Sc-qubits as particle detectors

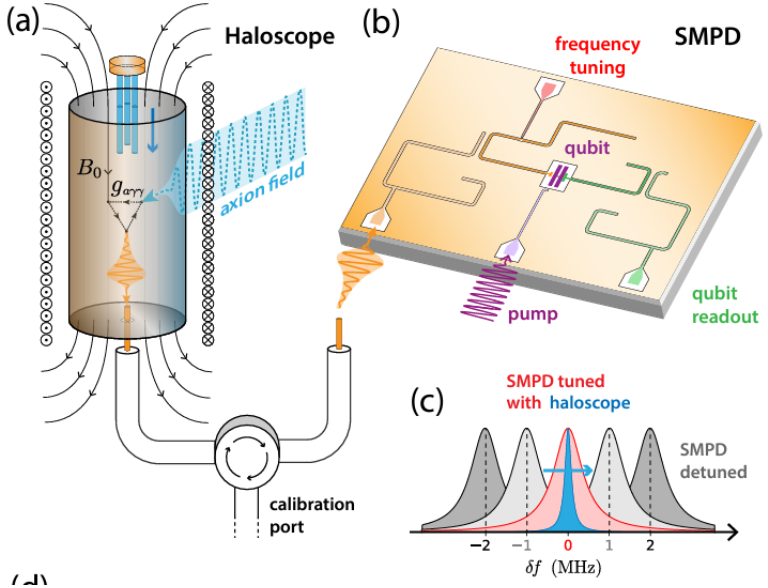
Istituto Nazionale di Fisica Nucleare

Angelo 24/7/2024

- State of the art -

Many proposals for QND readout of the status of a cavity during last years

C. Braggio et al, arXiv:2403.02321v2

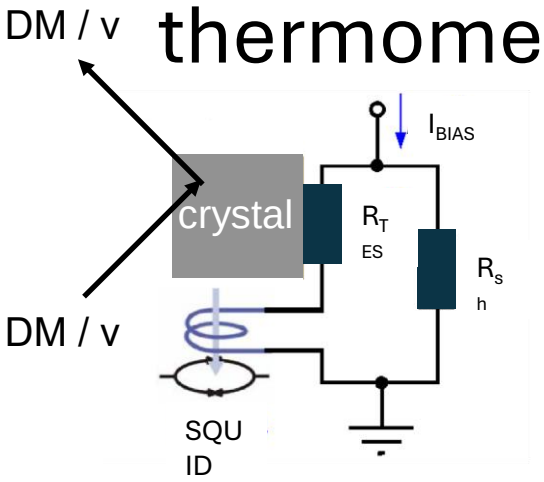


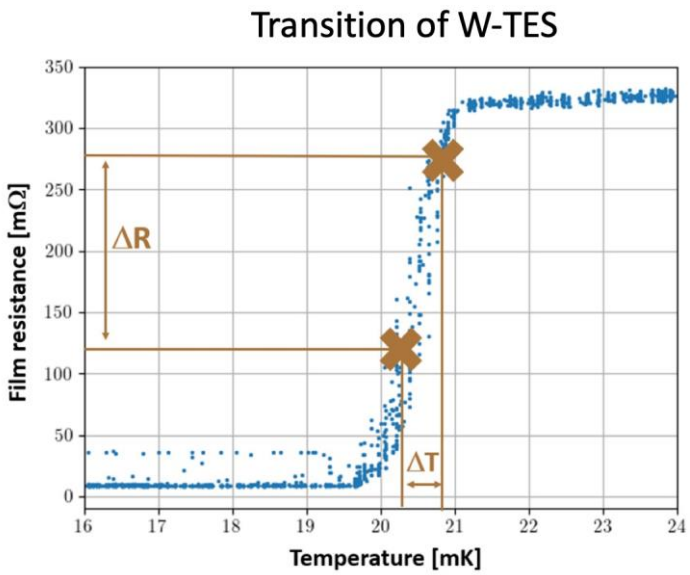
Can we imagine a phonon-mediated application?

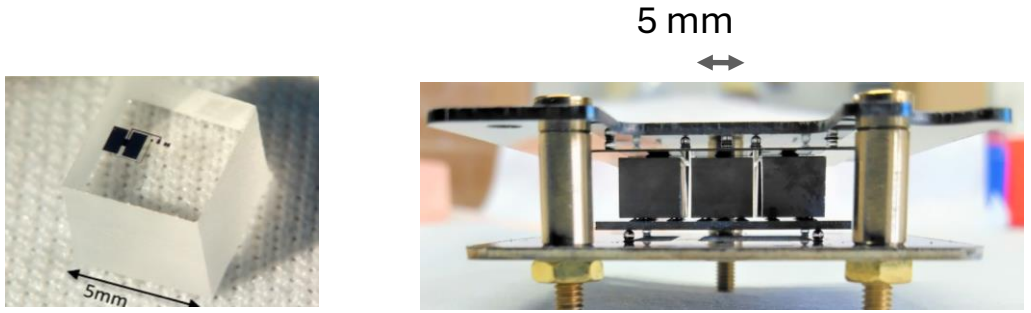
State of the art of phonon detection

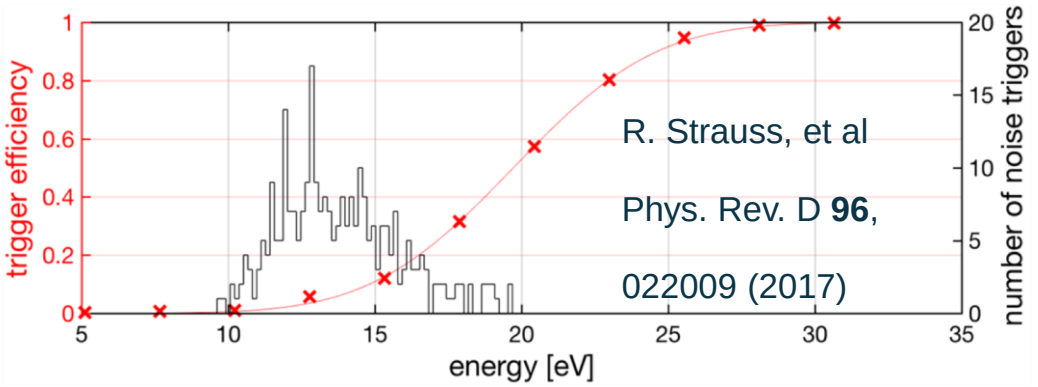
(CRESST/NUCLEUS experiments)

Superconducting thermometers (TES)







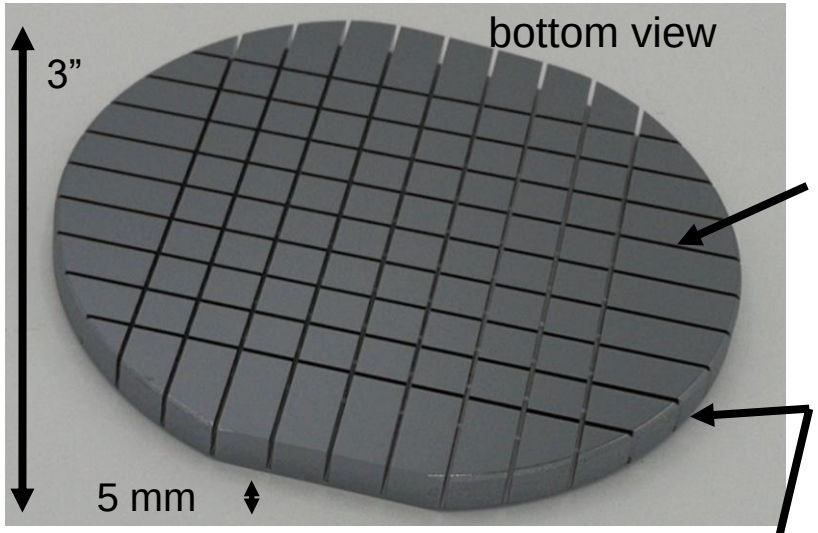


Limitation: individual readout

Pro: record-low energy threshold ~ 20 eV

BULLKID: KID-based phonon-mediated particle detector

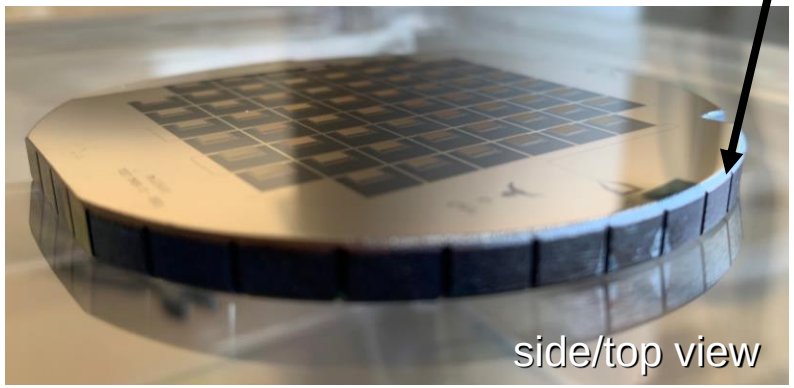
1. carving of dices in a thick silicon wafer



4.5 mm deep grooves
- 6 mm pitch
- chemical etching

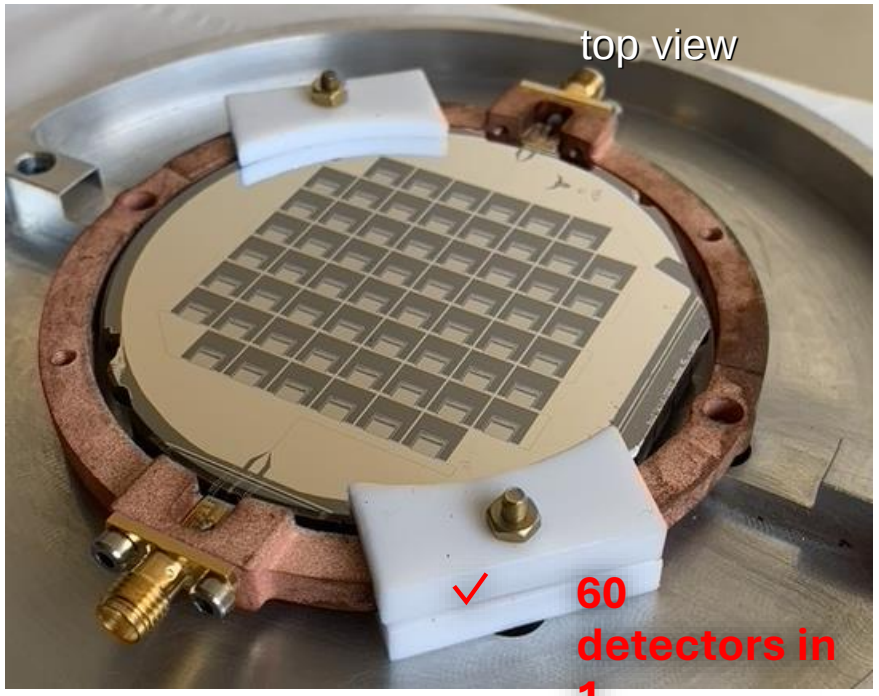
0.5 mm thick common disk:
- holds the structure
- hosts the KIDs

2. lithography of multiplexed KID array



KID array
- 60 nm aluminum film
- 60 KIDs lithography

3. assembly



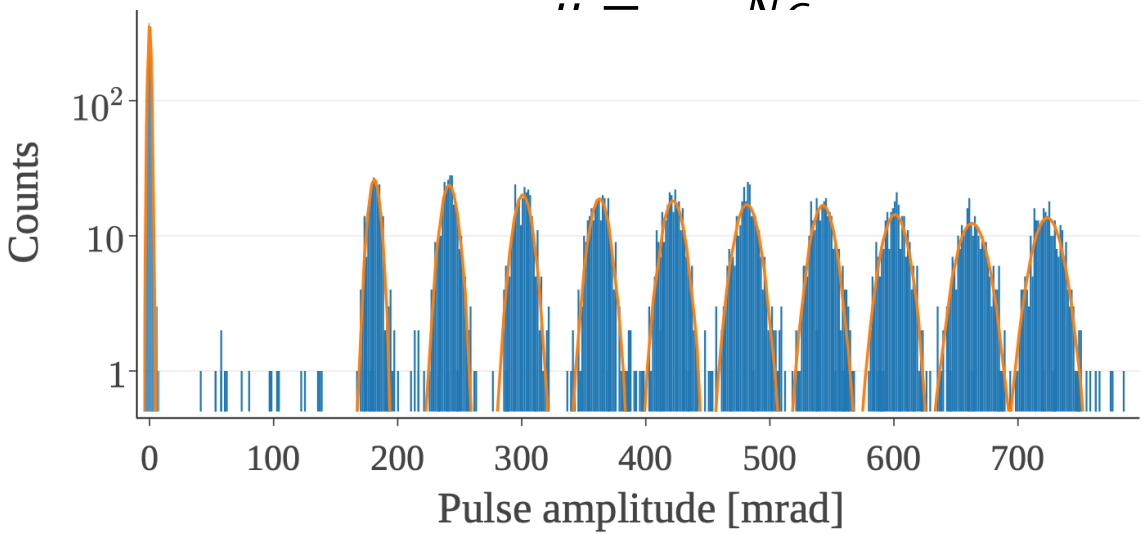
Assembly
- 3D-printed Cu holder
- Aluminum case

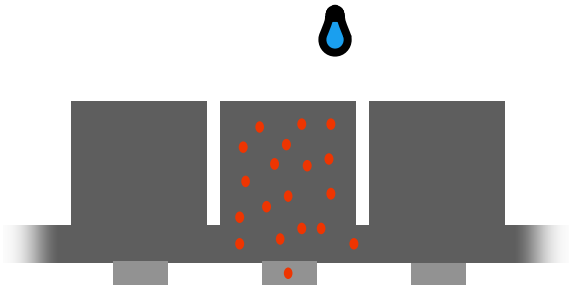
60 dices 0.35 g each

1 readout line

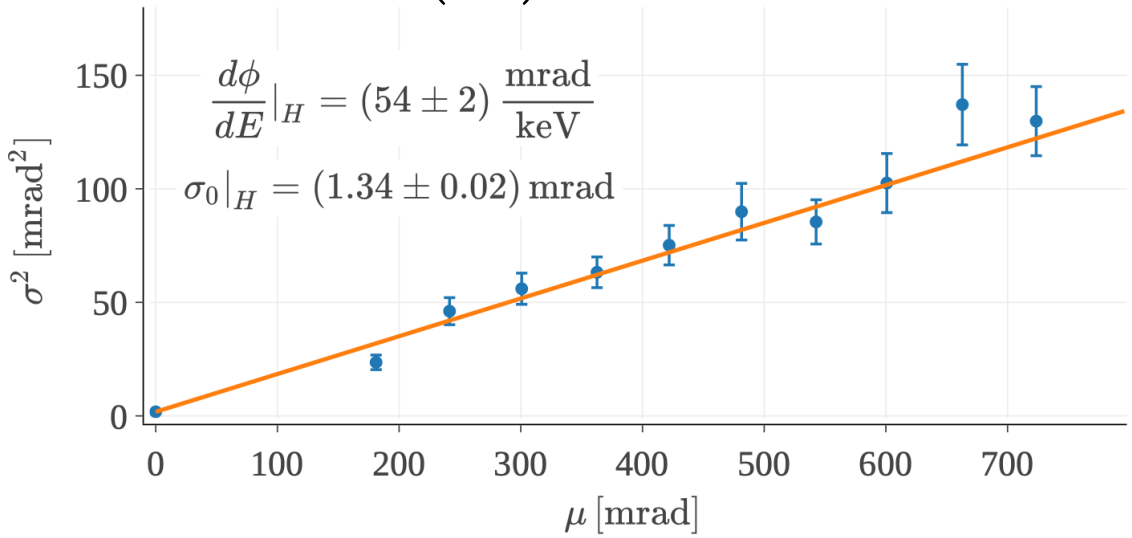
Energy calibration and resolution

Exploit the Poisson's statistics of bursts of N optical photons of known energy ϵ to extract the calibration constant $d\phi/dE$:





$$\sigma^2 = \sigma_0^2 + \left(\frac{d\phi}{dE}\right)^2 N\epsilon^2 = \sigma_0^2 + \frac{d\phi}{dE}\epsilon \cdot \mu$$



Average over 8 channels: **26 ± 7 eV**

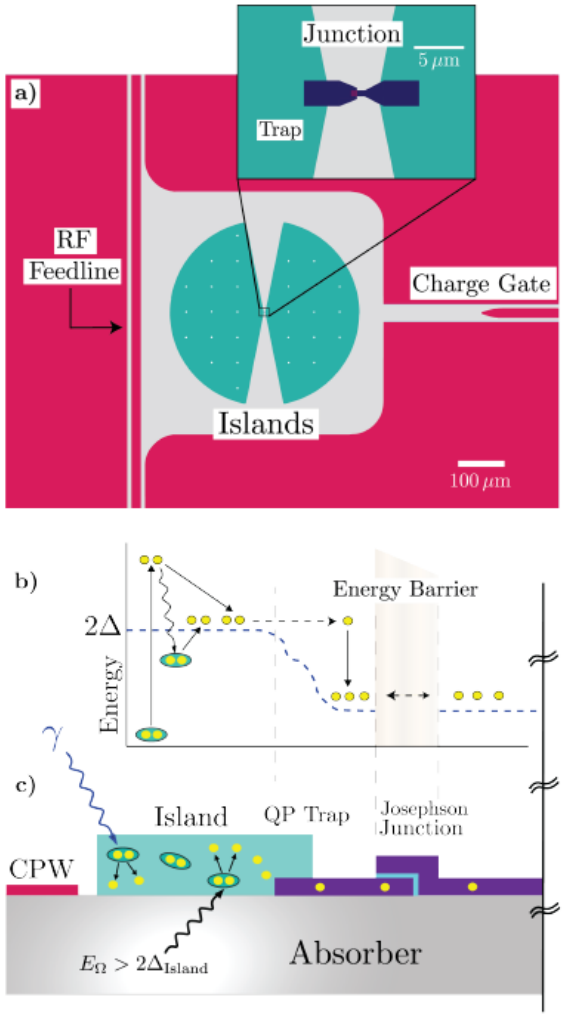
Energy threshold at 6σ 160 **± 13 eV**

A. Cruciani, et al, Appl. Phys. Lett. 121, 213504 (2022)

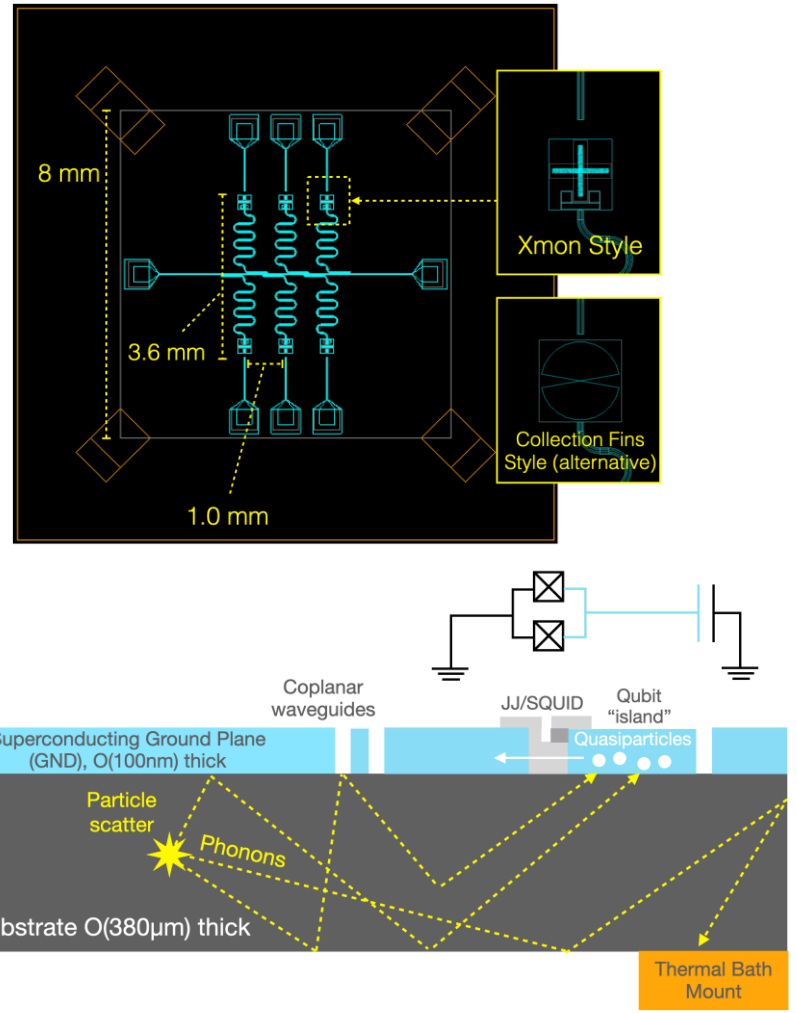
2 proposals as example

The Superconducting Quasiparticle-Amplifying Transmon: A Qubit-Based Sensor for meV Scale Phonons and Single THz Photons

Fink et al,
arXiv:2310.01345v3



Estimating the Energy Threshold of Phonon-mediated Superconducting Qubit Detectors Operated in an Energy-Relaxation Sensing Scheme

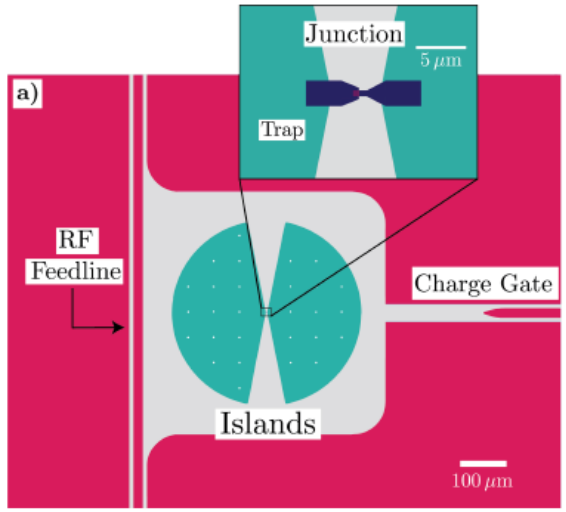


R. Linehan,
arXiv:2404.04423v1

2 proposals as example

The Superconducting Quasiparticle-Amplifying Transmon: A Qubit-Based Sensor for meV Scale Phonons and Single THz Photons

Fink et al, arXiv:2310.01345v3



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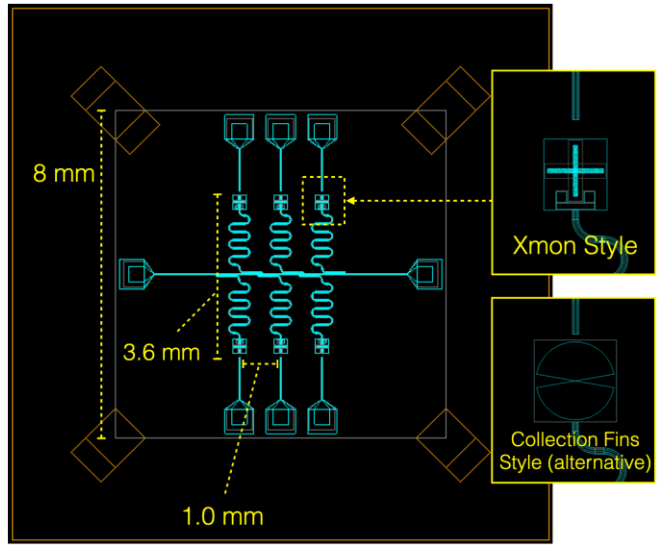
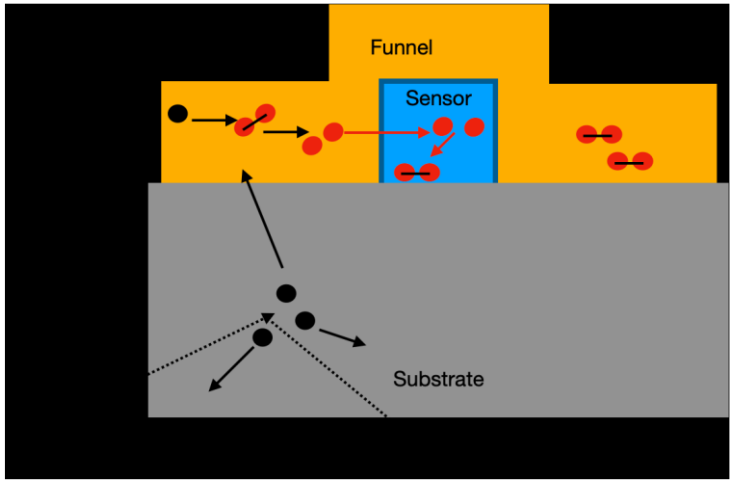
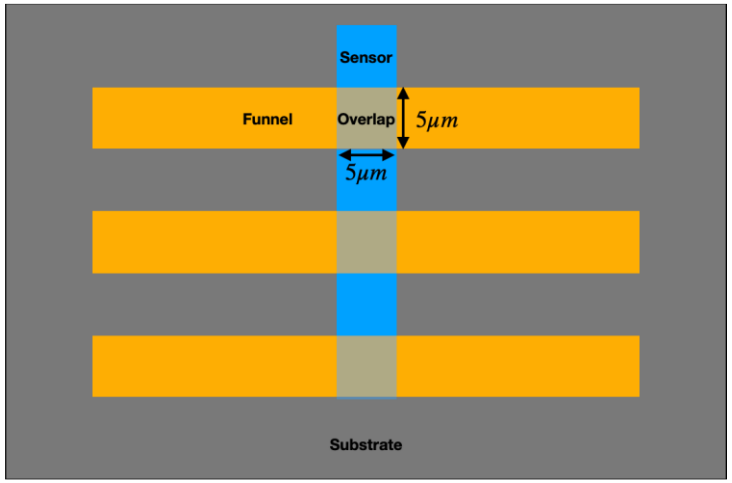


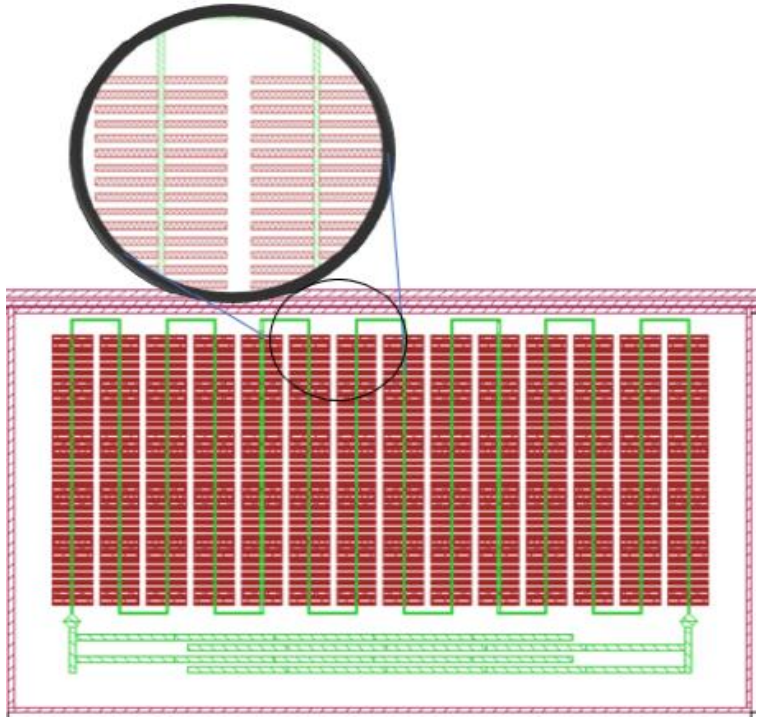
Design	Number of Qubits N_q	Qubit Design	Ground Plane	Si-SC phonon absorption prob. $p_{a,s}$	Si-Cu phonon absorption prob. $p_{a,c}$	Spatially-averaged phonon collection eff. $\eta_{ph,sp}$	Chip Threshold $E_{thr,chip}$
1	6	Xmon	Full	1.0	0.1	0.14%	737 eV
2	6	Xmon	Full	0.1	0.1	0.12%	860 eV
3	6	Xmon	Limited	1.0	0.1	2.07%	49 eV
4	6	Xmon	Limited	0.1	0.1	1.44%	71 eV
5	6	Xmon	Full	1.0	1.0	0.14%	737 eV
6	6	Xmon	Full	0.1	1.0	0.12%	860 eV
7	6	Xmon	Limited	1.0	1.0	1.76%	58 eV
8	6	Xmon	Limited	0.1	1.0	0.76%	135 eV
9	2	Xmon	Full	1.0	0.1	0.05%	1157 eV
10	10	Xmon	Full	1.0	0.1	0.24%	574 eV
11	2	Xmon	Limited	1.0	0.1	1.38%	41 eV
12	10	Xmon	Limited	1.0	0.1	2.39%	57 eV
13	6	Collection Fins	Limited	1.0	0.1	17.0%	O(0.1) eV
14	6	Collection Fins	Limited	0.1	0.1	12.6%	O(0.1) eV

BULLKID proposed upgrade

- Exploits QPs trapping using different metals for absorber and detector
- Role of the proximity effect?
- Test in progress

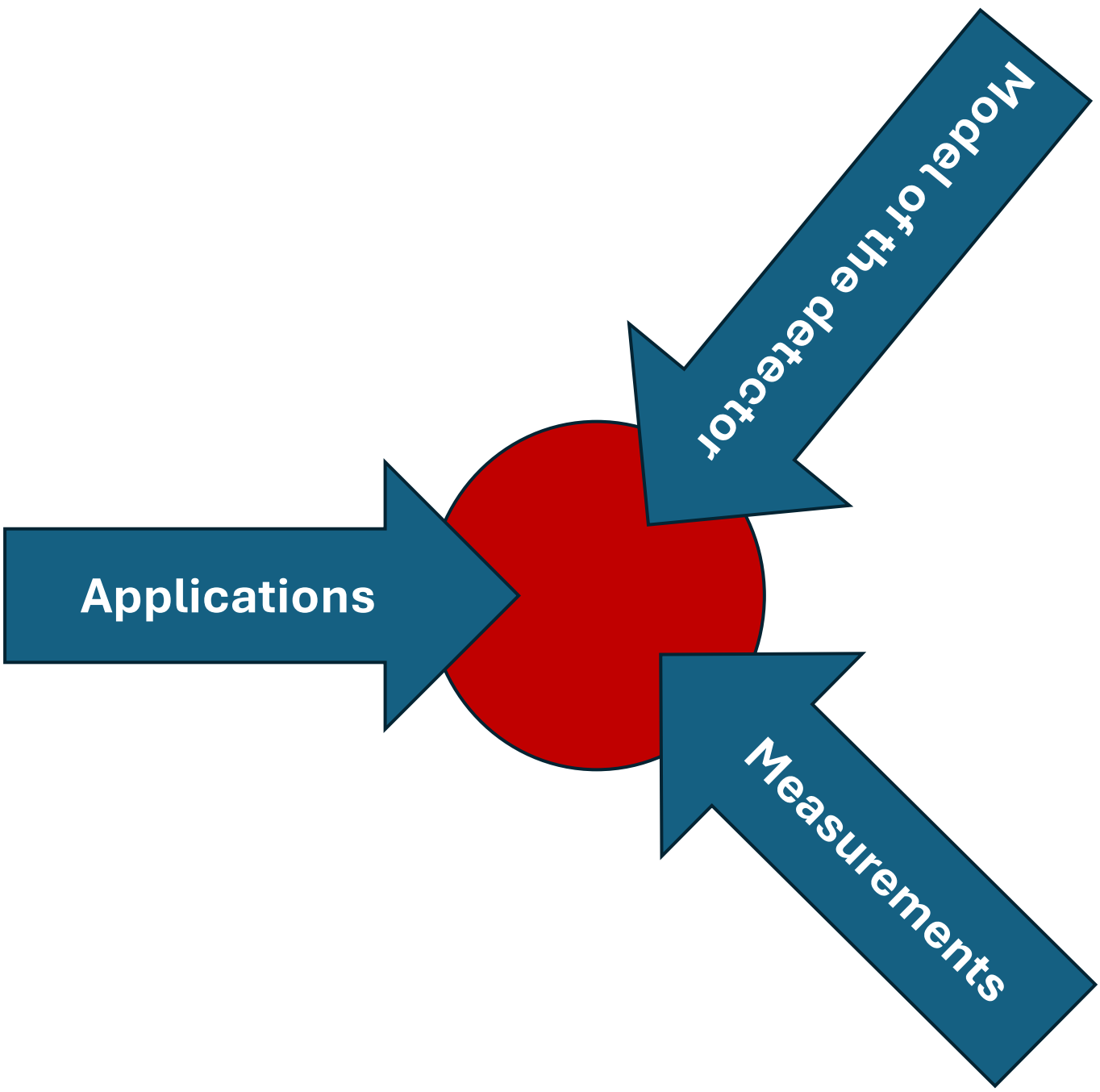






L. De Santis MD Thesis

A rough division of the work



A rough division of the work

WP	Activity	Where	
WP1 - Tools	Data handling	GSSI / Genova	New protocol and software for triggering
	Simulations software	RM1	Phonon simulations
	RO chain upgrade	FBK	JPA
WP2 – Qubit as detectos	Optical calibration		Design -> installation
	Self-tagging source	LNGS/GSSI	Use of source
	Performance	RM1/GSSI/ LNGS	Tests
WP3 – Det upgrade	Remove GP	RM1	Increase of efficiency
	Novel design	RM1	
	Neutron beam	Trento	Tests at neutron beam
	Package study	GSSI/LNGS	Radioassay and modelling
WP4 – Impact	Particle physics	RM1	Prespective for low energy DM
	Quantum Computing	Trento	Fault detection in quantum circuits