The CRESST-III Dark Matter Search

Status and Outlook

Christian Strandhagen | Universität Tübingen | IDM 2022, Vienna

CRESST

The CRESST Collaboration

CRESST

COMENIUS
UNIVERSITY
BRATISLAVA

INFN
Laboratori Nazionali del Gran Sasso

TUM
Technische Universität München

UNIVERSITY OF
OXFORD

MAX-PLANCK-INSTITUT
FÜR PHYSIK

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

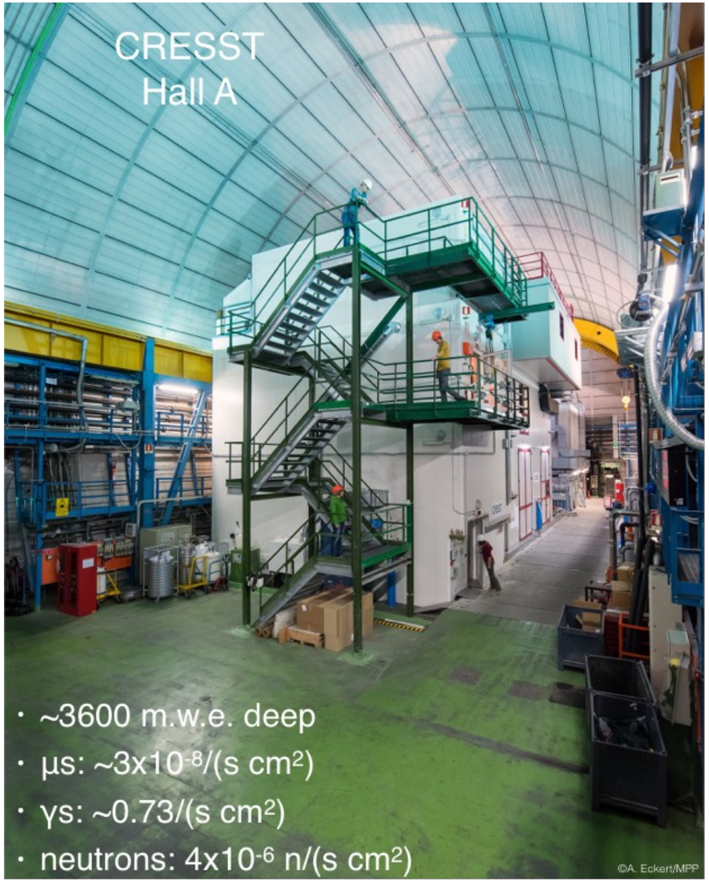
HEPHY
INSTITUTE OF HIGH ENERGY PHYSICS

TU
WIEN

The CRESST Experiment

The CRESST experiment is located in the LNGS underground lab in Italy.

The CRESST Experiment



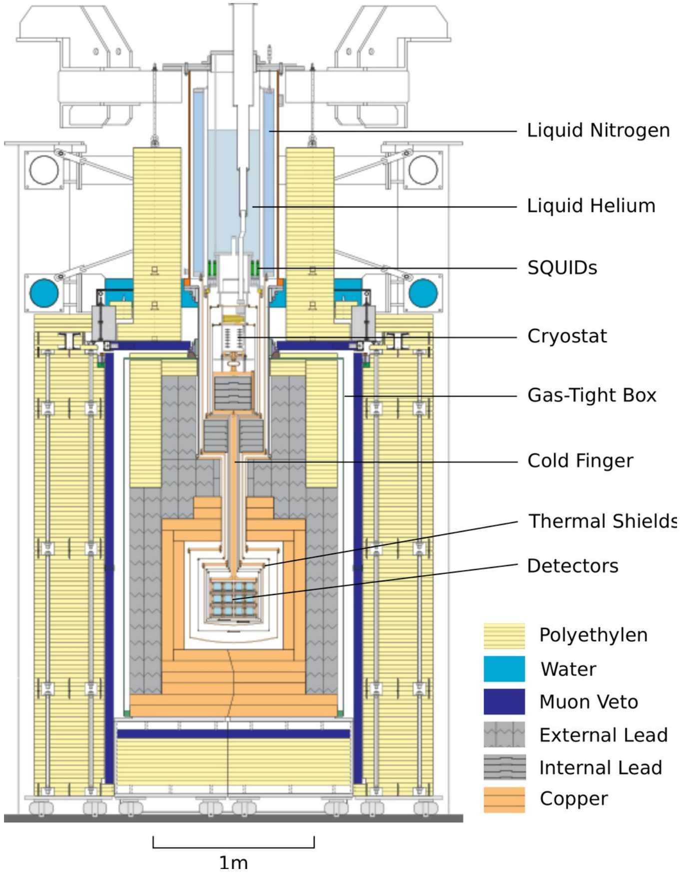
- ~3600 m.w.e. deep
- μs: ~3×10^{-8}/(s cm^2)
- γs: ~0.73/(s cm^2)
- neutrons: 4×10^{-6} n/(s cm^2)

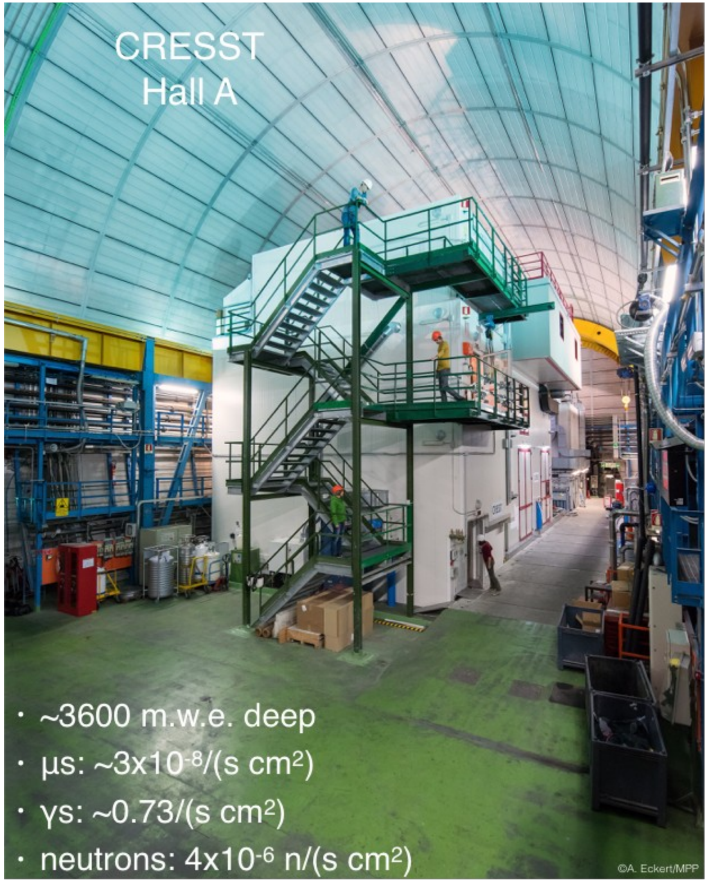
©A. Eckert/MPP

The CRESST experiment is located in the LNGS underground lab in Italy.

At least 1400 m of rock of the Gran Sasso d'Italia (2912 m) shield against cosmic muons.

The CRESST Experiment





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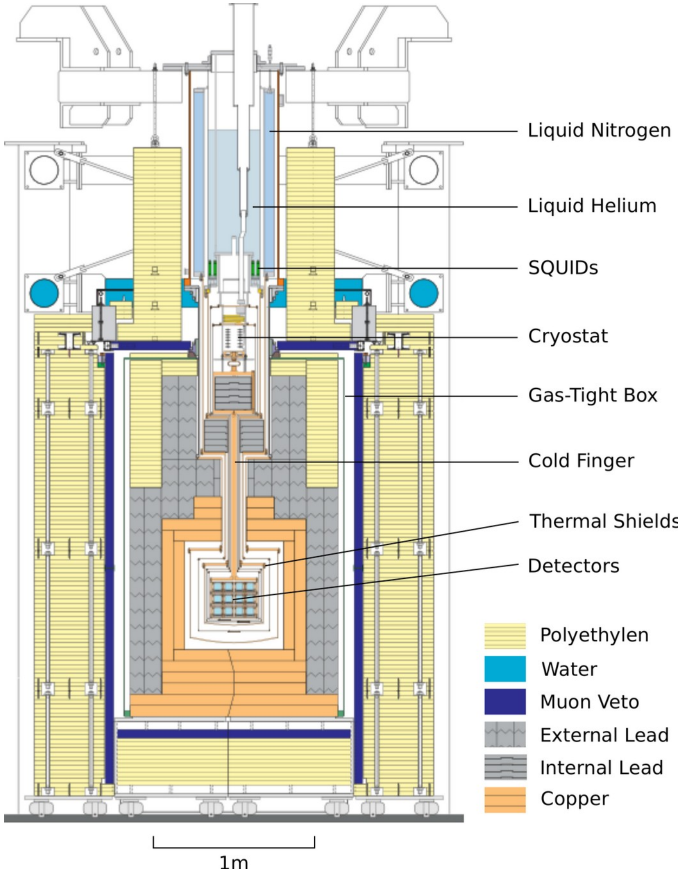
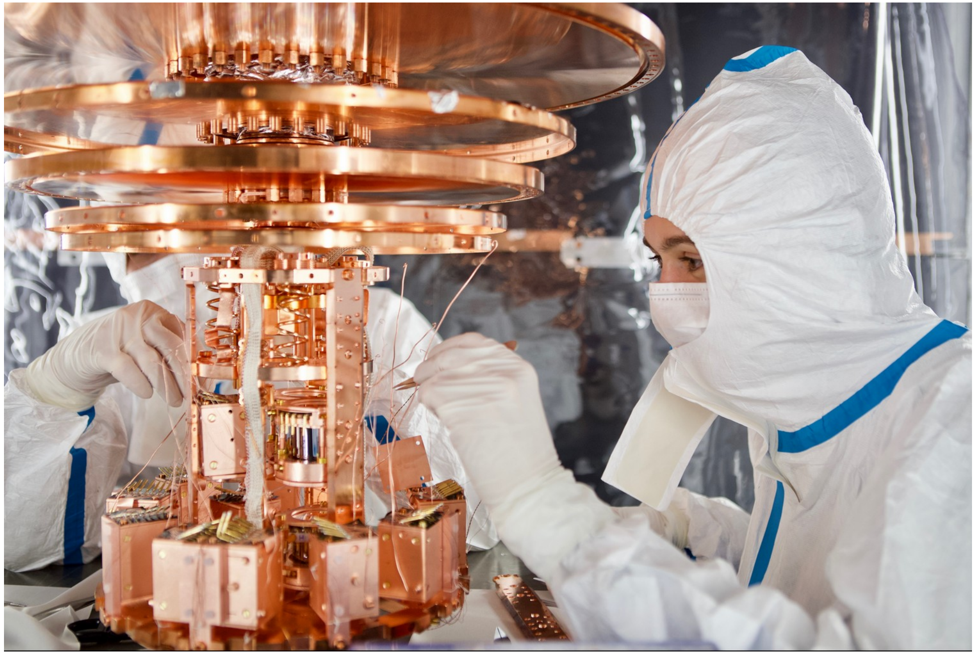
At least 1400 m of rock of the Gran Sasso d'Italia (2912 m) shield against cosmic muons.

The cryostat is enclosed by a layered shielding (PE, Pb, Cu) and an active muon veto.

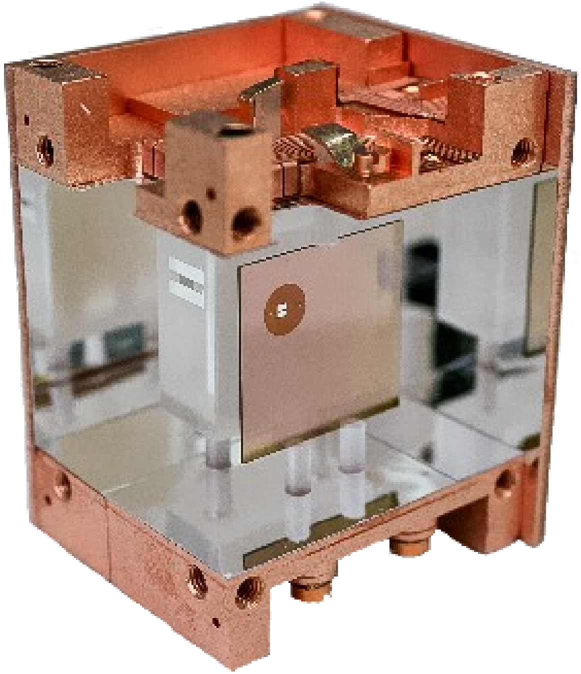
The CRESST Experiment

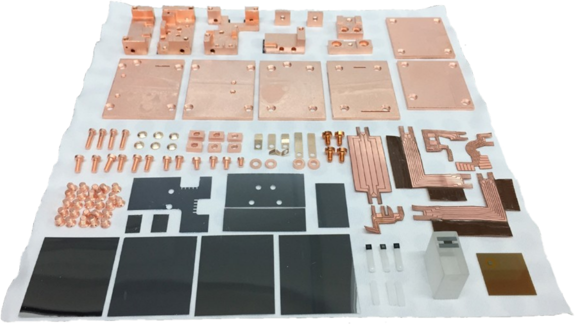




The detector modules are mounted in the so-called "carousel" and cooled to ~ 10 mK.

CRESST-III Detectors





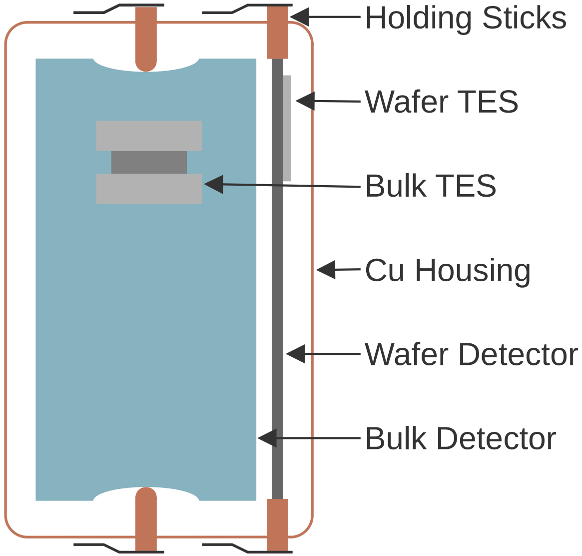
Main absorber: $(2x2x1)\ cm^3$, broad choice of materials
e.g. $CaWO_4$ (24 g), Al_2O_3 - sapphire (16 g), $LiAlO_2$ (10 g), Si (9 g)

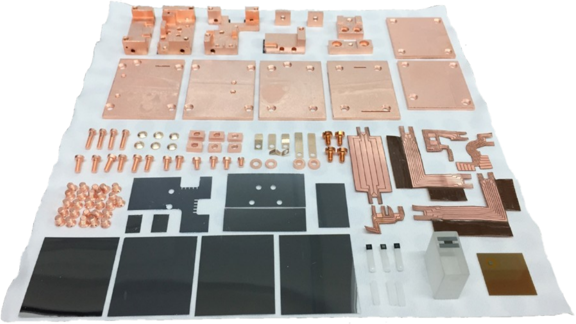
Thin wafer detector: $(2x2x0.04)\ cm^3$, Si or silicon-on-sapphire (SOS)
serves as light detector for scintillating absorbers

Holding structure: light-tight copper housing, scintillating reflector foil
detectors held by sticks from $CaWO_4$ or copper

Sensors: W-TES directly evaporated on the crystals

CRESST-III Detectors





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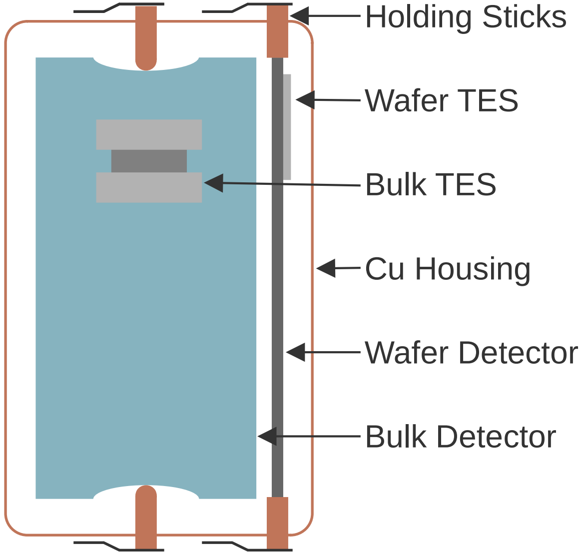
CRESST-III Detectors

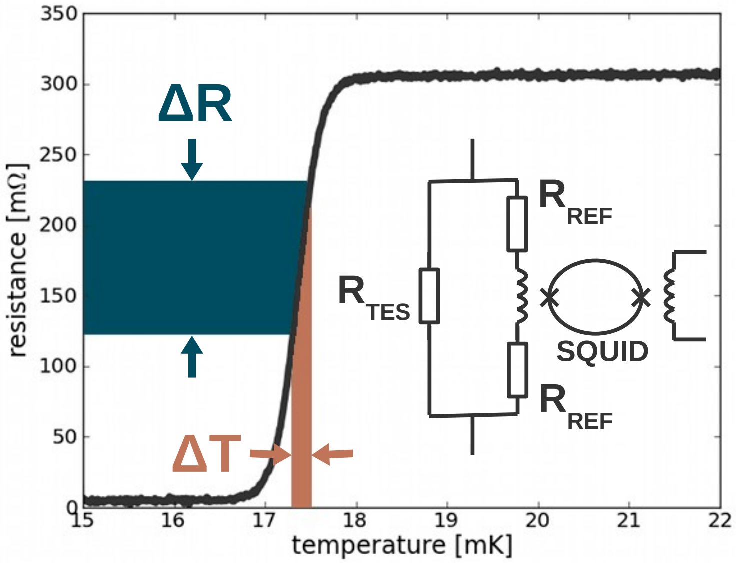
Transition Edge Sensor (TES)



small temperature rise
→ large increase in resistance

Read out by SQUID-based electronics.

Pulses injected through a separate heater are used to stabilize the operating point and probe the detector response over time.

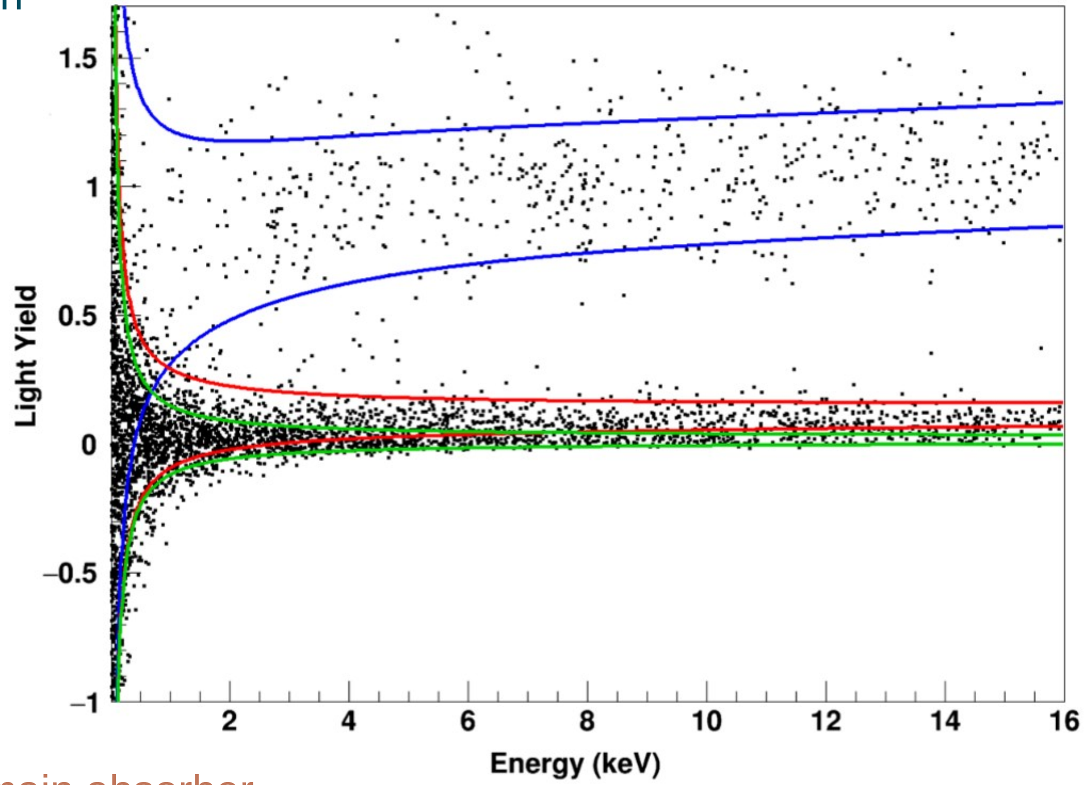


Sensors: W-TES directly evaporated on the crystals

Phonon-Light-Technique

For scintillating absorbers, the **light yield**[*] of an event depends on the interaction type:

Data taken with a neutron source



[*] light yield = detected light energy / energy in main absorber

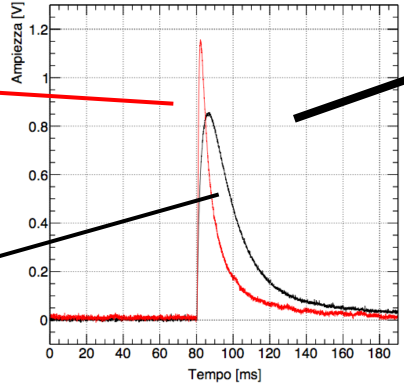
Phonon-Light-Technique

For scintillating absorbers, the **light yield*** of an event depends on the interaction type:

- **e$^-$/γ background** has a higher light yield

light energy

main absorber
(≈ total) energy



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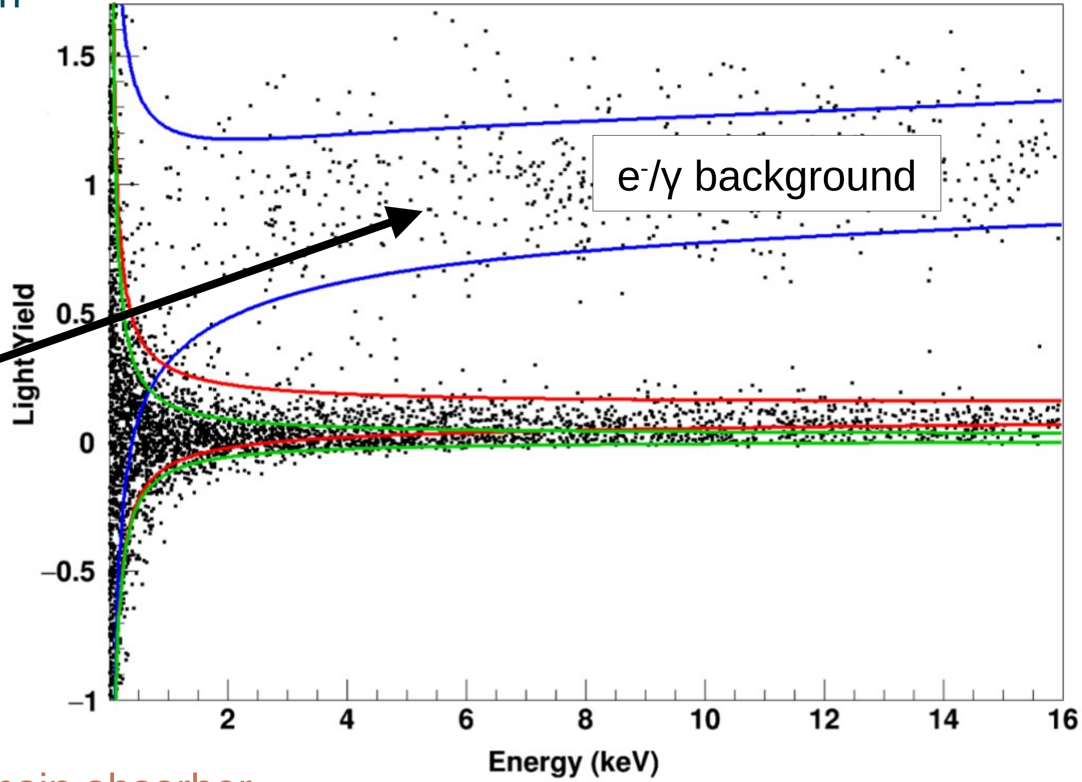

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Phonon-Light-Technique

For scintillating absorbers, the **light yield**[*] of an event depends on the interaction type:

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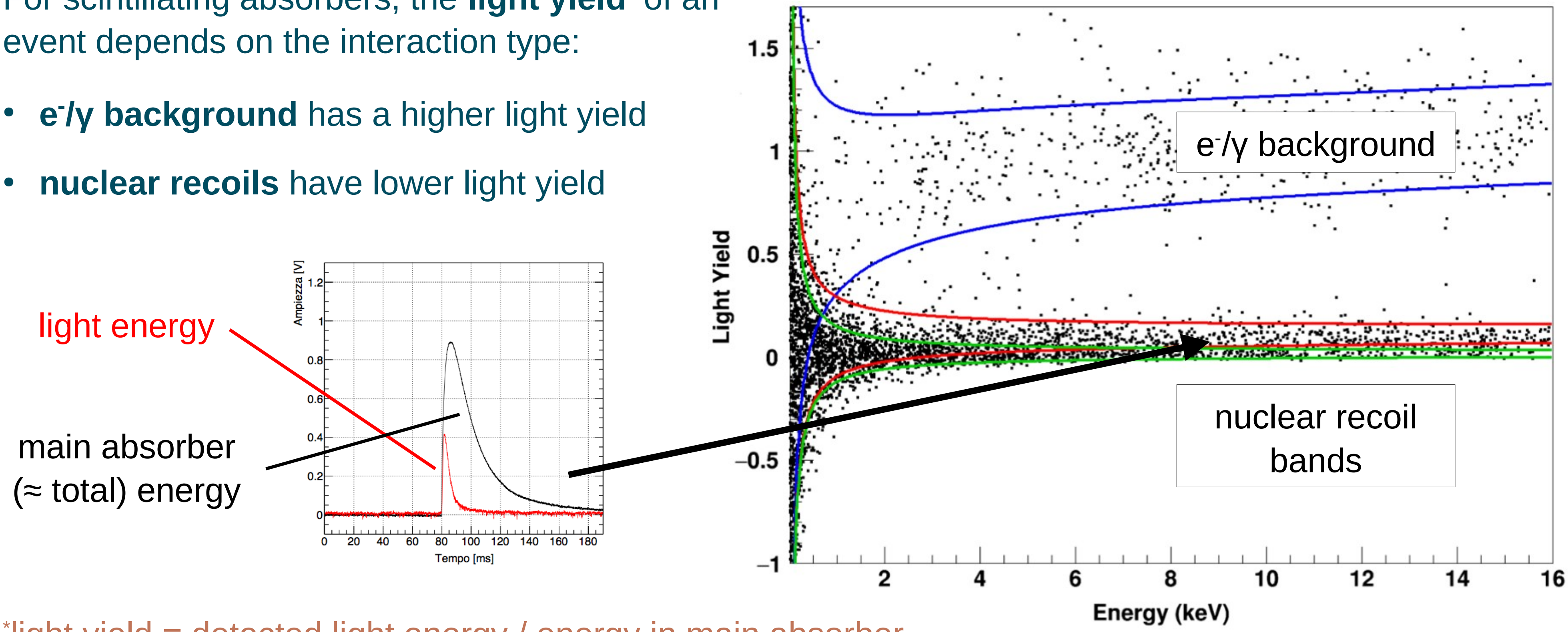

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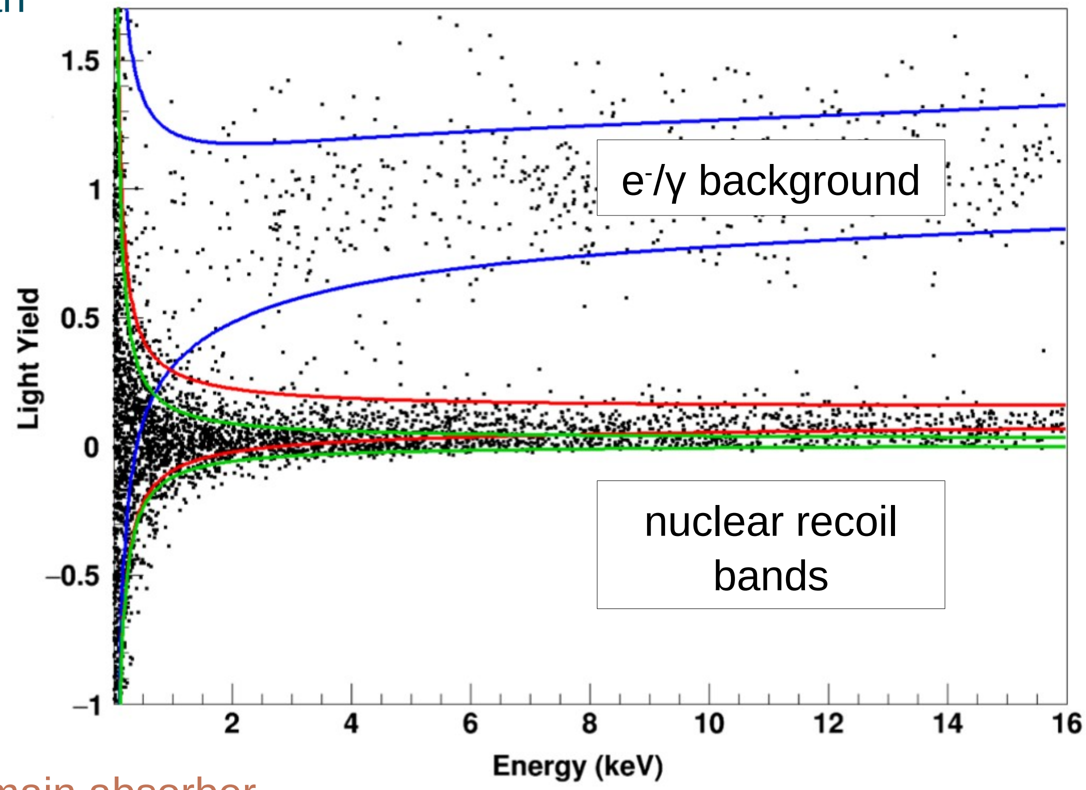
Phonon-Light-Technique

For scintillating absorbers, the **light yield**[*] of an event depends on the interaction type:

- **e⁻/γ background** has a higher light yield
- **nuclear recoils** have lower light yield
- events cluster in bands around the mean light yield; width of bands given by light detector resolution
- bands are less separated at lower energies
- position and width of the bands can be obtained from neutron calibration data

Data taken with a neutron source



[*] light yield = detected light energy / energy in main absorber

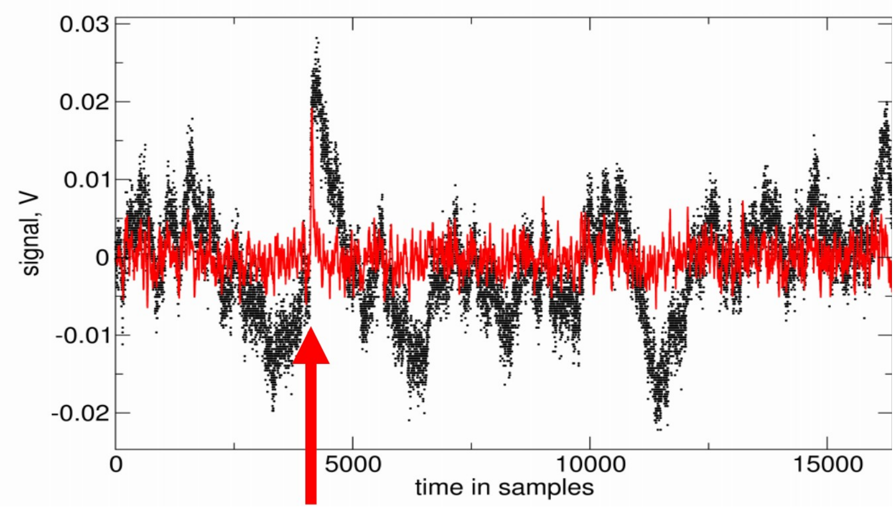
Data Processing

We record the **full data stream** on disk

→ apply **optimum (matched) filter** to the stream

Optimum filter output is used for:

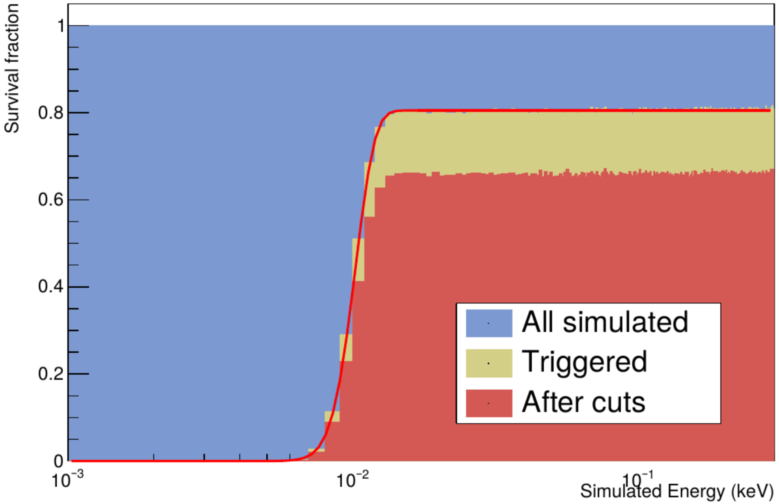
- offline triggering
- energy reconstruction



All analysis steps (calibration, data selection, …) are defined on a small training set

→ **DM search** is performed on a **blind data set**

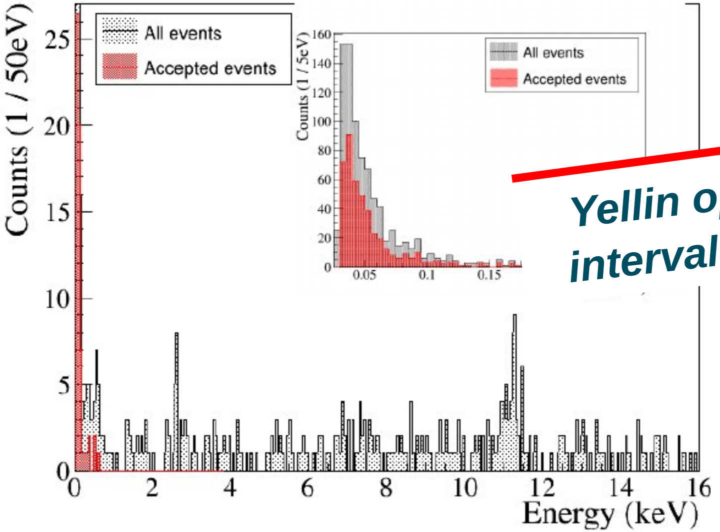
Survival probability of signal events is estimated with **artificial pulses** injected on the data stream and passed through the analysis pipeline



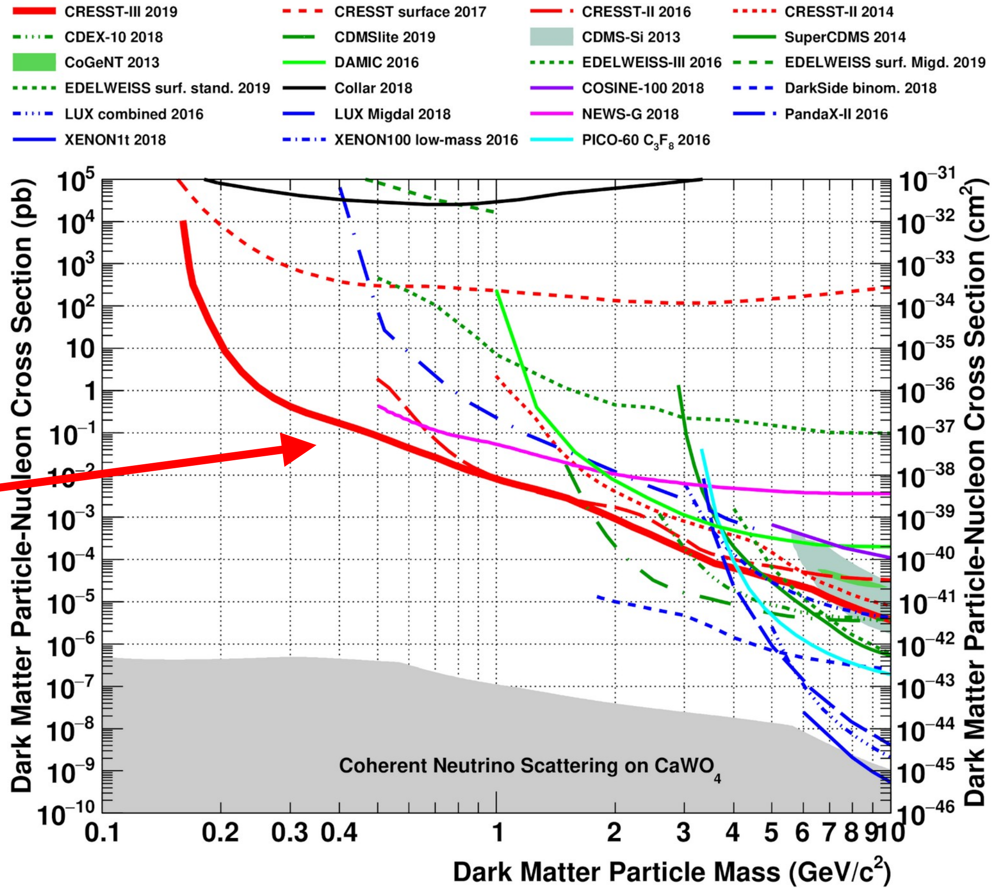
First Results from CRESST-III (2019)

Detector A – 23.6 g $CaWO_4$

data taking period	Oct 2016 – Jan 2018
exposure	5.698 kg · days
baseline resolution	4.6 eV
nuclear recoil threshold	30.1 eV



Yellin optimum interval method

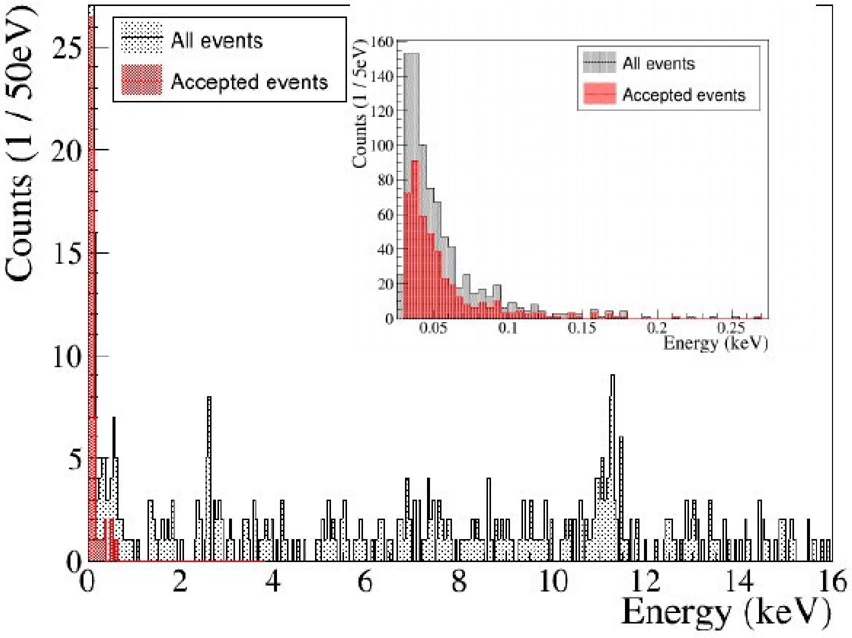


Phys. Rev. D 100, 102002 / arXiv:1904.00498

The Low Energy Excess (LEE)

First observations: 2016 – 2018

Detector A



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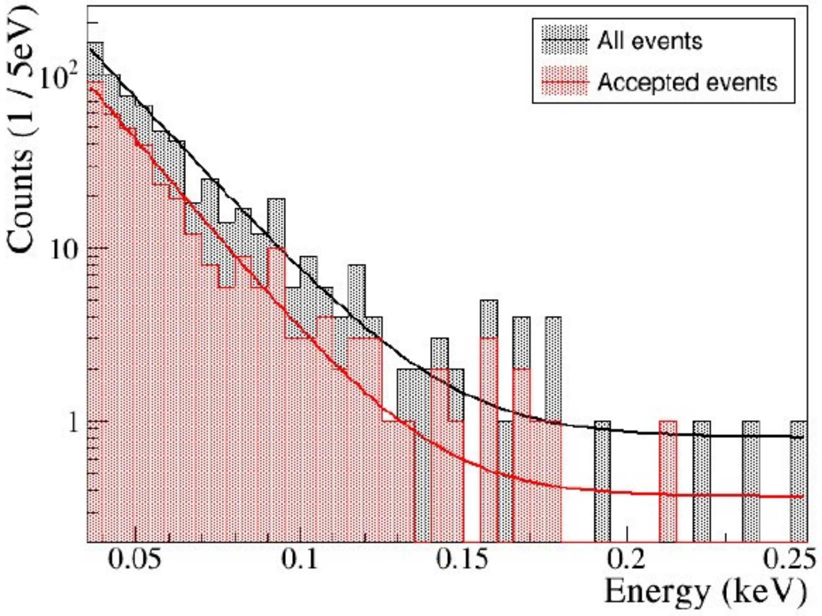
Unexplained event population at low energies

- high count rate
- steep rise in energy below ~200 eV

The Low Energy Excess (LEE)

First observations: 2016 – 2018

Detector A – Zoom



Unexplained event population at low energies

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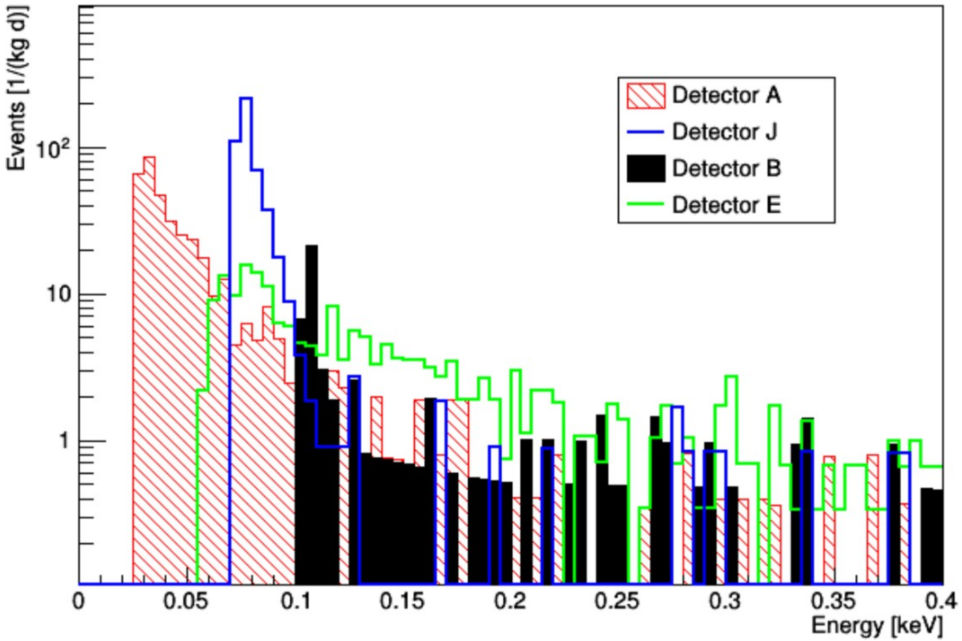
The Low Energy Excess (LEE)

First observations: 2016 – 2018

Overview of $CaWO_4$ Detectors



Unexplained event population at low energies

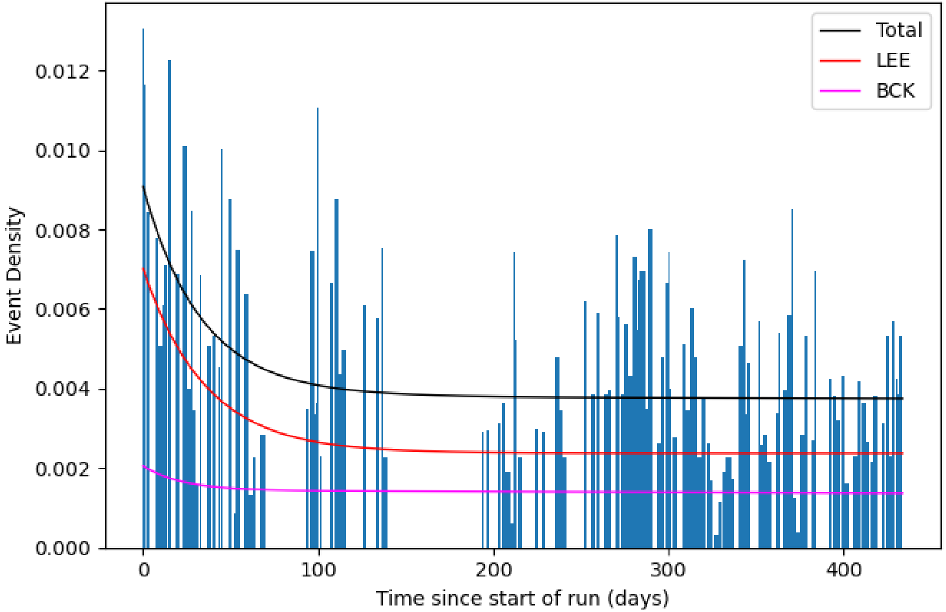
- high count rate
- steep rise in energy below ~200 eV
- different shape in different detectors

Detector	Threshold
Det-A	30.1 eV
Det-B	120 eV
Det-E	64.8 eV
Det-J	83.4 eV

The Low Energy Excess (LEE)

First observations: 2016 – 2018

Rate over time for Detector A



Unexplained event population at low energies

- high count rate
- steep rise in energy below ~200 eV
- different shape in different detectors
- count rate decreases over time

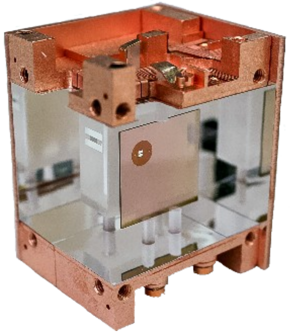
Shown at the first EXCESS Workshop in June 2021

Current Measurement Campaign

Managed to cool-down the detectors in summer 2020 – despite the pandemic

Took data for DM search from Nov 2020 until Aug 2021

Followed by neutron calibration and measurements of the LEE



Dedicated modifications to probe LEE:

- different target materials
- change how crystals are held
- remove scintillating components

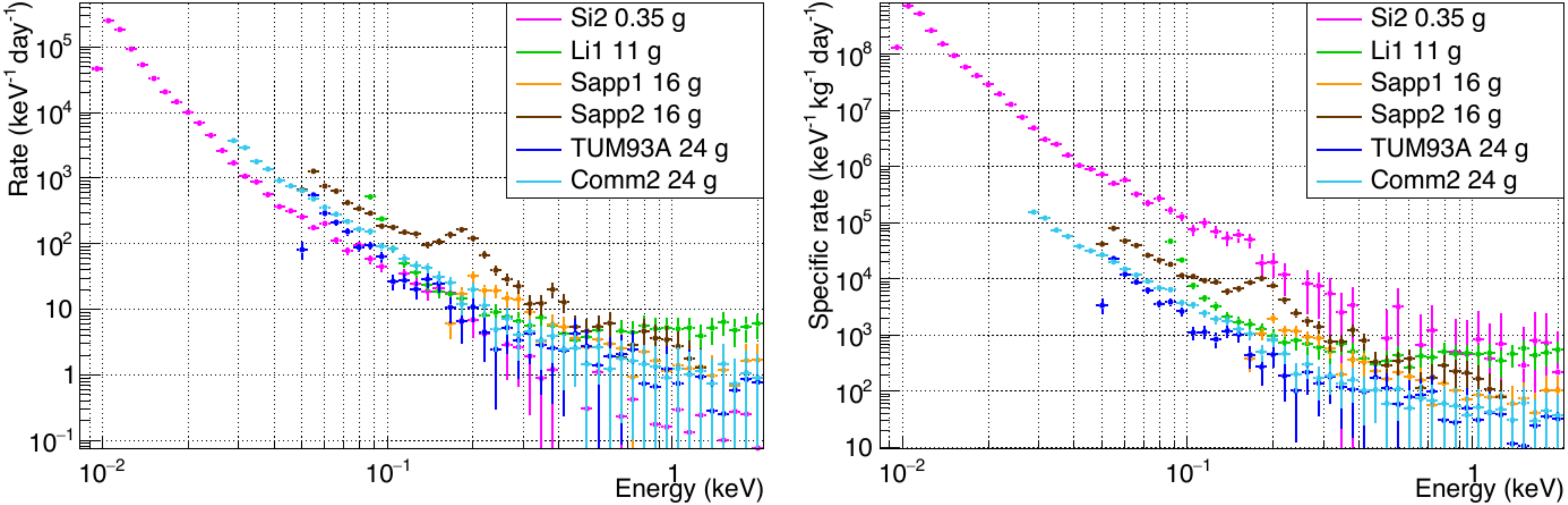
Routinely achieve thresholds < 100 eV

Name	Material	Holding	Foil	Mass	Threshold
Comm2	$CaWO_4$	bronze clamps	no	24.5 g	29 eV
TUM93A	$CaWO_4$	2 Cu + 1 $CaWO_4$	yes	24.5 g	54 eV
Sapp1	Al_2O_3	Cu sticks	no	15.9 g	157 eV
Sapp2	Al_2O_3	Cu sticks	yes	15.9 g	52 eV
Li1	$LiAlO_2$	Cu sticks	yes	11.2 g	84 eV
Si2	Si	Cu sticks	no	0.35 g	10 eV

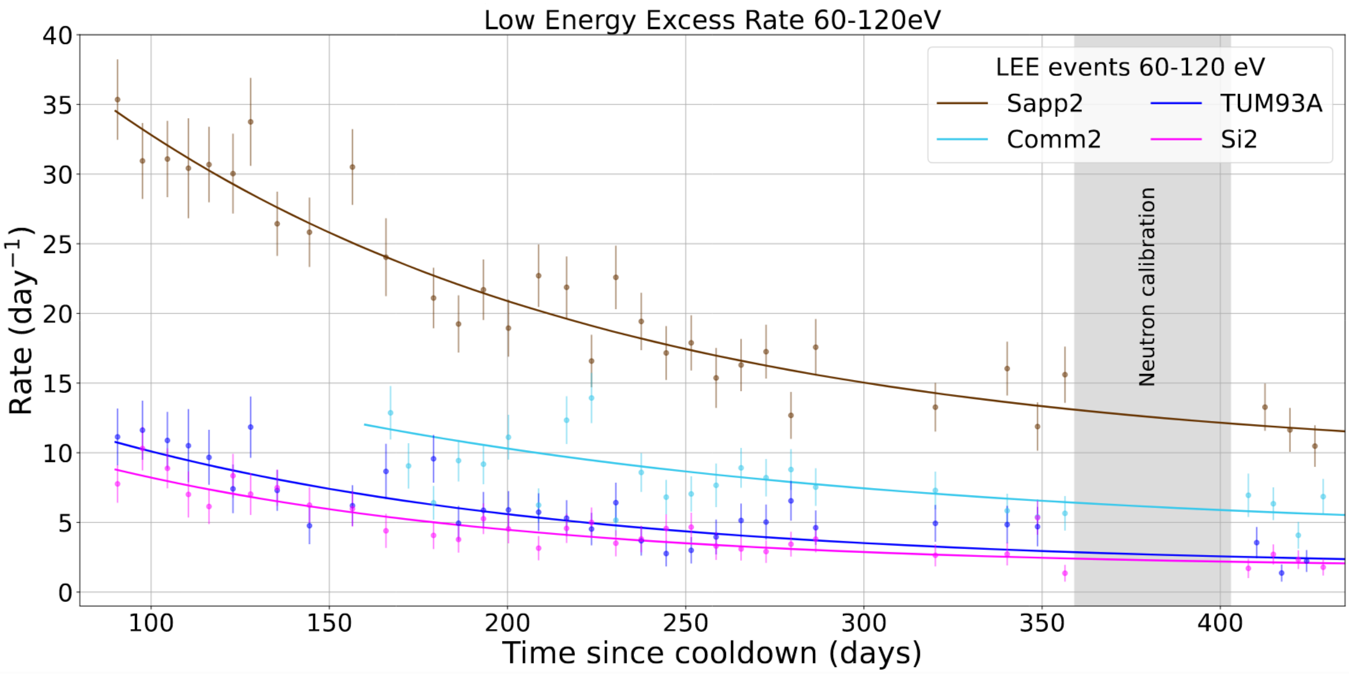
Observations on LEE

The LEE is observed in all these detectors (different materials and geometries).

Scaling the count rate by the absorber mass (right plot) does not improve the agreement between the count rates in different detectors.

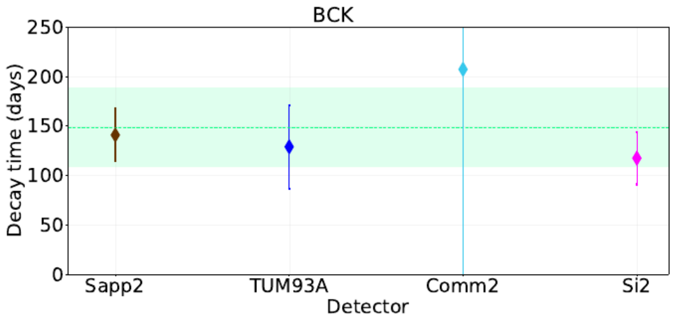


Time-evolution of LEE

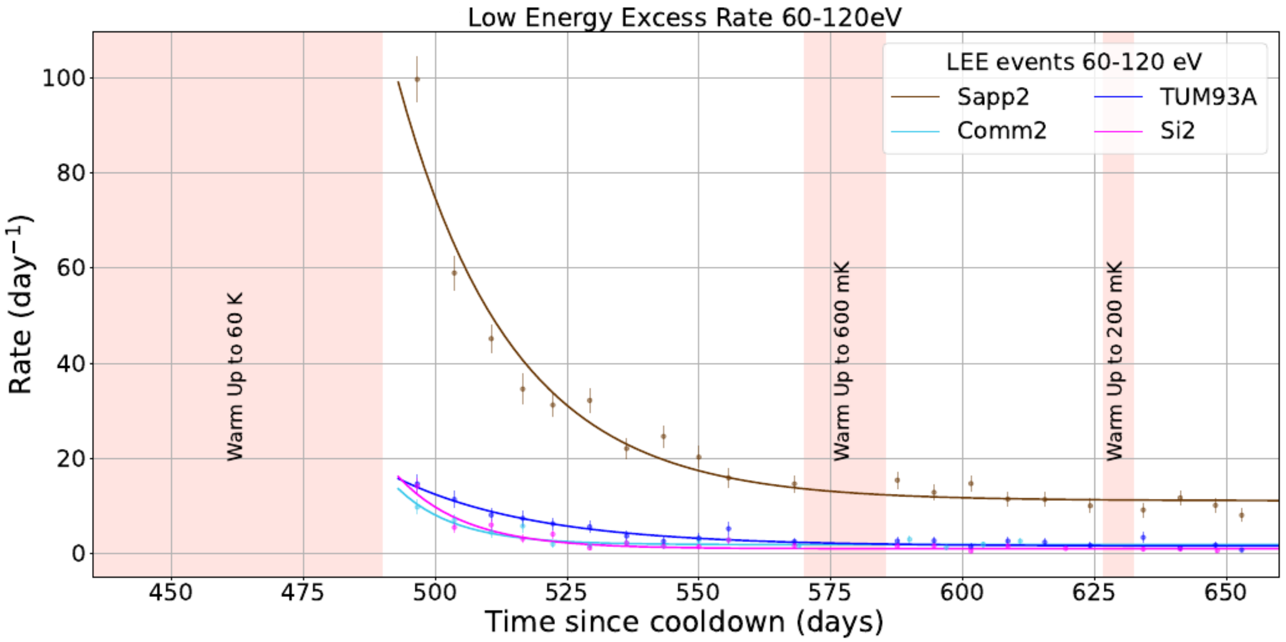


LEE count rate decreases over time in the DM data set (τ ≈ 150 d)

Subsequent neutron calibration has no effect on the LEE rate

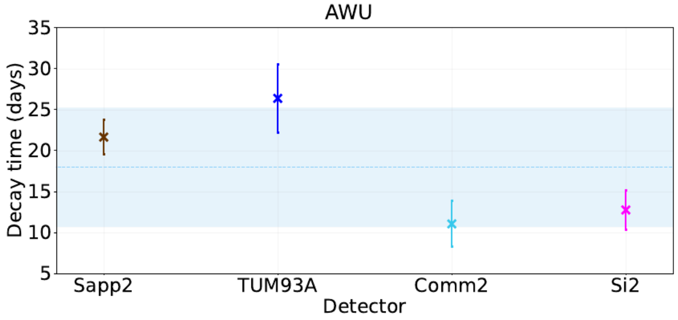


Time-evolution of LEE

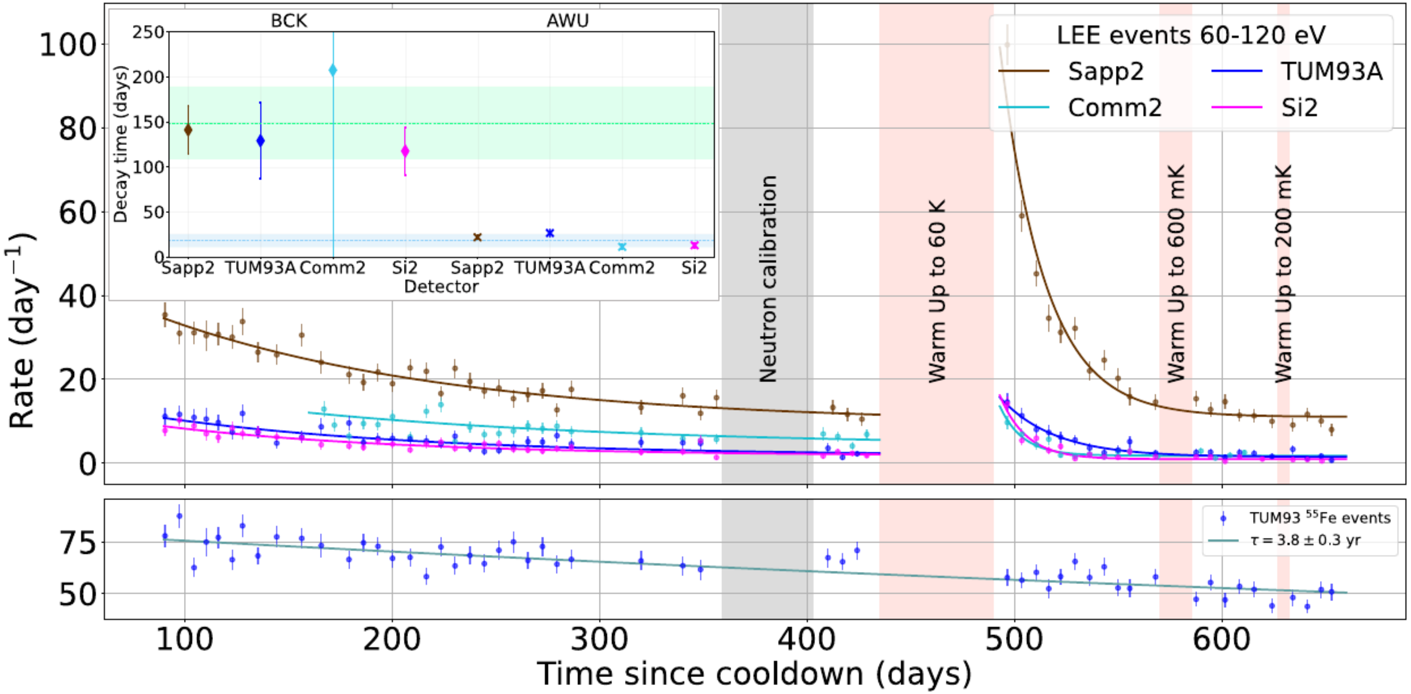


Warm-up to ~60 K leads to a sudden increase of the LEE rate, which then decreases again relatively fast (τ ≈ 18 d)

Warm-ups to ~200 mK and ~600 mK have no effect on the LEE rate



Time-evolution of LEE



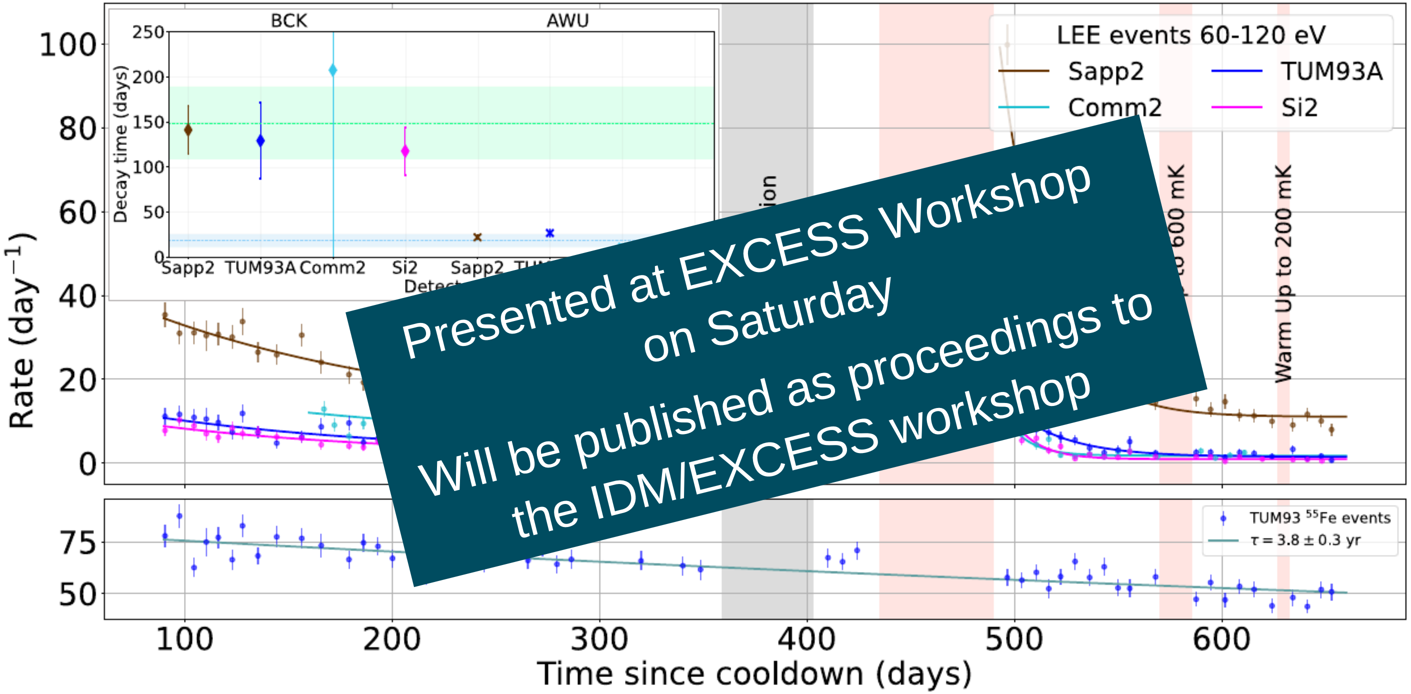
LEE count rate decreases over time in the DM data set ($\tau \approx 150$ d)

Subsequent neutron calibration has no effect on the LEE rate

Warm-up to ~60 K leads to a sudden increase of the LEE rate, which then decreases again relatively fast ($\tau \approx 15$ d)

Warm-ups to ~200 mK and ~600 mK have no effect on the LEE rate

Time-evolution of LEE



Presented at EXCESS Workshop on Saturday

Will be published as proceedings to the IDM/EXCESS workshop

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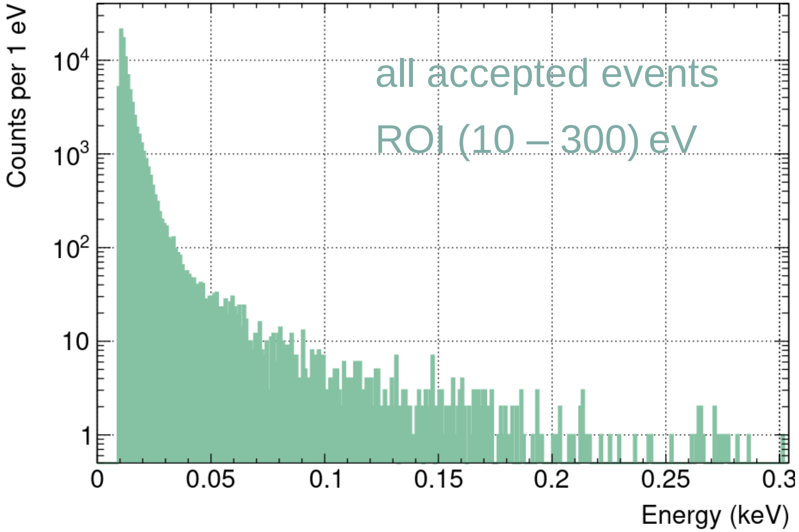
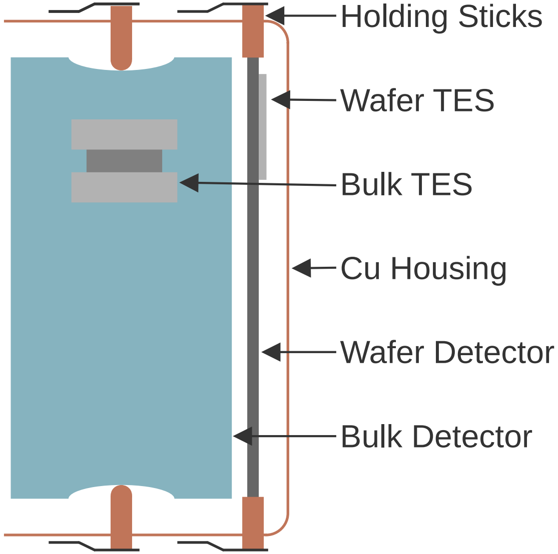
Results from a Si Wafer Detector

Si2 wafer detector – 0.35 g Si

data taking period	Nov 2020 – Aug 2021
exposure	55.06 g days
baseline resolution	1.36 eV
nuclear recoil threshold	10.0 eV





Using thin wafer detector as target and bulky detector as veto detector.

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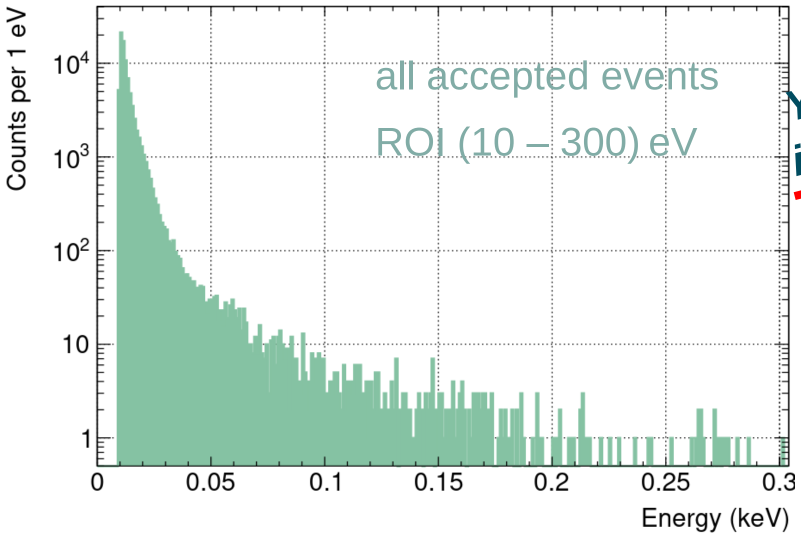

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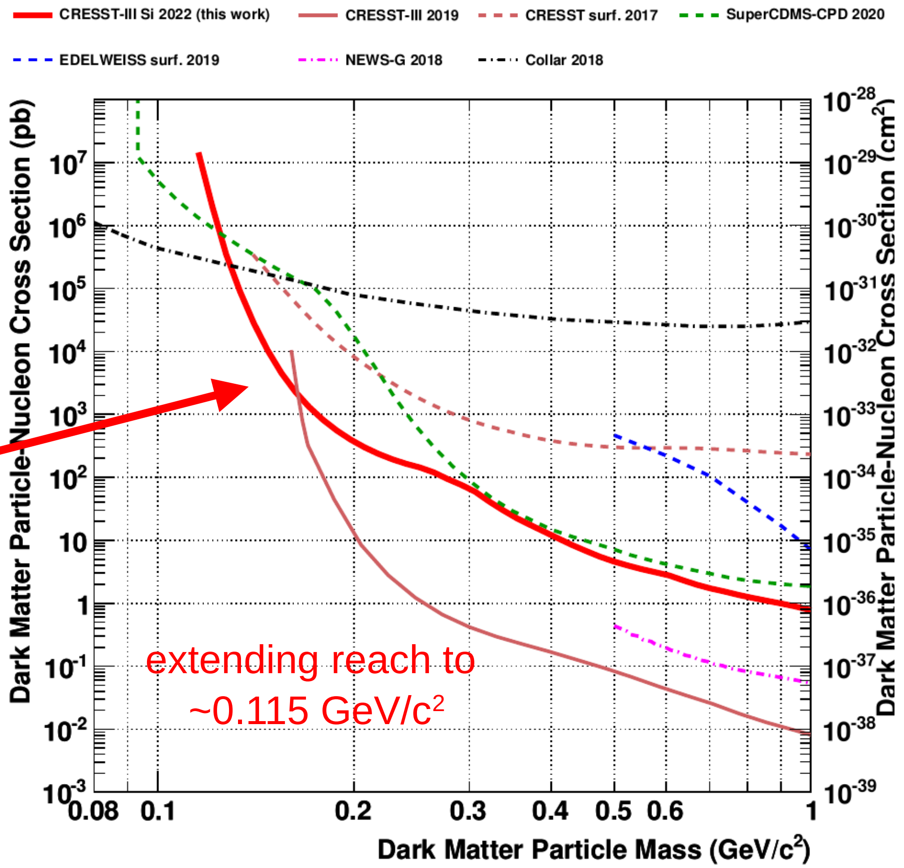


extending reach to ~0.115 GeV/c^2

publication in preparation

SD Limits with $LiAlO_2$ Detectors

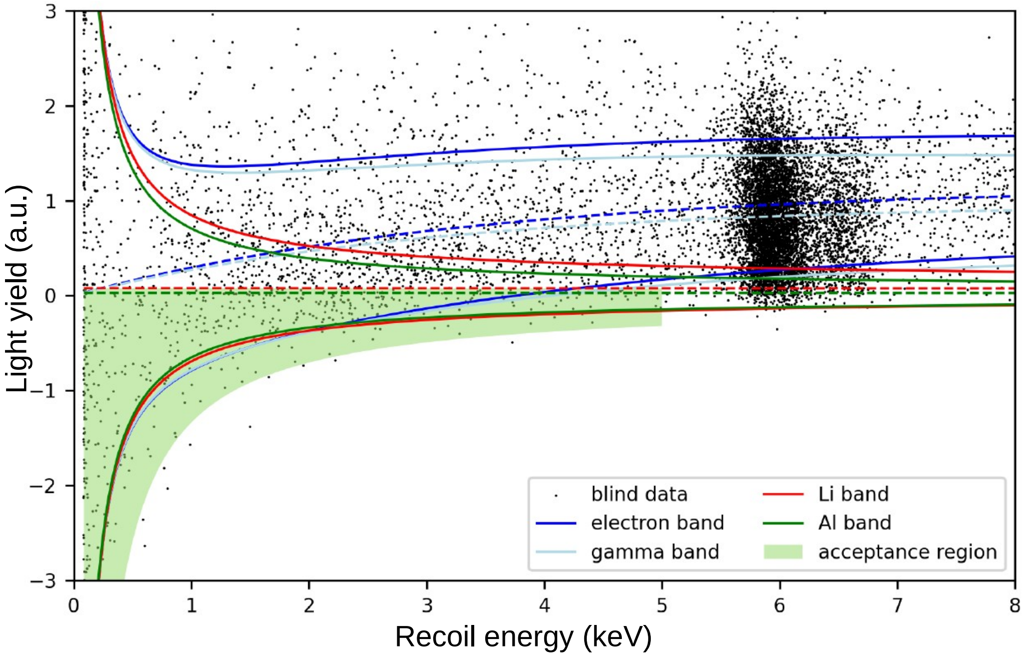
Li1 detector – 11.2 g $LiAlO_2$

data taking period	Nov 2020 – Aug 2021
exposure	1.161 kg days
baseline resolution	12.8 eV
nuclear recoil threshold	83.6 eV

$$\sigma_0^{SD} \propto \mu_N^2 \cdot \frac{J_N+1}{J_N} \cdot [a_p \cdot \langle S^p \rangle + a_n \cdot \langle S^n \rangle]^2$$

Isotopes sensitive to SD interactions:

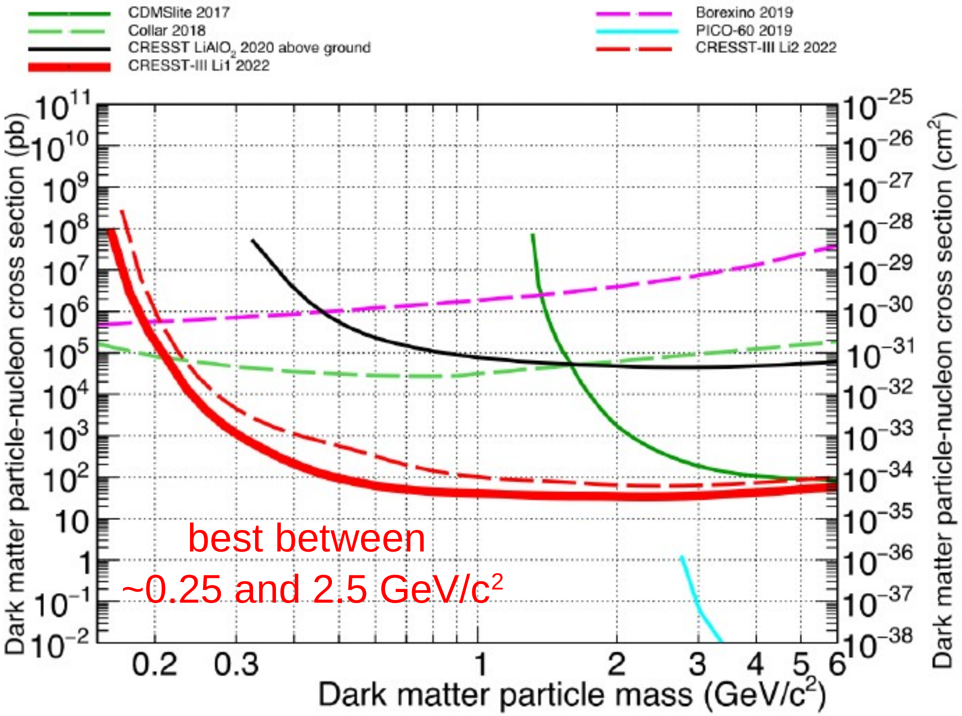
Isotope	$\langle S_p \rangle$	$\langle S_n \rangle$
^{6}Li	0.472	0.472
^{7}Li	0.497	---
^{27}Al	0.343	0.0296



arXiv:2207.07640

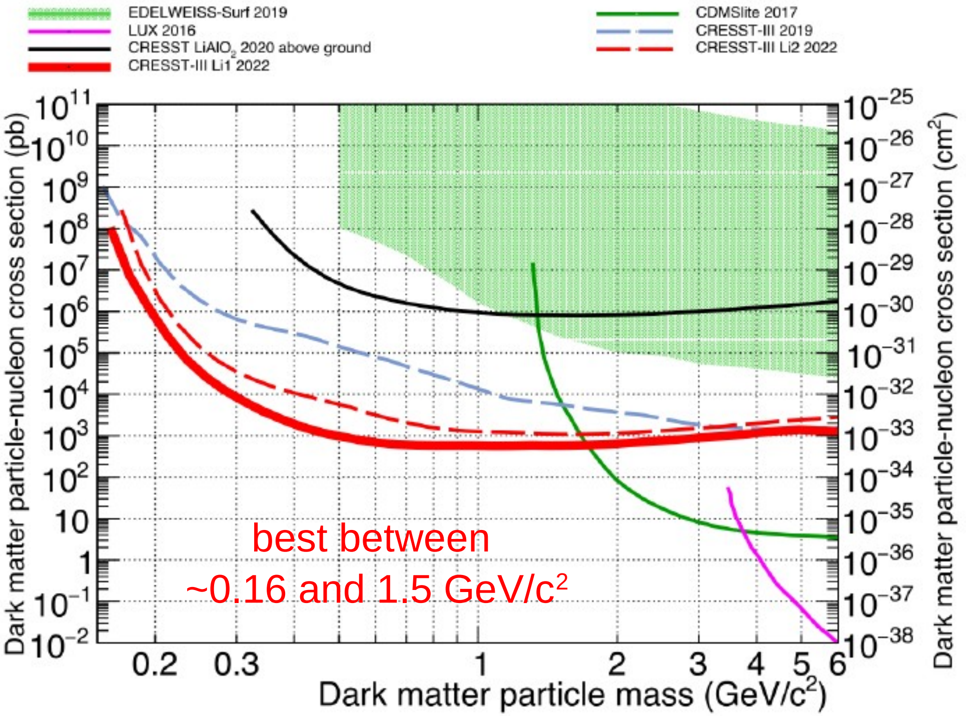
SD Limits with $LiAlO_2$ Detectors

Proton-only



best between ~0.25 and 2.5 GeV/c^2

Neutron-only



best between ~0.16 and 1.5 GeV/c^2

arXiv:2207.07640

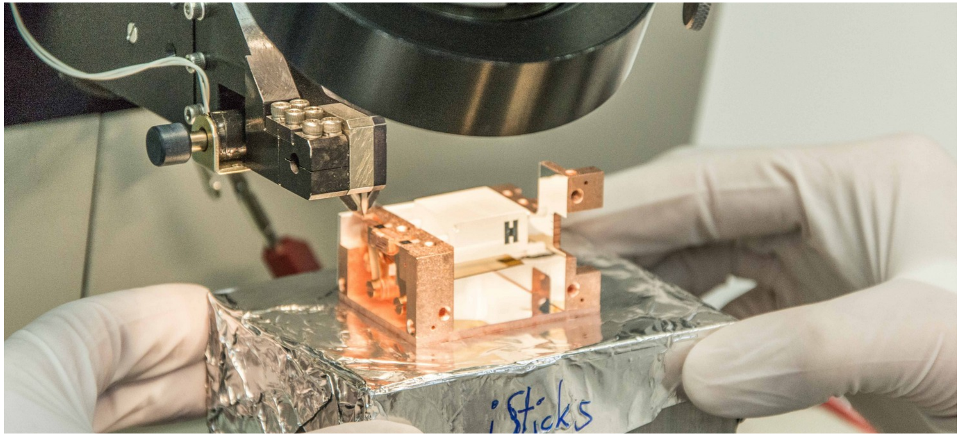
Great improvement over previous above-ground results! Extending reach to 0.16 GeV / c^2

What happens next?

Perform **additional warm-up tests** to collect additional information about the LEE.

Detector R&D is ongoing:

- even lower thresholds
- complementary materials
- stress-free holding
- mass production and reproducibility



Upgrade of the **read-out system to 288 channels** is being prepared:

- SQUIDs and wiring is already procured
- new DAQ and bias electronics is designed
- goal: installation at LNGS in 2023

Summary

Exciting **new dark matter results**:

- extending reach to lower masses with **10 eV threshold** Si detector
- unique ability to use a **wide-range of target materials** enables SD results with $LiAlO_2$ absorbers

Broad R&D program to **identify the origin of the LEE** and mitigate its effects

Ongoing efforts to **improve our detectors** (lower thresholds, increase radiopurity of crystals, …)

Preparing for a **major infrastructure upgrade** of the read-out electronics to accommodate up to 100 detector modules

Thanks for your Attention!

Please also check out the other CRESST contributions @ IDM:

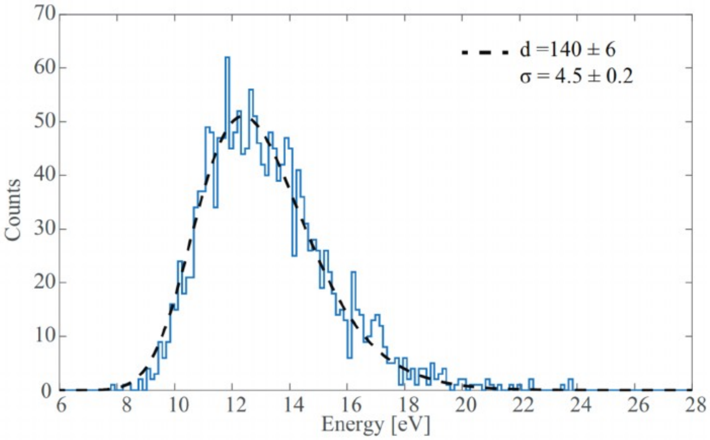
Talks		**Posters**
“Probing Li targets in CRESST-III” S. Gupta	up next!	*“Testing spin-dependent dark matter with lithium targets in CRESST-III”* – F.Wagner
“Characterization of a low background CaWO4 crystal for CRESST-III” A. Kinast	Thu 14:40	*“Neutron simulation studies and their implications for CRESST”* – A. Fuss
		“Using a likelihood fit to identify radioactive background components in the CRESST experiment” – J. Burkhart

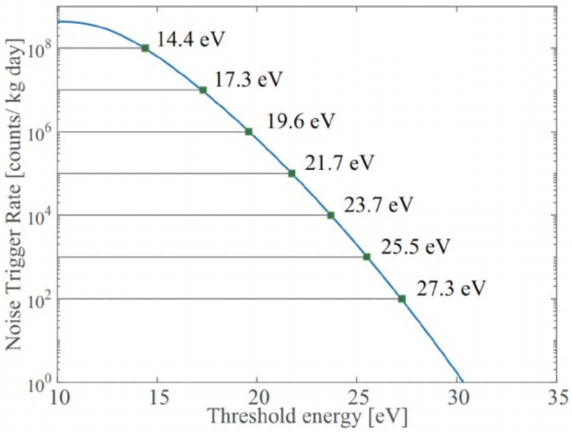
Threshold Determination

Analytical description of **amplitude distribution** of “empty” noise traces

→ see NIM A **940**, 492 (2019) / arXiv:1711.11459

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





Allows to define the threshold as a function of allowed noise trigger rate

Default choice in CRESST:
1 noise trigger / (kg day)

LEE Pulse Shape

Average of all pulses just above threshold (“LEE template”) agrees with expected signal pulse shape from particle interactions.