

Characterization of a large area hybrid pixel detector of Timepix3 technology for space applications

Research and Development of novel instrumentation for particle measurements in space

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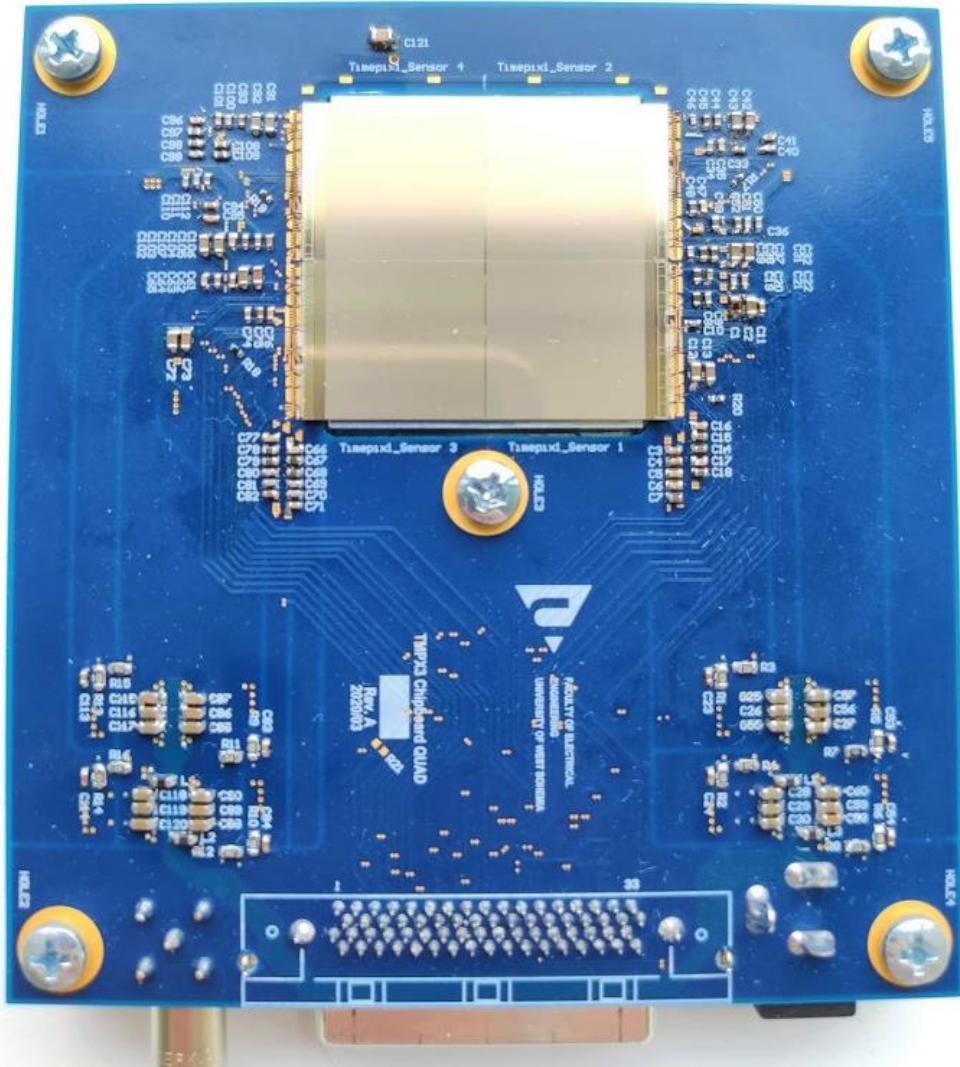
Timepix3 Quad

Timepix 3

- 256x256 pixel matrix ($\sim 2\text{cm}^2$), pixel pitch $55\mu\text{m}$
- 1.56ns time resolution
- Typical nominal power consumption $\sim 1.3\text{W}$
- Readout modes:
 - Frame-based (max ~ 1300 fps)
 - Data-driven ($\sim 40\text{Mhits/s}$), deadtime 475ns
- Simultaneous time of arrival (ToA) and time over threshold (ToT) measurement in each pixel.

Timepix 3 Quad

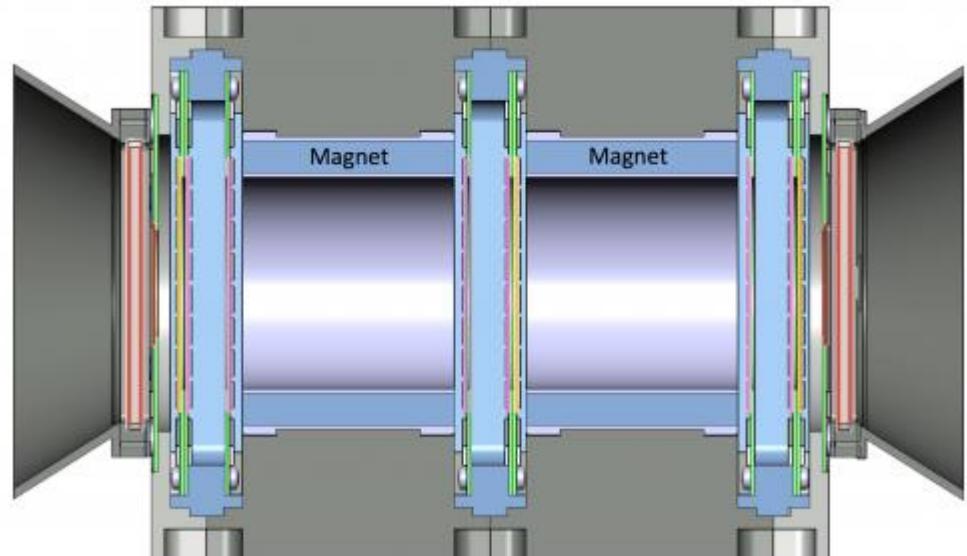
- 2x2 Timepix3 grid, (Si- $300\mu\text{m}$)
- Typical nominal power consumption $\sim 6\text{W}$
- Chips are glued to aluminium heat sink/support



Motivation

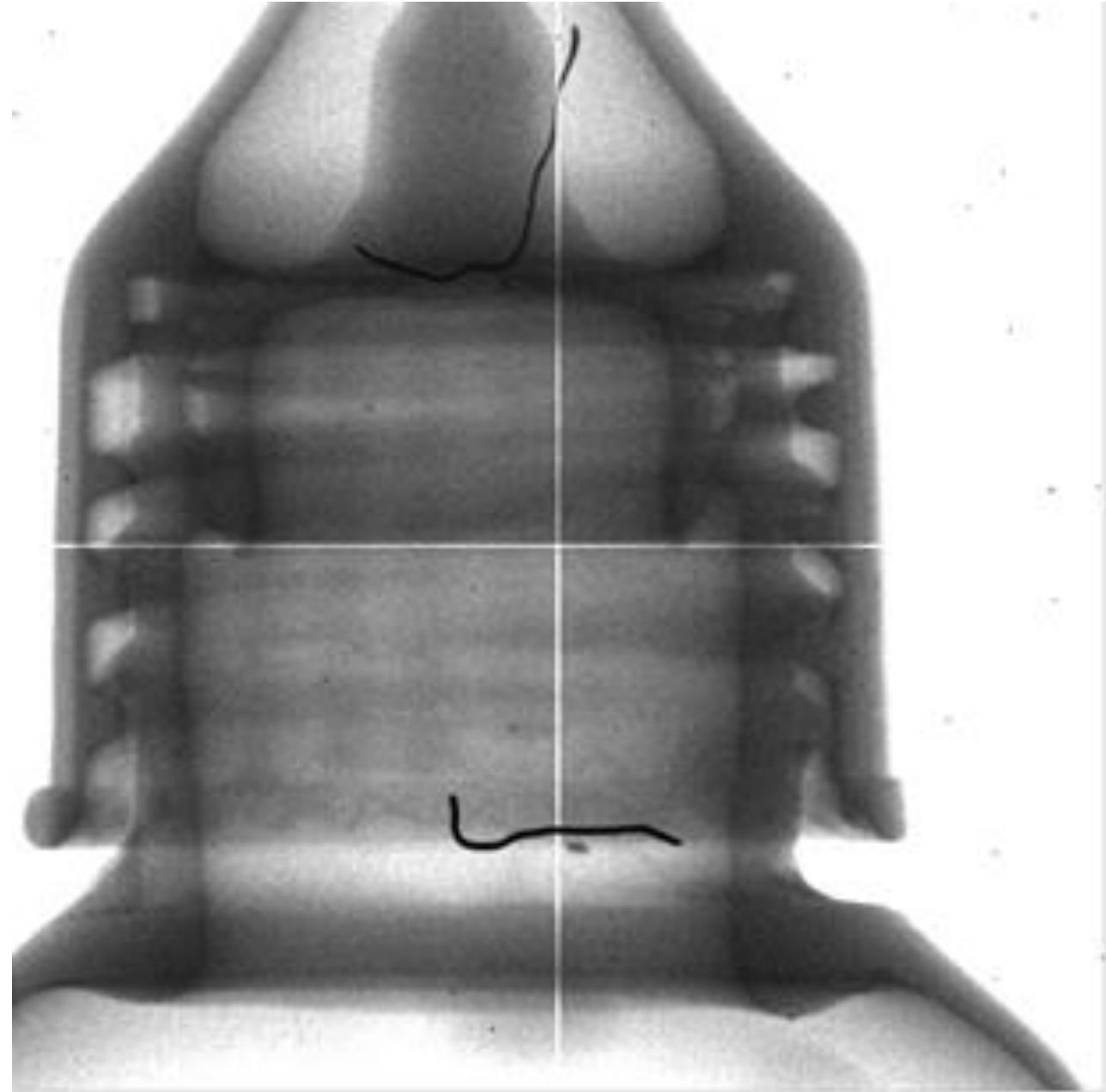
- PAN - Pixel Module (two Timepix3 Quads)
- First non-single chip Timepix3 for space
 - Effect of internal parameters
 - Stability of detector at different configurations
 - Effect of temperature on different types of parameter configurations

Mini.PAN active detection elements: **TOF**, **PIXEL**, **Strip-X**, **Strip-Y**



Penetrating Particle Analyzer

Timepix3 Quad X-ray imaging test



Timepix3 Quad Space challenges

- Limited power
 - Low power modes based on available power
- Limited downlink bandwidth
 - Onboard pre-processing capabilities and/or LP modes
- Wide range of temperatures
 - Effect of temperature on detector -> Compensation methods
 - Proper cooling
- Lightweight
- Launch conditions

Timepix3 Low power modes

P. Burian *et al* 2019 JINST **14** C01001

Motivation:

- Limited resources in space
- Lower power consumption
- Resources are not constant!

DAC	Low power	Standard settings
Ibias_Preamp_ON	8 (1.294V)	128 (1.157V)
Ibias_DiscS1_ON	8 (1.246V)	100 (1.059V)
Ibias_DiscS2_ON	8 (0.182V)	128 (0.333V)
Ibias_PixelDAC	20 (1.066V)	128 (0.942V)

Detector Low power modes

- Analog part
 - reduce the consumption by tuning the DAC settings
- Digital part
 - reduce the consumption by lowering matrix clock

Low power modes

Analog LP

- Internal DAC setting
- Nominal consumption ~800mW/chip
- LP consumption ~55mW/chip

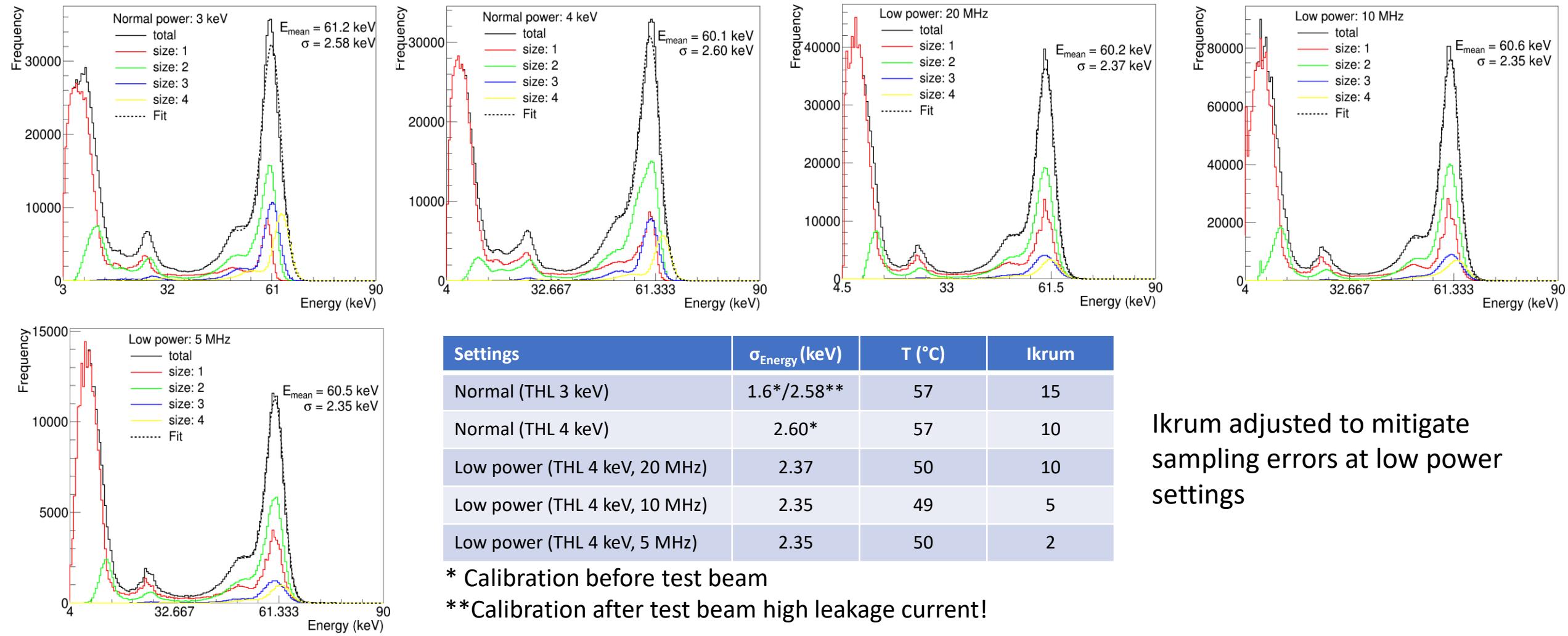
Digital LP

- System clock and **Reference clock**
- Bypass of PLL
- Nominal consumption ~600mW/chip
- 5MHz LP ~150mW/chip

Settings	Consumption (W)	Board Consumption (W)
Normal mode	6	6
Low power Analog	2.9	2.9
Low power 20 MHz	1.7*	2.2
Low power 10 MHz	1.5*	2.1
Low power 5 MHz	1.2*	2

* 4xTimepix chip. Quad value is different due to losses on voltage regulators in digital LP modes

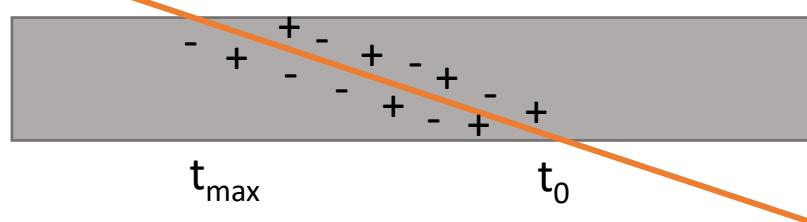
Energy Calibration – verification on ^{241}Am



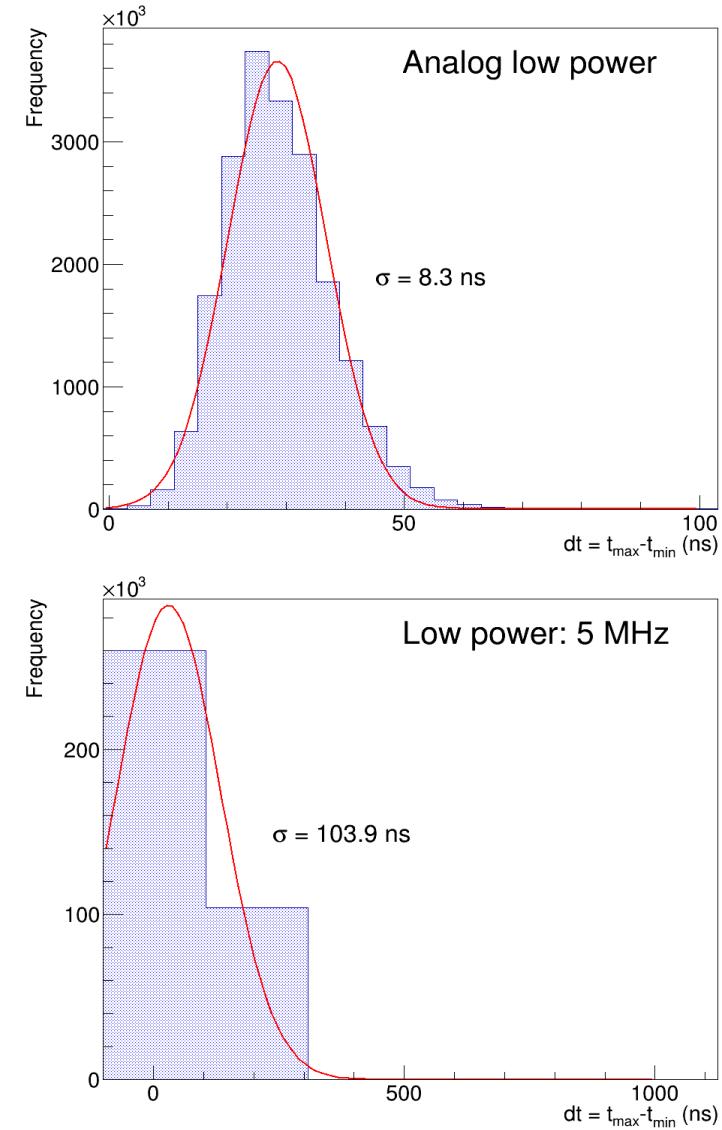
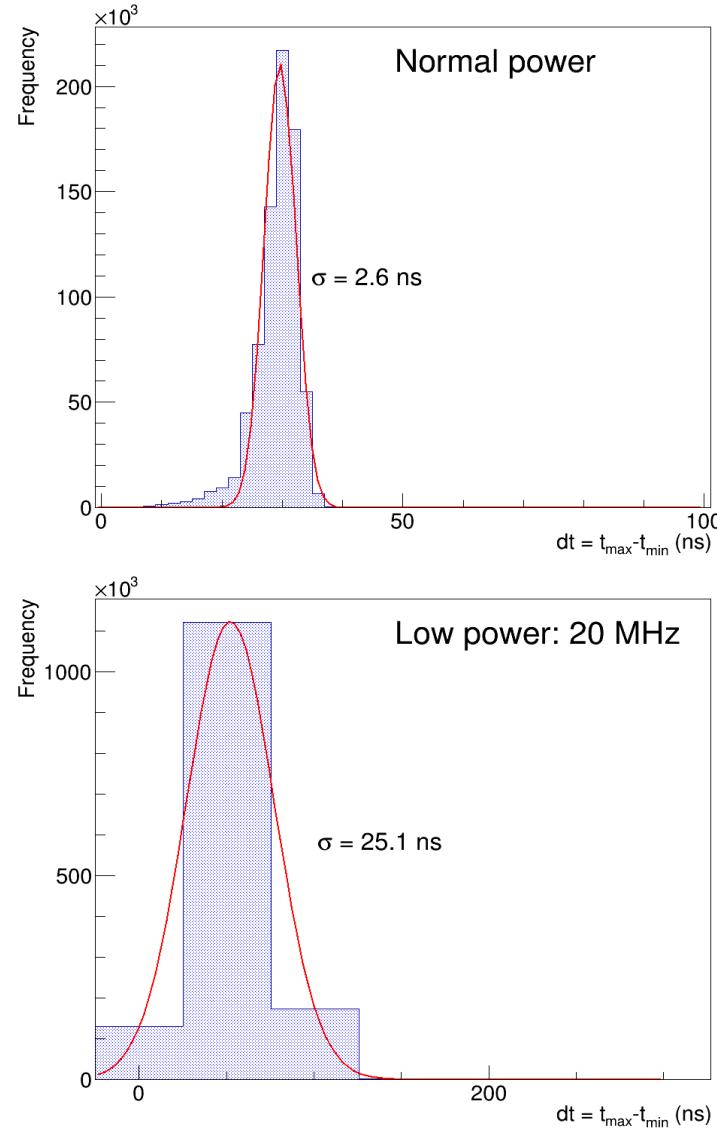
$$\sigma_{meas} = \sigma_{fit}/\sqrt{2}$$

Time resolution

Proton 240 MeV measurement at 70 degrees



Settings	$f_{sampling}$ (MHz)	σ_{meas} (ns)
Normal	640 (1.56 ns)	1.8
Analog low power	640 (1.56 ns)	5.9
Low power	20 (50 ns)	17.7
Low power	10 (100 ns)	28.1
Low power	5 (200 ns)	73.5



Measurements

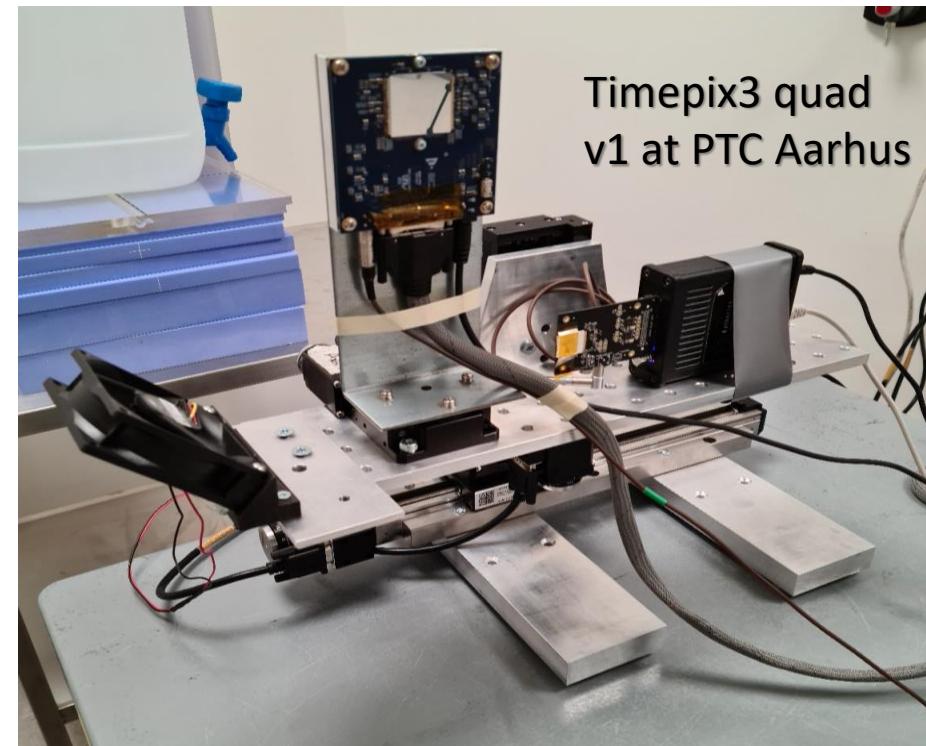
120 GeV pions at SPS

- Comparison of normal and analog low power mode (changed DACs) at different angles



Aarhus PTC – protons 80 MeV

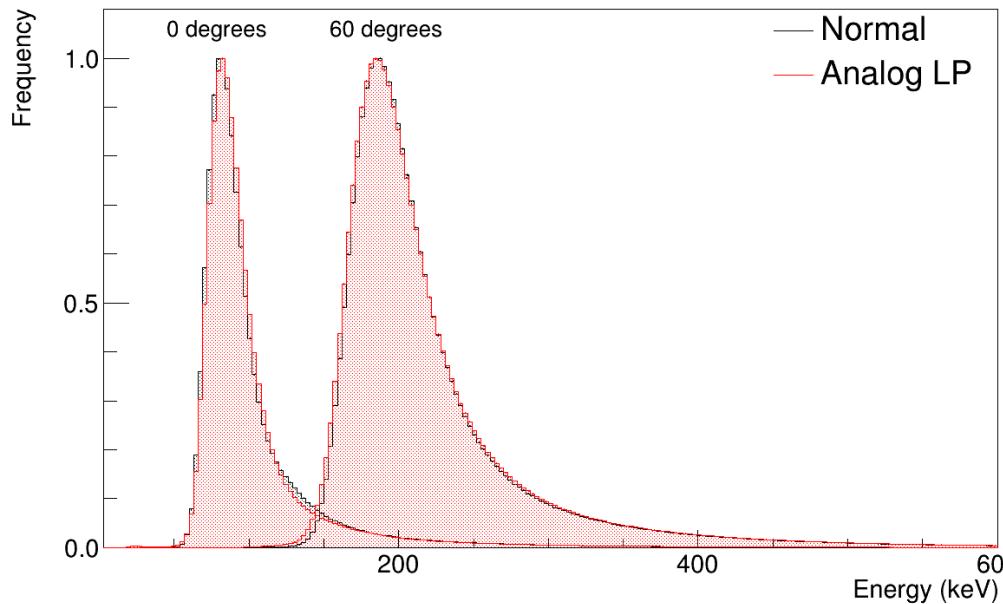
- Study of different low power schemes achieved by using different clock
- Comparison at different angles



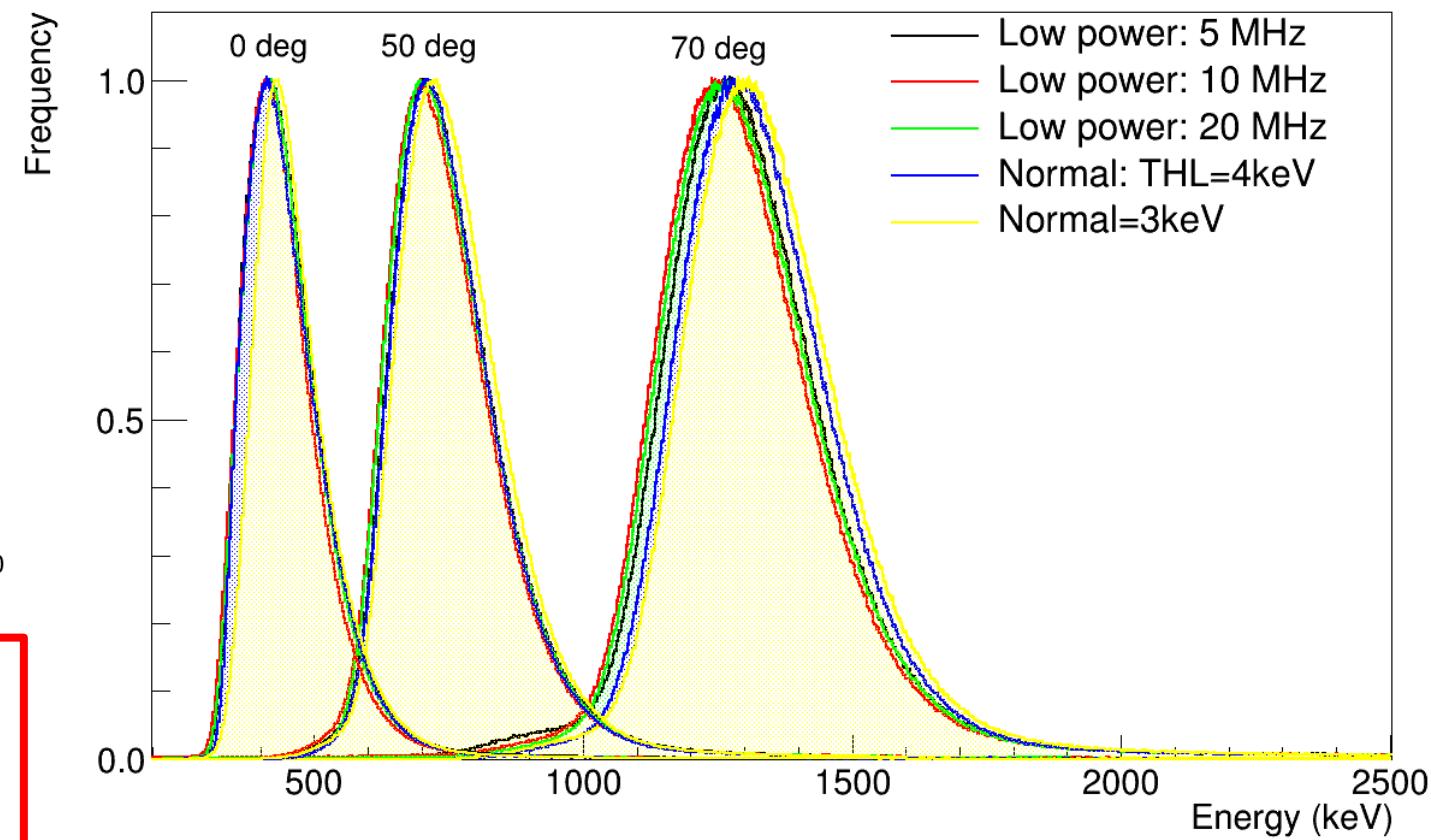
Energy response

DAC	Low power	Standard settings
Ibias_Preamp_ON	8(1.294V)	128(1.157V)
Ibias_DiscS1_ON	8(1.246V)	100(1.059V)
Ibias_DiscS2_ON	8(0.182V)	128(0.333V)
Ibias_PixelDAC	20(1.066V)	128(0.942V)

120 GeV/c pions - SPS CERN



Protons - 80 MeV - PTC Aarhus



From a spectroscopic point of view **no difference** in the HP and analog Low Power modes
→ Sampling frequency changes are successfully mitigated by adjustment of Ikrum (pulse length)

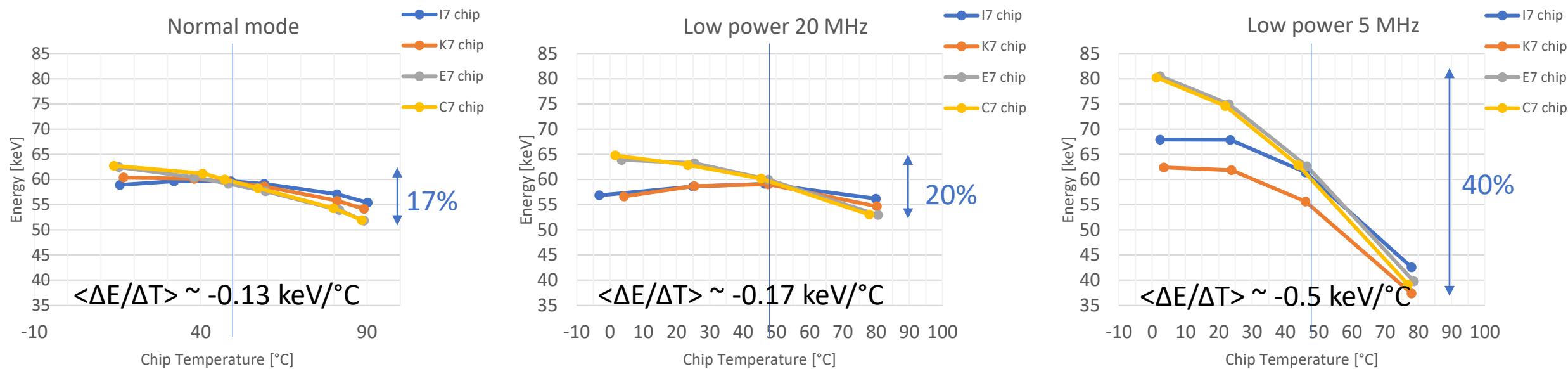
Thermal Tests

- Climate chamber range -20°C - +50°C
- ^{241}Am source 300kBq
- Detector calibrated with chip temp at +50°C ($\pm 1^\circ\text{C}$)
- Measured parameters
 - Temperature of **chip** and heatsink
 - Energy spectrum mean and sigma of our source
 - Internal DACs of Timepix3 chips
 - Stability of detector



Energy measurement dependence on temperature

Test chamber temperature range -20° -- 50°C (chip temperature 0° - 80°C)



- Temperature dependence varies with DAC settings and clock frequency used
- Measurements at digital low power mode show a stronger dependency on chip temperature and larger variation amongst the chips
 - Compensation for different temperatures is needed (Calibrations,...)

Conclusions

Detector is stable in whole temperature range for Normal mode and LP modes

Functionality of detector was tested on multiple beams

Dynamic changes of modes are possible based on needs of the mission

Settings	Consumption (W) Quad / chip	σ_E (keV)	$\langle dE/dT \rangle$ (keV/°C)	t_{pulse} (μs) ⁽³⁾	t_{dead} (μs) ⁽⁴⁾	σ_t (ns)
Normal (THL 3 keV)	6 / 1.5	1.6⁽¹⁾/2.58⁽²⁾	-0.13	5.0	0.45	1.8
Low power (THL 4 keV, 40 MHz)	2.9 / 0.73	1.7⁽²⁾	-0.17	8.0	0.45	5.9
Low power (THL 4 keV, 20 MHz)	1.7 / 0.43	2.37	-0.17	8.0	0.95	18
Low power (THL 4 keV, 10 MHz)	1.5 / 0.38	2.35	-	15.5	1.90	28
Low power (THL 4 keV, 5 MHz)	1.2 / 0.3	2.35	-0.5	30.0	3.80	74

⁽¹⁾ Calibration before test beam

⁽³⁾ Extracted from the 80 MeV proton measurement

⁽²⁾ Calibration after test beam high leakage current!

⁽⁴⁾ Calculated as 19 x clock period

Thank you for your attention!

Backup

Per-pixel energy calibration

Threshold at which noise
free operation was possible:
THL_{low} 2.75keV

