Optimisation of ^{6}Li-coated Silicon Detectors for Thermal Neutrons

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Funding: STFC CASE studentship

Outline

- STFC CASE studentship: partnership with Micron Semiconductor Ltd.
  - Existing partnership: LHCb VELO, ATLAS ITk
- Building upon work of previous PhD students
  - A. Omar (2018), M. Alsulimane (2023)

- Introduction and principles
- Simulations in Geant4
- Laboratory work
- Next steps

Neutron detection

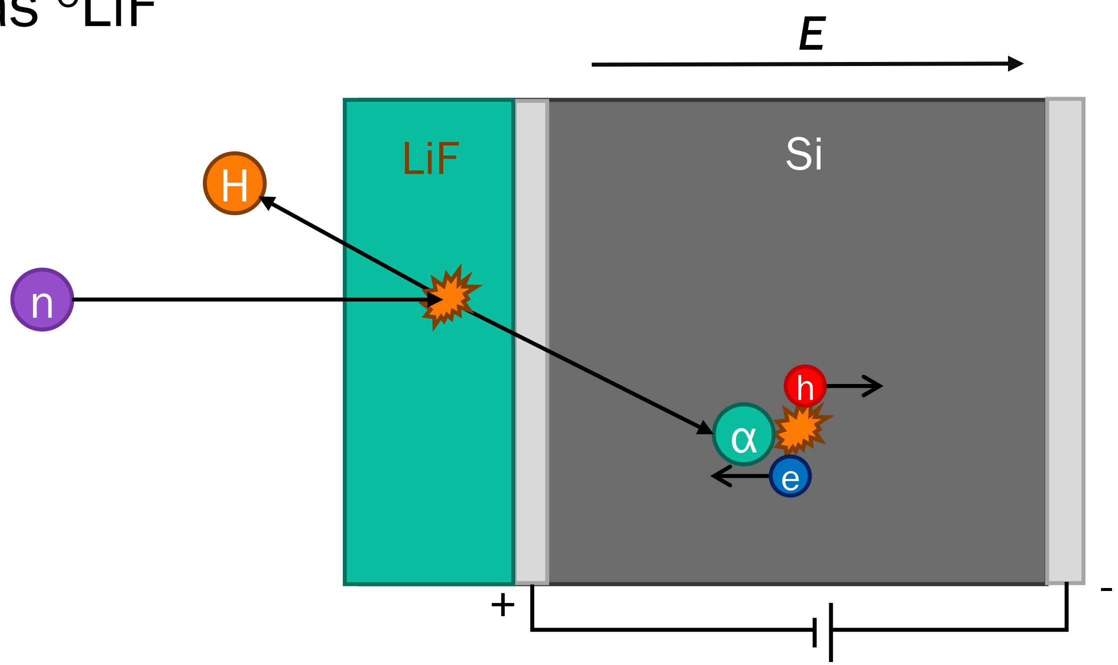
- Specialised detectors are required to detect neutrons
  - At room temperature, thermal equilibrium at ~0.025 eV -> “thermal” neutrons
  - Many applications: nuclear power, dark matter, medical…

- ^3He counters usually best for smaller applications
  - ^3He scarcity – problems for future usage

- Can silicon be used?
  - Insensitive to neutrons
  - Solution: coat with a neutron reactive converter

Converter layers

- Lithium-6 has a high neutron reaction cross section (~943 barn, thermal)
- Upon neutron capture:
  - $^{6}Li + n_{th} \rightarrow {}^{3}H(2.73MeV) + \alpha(2.05MeV)$
- Alpha and triton carry the energy – these are detected in the silicon
- ^{6}Li “stabilised” as ^{6}LiF

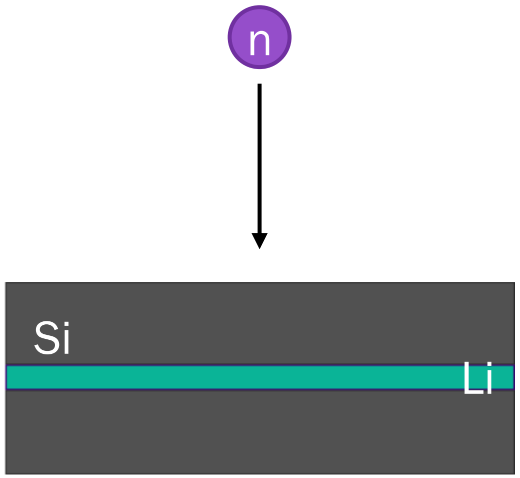


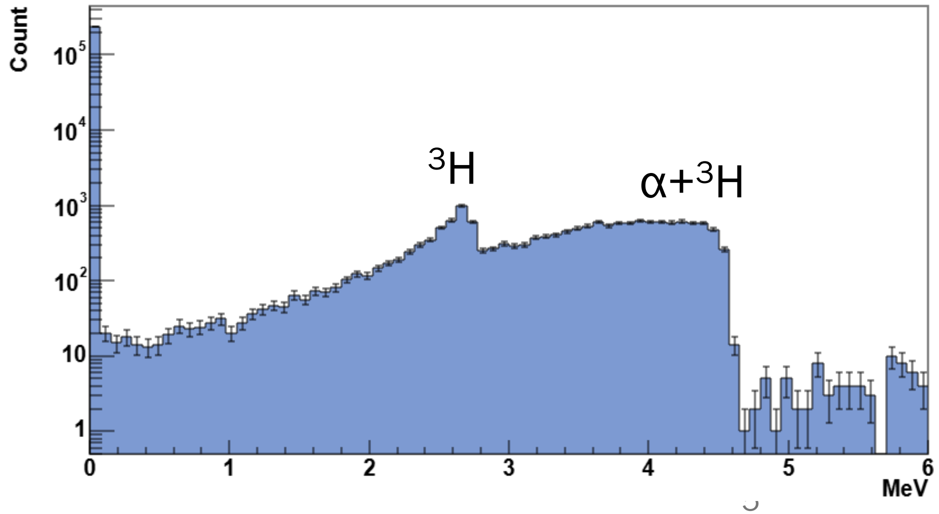
Geant4 simulation

- Geant4 used to simulate and optimise detectors
- Single layer of ^{6}LiF-coated Si

- Perfect beam of thermal neutrons generated
  - Measure energy deposition in Si per event (neutron + products)

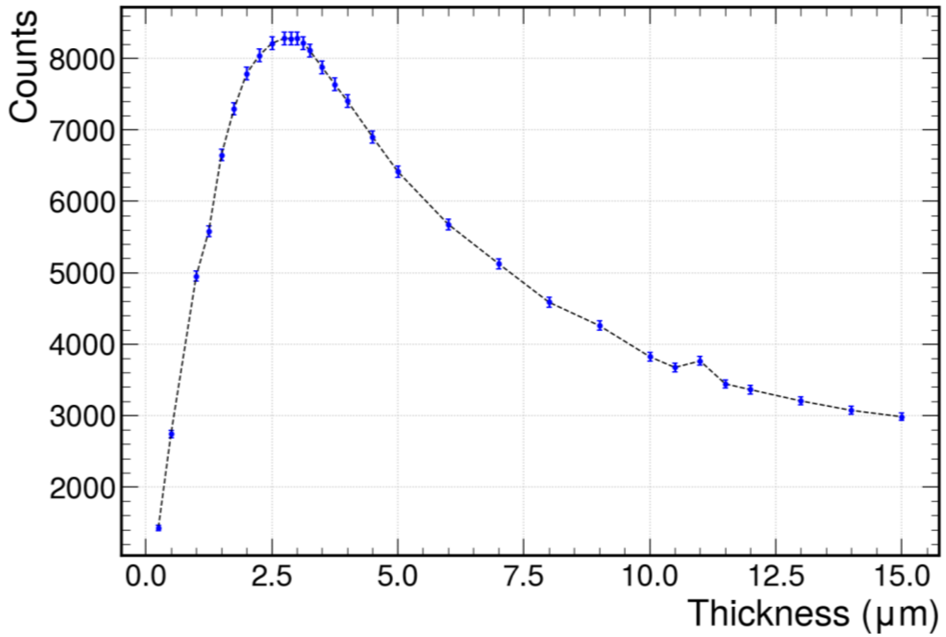
- "Sandwich" detectors currently implemented
  - Both products detected – gamma discrimination





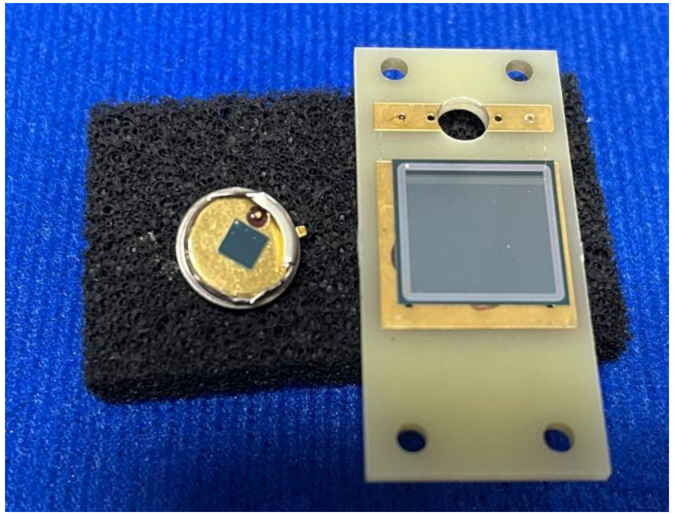
Geometry optimisation

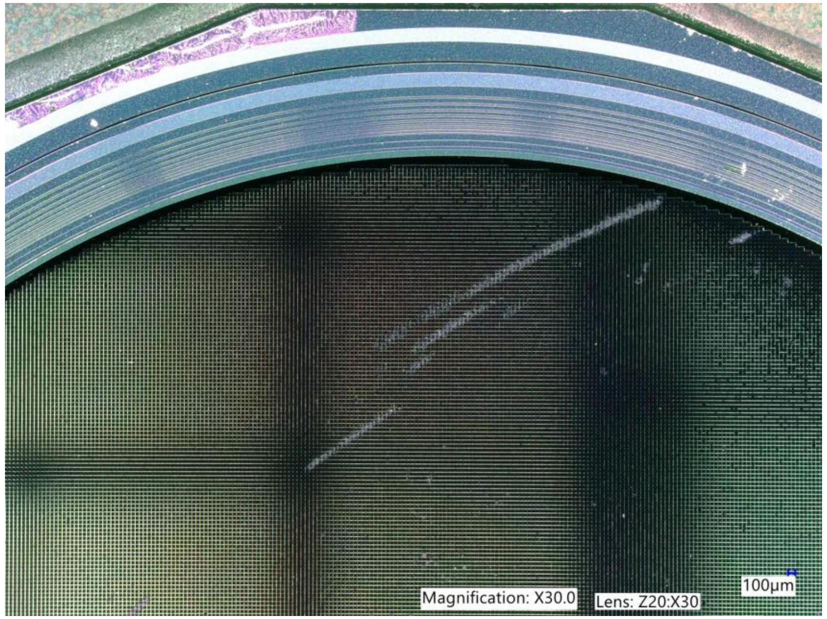
- Ideally: LiF only captures neutrons, Si captures all $^3H + \alpha$
  - Thicker LiF layer = more neutron captures
  - But also more $^3H + \alpha$ stopped…
- Must optimise layer thicknesses
  - For LiF sandwich: 3 µm of LiF optimal (coincidence)
  - Si thickness less important
- Trenched detectors
  - Maximise LiF/Si contact surface
  - Trade-off for coincidences
  - Manufacturing constraints too – contact Micron



Diode testing

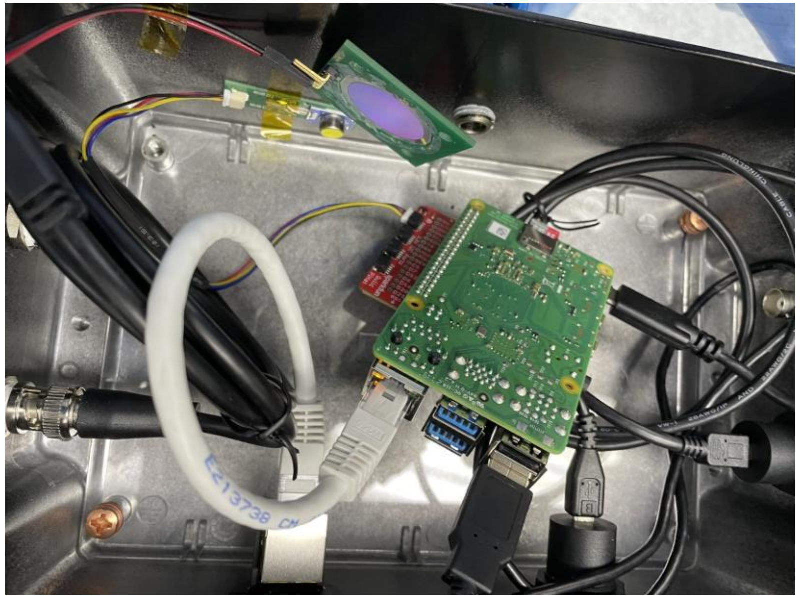
- Diodes available: BPX 61, CERN 1cm^2, Micron MSD024
  - All MSD024 coated and trenched
- 3 steps to testing:
  - IV characterisation – provide some performance info for the diode
  - Readout testing – configure DAQ/digitiser, calibrate energy
  - Neutron testing – self explanatory

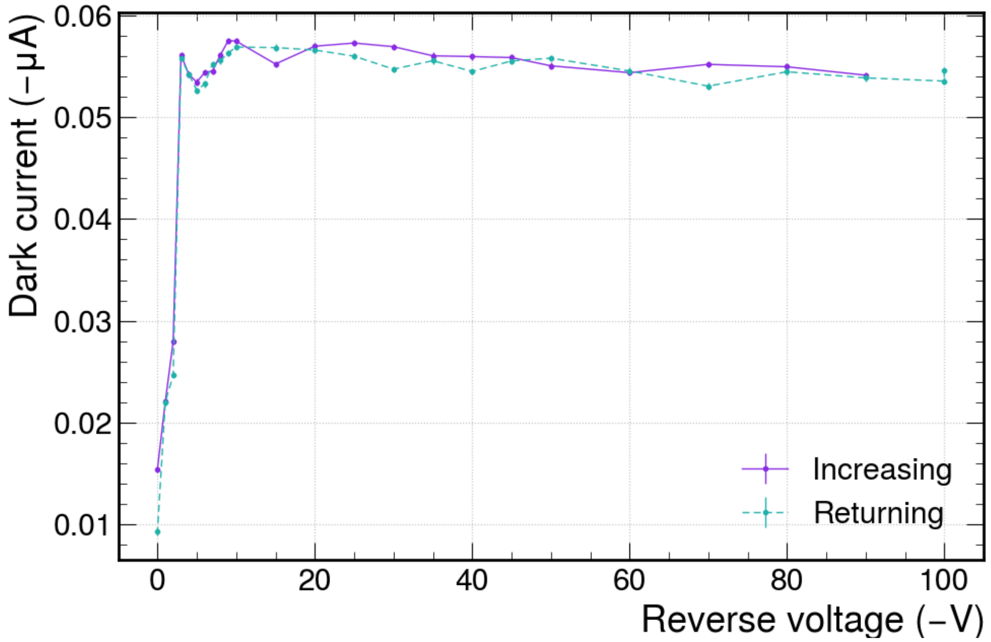




IV characterisation

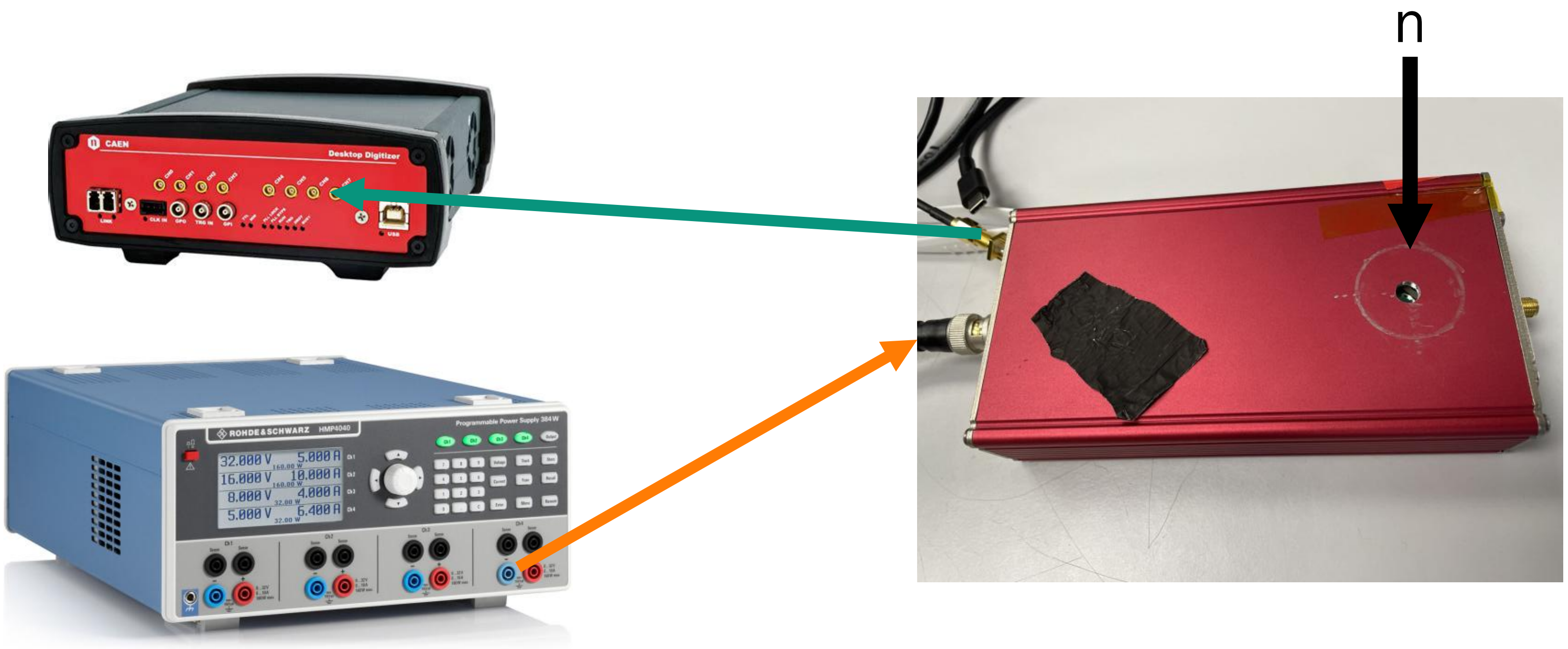
- 5x coated MSD024 in stock. Measure current-voltage (IV) curves
- Raspberry Pi setup as a controller, connected to power supply
- Environmental data measured in addition to IV

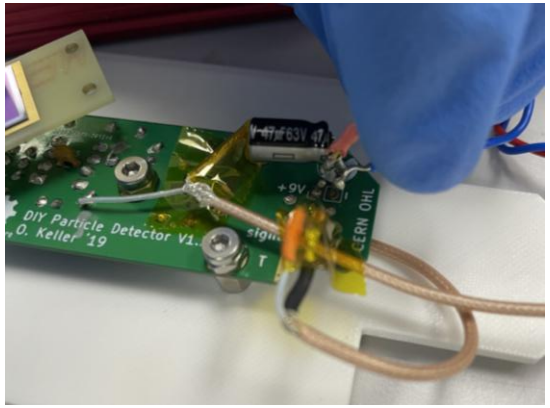




Readout/DAQ

- TLE2072-based board used for amplification and shaping
  - No bias; uses built-in voltage for now
- CAEN DT5730S digitiser
- Calibrate with triple-alpha source





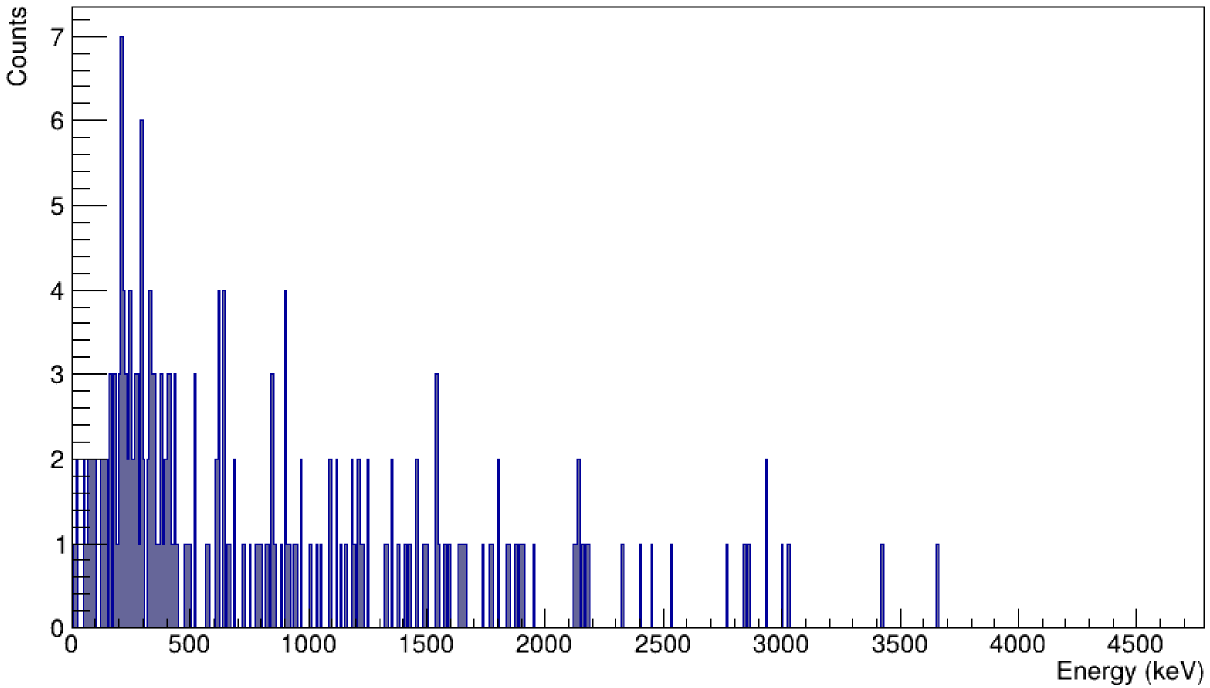
(not to scale)

Neutron testing

- CTL neutron source to be used
  - 370 MBq americium-beryllium (AmBe) source
- Only one measurement performed so far; CTL availability

- Coated BPX 61 used, 7000 seconds
  - Low rate: only 468 events. Small diode
  - No visible peaks >2 MeV; inconclusive

- Next: run with both coated and uncoated
  - Characterise background



Next steps

- Simulation improvements:
  - Model trenched detectors in Geant4
  - Implement a real neutron source

- Hardware improvements:
  - Implement a bias voltage
  - Take more neutron measurements (CTL depending…)
  - Packaging: current readout system is rather crude

- Technology readiness level (TRL) – currently around 4, aim for 5/6

- Visit Micron in the future

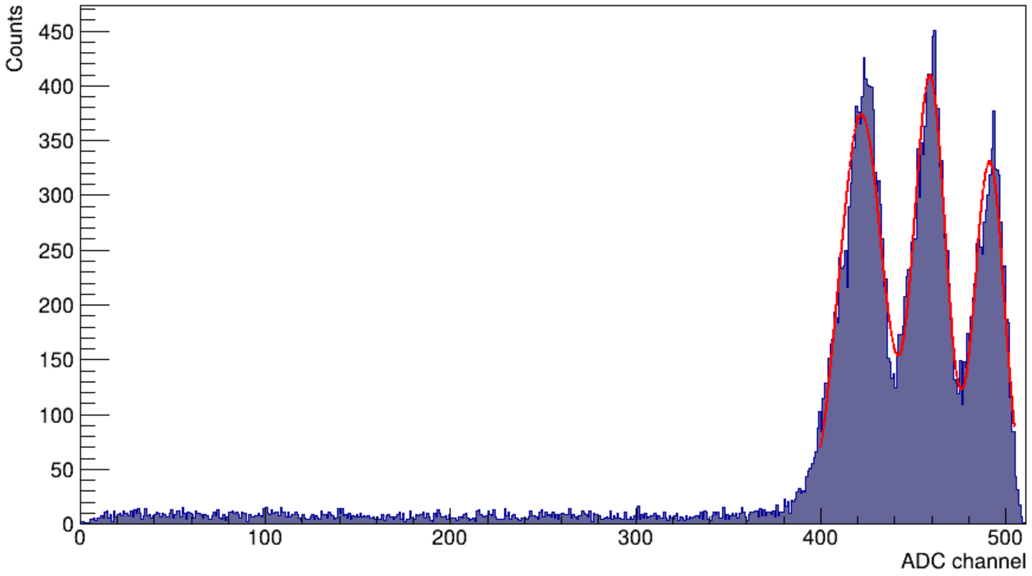
Any questions?

BACKUP

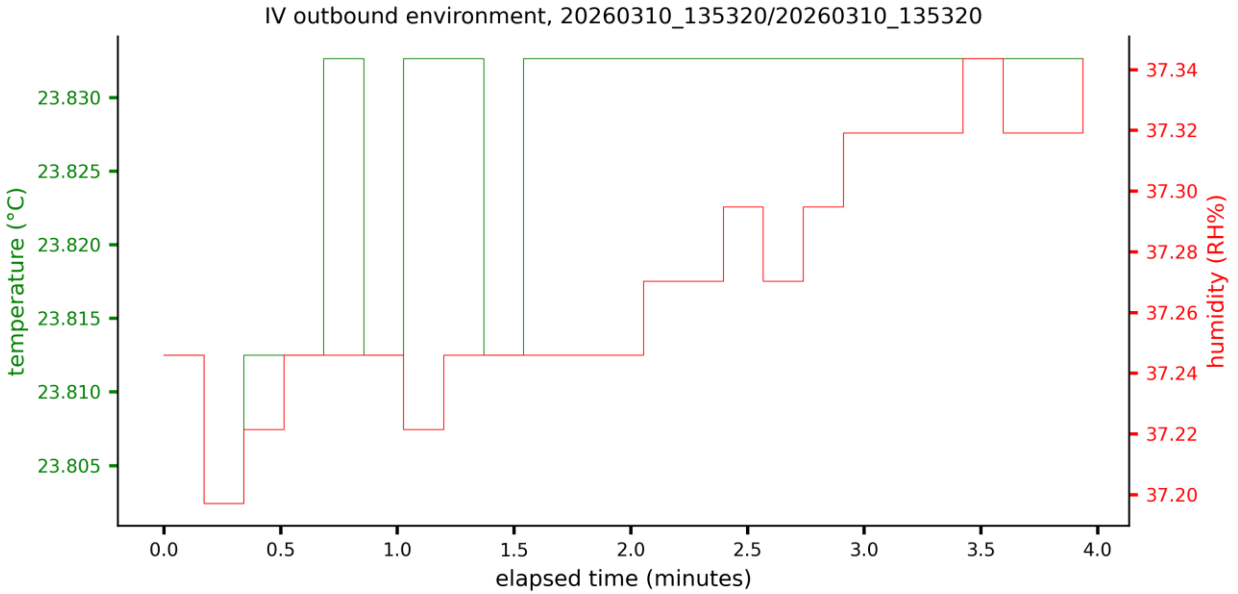
Calibration

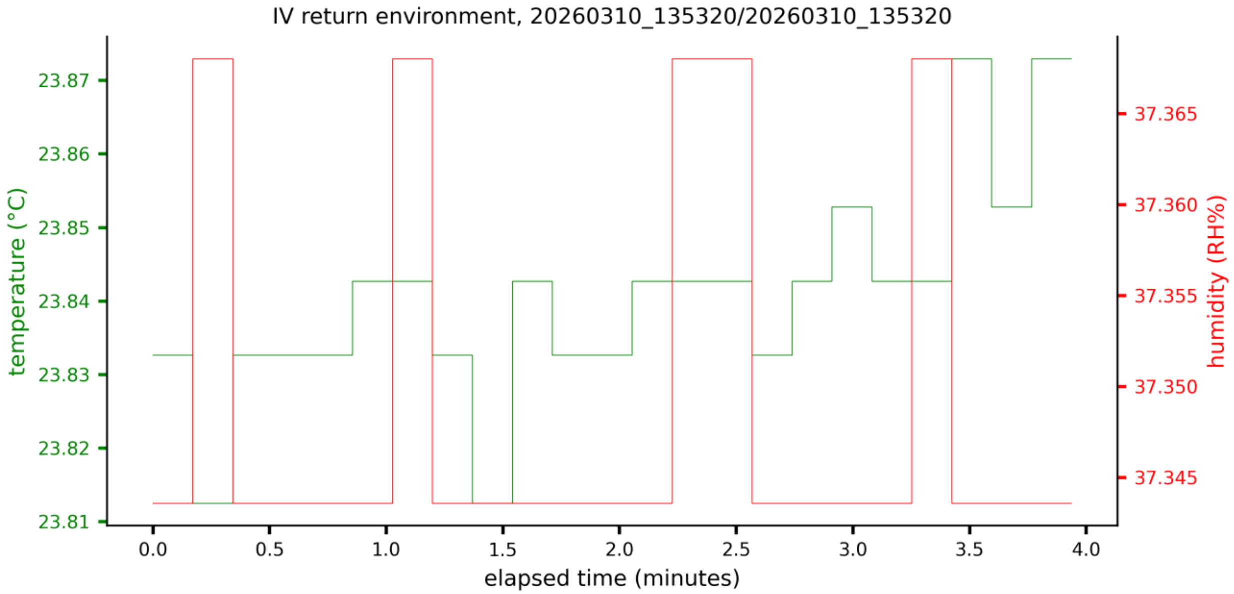
- Triple-alpha source ($^{239}Pu/^{241}Am/^{244}Cm$) used to calibrate energies
  - 3 peaks visible: fit their means (ADC channel) against “true” energies
  - Alphas lose energy in air/SiO_2; assume energy loss is linear
  - Assume y-intercept is dominated by energy loss of alphas

- BPX61 calibration: m = (9.40 ± 0.32) keV/ADC



Environmental data for 3312-2-4





Detecting Neutrons

- Various methods exist for neutron detection:
  - Calorimeters – dense material; elastic/inelastic scattering
    - Bulky; only suitable for larger experiments, and faster neutrons
  - Scintillators (usually gadolinium-doped) – photons
    - Poor background gamma discrimination
  - Gas counters (usually ^{3}He,$^{10}BF_3$, or other n-reactive material) – “indirect ionisation”
    - The best option for thermal neutrons? But, ^{3}He is scarce and $^{10}BF_3$ is toxic