FACULTY OF SCIENCES

International Workshop 26th iWoRiD on Radiation Imaging Detectors

Deploying Timepix3 in low-radioactivity natural settings: integrated workflow for charged particle detection and imaging

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Low-Radioactivity Settings

- Settings with naturally occurring radio-elements
- Terrestrial sources: rocks, soil, and minerals
- Uranium (U)-238, Thorium (Th)-232, Potassium(K)-40
- Alpha (α), beta (β) and gamma (γ) radiation
- Activity concentration: from 100 Bq/kg to 1000 Bq/kg. Higher in some rocks

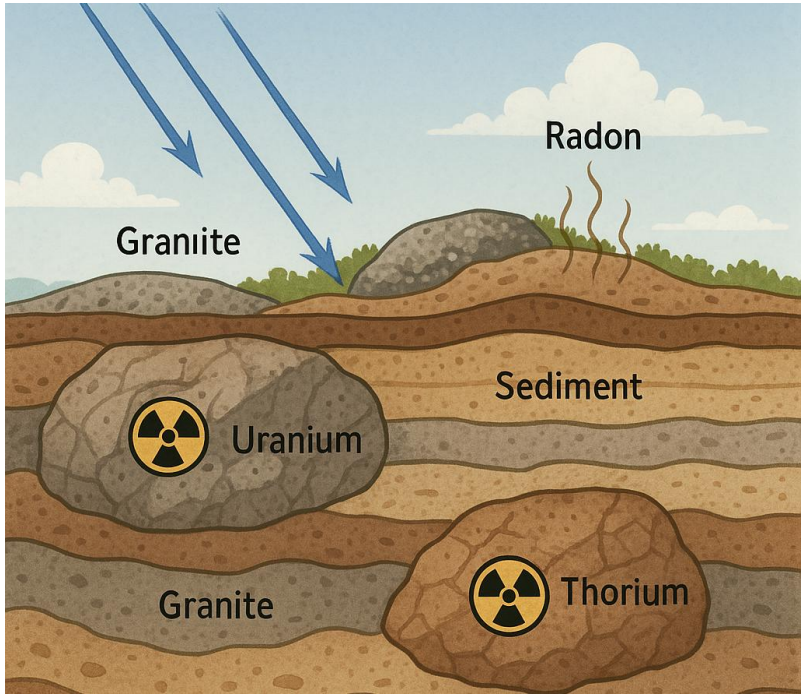

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Image source: AI

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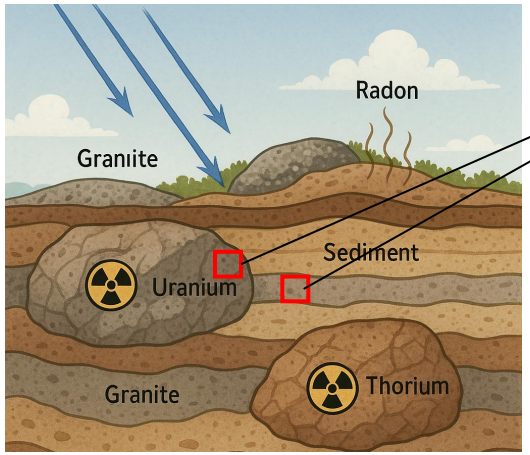
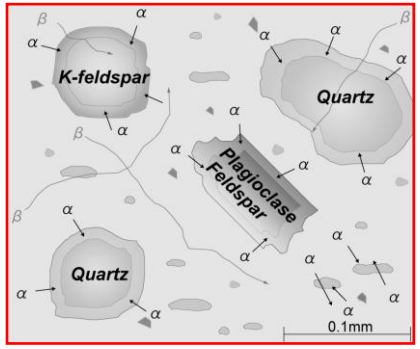
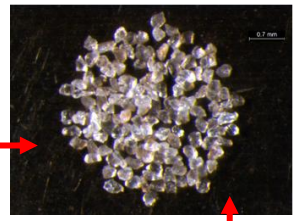
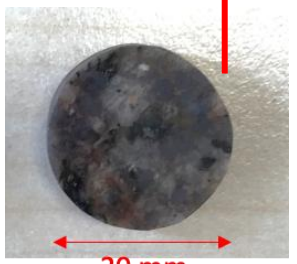
Luminescence Dosimetry

Study of radiation doses in samples through luminescence

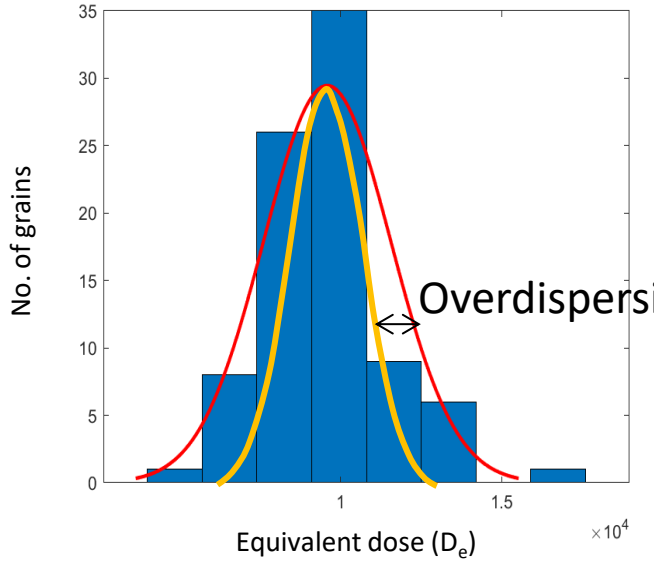








86 grains



D_e using luminescence methods

Overdispersion : Likely due to variation in doses received by individual grains (micro-dosimetry)

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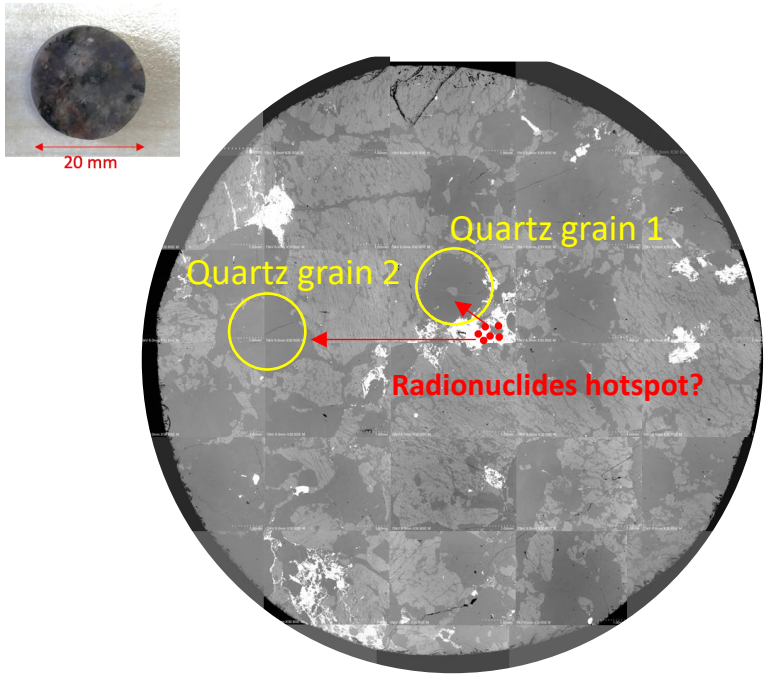
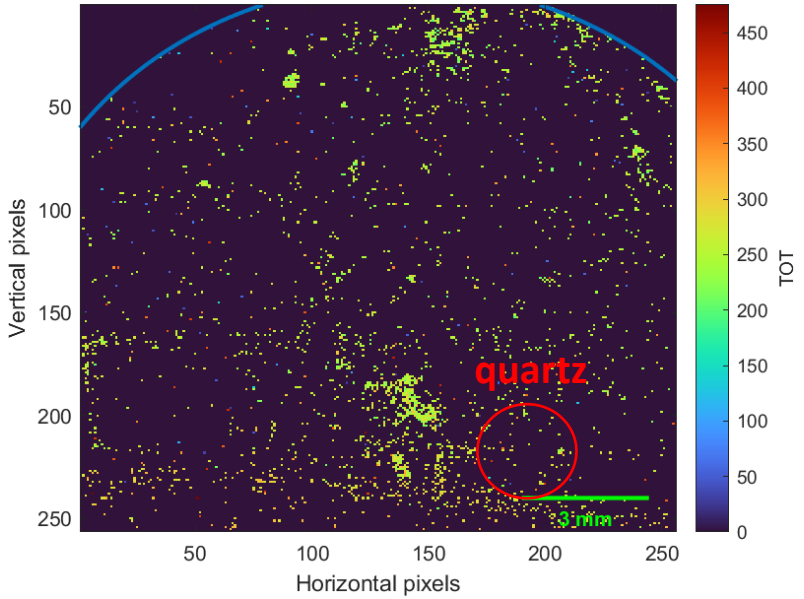
Can we address micro-dosimetry?

Radiation imaging for spatial distribution of radio-elements



SEM Image

Timepix3



Alpha particles map
(measurement time: 14 days)

Radio-elements (K, U and Th) can be traced back from the radiation maps and their influence can be calculated w.r.t distance.

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Integrated Workflow for Radiation Imaging of Natural Samples

- ✓ Particle reconstruction and identification
- ✓ Background suppression
- ✓ Energy calibration for alpha particles
- ✓ Radiation Maps on Rock surfaces

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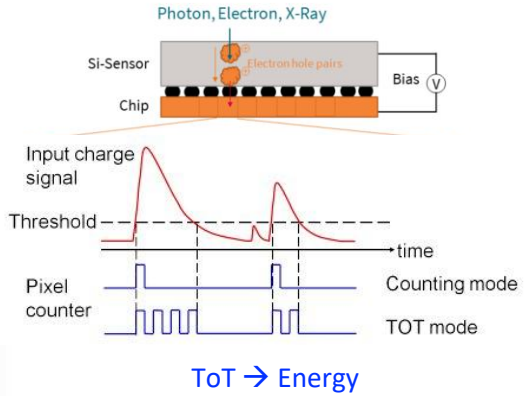
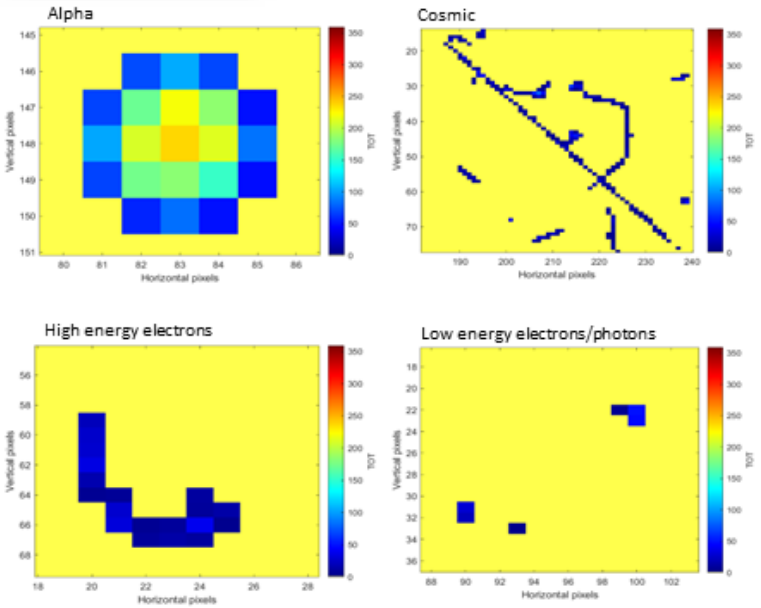
Timepix3

- Si-based (Thickness: 300 µm, Pixel size: 55 x 55 µm, Sensor resolution: 256 x 256 Pixels)
- Time resolution:1.6 ns, maximum readout speed: 40 million pixels / s
- Basic preparation (e.g., threshold equalization) at Physics department (University of Oxford)



ToT → Energy

Image source: Ponchut & Ruat (2013)



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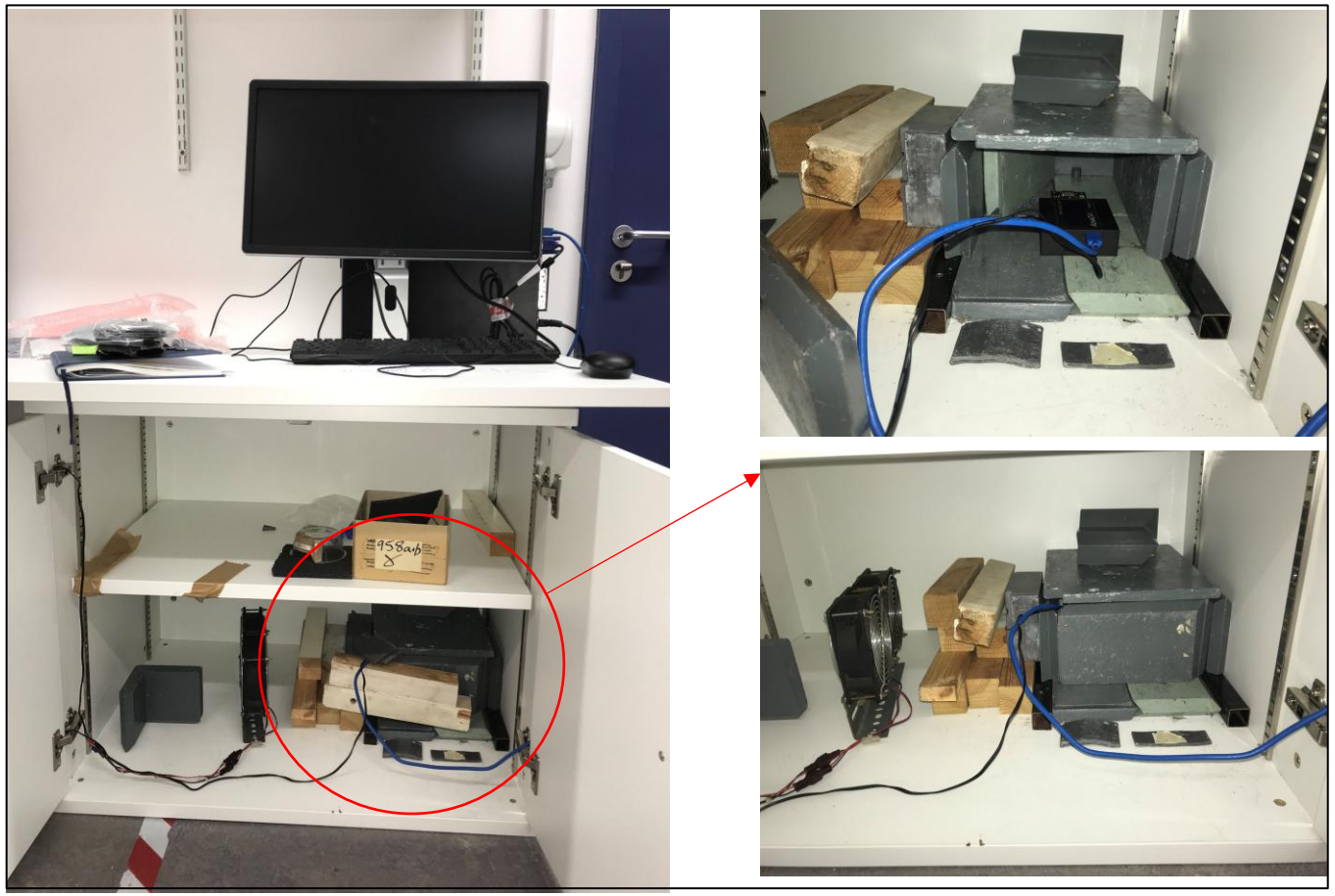
Imaging with Timepix3



Experimental set up

~0.21 clusters/s

Pu-239: **5.15 MeV**
Am-241: **5.49 MeV**
Cm-244: **5.80 MeV**

~600 clusters/s

Samples and calibration standard

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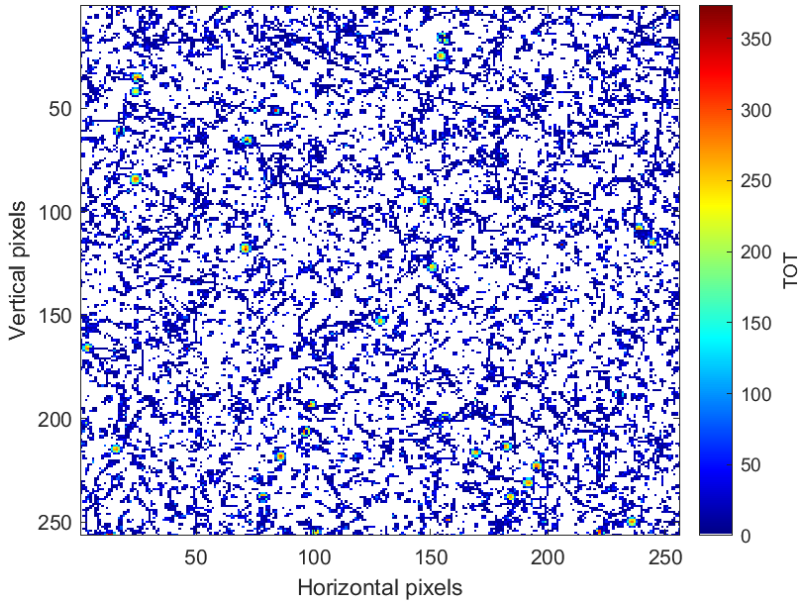
Cluster formation

Adjacent Time of Arrival (ToA) values form a cluster

Index	Matrix Index	ToA	ToT	FToA	Overflow
0	9684	6319522	8	9	0
1	9426	6319519	21	17	0
2	9173	6319523	6	14	0
3	9171	6319518	23	7	0
4	9429	6319520	25	8	0
5	9427	6319518	36	10	0
6	9172	6319520	11	20	0
7	9170	6319519	27	21	0
8	9428	6319519	38	21	0
9	49443	209473792		8	28	0
10	49188	209473791		2	26	0
11	49447	209473791		3	28	0
12	49452	209473790		6	15	0
13	49185	209473791		5	8	0
14	50481	209473798		2	11	0
15	49967	209473792		8	17	0
16	49451	209473790		12	17	0
17	50482	209473797		8	21	0
18	49449	209473790		17	13	0
19	48415	209473791		10	9	0
20	48931	209473790		2	15	0
21	48677	209473790		14	23	0
22	48673	209473791		4	1	0
23	49968	209473793		12	20	0
24	49702	209473791		9	26	0
25	49708	209473790		6	16	0
26	49711	209473792		10	22	0
27	49450	209473790		13	16	0
28	49448	209473790		32	14	0
29	49186	209473791		24	15	0
30	49444	209473791		11	18	0
31	48160	209473790		7	3	0
32	50225	209473794		10	14	0
33	48674	209473791		2	21	0
34	48933	209473790		21	23	0
35	49703	209473790		22	13	0
36	49709	209473790		16	16	0
37	49710	209473790		28	11	0
38	49704	209473790		44	14	0
39	48416	209473790		29	5	0
40	49187	209473791		22	16	0
41	49445	209473791		19	26	0
42	48419	209473791		3	21	0
43	48932	209473790		55	23	0
44	48672	209473791		13	5	0
45	48675	209473791		16	29	0
46	49701	209473791		10	25	0
47	48676	209473790		56	23	0
48	48928	209473792		4	15	0
49	48418	209473791		23	23	0
50	48161	209473790		9	4	0
51	48417	209473790		12	6	0
52	48929	209473791		26	10	0



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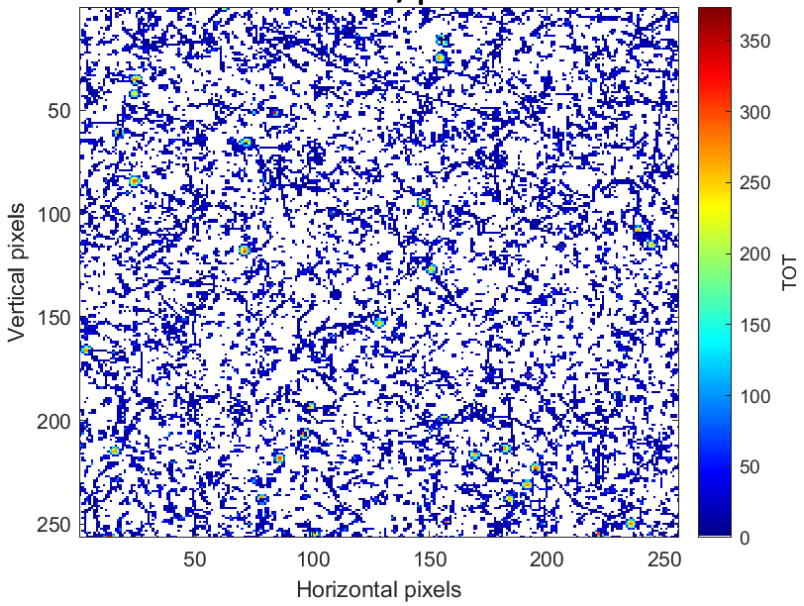
Particle Reconstruction and Identification

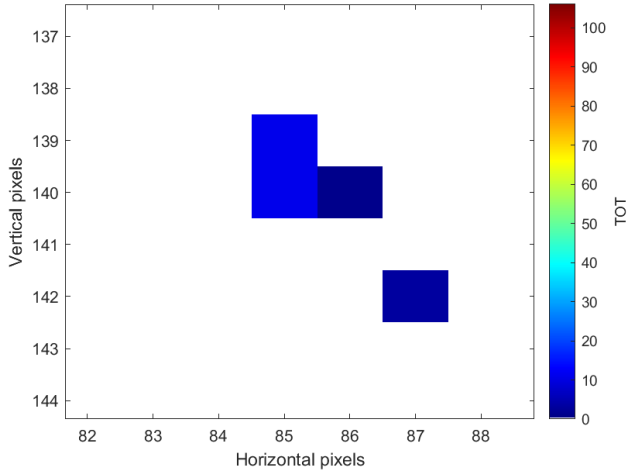
All clusters/particles



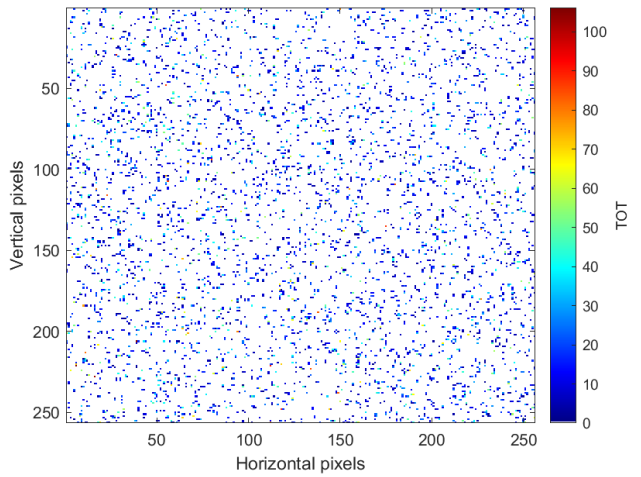
1-4 pixels hits

Rest after photon and alpha clusters

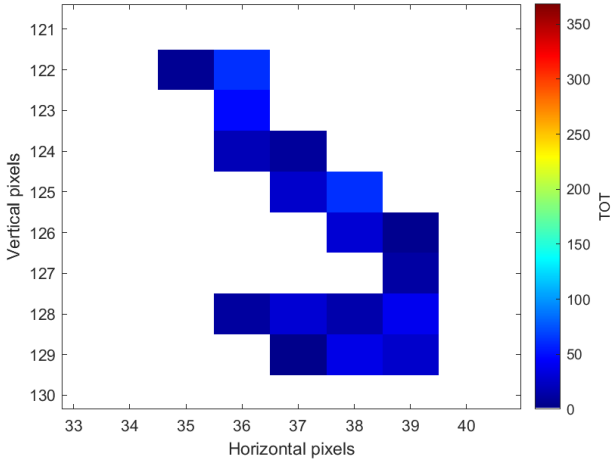
γ-photons or electron clusters



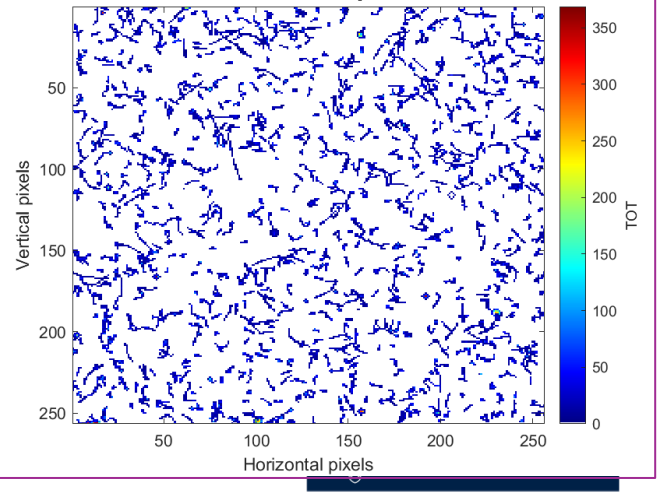
γ-photons or low-energy electrons



Electron or β particle cluster



Electrons or β particles



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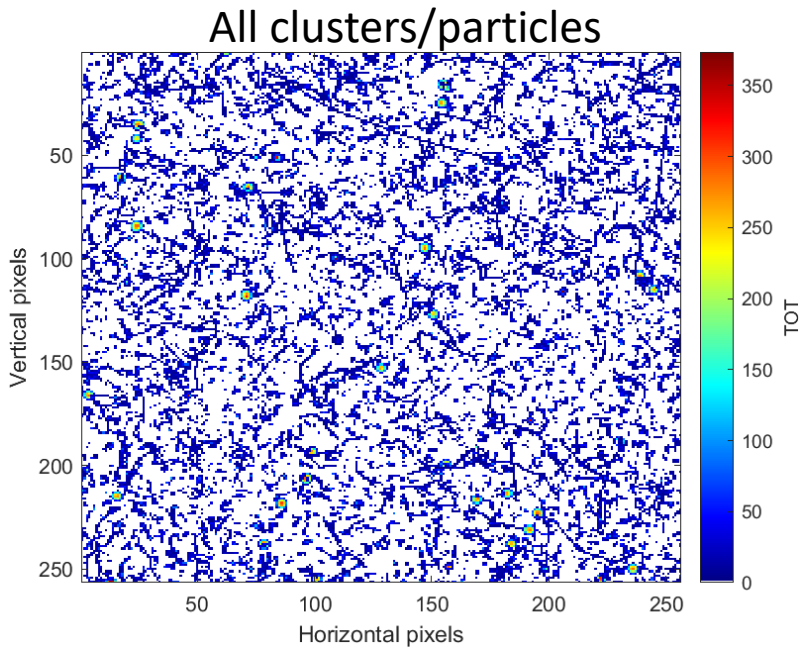
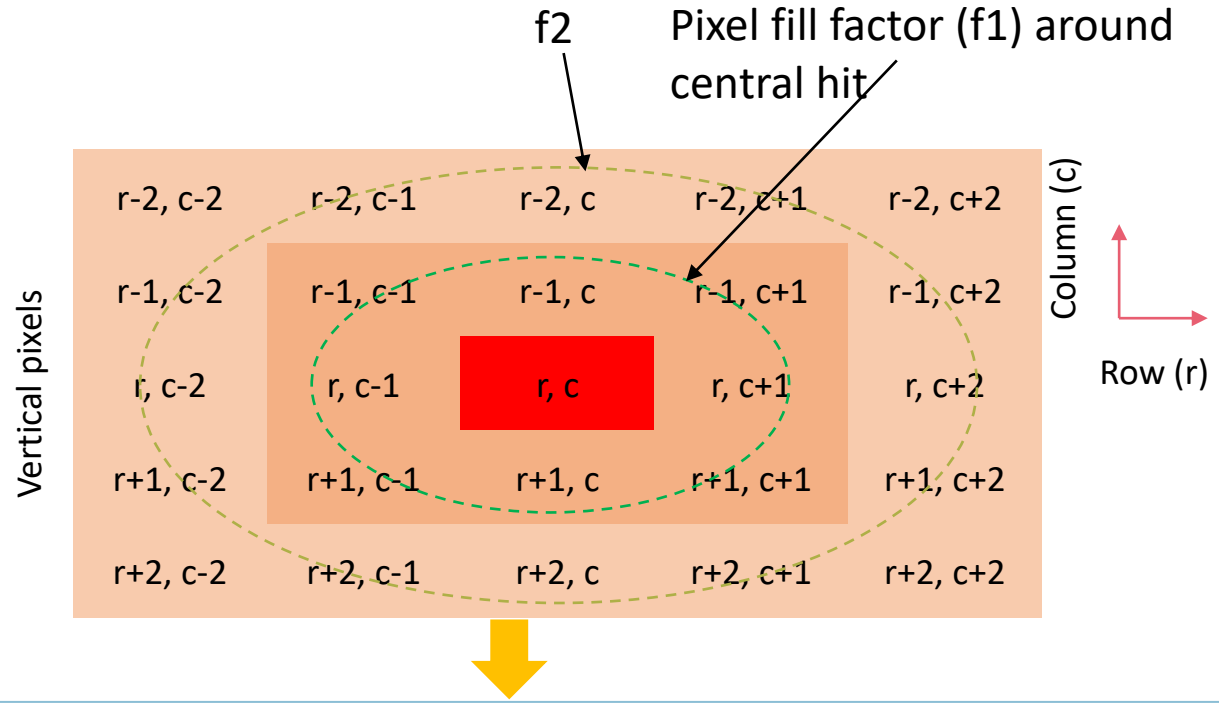
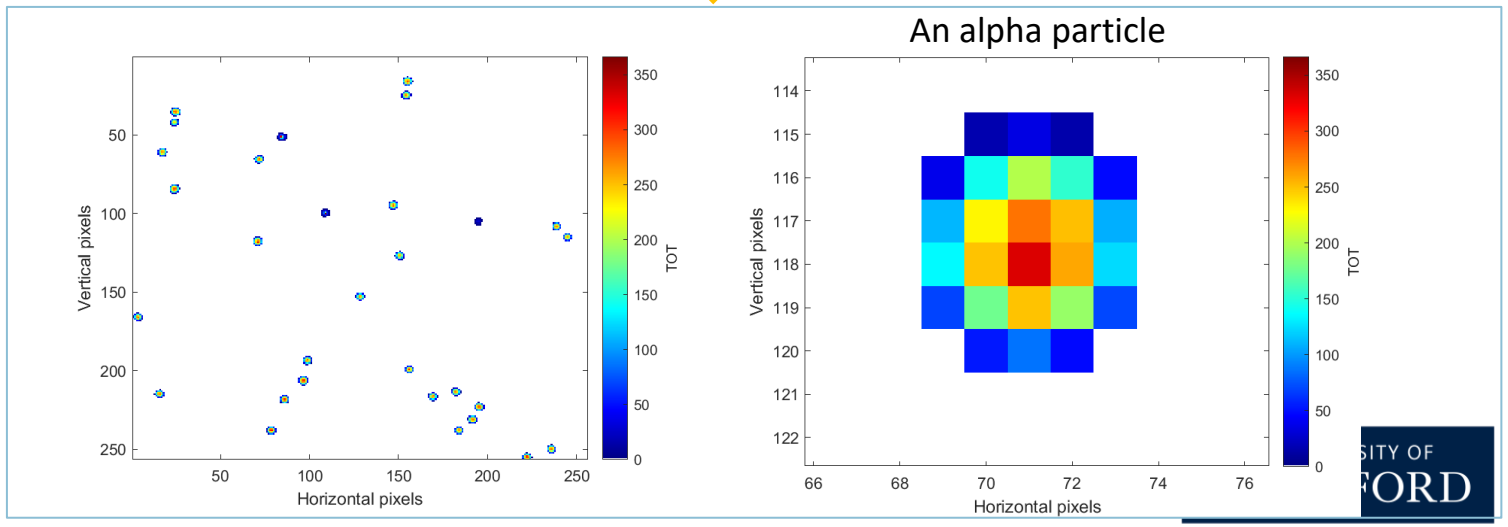
Particle Reconstruction and Identification







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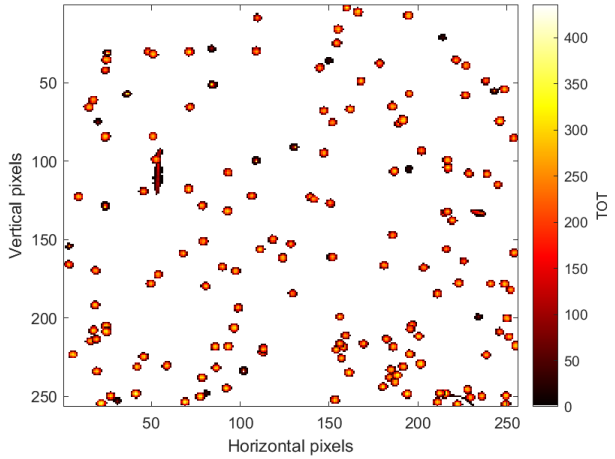
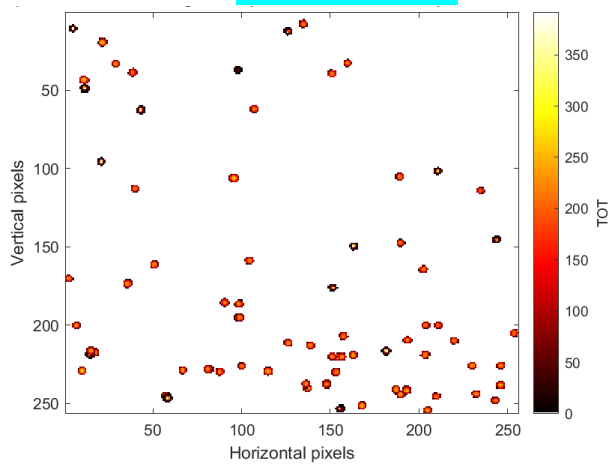
Background Suppression

Alpha particles (α)

~7 counts/hr

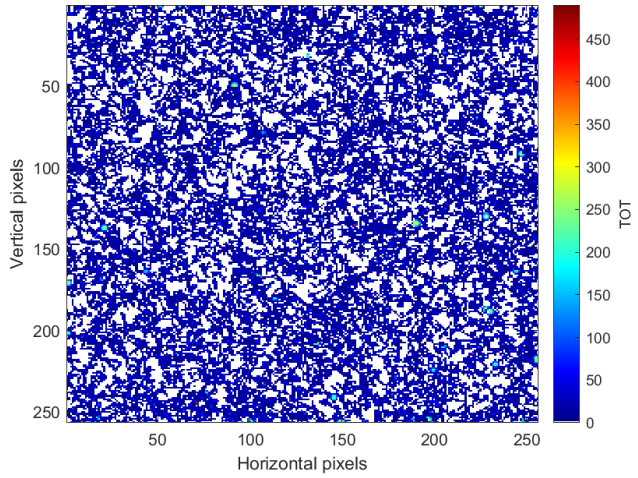


~3 counts/hr

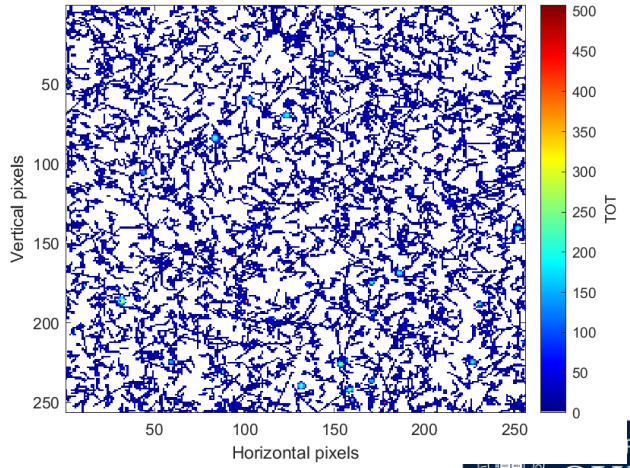


Beta particles (β)

~262 counts/hr



~117 counts/hr



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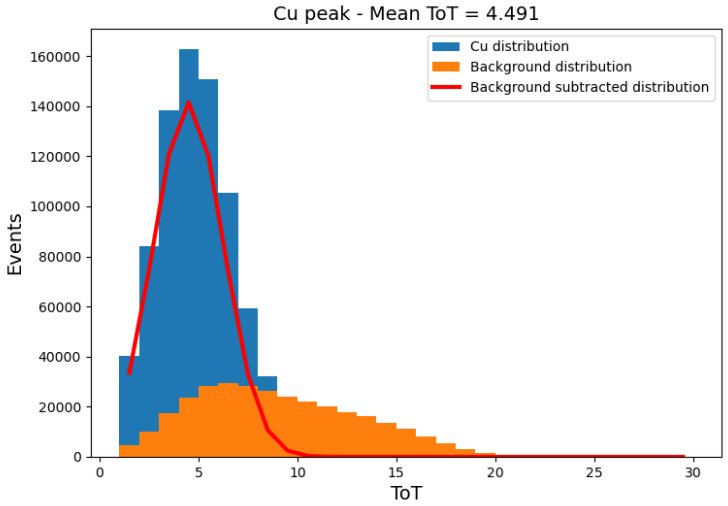
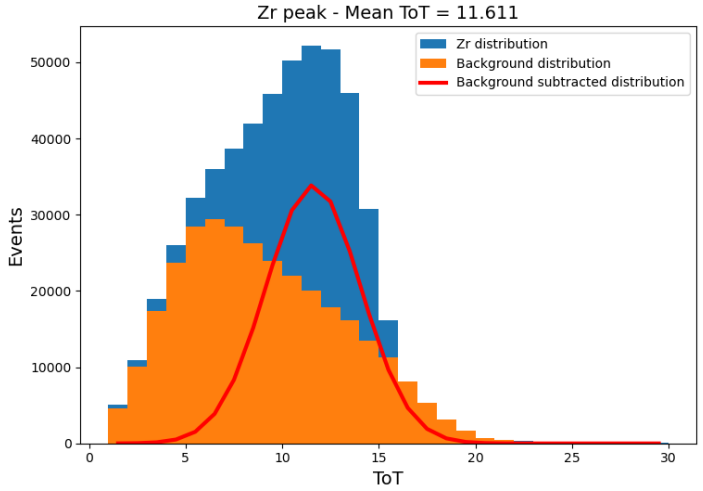
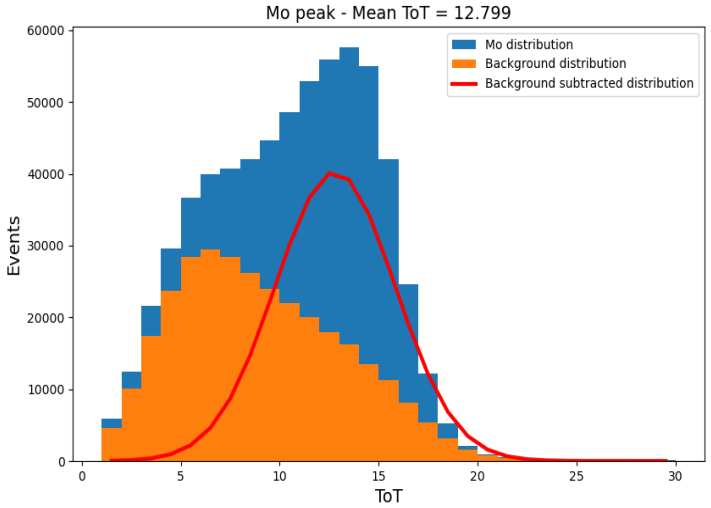
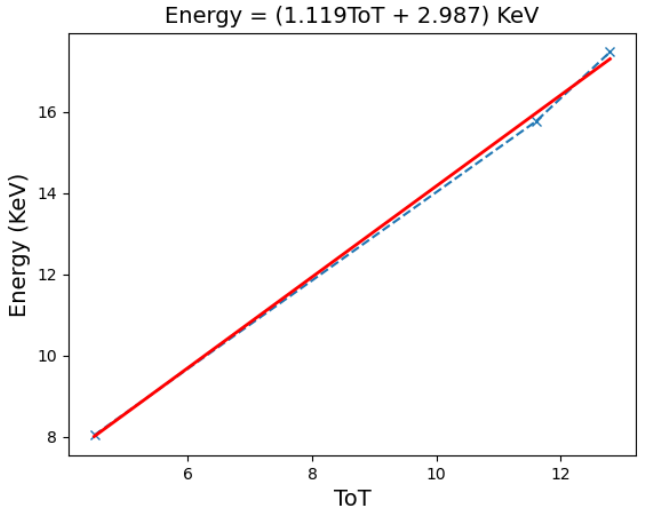
Energy Calibration at Low Energies

Full-matrix calibration









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Performed at Physics Department, University of Oxford

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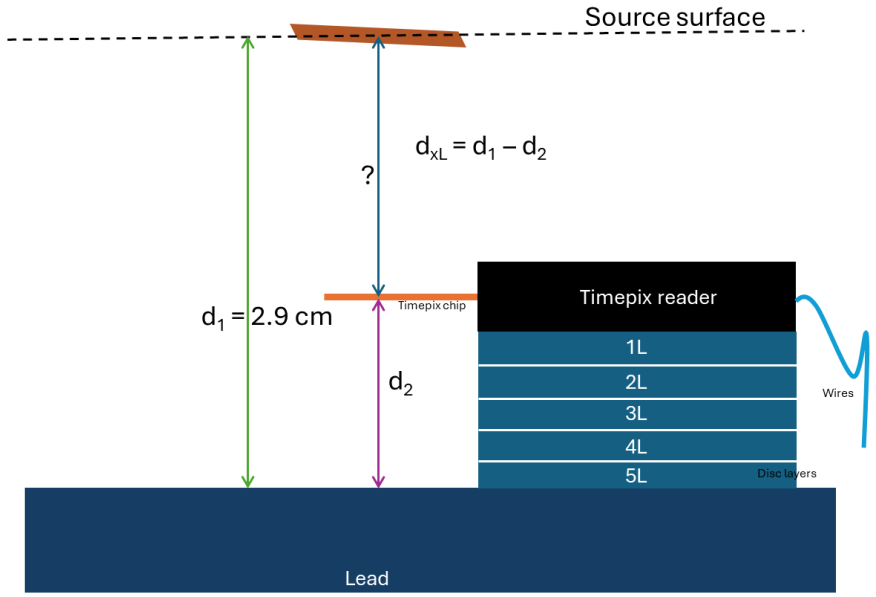
Energy Calibration at High Energies

Full-matrix calibration

Energy threshold: 2.24 keV, Biasing voltage: 50 V



d_{xL} = distance calculated between the source and chip for x layers (x = 1, 2, 3, 4 and 5) of floppy discs under the reader

$d_{5L} = 2.9 - 1.9 = 1$ cm

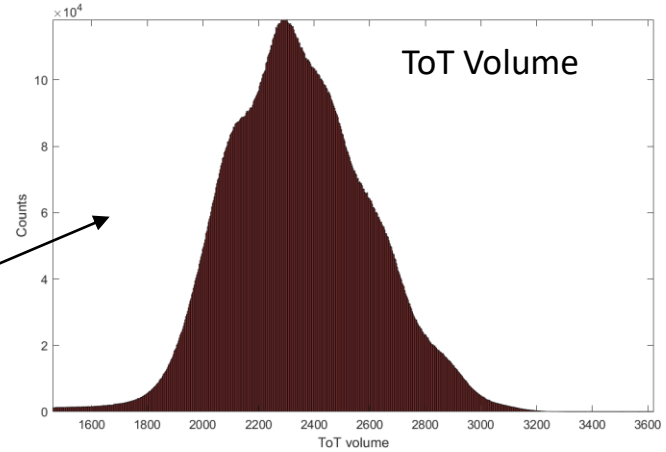
$d_{4L} = 2.9 - 1.6 = 1.3$ cm

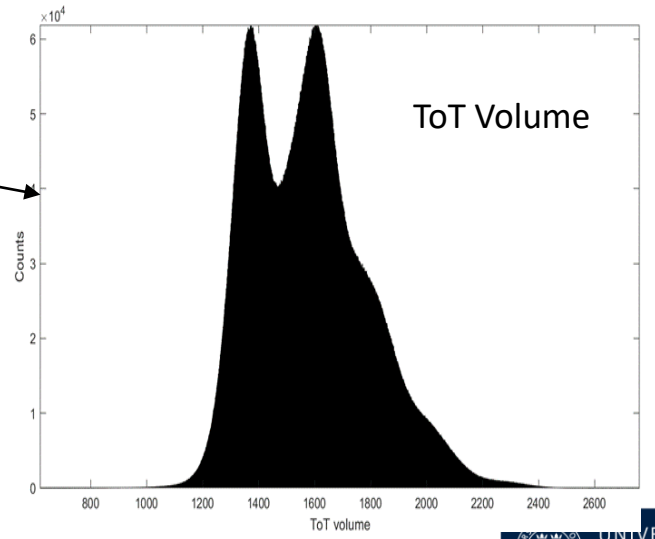
$d_{3L} = 2.9 - 1.3 = 1.6$ cm

$d_{2L} = 2.9 - 1.0 = 1.9$ cm

$d_{1L} = 2.9 - 0.7 = 2.2$ cm

$d_{0L} = 2.9 - 0.4 = 2.5$ cm





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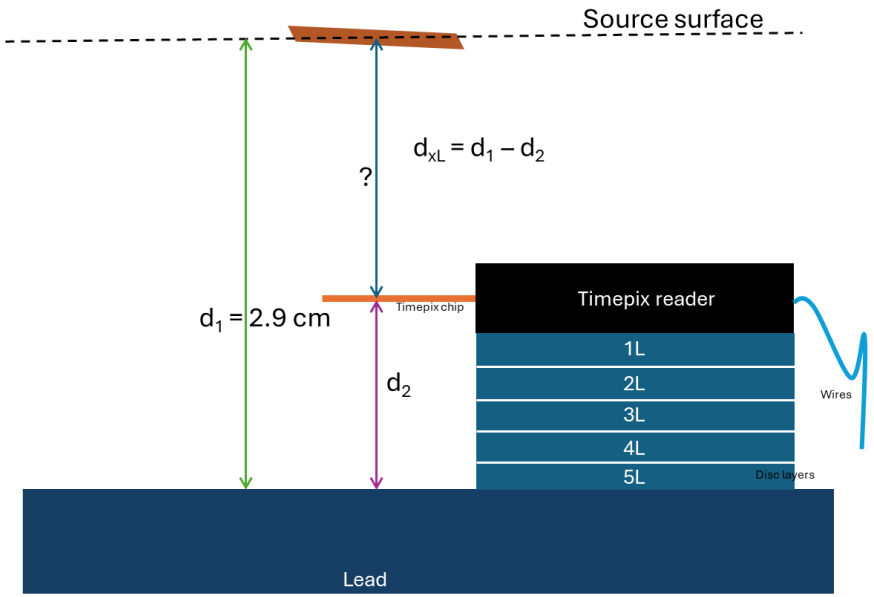
Energy Calibration at High Energies

Full-matrix calibration



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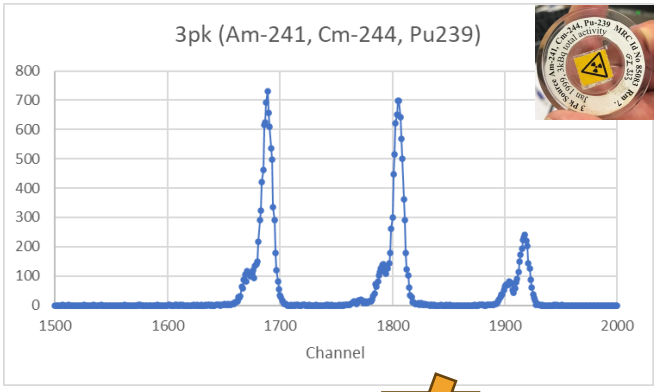

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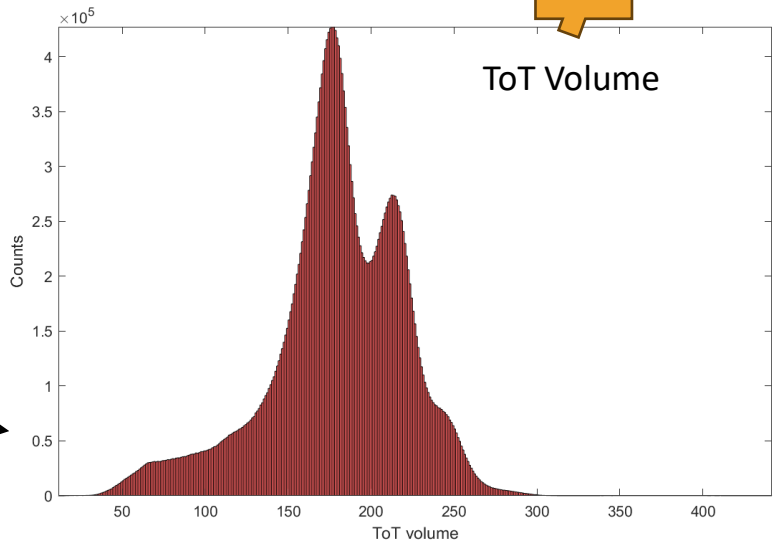

~2.2 cm gap between the chip and source could give the best resolution we could get.

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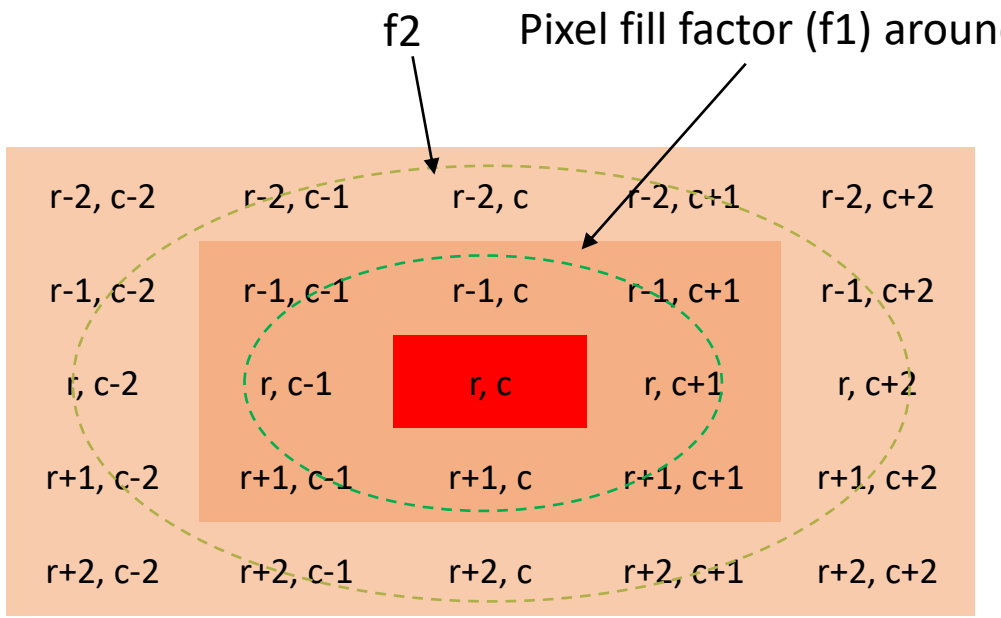
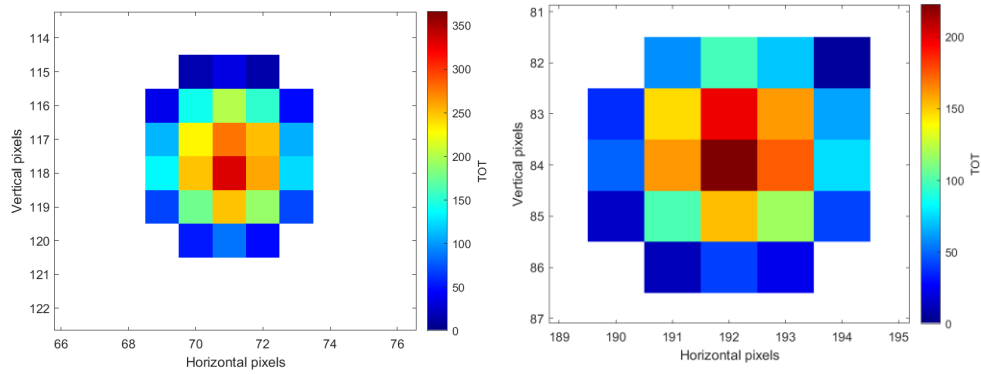
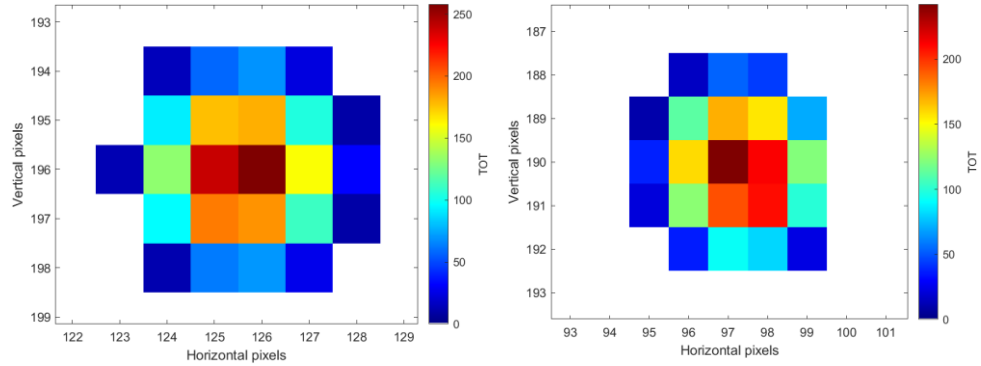
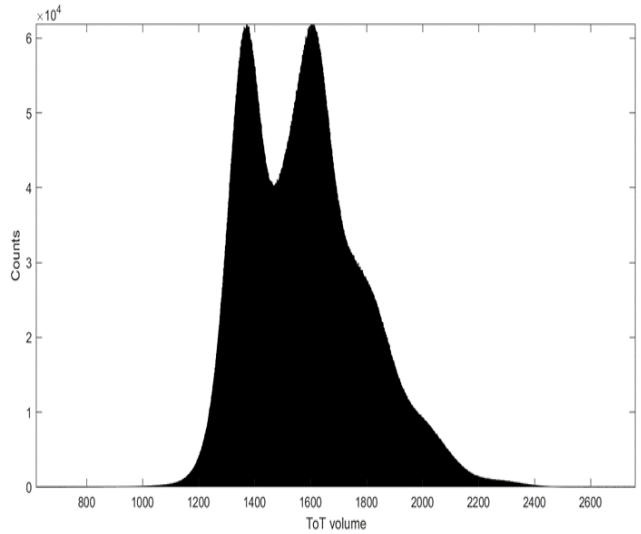
Influence of Alpha Particle Cluster Shapes





f1 > 90% and f2 > 80%





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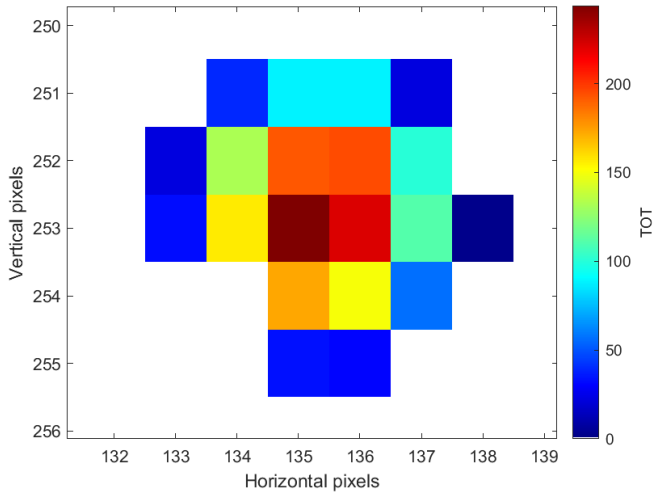
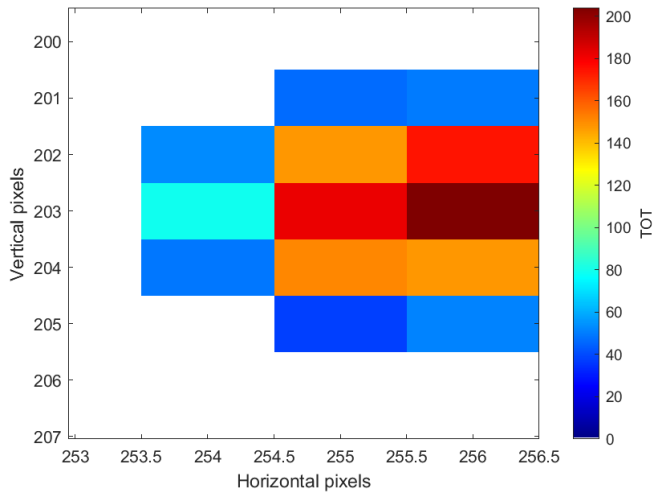
Influence of Alpha Particle Cluster Shapes

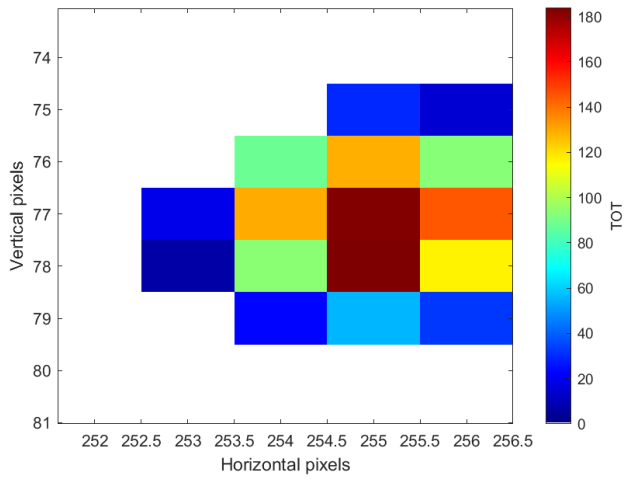
f1 ~ 60-90% and f2 > 60%



f1 ~ 60-90% and f2 > 40%



f1 > 90% and f2 < 40%



Checked with different cluster shapes, but calibration spectra didn't change significantly

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Future Improvements and Optimization Strategies

- Deconvolution to separate the peaks
- Simulations to check the calibration curve
- Perform pixel-level calibration
- Find and remove charge sharing
- Try different chip material/thickness
- Temperature stability
- ??

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Summary

- The Timepix3 detector has demonstrated remarkable capability in detecting and mapping alpha (α) and beta (β) radiation

- We successfully mapped α and β particles (potentially indicating their sources) on rocks and identified ‘hotspots’ and ‘coldspots’ within the sample

However,

An accurate calibration is required for determining energies of radiation emanating from samples

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