Studies of irradiated ATLASpix3.1 sensors for the LHCb MightyTracker

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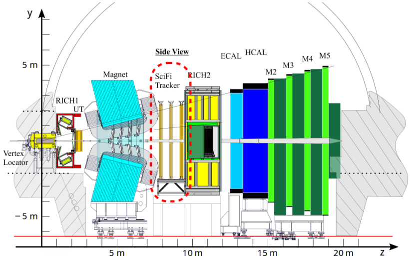
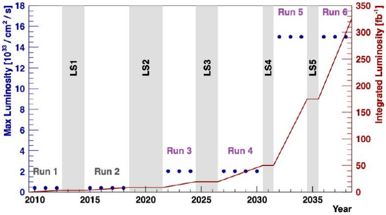
Introduction

- LHCb luminosity will be increased to $1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ for Run 5

$\rightarrow$ Upgrades for the detector systems are required

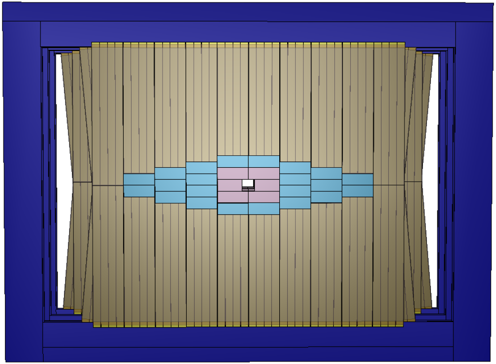
- Scintillating Fibre Tracker (SciFi) can't cope with the luminosity
- Occupancy too high for tracking
- Radiation damage destroys the fibres





Mighty Tracker

- Proposal: replace innermost part of the fibres with silicon
- Pinkish area for Run 4 and blue area for Run 5
- Technology:
  HV-CMOS MAPS
  - Cheap and can be very thin
  - Shown suitable radiation hardness
- Dedicated MightyPix sensor R&D
- First version submitted last week



Requirements:

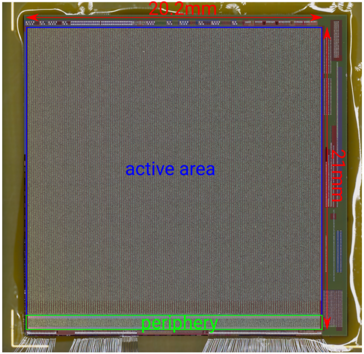
- Rad hard up to $\gtrsim 1 \times 10^{15} \mathrm{n_{eq}/cm^2}$
- In-time efficiency $> 99\%$

ATLASpix3.1

- Full reticle demonstrator for ATLAS ITk in TSI 180 nm HV-CMOS
- 20.2 mm × 21 mm
- 132 × 372 pixel with 150 µm × 50 µm
- Similar analogue front-end architecture as MightyPix

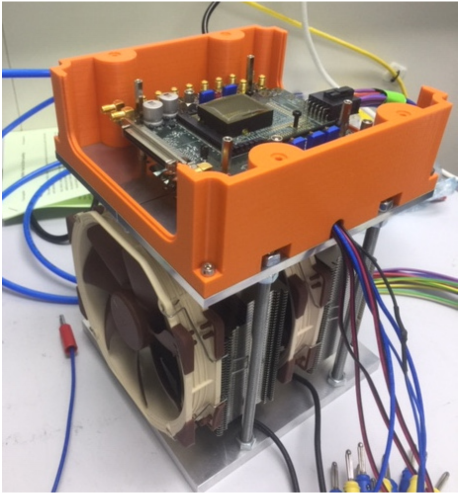
→ Use existing prototype to get an idea for performance, power, and cooling requirements

- Irradiated up to $3 \times 10^{15} n_{eq}/cm^2$



Setup @ University of Liverpool

- Cooling setup developed @ UoL
- Cooling of the backside of the sensor with a Peltier to $-30\,^{\circ}\mathrm{C}$
- Flushed with dry nitrogen
- Temperature and humidity measurement with Arduinos



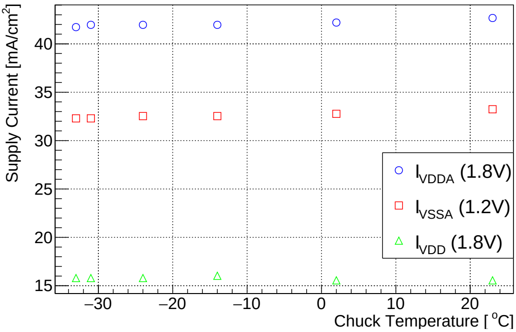
Power

- Important for powering and cooling scheme
- Normalised to total chip surface
- No significant effects observed

→ No major shift in performance expected

- Higher irradiated sensors require more power due to shifts in working points

$0n_{eq}/cm^2$



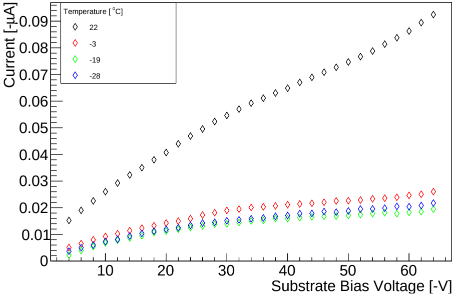
IVs

- Large leakage current induces more noise

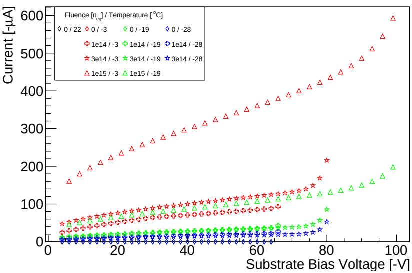
→ Keep leakage as low as possible with reasonable cooling

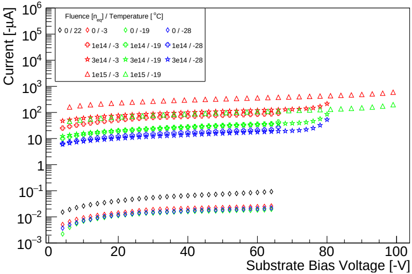
- Breakdown at −65 V
- Reduction below −19 °C small

$0 n_{eq}/cm^2$



IVs II

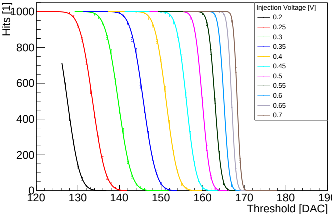


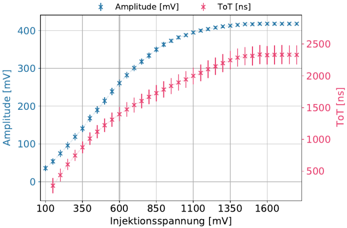


- Expected large current increase (expected)
- Increase in breakdown voltage with fluence (also expected)
- Reduction below $-19\,^{\circ}$C small

Analogue Performance

- Find linear region to characterise temperature dependence
- Inject signals and count the number of observed hits at different Thresholds
- Saturation effects clearly visible (MIP $\gtrsim$ 0.8 V)
- AP3.1 seems to saturate much earlier than AP3.0
- Expected as signals are larger due to reduced detector capacitance

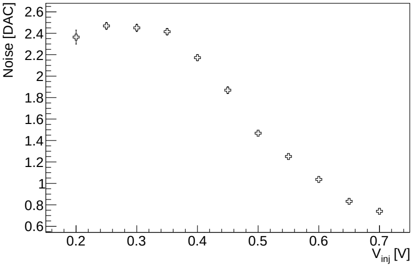




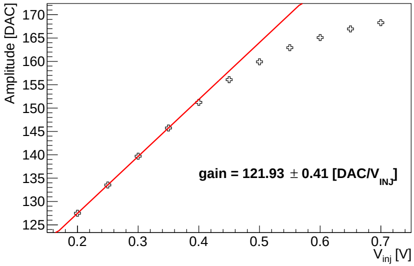
credit: BA thesis Lukas Mandok (Uni Heidelberg)

Noise and Gain

Noise



Amplitude



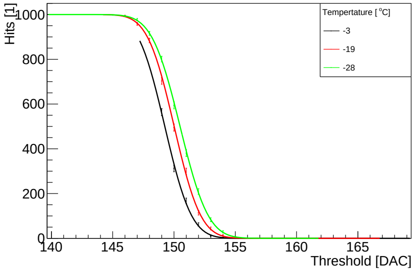
- S-curve described by $N(thr) = \frac{N_{Inj}}{2}(1 - erf(\frac{thr-\mu}{\sqrt{2}\sigma}))$
- μ = amplitude, σ = noise
- Saturation also damps the noise
- Already starts below 0.4 V
- Fitted gain for the linear region

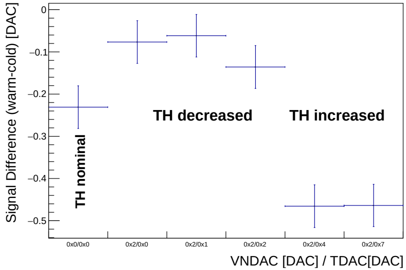
Temperature Dependence

- Signal seems increase with temperature
- Trimming (individual pixel threshold adjustment) is implemented differential

→ Always offset present

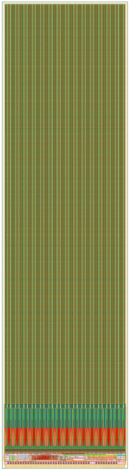
- Which part of the front end shifts how?
- Shift in gain also seen in effect of trimming





MightyPix Plans

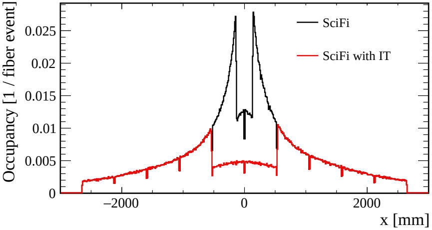
- Continue ATLASpix3.1 irradiation studies
  - Time Resolution
  - Efficiency
  - Optimising settings
  - Characterise sensors with high fluence
- DESY testbeam in June 2022 with ATLASpix3.1
- MightyPix1 measurements once it's delivered



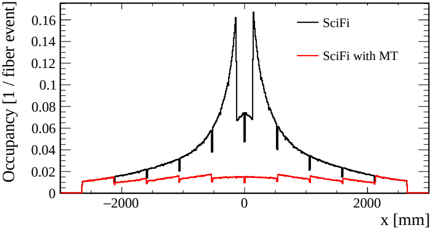
BACKUP

SciFi Occupancy

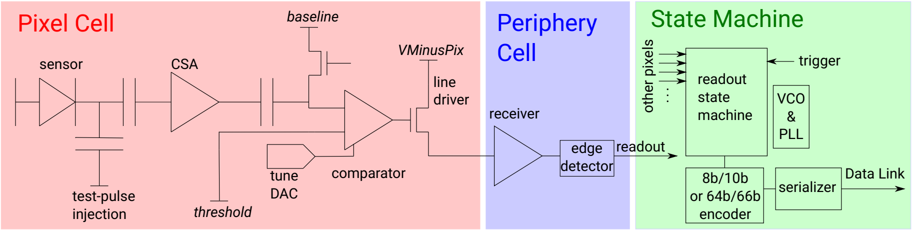
$2 \times 10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$



$1.5 \times 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$



AP3 Readout


Pixel Cell
sensor
CSA
baseline
VMinusPix
line
driver
test-pulse
injection
threshold
tune
DAC
comparator
Periphery
Cell
receiver
edge
detector
readout
State Machine
other pixels
readout
state
machine
trigger
VCO
&
PLL
8b/10b
or 64b/66b
encoder
serializer
Data Link

AP1 Irradiation

Summary of Efficiencies after Irradiation

- no tuning of pixels; ≤ 81/10000 pixel masked

Efficiency$_{40\ Hz}$	sub-strate	thick-ness	bias voltage (#masked pixel)			
fluence (neq/cm^2)	(Ω cm)	(µm)	60 V	70/75 V	80/85 V	90/95 V
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	≥ 99.6% (9)	≥ 99.7% (9)	≥ 99.9% (9)	
p 1e14 (10 MRad biased)	200	725	≥ 99.7%			

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

credit: PhD. Thesis A. Herkert (Uni Heidelberg)