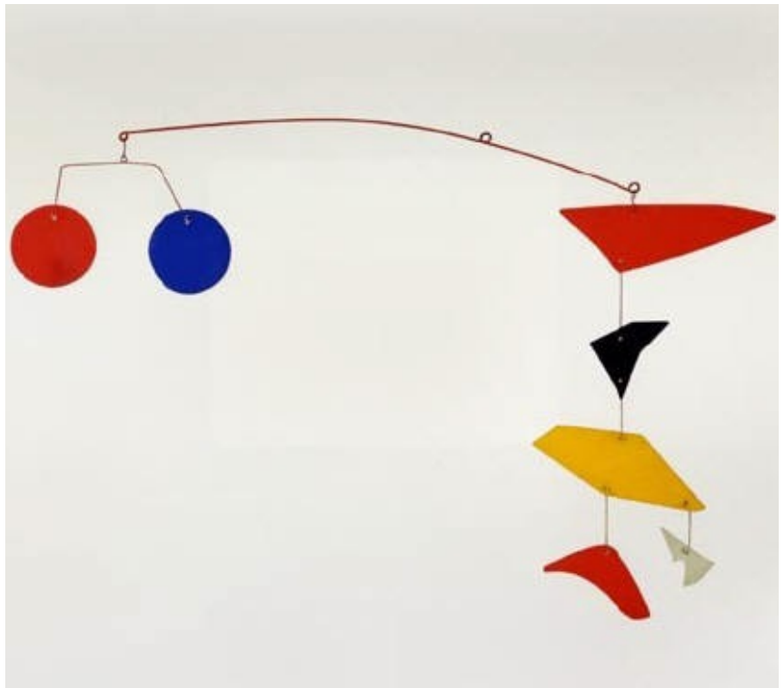
Istituto Nazionale di Fisica Nucleare
Sezione di Roma

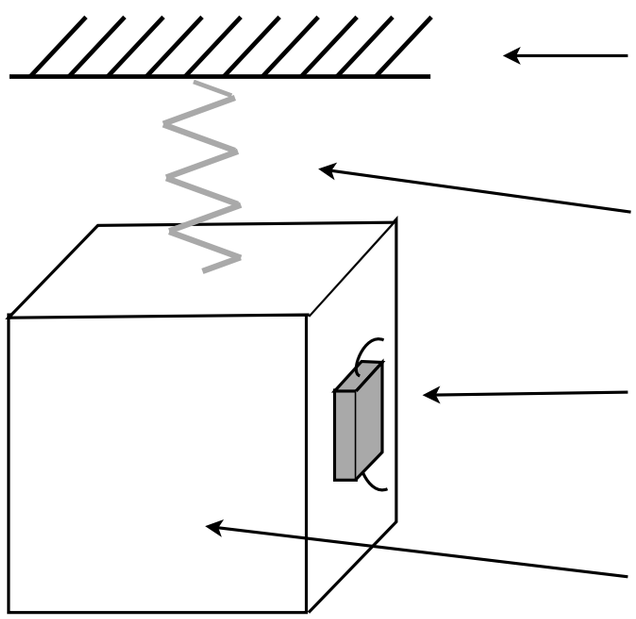
Cryogenic light detectors for background suppression: the CALDER project

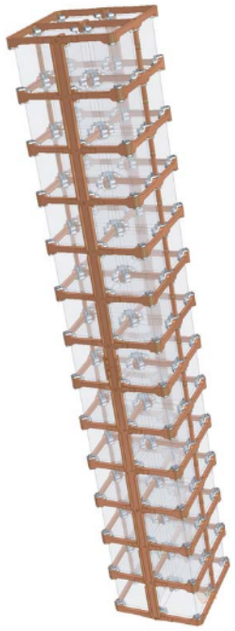


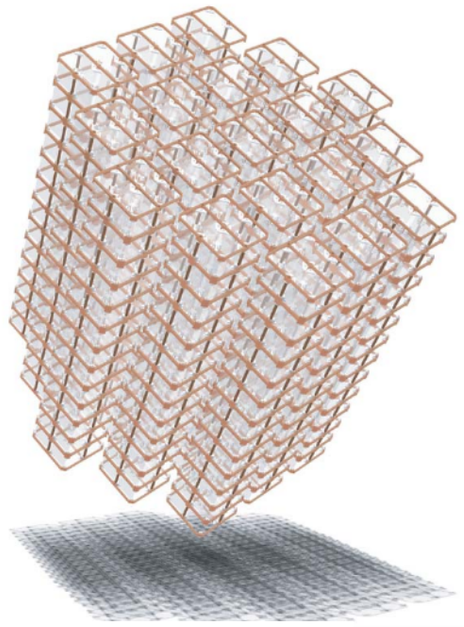
Nicola Casali on behalf of the CALDER collaboration

Low Temperature Detectors, Milano (Italy) Jul 21 - 26, 2019

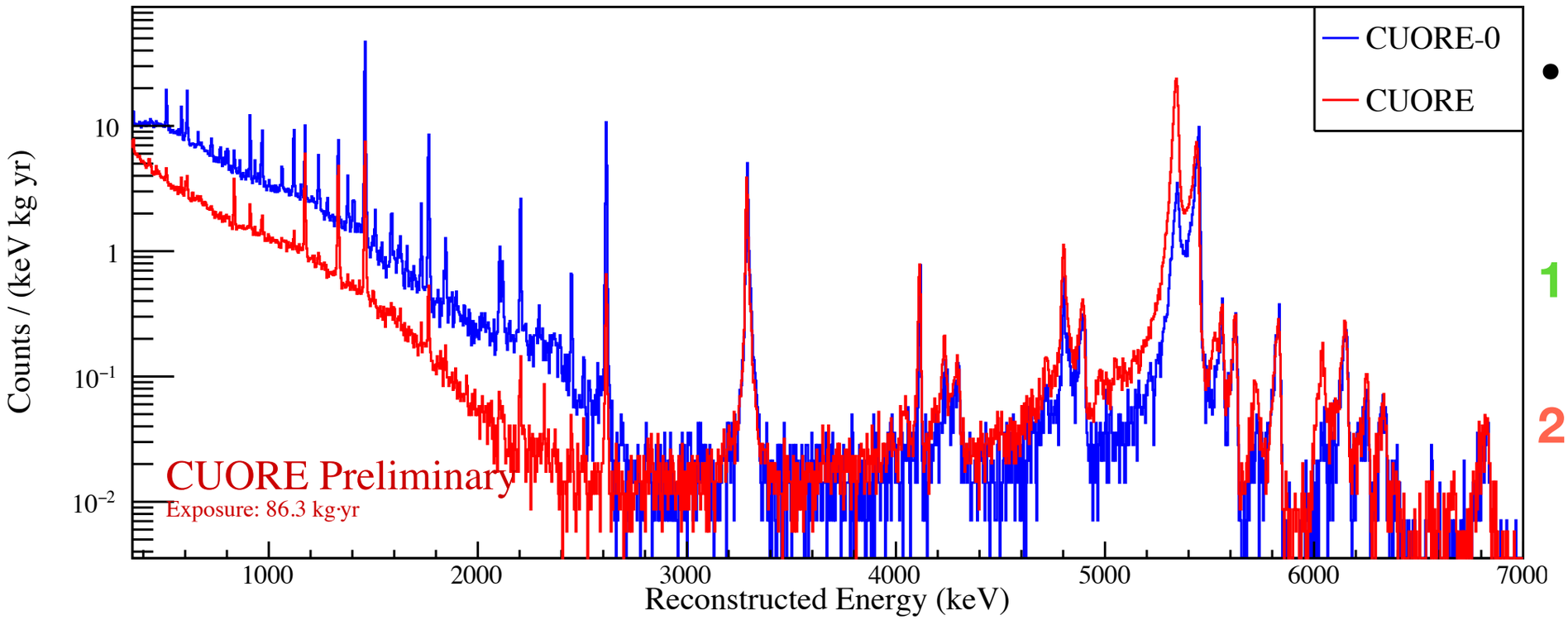
CUORE: the tonne-scale macro-calorimeters array







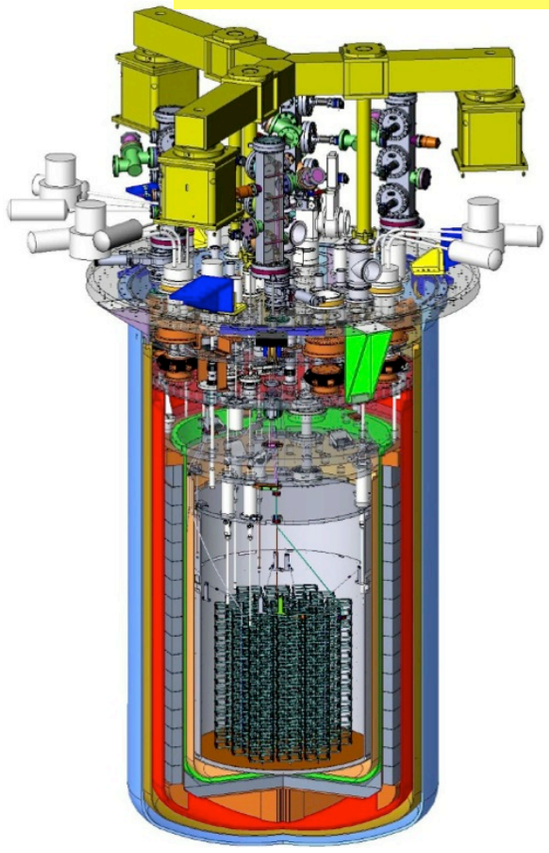
CUORE: 988 TeO_2 cryogenic calorimeters; now in data taking



- Searching for neutrino-less double beta decay:

1. **Signal -> peak at 2527 keV**
2. **BKG in the RoI ~ 250 counts/ton in 5 y data taking**

CUPID: CUORE Upgrade with Particle IDentification



CUPID Interest Group arXiv:1504.03612v1

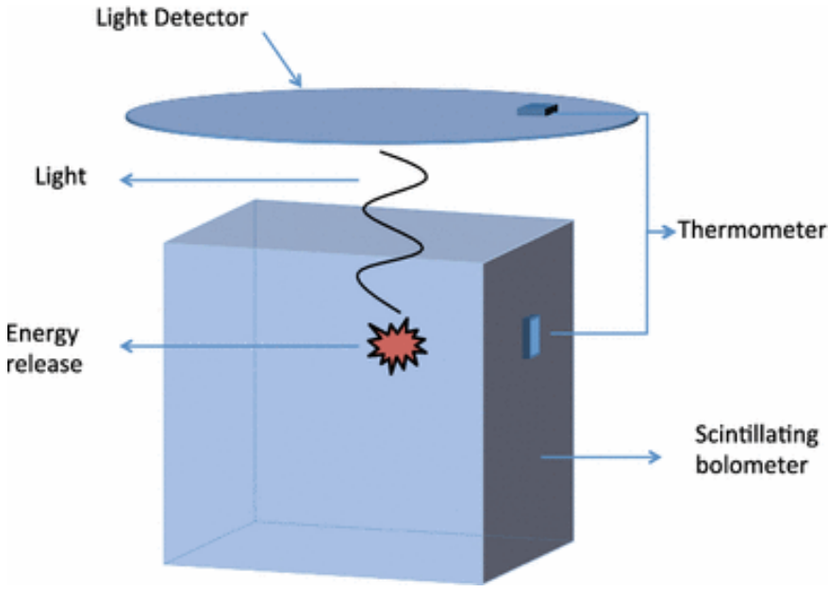
- Possibility to use the CUORE infrastructure for a future ton-scale 0νββ experiment

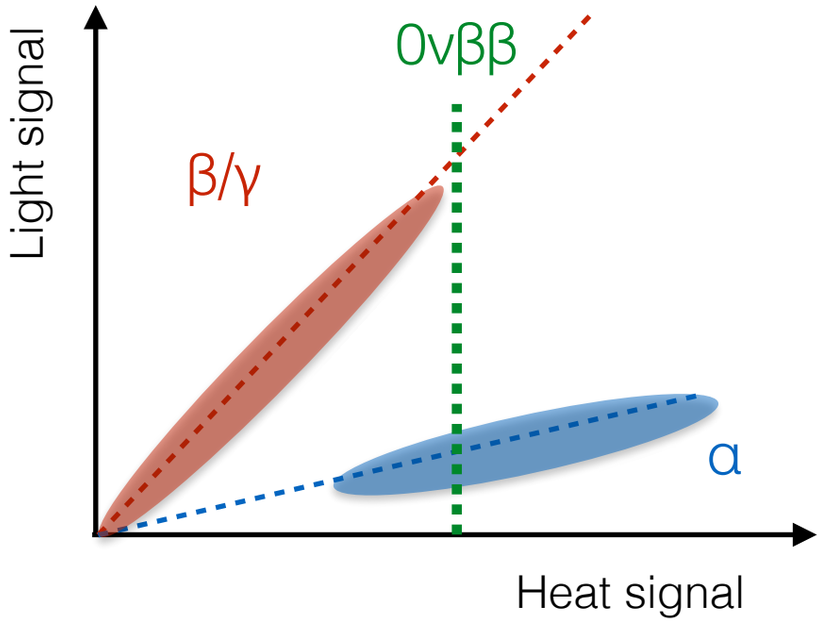
1. **250 kg of emitting isotope (isotopic enrichment)**

2. **BKG in the RoI ~ 1 counts/ton**

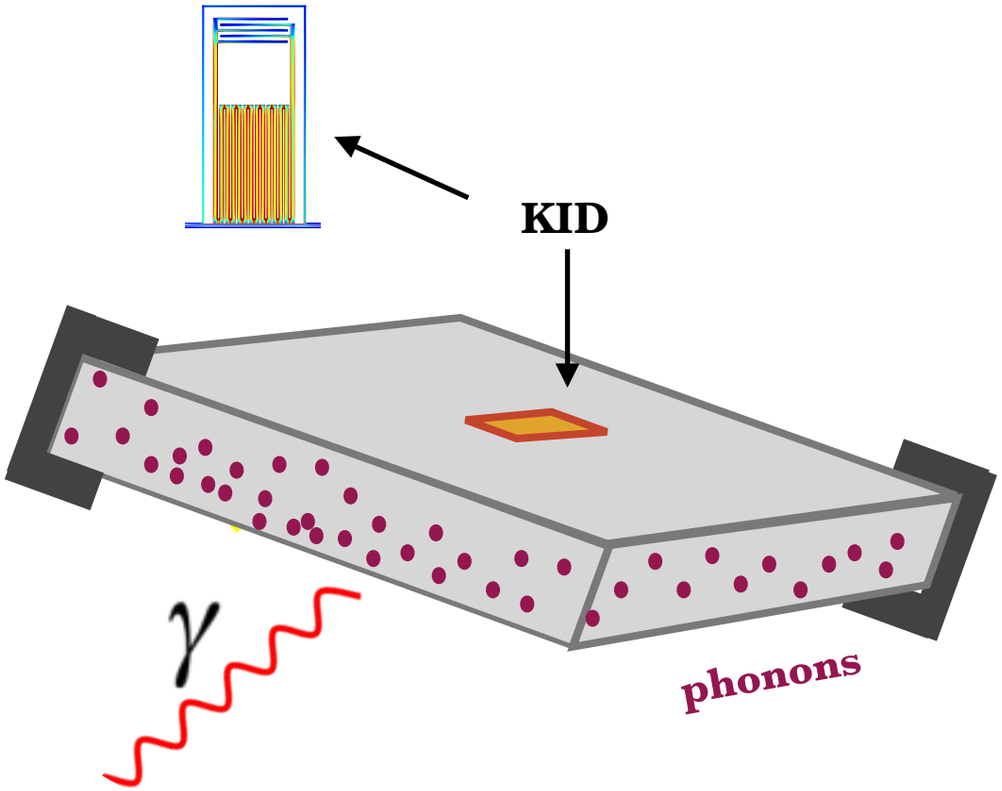
- Couple to each cryogenic calorimeter a light detector

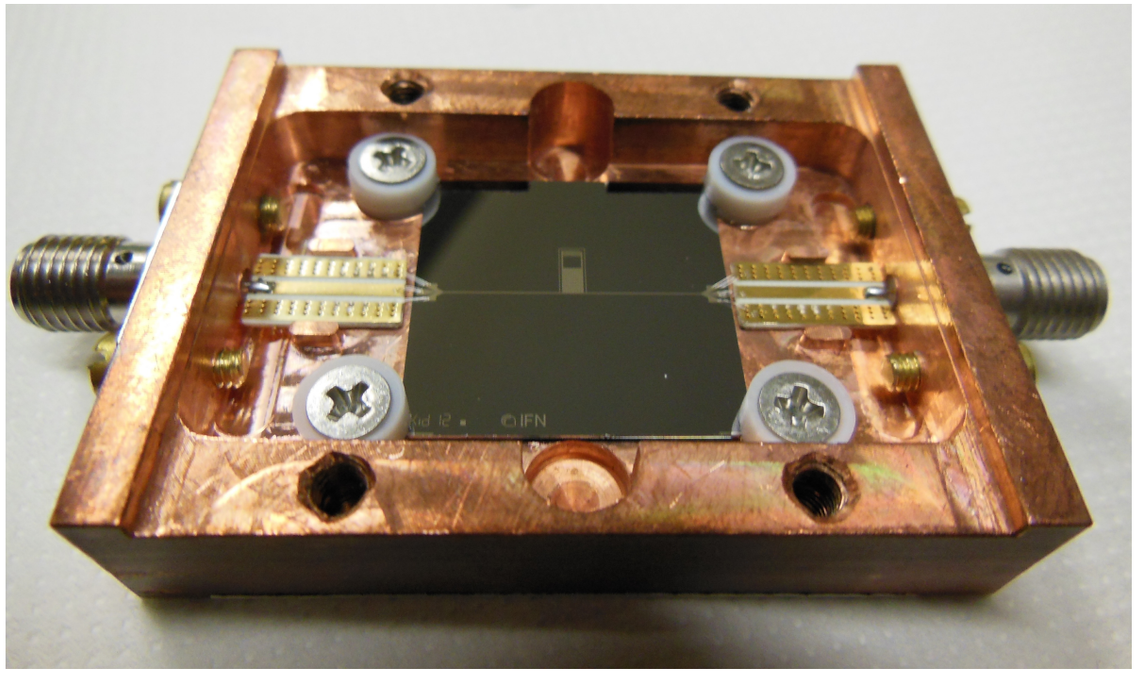
- Exploit differences in the LY between α and β/γ interactions





CALDER





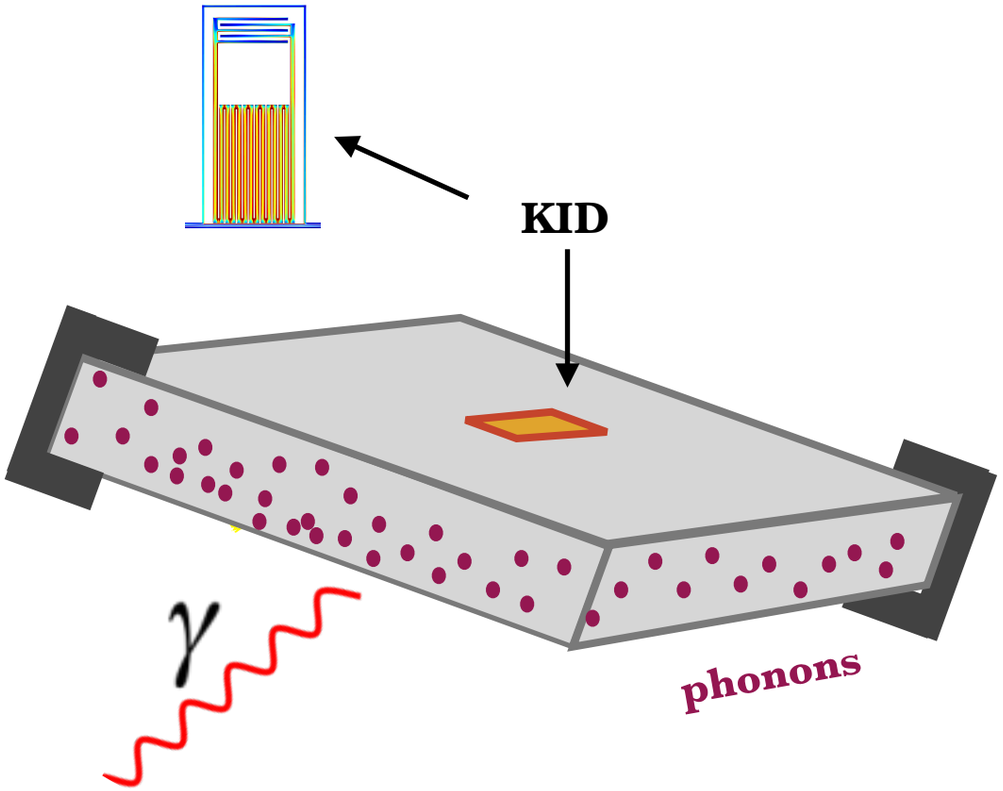
Cryogenic Wide-**A**rea **L**ight **D**etector with **E**xcellent **R**esolution
ERC Starting Grant, from March 2014

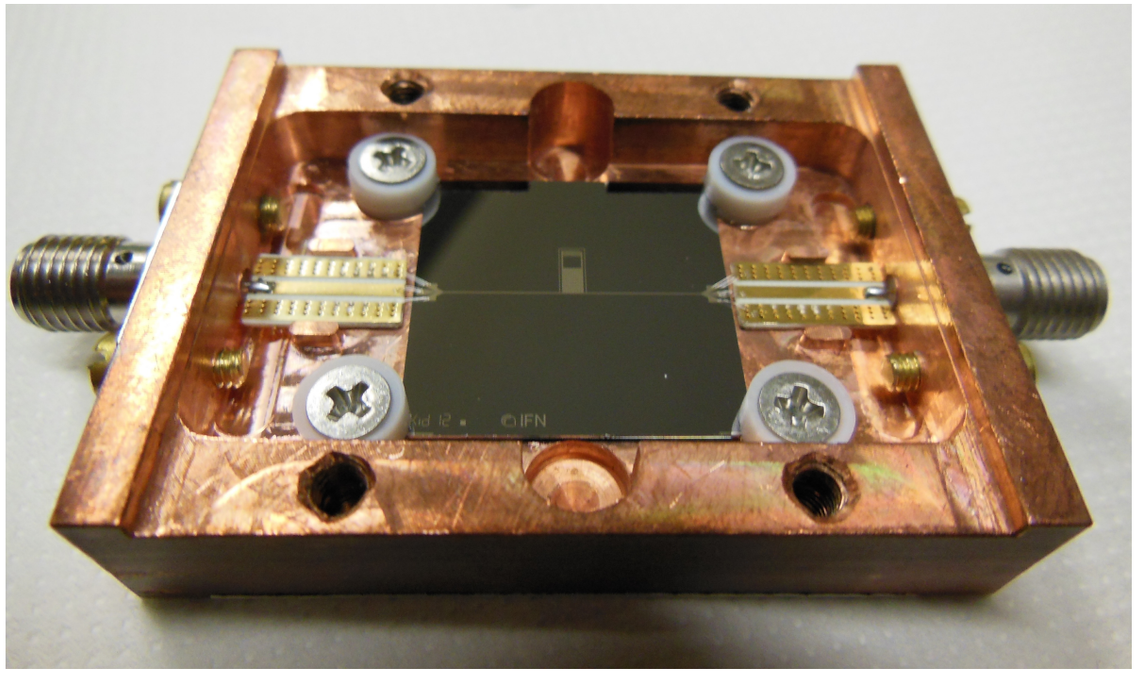
1. Read-out and analysis tools; optimization of the detector geometry using Al resonator and 2x2 cm^2 Si substrate -> 80 eV RMS

2. Test of more sensitive superconductors, such as Ti+TiN, or TiAl -> resolution < 20 eV

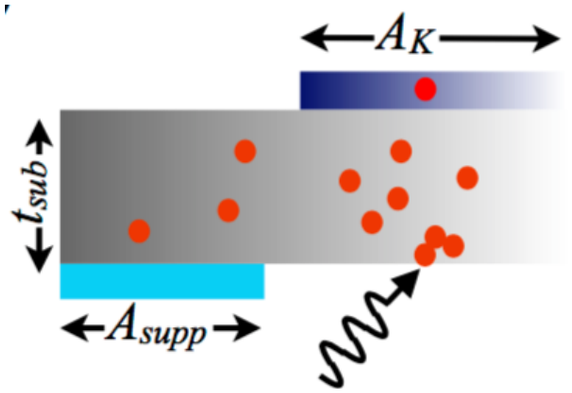
3. Scale-up to the final detector size of 5x5 cm^2.

Phonon-mediated approach





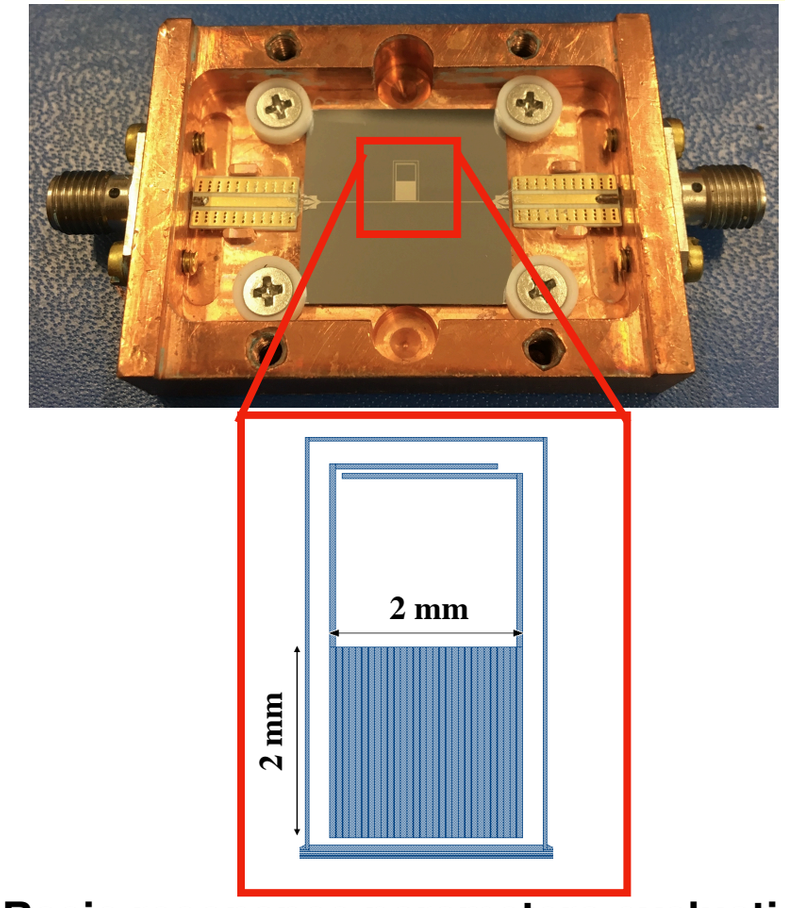
- To get around the poor KID active surface an indirect detection of the photon interactions was proposed

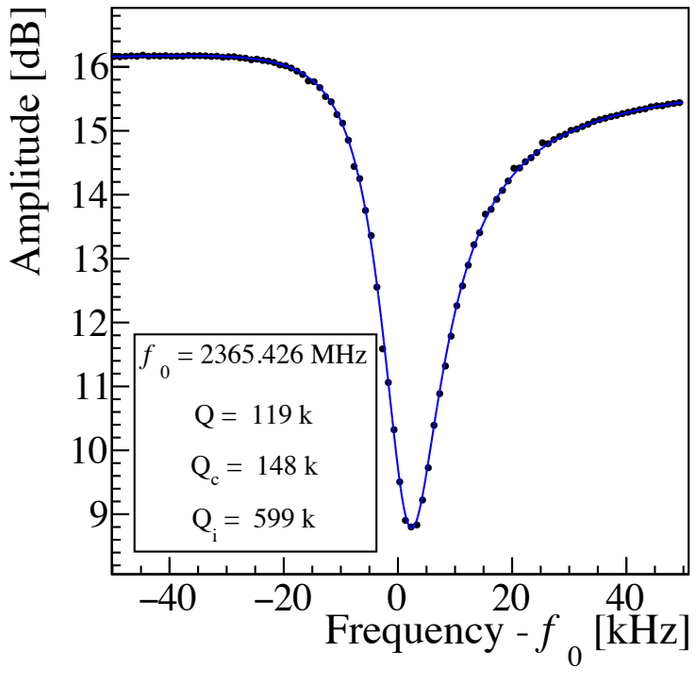


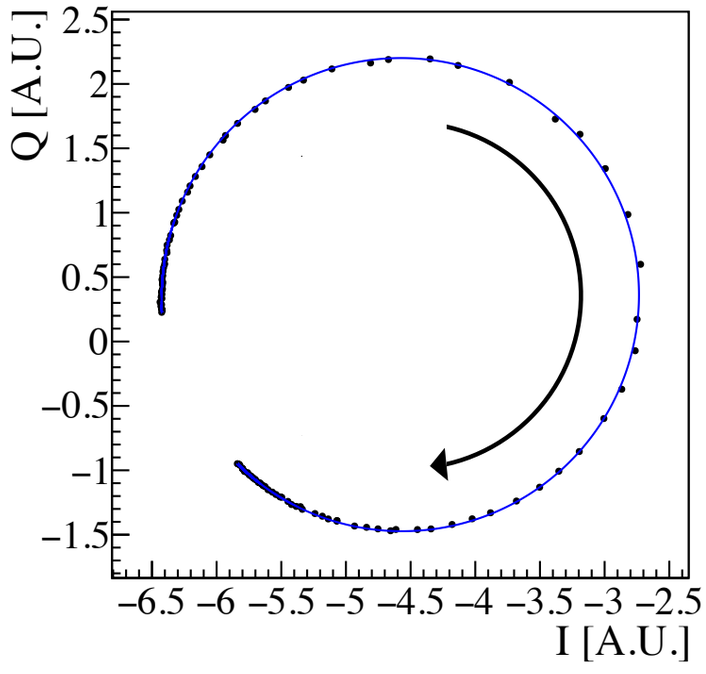
- KIDs are evaporated on a large (cm^2) insulating substrate (Si or Ge) that mediates the photon interactions converting them into phonons

- ….. with a drawback: **phonons collection efficiency**

Detector characterisation



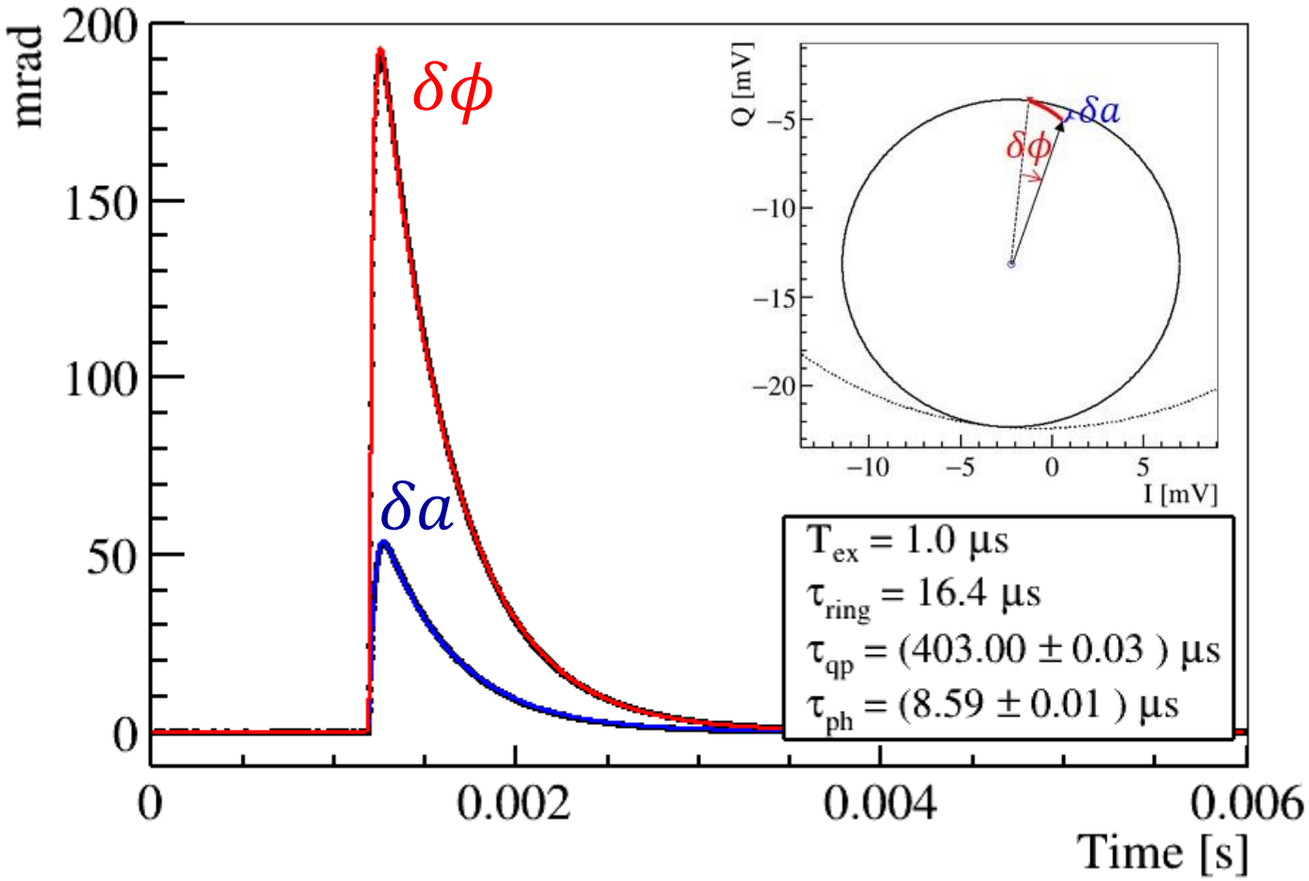




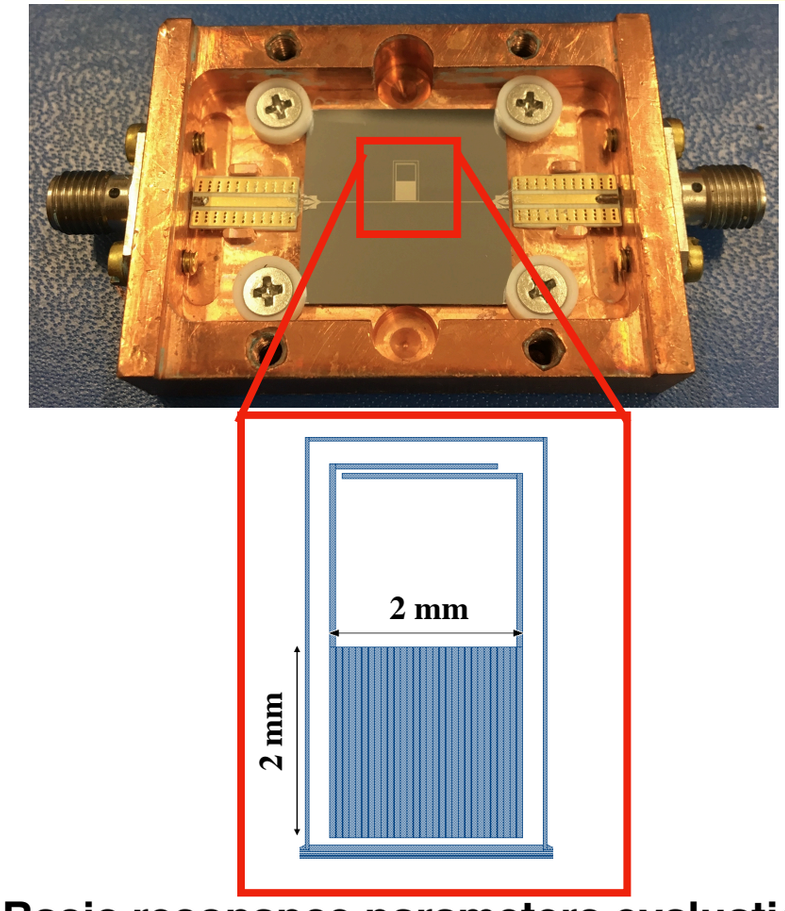
- **Basic resonance parameters evaluation with a fit of the frequency sweep of the transmitted signal**

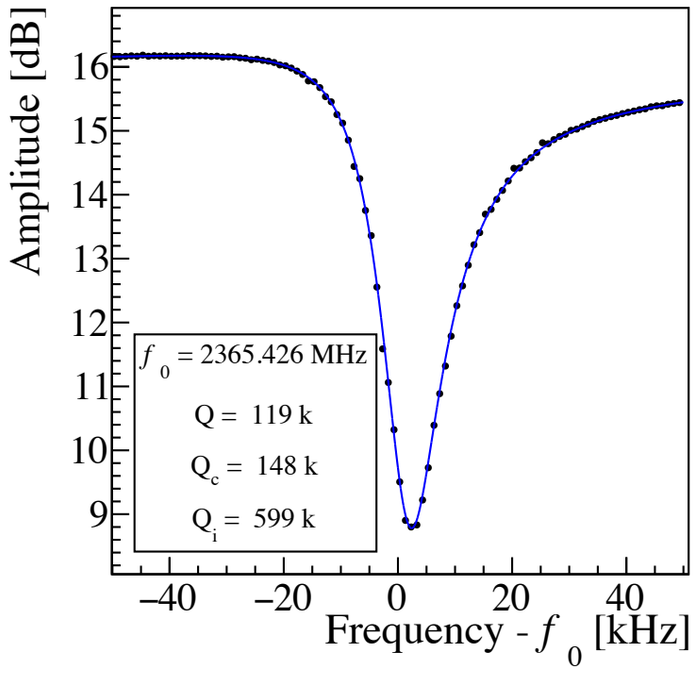
- **From the center of the resonance loop we monitor the amplitude and phase variations induced by energy depositions**

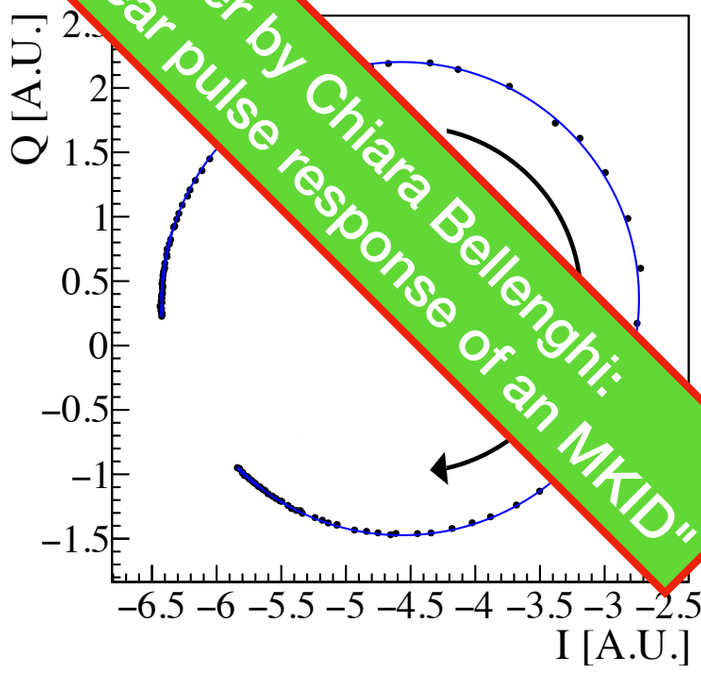
- **Calibrated optical pulses (400 nm led bursts) in the range between 0.1 and 30 keV; and X-rays from 55Fe/57Co (as cross-check for the energy calibration)**



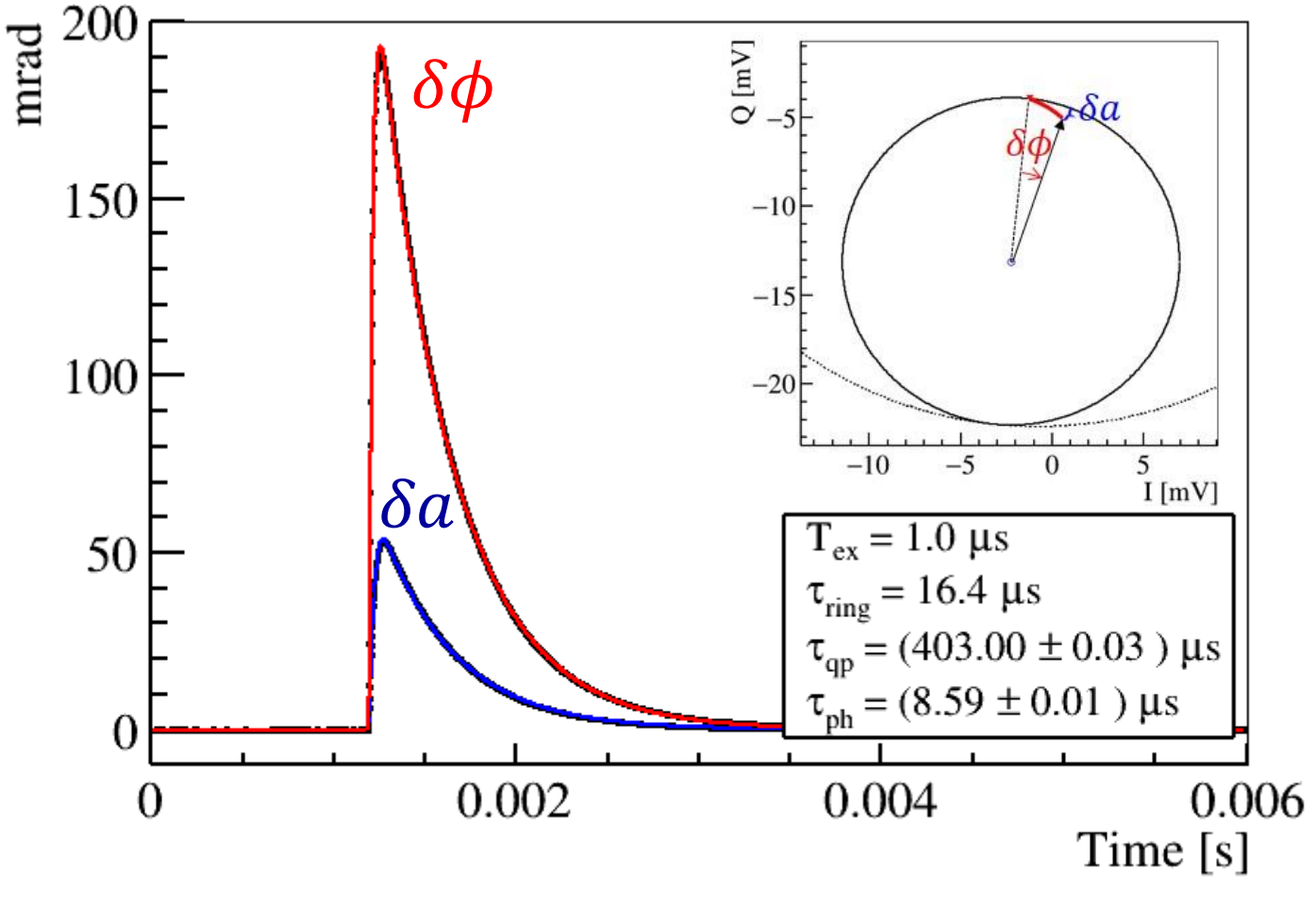
Detectors characterization







Poster by Chiara Bellenghi:
"Non-linear pulse response of an MKID"



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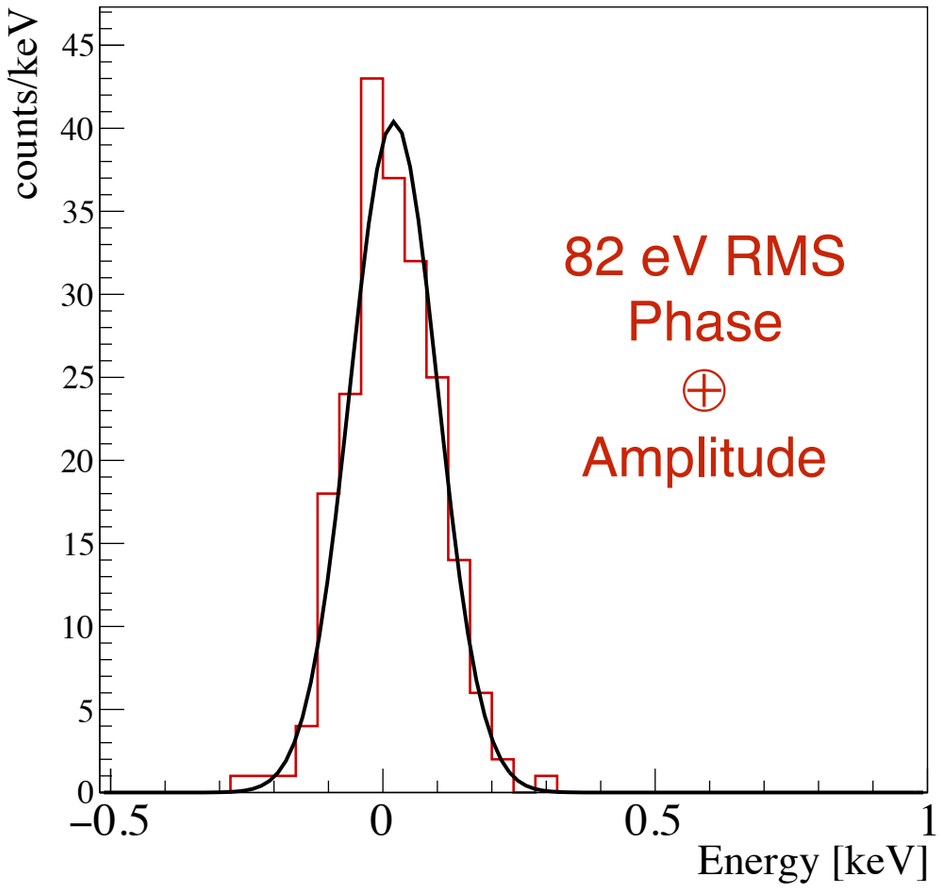
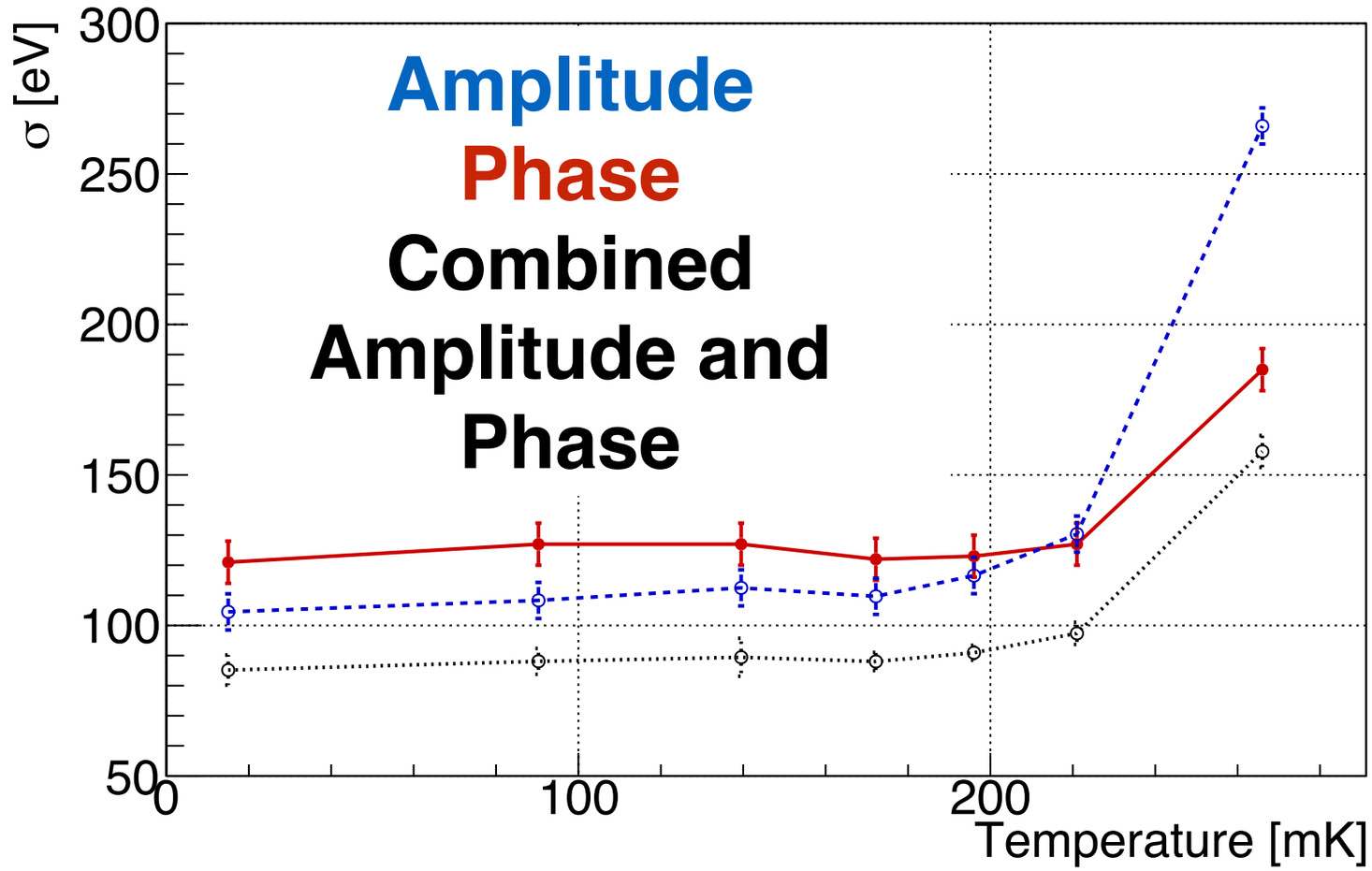
Al prototype: results





Resolution constant in a wide temperature range (10-200 mK)

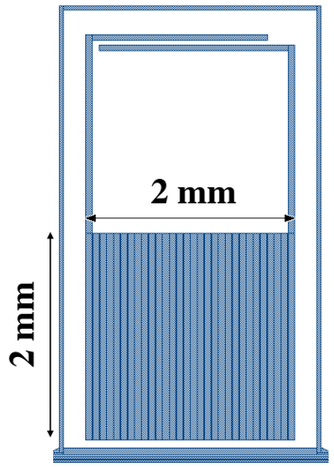
Combining phase and amplitude we obtained 82±4 eV

L. Cardani et al, Appl.Phys.Lett. 107 (2015) 093508
L. Cardani et al, Appl.Phys.Lett. 110 (2017) 033504

More sensitive superconductor: AlTiAl

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

	Al	Ti+Al	Ti+TiN
T_C [K]	1,2	0.6-0.9	0.5-0.8
L[pH/square]	0,35	1,2	6?
Q_i max	>10^6	$10^{5\text{-}6}$	?
Phonon ε	10%	10%	low?
Producer	IFN-CNR	CSNSM Neel-CNRS	CNR/FBK
Status	Completed	Completed	Aborted



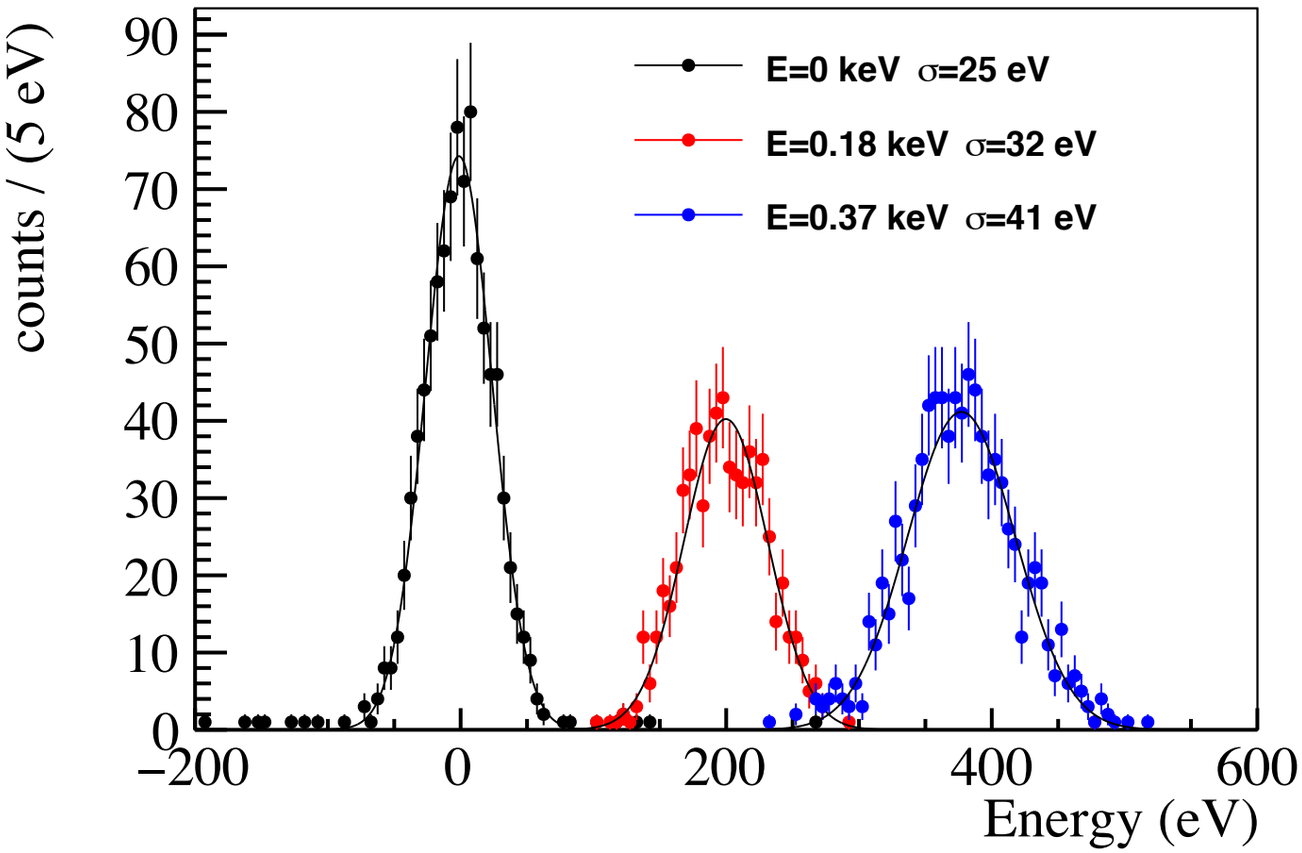
Same design as Aluminum films.

Titanium enhances Kinetic Inductance but lowers the internal *Q*.

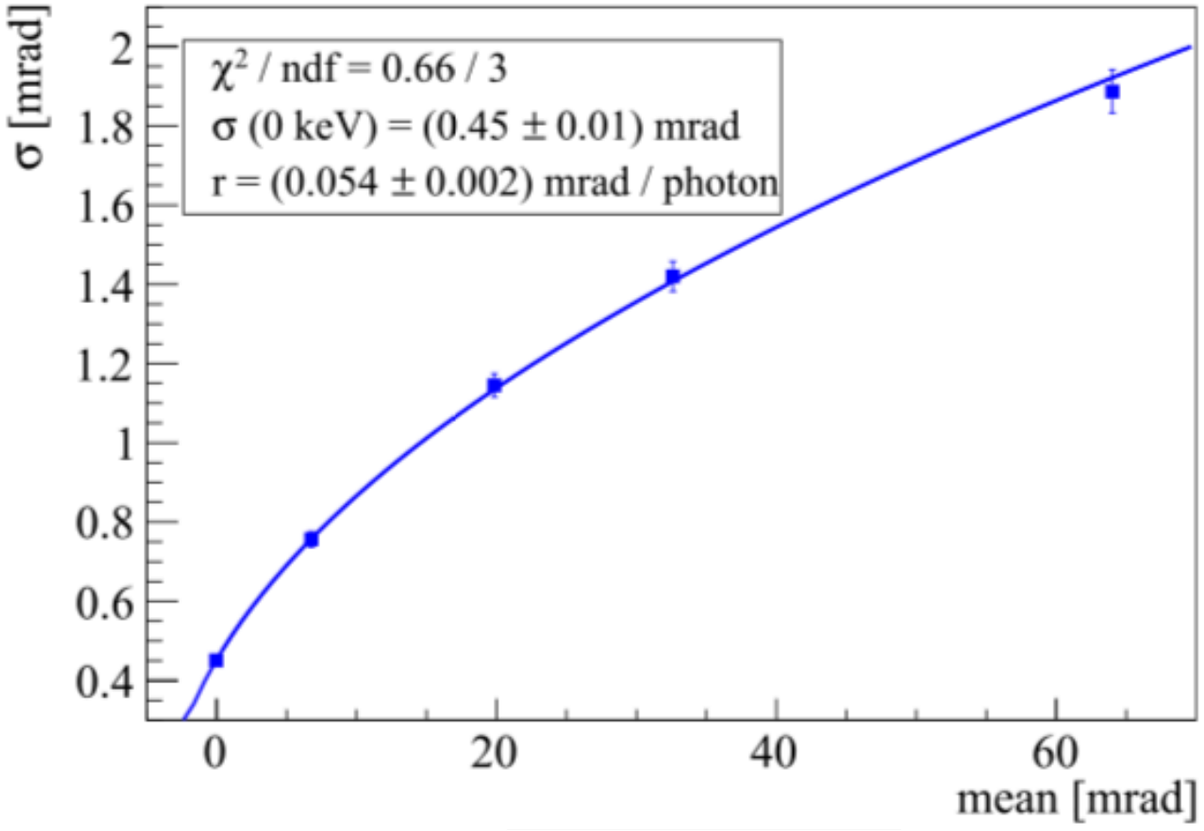
Tested different TiAl and AlTiAl multilayers. Best results from:

AlTiAl prototype: results

Energy scan with optical pulses



Absolute energy calibration with poisson



$$\sigma_{\mathrm{ph}} = \sqrt{N_{\mathrm{ph}}} \times r = \sqrt{m/r} \times r = \sqrt{m \times r}$$

$$\sigma = \sqrt{\sigma_0^2 + m \cdot r}$$

Phase Signal enhanced with respect to Al prototypes -> Phase RMS ~ 25 eV

Amplitude Signal is the same -> 80 eV RMS

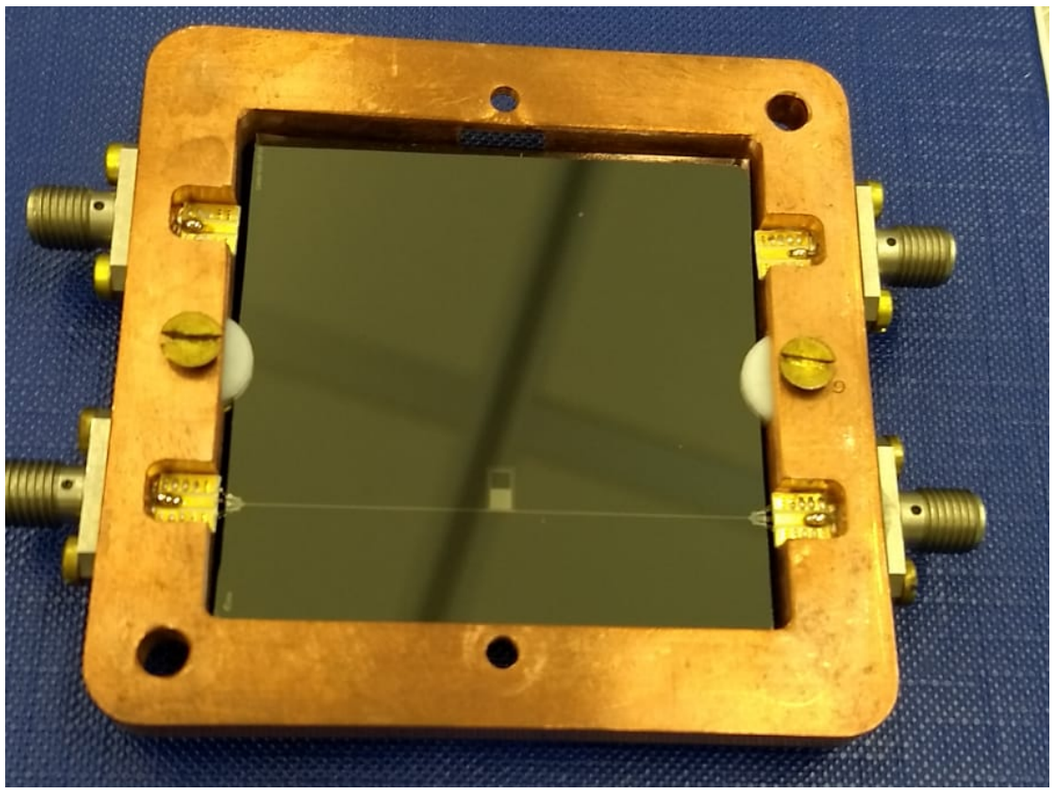
L. Cardani et al, SU.S.T. 31 7 (2018)

Last CALDER phase: the 5x5 cm² detector

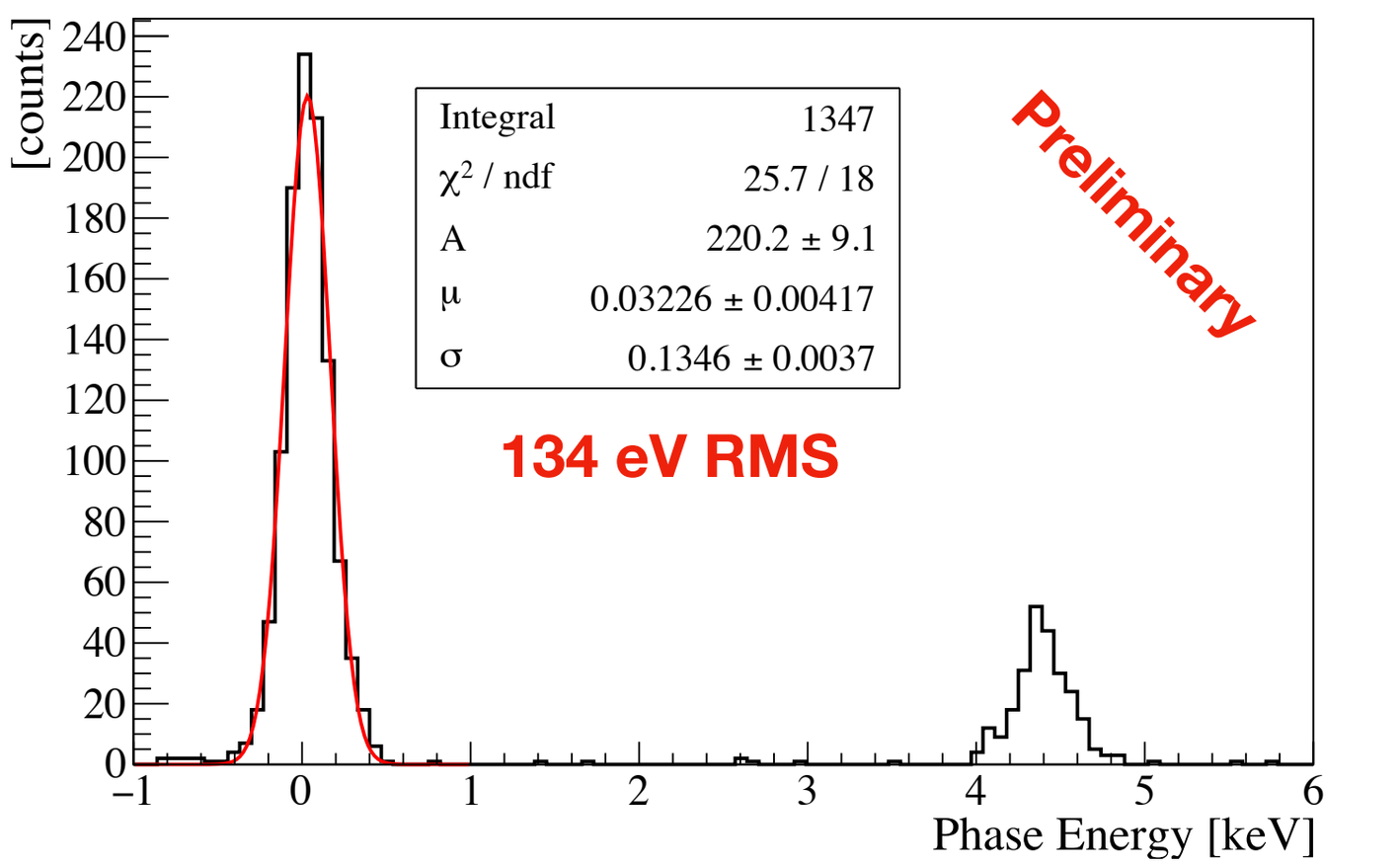
1. ~~Read-out and analysis tools; optimization of the detector geometry using Al resonator and 2x2 Si substrate -> 80 eV RMS~~

2. ~~Test of more sensitive superconductors, such as Ti+TiN, or TiAl -> resolution < 20 eV~~

3. Scale-up to the final detector size of 5x5 cm².

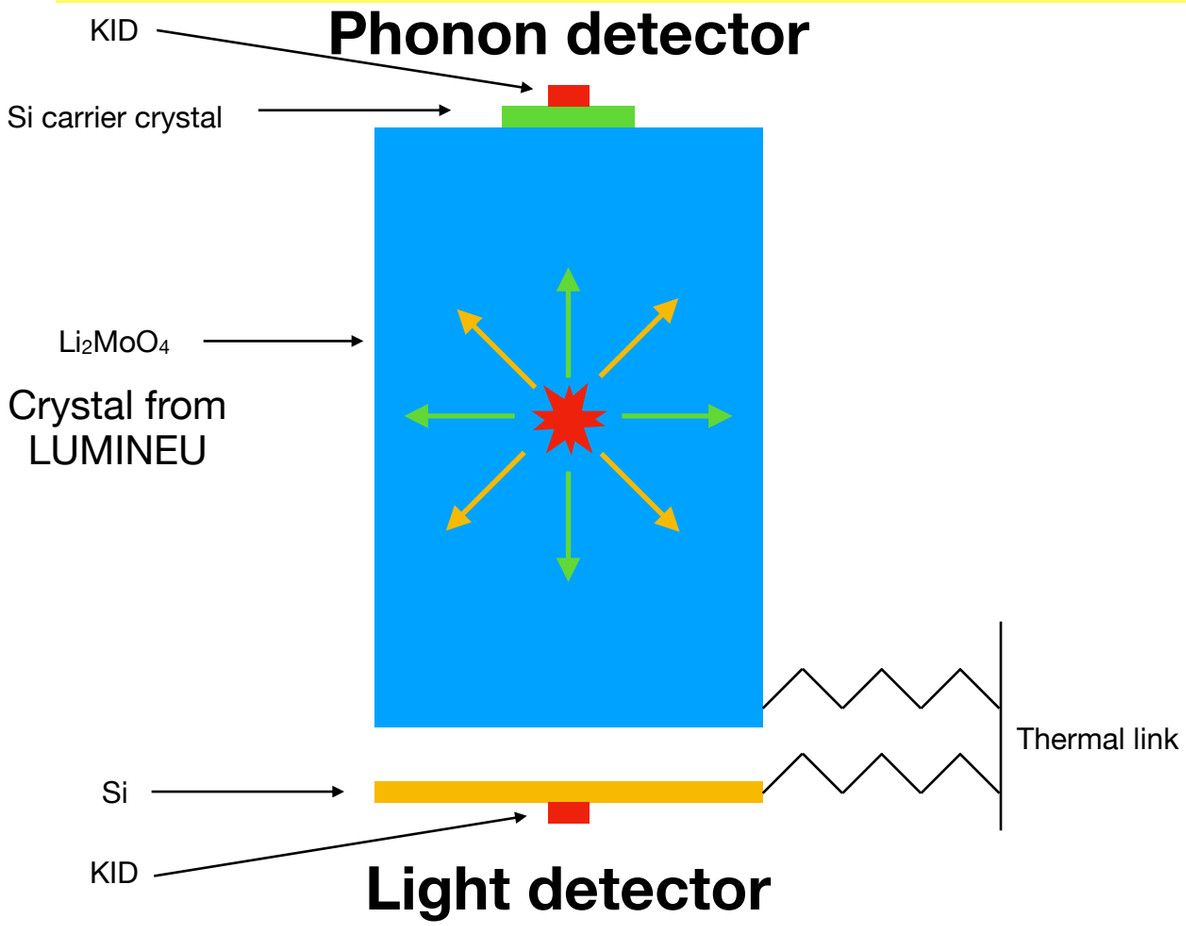


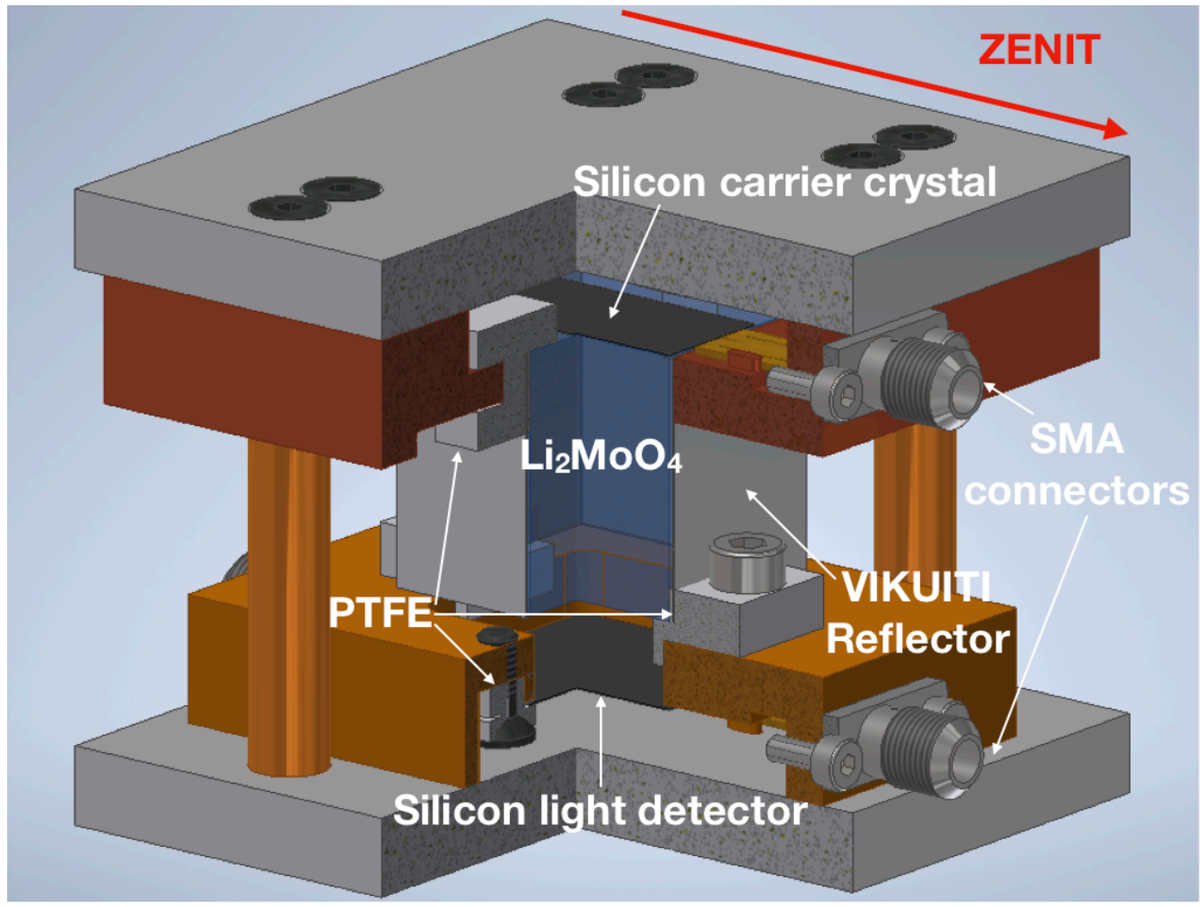
Al prototype



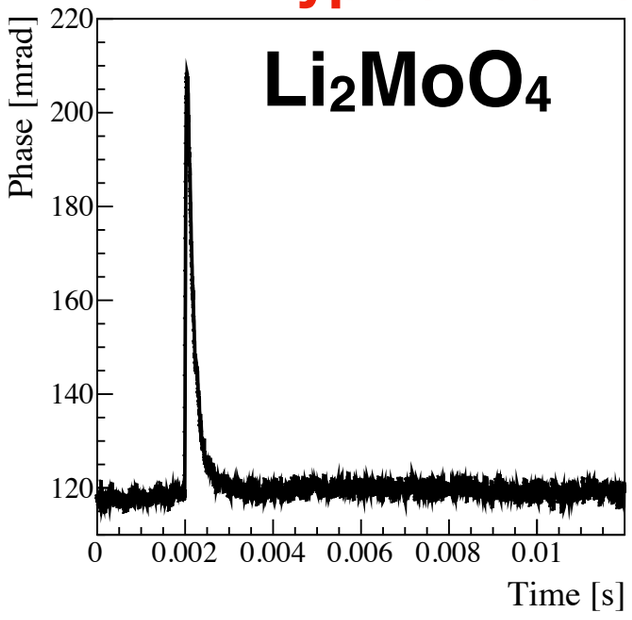
AlTiAl in production…

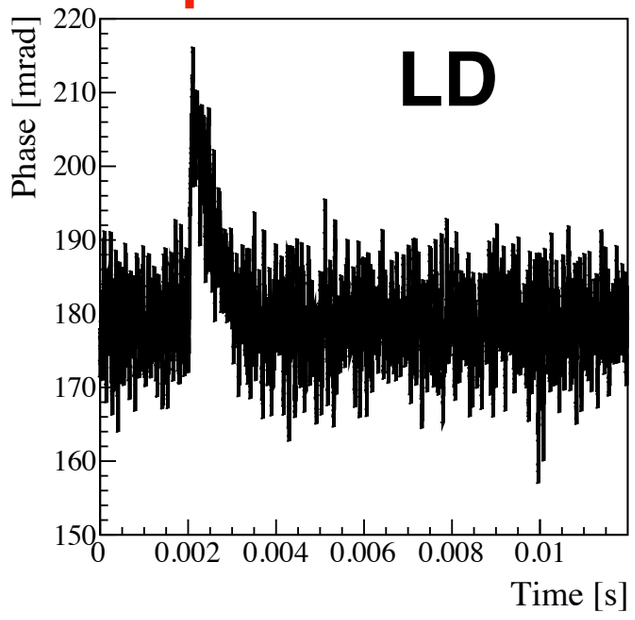
Simultaneous phonon and light read out of Li_2MoO_4 crystal with KIDs

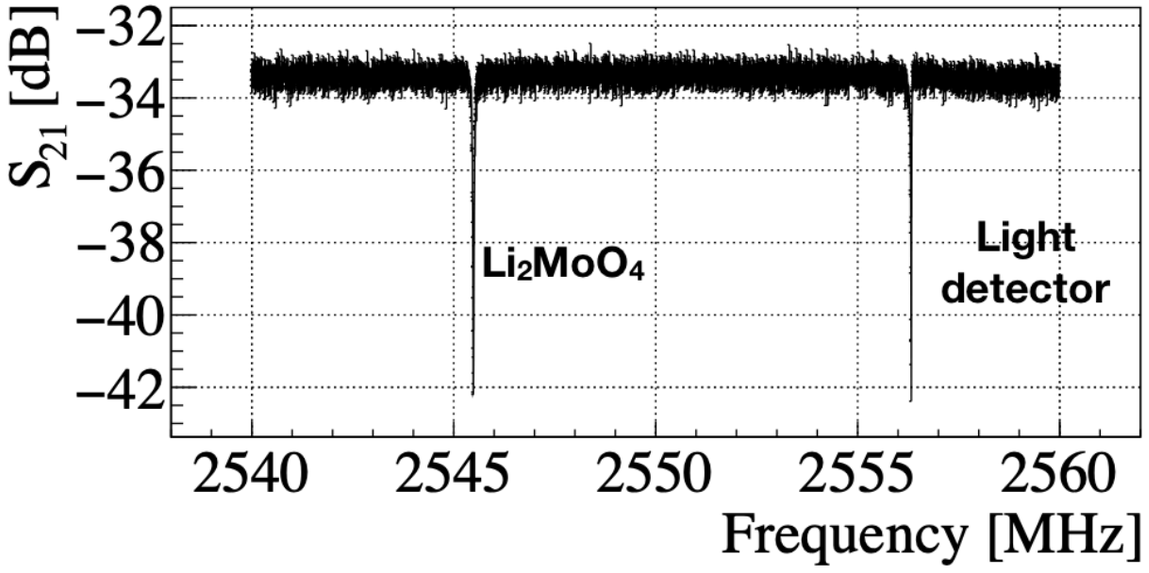




Typical coincidence pulses

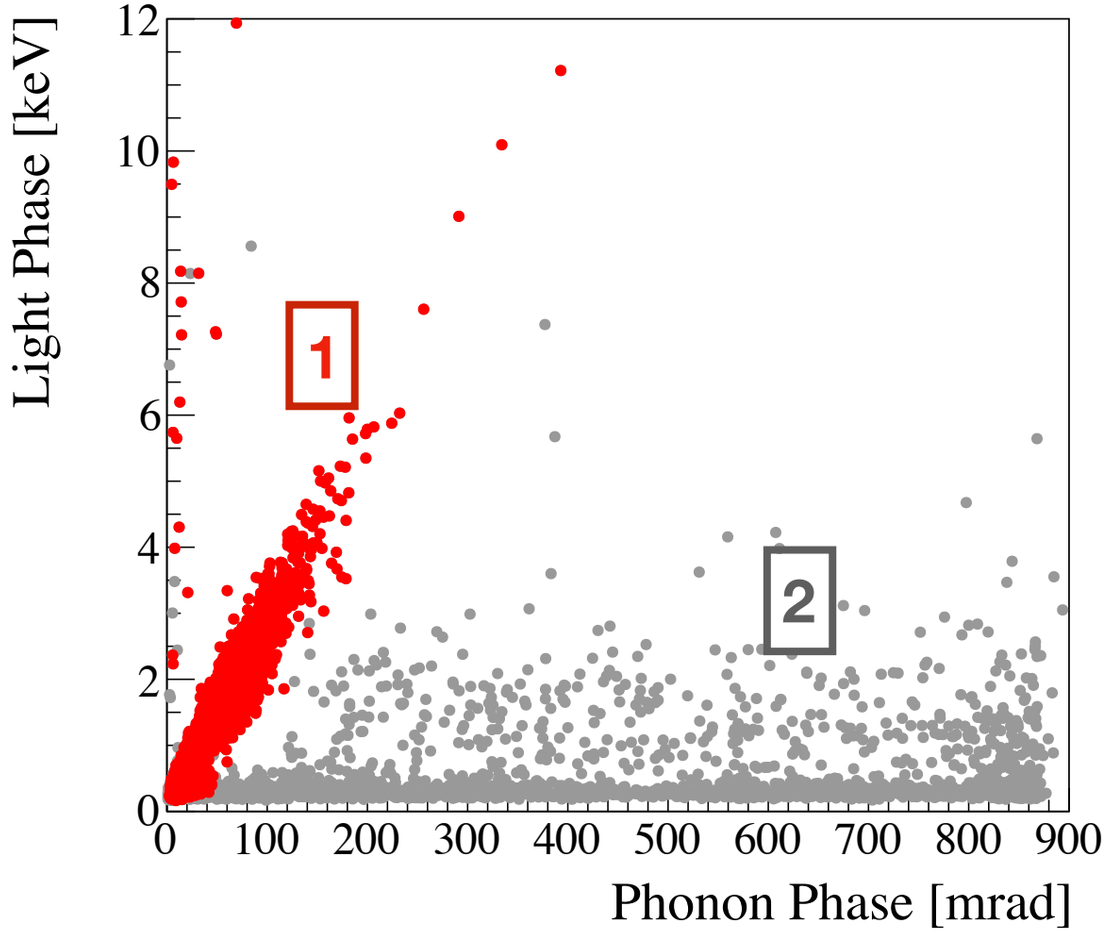


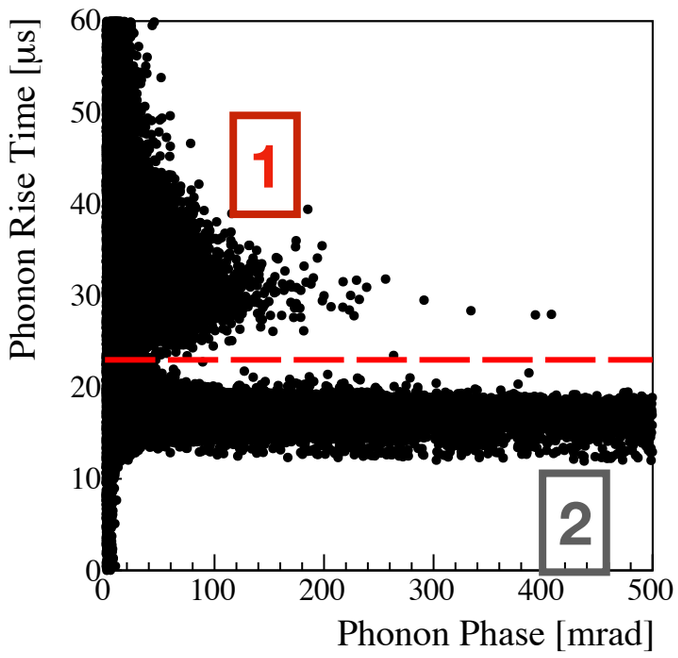


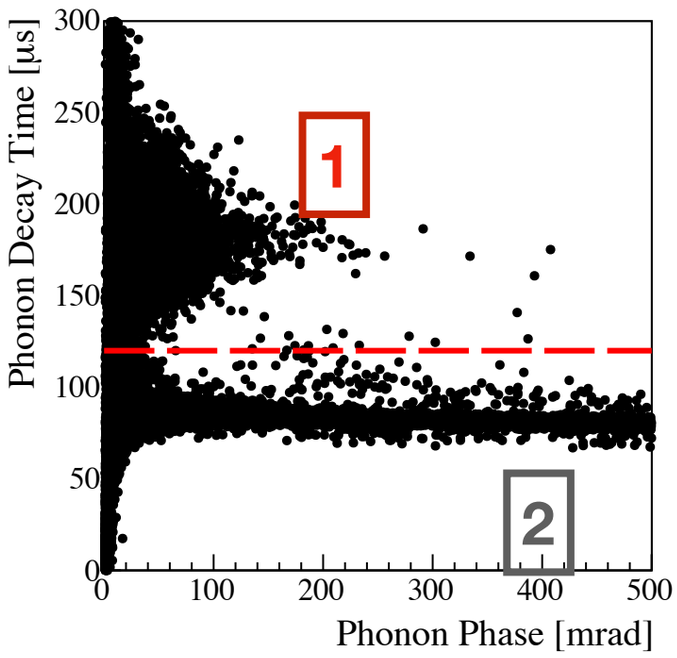


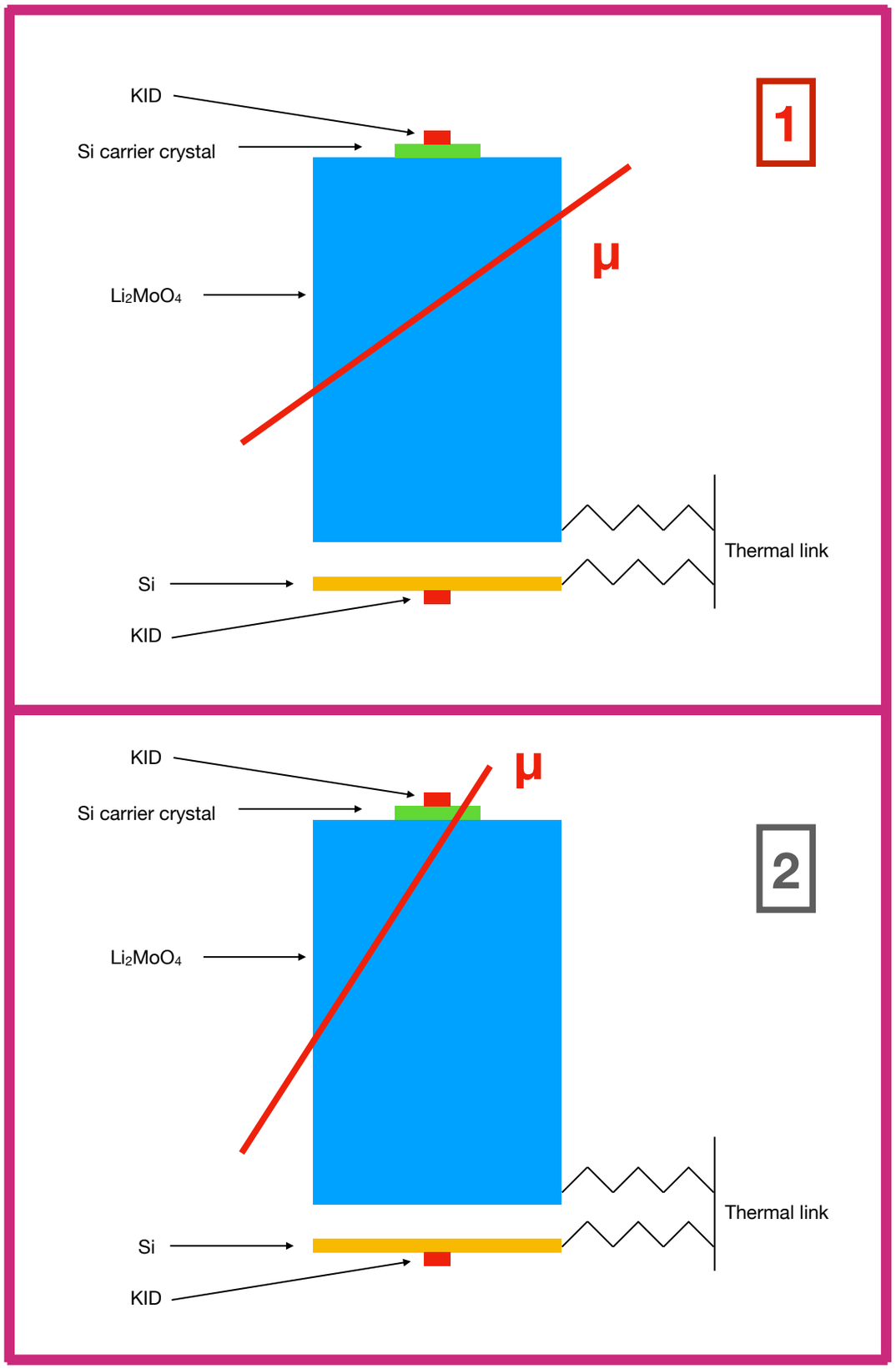
Simultaneous phonon and light read out of Li_2MoO_4 crystal with KIDs

Casali et al. arXiv:1907.03647









Conclusions

- The CALDER project is closing this year:

  A. 25 eV RMS with 10 μs response on 2x2 cm^2 Si light absorber

  B. last prototype: 5x5 cm^2 with AlTiAl resonators

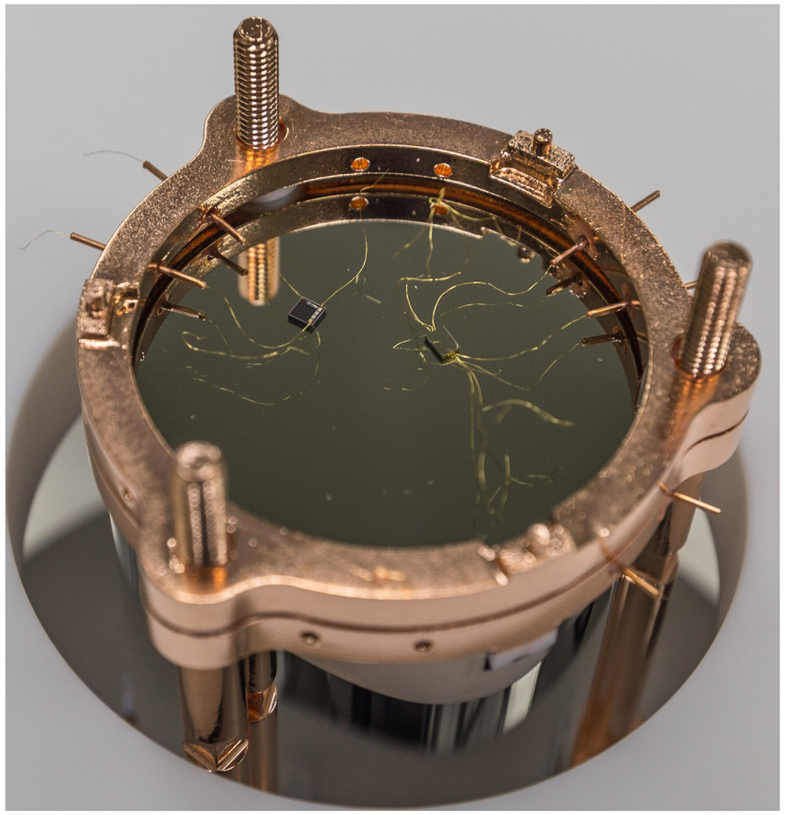
- First simultaneous measurement of phonon and light read out of a macro-calorimeter with KIDs.

- BULLKID: a study for an application of CALDER MKIDs in coherent neutrino scattering

Poster by Ivan Colantoni:
“BULLKID - BULky and Low-threshold KID“

BACKUP

Light detectors for CUPID



Talk by Laura Cardani:
"Final results of the CUPID-0 Phase-I experiment"

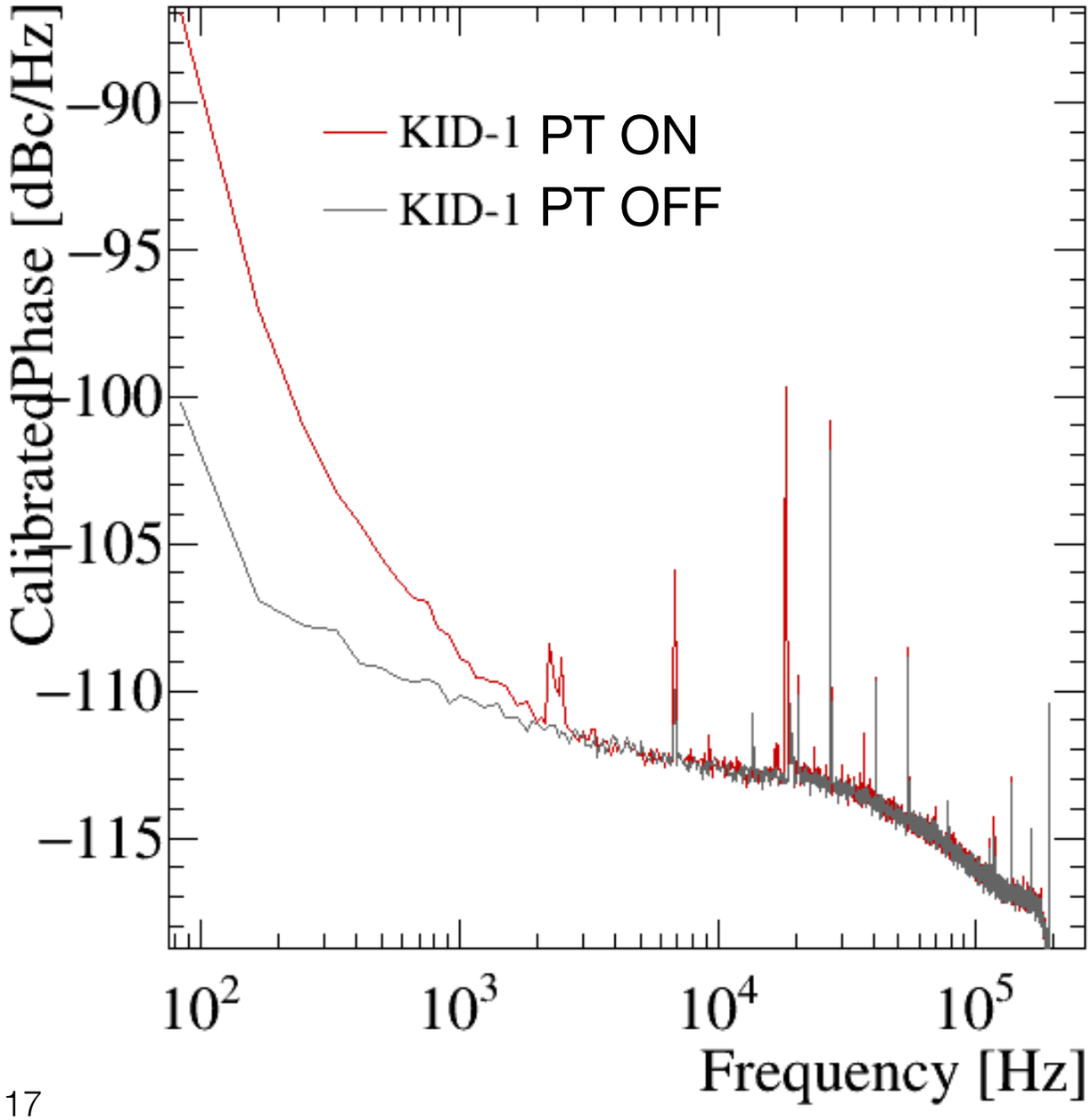
- NTD Ge based light detector: Ge-NTD glued on a disk shape Ge wafer:
  - ✳ 40 eV baseline RMS
  - ✳ 1.8 ms pulse Rise Time

enough for the first CUPID phase,
but not for the second one..

- Intense R&D activities exploiting TES, KID, NTD-Ge, + Neganov-Luke effect technologies to:
  - ✳ Improve the baseline RMS
  - ✳ Lower the pulse Rise Time

Pulse tube induced noise

A dry dilution refrigerator is precooled by a two-stage pulse tube refrigerator

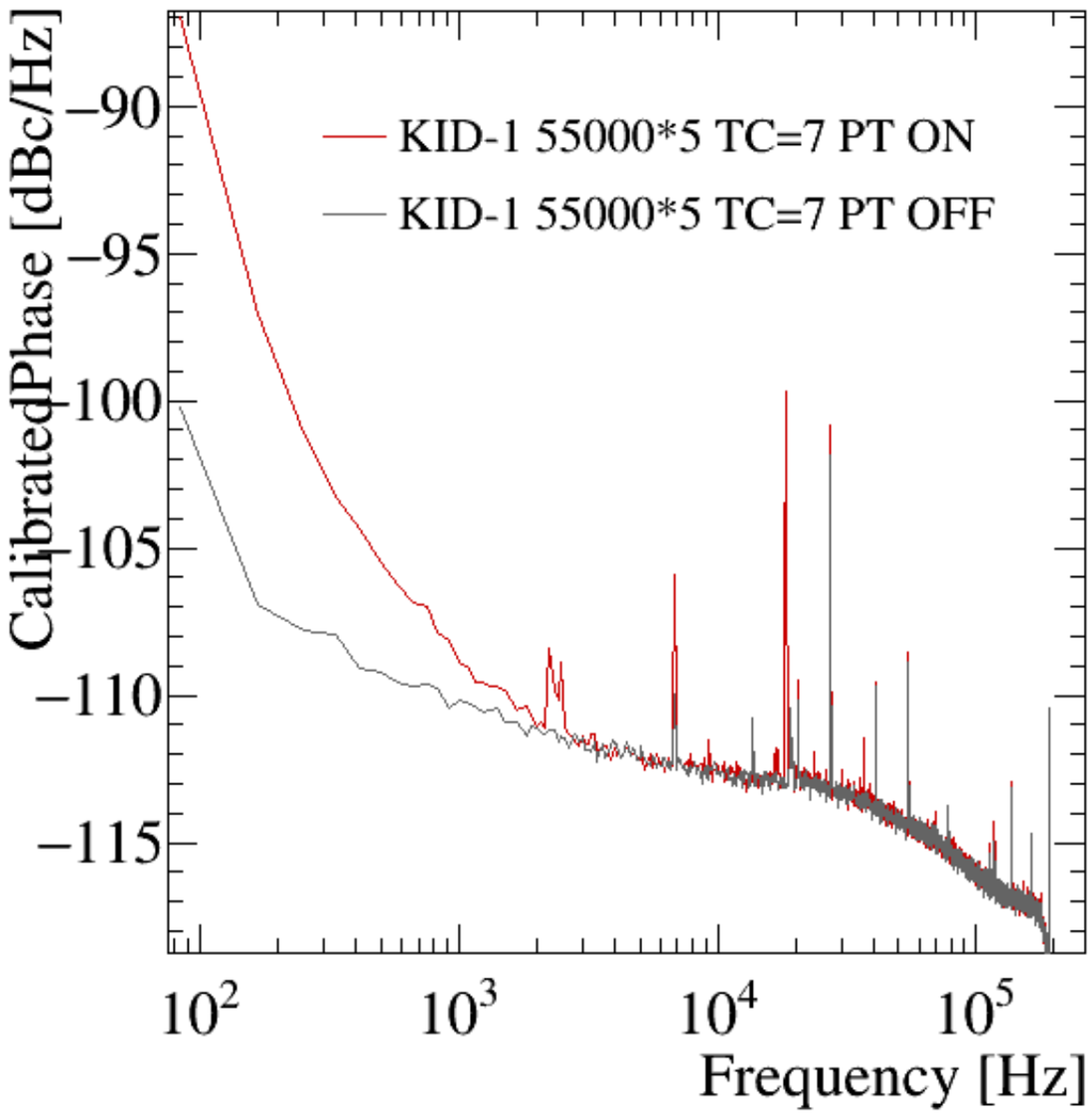


The vibrations are induced in all the refrigerator structure, as a result also on the detector

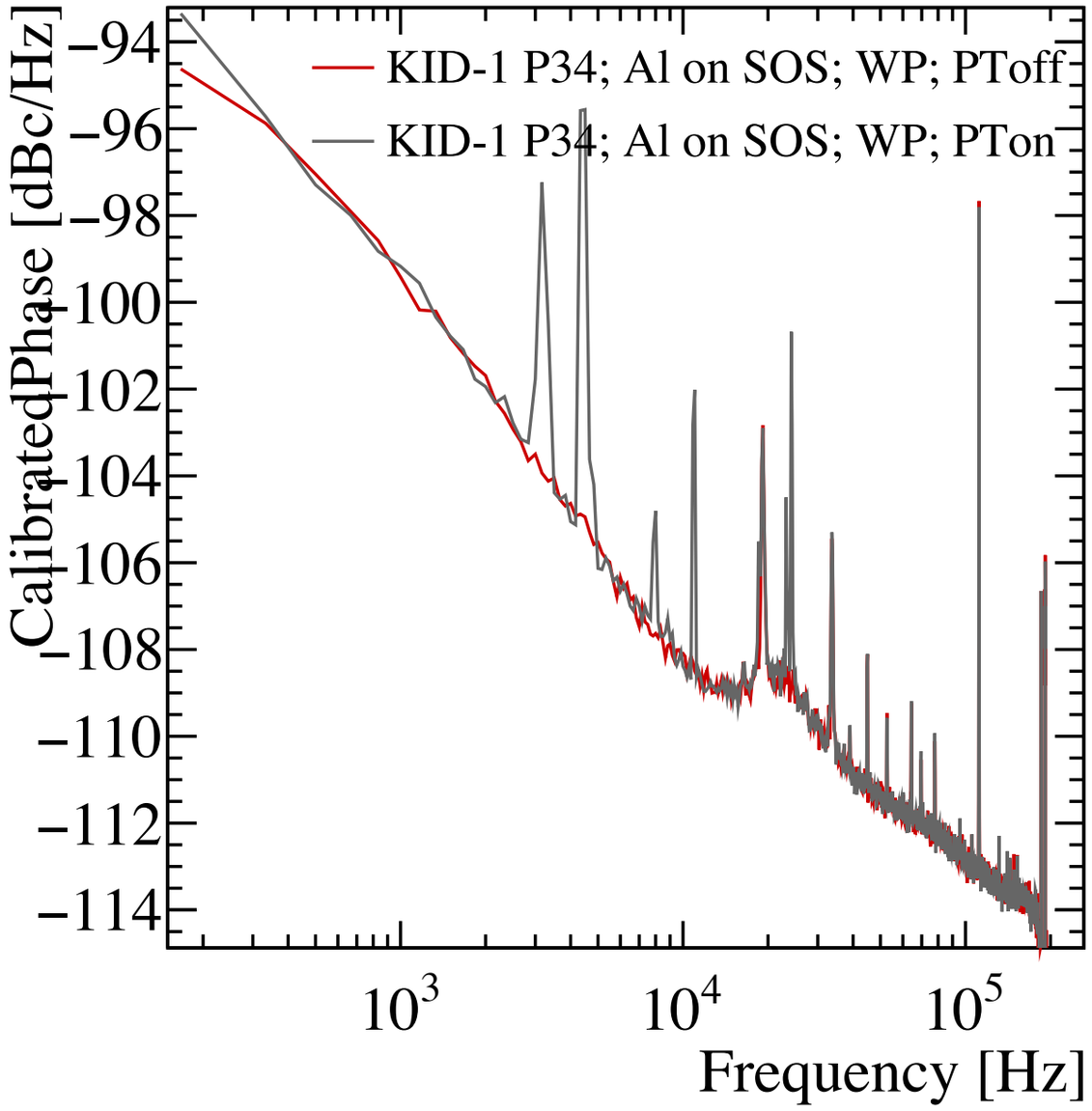
Worsening of the energy resolution

Silicon on Saphire substrate: SOS

Silicon



SOS



KIDs on (SOS) are barely affected by the Pulse Tube induced noise

Fundamental requirement for an application in the CUORE cryogenic facility