ÖAW HEPHY INSTITUTE OF HIGH ENERGY PHYSICS FWF Der Wissenschaftsfonds.

CRESST Cryogenic Rare Event Search with Superconducting Thermometers

Testing spin-dependent DM interactions with $LiAlO_2$ targets in CRESST-III

Shubham Gupta[1] - on behalf of the CRESST collaboration

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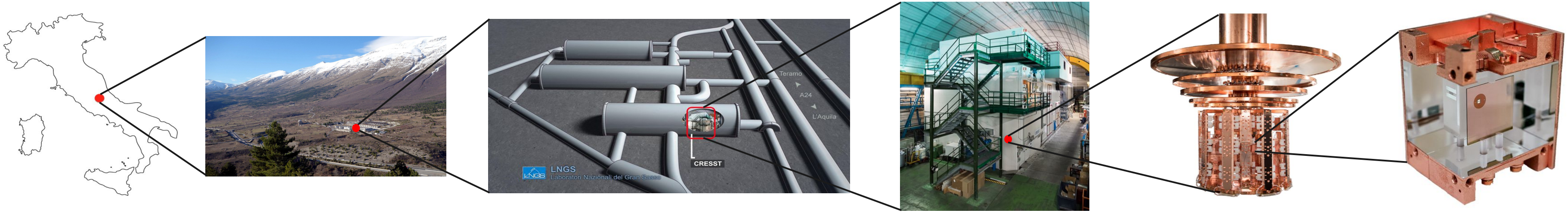
INFN LNGS · MAX-PLANCK-INSTITUT FÜR PHYSIK · TUM · TU WIEN · EBERHARD KARLS UNIVERSITÄT TÜBINGEN · COMENIUS UNIVERSITY BRATISLAVA · UNIVERSITY OF OXFORD

What is CRESST? (A quick recap)

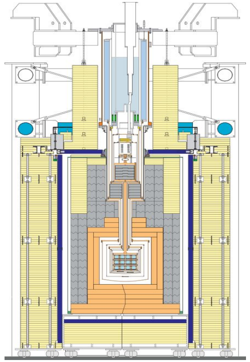
Cryogenic Rare Event Search with Superconducting Thermometers

What is CRESST?

Cryogenic Rare Event Search with Superconducting Thermometers



- Located under Gran Sasso massif
- Provides rock overburden of 1000m (eq. 3600m water)
- Measured muon flux 1 count/m^2/hour (around *O(5)* lower than surface)
- Polyethylene, lead and copper shieldings to prevent against background neutrons and gamma.



What is CRESST?

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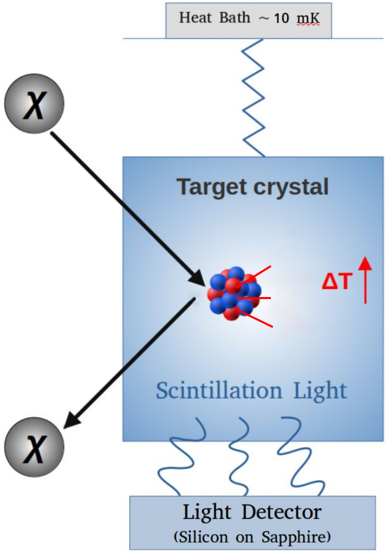
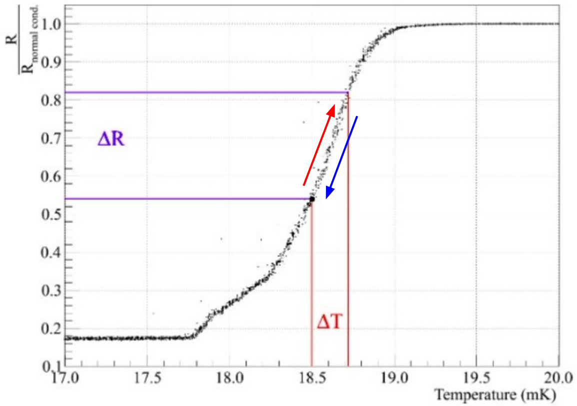
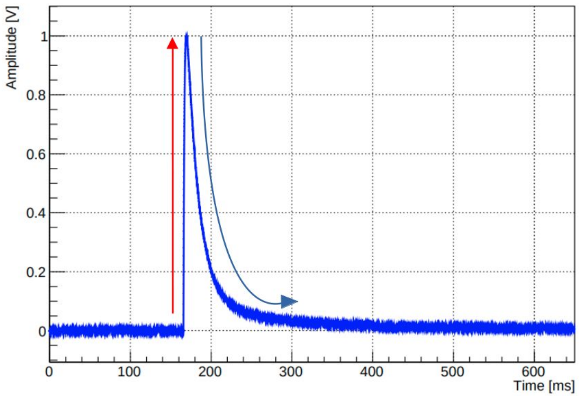


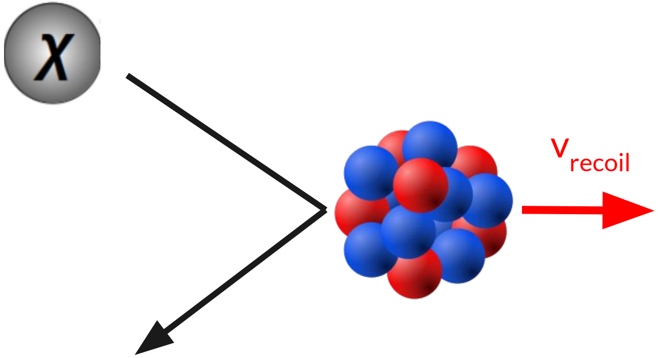
Transition Edge Sensors (TES)





Recoil energies *O(keV)* ⟶ Temperature increase *O(μK)* ⟶ Resistance change *O(mΩ)* ⟶ Voltage increase *O(mV)*

Idea behind DM searches with CRESST



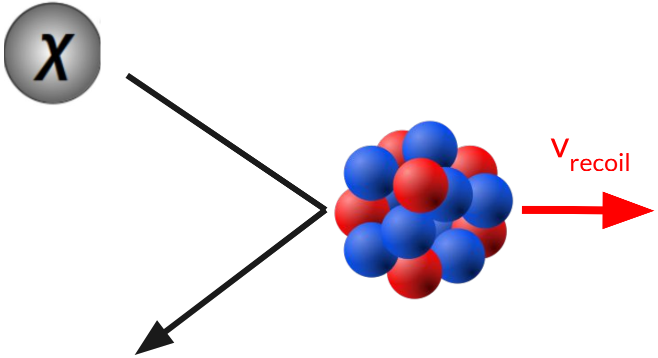
WIMP scattering off nuclei leads small energy depositions

These interactions are usually:

- Coherent (~A^2)
- Elastic
- Spin-independent

Cryogenic **Rare Event Search** with Superconducting Thermometers

Idea behind DM searches with CRESST



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Expected recoil rate:

$$\frac{\mathrm{d}R}{\mathrm{d}E_R} = \frac{\rho_\chi}{2 m_\chi \mu_N^2} \sigma_0 F^2(E_R) \int_{v_{\min}}^{\infty} \mathrm{d}^3 v \frac{f(\vec{v})}{v}$$

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Idea behind DM searches with CRESST

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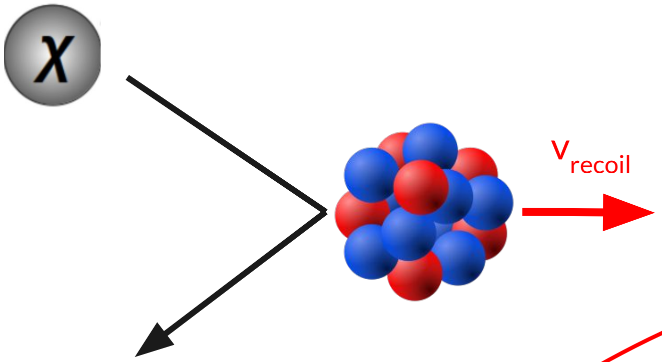

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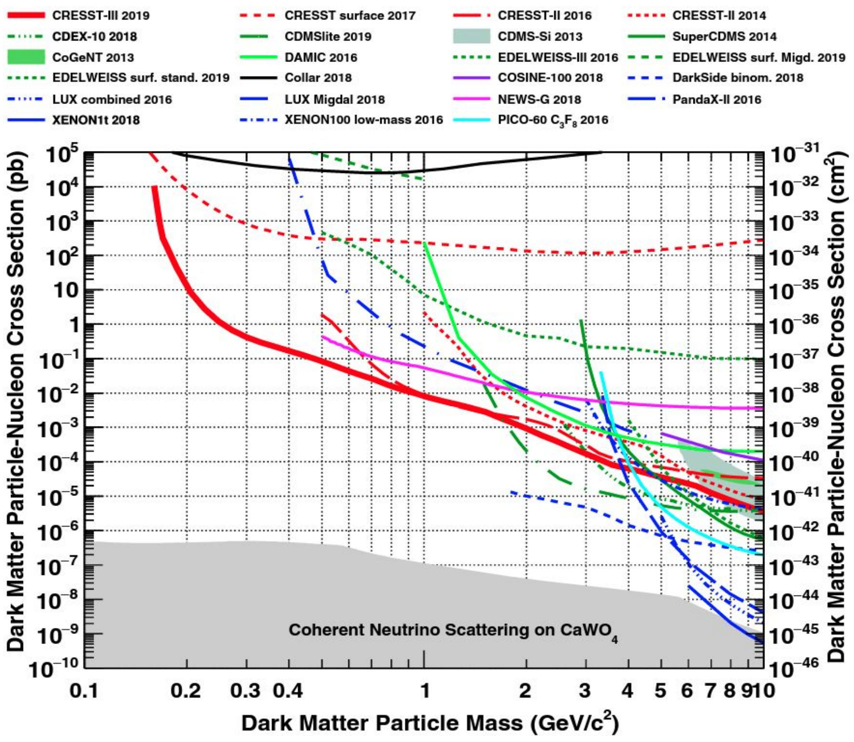
Inputs from:
- Astrophysics
- Nuclear physics

Probed

Results from spin-independent interactions using $CaWO_4$

Phys. Rev. D 100, 102002



Scenarios for spin-dependent interaction

The cross-section is given by:

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

where, a_p and a_n are effective coupling to protons and neutrons respectively
And $\langle S^p \rangle$ and $\langle S^n \rangle$ are the spin expectation values of protons and neutron respectively

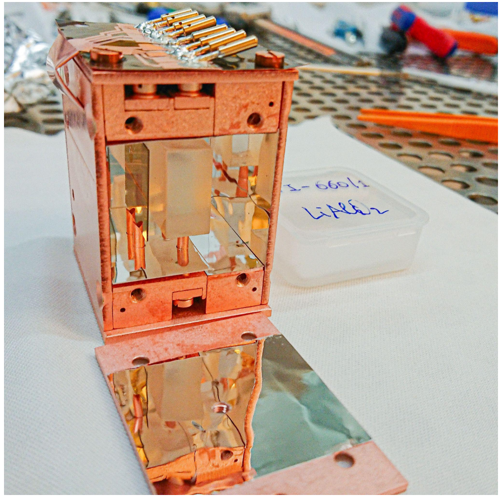
The expected recoil rate can be given by:

$$\frac{dR}{dE_R} = \frac{2\rho_0}{m_\chi} \sigma_{p/n}^{SD} \sum_{i,T} f_{i,T} \left(\frac{J_{i,T}+1}{3J_{i,T}} \right) \left(\frac{\langle S_{p/n,i,T} \rangle^2}{\mu_{p/n}^2} \right) \eta(v_{min})$$

where, $f_{i,T} = \frac{n_T \zeta^i m_T^i}{\sum_{i,T'} n_{T'} \zeta^i m_{T'}^i}$

is the fraction of isotope *i* of target *T* in the nucleus scaled by its mass.

Why $LiAlO_2$



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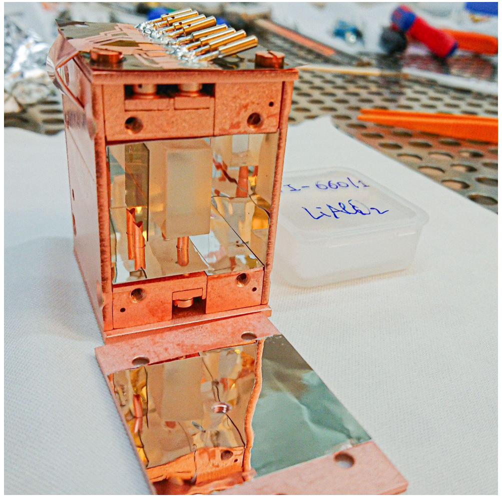

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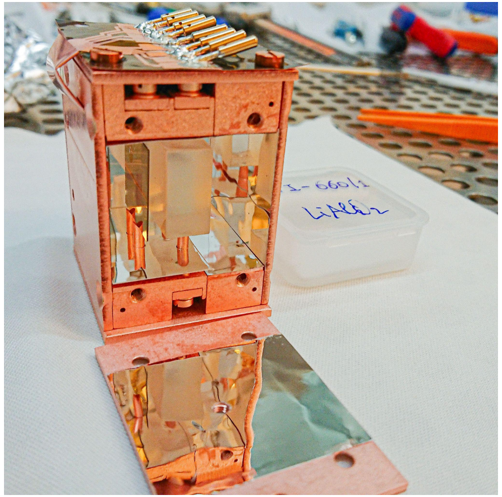

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- Contains traces of natural ^{6}Li (~7.5%) which also has an odd number of neutrons, thus can be used for probing spin-dependent interactions with neutrons.

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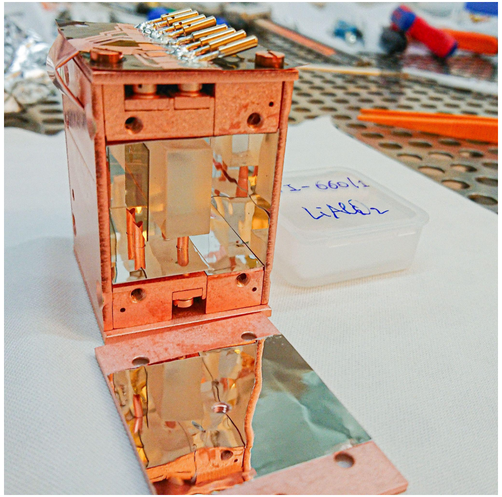

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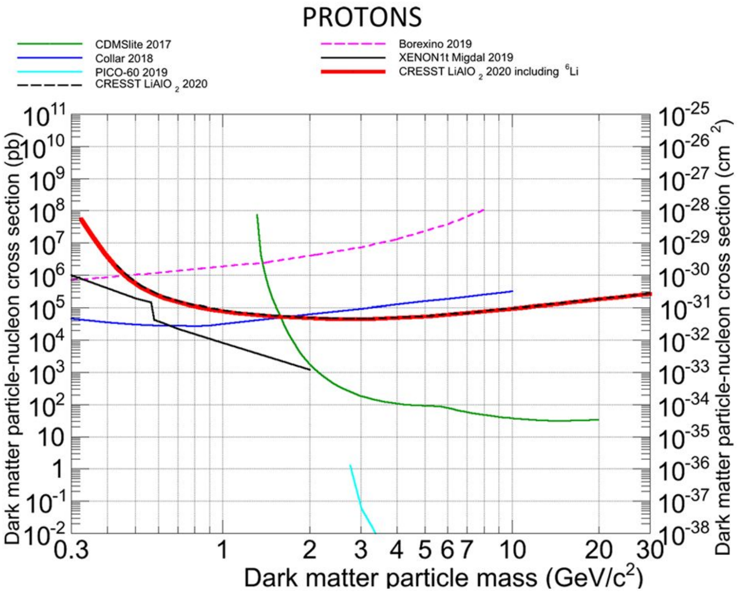
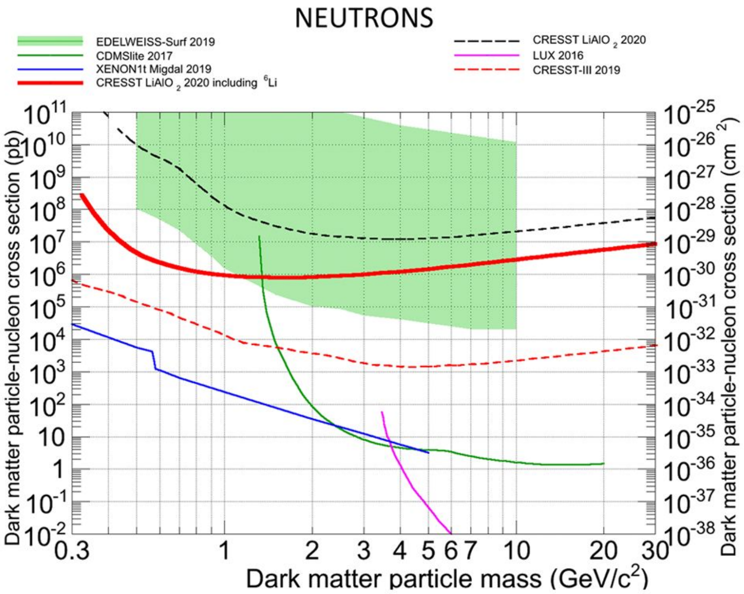
- Scintillator giving 340 nm scintillation light which can be absorbed by CRESST light detectors.

Results from above ground run

Eur. Phys. J. C 82, 207 (2022)





- Showed good potential to probe DM spin-dependent interactions underground with higher exposure

Details from the underground run

Two Li modules, namely Li1 and Li2 were employed

Module	**Li1**	**Li2**
Operating Channel	Phonon and Light	Phonon
Duration of Run	02/2021 to 08/2021	02/2021 to 08/2021
Target Mass (g)	10.46	10.46
Dimensions (cm^3)	2 x 2 x 1	2 x 2 x 1
Exposure (kg.days)	1.161	1.184
Resolution (eV)	13.10 ± 0.02	15.89 ± 0.18
Nuclear recoil threshold (eV)	83.60 ± 0.02	94.09 ± 0.13

Phys. Rev. D 106, 092008

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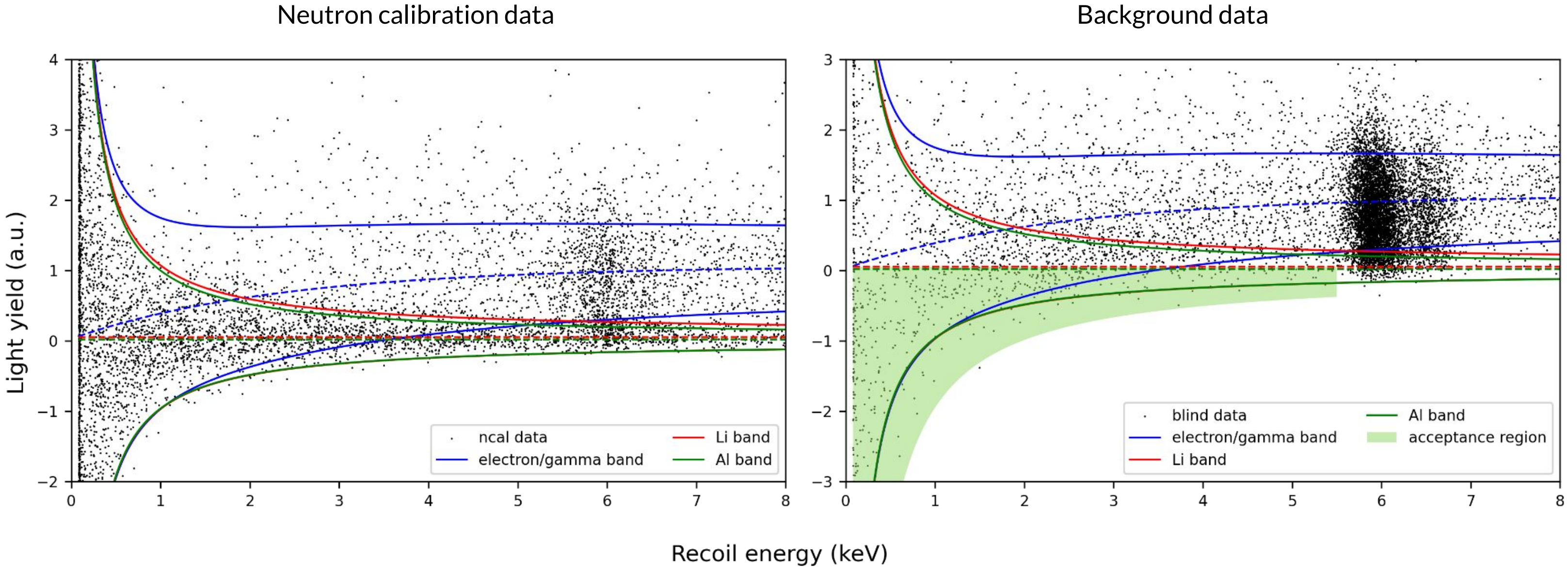
Phys. Rev. D 106, 092008

Results (Li1)



- Light channel readout helps in discriminating potential background (electron/gamma) events
- Mean of the Li nuclear recoil band and lower 99.5% of aluminium band is chosen as the region of interest for potential DM recoil candidates
- We define **83.60 eV - 5.5 keV** as the energy region of interest due to presence of X-rays from ^{55}Fe above that

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Results (Li1)

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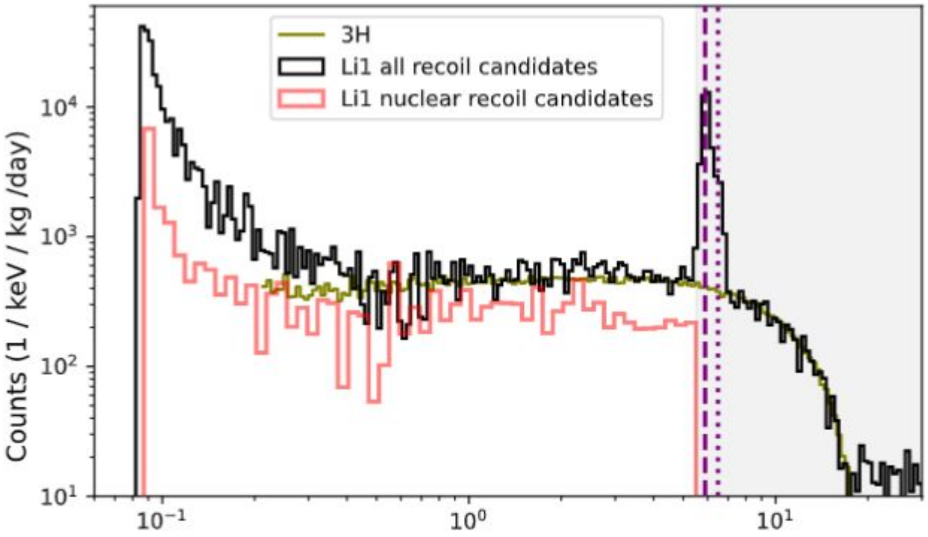

$$^6\text{Li} + n \rightarrow \alpha + {}^3\text{H} + 4.78\ \text{MeV}$$

Main features of the spectrum:

- Presence of Kα and Kβ ^{55}Fe lines used for energy calibration of the detector
- ^3H background due to its presence in the crystals after neutron activation
- Rising number of events at lower energies of unknown origin (LEE, under investigation)

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New results

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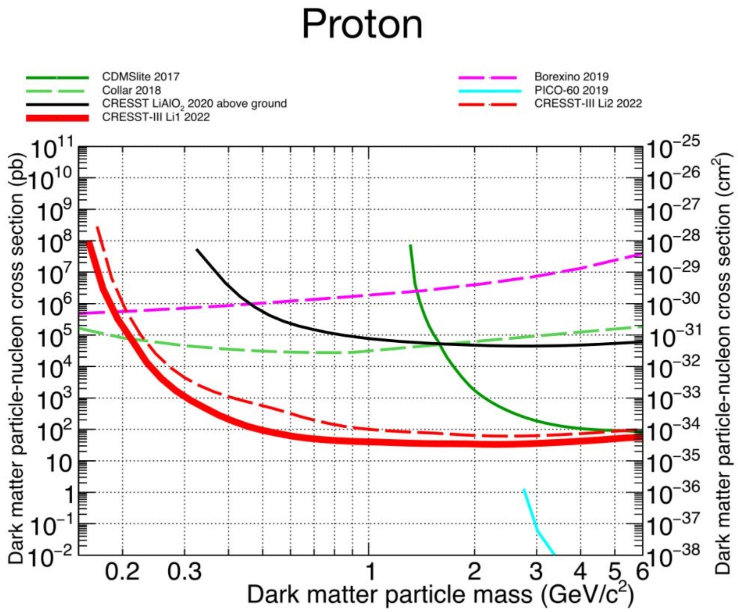
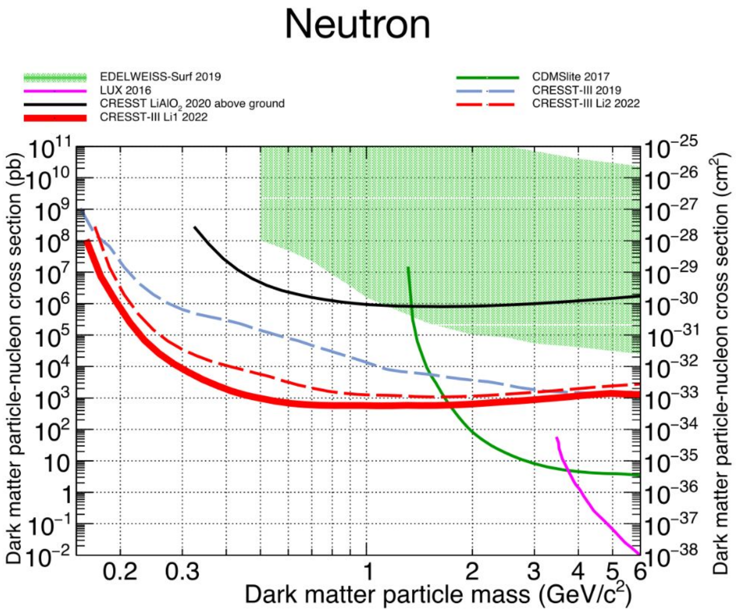
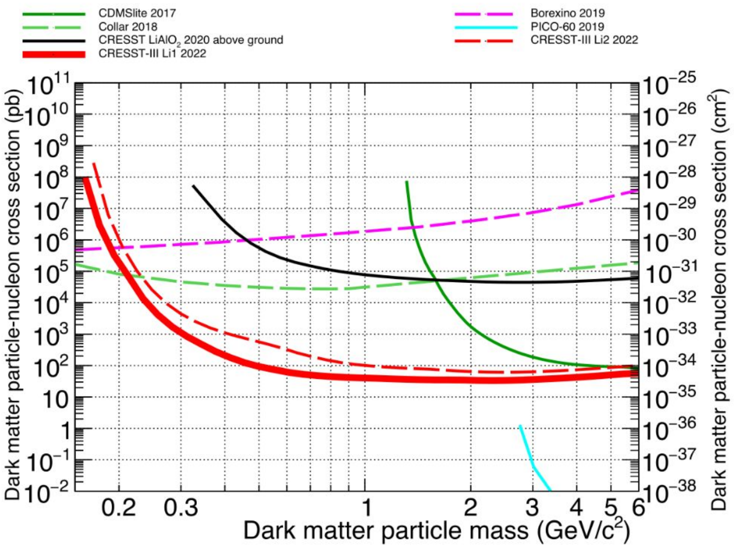


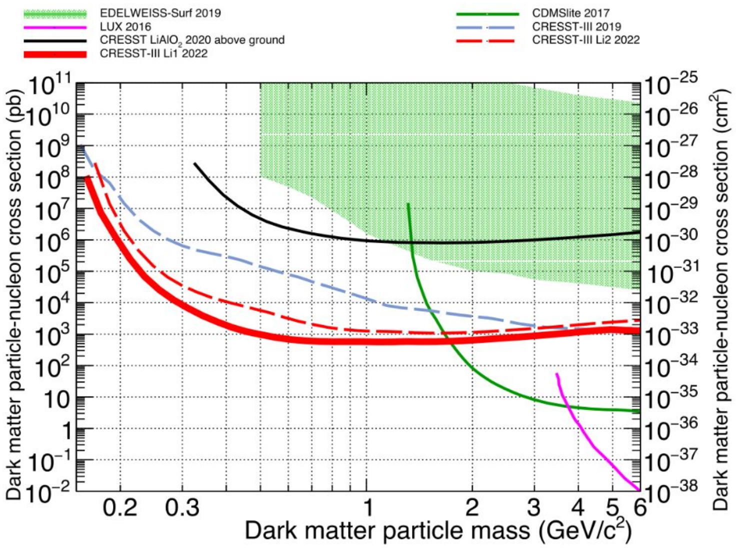


New results

Proton



Neutron



- 3 orders of magnitude improvement compared to above ground measurements.

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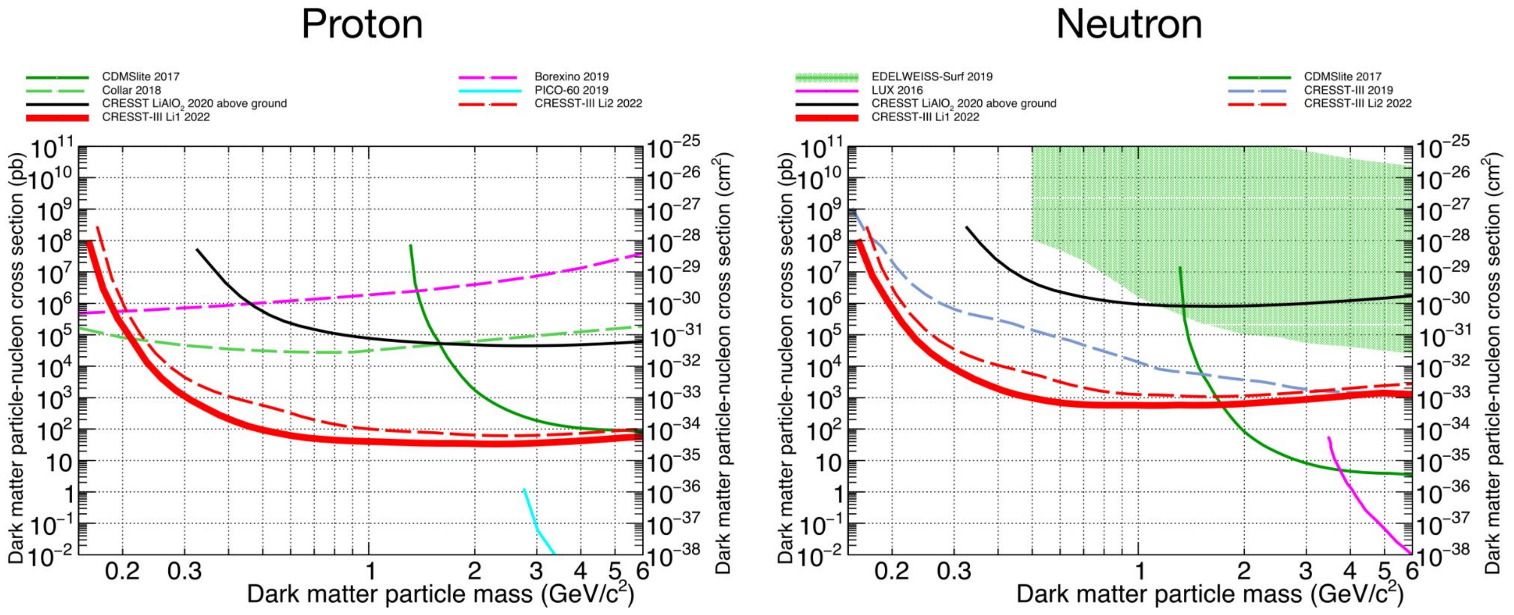

- 3 orders of magnitude improvement compared to above ground measurements.
- Most stringent limits for *proton-only* interactions in roughly **(0.2-2.5) GeV/c^2** and for *neutron-only* interactions in **(0.16-1.5) GeV/c^2** DM mass range.

New results

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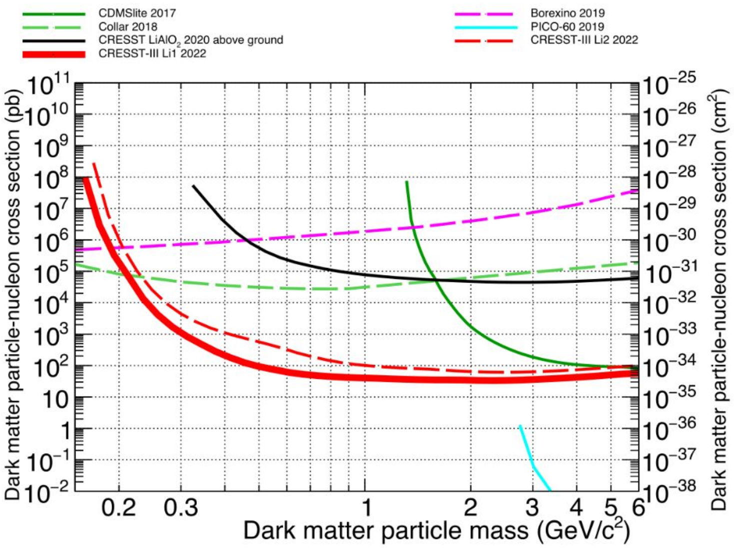

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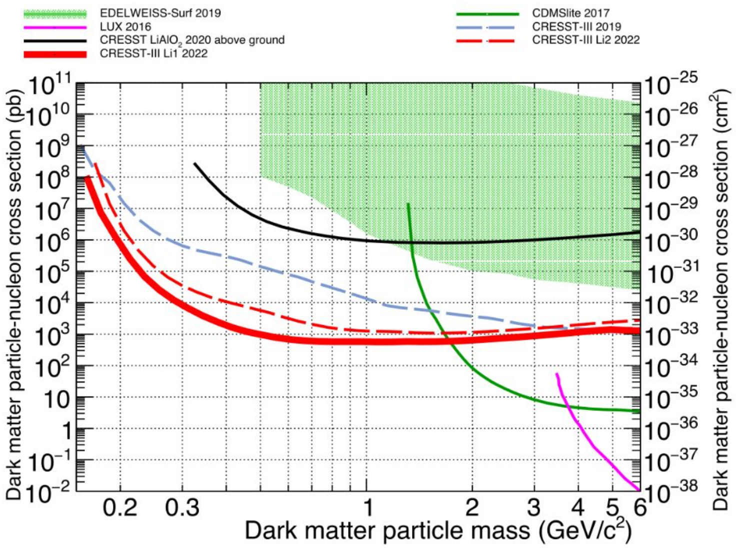
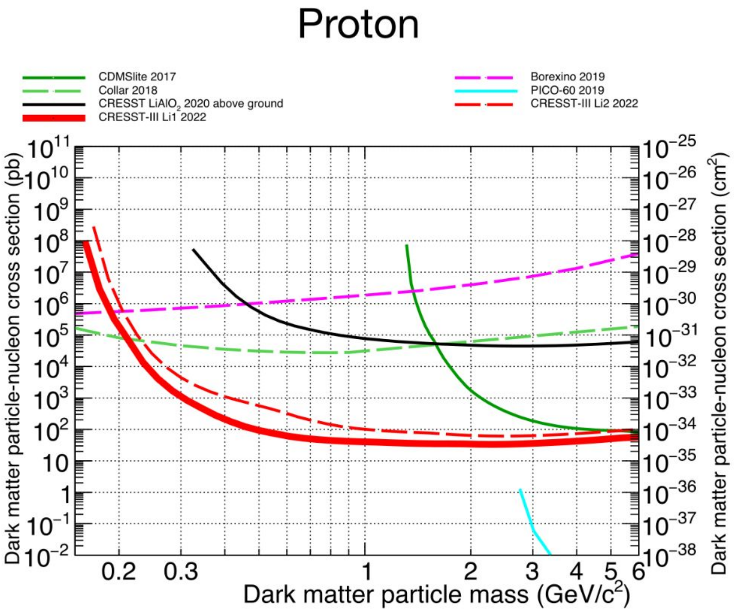
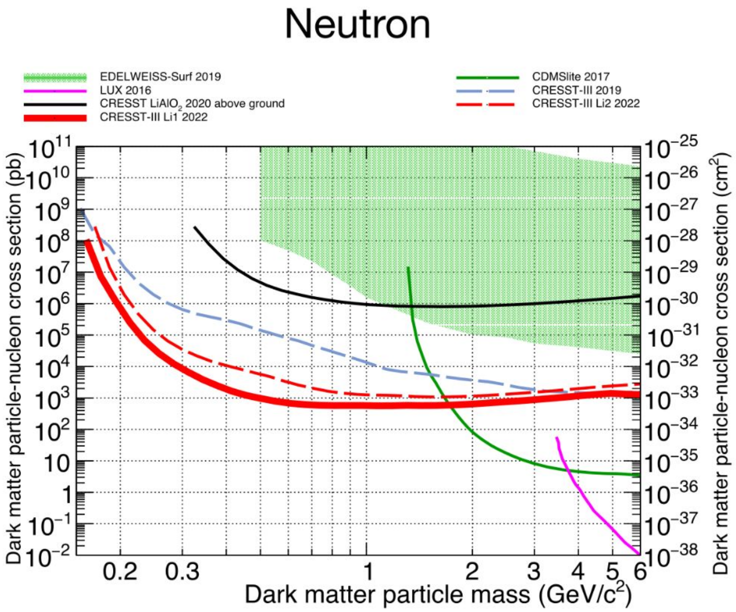


- Li1 shows better limits compared to Li2 due to its event discrimination power based on light channel readout.

New results





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- Li1 shows better limits compared to Li2 due to its event discrimination power based on light channel readout.
- Able to probe spin-dependent DM-nucleus interactions down to **160 MeV/c^2**

Conclusion

- The potential of $LiAlO_2$ as a target to probe spin-dependent DM nucleus interactions is demonstrated.
- CRESST now provides the most stringent limits for:
  - *proton-only* interactions between **(0.2-2.5) GeV/c^2** DM range
  - *neutron-only* interactions between **(0.16-1.5) GeV/c^2** DM range
- We are able to probe DM masses down to **160 MeV/c^2** for these types of interactions
- Effect of event discrimination can be seen when Li1 results are compared to Li2
- The excess of events at lower energies of unknown origin is seen also with $LiAlO_2$ modules. These decrease the sensitivity of these modules for low DM masses

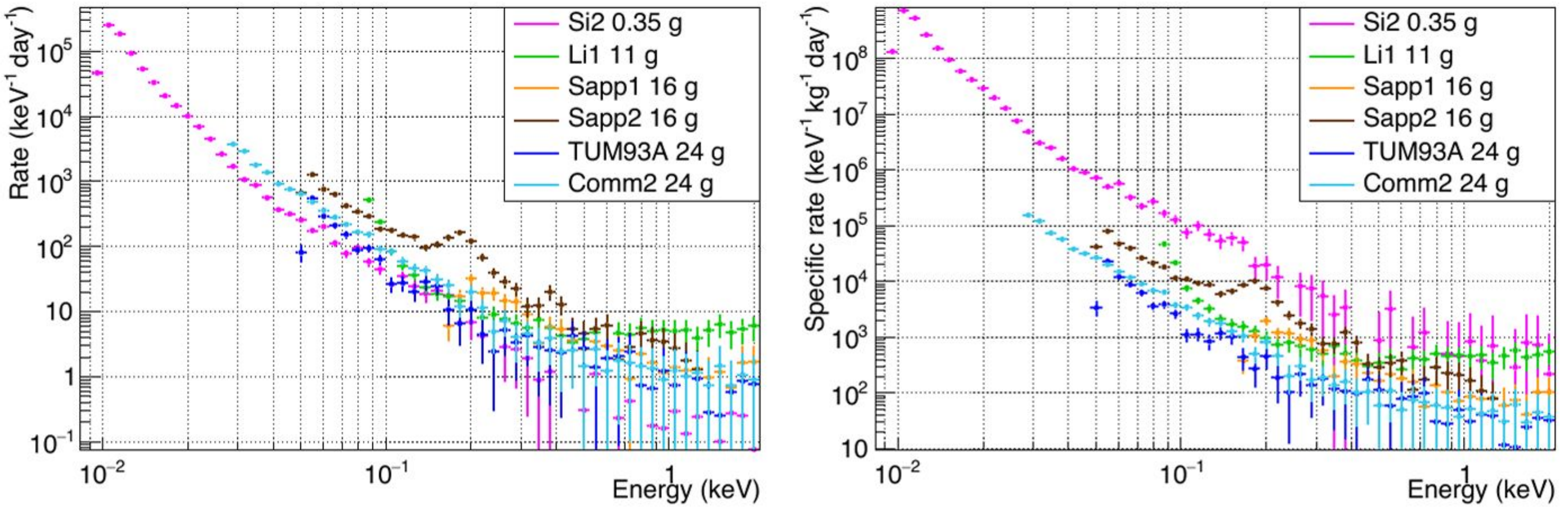
Other activities in CRESST

- The latest measuring campaign started in summer of 2020
- Principle aim of the current campaign is to try to understand the origin of the Low Energy Excess (LEE)
- Different detector materials were probed in order to understand the material dependence
- Different holding structure were used
- A threshold below 100 eV could be achieved for all but one modules

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

Latest Results on the LEE

arXiv:2207.09375



- The LEE was seen to be present in all the crystals
- Scaling the LEE by detector mass does not improves the agreement of excess in different detectors

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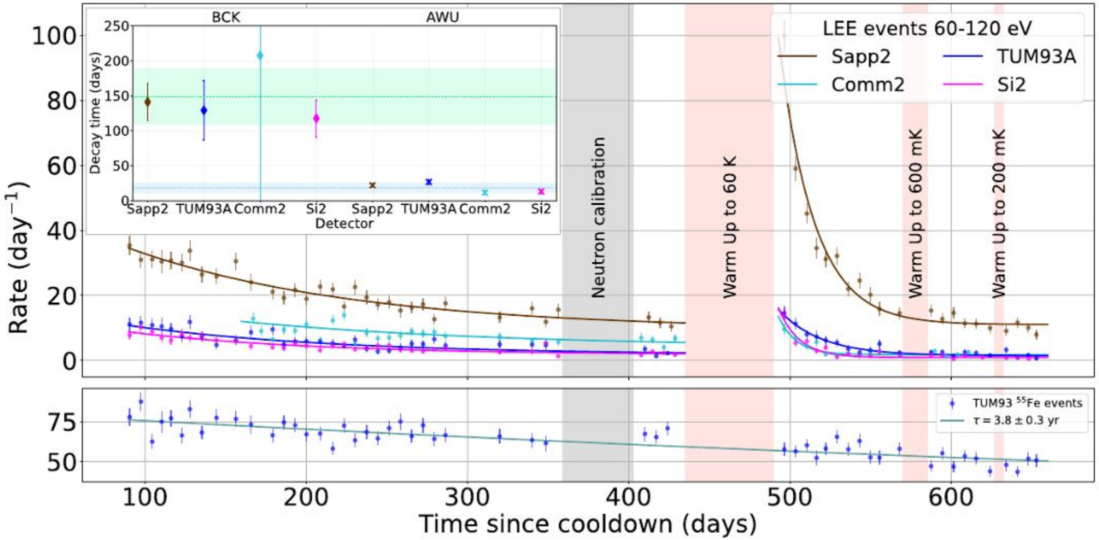

- The LEE is seen to be decreasing over time for all the detectors with around similar time constants
- No effect of neutron calibration was seen on the rate of LEE
- Warmup to **60K** is seen to have increased the LEE rate across all detectors and the it decays rather quickly
- Increasing temperatures to few mK - K does not seems to increase the rate (sets after particular temperature?)

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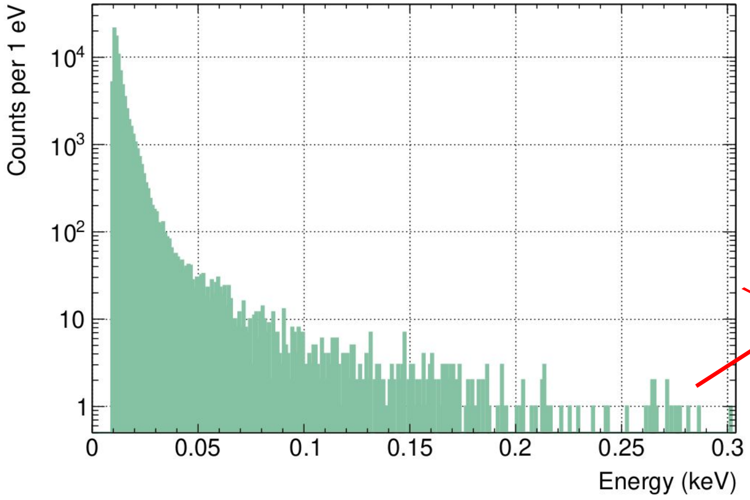
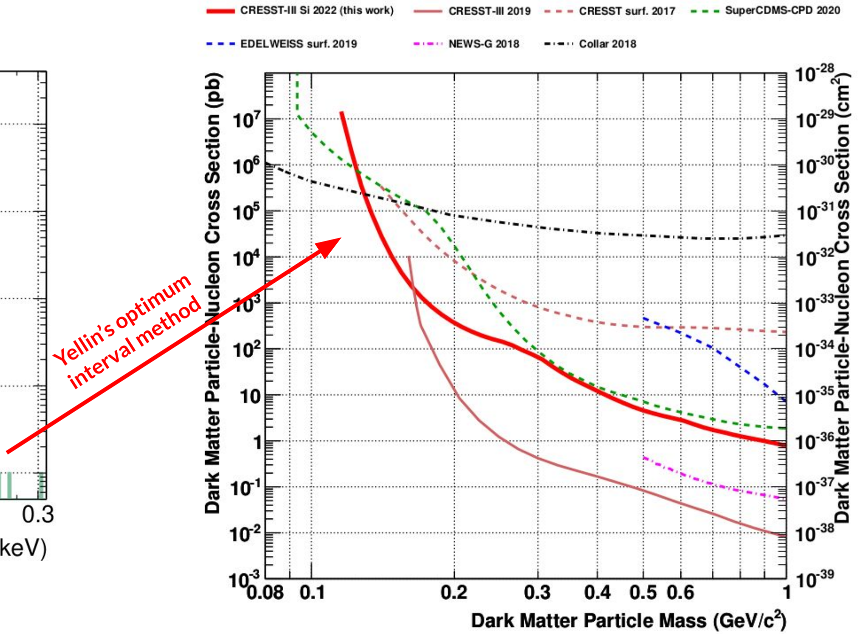
Latest Results on spin-independent limits using Si

arXiv:2212.12513

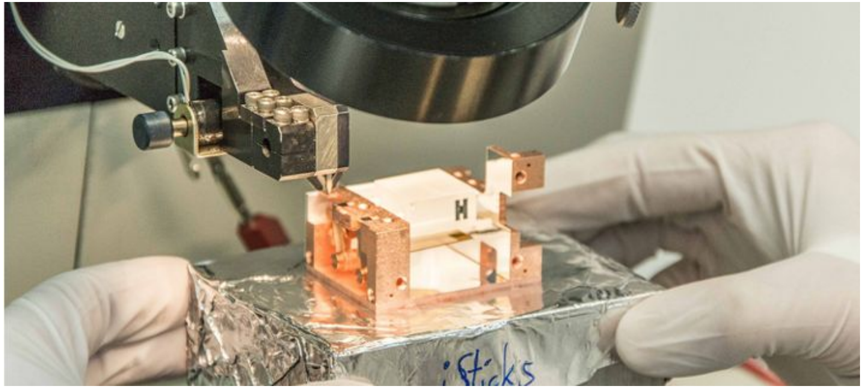




- Silicon wafer of 0.35 g was operated with 55.06 g-days exposure.
- An unprecedented resolution and threshold of **1.36 eV** and **10.0 eV** were obtained respectively.
- Extended the sensitivity of spin-independent interactions to **115 MeV/c^2**

Next steps

- Further warm ups to study the dependence of the rate on temperature, length of exposure of crystals to higher temperatures, material dependence of increase, etc.
- Detector R&D to achieve:
  - even lower thresholds
  - using other different materials
  - using stress-free holding structures
  - mass production
  - multiple sensors to study the origin of LEE
- The next upgrade is planned to have 288 read out channels for which:
  - SQUIDs and wiring is already produced
  - new DAQ and bias electronics is being designed
  - aim to do the installation by 2023 at LNGS



On the behalf of the
CRESST collaboration

Thank you for your attention

Any Questions?

Backup slides

Spectra comparison in Li1 and Li2

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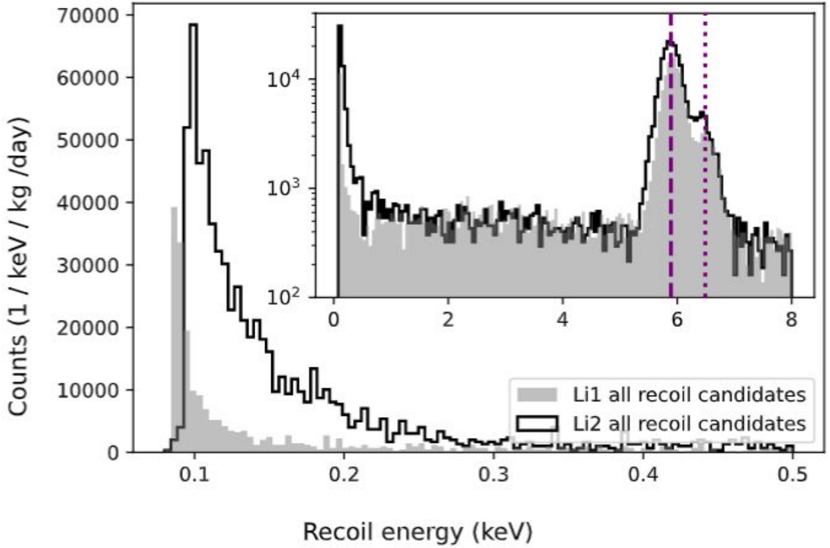
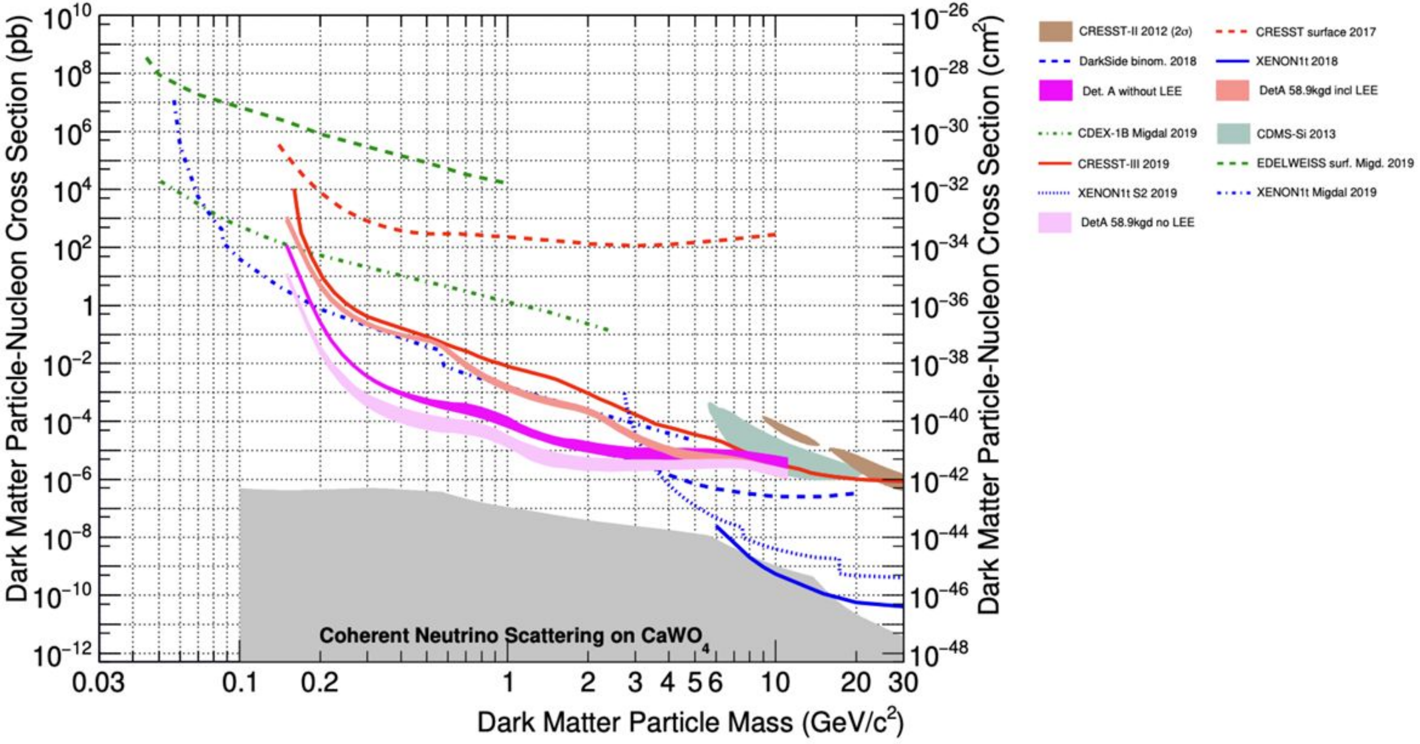


- The spectra look quite identical at higher energies
- Higher number of events seen for Li2 at lower energies coming mainly because of reflecting foil. These events can be taken out from Li1 due to its light readout channel.

Effect of LEE on exclusion limits



Det A - Spectra