



UNIVERSITY OF
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X-ray Irradiation Studies of ITk Pixel Modules Affected by the Core-Column Problem

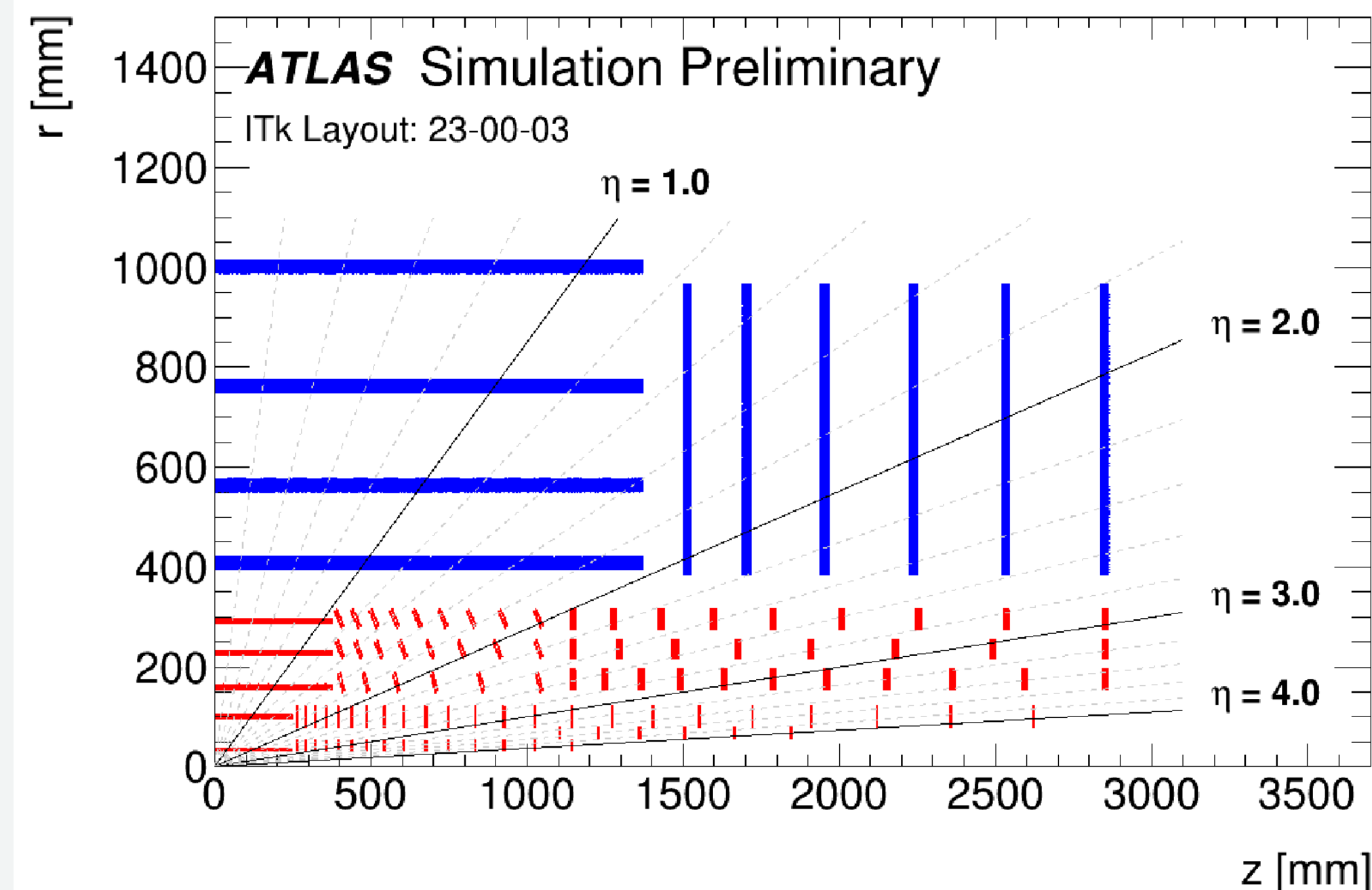
NICOLO SALIMBENI | 18 JUNE 2026

ATLAS Inner Tracker for the HL-LHC

For the High Luminosity LHC (HL-LHC) phase the current ATLAS tracking system will be replaced with a completely new one to handle the increased data rate.

The new Inner Tracker (ITk) will feature:

- only silicon detectors
- strip (ITk strips) and pixel (ITk pixels) sensors
- increased volume coverage
- higher granularity to cope with increased pile-up, yielding better position resolution



Schematic depiction of the ITk layout from ATLAS [TDR](#). Layers with strip modules in blue, layers with pixel modules in red.

ATLAS ITk pixel modules

ATLAS developed two types of pixel modules:

- **Quad** modules, with 4 front-end (FE) chips
- **Triplet** modules, with 3 FE chips

A silicon module is made out of three components, each tested individually before assembly:

- A PCB called module flex to power up and read the chips
- A 150 μm thick silicon sensor
- 4 (3) ITkPixv2 readout chips for quads (triplets)
 - One chip covers a $2 \times 2 \text{ cm}^2$ area, with a matrix of 400×384 pixels.
 - The pixel size is $50 \times 50 \mu\text{m}^2$ or $25 \times 100 \mu\text{m}^2$

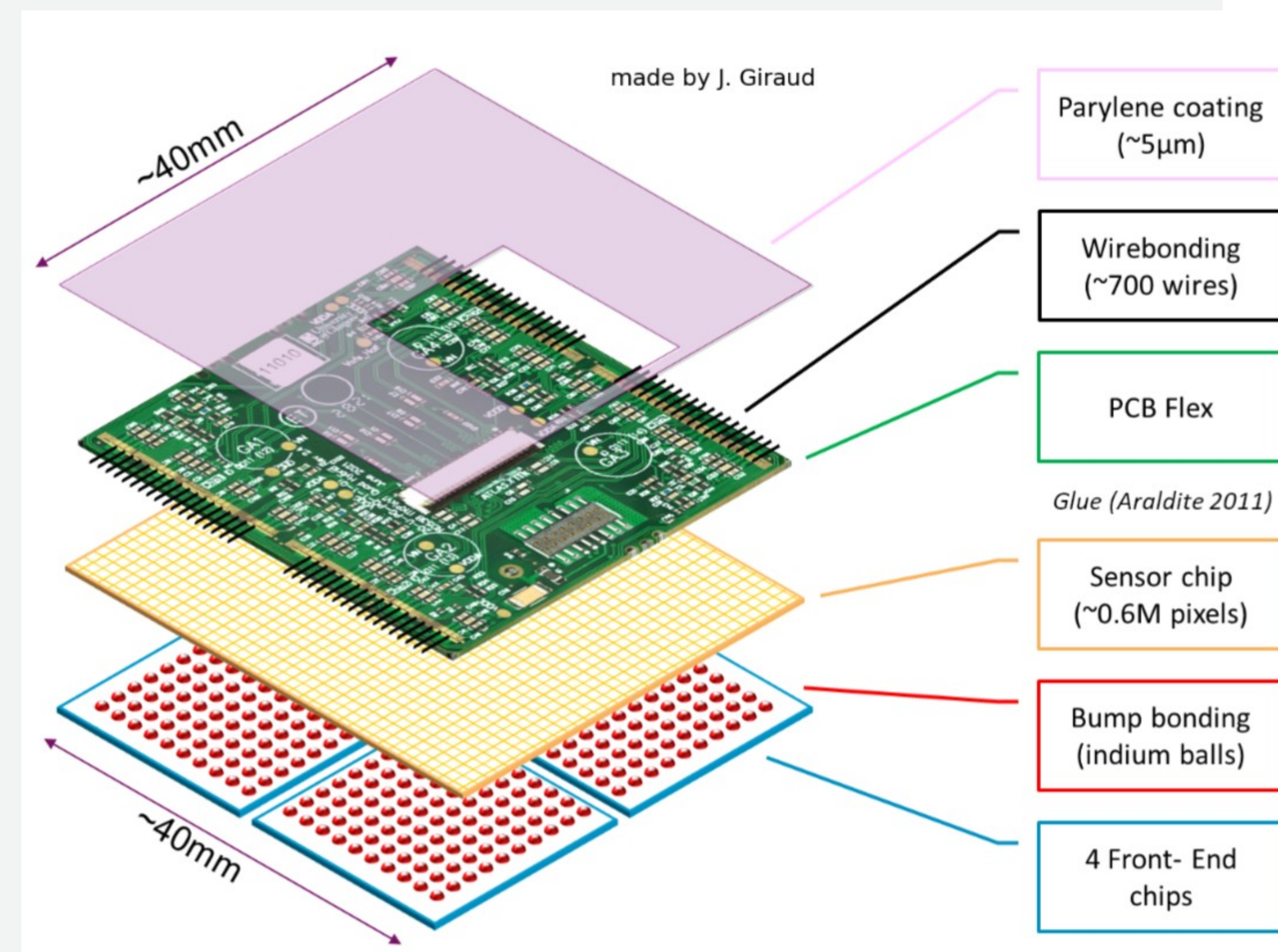


Diagram of a quad module and its constituent components from [here](#).

Core-Column problem

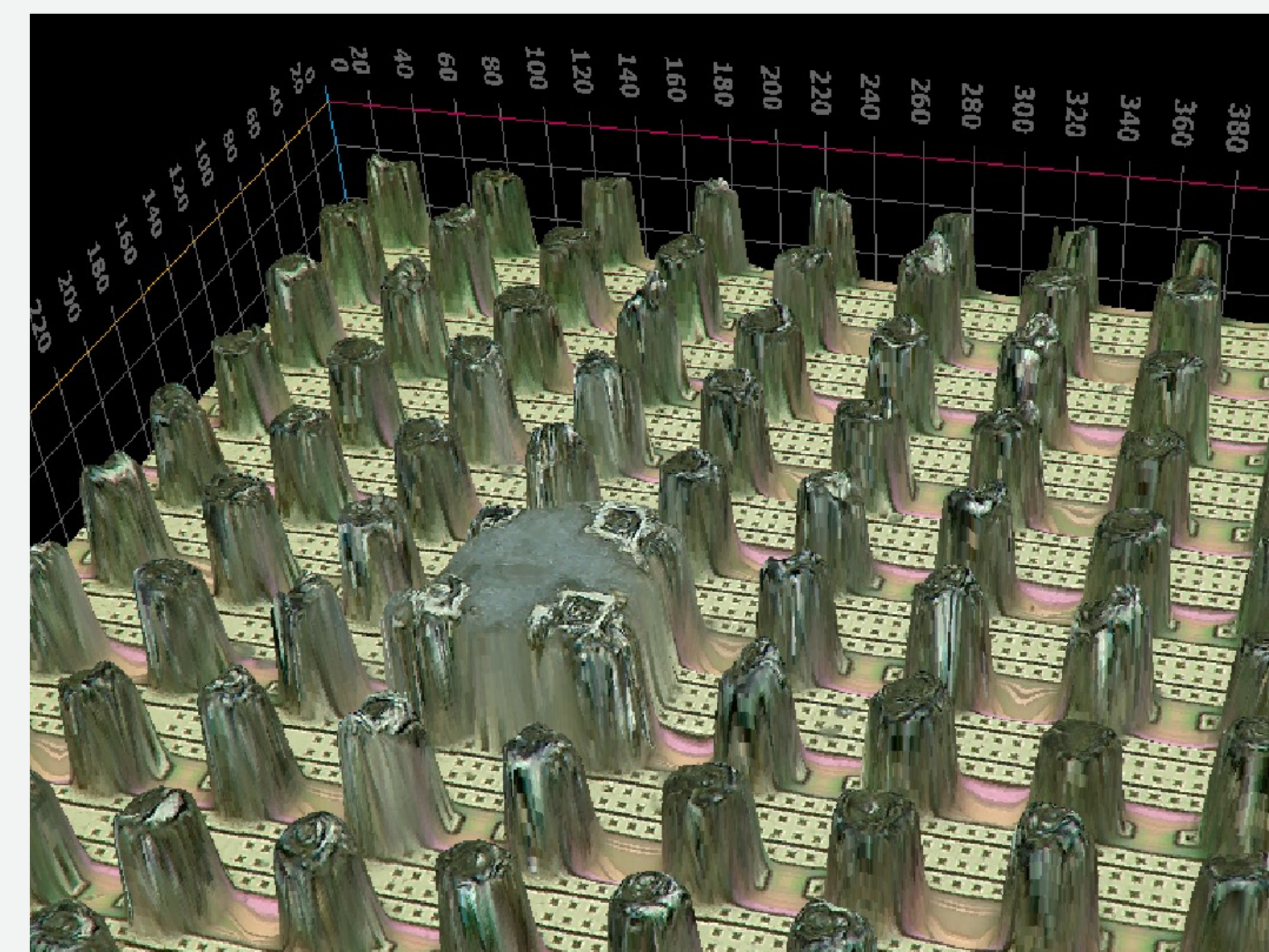
ITkPixv2 chips organize the readout of the matrix in 50 sectors called Core-Columns (CC), each of 8x384 pixels.

10% of the production modules show a non trivial “problem” known as Core-Column issue:

- Chip readout becomes stuck or produces random data
- Disabling the non-working CC restores the chip operation

It is not a chip issue - otherwise it would have been caught in wafer probing → suspect mechanical damage during sensor dicing or module assembly (picture on the right).

Due to funding and timing constraints the affected modules can't be replaced, and some must be used.



High resolution picture of a FE chip disassembled from a module affected by the CC problem from [here](#). Silicon debris has been found between the bonds used to read the pixels.

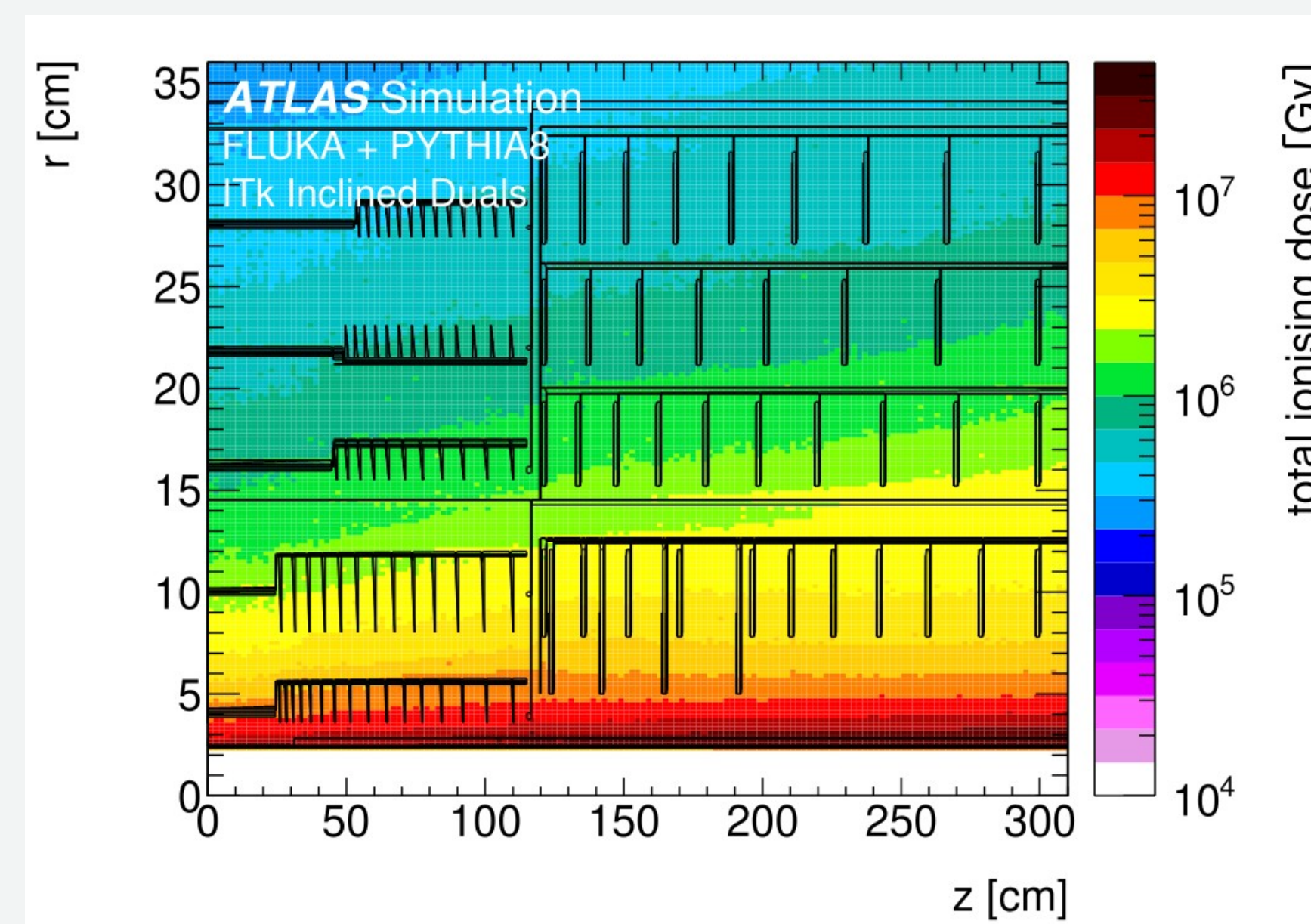
CC tests in Oxford

The cause of the CC issue is not understood. Affected modules are under study to see if their behaviour changes with operation.

CC module response to irradiation is critical at LHC:

- The CC issue is believed to originate in the chips → X-rays irradiation campaign. They contribute mainly to the Total Ionizing Dose (TID), which affects the electronics rather than the sensitive material
- An X-ray tube is used to deliver a total dose of 100 Mrad, in steps of 10 Mrad, to the chips
 - The chips are designed to withstand 1 Grad over the HL-LHC
- Two modules have been irradiated so far
- At each irradiation step, chip performance is monitored with a dedicated software developed by ATLAS called [YARR](#)

1 Gy = 100 rad



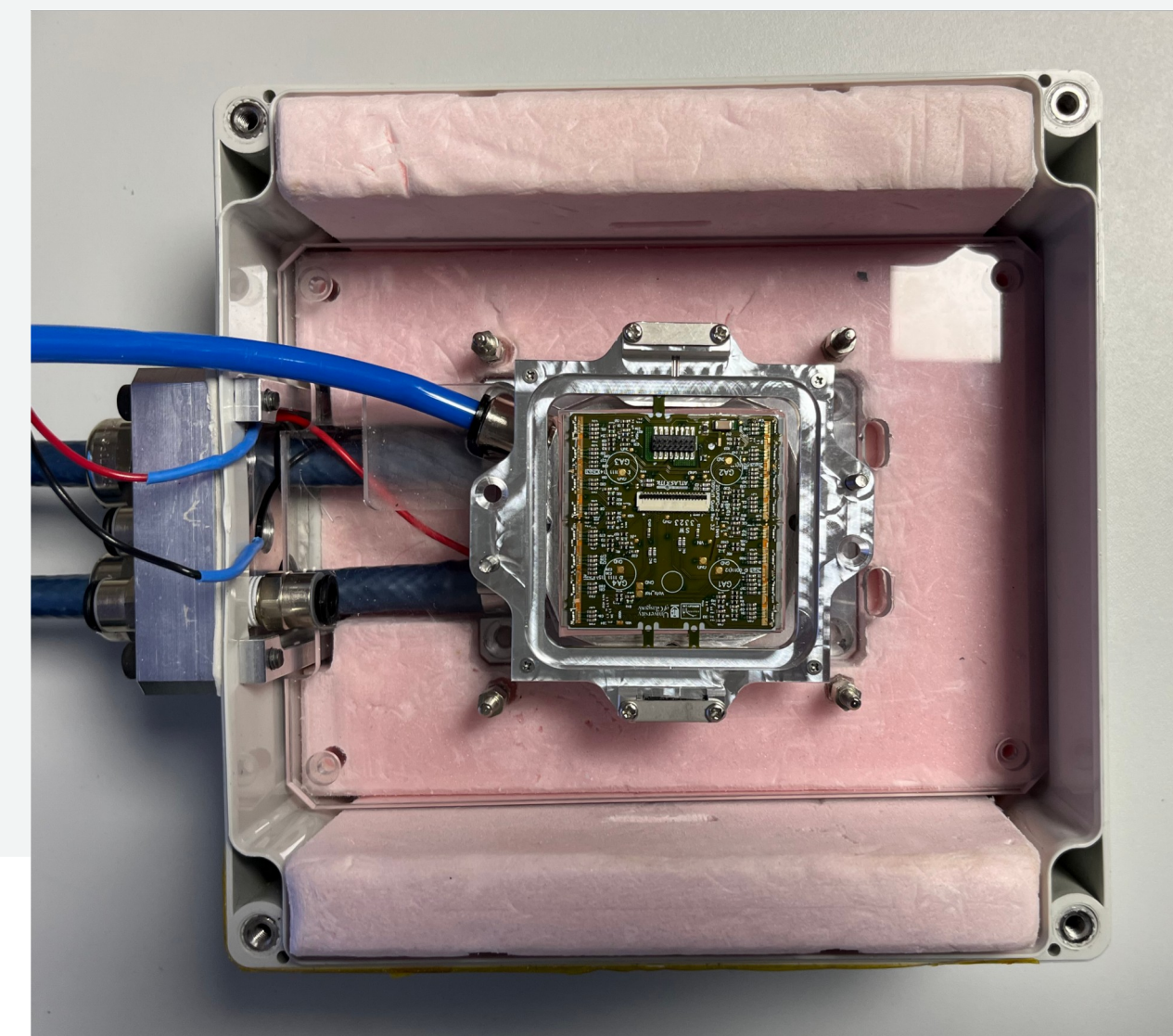
Distribution of the TID expected in the HL-LHC for the ITk pixel detector from [here](#).

X-ray setup

The setup developed allows realistic operating conditions:

- X-ray tube (top picture)
- Module mounted in a dry-air enclosure (bottom picture)
- Cooling system: chiller + Peltier plate, maintaining $\sim -10\text{ }^{\circ}\text{C}$
- DAQ computer
- Temperature and humidity sensors
- Power supplies and multimeters

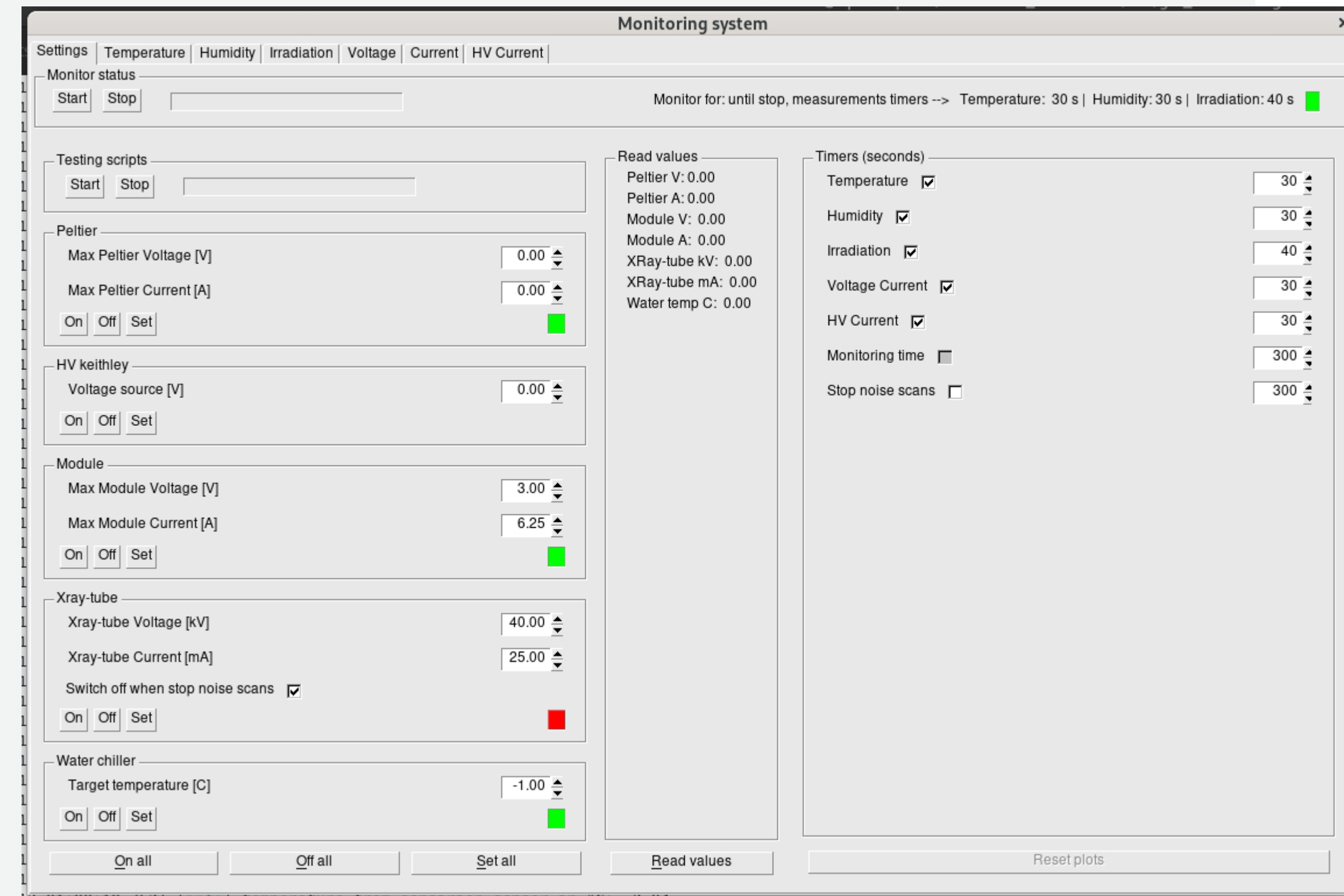
The module is placed in the X-ray setup, and triggers are continuously sent via noise scans during irradiation to emulate realistic operation.



Monitoring system

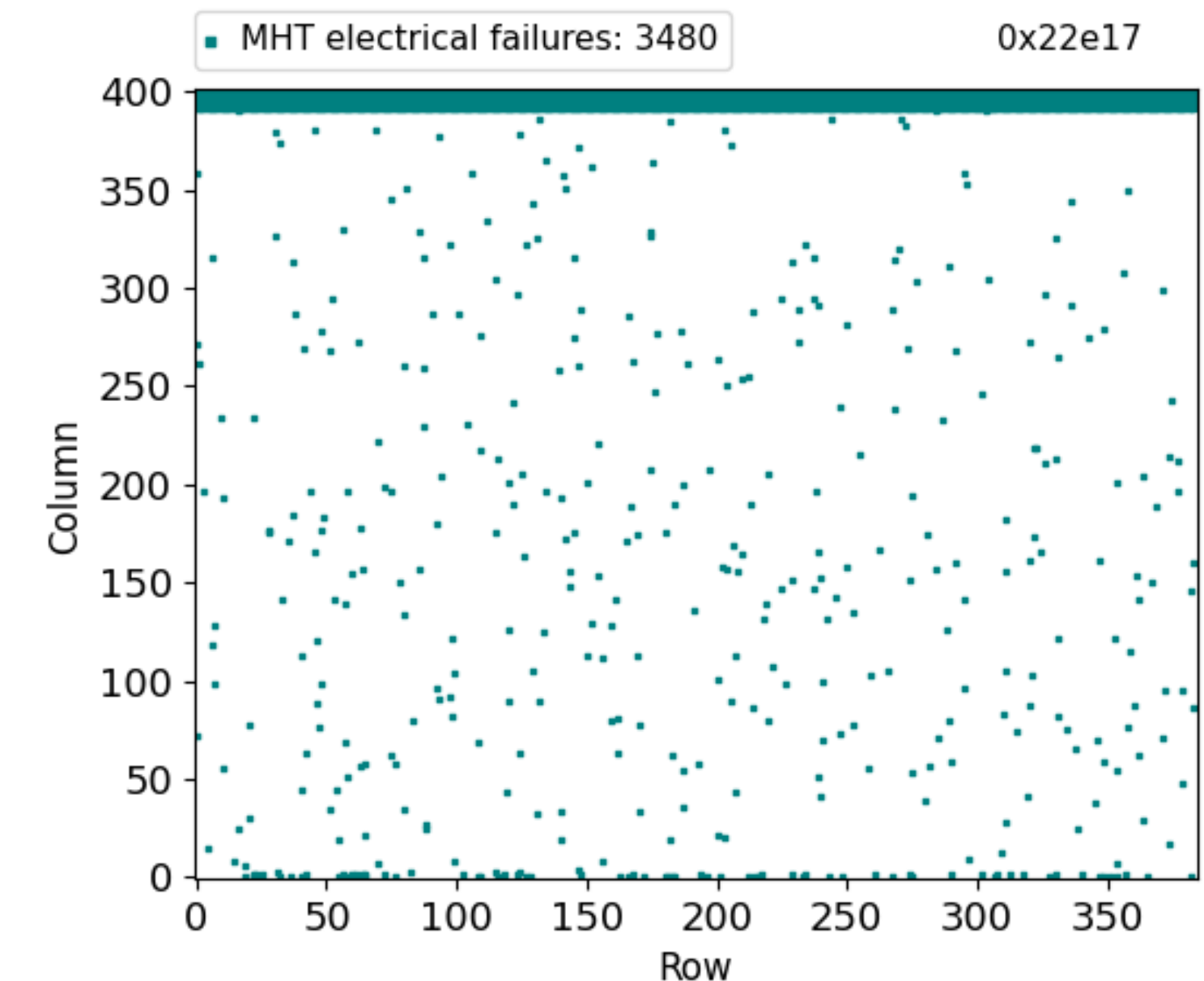
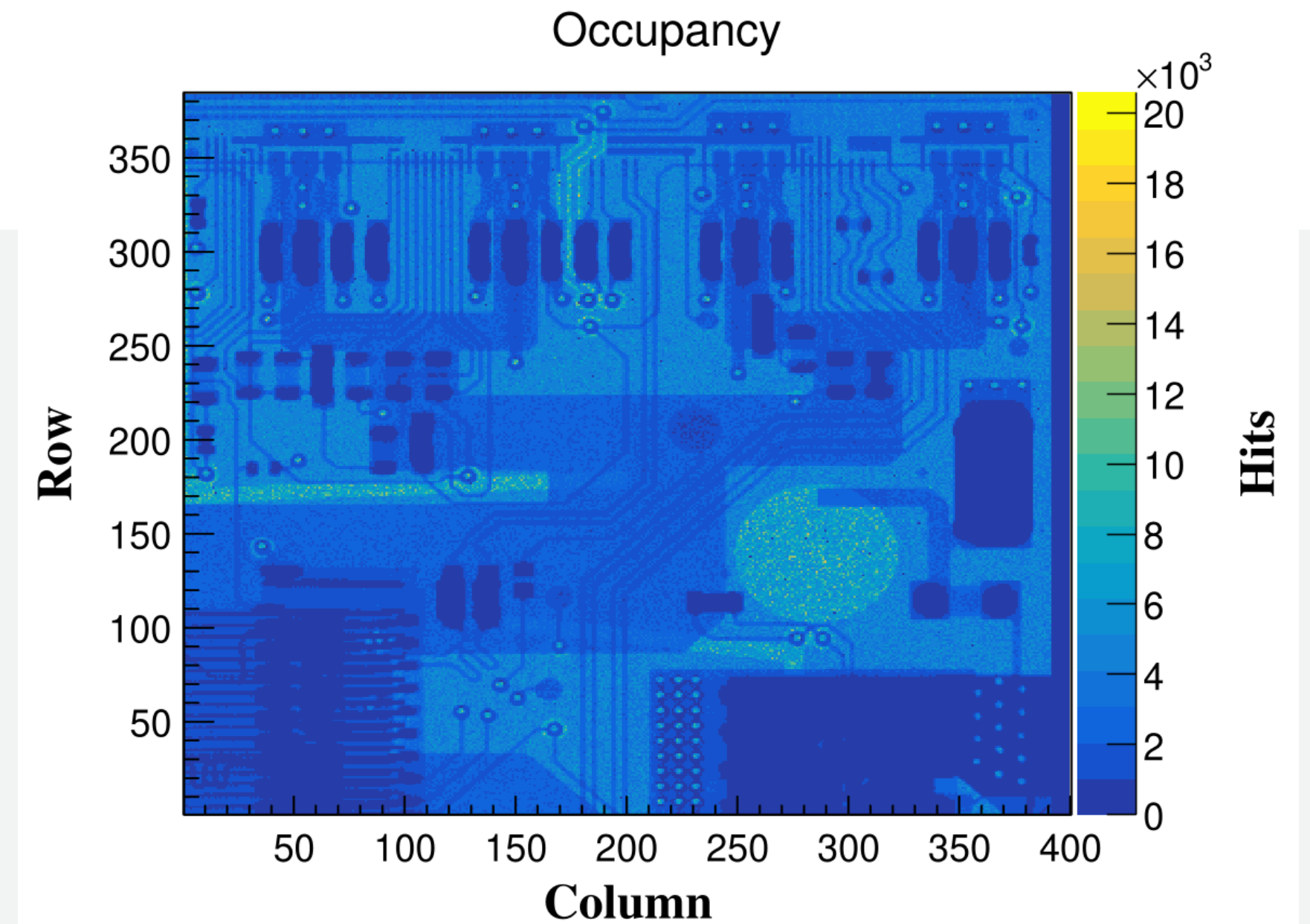
A GUI to monitor the data taking has been developed. It can:

- Control all the involved instrumentation remotely
- Monitor the temperature of the module, as well as the air temperature inside the box
- Monitor the humidity inside the box
- Monitor the X-ray flux using a photodiode.
- Monitor the HV voltage leakage current
- Handle “emergencies” such as excessively high module temperature or condensation



Test strategy

- To emulate real operation during the irradiation, triggers are sent constantly to the module at 1 kHz
- Every 30 seconds, an occupancy map is recorded (plot on the top)
- Once an irradiation cycle is completed the X-rays are switched off.
- Then a set of predefined tests in YARR is performed to identify non-working pixels.
- The summary of those tests is called *Minimum Health Test* (MHT, bottom plot)

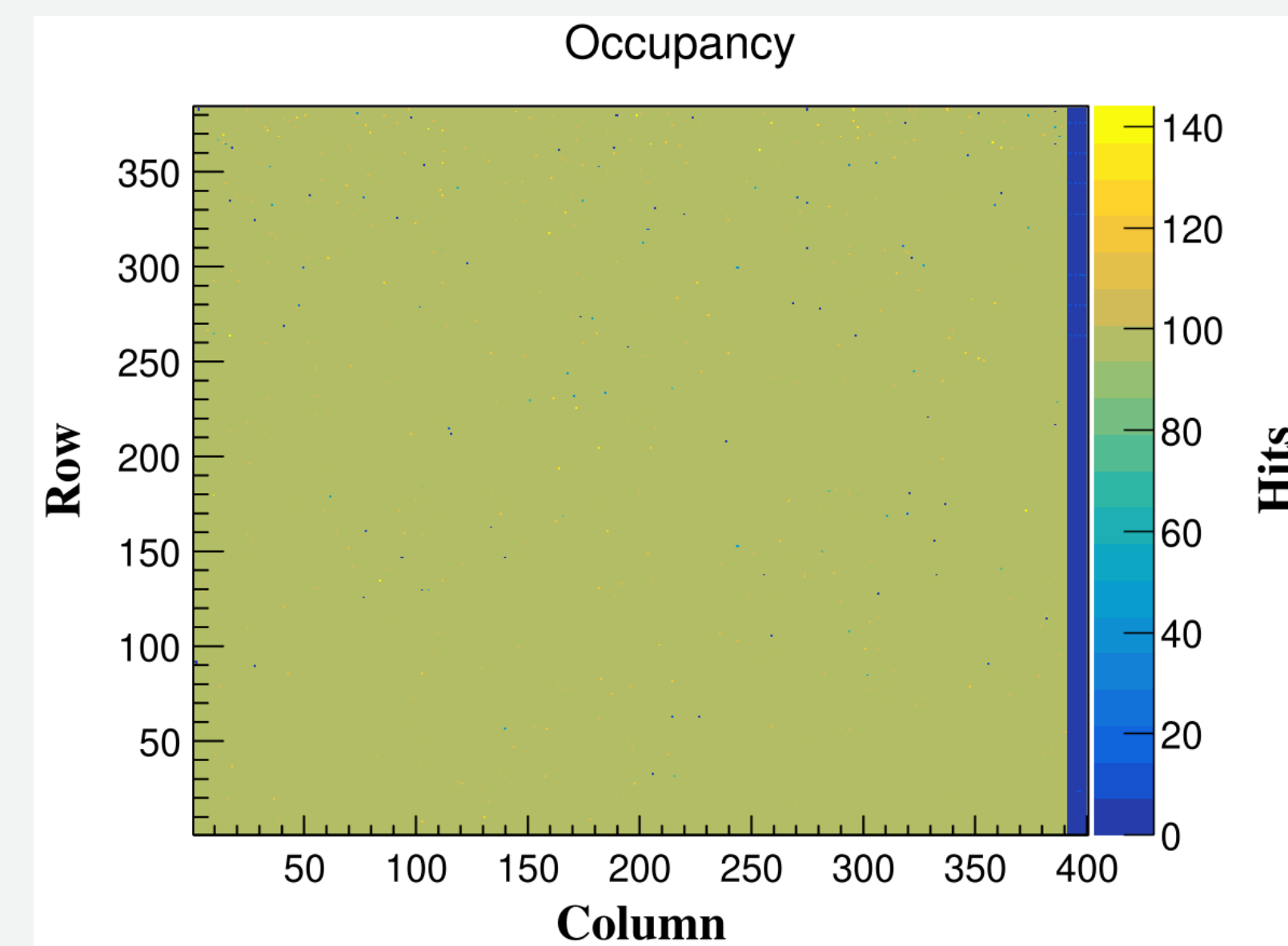


CC scan

The *CC scan* is part of the MHT, it:

- Enables one CC at a time
- Enables injection in all its pixels
- Injects charge 100 times
- Sends 100 triggers
- Decodes the chip response
- Moves to the next CC

At the end, it labels as “bad” all pixels with counts $\neq 100$. If a CC has more than 10% of such pixels, it is switched off.

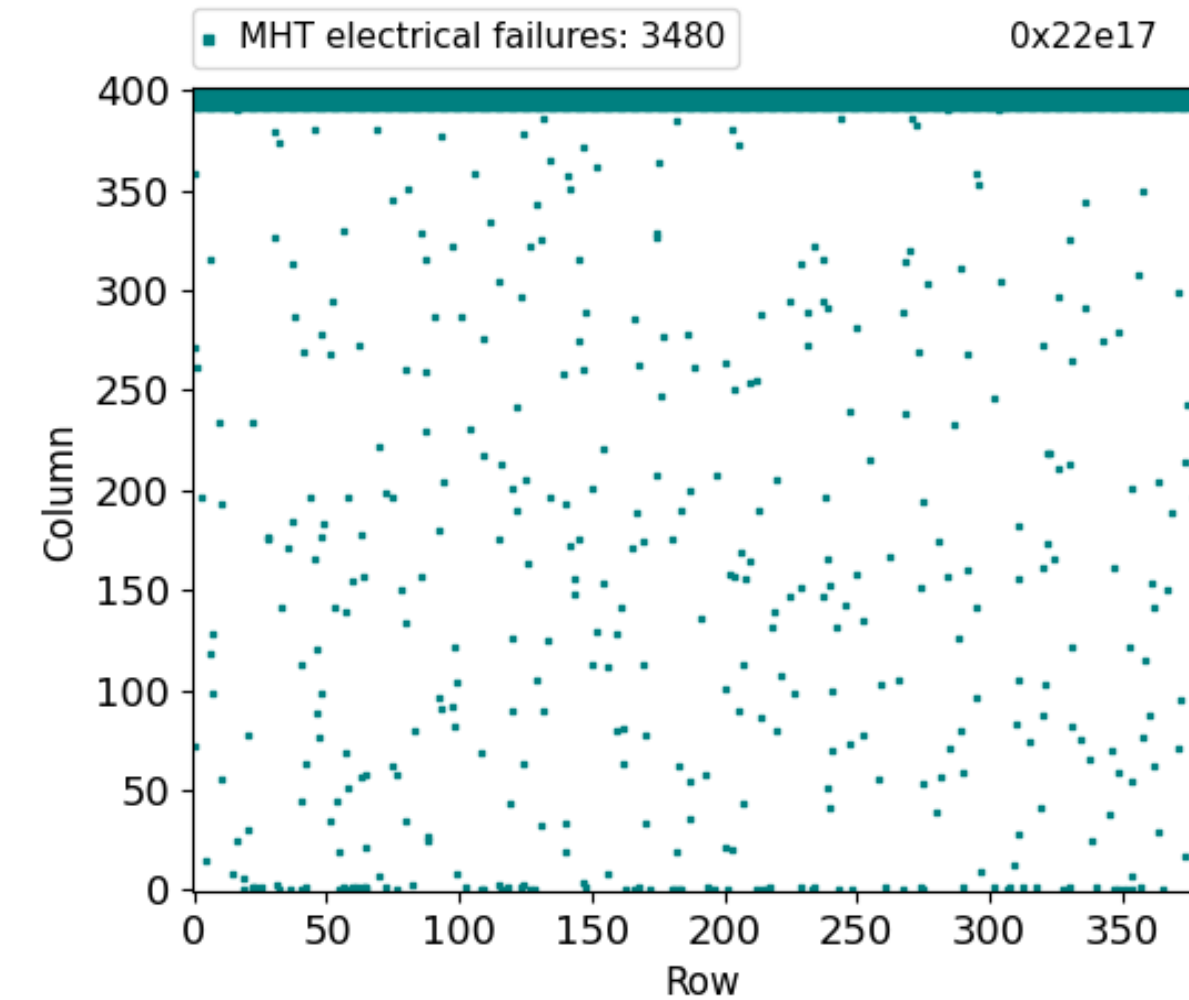


Module occupancy scan for one of the chips under study

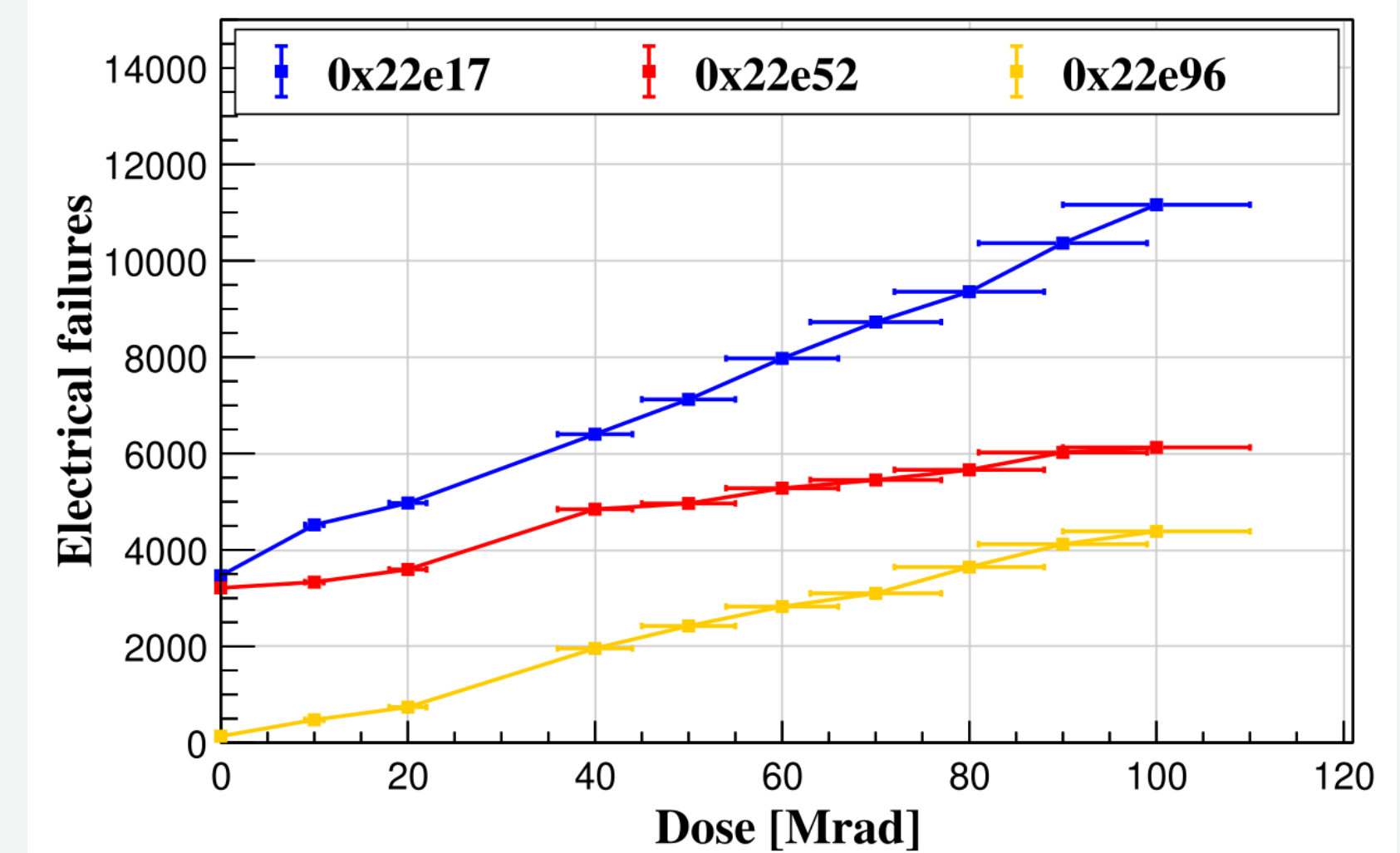
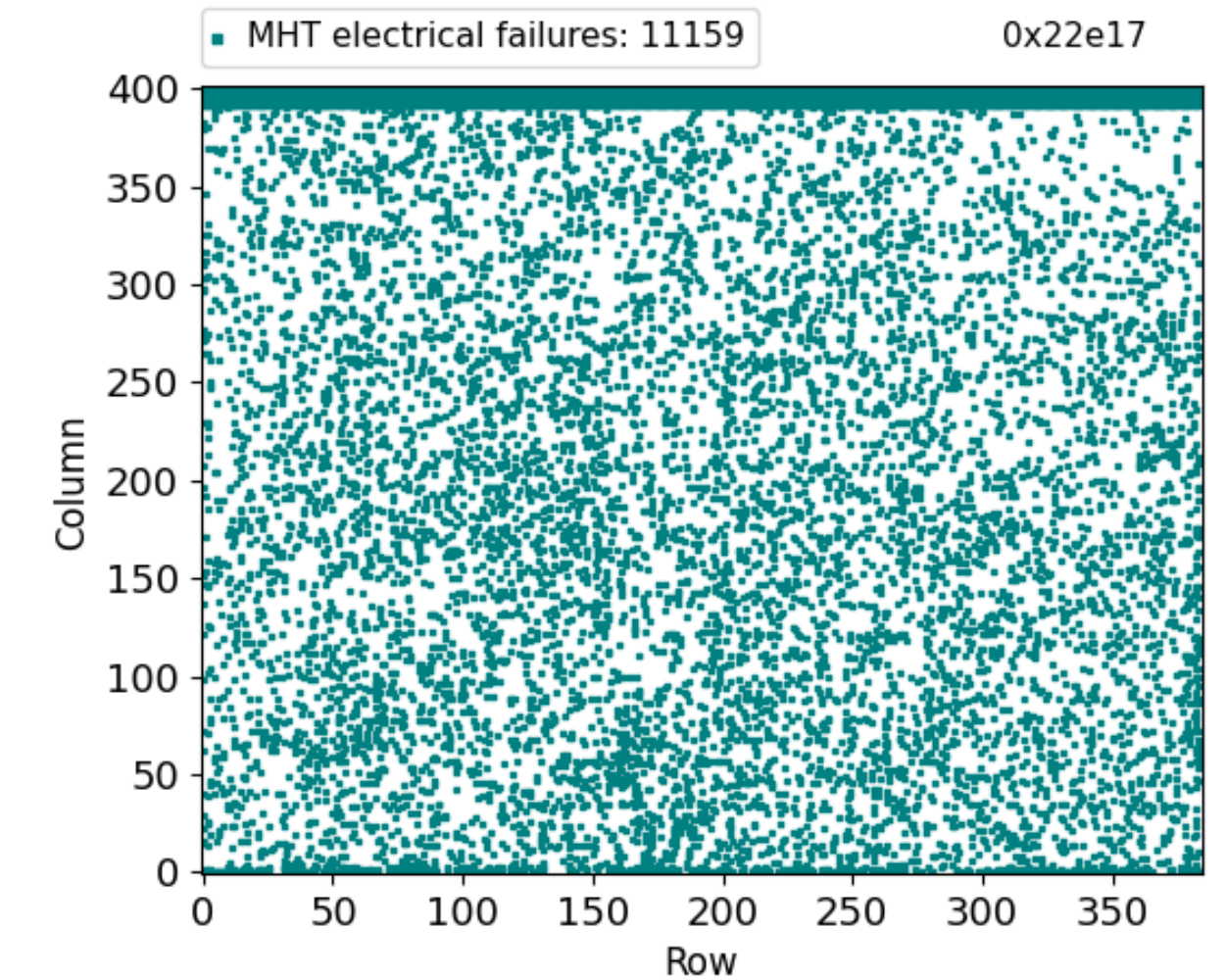
Results

- In all the chips studied so far the number of electrical failures increased, but no new CC issues appeared
- Up to ~75% of the failures can be recovered after retuning
- For 3 chips the evolution of the failures as a function of the dose has been tracked (plot on the bottom)

Before irradiation



After 100 Mrad



Conclusions

- Two quad modules have been studied so far, 7 chips tested in total (1 chip was non-operational since the beginning)
- Among those, 3 chips showed CC issues before irradiation
- **No** new CC issues have been observed so far after 100 Mrad
- These results have been shown at the ITk week at CERN and have been used to decide if modules with CC issues can be used in the final detector

What is next?

- 2 more modules are available for irradiation. One will be used to study in more detail the electrical failures, one will receive a higher dose.

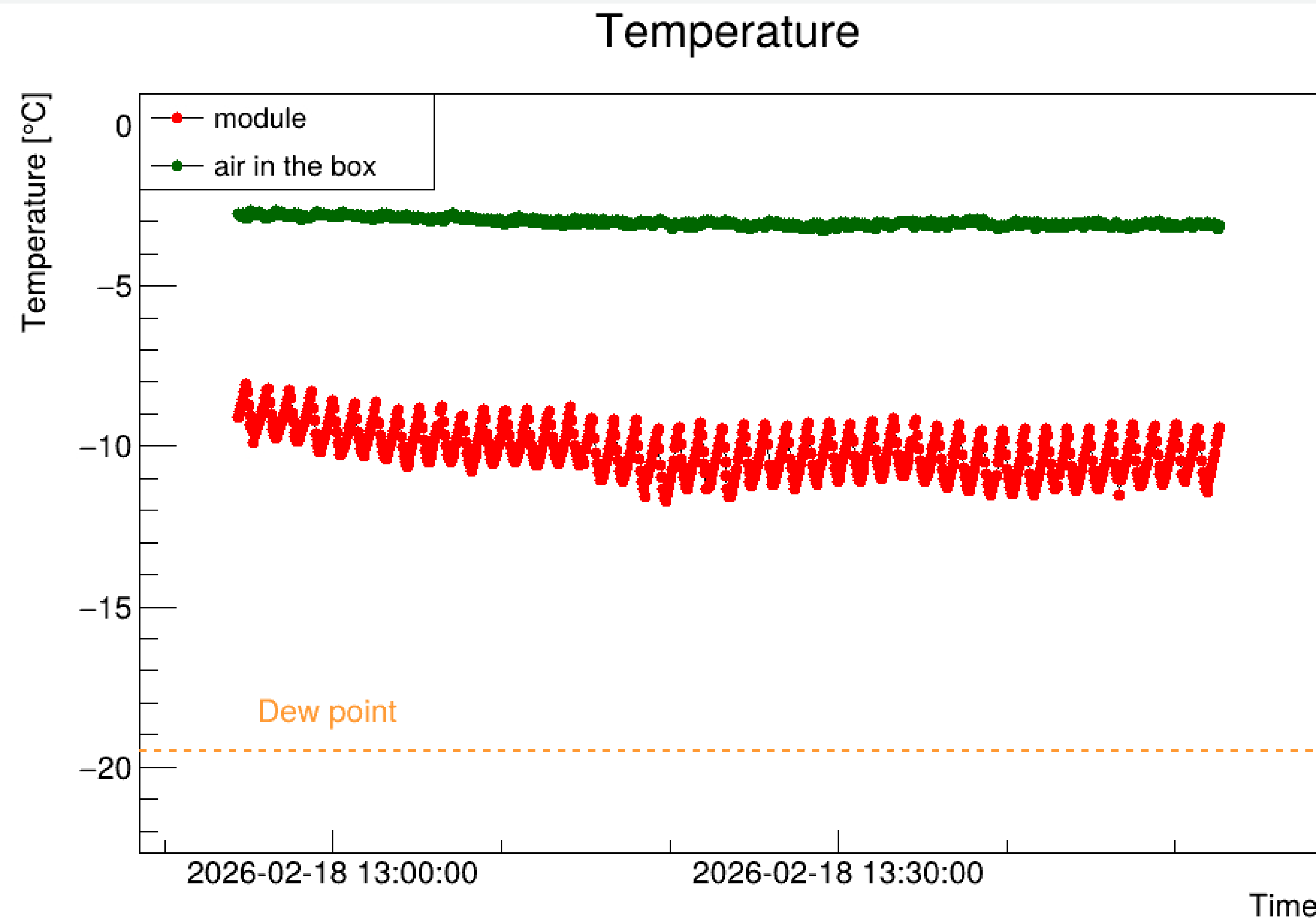


Thanks for your attention!



Backup slides

Module temperature during operation



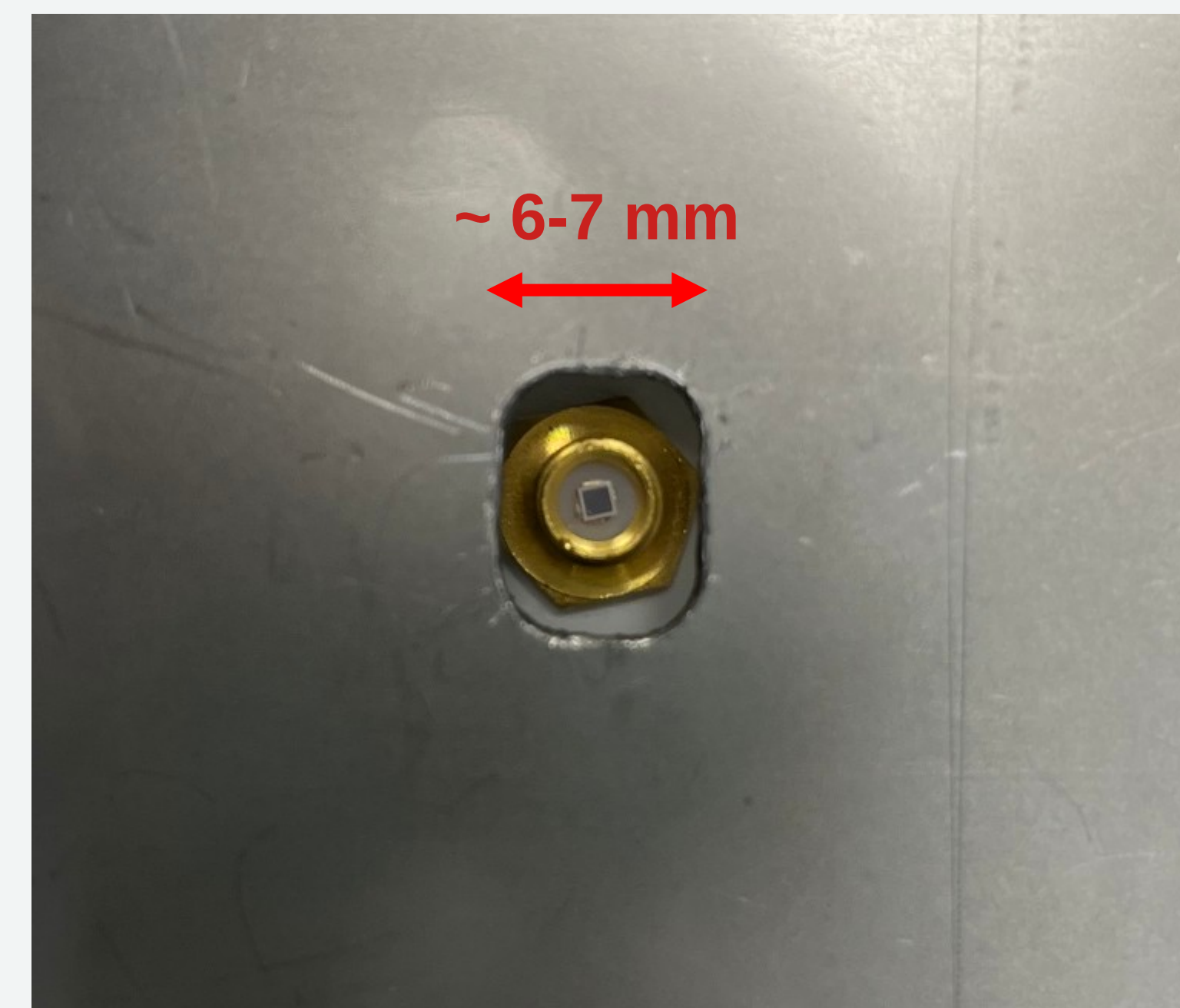
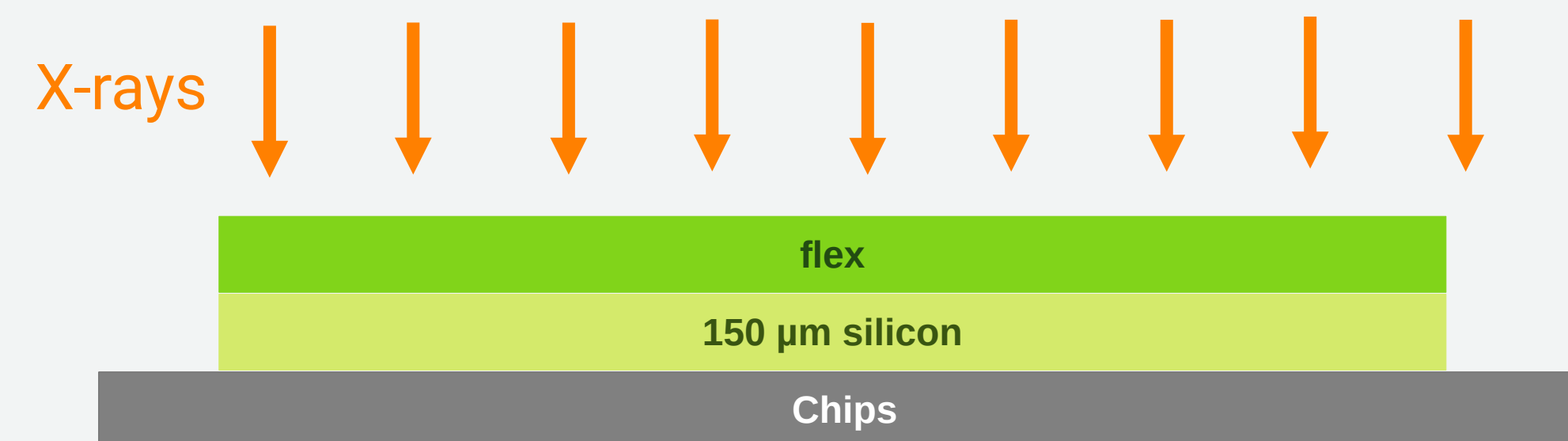
Dose received by the chips

The dose received by the chips is determined by the photons transmitted through the flex and the overlying silicon.

We measured this dose using a calibrated diode.

- ~140 μm of silicon and a flex are placed on top of the diode
- The diode uncertainty is $\pm 15\%$

Deposited dose in $\text{SiO}_2 \approx 0.30 \text{ Mrad/h}$



Shield design

Since the periphery of the chips is exposed directly to the X-rays, we need a structure that:

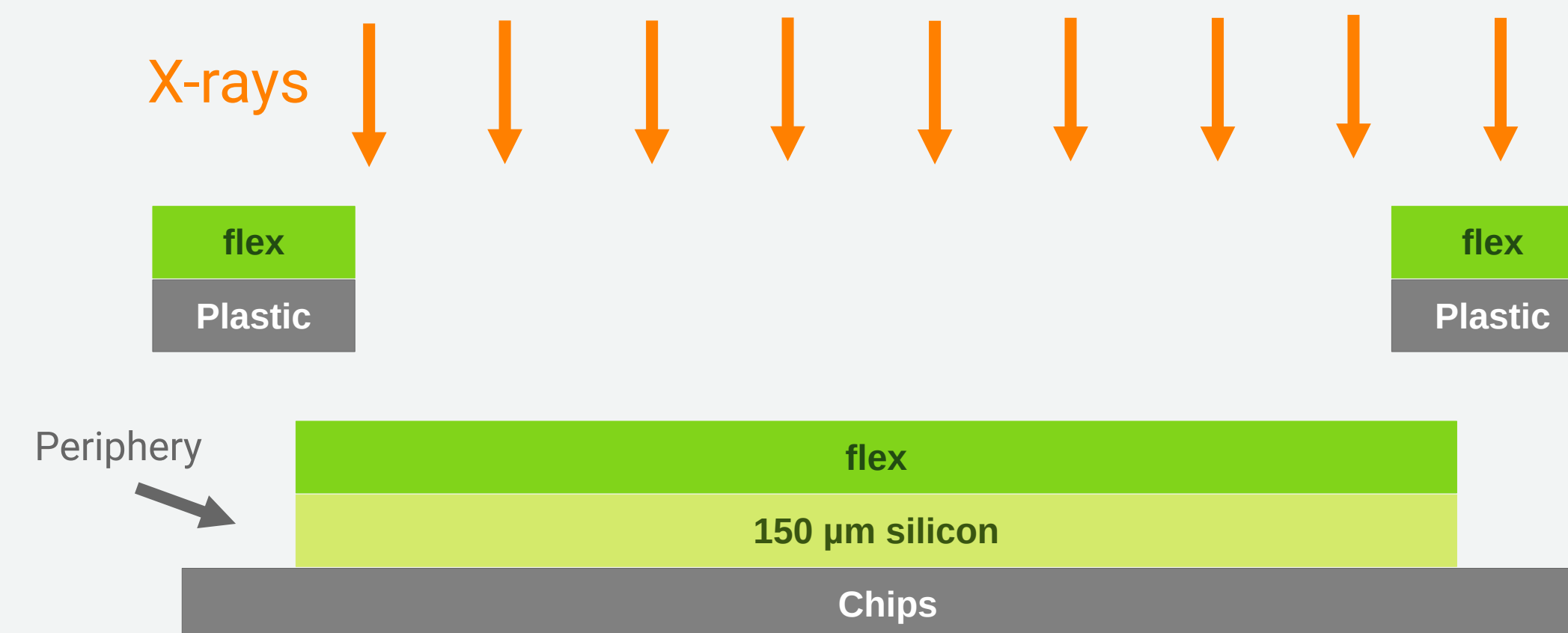
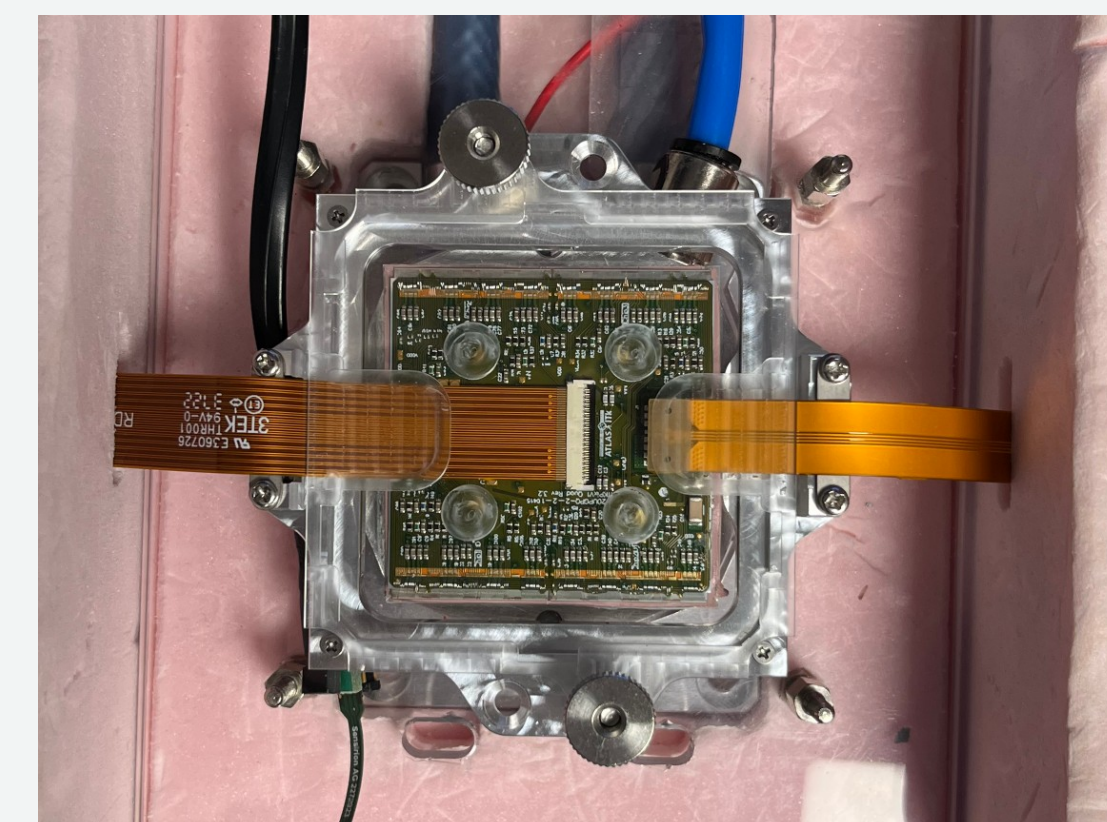
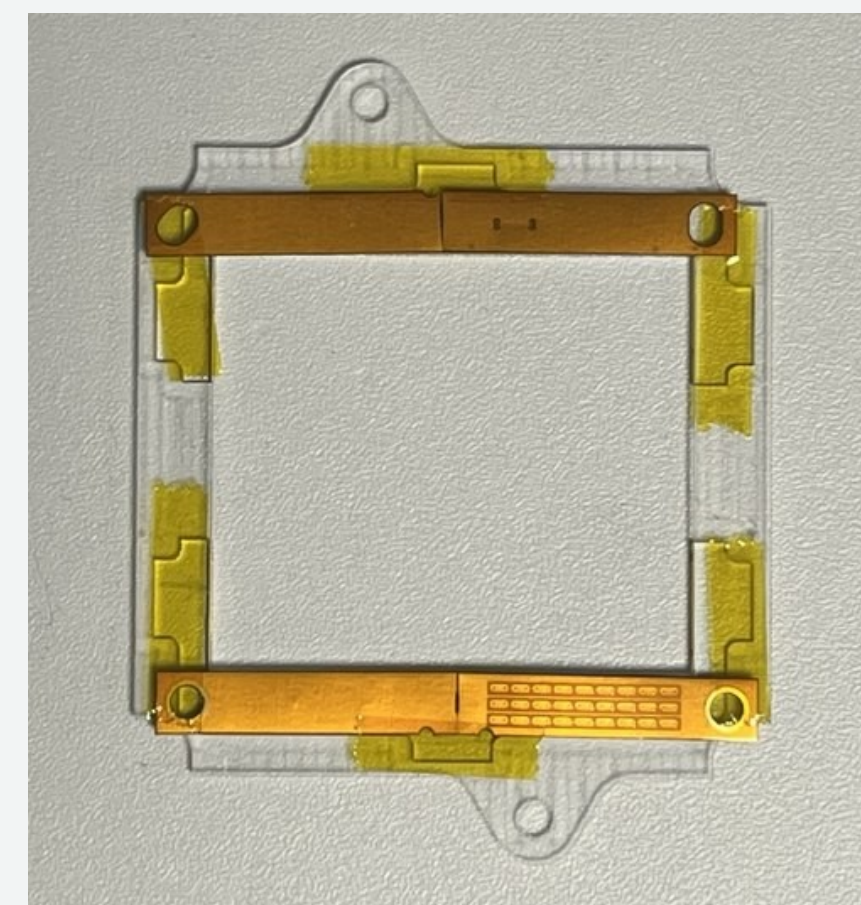
- Has approximately the same absorption as the sensor + flex.
- Is **very** easy to align to the module

We are using the plastic plate already used to cover the module in its storage box, which is easy to align thanks to the existing screws, together with a flex.

A square opening has been cut in the center to expose the chips.

Dose rate in SiO_2 after plastic + flex:

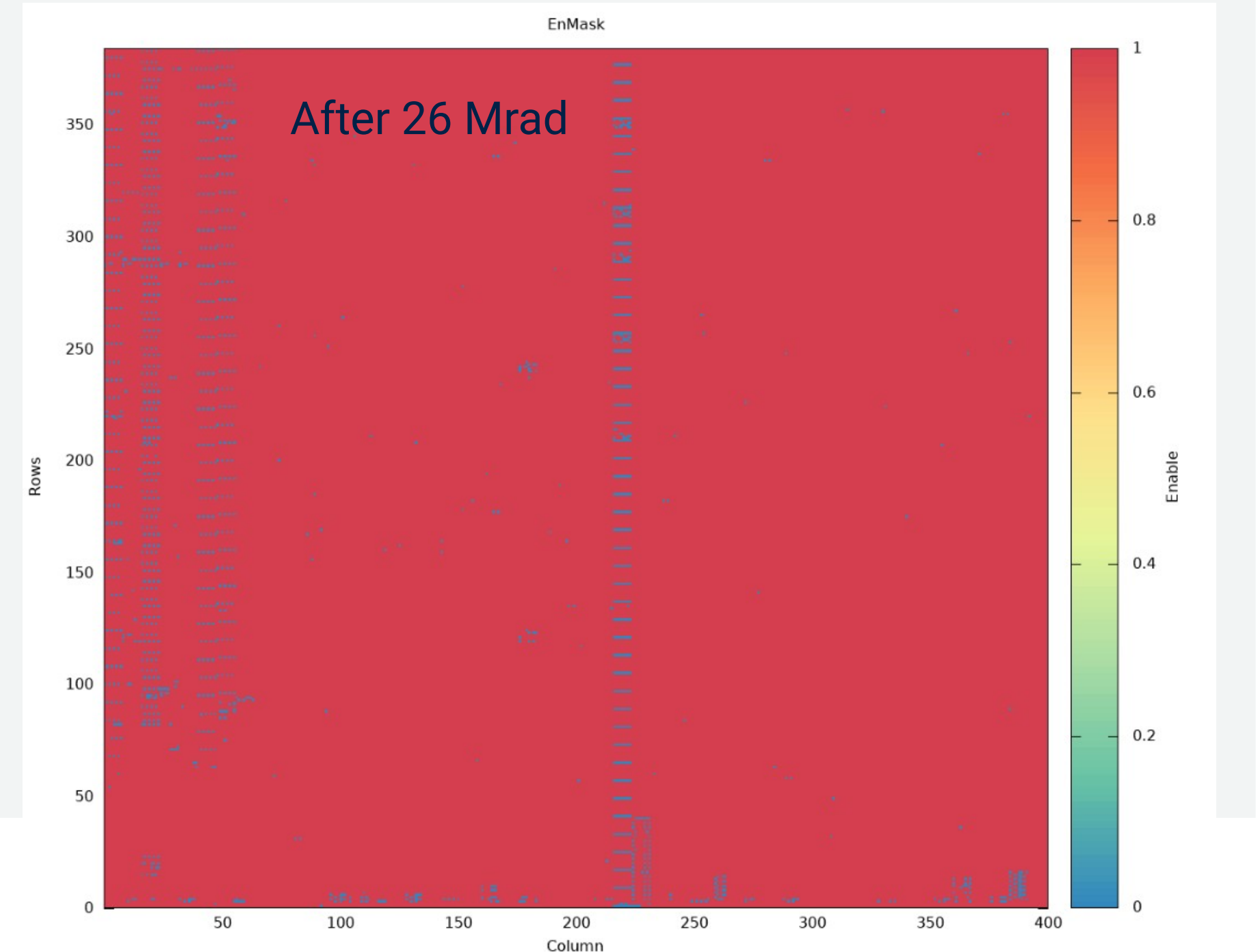
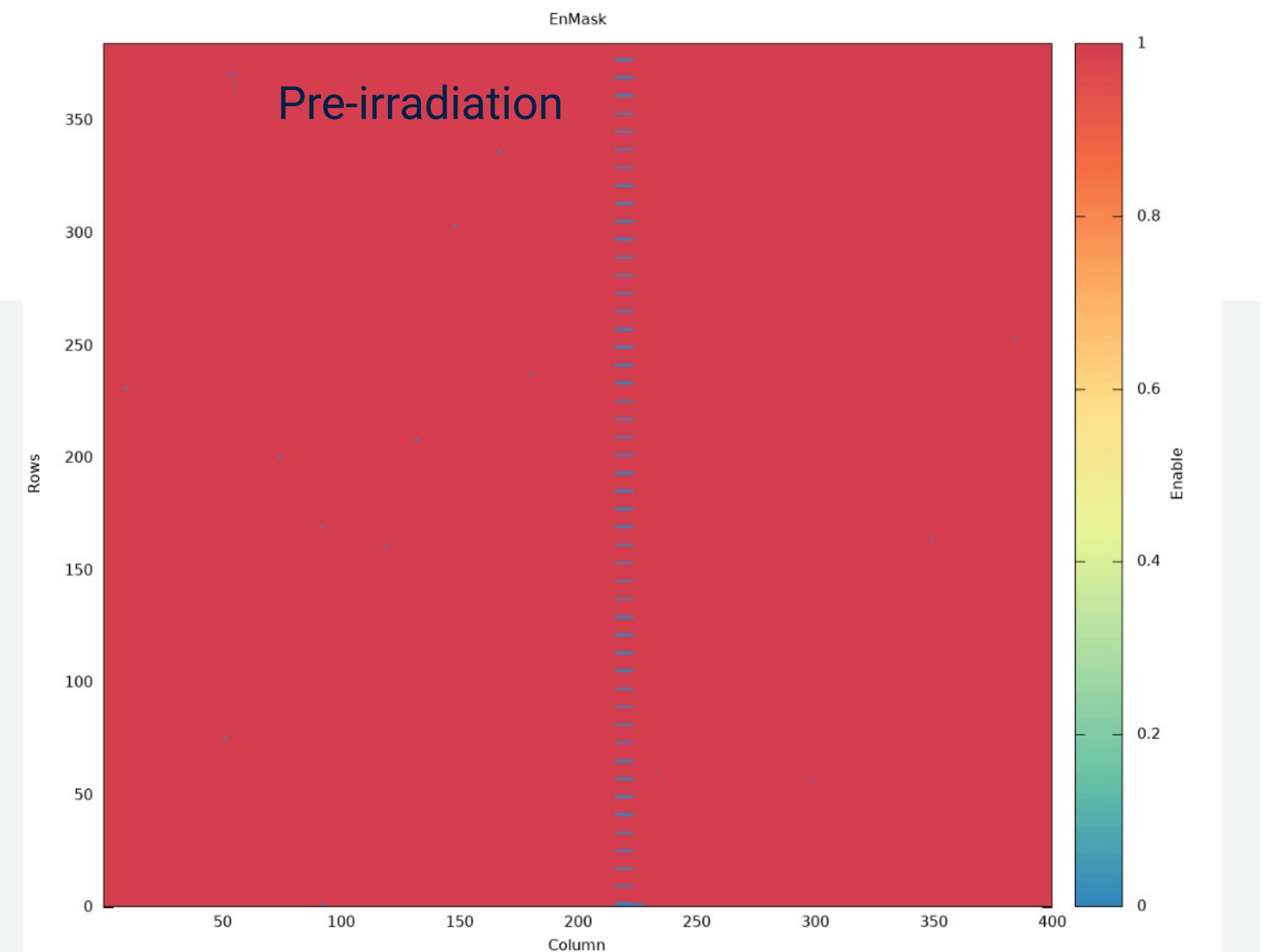
Dose rate $\approx 0.30 \text{ Mrad/h}$



Potential communication issues

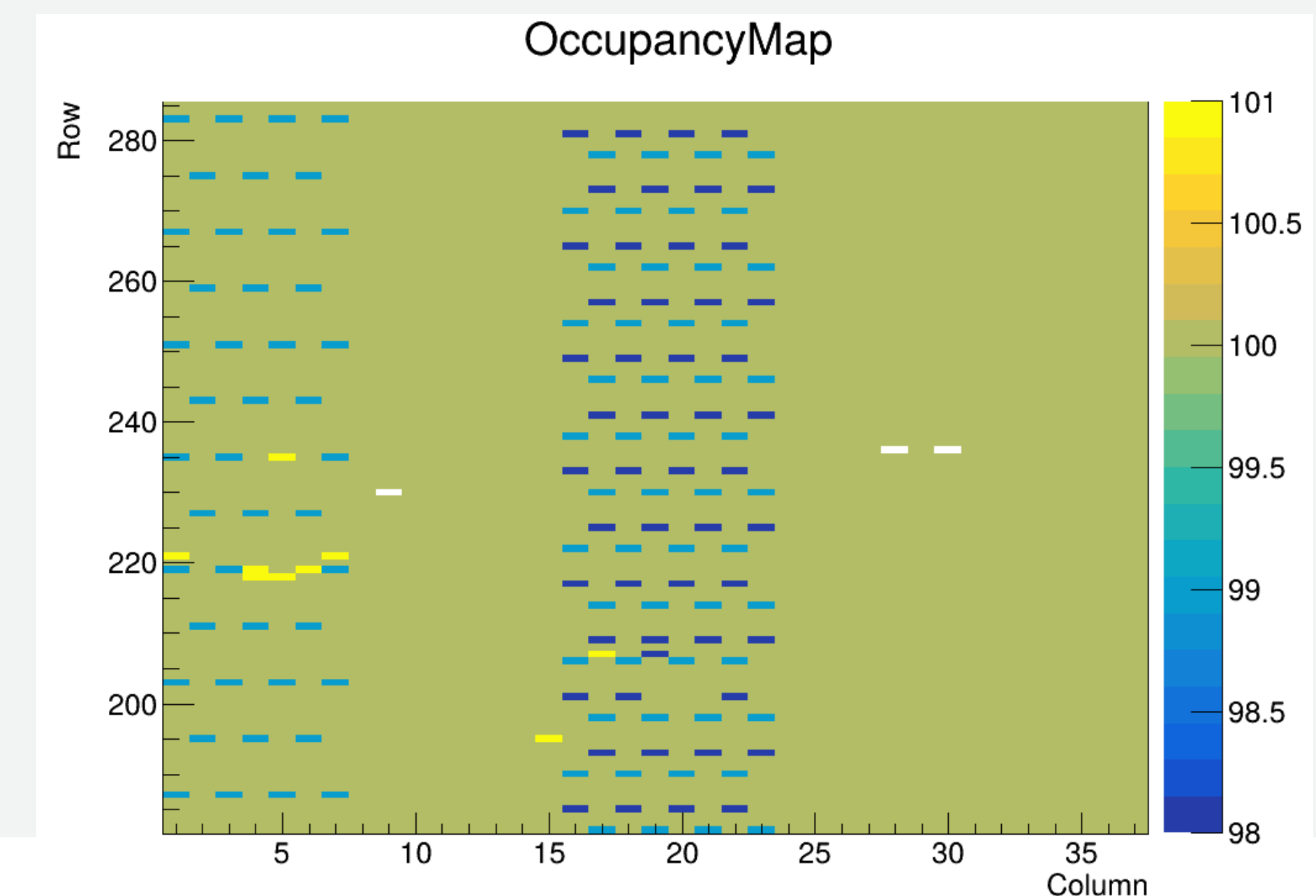
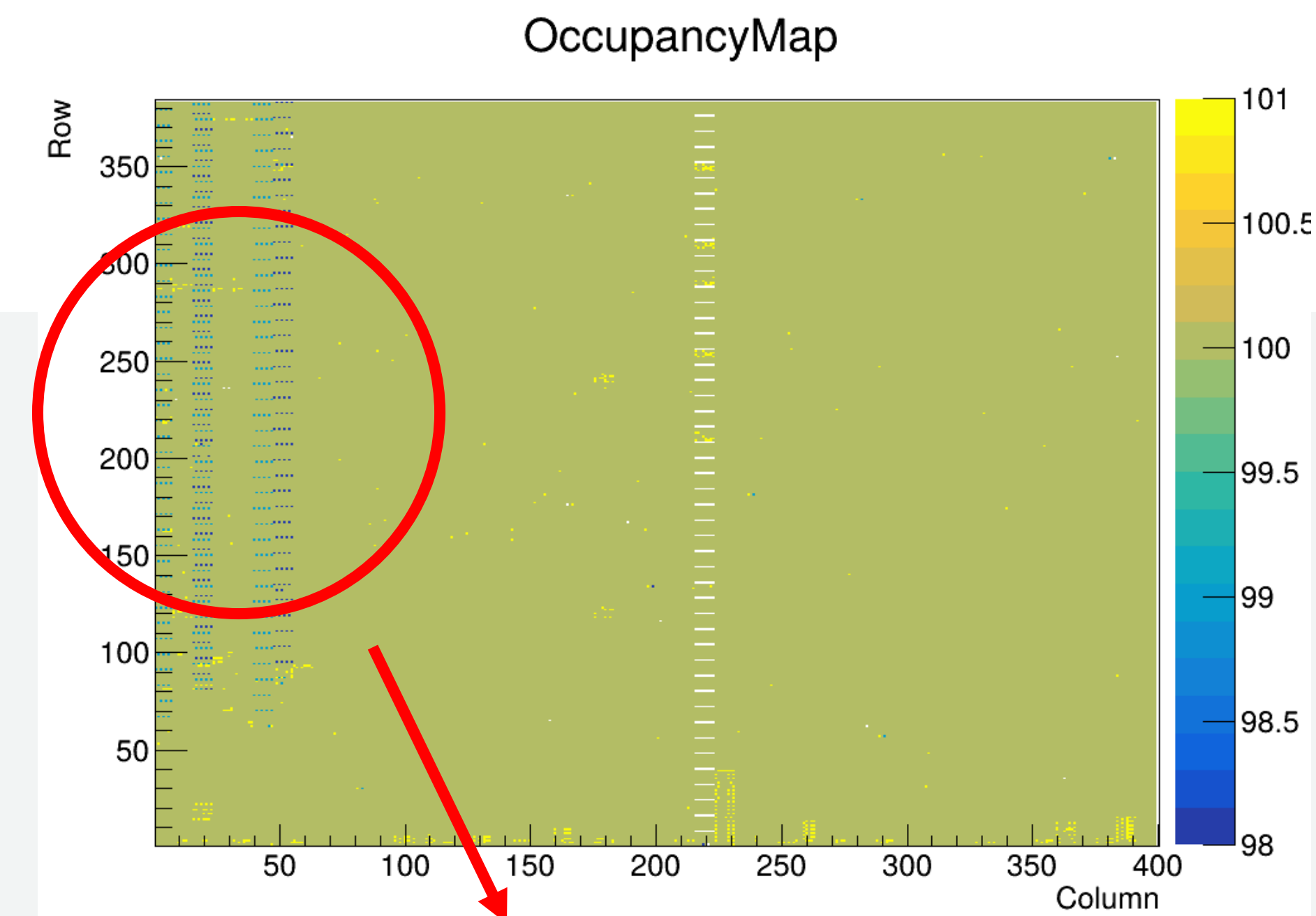
In these plots (“EnMask”), bad pixels are shown in blue and good pixels in red.

- The chip that exhibited a CC issue from the beginning appears to degrade with irradiation
- After 26 Mrad, it shows more bad pixels on one side
- The good chips, instead, do not show new CC issues



Closer look at the scan

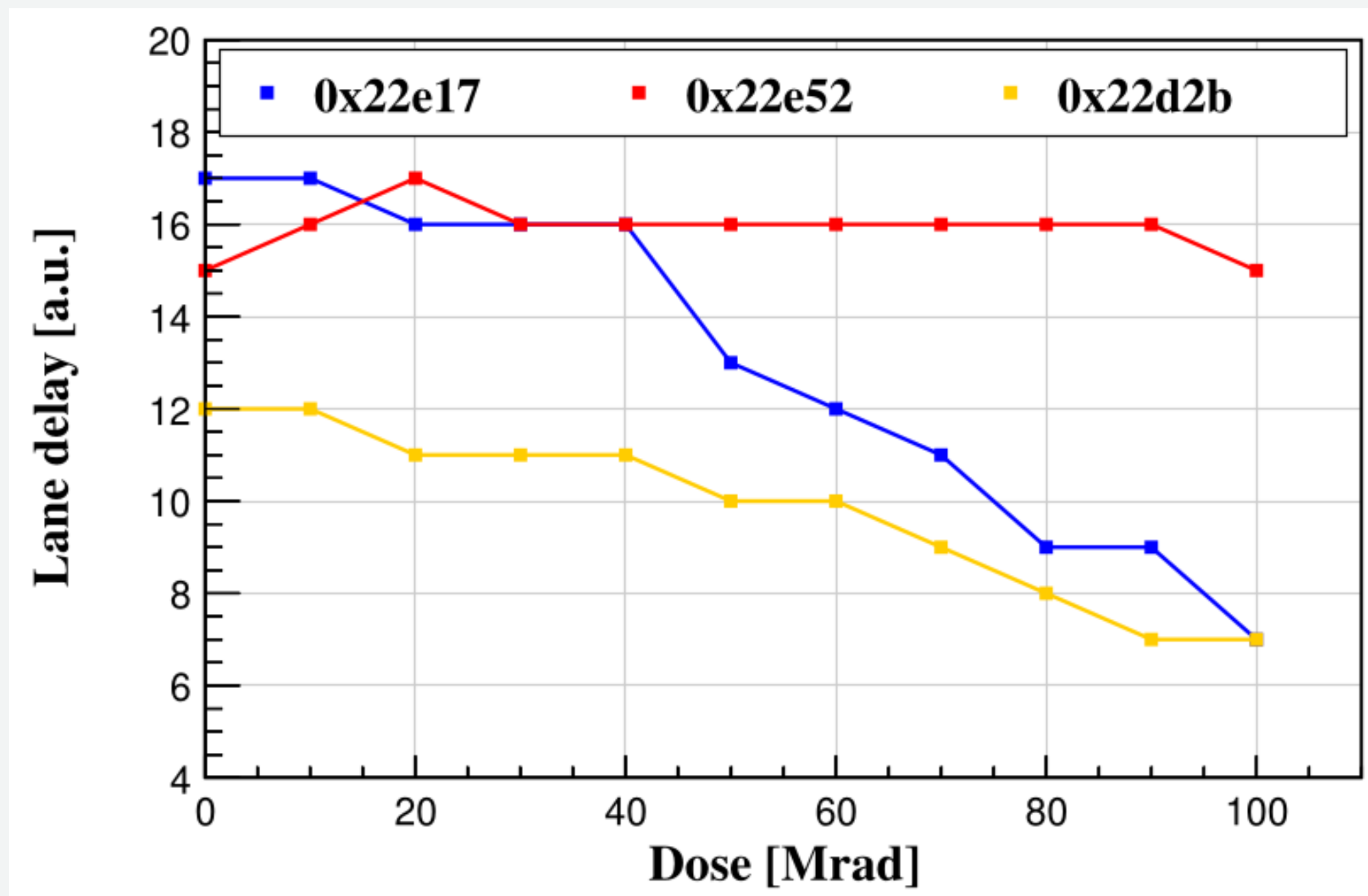
- The occupancy map for 100 injections and triggers is shown in the top-right plot
- The “original core column” appears dead, with no hits recorded
- In the “new” problematic pixels, 98–99 hits are observed (see zoomed plot)
- Possible explanations:
 - Missing trigger commands
 - Data transmission errors
 - Other readout inefficiencies



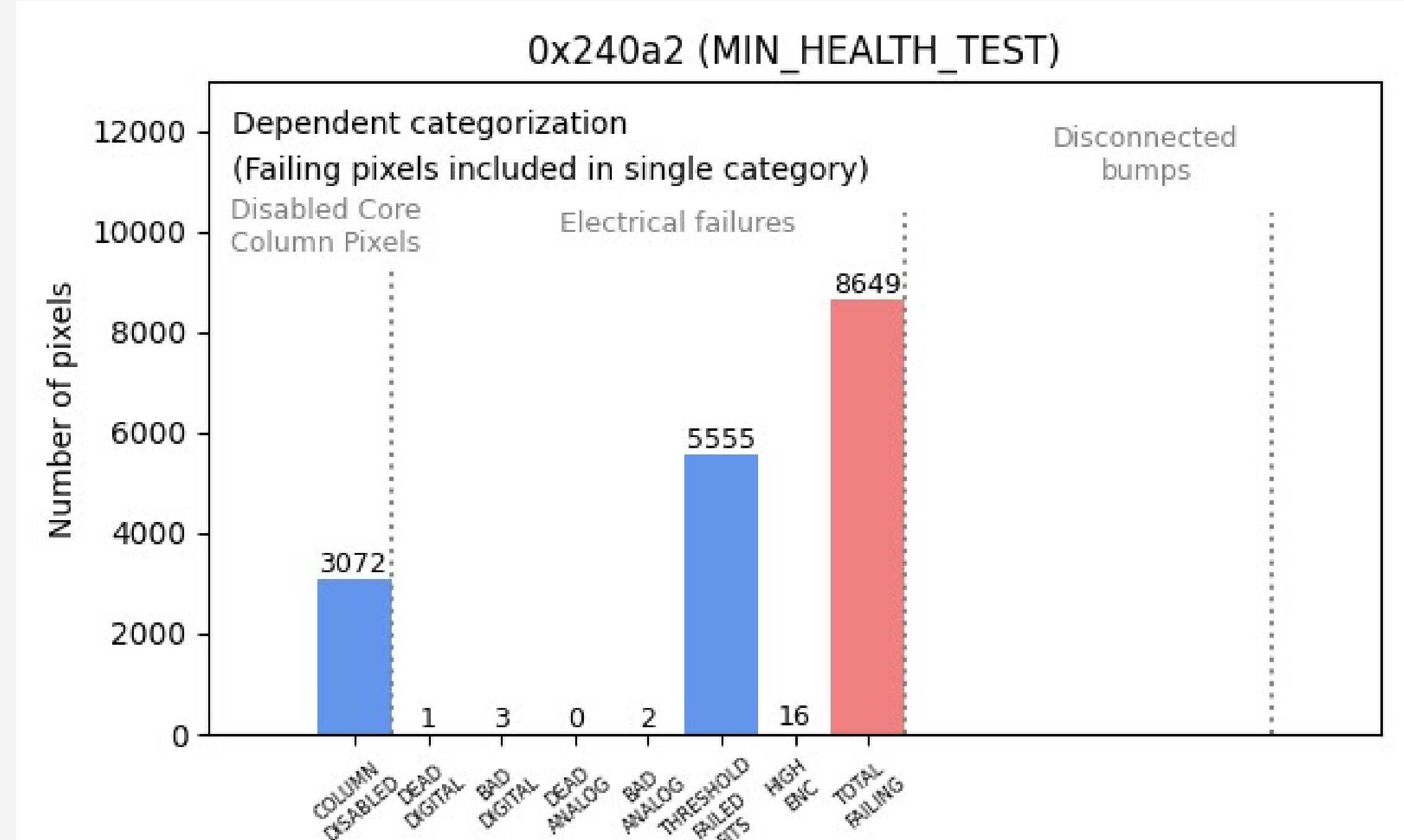
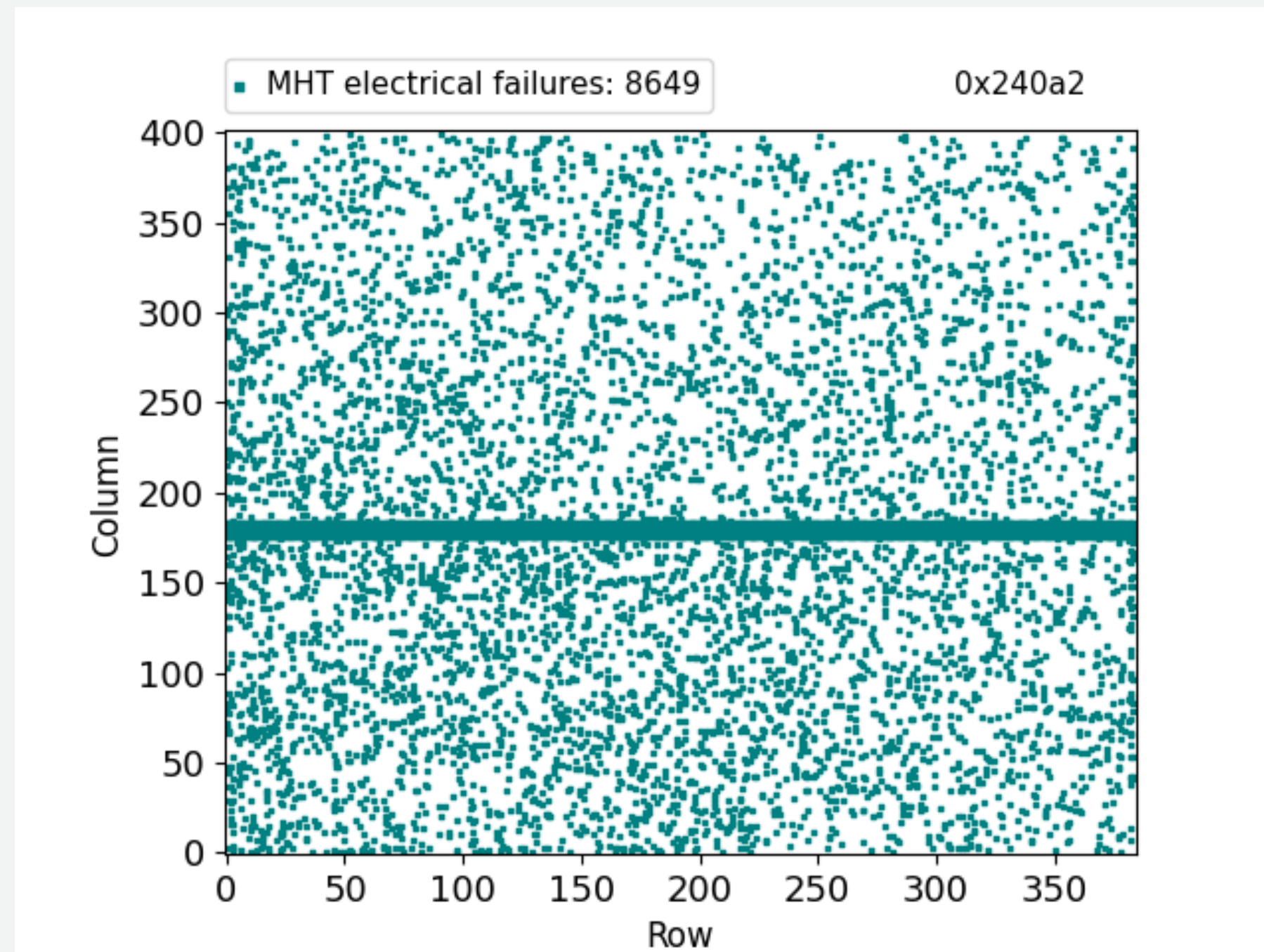
Chip-Computer communication optimization

Data is available only for the 2nd module.

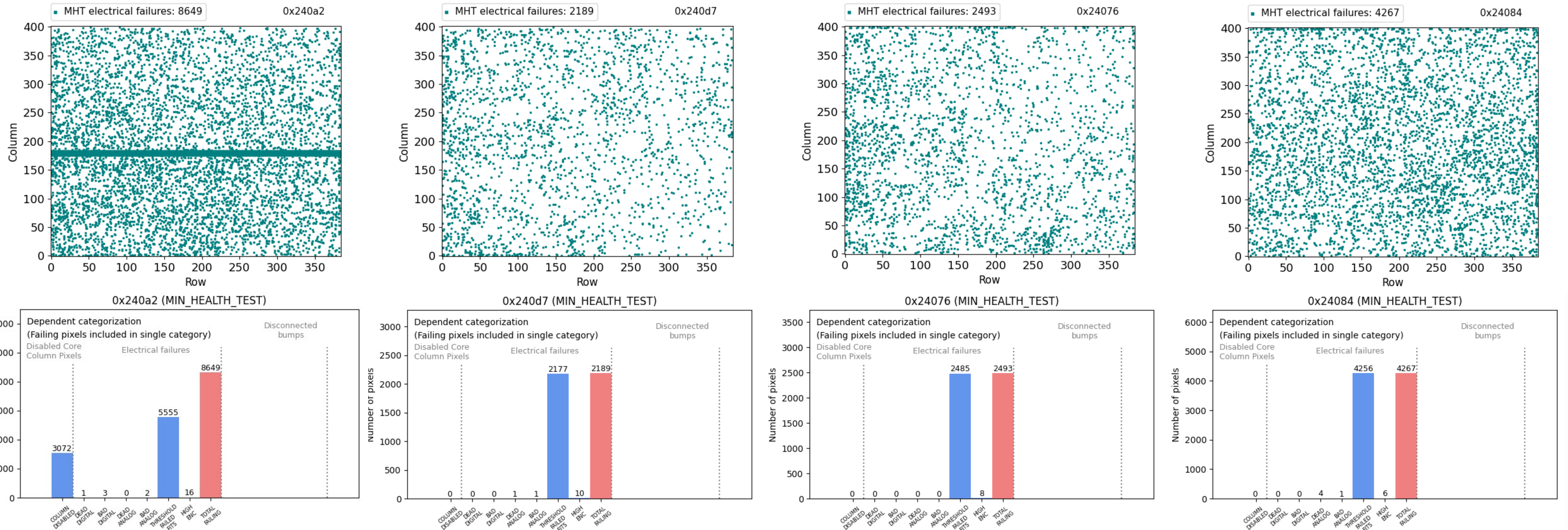
- One chip of the module was disabled → only three communication lanes were active.
- Two lanes show a change in the optimal delay
- This could explain why, in the first irradiation campaign, when the optimization was done only once at the beginning, some hits were missing. Commands could be lost between the PC and the module.



Electrical failures origin (1)



Electrical failures origin (2)



CC issue location

The latest public results on the occurrence and location of CC issues are shown [here](#).

- Large sample size in the production database with v1.1 quad modules tested warm
- Similar fractions of modules with core column issues seen at all vendors
- Core columns not confined to the edges

