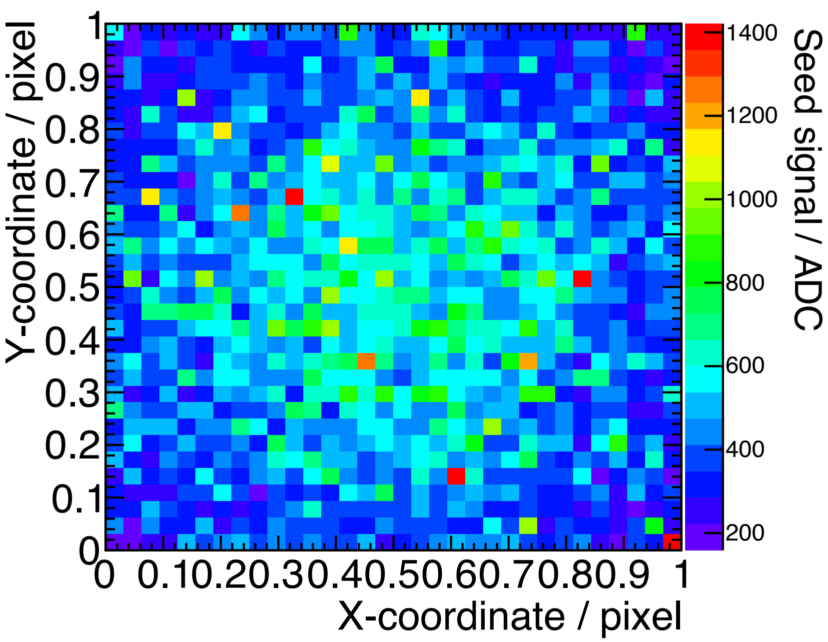
- Charge sharing and timing investigated on sub-pixel level

- Efficiency measurement and study of different pixel layouts currently ongoing

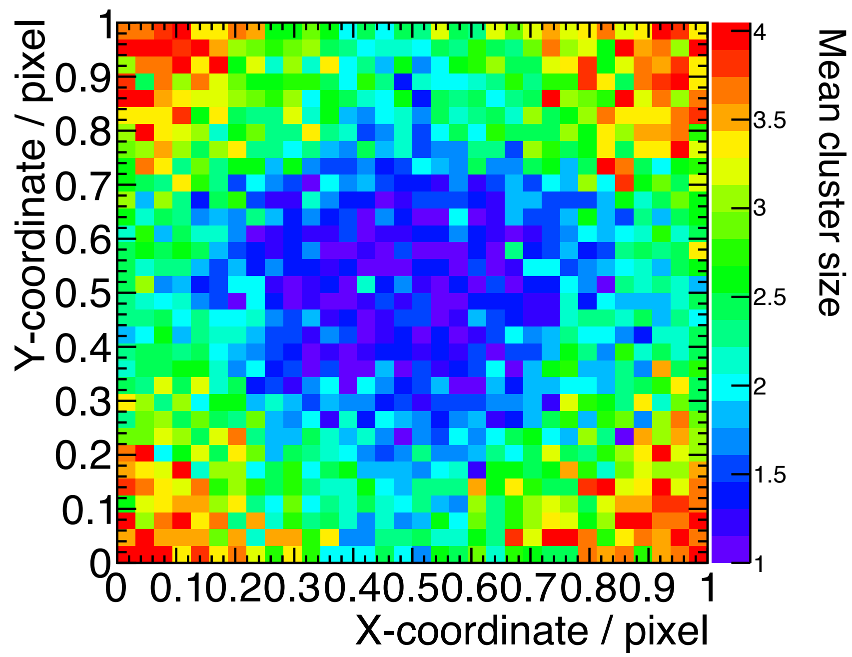
BACKUP

In-pixel timing at V_{bias} = 6 V

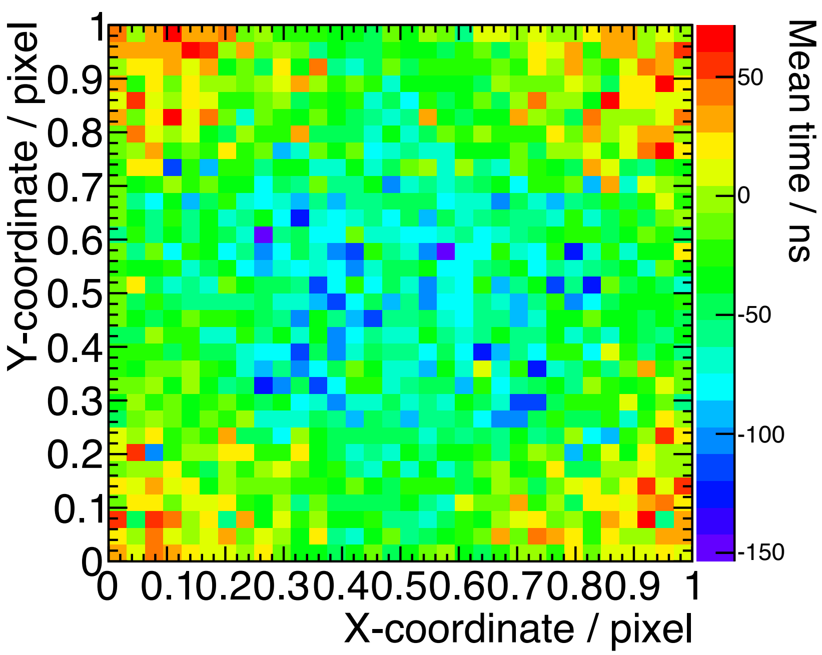
Seed signal = highest pixel signal in cluster:



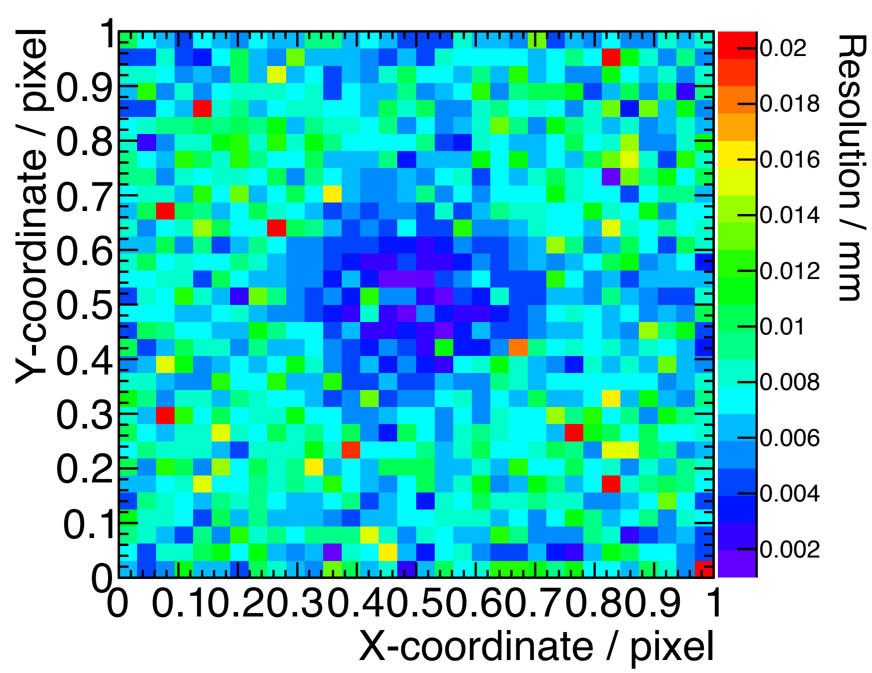
Mean cluster size:



Mean time of all pixels in cluster:



Resolution:



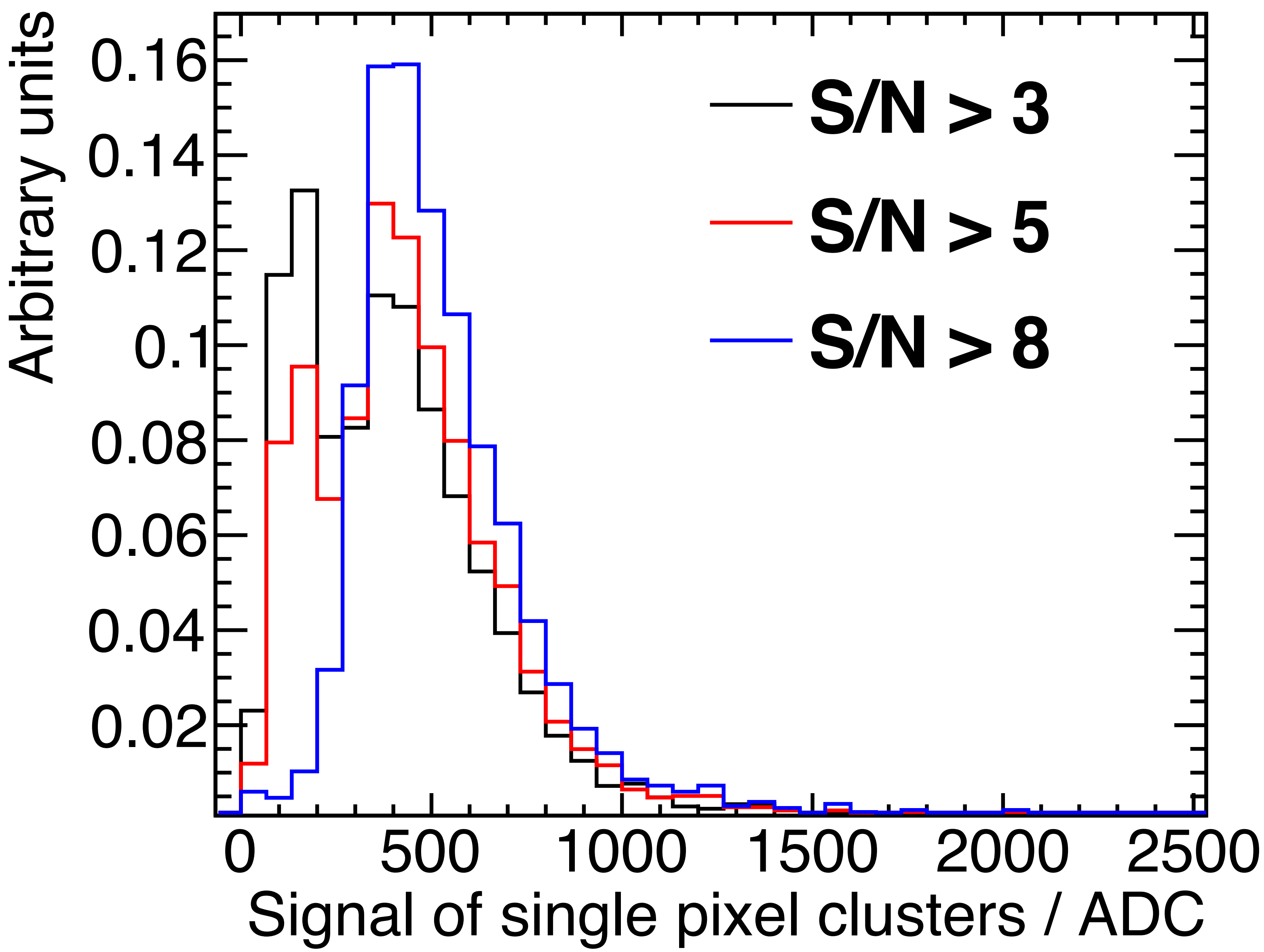
Observe behavior expected from charge sharing with in-pixel accuracy:

- Seed signal
- Cluster size
- Resolution
- Timing

↓

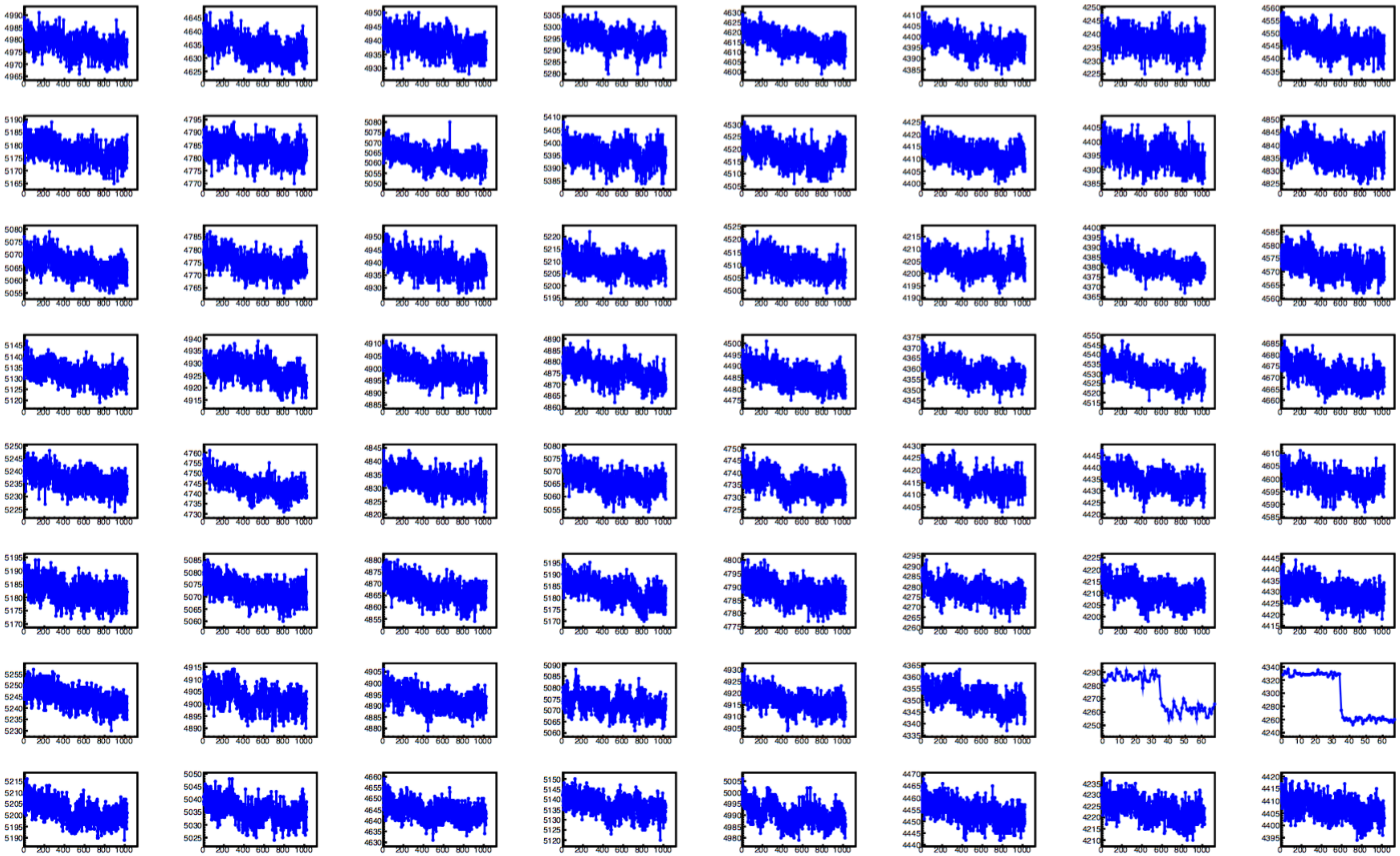
Analysis performs on great level of detail for observables we want to study

Cut on signal/noise (S/N)



- Select pixels with S/N > 8
- Note cut on DAQ level   frames are only readout if at least one pixel has S/N > 10

Common mode correction



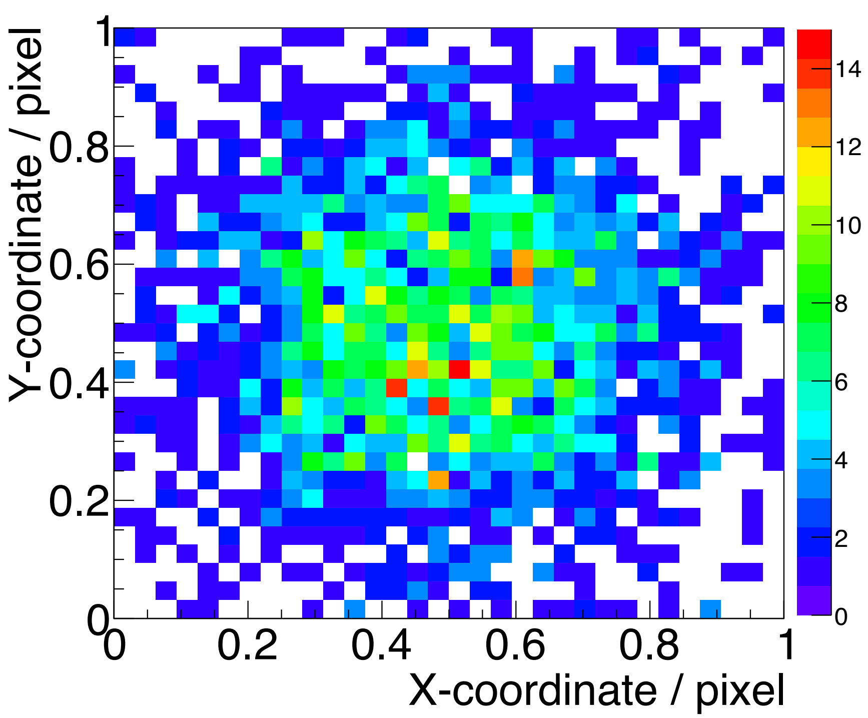
- Common mode visible in all pixels, different for different events

→ Correct on event basis:
  - Use all pixels with no hit to calculate common mode
  - Use all pixels with a hit → subtract common mode → use for further analysis

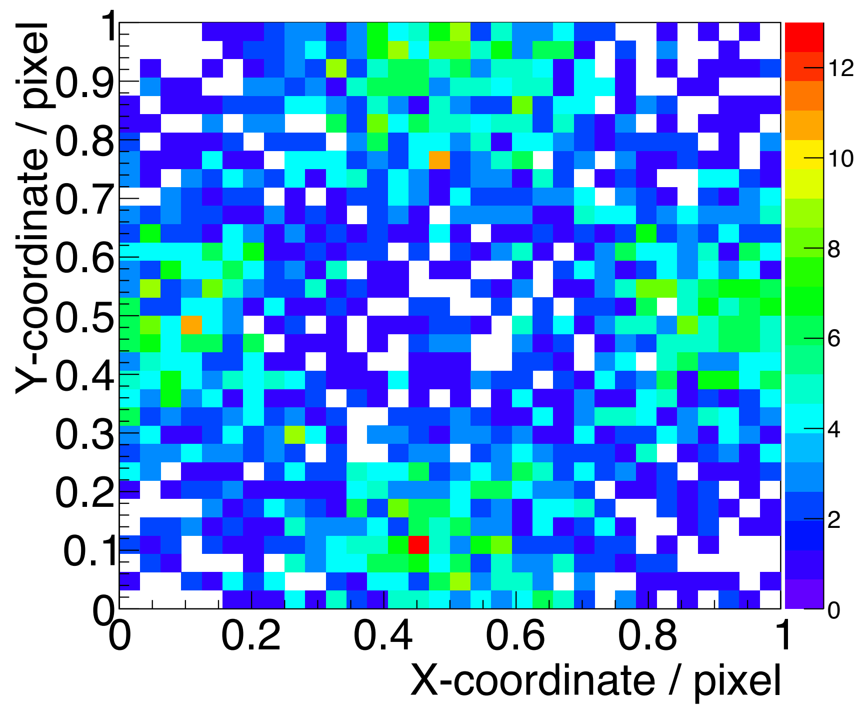
In-pixel studies at $V_{bias} = 6$ V

Hit map in pixel cell for different cluster sizes:

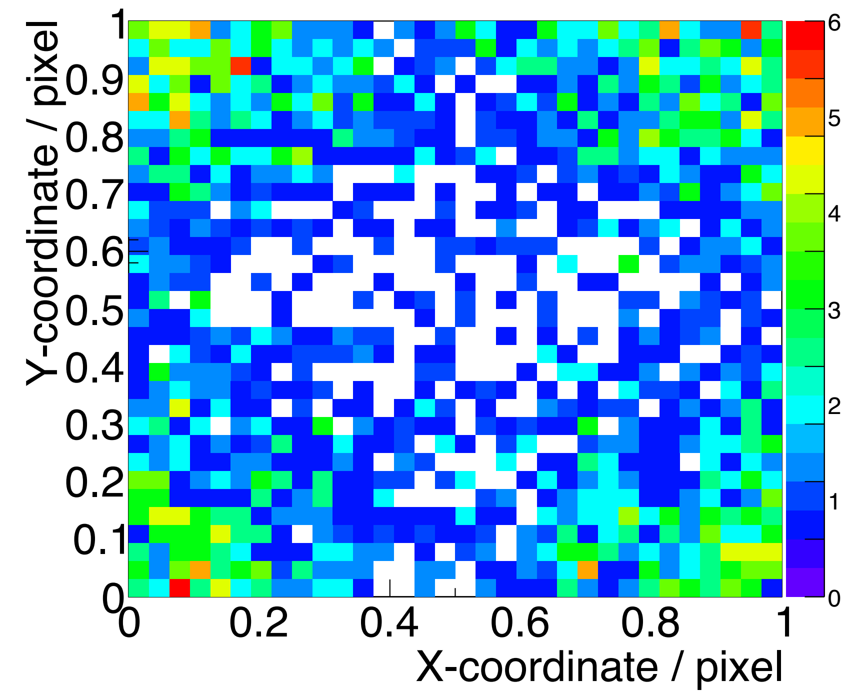
1-pixel hit:



2-pixel hit:

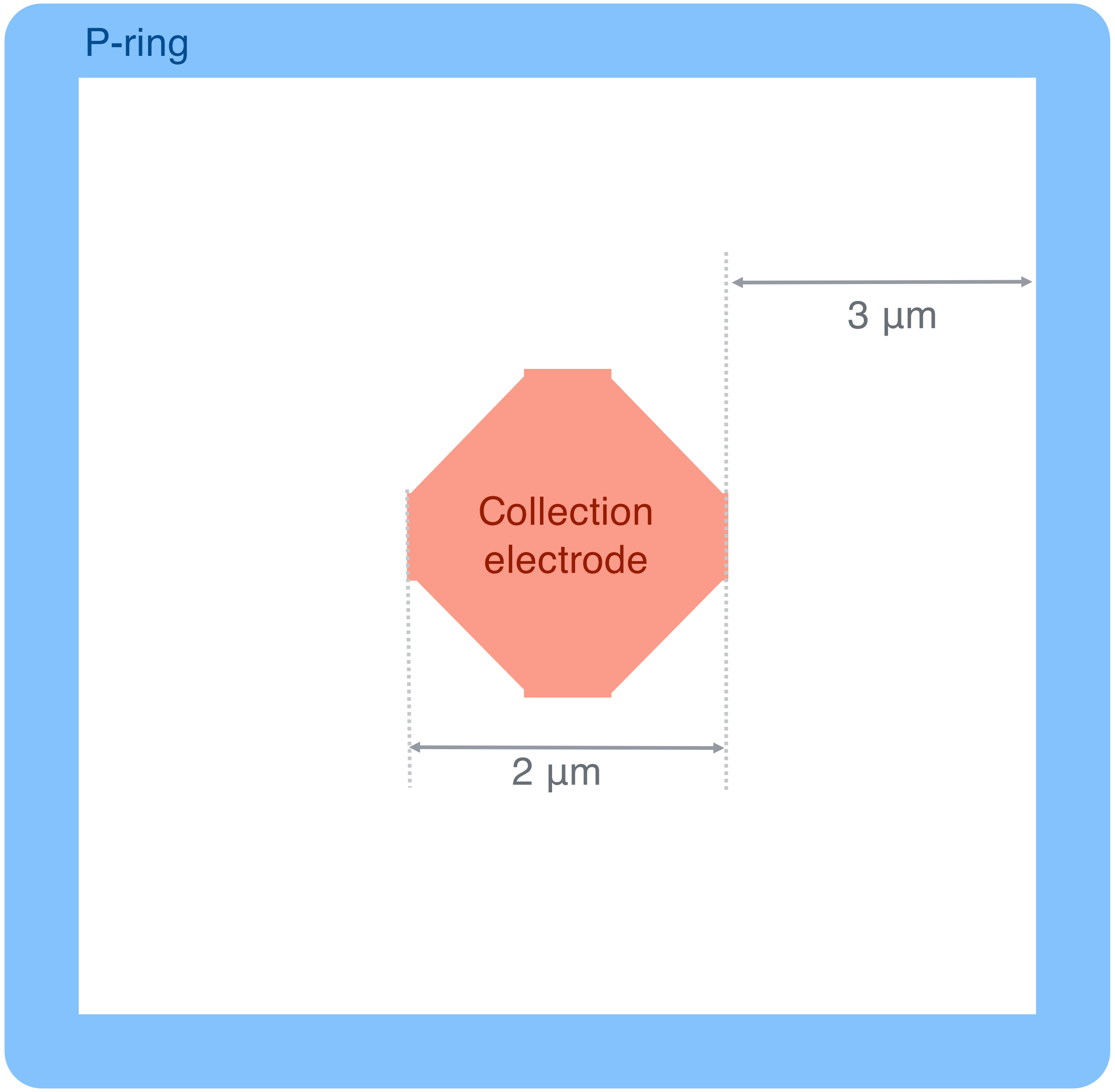


2-pixel hit:



Analysed data set

Pixel layout of studied mini-matrix:



- Study mini-matrix with pitch of 28 µm
- CMOS transistors outside p-ring

→ Shielded by deep n-wells

- Data recorded during June test-beam period

→ Investigator running in self triggering mode

- Add busy signal from investigator to telescope planes in current test-beam (ongoing) to perform efficiency measurements

Aim for analysed data presented in this talk:

→ Study spatial and timing resolution

Pixel schematic