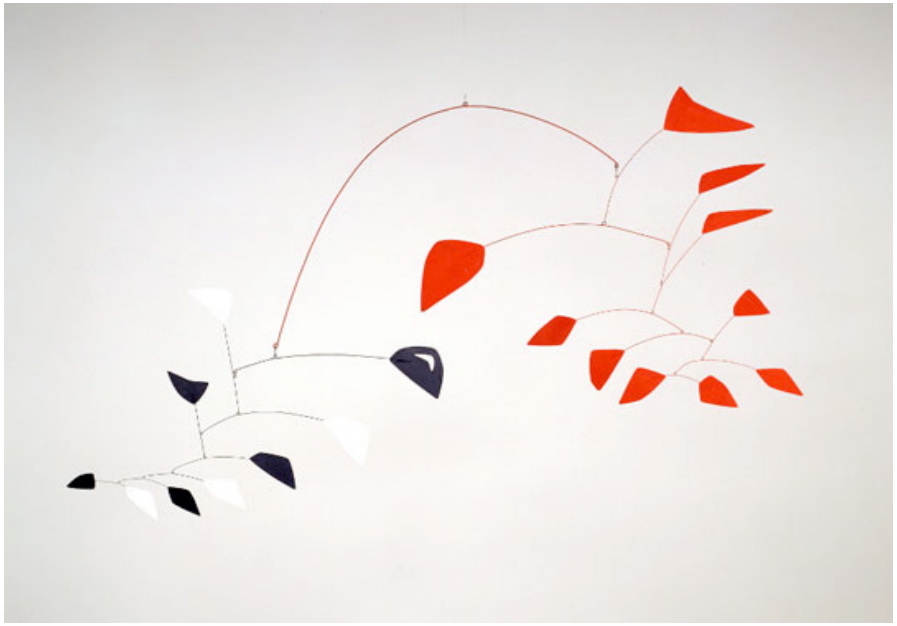


CALDER

CRYOGENIC LIGHT DETECTORS FOR NEUTRINO AND DARK MATTER SEARCHES

Angelo CRUCIANI

Sapienza, University of Rome

ISOTTA meeting - Orsay 2-December-2014

CALDER collaboration:

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

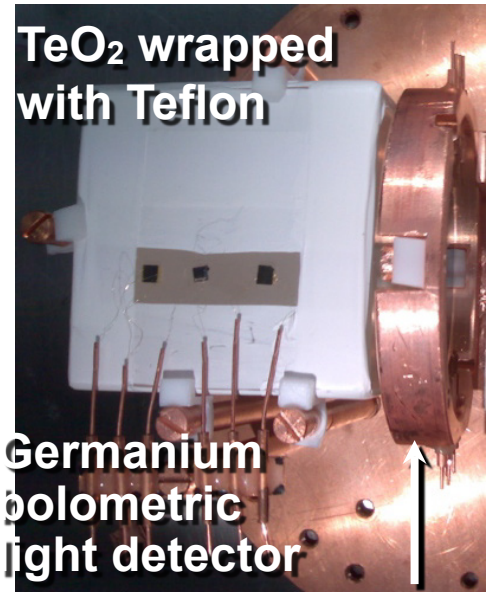
Istituto Nazionale di Fisica Nucleare: Tests at Gran Sasso Underground Lab.
C. Bucci C. Tomei and M. Vignati.

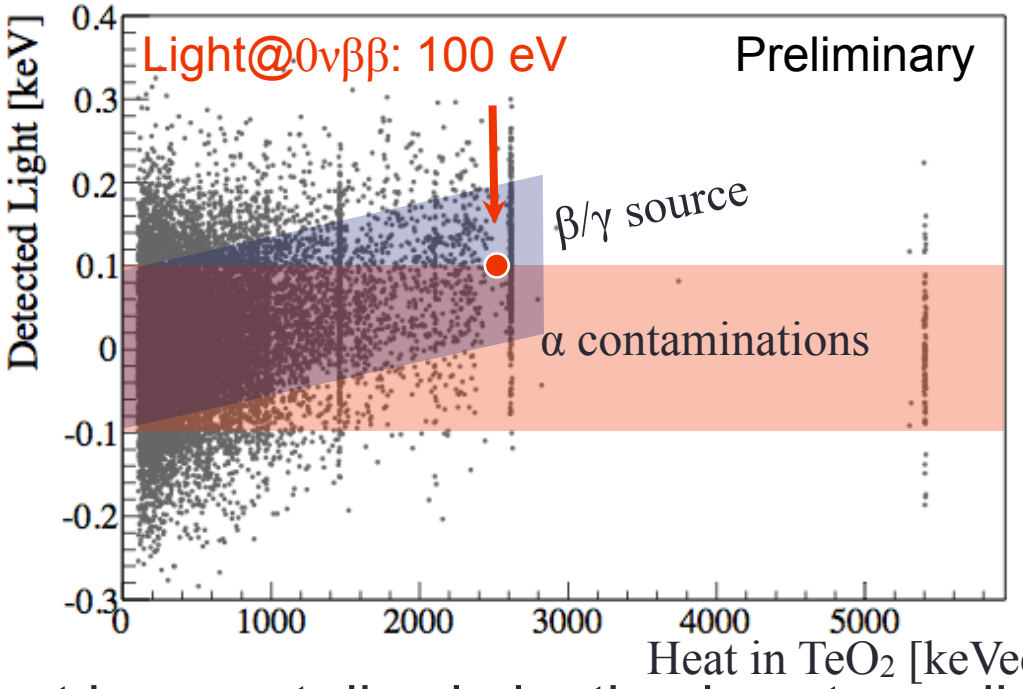
Consiglio Nazionale delle Ricerche: Detector fabrication.
M.G. Castellano and I. Colantoni.

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

Particle ID with Čerenkov

Discrimination of α interactions in CUORE: MeV βs (signal) emit a little Čerenkov light, αs (background) do not.





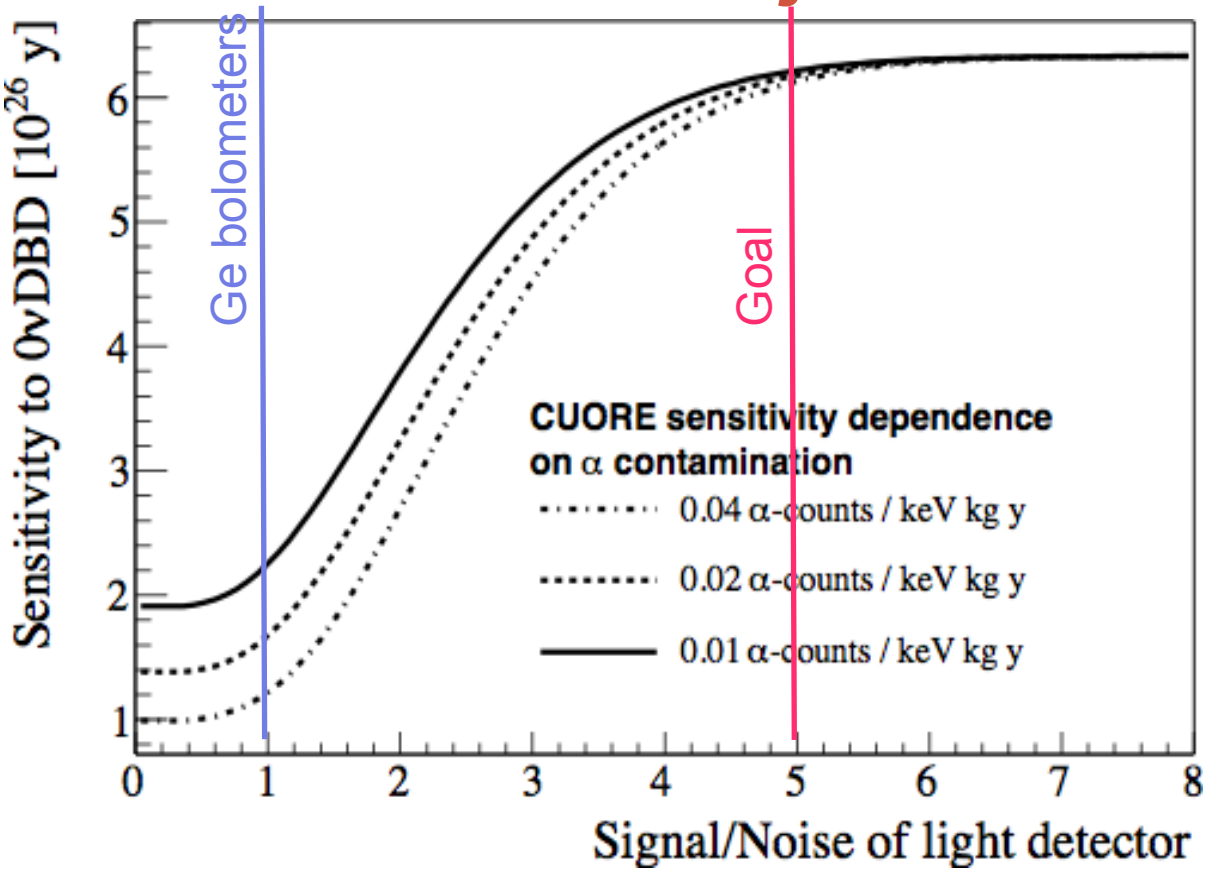
The light is visible but event by event discrimination is not possible: the noise of the light detector is high (100 eV RMS) compared to the Čerenkov signal (100 eV).

J. W. Beeman, M. Vignati (c.a.), et al., *"Discrimination of α and β/γ interactions in a TeO_2 bolometer,"* Astropart. Phys. 35 (2012) 558.

Requirement for an efficient rejection

Candidate Detectors

- ✓ TES
- ✓ **KID**
- ✓ LUKE
- ✓ MMC
- ✓ …



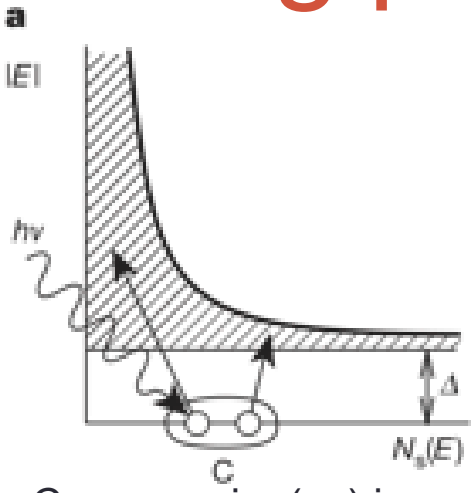
Kinetic Inductance Detectors (KIDs)

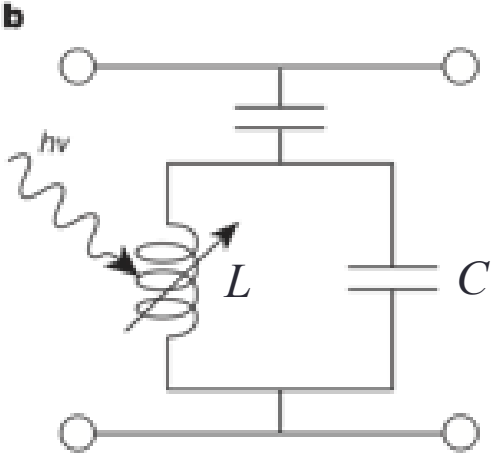
new technology invented at Caltech (*P. Day et al., Nature, 425 2003*)

- Excellent reliability
- Easy fabrication
- Easy readout: FPGA and 1 cold amplifier, high multiplexing

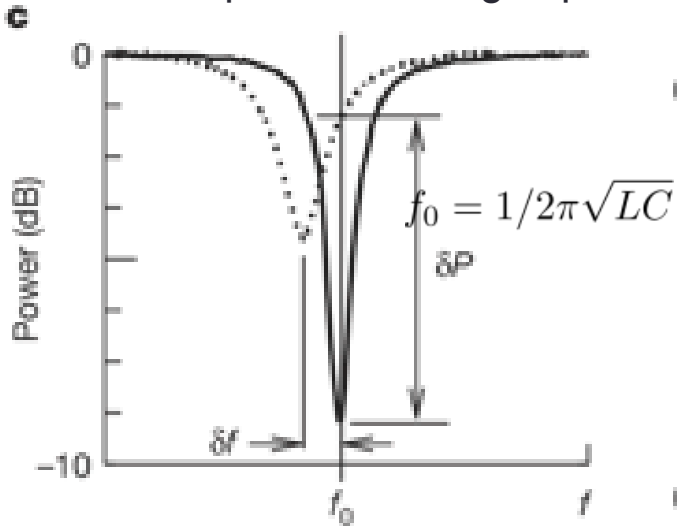
KID: Working principle

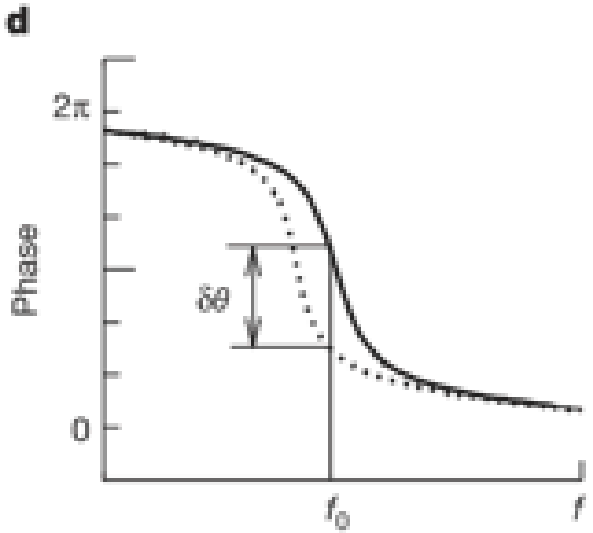
Day et al., Nature 425 (2003) 817





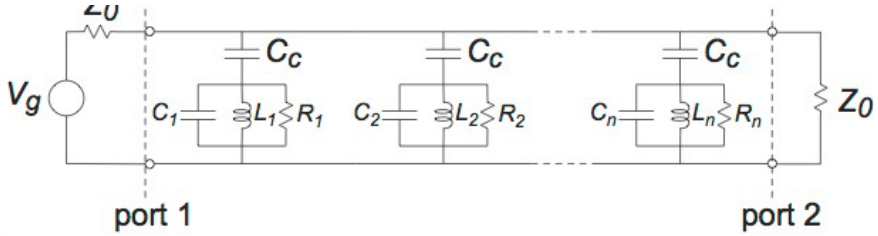
Cooper pairs (cp) in a superconductor act as an inductance (*L*).
Absorbed photons change cp density and *L*.

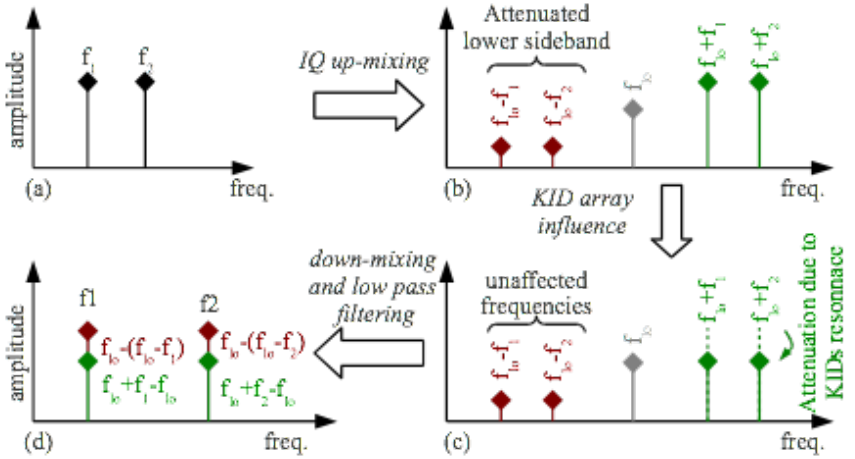


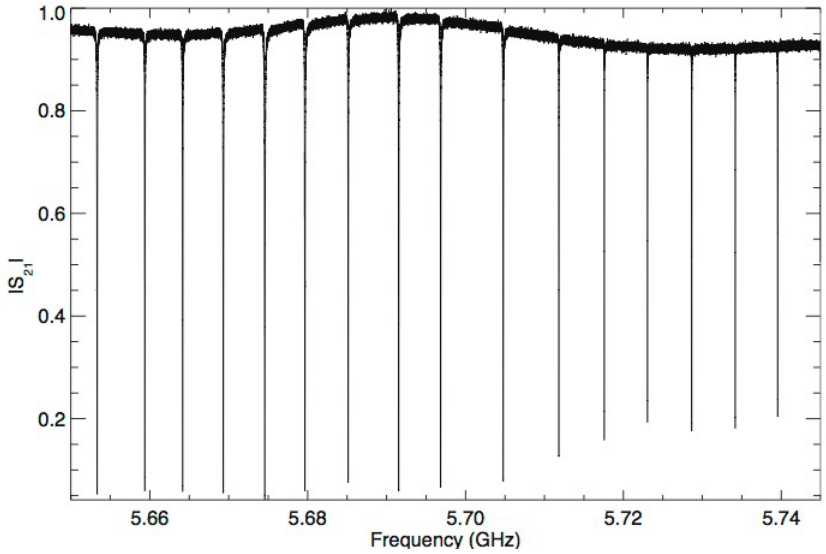


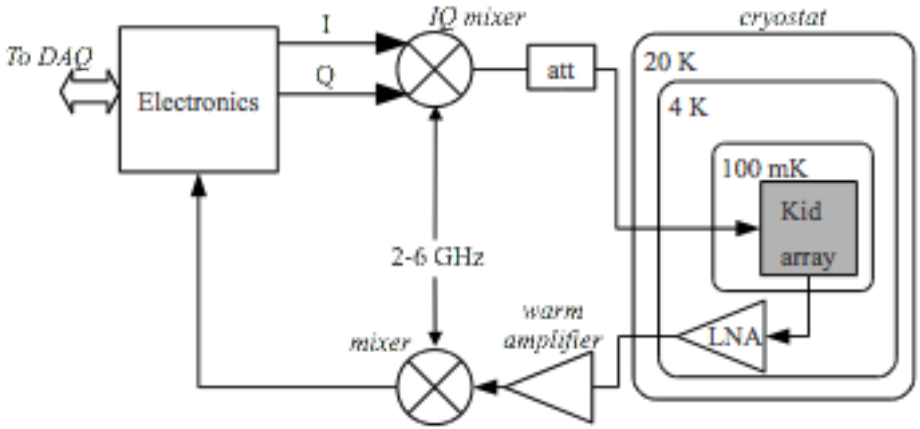
High quality factor (*Q*) resonating circuit biased with a microwave (GHz): signal from amplitude and phase shift.

Multiplexed readout of a KID array



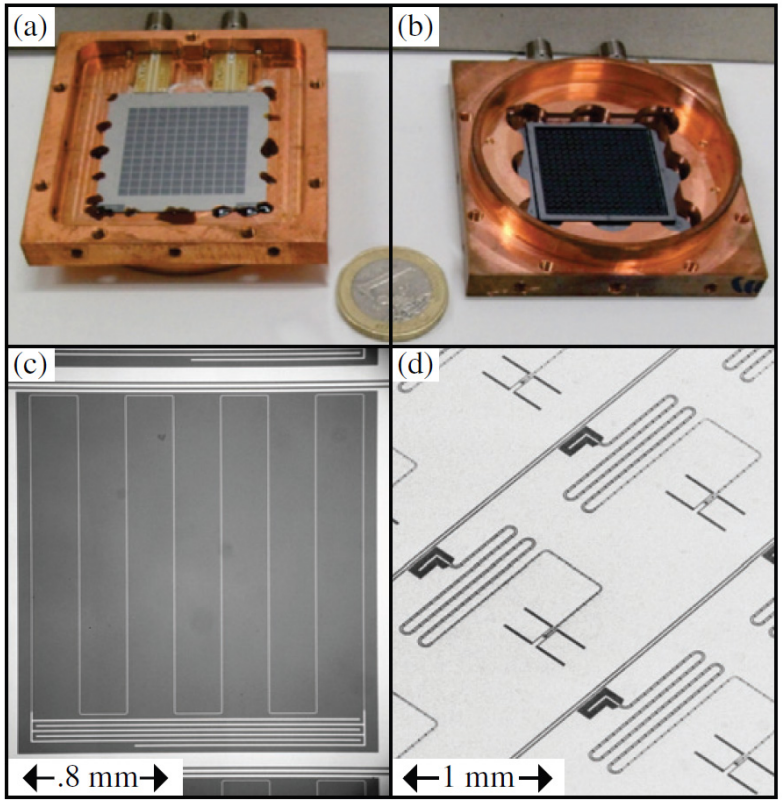






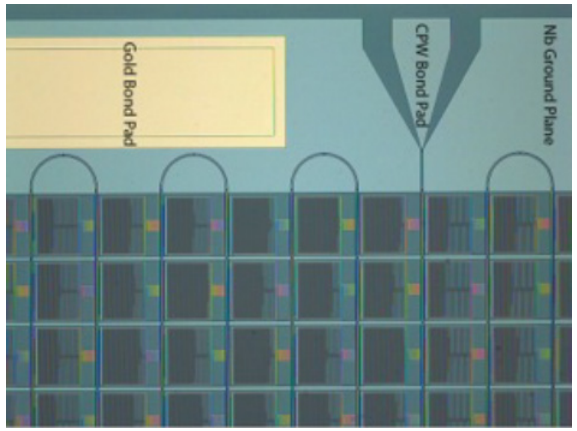
O. Bourrion et al, JINST 6 (2011) P06012.

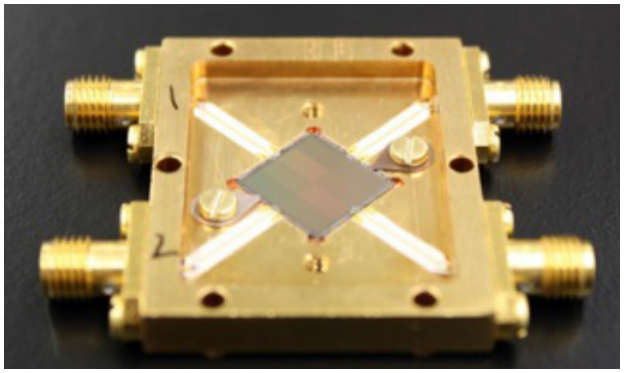
NIKA and ARCONS
first successful implementations



NIKA is a camera devoted to millimeter wave astronomy, developed by a collaboration, lead by Institut Néel (CNRS) et installed at the IRAM telescope

Monfardini et al., APJS 194 (2011)





ARCONS is a 2024 pixel spectrophotometer for optical and near-IR astronomy, developed by University of Santa Barbara

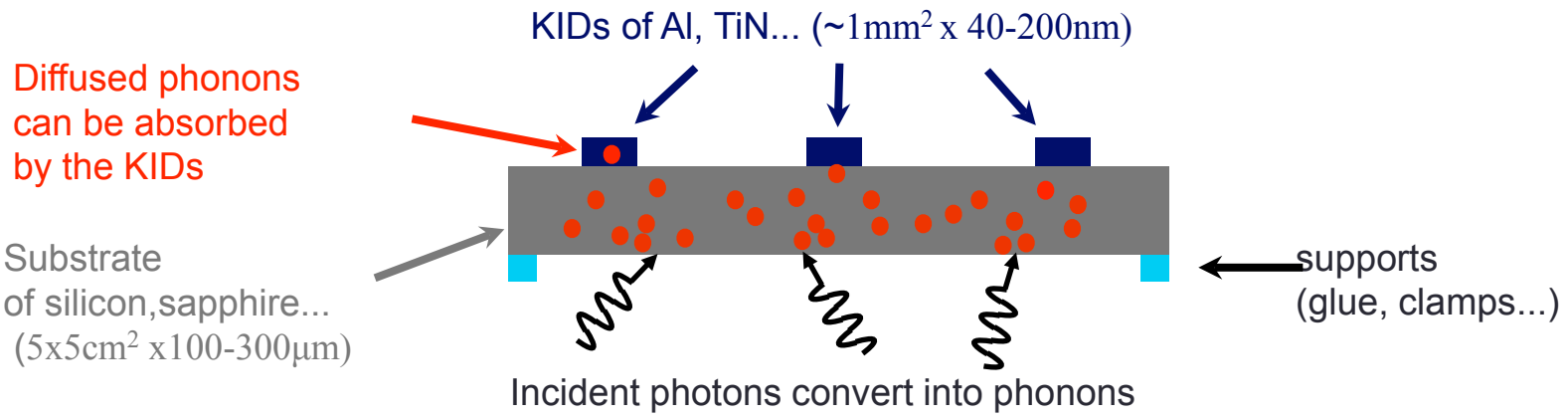
Mazin et al., PASP 123 (2013)

Our goals

	State of the art	goal	
Area	few mm^2	5x5 cm^2	difficult
ΔE [eV RMS]	< 1	< 20	achievable
T_{work} [mK]	80	10	pro

Problem of direct photon detection: area cannot be covered with 10^3 KIDs, too demanding for electronics (in the future we will need 10^3 light detectors).

Indirect detection: use a few KIDs (N_K =10-20) and athermal phonons in the substrate as mediators:

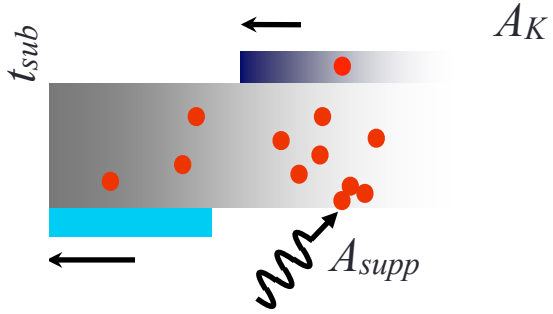


See also: *Swenson et al., APL 96 (2010) and Moore et al, APL 100 (2012)*

Scientific challenge

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

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



Substrate R&D: maximize transmission to the KIDs (p_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:

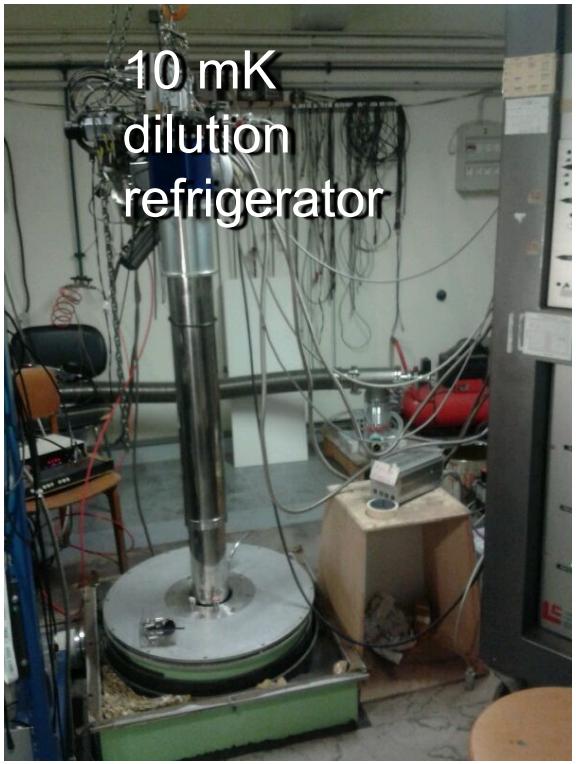
$$\Delta E \propto \frac{1}{\epsilon}\cdot T_c\sqrt{\frac{N_K A_K}{Q\,L}}$$

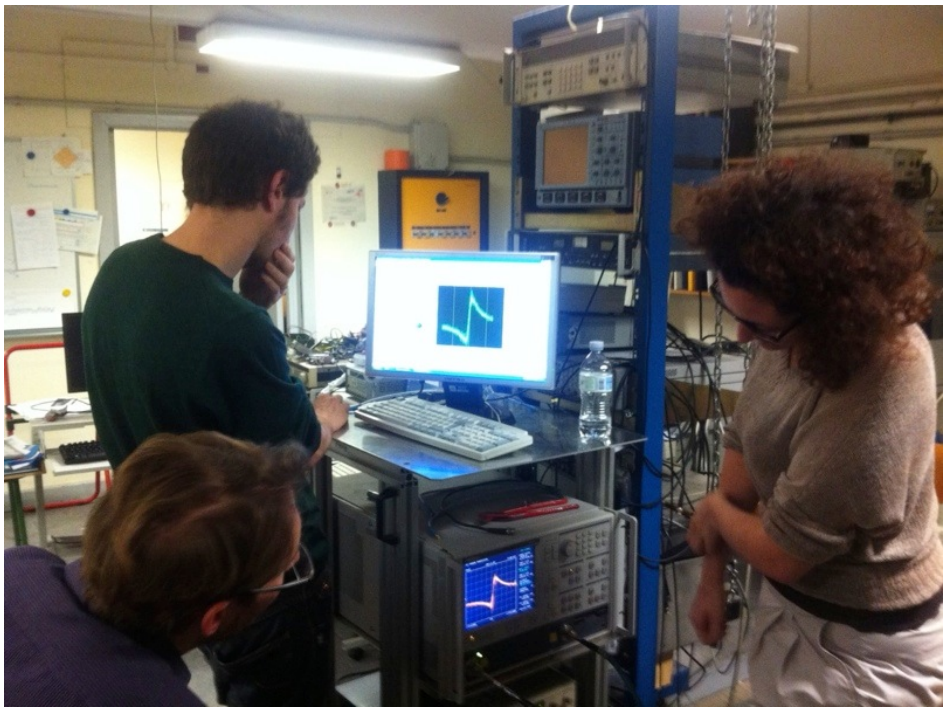
1) Maximize resonator (and consequently film) quality factor: $Q > 10^5$.

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

	Al	TiN (non stoich.)	Ti+TiN (stoich.)	Hf
T_c [K]	1.2	0.9	>0.4	0.12
L [pH/square]	0.5	3	30	*3*

Rome Lab

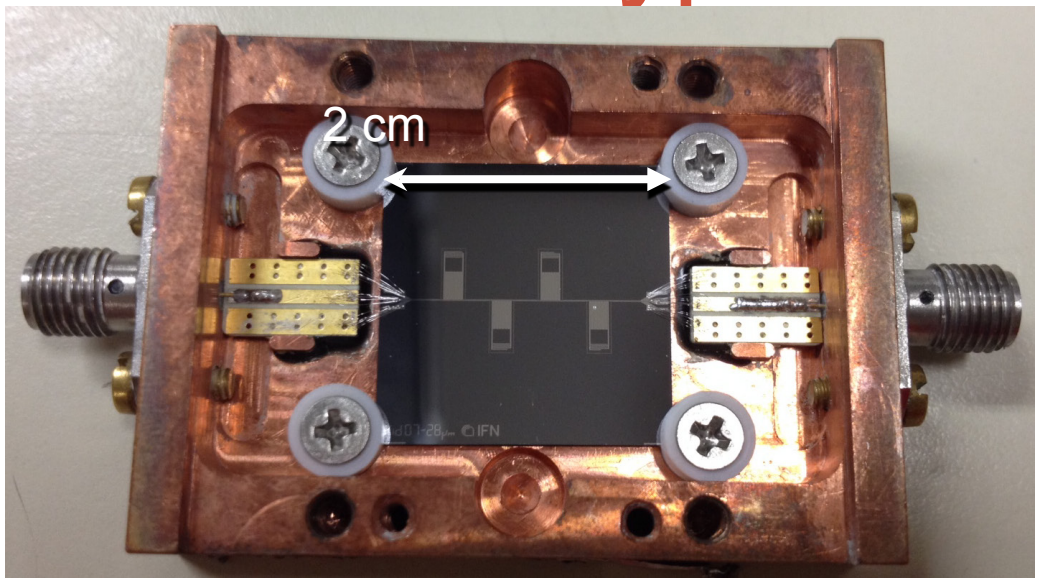




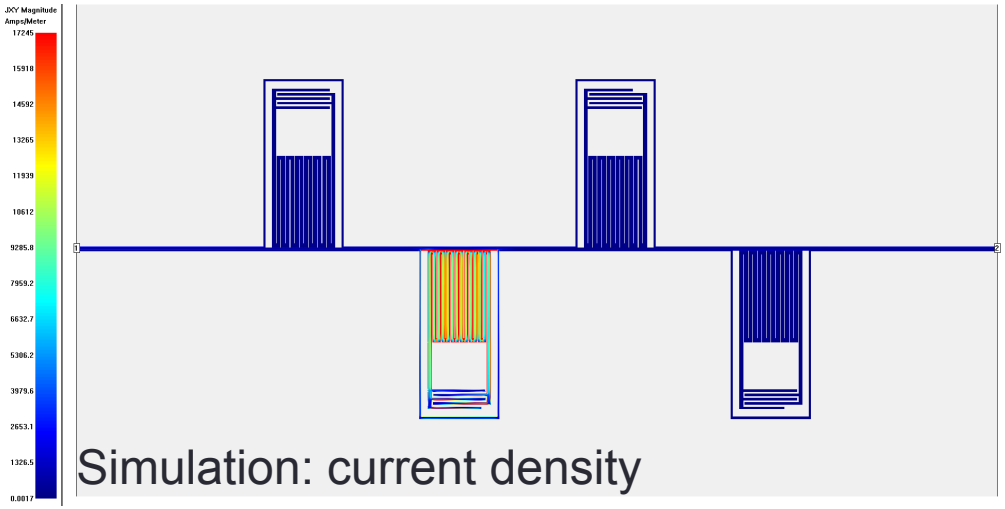
single cryogenic amplifier

Nixa: electronics board developed at LPSC (Grenoble)

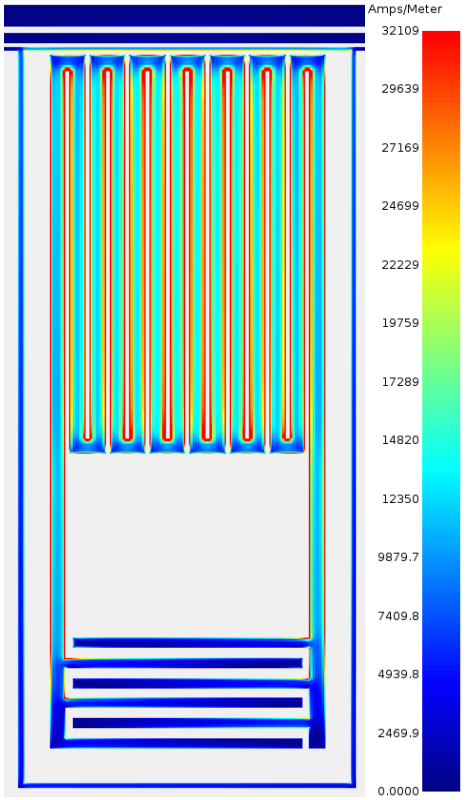
2nd Prototype



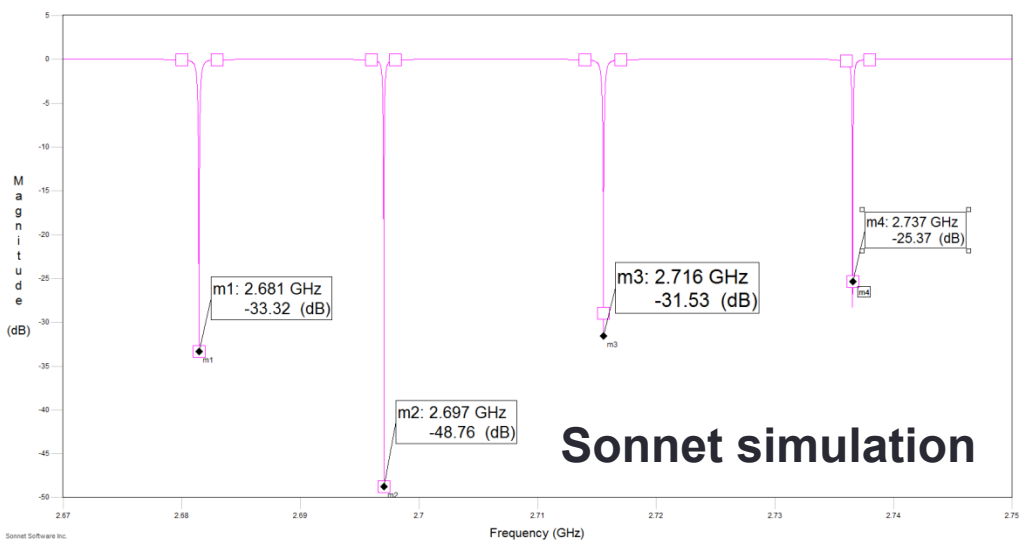
- Single pixel area: 2.4 mm^2.
- 4 pixels coupled to the same feed line.
- Frequency: 2.6 GHz (spacing 15 MHz).
- 40 nm Aluminum lithography on 300 um Silicon substrate

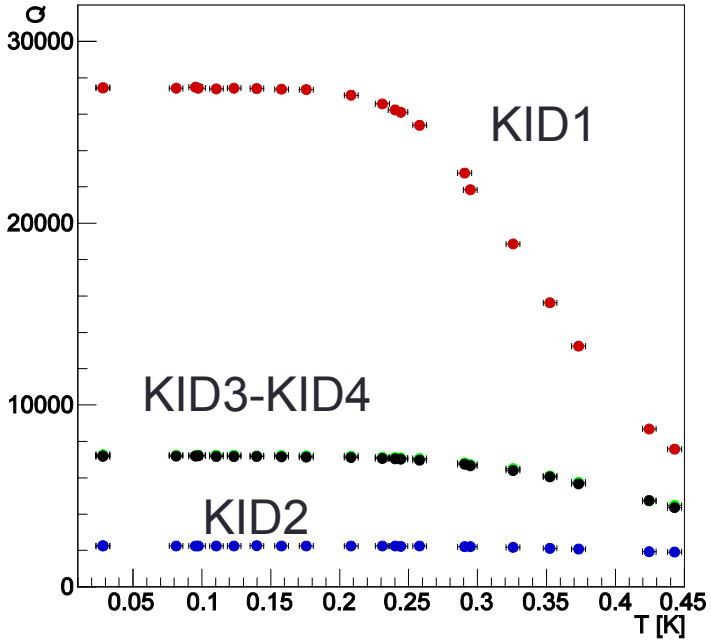


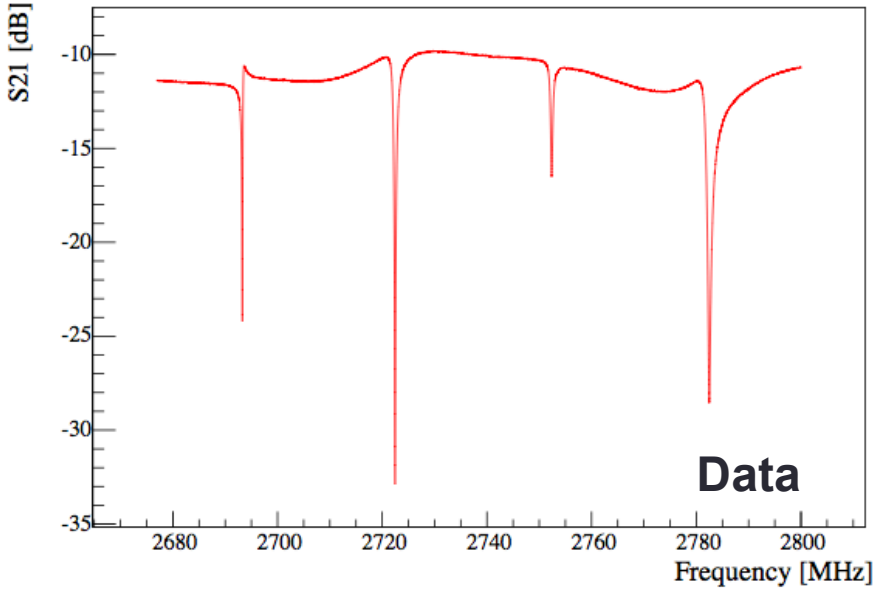
Simulation: current density



Q - factors





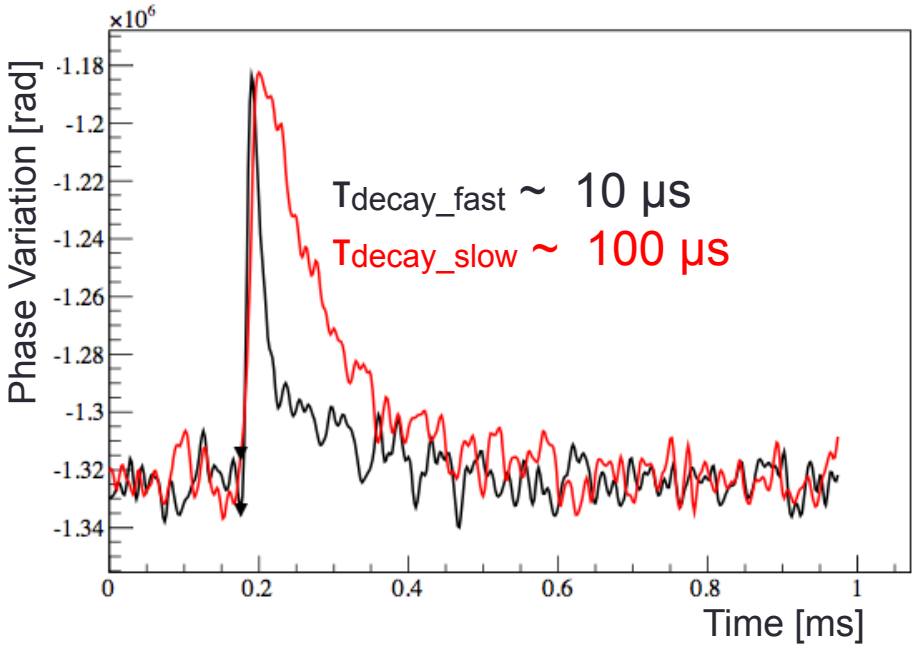


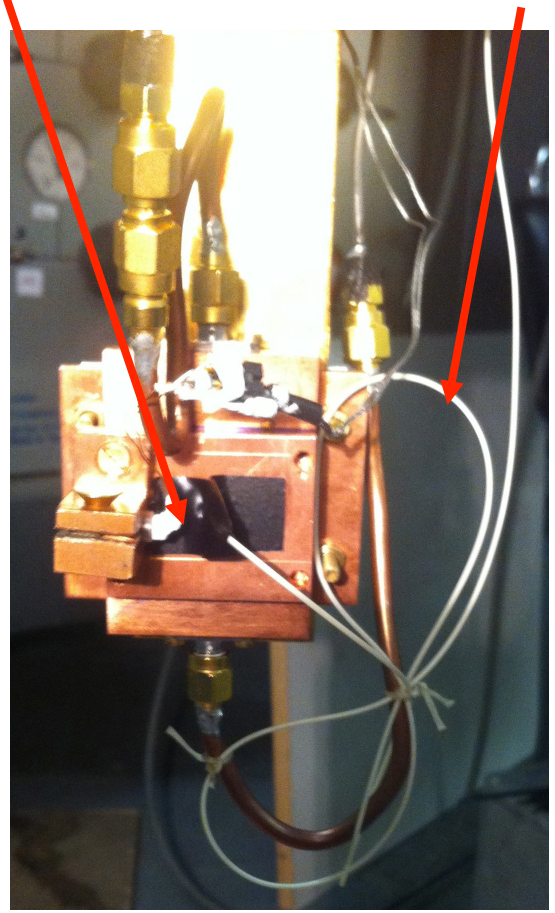
# reso	Simulated Q [k]	Measured Q [k]
1	8.0	27.5
2	8.0	2.0
3	8.0	7.0
4	8.0	6.5

Results – 1

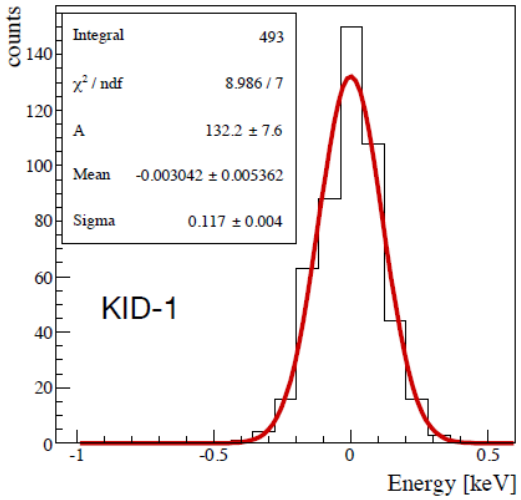
^{57}Co source (7 and 14 keV X-rays)

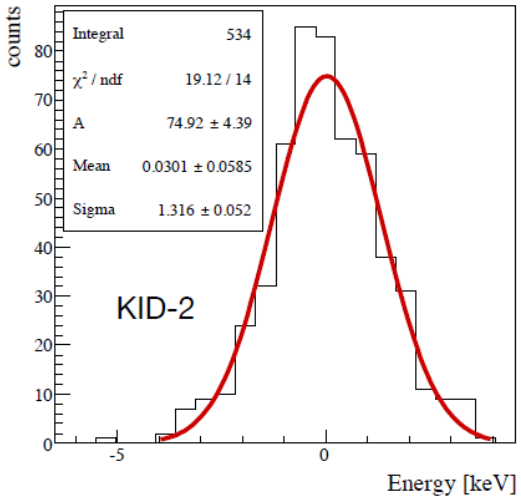
Optical fiber pulsed with LED

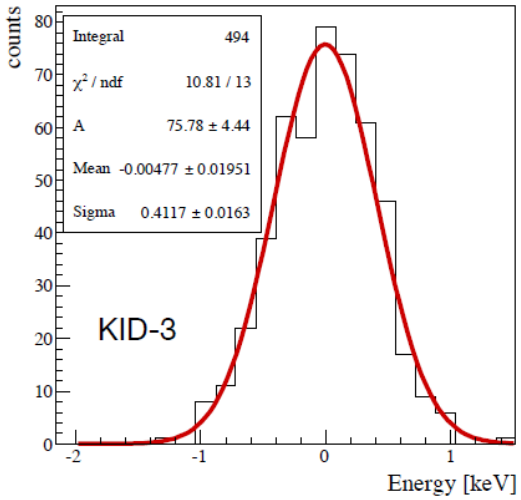


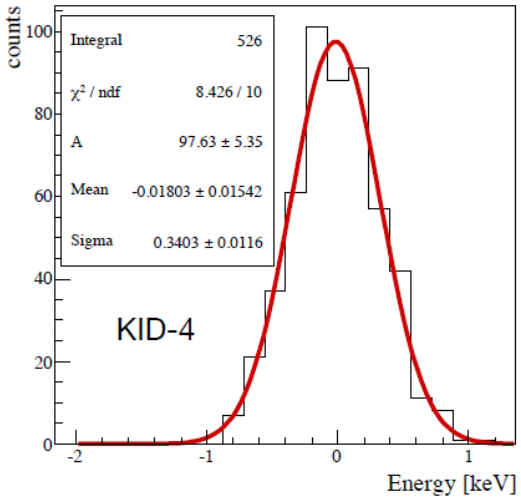


Results 2 – Baseline energy resolution

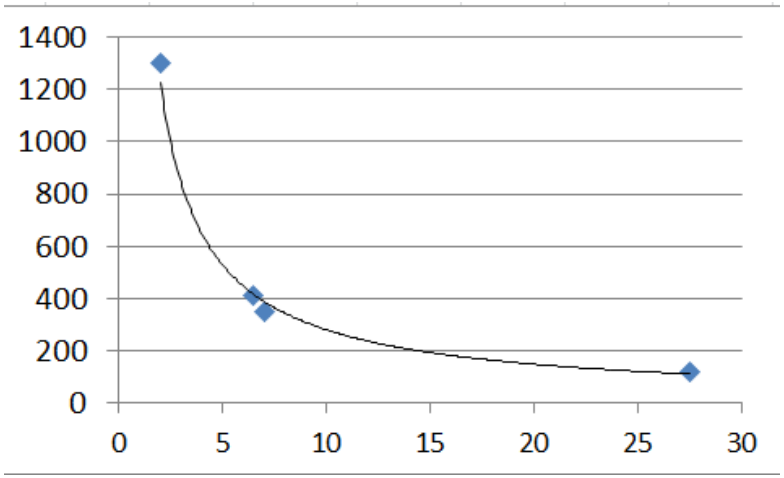








RMS [eV]



Q [k]

RMS of noise:

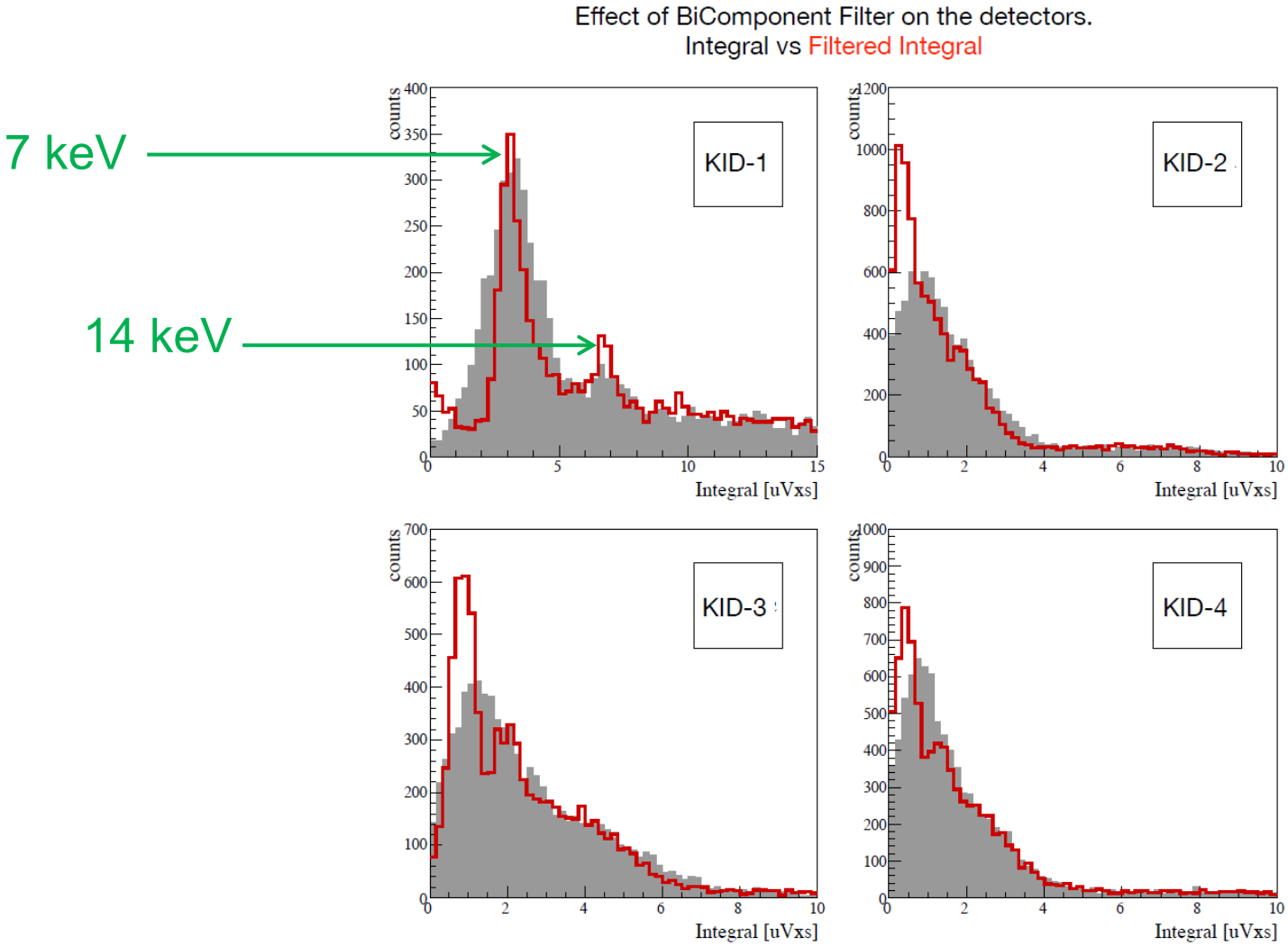
KID1 = 117 eV

KID2 = 1.3 keV

KID3 = 412 eV

KID4 = 340 eV

Results 3 – Single pixel energy spectrum



Next Steps

1) Increase Q-values with Al

Q [k]	1pix resolution [eV]	4pix resolution [eV]	Difficulty
50	90	180	Easy
100	60	120	Medium
200	40	80	Hard

2) Use different metals: TiN coming soon
expected improvement of resolution: 2 * 4 * 2 = 16
Tc Lk Eff

3) Maximize efficiency, using membranes and/or different substrates