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The XH cryogenic detector system: overview and recent studies

A HPGe micro-strip sensor

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High Precision X-ray Measurements 2025

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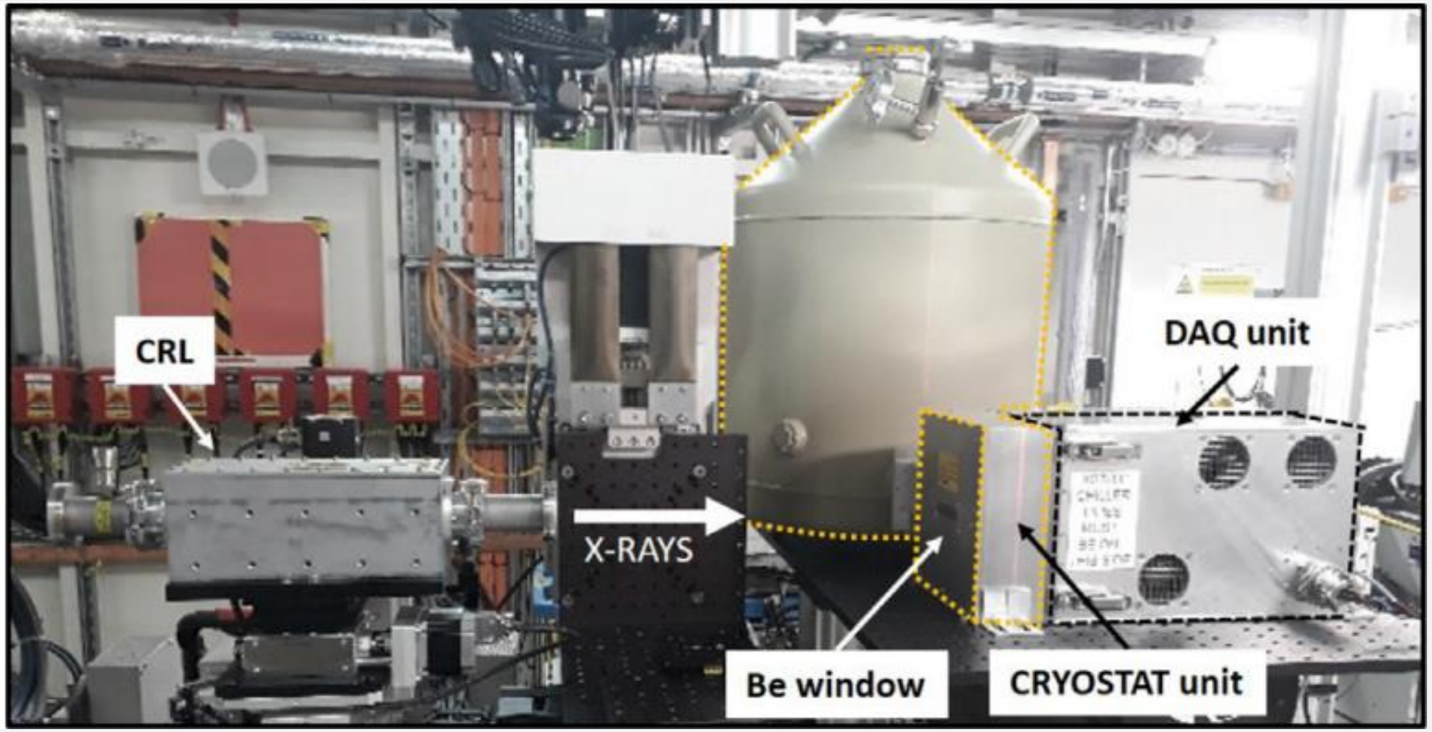
- Introducing the XH system:
  - Experimental application;
  - Cryostat unit;
  - DAQ unit;

- Tests on cryostat unit:
  - Stress tests during development;

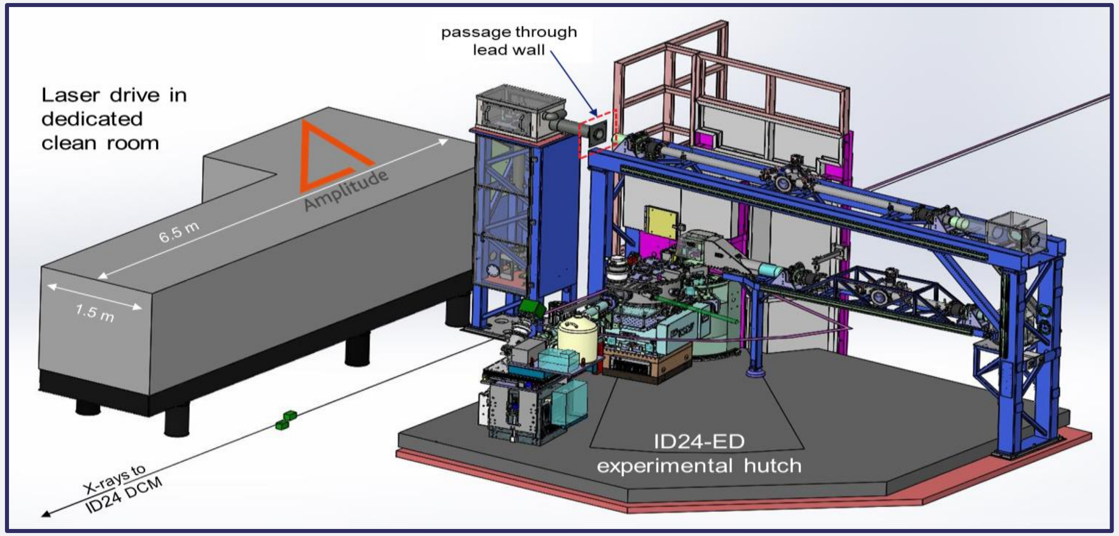
- Recent vacuum studies on cryostat unit:
  - Experimental setup and procedure;
  - RGA spectra, vacuum logs and IV curves;
  - Future irradiation work;

- Summary

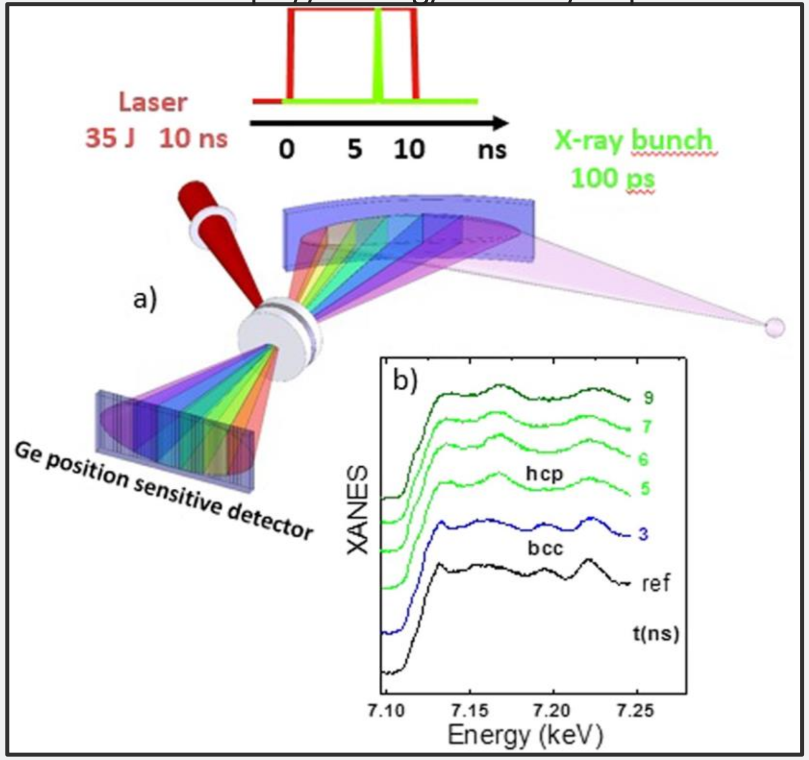


Experimental application

- XH is a detector currently deployed at the High Power Laser Facility (HPFL) at ESRF-EBS ID24.
- It is used in time-resolved Energy Dispersive X-ray Absorption Fine Structure (EXAFS).
- EBS beams are combined with the high-power laser to perform dynamic compression experiments in the ns time-scale.
- The extreme conditions of pressure and temperature created in the sample are used to study structure and properties of matter for solid state physics, materials and energy.
- A representative case is the study of warm dense matter, relevant to the description of planetary interiors.



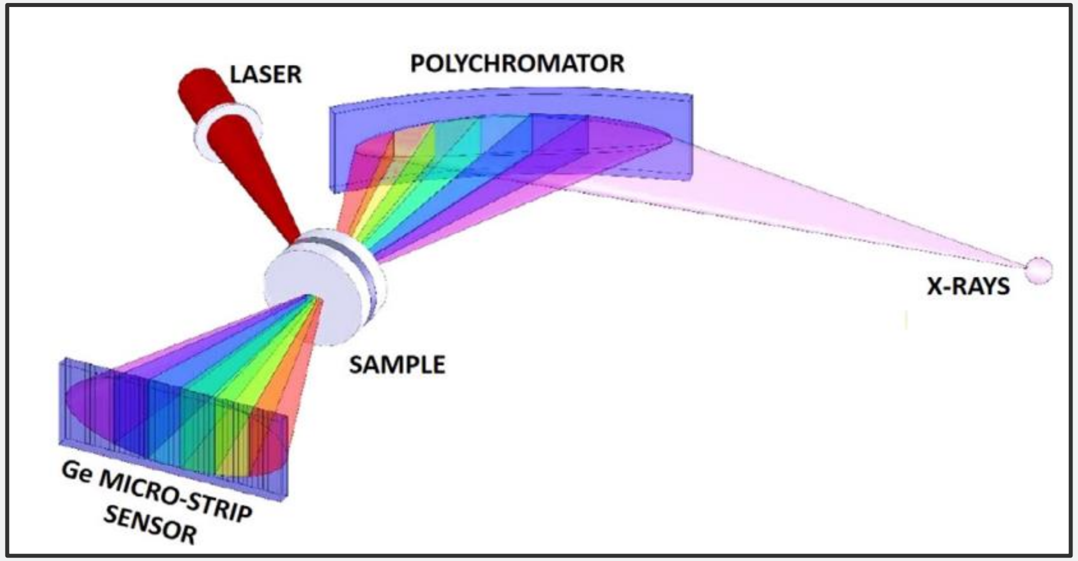
https://doi.org/10.1038/srep26402

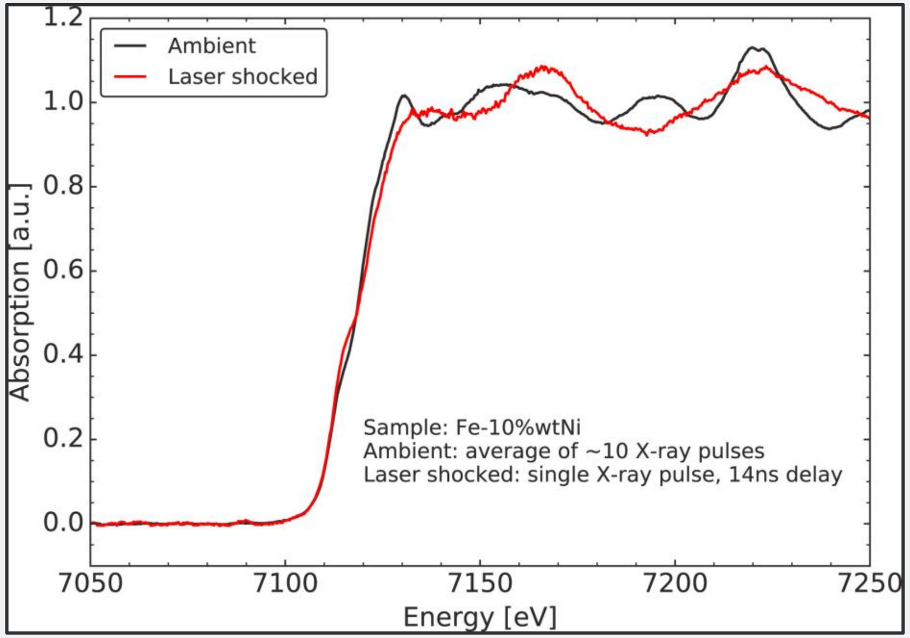


Probing local and electronic structure in Warm Dense Matter: single pulse synchrotron x-ray absorption spectroscopy on shocked Fe

Experimental application

- XH deploys an HPGe micro-strip sensor to detect the polychromatic transmitted pink beam.
- A back-illuminated HPGe sensor, with 1024 strips and 50 µm pitch.
- Each strip position corresponds to a different spectral component of the dispersed beam.
- EBS provides bright X-ray pulses, reducing photon statical noise on single shot measurements – sample is destroyed during exposure.





https://doi.org/10.1016/j.nima.2020.164932

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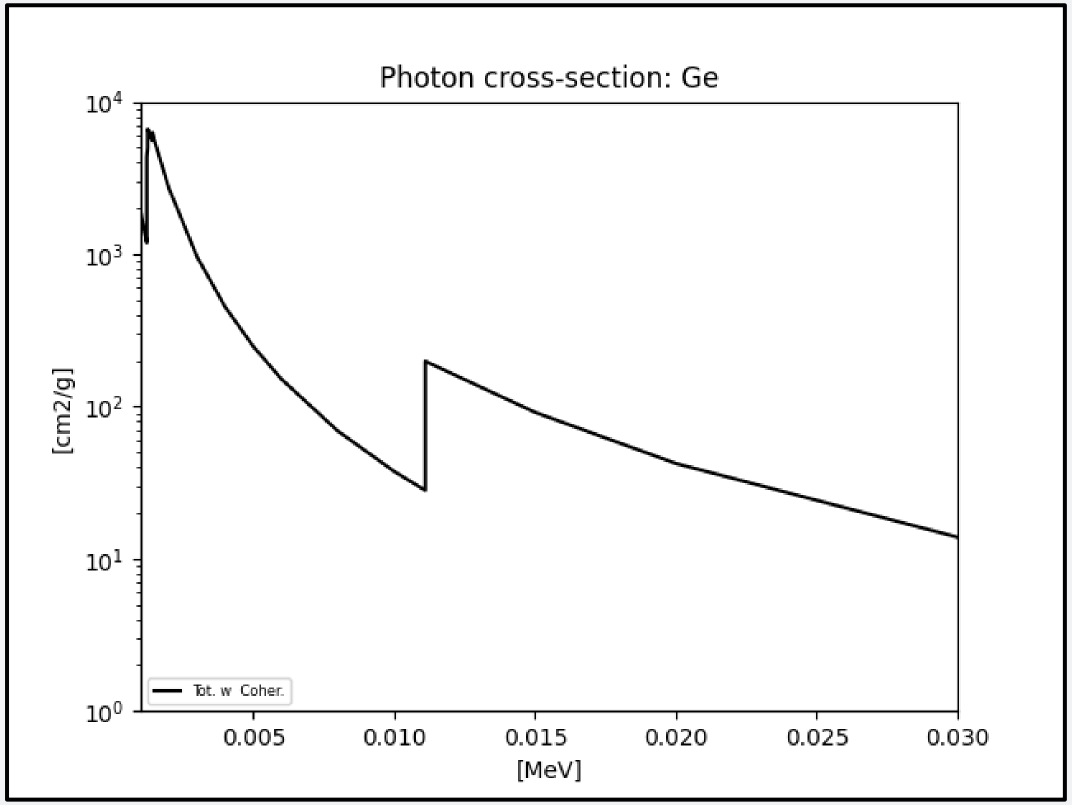
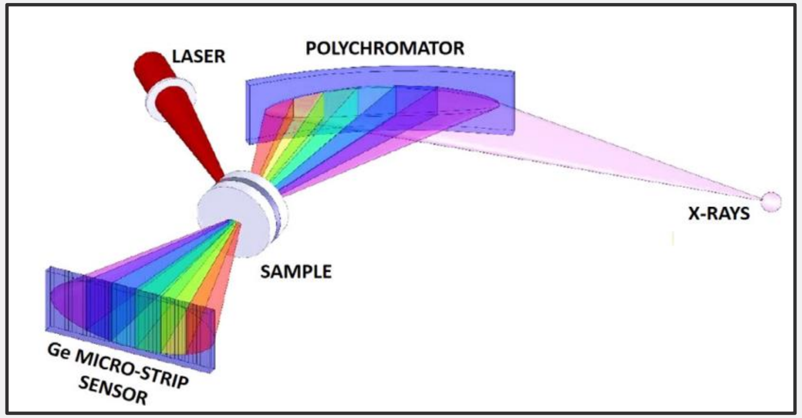
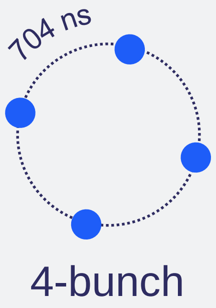
Experimental application

- At ID24, the primary energy range is: 5-27 keV
- The highest flux is expected at 7 keV with 4-bunch fill pattern: $39.6 \ast 10^6 \, \gamma$ / bunch (i.e. every 700ns, leading to $5.6 \ast 10^{13} \, \gamma$ / s total).
- Photons hit the detector over an area 50mm x 0.1mm.
- w/o sample: $\sim 1 \ast 10^{13} \, \gamma \, mm^{-2} \, s^{-1}$ are transmitted to the HPGe sensor.
- This creates a harsh radiation environment for the sensor.



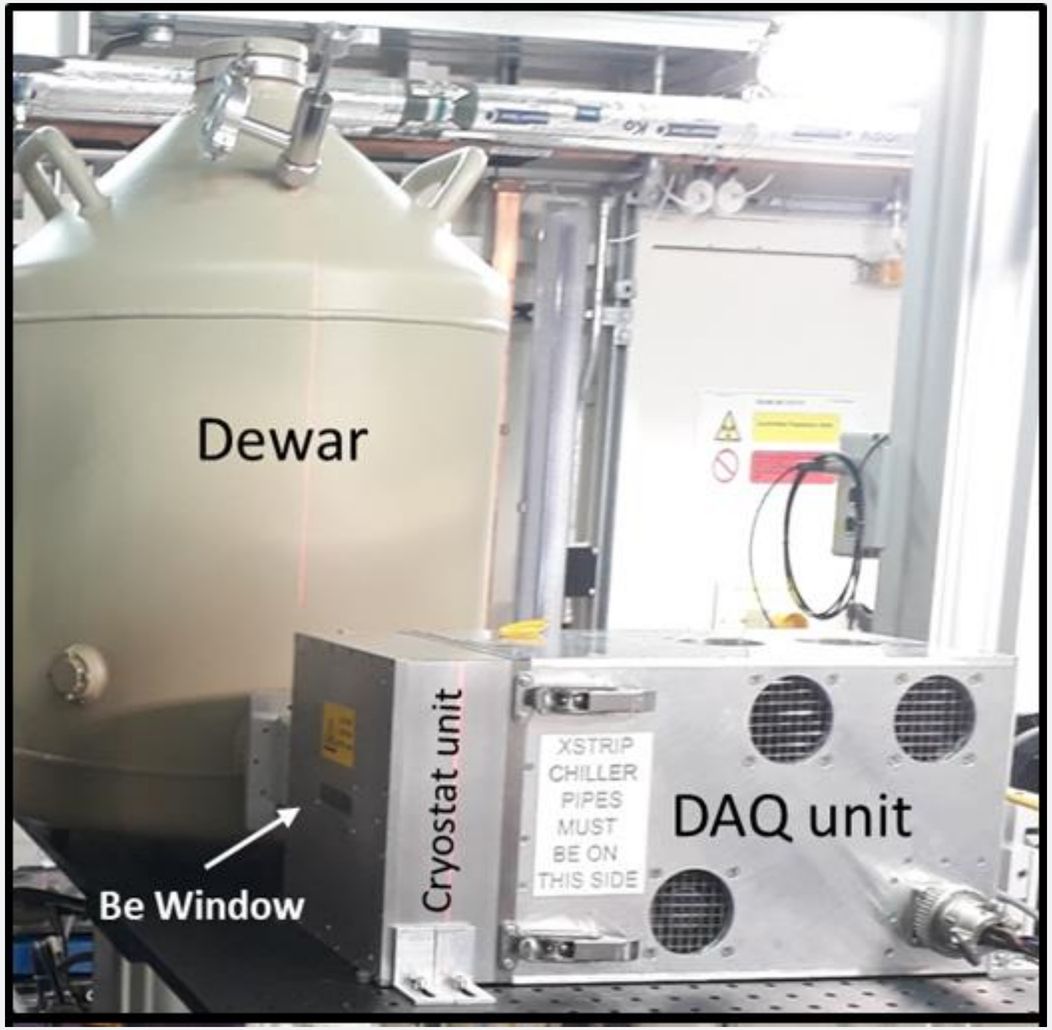




XH: cryogenic detector system

The system is made of two main units:

- the cryostat unit
- the data acquisition unit



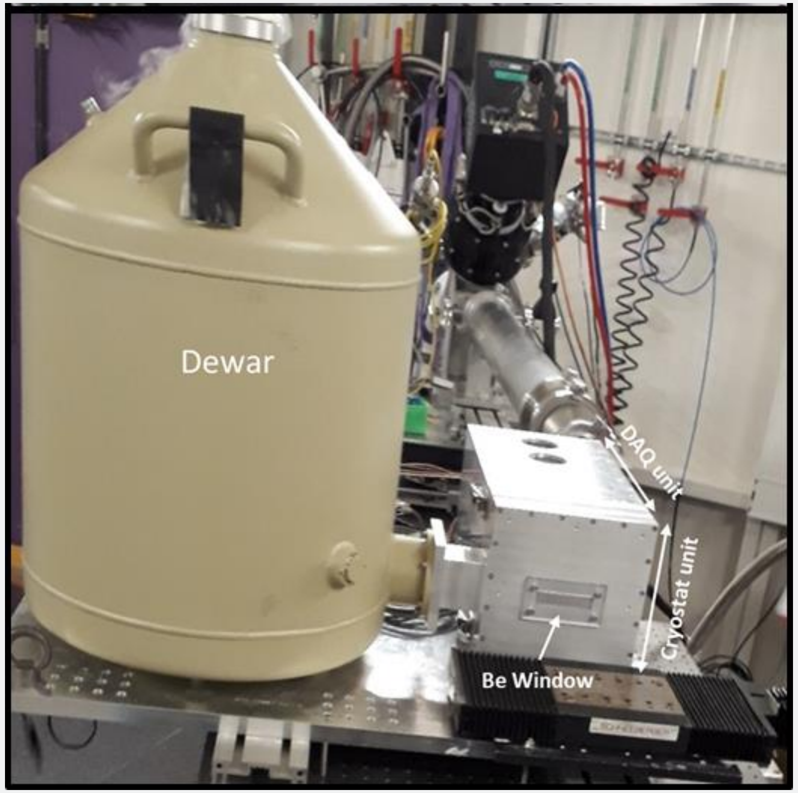
Cryostat unit

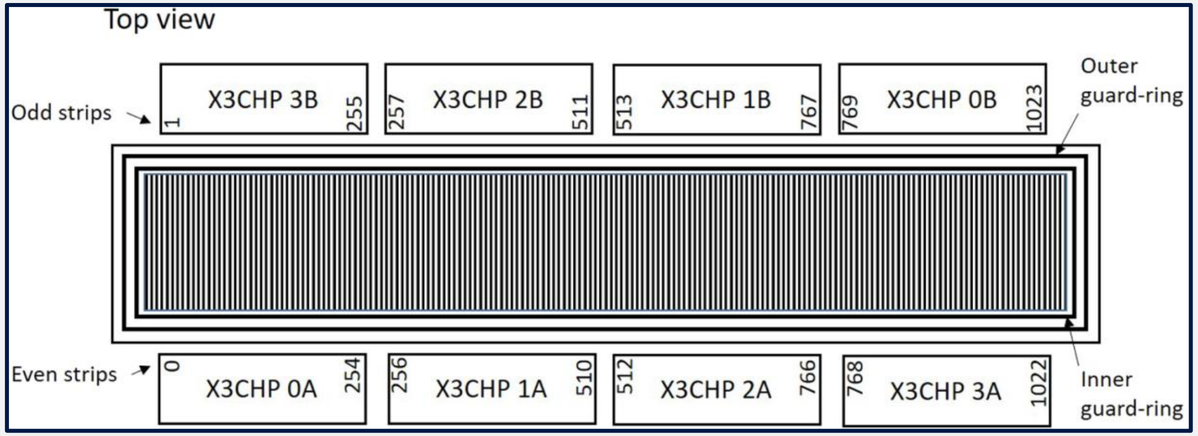
- Liquid Nitrogen (LN2) Dewar:
  - 30L, commercial off the shelve

- Detector chassis and internal cooling mechanics:
  - Custom made
  - Be window for X-rays access

- HPGe micro-strip sensor:
  - Procured from commercial supplier:
    - Mirion Technologies
  - 1024 strips, 50 µm pitch, 1.5 mm thickness

- Front-End electronics:
  - Custom made by STFC
  - X3CHIP, charge integrating
  - 128 channels/ASIC
  - Outer and Inner guard ring





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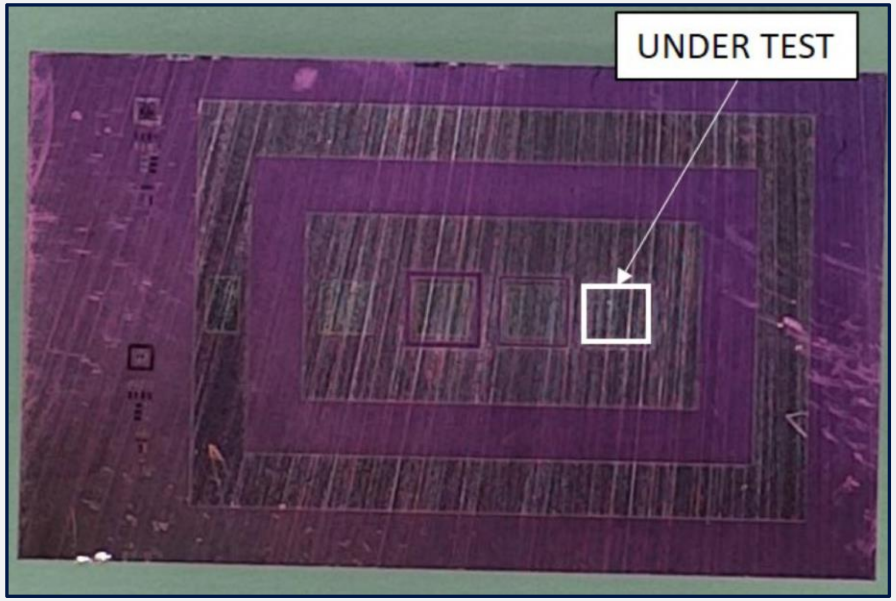
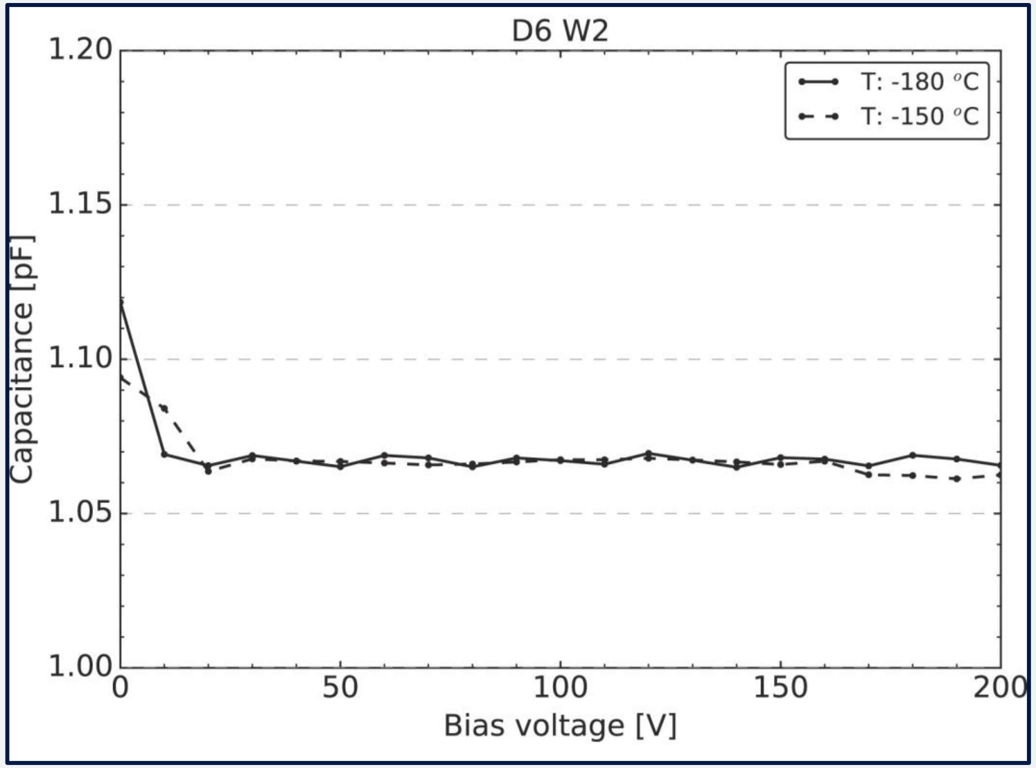
HPGe test pads



- Test structures with a similar set-up to the strip sensor were also manufactured.
- Capacitance – Voltage characteristics were assessed.
- Sensor fully depletes at ~30V at 2 representative temperatures.



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Stress tests on the cryostat unit

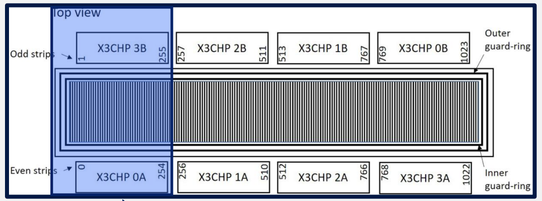
- The cryostat unit was thermally cycled 105 times.
  - Average ΔT ~ 150 °C, Max ΔT 173°C

- Sensor, electronics, interconnection were monitored at each iteration.

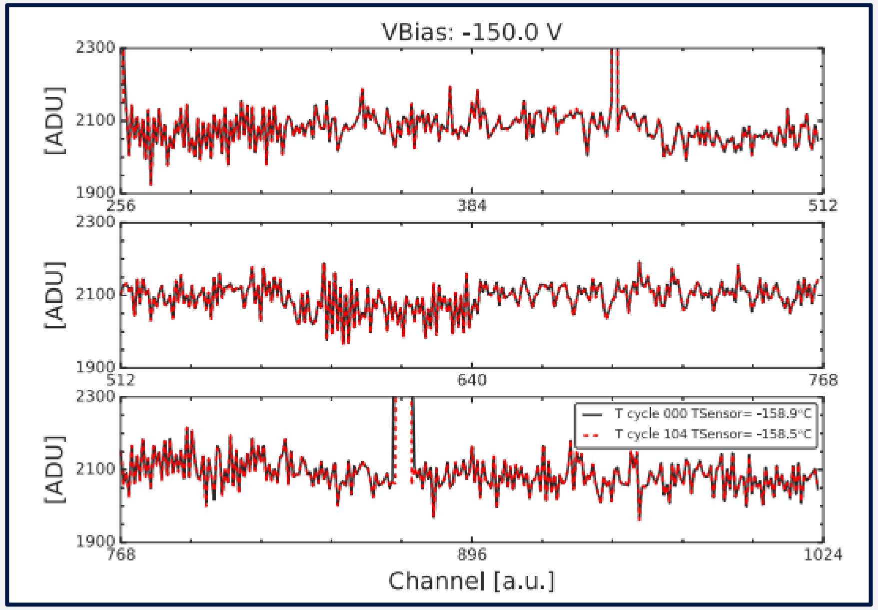
- In total, 525 IV curves were taken within 105 temperature cycles (i.e. 5 IVs/Tcycle).

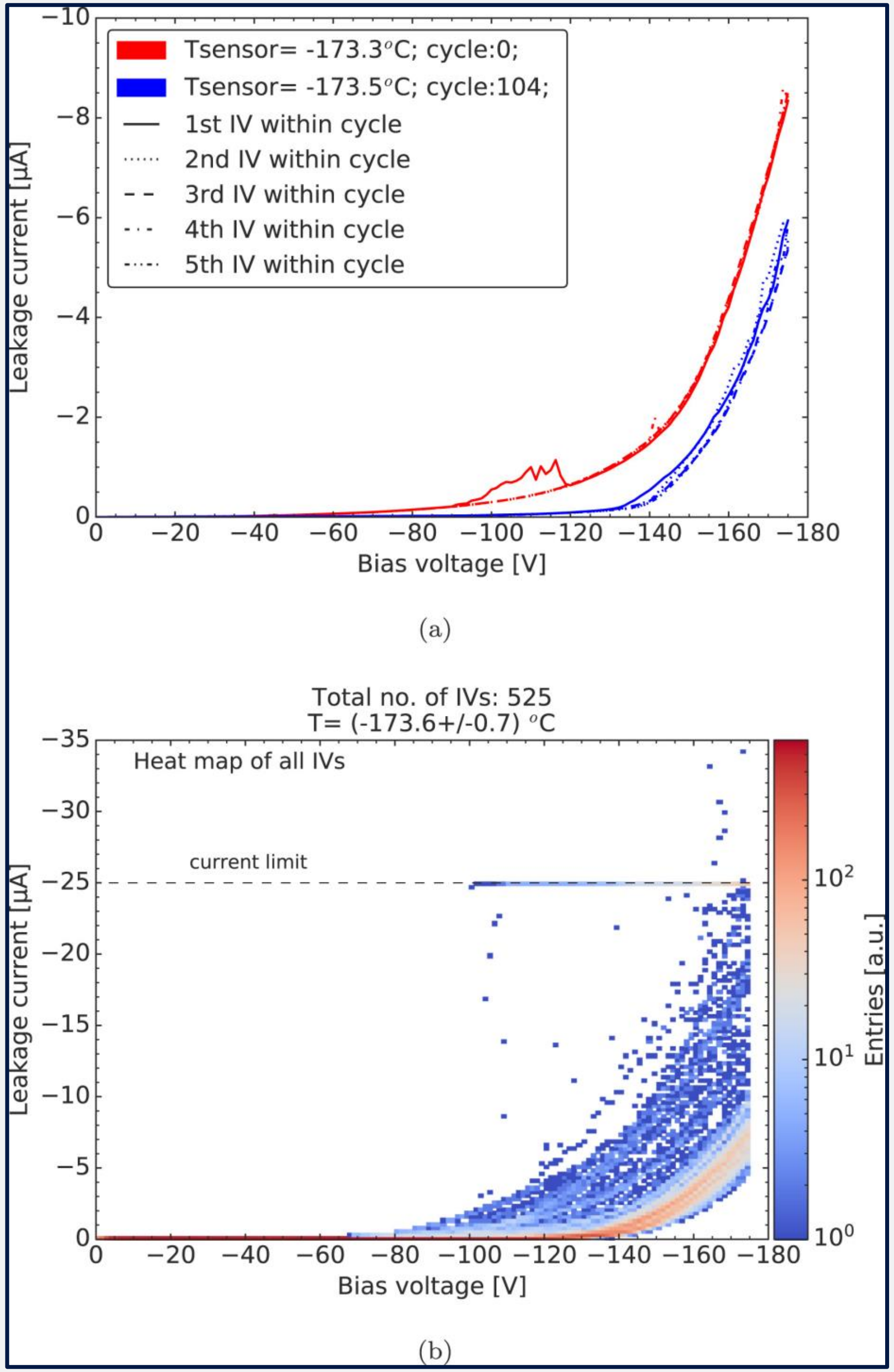
- The system was ‘baked-out’ 25 times over the period.
  - Bakeout consisted of vacuum pumping the cryostat at ~+55°C for 4 days.

- No evidence of failure detected at component of system level.
  - IVs always restored at baseline value after bakeout
  - No wire bonds detached
  - No front-end chip deteriorated



Not considered in the study, mechanically damaged.





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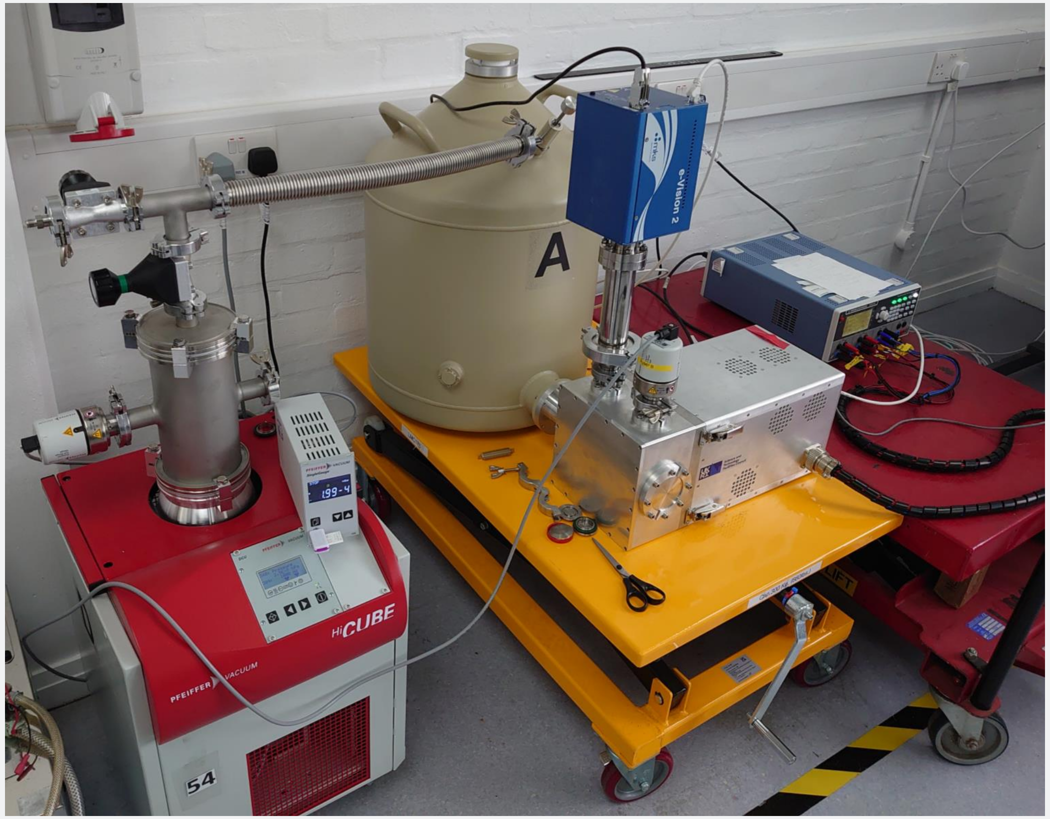
Vacuum studies on cryostat unit

- The cryostat unit houses the HPGe sensor and the front-end electronics.
- We are performing a set of measurements to characterise the vacuum deterioration inside the cryostat during long term operation.
- Investigating the interplay between the internal outgassing effects and the surface current on the sensor.
- A cryostat unit was equipped to measure vacuum.



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Experimental set-up:

Dewar

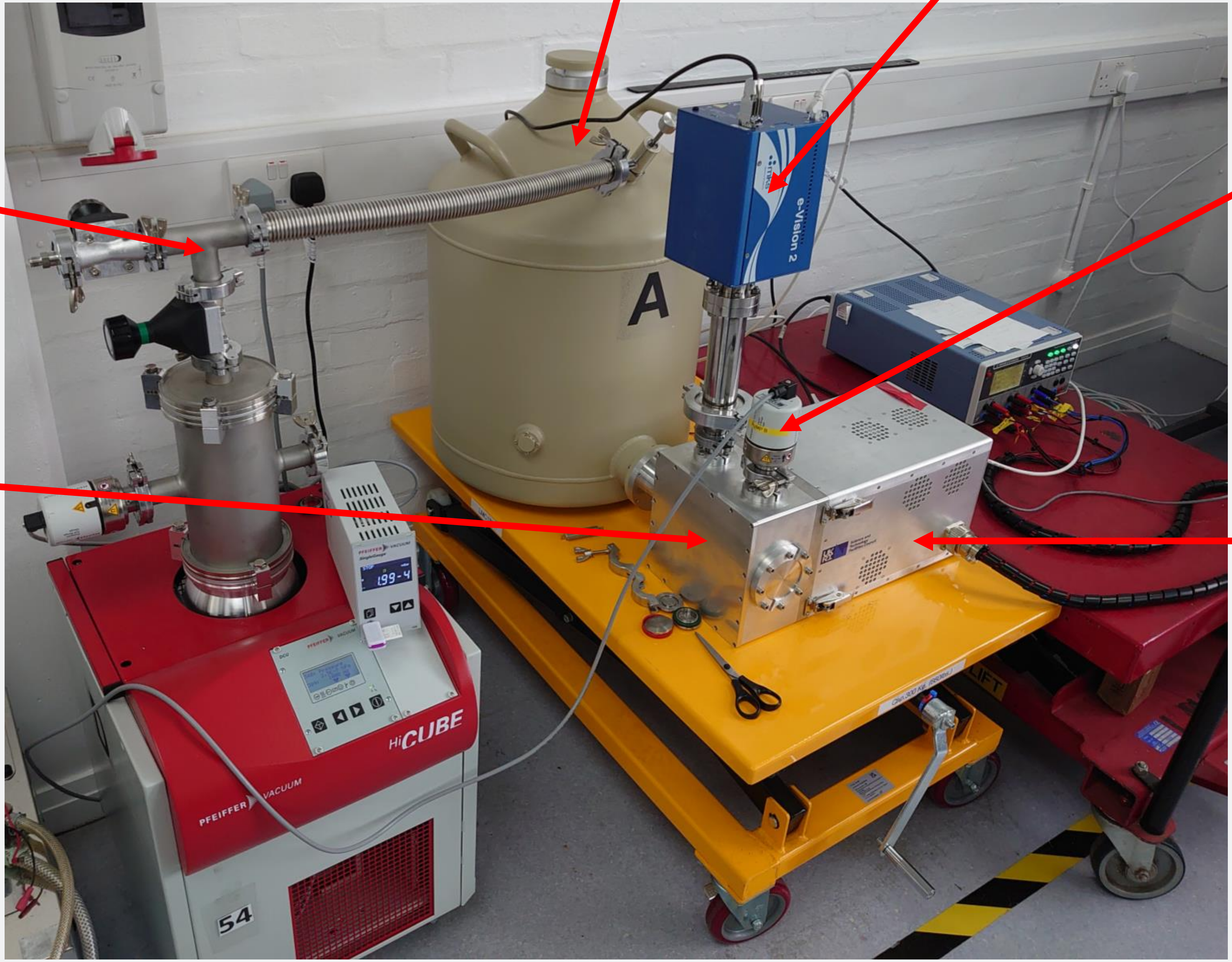
Residual Gas Analyser

Pump

Vacuum gauge

Cryostat unit

DAQ



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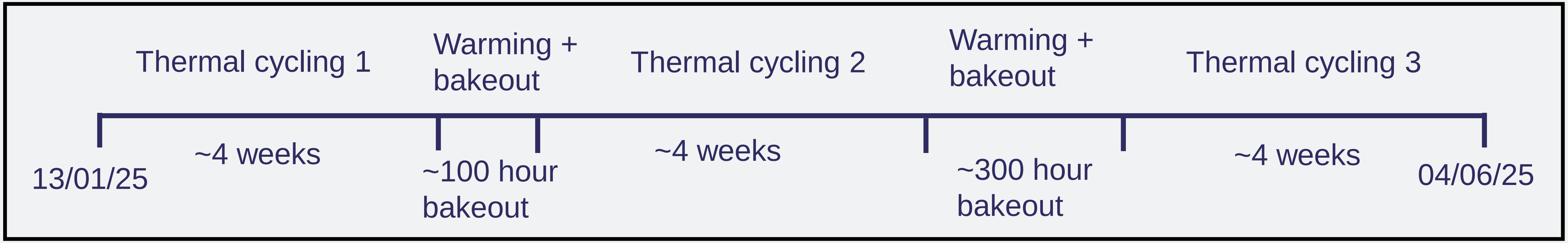
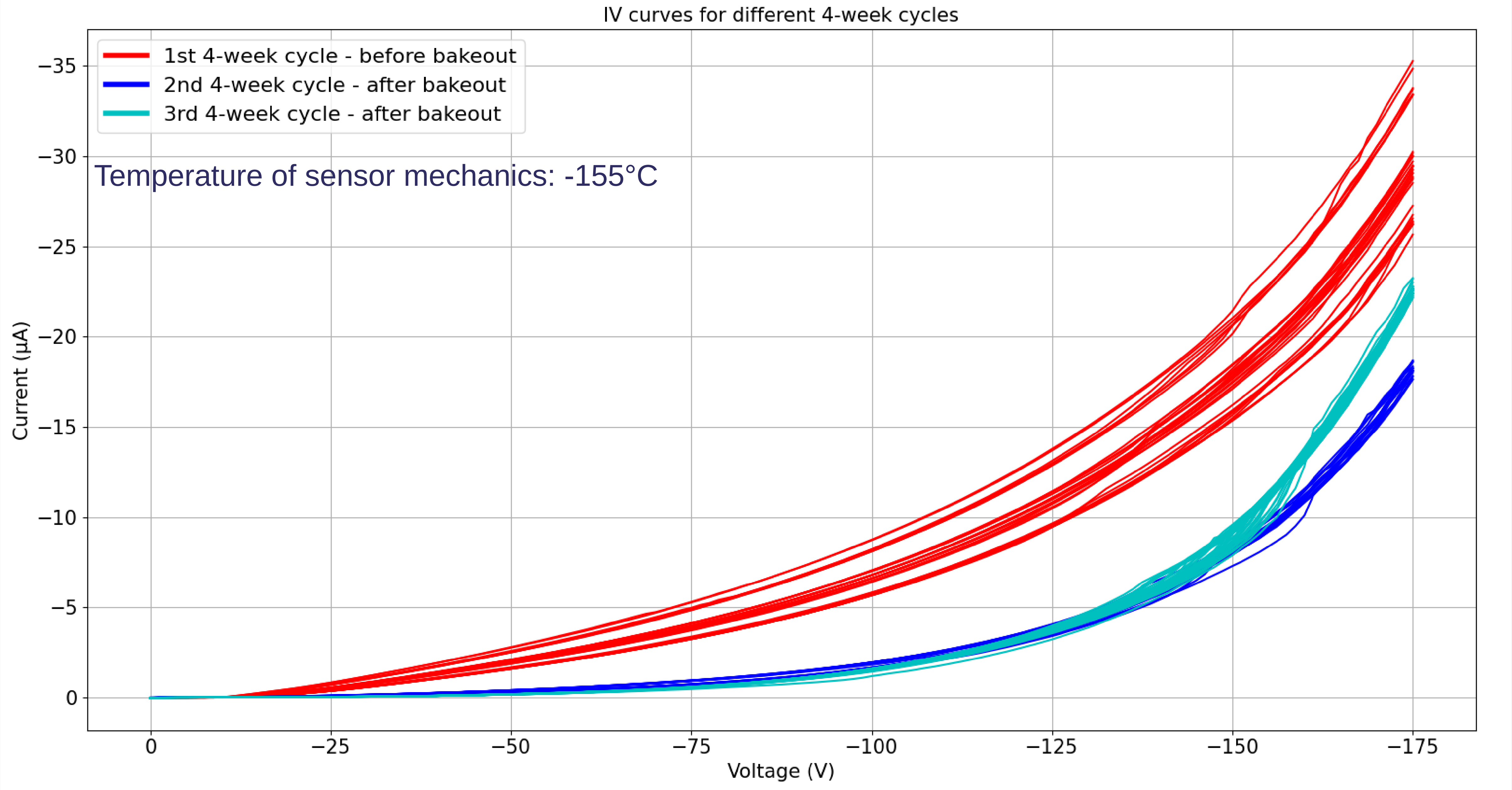
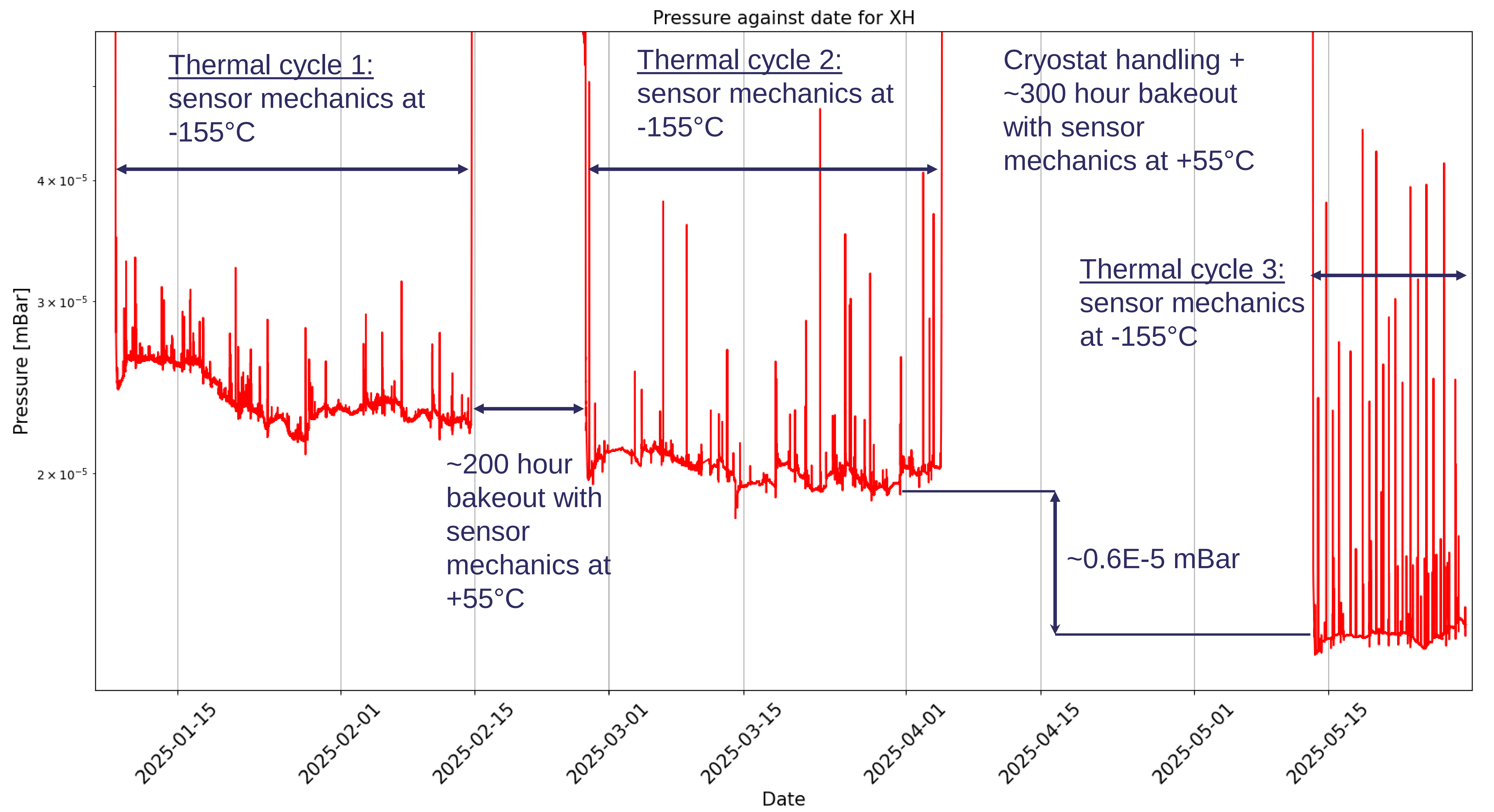
Procedure and timeline

- Applied high operational current to the headboard and heated it with a PID controller to -50°C.
- Continually took IVs, residual gas spectra and vacuum data within the ‘Thermal cycle’.
- After 4 weeks of this, perform bakeout and repeat.

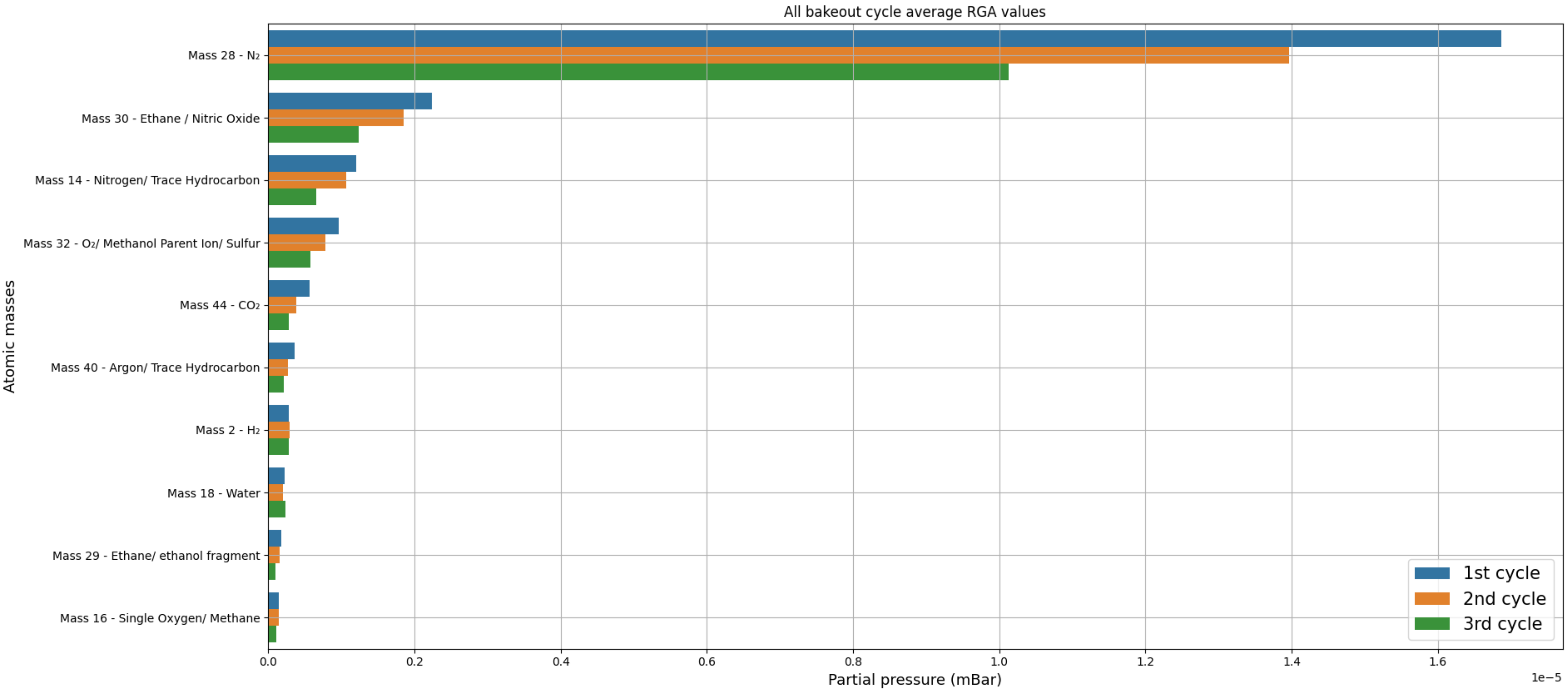


Pre and post-bakeout IV curves – at operational sensor temperature

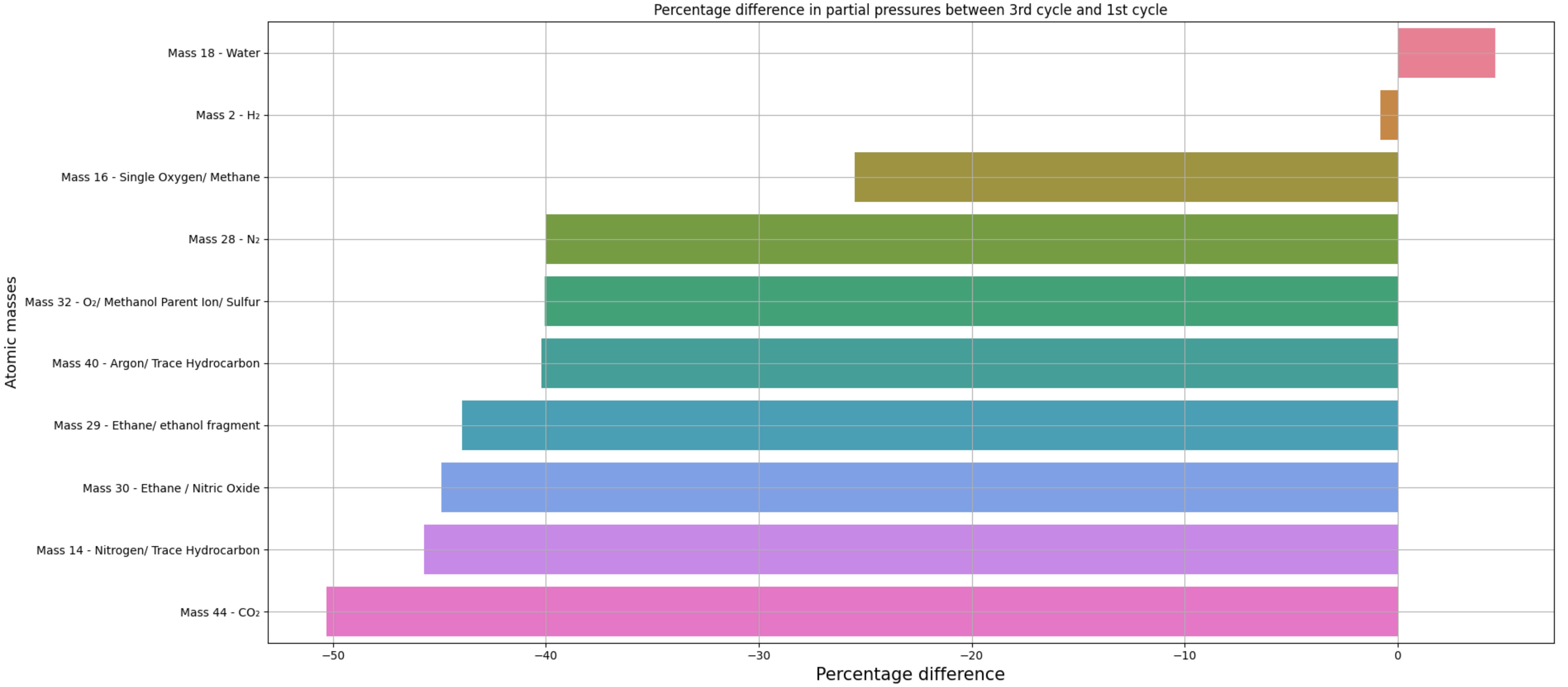



Pressure against date for XH
Thermal cycle 1:
sensor mechanics at
-155°C
Thermal cycle 2:
sensor mechanics at
-155°C
Cryostat handling +
~300 hour bakeout
with sensor
mechanics at +55°C
Thermal cycle 3:
sensor mechanics
at -155°C
~200 hour
bakeout with
sensor
mechanics at
+55°C
~0.6E-5 mBar
4×10^{-5}
3×10^{-5}
2×10^{-5}
Pressure [mBar]
2025-01-15
2025-02-01
2025-02-15
2025-03-01
2025-03-15
2025-04-01
2025-04-15
2025-05-01
2025-05-15
Date

Residual Gas Spectra – Thermal cycle 1 and 3 averaged RGA values



Residual Gas Spectra – Percentage difference between thermal cycle 1 and 3 averaged RGA values



Future studies - irradiations

- The XH cryostat has been fitted with a beryllium window.
- Daresbury Laboratory has an X-ray irradiation chamber which will be used to assess how the vacuum, residual gases and leakage current of the XH system perform under constant irradiation.
- Irradiating at 20 keV and 20 mA for prolonged periods
- Higher flux may be required at the ESRF.

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Summary

- XH is a HPGe microstrip sensor used for Energy Dispersive X-ray spectroscopy.
- Installed at the ESRF HPLF beamline analysing extreme states of matter - operated in a radiation harsh environment.
- The XH system was thermally cycled many times and remained consistent.
- Bakeouts have a direct impact on detector leakage current and cryostat vacuum level.
- Future research will assess radiation induced contamination of the sensor surface.

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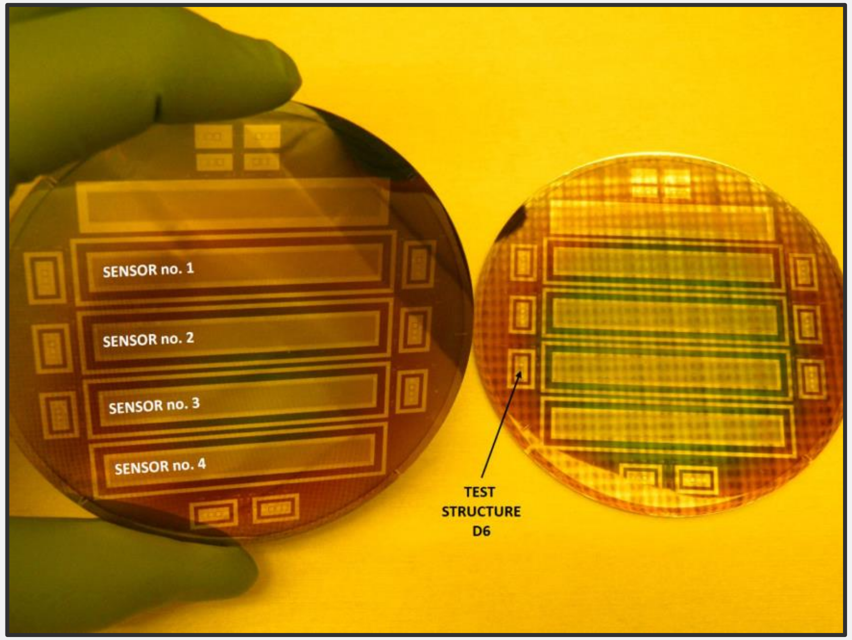
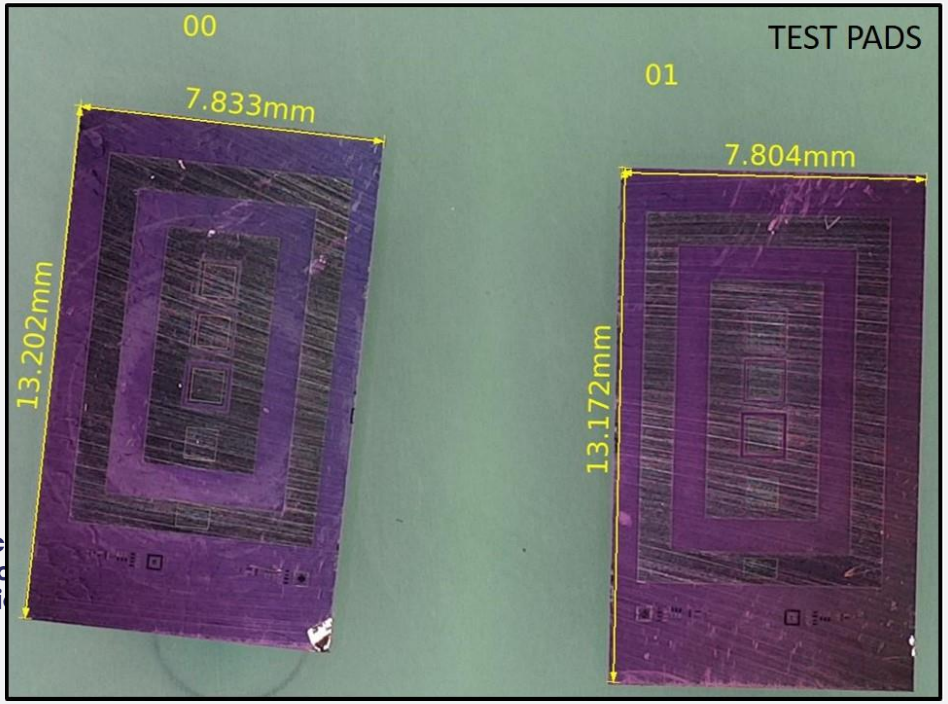
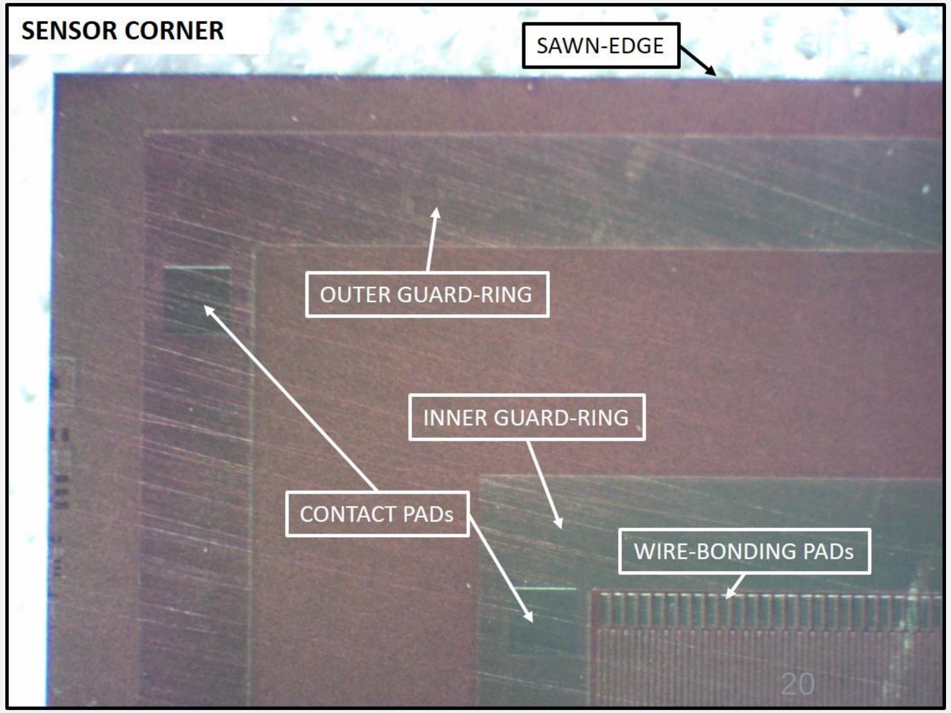
Back-up

HPGe micro-strip sensor

- 90 mm diameter wafers manufactured by Mirion Technologies
- Size: 1024 strips
- Strip pitch: 50 um with 20um gap
- Strip length: 5mm
- Sensor thickness: 1.5mm
- Two guard-rings
- Interleaved wire-bonding pads
- Back illuminated







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QC on cryostat unit: production version

- We perform a series of quality control measurements on cryostat units to validate the performance of the unit.
- IV characteristics:
  - 10 IVs back-to-back up 200V
  - 24hrs apart i.e. before after burn-in test
- Leakage current burn-in test:
  - 24 hrs at 200V
- Temperature Vs Pwr:
  - Sensor temperature <-170 C @ ~12W front end power (i.e head-boards)
- Visible light response:
  - Basic response test via an LED installed inside the cryostat