Phonon-mediated Dark Matter search with the BULLKID detector

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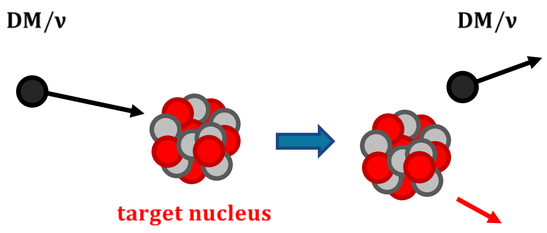
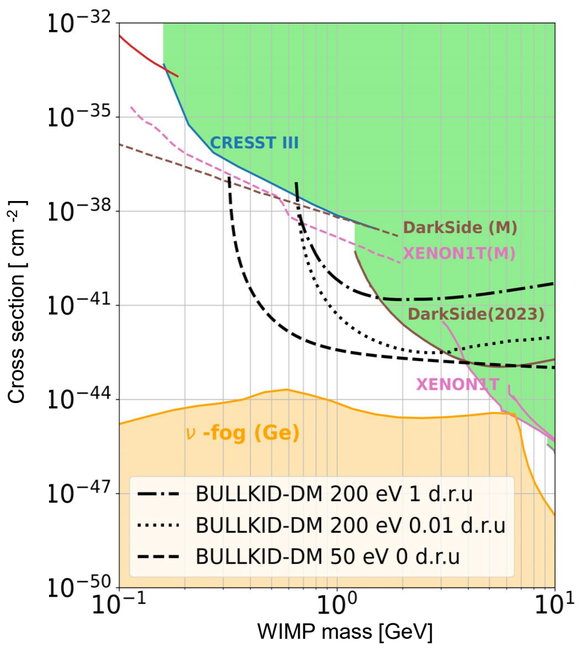
Project Goal

BULLKID is an R&D project targeting at the development of a detector for **direct light dark matter detection** and **coherent neutrino-nucleus scattering**.

The idea is to sense **phonons** produced by the nuclear recoil of such particles on a **diced silicon target** with a large array of **kinetic inductance detectors (KIDs)**.



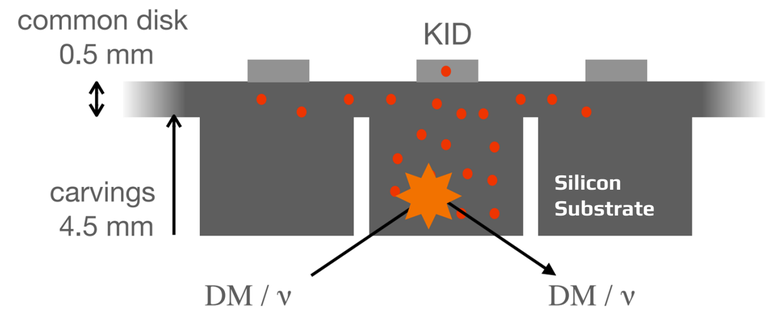


Why Phonons?

Nuclear recoils of light particles are hard to detect due to their **very low energy** ($\mathcal{O}$**(0.1-1) keV**).

Phonons are advantageous thanks to their low excitation energy ($\mathcal{O}$**(meV)**). This helps enhancing both **detection threshold** and **energy resolution**.

$$\text{signal} \propto \frac{\text{energy lost}}{\text{carrier cost}} \qquad \sigma_E \propto \frac{1}{\sqrt{N_c}}$$



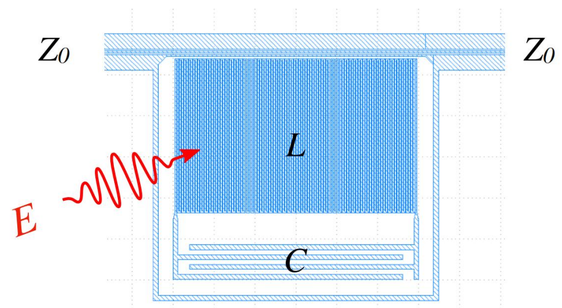
Kinetic Inductance Detectors (KIDs)

To detect phonons produced in the substrate, each dice is coupled to an **RLC superconductive resonator**.
Phonons impinging on the superconductor break electron-electron systems called **Cooper Pairs**.

Cooper pairs behave as an inductance (**kinetic inductance**), thus a change in their number produces a **shift of the resonant frequency** of the resonator.

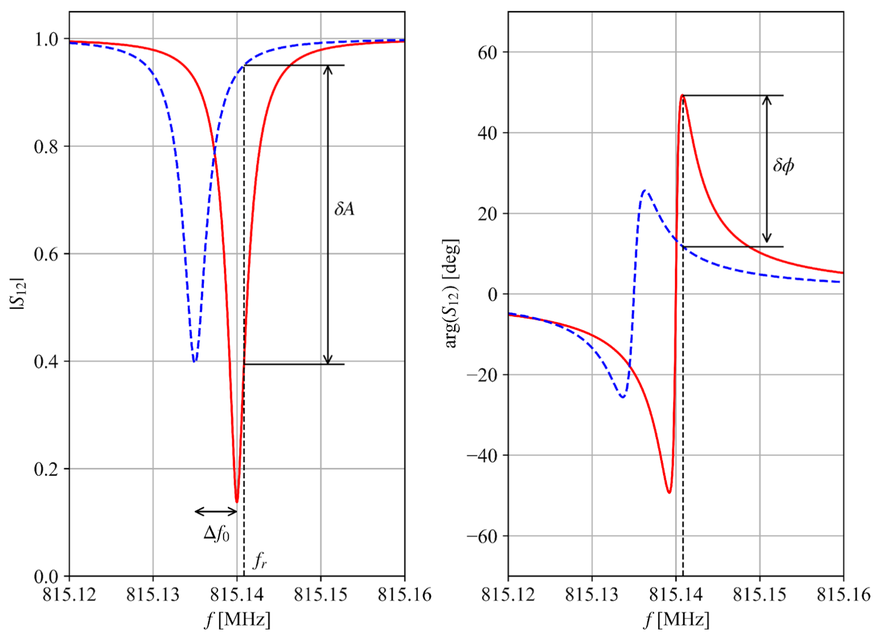
The signal can be measured both as an **amplitude** δA and a **phase shift** $\delta\phi$.

Each resonator has a different resonant frequency, allowing the **multiplexing** of many KIDs coupled to a **single transmission line**.

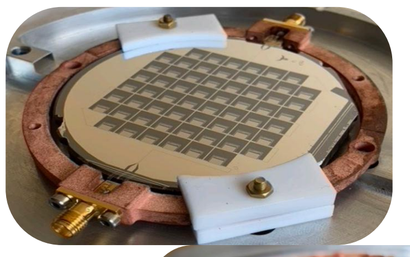


$$E \rightarrow \Delta n_{\text{pairs}} \rightarrow \Delta L \rightarrow \Delta f_0$$

$$f_0 = \frac{1}{2\pi\sqrt{LC}}$$



Towards full experiment



Prototype - 20 g / 60 dice
single 3" wafer
concluded in 2023

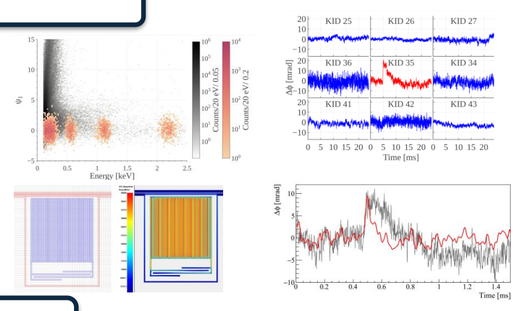
Demonstrator - 60 g / 180 dice
3-layer stack of 3" wafers
first operations summer 2024

R&D on large wafer
50 g / 145 dice
single 100 mm wafer
first operations fall 2024

BULLKID-DM - 600 g / ~2500 dice
16-layer stack of 100 mm wafers
commissioning in 2026 at Sapienza U.

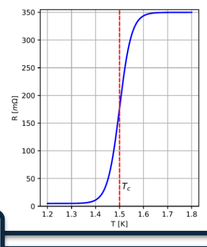
Activities

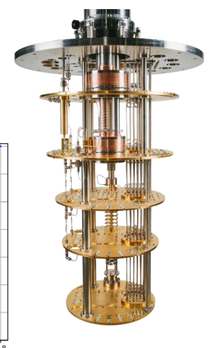
Our (main) activities focus on:
- **R&D on new KIDs**
- **Data Analysis**
- **Calibration**
- **Simulation of RF circuits**



Why is it interesting?

Low-Energy Particle Physics is an exciting and ever-expanding field. Concepts and techniques from other fields of physics are often needed to tackle the fundamental questions we want to ask:
- **RF electronics**
- **Cryogenics**
- **Condensed Matter** physics
- **Superconductivity** (and more...).





Contacts & References

Supervisors:
- Prof. Marco Vignati (marco.vignati@uniroma1.it)
- Dr. Angelo Cruciani (angelo.cruciani@roma1.infn.it)

Latest papers:
- A. Cruciani, et al, Appl. Phys. Lett. 121, 213504 (2022)
- D. Delicato, et al, Eur. Phys. J. C (2024)
- D. Delicato, et al, **arXiv:2412.07379** (2024)

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