BULLKID

BULky and Low-threshold Kinetic Inductance Detectors

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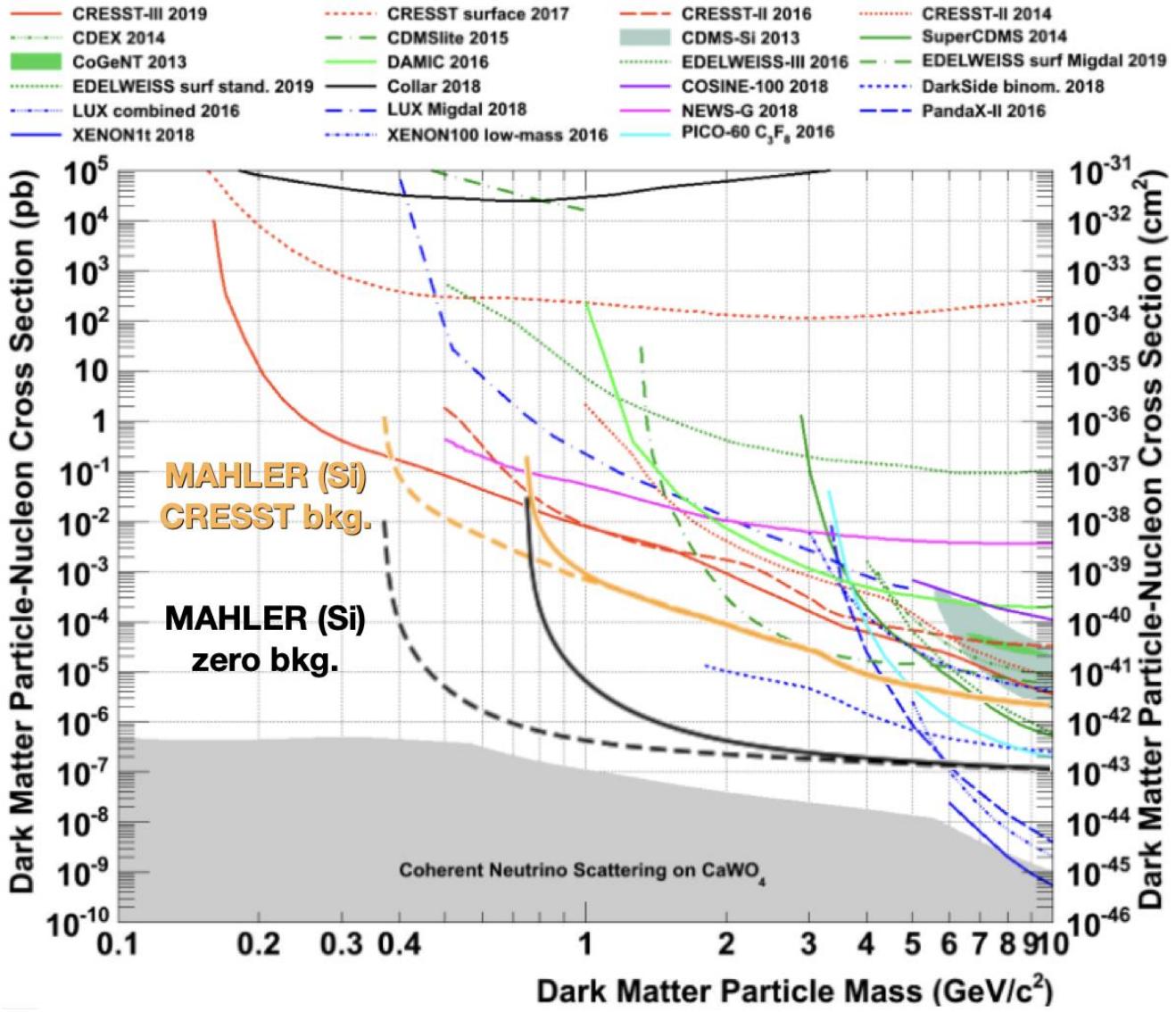
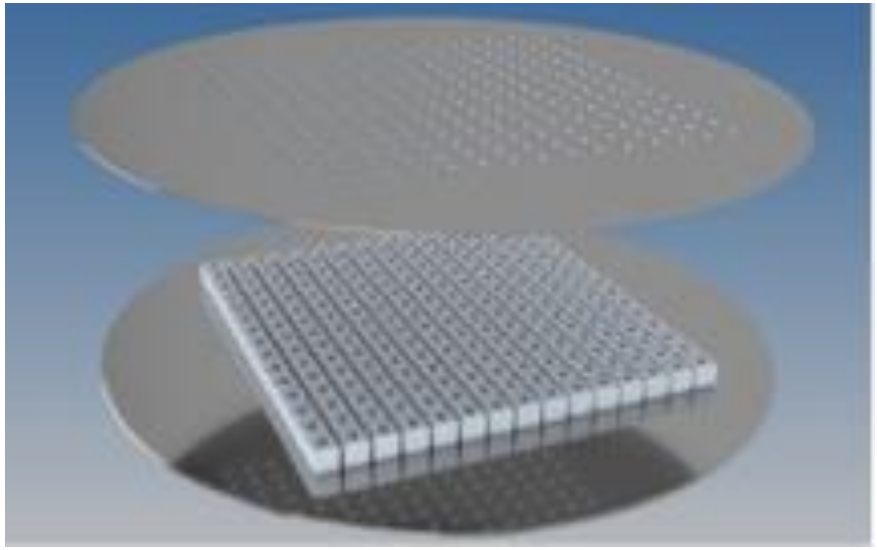
Motivation

- Coherent elastic neutrino-nucleus scattering and light dark matter searches require sensitive nuclear recoil detectors
- Cryogenic experiments with high mass, low energy threshold and high segmentation could play a crucial role.
- Here the example of the potentialities on DM search of MAHLER, a KID based experiment proposed by Sapienza a and INFN with a target of 0.6 kg of Silicon and energy threshold between 50 and 200 eV.



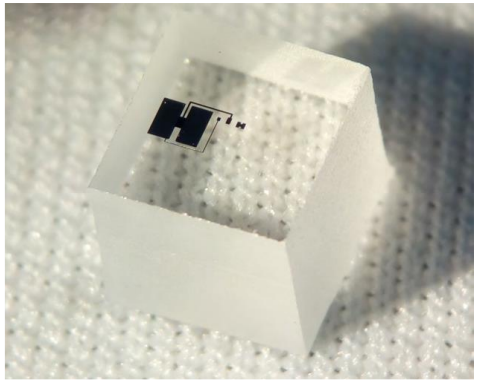
Cryogenic Detector experiments for **CEvNS**

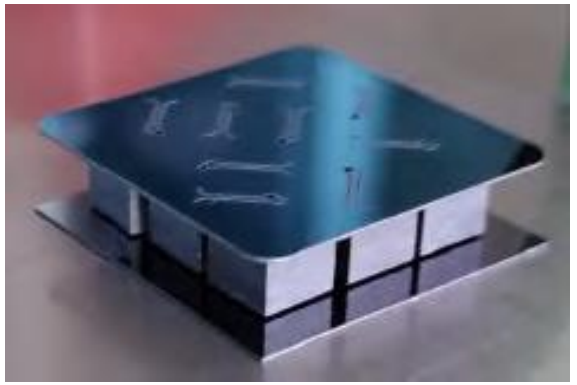
- Two ongoing experimentss on arrays of small cryogenic calorimeters in EUROPE:
  - Nucleus (Germany), based on TES sensors
    R.Strauss et al, Eur. Phys. J. C77 (2017) 506
  - Ricochet (France-USA), based on NTD sensors
    J. Billard et al, J. Phys. G44 (2017) 105101.
  - Both granted in 2018 by the
    European Research Council
- Next step: scale to 1 kg (1k detectors), difficult with TES and NTD technologies



Nucleus experiment – Phase 1

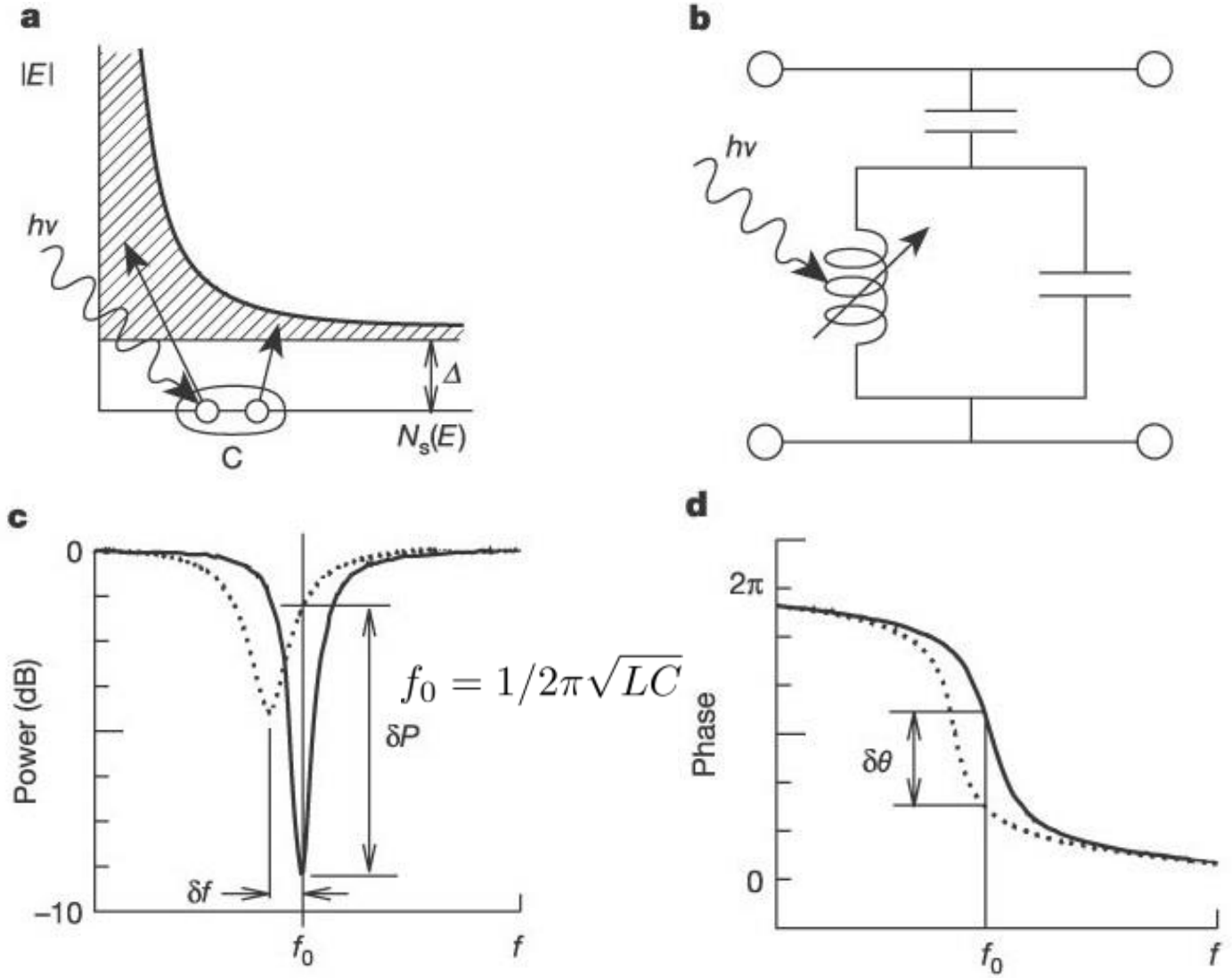
- 9 $\mathbf{Al_2O_3}$ ($\simeq$4 g) and 9 $\mathbf{CaWO_4}$ ($\simeq$6 g) crystal operating at millikelvin temperature
- Threshold energy resolution: 20 eV
- Single channel readout (no multiplexing)





Kinetic Inductance Detectors (KIDs)

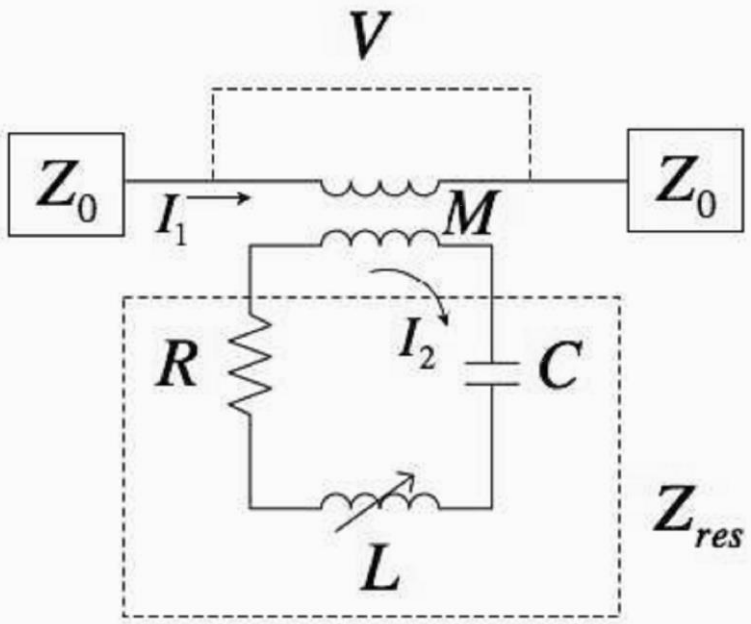
Day et al., Nature 425 (2003) 817

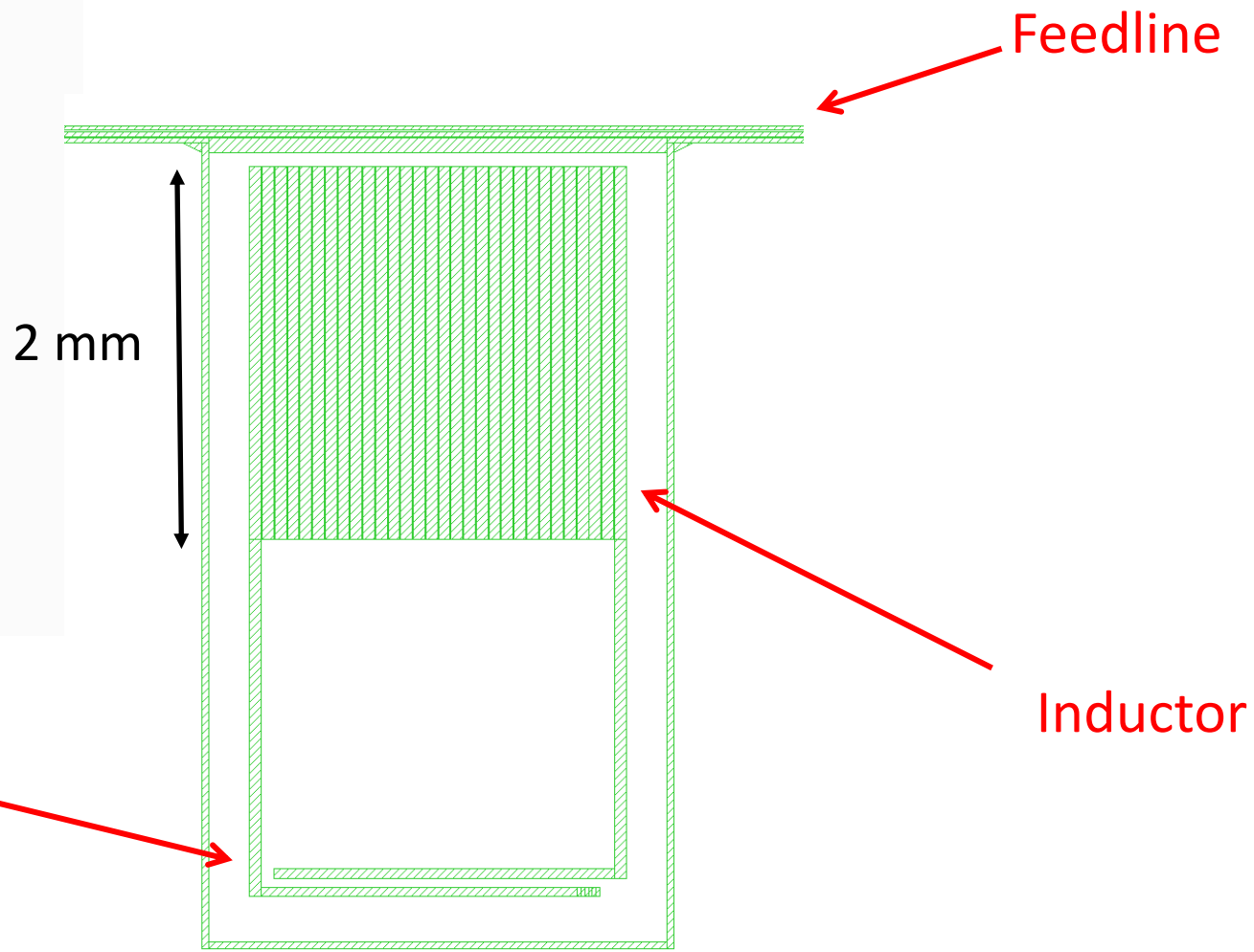


Cooper pairs (CP) in a superconductor act as an inductance (*L*).
Absorbed photons change CP density and *L*.

High quality factor (*Q*) resonating circuit biased with a microwave (GHz): Signal from amplitude and phase shift of the wave transmitted past the resonator.

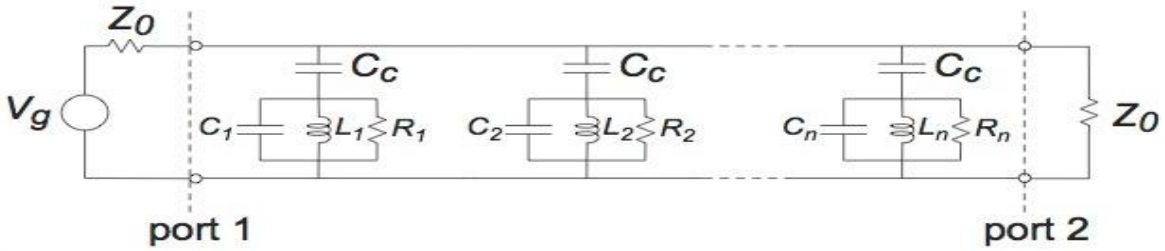
LeKID typical geometry

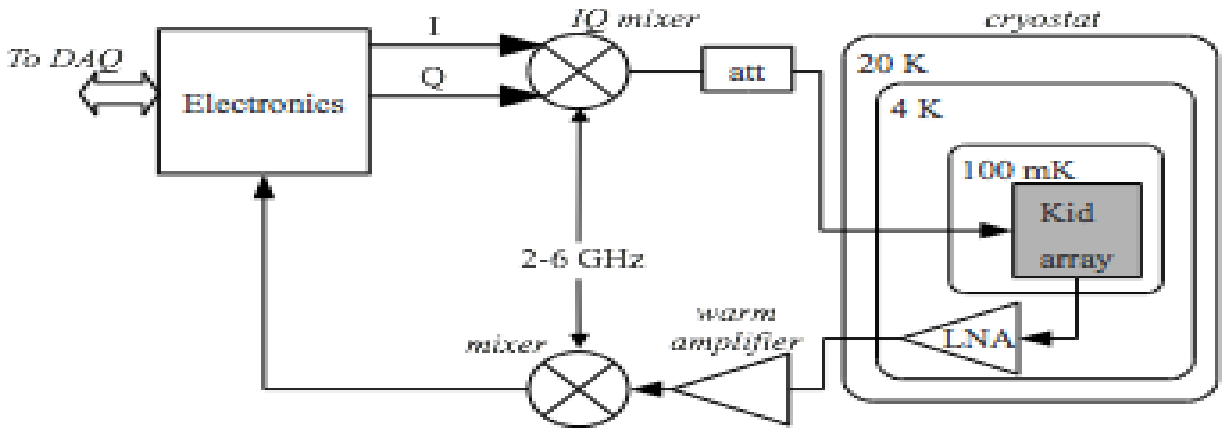


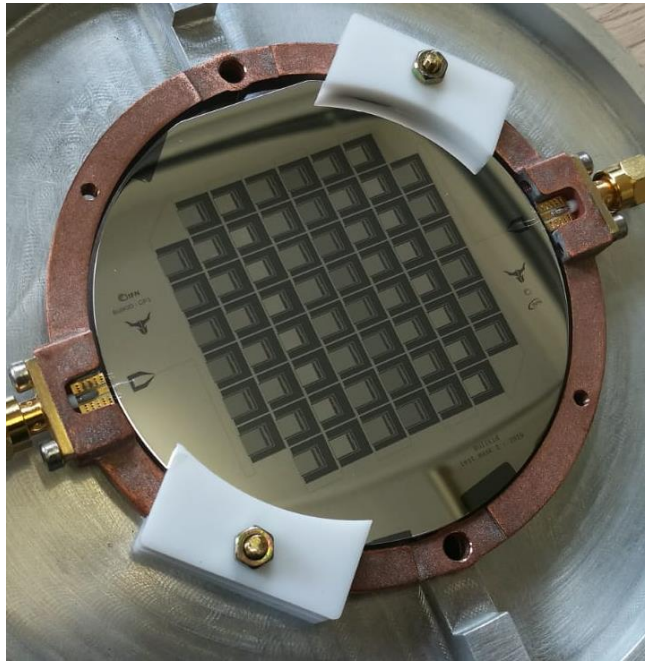


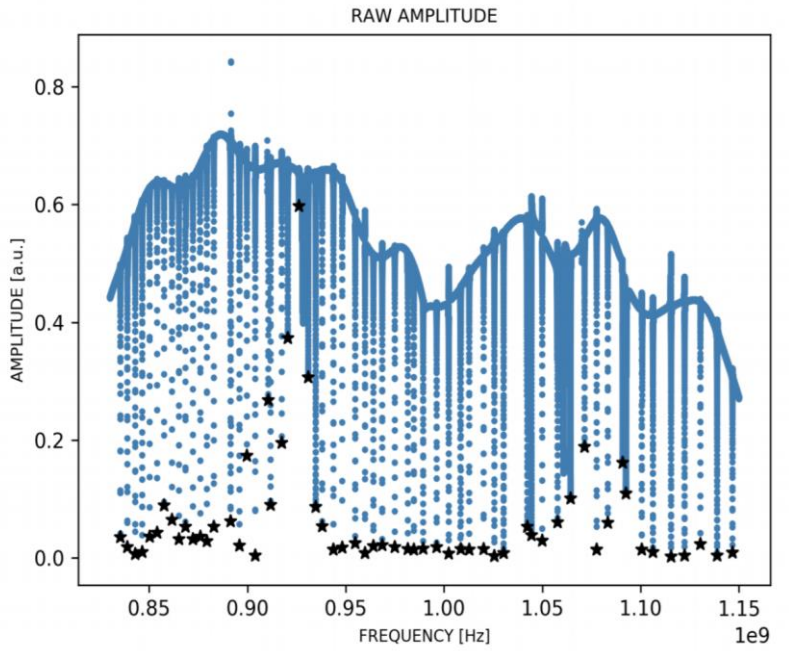
S. Doyle et al., JLTP 151 (2008)

Multiplexed readout of a KID array







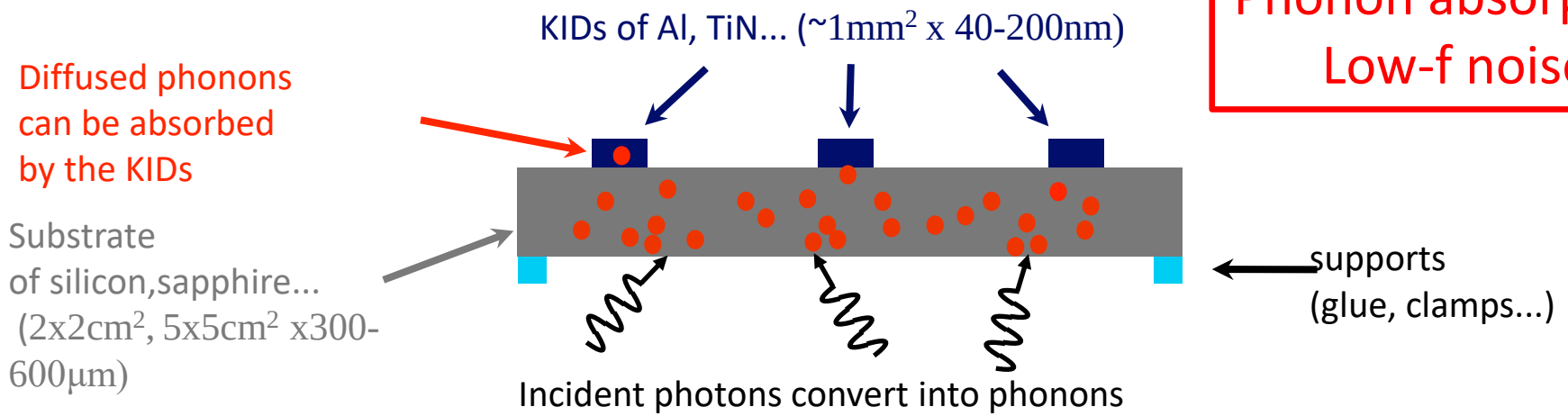


First BULLKID-test array

60/60 detectors alive!

CALDER project

CALDER was an ERC-SG project which develoed KIDs light detectors with area from 2x2 cm^2 to 5x5 cm^2 for CUPID



MAIN CHALLANGES:
Phonon absorption efficiency
Low-f noise reduction

Battistelli et al., EPJ C 75 353 (2015)

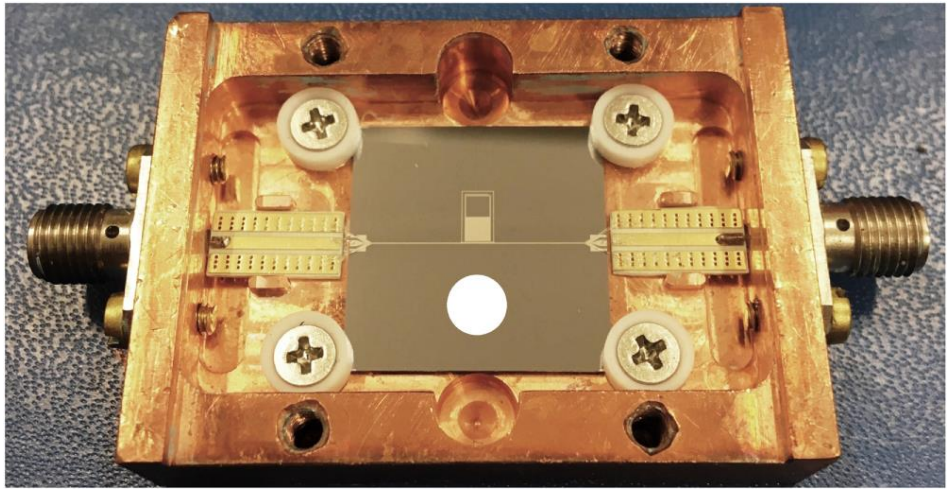
CALDER results

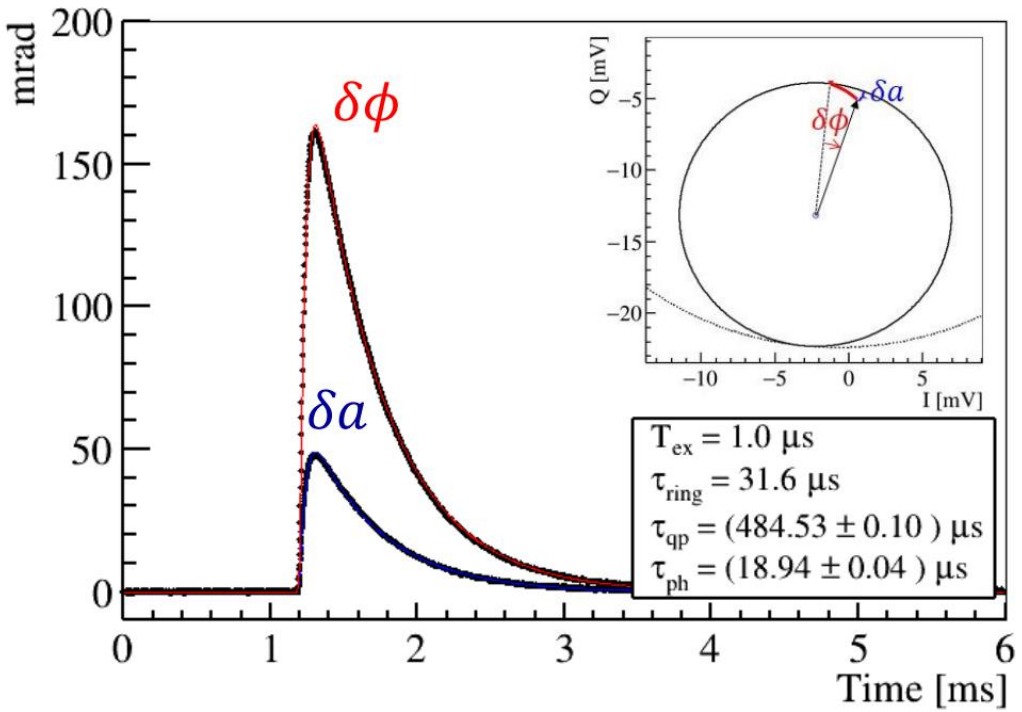
Best baseline resolution:

50 eV for Aluminium

25 eV for Al/Ti/Al trilayer

Typical phonon efficiency collection: 10%





Cardani et al., APL 107 093508 (2015)
Cardani et al., APL 110 033504 (2017)
Cardani et al., SUST 31 075002 (2018)
Martinez et al., Phy. Rev. App. 11(2019)
Casali et al., EPJ C 79 724 (2019)
Cardani et al., arXiv:2104.06850 (2021)

From CALDER to BULLKID

The aim of BULLKID is to take advantage of CALDER experience to develop KID, able to measure nuclear recoils induced by Dark Matter or neutrino scattering

Mass: increase the detector mass with KIDs on 5 mm instead of 300 µm thick wafers.

Sensitivity: reach a σ of 10-20 eV

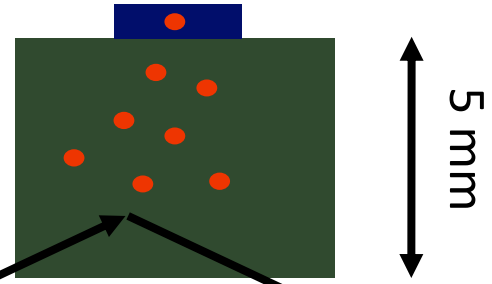
1st CHALLENGE:
Sensitivity boost (x2)

CALDER
Silicon
(2x2 cm²x 300 µm)

Al or TiAl LDs
(2mm² x 60-nm)

photons

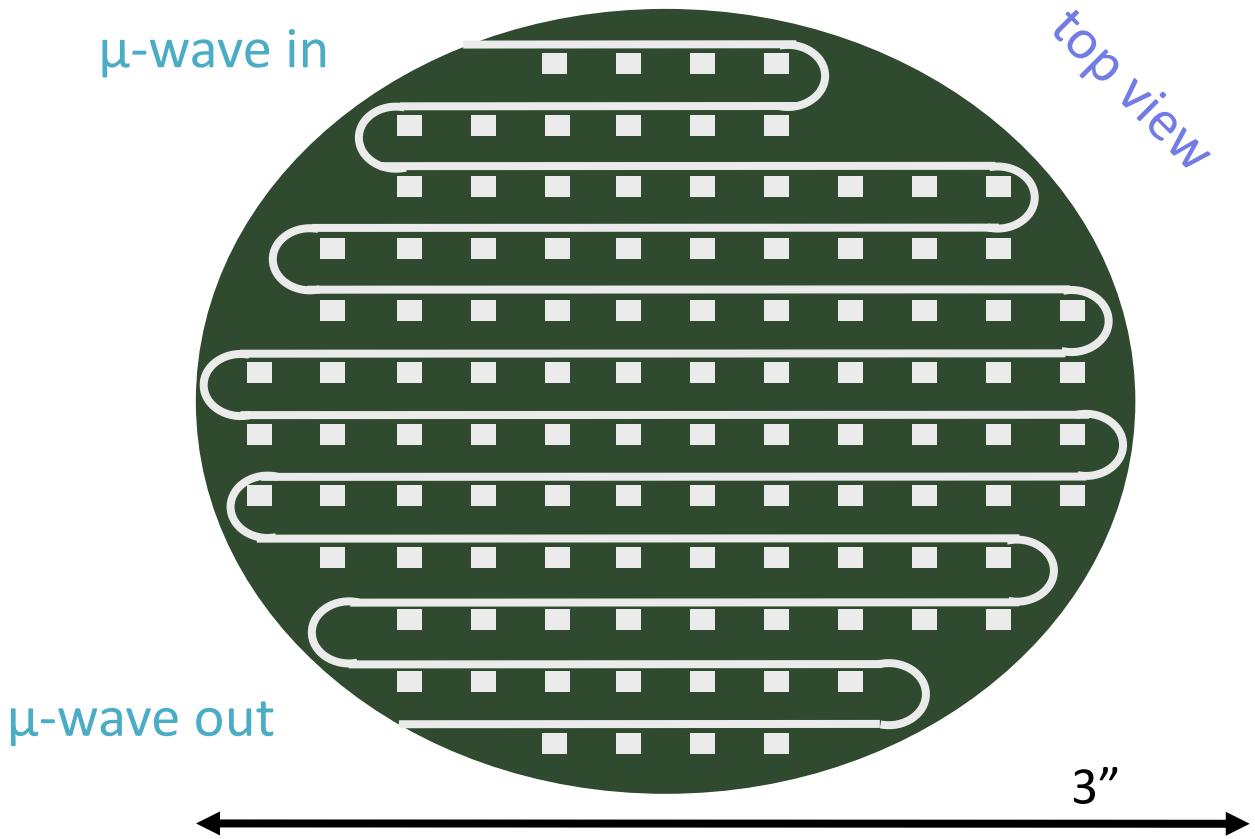
BULLKID
Silicon
(5x5x5 mm³)



Dak Matter / neutrino

Dak Matter / neutrino

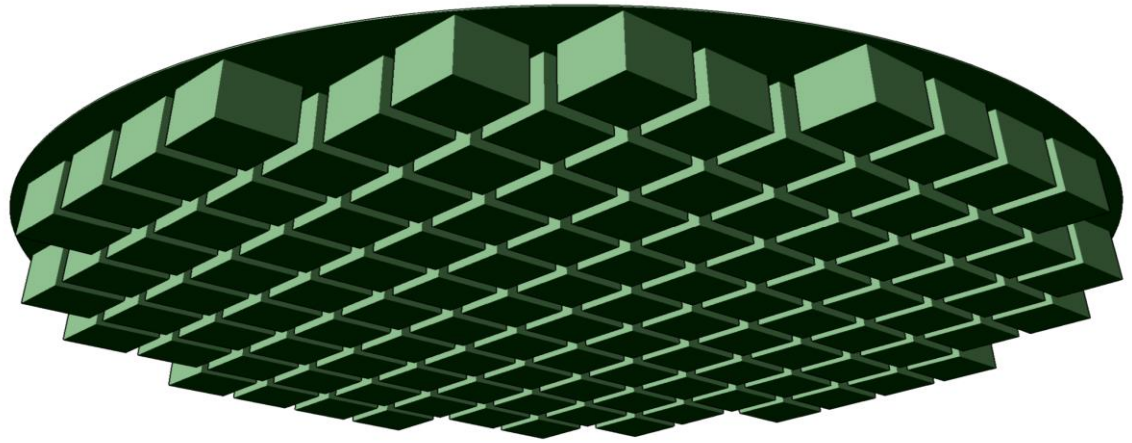
BULLKID array



- We will deposit about 100 KIDs at once on top of a 3” wafer.
- The KIDs will be coupled to the same feedline for multiplexing.

2nd CHALLENGE:
Effects ot the grooving

bottom view



- The wafer is diced from the bottom to create cubic voxels of 5x5x5 mm^3 .
- About 100 cubic voxels can be exploited (0.29 g each) for a total target mass of 29 g.

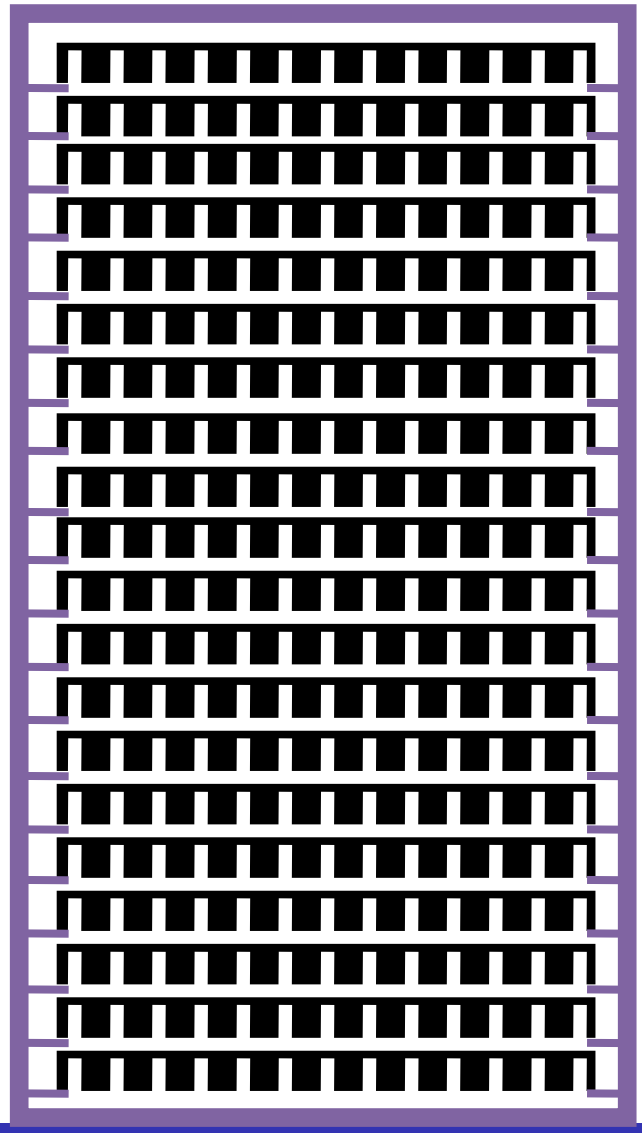
An experiment BULLKID based

BULLKID: one 3” 5mm thick wafer for a total target mass of 29 g.

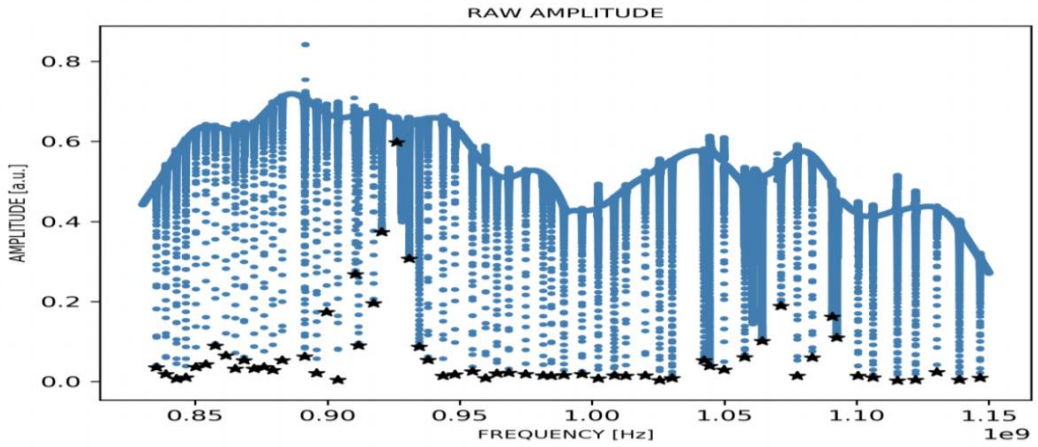
Possible experiment with O(kg) mass:

- Maybe 4” wafer and/or 1 cm wafers.
- Stack a number of wafers to reach the desired target mass.

- No inert material between inner voxels:
  - Background identification.
  - Fiducialization.



BULLKID status: electrical test of detectors



First tests to optimize pixel geometry for BULLKID applications were successful.

Electrical tests of the device at cryogenic temperature are in agreement with the design.

The baseline geometry for the array is ready.

BULLKID status: Superconductor R&D

$$\Delta E \propto \frac{T_C}{\epsilon\sqrt{QL}}$$

	Al	Ti+Al	W+Al	Hf
T_c [K]	1.2	0.5-0.9	0-0.9	0.1-0.5 (?)
L [pH/square]	0.35	1.5 (up to 3?)	Up to 10 (?)	20 (?)
Q_{max}	> 10^5	> 10^5	??	5 10^5
Phonon efficiency	10%	10%	??	??
QP LIFETIME [µs]	250	250	??	30
Fabrication	IFN-CNR	CEA/Néel	MPI-MUNICH	CNR/DIAS
Resolution [eV]	50-100	25		
STATUS	Completed	in progress (BASELINE)	In progress	Early stage

AlTiAl is the best so far, but there is still room for improvement.

Other SCs are in a preliminary phase

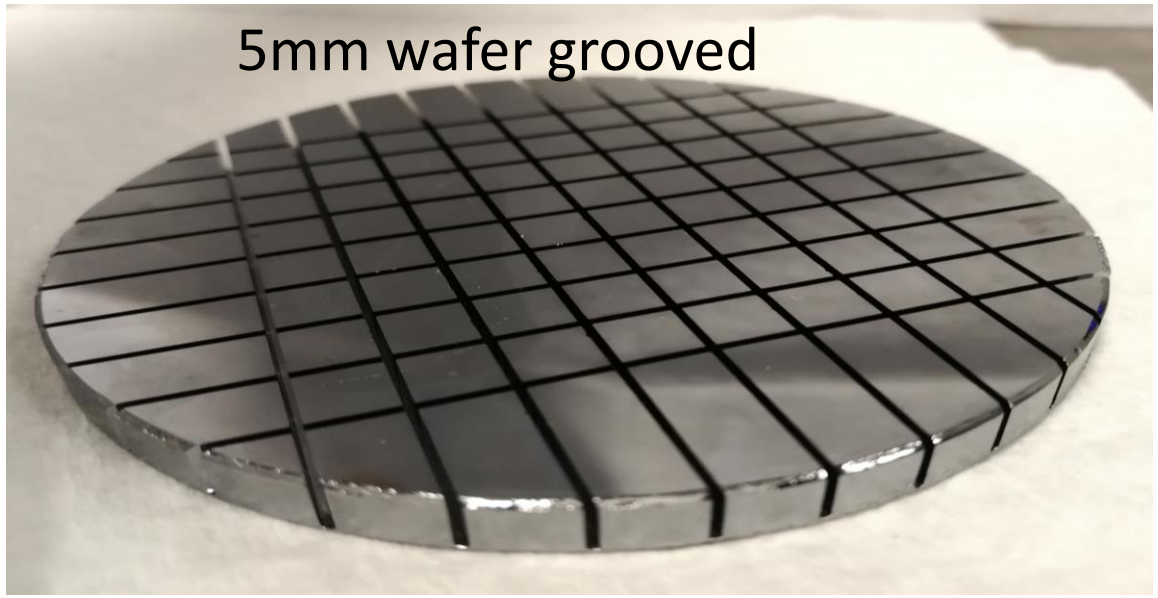
BULLKID status: dicing R&D

- First dicing tests were successful but with poor quality of the grooved dice surfaces (reduces phonon reflection).

- Improved the quality of the surfaces with chemical etching.

- Currently working on the KID lithographic process of the diced wafers

- First tests of the complete detectors expected before the summer.

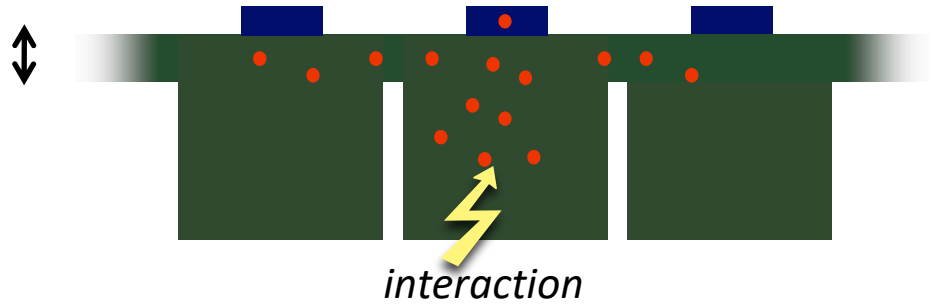


BULLKID questions...

BULLKID is investigating a new way to multiplex sensor and volume at the same time.

Open questions:

- **Will the grooving technique affect significantly phonon propagation?**
- **Do phonon escaping across the border of each voxel represents an important issue?**
- **Can KIDs reach the needed energy threshold?**



Hope to have (good) answers to these questions before the end of 2021!

BULLKID collaboration

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