SPACEMON: Space Environment Monitoring Workshop 11–13 June 2025 ESA/ESTEC

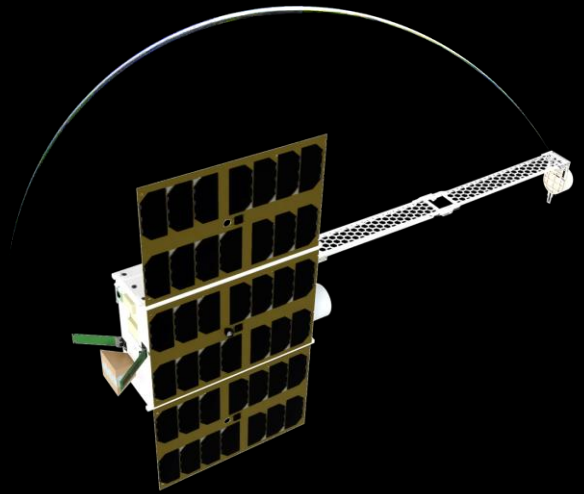
Aalto University

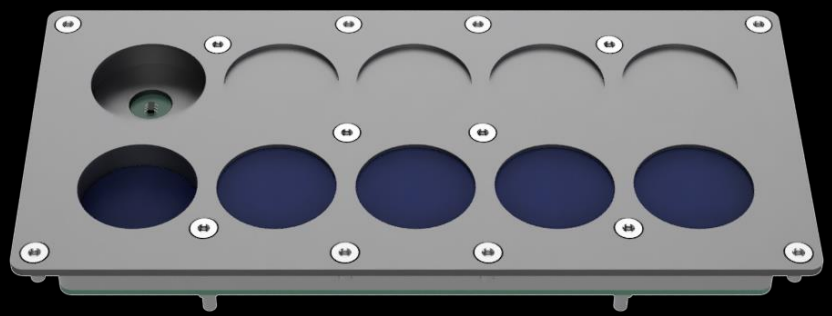
FORESAIL
FINNISH CENTRE OF EXCELLENCE IN RESEARCH OF SUSTAINABLE SPACE

RADIX
UNIVERSITY OF TURKU

The Foresail-2 Multilayer *Radiation Shielding Experiment*

Design and Radiation Testing





Anton Fetzer, Andre Nymann, Janardhan Silwal, Nitija Thapa, Marius Anger, Antoni Eritja Olivella, Tomi Kärkkäinen, Jaan Praks

Aalto University, Department of Electronics and Nanoengineering, Finland
Finnish Centre of Excellence in Research of Sustainable Space


SUOMEN AKATEMIA
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ACADEMY OF FINLAND
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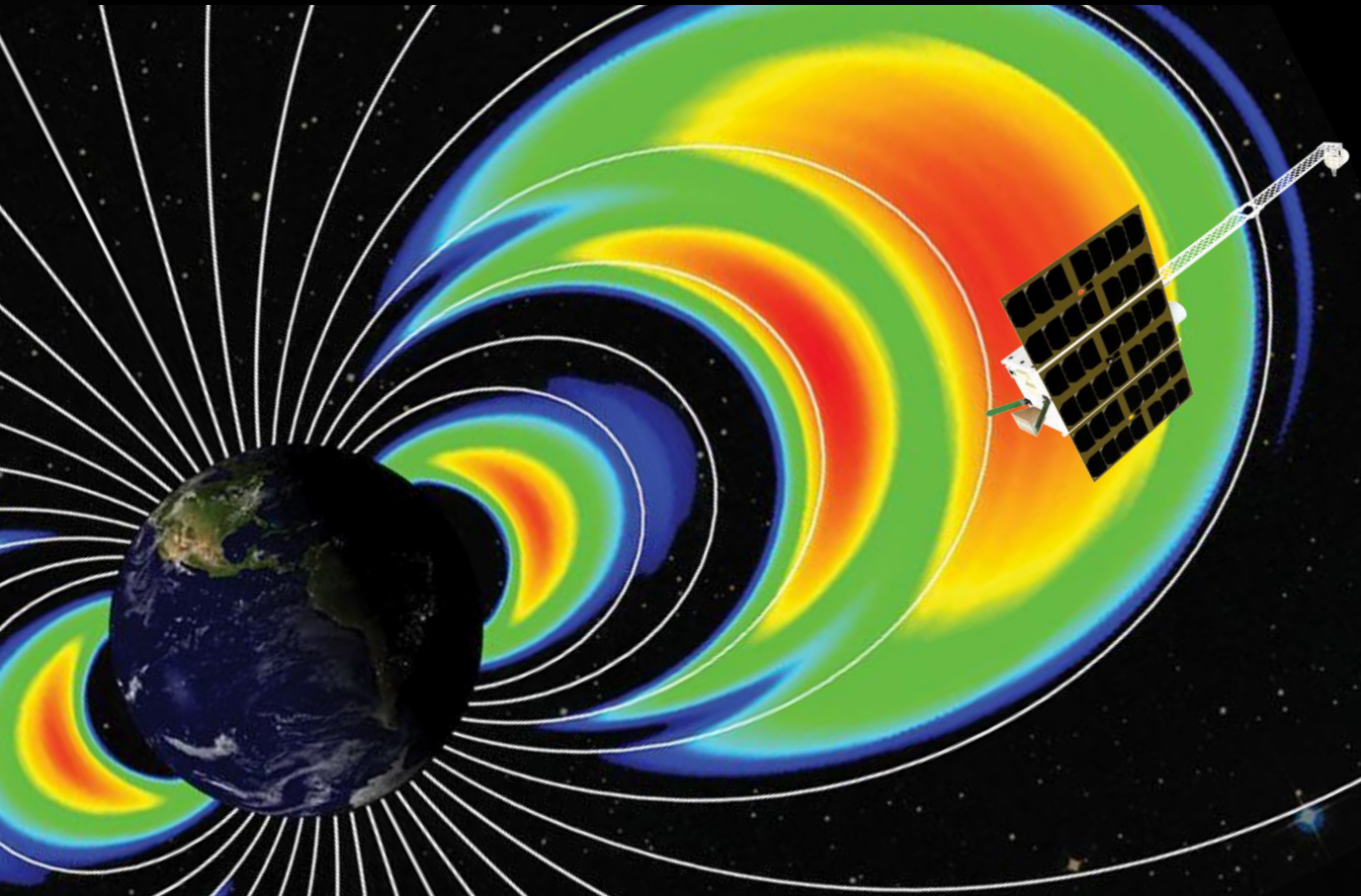
FINNISH METEOROLOGICAL INSTITUTE

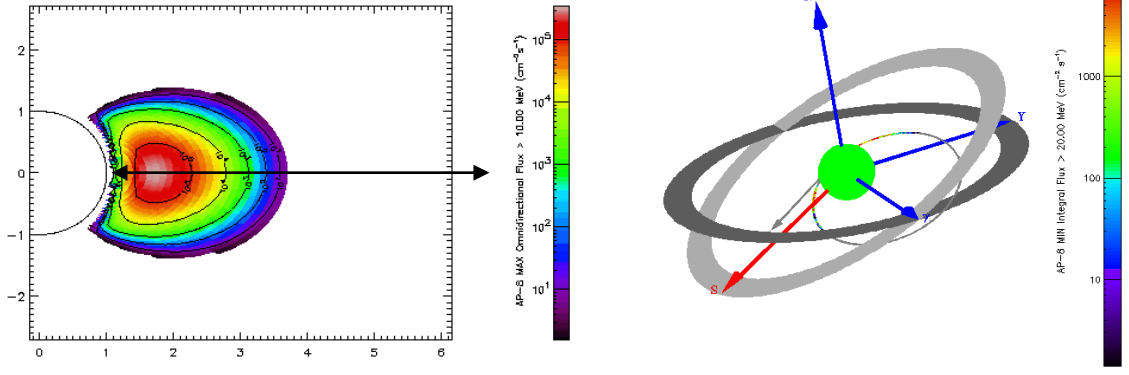
FORESAIL-2

Mission to the radiation belts with a CubeSat !

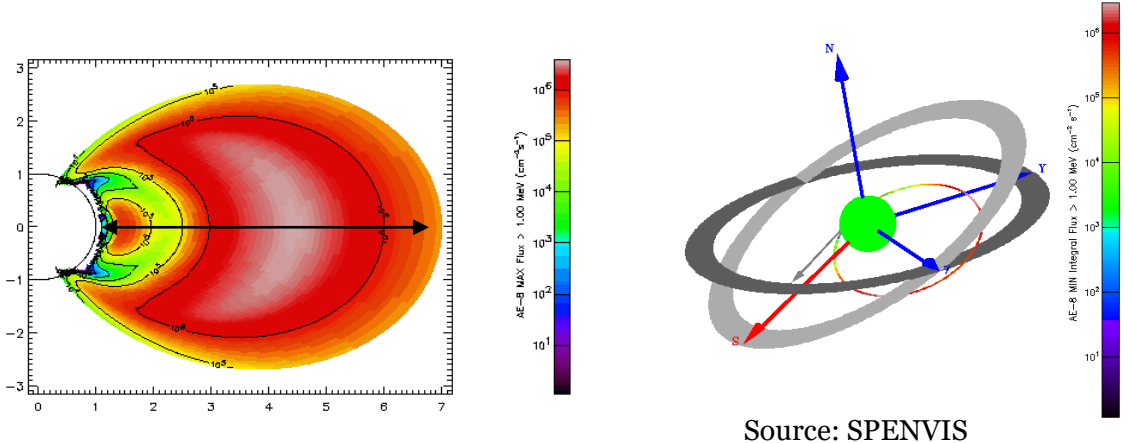


Foresail-2
Radiation Environment

Proton flux > 10 MeV



Electron flux > 1 MeV



Source: SPENVIS

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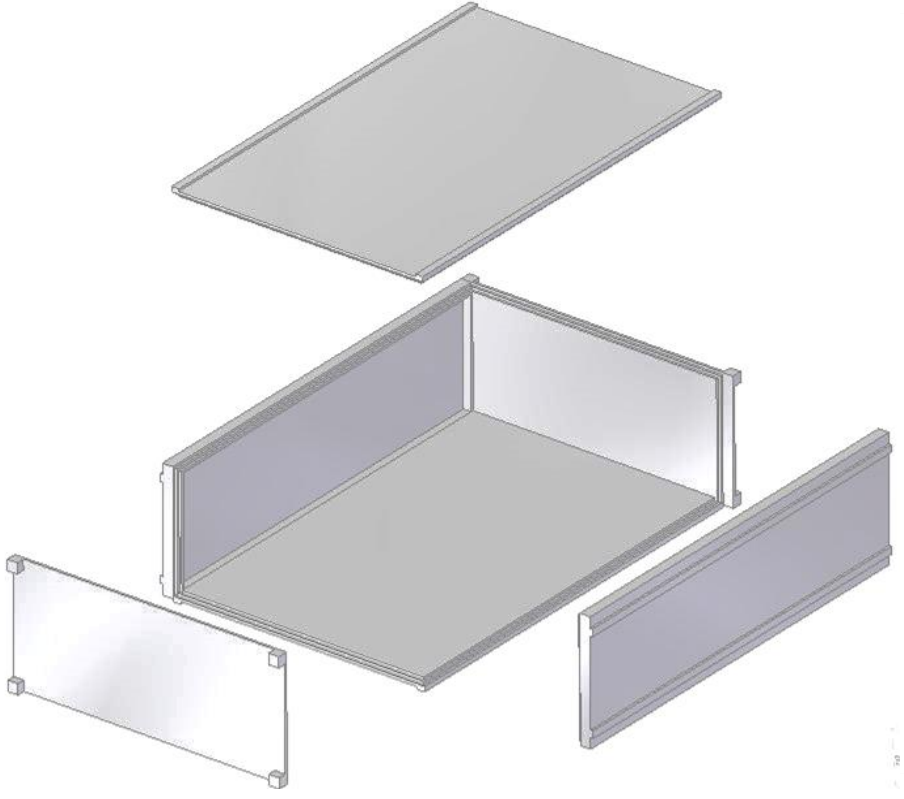
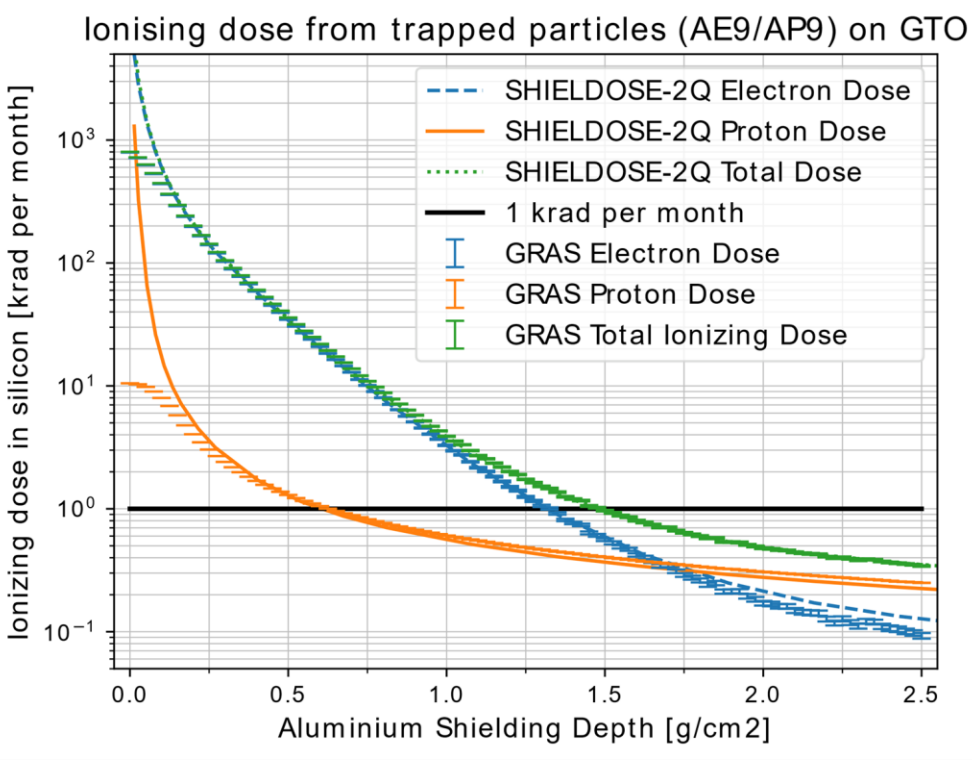
Foresail-2
Radiation Shielding





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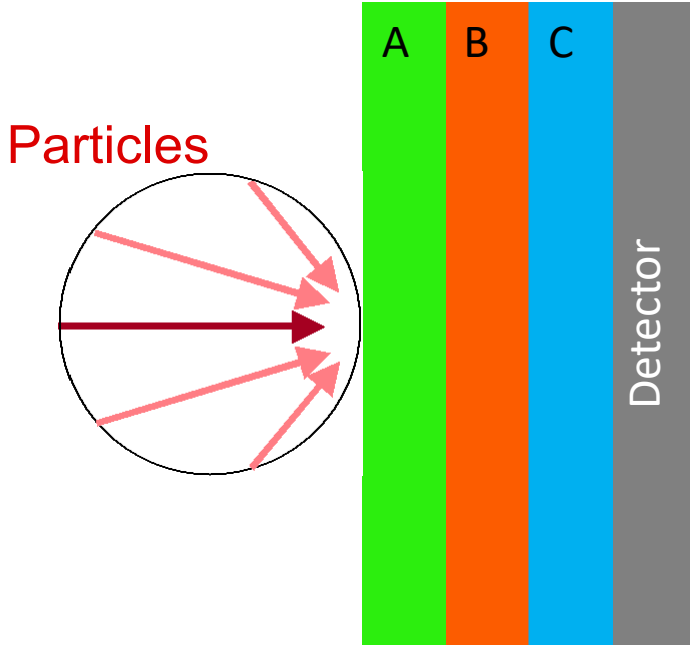
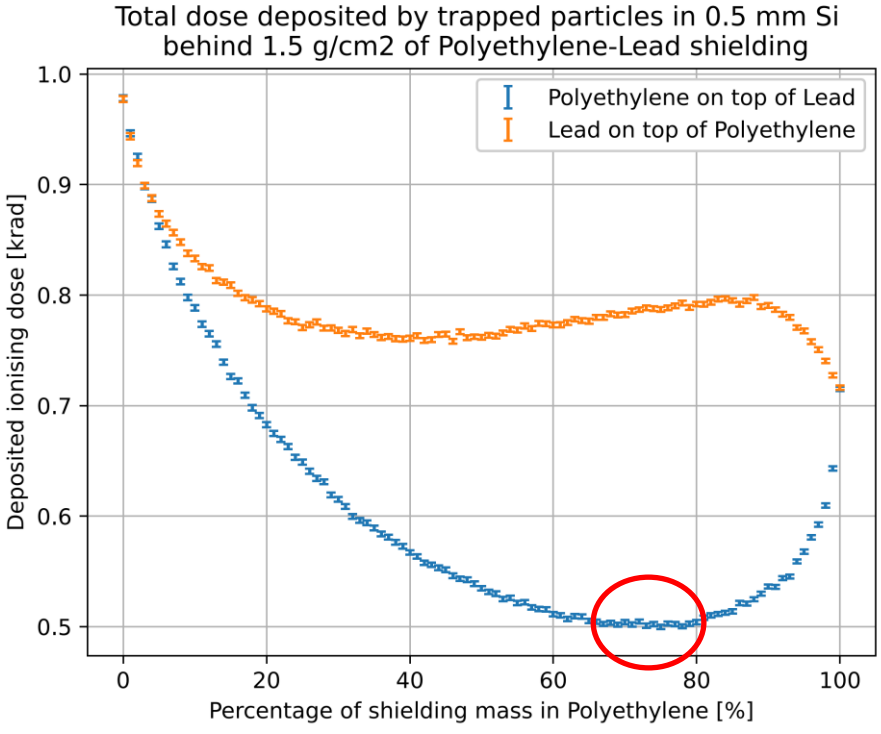
1.5 g/cm2 = 4.3 kg aluminium for 6U CubeSat

Multilayer Radiation Shielding Optimisation
with Geant4/GRAS





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Up to 30% less mass required than with aluminium shield

Available online at www.sciencedirect.com

ScienceDirect

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ADVANCES IN SPACE RESEARCH
(a COSPAR publication)

www.elsevier.com/locate/asr

Total ionising dose multilayer shielding optimisation for nanosatellites on geostationary transfer orbit

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Foresail-2

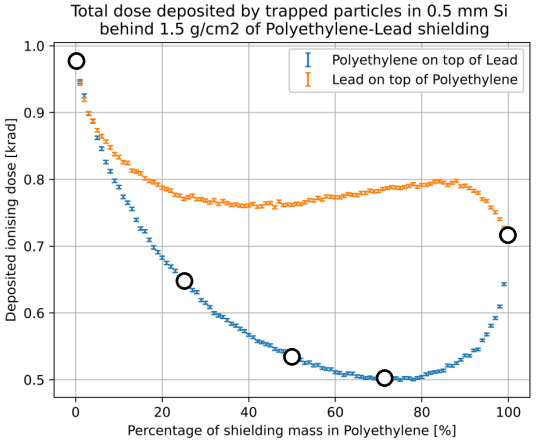
Multilayer *Radiation*
Shielding Experiment

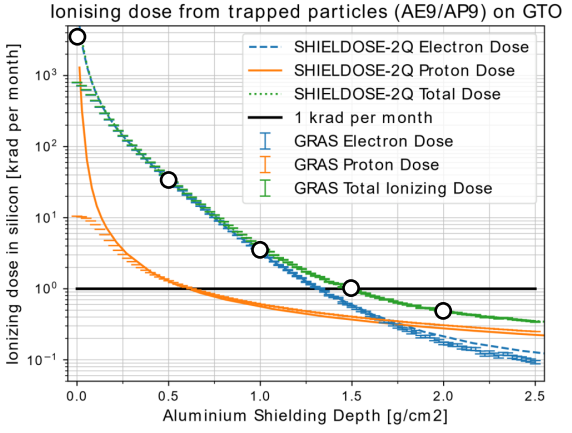
Instrument design

Scientific Objectives

Verify shielding simulations by measuring ionising dose behind

1. different mass ratios of Polyethylene-Lead two-layer shielding
2. different aluminium thicknesses





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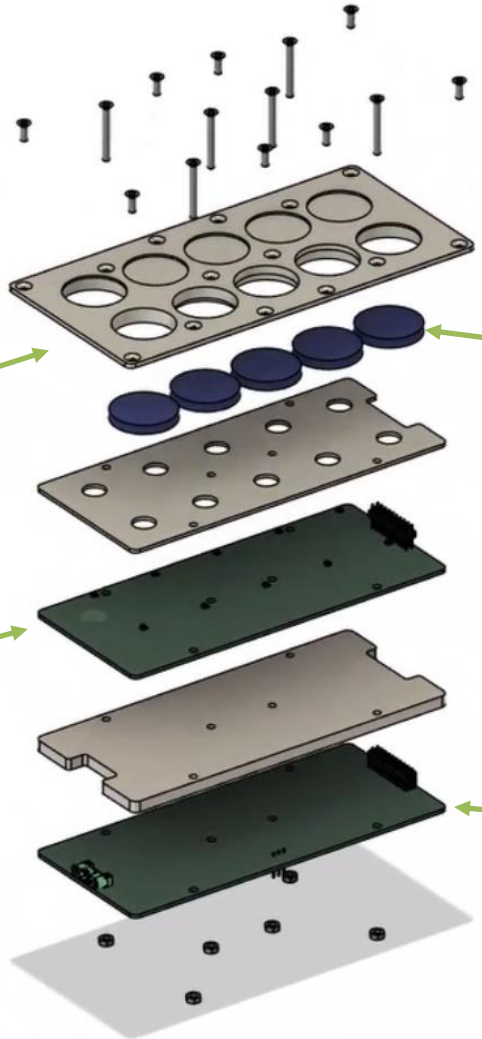
Foresail-2

Radiation Experiment

Foresail-2

Radiation Experiment



6mm aluminium top plate

Polyethylene-Lead multilayer samples

Sensor PCB

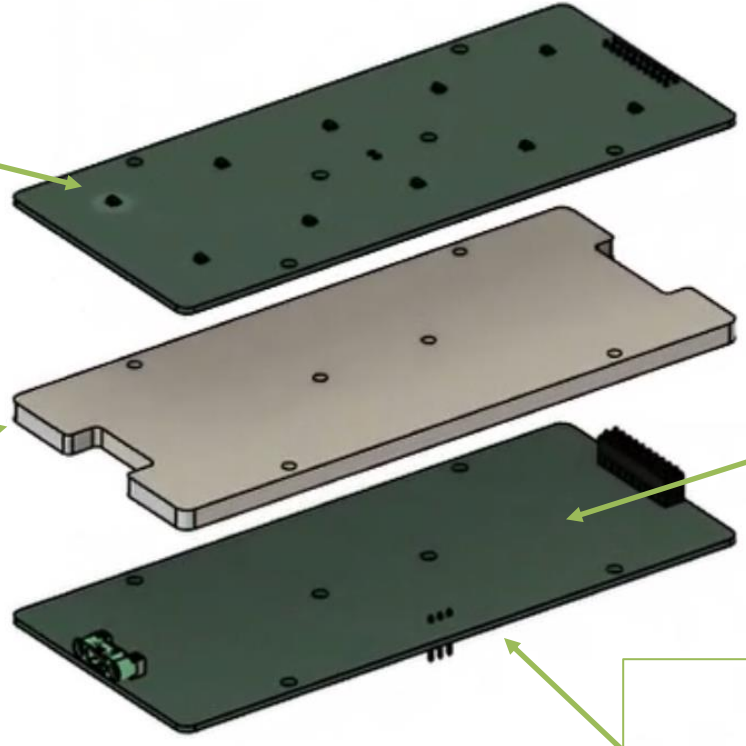
PCB for readout and processing

Foresail-2

Radiation Experiment

Foresail-2

Radiation Experiment



10 RadFet sensors

4mm aluminium backplate

Current sources and Switching matrix

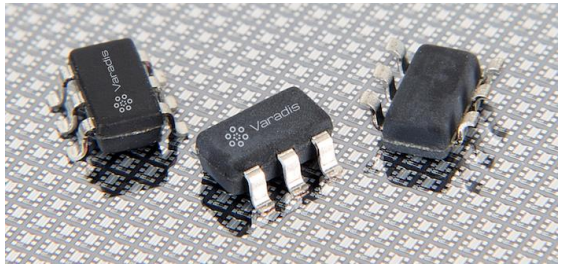
MSP430 microcontroller

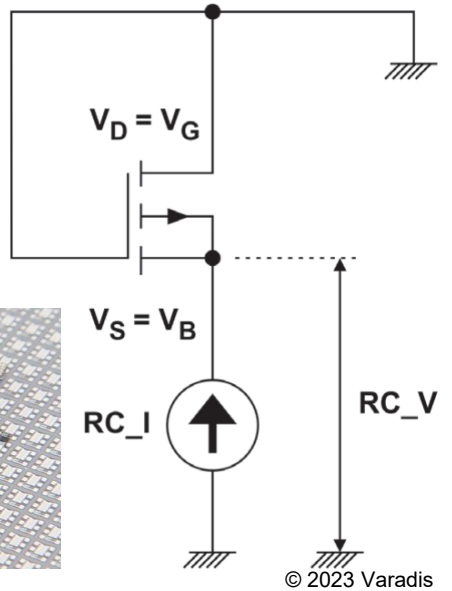
Radiation Experiment

Electrical design

RadFETs

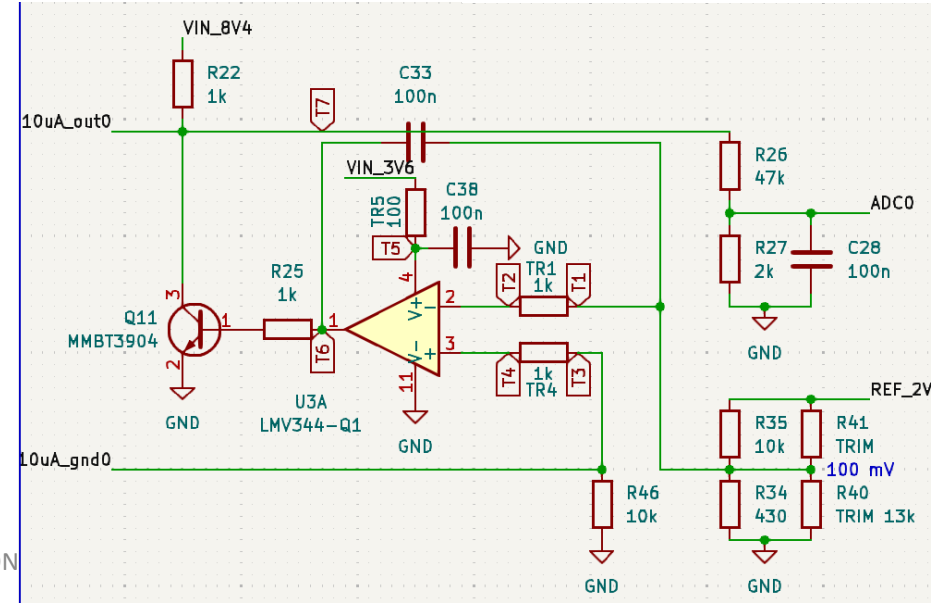
- VT01 & VT05
- Radiation sensitive MOSFETs
- Made by Varadis





10µA and 17µA current sources

- based on operational amplifiers



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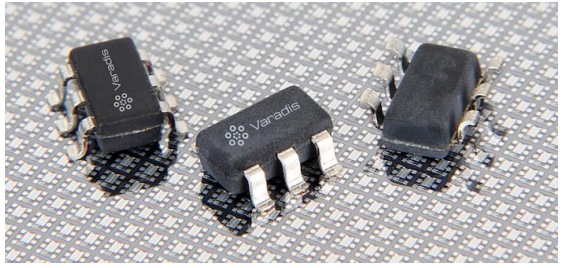
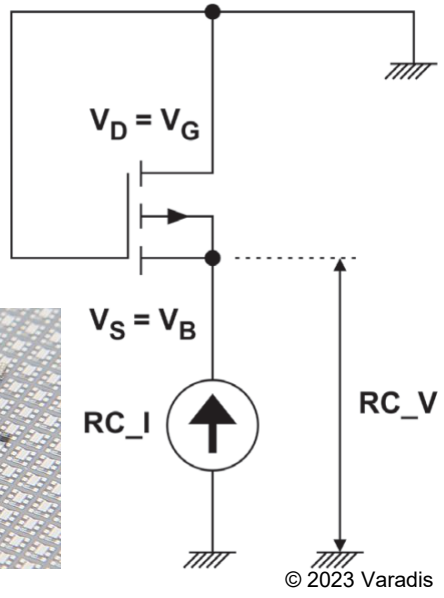


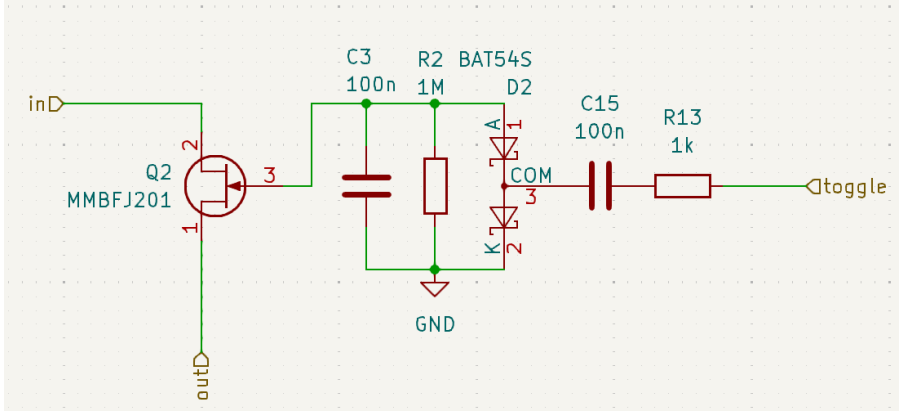


10µA and 17µA current sources

- based on operational amplifiers

JFET switches

- for channel selection



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Foresail-2

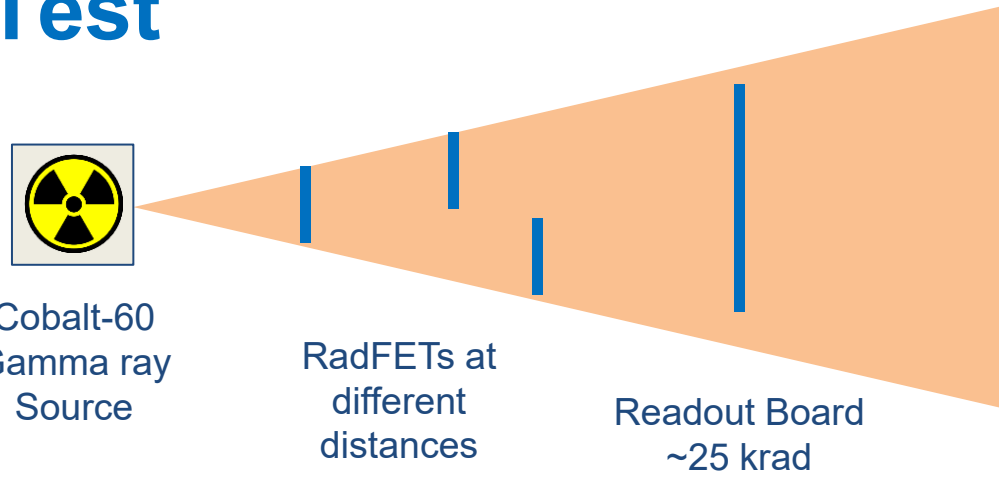
Multilayer *Radiation Shielding Experiment*

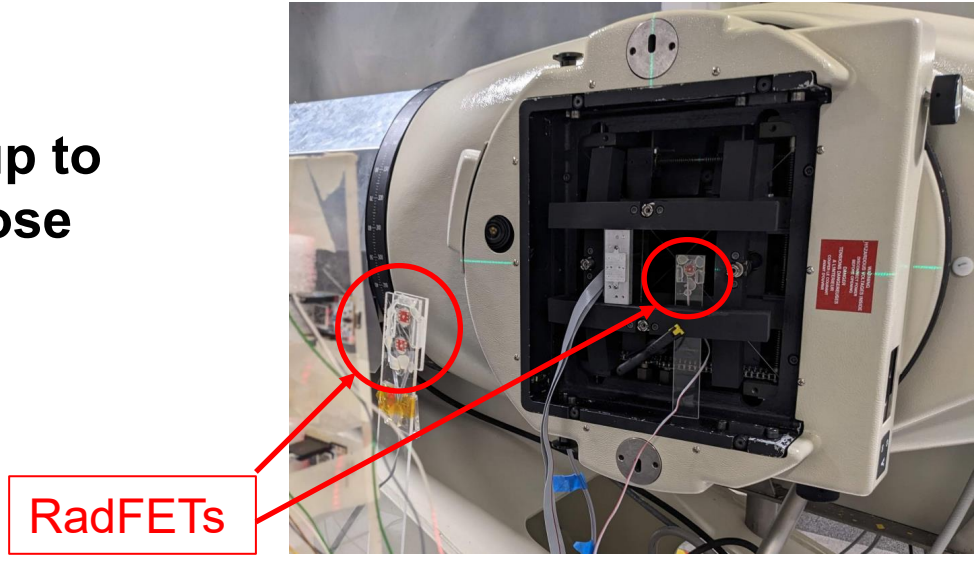
Radiation Testing

Total Ionising Dose Test

- **RadFET sensors tested to their expected doses**
  → Different distances from Cobalt-60 source

- **Readout electronics expected to receive up to 10 krad of ionising dose in space**





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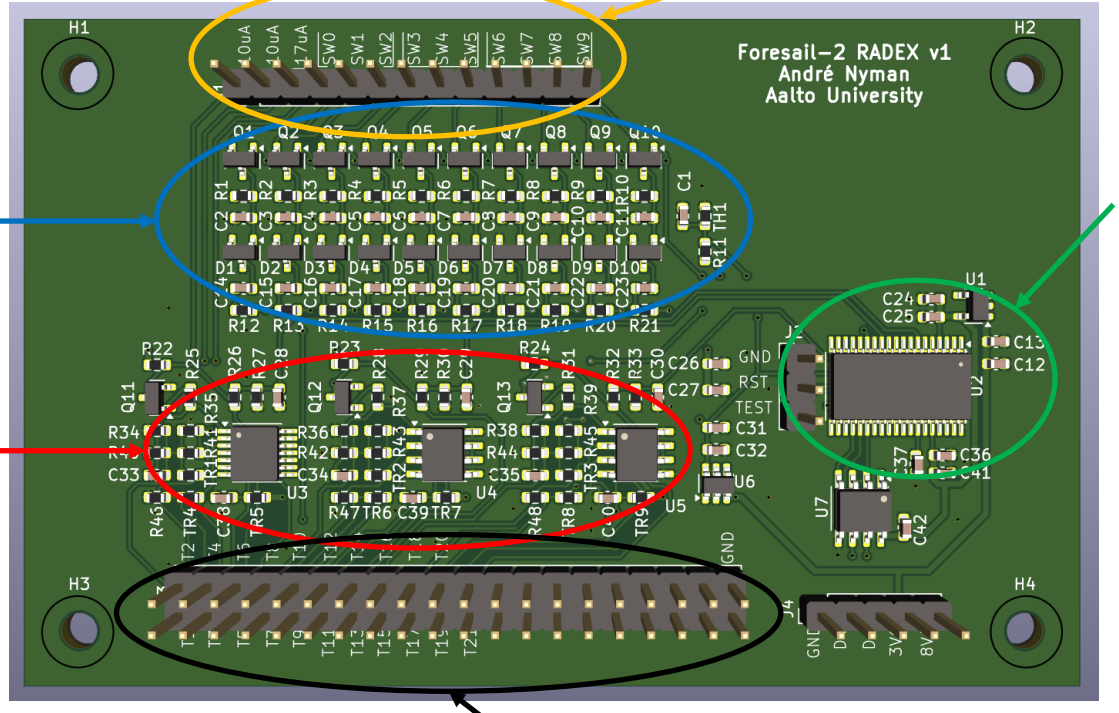
Electrical Prototype for Radiation Testing



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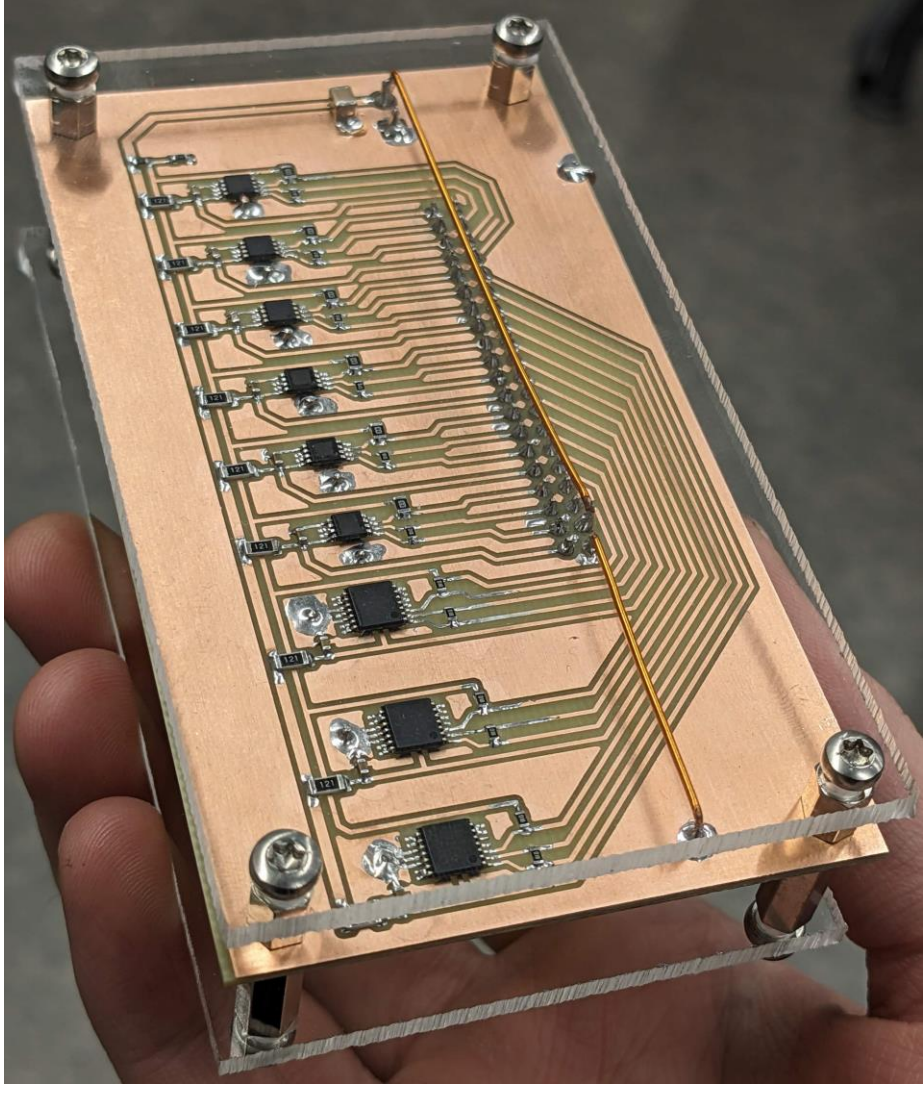
Component testing

Biasing board with

- 3 types of operational amplifiers
- 3 chips of each type
- All amplifiers biased



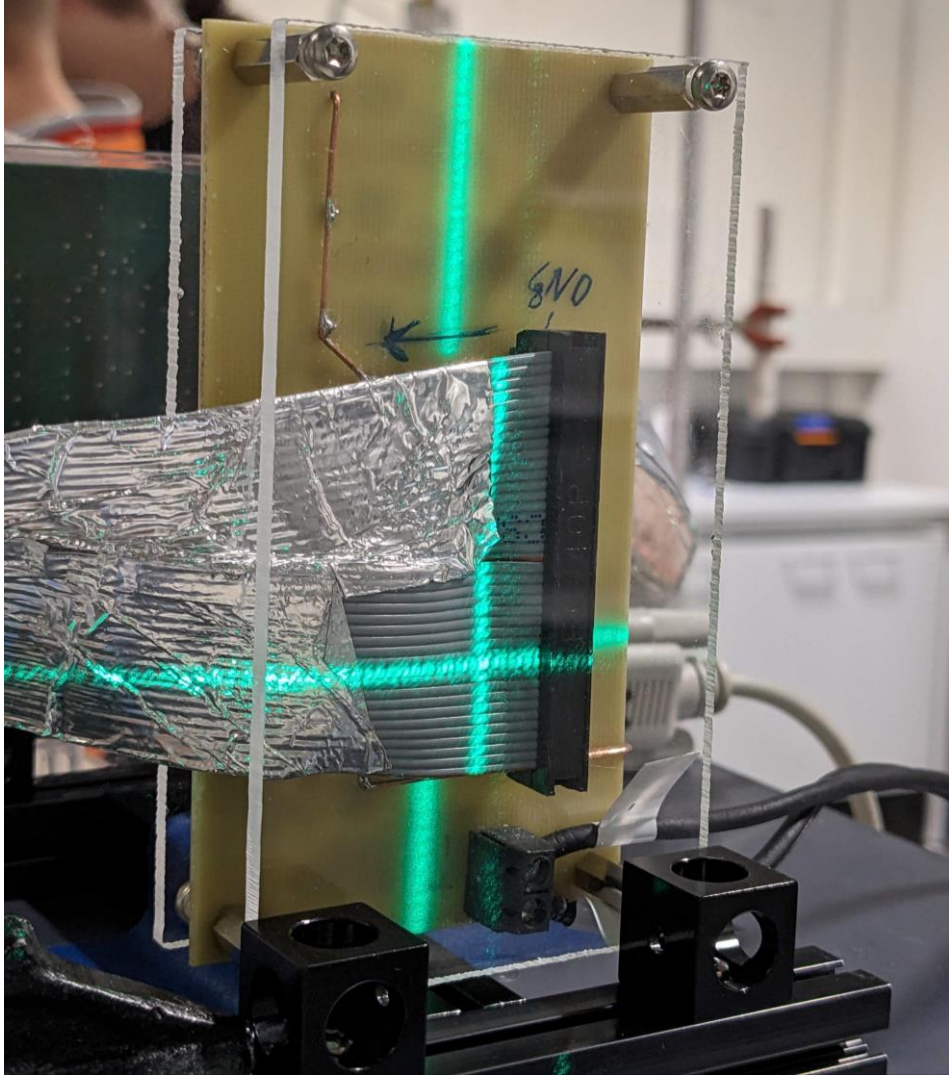
Component testing

Biasing board with

- 3 types of operational amplifiers
- 3 chips of each type
- All amplifiers biased

40 Voltage Channel to monitor

4 voltages per chip



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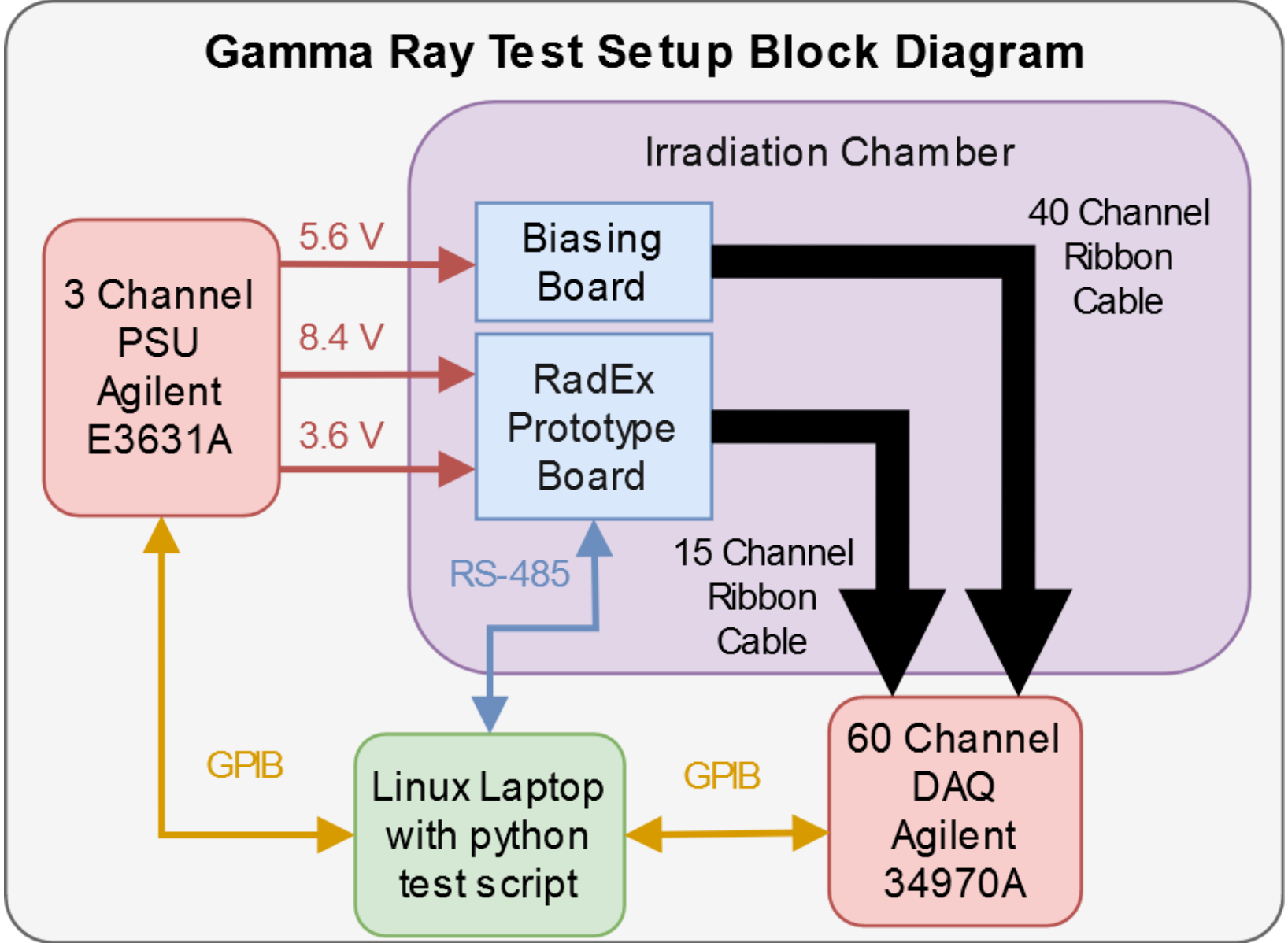
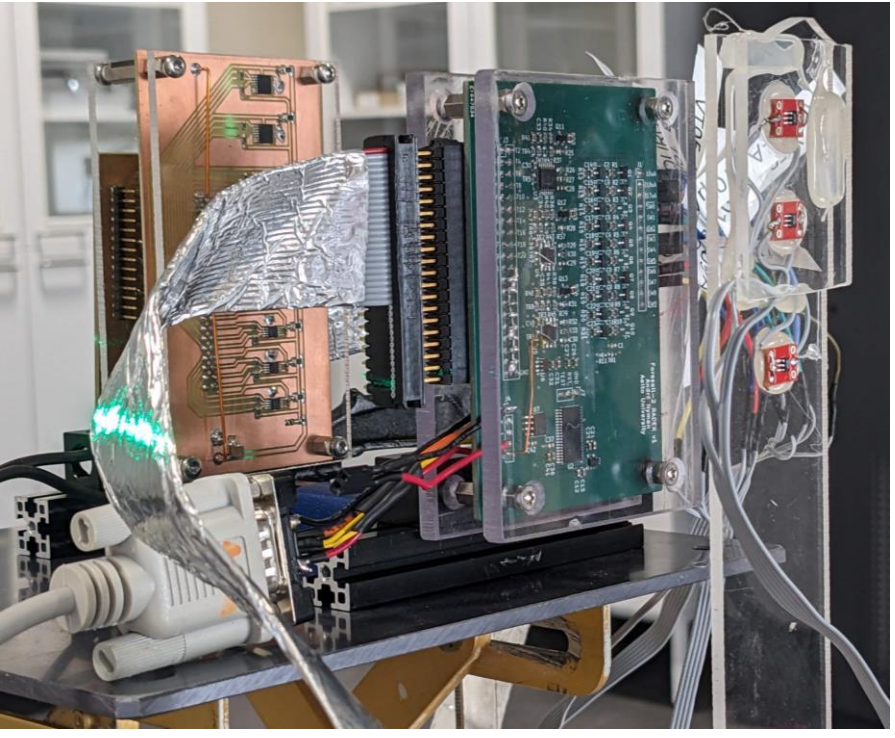
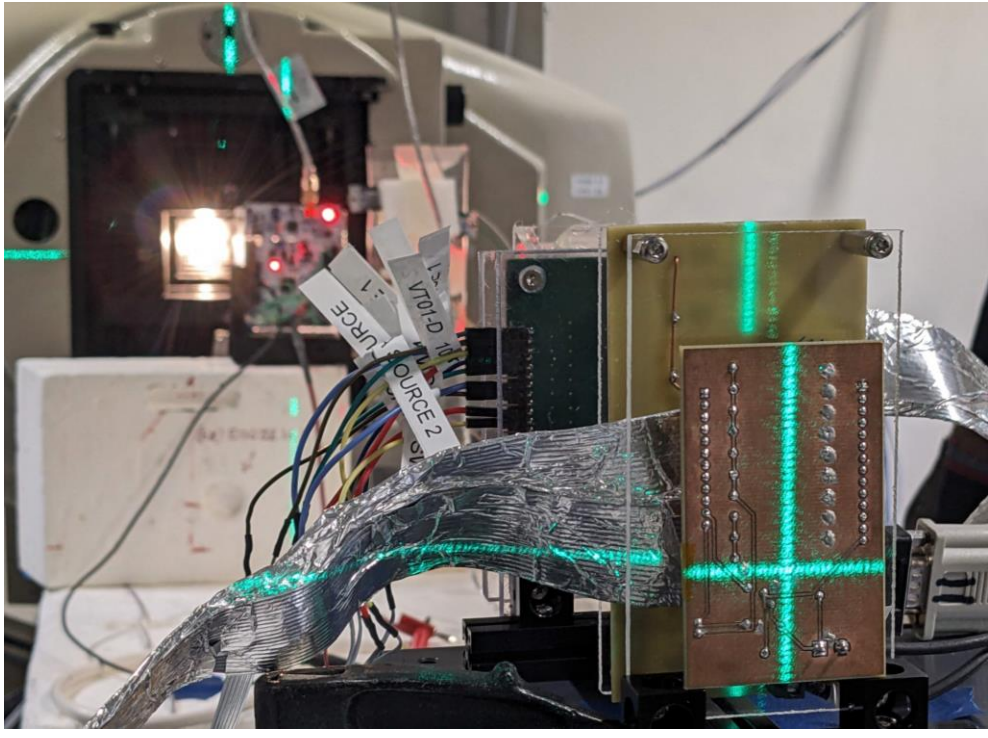

Gamma Ray Test Setup Block Diagram
Irradiation Chamber
3 Channel PSU Agilent E3631A
5.6 V
8.4 V
3.6 V
Biasing Board
RadEx Prototype Board
40 Channel Ribbon Cable
15 Channel Ribbon Cable
RS-485
GPIB
GPIB
Linux Laptop with python test script
60 Channel DAQ Agilent 34970A

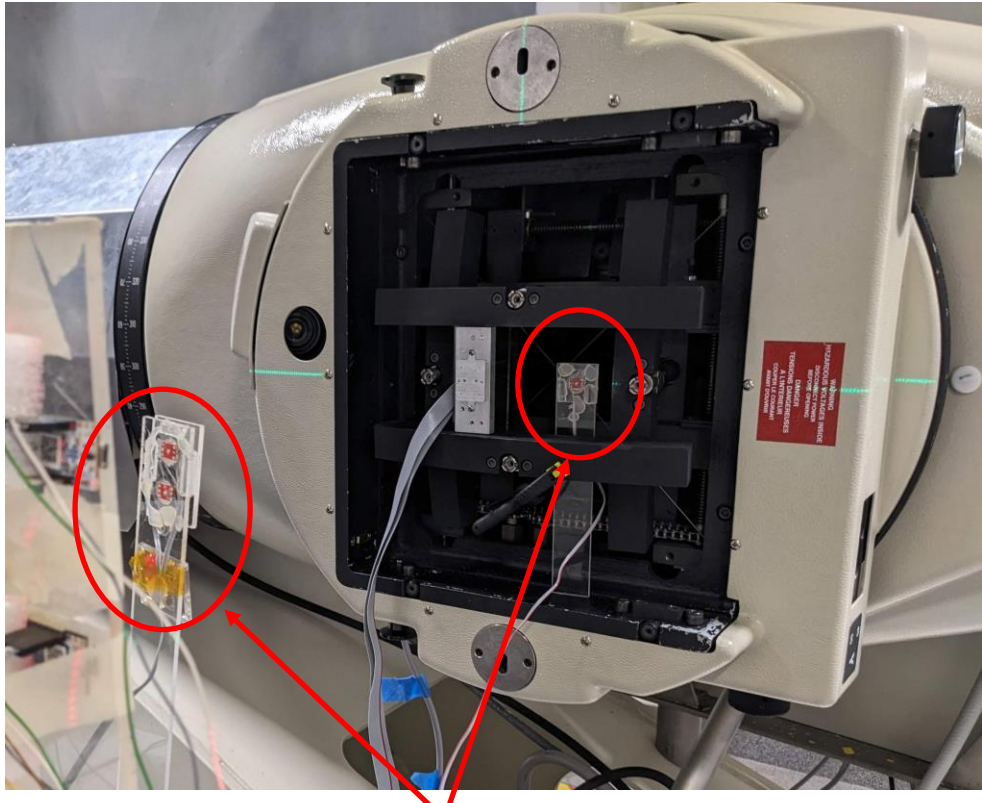
Gamma Ray Irradiation Setup





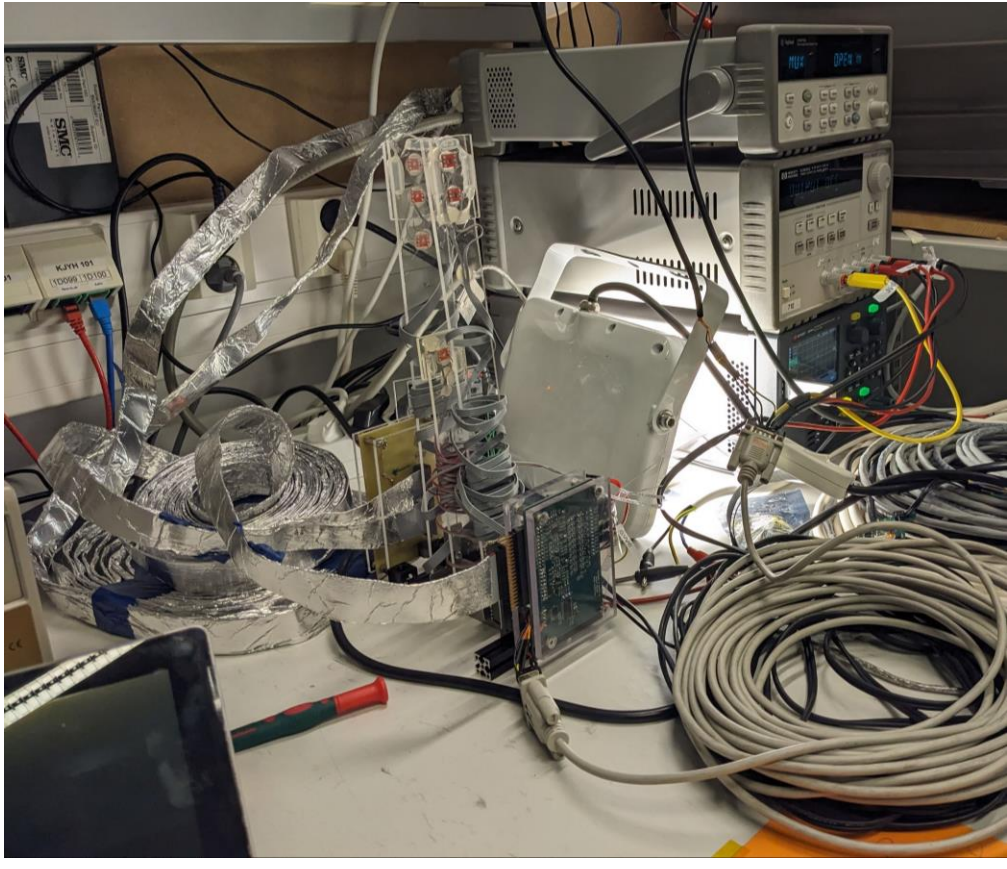
Irradiation and annealing schedule

- **Cobalt-60 gamma source at STUK in Vantaa, Finland**
- **Irradiation over a whole weekend**
- **65 hours**



Irradiation and annealing schedule

- Cobalt-60 gamma source at STUK in Vantaa, Finland
- Irradiation over the whole weekend
- 65 hours
- 1 Week room temperature annealing



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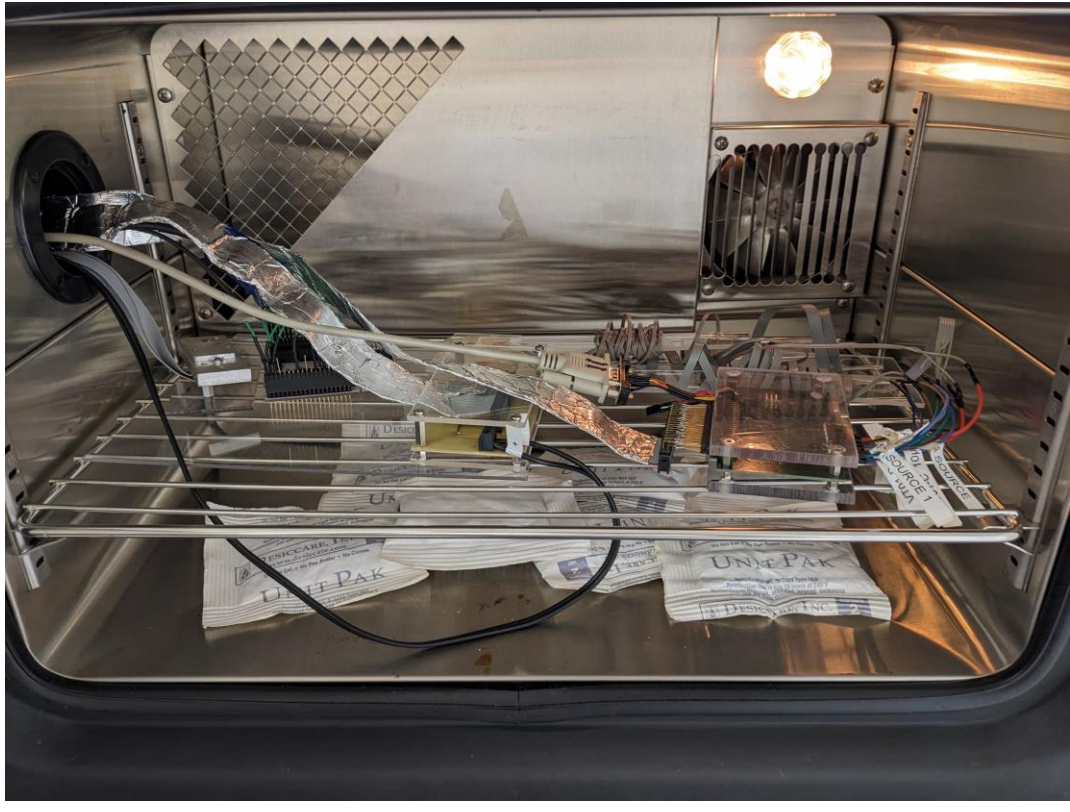
Irradiation and annealing schedule

- Cobalt-60 gamma source at STUK in Vantaa, Finland
- Irradiation over the whole weekend
- 65 hours
- 1 Week room temperature annealing
- 1 Week high temperature annealing at 100°C



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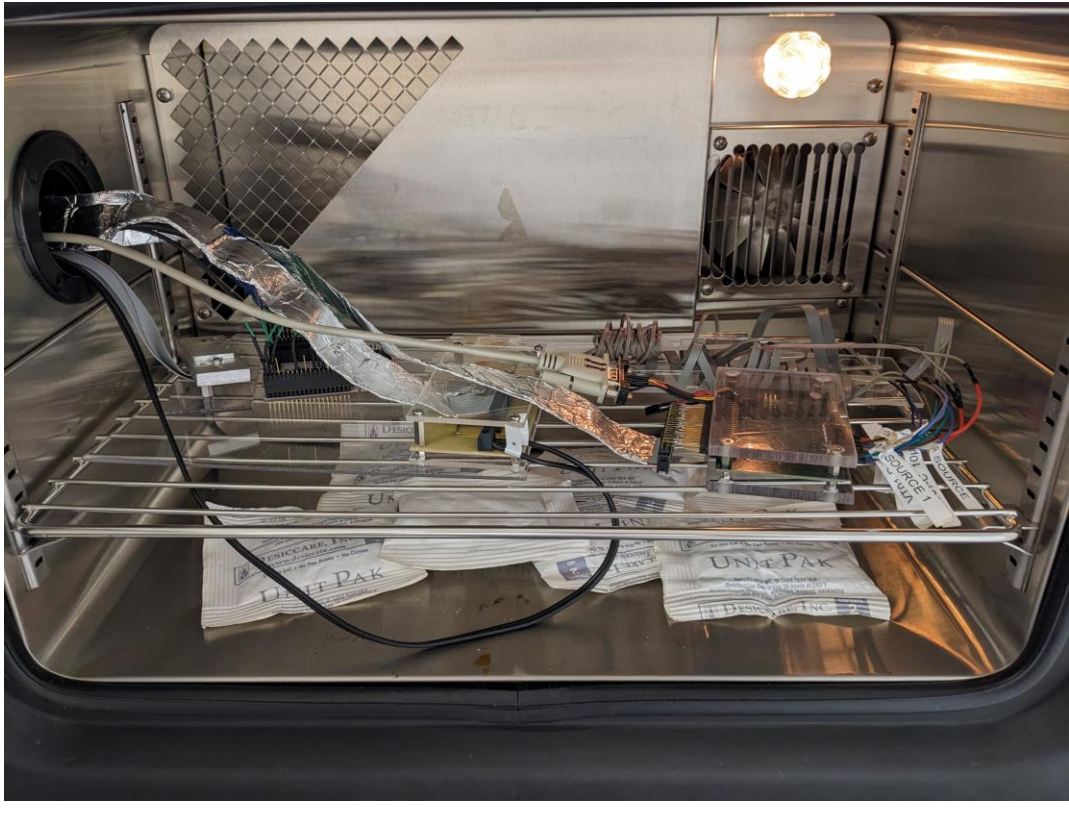
Irradiation and annealing schedule



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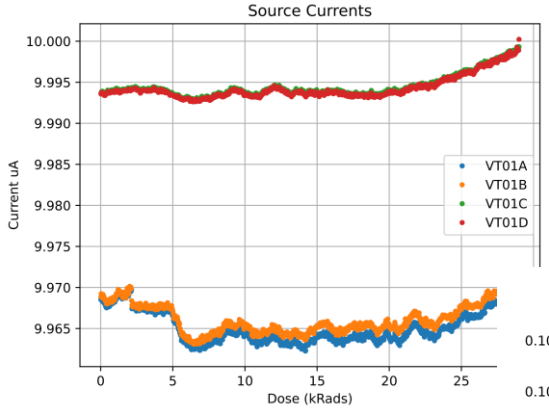
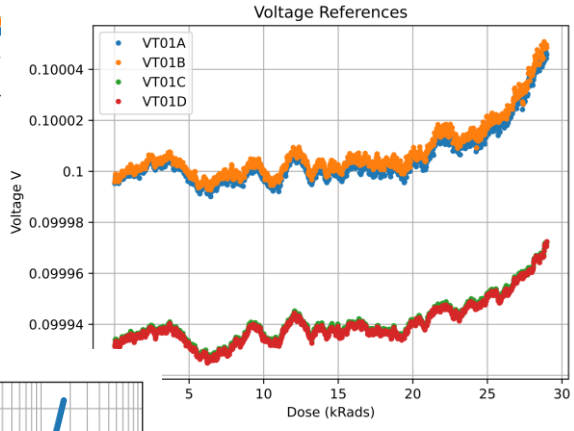
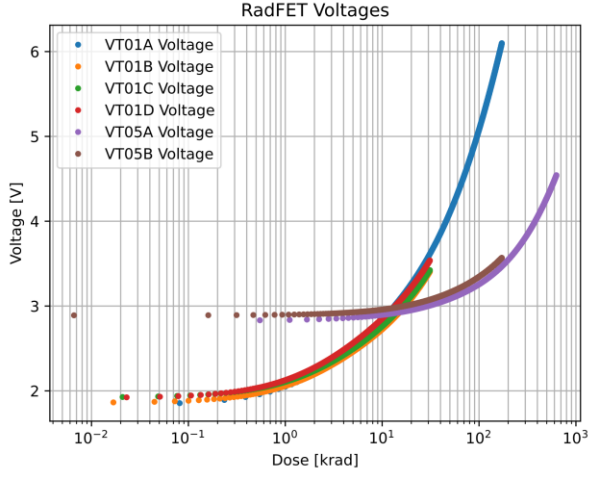
Co-60 test results

- Electrical prototype and components **qualified for 30 krad** of total ionising dose.
- **No** component **failures**
- Current sources stable
- Voltage reference stable
- ADC of the microprocessor stable
- RadFETs less sensitive than expected

  → **Grounding between measurements**







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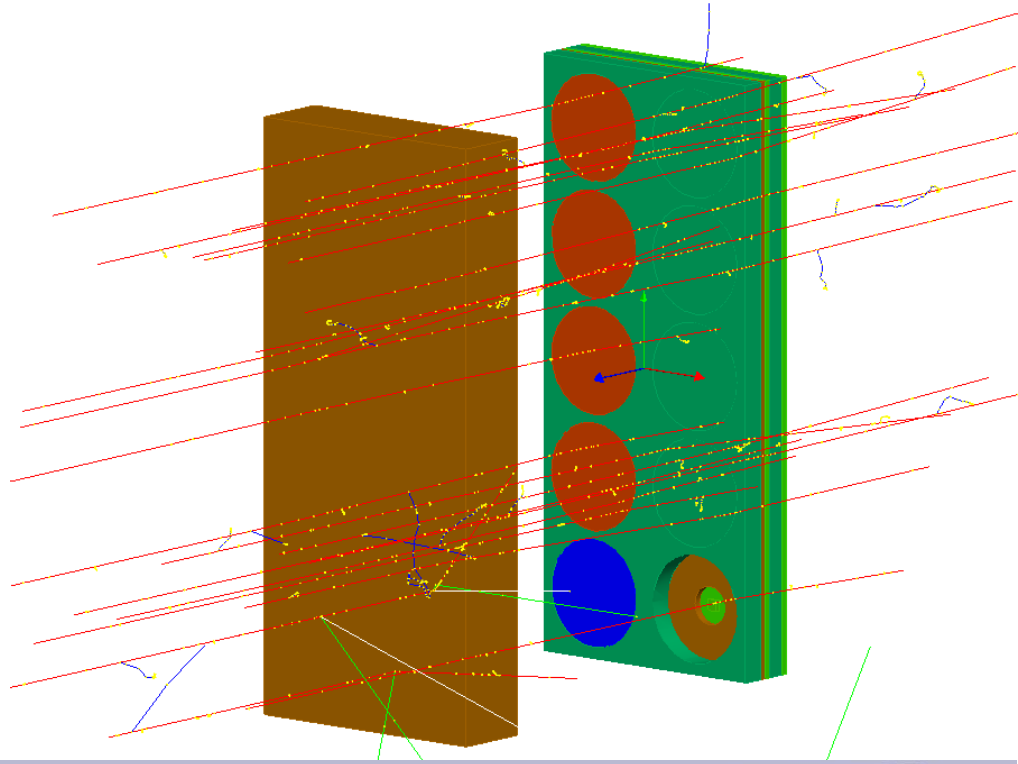
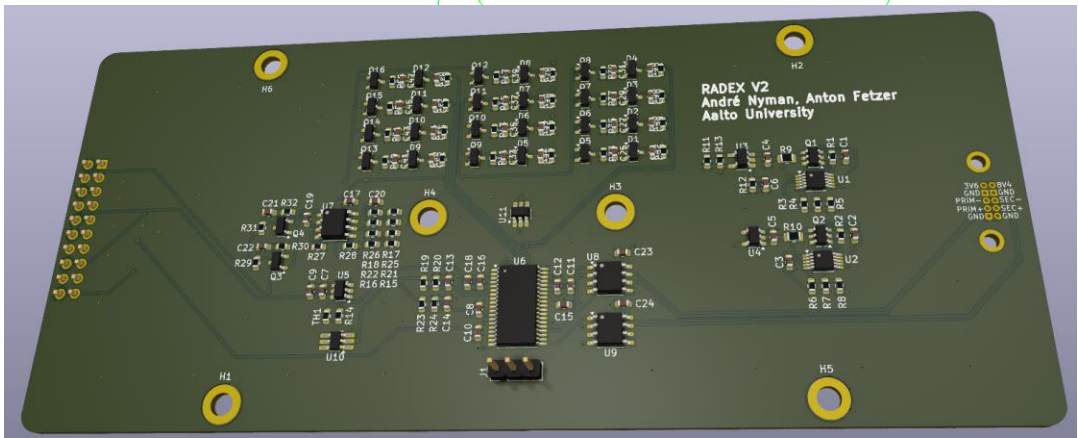
Proton Testing

Planned Proton beam test

- **27.6.2025**
- **Full mechanical and electrical prototype**
- **At proton accelerator of Skandionkliniken Uppsala**
- **70 MeV – 230 MeV**
- **2cm PMMA to move Bragg Peak into device**

1. **70 MeV → RadFETs**
2. **100 MeV → Readout PCB**





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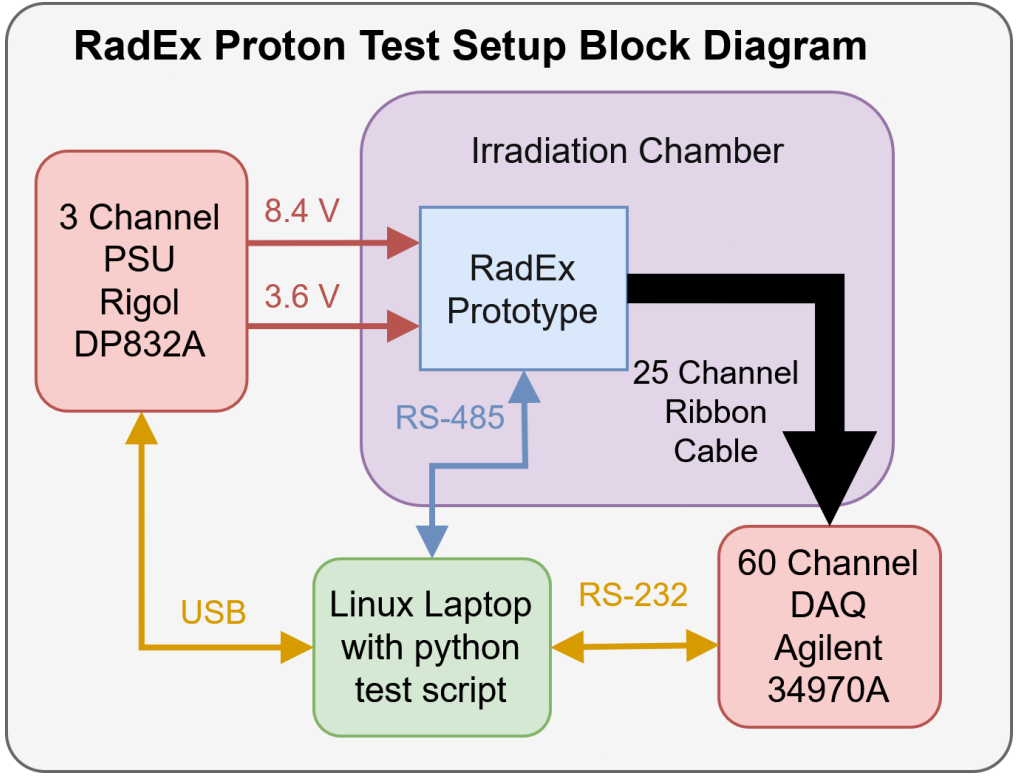

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The CRDS

Compact Radiation Dosimetry System

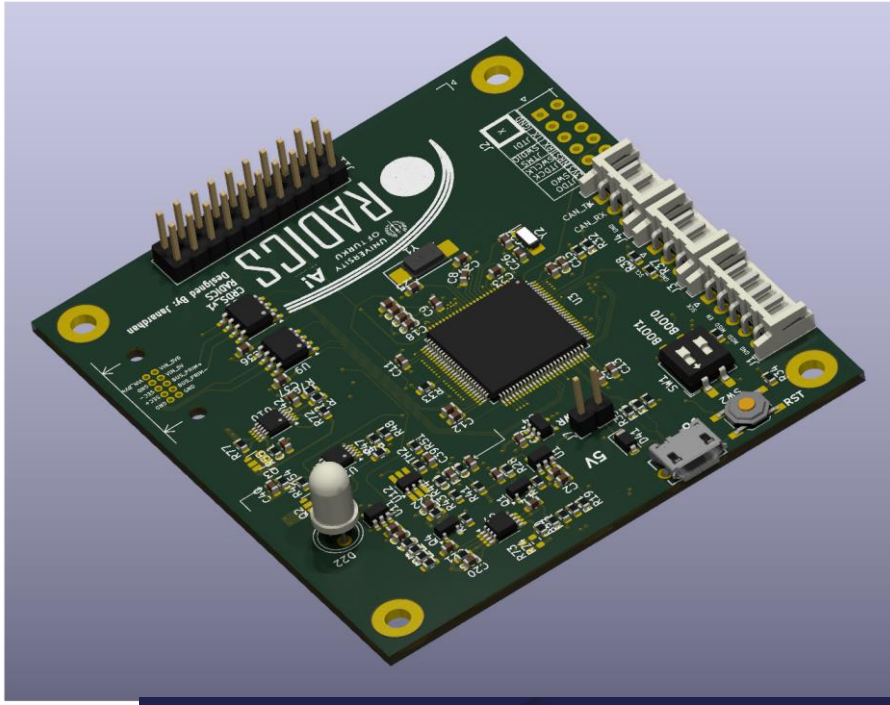
New Instrument Concept for internal dosimetry

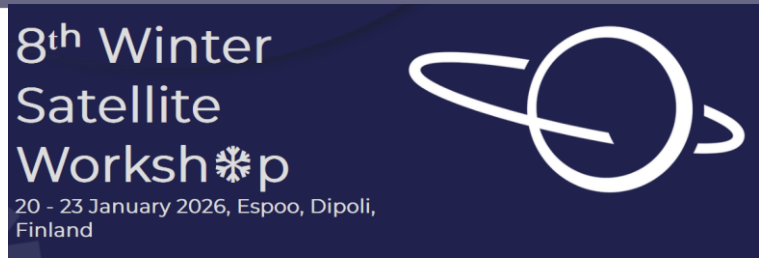
The CRDS
Compact Radiation Dosimetry System

- **New Instrument concept**
- Based on Paavo Heiskanen's comments at the Winter Satellite Workshop 2025 at Aalto University in Finland
- **Objectives:**

1. Total Ionising Dose
2. Displacement Damage
3. Rate of High LET particles

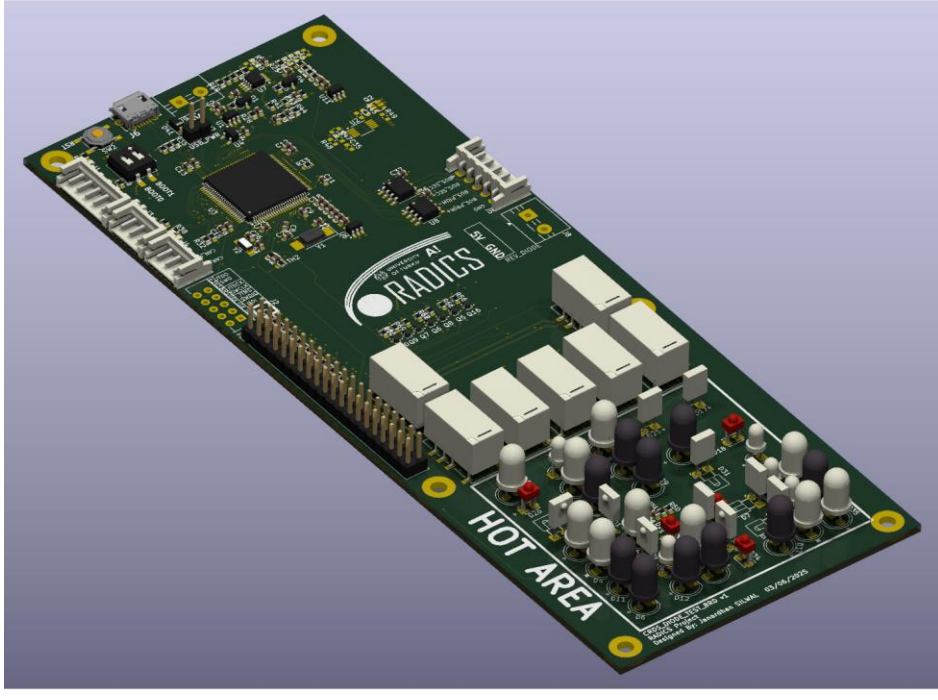
Inside the shielded avionics vault of several satellites





The CRDS
Compact Radiation Dosimetry System

- **Total Dose Sensor:**
  - based on RadFET from the Foresail-2 Radiation Experiment
- **Displacement Damage Sensor:**
  - GaAs LED forward voltage and reverse current



CRDS GaAs LED test board
For proton beam testing

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The CRDS
Compact Radiation Dosimetry System

- **Total Dose Sensor:**
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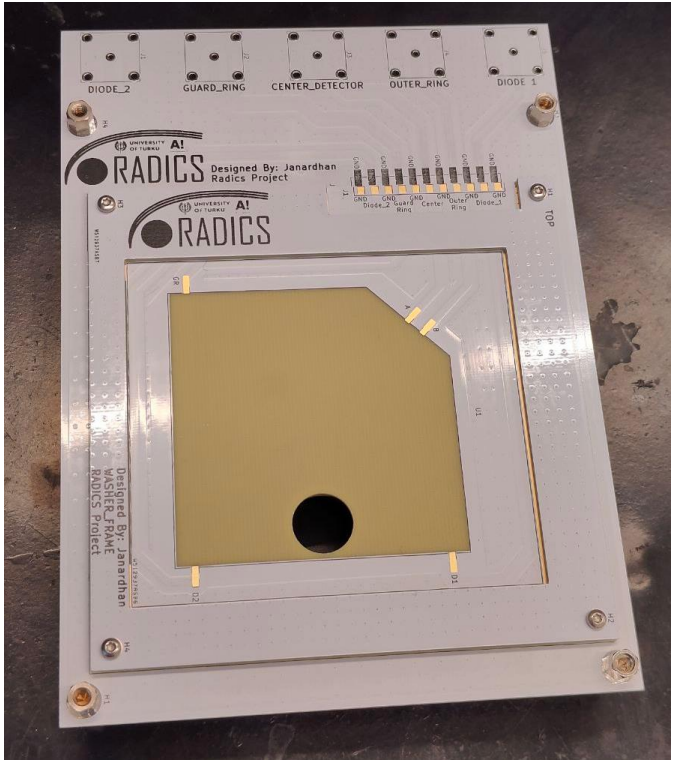
- **Displacement Damage Sensor:**
  - GaAs LED Forward voltage and reverse current
- **High LET counter**
  - Silicon Plate Detector
  - Counting above threshold



CRDS Silicon Plate Detector PCB

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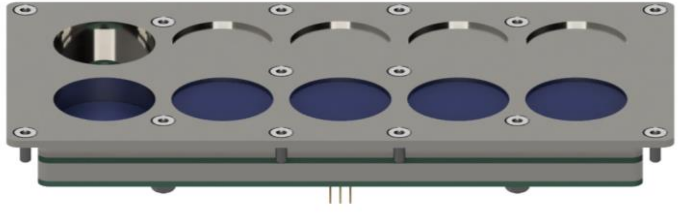
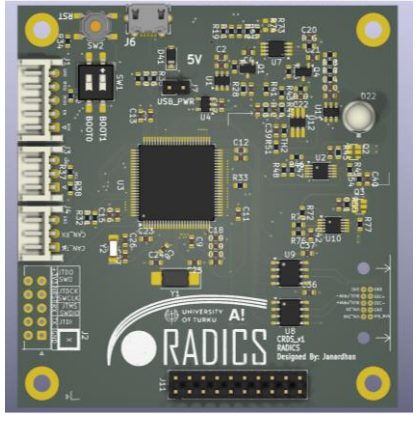
Conclusion

Foresail-2 Multilayer Radiation Shielding Experiment:

- Design complete
- Mechanical + Electrical prototype in proton beam this month





Compact Radiation Dosimetry System:

- Initial design for TID and DDD
- TID and DDD detector testing in Proton beam this month
- LET counter initial measurements

We are looking for partners who are interested in flying our radiation instruments!

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