GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

DESY Testbeam Results and More:

Timing Measurements, ATLASpix Rotations, New Sensors

CLICdp Collaboration Meeting

CERN, October 1st, 2020

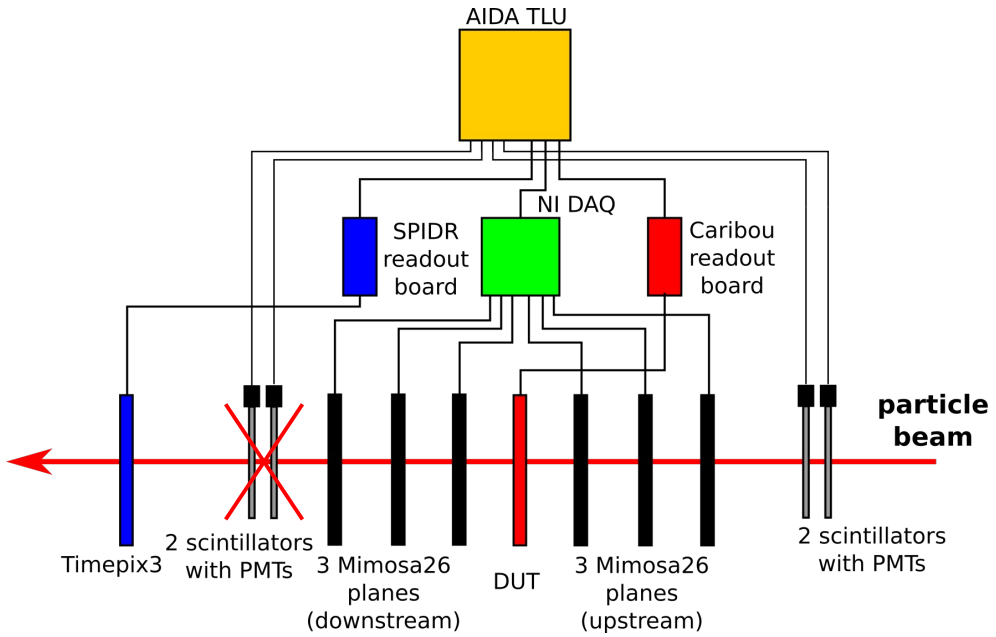
Jens Kröger

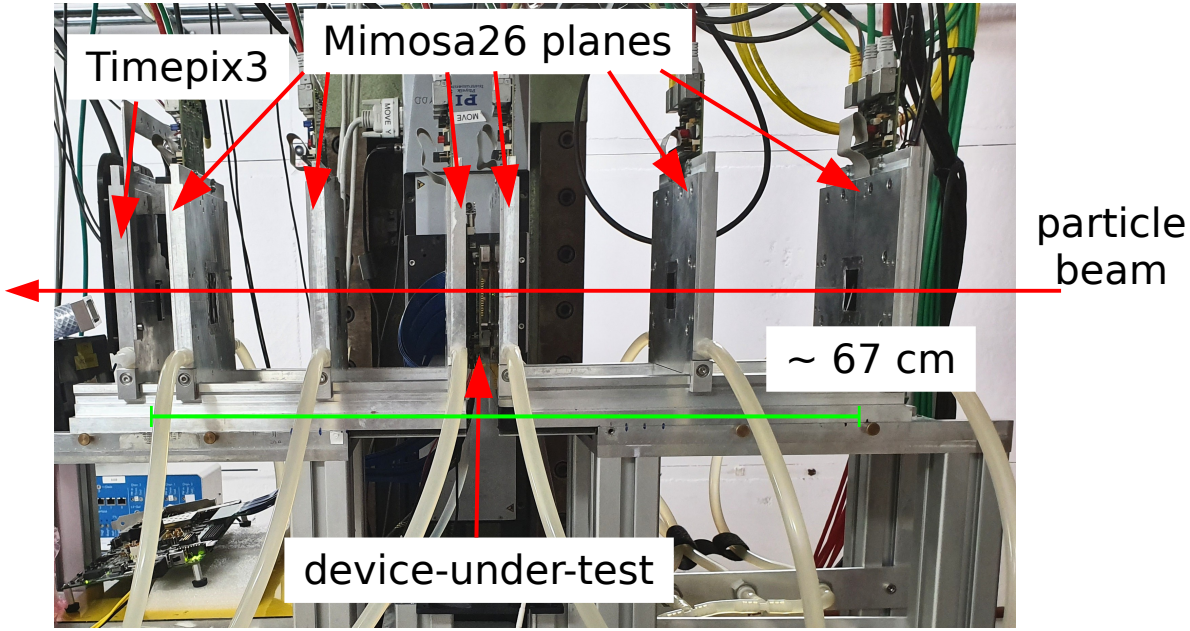
Heidelberg University & CERN

Reminder

Test Beam Setup at DESY

- **AIDA TLU** → provides global clock (time sync.) + triggers Mimosa Readout
- 2-3 scintillators + PMTs → input to TLU
- 6 Mimosa26 planes → good spatial resolution, “no” timing (2x 115µs bins rolling shutter)
- **Timepix3** → nanosecond track timestamps
- DUT → CLICpix2, **ATLASpix**, CLICTD





Reference Time Measurement

AIDA TLU:

- coincidence from 2-3 scintillators
  - coarse (25ns bins)
  - fine (780ps bins) for each scintillator
- “precise time = coarse + fine”
  - including measured delays (cables, TOF, …)

→ **2 scintillators: 600 ps**

→ 3 scintillators: 450 ps

Note:

- scintillators not tuned (potential for more)!
- repeat analysis for all test-beams (different scint.)

Timepix3:

- applied lab calibration by Florian Pitters
  → see *CLICdp-Pub-2019-001*
- **time resolution ~ 1.1 ns**
  - unfolded TLU resolution
  - cross-validated analysis with SPS data (2015)

→ fully sufficient for all current DUTs

+ validate TLU performance

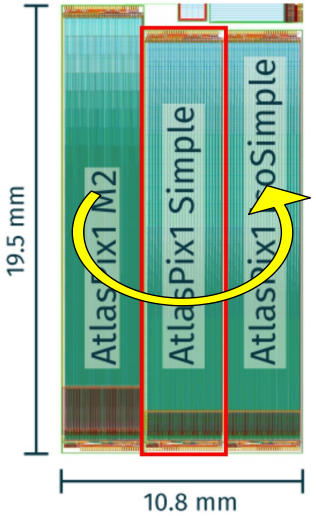
→ for highest timing resolution:

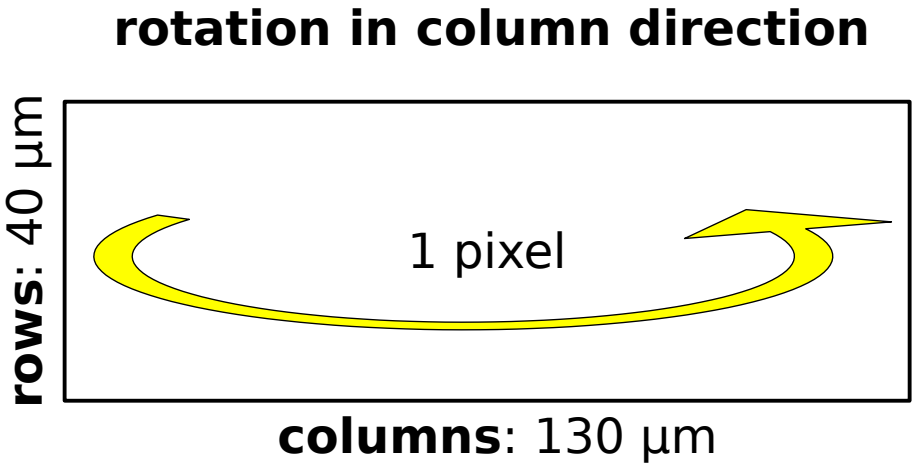
- use Timepix3 for track-by-track timestamp
- replace by nearest TLU timestamp

ATLASpix Rotation Scans

sensor dimensions:

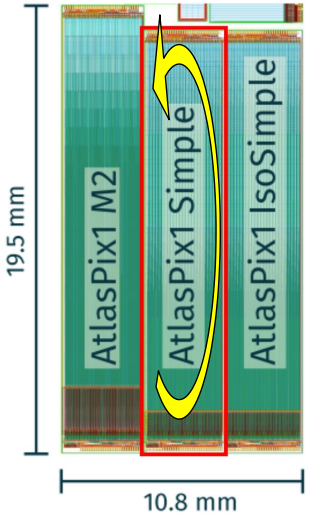
- 25 columns (130 µm pitch)
- 400 rows (40 µm pitch)

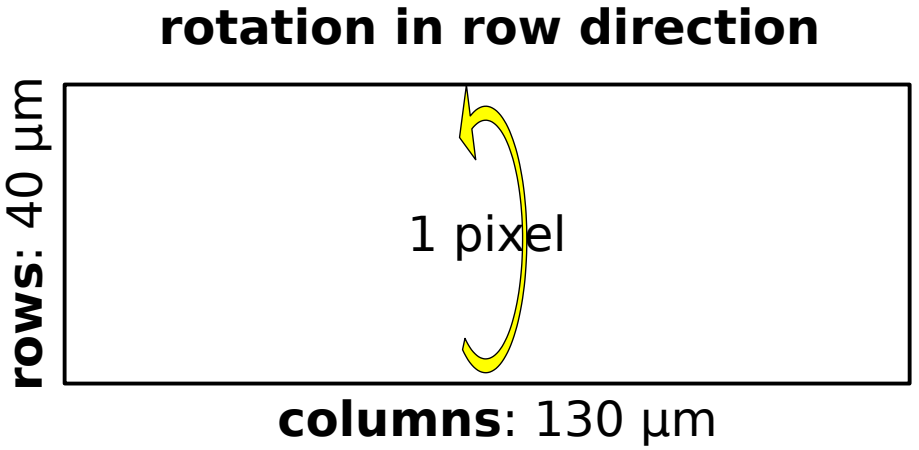




Use case in tracking detector:

- rotation in column direction
  - forward tracks
- rotations in row direction
  - low p_t tracks (more curled)

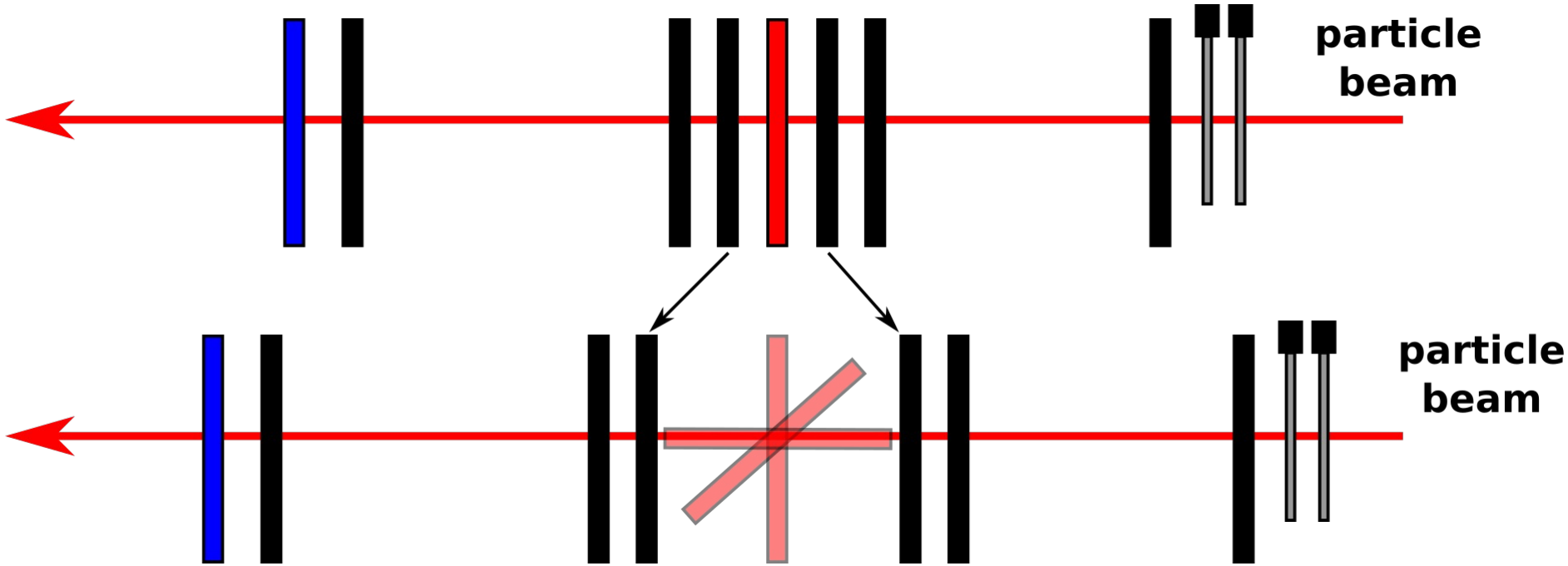




Rotation Analysis Objectives

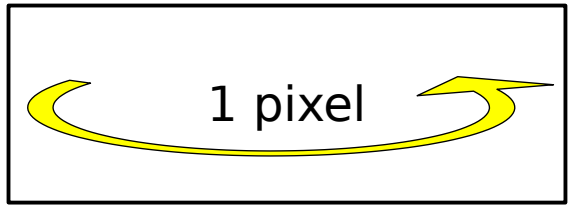
- **has not been done before**
  - cluster formation
  - depletion depth
  - timing performance
  - efficiency (?)

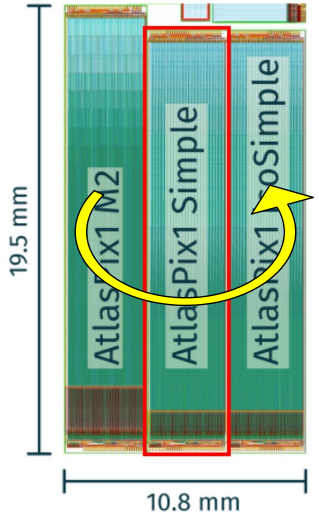
But: rotations require **larger** telescope spacing
→ **reduced** tracking precision



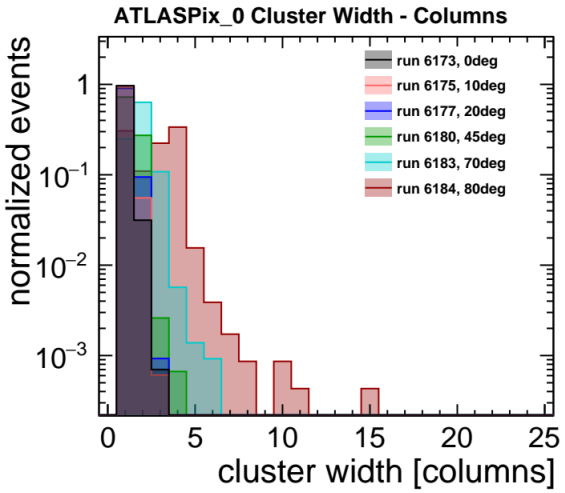
ATLASpix Rotation Scan

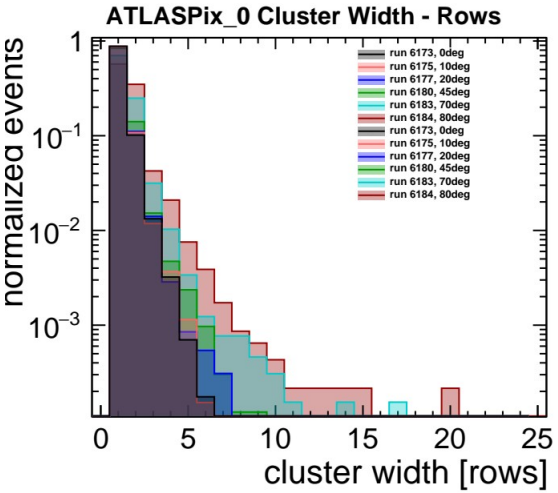
- **rotation in column direction**
- cluster width column
  → grows significantly
- cluster width row
  → grows slightly (angled tracks)
- cluster ToT and seed pixel ToT
  → clear angle dependence

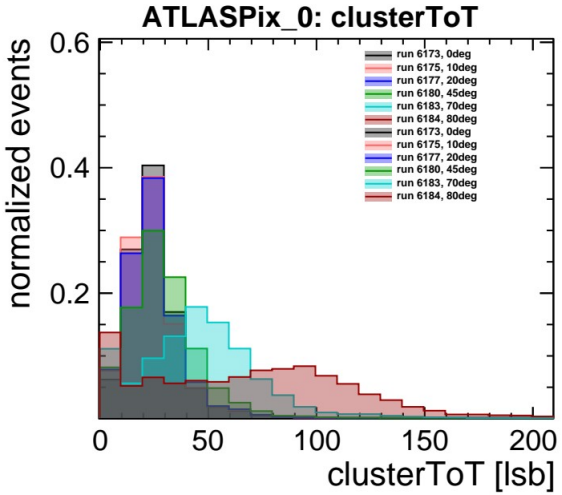


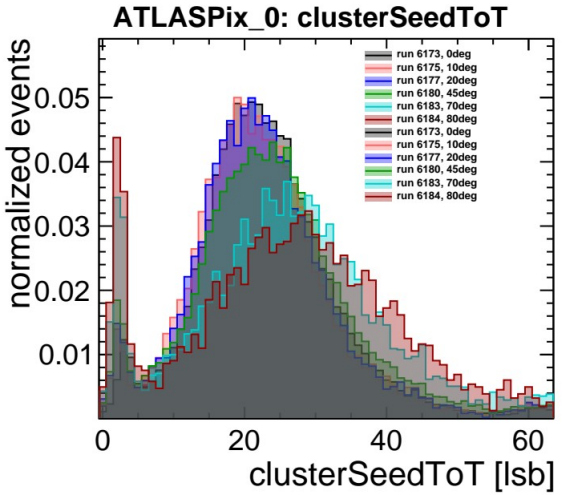


no tracking yet!
alignment work-in-progress





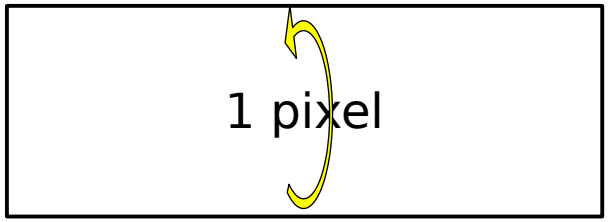


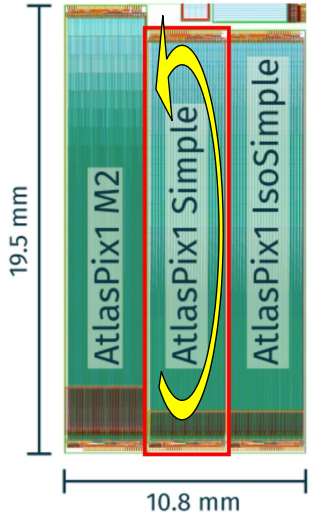


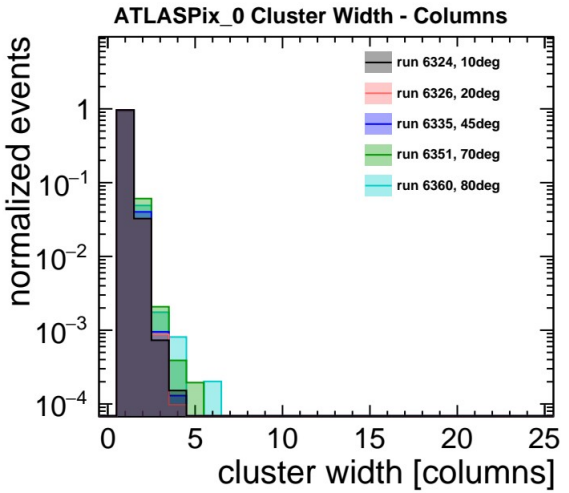
ATLASpix Rotation Scan

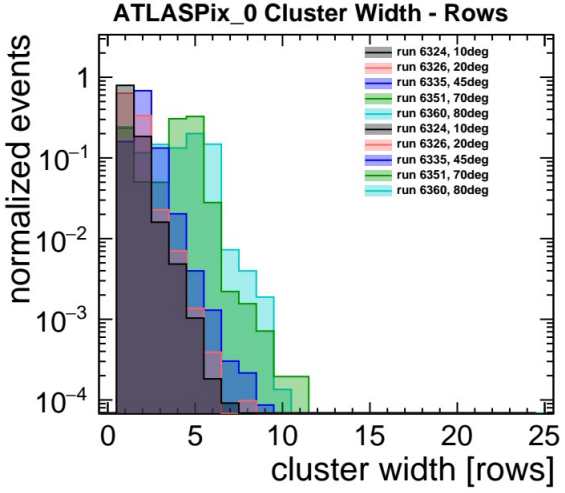
no tracking yet!
alignment work-in-progress

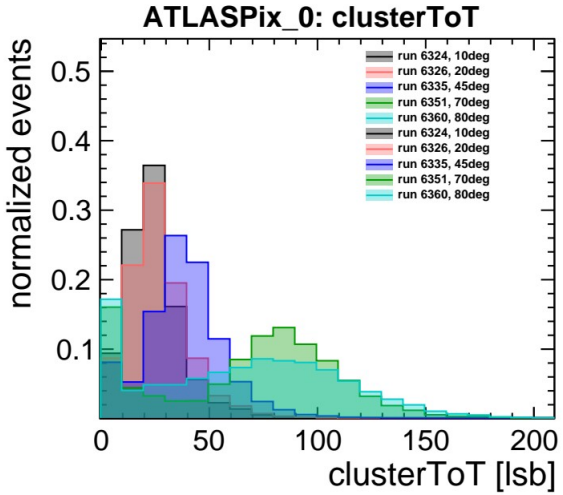
- **rotation in row direction**
- cluster width column
  → grows slightly (angled tracks)
- cluster width row
  → grows significantly
- cluster ToT and seed pixel ToT
  → clear angle dependence

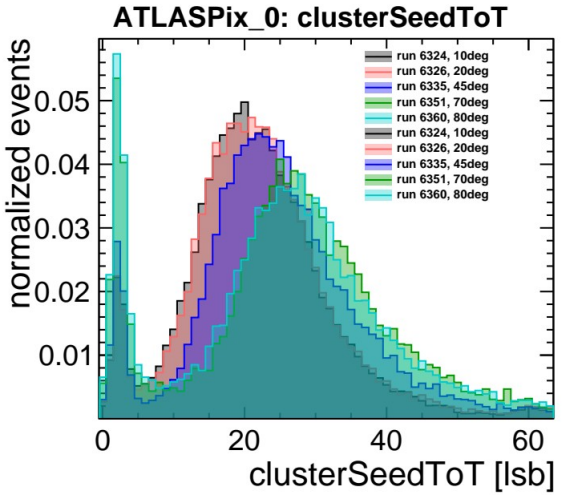






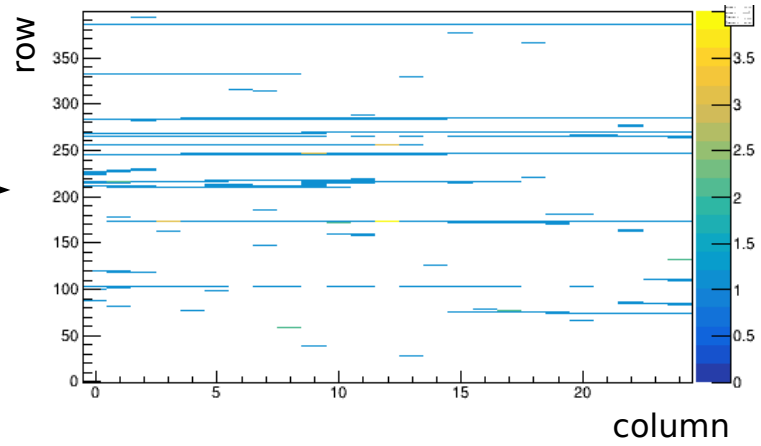




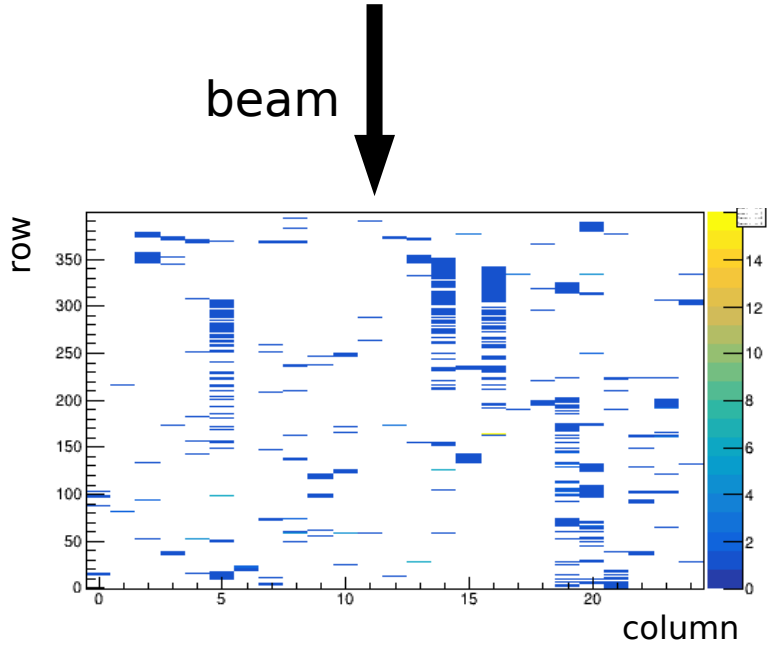


Event Displays at 90° Rotations

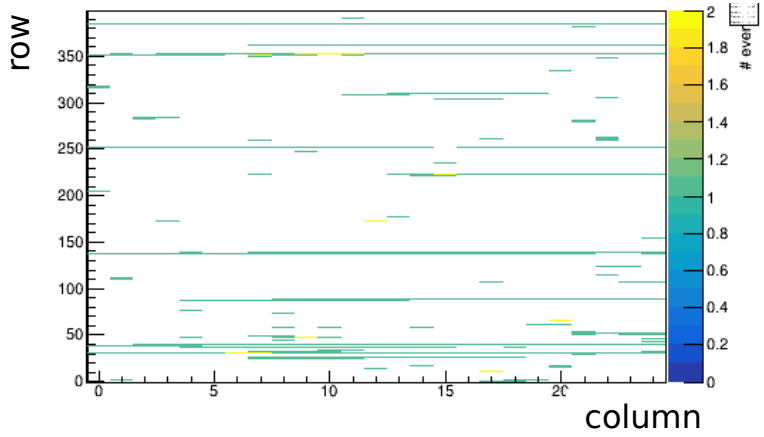
beam



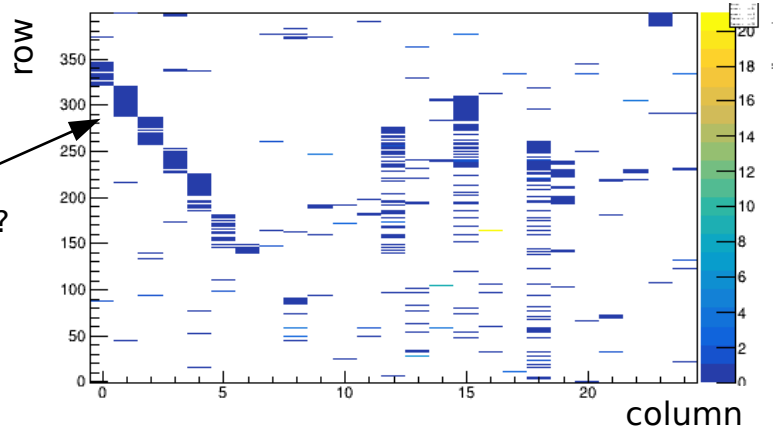
beam



beam



multiple scattering?



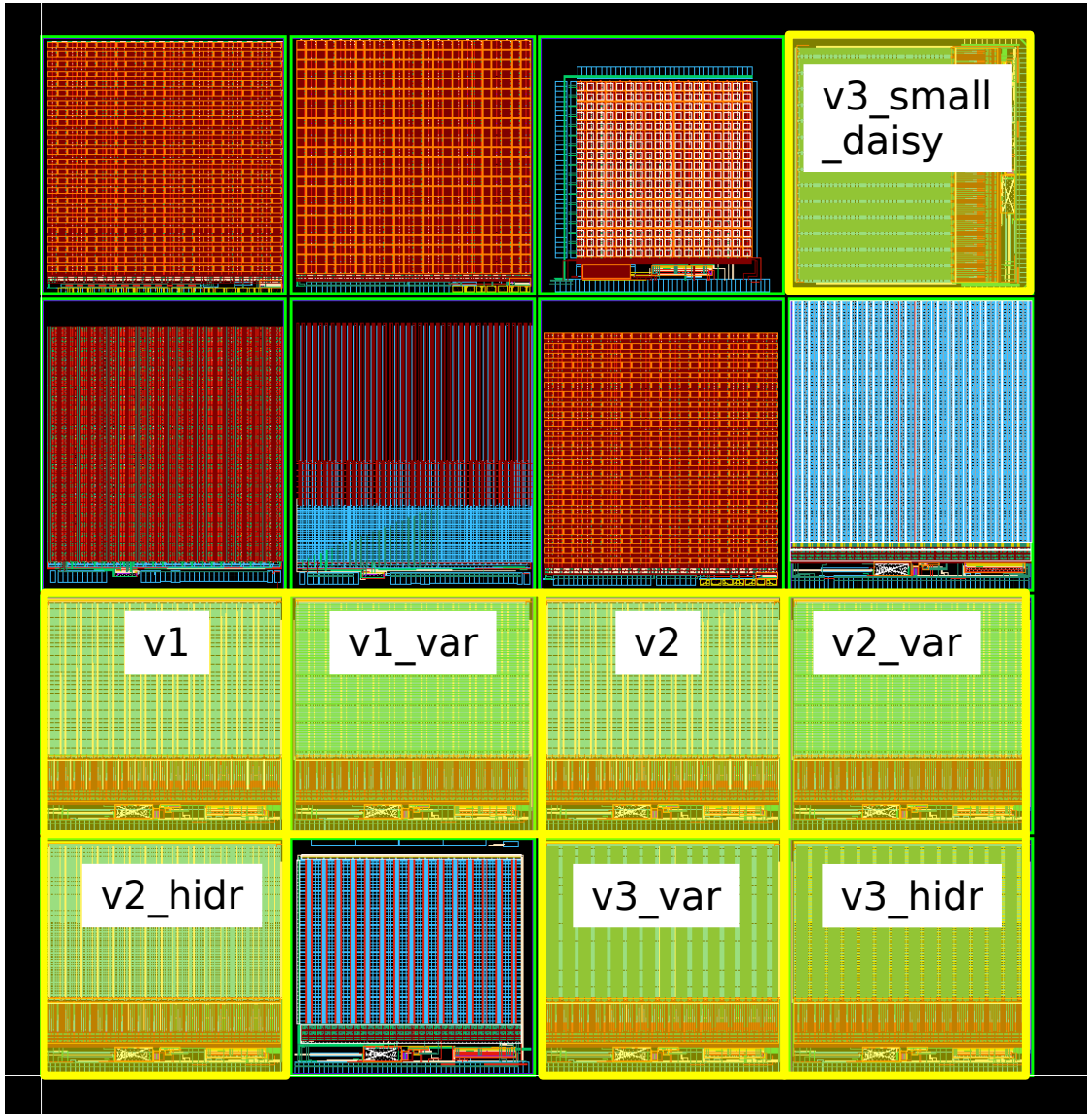
What's next after ATLASpix?

- **TSI engineering run** submitted in **May 2020** → called "Run2020"
- 8 new similar chips (+ 8 others)
  - for CLIC, LHCb, PANDA etc.
  - based on ATLASpix(3) design
- each sensor:
  - same size (~5x5 mm²)
  - same periphery and readout

→ 1 readout system:

  - directly compare 8 sensors

Reticle map of Run2020



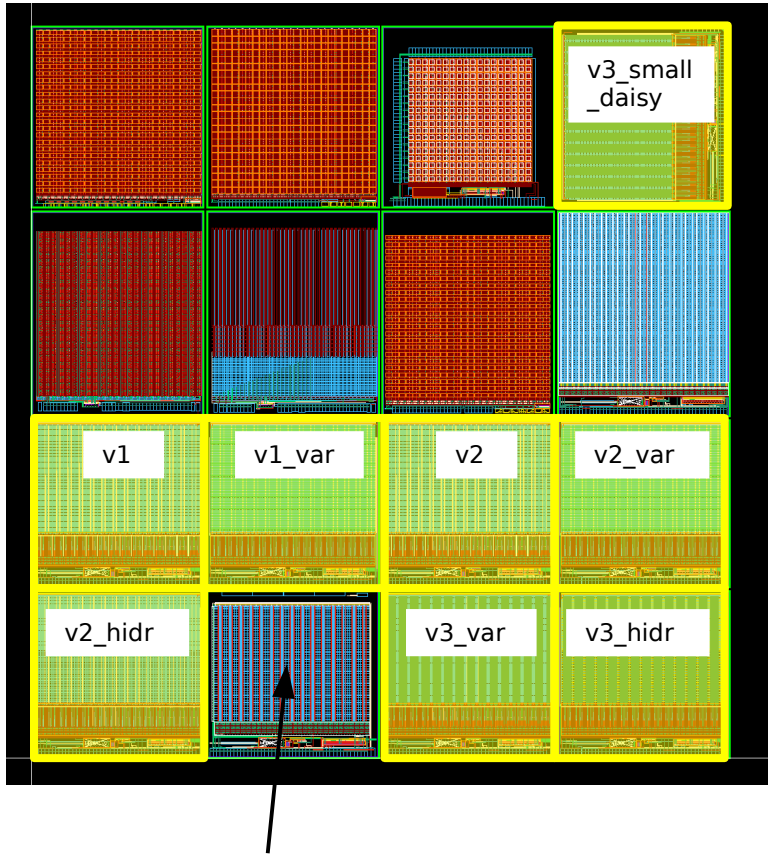
8 Similar Sensors

- same: size, periphery, readout, pinout
- different: comparators, amplifiers

- v1: NMOS comparator
  - well-known (safe option)
- v2: CMOS comparator
  - better performance expected
  - but: manufacturing risk due to additional deep p-well
- v3: comparator in periphery
  - very fast (only for large pixels)
  - allows daisy-chain readout

- v*:
  - 29 x 124 pixels
  - 25 x 165 µm²
- v*_var: *variable pixel size*
  - 50 x 165 µm² and
  - 100 x 165 µm²
- *_hidr: *high dynamic range*
  - 2 comparators:
    - one fast for timestamp
    - one slow for ToT

Reticle map of Run2020



small pixel HV-MAPS:

- 25 x 35 µm²
- CLIC Vertex Detector?

Image from Mu3e (Heidelberg)

Which are relevant for CLIC?

Reminder

CLIC tracker requirements

- spatial resolution:
  ~ 7 µm (transversal)
- max. granularity:
  1-10 mm pixel size (longitudinal)

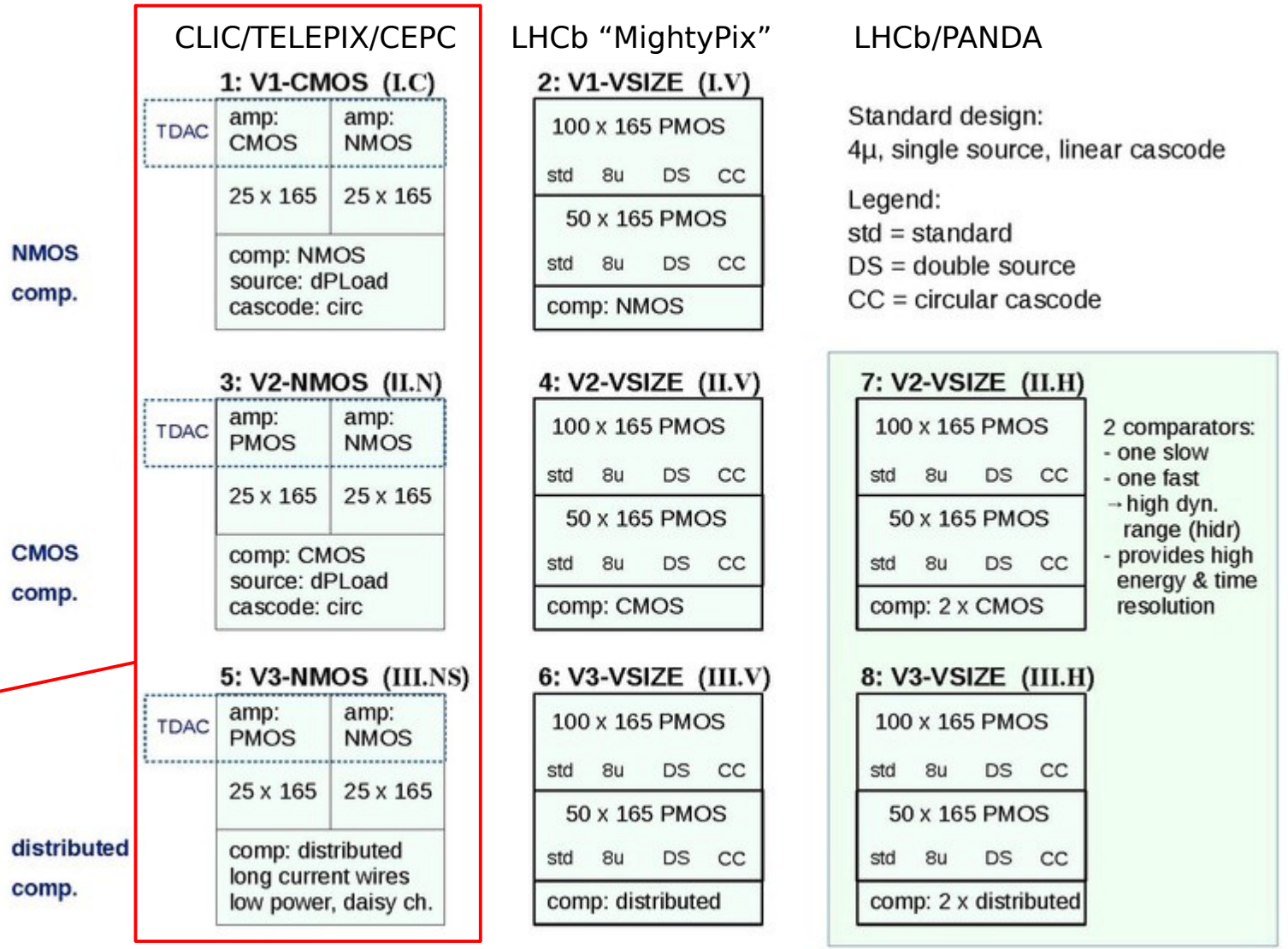
ATLASpix: 40 x 130 µm²

- transversal: 40 µm/√12 ~ 11.5 µm
  (binary resolution)
- longitudinal: 130 µm << 1 mm

New sensors: 25 x 165 µm²

- transversal: 25 µm/√12 ~ 7.2 µm
  (binary resolution)
- longitudinal: 165 µm << 1 mm

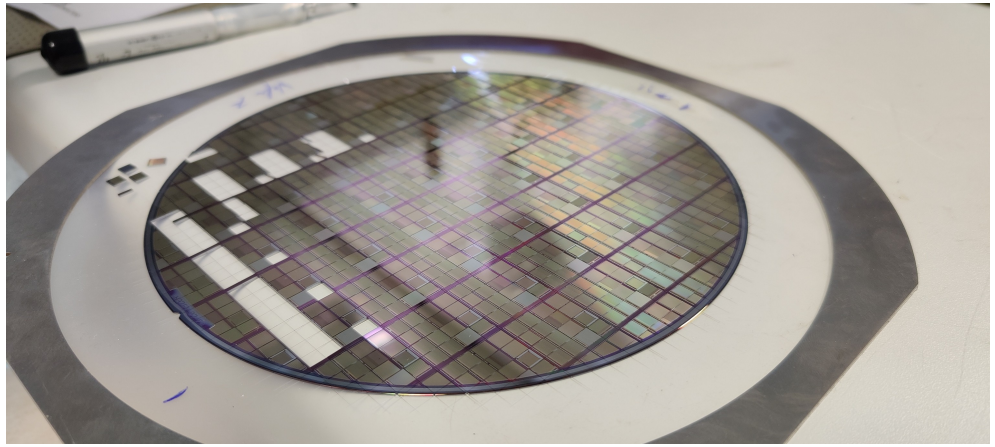
relevant for CLIC:

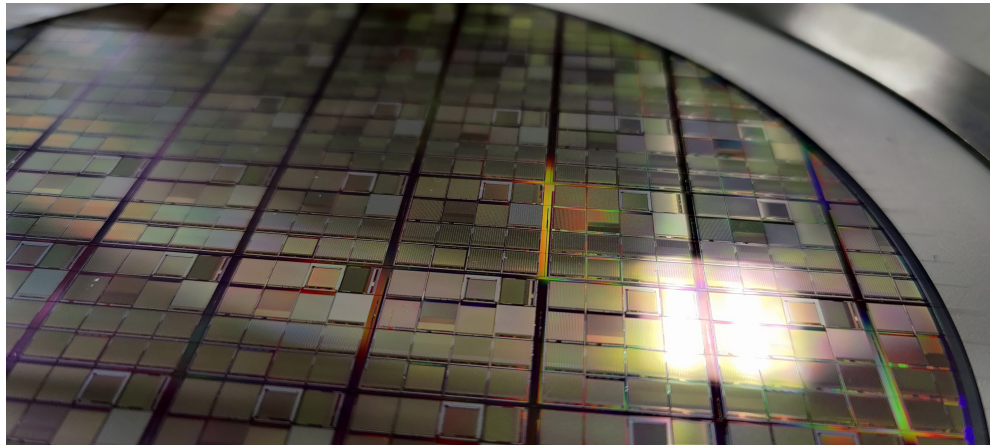


Timeline + Status

- submission in May 2020
- wafers received in September 2020
- 1 unthinned wafer diced at KIT (Karlsruhe)
- started testing in Heidelberg
- other wafers:
  thinning + dicing at Optim (France)
  → delayed by COVID
- first LHCb test-beam at DESY in 3 weeks
  - support by Mu3e group (Heidelberg)
  - support by me for reconstruction (Corryvreckan)

Wafer Picking in Karlsruhe





Summary:

Reference Time

- quantified precisely now
  - AIDA TLU: 450 – 600 ps
  - Timepix3: 1.1ns

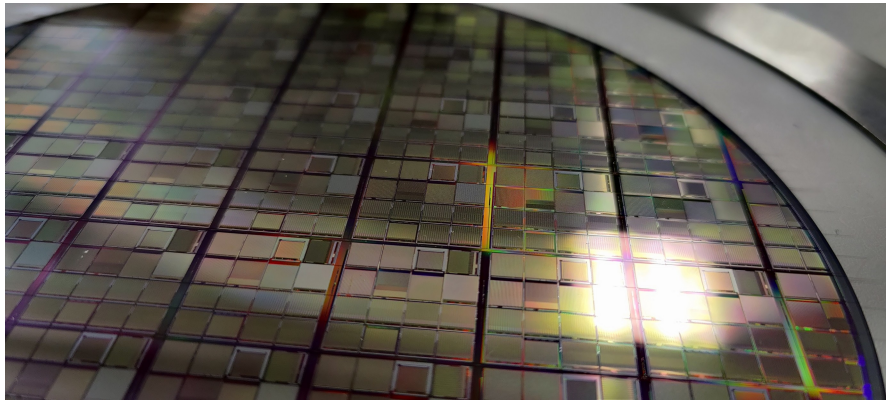
ATLASpix Rotation Scans

- first sanity checks
  → good data quality
- analysis ongoing
  → interesting physics results expected

Outlook:

New Sensors

- based on ATLASpix design
- produced by TSI,
  testing has begun in HD
- next: integration in Caribou



Acknowledgment:
The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF).

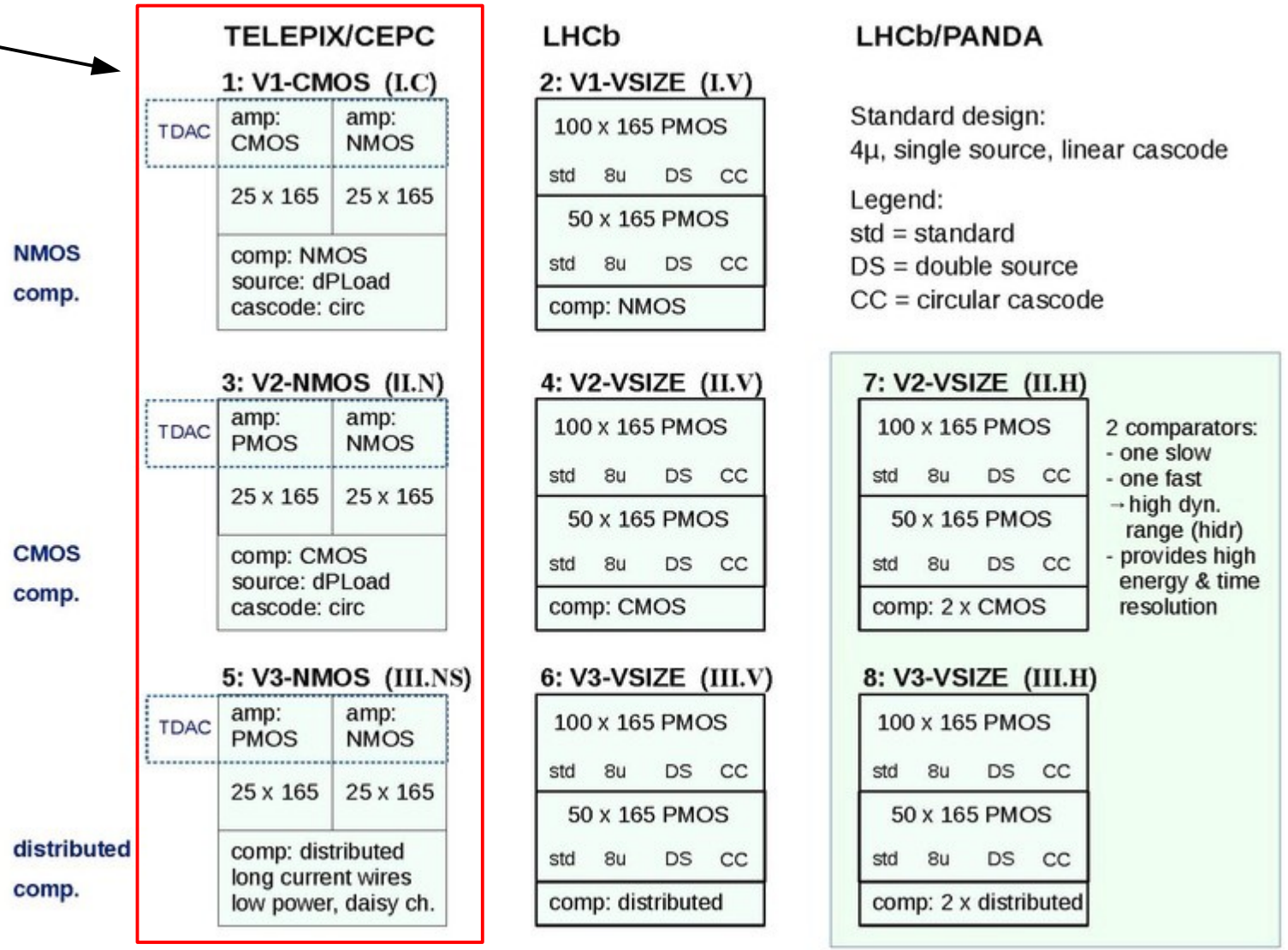
Backup

in case there are some questions...

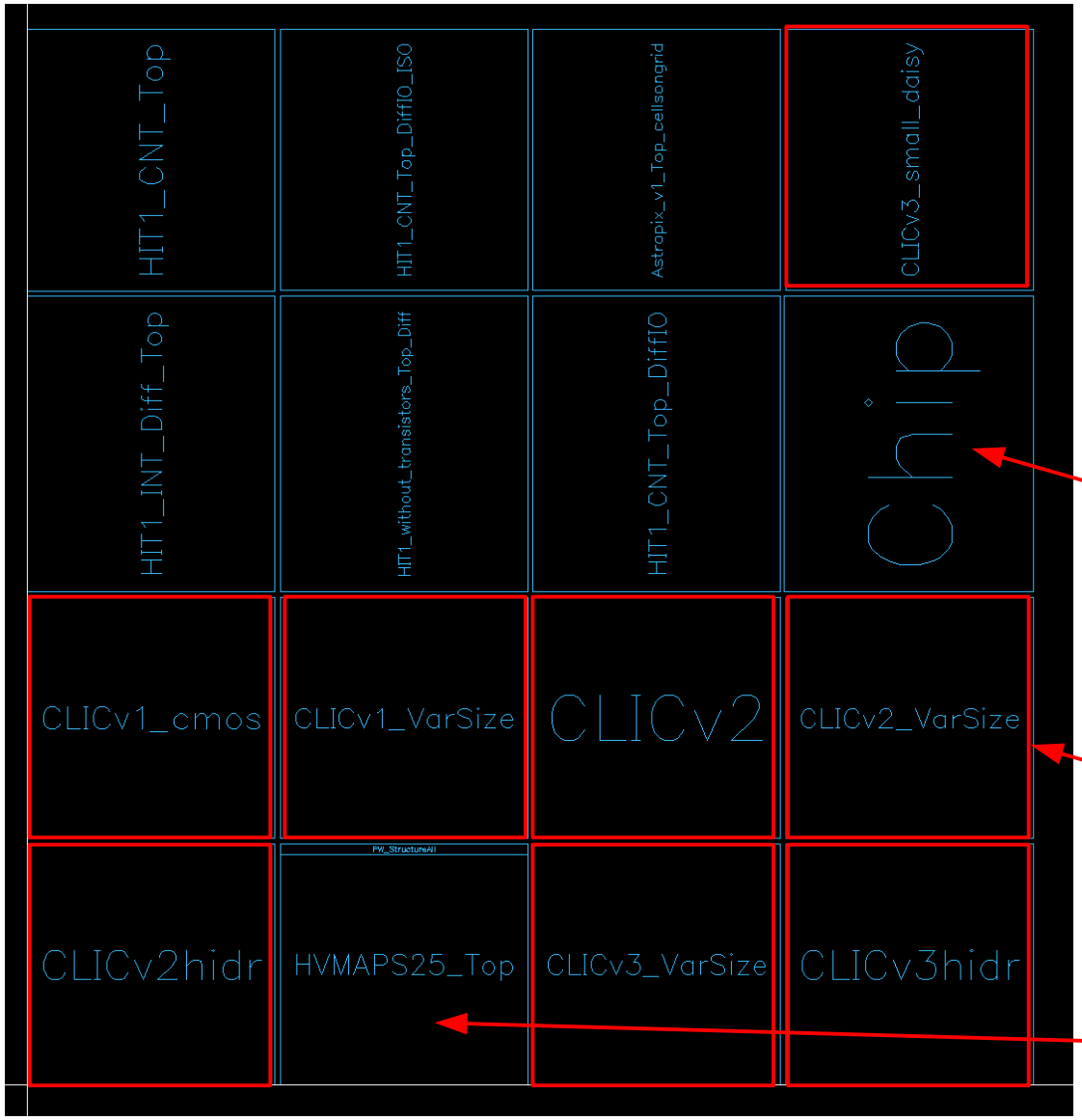
Run2020: More details on the sensors

- relevant for CLIC tracker:
  - ATLASpix: 40 x 130 µm²
  - now: 25 x 165 µm²

- each pixel contains:
  - n-well (electrode)
  - charge-sensitive amplifier (CSA)
  - output transistor
  - TDAC (not all matrices), 3 tune + 1 enable
  - injection switch + capacitor



Run2020: all chips on the reticle



for CEPC

covered in this talk

HV-MAPS with small pixels

Pros and Cons of the Different Designs

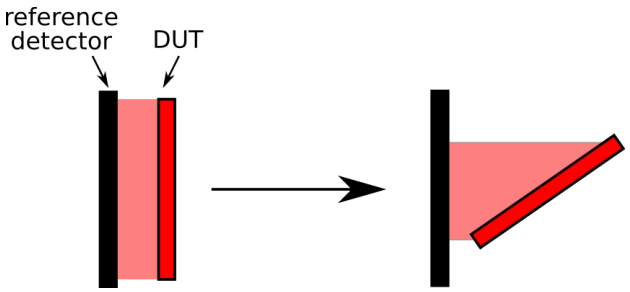
Comparators

- NMOS:
  - + standard used so far
  - - high current consumption
  - - larger delay than CMOS
  - - additional 2.1V
  - - reduced output amplitude
  - - large area, large capacitance
- CMOS:
  - + faster than NMOS at same current
  - + smaller
  - + more radiation tolerant (?)
  - - additional deep p-well (1st time for TSI) → some risk
- distributed
  - + very small capacitance in pixel
  - + fast, low power
  - + no additional p-well
  - - 2 lines per pixel → only feasible for larger pixels

Amplifiers

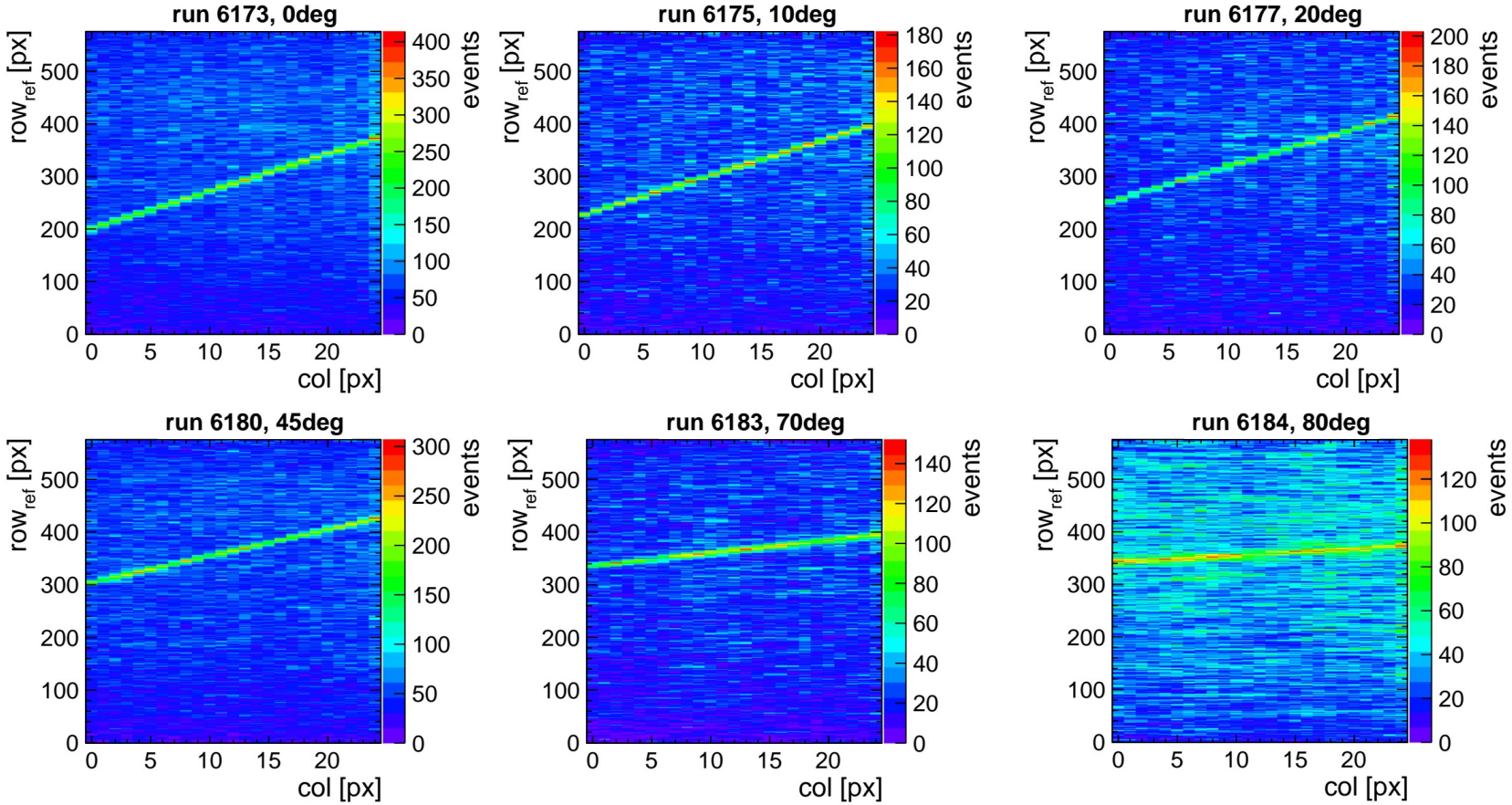
- PMOS:
  - + lower noise at high current
  - + smaller timewalk
  - + more suitable for larger pixels (large capacitance)
- NMOS:
  - + better timewalk at small currents
  - + more suitable for smaller pixels (small capacitance)
  - - some risk: more flicker noise + less experience
- CMOS:
  - + for very low bias current (like at CEPC)

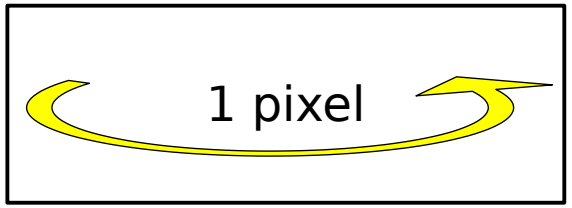
ATLASpix Rotation Scan:

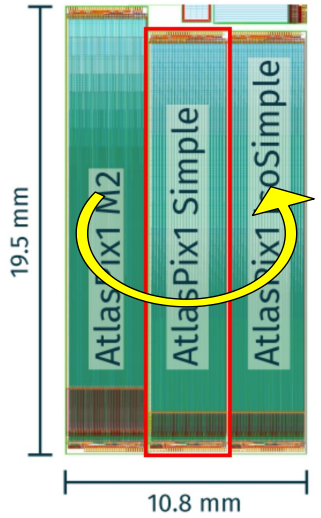


- **2D correlations** for rotation in **column** direction

  larger rotation → cover **all columns** on DUT with **fewer rows** of reference detector (rotated by 90°)



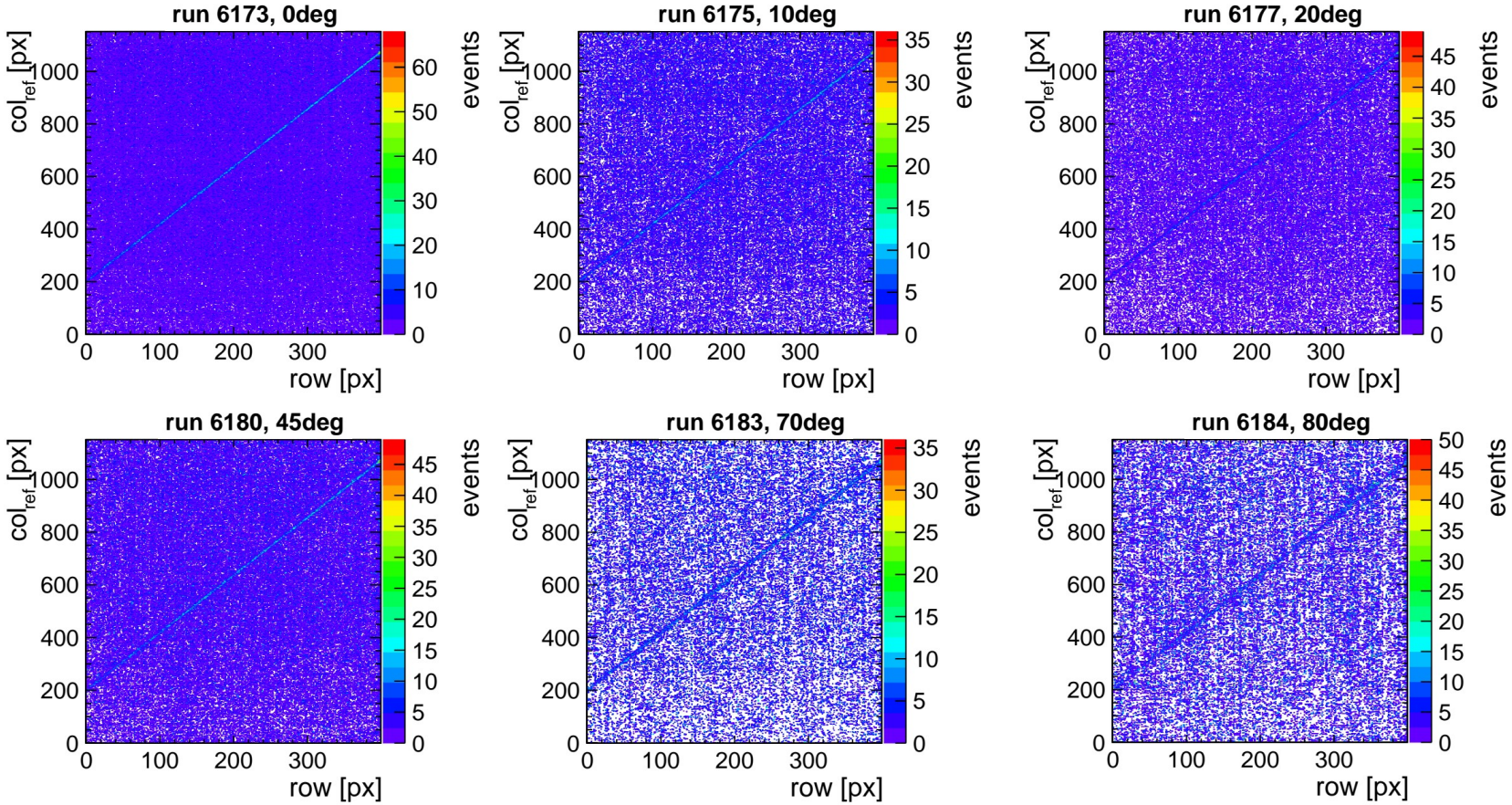


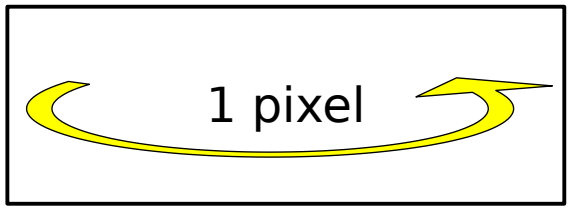


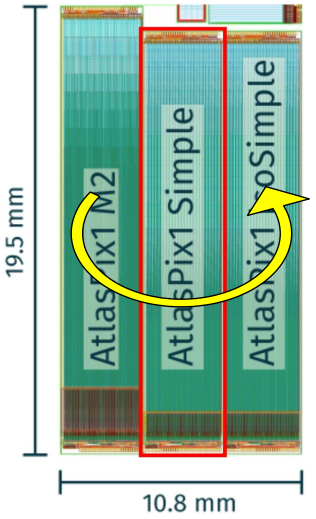
ATLASpix Rotation Scan:

- **2D correlations** for rotation in **column** direction

  as expected: no significant effect for rows



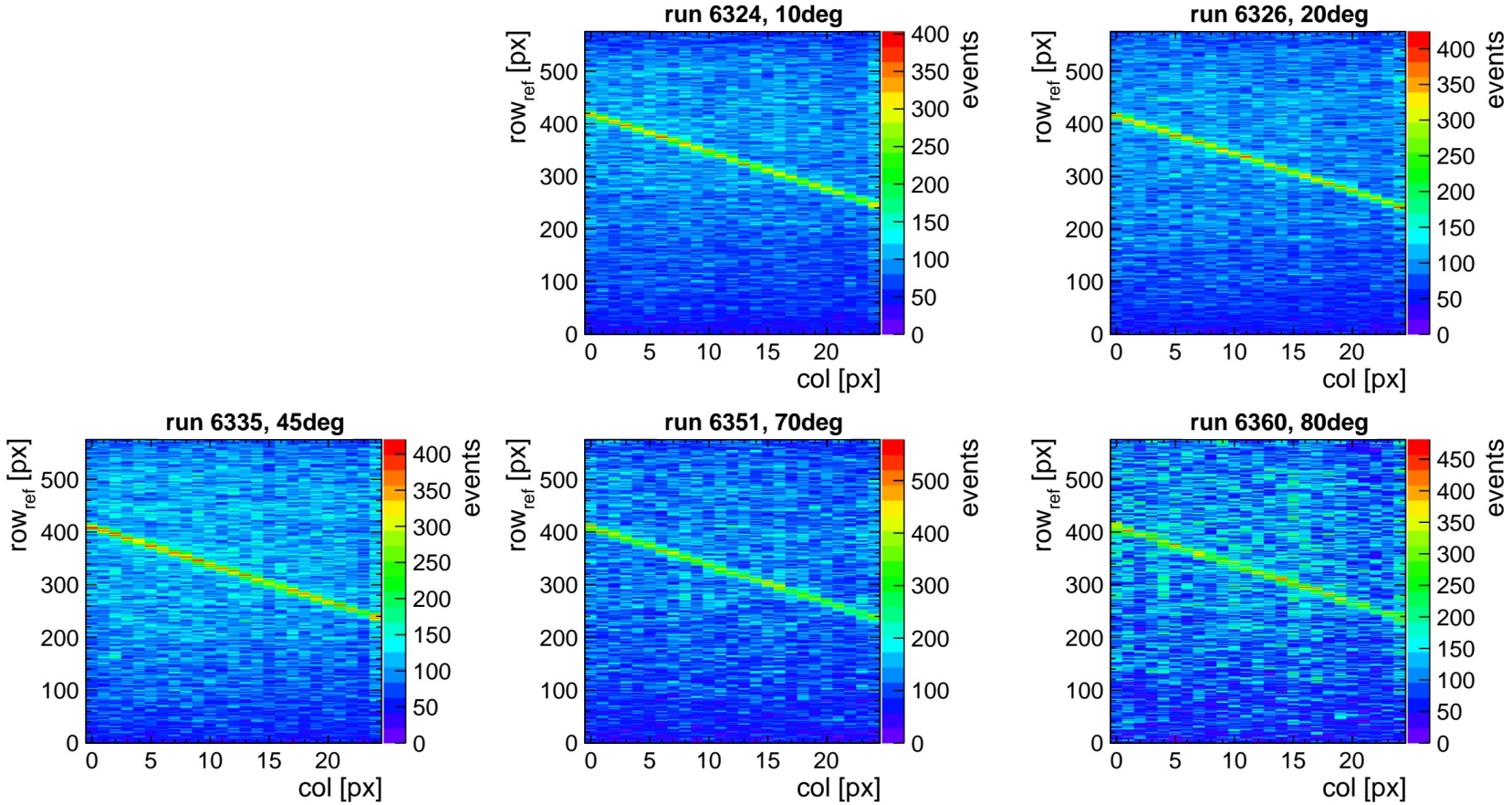


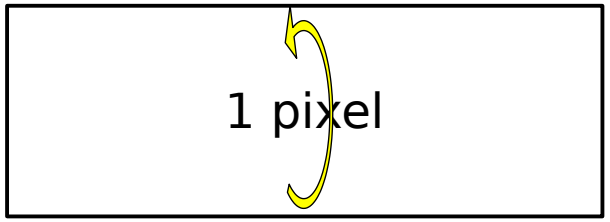


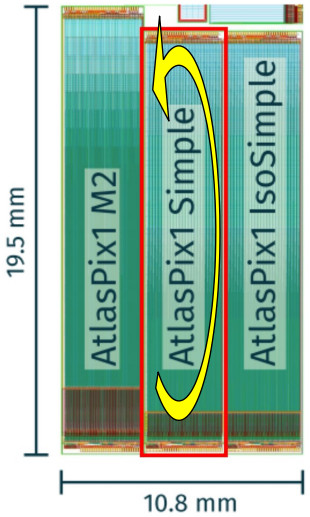
ATLASpix Rotation Scan:

- **2D correlations** for rotation in **row** direction

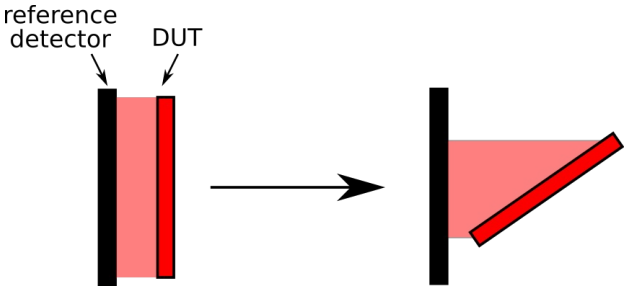
  as expected: no significant effect for columns







ATLASpix Rotation Scan:



- **2D correlations** for rotation in **row** direction

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