T. Rohe for the PSI-HEP group

Test beam results from DMAPS produced in LF110 and TSI 180

43rd RD50-Meeting 30.11.2023

DMAPS activities

Started work on DMAPS in 2019 in collaboration with ETHZ

- Evaluated several technologies
- Prototype test chips in two technologies
  - Small fill factor → LF 110 (MoTiC)
  - Large fill factor → TSI 180 (TSI-R4S)
- Possible use in PSI experiments
  - timing (roughly 0.1-1ns)
  - Data rate low
  - Basically no radiation hardness required
  - Thin (low energy particles)
  - «Low power» (operation in vacuum)

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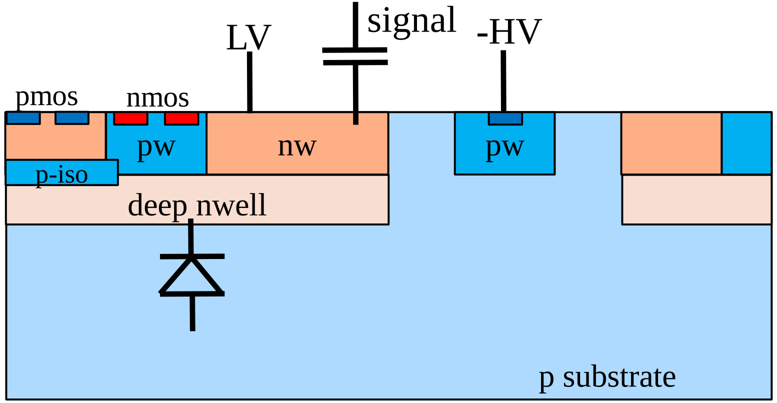
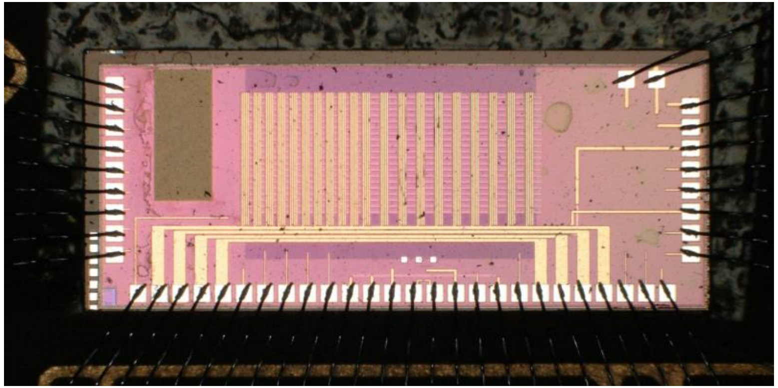
TSI 180 prototype with p-isolation well

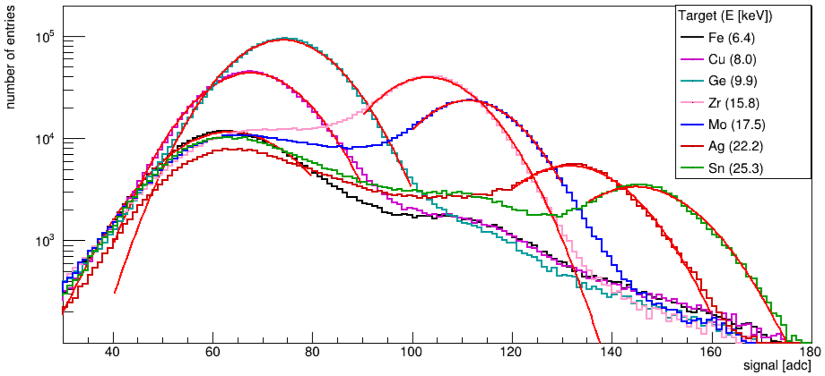
- Prototype run shared with KIT
- p-iso-well is not standard in this techonolgy (p-MOS transistors)
- P-substrate, resistivity ~370 Ωcm (spec)
- 20 × 20 pixels
- Pitch: 50µm × 100 (150) µm
- Simple R4S like architecture
- 4 bit trimmable discriminatiors in each pixel
- Narrow timetable:
  - Submitted 05/2022
  - Wafers received 12/2022
  - Diced (and thinned) chips received 05/2023
  - Test beam 06/2023
- Chip desinged by **Hans-Christian Kästli**

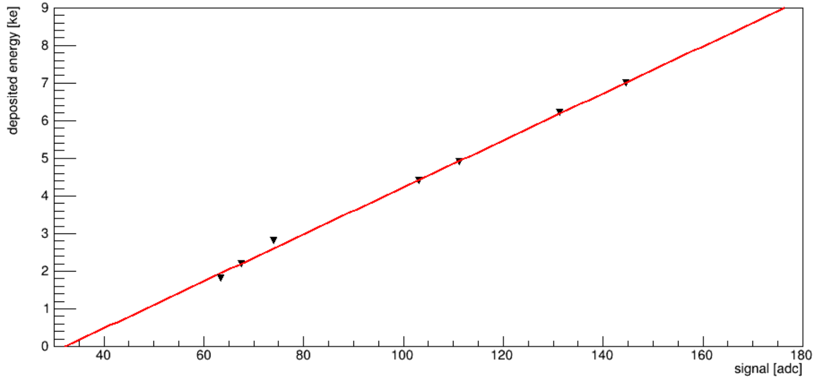




Pulse height calibration with X-rays

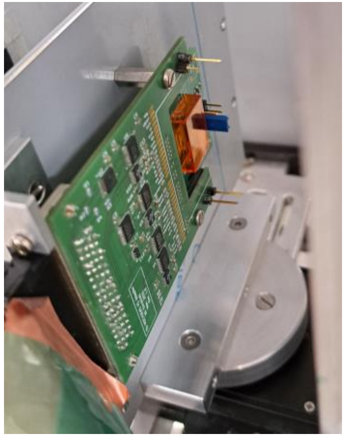
- Use X-ray tube with inserted targets
- Random triggers with a predefined rate
- Copper line (8.0 keV / 2200 electrons) is clearly visible
- Iron line (6.4 keV / 1800 electrons) also visible but spectum likely cut
- Threshold < ~1800 electrons
- Cross talk to the charge sensitive node at any digital activity → chip was set insensitive for readout
- Response of readout chain linear within the range of the targets
- Saturation for large signals (above ~10000 electrons)





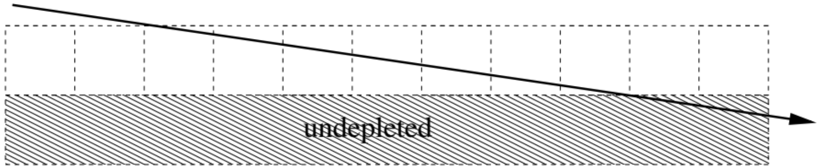
Testbeam set up at DESY

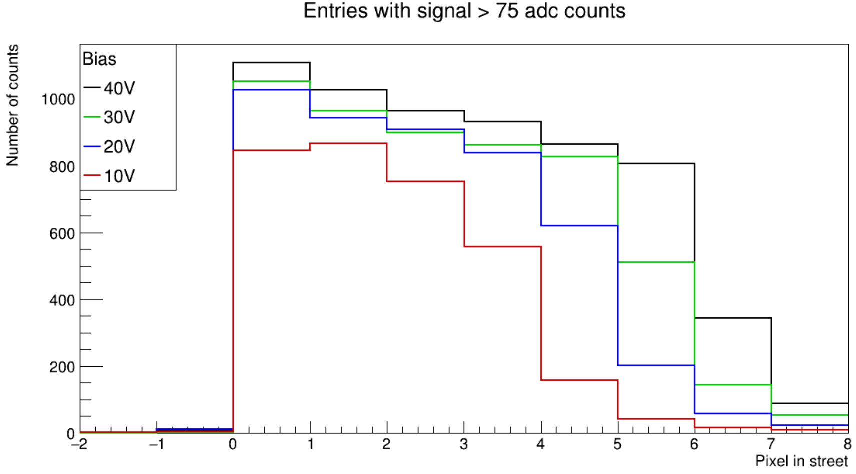
- DESY test beam beam line 22
  - 4.8 GeV electrons
  - 6 layer Mimosa telescope «Duranta»
  - RD53 single chip module as timing reference
- Data taken using discriminator
  - Bias scan at perpendicular incident angle
  - Angle scan (not shown here)
- With external trigger
  - «Long» run at perpendicular incidence angle
  - Bias scan at 80 degree incidence angle
- All results shown
  - Obtained using (modified) Corrywreckan
  - Preliminary



Estimation of depletion depth

- DUT measured with tilt of 80 degrees
  - Length of street → depletion depth
  - External trigger, full frame read out, no threshold
- Estimation with DUT data only
  - 6 pixels~50µm @ 40V
  - Doping: ~ $2\times10^{13}cm^{-3}$~600Ωcm
- Exact measurement not, yet, done
  - Telescope alignment and tracking
  - Exact measurement of the angle
  - Only use streets assosiated with tracks
  - Statistics (probably) too small

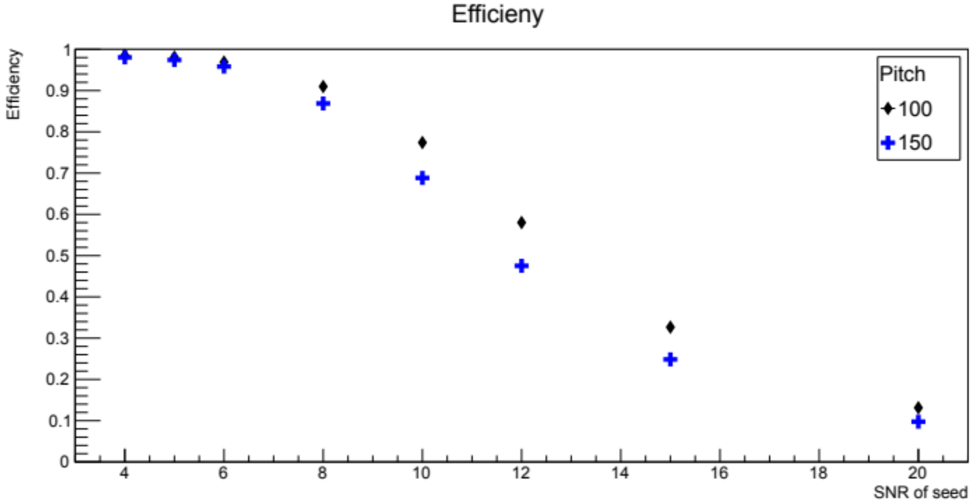


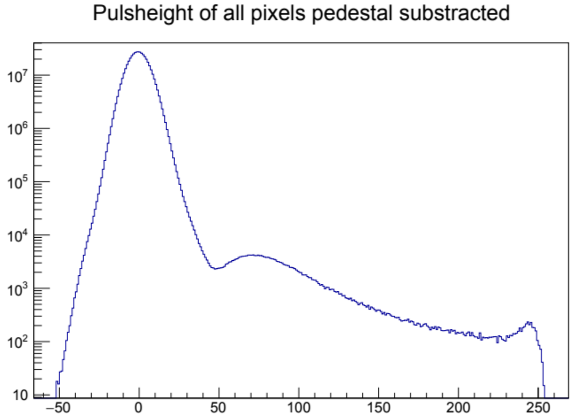


Track detection efficiency

$$\varepsilon = \frac{N_{\text{assoc.clusters}}}{N_{\text{tracks}}}$$

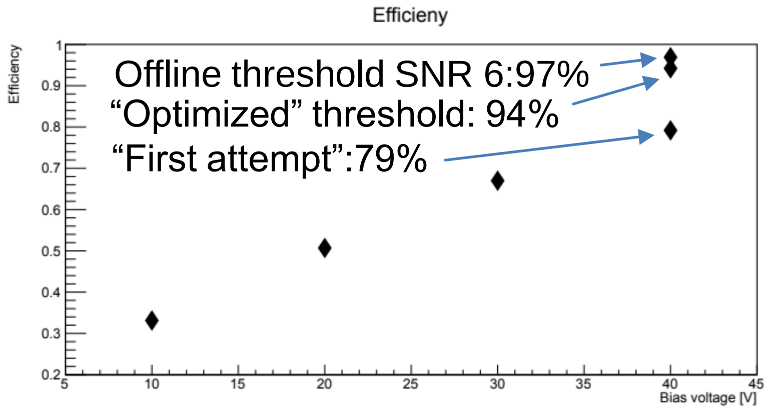
- Prependicular incidence
- Bias voltage of 40V
- External trigger and full frame readout
- Pedestals: result of a Gauss-fit to the centre of the pulse height distribution
- Noise: sigma of the Gauss
- Offline threshold for each pixel in units of SNR
- Signals are too small to be clearly separated from the noise
  - Higher resistivity substrate
  - Higher bias Voltage
- Calibration not valid here (sampling time)

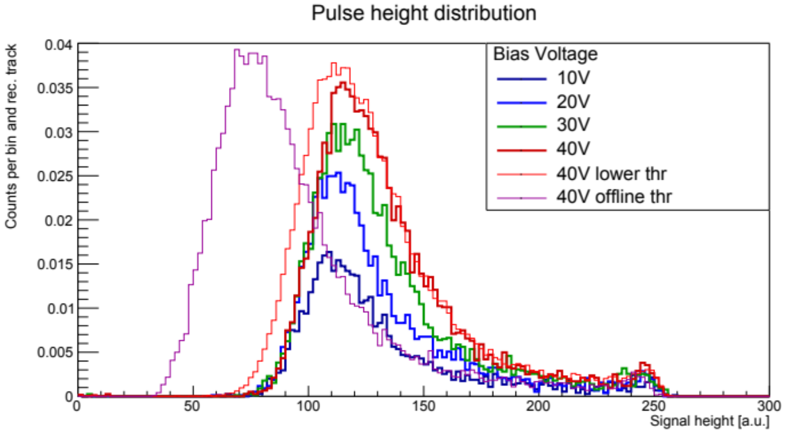




Track detection efficiency with discriminator

- Used the in pixel discriminator
- Threshold adjustment difficult
- Exact value of threshold not known (is about 2000 electrons)
- Efficiency of 94% with discriminator and «optimized» threshold is not sufficient
  - Threshold cannot be lowered further (cross talk)
  - Signal should be increased (higher resistive material)
  - Lost tracks are concentrated at the pixel corners
- Pulse height distribution with external trigger is shifted to lower values as sampling is delayed





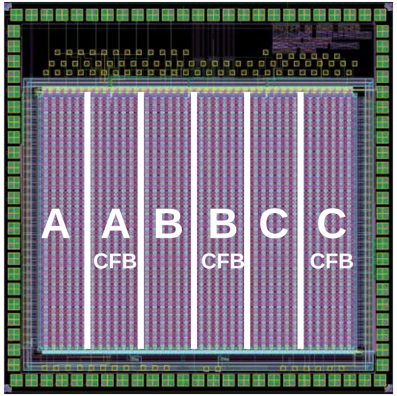
Future of this project

- Results encouraged us to continue in view of physics experiments at PSI
- PSI was on the way to design new demonstrator chip
  - 800-1500 Ω cm substrate (to get higher signal)
  - Full size 20mm × 20mm
  - TDC in each double column
- **TSI** was bought by Bosch and **stopped the 180nm line**
- We see two possible ways to continue
  - ams-OSRAM
    - (Almost) exactly the same process (large chip not a too large risk)
    - First contacts were positive
  - Translate to LF 150
    - Effort ~6 month
    - First chip would be a small MPW (May 2024 ?)

MoTic: LF110 chip including timing

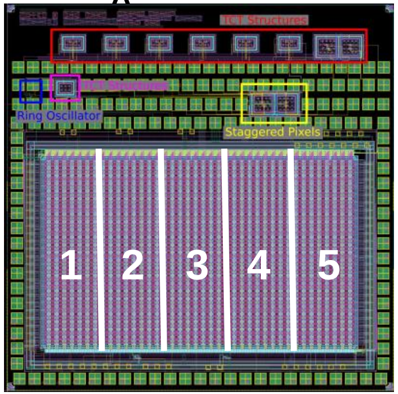
- Goals
  - Spatial resolution < 10µm
  - Timing < 1ns
- Modified LFoundry 110nm process
- Full frame readout with external trigger
- Trimmable in-pixel discriminators
- 1 TDC shared by 4 pixel
- Small electrodes with small capacitance (designed by ARCADIA)
- Back-side processing for guard rings and metal contacts (thick substrates)
- Depletion from back-side
- Active thickness: 48, 100, 200µm
- Thesis by **Stephan Burkhalter**, ETH
- Most slides copied from **Aliakbar Ebrahimi**, PSI, Vertex 2023

Same sensor
6 different amplifiers
80 columns, 64 rows
50 x 50µm^2



MoTiC A

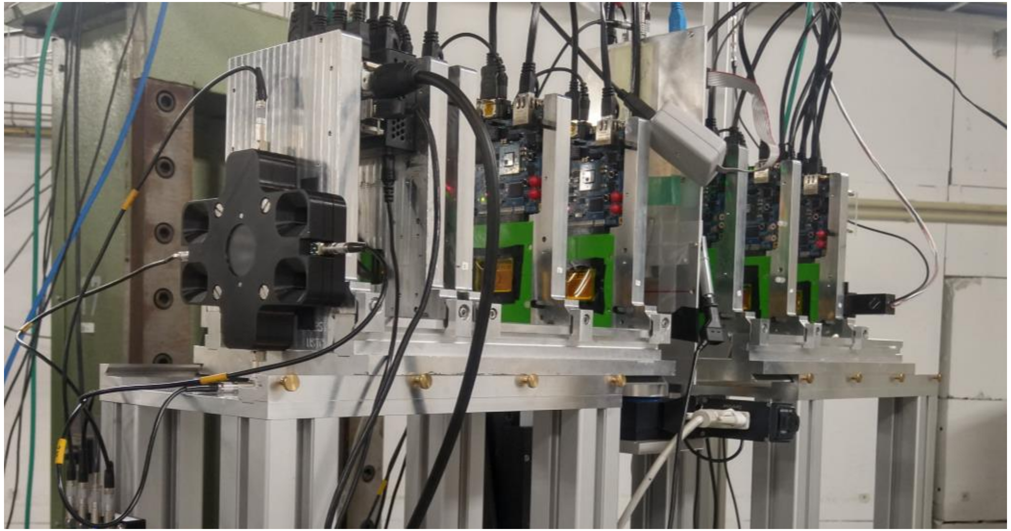
Same amplifier (C)
5 different sensors
80 columns, 48 rows
50 x 50µm^2

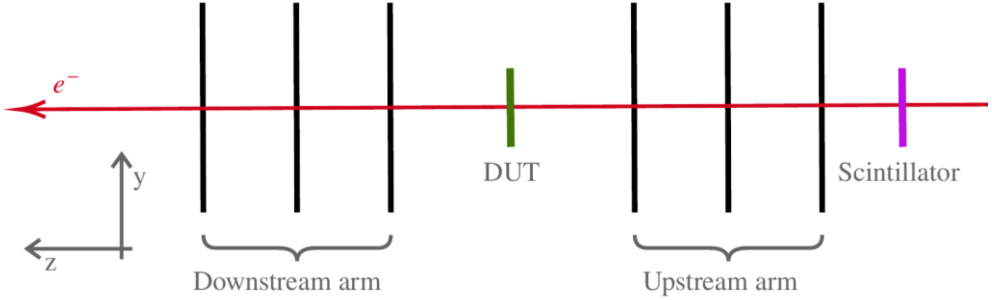


MoTiC B

Test beam at DESY-II

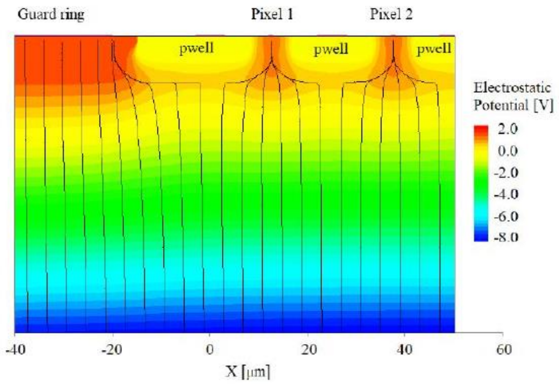
- Adenium Telescope
  - 6 planes of Alpide sensors
  - 29.24µm x 26.88µm pixels
  - 50µm thick
  - Spatial resolution < 5µm
- Non-irradiated samples
- 4GeV electrons
- Room temperature
- Offline Threshold: 8 x RMS
- Analysed using (modified) Corryvreckan
- Some further analysis in Python

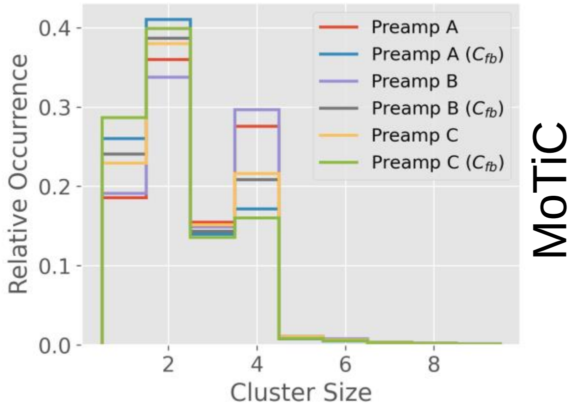


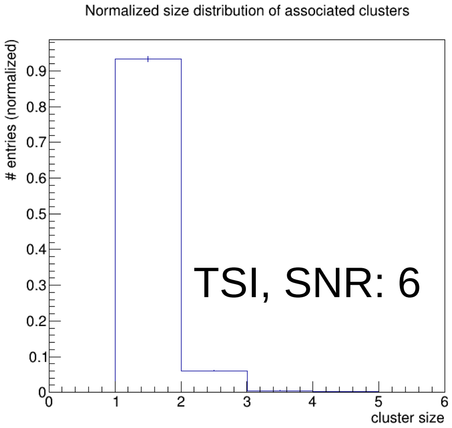


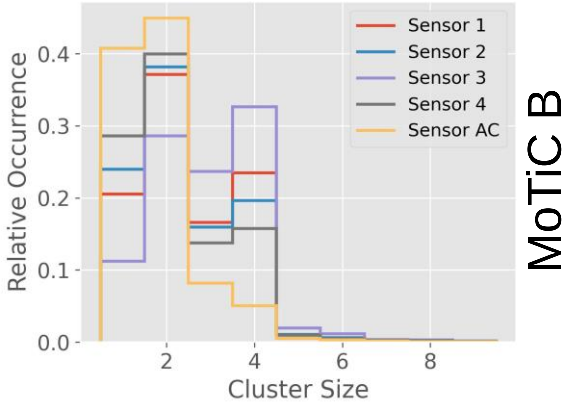
Cluster size

- Much larger than 1 (in contrast to large fill factor TSI chip)
  - Seen also in Laser / TCT measurements
  - Expected from simulations (ARCADIA collaboration)
- Low E-field below the p-wells
- Amplifier C has lower gain
  - Less pixels reach the threshold
  - Motic B









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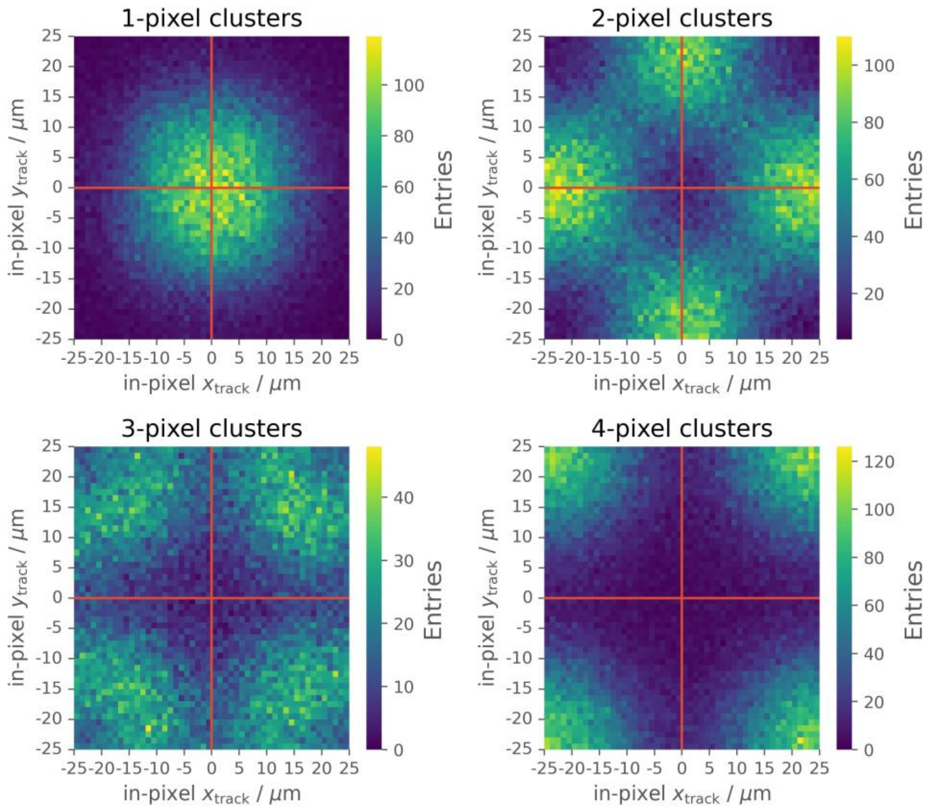
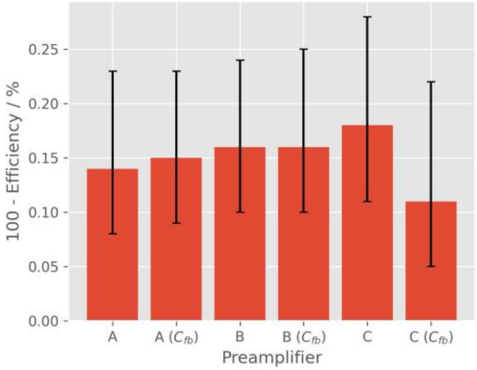


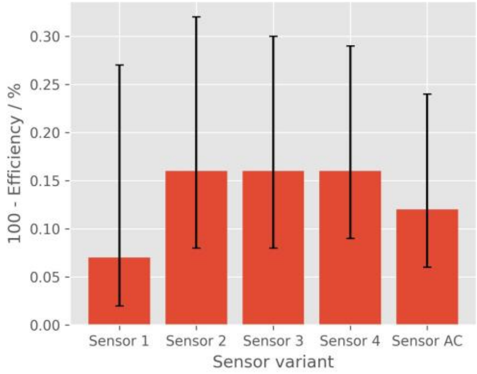
MoTiC A

Hit detection efficiency

$$\varepsilon = \frac{N_{\text{assoc.clusters}}}{N_{\text{tracks}}}$$

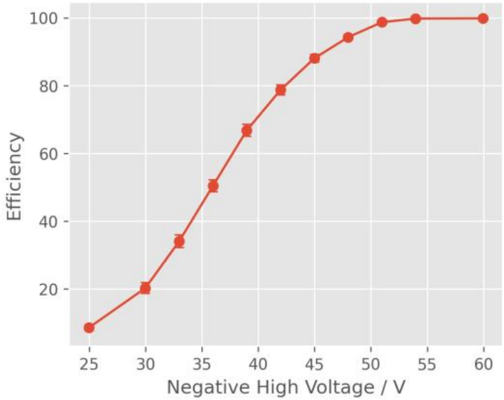
- Offline threshold
- Hit efficiency > 99.8%
- MoTiC A
  - 200 µm thick
  - Max. efficiency at V_{bias} > ~55V
- MoTiC B
  - Max. efficiency at V_{bias} > ~50V
  - AC variant efficient at V_{bias} > ~40V

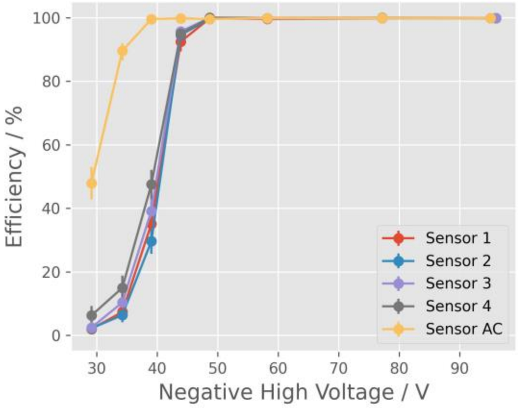




MoTiC A

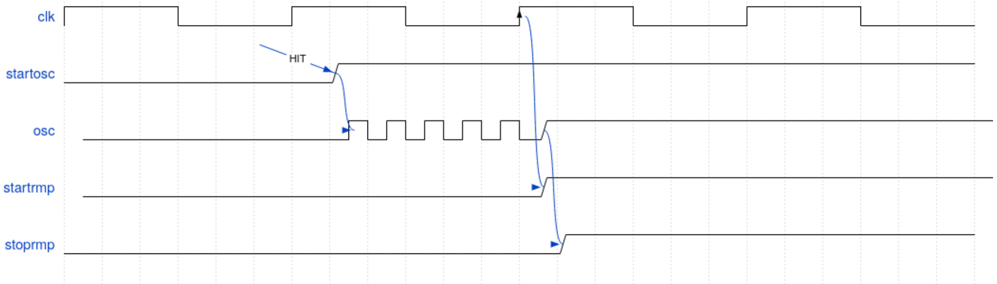
MoTiC B

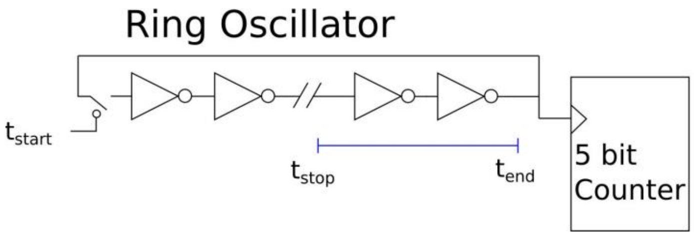


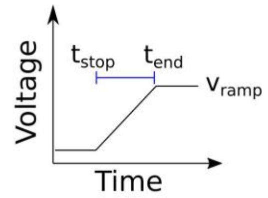


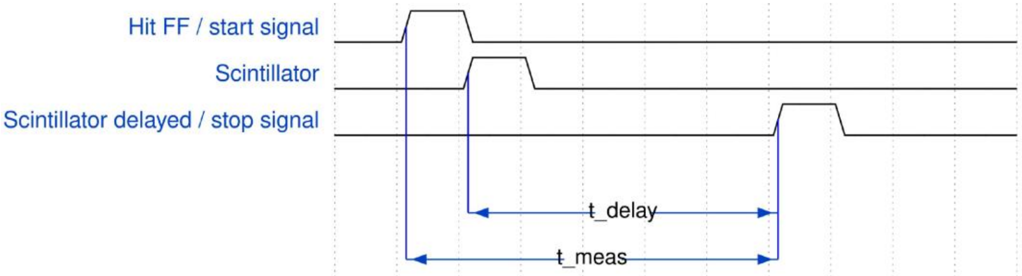
Time measurement

- 4 pixels share a TDC
  - Ring oscillator
  - «Ramp»: Capacitor and current source (not used in test beam)
- $t_{TDC} = (cnt_{OSC} \times \tau_{OSC}) - t_{ramp}$
  - $\tau_{OSC} \sim 1.2$ns
- No clock at test beam
- Hit FF used as start
- Signal from a dedicated fast trigger system used as stop
  - Coincide of 2 dual readout scintillators
  - Jitter less than 200ps





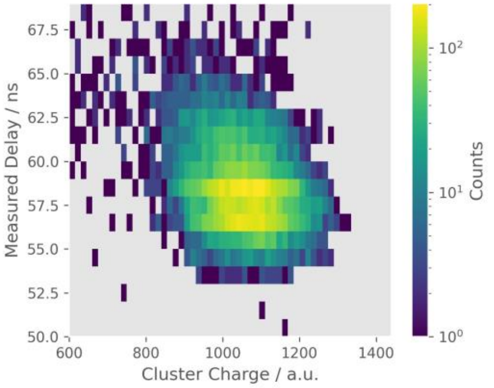




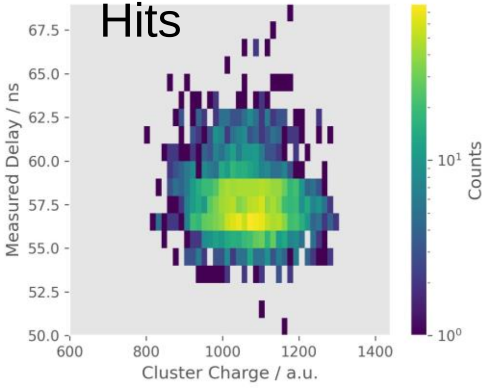
Time measurement

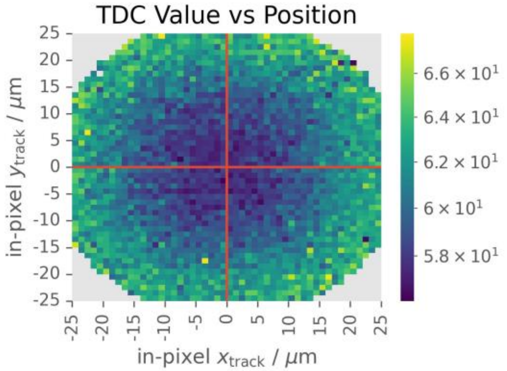
- MoTic A
- Only 1 pixel clusters
- Drift time depends pulse height
- For central hits much less pulse height dependence
- For measurement of signal drift time only pulses > 800 adc used (less time walk)
- Difference between central and peripheral hits ~5ns
- Compatible with simulations and laser measurements done by ARCADIA collaboration
- Addition of gain layer to the process would be a «game changer»

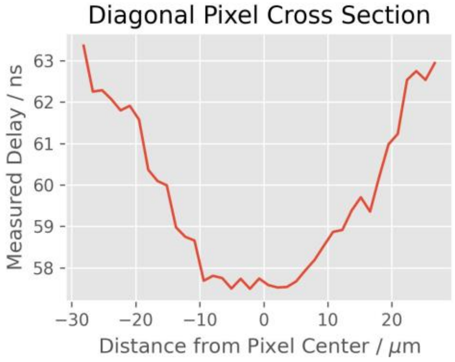
All Hits



Central Hits







Summary

DMAPS (small chips) with large and small fill factor produced and characterized in test beam:

TSI:

- Hit efficiency > 90%
- Cross talk between digital electronics and collection electrode → high threshold → use substrate with higher resistivity to increase signal and SNR
- Continuation of project either with ams or LF150

LF110

- Hit efficicency > 99.8%
- Timing resolution < 1.2ns
- Charge colltection quite slow → gain layer offered by LF would be of reat benefit
- Spatial resolution (not shown here) < 5µm

Acknowledgement

Many thanks to the DESY test beam support team

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).