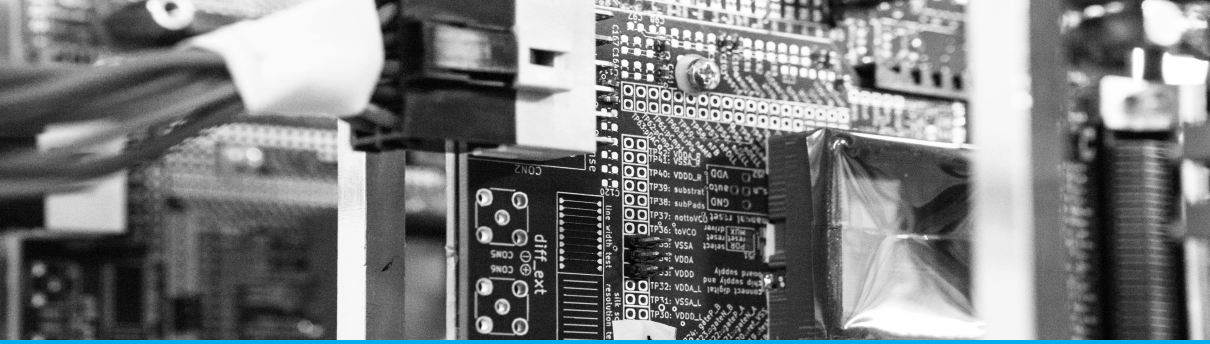


The Very Large HV-MAPS Tracking Telescope

David Maximilian Immig

BTTB9, 09.02.2021

HighRR

Bundesministerium
für Bildung
und Forschung

Why do we do, what we do

Telescope usage:

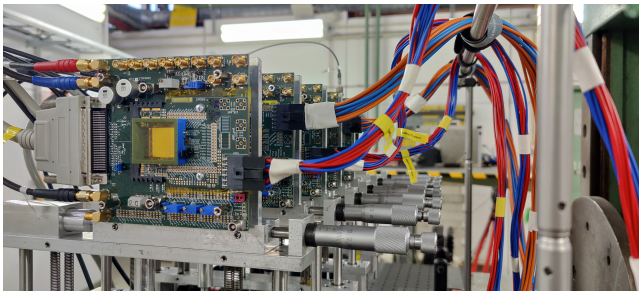
- study of several HV-MAPS prototypes

$\rightarrow$ test beam campaigns at several facilities like DESY, PSI, MAMI

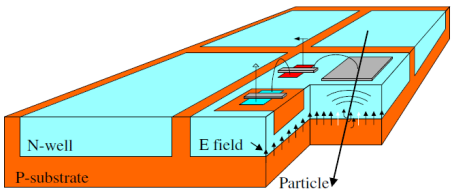
- modular and compact design

Requirements:

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



High-**V**oltage **M**onolithic **A**ctive **P**ixel **S**ensor



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

Monolithic design:

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

Commercially available processes:

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

Characteristics:

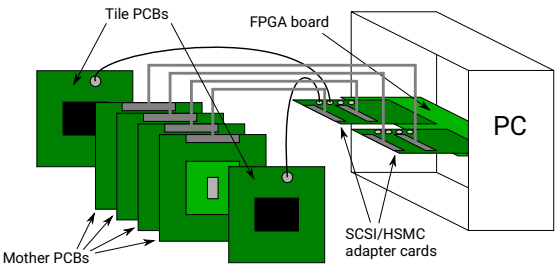
- low-ohmic substrate (10-200 Ω cm)
- deep n-well diode is reversely biased

→ ∼10-30 µm depletion zone allows fast charge collection via drift

- chips can be thinned to 50 µm

Telescope Concept

- 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]

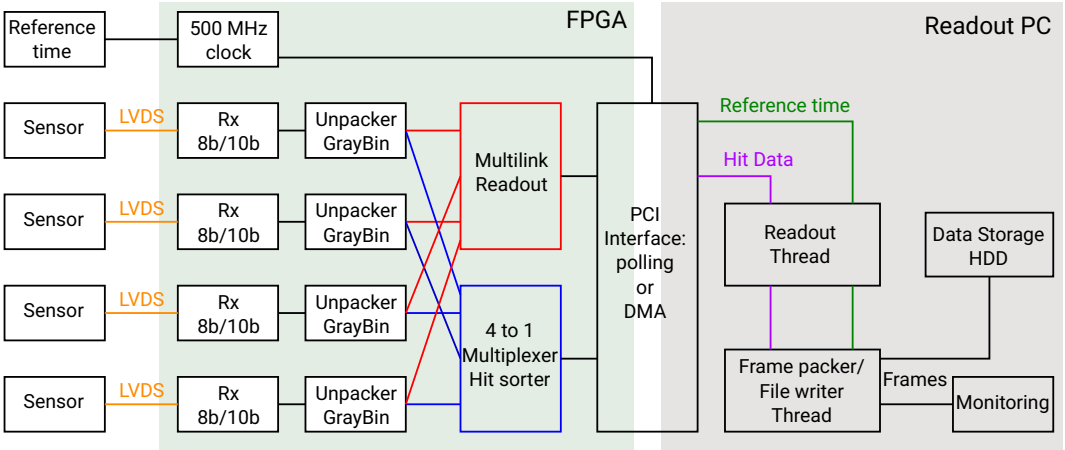
Mother PCB:

- 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)

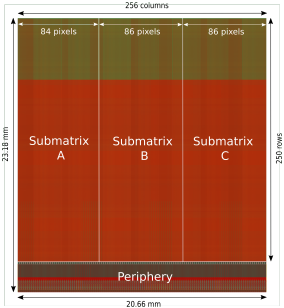
ATLASPix3 vs MuPix10

	Matrix [pixel]	Pixel size [μm^2]	Active area [mm^2]	Substrate [Ω cm]	Comparator	ToA+ToT [bits]	LVDS links
ATLASPix3	132×372	150×50	19.8×18.6	200	NMOS[1]	10+7	1
MuPix10	256×250	80×80	20.48×20.0	20, 200	2xNMOS[2]	11+5	3+1

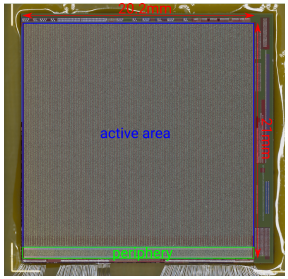
- development in the scope of the HV-MAPS collaboration
- both full-scale prototypes are produced in an 180 nm process by TSI Semiconductor
- both sensors feature a continuous readout

1 in-pixel comparator

2 both comparators in periphery

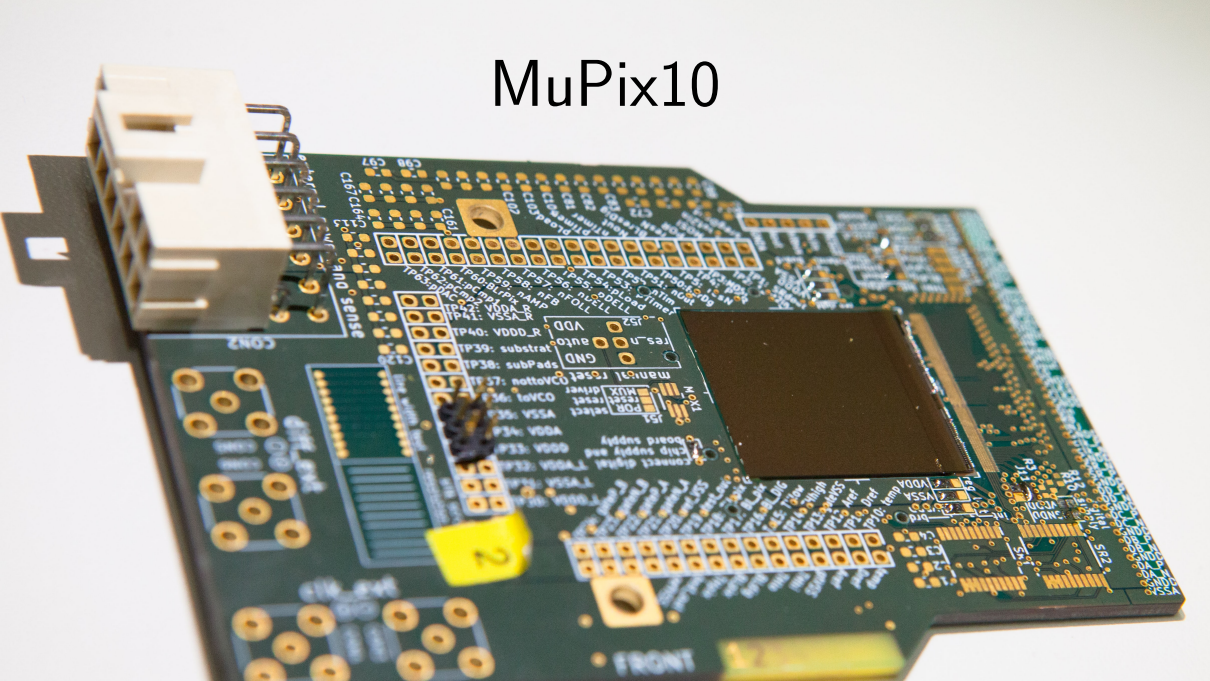


MuPix10

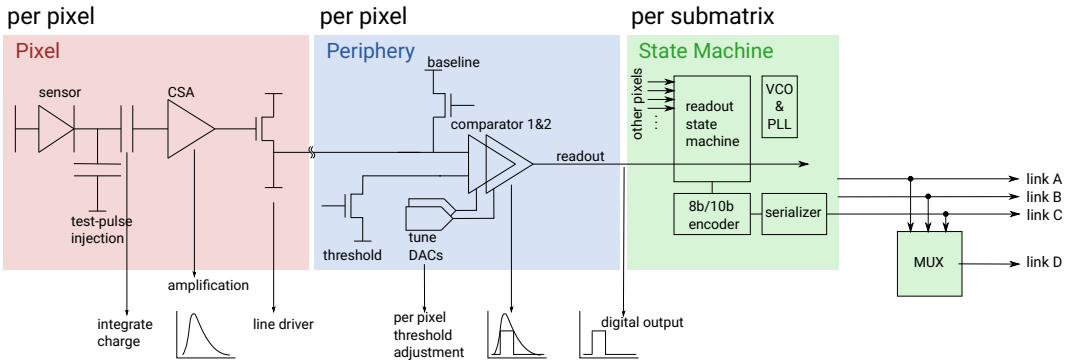


ATLASPix3

MuPix10



Readout Structure: MuPix10



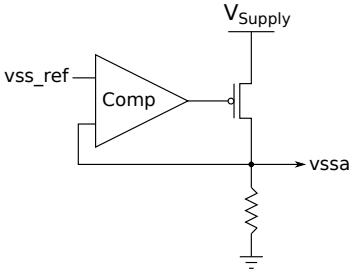
[H. Augustin arXiv:2012.05868]

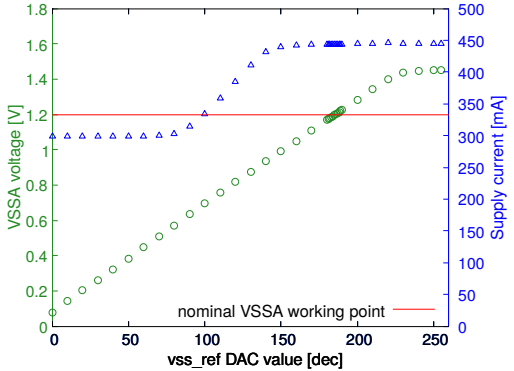
VSSA Regulator: Powering of the CSA (New)

- linear series regulator with differential amplifier for level adjustments

$\rightarrow$ configurable by the reference value vss_ref

$\Rightarrow$ MuPix10 operational via 1 supply voltage (+HV)

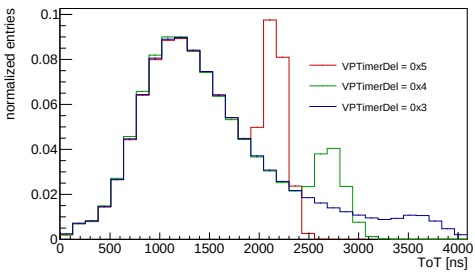


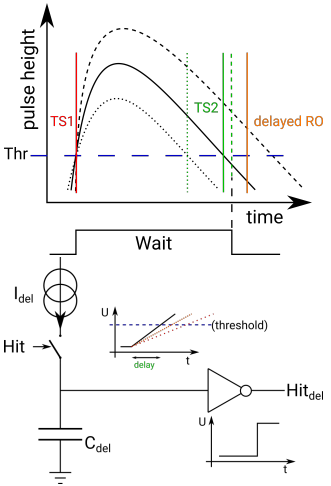


[H. Augustin arXiv:2012.05868]

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

1. hit is registered and its readout is withhold
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)





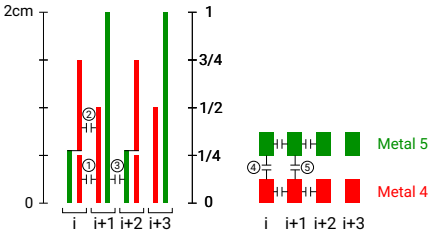
[H. Augustin arXiv:2012.05868]

Minimise Signal Line Crosstalk (New)

- neighbouring lines form parallel plate capacitor → scales with adjacent length

⇒ a signal can create cross talk pulses

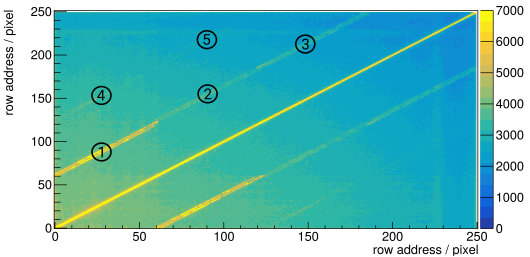
- 2 metal layers (each 125 lines/column)



[H. Augustin arXiv:2012.05868]

1. reduce neighbouring line length (1/4 of maximal length)
2. distinguish cross talk hits with recognisable patterns
   - off diagonal correlation → cross talk

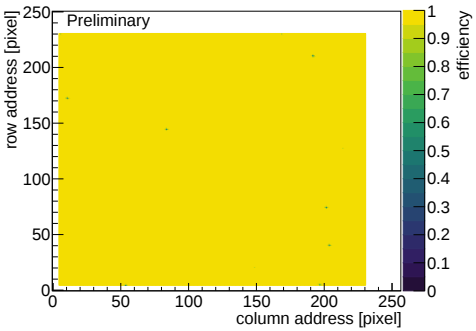
⇒ Estimated crosstalk probability <1.5 %

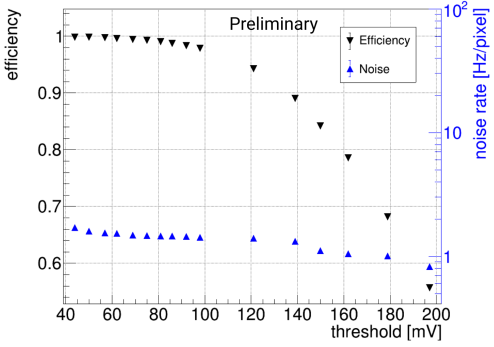


Preliminary Performance Results MuPix10

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

Efficiency	$> 99\,\%$
Noise Rate	$< 2\,\mathrm{Hz/Pixel}$
Power Consumption	$< 200\,\mathrm{mW/cm^2}$



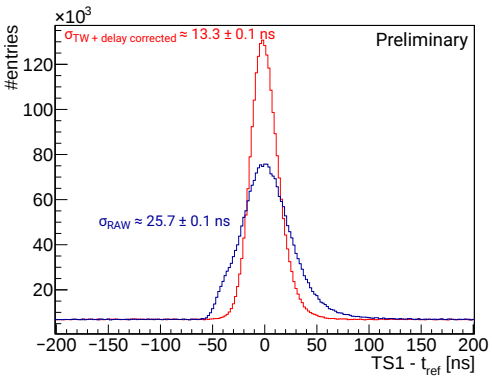


Preliminary Performance Results MuPix10

Efficiency	$> 99\,\%$
Noise Rate	$< 2\,\mathrm{Hz/Pixel}$
Power Consumption	$< 200\,\mathrm{mW/cm^2}$
Time resolution RAW	25.7 ns
Time Resolution corrected	13.3 ns

- the measured time resolution on test beam is worse than expected

$\rightarrow$ MuPix8:
time resolution raw $\mathcal{O}(11\,\mathrm{ns})$
time resolution corrected $\mathcal{O}(7\,\mathrm{ns})$
[J. Hammerich, Master Thesis]

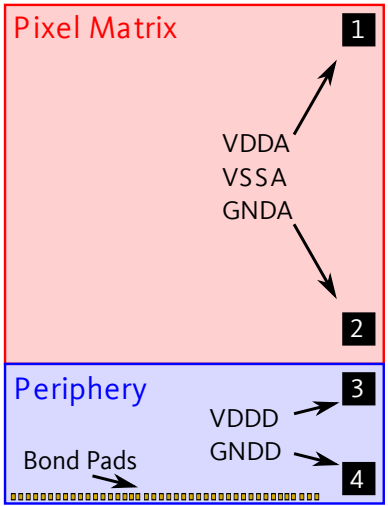


Update from the Lab: We can do better ...

- test outputs for internal voltages levels at different points on the chip

$\rightarrow$ negligible voltage drops within power grid: $\mathcal{O}(1 - 4\,\mathrm{mV})$

$\rightarrow$ significant voltage drop from bond pads to power grid: $\mathcal{O}(200\,\mathrm{mV})$



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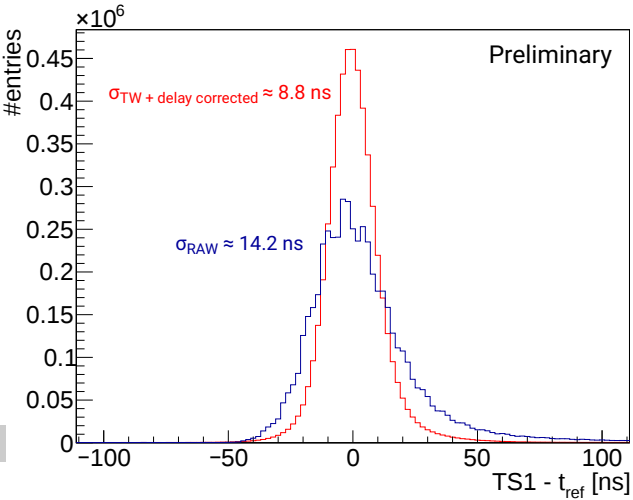
→ negligible voltage drops within power grid: $\mathcal{O}(1 - 4\,\mathrm{mV})$

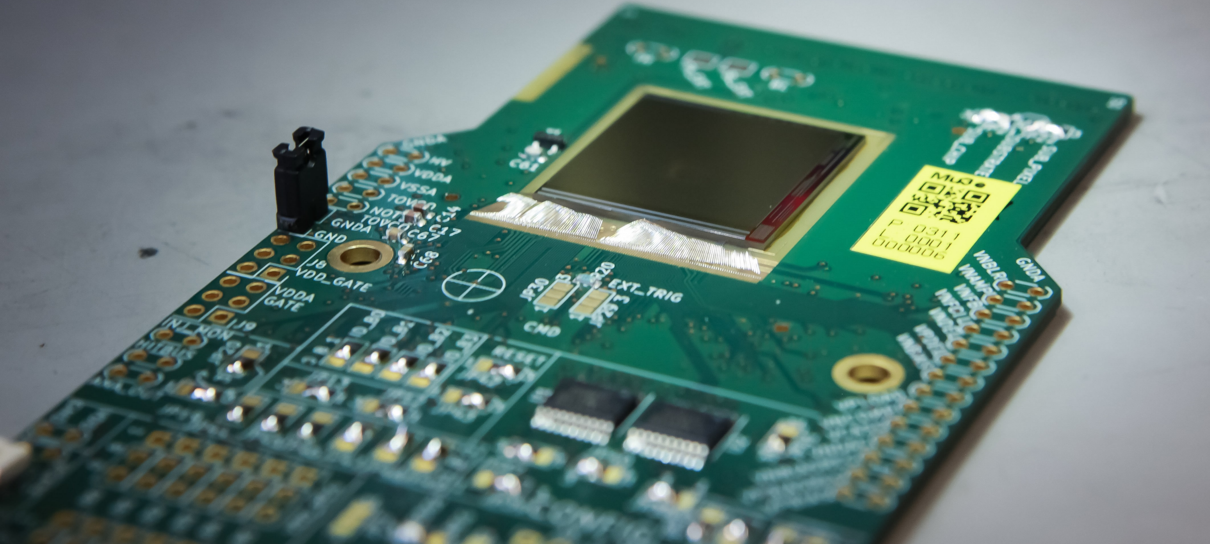
→ significant voltage drop from bond pads to power grid: $\mathcal{O}(200\,\mathrm{mV})$

⇒ adaption significantly improves time resolution (no optimised settings yet)

	LV untuned	LV tuned
before correction	25.7 ns	14.2 ns
after correction	13.0 ns	8.8 ns



ATLASPix3

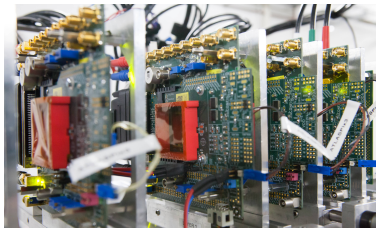


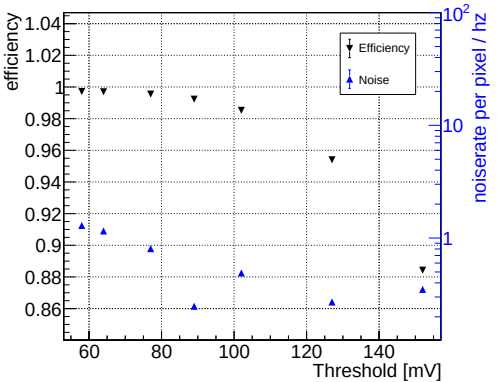
HV
VDDA
VSSA
GNDA
GND
J8
VDD_GATE
VDDA
GATE
J9
C61
C67
C17
EXT_TRIG
CMD
RESET
P 0311
L 0001
000006

Performance ATLASPix3

Efficiency	$> 99\,\%$
Noise Rate	$< 2\,\mathrm{Hz/Pixel}$
Time Resolution$_{\mathrm{RAW}}$	$\approx 8\,\mathrm{ns}$
Time Resolution$_{\mathrm{corrected}}$	$\approx 5\,\mathrm{ns}$
Power Consumption	$\approx 150\,\mathrm{mW/cm^2}$

$\Rightarrow$ w/o threshold tuning or pixel masking





[D. Kim, Master Thesis]

Performance ATLASPix3

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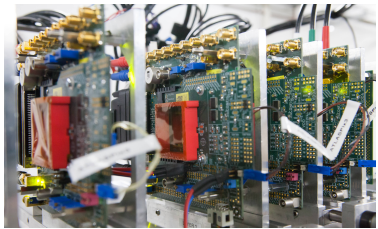
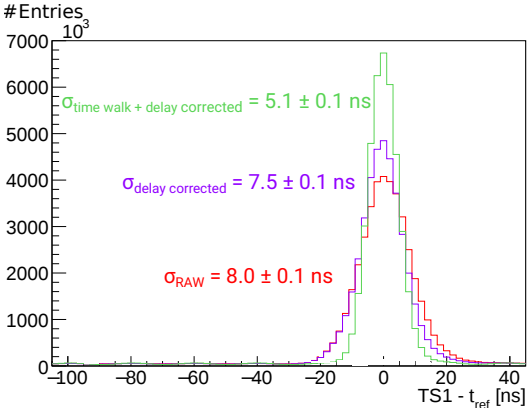




[D. Kim, Master Thesis]

Take-Away Message

- currently 2 types of sensors with a size of about $2 \times 2\,\mathrm{cm}^2$ for telescope usage

$\rightarrow$ the high modularity allows to serve 14 different sensors so far

- MuPix10 study from the lab requires further investigations[1] on test beam

	Efficiency	Noise Rate	TR RAW	TR corrected	Power Con.
MuPix10	$> 99\,\%$	$< 2\,\mathrm{Hz/Pixel}$	$\leq 14.2\,\mathrm{ns}$[1]	$\leq 8.8\,\mathrm{ns}$[1]	$< 200\,\mathrm{mW/cm^2}$
ATLASPix3	$> 99\,\%$	$< 2\,\mathrm{Hz/Pixel}$	8.0 ns	5.1 ns	$150\,\mathrm{mW/cm^2}$

What else is going on:

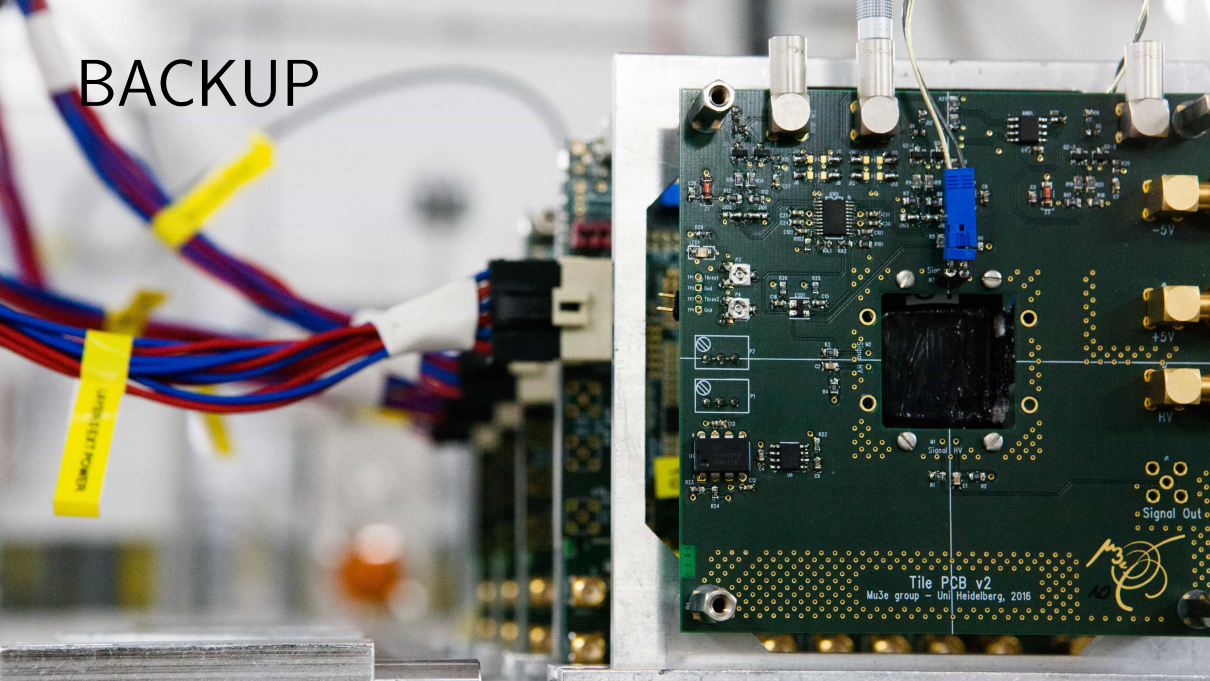
- R&D sensors Run2020 feature different pixel sizes, comparator and amplifier types

$\Rightarrow$ see talk by A. Meneses: "The MightyPix HV-CMOS sensor for LHCb Upgrade 2"

- 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


-5V
+5V
HV
Signal Out
Tile PCB v2
Mu3e group – Uni Heidelberg, 2016

MuPix10 Specification

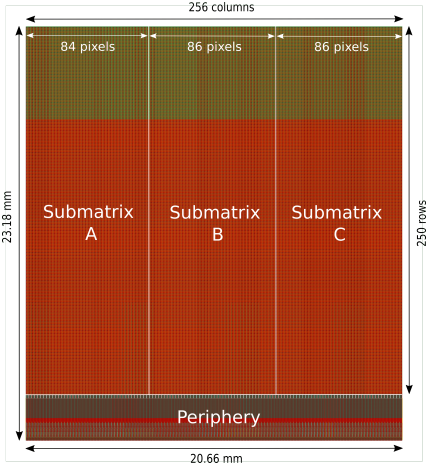
- full scale sensor produced by TSI

→ 20 & 200 Ω cm substrate

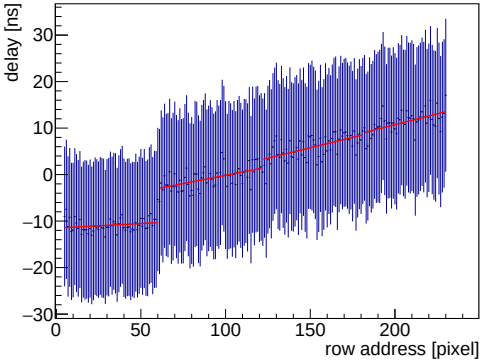
→ 50, 100 & 650 µm thinned wafers

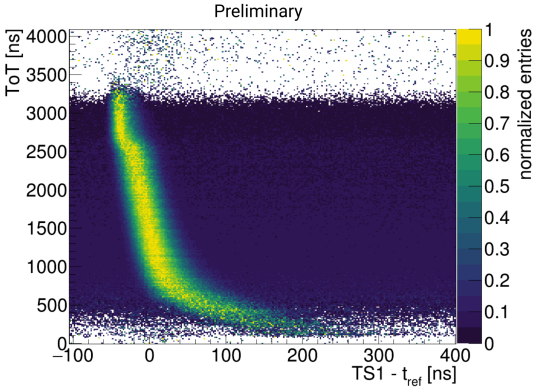
- trigger-less readout mode available
- powering via regulator possible
- threshold and baseline levels generated on-chip

Matrix [pixel]	256×250
Pixel size [µm^2]	80×80
Active area [mm^2]	20.48×20.0
ToA+ToT [bits]	11+5
Tuning+Masking [bits]	2x3+1
LVDS links	3+1



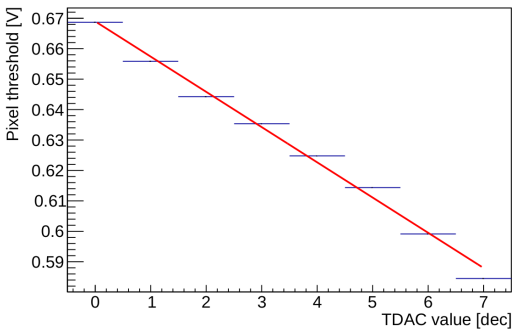
MuPix10 Signal Line Delay & Time Walk





MuPix10 Threshold Tuning

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

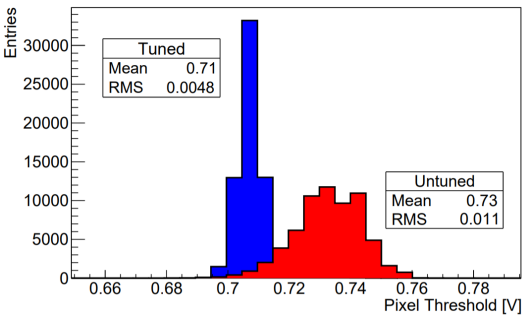


[H. Augustin arXiv:2012.05868]

MuPix10 Threshold Tuning

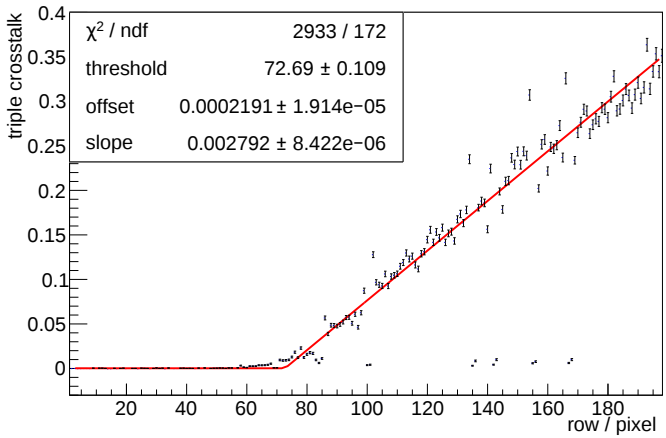
- globally applied threshold to 2 comparators
- 3 bit DAC/comparator for threshold tuning + 1 bit to "mute" pixel
- threshold dispersion minimized from 11 mV (240 e^-) to 4.8 mV (79 e^-)

$\rightarrow$ effect to be studied on future test beam



[H. Augustin arXiv:2012.05868]

Line Crosstalk MuPix8



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

ATLASPix3 Specification

- 1. large scale sensor produced by TSI

→ 200 Ω cm substrate

→ 100 µm & 650 µm thinned wafers

- triggered & trigger-less readout mode available
- powering via shunt regulators possible
- threshold and baseline levels generated on-chip

Matrix [pixel]	132×372
Pixel size [µm^2]	150×50
Active area [mm^2]	19.8×18.6
ToA+ToT [bits]	10+7
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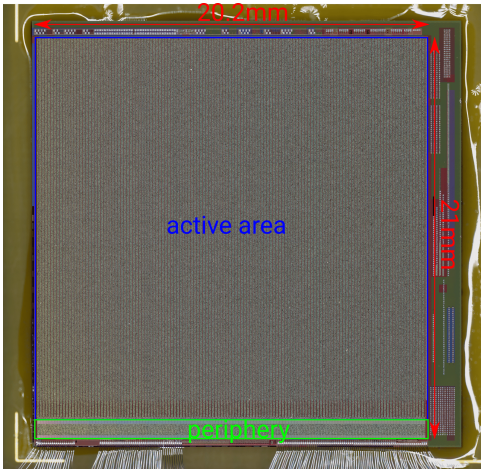
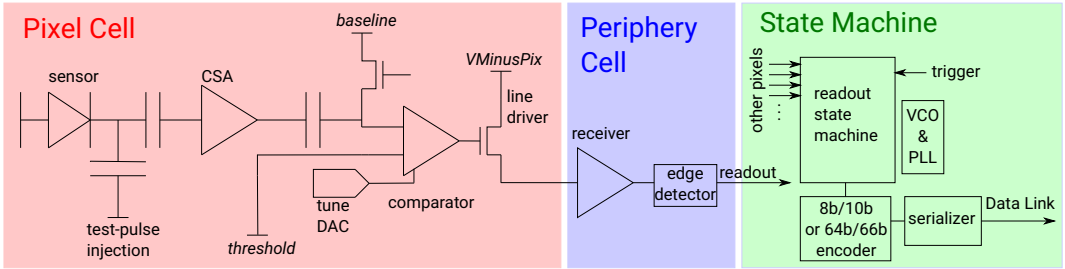
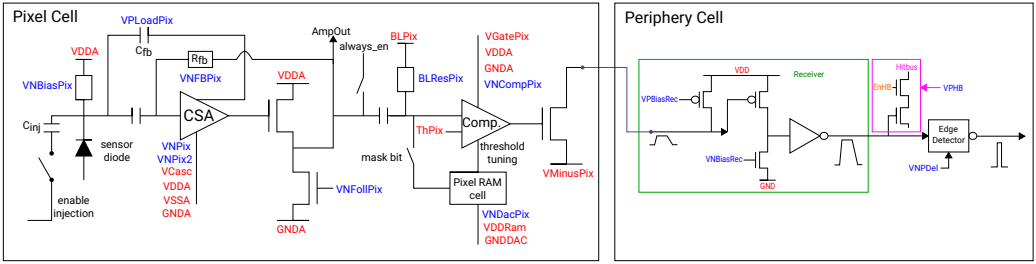


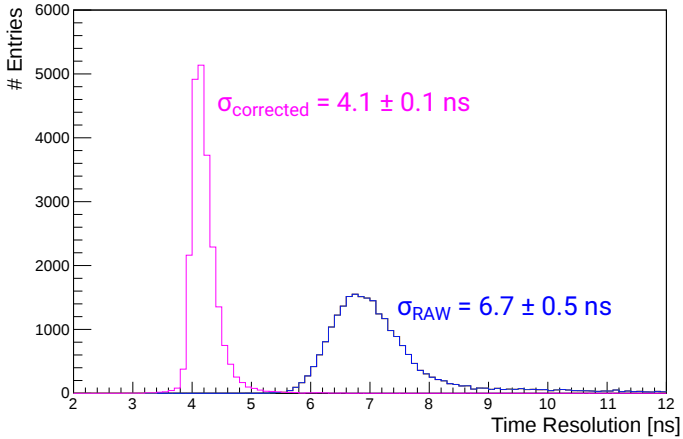
Readout Structure: ATLASPix3



ATLASPix3: Pixel & Digital Partner Cell



Single Pixel Time Resolution ATLASPix3



[D. Kim, Master Thesis]