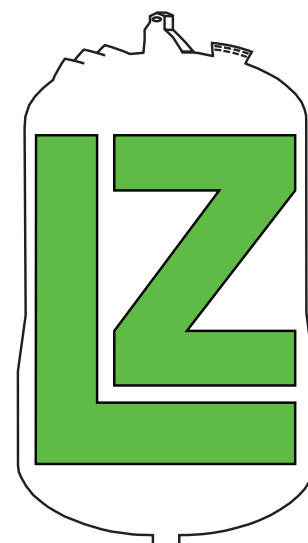


Constraining Environmental Backgrounds for Rare Event Searches with LZ



THE UNIVERSITY
of EDINBURGH



Ellie Bishop

on behalf of the LUX-ZEPLIN Collaboration

Identification of Dark Matter

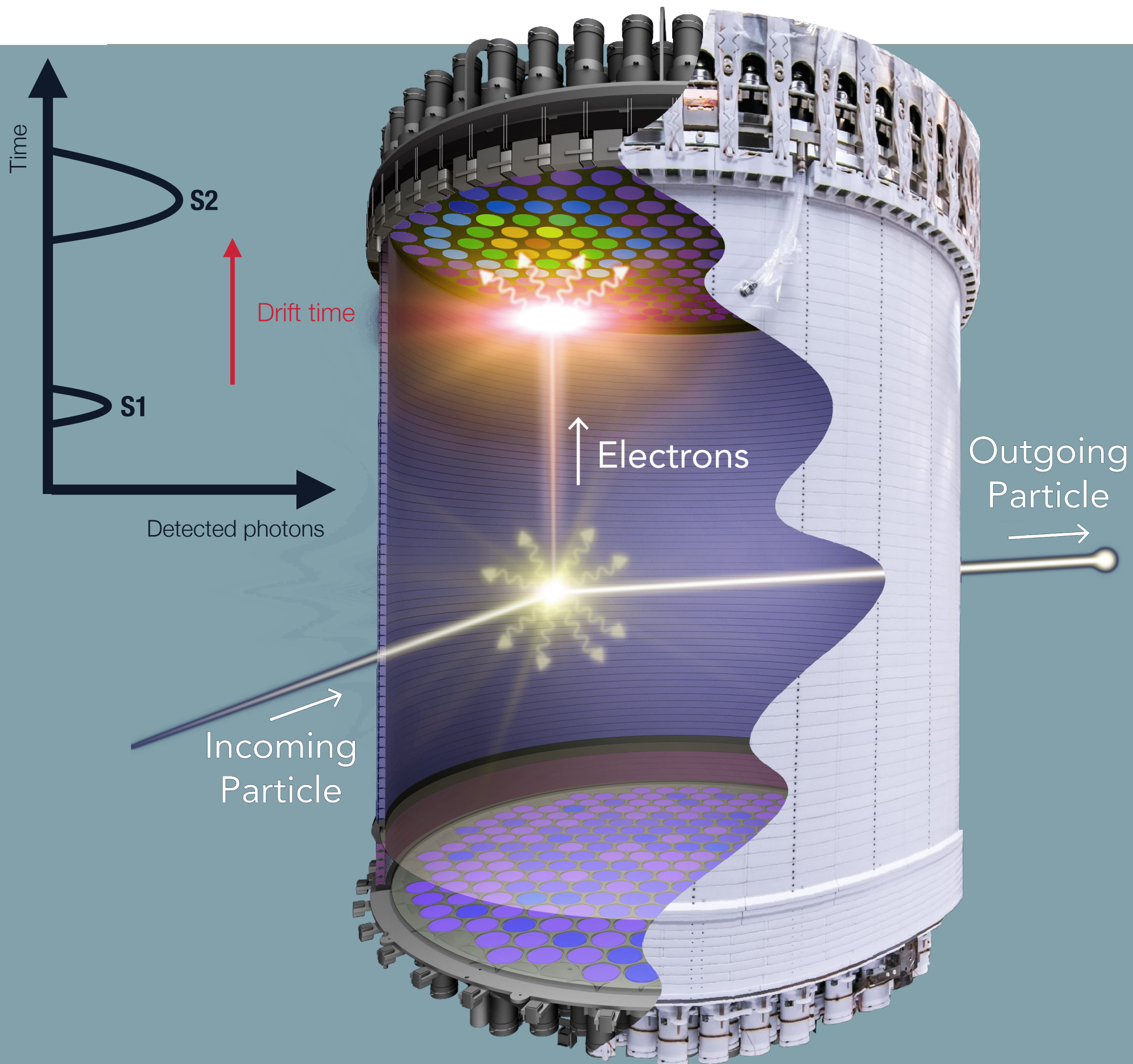
2nd June 2026

The **LUX-ZEPLIN** Experiment



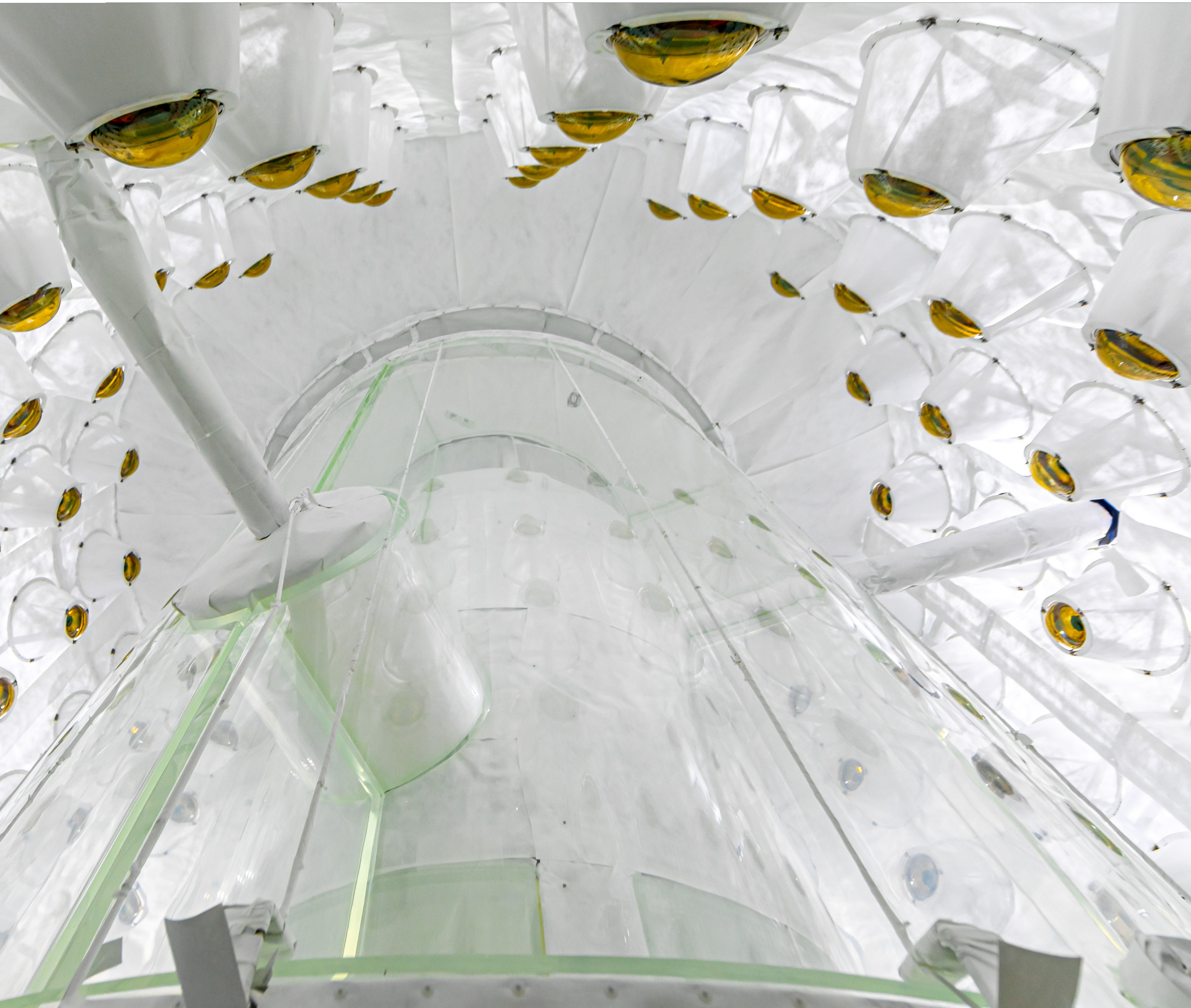
- **Aim:** Direct detection of dark matter via scattering with the liquid xenon (LXe) target
- **Location:** 4,850 feet underground at the Sanford Underground Research Facility (SURF) in South Dakota, USA
- **Detector:** 7 tonne dual-phase xenon time projection chamber (TPC) surrounded by two active vetoes
 - Skin: 2 tonnes of LXe
 - Outer Detector (OD): 17 tonnes of Gd loaded liquid scintillator
- **Signals:** S1 - prompt scintillation
S2 - electroluminescence

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The Outer Detector (OD)



- **Neutron veto** - crucial to the WIMP search
- 17t of **GdLS** - liquid scintillator loaded with 0.1 % gadolinium
 - Neutron capture signal is 3-5 γ s with ~ 8 MeV between them
- Above 200 keV **environmental backgrounds** are dominant



A vertical cross-section of a neutron star, showing its internal layers. The layers are labeled from top to bottom: Crust, Outer Core, Inner Core, and Quark Core. The Crust is the outermost layer, followed by the Outer Core, then the Inner Core, and finally the Quark Core at the center. A purple dot labeled μ is located in the Crust layer, with a purple arrow pointing upwards. A red dot labeled n is located in the Outer Core layer, with a red arrow pointing downwards. A blue wavy arrow labeled γ is located in the Inner Core layer, pointing to the right. A green circle labeled R_n is located in the Quark Core layer, pointing to the right.

- Rn

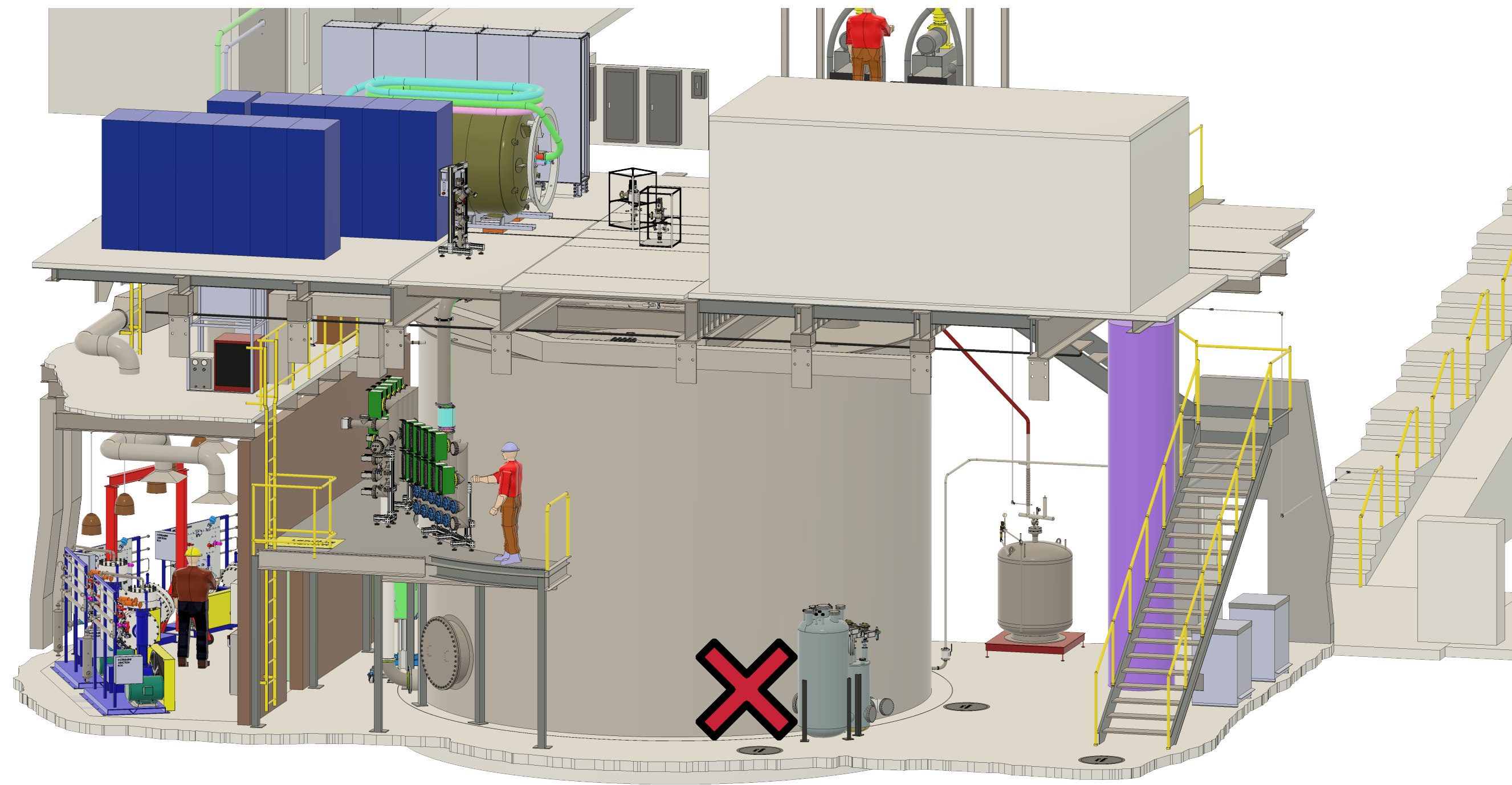


The Environmental Monitoring Station

- The EMS measures three key cavern backgrounds:

Neutron rate, **gamma** spectrum and **radon** concentration

- Installed at SURF April-May 2024
- Located just outside LZ's water tank



EMS: Motivation

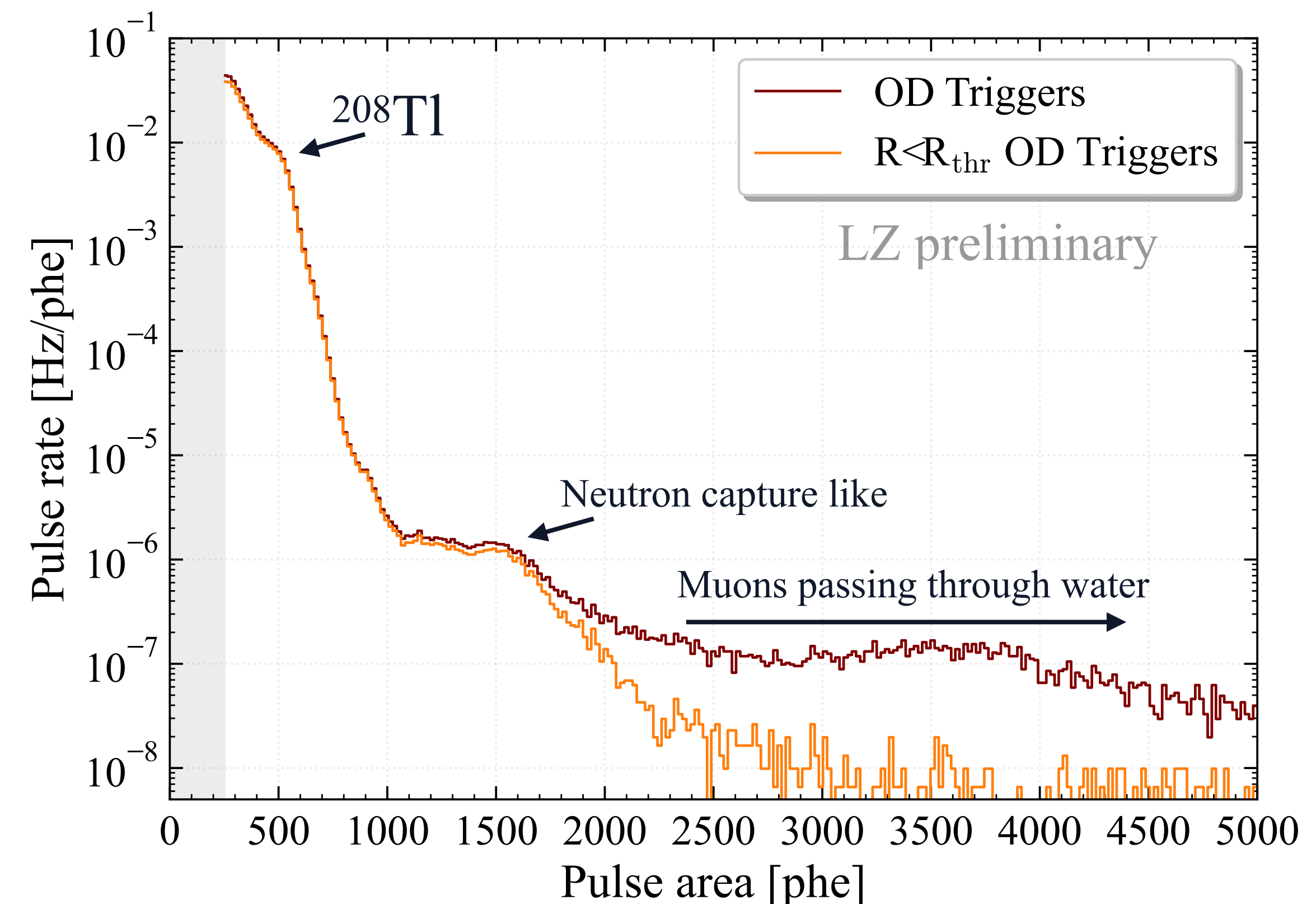
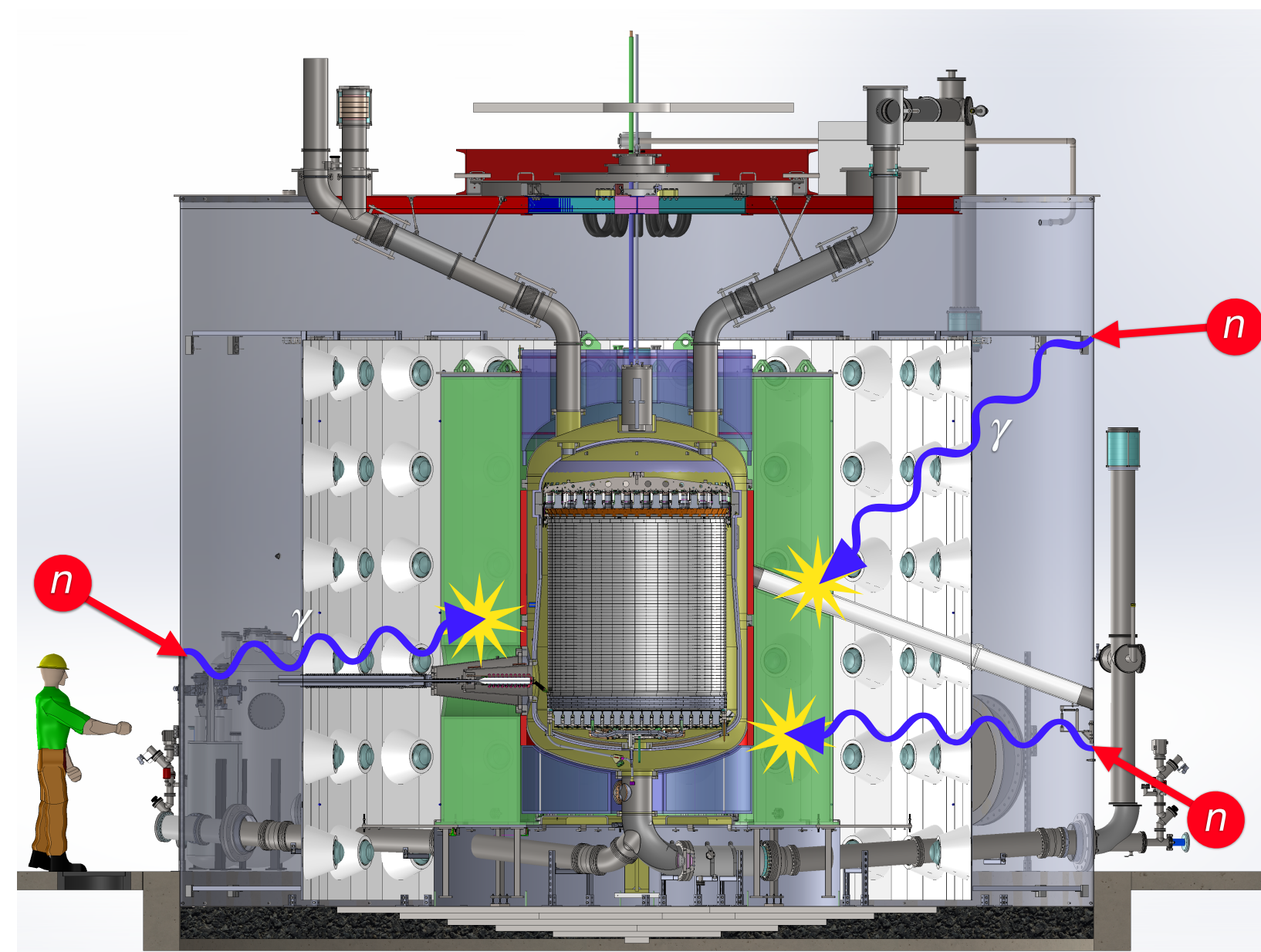
- **Long term monitoring** of cavern conditions
- **Live monitoring** of cavern conditions
- Enabling early response to changes in cavern conditions:
 - Ventilation
 - Radioactive source deployment



EMS: Motivation

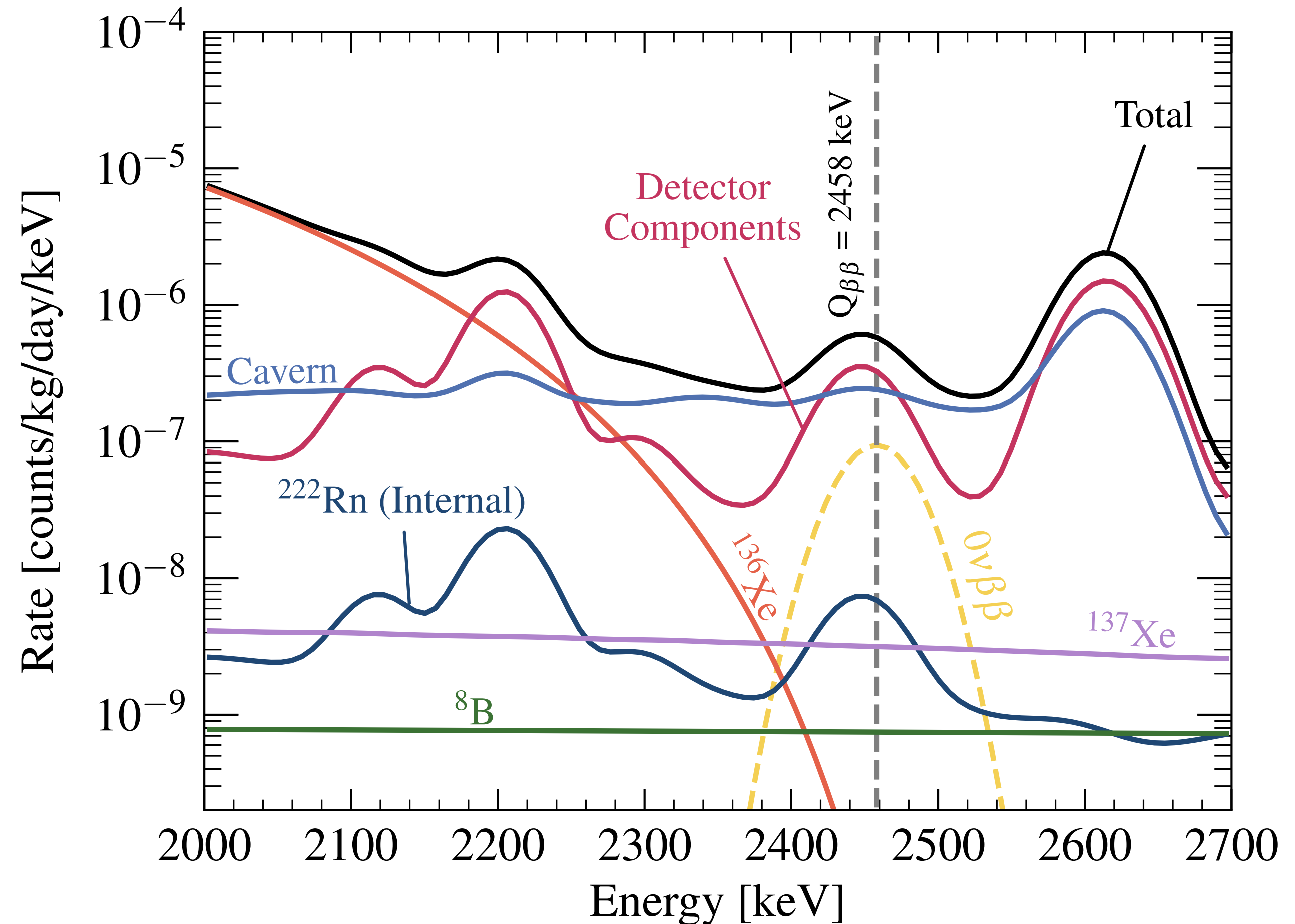
- Constrain **external neutron rate**
- External neutrons capture on elements in **steel** of water tank
- Resulting energetic gammas reach the OD and mask measurement of **internal neutron rate**

Isotope	$Q_{n,\gamma}$ (MeV)
^{157}Gd	7.94
^{155}Gd	8.53
^{56}Fe	7.65
^{50}Cr	9.26
^{52}Cr	7.54
^{58}Ni	9



EMS: Motivation

- Constrain cavern gamma background for $0\nu\beta\beta$ search
- **Major background** around the ^{136}Xe Q-value
- High-energy cavern γ -rays fall into the signal region
- Th-chain: ^{208}Tl (2615 keV)
- U-chain: ^{214}Bi (2448 keV)



LZ, 2020, Phys. Rev. C 102, 014602

EMS: Design Breakdown

a) **BF₃** enclosure

b) **NaI** enclosure

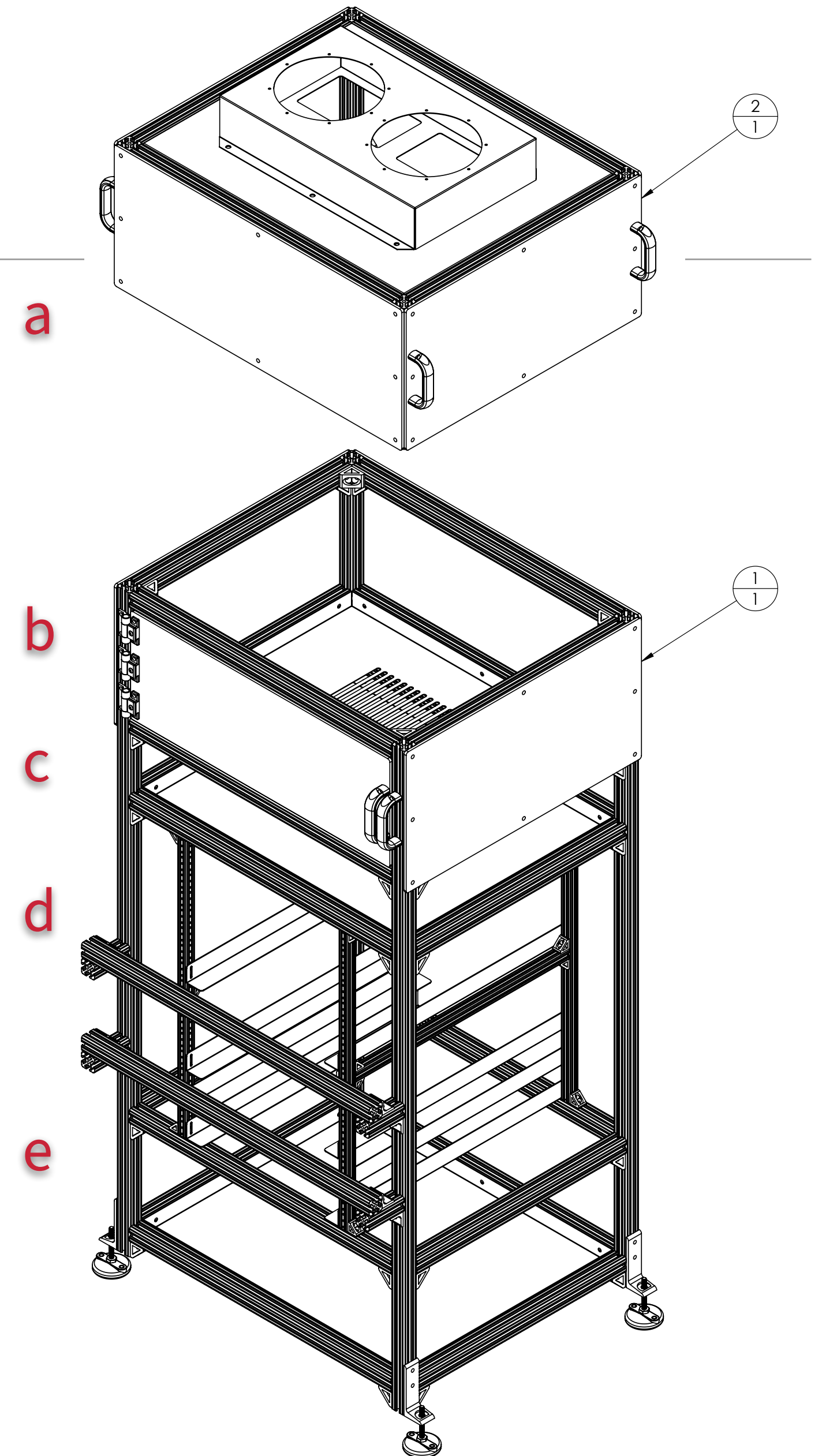
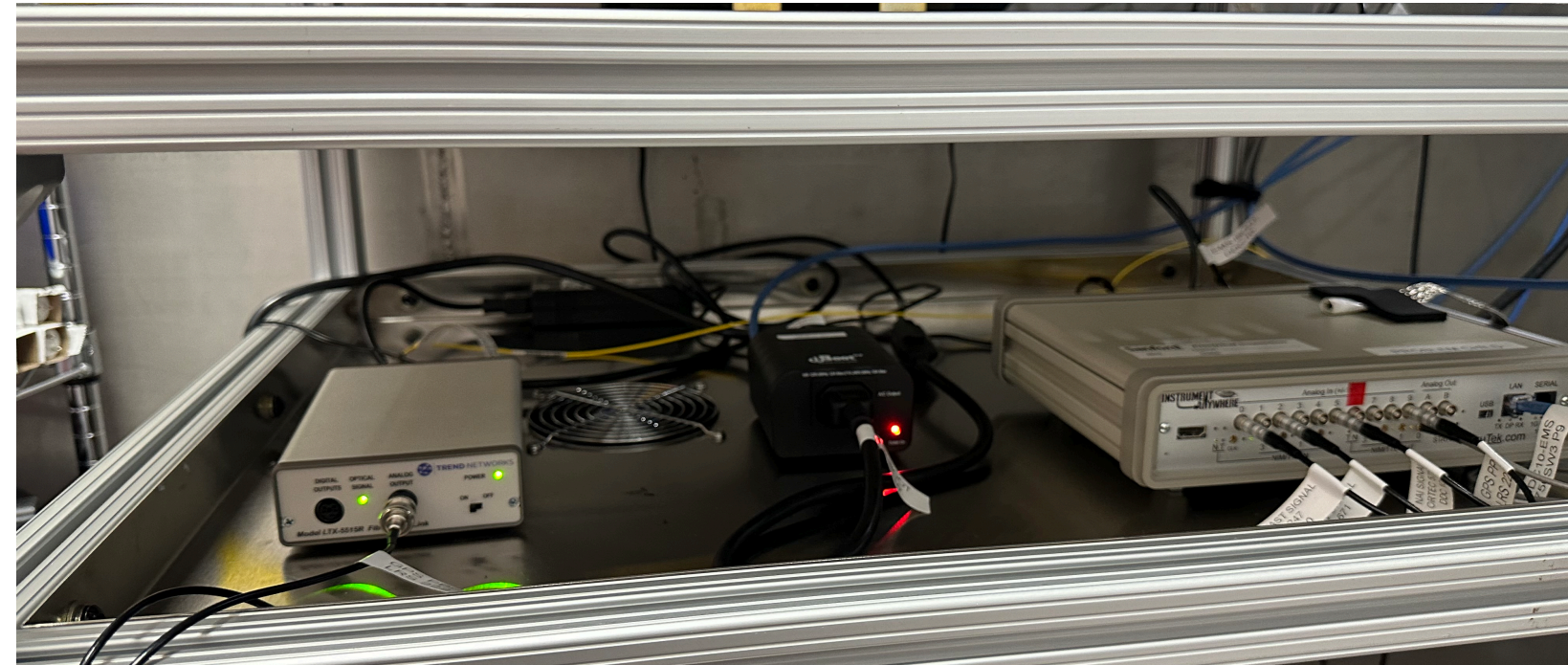
c) Electronics shelf

- Digitiser - DDC-10
- GPS pulse receiver

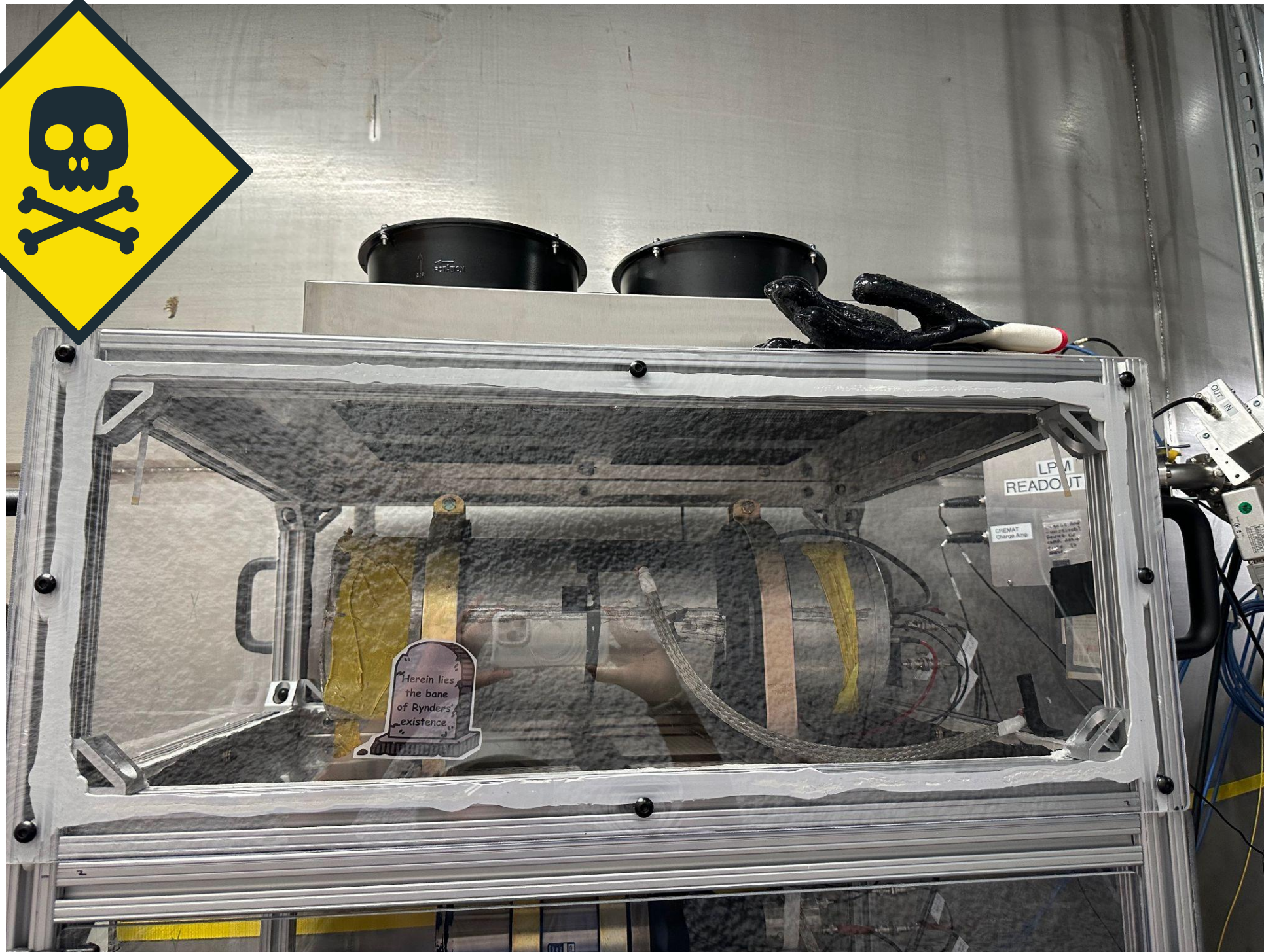
d) NIM crate

- HV for BF₃ and NaI
- Pulse shaping and amplification

e) **Radon** monitoring equipment



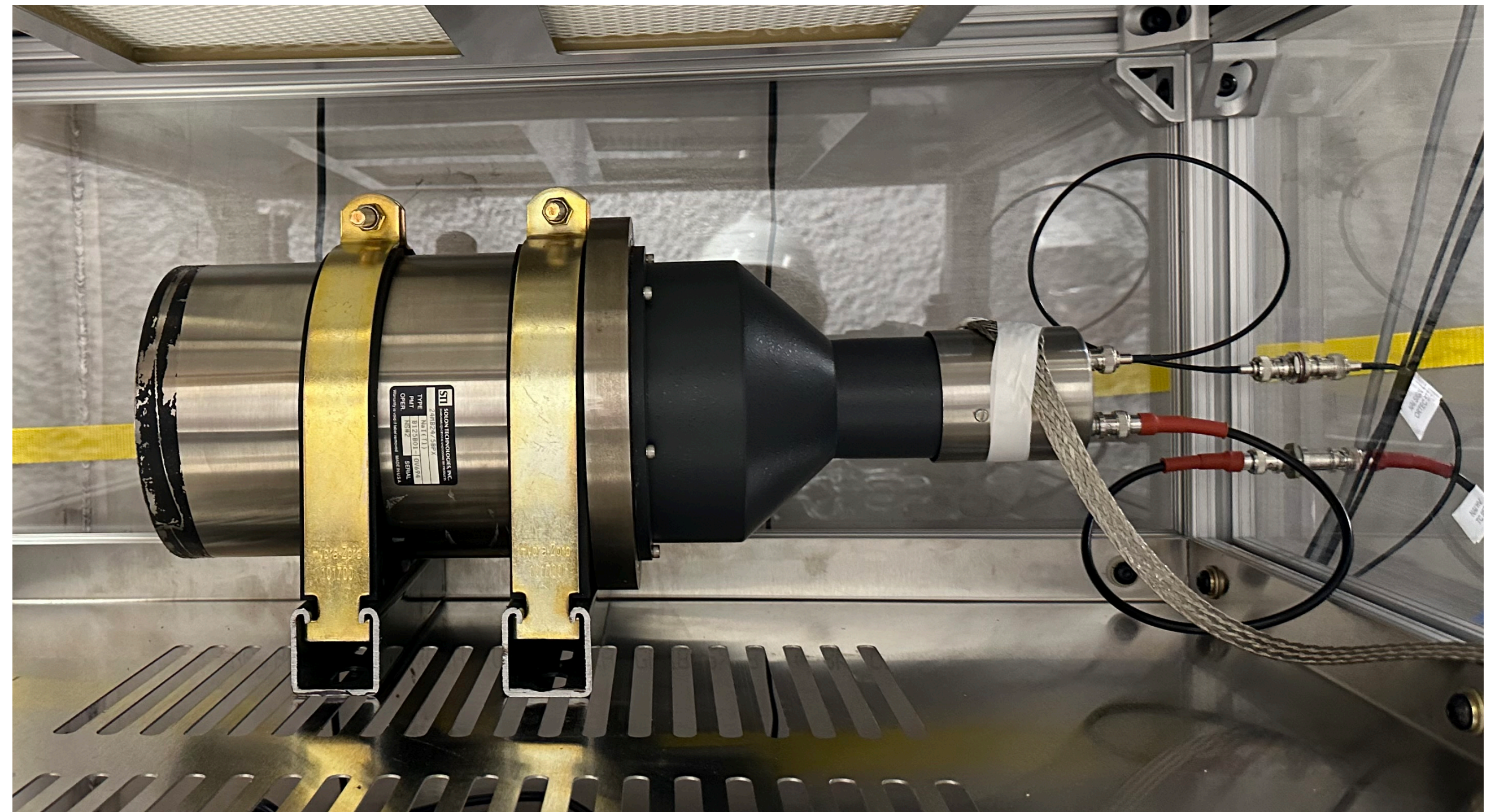
BF₃ Tube



- **Neutron** detector
 - Boron trifluoride gas - enriched with ${}^{10}\text{B}$
 - Surrounded by paraffin moderator
- Thermal neutrons capture in the BF₃ - producing **alphas**
- Proportional counter:
 - α causes ionisation in the BF₃
 - Ionisation electrons are accelerated in an E field
 - Secondary ionisation occurs - producing a pulse

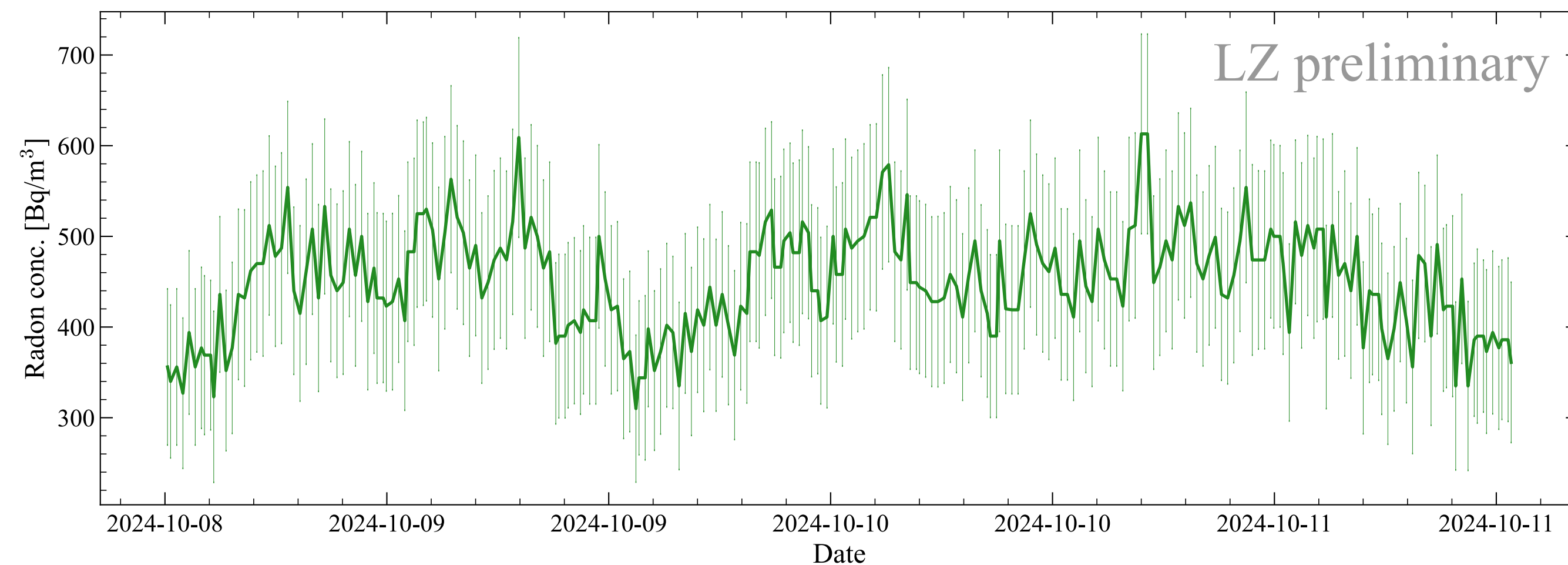
Nal Crystal

- **Gamma-ray** detector
- 6x6" NaI(Tl) crystal
- Inorganic scintillation detector
 - γ -ray strikes NaI producing scintillation
 - PMT collects scintillation light
 - Number of photoelectrons produced $\propto$ energy deposited by γ -ray



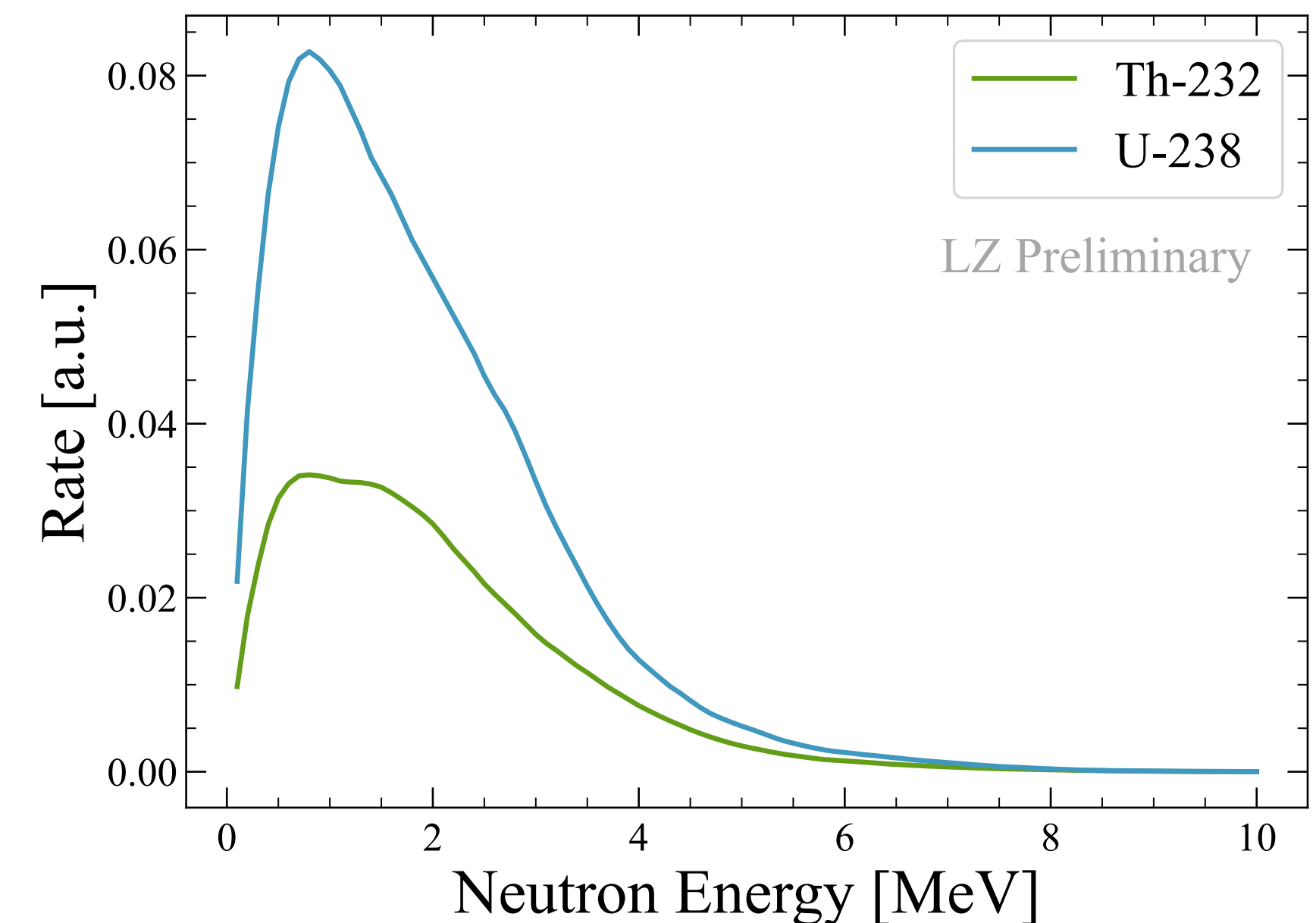
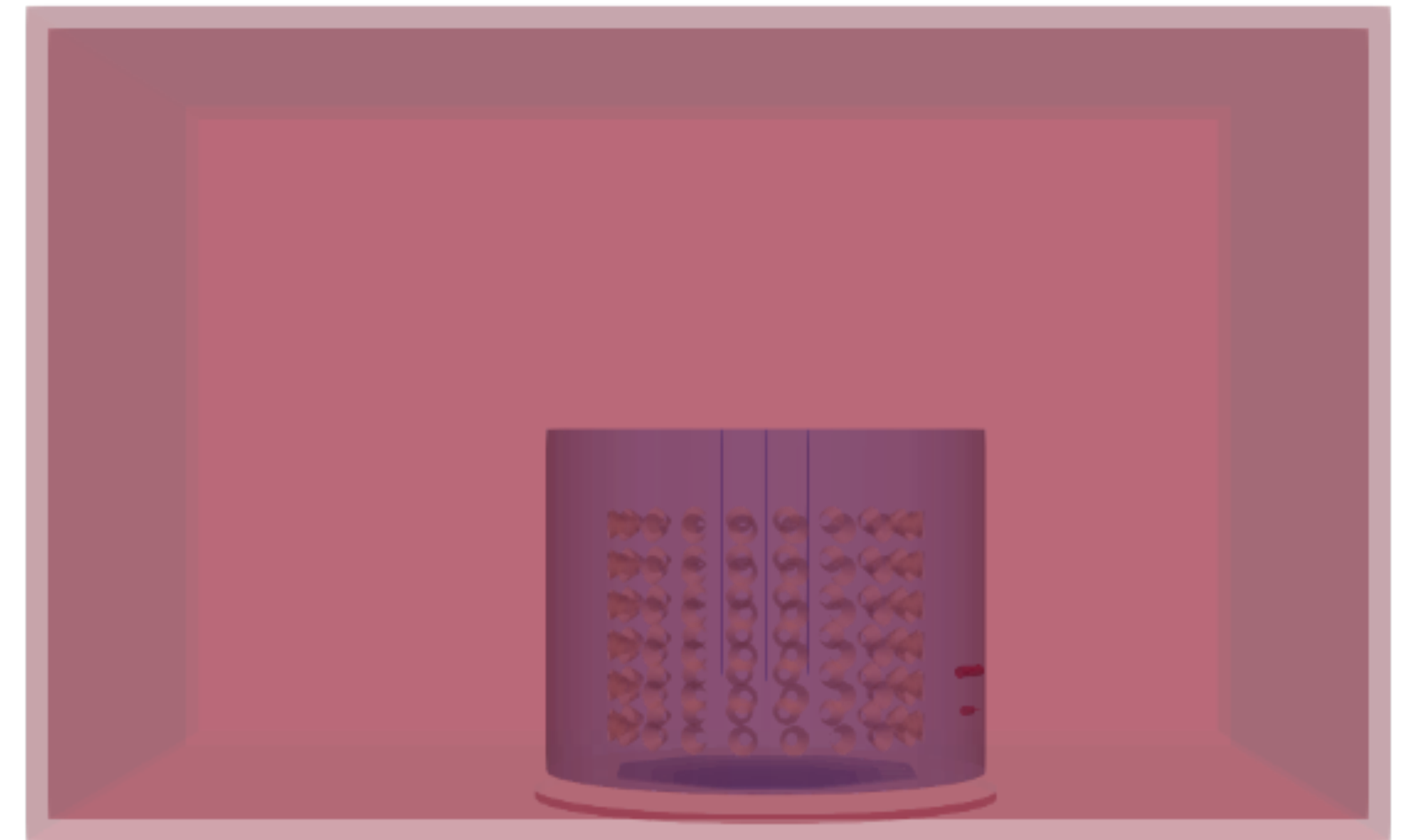
Radon monitoring

- Regularly sample cavern air using a **Rad-7**
 - Measures radon concentration using alphas from the Rn decay chain
 - Drystik used to reduce air humidity before entry to Rad-7
- Rn concentration significantly affected by changes in **underground ventilation**



EMS: Simulations

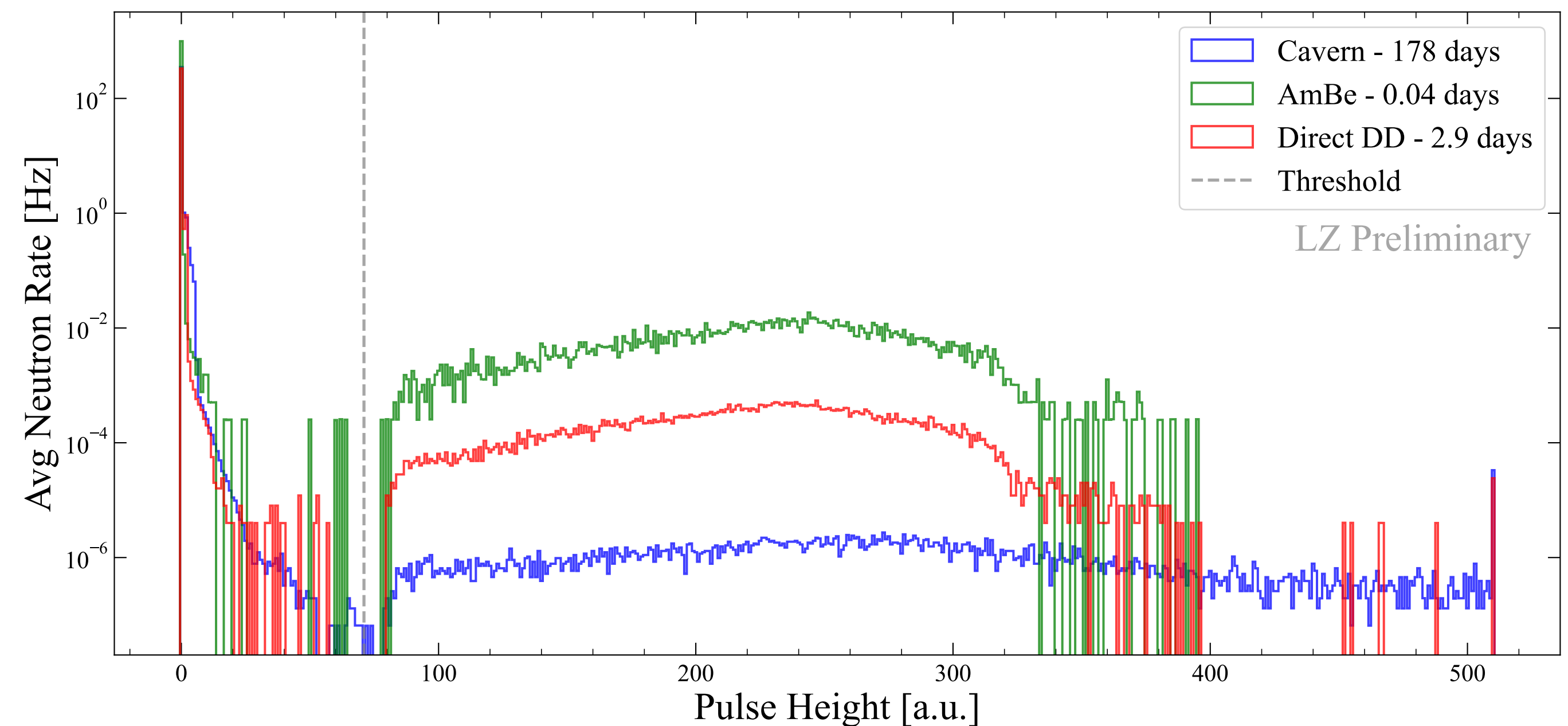
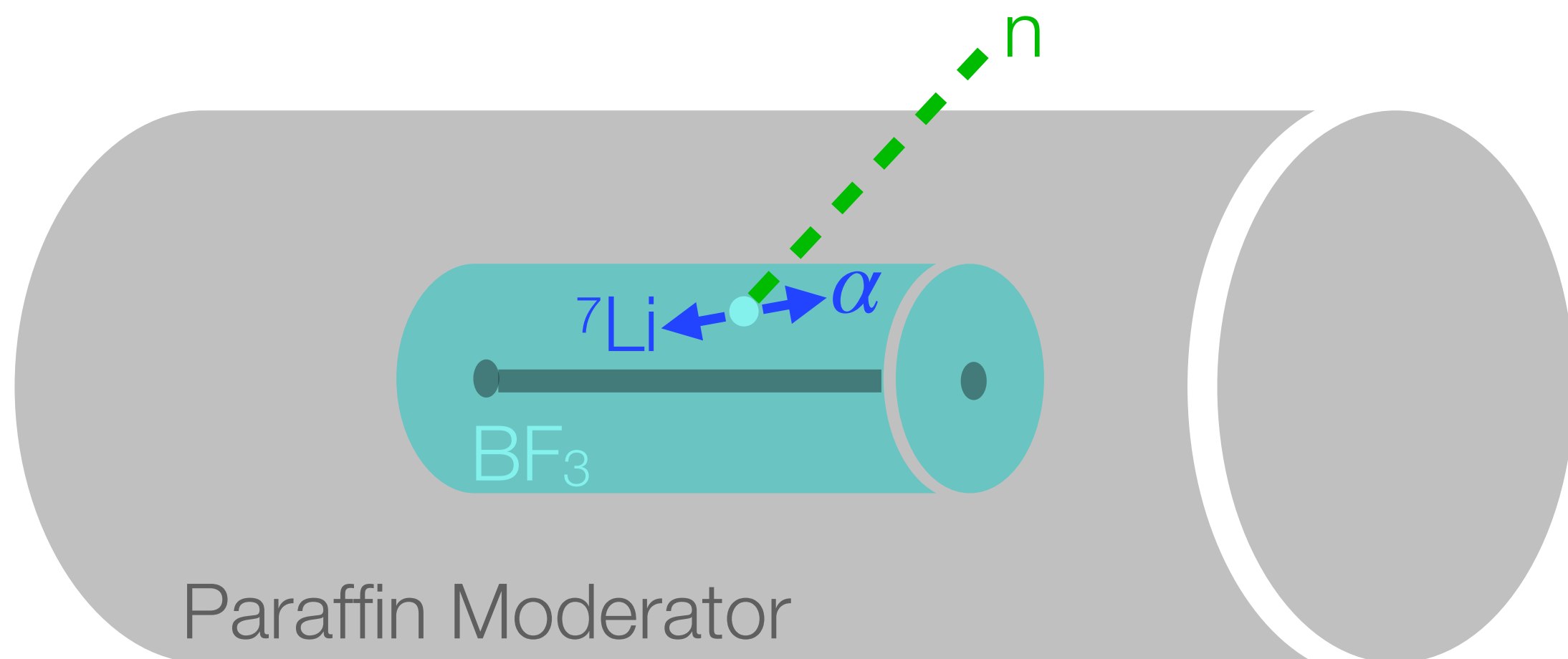
- Custom geometry built within LZ simulation framework (based on Geant4)
 - Contains the Cavern walls, Gravel beneath water tank, Water tank and the EMS detectors
 - The cavern is modelled as a simple shell of rock (30 cm)
- Radioactive decay chains (**U, Th, K**) are simulated in the rock shell
 - Gammas: use G4Decay
 - Neutrons: provide input spectra from SOURCES4A
- Use **event biasing** to get better statistics
- Energy deposits in the EMS detectors are recorded



EMS: **BF₃** Calibration

- **AmBe** deployment
 - No energy calibration - just counting neutrons
 - Compare with sims to get efficiency

$$\epsilon = \frac{R_{exp}}{R_{sim}} = 0.86 \pm 0.01$$



EMS: **NaI** Calibrations

- ^{22}Na , ^{137}Cs and ^{60}Co deployments

- **Energy** scale:

Fit known gamma peaks



Linear energy conversion

- **Resolution** of detector:

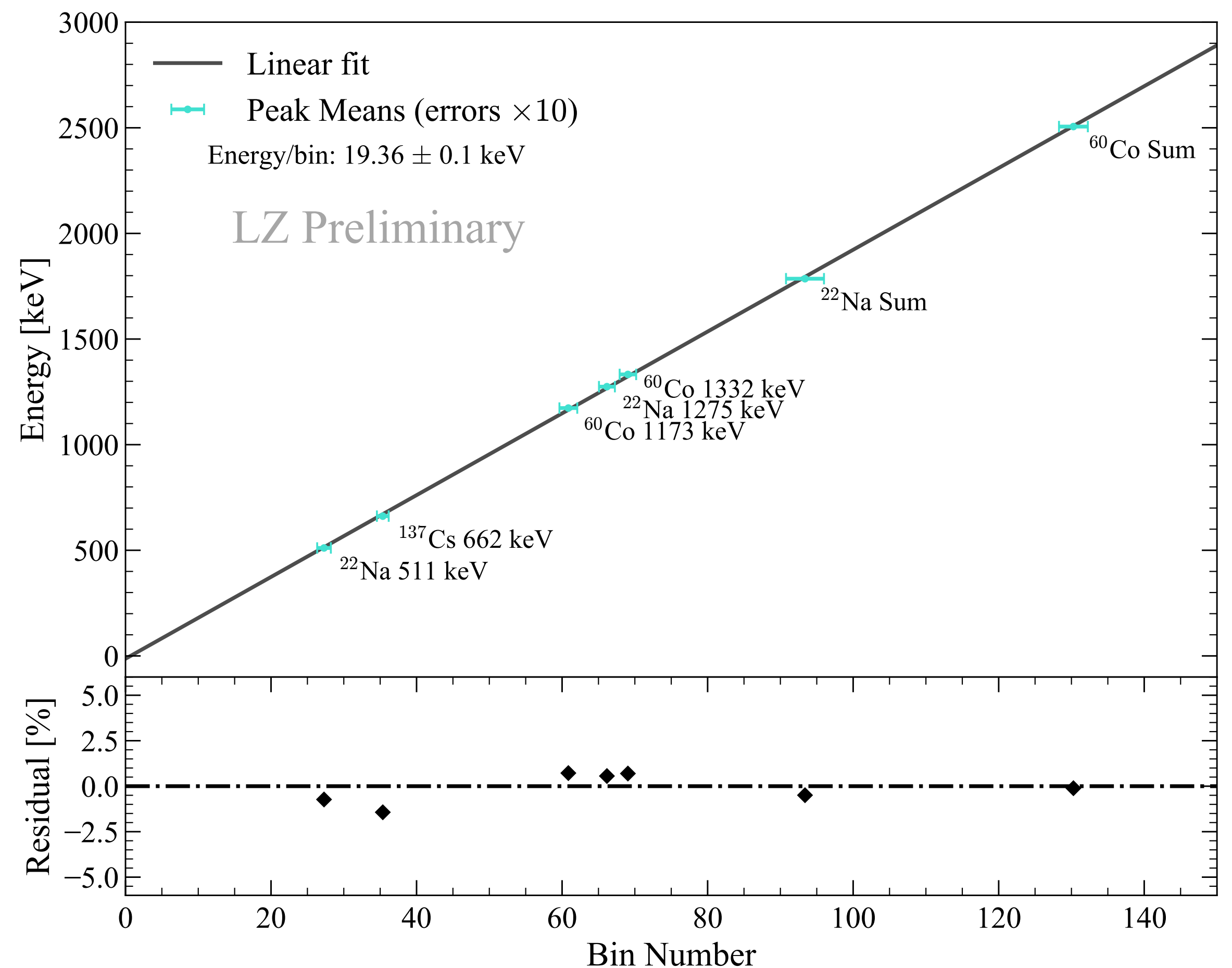
Peak widths



Fit resolution curve



Extract resolution parameters

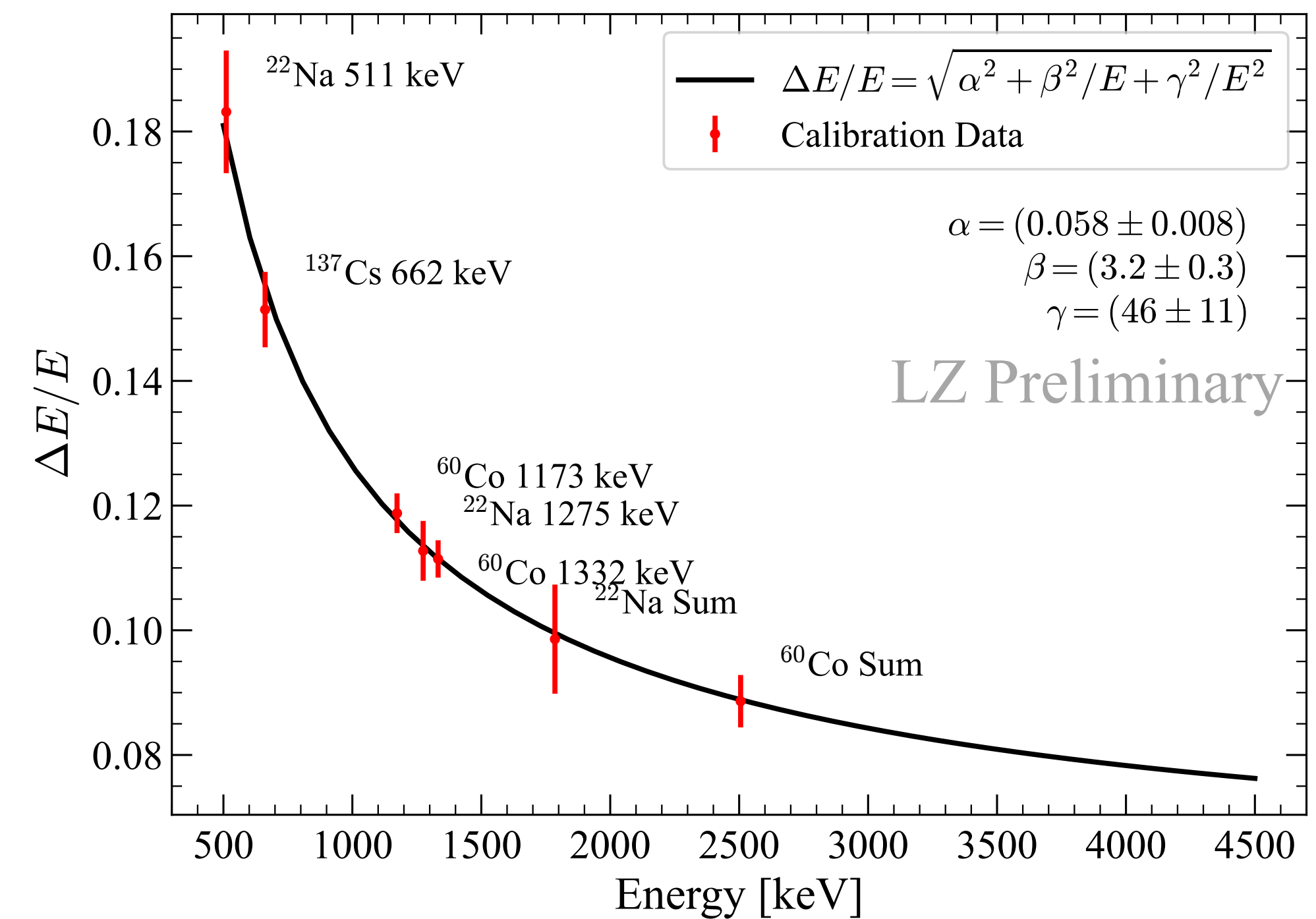
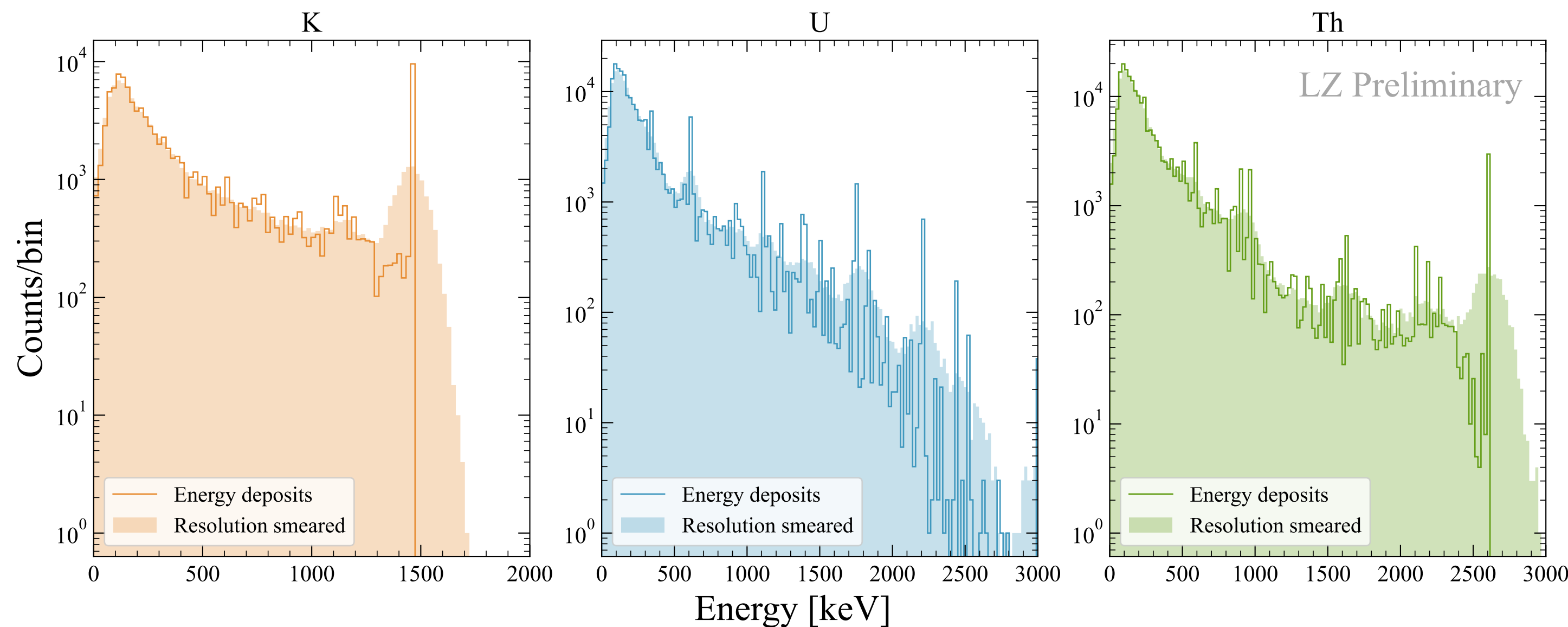


EMS: **NaI** Calibrations

- NaI **resolution** modelled with:

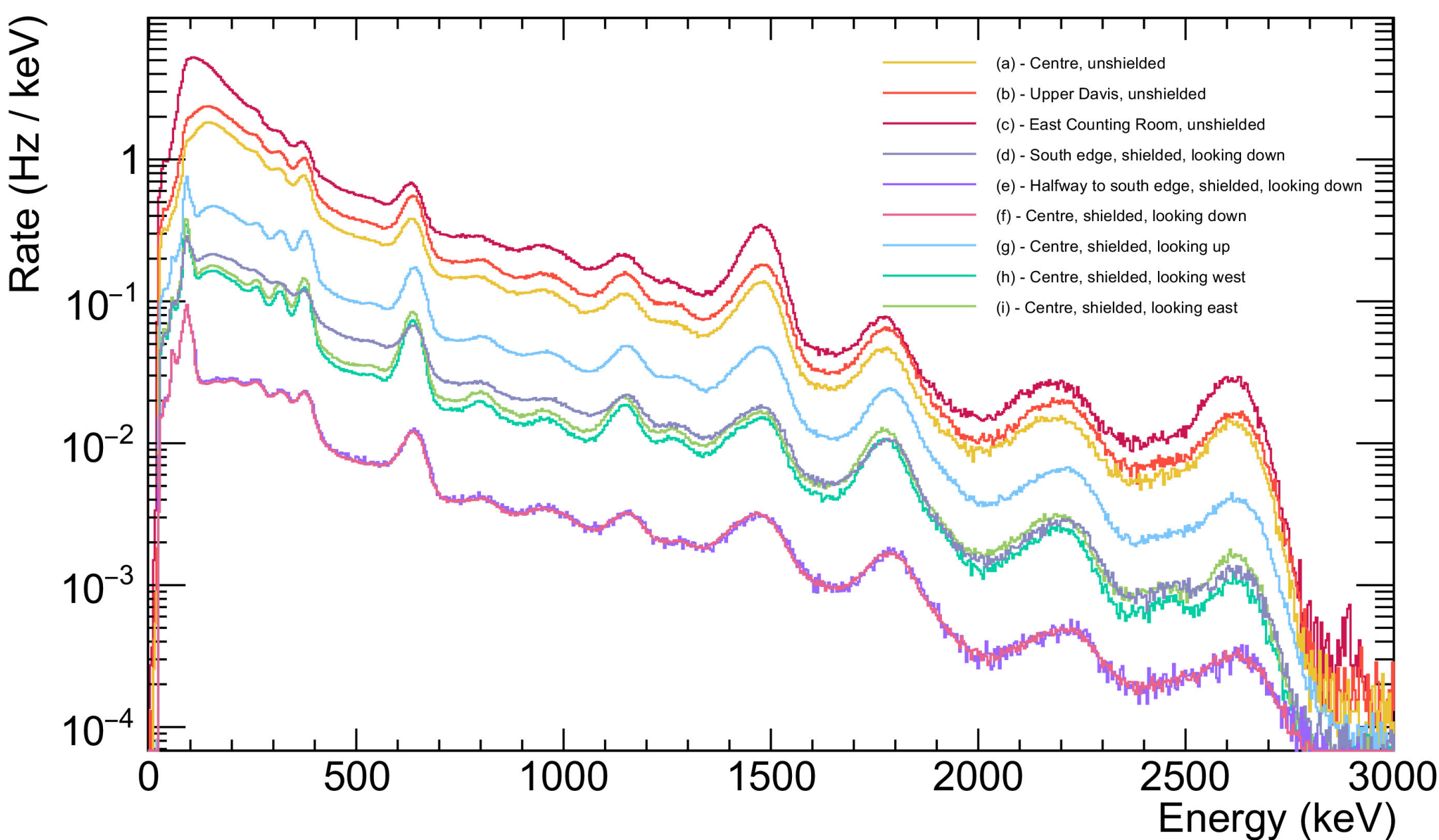
$$R = \frac{\Delta E}{E} = \sqrt{\alpha^2 + \frac{\beta^2}{E} + \frac{\gamma^2}{E^2}}$$

- Resolution parameters used to apply **smearing** to simulated data
- Get data/sim efficiency from fitting simulated calibrations to data



Previous Cavern Measurements

- Previous **cavern γ -ray** measurements were made in 2017
 - Also using a NaI detector
 - Prior to any LZ infrastructure installation - measurements were taken from multiple locations



Astroparticle Physics 116 (2020) 102391



Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

Measurement of the gamma ray background in the Davis cavern at the Sanford Underground Research Facility

[10.1016/j.astropartphys.2019.102391](https://doi.org/10.1016/j.astropartphys.2019.102391)

Position of measurement	Label	⁴⁰ K - 1461 keV		²³⁸ U - 1764 keV		²³² Th - 2614 keV	
		Rate (Hz)	A _m (Bq/kg)	Rate (Hz)	A _m (Bq/kg)	Rate (Hz)	A _m (Bq/kg)
Centre of water tank, unshielded	a	10.33 ± 0.04	285 ± 1	2.55 ± 0.02	36.9 ± 0.4	2.12 ± 0.02	15.2 ± 0.1
Upper Davis, unshielded	b	13.82 ± 0.07	135 ± 4	1.56 ± 0.02	10.4 ± 0.2	2.498 ± 0.004	8.8 ± 0.1
East Counting Room, unshielded	c	28.8 ± 0.1	264 ± 1	2.98 ± 0.03	18 ± 0.2	4.31 ± 0.03	12.2 ± 0.2
Edge of tank, looking down	d	1.01 ± 0.01	182 ± 2	0.875 ± 0.005	31.4 ± 0.2	0.214 ± 0.002	16.7 ± 0.1
Halfway to edge of tank, looking down	e	0.167 ± 0.002	-	0.141 ± 0.002	-	0.0487 ± 0.0001	-
Centre looking down	f	0.300 ± 0.001	-	0.157 ± 0.001	-	0.0560 ± 0.0004	-
Centre of tank, looking up	g	3.47 ± 0.01	214 ± 1	1.29 ± 0.01	48.4 ± 0.2	0.650 ± 0.004	9.5 ± 0.1
Averaged activities	-	-	220 ± 60	-	29 ± 15	-	13 ± 3

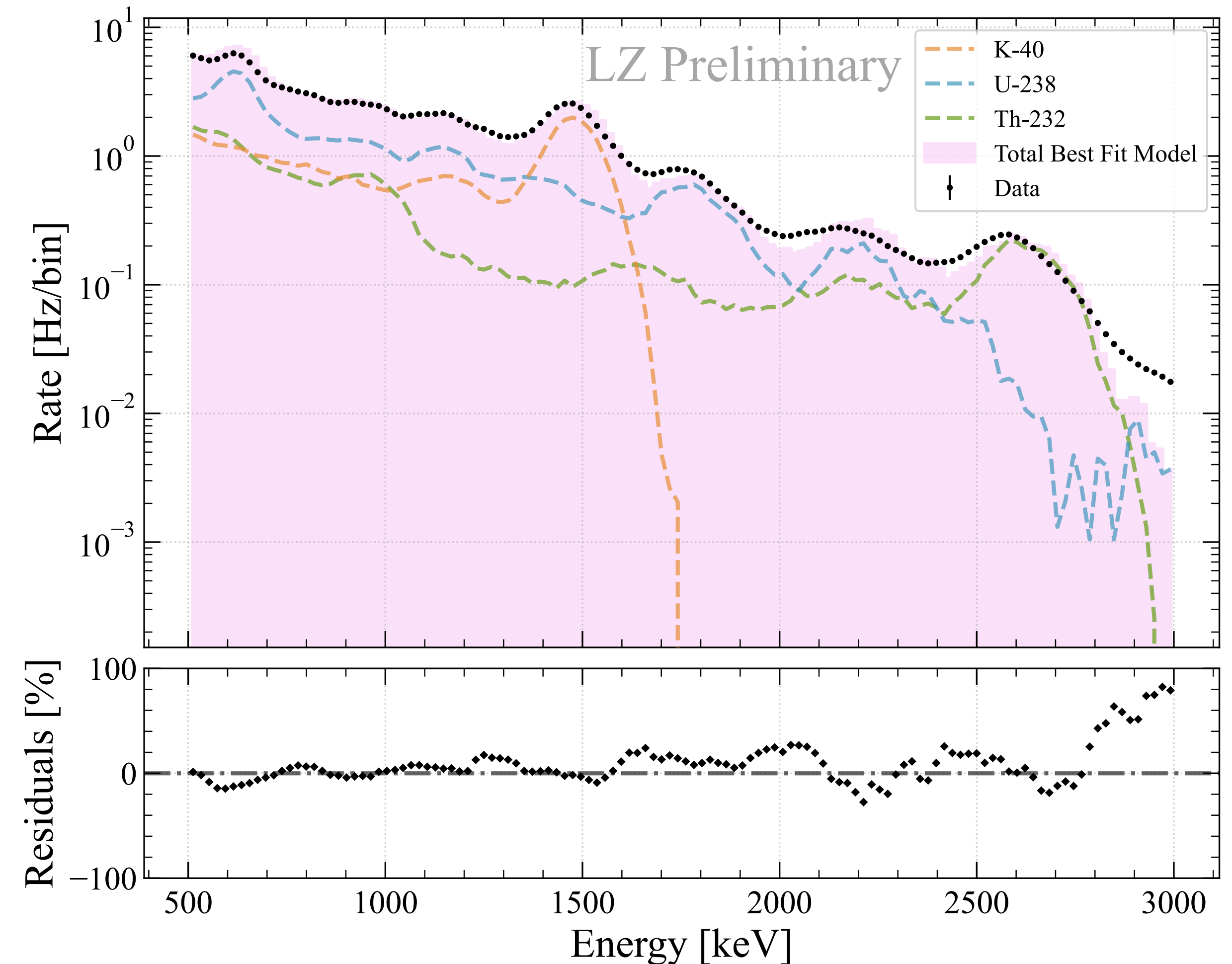
Cavern Gammas

- Fitting of simulated data with NaI cavern background data
 - K, U, Th are allowed to float up and down and move slightly in Energy
- All activities are within 1σ of previous measurements:

^{40}K : 160 ± 70 Bq/kg

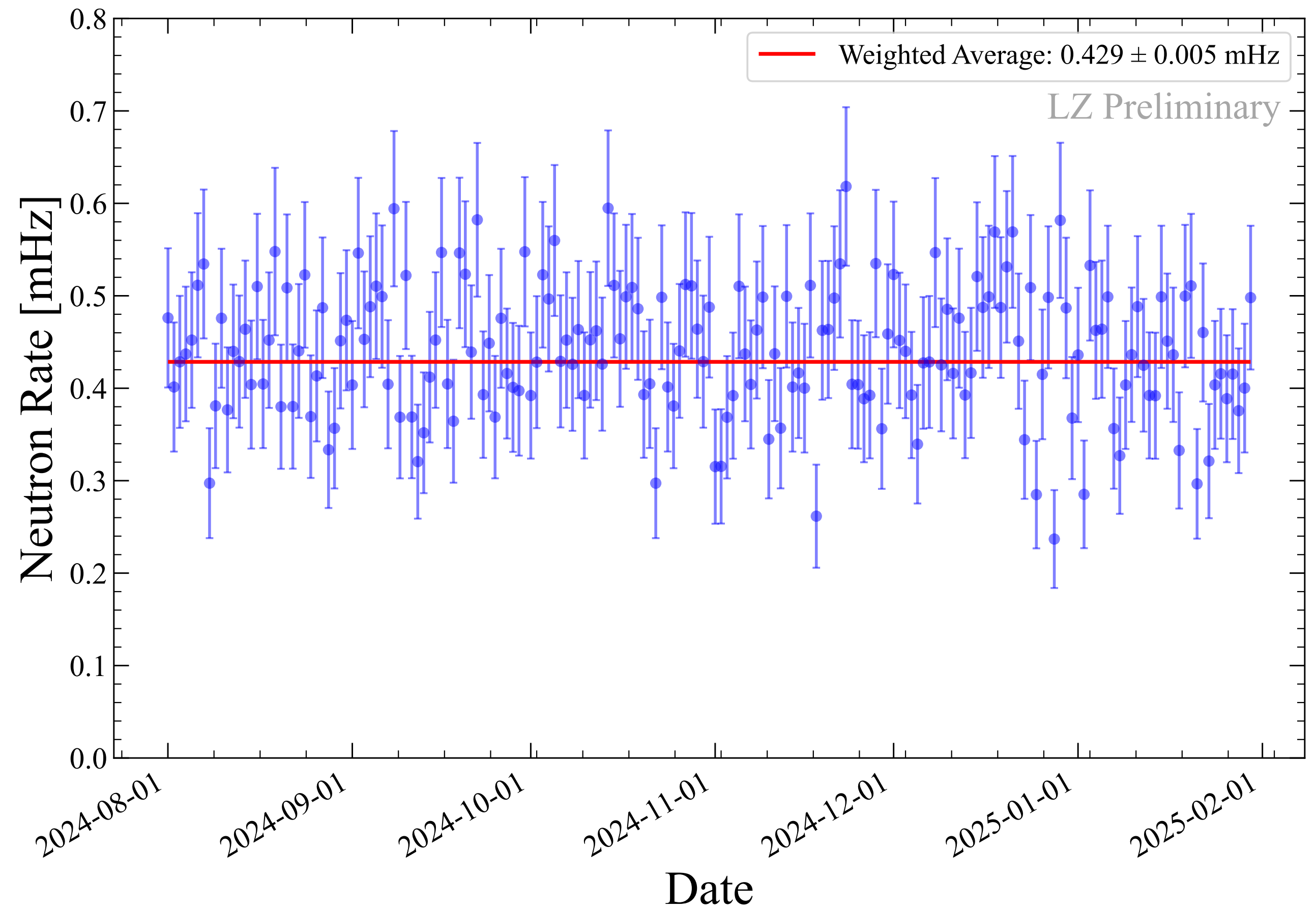
^{238}U : 24 ± 10 Bq/kg

^{232}Th : 8 ± 6 Bq/kg



Cavern Neutrons

- Daily neutron rate in the BF3
 ~ 0.4 mHz
- Fluctuates slightly - but is stable
- In cavern simulations the rate is:
 0.24 ± 0.11 mHz
- Within 2σ of the rate seen in data
 - allowing us to use these simulations to predict the externally produced high energy rate in the OD



Summary

- The Environmental Monitoring Station is a live standalone background monitor
 - We will have long term monitoring of key cavern backgrounds for the remainder of LZ's lifetime
 - Enables a quick response to changes in cavern conditions
- Preliminary results are in agreement with the rock activities measured previously
- Cavern gamma measurements are vital for the $0\nu\beta\beta$ search
- Constrained the external neutron rate with the EMS and have validated cavern simulations
 - Can now make a measurement of the internal neutron rate - essential as LZ's exposure grows and neutrons become more significant

Ultimately: The EMS exists to support LZ's searches for new physics by demonstrating a complete understanding of LZ's environmental backgrounds.

This is crucial in the case of an emerging dark matter or $0\nu\beta\beta$ signal.

Acknowledgements



@lzdarkmatter

<https://lz.lbl.gov/>

- ▶ Black Hills State University
- ▶ Brookhaven National Laboratory
- ▶ Brown University
- ▶ Center for Underground Physics
- ▶ **Edinburgh University**
- ▶ Fermi National Accelerator Lab.
- ▶ **Imperial College London**
- ▶ **King's College London**
- ▶ Lawrence Berkeley National Lab.
- ▶ Lawrence Livermore National Lab.
- ▶ **LIP Coimbra**
- ▶ Northwestern University
- ▶ Pennsylvania State University
- ▶ **Royal Holloway University of London**
- ▶ SLAC National Accelerator Lab.
- ▶ South Dakota School of Mines & Tech
- ▶ South Dakota Science & Technology Authority
- ▶ **STFC Rutherford Appleton Lab.**
- ▶ Texas A&M University
- ▶ University of Albany, SUNY
- ▶ University of Alabama
- ▶ **University of Bristol**
- ▶ **University College London**
- ▶ University of California Berkeley
- ▶ University of California Davis
- ▶ University of California Los Angeles
- ▶ University of California Santa Barbara
- ▶ **University of Liverpool**
- ▶ University of Maryland
- ▶ University of Massachusetts, Amherst
- ▶ University of Michigan
- ▶ **University of Oxford**
- ▶ University of Rochester
- ▶ **University of Sheffield**
- ▶ **University of Sydney**
- ▶ University of Texas at Austin
- ▶ University of Wisconsin, Madison
- ▶ **University of Zürich**

LZ (LUX-ZEPLIN) Collaboration, 38 Institutions,
250 scientists, engineers, and technical staff



LZ Collaboration Meeting at UCLA, March 2025

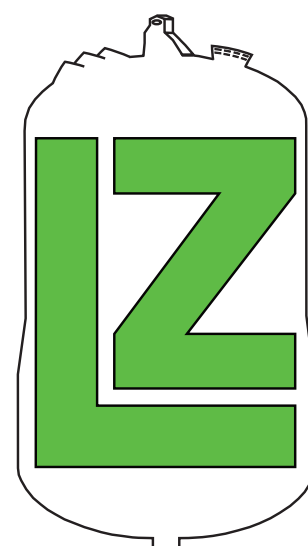


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Thank you



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Backup

