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Irradiations II

Outline

- Single event effects
- Low dose rate irradiations
- Decomissioning
- PEPT: an example of irradiations for industrial applications

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Why do we need irradiation facilities?

- Many of you will be involved in developing or working with apparatus that will be deployed in environments with radiation
- Unless the devices you are using are low cost and easy to replace, it will be necessary to design them such that they can survive radiation damage and continue to perform to specification up to the end of their required lifetime
- Irradiation facilities allow us to take instrumentation and expose it to a radiation field in a controlled (and usually accelerated) way, taking the instrument to its end of life state
- We can then measure the irradiated device to test its performance at end of life and adjust or approve designs accordingly
- There is also a use for irradiations from an operational point of view, i.e. how does my device perform when the unwanted effects of radiation are disturbing the measurements in 'real time' -> single event effects / upsets / transients

Why do we need irradiation facilities?

- There are also additional uses for irradiation facilities that are perhaps less familiar:
  - Sterilisation of medical products without removal of packaging
  - Production of isotopes for medicine and industry
  - Irradiations for automotive and aeronautical parts where low dose rates (cosmic rays) over long times can be a factor contributing to reliability

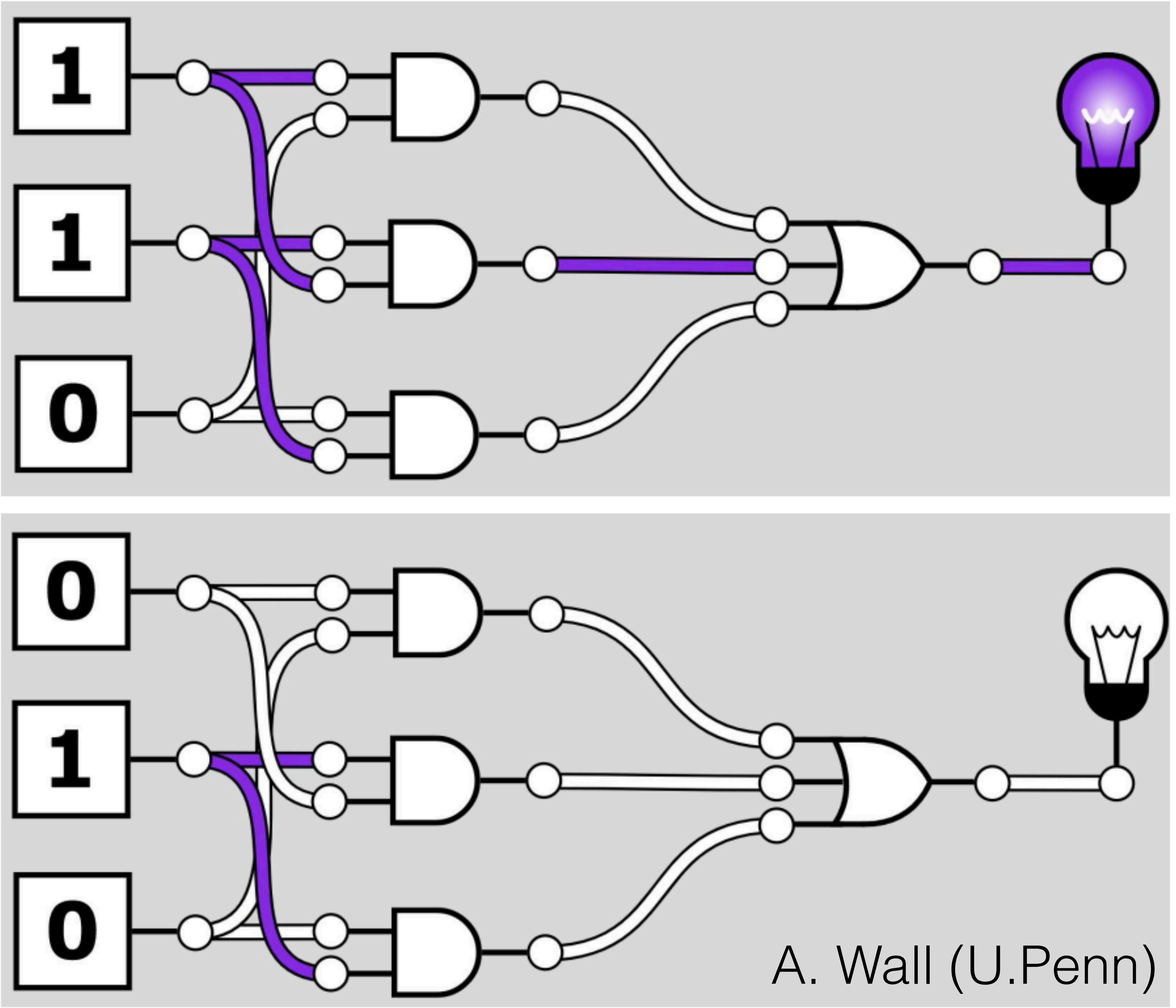
Single event effects

- Electronics deployed in radiation environments with high fluences will occasionally experience large energy deposits from (heavy) ions
- Because of their charge (remember Z term in beta-bloch) and/or low energy these particles are highly ionising
- The large linear energy transfer (LET) / dE/dx of these ions can generate enough e-h pairs to flip logic states within configuration registers or data causing unwanted effects during the operation of the detector known as ‘single event effects’
- In order to develop devices robust against these effects, dedicated irradiations can made to test how susceptible a design is by running it while the irradiation is in progress emulating an ‘extreme’ version of the real experimental environment

Single event effects

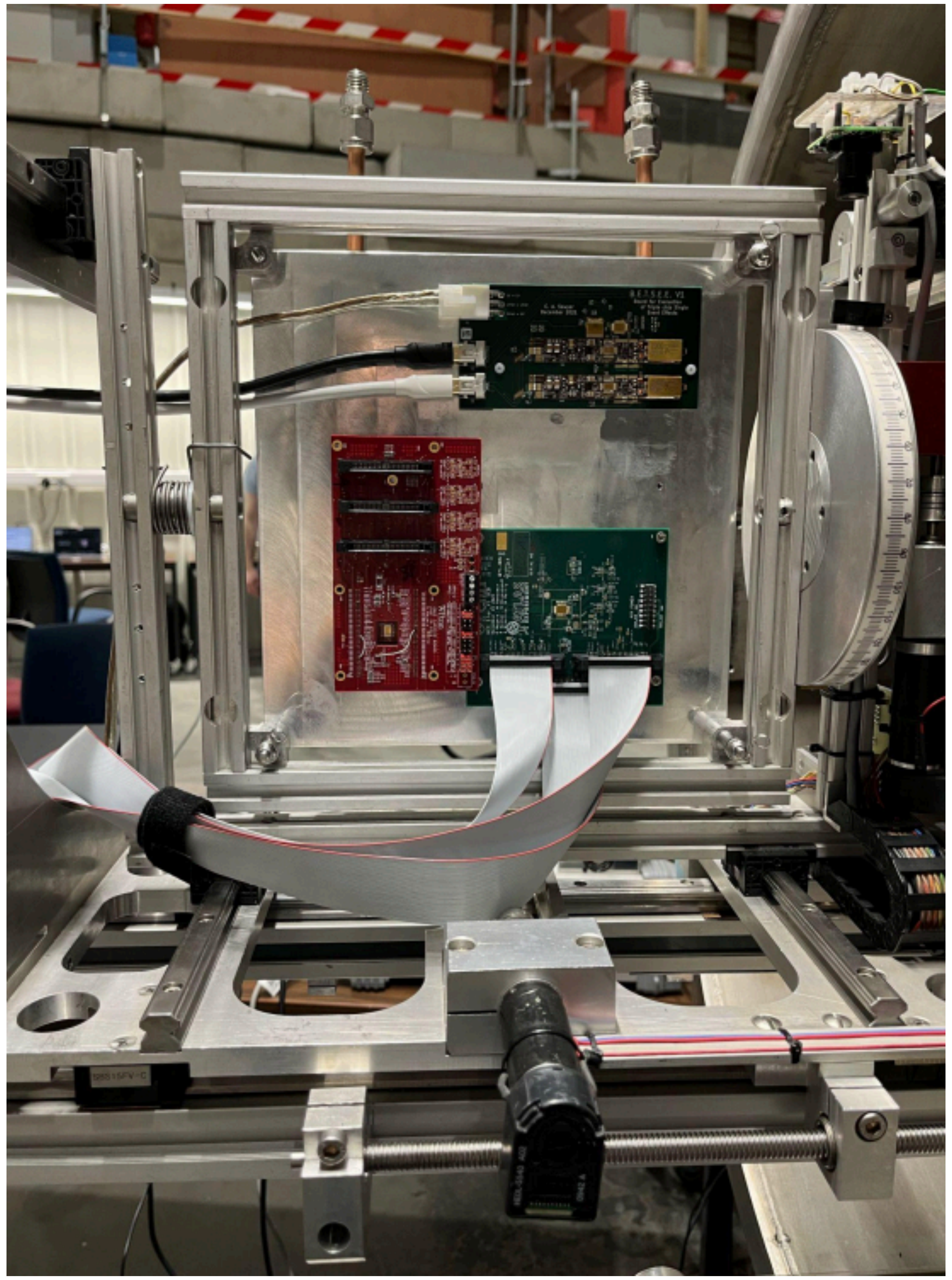
- Linear energy transfer (LET) is the energy loss per unit length in a material
- Ions that have a higher LET will cause more bit flips
- LET can be varied by choosing different ions (Z) or energies to see where the detector is most susceptible to SEEs
- Logic within readout electronics can be made robust against SEEs by using triplication and majority voting

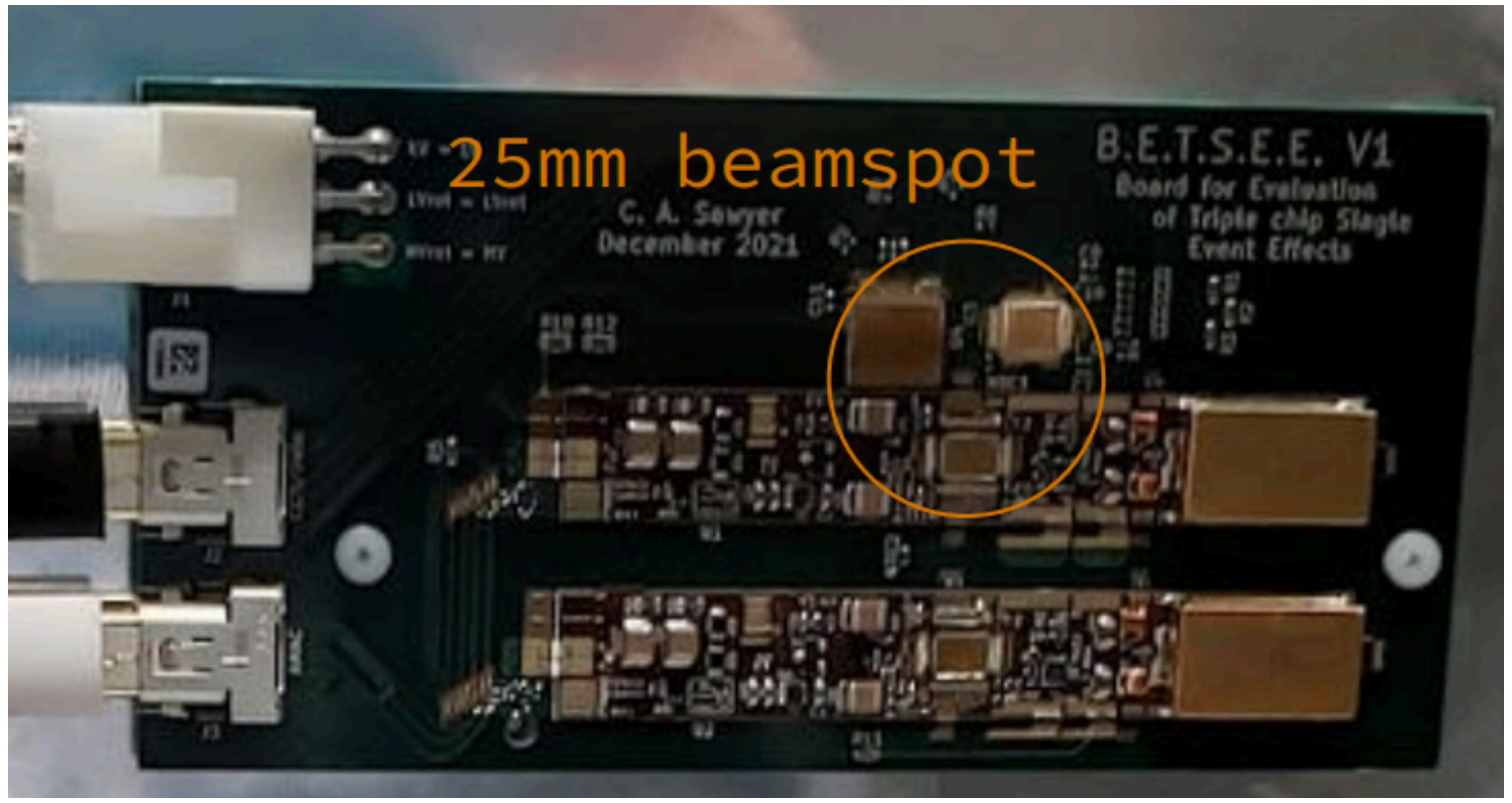
Triplication and majority voting

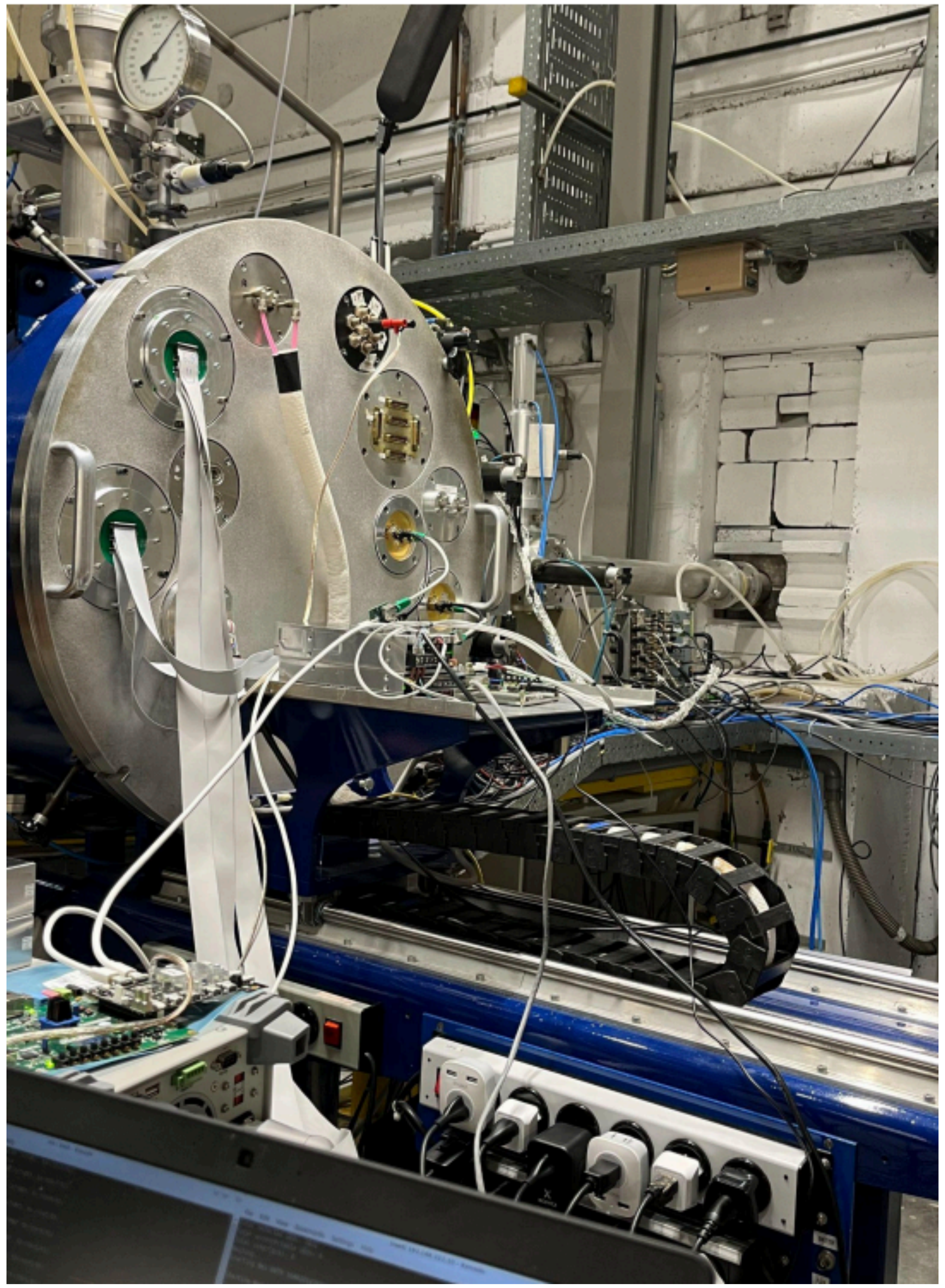


Single event effects

UCLouvain

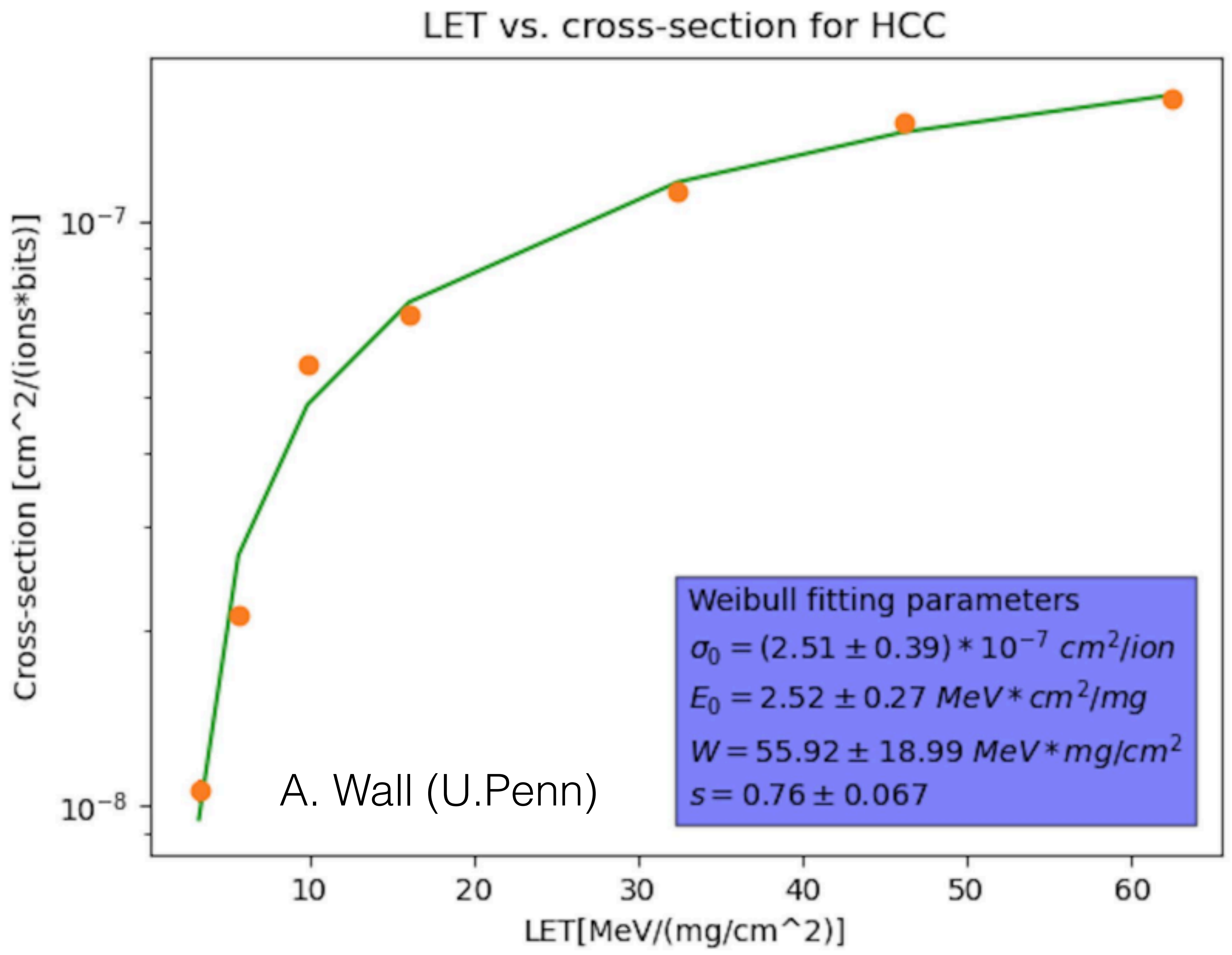






Ions beams available: $^{13}C^{4+}$, $^{22}Ne^{7+}$, $^{27}Al^{8+}$, $^{36}Ar^{11+}$, $^{53}Cr16+$, $^{84}Kr^{25+}$, $^{103}Rh^{31+}$, $^{124}Xe^{35+}$

Single event effects



Element	Fluence [ions/cm^2]	LET$_{eff}$ [MeV/(mg/cm^2)]
Al	3.0E7	5.7
Cr	1.3E8	16.1
Kr	1.5E8	32.4

$$\sigma = \frac{\#\ SEUs}{fluence \cdot \#\ bits\ monitored}$$

Low dose rate irradiations

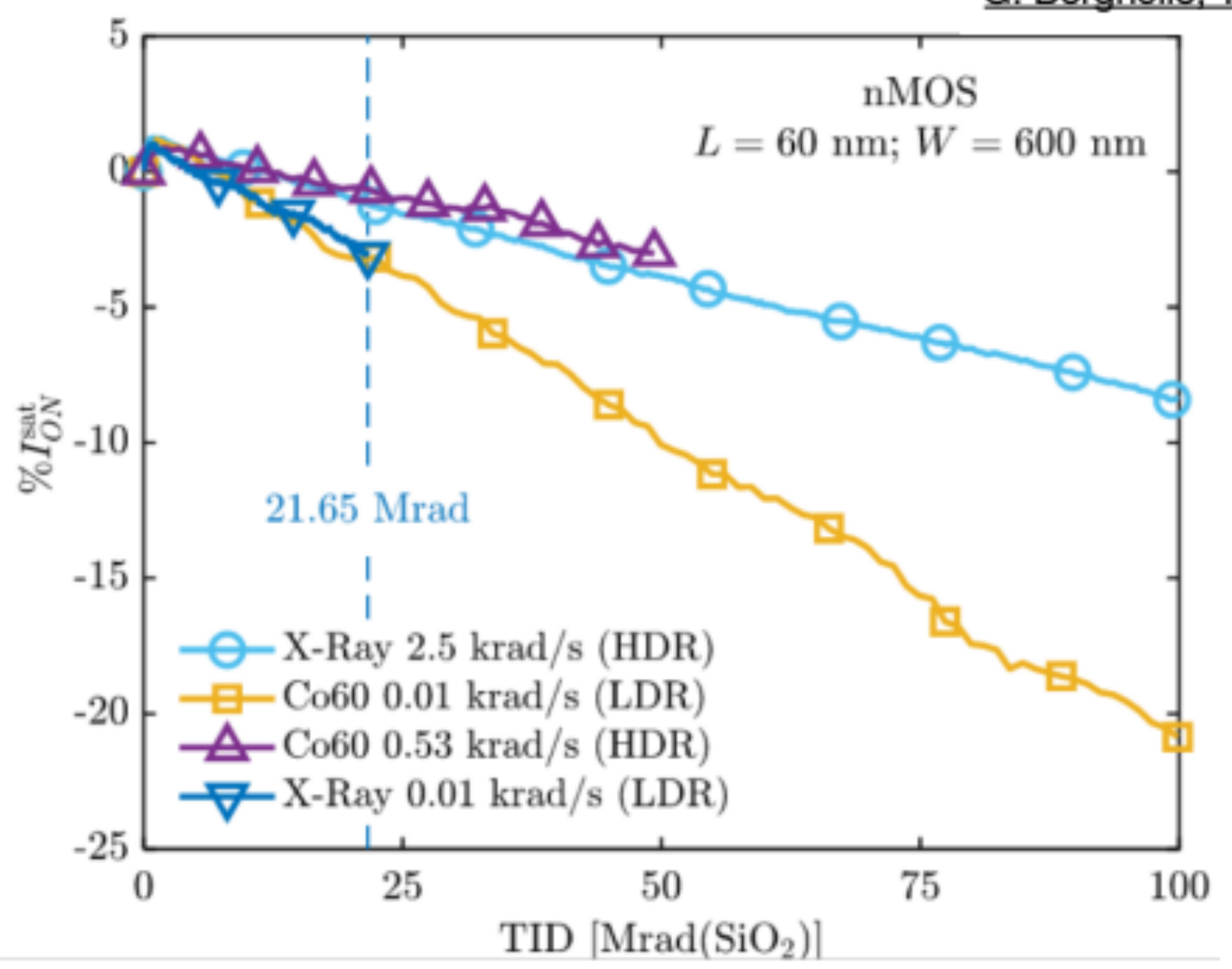
- Another operational aspect that irradiations can be used to understand is the effects of dose rate

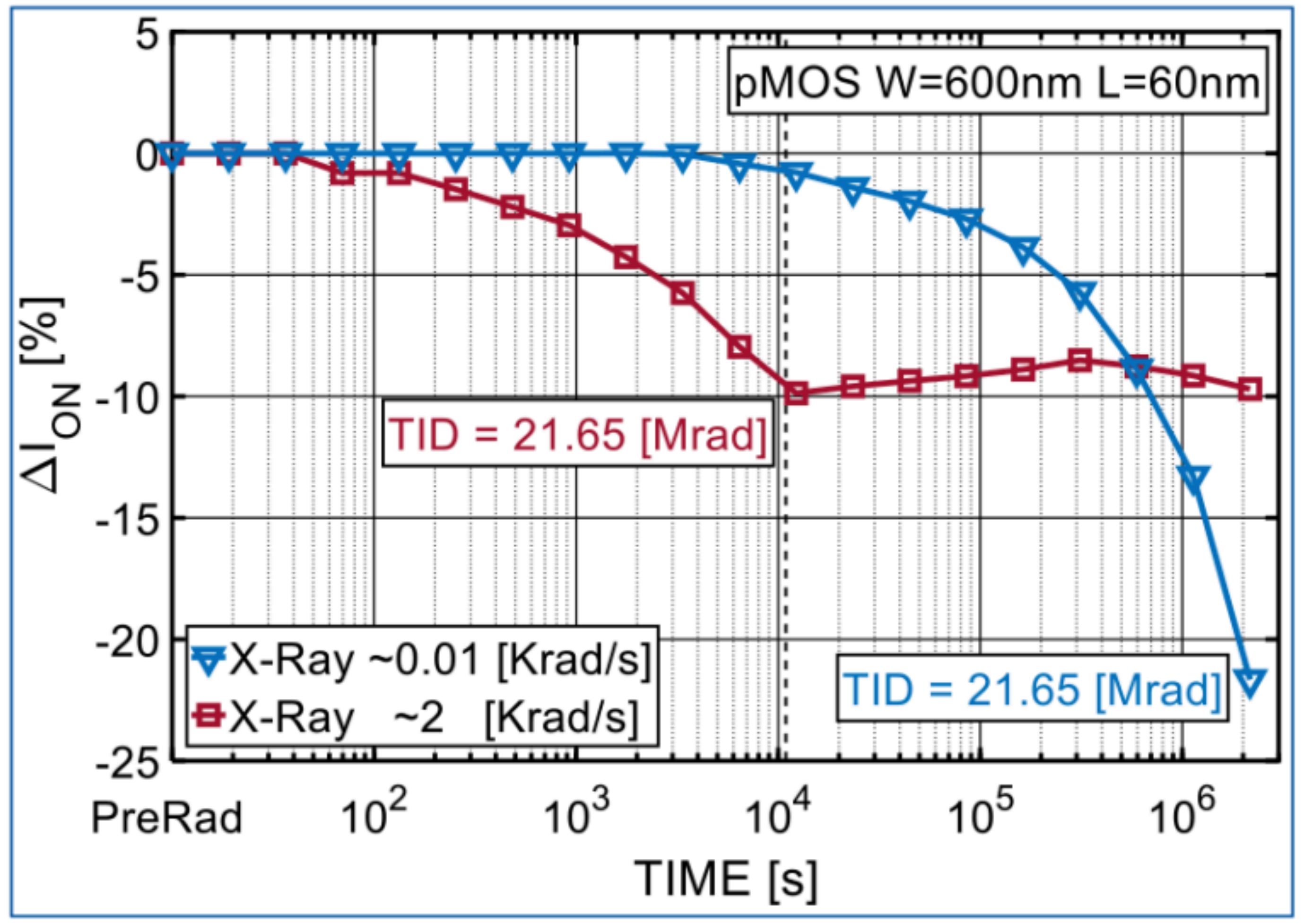
- Different to the irradiations we discussed last week since these are carried out a high dose rate in order to reach conditions that represent the end of life or 'worst possible case' for total dose/fluence received

- For the typical ASIC circuitry used particle physics it is not well understood how dose rate effects the performance of the device particularly for the digital parts of the chip

- The indication is, that slow dose, especially for the smaller transistors used in the digital circuitry, ie a dose rate akin to that of real operational conditions can be worse than high dose rate seen after 'normal' high dose rate irradiations

G. Borghello, TID 65nm MOSFET

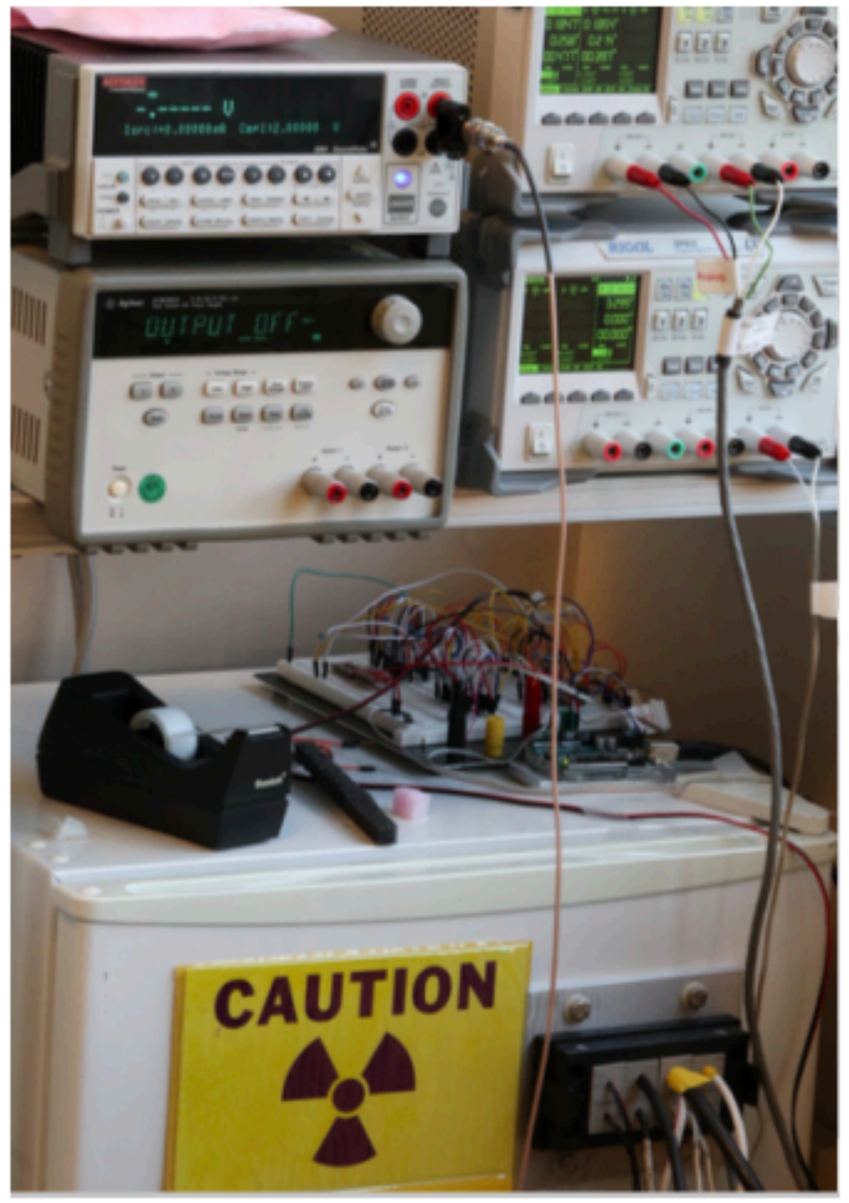




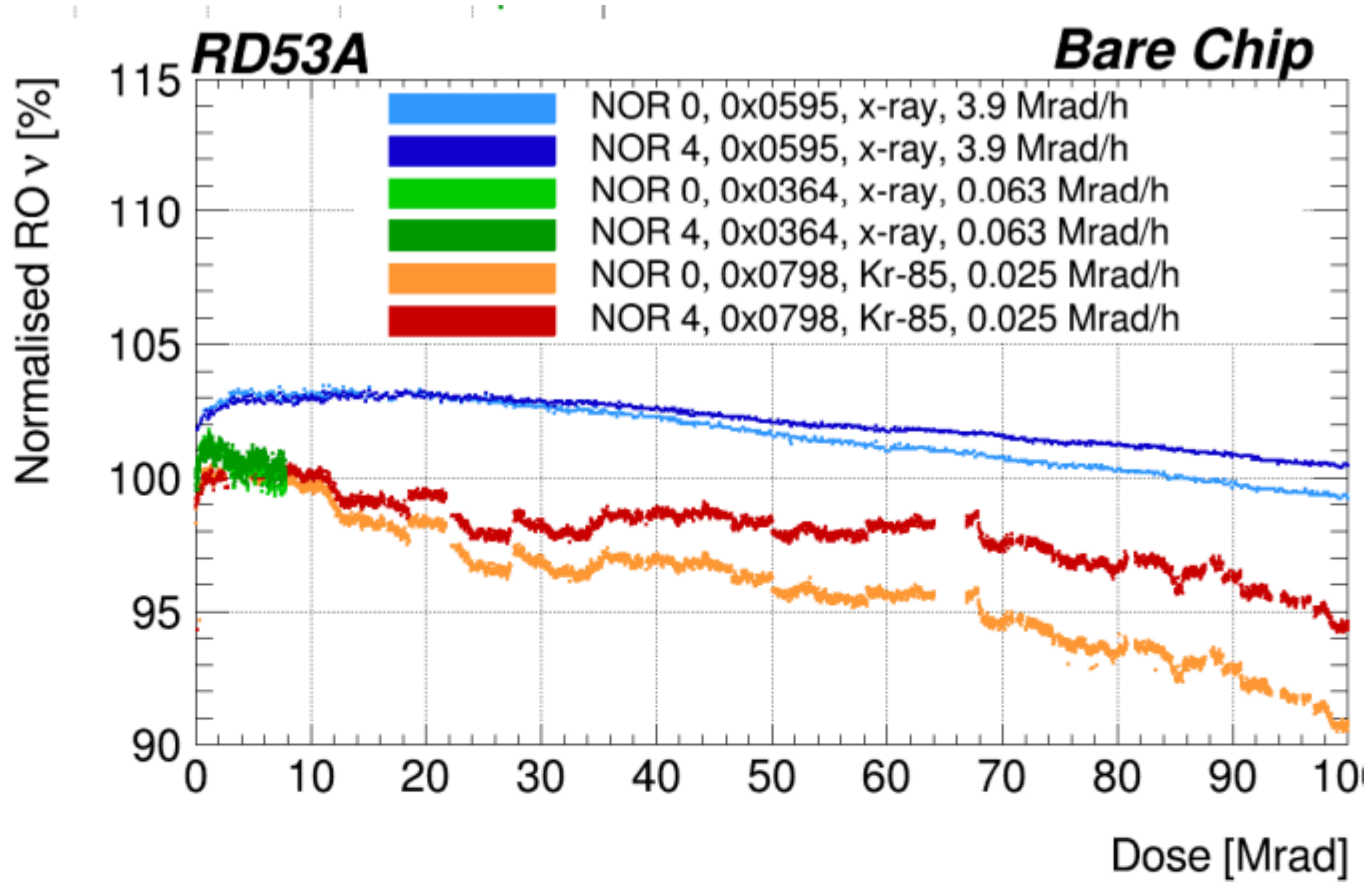
Faccio & Borghello

Low dose rate irradiations

- An example setup to investigate these effects is: SLIPPER setup at Berkeley: SLow Irradiation of Phase-II PixEl Readout
- Gaseous Kr-85 beta source used as ionising radiation source -> TID not NIEL ie damage to electronics and surface layers
- 2.2 GBq! (60 mCi) of 7 Rad/s (0.025 MRad/h)
- ASIC kept busy during irradiation by running continuous scans and reading back data to mimic real operation
- Monitoring of circuitry ie ring oscillators and current consumption of chip to understand low dose rate effects

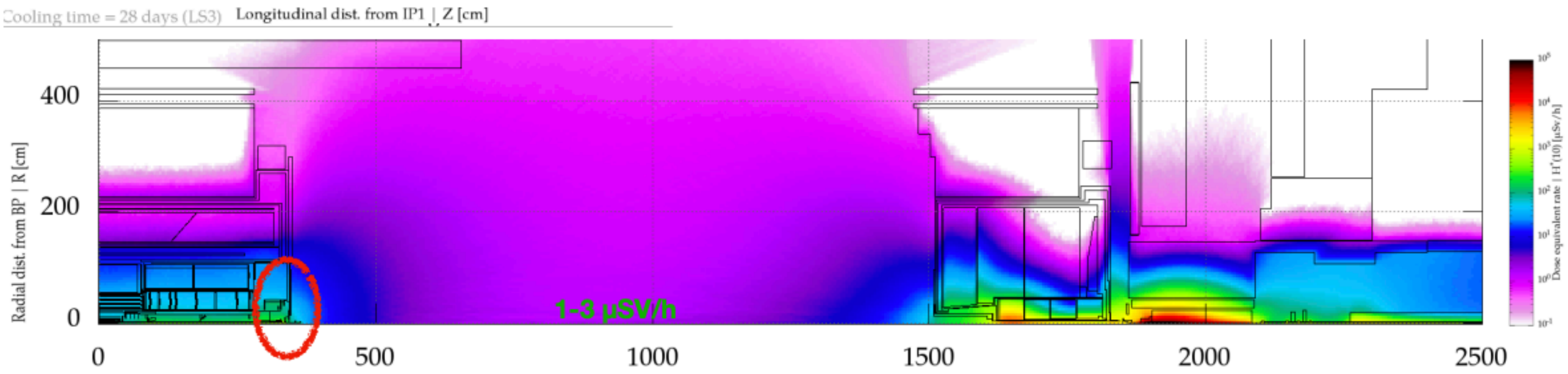


A. Dimitrievska (Berkeley), TWEPP



Decomissioning

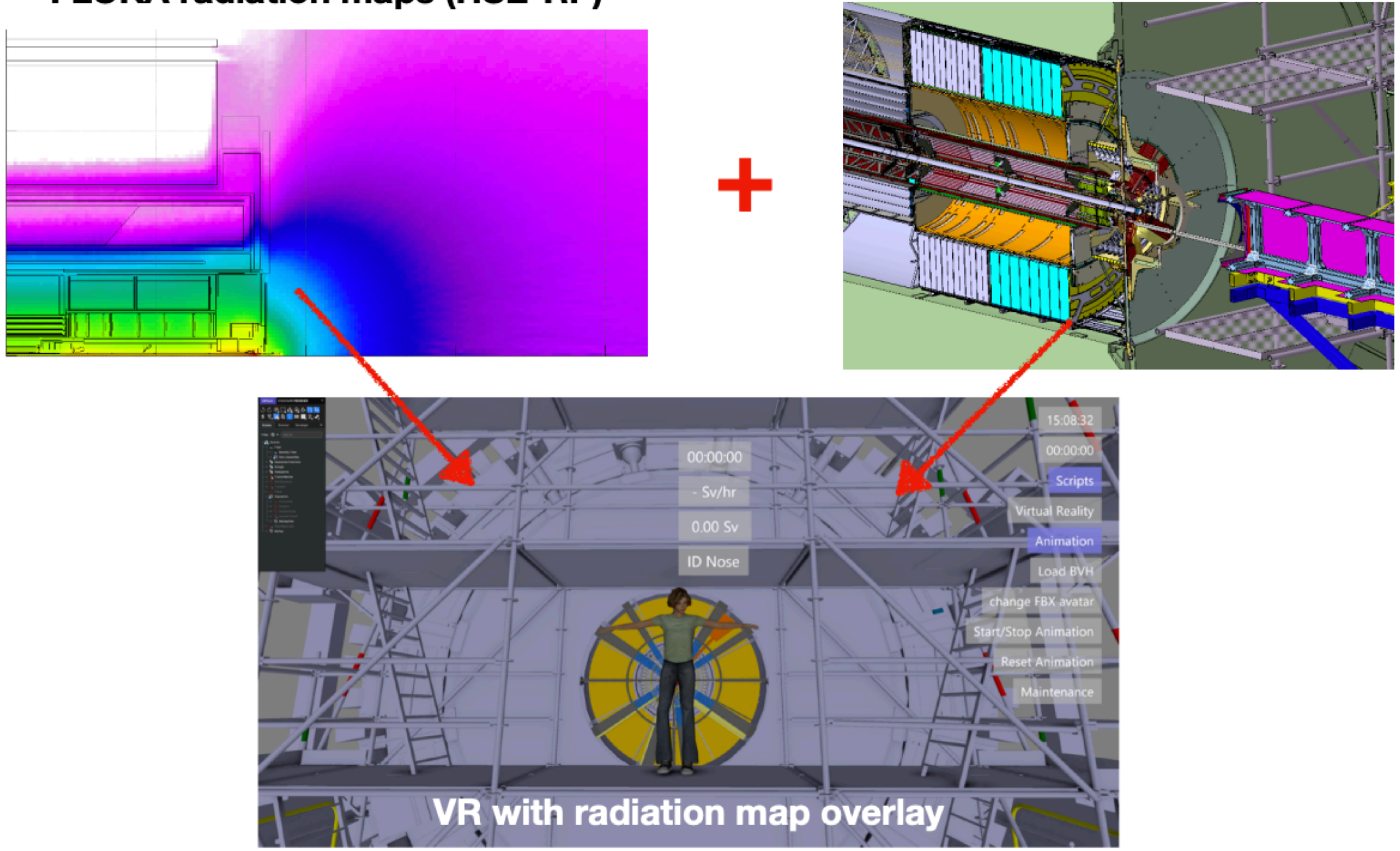
- Experiments in high luminosity environments will require decommissioning at the end of their lifetime due to the activation of the components in the detector
- The dose due to activated components must be estimated in order to determine safe working conditions
- Relevant to irradiations since the same simulations used to estimate the dose/fluence for irradiations can also be used to generate the dose maps for estimation of activation and safe working conditions

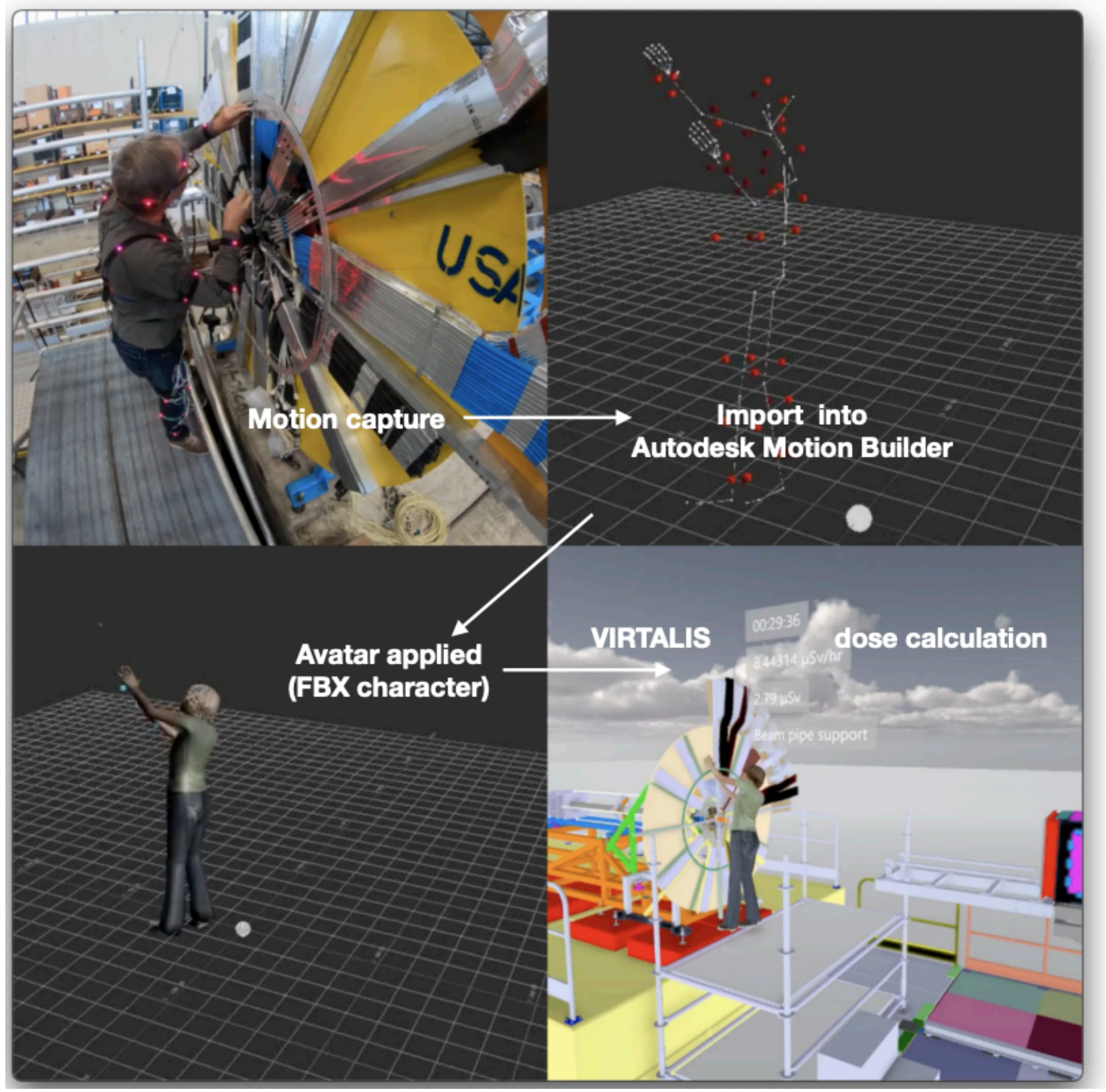


Decomissioning

FLUKA radiation maps (HSE-RP)

CATIA detailed drawings





M.R. Jäkel (CERN), D2IC workshop

PEPT: Positron Emission Particle Tracking

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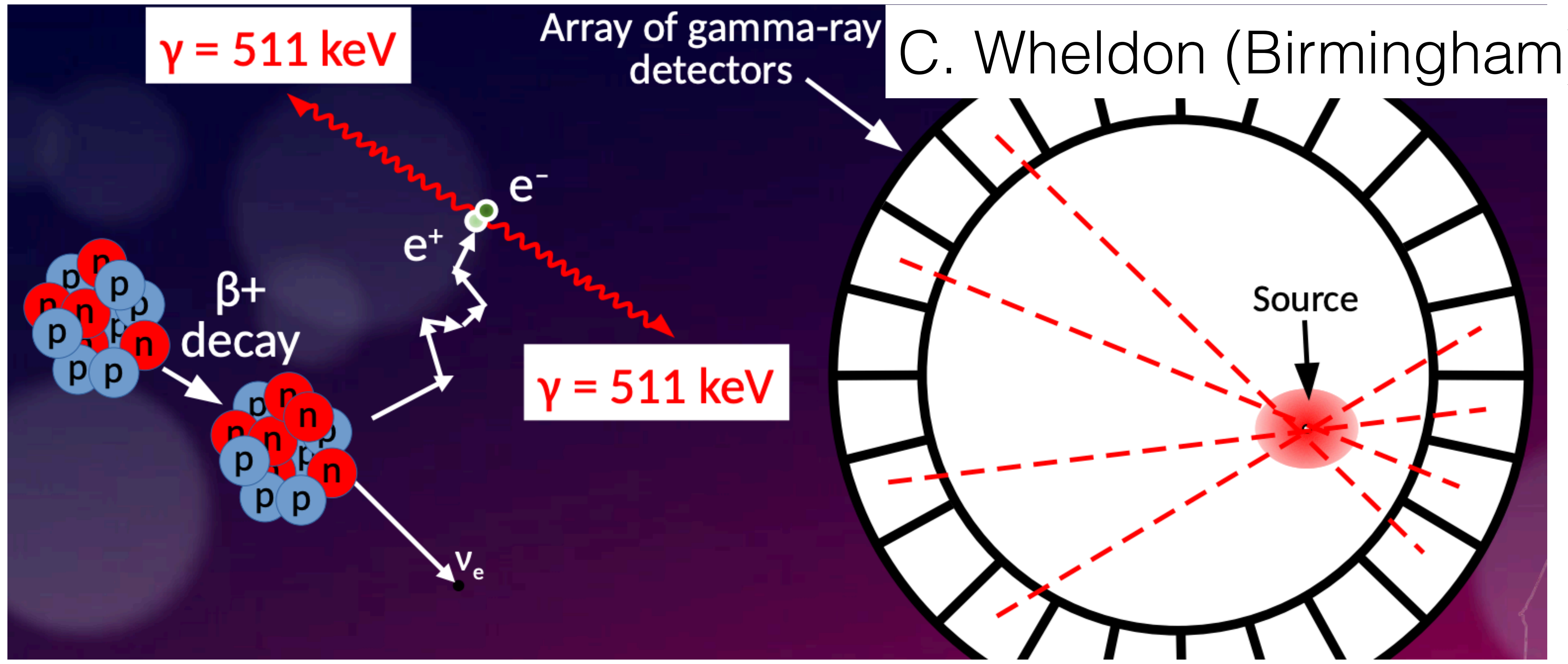
Fig. 2. (A) Dishwasher in between PEPT cameras. (B) Dishwasher loaded with crockery and cartesian coordinates reference system.

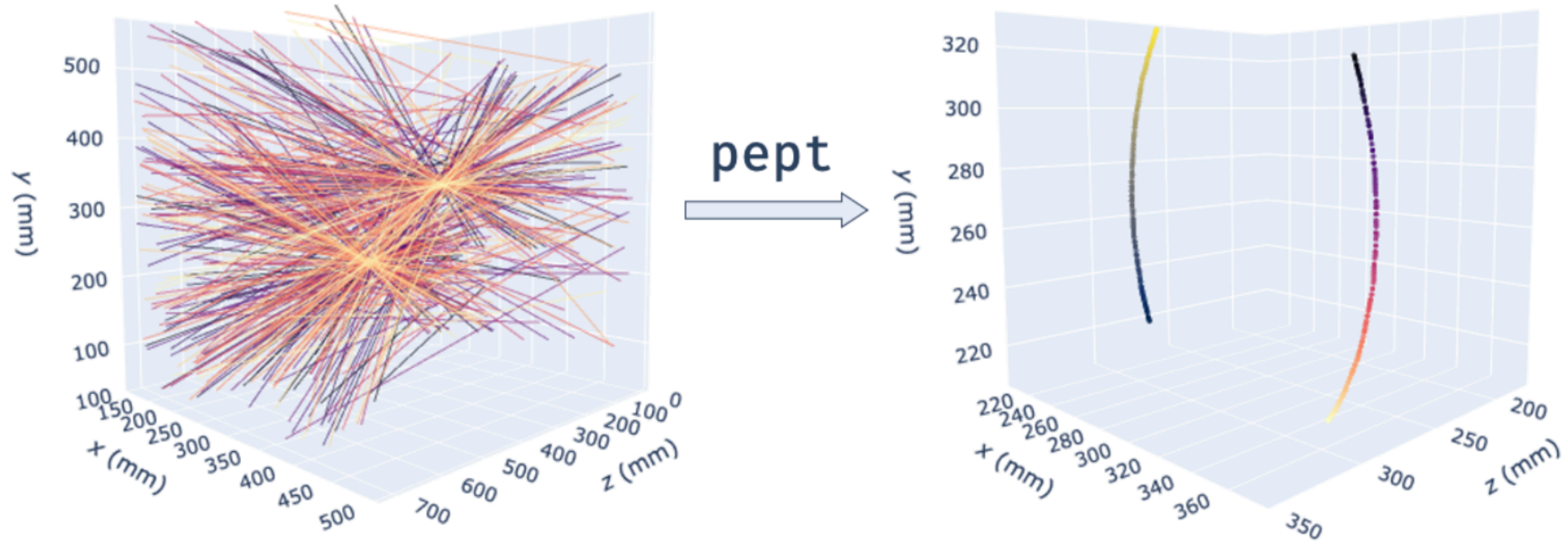
https://www.sciencedirect.com/science/article/pii/S1385894714010870#f0010

Figure

Caption

Figure 11. A single slice through a series of tomographic images showing the mixing of a small amount of labelled powder with the unlabelled bulk powder in a pharmaceutical blender.





Transforming gamma rays, or lines of response (left) into individual tracer trajectories (right) using the *pept* library. Depicted is experimental data of two tracers rotating at 42 RPM, imaged using the University of Birmingham Positron Imaging Centre's parallel screens PEPT camera.

Summary

- The applications of irradiations as tool both inside and outside of physics research are broad
- There are other scientific and industrial applications not discussed here
- Hopefully this at least gives you an idea of the kind of investigations that are possible with this tool and how they might relate to your own field of research