BULLKID: Monolithic array of particle absorbers sensed by Kinetic Inductance Detectors

23/03/2023

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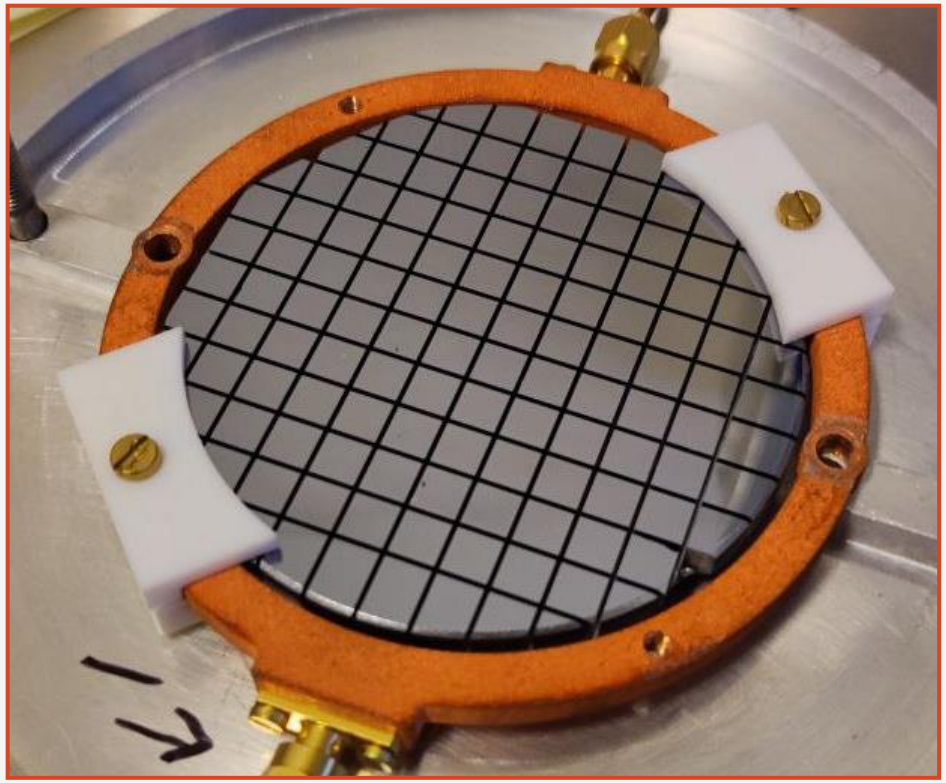
Project goal

Obtain a cryogenic, low threshold nuclear recoil detector for coherent neutrino nucleus scattering and light dark matter ($0.1 \div 10$ GeV) searches.

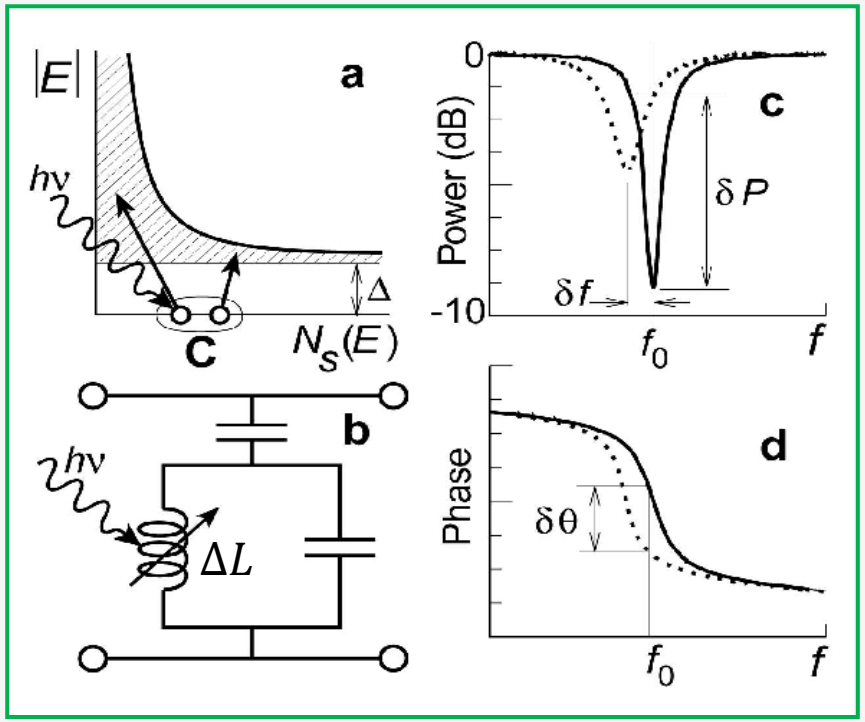
Detector specifications:

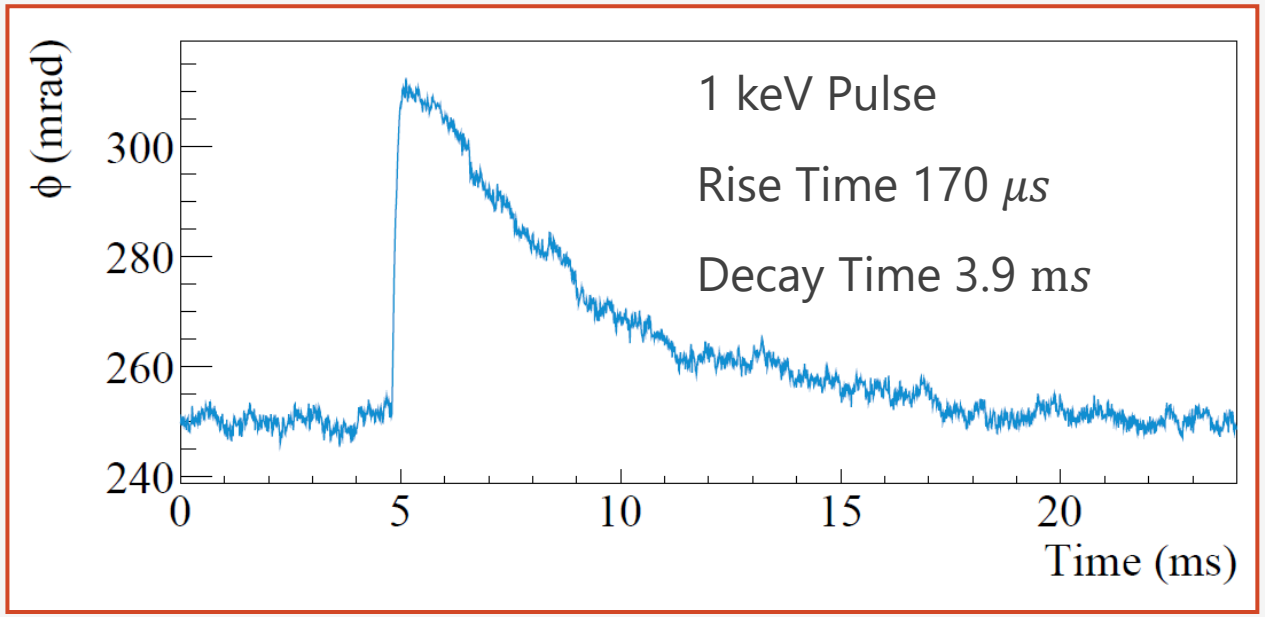
- Phonon sensors
- Background rejection
- Silicon or Germanium target
- Target mass ≈ 1 kg
- Energy threshold ≈ 100 eV
- High segmentation (≈ 2000 detector units)



Microwave Kinetic Inductance Detectors (MKIDs)

Day et al., Nature 425 (2003) 817

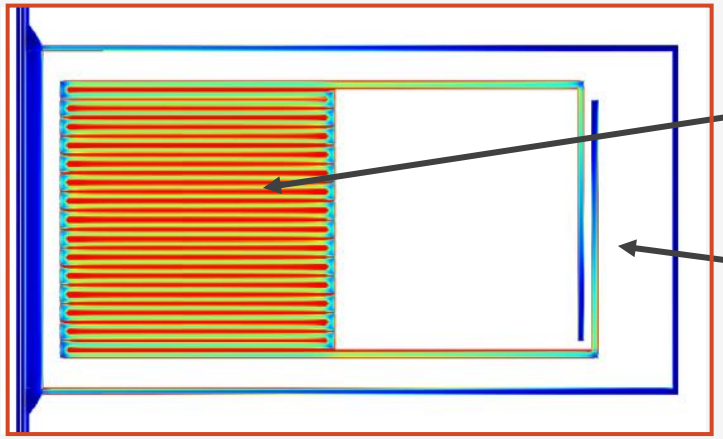




Core of the device is a superconducting RLC resonator

a/b) Phonon absorption -> Cooper pair breaking (ΔL)

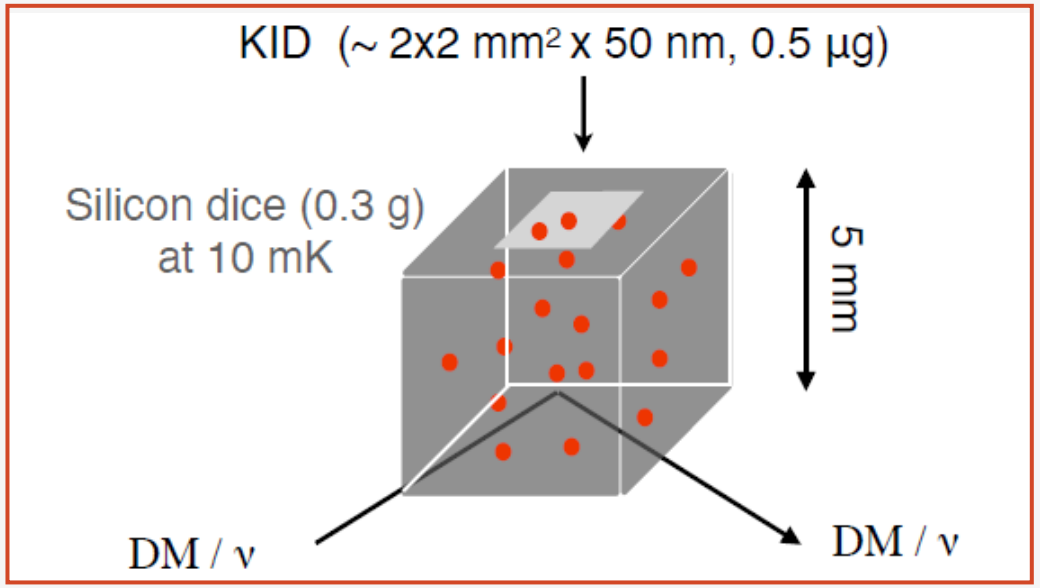
c/d) Resonator $f_0 = 1/\sqrt{LC}$ thus $\Delta L \rightarrow \Delta f_0$



Inductive meander (L)

Capacitive fingers (C)

BULLKID: Kinetic Inductance Detectors coupled to silicon absorbers



Phonons created by the nuclear recoil are confined in the voxel and are detected by the associated MKID

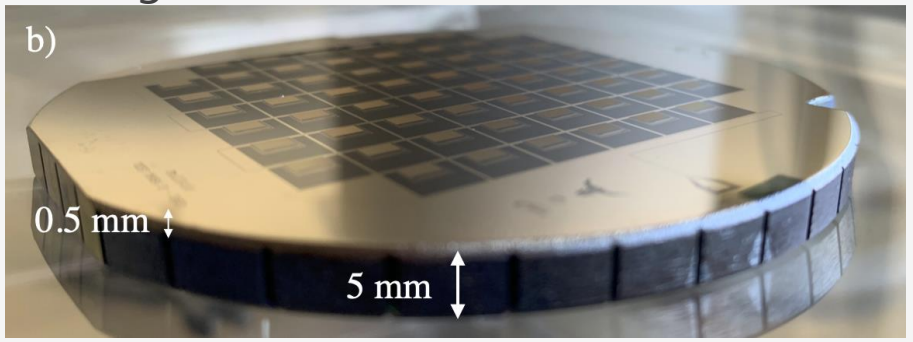
A 0.5mm common disk holds the structure and hosts the lithography for 60 KIDs

The absorber is segmented by 4.5mm grooves to improve phonon collection efficiency

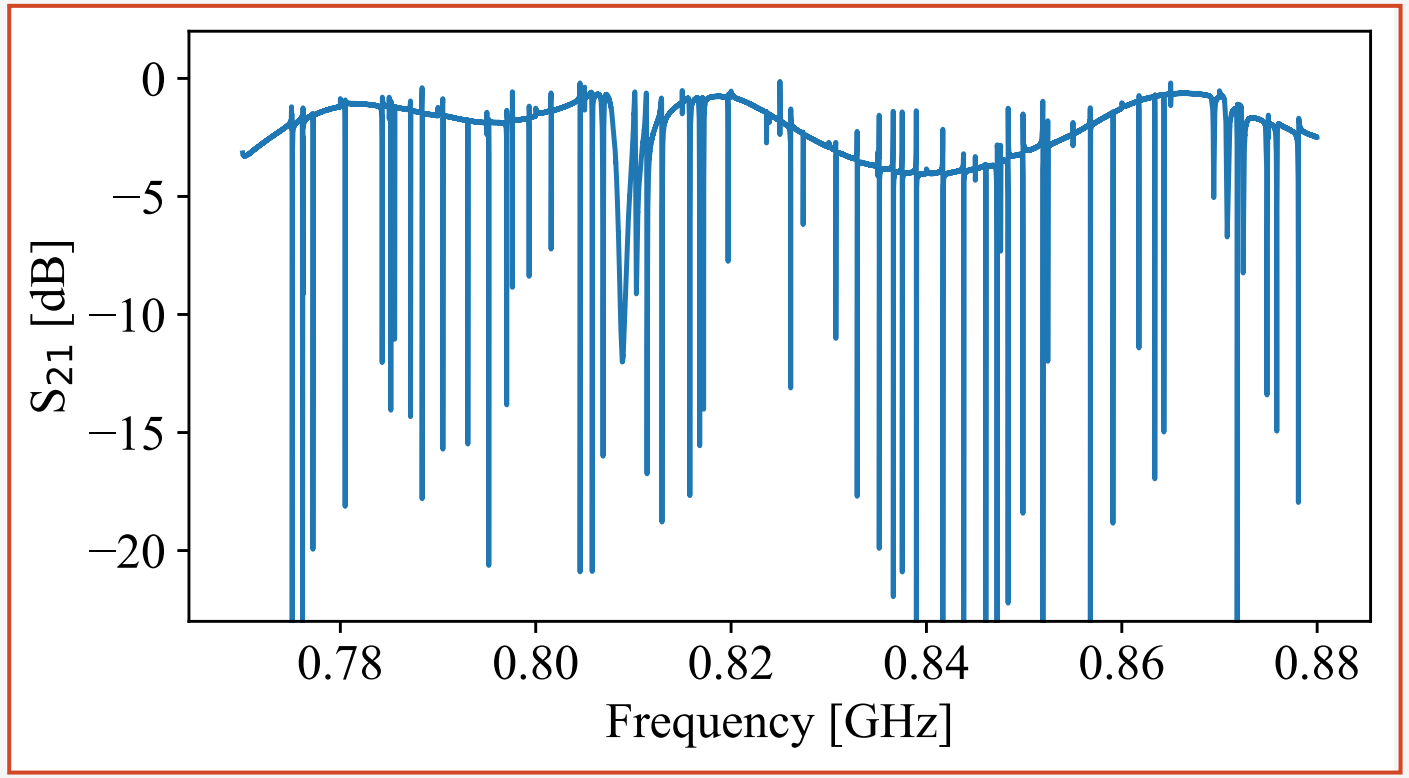
Total active mass is 19g

Diced silicon absorber

MKID array on the other side of the wafer hosting 60 resonators (60 nm Al)

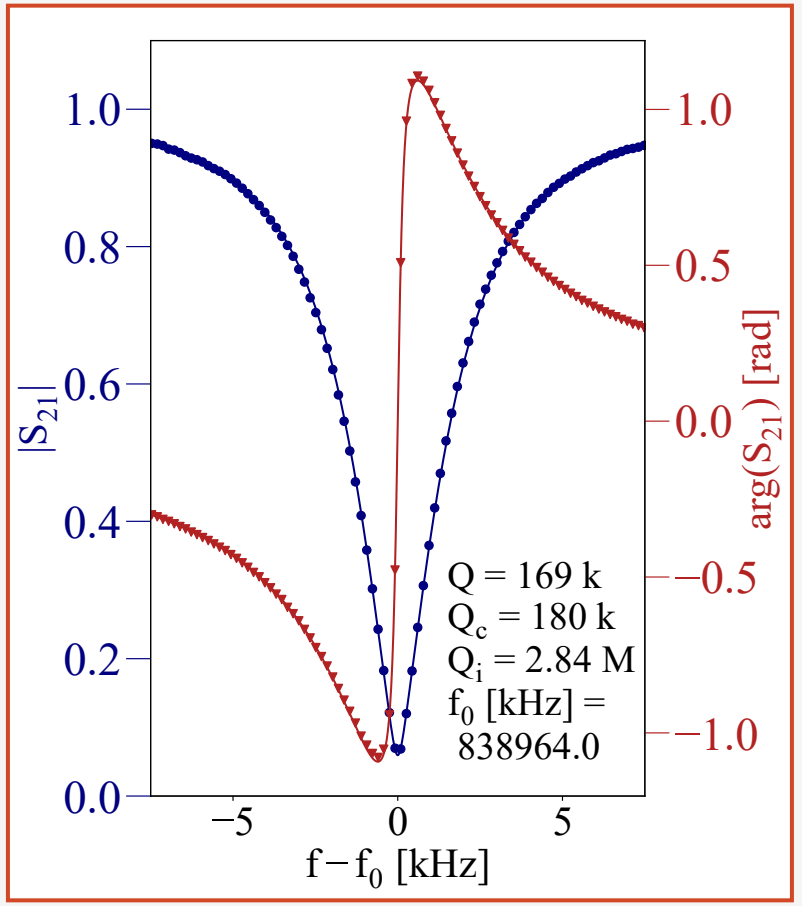


Latest results (Appl. Phys. Lett. 121, 213504 (2022))



58/60 resonators active

Detector response not uniform across the array (now solved)

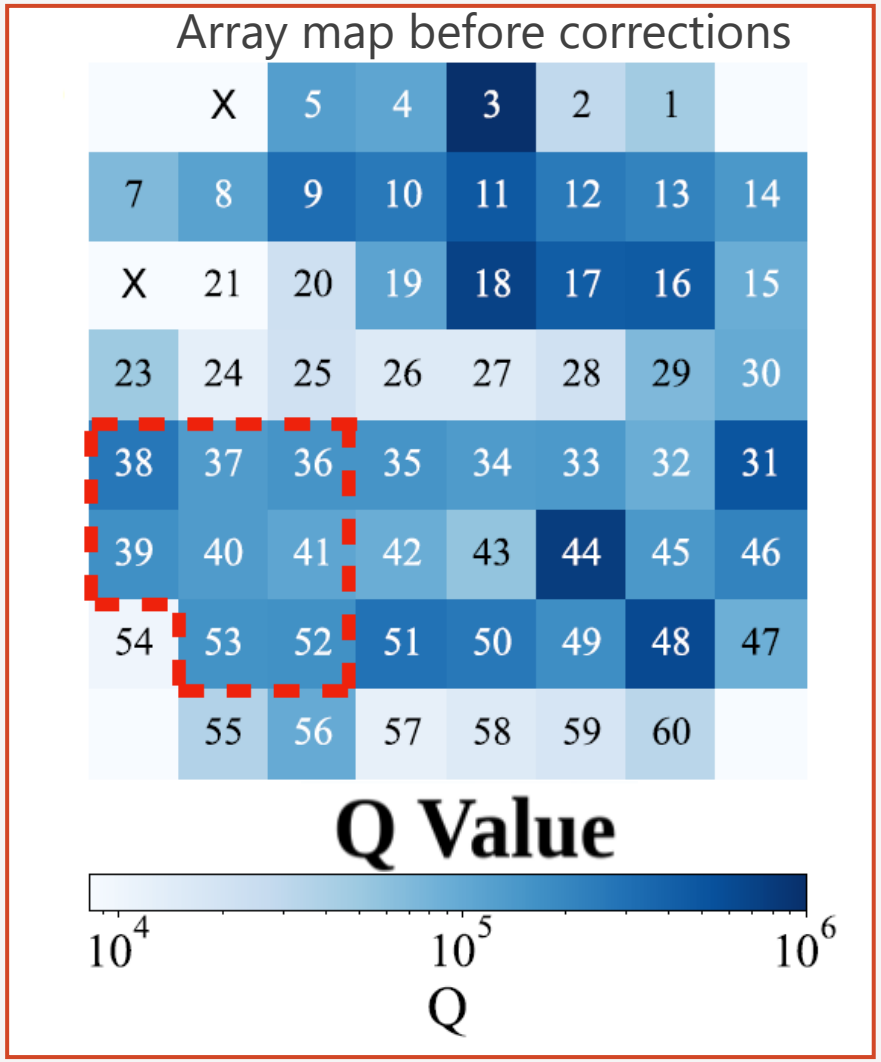


Fit of Resonator 40

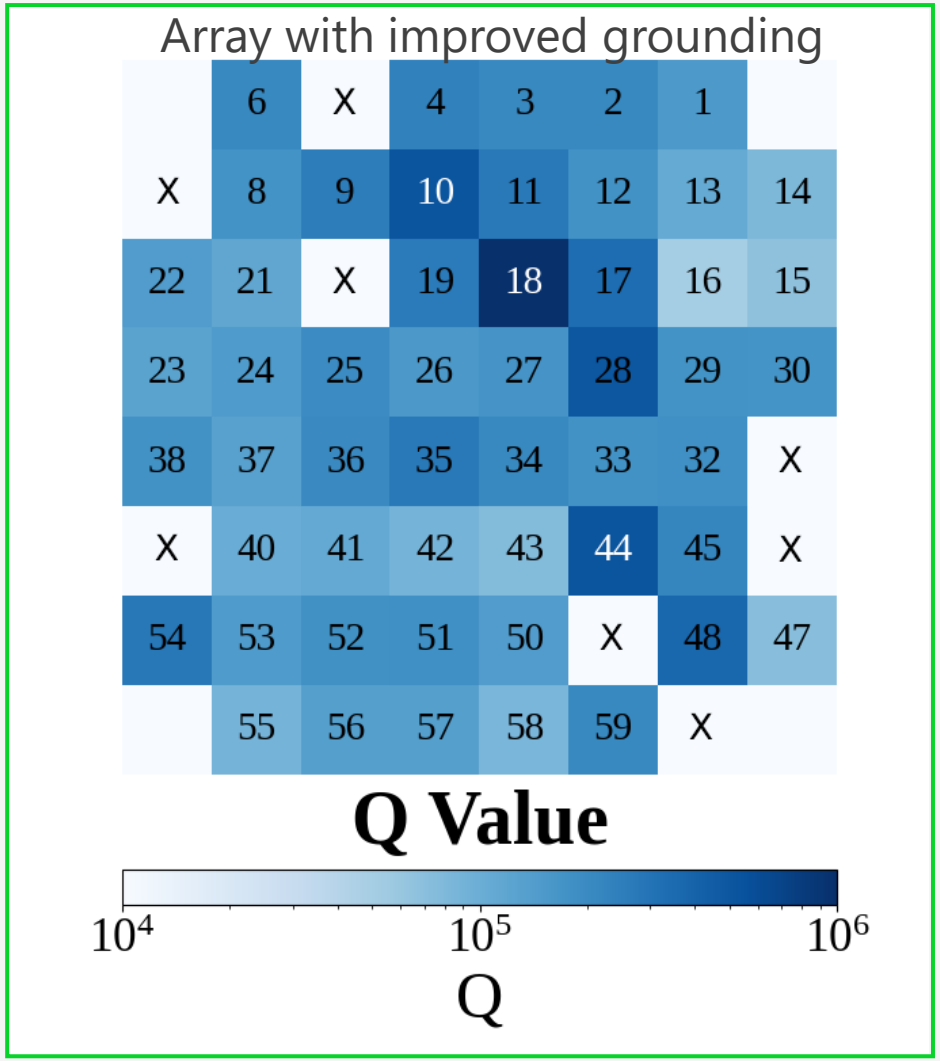
Improvement of uniformity

Appl. Phys. Lett. 121, 213504 (2022)

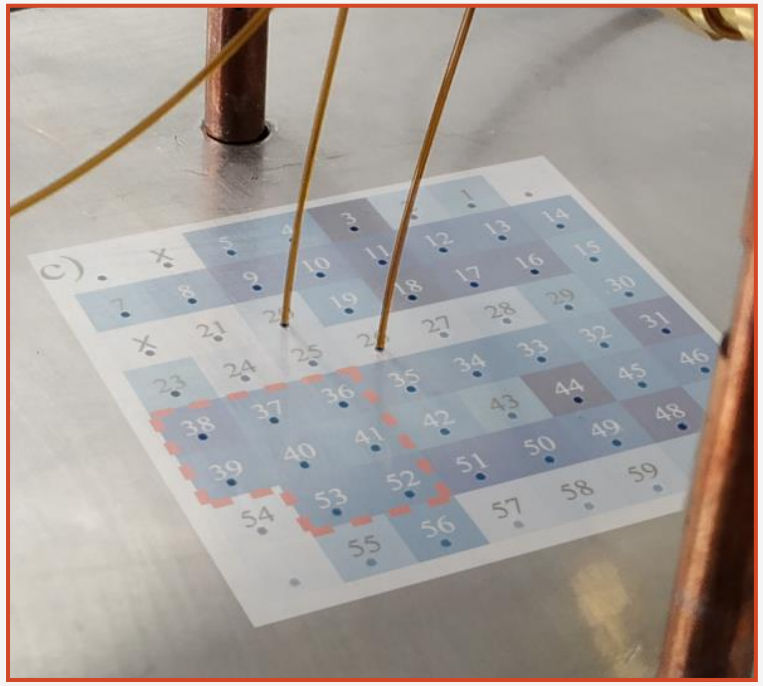
Array map before corrections

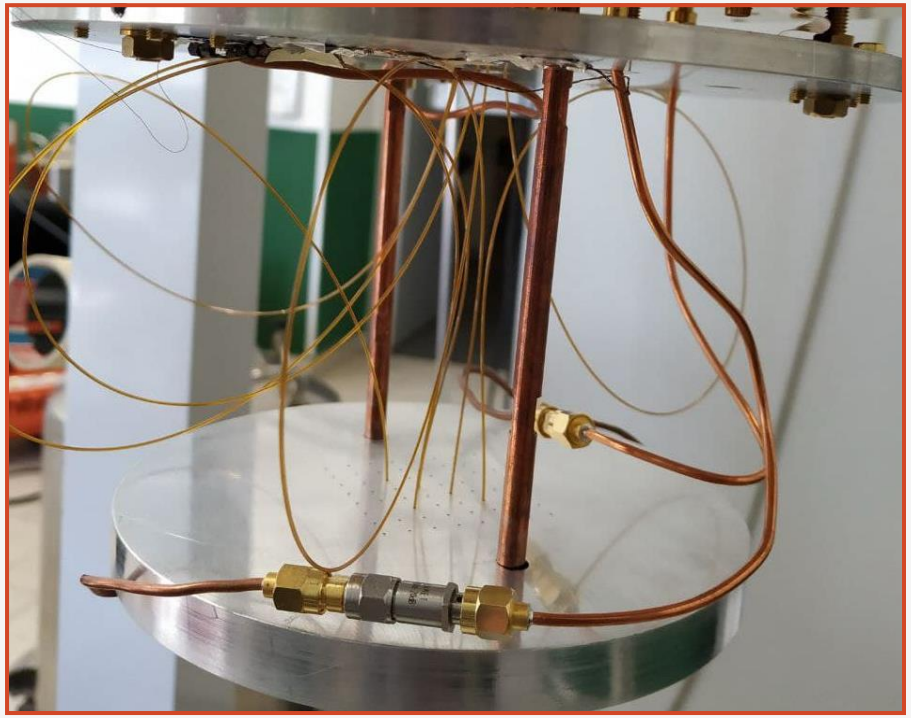


Array with improved grounding



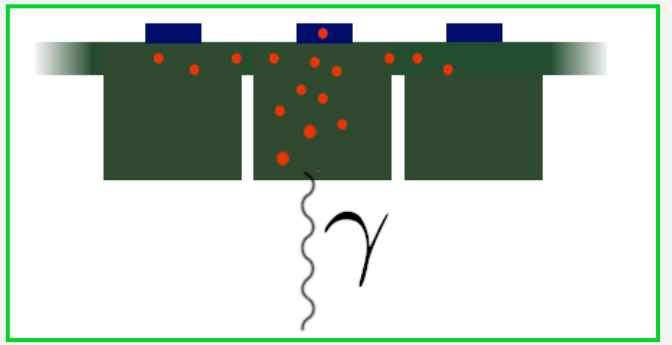
Optical calibration setup





8 optical fibers firing on the diced side of the detector

400 nm UV lamp (ϵ_{ph} = 3.1 eV)



Optical calibration results

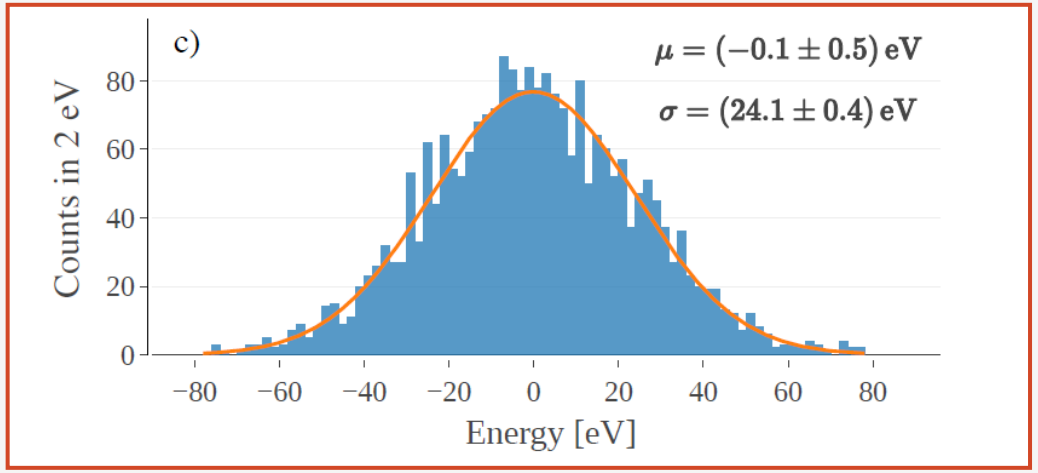
$$\sigma = \sqrt{\sigma_0^2 + \epsilon_{ph} \cdot \frac{d\phi}{dE} \cdot \mu}$$

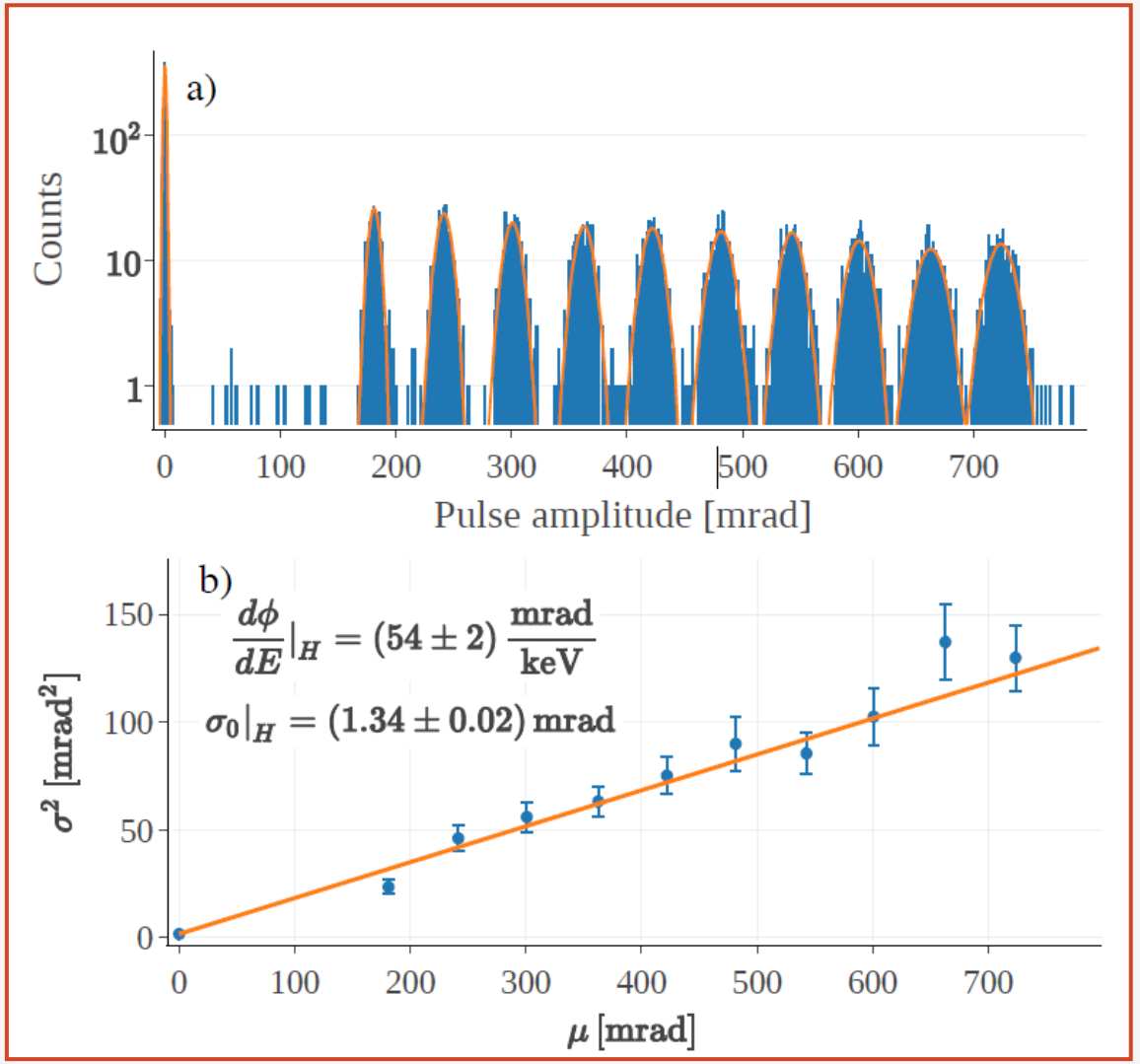
- σ_0 (resolution)
- $\frac{d\phi}{dE}$ (responsivity)

Average resolution across 8 pixels:

$$\sigma_0|_H = 26 \pm 7 \text{ eV}.$$

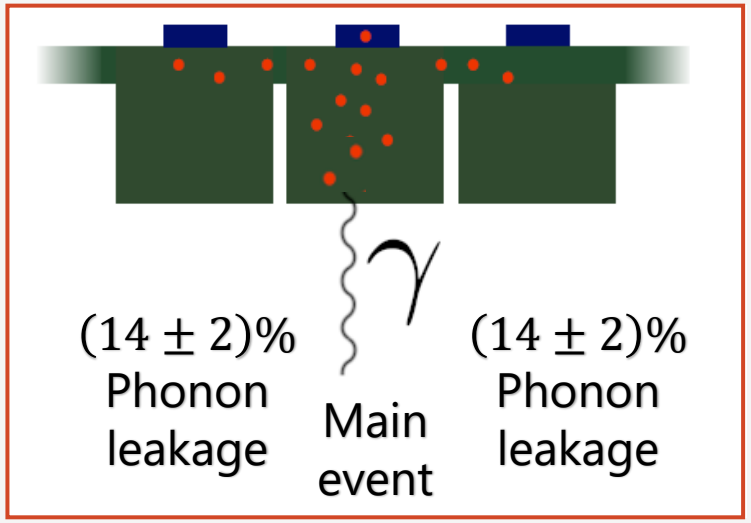
Allowing for a **threshold ≈ 150 eV**

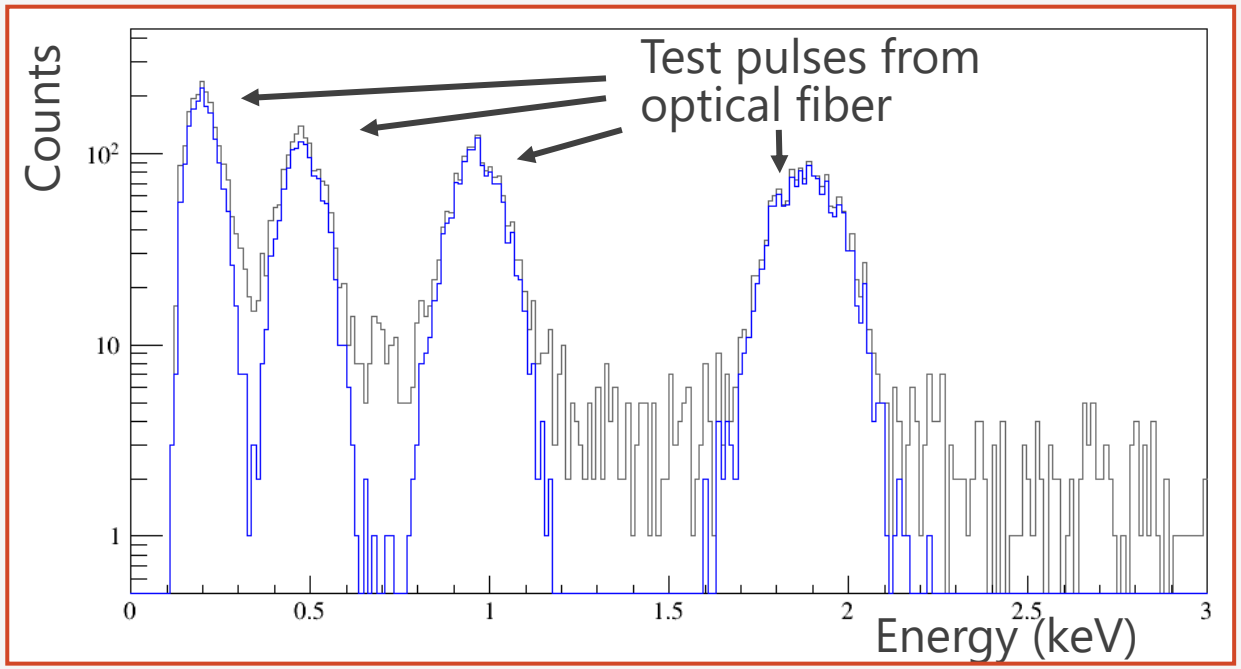




Above ground background

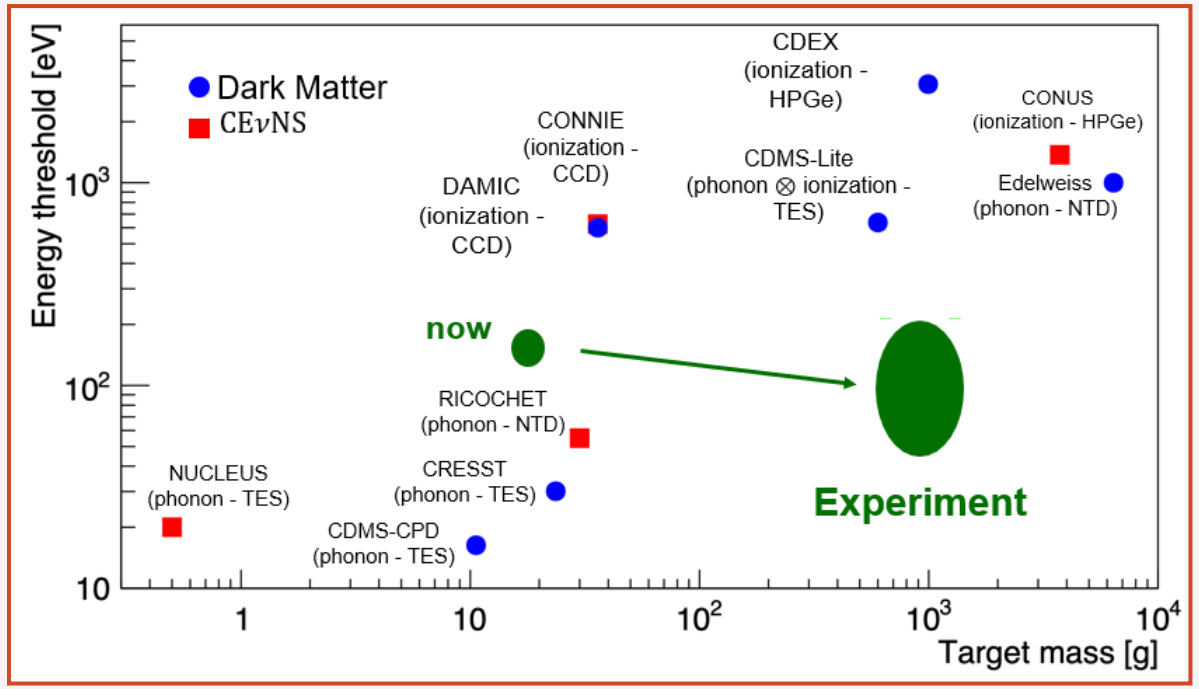
Cut strategy: trigger on central pixel and exclude events that record a signal in the neighbours not compatible with x-talk

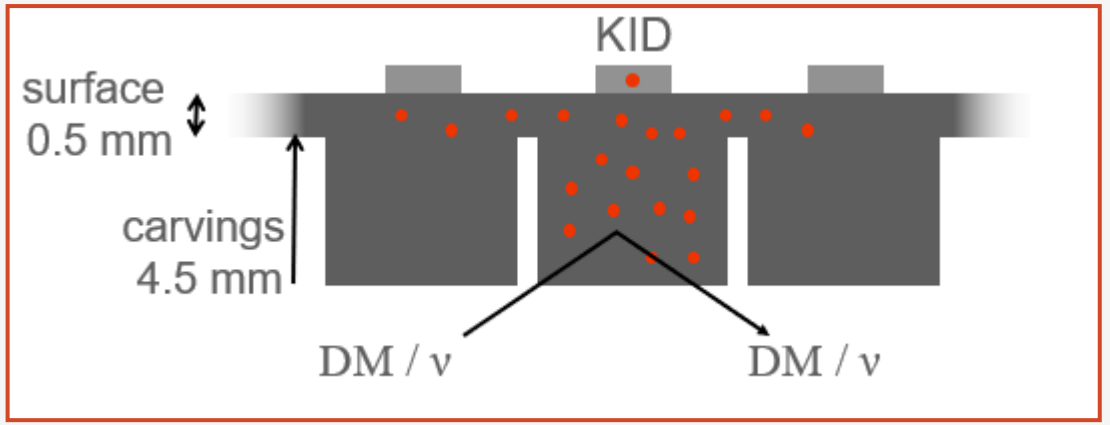


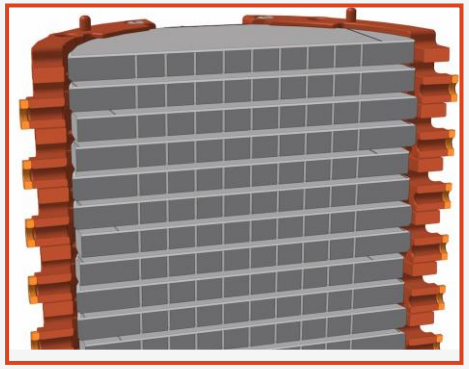


Test of the cut: events not interacting with the central voxel are discarded

Towards the experiment







Target mass:

- 3" wafers –> 4" wafers
- Vertical stack of wafers

Threshold (ongoing R&D):

1. Replace Al with Al-Ti-Al KIDs - 5x kinetic inductance

2. Deeper carvings for higher phonon focussing

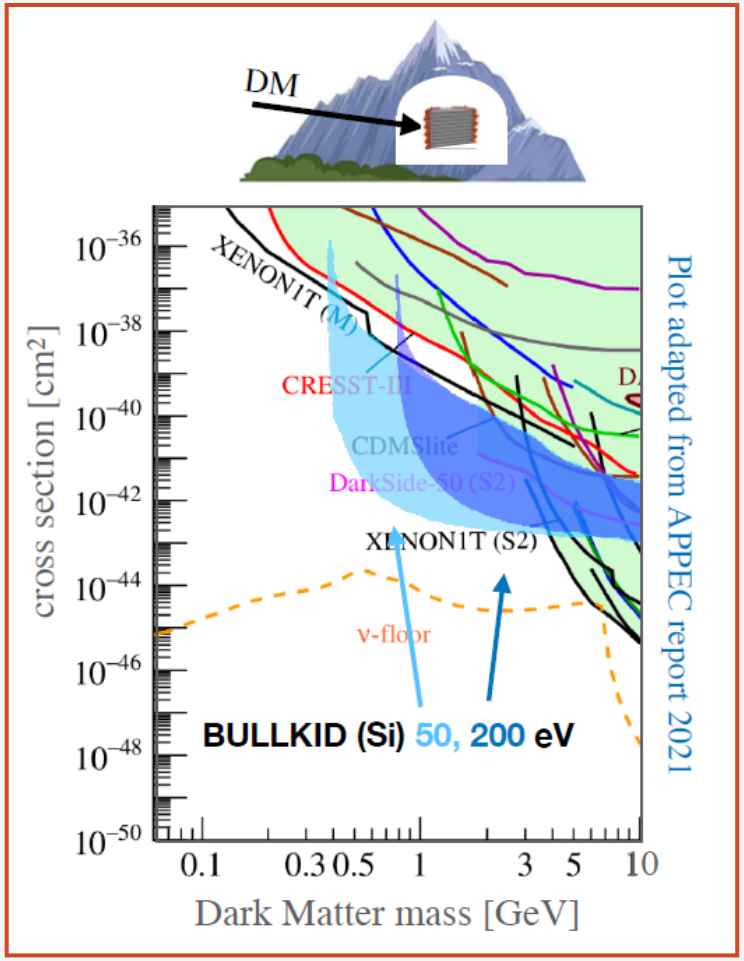
+port the technology to Germanium wafers (10x neutrino x-sec, does not apply to Dark Matter)

Towards the experiment

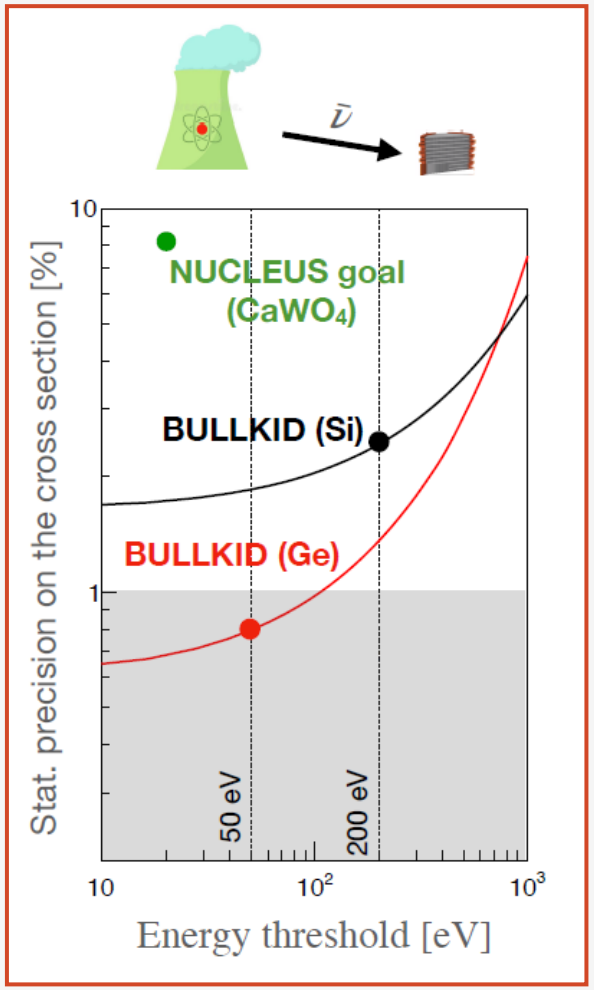
Produce a scalable nuclear recoil detector with:

- 0.6 Kg (Si) / 1.3 Kg (Ge)
- 2000 detector units
- 200 ÷ 50 eV Threshold

Dark matter experiment



Neutrino scattering experiment



Conclusion

Thank you for your attention!