Direct Dark Matter search with the CRESST experiment

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on behalf of the CRESST collaboration

BiCoQ Conference: from gravity to particles

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

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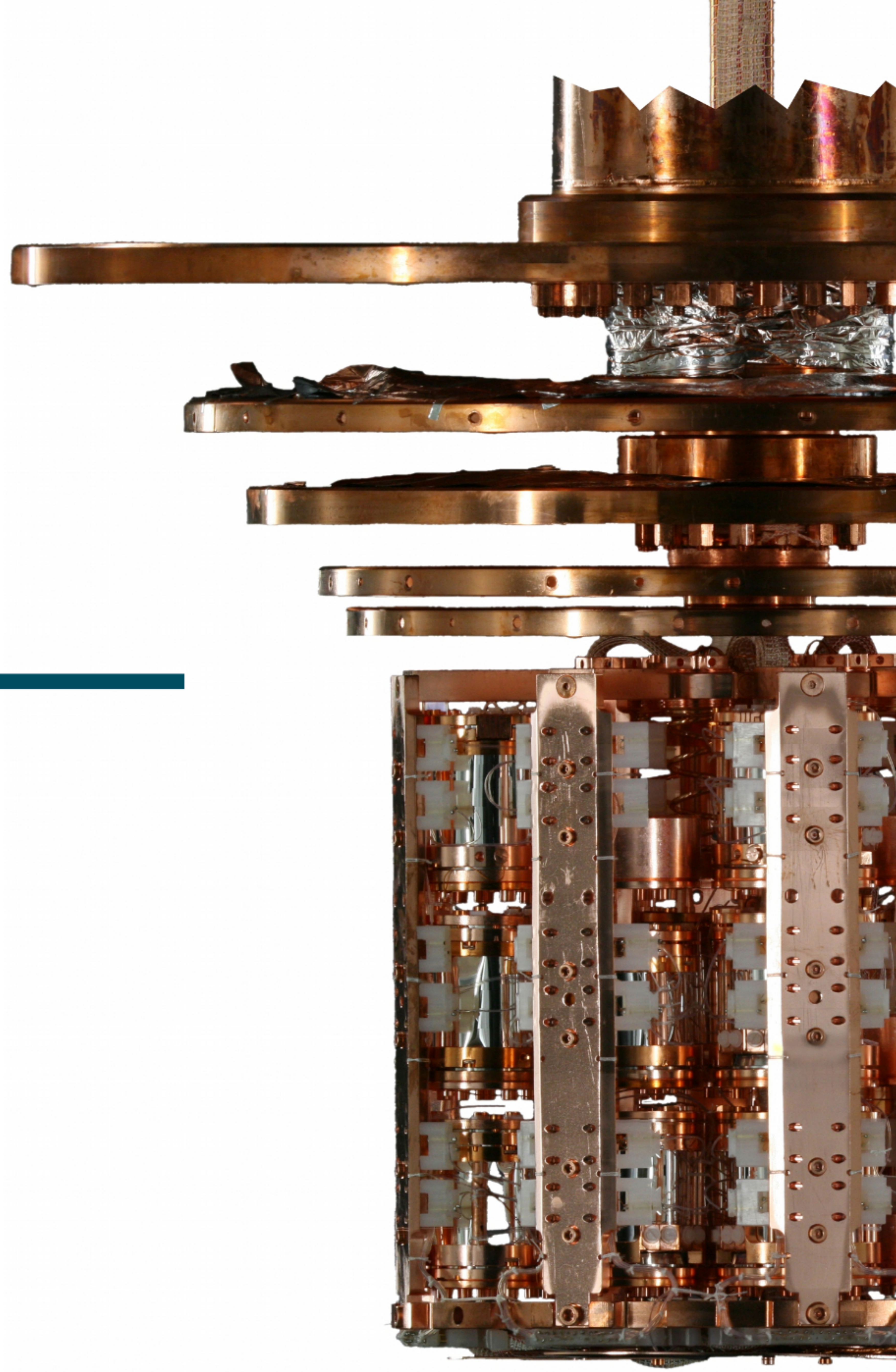

The CRESST collaboration

The CRESST collaboration consists of 10 institutions and ~60 members

MAX-PLANCK-INSTITUT FÜR PHYSIK
INFN LNGS Istituto Nazionale di Fisica Nucleare Laboratori Nazionali del Gran Sasso
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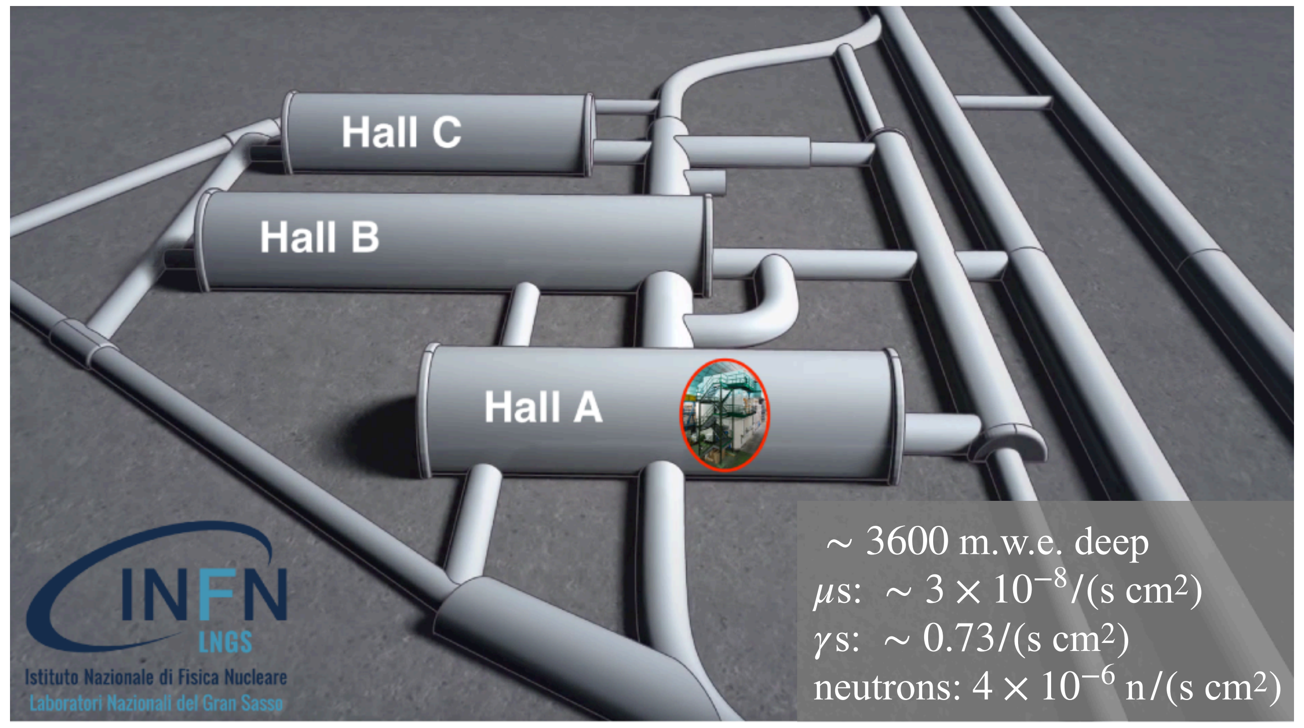
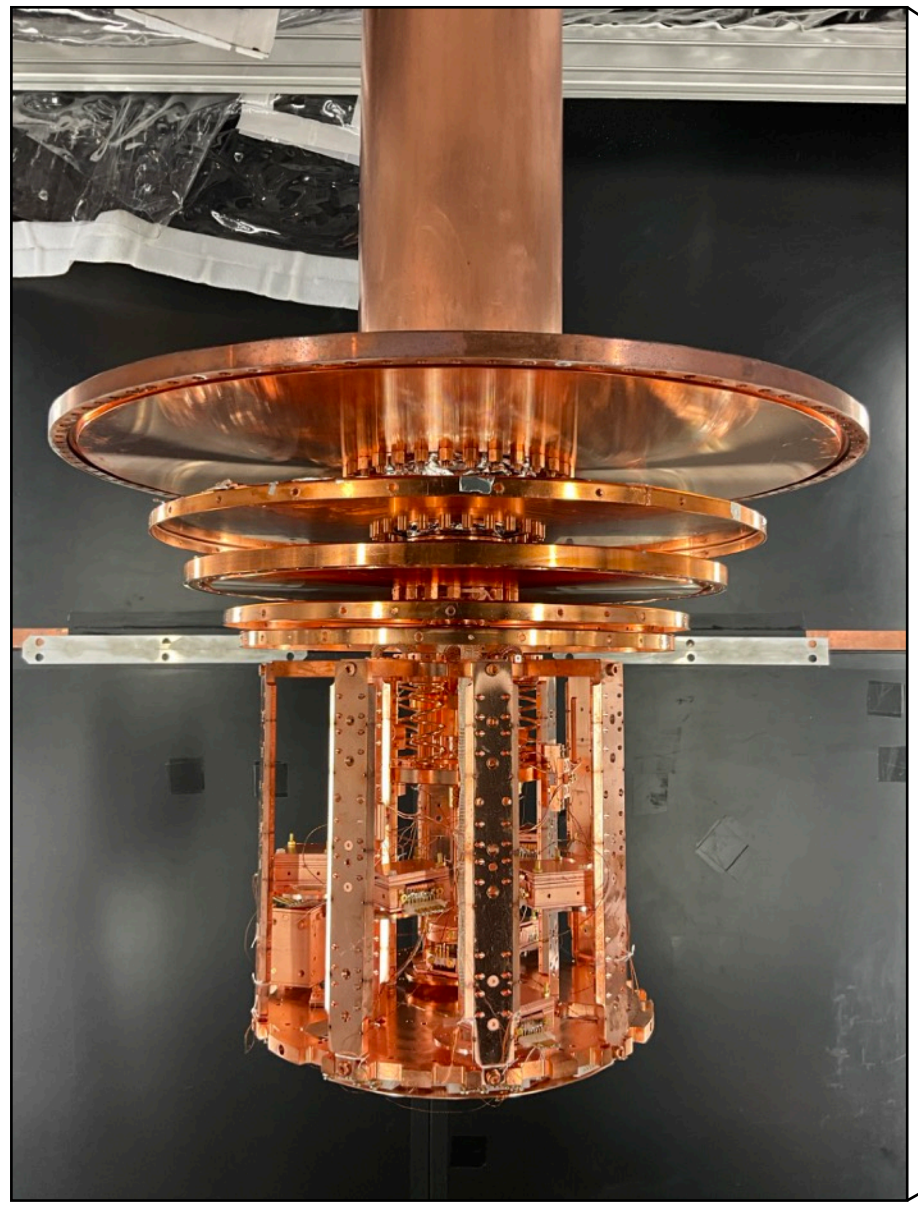
The CRESST experiment

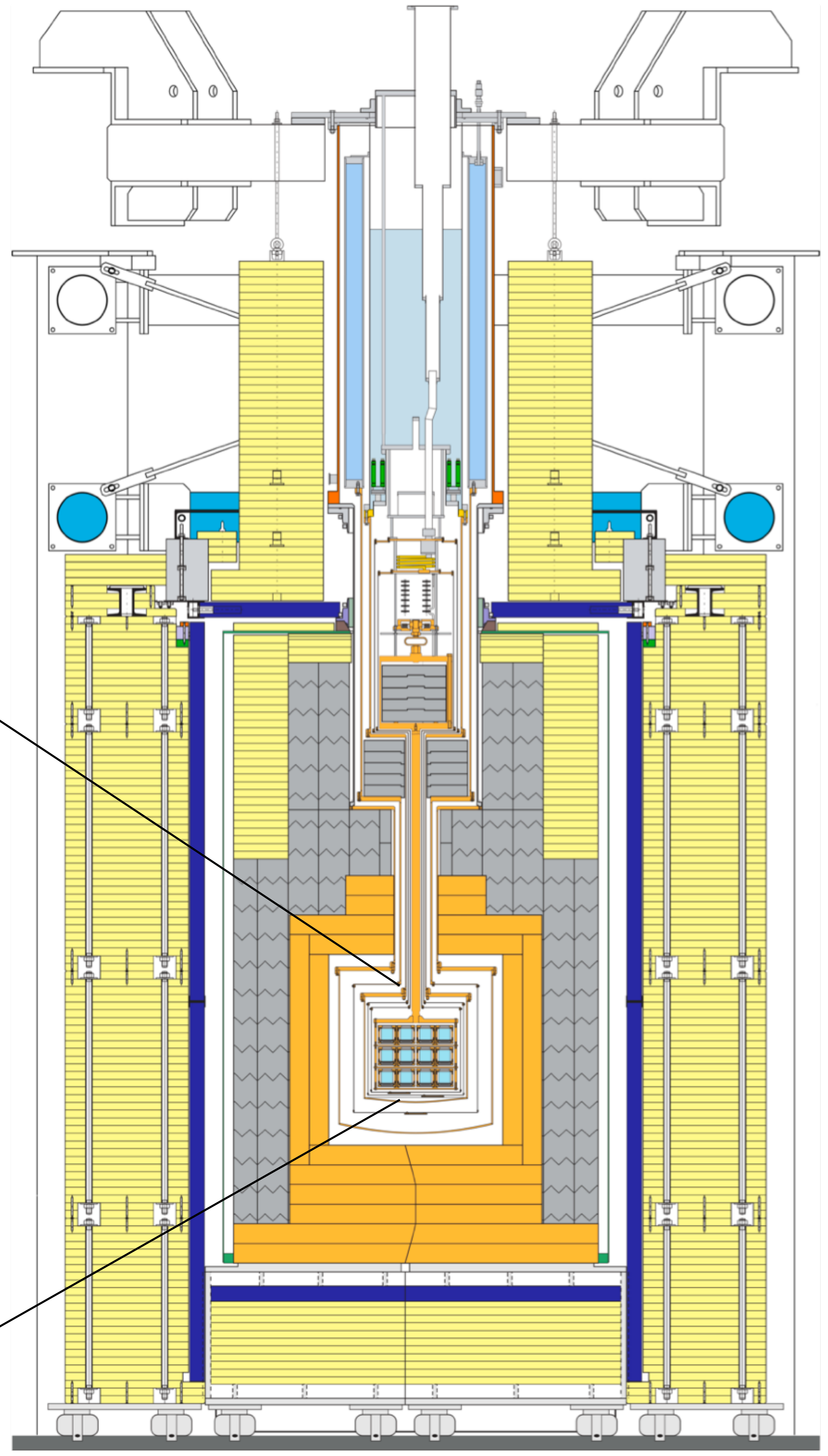
Cryogenic **Rare Event Search** with Superconducting Thermometers

CRESST aims to directly detect dark matter particles by studying their scattering off target nuclei using cryogenic detectors operated at ~15 mK

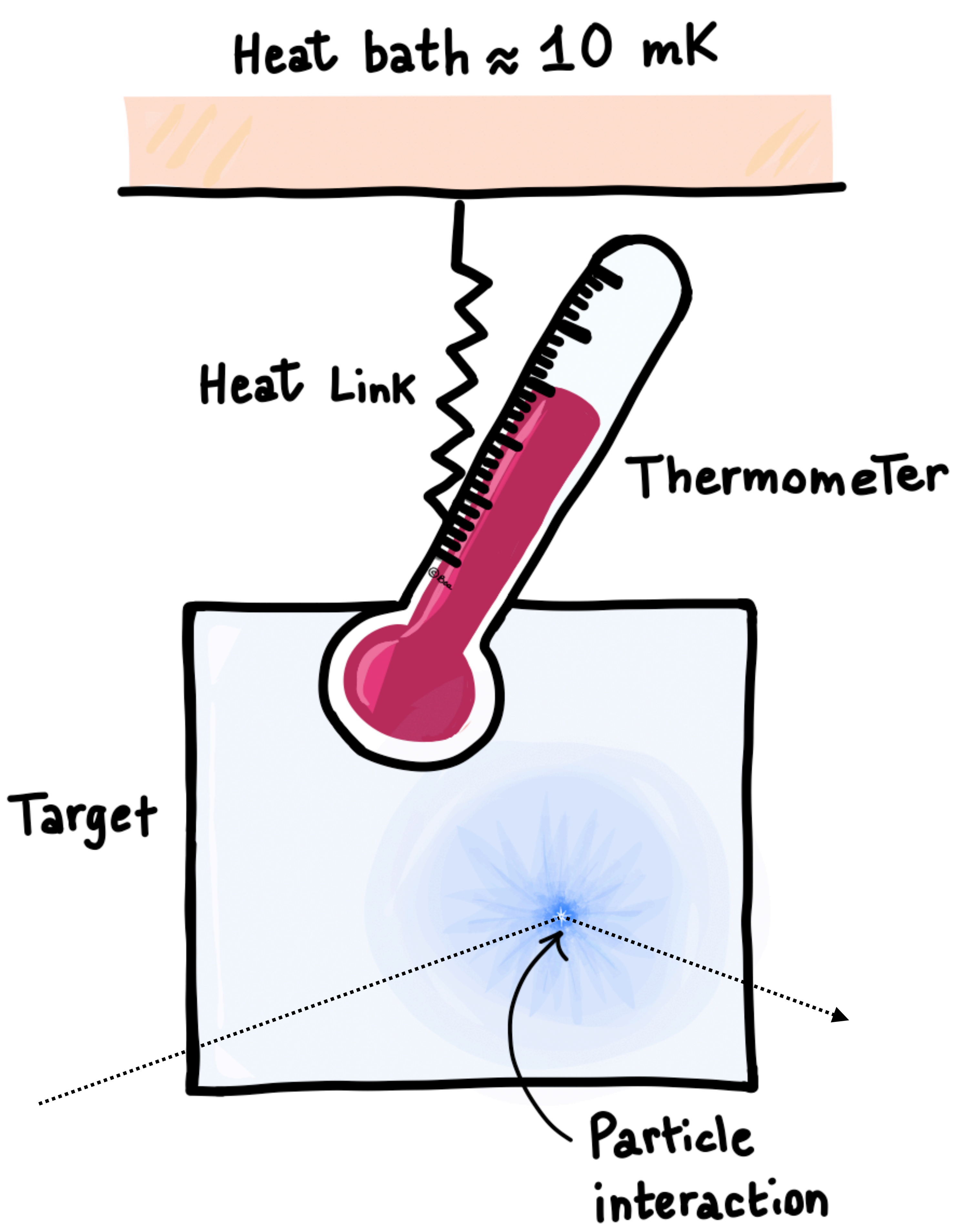
@LNGS Hall A







CRESST working principle



- Particle interaction in a target crystal
- Energy deposition leading to a temperature increase
- Transition Edge Sensors (TESs) adopted to measure the temperature variation

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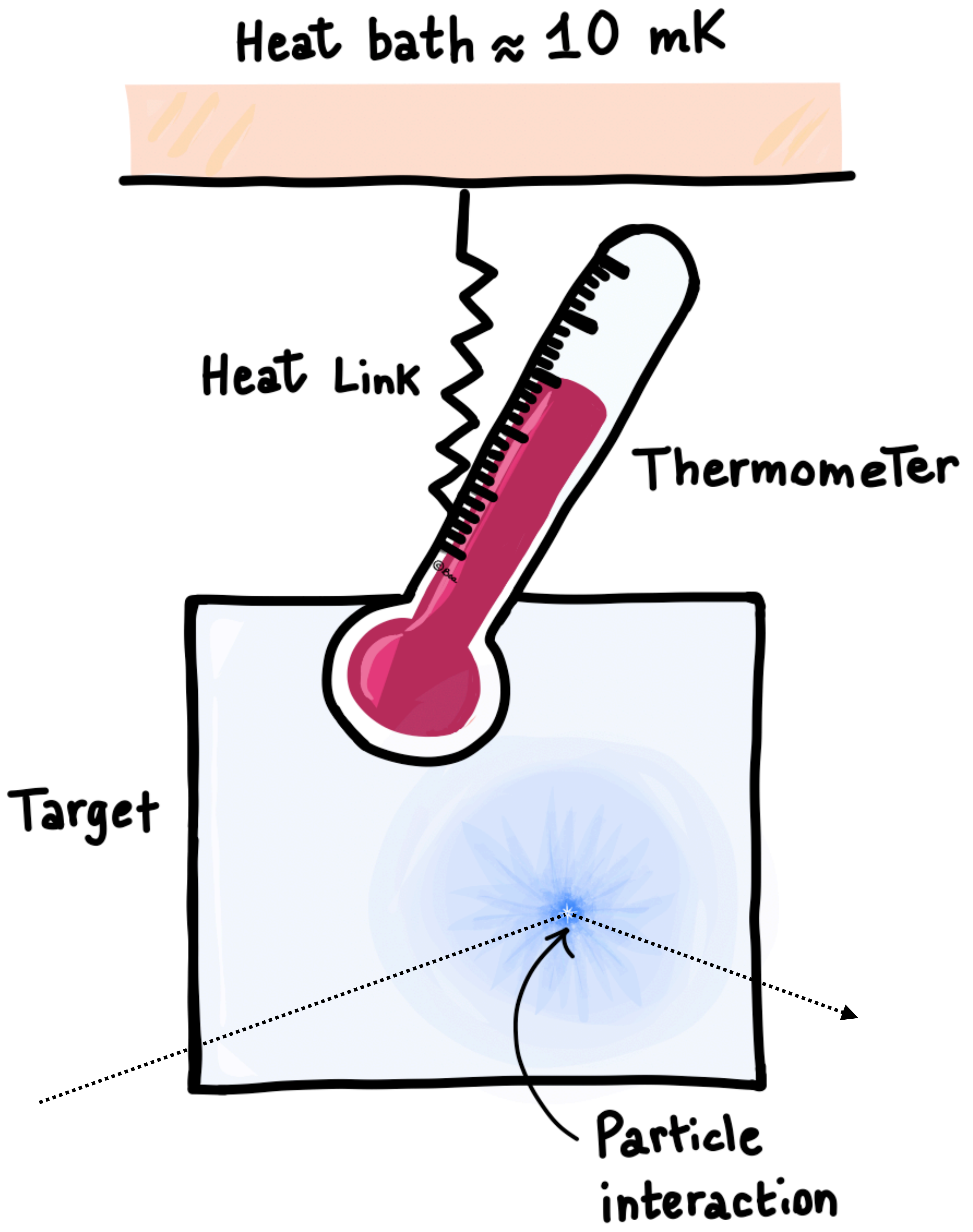

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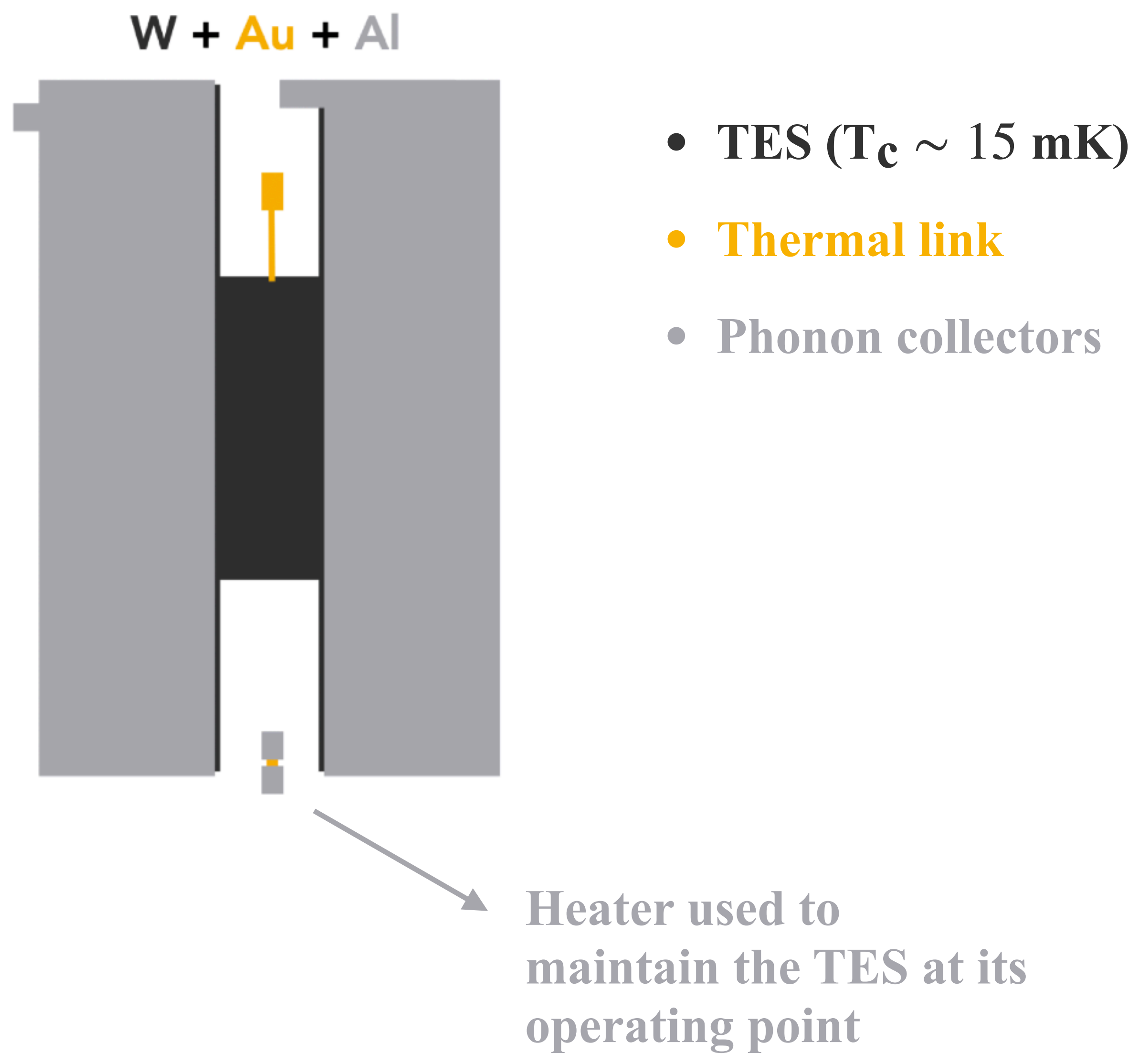
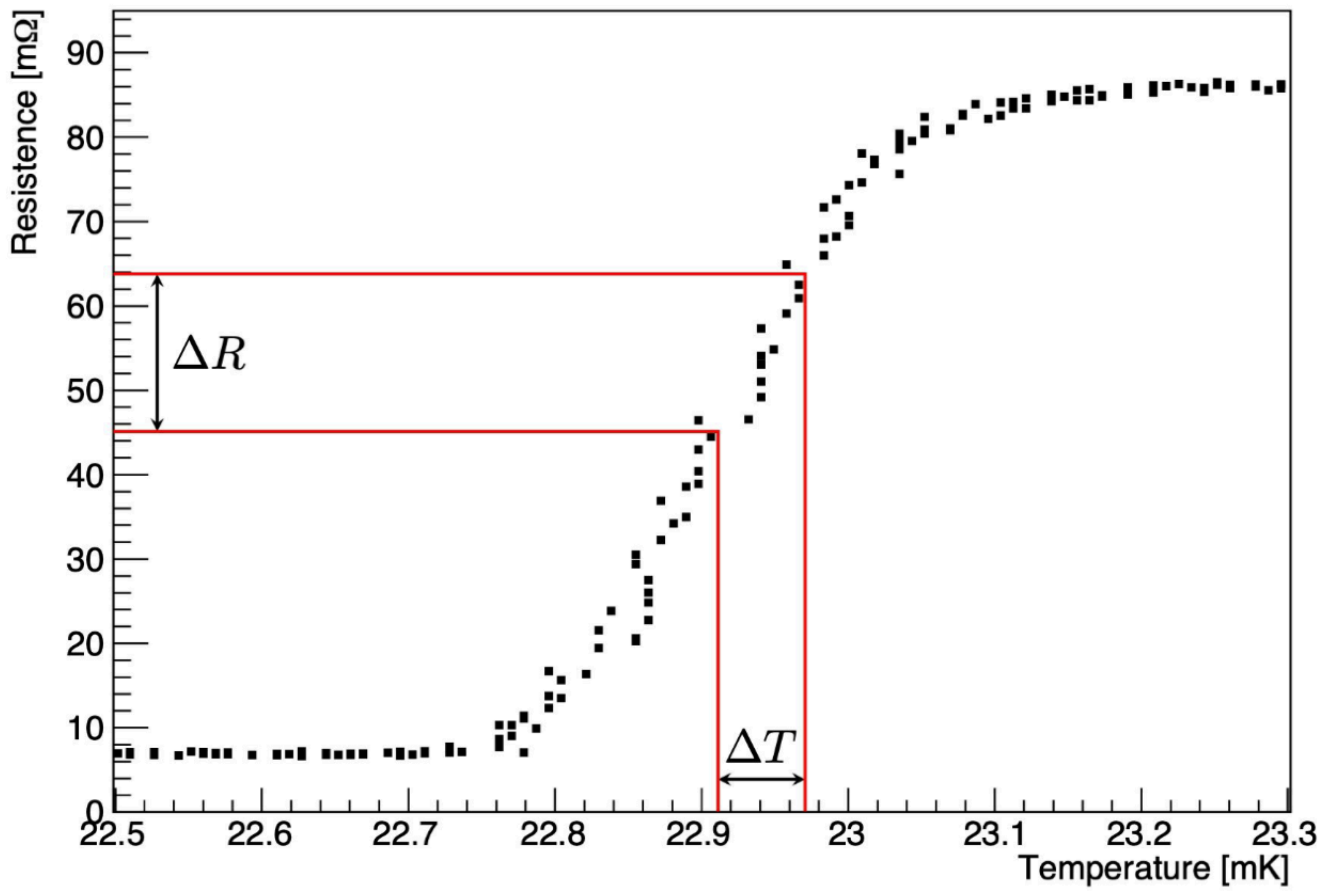
- Transition Edge Sensors (TESs) adopted to measure the temperature variation

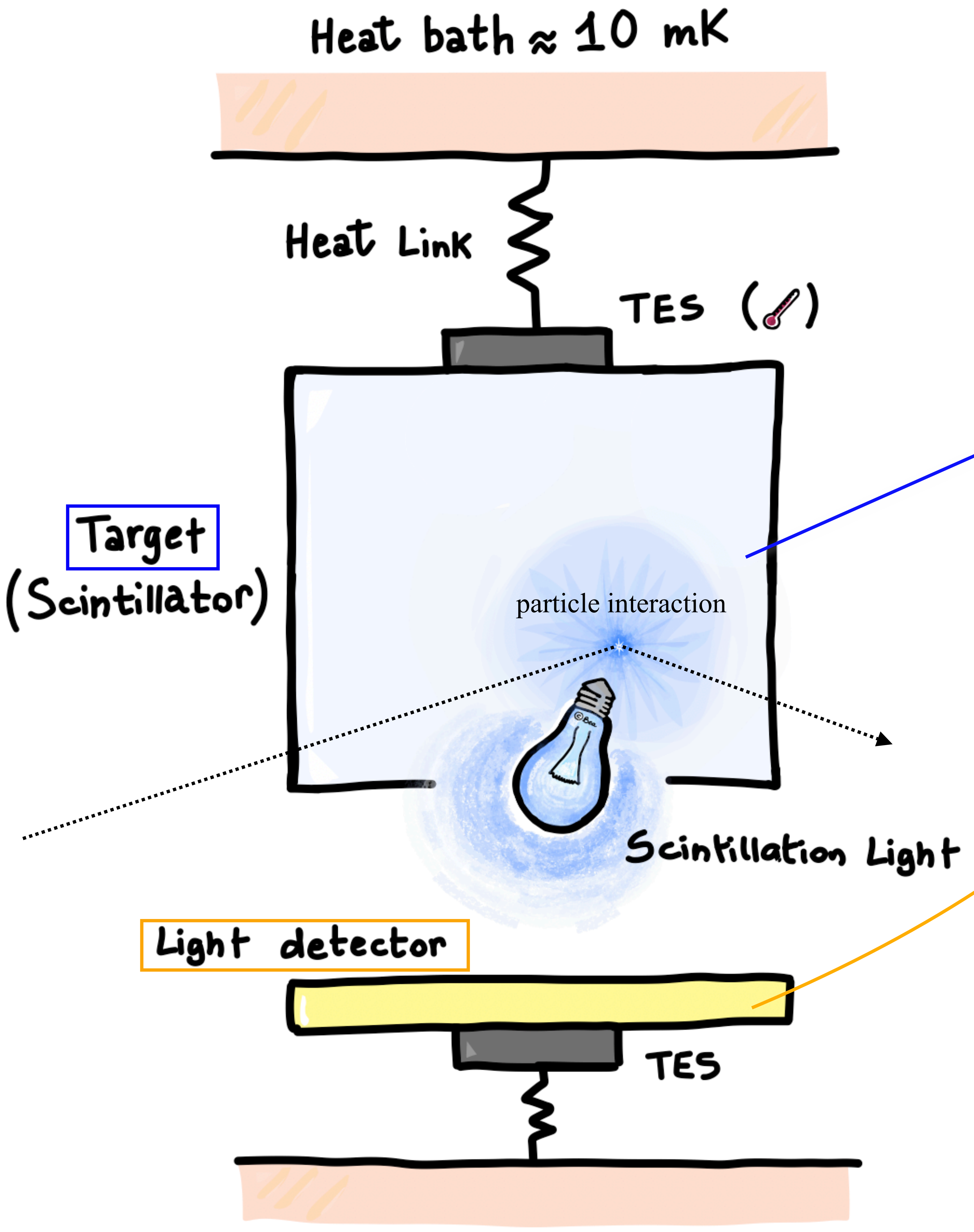
TES consists of thin superconducting tungsten film deposited on the crystal and maintained within the superconducting transition region

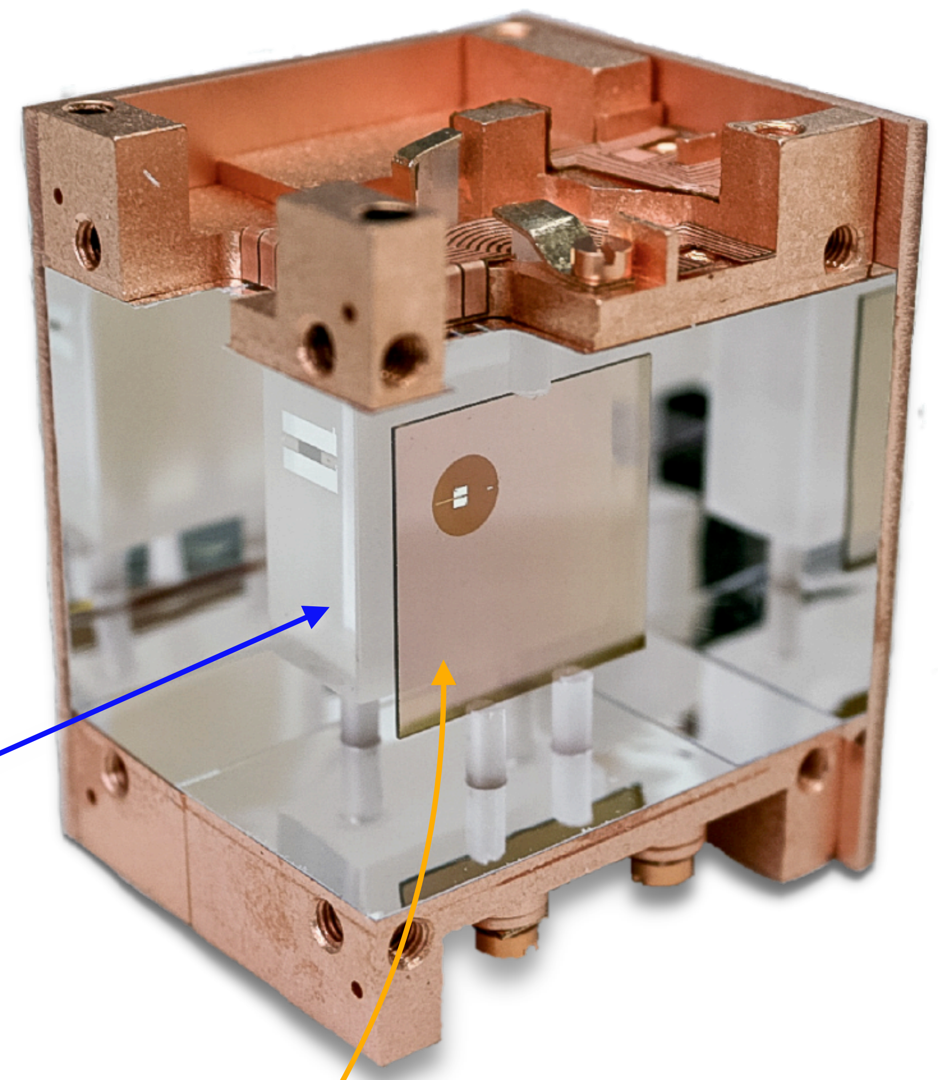




$\Delta E \sim$ keV → $\Delta T \sim \mu$K → $\Delta R \sim$ mΩ

The CRESST detectors

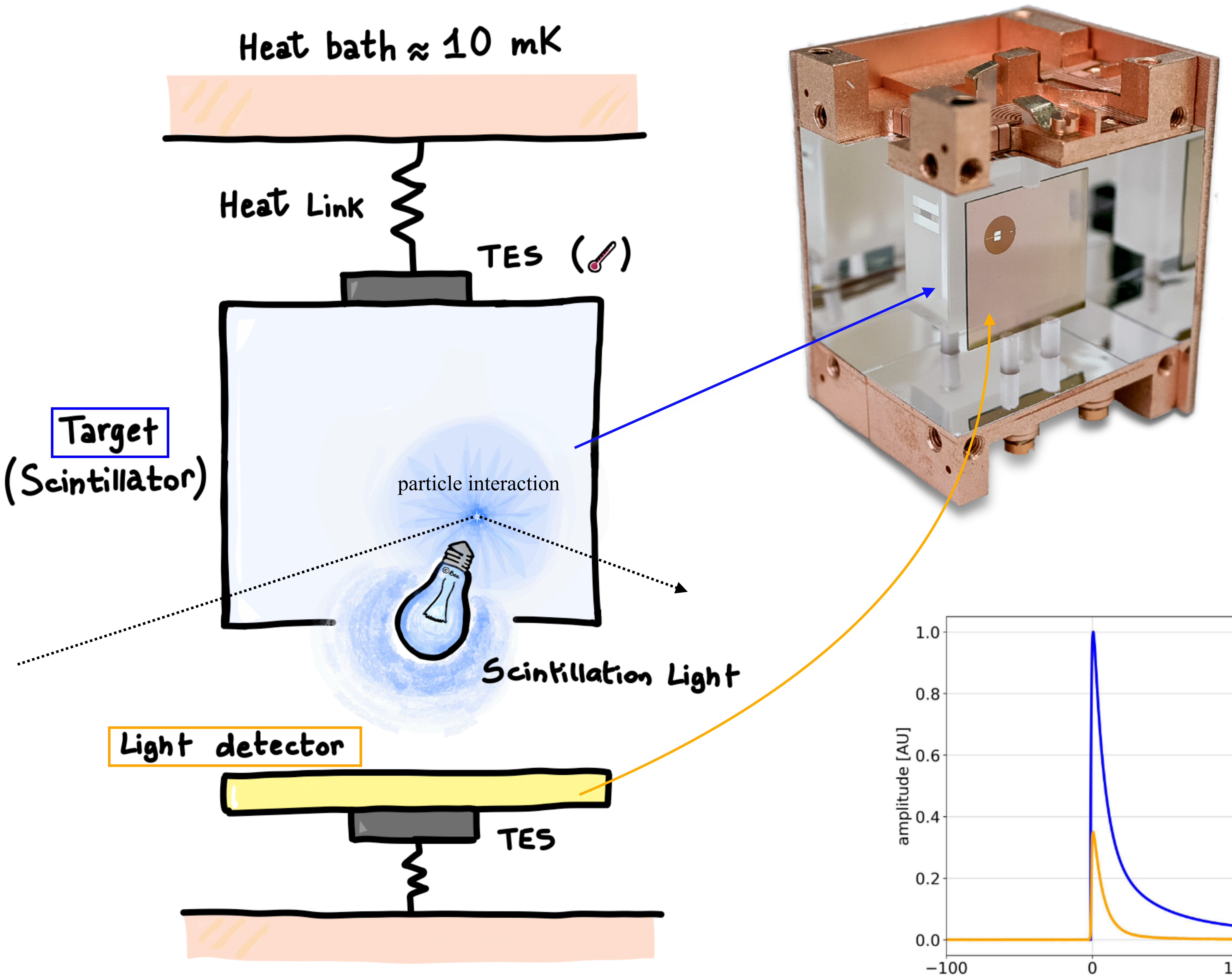




Standard detector:

- Optimised for sub-GeV Dark Matter search range
- Scintillating $CaWO_4$ crystal as main absorber (20x20x10) mm^3
- Silicon-on-Sapphire (SOS) wafer as light detector for particle discrimination and background rejection
- Both crystals equipped with TES

The CRESST detectors



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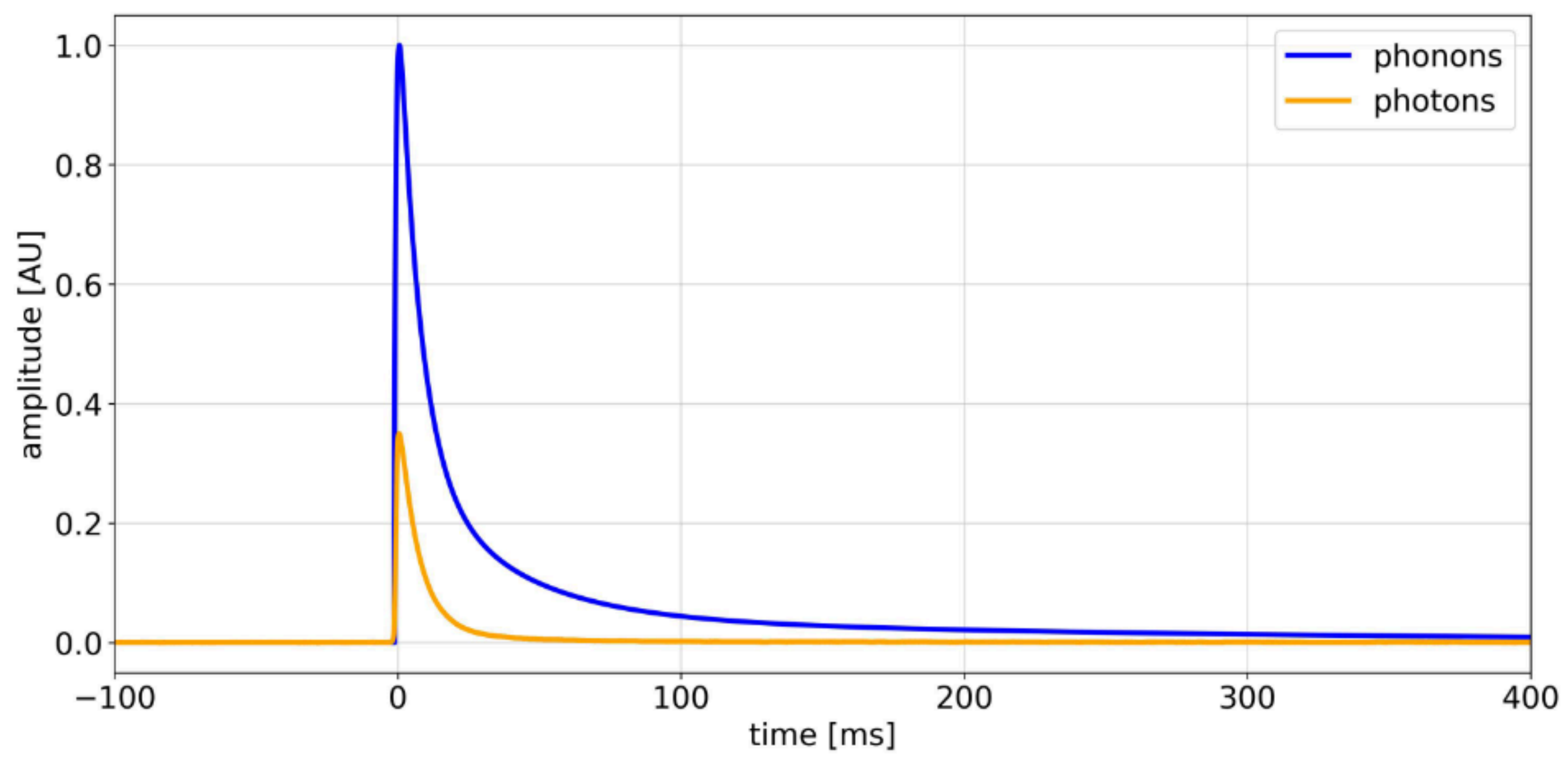
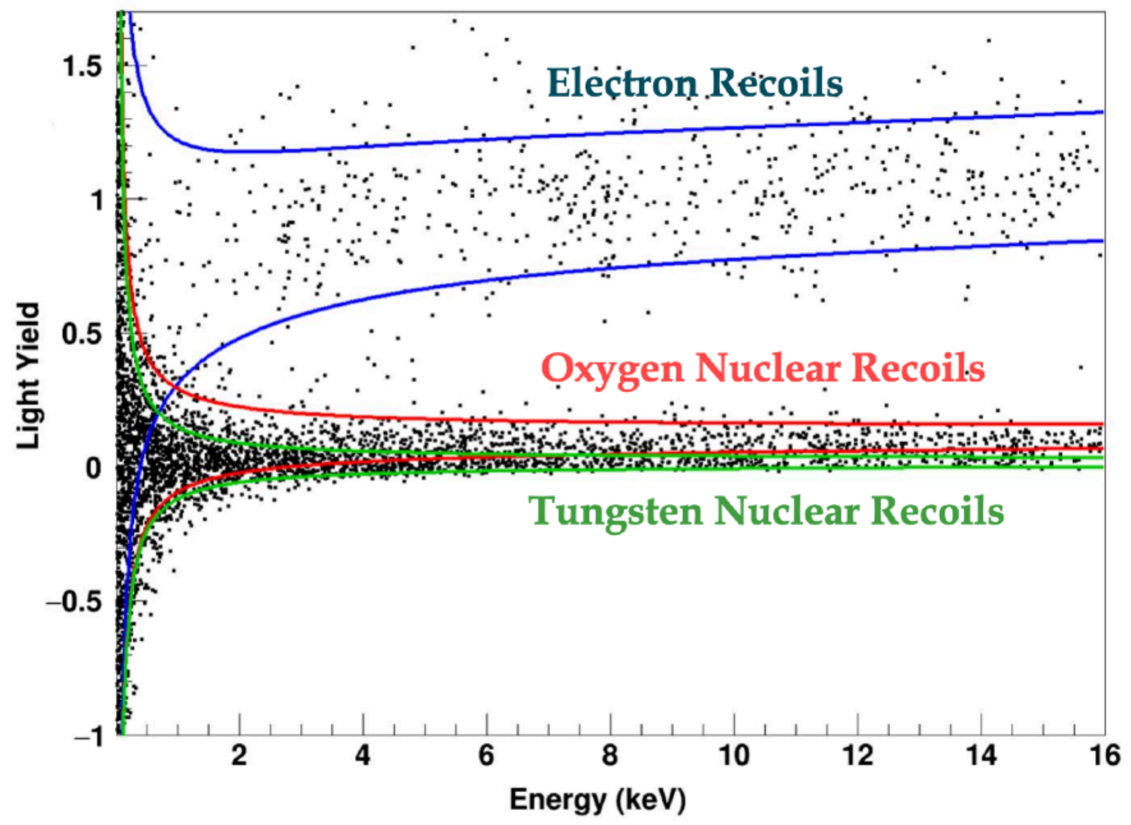
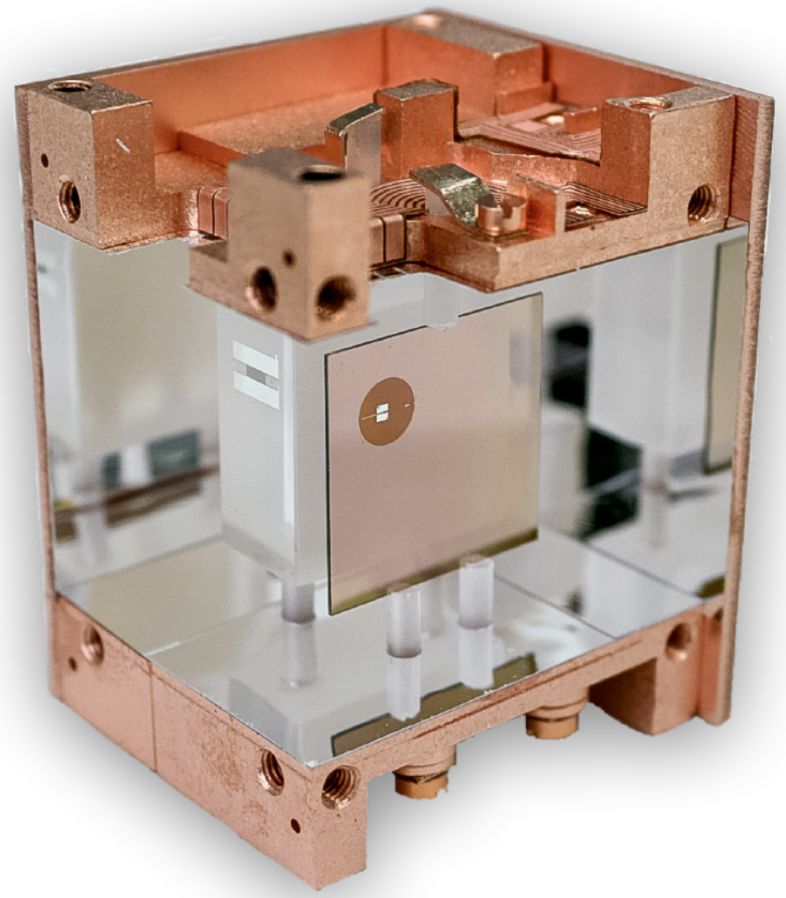
The ratio between photon and phonon signals defines the light yield





The CRESST-III evolution

2016-2018



https://doi.org/10.1103/PhysRevD.100.102002

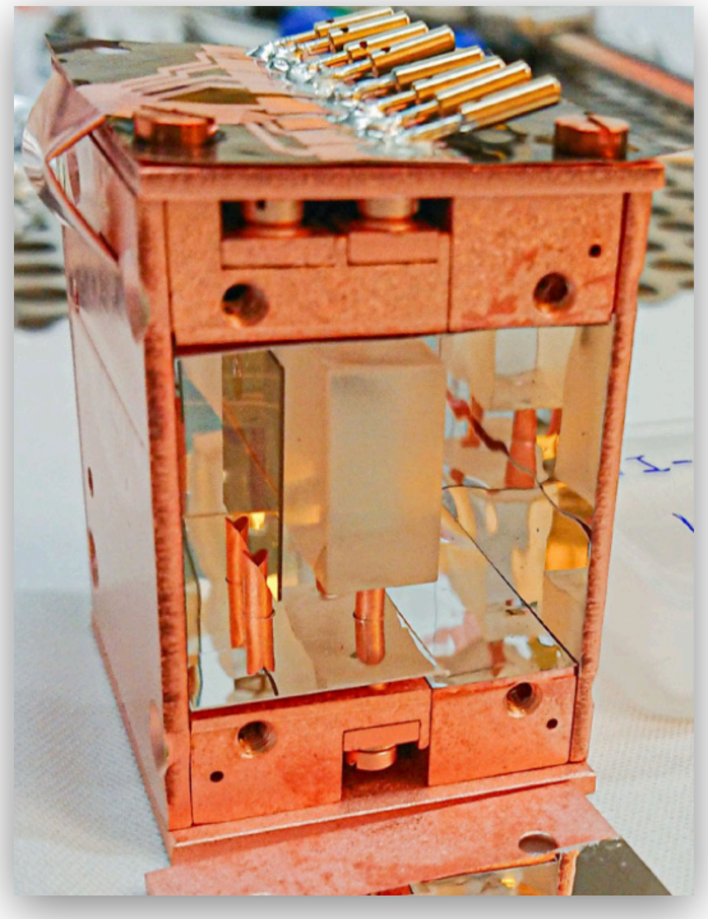
$CaWO_4$ (Det. A)

$m = 24$ g

$E_{th} = 30.1$ eV

First evidence of LEE

2020-2021



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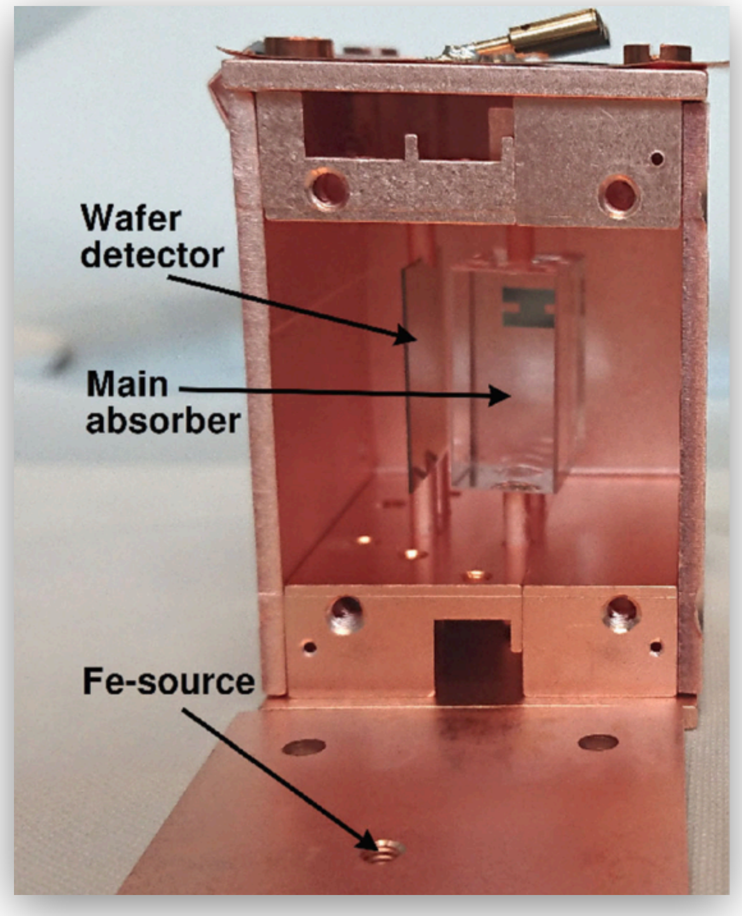
$LiAlO_2$

$m = 10.46$ g

$E_{th} = 83.6$ eV



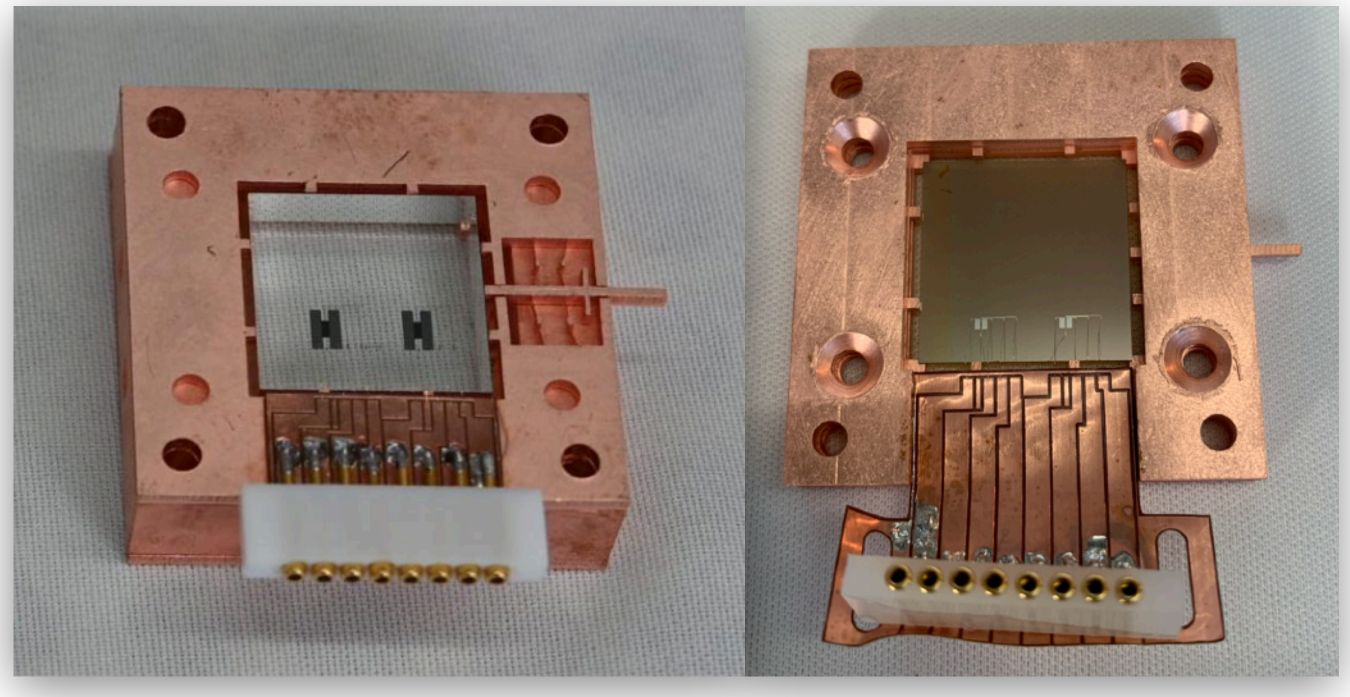
https://doi.org/10.1103/PhysRevD.110.083038

SOS-wafer

$m = 0.6$ g

$E_{th} = 6.7$ eV

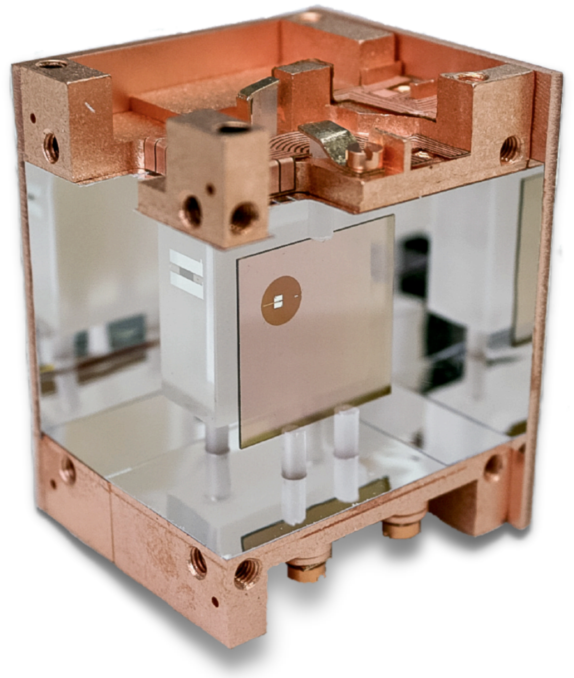
Current CRESST run



doubleTES

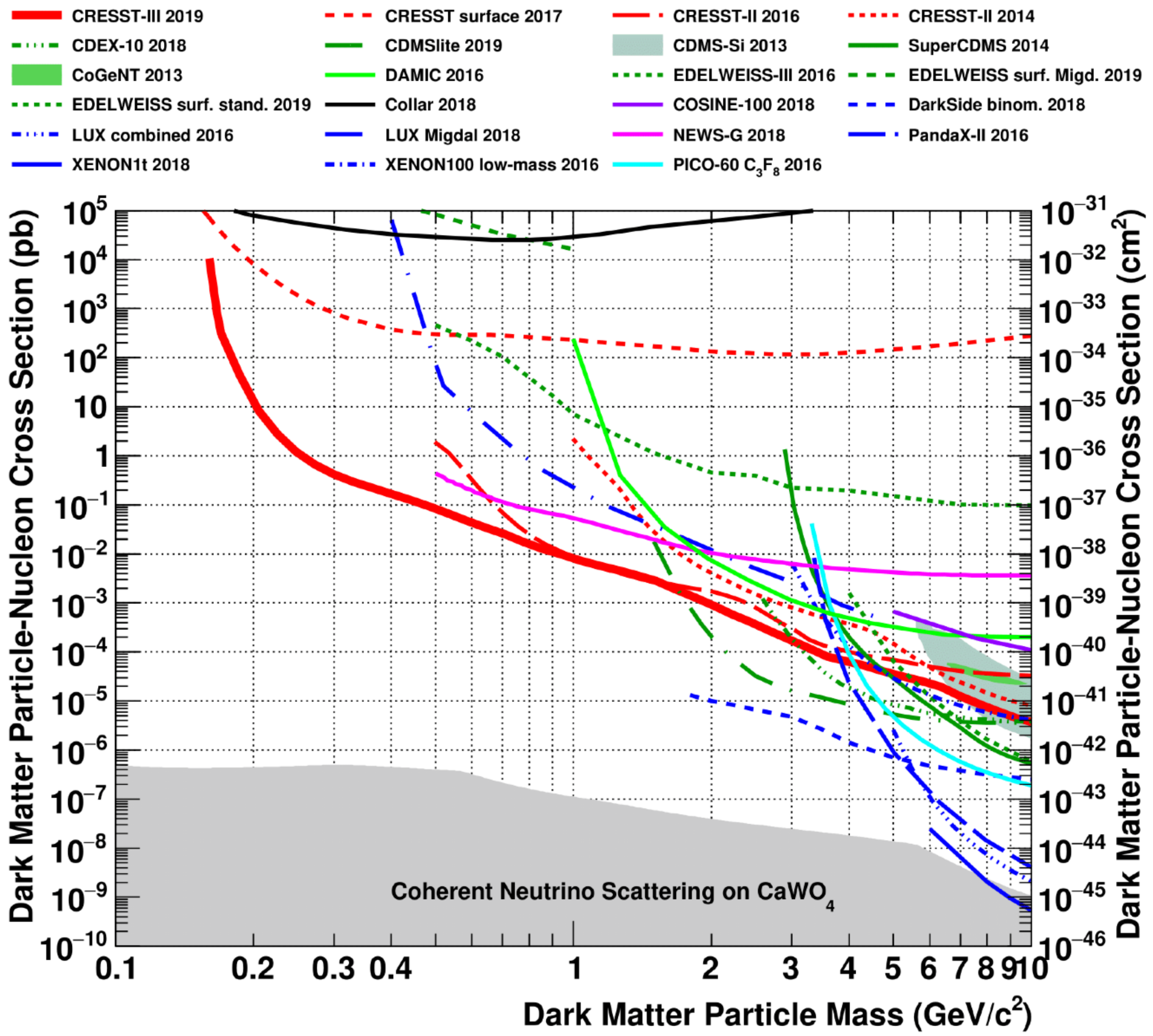
$m = 24$ g / 0.6 g

CRESST-III first results



Spin independent limit in the sub-GeV range

- Crystal: 23.6 g $CaWO_4$
- Data taking period: Oct 2016 - Jan 2018
- Exposure: 5.698 kg·days
- Baseline resolution: 4.6 eV
- Energy threshold: 30.1 eV



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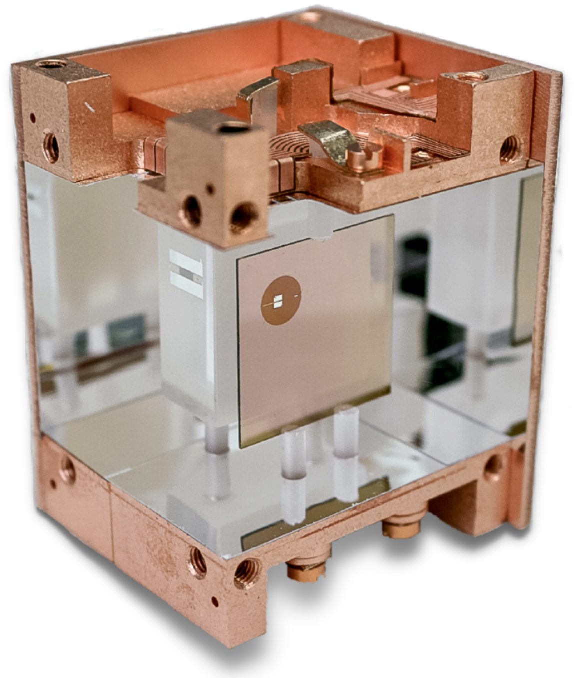

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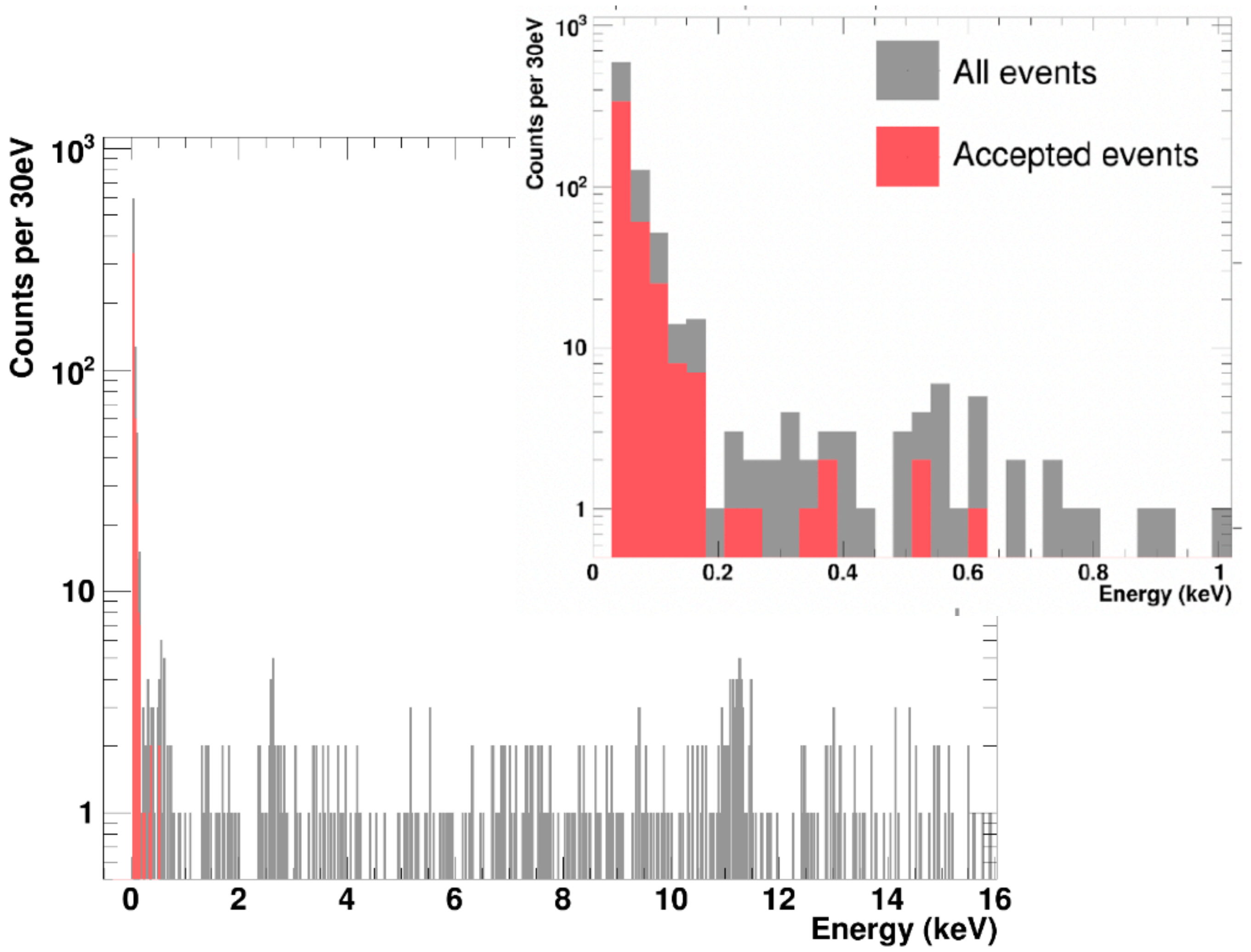
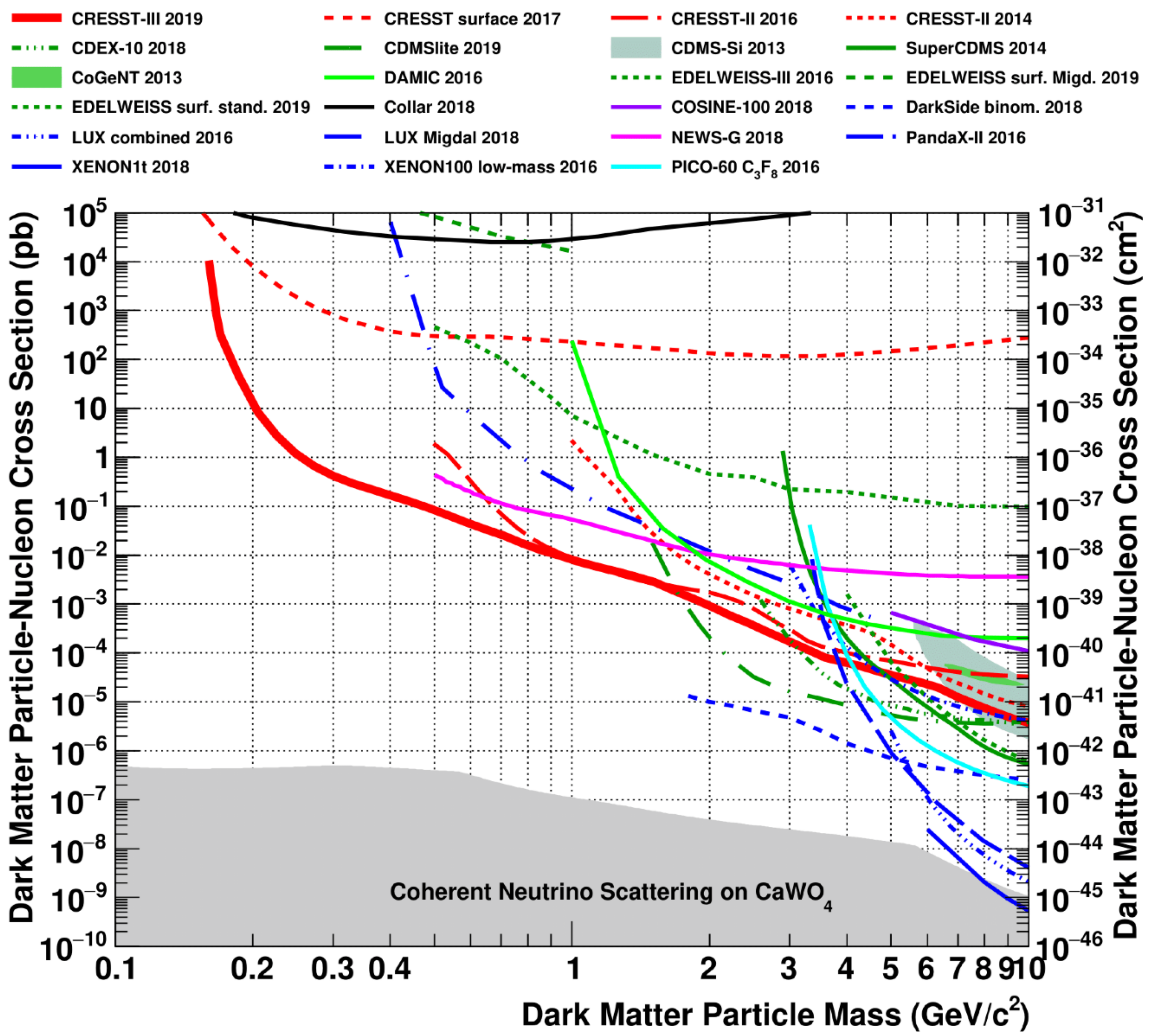
Observation

- Rise of event rate at energies below 200 eV
- Background of unknown origin known as **Low Energy Excess (LEE)**





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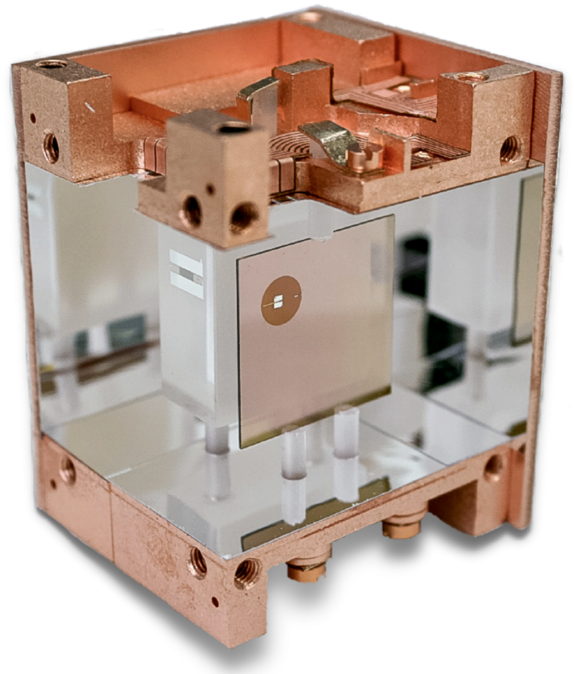

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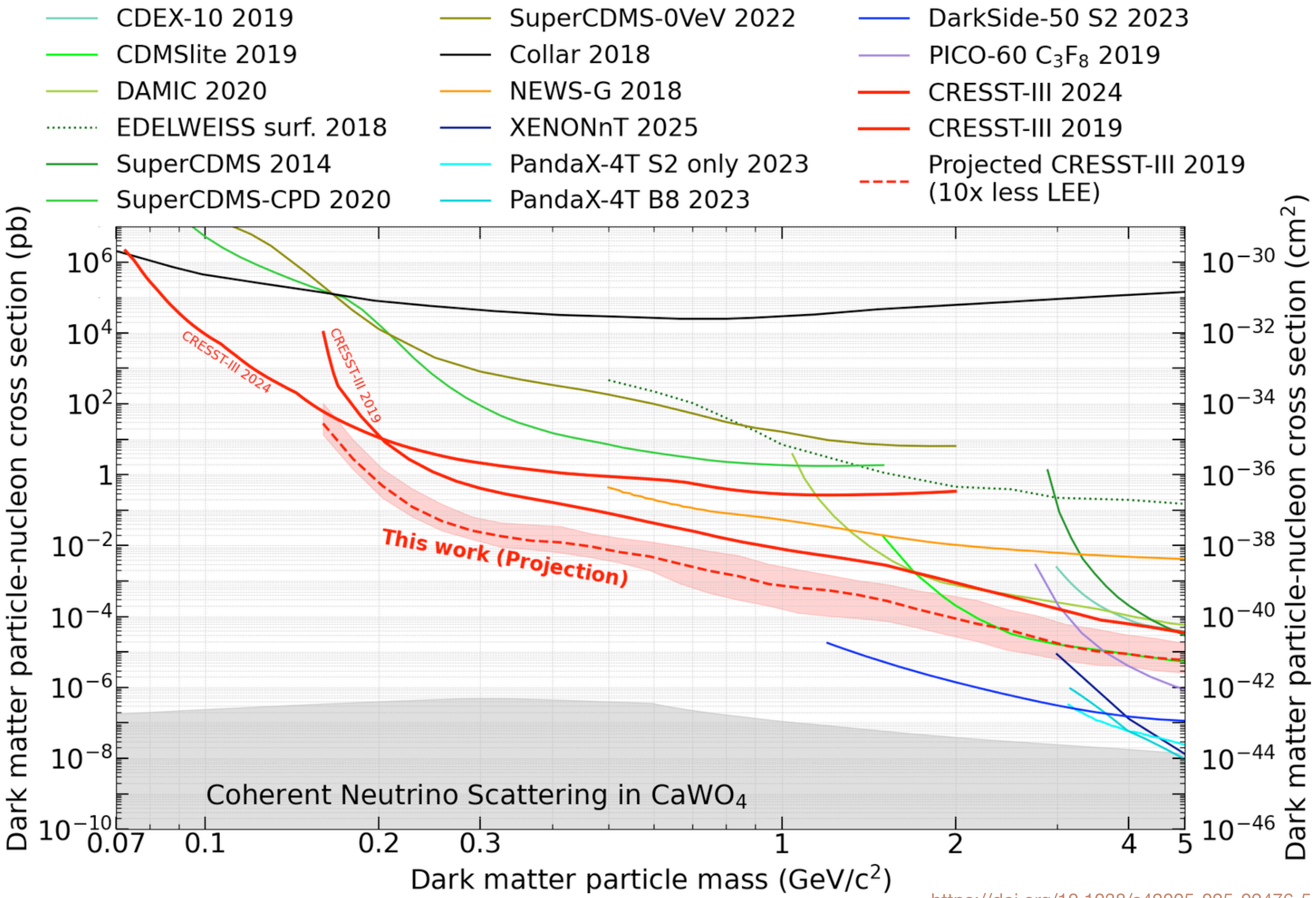
Impact on dark matter searches

- Dominate the spectrum at very low energies
- Limits the experimental sensitivity

Strategy

- Dedicated measured campaigns to investigate the origins of LEE
- Above ground studies



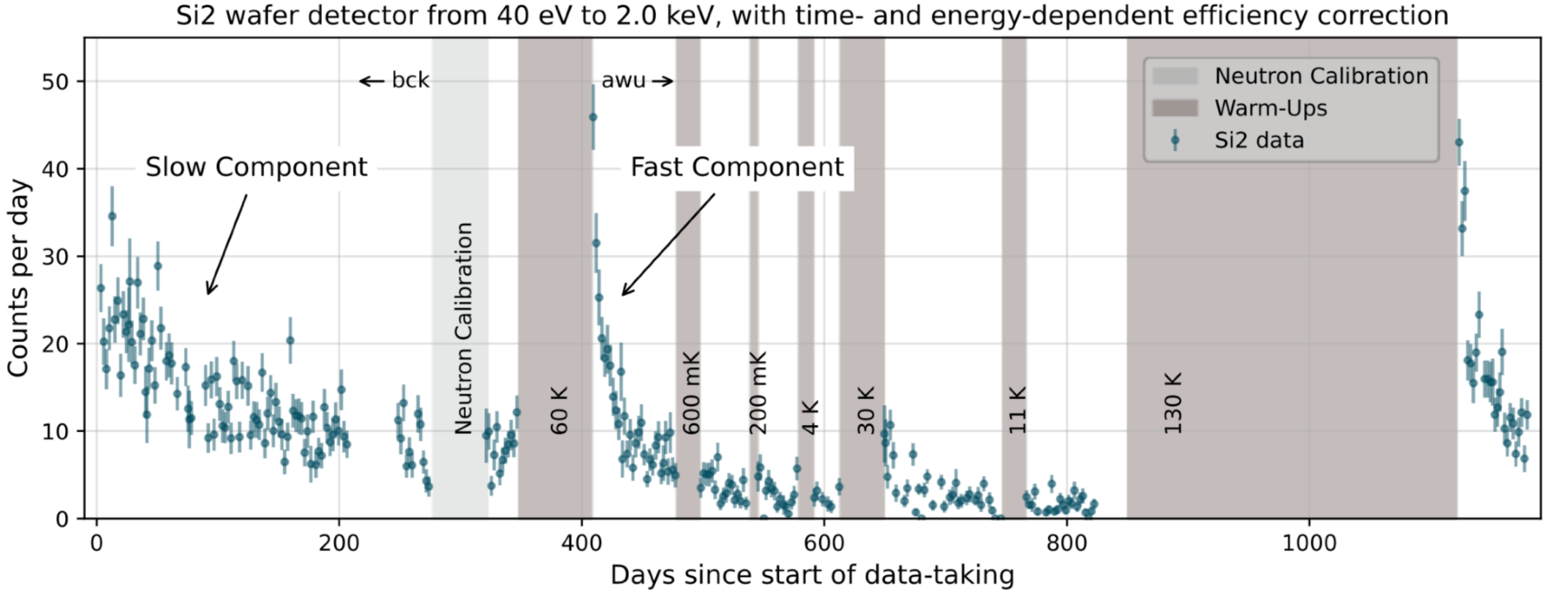
https://doi.org/10.1038/s42005-025-02476-5

LEE investigations

The current efforts are focused on understanding and mitigation of the LEE

Temporal behaviour of LEE:

- Decays with time (fast and slow components observed)
- The fast component resets after each warm-up cycle



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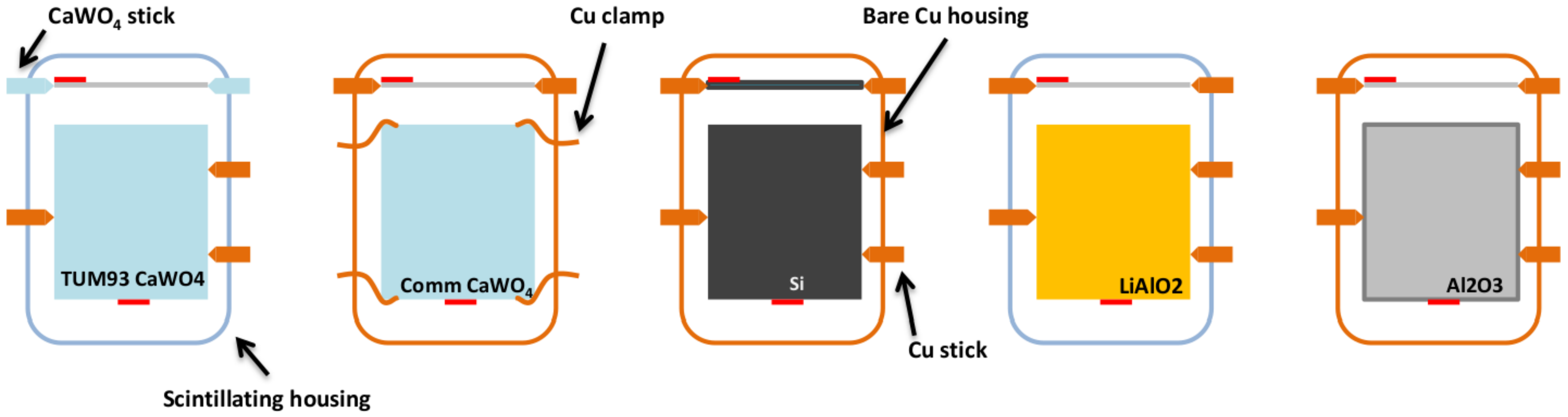
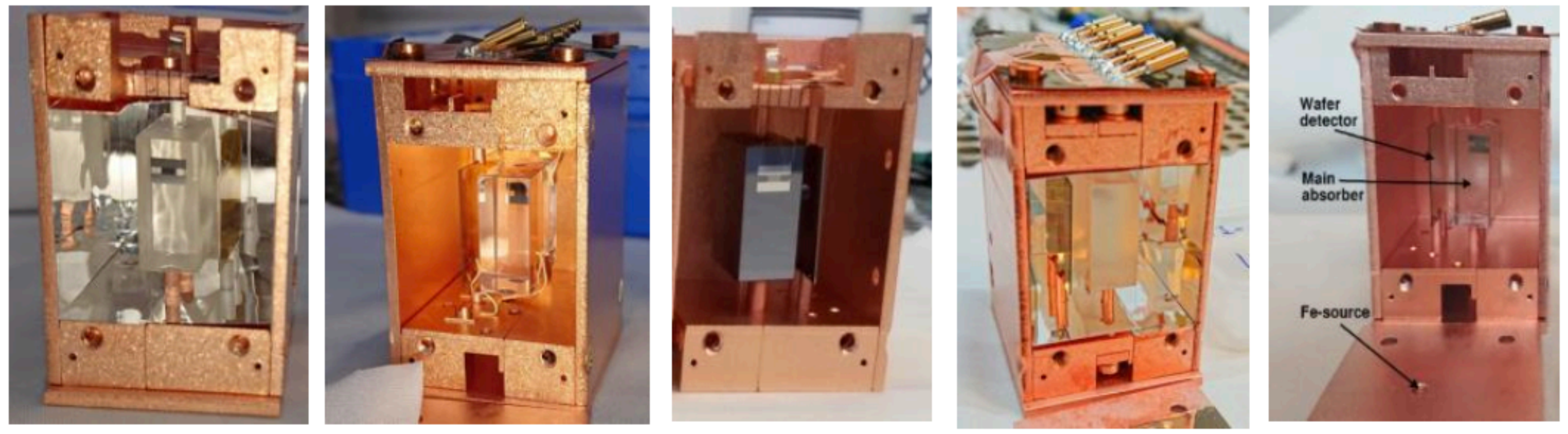
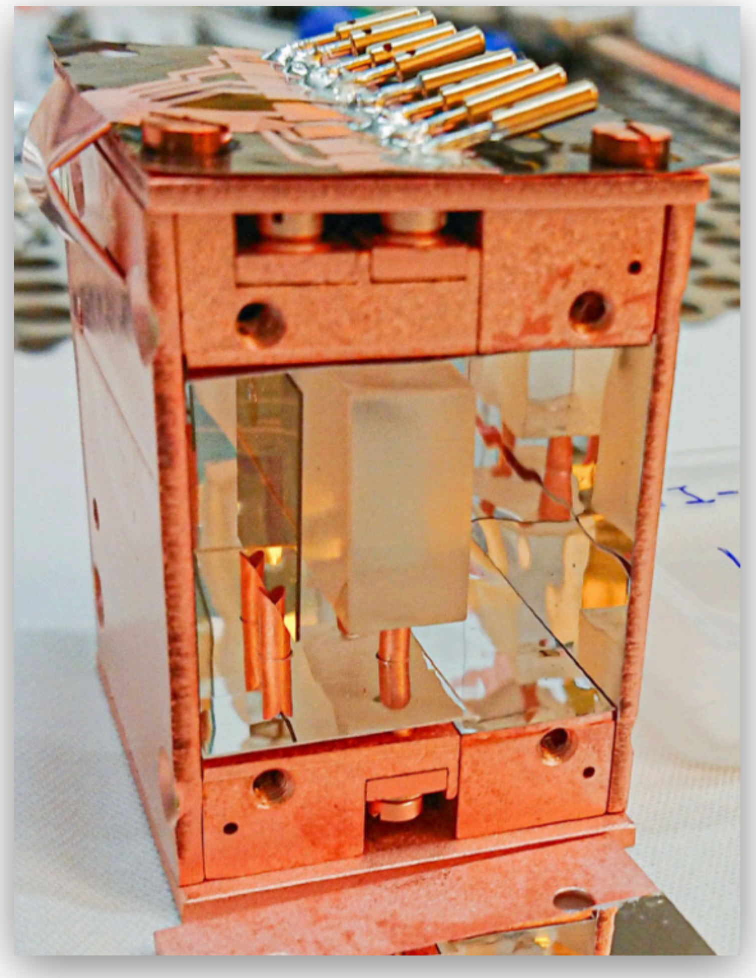
Dedicated detector modifications:

- Material
- Mass
- Holding method
- Scintillating materials
- Geometry





Spin dependent Dark Matter results



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Dark Matter limit with $LiAlO_2$ as absorber

- Crystal: 10.46 g $LiAlO_2$
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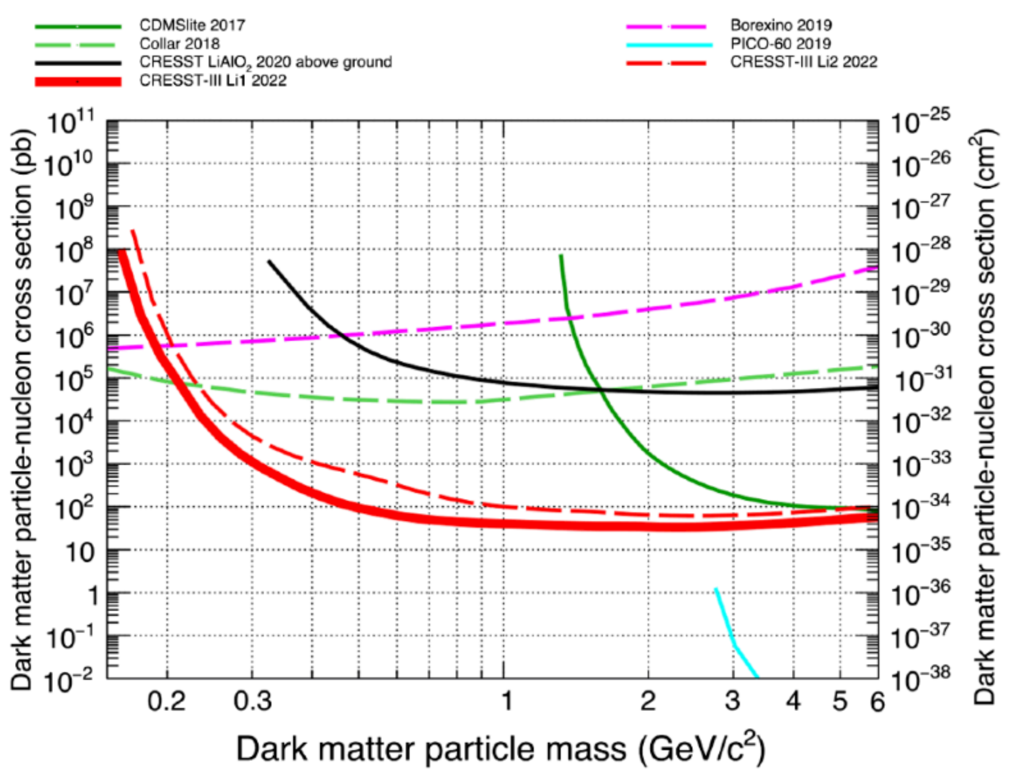
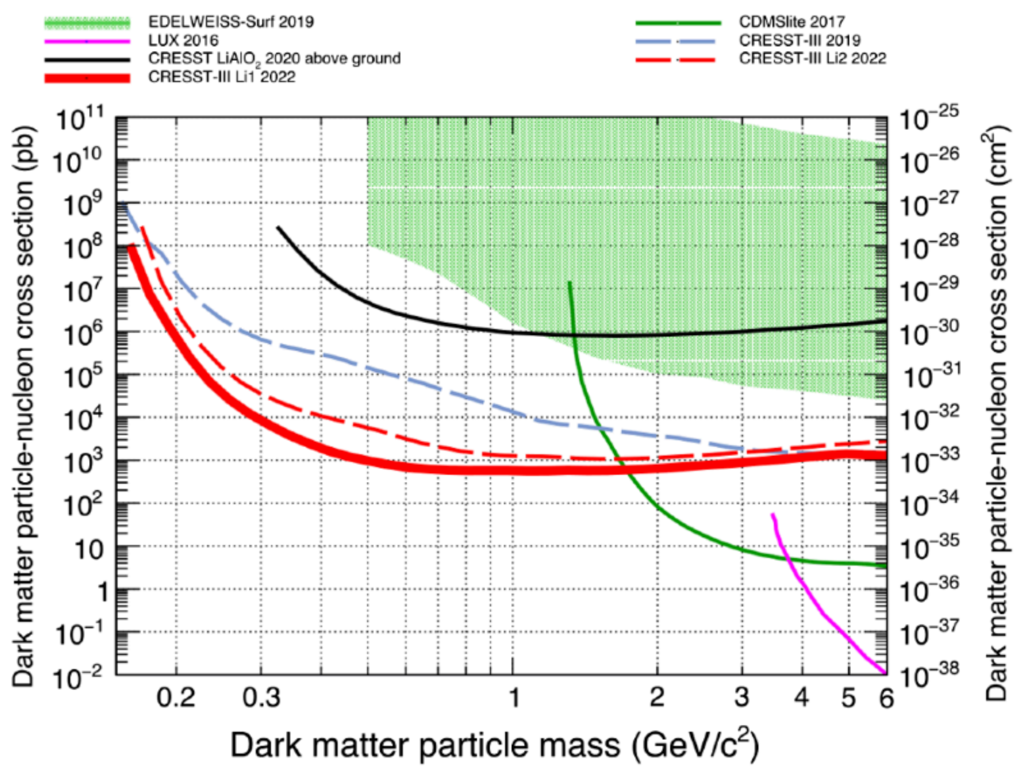
Spin Dependent - proton



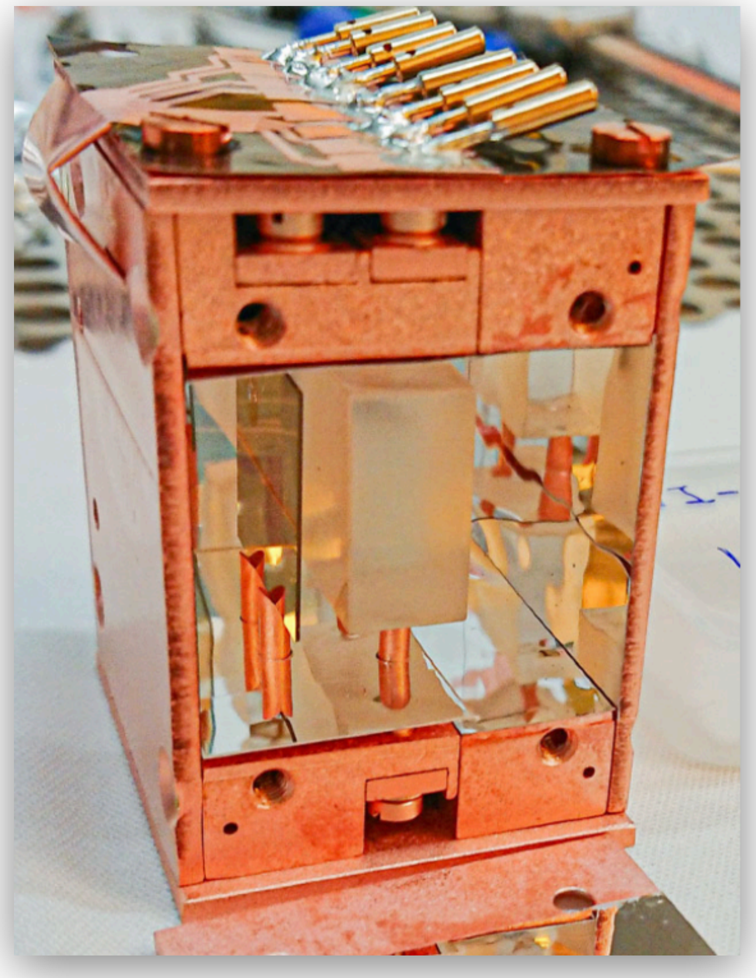
Spin Dependent - neutron

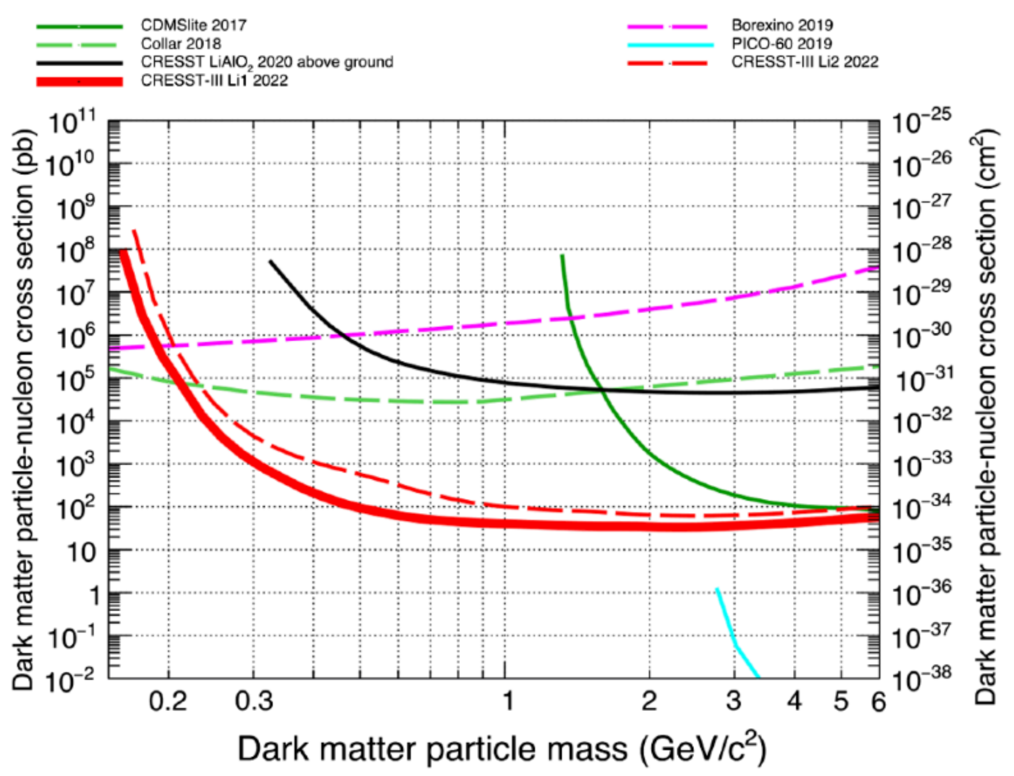


Spin dependent Dark Matter results

CRESST

Spin Dependent - proton





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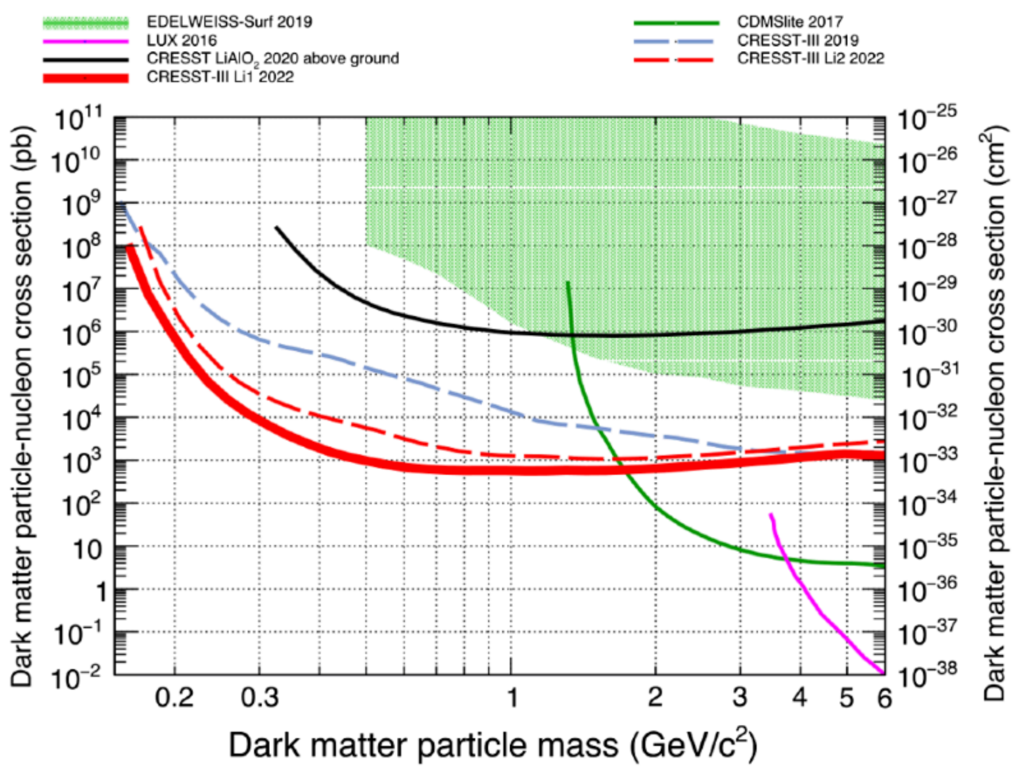

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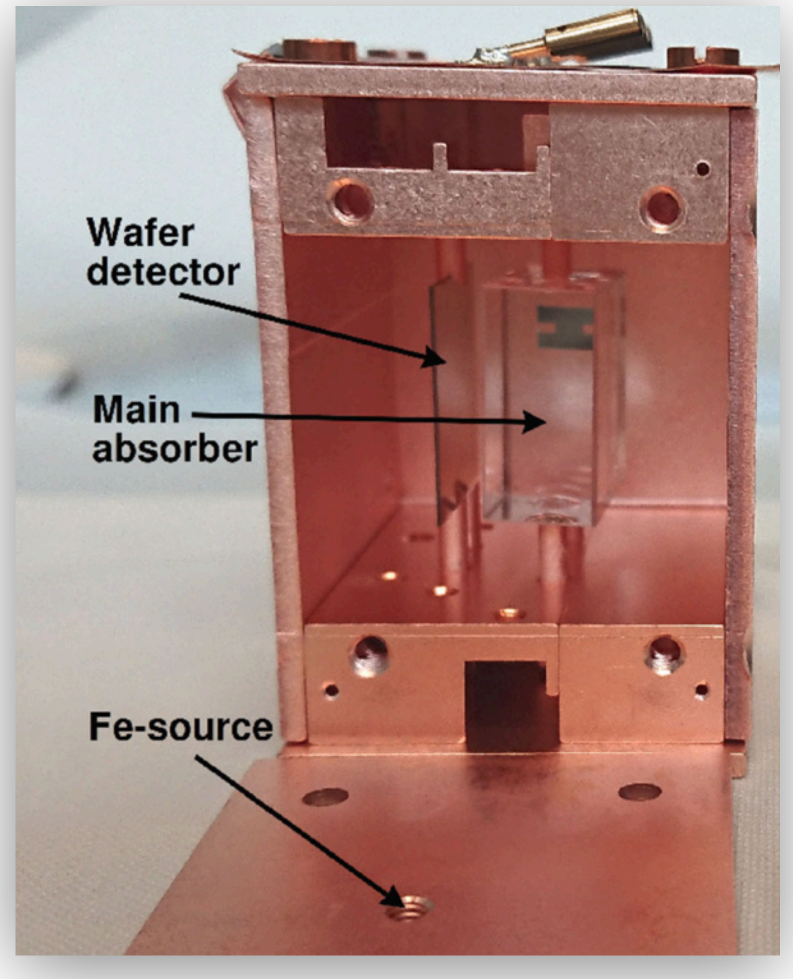

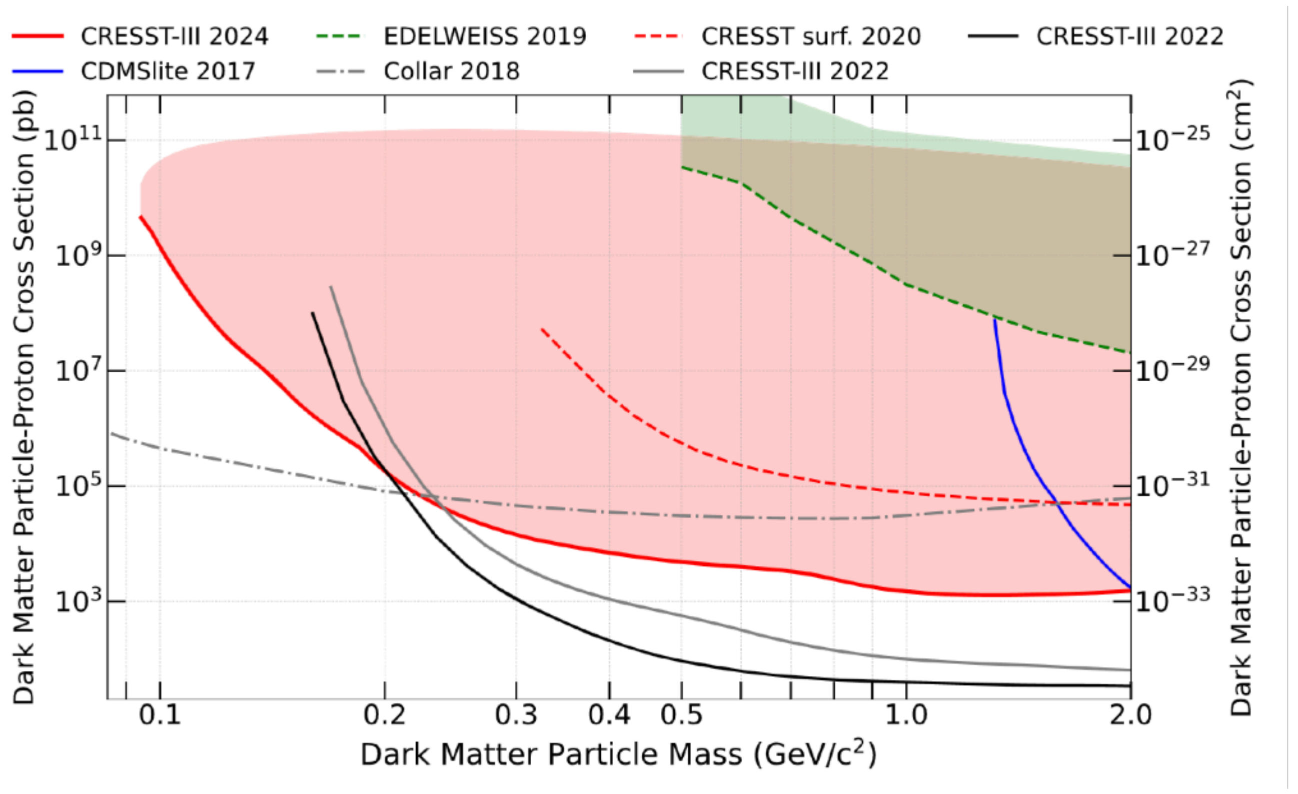

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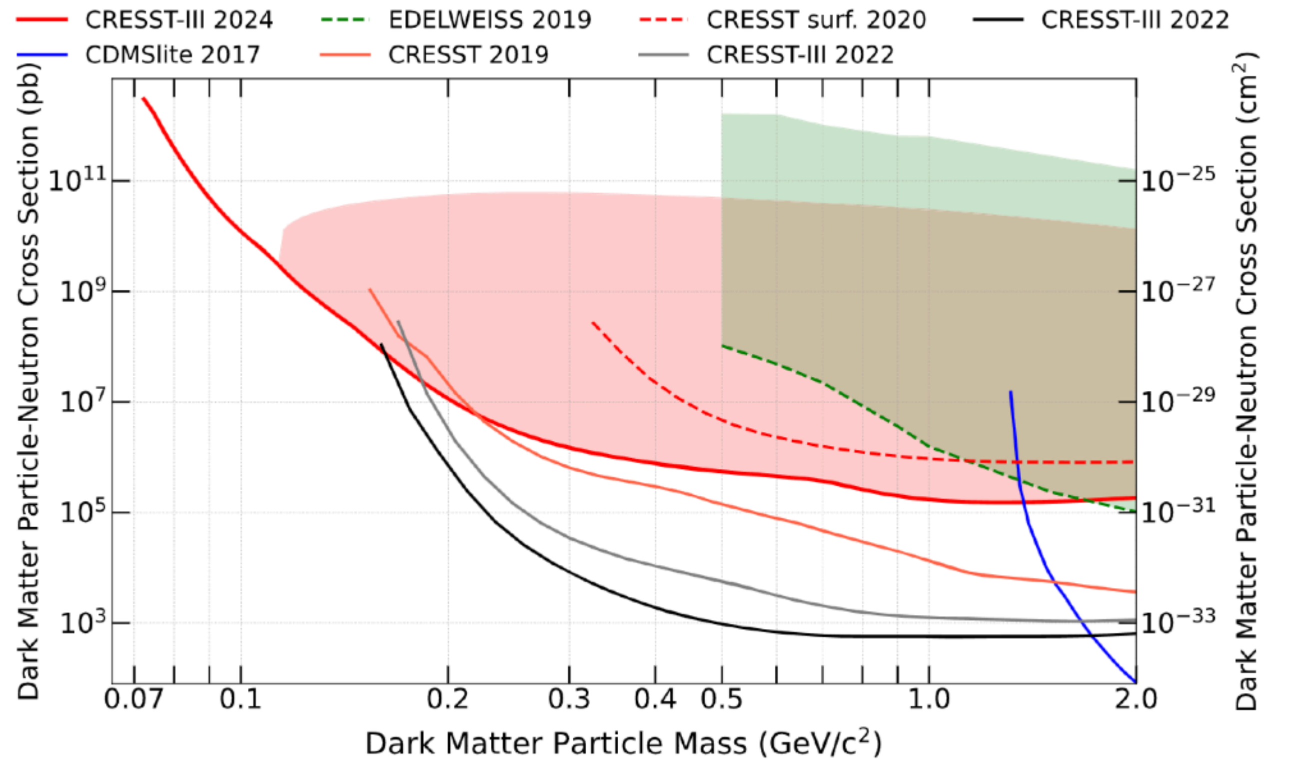
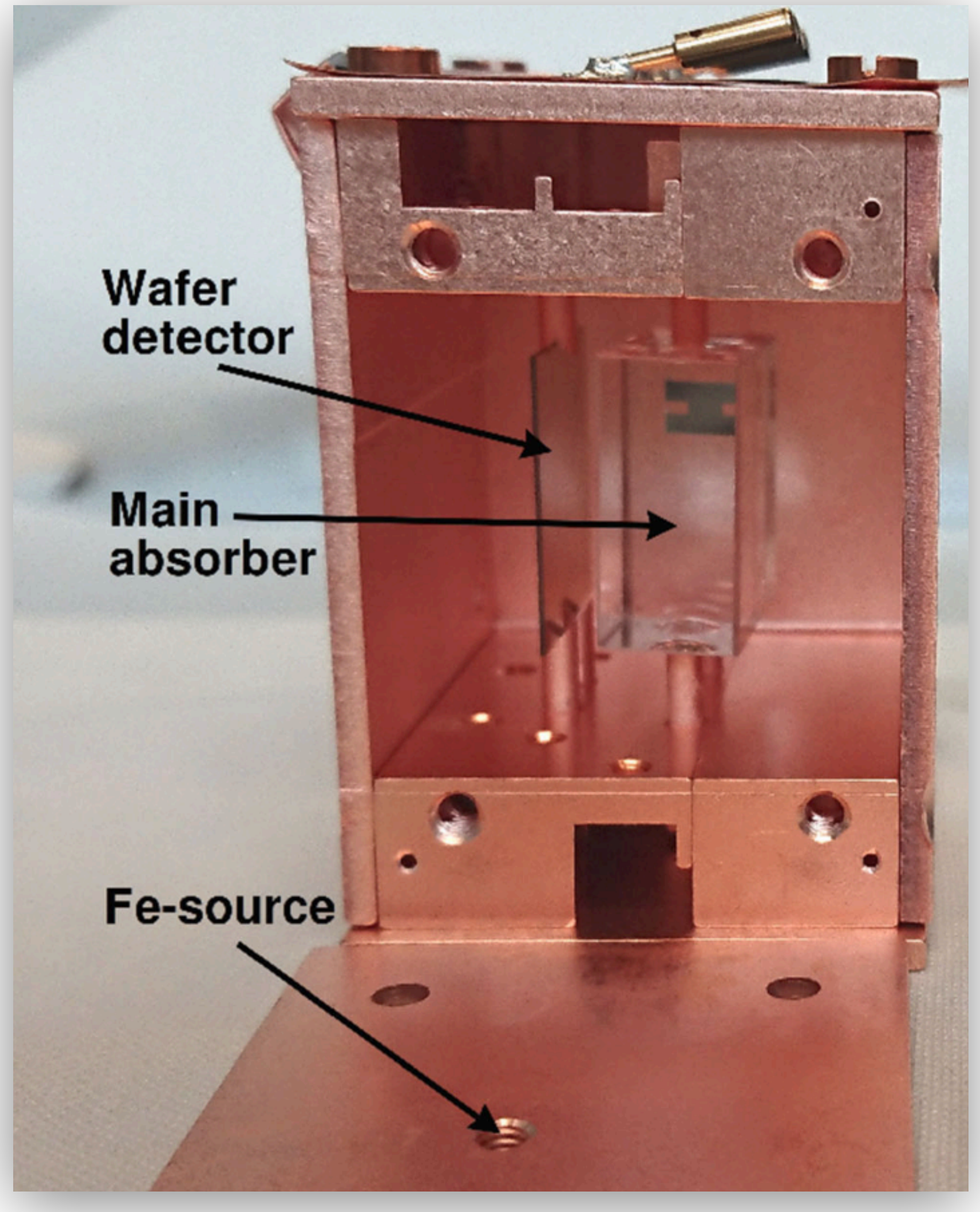


Dark Matter limit with light detector as absorber

- Crystal: 0.6 g Al$_2$O$_3$
- Data taking period: Nov 2020 - Aug 2021
- Exposure: 138 g·days
- Baseline resolution: 1.0 eV
- Energy threshold: 6.7 eV

Low threshold Dark Matter results



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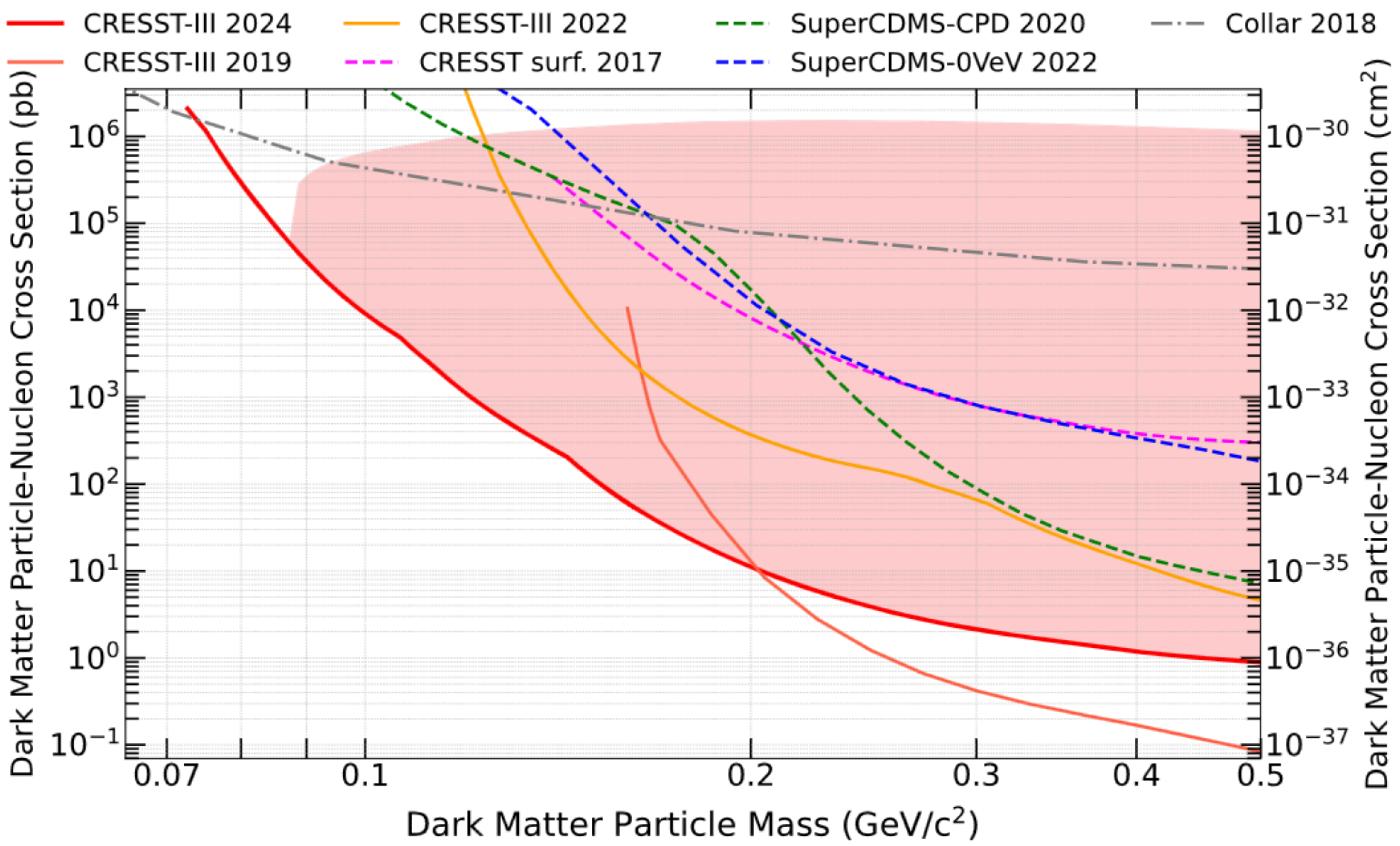
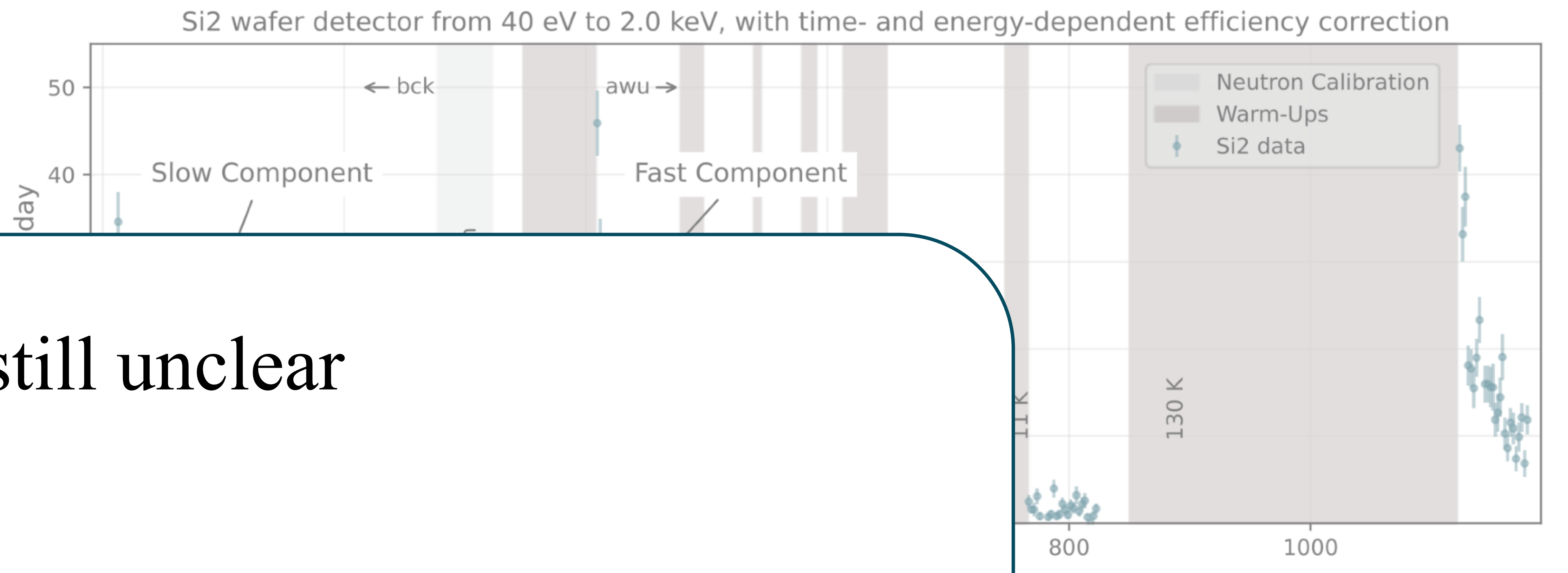
Spin Independent



LEE investigations



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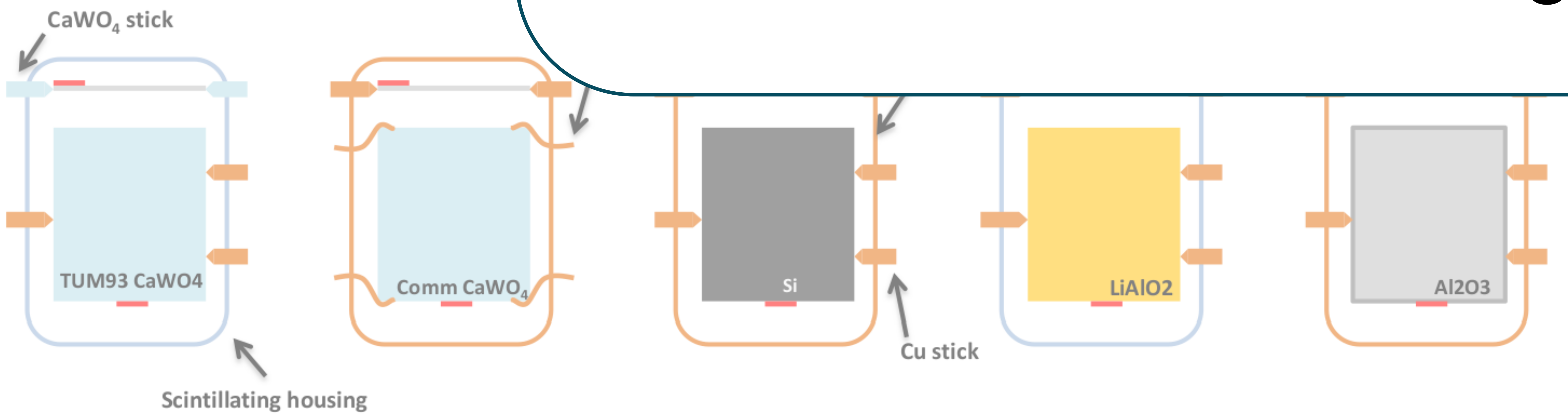
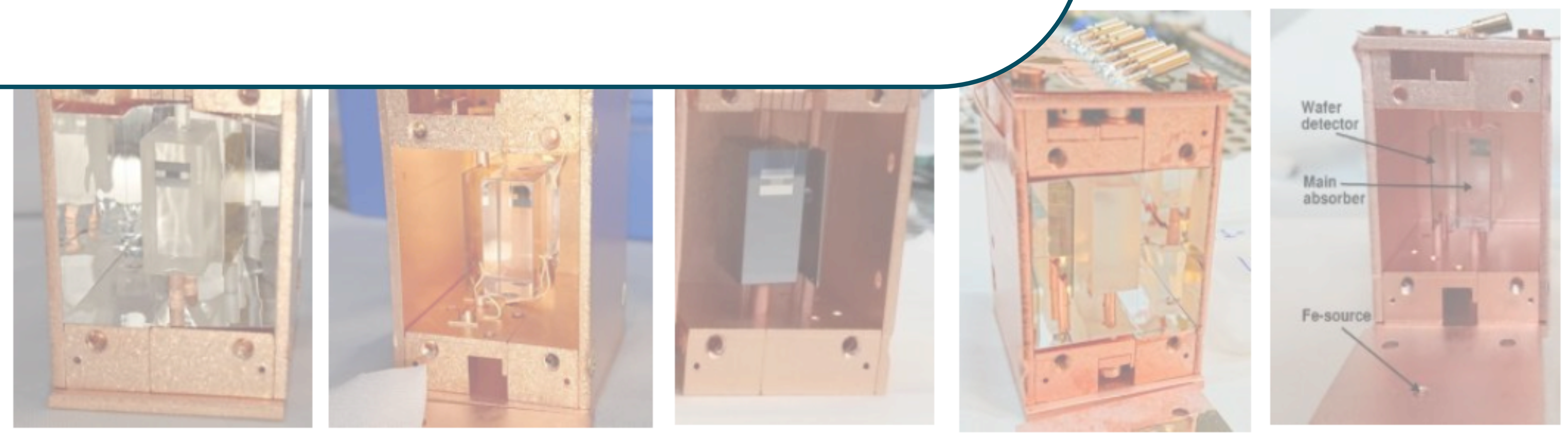
The origin still unclear

A new generation of detectors is required to improve our understanding of this signal





The doubleTES

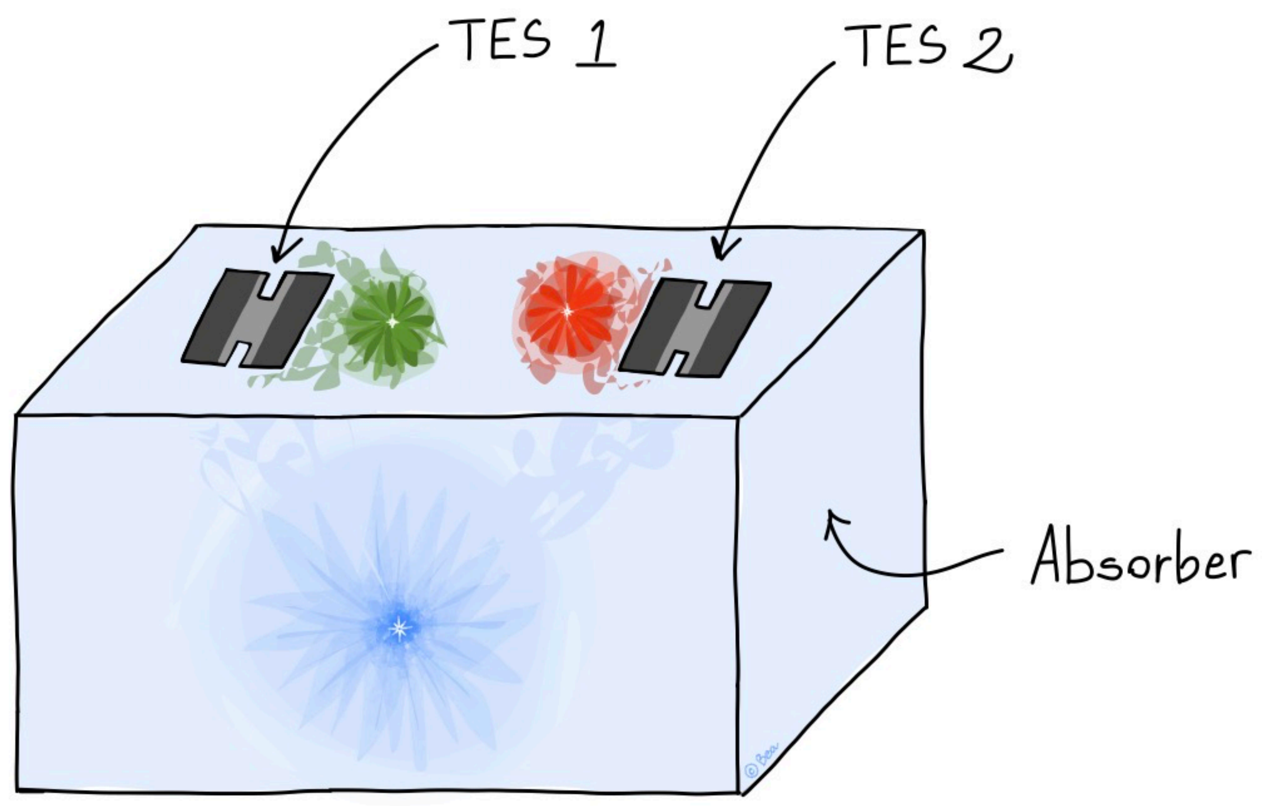
Crystal absorber instrumented with two TESs to localise the origin of events

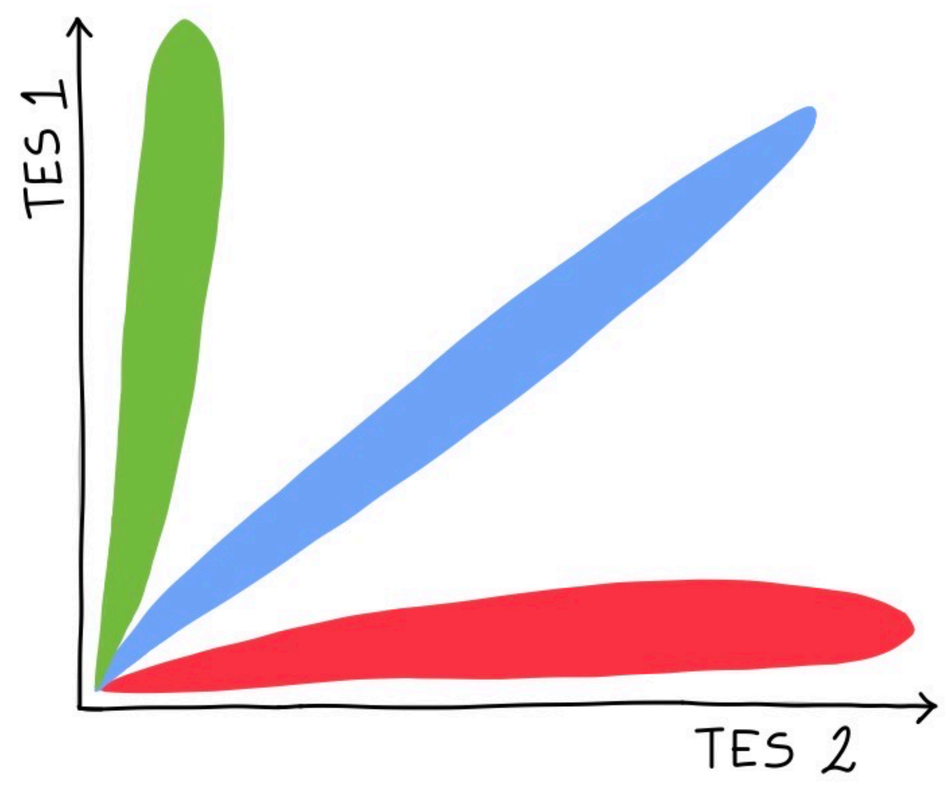
Events in the absorber:

- Shared energy deposition
- Both TESs show identical response

Events in/near the TES:

- Localised signal
- single-TES response





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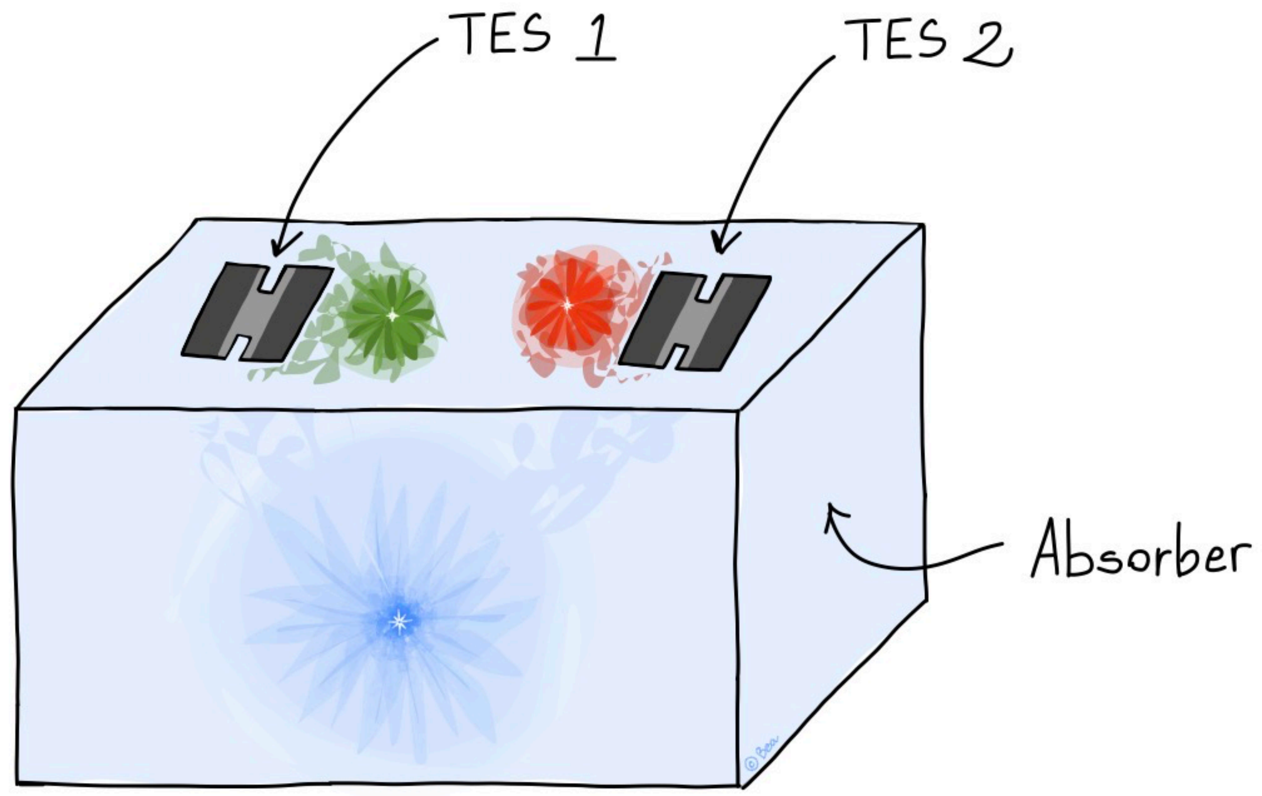
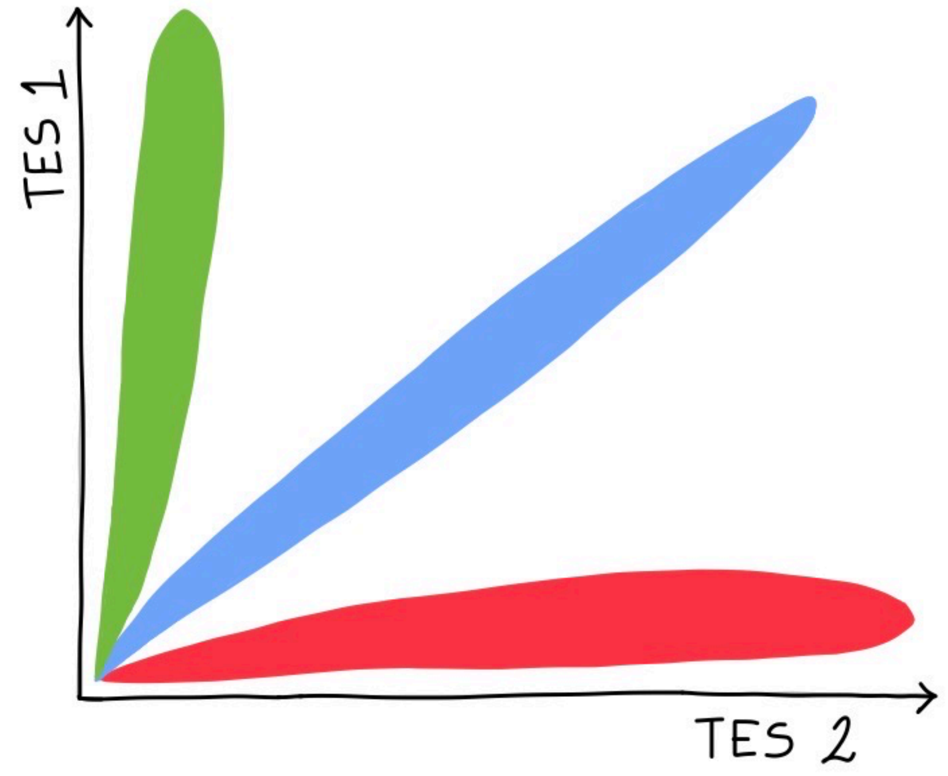
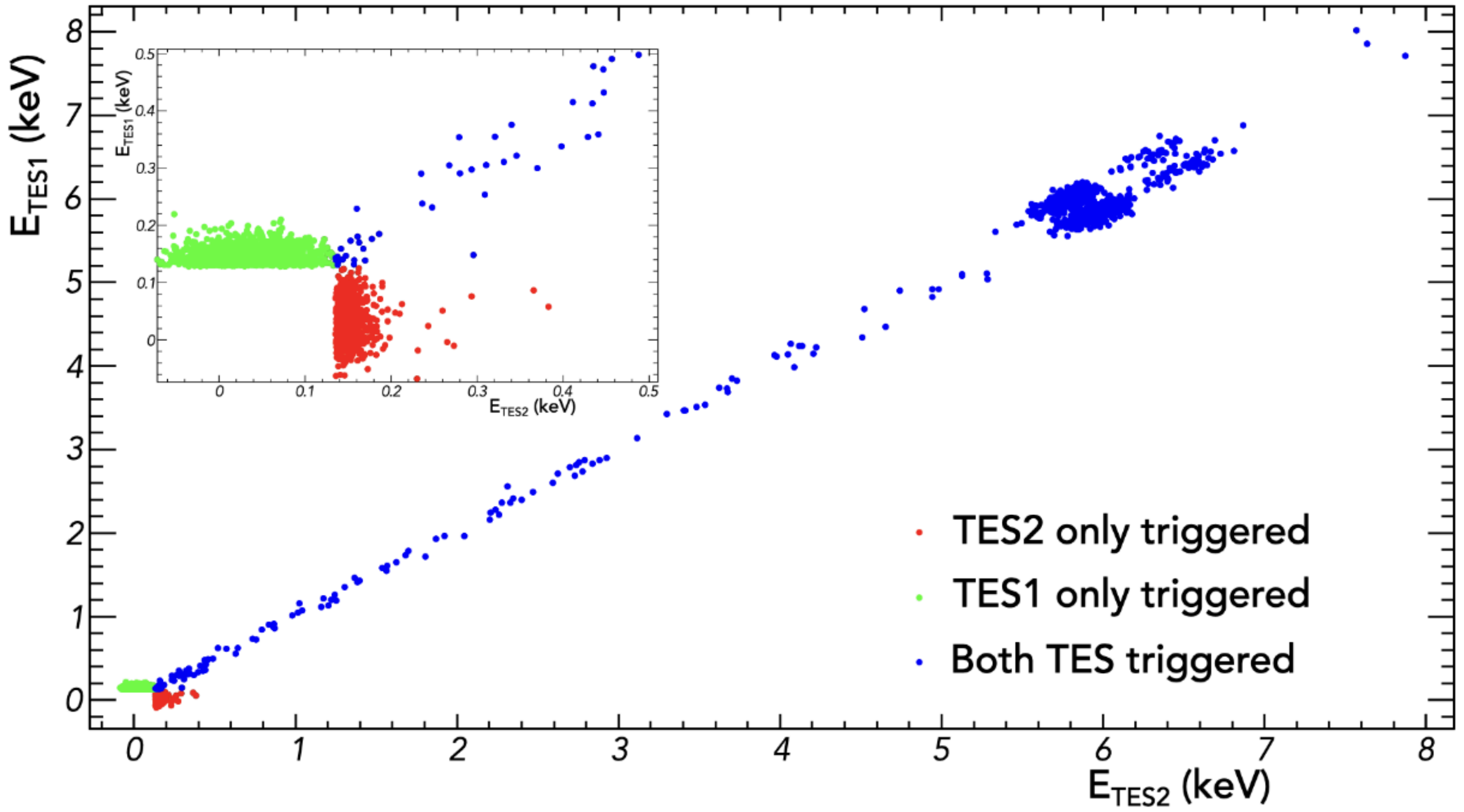




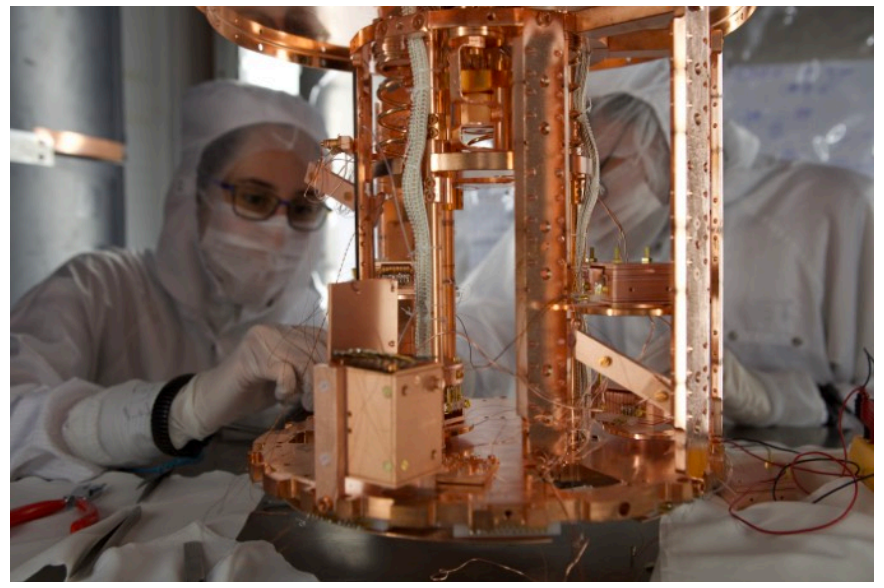
First results:

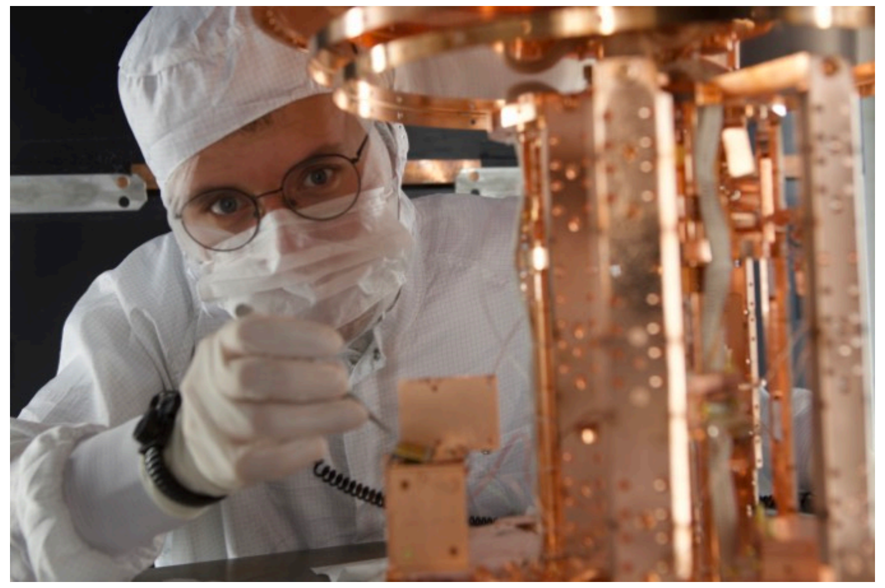
- Several doubleTES modules tested above ground
- Results are promising and consistent with expectations

https://doi.org/10.1140/epjc/s10052-024-13282-8



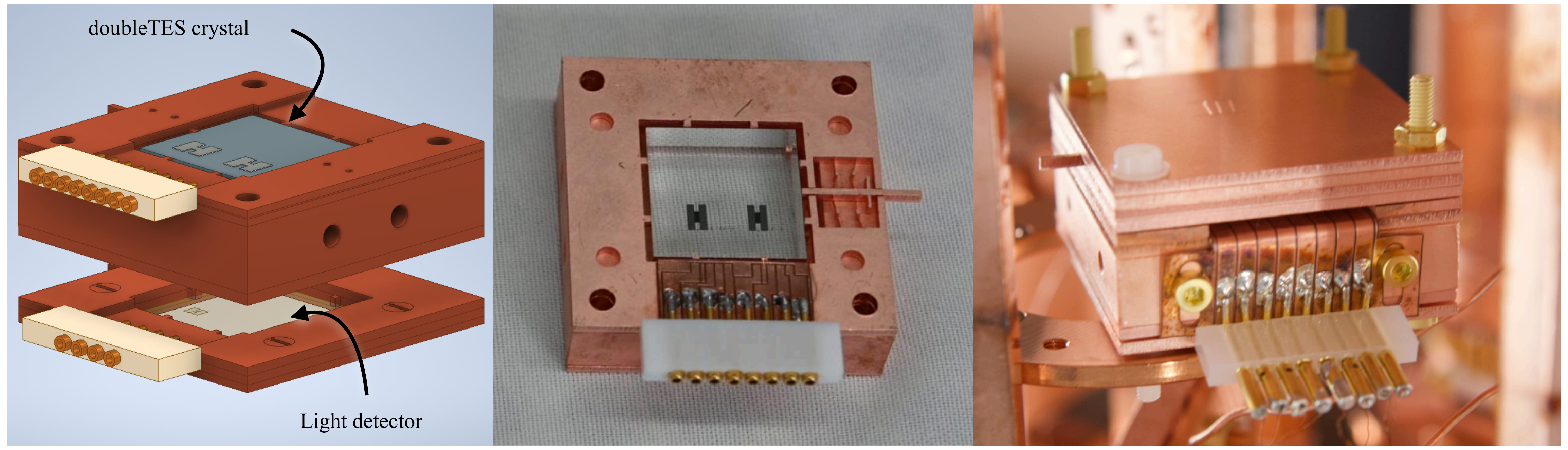
Adoption of doubleTES modules in the CRESST measurement campaign

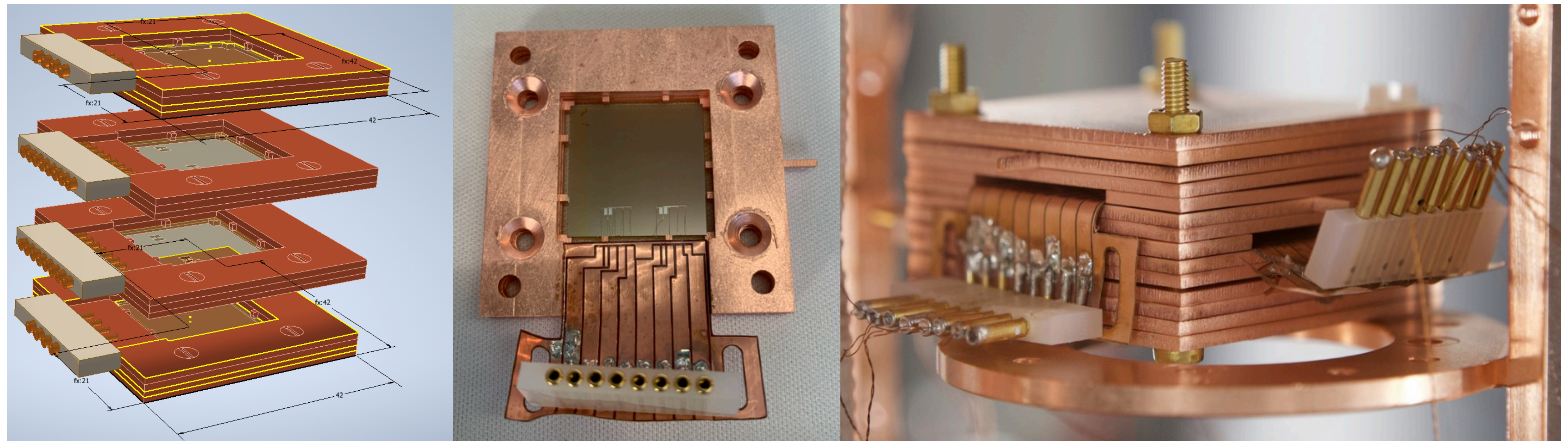




CRESST doubleTES modules

In-depth investigation of the LEE using new detector designs





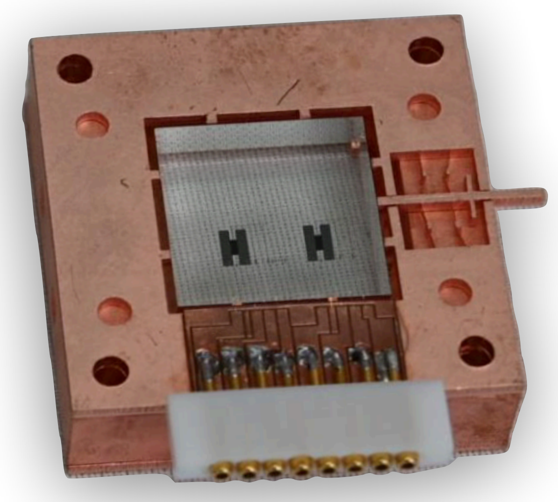
5x doubleTES

- $CaWO_4$ target crystal ~24 g and (20x20x10) mm^3
- Gravity-assisted holding scheme for stress minimisation
- Coupled with a light detector for particle discrimination

doubleTES wafer Stack

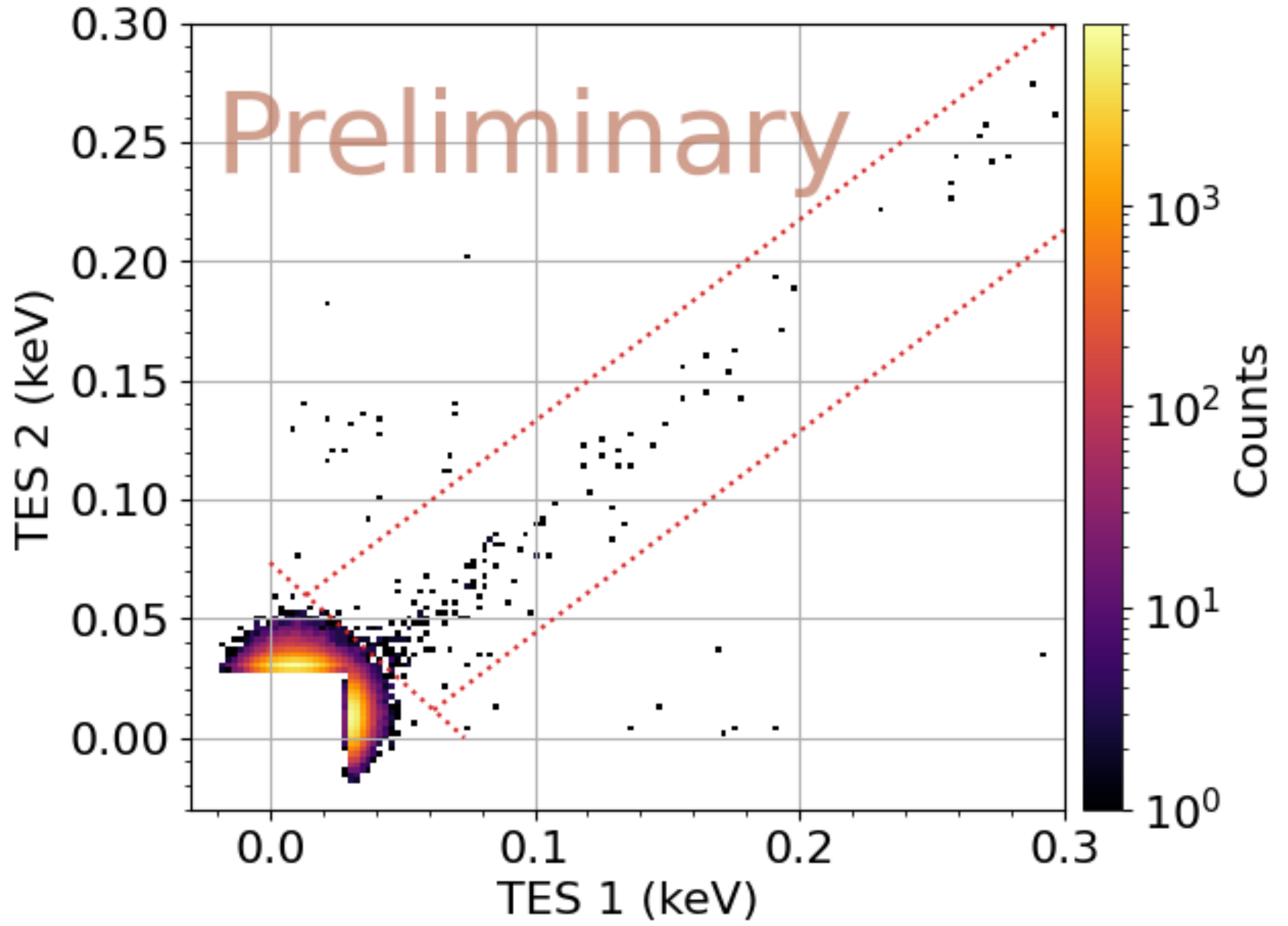
- 4x Silicon-On-Sapphire wavers ~0.6 g and (20x20x0.4) mm^3
- Gravity-assisted holding scheme for stress minimisation
- Anti-coincidence cut

$CaWO_4$ doubleTES results



- Reached energy thresholds of ~35 eV
- Possible to distinguish two different LEE components: shared and singles events
- Performances:

Detector	Baseline resolution TES1	Baseline resolution TES2
doubleTES 2	~7 eV	~7 eV
doubleTES 5	~8 eV	~7 eV



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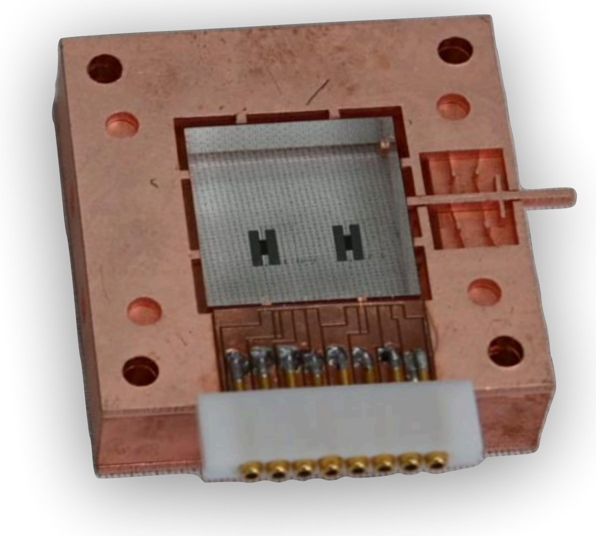

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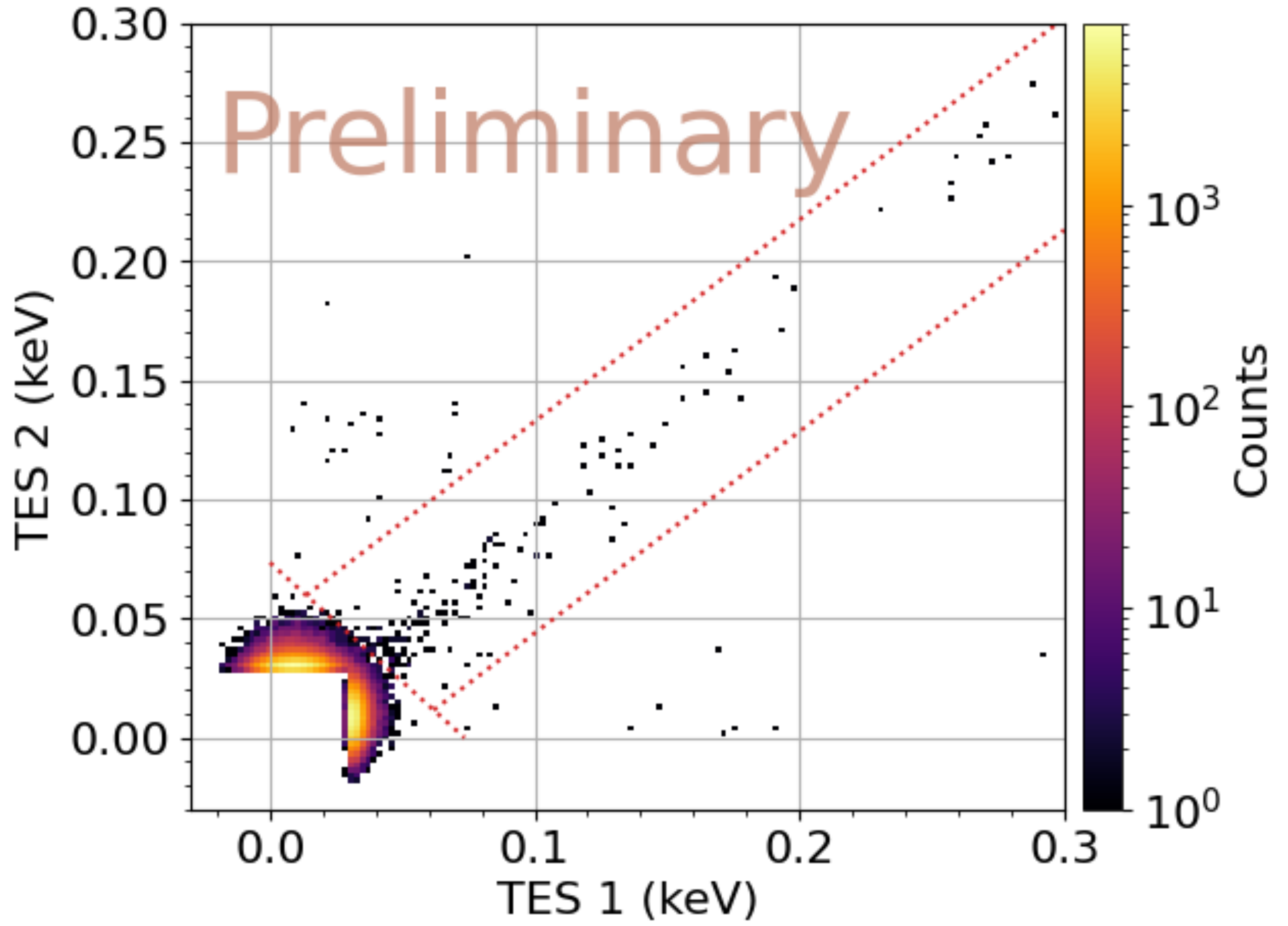
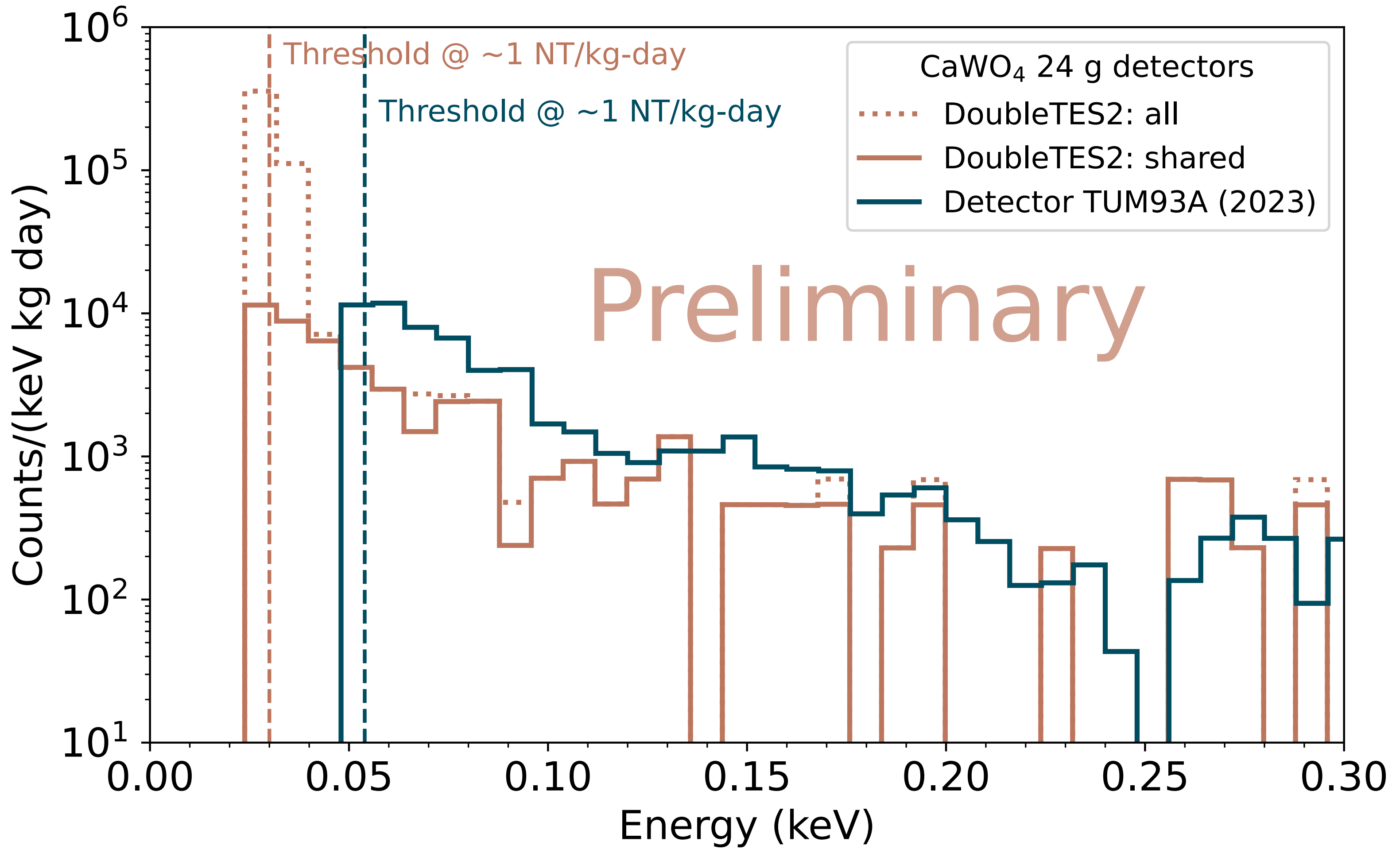
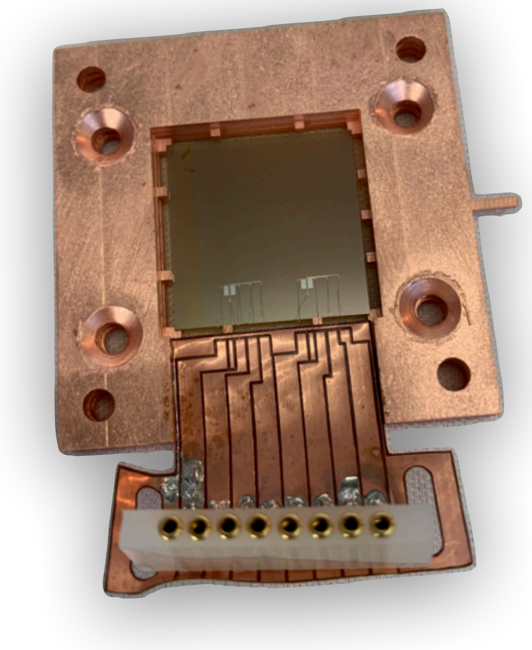


- The double-TES design enables lower detector thresholds
- Due to dominant uncorrelated noise, similar baseline resolutions yield to different energy thresholds
- Lower thresholds extend the sensitivity to low-mass Dark Matter, opening access to a broader parameter space

Next step: collect a blind dataset and perform a Dark Matter analysis



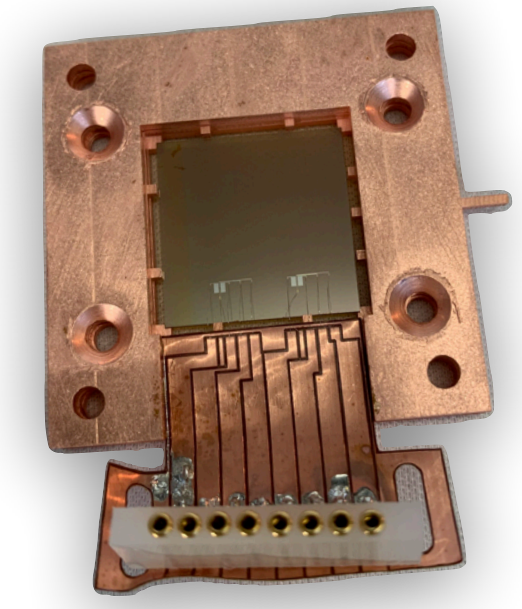
Stack results



- Reached very low energy thresholds (<10 eV) and excellent energy resolution
- 8 fully working TESs
- Optimised for low-mass Dark Matter searches
- ^{55}Fe source for calibration

Detector	Baseline resolution TES1	Baseline resolution TES2
Stack1	1.4 eV	1.1 eV
Stack2	1.2 eV	1.0 eV
Stack3	1.7 eV	1.5 eV
Stack4	1.4 eV	3.9 eV

Stack results



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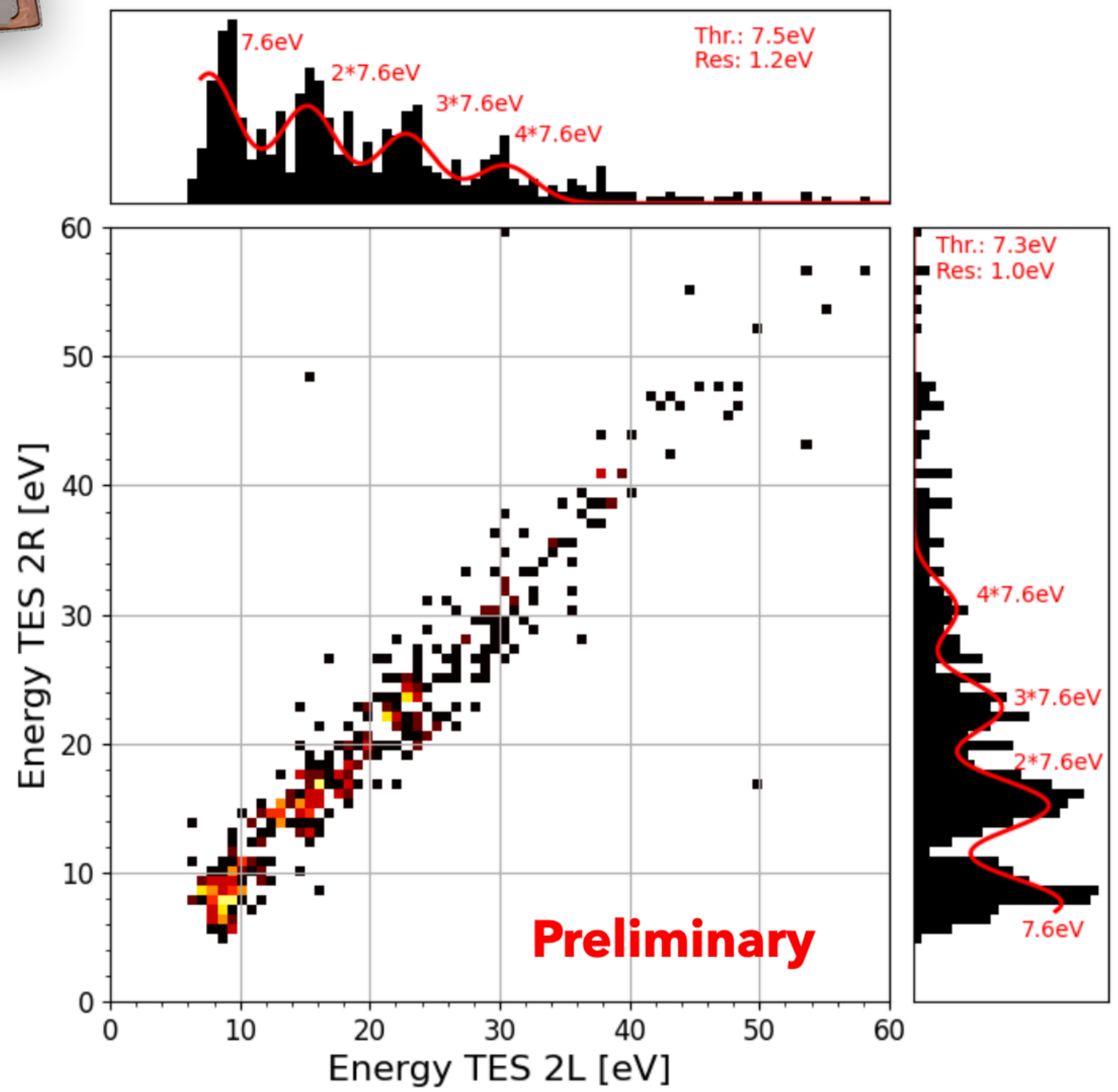
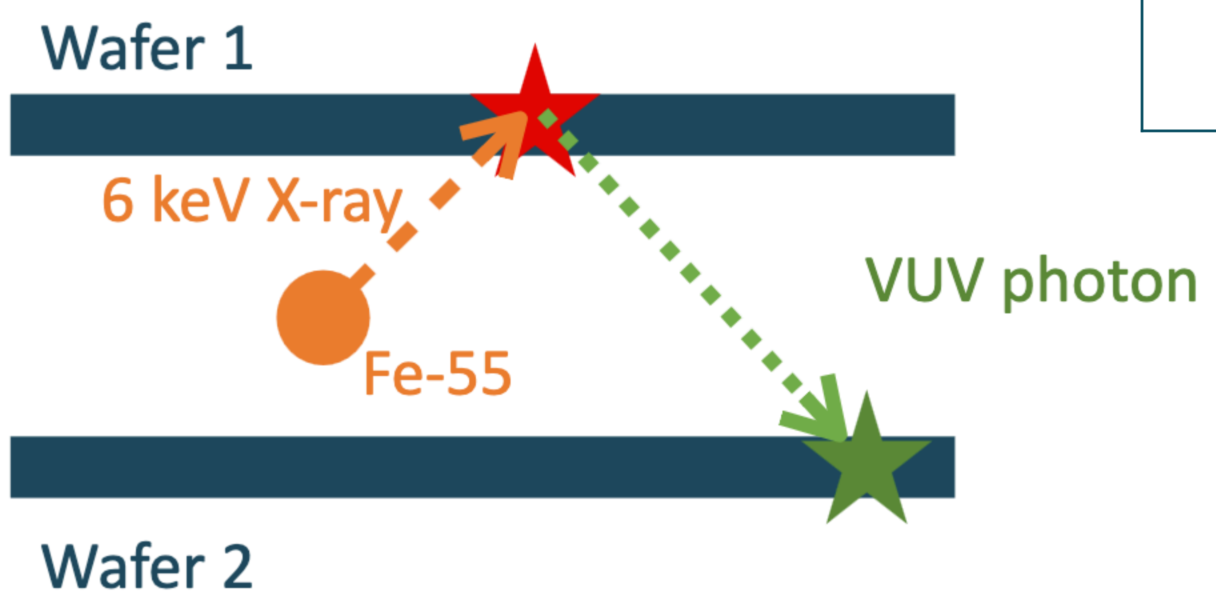




- Low energy thresholds allow the detection of single photons from vacuum-ultraviolet (VUV) luminescence in nearby wafers
- Previously observed in CRESST

https://doi.org/10.1103/PhysRevD.110.083038

Conclusions and outlook

- CRESST energy thresholds allow exploration of the low-mass Dark Matter parameter space, extending sensitivity down to sub-GeV/c² mass range
- The flexibility of the detector technology allows operation with multiple target crystals, providing sensitivity to both spin-independent and spin-dependent interactions
- DoubleTES detectors operated in the CRESST cryostat reveal distinct components of LEE and enable a significant reduction of the detector energy threshold
- A dedicated Dark Matter run is underway, with blind data expected to be collected in the near future

Stay tuned and thank you!

Backup

CRESST-III calibration method

New calibration technique for low nuclear recoil energy in $CaWO_4$ and Al_2O_3 crystals through (n, γ) reactions

CRAB Collaboration 2021 JINST 16 P07032

$CaWO_4$

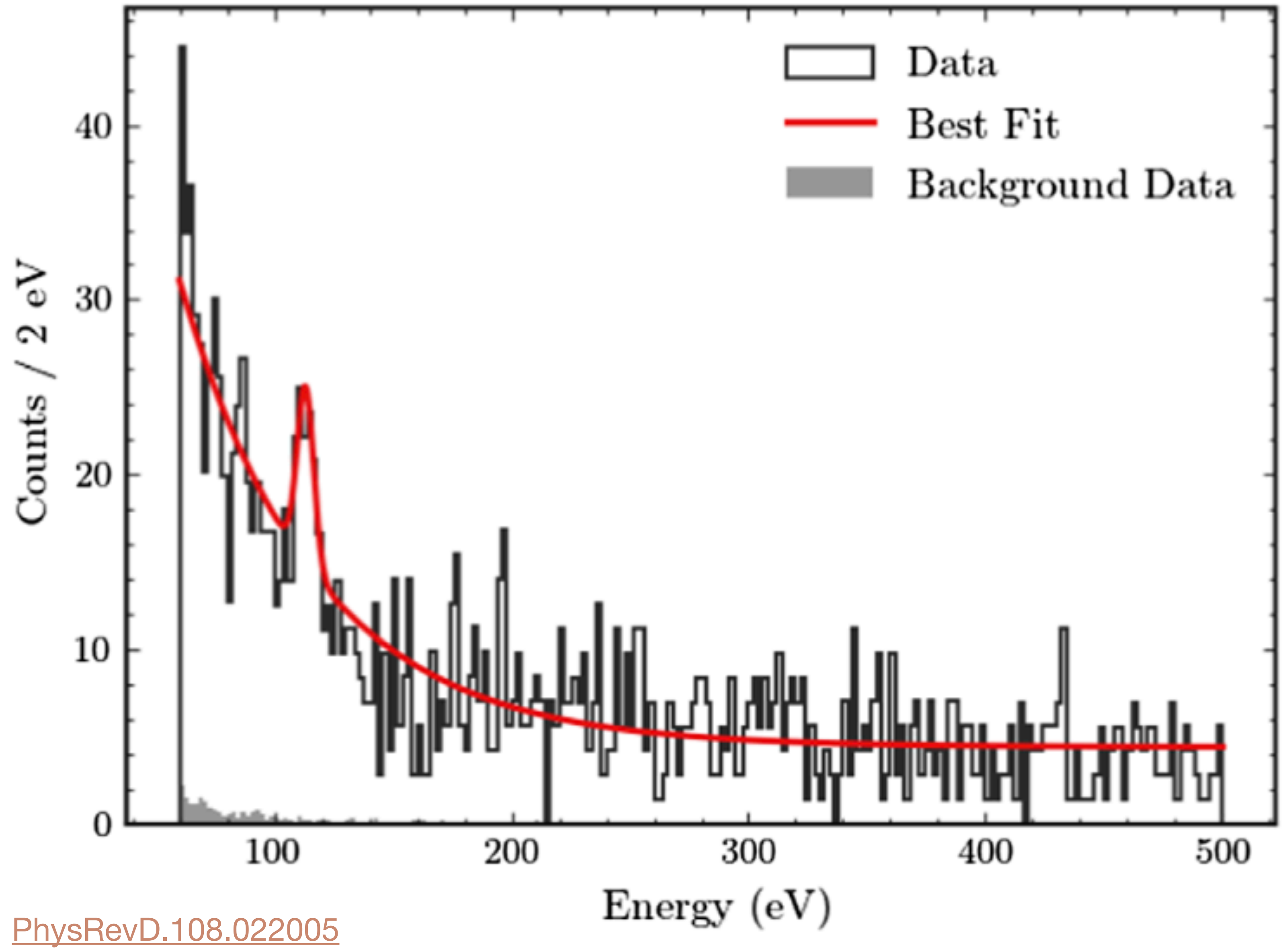
$^{182}W(n, \gamma)\,^{183}W$

De-excitation γ of 6.1 MeV and W nuclear recoil of 112 eV

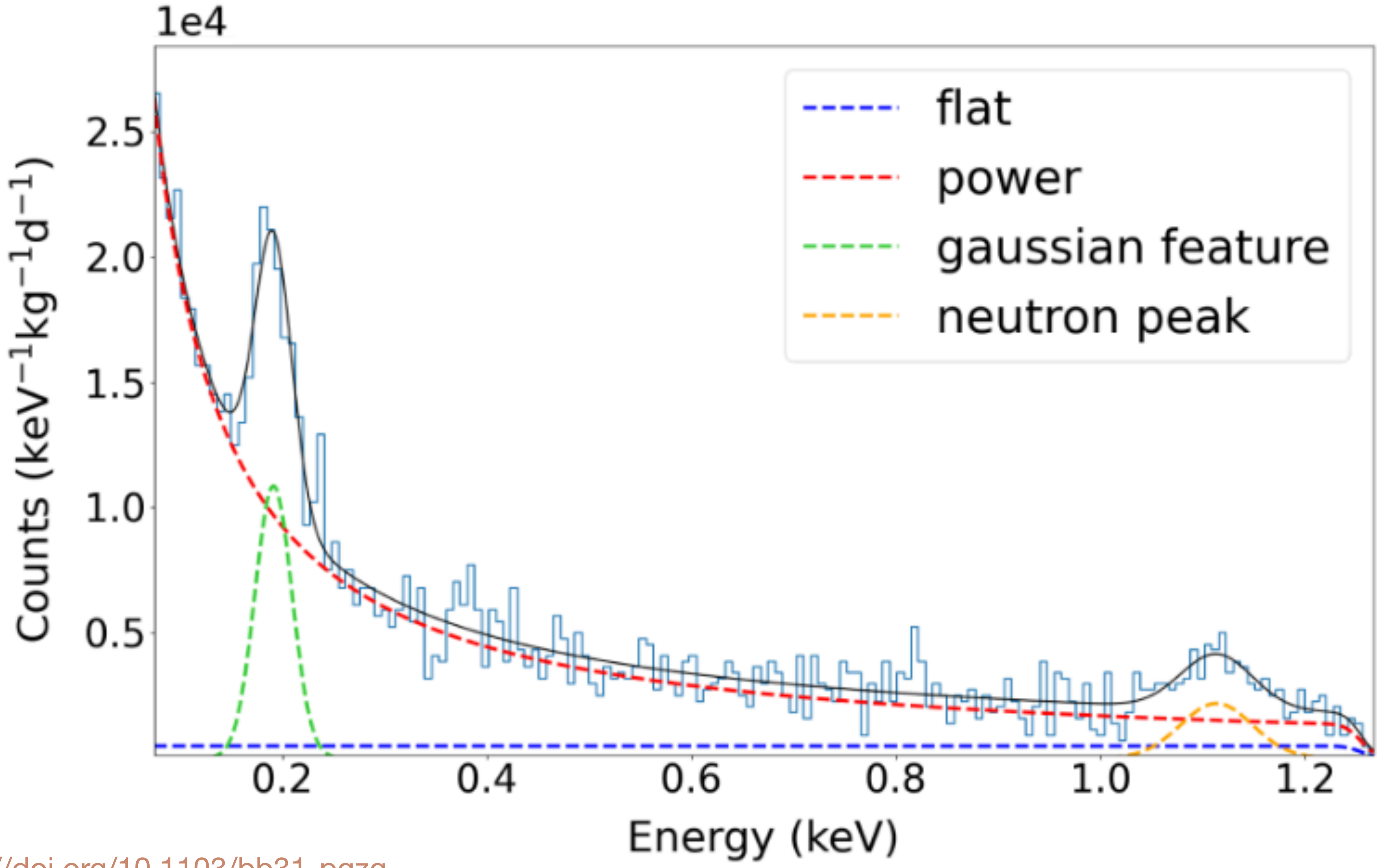
Al_2O_3

$^{27}Al(n, \gamma)\,^{28}Al$

De-excitation γ of 7.7 MeV and Al nuclear recoil of 1144 eV



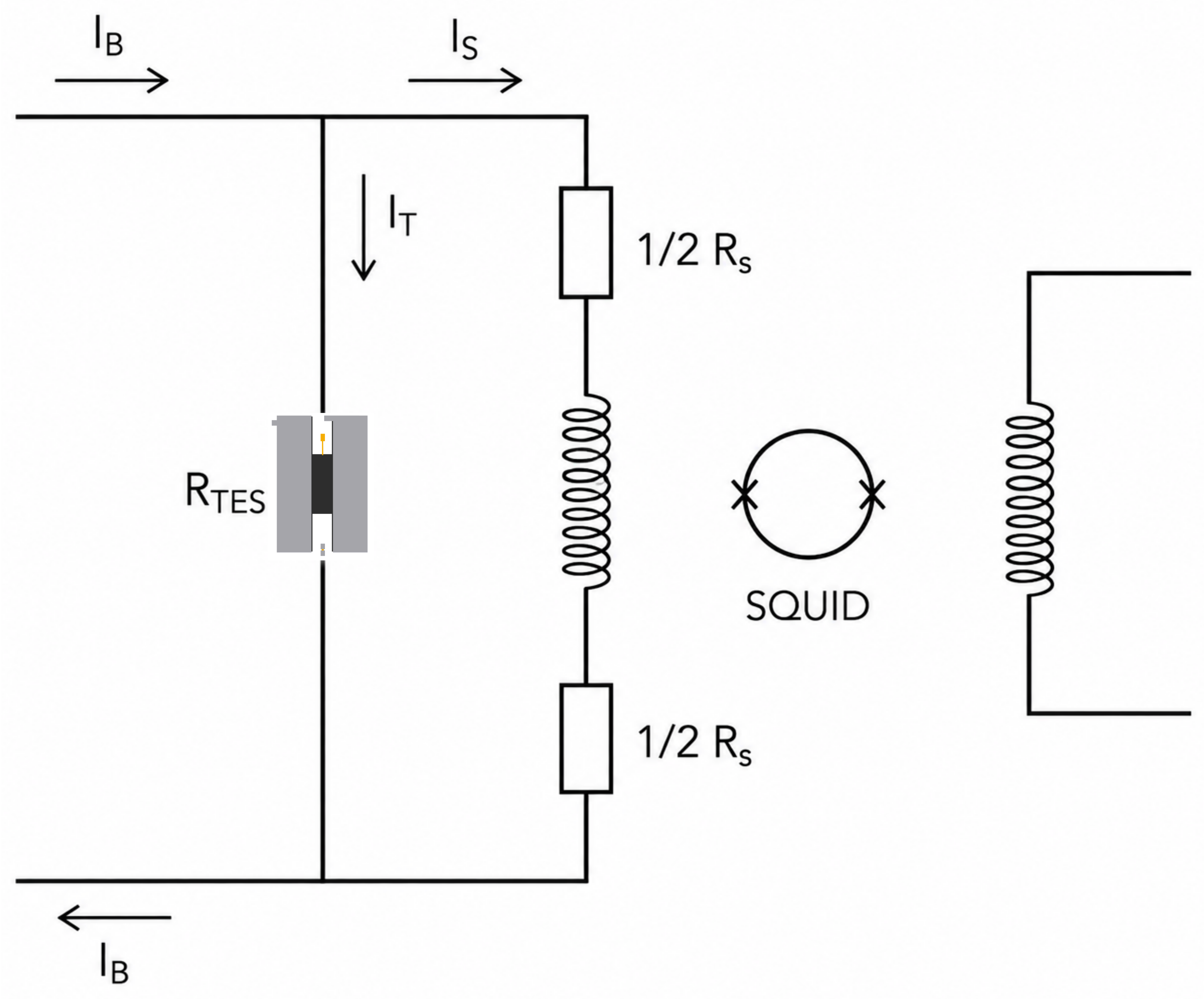
PhysRevD.108.022005



https://doi.org/10.1103/bb31-pgzg

Readout circuit

TES resistance variations are readout by a SQUID, which converts the resulting current changes into a measurable voltage signal



Current CRESST run timeline

CRESST

Francesca Pucci

Searching for light dark matter with the CRESST experiment