

A Very Large HV-MAPS Tracking Telescope

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DPG 2021, 17.03.2021



Why do we do, what we do

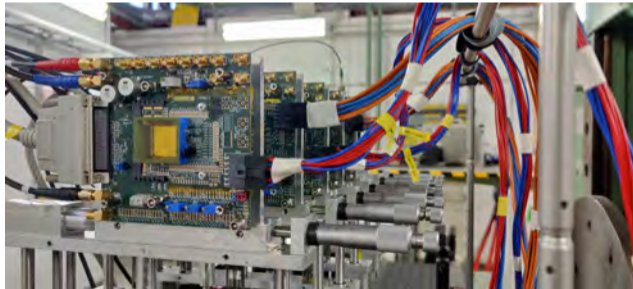


Telescope usage:

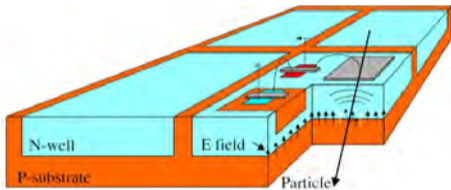
- study of several HV-MAPS prototypes
- test beam campaigns at several facilities like DESY, PSI, MAMI
- modular and compact design

Requirements:

- high rate capabilities
- good timing and spatial resolution
- ultra-low material budget
- long lifetime → radiation hardness



High-Voltage Monolithic Active Pixel Sensor



[I. Peric, P. Fischer et al., NIM A 582 (2007) 876]

Monolithic design:

- active matrix & readout in one entity
- in-pixel electronics

Commercially available processes:

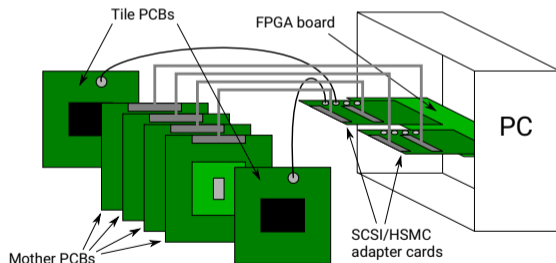
- HV-CMOS processes up to 120 V
- AMS 180 nm & TSI 180 nm

Characteristics:

- low-ohmic substrate ($10\text{-}200\ \Omega\ \text{cm}$)
- deep n-well diode is reversely biased
→ $\sim 10\text{-}30\ \mu\text{m}$ depletion zone allows fast charge collection via drift
- chips can be thinned to $50\ \mu\text{m}$



- 4-8 layers + 2 scintillating tiles for time reference
- reference layers and DUT can be of different sensor types → 14 HV-MAPS prototypes



[A.Herkert doi:10.11588/heidok.00027893]

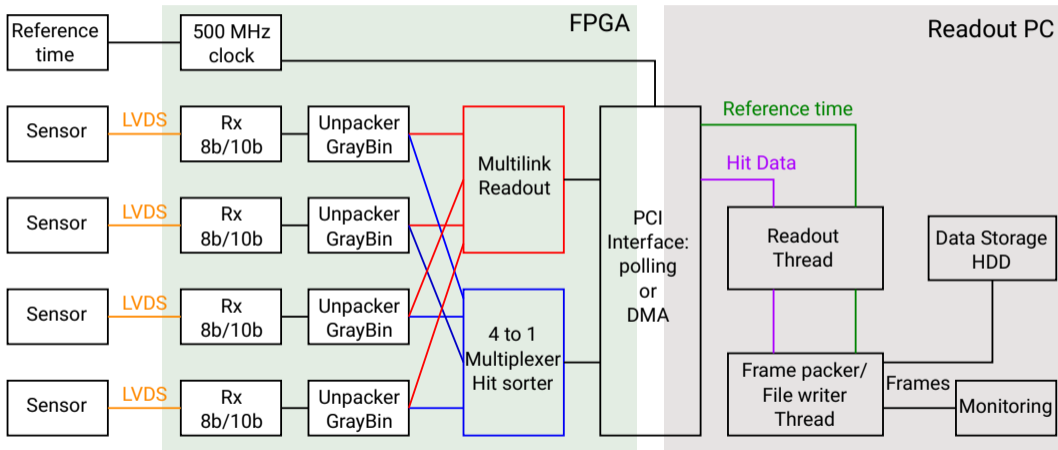
Mother PCB:

- interface for insertable PCBs of different sensor prototypes
- connection via SCSI-III to FPGA

SCSI/HSMC adapter cards:

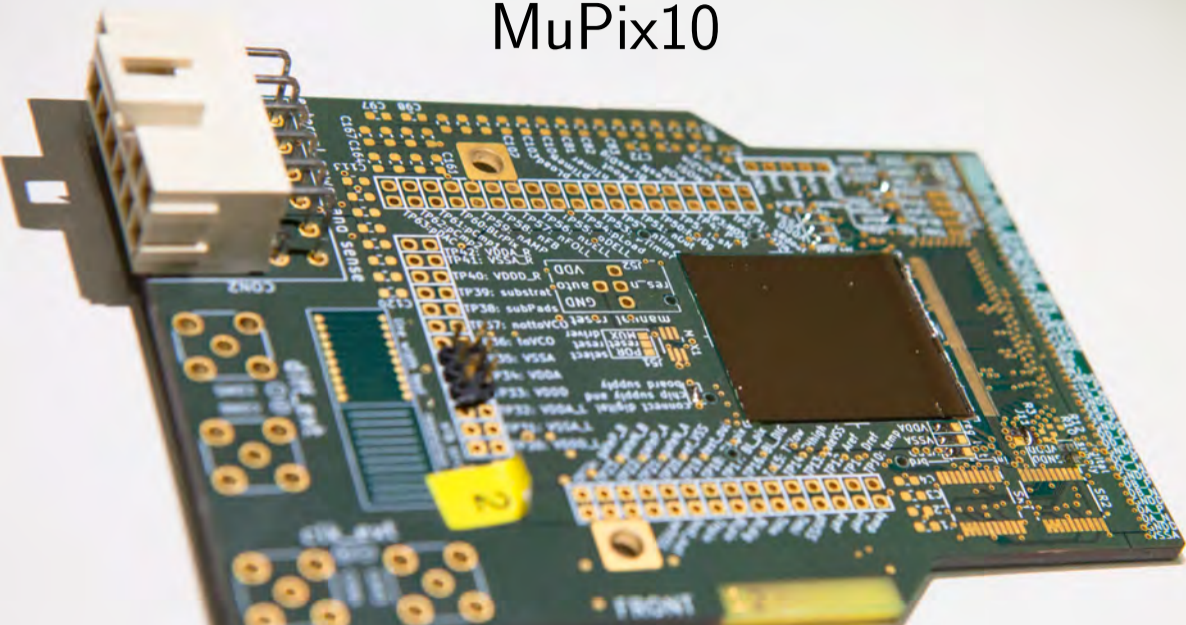
- interface between mother PCB/ time reference data to FPGA

Readout: From Sensor to Disc



[L. Huth doi:10.11588/heidok.00025785] (modified)

MuPix10

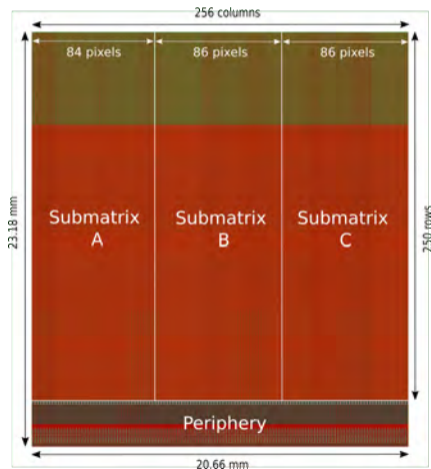


MuPix10 Specification

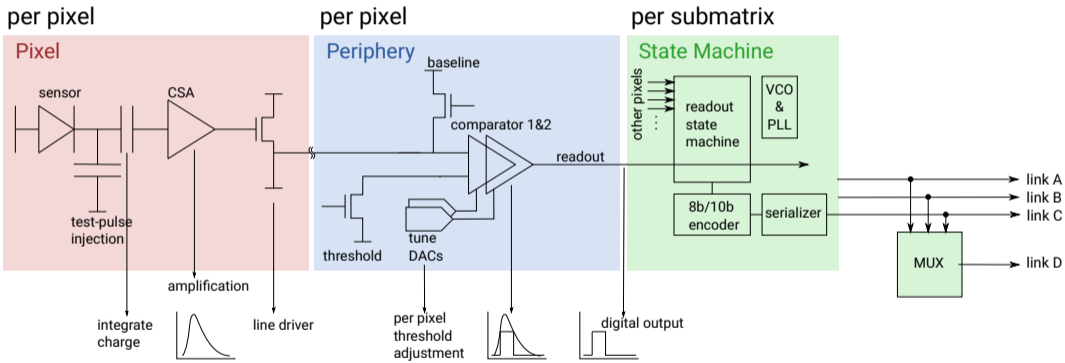


- full scale sensor produced by TSI
- 20 & 200 Ω cm substrate
- 50, 100 & 650 μ m thinned wafers
- continuous readout
- powering via regulator possible
- threshold and baseline levels generated on-chip

Matrix [pixel]	256 \times 250
Pixel size [μ m ²]	80 \times 80
Active area [mm ²]	20.48 \times 20.0
ToA+ToT [bits]	11+5
Tuning+Masking [bits]	2 \times 3+1
LVDS links	3+1



Readout Structure: MuPix10



[H. Augustin arXiv:2012.05868]

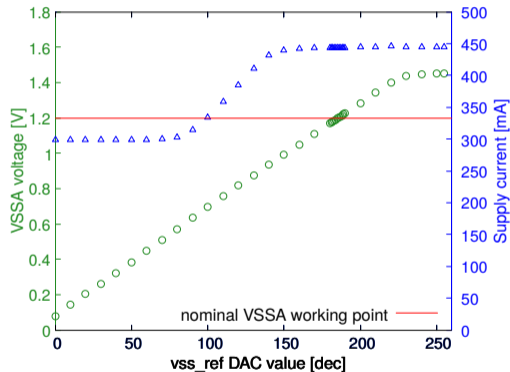
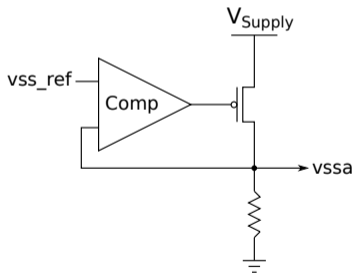
VSSA Regulator: Powering of the CSA (New)



- linear series regulator with differential amplifier for level adjustments

→ configurable by the reference value `vss_ref`

⇒ MuPix10 operational via 1 supply voltage (+HV)

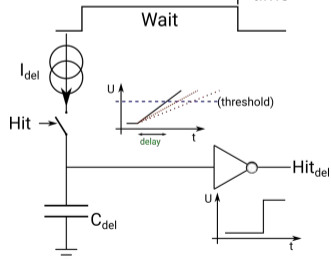
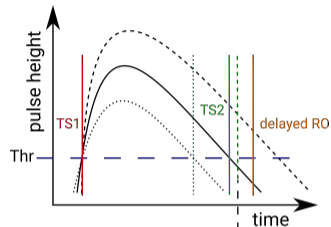
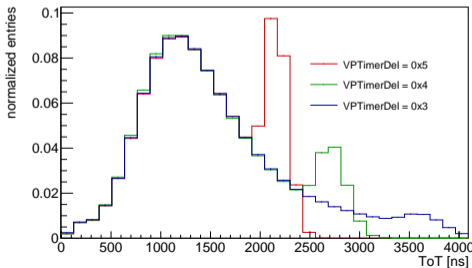


[H. Augustin arXiv:2012.05868]

ToT Sampling: Maintain Data Chronology & RO-Speed (New)



1. hit is registered and its readout is withheld
2. current source (adjustable by 6 bit DAC: VPTimerDel) charges a capacitance
3. discriminating element enables RO if rising voltage crosses threshold (ToT is sampled now at the latest)



[H. Augustin arXiv:2012.05868]

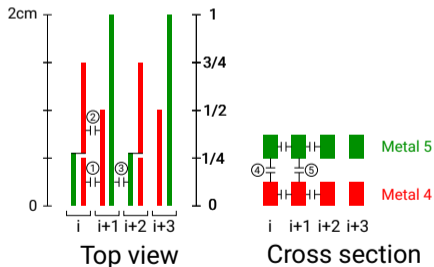
Minimise Signal Line Crosstalk (New)



- neighbouring lines form parallel plate capacitor \rightarrow scales with adjacent length

\Rightarrow a signal can create cross talk pulses

- 2 metal layers (each 125 lines/column)



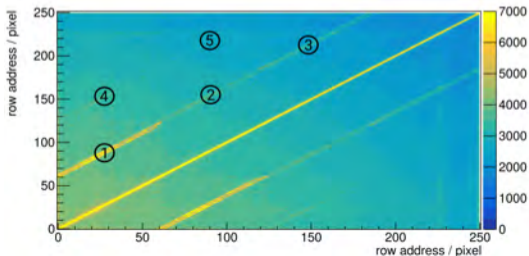
[H. Augustin arXiv:2012.05868]

- reduce neighbouring line length (1/4 of maximal length)

- distinguish cross talk hits with recognisable patterns

- off diagonal correlation \rightarrow cross talk

\Rightarrow Estimated crosstalk probability $< 1.5\%$



Preliminary Performance Results MuPix10

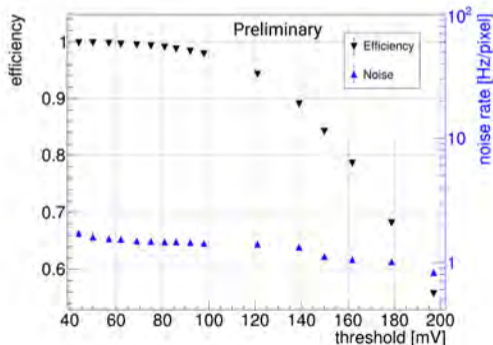
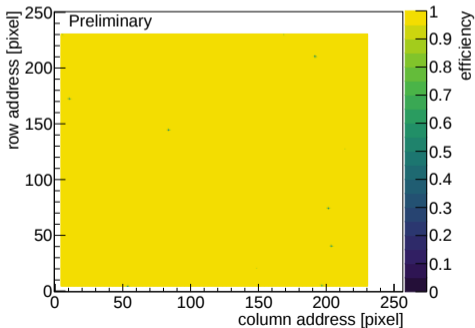


- 1 supply voltage (usage of VSSA regulator) + HV
- w/o threshold tuning or pixel masking

Efficiency > 99 %

Noise Rate < 2 Hz/Pixel

Power Consumption < 200 mW/cm²

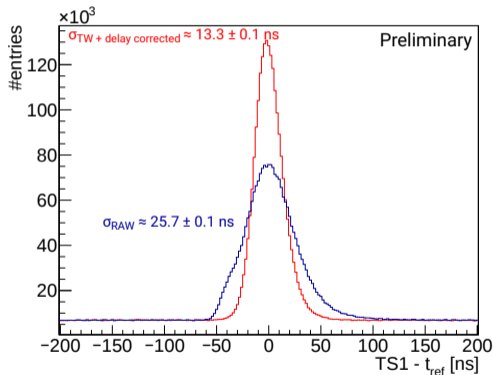


Preliminary Performance Results MuPix10



Efficiency	> 99 %
Noise Rate	< 2 Hz/Pixel
Power Consumption	< 200 mW/cm ²
Time resolution RAW	25.7 ns
Time Resolution corrected	13.3 ns

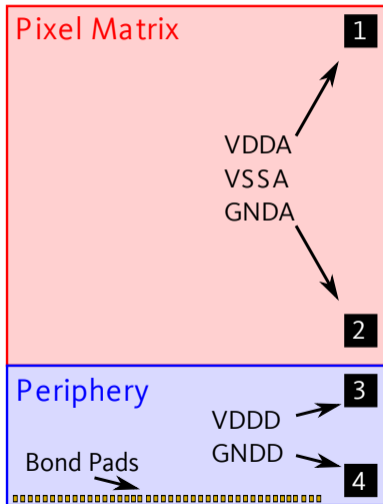
- the measured time resolution on test beam is worse than expected
- MuPix8:
- time resolution raw $\mathcal{O}(11 \text{ ns})$
 - time resolution corrected $\mathcal{O}(7 \text{ ns})$
- [J. Hammerich, Master Thesis]



Update from the Lab: We can do better ...



- test outputs for internal voltages levels at different points on the chip
- negligible voltage drops within power grid: $\mathcal{O}(1 - 4 \text{ mV})$
- significant voltage drop from bond pads to power grid: $\mathcal{O}(200 \text{ mV})$

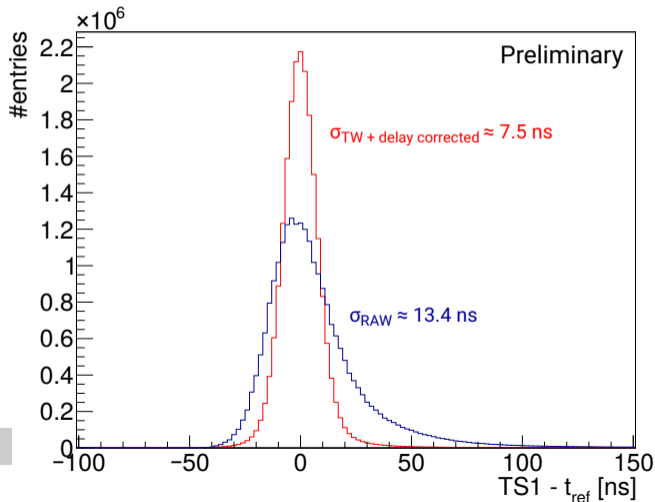


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- ⇒ adaption significantly improves time resolution

	LV untuned	LV tuned
before correction	25.7 ns	13.4 ns
after correction	13.3 ns	7.5 ns



Take-Away Message



- currently 2 (MuPix10 & ATLASPix3) types of sensors with a size of about $2 \times 2 \text{ cm}^2$ for telescope usage
- T64.9: D. Kim "Timing Study and Optimization of ATLASPix3 a full-scale HV-MAPS Prototype"
- the high modularity allows to serve 14 different sensors so far
- MuPix10 study from the lab requires further investigations¹ on test beam

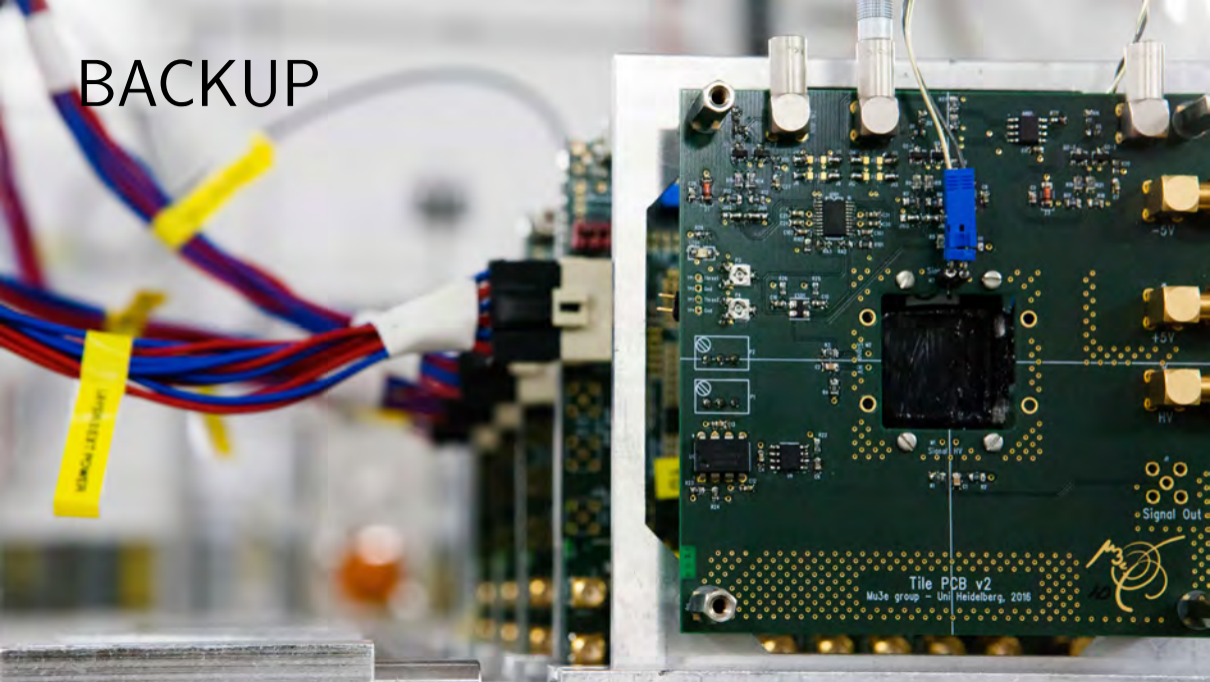
	Efficiency	Noise Rate	TR RAW	TR corrected	Power Con.
MuPix10	> 99 %	< 2 Hz/Pixel	$\leq 13.4 \text{ ns}^1$	$\leq 7.5 \text{ ns}^1$	< 200 mW/cm ²

What else is going on:

- ATLASPix3.1 submitted, submission of MuPix11 within first half 2021

"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)". (NIMA, Volume 922, 1 April 2019, Pages 265-286)

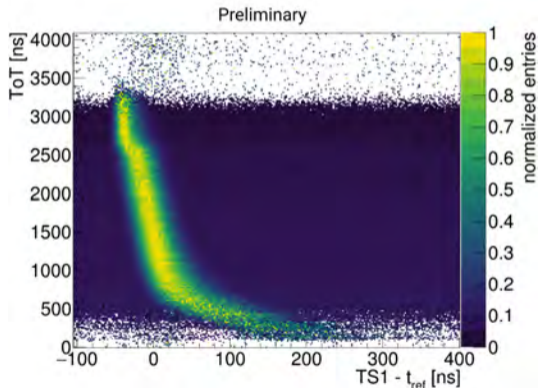
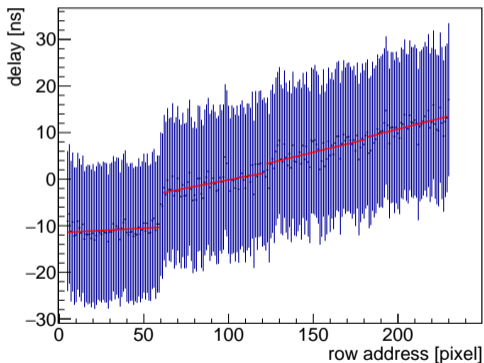
BACKUP



Tile PCB v2
Mu3e group - Uni Heidelberg, 2016



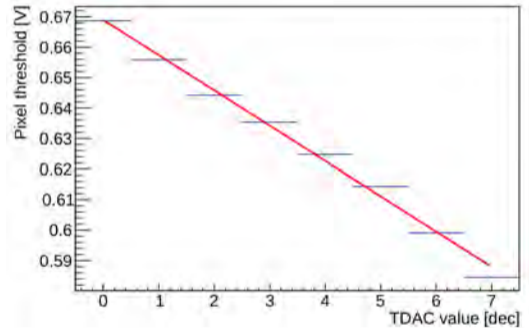
MuPix10 Signal Line Delay & Time Walk



MuPix10 Threshold Tuning



- globally applied threshold to 2 comparators
- 3 bit DAC/comparator for threshold tuning + 1 bit to "mute" pixel

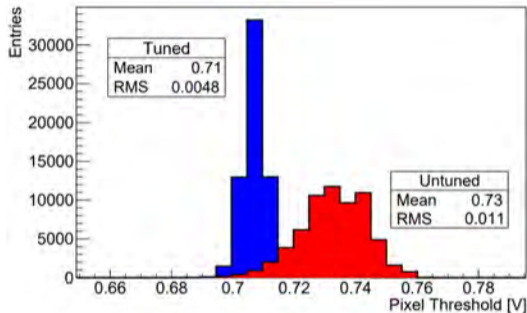


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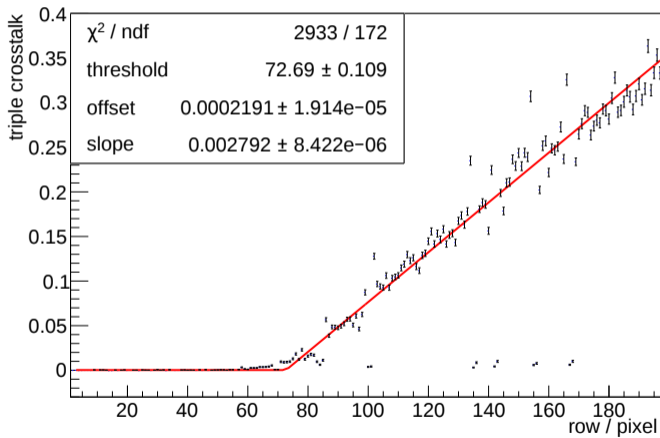
MuPix10 Threshold Tuning



- globally applied threshold to 2 comparators
 - 3 bit DAC/comparator for threshold tuning + 1 bit to "mute" pixel
 - threshold dispersion minimized from 11 mV ($240 e^-$) to 4.8 mV ($79 e^-$)
- effect to be studied on future test beam



[H. Augustin arXiv:2012.05868]



[L. Huth doi:10.11588/heidok.00025785]