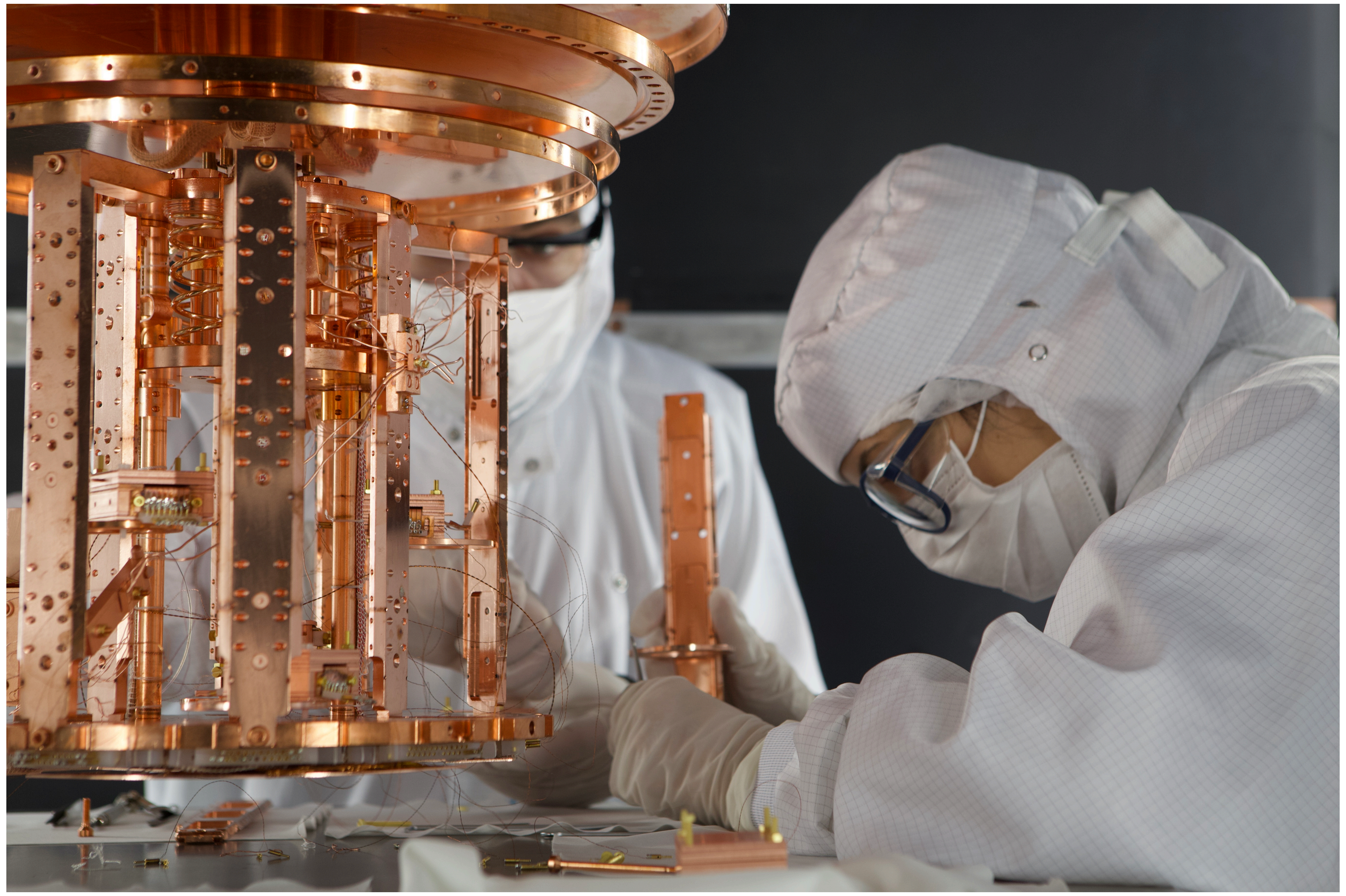
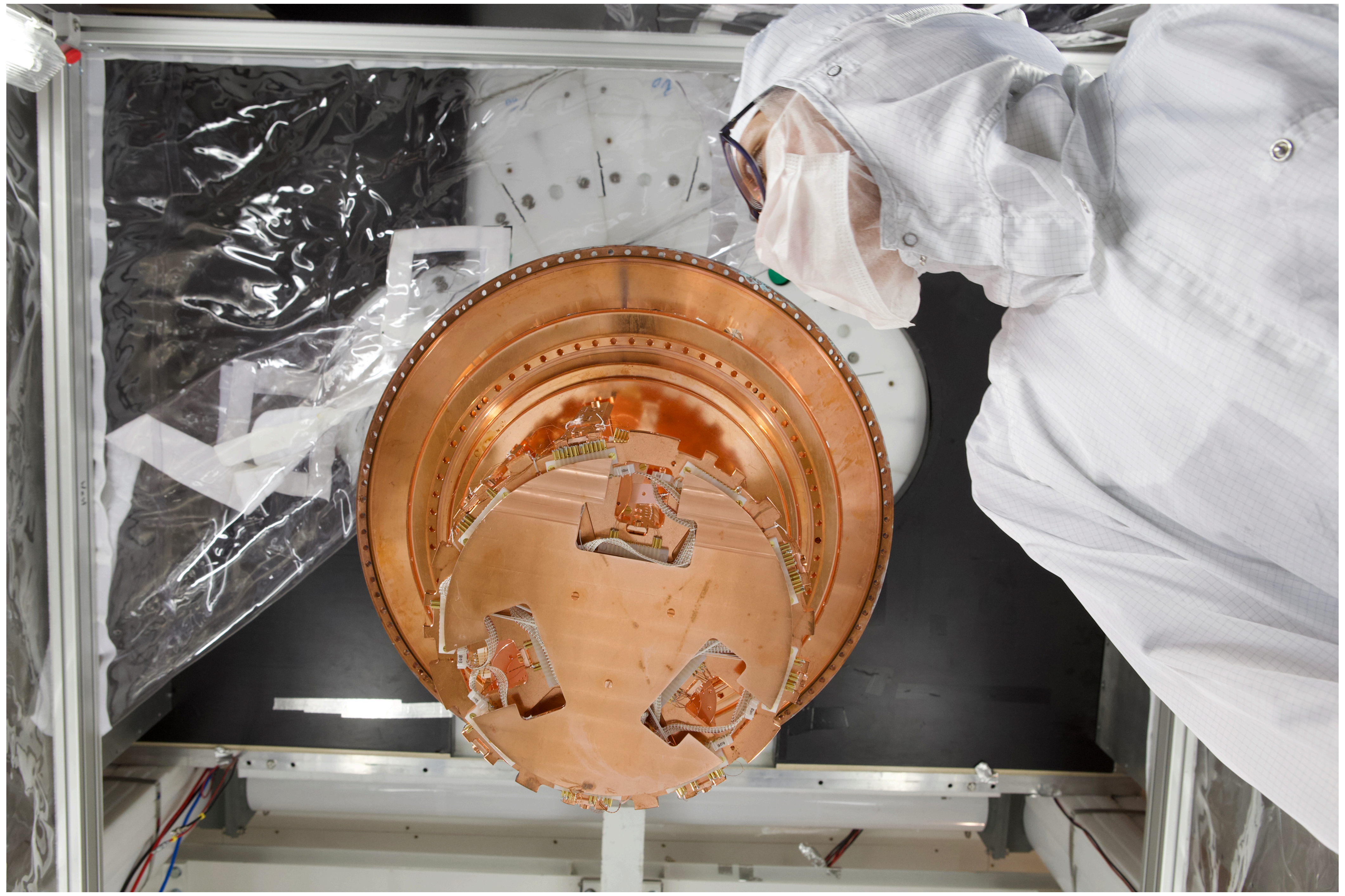
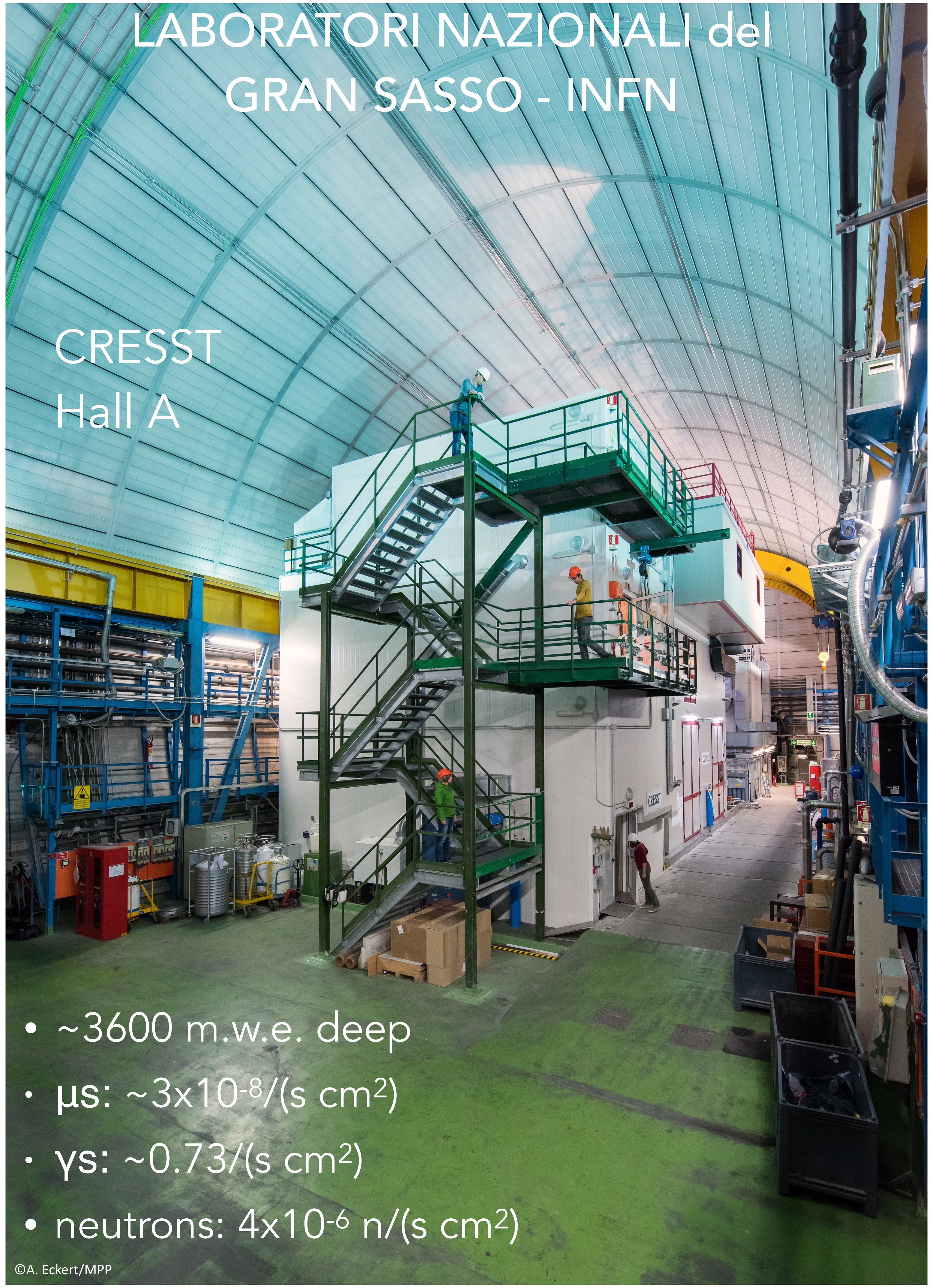
Searching for light Dark Matter with the CRESST Experiment

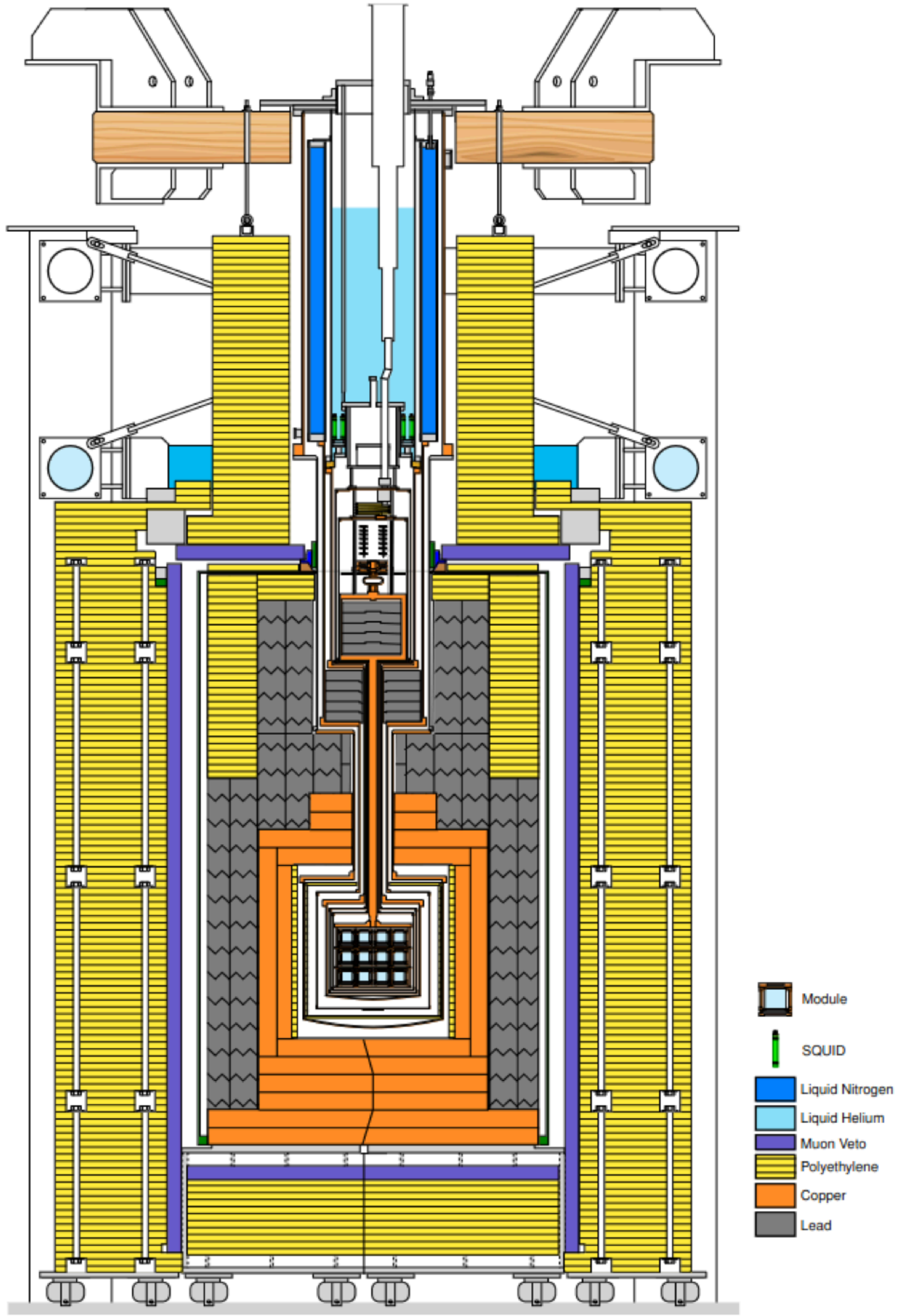
Paolo Gorla - LNGS





The CRESST experiment

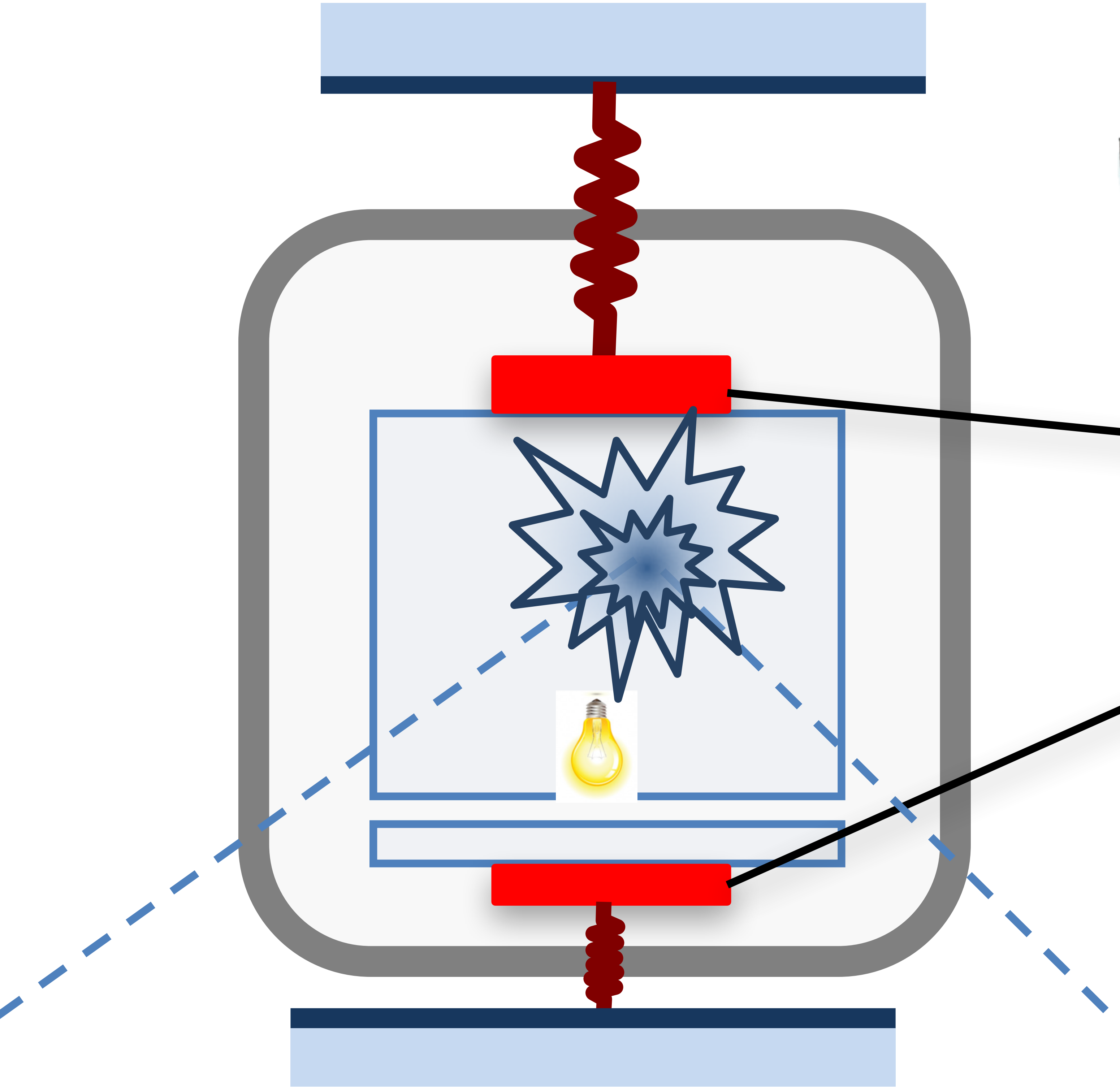


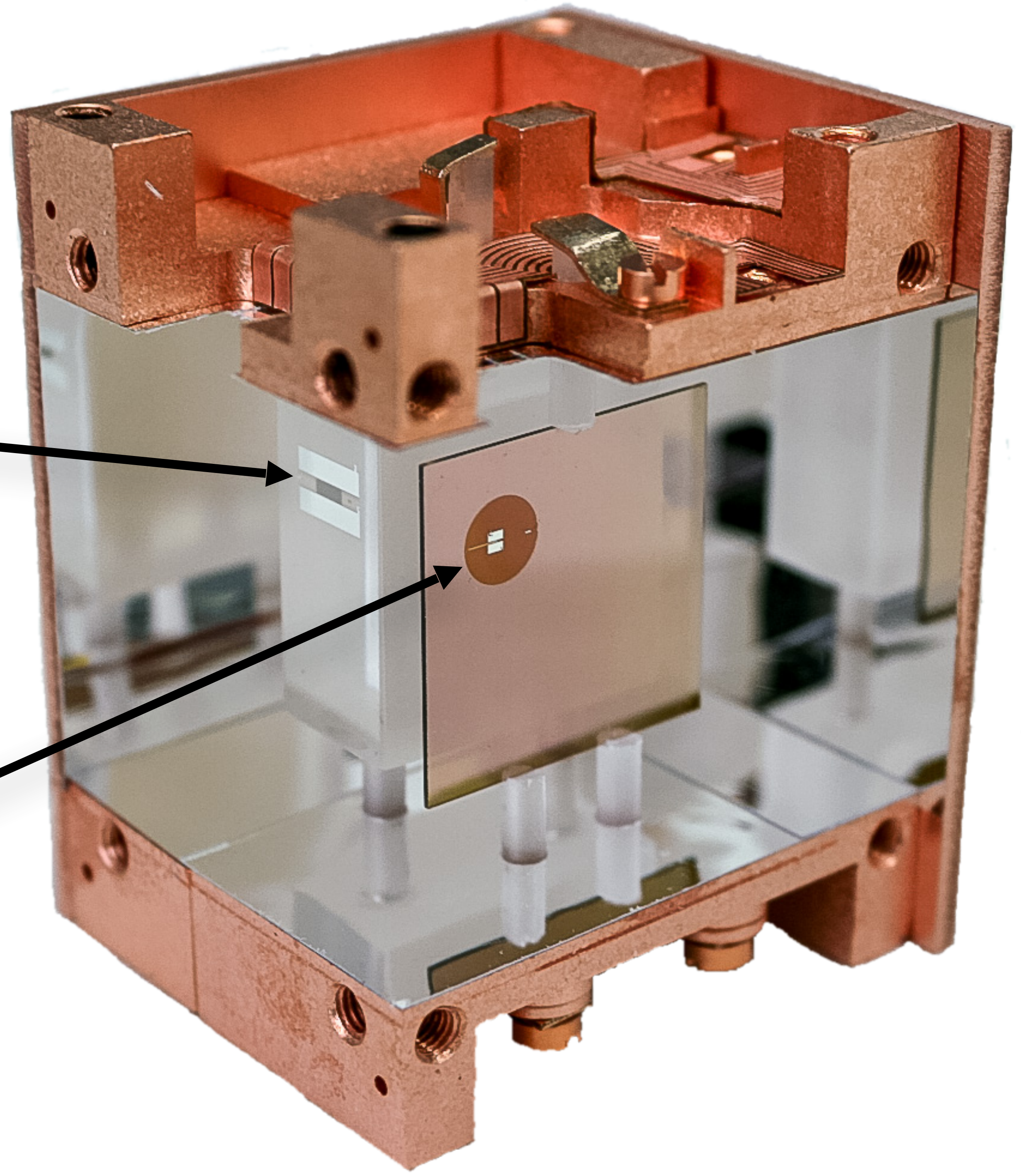


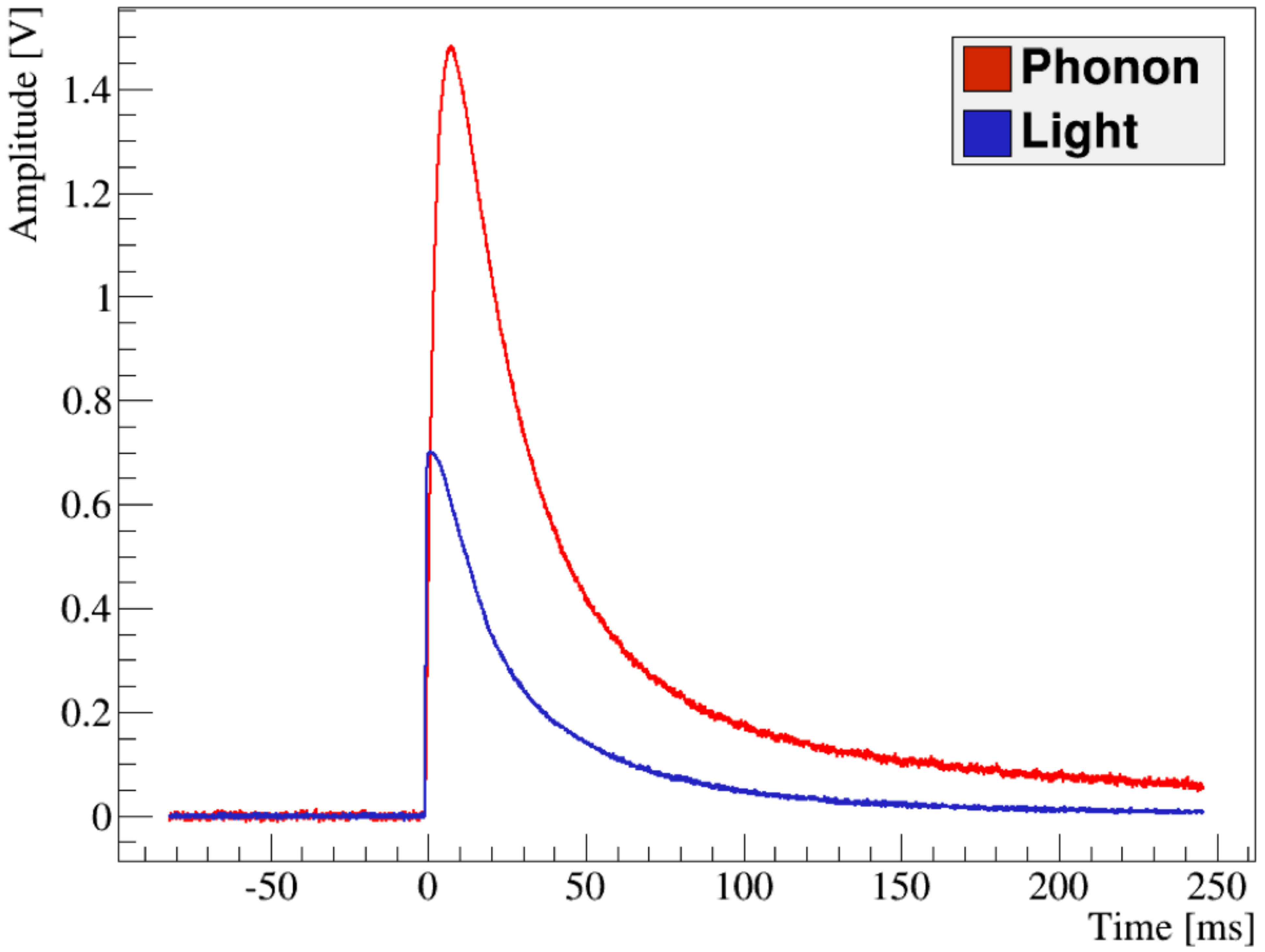
CRESST goal: direct detection of dark matter particles via their scattering off target nuclei in cryogenic detectors, operated at ~15 mK

CRESST-III detectors are optimised for low mass (< few GeV) DM searches

The CRESST-III detector module





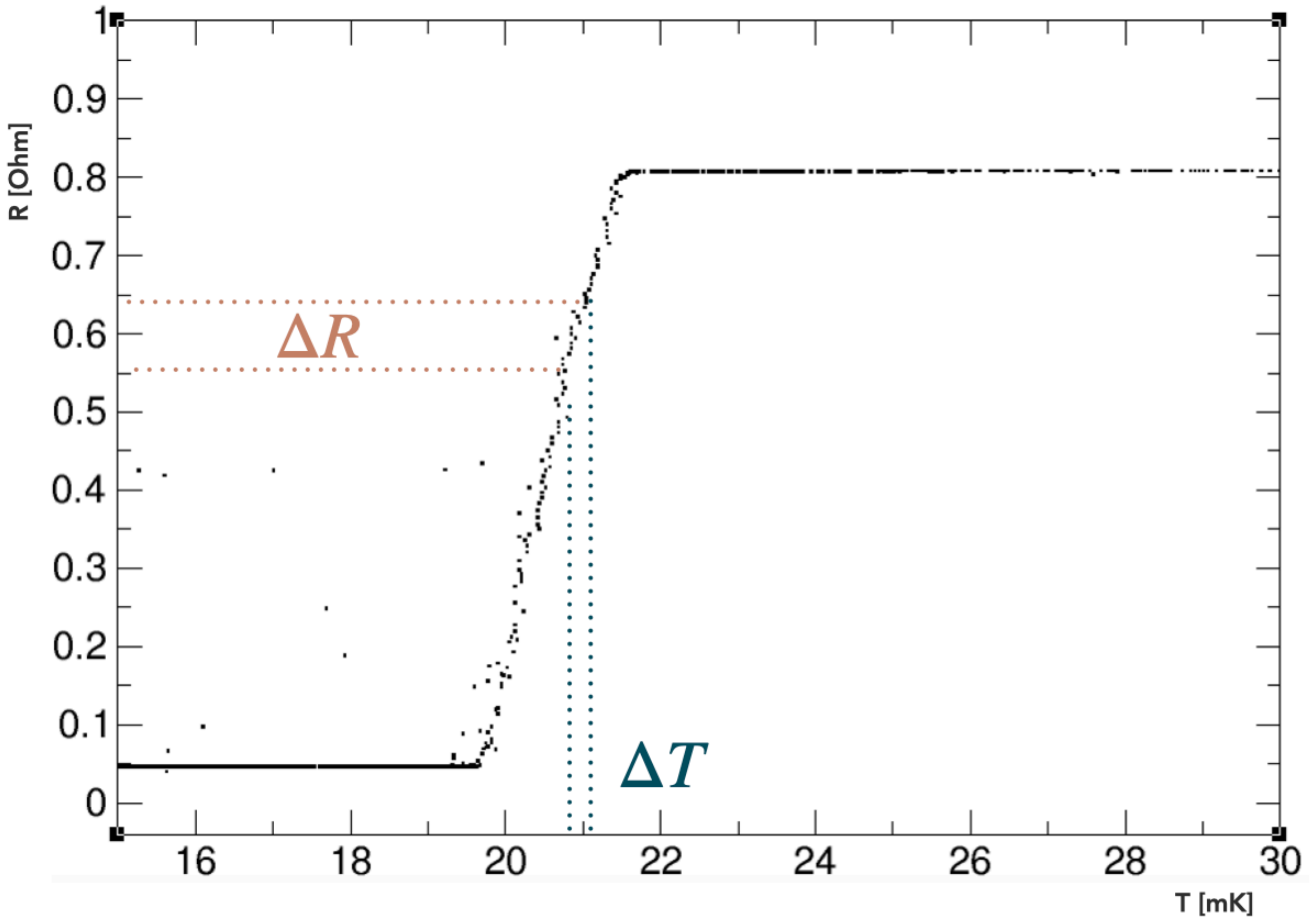


CRESST standard detectors are composed of a scintillating crystal as the main absorber, paired with a Silicon-on-Sapphire wafer as light detector.

- Phonon signal (>90%): precise measurement of the deposited energy, independently of the type of particle
- Light signal (few %): depends on the particle and on the type of recoil

Transition Edge Sensor

- Tungsten thin films operated in their superconducting transitions
- Energy deposits measured as variations in the sensor's temperature



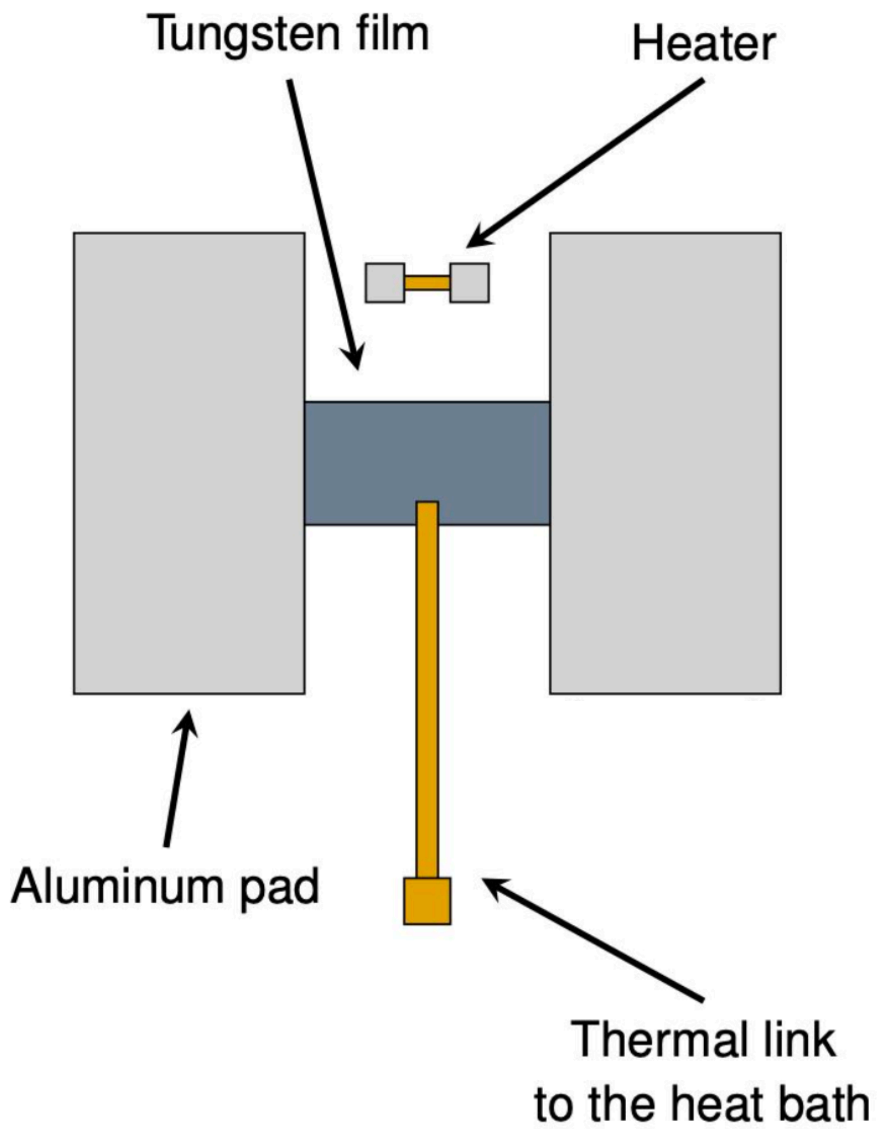
Energy Deposition $\sim keV$

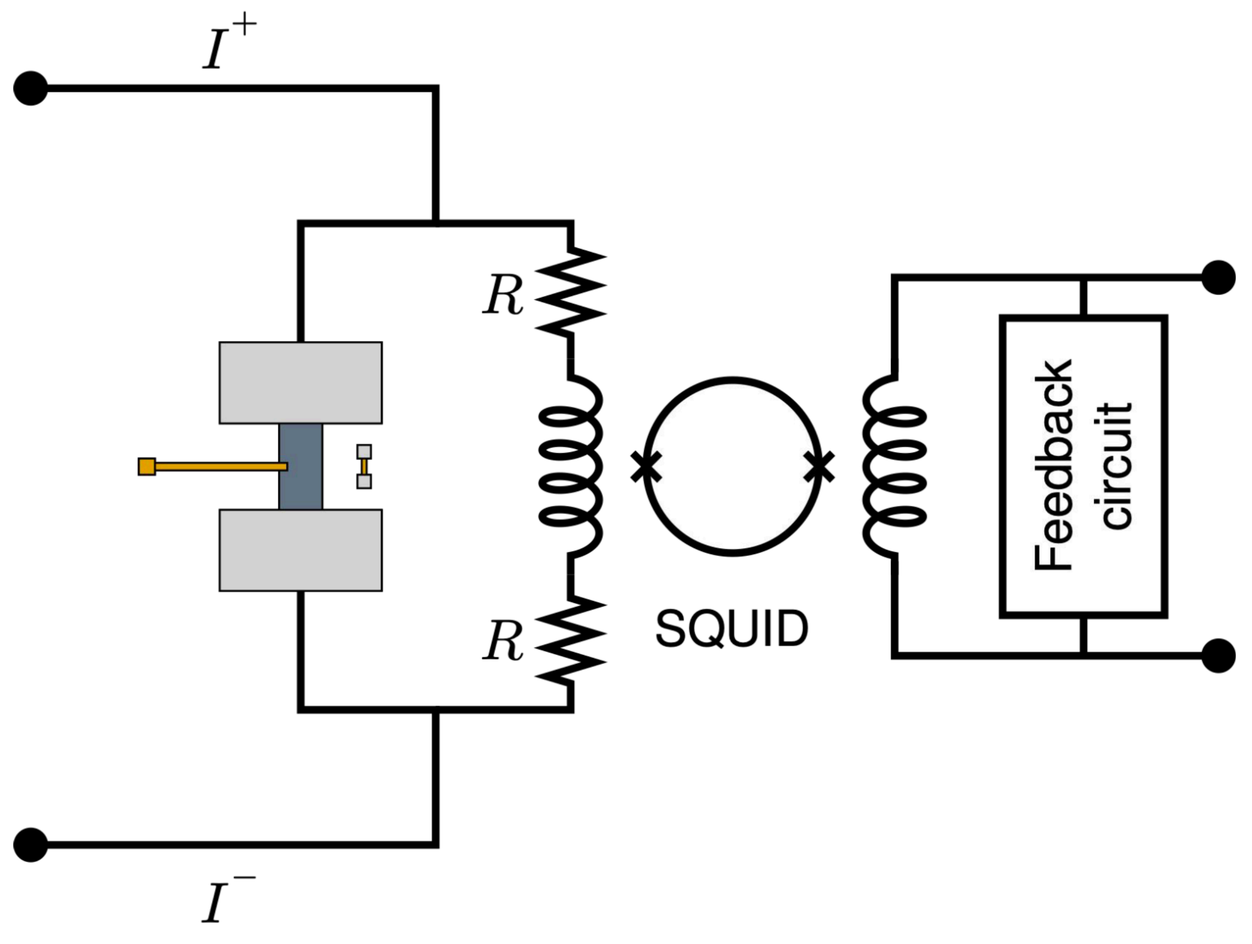
↓

Temperature Rise $\sim \mu K$

↓

Resistance change $\sim m\Omega$

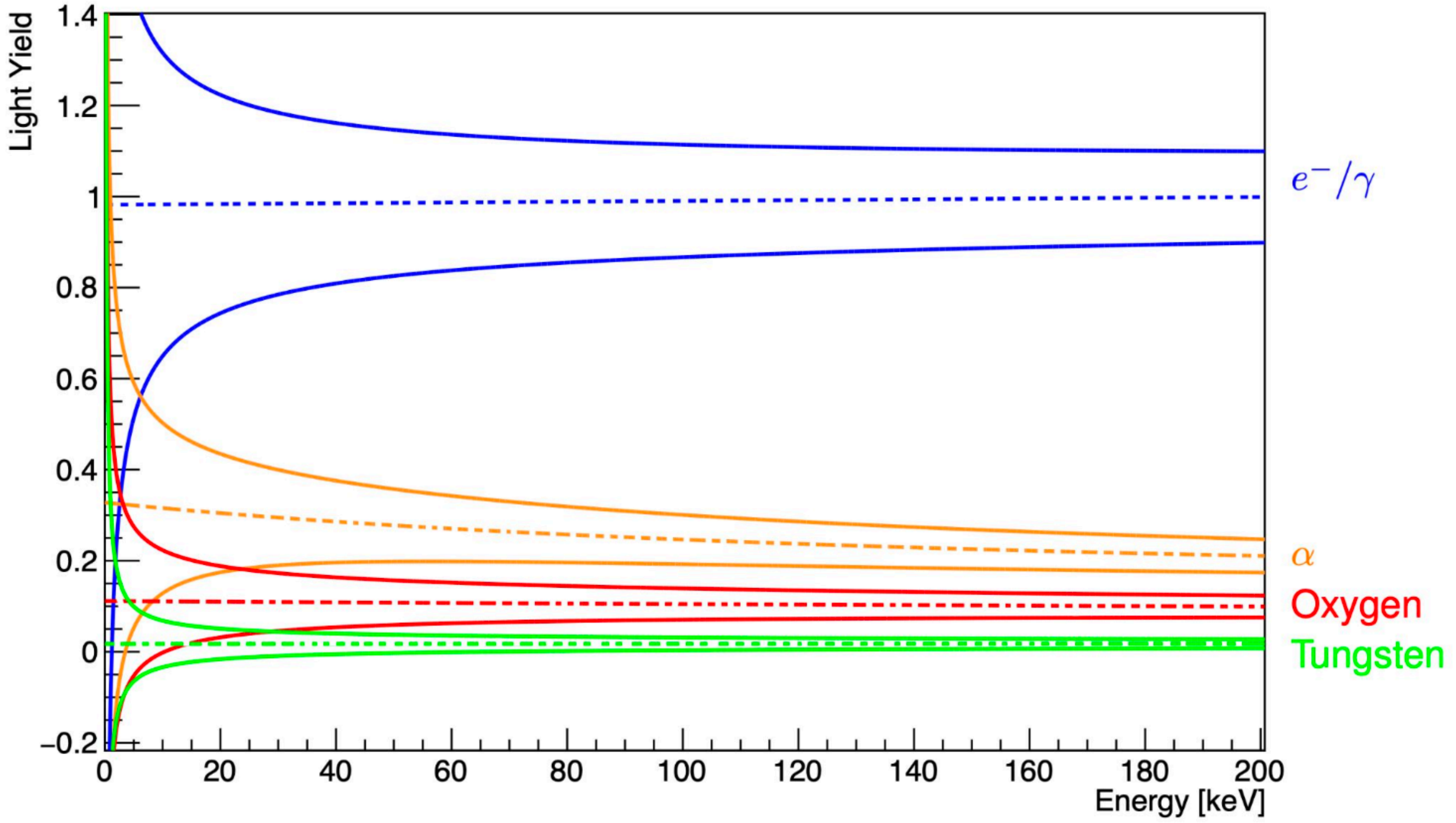




Particle discrimnation

The double readout of light and phonon signals allows for separating potential signal events (**nuclear recoils**) and the dominant radioactive background (**electron recoils**) and defining different bands.

$$LY = \frac{\text{Light signal}}{\text{Phonon signal}}$$



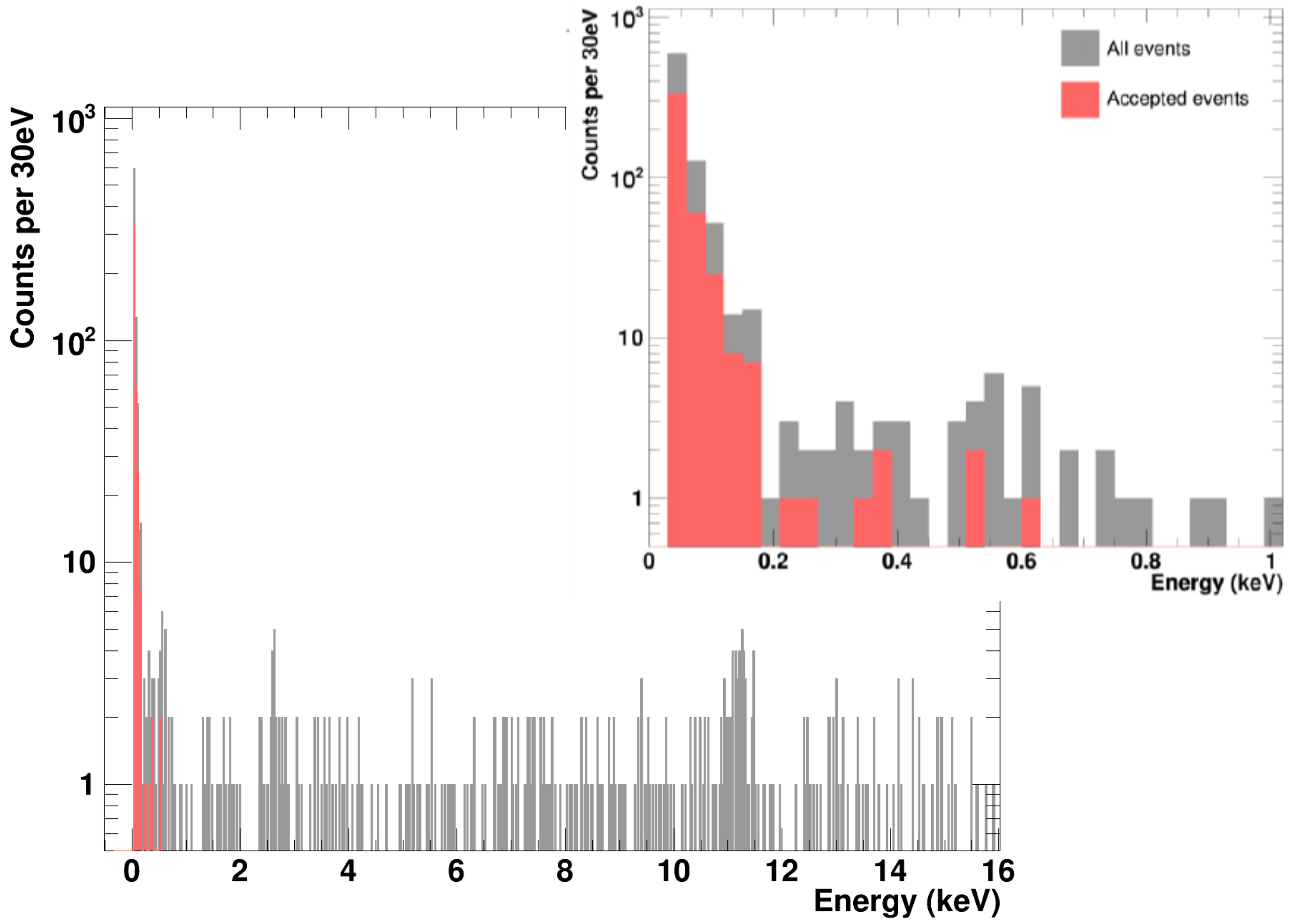
CRESST-III: First LEE Observation

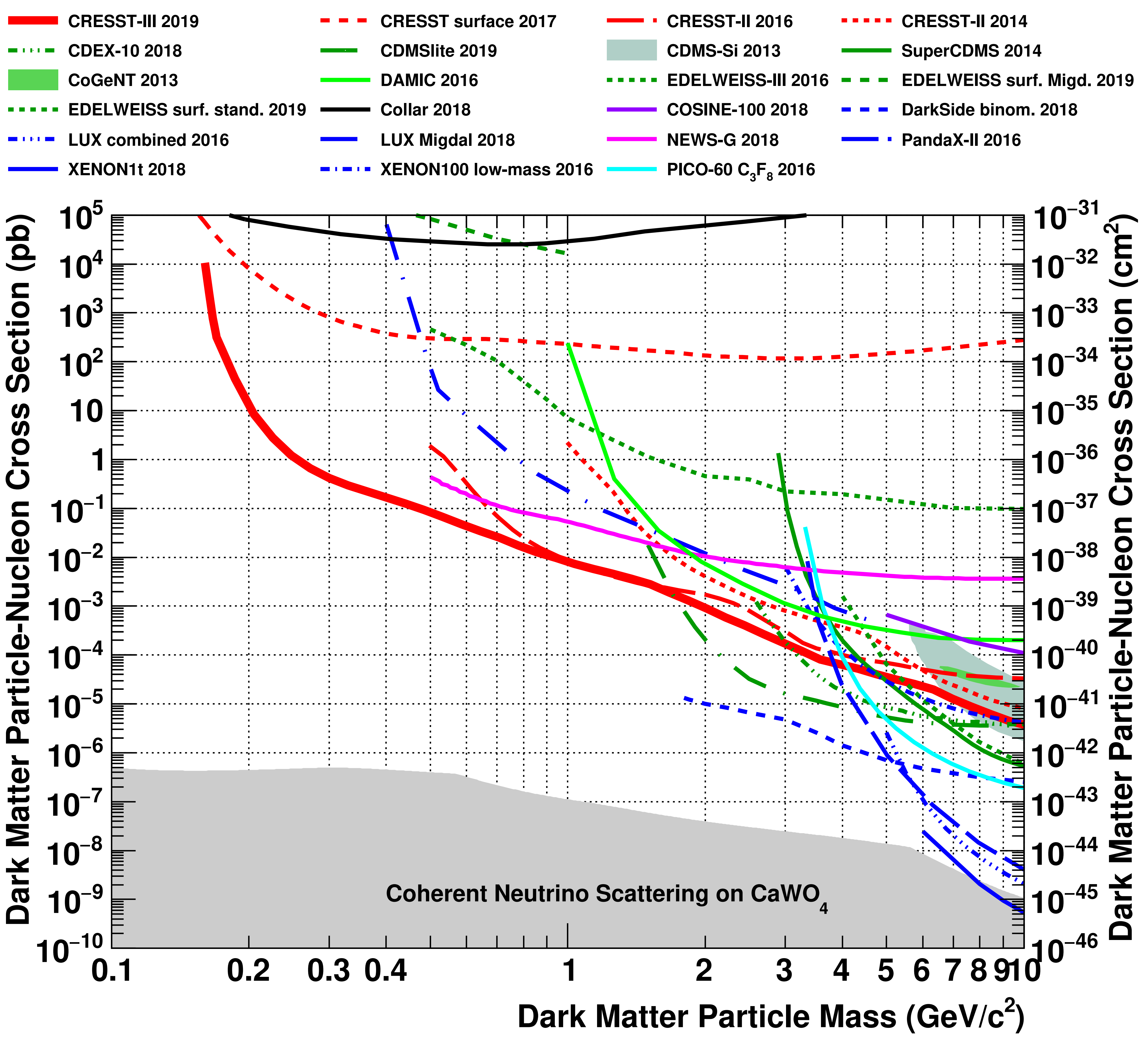
- Spin independent limit with Detector A

Crystal: 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

First Observation of a Low Energy Excess (LEE):

- Rise of particle-like events at energies below 200 eV
- Observed in multiple detector modules





Phys. Rev. D 100, 102002 (2019) / arXiv: 1904.00498

S

- Idea: Instrument the absorber with two TES
  - If the signal is originated in the absorber the two TES will show the same response
  - If the signal is originated in or close to the sensor, the two response signals will be different
- Currently installed in CRESST setup

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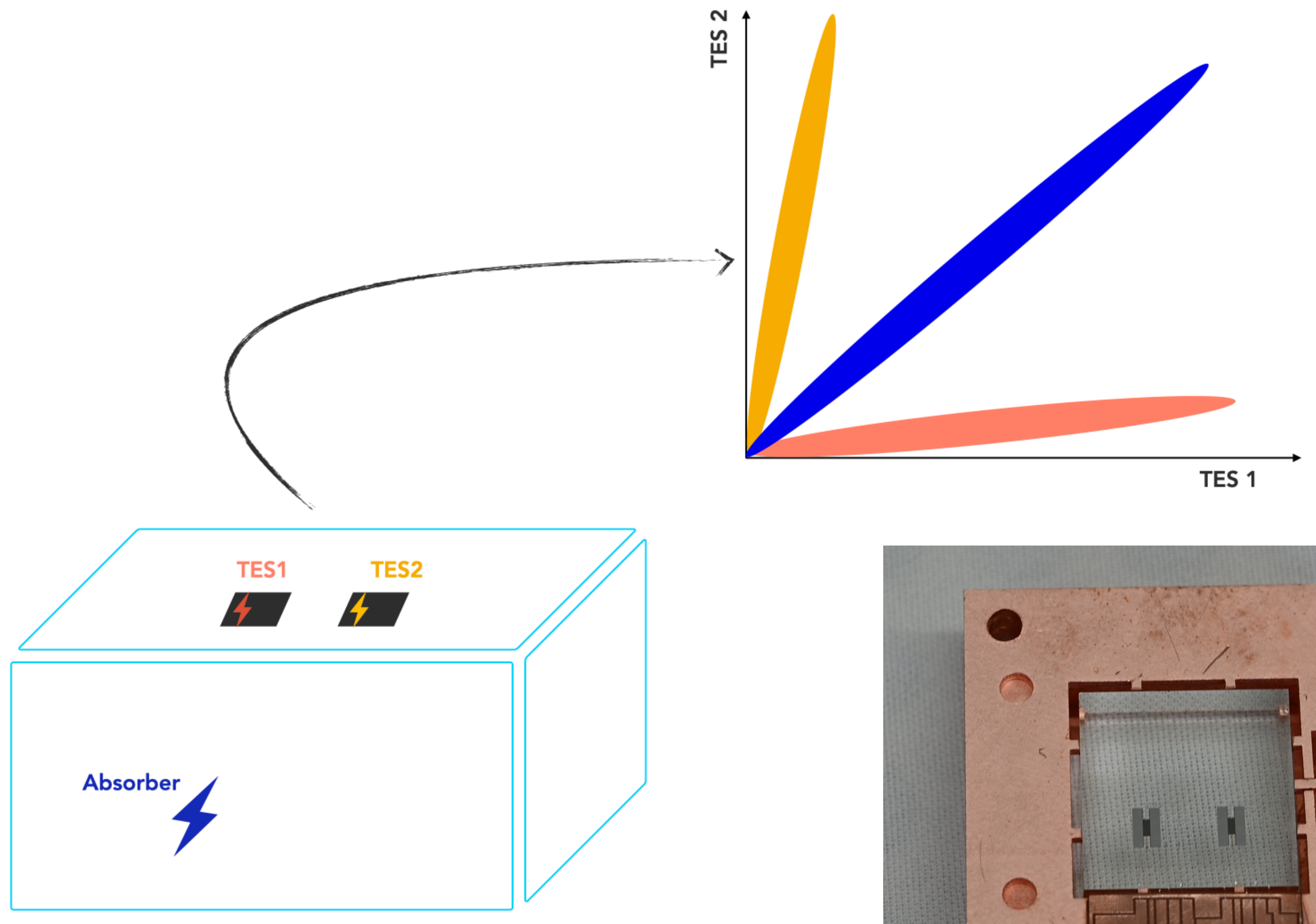
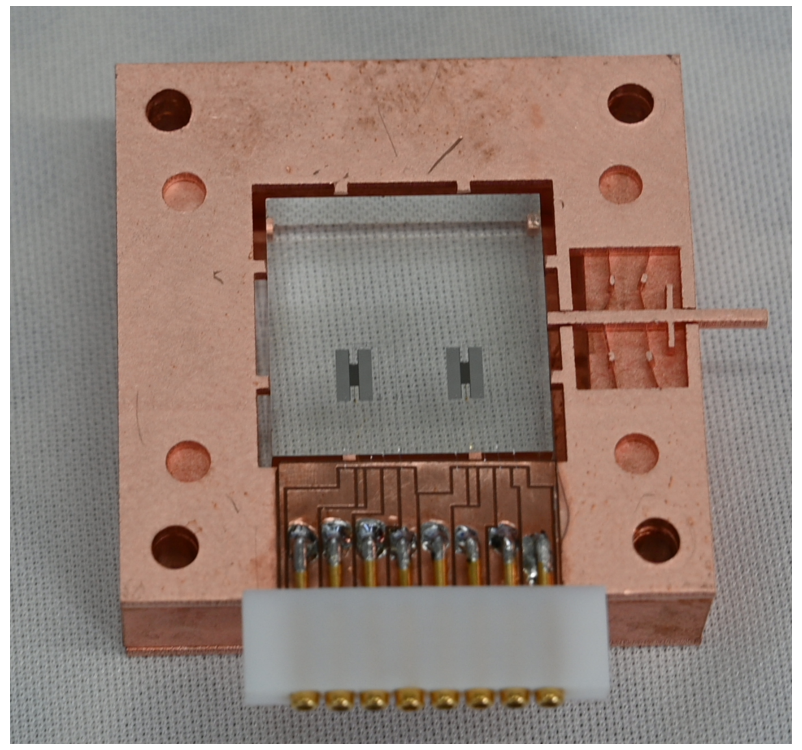
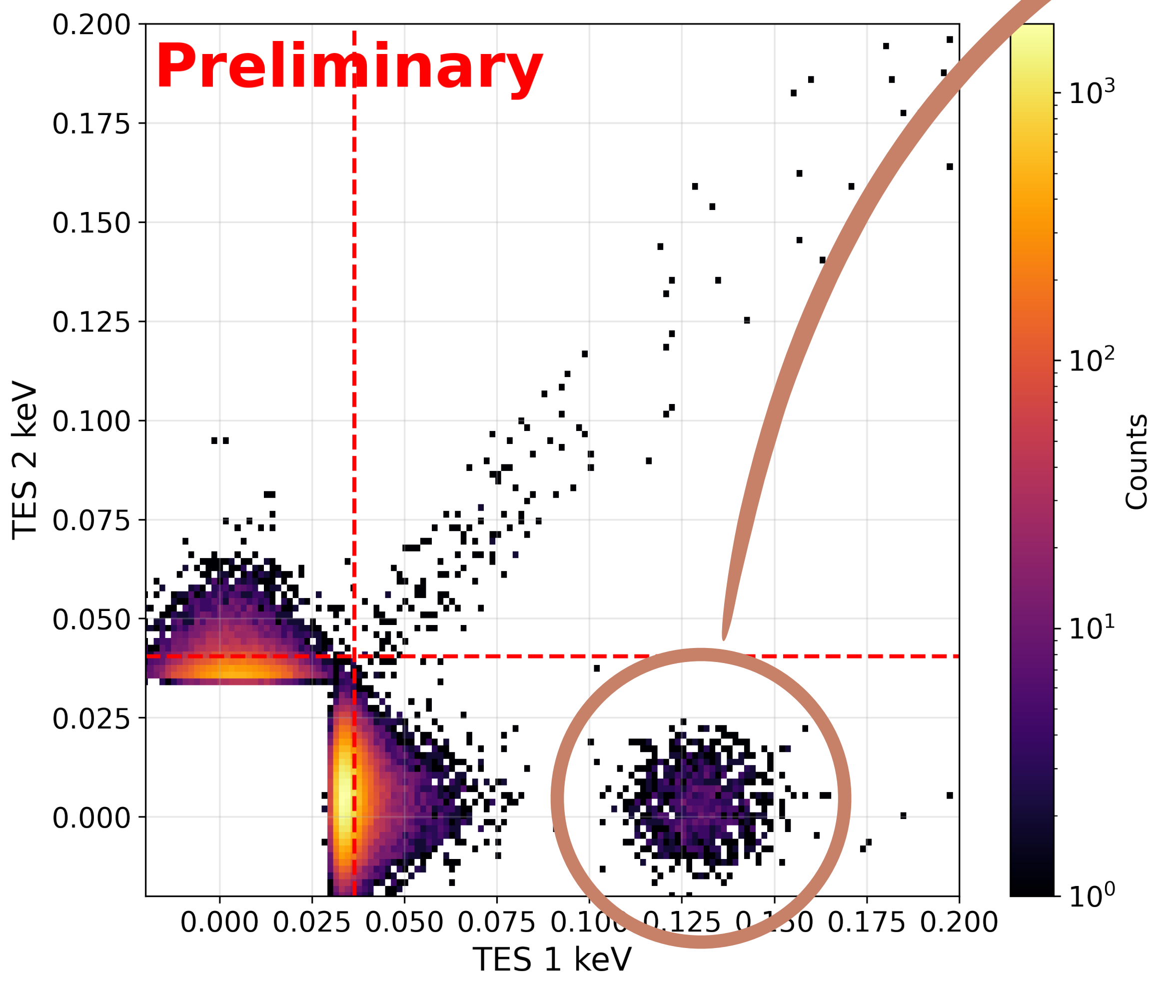
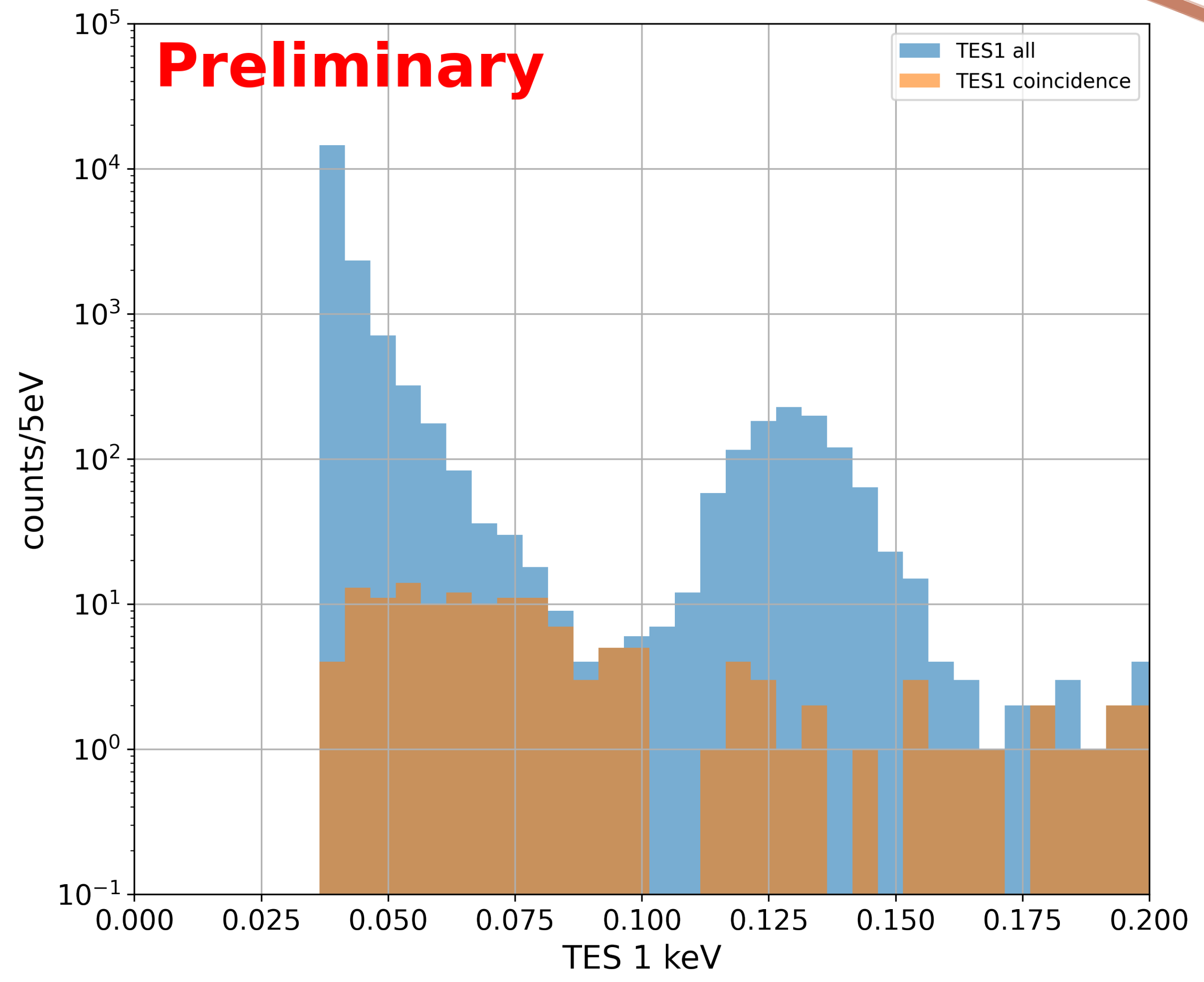
10.1140/epjc/s10052-024-13282-8

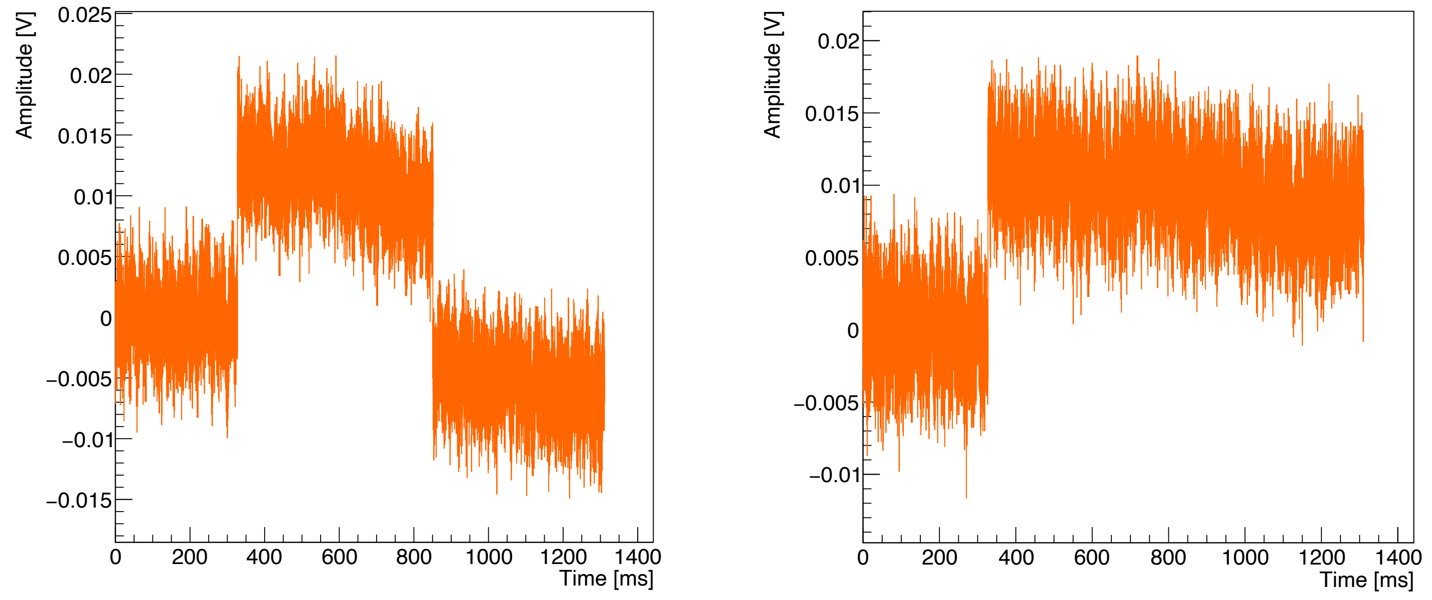




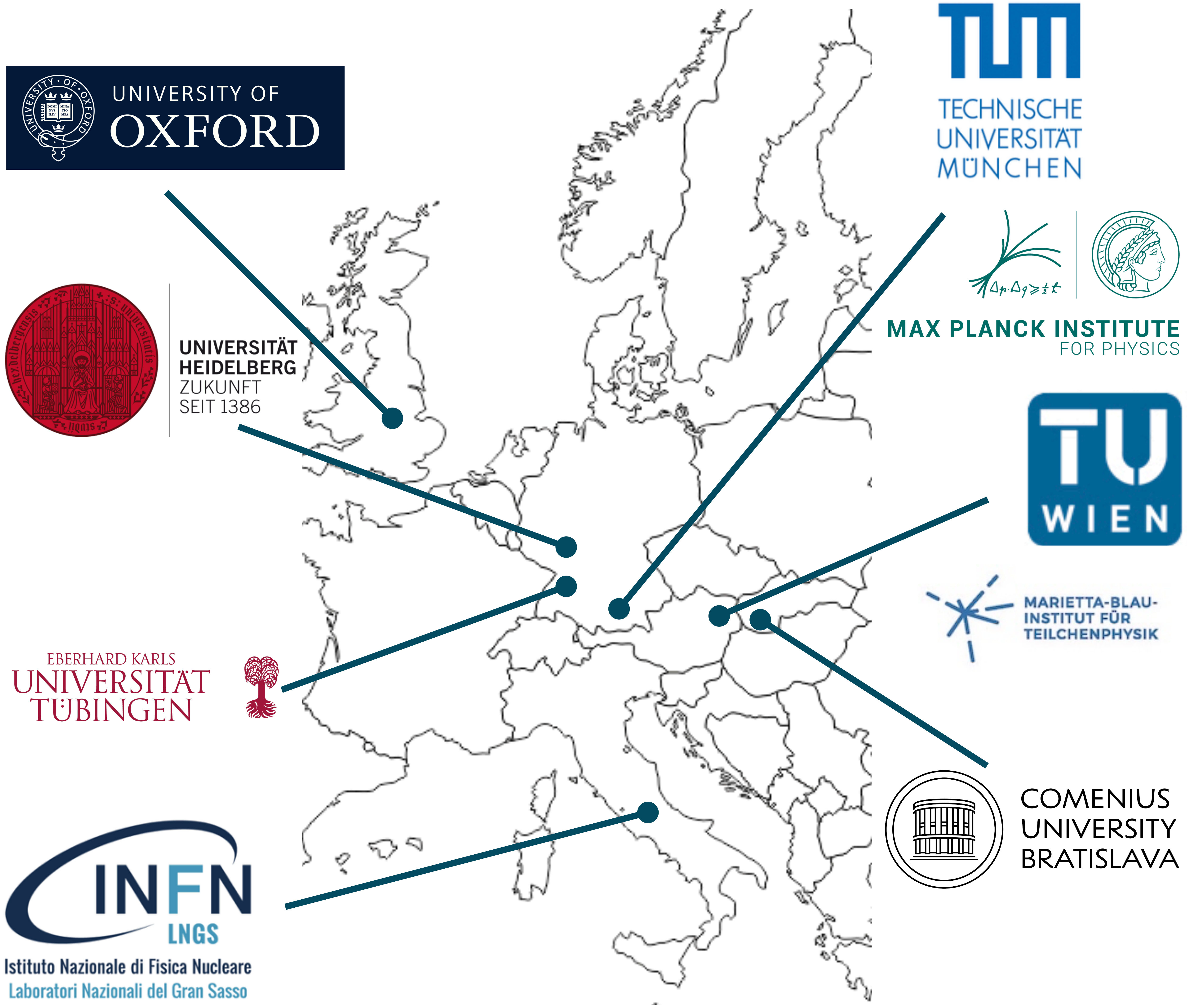




DoubleTES is also very effective in removing electronics artefacts



The CRESST collaboration



~55 people from 9 different institutes in Europe

In the next few years, the CRESST experiment will further push its sensitivity to dark matter, increasing its sensitivity (with R&D studies) and exposure (with the upcoming CRESST upgrade).

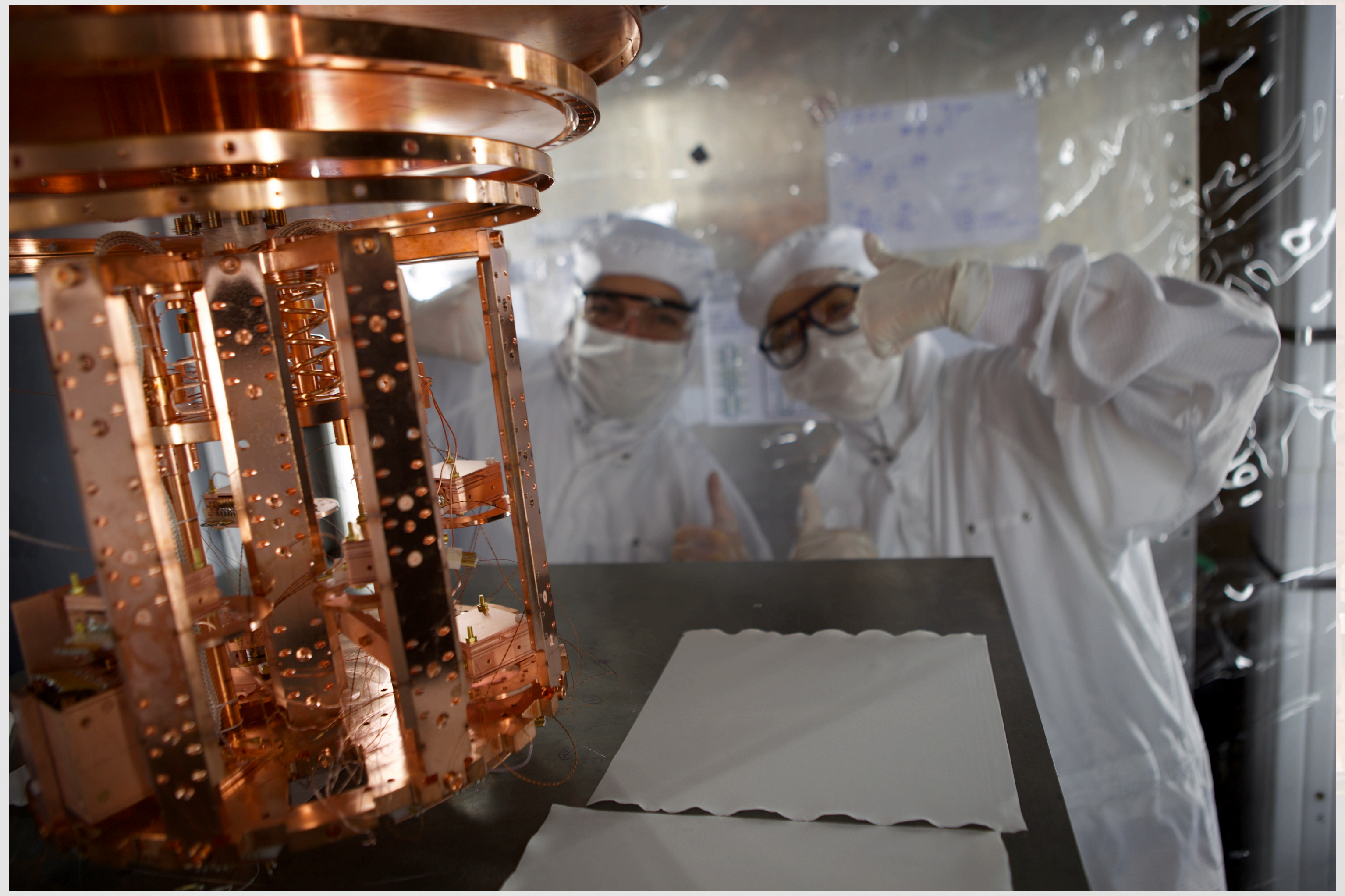
Hardware:

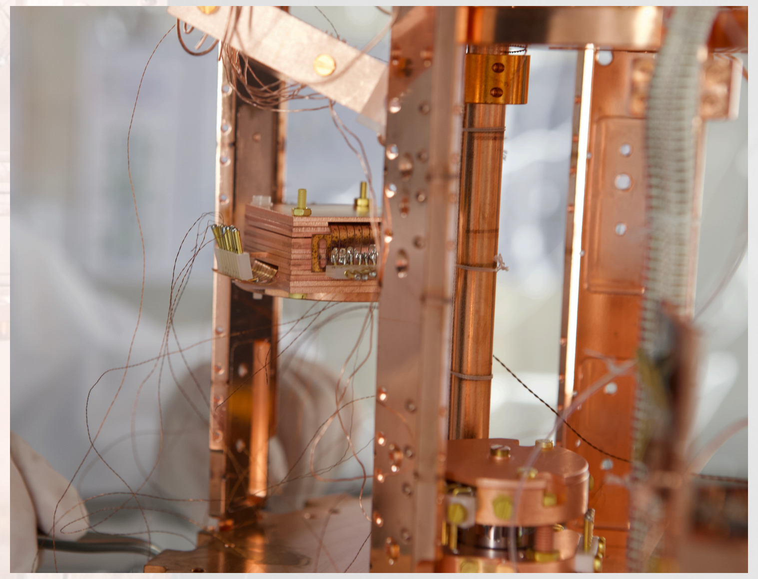
- Development and test of innovative dark matter detectors
- Studies of the TES design to improve performance and increase sensitivity
- Identification of the Low Energy Excess
- Upgrade of the cryogenic facility

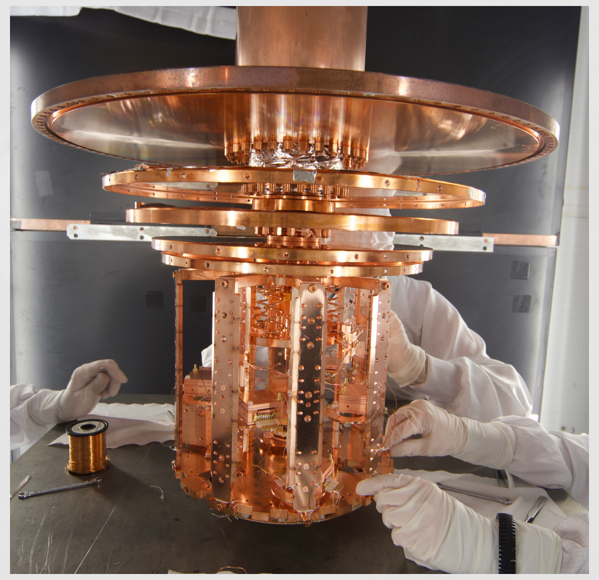
Software:

- Dark matter analysis (standard & non-standard)
- Other rare events analysis
- Studies of the LEE
- Upgrade of the analysis framework

Thank you for your attention







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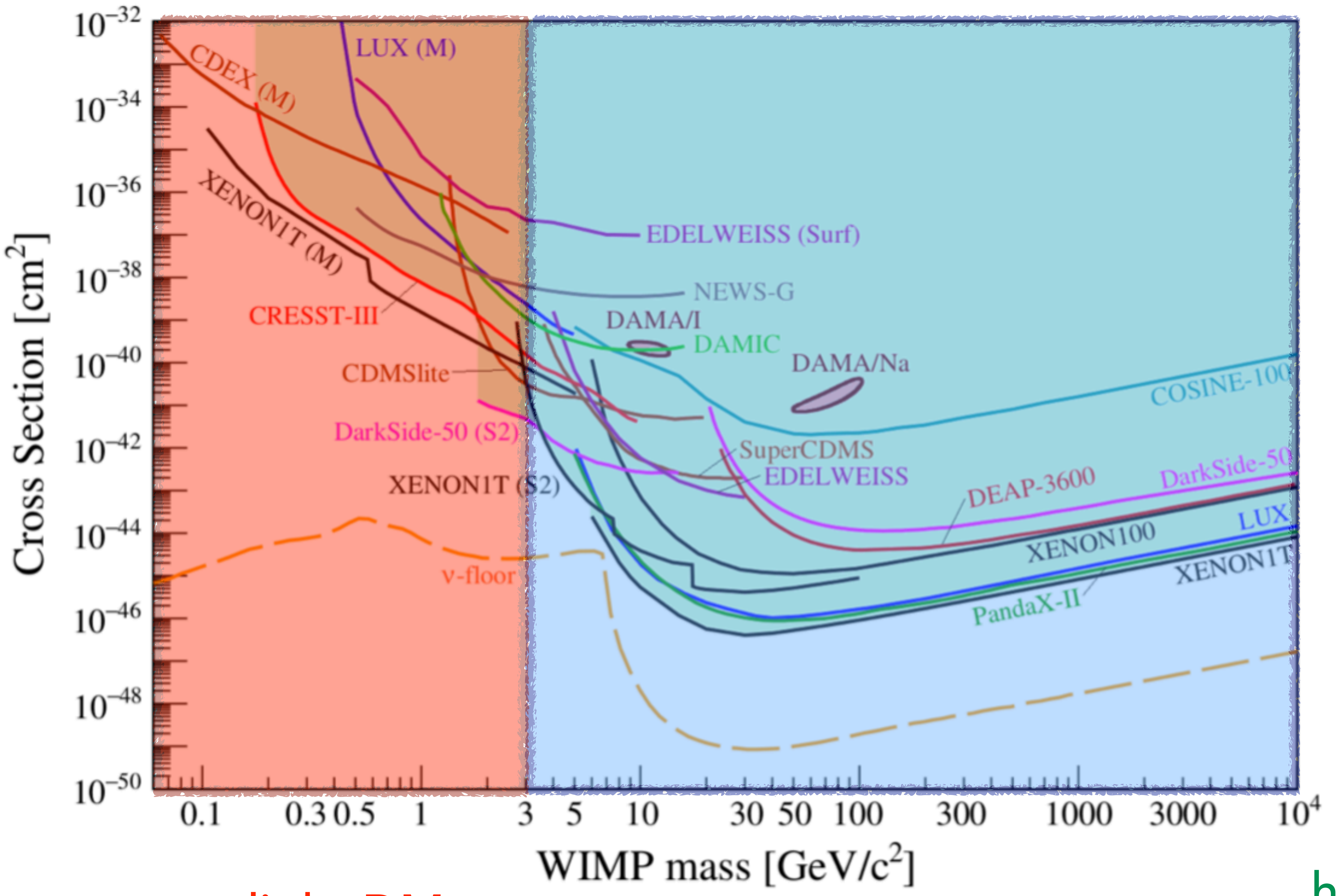
Backup slides

Light DM search



There is no official definition of light-DM, usually we refer to < few GeV/c²

. . .

ultralight DM
<0.1 GeV/c²

Axions$_{QCD}$ peV/c²<m$_a$<meV/c²

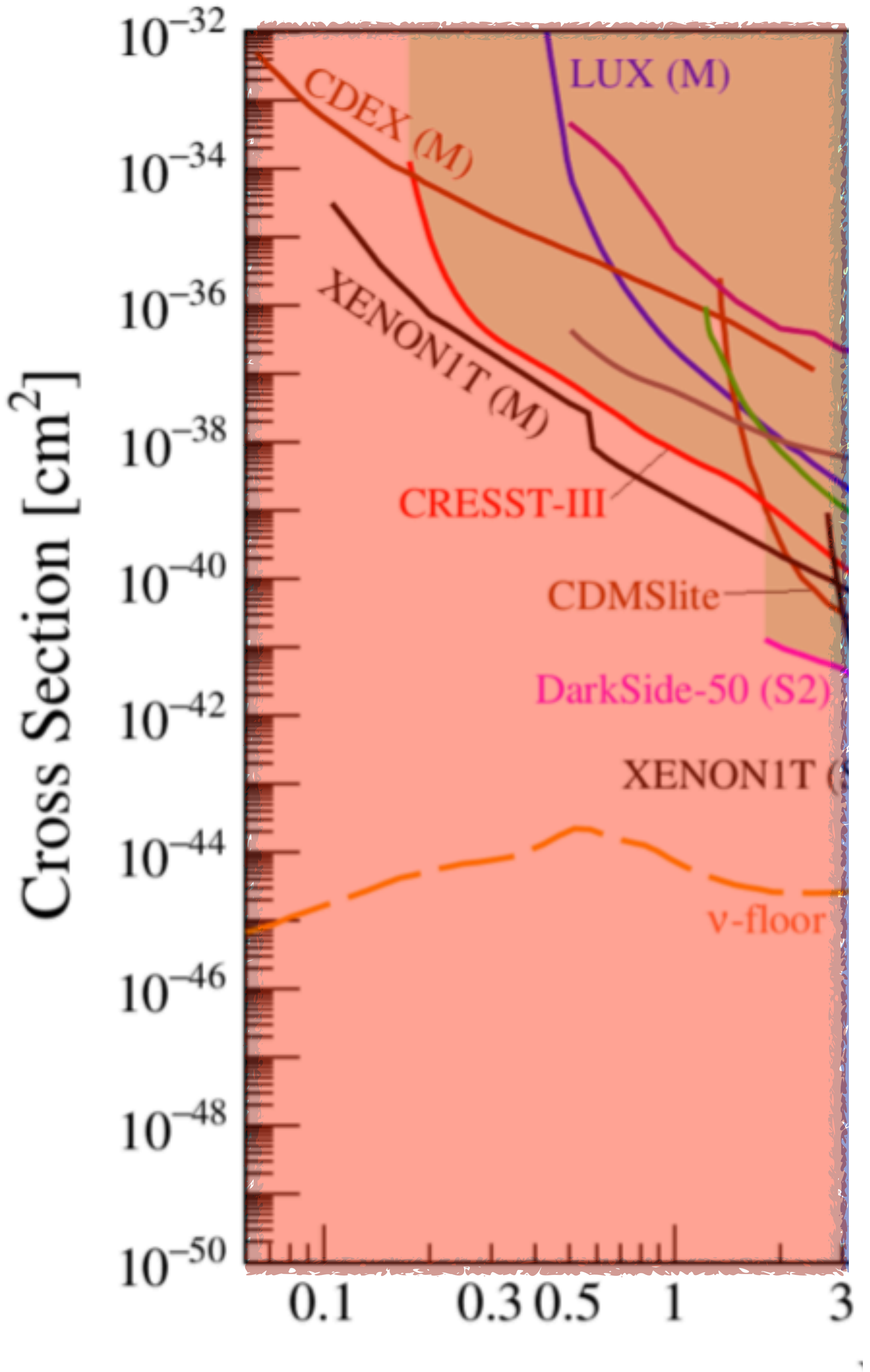
light DM
0.01< m_{DM} < 3 GeV/c²

WIMPs
> 3 GeV/c²

. . .

heavy/superheavy DM
—> PeV/c²

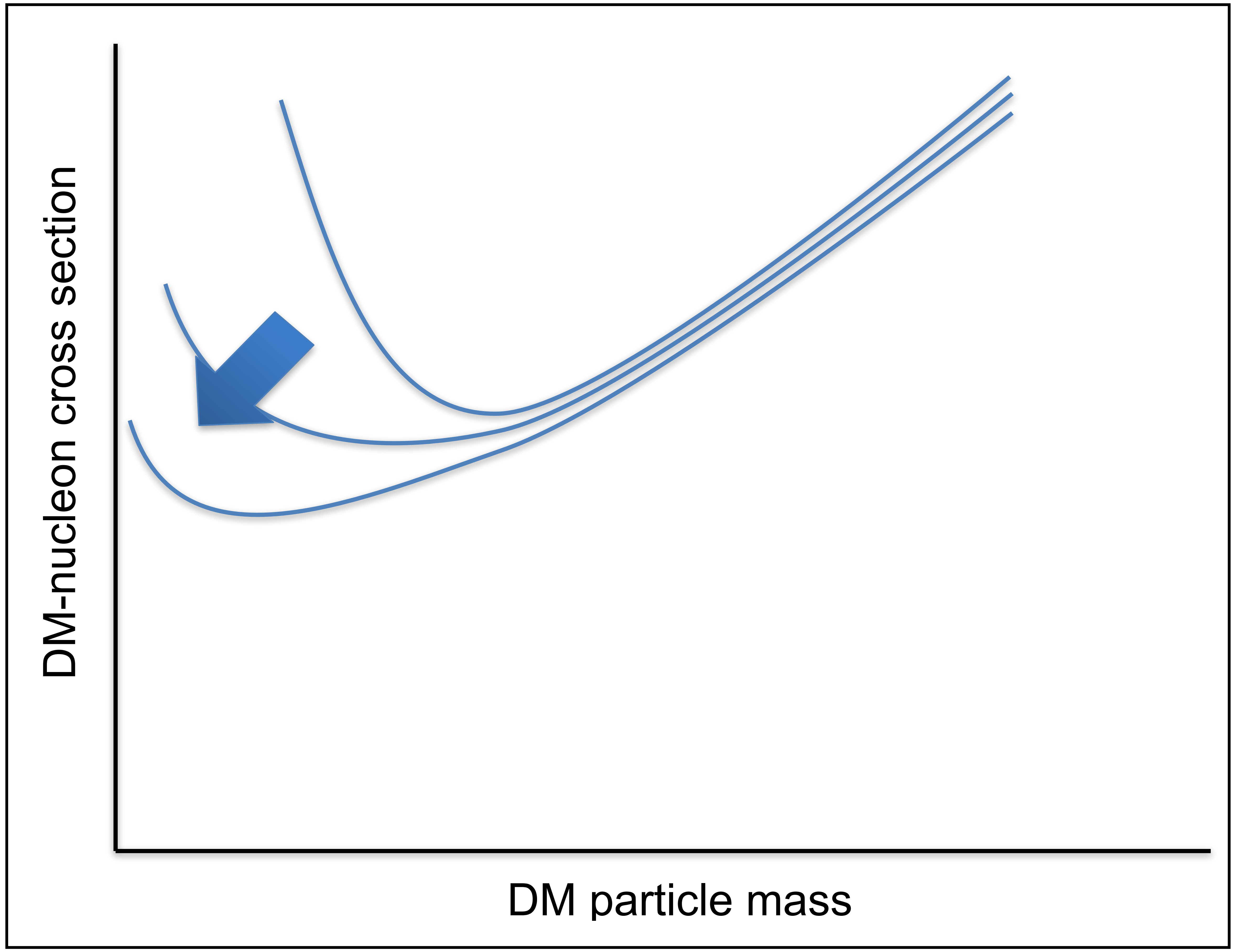
Light DM search



light DM

$0.01 < m_{DM} < 3\ GeV/c^2$

At light DM masses, sensitivity is dominated by performances (energy threshold)



CRESST-III Dark Matter Results

Dark matter limit using light detector as main absorber

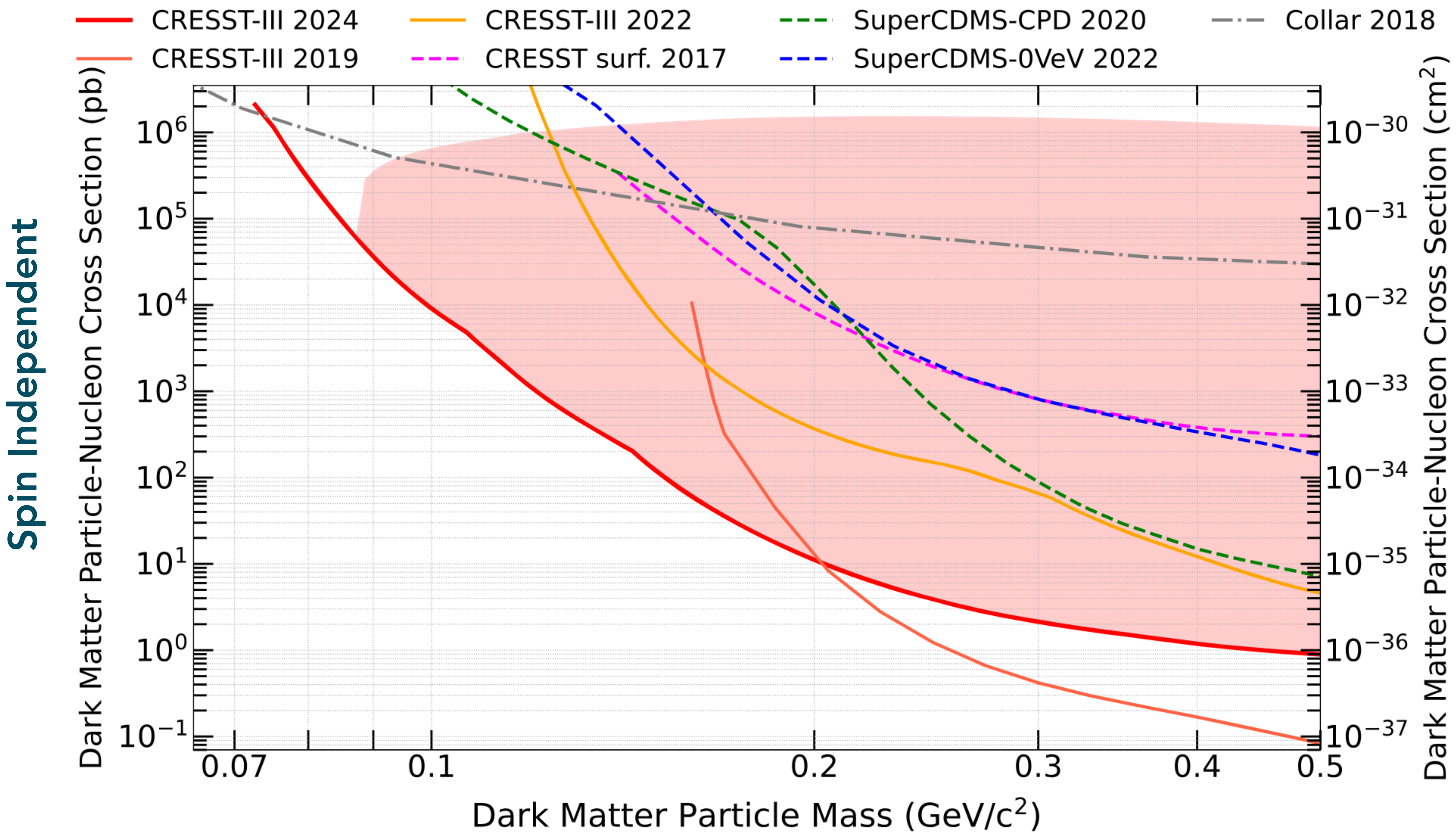
Crystal: 0.6 g Al_2O_3

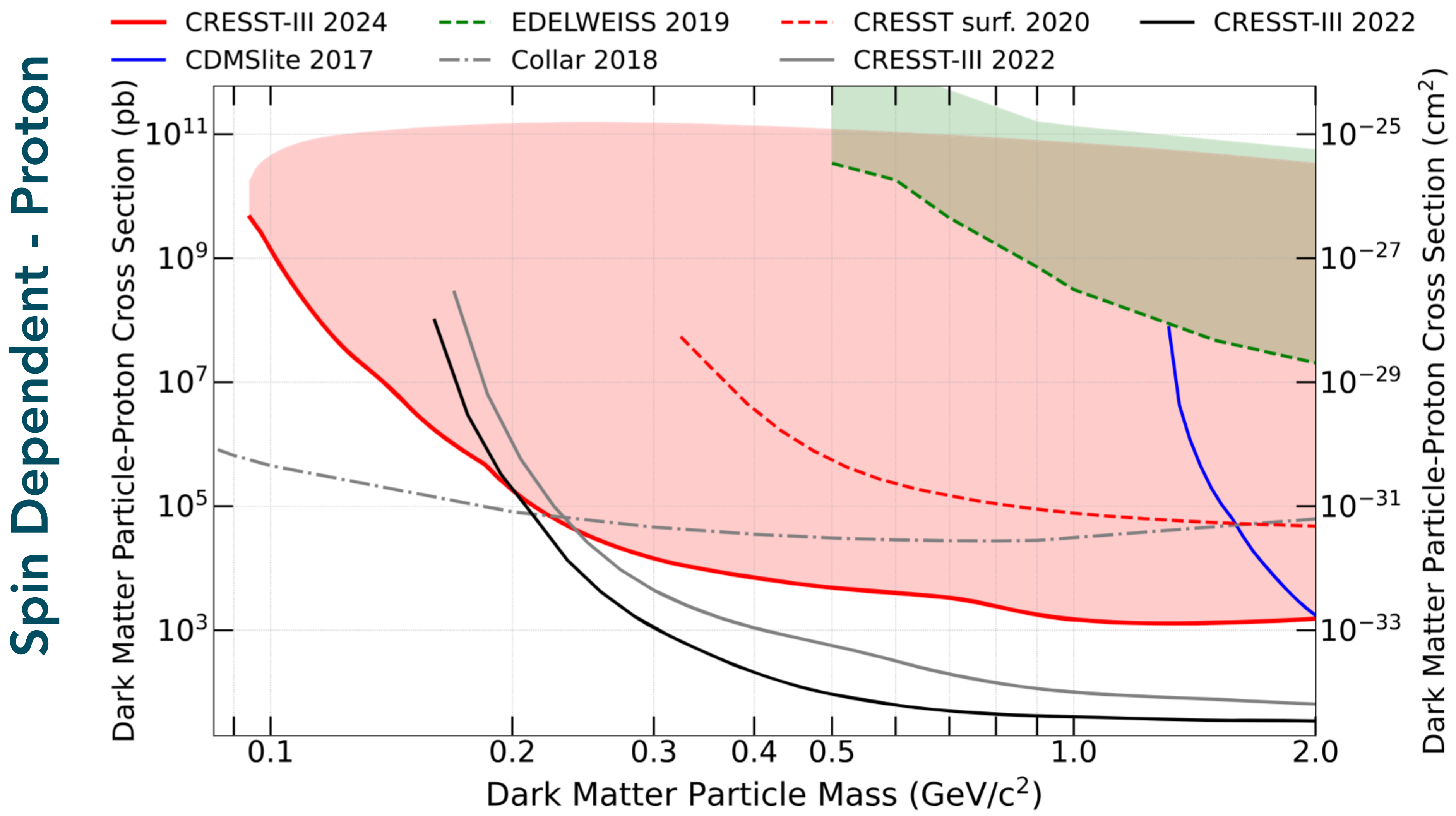
Data Taking period: Nov. 2020 - Aug. 2021

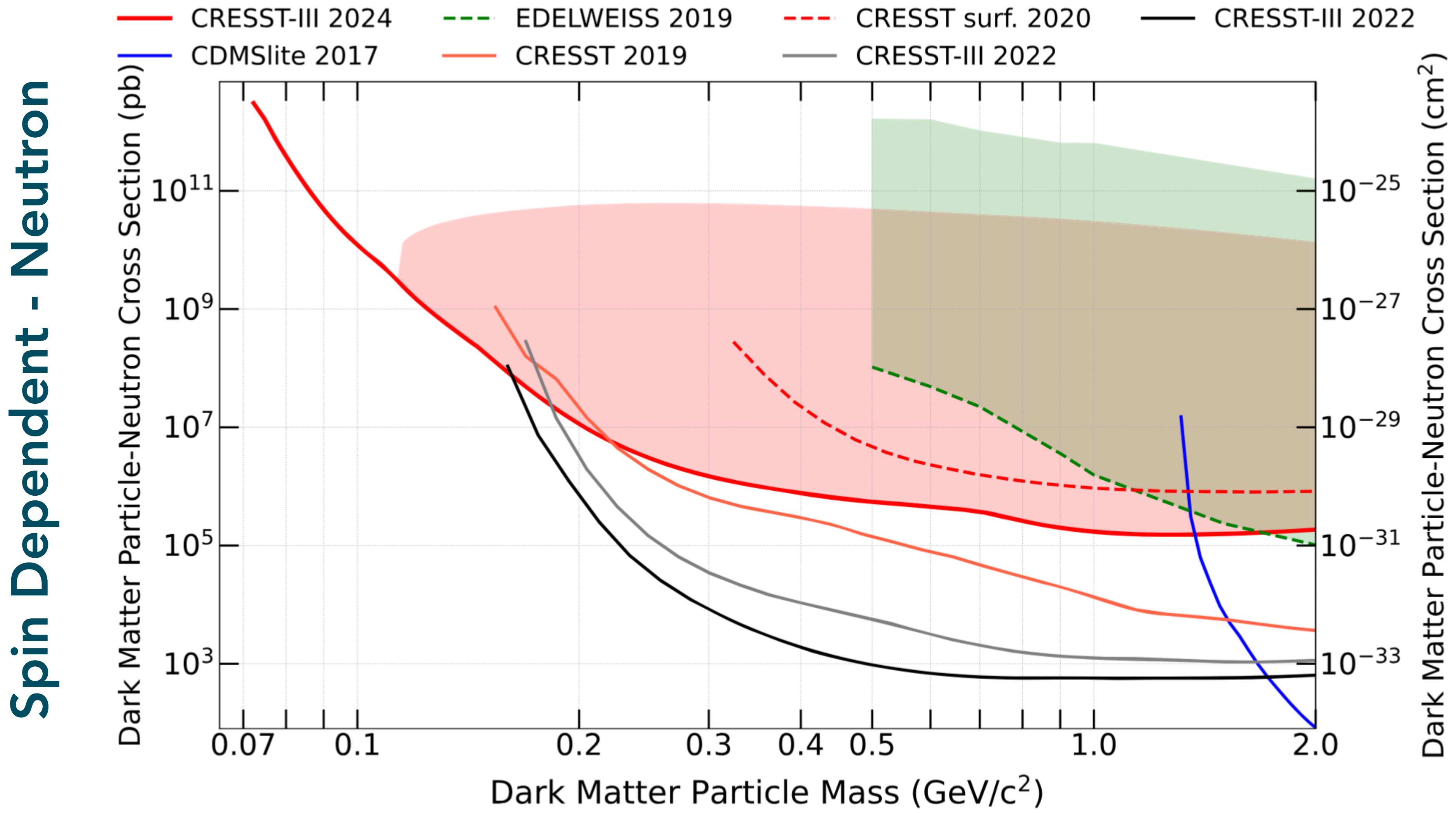
Exposure: 138 g·days

Baseline Resolution: 1.0 eV

Nuclear recoil threshold: 6.7eV







10.1103/PhysRevD.110.083038

CRESST-III: New Calibration Methods

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

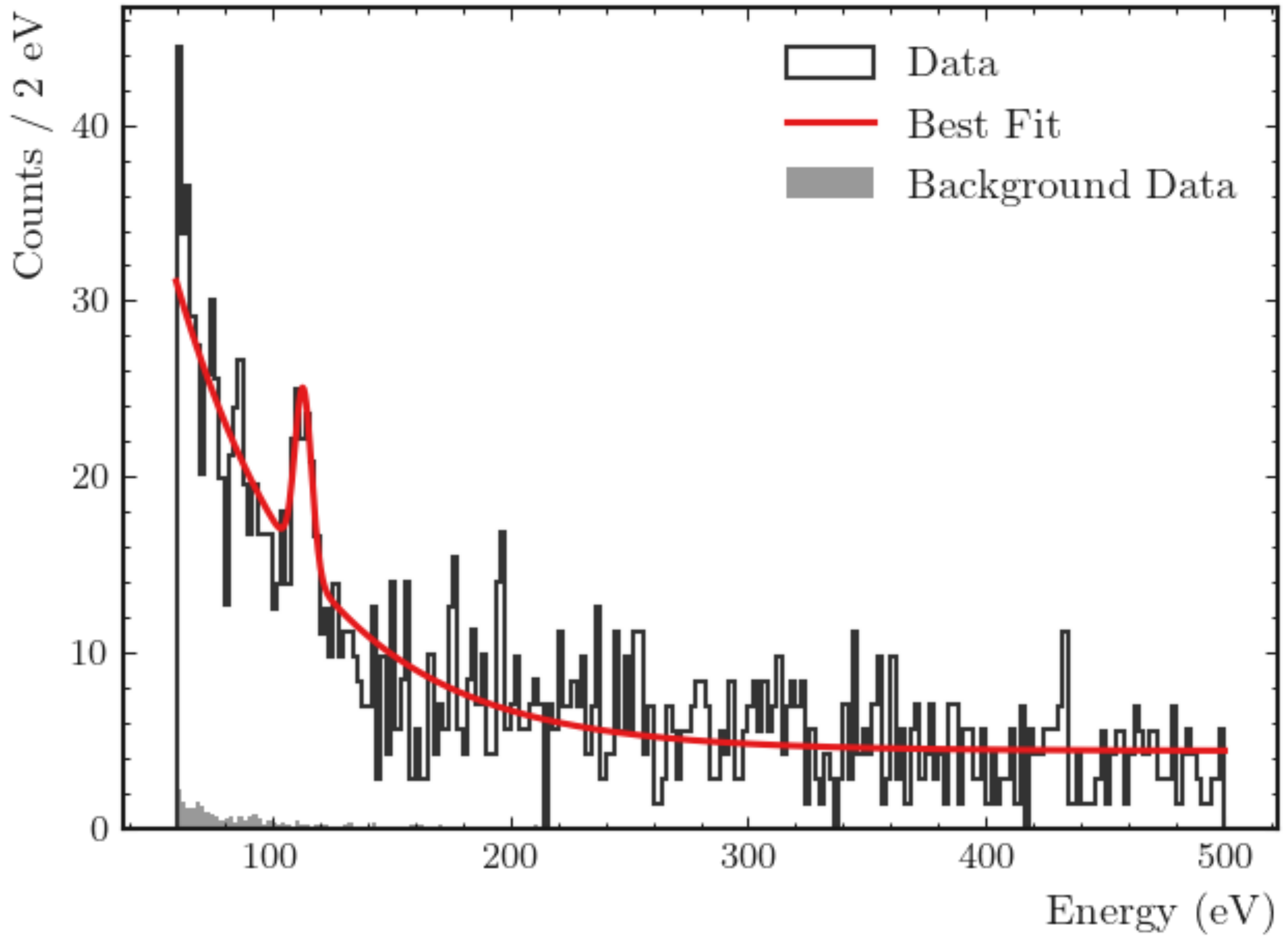
CRAB Collaboration 2021 JINST 16 P07032

$CaWO_4$

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

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

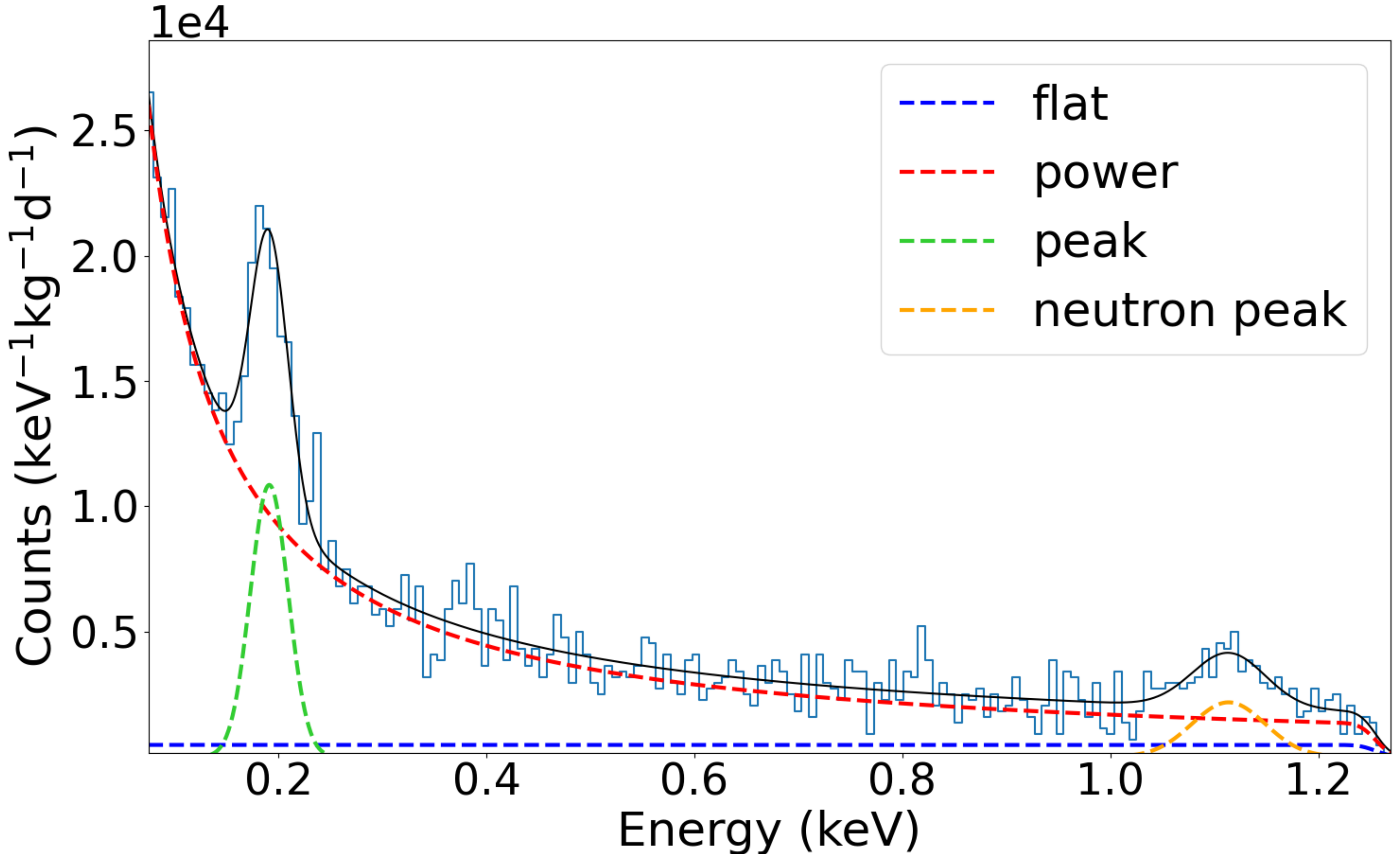
Phys. Rev. D 108, 022005



Al_2O_3

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

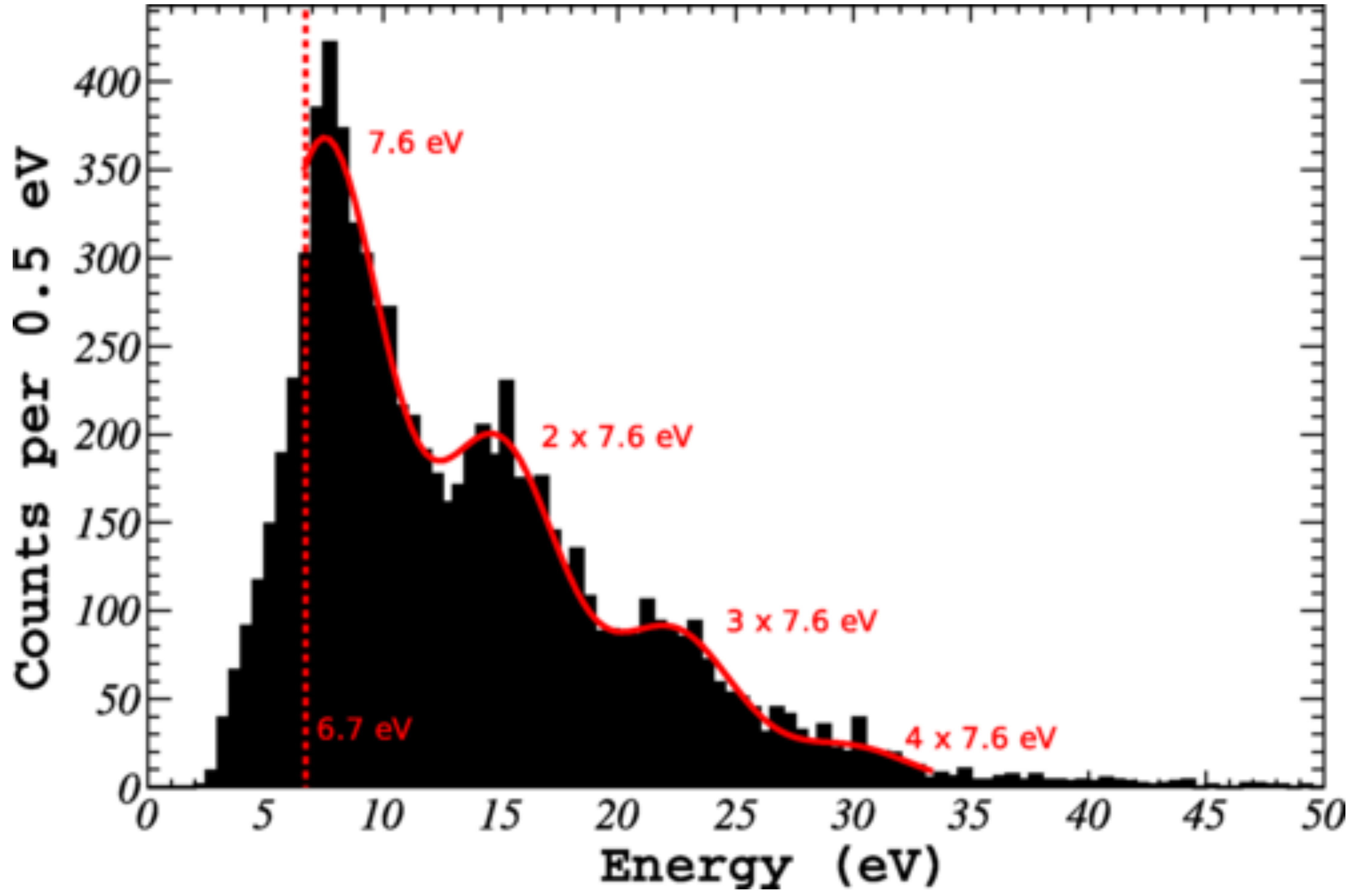
De-excitation γ of 7.7 MeV
and Al nuclear recoil of 1144 eV



Phys. Rev. D 112, 102008

CRESST-III: New Calibration Methods

- Ultra-pure sapphire crystals emit luminescence at 7.6 eV via radiative decay of excitons
- High energy deposition → multiplication of electronic excitations → creation of multiple luminescence photons
- Process is fast → various photons detected as a single event with multiple of single photon energy
- Validation of calibration performed with ^{55}Fe source (5.9 and 6.5 keV) down to threshold
- First measurement of single photons in CRESST



Phys. Rev. D 110, 083038

LEE Investigation

- Understanding & mitigating LEE fundamental to improve CRESST DM sensitivity
- Several modifications to CRESST-III design to investigate different hypotheses on the LEE origin:

Different target materials tested
- Material dependence
- Stress induced by holder

Tested slow grown crystals
- Internal stress
- Scintillation light

LD analysed as target crystals
- Detector geometry

Holding scheme modified

Removed all scintillating parts