New excess measurements from NUCLEUS

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on behalf of the NUCLEUS collaboration

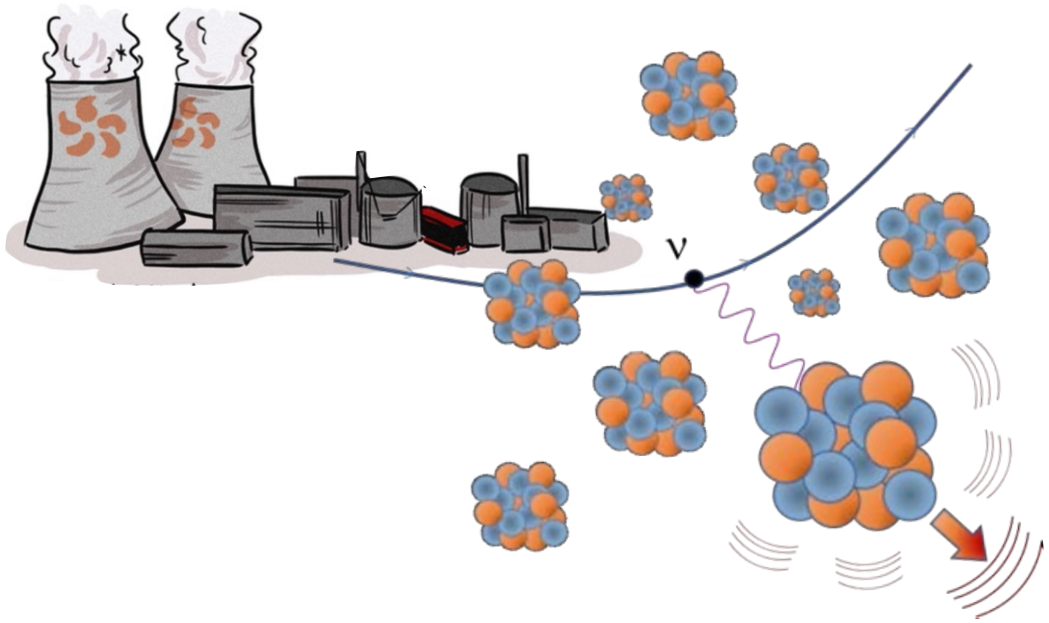
Excess Workshop 2024, Rome
06.07.2024

The NUCLEUS collaboration

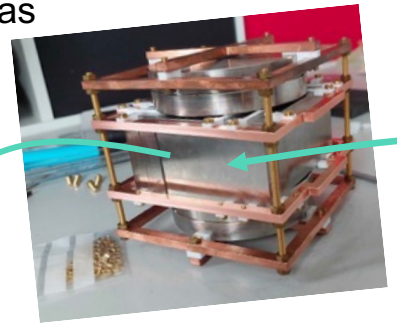
≈ 55 members

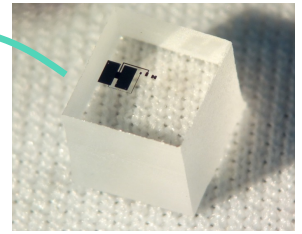
The NUCLEUS Experiment

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)



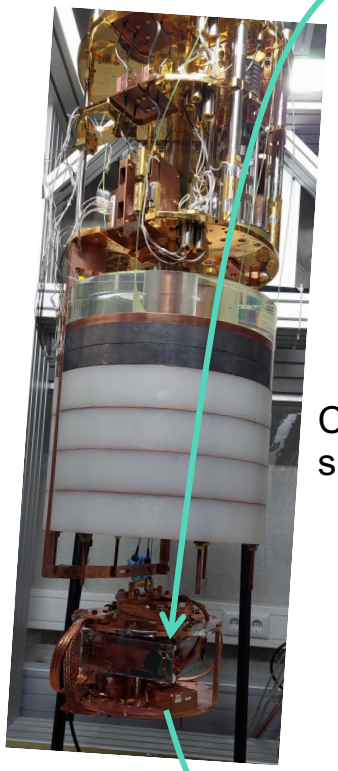
HPGe detectors as cryogenic veto



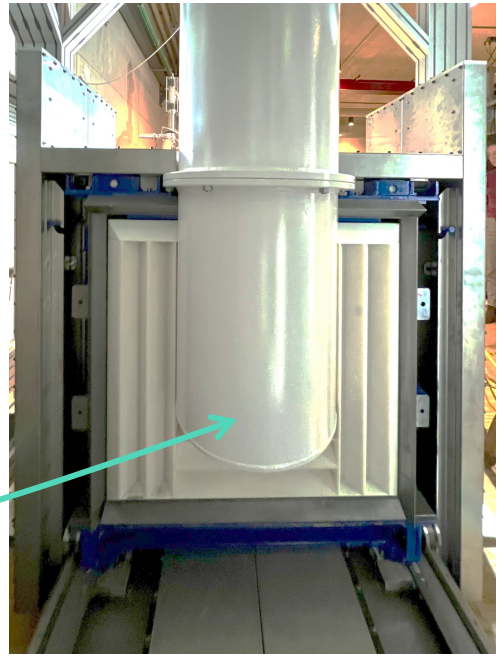


5mm

$CaWO_4$ target detector
Threshold: 20-30eV

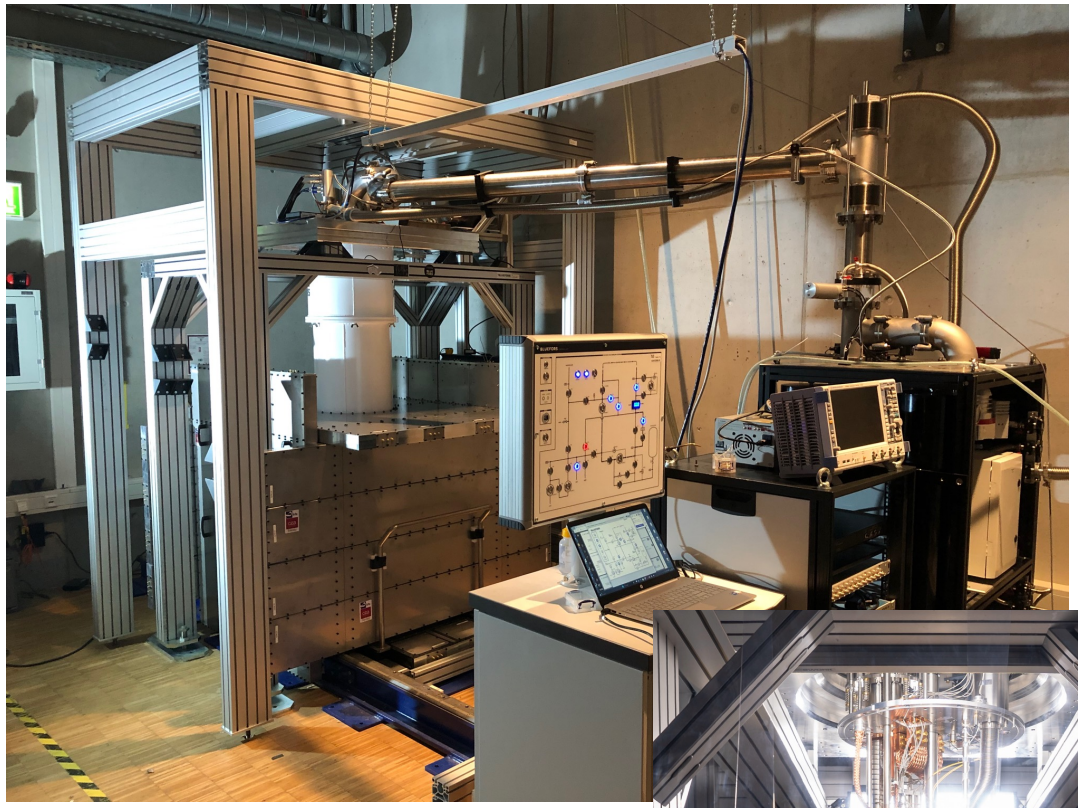


Cryogenic shielding



Active and passive external shields

NUCLEUS Status in Munich and Chooz

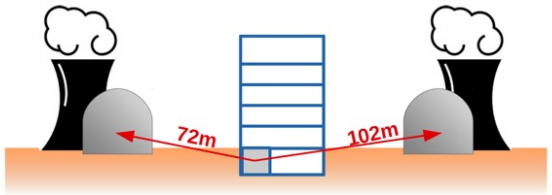


Construction of NUCLEUS setup completed end of 2023

Commissioning ongoing…

New clean tent around cryostat

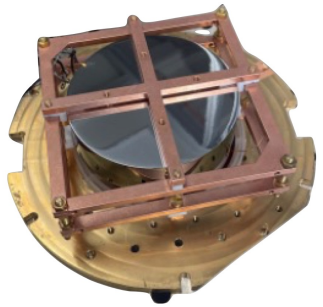
New NUCLEUS laboratory at Chooz nuclear power plant, France



Construction of “Very-Near-Site” (VNS) completed

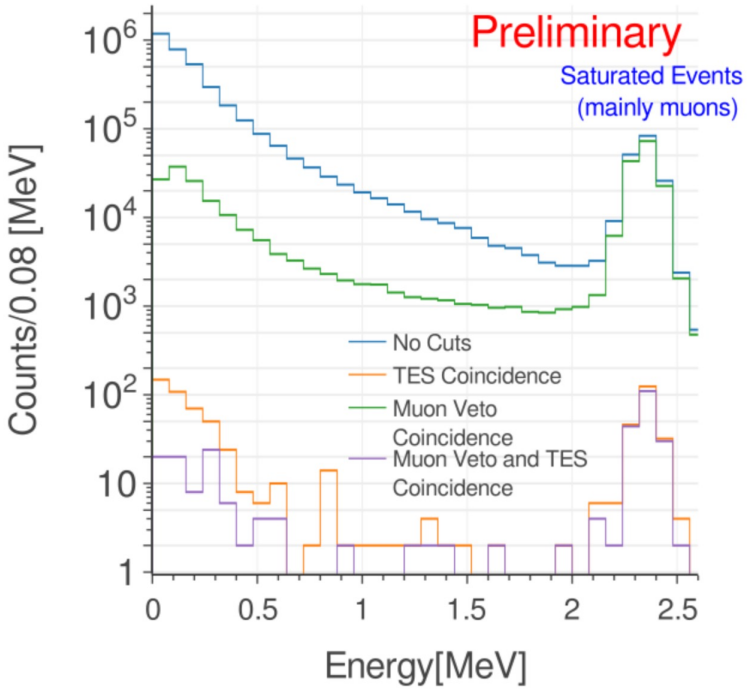
Recent News from NUCLEUS Commissioning

First data from full NUCLEUS detector system (April 2024)

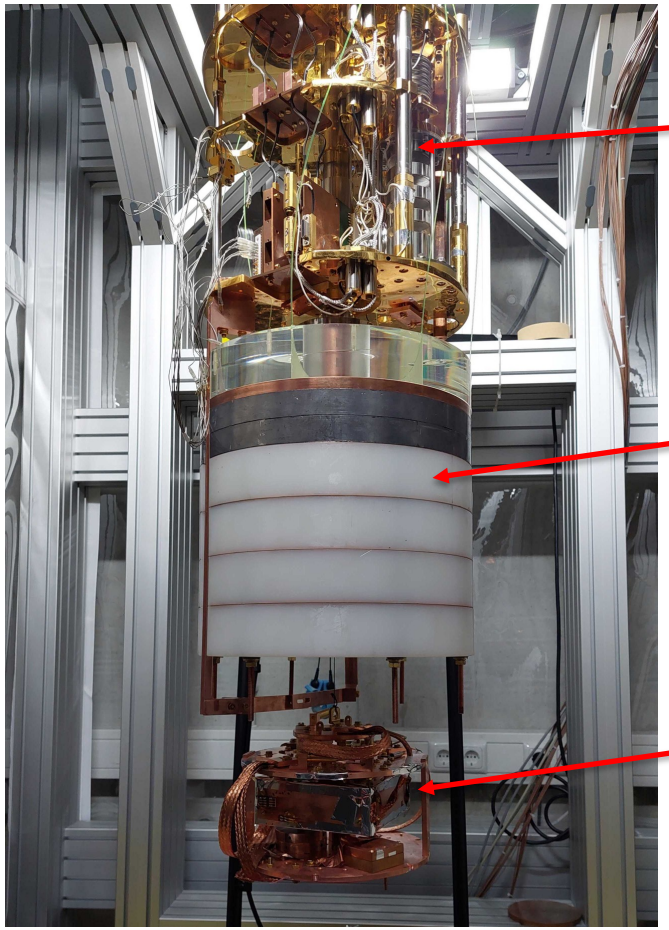


Cryogenic Outer Veto

Cryogenic outer veto in coincidence with
- Muon veto
- TES target detector



Full setup installed (June 2024)

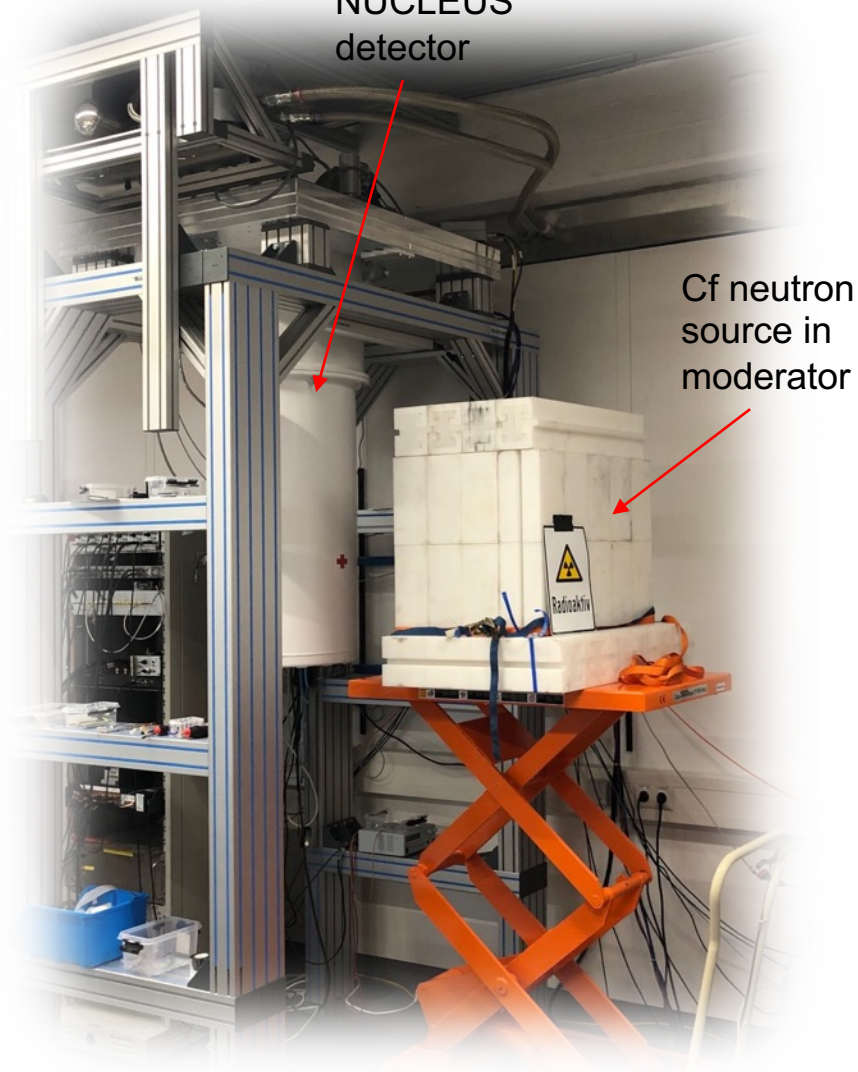


Cryostat (10mK) and readout

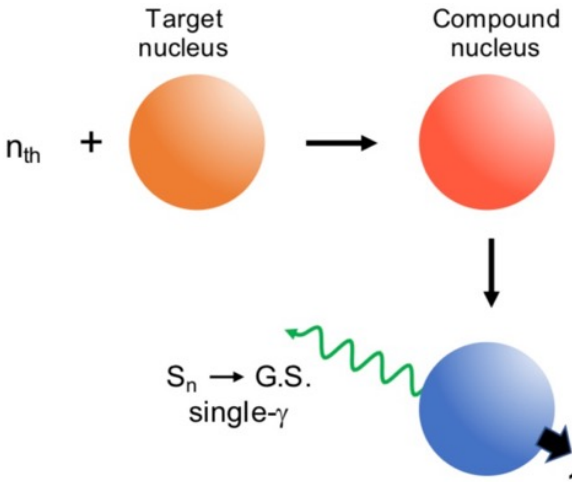
Cryogenic shielding and muon veto

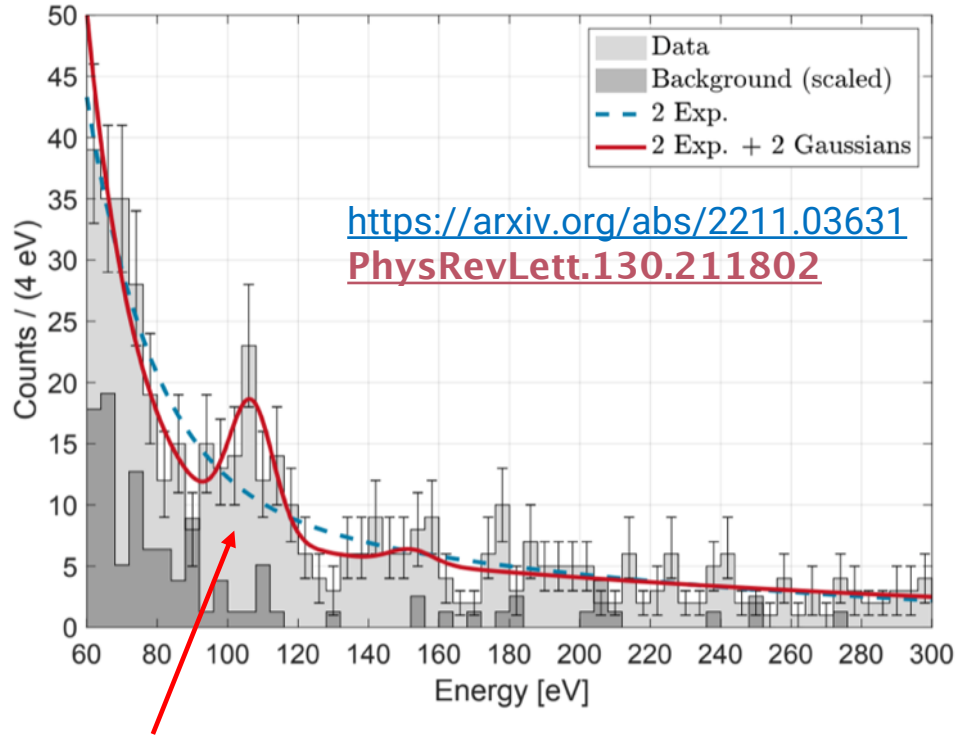
Cryogenic detector on spring suspension

Milestone Result in 2022: Calibration at 100eV



Capture of thermal neutrons on a NUCLEUS target crystal
→ First observation of a 100 eV scale nuclear recoil peak





https://arxiv.org/abs/2211.03631
PhysRevLett.130.211802

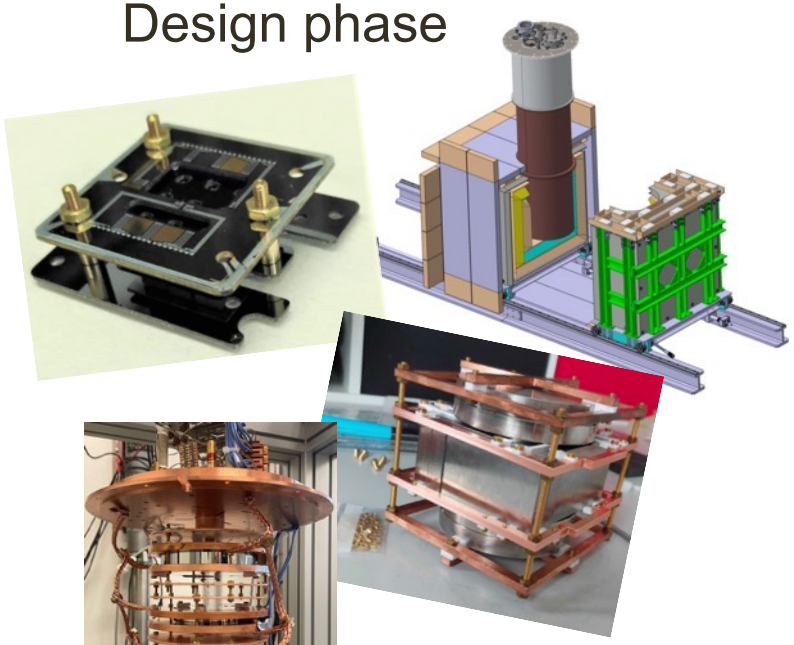
100eV scale nuclear recoils

New CRESST results with higher significance
Phys. Rev. D 108, 022005 (2023)

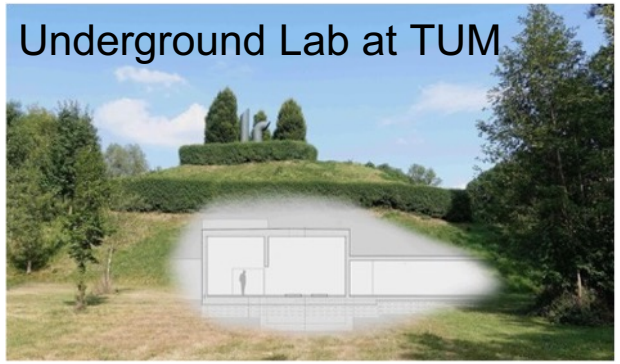
NUCLEUS Timeline

2023 — **now** — End 2024

Design phase



Blank Assembly & commissioning



→ Mechanical integration tests
→ Calibrations at keV energies and below
→ Detector performance
→ Background studies at sub-keV

On-site installation

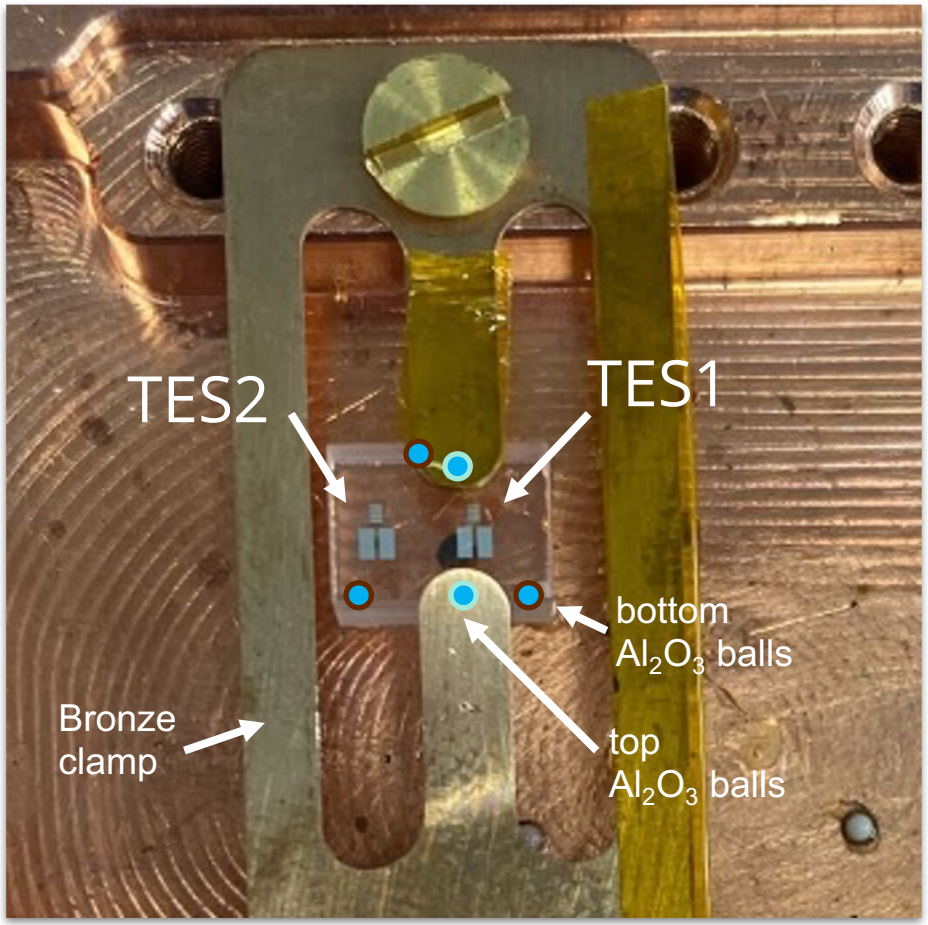
2025 — >2026

NUCLEUS-10g physics run
Phase 1: first physics with CEνNS

Towards NUCLEUS-1kg
Phase 2: precision physics with CEνNS

DoubleTES pioneered by CRESST: arXiv:2404.02607

The detector: Al_2O_3 crystal with 2 TES



Target:
Al_2O_3 crystal | 5x5x7.5mm³ | 0.75 g

Holding structures: 3 Al_2O_3 balls from below + 2 Al_2O_3 balls from above supported by brass clamps

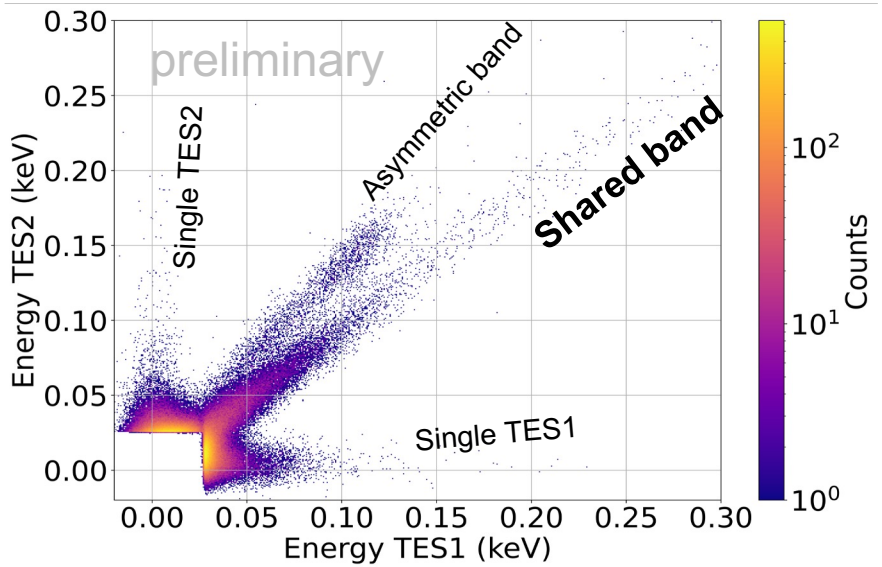
^{55}Fe source is mounted above the detector module.

Independent analysis cross-checks performed

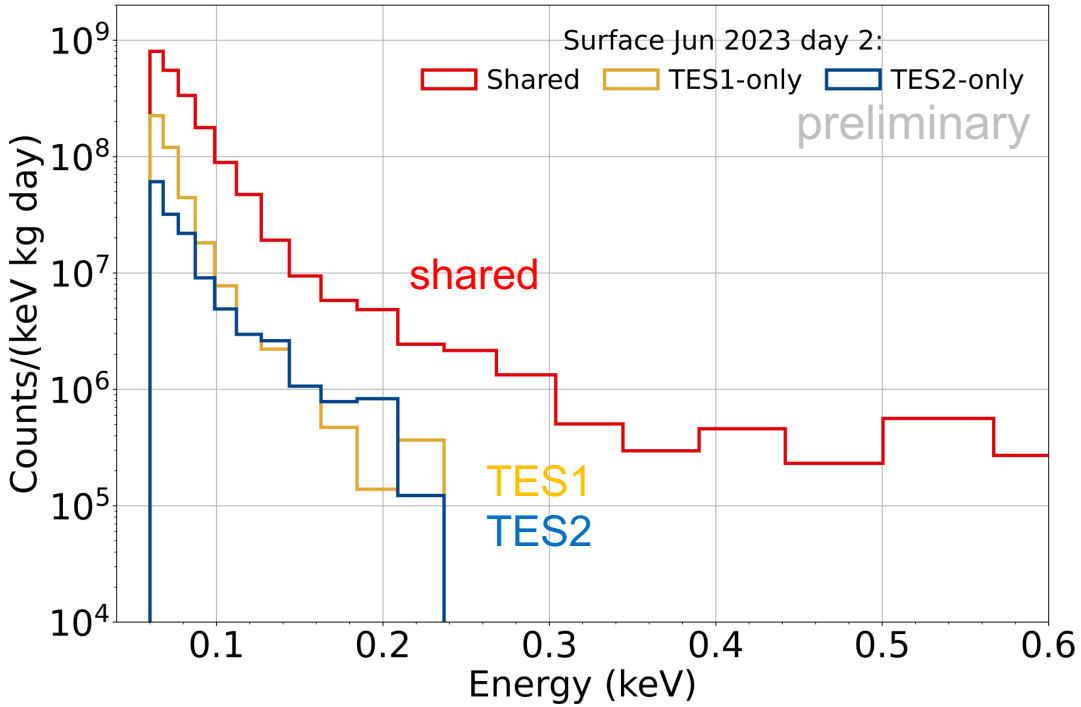
Surface measurements June 2023

Dry dilution refrigerator at TUM
- no-shielding
- Minimal overburden (20cm of concrete)

Data taking: end of June 2023



F. Pucci @Excess 2023



Singles are subdominant!

Jun 2023 → Jun 2024

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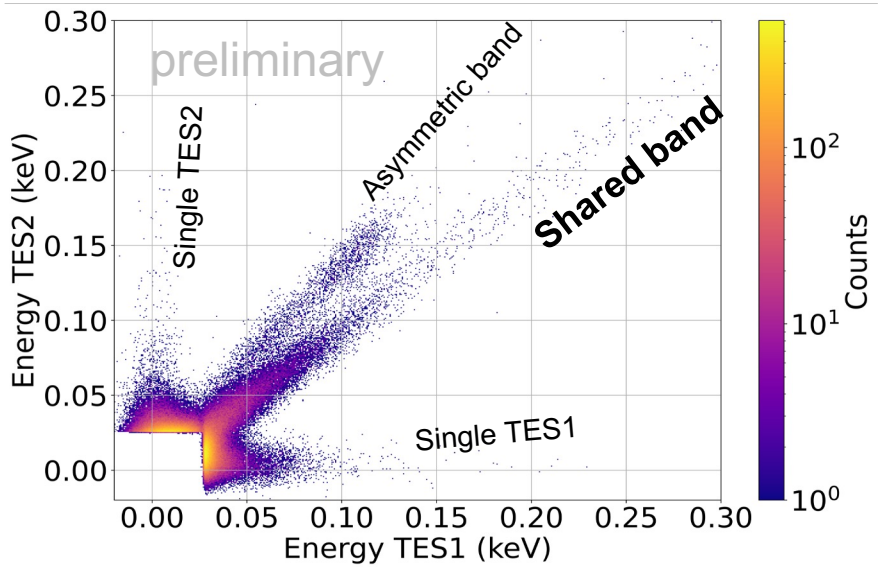

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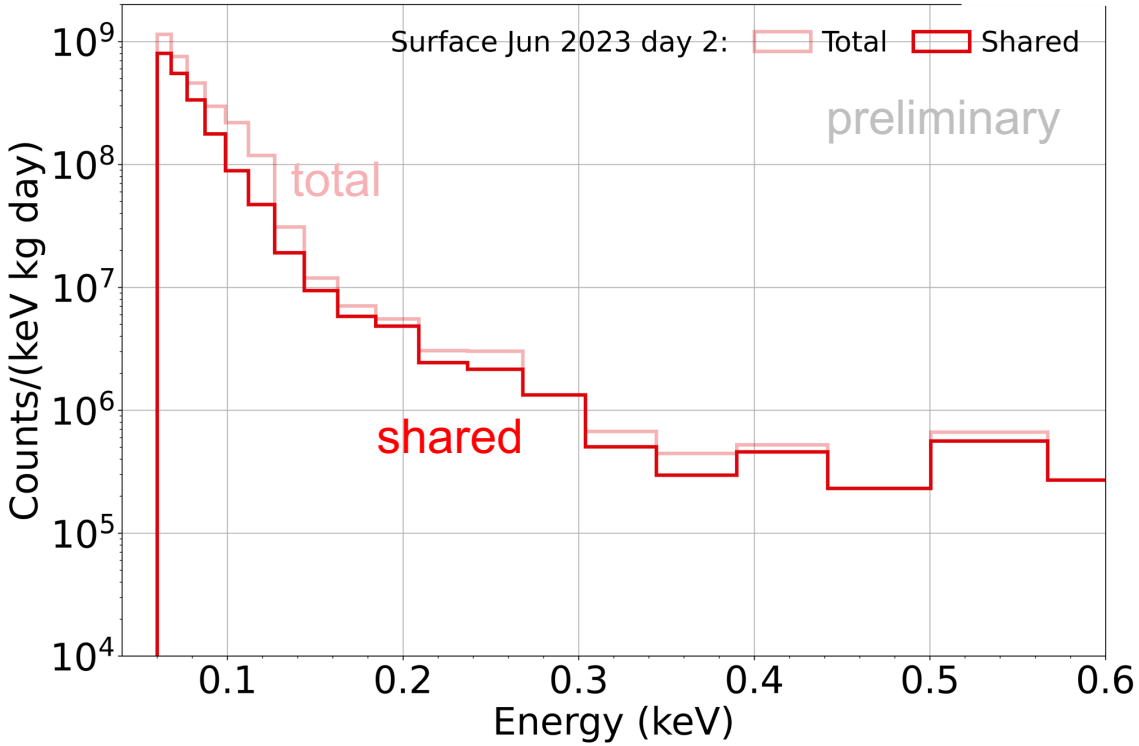
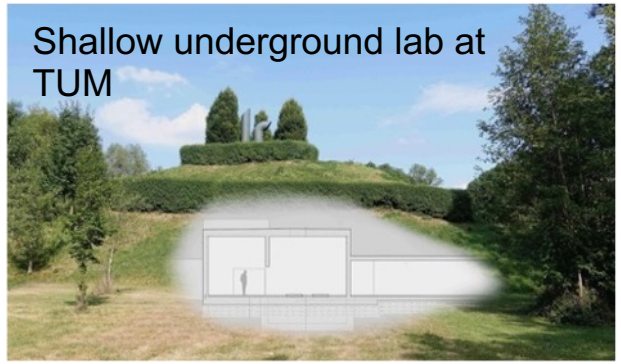


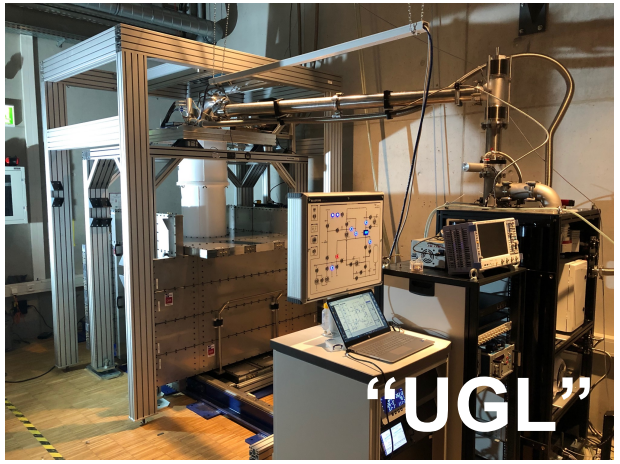
Jun 2023 → Jun 2024

UGL measurements March 2024

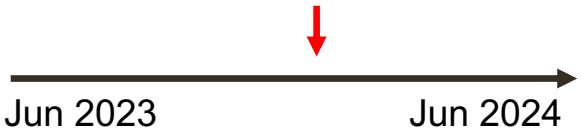


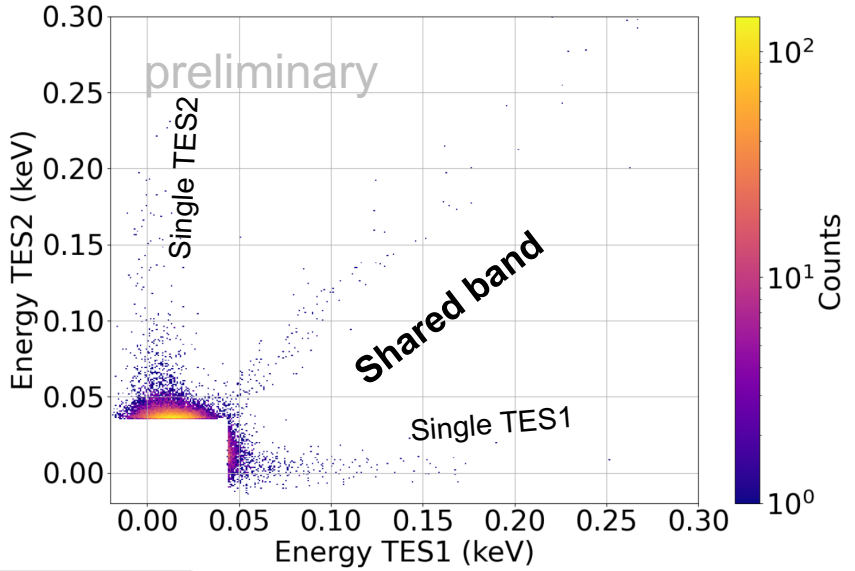
Dry dilution refrigerator at UGL
- multi-layer shielding (PE, Pb)
- 10 m.w.e. (muons /3, no cosmic n's and p's)

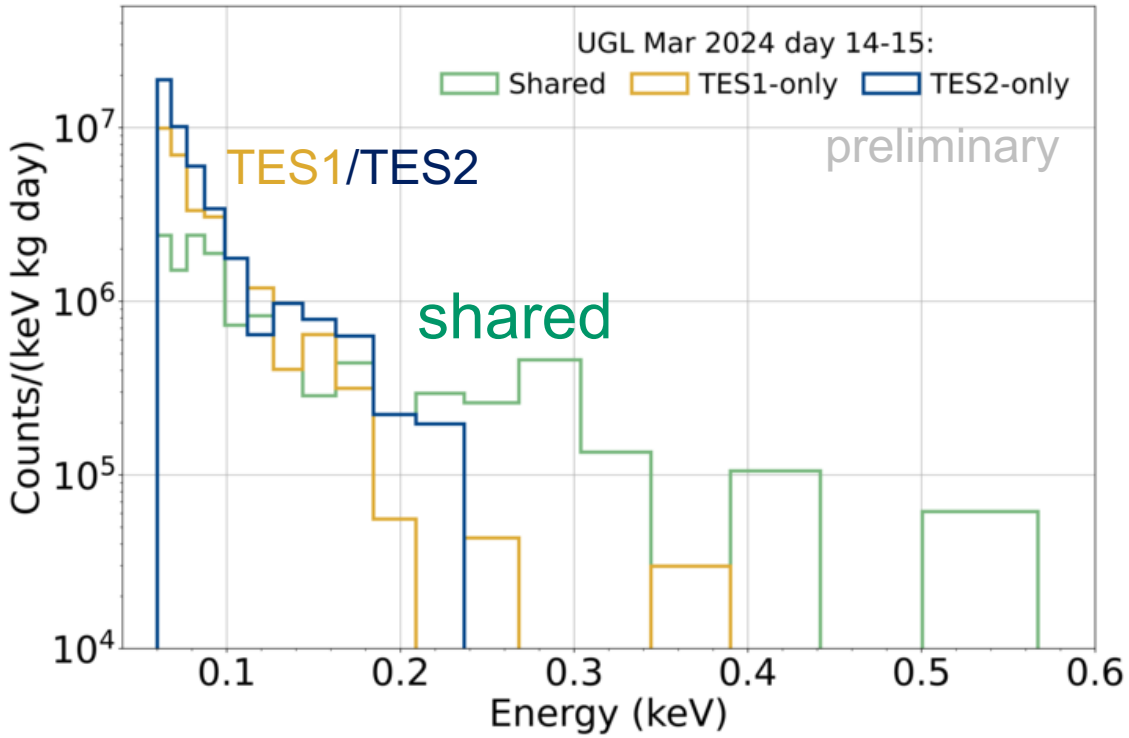
- data taking: March 2024



NUCLEUS setup

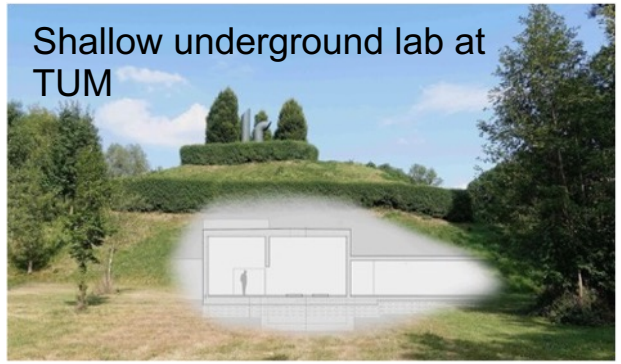






"Singles <u>dominant</u> at low E"

UGL measurements March 2024



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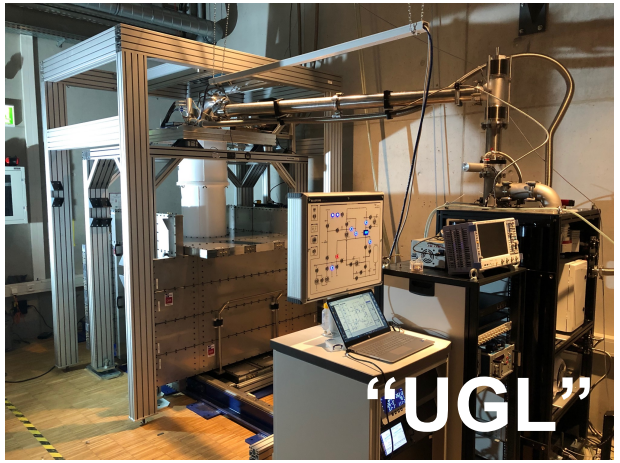
- data taking: March 2024



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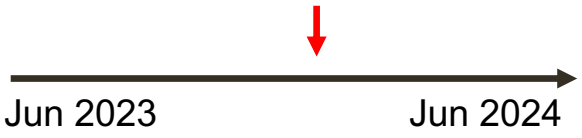
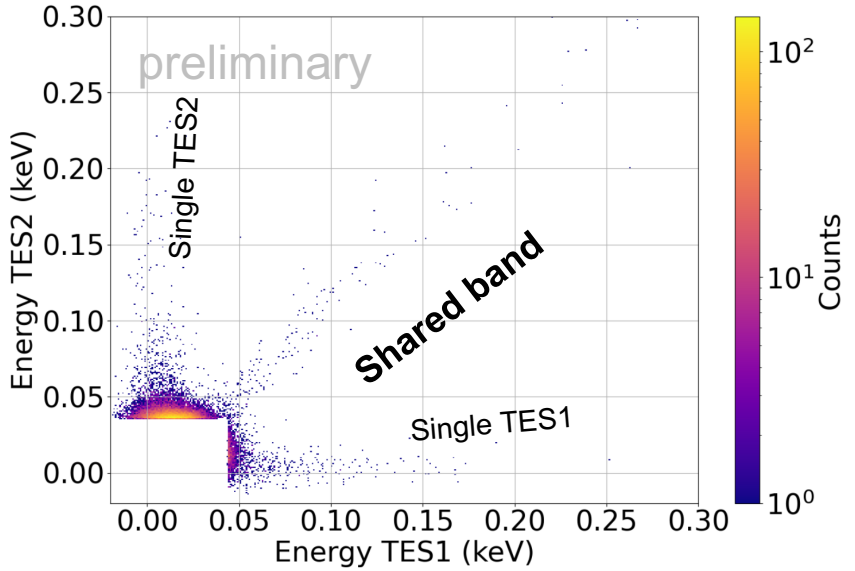
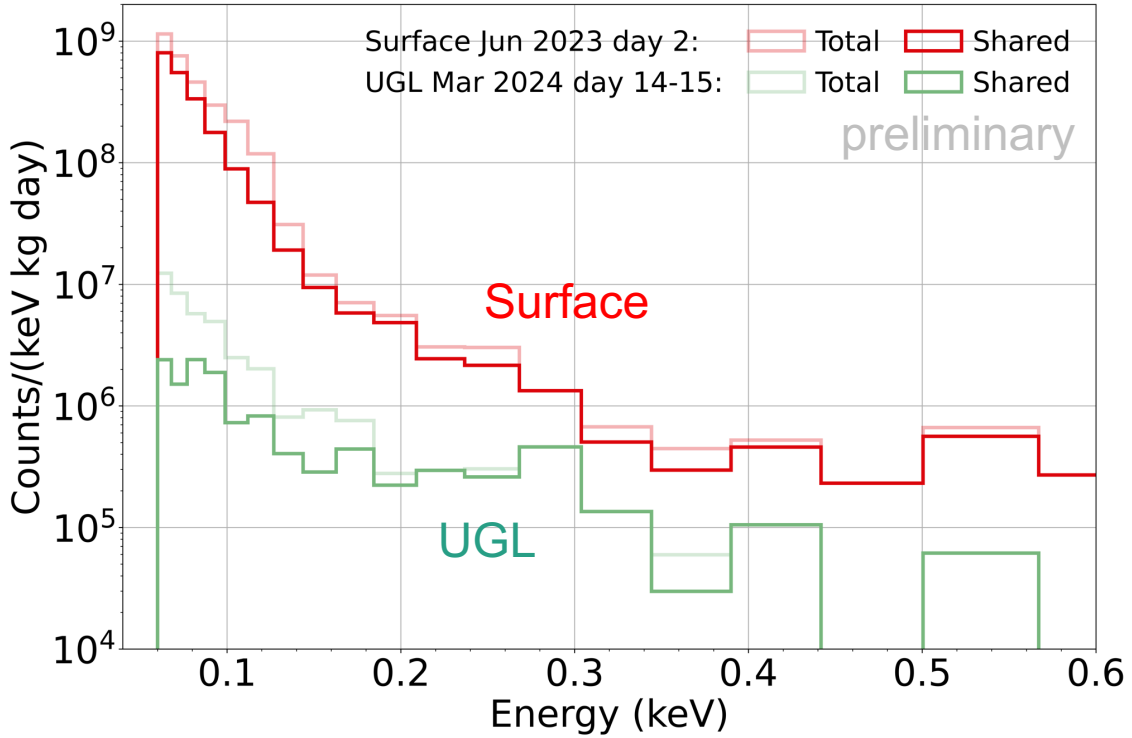
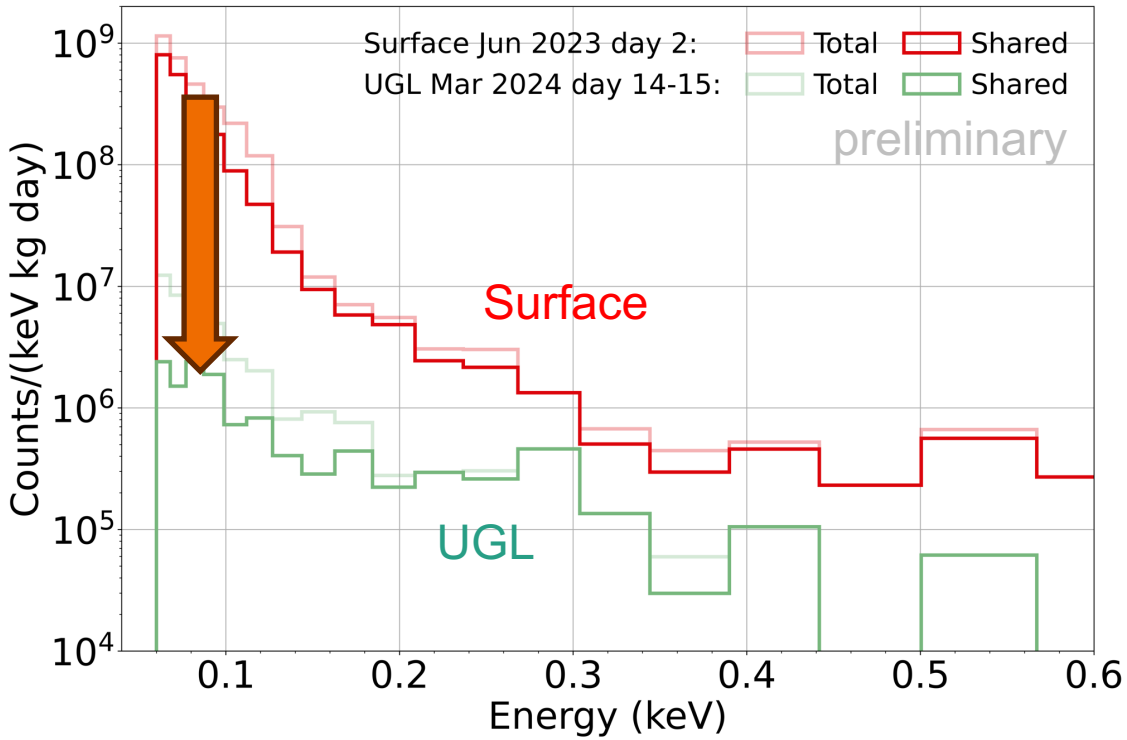






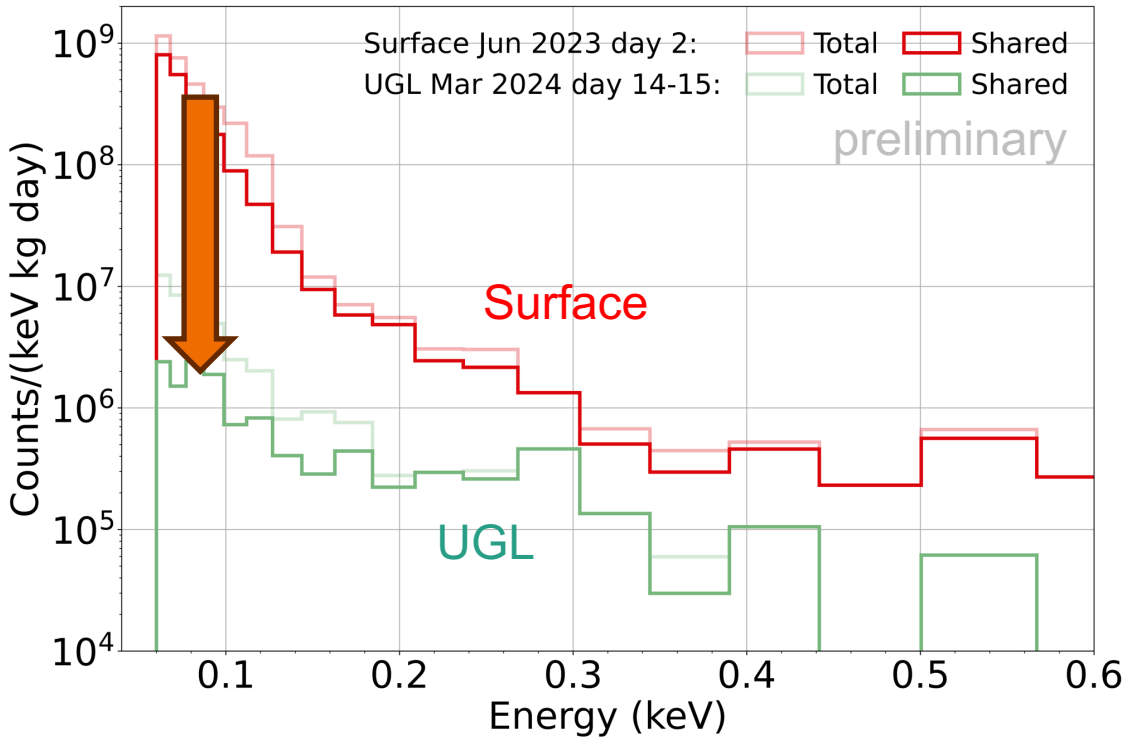
Shared band reduced by 2 orders of magnitude!

Particles, really ?



Let's check again at surface!

Particles, really ?

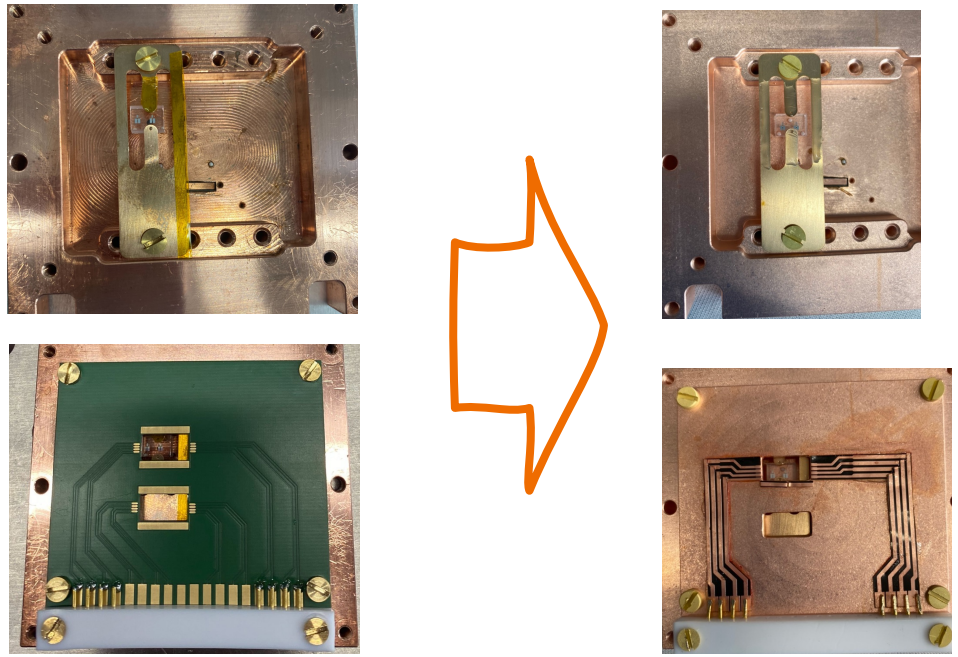


Let's check again at surface!

Before mounting again at surface…

Important detail:
scheduled cleaning procedure for NUCLEUS

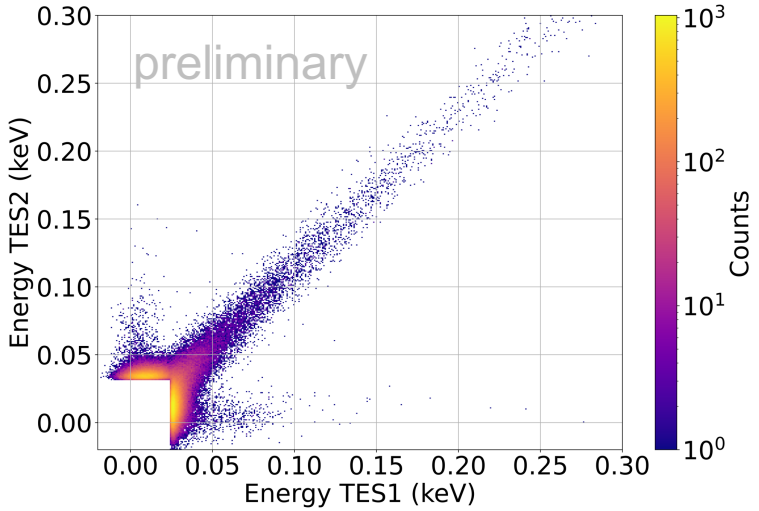
- Unmounting
- Cleaning/etching + clean PCB
- Remounting

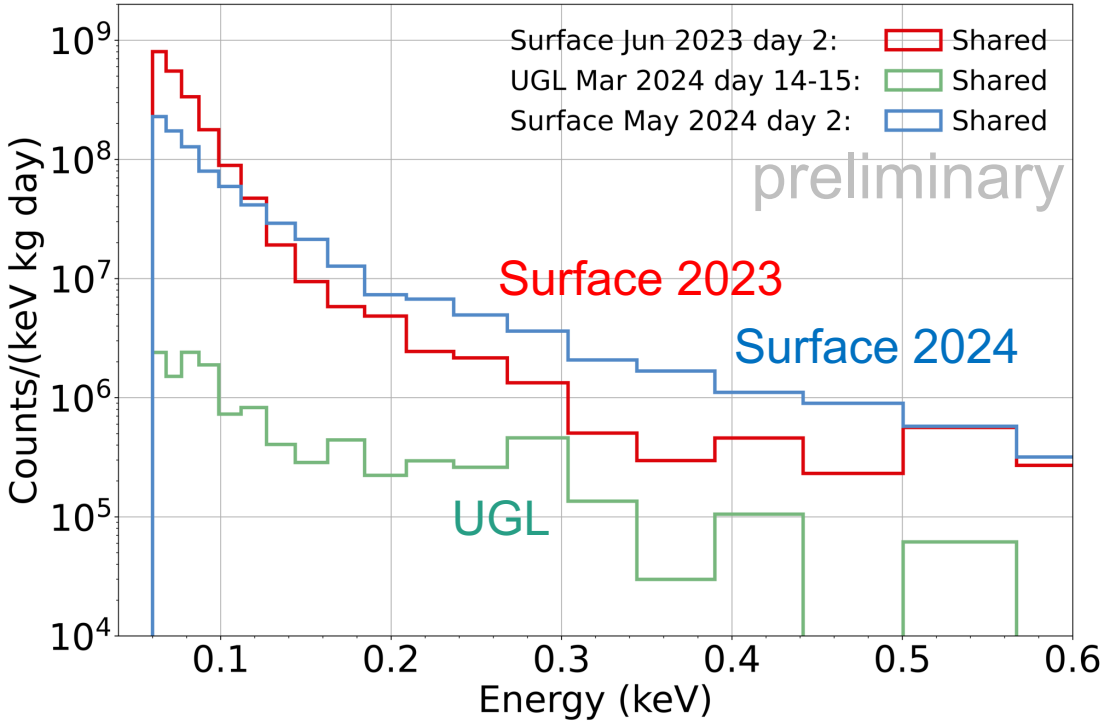


Back at Surface in May 2024

Dry dilution refrigerator at TUM
- no-shielding
- Minimal overburden (20cm of concrete)

Data taking: May 2024

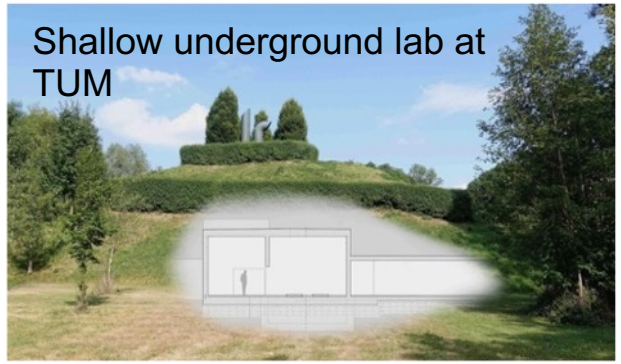




“Wow, it’s back at surface level!

So really, particles?”

AND back to the UGL in June 2024



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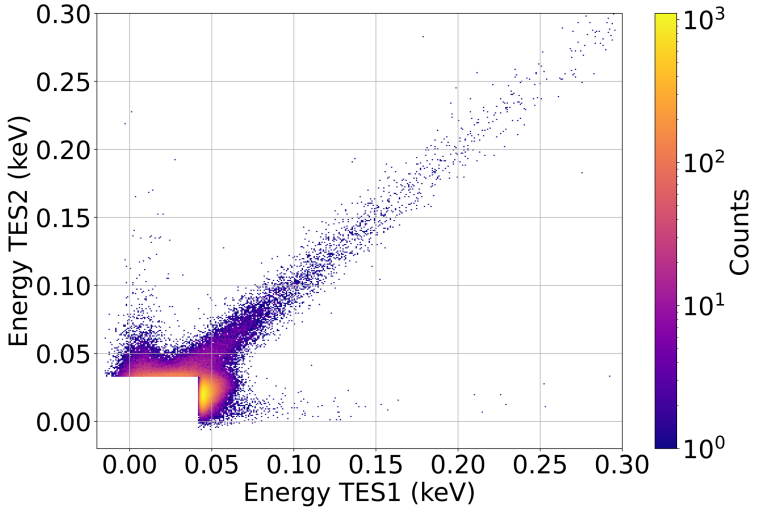
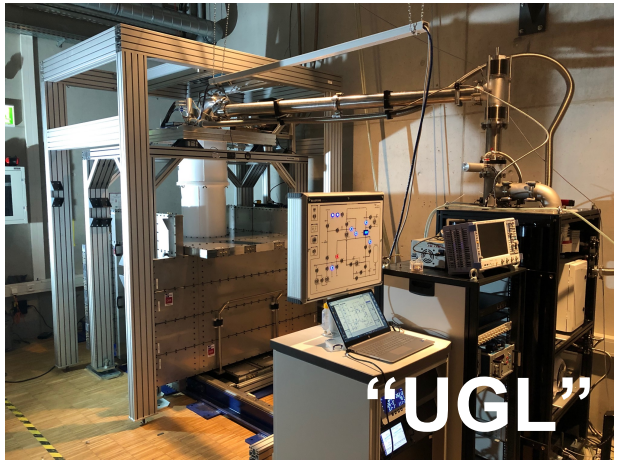
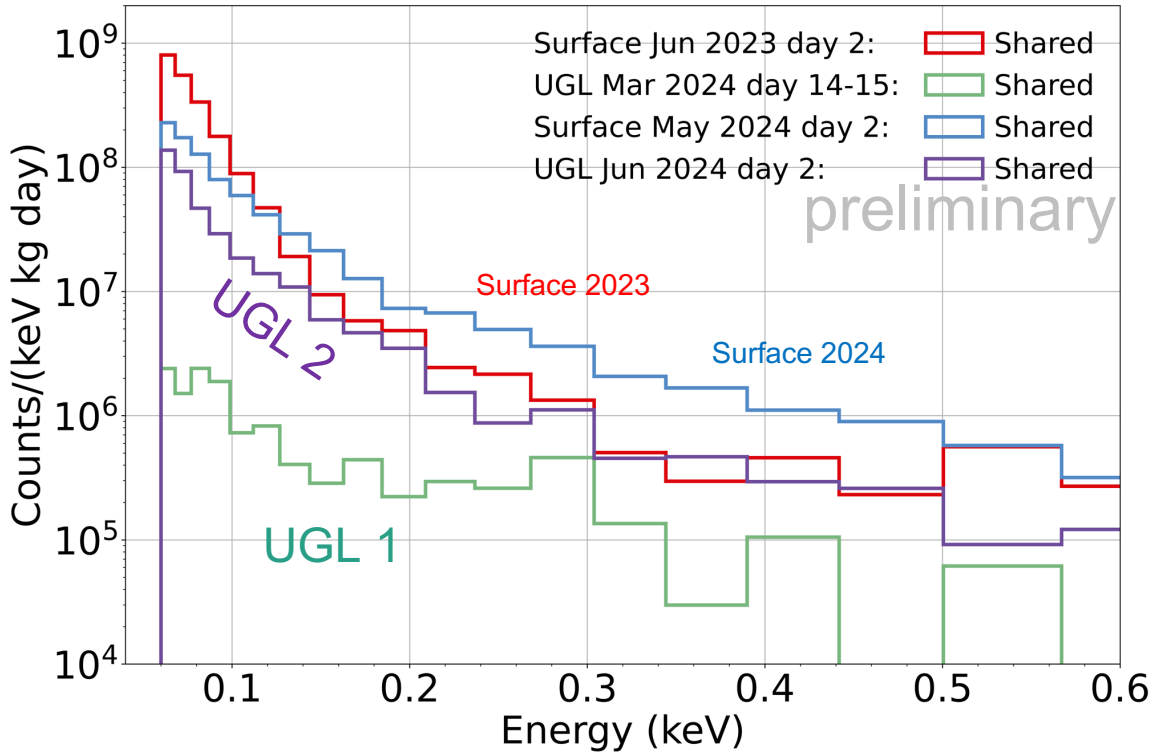
- multi-layer shielding (PE, Pb)
- 10 m.w.e. (muons /3, no cosmic n's and p's)
- data taking: June 2024



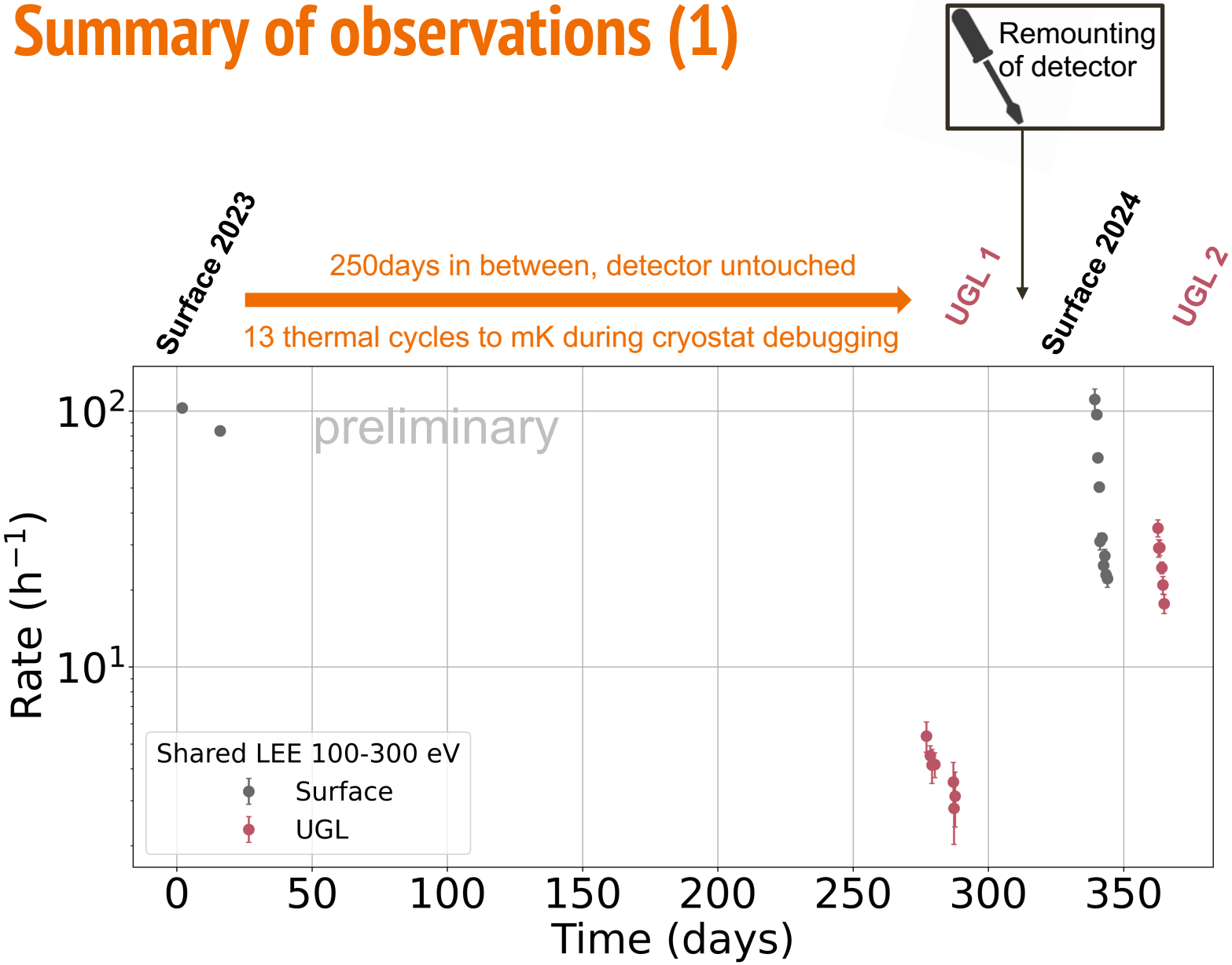


NUCLEUS setup



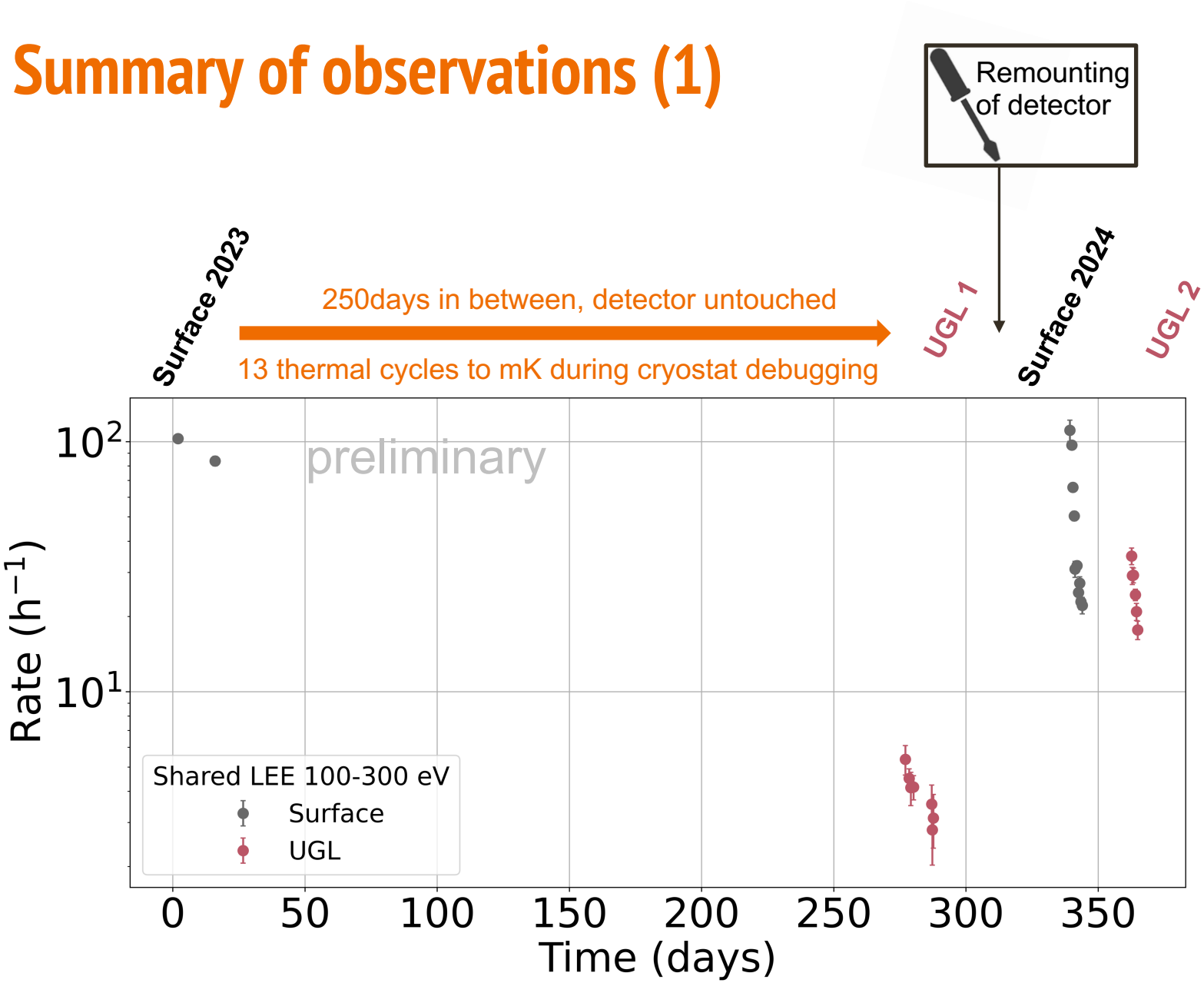
"Rate remains at Surface level "

Summary of observations (1)



Shared Excess

Summary of observations (1)

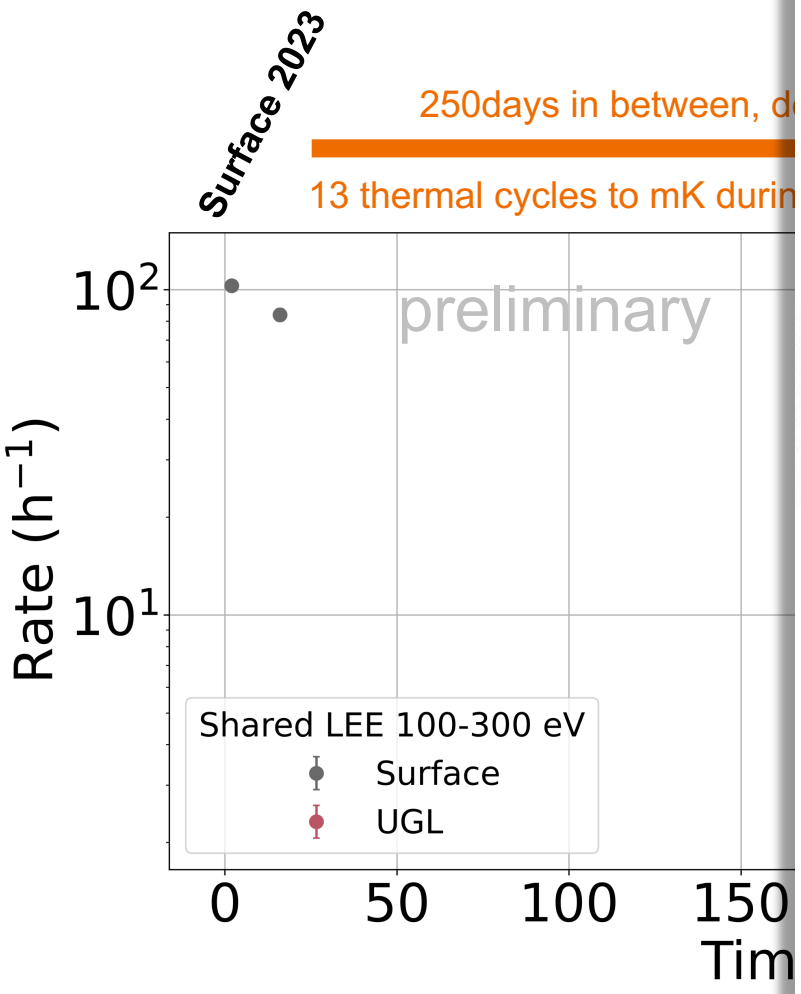


Shared Excess

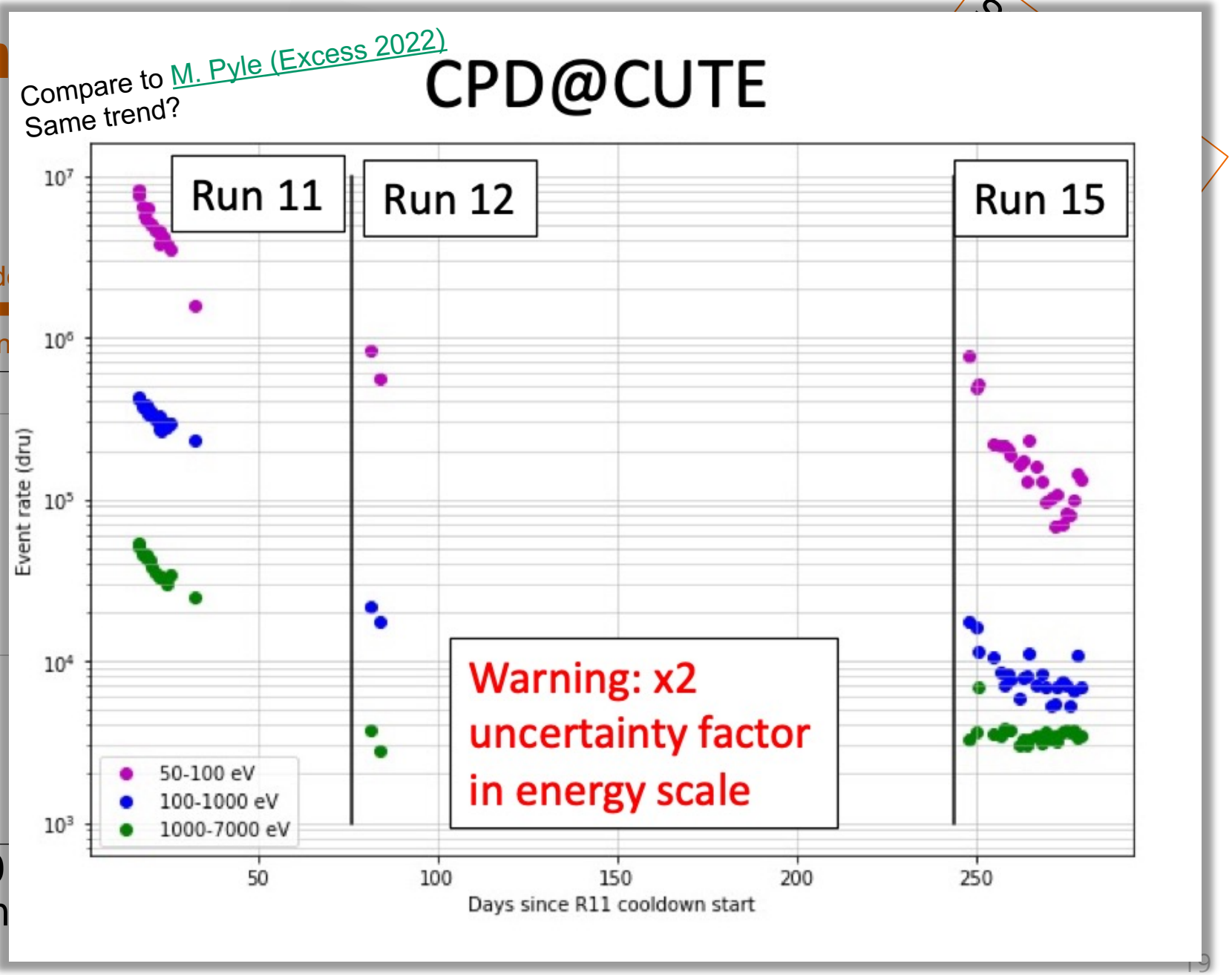
Interesting observations:

1) Excess rate seems to decay with **waiting time** or due to **cooling cycles**
2) Remounting seems to reset Excess rate

Summary of observation



Compare to M. Pyle (Excess 2022)
Same trend?



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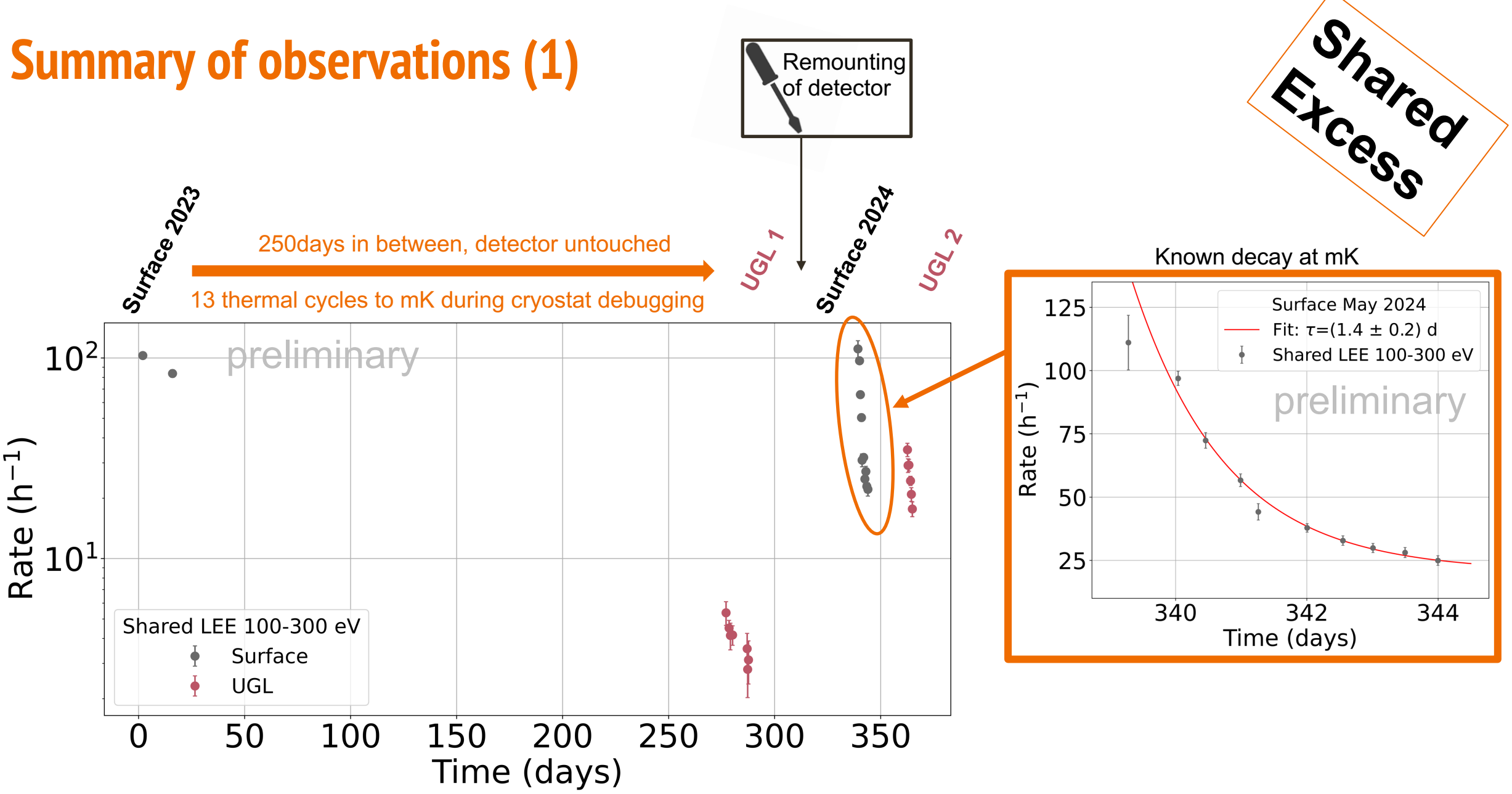
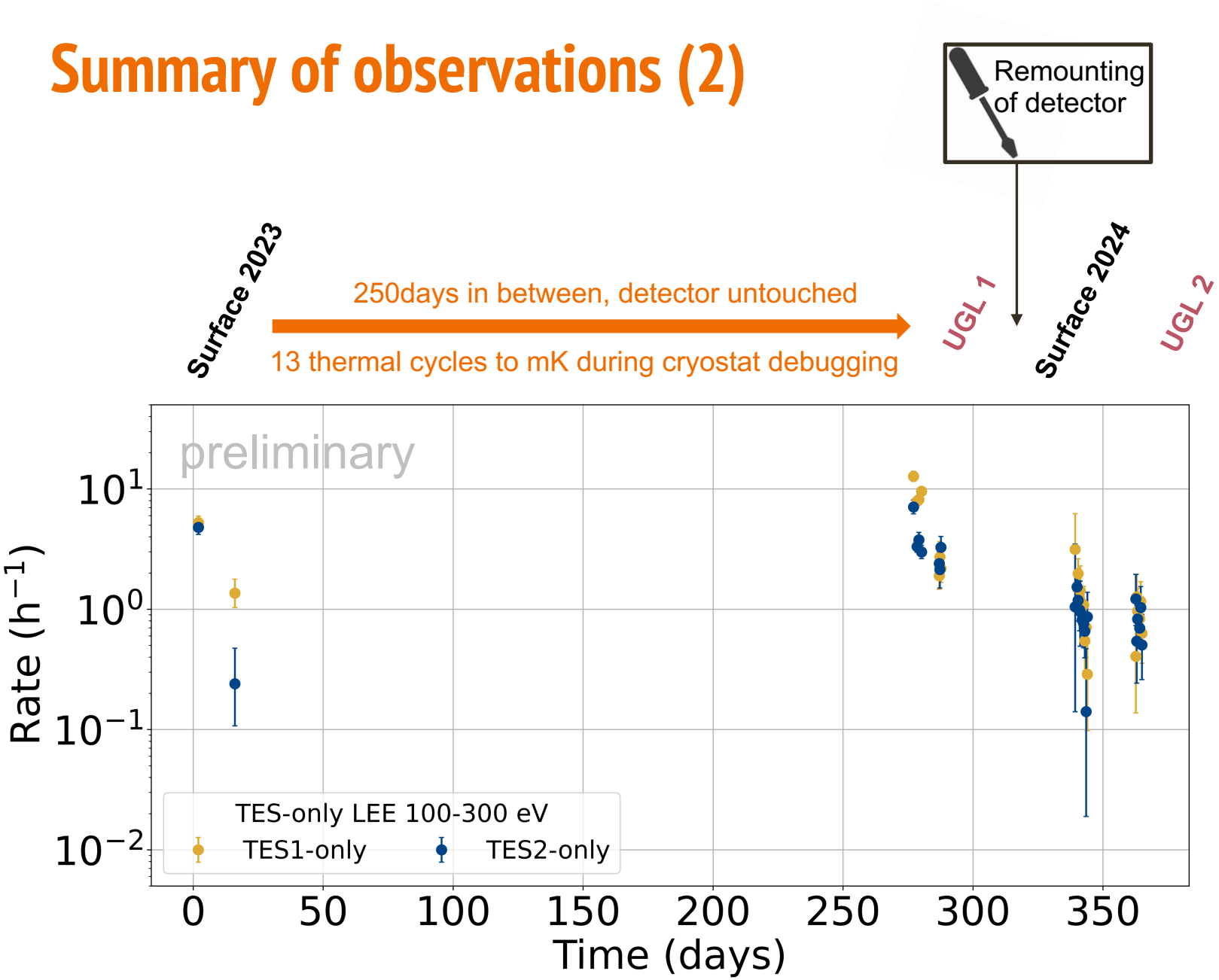


Summary of observations (2)

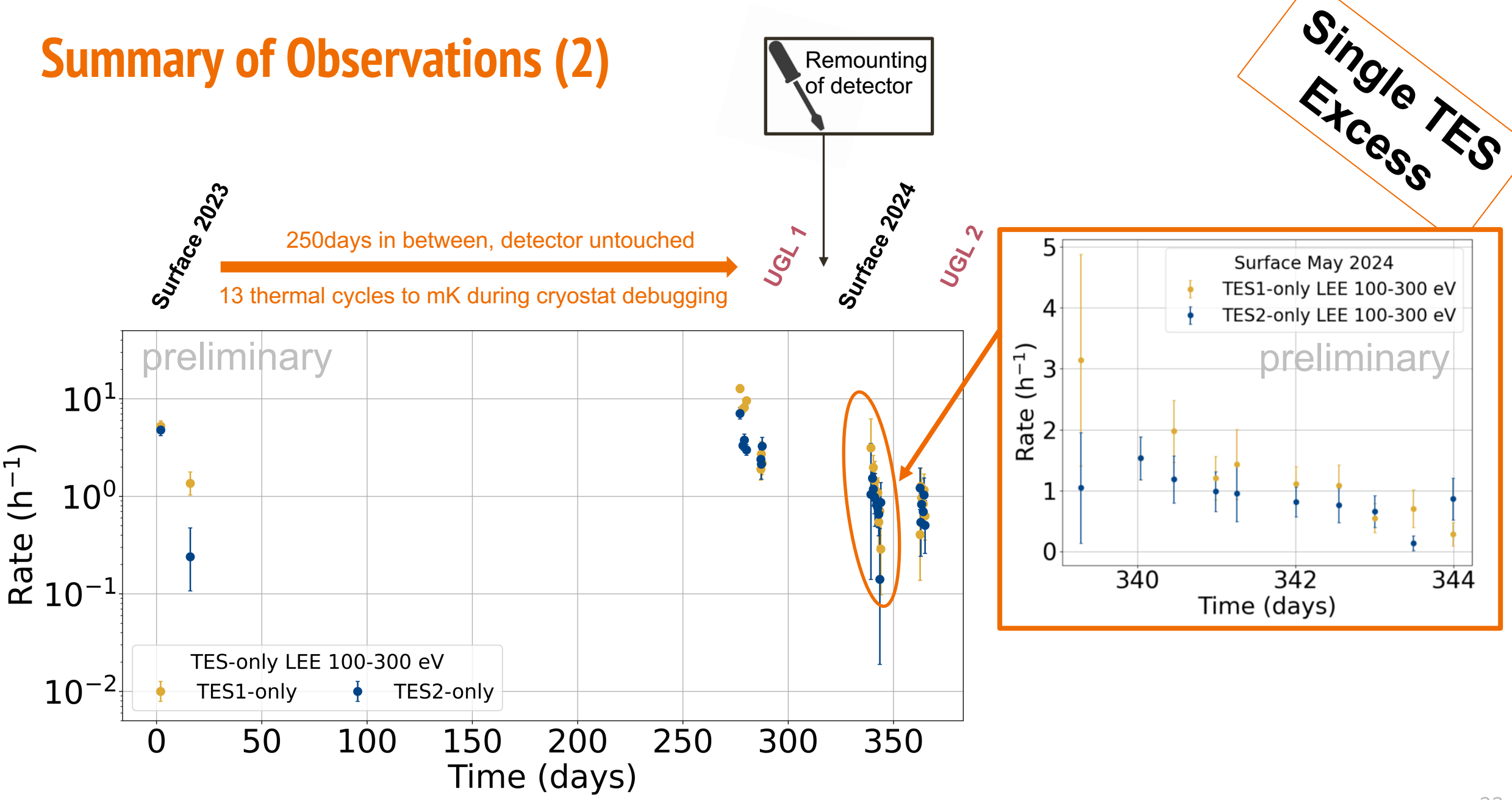
Single TES Excess



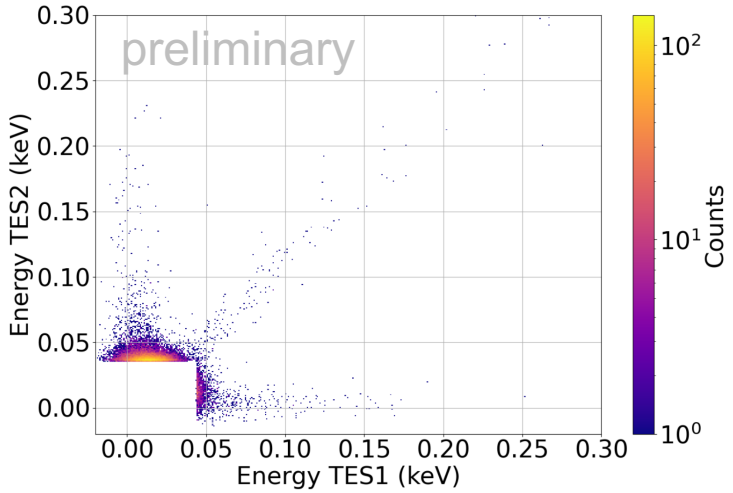
Interesting observations:

1) Single TES rate remains (almost) constant
2) Remounting seems to not affect single TES rate

Summary of Observations (2)



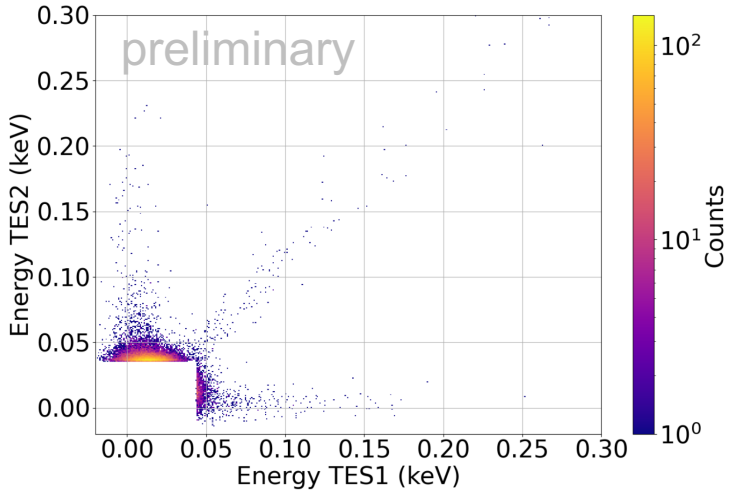
Conclusion of NUCLEUS Measurement Series



What we know:

- All observation hint towards **solid-state effect** as origin for Excess
- Double TES detectors show evidence for **TES-related Excess**
- **Time dependence** of Excess observed at cold

Conclusion of NUCLEUS Measurement Series



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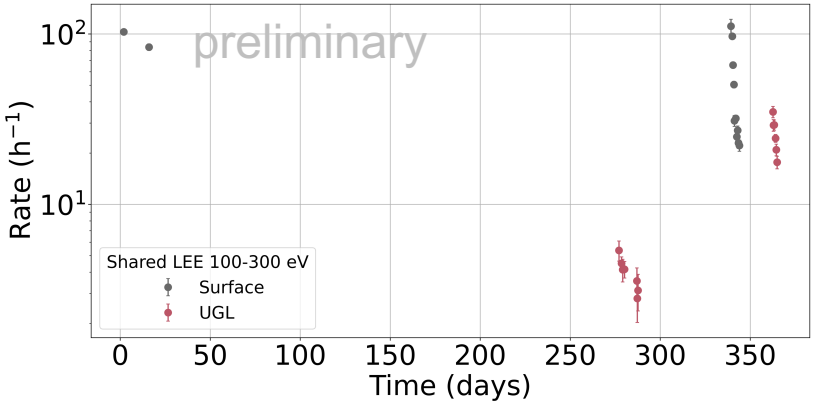


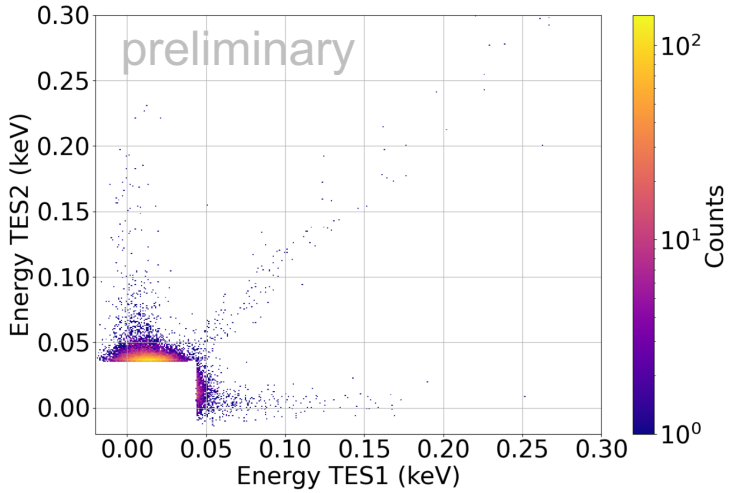
<u>Implications from new NUCLEUS measurements:</u>

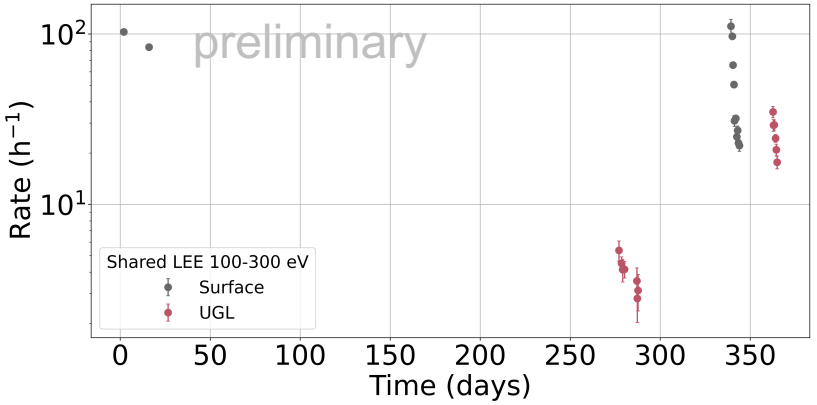
- Particle origin is not dominant at surface locations!
- Shared-band Excess: change in rate observed.
- **Reset of shared-band Excess by re-assembling the detector**
- Single TES Excess: no significant time dependence observed
- Single TES Excess seems unaffected by re-assembling the detector

➢ **Single-TES Excess** increasingly **dominate** as shared rates decay

➢ **Double TES detectors are required** to reach low Excess rates

Conclusion of NUCLEUS Measurement Series





What we know:

- All observation hint towards **solid-state effect** as origin for Excess
- Double TES detectors show evidence for **TES-related Excess**
- **Time dependence** of Excess observed at cold

Implications from new NUCLEUS measurements:

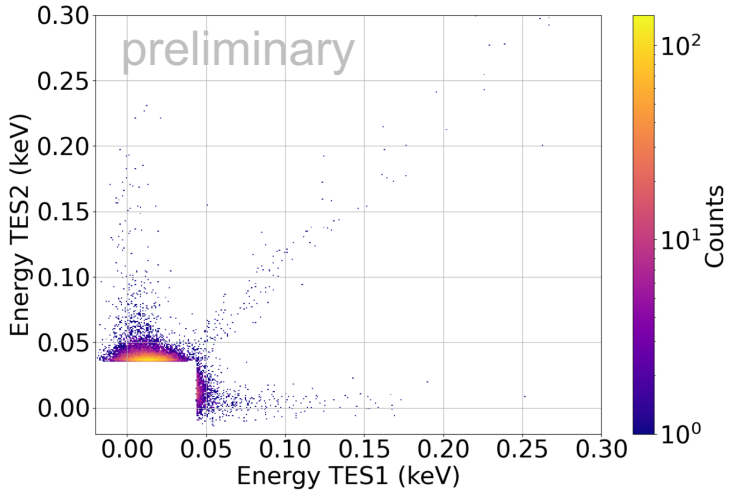
- Particle origin not dominant at surface locations!
- Shared-band Excess: change in rate observed
- **Reset of shared-band Excess by re-assembling the detector**
- Single TES Excess: no significant time dependence observed
- Single TES Excess seems unaffected by re-assembling the detector

➢ **Single-TES Excess** increasingly **dominate** as shared rates decay
➢ **Double TES detectors are required** to reach low Excess rates

Speculations:

- Decay of shared-band Excess at 300K ?
- Reduction of shared-band Excess due to thermal cycles?
- After rejection of TES-related Excess → external stress on detector dominant?
- Crystal internal stress unlikely ?
- Gravity-bearing holder OR active holders – the way to go?

Conclusion of NUCLEUS Measurement Series



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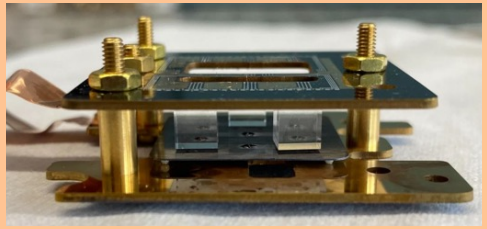
Our track to fight the **Excess**

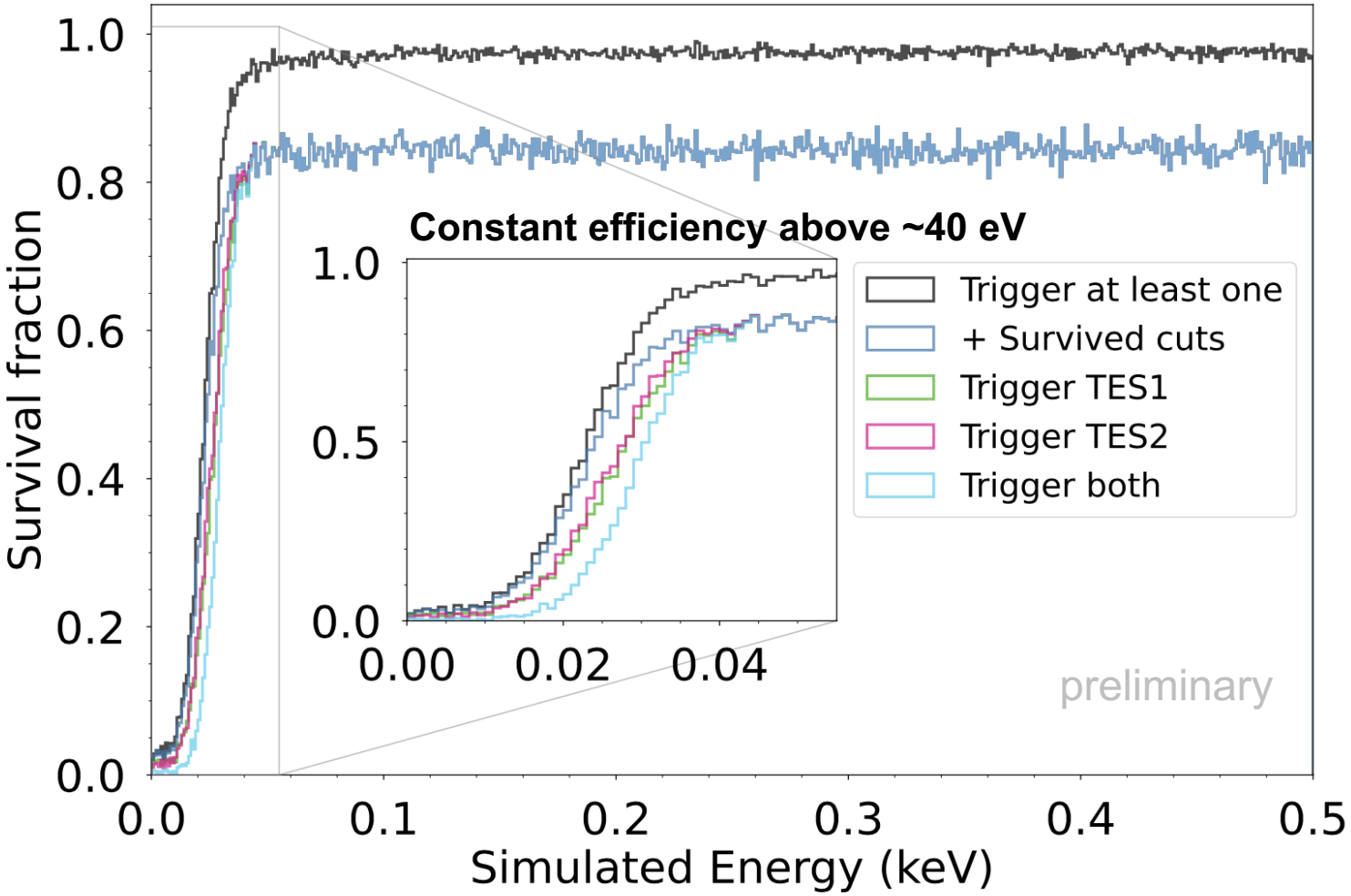
- **Use Double-TES** readout to reject Single-TES Excess
- Perform long Background Run (Jul-Sept) to **study Excess time dependence**
- Study **impact of thermal cycles**
- **Use active holders** to study/reject holder-related Excess sources



Active NUCLEUS detector holder in the pipeline

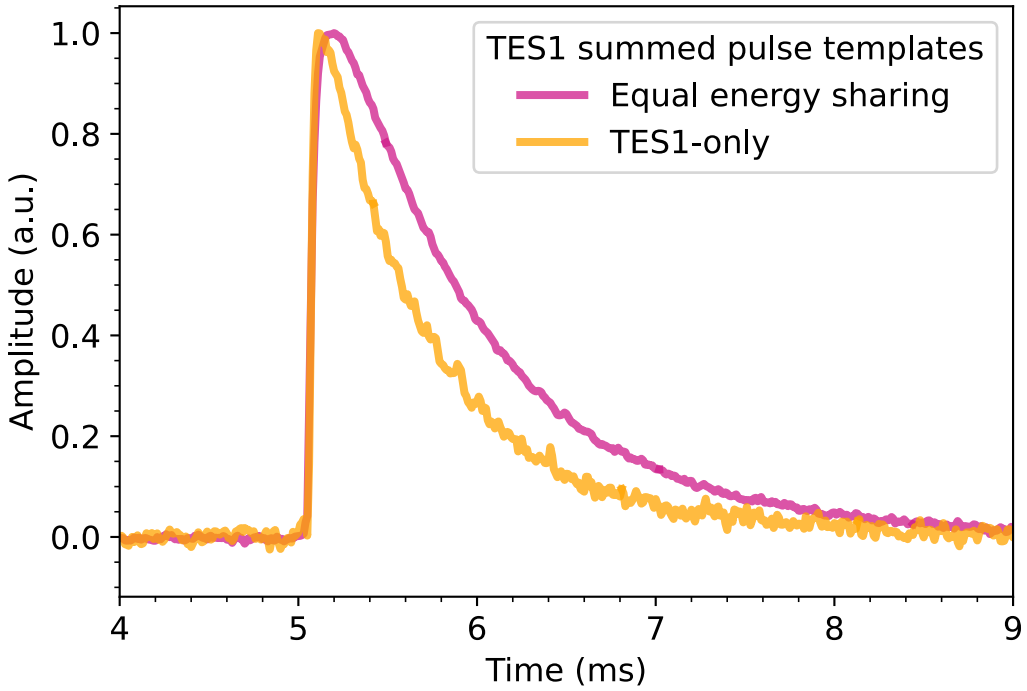
Backup slides

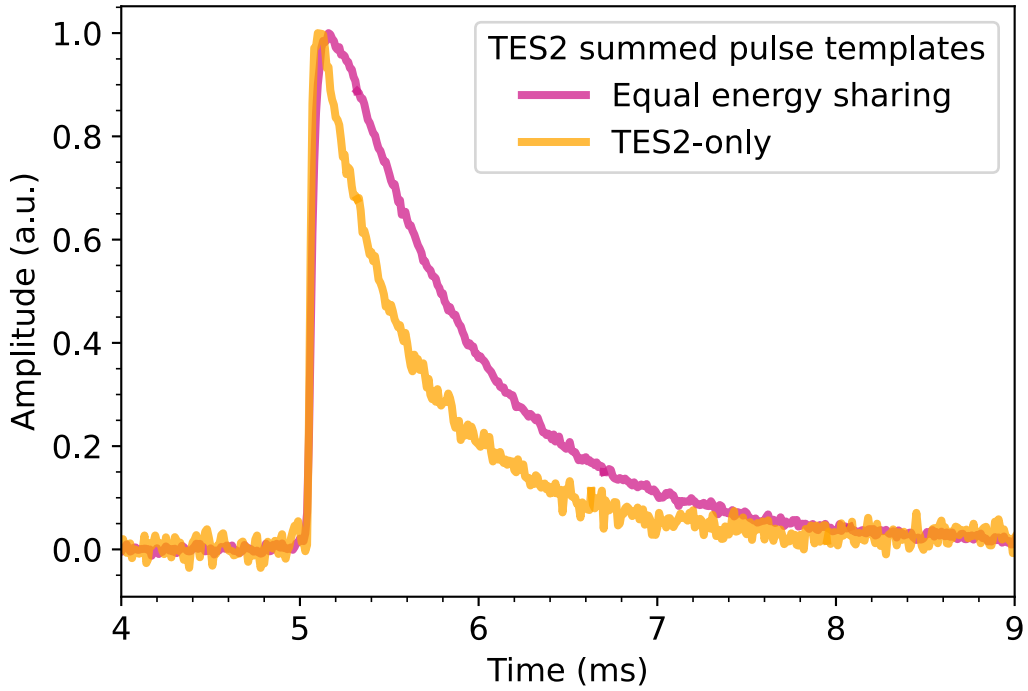
Trigger and cut efficiency



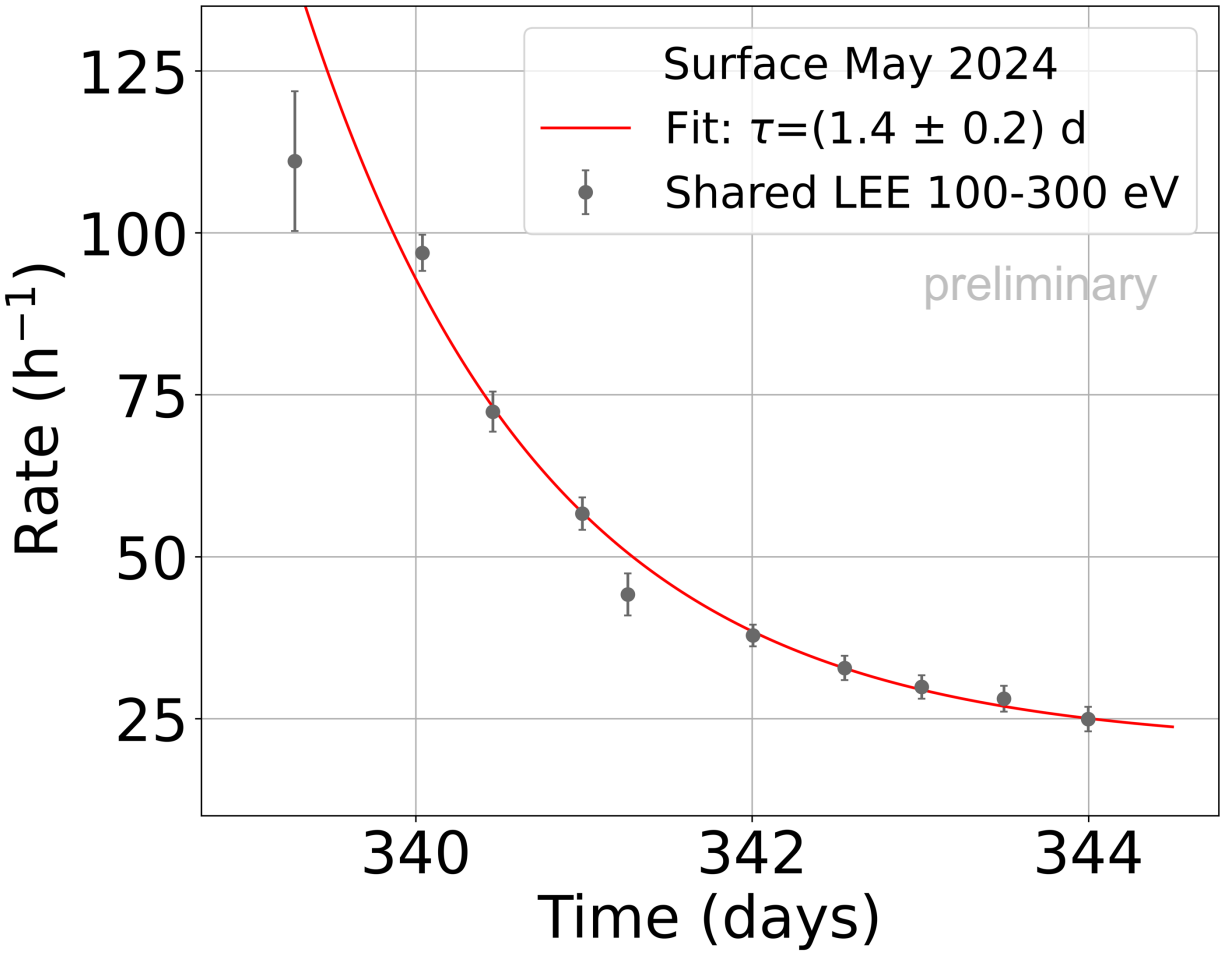
- Simulate simultaneous events in the data stream
- Apply triggering and analysis cuts
- Efficiency is the survived fraction

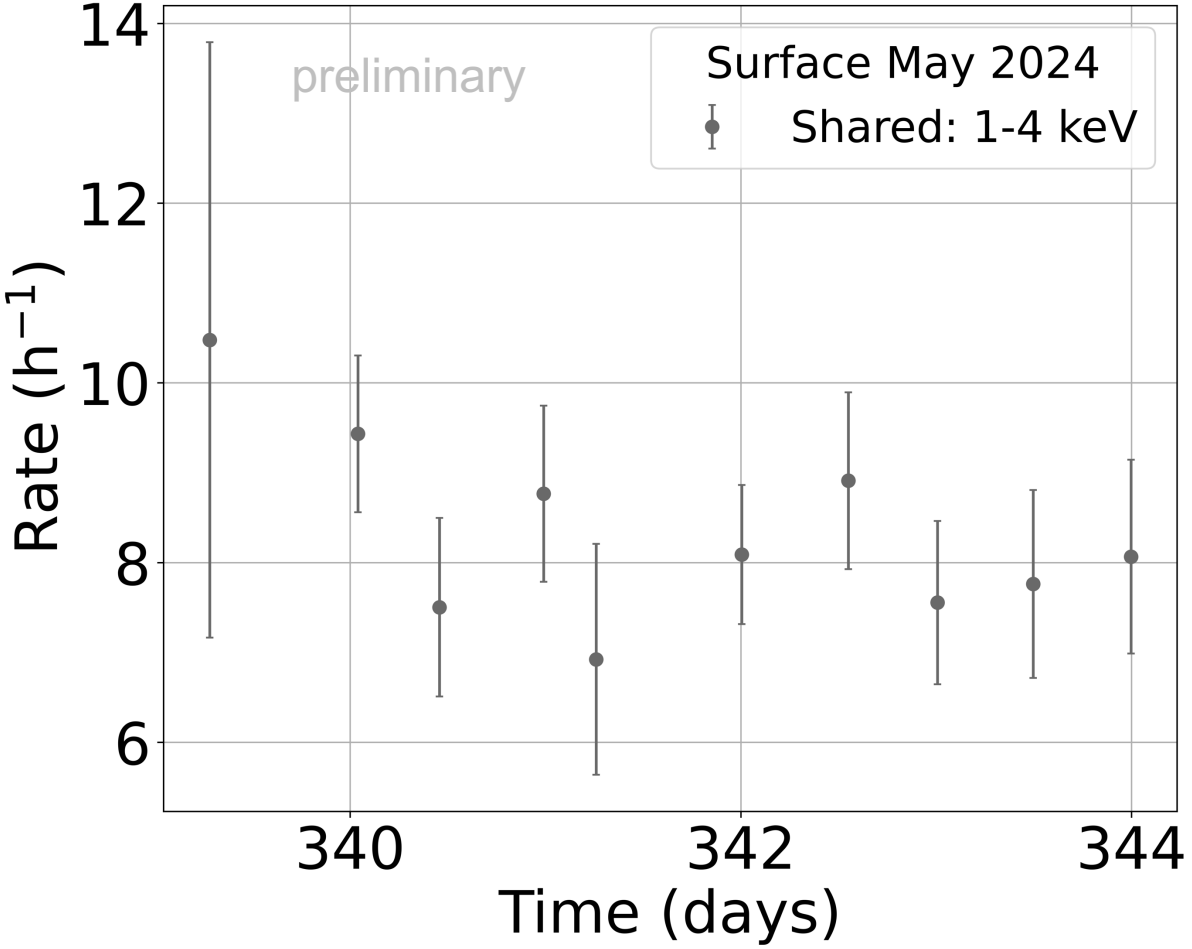
Pulse shapes





Rate evolution

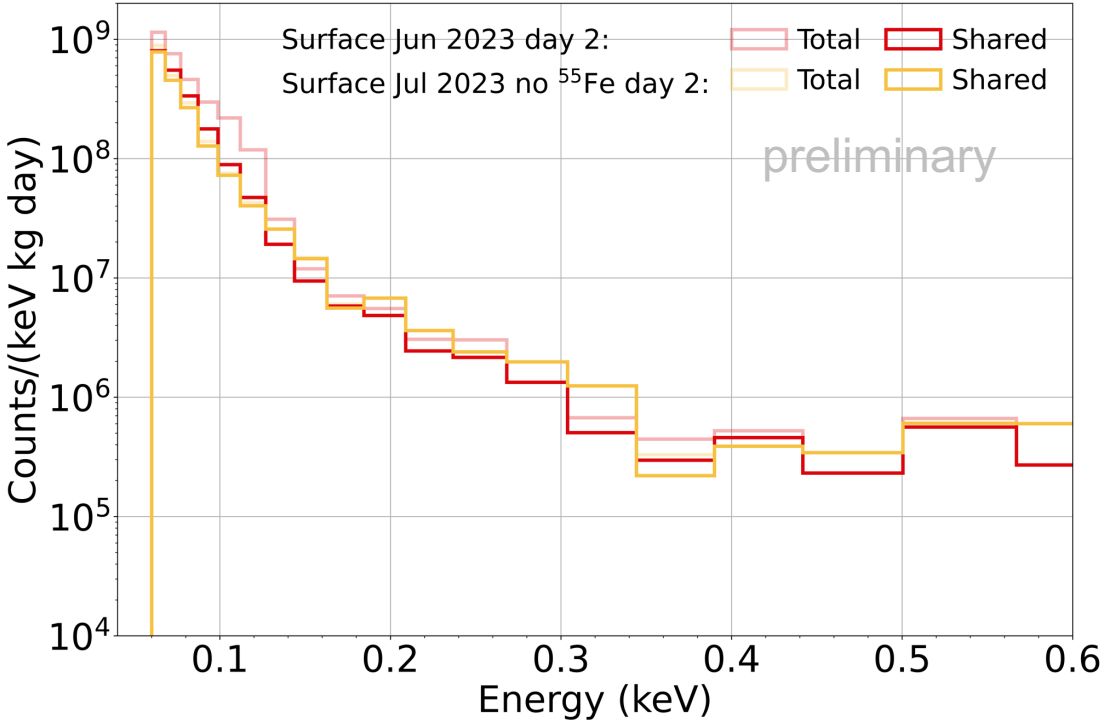




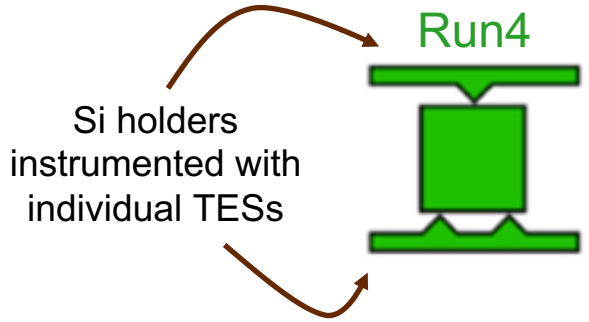
Surface measurements July 2023 no Fe source

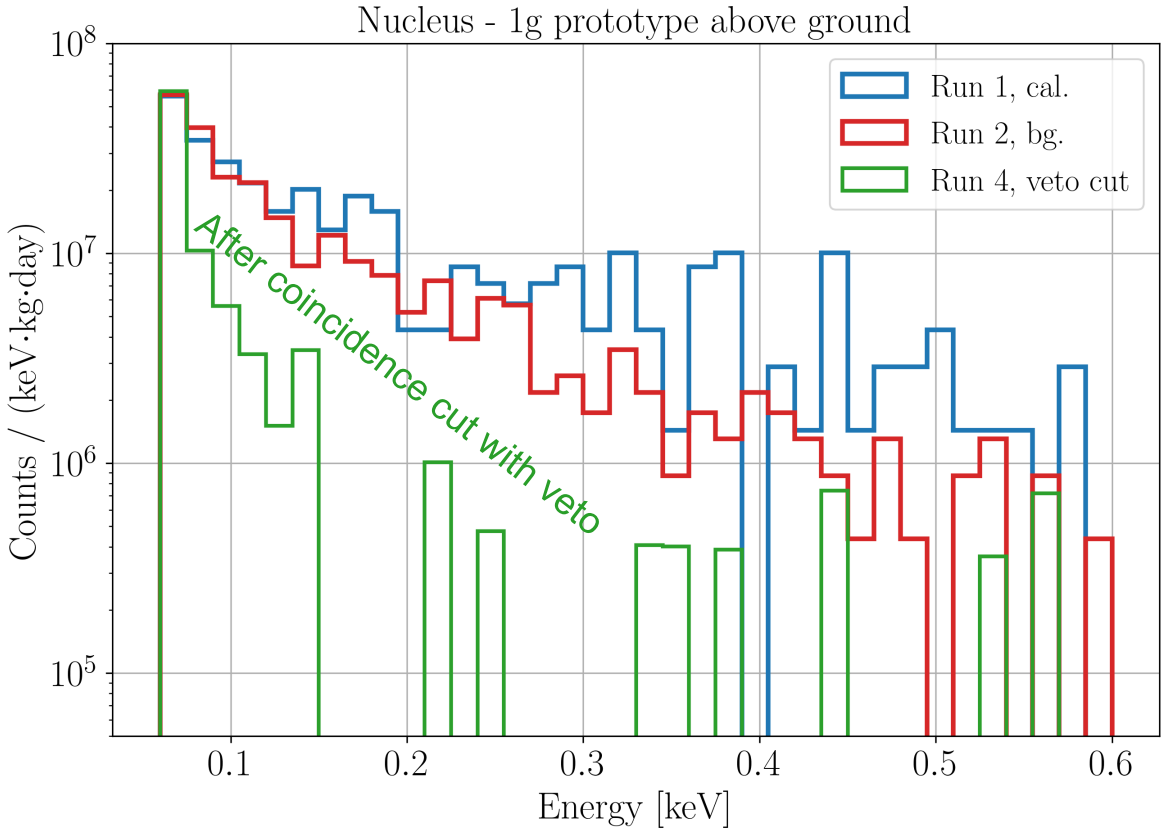
Dry NUCLEUS cryostat, no-shielding (1st floor lab)

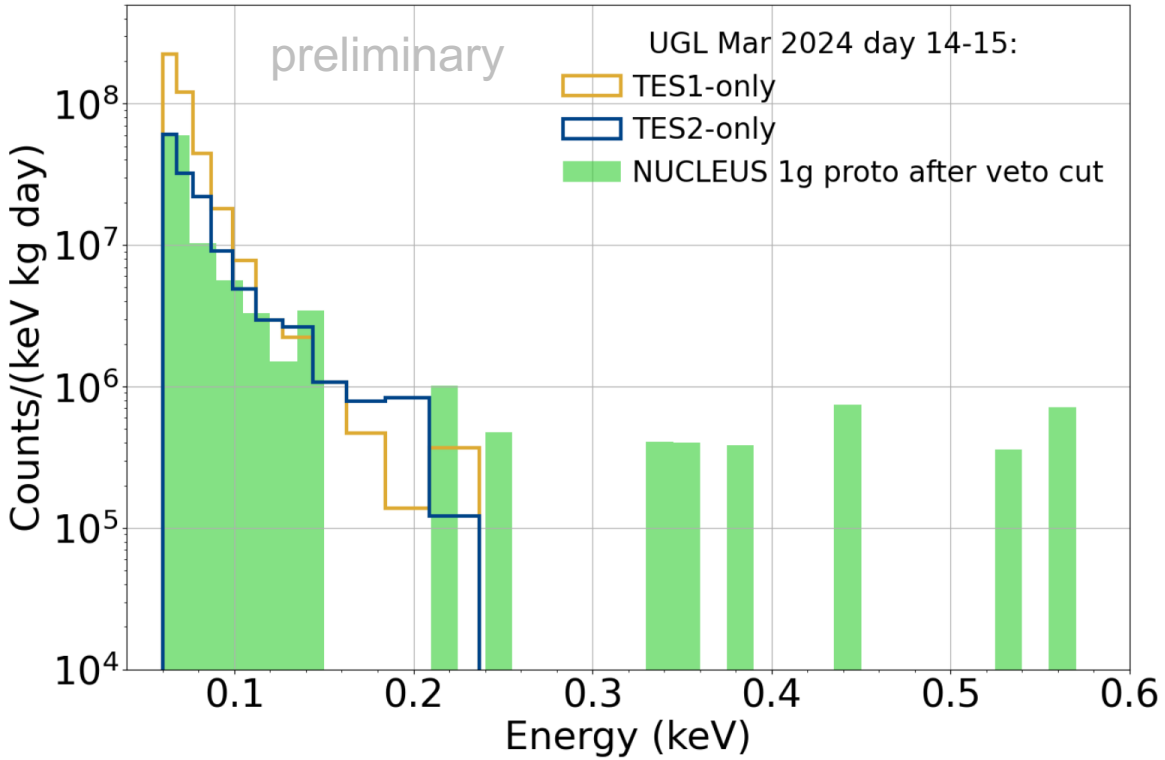
Data taking: July 2023 @ TUM



NUCLEUS prototype measurements



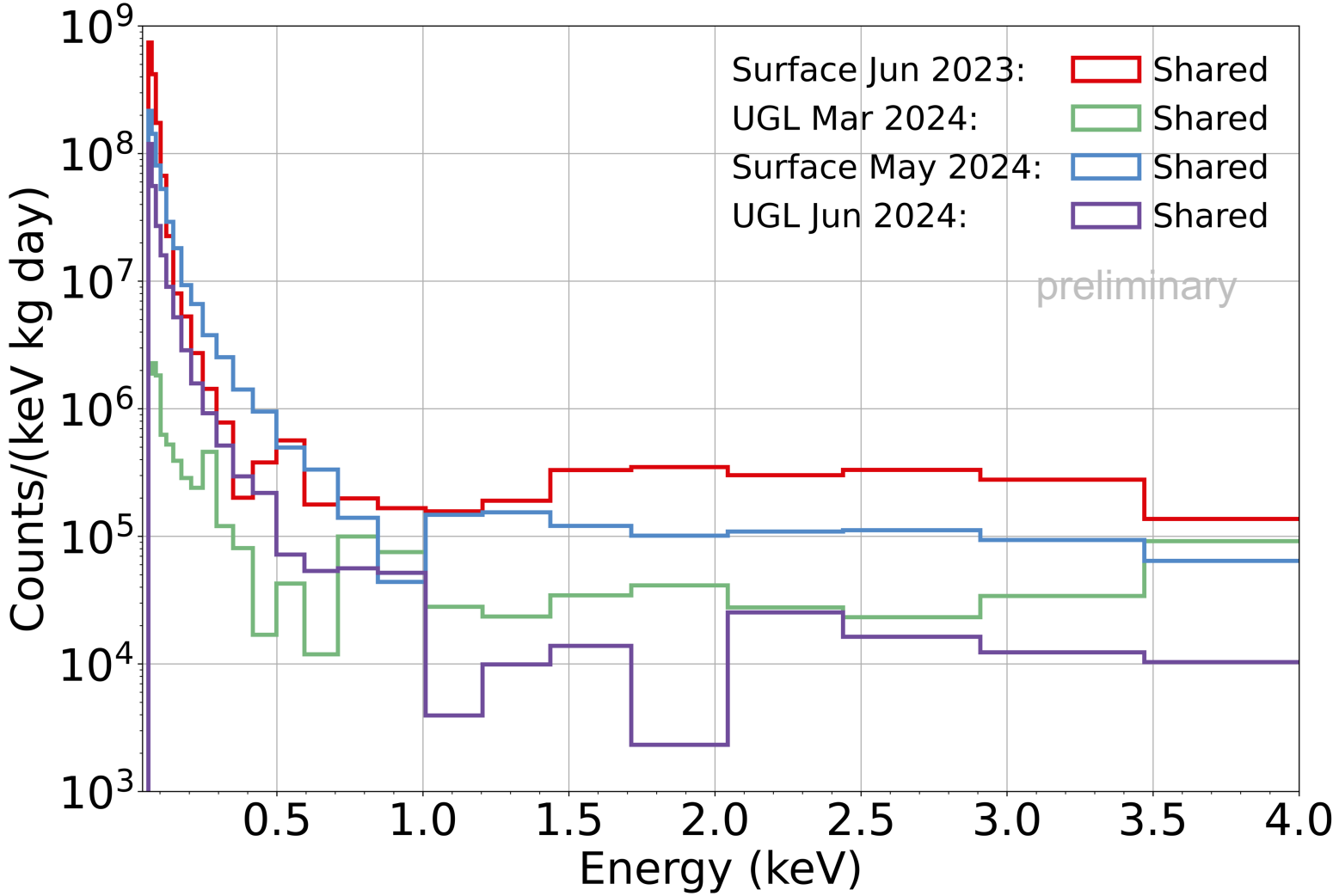




J. Rothe @EXCESS 20221

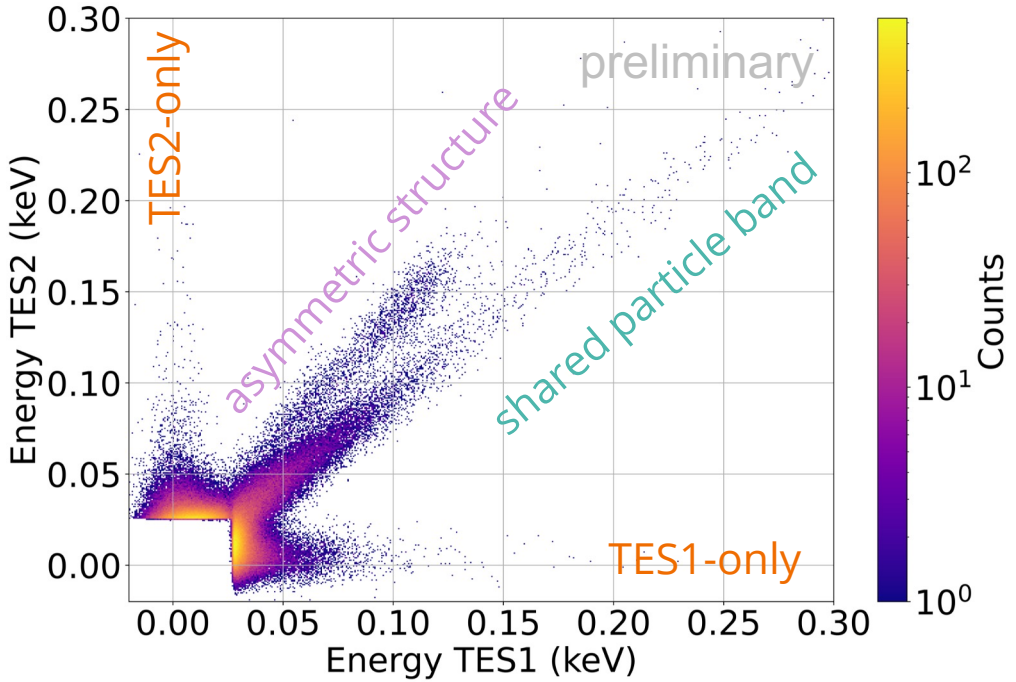
J Low Temp Phys 199, 433–440 (2020)

Background at higher energies



Low energies: events with a signal in only one of the TES are observed.

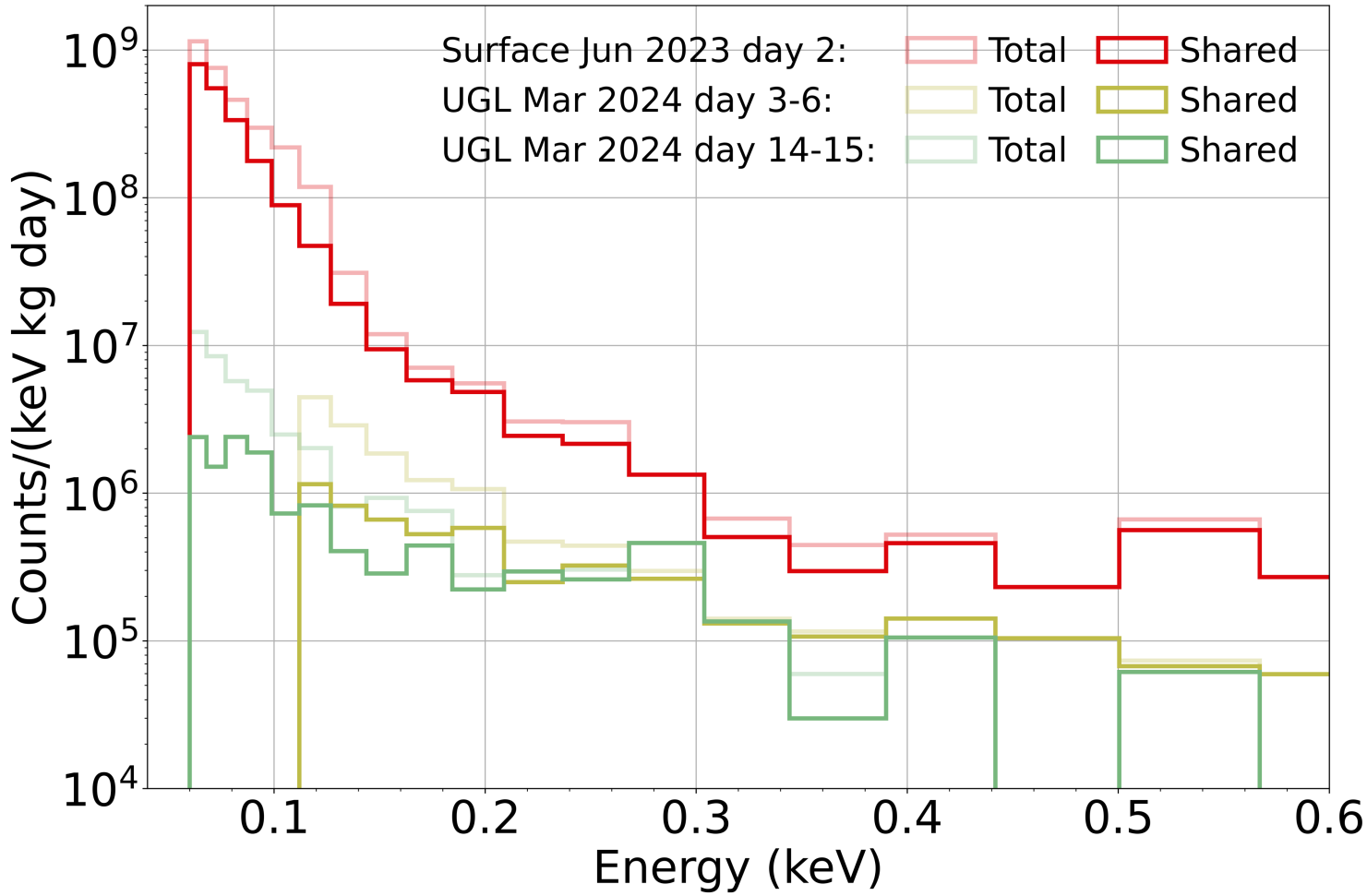
Events after the quality and pulse shape cuts



Additional structure with an asymmetric energy sharing between two TES.
Position dependence? (not yet understood).

Majority of excess events above 50 eV belong to the shared particle band.

UGL March 2024



Consistency between 2 independent analyses