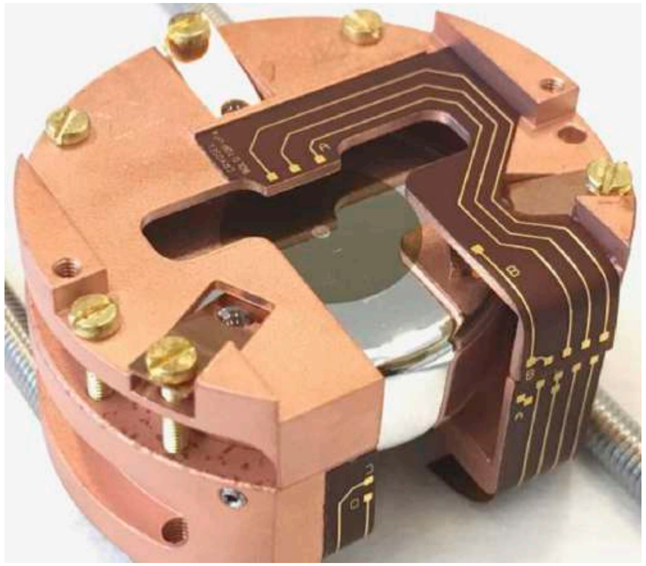
SubGeV Dark Matter searches with EDELWEISS and CRYOSEL



- EDELWEISS program for sub-GeV DM search with cryogenic Ge

- Recent results with athermal phonons using NbSi TES:

PRD 106, 062004 (2022) *Migdal search*

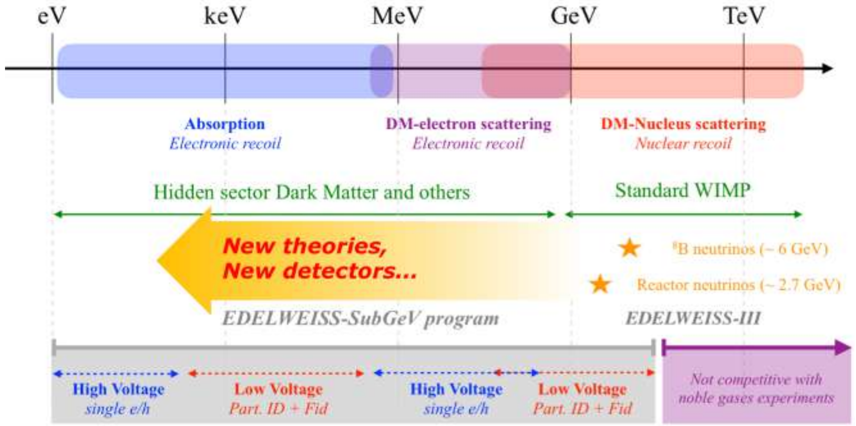
arXiv:2303.0267 *Heat-only background*

J. Gascon
Lyon 1, CNRS/IN2P3/IP2I
on behalf of the EDELWEISS collaboration

Edelweiss Sub-GeV program

New mass domain, new interactions…

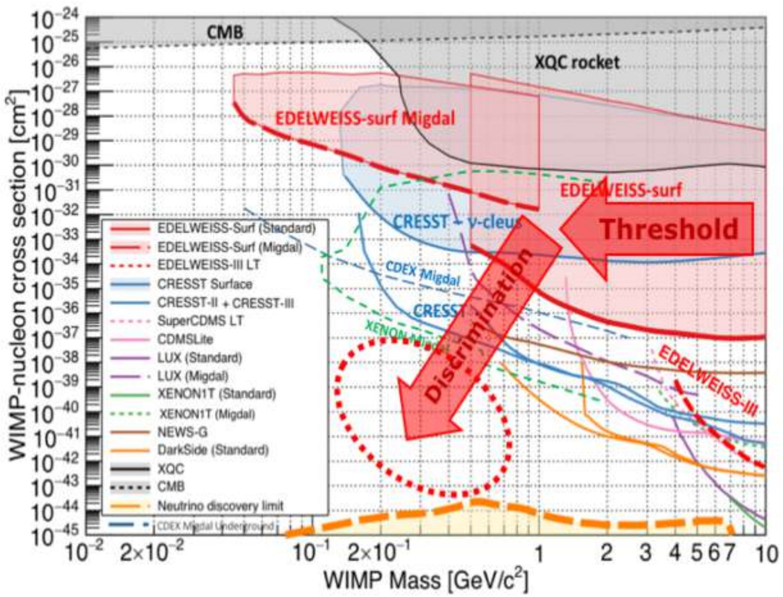
R. Essig + F. Reindl 's talks



- Current and future expts limited by bkgs:
  ➔ **improved threshold not sufficient, also require discrimination**
  - Electron/Nuclear recoils/"heat-only"
  - Surface/Bulk

- Challenge: **transposing rejection performance of EDELWEISS-III 860 g heat-and-ionization Ge detectors from keV to eV scales!**
  - Ex: few ~10^{-43} cm^2 @ ~1 GeV with ~kg-size array requires improving **σ_{phonon} x 50** and **σ_{ion} x 10**

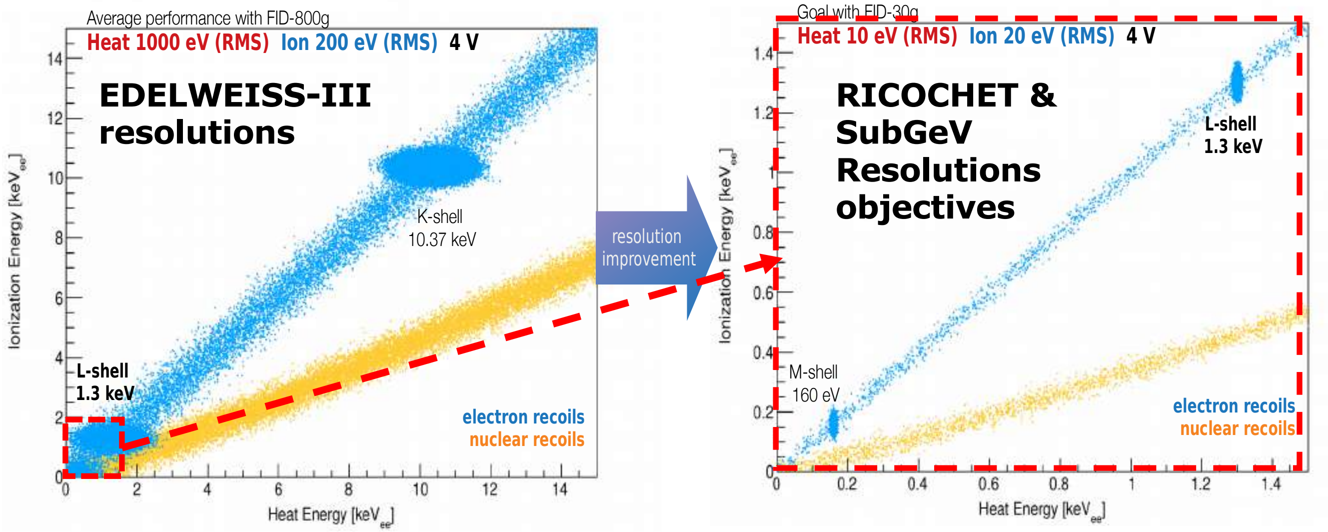
See P. Cushman's talk



Targets: *σ_{phonon} ~10 eV and σ_{ion} ~20 eV$_{ee}$*

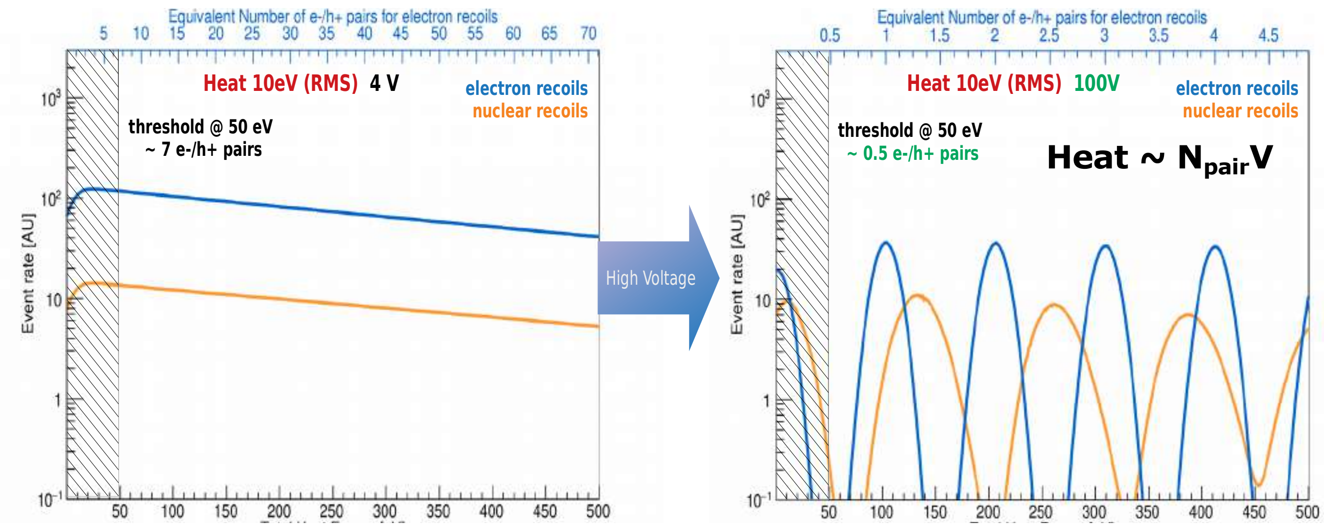
- **Common R&D with RICOCHET *(CENNS @ ILL)***
- Reduction of mass + sensor optimization: **EDELWEISS-SURF 17.7 eV** **[PRD 99, 082013 (2019)]**
- Keep ability to apply HV for phonon signal NTL amplification & sub-e$^-$ resolution.**[PRL 125, 141301 (2020)]**
  Milestone: RED30 electron-DM + DP results

EDELWEISS SubGeV two complementary modes



LV

➜ Use ionization to discriminate Electron Recoils, Nuclear Recoils and Heat-Only populations



HV

➜ Use Neganov-Trofimov-Luke amplification of phonon resolution to resolve single electron-hole pairs

… But ionization can't be used for discrimination at low E

LV: RICOCHET low-voltage detectors

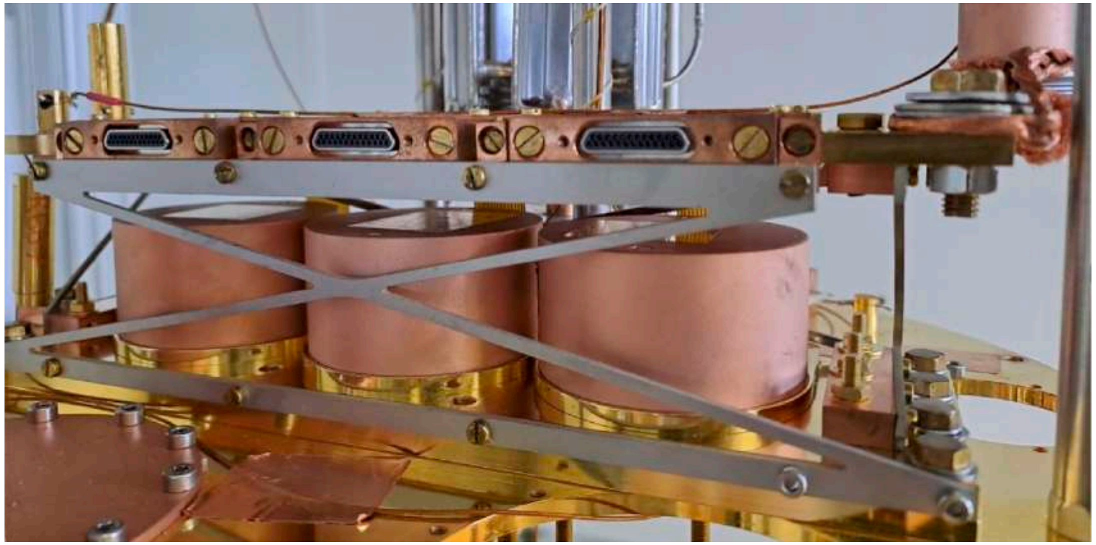
Joint R&D with RICOCHET:

HEMT ionization readout

High Electron Mobility Transistor, operated at ~1K

Low-C detector & cabling

[arXiv:2111.10308, JLTP 199, 798 (2020)]



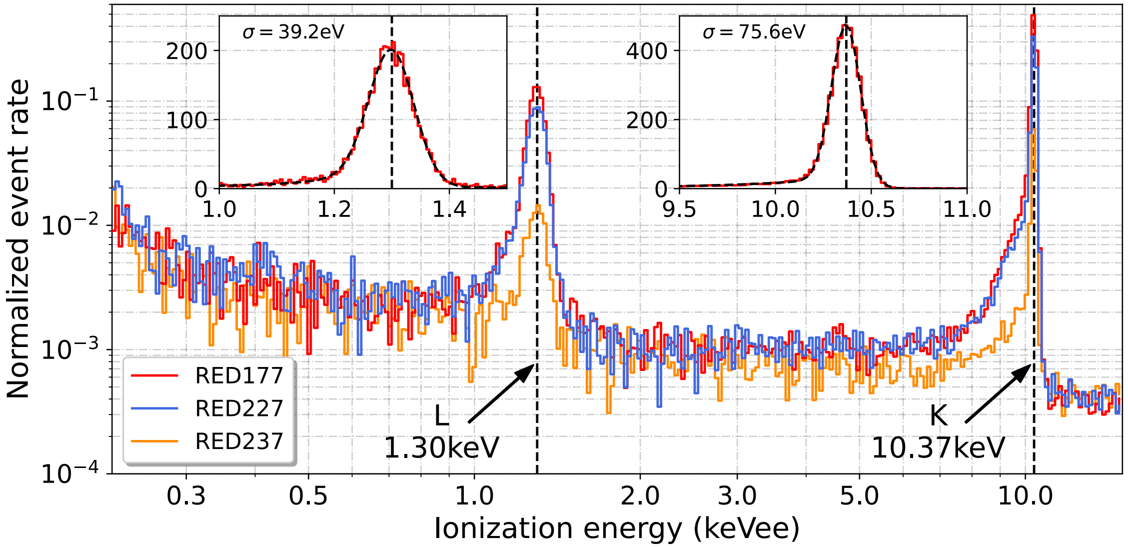
New result:

3x 40g Ge RICOCHET detectors with σ_{ion} in 30 eV_{ee} range

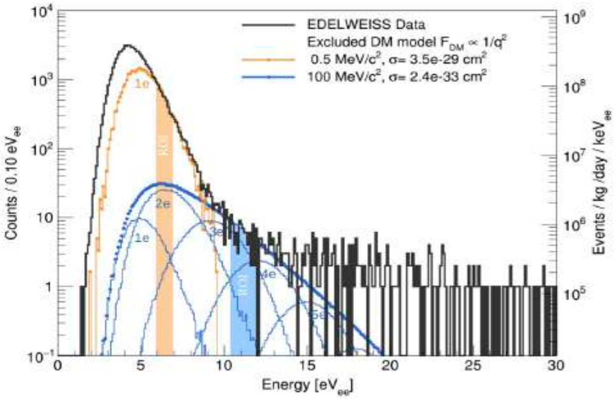
➔ *x7 to x11 better than EDELWEISS-III*

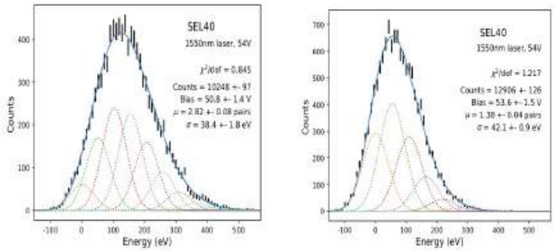
➔ Excellent prospects for HO rejection at low energy in DM searches

J. Billard, Magnificent CENNS 2023



HV: NTL-amplified Ge detectors





[JLTP 209, 263 (2022)]

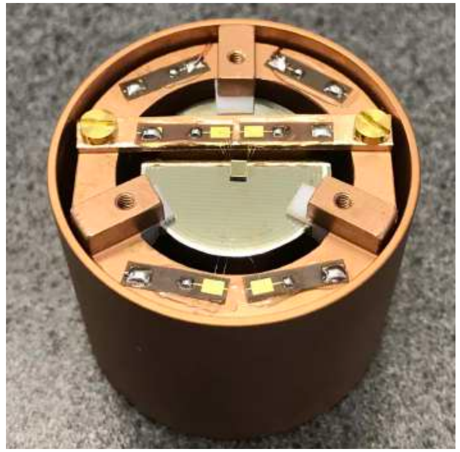
RED30: 33 g Ge + NTD

[PRL 125, 141301 (2020)]

σ = 0.53 e- @78V in Ge @LSM

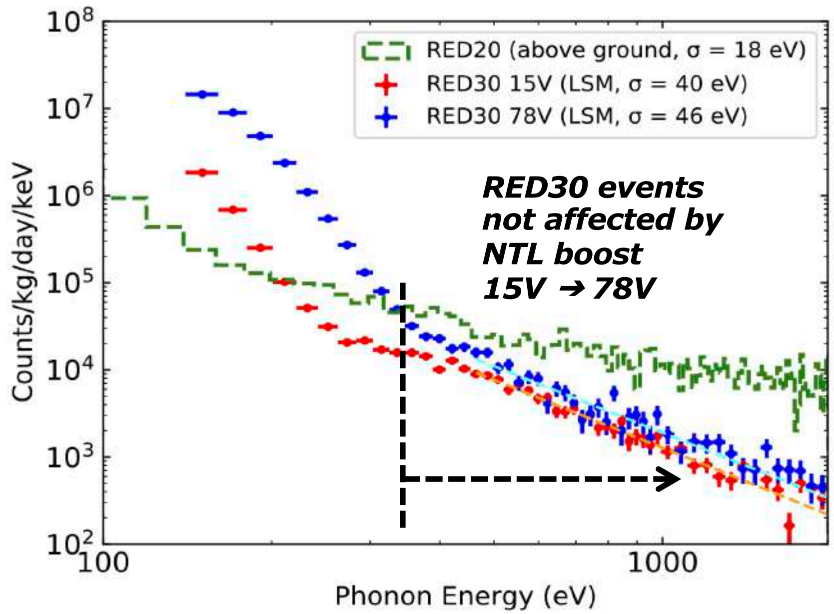
Toward single e$^-$-hole pair sensitivity in Ge

Competitive DM-electron + Dark Photon limits

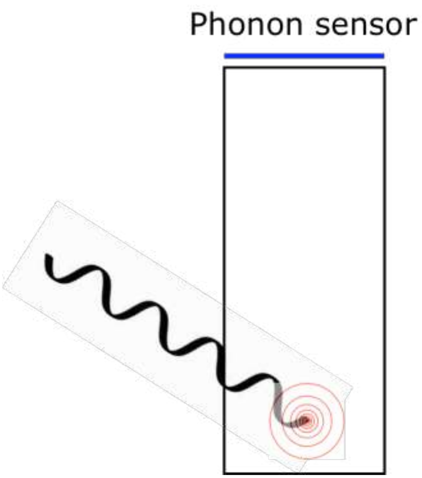


➔ *Main limitation is not resolution, but Heat-Only background*

Must be controlled to benefit from improvements in resolution & HV
Is bkg related to NTD readout?



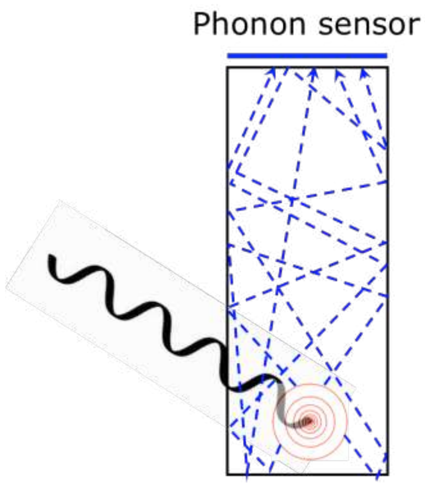
Different kinds of phonons



Primary phonons

Short mean free path

In general, do not reach sensor

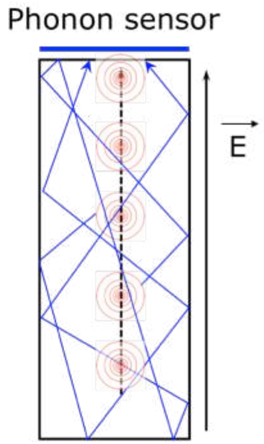


Ballistic phonons
From decay of primary phonons

Long mean free path

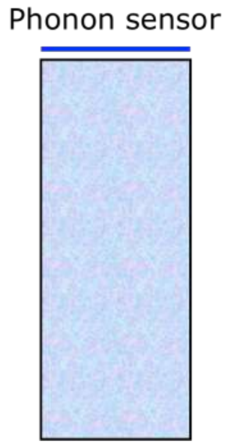
Detectable in TES sensor

If $\vec{E}$ field applied



Additional NTL phonons
"Primary" +
Ballistic
production
along field lines

Primaries at end of field lines detectable in TES sensor



Thermal phonons
From decay of ballistic phonons

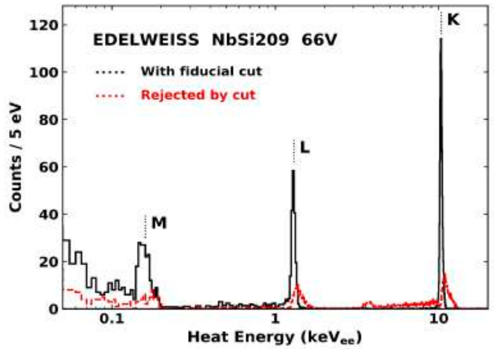
Detected by Ge-NTD thermistance

HO signal difference between TES and NTD?

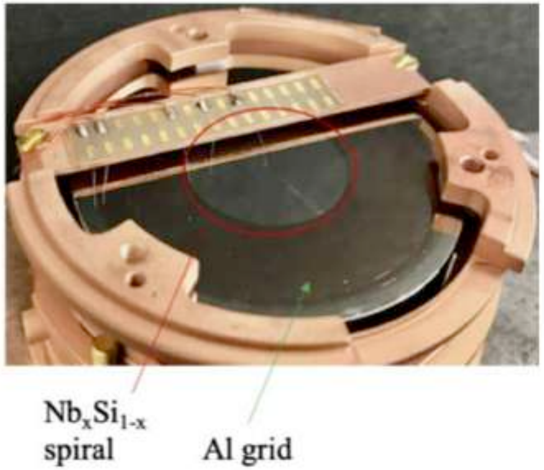
NbSi TES athermal phonon sensor

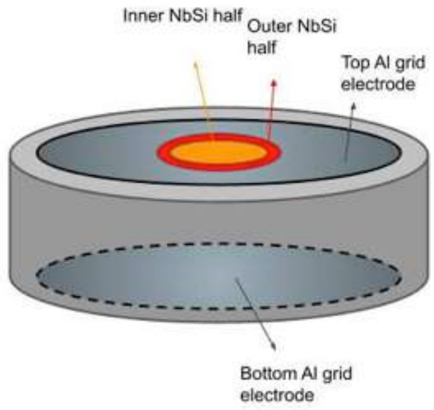
PRD 106, 062004 (2022)

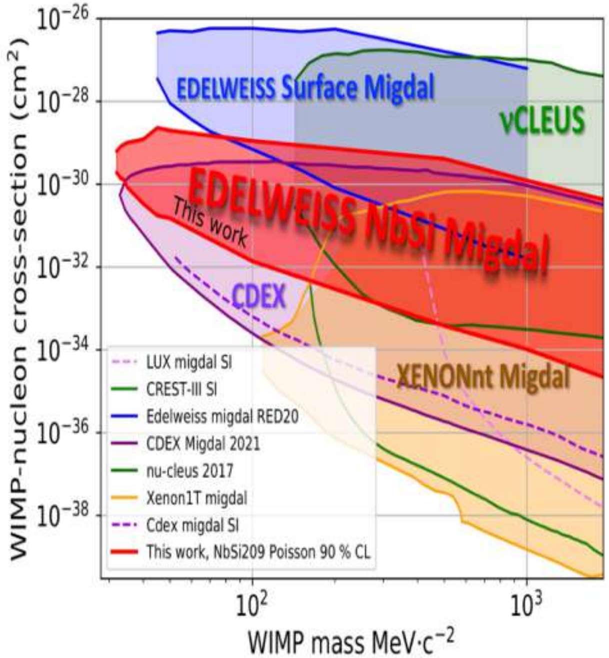
- **200 g Ge detector @ LSM**
- TES = 20 mm wide NbSi spiral (single 10 μm line, 10 nm thick, split in two sensors) with T_c = 44 mK
- **σ = 4.5 eV_{ee} @ 66V**



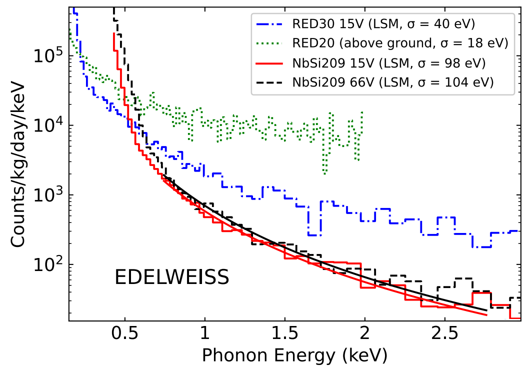
- Some HO reduction wrt NTD: X 100 improvement wrt previous EDW Migdal limits
- **... But HO background is still the main limitation!**







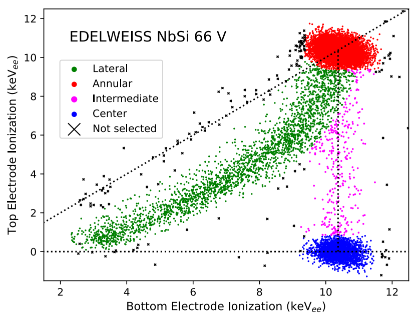
HO nature of background derived from absence of NTL amplification between 15V ➔ 66V

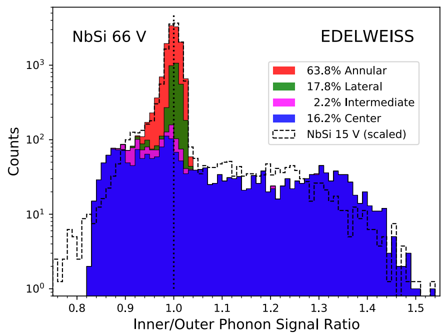


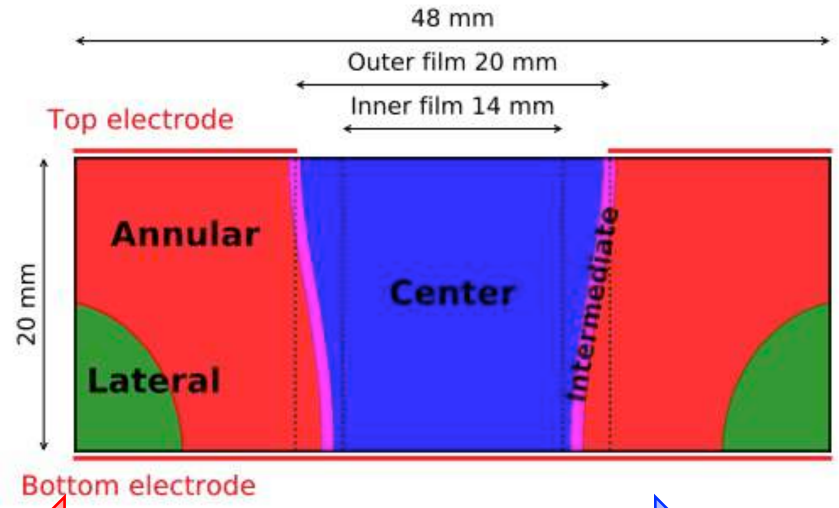
HO with high-energy NTL phonons

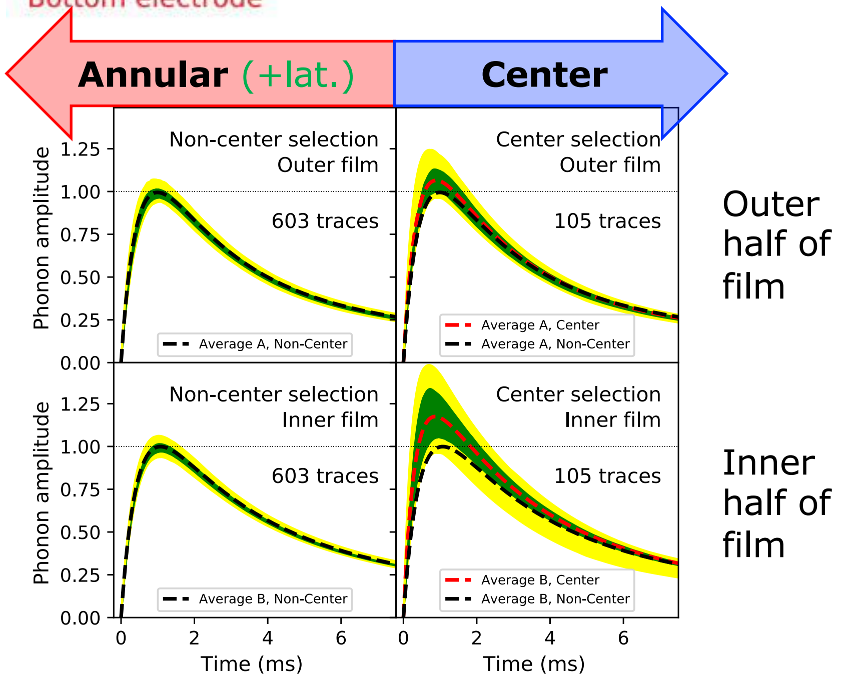
New arXiv:2303.02067

- Previous results obtained from **annular** region, where *field lines do not intersect the NbSi film*
- Signal from **center** region shows sign of sensitivity to primary NTL phonons : prompt signal excess
  - in only one of the two 1/2 of the film
  - faster risetime
  - amplitude scales with applied bias





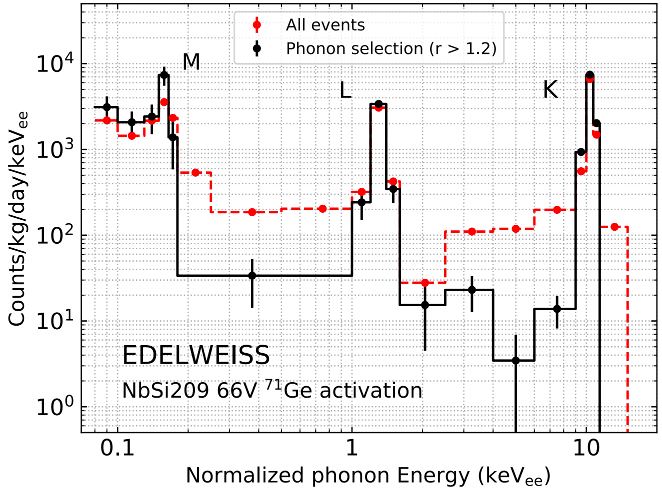




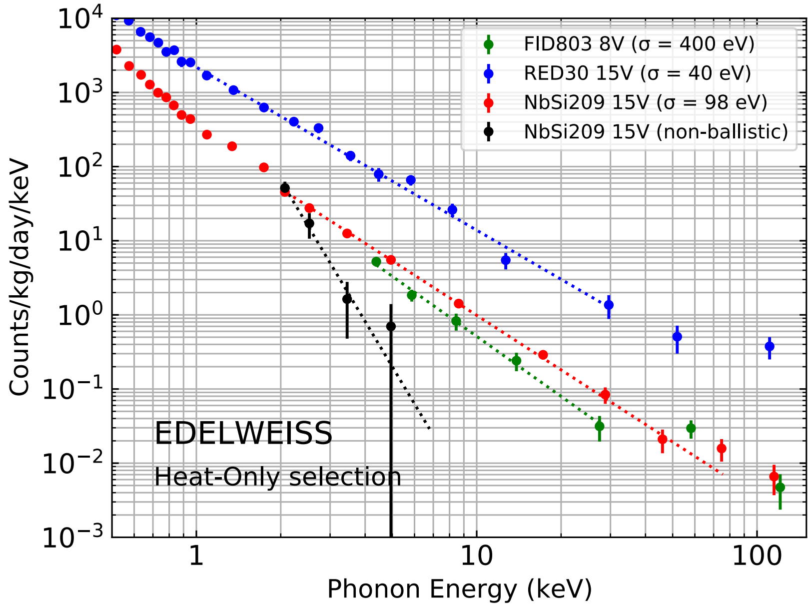
- **Interpretation confirmed using localization provided by signal on top & bottom electrodes**

Position-dependent phonon signal

- **Tag non-ballistic NTL phonons using inner/outer film asymmetry**
  - Reduced efficiency to 4.6% of 200 g
  - Eliminates events from outer edge of detector (as seen on tail of mis-collected charge events of ^{71}Ge K and L lines)
- **Tag of ionizing events!**
  - Migdal limits improved by x2.8 at 1 GeV
- **Significant reduction of HO bkg**
  - factor >5 @ 90%C.L. (statistics limited)
  - phonon resolution limit tag to >150 keV_{ee}



arXiv:2303.02067



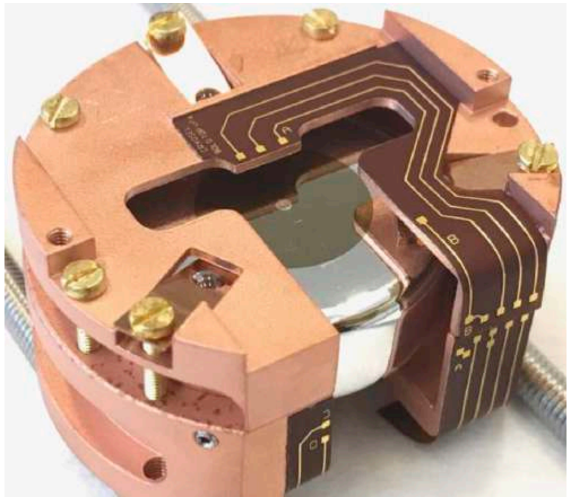
Wishlist for use as DM detector:

- Improve energy resolution (go back to NTD to get RED30 sub-e resolution?)
- Increase volume where NTL-boosted events can be detected, i.e field lines end on NbSi film
- But reduce efficiency to HO events randomly distributed in volume (or surface)

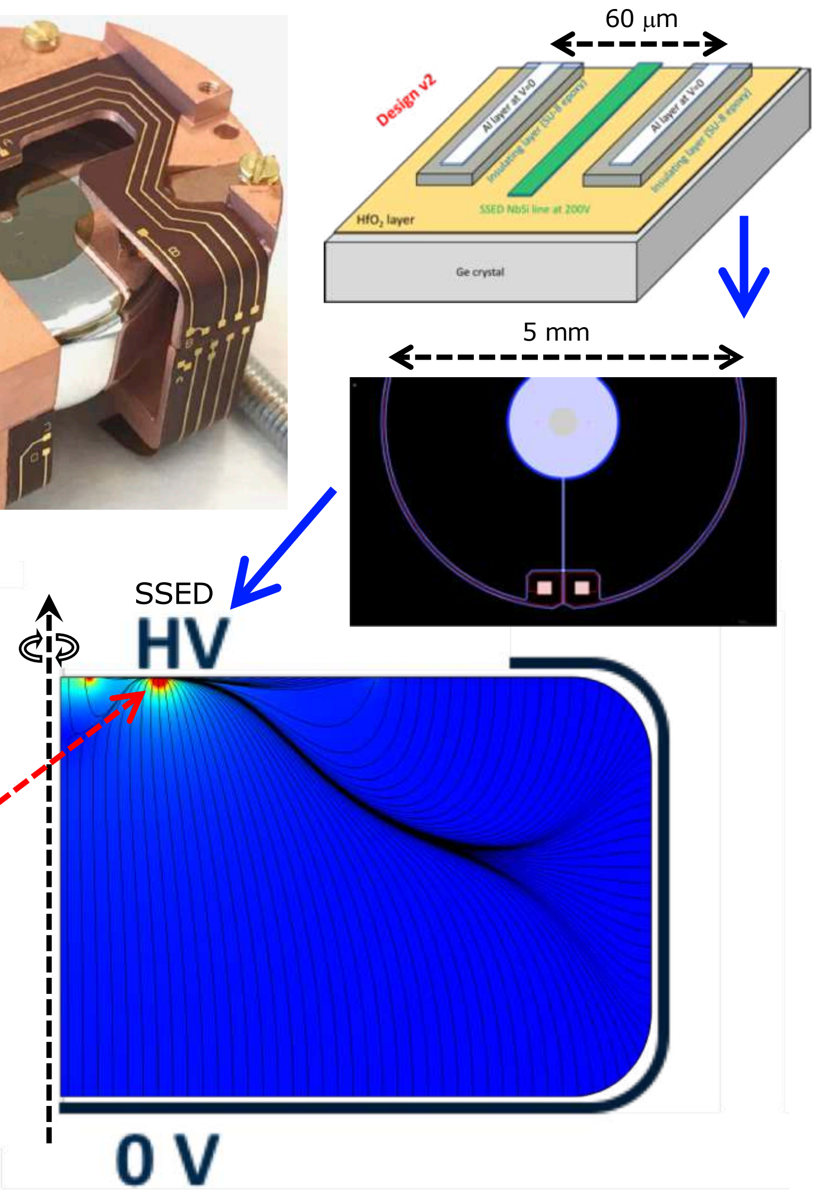
➔ CRYOSEL design

CRYOSEL concept

- 40 g Ge crystal
- Phonon sensor = single NbSi strip (10 μm wide) forming a 5 mm-wide circle
- Use this small film as Point-Contact-like electrode of HV detector
- NTD glued on large enveloping electrode (high-resolution NTL-amplified heat measurement)
- NbSi operated as SSED (Superconducting Single-Electron Detector)
- *Detector kept well below T_c so that SSED is only triggered by large bursts of primary NTL phonons from* *high-field region* *just in front of it*
- *Most HO will not trigger SSED*

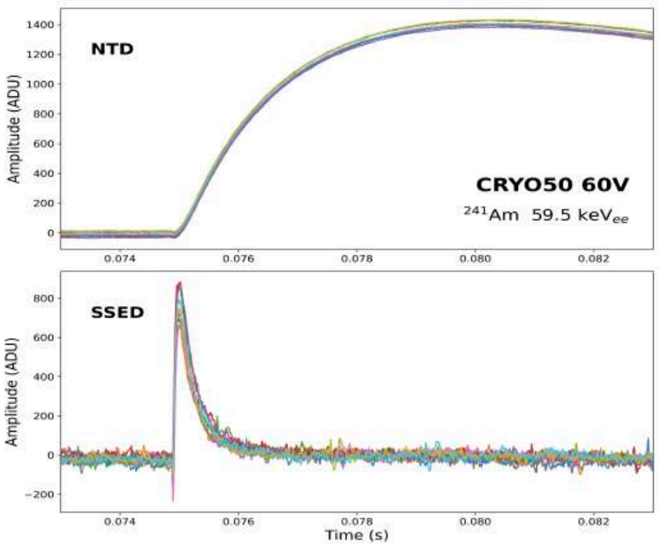


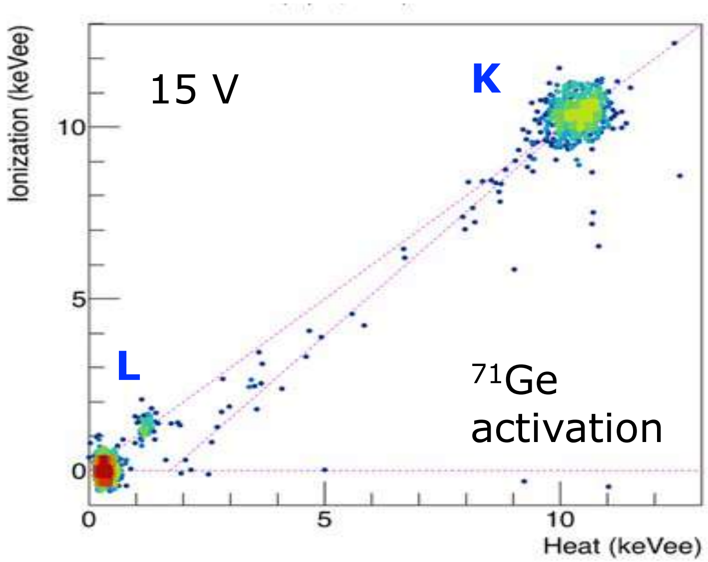
CRYO50



CRYOSEL first pulses and plans

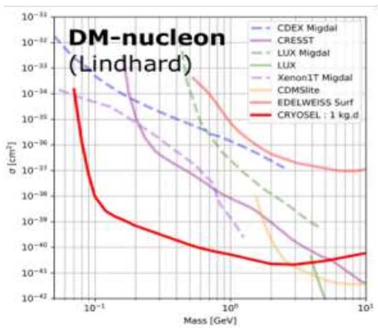
- NTL Pulses observed on SSED with Tc=46 mK on a 40g Ge with a NTD at 16 mK
- SSED pulses disappear at 0 V, as expected
- Rather sharp K and L ^{71}Ge lines observed on NTD despite very inhomogeneous field

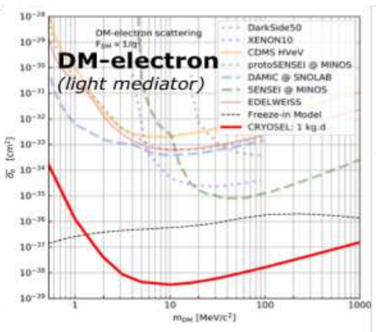


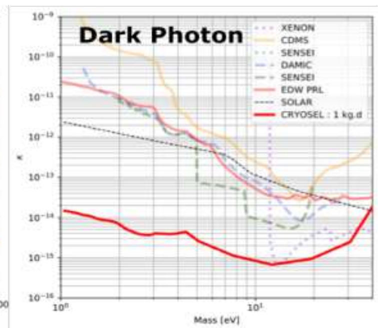


Systematic studies of SSED response just started!

Physics reach of a single 40 g CRYOSEL detector with single-electron tag x 1 month in BINGO cryostat @ LSM







BINGO: see arXiv:2301.06946 and
http://www.bingo-neutrino.eu/
https://indico.in2p3.fr/event/27894/contributions/115920/

Conclusions

EDELWEISS transitioning successfully in a new SubGeV program with cryogenic Ge detectors

- Objective: ~1kg array in new cryostat @LSM *(collab. with TESSERACT?)*:
  - Sub-GeV DM interaction producing nuclear recoils, with *event-by-event identification* with RICOCHET-like detectors
  - Exploit NTL boost to explore MeV Dark Matter interaction with electrons and eV Dark Photon

Order of magnitude improvements of performance achieved so far, with significant new search results:

- Ionization: $\sigma \sim$ 30 eV_{ee} in 40 g Ge - *synergy with RICOCHET*
- Phonon: $\sigma =$ 17.8 eV in 33 g Ge
- HV : $\sigma =$ 0.53 e- @78V in 33 g Ge
- HO reduction observed using athermal phonons with 200g NbSi

+ Development of charge-tag with SSED (CRYOSEL in BINGO @ LSM)