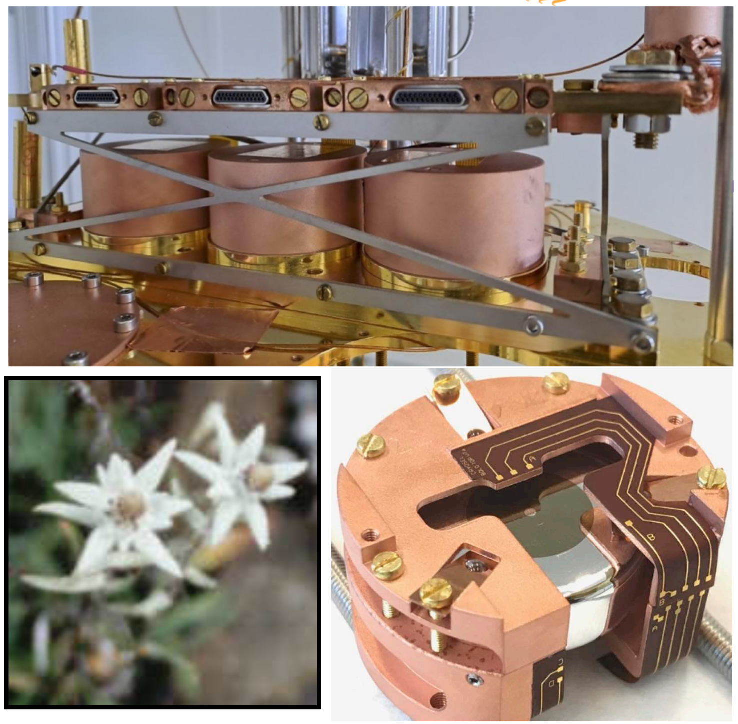
Heat-Only event suppression in EDELWEISS + RICOCHET/CRYOCUBE

RICOCHET
A Coherent Neutrino Scattering Program



RICOCHET: charge measurement with a 1K HEMT preamplifier

arXiv : 2306.00166

EDELWEISS: Heat-Only background with athermal phonons

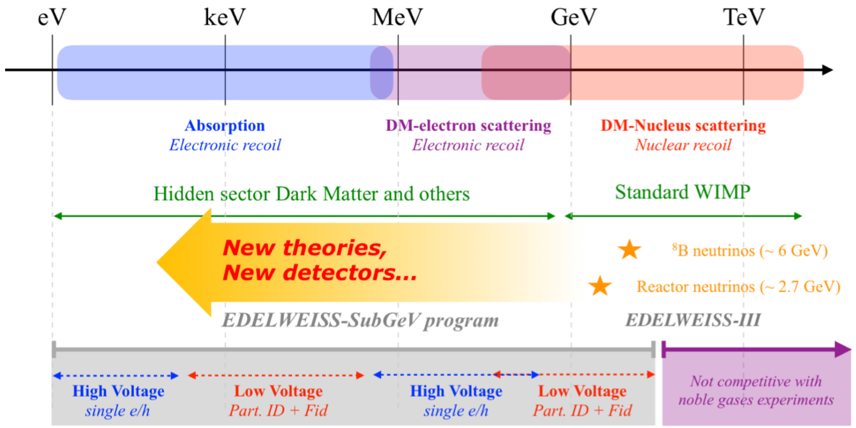
PRD 108, 022006 (2023)

EDELWEISS CRYOSEL: Tagging Neganov-Luke-Trofimov phonons

J. Gascon
Lyon 1, CNRS/IN2P3/IP2I

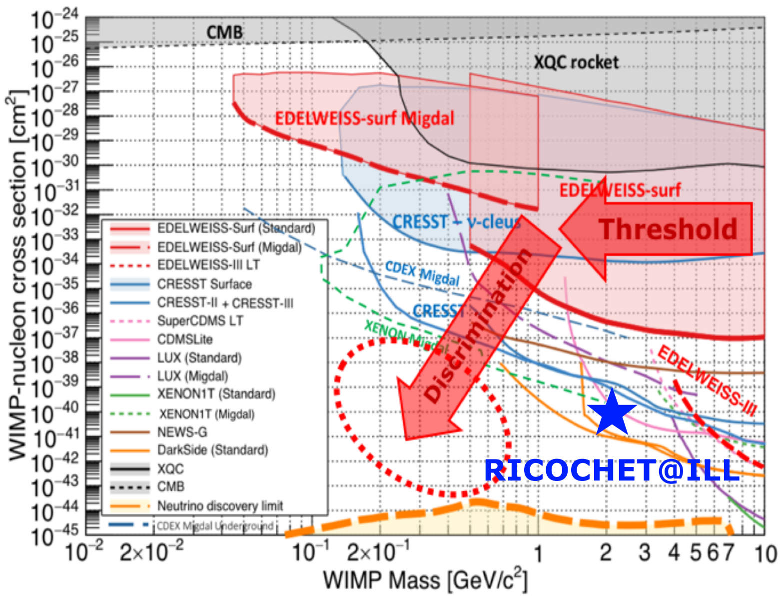
Sub-GeV & CENNS program

New mass domain, new interactions…



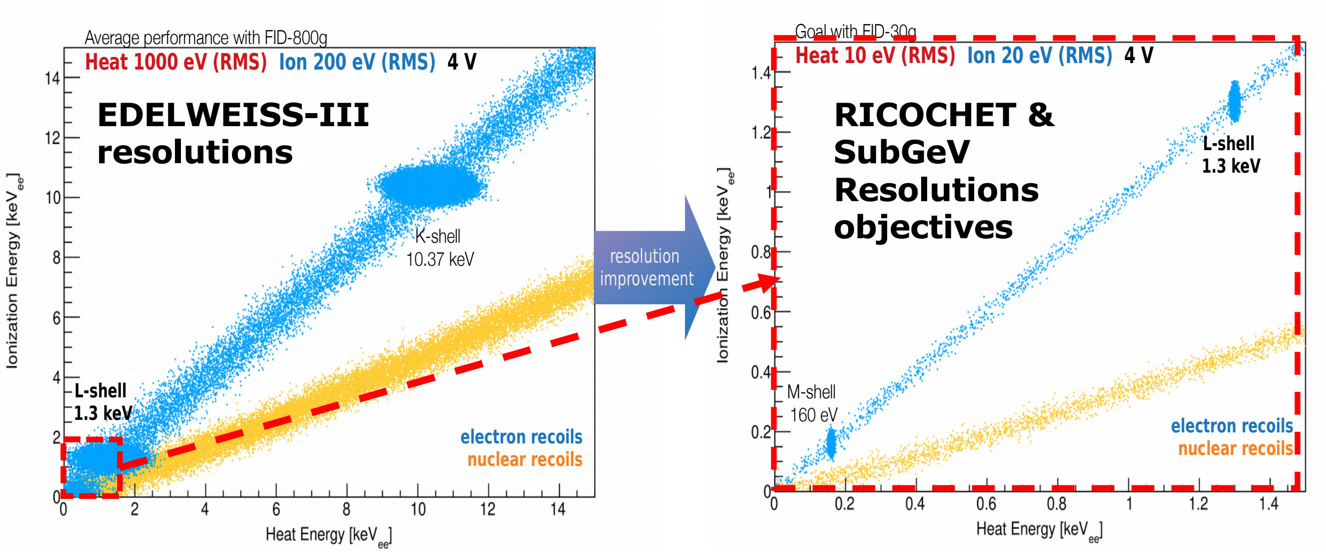
- Current and future expts limited by bkgs:
  ➔ improved threshold not sufficient, also require discrimination
  - Electron/Nuclear recoils/"heat-only"
  - Surface/Bulk
- Challenge: **transposing rejection performance of EDELWEISS-III 860 g heat-and-ionization Ge detectors from keV to eV scales!**
  - Ex: few ~10^{-43} cm^2 @ ~1 GeV with ~kg-size array requires improving σ_{phonon} **x 50** and σ_{ion} **x 10**

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



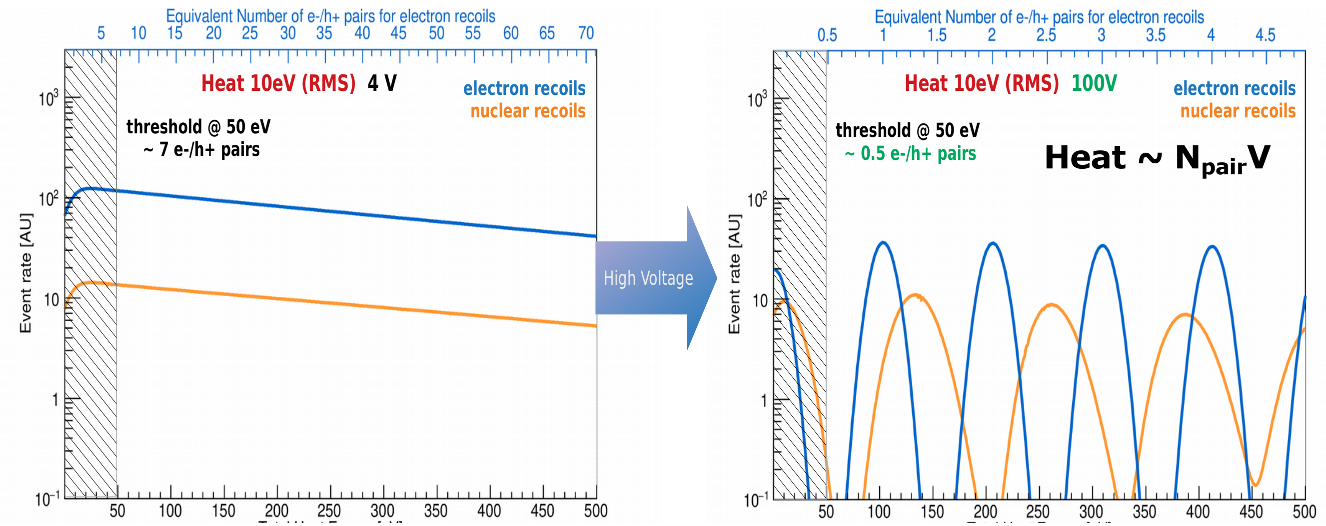
- **Common R&D with RICOCHET *(CENNS @ ILL)***
- Reduction of mass + sensor optimization:
  EDELWEISS-SURF 17.7 eV [PRD 99, 082013 (2019)]
- Keep ability to apply HV for phonon signal NTL amplification & sub-e$^-$ resolution.[PRL 125, 141301 (2020)]
  Milestone: RED30 electron-DM + DP results

EDELWEISS SubGeV two complementary modes



LV

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



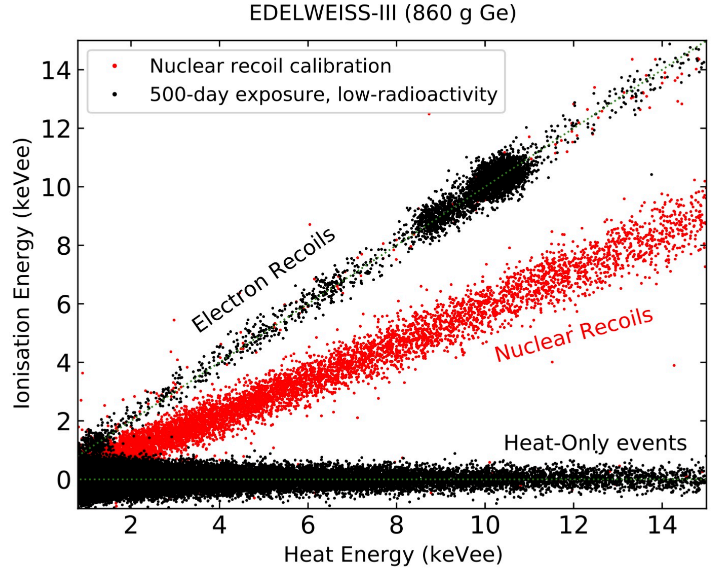
HV

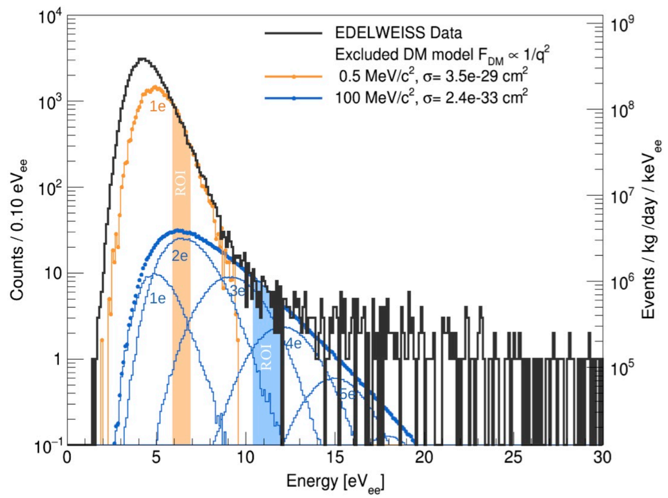
→ Use Neganov-Trofimov-Luke amplification of phonon resolution to resolve single electron-hole pairs

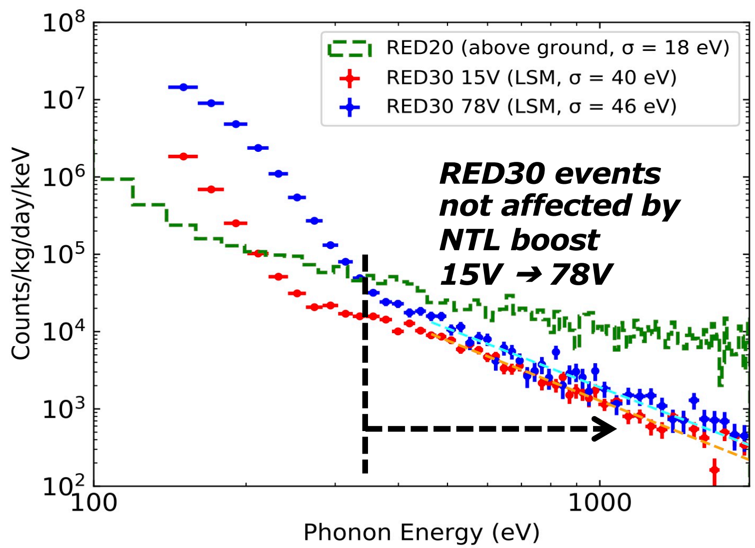
… But ionization can't be used for discrimination at low E

Limitation in both cases: “Heat-only events”

- ***LV:*** despite large EDELWEISS-III large target mass (20 kg Ge) and excellent ER/NR separation, results limited by large HO population
- ***HV:*** despite σ =0.53 e^- resolution on 33g @ 78V, results also limited by HO







- HO nature confirmed by absence of NTL boost from 15V to 78V

LV: RICOCHET low-voltage detectors

HEMT ionization readout

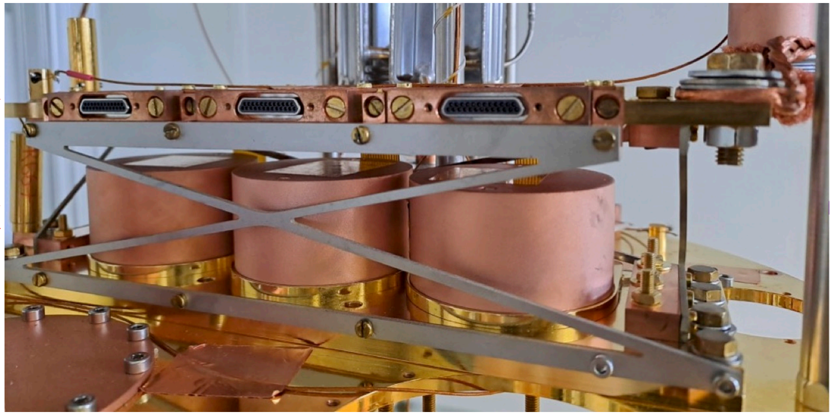
High Electron Mobility Transistor, operated at ~1K, a few cm away from electrode -> Low capacity cabling

+ Optimization of the detector capacity

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

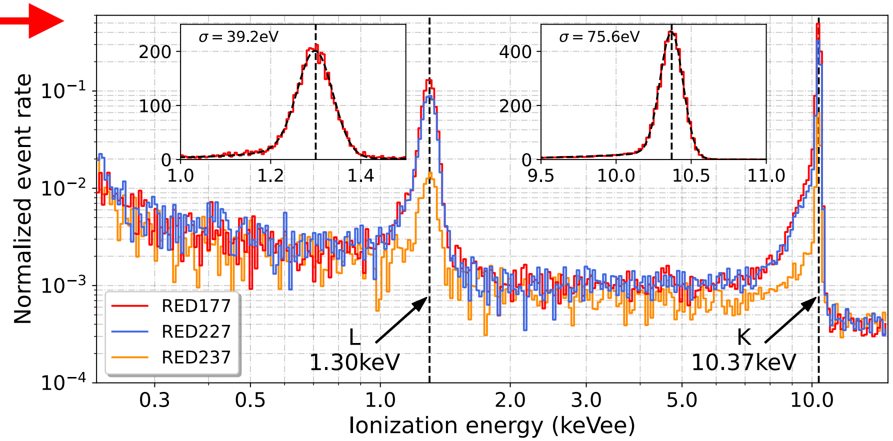
1K HEMT

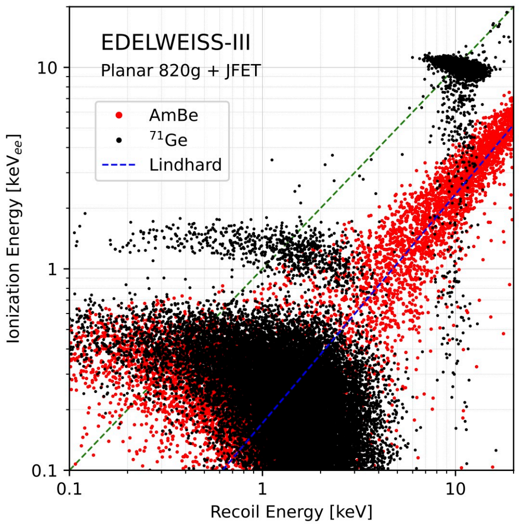
15 mK Ge

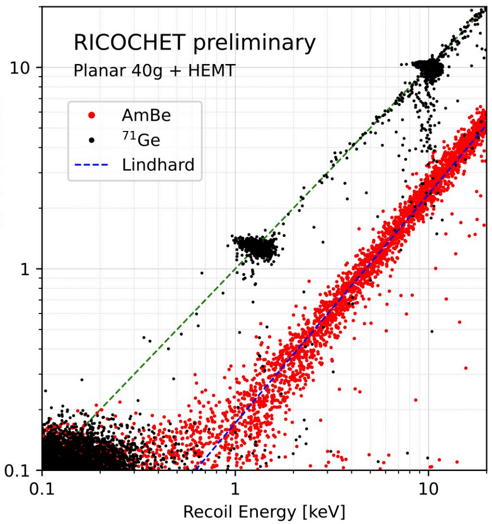


3x 40g Ge RICOCHET detectors with σ_{ion} in 30 eV_{ee} range

[ArXiv : 2306.00166]



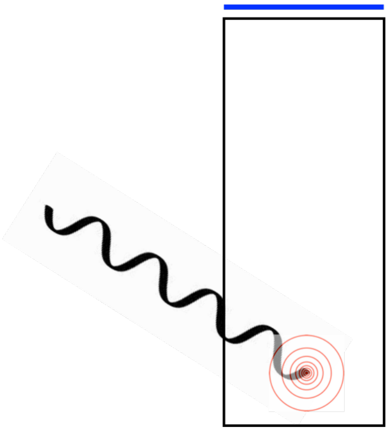




➔ *x7 to x11 better than EDELWEISS-III*

➔ Excellent prospects for HO rejection at low energy in RICOCHET, but also in DM searches

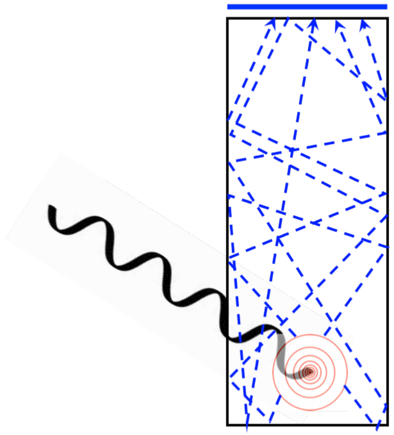
Different kinds of phonons



Primary phonons

Short mean free path

In general, do not reach sensor

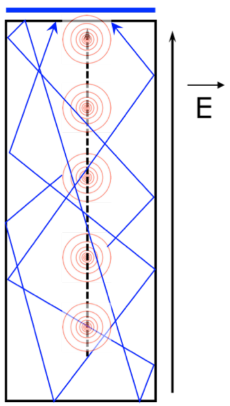


Ballistic phonons
From decay of primary phonons

Long mean free path

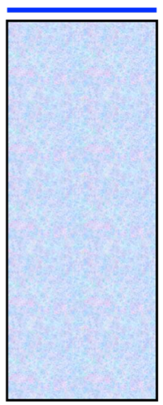
Detectable in TES sensor

If $\vec{E}$ field applied



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

Primaries at end of field lines detectable in TES sensor
+ Higher efficiency for ballistic phonons



Thermal phonons
From decay of ballistic phonons

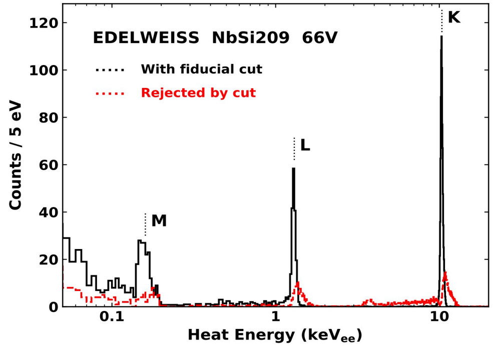
Detected by Ge-NTD thermistance

HO signal difference between TES and NTD?

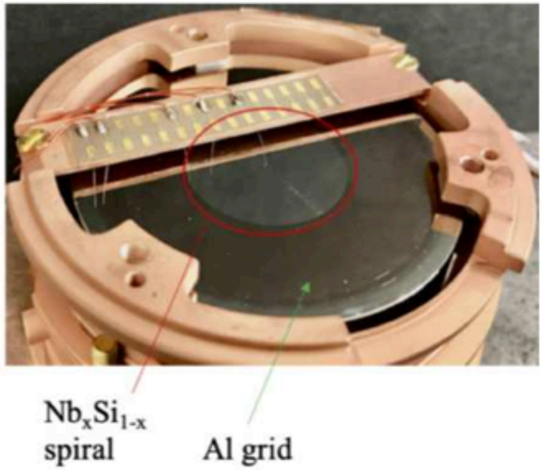
NbSi TES athermal phonon sensor

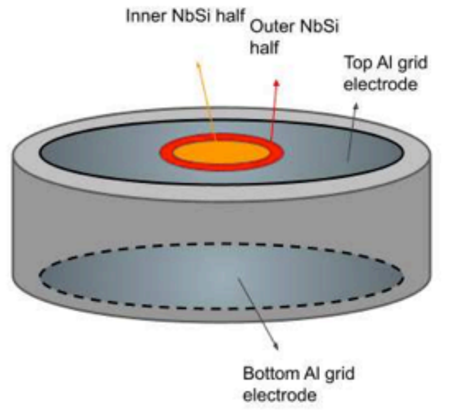
PRD 106, 062004 (2022)

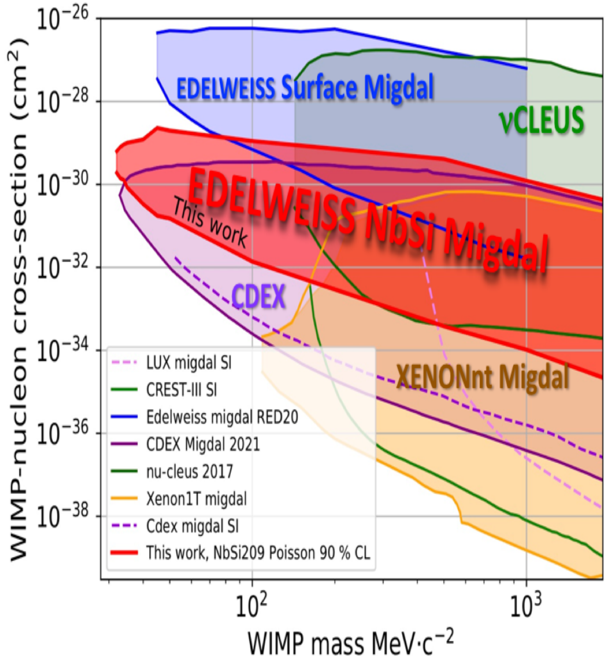
- **200 g Ge detector @ LSM**
- TES = 20 mm wide NbSi spiral (single 10 μm line, 10 nm thick, split in two sensors) with T_c = 44 mK
- **σ = 4.5 eV_{ee} @ 66V**



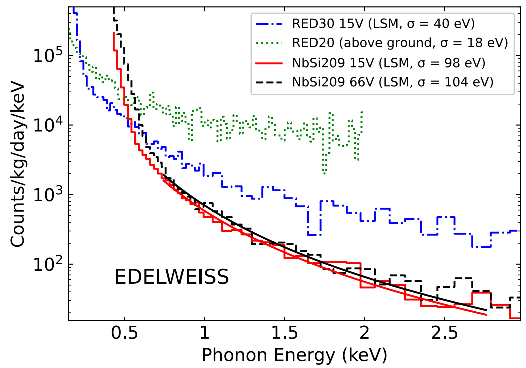
- Some HO reduction wrt NTD: X 100 improvement wrt previous EDW Migdal limits
- **... But HO background is still the main limitation!**







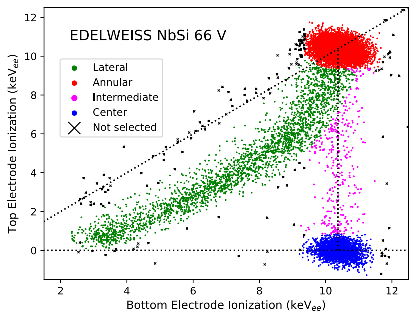
HO nature of background derived from absence of NTL amplification between 15V ➔ 66V

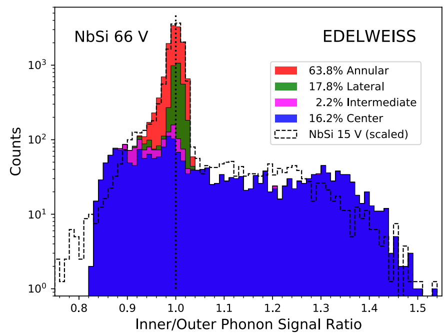


HO with high-energy NTL phonons

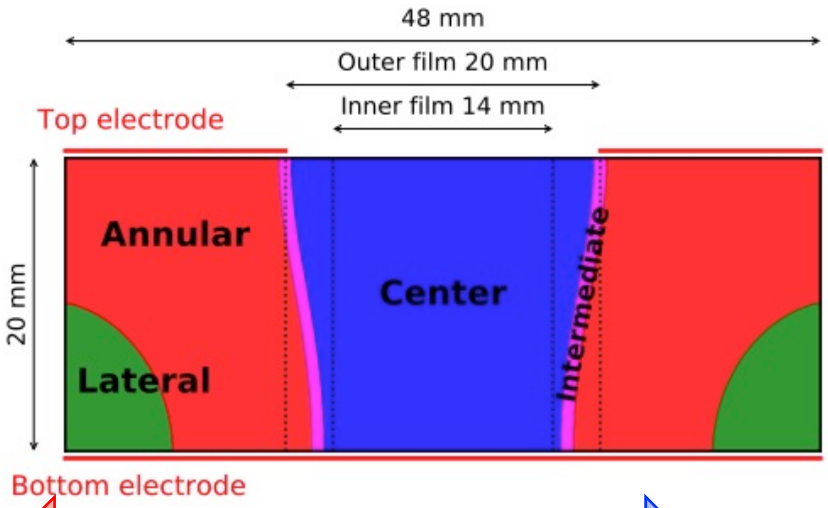
New arXiv:2303.02067

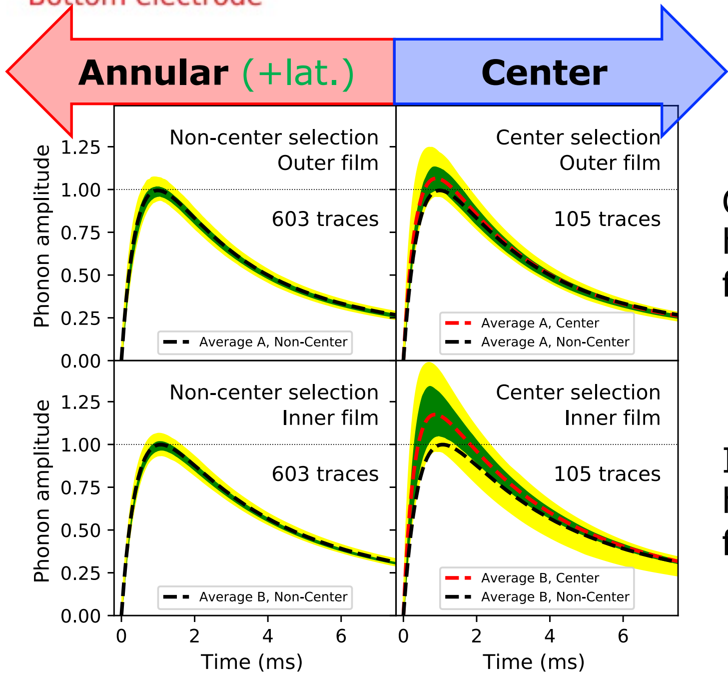
- Previous results obtained from **annular** region, where *field lines do not intersect the NbSi film*
- Signal from **center** region shows sign of sensitivity to primary NTL phonons : prompt signal excess
  - in only one of the two 1/2 of the film
  - faster risetime
  - amplitude scales with applied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





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



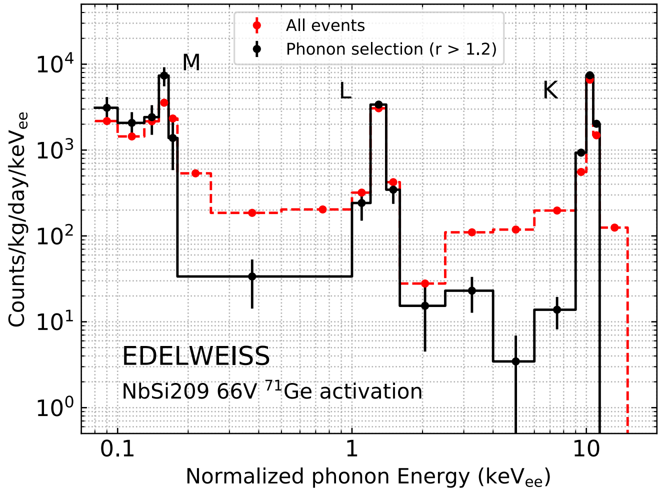


Outer half of film

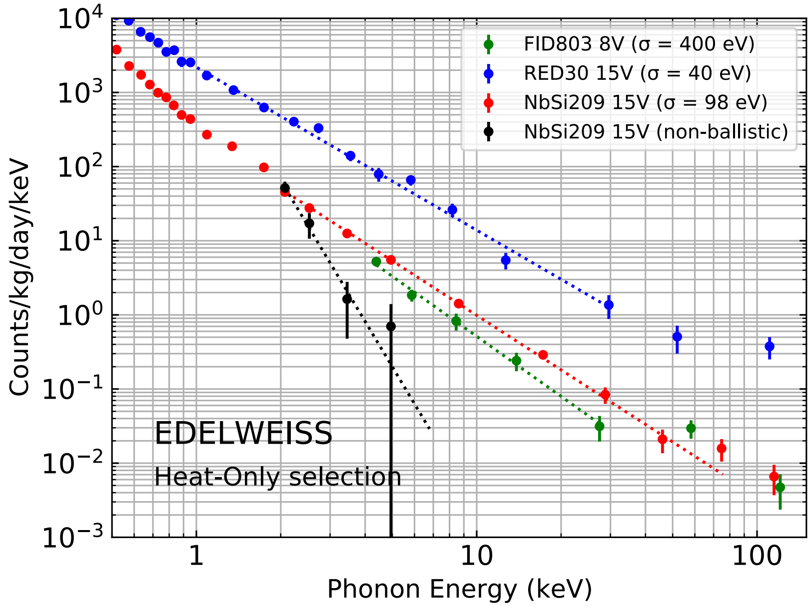
Inner half of film

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



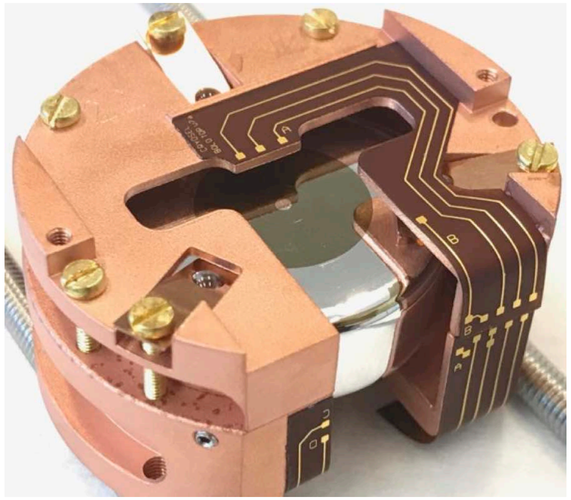
Wishlist for use as DM detector:

- 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)

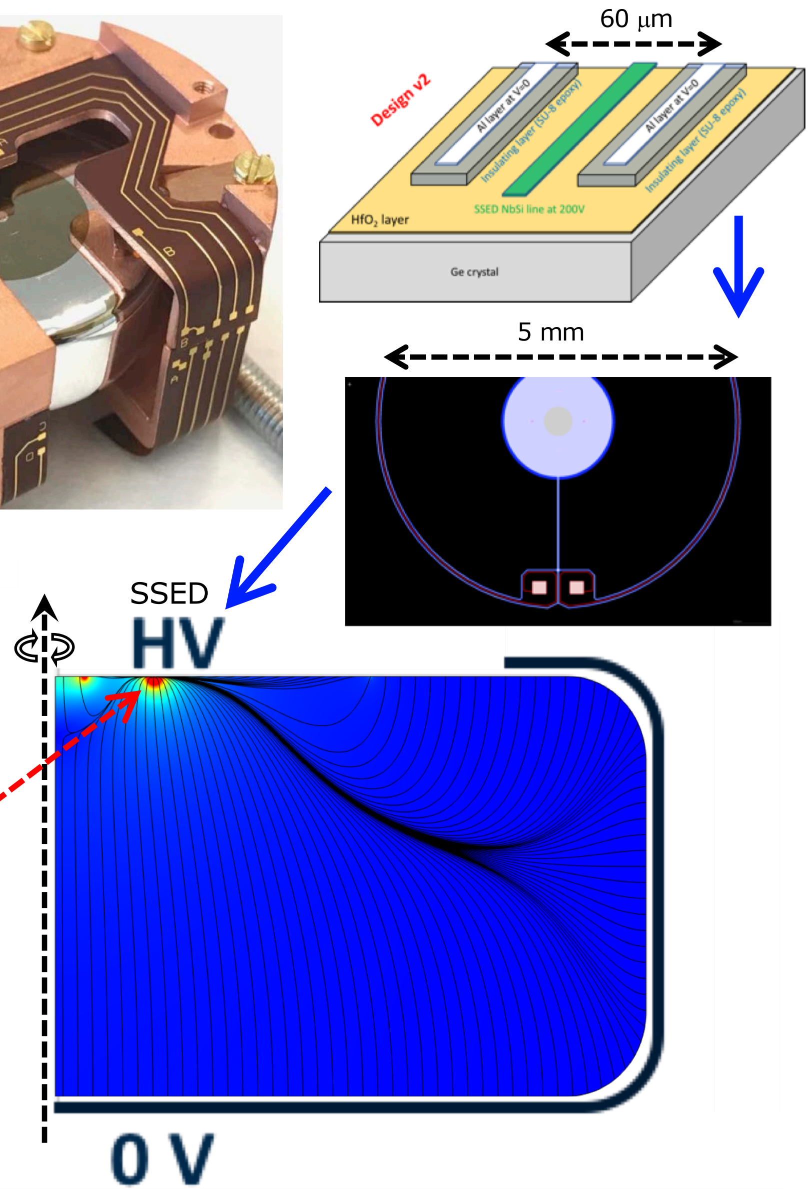
➔ CRYOSEL design

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*



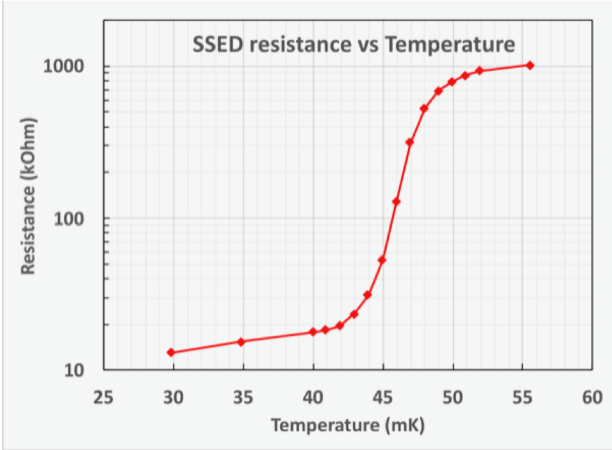
CRYO50

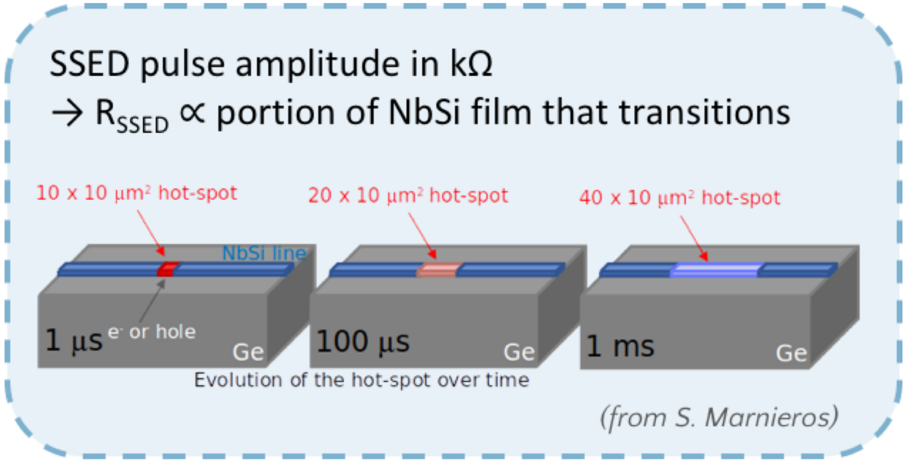


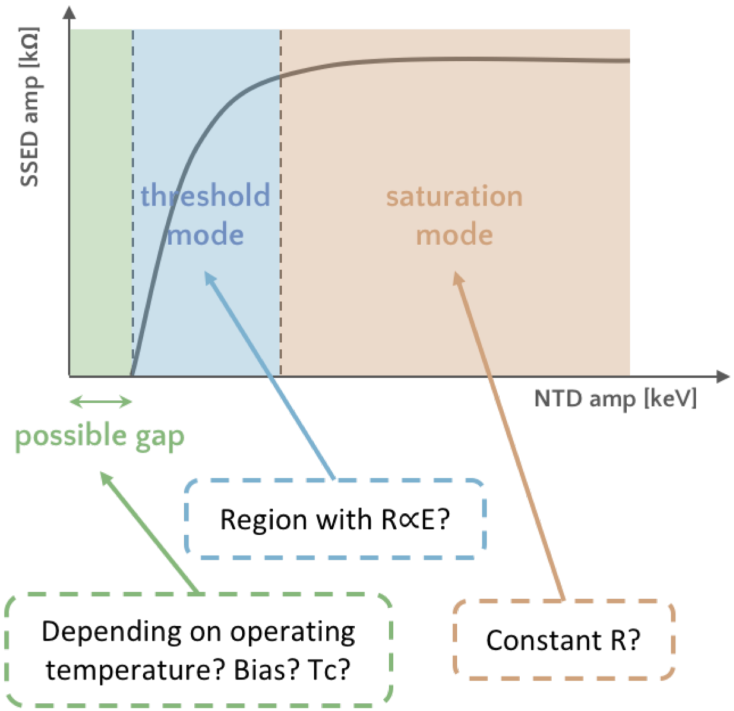
SSED response

- Operation of SSED well below its Tc, so that phonon from HO events are not able to trigger a hot spot in the NbSi film

First prototype:
Tc ~ 46 mK
well above
Toperation
~ 15 mK



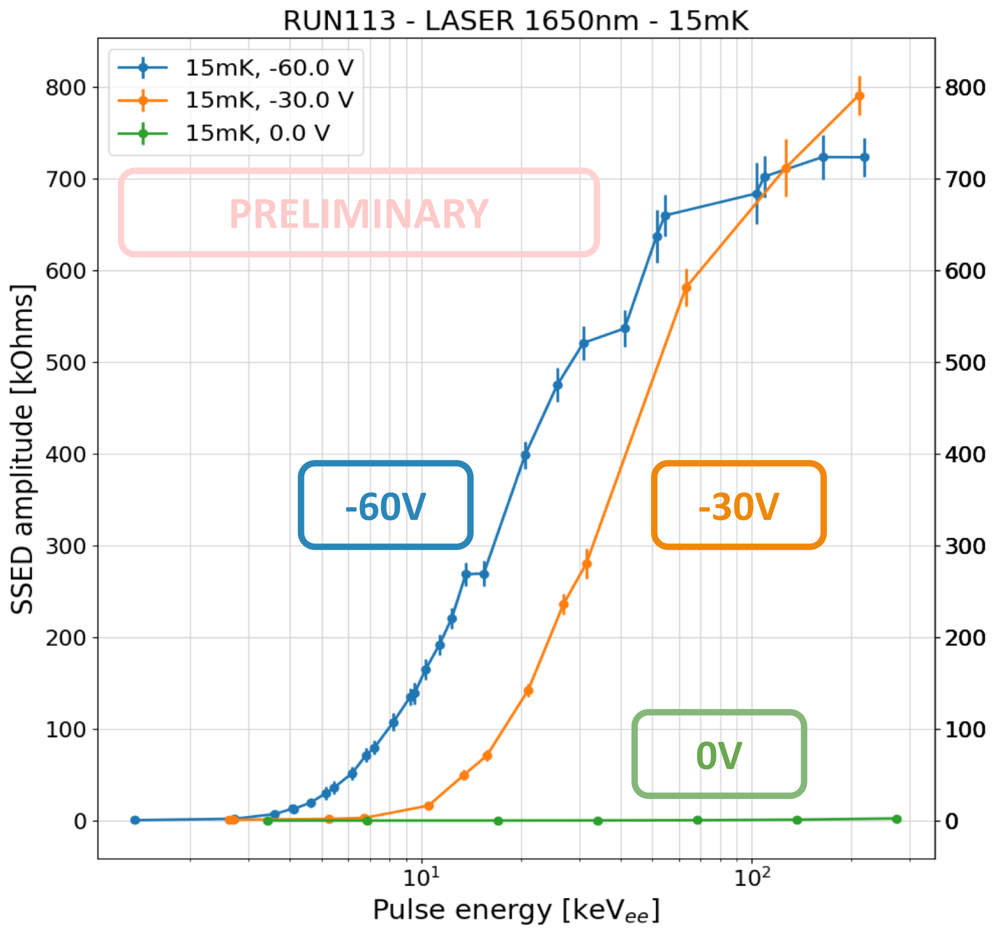




- Lifetime and amplitude of signal (in kΩ) depend on hot spot evolution

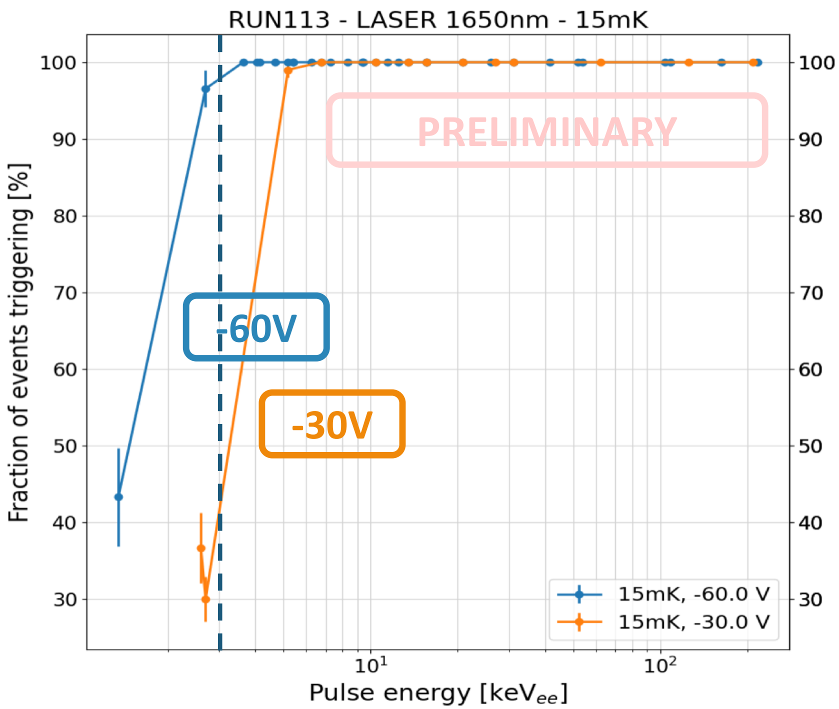
Response vs applied bias

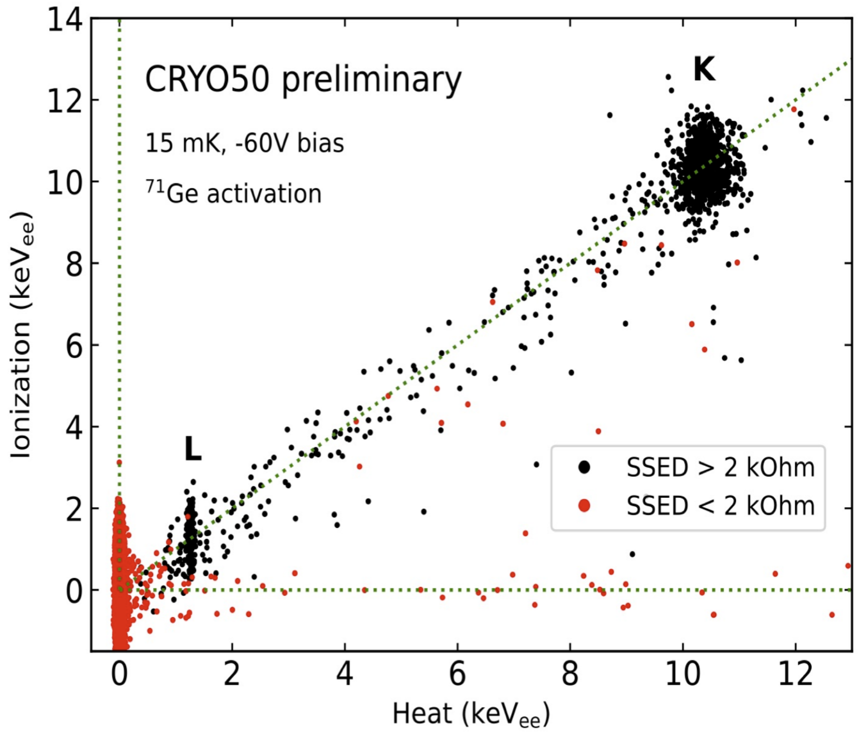
- Charge calibration using ^{71}Ge K+L activation lines
- Use IR 1650 nm laser pulses to probe all the crystal volume.
- The three modes are observed: some gap, a increase and then a saturation close to 1 MΩ.
- The signal increases as the bias (i.e. with the NTL phonon yield)
- No equivalent increased at 0V (no NTL phonons)



SSED use as NTL phonon tag

- Operation of SSED as NTL phonon "tag": 5σ thresh = 1.250 kΩ
- With laser pulses, ~100% trigger at 2.6 keVee @ 60V
- Tag operation confirmed by K+L+HO ionization vs NTD data
- Threshold still far from goal → improvements to come from film with increased phonon efficiency, from increased bias and from reduced T_c.

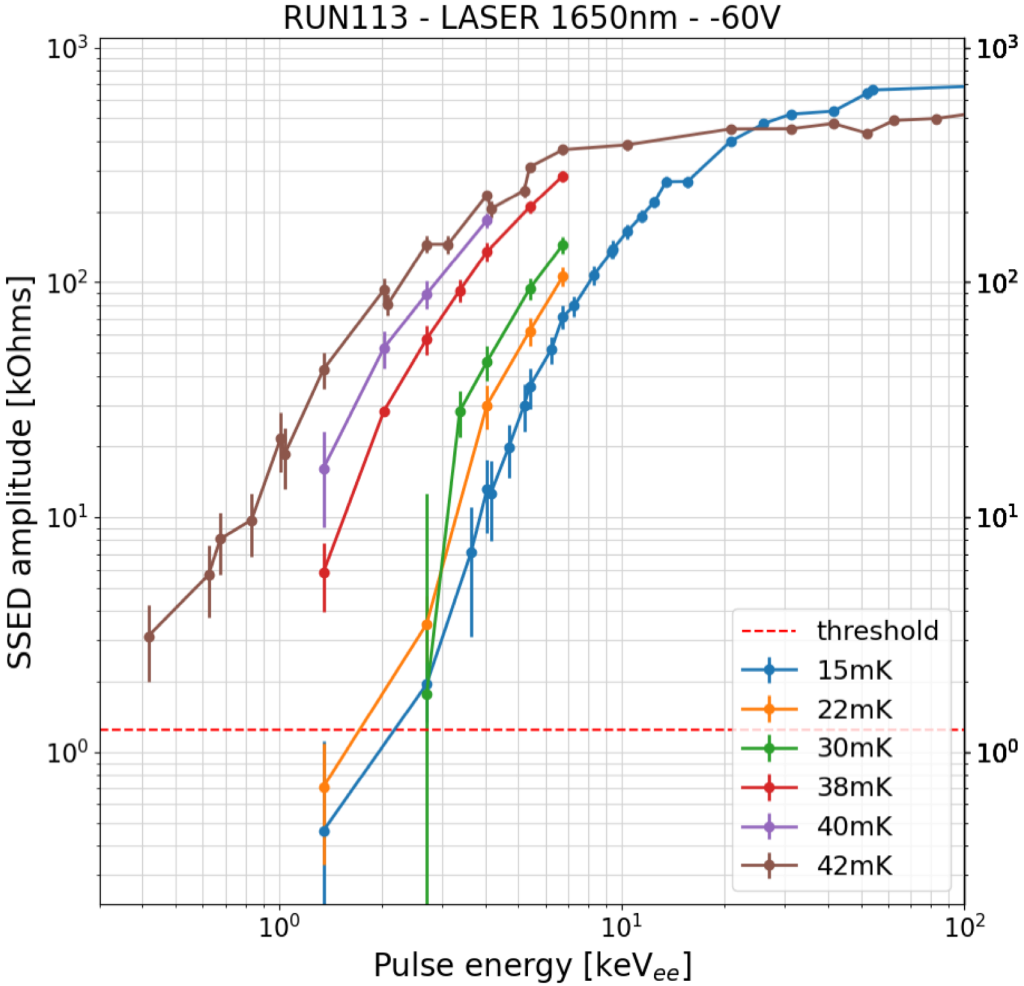




Reduction of T_c-Toperation

- Lowering of the discrimination threshold by reducing the difference between T_c and $T_{operation}$

- Operation of the SSED film as a TES is worth exploring



Conclusions

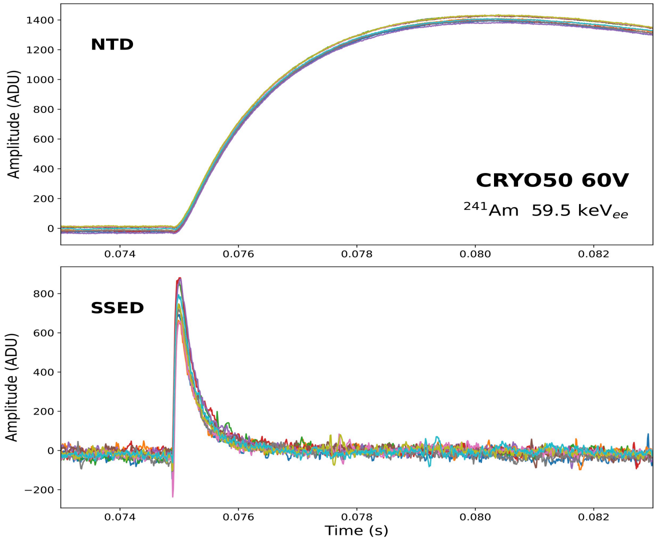
- Discrimination at LV in RICOCHET: development of a 1K HEMT amplification, 30 eV_{ee} resolution achieved
- Discrimination at HV: development of NbSi SSED sensor to tag charge and reject HO background → CRYOSEL.
- First prototype with SSED sensor confirms expected behavior, work to improve threshold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

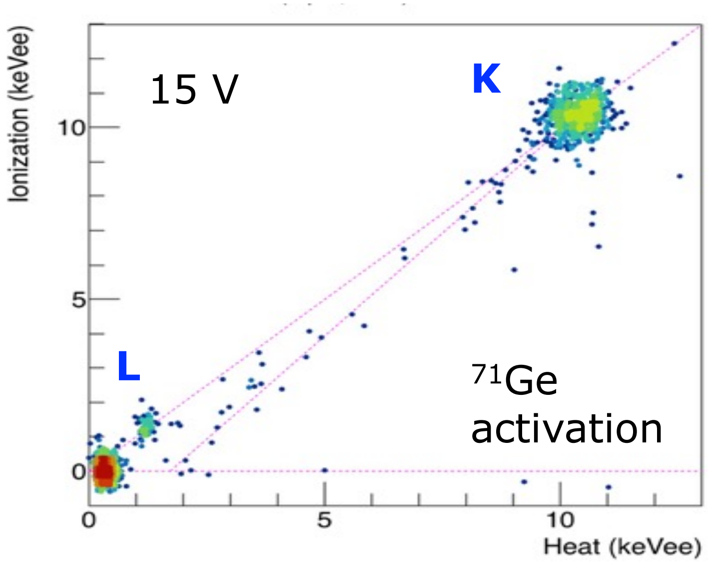
- Excellent DM results expected starting with a single 40~g SSED detector (in BINGO@LSM)
- LV and HV Ge detectors with background discrimination as proposal of contribution to TESSERACT at LSM.

Backup

CRYOSEL first pulses and plans

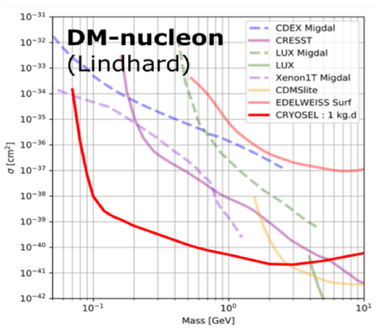
- NTL Pulses observed on SSED with Tc=46 mK on a 40g Ge with a NTD at 16 mK
- SSED pulses disappear at 0 V, as expected
- Rather sharp K and L ^{71}Ge lines observed on NTD despite very inhomogeneous field

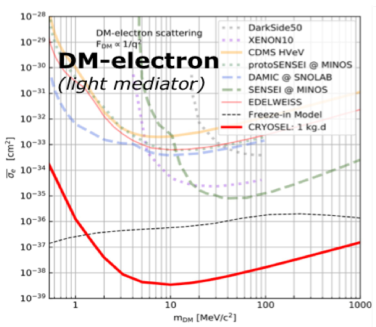


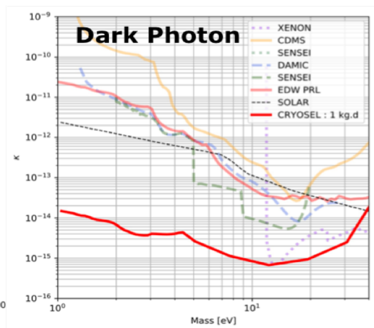


Systematic studies of SSED response just started!

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/