Simulations of thermal excursions arising from cosmic rays on the X-IFU detector wafer

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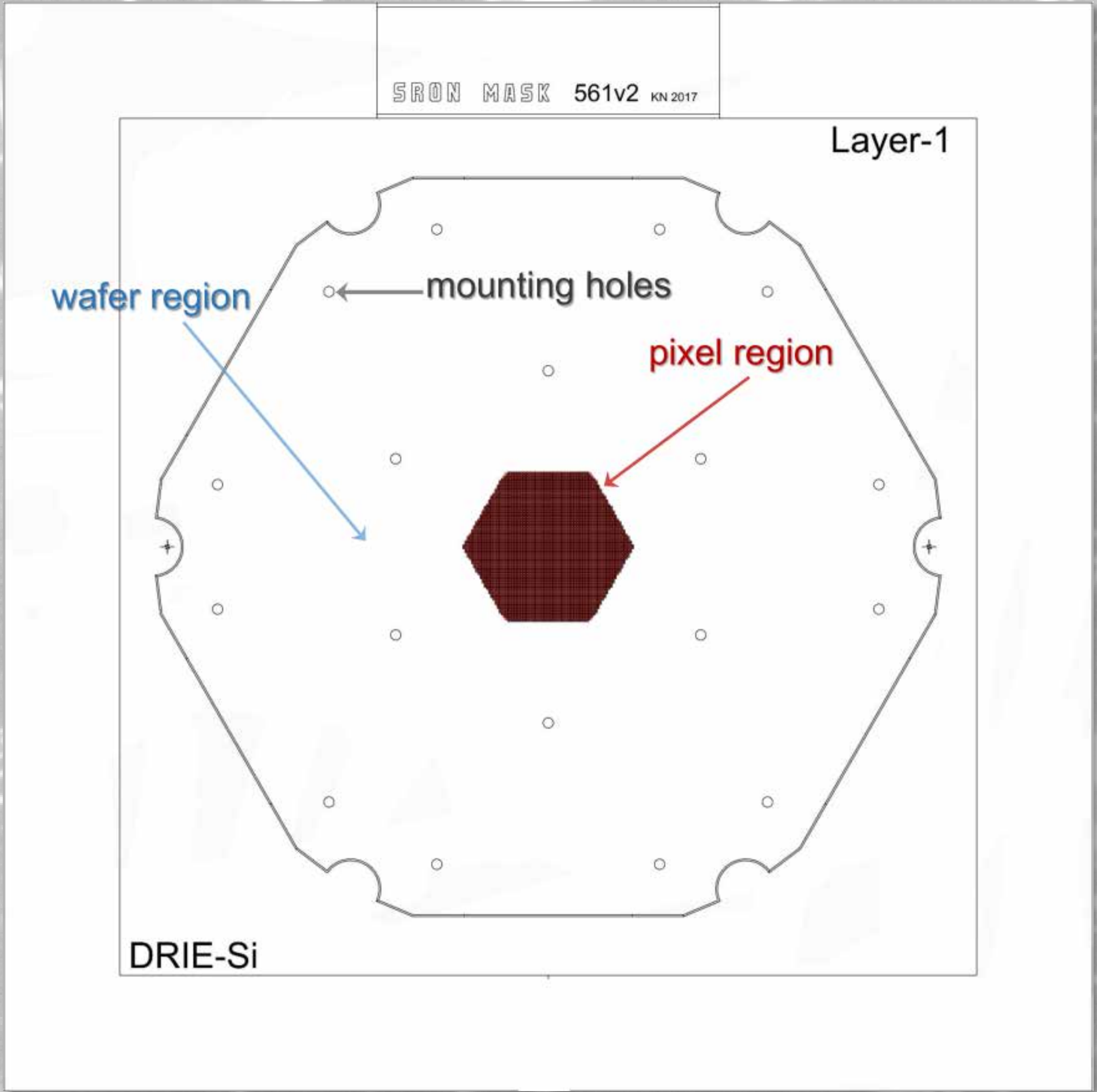
Introduction

Cosmic rays impacting the instrument can affect the energy resolution in the following ways:

- Impacts on the Focal Plane Assembly (FPA) which create heating in cryogenic structures
- Impacts directly on the detectors
- Impacts on the Si “muntin structure” (grid) below the detectors
- *Impacts on the much larger detector wafer.*

Goals:

- Develop a FEM simulation in **COMSOL** for the X-IFU detector wafer
- Probe the **thermal fluctuations** arising from “cosmic rays”
- Produce library of $\Delta T(t)$ curves
- Use this to **simulate “effective bath temperature” timelines** based on energy depositions predicted in the wafer.
- Test the effect of this on the **instrument energy resolution.**

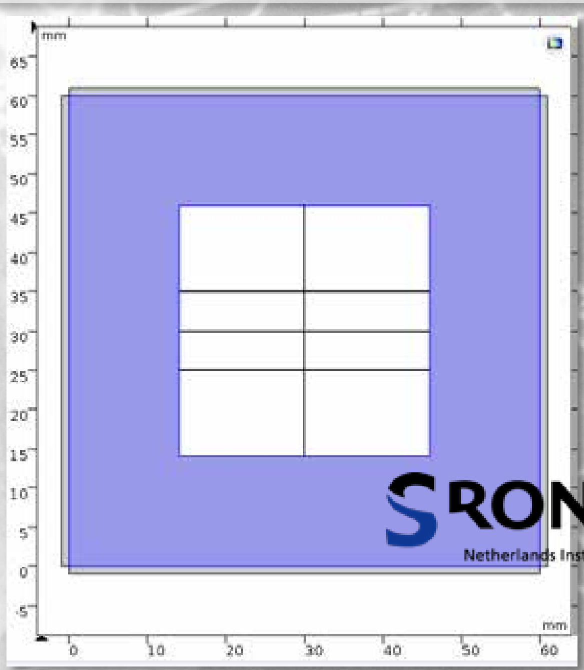


Thermal Model

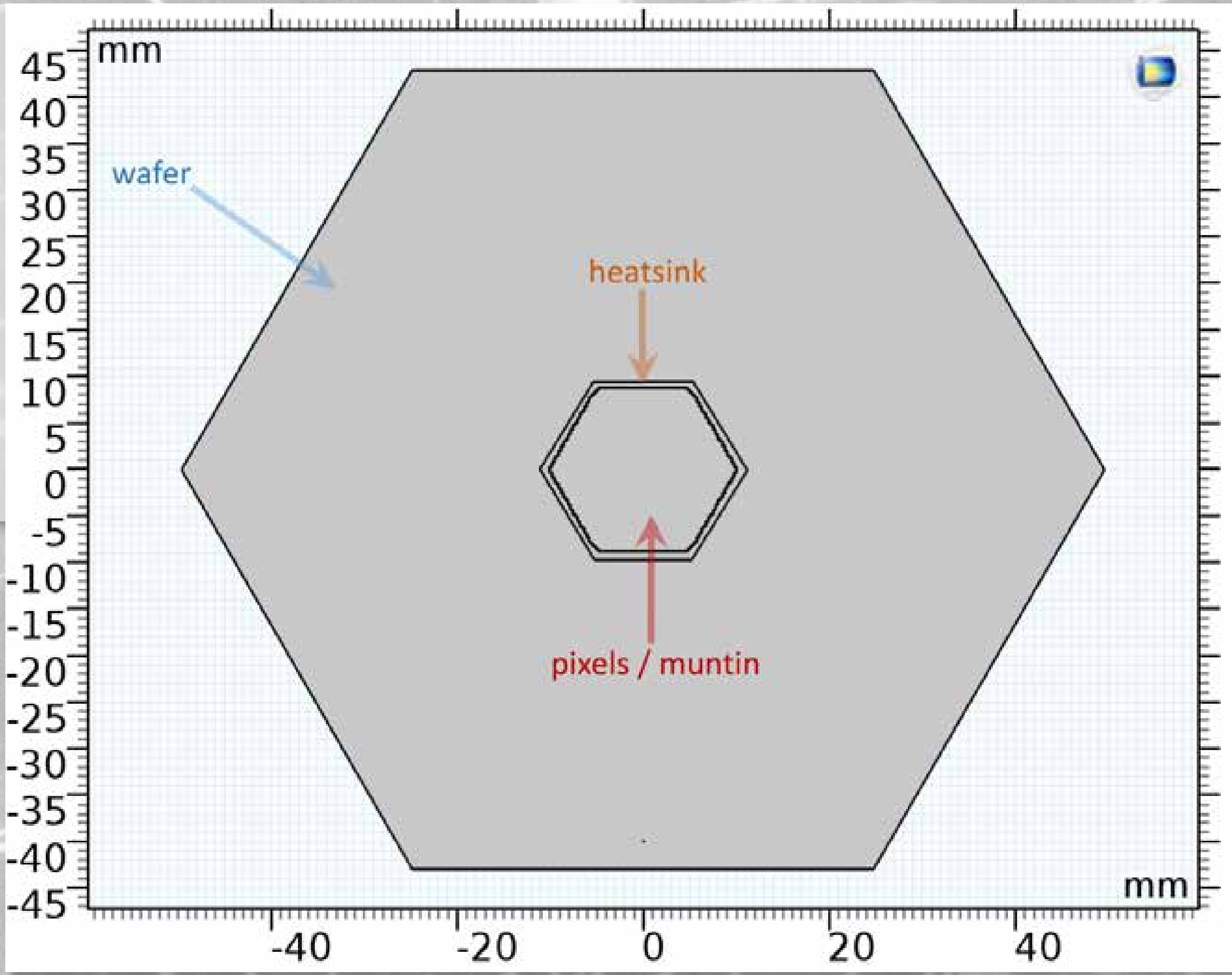
COMSOL model adapted from simulations of the SAFARI detector wafer, performed at SRON by M. P. Bruijn.

2d model with virtual layers for each material

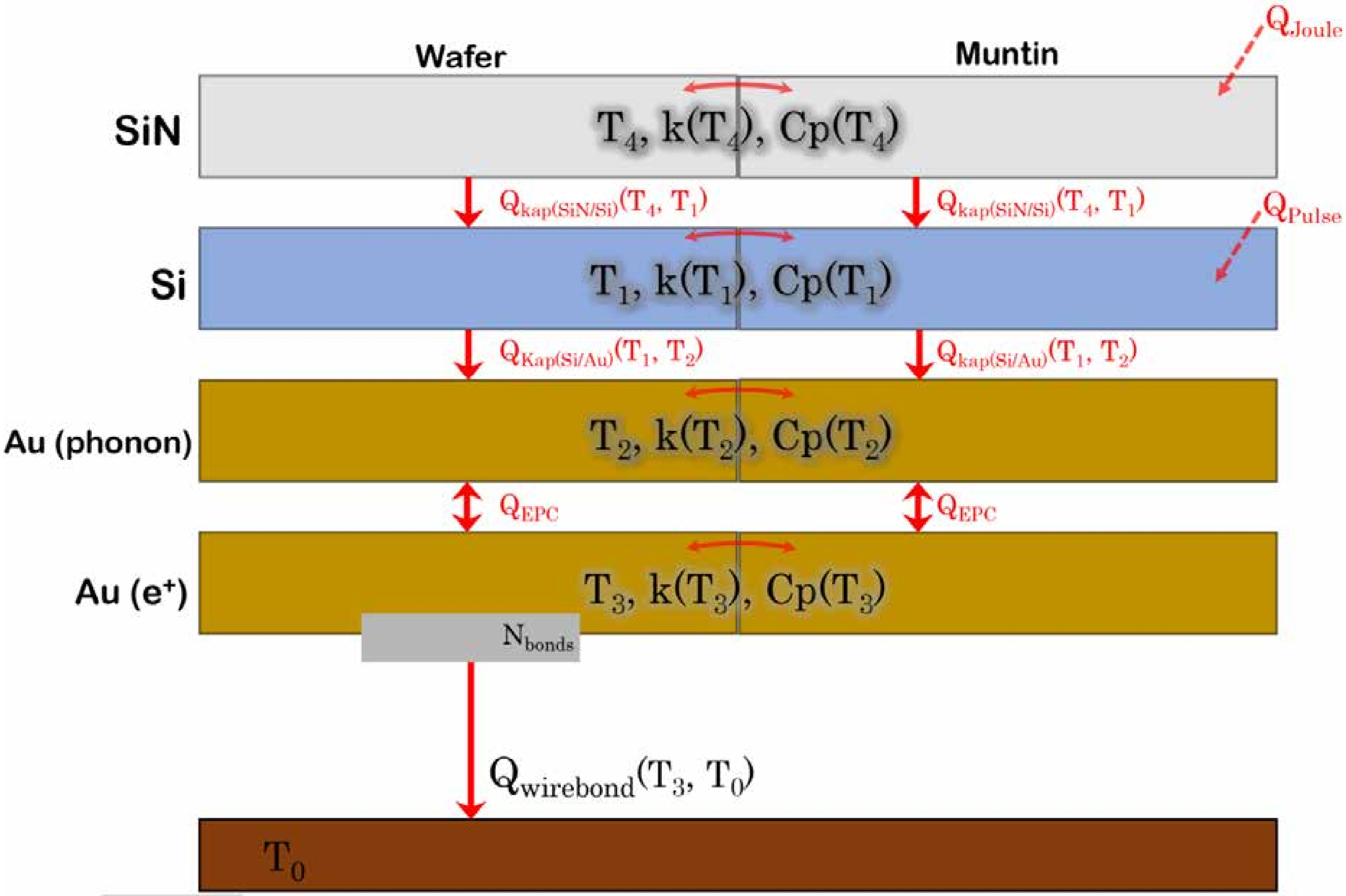
Geometry, material parameters, various attributes updated for X-IFU



SRON
Netherlands Institute for Space Research

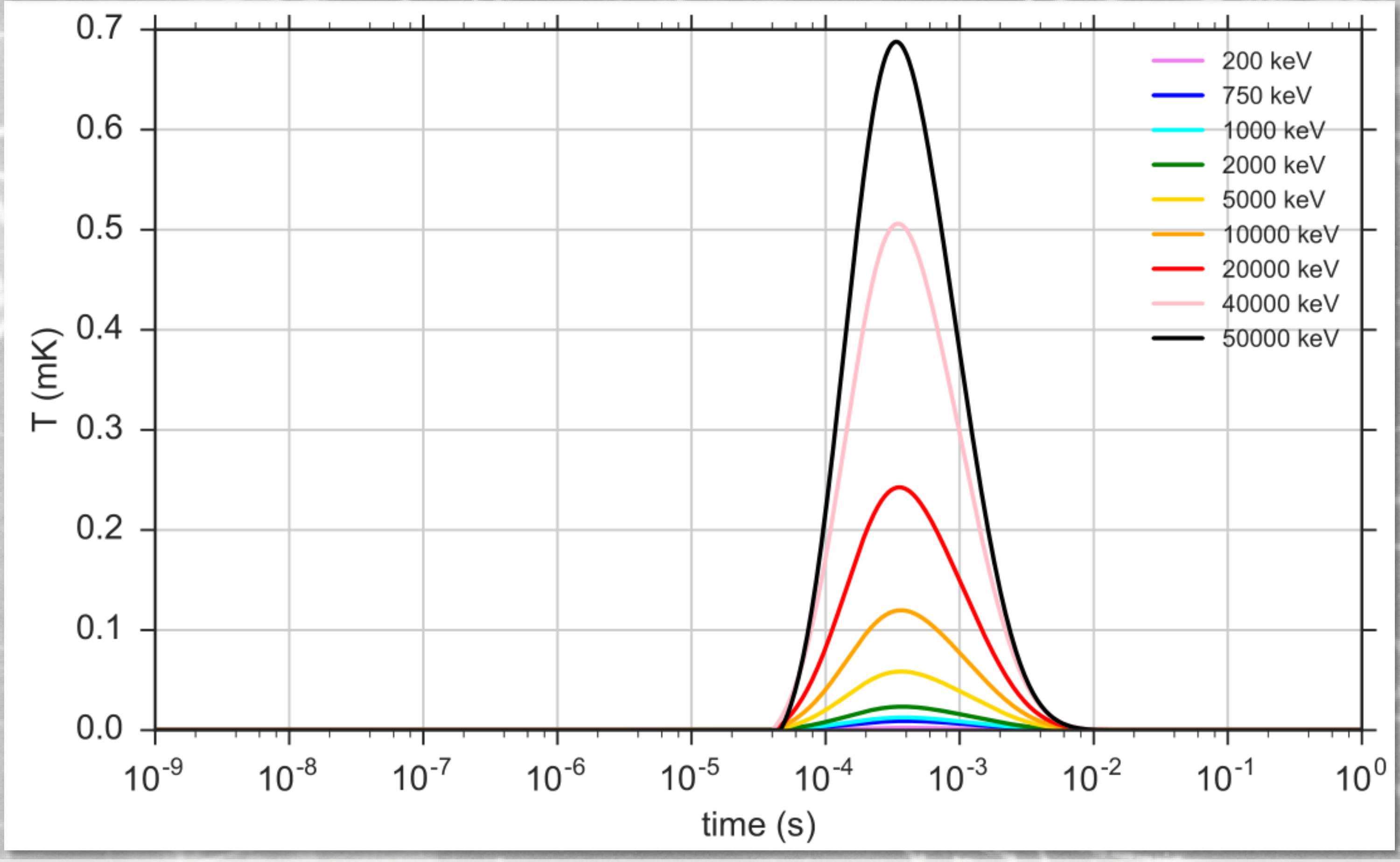


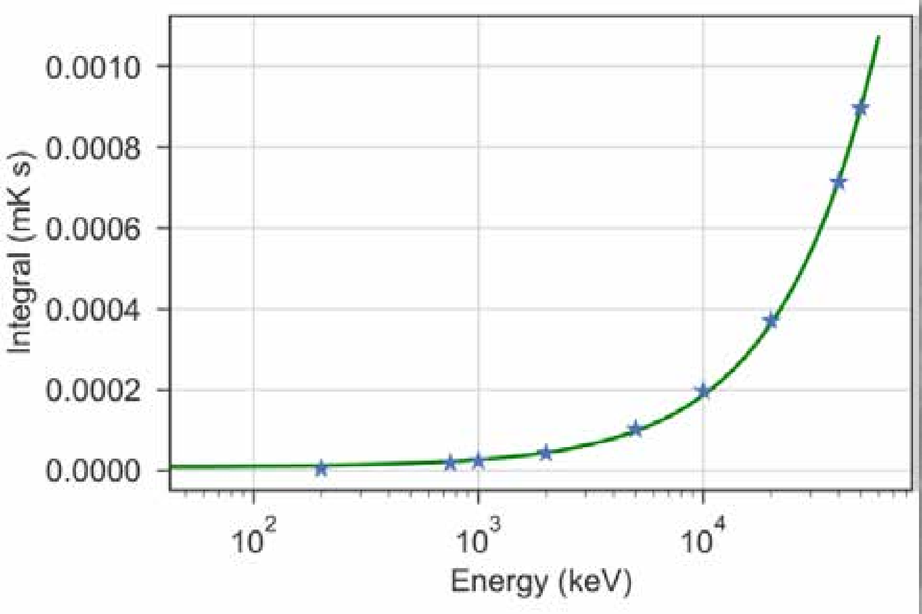
Thermal Model

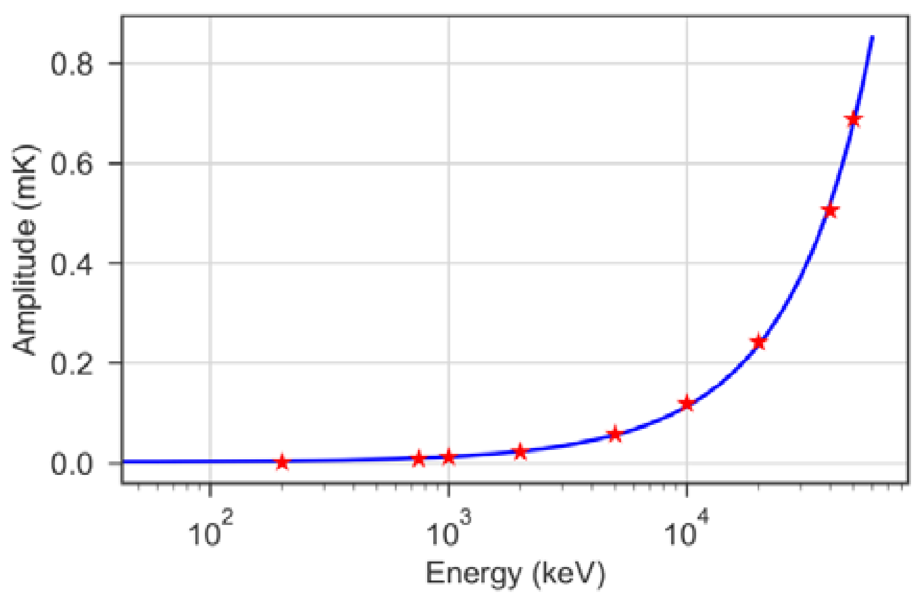


Linearity Testing

Testing the output by changing only the energy –
do amplitudes and integrals scale in believable ways?

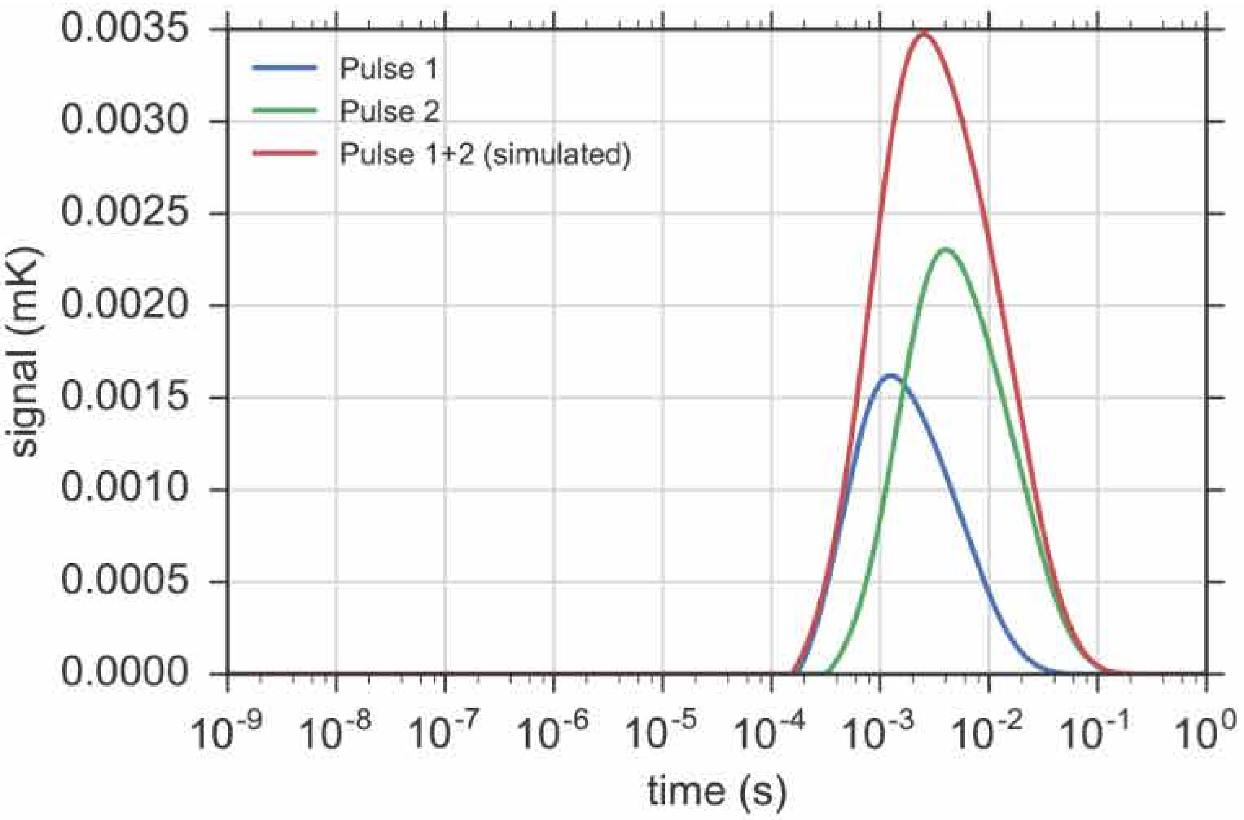


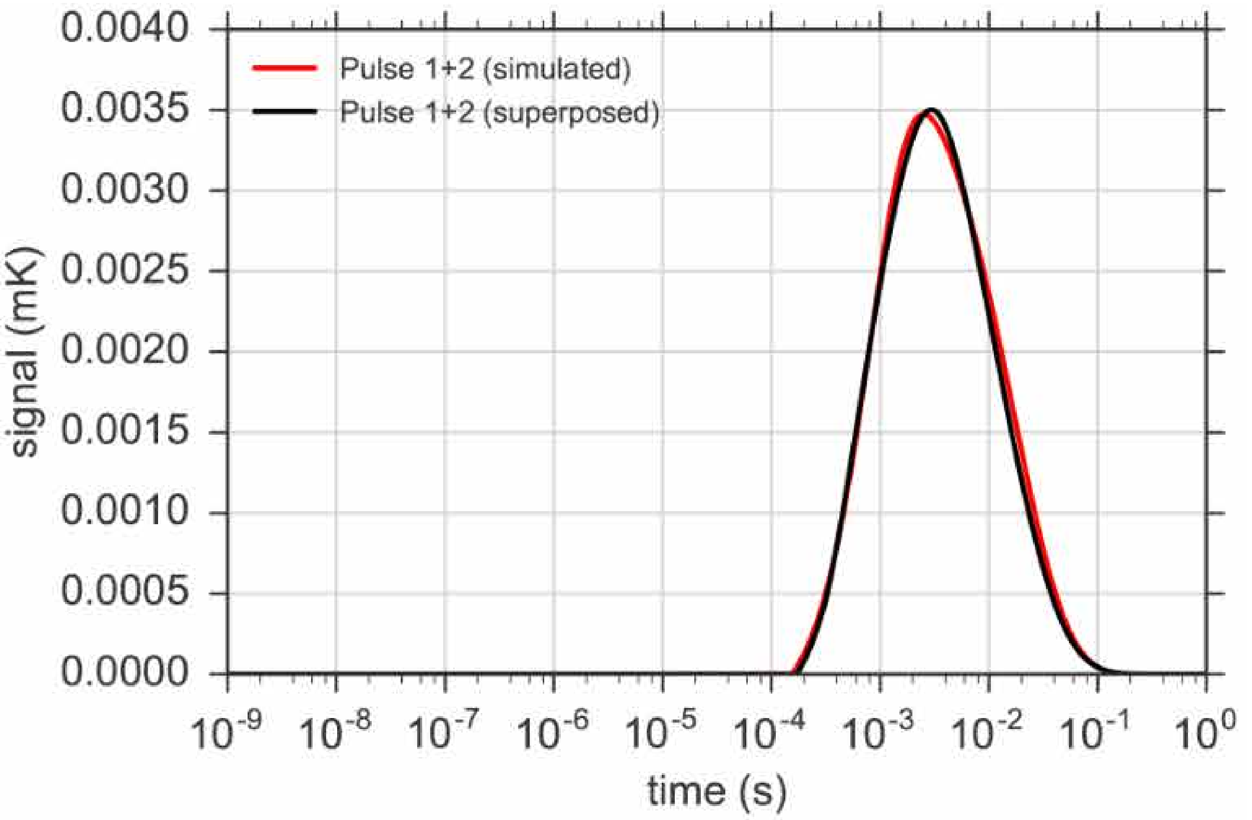




Linearity Testing - Superpositions

Superposition tests:
To produce timelines outside of COMSOL, it is important that Pulse1 + Pulse 2 = Simulation(Pulse1 + Pulse2).

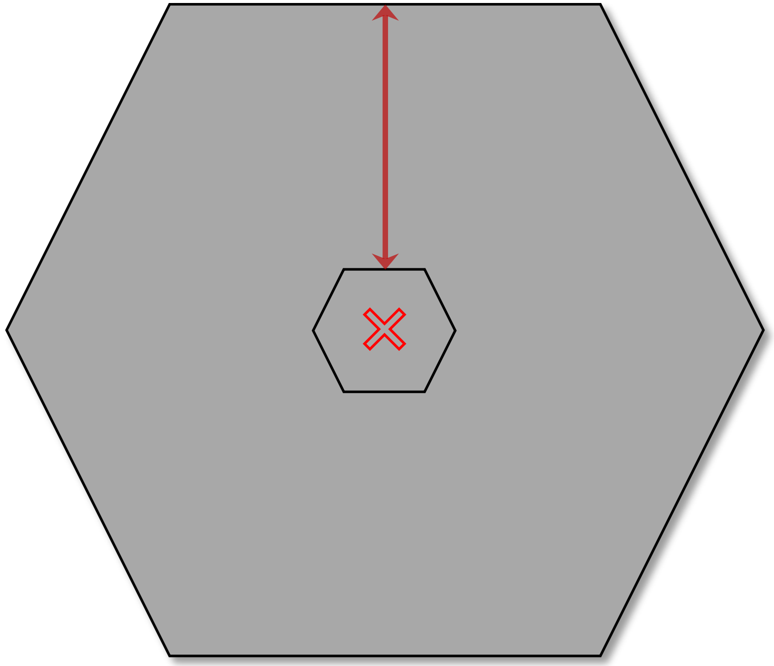


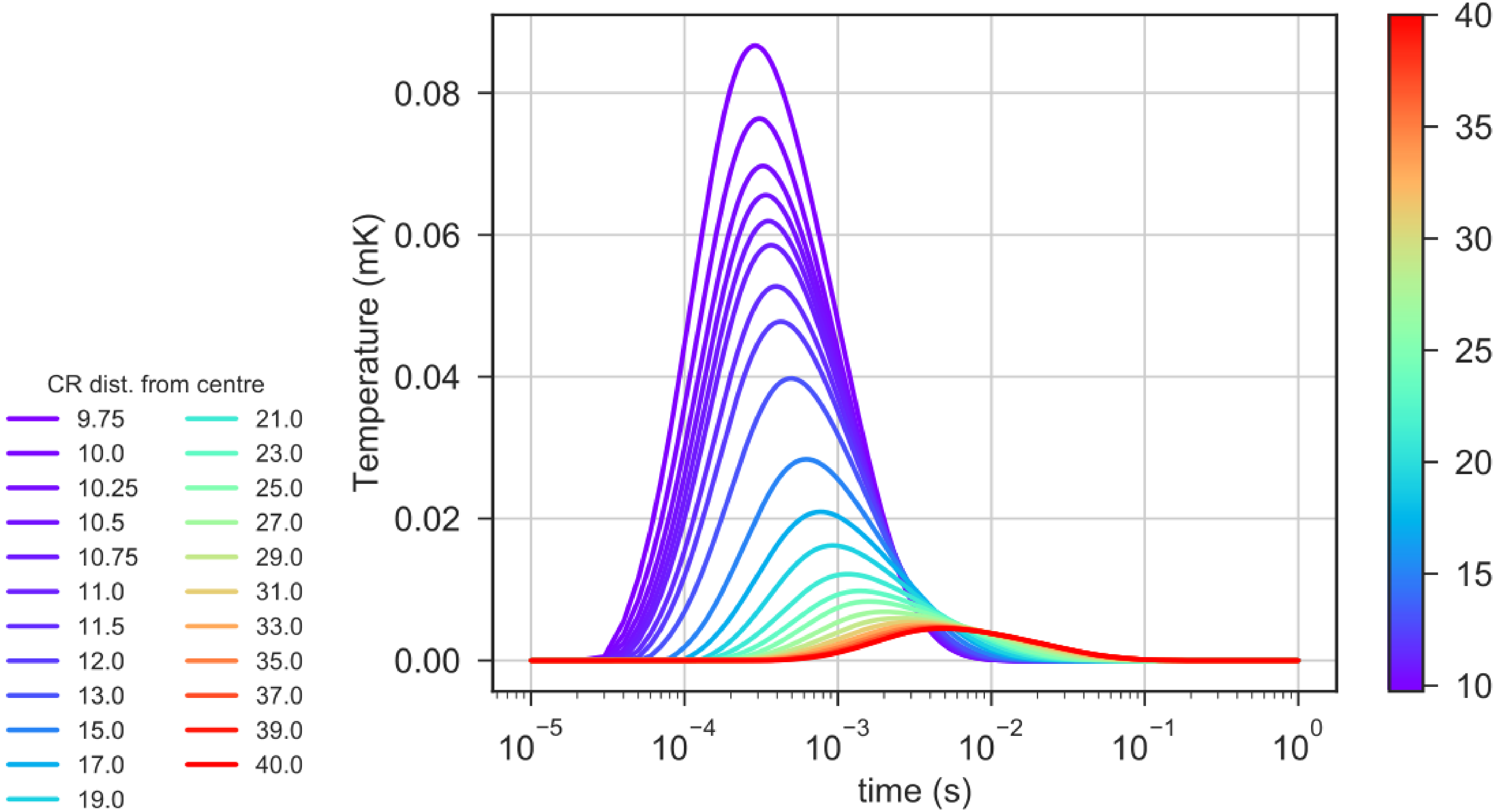


Results:
It works, and it saves a lot of time.

Results - Pulse shape with varying distance

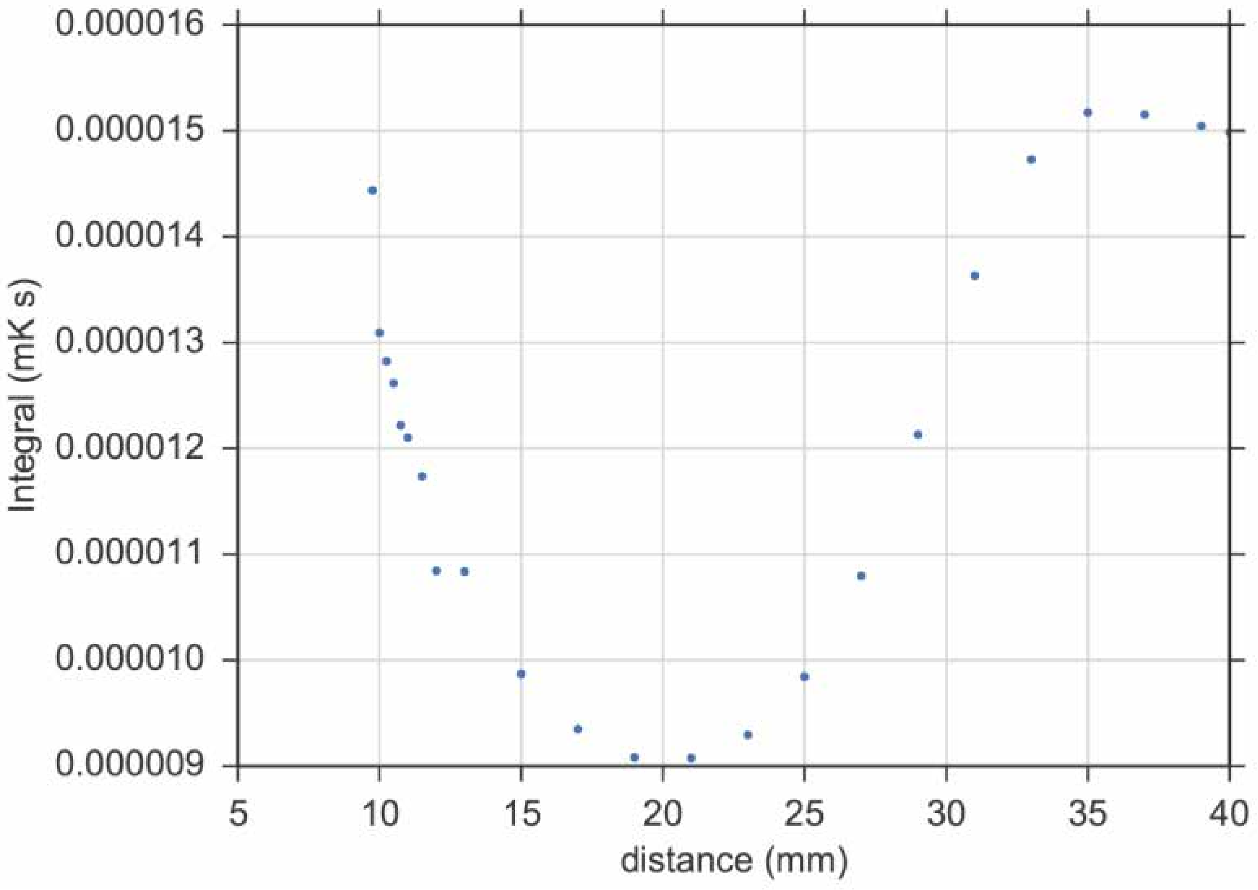
We inject 500 keV into the wafer at various distances from (0,0) and read *T(t)* at (0,0).
We see that pulses closest to the centre have highest amplitudes but decay quickly.
As distance increases, the pulses become smaller in amplitude but decay much more slowly.

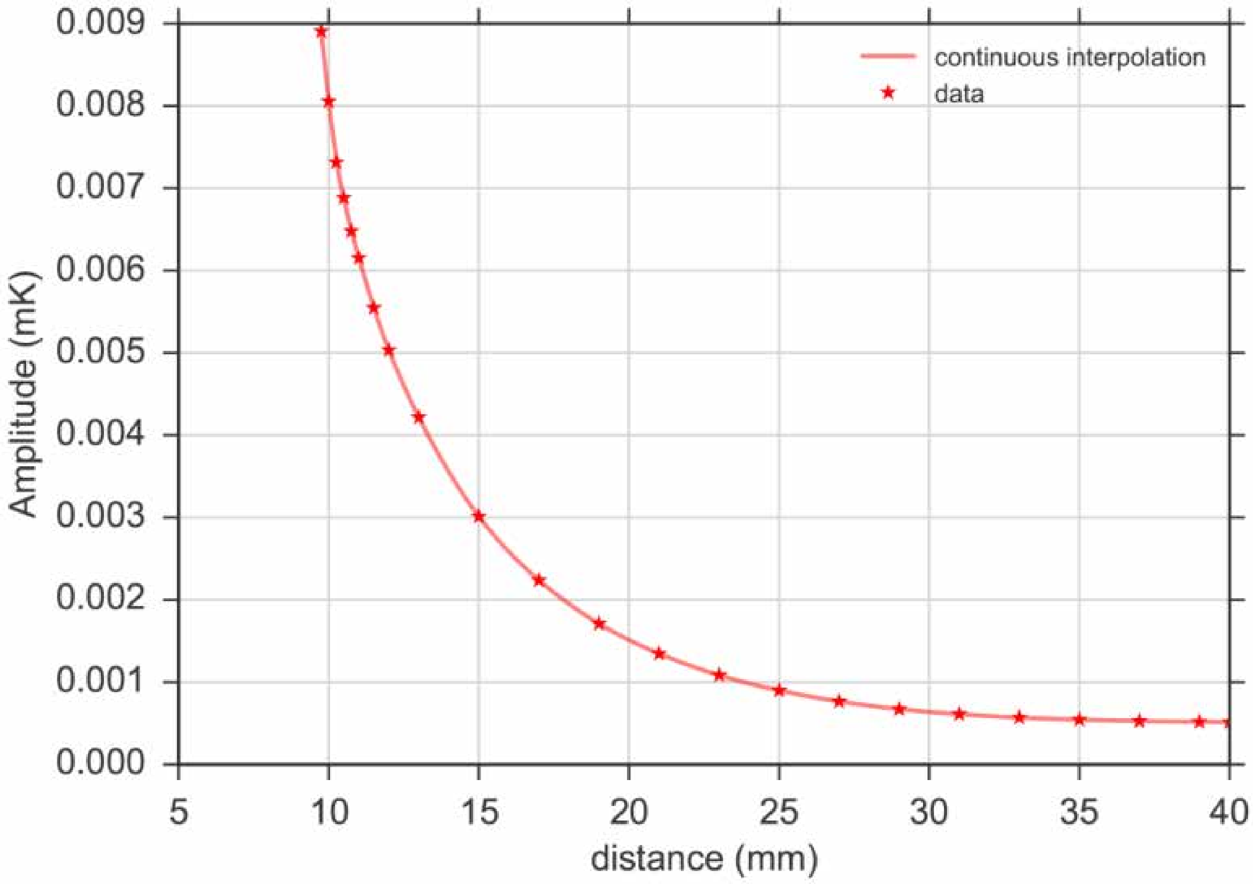




Results - Pulse shape with varying distance

We cannot apply the usual paradigm in this case where the integral is the best representative of the total energy.
For this reason, we depend on interpolations of the amplitude relationships for pulse scaling.





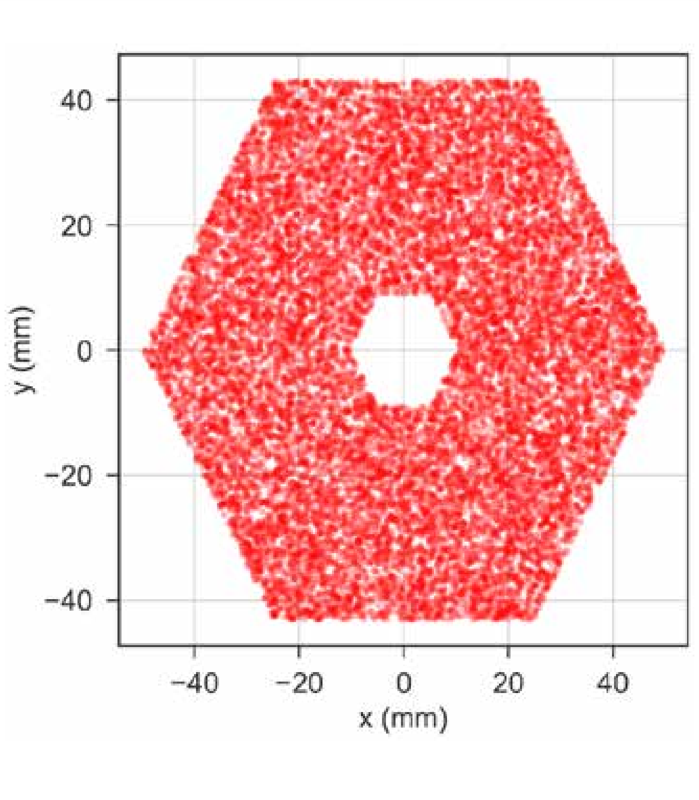
Production of timelines in Python

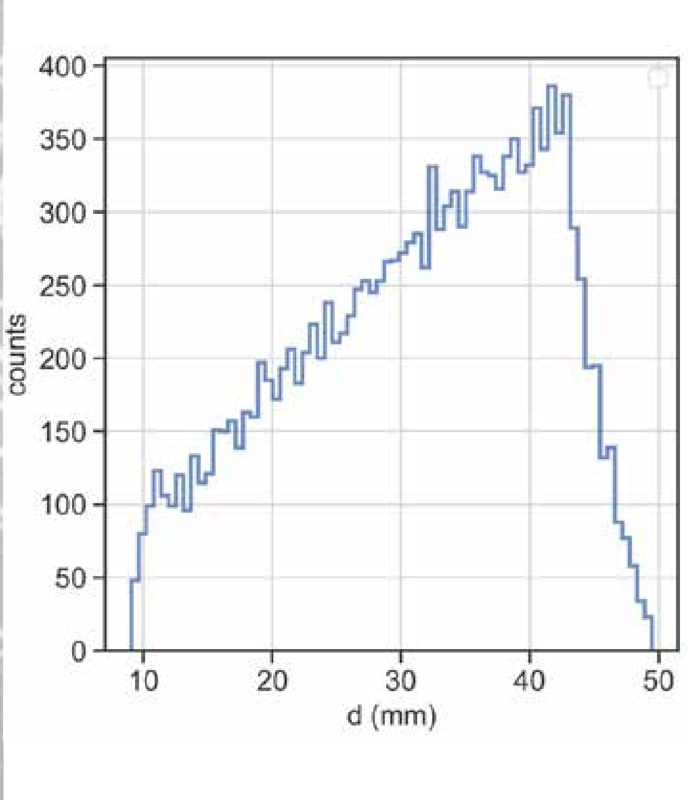
We use data provided by other members of the Athena background working group at the Italian National Institute for Astrophysics (INAF), who have simulated the **particle interactions and energy depositions expected to impact the X-IFU wafer in GEANT4**.

Simulation results provide a **list of primary and secondary energy depositions,** and their *x*, *y*, *E*, and *dt*.

We loop over each primary event, and generate a pulse for each secondary event at each *dt*.

From this, we can generate 86 seconds of *T(t)* on the wafer at (0,0) in Python.





Pulse production process:

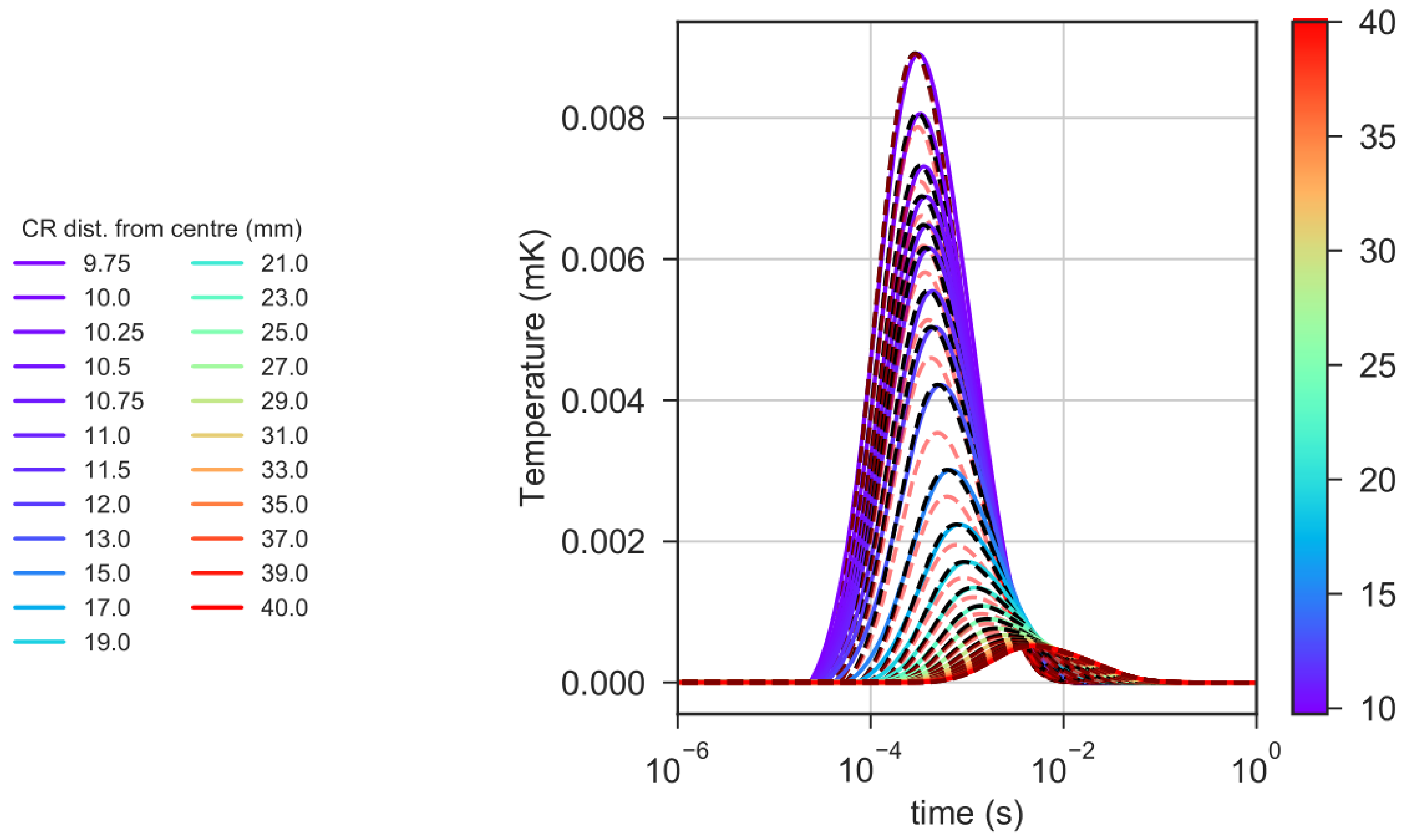
1. Choose the nearest energy to the one in the loop.
2. Choose the nearest distance to the simulated distances at that energy.
3. Normalise that pulse.
4. Scale the amplitude of that pulse depending on the energy-amplitude interpolated relationships.
5. If the distance is more than 25% larger or smaller than its nearest neighbour in the pulse library, scale it to its probable inter-distance height based on the amplitude-distance interpolated relationships.

Energy and distance scaling

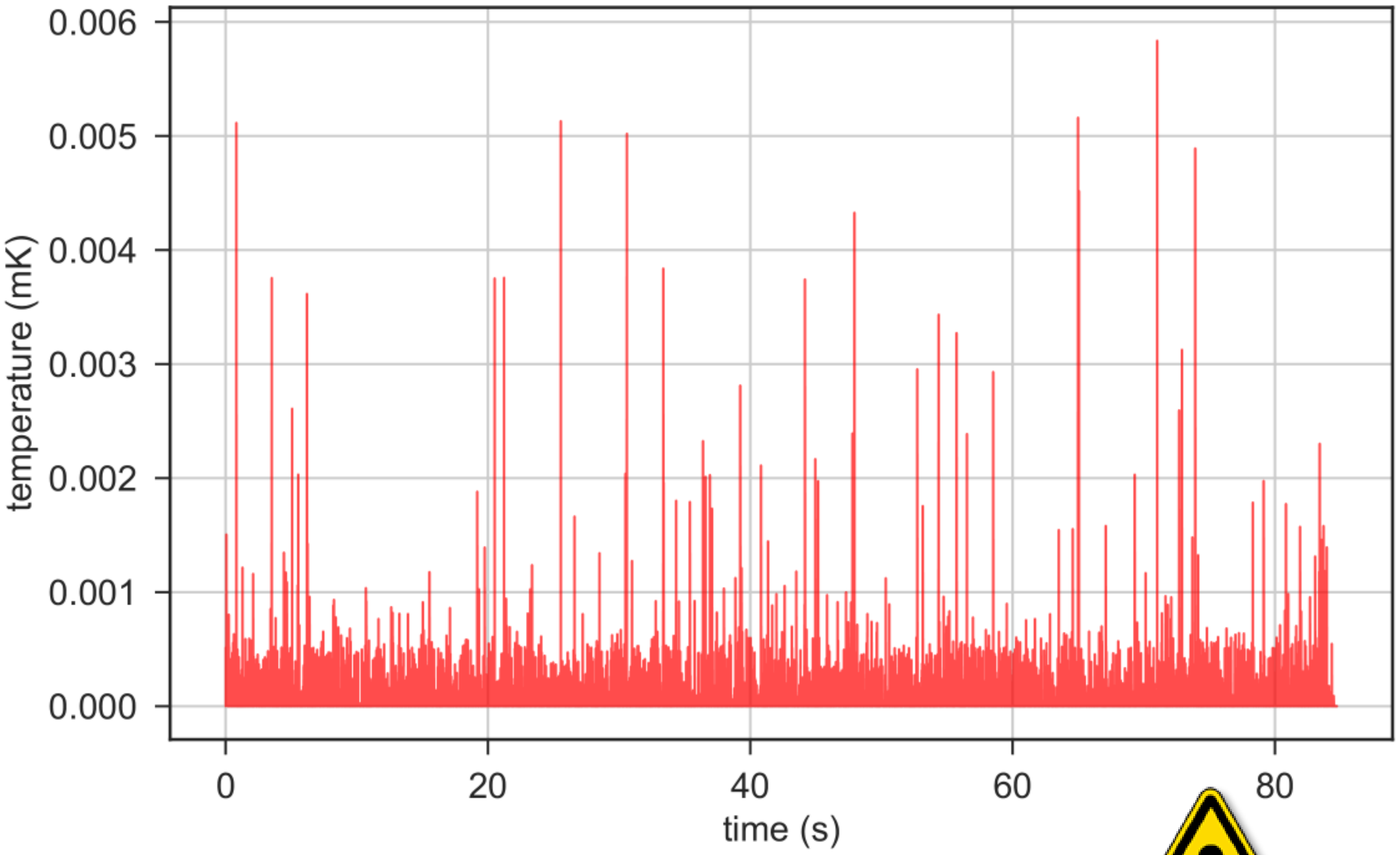
Solid coloured lines: 500 keV pulses

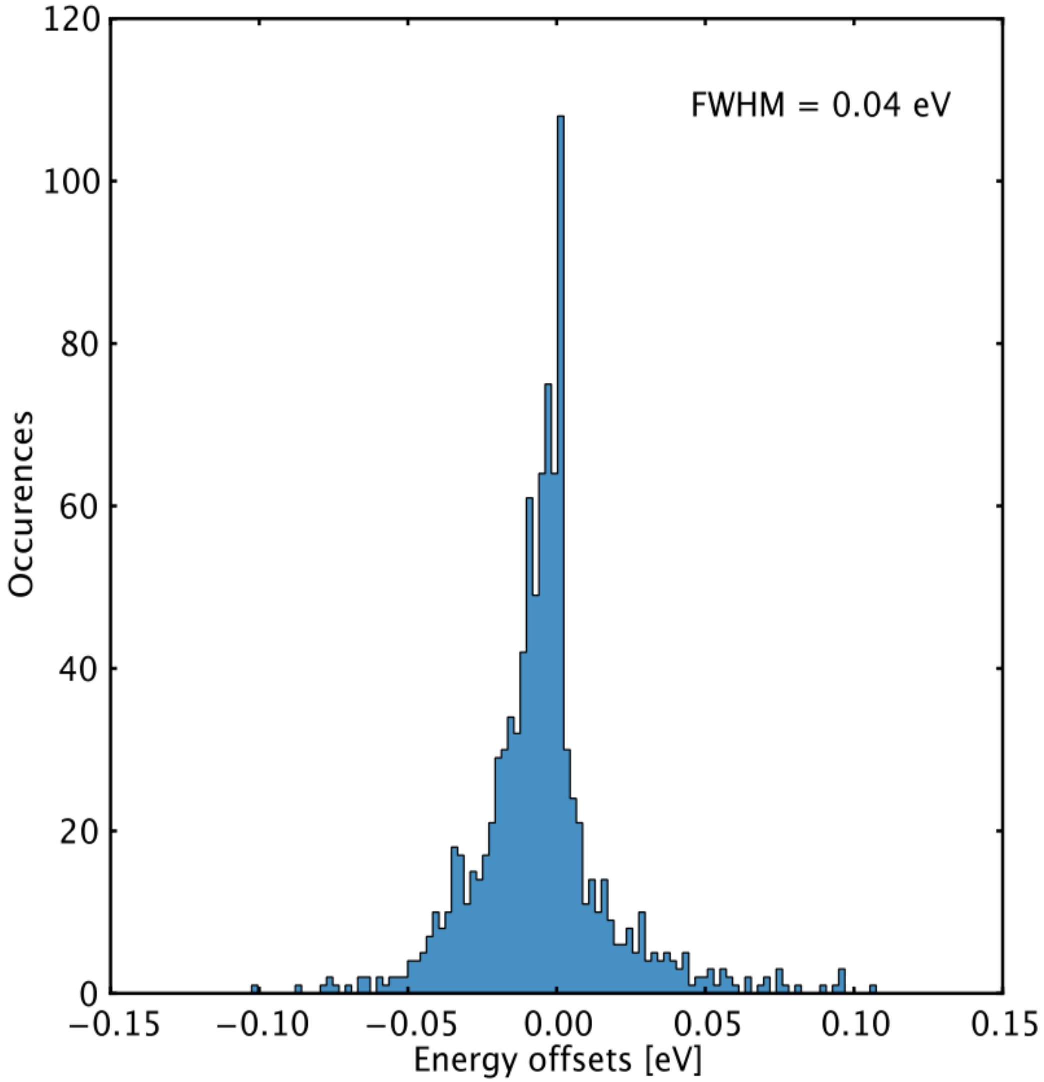
Black dashes: Energy-scaled 5000 keV pulses

Red dashes: Half-distance energy-scaled 5000 keV pulses



Secondary event timelines

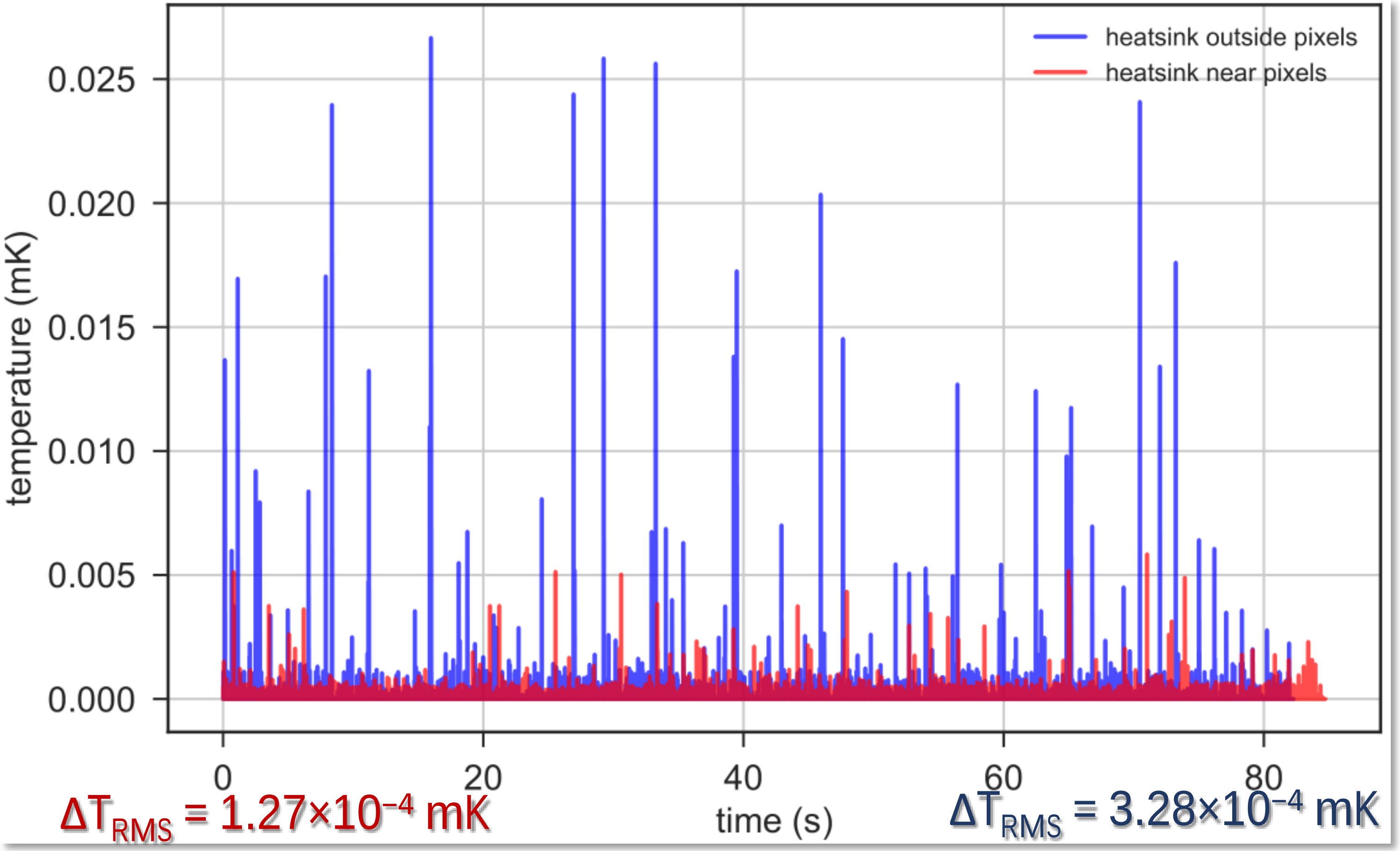




$\Delta T_{RMS} = 1.27\times10^{-4}$ mK

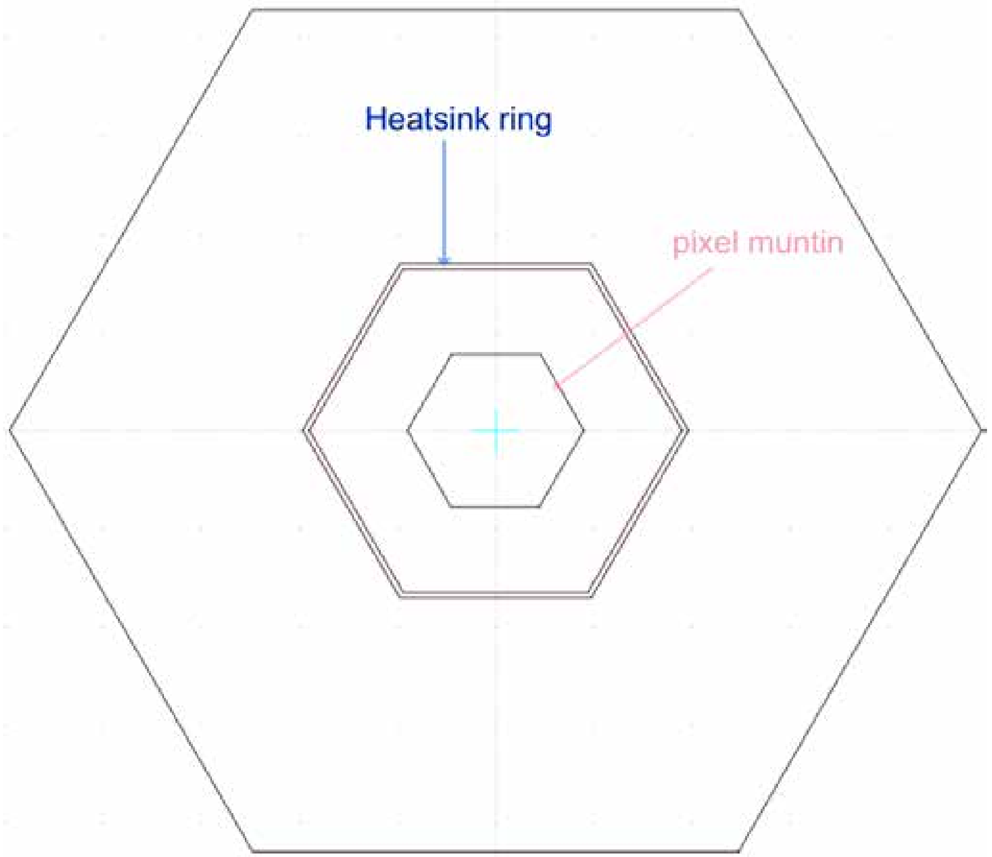
Budgeted X-IFU ΔT_{RMS}:
1.8×10^{-4} to 4.2×10^{-4} mK

Heatsink modifications

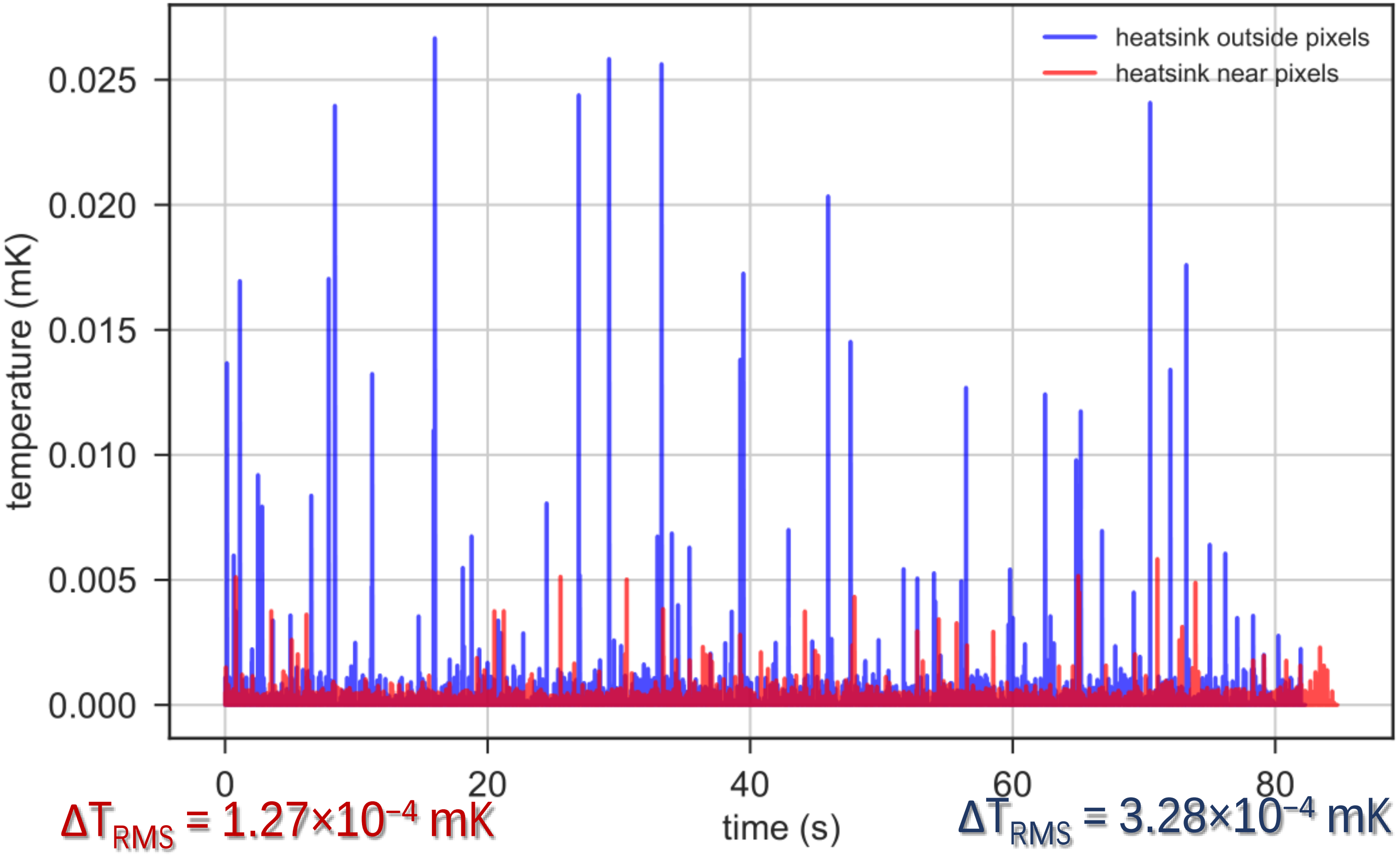


$\Delta T_{RMS} = 1.27\times10^{-4}$ mK

$\Delta T_{RMS} = 3.28\times10^{-4}$ mK

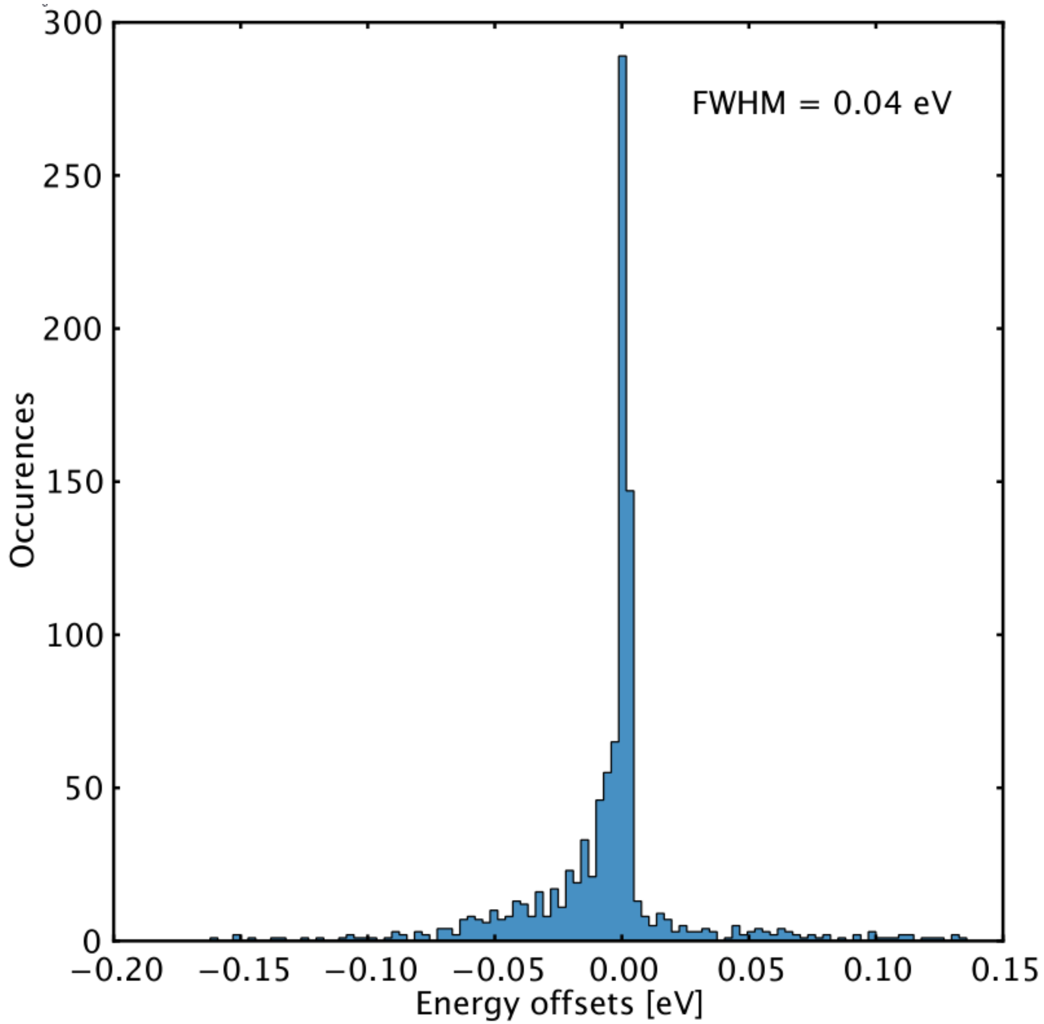


Heatsink modifications



$\Delta T_{RMS} = 1.27\times10^{-4}$ mK

$\Delta T_{RMS} = 3.28\times10^{-4}$ mK



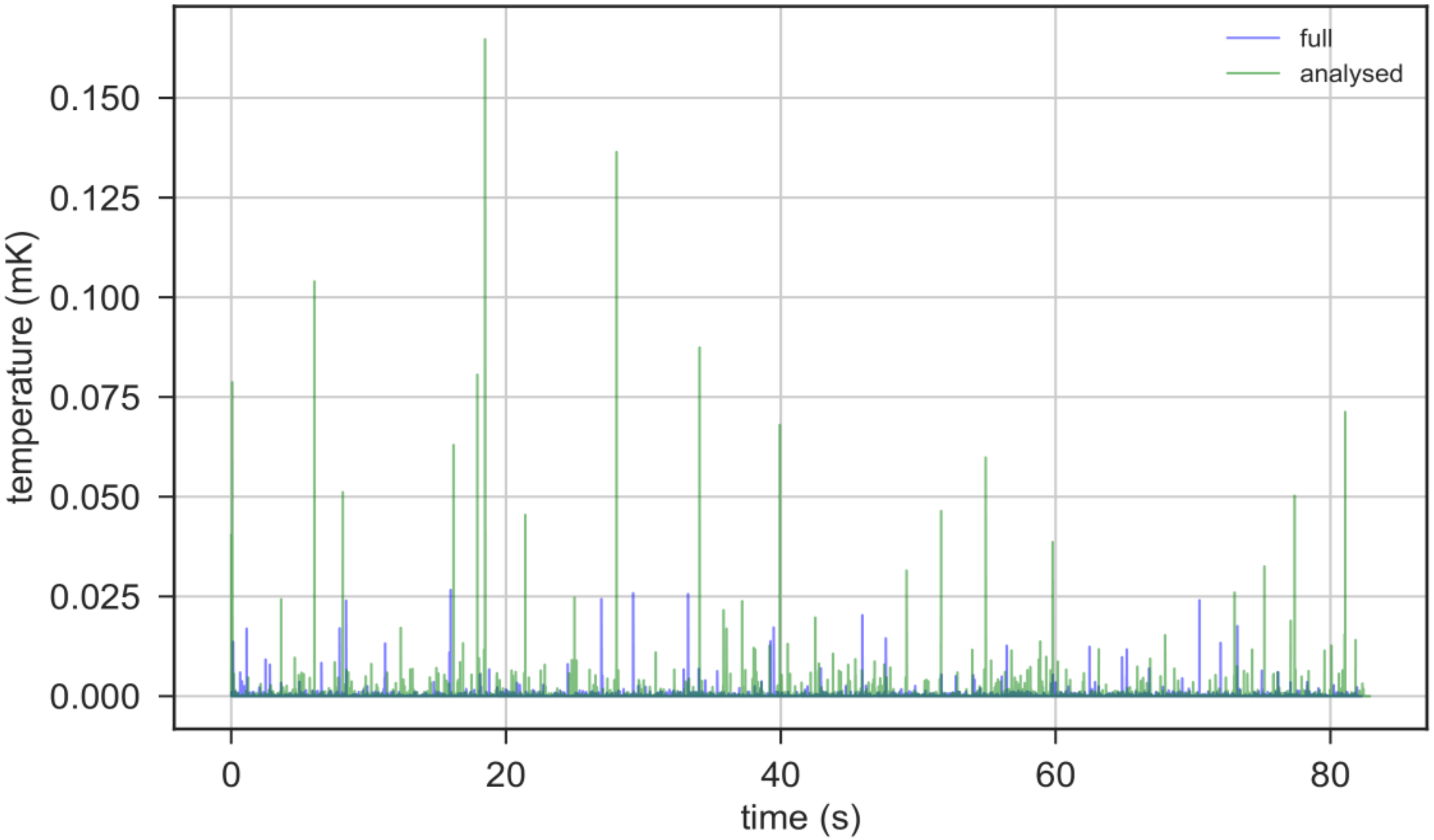
primary vs. secondary GEANT4 data

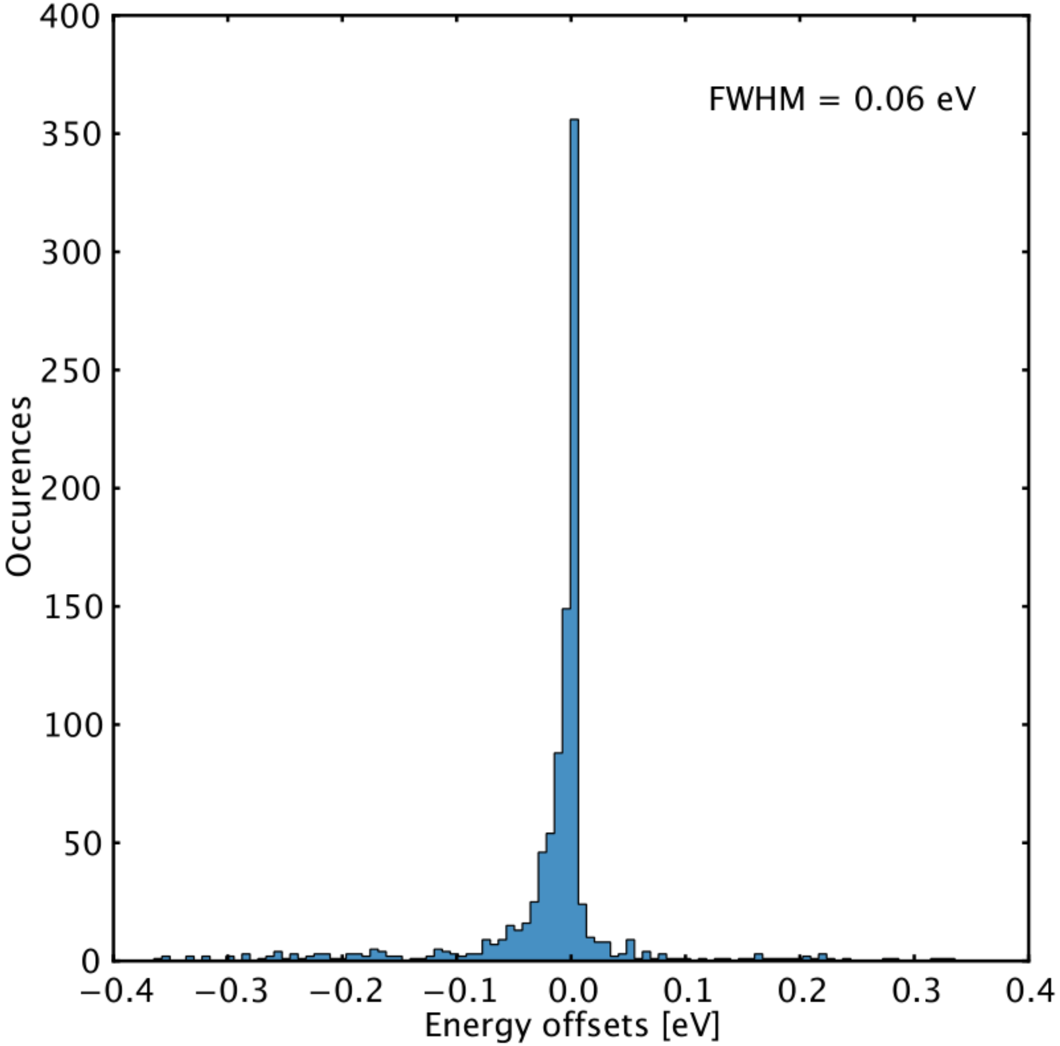
	Primary events	Secondary events
E_{mean}	452.17 keV	0.576 keV
No. events	15158	11909590
$t_{Computation}$	20 minutes with 8 GB of RAM	4 days with 160 GB of RAM
Advantage	Fast, easy	Most faithful reproduction of data
Disadvantage	Less accurate	Lengthy computation

primary vs. secondary timelines

$\Delta T_{RMS} = 1.64\times10^{-3}$ mK

$\Delta T_{RMS} = 3.28\times10^{-4}$ mK





Conclusions

- Thermal excursions on wafer **do not present a significant degradation to energy resolution**, but we have **only considered diffusive transport**. Ballistic will be relevant also.
- Direct hits on detectors, or on muntins, **probably have a larger effect**.
- Change of shape of energy offset with moved WB location implies that this may be a per-detector location-specific effect à energy resolution gradient?
- Can use this tool to probe effects of design changes (e.g. location of wirebonds to heatsink)

Must address parametric uncertainties and also ballistic transport.

Finally, all of this must be validated with an **experiment**.