CRESST-III and the quest of the Low Energy Excess

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The CRESST collaboration

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

Is a **direct detection of Dark Matter** experiment

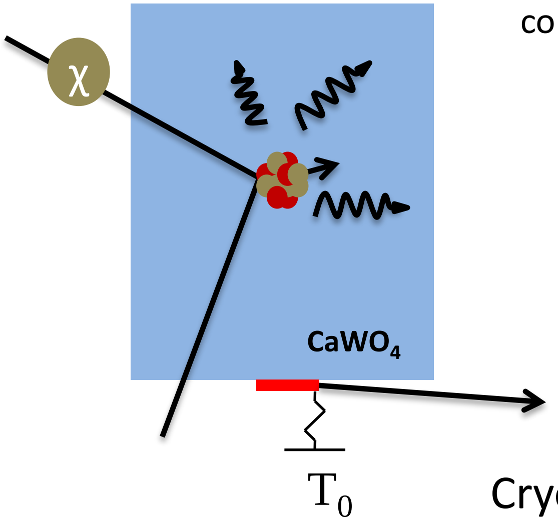
The CRESST strategy

The signature of dark matter in a direct detection experiment consists of a recoil spectrum of single scattering events.

$$\frac{dR}{dE}(E,t) = \boxed{\frac{\sigma_0}{m_\chi}} \cdot F^2 \cdot \frac{\rho_0}{2\mu_A^2} \int_{v_{min}}^{v_{esc}} \frac{f(\mathbf{v},t)}{v} d^3v$$

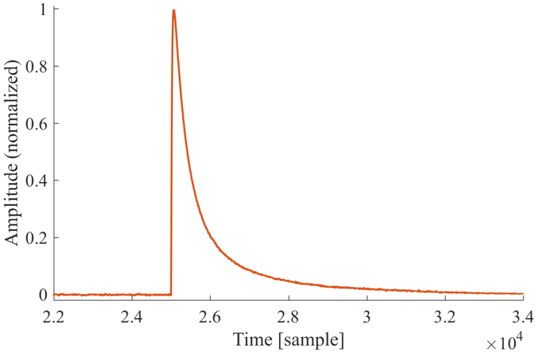
CRESST focused on achieving the best nuclear recoil threshold -> improve sensitivity

Cryogenic detector



- To an energy deposit in the target corresponds a proportional temperature rise

$$\Delta T(t) = \frac{\Delta E}{C} \cdot e^{\frac{G}{C}t}$$



Sensitive thermometer

Cryogenic temperature ~ 10mK

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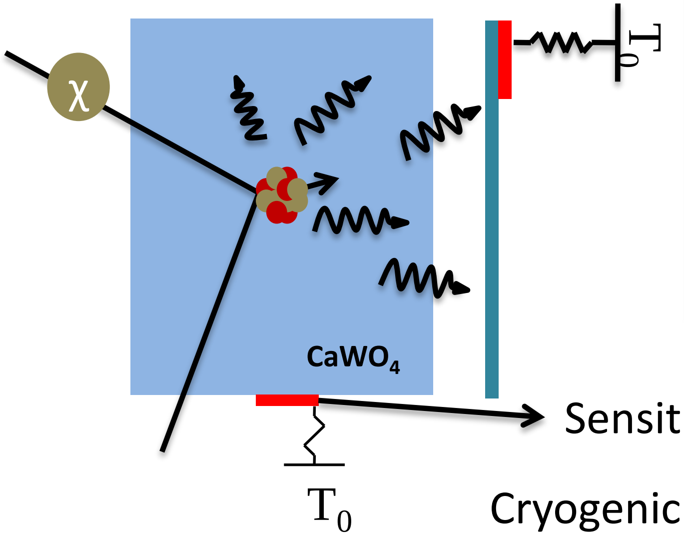
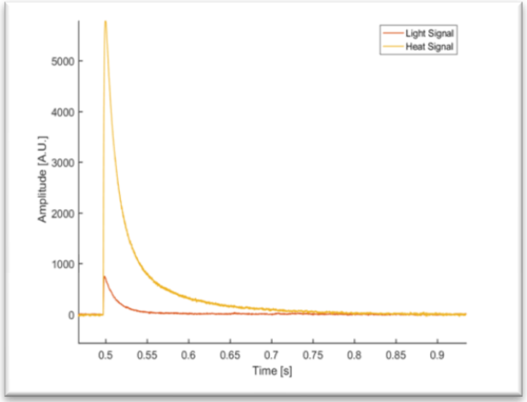
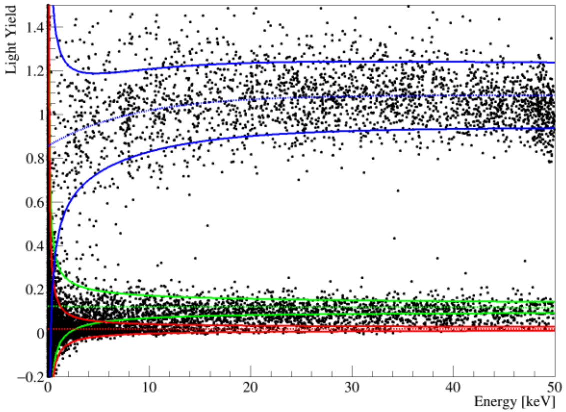


Sensitive thermometer

Cryogenic temperature ≈ 10mK





Light yield characteristic of the type of particle

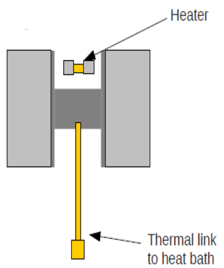
→**Particle discrimination**

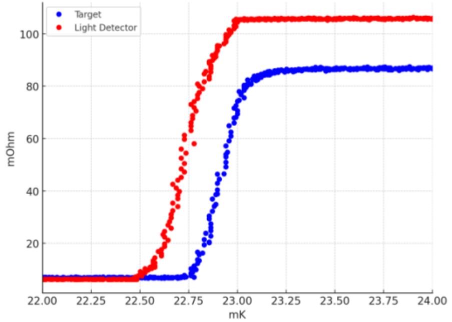
CRESST-III detectors

Energy resolution

Scintillating 24 g $CaWO_4$ crystals as target

- W-TES sensor for T read-out
- 50 eV threshold

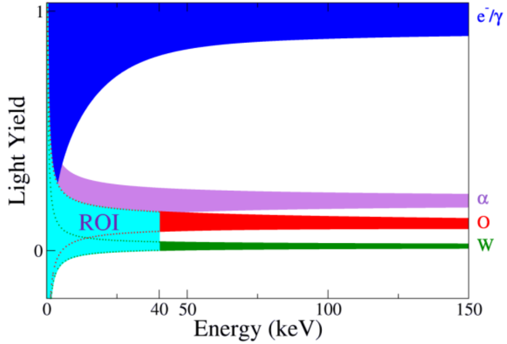


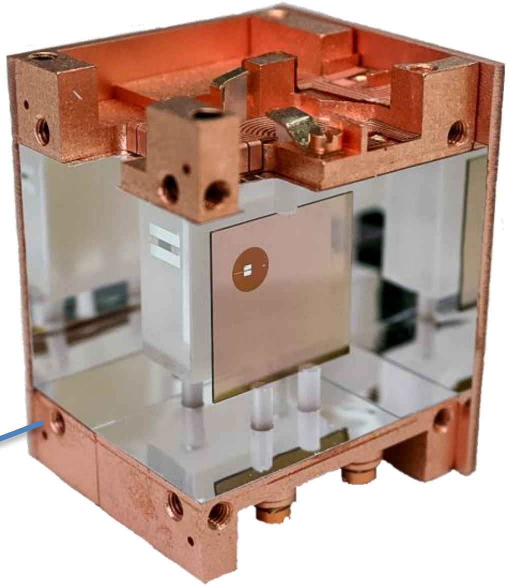


Particle discrimination

Light detector SOS

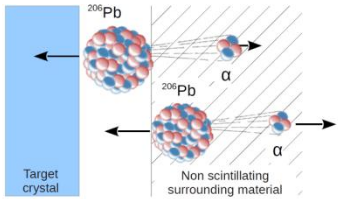
- Cryogenic detector $T_0 \approx 10mK$
- W-TES sensor for T read-out





Housing

- Reflecting & scintillating foil
- Fully scintillating

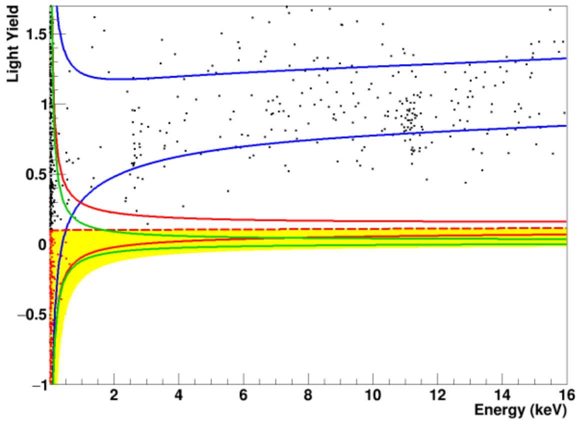


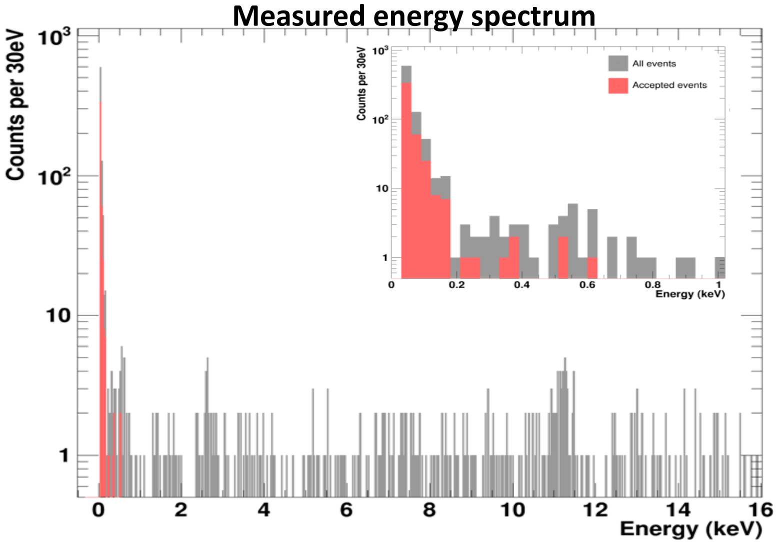
CRESST-III - (Low threshold) - 2019

Measured background below ≈300eV for the first time with a massive calorimeter

- **Data taking period:** 11/2016 to 02/2018
- **Detector mass:** 24 g
- **Total exposure:** 5.7 kg day
- **Analysis Threshold:** 30.1 eV

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



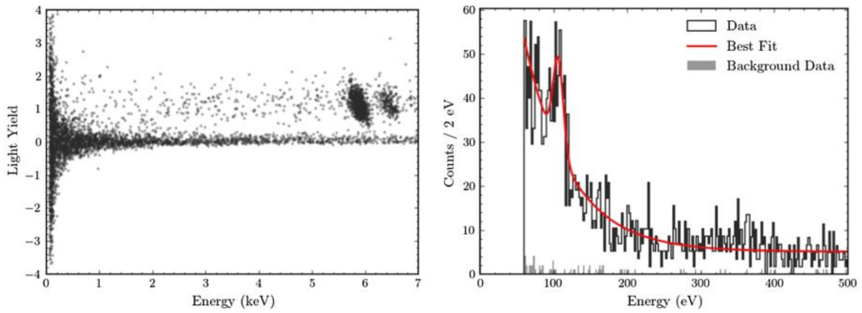


The Low Energy Excess (LEE) in CRESST: Unexplained increase in detected events rate for energies below 200eV.

To improve sensitivity to DM, it is important to understand the unknown background at low energy.

In-depth study of detector response

➢ **Study of energy calibration at low energy.**



Phys. Rev. D: https://doi.org/10.1103/PhysRevD.108.022005

Energy calibration for nuclear recoil

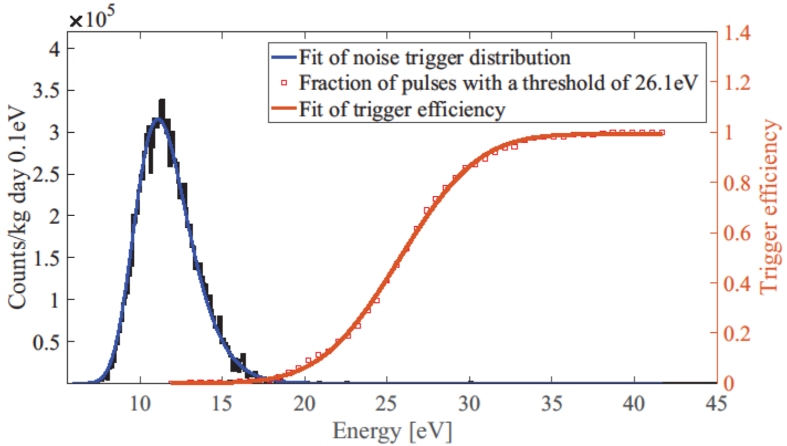
$^{182}W(n,\gamma)^{183}W$

de-excitation with a single γ (6.1MeV)

→ mono-energetic nuclear recoil 112.4eV

➢ **Rigorous threshold analysis**:

threshold determined by accepted noise trigger rate



50% trigger efficiency **@threshold of 26.1 eV**

Analysis Threshold: 30.1 eV -> 1 noise event/(kg day)

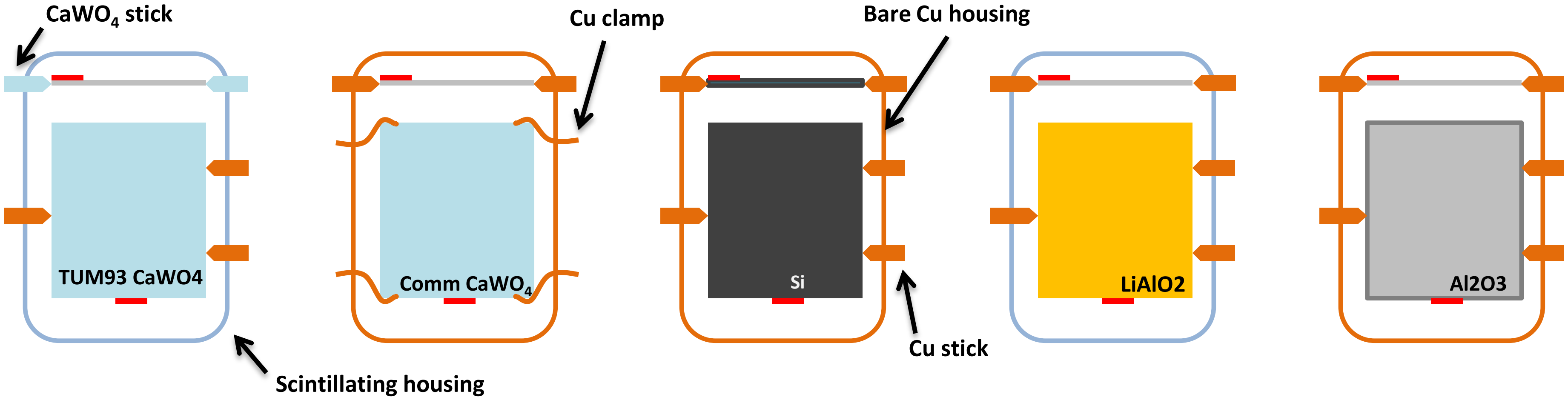
[J Low Temp Phys. https://doi.org/10.1007/s10909-018-1948-6]

➢LEE is not due to a miscalibration

➢LEE is not a pedestal trigger

CRESST-III - (LEE investigation)

- ❑ Material dependence
  - different target material
- ❑ Stress induced by holding
  - two holding structures
- ❑ Internal stress
  - two crystal suppliers
- ❑ Scintillation light
  - no scintillating material
- ❑ Detector geometry
  - analysis of LD as target



Multiple design modifications were applied in the following data-taking campaign to identify the source of the LEE background

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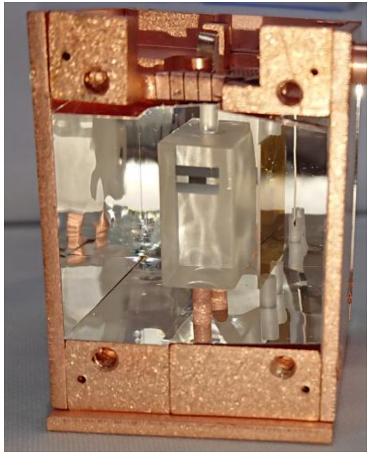
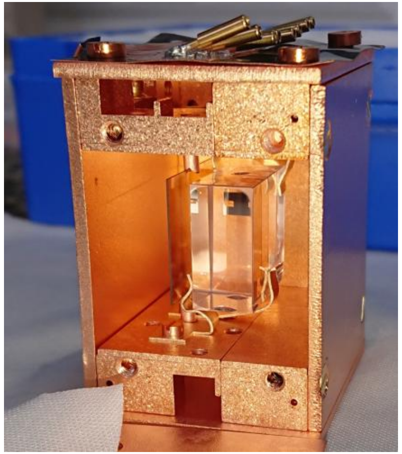
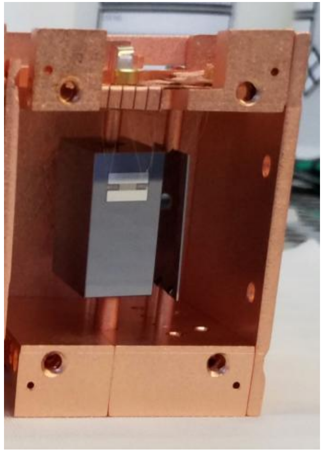
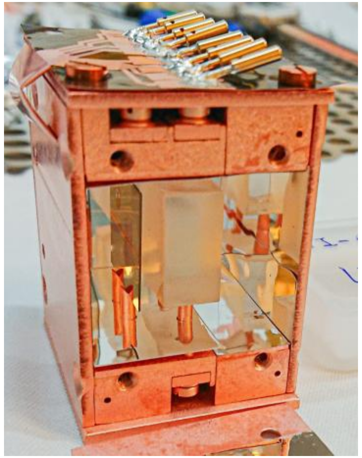
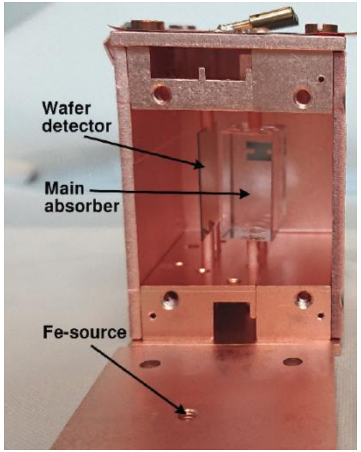

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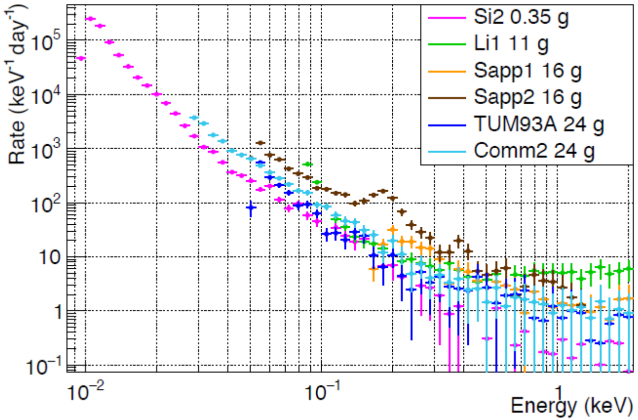
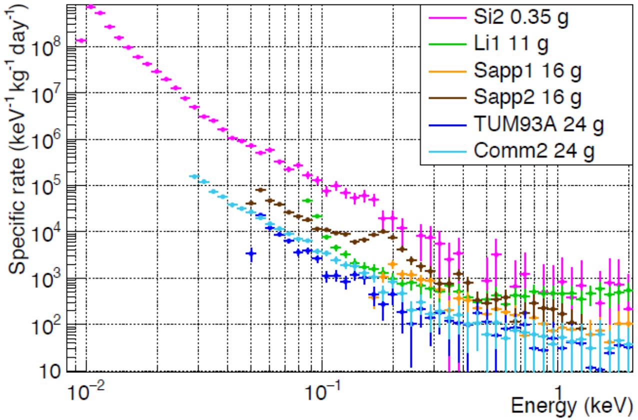




None of the modifications clearly correlate with the LEE

Latest observations on the low energy excess in CRESST-III
e-Print: 2207.09375 [astro-ph.CO]
DOI: 10.21468/SciPostPhysProc.12.013

- The rate of the excess decays with time
- The spectral shape is well described by a power law

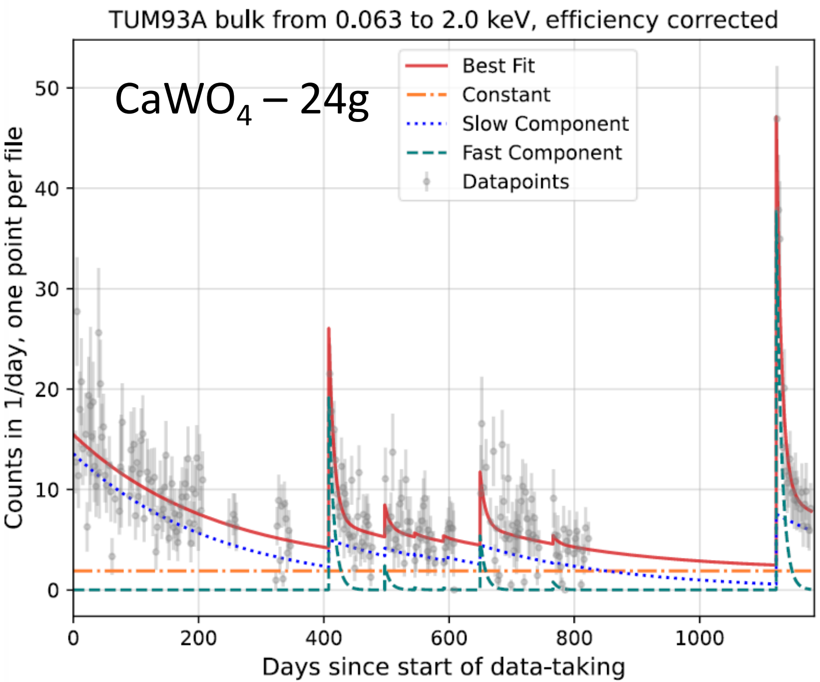
$$N(E,t) = C + E^{-\varepsilon} \cdot (N_{slow} e^{-\frac{t}{\tau_{slow}}} + N_{fast} e^{-\frac{t}{\tau_{fast}}})$$

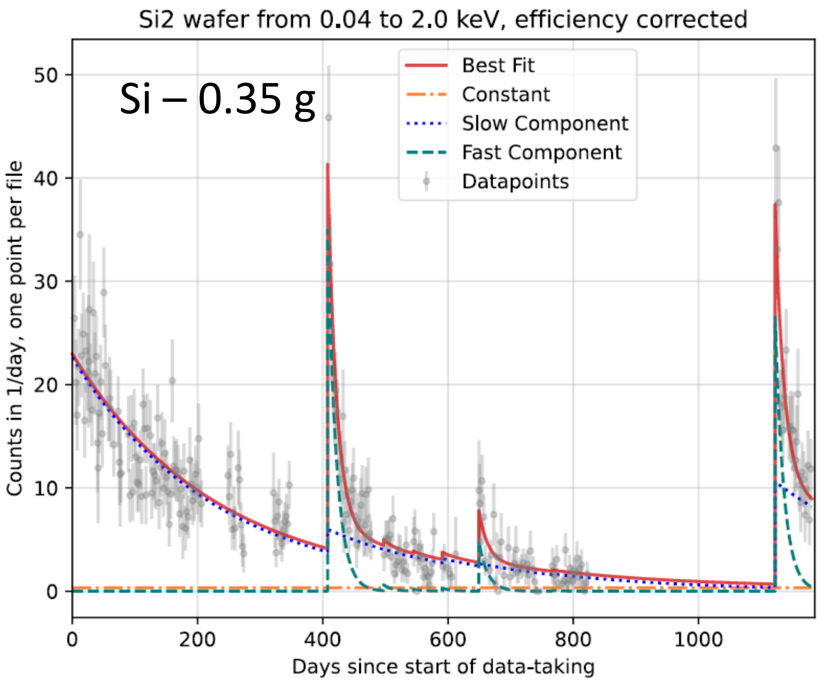
Fit done on all modules with good performance above 40eV

Find a description of the LEE that works consistently for all CRESST detectors.

Warm-up cycles

The plots show the rate recorded over time during warm-up cycles





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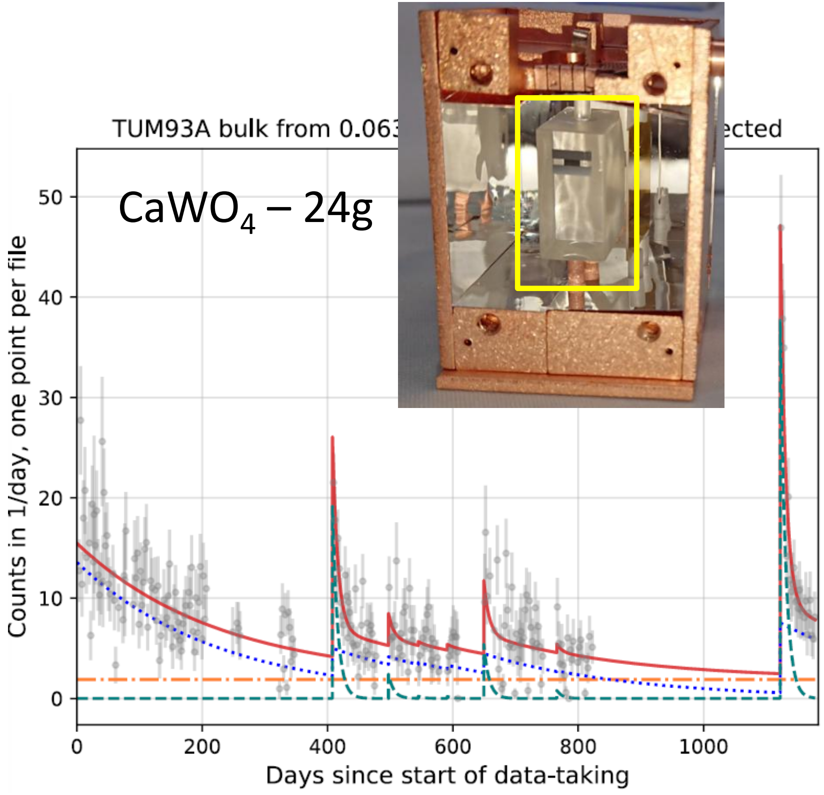

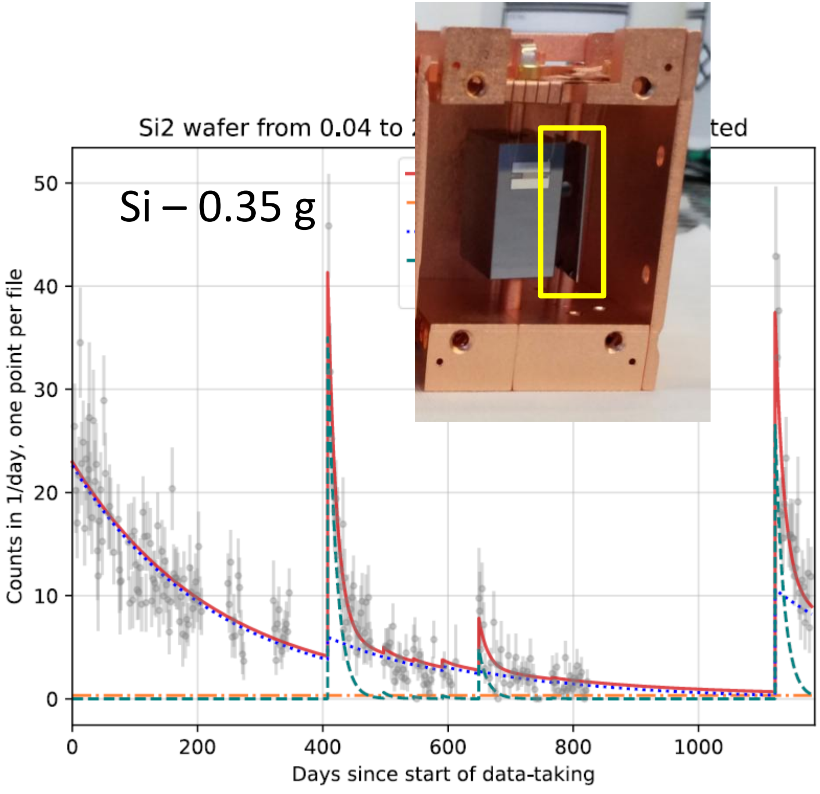

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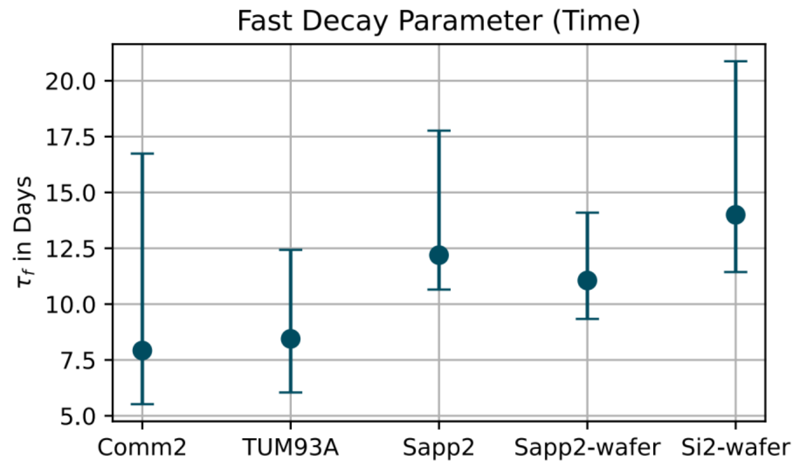
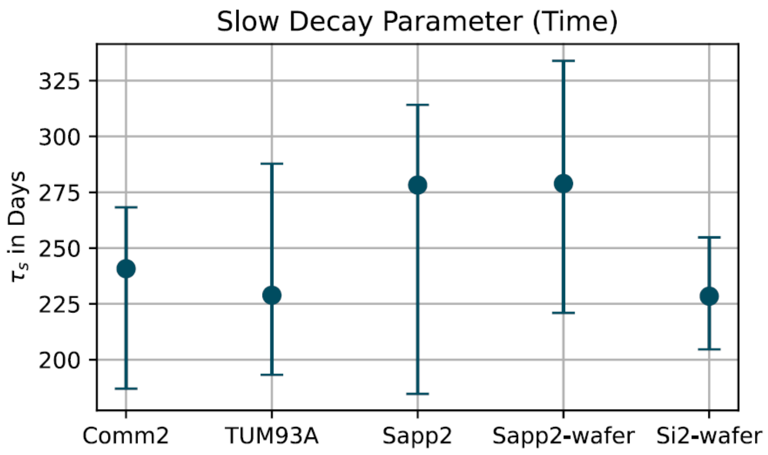
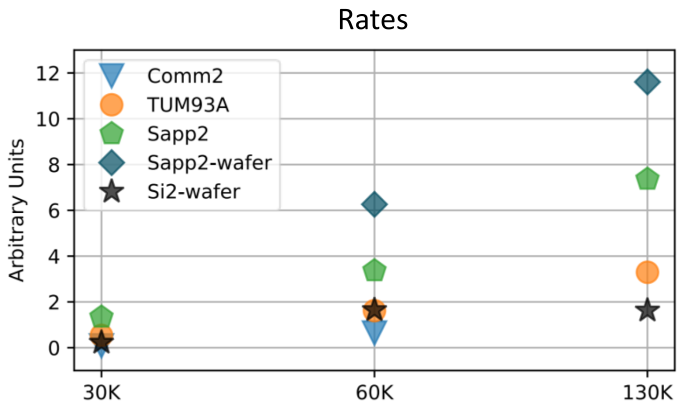


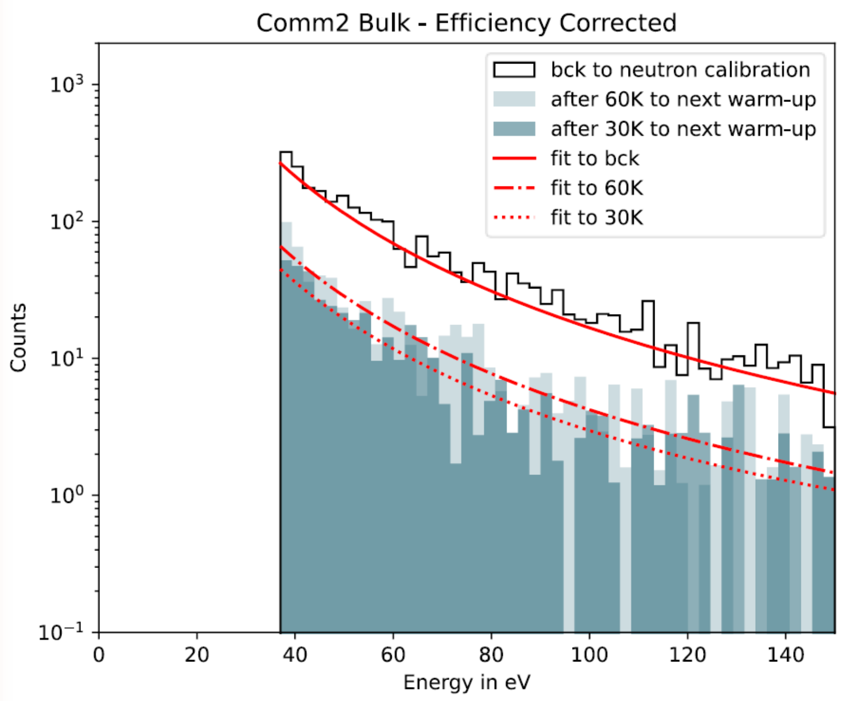


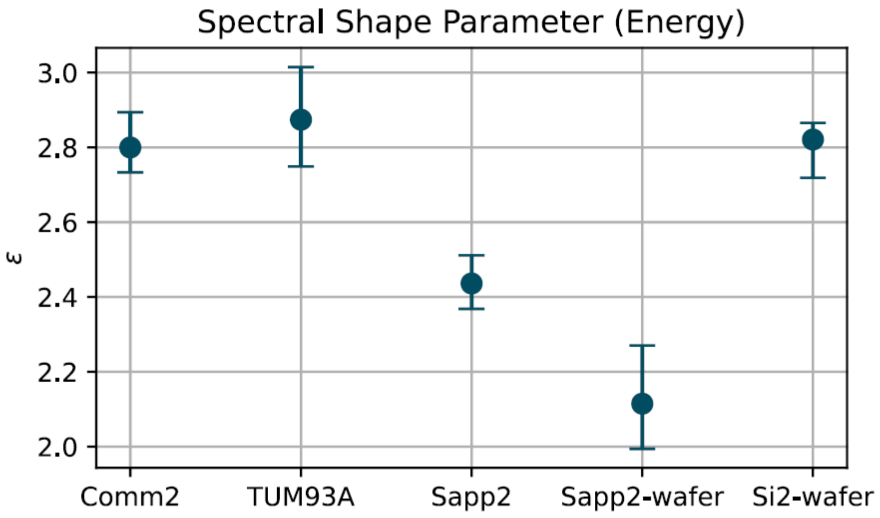
- ➢Exponential decay of event rate
- ➢Increased rate after warm-up
- ➢Two decay constants
  - Fast decay ≈ 10 days
  - Slow decay ≈ 250 days
- ➢Rate reset tends to correlate with warm-up temperature



Spectral shape

For all detectors, **spectral shape above 40 eV** is well described by single power law





Poster session:
Analysis of the CRESST warm-up test data
Sarah Kuckuk on behalf the CRESST collaboration

What next?

What do we have learned from this long investigation campaign?

- Rate decays over time with two time constants
- The rate “resets” after warm-up cycles
- It is not compatible with external radioactivity/common source
- Different internal/external stress does not reflect in the measured excess
- Excess is not due to passive scintillating parts
- The spectral shape is well described by a single power law
- Similar rate shows up in all detectors regardless difference in mass, surface and TES dimension

EXCESS23@TAUP :

Hypothesis:

Possible origin of part of LEE at interface between crystal and TES

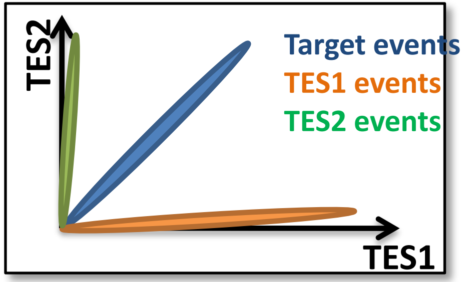
caused by mismatch of Thermal Expansion Coefficients (TEC)

EXCESS23@TAUP

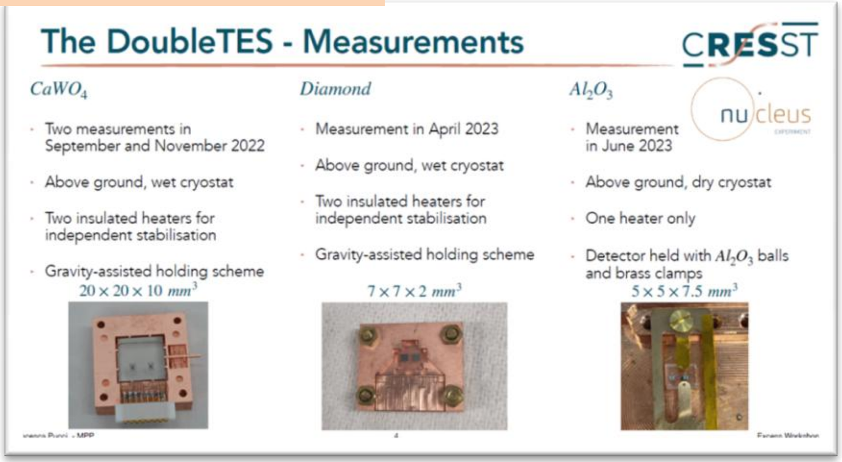
Double readout developed independently in CRESST and SPICE/HeRALD collaborations

Goal: Measure the excess in coincidence within the two sensors

- Test TES induced events
- Events induced by mismatch of sensor/absorber differential thermal contraction



F. Pucci: **Results of doubleTES detectors**
https://indico.cern.ch/event/1213348/



R. Romani: **Observations of the LEE in a Two Channel SPICE Athermal Phonon Detector**
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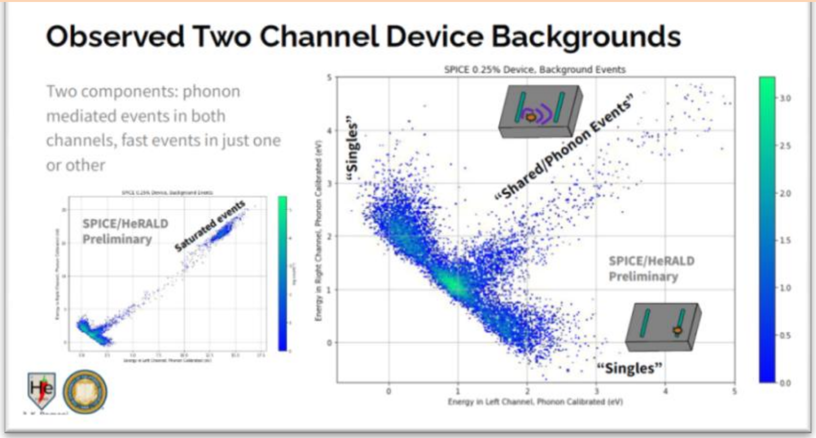
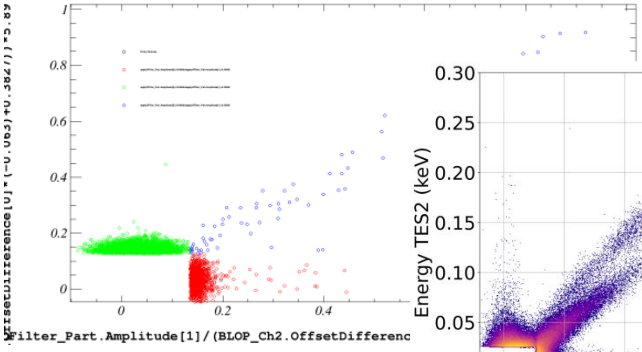
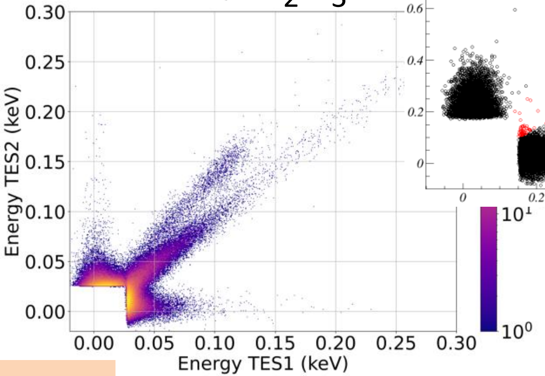


EXCESS23@TAUP – Double sensors results

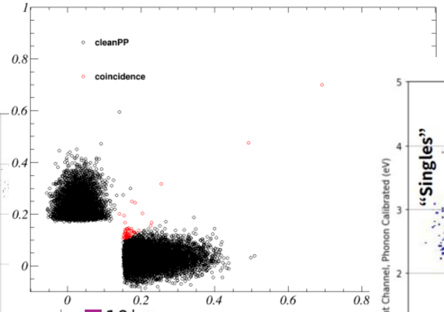
$CaWO_4$



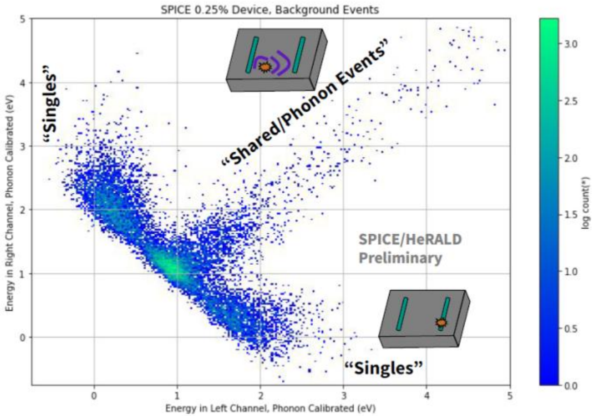
Al_2O_3



Diamond



Si



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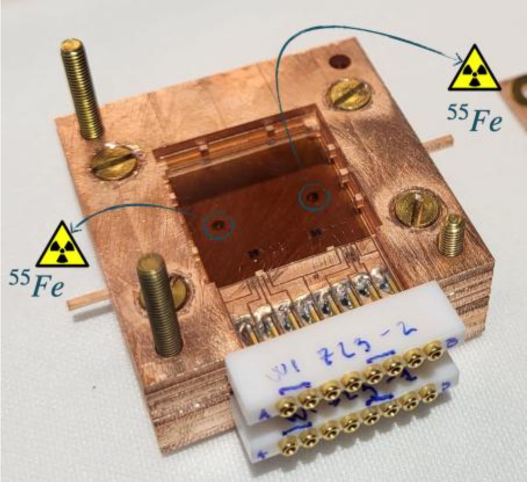
From **test above ground** presented @ EXCESS23:

- TES related events are 1 component of the excess
- Rise in rate towards low energy for shared events

CRESST-III - New detectors

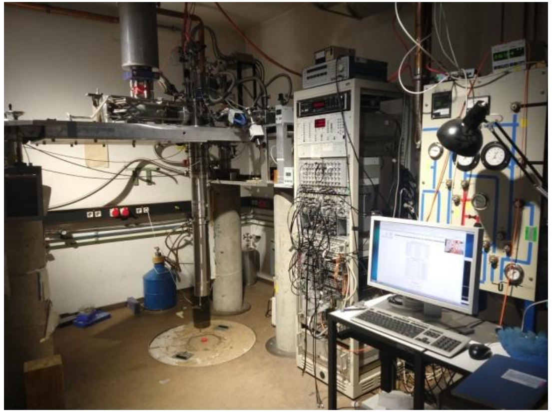
To access to lower energies we developed a double sensor onto sapphire wafer detectors



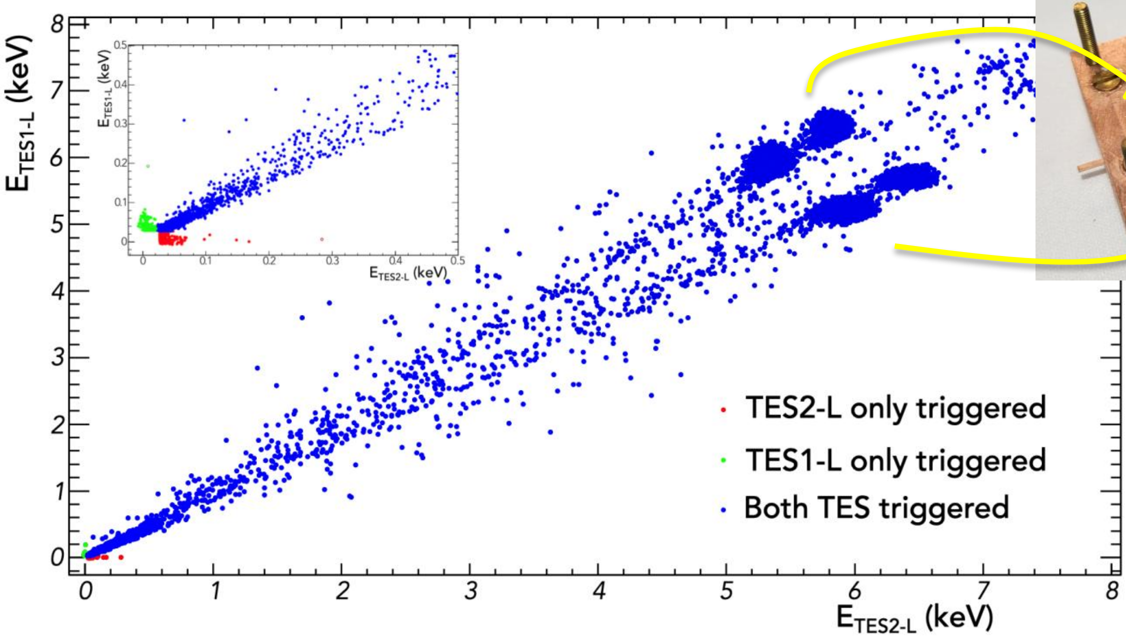
- ❑Target wafer rests on its corners w/o any force apply to it
- ❑Two collimated x-ray ^{55}Fe sources
- ❑Two TESs
- ❑Isolated heater elements on top of each TES

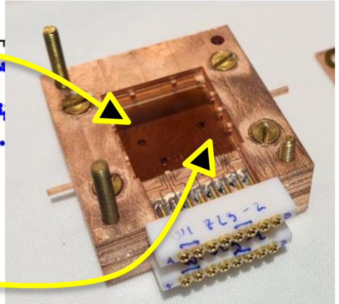
Cooled down **twice** at Max Planck institute for physics in Munich.

- first data taking September 2023
- second data taking October 2023 without x-ray source
  - 10 days normal data
  - 10 days with additional radiation shield



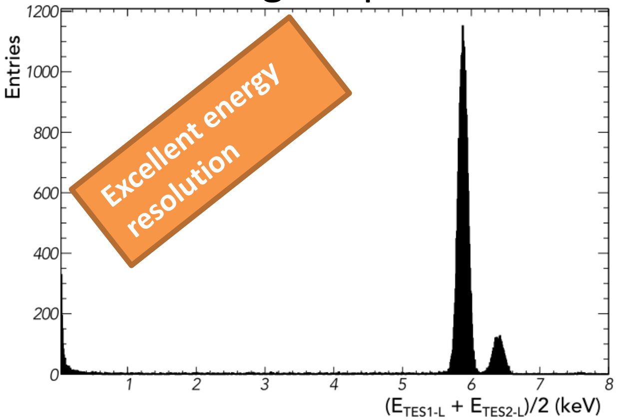
CRESST-III - New detectors result





Position dependence due to signal collection competition and thin detector geometry

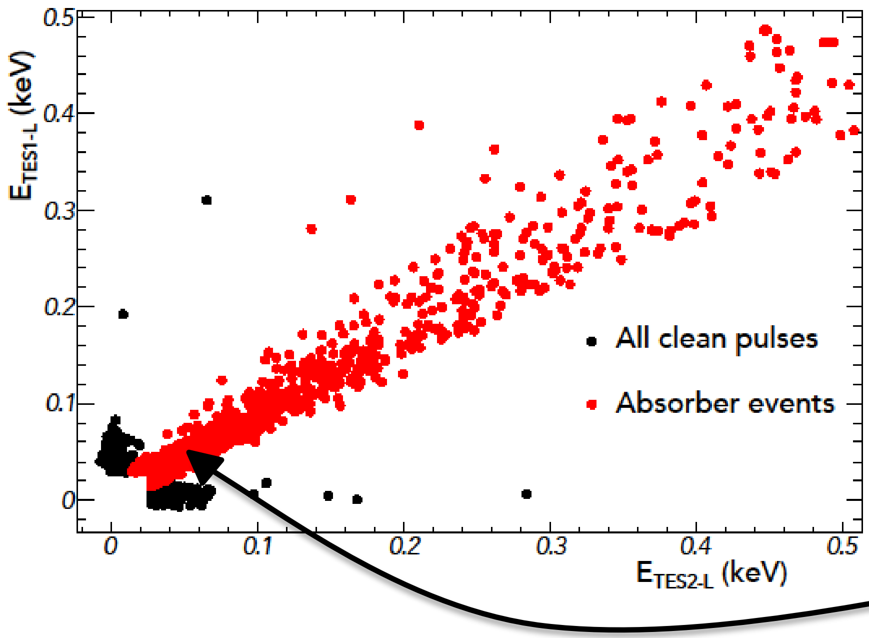
Averaged spectrum

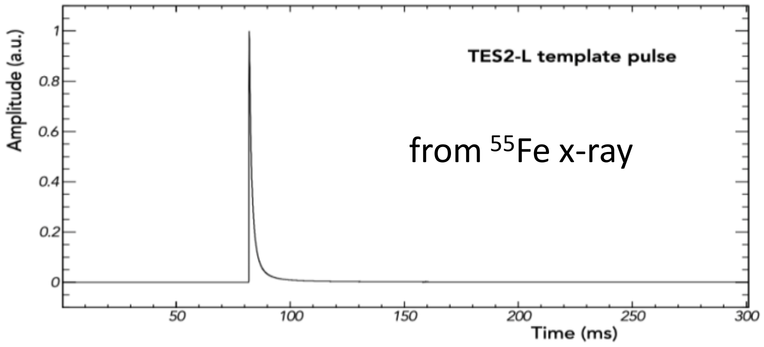


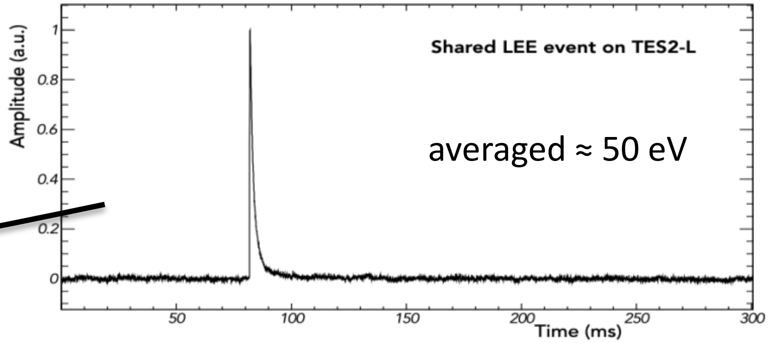
TES1-L	baseline resolution of (5.4±0.1) eV trigger threshold 27 eV
TES2-L	baseline resolution of (4.1±0.1) eV trigger threshold 20.5 eV

SUBMITTED epjc: e-Print: 2404.02607

CRESST-III - New detectors result



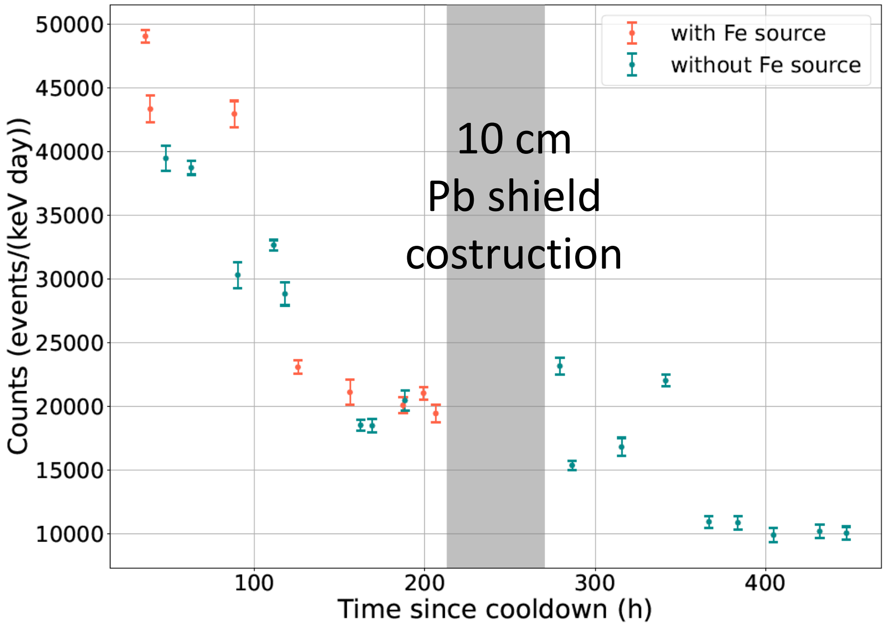




- ➢ TES related events are 1 component of the excess
- ➢ Rise in rate towards low energy for shared events
- ➢ Same particle pulse shape

SUBMITTED epjc: e-Print: 2404.02607

CRESST-III - New detectors result



By removing the X-ray source we excluded a contribution to the LEE from the calibration source

Adding an extra Pb shield we reduced the radiation at the experimental volume of a factor ≈ 3

comparison of the 3 measurements:

- ➢ The LEE does not depends on the detector rate (with and without X-ray source)
- ➢ External radiation is not the source of LEE

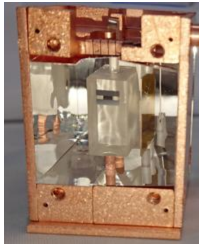
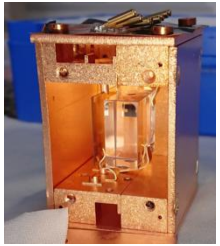
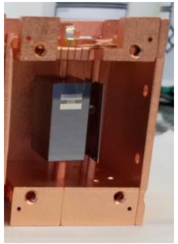
- ➢ Observation of decay times compatible with the underground CRESST measurement (10.2 ± 1.1) days.

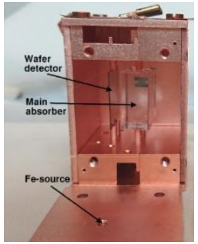
Poster session:
DoubleTES detectors to investigate the CRESST low energy background: results from above-ground prototypes
Francesca Pucci on behalf the CRESST collaboration

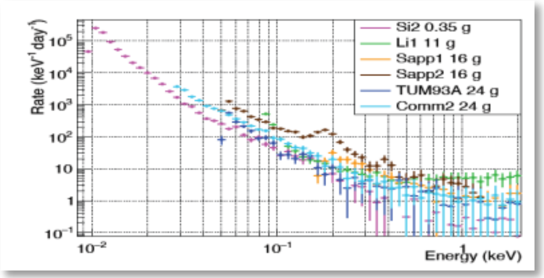
Conclusion

Low energy excess strongly limits the sensitivity of the CRESST experiment

- Detailed study and modeling of the low energy excess with a variety of detector disfavors particle, intrinsic stress or external stress origins.





The doubleTES design proved to be able to distinguish different components of the excess at threshold. This distinction is critical in our ongoing quest to understand the origins of the LEE.

- ➢TES related events are 1 component of the excess
- ➢ Rise in rate towards low energy for shared events
- ➢The LEE does not depend on the detector rate
- ➢ External radiation does not impact the LEE