CALDER

Cryogenic light detectors for neutrino and dark matter searches

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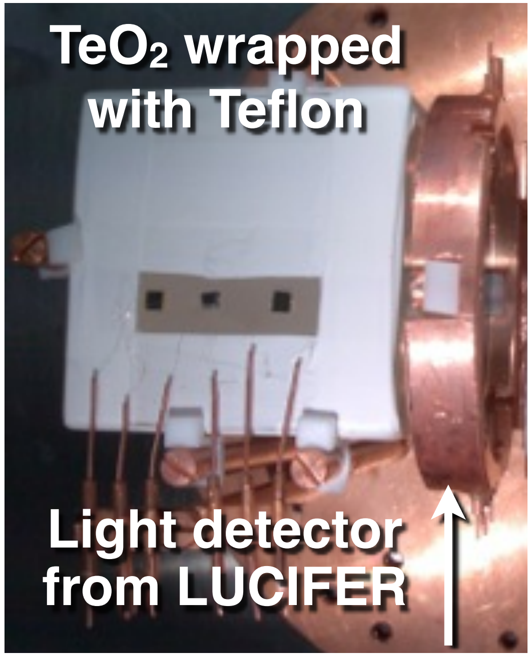
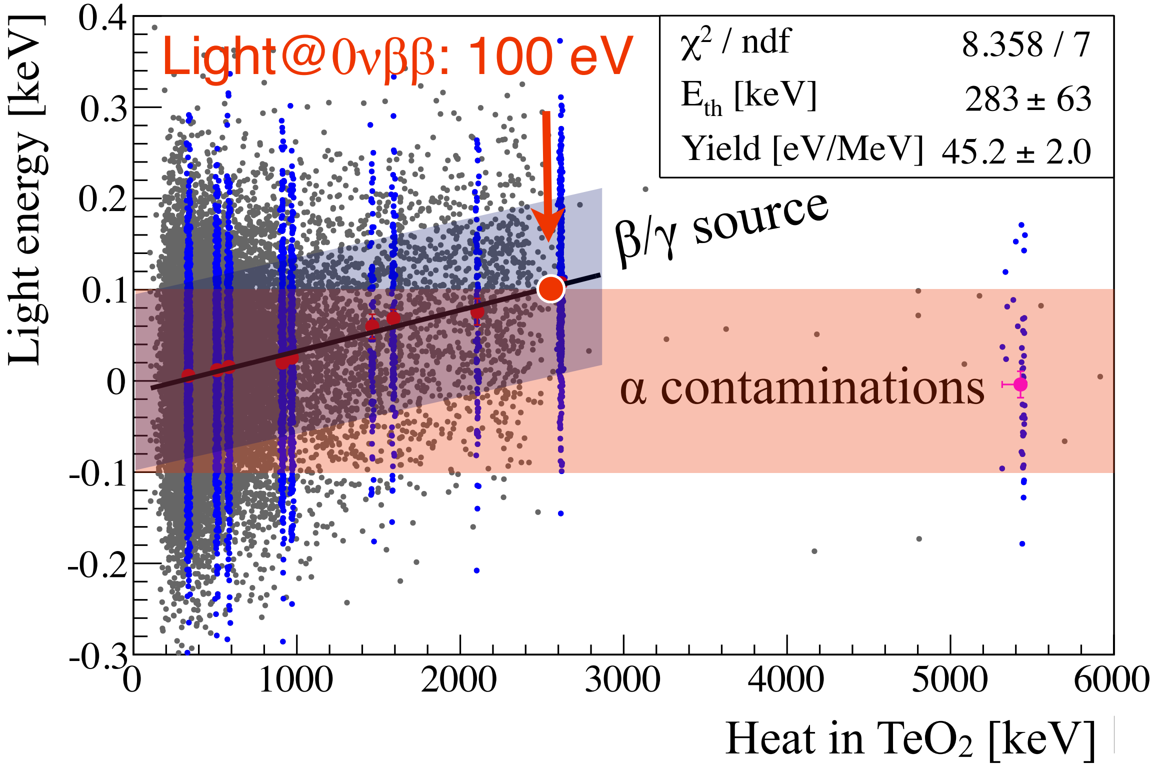
What Next, LNGS 15-October-2014

α bkg removal in TeO_2

Rejection technique: detect the Čerenkov light emitted by βs (signal) and not by αs.

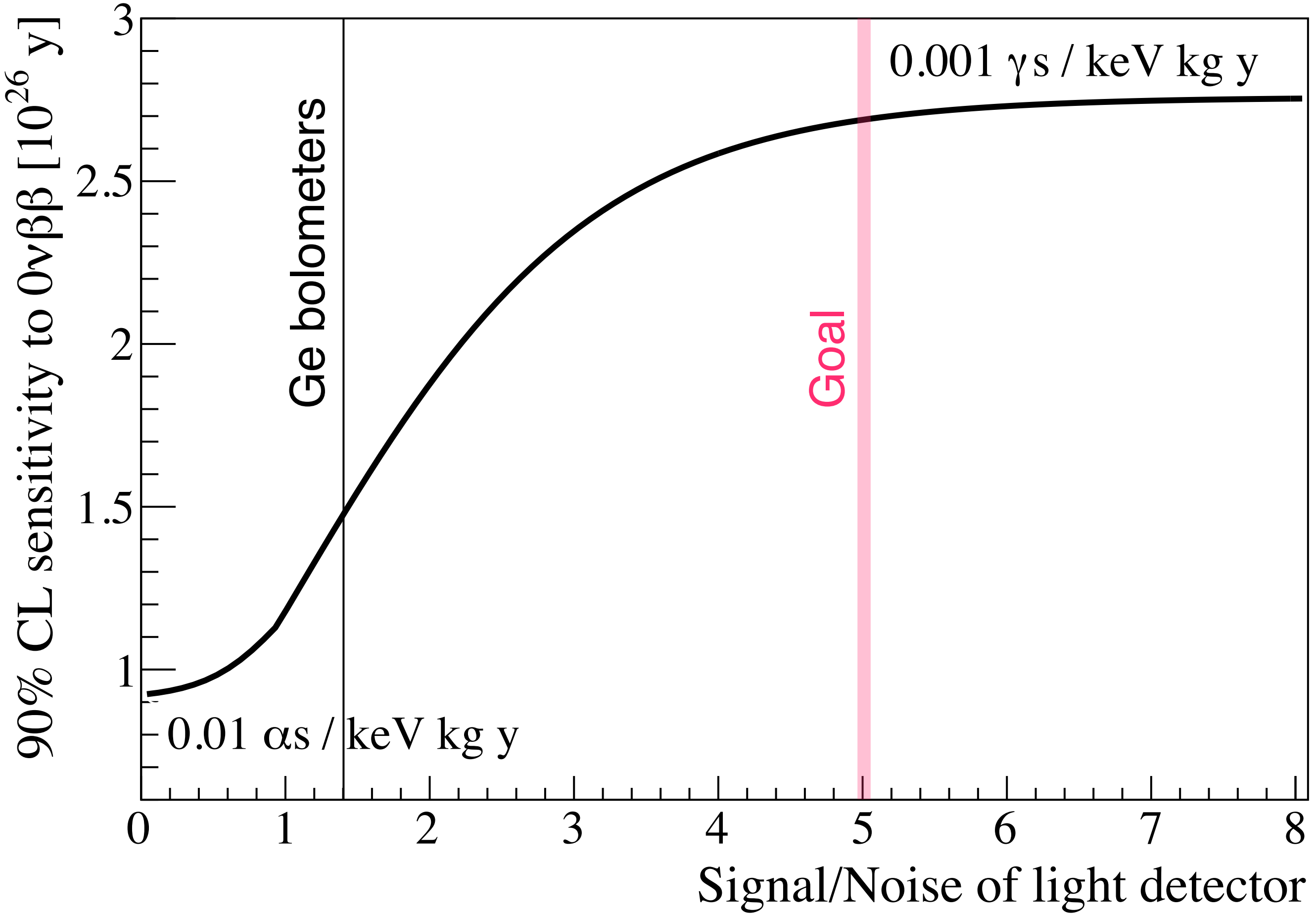




Casali, Vignati, et al., arXiv:1403.5528

Noise of present light detectors is too high (70-100 eV RMS) compared to the signal (100 eV) ⟶ **need new light detectors.**

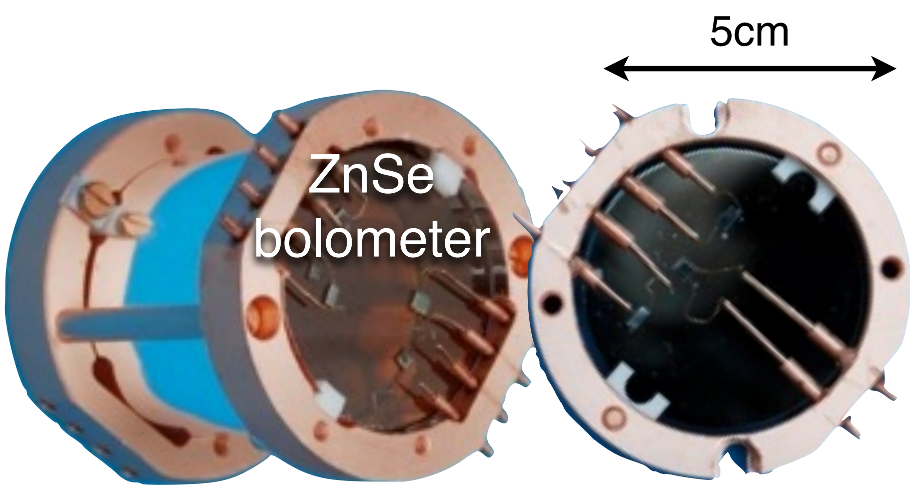
Sensitivity of the light detector



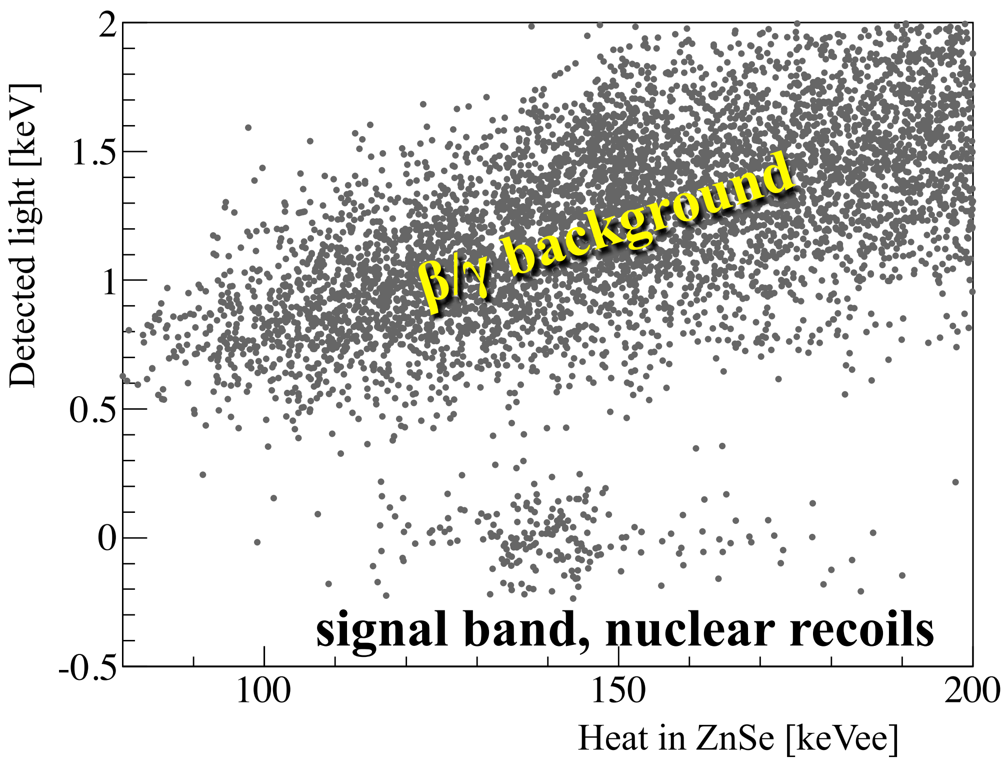
With a 100 eV signal, to obtain S/N > 5 we need a **noise < 20 eV RMS.**

Dark Matter with ZnSe

Identification of nuclear recoils in LUCIFER: nuclear recoils (signal) do not emit light , β/γs (background) emit a few light. The discrimination is in principle possible at 10 keV (the DM search region),



J. W. Beeman et al., JINST 8 (2013) P05021



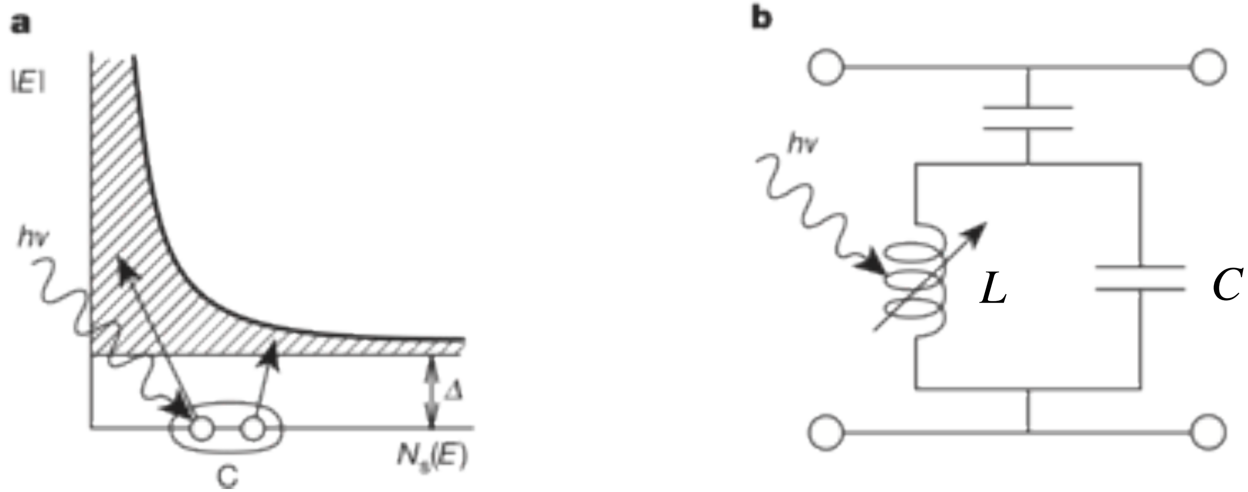
By using light detectors with noise below 20 eV RMS, **LUCIFER** could be a **0νββ and DM experiment at the same time**.

Which light detector technology?

- ? **Neutron Transmutation Doped** (**NTD**) **thermistors**, currently used in LUCIFER:
  - ‣ Average $\Delta E \sim 100$ eV**,** too large. Not reproducible.
  - ‣ Could be improved using the Neganov-Luke effect.
- ? **Transition Edge Sensors (TES)**, à la CRESST Dark Matter experiment:
  - ‣ $\Delta E < 20\text{-}30$ eV, good!

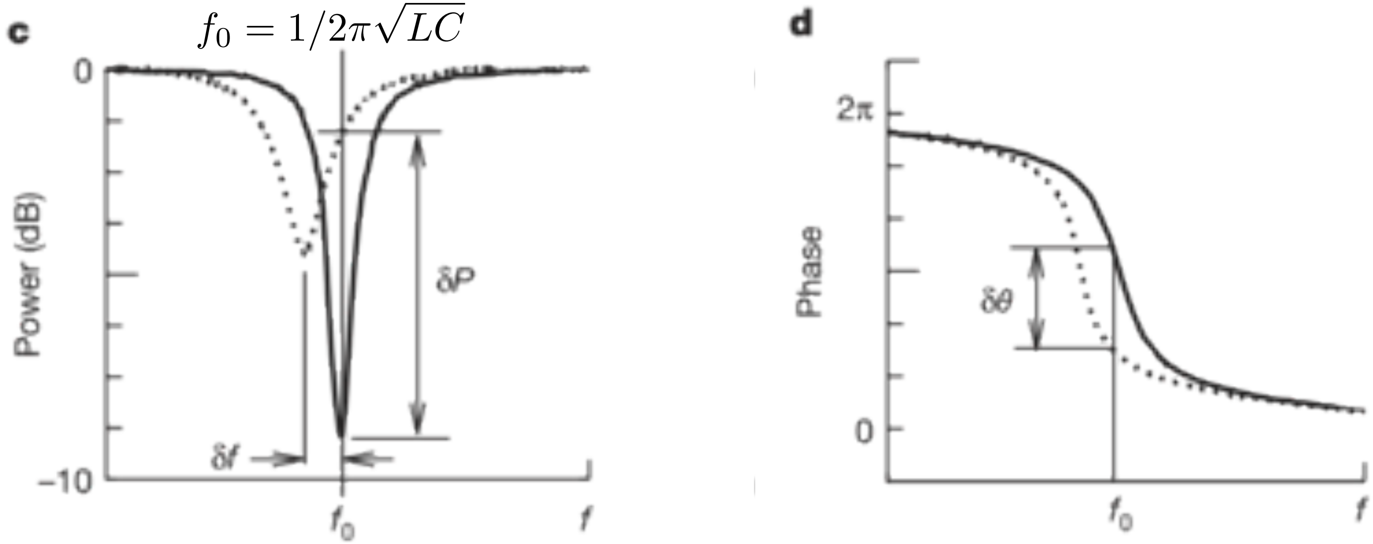
  R&D needed in view of the scale up to 1000 detectors:
  - ‣ Complicated readout: SQUID amplifiers, small multiplexing.
- ? **Magnetic Metallic Calorimeters (MMC),** already used by AMoRE
  - ‣ In principle comparable to TES, but again require read-out R&D.
- ? **Kinetic Inductance Detectors (KID)**: new technology invented at Caltech and JPL, first paper: P. Day et al., Nature, 425 (2003) 817:
  - ‣ Excellent reliability.
  - ‣ Easy readout: FPGAs and 1 cold amplifier, high multiplexing.
  - ‣ But, need to develop a large area light detector to monitor bolometers.

KID: Working principle



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

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

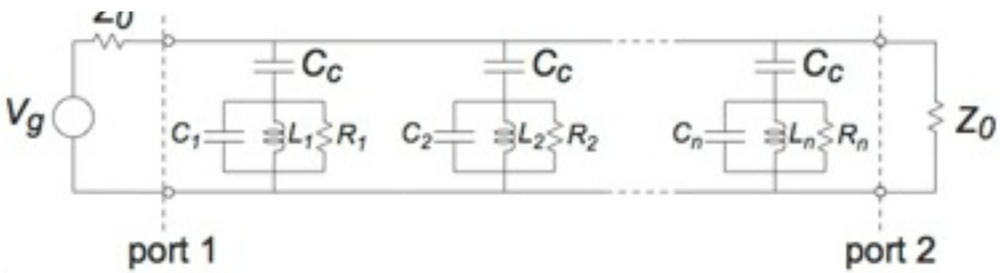


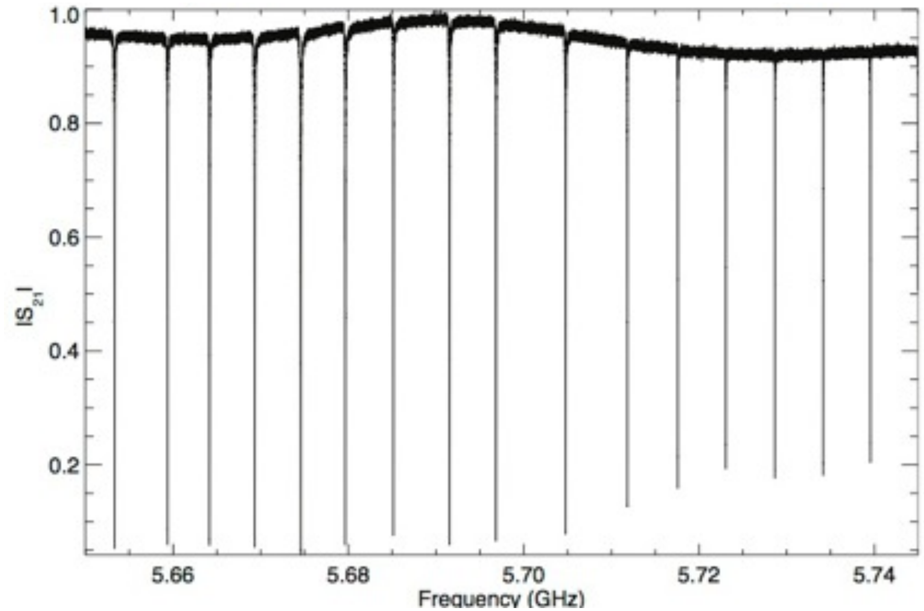
High quality factor (*Q*) resonating circuit biased with a microwave (GHz): signal from amplitude and phase shift.

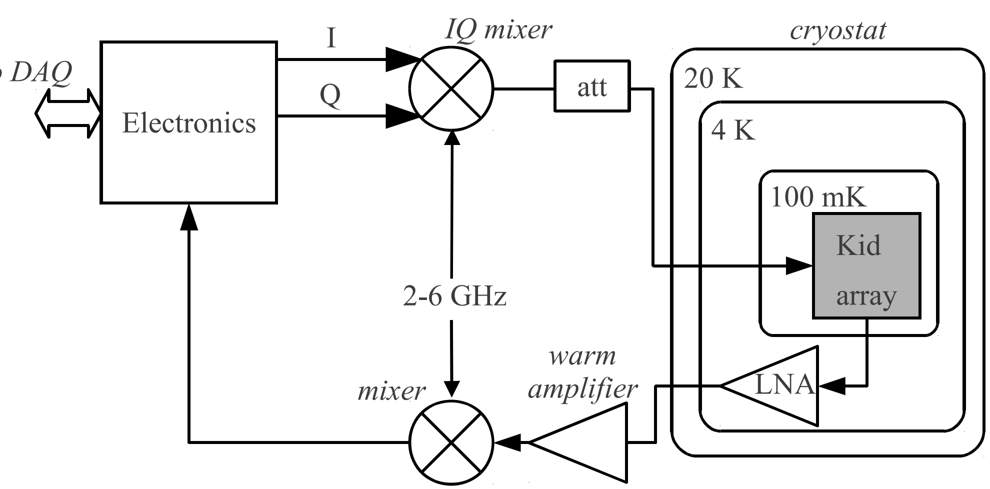
Day et al., Nature 425 (2003) 817

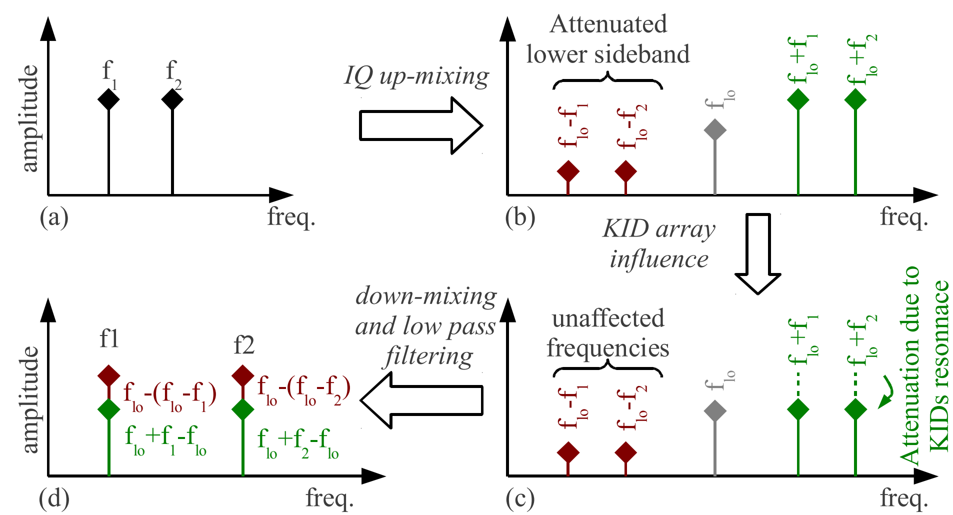
Multiplexed readout of a KID array

O. Bourrion et al, JINST 6 (2011) P06012.





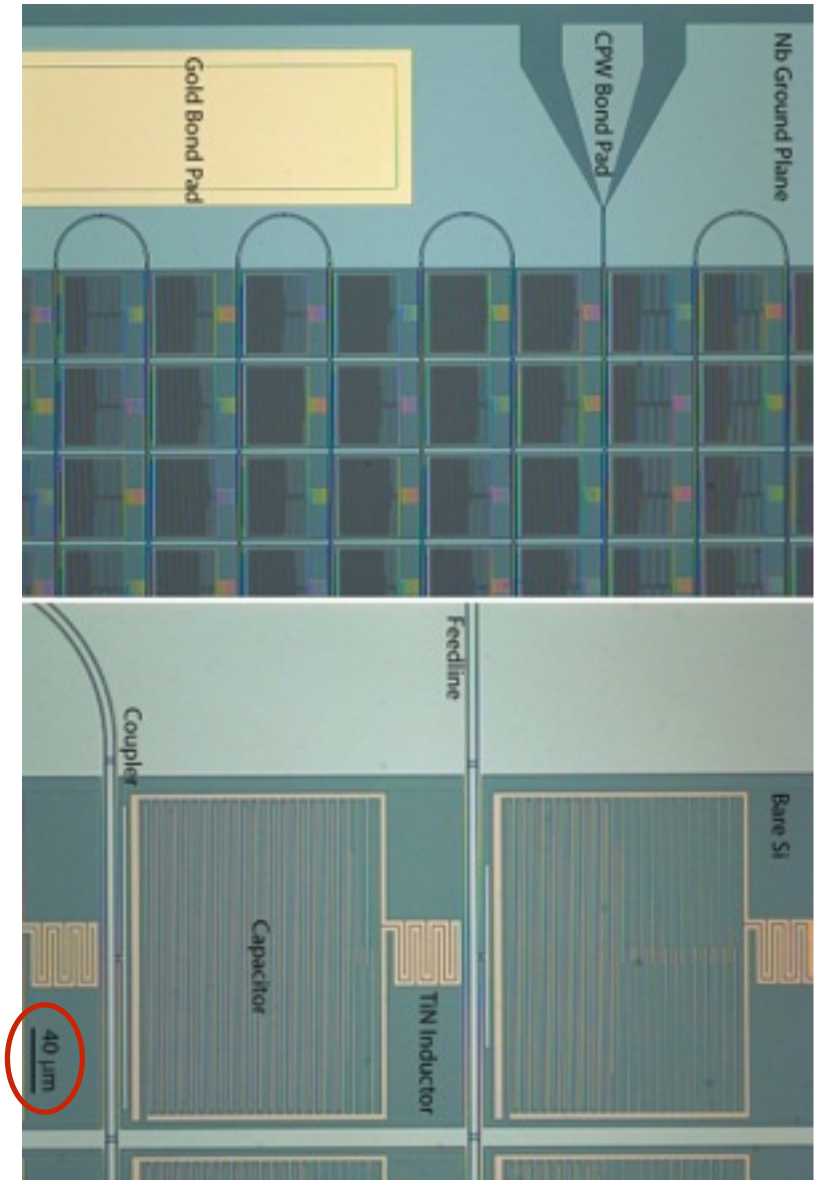


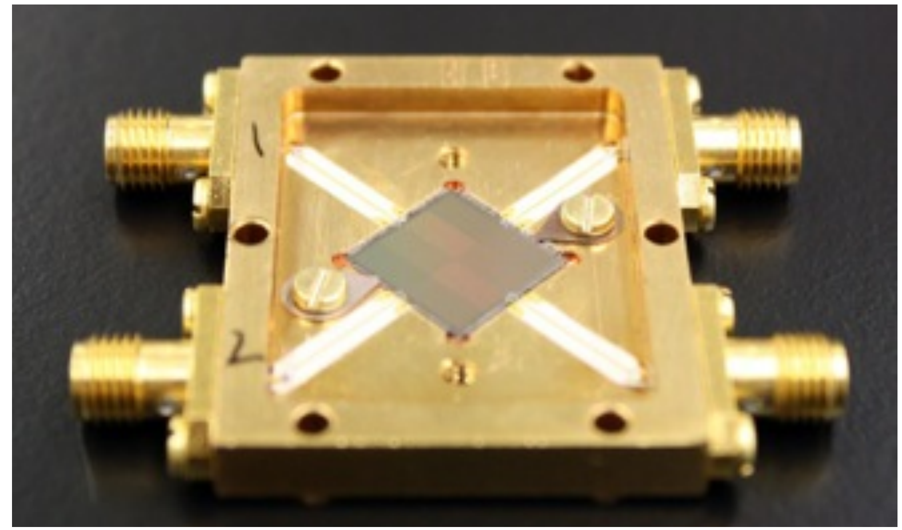


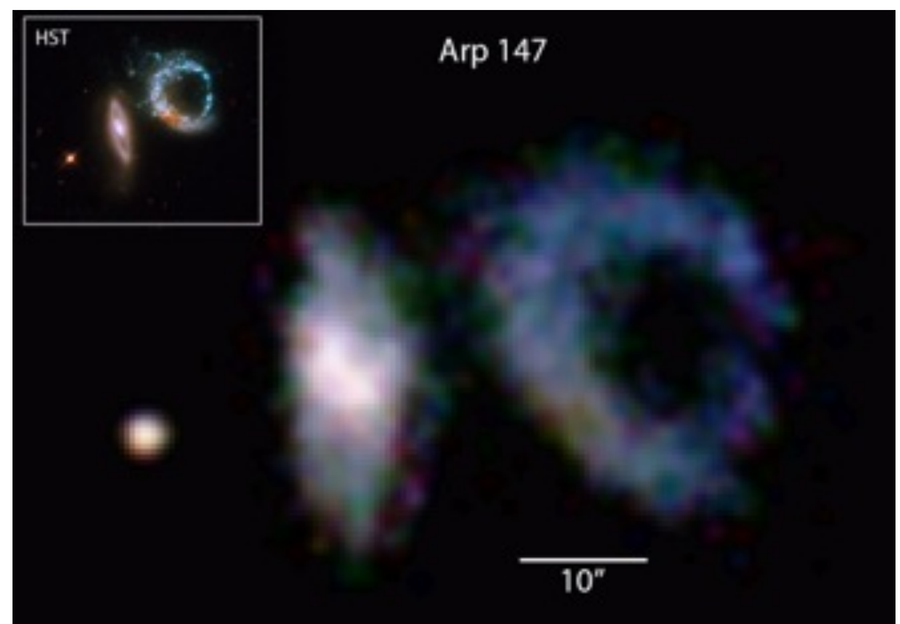
A successful implementation

ARCONS: A 2024 Pixel Optical through Near-IR Cryogenic Imaging Spectrophotometer

Mazin, B.A. et al, PASP, 123, 933, 2013.



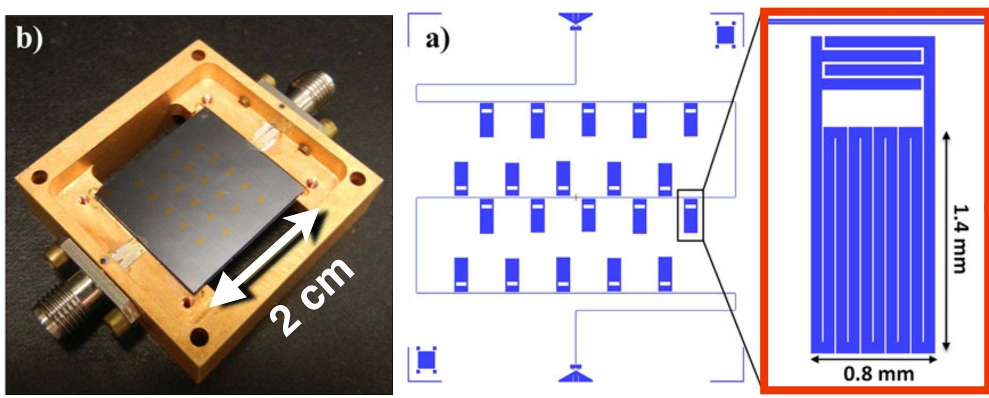




Light detector with KID sensors

	State of the art	goal	
Area	few mm	5x5 cm	difficult
ΔE [eV RMS]	< 1	< 20	achievable
T	80	10	pro

Moore et al., Appl. Phys. Lett, 100 (2012) 232601



Problem

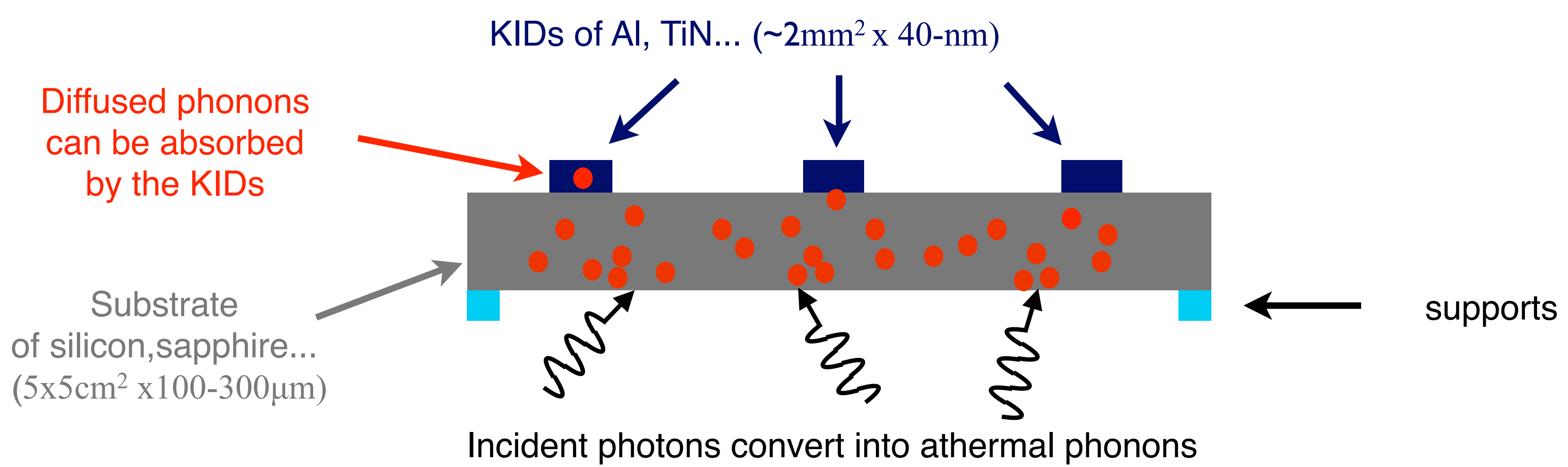
Direct photon detection: maximum area of few mm^2 (wavelength limited)

Other problem: area cannot be covered with 10^3 KIDs, too demanding for electronics (in the future we will need 10^3 light detectors).

CALDER's strategy

Indirect detection - à la CRESST

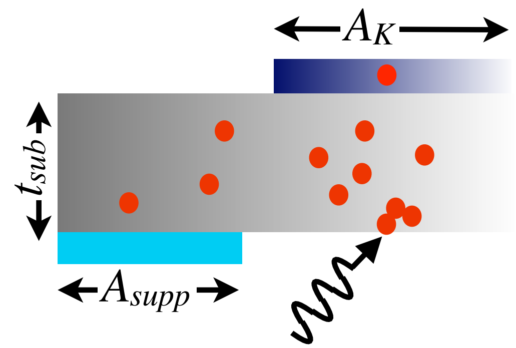
use a few KIDs (N_K=1-10) and athermal phonons in the substrate as mediators



Scientific challenge: sensitivity

Problem: loss of phonon collection efficiency (ε) through the supports and via thermalization:

$$\frac{1}{\epsilon} = 1 + \frac{1}{N_K A_K p_K} \left(A_{supp}\, p_{supp} + A_{sub} \frac{t_{sub}/v_{sound}}{\tau_{thermal}} \right)$$



Geometry R&D: maximize transmission to the KIDs ($p_K A_K$). Minimize support area (A_{supp}), transmission prob. to supports (p_{supp}) and substrate thickness (t_{sub}).

KID R&D: ε loss compensated by KID sensitivity:

$$\Delta E \propto \frac{1}{\epsilon} \cdot T_c \sqrt{\frac{N_K A_K}{Q\, L}}$$

1) Maximize film quality factor: $Q > 10^5$.

2) High inductivity (L) and low T_c superconductors thanks to T_{work} =10 mK:

	Al	TiN (non stoich.)	Ti+TiN (stoich.)	Hf
T	1.2	0.9	>0.4	0.12
L [pH/square]	0.05	3	30	*3*

CALDER Collaboration

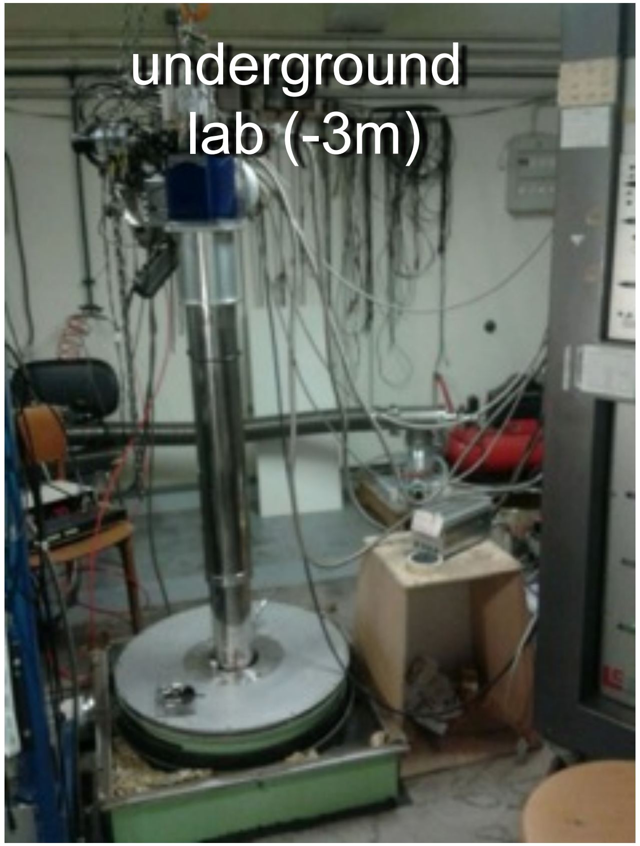
Sapienza University of Rome:
KID Design, Cryogenic tests, Data Analysis.
E. Battistelli, F. Bellini, L. Cardani, C. Cosmelli, A. Cruciani, P. de Bernardis, S. Masi and M. Vignati.

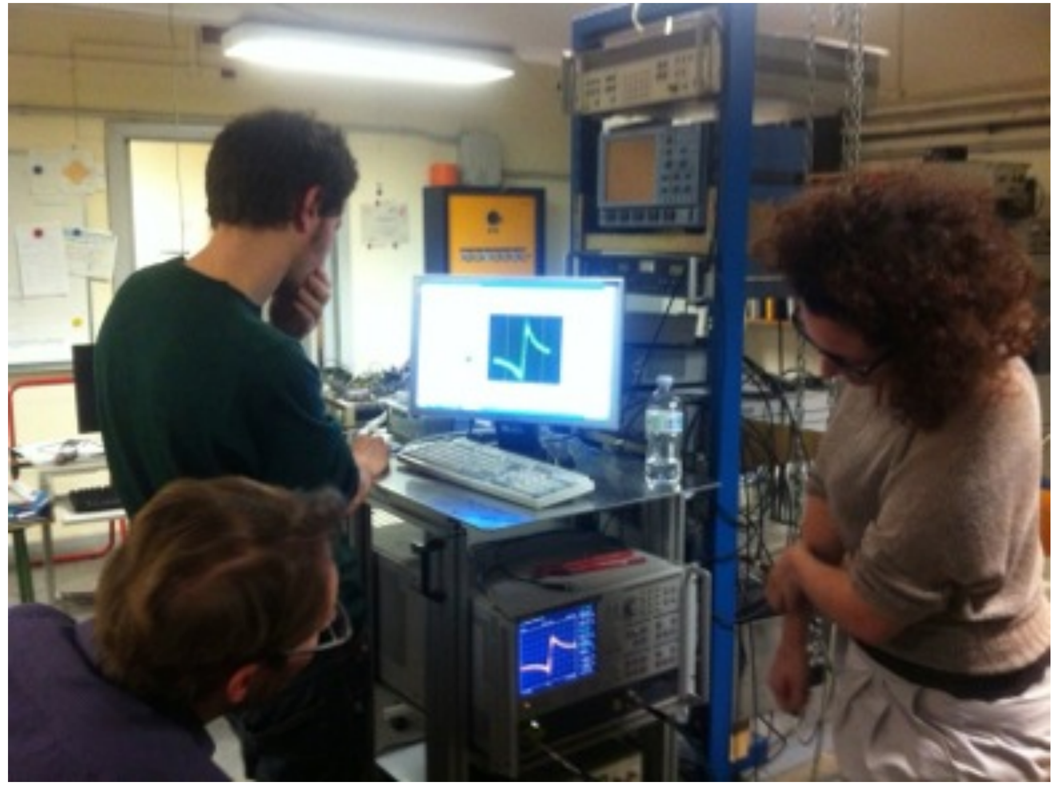
Istituto Nazionale di Fisica Nucleare:
Tests at Gran Sasso Underground Lab.
C. Bucci, C. Tomei and M. Vignati (from 11/14).

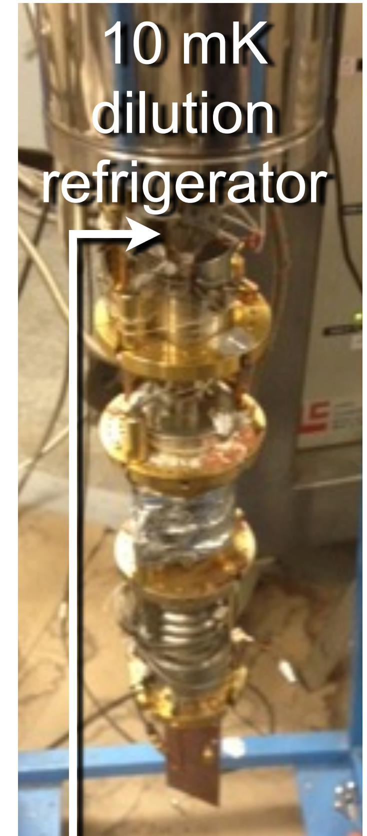
Consiglio Nazionale delle Ricerche:
Detector fabrication.
I. Colantoni and M.G. Castellano.

Università degli studi di Genova:
Electronics and DAQ.
S. Di Domizio.

Sapienza/INFN Lab in Rome





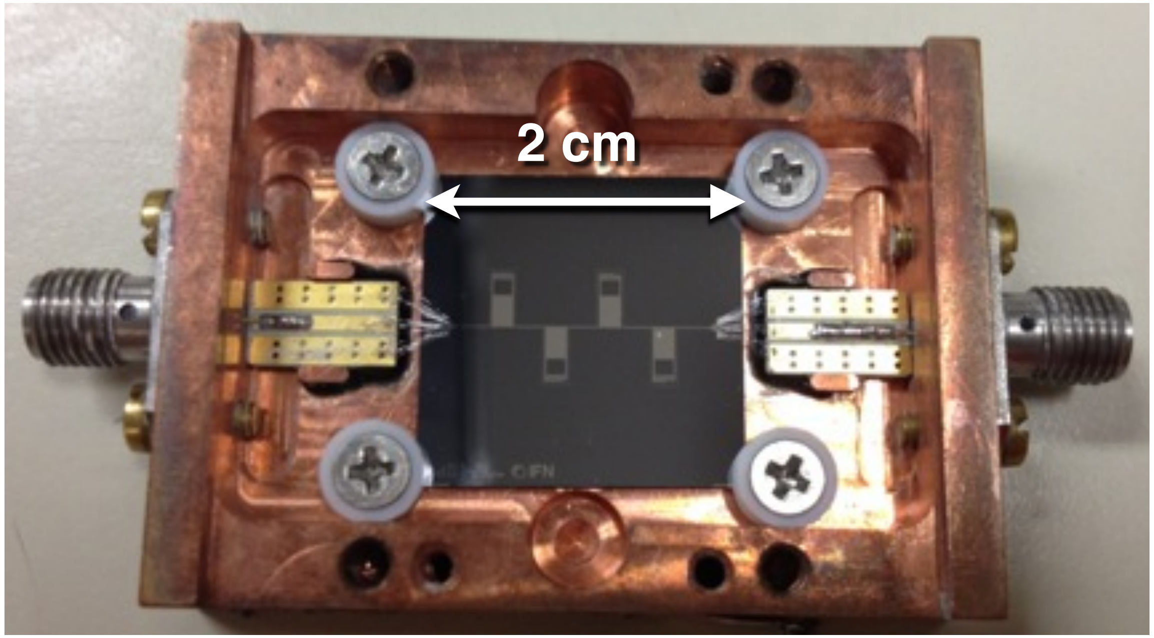


single
cryogenic
amplifier

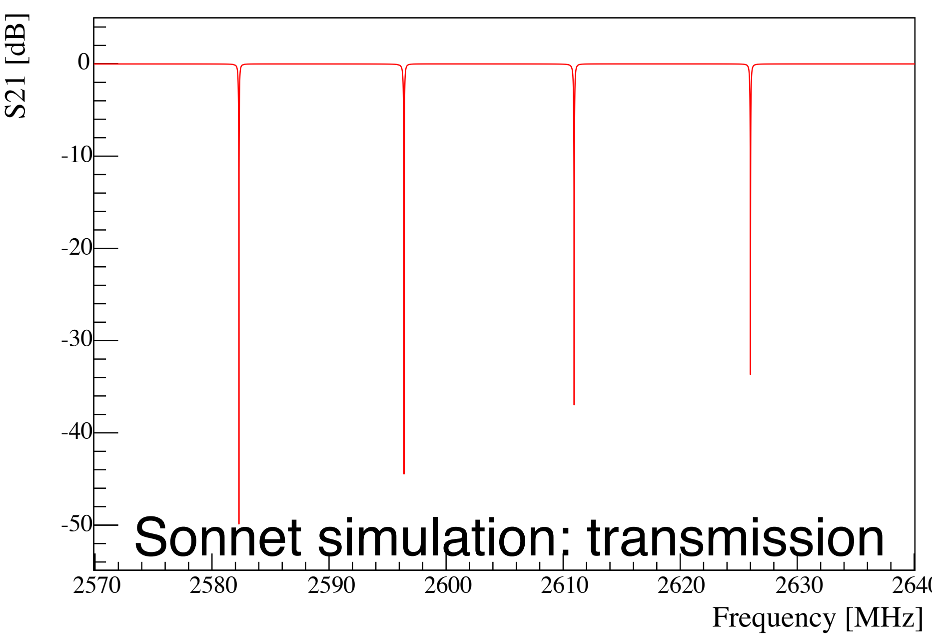
Nixa: electronics board developed at LPSC (Grenoble)

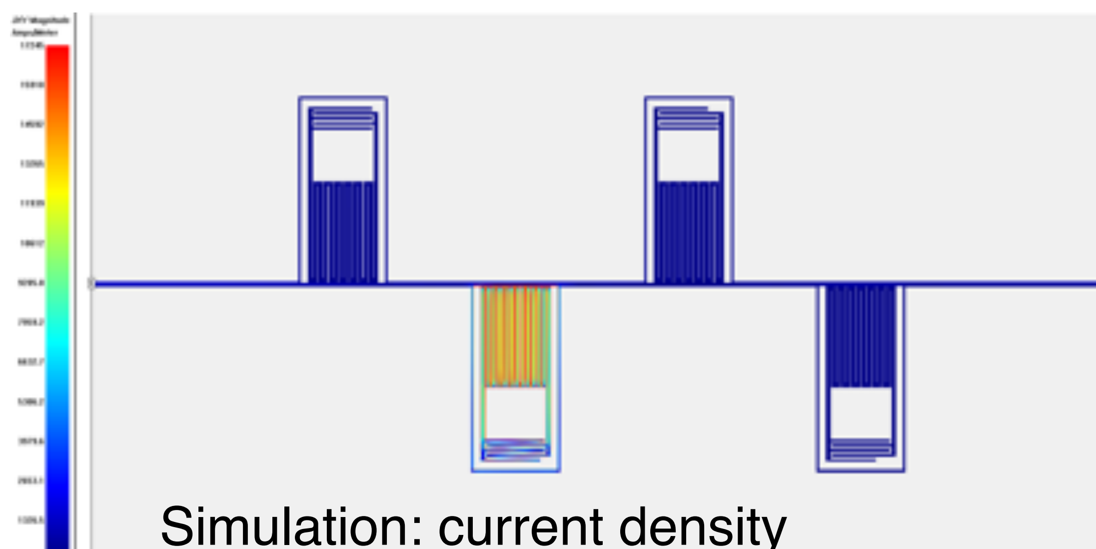
O. Bourrion et al., JINST 8 C12006 (2013)

2nd Prototype



- Single pixel area: 2.4 mm^2.
- 4 pixels coupled to the same feed line.
- Frequency: 2.6 GHz (spacing 15 MHz).
- 40 nm Aluminum lithography on Silicon substrate

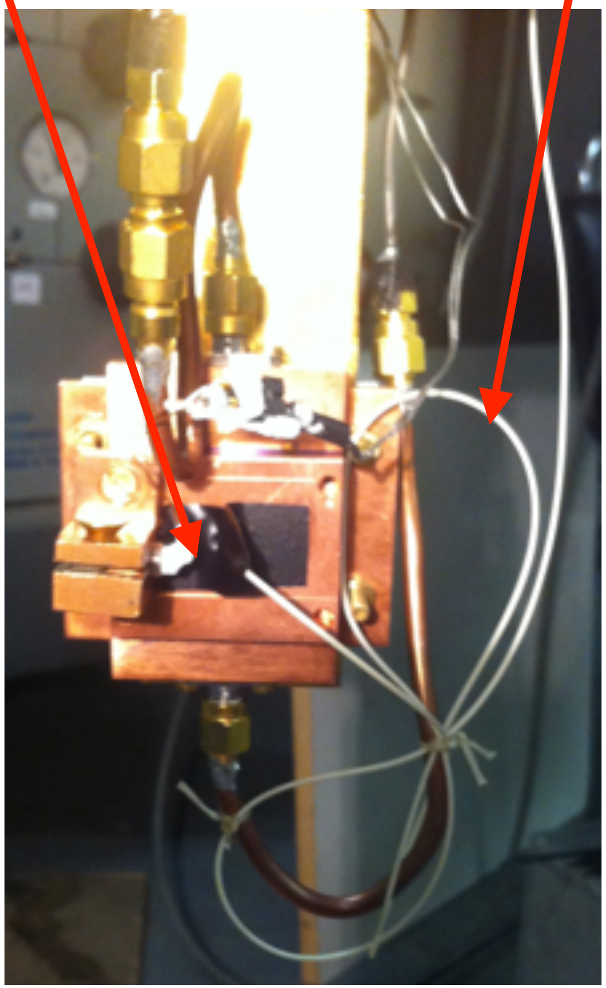


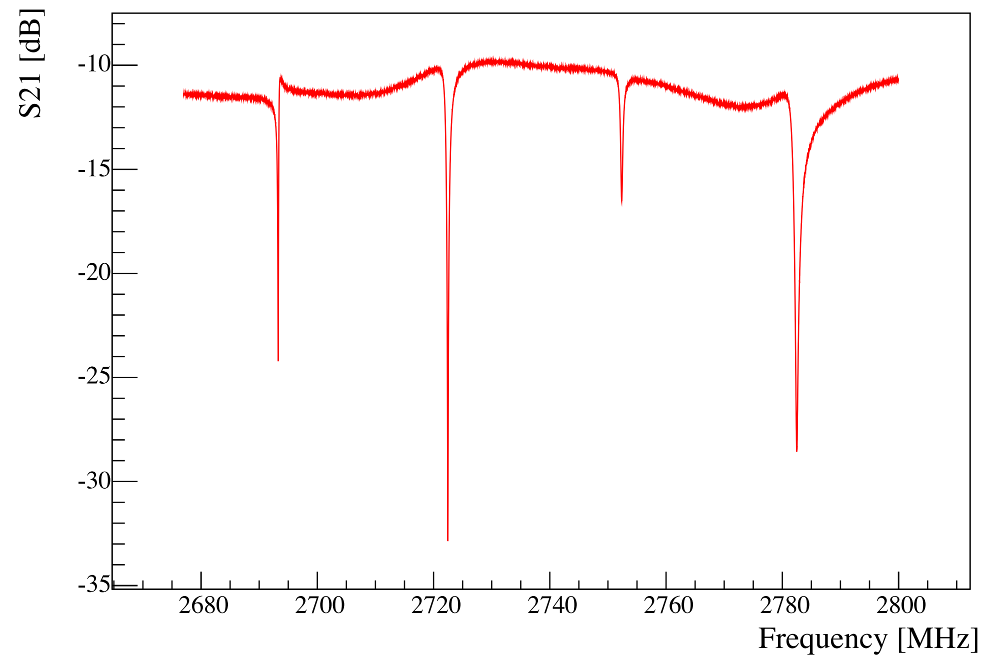


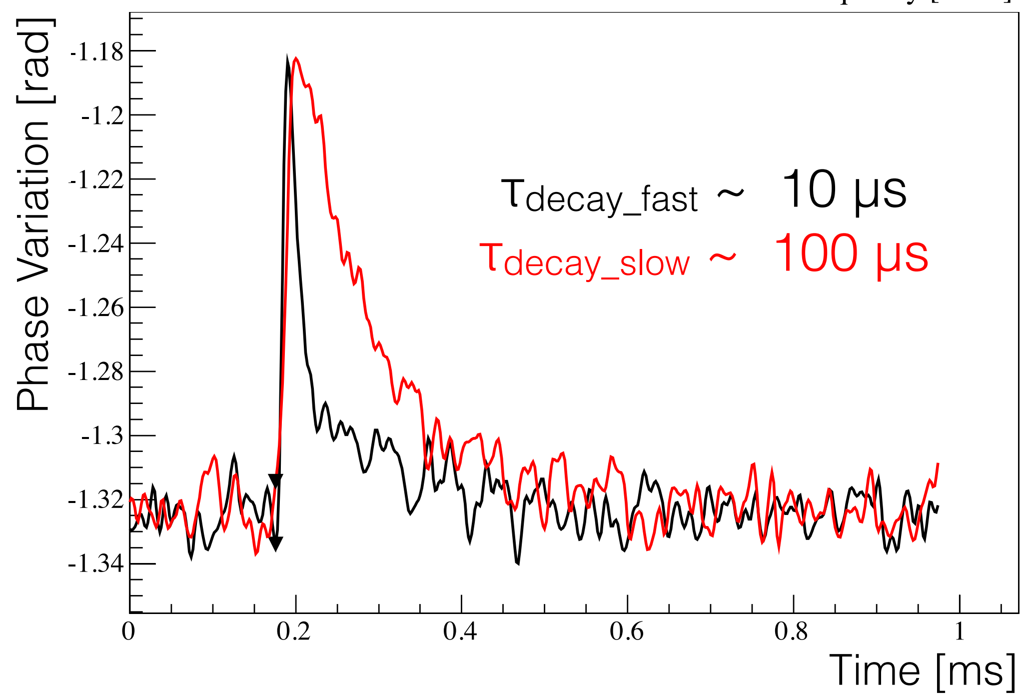
Data

^{55}Fe source
(6 keV X-rays)

Optical fiber pulsed
with LED







Status and program

2013-2014 Cryostat setup (reached 10-15 mK), readout (12 pixels in parallel up to now), data analysis, and first prototypes (9 and 4 pixels) with low Q.

2014-2015 Finalize production and test of Aluminum sensors at high Q, reach 50-100 eV baseline noise.

2015-2016 Develop and test TiN - Ti/TiN sensors, reduce the number of pixels per detector (1-4), reach < 20 eV baseline noise.

2016-2017 Integration with the CUORE/LUCIFER setup at LNGS. Build a demonstrator with an array of TeO bolometers monitored by the new light detectors.

A new proposed project

EPIC-MAPS

Low temperature detector technology for broad band high energy resolution spectroscopy

DETECTOR CONCEPT

Operate Kinetic Inductance Detectors as quasi-equilibrium thermal sensors
→ Sensitivity limited by thermodynamic fluctuations
→ Combine high efficiency, high resolution and high count rates

IMPLEMENTATION

→ Exploit recent developments in superconducting materials with low, tunable T_c
→ Simple readout thanks to the intrinsic frequency multiplexing of KIDs

DEMONSTRATOR

Realize a ready-to-use 1K-pixel X-ray detector to be deployed at a synchrotron facility

APPLICATIONS

Short pulse X-ray sources, nuclear safeguard, astrophysics, neutrino physics, etc

LONG TERM VISION

Build an scientific community of interdisciplinary nature and establish Europe as a leader in this field

From S. Di Domizio

A new proposed project

EPIC-MAPS

Project submitted for a H2020-FETOPEN-2014-2015-RIA grant

PI: A. Nucciotti (UniMiB)

Project duration: 4 years

INFN

People: S. Di Domizio (GE, INFN PI), V. Bocci and M. Vignati (ROMA1)

Tasks: electronics, signal processing, detector design and commissioning

10 Institutions involved

- Università di Milano-Bicocca
- Istituto Nazionale di Fisica Nucleare
- CNRS / Institut Néel and LPSC
- CEA/INAC/SBT
- Lund University
- Fondazione Bruno Kessler
- Consiglio Nazionale delle Ricerche
- Ruprecht-Karls-Universität Heidelberg
- Johann Wolfgang Goethe Universität
- MITO Technology

From S. Di Domizio