BULLKID: Array of particle absorbers sensed by Kinetic Inductance Detectors

Daniele Delicato on behalf of the BULLKID-DM collaboration

BULLKID is a R&D project aiming to pair an array of **Kinetic Inductance Detectors** with a **diced silicon absorber,** achieving mass **scalability up to the Kg scale** and **high segmentation**.

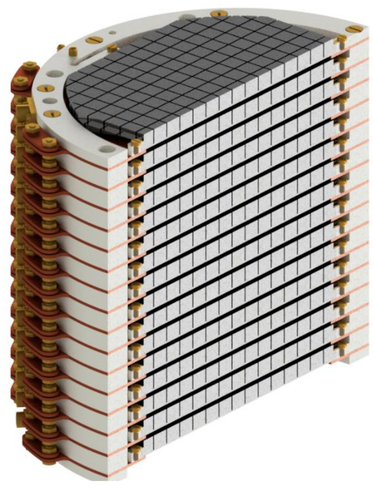
An average baseline resolution of $\mathbf{27 \pm 6}\ \boldsymbol{eV}$ makes it a suitable detector for **low-energy** processes such as direct interactions of **dark matter** and coherent elastic **neutrino-nucleus scattering**.

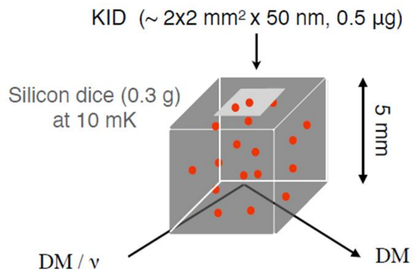
The above ground unshielded operation of this prototype has led to the characterization of a **background** level **of 2·10^6 counts/(kev·kg·day)** flat **down to an energy threshold of 160 eV.**

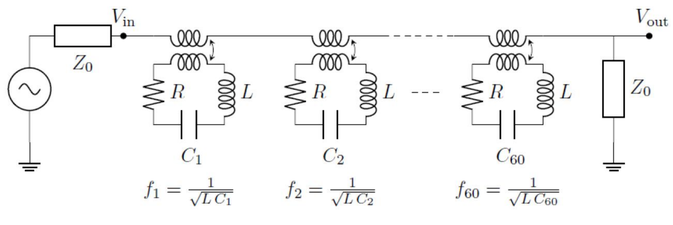
We present the **status** of the project and its **future development** towards an improvement in terms of **threshold** and **active volume of the detector**.

BULLKID: Kinetic Inductance Detectors coupled to silicon absorbers [1]

- **Phonon-mediated** detection of nuclear recoils
- **Scalable** and **highly segmented** silicon absorber
- **145** 5x5x5 mm^3 **silicon cubes per 4' wafer**
- Target **mass is 0.6 Kg (16x 4' wafers)**

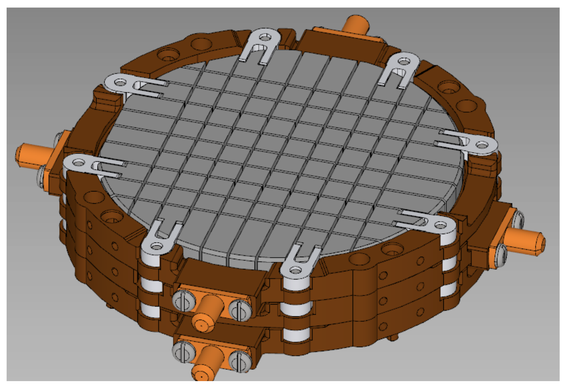




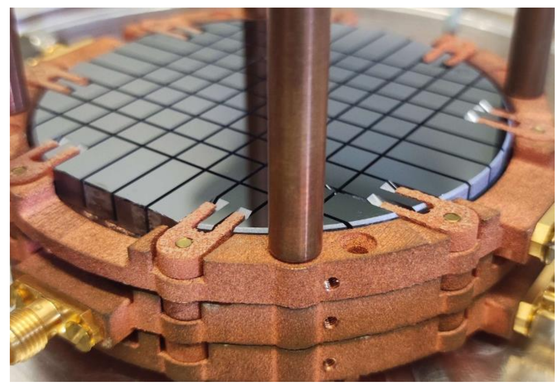


3x 3-inch Demonstrator

- **Intermediate step** before moving to a **full scale array**
- 3x **3-inch** silicon wafers for a total of **180 units and 61g of active silicon**



KIDs on Ge

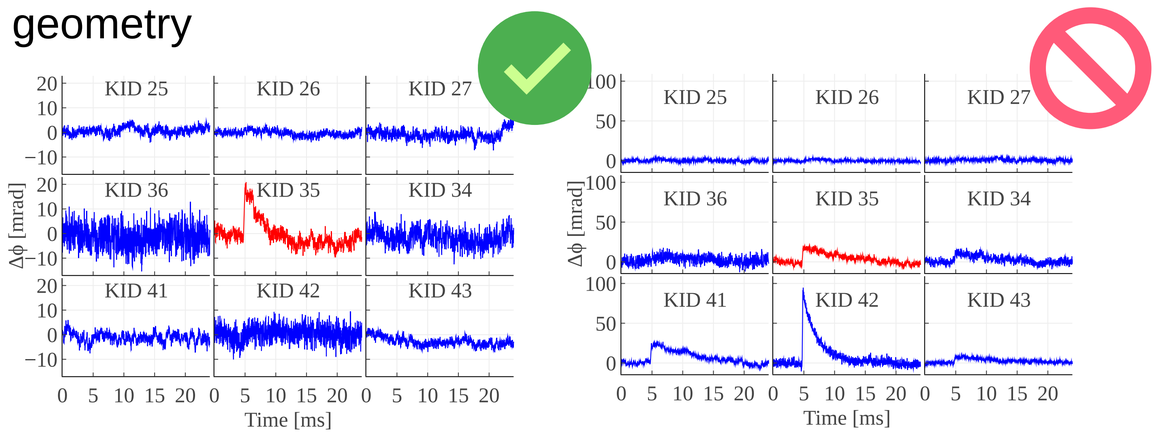


4-inch design

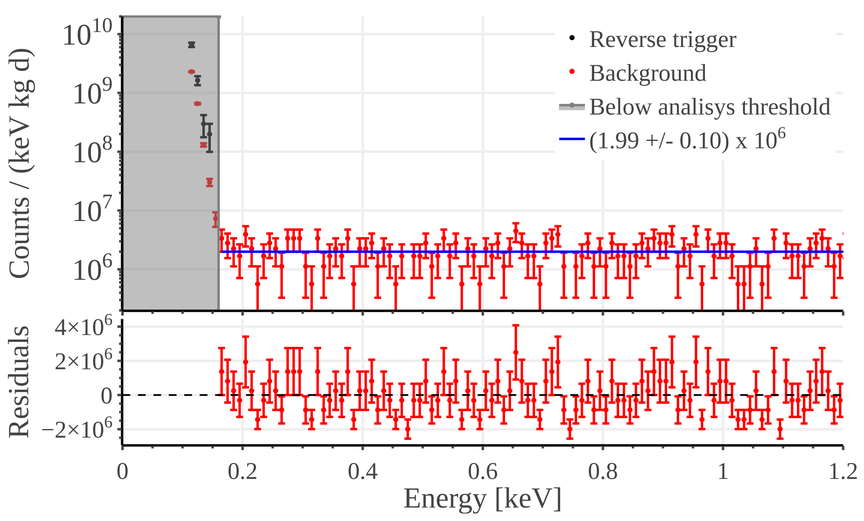
Cluster cuts for low energy data selection

To select only events interacting with a chosen voxel:

- Acquire simultaneously a central voxel and 8 surrounding neighbours
- **Characterize the expected phonon x-talk** ratio $\mathrm{m_r} = \langle A_m/A_n \rangle$
- **Reject events not compatible** with the expected geometry

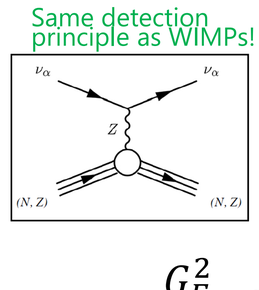


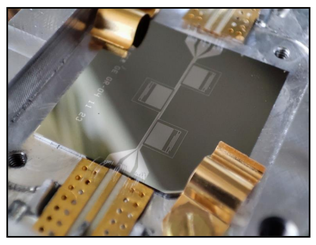
Surface background acquired by a 0.34 die over 40h **[2]**



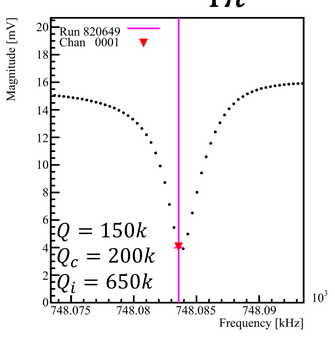
Same detection principle as WIMPs!

Observed in 2017 by COHERENT

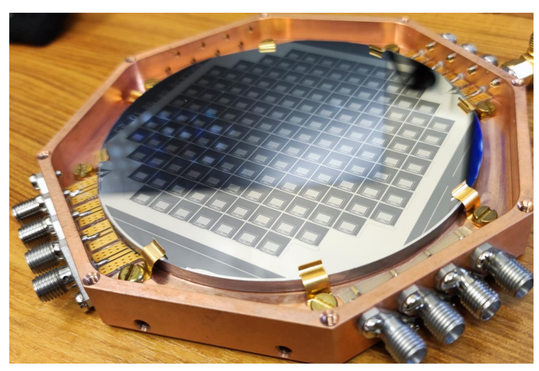




$$\sigma_{CE\nu NS} \approx \frac{G_F^2}{4\pi} E_\nu^2 N^2 \rightarrow \boldsymbol{\sigma_{Ge} \approx 10 \cdot \sigma_{Si}}$$



However **Ge oxide is not inert**!
Qi seems promising, energy calibration is the next step



- Upgraded pixel count from 60 to 145 per wafer
- Easier scalability towards the Kg range with less wafers

KID R&D

Goal: maximize SNR

$$\frac{\mathrm{d}\phi}{dE} = \eta \frac{\alpha S_\phi(\omega, T) Q}{N_0 V \Delta_0^2}$$

$\frac{L_k}{L_{tot}}$ depends on pixel geometry and material

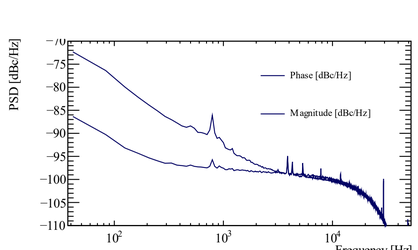
Quality factor of the resonator

$\frac{\boldsymbol{Signal}}{\boldsymbol{Noise}}$ Difficult to reduce

Energy to quasi-particles efficiency

Volume of the KID

Gap of the superconductor metal



- Optimized KID design to maximize α
- Metallized layer optimized to increase α and reduce Δ_0
- R&D on deeper grooves to increase η

For more details and results see:

1) A. Cruciani *et al*., "BULLKID: Monolithic array of particle absorbers sensed by kinetic inductance detectors", *Appl. Phys. Lett.* 121, 213504 (2022)

2) D. Delicato *et al*., "Low-energy spectrum of the BULLKID detector array operated on surface", *EPJC*, 84,353 (2024)