Sub-GeV dark matter searches with EDELWEISS & CRYOSEL

GDR DUPhy

[arXiv:2303.0267]

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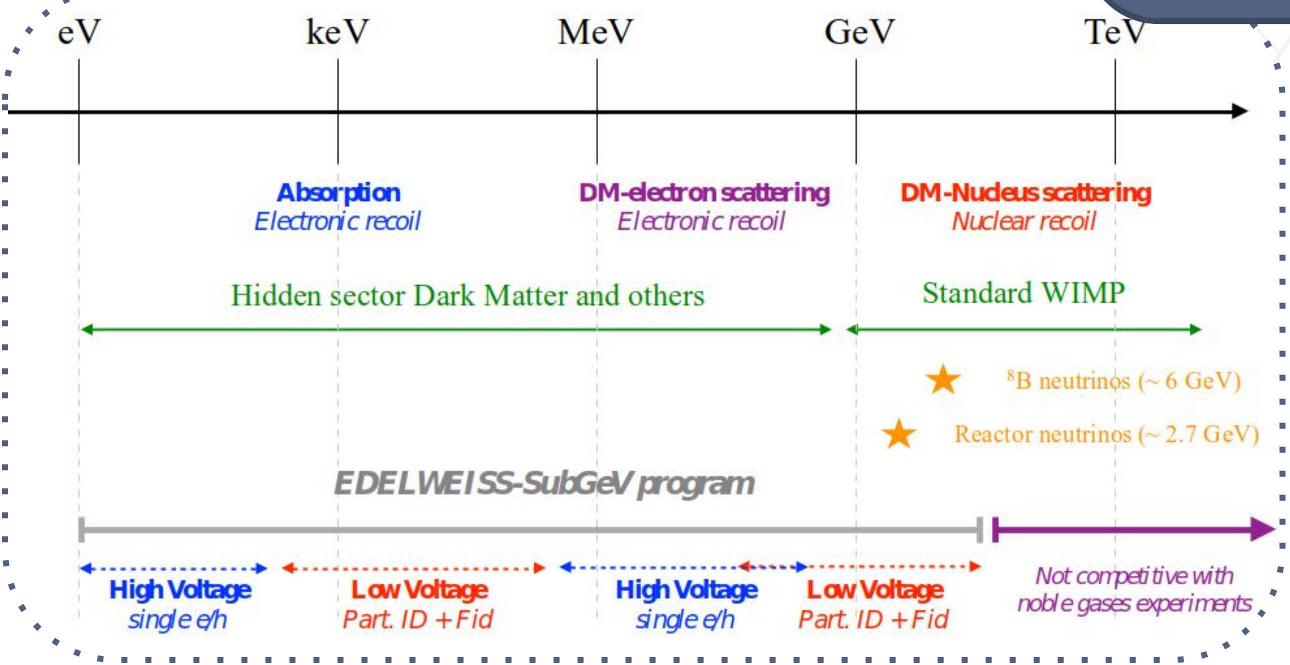
Elsa Guy

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

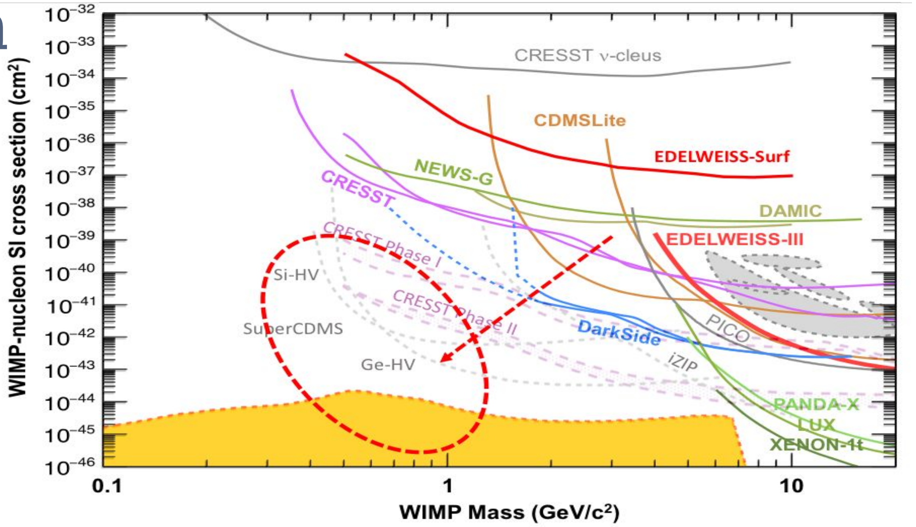
EDELWEISS Sub-GeV program

→**Sub-GeV : challenging search area**
→ **LV :** use ionization to discriminate ER/NR/HO (Ricochet + *J. Billard's talk)*
→ **HV :** use NTL amplification of phonon resolution to resolve single e^{+}/h^{-} pairs



EDELWEISS Sub-GeV program

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



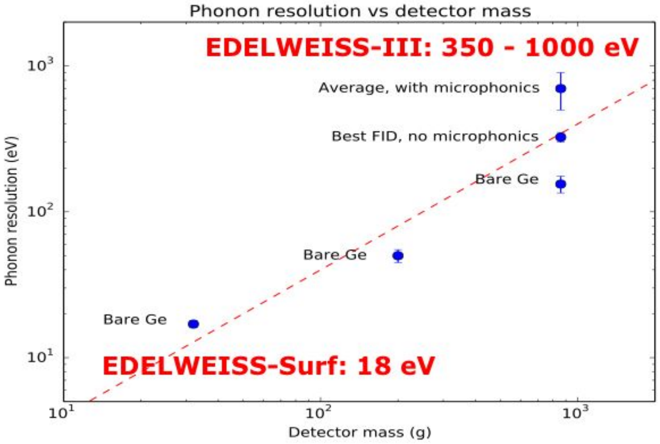
Goals :

→ 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, cf. J. Billard's talk),

→ reach cross sections down to 10^{-43} cm²,

→ reduce background.



Progress in phonon channel :

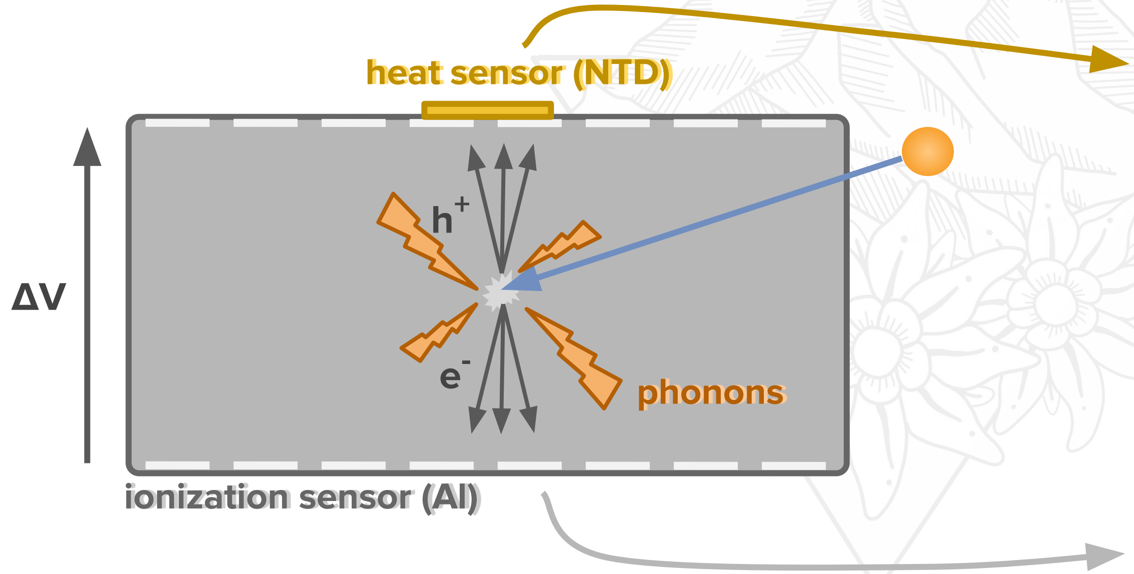
→ Reduce detector mass : 17 eV achieved
EDELWEISS-Surf [PRD 99 082013 (2019)]
33 g Ge bolometer.

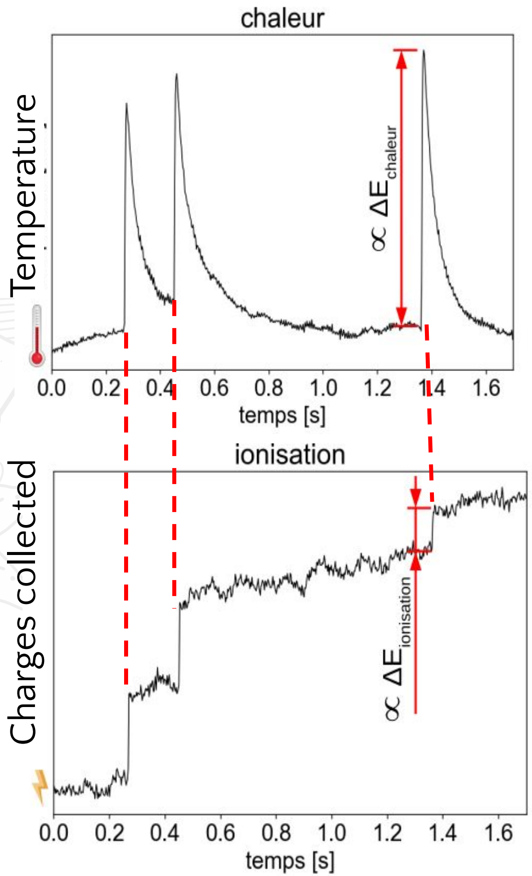
→ Apply HV to amplify signals : 1.6 eV achieved
Electron-DM results [PRL 125, 141401 (2020)]
78 V applied onto 33 g Ge bolometer.

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

Direct detection with EDELWEISS

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





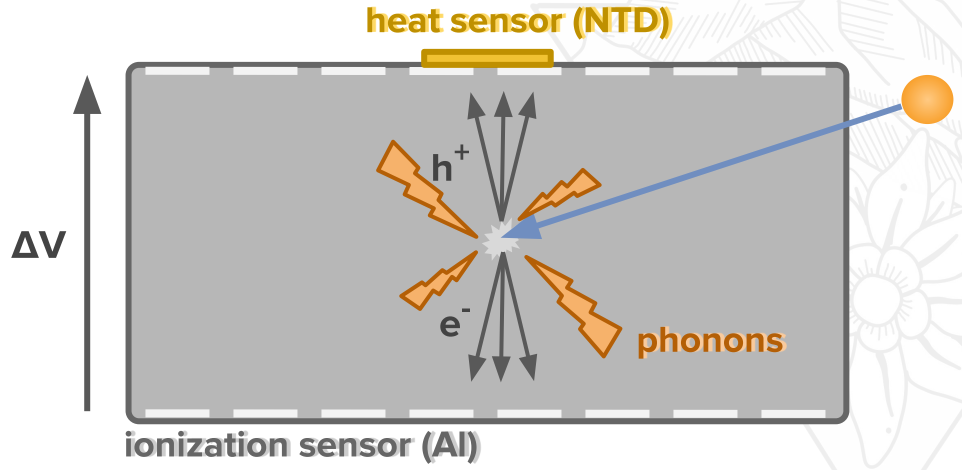
Direct detection with EDELWEISS

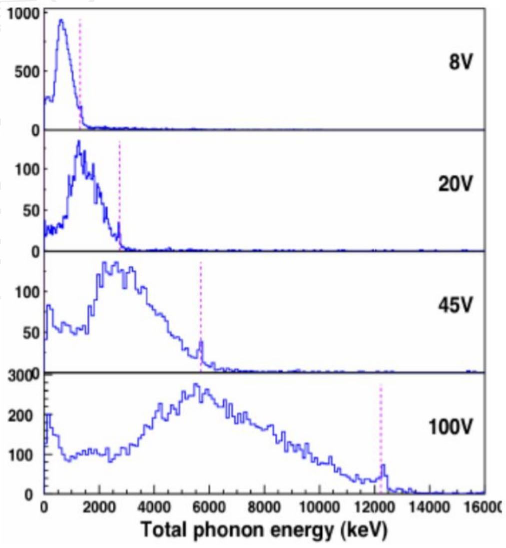
→ Ge semiconductor cylindrical crystals (4 → 800g)
→ Simultaneous measurement: **heat** & **ionization**
→ Operated at cryogenic temperature ~16mK

Luke amplification

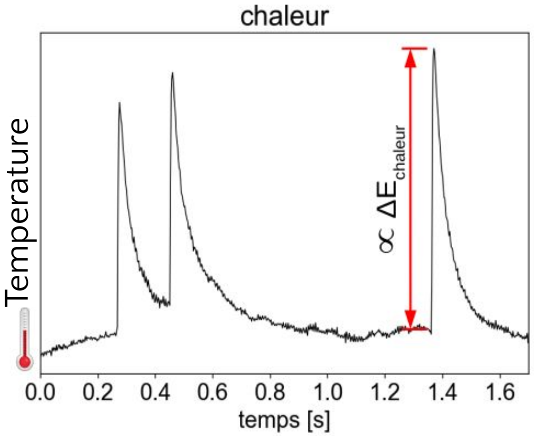
$$E_{heat} = E_{recoil} + E_{Luke} = E_{recoil} + N_p \Delta V$$

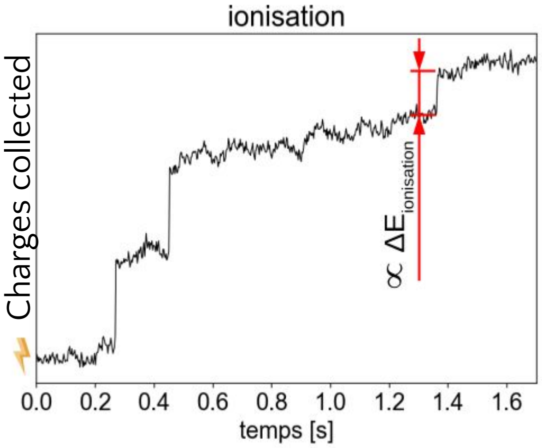
$$E_{heat} = E_{recoil}\left(1 + \frac{\Delta V}{\epsilon}\right) \quad \textit{particle-ID dependent}$$

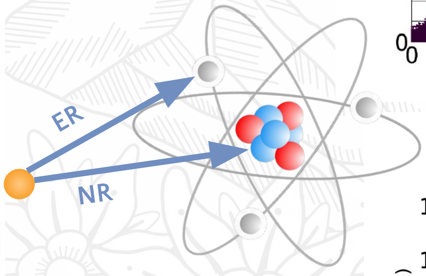


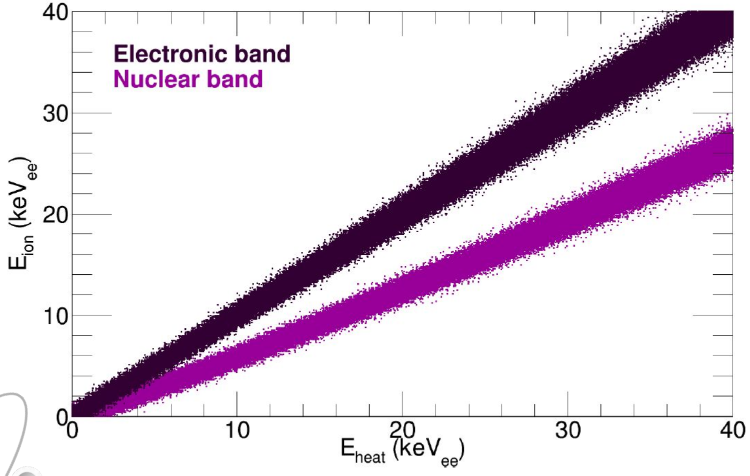


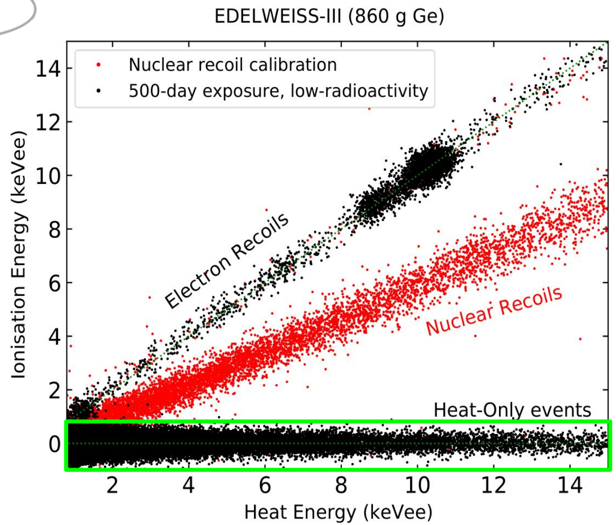
The problem of HO



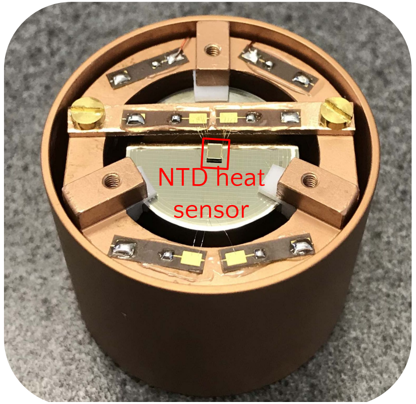






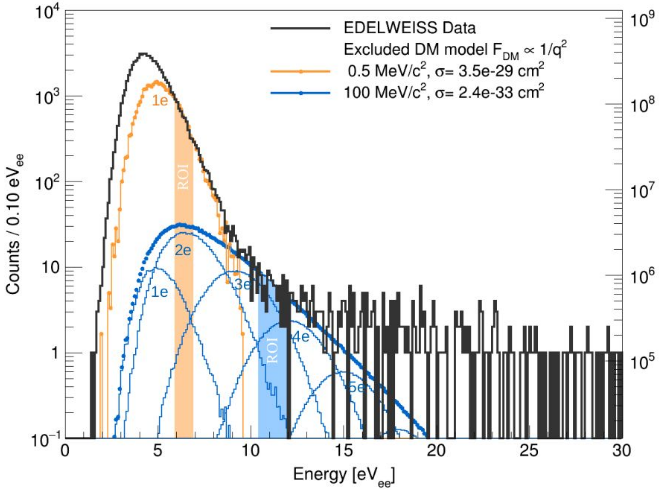


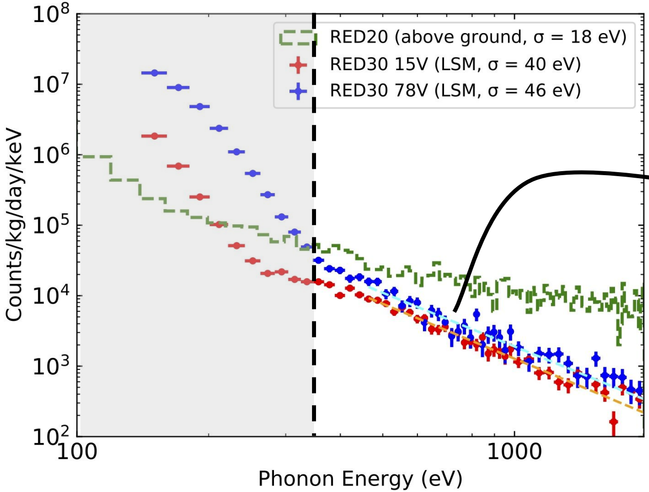
HV - NTL amplified Ge detectors



→ **RED30 (Ge-NTD), 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
→ Competitive DM-e⁻ & DP limits



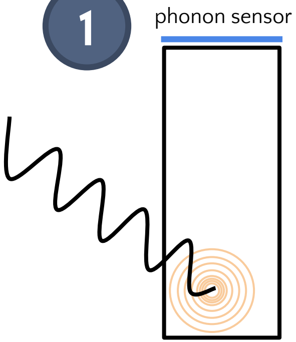


But, RED30 events not affected by NTL boost : 15V → 78V

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

Different kinds of phonons and different sensors

1

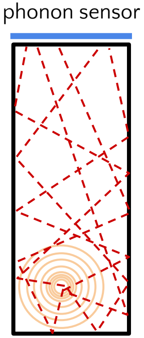


Primary phonons

Short mean free path

In general, **do not reach sensor**

2

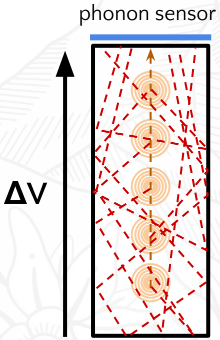


Ballistic phonons
(from decay of primary phonons)

Long mean free path

Detectable in TES

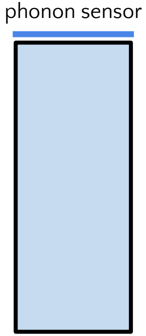
3 When applying an electric field :



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

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

4



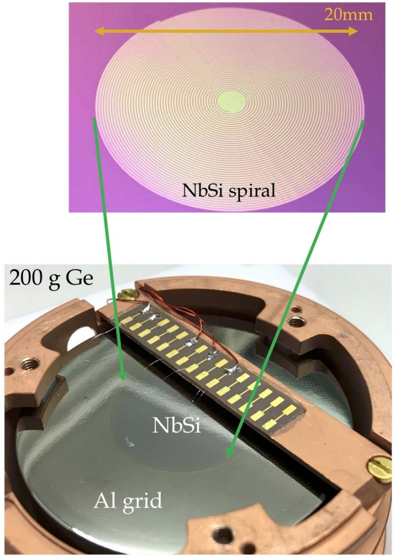
Thermal phonons
(from decay of ballistic phonons)

Detectable in Ge-NTD thermistance (as in RED30)

TES sensor

Ge-NTD sensor

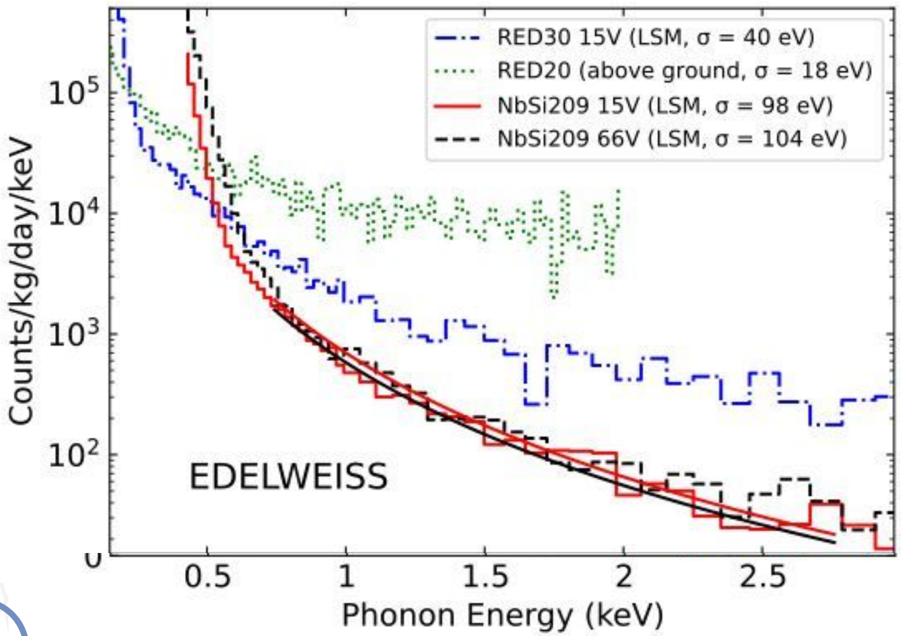
NbSi TES athermal phonon sensor



→ **NbSi209 w/ NbSi TES heat sensor** (detect **ballistic** + **primary** phonons)

→ 200g Ge bolometer at LSM

→ ionization signal: Al electrodes lithographed on top and bottom surfaces



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

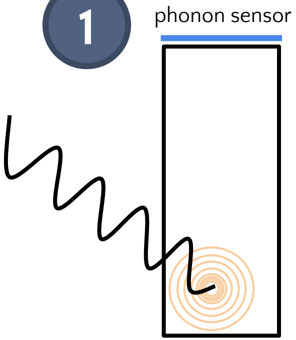
Tagging NTL phonons ?

→ Conclusion of [PRD 106 062004](#) (2022) : detecting athermal **ballistic** phonons **does not** get rid of HO events

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

- Charge read-out via electrode?
  → presently limited to σ~10 e⁻ (c.f. Ricochet)
- As they accelerate in the E field, charges emit NTL phonons **(3)** :
  → we can selectively detect some of these phonons if NTL phonons can be “localized” in a sensor with some position dependence (i.e. **not ballistic**) : phonons must either have **short mean free paths**, or can be very efficiently absorbed by the nearby sensor

1

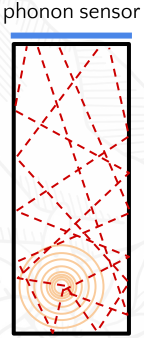


Primary phonons

Short mean free path

In general, **do not reach sensor**

2

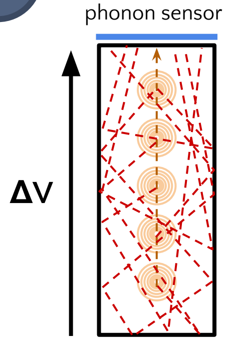


Ballistic phonons
(from decay of primary phonons)

Long mean free path

Detectable in TES

3 When applying an electric field :



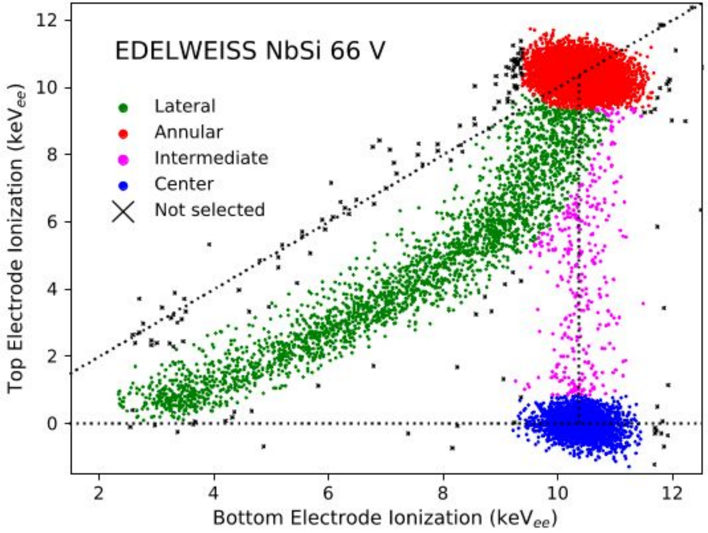
Additional NTL phonons : primary + **ballistic** production **along field lines**

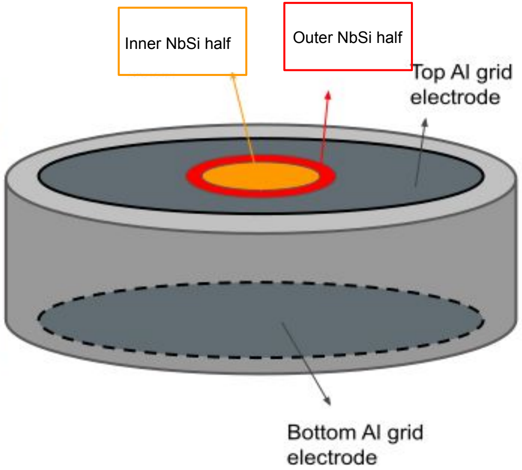
→ **primaries** at the end of field lines **detectable in TES**

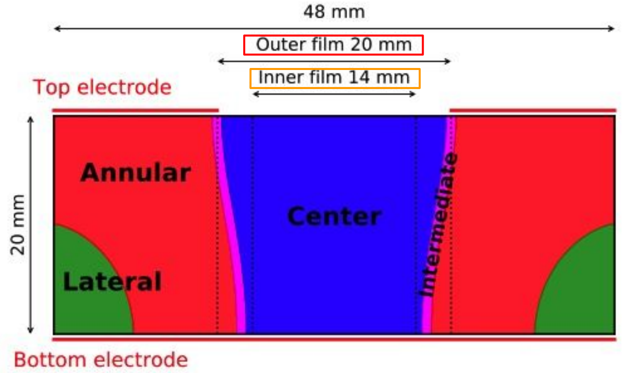
Tagging NTL phonons ?

→ Experimental confirmation :
new arXiv:2303.02067

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



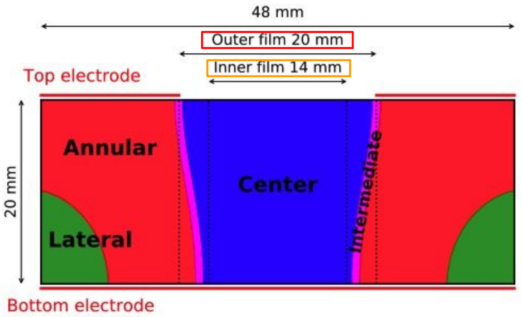




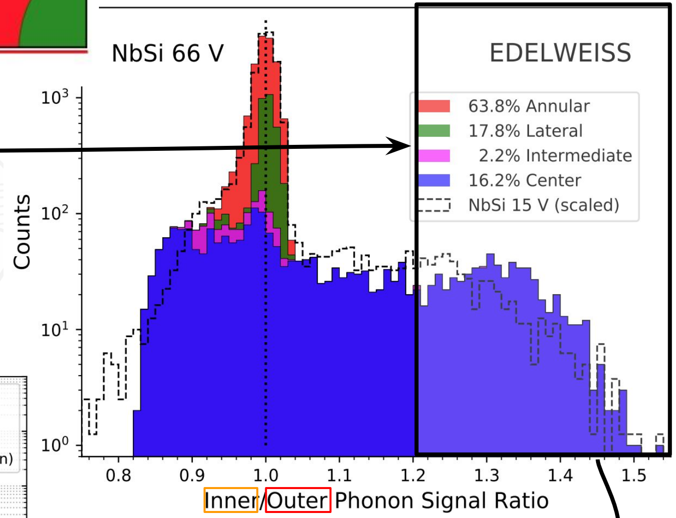
Tagging NTL phonons ?

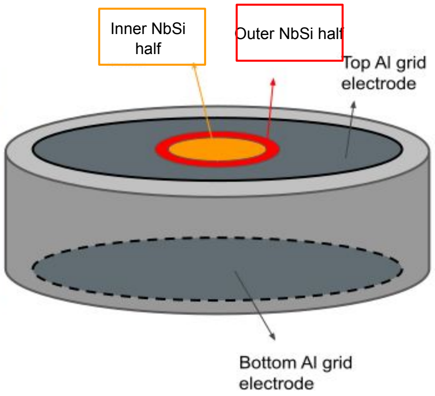
→ Clear signal of extra phonon in TES component (excess in inner part of the film) associated with NTL phonons emitted in this volume **(center)**

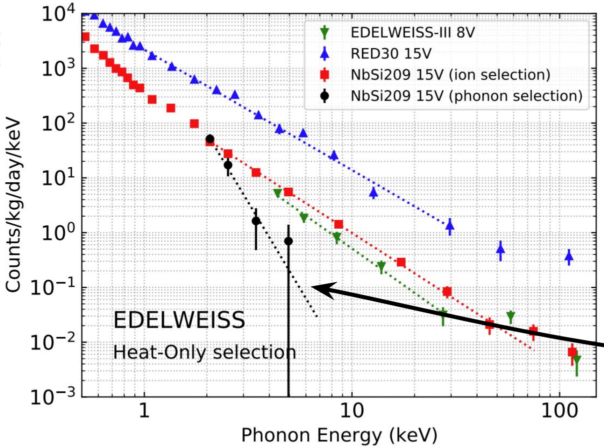
→ Tagging this component **rejects HO events**! Opens the possibility of a NTL phonon- based charge tag : **CRYOSEL**?



excess of events in inner film



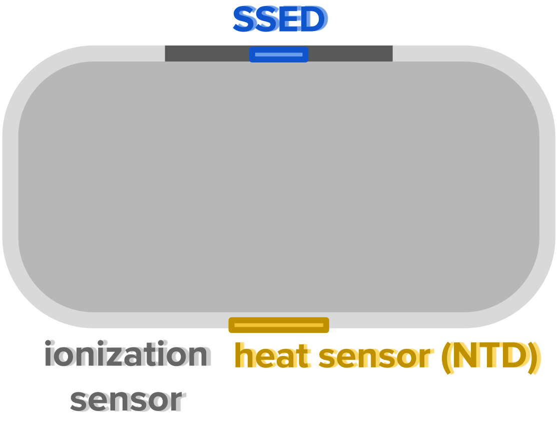


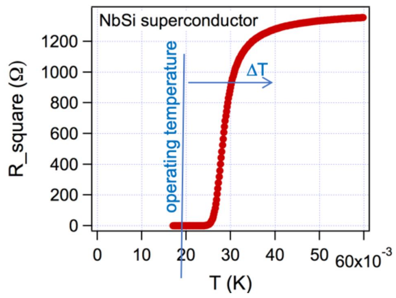


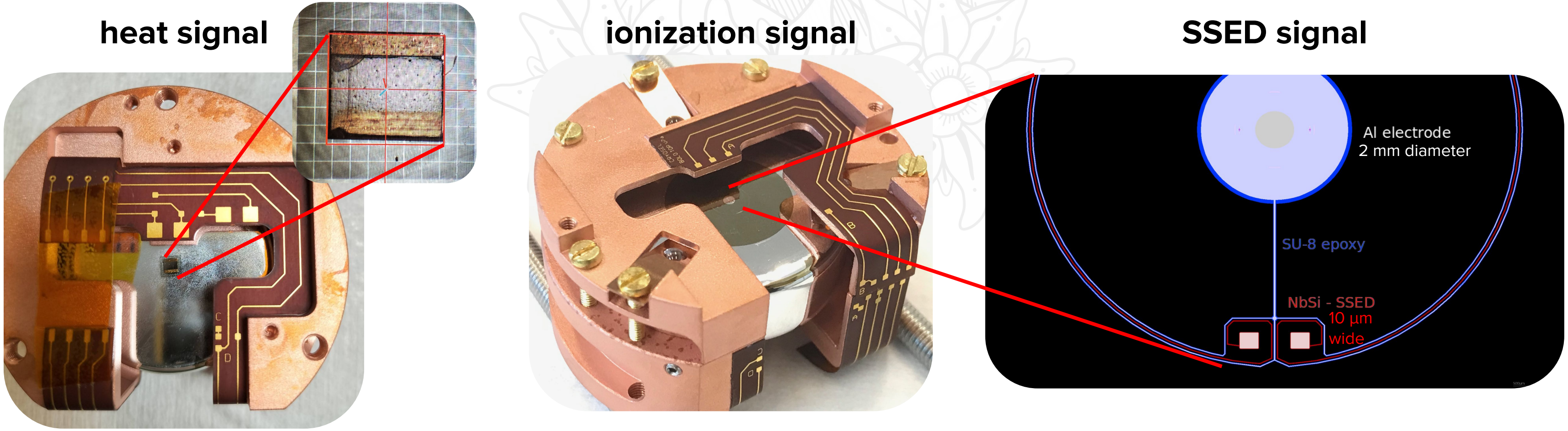
rejection of HO!

CRYOSEL project

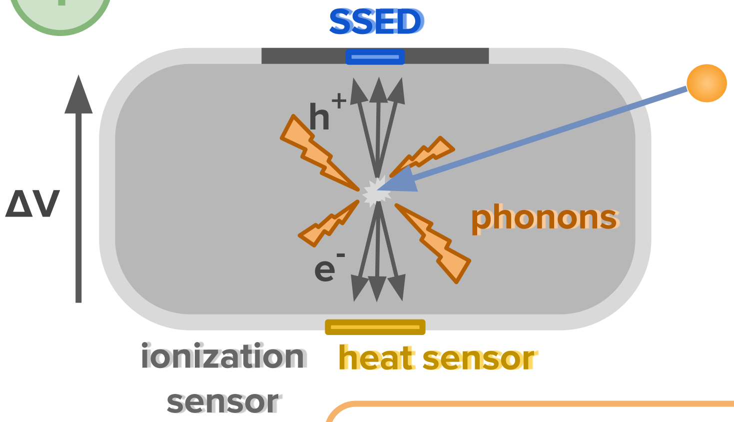
→ Reduce HO -> tag production of charges
→ keep NTD thermistance as a reliable heat sensor
→ new sensor design: **SSED**
  "*Superconducting Single Electron Device*"
  sensitive to the production of a single e^-
→ 40g Ge detector, σ_{phonon} = 20 eV, 200 V bias,

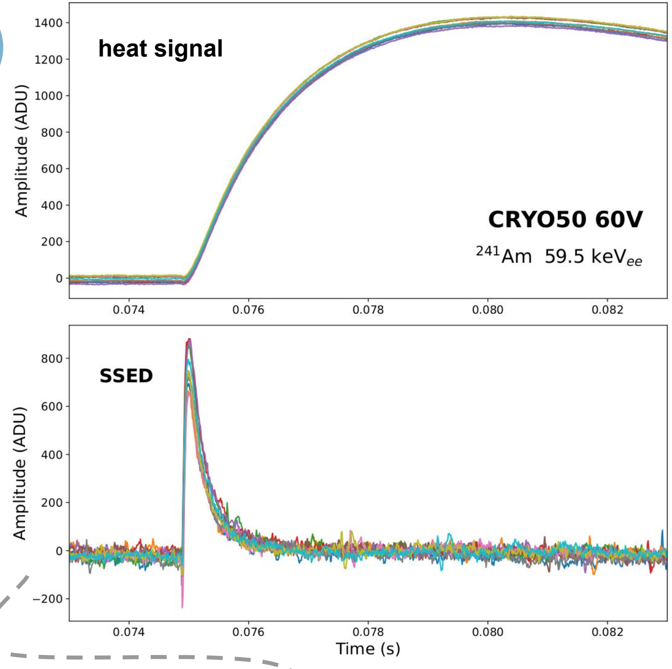


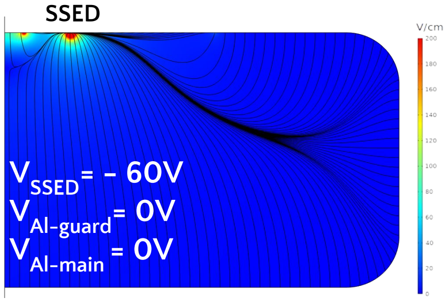


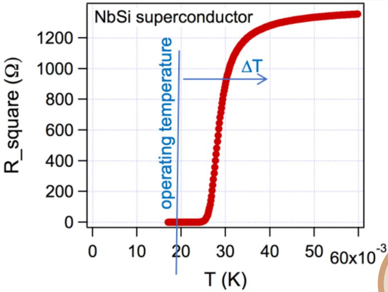


CRYOSEL project









act as **HO veto**

CRYO50, first prototype with operational SSED
→ need to **study SSED behavior**

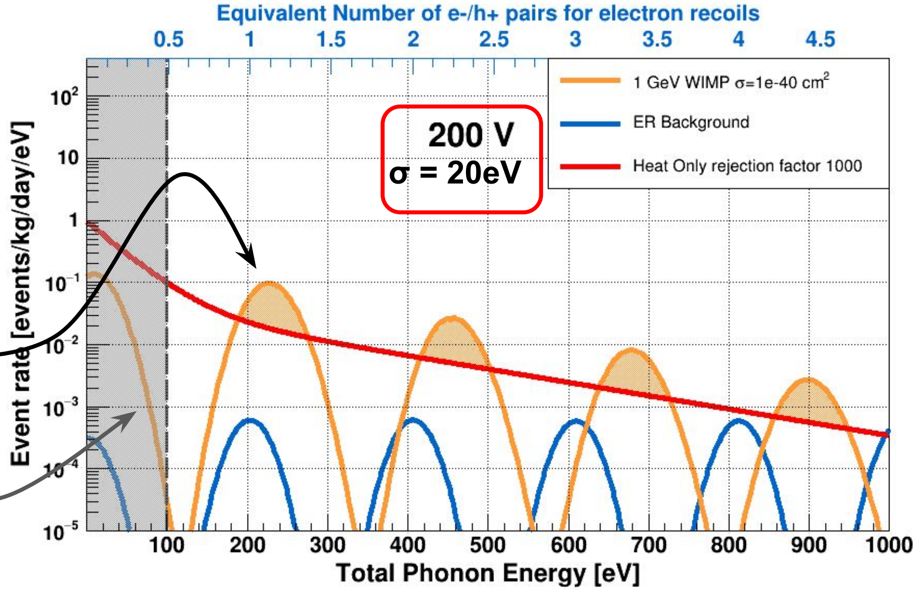
CRYOSEL project

- Mean energy to create one e^-/h^+ pair in Ge, **$\epsilon \approx 3$ eV** (ER)

- Use **Luke boost** to discretize the charges & amplify the energy deposited by single charge to energies that can be detected

- **At 200V**, E_{heat} = 3 x (1 + 200/3) = 203 eV, want σ = 20 eV to be sensitive to a single e^-/h^+ pair → 5σ threshold at 100 eV

- **Need:** A detector that sustains **high voltage**, a **good heat resolution**, a **low SSED threshold** (single charge) for HO veto.

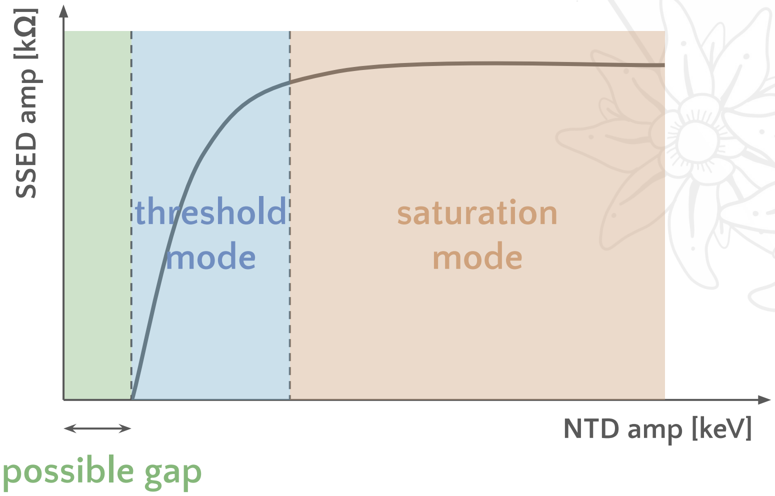


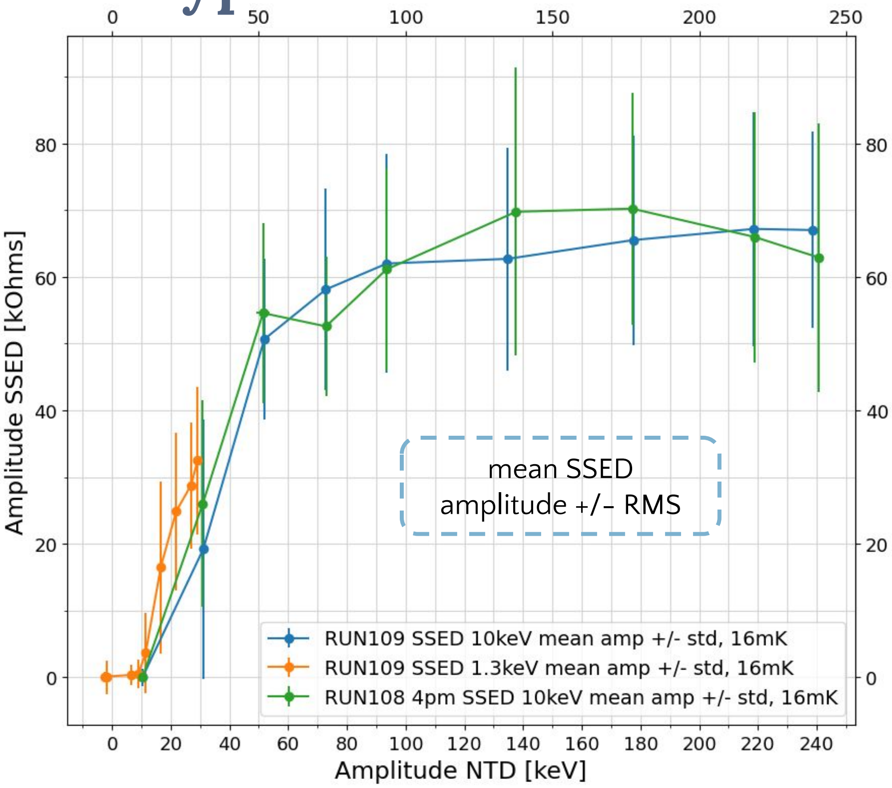
Transition observed in first prototype

Use calibration peaks (10.37 keV & 1.3 keV) as probes by using Luke amplification.

Three datasets :

- From RUN109 10.37 keV
- From RUN109 1.3 keV
- From RUN108 10.37 keV





→ We want a **HO veto**, what actual fraction of events trigger the SSED ?

SSED triggering efficiency

5σ threshold ~ **1.250 kΩ**

<u>Three datasets :</u>

- From RUN109 10.37 keV
- From RUN109 1.3 keV
- From RUN108 10.37 keV

<u>Limitations in threshold characterization :</u>

Only two exploitable characteristic peaks

Bias and E_{recoil} are intrinsically linked because of Luke effect

→ Low bias, low field, no triggering ?

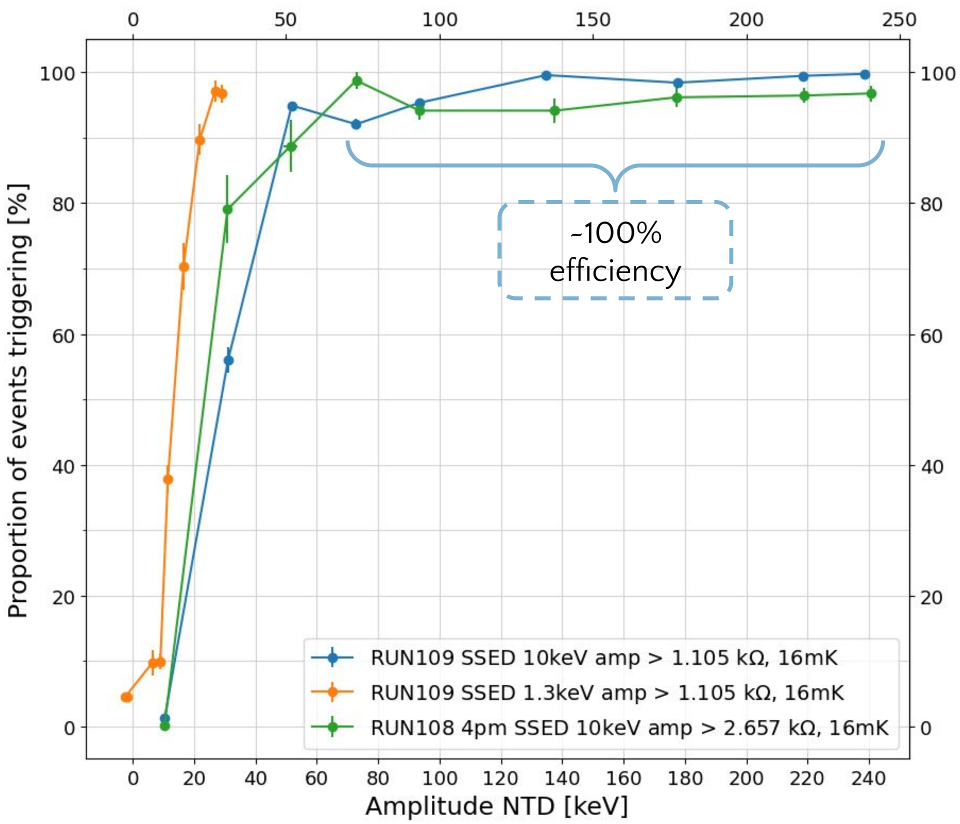
→ Low bias, bad charge collection

→ High bias (1.3 keV data) better collection & lower threshold

<u>Next step :</u>

LASER probing

→ Allows to tune pulse energy at any operating temperature and bias



Conclusion and perspective

- With this first fully operational CRYOSEL prototype we have been able to :

  → First confirmation that SSED behaves as expected,

  → First characterization of the new SSED sensor,

  → Results that will allow useful inputs to further improve CRYOSEL design

- Current step : pulsed laser to tune pulse energy and probe transition at any bias or temperature,
- Next step is the arrival of new prototypes with enhanced phonon efficiency at lower temperature
- Test of final prototype in 2024 in BINGO cryostat @ LSM, physics run

Thank you for your attention !