Direct Dark Matter Search with the CRESST III Experiment

Status and Prospects

Scientific Committee Meeting
October 3, 2024

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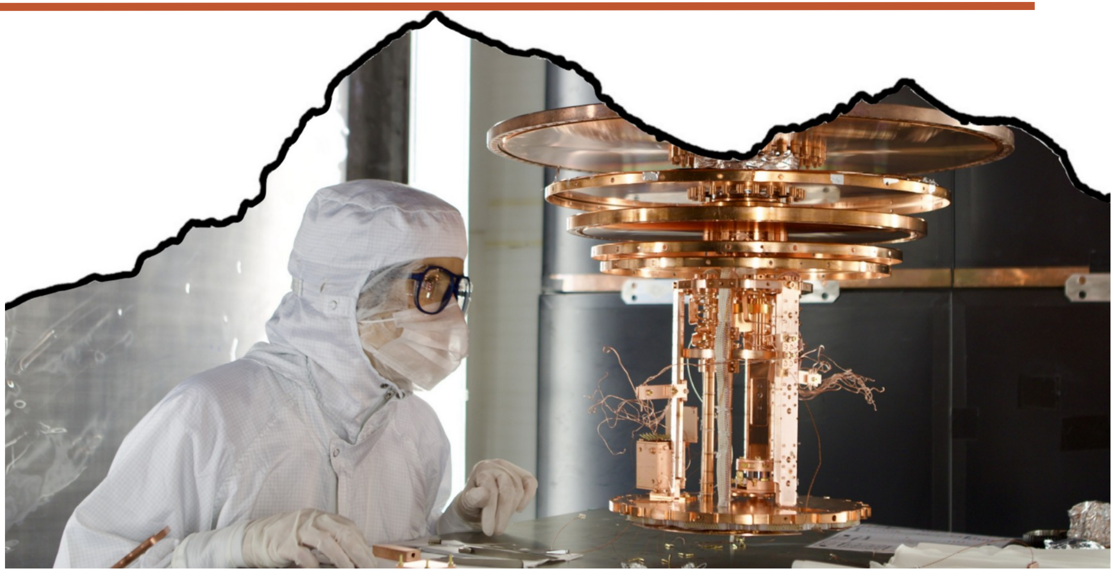
on behalf of the CRESST collaboration

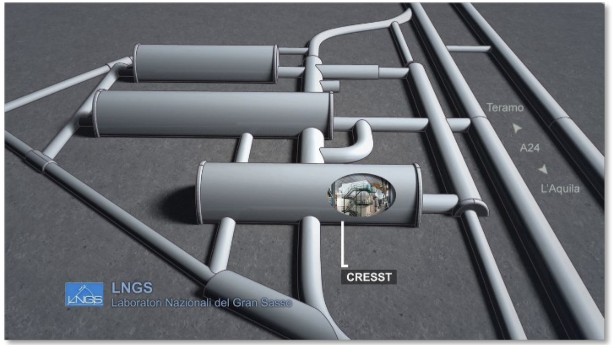


The CRESST Collaboration

~60 members
9 institutions
5 countries

Cryogenic **R**are **E**vent **S**earch with **S**uperconducting **T**hermometers

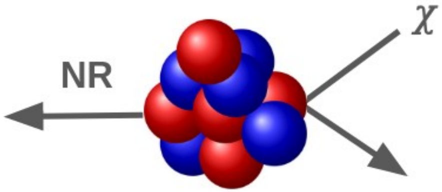
Located in hall A

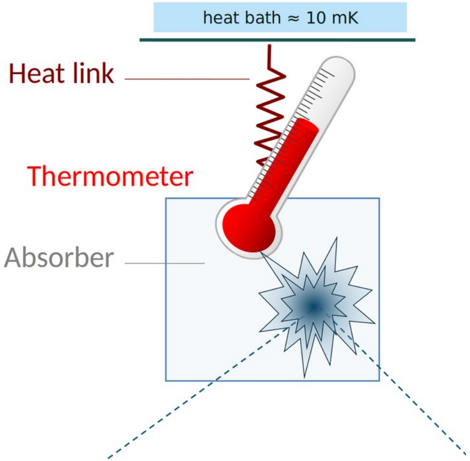


COMENIUS UNIVERSITY BRATISLAVA · UNIVERSITÄT HEIDELBERG ZUKUNFT SEIT 1386 · HEPHY INSTITUTE OF HIGH ENERGY PHYSICS · TU WIEN · INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso · MAX PLANCK INSTITUTE FOR PHYSICS · EBERHARD KARLS UNIVERSITÄT TÜBINGEN · UNIVERSITY OF OXFORD · TECHNISCHE UNIVERSITÄT MÜNCHEN

The CRESST Experiment

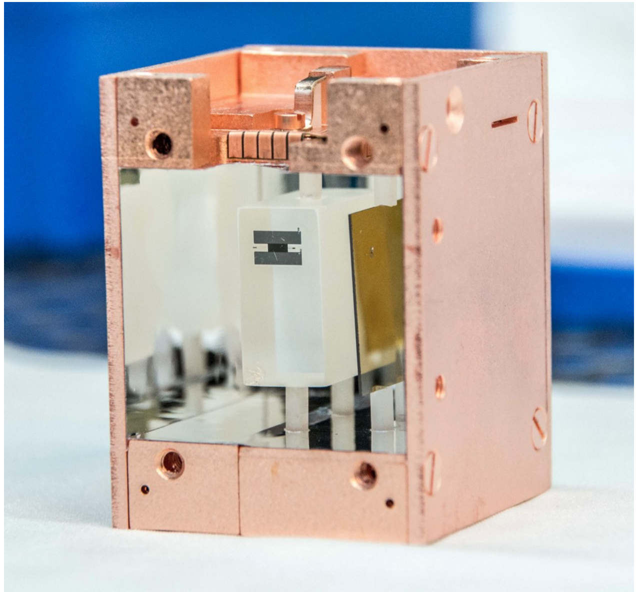
- Detects potential DM particles via scattering off nuclei
- A particle interaction causes an energy deposition in the crystal
  → $\Delta T = \Delta E/C$
- Temperature measurement via Transition Edge Sensor (TES)





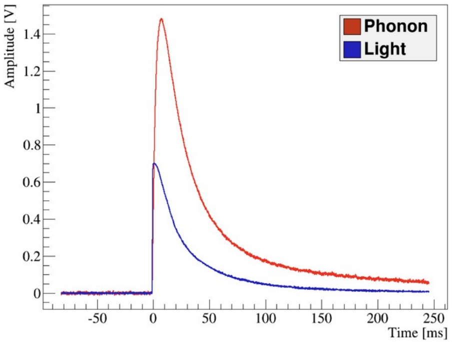
CRESST III Detectors

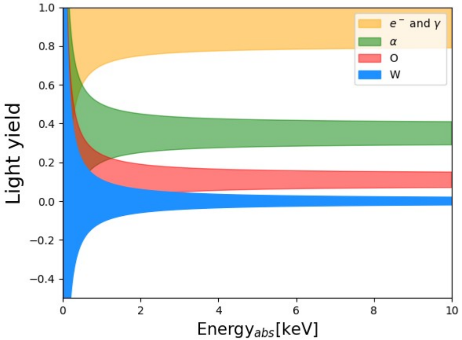
Aimed at detecting sub-GeV DM



Standard Detector:

- Scintillating $CaWO_4$ crystal as main absorber (2x2x1) cm^3
- Additional light detector for active background discrimination
- Simultaneous readout of phonon and light channels

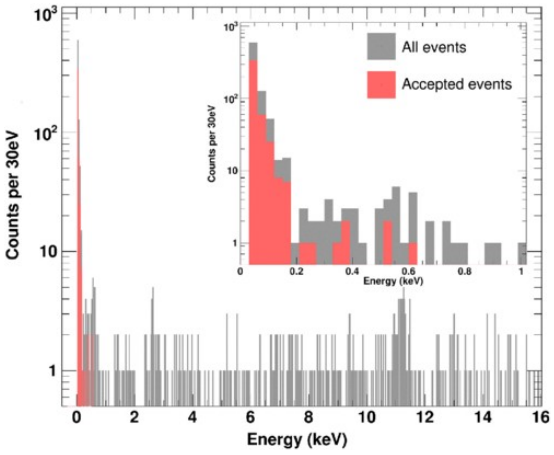




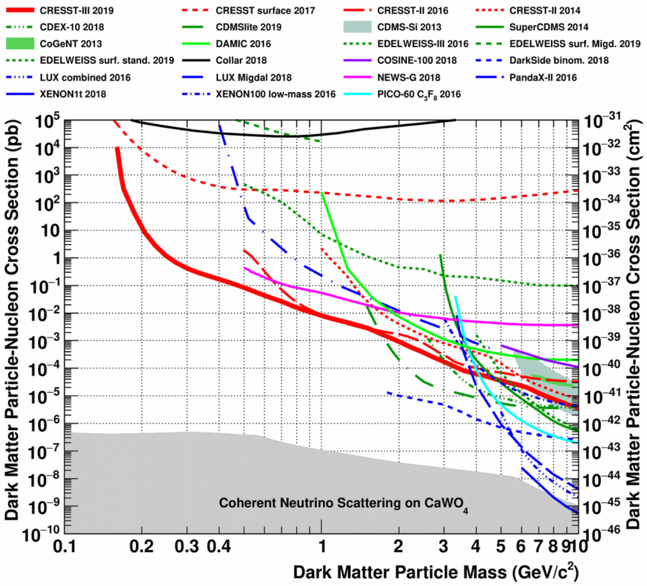
Reaching Low Energies

- Thanks to the CRESST III detector design we reached a nuclear recoil energy threshold of **30.1 eV**

Phys. Rev. D 100, 102002



We observed an excess of events of unknown origin **“Low Energy Excess”** (LEE)



Sensitivity limited by LEE

- Following run → dedicated **modifications** to the standard CRESST III detector design
→ probe possible LEE origins

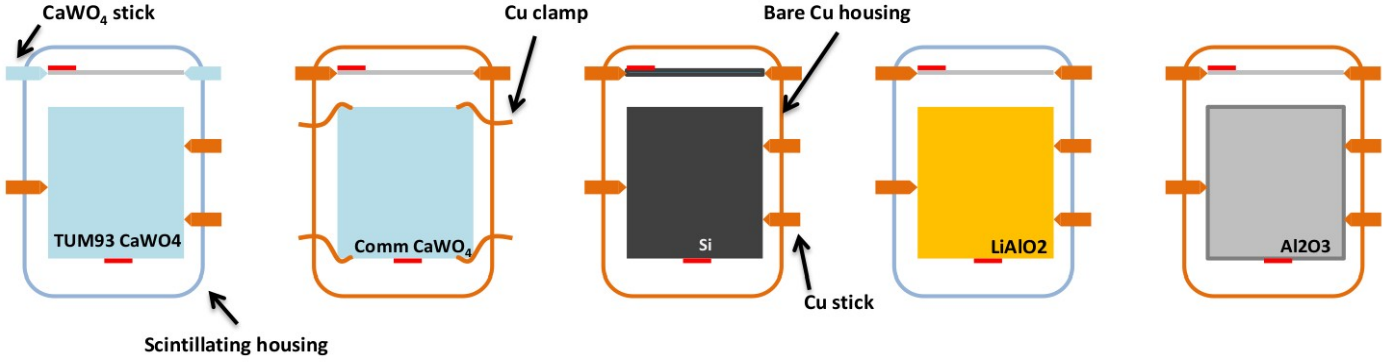
Possible Origins of the LEE

Related to target material?

Depending on crystal growth parameters?

Related to scintillating materials?

Dedicated modifications:



Caused by holder?

Depending on detector geometry?

Possible Origins of the LEE

Related to target material?

Tested several materials

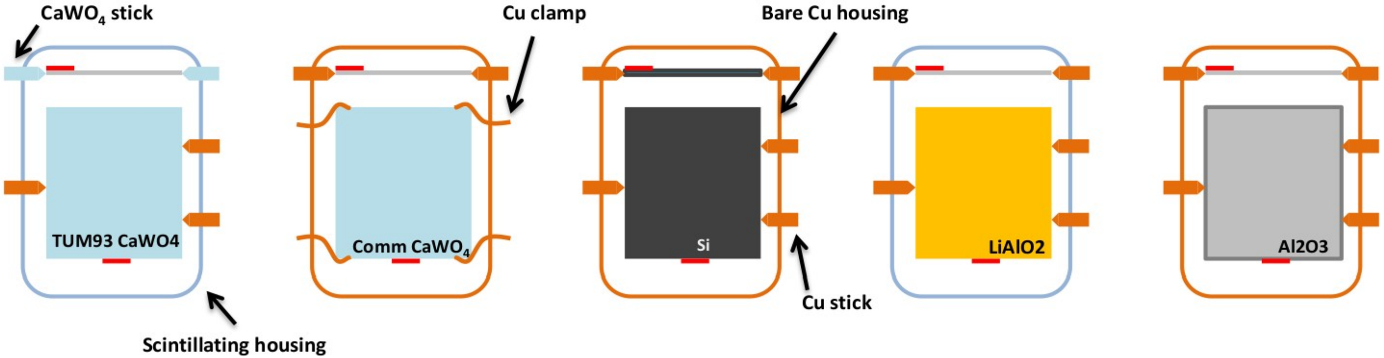
Depending on crystal growth parameters?

Tested slow grown crystal

Related to scintillating materials?

Removed scintillating materials

Dedicated modifications:



Adopted different holding mechanisms

Caused by holder?

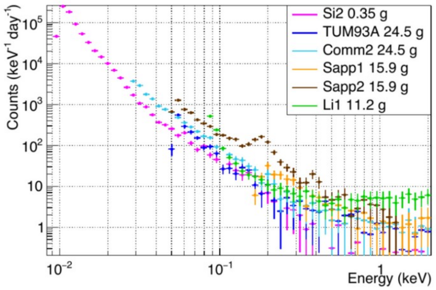
Analyzed LEE in a wafer detector

Depending on detector geometry?

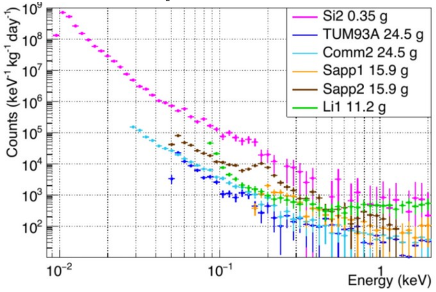
LEE Energy Spectrum

arXiv:220709375v2

Rate



Rate per unit mass



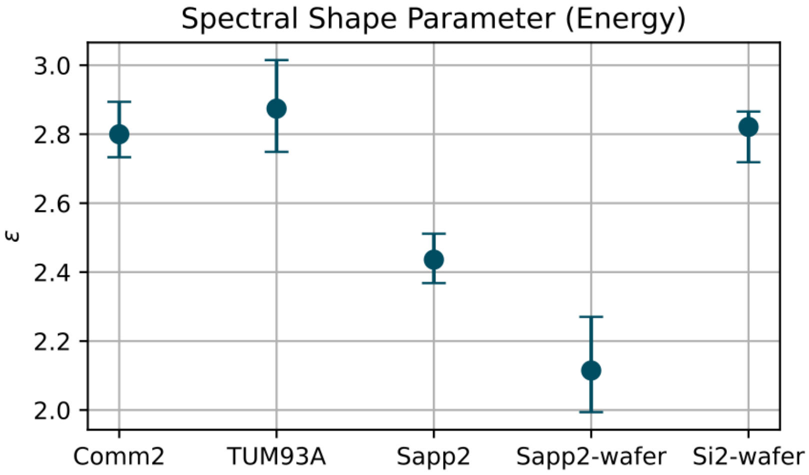
The LEE is observed in every material and geometry

Rate does not scale with mass

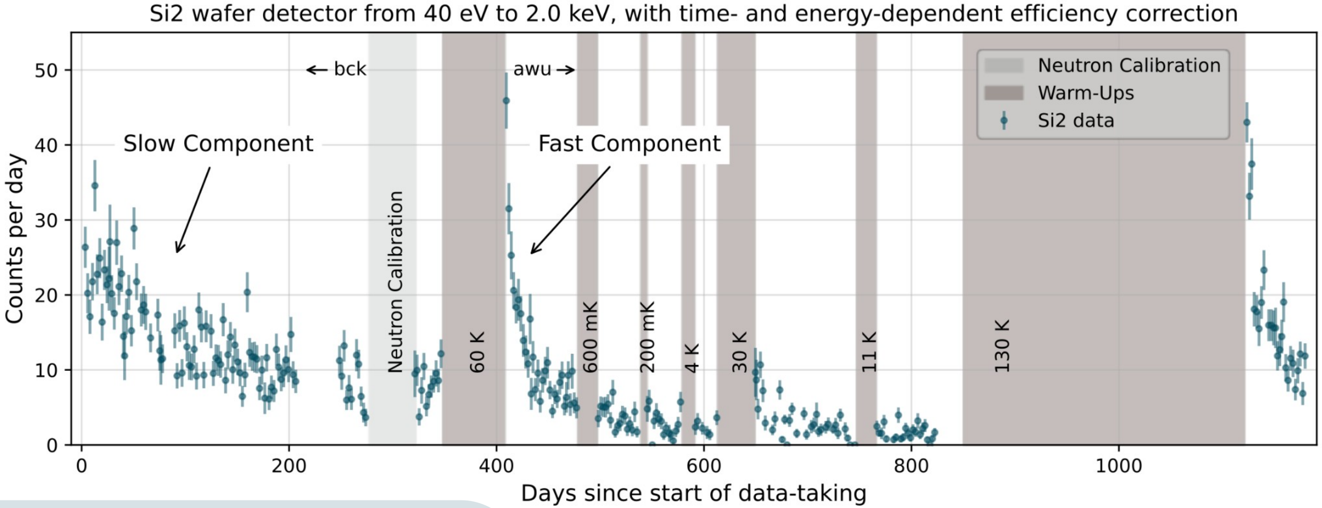
None of the modifications had a significant impact on the LEE

The spectral shape is well described by a power-law

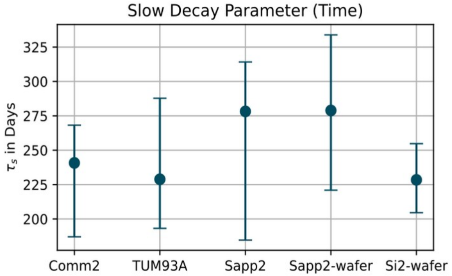
$$N(E,t) = C + E^{-\varepsilon}$$

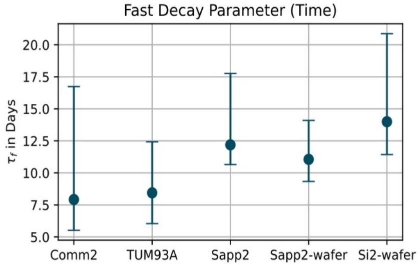


LEE Time Dependence



Rate monitoring over time:
- Rate decays exponentially in time
- Reset of the rate after warm-up cycles
- Two decay constants
  - Fast decay ~ 10 days
  - Slow decay ~ 250 days





Summary LEE

What we learned about the LEE:

- Rate decays over time and resets after warm-up
  → excludes radioactive origin

- Observations are compatible with LEE rate **not** dependent on
  - Material/growth parameters
  - Mass
  - Scintillating materials
  - Detector geometry
  - Holding method

Possible origins to test:

- Holding induced stress
- Interface crystal-TES

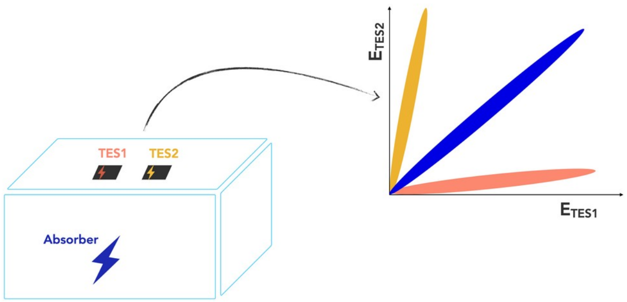
↓

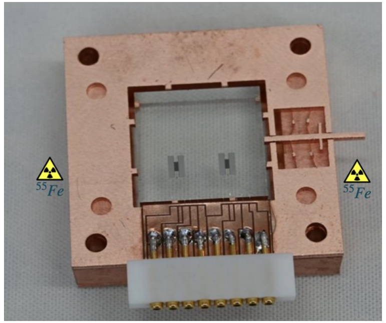
Development of new detector designs

DoubleTES Module

Idea:
Instrument the crystal with two TESs

- Events in absorber
  → two TESs show same response
- Events in/close to the sensor
  → response is different



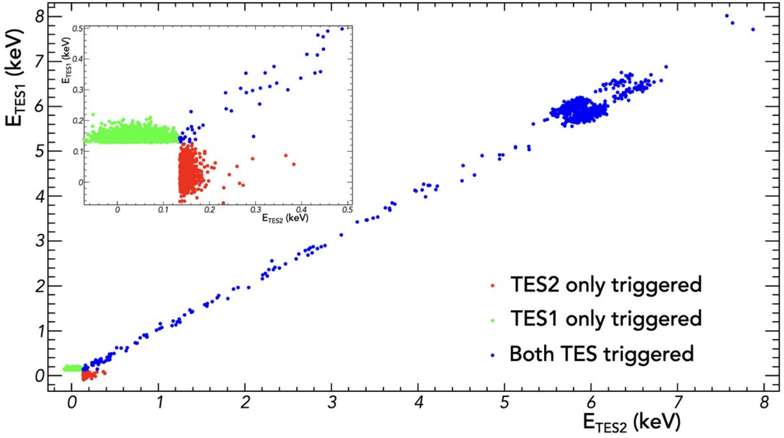


We can probe origin of LEE in:

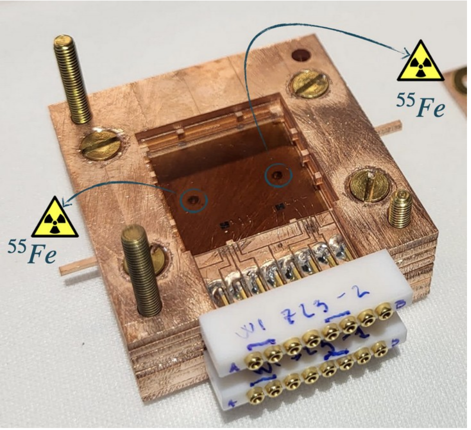
- TES induced events
- Interface between crystal and sensor

Test above ground

arXiv 240402607
EPJC final review



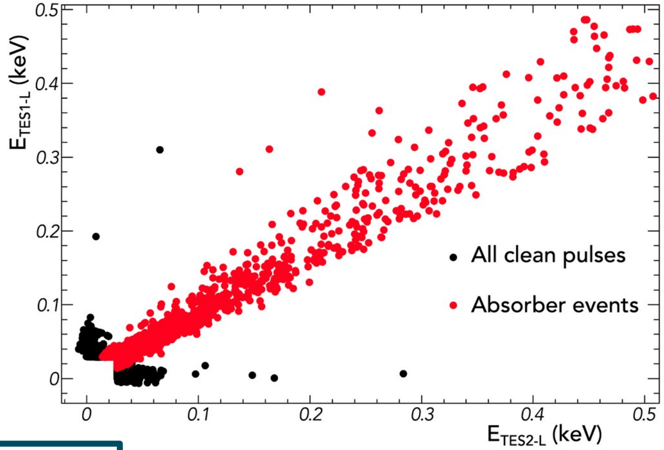
DoubleTES Module



Second measurement:
Double TES on sapphire wafer to access lower thresholds
→ Better study of LEE

Test above ground

arXiv 240402607
EPJC final review



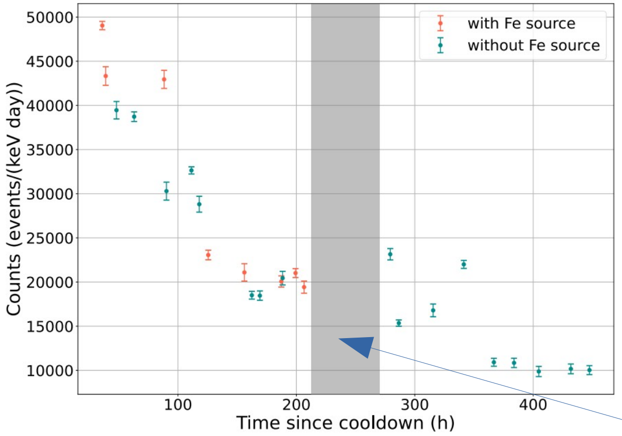
Conclusion from both above ground measurements:

- There are multiple components to the excess
- Single TES events are one component of the excess

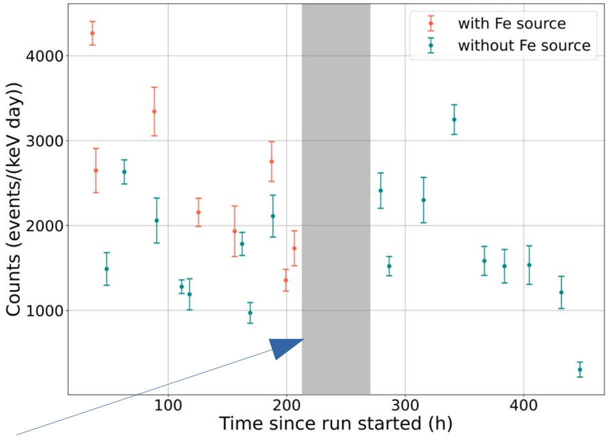
DoubleTES - Time Dependence

- **Absorber** component of the LEE decays with a time constant of ~10 days
- No clear decay observed for the **single TES** components in the limited time frame (~450 h)

Absorber events



Single-TES events

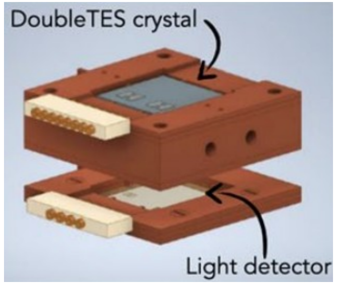


Installation of additional radiation shield

Run37 Detectors

Mounted in recently started Run37:

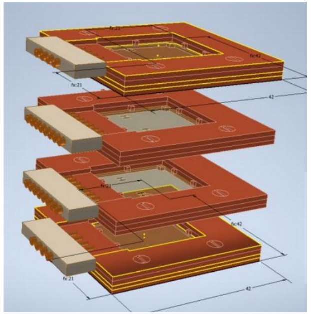
DoubleTES



- $CaWO_4$ crystal 20x20x10 mm^3
- Operated with two TESs
- Gravity assisted holder
- Light detector (Silicon-On-Sapphire wafer)

sensitive to sensor events + exposure

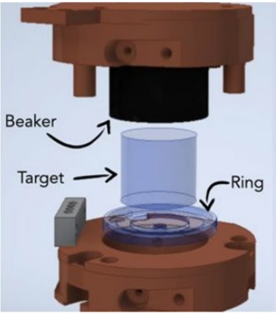
DoubleTES-Stack



- 4 Silicon-On-Sapphire wafers 20x20x0.4 mm^3
- All operated with two TESs
- Gravity assisted holder

sensitive to sensor events + low thresholds + surface veto

Mini Beaker



- Sapphire cylindrical crystal → 4 cm^3
- Connected to a sapphire ring → identification of events transmitted by holder
- Silicon beaker

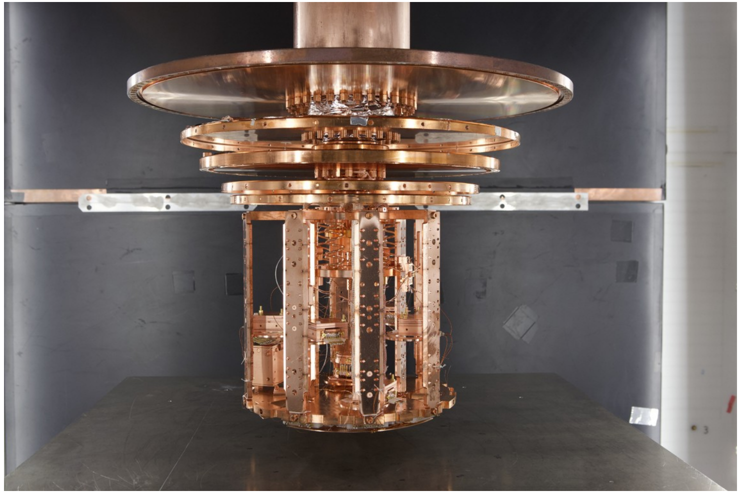
4π veto

+ 1 standard CRESST-III module from Run36 as reference

Current Status

New run started in April 2024

- Several double TES running
- Optimization done
- Calibration ongoing

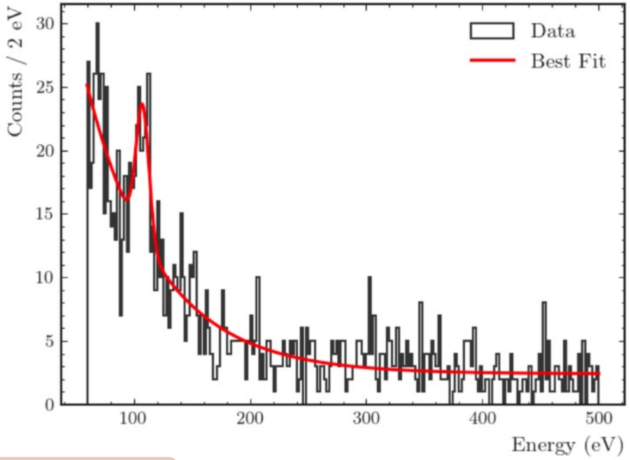


Detectors:

- 5 double TES + light detector
  → Total 15 channels
  → only 2 TES not operated
- 1 light detector stack
  → composed of 4 light detectors → 8 channels all working
- 1 Mini beaker → 3 channels all working
- 1 Detector unchanged from Run36 as reference → 2 channels all working

Double TES

- Double TES modules are not calibrated with an iron source inside the module (like previous run)
- Calibration via neutron capture peak (feasibility shown in previous run)
- Neutron calibration - data taking ongoing



Phys. Rev. D 108,022005

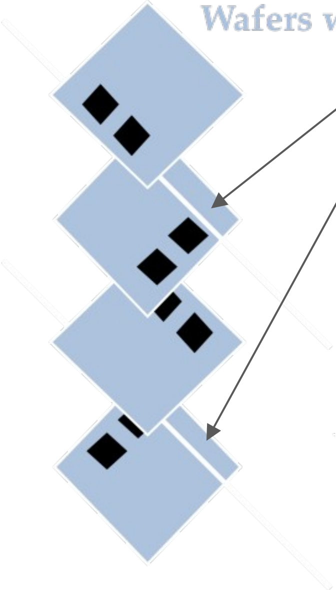
Energy calibration for nuclear recoil

$^{182}W(n,\gamma)^{183}W$

de-excitation with a single γ (6.1MeV)

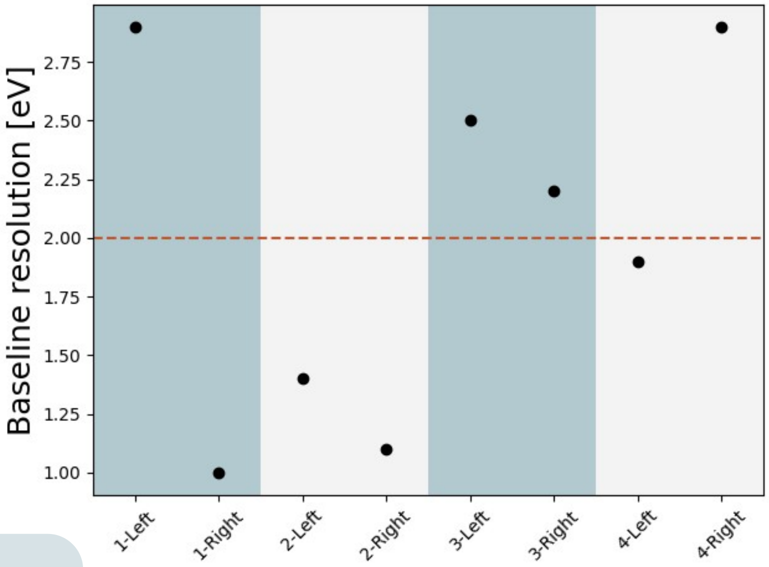
→ mono-energetic nuclear recoil 112.4eV

Light Detector Stack



- 8 working channels
- Calibrated with ^{55}Fe source
- Low energy thresholds thanks to low mass targets

Preliminary



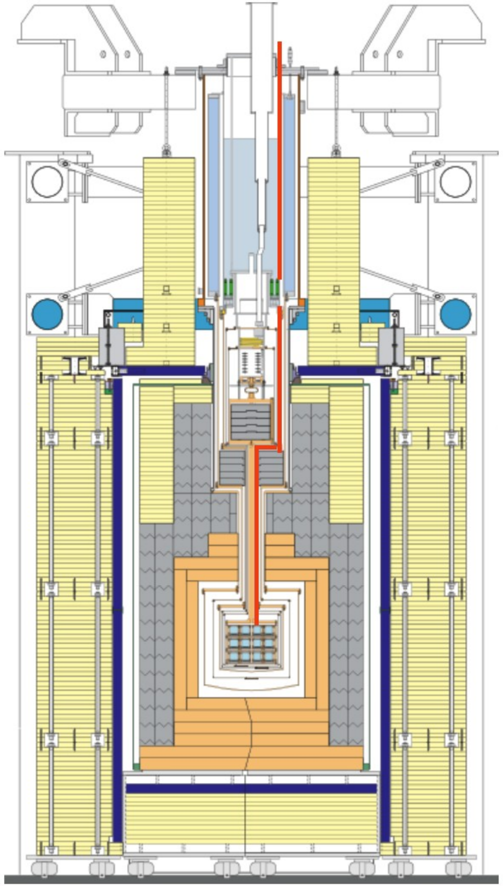
All channels of the channels have a baseline resolution below 3eV (threshold below ~ 15eV)

Next Steps

- Complete neutron calibration (fall 2024)
- Start background data taking (fall 2024)
- First Double TES data expected by spring 2025
- End of experimental Run37 in summer 2025 (when the He liquefier will be discontinued for upgrade)*

* Could be revised if the LEE reduction allows relevant sensitivity improvement

Readout Renewal

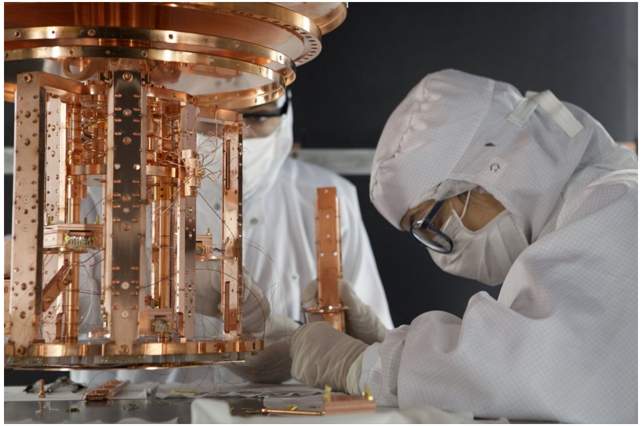


- Over the years, significant aging of the readout chain reduced the number of useable channels
  - reduces the test capabilities
  - limits reachable exposure

- New readout chain (288 channels) already funded by agencies and almost completely procured
- New readout electronics being produced
- Installation planned after the end of Run37 aligned with the stop of the He production plant

Summary

- CRESST is making continuous progress in understand the LEE
- New run ongoing
- Several double TES running
- Calibration ongoing
- Results coming soon

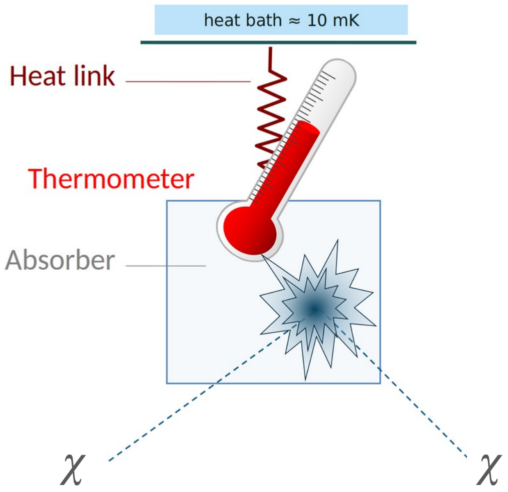


Stay tuned!

BACKUP

Cryogenic Calorimeters

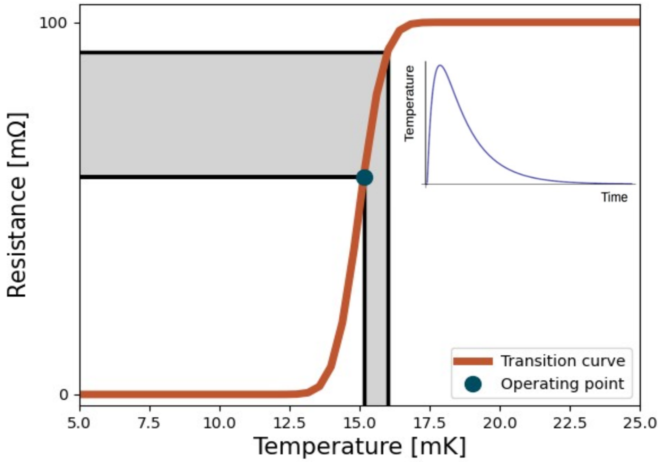
- Basic setup: crystal equipped with temperature sensor
- A particle interaction causes an energy deposition in the crystal
- Calorimeter equation: ΔT=ΔE/C



For low heat capacity (true at low temperatures)
⇨ low energy deposition can lead to significant temperature variation

- Read out by Transition Edge Sensor (**TES)**

The Transition Edge Sensor



Energy deposition in absorber ~keV

↓

Temperature rise in TES ~μK

↓

Resistance change ~mΩ

- Sensor is operated at the transition between normal- and superconducting phase
- Very small temperature variations can be read out through measurable changes in the resistance

Spin Dependent Limits

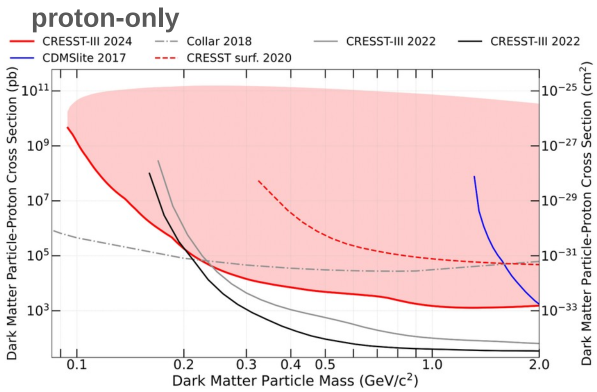
	$LiAlO_2$	Al_2O_3
Mass	11.2 g	0.6 g
Data taking	Nov 20 -Aug 21	Nov 20 - Aug 21
Baseline resolution	12.8 eV	1.0 eV
Energy threshold	83.6 eV	6.7 eV

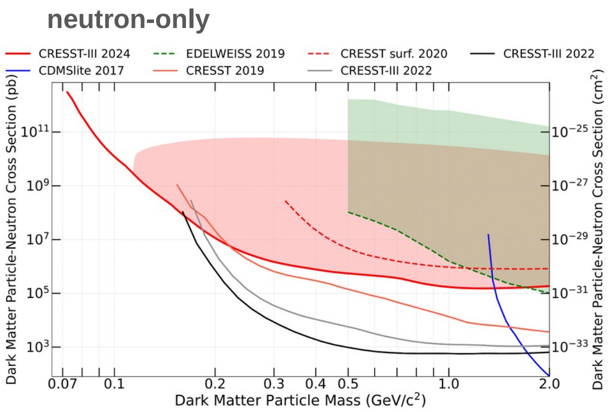
SD rate: $\frac{dR}{dE} \sim \frac{(J+1)}{J} \langle S_{p/n} \rangle^2$

Lithium aluminate
- Contains ^{6}Li, ^{7}Li, ^{27}Al
- High $\langle S_{p/n} \rangle$ values
  → high sensitivity

Sapphire
- Contains ^{27}Al
- Low energy threshold
  → sensitive to very low DM masses

Improved SD limits for both proton- and neutron-only case

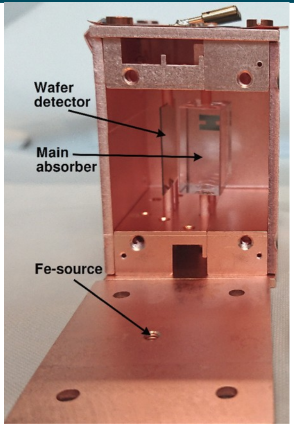




arXiv:2405.06527 — sapphire

Phys. Rev. D 106, 092008 — lithium aluminate

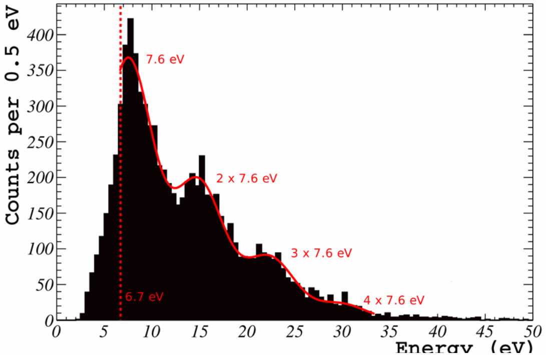
New Calibration: Sapphire VUV Luminescence



New calibration:
vacuum ultraviolet (VUV) luminescence **@7.6 eV** from the nearby sapphire crystal is observed in the wafer

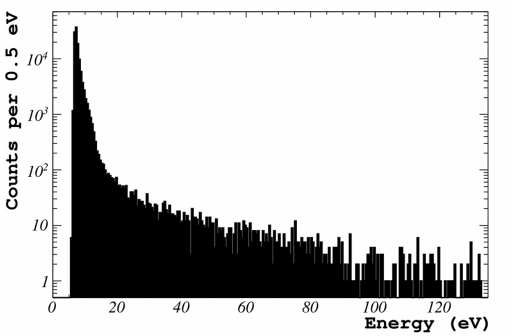
arXiv:2405.06527

Iron events

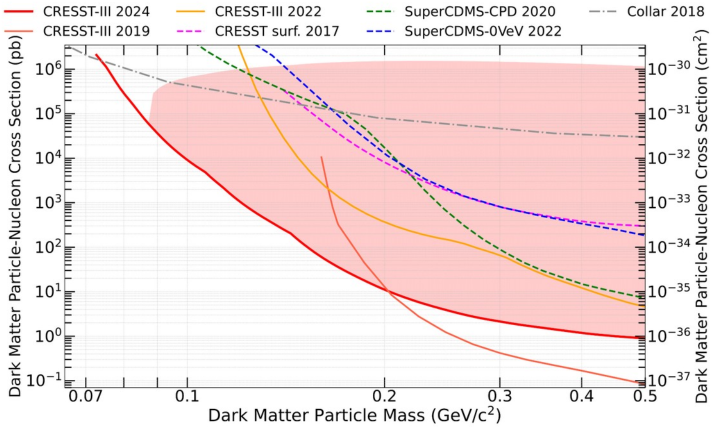


Single photon detection @N x 7.6 eV

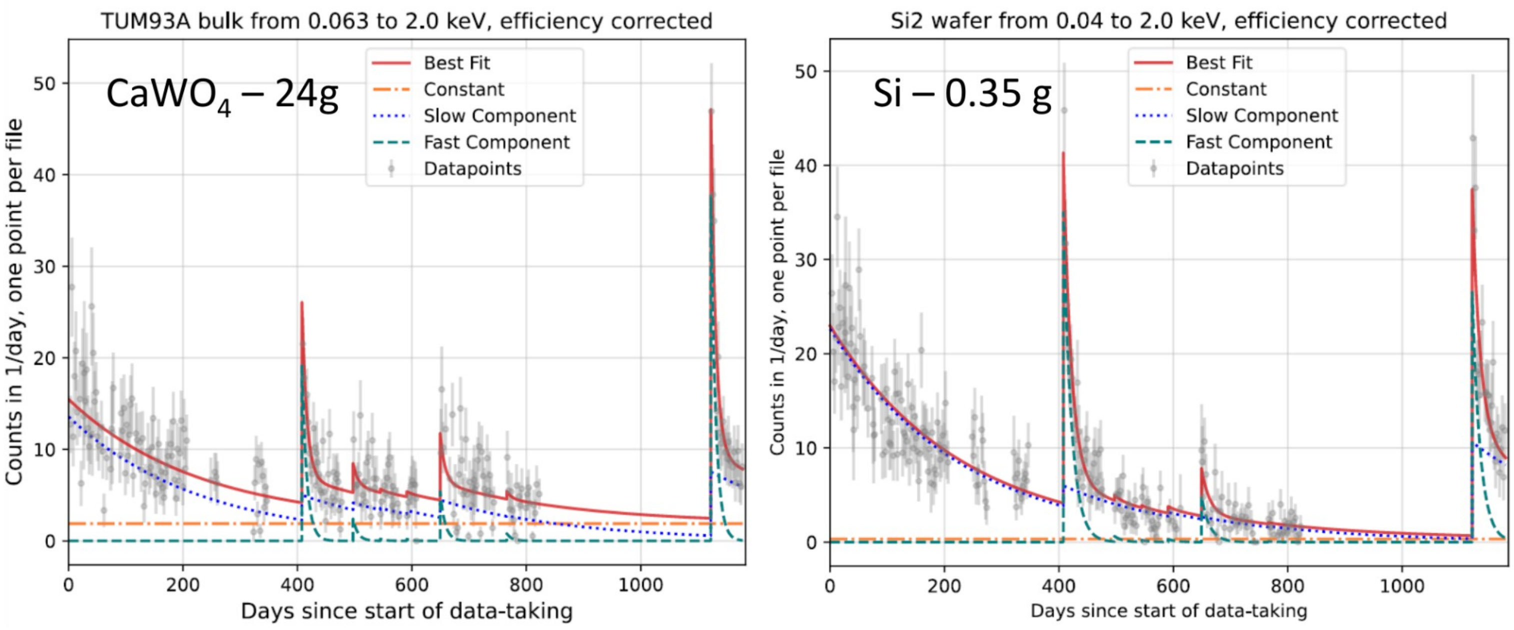
Calibrated spectrum



Spin-Independent exclusion limits
→ probe new parameter space

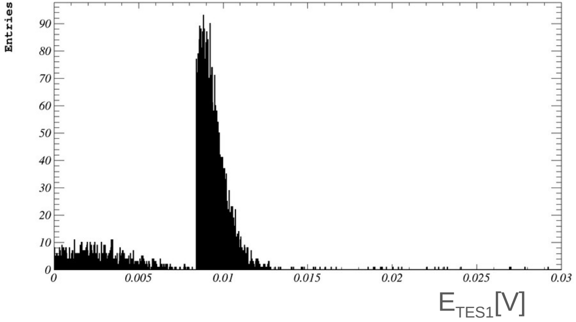


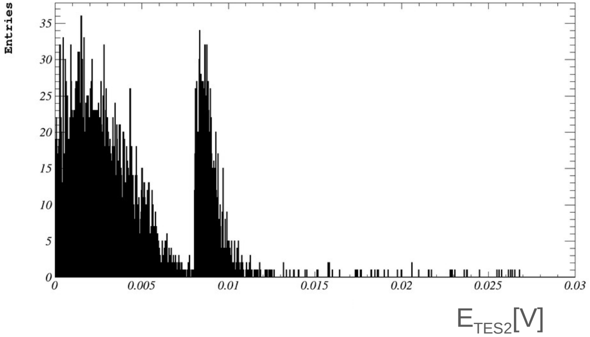
LEE Components



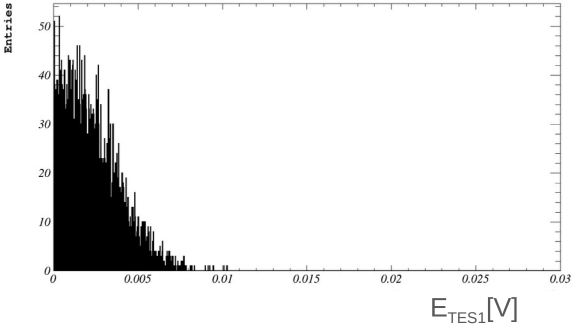
Double TES - Noise Study

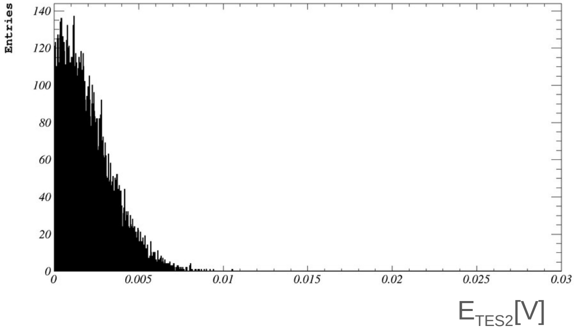
Non-calibrated spectra below threshold:



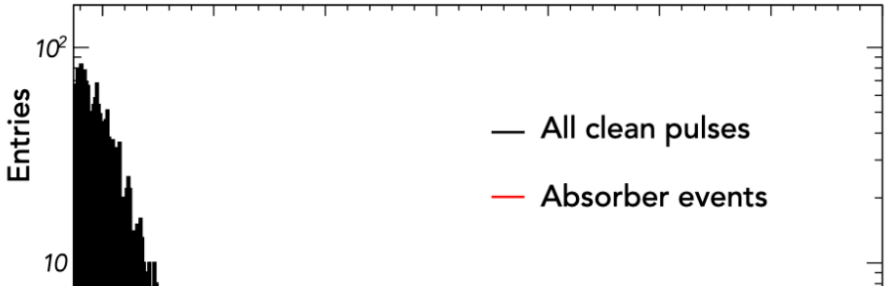


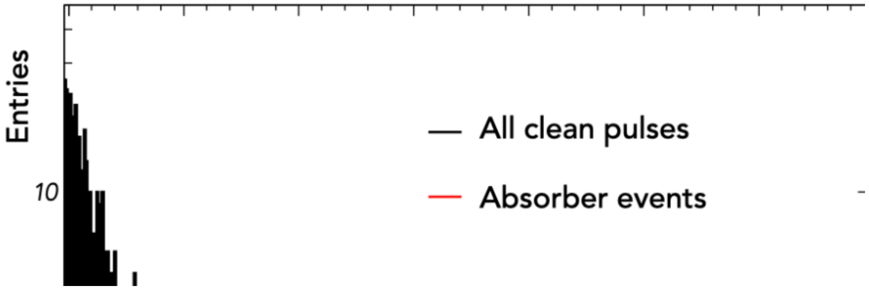
Inverted stream data (positive-negative) - non-calibrated noise spectra:





Double TES - Calibrated Spectra





Single TES events contribute to the LEE