Cryogenic **Rare Event Search**
with Superconducting Thermometers

Latest observations on the low energy excess in CRESST-III

Excess Workshop Vienna 2022

D. Fuchs, M. Kaznacheeva, A. Kinast, A. Nilima

for the CRESST collaboration

July 16, 2022

Outline

CRESST
Cryogenic **Rare Event Search** with Superconducting Thermometers

INFN LNGS
Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali del Gran Sasso

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TECHNISCHE UNIVERSITÄT MÜNCHEN

UNIVERSITAS COMENIANA BRATISLAVENSIS · MCMXIX ·

MAX PLANCK INSTITUTE FOR PHYSICS

EBERHARD KARLS UNIVERSITÄT TÜBINGEN

HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

TU WIEN
TECHNISCHE UNIVERSITÄT WIEN

UNIVERSITY OF OXFORD

The CRESST Experiment

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

- $\sim$ 3600 m.w.e. deep
- μs: $\sim 3 \cdot 10^{-8}$ /(s cm^2)
- γs: ~ 0.73 /(s cm^2)
- neutrons: $4 \cdot 10^{-6}$ n/(s cm^2)

CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ~15 mK

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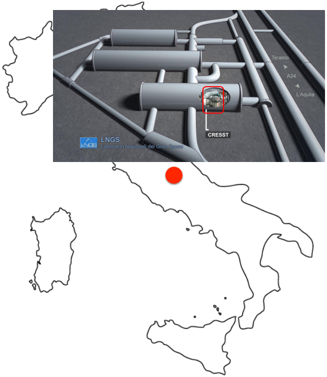

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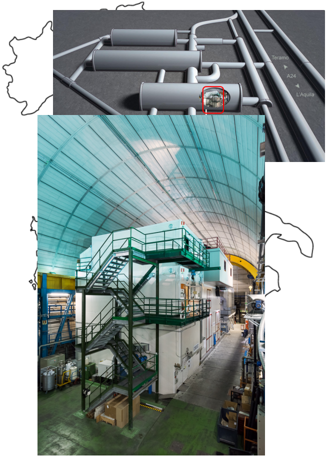

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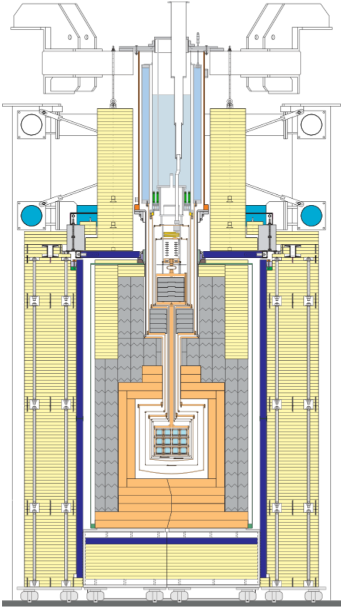
CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ∼15 mK

CRESST Setup

Shielding:

- polyethylene (10t)
- muon veto system
- lead (24t)
- copper (10t)



Detector Modules

Standard design

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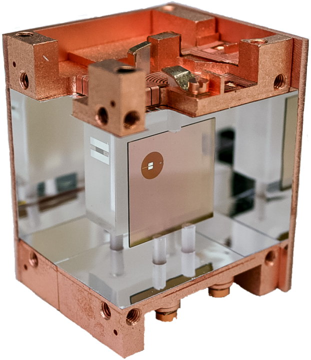
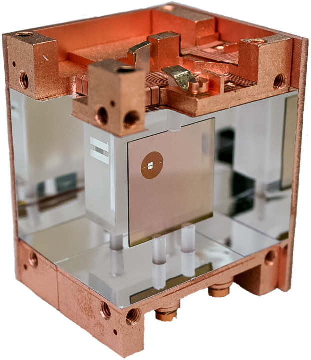


Detector Modules

Standard design

- $(20x20x10)mm^3$ target crystals
- scintillating $CaWO_4$
- W-TES sensor
- $E_{thr} \leq 100eV$ (nuclear recoils)



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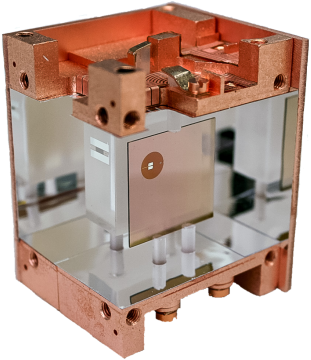

Light detector:

- Silicon-on-Sapphire $(20 \times 20 \times 0.4)\text{mm}^3$ wafer
- Particle discrimination

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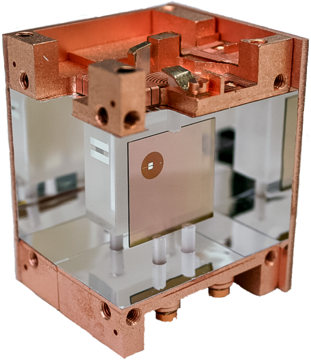


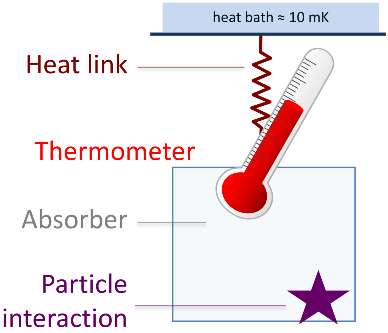
Light detector:

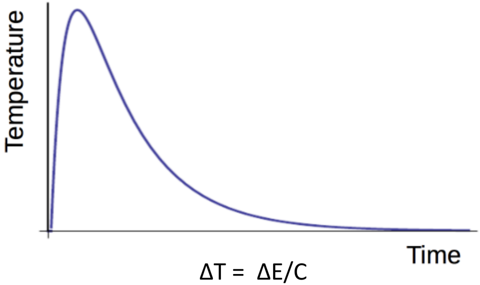
- Silicon-on-Sapphire $(20x20x0.4)mm^3$ wafer
- Particle discrimination

Housing & Holding:

- Scintillating reflective foil (Vikuiti™)
- (Instrumented) $CaWO_4$ holding sticks

Cryogenic Calorimeter

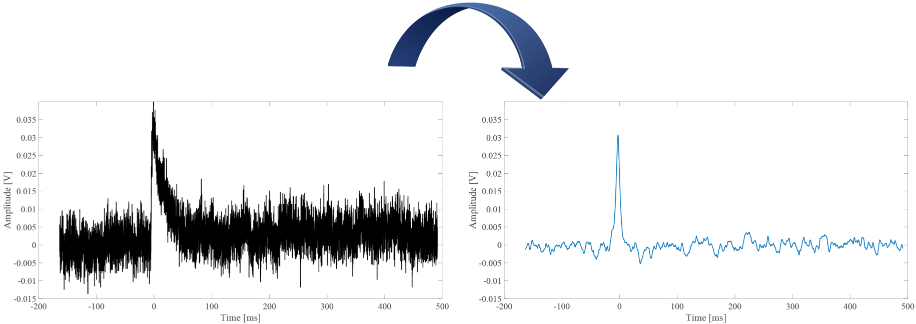




Data Analysis

Continuous DAQ + Optimum Filter

- Dead-time free DAQ: detector output is continuously recorded
- Maximize Signal-to-Noise ratio in frequency space



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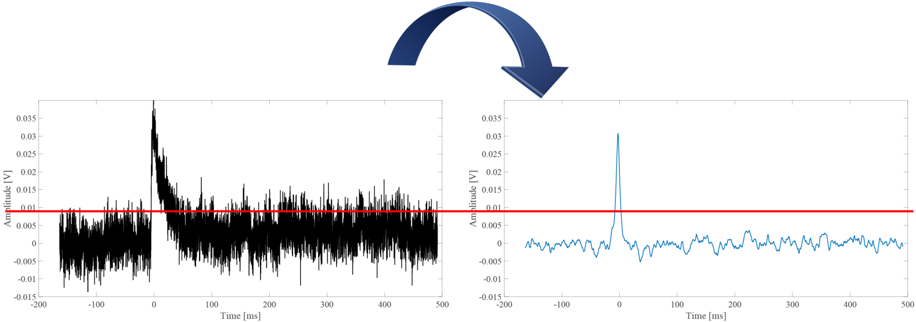
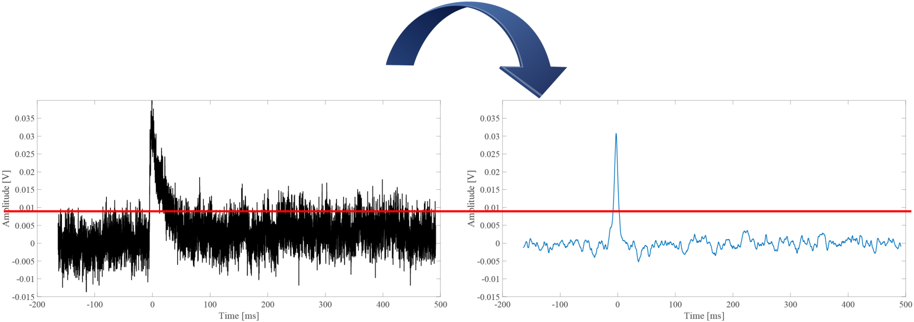
- Define threshold by choosing accepted number of noise triggers



Data Analysis

Continuous DAQ + Optimum Filter

- Dead-time free DAQ: detector output is continuously recorded
- Maximize Signal-to-Noise ratio in frequency space
- Define threshold by choosing accepted number of noise triggers
- Select Events above threshold

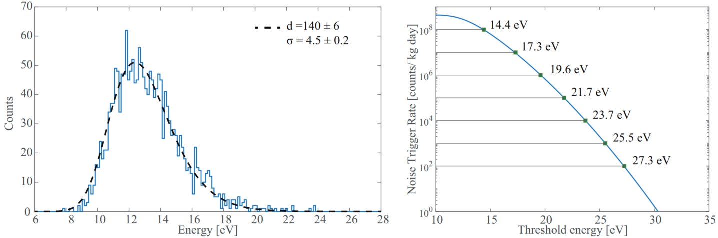


Data Analysis

Threshold determination

- Analytical description of amplitude distribution of filtered empty baselines
- Define threshold choosing accepted number of noise triggers per kgd

$$NTR(x_{thr}) = \frac{1}{t_{win} \cdot m_{det}} \cdot \int_{x_{thr}}^{\infty} P_d(x_{max})$$



(J Low Temp Phys (2019) | doi.org/10.1007/s10909-018-1948-6)

Data Analysis

Event Selection and Energy Calibration

- Apply data selection criteria, designed to keep only valid pulses

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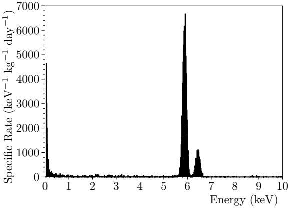
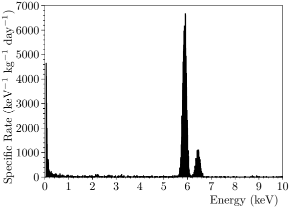
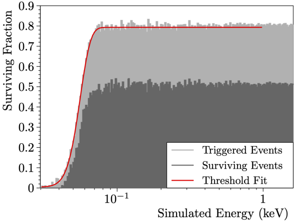


Data Analysis

Event Selection and Energy Calibration

- Apply data selection criteria, designed to keep only valid pulses
- Calibration of cleaned data with radioactive source
- Perform simulation to calculate survival probabilities after trigger and selection criteria

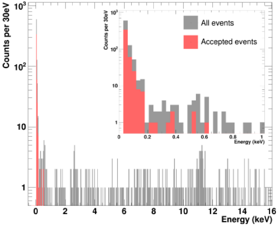




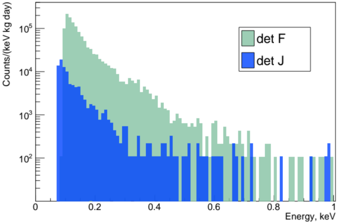
Outline

First observations of Excess

Run34 (05/2016 - 02/2018):
$CaWO_4$ crystal
23.6 g
30.1 eV threshold
scintillating foil
instrumented $CaWO_4$-holding sticks

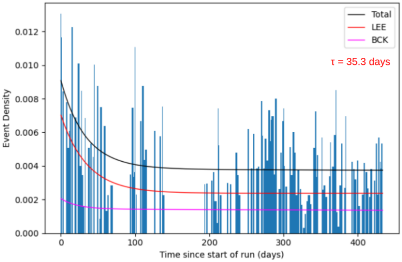


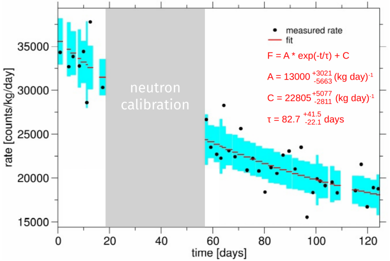
Run35 (11/2018 - 10/2019):
Al_2O_3 (Sapphire) crystals
15.9 g
76.9 eV & 66.5 eV thresholds
scintillating foil
non instrumented $CaWO_4$-holding sticks



First observations of Excess

In both cases decrease over time:



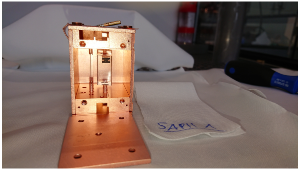


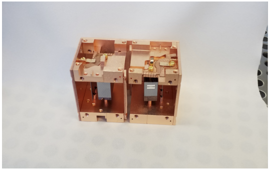
Modifications of modules
for Run36 (11/2020 - still running)

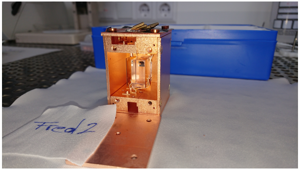
Test different configurations to find source of unknown background:

- Materials ($CaWO_4$, $LiAlO_2$, Al_2O_3, Si)
- Replace $CaWO_4$ holding sticks with Cu sticks
- Some modules with bronze clamps instead of sticks
- Remove scintillating foil
- One fully non-scintillating module
  (Si as main absorber and wafer detector)
- Introduction of ^{55}Fe source for low energy calibration (since Run35)

List of Modules



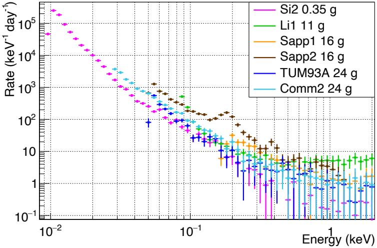


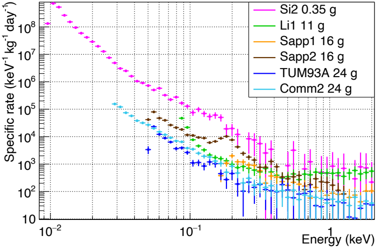


Module	Material	Holding	Foil	Mass (g)	Threshold (eV)
Si2	Si	Cu	No	0.35	10
Sapp1	Al_2O_3	Cu	No	16	157
Sapp2	Al_2O_3	Cu	No	16	52
Li1	$LiAlO_2$	Cu	Yes	11	84
TUM93A	$CaWO_4$	2 Cu + 1 $CaWO_4$	Yes	24	54
Comm2	$CaWO_4$	Bronze Clamps	No	24	29

Outline

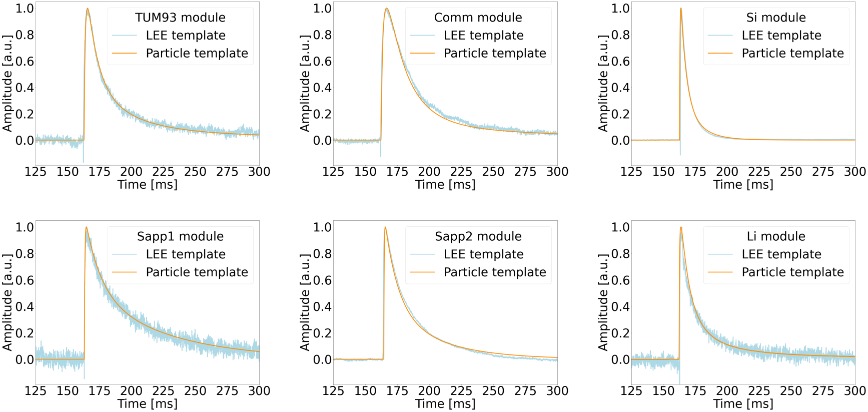
Energy spectra





- Excess seen in all detectors!
- Rate does not scale with mass
- Common single particle origin like DM or external radiation disfavoured

Averaged LEE Pulse vs Particle Templates

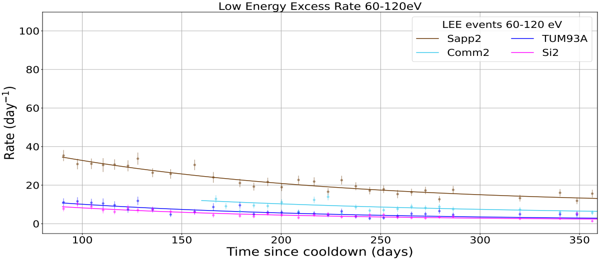


⇒ Excludes noise or electronic artifacts

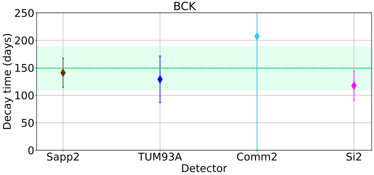
Outline

Decrease over time

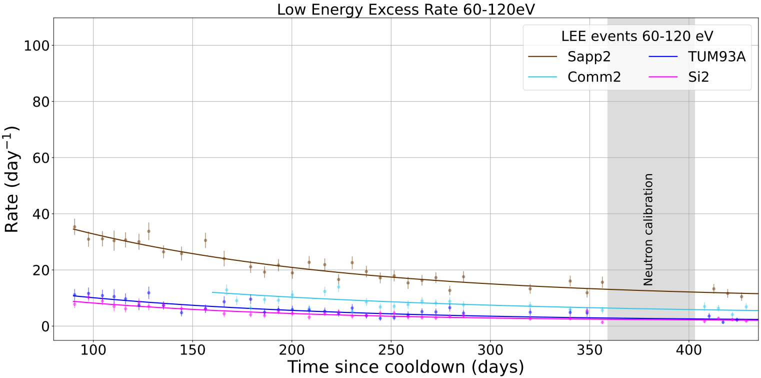
- Common energy range of 60 - 120 eV
- Bins of $\sim$ 150 h



- Exponential decay of LEE seen in all detectors!
- Decay times agree with each other
- Mean: (149 $\pm$ 40) days



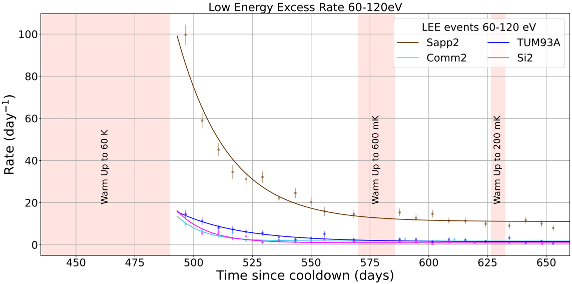
Neutron calibration



- No influence of neutron calibration on the LEE rate

Warm-up tests

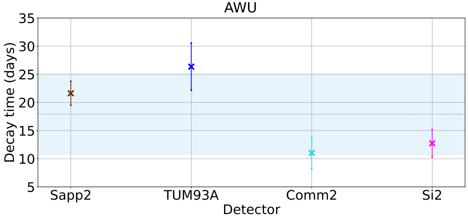
Warm-up to three different temperatures:
60 K, 600 mK, 200 mK



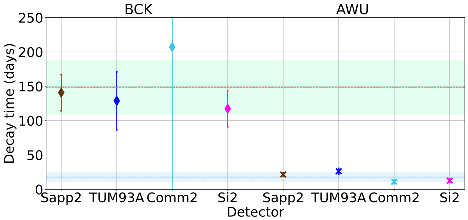
- Strong rise of rate after warm-up to 60 K
- Again exponential decay in all detectors!
- No influence of warm-up to lower temperatures (200 mK, 600 mK)

Decay times

- Comparable decay times
- Mean: (18 ± 7) days

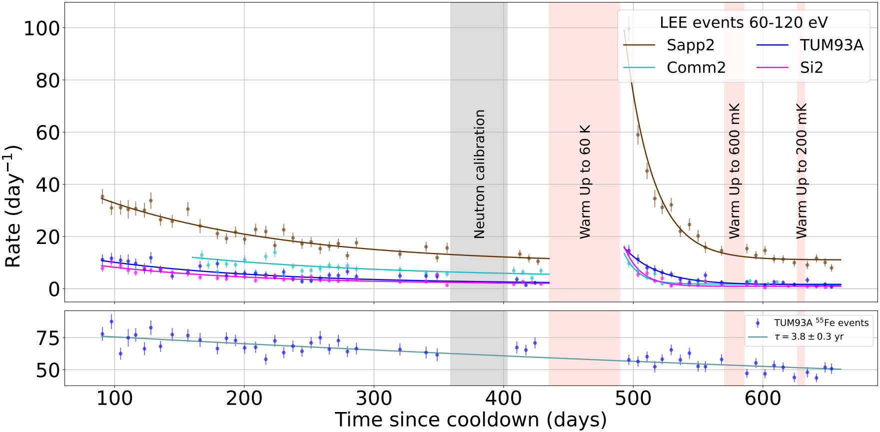


But: LEE decays much faster after Warm up



Time dependence

^{55}Fe source as reference



$\Rightarrow$ Can exclude external and intrinsic radioactivity
And another argument against a DM origin

Outline

Observations

- LEE present in all detectors
- No significant impact on the presence of the LEE by detector modifications
- LEE events have same pulse shape as particle recoil events
- Exponential decay of rate
- Increased rate after warm-up to 60 K
- Faster decay after warm-up to 60 K
- No effect of warm-up to 600 mK and 200 mK

Conclusions

Exluded hypotheses on major contributions:

- Dark matter interactions
- External and intrinsic radioactivity
- Noise triggers and electronic artifacts
- Scintillation light

Possible options under further investigation:

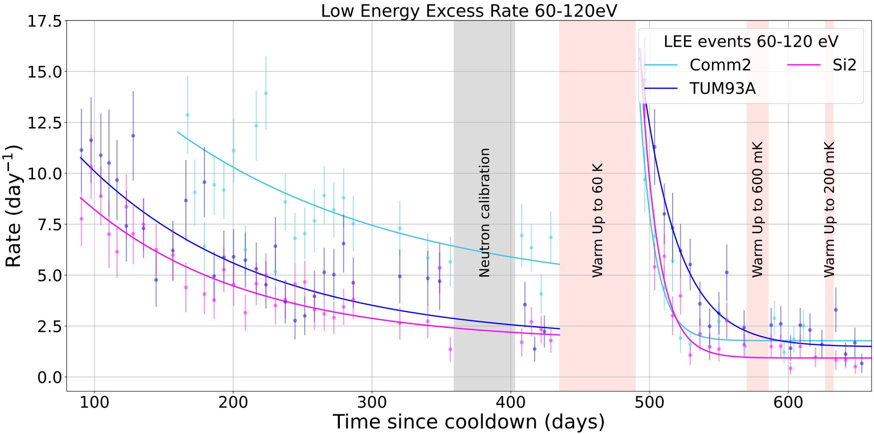
- Intrinsic crystal effects
- Sensor related effects (e.g. from TES film deposition)
- Holding induced stress

- R & D ongoing

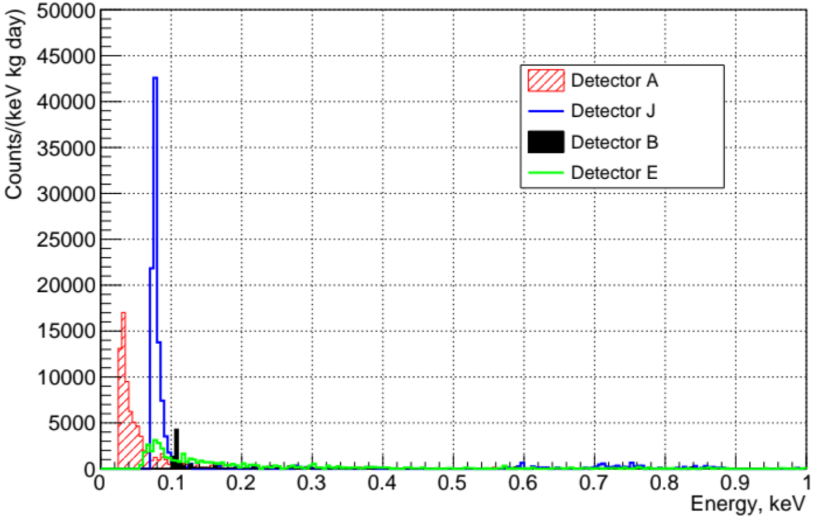
BACKUP

Time dependence

without Sapp2

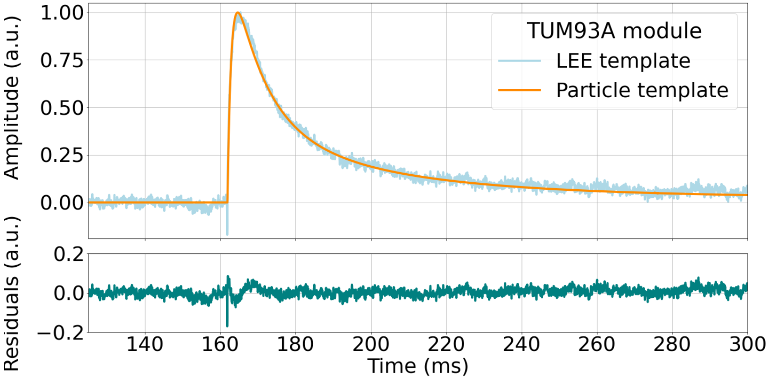


Excess in CRESST-III First Run



LEE vs Particle template

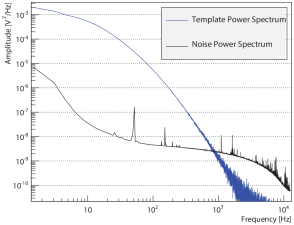
Residuals

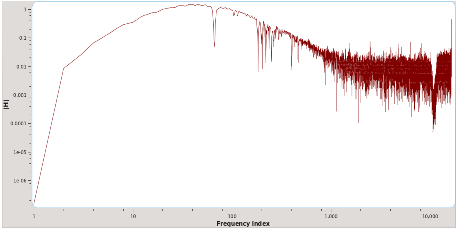


Optimum Filter

- Filter kernel $H(\omega)$: maximize Signal-to-Noise ratio in frequency space:

$$H(\omega) = K \frac{\widehat{s}^*(\omega)}{N(\omega)} e^{-i\omega\tau_M}$$





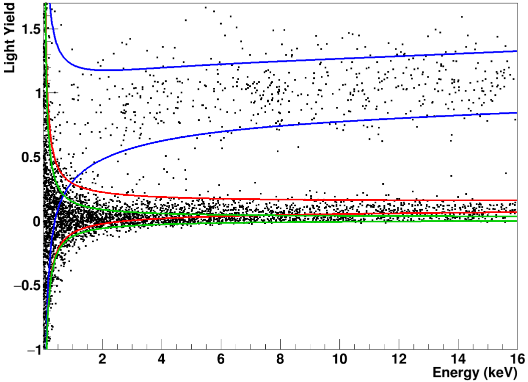
- Convolute real pulse with filter kernel:

$$y_F(t) = \frac{A}{\sqrt{2\pi}} \int_{-\infty}^{\infty} H(\omega)\widehat{s}(\omega)e^{i\omega t}\,\mathrm{d}\omega$$

Neutron Calibration

Light Yield: $LY = E_L / E_{Ph}$

Band Fits QF

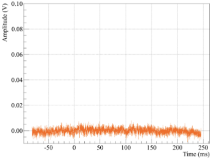


e/γ events

Oxygen nuclear recoils

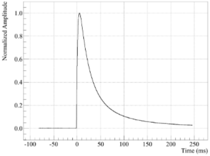
Tungsten nuclear recoils

Efficiency



Empty baseline

+



Averaged pulse

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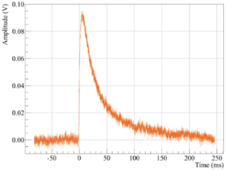

Simulated pulse