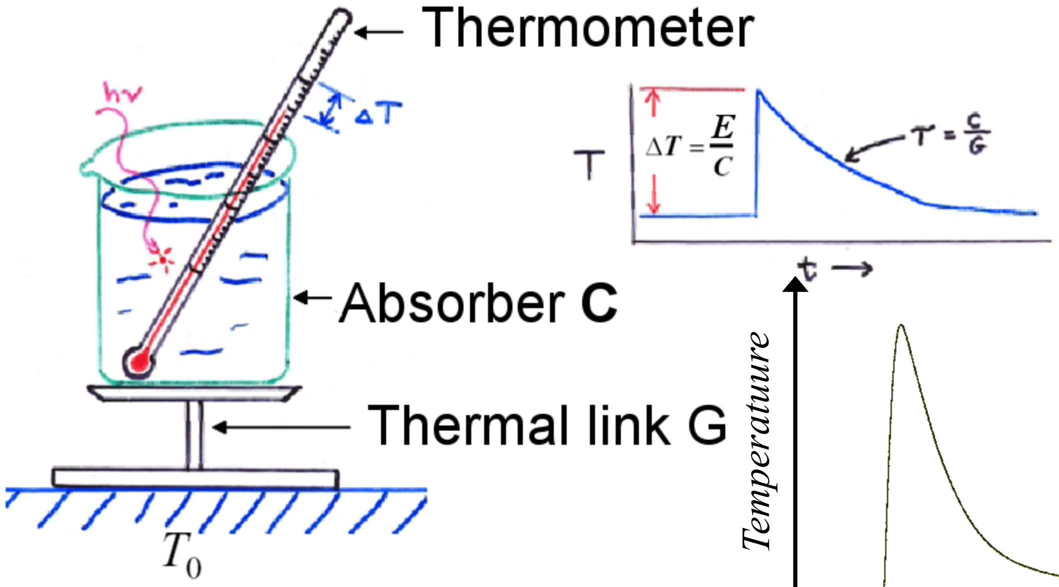
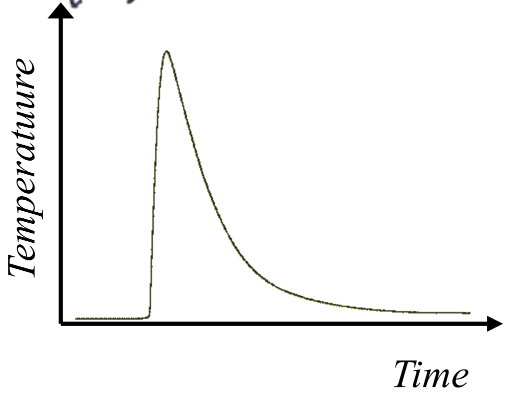
Bolometric advanced technologies for background mitigation

Bolometers In few words
Bolometers fro Rare Events Physics
REP: **Particle identification & Background Rejection**

Stefano Pirro – INFN-LNGS

Cryogenic bolometers at "zero level"





Cryogenic particle detection Springer (2005) ISBN 978-3-540-20113-7

JN Ullom DA Bennet *Supercond. Sci. Technol*. 28 (2015) 084003

SP , P Mauskopf *Annual Review of Nuclear and Particle Science* Volume 67, 2017

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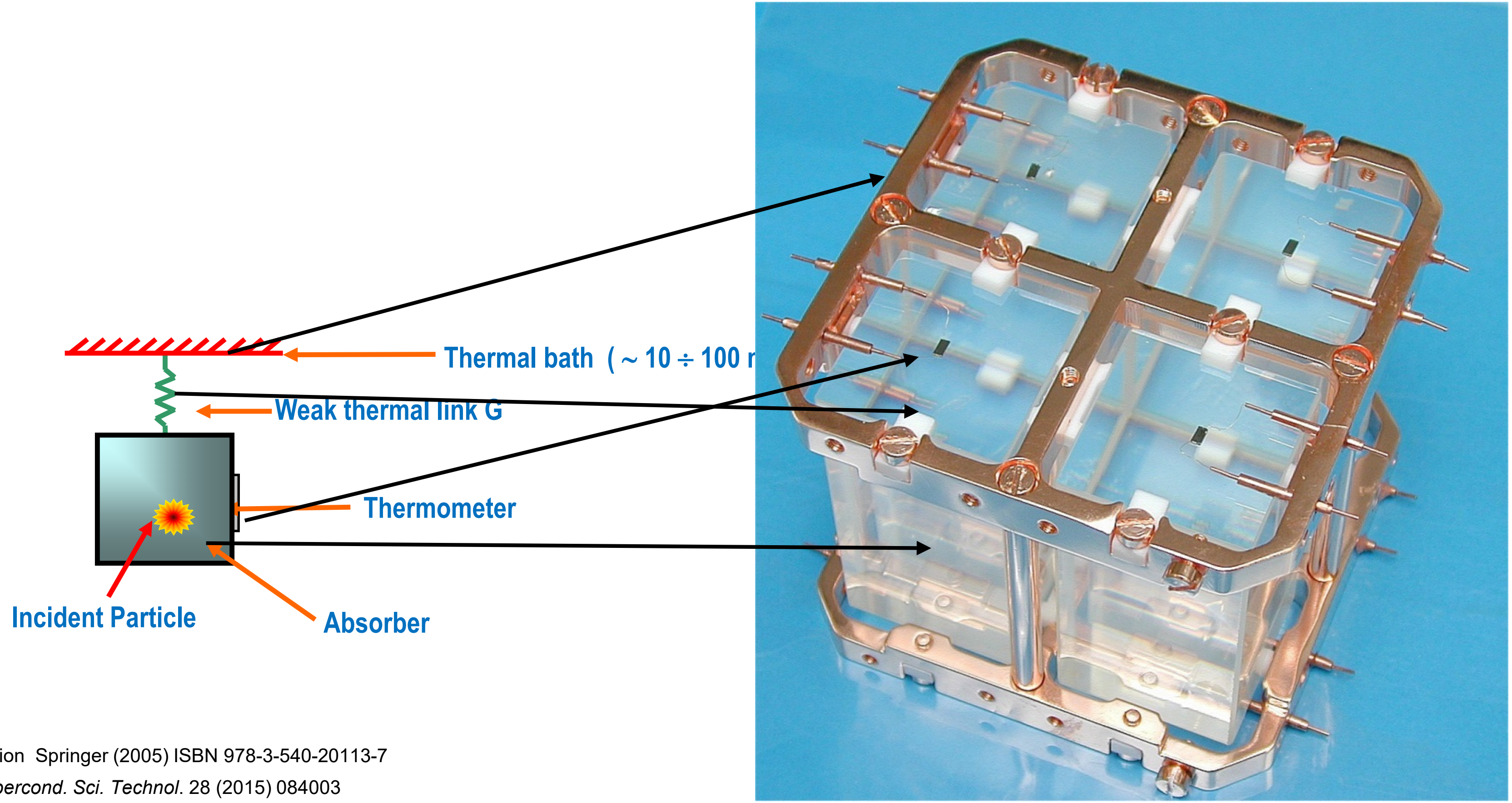

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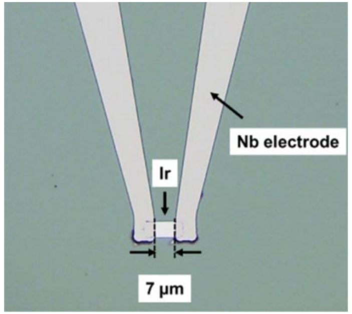
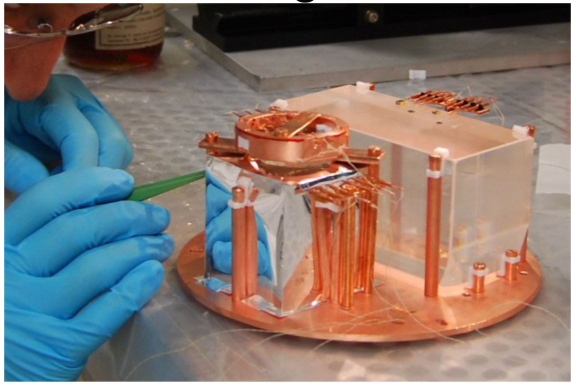
Bolometers (calorimeters)

~ 8* 10^{-15} kg



Y. Miura et al. https://doi.org/10.1016/j.nima.2019.04.074

2.1 kg



L. Cardani et al. https://doi.org/10.1088/1748-0221/7/01/P01020

photon & X-ray applications
~0 ÷ 50 μg

Rare event physics (REP)
~ > 1 g

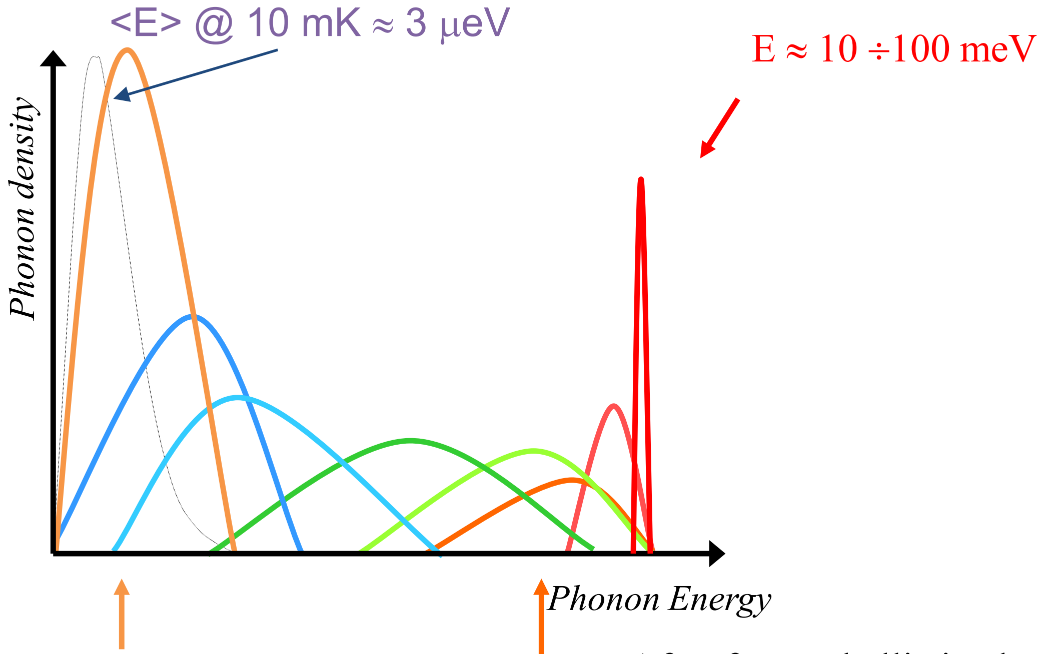
MICRO

ΔE~ fractions of eV

MACRO

ΔE~ few keV

Ballistic and thermal phonons for massive bolometers



After few ms thermal phonons
Si and Ge Thermistors

After few μs ballistic phonons (few *meV*)
TES, MMC ==> spatial resolution

ε_a ~ tens μeV – few meV

D. Twerenbold Rep. Prog. Phys. 59 (1996) 349

Bolometers Vs conventional detectors *for single particle detection*

Pros

ΔE/E of the order of few ‰

Energy thresholds less than eV

Possibility to be made of almost any kind of material (but gases)

Cons

Works in the few hundreds of mK range

At least 1 day to run the detector

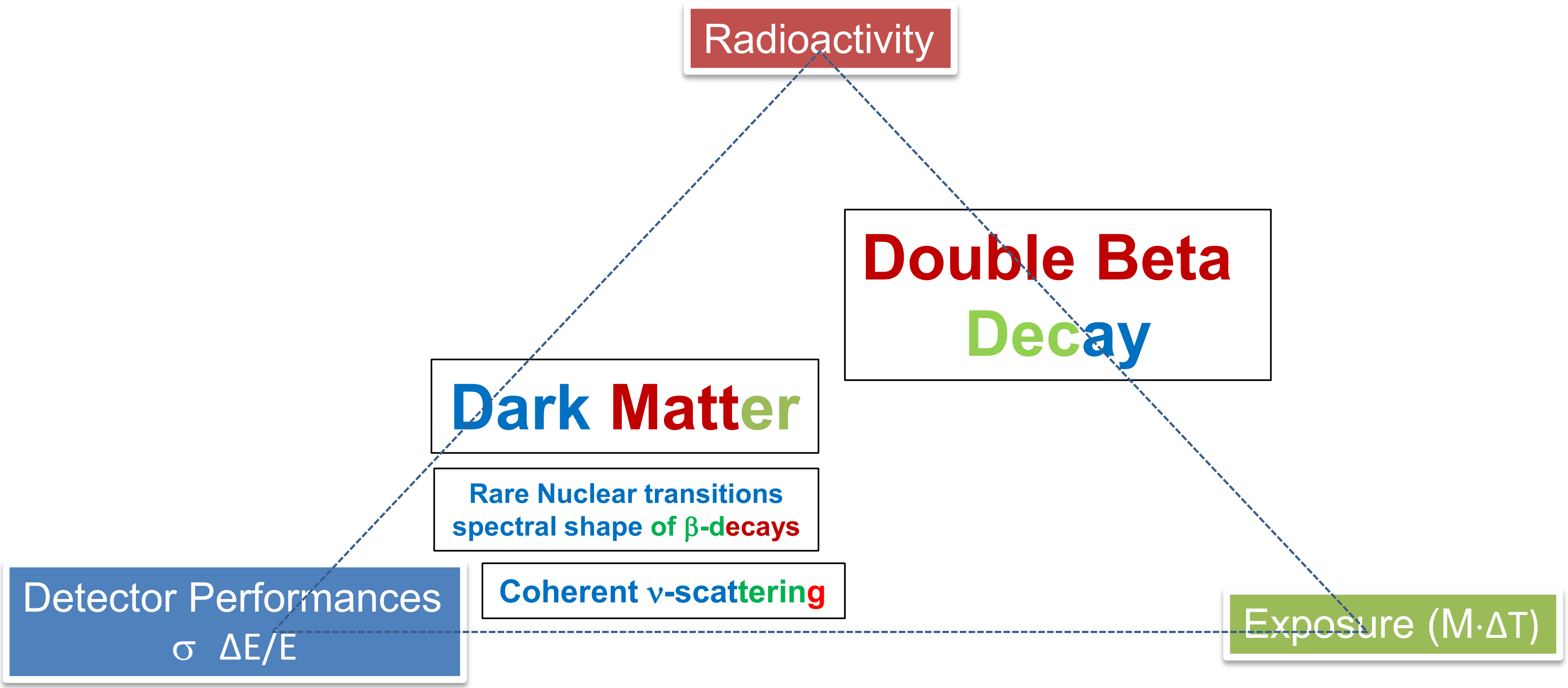
Works in the few hundreds of mK range

Detector enclosed “in a Matrioska” of shields

Pulse time development much larger than Conventional detectors (pile-up)

SP , P Mauskopf *Annual Review of Nuclear and Particle Science* Volume 67, 2017

Bolometers for Rare Event Physics… Three main challenges



DM bolometers "corrected" the strategy (towards lower thresholds rather than Exposure) after the operation of L noble gas detectors

Bolometers in fundamental physics: Particle recognition

Dark Matter : neutral Particle Vs Charged and **uncharged** background (**n**,γ,β,α)

Double Beta Decay: two electrons Vs Charged background (**n**,γ,β,α)

Nuclear Instruments and Methods in Physics Research A279 (1989) 382–387
North-Holland, Amsterdam

DETECTION OF LOW ENERGY SOLAR NEUTRINOS AND GALACTIC DARK MATTER WITH CRYSTAL SCINTILLATORS

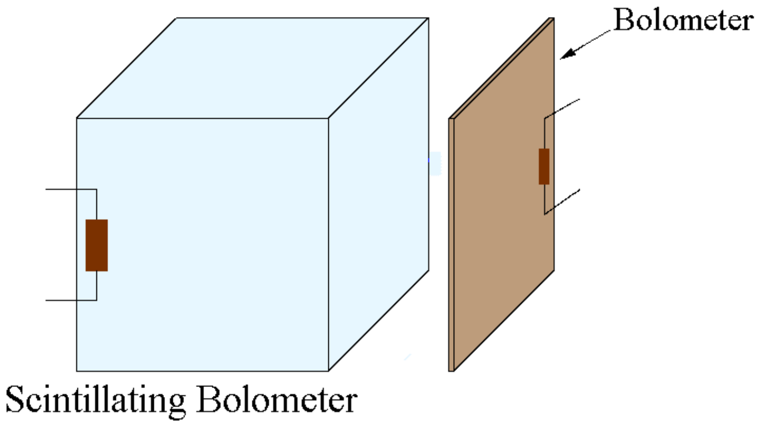
L. GONZALEZ-MESTRES and D. PERRET-GALLIX

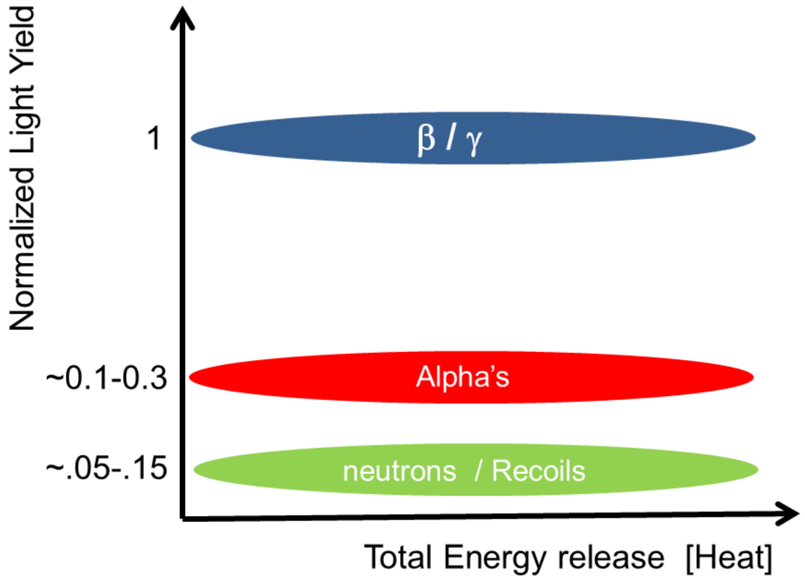
LAPP, Annecy-le-Vieux, France

We suggest that dedicated scintillating crystals (DSC) may provide a way to detect low energy solar neutrinos and, possibly, galactic dark matter. DSC are scintillating monocrystals grown from a compound containing a large relative amount of the target material. The target element (or isotope) is chosen for its larger interaction cross-section and/or the specific signature it may provide, easing background rejection. A ^{115}In target appears to be the natural choice for solar neutrinos, and we propose to grow high quality scintillating crystals made of a suitable indium compound. Several targets can be considered for the detection of galactic dark matter, depending on WIMP interaction properties. We mainly focus on the detection of Majorana fermions through inelastic scattering. We finally propose to investigate the feasibility of composite cryogenic devices based on scintillating crystals at low temperature. A good time resolution would be obtained through the detection of the light pulse even on large crystals, whereas the energy resolution would be provided by bolometric readout (sensitive to thermal phonons) and low temperature photosensitive devices.

Scintillating Bolometers: Heat and Light for Bkg mitigation

Operating Temperature for _massive_ detectors: 10÷30 mK





First light-heat scatter plot 1997 with BLD Coron et al.

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 386 (1997) 453–457

NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH Section A

Alpha/gamma discrimination with a CaF_2(Eu) target bolometer optically coupled to a composite infrared bolometer

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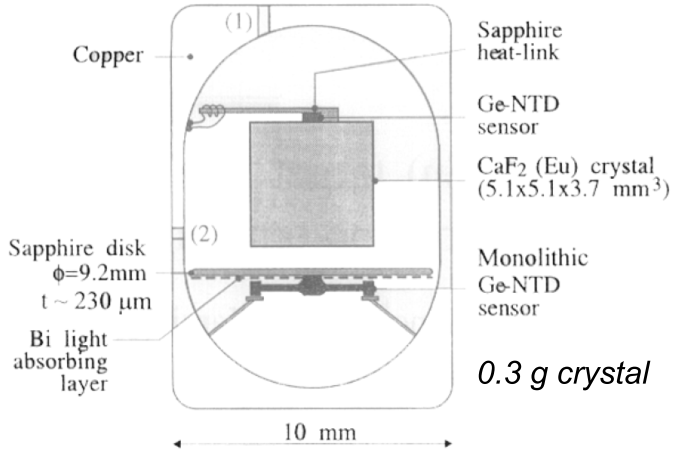
Received 15 August 1996; revised form received 18 November 1996

Abstract

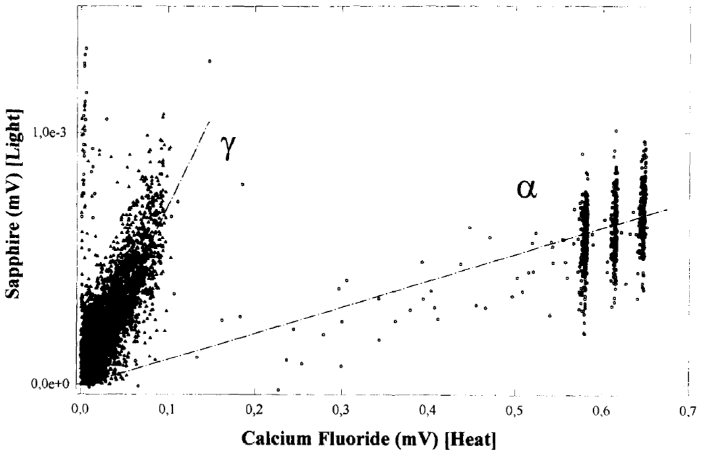
On account of its qualities for dark matter research, a 300 mg luminescent CaF_2(Eu) bolometer light-coupled to an infrared sapphire bolometer has been successfully investigated. At a working temperature of about 130 mK, a discrimination between alpha particles and gamma irradiation has been achieved. The rejection power as a function of energy is given. We finally discuss an extrapolation of our results to CaF_2(Eu) targets of several grams and lower working temperatures.

PACS: 07.57.Kp

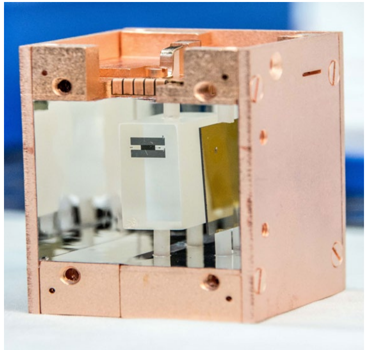
Keywords: Bolometers; Scintillation; Identification; Dark matter detection

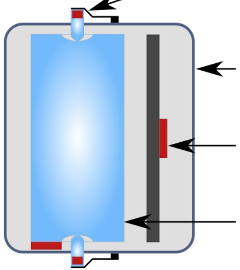


0.3 g crystal



Present Status for DM: Heat and Light (CRESST)



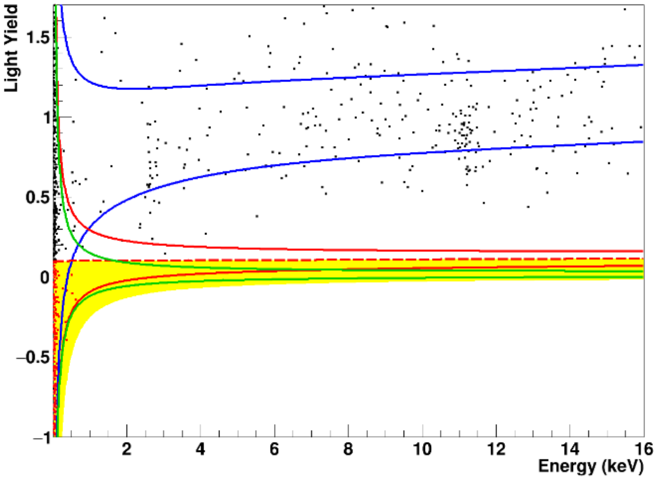


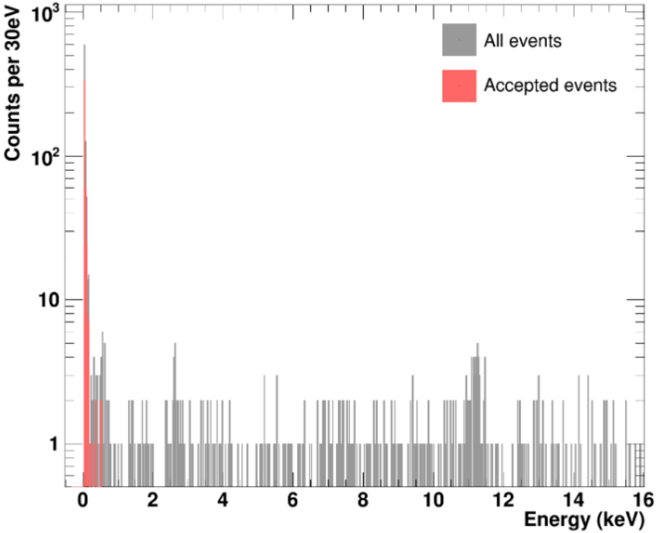
Detector layout optimized for low-mass dark matter

Radical reduction of dimension (300→25g)

- Cuboid crystals of (20×20×10)mm^3 (**≈24g**)
- With self grown crystals **≈4 counts/(keV kg day)**
- Threshold design goal **<100 eV threshold**
- **(best threshold 30 eV)**
- Fully scintillating housing
- Instrumented sticks

A. H. Abdelhameed et al., Phys. Rev. D 100, 102002 (2019)

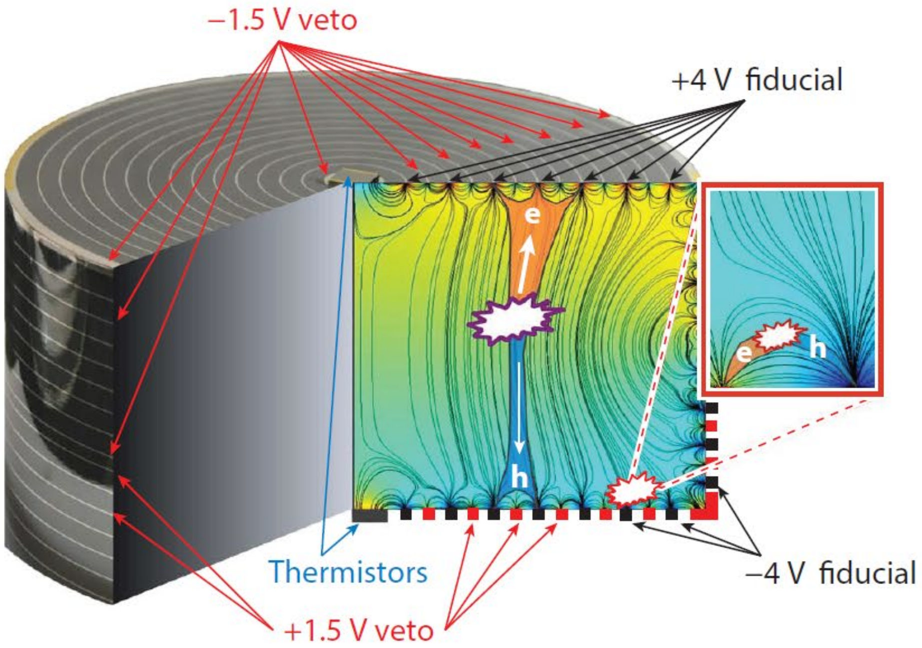


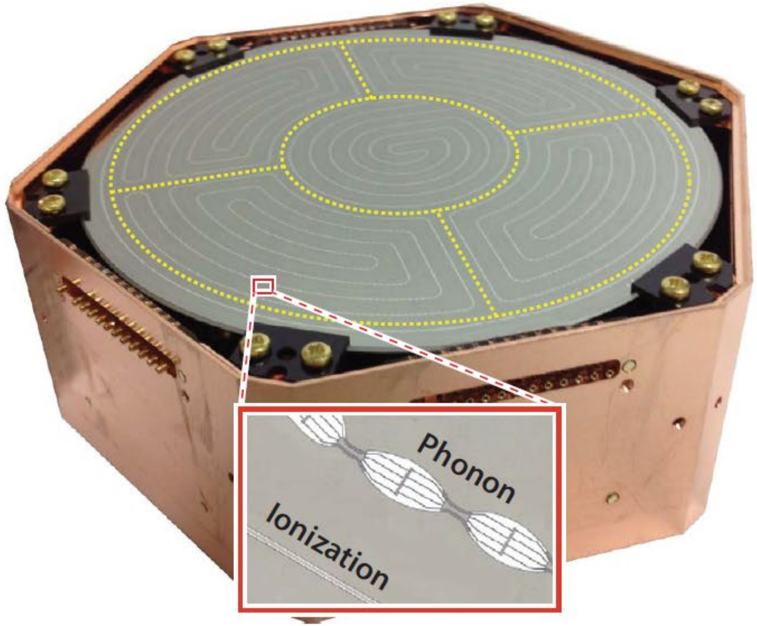


3.6 kg ·d
35% LT
(15 months)

Double Readout for DM: Heat-Ionization (Edelweiss + SuperCDMS)

In this case, clearly, only Semiconductor crystals can be used, operated as calorimeters and at the same time, as diodes

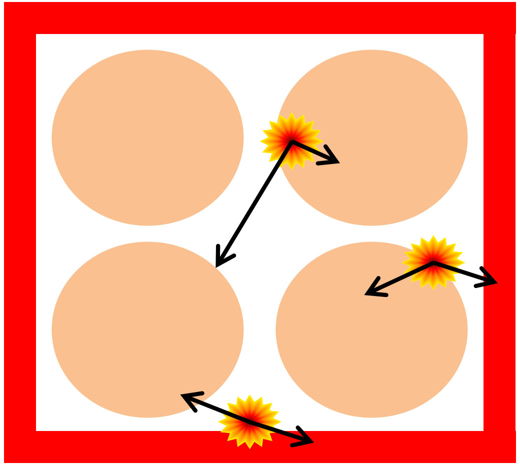


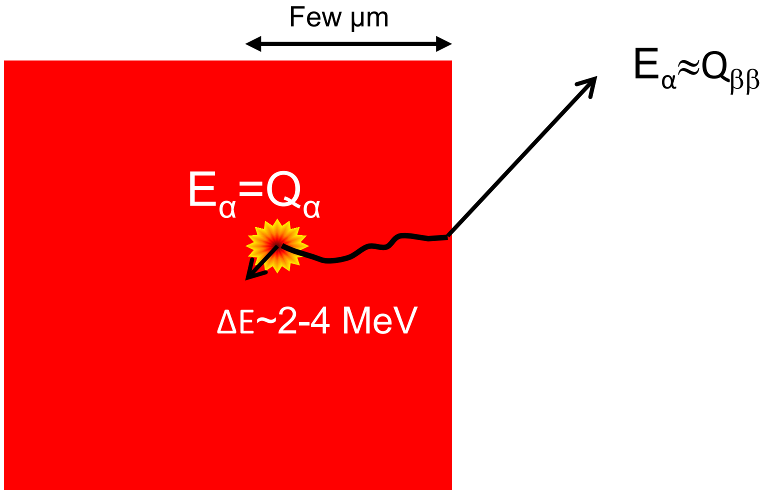


The ultimate frontier: *Surface* contaminations (DBD)

Bolometer are total active detectors: they are *surface* sensitive

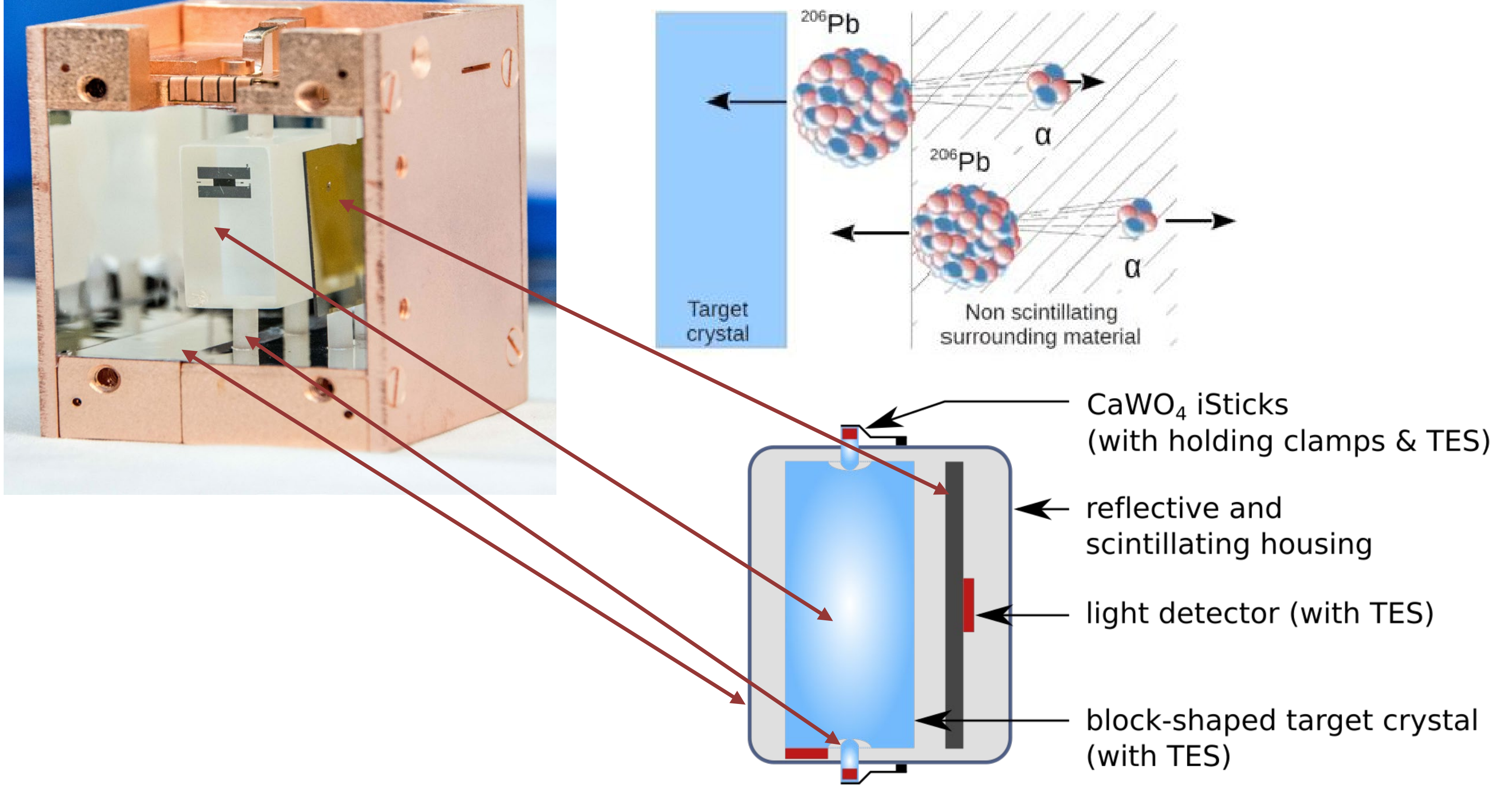
Most of the natural alpha decays has Q_α= 4-6 MeV





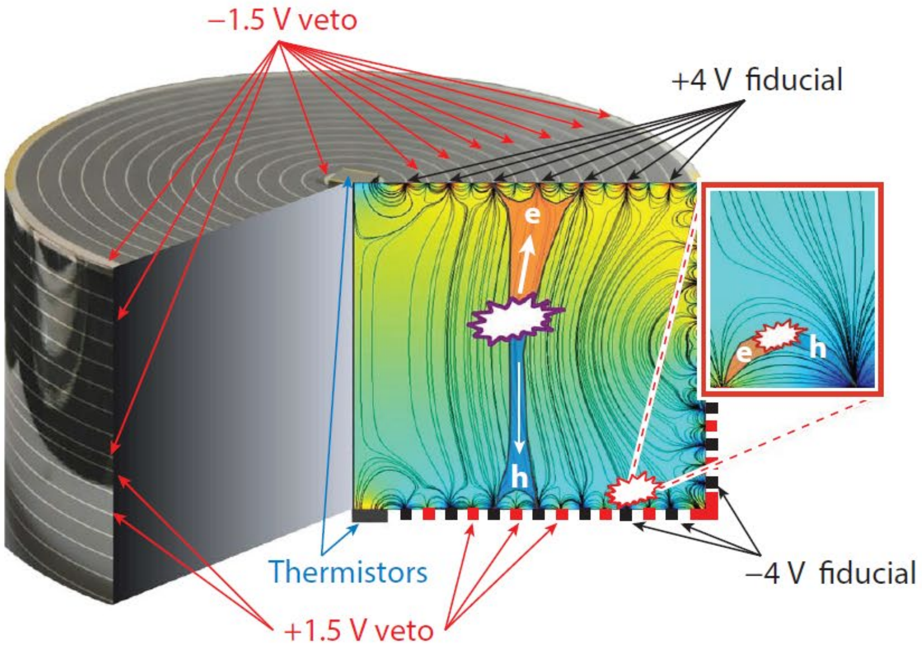
The ultimate frontier: ***Surface*** contaminations mitigation (DM)

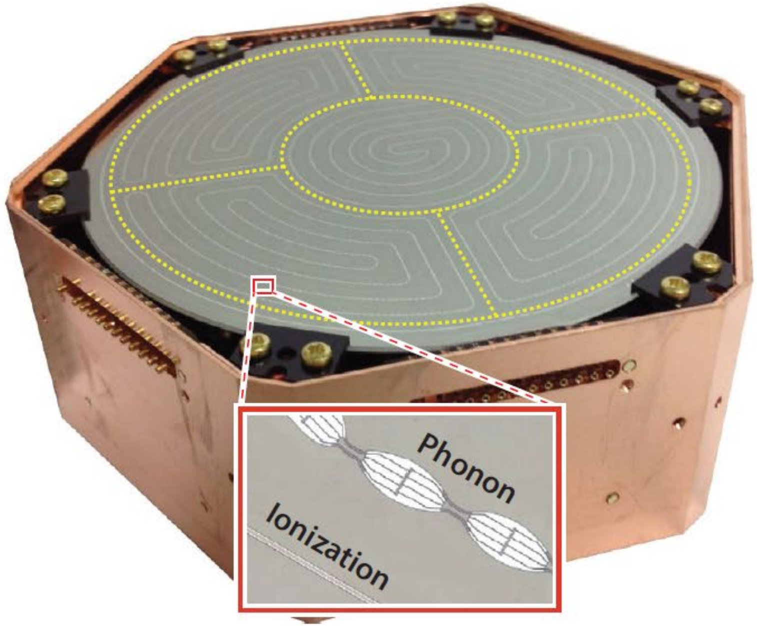
Nuclear Recoils from surface



Heat-Ionization (Edelweiss + SuperCDMS): Surface event

In this case, clearly, only Semiconductor crystals can be used, operated as calorimeters and at the same time, as diodes



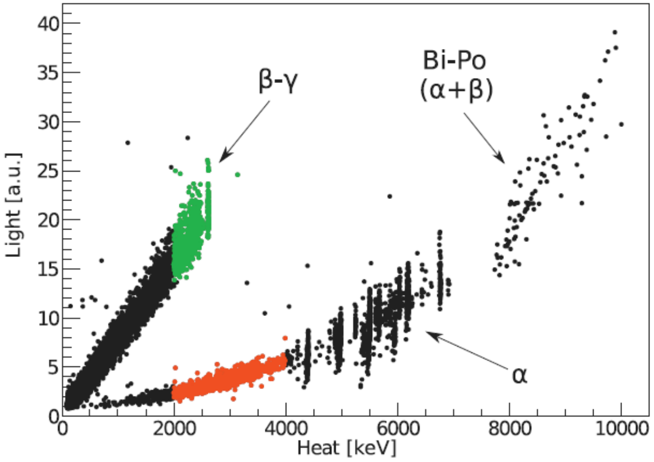


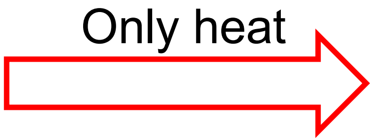
The fiducial electrodes collect the charge of events releasing energy inside the detector while charge depositions taking place a few millimeters from the surfaces are tagged by signals on a veto electrode

The ultimate frontier: *Surface* contaminations (DBD)

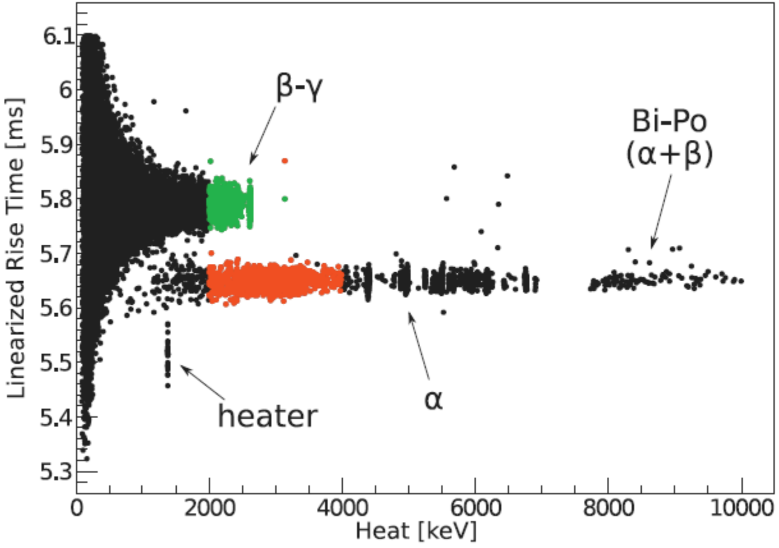
In case of scintillating crystals, besides heat/light discrimination, it can happen that the time development of the heat Signal depends upon Particle type (i.e. α or γ/β)

Light + Heat Scatter Plot ($CaMoO_4$)





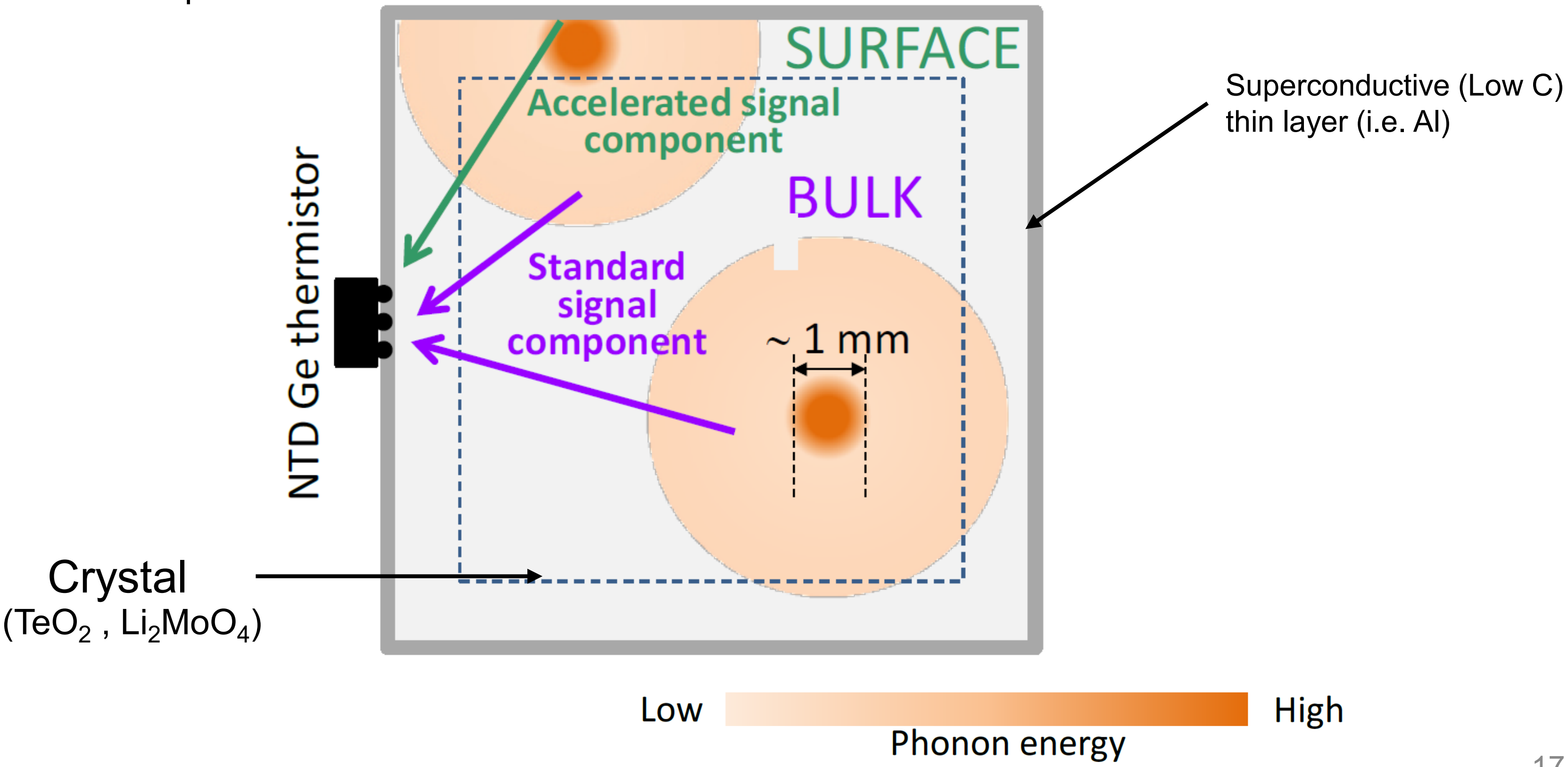
Only Heat Signal



This feature can be explained by the relatively long scintillation decay time (of the order of hundreds of microseconds) observed at cryogenic temperatures in some crystals. This long decay, combined with a high percentage of non-radiative de-excitations of the scintillation channel, will produce delayed phonons (i.e., heat) in the crystal. This extremely tiny, but measurable, time-dependent phonon release has different absolute values for isoenergetic α and β/γ particles due to their different scintillation yields.

The ultimate frontier: *pulse shape modifiers* (DBD)

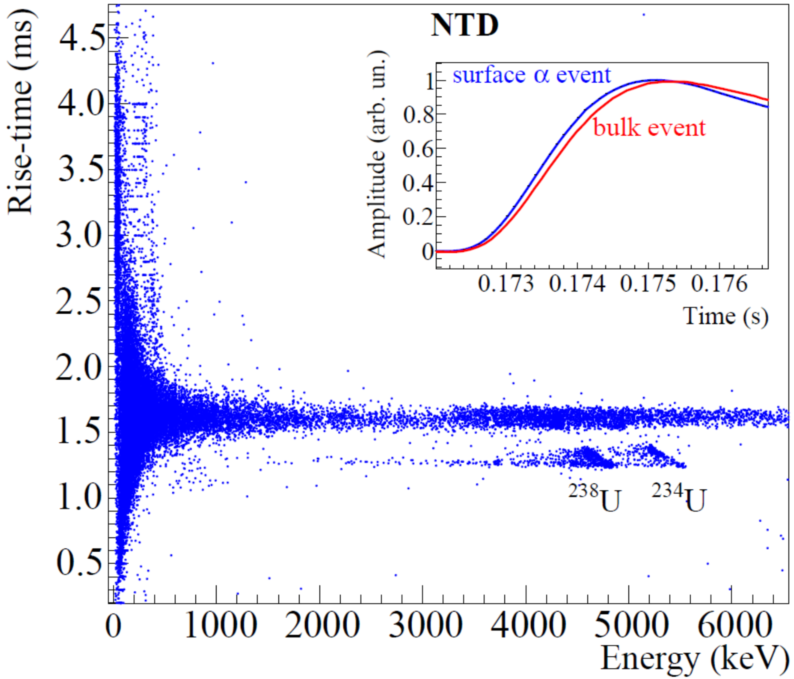
The idea is to induce a difference in the “phonon shower” of surface events w.r.t. bulk events. Some kind of induced PulseShape Modification



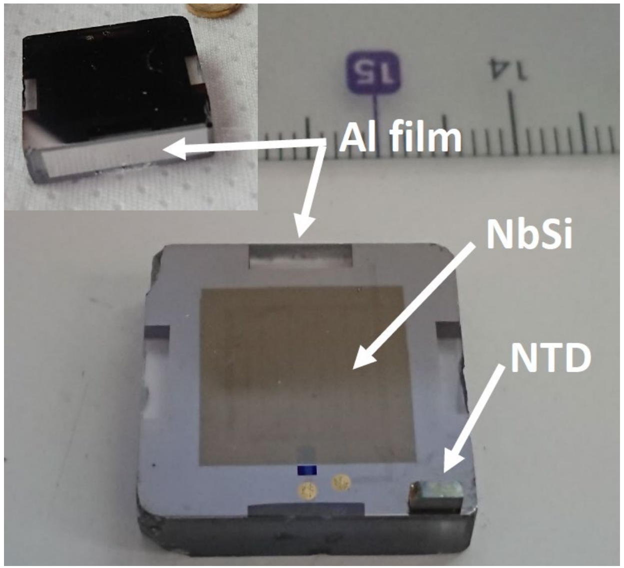
Hawraa Khalife these de doctorat (Paris-Saclay), Orsay 21-01-2021

The ultimate frontier: *pulse shape modifiers* (DBD)

The first measurement performed @ Orsay show that it is possible to disentangle



25x25x5 mm^3 TeO$_2$



Particle discrimination only through Heat

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Thank you !