ESR2

High-Z sensor materials on Medipix3RX

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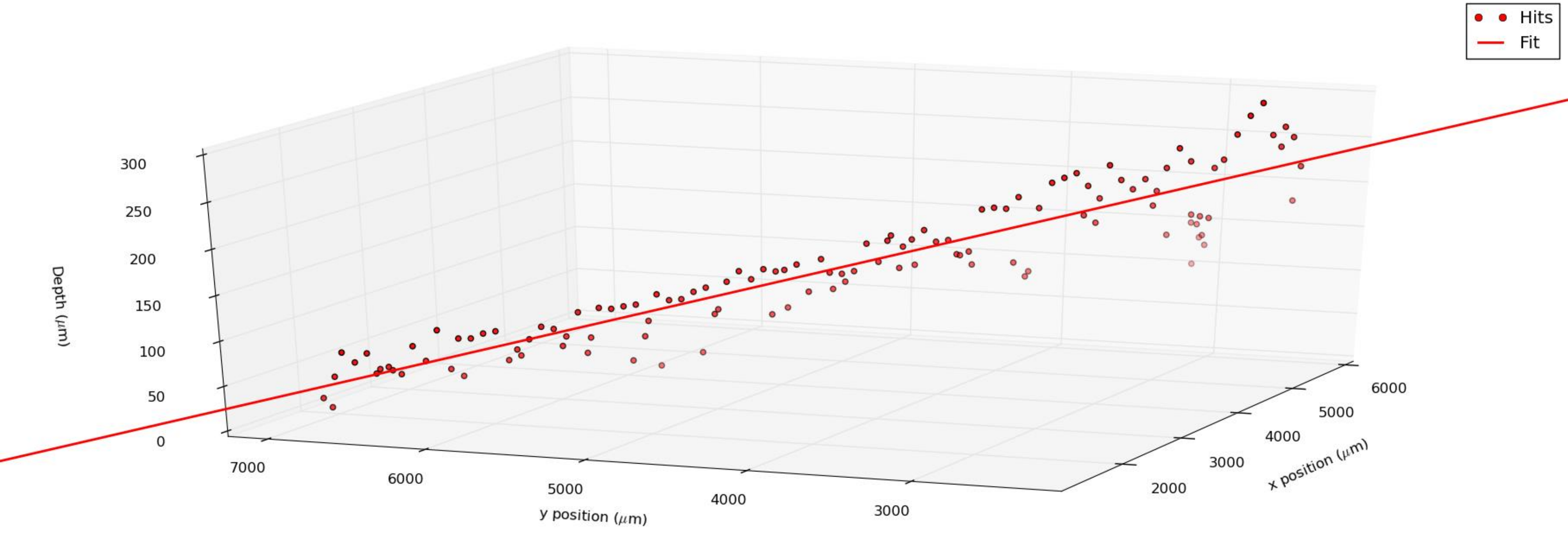
1. Mid Sweden University
2. CERN

ARDENT WORKSHOP 2014 - SCHWARZENBRUCK

OUTLINE

- Summary of research activities
- Comparison between CdTe, CZT and Silicon bump bonded to Medipix3RX
  - Measurement setup
  - Calibration
  - Energy resolution
  - Flat field at 25 keV
  - Single pixel energy resolution
  - First look at MTF with CZT assemblies
  - Conclusions
  - Future work

	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-



Note: Not to scale!

Bias 100V, Ikrum 5, with time walk correction

RESEARCH ACTIVITIES AND CONFERENCES
SINCE THE LAST WORKSHOP

- IEEE Conference in Seoul
  - Dosimetry workshop: Measurement of backscattered radiation in a CT room using Dosepix
  - RTSD: Spectral resolution and optimized threshold equalization of a charge summing hybrid pixel detector
- Beam time in Legnaro for Gempix and Timepix (with converters)
- Geant4Medipix: A simulation framework for hybrid pixel detectors
- First measurements with Timepix3
  - Oral presentation at the 16^{th} iWoRID conference in Trieste, Italy
  - Co author on two poster presentations
- Characterization of CdTe and CZT bump bonded to Medipix3RX
  - Including 2 weeks in the X-ray lab in Sundsvall and a planned test beam at the ANKA synchrotron
- RQR, Medical beam quality measurements using Dosepix. In collaboration with IRA, Lausanne
  - Presented as a poster on the IRPA 2014 conference in Geneva

LIST OF PUBLICATIONS
PEER REVIEWED

1. E Frojdh, R Ballabriga, M Campbell, M Fiederle, E Hamann, T Koenig, X Llopart, D de Paiva Magalhaes and M Zuber, **Count rate linearity and spectral response of the Medipix3RX chip coupled to a 300m silicon sensor under high flux conditions** , JINST Vol 9, April 2014
2. M De Gaspari, J Alozy, R Ballabriga, M Campbell, E Fröjdh, J Idarraga,c, S Kulis, X Llopart, T Poikela, P Valerio and W Wong**, Design of the analog front-end for the Timepix3 and Smallpix hybrid pixel detectors in 130 nm CMOS technology** ,JINST Vol 9, January 2014

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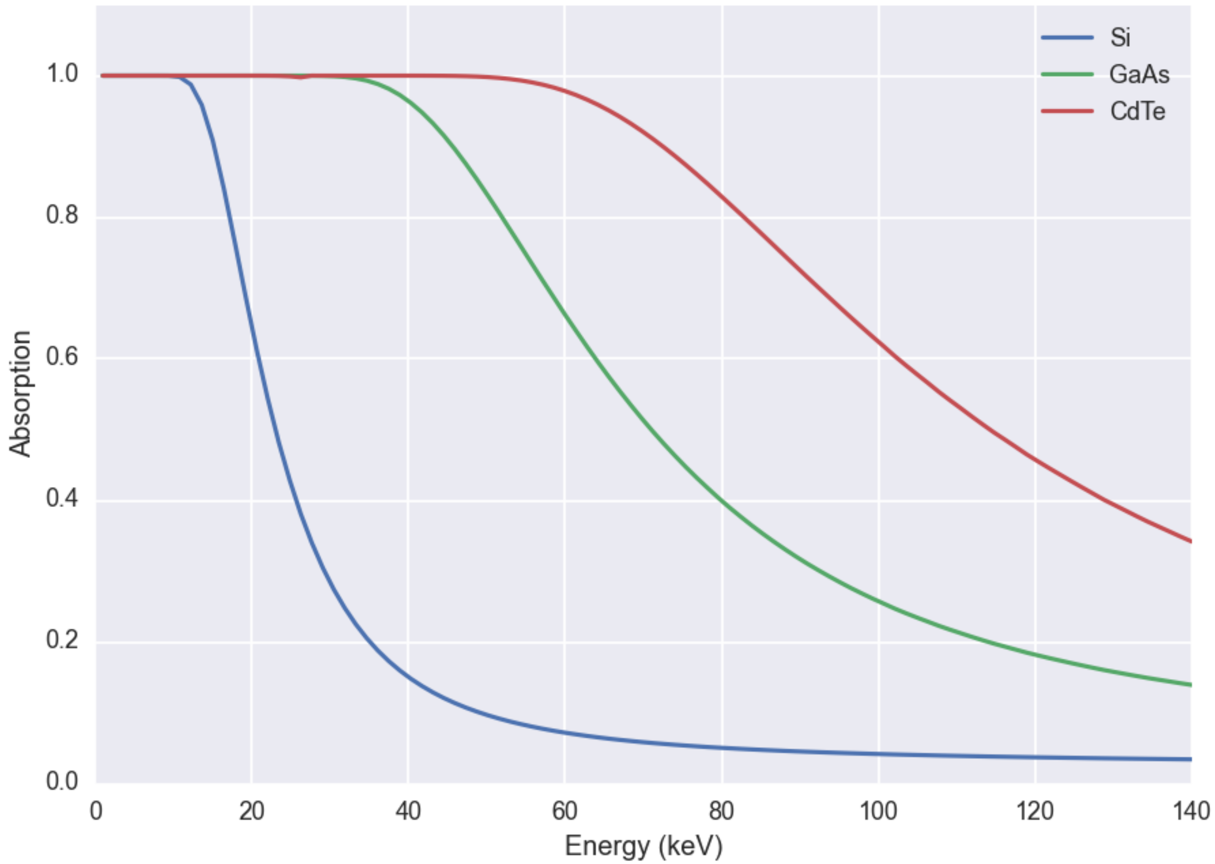
3. Frojd, E.; Frojdh, C.; Gimenez, E.N.; Krapohl, D.; Maneuski, D.; Norlin, B.;O'Shea, V.; Wilhelm, H.; Tartoni, N.; Thungstrom, G.; Zain, R.M., Probing Defects in a Small Pixellated CdTe Sensor Using an Inclined Mono Energetic X-Ray Micro Beam , Nuclear Science, IEEE Transactions on , vol.60, no.4, pp.2864,2869, Aug. 2013
4. R Ballabriga, J Alozy, G Blaj, M Campbell, M Fiederle, E Frojdh, E H M Heijne, X Llopart, M Pichotka, S Procz, L Tlustos andWWong, The Medipix3RX: a high resolution, zero dead-time pixel detector readout chip allowing spectroscopic imaging , JINST Vol 8, February 2013
5. E. Fröjdh, C. Fröjdh, E.N. Gimenez, D. Maneuski, J. Marchal, B. Norlin, V. O'Shea, G. Stewart, H. Wilhelm, R.M Zain and G. Thungström, Depth of interaction and bias voltage depenence of the spectral response in a pixellated CdTe detector operating in Time-OverThreshold mode subjected to monochromatic Xrays ,JINST Vol 7, March 2012
6. D. Maneuski, V. Astromskas, E. Fröjdh, C Fröjdh, E.N. Gimenez, J. Marchal, V. O'Shea, G. Stewart, N. Tartoni, H. Wilhelm, K.Wraight and R.M. Zain Imaging and spectroscopic performance studies of pixellated CdTe Timepix detector , JINST Vol 7, January 2012
7. S. Reza, W.S. Wong, E. Fröjdh, B. Norlin, C. Fröjdh, G. Thungström and J. Thim Smart dosimetry by pattern recognition using a single photon counting detector system in time over threshold mode , 2012 JINST Vol 7, January 2012
8. E. Fröjdh, B. Norlin, G. Thungström and C. Fröjdh X-ray absorption and charge transport in a pixellated CdTe detector with single photon processing readout , JINST Vol 6, February 2011
9. E. Fröjdh, A. Fröjdh, B. Norlin, C. Fröjdh, Spectral response of a silicon detector with 220m pixel size bonded to MEDIPIX2 , NIMA:, Volume 633, Supplement 1, May 2011, Pages S125-S127
10. A. Fröjdh, E. Fröjdh, G. Thungström, C. Fröjdh, B. Norlin, Processing and characterization of a MEDIPIX2-compatible silicon sensor with 220m pixel size , NIMA, Volume 633, Supplement 1, May 2011, Pages. S78-S80,

MOTIVATION FOR HIGH-Z MATERIALS



Absorption in 1 mm

FLUORESCENCE

IN HIGH-Z MATERIALS

Mean free path of fluorescence photon [μm]

Fluorescence yield [%]

Energy fluorescence photons [keV]

Z

Material	N	K_1	L_2	L_3	$K_{\alpha 1}$	$K_{\alpha 2}$	$d_{\alpha 1}$	$d_{\alpha 2}$	$\eta[\%]$
Si	14	1.84	0.10	0.10	1.74	1.74	11.86	11.86	4.1
GaAs									
Ga, 48.20%	31	10.36	1.14	1.11	9.25	9.22	40.62	40.28	50.5
As, 51.80%	33	11.87	1.36	1.32	10.54	10.50	15.62	15.47	56.6
CdTe									
Cd, 46.84%	48	26.71	3.73	3.53	23.17	22.98	113.20	110.75	83.6
Te, 53.16%	52	31.81	4.61	4.34	27.47	27.20	59.32	57.85	87.3

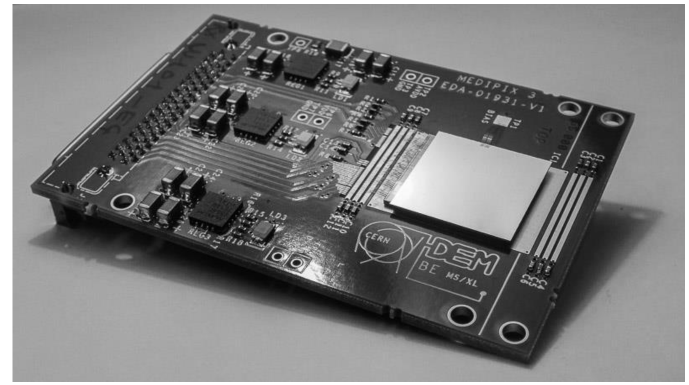
The mean free path of the fluorescence photons is in the same order of magnitude as the pixel pitch

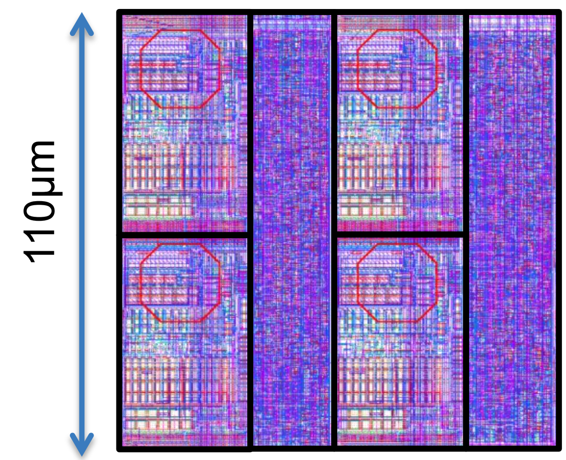
The fluorescence yield increases with the atomic number

Table: L. Tlustos, PhD thesis

MEDIPIX3RX

- 256x256 pixels
- 55x55 um pitch
- Charge summing over dynamically allocated 2x2 pixel clusters
- 2x12bit counters and 2 thresholds per pixel
- 5 bit Threshold adjustment dac
- Highly configurable
  - 4 different gain modes
  - Single pixel or charge summing
  - Electron or hole collection
  - Intrinsic 55um pixel pitch or 110um pixel pitch using eight thresholds per pixel

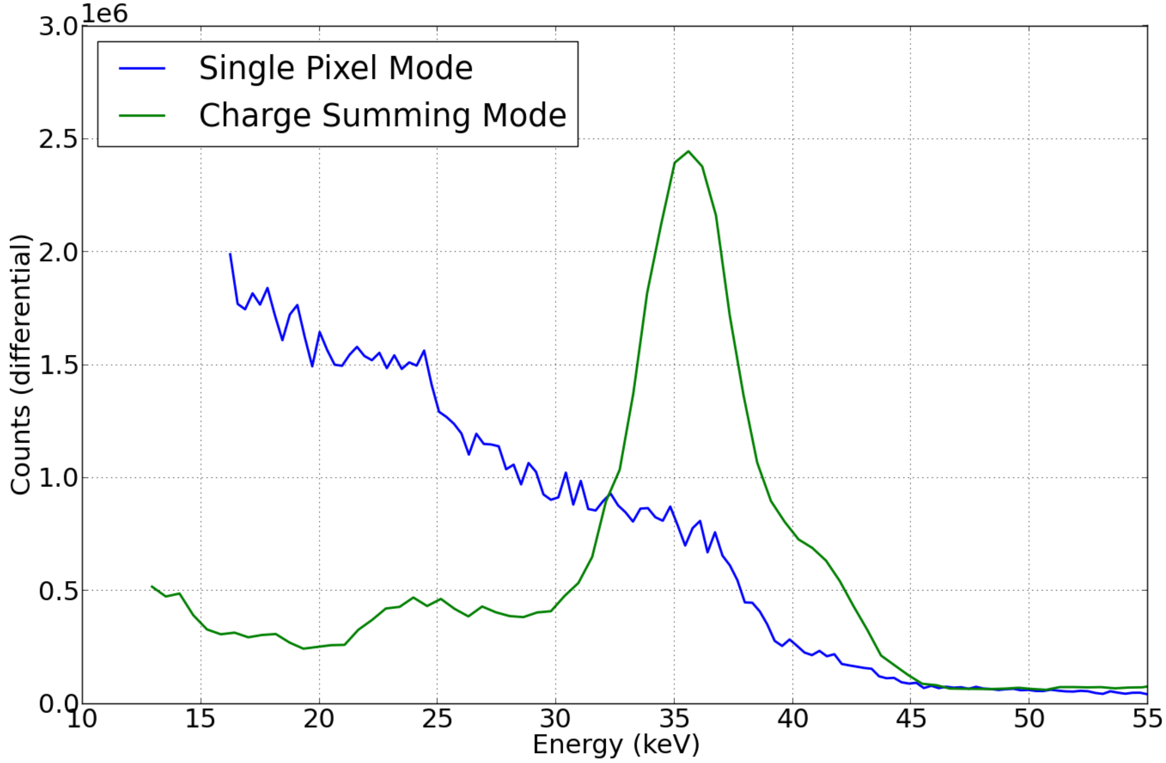




Layout of 2x2 pixels

MEDIPIX3: CHARGE SUMMING

2MM TICK CdTe SENSOR 110UM PITCH



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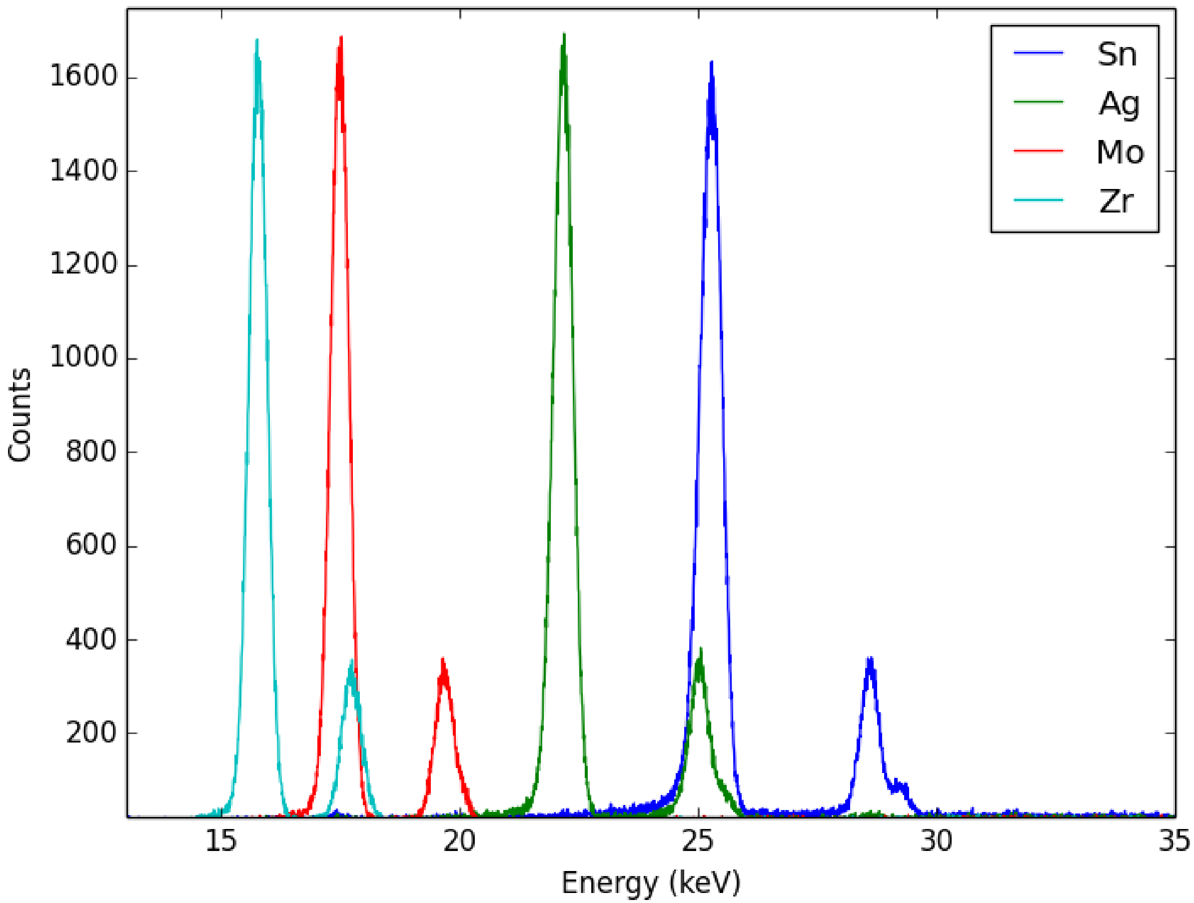
SENSORS

	W109_C3	W1127_I6	W146_F9	W146_F10
Material	Silicon (n-on- p)	CdTe	CZT	CZT
Pixel size	55 um	110 um	110 um	110 um
Thickness	200 um	2 mm	2 mm	2 mm
Bias voltage	-60 V	-600V	-600V	-600V
Leakage current	< 2 uA	~4uA	< 0.5 uA	< 0.5 uA

CALIBRATION – CSM

1. VERIFICATION OF INPUT SPECTRUM

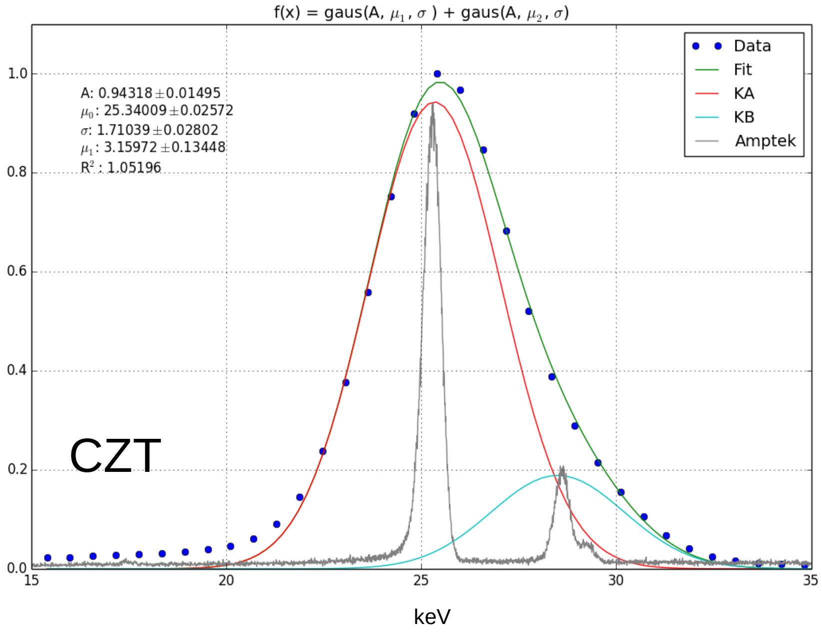


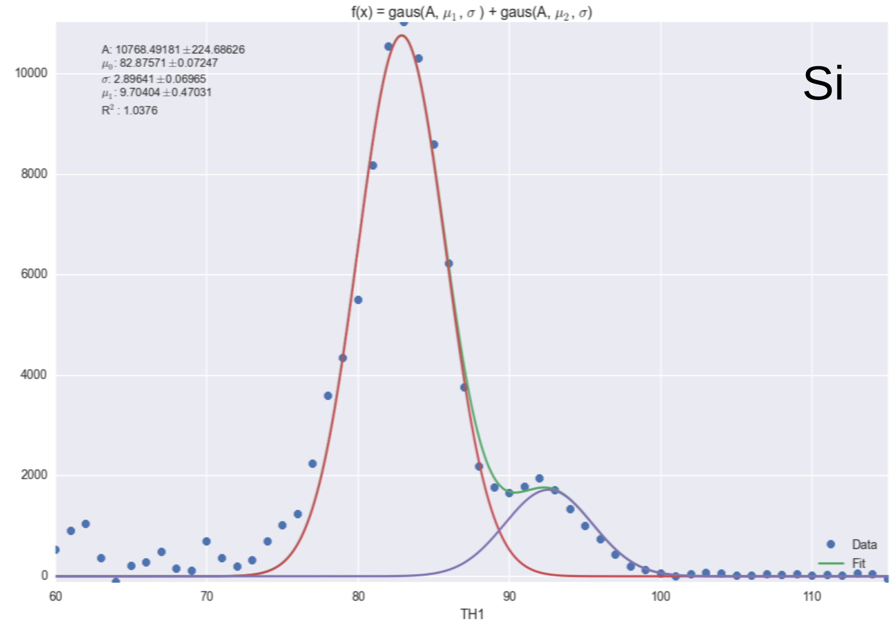
	kα
Zirconium	15.7
Molybdenu m	17.5
Silver	22.2
Tin	25.3

Amptek X-123CdTe Spectrometer

CALIBRATION – CSM

2. FIT OF THE PEAK WITH TWO GAUSSIANS





Same sigma is used and the ratio between the kα and kβ peak is 0.22 for CZT and 0.16 for Silicon

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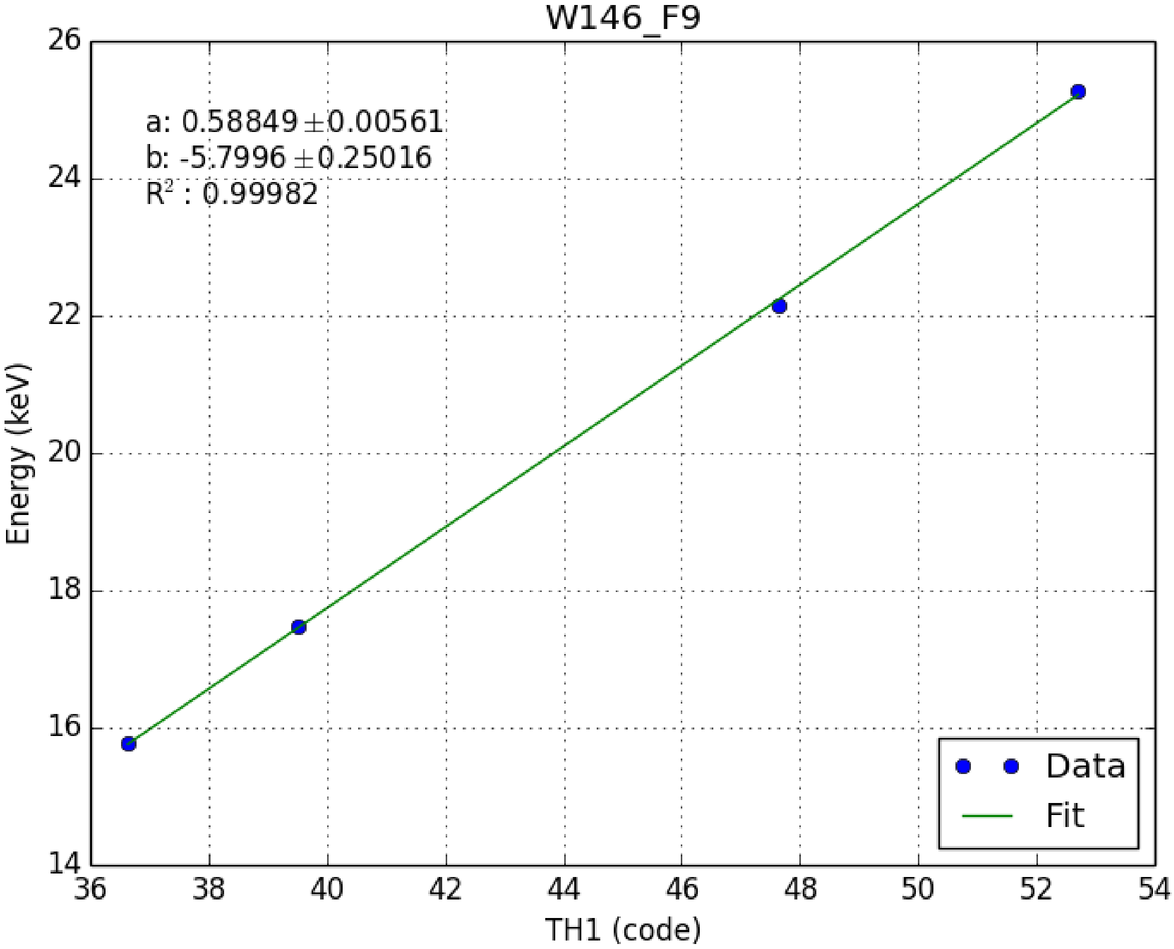
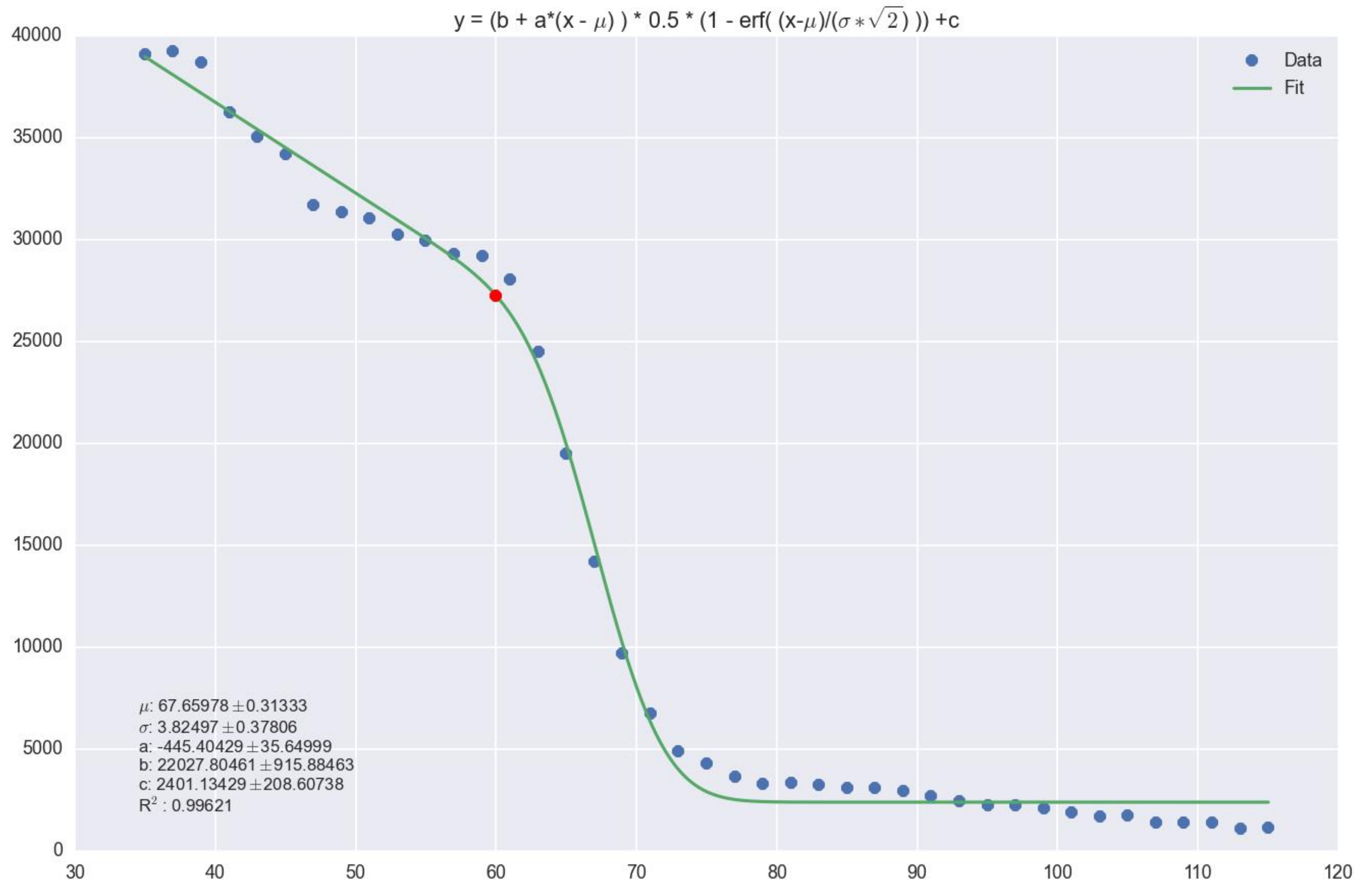
CALIBRATION – CSM

3. LINEAR FIT TO THE FOUR PEAK POSITIONS



CALIBRATION – SPM

2. FITTING THE DIFFERENTIATED SPECTRUM WITH AN ERROR FUNCTION



ENERGY RESOLUTION

CSM, FWHM (keV)

	15.7	17.5	22.2	25.3
W109_C3 (Silicon)	2.25	2.26	2.55	2.65
W109_C3 (Silicon)*	2.25	2.31	2.34	2.43
W146_F9 (CZT)	3.73	3.97	4.31	4.51
W146_F10 (CZT)	4.32	4.44	5.17	5.24
W146_F10* (CZT)	4.67	4.91	5.15	5.32
W1127_I6 (CdTe)	3.12	3.09	3.53	3.69

*HGM/High Equalized at 7000e--

Advanced Radiation Dosimetry European Network Training

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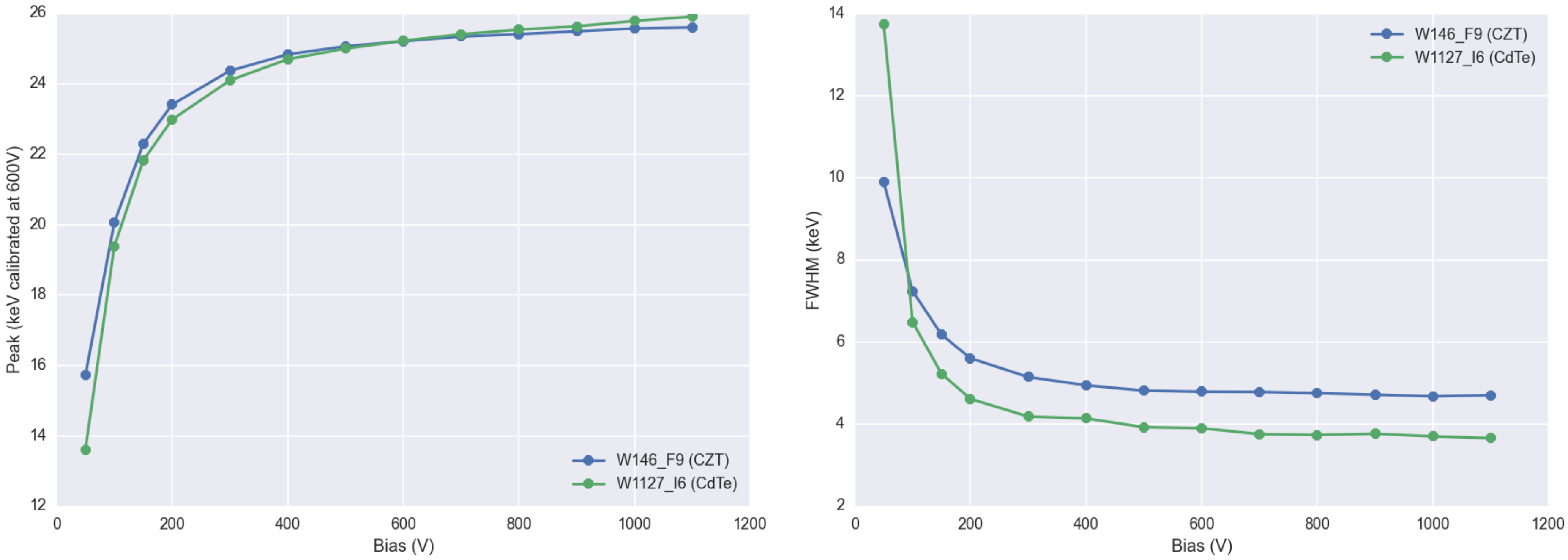
DEPENDENCE ON BIAS VOLTAGE

25keV Sn FLUORESCENCE

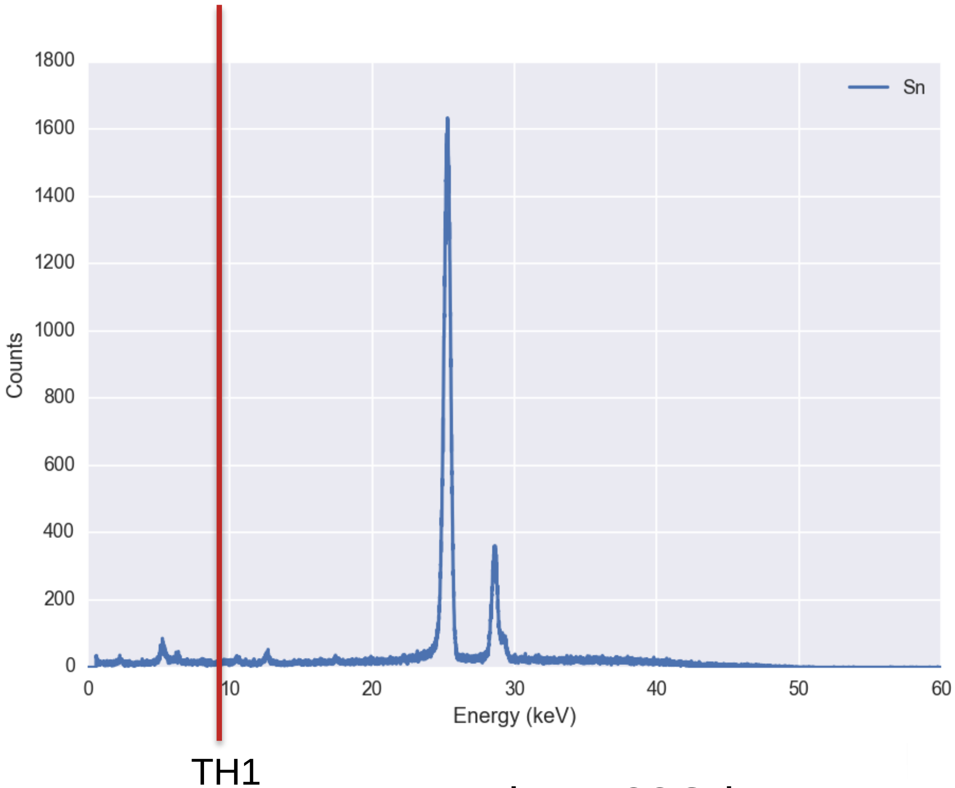


Both materials show similar characteristics

FLAT FIELD

- Fluorescence from Sn (25keV)
- Threshold at ~ 9 keV
- Threshold mismatch should have only a small influence on the number of counts.

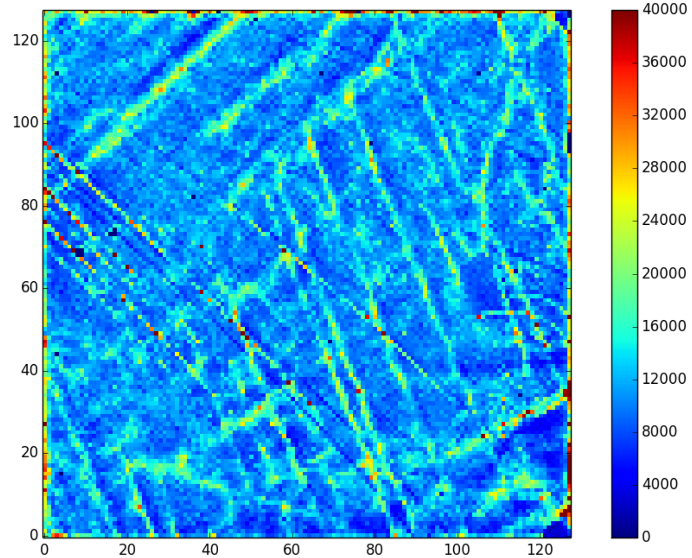
- HGM, Moderate

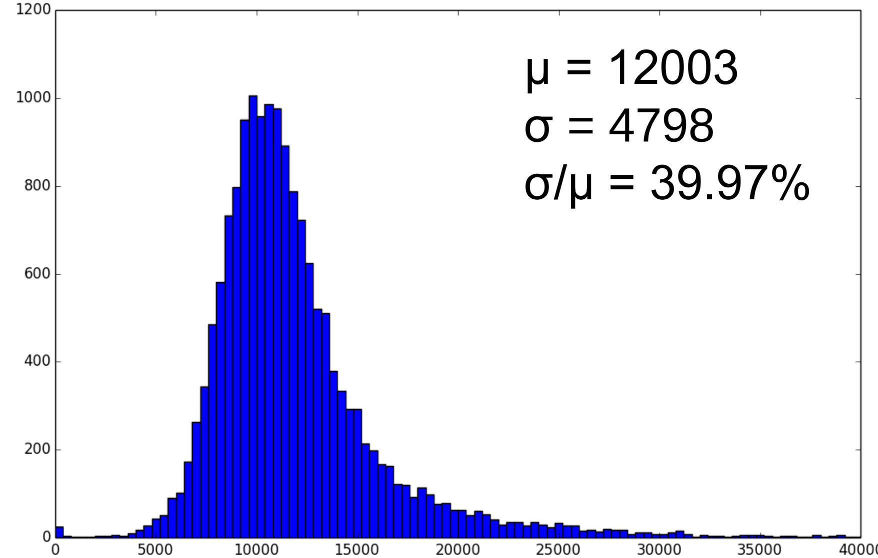


Amptek X-123CdTe

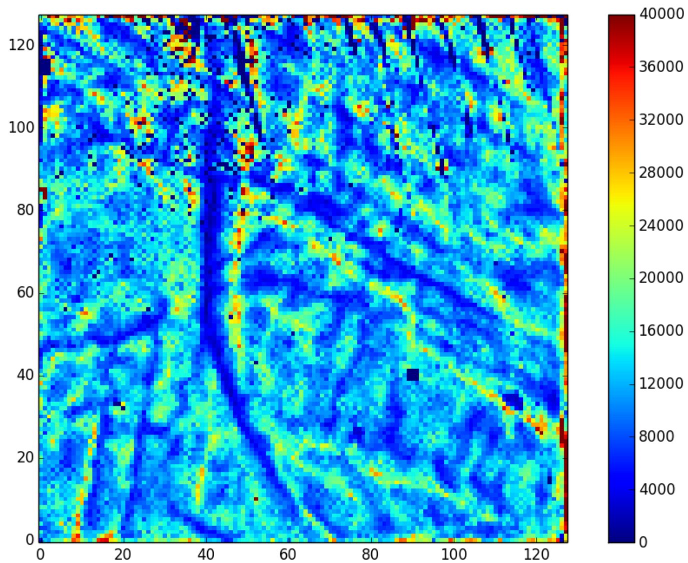
FLAT FIELD

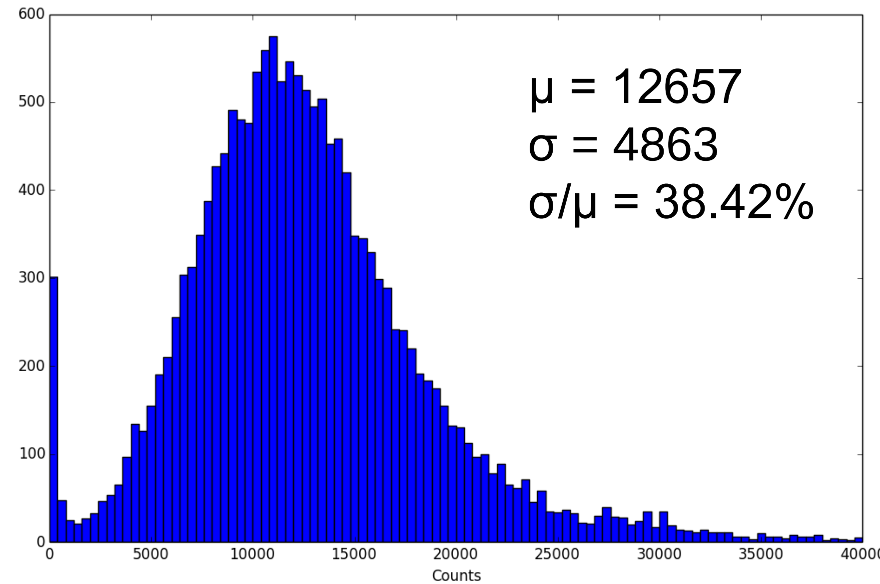
W146_F9





W146_F10



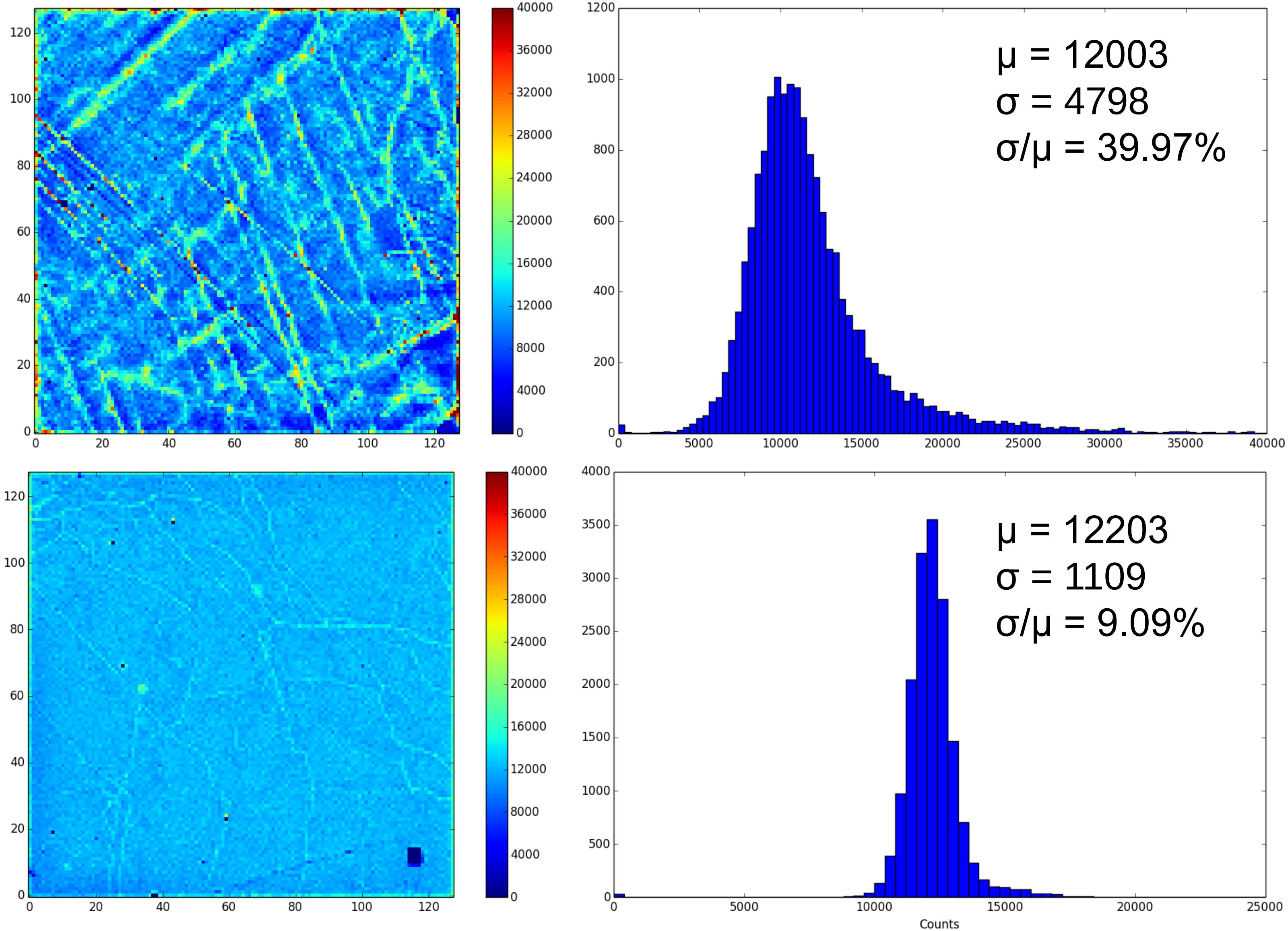


Note! Poisson limit σ ~ 110

FLAT FIELD

W146_F9

W146_F10



Note! Poisson limit σ ~ 110

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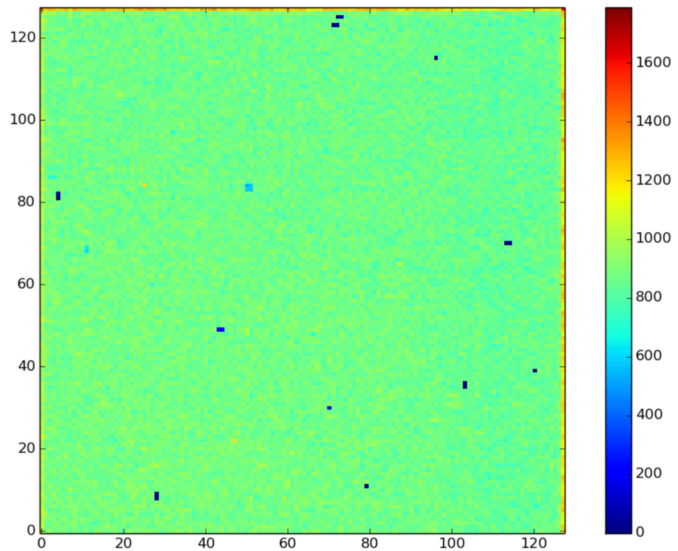
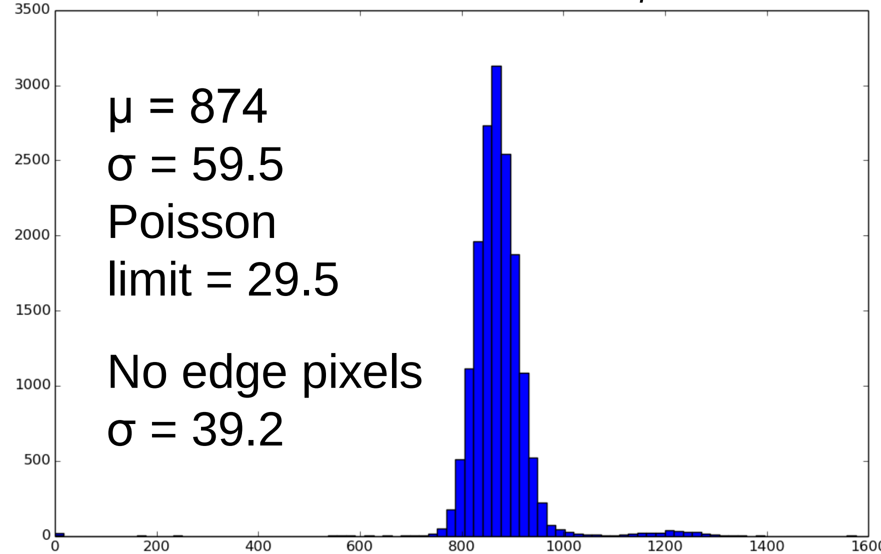
FLAT FIELD

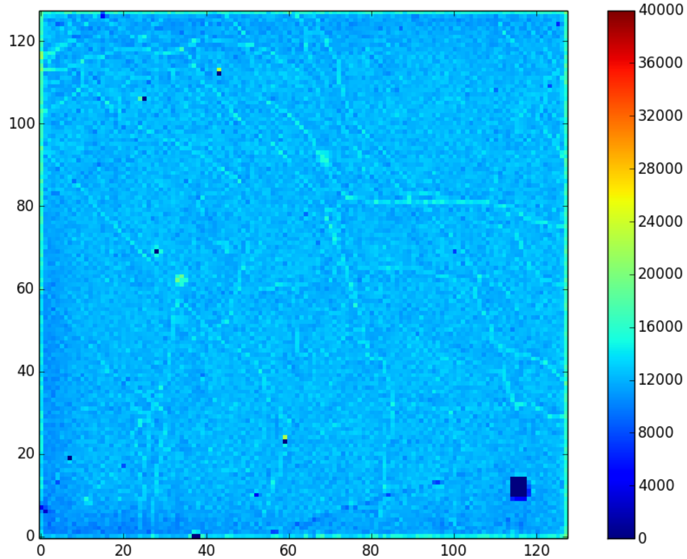
W109_C3

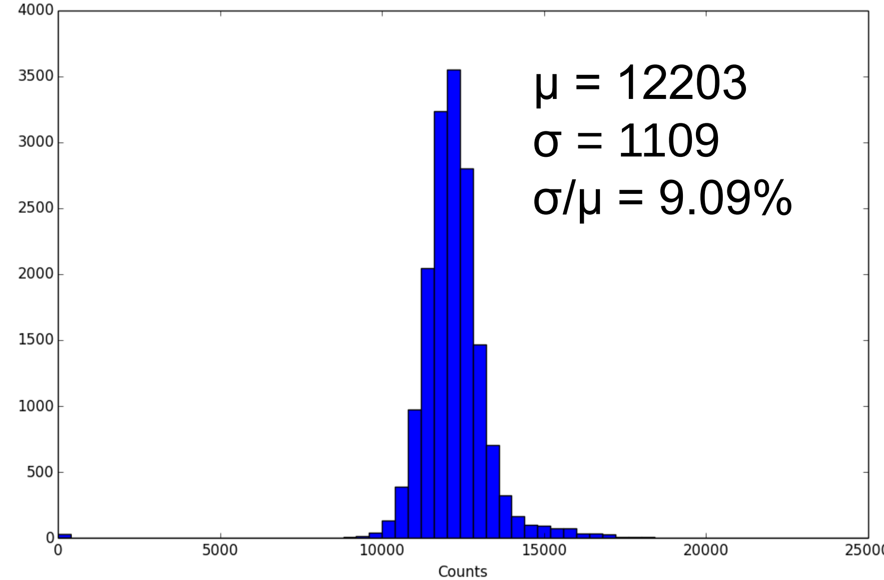


Less statistics due to lower absorption



W146_F10

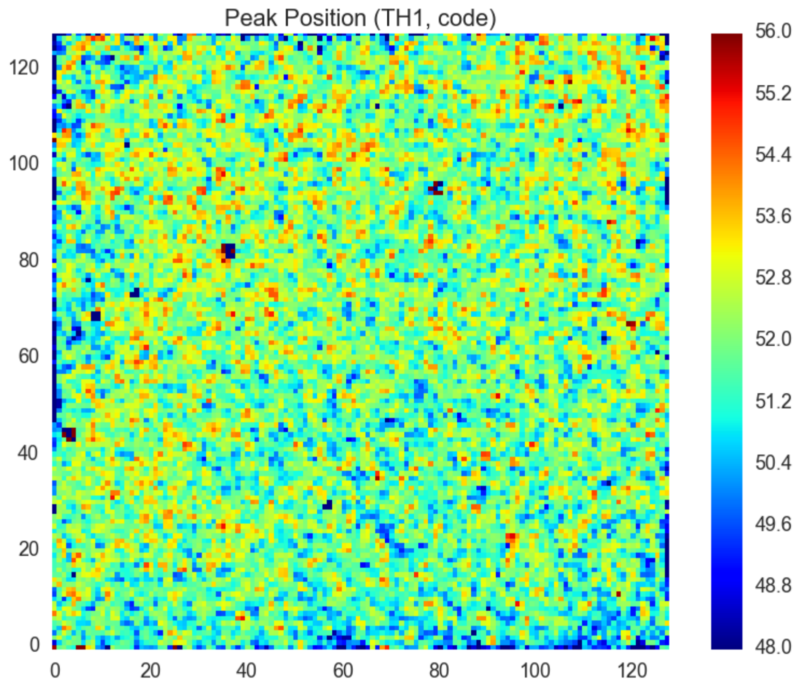


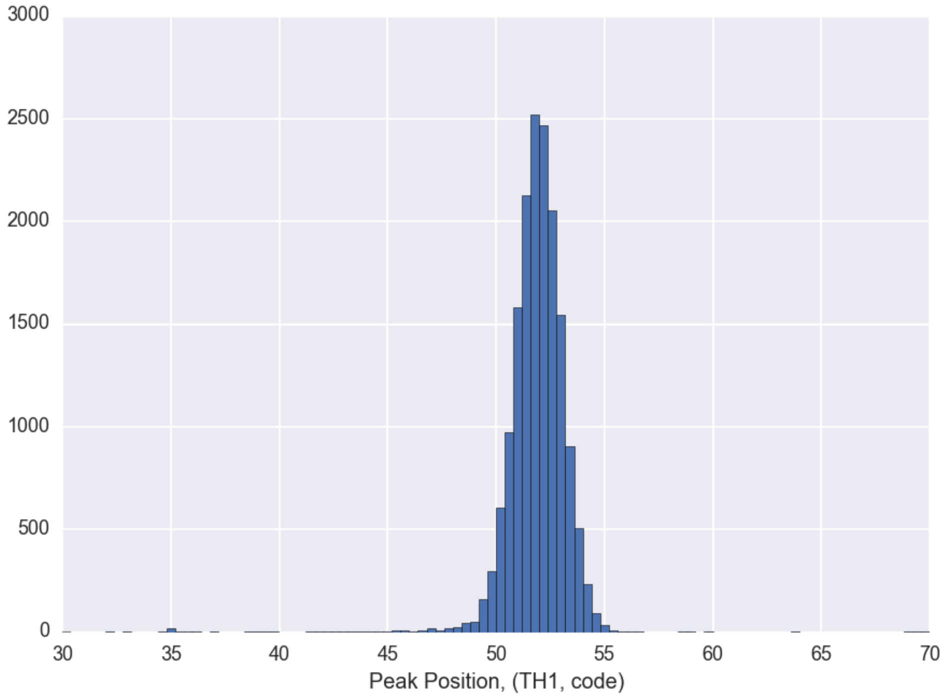


Note! Poisson limit σ ~ 110

PEAK POSITION (CZT)

CSM, 25keV Sn FLUORESCENCE



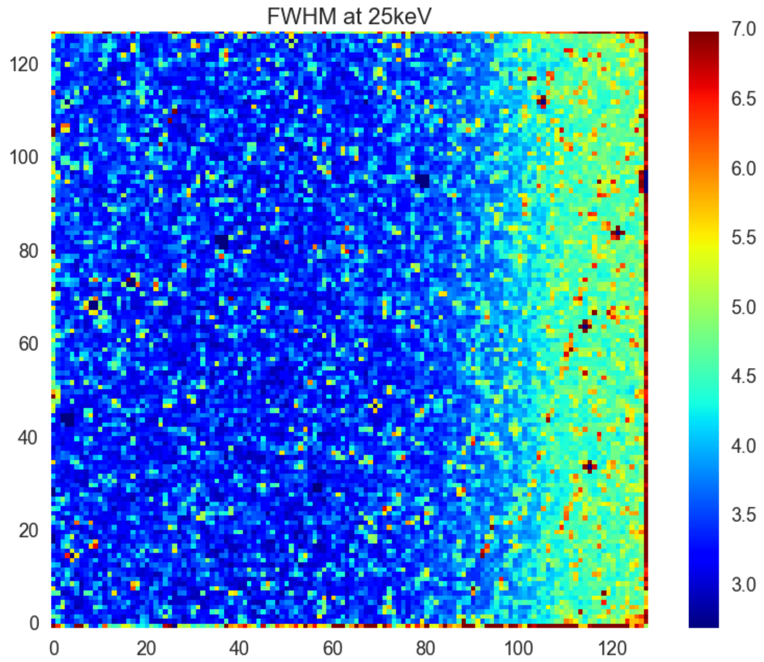


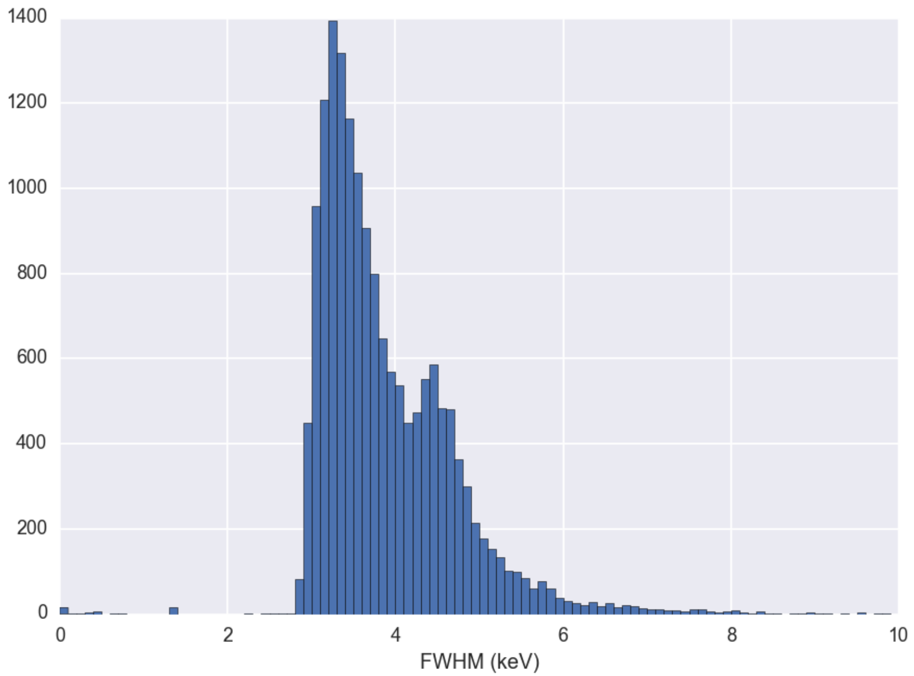
σ = 2.24 TH1 step

σ = 1.32 keV

ENERGY RESOLUTION (CZT)

CSM, 25keV Sn FLUORESCENCE





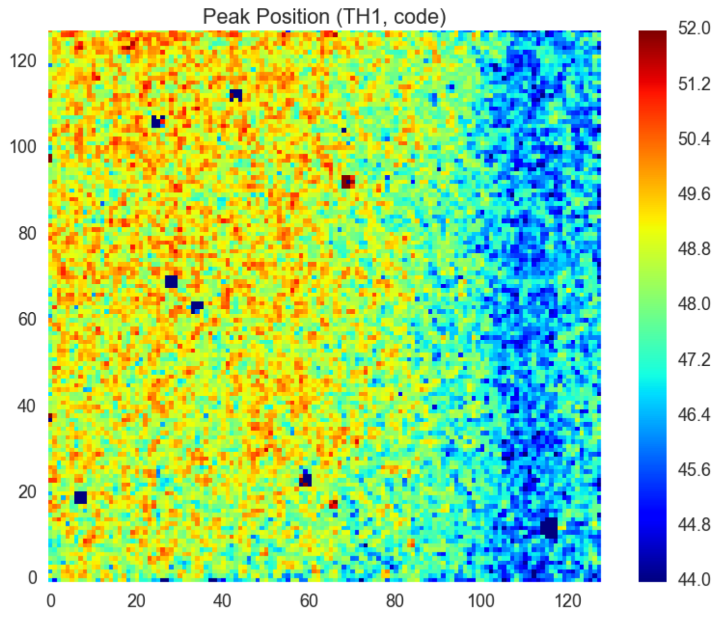
$\mu = 3.89$ keV

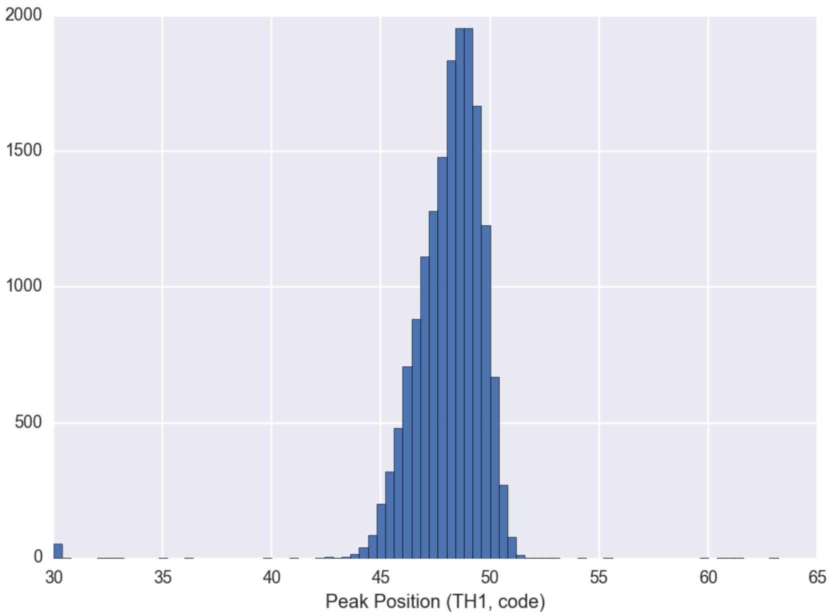
$\sigma = 0.97$ keV

Note: The increased noise on the right side is minimized in Medipix3RXv2 respin

PEAK POSITION (CdTe)

CSM, 25keV Sn FLUORESCENCE



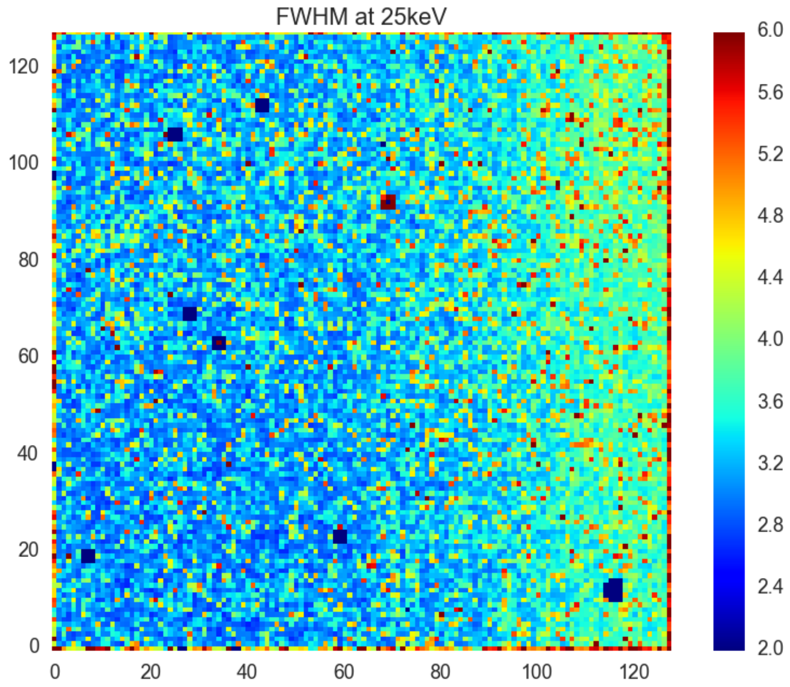


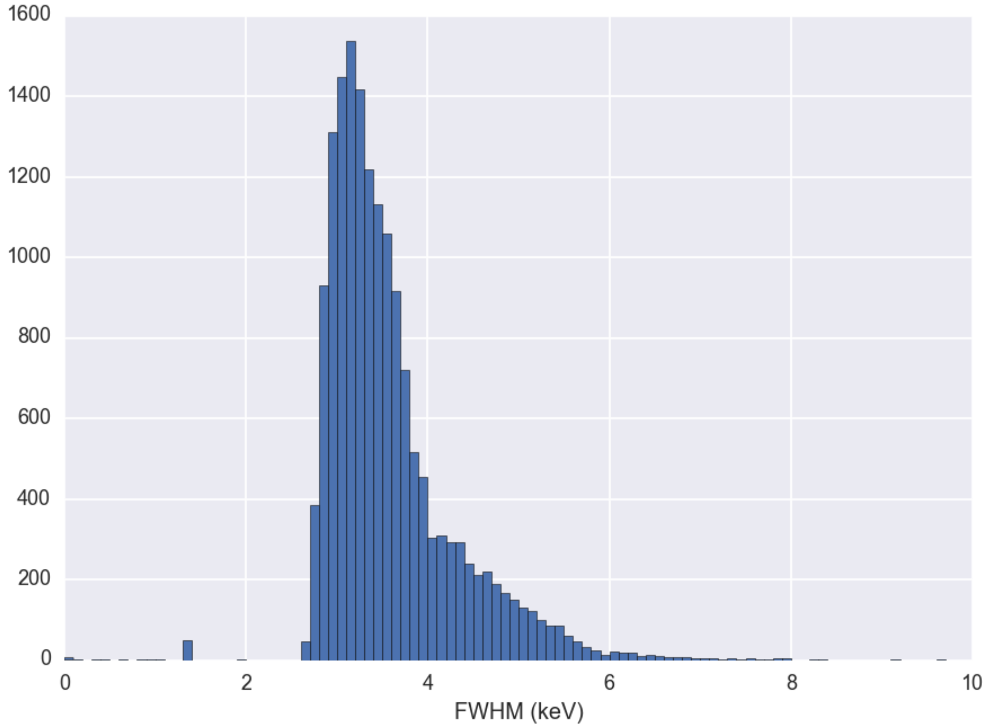
σ = 1.93 TH1 step

σ = 1.12 keV

ENERGY RESOLUTION (CdTe)

CSM, 25keV Sn FLUORESCENCE



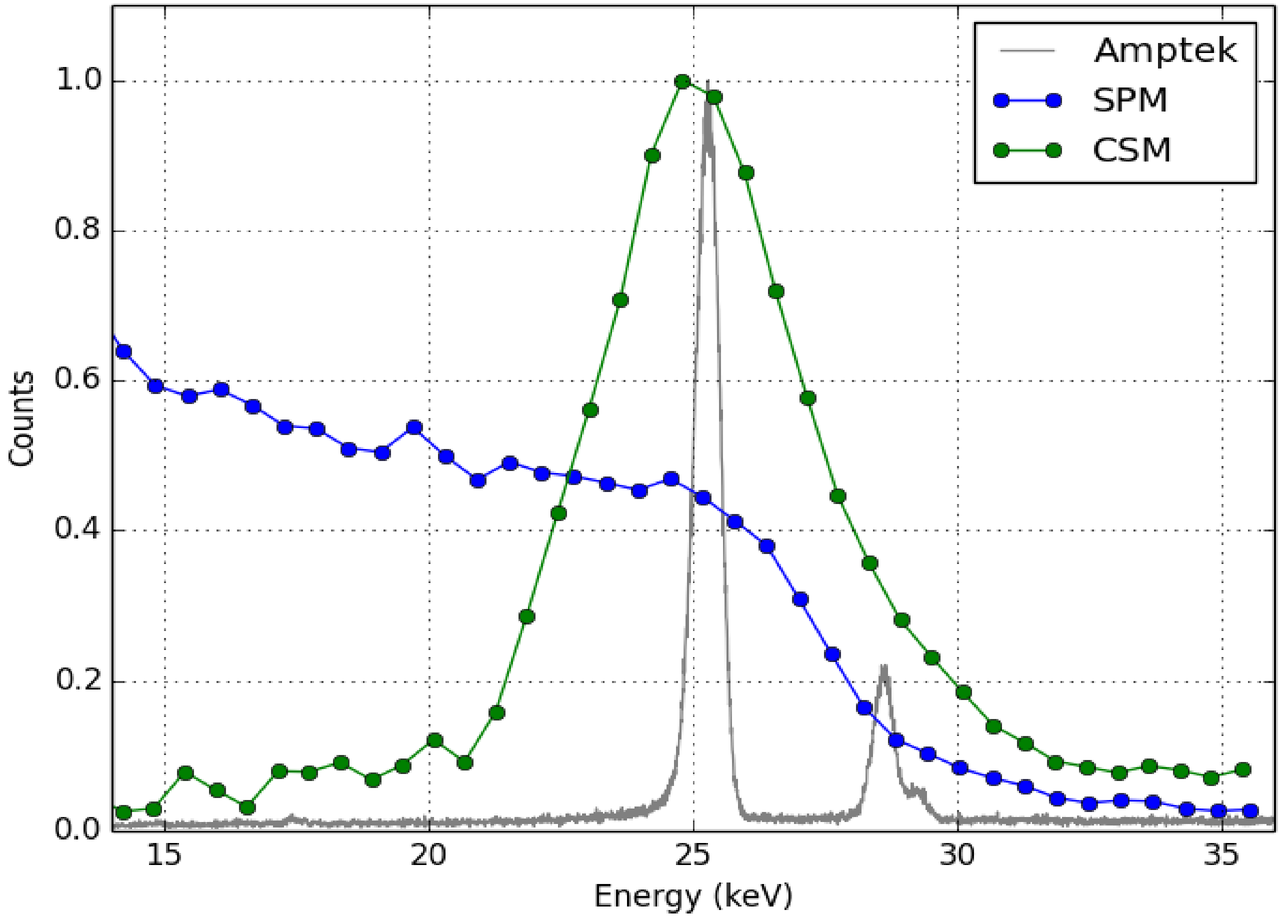


μ = 3.56 keV

σ = 0.73 keV

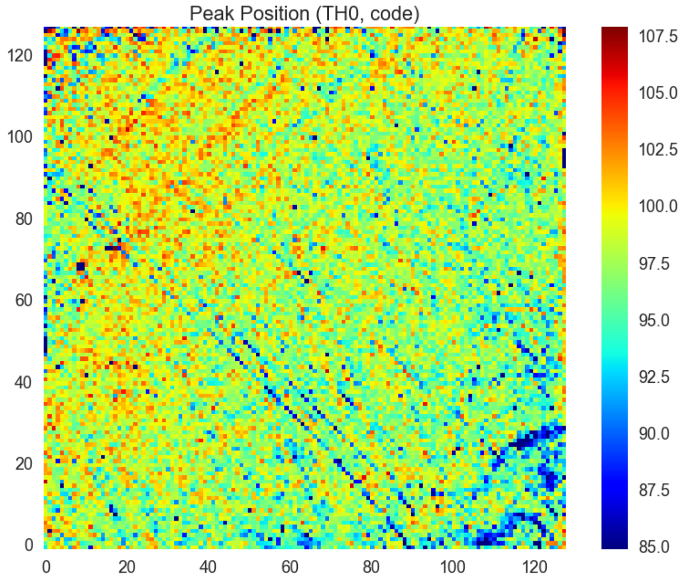
PEAK/EDGE POSITION (CZT)

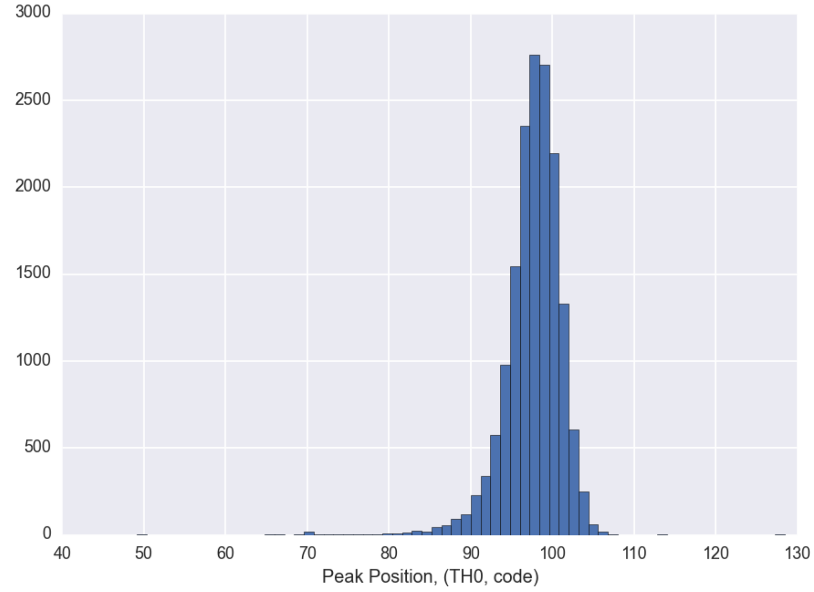
SPM, 25keV Sn FLUORESCENCE



PEAK/EDGE POSITION (CZT)

SPM, 25keV Sn FLUORESCENCE





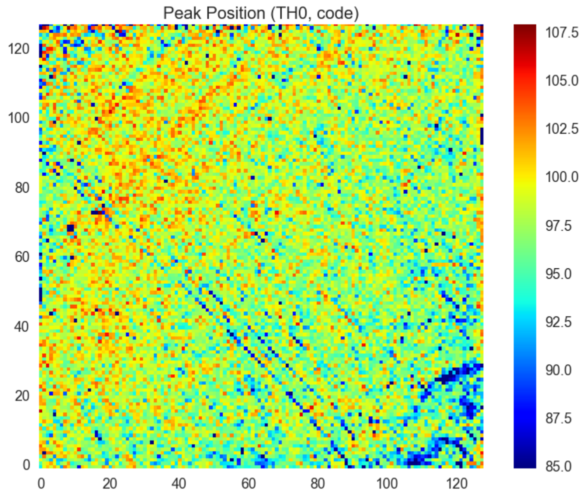
σ = 5.36 TH0 step (*Note! the gain is ~2x of TH1*)

σ = 1.63 keV

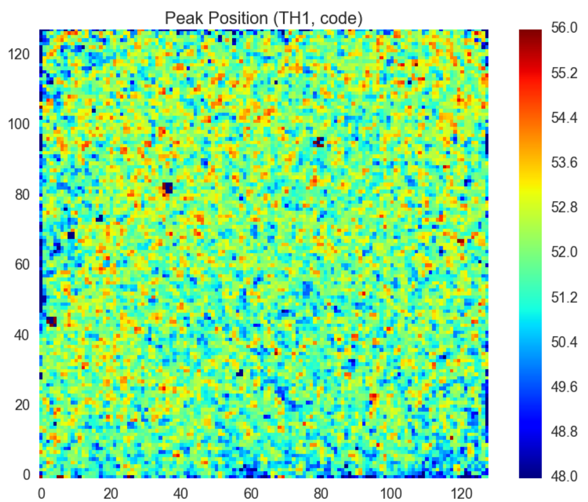
PEAK/EDGE POSITION (CZT)

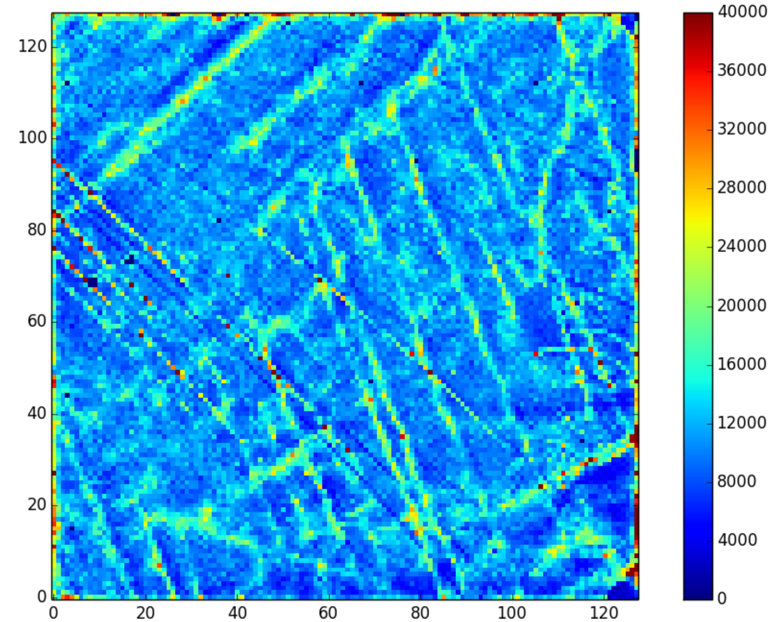
SPM, 25keV Sn FLUORESCENCE

SPM



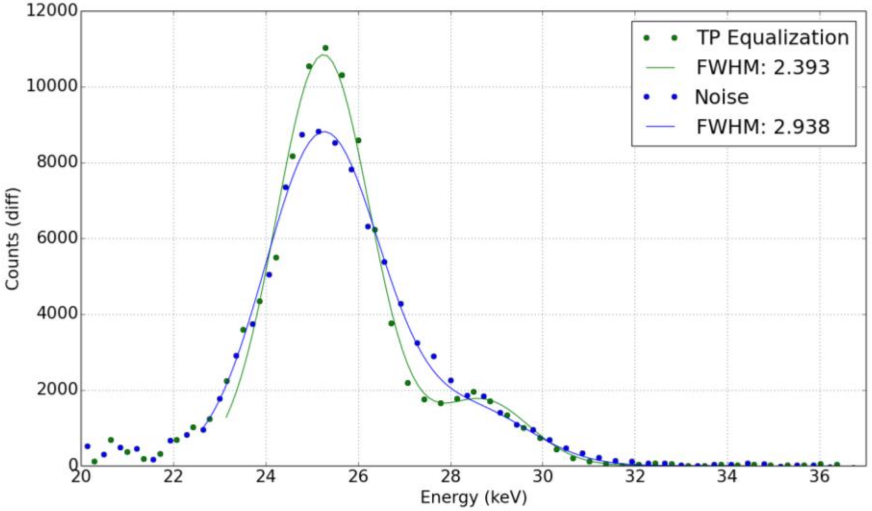
CSM



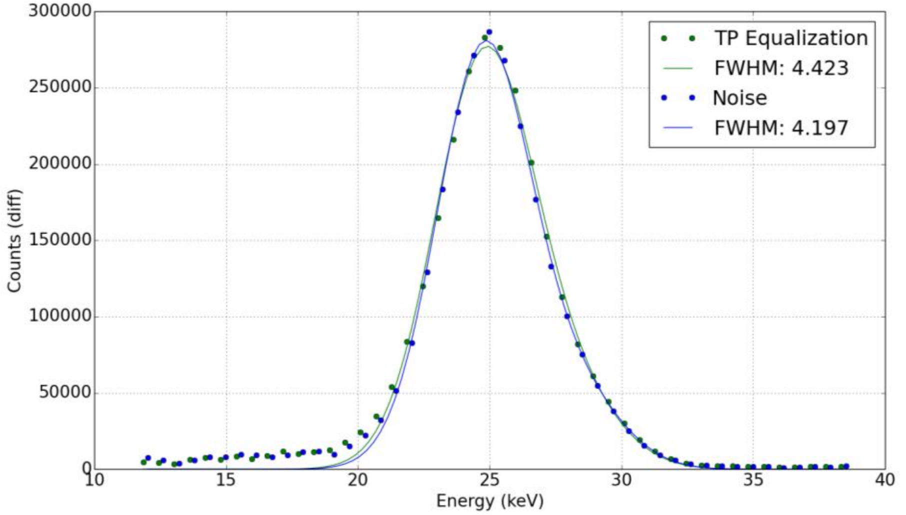


Counts, 25keV, CSM

NOISE VS. TP EQUALIZATION



Silicon



CZT

No improvement In energy resolution for CZT

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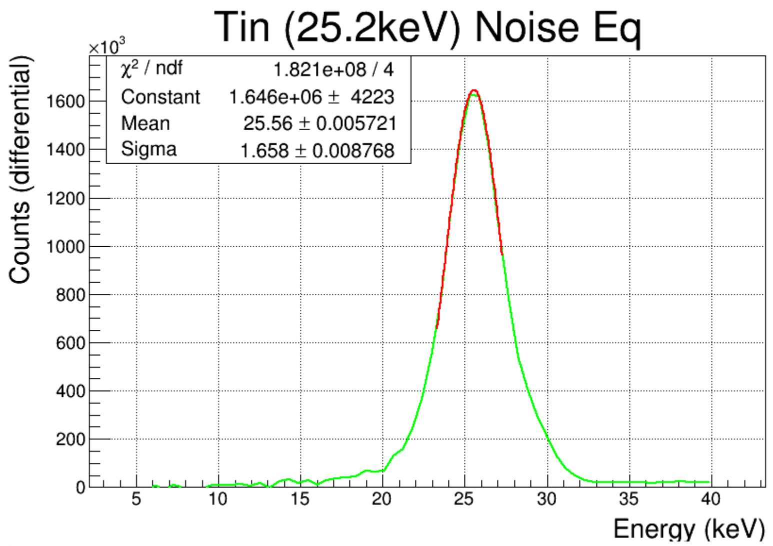
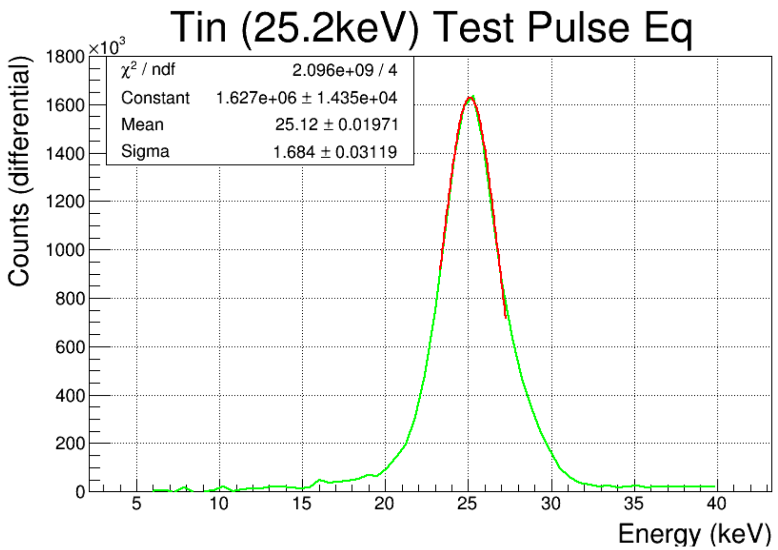
NOISE VS. TP EQUALIZATION

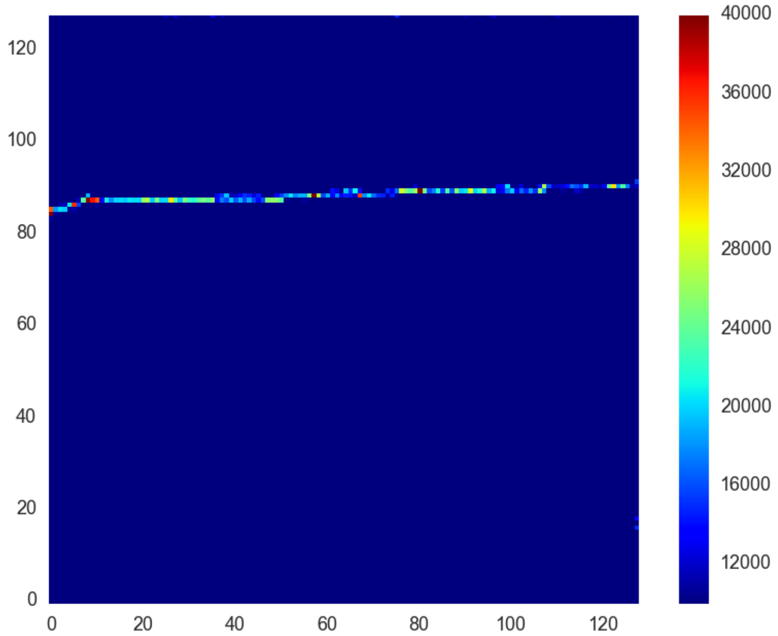


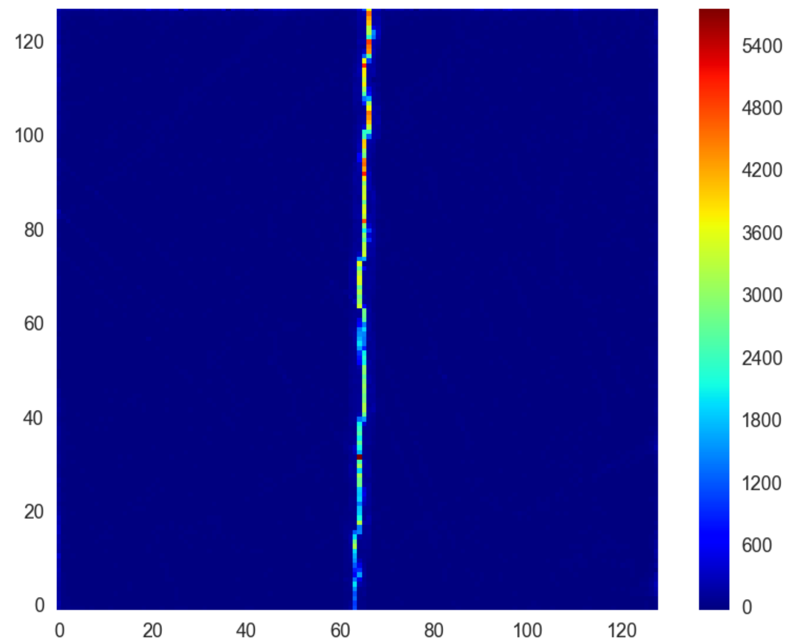


No improvement In energy resolution for CdTe, even a slight degradation.

LINE IMAGES, CZT

W146_F0, CSM





Measurements using a tungsten slit reveals displacement of charge. This is believed to be the main cause of the count rate differences in the sensor.

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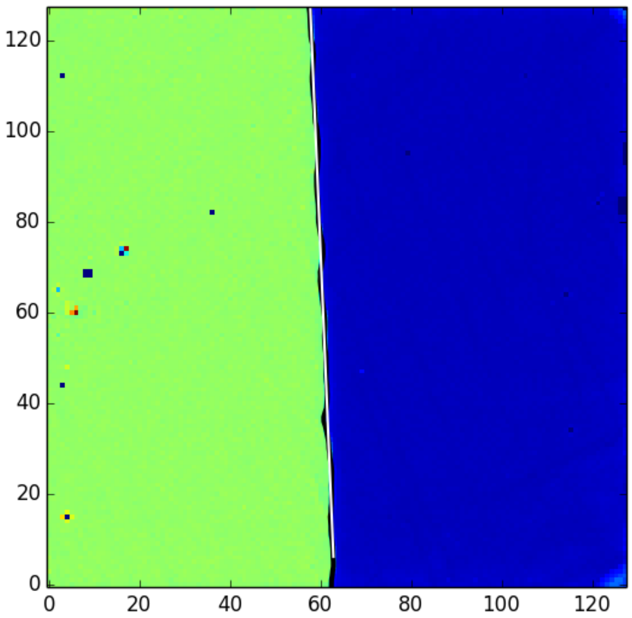
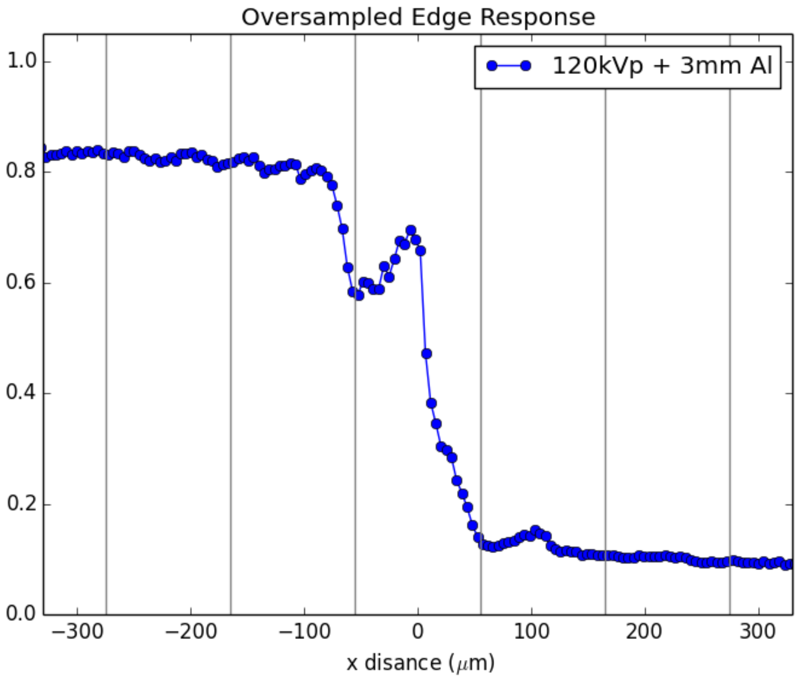
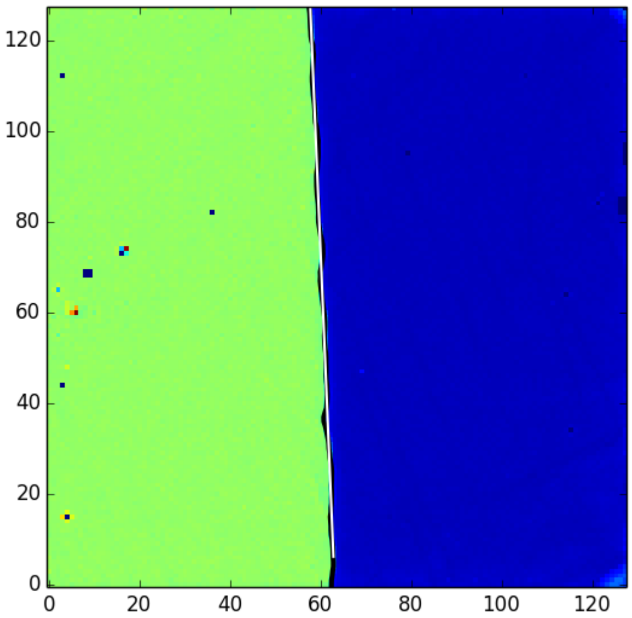
SLANTED EDGE MTF

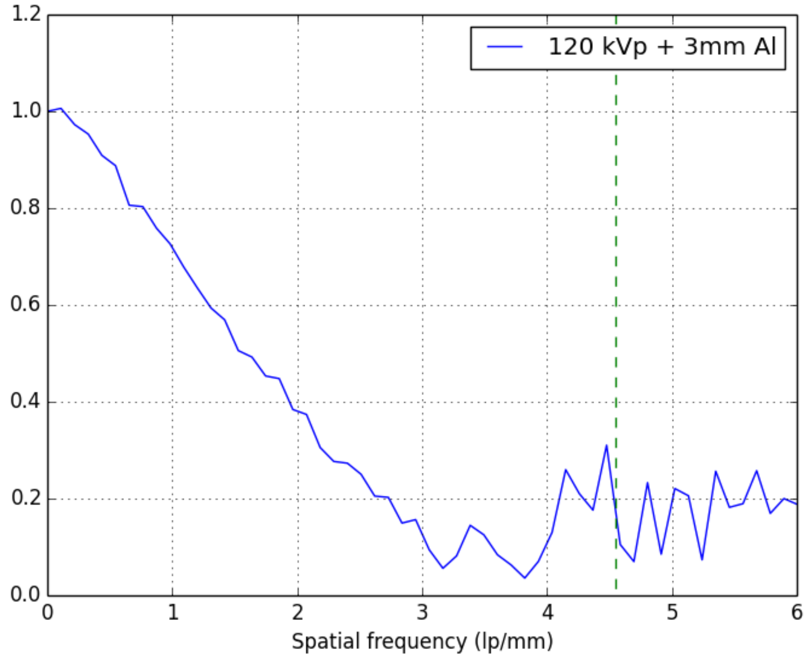




Tungsten edge
120kVp + 3mm Al

SLANTED EDGE MTF





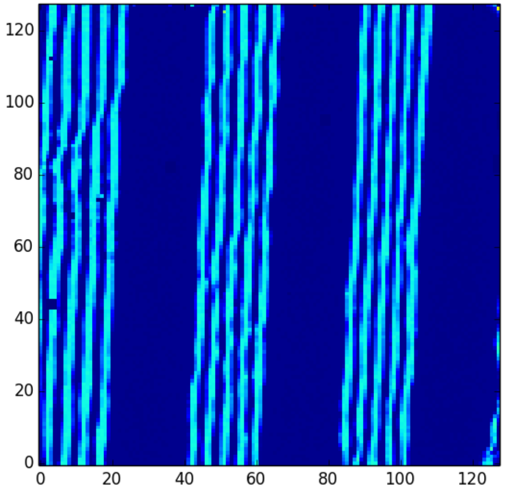
Tungsten edge
120kVp + 3mm Al

CONCLUSIONS

- Both CdTe and CZT displays good energy resolution across the sensor
- The lack of improvement in energy resolution using a test pulse calibration suggest gain differences induced by the sensor for both CdTe and CZT
- Large count rate differences are observed in the CZT sensors, probably caused by charge displacement due to an inhomogeneous electrical field
- Imagining performance is greatly affected by this charge displacement

FUTURE WORK

- Long term stability and polarization
- Improvements in the equalization procedure.
  - Precise TP measurement.
  - Ideas to use radiation
- Low energy response (3-8 keV)
- High energy response (120-662 keV)
- NPS, MTF, DQE



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