TAUP VIENNA 2023

Edelweiss
Expérience pour DEtecter Les WIMPs En Site Souterrain

Sub-GeV dark matter searches with EDELWEISS & CRYOSEL

TAUP2023

28/08/2023

iP2i LES 2 INFINIS LYON

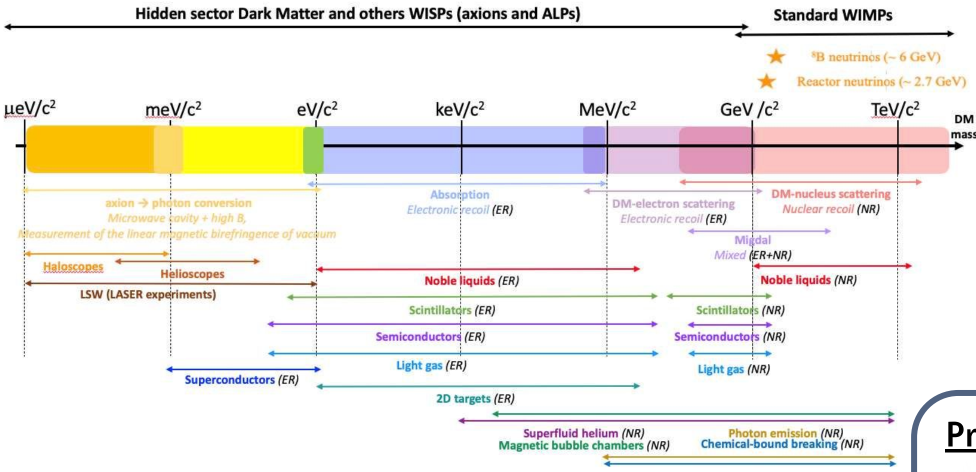
cnrs dépasser les frontières

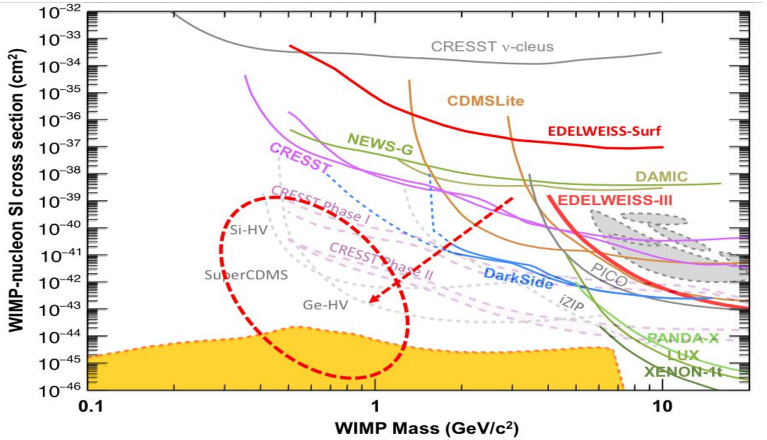
IN2P3 Les deux infinis

Elsa Guy

on behalf of the ***EDELWEISS collaboration***

EDELWEISS Sub-GeV program





Sub-GeV searches :
→ currently **background limited !**

Goals :

→ particle ID down to 1 GeV/c² and below,
→ improvement of resolutions down to σ_{phonon} = 10 eV (for thresholds) and σ_{ion} = 20 eV_{ee} (for discrimination at LV),
→ reach cross sections down to 10^{-43} cm²,
→ reduce background.

Progress in phonon channel :

→ Reduce detector mass : 17 eV achieved
EDELWEISS-Surf [PRD 99 082013 (2019)]
33 g Ge bolometer.

→ Apply HV to amplify signals : 1.6 eV achieved
Electron-DM results [PRL 125, 141401 (2020)]
78 V applied onto 33 g Ge bolometer.

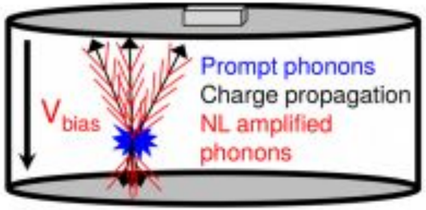
→ Probing bkg using TES : alternative phonon sensor
Migdal with NbSi TES [PRD 106 062004 (2022)]
200g Ge bolometer operated at 66V

→ ***Future collaboration with DM exp TESSERACT at LSM !***

The “heat-only” problem with HV

→ HO events = no charge produced
→ no charge produced = no NTL amplification

What is NTL ?

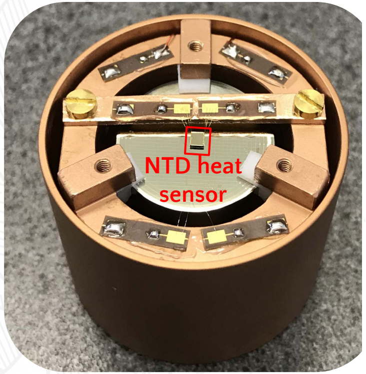


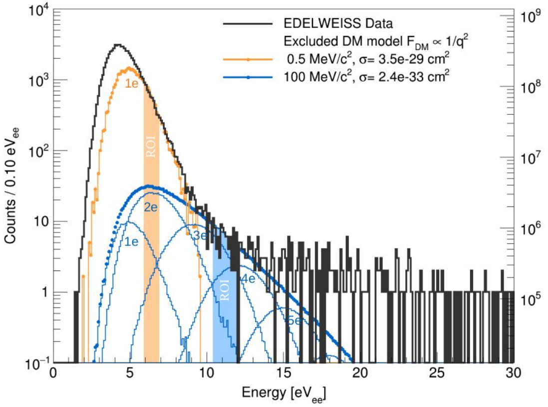
$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p \Delta V$$

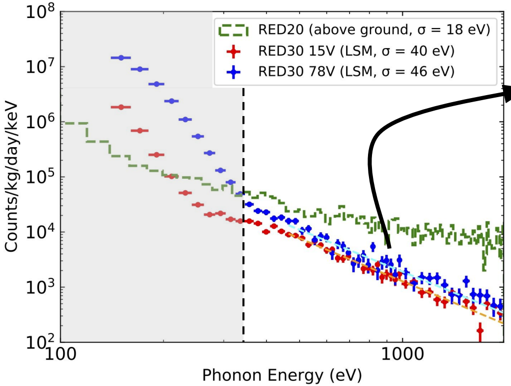
$$E_{heat} = E_{recoil}\left(1 + \frac{\Delta V}{\epsilon}\right) \quad \textit{particle-ID dependent}$$

→ HV = gain in resolution
→ **σ = 0.53 e⁻**
by applying 78V on a 33g Ge bolometer
[PRL 125, 141401 (2020)] @LSM

→ Toward **single e⁻/h⁺ pair** sensitivity in Ge



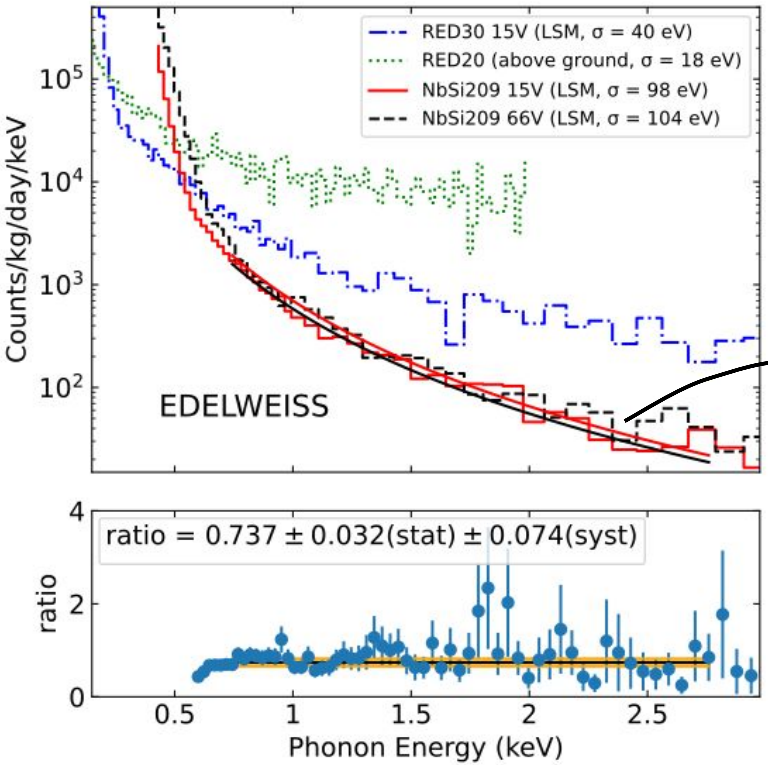


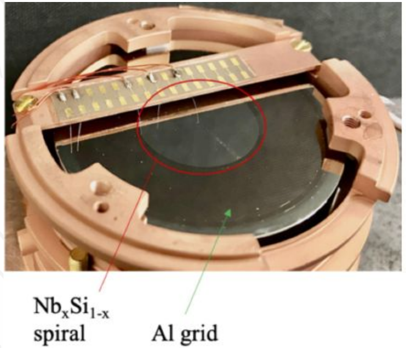


RED30 events not affected by NTL boost : 15V → 78V

Main limitation :
HO background !
→ Related to NTD readout ?

The "heat-only" problem athermal phonons





Use different type of phonon sensor : **NbSi TES**

NbSi phonon sensor events **still** not affected by NTL boost : **15V** → **66V**

Limit on events associated with charges **< 0.04%** above 0.8 keV. [PRD 106 062004 (2022)]

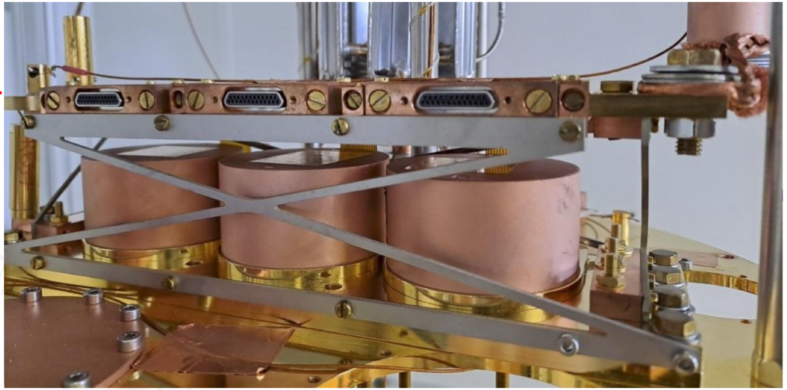
→ **Detecting athermal ballistic phonons does not get rid of HO events!**

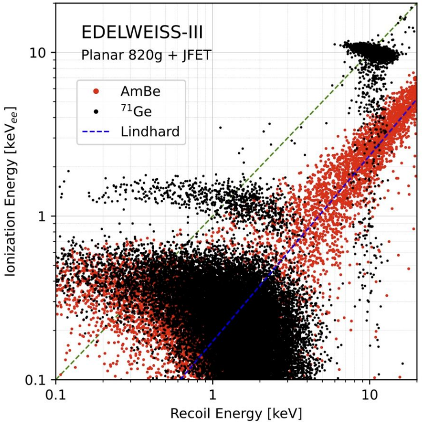
Tagging the presence of charge

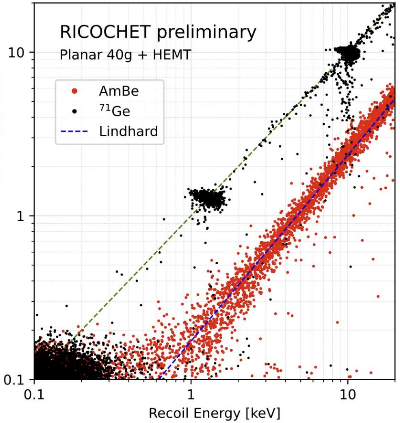
How can the **presence of charge** be tagged?

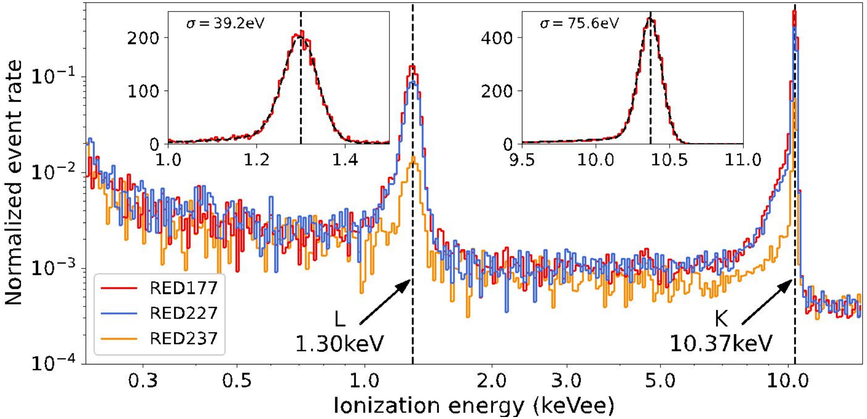
➔ Using charge read-out via electrode?
Joint R&D with RICOCHET **HEMT ionization readout**.

New result on 3x40g Ge detectors: **σ_{ion} in 30 eVee range** [arXiv:2306.00166] → x7 to x11 better than EDELWEISS-III ***but still limited to σ_{ion} ~ 10 e⁻ !***









→ Large gain in discrimination relative to EDELWEISS-III !

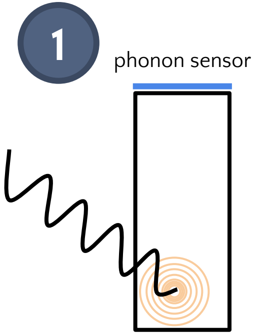
Tagging the presence of charge

How can the **presence of charge** be tagged?

➔ By tagging NTL phonons :

$$E_{phonon} = E_{primary} + E_{NTL}, \qquad E_{NTL} = N_{charge} * |V|$$

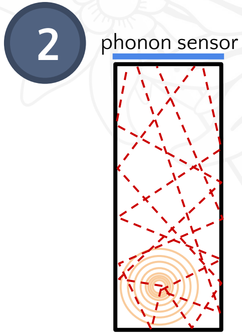
When applying electric field, charges emit additional phonons as they accelerate through the crystal (3) : we can selectively detect some of these phonons if they can be "localized" in a sensor with some position dependence : phonons must either have **short mean free paths** (primary phonons), or can be **very efficiently absorbed** by the nearby sensor (in the case of ballistic phonons).



Primary phonons

Short mean free path

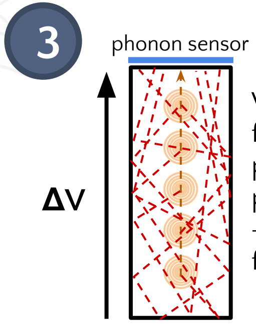
In general, **do not reach sensor**



Ballistic phonons
(from decay of primary phonons)

Long mean free path

Detectable in TES

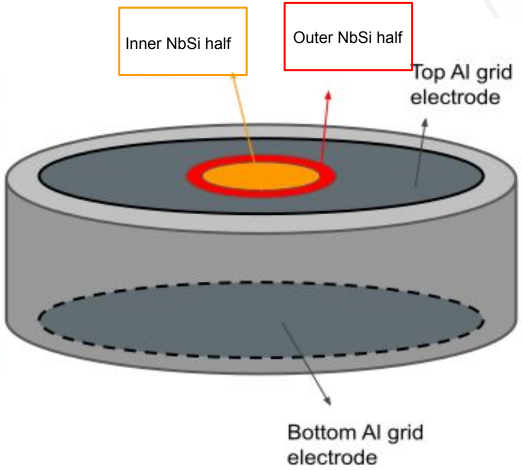


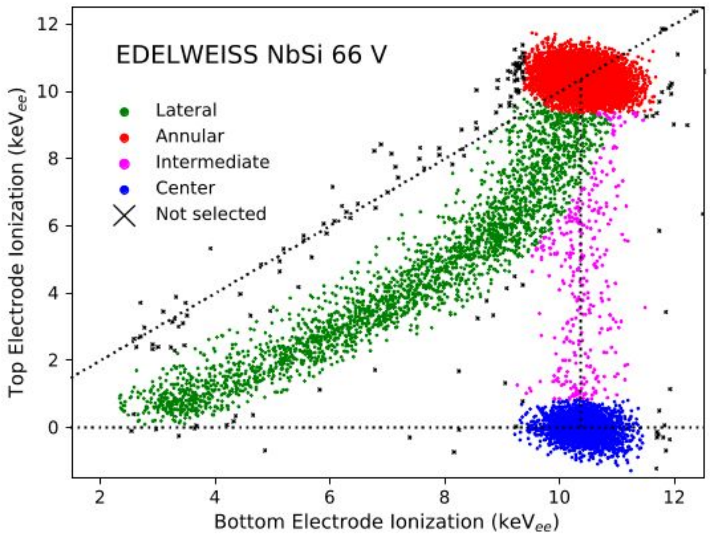
When applying an electric field → additional NTL phonons : **primary** + **ballistic** production **along field lines** → **primaries** at the end of field lines **detectable in TES**

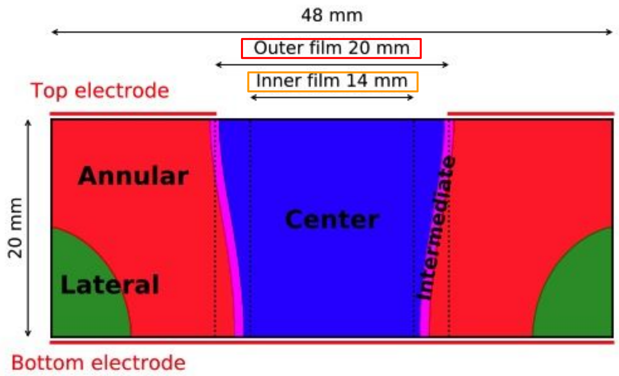
Tagging NTL phonons ?

→ Experimental confirmation :
[PRD 108, 022006 (2023)]

→ Electrode geometry makes it possible to identify charged events occurring right in the volume facing the sensor **(center)**



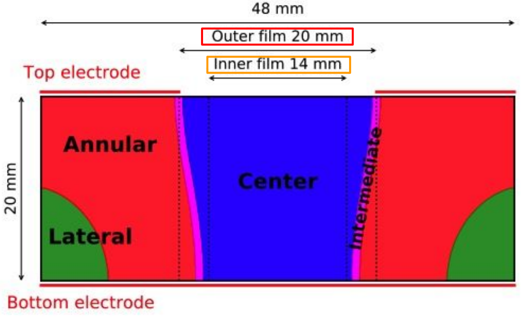




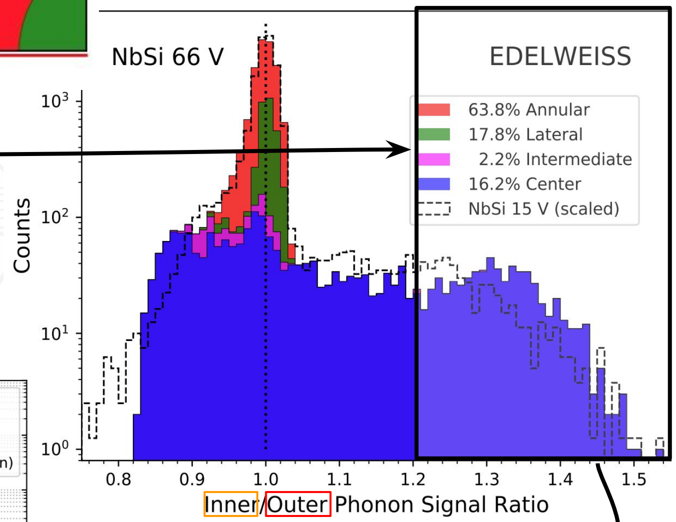
Tagging NTL phonons ?

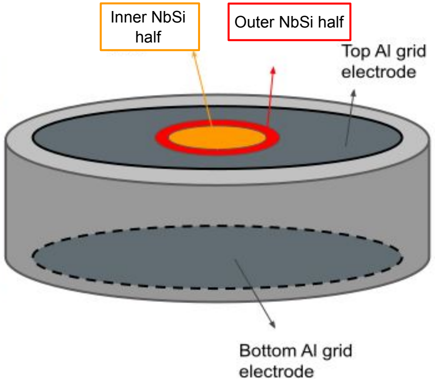
→ Clear signal of extra phonon in TES component (excess in inner part of the film) associated with NTL phonons emitted in this volume (center).

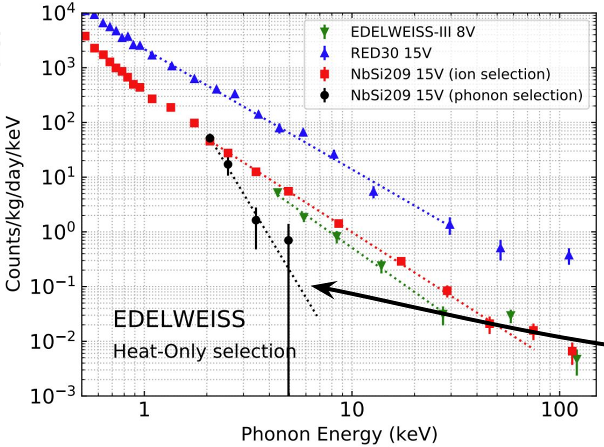
→ Tagging this component **rejects HO events**! Opens the possibility of a NTL phonon-based charge tag : **CRYOSEL**?



excess of events in inner film







rejection of HO!

CRYOSEL project

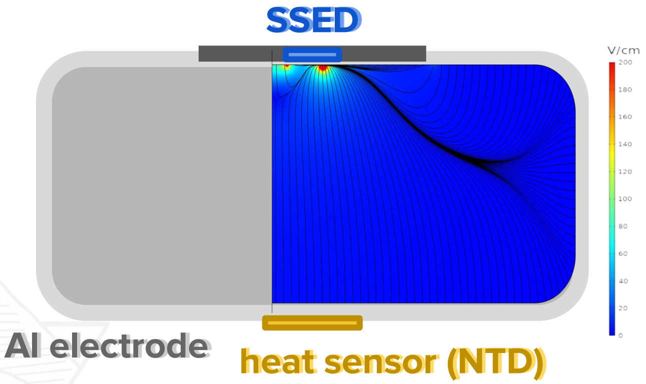
→ Reduce HO -> tag production of charges

→ keep NTD thermistance as a reliable heat sensor

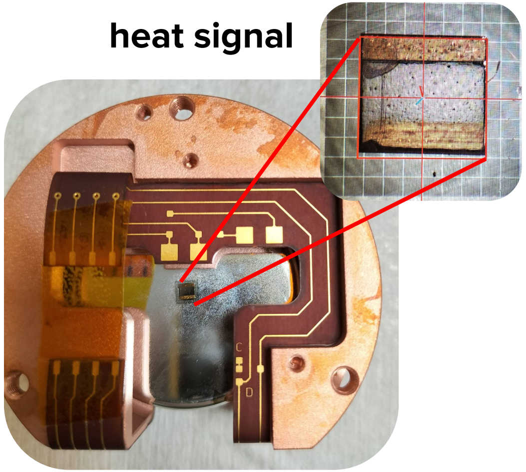
→new small sensor **SSED** "*Superconducting Single Electron Device*" :

field lines are constrained toward SSED → creation of "hotspot" of NTL phonons in direct vicinity of sensor

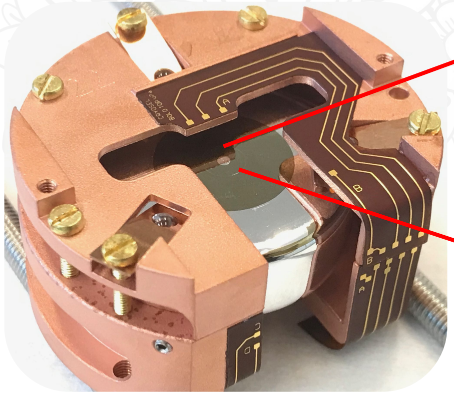
→ 40g Ge detector, **goals** : σ_{phonon} = 20 eV, 200 V bias,



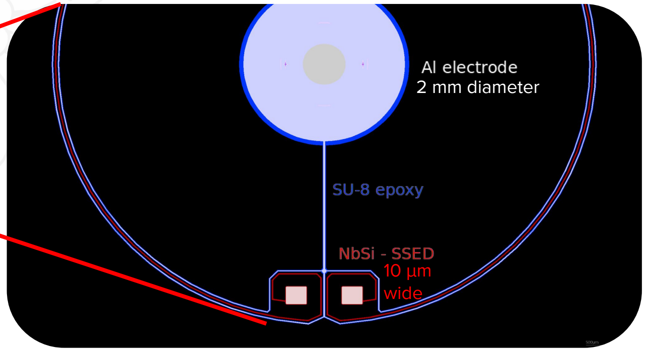
heat signal



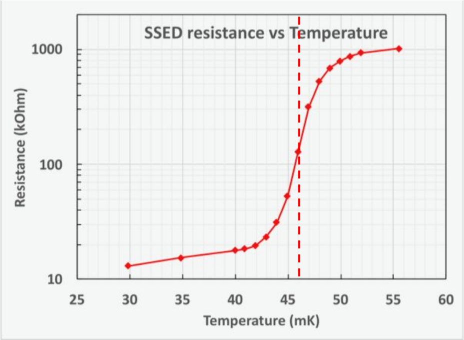
ionization signal



SSED signal



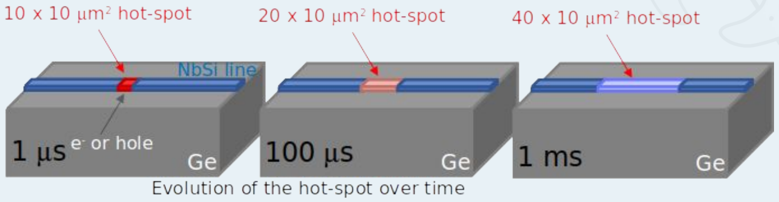
Characterizing SSED response



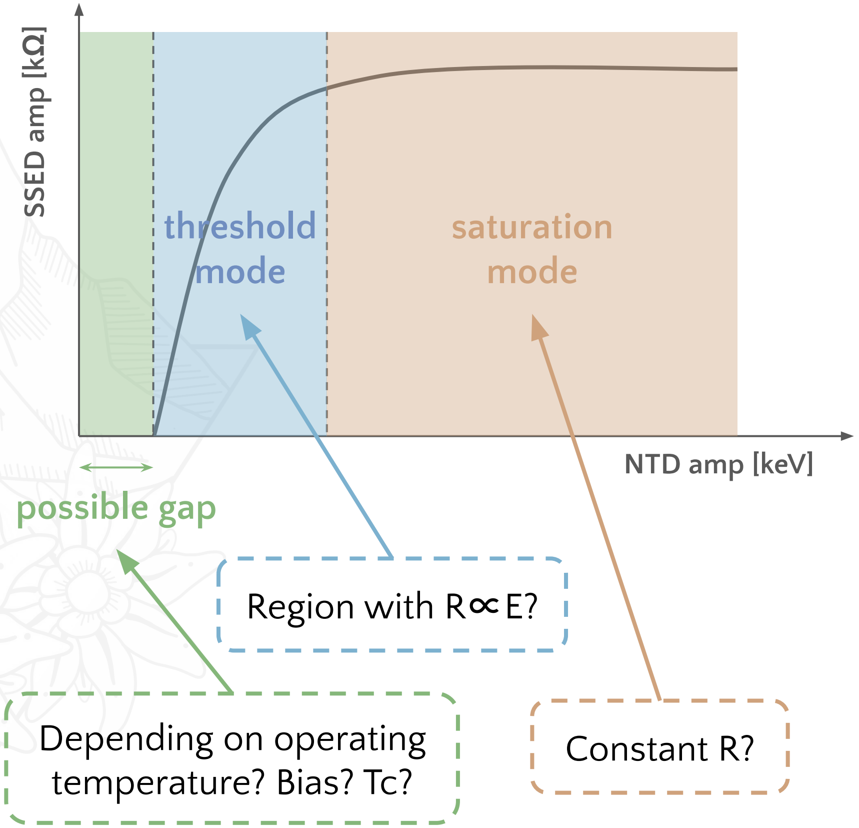
SSED → NbSi circular line 10 μm width, 5 mm diameter,
Operated at temperature T_{op} << Tc (prevent HO from triggering).
New technology, needs **first demonstration** of working principle

SSED Tc = 46 mK,
R_{SSED} = 1 MΩ for T_{SSED} > Tc

SSED pulse amplitude in kΩ
→ R_{SSED} ∝ portion of NbSi film that transitions

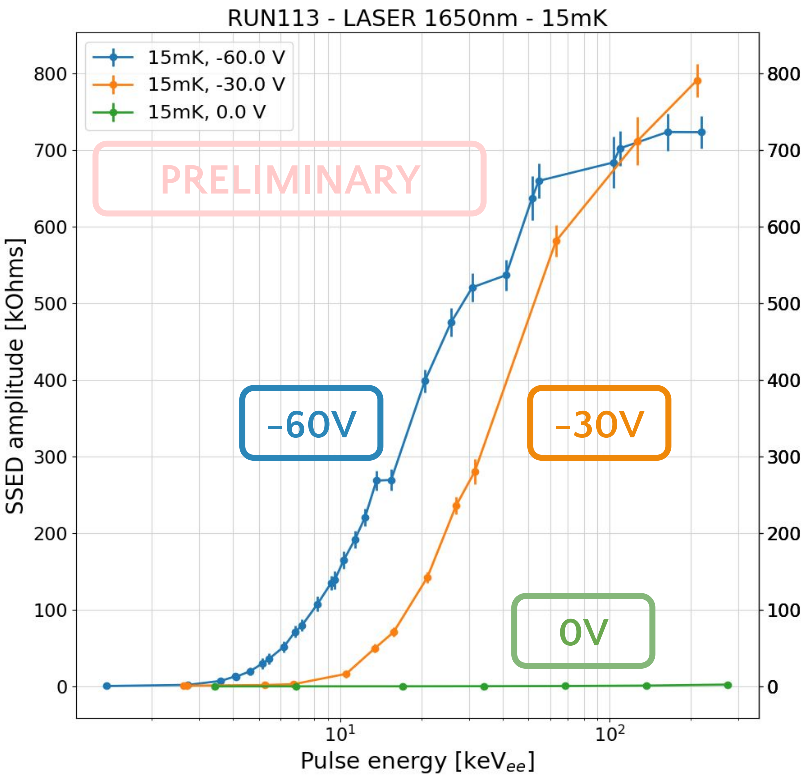


(from S. Marnieros)



→ **Let's verify this behavior!**

Characterizing SSED response : bias



↗ bias, ↘ threshold

→ Charge calibration using ^{71}Ge KLM lines,

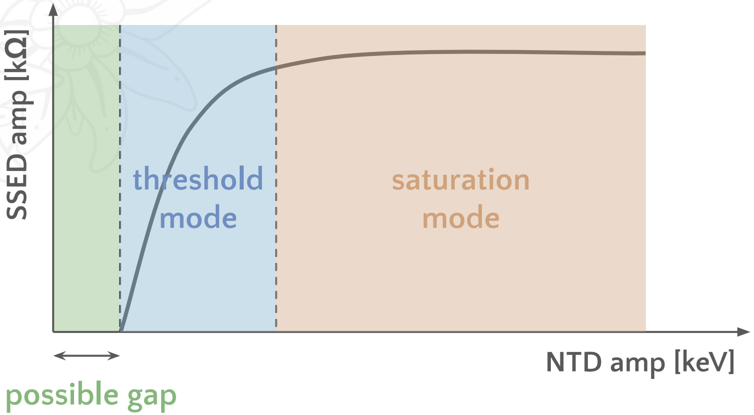
→ Use IR 1650 nm laser pulses to probe the whole crystal volume.

→ Response matches expectations :

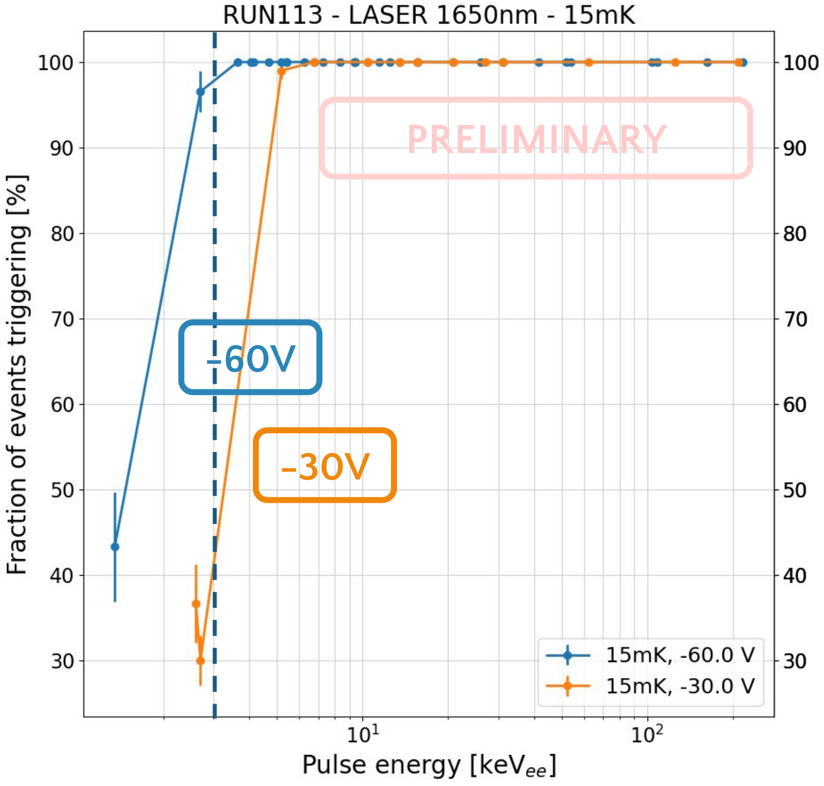
a **gap**, a **TES mode** and a **saturation mode**

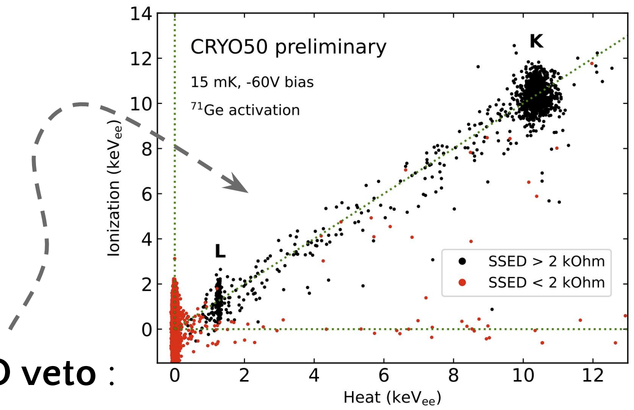
→ Larger bias lowers the threshold thanks to additional Luke phonons,

→ Presence of the energy gap, prevents HO contamination.



Characterizing SSED response : bias





→ SSED acts like **HO veto** :
require SSED amp > threshold
→ Here, 5σ threshold = 1.250 kΩ

At 60V : SSED trigger efficiency close to 100% at 2.6 keVee

Present threshold still far from single e⁻ goal → improvements in next prototypes : increasing phonon efficiency, maximum bias and reducing Tc.

Take away messages

→ Adapting EDELWEISS detectors to sub-GeV DM search :

- Discrimination at LV: joint development with RICOCHET of a 1K HEMT amplification, with 30 eVee resolution achieved
- Discrimination at HV: development of NbSi SSED sensor to tag charge and reject HO background → CRYOSEL.
- First prototype with SSED sensor confirms expected behavior, work to improve threshold in progress (lowering Tc, improve phonon collection efficiency, increase bias)

→ Excellent physics results expected starting with a single 40-g SSED detector (in BINGO@LSM)

→ LV and HV Ge detectors with background discrimination as proposal of contribution to TESSERACT@LSM.

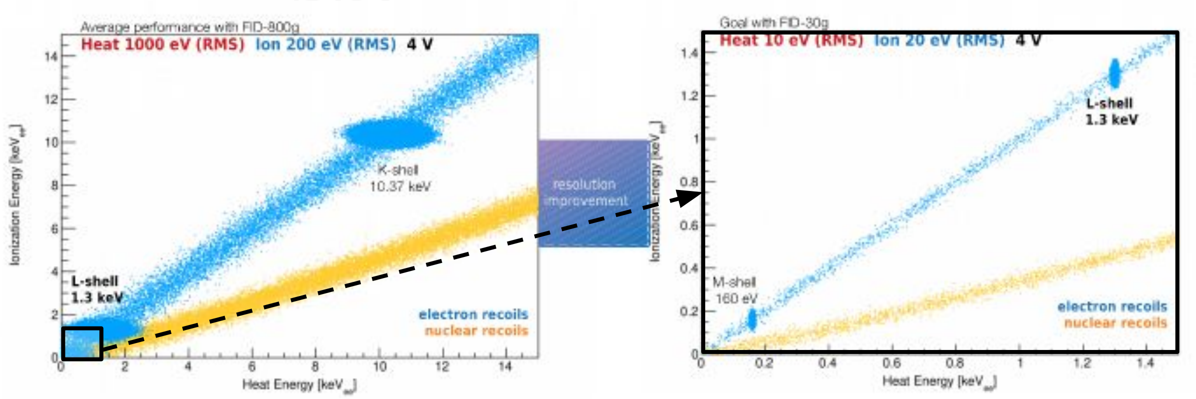
Thank you for your attention !

Back up

EDELWEISS Sub-GeV program

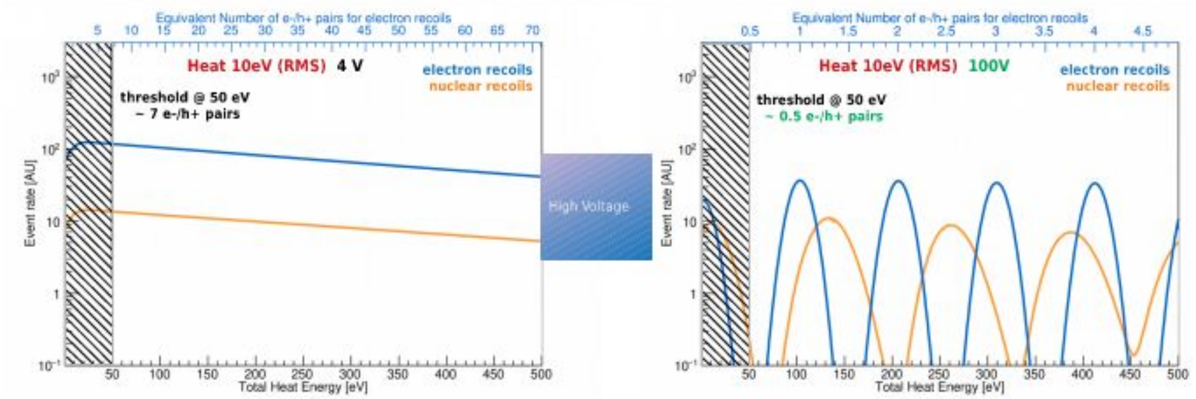
LV

Use ionization to discriminate ER/NR/HO



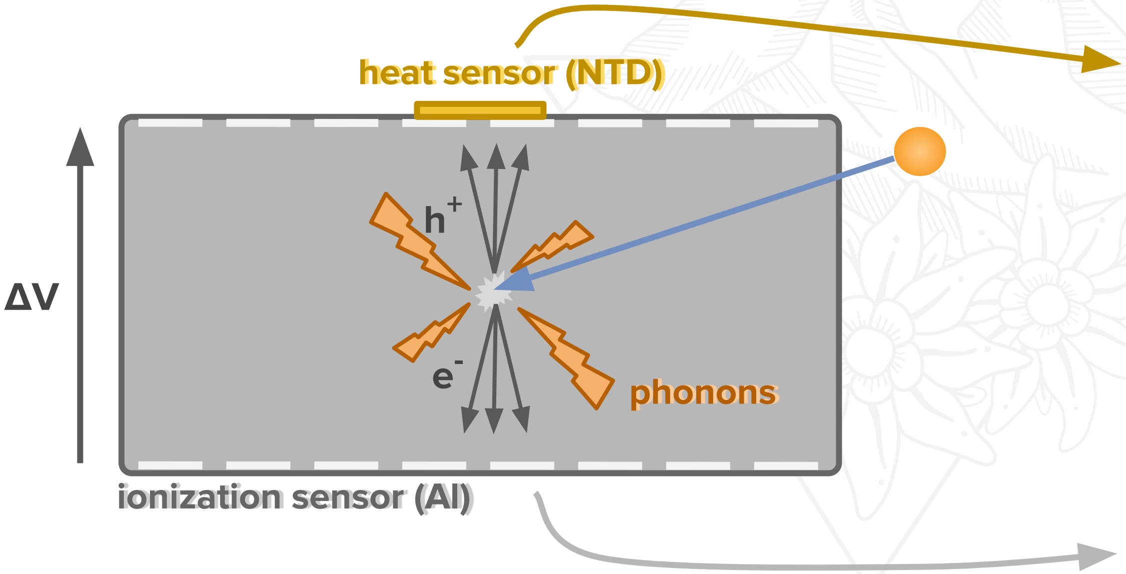
HV

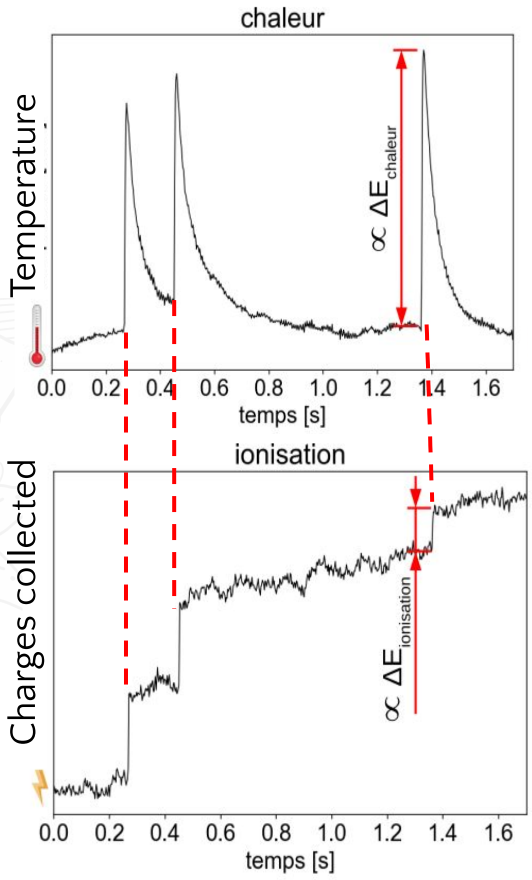
Use NTL amplification of phonon resolution to resolve single e^+/h^- pairs



Direct detection with EDELWEISS

→ Ge semiconductor cylindrical crystals (4 → 800g)
→ Simultaneous measurement: **heat** & **ionization**
→ Operated at cryogenic temperature ~16mK





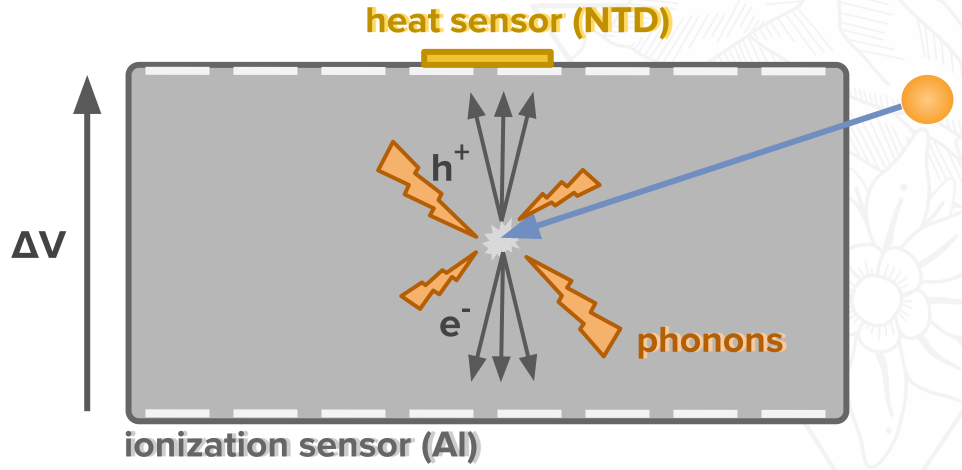
Direct detection with EDELWEISS

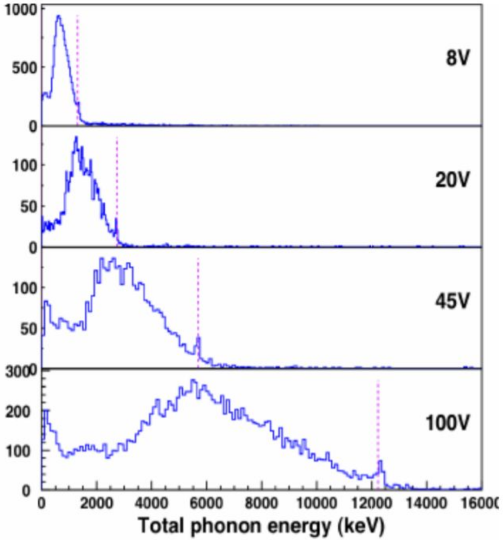
→ Ge semiconductor cylindrical crystals (4 → 800g)
→ Simultaneous measurement: **heat** & **ionization**
→ Operated at cryogenic temperature ~16mK

Luke amplification

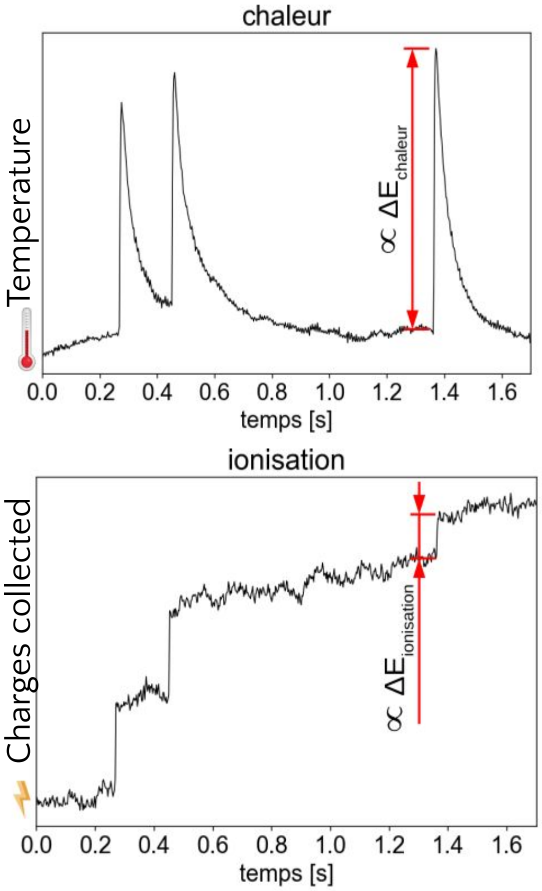
$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p \, \Delta V$$

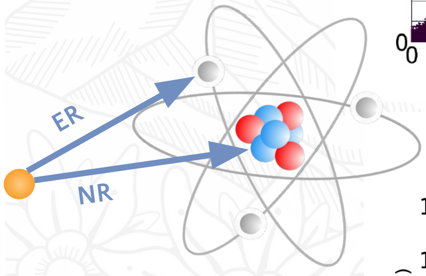
$$E_{heat} = E_{recoil}\left(1 + \frac{\Delta V}{\epsilon}\right) \quad \textit{particle-ID dependent}$$

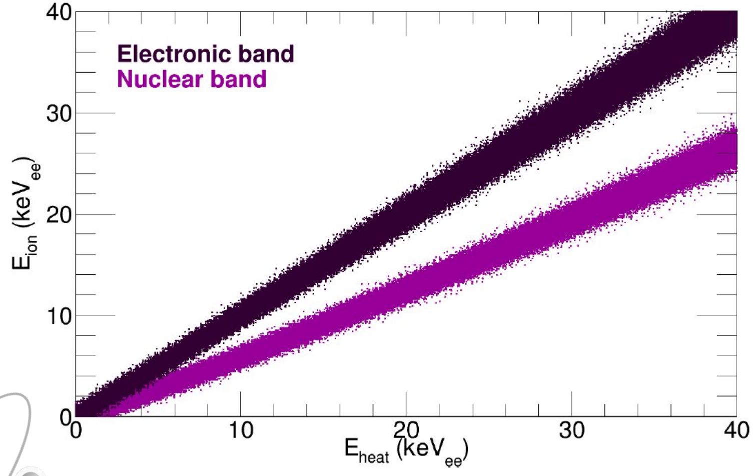


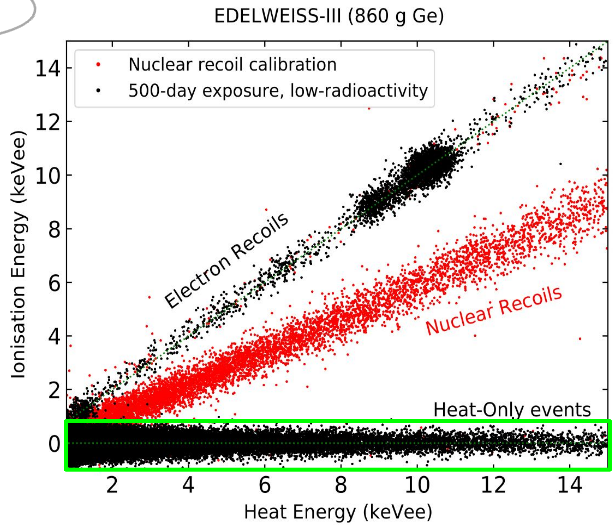


The problem of HO









LV - Ricochet low-voltage detectors

Joint R&D with Ricochet : HEMT (High Electron Mobility Transistor) ionization readout [JLTP 199, 798 (2020)]

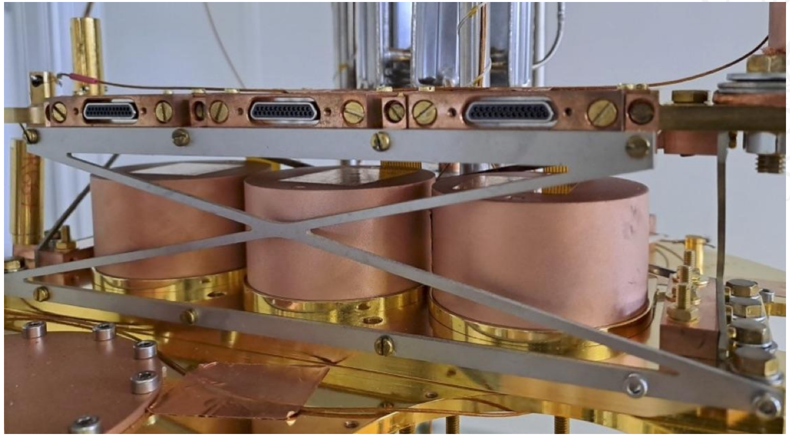
→ operated at ~1K

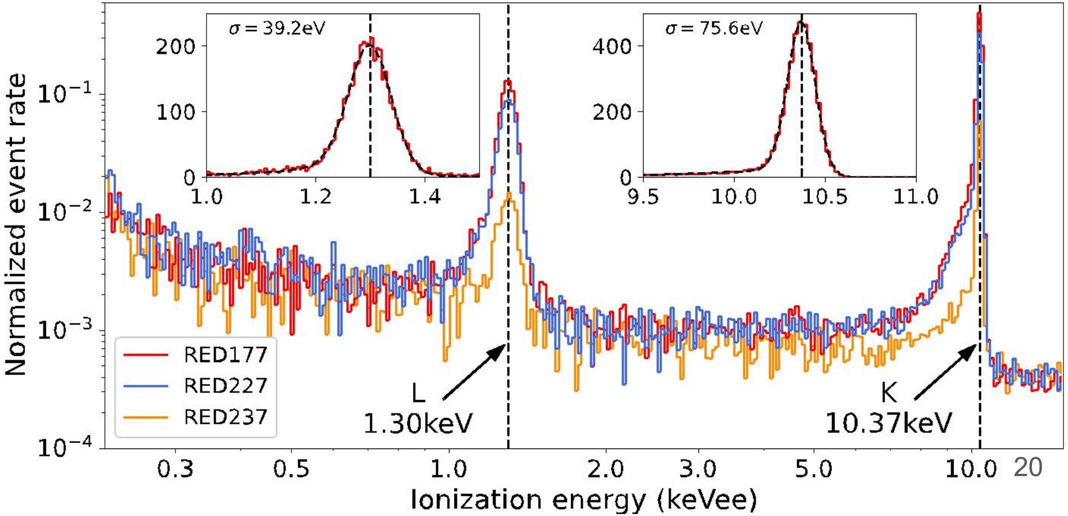
→ low-C detector & cabling

New result [arXiv:2306.00166 (2023)] : 3x 40g Ge Ricochet detectors with **σ_{ion} in 30 eV_{ee} range !**

→ x7 to x11 better than EDELWEISS-III

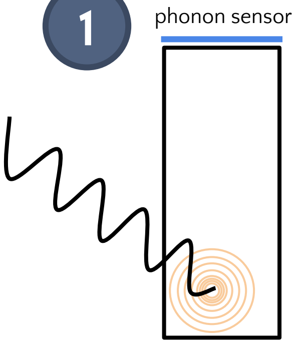
→ excellent prospects for HO rejection at low energy in DM searches





Different kinds of phonons and different sensors

1

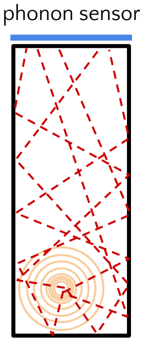


Primary phonons

Short mean free path

In general, **do not reach sensor**

2

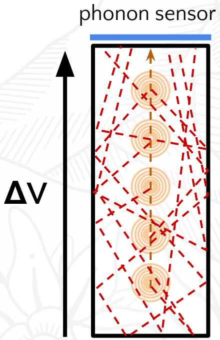


Ballistic phonons
(from decay of primary phonons)

Long mean free path

Detectable in TES

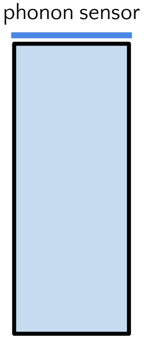
3 When applying an electric field :



Additional NTL phonons : **primary** + **ballistic** production **along field lines**

→ **primaries** at the end of field lines **detectable in TES**

4



Thermal phonons
(from decay of ballistic phonons)

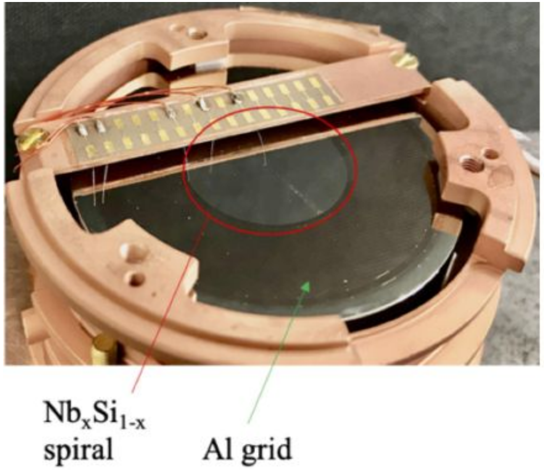
Detectable in Ge-NTD thermistance (as in RED30)

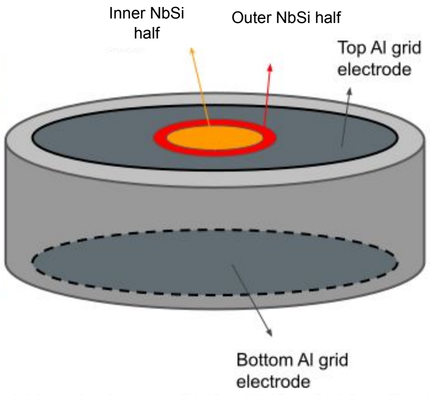
TES sensor

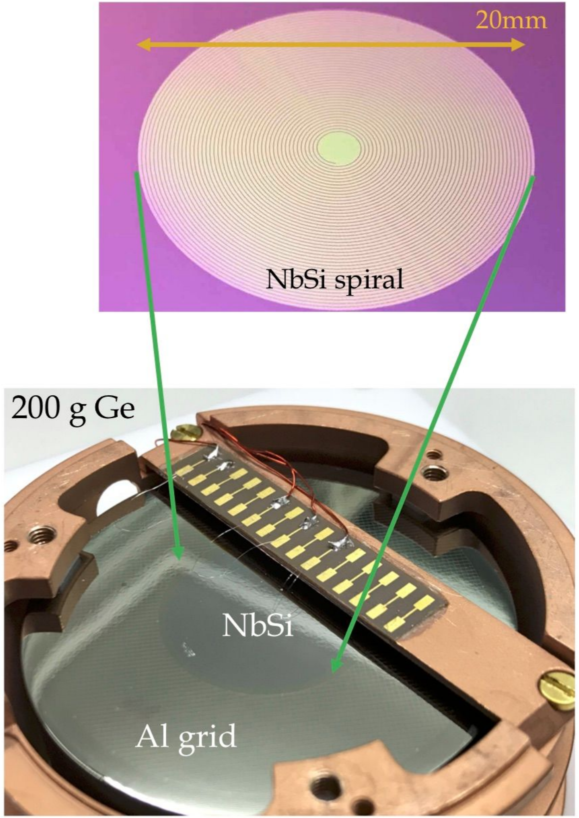
Ge-NTD sensor

NbSi TES athermal phonon sensor

NbSi TES : T_c = 44 mK
20 mm wide spiral
single 10 µm line
10 nm thick
split into two sensors

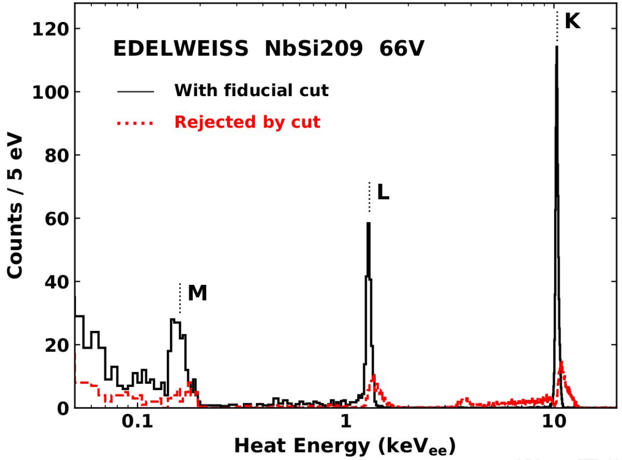


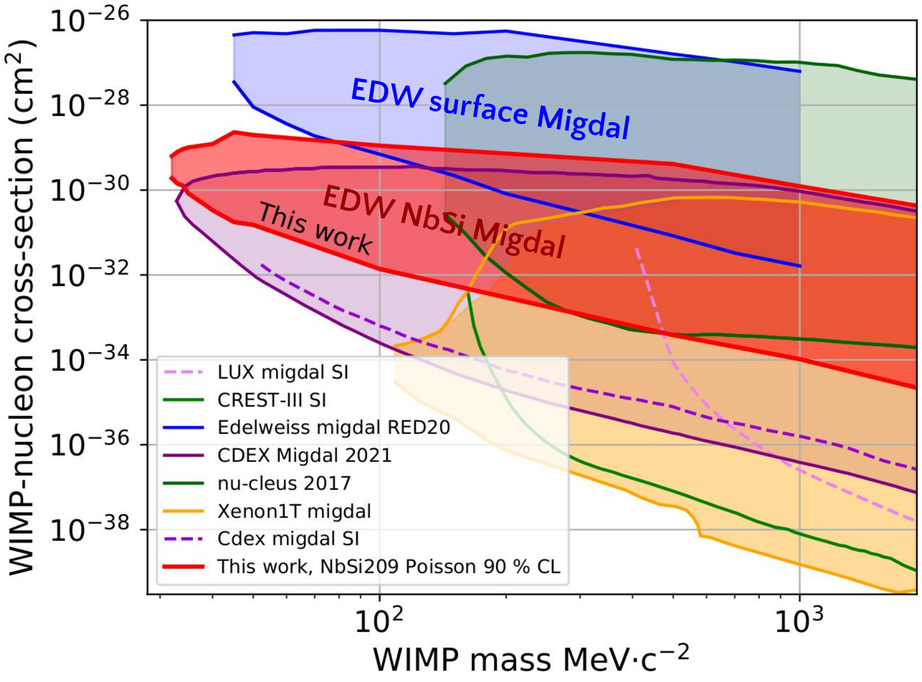




→ 200g Ge bolometer at LSM
→ **heat signal:** NbSi Transistor Edge Sensor (TES)
→ **ionization signal:** Al electrodes lithographed on top and bottom surfaces

NbSi TES athermal phonon sensor





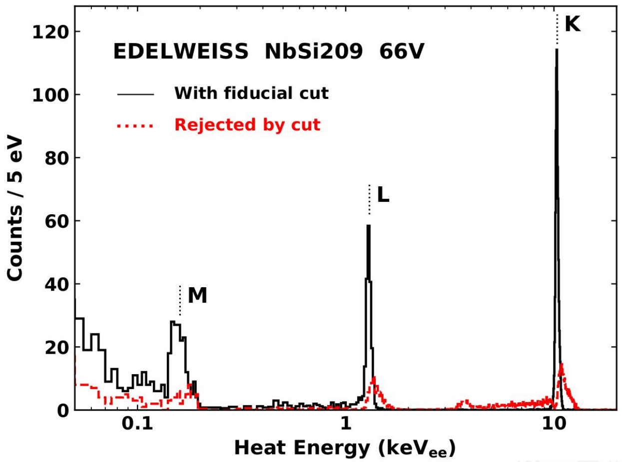
→ **Calibration from K, L, M, ^{71}Ge decay line**,

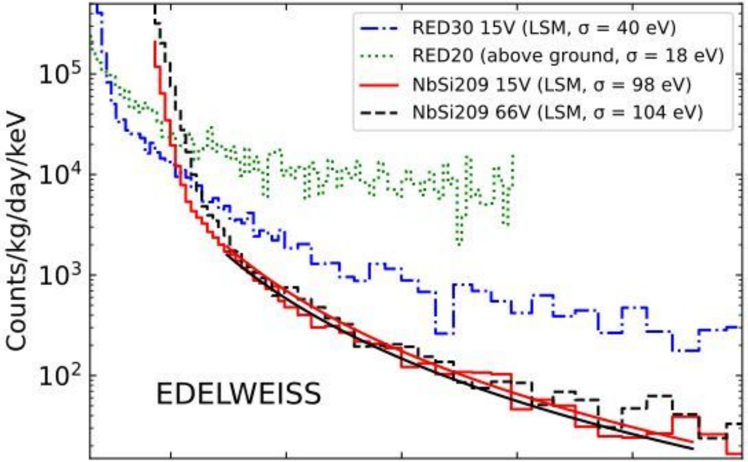
→ **Heat baseline resolution 100 eV** on total energy, i.e. **4.5 eVee** for ER at 66V,

→ Some HO reduction wrt NTD :

x100 improvement wrt previous EDW Migdal limits

NbSi TES athermal phonon sensor





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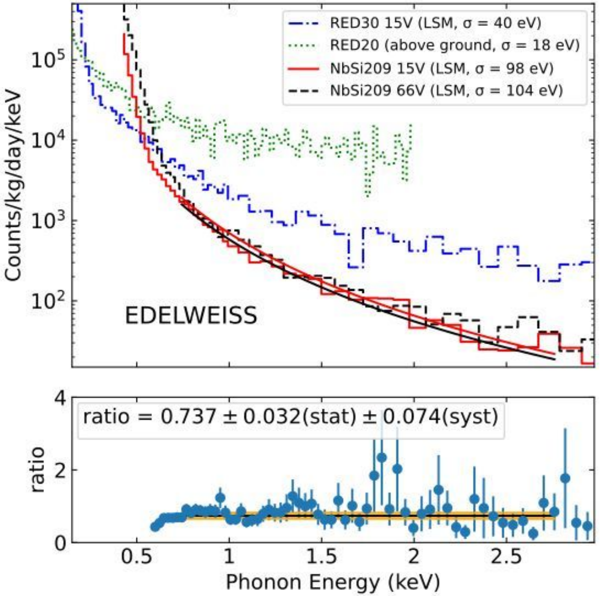
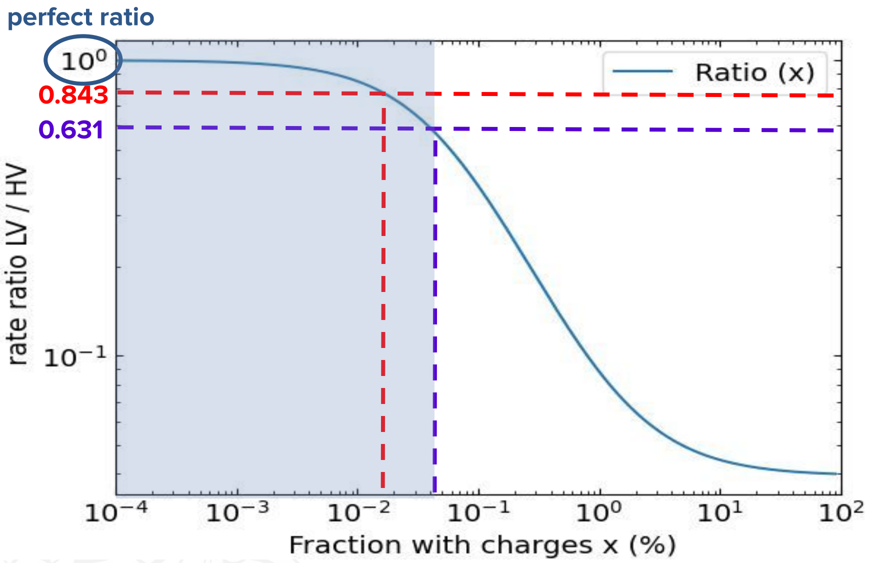
→ Some HO reduction wrt **RED30 & its NTD** :
x100 improvement wrt previous EDW Migdal limits
→ [PRD 106 062004 (2022)]
But NbSi209 events **still** not affected by NTL boost : **15V** → **66V**

→ **HO background is still the main limitation !**

NbSi TES athermal phonon sensor

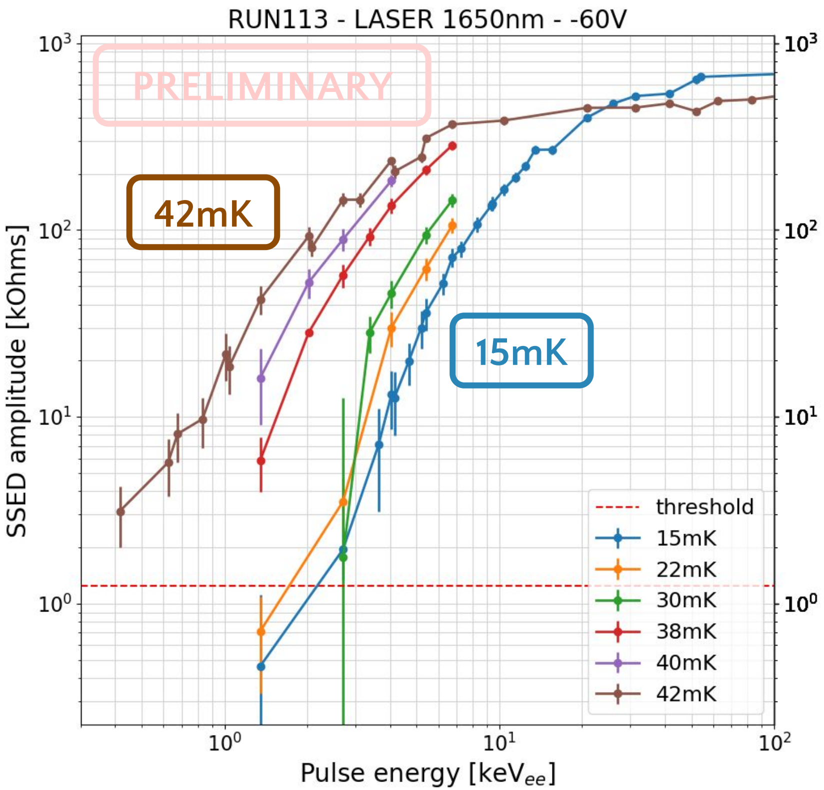
→ no production of charges
→ not affected by NTL boost !





→ Worst case scenario (ratio = 0.631) :
→ fraction of events producing charges = 0.04%.
→Phys. Rev. D 106, 062004 (2022)

Characterizing SSED response : temperature

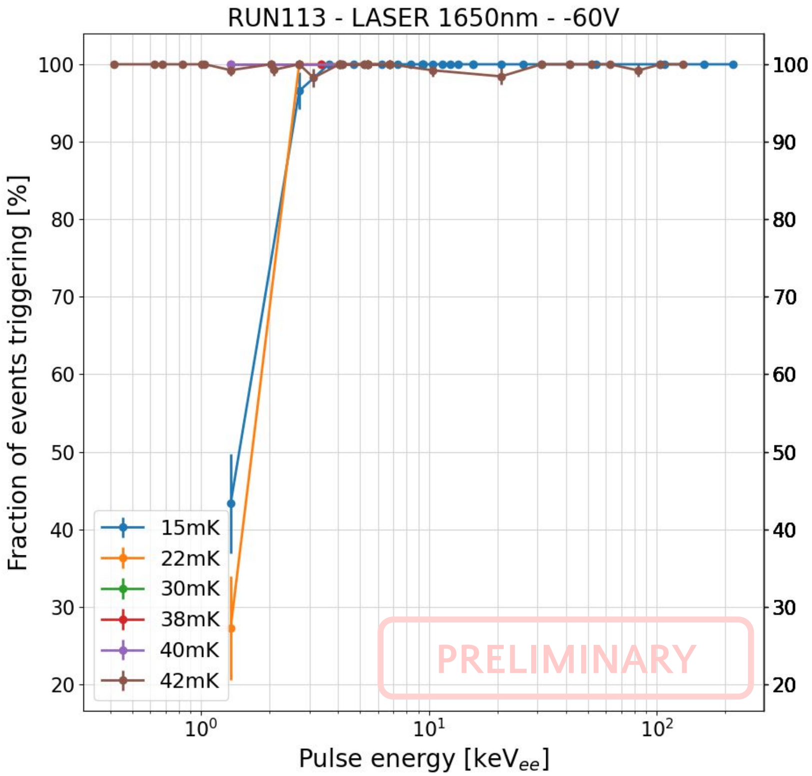


↗ operating temperature, ↘ threshold

→ The closer T_{op} is from T_c , the less energy the SSED needs to trigger

→ Importance of T_{op}/T_c gap in detector performance

Characterizing SSED response : temperature



→ SSED acts like **veto** :

needs to trigger for amp > threshold

→ Here, 5σ threshold = 1.250 kΩ

↗ operating temperature, ↘ T_{op}/T_c gap,

↗ trigger efficiency

→ 100% efficiency < 2 keVee at T_{op} = 38 mK (T_c = 46 mK)

→ Importance of T_{op}/T_c gap in detector performance

→ Next prototype w/ lower T_c (and higher maximum applied voltage)