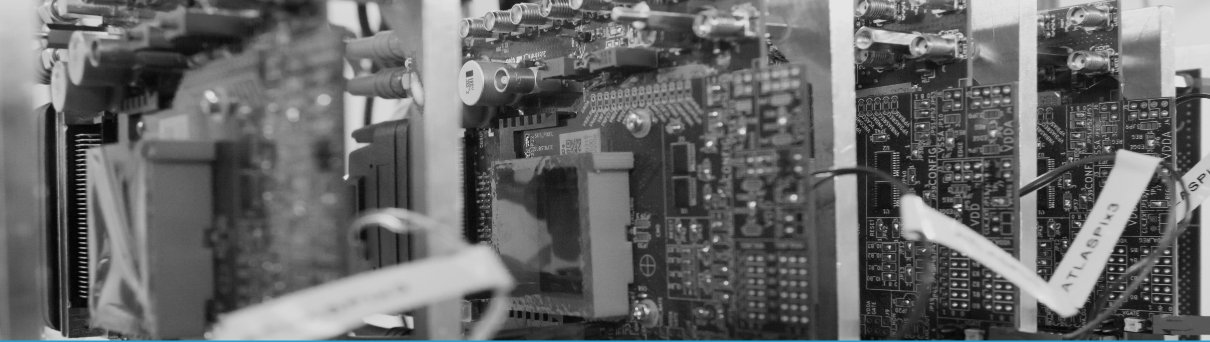


An HV-CMOS-based Tracking Telescope

David Maximilian Immig

BTTB8, 30.01.2020

HighR

Bundesministerium für Bildung und Forschung

Why do we do, what we do

Telescope usage:

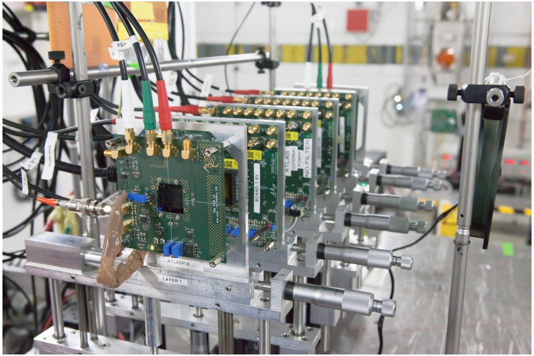
- Study of several sensor prototypes

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

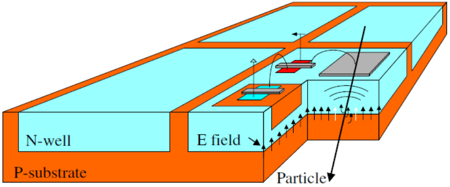
- Modular and compact design

Requirements:

- High rate capabilities
- Good timing and spatial resolution
- Ulta-low material budget
- Long life $\rightarrow$ radiation hardness



High-Voltage Monolithic Active Pixel Sensor



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

Monolithic design:

- Active pixel 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:

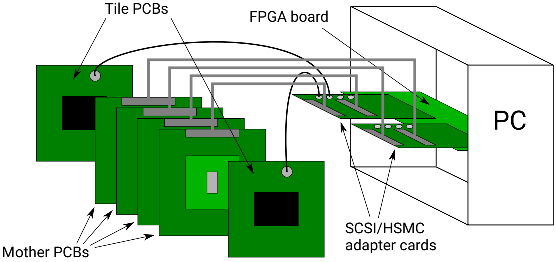
- Low-ohmic substrate (10-200 Ω cm)
- Deep n-well diode is reversely biased

$\rightarrow$ ~10-30 μm depletion allows fast charge collection via drift

- Chips can be thinned to 50 μm

Telescope Concept

- 4 to 8 Layers + 2 scintillating tiles for time reference
- Reference layers and DUT can be of different sensor type → 5 different sensor types implemented so far



[A.Herkert]

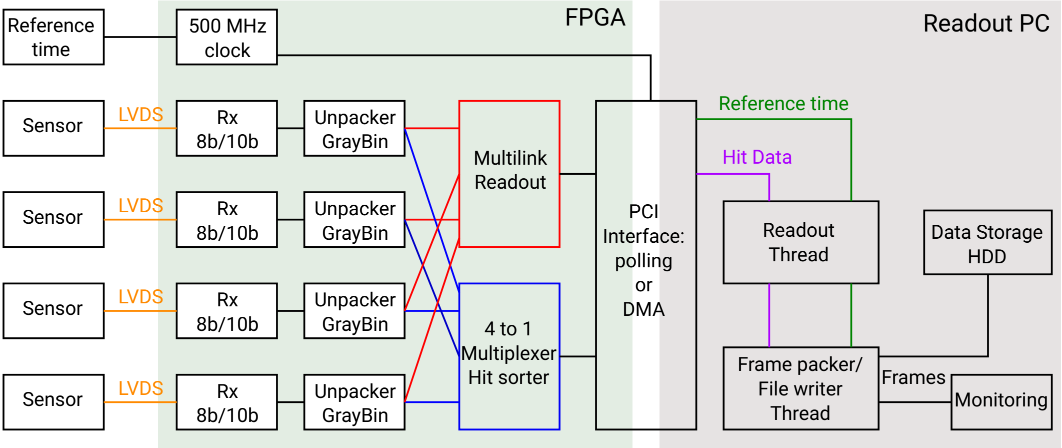
Mother PCB:

- Interface for insert-able PCBs of different sensor prototypes
- Connection via SCSI-III with FPGA

SCSI/HSMC adapter cards:

- Interface between Mother PCB/ time reference data to FPGA

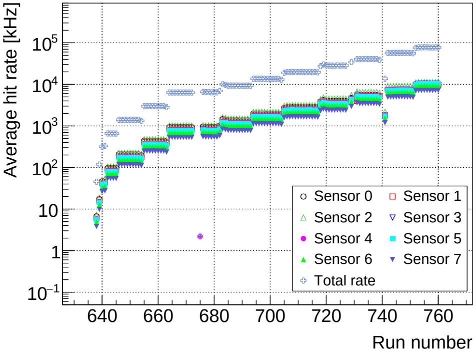
Readout: From Sensor to Disc



Telescope Performance

- MAMI Beam used as stress test (DMA used)

→ Up to 10 MHz particle rates (80 MHz hits)



[2]

[2] S. Dittmeier, Fast data acquisition for silicon tracking detectors at high rates, PhD thesis, Heidelberg University, 2018

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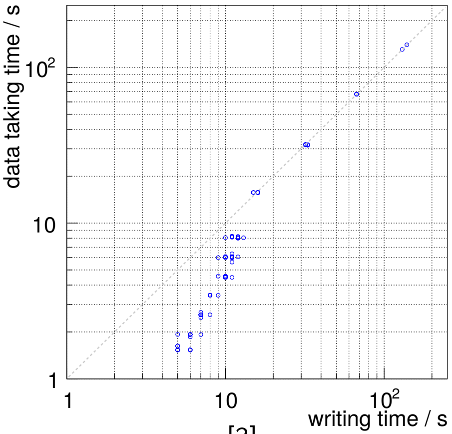
- Writing time limited by HDD to ≈ 100 Mbit/s



[3]

[3] L. Huth, A High Rate Testbeam Data Acquisition System and Characterization of High Voltage Monolithic Active Pixel Sensors, PhD thesis, Heidelberg University, 2018

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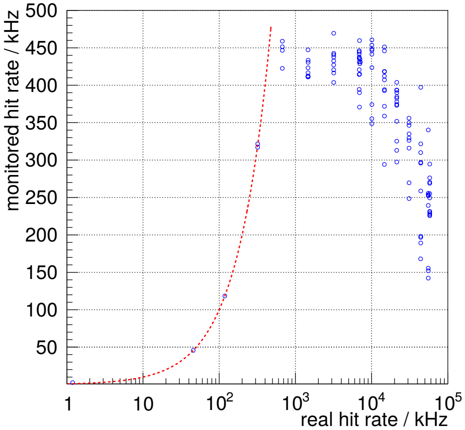

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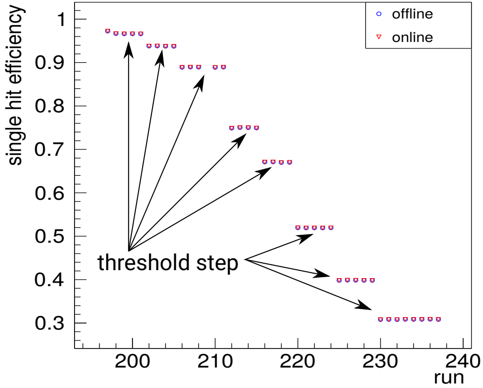
- MAMI Beam used as stress test (DMA used)

→ Up to 10 MHz particle rates (80 MHz hits)

- Writing time limited by HDD to ≈ 100 Mbit/s
- Monitoring processes up to 500 kHits/s
- Full online reconstruction tested with 22.5 kTrack/s (limited particle rate)

→ Tested for individual runs for different threshold steps

⇒ Online & offline efficiency are identical



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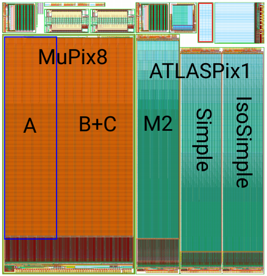
Test Beam Highlights

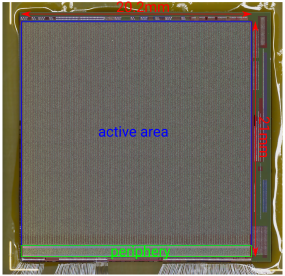
MuPix8 vs. ATLASPix1 vs ATLASPix3

	Matrix [pixel]	Pixel size [µm²]	Active area [mm²]	Substrate [Ω cm]	Comparator	ToA+ToT [bits]	LVDS links
MuPix8	128×200	81×80	10.37×16.0	20, 80, 200	2 in digital partner cell	10+6	3+ 1mux
ATLASPix1	25×400	130×40	3.25×16.0	20, 80, 200	NMOS[1]/ CMOS[2]	10+6	1
ATLASPix3	132×372	150×50	19.8×18.6	200	NMOS	10+7	1

- MuPix8 & ATLASPix1 produced in AMS ah18
- ATLASPix3 produced by TSI

[1]Simple [2]IsoSimple



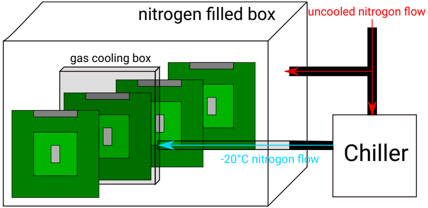


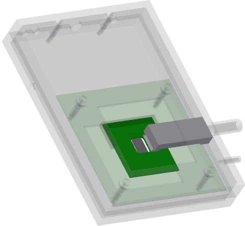
ATLASPix_Simple Irradiation Study

- Irradiated samples are tested in same telescope, but DUT layer is extended by "cooling box"

→ $-20\,^{\circ}$C nitrogen gas as cooling medium

⇒ Sensor temperature $\approx 0\,^{\circ}$C to $5\,^{\circ}$C





[1]

[1] A. Herkert, Characterization of a Monolithic Pixel Sensor Prototype in HV-CMOS Technology for the High-Luminosity LHC, PhD thesis, Heidelberg University, 2020

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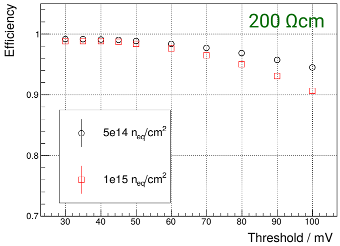
- Irradiated samples are tested in same telescope, but DUT layer is extended by "cooling box"

→ −20 °C nitrogen gas as cooling medium

⇒ Sensor temperature ≈ 0 °C to 5 °C

- No threshold tuning, but noisiest pixel masked
- Goal of efficiency over 97 % reached



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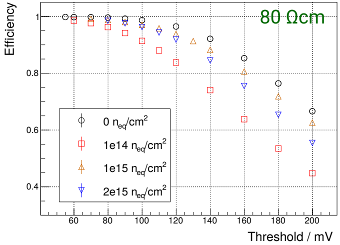

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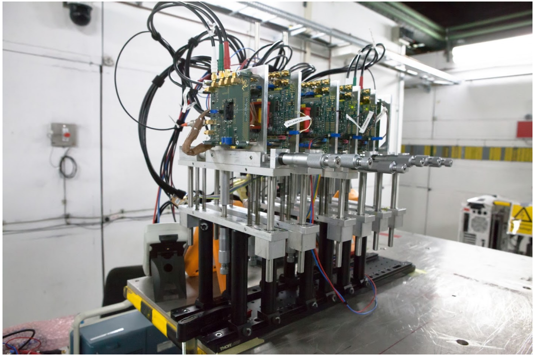
Resistivity / Ωcm	Fluence / n_{eq}/cm^2	#masked pixels	-60 V	-70 V	$-80/85$ V
			Efficiency / %		
80	$1 \cdot 10^{14}$	26	96.3	97.5	98.3
	$5 \cdot 10^{14}$	17	99.5 (2)	-	-
	$1 \cdot 10^{15}$	38	99.3	-	99.5
	$2 \cdot 10^{15}$	81	98.5	98.4	98.6
200	$5 \cdot 10^{14}$	14	99.2	-	-
	$1 \cdot 10^{15}$	18	98.8	-	-
	$2 \cdot 10^{15}$	55	96.5	-	98.7 (5)
	p $5 \cdot 10^{14}$	≤ 9	99.6	99.7	99.9

average noise rate $\leq$40 Hz/pixel
[1]

[1] A. Herkert, Characterization of a Monolithic Pixel Sensor Prototype in HV-CMOS Technology for the High-Luminosity LHC, PhD thesis, Heidelberg University, 2020

Commissioning Test Beam at DESY

- Fast integration of ATLASPix3 in DAQ software as well as testing within ∼2 weeks before the test beam
- Commissioning of 4 layer ATLASPix3 telescope on DESY test beam



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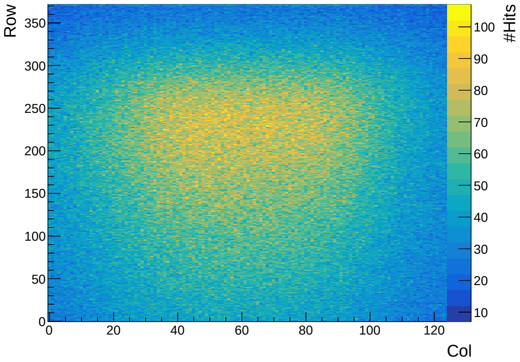
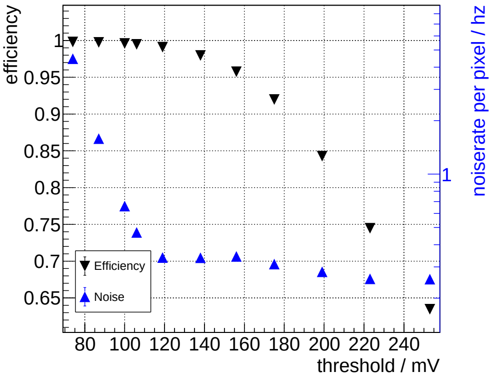
- No distinct optimization of settings performed yet



Commissioning Test Beam at DESY

- Fast integration of ATLASPix3 in DAQ software as well as testing within ∼2 weeks before the test beam
- Commissioning of 4 layer ATLASPix3 telescope on DESY test beam
- No distinct optimization of settings performed yet
- Efficiency over 99 % out of the box
- W/o threshold tuning or pixel masking

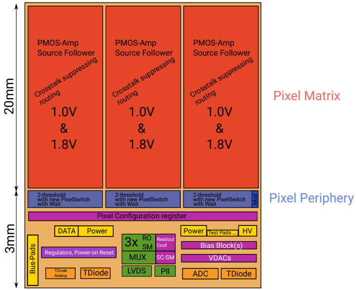


The Future of the Telescope

Future Improvements

MuPix10 features (expected arrival in March):

- Active area of $20.48 \times 20\,\mathrm{mm}^2$ with quadratic pixel pitch of $80\,\mu\mathrm{m}$
- 11 b ToA + 5 b ToT information
- 3+1(mux) LVDS links



Development of quad modules:

- 2×2 sensor with $\sim 4 \times 4\,\mathrm{cm}^2$ active area in total

$\rightarrow$ ATLASPix3 and/or MuPix10

Further sensor developments (spring 2020):

- TelePix with $25 \times 150\,\mu\mathrm{m}^2$ pixel size
- R&D for $25 \times 25\,\mu\mathrm{m}^2$ pixel size

Revision of the setup:

- Compactify and improve flexibility and modularity
- Consideration of modern connector standards

Take-Away Message

- Current telescope fairly compact and features good modularity

→ Serves 5 different sensor types (+ MuPix10 soon)

→ Plan to revise the telescope and modern connector standards have to be considered

⇒ Increase flexibility to serve different developments and sensor prototypes

- ATLASPix3 shows promising results with an efficiency over 99 %

→ Further studies required for time resolution etc and other features of ATLASPix3 have to be tested

"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

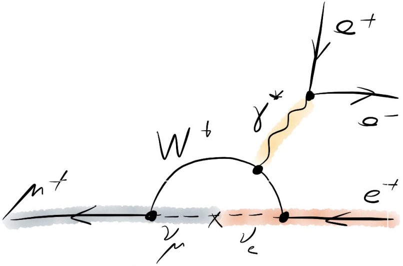
Mu3e

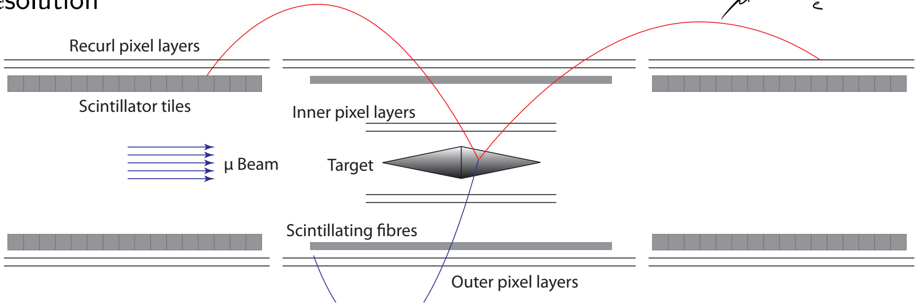
Charged-lepton flavor violation:

- $\mu^+ \to e^+e^-e^+$ BR$< 10^{-15}$ (Phase-I)

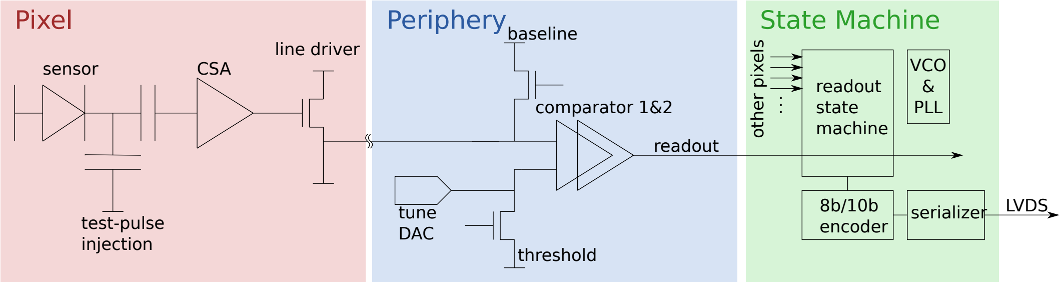
$\rightarrow$ 10^8 muons/s stopped

$\Rightarrow$ thin pixel tracker with high rate capability & good timing and vertex resolution

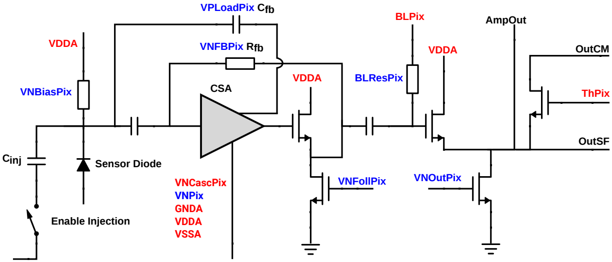




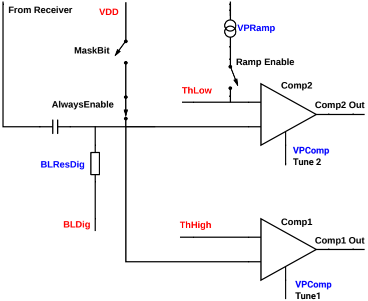
Readout Structure: MuPix8



MuPix8: Pixel & Digital Partner Cell

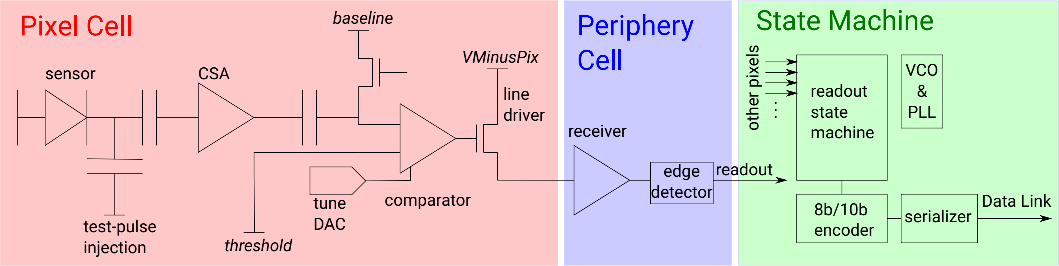


Sketch of pixel cell of MuPix8

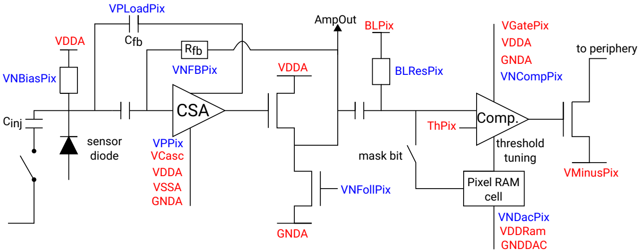


Sketch of digital partner cell of MuPix8

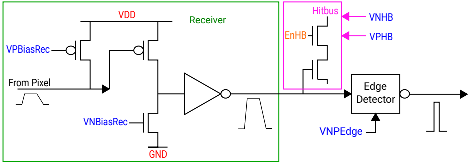
Readout Structure: ATLASPix1



ATLASPix1: Pixel & Digital Partner Cell

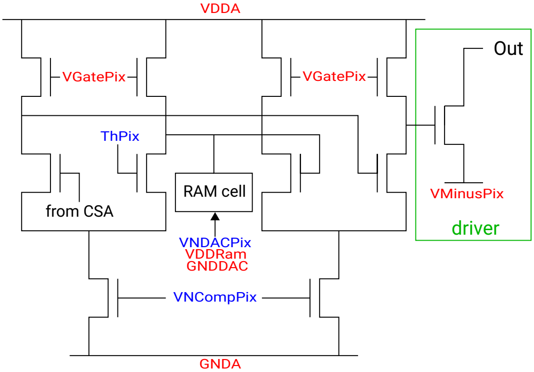


Sketch of pixel cell of ATLASPix1

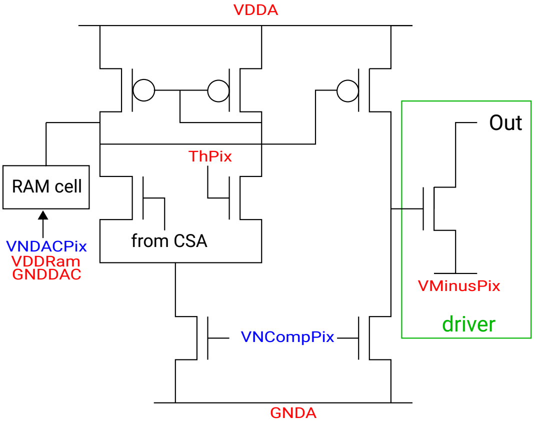


Sketch of digital partner cell of ATLASPix1

ATLASPix1: NMOS-based & CMOS Comparator

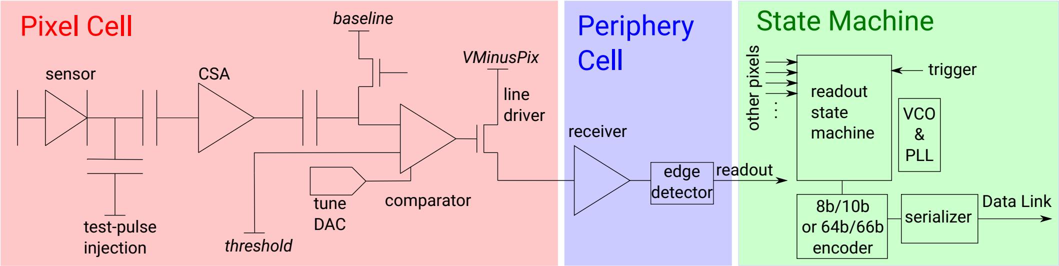


Sketch of NMOS-based comparator of ATLASPix1

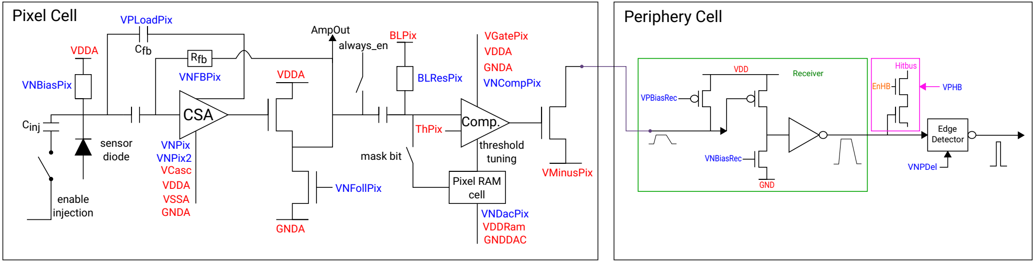


Sketch of CMOS comparator of ATLASPix1

Readout Structure: ATLASPix3



ATLASPix3: Pixel & Digital Partner Cell



ATLASPix3 Specification

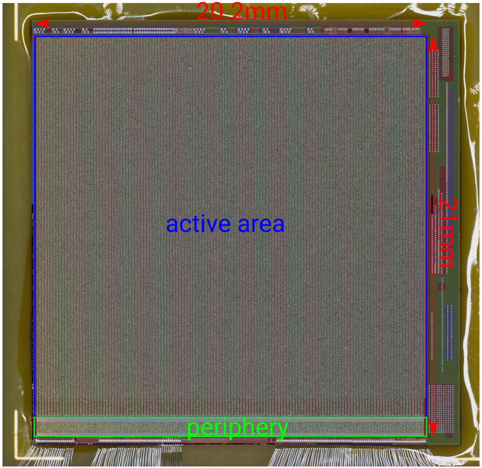
- 1. large scale sensor produced by TSI

→ 200 Ω cm substrate

→ 100 µm & 650 µm thinned wafers

- Untriggered readout mode available
- Powering via shunt regulators possible
- Threshold and baseline levels generated on-chip

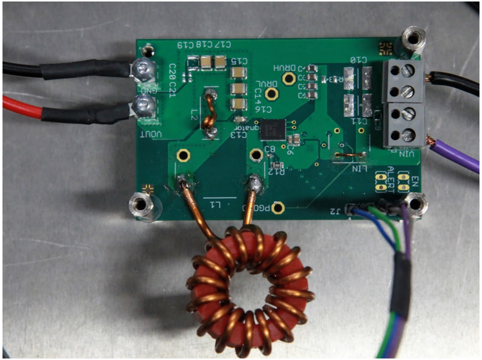
Matrix [pixel]	132×372
Pixel size [µm^2]	150×50
Active area [mm^2]	19.8×18.6
ToA+ToT [bits]	10+7
Tuning+Masking [bits]	3+1



A step to Mu3e: DC-DC Powering Feasibility

- Low voltages supplied via DC-DC converter developed for module powering of the Mu3e experiment
- Study experimental conditions: all filter capacitances removed
- Supply voltage for digital and analog part shorted
- Efficiency still over 99 %, however erratic noise increase (under investigation)

⇒ Powering with DC-DC converter of entire telescope planned



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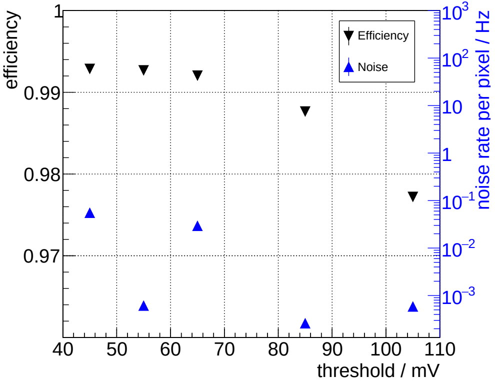

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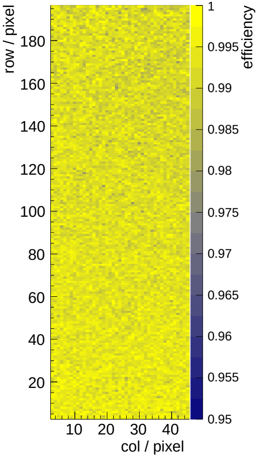
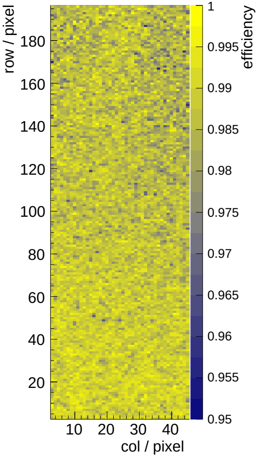


Th = 45 mV



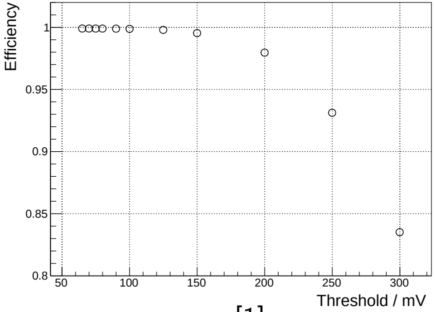
Th = 85 mV

Test Beam Commissioning: ATLASPix_IsoSimple Efficiency Study

- CMOS comparator: deep p-well to isolate PMOS transistors

→ increased pixel capacitance

- Advantage: 1 supply voltage less for comparator & faster switching → less delay
- Efficiency above 99 %



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