



Towards MightyPix, an HV-MAPS for the LHCb Mighty Tracker Upgrade

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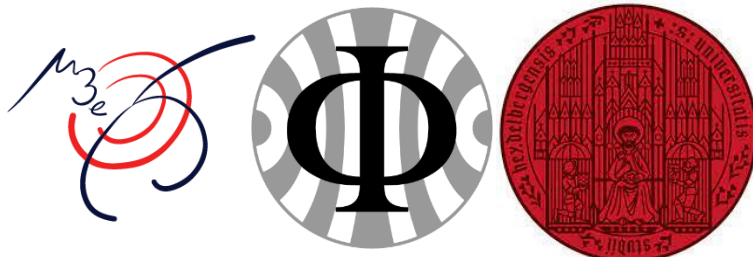


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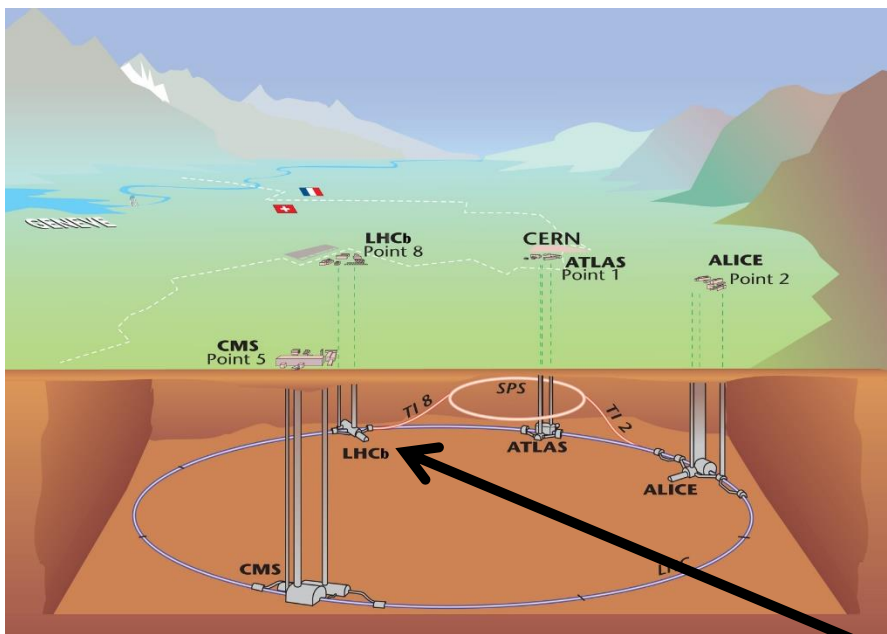
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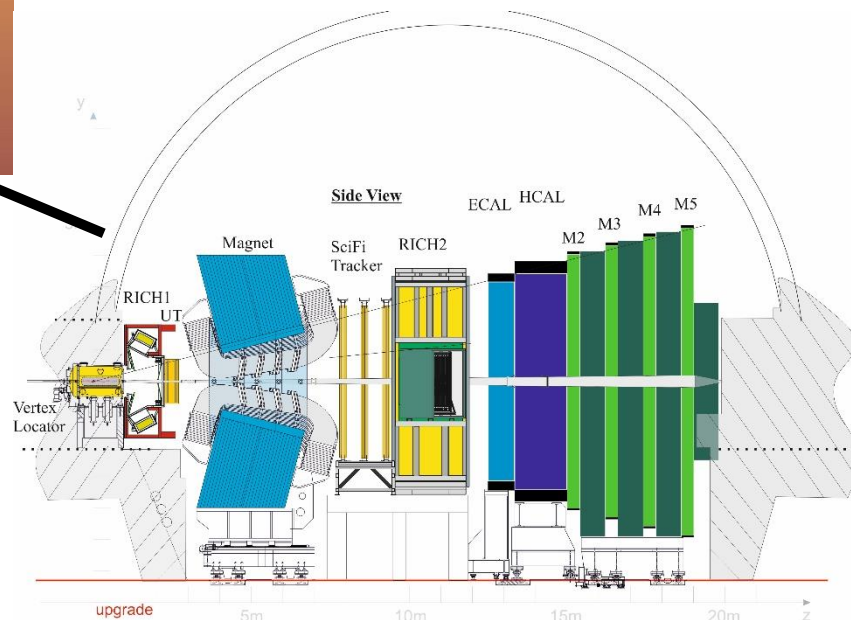
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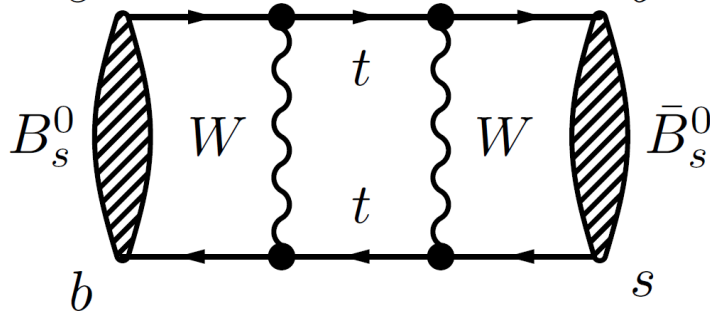


credit:CERN

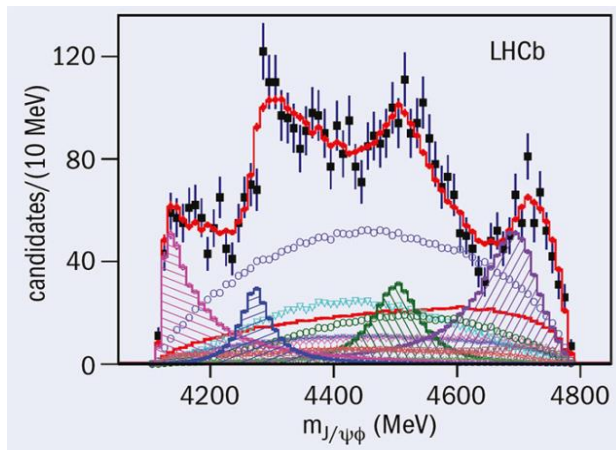
- Single arm forward spectrometer @ LHC
- $2 < \eta < 5$
- $10 < \theta < 300 / 250$ mrad



$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} d \\ s \\ b \end{bmatrix}.$$

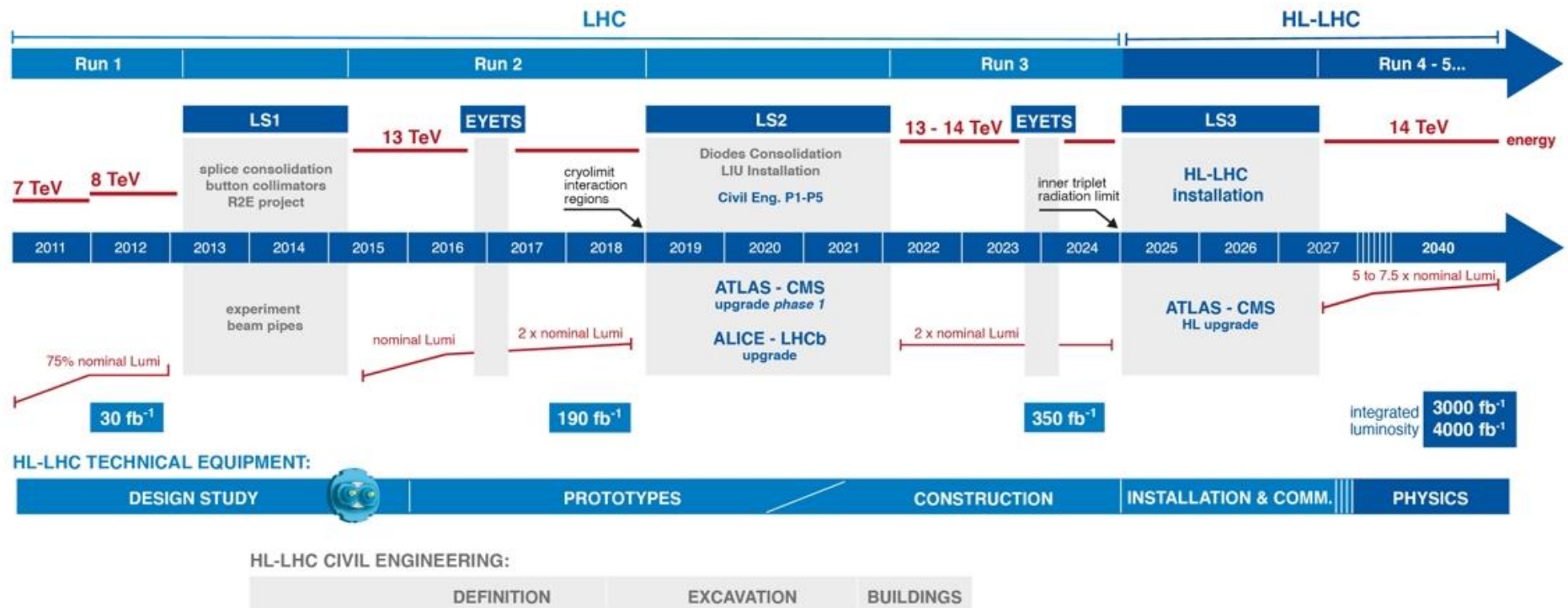


- LHCb studies flavour physics
- Focus on indirect searches for BSM physics
- Highlight: Discovery of Tetra- ($qq\bar{q}\bar{q}$) and Pentaquarks ($qqqq\bar{q}$)

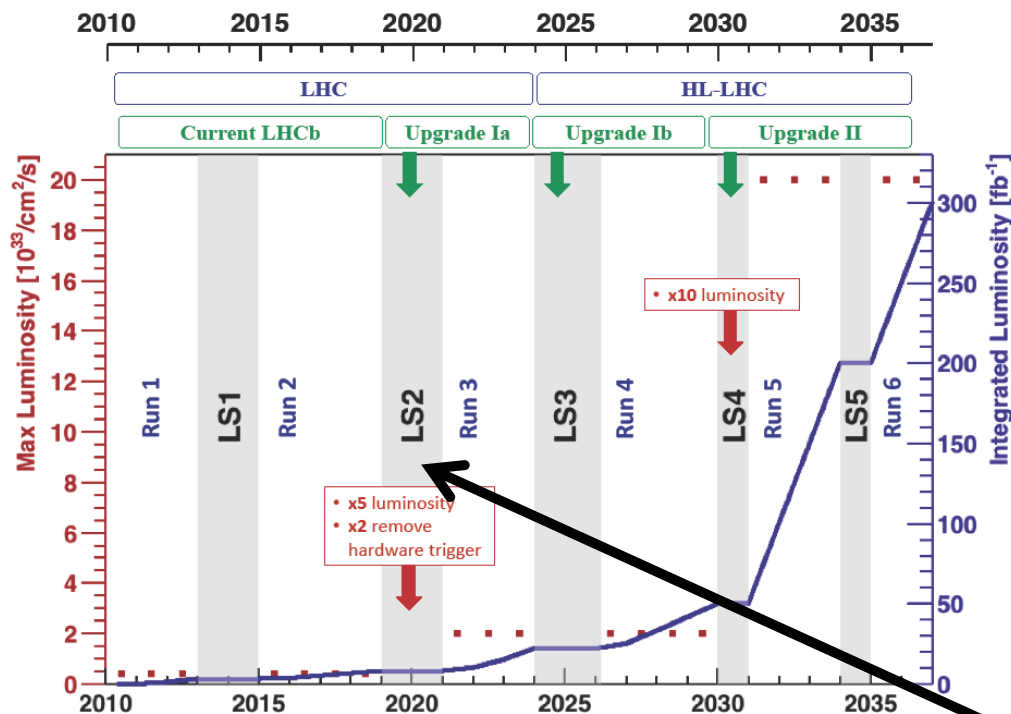




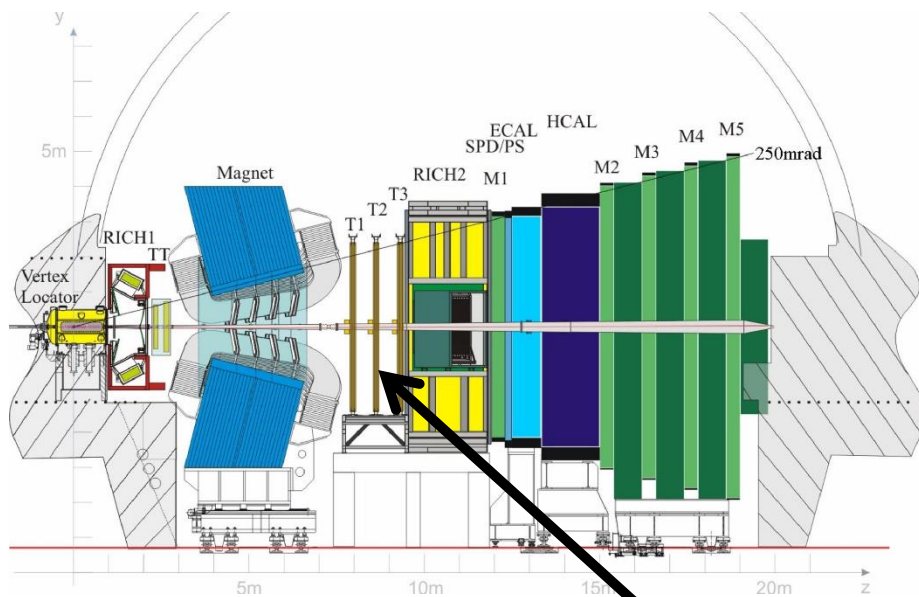
LHC / HL-LHC Plan



credit:HL-LHC working group



- Many detectors systems reached their end of life
- Increased rate and radiation tolerance required
- Switch to full software trigger
- We are here

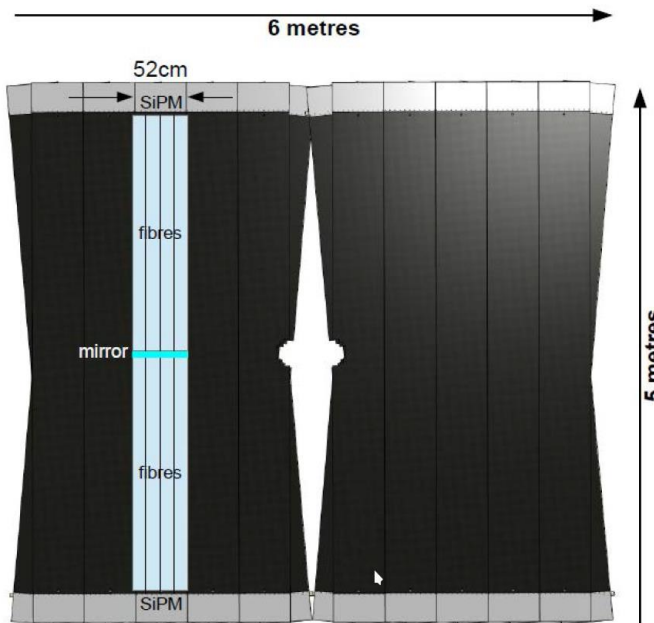


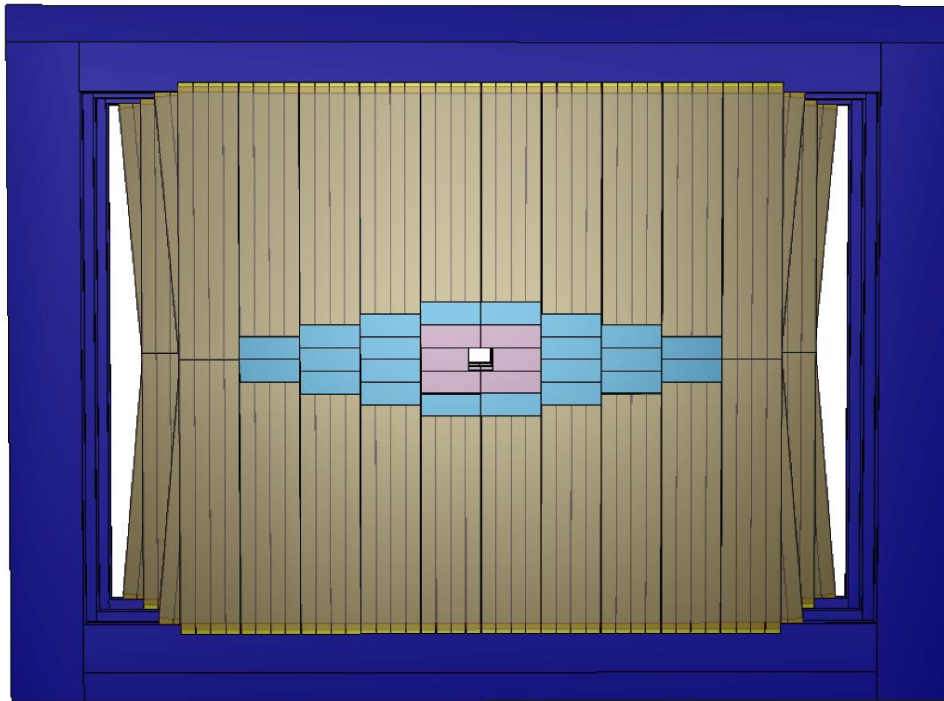
- Currently, the Inner and Outer Tracker is replaced by a scintillating Fibre Tracker (SciFi)

- However, the inner part of the SciFi will also have to be replaced next upgrade

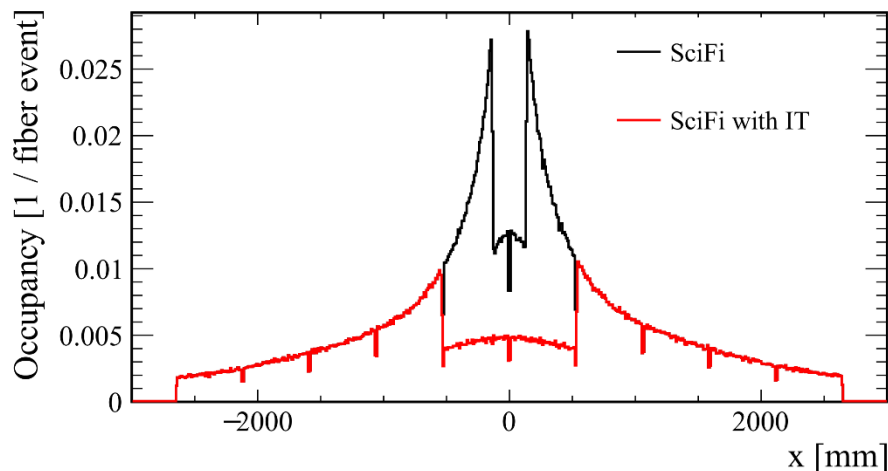
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X U V X

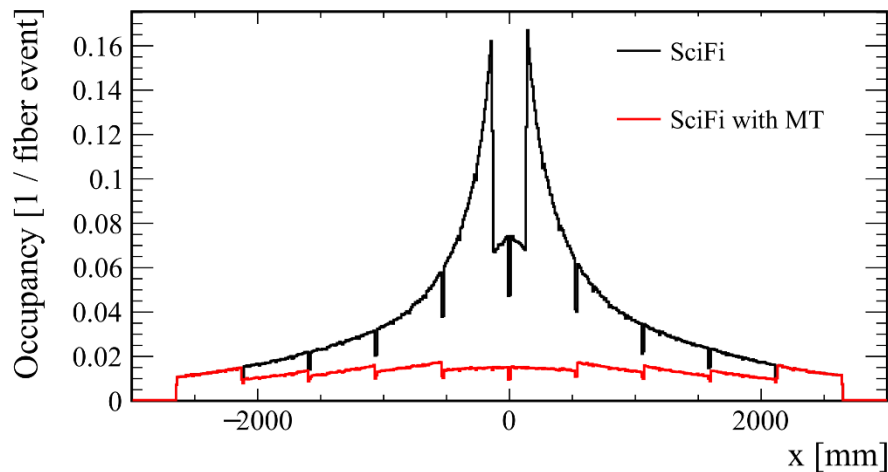




- Replace central part of the SciFi with thin pixel sensors
- Staged approach:
 - Innermost part (IT - pinkish) in Upgrade Ib
 - Full area (Middle Tracker (MT) - blue) in Upgrade II

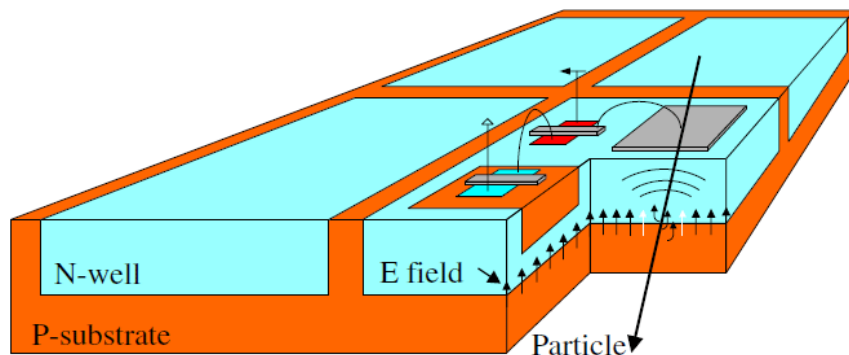


2e33



1.5e34

- Fibre only tracker would have a very high occupancy
 - High ghost rate
 - Lower tracking efficiency
 - Combinatorics flood the software trigger
- High radiation dose makes fibres go blind

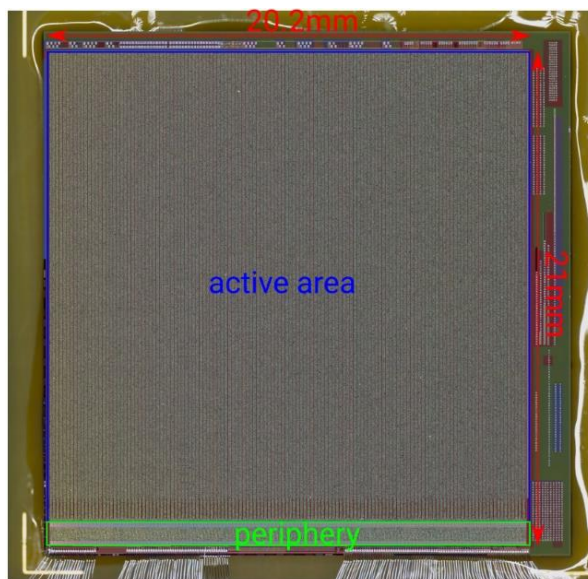


I.Peric, P. Fischer et al., NIM A 582 (2007) 87

- Deep n-well in p substrate
- Fast charge collection in reversed biased pn-junction as sensitive element
- Logic in n-well floating w.r.t substrate
- Analogue front-end in the pixel cell
- Digital logic in periphery
- Thinning below $100\mu\text{m}$
- Cheap commercial HV-CMOS process
- Radiation resistant

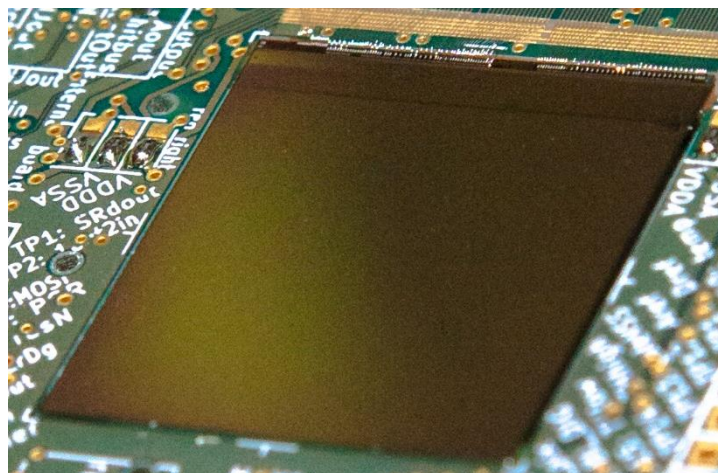
credit: MSc Thesis D. Kim

ATLASpix3



- Designed for proposed ATLAS iTK upgrade
- $150\mu\text{m} \times 50\mu\text{m}$ pixel size
- 132×372 pixel matrix
- $20.2\text{mm} \times 21\text{mm}$ total area
- Resubmitted as 3.1 with minor changes

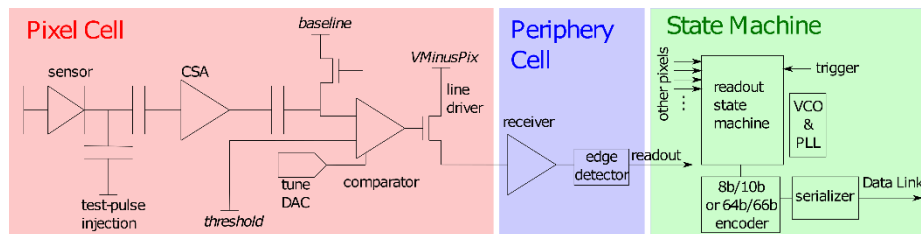
MuPix10



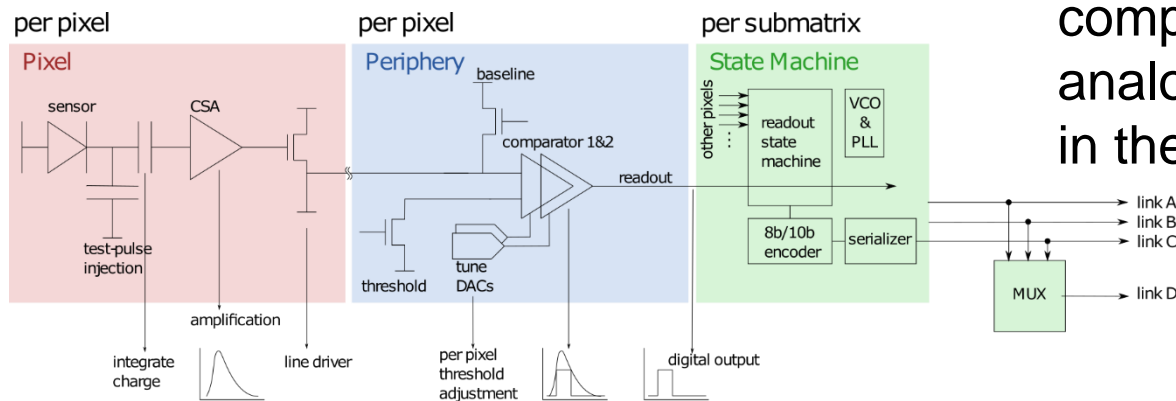
credit: <https://arxiv.org/abs/2012.05868>

- Full scale prototype for the Mu3e pixel tracker
- $80\mu\text{m} \times 80\mu\text{m}$ pixel size
- 256×250 pixel matrix
- $20.66\text{mm} \times 23.18\text{mm}$ total area

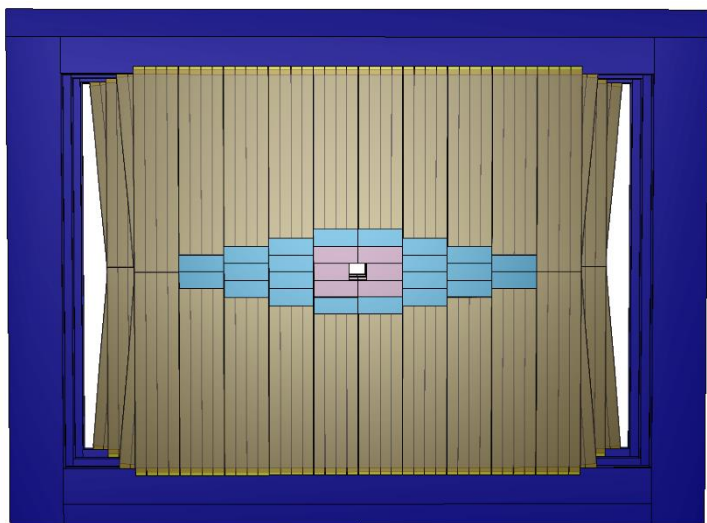
ATLASpix3



MuPix10



- Amplifier in the sensor diode
- Each analogue pixel has a corresponding digital periphery cell
- ATLASpix3 has comparator in the analogue pixel, MuPix10 in the periphery cell



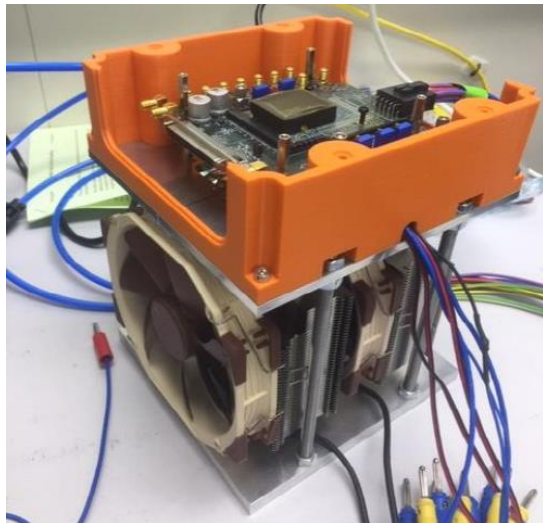
- >99% in-time efficiency per BX ($\approx 3-4$ ns Gaussian σ)
- $150 \times 50 \mu\text{m}^2$ or $300 \times 100 \mu\text{m}^2$ pixel size
- $100-150 \mu\text{m}$ thick
- $\sim 2 \times 2 \text{cm}^2$ area
- 6×10^{14} neq/cm² NIEL / 40 MRad TID
- <300 mW/cm² power consumption

So far achieved:

Sensor	Efficiency [%]	Time Resolution (Gaussian σ) [ns]
MuPix10	>99	8.1 ± 0.1
ATLASpix3.0	>99	4.1 ± 0.1

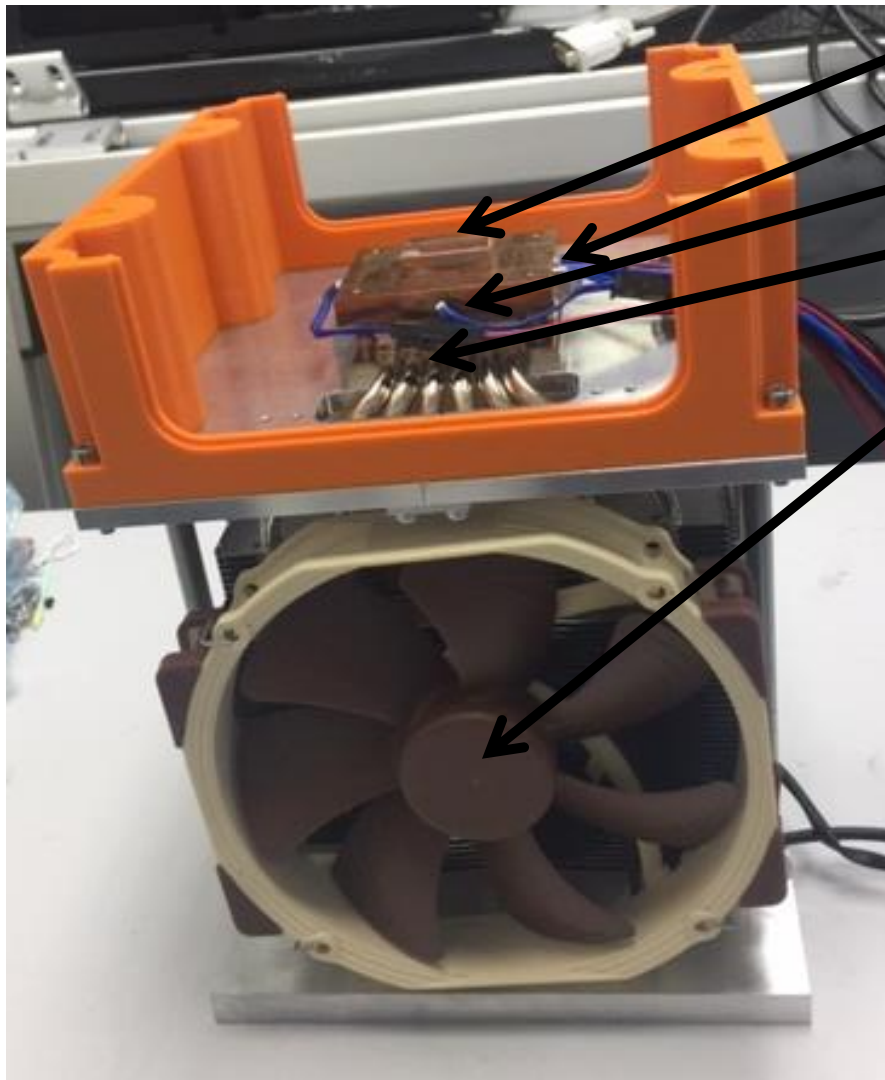
BSc Thesis F. Frauen

MSc Thesis D. Kim

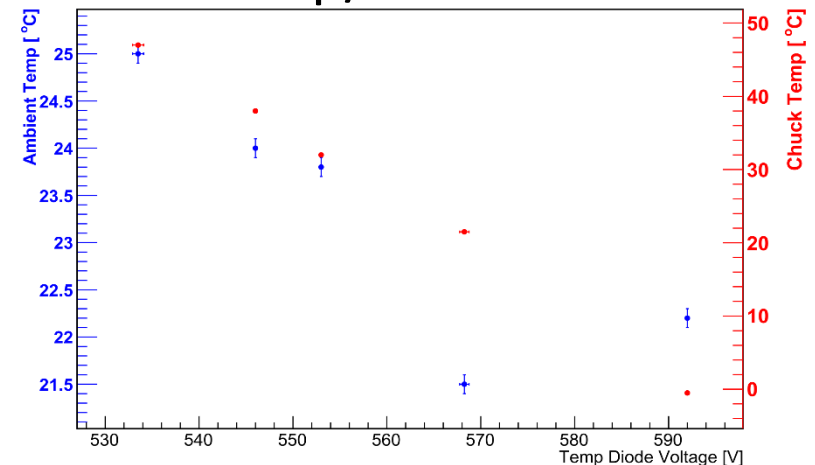


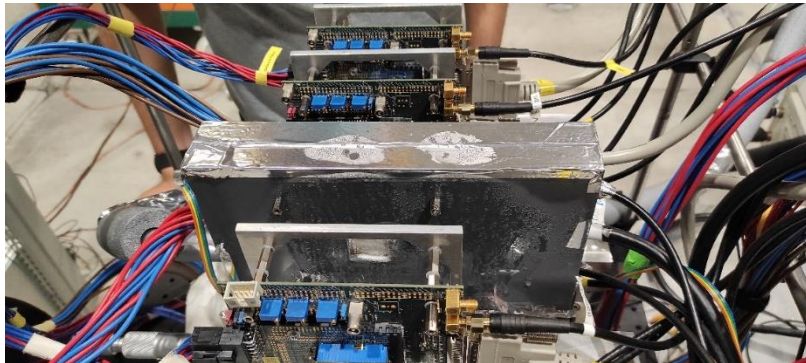
- Study efficiency, time resolution, power consumption, and temperature dependence
- Irradiation with neutrons at Ljubljana
- Lab setup in final stages of commissioning

Fluence [neq/cm ²]	MuPix10 – 100μm	MuPix10 – 625μm	ATLASpix 3.1 – 625μm
1e14	✓	✓	✓
3e14	✓	✓	✓
1e15	✓	✓	✓
3e15	✓	✓	✓
9e15	✓	✓	

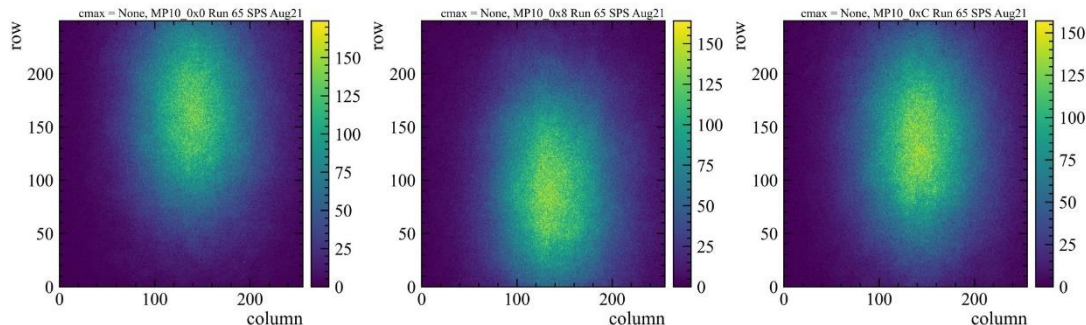
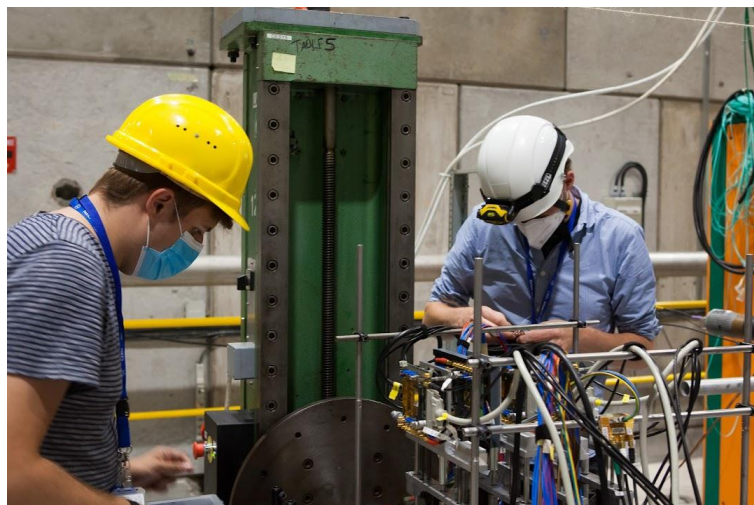


- Copper chuck
- Heater
- Temperature sensors
- Peltier element
- CPU cooler
- Humidity sensor
- Arduino controlled
- Temperature diode on chip/PCB

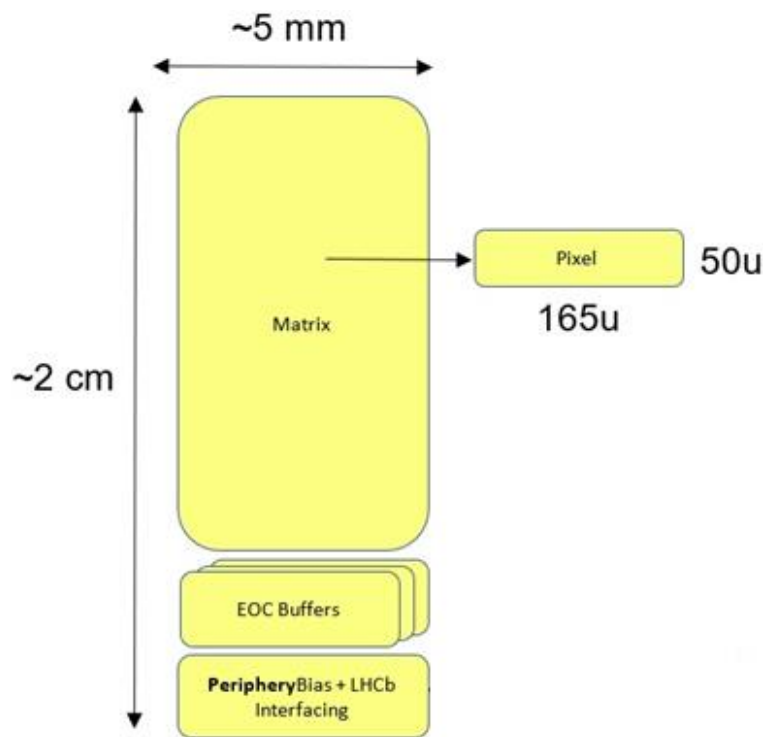




- Studied cooled unirradiated MuPix10
- Temperature dependence not studied yet
- Commissioning of testbeam cooling system
- Analysis ongoing

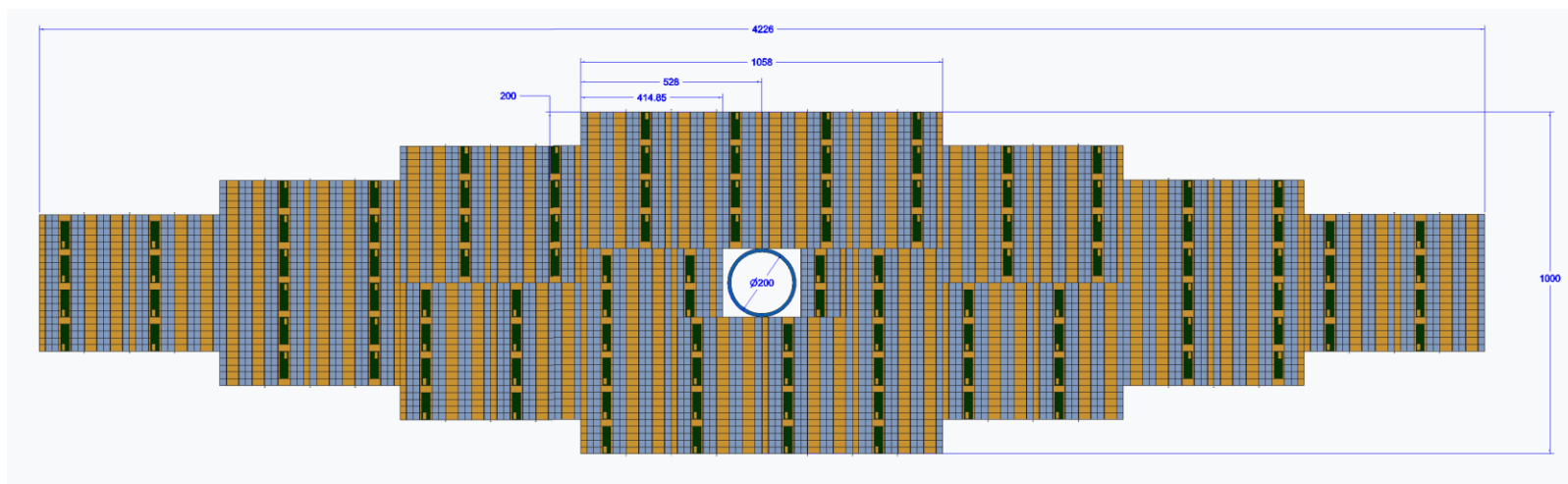


Credits: D. Kim, K. Padeken



- Full column length
- Analogue frontend based on ATLASp3
- LHCb compatible readout (lpGBT)
- Design and verification ongoing
- Submission planned for October 21

- MightyTracker proposed LHCb upgrade II for the HL-LHC
- Monolithic HV-CMOS sensors chosen as technology
- MightyTracker group new in developing HV-CMOS
- Characterising existing prototypes while designing our own
- Measurements with irradiated samples coming soon™
- Focus on temperature studies – few studies for HV-CMOS so far
- MightyPix1 to be fully IpGBT compatible and submitted soon™





Backup



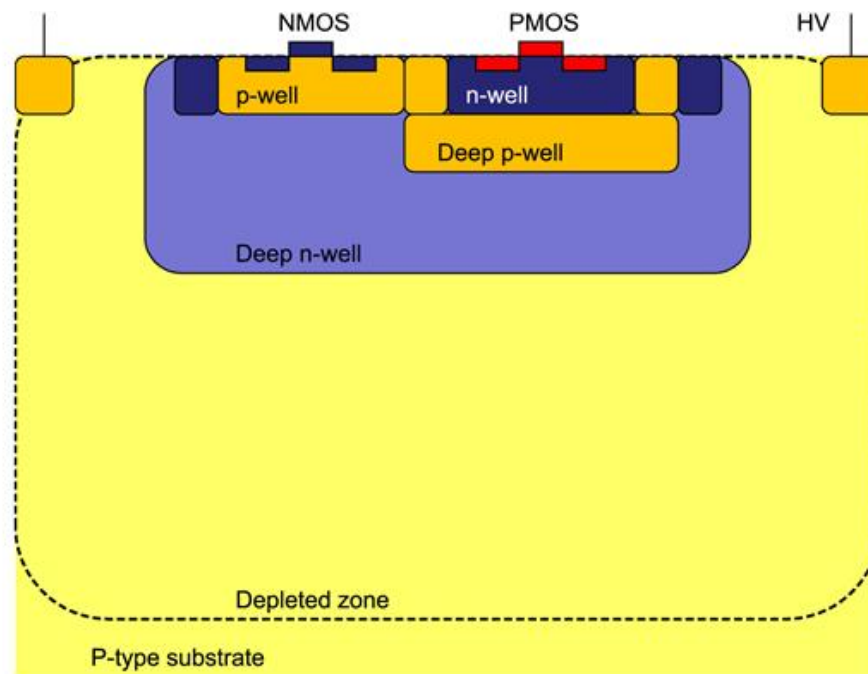
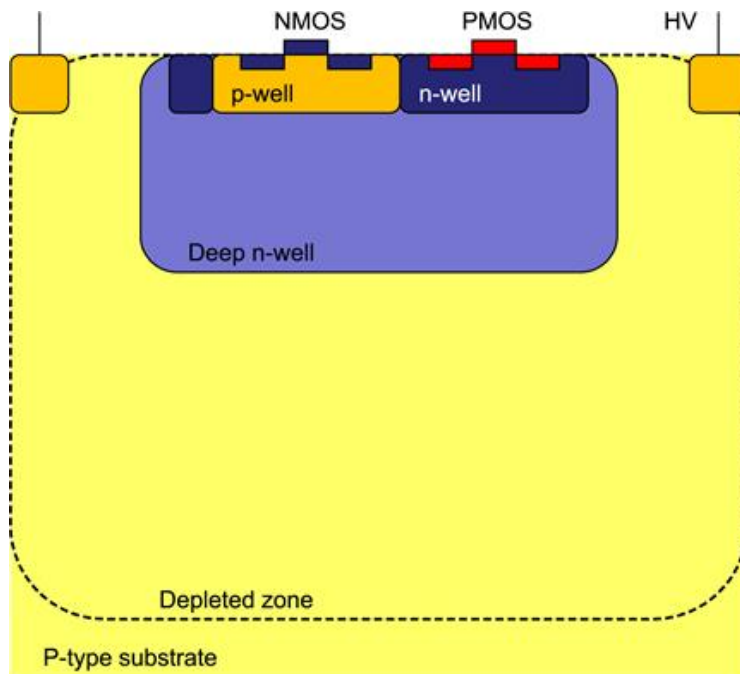
Summary of Efficiencies after Irradiation

- no tuning of pixels; $\leq 81/10000$ pixel masked

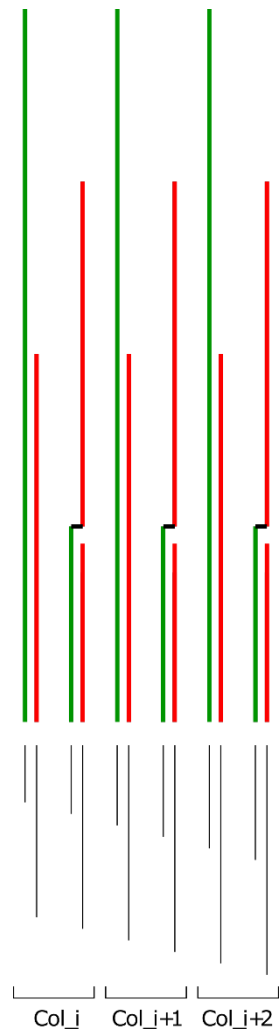
Efficiency _{40 Hz}	sub- strate	thick- ness	bias voltage (#masked pixel)			
			60 V	70/75 V	80/85 V	90/95 V
fluence (neq/cm ²)	(Ω cm)	(μ m)				
n 2e15	80	62	98.5% (81)	98.4% (81)	98.6% (81)	
n 1e15	80	62	99.3% (38)		99.5% (38)	99.5% (39)
n 5e14	80	62	99.5% (19)			
n 2e15	200	100	96.5% (55)		98.7% (60)	98.7% (55)
n 1e15	200	100/725	98.7% (18)	99.4%	99.5%	99.4%
n 5e14	200	100	99.2% (14)			
p 5e14 (50 MRad)	200	100	$\geq 99.6\%$ (9)	$\geq 99.7\%$ (9)	$\geq 99.9\%$ (9)	
p 1e14 (10 MRad biased)	200	725	$\geq 99.7\%$			

\geq means that the 40 Hz/pixel noise limit was not reached

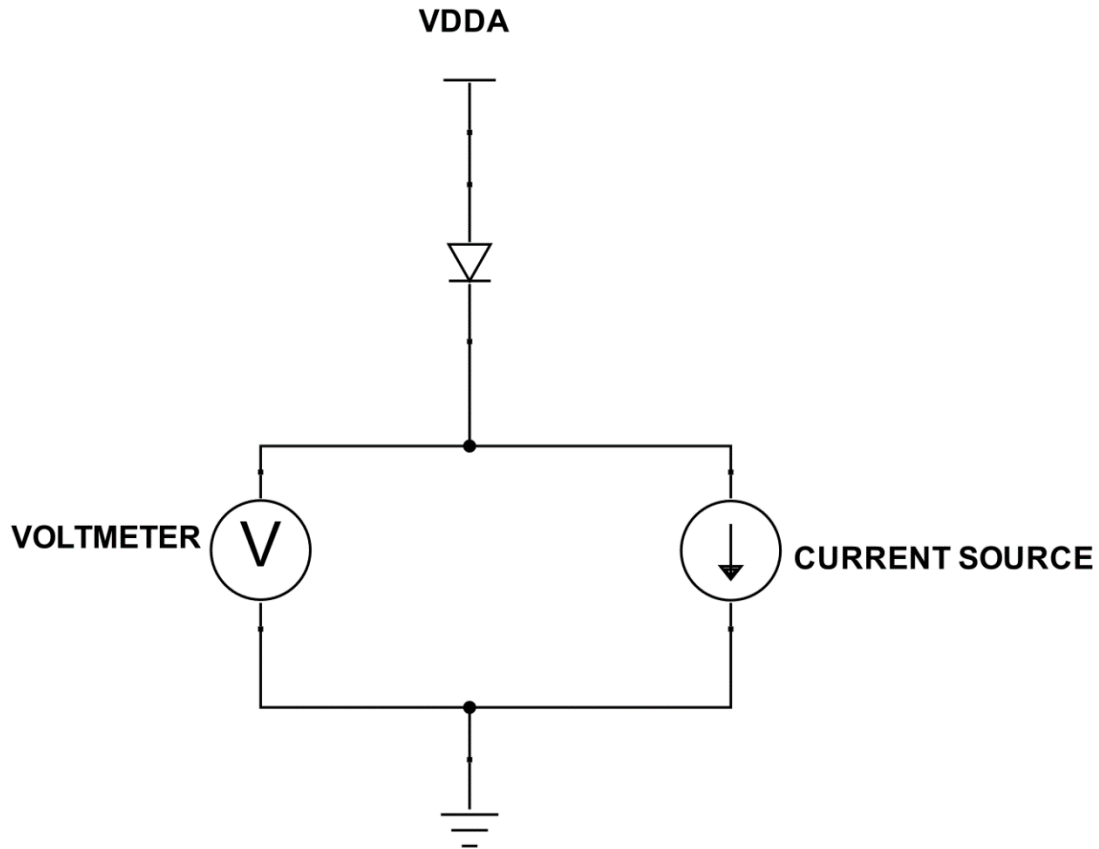
credit:A. Herkert

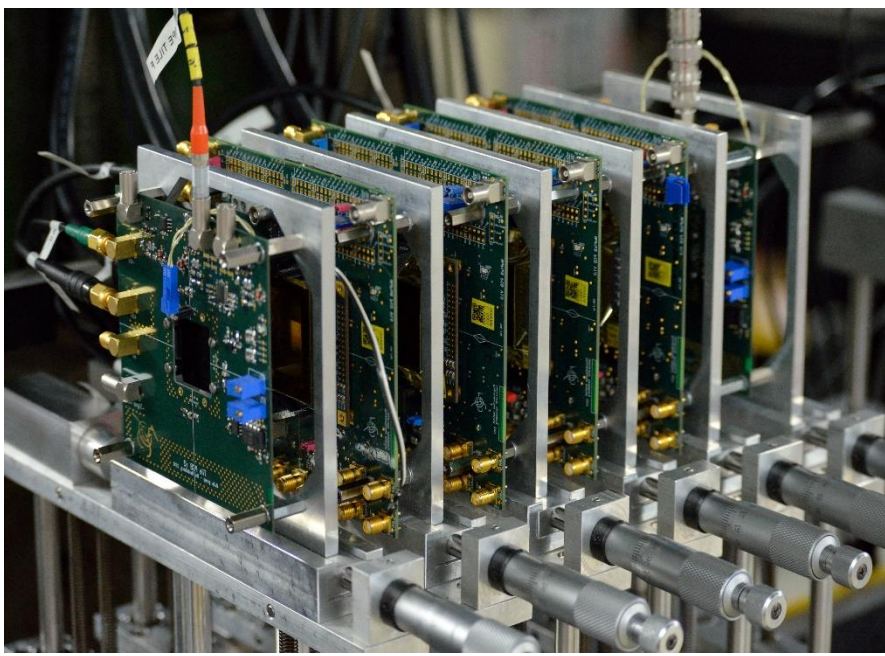
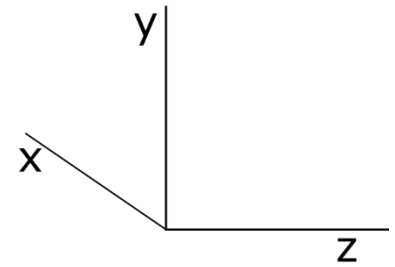
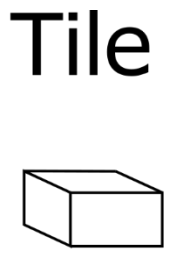
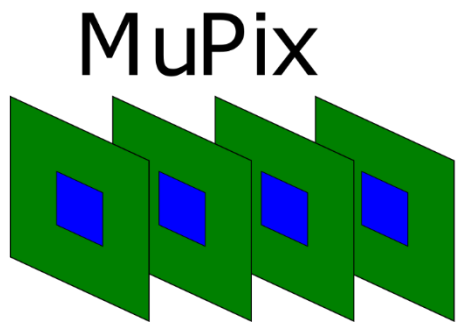
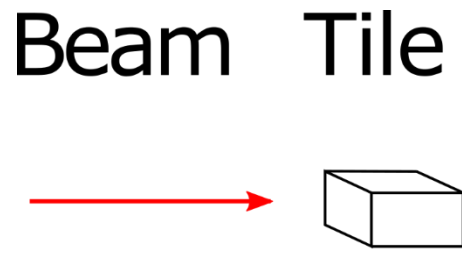


credit: <https://doi.org/10.1016/j.nima.2018.06.060>



credit: H. Augustin





credit: L. Huth