TIMEPIX3

First measurements and characterization of a hybrid pixel detector working in event driven mode

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iWoRID 2014 – Trieste, Italy

OUTLINE

- Introduction to Timepix3
- Measurement setup
- Noise measurements
- Threshold spread
- Count rate performance
- Energy calibration in Photon Counting mode
  - Energy resolution
  - Threshold and gain dispersion
- Energy calibration in Time over Threshold mode
  - Energy resolution
  - Gain dispersion
- Time walk correction
- Time and energy measurements of cosmic particles
- 3d track reconstruction using depth of interaction information

SPECIFICATIONS

	Timepix3
Pixel matrix	256 x 256
Pixel size	55 x 55 μm^2
Technology	CMOS 130 nm
Measurement modes	• Simultaneous 10 bit TOT and 18 bit TOA • 18 bit TOA only • 10 bit PC and 14 bit integral TOT
Readout type	• Data driven • Frame based (both modes with zero suppression)
Dead time	>475 ns (pulse processing + packet transfer)
Maximum count rate	85.3 Mhits / s
Minimum time resolution	1.56 ns
Power pulsing	Yes
Minimum threshold	~500 e-

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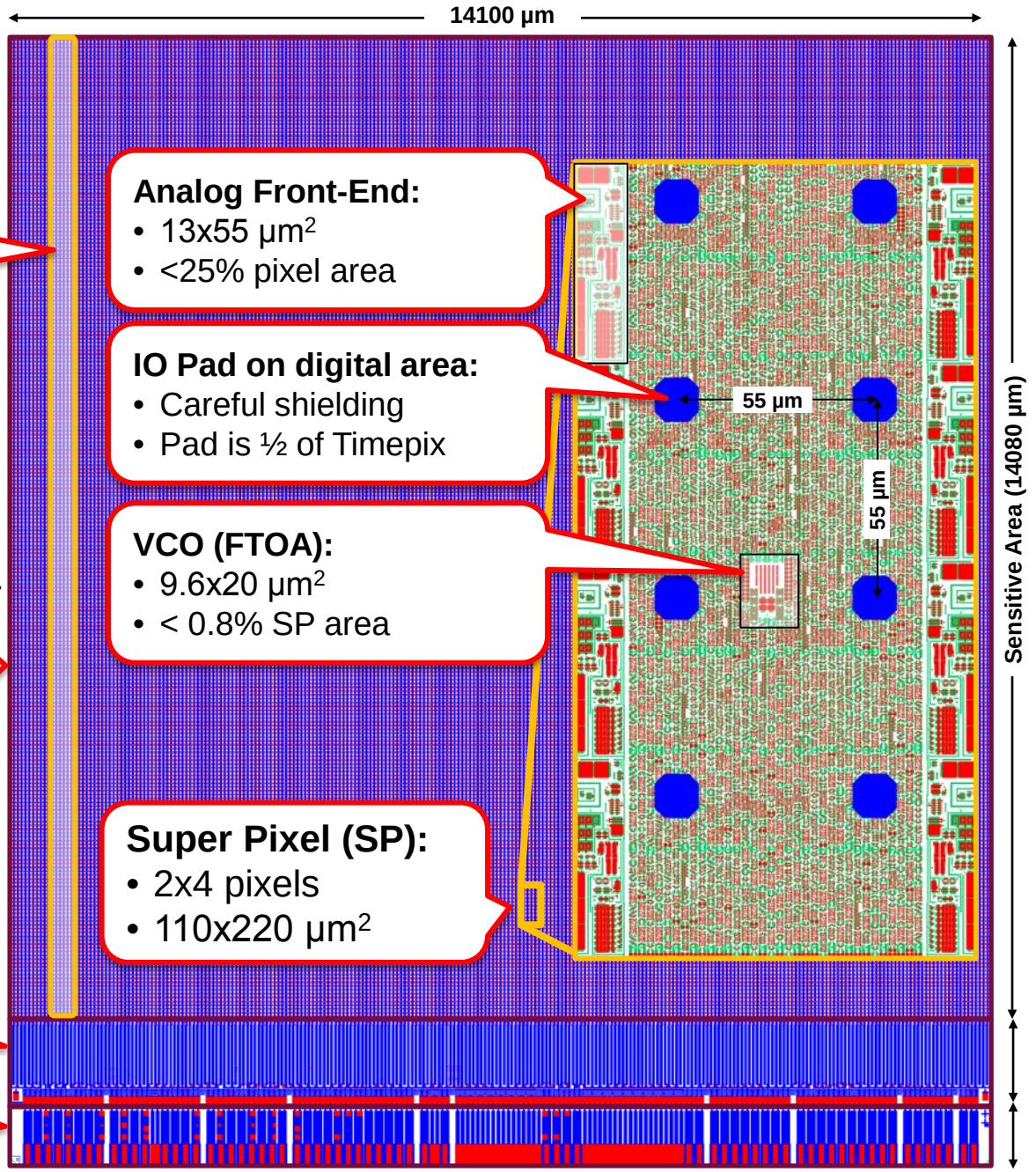
Double column:
2x256pixels
64 super pixels

Full Pixel Matrix:
256x256 pixels
128 double columns

8192 VCOs
(640MHz)
177 Mtransistors

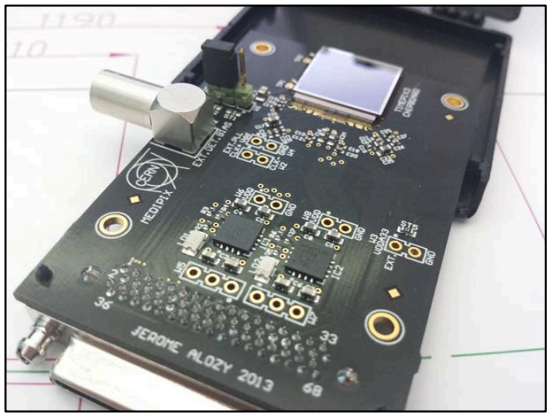
Active Periphery

Pad Extenders:
Removed if TSV

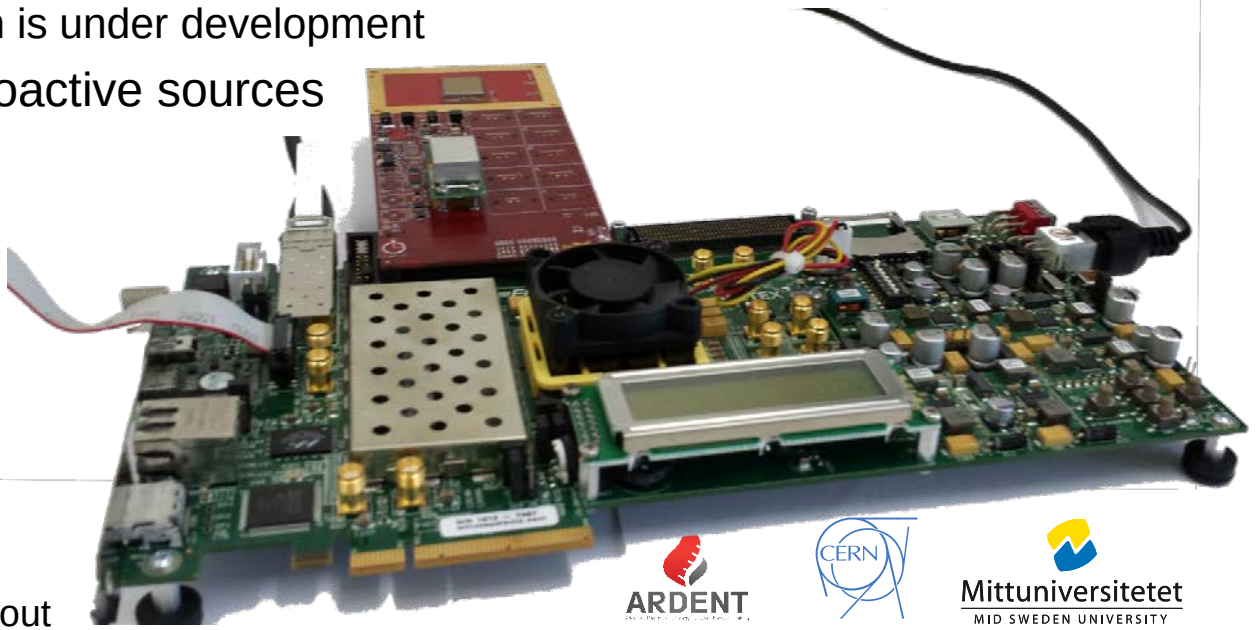


MEASUREMENT SETUP

- Timepix3 mounted on CERN PCB
- 300um p-on-n Silicon sensor (ADVACAM)
- SPIDR Readout (NIKHEF)
  - Virtex 7 FPGA
  - 10 gigabit Ethernet link
  - Flexible and scalable firmware
  - Prototype built on evaluation board used but production version is under development
- Cu X-ray tube + radioactive sources



Timepix3 on Cern PCB



SPIDR Readout

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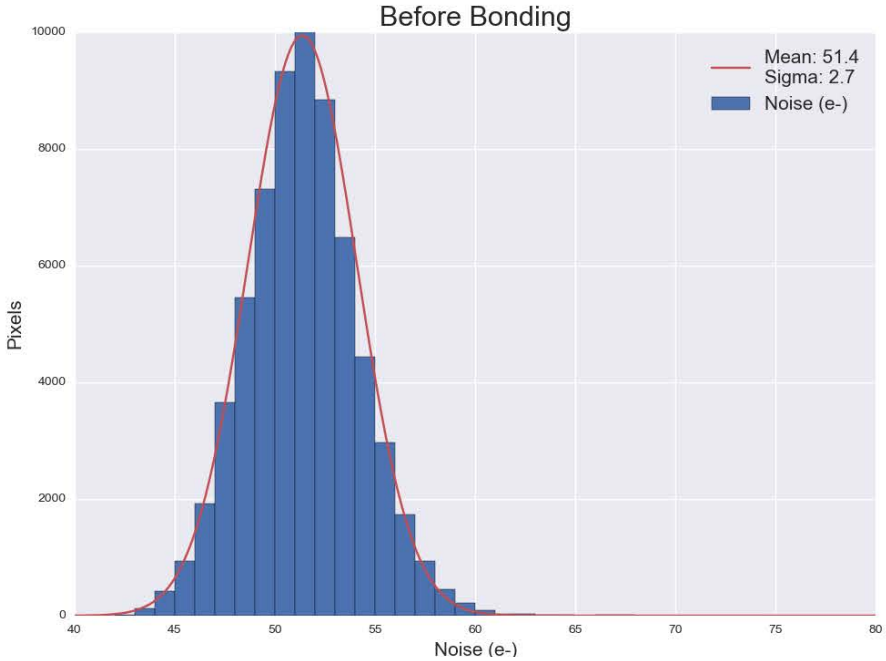
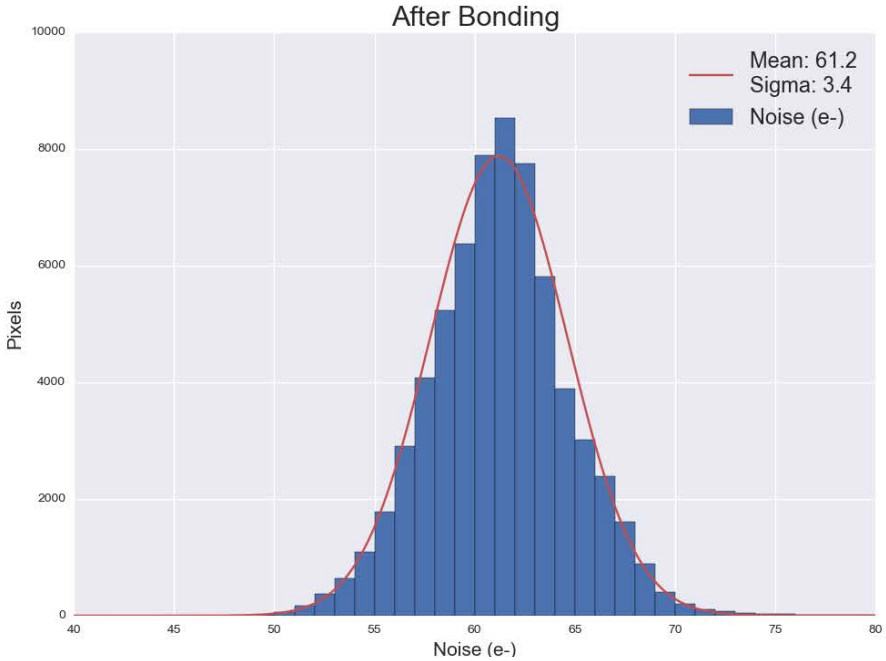
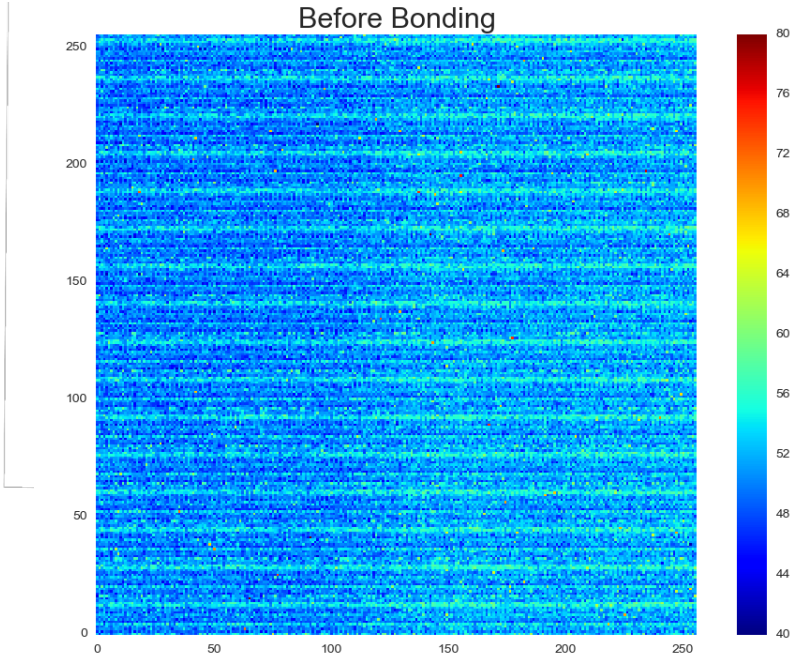
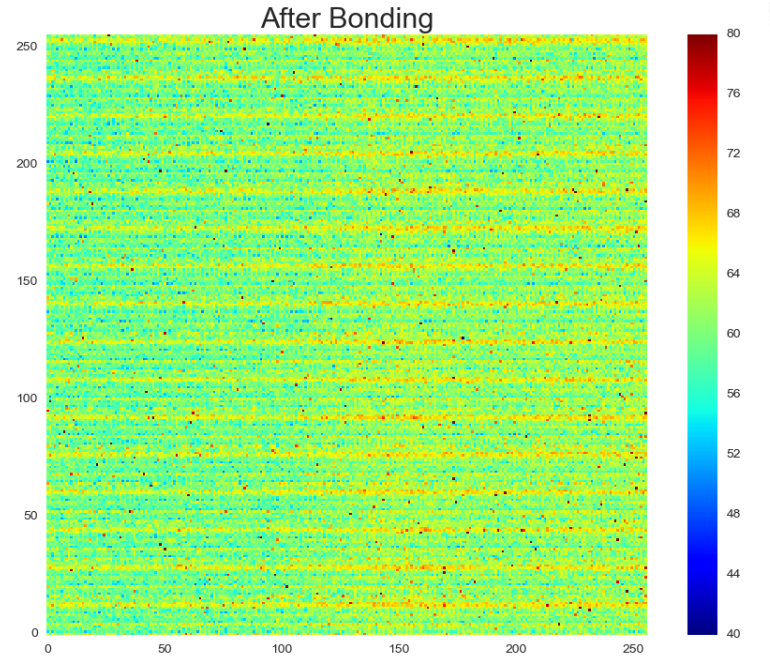
NOISE BEFORE AND AFTER BONDING

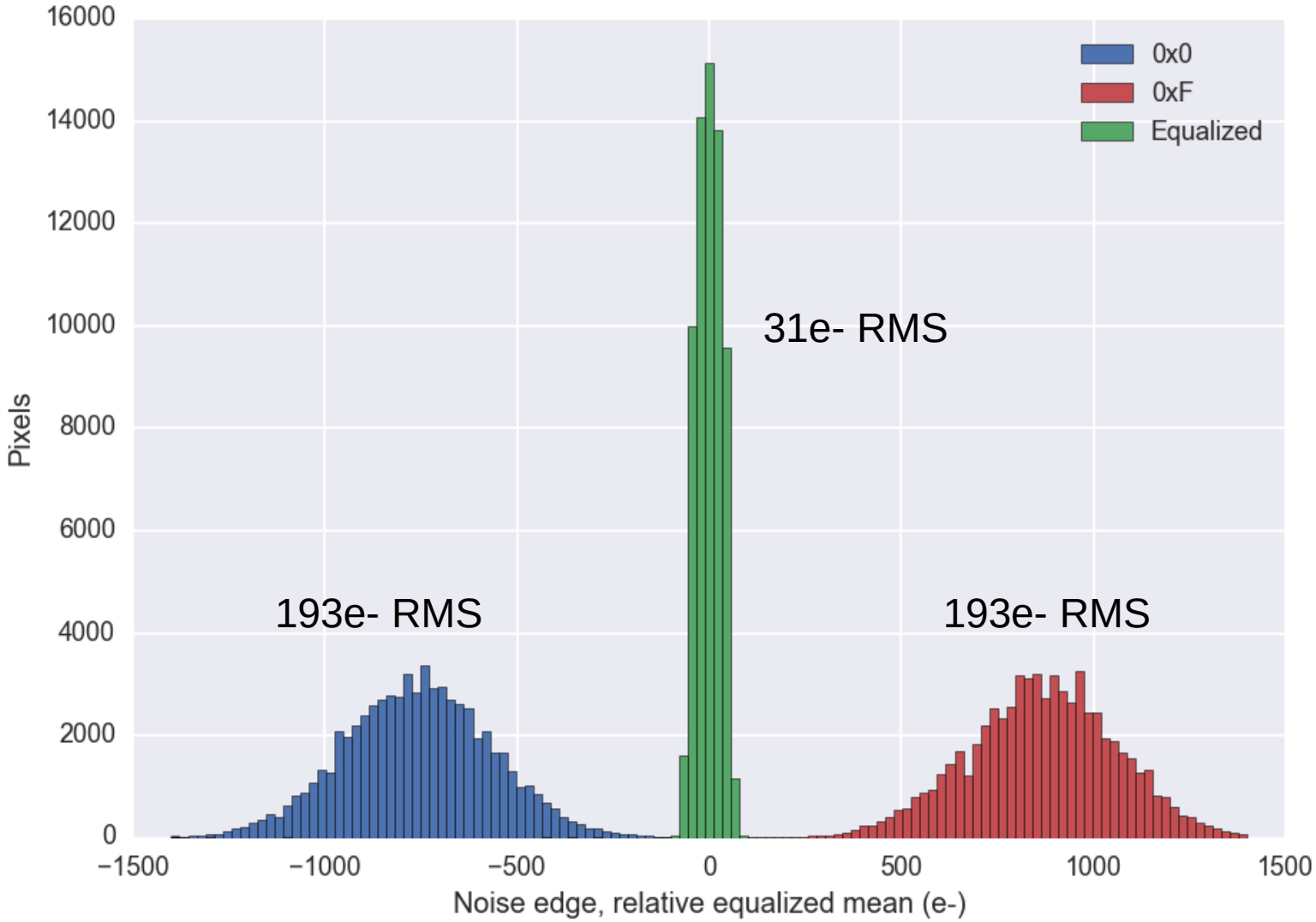








THRESHOLD DISPERSION



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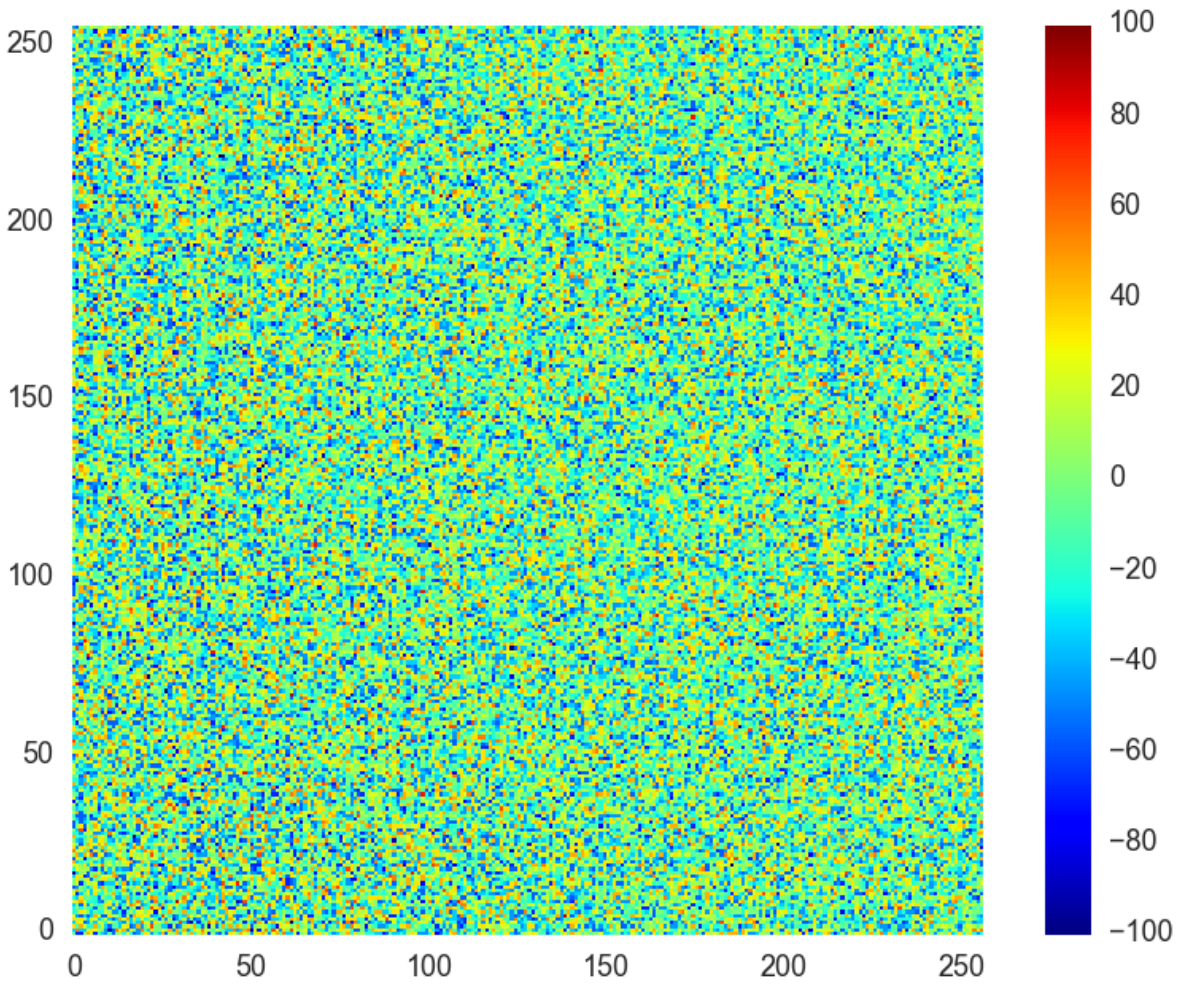
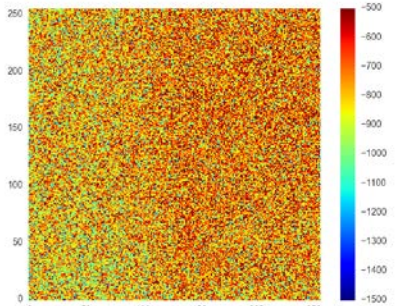
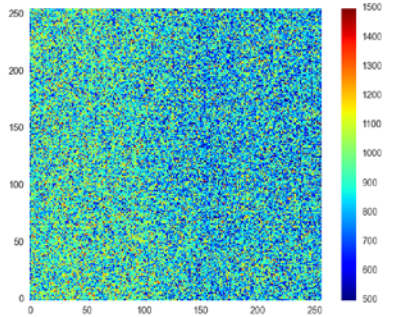
THRESHOLD DISPERSION





0x0

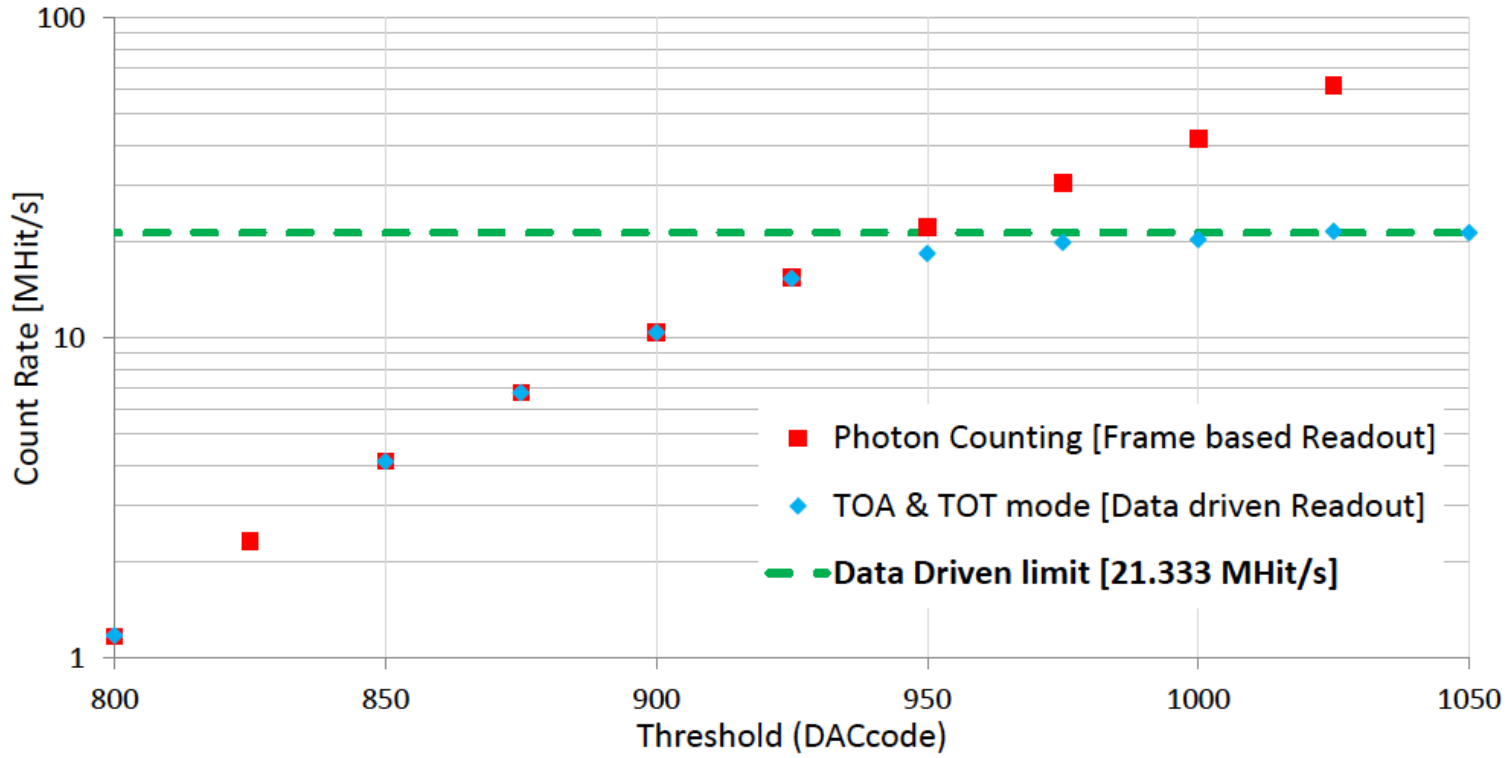


0xF

After equalization

Note: color scale 5x more narrow

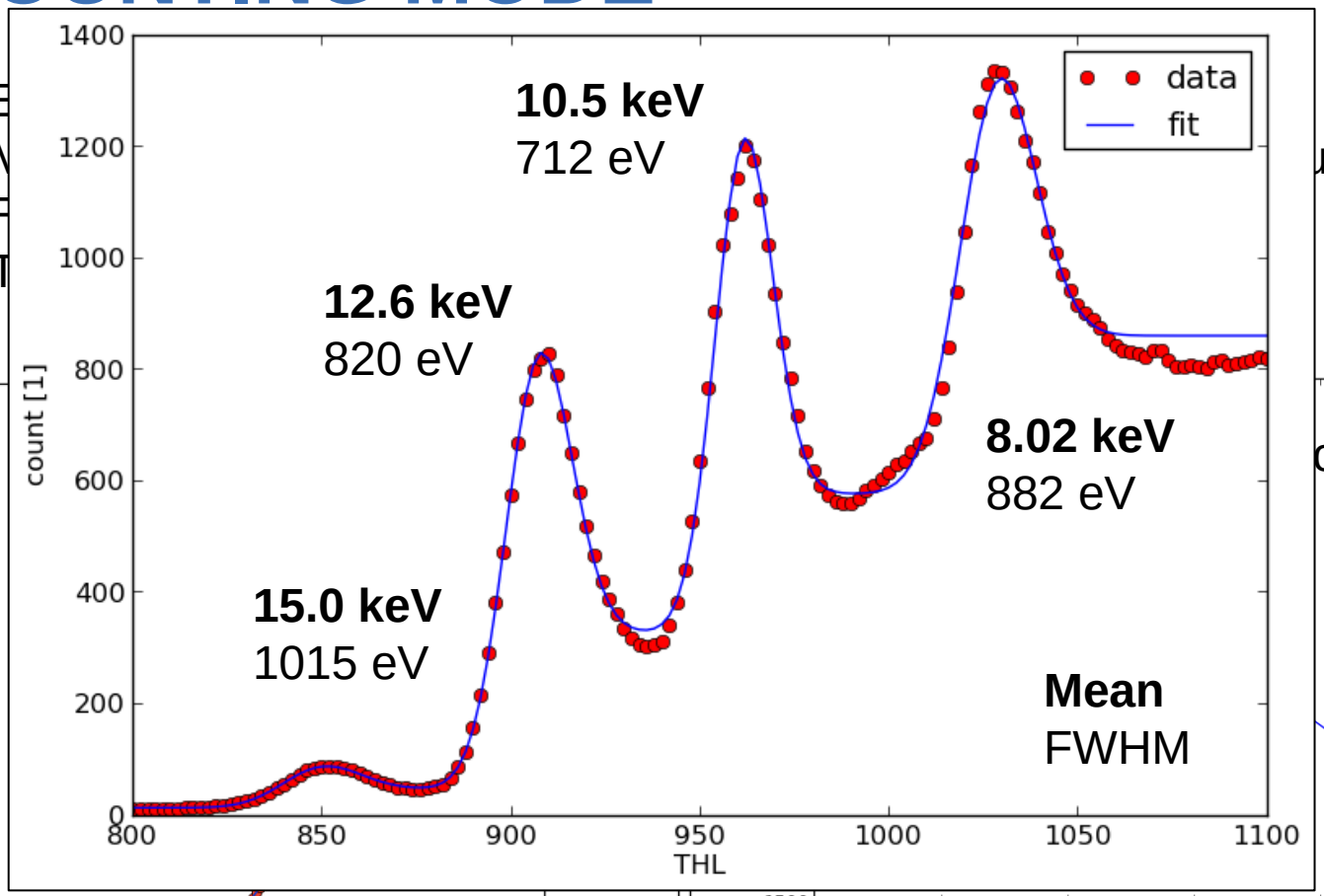
MAXIMUM COUNT RATE IN DATA DRIVEN MODE



Measurement limited by output bandwidth (8x160Mbps)
Maximum possible count rate is 85.33 Mhits/s with 8x640Mbps

ENERGY CALIBRATION IN PHOTON COUNTING MODE

- E
- M
- P
- T



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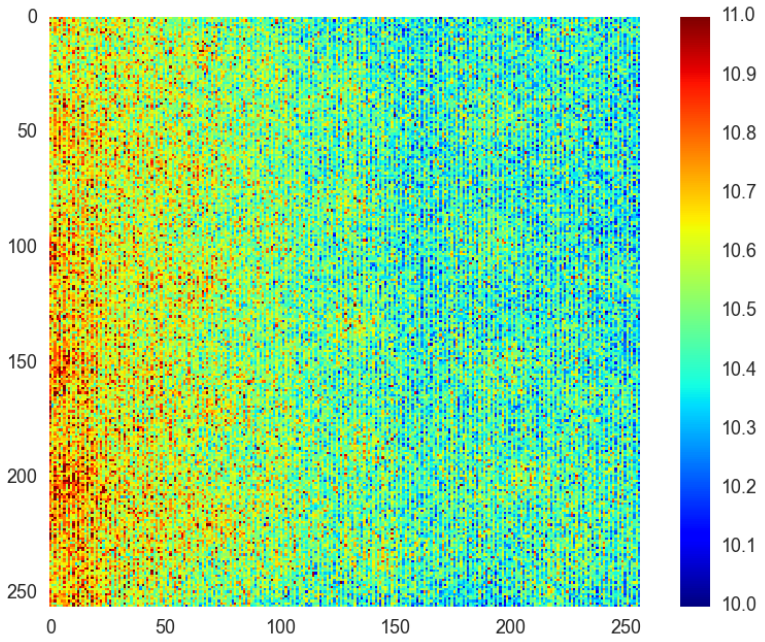
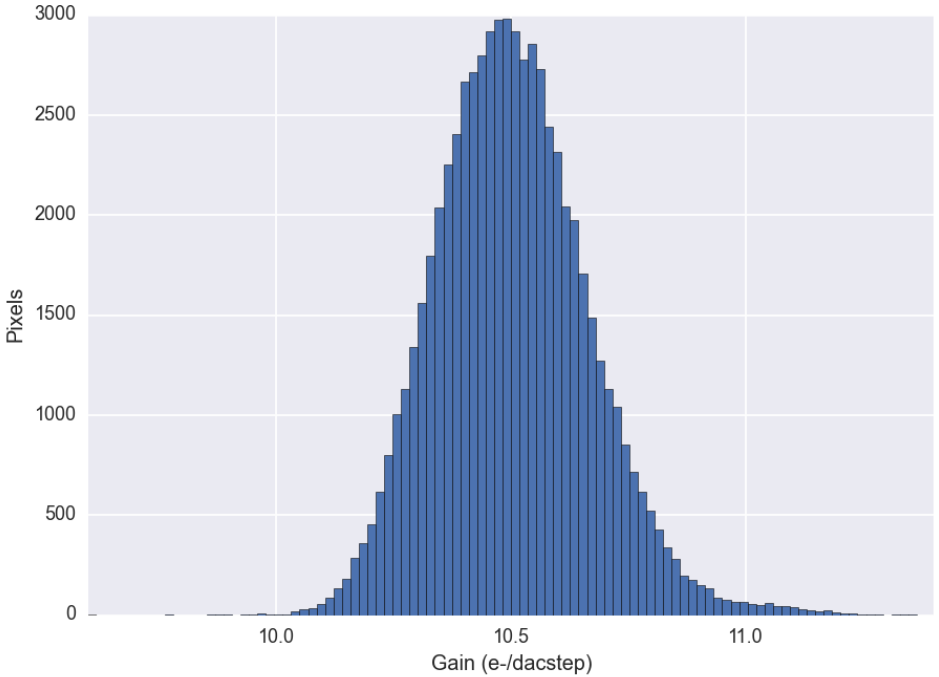
GAIN DISPERSION IN PHOTON COUNTING MODE

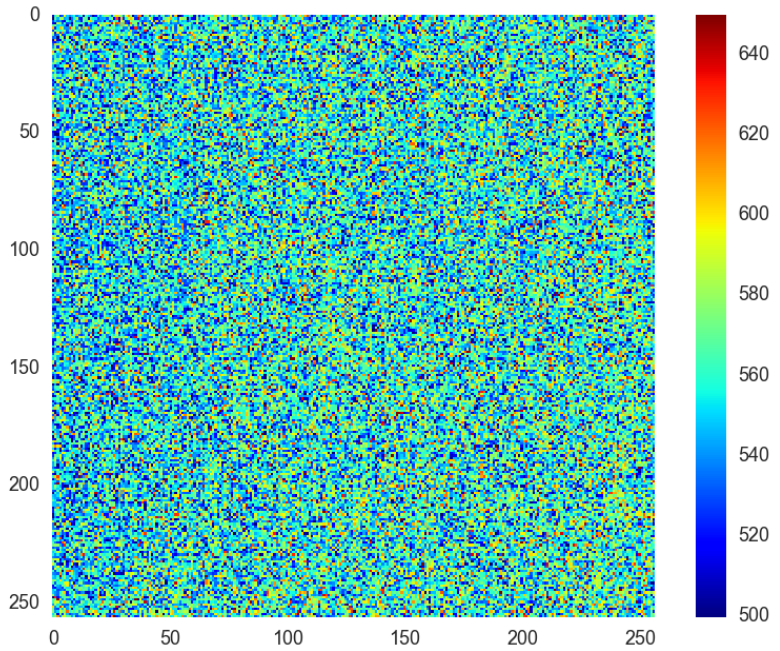


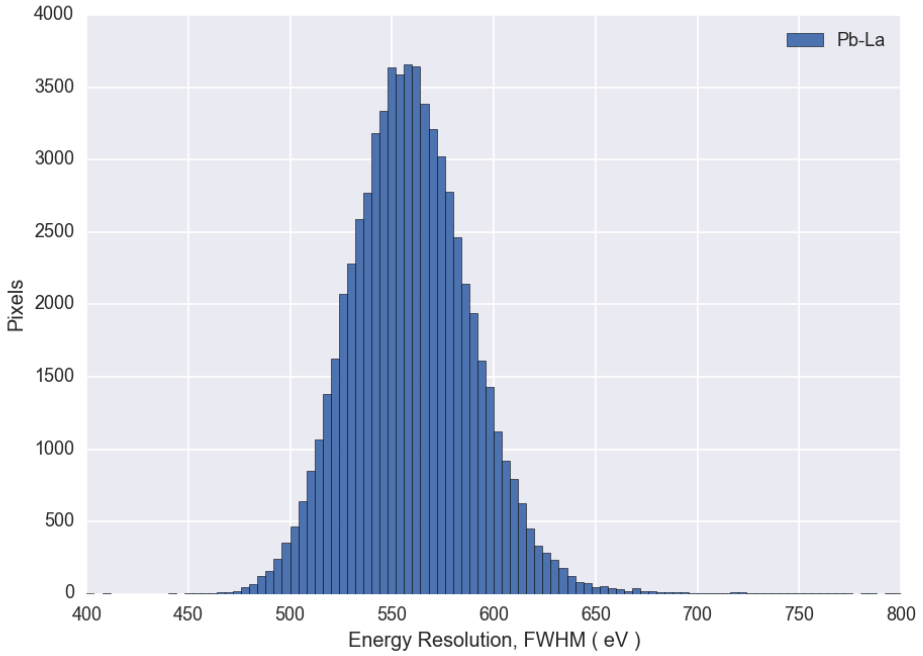


Mean: 10.5 e-
Sigma: 1.68%

Ikrum: 5

SINGLE PIXEL ENERGY RESOLUTION





Mean 559 eV FWHM
Sigma: 6.15 %

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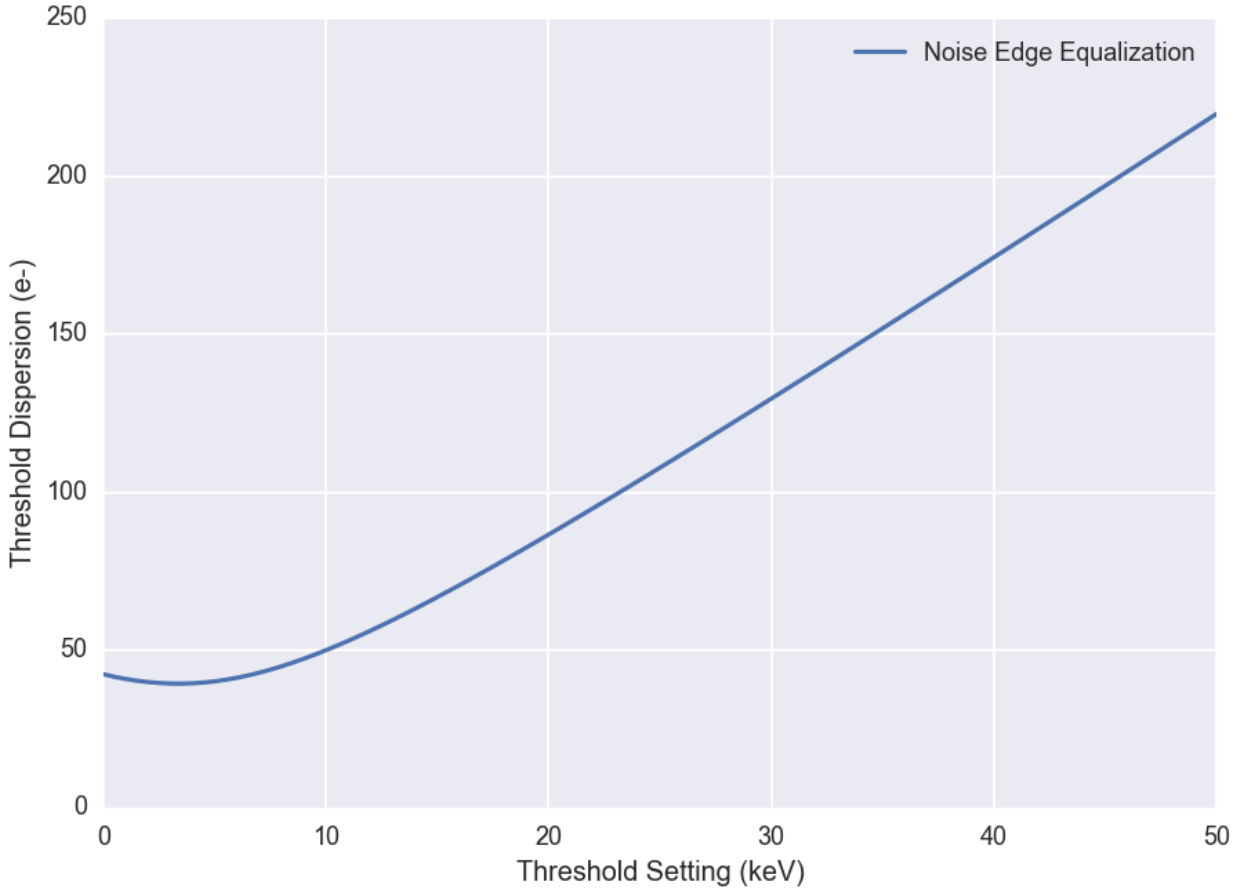
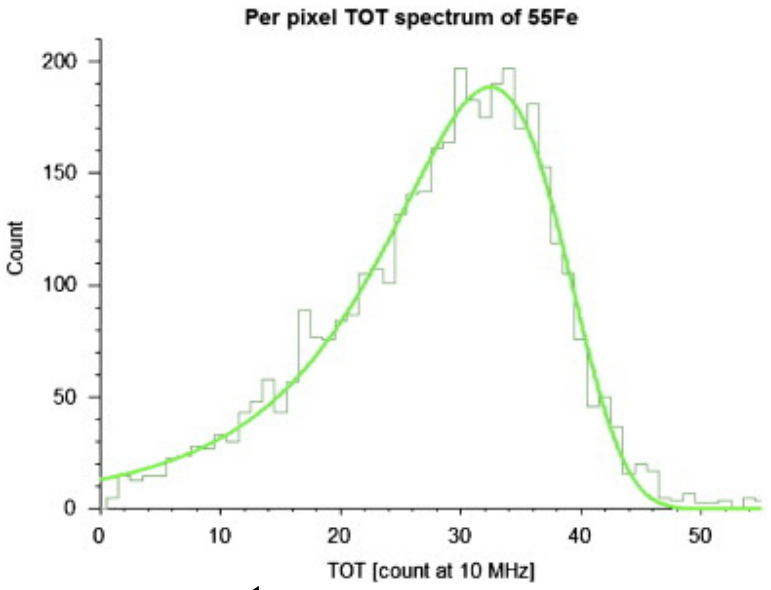
THRESHOLD DISPERSION IN PHOTON COUNTING MODE



Ikrum: 5, 100V,

ENERGY CALIBRATION: TIME-OVER-THRESHOLD

- Method published by J. Jakubek.
- Using only 3 peaks
- ^{109}Cd and ^{241}Am for linear range and ^{55}Fe in the non linear range



$$M_{a,b,c,t,\mu,\sigma,A}(s) = G_{\mu,\sigma,A}(f^{-1}_{a,b,c,t}(s))$$

J. Jakubek, Precise energy calibration of pixel detector working in time-over-threshold mode NIM-A Vol 633 Supplement 1 May 2011

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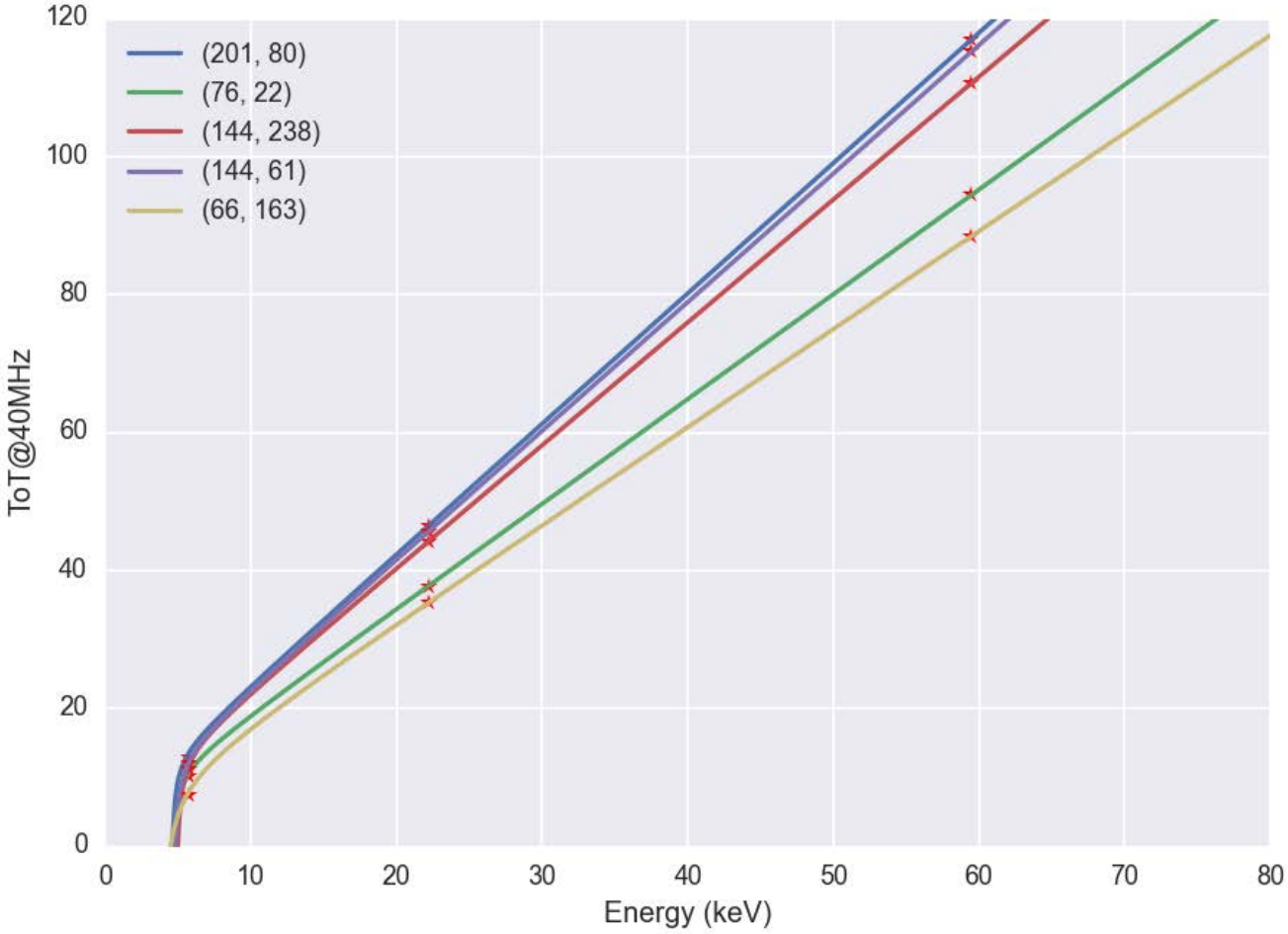
ENERGY CALIBRATION: TIME-OVER-THRESHOLD



- TH ~ 1000e-
- Large spread in gain

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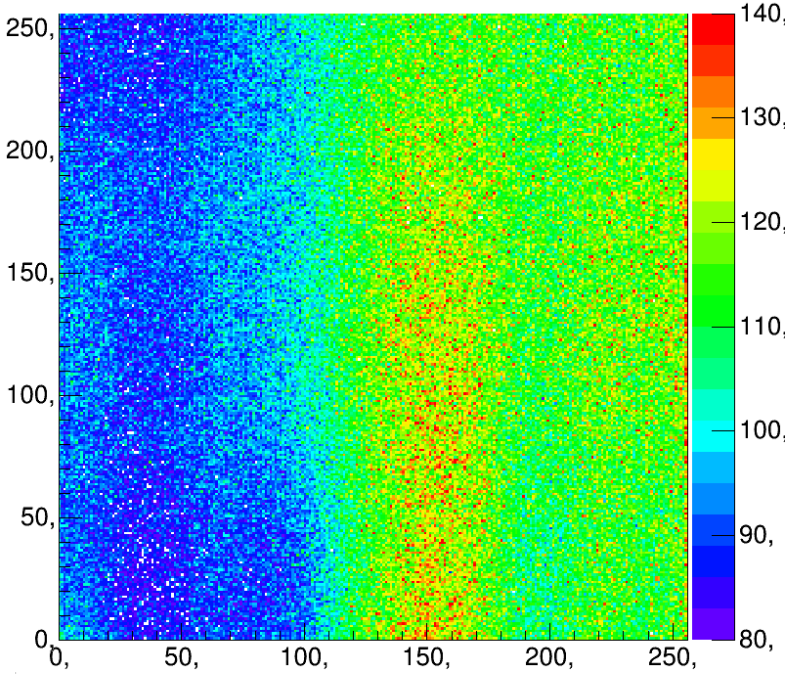
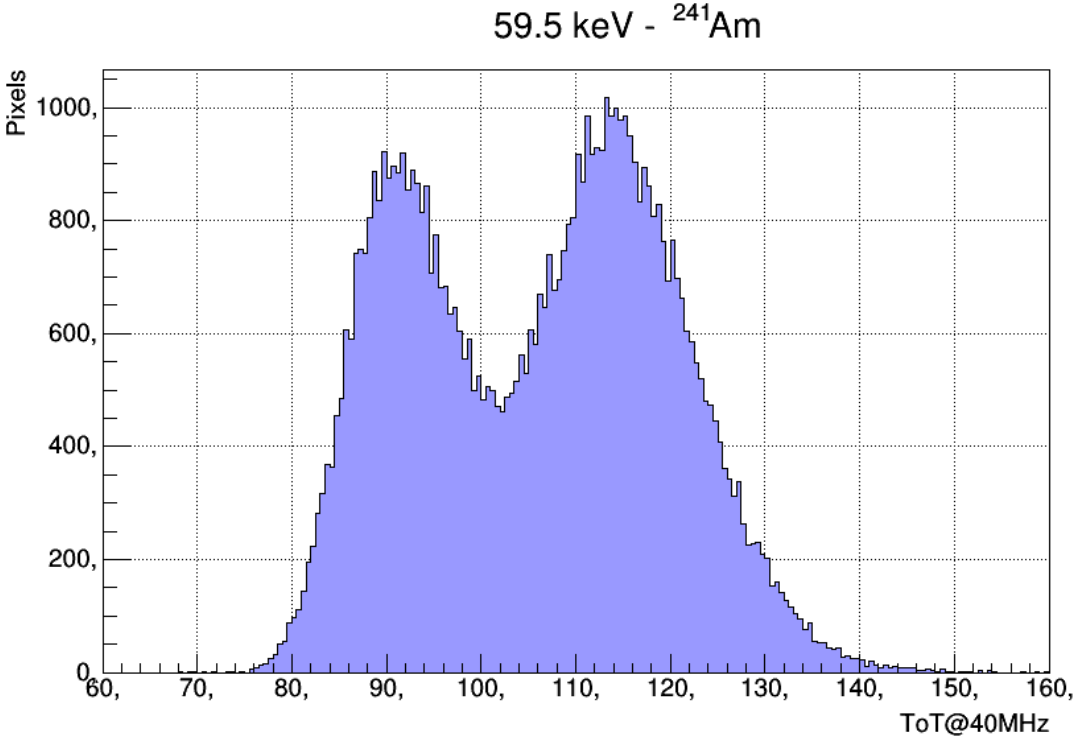
^{241}Am PHOTOPEAK POSITION





Gain spread from calibration: 14.5%

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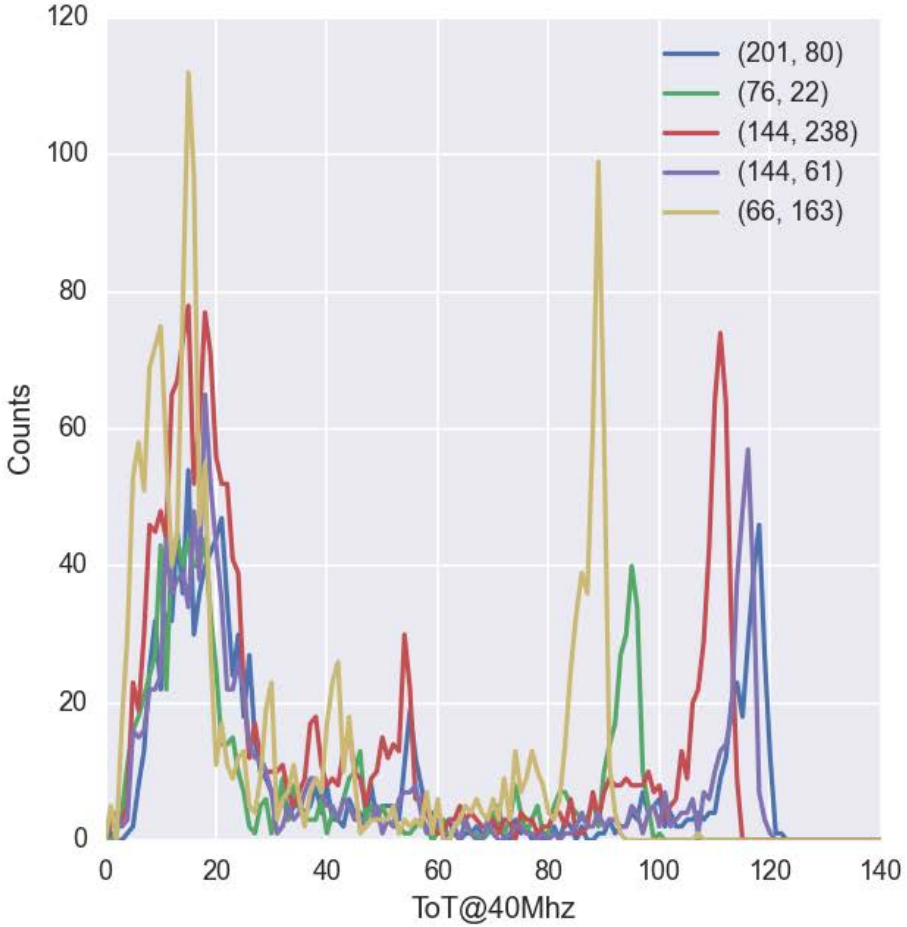
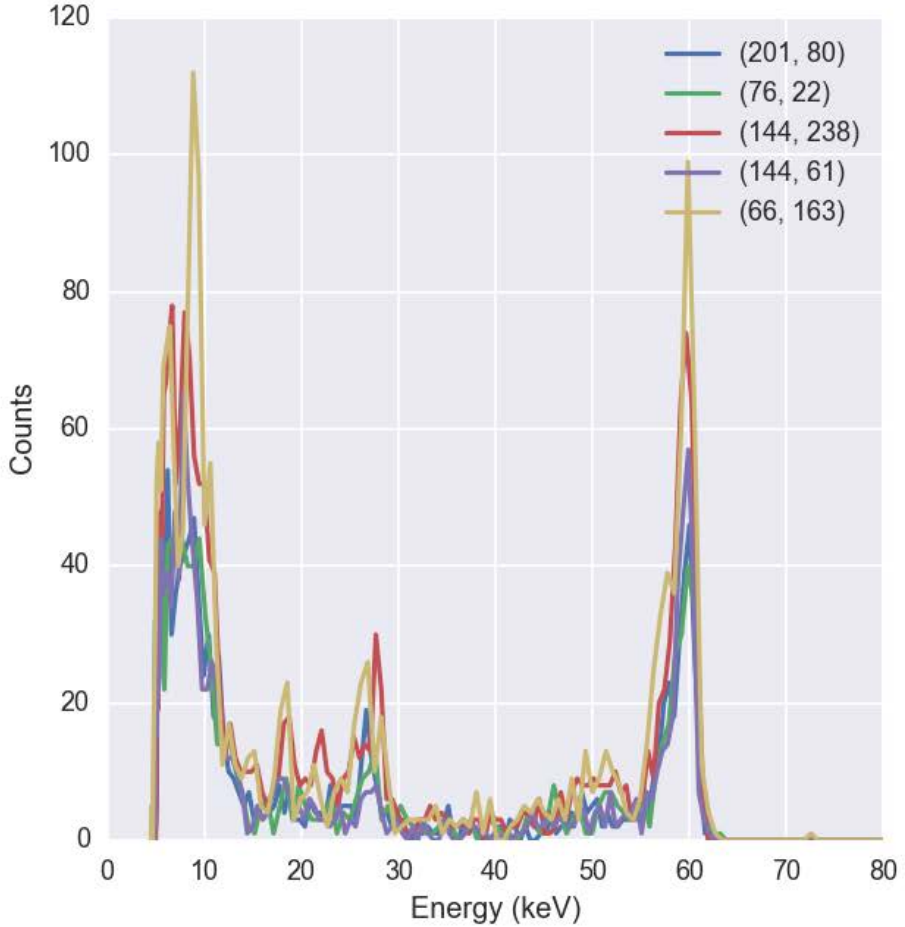
ENERGY CALIBRATION: ^{241}Am





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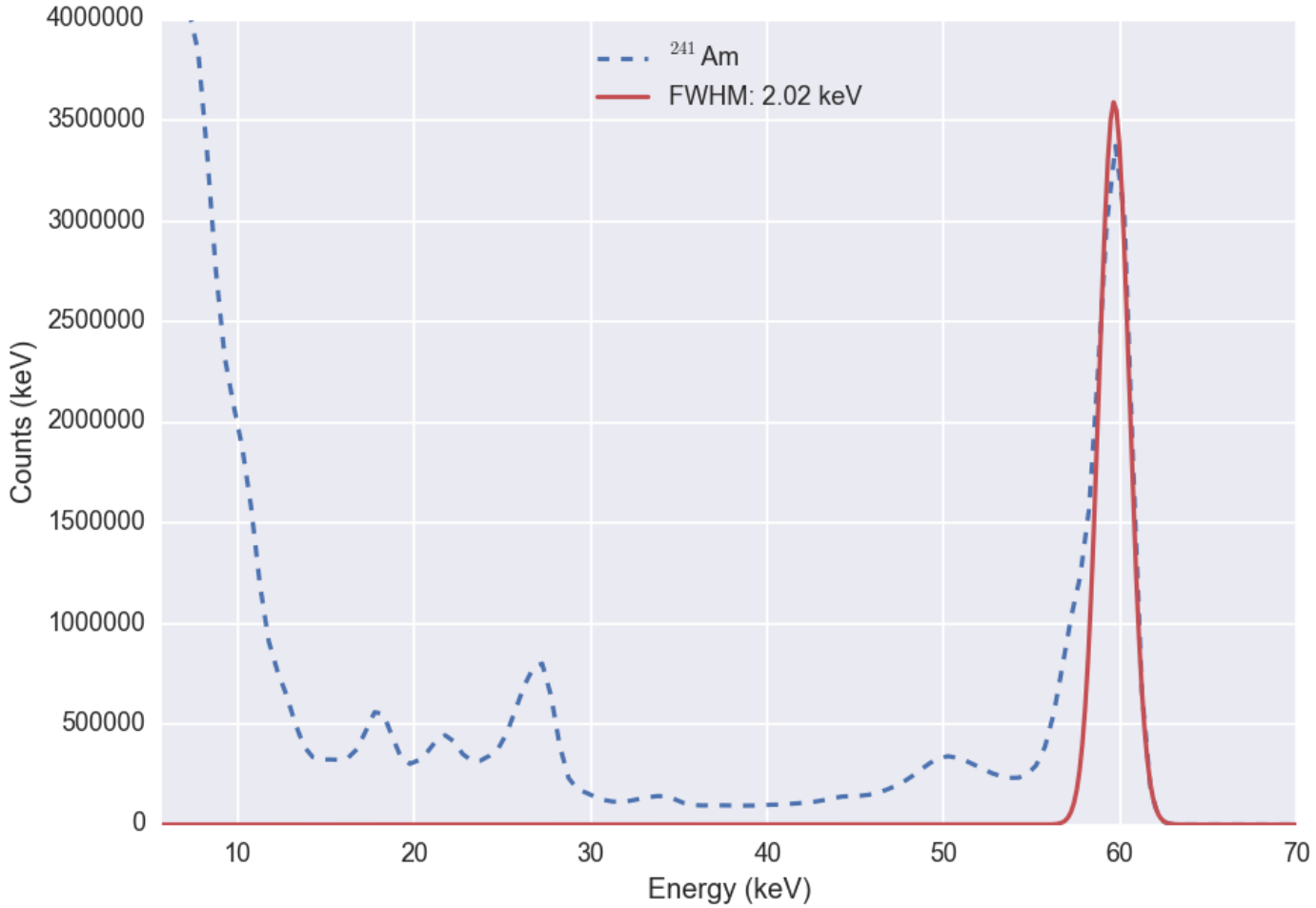
ENERGY RESOLUTION FOR SINGLE PIXEL HITS USING FULL MATRIX



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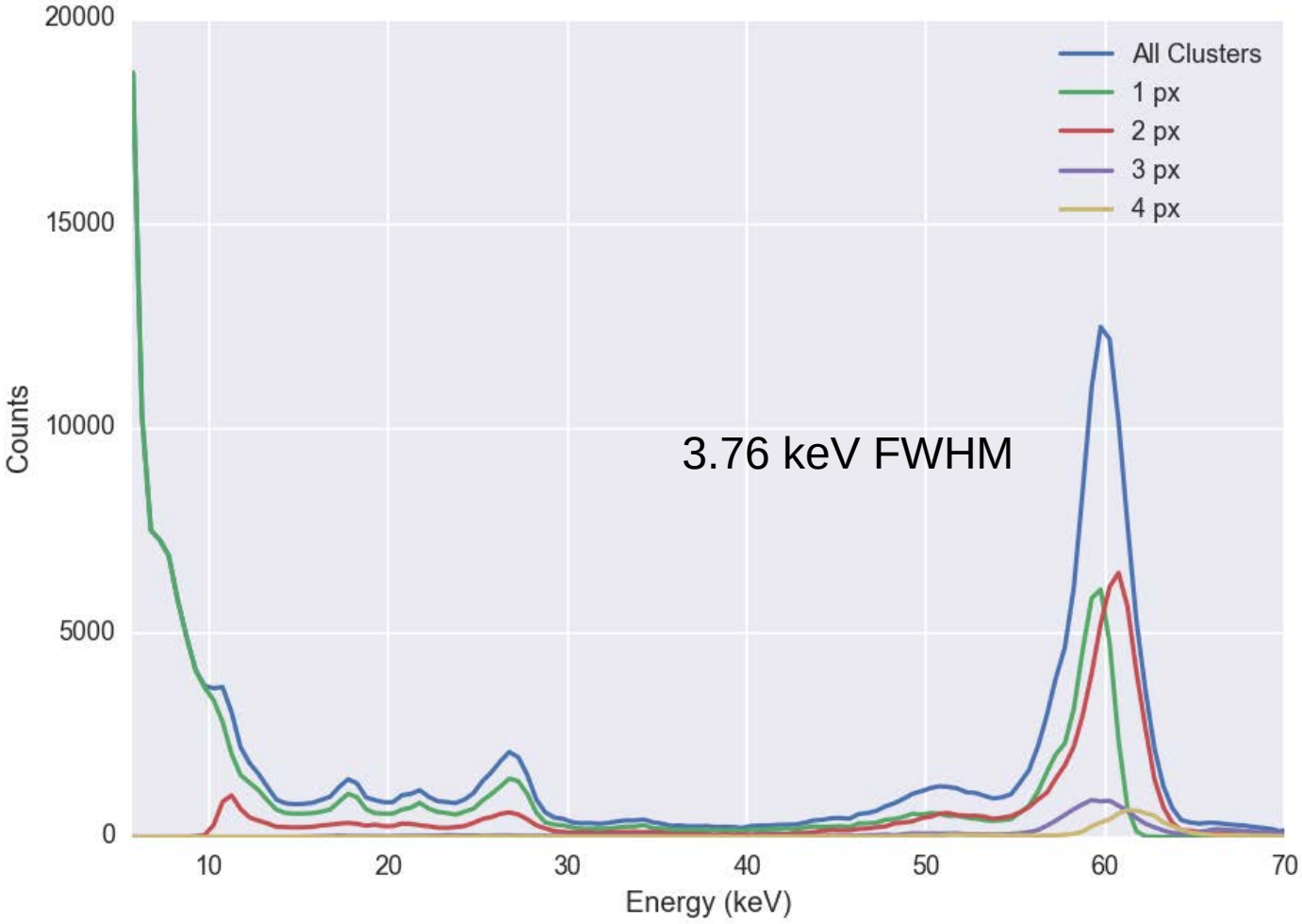
CALIBRATION VERIFICATION: ^{241}Am



- “knee” for the surrogate is lower than Timepix1
- Need to fit on more points
- Better calibration will improve energy resolution

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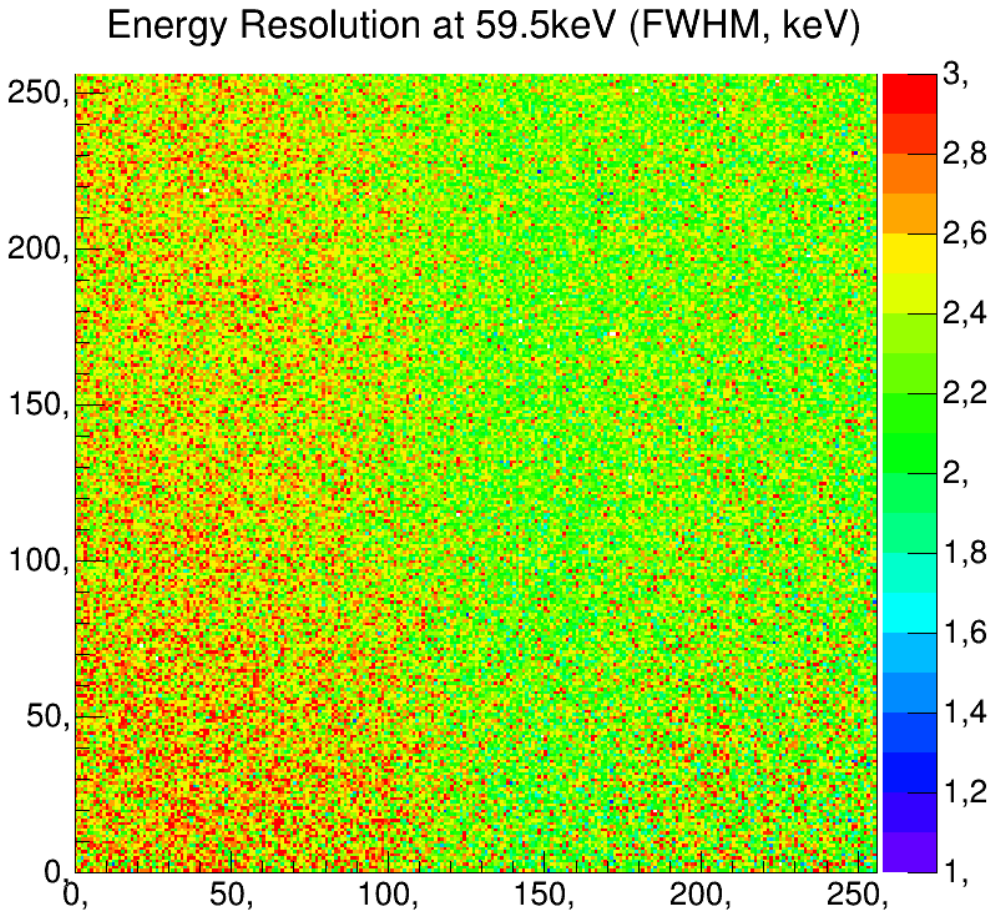
ENERGY RESOLUTION FOR SINGLE PIXEL HITS USING FULL MATRIX



Slightly worse energy resolution in the area with low gain but no big impact on overall energy resolution

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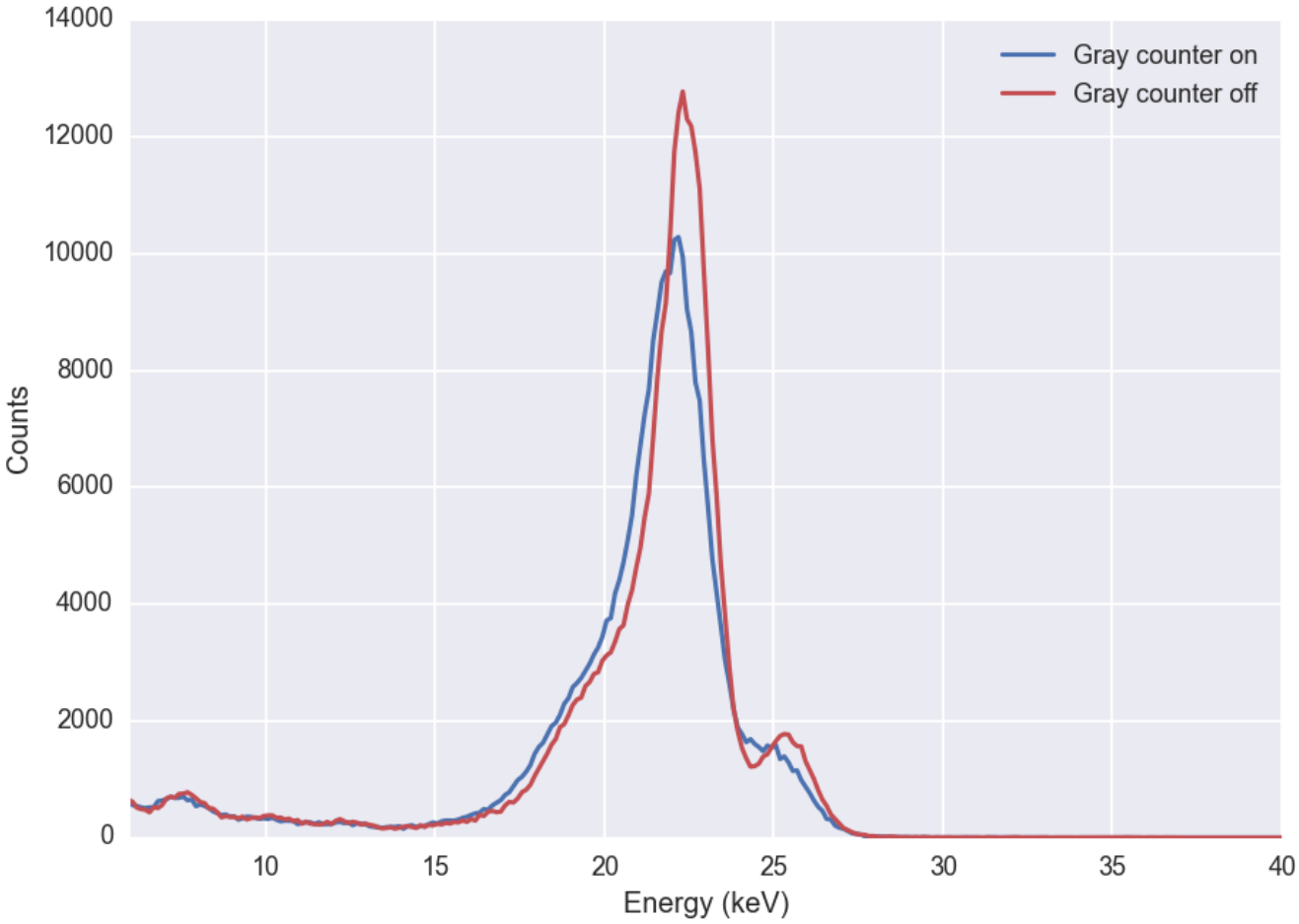
NOISE COUPLING WITH TIMING ON



- ^{109}Cd (Ag XRF)
  - 22.1 keV
  - 24.9 keV
- FWHM: 1.92 keV
- FWHM: 2.44 keV
- Single pixel hits only
- Might impact lowest usable threshold for timing measurements

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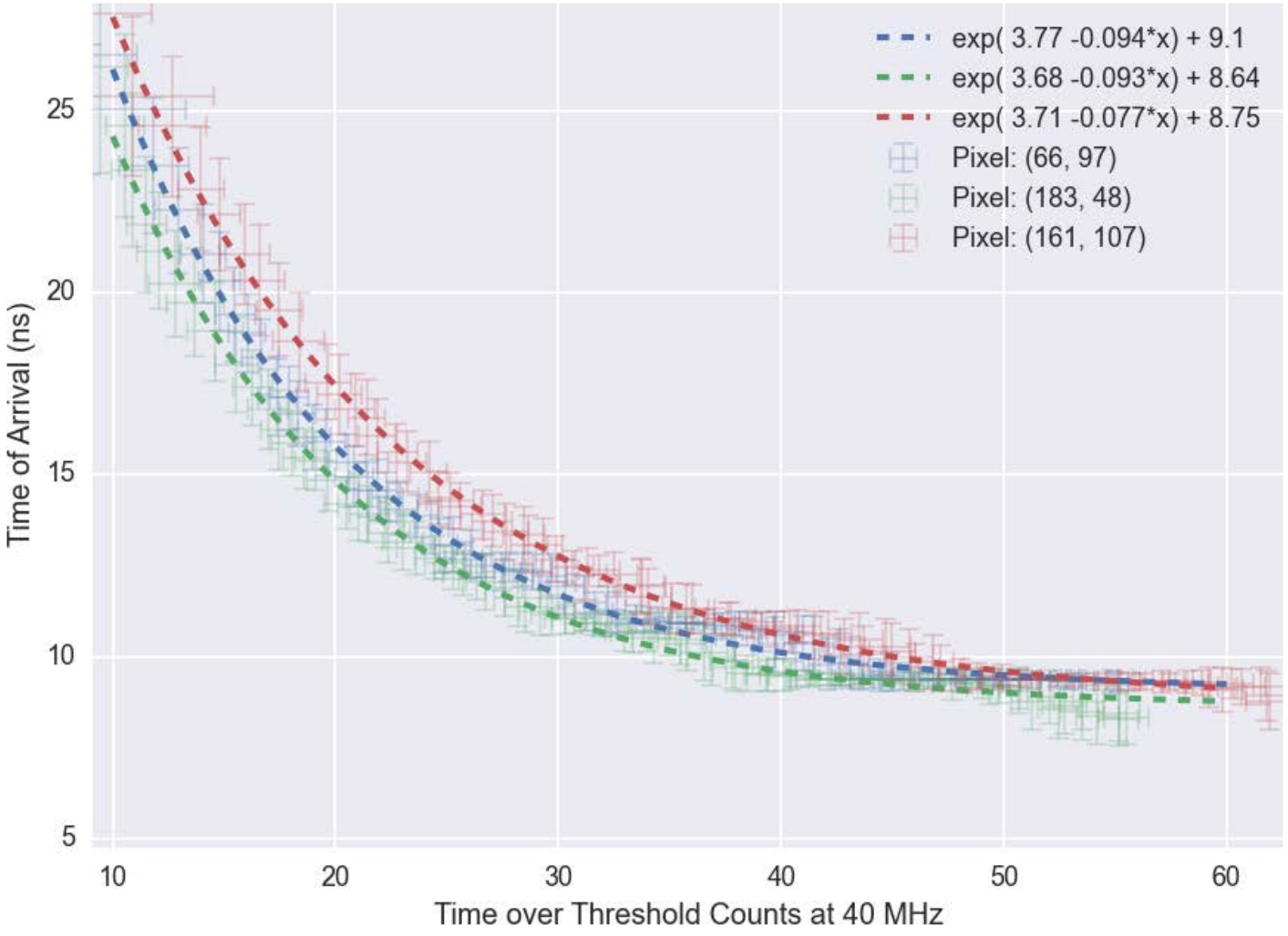
TIME WALK CORRECTION

- Using time and energy information it is possible to correct for time walk.
- We measure the time walk by taking the difference between the digital and the analog test
- The response of each pixel if fitted with an exponential function + constant
- From this we extract time walk and latency

- *Note: To optimize time measurements the chip should probably be run with different DAC settings than in this experiment*

TIME WALK CORRECTION



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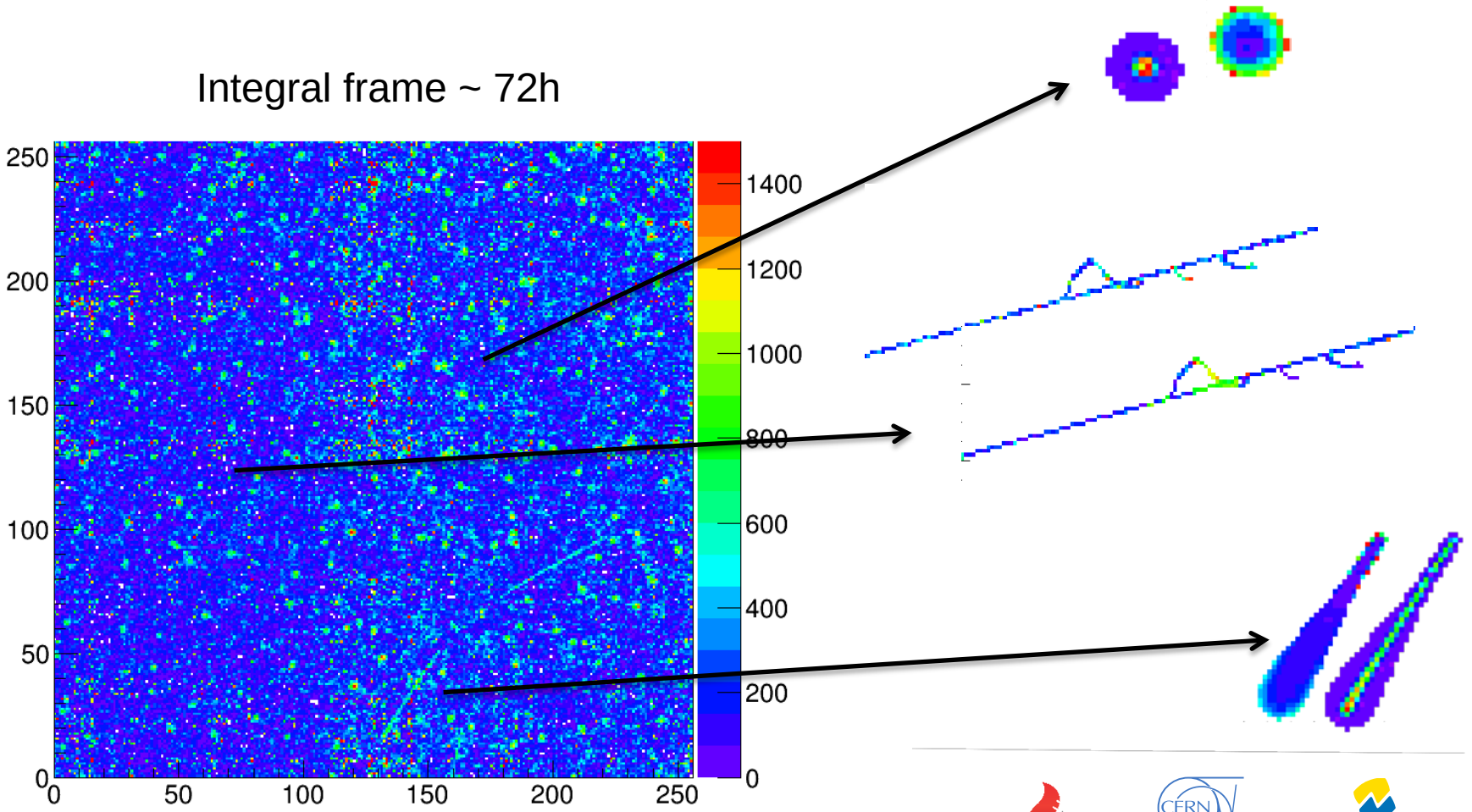
ENERGY AND TIME MEASUREMENTS WITH COSMIC PARTICLES



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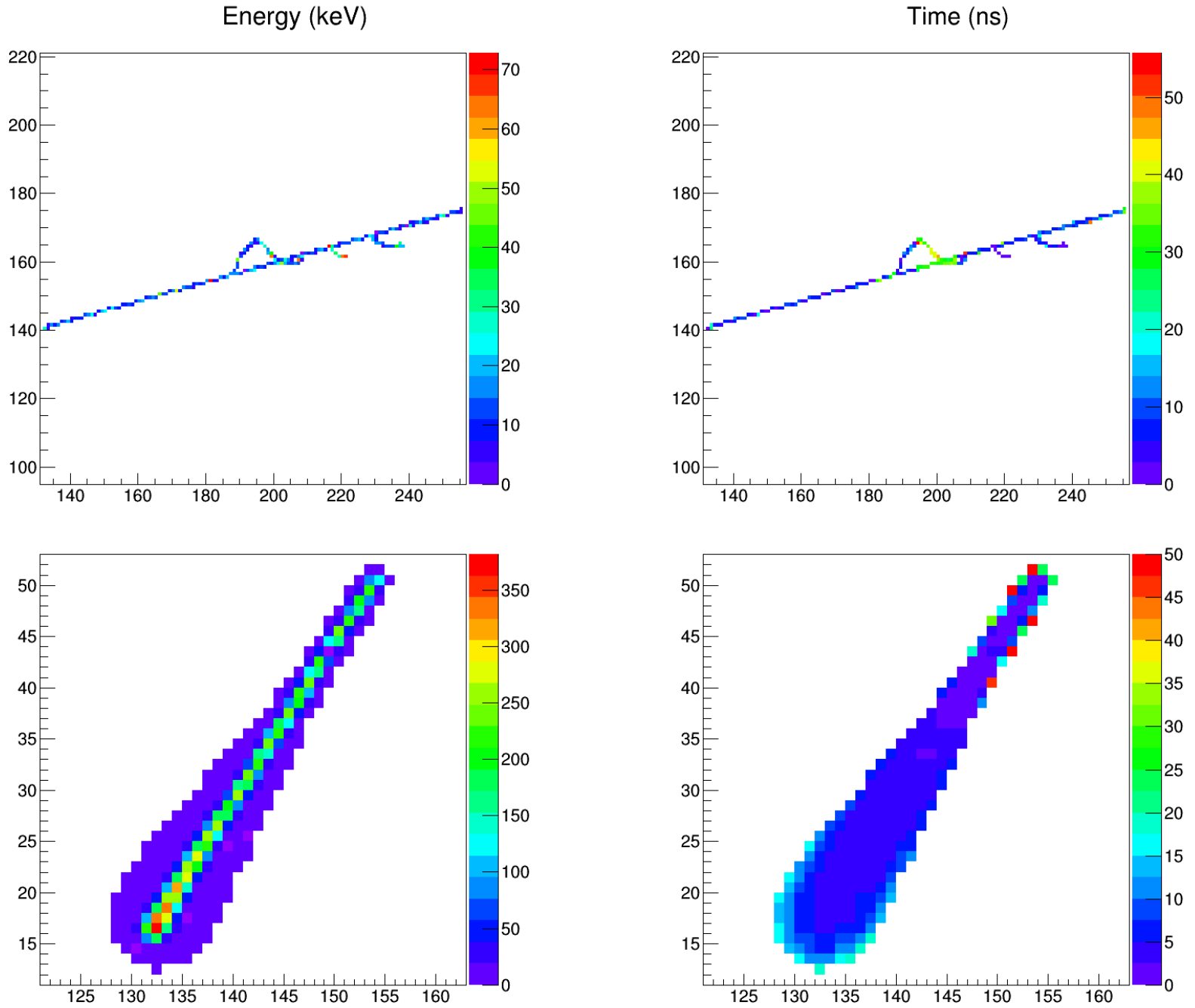
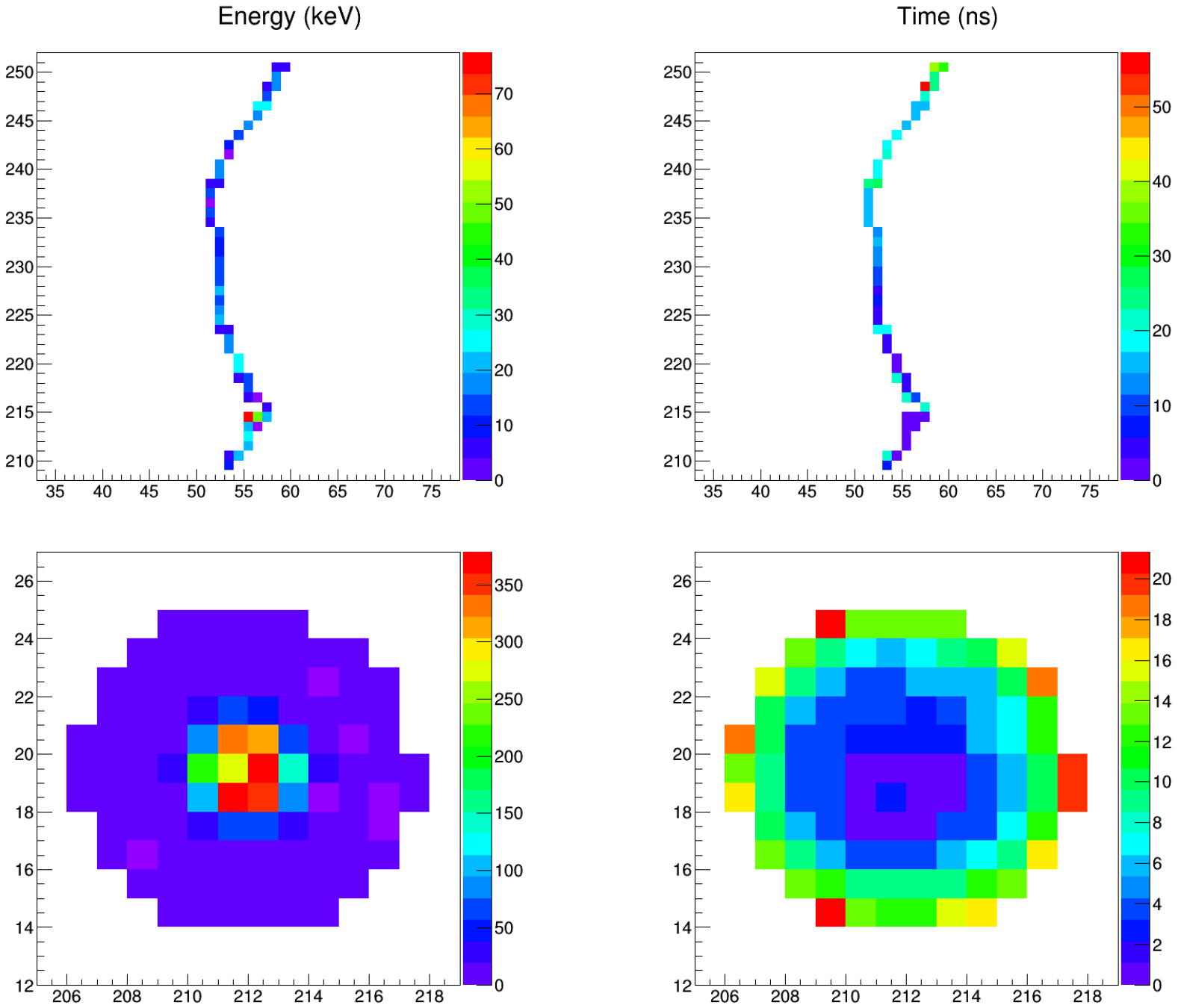
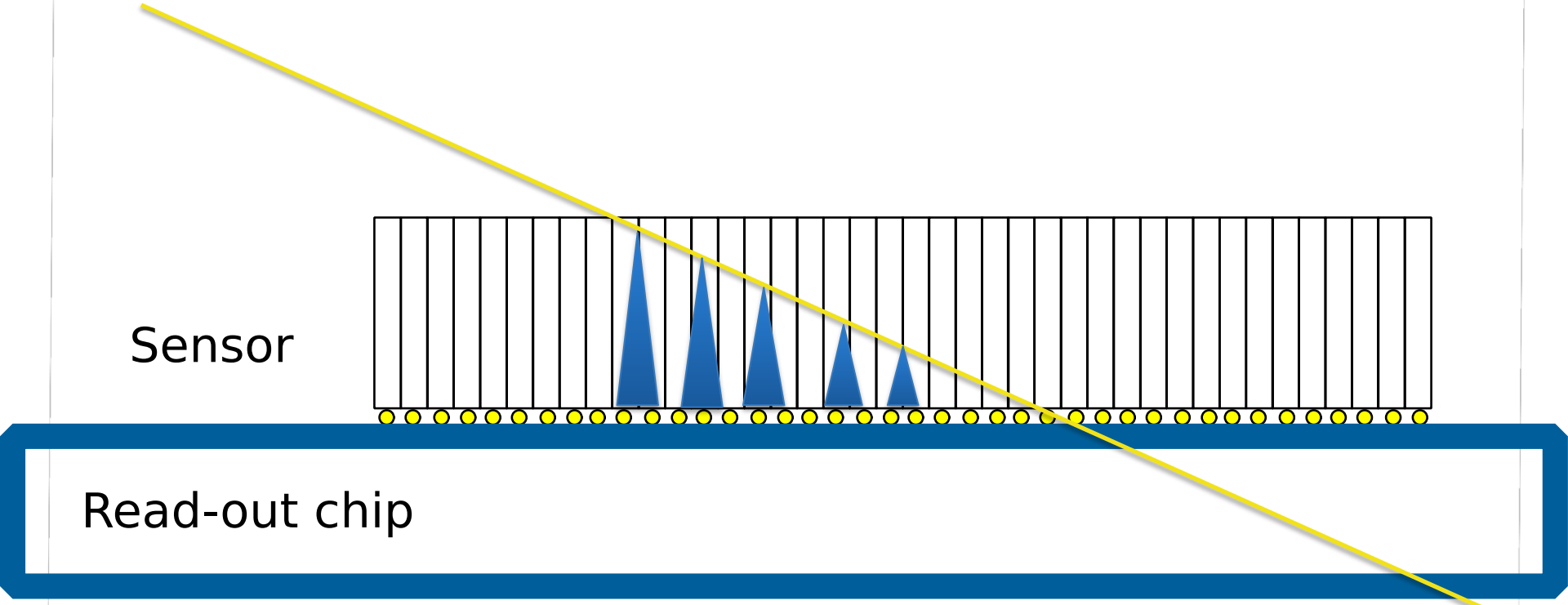
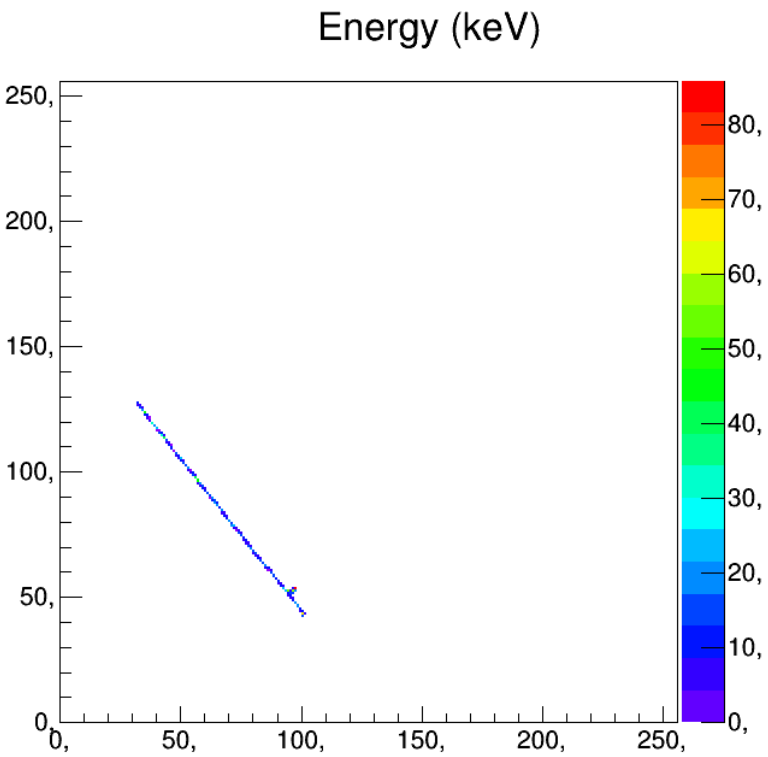


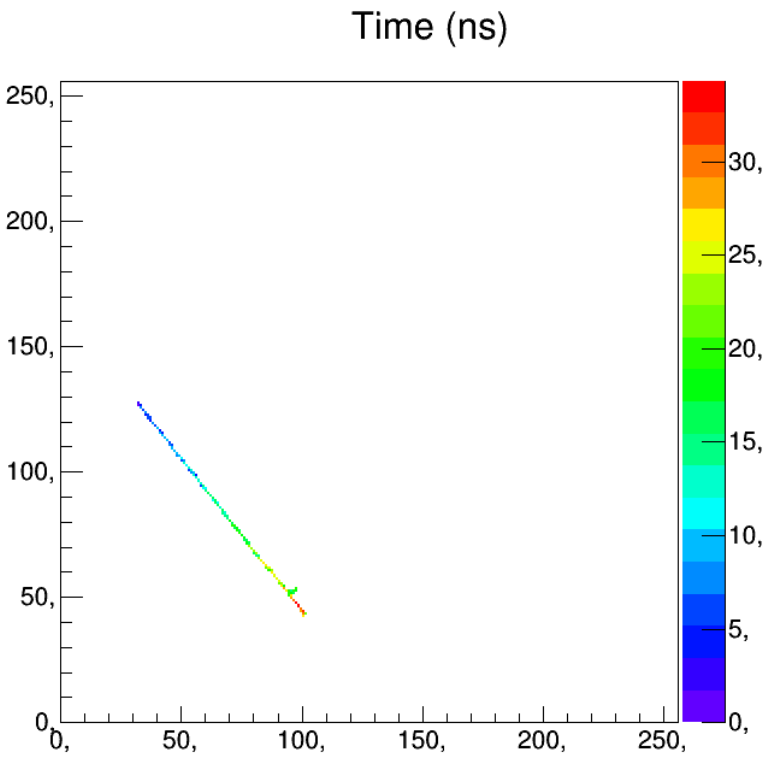
Bias 100V, Ikrum 5, **without** time walk correction



Bias 100V, Ikrum 5, **without** time walk correction


Sensor
Read-out chip





Bias 100V, Ikrum 5, with time walk correction

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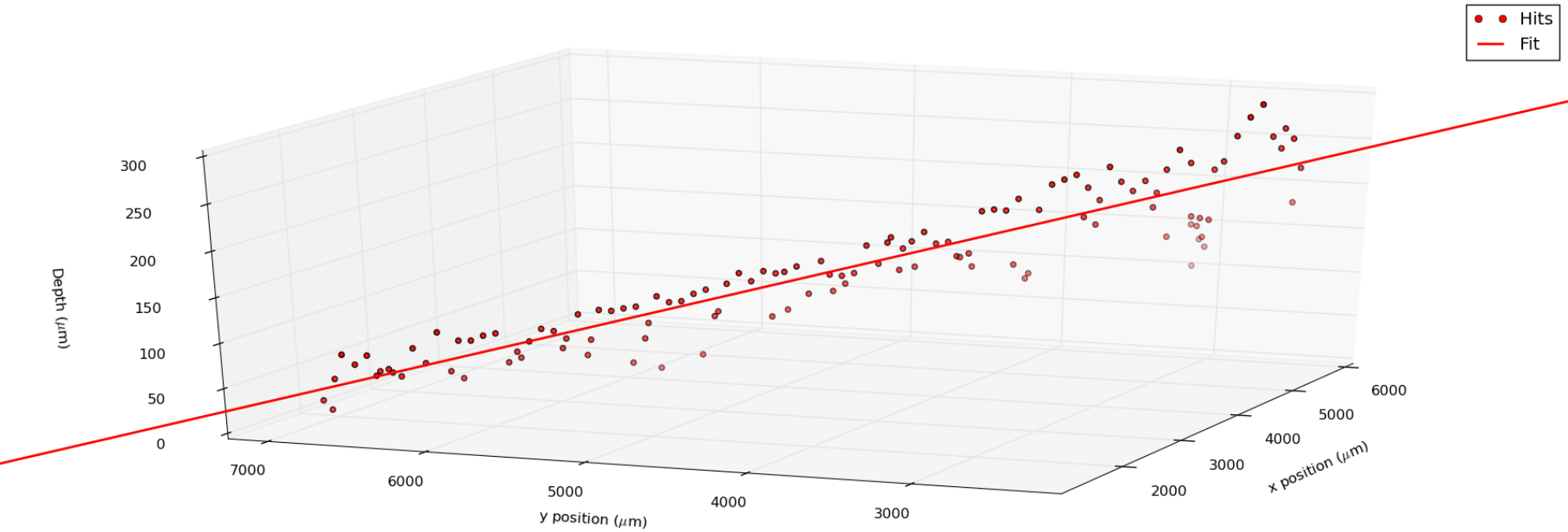

Note: Not to scale!

Bias 100V, Ikrum 5, with time walk correction

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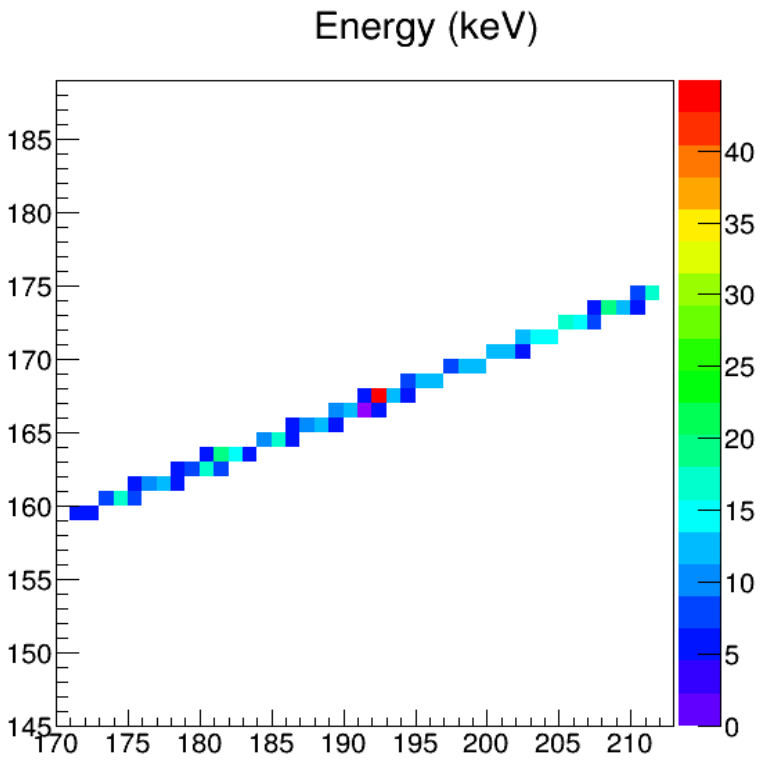
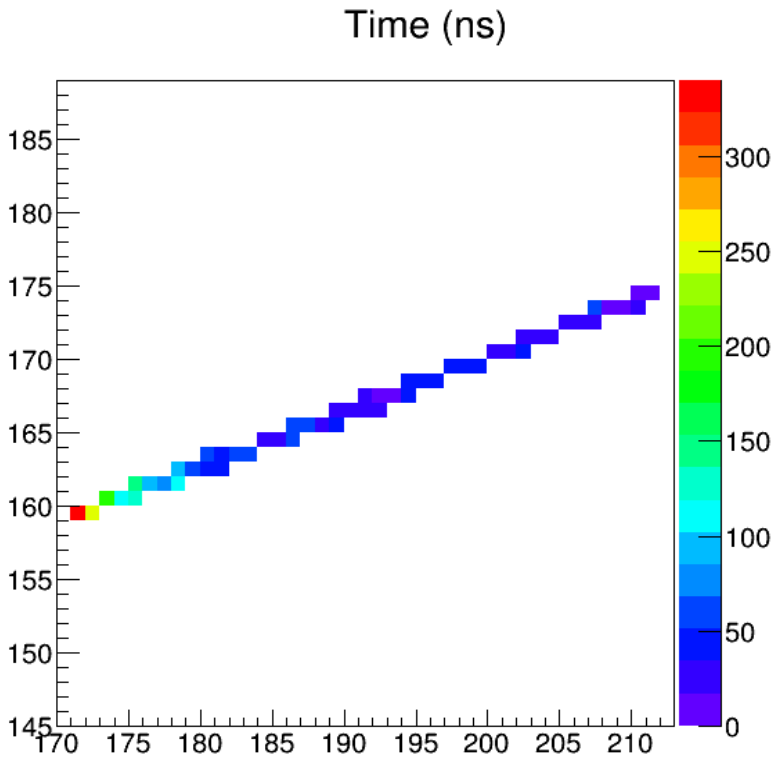
TRACKS WITH LOW BIAS VOLTAGE





Bias 20V, Ikrum 5, with time walk correction

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CONCLUSIONS

- Noise after bonding is 61e-RMS
- Minimum threshold ~ 2 keV or 550 e-
- Energy resolution in PC mode is 712 eV at 10.5 keV
- Energy resolution for **single pixel hits** in ToT mode is 1.92 keV at 22 keV
- High gain spread observed in ToT mode but can be corrected with calibration
- Energy and time measurements of cosmic rays indicate that we can measure depth of interaction in the sensor using the drift time.
- Optimization of the timing resolution will require different settings compared to optimizing for energy resolution.

- *Note: Measured for a single assembly only.*

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