PAUL SCHERRER INSTITUT

DMAPS Activities at PSI

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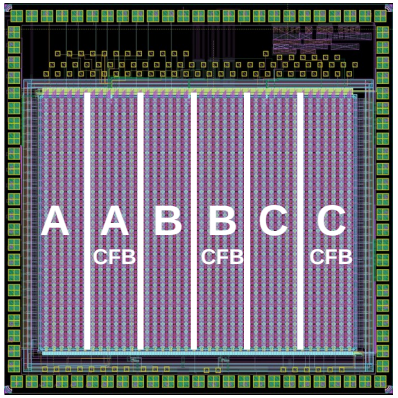
Introduction

- PSI HEP group in collaboration with ETHZ has a generic R&D program for DMAPS since 2019
- Goal: position sensitive detectors featuring timing for possible applications in PSI in-house experiments
- Aiming for
  - Timing resolution 0.1 - 1ns
  - Spatial resolution < 10µm
  - Thin (low energy particles)
  - Low power (operation in vacuum)
  - Low data rate
  - No radiation hardness requiered
- Prototype chips in two technologies
  - MoTiC: small fill factor in LF 110
  - TSI-R4S: large fill factor in TSI 180

MoTiC: Monolithic Timing Chip

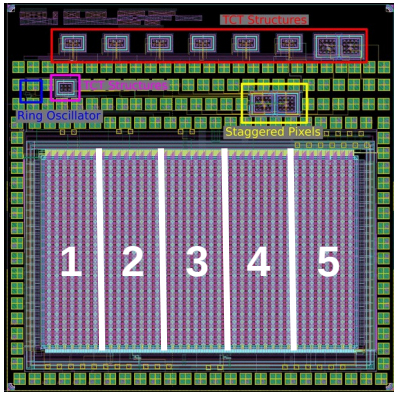
- Modified LFoundry 110nm process
- Full frame readout with external trigger
- In-pixel discriminators
- 1 TDC shared by 4 pixel
- Sensing elements designed by ARCADIA
- Small electrodes with small capacitance
- Back-side processing for guard rings and metal contacts
- Depletion from back-side
- Active thickness: 48, 100, 200µm
- Thesis by Stephan Burkhalter, ETHZ

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



MoTiC A

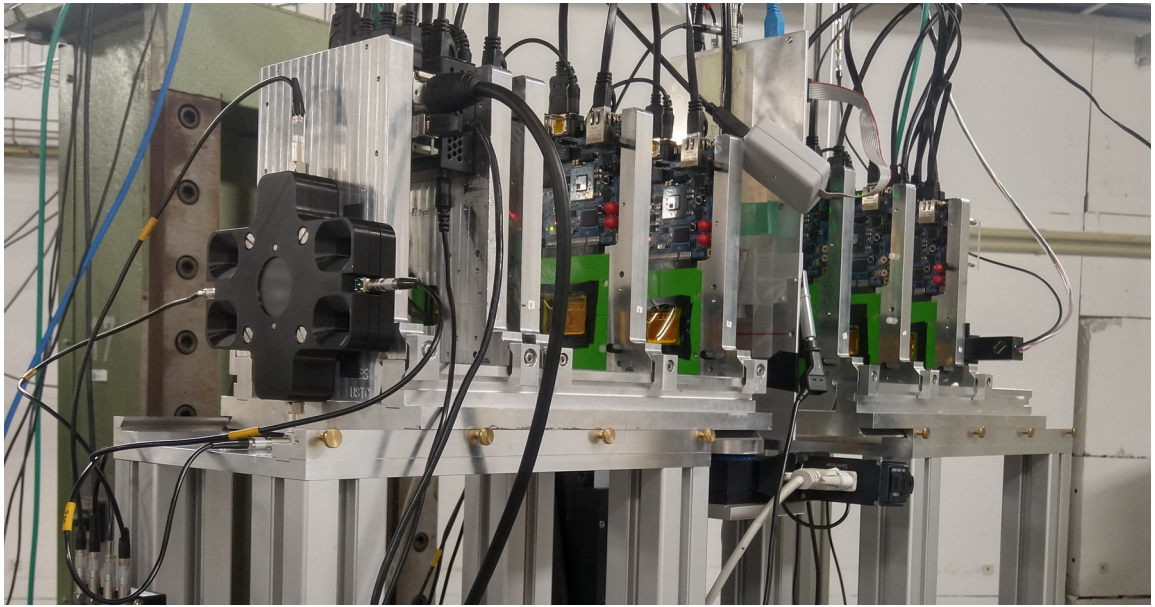
Same amplifier (C)
5 different sensors
80 columns, 48 rows
50 x 50µm^2

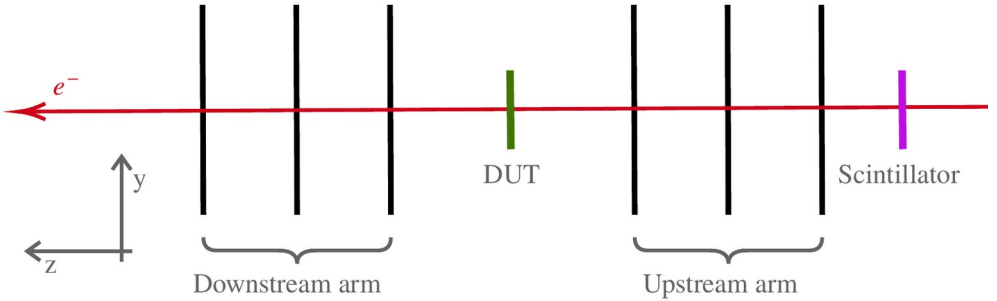


MoTiC B

Beam Test at DESY II

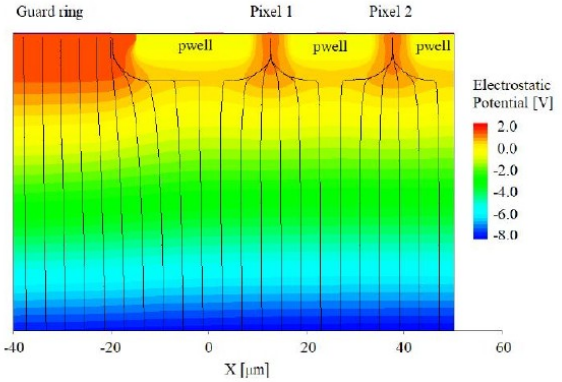
- Adenium Telescope
  - 6 planes of Alpide sensors
  - 29.24µm x 26.88µm pixels
  - 50µm thick
  - Spatial resolution < 5µm
- Non-irradiated samples
- 4GeV electrons
- Room temperature
- Offline Threshold: 8 x RMS
- Analysed using (modified) Corryvreckan
- Some further analysis in Python

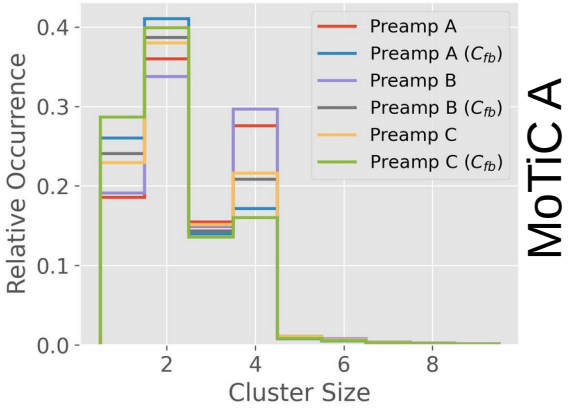


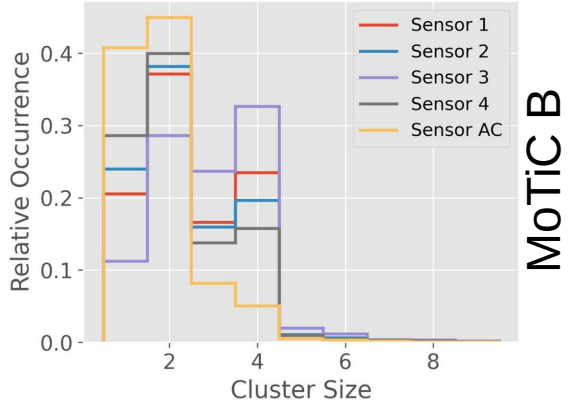


Cluster Size

- Larger than 1 at prependicular incidence
  - Also seen in laser / TCT measurements
  - Expected from ARCADIA simulations
- Low electric field below the p-wells
  → longer charge collection time
  → higher probability of diffusion
- MoTiC B has relatively low-gain preamplifier
  → many pixels don't reach the threshold
  → smaller cluster size







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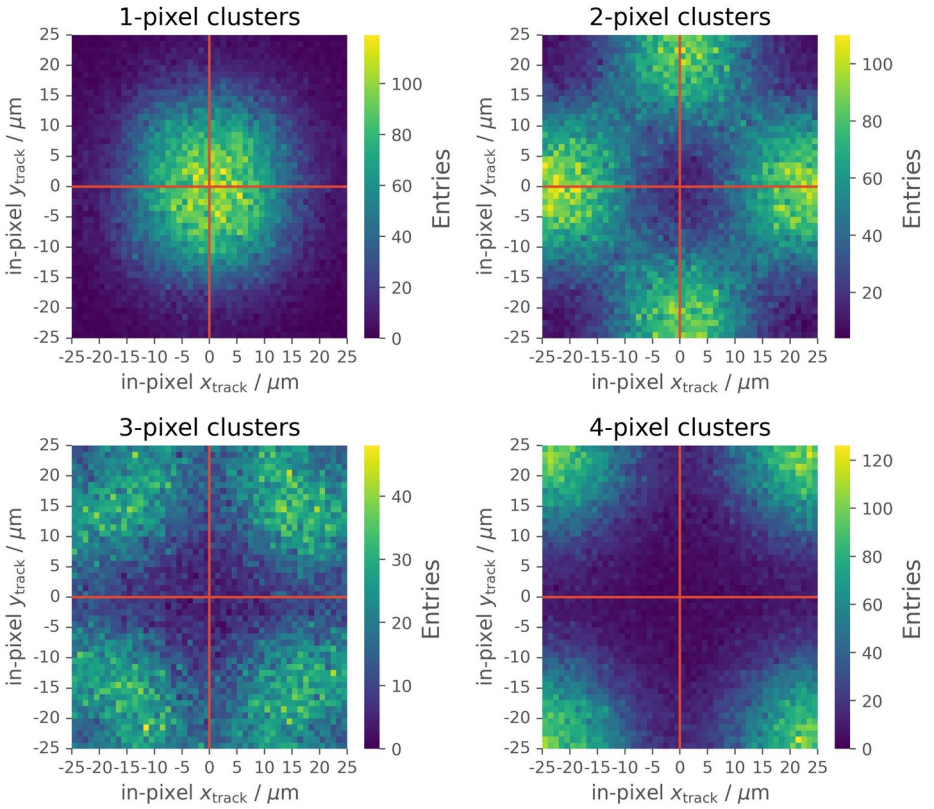
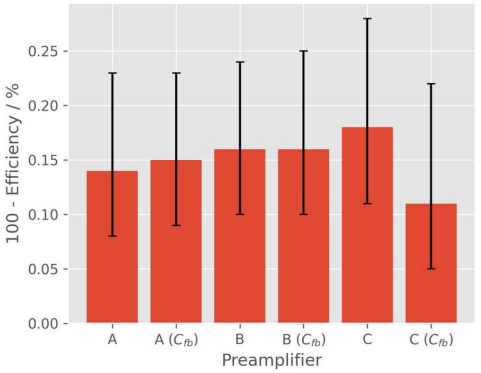
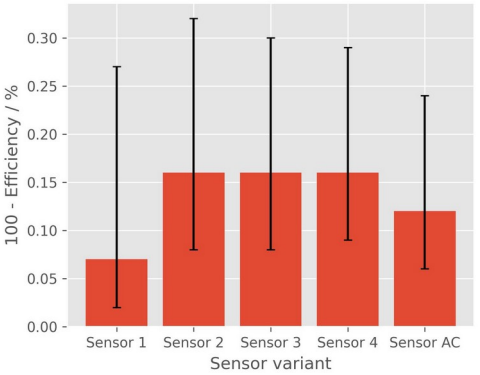


MoTiC A

Hit Detection Efficiency

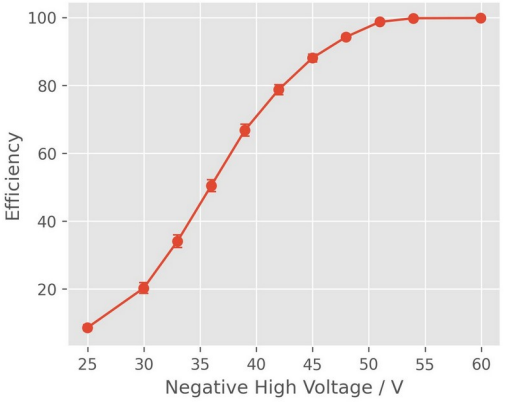
- $\varepsilon = \frac{N_{\text{assoc.clusters}}}{N_{\text{tracks}}}$
- Offline threshold
- Hit efficiency > 99.8%
- MoTiC A
  - 200 µm thick
  - Max. efficiency at V_{bias} > ~55V
- MoTiC B
  - Max. efficiency at V_{bias} > ~50V
  - AC variant efficient at V_{bias} > ~40V

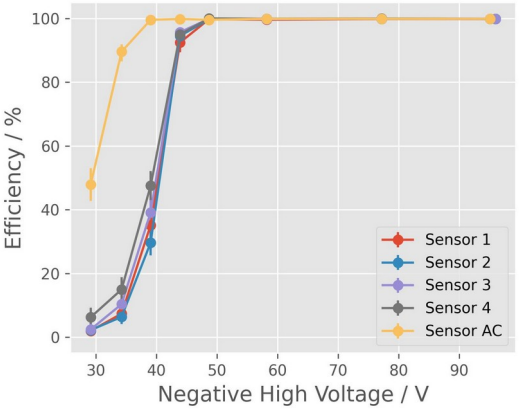




MoTiC A

MoTiC B

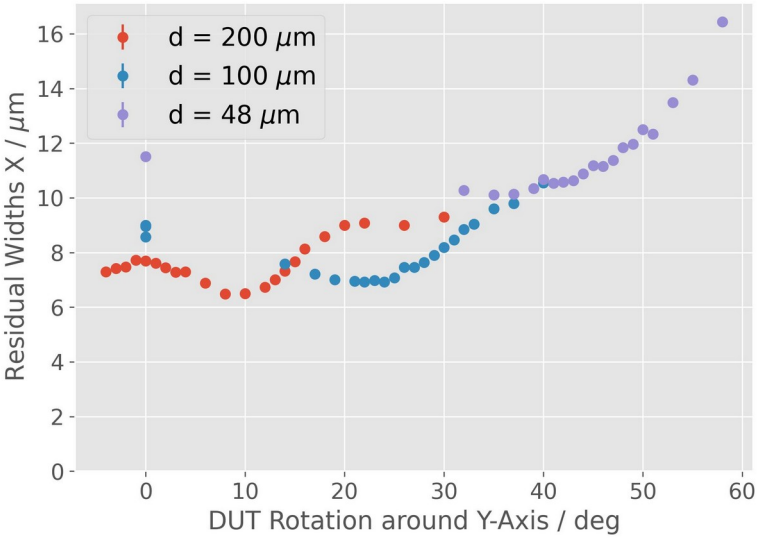


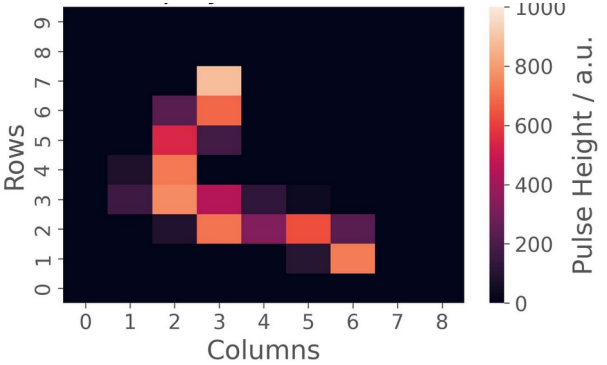


Spatial Resolution

- $\sigma_{hit} = \sqrt{RMS^2_{dut} - \sigma^2_{TEL}}$
- Center of Gravity
- Truncated RMS of DUT residuals
  - Dicard values outside ±6 RMS
- Resolution at vertical incidence better than resolution of binary readout (14.4µm)
- Optimal angle differs from arctan(pitch/thickness)
- Best resolution: **4.8µm** for the 200µm thick sensor

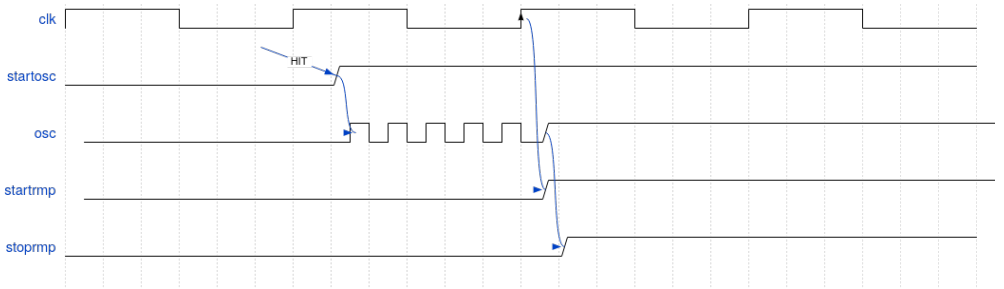
Type	t / µm	Angle / deg	$\sigma_{residual}$ / µm	σ_{tel} / µm	σ_{DUT} / µm
MoTiCv1 A	200	0	7.7 ± 0.1	4.4 ± 0.5	6.3 ± 0.4
MoTiCv1 A	200	8	6.5 ± 0.1	4.4 ± 0.5	4.8 ± 0.5
MoTiCv1 A	100	0	9.0 ± 0.1	4.4 ± 0.5	7.9 ± 0.3
MoTiCv1 A	100	21	6.9 ± 0.1	4.4 ± 0.5	5.3 ± 0.4
MoTiCv1 A	48	0	11.5 ± 0.1	5.0 ± 0.5	10.4 ± 0.3
MoTiCv1 A	48	37	10.1 ± 0.1	5.0 ± 0.5	8.8 ± 0.3

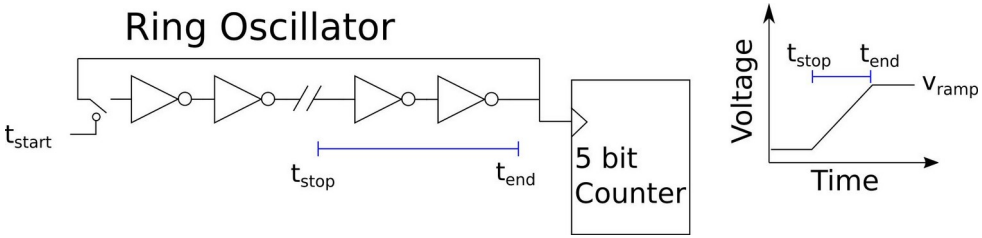


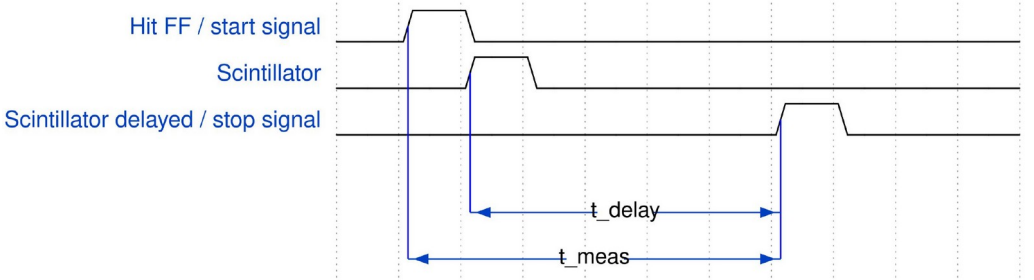


Time Measurements - ATDC

- Every 4 pixels share a TDC
- $t_{TDC} = (cnt_{OSC} \times \tau_{OSC}) - t_{ramp}$
- 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



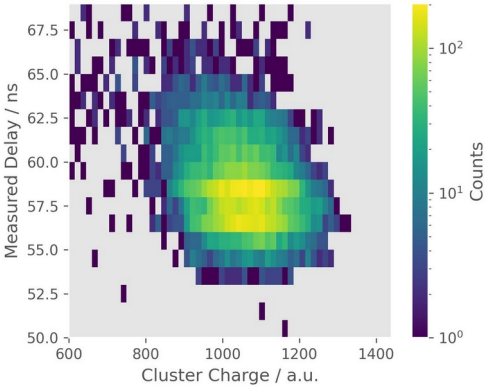




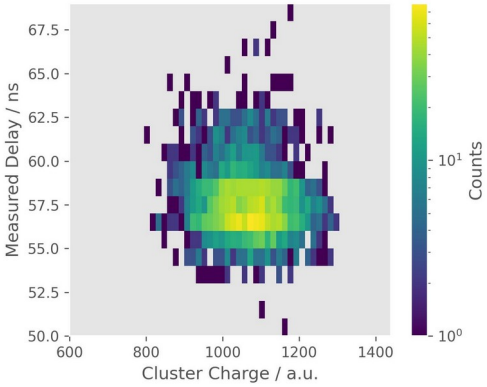
Drift Time Measurements

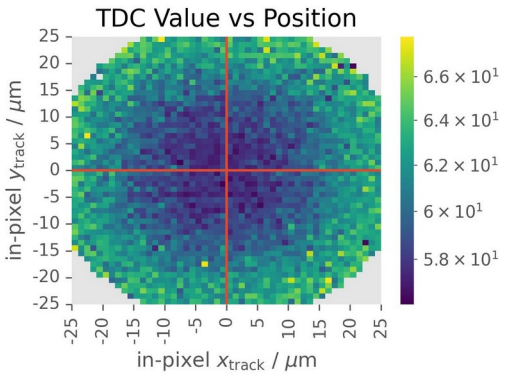
- MoTiC A
- Only 1-pixel clusters
- Central hits have much less pulse-height dependence
- Pulse height > 800 ADC for drift time measurements
- Difference between central and peripheral hits ~ 5ns
- Compatible with simulatins and laser measurements performed by ARCADIA
- Addition of a gain layer to the process would be of great advanage

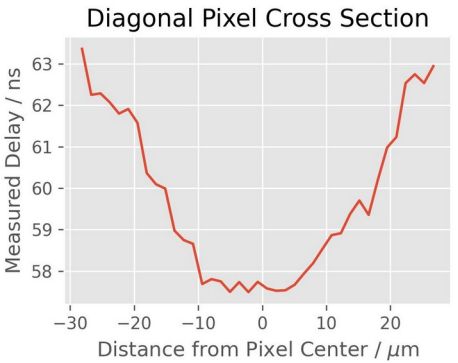
All Hits



Central Hits

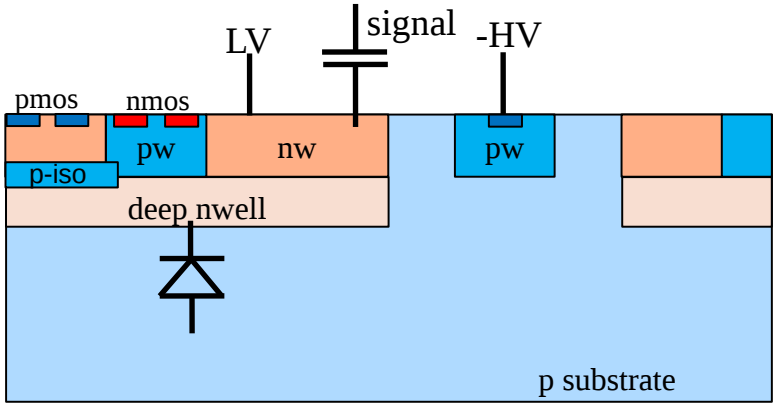


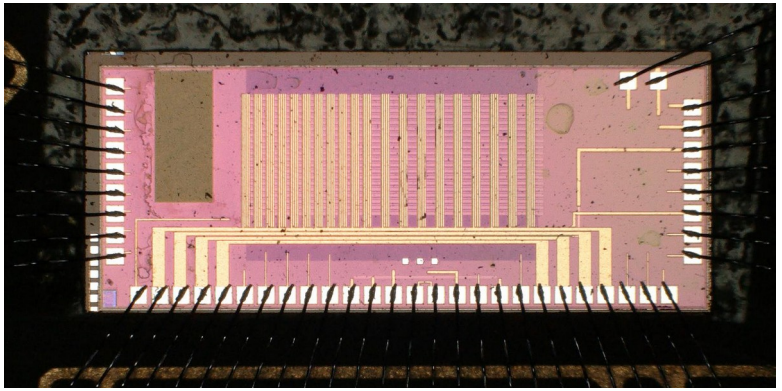




TSI-R4S – Large Fill Factor in TSI 180

- P-iso-well is not standard in the process
- P-substrate, resistivity ~370Ωcm
- Simple architecture similar to ROC4SENS
- 4-bit trimmable discriminators in each pixel
- Large electrodes with high capacitance
- Depletion from front-side
- Active thickness: 200µm
- Slides mostly copied from RD50 presentation by Tilman Rohe

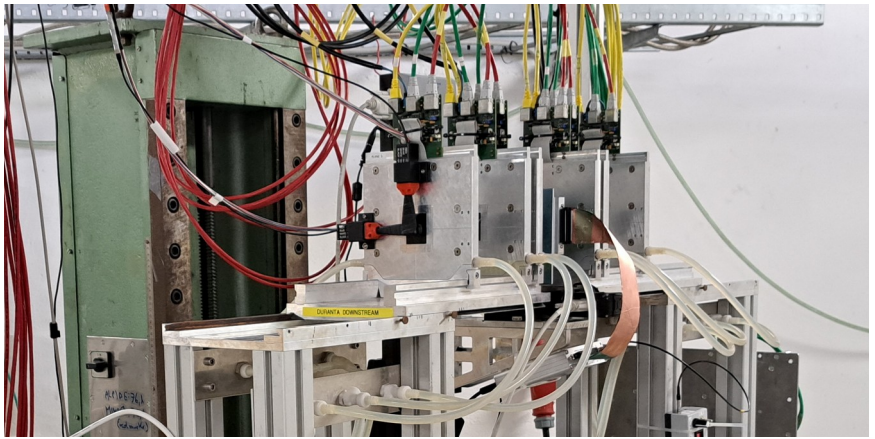


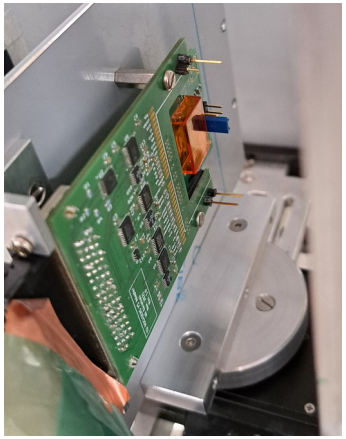


20 columns, 20 rows
50 x 100/150µm^2

Beam Test at DESY II

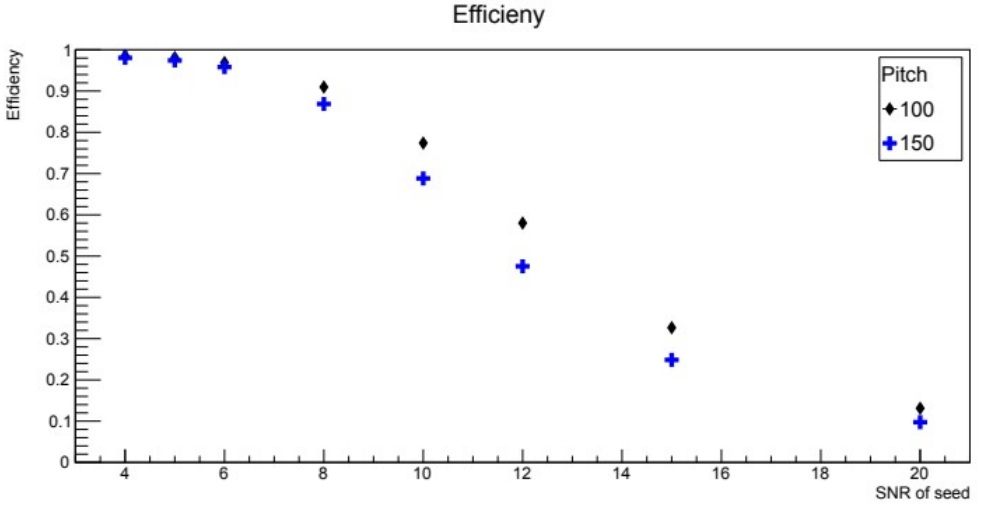
- Duranta Telescope
  - 6 planes of mimosa sensors
  - 18µm x 18µm pixels
  - 50µm thick
  - Spatial resolution < 5µm
- RD53 single chip module as timing reference
- Non-irradiated samples
- 4.8GeV electrons
- Room temperature
- Data taken with online and offline thresholds
- Analysed using (modified) Corryvreckan

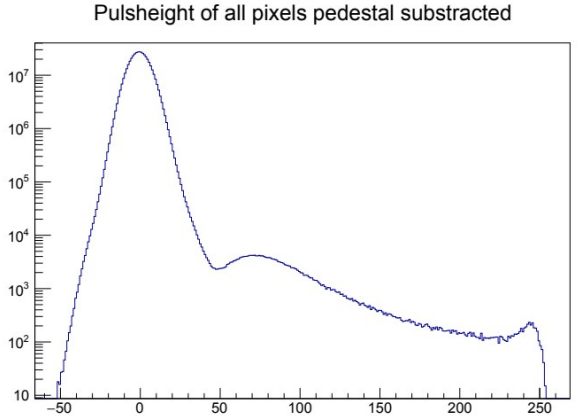




Hit Detection Efficiency – Offline Threshold

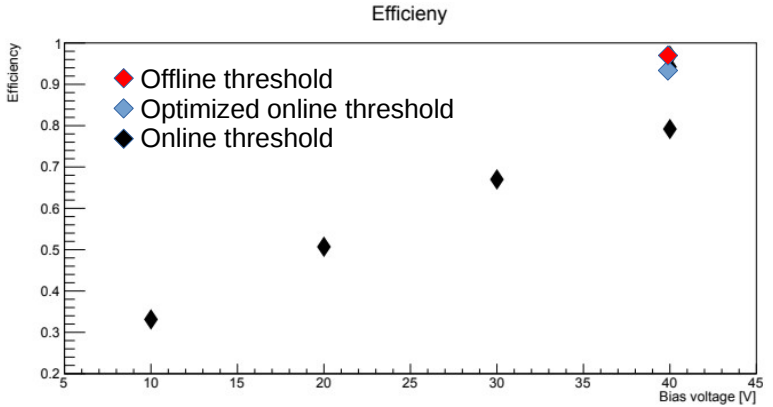
- $\varepsilon = \frac{N_{\text{assoc.clusters}}}{N_{\text{tracks}}}$
- Perpendicular incidence
- Bias voltage 40V
- External trigger and full frame readout
- Pedestal from a Gaussian fit to the pulse-height distribution
- Noise: sigma of the Gaussian fit
- Offline threshold for each pixel in SNR units
- Signals are too small to be reliably seperated from the noise
- Offline hit detection efficiency > 97%

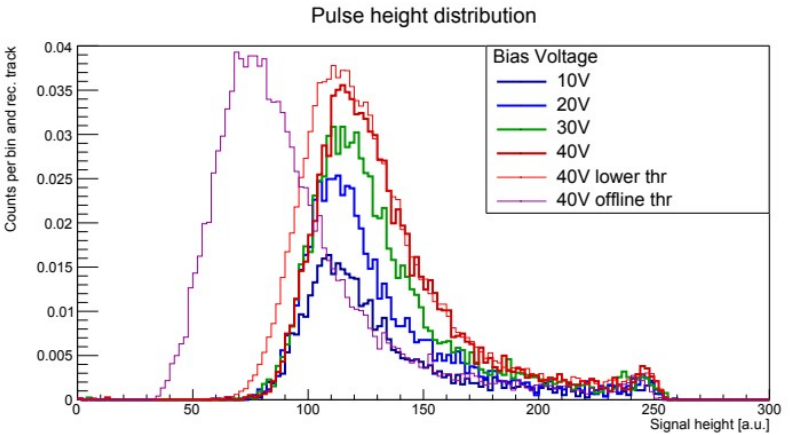




Hit Detection Efficiency – Discriminator

- Used in-pixel discrimination
- Exact value of threshold unknown
  - About 2000 electrons
- Hit detection efficiency > 94%
- Efficiency is not sufficient
  - Lost tracks are concentrated at the pixel corners
- Signal should be increased
  - Higher resistivity substrate
  - Improved guard rings for higher bias voltage
- Lower threshold after improved shielding





Summary

- Two DMAPS prototype chips with small fill factor and large fill factor produced and tested
- MoTiC: small fill factor LF 110
  - Hit efficiency > 99.8%
  - Spatial resolution < 5µm
  - Coarse timing resolution < 1.2ns
- TSI-R4S: large fill factor TSI 180
  - Hit efficiency > 94%
  - Cross-talk between digital electronics and collection electrode → High Threshold
- Large fill factor project continues with LF 150
  - Improved shielding
  - Substrate with higher resistivity to increase signal and SNR
  - Prototype to be submitted in May

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)